APPENDIX 1: LEVEL 1FLORA AND VEGETATION SURVEY

Report of a Level 1 Flora and Vegetation survey at the Yalyalup Proposed Mine Area

Prepared for Doral Mineral Sands
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Executive Summary

Ecoedge was engaged by Doral Mineral Sands in September 2015 to undertake a Level 1 Flora and Vegetation Survey of remnant vegetation within the proposed mining area at Yalyalup.

The Project Area, which totalled 1,546 ha, contained about 78 ha of remnant native vegetation.

The field assessment was carried out on 16th September and 13th and 14th October 2015

The field assessment was carried out on 16th September, 13th and 14th October 2015 and 18th February 2016 in accordance with the Environmental Protection Authority (EPA) Guidance Statement 51, "Terrestrial Flora and Vegetation Surveys for Environmental Impact Assessment in Western Australia" (EPA, 2004). All areas of remnant native vegetation within the Project Area were visited on foot or by vehicle and data on plant species composition and vegetation condition was collected at 105 sites.

The survey resulted in the identification of one hundred and forty-nine taxa of vascular plants, of which 57 taxa (38%) were introduced species. The relatively low number of native species found within the approximately 78 ha of native vegetation in the Project Area is a result of many years of degradation of the small fragments of native bush.

Two taxa of Declared Rare Flora (*Banksia squarrosa* subsp. *argillacea*, *Verticordia plumosa* var. *vassensis*) and two Priority flora (*Loxocarya magna* and *Calothamnus quadrifidus* subsp. *teretifolius*) were found within the Project Area.

Two weeds found within the Project Area, *Asparagus asparagoides** and *Zantedeschia aethiopica**, are listed as Pest Plants by the Department of Agriculture and Food. Both are in the C3 (management) category for the whole of the State.

Eight vegetation units were recognised in the Project Area.

Vegetation Unit A1 appears to be a degraded form of SWAFCT01b (Southern *Corymbia calophylla* woodlands on heavy soils), which is listed as a threatened ecological community by the Department of Parks and Wildlife, with the threat status of "Vulnerable".

Vegetation Unit A2, which only occurs on McGibbon Track, has characteristics of both SWAFCT01b (because of the overstorey of *C. calophylla*) and SWAFCT02 (Southern wet shrublands), a threatened ecological community listed as Endangered by the Department of Parks and Wildlife. Floristically it is much closer to SWAFCT02, as such, the occurrence of Unit A2 at the northern end of McGibbon Track is inferred to be an occurrence of the threatened ecological community SWAFCT02.

Vegetation Unit B1 is recognised as a threatened ecological community, this being "SWAFCT10b - Shrublands on southern Swan Coastal Plain Ironstones (Busselton area)". The

“Busselton Ironstones” are listed as Critically Endangered by the Department of Parks and Wildlife. The community is also listed as Endangered under the *Environment Protection and Biodiversity Conservation Act 1999.*

Vegetation Unit B2 appears to be a severely degraded form of SWAFCT10b, recognisable by the presence of massive ironstone and lateritic boulders at or near the soil surface. Generally, the only native species still present are the trees *Eucalyptus rudis* which is also present within Unit B1 on McGibbon Track, and sometimes *Melaleuca rhaphiophylla*.

Vegetation Unit C1 is associated with the winter streams that flow northwards through the western half of the Project Area and which empty into the Sabina River. Unit C1 appears to belong to the “Riverine Jindong Plant Communities”, associated as it is with the loams of the Jindong soil-landscape subsystem of the Abba Plains.

Both vegetation units C2 and C3 are restricted to a single occurrence. Vegetation Unit C2 occurs in a seasonally-wet, shallow depression, perhaps associated with a lens of clay near to the surface. Unit C2 is all in “Completely Degraded” condition.

Vegetation Unit C3 is comprised a few small patches of wet shrubland in “Degraded/Good” or “Good” condition, on the verge at the western end of Princefield Road. It has similarities to the “SWAFCT09 - Dense shrublands on clay flats” threatened ecological community.

Vegetation Unit D is comprised predominantly of *Agonis flexuosa*, with scattered *Banksia attenuata* over pasture Originally it would have resembled the SWAFCT21b (Southern *Banksia attenuata* woodlands) floristic community type, which is a Priority 3 ecological community, but has been completely degraded by livestock grazing.

Most remnant native vegetation in the Project Area, and all remnant vegetation on farmland, is in “Completely Degraded” condition. The only vegetation deemed to be in “Good” condition is at the northern end of McGibbon Track and a small area on Princefield Road. A few other small areas were rated as “Degraded/Good” condition on McGibbon Track, Princefield Road and Yalyalup Road.

