DESKTOP STUDY ON SUCCESSFUL REHABILITATION PROCEDURES

YOONGARILLUP MINERAL SANDS PROJECT

DORAL MINERAL SANDS

FEBRUARY 2014

EXECUTIVE SUMMARY

Doral Mineral Sands Pty Ltd proposes to mine the Yoongarillup Mineral Sands Deposit. The life of mine is expected to be three years, including an initial pre-mine establishment phase and three mining phases. Rehabilitation and mine closure will be implemented at the cessation of mining; this phase is likely to take up to five years.

The Proposal was referred to the Environmental Protection Authority (EPA) under section 38 of the *Environmental Protection Act 1986* (EP Act) on 22 March 2012. On the 27 August 2012, the EPA determined the level of assessment for the Proposal as Public Environmental Review (PER) with a four week public review period because the proposal raises significant environmental factors.

In January 2013, the EPA issued the final Environmental Scoping Document to define the requirements of the PER. The EPA required Doral Mineral Sands Pty Ltd to undertake a desktop study of successful mine rehabilitation procedures for inclusion in the PER document. This document has been prepared to fulfil the requirement of a desktop study of successful mine rehabilitation procedures.

The EPA requirement to prepare a 'desktop study of successful mine rehabilitation procedures' is very broad therefore this desktop study aims to provide detail on and examples of leading successful rehabilitation procedures that have relevance to the rehabilitation of disturbed areas after near surface mining in the southwest region of Western Australia.

After review of the international and national body of relevant literature the factors listed below were considered to be critical for successful rehabilitation after near surface mining in southwest Western Australia. These factors are addressed to varying levels of detail, depending on relevance and impact, in this desktop study:

- Characterization and reconstruction of soil profiles including:
  - Pre-mining characterization of natural soil profiles and landforms;
  - Removal and management of vegetation and topsoil; and
  - Soil profile reconstruction to support post mining land use objectives.

- Species selection and seed management including:
  - Plant species selection; and
  - Seed collection, storage and treatment.

- Plant establishment including:
  - Plant establishment techniques;
  - Controlling threats to rehabilitation success; and
  - Completion criteria and monitoring.

The desktop study reviewed and documented where possible, successful procedures for the various aspects of rehabilitation after mining in the southwest of Western Australia. A summary is provided below.

CHARACTERISATION AND RECONSTRUCTION SOIL PROFILES

Pre-mining characterisation of natural soil profiles and landforms

End land use planning and rehabilitation objectives must be based baseline assessment of soil, flora and fauna to ensure that realistic capacity and requirements are determined.

Baseline soil assessment

- Test soil for chemical, physical and biological characteristics to use in end-land use and rehabilitation planning;
- Identify useful and hostile materials and treat each appropriately ; and
- Assess whether land capability can be improved through amelioration.

Baseline flora and vegetation

- Survey vegetation to identify seed sources, determine future seeding mixes and rates; and
- Ongoing monitoring of reference sites allow for assessment of progress of rehabilitation areas.

Baseline fauna survey

- Survey fauna populations to develop protection protocols and habitat reconstruction strategies, and as a means of assessing the progress of rehabilitation areas in relation to fauna re-colonisation; and
- Identify and inspect habitat trees prior to felling to relocate resident animals and retain useful hollows for use in rehabilitation programs.

Removal and management of vegetation and topsoil

Topsoil handling

- Double strip topsoil and subsoil and replace in correct order to produce optimal results;
- Where possible, direct transfer topsoil ;
- Do not strip and stockpile soil when it is wet;
- Where possible, strip topsoil when the native seed bank is most abundant, usually in autumn;

- If possible, direct transfer topsoil to areas requiring rehabilitation to take advantage of the seed bank; and

- Rip after applying the topsoil.

Topsoil stockpiling

- If stockpiling is absolutely necessary, the stockpiles should only be 1-3 m high and sown with target species. If there is a lot of weed colonisation, they should be scalped off prior to spreading the soil. Mixing the stockpile at spreading redistributes nutrients which have accumulated at the base of the stockpile; and

- Keep good records of stockpiles and clearly signpost in the field.

Topsoil substitutes and ameliorants

- Biosolids applied to the surface should be avoided when rehabilitating to native ecosystems as it encourages weed growth;

- Compost has potential for being a suitable topsoil substitute but would need site specific trials to confirm its suitability; and

- Fertiliser can be used at seeding and planting but then use symbiotic soil microbe inoculation to ensure long term plant nutrition and nutrient cycling.

Soil profile reconstruction to support post mining land use objectives

- The reconstruction of essential abiotic landform elements represents a critical first step in the rehabilitation of highly disturbed post-mining ecosystems (Doley et al. 2012); and

- A critical stage in re-establishing a sustainable forest ecosystem is the reconstruction of soil profiles that are suitable to support the rehabilitated ecosystem in the long term and therefore a comprehensive understanding of the undisturbed soil profile and characteristics is vital to the reconstruction of a ‘natural type’ soil profile that provides suitable rooting medium for the rehabilitated vegetation.

SPECIES SELECTION AND SEED MANAGEMENT

Plant species selection

- Species used in rehabilitation must be local and appropriate to the target community;

- Include as many species as possible and from all vegetation strata represented in the target community;

- Best practice suggests local provenance seed will give best results, but if seed source populations are small additional sources should be included to increase genetic diversity;

- Develop a mosaic of vegetation types rather than a homogeneous cover;

- Include short-lived Acacia species but not at excessive densities;

- For pasture rehabilitation consider including a cover crop where needed to help stabilize the soil and add organic matter; and

- Raise tubestock seedlings of those species which establish poorly either from direct seeding, from the topsoil seed bank (where available), or through natural invasion.

Seed collection, storage and treatment

- Identify vegetation for seed collection and develop a program to collect species at optimal times;

- When collecting seed do not collect more than 20% of the crop to avoid disrupting natural life cycling and feeding by fauna;

- Collect seed from any felled vegetation in the mine path;

- Keep good records of seed collection dates and sites;

- Store seed in optimal conditions to maintain maximum viability;

- Some seed will need pre-treatment to break dormancy prior to seeding;

- Germination field trials should be carried out to determine optimal seeding rate, particularly for key species;

- Seed prior to some reliable rainfall, preferably in autumn; and

- Keep good records of when and how areas were prepared and seeded, the seed mix and rate to compare outcomes.

PLANT ESTABLISHMENT

Plant establishment techniques

- Protect understorey species with tree guards if herbivory (kangaroos) levels are high;

- Fertilizer tablets may be used to assist plant establishment but do not place fertilizer tablets close to seedling roots;

- Control competitive weeds with herbicide or mulch;

- Where practicable, transplant very slow growing or difficult to propagate species from areas in the mine path to rehabilitation areas, with minimal root disturbance and making sure to match soil types of source and destination areas as much as possible;

- Inoculate tube stock seedlings with mycorrhizal fungi and rhizobia bacteria where applicable, prior to planting to ensure long-term plant nutrition and sustainable nutrient cycling;

- Inoculate direct seeding areas either by using good quality soil from remnant vegetation areas, coating seed with inoculum prior to seeding, inoculating plants after germination or by including some inoculated tube stock planting as sources; and

- Create numerous small rock or log piles rather than a few large ones in rehabilitated areas to encourage fauna return.

Controlling threats to rehabilitation success

- Conduct regular monitoring to detect weed and feral animal impacts including uncontrolled grazing by animals e.g. kangaroos;

- Develop and implement a weed species specific management plan; and

- Develop and implement a feral animal control program, where possible in conjunction with neighbouring landowners and relevant authorities.

Completion criteria and monitoring

- Keep rehabilitation objectives and completion criteria flexible to allow for changes in mine operations, knowledge and technological advances;

- Keep detailed records of all rehabilitation efforts and management procedures used on an appropriate system linked to other GIS based information if possible;

- Select and monitor unmined reference sites to help assess the development of native ecosystem rehabilitation towards the agreed objectives and any completion criteria;

- Monitor frequently at first and less as the system ages, with increased frequency after a significant environmental event such as fire or drought;

- Monitor in each season when possible to detect cryptic species which are only visible at certain times of the year;

- Conduct both quantitative and qualitative monitoring surveys using accepted methods;

- Conduct long-term monitoring to follow the development of the system towards rehabilitation objectives and help refine completion criteria over time;

- Identify problems and act to remedy them promptly; and

- Manage fire to benefit rather than degrade rehabilitated areas.

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1 BACKGROUND

1.1 PROJECT OVERVIEW

Doral Mineral Sands Pty Ltd proposes to mine the Yoongarillup Mineral Sands Deposit. The life of mine is expected to be three years, including an initial pre-mine establishment phase and three mining phases. Rehabilitation and mine closure will be implemented at the cessation of mining; this phase is likely to take up to five years.

The Yoongarillup Mineral Sands Project is located approximately 17 kilometres southeast of Busselton and 250 kilometres south of Perth, Western Australia in the City of Busselton.

Doral Mineral Sands Pty Ltd proposes to develop the Project by mining the strand of heavy mineral deposit (approximately 4.0 million tonnes) located on mining tenements M70/459 and M70/458. The Proposal will involve the excavation of several mine pits using dry mining techniques to a maximum depth of 20 metres below ground level.

The Proposal has a total ground disturbance of 95.71 hectares with approximately 86.81 hectares of the proposed disturbance area located within cleared farmland (current uses include beef cattle, dairy cattle and pasture) and an additional 8.90 hectares located within State Forest No. 33, of which 0.22 hectares has previously been cleared. This area is referred to as the State Forest sub area.

State Forest No. 33, also known as Millbrook State Forest, is managed by the Department of Parks and Wildlife and lies within the Whicher Scarp Land System (DAFWA, 2007), immediately adjacent to the Whicher National Park. *A Floristic Survey of the Whicher Scarp* (Keighery *et al.* 2008) places the project area in the Central Whicher Scarp. This is described as having moderate north facing slopes with areas of laterite capped rises and soils ranging from deep sands to sand, gravel, silt, clay and ironstone combinations.

Ecoedge Environmental (2013) rated the vegetation within the State Forest sub-area as Very Good or Excellent condition, with only a small area (0.08 hectares) on the northern boundary previously being used as a sand pit being rated as Completely Degraded. The portion classified as Very Good rather than Excellent (approximately 73% of the State Forest sub-area), has previously been partly cleared as evidenced by old windrows of fallen trees scattered throughout. Based on the size of the regrowth eucalypts, Ecoedge Environmental (2013) estimates the clearing was probably conducted during the period 1950-1965, perhaps in readiness for pine planting that did not eventuate.

Parts of the previously cleared area are relatively species poor and there is evidence of heavy kangaroo grazing through the State Forest sub-area. A strip around the east and north sides of the State Forest sub-area shows no signs of previous clearing which resulted in the vegetation being classified as excellent condition. Phytophthora disease is present along the eastern boundary and part of the western boundary, evidenced by scattered deaths of *Eucalyptus marginata* and

Xanthorrhoea species (Moore Mapping, 2014). Scattered deaths of *Banksia grandis*, particularly near the southern boundary of the State Forest sub-area are a result of drought. Dumping of domestic and farm refuse has been carried out in various places along the tracks in the northern and western parts. (Ecoedge Environmental, 2013). The proportion and cover of introduced species is generally low throughout.

The disturbed areas post mining, will be progressively rehabilitated back to pasture and native vegetation, as agreed with the land owners and consistent with pre-mining land use.

1.2 PURPOSE OF DOCUMENT

The Proposal was referred to the Environmental Protection Authority (EPA) under section 38 of the *Environmental Protection Act 1986* (EP Act) on 22 March 2012. On the 27 August 2012, the EPA determined the level of assessment for the Proposal as Public Environmental Review (PER) with a four week public review period because the proposal raises significant environmental factors.

In January 2013, the EPA issued the final Environmental Scoping Document (ESD) to define the requirements of the PER. The EPA determined that *Rehabilitation and Mine Closure* was one of the environmental factors relevant to the proposal and required Doral Mineral Sands Pty Ltd to undertake a *desktop study of successful mine rehabilitation procedures* and to '*identify and propose completion criteria'* for inclusion in the PER document. This report has been prepared to fulfil the requirement of a desktop study of successful mine rehabilitation procedures.

