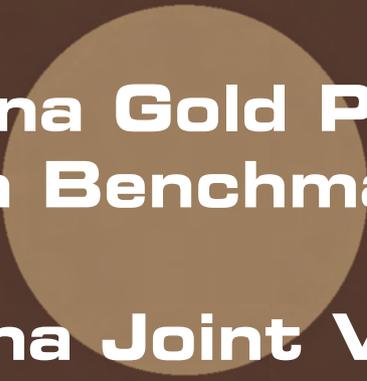# Tropicana Gold Project: Rehabilitation Benchmarking Study

Tropicana Joint Venture

360 environmental

environmental management consultants

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Tropicana Gold Project: Rehabilitation Benchmarking Study

Tropicana Joint Venture

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Disclaimer

Executive Summary

This rehabilitation bench-marking study has been developed for the Tropicana Joint Venture's proposed Tropicana Gold Project (the Project). Successful rehabilitation of the Project area will be an important factor in enabling the site's owner (the Tropicana Joint Venture) to relinquish its responsibility back to the State. The success of any mine-site rehabilitation program revolves around planning, acquiring site-specific knowledge, undertaking appropriate trials and a embracing a flexible attitude to changing practices over the course of the Project's life.

The aim of this report is to provide a summary of current industry practices that can guide the rehabilitation activities for the Project. As there are no direct analogue mines for the Project, similarities such as climate and substrate have been used to identify sites with some similarities. In addition, other sites in dissimilar environments have been reviewed to examine more general rehabilitation planning considerations (e.g. iterative design of landforms in relation to water infiltration and run-off).

The following points will be taken into consideration in rehabilitation planning for the Project:

- Physical and Structural Factors (Section 2):
    - o reconstruction of the landform – geomorphological approach to enable the final landform to blend as much as possible into the surrounding natural environment
    - o design of the cover system – stability, ability to contain waste material and ability to support the designed vegetation community
    - o infiltration and water retention of the final landform – important for stability of the final landform and also for sustaining the designed vegetation community
    - o soil properties – characteristics such as organic matter and nutrient content will be critical in the success of sustaining the designed vegetation community

- Biological Factors (Section 3):
    - o design of the community – aspects of the natural environment that are found on similar substrates/ landscapes will be used in the designed vegetation community for all disturbance areas
    - o provenance of species – to optimise the rehabilitation outcome it is important to identify the optimal seed collection area while not compromising the regeneration capacity of the natural environment
    - o revegetation techniques – direct return of harvested topsoil/ growing media is the preferred method, however some stockpiling will be required and it may be necessary to establish an onsite nursery for recalcitrant species or Priority Flora.

Although this document broken down into sections covering the physical and biological facets of rehabilitation (sections 2 and 3), it is important to realise that rehabilitation of a mine site is an integrated process, with many interfaces and relationships between physical and biological aspects of closure.

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1. Introduction

Successful rehabilitation of a mine is an important factor in enabling the company to relinquish its responsibility back to the State. The success of a rehabilitation program revolves around planning, site-specific knowledge, appropriate trials and a flexible attitude to changing practices over the course of the mining project's life. An adaptive management approach is particularly important for the incorporation of new knowledge and new technologies as they become available over the life of a mine. An adaptive management and risk based approach is a useful base from which to work in the implementation of a project's rehabilitation program.

There are many important aspects to rehabilitation; most can be grouped under the following broad themes:

- Gathering site-specific knowledge of the biological and physical environment.
- Planning for rehabilitation from the earliest stages of the project.
- Appropriate progressive rehabilitation.

Crucial to any successful rehabilitation program is a sound knowledge of the environment, both physical and biological. Sound knowledge minimises the risk of rehabilitation failure, maximises the likelihood of success and ensures that opportunities are identified and exploited as they arise.

Early planning for rehabilitation can provide assurance to regulators and stakeholders that the company is prepared for and capable of providing a walk-away solution. Good planning will enable a company to go about its daily business in a strategic manner, always planning for the eventual rehabilitation and closure of the site.

An integral part of the planning process for rehabilitation is the identification of appropriate landforms and biological communities for incorporation into the constructed landscape. As part of the planning process (and review of closure plans as the operational phase progresses) it is critical that the engineering and biological aspects of rehabilitation are considered together – engineering considerations for final landforms must consider the aimed-for ecosystem and vice versa. Selection of vegetation communities and the shape of the final landforms are critical to enable the constructed landscape to blend into the existing environment as much as possible. Along with selecting the community and landform, a company should select analogous research and monitoring sites for the planned rehabilitated communities at as early a stage as possible so that baseline research into the physical and biological features of the target communities can be understood (e.g. water holding capacity, erosion parameters).

The importance of progressive rehabilitation in successful mine closure is widely recognised within the mining industry – by owners, regulators and other stakeholders. Progressive rehabilitation of a site flows best from a comprehensive and accurate life of mine plan. This ensures that operators/ owners are aware of and understand as many of the factors relevant to achieving rehabilitation of a site in the earliest possible timeframe. For example, at an early stage it is important to understand the volume of waste generated and the shape of the final landform so that the amount of cover material (e.g. capping and growth medium) can be calculated and assurances made that sufficient volume will be available.

1.1. Purpose of this Document

This rehabilitation bench-marking study has been developed for the Tropicana Joint Venture's proposed Tropicana Gold Project (the Project). As currently proposed, the Project consists of the following areas of disturbance, with varying requirements in terms of rehabilitation:

- Operational Area
- Mine Access Road
- Water Supply Borefield and Pipeline Corridor
- Communications Corridor.

This study focuses primarily on the Operational Area, as this will be where most rehabilitation effort will be expended. The Operational Area consists of mine voids, waste landforms, airstrip, village and other supporting infrastructure.

The aim of this report is to provide a summary of current industry practices that can guide the rehabilitation activities for the Project. As there are no direct analogue mines for the Project, similarities such as climate and substrate have been used to identify sites with some similarities to the Project.

1.2. Existing Environment

The Operational Area of the Project is located within the Great Victoria Desert (GVD) bioregion (Figure 1). The GVD is a massive bioregion, covering approximately 418,800 km^2 of land, half of which is in Western Australia (Australian Natural Resources Atlas 2008a). The GVD is described as an active sand-ridge desert of deep Quarternary Aeolian sands with a tree steppe of *Eucalyptus gongylocarpa*, mulga and *E. youngiana* over hummock grassland dominated by *Triodia basedowii* (McKenzie et al. 2002). The climate is arid, with summer and winter rainfall (e.g. Yamarna Station [Bureau of Meteorology 2009]).

The Tropicana to Transline Communications Corridor and the Pinjin Mine Access Corridor are predominantly located in the GVD, but also cross into the Murchison (Pinjin), Coolgardie and Nullabor (Tropicana to Transline) bioregions (Figure 1).

Figure 1: Biogeographic regions of Australia and the Tropicana Gold Project

1.2.1. Climate

The GVD climate is arid, with evaporation potential greatly exceeding rainfall and average annual rainfall of less than 200mm. In general, desert rainfall is often sporadic and localised. In the GVD, rainfall generally comprises seasonal thunderstorms and cyclone related rain events during the summer months, and scattered showers during the winter months.

The nearest Bureau of Meteorology weather stations to the Operational Area are Laverton Airport (approximately 230 km northeast), Balgair (approximately 250 km southeast) and Yamarna Station (approximately 145 km northwest – site no longer monitored). Yamarna Station is likely to be the most representative of long term meteorological conditions at the Operational Area, particularly with regard to rainfall and temperature (Heggies 2009). Weather was monitored by the Bureau of Meteorology at Yamarna Station between 1967 and 2008. At Yarmana, average air temperatures during the day tend to be warm to hot, varying between 18.8°C and 20.8°C in winter and 34.2°C and 35.9ºC in summer. Average air temperatures during the night tend to be very cold to warm, varying between 4.2°C and 5.9ºC in winter and between 19.1ºC and 20.6ºC in summer. Average rainfall is approximately 225 mm, with most rain usually falling in February and least in September (Bureau of Meteorology 2009). Approximately 146 mm of rainfall was recorded at the Operational Area during 2008 by the Joint Venture, most of which fell during the late spring and summer months. When

compared with the median monthly rainfall recorded historically at Yamarna, the dataset recorded during 2008 at the Operational Area can be considered below the typical regional trend (Heggies 2009).

1.2.2. Soil and Landforms

The GVD is a vast sandbelt consisting of longitudinal sandplains and dunes (mostly running east-west) separated by interdune corridors (or swales) and sand plains (Plate 1). The majority of the Operational Area lies in a broad valley between an extensive yellow/ orange sand dunefield (with a high incidence of conservation significant flora, and preferred habitat of conservation significant fauna) and a local rocky high point (Plate 2). Areas of breakaway are also present (Plate 3).

Plate 1: Longitudinal Sand dunes and Interdunal Corridors with historic fire scar near the Operational Area

Plate 2: Hat Trick Hill – a local high point on the eastern side of the Operational Area

Plate 3: Laterite Break-away in the Operational Area.

The stratigraphy across the Operational Area consists of at least five distinct lithological groups:

- Quaternary aeolian sand dunes, alluvium and lake deposits
- Cenozoic laterite weathering profile
- Cenozoic alluvium and colluvium deposits
- Permian Paterson Formation
- Achaean basement.

Many of the higher hills around the Operational Area are topped by a veneer of unconsolidated sandplain with regular west to north-northwest sand ridges up to several kilometres in length by 14 m high and about 200 m wide. The interdunal areas are often a veneer of one or two metres of sand sheet, but equally as often the interdunal zones are windswept, exposing the underlying red-brown earth, colluvium or the ferruginous hard cap.

Cenozoic deposits above the target ore body of the Project are comprised of several metres of fluvial infill, thickening to about 30 m in the deepest section. The Cenozoic deposits are mostly a mixture of fine-grained interbedded silty and clayey fluvial and lacustrine deposits; however, several drill holes have intersected 3 to 5 m of a basal gravel unit comprised of medium to coarse quartz sand with occasional clayey rounded pebble gravel (AngloGold Ashanti Australia, unpublished data).