A regional ecological linkage axis line running through the western half of Project Area, along the Sabina River. Vegetation within this portion of the Project Area directly forms part of a regional ecological linkage.

Four Environmentally Sensitive Areas have been mapped by the Department of Parks and Wildlife within the Project Area, relating to occurrences of Declared Rare Flora.

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Statement of limitations

Reliance on Data

In the preparation of this report, Ecoedge has relied on data, surveys, analyses, designs, plans and other information provided by the Client and other individuals and organisations, most of which are referred to in the report. Unless stated otherwise in the report, Ecoedge has not verified the accuracy or completeness of the data. To the extent that the statements, opinions, facts, information, conclusions and/or recommendations in the report are based in whole or in part on the data, those conclusions are contingent upon the accuracy and completeness of the data. Ecoedge will not be liable in relation to incorrect conclusions should any data, information or condition be incorrect or have been concealed, withheld, unavailable, misrepresented or otherwise not fully disclosed to Ecoedge.

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1 Introduction

Ecoedge was engaged by Doral Mineral Sands (DMS) in September 2015 to undertake a Level 1 Flora and Vegetation Survey of remnant vegetation within the proposed mining area (PMA) at Yalyalup (herein referred to as the 'Project Area').

The Project Area, which totalled 1,546 ha, contained about 78 ha of remnant native vegetation (**Figure 1**). Within the Project Area, some private land holdings could not be accessed for the survey as permission could not be obtained by DMS from the landholders. Lots unable to be surveyed are shown in **Figure 2**.

Only one flora survey is known to be carried out within the Project Area, that being restricted to the Busselton ironstone vegetation (and its vicinity) on McGibbon Track prior to 2007 by Andrew Webb of the Department of Parks and Wildlife[1]. A list of the species recorded for the McGibbon Road ironstone vegetation by Mr. Webb is provided in Appendix 3.

The field assessment was carried out on 5th September, 13th and 14th October and 5th November 2015 in accordance with the Environmental Protection Authority (EPA) Guidance Statement 51, "Terrestrial Flora and Vegetation Surveys for Environmental Impact Assessment in Western Australia" (EPA, 2004).

This report compiles findings of the field survey.

1.1 Scope and objectives

The scope and objectives of the flora survey were to carry out a Level 1 flora and vegetation assessment to determine whether there are any significant flora values within the Project Area. The survey scope included the following requirements:

- Conduct an assessment of flora and vegetation values within the Project Area;
- Conduct a review of other literature to summarise the values of flora and vegetation significance in the project area;
- Conduct field assessments to:
    - Identify the vascular flora species present;
    - Determine the presence or absence of Declared Rare Flora (DRF), Priority or Significant Species, where found, record relevant information for each, including species, number of individuals/estimated population size.
    - Assess conservation significance of vegetation and flora;
    - Define and spatially map vegetation condition;
    - Define and spatially map vegetation communities; (achieved through the installation of a number of floristic relevés)

[1] Mr A. Webb, botanist, Department of Parks and Wildlife, Bunbury, *pers. comm*. 17/02/2016.

    - Define and map threatened and priority ecological communities
- Prepare a report detailing findings of the field survey

1.2 Biogeographic region and location

The Project Area is situated within Perth Coastal Plain (SWA2) sub-region of the Swan Coastal Plain biogeographic region, as defined in the Interim Biogeographical Regionalisation for Australia (IBRA) (Australian Government, 2009). The northwest corner of the Project Area is located approximately 8.4 km southeast of the Busselton townsite (Error! Reference source not found.). The site is within road reserves and freehold land in the City of Busselton and is zoned Agriculture under the City's Local Planning Scheme 21 (City of Busselton, 2015).

1.3 Geology

Within the Swan Coastal Plain landform, the Project Area is situated on the Abba Plains land system (213Ab). The Abba Plain is a level to gently undulating plain formed on alluvium. It is situated on the southern Swan Coastal Plain and extends for about 10 km inland between the Ludlow Plain system to the north and the foot of the Blackwood Plateau system to the south. It lies approximately 10-40 m above sea level and contains extensive areas of poor drainage (Tille and Lantzke, 1990).

Soil-landscape systems have been further divided into subsystems, and within these into soil phases or mapping units. Within the Abba Plains, the Project Area is situated on soils of the Abba and Jindong Subsystems.

Within the Abba Subsystem, Tille and Lantzke (1990) have identified eleven soil phases or mapping units. Six of these occur within the Project Area. Two of the four units mapped for the Jindong Subsystem are present within the Project Area. Soil phases of the Project Area are described in **Table 1** and mapped in **Figure 3**.