1.3 SCOPE OF DOCUMENT

The EPA requirement to prepare a '*desktop study of successful mine rehabilitation procedures*' is very broad therefore this desktop study aims to provide detail on and examples of leading successful rehabilitation procedures that have relevance to the rehabilitation of disturbed areas after near surface mining in the southwest region of Western Australia.

The primary focus is the rehabilitation of native vegetation as the State Forest sub-area of the Doral Mineral Sands proposal has been identified as being of high conservation value (DAFWA, 2007) and the complexities of rehabilitating the State Forest sub-area to the agreed end land use are greater than rehabilitating the cleared farmland back to land suitable for agricultural use.

Although successful rehabilitation of native vegetation is the primary focus is it recognised that mining minerals sands involves considerable soil disturbance and loss of chemical, biological and physical fertility which can have an impact on the successful rehabilitation of pastures. Therefore, successful rehabilitation procedures, as applied to the return of cleared farmland to land that is suitable for agricultural use, have also been addressed.

1.4 DESKTOP STUDY METHODOLOGY

1.4.1 Literature Review

An initial literature review looked at international and Australian examples of successful rehabilitation techniques post surface mining and papers such as Boone *et al.* (1986), Reddell and Hopkins (1994), Daniels (no date (after 2003), Holmes (2001), Hall *et al.* (2010) and Gould, (2011) provided some insight into leading practice for successful rehabilitation after mineral sands and other surface mining in the broader context. There are a considerable number of factors with the potential to limit effective rehabilitation. These factors are not however, universally applicable as they vary between bioregions and locations and some also vary seasonally (EPA, 2006).

After review of the international and national body of relevant literature the factors listed below were considered to be critical for successful rehabilitation after near surface mining in southwest Western Australia. These factors are addressed to varying levels of detail, depending on relevance and impact, in this desktop study;

- Characterization and reconstruction of soil profiles including:
  - Pre-mining characterization of natural soil profiles and landforms;
  - Removal and management of vegetation and topsoil; and
  - Soil profile reconstruction to support post mining land use objectives.

- Species selection and seed management including:
  - Plant species selection; and
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- Plant establishment including:
  - Plant establishment techniques;
  - Controlling threats to rehabilitation success; and
  - Completion criteria and monitoring.

Locating examples of '*successful*' post minerals sands mining rehabilitation procedures has proven to be challenging for the reasons discussed below.

Firstly, the meaning of '*successful rehabilitation'* is not used consistently throughout the literature or even by Western Australian regulatory bodies and perhaps more critically, there are not yet uniform standards or criteria for determining 'successful' rehabilitation (Mudd, 2009).

Secondly, a major issue which is not widely acknowledged is that of the long-term effectiveness of rehabilitation measures. That is, the long-term performance of various approaches to mined land rehabilitation to restore a productive land use following mining. Although the engineering and regulatory standards are considerably better at present than in the past, there remains concern over long-term effectiveness (Mudd, 2009). Rehabilitation considered successful at one point in time has later been re-assessed using different assessment criteria and often then deemed not quite as successful. Gould (2011) concluded that assumptions about rehabilitation success needed to be reviewed.

Thirdly, the assessment of successful rehabilitation, usually by the Department of Mines and Petroleum, post mineral sands mining that has resulted in relinquishment of mining tenements is often based on rehabilitation outcomes (completion criteria) established by the mining company at an earlier time, when the rehabilitation procedures were often not as well researched, understood and implemented as the rehabilitation procedures that are currently available. For example, during the 1990's the focus of most mine site rehabilitation programs was to establish good density and cover of vegetation across the disturbed area. While this resulted in rehabilitated sites that were essentially stable and looked aesthetically pleasing, it did not necessarily mean that the rehabilitated areas were moving towards functional ecosystems (Thompson and Thompson, 2004). The obvious danger with assuming that restoring flora equals restoring fauna is to declare a site restored when only one component of its biodiversity has actually returned, while the fate of fauna remains unknown. This represents a serious threat for the conservation of biodiversity in general and for the long-term resilience of ecosystems (Cristescu *et al.,* 2013; Fischer, Lindenmayer & Manning, 2006).

Lastly, the effectiveness of the rehabilitation techniques applied to a former mine site is a critical issue for both the mining sector as well as local communities. This is a widely acknowledged issue but there is very little in the way of both qualitative and quantitative measures to address 'sustainable' rehabilitation. There is also very little reporting of data on rehabilitation (Mudd, 2009). Much of the rehabilitation of minerals sands mining in southwest Western Australia is not yet mature enough to provide evidence of successful sustainable, in the long term, rehabilitation that has implemented currently accepted leading practice procedures.

For the reasons described above this desktop study has reviewed and where appropriate included leading practice rehabilitation procedures that are relevant within the context of the proposed Yoongarillup Mineral Sands project.

Given the lack of published successful procedures for the rehabilitation after mining of jarrah forest in the southwest of Western Australia, this desktop study has drawn heavily on published information regarding the rehabilitation procedures used by Alcoa in their bauxite mines located in the southwest of Western Australia. Although bauxite mining in southwest Western Australia occurs on the Darling Range and not the Swan Coastal Plain and the process is similar but not quite the same as mineral sands mining, the rehabilitation work undertaken by Alcoa contributes an important body of robust scientific research on procedures that facilitate successful rehabilitation. The leading practice principles for the rehabilitation developed by Alcoa, given the similarities in location and mining, can be used to supplement the body of knowledge about successful mineral sands rehabilitation procedures.

1.4.2 Glossary of terms

The literature review revealed that there is considerable flexibility in the terminology used and therefore it is considered useful to provide the definitions of the terminology used for this study.

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

“*a process where disturbed land is returned to a stable, productive and self-sustaining condition, taking future land use into account. The 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).

Seed Bank: a place where seed persist in a viable form. In this document the seed bank is the existence of viable seed in the soil. Canopy seed banks can also exist for some Eucalyptus species and species of Banksia where seed is held on the plant until some phenomenon (drying or fire) releases them. Seed stores, for seeding programs could also be defined as seed banks.

Subsoil: (near surface soils) Layer of soil underneath the topsoil, usually has higher clay content, denser and stronger in colour. In most cases it is a poor medium for growth without the topsoil layer.

Successful: as the accomplishment of an aim or purpose.

Topsoil: (surface soil) Original surface layer of mineral soil containing material that is usually darker, more fertile and better structured than the underlying layers.

2 SUCCESSFUL PROCEDURES FOR REHABILITATION OF NATIVE VEGETATION

2.1 OVERVIEW

This section of the desktop study includes publically available examples of successful or leading practice procedures applicable to the rehabilitation of native vegetation impacted by surface mining.

The following aspects are addressed:

- Characterization and reconstruction of soil profiles including:
  - Pre-mining characterization of natural soil profiles and landforms;
  - Removal and management of vegetation and topsoil; and
  - Soil profile reconstruction to support post mining land use objectives.

- Species selection and seed management including:
  - Plant species selection; and
  - Seed collection, storage and treatment.

- Plant establishment including:
  - Plant establishment techniques;
  - Controlling threats to rehabilitation success; and
  - Completion criteria and monitoring.

The examples of successful procedures for characterisation and reconstruction of soil profiles have been included because they are relevant to the specific soil conditions of the forest sub area of the proposed Yoongarillup Minerals Sands Mine.

The soil assessment for the Yoongarillup Mineral Sands project undertaken by Landloch (2014) provided the following summary of soil properties for the soil on the cleared farmland.

Most of the soil within the disturbance footprint is described as Pale Deep Sands. The soil is acidic sand material that is poorly structured (massive). Surface soils are water repellent (hydrophobic) which can result in increased potential for erosion from water and wind while it is stockpiled. The surface 10 cm contain the highest level of nutrients, but significant levels are also found down to 30 cm. The subsoil, while more acidic and lower in nutrients, will be useful as a plant growth medium to place above the production waste that will be backfilled into the pit.

2.2 CHARACTERIZATION AND RECONSTRUCTION OF SOIL PROFILES

2.2.1 Overview

In forested areas the natural process of soil development can take hundreds of years. Where the soil profile has not been disturbed the soil profile on underlying native vegetation may have taken centuries to develop from parent material and organic matter.

Bell (2004) listed the key components of rehabilitation as being:

(1) Comprehensive characterisation of soils, overburden and wastes in terms of their potential for plant growth and for water contamination;

(2) Selective handling of soil and overburden to create a satisfactory (non-hostile) root zone for plants and to protect water resources; and

(3) Construction of a post-mining landscape, which is stable against the erosive forces of wind and water to ensure sustainability of the defined post-mining land use and the protection of surrounding water resources.

This section includes examples of successful or leading practice procedures for the characterisation and reconstruction of soil profiles and addresses the following aspects:

- Pre-mining characterization of natural soil profiles and landforms;
- Removal and management of vegetation and topsoil; and
- Soil profile reconstruction to support post mining land use objectives.

There are a considerable number of examples of leading practice procedures for characterisation and reconstruction of soil profiles. The examples included in this section are relevant to the specific soil conditions of the vegetated forest sub area areas of the proposed Yoongarillup Minerals Sands Project.

2.2.2 Pre-mining characterization of natural soil profiles and landforms

A critical stage in re-establishing a sustainable forest ecosystem is the reconstruction of soil profiles that are suitable to support the rehabilitated ecosystem in the long term. A comprehensive understanding of the undisturbed soil profile and characteristics is vital to the reconstruction of a 'natural type' soil profile that provides suitable rooting medium for the rehabilitated vegetation (Herath *et al.*, 2008). It will also inform the optimal way in which soils are stripped, stockpiled, and respread.

It is clear from the research that unless there is careful management of the restoration of the natural soil profile, the effort and investment made to restore plant diversity after mining, including topsoiling, seeding, infill planting, fertilizing, mulching etc. may be wasted and the rehabilitation effort will struggle to succeed (Herath *et al*., 2008).

Herath, *et al.* (2008) in their study on successful rehabilitation of species-rich heathlands after mining for heavy minerals suggested that the most important factor limiting development of a self-sustaining plant community in the restored shrublands was the lack of sustainable rooting medium. As a result of this study, it was determined that the reconstruction of a natural type soil profile was probably the most critical stage in the rehabilitation process.

Work on establishing an in-depth understanding of the soils material properties should start as early as the exploration phase and continue through the prefeasibility and feasibility phases as a basis for mine planning. The requirement to continue characterisation continues during the operation of the mine, especially of the tailings and other waste products that may be used to contribute to the reconstruction of the soil profile (Bell, 2004).

The importance of a ‘natural type, reconstruction of the soil profile can be demonstrated by the Dell, Bartle and Tacey (1983) study on root occupation and root channels of jarrah (Eucalyptus marginata Sm.) forest subsoils. This study found that the major descending roots are confined to channels that extend vertically from fissures and conduits in the shallow subsurface caprock layer deep in the clay subsoil. The channels are permanent features of the profile and are occupied by successive generations of trees. If the soil profile reconstruction is not carefully managed and the profile does not allow for the establishment of root channels then the long term success of the rehabilitated vegetation will be compromised.

Szota *et al*. (2007) investigated coarse root systems of Jarrah (Eucalyptus marginata Donn ex Sm.) trees at a 13-year-old restored bauxite mine site in south-western Australia. Excavations in an area with small trees (low-quality site) revealed that deep ripping equipment had failed to penetrate the cemented lateritic subsoil, restricting coarse roots (roots >5 mm in diameter) to the top 0.5 m of the soil profile, resulting in fewer and smaller Jarrah trees. An adjacent area within the same pit (high-quality site), had a kaolinitic clay subsoil which coarse roots penetrated to the average ripping depth (1.5 m).

Characterisation of the soil’s properties normally involves mineralogical, physical (horizon depths) and chemical analyses; microbiological analyses may also be conducted at the early stage of planning, but more commonly find a role in assessment of the performance of the reconstructed ecosystems on the rehabilitated land.

