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Desktop Assessment of the Potential Presence of Groundwater Dependent Ecosystems at the Twin Bonanza Project, Tanami Desert

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1. EXECUTIVE SUMMARY

The Twin Bonanza Project area is located approximately 750km northwest of Alice Springs and 16km from the Northern Territory- Western Australia border. The project area is situated approximately 33km south of the Tanami Track and is within MLA29822. MLA29822 has been held by ABM Resources NL (ABM) since 2010, when it was acquired from Newmont Asia Pacific.

Low Ecological Services PL (LES) were contracted in March 2014 by ABM to address a comment from the NT Environment Protection Agency (NTEPA) relating to the draft Environmental Impact Statement for the twin Bonanza project (ABM Resources NL, 2014). The NTEPA requested that a local assessment of the extent of Groundwater Dependent Ecosystems (GDEs) be completed, on the basis that within the palaeochannel areas, groundwater has been recorded at less than 10 metre below ground level.

A combination of landscape mapping, literature review and expert knowledge was used in this assessment to assess the potential presence of GDEs. Low Ecological Services have conducted surveys in the Tanami region for over twenty years and therefore experience of the area is high.

Using the methods outlined in Eamus et al (2006), the subsurface water supply provides potential for GDEs to be present in the palaeochannels surrounding the project area including the Nora palaeochannel to the west. However, it is unlikely that GDEs are present within the palaeochannels west of the Twin Bonanza project area based on previous studies conducted in the Tanami region and the domination of spinifex in the palaeochannels. The presence of facultative phreatophytic species indicates that in extending periods of drier than average years, trees may utilise groundwater but it is not foreseen that the planned water extractions will negatively impact ecosystems. Despite this, It is advised that a monitoring program be put in place to detect any change in vegetation condition.

The following steps are recommended to ensure that ecosystems are not negatively impact by water extraction in the palaeochannels:

- Utilise multiple extraction bores positioned at least 1km apart to spread the cone of depression across the watertable;
- Conduct monitoring of groundwater levels and groundwater quality (see below); and,
- Conduct Tree Health surveys (see below).

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DISCLAIMER

2. INTRODUCTION

2.1. Background

2.1.1. Location

The Twin Bonanza Project area is located approximately 750km northwest of Alice Springs and 16km from the Northern Territory- Western Australia border. The project area is situated approximately 33km south of the Tanami Track and is within MLA29822.

2.1.2. Twin Bonanza project

MLA29822 has been held by ABM Resources NL (ABM) since 2010, when it was acquired from Newmont Asia Pacific. ABM has conducted extensive drilling and surface sampling programs in addition to widespread exploration prior to acquisition. High grade gold deposits have been identified and ABM plan to mine the area in three stages; open pit mining to 5 metres depth in stage 1, to 35 m depth in Stage 2 and further deepening of pits in Stage 3 (ABM Resources NL, 2014).

It is estimated that mining operations will require water at an extraction rate of at least 11.1L/s amounting to 930m^3/day for use in ore processing, dust suppression, laundering, showers and a wash down bay (ABM Resources NL, 2014). Water supply will be extracted from groundwater using existing bore locations located in bedrock aquifers within the ML and the palaeochannel to the west of the project area (ABM Resources NL, 2014). Further bores are likely to be needed during the life of the mine and will likely be located in the palaeochannel areas (ABM Resources NL, 2014). Palaeochannels are the preferred groundwater location due to a higher rate of extraction and proximity of the water table to the surface. This proximity may also mean the Groundwater dependent ecosystems are present and that extraction of the water could be detrimental to these environments.

2.1.3. Groundwater Dependent Ecosystems

Groundwater Dependent Ecosystems (GDEs), also known as Groundwater Sensitive Ecosystems (GSE) are ecosystems that require access to groundwater to meet all or some of their water requirements so as to maintain the communities of plants and animals, ecological processes they support, and ecosystem services they provide. (Richardson, et al., 2011). Groundwater supply to ecosystems in particularly important in arid and semi –arid regions due to low precipitation rates, high evaporation rates resulting in scarce supplies of surface water (Eamus, et al., 2006).

GDEs can be divided in three distinct classes (Eamus, et al., 2006; Richardson, et al., 2011):

Type 1: **Aquifer and cave ecosystems**- "These ecosystems typically include karst aquifer systems fractured rock and saturated (consolidated and unconsolidated) sedimentary environments. The hyporheic zones of rivers, floodplains and coastal environments are also included in Type 1. The deep subsurface groundwater environment provides relatively stable, lightless environmental conditions with restricted inputs of energy and low productivity which allows a particular suite of subsurface ecosystems to prosper. The ecological diversity is created from variable geology, oxygen, carbon and nutrient gradients (linked to the dynamics of water flow) and physico-chemical conditions. Subsurface ecosystems provide an important supporting service of bioremediation of contaminated groundwater, and provide an important role in carbon and nutrient cycling" (Richardson, et al., 2011).

Type 2: **Ecosystems dependent on the surface expression of groundwater**- These "include wetlands, lakes, seeps, springs, river baseflow, coastal areas and estuaries that constitute brackish water and marine ecosystems. In these cases, the groundwater extends above the earth surface, as a visible expression. Examples include the mound springs of the Great Artesian Basin), and wetlands in the south-eastern part of South Australia. In these situations groundwater provides water to support aquatic biodiversity by providing access to habitat (especially when surface runoff is low) and regulation of water chemistry and temperature' (Richardson, et al., 2011).

Type 3: **Ecosystems dependent on subsurface presence of groundwater-** (via the capillary fringe) include terrestrial vegetation that depends on groundwater fully or on a seasonal or episodic basis in order to prevent water stress and generally avoid adverse impacts to their condition. In these cases, and unlike the situation with Type 2 systems, groundwater is not visible from the earth surface. These types of ecosystem can exist wherever the watertable is within the root zone of the plants, either permanently or episodically.

2.2. Objectives

The objective of this study is to assess the potential for GDEs to exist in the area of the Twin Bonanza project area, particularly in the Nora palaeochannel located to the west of the project area. If the potential occurs, recommendations are to be given as how to further investigate their presence.

2.3. Scope of Works

Low Ecological Services PL (LES) were contracted in March 2014 by ABM to address a comment from the NT Environment Protection Agency (NTEPA) relating to the draft Environmental Impact

Statement for the twin Bonanza project (ABM Resources NL, 2014). The NTEPA requested that a local assessment of the extent of GDEs be completed, on the basis that within the palaeochannel areas, groundwater has been recorded at less than 10 metre below ground level.