Table 1. Soil Mapping Units occurring within the Project Area (Tille and Lantzke, 1990).

Soil Mapping Unit	Description
213AbABw	Winter wet flats and slight depressions with sandy grey brown duplex (Abba) and gradational (Busselton) soils.
213AbABvw	Small narrow swampy depressions along drainage lines. Alluvial soils.
213AbAB1	Flats and low rises with sandy grey brown duplex (Abba) and gradational (Busselton) soils.
213AbABd	Gently sloping low dunes and rises (0-5% gradients) with deep bleached sands.
213AbABwi	Winter wet flats and slight depressions with shallow red brown sands and loams over ironstone (i.e. bog iron ore soils).
213AbABwy	Poorly drained depressions with some areas which become saline In summer. Shallow sands over clay subsoils (i.e. Abba Clays).
213AbJD1	Well drained flats with sandy gradational grey brown (Busselton) soils, some red brown sands and loams (Marybrook Soils).
213AbJDf	Well drained flats with deep red brown sands, loams and light clays (i.e. Marybrook soils).

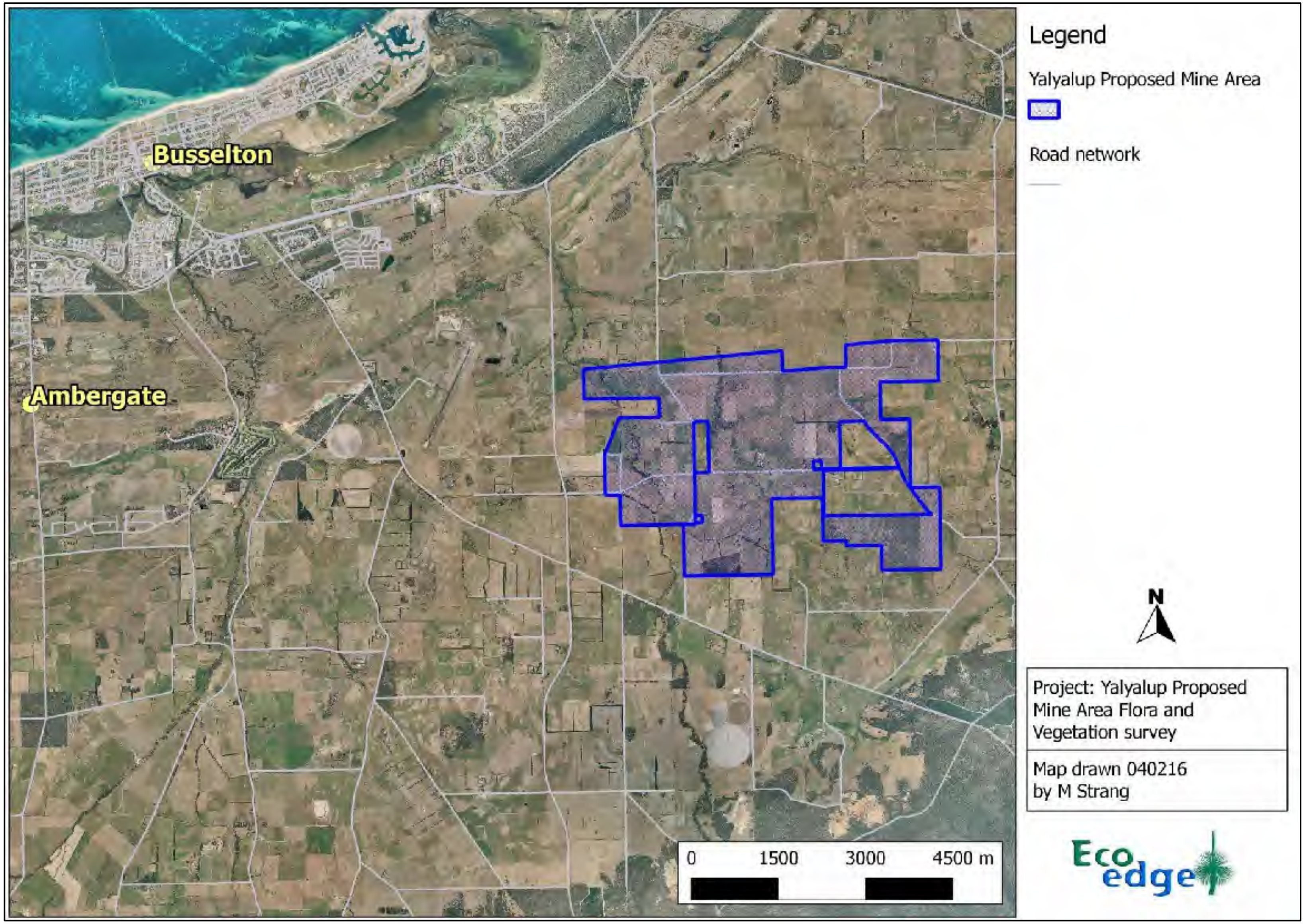

Figure 1. Aerial Photograph showing location of Project Area.

