OLYMPIC DAM EXPANSION

DRAFT ENVIRONMENTAL IMPACT STATEMENT 2009

APPENDIX T

REHABILITATION AND CLOSURE

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APPENDIX T

REHABILITATION AND CLOSURE

This appendix provides supplementary information to Chapter 23, Rehabilitation and Closure, of the Draft EIS. Information within this appendix was obtained from assessments by Outback Ecology Pty Ltd and Outback Native Seeds Pty Ltd.

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APPENDIX T1

Review of leading practice rehabilitation of mines in the arid zone

T1 REVIEW OF LEADING PRACTICE REHABILITATION OF MINES IN THE ARID ZONE

T1.1 INTRODUCTION

The term ‘rehabilitation’ is often interchanged with ‘restoration’ and ‘reclamation’. Rehabilitation in this review is used in preference to restoration and reclamation and is defined as follows:

“a process where disturbed land is returned to a stable, productive and self-sustaining condition, taking future land use into account. This process differs from the narrower definition of restoration by not aspiring to fully replace all of the original components of an ecosystem” (EPA 2006).

In relation to biological aspects, ‘restoration’ implies attempts to return vegetation to its original state, while rehabilitation acknowledges that vegetation will be permanently altered, but where appropriate, seeks to return a self-sustaining native plant community that is as close to the original as possible (EPA 2006).

The rehabilitation sequence is normally considered to comprise of the following activities:

- developing designs for appropriate landforms for the mine site
- creating landforms that will behave and evolve in a predictable manner, according to the design principles established
- establishing appropriate sustainable ecosystems (DITR 2006).

This appendix focuses primarily on establishing appropriate sustainable ecosystems and aims to provide detail on the principles and examples of leading practice, including an integration of leading practice in arid zone mine rehabilitation. The following important components are considered separately in this review (see Sections T1.4 to T1.6):

- characterisation and reconstruction of soil profiles
  - pre-mining characterisation of natural soil profiles and landforms, in relation to vegetation communities
  - characterisation of waste materials, for optimal placement in waste landforms
  - removal and management of vegetation and topsoil
  - soil profile reconstruction, including store-and-release surfaces, to support post-mining land use objectives
- species selection and seed management
  - plant species selection
  - seed collection, storage and treatment
- plant establishment
  - plant establishment techniques
  - controlling threats to rehabilitation success
  - completion criteria and monitoring.

T1.2 MINING OPERATIONS IN ARID ZONES

A large proportion of mining in Australia occurs within arid/semi-arid zones that typically receive less than 500 mm of rainfall with greater than 2,000 mm pan evaporation annually. Rehabilitation issues within this climatic zone can be unique in that, due to high evaporation rates and hence large soil suctions, infiltration and deep drainage occurs to a lesser extent than in higher rainfall areas. Consequently, some of the principles of mine rehabilitation from other climatic zones may not be readily transferable.

The climate at Olympic Dam falls at the ‘arid-end’ of the climatic range for Australian mine sites. However, it was not useful to restrict this review to only those operations receiving annual rainfall which approximates to that of Olympic Dam (168 mm), as too few fall within that band. Therefore, rehabilitation strategies for mining operations within areas generally receiving less than 350 mm of average annual rainfall were considered (Table T1.1). One exception was the Tanami operation in the Northern Territory (430 mm average annual rainfall), which was included because detailed rehabilitation planning was available at this site. All of the sites considered experience high average annual pan evaporation rates (>2,000 mm per year), in line with that experienced at Olympic Dam.

It is important to note that, in spite of overall aridity, many of the sites considered are more susceptible than Olympic Dam to torrential rain events that can have a detrimental effect on rehabilitation works. It is assumed that rehabilitation strategies employed at those sites that experience sporadic, very heavy rain events, can be transferred to Olympic Dam, where the low rainfall tends to be more evenly distributed (refer Chapter 8, Meteorological Environment and Climate). It is also noted that there are several well-described operations from North America that have similar precipitation rates, but a proportion of this precipitation is actually snow. It is difficult to transfer specific information from these sites because of the particular conditions associated with snow melt, including cooler temperatures, low to modest rates of evaporation and greater infiltration (Campbell 2004). As such, these mines have been excluded from this review.

In terms of natural landforms and soils, the majority of the sites considered were characterised by red earths or red earths and hardpans with variable stoniness and loamy sands to sandy-loams (Campbell 2004). Only the Telfer site in WA and Namakwa Site in South Africa are characterised by vegetated sandy substrates similar to those present at Olympic Dam.

T1.3 GOVERNMENT AGENCIES AS A SOURCE OF LEADING PRACTICE

The principal published source of information on leading practice in environmental management for the Australian mining industry is the "Best Practice Environmental Management in Mining" series (DEH 2002). Most state regulatory agencies direct proponents to this series as either the sole source or as complementary to other information/state guidelines.

The Department of Primary Industries and Resources of South Australia (PIRSA) does not have any guidelines regarding soil management and rehabilitation. In addition to the Commonwealth 'Best Practice' series, proponents are currently directed to guidelines from other states where applicable (J. Randall, pers. comm.). The NSW Department of Primary Industries usually expects operators to propose site-specific rehabilitation methods as part of their Mining Operations Plan and also refers proponents to the Commonwealth 'Best Practice' series. The Environmental Protection Agency (EPA) of Queensland currently refers to the former Department of Minerals and Energy Technical Guidelines from 1995, as well as the Commonwealth 'Best Practice' series.

The Department of Industry and Resources (DoIR) in Western Australia has recent guidelines for preparation of a Mining Proposal Document (DoIR 2006), which is required for new mining operations. These guidelines emphasise the requirement to characterise waste rock, tailings, soils and soil profiles such that rehabilitation can be based on the properties of these materials. There is also a requirement to detail the rehabilitation procedures proposed for each project component, with a recommendation that trials be undertaken as soon as possible to develop and validate the proposed methodologies for closure. In addition, the Environmental Protection Authority (EPA) of Western Australia has recently released a Draft Guidance Statement for Rehabilitation of Terrestrial Ecosystems (EPA 2006). The statement details rehabilitation objectives and compares internationally-recognised standards for assessing rehabilitation outcomes with those currently used in Western Australia and discusses the importance of scientific knowledge as a basis for effective rehabilitation. However, it does not stipulate specific rehabilitation methods.

As part of its *Leading Practice Sustainable Development Program for the Mining Industry*, the Commonwealth Department of Industry, Tourism and Resources has produced two booklets: *Mine Rehabilitation* (DITR 2006a), and *Mine Closure and Completion* (DITR 2006b). These booklets outline the principles and practices of mine rehabilitation with emphasis on landform design and revegetation. Particular emphasis is given to the restoration of natural ecosystems, especially the re-establishment of native flora and fauna. Topics covered include rehabilitation objectives, soil handling, earthworks, revegetation, soil nutrients, fauna return, maintenance, success criteria and monitoring. Each of these principles is relevant to rehabilitation strategies proposed for Olympic Dam.

In the following sections, critical phases of the rehabilitation sequence are considered and relevant leading practices identified.

Table T1.1 Sites considered in this review of leading practice in arid zone rehabilitation

Site	Annual rainfall (mm)	Reference
Paddington Gold Mine, WA	268	Loney 1998
St Ives Gold Operations, WA	268	Vasey et al. 2000
Tanami Operations, NT	430	TMJV 2004
BHP Billiton Iron Ore, WA	310	OES 2005a
KCGM Operations, WA	268	Bussell 2000
Bottle Creek Gold Mine, WA	190	Anderson et al. 2002
Mount Keith Nickel Operations, WA	292	MKO Nickel West 2005
Mt McClure Gold Mine, WA	250	Lacy and Slight 2005
Morenci Mine, USA	330	Milczarek et al. 2003 in Campbell 2004
Fortnum Gold Mine, WA	198	Lacy et al. 1999
Coburn Mineral Sand Mine, WA	240	URS 2005a
Port Hedland to Telfer Pipeline Corridor, WA	312	OES 2005c
Namakwa Mineral Sands Mine, South Africa	150	URS 2005b
Challenger Gold Operation, SA	180	K. McCormick, pers. comm.
Murrin Murrin Nickel Operations, WA	222	Stevens 2006
Prominent Hill Copper-Gold Project, SA	160	OES 2006
Nevoria Gold Mine, WA	293	OES 2004a
Kundana Operations	267	Swain et al. 2004
Paddy's Flat Mine, Meekatharra	221	Lacy 1997
Barrow Island Operations, WA	320	URS 2004
Jack Hills Iron Ore Project, WA	236	MBS 2006
De-Na-Zin and Gateway Coal Mines, USA	191	Wendell and Westerman 2004

T1.4 CHARACTERISATION AND RECONSTRUCTION OF SOIL PROFILES

T1.4.1 Pre-mining characterisation of natural soil profiles and landforms, in relation to vegetation communities

A key objective of rehabilitation is to create ecosystems that are self-sustaining and/or capable of being managed without unwarranted additional expense (EPA 2006). In addition, there is to be sufficient representation of species to allow vegetation to be identified as belonging to a nominated plant community type (EPA 2006), with a further goal that this community occurs on analogous sites within the near vicinity.