The scope of works is as follows:

- Review and collate existing data on data relating to GDEs;
- Use literature review and landscape mapping to assess the possible presence of GDEs with the Twin Bonanza project area;
- Recommend methods of investigated potential GDEs,; and,
- Prepare a report containing the above information.

3. METHODOLOGY

A combination of landscape mapping, literature review and expert knowledge was used in this assessment to assess the potential presence of GDEs. Low Ecological Services have conducted surveys in the Tanami region for over twenty years and therefore experience of the area is high.

Australian Groundwater-dependent Ecosystems Toolbox Part 1: Assessment Framework (Richardson, et al., 2011) and the Australian Groundwater-dependent Ecosystems Toolbox Part 2: Assessment Framework was used as a guide during this assessment. The assessment framework has three stages, with Stage 1 (assessing the potential presence of GDEs) being dealt with in this study.

The GDE Toolbox outlines a set of questions derived from Eamus et al (2006) for assessing the potential presence of a GDE. Eamus et al suggest that if there is an affirmative answer to any one of the questions then a GDE is potentially present. These questions are illustrated in Table 1 taken from Richardson et al (2011). Shaded questions are those which can be answered in Stage 1 of assessment. This study aimed to answer those questions.

Ecosystems reliant on surface expressions of groundwater	*Ecosystems reliant on the subsurface presence of groundwater*
• Does a stream/river continue to flow all year, or a floodplain waterhole remain wet all year in dry periods? • For estuarine systems, does the salinity drop below that of seawater in the absence of surface water inputs? • Does the volume of flow in a stream/river increase downstream in the absence of inflow from a tributary? • Is the level of water in a wetland maintained during extended dry periods? • Is groundwater discharged to the surface for significant periods of time each year at critical times during the lifetime of the dominant vegetation type?	• Is groundwater or the capillary fringe above the watertable present within the rooting depth of any vegetation? • Does a proportion of the vegetation remain green and physiologically active (principally, transpiring and fixing carbon, although stem-diameter growth or leaf growth are also good indicators) during extended dry periods?
	• Within a small region (and thus an area having the same rainfall and same temporal pattern of rainfall across its entirety), and in an area that does not receive overland flow and has no access to stream or river water, do some ecosystems show large seasonal changes in leaf area index while others do not?
	• Is the level of water in a wetland/swamp maintained during extended dry periods?
• Is the vegetation associated with surface discharge of groundwater different (in terms of species composition, phenological pattern, leaf area index or vegetation structure) to vegetation nearby that is not thought to access groundwater? • Is the annual rate of water use by the vegetation significantly larger than annual rainfall at the site and the site does not receive overland flow? • Are plant water relations (especially pre-dawn and midday water potentials and transpiration rates) indicative of lower water stress (potentials close to zero, transpiration rate larger) than for vegetation nearby not accessing groundwater? • Is occasional (or habitual) groundwater release at the surface associated with key developmental stages of vegetation (such as flowering, germination, seedling establishment)?	• Is the vegetation associated with surface discharge of groundwater different (in terms of species composition, phenological pattern, leaf area index or vegetation structure) to vegetation nearby that is not thought to access groundwater? • Are seasonal changes in groundwater depth larger than can be accounted for by the sum of lateral flows and percolation to depth (that is, is vegetation a significant discharge path for groundwater)? [If error terms in the estimation of lateral flow and percolation to depth are of similar of greater magnitude than the rate of vegetation use, this method may not be appropriate.]

Figure 1 Questions to help determine the potential presence of GDE (Eamus et al, 2006) Taken from Richardson et al (2011)

Landscape mapping (Assessment Tool 1, (Richardson, et al., 2011)) as part of Stage 1 of the toolbox was utilised to attempt to answer the above questions. This approach involved the analysis of landscape/regional datasets and was based on the principle that the biophysical can be used as indicators to identify potential GDEs.

Data was visualised and maps constructed using the GID programme ArcMap 10.1.

3.1. Data limitations

The Twin Bonanza bioregion is located within a data-limited region in terms of data available relating to GDEs. The majority of the datasets available are broad scale, and therefore the information provides a baseline assessment only. It must be recognised that the limitations of the data affect the level of certainty of the presence or absence of GDEs, and conclusions should be reassessed if further data becomes available.

4. RESULTS

4.1. Geographic location

The Twin Bonanza project area is located within the Tanami bioregion and the Tanami P1 sub-bioregion. This bioregion is described as consisting of "mainly red Quaternary sandplains overlying Permian and Proterozoic strata which are exposed locally as hills and ranges. The sandplains support mixed shrub steppes of *Hakea suberea*, desert bloodwoods, acacias and grevilleas over *Triodia pungens* hummock grasslands. *Acacia* shrublands over hummock grass communities occur on the ranges. Alluvial and lacustrine calcareous deposits occur throughout. In the north they are associated with Sturt Creek drainage, and support *Chrysopogon* and *Iseilema* short-grasslands often as savannas with River Gum. The climate is arid tropical with summer rain." (Department of Land Resource Management, 2014).

The project area is within the MacKay Drainage Basin (DB) (Bureau of Meteorology, 2014), part of the Western Plateau drainage division (Duguid, et al., 2005). MacKay DB covers approximately 177,470km^2 of arid NT. It is characterised by a very low relief and drainage systems characterised by minor saline channels with some associated with sub surface palaeo-drainages, and saline lakes (Duguid, et al., 2005).

4.2. Groundwater Dependent Ecosystem Atlas

A search of the Groundwater Dependent Ecosystem Atlas showed no reported Aquifer/cave GDEs located within the MacKay Drainage Basin (DB).

The MacKay DB has many ecosystems **dependent on surface expression of groundwater** including various lakes and wetlands. None of these are located in the vicinity of the project area with the closest located 19 km to the west. Figure 2 illustrates the location of surface expression GDEs in relation to the project area.

The region surrounding the project area has not been surveyed for **ecosystems dependent on the subsurface presence of groundwater**. Areas across the western Australian border have been defined and were utilised for determining the possible presence of subsurface GDEs within the project area.

The defined GDEs are defined according to their dependence on groundwater and given a ‘Low’, ‘Moderate’ or ‘High score’. Figure 2 illustrates the presence of sub surface presence of groundwater GDEs within the MacKay DB in Western Australia. The GDEs are labelled according to their GDE atlas reference number (Bureau of Meteorology, 2014). It is unknown how these GDEs were assessed or if any field studies were conducted. Definitions may therefore be unreliable.