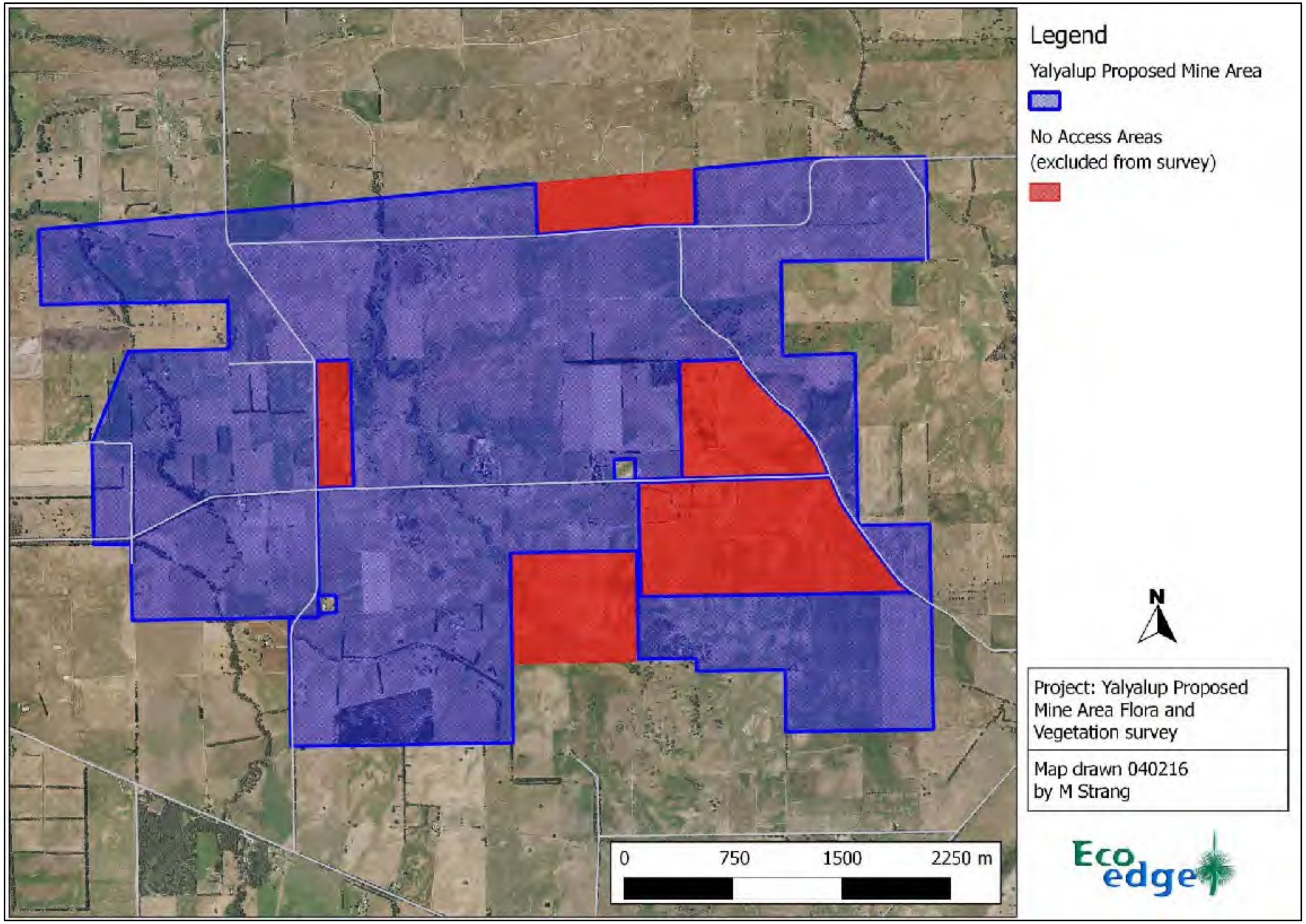

Figure 2. Yalyalup Project Area showing the areas not able top be accessed during the survey due the lack of landholder permission.