Effective vegetation rehabilitation requires an understanding of soil profiles associated with the selected communities as these may constrain root growth and determine plant-available water (Jasper and Braimbridge 2006). The assessment of soil profiles should include chemical properties such as pH and salinity, together with physical aspects such as texture and structure. In situations where reconstructed soil profiles may be very different to those prior to mining (e.g. rehabilitated rock storage facilities), it is often appropriate to search more widely for similar soils and consider the particular vegetation communities that are supported by those soils (Jasper and Braimbridge 2006).

Pre-mining characterisation can extend to attributes of landforms. For example, at the Paddington Gold Mine near Kalgoorlie (WA), individual natural landforms within the area were assessed to determine their slopes, soils and vegetation characteristics. These characteristics were then incorporated into design of the landforms and associated rehabilitation (Loney 1998). Subsequent monitoring indicated that rehabilitation of the landforms at this site was performing well (OES 2004b).

As an additional measure of natural soils and landscapes, it can be useful to have information on rates of erosion from local natural landforms as a baseline for future comparison. This approach has not been commonly reported. Although at the St Ives Gold Operations near Kambalda (WA), rainfall simulation has been used to examine the processes of infiltration, runoff and erosion on both existing waste landforms and an undisturbed natural site (Vasey et al. 2000). Data from the natural site allowed a direct comparison with current erosion rates on unsuccessfully rehabilitated waste landforms, as well as indicating rates to be expected once a rehabilitated vegetation community had established.

T1.4.2 Characterisation of waste materials for optimal placement in waste landforms

Rehabilitation strategies at each site are largely dependent on the properties of the materials to be rehabilitated and on the attributes of the target vegetation community. It is for this reason that recent rehabilitation guidelines (e.g. DoIR 2006; DTIR 2006) are less prescriptive and refer only to the requirement to characterise materials and undertake rehabilitation in accordance with waste material properties. Important properties include acidity, salinity, sodicity, erodibility, particle size distribution, strength, water-holding capacity, hydraulic conductivity, potential for acid formation, nutrient and metal availability and biological components (Jasper and Braimbridge 2006). All of these properties will influence the success of rehabilitation.

Geochemistry and acid formation

Geochemical characterisation of waste and tailings is now widely practised throughout the industry as a standard element of mine planning. Sufficient sampling is required to estimate sulphide and carbonate mineral abundances and minor-element enrichments at the 'metre scale' (Campbell 2006). Adequate drilling and sampling should be undertaken within the waste-zone to formulate a generic waste-zone model for the deposit (Campbell 2006). More detailed characterisation is sometimes practised, such as that recently developed by Ansto Minerals to characterise the reactivity of sulphidic materials at Mt Tom Price Iron Ore Mine WA (Bennett et al. 2005). The geochemical characterisation work undertaken for the proposed Olympic Dam expansion analysed 2.5 million samples.

Erosion

Tunnel erosion is a common cause of erosion failure on waste landforms (Vacher et al. 2004). Some materials may be particularly susceptible to tunnel erosion and the risk of tunnelling and exposing reactive materials is a consideration when determining the strategy and sequence for placement of materials within waste landforms. Initial assessment of soil chemical and physical data is required using properties such as electrical conductivity, exchangeable sodium percentage, particle size distribution and clay mineralogy followed by, if required, tests to specifically assess susceptibility to tunnel erosion, such as the pin-hole test (Vacher et al. 2004)

Industry examples of the application of waste characterisation

A recent example of detailed waste characterisation was at the Newmont Tanami Operations in the Northern Territory, where tailings and waste rock were characterised for the following parameters: Emerson class value, CEC, clay % ratio, ESP, dominant particle size, fines fraction (% material <5 mm), clay fraction (% material <2 μm), durability of rocks, electrical conductivity (EC) and mineralogy (XRD). These physical and chemical parameters were then used to rate the likely stability on a landform of each material, such that an appropriate location for placement within the landforms could be determined (TMJV 2004). This data was also used to develop a gully assessment system for long-term erosion monitoring.

A second example of waste characterisation to enhance rehabilitation outcomes is a current program for BHP Billiton Iron Ore in the Pilbara region in WA. Materials that were considered most likely to be available as a rehabilitation growth medium over the life of each mine were analysed for likely stability (physical properties) and capacity to support plant growth (availability of water and nutrients). Properties measured included soil texture, slaking and dispersion properties, rockiness, strength of soil crusts, pH, electrical conductivity, nutrients, exchangeable cations and exchangeable sodium percentage (OES 2005a). The primary outcome of this work was to develop initial recommendations for the choice of materials as 'plant growth media' suitable for the outer surface of landforms. As part of this study, rainfall simulation investigations are being conducted on the waste materials with the objective of providing a measure of their actual erodibility. Field data will then be correlated with predicted erodibility of the materials based on physical and chemical properties. The subsequent relationship between predicted and actual erosion will allow the performance of waste materials to be more accurately predicted in the future with lessons learnt transferred to other BHP Billiton mines such as Olympic Dam.

T1.4.3 Removal and management of vegetation and topsoil

Appropriate re-use of topsoil, and possibly subsoils, is essential for achieving a successful and timely rehabilitation outcome. Topsoil is valuable because of its store of seeds, organic matter, nutrients and soil microbes (Jasper 1994), all of which are absent from mine wastes. Topsoil should be viewed as a strategic resource that, if properly salvaged, preserved and respread, can significantly reduce revegetation timeframes (DoIR 2006).

In a December 2005 review of the Australian mining industry for topsoil and vegetation handling, undertaken by Outback Ecology for the BHP Billiton Ravensthorpe Nickel Operation (OES 2005b), the following techniques were determined to be leading practice:

- baseline soil and vegetation assessment to identify heterogeneity of topsoil and subsoil material in relation to vegetation communities to develop recommendations for depth of appropriate stripping operations
- mapping of soil and vegetation units
- salvage of vegetation for return to the surfaces of appropriate stockpiles or to rehabilitated areas. Where possible this is not done during periods of flowering and seed-set. The vegetation mulch provides surface protection and is a source of seed and organic matter

- stripping of soil during drier months
- using low-salinity water, if available, for dust suppression during soil handling operations
- direct return of topsoil where possible to areas ready to be rehabilitated
- if stockpiling is necessary, then paddock-dumping of topsoil in swales in an area not to be disturbed to a maximum depth of 2 m. The soil stockpiles are created by placing successive truckloads of soil sufficiently far apart to create depressions between loads. This acts to collect water and promote germination and plant cover. In general the layout of the stockpile facilitates free draining, aerobic storage conditions
- separate stockpiling of topsoil and subsoil, including separation of different soil units where applicable
- recording of relevant information regarding material in individual stockpiles (e.g. soil type, vegetation unit, date of stripping, soil volumes, seed mix, proposed use)
- constructing stockpiles to reduce erosion
- seeding of topsoil stockpiles, directly following placement, to enhance erosion control and promote biological activity in the soil. Identify stockpiles with appropriate signage and record locations on site maps
- implementation of a weed control strategy for stockpiled soils
- screening soils to remove gravel fraction, where applicable, and thus concentrating valuable components such as soil stored seed. This is most applicable if topsoil is to be used immediately, but may need to be transported long distances
- collection, storage and return of habitat trees and logs, where applicable, to rehabilitated areas
- undertake field trials to determine most appropriate re-spreading depth, ripping or scarifying treatments, nutrient requirements and amendment for surface stability.

T1.4.4 Soil profile reconstruction, including store-and-release surfaces, to support post-mining land use objectives

The appropriate reconstruction of soil profiles using mine waste to support native vegetation is an important challenge in rehabilitation. Components of constructed soil profiles to form a growth medium include topsoil, subsoil and benign waste. Possible addition of more specialised layers for particular purposes, such as a clay barrier seal or a capillary break layer, can be considered. The sources of surface materials may be diverse, typically reflecting those available at each site, with examples including topsoil or oxidised waste rock compacted silty sandy-clay, clayey oxidised waste rock, or benign fine-grained tailings fresh waste rock with minimal fines, or quarried rock with minimal fines (DITR 2006).