4.3. Defined Subsurface GDEs within the MacKay Drainage Basin and Tanami P1 subregion

Defined GDE’s within the MacKay DB and the Tanami P1 subregion were used as a reference for defining possible GDEs with the project area just to the similarity in geomorphology, vegetation types and drainage patterns.

A total of 30 GDEs were found, consisting of one high level of dependence on groundwater GDE, three moderate level of dependence on groundwater GDEs and 27 low level of dependence on groundwater GDEs. A full description of ecosystems in WA is included in Appendix 1.

Limited information is available on the GDEs identified, including detailed information on the vegetation present. Information provided shows that all are located in low lying areas and are associated with drainage lines and/or in areas of sandplain or sand hills, many with longitudinal dunes.

Palaeochannel mapping data for Western Australia, South Australia and the Northern Territory was is available through the study Bell, et al (2012). This mapping is at a broad scale and further mapping of palaeochannels in the project area has been mapped by ABM. An assessment of the location of palaeochannels and the defined sub surface GDEs in Western Australia (Figure 2) appears to show a correlation between them. Despite this, there are large areas of palaeochannel which do not contain GDEs.

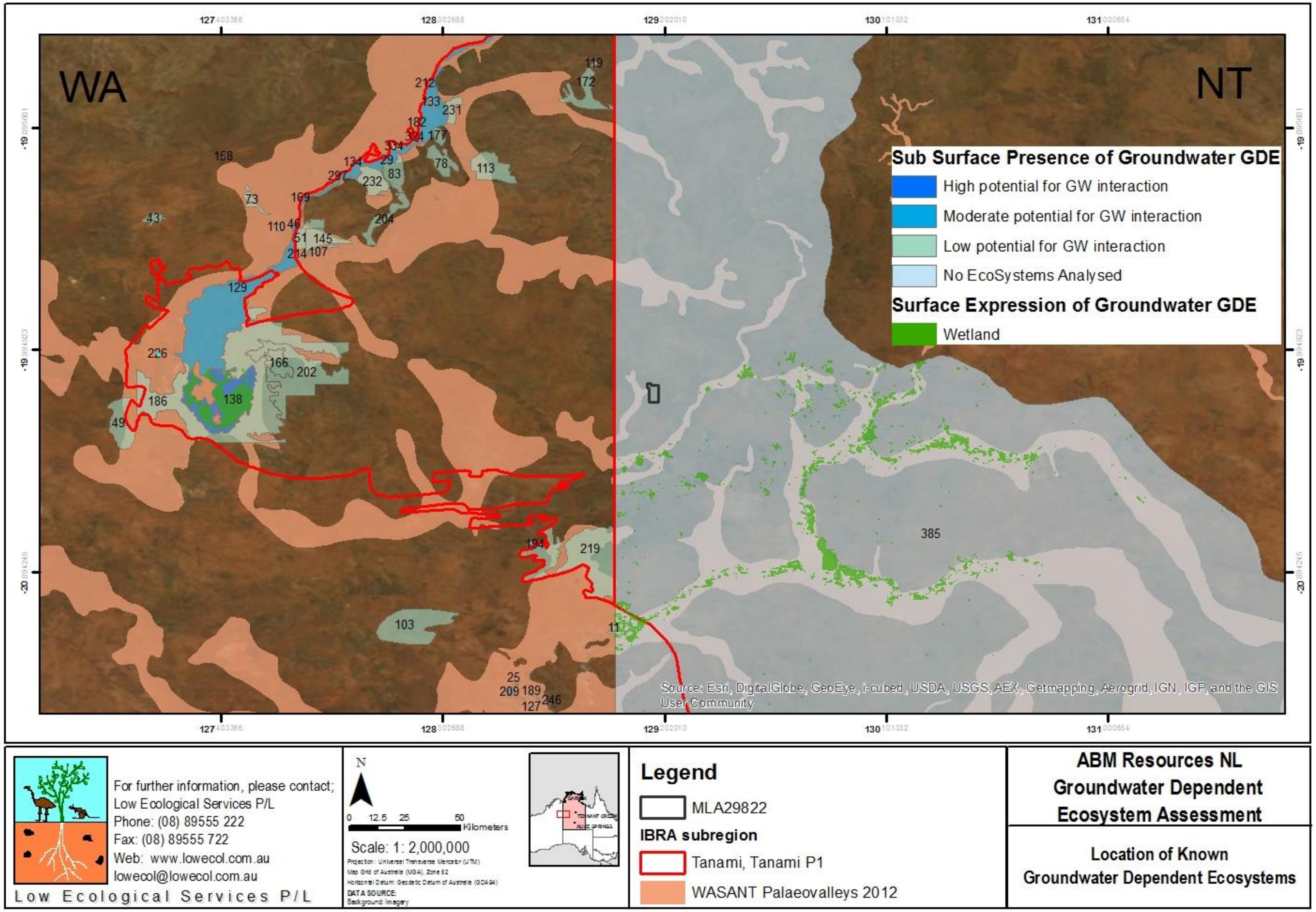

Figure 2 Location of Known Groundwater Dependent Ecosystems (GDE source: GDE Atlas, 2014, Palaeochannels source: (Bell, et al., 2012))

4.3.1. Regolith Mapping

Australia has been divided into 392 Regolith terrain units on the basis of dominant topography, geology and regolith (Chan, 2013). Regolith terrain mapping of The Twin Bonanza MLA, including a 5km buffer, contains a total of 15 regolith units. All regoliths, with the exception of SVer and SVee, contain sand plains and/or sand hills and therefore cannot be ruled out as containing a GDE without detailed on ground or high resolution aerial/satellite imagery investigation. The AAp and Chep4 regolith units correspond to the location of the known Nora palaeochannel (west of the project area). The location of these regolith units are illustrated in Figure 3. Full descriptions of the 15 regolith units found within a 5km buffer of the MLA are provided in Appendix 2.