The value of laboratory analyses in the characterisation of mine-site materials is highly dependent upon the use of a rigorous sampling protocol. Whilst laboratory analyses can provide a useful guide as to the potential of soils and mine wastes to support plant growth, plant growth trials in the glasshouse and finally on the mine site, will provide a clearer assessment of rehabilitation options (Bell, 2004).

Pre-mining characterisation of surface and subsurface soils should include, but not limited to, assessment of the following properties:

- Soil pH;
- Electrical Conductivity (EC);
- Particle size distribution (gravel, sand, silt, clay);
- Total Nitogen;
- Total Phosphorus;
- Organic Carbon;
- Available (Colwell) P and K;
- Available Sulphur (KCl);
- Available trace elements (Copper, Zinc, Manganese and Iron);
- Exchangeable cations ($Ca^{2+,}$ $Mg^{2+,}$ Na^{+}, K^{+} and Al^{3+});
- Effective Cation Exchange Capacity;
- Exchangeable Sodium Percentage;
- Particle size distribution (gravel, sand, silt, clay);
- Hydrophobicity (surface soils only); and
- Emerson class number.

2.2.3 Removal and management of vegetation and topsoil

Stockpiled topsoil becomes highly degraded the moment this long-term structure is disturbed. Strohmayer (1999) reported that there is one timeframe where the most damage occurs. This timeframe is when topsoil is initially stripped from the ground. Changes that occur in soil include increased bulk density, decreased water holding capacity, chemical changes, reduced nutrient cycling, reduced microbial activity, and loss or reduction of viable plant remnants and seeds.

The management focus of stockpiled forest topsoil is to maintain a biologically active and fertile soil resource with the greatest amount of seed before re-spreading.

Topsoil Removal

The soil profile is made up of a number of layers, including the topsoil, subsoil and overburden layers.

van Gorp, and Erskine, (2011) evaluated the relative effectiveness of different topsoil strategies following mining. This study compared restoration success of three topsoil techniques at rehabilitated sand mine sites on North Stradbroke Island, Queensland, between two and eleven years of age.

The three soil placement techniques compared were:

1) Stockpiled soil;

2) Directly returned fresh soil; and

3) Double stripping, where the uppermost few centimetres of topsoil (A horizon) is stripped separately to the subsoil (B horizon) and returned in sequence.

Restoration success was assessed using a number of soil and vegetation indicators. The results demonstrated that double-stripping and direct return of topsoil generally yielded improved understory species richness and recruitment from the soil seed bank compared to stockpiling (van Gorp, and Erskine, 2011).

It is recommended (van Gorp, and Erskine, 2011; Koch, 2007a; Koch, 2007b; Bell, 2004; Ward and Koch, 2000) that topsoil is removed in two layers (known as double stripping): the upper ten to fifteen centimentres is referred to as topsoil, and the remainder, usually about forty centimetres, is known as subsoil. Double stripping maintains the concentration of seeds and organic matter at the surface of the rehabilitated soil profile.

It is also recommended (Koch, 2007a; Koch, 2007b; Bell, 2004; Ward and Koch, 2000) that the topsoil, which contains much of the soil organic matter, nutrients, micro-organisms and seeds, is used immediately after stripping to rehabilitate a nearby area (known as direct return). Directly returned topsoil may contain over fifty percent of the original unmined forest topsoil seed reserve, compared to fifteen percent when topsoil is stockpiled (Koch *et al*., 1996).

To gain the maximum benefit from the seed in the topsoil it is best to carry out clearing, soil stripping, soil return and ripping in quick succession during the dry summer months (November to April) when the maximum amount of seed is in the soil. It is important to avoid delays in the handling of the soil, particularly during the wet winter period.

The use of scrapers for topsoil stripping is not recommended. The combined use of a front-end loader, truck and bulldozer for the removal, transport, and spreading of topsoil is the best combination to reduce compaction (Department of Industry Tourism and Resources, 2006).

Carry graders have been successfully used to strip thin layers of soil from mineral sand operations in southwest Western Australia. These machines have the precision to strip topsoil at the required or recommended depths and large flotation tyres that reduce compaction (Pratt, A., *pers.com*. 2014).

Once the topsoil and subsoil have been removed, overburden can be stockpiled. The overburden contains few seeds and nutrients so stockpiling does not significantly affect its properties (Koch, 2007).

Dieback and dieback-free topsoil and overburden should be removed, transported and stored separately.

Trucks and loaders can be used to return soil from stockpiles and dozers and graders used to level the soil across the landscaped surface.

Topsoil Management

The Leading Practice Sustainable Development Program for the Mining Industry guide on mine rehabilitation (Department of Industry Tourism and Resources, 2006) provides evidence that when soil is stockpiled more than three metres deep, chemical effects such as accumulation of ammonium and anaerobic conditions occur in the topsoil at the base of the pile. Other detrimental biological effects include absence of propagules and decrease in viability of buried seeds.

The following techniques were determined to be leading practice for topsoil and vegetation handling in a December 2005 review of topsoil and vegetation handling, undertaken by Outback Ecology (BHP Billiton, 2009):

- Baseline soil and vegetation assessments to identify heterogeneity of topsoil and subsoil material in relation to vegetation communities to develop recommendation for depth of appropriate stripping operations;

- Mapping of soil, vegetation units and any areas of dieback;

- Salvage of vegetation for return to the surfaces of appropriate stockpiles or to rehabilitated areas. Where possible this should not be 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 should occur during drier months;

- Use of low salinity water for dust suppression during soil handling operations;

- Where possible, direct return of topsoil 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 two metres. The soil stockpiles should be 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 should facilitate 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;

- Implement weed control strategy for stockpiled soils;

- Screening soils to remove gravel fraction, where applicable, and therefore 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 to encourage the return of terrestrial fauna; and

- Undertake field trials to determine the most appropriate re-spreading depth, ripping and scarifying treatments, nutrient requirements and amendment for surface stability.

2.2.4 Soil profile reconstruction to support post mining land use objectives

Reconstruction of soil profile

Soil Profile reconstruction aims to restore the original, natural landscape.

Pre-ripping can be undertaken prior to the soil return stages of the rehabilitation process. The objective of pre-ripping is to relieve mining-related soil compaction and fracture the ground. This can be important because the pit floor becomes much harder than the surrounding non-mined areas due to heavy vehicle compaction and the removal of the ore during the mining process.

For mineral sands mining the reconstructed soil profile (root zone) can consist of soil, overburden spoil, tailings or various combinations of these materials. The particular combination will depend on the requirements of the vegetation to be established; for example, where a return to native vegetation is required, the entire soil profile may need to be conserved and replaced in order to achieve the required outcome.

Irrespective of the nature of the vegetation to be established on a rehabilitated landscape, a major consideration is the depth of favourable root zone necessary to provide sufficient anchorage (particularly for trees in wind-prone areas) and sufficient available water to enable the plant community to survive through seasonal water stress. To achieve these requirements, a depth of more than two metres of root zone material is generally required. The actual depth required will be influenced by knowledge of the original profile, the nature of the vegetation and current climate conditions (Bell, 2004).

The following procedure is used by Alcoa during the reconstruction of the soil profile phase of their rehabilitation (Koch, 2007a; Nicholas and Grant, 2007).

- Generally, before overburden and topsoil is returned in the correct sequence the reconstructed landscape is contour ripped to a depth of approximately 1.5 metres. This ripping relieves soil compaction that could restrict root growth, encourages water infiltration, and reduces the risk of erosion. Ripping should be carried out in summer and autumn to maximize shatter of the compacted clayey subsoil;

- Contour lines at three to five metres vertical intervals are surveyed and marked in the field and ripping accurately follows the contours. The ripping creates furrows approximately 0.4 metres in height and 1.5 metres wide. The contour furrows are critical for preventing rainfall runoff and soil erosion; and

- Following ripping, a few tree stumps, logs and rocks are returned to the mined areas to provide habitat for fauna.

Research has shown that deeper ripping helps the vegetation grow into a sustainable forest by creating a structured root zone and increasing both recharge and plant available water (Kew, Mengler, and Gilkes, 2007).

Alcoa is currently using a real-time monitoring system located in the cab of the dozer to monitor the area that has been ripped and the depth of ripping. This monitoring system provides guidance and enables the dozer operator to meet targets and identifies areas where rework is required prior to shifting to another location.

Following pre-ripping, a grader should be used to smooth and prepare the surface for the return of topsoil and overburden.

Direct Return of topsoil

Van Etten, McCullogh and Lund (2011) in their paper on *"Sand mining restoration on the Swan coastal plain: learning from monitoring previous rehabilitation attempts*" found their study supported generally-accepted 'best' practice for restoration of disturbed land using topsoil.

Specifically, Van Etten, McCullogh and Lund (2011) demonstrated the advantages of using direct return of topsoil with superior restoration of native species and plant density in areas treated with fresh topsoil compared to where applied topsoil had been stored for several years.

Rokich *et al.* (2000) reported that mean seedling numbers and species richness emerging from three year old topsoil was only thirty four percent and sixty one percent respectively, of that recorded in areas where fresh topsoil was applied for rehabilitated *Banksia* woodland following sand mining near Perth.

The decline in seedling emergence from topsoil following storage is generally attributed to loss of seed viability over time, although others point to the role of seed damage when placed in large piles, early germination when piles are kept moist, or to dilution effects when surface layers containing most seeds are mixed with deeper layers (Rokich *et al*., 2000; Scoles-Sciulla and DeFalco, 2009).

Rokich *et al.* (2000b) in their analysis of the effects of topsoil handling and storage methods undertaken to optimize the potential rehabilitation of southwest Western Australian Banksia woodland species present before site disturbance found that an increase in the depth of topsoil stripped from the Banksia woodland, from ten to thirty centimetres, correlated to decreasing seedling recruitment from the soil seed bank by a factor of three following in situ re-spreading in an area to be restored. These results concur with an ex situ trial on the effects of depth of seed burial on seedling recruitment that showed most species failed to emerge from depths ***greater than two centimetres***.

In situ stockpiling of the woodland topsoil for one or three years demonstrated a substantial and significant decline in seedling recruitment to fifty four percent and thirty four percent of the recruitment achieved in fresh topsoil, respectively. Stripping and spreading during winter substantially depressed seedling recruitment, compared with autumn operations, as did in situ stockpiling followed by spreading in the wet season, or stockpiling in winter followed by spreading in spring (Rokich *et al*., 2000).

No loss in total seedling recruitment occurs when replaced topsoil and subsoil is ripped to eighty centimetres following spreading of topsoil in sites to be restored. Conclusions from this study were that:

(1) Correct handling of the topsoil, stripped and replaced fresh and dry (autumn direct return) to the maximum depth of ten centimetres, can be used to optimize revegetation of species-rich plant communities with this type of seed bank; and

(2) Ripping of topsoil and subsoil to ease compaction of newly restored soils does not diminish the recruitment potential of the soil seed bank in the replaced topsoil (Rokich *et al*., 2000).

2.3 SPECIES SELECTION AND SEED MANAGEMENT

2.3.1 Plant species selection

In the jarrah forest of Western Australia the soil seed bank ranges from several hundred up to about 1,500 native seeds per square metre (Tacey & Glossop, 1980; Vlahos & Bell, 1986; Koch *et al*., 1996; Ward *et al*., 1997; Smith *et al*., 2000) and therefore is an important resource for the rehabilitation process. Studies have demonstrated that the soil seed bank can contribute more than 70% of the plant species richness and is therefore probably the single most important resource for the rehabilitation process. The management of the topsoil which contains the soil seed bank is therefore critical to creating the species richness that is required for successful rehabilitation.

Species should be selected based on their presence in broad-scale pre-mining vegetation surveys and the vegetation control plots (Koch, 2007b).

Detailed vegetation control plots should be permanently established in forest site vegetation types adjacent to mining areas based on the proportion of each site vegetation type to be impacted by the future mining.

Alcoa establish twelve to fifteen plots of twenty by twenty metres in areas that will not be mined in each new mining envelope. Within these plots all trees are identified and measured, and numbers and cover of all understorey plants are recorded in twenty by four square metre quadrats (eight square metres) (0.008 ha) within each twenty by twenty metre plot. These plots provide controls that are compared to identical plots in the rehabilitated areas.