Topsoil and subsoil

Ideally, a reconstructed soil should have fresh topsoil (50–100 mm) over a subsoil (at the metre scale), which accommodates root growth and stores adequate plant-available water. The total depth of topsoil to be used in rehabilitation is governed by factors such as the target vegetation, the quantity and quality of the soils available and the nature of the underlying material (DITR 2006). It is important that on sloping surfaces adequate erosion protection is achieved by using rocky topsoil or incorporating rocky materials. If the topsoil is prone to erosion then only shallow layers are to be used.

If the underlying material does not have major limitations to plant growth, such as high salinity, then as little as a 50 mm layer of topsoil may be adequate for establishing vegetation (DITR 2006). However, if the underlying material does have limitations to plant growth, a 100–200 mm layer of topsoil used in combination with a capillary break may be more appropriate. The effective rooting depth that is created will determine the long-term nature and productivity of the vegetation, including species richness, diversity and production (Bowen and Schuman 2005). The optimum combination of topsoil and subsoil depth, capillary breaks, ripping depths and possible soil amendments is specific to each site and is to be identified by conducting trials from the earliest possible stage of the mining operation.

Typical examples of soil profile reconstruction that have led to successful rehabilitation outcomes include the Bottle Creek Gold Mine in WA, where soil profile reconstruction included 500 mm of waste rock, topsoil to an average depth of 100 mm and deep ripping along the surface of the contour (Anderson et al. 2002). Similarly, at the Paddington Gold Mine near Kalgoorlie, successful rehabilitation has been achieved with layers of topsoil to 150 mm depth over mine waste prior to ripping, seeding and fertilising (Loney 1998). At the BHP Billiton Mount Keith operation, profile reconstruction comprises caprock spread to a thickness of 300–400 mm, with topsoil to 100–150 mm and then contour ripping to a minimum depth of 800 mm using winged tynes, with a maximum space between rip lines of 3 m (MKO Nickel West 2005).

Capillary breaks

A layer of coarse material forming a capillary break may be included as part of reconstructed soil profiles, on saline waste material such as tailings to prevent the upward movement of salt. For example, incorporating a capillary break of coarse rocky waste with appropriate particle size distribution under a constructed surface on hypersaline tailings was shown to be effective in preventing upward movement of salt and thus allowed vegetation establishment over a substrate otherwise unsuitable for plant growth at the KCGM operations in Kalgoorlie, WA (Bussell 2000). By establishing a capillary break of as little as 200 mm thick on the tailings surface, surface soil remained at approximately 10 to 20 dS/m (EC_e), compared to 50 dS/m (EC_e) without the capillary break (Bussell 2000).

Store-and-release surfaces

Store-and-release surfaces are essentially a constructed soil profile that is designed with an additional specific objective of preventing deep percolation of rainfall. These surfaces are applicable in many situations in rehabilitation in the arid zone. In semi-arid/arid settings, where oxygen availability is invariably non-limiting, water availability is the rate determining factor for sulphide oxidation (Alarcon Leon et al. 2004). Therefore, where potentially acid-forming material is being contained within a waste landform, a store/release surface can reduce infiltration of water through the profile and the subsequent generation of acid.

Store-and-release surfaces consist of a layer of soils or mine wastes, possibly over a compacted clay barrier and/or a coarse capillary break. By absorbing and storing incident rainfall, percolation into underlying wastes is minimised. Soil moisture is 'released' from the surface layers through evaporation from the soil surface and evapotranspiration by vegetation. Therefore, maintaining a living vegetation cover to maximise evapotranspiration losses is an important component for a successful store-and-release cover (Williams et al. 2005).

An example of a store-and-release surface over potentially acid-forming material is at the Kidston Mine, where a compacted clayey soil seal about 500 mm thick was placed on a 3% grade dump surface, overlain by vegetated rocky soil mulch hummocks to a minimum depth of about 1,500 mm (Williams et al. 2005). Clay barrier layers such as this example are designed to be perpetually saturated and are only appropriate in areas receiving sufficient rainfall.

A further example of the use of store/release surfaces to manage potentially acid-forming wastes is the closure of the Mt McClure Gold Mine (WA) which was awarded a Golden Gecko Award for Environmental Excellence from the WA Government. Detailed water-retention studies were conducted on the various benign waste materials at the site and 'oxide' regolith and 'caprock' were selected and placed at sufficient depth (1,000 to 1,500 mm) to minimise rainfall percolation to underlying wastes (Campbell 2004). Using the same principles, surface thicknesses of 2,000 mm and 4,000 mm regolith were used in trials at the Mt Whaleback Iron Ore Mine near Newman (WA) and resulted in surface storage capacities of 100–200 mm and 200–400 mm respectively (O'Kane and Waters 2003).

In an example from North America, a surface trial on a tailings storage facility at the Morenci Mine in Arizona compared 300 mm and 600 mm of surface material with sparse or dense rangeland vegetation coverage, resulting in surface storage capacities of 30–90 mm (Milczarek et al. 2003; in Campbell 2004).

The water-retention capacity of surface materials and the depth at which they are placed are the critical factors affecting both function of the surface in reducing percolation and the supply of sufficient plant-available water for vegetation to survive in dry periods. Both aspects need to be understood to establish a successful store-and-release surface.

Non-specific surface approaches for tailings

While plant rehabilitation at the Olympic Dam tailings storage facility is not recommended due to the possible metal uptake by vegetation, the following provides some typical industry practices for rehabilitation of tailings storage facilities (TSF). Lacy and others (2004) summarised non-specific surface approaches into five categories, dependent on the nature of the TSF, as follows:

- Physical stabilisation – the application of a coarse mulch layer to counter the erosive effects of wind and water. This needs to be resilient and stable over time to protect the local environment. It can be conducive to plant colonisation through provision of germination niches and a favourable microclimate(s). Materials that are typically used include: oxide waste rock, laterite waste rock, topsoil, competent fresh rock (non-acid forming), mill scats and alluvial mining gravels. Physical barriers such as fences or artificial barriers are also used to achieve initial stabilisation.
- Vegetative stabilisation – depends on the suitability of the tailings to directly support plant growth and relies on vegetation to create the same effects as a physical barrier while returning the TSF to a beneficial use
- Chemical amendments – alter physical structure or chemical make-up of the tailings to make them conducive to the establishment and survival of plants and include gypsum, PVA-type compounds, lime and fertilisers.
- Chemical stabilisation – may be used in circumstances where the surfaces are unstable. Sealants can be sprayed or incorporated into the surface of the tailings to create a hard or non-erosive crust, to prevent wind and water erosion. Examples include resinous adhesives, bitumen-based compounds, sodium-silicate chemicals (geopolymers), lignosulphonates, cement and elastomeric polymers.
- Combinations of these treatments can be used. Hydro-seeding is an example of stabilising processes using a combination of physical, chemical and vegetative stabilisation.

T1.5 SPECIES SELECTION AND SEED MANAGEMENT

T1.5.1 Plant species selection

Species selected for rehabilitation should occur within the general area of the site concerned to ensure adaptation to the climate. Importantly, this selection should also reflect the chemical and physical properties of the soils in which they naturally occur in relation to those in which they will be established. Not all local plant species will necessarily be available or suitable for revegetation programs. Some species reproduce vegetatively, set small amounts of seed infrequently, or have dormancy issues that are difficult to manage. Further, they may be climax community species with very specific soil and aspect requirements not suited to the early successional environments on mine landforms. Consequently, target species may be those that are collectable in quantity, are relatively straight forward to process and store, have defined treatments for dormancy release and are recognised as early coloniser species or 'generalists'.

Further investigation of plant reproduction biology and soil-vegetation associations at Olympic Dam if and when operations commenced would assist in refining this list.

A list of plant species that are likely to be important in re-establishing vegetation on disturbed areas at Olympic Dam is included in Appendix T2. However, further investigation of plant reproduction biology and soil-vegetation associations at Olympic Dam if and when operations commenced would assist in refining this list. A summary of information on the key families and species follows:

AMARANTHACEAE

- Main genus is *Ptilotus*, which is widespread in the Australian arid zone and characterised by many annual species, with some perennials.
- Have been actively used in mine rehabilitation with varying success, some species being well-adapted to colonising disturbed ground.
- Seed requires appropriate personal protective equipment when handling as it is an irritant to skin, eyes and respiratory tracts.