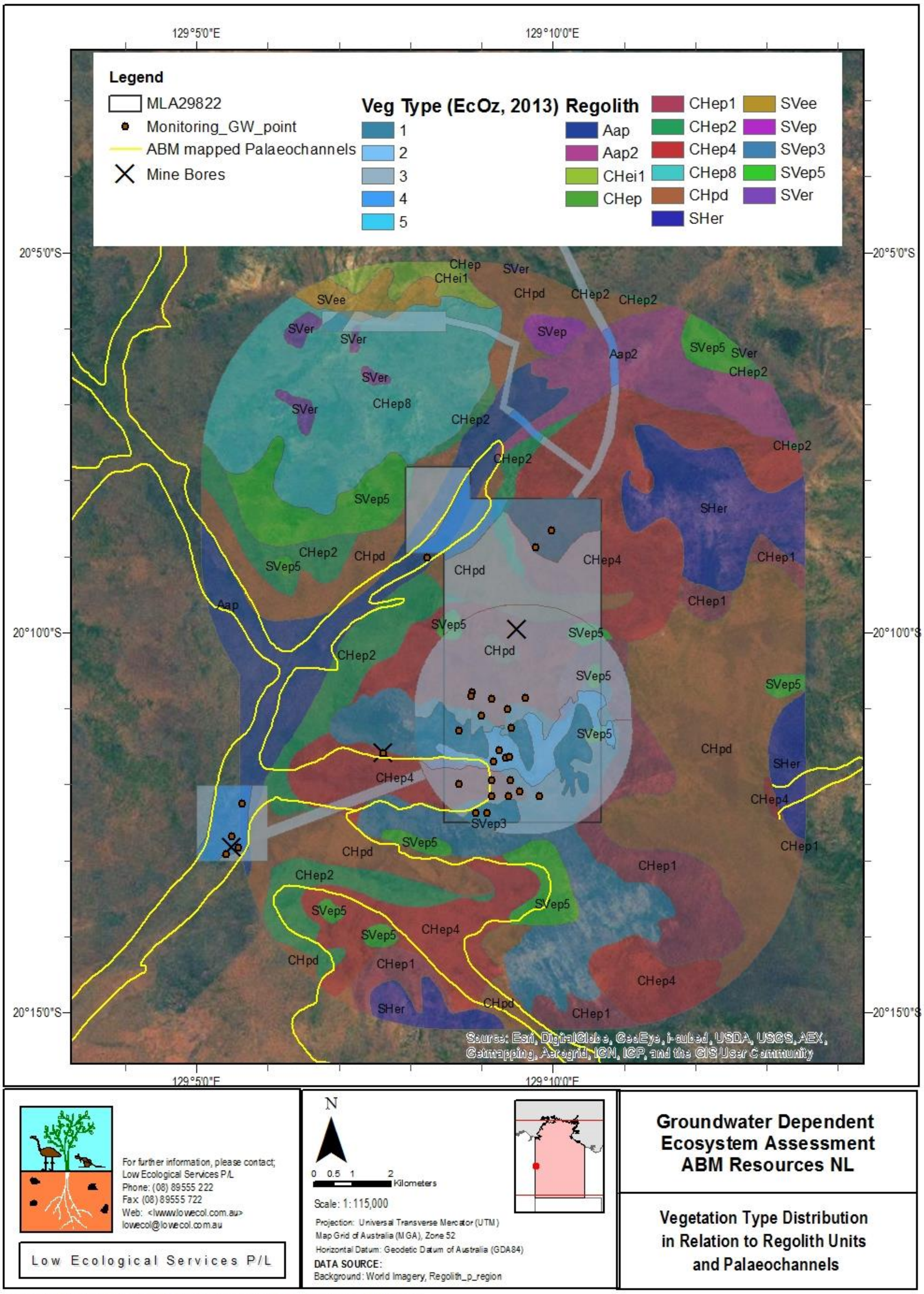

Figure 3 Regolith units within 5km of MLA29822 and Vegetation type distribution (Regolith terrain unit data, palaeochannel, Groundwater monitoring points and extraction bore data provided by ABM)

4.4. Groundwater depths

A preliminary groundwater assessment of the Twin Bonanza project area was conducted by Earth Systems in 2013. Groundwater levels were found to be between 5 and 10 mblg in the palaeochannels and 20 to 150 mbgl in the bedrock aquifers (Earth Systems, 2013; ABM Resources NL, 2014).

4.5. Assessment of vegetation

A vegetation survey was conducted in 2012/2013 by EcOZ to define vegetation types with MLA29822, the access track, airstrip and the location and access to Timmy's (Strezza's) bore located to the west of the MLA within the Palaeochannel. Five vegetation types were identified within the survey area (Figure 3).

The majority of the survey area does not have vegetation associated with Groundwater dependent ecosystems.

Sites located within palaeochannels did exhibit vegetation which may be groundwater dependent flora species. In the survey conducted by EcOz, these sites were described as "Low *Corymbia opaca* or *Eucalyptus victrix* ± *Eucalyptus brevifolia* open woodland with tall *Acacia sericophylla* open shrubland over Triodia pungens open hummock grassland. Occurs in Palaeochannels and drainages"

Both *Corymbia opaca* (Desert Bloodwood) and *Eucalyptus victrix* (Coolabah) are known facultative phreatophytic species (O' grady, et al., 2009; O' grady, et al., 2006; Loomes, 2010), trees which are deep rooted plant species that tap into groundwater, via the capillary fringe, to satisfy at least some portion of their environmental water requirement, but will also inhabit areas where their water requirements can be met by soil moisture reserves alone (Pritchard, et al., 2010). That is, the species will be groundwater dependent in some environments, but not in others.

A study conducted by Loomes (2010) in the Pilbara found *Eucalyptus victrix* growing in areas where the water table was as low as 7 m from the ground. *Corymbia opaca* is reported to draw water from as far as 20 m below ground level (Department of Natural Resources, Environment, the Arts and Sport , 2009). Groundwater depths reported by Earth Systems are within range for both of these species (Earth Systems, 2013).

Despite this, the domination of halophytes and spinifex in the palaeochannels indicates that the ecosystem is located in a long term frequently dry environment with the clayey soil providing sufficient moisture.

4.6. Potential GDE assessment Questions

Eamus et al (2006) posed a list of questions to assess the potential presence of sub surface GDEs. If one of these questions receives an affirmative answer then a GDE has the potential to be present. It is possible to answer three of these questions in Stage one. The questions and results of the desktop survey are given in Table 1.

Table 1 Questions posed by Eamus et al (2006) to assess the potential presence of a GDE within a sub-surface presence groundwater GDE

Question (Eamus et al, 2006)	Result	Comment
Is the groundwater or the capillary fringe above the watertable present within the rooting zone of any vegetation?	Yes	The water table has been reported as sitting between 5-10mbgl (Earth Systems, 2013) and tree species *Corymbia opaca* and *Eucalyptus victrix* have been reported with roots to 20m and 7m respectively (Department of Natural Resources, Environment, the Arts and Sport , 2009; Loomes, 2010).It is unlikely that these tree species will be negatively affect (see discussion)
Does a portion of the vegetation remain green and physiologically active (principally, transpiring and fixing carbon, although stem-diameter growth are also good indicators) during extended dry periods?	Unknown	But spinifex and halophytes are the dominant plants in the palaeochannels indicating a long term frequently dry environment
Is the level of water in a wetland/swamp maintained during extended dry periods?	N/A	No wetlands or swamps in the vicinity of the project area

5. DISCUSSION

Using the methods outlined in Eamus et al (2006), the subsurface water supply provides potential for GDEs to be potentially present in the palaeochannels surrounding the project area including the Nora palaeochannel to the west. However, the domination of the palaeochannels by Spinifex and halophytes with few large trees indicates this is not likely the case. GDEs may be present in the fringing land units but the ability of deep rooted trees to survive extended drought periods suggest there will be little impact of the mining operation, in the short term.