Alcoa's species selection procedure excludes several fast-growing fire-ephemeral species from the seed mix because they are very vigorous and could dominate post-mining areas. The rehabilitation effort does not currently aim to reinstate the specific pre-mining site vegetation types in each mine pit, although returning the topsoil seed bank does reinstate the same plant species in each pit to some extent. The major changes in the soil profile and landscape during mining and restoration (Kew *et al*. 2007; Koch 2007b) override the more subtle soil and landscape differences that control the pre-mining site vegetation types.

Some species produce very little seed and are therefore difficult to restore from the natural seed bank or from collected seeds. These are called **recalcitrant** species. Recalcitrant species are often species that recover from natural disturbances such as fire by re-sprouting from tubers, rhizomes and other underground parts. Re-sprouting species give the jarrah forest a high resilience to natural disturbances, particularly fire and grazing, and hence are a crucial component of the ecosystem.

Some species do not establish well from seed, and or seed availability is limited, in which case seedlings need to be raised and planted into the rehabilitation area. This has been found to be the case for a range of herbaceous species and in areas with high weed competition (Nussbaumer *et al*., 2011). Tubestock can be produced from seed, cuttings or tissue culture. They should be planted into the bottom of rip lines and depending on weather conditions they benefit from some initial watering. Seedlings establish better in autumn than summer due to cooler establishment conditions. Depending on the level of herbivory at a given time, tree guards or electric fencing may be needed to protect seedlings, and understorey species have been found to require tree guards even when herbivory of canopy and upper middle storeys is low. Control of feral herbivores may be needed to reduce herbivory.

Recalcitrant species can be grown from either cutting, small amounts of collected seed or from tissue culture. Many of these species, particularly the grass-like rushes and sedges and the grass-trees of the Xanthorrhoeaceae family, are the favourite food source for kangaroos in the post-mining rehabilitated areas and can be killed by intensive grazing. This has two implications; firstly, that these species have an important function in the restored ecosystem as kangaroo food and secondly, the plants need protection when they are small, otherwise they can be killed by overgrazing. Small mesh bags can be used to protect the grass-like species from overgrazing (Koch, Richardson and Lamont, 2004).

2.3.2 Seed collection, storage and treatment

Seed collection

Natural seed from the returned topsoil and seed that is manually collected and hand or machine spread at the time of ripping, is responsible for returning the majority of jarrah forest plant species to rehabilitated areas post mining. Seed stored in the topsoil, rather than applied seed, is the major contributor to plant diversity.

Seed loads in the topsoil are high as demonstrated by Vlahos and Bell (1986) who found an average 767 (range 377–1,579) readily germinable seeds per square meter in forest topsoil. Most jarrah forest understorey species cannot germinate from much deeper than about two centimetres therefore care must be taken to ensure that the topsoil containing the viable seeds returned to areas undergoing rehabilitation is not buried too deep to allow the seeds to germinate.

Studies have quantified the ability of germinating plants to emerge from various levels of burial (Grant *et al.* 1996), the seasonal changes in the seed bank (Ward *et al.,* 1997), the depth distribution of the seeds (Koch *et al,.* 1996), and the effects of different soil handling procedures on the seed bank (*Koch et al.,* 1996; *Ward et al.,* 1996). These research findings have led to the following recommendations to maximize the contribution of the topsoil seed bank for rehabilitation:

- Strip the topsoil from new mining areas and return the soil to restored areas in the dry season (summer to autumn in this climate type);

- Return the topsoil from new mining areas to restored areas directly with no storage period (avoid stockpiling the soil). This is called direct return of topsoil;

- Carry out the final soil tillage (deep ripping) in the dry season (summer–autumn); and

- As most jarrah forest understorey species cannot germinate from much deeper than about two centimetres care must be taken to ensure that the topsoil containing the viable seeds is not buried too deep to allow the seeds to germinate.

The addition of provenance-correct seeds adds significantly to post-mining species richness. Seed should be manually collected within about twenty kilometres of the area in which it is to be used. Using local 'provenance correct' seed ensures the genetic diversity of the rehabilitated area is maintained (Koch, 2007a).

Seed Treatments

Heat or smoke treatments to increase germinability are often used prior to broadcasting collected seeds within the rehabilitation area.

Ruthrof *et al.* (2011) tested the efficacy of smokewater to determine the potential germination from soil seed bank in three management sites: a forest site prior to restoration, an ex-pine plantation site and an ex-mine site. Results showed that smokewater significantly increased the germination from the soil seedbank and significant differences in the level of germination of weed species from the soil seedbank were seen between the three management sites. This use of smokewater may therefore be a useful tool to help predict differences in the soil seedbank compared with predicting soil seedbank based on land use history and recent condition.

Turner *et al.* (2006) investigated means to optimize rehabilitation techniques following sand mining. Specifically, the study investigated the use of polymer seed coatings, time of sowing application, and in situ raking of the topsoil to optimize seedling recruitment to site.

For polymer seed coatings, an ex situ trial was undertaken to evaluate seed coating effects on seedling emergence. Results demonstrated that seed coatings did not significantly inhibit maximum emergence percentage of ten Banksia woodland species (out of eleven evaluated), but coated seeds from four species were on average two to six days slower to emerge than non-coated seeds. Seed coatings were found to have a greater effect in situ, with more coated seeds emerging than non-coated seeds.

Turner *et al.* (2006) found that topsoil raking (following seed sowing) and time of sowing had the greatest impact on seedling emergence, with higher emergence following topsoil raking (5- to 90-fold increase) and sowing in May (late autumn) (1.4- to 12-fold increase) rather than in July (mid-winter).

2.4 PLANT ESTABLISHMENT

2.4.1 Plant establishment techniques

Resampling of permanent plots by Alcoa revealed that species composition of older post-mining areas does not become more similar to unmined forest over one to three decades. Few species (mostly orchids) establish after the first year of restoration and adherence to the initial floristic composition model of forest succession applies to jarrah forest mine site restoration in Western Australia. The strategy, therefore, is to maximize the diversity of understorey species in newly restored sites at the first attempt.

Following the return of overburden and topsoil the area to be rehabilitated is ripped to a minimum depth of 0.8 m on contour by a dozer fitted with three tines. Ripping is undertaken on contour that is along lines with the same elevation, to increase the soil's water storage capacity. Mounds created by the contour ripping also stops soil erosion. The minimum depth of 0.8 m is deep enough to alleviate the re-compaction caused by the soil return operation. The pre-ripping operation, which is carried out after landscaping to a minimum depth of 1.5 m allows deep root growth and water infiltration.

Seed is applied immediately onto the freshly ripped ground by a computer controlled air-seeder machine mounted on the contour ripping dozer. Research has shown that the timing of the applied seeding is important and ripping in dry soil conditions between December and April optimises plant establishment. Ripping in the dry season also allows good establishment of plants from the natural soil seed bank which otherwise be destroyed if the ripping was carried out in winter. Dry season ripping also prevents dieback spread from wet soil, produces a better soil structure and avoids large machines being bogged in wet soil.

Prior to the onset of winter rains, the areas are seeded with a seed mix that contains seventy to one hundred local plant species. Seeding immediately after ripping maximizes plant establishment from the applied seed (Ward *et al.,* 1996). Seed is either broadcast by hand or applied directly on to the freshly ripped ground by a seeding machine attached to the ripping bulldozer. The seed mix is applied at about two kilograms per hectare. Seed of the dominant tree species, jarrah and marri, are included in the mix.

Only indigenous species are included in the seed mix, and all the seed are sourced from within twenty kilometres of each mine to retain local genetic material in the rehabilitated areas. Plant species that cannot be established from topsoil or applied seed (known as recalcitrant species) are propagated at Alcoa's nursery and planted in rehabilitated areas in the first winter. Nursery plants are produced from treated seed, cuttings or tissue culture. In 2002, over 240,000 recalcitrant plants were planted at a rate of over four hundred per hectare. Kangaroos graze some of the recalcitrant species so these plants are protected with tree guards. Five hundred kilogram per hectare of fertilizer is applied. The fertilizer mix is based on di-ammonium phosphate with added potassium and micronutrients (sixteen percent phosphorus, fourteen percent nitrogen, five percent potassium plus copper, zinc, manganese and molybdenum) are applied by helicopter in spring.

Jarrah responds to both nitrogen and phosphorus fertilizers when very young but the response to early nitrogen application is not significant after approximately one decade. In Alcoa's experience between one- and two-thirds of jarrah established from seed grow into saplings, but this proportion decreases with increasing tree density. Closer tree spacing results in more single-stemmed Jarrah trees at the expense of growth. Tree seed used for rehabilitation should be sourced from areas close to the rehabilitation site with similar soil type and rainfall. Seed from outlier populations and coastal plain vegetation types should not be used.

At Alcoa the introduction of mechanical seeding by dozer was a major improvement in the seeding process by not only replacing the strenuous work of hand seeding, but also seed is broadcast directly onto freshly ripped ground. A feature of the air-seeder is the ability to handle mixed seed from the jarrah forest of varied size and shape. It can deliver very small amounts of seed. The seed application rate is as low as 1.1 - 1.5 kilograms per hectare. Such low seed rates are achieved by seed moving from a seed bin through a chute onto the face of a slowly turning sponge which turns and drops the seeds into the delivery chute. The speed of the turning sponge is controlled by the speed of the dozer. When the dozer stops the seed delivery stops.

Fertilising is conducted every year as the final part of Alcoa's mine rehabilitation process. Each summer, all pits in which mining has been completed are rehabilitated. This rehabilitation commences during November and is completed in April each year. During the following winter, once temperatures have cooled and the winter rain has set in, the seeds in the rehabilitated areas germinate. All newly rehabilitated pits are fertilised during August to encourage strong growth of these new seedlings.

A single application of fertiliser is applied. The fertiliser contains nitrogen, phosphorous, and potassium, and also the micronutrients copper, molybdenum and zinc. The nitrogen, phosphorus and potassium application rates are forty, forty and twenty five kilograms per hectare respectively.

Methods of fertilizing

Alcoa's research into fertilising techniques has found that the most efficient method of fertiliser application is by aerial top dressing using a helicopter. Aerial top dressing removes the need to have machines travel over the rip lines, a practice that is not safe for operators and causes re-compaction of the topsoil.

Adding nutrients beneath planted seedlings can improve rehabilitation success in revegetation efforts, according to a Murdoch University study undertaken by Dr Katrina Ruthrof (2013).

Ruthrof (2013) tested the efficacy of various commercially available plant treatments on seedling establishment at two degraded Eucalyptus gomphocephala woodlands, one in the Ludlow Tuart forest and one in the Yalgorup National Park. Researchers tested five treatments on the seedlings including a slow release fertiliser tablet, a clay based amendment for sandy soils, a biostimulant, a hydrophilic co-polymer containing slow release fertiliser and a chelating (heavy metal removing) agent. Higher levels of survival were seen at both sites and early survival and health was increased at one site through the addition of nutrients.

The fertiliser tablet was found to be the most successful, doubling the rate of success in seedling establishment from 53 to 97 per cent in Yalgorup. Given that these plant species naturally recruit following fire, which releases nutrients from the soil, it's reasonable that the added fertiliser would assist with establishment.

The researchers concluded that if large scale revegetation activities are to be successful and cost effective, the efficacy of techniques aimed at advancing the establishment of seedlings needs further investigation (Ruthrof, 2013).

Ploughing, deep-ripping and scarifying
Many rehabilitation operations involve soil cultivation to ease compaction.

Ward, Koch & Ainsworth (1996) investigated the effects of different ripping, seeding, and scarifying dates on the establishment of plants from propagules stored in the topsoil and from applied seed on areas being rehabilitated after mining. Ripping late (April) or scarifying in June significantly reduced the number of species and numbers of individual plants that established from propagules in the topsoil. Species originating from broadcast seed were most numerous when the seed was broadcast in April or after scarifying in June. Scarifying before seeding, particularly in June, increases the establishment of species from broadcast seed. To make best use of the applied seed, without jeopardizing the establishment of species from the topsoil, pits should be ripped and sown by April.