ASTERACEAE

- Family contains significant number of species that are generally ephemerals.
- Mechanically-harvestable in favourable seasons.
- Have not been very successful in mine rehabilitation, but it is unclear if this is a seed quality and/or a soil related issue.

CHENOPODIACEAE (Chenopods)

- Several genera that are keystone species for arid and semi-arid mine rehabilitation.
- Comprises annual forb and sub-shrubs through to long-living perennial large shrub species that can colonise disturbed and hostile soils.
- Seed is easily collected by hand in large quantities in good years, with many species responding quickly to rainfall events.
- *Maireana* and *Atriplex* are the most suitable genera, with many species that can be cultivated for seed production.
- *Chenopodium, Einadia, Enchylaena* and *Rhagodia* are generally collectable.
- *Scleroleana* is widespread and a useful ground cover but difficult to handle due to spiny fruiting bodies and seems to have germination inhibitors that need further investigation.
- Seed of this family has shorter storage life than most others.

FABACEAE

- With the genera *Acacia* and *Senna*, this family is important in terms of arid land mine rehabilitation.
- *Acacia* dominates as an overstorey or midstorey shrub/small tree across much of the arid lands. Many species are generalists, while others are specific to particular habitats.
- Seed ecology is relatively well known and dormancy easily countered.
- In good years seed can be obtained in large quantities and can be stored under appropriate conditions more or less indefinitely with minimal loss of viability.
- Seed is easily processed and offers good storage efficiency in terms of weight to volume.

MALVACEAE

- Offers potential in mine rehabilitation but more work is required on its seed ecology.
- Several species may be suitable for seed production.

MYOPORACEAE

- Mainly the genus *Eremophila*, which features in many arid land vegetation systems, often as the dominant species in a climax community.
- *Eremophila* species have been regularly included in mine rehabilitation seed mixes but with poor germination, due to inadequate seed pre-treatment.
- More easily propagated vegetatively than from seed.

MYRTACEAE

- Includes the genera *Eucalyptus* and *Melaleuca* and is very important in land rehabilitation.
- In the Olympic Dam region, both genera have very specific habitats and vegetative community associations.
- Unless specific habitats are to be rehabilitated (e.g. borrow pits), or re-created in landforms, they may have little application except for amenity use.

POACEAE

- A range of annual and perennial grasses, that have been utilised in mine rehabilitation programs when available but with limited success, most likely due to issues related to seed ecology and quality, and soil properties.
- In good seasons, seed is mechanically-harvestable and many species lend themselves to cultivation for seed production.
- Relevant information available on temperate native grass species that can be applied to arid lands.

PROTEACEAE

- In the project area this family includes the genera *Grevillea* and *Hakea*.
- Has application in land rehabilitation, although the cost of seed procurement often prohibits their inclusion in direct seeding.
- Family has woody fruits that have to be removed from the plant to be stimulated to open, with each fruit only containing 2 seeds, making seed collection very labour intensive.
- Appropriate species often included in seed mixes at low rates.

SAPINDACEAE

- The genera *Alectryon* and *Dodonaea* occur in the project area and are suitable for inclusion in rehabilitation.
- Seed is generally collectable in good quantities in favourable seasons.
- Hard seed coats promise suitability to prolonged storage times.

SOLANACEAE

- This family has a range of potentially suitable genera for rehabilitation (e.g. Wild Tomato *Solanum* spp.).
- More work is required on dormancy issues especially for the genus *Solanum*.
- Certain species have potential for cultivation for seed production.

ZYGOPHYLLACEAE

- Has genera that are known to be successful in arid land rehabilitation, particularly *Zygophyllum* and *Nitraria*.
- Many species are colonisers of disturbed ground and are easily collected by hand. Availability in favourable seasons is usually good, with most of the *Zygophyllum* species potentially suitable for cultivation for seed production.

T1.5.2 Seed collection, storage and treatment

The basic procedure for the procurement of native seed as outlined by Linington (2003) is targeting and collection, seed cleaning and drying, viability testing and packaging and storage.

Typically in the arid zone, seed for mine rehabilitation is contract-collected in the season prior to rehabilitation, although a less-preferred option is to acquire seed from commercial stocks. The latter approach will often compromise provenance and limit the range of species that can be used. In some cases, mining companies have developed site-based, seed storage facilities, with seed collected by company personnel or contractors. However, despite the significant investment in capital and labour to procure the seed, it has proved difficult for sites to maintain seed quality in storage, with seed being vulnerable to insect and rodent attack as well as variations in temperature and humidity. A further issue in seed management is that seed is often used in rehabilitation programs without baseline data on quality, storage history, and other factors that may affect germination in the field, making it impossible to fully understand the factors contributing to rehabilitation outcomes.

'Seed Production Areas' or 'Orchards' are an emerging technology that can be utilised to supply seed from difficult-to-obtain species and to improve reliability of supply for core rehabilitation species, particularly annual and perennial forbs, herbs and grasses. This technology involves cultivation of specific species to produce seed, and is being applied successfully to the production of temperate native grasses and has the potential to reduce supply risk for arid land seeds. Such an approach would require an investment in research and development, with dedicated personnel to implement trials for establishment and harvesting.

Appropriate storage of native seed is critical to seed quality. Seed banks or seed stores may range from basic sheds or sea containers, to more advanced facilities with temperature controlled environments. The most significant recent development in terms of leading practice seed management has been the Millennium Seed Bank Project based in the United Kingdom. Publications produced for that project and the Australian Florabank guidelines developed by Mortlock (1998) offer detailed and appropriate information on storage of Australian native seed.

Timing of seed collection

Seed collection for arid land mine rehabilitation requirements has generally been subject to a short-term planning cycle. Typically, planning revolves around annual financial budgets and the anticipated rehabilitation requirements for the following season, and does not allow for the longer-term climate cycles typical of Australia's arid regions. Put simply, the greatest quantities of quality local-provenance seed, and the broadest range of species, are only available in exceptional (high rainfall) seasons. Above-average seasons may also be suitable for harvesting some key species, particularly the shorter-lived perennial and annual forbs, herbs, grasses and shrubs.

As an indication of likely seed production frequency, long term rainfall records from Roxby Downs were matched against map data of rainfall distribution across Australia represented as growing seasons rather than calendar years (see Flood and Peacock 1998). Rainfall records spanned from 1931 to 2003, although years 1978 to 1981 were missing. In summary, in the 72 years of rainfall data supplied there were:

- 6 exceptional growing seasons – where rainfall was either double or triple long-term averages, or two consecutive above-average seasons combined for an excellent growing season
- 4 good growing seasons that would most likely allow for collections of a wide range of species
- 6 seasons that would represent collection opportunities for core revegetation species (e.g. *Atriplex vesicaria*)
- 26 years exceeding the long-term average of 167 mm. Average to above-average seasons will still allow seed collection opportunities, but the breadth of species available will be significantly reduced along with the quantity and quality of seed available. However, seasons such as this will allow for 'topping' up of seed reserves with key revegetation species.

This review indicates that exceptional and good seasons occur, on average, once every ten years. It also infers that only one out of every 3 seasons will provide good seed collection opportunities for local provenance collection. As such, on-going seed collection throughout the mine life is required to maintain seed store stocks in arid/semi-arid environment. In exceptional or good seasons, effort should focus on collecting species that only occur in quantity during optimal growing conditions (e.g. *Swainsona formosa* and *Acacia aneura* amongst others) as these periods may offer the opportunity to procure 10–20% of total seed requirements if enough resources are mobilised.

Tendering of seed collection to contractors

Mining operators often prefer to undertake their own seed collection programs using dedicated or general personnel. This can be successful, especially when there are only limited areas or very sensitive environments to be rehabilitated. Having personnel dedicated to this task can be advantageous, as they can react to rainfall events and the subsequent flowering and fruit set of ephemeral species. However, the scale of the proposed expansion at Olympic Dam will require large quantities of seed for which suitably experienced and qualified contractors may be required to capitalise on the limited windows of opportunity that are presented by good seasons.

It is current industry practice to contract a collector for one to three seasons of provenance collection. The seed is generally collected at a kilogram rate, rather than a day rate, with prices set during the tendering process.

This practice could be improved by the contract including the following:

- A target list of species required for the rehabilitation with flexibility to allow for seasonal availability.
- Maximum quantities required for the given season based on species percentages in seed mixes, predicted storage life of the seed and seasonal availability.
- Quality parameters (i.e. minimum acceptable standards for purity, viability and germination) allowing for seasonal variation and its effect on quality.
- Pricing based on a kilogram rate to ensure efficiency and productivity.