Tree Health studies conducted between 1994 and 2012 by Low Ecological Services at the nearby Newmont Borefields showed that trees and shrubs were not visibly negatively impacted from drawdown over 30 years (Low and various co-authors, 1994 to 2012 reports for Normandy and Newmont). Similar conditions are likely to be present in the vicinity of the Twin Bonanza Project. It is unlikely that water extraction for the Twin Bonanza project area will cause a drawdown large enough to affect the vegetation in the palaeochannels with rainfall replenishing the ground and soil sources of water. The clayey soil present in the type of palaeochannel is efficient at retaining water.

All vegetation recorded is adapted to arid conditions (EcOz, 2013) although, it is possible that if there is an extending period of drier than average years, that tree and shrub species may be required to utilise the groundwater. It is not likely that the current proposed life of the mine, approximately seven years, will affect the groundwater levels enough to affect the vegetation growth.

Several actions can be taken to further ensure that ecosystems are not negatively impacted

6. RECOMMENDATIONS

The following steps are recommended to ensure that ecosystems are not negatively impact by water extraction in the palaeochannels:

- Utilise multiple extraction bores positioned at least 1km apart to spread the cone of depression across the watertable;
- Conduct monitoring of groundwater levels and groundwater quality (see below); and,
- Conduct Tree Health surveys (see below).

It is recommended that a monitoring programme be put in place to assess if any ecosystems are being negatively affected by the extraction of water. Tree health surveys along with measurements of groundwater levels and quality should be conducted regularly.

It is important that baseline results are obtained prior to water extraction to provide a background to assess future results from. It is also equally important that a number of control sites outside of the water extraction zone are monitored to allow any changes in vegetation condition to be attributed to the correct cause, as changes may not necessarily be caused by the water extraction. Control sites should be located within a palaeochannel land unit and outside of the drainage system. Proposed groundwater monitoring bores are shown in figure 3. Tree health surveys should then be conducted at least annually and immediately if vegetation condition appears to have changed. Groundwater monitoring can be conducted according to the mines groundwater monitoring plan but at least quarterly is advised.

Tree health surveys can be adapted to the site but an example conducted at the Granites mine, Tanami is provided in Appendix 3. It involves having permanent quadrats which incorporate bore sites and controls sites measuring 100m x 100m quadrats. The site characteristics, species within the quadrat, the number of live and dead trees, counts of specific trees to be monitored, the condition of the leaves, the general condition of the site, fire history and photo-point monitoring of a set number of predefined trees are recorded during each survey at each site.

Results from the tree health surveys can then be assessed against groundwater quality and depth data to assess the effect, if any, water extraction is having on the ecosystems.

As tree health surveys have been conducted at the Granites for many years in may be advantageous to request data obtained in their surveys to be utilised in the monitoring at Twin Bonanza.

7. CONCLUSIONS

It is unlikely that Groundwater Dependent Ecosystems are present within the palaeochannels west of the Twin Bonanza project area based on previous studies conducted in the Tanami region and the domination of spinifex in the palaeochannels. The presence of facultative phreatophytic species indicates that in extending periods of drier than average years, trees may utilise groundwater. It is not foreseen that the planned water extractions will negatively impact ecosystems but it is advised that a monitoring program be put in place to detect any change in vegetation condition.

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9. APPENDICES

Appendix 1 Description of sub surface presence of grounder water GDEs

GDE Atlas ref no.	Location	Ecosystem type	Geomorphology	Landscape	Groundwater flow	Potential for Groundwater Interaction
219	128°55'33.043"E 20°45'2.269"S	Hummock grasslands, shrub steppe; mixed shrubs over soft spinifex	Sandplain with minor longitudinal dunes in south; floodplains and floodouts on margins; stony rises in north.	Low lying	Intermediate	Low
194		Mosaic: Hummock grasslands, open low tree steppe; desert bloodwood and feathertop spinifex on sandhills / Hummock grasslands, shrub steppe; mixed shrubs	Sandplain with minor longitudinal dunes in south; floodplains and floodouts on margins; stony rises in north.	Slope	Intermediate	Low
186	127°33'7.403"E 20°15'55.183"S	Gently undulating sandplain with sandy rises, salt pans and occasional dunes supporting hummock grasslands with stunted eucalypts and acacias.	East-west longitudinal dunes locally broken by narrow sandstone ranges.	Low Lying	Intermediate	Low
202	127°44'31.92"E 20°6'33.024"S	Low linear or rounded hills and associated valley floors and marginal sandplains, supporting soft spinifex hummock grasslands or sparse low snappygum	East-west longitudinal dunes locally broken by narrow sandstone ranges.	Low lying	Intermediate	Low

GDE Atlas ref no.	Location	Ecosystem type	Geomorphology	Landscape	Groundwater flow	Potential for Groundwater Interaction
226		Gently undulating plains with sandy rises and dunes with hummock grasslands with desert oak and acacia shrubs.	Floodout with distributary channels and claypan.	Low Lying	Regional	Low
138	127°27'59.37"E 20°6'49.093"S	Lakes and surrounding floodplains supporting tussock and hummock grasslands and scattered shrubs and trees.	East-west longitudinal dunes locally broken by narrow sandstone ranges.	Low Lying	Intermediate	High
129	128°14'28.779"E 19°3'7.991"S	Drainage lines, depressions, alluvial plains and sand rises associated with the Sturt Creek drainage system. Shrublands of eucalypts, eremophilas	Floodout with distributary channels and claypan.	Low Lying	Intermediate	Moderate
297		Two medium-sized areas, in the south-east and south-west corners of the area, of gently undulating red soil "desert" with shrub vegetation.	East-west longitudinal dunes locally broken by narrow sandstone ranges.	Low Lying	Intermediate	Moderate
88	127°51'26.314"E 19°18'59.395"S	Two medium-sized areas, in the south-east and south-west corners of the area, of gently undulating red soil "desert" with shrub vegetation.	East-west longitudinal dunes locally broken by narrow sandstone ranges.	Low Lying	Intermediate	Moderate
166	127°37'6.682"E 20°6'2.137"S	One large area of gently undulating red sandy "desert" with shrub vegetation along the southern edge of the area.	East-west longitudinal dunes locally broken by narrow sandstone ranges.	Low Lying	Intermediate	Low