Soil testing found that the soils were mainly between pH 6 and pH 8. Salinity generally increased with depth ranging from non-salty to moderately saline. Average nutrients for the Operational Area soil and regolith material were generally low for total nitrogen and all extractable nutrients, as is commonly found in arid zone soils.

1.2.3.   Vegetation and Flora

The Joint Venture commissioned vegetation mapping and flora surveys across approximately 230,000 ha covering the Operational Area, Pinjin Mine Access Road, Tropicana-Transline

Communications Corridor, the Minigwal Water Supply Area, borefield pipeline corridor and an extensive area surrounding these disturbance zones (disturbance will be up to approximately 3,440 ha).

Operational Area

The main component of the vegetation and flora surveys covered an area of 131,000 ha centred around the Operational Area (*ecologia* Environment 2009). Eleven major vegetation communities were identified in the survey (Figure 2):

1.   Mixed Eucalypt woodlands over mixed open shrubs and *Triodia basedowii*

2.   *Eucalyptus gongylocarpa* (Marble Gum) over *Triodia desertorum* or *T. basedowii*

3.   Scattered *E. gongylocarpa* over mixed shrubs and *Triodia desertorum* or *T. basedowii*

4.   Undulating plains: open mallee *Eucalyptus concinna* over sparse to open low shrubs over open *Triodia scariosa*

5.   Clay Pan: Scattered *Acacia nyssophylla/ Grevillea sarissa* over open herbs and grasses

6.   Major saline clay pan complex

7.   Clay loam plains: *Acacia aneura* woodlands over soft grasses and *Triodia basedowii*

8.   Rocky breakaways and associated slopes: open *Acacia quadrimarginea/ Dodonaea rigida* over sparse mixed shrubs over mixed soft grasses

9.   Grasslands: open to moderately dense *Casuarina pauper* woodland over open mixed shrubs and scattered soft grasses and/ or *Triodia scariosa*

10.   Scattered trees over open low shrubs and moderately dense tussock grasslands

11.   Narrow drainage channels: sparse *Acacia aneura* over sparse to open shrubs and moderately dense tussock grasses

The vegetation within the survey area was generally found to be in good condition, although some areas are undergoing post-fire regeneration. Lightning derived fires are common in the region between and can cause a significant amount of damage to the environment.

A total of 445 taxa were recorded by *ecologia* Environment, including three naturalised alien taxa. 57 families were represented by 162 genera. The most diverse families were Poaceae (47 taxa); Chenopodiaceae (45 taxa), Mimosaceae (41 taxa), Myrtaceae (33 taxa) and Asteraceae (31 taxa). The dominant genera were *Acacia* (40 taxa), *Eremphopila* (25 taxa) and *Eucalytpus* (19 taxa).The following species of conservation significance were recorded across the 131,000 ha survey area (*ecologia* Environment 2009):

●   *Conospermum toddii* (Victoria Desert Smokebush) - listed as Endangered and protected under both the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), and *Wildlife Conservation Act 1950* (WC Act) (listed as Declared Rare flora (DRF)

●   13 Priority species:

- o *Dampiera eriantha* (P1)
- o *Baeckea* sp. Sandstone (C.A Gardner s.n. 26 Oct 1963) (P1)
- o *Baeckea* sp. Great Victoria Desert (A.S. Weston 14813) (P2)
- o *Dicrastylis nicholasii* (P2)
- o *Malleostemon* sp. Officer Basin (P2)
- o *Olearia arida* (P2)
- o *Grevillea secunda* (P2)
- o *Acacia eremophila* numerous-nerved variant (P3)
- o *Acacia eremophila* var. *variabilis* (P3)
- o *Microcorys macredieana* (P3)
- o *Micromyrtus stenocalyx* (P3)
- o *Daviesia purpurascens* (P4)
- o *Lepidobolus deserti* (P4).

Three weed species were recorded in the survey:

- *Sonchus oleraceus* (Sowthistle)
- *Spergulia rubra* (Red Sand Spurrey)
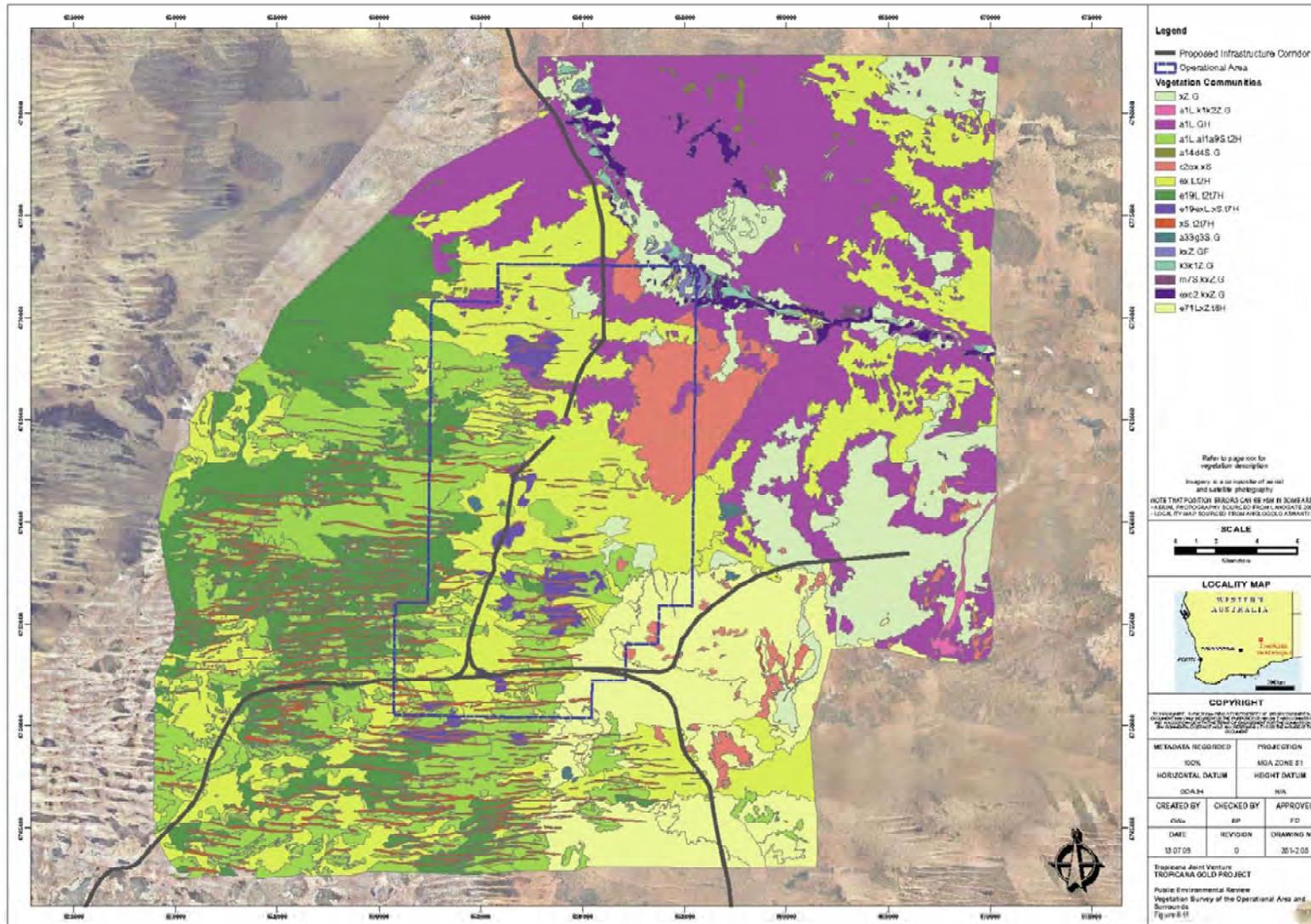- *Erodium aureum*.

Figure 2: Operational Area and surrounds - 131,000 ha Area (source: Tropicana Joint Venture (2009))

Pinjin Mine Access Road and Public Bypass

Mattiske Consulting Pty Ltd was commissioned to survey and map the vegetation and flora values of the proposed Pinjin Infrastructure Corridor and Public Bypass Road (Mattiske Consulting 2009). The total area mapped was approximately 20,000 ha which is approximately 34 times larger than the proposed disturbance footprint.

The vegetation was found to vary in condition from pristine, in non-disturbed areas of native vegetation at the eastern end, to good in areas that have been altered by fire. Six major vegetation communities were identified, which could be further broken down into numerous sub-communities.

The major communities were:

- *Eucalyptus* Woodland
- *Casuarina* woodland
- *Acacia* woodland
- Shrubland
- Grassland
- Chenopod Shrubland

The survey identified 267 taxa from 44 families, 122 genera, the most diverse families were: Myrtaceae (37 taxa), Chenopodiaceae (25 taxa), Mimosaceae (22 taxa); Myoporaceae (18 taxa), Proteaceae (14 taxa), and Papilionaceae (14 taxa).

Listed species identified in the survey were:

- *Baeckea* sp. Great Victoria Desert (A.S. Weston 14813) (P2)
- *Dicrastylis nicholasii* (P2)
- *Grevillea secunda* (P2)
- *Olearia arida* (P2)
- *Thryptomene eremaea* (P2)
- *Dicrastylis cundeeleensis* (P3)
- *Eucalyptus pimpiniana* (P3)
- *Microcorys macrediana* (P3)
- *Micromyrtus serrulata* (P3)
- *Micromyrtus stenocalyx* (P3)
- *Comesperma viscidulum* (P4)
- *Daviesia purpurascens* (P4)
- *Lepidobolus deserti* (P4).

One potentially new species of *Hibbertia* was recorded during the survey. Specimens collected do not match the only known species from the GVD Region, *Hibbertia exasperata*, or any other species of *Hibbertia* from surrounding regions.