- Designated collection zones in relation to distance from the rehabilitation site. If seed is not available from a designated zone, allowance should be made to collect it from a compatible land system. For example, the Native Seed Collection and Management Procedures employed by BHP-Billiton Nickel West's Mount Keith Operations (Lakis 2005) make this allowance, following consultation between environmental personnel and contractors.
- Contractors to supply field processing equipment, but be given access to final processing at the seed storage and processing facility. Ideally, if a purpose-built facility was constructed, the seed would not need to leave the site.

Facilities for seed management

The expanded operations at Olympic Dam may justify constructing a purpose-built facility for the processing and storage of seed, given the long predicted mine life. Should this occur, those elements considered essential to meet its intended purpose are discussed below (see also Table T1.2 for a threat and response profile).

Table T1.2 Properties of a seed storage facility

Threat	Control / response
Humidity and temperature	Store in controlled environment
Insects	Fumigate with inert gas, bait storage containers (i.e. mothballs)
Rodents	Store off ground and/or in sealed containers. Active baiting. Seal main storage area to minimise access.
Fungal attack	Adequate drying during processing, store in controlled environment
Ultraviolet light	Store in dark area, out of direct sunlight (opaque containers)
Water damage	Store off ground and/or in sealed containers

A large, insulated shed could be the basis of the seed bank facility, with the following areas recommended:

- Holding area. Initial collections of material are likely to be bulky and a large, temporary storage space is required for seed as it is collected and field processed (initial drying). This area needs to be weather and rodent proof, with measures taken for insect control (e.g. baiting).
- Processing centre. This area would contain equipment for cleaning and treating the seed to enhance germination potential, as well as batching and mixing seed for application in rehabilitation. Good ventilation and dust extraction equipment is essential for health and safety of personnel.
- Controlled-humidity drying room. This is utilised to desiccate seed and improve longevity. Some species may require drying before cleaning, although many may only require 'final' drying before storage. The preferred conditions are a temperature of 10–25 °C and a relative humidity of 10–15%.
- Main storage area. Where all seed is stored after drying and cleaning. This area would need to be air-conditioned and have low relative humidity. Long term storage requires -18 °C as a minimum at 3–7% moisture content (Linington 2003), although if seed is used more rapidly a constant temperature environment is sufficient. This area needs to be insect, rodent and moisture proof. Soft seeds require approximately 1 cubic metre for 50 kg of seed, with 200 kg of hard seed per cubic metre. The main storage area should accommodate at least 10,000 kg of each of hard and soft seed (i.e. about 250 cubic metres of seed requiring a shed about 20 m x 10 m x 5 m).
- Office / laboratory. A dust proof area to maintain the database and undertake seed testing.
- Lunchroom / toilet.

An important safety aspect of such a facility is to limit staff exposure to the dehydrating conditions of the drying room and the final storage area. Wheeled containers assist in this aspect and 'Wheelie' bins, as used for rubbish and recycling, are very suitable as they have been designed to be weather and rodent resistant, and easily moved by personnel. Heavy seeds (i.e. hard seeded species) are best stored in laminated plastic bags in lots of 5 kg or less and treated with inert gas (e.g. CO_2), which both fumigate the seed and slow its metabolic rate through deprivation of oxygen (Mortlock 1998).

A stock management system that uses barcodes and portable scanner technology is valuable so that personnel can efficiently locate and manage the seed contained in the seed store. Information recorded in such a system may include:

- collection details (e.g. location, vegetation association, soil type, date, processing time)
- viability, germination and purity information
- recommended dormancy-release treatments.

Seed testing and treatment

Baseline testing of seed is essential to achieving the best outcomes in a rehabilitation program. Generally, testing should provide the following information:

- germination (the number of seeds capable of germinating)
- purity (the amount of inert material represented as a percentage of the total weight of the sample).

The most important aspect in mine rehabilitation is the number of germinable seeds per gram. Viability tests alone are not a direct measure of the number of seeds capable of germinating (Gosling 2003). This, along with the physical size of the seed (number of seeds per gram), will determine the seed rates to be used for each species.

Treatments to enhance germination

Many Australian native species have physical controls (hard-seeded) or physiological inhibitors (dormancy) that determine germination. These strategies are generally linked to protection from extreme environmental factors such as high temperatures, uncertain soil moisture availability and competition from other species. The seed ecology of native species is often complex and may be poorly known for many of the species of interest in the Olympic Dam region. Preferred treatments for each species can be determined as part of the seed testing process. It is important to utilise methods that can be applied consistently to large volumes of seed, such as:

- Hot water treatment or mechanical or acid scarification of hard coated seeds. It is considered best practice to only treat a percentage (usually 50%) of such species to leave a 'store' of hard seeds in case of germination failure arising from adverse climatic conditions.
- Smoke may assist some species, but this is not as critical in arid zones as in other Australian ecosystems.
- Capsule release, which involves removal of the fruit from seed that is a naked caryopsis only. This contributes to a far higher rate of laboratory germination in most chenopod species and some native grass species. However, work on the native grass *Austrodanthonia fulva* demonstrated that while laboratory germination was vastly improved, field germination decreased (Cole et al. 2004). Removal of the fruiting body allows the estimated number of germinable seeds per gram to be qualified, although the naked seed will require some sort of protective coating.
- Giberellic acid, like smoke treatment, this may assist germination of certain species.

Seed coating

Seed coating or pelleting of agricultural seeds and some native species is a proven practice, with seed usually coated with a clay-based surface, with inoculant and fertiliser sometimes included. However, coating technology continues to improve with the refinement of polymer coatings that limit damage to seed during the coating process. A range of additives also gives new opportunity to improve revegetation success. Seed coating allows in the field 're-protection' of species that are known to have improved (laboratory) germination after removal of the fruiting body. For seeds that are difficult to sow, seed coating can provide improved specific density and facilitate better calibration of mechanical seed application equipment. Coating additives can include:

- fungicides
- trace elements
- insecticides
- hydrophobic elements, to limit 'false starts' in seed germination
- hydrophilic elements to attract moisture to assist germination.

T1.6 PLANT ESTABLISHMENT

Establishment of a diverse vegetation community can involve the use of direct topsoil return, seeding, hydroseeding, planting of seedlings (including from tissue-culturing), translocation and habitat transfer and natural re-colonisation (DITR 2006). Where it is not feasible to allow natural revegetation to occur, for example due to the distance from appropriate undisturbed vegetation, then direct seeding is considered the main revegetation method for rehabilitation at Australian mine sites.

A typical example of arid zone rehabilitation is at the Fortnum Gold Mine (WA), where a combination of native seed collection, germination and sapling relocation resulted in the establishment of successful rehabilitation (Lacy and Slight 2005). At the proposed Coburn Mineral Sands project near Shark Bay (WA), additional strategies proposed are to treat seeds of recalcitrant species to increase germination potential, and seeds of late successional species to prevent insect and fungal attack (URS 2005a).

T1.6.1 Plant establishment techniques

Role of a nursery and the use of seedlings

Seedlings, generally referred to by the nursery and revegetation industry as tube stock, have limited application in arid land mine rehabilitation. This is due to the expense in acquisition and planting of the tube stock and the requirement for some ongoing reticulation to enable adjustment to natural environmental conditions. Tube stock use may be suitable on a small scale or where there is a desire to establish rare flora species that are difficult to grow from direct seeding ('recalcitrant'). This approach uses specialised seed treatments, cuttings or tissue culturing, which is routinely practised by Alcoa World Alumina in restoration of jarrah forest in Western Australia (Koch et al. 1994). Continued advances in water-retaining soil applications may increase the practicality of using tube stock in arid environments. However, inputs into seed biology research, procurement and storage, together with soil characterisation and handling, will yield better long-term results for rehabilitation than investment in a horticultural operation.

Hand seeding

Hand seeding is most appropriate for small areas, although it is labour intensive and there are safety issues when on rough or steep terrain.

Mechanical seeding

Mechanical seeders may be mounted on a bulldozer with a multi-shank ripper box, enabling a one pass operation that contour rips, seeds and fertilises in a single pass. Usually, these seeders are designed to be quickly fitted to a range of suitable platforms. The seed boxes facilitate application of a large range of seed, but require a competent operator to successfully calibrate the seed rates. Seed is best applied directly to freshly-ripped material, allowing good seed-soil contact. Average completion rates are around 10 hectares per day, assuming a 12-hour shift, meaning that large areas can be completed reasonably quickly. Mechanical seeding would be the most appropriate technique for applying seed to store-release surfaces on top of waste landforms, TSF surfaces and slopes of less than 20°.