GDE Atlas ref no.	Location	Ecosystem type	Geomorphology	Landscape	Groundwater flow	Potential for Groundwater Interaction
107	127°46'9.256"E 19°36'14.163"S	Sedgeland; sedges with open low trees; coolabah over various sedges	East-west longitudinal dunes locally broken by narrow sandstone ranges.	Low Lying	Intermediate	Low
214	127°45'30.663"E 19°36'29.152"S	Mixed short grass and spinifex with scattered coolabah	East-west longitudinal dunes locally broken by narrow sandstone ranges.	Low Lying	Intermediate	Low
145	127°48'37.206"E 19°32'31.861"S	Hummock grasslands, low tree steppe; eucalypts over soft spinifex and feathertop spinifex between sandhills	East-west longitudinal dunes locally broken by narrow sandstone ranges.	Low Lying	Intermediate	Low
51	127°47'18.059"E 19°28'48.054"S	Gently undulating sandplain with regular parallel dunes supporting acacia, grevillea and melaleuca shrublands and hummock grasses.	East-west longitudinal dunes locally broken by narrow sandstone ranges.	Low Lying	Intermediate	Low
204	128°0'55.914"E 19°32'56.723"S	Hummock grasslands, low tree steppe; snappy gum over soft spinifex	Sandplain with scattered low ranges and tablelands and occasional granitic and sedimentary hills.	Low lying	Local	Low
232	128°2'17.849"E 19°19'45.915"S	Two medium-sized areas, in the south-east and south-west corners of the area, of gently undulating red soil "desert" with shrub vegetation.	East-west longitudinal dunes locally broken by narrow sandstone ranges.	Low Lying	Intermediate	Low
83	128°6'34.543"E 19°16'32.103"S	Low linear or rounded hills and associated valley floors and marginal sandplains, supporting soft spinifex hummock grasslands or sparse low snappygum	Sandplain with scattered low ranges and tablelands and occasional granitic and sedimentary hills.	Low Lying	Local	Low

GDE Atlas ref no.	Location	Ecosystem type	Geomorphology	Landscape	Groundwater flow	Potential for Groundwater Interaction
334	128°6'17.43"E 19°9'15.795"S	Two medium-sized areas, in the south-east and south-west corners of the area, of gently undulating red soil "desert" with shrub vegetation.	Sandplain with scattered low ranges and tablelands and occasional granitic and sedimentary hills.	Low Lying	Regional	Low
182	128°12'13.847"E 19°5'44.301"S	Two medium-sized areas, in the south-east and south-west corners of the area, of gently undulating red soil "desert" with shrub vegetation.	Sandplain with scattered low ranges and tablelands and occasional granitic and sedimentary hills.	Low Lying	Intermediate	Low
324	128°10'51.237"E 19°7'54.961"S	Two medium-sized areas, in the south-east and south-west corners of the area, of gently undulating red soil "desert" with shrub vegetation.	Sandplain with scattered low ranges and tablelands and occasional granitic and sedimentary hills.	Low Lying	Intermediate	Low
78	128°17'24.835"E 19°13'34.387"S	Low linear or rounded hills and associated valley floors and marginal sandplains, supporting soft spinifex hummock grasslands or sparse low snappygum	Sandplain with scattered low ranges and tablelands and occasional granitic and sedimentary hills.	Low Lying	Local	Low
177	128°17'41.948"E 19°8'43.463"S	Low linear or rounded hills and associated valley floors and marginal sandplains, supporting soft spinifex hummock grasslands or sparse low snappygum	Sandplain with scattered low ranges and tablelands and occasional granitic and sedimentary hills.	Low Lying	Local	Low
113	128°33'25.726"E	Hummock grasslands, shrub steppe; corkwood	Sandplain with scattered low ranges	Low Lying	Intermediate	Low

GDE Atlas ref no.	Location	Ecosystem type	Geomorphology	Landscape	Groundwater flow	Potential for Groundwater Interaction
	19°15'51.718"S	(Hakea suberea) & acacia species over soft spinifex	and tablelands and occasional granitic and sedimentary hills.			
133	128°15'22.182"E 18°59'20.079"S	Two medium-sized areas, in the south-east and south-west corners of the area, of gently undulating red soil "desert" with shrub vegetation.	Sandplain with scattered low ranges and tablelands and occasional granitic and sedimentary hills.	Low Lying	Intermediate	Low
231		Two medium-sized areas, in the south-east and south-west corners of the area, of gently undulating red soil "desert" with shrub vegetation.	Sandplain with scattered low ranges and tablelands and occasional granitic and sedimentary hills.	Low Lying	Intermediate	Low
123	128°21'24.416"E 19°0'38.273"S	Mosaic: Sedgeland; sedges with low tree savannah woodland; coolabah over various sedges / Hummock grasslands, grass steppe; soft spinifex	Sandplain with scattered low ranges and tablelands and occasional granitic and sedimentary hills.	Low Lying	Intermediate	Low
172	128°54'23.527"E 18°59'53.777"S	Low linear or rounded hills and associated valley floors and marginal sandplains, supporting soft spinifex hummock grasslands or sparse low snappygum	Sandplain with scattered low ranges and tablelands and occasional granitic and sedimentary hills.	Low Lying	Local	Low
119	128°55'40.536"E 18°49'46.692"S	Low linear or rounded hills and associated valley floors and marginal sandplains, supporting soft spinifex hummock grasslands	Sandplain with scattered low ranges and tablelands and occasional granitic and sedimentary hills.	Low Lying	Local	Low

GDE Atlas ref no.	Location	Ecosystem type	Geomorphology	Landscape	Groundwater flow	Potential for Groundwater Interaction
		or sparse low snappygum				

Appendix 2 Description of regolith units within 5km of the Twin Bonanza project area