One introduced (weed) species, *Salvia verbenaca* (Wild Sage) was recorded.

Tropicana-Transline Communications Corridor

The Joint Venture commissioned *ecologia* Environment (2009) to survey 43,000 ha around the proposed Tropicana-Transline Communications Corridor (fibre optic). Vegetation condition ranged from pristine to degraded with fire being the main factor affecting condition. Nine major communities observed along the survey corridor were:

- Mixed *Eucalyptus* woodland over hummock grassland
- *Callitris preissii* tall shrubland
- Mixed *Eucalyptus* woodland over *Triodia scariosa* hummock grassland
- Mixed *Eucalyptus* woodland with *Acacia* understorey, over *Triodia desertorum* hummock grassland
- *Triodia rigidissima* hummock grasslands
- *Acacia aneura* woodland
- Low mixed shrubland
- *Triodia basedowii* hummock grassland
- *Eucalyptus/ Casuarina* mallee/ shrubland over chenopods.

The survey identified 417 flora taxa comprising 52 families, 142 genera and 372 confirmed species. The most diverse families were: Myrtaceae (43 taxa), Mimosaceae (34 taxa), Poaceae (29 taxa), Chenopodiaceae (26 taxa) and Myoporaceae (25 taxa). The most diverse genera were *Acacia* (34 taxa), *Eucalyptus* (29 taxa) and *Eremophila* (24 taxa).

Listed flora identified during the survey were:

- *Dampiera eriantha* (P1)
- *Baeckea* sp. Great Victoria Desert (A.S. Weston 14813) (P2)
- *Dicrastylis nicholasii* (P2)
- *Grevillea secunda* (P2)
- *Isotropis ?canescene* (P2)
- *Malleostemon* sp. Officer Basin (P2)
- *Olearia arida* (P2)
- *Physopsis chrysotricha* (P2)
- *Dicrastylis cundeeleensis* (P3)
- *Microcorys macredieana* (P3)
- *Micromyrtus stenocalyx* (P3)
- *Comesperma viscidulum* (P4)
- *Daviesia purpurascens* (P4)
- *Lepidobolus deserti* (P4).

Other species of conservation interest recorded during the survey were:

- A previously undescribed taxon - *Caesia talinyka*, likely to be listed as a Priority taxon
- Range extensions - *Allocasuarina campestris*, *Adriana urticoides* var. *hookeri*, *Eucalyptus intertexta* and *Swainsona colutoides*.

Two unconfirmed species were recorded during the survey - *Psydrax ?ammophila* and *Solanum ?chippendalei*. If confirmed, these would represent large range extensions.

One weed species was recorded during the survey - *Carrichtera annua* (Ward's weed).

Minigwal Water Supply Area and Borefield Pipeline

Botanica Consulting (2009) was commissioned to survey and map the vegetation and flora values of the Minigwal Water Supply Area and Borefield Pipeline corridor 44,000 ha of native vegetation has been mapped area mapped is approximately 200 times larger than the proposed disturbance area. Vegetation condition for all vegetation groups varies from excellent to degraded. The areas classified as degraded have been affected by severe fires over 5-10 years. Five major plant communities where identified within the survey area based on landform, these were broken down in 13 sub-communities:

- Longitudinal red sand dunes - Scattered *Eucalyptus gongylocarpa* over mixed shrubs over *Triodia basedowii*
- Sandy flats and swales – 7 various subcommunities
- Rocky breakaway and stony rises – Three sub-communities of mixed *Acacia* over mixed shrubs
- Lake edge community - Moderately dense *Eucalyptus mannensis* ssp *mannensis* over isolated shrubs and scattered *Triodia basedowii*
- Dry clay pan - *Eucalyptus horistes* over low mixed shrubs dominated by *Atriplex vesicaria*.

Botanica Consulting (2009) report that 179 species comprising of 35 Families and 81 Genera were identified in the survey. The most diverse families were: Mimosaceae (31 taxa); Myrtaceae (26 taxa); Myoparaceae (18 taxa); Chenopodiaceae (15 taxa); Lamiaceae (13 taxa); and, Poaceae (12 taxa). The most diverse genera were *Acacia* (31 taxa); *Eremophila* (18 taxa) and *Eucalyptus* (15 taxa). Species of conservation interest that were located during the survey were:

- *Baeckea* sp. Great Victoria Desert (A.S. Weston 14813) (P2)
- *Dicrastylis nicholasii*   (P2)
- *Olearia arida* (P2)
- *Dicrastylis cundeeleensis* (P3)
- *Microcorys macrediana* (P3)
- *Daviesia purpurascens* (P4)
- *Lepidobolus deserti* (P4).

Ecological Communities of Conservation Interest

Some of the regional vegetation communities located east and south of the Operational Area show similarities with the 'Yellow sandplain communities of the Great Victoria Desert' which is currently listed as a Priority Ecological Community (PEC). Detailed description and mapping of the PEC is yet to be carried out by DEC. The Joint Venture has used various plant species, landform and the sand colour to make a preliminary determination of the PECs distribution around the Project's footprint. None of the communities presumed to represent the PEC will be disturbed by the Operational Area. Some of the areas considered by the Joint Venture to potentially represent the PEC will be disturbed by the proposed Mine Access Road, see the

Public Environmental Review documentation for further detail (Tropicana Joint Venture, 2009). The PEC will not be discussed further in this document as impacts are anticipated to be minor.

1.3. Mining Method

The mining methodology proposed for the Operational Area is traditional open cut mining, resulting in the formation of up to four open pits (which will remain after mining), several waste material landforms (WMLs) and a tailings storage facility that will be integrated into one of the WMLs and various other items of infrastructure that will be removed and rehabilitated or transferred into the responsibility of a third party at the time of closure.

1.3.1. Waste Materials

One of the potentially challenging wastes that are routinely managed by mining companies is acid-forming waste. The Joint Venture commissioned the geochemical characterisation of samples from the Operational Area by SRK Consulting (2009) and Landloch (2009a), with the aim of investigating acid generating potential. This work has shown that the majority of the waste material (70% - 75%) can be expected to be non acid forming. Approximately eight percent of the waste material could be expected to be potentially acid form, although this could be as high as 15%. This material is associated with a small number of rock types including:

- Ferruginous cherts
- Feldspathic gneiss
- Sulfide rich sediments
- Schists
- Pegmatites.

It should be noted, that an assessment of relative abundance of each lithological unit selected as part of the geochemical analysis program showed a sampling bias towards sulfide mineralisation and therefore acid generating potential may have been overestimated.

The strategy for preventing acid formation and migration will be to co-dump with non-acid forming waste. The dilution and potential neutralisation of potentially acid forming waste by mixing it using a co-dumping procedure is intended to avoid the creation of a cell of waste that could be potentially harmful if exposed.

Work carried out by Landloch (2009b) has determined that infiltration of rain from the soil surface, through a one metre capping layer and out of the base of a 10 m layer of inert waste material is predicted to be insignificant.

1.3.2. Final Landform

The Joint Venture's aim for closure is to produce a safe, stable, non-polluting landform, supporting a self-sustaining ecosystem across all areas of direct disturbance. The visual concept for rehabilitating the Operational Area is to incorporate aspects of local landforms and plant communities in the final landform. This approach of modelling parts of the final

constructed landform on the surrounding natural environment is aimed to result in an integrated (ecologically and aesthetically) final landscape, rather than the traditionally bermed waste dumps commonly associated with gold mining in Western Australia. Aesthetic impacts on the final landscape are also being minimised by incorporating the tailings storage facility into the waste landform, thereby blending the outline of the facility into a more natural landform, rather than leaving it as a hard-edged rectangle in the middle of an undulating landscape.

Broadly speaking, the Operational Area of the Project occurs in a dune-field with dunes at a relief of approximately 35 m with slopes of approximately 15 degrees. The major landforms at the Operational Area (once rehabilitated) will not exceed 35 m in height so as to be within the normal relief and will have a maximum slope of 15 degrees which has been modelled to be stable (Landloch, 2009c and 2009d).

2. Physical and Structural Factors Important for Successful Rehabilitation

The following sections are a summary of aspects that should be considered during the planning and implementation of rehabilitation for the Project. The focus is on the major constructed landforms at the Operational Area, for example the WMLs and tailings storage facility and in particular the design of capping and cover systems to protect the surrounding environment from potential environmental hazards (e.g. potentially acid forming waste).

2.1. Reconstruction of Soil Profile/ Landform

2.1.1. Soil Properties

Compaction

Compaction of substrate is expected to result from the use of heavy earth-moving equipment during the construction and operational phases of the Project and in the formation of the final landscape. Achieving the designed level of hydraulic conductivity in various layers of a cover system may also require a specific amount of compaction. Compaction can limit plant growth by preventing root penetration or altering the movement of nutrients and/ or water through the substrate. One option to relieve compaction is to rip the landform's surface to relieve compaction, however this also alters hydraulic conductivity and thus must be considered in the design process of the cover system, rather than carried out ad-hoc. Fourie et al.(2008) suggest that surface ripping is likely to be a sufficient management tool to overcome compaction issues on most mine sites.

Organic Matter

Soil organic matter contributes to the physical, chemical and biological function of soils. Organic matter is critical for soil aggregation and structure in soils with a low clay content. It is also generally the major source of plant nutrients including nitrogen, phosphorus and sulphur, and therefore has a major impact on plant productivity/ growth rates and biomass. Changes in soil organic matter (usually loss) associated with the stripping and management of soils/ growth medium harvested for rehabilitation can have dramatic impacts on the success of a rehabilitation program (Loch et al. 2008).