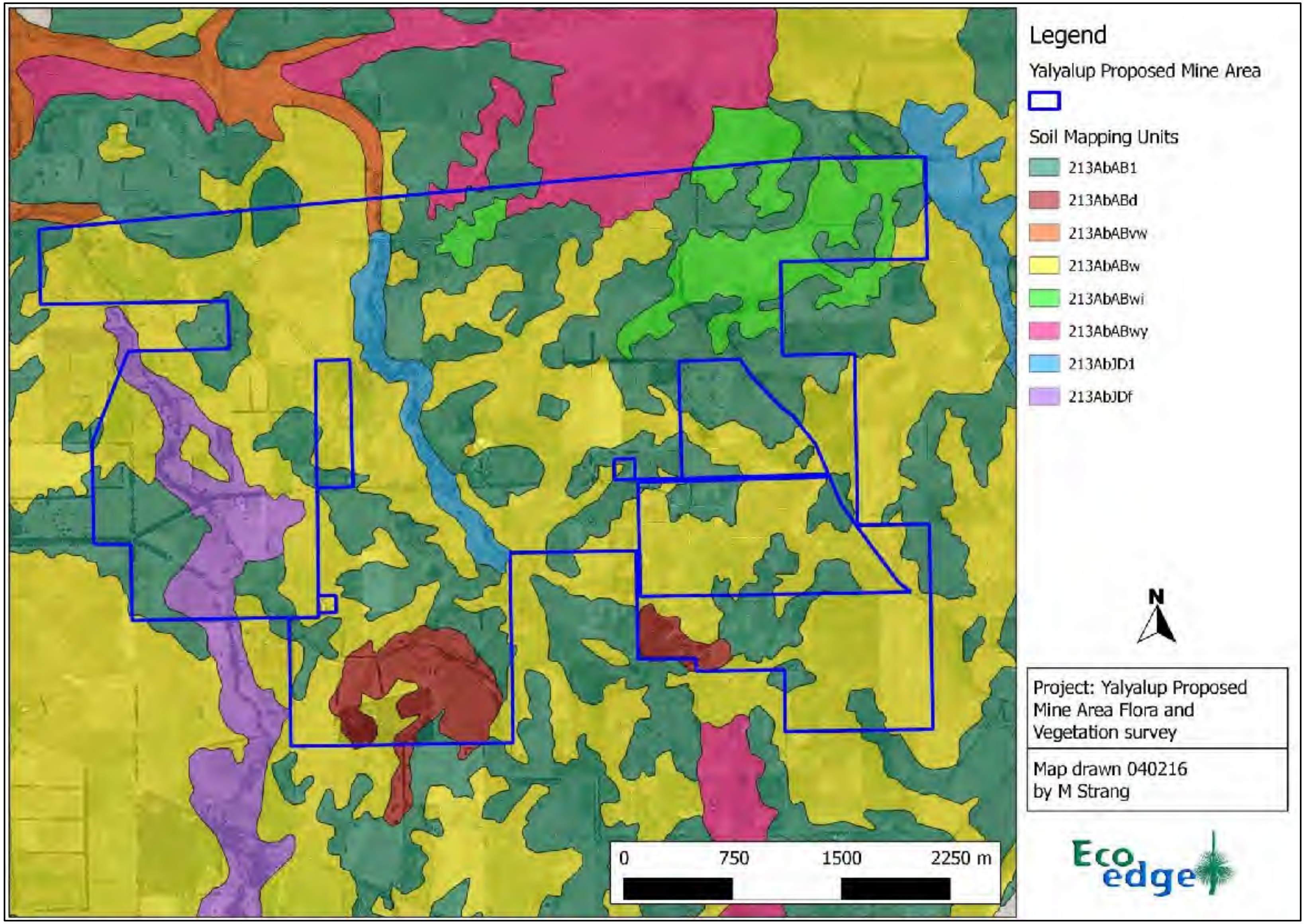

Figure 3. Soil landscapes occurring within the Project Area.

1.4 Vegetation

Variation in vegetation mainly reflects the variations in soil and moisture condition of a landscape. Historically, the vegetation types in the Project Area would have reflected the topography and soils, with the Swan Coastal Plain vegetation being distinct from that found on the slopes of the Darling Scarp or Blackwood Plateau.

The South West Biodiversity Project Mapping and Information Installment 2 (Molloy *et al.*, 2007) provides a map of the Vegetation Complexes in the southern Swan Coastal Plain, an area not included in previous surveys such as that of Heddle *et al.* (1980). The Molloy *et al.* (2007) mapping utilises the Regional Forest Agreement (RFA) mapping of Mattiske and Havel (1998) as well as the Swan Coastal Plain (SCP) mapping of Heddle *et al.* (1980) to fill gaps in these datasets.