Reid *et al.* (2004) studied plant abundance and diversity for plots that were ploughed or deep-ripped and plots that were scarified and found that plots that were deep ripped recorded the greatest plant abundance and diversity.

Significantly, Rokich *et al.* (2000) found that ripping had no significant effect on seedling recruitment and species richness. The study reported that ploughing was an effective and cost efficient method of soil preparation prior to broadcast seeding. Although deep-ripping generated similar results to ploughing, it was the most expensive treatment. Scarifying the soil was the cheapest treatment, but resulted in lower establishment rates for seedlings. Soil treatments would be more efficient if carried out over a larger area and the costs per hectare would therefore be less.

Croton and Ainsworth (2007) described the science behind the deep ripping procedure used by Alcoa in the southwest. Deep ripping, using a conventional chisel-tine to a nominal depth of 1.4 metre, was introduced to Alcoa's operations on the Darling Plateau in 1969 following wind throw of a number of trees. Although research into mine floor compaction showed that this ripping depth was sufficient to remove the mining compaction, tillage studies showed that plastic failure around the point of a conventional tine ripping to this depth was actually adding to deep compaction rather than removing it. To improve tillage at depth, wing-like structures were attached to the shank of a conventional chisel-tine directly behind the point. These wings lift and till the soil across a broad front. Wingspans between 0.75 and 1.8 metres were tested, and a final design of 1.8 metre wingspan adopted for ripping during the 1980s and 1990s. Availability of suitable steels in the late 1990s allowed the winged tines to be fabricated from scratch, enabling the fitting of wear plates to almost completely eliminate shank wear and breakage problems, though these additions have resulted in some loss of tillage efficiency. Modification of the bulldozer ripping box is highly desirable for ripper design to be improved further, particularly to overcome lateral sliding when contour ripping is undertaken on steep slopes.

An alternative is to divide the ripping process in two: a pre-rip up and down the slope followed by shallow ripping on contour. A two-step ripping process is used at the Alcoa's bauxite mines.

Ecosystem development

Ecosystem processes take time to develop as the vegetation matures, and other plants and animals recolonise over time. Some of the critical ecosystem processes include the accumulation of litter, redevelopment of nutrient pools and the successional development of the established vegetation. The primary source of soil organic carbon is from plant litter and this is related to the productivity of the vegetation biomass. In developing reforested systems, litter fall tends to be higher than in native stable systems. The rapid increase in litter stocks occurs as part of the natural successional cycle as re-seeders are replaced by the standard re-sprouting trees that make up the over-storey in a mature forest canopy (Tibbett, 2010).

The contour furrowing that results from soil ripping aids these processes by ensuring that resources such as water, leaf litter and nutrients are captured and used *in situ* or recycled. The furrows also concentrate the litter, allowing decomposition processes to commence earlier.

Litter re-accumulates rapidly in rehabilitated sites, sourced mainly from seeded eucalypt and legume species. Within three to five years, rehabilitated areas have accumulated the same amount of litter as unmined forest sites contain after the same period of time following burning (Ward, 2000).

Rehabilitated sites rapidly redevelop nutrient pools in the soil, litter and under-storey vegetation, but the pool contained within trees takes longer to develop (Ward & Koch 1996). High densities of legume species are established in rehabilitated areas to provide nitrogen fixation, water use and soil stabilization. These species are generally short-lived and their senescence leads to accumulation of highly flammable material that increases the risk of fire. Unmined jarrah forest is periodically burnt and a number of research projects have now investigated prescription burning in rehabilitated areas (Grant & Loneragan 1999, Smith 2001). Disturbance associated with fire is a critical stage in the development of the rehabilitated ecosystem, as it provides further opportunity for plant re-colonization, regeneration and multiplication and for cycling of nutrients. Fire also modifies the structure of the young forests, leading to the development of a more clearly stratified, two-tiered structure of canopy and understorey, more similar to the natural forest.

Research by Grant C.D., Ward, S.C., and Morley, S.C. (2007) found that a critical aspect of re-establishing a self-sustaining jarrah (*Eucalyptus marginata*) forest ecosystem to mined areas is to ensure that vital ecosystem functions such as litter decomposition and nutrient cycling are returned. Significant research has been undertaken over the past twenty years relating to litter decomposition and nutrient cycling. Studies have shown that litter accumulates rapidly in restored areas (1–4 ton per hectare per year) and the accumulated litter tends to be richer in nitrogen due to intentionally elevated densities of nitrogen-fixing species. This leads to a lower carbon:nitrogen ratio (60:1 compared to 130:1 in unmined forest) that may promote mineralization of organic nitrogen to inorganic forms in restored areas. The major nutrient store in the unmined forest is in the soil and returning soil during the rehabilitation process largely conserves this resource, particularly in relation to phosphorus. Short-term plant macronutrient requirements for growth are readily restored by fertilizer application. Studies on the re-accumulation of nutrient pools in the successional development of restored areas have shown that pools equivalent to the unmined forest are established within ten to twenty years. Ongoing research is focusing on the rates of cycling processes in burnt and unburnt restored areas, and comparing these to the unmined forest to ensure that key functions have been re-established.

So, T., Ruthrof, K.X. and Dell, B. (2011) found that inoculation with beneficial soil microorganisms has the potential to enhance success of rehabilitation, particularly in harsh Mediterranean-type ecosystems (MTE's). They investigated the effects of microorganisms (mycorrhizal fungi and root nodule bacteria) and planting material (seed and nursery-raised seedlings) on early establishment and growth of two key post-disturbance colonizing species with different life histories, life forms and functional types (*Eucalyptus gomphocephala* and *Acacia saligna*) under field conditions. Establishment and growth was monitored at thirteen months, following the first MTE drought period. For E. *gomphocephala*, establishment was higher for seedlings (81%) than for seeding (7.5%). Inoculation with ectomycorrhizal fungal spores was not beneficial. For A. *saligna*, establishment was also higher for seedlings (84%) than for seeding (42.5%). Mycorrhizal fungal inoculum had no effect on establishment or growth. This study has shown that in harsh MTE conditions the use of seedlings is more effective than seeding in degraded woodlands even when attempting to reintroduce key colonizing species. The microorganism treatments tested did not result in significant improvement in establishment or growth.

Jasper, D.A. (2007) studied beneficial soil microorganisms are integral to nutrient availability and uptake for plants in restoration. They include mycorrhizal fungi and nitrogen-fixing bacteria, together with the soil microbial populations which contribute to nutrient availability. Around seventy percent of jarrah forest plant species form arbuscular mycorrhizas, and approximately a quarter also form ectomycorrhizas. Many are also legumes. In addition, around seventy orchid species depend on mycorrhizal symbioses. Therefore, symbiotic soil microorganisms are important in the ecosystem. Arbuscular mycorrhizal fungi recover to pre-mining levels in bauxite restoration in five years. Ectomycorrhizal fungi are poorly adapted to disturbance; however, they are able to reinvade through wind-blown spores. The density of ectomycorrhizal fungi has been found to be equivalent in seven-year-old restoration and adjacent forest, but both abundance and diversity are correlated with development of a litter layer. Fortunately, rhizobia are known to be tolerant of soil disturbance, and failure of N-fixation by legumes has not been reported in restoration. Other N-fixing symbioses, such as between Allocasuarina and Frankia or Macrozamia and Nostoc, have not been investigated in restored mines. Soil microbial biomass C achieves near equivalence after about eight years and appears to be driven by vegetation productivity and related inputs of C into the soil. There is little field evidence that the absence, or very low levels, of soil microbial symbionts will have a substantial impact on plant growth in restoration. Therefore, deliberate reintroduction of these microorganisms does not appear justified. However, soil management to enhance the survival of soil biological components is recommended.

2.4.2 Controlling threats to rehabilitation success

Climate Change

A statistically significant decrease (approximately thirty percent or more) in rainfall in southwest Western Australia, since the middle of last century, has been reported in a number of studies (Li, Chambers & Nicholls, 2005; Andrich & Imberger, 2012).

The causes of the rainfall decreases in southwest Western Australia, over the last sixty years remain an open question. It is not clear whether it is associated with natural variability, the greenhouse effect, or other anthropogenic influences, such as land clearing or pollution (Li, Chambers & Nicholls, 2005) and for the purposes of this desktop study it does not matter. The fact remains that the rainfall has decreased since the mid-20th century with the decrease largely concentrated in the early part of the cool season (May, June & July) while the later rainfall (August-September-October) has not changed very much.

The climatic regime is the single most important factor to consider when developing options for mine rehabilitation especially plant species selection and management. If the ultimate objective is to achieve a sustainable ecosystem it must be consistent with prevailing climatic conditions and the potential climate changes considering the ecosystem should be functional by the middle of the 21st century under changed climate (Vallejo *et al*., 2012). Rainfall and temperature place real constraints on what can be achieved with respect to rehabilitation after mining (Department of Resources Tourism and Industry, 2006).

Mediterranean type ecosystems such as those found in Western Australia's southwest are increasingly at risk from the drier and hotter conditions brought by a changing climate. Although Mediterranean type ecosystems woodlands have some resilience to extremes such as drought and fire, the climate shift threatens their longer term survival (Ruthrof, 2013) and no one knows how ecotypes and genotypes of Mediterranean plant species will respond to the projected intensification of drought and new, more severe fire regimes. To cope with the uncertainty induced by climate change, rehabilitation and management must be adaptive and try to improve ecosystem resistance and/or resilience, and managing landscapes to facilitate species migration (Stephens *et al*., 2010).

Climate changes may impact on rehabilitation at the end of mining where a change in climate conditions means that vegetation must be different to that prior to mining. Any changes in climate should dictate a mine's rehabilitation plan rather than automatically attempting to rehabilitate based on pre-mine conditions, as new conditions may not support the pre-mine environment. Rehabilitation is considered to be 'difficult' to plan for when future temperature and rainfall conditions may be uncertain (Hodgkinson *et al*., 2010).

Weeds

Seedling establishment of many native woody species is significantly reduced in the presence of annual weed species (Hobbs, 2001). Weeds commonly establish after disturbance (Hussey *et al.,* 1997) and often use the disturbance caused by fire as the opportunity to invade an area (Brown and Brooks, 2002).

Maher, Standish and Hallett (2008) found that weed cover negatively affected species establishment and density at restored trial sites. Higher levels of weed cover reduced the percentage of species that established and density of some species, in particular *Banksia attenuata* and *Eucalyptus todtiana*. However, weed cover did not reduce the density of all species. Some species therefore appear to be more sensitive to competition from weeds.

Dieback (Phytophthora cinnamomi)

Phytophthora cinnamomi has a scattered distribution in the southwest jarrah forest that results in most mine pits having infested and un-infested portions. Also, there are generally large areas of un-infested forest adjacent to mine pits. Consequently, the potential to spread the pathogen into un-infested forest is very high.

The Dieback Working Group "Management of Phytophthora Dieback in Extractive Industries" (no publication date) provides guidance in the prevention and management of dieback in Western Australia.

Procedures to manage dieback:

- Mapping the presence;
- Scheduling high risk mining operations during low risk periods of the year;
- Restricting vehicle movements between infested and un-infested areas;
- Cleaning of vehicles before entering dieback free areas;
- Not mixing infested and un-infested soils;
- Training all field staff in the procedures;
- Minimising the movement of Dieback soils; and
- Controlling water movement to prevent flow to un-infested areas.

2.4.3 Completion criteria and monitoring

A challenge that concerns the entire rehabilitation and restoration community is to establish standards to measure the degree of success or failure of rehabilitation (Hobbs and Harris, 2001; Hobbs, 2003). Ruiz-Jaen and Aide (2005) listed nine attributes that a successfully restored ecosystem should have. Unfortunately, as they point out, the costs involved are usually prohibitive and they often require long term studies. Thus any completion criteria will need to be a compromise between what is desirable and what is practical.

To complicate the matter, the scientific basis for choosing how to measure rehabilitation / restoration success is still being debated (Doley and Audet, 2013).

There is probably no one superior paradigm in selecting indicators for rehabilitation success (Ehrenfeld, 2000). Indeed to gauge the success of rehabilitation, indicators will have to represent different levels of the ecosystem, from single species ecology to ecosystem processes and functions (Tongway & Hindley, 2003; Lindenmayer, *et al*. 2007).