Applying seed in hydromulching

Hyrdomulching is widely used for the stabilisation of civil works and mining operations, particularly in highly erosive conditions (e.g. sandy or steep) where rapid stabilisation is required to limit soil erosion. Hydromulching involves application of a mixture of paper pulp, a glue (referred to as a tackifier), dye, seed and fertiliser (if required), via a high-pressure water cannon mounted on a mixer truck.

Hydromulching has been trialled in the WA Goldfields and although relatively successful, it is expensive ($0.35–0.45 per sqm) and holds little advantage over conventional mine rehabilitation techniques, such as contour ripping and seeding. However, it is useful in selected areas where immediate surface stabilisation is required. It is recommended that seed is applied first, although this is less critical if the tackifier is not added.

The hydromulching / seeding process is likely to be most useful for angle of repose slopes that are unsuitable for mechanical or hand seeding. However, the size of the slopes can be a limiting factor. The largest, most powerful hydromulching units have a maximum delivery range of 40–50 linear meters (R. McInnes and G. Kerr, pers. comm.).

Aerial seeding

Helicopters can be used to apply seed directly or with hydromulching. Aerial hydromulching would be complex and expensive, as three mixing trucks are needed to support one helicopter. Consequently, a large area would need to be treated to justify mobilisation of the equipment. Direct aerial application of seed may be limited by the variability in specific density of the seeds of native species, although this may be overcome through seed coating.

Surface preparation and protection

Natural vegetation communities in arid and semi-arid areas rely on the harvesting or focusing of water and nutrients to support the establishment and sustainability of patches or bands of perennial vegetation (Tongway and Hindley 2004). 'Banded' and 'island' vegetation systems are thus typical of arid landscapes and support the principle of creating core habitats in rehabilitated areas. Through the creation of a patchy array of habitats and community types, a landscape can support a greater overall biodiversity than an evenly spread, uniform community.

An extension of this concept for plant establishment is to rip the soil surface using winged ripping tynes. This is common practice on most mining sites as the resultant ripline harvests water, provides a range of habitats and, if placed on the contour correctly, helps to minimise run-off and rill erosion. For flatter areas with lighter, deeper soils, the use of a large, offset, scalloped disc will achieve a similar result. Unless surveyed precisely, grader-built contour banks and similar larger scale earthworks are unnecessary if the only objective is to establish vegetation.

In areas where a sandy substrate is used in rehabilitation, it may also be necessary to stabilise the surface to minimise wind erosion and allow vegetation establishment. A recent arid zone example is the dune stabilisation that has been undertaken along the length of the Gas Pipeline Corridor from Port Hedland to Telfer Gold Mine (OES 2005c). Four treatments were used:

- soil stabilisation spray (Gluon 240®)
- hessian fencing
- geo-textile matting (jute mesh 'Soil Saver®')
- supplemental seeding (no soil surface treatment).

Observations on field performance of these treatment options in sand dune environments were that:

- Dune surfaces sprayed with Gluon 240® had a continuous, robust and stable surface crust that was resistant to wind. Germination of native seedlings through this surface crust was observed. Advantages of this stabilisation technique include retention of seed stock following seeding and binding of vegetative mulch to the dune.
- Hessian fencing was not effective. Although the fences were built to a height of 900 mm, to be effective they would need to be higher, be constructed of more permeable material and have additional reinforcing.
- This rehabilitation work used only a small area for trialling the geo-textile matting and it was not possible to draw conclusions on its effectiveness, although it was considered that application on larger unstable dunes would be impractical (OES 2005c).

At the Namakwa Sands Mineral Sands Mine in South Africa, the use of windbreaks resulted in vegetation becoming established adjacent to the windbreaks before advancing between them (URS 2005b). Similar barrier fencing concepts are commonly used on mineral sand mines across Australia to minimise wind erosion.

An application of vegetative mulch is also beneficial in providing some physical surface protection as well as a source of organic material for soil improvement and a potential source of seed. Wind-blown sand can accumulate around the vegetative material, creating a mound and increasing surface roughness (OES 2005c). Wherever possible, vegetation that is removed prior to soil stripping should be retained and spread in suitable areas to take advantage of these attributes. For rehabilitation of mines in heathland environments, it has become routine practice to mechanically harvest standing vegetation prior to mining, and to immediately spread the vegetation mulch over topsoil that has been respread (Jefferies et al. 1991), which can contribute a substantial proportion of seed.

Creation of fauna habitat

The key components of fauna habitat, such as hollows in trees or logs and soil burrows, may not be present within rehabilitated areas for decades and hence it may be valuable to construct potential habitats in some rehabilitated areas should this be an agreed post-mining land use. Creation of fauna habitat from rocks and logs is routinely carried out at bauxite mines in the south-west of WA (Nichols et al. 1991). At the Wheelara Hill BHP Billiton iron ore operation near Newman, Western Australia, it is intended that fauna refuge areas be created through the selected placement of timber and/or boulders across the re-profiled surface together with the creation of rocky cliff features, vegetation debris, logs and rocks (BHP Billiton Iron Ore 2005).

T1.6.2 Controlling threats to rehabilitation success

Threats to the successful establishment of vegetation include weeds and grazing animals such as goats, stock, kangaroos and rabbits. Leading practice in rehabilitation involves planning and implementation of controls for these threats.

A review of the risks presented by weed species at Olympic Dam (Pethybridge 2002) identified that a more co-ordinated and strategic approach to weed management was required at the site. While there are a number of species that could be considered to represent immediate threats (e.g. *Tamarisk aphylla* – Athel pine), this review has focused on those species that may inhibit revegetation outcomes.

Species listed in the Weed Survey and Risk Assessment by Pethybridge (2002) that may have an impact, or have been demonstrated to impede successful mine rehabilitation in similar arid conditions include:

- *Echium plantagineum* (Salvation jane)
- *Asphodelus fistulosis* (Onion weed)
- *Xanthium spinosum* (Bathurst burr)
- *Cenchrus ciliaris* (Buffel grass)
- *Acetosa vesicaria* (formerly *Rumex vesicarius*) (Ruby dock)
- *Salsola kali* (Roly poly).

Of these, two of the most potentially problematic weeds are *Acetosa vesicaria* (Ruby dock) and *Cenchrus ciliaris* (Buffel grass).

While only an annual species, *Acetosa vesicaria* is a rapid coloniser of disturbed sites and poor soils and may inhibit germination of desirable species. *Acetosa vesicaria* routinely adds to the rehabilitation cost of mine landforms throughout the Western Australian Goldfields because control is required by regulation, with labour-intensive herbicide application needed to control further spread.

Cenchrus ciliaris, originally imported into Australia as pasture species for low rainfall areas, is now an invasive weed, particularly in central Australia in the West MacDonald Ranges. It can be found along much of the Stuart Highway along roadsides where it receives additional run-off water. Similarly, in rehabilitation at Olympic Dam it is most likely to be common in areas receiving surface water flow.

Uncontrolled grazing by a range of native and exotic animals can severely limit the establishment and survival of vegetation on rehabilitated areas (e.g. Koch et al. 2004). Observations in arid environments such as on Barrow Island, with high populations of native Australian fauna, suggest that fencing rehabilitated areas can enhance plant density and particularly species diversity as native animals are likely to selectively graze vegetation, particularly seedlings. In addition, introduced animals, particularly goats, are a problem in parts of the WA Goldfields because they favour the elevated landforms and access to water in open pits.

Control measures

A assessment would be made of the risk of weed invasion associated with the Olympic Dam expansion to determine the suitability and applicability of weed control measures for each aspect of the expansion. The following procedures provide a general framework for managing weed risks in areas to be rehabilitated:

- light vehicles should be subjected to an automatic wash-down procedure before and after entering mining areas
- contractor earthmoving equipment entering the site should be either certified weed free or assessed for cleanliness and washed down if required
- mobile equipment that leaves a site to work in another location known to support weeds should be cleaned upon its return
- disturbed areas should be monitored for weeds, with weeds present assessed for their risk for invasiveness and spread and appropriate measures implemented. Road drains and lay-down areas are high risk areas for weed infestation
- exclude stock
- during seed collection, the use of vacuums to harvest fallen seed should be avoided, as there is high risk of contamination by weed species.

Interaction of fauna with the rehabilitated landform will contribute to the introduction of seed and other biological material. During active rehabilitation an effort should be made to exclude feral grazing species and limit native grazing fauna as this would enhance vegetation growth and reduce weed spread.