As shown in **Table 2**, remnant vegetation within the Project Area was mapped as four different components of the Abba Complex, which are described in **Table 2.**

Table 2. Vegetation Complexes mapped as occurring within the Project Area (Molloy *et al.,* 2007).

Vegetation Complex	Description
Abba (Aw)	Mosaic of tall shrubland of *Melaleuca viminea* and woodland of *Eucalyptus rudis-Melaleuca rhaphiophylla* with occasional *Corymbia calophylla* on broad depressions in the humid zone (Lowland vegetation)
Abba (AF)	Woodland of *Corymbia calophylla-Agonis flexuosa* and tall shrubland of Myrtaceae-Proteaceae spp. on terraces and valley floors in the humid zone (Lowland vegetation)
Abba (AB)	Woodland and open forest of *Corymbia calophylla* on flats and low rises in the humid zone (Upland vegetation)
Abba (Ad)	Woodland of *Corymbia calophylla-Agonis flexuosa-Allocasuarina fraseriana-Nuytsia floribunda* on mild slopes in the humid zone (Upland vegetation)

In 2001, the Commonwealth of Australia stated National Targets and Objectives for Biodiversity Conservation, which recognised that the retention of 30%, or more, of the pre-clearing extent of each ecological community was necessary if Australia's biological diversity was to be protected (Environment Australia, 2001). This level of recognition is in keeping with the targets set in the EPA’s Position Statement on the 'Environmental protection of native vegetation in Western Australia: clearing of native vegetation, with particular reference to the agricultural area' (EPA, 2000). With regard to conservation status, the EPA has set a target of 15% of pre-European extent for each ecological community to be protected in a comprehensive, adequate and representative reserve system (EPA, 2006).

Table 3 lists the percentage remaining of each vegetation complex and the percentage of each vegetation complex in formal and formal plus informal reserves. It also lists whether each vegetation complex meets the Commonwealth's 30% target (Environment Australia, 2001) and the EPA's 15% target (EPA, 2006). As is evident in **Table 3,** none of the Vegetation Complexes present within the Project Area meet the Commonwealth's 30% target or the EPA's 15% target.

Table 3. Vegetation Complexes of the Project Area with regard to the EPA and Commonwealth retention targets (DEC 2007).

Vegetation Complex	% Remaining of pre-European	Is the 30% Target Met?	% in Formal Reserves	% in Formal + All Informal Reserves	Is the 15% Target Met?
Abba (Aw)	3.2%	No	0.1%	0.1%	No
Abba (AF)	11.2%	No	1.2%	1.2%	No
Abba (AB)	4.6%	No	0%	0%	No
Abba (Ad)	19.7%	No	0.1%	0.1%	No

1.4.1 Ground Water Dependent Ecosystems

Groundwater-dependent ecosystems (GDEs) may be defined as 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). Richardson *et al*., (2011) identified three types of groundwater dependent ecosystems:

1. Aquifer and cave ecosystems including stygofauna (fauna that live in groundwater) in fractured rock aquifers

2. Ecosystems dependent on surface expression of groundwater including base flow (e.g. fish in remnant aquatic pools), wetlands, mound springs and sea grass beds

3. Ecosystems dependent on subsurface presence of groundwater where roots tap into the groundwater system (via the capillary fringe). They 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 (above), 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.

Type 3 GDEs (ecosystems dependent on subsurface presence of groundwater, as defined above) may be difficult to identify in the field and their identification may require a detailed knowledge of local hydrogeology, ecosystems dynamics and plant physiology. Dependence on groundwater can be variable, ranging from partial and infrequent dependence, i.e. seasonal or episodic, to total (entire or obligate), continual dependence. It is often difficult, however, to determine the nature of this dependence (Serov *et al*., 2012).

With regard to specific hydrological and GDE studies within the Project Area (which is situated within the Busselton-Capel Groundwater Area) some work has been carried out on behalf of the Department of Water to identify GDEs and to relate changes in groundwater levels to changes in plant health in South West groundwater areas (e.g. Hyde, 2006; Wilson and Froend, 2010). Long-term changes in groundwater levels on the Swan Coastal Plain are reviewed in Golder Associates (2008) and DoW (2009a, b).