Mineral and Nutrient Content

Soil nutrient status and the bioavailability of those nutrients are major factors in controlling plant productivity, and therefore the rate and progress of revegetation in a rehabilitation program. Long-term success of rehabilitation is dependant on good vegetation development, and in many circumstances, vegetation development is directly linked to soil/ growth medium quality. Initial levels of organic carbon and nitrogen in growth medium can be crucial for vegetation establishment and the long-term success of a rehabilitation program (Loch et al. 2008). In preparing sites for rehabilitation, the recognition that stockpiled soil/ growth medium

could be considered at best sub-optimal (and at worst, poor quality) in terms of mineral and nutrient content as a result of stripping and management practices is a useful perspective (Loch et al. 2008). Williams and Pratt (2008) have demonstrated that the addition of minerals such as phosphorus can have favourable results for the growth and productivity of native plants despite the common assumption that natives don't need additional minerals as they have evolved with access to only low levels of phosphorus. Therefore, some aspects of the poor quality of stripped and stored soil/ growth medium can potentially be overcome by the judicious use of soil additives. Of course, overuse of fertilisers can have negative effects on the growth of native plants by stunting growth or even killing plants (Williams and Pratt 2008).

Although an accelerated rate of revegetation may be attractive in some mining circumstances (e.g. for the prevention of erosion) it is not always the best option for a rehabilitation program because biodiversity can suffer with increased productivity. The relationship between productivity and biodiversity is not clear – in some cases high productivity and high plant growth rates can be associated with low biodiversity (e.g. a monoculture) in other cases the relationship is reversed and in yet other cases there is evidence for an inverted U-shape relationship, with highest biodiversity at intermediate levels of productivity (Diaz et al. 2006). Thus a nutrient rich, highly productive, fast growing revegetation program may not lead to the desired outcome in terms of biodiversity, and the relationship between bioavailable nutrients/ productivity and biodiversity is likely to be system specific (Diaz et al. 2006).

2.1.2. Infiltration and Water Retention

A key consideration for the long-term success of the re-constructed landform is that the final landform will be able to retain sufficient water to support a fully functional ecosystem. Dunes in the area are likely to act as storage points for water as is the case in the Great Sandy Desert (Grigg et al.2008a). Grigg et al. (2008a) concluded that dunes hold more water than adjacent interdunes, thus sustaining more favourable water status further into the dry season for deep-rooted plant species. This dune water is likely to be critical to support vegetation on the crests and sides of dunes in the Operational Area, including Marble Gums which are an iconic species in the area. Water storage in the final constructed landform for the Ranger Mine was also a key consideration in that project's closure planning (Hollingsworth et al. 2006). As such, Ranger commissioned modelling to determine whether or not the designed landform and designed substrate composition would be appropriate to support the designed vegetation community and to have erosion/ sedimentation characteristics in keeping with the surrounding natural environment (Hollingsworth et al. 2006). Although in a very different environment to the Tropicana Gold Project, the Ranger Mine (monsoonal area in the Northern Territory) demonstrates the importance of iterative design and testing (modelling) of the final constructed landform with regard to infiltration, run-off and slope stability.

Landloch (2009c) has determined that infiltration rates are high in the dunes, and significantly lower in the interdunal areas. A matched dune-swale pair above the Havana deposit (southern end of the proposed pit (s)) showed that infiltration into the dune was approximately twice as high as infiltration into the swale (141 versus 71 mm/h). Similarly, infiltration was approximately twice as high in a dune (77 mm/h) compared to its matched swale (44 mm/h)

over the Tropicana deposit (northern end of the proposed pit (s)) As well as being important for revegetation of the final landforms, infiltration and water-holding capacity is also relevant to erosion (see sections 2.1.4 and 2.1.6).

2.1.3.   Cover Design for Waste Material

Cover Systems

Without an appropriate cover system (often composed of multiple layers of different materials) to separate environmentally harmful waste material from the surrounding substrate, growth medium, soil fauna, flora, terrestrial fauna and water (ground and surface) it is possible that potential contaminants could migrate into the surrounding environment. Contamination of surface and ground waters is traditionally the prime consideration in cover design, however contamination of substrate through an inappropriate or failed cover can lead to problems in rehabilitation whereby the contaminant impacts soil fauna or prevents plant growth or prevents the habitation of an area by fauna expected to recolonise the site. In some cases the availability of a contaminant for uptake into the biological system (e.g. flora [Wickland et al. 2007 and Diaz et al. 2006]) can lead to bioaccumulation of the contaminant in the flora and fauna of the area, with a range of ecological responses possible. Thus a successful cover or barrier between any environmentally harmful waste material (whether it be tailings, waste ore or a putrescibles landfill) and the natural environment is a critical component of a mine site's successful rehabilitation and closure.

Historically, mining companies have advocated an impermeable layer in the construction of covers for waste landforms and tailings facilities because of the high importance placed on keeping the waste free from water. There are many instances where the impermeable hydraulic barrier has not performed as expected, particularly in arid and semi-arid environments (Fourie and Tibbett 2007). In response to this, there has been a move away from the prescriptive attitude that an impermeable layer is the only approach to an acceptance that performance based assessment might lead to a better overall outcome while still avoiding negative impacts associated with an interaction between water and waste (Fourie and Tibbett 2007).

An alternative to the traditional hydraulic barrier is the 'store and release'/ evapotranspirative system where water storage capacity is built into the design of the cover system. The store and release cover system is designed to have capacity to temporarily store water from rainfall events which then evaporates over time (Campbell 2004). Provided that the rain fall events are in-frequent and that the evaporation potential is greater than local rainfall these systems can be a successful alternative to a traditional hydraulic barrier (Fourie and Tibbett 2007). The balance in evaporation versus rainfall is strongly drying for the Operational Area, thus these systems hold great potential for this Project. An advantage of cover systems that incorporate store and release functionality is that their properties appear to remain more stable over time (though changes do also take place) than cover systems based on a traditional hydraulic barrier (see multiple references in Fourier and Tibbett 2007).

Cover Design

It is important that a wide variety of factors are considered during design of the cover system. Factors that could be considered include:

- compaction
- hydraulic profile
- porosity
- waterbinding capacity
- impact of designed vegetation community on:

    o water infiltration
    o preferential flow paths
    o infiltration of plant roots into the cover

- impact of fauna (particularly burrowing fauna such as termites)

Another important consideration in cover design is the impact of orientation and slope on evaporation and water balance (Weeks and Wilson 2007). Slope orientation and steepness both have impacts on the local microclimate (e.g. alterations to net radiation and wind movement). Weather monitoring points are generally placed in a level environment, and while data gathered from these locations may show broad similarity to microclimates experienced on the slopes of a waste landform (and hence the cover system), they can be expected to exhibit some degree of inaccuracy, which can then go on to impact the modelled water balance for the landform and cover. If data on the microclimate of slopes representing the orientation of the designed final landform can be incorporated into modelling of the water balance of a designed waste cover system then more accurate measures of water balance should result (Weeks and Wilson 2007). Weeks and Wilson (2007) present an example of how water balance impacts of net radiation on evaporation from the north and south facing slopes were an order of magnitude greater than the evaporation difference between the crest and toe of the slope, highlighting the importance of considering net radiation in water balance modelling.

Changes in the Cover System

Regardless of the cover type, consideration of the changing characteristics of the cover itself, the waste beneath it and the growing ecological community above it as time progresses are important in developing a true walk-away solution for mine closure. These considerations require ongoing review as new information comes to hand during the mining process, rehabilitation trials and trials of cover performance under actual site conditions.

As site rehabilitation continues over time (plants grow, growth medium properties change, fauna recolonise and soil microbe communities change) the aspects of the cover system can also be expected to change (perhaps in ways that are not anticipated at the initial design stage). Accepting that changes in infiltration, evaporation, porosity and carbon content are inevitable in a developing ecosystem as vegetation grows, roots dies, litter falls and fauna such as termites and ants re-colonise is an important consideration in design, monitoring and fine-tuning of a cover system (Fourie and Tibbet 2007). For example, if the potential impacts of vegetation are inadequately considered in the design phase, unexpected impacts to cover

performance can occur (e.g. alterations to water balance through evaportranspiration and physical changes to the cover due to root penetration; Wickland et al.[2007]) leading to sub-optimal cover performance that may have been avoidable.

In order to assess the progress of the cover system towards a steady-state, it is likely to be necessary to monitor the performance of the cover system and the rehabilitating surface over many years, to assess performance versus modelled predictions (Fourie and Tibbet 2007).

Revegetation and the Cover System

Apart from providing a competent barrier to prevent negative impacts associated with an interaction between waste and the environment, another important consideration in the design and operation of a waste cover is that the cover system needs to provide a stable and suitable base for the revegetation of the final landform.

As the pattern of revegetation is highly unlikely to be uniform across a constructed landform, some areas of a cover can be expected to be subject to variation in water balance (e.g. increased infiltration as patches of vegetation retard water flow across the surface, increased evapotranspiration) (Fourier and Tibbett 2007; Ludwig et al. 2005). This needs to be considered for the longterm stability of the landform, and the longterm security of the waste within the landform.

2.1.4.   Topsoil/ Growth Medium

The appropriate selection growing medium (topsoil, sand) for a rehabilitation program is important for its success. The germination of some plant species is dependent on particular conditions that are influenced by the composition of the growing medium. Leading practice for growth media management would be to mirror as far as practical the media on analogous landforms in the existing environment, thus enabling the constructed vegetation community to mirror similar communities in the area. For example, differences in growth media might be expected on dune crests, interdunal areas, rocky outcrops and the toes of dunes, and these differences in media would be reflected in differences in vegetation communities across these habitats. An example of how growing media differs between dunes and interdunal areas is provided by Grigg et al. (2008a) who showed that organic matter, nutrient concentration, and clay and silt content were greater in interdunes than dunes. In order to establish a reconstructed landscape that is compatible with the adjacent environment (or some other habitat type and associated vegetation community) on the final landform of a site, consideration of growth media composition will be required. Attempting to place a species that prefers a nutrient rich/ water poor habitat on the top of a reconstructed landform that does not have these characteristics are likely fail.