Industry examples of control of threats

At the Fortnum Gold Mine near Meekatharra in WA, electric fences were installed around the revegetated waste dumps to prevent grazing by cattle (Lacy et al. 1999). In addition, there is on-going control of kangaroos and spraying of aggressive weeds to reduce competition and facilitate the development of sown species. At the Mt McClure Gold Project in WA, goat mustering and culling was undertaken in the mine area prior to closure and a goat-proof fence was constructed around all rehabilitation areas (Lacy and Slight 2005). A comprehensive weed eradication program was also undertaken in the mining and exploration areas with follow up spraying.

In an example from the South Australian arid zone, grazing animals were excluded at the Challenger Gold Operation in South Australia, by fencing the mining lease to prevent access by sheep, with licensed periodic kangaroo culling undertaken in the area. Weed control spraying in rehabilitation focuses on minimising any weed germination prior to native seedlings becoming established.

T1.6.3 Monitoring and completion criteria

Concepts of completion criteria

The overall objective of mine rehabilitation is to establish sustainable landforms and ecosystems that meet the requirements of an identified end land use. Defining the end use is clearly an essential first step. It is also necessary to determine whether appropriate landforms and ecosystems have been successfully achieved. Successful rehabilitation requires that the key physical and biological components of the target ecosystem have established. Logically, success would be measured in terms of the similarity to the target ecosystem. However, the ecological and successional processes that are required to achieve similarity occur over longer timeframes than those that may be acceptable to local stakeholders, regulators or mining companies. Therefore, early indicators that the ecosystem is on track to achieving the target ecosystem are required. These indicators should combine measures of the physical integrity and stability of rehabilitated areas together with observations of the biological environment.

Completion (or performance) criteria are to be developed for each site (DoIR 2006). It is preferred that they be developed from rehabilitation trials and site experience rather than baseline studies of local sites that may have little edaphic or physical/chemical similarity to mine soils. Completion criteria most commonly used for mine rehabilitation in arid environments (EPA 2006) include:

- health and safety considerations
- stable landforms
- suitable for agreed land use (and economic values retained if this was an agreed end land use)
- sustainability without additional inputs
- no significant problems with pollutants
- that hydrology (water quality and availability) is appropriate
- that vegetation is resilient and self-sustaining
- that plant species diversity reaches targets
- adequate control of weeds.

As a comparison, the draft mine rehabilitation booklet from DITR (2006) identifies success criteria being grounded on ecological principles, include the following:

- quality of surface and ground waters at agreed monitoring points is in compliance with agreed conditions
- reconstructed landforms are stable and able to support the intended subsequent land use(s)
- vegetative cover is healthy, persistent and at a level sufficient to stabilise the surface under the pressures of the intended subsequent land use(s).

Where site specific knowledge is limited, the development of criteria should be postponed until sufficient data are available, or the criteria should be based on available knowledge and reviewed and refined as necessary when site-specific data become available (DITR 2006). Ongoing review is also necessary as different criteria may also need to be applied at different stages of rehabilitation.

Monitoring

Monitoring provides the information to gauge if completion criteria have been achieved. The rehabilitation monitoring program is to reflect the criteria or indicators used to assess completion, and therefore should:

- comprise the minimum set of key indicators that when monitored will describe major trends in the development or decline of an ecosystem
- describe the condition of primary elements in the ecosystem
- indicate the extent of pressures exerted on the ecosystem
- monitor the responses to changes in condition
- contain indicators that track changes in vegetation, which is central to the long-term sustainability of terrestrial ecosystems.

Effective indicators are:

- robust and capture environmental change
- unambiguous
- able to provide early warnings of potential issues
- capable of providing accurate data
- applicable to a variety of ecosystems
- scientifically credible
- easy to understand
- cost-effective.

In practice, monitoring of rehabilitation will typically include:

- an assessment of surface (and slope) stability
- the performance of constructed surfaces
- properties of the soil or root zone media
- plant community structural attributes
- plant community composition
- selected indicators of ecosystem functioning (DITR 2006).

Current methods of measuring ecosystem restoration range from measures of pattern through intensive botanical surveys of surface, density, diversity and structure, to approaches that focus on processes such as Ecosystem Function Analysis (Tongway and Hindley 2004) and remote sensing techniques based on soil and vegetation reflectance spectra (e.g. Hick and Ong 1999). The timing of data collection using these methods should be standardised (DITR 2006).

Industry examples of rehabilitation monitoring

Monitoring at the recently-closed Mt McClure operations involves the use of Ecosystem Function Analysis (EFA), undertaken on rehabilitation sites at Mt McClure since 2004. To complement the EFA data, a system of rehabilitation classification is currently being used to integrate the EFA data and allow reference to the WA Department of Industry and Resources categories for bond reconciliation (H. Lacy, Principal – Outback Ecology, 2006, pers. comm.).

At the Coburn Mineral Sands project, south of Exmouth in the arid north-west of WA, it is proposed that monitoring will consist of quarterly monitoring using Landscape Function Analysis (LFA), a soil monitoring program to compare undisturbed analogue sites and the reconstructed profile and establishment of permanent vegetation and fauna monitoring plots. A performance indicators table has been established that details task, frequency, timing, responsibility, status and corrective actions. This table provides a checklist for implementation by mining and rehabilitation personnel as well as for auditing of rehabilitation performance by regulators (URS 2005a).

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APPENDIX T2

Plant species that may be used in revegetation activities at Olympic Dam

Table T2 Plant species that may be used in revegetation activities at Olympic Dam

Family	Species	Common name	Form	Soils, aspects and habitats	Potential habitat use on landform	Collection availability	Ease to collect	Rehab potential	Seed orchard potential
Cupressaceae	*Callitris glaucophylla*	White Cypress Pine	Perennial tree	Deeper sands	RDSC, CS	3	3	3	
Amaranthaceae	*Ptilotus polystachyus* var. *polystachyus*	Long Tails	Annual forb	Sandy soils of sand dunes and plains	RDSC	2	3	3	
	Ptilotus obovatus	Silvertails	Perennial shrub	Variety of soils	RDSC, CS, ARS	4	3	3	
Caesalpinaceae	*Senna* ft *coriacea*	Desert Cassia	Perennial shrub	Rocky hillsides & deep sands	RDSC, ARS, CS	3	5	4	Maybe
	Senna ft *petiolaris*	Punty Bush	Perennial shrub	Deep sands	RDSC, CS	3	5	4	Maybe
	Senna ft *filifolia*	Punty Bush	Perennial shrub	Alkaline sandy soils	RDSC, CS	3	5	3	Maybe
Chenopodiaceae	*Atriplex angulata*	Fan Saltbush	Perennial subshrub	Range of soil types	RDSC, CS, TSF	2	4	4	Yes
	Atriplex fissivalvis	Gibber Saltbush	Annual forb (wet winters only)	Stony desert soils	ARS				
	Atriplex holocarpa	Pop Saltbush	Annual forb	Disturbed sites	RDSC, CS, TSF	3	4	5	Yes
	Atriplex limbata	Spreading Saltbush	Perennial forb	Sandy soils along drainage lines	RDSC, CS, TSF	2	3	3	Yes
	Atriplex lindleyi	Baldoo	Annual forb	Various soils & aspects	RDSC, CS, TSF	4	4	5	Yes
	Atriplex pseudocampanu-lata	Mealy Saltbush	Erect annual sub shrub	Disturbed sites	RDSC, ARS, CS, TSF	2	4	4	Yes
	Atriplex spongiosa	Pop Saltbush	Annual forb	Disturbed sites	RDSC, CS, TSF	3	4	5	Yes
	Atriplex velutinella	Sandhill Saltbush	Short lived perennial forb	Various soils, including sandhills & stony gibber plains	RDSC, ARS, CS	3	4	4	Yes
	Atriplex vesicaria	Bladder Saltbush	Perennial shrub	Various soils & aspects	RDSC, ARS, CS, TSF	5	5	4	Maybe
	Chenopodium desertorum	Desert Goosefoot	Perennial subshrub	Stony desert soils on hillsides	ARS	3	2	4	Maybe
	Dissocarpus paradoxus	Cannon Balls	Perennial shrub (short lived)	Various soils, including sandhills & stony gibber plains	RDSC, CS, TSF	4	4	3	Maybe
	Enchylaena tomentosa	Ruby Saltbush	Perennial shrub	Various soils & aspects	RDSC, ARS, CS	3	2	4	Yes
	Halosarcia spp.	Samphires	Perennial shrub	Saline salt lakes & marshes	TSF	3	2	4	
	Maireana aphylla	Cotton Bush	Perennial shrub (long lived)	Alluvial plains, cracking clays	RDSC, TSF	3	3	4	Maybe
	Maireana astrotricha	Low Bluebush	Perennial shrub (long lived)	Wide range of soil types	RDSC, CS	2	3	3	
	Maireana brevifolia	Short Leaf Bluebush	Perennial shrub	Coloniser, saline & alkaline soils & drainage lines	RDSC, ARS, CS, TSF	2	3	3	Maybe
	Maireana erioclada	Rosy Bluebush	Perennial subshrub	Mainly red earth soils	RDSC	2	4	3	
	Maireana georgei	Golden Bluebush	Perennial shrub (short lived)	Coloniser, saline & alkaline soils, stony uplands	RDSC, ARS, CS, TSF	2	4	4	Yes