Regolith Unit	Land form	Regolith Summary	Weathering	Full Description
Aap	Extensive low relief depositional plains	Alluvial and colluvial sediments consisting of sand, silt and clay forming extensive low relief depositional plains.	unknown	Alluvial and colluvial sediments consisting of sand, silt and clay forming extensive low relief depositional plains. River channels are poorly defined and largely inactive. Alluvial sediments are mainly covered by sheetflow and aeolian ferruginous fine to medium quartzose sand. Minor gravelly lags and calcrete. Local lake or swamp sediments consist of mottled clays. Local heaving of calcrete.
Aap2	Forms alluvial and colluvial depositional plains.	Alluvial and colluvial sheetflow sediments consisting of sand, clays and highly ferruginous Fe granules and nodules.	unknown	Alluvial and colluvial sheetflow sediments consisting of sand, clays and highly ferruginous Fe granules and nodules. Clay increasing at depth. Lags consist of Fe gravels and granules with minor quartz. Forms alluvial and colluvial depositional plains. Minor erosional plains.
CHei1	Pediments and erosional plains	Colluvial fan and sheetflow deposits consisting of medium to fine ferruginous quartzose sand, lithic fragments, quartz and minor Fe nodules.	highly weathered	Colluvial fan and sheetflow deposits consisting of medium to fine ferruginous quartzose sand, lithic fragments, quartz and minor Fe nodules. Micaeous and feldspathic sand and gravel locally common. Sediments generally < 2 m thick over saprolite. Forms low angle colluvial fans and pediments.

Regolith Unit	Land form	Regolith Summary	Weathering	Full Description
CHep	Forms extensive sheetwash colluvial plains and erosional plains.	Sheetflow deposits consisting of medium to fine ferruginous quartzose sand, in places scattered ferruginous nodules and lithic fragments.	highly weathered	Sheetflow deposits consisting of medium to fine ferruginous quartzose sand, in places scattered ferruginous nodules and lithic fragments. In places micaeous sand and medium textured clays. Reworked aeolian sand and local residual sand and clay. In places alluvial sediments covered by colluvial sand. Forms extensive sheetwash colluvial plains and erosional plains.
CHep1	Forms extensive low relief colluvial covered erosional plains and minor depositional plains.	Sheetflow and minor alluvial deposits consisting of ferruginous fine to coarse quartzose sand and sandy clays. Aeolian sand reworked sheet wash.	highly weathered	Sheetflow and minor alluvial deposits consisting of ferruginous fine to coarse quartzose sand and sandy clays. Aeolian sand reworked by sheetflow processes. Quartz, lithic, ferruginous gravel/granular lags. Residual quartzose sand. Micaeous sand locally common. Subcrop, saprolite typically within 2 metres of surface. Forms extensive low relief colluvial covered erosional plains and minor depositional plains.
CHep2	Forms sheetwash colluvial sediments on erosional and depositional plains.	Sheetflow deposits consisting of Fe nodules and granules over medium to fine ferruginous quartzose sand. Reworked aeolian sand and local alluvial sediments.	very highly weathered	Sheetflow deposits consisting of Fe nodules and granules over medium to fine ferruginous quartzose sand. Reworked aeolian sand and local alluvial sediments. Residual sand and clays. Highly weathered ferruginous saprolite or Fe duricrust likely to be within 2m of the surface. Lags consist of Fe nodules and granules and minor quartz. Forms sheetwash colluvial sediments on erosional and depositional plains.

Regolith Unit	Land form	Regolith Summary	Weathering	Full Description
CHep4	Forms erosional plains, lag covered colluvial plains and minor rises.	Thin cover (generally less than 1 metre) of ferruginous sheet flow sand, Fe nodules and gravels over Fe duricrust or saprolite. Saprolite typically highly ferruginous.	very highly weathered	Thin cover (generally less than 1 metre) of ferruginous sheet flow sand, Fe nodules and gravels over Fe duricrust or saprolite. Saprolite typically highly ferruginous and mottled at depth. In places ferruginous lithic fragments and Fe nodules are cement by Fe to form ferruginous duricrust. Ferruginous lithic and Fe nodular lags common. Minor quartz lag. Forms erosional plains, lag covered colluvial plains and minor rises.
CHep8	Forms rises and erosional plains.	Highly ferruginous sheetflow colluvial sand (typically less than .5 metre) and gravels over Fe duricrust, ferruginous and mottled saprolite. Minor pockets of alluvial clay and sand	very highly weathered	Highly ferruginous sheetflow colluvial sand (typically less than .5 metre) and gravels over Fe duricrust, ferruginous and mottled saprolite. Minor pockets of alluvial clay and sand. Fe gravel and granule lags common, minor quartz lags. In places exposed Fe duricrust forming indurated pavements. Forms rises and erosional plains. Forms rises and erosional plains.
CHpd	Forms extensive low relief depositional plains and minor erosional plains.	Sheetflow and minor alluvial deposits consisting of ferruginous fine to coarse quartzose sand and minor gravel. In places longitudinal dunes.	unknown	Sheetflow and minor alluvial deposits consisting of ferruginous fine to coarse quartzose sand and minor gravel. In places longitudinal dunes and sand spreads. Aeolian sand reworked by sheetflow processes. In places ferruginous gravel and Fe nodules at approximately 1 metre depth. However thickness of sand over saprolite highly variable. Local patchy quartz, lithic and Fe nodule/granule lag. Forms extensive low relief depositional plains and minor erosional plains.

Regolith Unit	Land form	Regolith Summary	Weathering	Full Description
SHer	Forms rises (9-30m relief).	Ferruginous saprolite, partly covered by lags, stony lithosols and sheetflow sand. Local patches of Fe duricrust and Fe duricrust cementing the top of a deeply weathered profile.	highly weathered	Ferruginous saprolite, partly covered by lags, stony lithosols and sheetflow sand. Local patches of Fe duricrust and Fe duricrust cementing the top of collapsed saprolite. Ferruginous lithic and quartz lags. Forms rises (9-30m relief).
SVee	Forms escarpments, pediments and minor rises.	Escarpment exposing highly weathered ferruginous bedrock. Fe duricrust delineate the top of the scarp.	very highly weathered	Escarpment exposing highly weathered ferruginous bedrock. Fe duricrust delineate the top of the scarp. Fe duricrust consist of collapsed highly ferruginous saprolite (commonly weakly horizontally layered) with local Fe segregation developing within the upperpart of the mottled zone. Down slope from scarp edge saprolite largely covered by ferruginous lags and colluvium. Forms escarpments, pediments and minor rises.
SVep	Forms erosional plains and rises.	Saprolite largely covered with a veneer of lithic fragments, gravel lags and ferruginous sand.	very highly weathered	Saprolite largely covered with a veneer of lithic fragments, gravel lags and ferruginous sand. Lags consist of lithic fragments, Fe gravels and quartz. Forms erosional plain and rises.
SVep3	Forms erosional and lag covered colluvial plains.	Thin cover (typically < .4 metre) of sheetflow sediments consisting of ferruginous sand and clay over mottled saprolite.	very highly weathered	Thin cover (typically < .4 metre) of sheetflow sediments consisting of ferruginous sand and clay over mottled saprolite. Lags consist of quartz, lithic fragments and Fe gravels/granules. Residual clay soils common. In places