Management of growing media to keep media from different land systems separate can aid in rehabilitation success. To some extent this can be managed through appropriate scheduling and planning so that stripped growth media from one area is directly returned to an analogous area. However, as direct return is not usually possible for all stripped growth media on any mine site, the stockpiling of media is usually necessary, however a loss of nutrients and

organic material (and concomitant decrease in quality) can be expected with long-term stockpiling (Loch et al. 2008). Rather than mixing sand from dunes, gravelly areas and interdunes together in the same stockpile, it would be advisable that these media be kept separate as far as practical.

2.1.5. Slope and Surface Stability

Determining an appropriate slope for the re-constructed landform, in combination with the composition and depth of the outer layer of soil/ growth medium and the establishment of a vegetated cover, is an important consideration in the establishment of a stable slope. Even with vegetated cover, slopes that have been inappropriately designed for local conditions can be prone to substantial erosion problems. For example, prior to 2004, all waste landforms at the Murrin Murrin Nickel Cobalt Project (approximately 60 km north-east of Leonora and Western Australia) were battered to a slope of up to 20 degrees, with backward sloping berms at a vertical height of approximately 3-12 m. Despite there being a good level of vegetative cover over the slopes, the slopes were prone to significant erosion, leading to vertical gullies down the sides of the landforms (Loch et al. 2006).

Erosion of slopes can be induced by a number of factors including wind and water movement, and controlled by factors including landform design and vegetation cover. The Joint Venture has carried out preliminary analysis of wind and water mediated erosion in the Operational Area. Results indicate that the potential for significant surface water runoff and runoff-induced erosion is extremely small (Landloch 2009c) under the modelled conditions. However, as sandy soils are typically non-cohesive and are readily loosened by the force of wind once the threshold wind velocity is exceeded there is potential for wind erosion of the constructed landform at the Operational Area and this will require management (Landloch 2009d).

Erosion Management

The Joint Venture is aiming to minimise erosion issues for the final constructed landform by taking a geomorpholoigcal approach to landform design (Sawatasky et al.2008). The final slope and height of the WMLs will be within the limits of the natural landforms already present in the area (Landloch 2009c). By adopting similar characteristics to the adjacent natural environment, the Joint Venture hopes to create an aesthetically pleasing and stable landform. This geomorphological approach requires a sound knowledge of factors including rainfall patterns, evapotranspiration and erosion to be successful (Sawatasky et al. 2008). Work carried out by Landloch (2009b, c and d) has assisted the Joint Venture in understanding potential erosion issues for the Operational Area.

Vegetation plays a role in slope stability in natural and reconstructed landscapes – roots add reinforcement to the substrate, bind the growth medium against movement by wind and water, and vegetation cover slows down surface water flow. Typically, soil has very high compression strength, however it has very poor tensile strength. The roots of vegetation are typically the opposite – thus by combining roots and soil, tensile and compression strength results (Fourie 2007). Fourie (2007) demonstrated that the roots of grasses improved the strength of clayey sand soils (a natural clayey colluvium) and a poorly graded sand (crushed and washed silica,

free of clay fines). This demonstrates the support that roots can give to growth media against erosion.

Without intervention, unvegetated soil or sand areas are susceptible to wind erosion and cannot be expected to revegetate naturally. Surface stabilisation can be achieved by increasing surface resistance through placement of rock or vegetation debris on the soil or sand surface, or application of temporary surface treatments (adhesives). Rock need not be larger than approximately 5-10 mm in diameter to be effective in limiting wind erosion (Landloch 2009d). In areas where the incorporation of rock or gravel is incompatible with the designed landform and vegetation community, the use of mulching material/ vegetation debris (branches, boughs, brushing collected during initial clearing of the site) as an early intervention prior to establishment of a vegetated cover is likely to be effective in controlling erosion. An additional advantage of placing vegetation debris on reconstructed landforms is that it can provide habitat for fauna and as the debris breaks down it contributes organic matter and nutrients into the growing medium.

The substrate on top of the final landforms at the Operational Area is currently planned to be a mix of gravels and sands to control wind erosion. The re-constructed vegetation community will incorporate aspects of naturally occurring communities in rocky areas surrounding the landform and thus blend into the landscape (Plate 4).

Plate 4: Quartzite Ridge with mixed *Acacia* Species

3. Biological Factors Important for Rehabilitation

Aspects of natural vegetation communities in the area around the Project will be used in the design of re-constructed communities for the final landform. A description of existing vegetation and flora across the Project areas is provided above in section 1.1.3. The Joint Venture does not aim to duplicate the surrounding communities, but to take aspects that are suited to the designed physical position in the final landform (e.g. slopes, flat) and its substrate characteristics (e.g. gravelly top or sandy slopes).

3.1. Revegetation

3.1.1. Species Selection

There are several important considerations in selecting species for use in revegetating areas disturbed over the life of the Project. These include (but are not limited to):

- design/ engineering considerations – how the developing and established communities will interact with the designed landform including the cover system
- aesthetic considerations – whether the final product will blend into the surrounding landscape
- biological considerations – whether the designed communities will be able to persist in the engineered landscape.

Some of these considerations are discussed in the following sections.

Impact on Cover System

In order to produce a walk away solution at closure, a functional cover system is an item of extreme importance. As discussed in section 2.1.4, design of a cover system should incorporate the consideration of how the designed plant community for a landform will interact with the cover system, and how this will affect functionality. Two key areas in which a vegetation community interacts with a cover system are in stability and hydrology. Plant species with deep roots have the potential to draw moisture out of the waste landform at greater depths. This can be an advantage in minimising the water-waste interaction. However, the natural death of a plant's roots can create preferential water flow paths through the cover system which can then send water deeper into the waste landform which might be a disadvantage in some cover designs. Therefore plant selection and cover design most occur together so that issues related to the hydrology of the cover system and vegetation community are considered.

The roots of plants can also have beneficial impacts on the stability of cover systems and slopes in the final landform. Early successional, fast-growing, shallow rooted species can aid surface stability early in the life of a sloped landform. Deeper rooted, slow growing species can aid landform stability later in the life of the landform. Appropriate consideration of root

architecture as part of species selection can maximise the advantage that plant roots impart to a re-constructed landform (Fourie 2007).

Keystone Species/ Ecosystem Engineers

Keystone species in the area surrounding the Operational Area appear to include:

- Hummock grasses (e.g. *Triodia basedowii*) which are a critical habitat requirement for several fauna species including the Sandhill Dunnart and Mulgara.
- Trees such as Marble Gum are an iconic plant in the GVD and are likely to play an important role in the hydrology of the landscape, and in providing habitat for fauna (e.g. hollows for nesting birds).
- Woodlands and thickets of Mulga play an important role in providing habitat for fauna (e.g. Malleefowl and litter dependent invertebrates) and also likely to play a role in nutrient cycling through their provision of litter fall under a closed canopy (particularly in thickets).

Metallophytes

Plants (also microbes, lichens etc.) that have evolved on mineral rich substrates are able to tolerate high metal concentrations. This tolerance makes them an ideal choice in designing an ecosystem for mine closure (Baker and Whiting 2008). An interesting conundrum regarding metallophytes is that they are at risk of mining because they live in the substrate above ore bodies, but are potentially an excellent choice for waste landform revegetation because of their tolerance to metals in the substrate (Baker and Whiting 2008). Thus species (and particularly genetic stock) from the area over the ore body at the Operational Area could have advantages over similar species (or genetic stock) from areas away from the ore body. Metallophytes can be distinct species or they can be genetic variants of common species that have locally adapted to high metal concentrations (Baker and Whiting 2008) – e.g. the individuals living over the ore body may be locally adapted to the higher than normal concentrations of gold and other minerals associated with the ore body, and conspecifics located away from the ore body may be less tolerant. Due to the lack of knowledge of metallophytes in the GVD, the Joint Venture may consider proceeding under the assumption the individuals/ genetic stock above the ore body have metallophytic characteristics and are therefore a target for waste-landform rehabilitation - a consideration for provenance and research.

3.1.1. Placement of Species in the Landscape

Similar to the vegetation surrounding the Operational Area of the Project, where the largest trees in the landscape (typically Marble Gums) are found on the upper slopes and crests of sand dunes, Grigg et al. (2008a) observed that throughout the Great Sandy Desert, the largest trees in the landscape were only ever found on the upper slopes of the sand dunes. Grigg et al. (2008a) concluded that dunes hold more water than adjacent interdunes, thus sustaining more favourable water status further into the dry season for deep-rooted plant species. This dune water is likely to be critical to support vegetation on the crests and sides of

dunes including large trees such as *Corymbia chippendalei* in the Great Sandy Desert and Marble Gum in the GVD (Grigg et al.2008a and *ecologia* Environment 2009). Conversely, species in interdunal areas can be expected to be more desiccation tolerant (e.g. *T. basedowii*) and to develop root systems with greater ability to access water where and when it is available (Grigg et al.2008a and 2008b).

Differences other than water holding capacity can also be expected in different land systems around the Project. For example interdunes might be expected to have a higher proportion of organic matter and fine clay, higher microbial activity and higher nitrogen content than dunes (Grigg et al.2008a). Differences in clay content and other physical characteristics between dunes and interdunes can also be expected to lead to differences in soil strength and the ability of plants to develop roots in substrate compacted by mining activities (Fourie et al.2007).

In designing the placement of different species in the reconstructed landform, consideration of substrate preferences, hydrology and preference for different geographical locations in the landform should be considered.

3.1.2. Provenance of Species

Identifying and utilising appropriate provenance seed/ propagules for a revegetation program is an important part of planning for rehabilitation. Completion criteria for a site may include a specified provenance zone thus adherence to the zone (or re-negotiation of the zone if it is found to be inappropriate as rehabilitation progresses) can be an important part of reaching site relinquishment. The importance of an appropriate provenance for plants in a revegetation program has been demonstrated by Diaz et al. (2006) who studied the success of plants from different locations in a revegetation experiment in the United Kingdom. They found that geographically local plants performed better than plants from more distant localities, as was expected. They also found that plants from sites that were ecologically similar to the revegetation site performed better than those from more dissimilar sites. Although intuitively obvious, this is an important demonstration – an appropriate provenance for best revegetation success should consider ecological as well as geographic factors. There is little use in stating a geographic radius as the provenance for a particular site and not considering the ecological factors of the reconstructed landform. For example, a geographical provenance zone of 10 km might be allocated to a particular revegetation site, but this should not lead to seed from an interdunal area within the provenance zone being accepted as appropriate for use on a constructed rocky outcrop. When the provenance zone for a rehabilitation program is developed, consideration should be given to ensuring that an appropriate ecological analogue for all parts of the re-constructed landscape is present within the zone.