Del Borello (2008) describes an adaptive management framework for the environmental water provisions for specified groundwater-dependent sites for the South West groundwater areas allocation plan. It sets specific groundwater level or discharge triggers (or thresholds) and identifies the appropriate management responses when thresholds are reached. This feedback mechanism is designed to enhance management of selected high-value groundwater-dependent ecosystems across the plan area and provide information for the next phase of allocation planning.

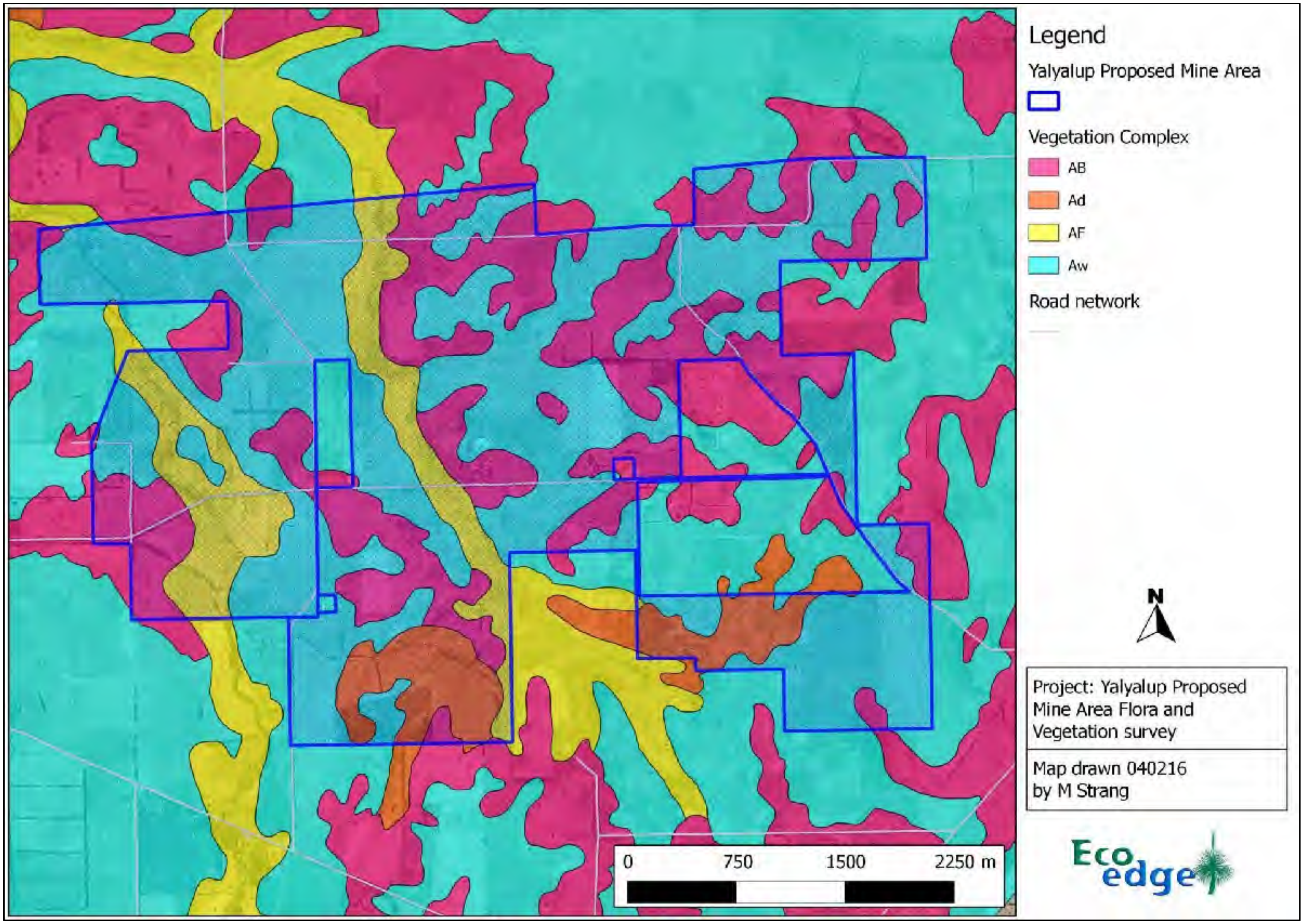

Figure 4. Vegetation complexes mapped as occurring within the Project Area.

1.5 Threatened and Priority Ecological Communities

Ecological communities are defined by Western Australia's Department of Parks and Wildlife (DPaW, previously the Department of Environment and Conservation (DEC)) as "...naturally occurring biological assemblages that occur in a particular type of habitat. They are the sum of species within an ecosystem and, as a whole, they provide many of the processes which support specific ecosystems and provide ecological services." (DEC, 2010).