Table T2 Plant species that may be used in revegetation activities at Olympic Dam (cont'd)

Family	Species	Common name	Form	Soils, aspects and habitats	Potential habitat use on landform	Collection availability	Ease to collect	Rehab potential	Seed orchard potential
	Maireana pentatropis	Erect Mallee Bluebush	Perennial shrub (short lived)	Coloniser, sandy soils, calcareous soils with mallee or casuarina woodland	RDSC, CS	4	4	4	Yes
	Maireana pyramidata	Black Bluebush	Perennial shrub (long lived)	Coloniser, saline & alkaline soils & drainage lines	RDSC, ARS, CS, TSF	4	4	5	Maybe
	Maireana sclerolaenoides	Wooly Fruit Copperburr	Perennial forb	Wide range of soil types	RDSC, ARS, CS	2	3	4	Yes
	Maireana sedifolia	Pearl Bluebush	Perennial shrub (long lived)	Dominant species understorey or shrubland in deep alkaline loams or clays	only if alkaline soils	2	4	2	
	Rhagodia spinescens var. *deltophylla*	Spiny Saltbush	Perennial shrub	Wide range of soil types	RDSC, ARS, CS, TSF	3	2	4	Maybe
	Sclerolaena diacantha	Grey Copperburr	Short lived perennial forb	Most common on sandplains	RDSC, ARS, CS, TSF	3	4	3	Maybe
Convulvulaceae	*Convolvulus erubescens*	Grassy Bindweed	Perennial climber or forb	Wide range of soil types	RDSC	2	3	3	Yes
	Convolvulus remotus	Common Binweed	Perennial climber or forb	Wide range of soil types	RDSC, ARS, CS	2	3	4	Yes
Euphorbiaceae	*Euphorbia drumondii*	Caustic Weed	Annual or perennial forb	Various soils, particularly sand plains & dunes	RDSC, ARS, CS, TSF	2	2	4	Yes
Malvaceae	*Abutilon halophilum*	Plains Lantern Flower	Perennial forb	Clay soils on gibber plains, hill slopes	ARS	3	2	3	Maybe
	Abutilon otocarpum	Desert Lantern	Perennial forb	Deep sand on dune swales	RDSC	3	2	3	Maybe
	Sida corrugata	Corrugate Sida	Short lived perennial forb	Deep sand on dune swales	RDSC, CS	2	1	3	Maybe
Fabaceae	*Acacia aneura*	Mulga	Perennial tree (long lived)	Various	RDSC, ARS, CS	2	4	4	
	Acacia brachystachya	Turpentine Mulga	Perennial tree (long lived)	Deep soils & rocky hills	RDSC, ARS, CS	2	4	4	
	Acacia kempeana	Witchetty Bush	Perennial shrub/tree	Deep soils	RDSC	2	4	3	
	Acacia ligulata	Umbrella Bush	Perennial shrub/tree	Deep sands, sandhill crests	RDSC, CS	3	3	4	
	Acacia linophylla	Bowgada	Perennial shrub/tree	Deep sandy soils	RDSC	3	4	3	
	Acacia oswaldii	Umbrella Wattle	Perennial shrub/tree	Calcareous sandy & loamy earths	RDSC, CS	3	3	4	
	Acacia papryocarpa	Western Myall	Perennial tree (long lived)	Limestone plains	(limited to calcareous soil types)	1	3	1	
	Acacia ramulosa		Perennial shrub/tree	Deep sandy soils	RDSC	3	4	3	
	Acacia tetragonophylla	Dead Finish	Perennial shrub/tree	Various soils, particularly along creek lines	RDSC, ARS, CS	3	3	4	

Table T2 Plant species that may be used in revegetation activities at Olympic Dam (cont'd)

Family	Species	Common name	Form	Soils, aspects and habitats	Potential habitat use on landform	Collection availability	Ease to collect	Rehab potential	Seed orchard potential
	Acacia victoriae	Prickly Acacia	Perennial shrub/tree	Various, copes with saline soils	TSF	4	5	5	
	Crotalaria cunninghamii	Regal Bird Flower	Perennial shrub	Deep sands, sandhill crests	RDSC	3	3	3	
	Swainsona formosa	Sturts Desert Pea	Prostrate annual forb	Various, particularly sandplains	RDSC	1	4	3	Yes
	Swainsona stipularis	Orange Darling Pea	Shrubby perennial forb	Clay soils & gibber plains	RDSC, TSF	2	3	2	
	Swainsona villosa		Annual/perennial forbs	Stony plains & sandplains	RDSC, TSF	2	3	3	Maybe
Pittosporaceae	*Pittosporum angustifolium* (formerly *phyllireoides)*	Native Apricot	Perennial shrub/tree	Various	RDSC, ARS, CS	3	2	3	
Proteaceae	*Hakea leucoptera*	Needlebush	Perennial shrub/tree	Sandy soils on sandplains	RDSC, ARS, CS	2	1	4	
Sapindaceae	*Dodonaea viscosa* ssp. *angustissima*	Narrow Leaf Hopbush	Perennial shrub/tree	Deep sands & dune swales	RDSC, CS	4	3	4	
Solanaceae	*Lycium australae*	Australian Boxthorn	Perennial shrub	Sandy loam soils, sand dunes	RDSC, CS	3	2	4	
	Solanum spp.	Wild Tomato	Perennial forbs and shrubs	Various	RDSC, CS	2	3	3	Yes
Zygophyllaceae	*Nitraria billardierei*	Nitre Bush	Perennial shrub	Range of soils, particularly disturbed sites	TSF	4	3	4	
	Zygophyllum aurantiacum	Shrubby Twinleaf	Perennial shrub (short lived)	Range of soils, particularly disturbed sites	RDSC, CS, TSF	4	4	5	Yes
Poaceae	*Aristida contorta*	Kerosene Grass	Annual or short lived perennial grass	Various soils, including sandplains & hills, rocky hillsides	RDSC, ARS, CS	3	4	3	
	Astrebla pectinata	Mitchell Grass	Perennial tussock grass	Clay soils, gibber plains, watercourses & floodouts	ARS, CS	2	4	2	Yes
	Austrostipa nitida	Speargrass	Short lived perennial	Lighter soils on sandplains, disturbed areas	RDSC, ARS, CS	3	4	3	
	Austrostipa scabra	Speargrass	Short lived perennial	Lighter soils on sandplains, disturbed areas	RDSC, ARS, CS	3	4	3	
	Cymbopogon ambiguus	Lemon Scented Grass	Perennial tussock grass	Stony creek beds, rocky hill slopes	ARS, CS	3	2	4	Yes
	Digitaria brownii	Cotton Panic Grass	Perennial tussock grass	Sandy soils, sometimes stony ridges	RDSC, ARS, CS	2	4	4	Yes
	Eragrostis dielsii	Lovergrass	Spreading annual/perennial	Various, sometimes dune swales	RDSC	2	4	2	
	Eragrostis eriopoda	Wollybutt	Perennial tussock grass	Red sands of sand dunes & plains	RDSC	2	4	3	Yes
	Eragrostis setifolia	Neverfail	Perennial tussock grass	Clay soils, gibber plains, watercourses & floodouts	RDSC, CS	2	4	3	Yes
Aizoazeae	*Carpobrotus rossi*	Native Pig Face	Spreading perennial forb	Saline sandy soils, variety of other soils	RDSC, TSF	3	1	4	Maybe

Codes / Abbreviations
Collection availability: 5 is good availability, 1 low availability. Refers to either a species seasonal availability, and/or the fact it may not be prolific seeder or widespread plant.
Ease of collection: 5 is easy to collect in quantity, 1 represents a species difficult to harvest. Refers to labour involved and ability to source suitable patches.
Rehabilitation potential: 5 represents demonstrated performance in rehabilitation, 1 is unknown or poor performance. Rating is limited to industry knowledge and experience from other sites.