Plant diversity is the most common completion criteria used for assessing rehabilitation success and is often assumed as a surrogate for all other types of organisms (EPA, 2006). Even though species richness is acknowledged as being vitally important in assessing rehabilitation success, specific species richness targets are rarely found in published completion criteria (Nichols, 2006) apart from those for Alcoa's Western Australian mines and for Cable Sands' Jangardup mine (URS,2008).

In Western Australia, governmental guidelines on mining rehabilitation state that in most cases, it is too difficult to directly measure fauna, and thus habitat variables, in particular flora, should be used as proxies (Environmental Protection Authority, 2006). This underlines the current rehabilitation theory that flora criteria are assumed to serve the double goal of reflecting their own state as well as being a proxy for fauna re-colonisation success.

It would be advantageous to have completion criteria that refer to the rehabilitation process rather than criteria that can only be measured months after rehabilitation, which makes correction difficult.

New criteria could specify that all areas should receive combinations of direct return of the topsoil, planting seedlings, sowing seed, directly transplanting species and where applicable translocating blocks of topsoil with intact vegetation to maximise the possibility that the species richness targets are met (URS, 2008).

Success criteria of thirty species per one hundred square metres were set for Jangardup (URS, 2008). This appears to be based on sixty percent of the approximately fifty species per each one hundred square metres found in native bushland in the area.

Sixty percent is a conservative target for contemporary rehabilitation. Also, this figure doesn't distinguish between species established easily from seed and more recalcitrant species that may be common or even dominant in the pre-mining vegetation.

The use of one hundred square metre plots as the basis for the species richness targets at Yarloop and Jangardup appears to be as arbitrary as the eighty square metre plots used by Alcoa for their species richness completion criteria (Koch 2007b). Botanical assessment of rehabilitation is a highly skilled, time-consuming and expensive task. The sampling system needs to be designed so that the method chosen delivers the maximum useful information for the least effort. The sampling system used by Bemax at Yarloop and Jangardup has been criticised by the consultant employed to do the botanical monitoring work (Bennett Environmental Consulting 2005). The method also seems to be open to statistical criticism because the sampling transects are not independent and the sampling design may not adequately sample the whole rehabilitation site.

Monitoring and Research

To ensure that rehabilitated areas develop towards the identified rehabilitation objective, monitoring is conducted at an early stage and any unsatisfactory sites should be remediated quickly.

The well-established monitoring regime used by Alcoa is described below.

All rehabilitated areas are assessed at nine months for eucalypt, legume and weed density. Completion criteria specify that rehabilitation should contain 1,300 stems per hectare of eucalypts and one legume plant per square metre. Sites that contain less than five hundred stems per hectare of eucalypts and less than 0.5 legume plants per square metre may need to be reseeded. Occasional infestations of weed species are noted and sprayed.

When sites are fifteen months old, plant species richness is measured. Completion criteria require that sites have greater than fifty percent of the understorey species richness of the unmined forest, but the company's internal objective is to average one hundred percent across all sites.

The successional development of the plants and animals over time should be assessed through long-term vegetation and fauna monitoring programs (e.g. Nichols & Gardner 1998).

At Alcoa, flora monitoring programs area undertaken in the rehabilitated areas each year. In March when the rehabilitation is nine months old the areas are monitored to check that the number of established plants meets agreed standards. Areas of erosion or weeds are also identified at this stage and treated if required. The timing of this monitoring allows for any reseeding or replanting that is required, to be carried out before the next winter.

The second monitoring occurs in the second spring after establishment, when the rehabilitation is fifteen months old). Between ninety and one hundred and fifty plots, each eighty square meters in total area, are placed randomly in that year's rehabilitated areas. In each of these eighty square meter plots all plant species are identified and counted. Weeds or introduced species are not included in this species count. The results from these plots are compared to control plots in un-mined forest and this comparison is used each year to determine if the internal target has been reached.

Each year, a selection of these fifteen month rehabilitation monitoring plots are permanently pegged and become part of a long term vegetation monitoring program. These plots are re-monitored at one, six, fifteen, twenty, thirty and fifty years of age. In these plots the density and cover of all plants is recorded as well as the vegetation structure and tree growth. These plots facilitate the monitoring of long term changes in the vegetation and the information can then be used to improve rehabilitation practices.

3 SUCCESSFUL PROCEDURES FOR REHABILITATION OF PASTURE

3.1 OVERVIEW

For various reasons significantly less information is available discussing successful procedures for the rehabilitation of disturbed land where the intended end land use is agricultural as most mining companies are primarily concerned with establishing native ecosystems following mining.

This section of the desktop study includes publically available examples of successful or leading practice procedures applicable to the rehabilitation of farmland impacted by surface mining. The following aspects are addressed:

- Characterization and reconstruction of soil profiles including:
  - Pre-mining characterization of natural soil profiles and landforms;
  - Removal and management of vegetation and topsoil; and
  - Soil profile reconstruction to support post mining land use objectives.

- Species selection and seed management including:
  - Plant species selection; and
  - Seed collection, storage and treatment.

- Plant establishment including:
  - Plant establishment techniques;
  - Controlling threats to rehabilitation success; and
  - Completion criteria and monitoring.

The examples of successful procedures for characterisation and reconstruction of soil profiles have been included because they are relevant to the specific soil conditions of the already cleared pasture areas at the proposed Yoongarillup Minerals Sands Mine.

The soil assessment for the Yoongarillup Mineral Sands Project undertaken by Landloch (2014) provided the following summary of soil properties for the soil on the cleared farmland.

Most of the soil within the disturbance footprint is described as Pale Deep Sands. The soil is acidic sand material that is poorly structured (massive). Surface soils are water repellent (hydrophobic) which can result in increased potential for erosion from water and wind while it is stockpiled. The surface 10 cm contain the highest level of nutrients, but significant levels are also found down to 30 cm. The subsoil, while more acidic and lower in nutrients, will be useful as a plant growth medium to place above the production waste that will be backfilled into the pit.

The topsoil and subsoil stockpiles will be prone to erosion, particularly when bare of vegetation. Landloch (2014) reported that the surface and subsurface soils are quite erodible even at very low gradients. The dominance of sand sized particles in the soil means that they lack cohesion and are readily eroded by flowing water. In addition, as the soils are hydrophobic there will be a tendency for rainfall to runoff rather than infiltrate the soil profile. Rapid establishment of vegetation will be essential. Assessment of stable batter gradients should also be conducted for the soils. This can be done through laboratory or field based assessment of soil erodibility.

For Yoongarillup, key risks related to soils from the land currently used for agricultural purposes include the presence of hydrophobic soils, soil erosion, and the need to re-establish soil profiles that are able to support cropping activities (Landloch, 2014).

3.2 CHARACTERIZATION AND RECONSTRUCTION OF SOIL PROFILES

An unavoidable consequence of the mineral sands mining process is the disturbance of the soil's matrix structure due to the pre-mining stripping of the topsoil layers therefore the reconstruction and restoration of soil profiles to facilitate previous land uses, satisfying criteria of drainage, erosion and sustainability require careful consideration, planning and management.

3.2.1 Pre-mining characterization of natural soil profiles and landforms

An important element in successful rehabilitation for land that is to be returned to agricultural use is an in-depth understanding of the soil material's properties which will inform the way they are stripped, stockpiled, and respread.

To this end a soil assessment to provide information on the properties of the undisturbed soil is an essential first step.

Pre-mining characterisation of surface and subsurface soils should include, but not limited to, assessment of the following properties:

- Soil pH;
- Electrical conductivity (EC);
- Particle size distribution (gravel, sand, silt, clay);
- Total nitrogen;
- Total phosphorus;
- Organic Carbon;
- Available (Colwell) phosphorus and potassium;
- Available Sulphur (KCl);
- Available trace elements (copper, zinc, manganese, and iron);

- Exchangeable cations;
- Effective Cation Exchange Capacity;
- Exchangeable Sodium Percentage;
- Particle size distribution (gravel, sand, silt, clay);
- Hydrophobicity (surface soils only); and
- Emerson class number.

Where soils are hydrophobic there will be a tendency for rainfall to runoff rather than infiltrate the soil profile. This will have implications for stockpile management and rapid establishment of vegetation will be essential.

3.2.2 Removal and management of vegetation and topsoil

Bell (2004) found that the two most important aspects of soil removal and placement are the nature of the equipment to be used and the moisture content of the soil. Both of these factors will influence the degree of soil compaction and structural breakdown that inevitably occurs during these procedures.

Severe compaction can be difficult to ameliorate and can lead to a reduction in root growth. Extensive evidence from the USA indicates that, when replacing a considerable depth of soil, compaction is one of the major factors limiting the achievement of pre-mining yields on land being returned to cropping (Bell, 2004).

Bell (2004) has provided general guidance for soil removal and placement where the intended end land use is agricultural:

Scrapers are perhaps the most versatile machines for selective removal of soil horizons, but they can cause significant compaction of underlying material during soil placement and have a limited haul distance and are therefore not recommended. Bulldozer spreading of soil from soil stockpiles strategically placed by dumping from trucks is one measure that can be used to reduce compaction. The use of the combination of front end loader, truck and bulldozer for the removal, transport and spreading of soil is the best combination to reduce compaction.

For all soils, there is a moisture content above which it cannot be handled by equipment without being compacted to a point where plant growth will seriously be affected. The bulk density of a soil steadily increases to a maximum as its water content is increased when a constant load is applied. For many soils when moist, a fully loaded scraper can increase bulk densities above the critical values for root growth. Bulk density is an indirect measure of aeration and mechanical impedance which directly affect plant growth, and values above which plant growth is affected, for soils at field capacity, range from about 1.3 grams per cubic centimetre for clay soils to 1.8 grams per cubic centimetre for sandy soils.

3.2.3 Soil profile reconstruction to support post mining land use objectives

A review of recently available rehabilitation management plans (MBS Environmental, 2011; Bemax, 2006) for minerals sands mining projects located in the southwest of Western Australia all appear to recommend that reconstruction of soil profile should be based on the different types of soil disturbance and separated into management areas. For example mine pit and infrastructure areas should be defined as different management areas where:

- Infrastructure areas are those areas that will have been used for a combination of activities including stockpiling soils, access roads or plant sites. The underlying soil profile will remain unchanged, but during rehabilitation surface ripping may be required to alleviate compaction; and

- Mine pit areas will require soil profile reconstruction. Some areas, which previously consisted of a deep sandy profile, may have an improved capacity to support pasture growth after mining.

The upper soil profile should be removed and stockpiled from both mine pit and infrastructure areas.

Braimbridge and Jasper (2001) studied the soil profiles at the Jangardup mineral sands mine, located on the Scott Coastal Plain, approximately forty seven kilometres from Nannup, Western Australia. The study assessed the characterisation of reconstructed mine waste profiles at the then Cable Sands, Jangardup mine site against suitability for plant growth. Soil profiles at Jangardup were reconstructed by the deposition of coarse tailings (clay content ranging from eight to thirty percent), clay slimes and topsoil, to form the various layered 'horizons' evident in each pit. These layers were found to vary greatly in composition and depth. The topsoil was taken from the site prior to mining and was replaced at varying depths.

The study found that the return of rehabilitated land to pasture at Jangardup met with mixed success. Whilst an acceptable level of pasture growth was achieved during the winter months, the possible restriction of pasture production during summer was an area of concern.

It was apparent that the greatest constraint to improved pasture production on the reconstructed profiles at Jangardup was the inability of plant roots to penetrate deeply into the profile and access available moisture and nutrients. Some of the coarse tailings material and most of the fine tailings layers were poorly structured, compacted, slaked upon rewetting, and prone to hard setting and had low hydraulic conductivities. The plastic, anaerobic conditions of much of the fine clay slimes also inhibited root growth and subsequent pasture production. The depth to which root penetration is required for 'adequate' pasture production obviously varies greatly depending on individual profile characteristics, rainfall and plant species, and was indeterminable from the Braimbridge and Jasper (2001) study.