An important caveat to the preference of using local provenance seed is the ecological cost – if only a limited amount of local seed is available the removal of seed for a rehabilitation project could have negative consequences for natural recruitment and ecological function in the donor area. For example, if several seasons of poor rainfall (and limited seed-set) occur in the lead up to a revegetation program the collection of provenance correct seed without impacting the donor area might not be possible. In this case, the balance of revegetating the

site with provenance correct seed and impact to the local donating environment should be discussed with relevant stakeholders.

3.1.3.   Species Return

There are several mechanisms to introduce species to a reconstructed landform including:

- direct return of topsoil
- broadcast seed application
- planting of seedlings or cuttings
- natural colonisation.

Topsoil Management

Leading practice topsoil management for most revegetation programs often involves dry-stripping and direct return immediately prior to the rainfall season. Given that rainfall is unpredictable in the arid environment of the Project, planning for stripping and direct return of topsoil prior to rainfall is likely to be difficult if not impossible. The Joint Venture will attempt to use direct return (rather than stockpiling) where practical, however ensuring that direct return occurs prior to rainfall will not be possible due to the unpredictable nature of rainfall in the area. Also, stockpiling will be necessary for some areas that will be disturbed early in the life of the project but will not be available for revegetation until later in the life of the Project (e.g. the WMLs).

An important consideration in the stockpiling of soils/ growth media is that the quality of the stockpiled soil/ media can be affected by several factors including (but not limited to):

- Extended time spent on the stockpile leads to breakdown/ death/ reduction in potency of biologically active constituents (e.g. microbes, seed bank).
- The mixing of soil/ media stripped from various areas (e.g. areas of high floristic diversity and naturally bare areas) results in the topsoil have mixed properties of both areas. For example, soil/ media from areas with high floristic diversity and areas beneath under trees showed high levels of organic carbon, areas naturally devoid of vegetation showed lower, highlighting the sub-optimal state of the substrate for vegetation growth (Loch et al. 2008). In mixing substrate from various areas, the quality of all topsoil is homogenised, so that even stockpiles exhibiting the best characteristics in terms of mineral and nutrient content are of lower quality (in terms of growth promotion) than soil/ media from the best quality areas pre-harvest.

While it would be logistically challenging to keep all stripped growth media separated into many classes (and this would lead to increased clearing impacts due to the need for an increased number of low volume stockpiles rather than a smaller number of high volume stockpiles), consideration should be given to keeping the very best pre-strip growth media separate for preferential use with recalcitrant or Priority species. This could be expected to maximise the revegetation success of these species from direct return (with supplementary seeding or planting if necessary)

Seed and Seedlings

Supplementing natural germination from direct return and stockpiled soil/ growth media with direct seeding and/ or the planting of seedlings is common practice in revegetation projects. This enables the company to manipulate the speed of revegetation and the composition of the final community in order to produce the designed community and meet completion criteria. Using plants with the ability to reproduce vegetatively (e.g. via rhizomatous growth) can be useful in revegetating a sloped landform because the elevated position in the landscape and windswept nature of an elevated landscape can cause difficulties for seedling establishment; for example, through sand accumulation and burial or the exposure of root systems (Danin 1996, references in Grigg et al.2008a and 2008b). These difficulties can be accentuated after fire, as safe micro-sites for germination are likely to be scarce in elevated sections of the landscape (Grigg et al.2008a).

The establishment of seed collecting protocols, storage protocols and a nursery for raising seedlings (if appropriate) and potentially for maintaining stock (e.g. Priority species) will need to be developed as the Project progresses.

Natural Colonisation

Natural colonisation from surrounding areas may occur as rehabilitation progresses. It may be possible for the Joint Venture to leave small islands of native vegetation within the clearing footprint (most likely at areas of disturbance such as the village where the footprint is most flexible, but also potentially around administrative buildings within the mining area). These islands could be preferentially located to retain Priority, recalcitrant (or suspected recalcitrant) species so that natural re-colonisation might occur.

4. Rehabilitation Research

The Joint Venture has identified the need for input into a rehabilitation research program for the Project as a critical step in successful closure and relinquishment of the site. This is primarily due to the lack of available and relevant information on rehabilitation techniques for the area, and also in recognition of the need to avoid adopting rehabilitation techniques that may have been successful at other arid or semi-arid sites to meet the Project's aim of leading practice for rehabilitation. The Joint Venture has prepared a preliminary Rehabilitation Research Program – the Program aims to identify gaps in current knowledge and prioritise research topics to ensure that the Project is rehabilitated to leading practice standards. The Rehabilitation Research Program will be ongoing throughout the life of the Project and fits into overall rehabilitation planning and stakeholder consultation as shown in Figure 3.
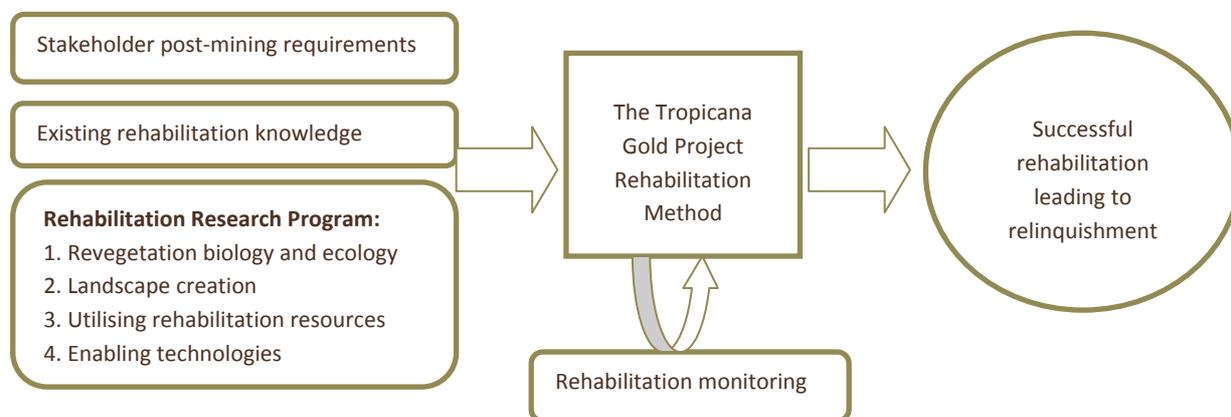

Figure 3: Rehabilitation planning, monitoring and completion for the Tropicana Gold Project

4.1. Pre-mining Research

4.1.1. Research Completed or Commissioned

The following baseline information has been investigated as part of the pre-feasibility study and environmental impact assessment for the Project (list is not exhaustive, other work has also been commissioned and/ or completed):

- Existing flora, vegetation and faunal composition of all disturbance areas (section 6, Tropicana Joint Venture [2009]).
- Water infiltration into natural substrate and modelling of infiltration into the WML (Landloch 2009b and c).
- Water and wind mediated erosion (Landloch 2009c and d).
- Material characterisation (SRK 2009).
- Preliminary work on invertebrates that might be used as indicators of rehabilitation success.

A brief summary of some of the results of these project has been provided in section 1.3.1, further information on infiltration and erosion is provided below.

Water Infiltration

Landloch was commissioned to investigate infiltration rates of the sandy substrate at the Operational Area and to investigate the potential of rain water to access waste material within the WML (Landloch 2009b and c). Predicted average annual runoff was 10 mm/y and erosion was 8 t/ha/y. As the majority samples tested had infiltration rates >70 mm/h, it can be concluded that the potential for significant runoff and runoff-induced erosion is extremely small (Landloch 2009c). Infiltration of rain through a one metre of growing medium and a 10 m layer of inert waste material to contact co-dumped inert, neutralising and potentially acid forming waste material is predicted to be insignificant.

Wind Erosion

The susceptibility of the surface dune materials to wind erosion is largely determined by the materials' particle size distribution and soil structure and wind strength. Sandy soils are typically non-cohesive and are readily loosened by the force of wind once the threshold wind velocity is exceeded (Landloch 2009d). Landloch (2009d) indicate that there may be potential for wind erosion to be significant on the constructed landforms at the Operational Area. Wind erosion modelling of the sand material on a 15° slope with wind data from Laverton suggests that wind erosion will need to be managed. The Joint Venture plan to cap the upper slopes of the waste landforms with a mix of gravel and sand to ensure a stable top to the constructed landforms.

4.2. Early Mining Research

As construction and the early phases of operations proceed the following topics for research will be considered:

- Investigate root morphology (replicate work by Grigg et al. [2008a]) by taking advantage of opportunities to gather as much data from trees/ vegetation that will need to be cleared as part of overburden/ topsoil stripping in areas under the proposed WMLs and other items of infrastructure and over the proposed pits. This information can be fed into the cover design and also used in identifying species of use in landform stabilisation, and to determine appropriate species for use in different parts of the constructed landform.
- Investigate soil/ growing media directly adjacent to species targeted for rehabilitation to describe physical characteristics that support particular species. These characteristics could then be tested in rehabilitation trials to identify the aspects of the growing medium that are most important for the species persistence in the final landform (e.g. mineral content, particle size, water holding capacity).
- Developing a series of slopes to:
  - o examine actual erosion and compare against predictions
  - o trial direct return and seeding success at different points on the constructed slope.