Regolith Unit	Land form	Regolith Summary	Weathering	Full Description
				exposed iron stained saprolite. Forms erosional and lag covered colluvial plains.
SVep5	Forms lag erosional and colluvial plains	Veneer of highly ferruginous lithosols, sand and lags over ferruginous saprolite. In places exposed saprolite forming stony pavements. Lags consist of ferruginous lithic	very highly weathered	Veneer of highly ferruginous lithosols, sand and lags over ferruginous saprolite. In places exposed saprolite forming stony pavements. Lags consist of ferruginous lithic fragments, Fe granules and quartz. Pockets of collapsed saprolite cemented by iron. Saprolite is typically highly weathered and mottled. Forms lag and sand covered erosional plains and rises.
SVer	Forms rises and highly ferruginous plateaux.	Highly ferruginous saprolite partly covered by ferruginous lags consisting of lithic fragments, Fe gravel and Fe granules. Stony lithosols common.	very highly weathered	Highly ferruginous saprolite partly covered by ferruginous lags consisting of lithic fragments, Fe gravel and Fe granules. Stony lithosols and ferruginous sand. Pockets of ferricrete and Fe duricrust cementing the top of the saprolite and gravel lag layer. Saprolite is typically highly weathered and mottled. Forms rises and highly ferruginous plateaux.

Appendix 3 Example of Tree Health survey

Tree health data sheet (Taken from Low *et al.* (2001)).

Site Number:

Bore Number:

Date:

Time:

Observers:

Landscape Unit:

Climatic conditions:

- ☐ Dry
- ☐ Recent rain (no visible impact on vegetation)
- ☐ Recent rain (visible impact on vegetation)
- ☐ Wet

Bore GPS coordinates:

Site Characteristics

3. The general site characteristics of the permanent 100m x 100m quadrat could be described as:

- ☐ Flat
- ☐ Hilly / gentle slopes
- ☐ Drainage depression area
- ☐ Other........................
- ☐ Clayey substrate
- ☐ Sandy substrate
- ☐ Rocky substrate
- ☐ Bare ground
- ☐ Dense shrubs
- ☐ Dense trees
- ☐ Open grassland
- ☐ Scattered shrubs
- ☐ Scattered trees

General Health Assessment

4. Count and record the number of living trees taller than 2m, shrubs taller than 1m and ground cover species within the permanent 100m x 100m area.

Species	Number	
	Live	Dead
Shrubs		
5 Dominant ground cover species		

5. Count and record the total number of dead Bloodwood trees over 2m in height within the permanent 100m x 100m quadrat area.

Total number of dead trees (Sandpaper Bloodwood and Bloodwood trees):

6. The general features of the permanent quadrat could be described as being (more than one condition can be checked)

- ☐ Dry
- ☐ Wet
- ☐ Burnt
- ☐ Flooded/ponded surface water
- ☐ Washed out
- ☐ Green lush vegetation
- ☐ Salt crusted surface
- ☐ Cryptogam crusted surface (algal surface crust)

7. Fire History

(a) Has a fire burnt the vegetation in the quadrat? Y/N

(b) If no, go to question 8. If yes, is the vegetation regenerating? Y/N

(c) Regeneration from fire could be described as (check appropriate box):

- ☐ Nil/poor regeneration, fire recent
- ☐ Nil/poor regeneration, fire not recent
- ☐ Trees showing better regeneration than shrubs and grasses (fresh leaves and shoots on trees)
- ☐ Ground cover (grasses and shrubs) showing better regeneration than trees
- ☐ Trees and ground cover regenerating well
- ☐ Very little sign of fire, vegetation almost or completely regenerated

8. Other observations or comments on general vegetation of quadrat, or surrounding vegetation?

Photo-point monitoring of five permanently marked mature trees or shrubs

Bore Number:	**Tree or Shrub 1 (0-20m zone)**	**Tree or Shrub 2 (20-40m zone)**	**Tree or Shrub 3 (40-60m zone)**	**Tree Shrub 4 (60-80m zone)**	**Tree or Shrub 5 (80-100m zone)**
9. Photograph ID/ Number:					
10. GPS Coordinates					

Vegetation health

11. The health of the individual could be described as (check appropriate box for each tree):

Health Class	**Tree or Shrub 1**	**Tree or Shrub 2**	**Tree or Shrub 3**	**Tree or Shrub 4**	**Tree or Shrub 5**
1. Virtually no leaves. Tree or shrub dead or nearly dead.					
2. Very sparse foliage. More leafless branches than those with leaves.					
3. Reduced foliage density, obvious sign of dieback.					
4. Dense foliage, slight sign of dieback. Some dead leafless branches.					
5. Very dense foliage, no sign of previous dieback. No dead leafless branches.					

Performance indicators

A visual assessment of specimen vigour can be assessed by the following attributes (circle appropriate descriptions):

	Tree or Shrub 1	**Tree or Shrub 2**	**Tree or Shrub 3**	**Tree or Shrub 4**	**Tree or Shrub 5**
12. Has the tree or shrub been burnt from a recent or previous fire? (Circle one)	Recent Previous None	Recent Previous None	Recent Previous None	Recent Previous None	Recent Previous None
13. Are there new shoots present on the photo point tree?	Yes No	Yes No	Yes No	Yes No	Yes No
14. What is the amount of leaf fall? (observed by amount ground leaf litter)	High Moderate Low None	High Moderate Low None	High Moderate Low None	High Moderate Low None	High Moderate Low None
15. Is the tree or shrub flowering, fruiting or seeding?	Flowering Fruiting Seeding No	Flowering Fruiting Seeding No	Flowering Fruiting Seeding No	Flowering Fruiting Seeding No	Flowering Fruiting Seeding No
16. Are tree seedlings present in the vicinity?	Yes No	Yes No	Yes No	Yes No	Yes No
17. Leaf colour can be described as: Red (R); Yellow (Y); Yellow-Green (YG); Blue-Green (BG); Tan (T); Other (describe)……………………………..……	Red Yellow Y-Green B-Green Tan Other	Red Yellow Y-Green B-Green Tan Other	Red Yellow Y-Green B-Green Tan Other	Red Yellow Y-Green B-Green Tan Other	Red Yellow Y-Green B-Green Tan Other
18. What is the estimated canopy cover? (see reference sheet)					