The moisture content, nutrient status and cation exchange capacity of the reconstructed profiles were seemingly capable of sustaining plant growth. However, as the bulk of root growth at depth was restricted to the cracks and voids of the layers with some structure, much of the moisture and nutrients held deep within the soil matrix were unavailable to plants. Over time, as the reconstructed profiles dried, some cracking and structural development occurred.

The cation exchange capacity is a measure of the ability of a soil to retain and release cations and is strongly influenced by the texture of the soil, the mineralogy of the clay fraction of the soil and the organic carbon content. This determines the ability of a soil to retain plant essential nutrients and can also affect some physical properties.

As a result of Braimbridge and Jasper's (2001) assessment of the soil profiles at the Jangardup mine site they detailed techniques to enhance profile drying, soil structure and root growth which included:

- Deep ripping, which has been shown to increase unsaturated hydraulic conductivity and root penetration. The effects of ripping are enhanced if the ripping is conducted at a lower moisture content to maximise shattering of the confining layers. Trialling of site specific ripping practices and measurements of associated soil strength (e.g. penetrometer measurements) and root penetration is recommended to determine the long-term effects of ripping.

- The mixing of tailings materials prior to deposition and deposition at lower moisture content is also be beneficial to the structure of the reconstructed profiles. Allowing slime layers to dry before the deposition of a sand layer also accelerates structural development at depth by encouraging sand penetration into cracks in the fine, poorly structured layers.

- The addition of dried fine tailings material to the topsoil has been shown to reduce water repellence. The rates and methods of clay application should be investigated as there would most likely be benefits to pasture growth and resulting plant water use as a direct result of reduced water repellence in both the rehabilitated and undisturbed areas.

3.3 SPECIES SELECTION AND SEED MANAGEMENT

Where the intended end land use is a return to agricultural use plant species selection should be undertaken in consultation with the land owner.

Seed collection, storage and treatment are not required for the rehabilitation of disturbed land where the end land use is a return to agricultural use.

3.4 PLANT ESTABLISHMENT

3.4.1 Plant establishment procedures for rehabilitated pasture

There is considerable experience in rehabilitating farmland on the Swan Coastal Plain. Revegetation procedures used for re-establishment of farmland after mining at Waroona, Jangardup, Tutunup, Yarloop and Benger mine sites have been investigated for this desktop study and although detailed rehabilitation procedures have not been located some information is available in the publically available rehabilitation management plans for the sites above. The available information is provided below.

- Consultation with the landowner and the Department of Agriculture and Food on the appropriate pasture species in particular areas, seeding rates, fertiliser types and application rates are essential;

- Pasture is sown mechanically into the restored landforms using standard agricultural machinery;

- The annual rainfall and temperature of the mine area limits the growth season of annual species from approximately May to October. Within this time window, two seeding measures can be undertaken;

    - Full pasture species mix, to be planted in mid to late May. This allows the maximum time for germination, establishment and seed set, to re-establish a self-functioning pasture;

    - Where landforms are completed outside of May, a temporary ‘stubble crop’ may be planted in August. An August planting allows sufficient time to establish a stubble crop with sufficient root growth for soil stabilisation and plant height to provide wind break cover at ground level. Other forms of stabilisation, such as hydromulch, may be used as an alternative to stubble crops; and

- Reseeding will also occur in the second year to ensure full establishment of pasture to sustain grazing and enable self-sustaining pasture through natural re-seeding.

The methodology for seeding is summarised below:

- Seedbed preparation using secondary tillage implements (scarifier and harrows);

- Seed mix applied at twenty kilogram per hectare using an "Aitchison" seeder. The seed mix consists of sub clover and ryegrass varieties, the clover seed being inoculated via lime pelleting;

- After seeding, the area is rolled to provide a firm seed bed for pasture establishment; and

- Fertiliser is applied at 400 kilograms per hectare using a super-spreader. The fertiliser comprises superphosphate and potash with added trace elements of copper, zinc and molybdenum. In addition, lime is applied at four tonnes per hectare.

Rehabilitated mine areas should not be handed back to the landowner until a self-sustaining pasture has been established. Establishing rehabilitated self-sustaining pasture often takes up to take two years. During this period, it is recommended that stock is excluded from rehabilitation areas by fencing rehabilitated areas.

3.4.2 Controlling threats to rehabilitation success

The soils of the Swan coastal plain are dominated by sandy soils that are naturally infertile, have limited capacity to retain applied nutrients, particularly nitrogen and phosphorus and are often hydrophobic (Bolland, 1998). This is often a problem for rehabilitation of agricultural land after mining and research has demonstrated that carefully used soil amendments can help to improve the success of the rehabilitation effort. Use of various soil amendments that have recently demonstrated successful outcomes and that may be considered for the rehabilitation of the agricultural land at Yoongarillup are discussed below.

Use of Clay Materials

Waddell, Mann and Allen (2002) in their study into the use of natural clays and industrial residues with green waste compost to improve the quality of Perth coastal plain soils found that the addition of clay materials and some mineral processing residues improved soil quality by increasing nutrient retention, reducing soil hydrophobicity, raising soil pH and improving the cropping potential of the soil with reduced reliance on chemical fertilisers.

The addition of clay is a traditional method of reducing hydrophobicity as it increases the overall surface area of the soil and reduces the effects of organic waxes within the soil matrix. Clay addition also has the benefit of increasing soil strength which will allow the soil to more effectively resist erosion (Harper and Gilkes, 2004).

Clay types differ in their ability to reduce repellence. The efficacy of clay in ameliorating repellent soils depends on specific surface area, mineralogy and dispersion. Clays that readily disperse and bind to sand grains and organic waxes as a thin coating ‘mask’ the hydrophobic sites. Sodium-dominated kaolinitic and illitic clays will reduce water repellence in sands to a greater extent than other clay types (e.g. smectite). Sodic kaolinitic clays are ideally suited to masking water repellence given that they readily disperse, have a low width to thickness ratio and a comparatively high surface area of forty square metres per gram. It is fortuitous that most of the subsoils on the south coast of Western Australia associated with repellent sands are sodic kaolinitic clays (Department of Agriculture and Food, 2009).

Relationships between non-wetting and dispersive kaolinitic clay content invariably show an exponential decline in repellence with increasing clay content; Repellence is often negated above three to five percent clay for sand plain soils on the south coast. The amount of organic carbon within the soil will also affect the amount of clay needed to be applied (Department of Agriculture and Food, 2009)

If the addition of clay is used the following investigation would need to be undertaken to determine the:

- composition of the clay;
- salt content;
- appropriate application rates; and
- appropriate application methods.

One mineral sand mine in southwest Western Australia has trialled the use of clay waste to improve the quality of the topsoil replacement after mining. The trial showed that clay could be applied via a slurry mix sprayed from a water truck. This trial demonstrated that if the application rates are too high, a boggy, wet soil prone to pugging due to the blocking of soil pore spaces with fine clay material will result (Landloch, 2014).

Use of Biosolids

Other research by Rate, Lee and French (2004) found that organic amendments such as biosolids (digested sewage sludge) can contribute organic carbon to the rehabilitating system and improve soil chemical fertility and physical conditions. The use of biosolids can also introduce the risk of contamination of the soil–plant system with heavy metals, but nevertheless can be a useful source of trace elements to plants if the concentrations of these elements are low in unamended soil.

Rate, Lee, and French (2004) conducted a glasshouse experiment growing a mixed annual ryegrass (*Lolium rigidum*) subterranean clover (*Trifolium subterraneum*) using two soil materials (residue sand/clay and conserved topsoil) from a mineral sands mine amended with different rates of biosolids (zero, ten, twenty, fifty dry tonne per hectare), and including a liming treatment (two tonne per hectare). Total concentrations of metals (arsenic, cadmium, cobalt, chromium, copper, nickel, lead and zinc) in soil increased with increasing rate of biosolids application. Metal uptake was generally lower where topsoil was present and was decreased by liming. With increasing biosolids application, plant metal concentrations increased for cadmium, nickel and zinc but decreased or were erratic for other elements. In clover, biosolids application removed the zinc deficiency observed where biosolids were not applied.

Plant uptake of all elements increased with increasing biosolids application, suggesting dilution by increased plant biomass was responsible for erratic metal concentration results. Despite the observed increases in uptake of metals by plants, metal concentrations in both species were low and below food standard thresholds. It is unlikely that a single application of biosolids in this system posed a threat from heavy metal contamination of soils or plants, and was beneficial in terms of zinc nutrition of *Trifolium Subterraneum*.

Rate, Lee and French (2004) concluded that for rehabilitation of soil materials to support pasture after mineral sands mining the use of biosolids is a viable option for improving soil chemical and physical fertility.

Use of Manufactured Soils

Encycle Consulting Pty Ltd in their document on the Manufacture of soil for the New Perth Bunbury Highway detailed activities undertaken in the manufacture of soil for the New Perth Bunbury Highway. In scenarios where the existing soil was deemed unsuitable for direct reuse on areas to be rehabilitated because of high concentration of weed infestations, poor soil structure or low organic matter content it was found that the use of manufactured (composted) soil enhanced the ability of the soil to act as a good medium to ensure successful revegetation (Encycle Consulting, 2011).

Composting is a process by which organic materials are decomposed by micro-organisms. Basically anything that was once living can be composted by micro-organisms given suitable conditions of adequate moisture and oxygen. During the composting process the organic carbon is converted into more complex forms such as humus. Humus significantly improves the features and function of soils.

The organic materials used in the composting process on New Perth Bunbury Highway included onsite soils, green waste from cleared and chipped vegetation and imported product that had been produced via a composting process. These materials were mixed and water was added to initiate the composting process. The heat generated by an active compost process leads to pasteurisation of the materials. Pasteurisation occurs when the compost piles reaches and maintains temperatures of fifty five degrees centigrade for three consecutive days. This destroys weed seeds and pathogens such as dieback that may be present in the stockpiles. The compost piles were turned to ensure pasteurisation of the whole pile. Water was added to maintain moist conditions inside the pile, with moisture and temperature being monitored during composting.

The composted product (either a soil amendment incorporated into the soil or mulch spread on the surface) was also found to mitigate against issues such as dieback, erosion, nitrogen drawdown and water repellent soils. A summary on how mitigation is achieved for the above issues is outlined below.

Dieback

Isolating and controlling the spread of dieback requires careful management. Soil that has been classified as containing dieback has to be excavated and either disposed of off-site (to an appropriate facility), spoiled and buried or stockpiled separately and only re-used within known dieback infested areas.. This increases handling costs and increases the potential for dieback to be spread across the disturbed site. Composting material to a temperature of more than fifty five degrees centigrade eradicates the presence of pathogens such as dieback and renders the product suitable for use in construction and revegetation.

Erosion

Due to the low organic matter content present in the most Western Australian soils the usual practices of blading and respreading will not provide adequate protection against erosion caused by wind and rainfall. The organic matter and, more importantly, the biological activity in a manufactured soil help to prevent wind and water erosion.

Nitrogen drawdown (poor plant health)

When un-composted green waste is spread onto the soil surface, micro-organisms will act to try to degrade this material. As the micro-organisms break the un-composted material down, they need to draw nutrients (particularly nitrogen) out of the surrounding soil, a process that is called "nitrogen drawdown". This results in competition for nutrients between plant roots and the green waste, and can have detrimental effects on plant growth and health. Fully composted mature soil blends prevent this process from occurring.

Water repellent soils

Hydrophobic soils can occur by spreading un-composted green waste on the surface as mulch. When this material is left to sit on the surface and break down, it releases a waxy, oily material that coats individual grains of sand in the soil. Consequently, when soils dry out and rainfall occurs, the waxy, oily coating on the grains prevents water from soaking in and the soil remains dry (Walton, 2009). Composting materials and adding them to sandy soils allows for micro-organisms to break down the waxy, oily substances along with organic matter in the compost. In addition, the composted organic matter allows water to adsorb and penetrate into and through particles in the soil (Encycle Consulting, 2011).