4.3.   Long-term/ Regional Research

4.3.1.   Metallophyptes

Testing for metal-tolerance is not a simple procedure and in many cases the characteristic of tolerance is assumed based on a plants presence at a site of high concentration (Baker and Whiting 2008). In terms of research "It is evident that to re-introduce the local metallophyte biodiversity, these plants must be identified, conserved and studied in relation to their metal tolerance and ecological function" (Baker and Whiting 2008). Research into metallophytes has biodiversity conservation and closure/ economic implications:

- Identifying metallophytic species/ local variants will enable their conservation (biodiversity implications).
- The identification of metallophytic species/ variants may also enable the Joint Venture to tailor future revegetation activities in the area (for the Project and the wider exploration tenement package) resulting in economic implications related to the greater success of revegetation and also resulting in reputational enhancement with stakeholders and society in general.

5. Monitoring and Adaptive Management

An adaptive management approach to rehabilitation is widely recognised as being important in successful closure. Tongway (2008) highlights the importance of monitoring from the very beginning of a project. This enables the company to have an appropriate baseline for pre-rehabilitated (and ideally pre-disturbance) conditions, and also gives maximum chance of monitoring through low frequency events. For the Project, a low frequency event may be a period of unusually high rainfall – monitoring the natural and trial landforms in the area would provide valuable data to predict how the final landform might react under periods of high rainfall (e.g. impact on stability and erosion). If landform trials and monitoring locations not in place prior to the rainfall event, the opportunity to predict final landform performance may be lost.

The early stages of a monitoring program would normally focus on physical and engineering aspects of rehabilitation (e.g. erosion, stability, hydrology). Later stages would normally focus on biological aspects.

5.1. Monitoring Rehabilitation Progress in an Arid Environment

A highly functional landscape (whether natural or constructed) is a biophysical system that retains resources within its system, rather than allowing then to dissipate into the surrounding environment. It is important to note that natural landscapes are heterogeneous over space and time and this contributes to their functionality and resilience. This heterogeneity can be observed at multiple scales, for example:

- broadscale – interdunes versus dunes
- small scale - beneath plants versus bare areas.

For example, some areas within a landscape may have higher levels of organic matter or nutrients due to a local depressions in which these factors may accumulate over time, or by the presence of long-lived plants whose roots increase soil porosity and whose leaf fall accumulates as surface litter over time. Patches of vegetation impede surface water flow limiting erodability (i.e. slowing the water down so it does less damage) and increased infiltration (reduced flow speed increases opportunity for water to penetrate the substrate). Patchiness can be encouraged by planning a heterogeneous planting scheme rather than a regular one – promoting the formation of clumps or bands of vegetation. In addition to improved infiltration, clumps of plants also demonstrate greater productivity than plants in inter-patch areas (Ludwig et al. 2005), further contributing to the heterogeneity and resilience of a site.

Rehabilitation programs in regions such as the GVD where rainfall (and hence growing seasons) cannot be predicted and annual rainfall figures can vary dramatically face a challenge for estimating the rate at which vegetation will establish and develop, the rate of successional changes in species composition, and hence the period of time that will be required to reach

completion criteria for the site. In the northern parts of Australia (reliable summer rainfall) and the southern areas (reliable winter rainfall) assessing the likely progress of a revegetation program before it begins, and the setting of goals over a specific time period, is comparatively simple because rehabilitation practitioners have a good understanding of successional changes and likely growth rates (Nichols and Latham 2007). Traditional measures of rehabilitation progress in predictable and well studies rehabilitation systems such as stems per unit area or diversity indices cannot be relied upon to accurately assess revegetation in an unpredictable environment. The impact of large scale fires presents an additional challenge in setting goals for revegetation (Nichols and Latham 2007). The GVD is subject to large scale, poorly controlled fires, and future fires could potentially affect areas in the process of revegetation by the Joint Venture.

In areas where the progress of revegetation cannot be reliably predicted, alternative mechanisms for assessing progress are required. For example, in an area of unpredictable rainfall (seasonally and annually) subject to several consecutive seasons of below average rainfall a monitoring plot would be unlikely to show a steady pattern of increase in vegetation characteristics such as number of stems or percentage cover as these characteristics tend to increase with rain, and in an environment where rain is not reliable, a reliable trend in characteristics could not be expected. In addition, following fire, the density of some species may increase dramatically and diversity measures fall as fire-germinating species dominate monitoring sites. Rather than seeing these occurrences as a failure of rehabilitation (because graphs of diversity, density or cover have not been able to establish a consistent trend, or have altered significantly in their trend) perhaps they should instead be interpreted against how the revegetation is behaving in comparison to appropriate reference sites, which, if properly selected and subject to the same environmental impacts (e.g. fire), could be used as a measure of the resilience of the rehabilitated sites. If the reference and monitoring sites are showing similar levels of impact and recovery following the fire or dry period (or other environmental variable) then the revegetation could be seen as progressing toward the desired outcome – integration with the existing environment.

One of the challenges with a revegetation monitoring program in an unpredictable environment is determining when lack of progress is due to inherent environmental factors (e.g. consecutive years of poor rainfall) and when it is due to poor management. The Joint Venture will employ several techniques to gain an in depth understanding of how their revegetation program is tracking towards final integration into the natural environment.

5.2. Monitoring

Many aspects of a rehabilitation and closure program require monitoring to track progression toward, and demonstrate attainment of, closure criteria and rehabilitation targets. Aspects of rehabilitation that are routinely monitored include:

- Physical characteristics:
  - erosion
  - stability of constructed landforms

- composition of soil/ growth medium
- groundwater quality and drawdown
- hydrological characteristics/ water balance of constructed landforms

- Biological characteristics:
  - species composition
  - floristic diversity
  - density
  - vegetative cover
  - fauna return

- Change over time.

A selection of these characteristics are discussed below.

5.2.1. Vegetative Cover

A challenge of rehabilitation in semi-arid environments (and also arid environments) in comparison to more mesic environments is that vegetative cover may not be an appropriate measure of progress as there are usually many patches of cover-less substrate in the natural environment (Nichols and Latham 2007). For example at the Operational Area, bare areas of sand are often evident in hummock grassland where there is very little cover over the substrate. This is in contrast to other areas where cover percentages may be nearing 100% such as in Mulga thickets.

Monitoring of the progress of rehabilitation in semi-arid and arid areas would be better served to compare rehabilitated areas against local analogues rather than making the assumption that a higher percentage cover indicates better rehabilitation. Linked to this is the need to recognise that percentage cover may not always be an appropriate completion criteria or progress target. Perhaps a better target or criteria would be a limit to surface erosion (that reflects natural levels of erosion in the landscape) - how a company stays within that limit could include manipulation of levels of cover and types of species, and also design of the slope.

5.2.2. Species Composition

Using analogous reference sites (e.g. the slope of a natural dune or nearby hills as an analogue to the slope of a WML) rather than simply monitoring changes over time on rehabilitated sites can also be used to identify short-comings in the rehabilitation program of both physical and biological characteristics like erodability and species composition. For example, at the Marandoo mine in the Pilbara, an assessment of rehabilitating areas against analogous reference site led to the identification of a shortfall in spinifex in the rehabilitating sites (Nichols and Latham 2007). Such information can be used to identify the need to increase effort in returning a particular species (or a similar species) in future rehabilitation, and to remediate existing rehabilitation.

5.2.3. Composition of Soil/ Growth Medium

Levels of soil/ growth medium organic matter are typically low in arid zones, especially where soils are sandy (Loch et al. 2008). Levels of organic matter and other necessities for plant development (e.g. nitrogen and phosphorous) are known to vary between land systems within the same area (Grigg et al.2008a). The monitoring of soil organic carbon is considerably more difficult where vegetation shows high levels of spatial heterogeneity (this theme of difficulties in monitoring variables across a heterogenous setting appears again below in regard to hydrology and cover systems). Nonetheless, development of background information on soil organic carbon levels and factors affecting its accumulation is an essential first step to improving the management of topsoil and the assessment of vegetation condition (Loch et al. 2008).

5.2.4. Water Balance of Cover Systems

A critical component for the success of a rehabilitation project is a successfully functioning cover system for potentially environmentally hazardous waste. The water balance of a cover system is one of its main functional variables. One consideration in assessing water balance in a cover system is that monitoring over large, heterogenous (spatially and temporally) areas from a limited number of discrete points is unlikely to generate an accurate picture of true water balance across the landform (Haymont and Campbell 2008). This is further complicated by scale-related factors, and limitations to accuracy when up-scaling results on a small test-cover to a full-size cover system. An additional challenge is extrapolating the results of cover monitoring over a few years (e.g. from a few years of a cover trial, or from a few years after the final covers installation on a WML) to long-term expectations in cover performance (e.g. post closure and relinquishment) (Haymont and Campbell 2008). Haymont and Campbell (2008) question the common reliance on technical monitoring devices – "There is field evidence that, under the conditions of the Australian interior, moisture contents recorded by [capacitance-sensors] may be appreciably biased on the high side in dry soils / covers, due to a soil-temperature effects. This can give the impression that there is less pore-space available for water retention in the cover for summer storms, and thereby erroneously imply that thicker covers are necessary." Haymont and Campbell (2008) go on to argue that the expense (in terms of capital expenditure, maintenance expenditure and time) of highly instrumented cover monitoring systems may not be balanced by the value of the results generated and that walkover surveys and groundwater monitoring can be are a more direct method of identifying cover system failures. For example, direct observation during a walkover survey could identify local incidents of slumping or piping that might be missed by an instrumented monitoring system and groundwater monitoring can identify other failures of the cover system. In some cases, simple monitoring methods may be more beneficial and present better value than methods heavily reliant on technology.

5.3. Methods for Monitoring Rehabilitation

As noted in the previous section, in some cases, the best method of monitoring may be the simplest and most straight-forward. However, as a general rule, multiple monitoring techniques may be necessary to capture the diversity of factors and trends that can impact progress towards rehabilitation targets and final completion criteria. A selection of monitoring techniques are discussed below.