Other successful methods of addressing the water repellent nature of soil that may be considered include:

Application of surfactants

Surfactants are wetting agents that reduce repellence by lowering surface water tension, which improves infiltration and may help breakdown of the water repelling waxes and oils that coat soil particles. This may be useful if stockpiling periods are short. Surfactants are commonly applied at seeding and banded at the base of the furrows within the sowing lines. Application happens through nozzles behind the press wheels which form the furrow. Furrow stability is important as any soil movement on top of the banded surfactant will significantly reduce its efficacy. By reducing the surface tension of water surfactants can decrease the capacity of water to be held by the larger pore sizes typically found in sandy textured soils resulting in increased leaching. For this reason the banded surfactants generally have a short life-span in the soil and are biodegraded over weeks so that they can assist with water entry early in the season but do not promote excessive leaching later in the season (Department of Agriculture and Food, http://grains.agric.wa.gov.au/node/wetting-agents-water-repellent-soils Last Accessed February 2014).

Mixing the topsoil with the upper section of the subsoil
Hydrophobicity is generally restricted to the top ten centimetres of the soil profile (Carter and Hetherington, 2006) and subsoil mixing will dilute the effects of organic waxes. Mixing may reduce the nutrient status of the agricultural soils which would then need amending via application of fertiliser (Landloch, 2014).

3.4.3 Completion criteria and monitoring

Completion criteria
The overall objective of the rehabilitation of agricultural land disturbed by mining is to restore the disturbed land to a productive land use that is consistent with the requirements of the landowner.

Achieving this outcome is strongly dependent on the restoration of a functional soil profile (EPA, 2006). Soil profile conditions and subsequent pasture productivity will vary across the property depending on whether disturbed areas have been previously mined. Some areas of the rehabilitated pasture will not have been mined but will had had the topsoil removed and the surface may have been compacted to allow for infrastructure

Examples of successful completion criteria for the rehabilitation of pasture in southwest Western Australia have been difficult to locate. There are very few publically available examples of detailed completion criteria developed for scenarios where rehabilitation to native vegetation is required but there are even less for rehabilitation to agricultural use. Grigg, Emmerton, and McCallum (2001) undertook a review of pasture-based rehabilitation efforts in central Queensland after coal mining to make progress towards the development of completion criteria suitable for relinquishment purposes. As an outcome of this review Grigg, Emmerton, and McCallum (2001) proposed the following completion criteria for rehabilitated pasture land in Queensland. These completion criteria have been included to provide example of the approach that can be used for developing completion criteria for the rehabilitation of land where the end land use is to be agricultural.

- Achieve and maintain vegetation cover of at least seventy percent - Vegetation cover forms the single most important control on erosion. Erosion rates are significantly reduced for cover levels of fifty percent but higher cover levels are considered necessary for adequate control. Soil movement can still occur at high cover, dependent on other factors;

- Regrade slopes to less than twelve percent - High levels of cover are in themselves not necessarily adequate. Significant movement can still occur for cover more than seventy percent on slopes exceeding twelve to fifteen percent. Maintaining slope gradients at less than twelve percent appears to be associated with low erosion rates;

- Media properties reducing infiltration affect the influence of vegetation and slope - Surface materials which have poor particle size distribution (similar proportions of fine sand, silt and non-active or only slightly active clays) combined with elevated exchangeable sodium percentage or dispersion tend to have lower infiltration and transmission rates. Levels of runoff are higher than on rehabilitated areas with relatively favourable characteristics and erosion rates are higher through an increased volume of runoff and through dispersion. This is further compounded by lowered plant growth (as less water is available for growth). Rock content is considered to reduce erosion through surface protection in a manner similar to vegetation, and in disruption of rill development;

- Reduce root zone salinities to less than 0.6 deci Siemens per meter (dS/m) (on 1:5 basis) - Salinity levels of less than 0.6dS/m in the surface forty centimetres support pastures with dry matter levels capable of providing the minimum cover necessary for erosion control. However, the impacts of dry matter removal through grazing may warrant a lower "threshold" value. Low initial site salinity will assist in rapid vegetation establishment, thereby reducing the risk of erosion;

- Media properties influence salinity reduction over time - The same factors which affect infiltration, runoff (and subsequent erosion) also impact on root zone salinity through the development of leaching profiles. Surface materials which have poor particle size distribution combined with elevated exchangeable sodium percentage or dispersion tend to have lower infiltration and transmission rates. Slope and surface roughness (ripping) have an effect on infiltration in the short term but in the longer term their effects are minimised; and

- A minimum cation exchange (CEC) capacity of eight to ten is required for adequate nutrient retention - Soil fertility (available phosphorus, nitrogen and sulpher, plus cations (mainly potassium) impacts on pasture dry matter. However, past fertiliser application and spoil mixing mask longer term equilibrium levels of these nutrients. CEC provides a more usable indicator of long-term nutrient status. Low CEC is mainly associated with materials containing a high proportion of coarse particles, subject to higher leaching and nutrient rundown. As a guide, materials with a sand content of seventy five percent or more are likely to have inadequate nutrient retention capacity. Clay mineralogy will be important in determining CEC.

Performance monitoring

After pastures are established, they should be continually monitored and managed. A short period of grazing can be applied in the first spring after sowing to promote a healthy component of clover amongst the ryegrass, and assist in discouraging any pasture weeds (e.g. capeweed) from becoming dominant. Any problem weeds (e.g. blue lupins, cotton bush, rushes) should be controlled via herbicide application.

Performance monitoring after the rehabilitation of land to be used for agricultural purposes should include:

- Excavation of test pits to check root development and soil penetration;
- Assessment of pasture productivity (usually for a minimum of two seasons and undertaken by a qualified agronomist); and
- Regular assessment of weed numbers.

4 SUMMARY

4.1 OVERVIEW

This desktop study has reviewed and documented where possible, successful procedures for the various aspects of land rehabilitation after mining in the southwest of Western Australia

A summary of the findings are provided below.

4.2 CHARACTERISATION AND RECONSTRUCTION SOIL PROFILES

4.2.1 Pre-mining characterisation of natural soil profiles and landforms

End land use planning and rehabilitation objectives must be based baseline assessment of soil, flora and fauna to ensure that realistic capacity and requirements are determined.

Baseline Soil Assessment

- Test soil for chemical, physical and biological characteristics to use in end-land use and rehabilitation planning;
- Identify useful and hostile materials and treat each appropriately ;
- Assess whether land capability can be improved through amelioration; and
- Identify thickness and variability of topsoil and subsoil.

Baseline Flora and Vegetation

- Survey vegetation to identify seed sources, determine future seeding mixes and rates; and
- Ongoing monitoring of reference sites allow for assessment of progress of rehabilitation areas;

Baseline Fauna Survey

- Survey fauna populations to develop protection protocols and habitat reconstruction strategies, and as a means of assessing the progress of rehabilitation areas in relation to fauna re-colonisation; and
- Identify and inspect habitat trees prior to felling to relocate resident animals and retain useful hollows for use in rehabilitation programs.

4.2.2 Removal and management of vegetation and topsoil

Topsoil handling

- Double strip topsoil and subsoil and replace in correct order to produce optimal results;

- Where possible, direct transfer topsoil ;
- Do not strip and stockpile soil when it is wet;
- Where possible, strip topsoil when the native seed bank is most abundant, usually in autumn;
- If possible, direct transfer topsoil to areas requiring rehabilitation to take advantage of the seed bank; and
- Rip after applying the topsoil.

Topsoil stockpiling

- If stockpiling is absolutely necessary, the stockpiles should only be 1-3 m high and sown with target species. If there is a lot of weed colonisation, they should be scalped off prior to spreading the soil. Mixing the stockpile at spreading redistributes nutrients which have accumulated at the base of the stockpile; and
- Keep good records of stockpiles and clearly signpost in the field.

Topsoil substitutes and ameliorants

- Biosolids applied to the surface should be avoided when rehabilitating to native ecosystems as it encourages weed growth;
- Compost has potential for being a suitable topsoil substitute but would need site specific trials to confirm its suitability; and
- Fertiliser can be used at seeding and planting but then use symbiotic soil microbe inoculation to ensure long term plant nutrition and nutrient cycling.

4.2.3 Soil profile reconstruction to support post mining land use objectives

- The reconstruction of essential abiotic landform elements represents a critical first step in the rehabilitation of highly disturbed post-mining ecosystems (Doley et al. 2012); and
- A critical stage in re-establishing a sustainable forest ecosystem is the reconstruction of soil profiles that are suitable to support the rehabilitated ecosystem in the long term and therefore a comprehensive understanding of the undisturbed soil profile and characteristics is vital to the reconstruction of a ‘natural type’ soil profile that provides suitable rooting medium for the rehabilitated vegetation.

4.3 SPECIES SELECTION AND SEED MANAGEMENT

4.3.1 Plant species selection

- Species used in rehabilitation must be local and appropriate to the target community;

- Include as many species as possible and from all vegetation strata represented in the target community;
- Best practice suggests local provenance seed will give best results, but if seed source populations are small additional sources should be included to increase genetic diversity;
- Develop a mosaic of vegetation types rather than a homogeneous cover;
- Include short-lived Acacia species but not at excessive densities;
- For pasture rehabilitation consider including a cover crop where needed to help stabilize the soil and add organic matter; and
- Raise tubestock seedlings of those species which establish poorly either from direct seeding, from the topsoil seed bank (where available), or through natural invasion.

4.3.2 Seed collection, storage and treatment

- Identify vegetation for seed collection and develop a program to collect species at optimal times;
- When collecting seed do not collect more than 20% of the crop to avoid disrupting natural life cycling and feeding by fauna;
- Collect seed from any felled vegetation in the mine path;
- Keep good records of seed collection dates and sites;
- Store seed in optimal conditions to maintain maximum viability;
- Some seed will need pre-treatment to break dormancy prior to seeding;
- Germination field trials should be carried out to determine optimal seeding rate, particularly for key species;
- Seed prior to some reliable rainfall, preferably in autumn; and
- Keep good records of when and how areas were prepared and seeded, the seed mix and rate to compare outcomes.

4.4 PLANT ESTABLISHMENT

4.4.1 Plant establishment techniques

- Protect understorey species with tree guards if herbivory (kangaroos) levels are high;
- Fertilizer tablets may be used to assist plant establishment but do not place fertilizer tablets close to seedling roots;
- Control competitive weeds with herbicide, mulch or weed mats;

- Where practicable, transplant very slow growing or difficult to propagate species from areas in the mine path to rehabilitation areas, with minimal root disturbance and making sure to match soil types of source and destination areas as much as possible;
- Inoculate tube stock seedlings with mycorrhizal fungi and rhizobia bacteria where applicable, prior to planting to ensure long-term plant nutrition and sustainable nutrient cycling;
- Inoculate direct seeding areas either by using good quality soil from remnant vegetation areas, coating seed with inoculum prior to seeding, inoculating plants after germination or by including some inoculated tube stock planting as sources; and
- Create numerous small rock or log piles rather than a few large ones in rehabilitated areas to encourage fauna return.

4.4.2 Controlling threats to rehabilitation success

- Conduct regular monitoring to detect weed and feral animal impacts including uncontrolled grazing by animals e.g. kangaroos;
- Develop and implement a weed species specific management plan; and
- Develop and implement a feral animal control program, where possible in conjunction with neighbouring landowners and relevant authorities.

4.4.3 Completion criteria and monitoring

- Keep rehabilitation objectives and completion criteria flexible to allow for changes in mine operations, knowledge and technological advances;
- Keep detailed records of all rehabilitation efforts and management procedures used on an appropriate system linked to other GIS based information if possible;
- Select and monitor unmined reference sites to help assess the development of native ecosystem rehabilitation towards the agreed objectives and any completion criteria;
- Monitor frequently at first and less as the system ages, with increased frequency after a significant environmental event such as fire or drought;
- Monitor in each season when possible to detect cryptic species which are only visible at certain times of the year;
- Conduct both quantitative and qualitative monitoring surveys using accepted methods;
- Conduct long-term monitoring to follow the development of the system towards rehabilitation objectives and help refine completion criteria over time;
- Identify problems and act to remedy them promptly; and
- Manage fire to benefit rather than degrade rehabilitated areas.

5 REFERENCES AND BIBLIOGRAPHY

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