5.3.1. Ecosystem and Landscape Function Analyses

A landscape or ecosystem function analysis for the monitoring of rehabilitation compares rehabilitating sites to reference sites in the surrounding environment to examine the rate and success of rehabilitation using various indicators of biotic and abiotic processes including soil surface stability, erosion data, vegetative cover and presence of fauna. Tongway and Ludwig (2006) state that an understanding landscape function requires an understanding of the following aspects:

- Spatial relationship between landscape elements
- Flows of energy, minerals and water between landscape elements
- Dynamics of landscape elements over time.

In addition to this, an understanding of what comprises each landscape element is obviously critical in order to gain a full appreciation of landscape function and how this can be incorporated into a successful rehabilitation outcome for closure.

Linking observable patterns in the landscape (e.g. noting the presence of a more diverse flora on the crests of dunes) with the underlying drivers of those patterns is the crux of understanding landscape function (Tongway and Ludwig 2006). If those drivers can be identified, the Joint Venture can attempt to recreate those conditions in its rehabilitation of disturbed areas resulting from Project activities. Understanding what processes and factors drive different floristic (and faunal) communities to form and persist in different areas within the landscape will assist in successful rehabilitation. Factors associated with the preference of different flora for dune crests may include substrate moisture or mineral content or energy availability in the form of sunlight/ warmth – identifying what drives and maintains factors like nutrient and moisture content (e.g. inputs from leaf litter and the activity of soil fauna, nutrient off-takes from herbivory, water holding capacity of the dune) will assist in the rehabilitation of natural and constructed dune landforms.

Landscape/ Ecosystem Function Analysis can be used as a valuable tool in assessing the progress of rehabilitation (e.g. comparing infiltration, soil respiration, stability/ dispersion - one would expect new rehabilitation to have lower functionality that would increase as the rehab develops/ is remediated as required), and in providing evidence that a self-sustaining ecosystem has been produced.

Ecosystem Function Analysis was used successfully on the Mt McClure site by View Resources (who purchased it from Newmont) to demonstrate the success of rehabilitation on the site and therefore decrease their financial bonds on the site (Mackenzie et al. 2007). This

example demonstrates the advantages of progressive rehabilitation and the completion of a regular, high standard and appropriate monitoring regime.

Although it is a commonly used tool in the monitoring of rehabilitation progress, it should be noted that Landscape/ Ecosystem Function Analysis is not a perfect solution to rehabilitation monitoring as there are problems inherent in comparing mined and un-mined reference sites (Nichols and Latham 2007). Some of these problems are that the un-mined reference sites are unlikely to be completely replicable in the rehabilitated environment, particularly when rehabilitating a waste landform like a WML or tailings facility. For example, although the top layer of growth medium might be a good match for the top layer of soil/ growth medium in the rehabilitated site the deeper layers of the landform are unlikely to be the same (presence of a cover system to cap the waste) which will have implications for substrate function over time.

Even in cases where the use of Landscape/ Ecosystem Function Analysis is constrained in comparisons between mined and unmined sites, it can still be useful in monitoring change over time on a rehabilitation plot (Nichols and Latham 2007).

5.4.   Fauna Recolonisation

The presence of various faunal groups on a rehabilitated site can be used as an indicator of rehabilitation progress and success. As vertebrate fauna are often the last biotic aspect of a re-constructed ecosystem to colonise a rehabilitated mine site they can be a useful indicator of the progress and success of a rehabilitation program (Thompson and Thompson 2006). Conversely, the absence of vertebrate fauna could be an indicator that a self-sustaining ecosystem has not yet been reached. In addition, vertebrate fauna may re-colonise a site but then disappear over time, also indicating that the site may not be self-sustaining.

A monitoring program for vertebrate fauna use of post-mining landforms at Ora Banda (approximately 50 km north of Kalgoorlie) demonstrated that not all species present in the surrounding area were present on the landforms (Thompson and Thompson 2006). The authors hypothesised over the likely rate of return for some species not yet present on the landforms, noting that species with habitat requirements that take time to develop (e.g. deep leaf litter) will be the last to recolonise. Thompson and Thompson (2006) note that a true re-construction of the surrounding environment at Ora Banda will be challenging as the designed landforms are significantly different in structure (height, slope) and function (water flow, erodability) to the surrounding environment and this may prevent the establishment of the normal fauna assemblage as conditions on the landforms will remain significantly different from the surrounding landscape. This is anticipated to be less of an issue for the Project as the design of the final constructed landform more closely matches the surrounding natural landforms in terms of height, slopes, water shedding ability and erodability.

Invertebrate fauna also have a role to play in the monitoring of rehabilitation progress and success. As invertebrates play vital roles in the functioning terrestrial ecosystems, particularly in roles associated with pollination, propagule dispersal and nutrient cycling which are important in the recruitment of plants, as well as making up a large proportion of the biomass of functioning ecosystems, their value as indicators should not be overlooked in favour of the

more charismatic vertebrates (Majer et al. 2006). Monitoring of terrestrial invertebrates has two significant advantages over terrestrial vertebrates – most invertebrate groups can be sampled, processed and identified with less staff time, and a larger number of species can be investigated per unit of effort, leading to greater sensitivity of analysis (Majer et al. 2006).

5.5.   Other Options for Monitoring Rehabilitation

There are many other options for monitoring the progress of rehabilitation. Some are technologically simple, and others require more significant technical input. Photopoints to monitor rehabilitation progress over time can be useful in qualitatively assessing progress. Aerial photography can be used to qualitatively and quantitatively monitor progress as can analysis of multispectral imagery.

As is the case with most (if not all) monitoring techniques, the sooner the baseline is started, the more accurate and useful are the results (Tongway 2008).

5.6.   Completion Criteria and Progress Targets

In areas where rehabilitation techniques have not been well studied it is important to note that the setting of specific yet achievable completion criteria and monitoring targets will be difficult. As rehabilitation research and trials progress, criteria with greater specificity will become possible. Criteria for dissimilar areas of rehabilitation are likely to need to be different, reflecting the aim for each area of rehabilitation. Of course, the overall, long-term aim should be to provide a safe, stable, non-polluting landform and self-sustaining ecosystem. A complicating factor in setting specific progress targets and completion criteria for the Project at this early stage is that, as well as being located in a landscape with no rehabilitation analogue, the Project is also located in an area with unpredictable rainfall, little locality-specific climatic data and a poorly studied flora (in terms of germination and propagation etc). These are challenges that will be addressed as the Project proceeds and the Joint Venture will regularly review completion and progress criteria in consultation with relevant stakeholders as trials progress and new knowledge/ technologies are developed.

One potential analogue project identified during the production of this document is the Trekkopje Uranium Project in Africa. Trekkopje is located in the Namib Desert and thus has some physical similarities with the Project (e.g. arid environment, distant neighbouring indigenous communities). The main considerations for rehabilitation at Trekkopje include (from Limpitlaw et al.2008):

- slope stability
- landscape integration
- plant rescue from the clearing footprint and subsequent propagation in a nursery.

Further investigation of potentially analogous projects may result in additional lessons and information for the closure of the Project. As the Project is located in a remote, arid environment with no significant rehabilitation history it is likely that a variety of part-analogue

projects might be identified (e.g. Trekkopje, Telfer and Challenger), rather than one or two strongly analogous projects.

6. Timing

The importance of early consideration of rehabilitation and closure requirements for a mining operation is widely recognised (e.g. Tongway [2008], Finucane [2008]). The Joint Venture began planning for closure and rehabilitation in the pre-feasibility stage of the Project (e.g. considering the final shape of waste landforms). The current stage of rehabilitation is conceptual, with the Joint Venture aiming to add detail regarding specific rehabilitation techniques and plant selection as information is gathered on topics such as the water holding potential of dunes, nutrient content of substrate, erodability and plant propagation. The Project's Conceptual Closure and Rehabilitation Strategy outlines the following progression for rehabilitation and closure planning:

1. Conceptual Mine Closure and Rehabilitation Strategy – as submitted with the PER, this strategy documents the concepts behind the closure and rehabilitation outcomes and the principles that will be incorporated into the closure and rehabilitation strategies.
2. Proposed Mine Closure and Rehabilitation Strategy – will be prepared within five years of Project commencement. The plan will be reviewed every 3-5 years.
3. Approved Mine Closure and Rehabilitation Plan – will be submitted to the relevant stakeholders for approval 3-5 years prior to closure of the Project.

A Closure and Rehabilitation Research and Development Strategy will progress alongside closure planning, aiming to inform rehabilitation and closure activities for the Project. The strategy will combine existing broad-scale rehabilitation knowledge with a research program tailored to improve the Joint Venture's understanding of rehabilitation requirements for the Project. This strategy will be a live document that will be modified to meet the requirements of the Project's closure and rehabilitation objectives.

7. Limitations

This report is produced strictly in accordance with the scope of services set out in the contract or otherwise agreed in accordance with the contract. 360 Environmental makes no representations or warranties in relation to the nature and quality of soil and water other than the visual observation and analytical data in this report.

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Aspects of this report, including the opinions, conclusions and recommendations it contains, are based on the results of the investigation, sampling and testing set out in the contract and otherwise in accordance with normal practices and standards. The investigation, sampling and testing are designed to produce results that represent a reasonable interpretation of the general conditions of the site that is the subject of this report. However, due to the characteristics of the site, including natural variations in site conditions, the results of the investigation, sampling and testing may not accurately represent the actual state of the whole site at all points.

It is important to recognise that site conditions, including the extent and concentration of contaminants, can change with time. This is particularly relevant if this report, including the data, opinions, conclusions and recommendations it contains, are to be used a considerable time after it was prepared. In these circumstances, further investigation of the site may be necessary. It should further be recognised that potential future impacts on site environmental conditions relating to global warming are beyond the scope of this investigation. Potential impacts may include, but are not limited to, changes in weather patterns that result in flooding or drought, subsequent changes in soil conditions, distribution of flora and fauna, altered vector impacts and increased fire hazards. Further investigation of the site in relation to these factors may be required.

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