A threatened ecological community (TEC) is one which is found to fit into one of the following categories; Presumed Totally Destroyed (PD), Critically Endangered (CE), Endangered (E) or Vulnerable (V) (DEC, 2010). Possible threatened ecological communities that do not meet survey criteria are added to DPaW's Priority Ecological Community Lists under Priorities 1, 2 and 3 (referred to as P1, P2, P3). Ecological Communities that are adequately known, are rare but not threatened, or meet criteria for Near Threatened, or that have been recently removed from the threatened list, are placed in Priority 4 (P4). These ecological communities require regular monitoring. Conservation Dependent ecological communities are placed in Priority 5 (P5) (DEC, 2010). The current listing of Threatened and Priority Ecological Communities is specified in DPaW, 2015a and 2015b.

Threatened Ecological Communities can also be listed under the Commonwealth *EPBC Act* (Department of the Environment (DotE), 2015a; Department of Environment, Water, Heritage and the Arts (DEWHA), 1999). There are three categories of TEC under the *EPBC Act*: Critically Endangered (CE), Endangered (E) and Vulnerable (V). These are defined in **Table 4**.

Table 4. Categories of Threatened Ecological Communities under the *EPBC Act* (DotE, 2015a).

Category	Definition
Critically endangered	If, at that time, an ecological community is facing an extremely high risk of extinction in the wild in the immediate future (indicative timeframe being the next 10 years).
Endangered	If, at that time, an ecological community is not critically endangered but is facing a very high risk of extinction in the wild in the near future (indicative timeframe being the next 20 years).
Vulnerable	If, at that time, an ecological, community is not critically endangered or endangered but is facing a high risk of extinction in the wild in the medium–term future (indicative timeframe being the next 50 years).

A Protected Matters Search Tool query for communities listed under the *EPBC Act* occurring within a 5 km radius of the Project Area was undertaken (DotE, 2015b, **Appendix 1**), and the current DPaW TEC and PEC listings were consulted (DPaW 2015a; 2015b).

Threatened and priority ecological communities known to occur within 5 km of the Project Area are listed in **Table 5.**

Table 5. Threatened ecological communities occurring within 5 km of the Project Area (Gibson *et al*., 1994; DPaW, 2015a, 2015b; DotE, 2015b).

Community Name	Community Description	Status (WA)	Status (*EPBC Act*)
Claypans of the Swan Coastal Plain	Includes the following Western Australian listed Threatened Ecological Communities (TECs): • Herb rich saline shrublands in clay pans (SWAFCT07) • Herb rich shrublands in clay pans (SWAFCT08) • Dense shrublands on clay flats (SWAFCT09) • Shrublands on dry clay flats. (SWAFCT10a) and the following Priority Ecological Community: • Clay pans with shrubs over herbs	…	CR
SWAFCT10b - Shrublands on southern Swan Coastal Plain Ironstones (Busselton area)	Species rich plant community located on seasonal wetlands on ironstone and heavy clay soils on the Swan Coastal Plain near Busselton. Much of the high species diversity comes from annuals and geophytes.	CR	EN
SWAFCT01b – Southern *Corymbia calophylla* woodlands on heavy soils	Dominated by *C. calophylla* and *Eucalyptus marginata. Acacia extensa, Hypocalymma angustifolium* and *Xanthorrhoea preissii* are important shrubs. Mainly occurs south of Capel.	VU	
SWAFCT21b - Southern *Banksia attenuata* woodlands	Structurally, this community type is normally *Banksia attenuata* or *Eucalyptus marginata – B. attenuata* woodland. Common taxa include *Acacia extensa, Jacksonia* sp. *Busselton, Laxmannia sessiliflora, Lysinema ciliatum* and *Johnsonia acaulis.*	P3	

1.6 Threatened and Priority Flora

Species of flora and fauna are defined as having Declared Rare (Threatened) or Priority conservation status where their populations are restricted geographically or threatened by local processes. The Department of Environment Regulation recognises these threats of extinction and consequently applies regulations towards population and species protection.

Declared Rare (Threatened) Flora species are gazetted under Subsection 2 of Section 23F of the *Wildlife Conservation Act 1950* (*WC Act*) and therefore it is an offence to 'take' or damage rare flora without Ministerial approval. Section 6 of the *WC Act* defines 'to take' as "… to gather, pick, cut, pull up, destroy, dig up, remove or injure the flora or to cause or permit the same to be done by any means."

Priority Flora are under consideration for future declaration as 'rare flora', dependent on more information. Species classified as Priority One to Three are in need of further survey to determine their status, while Priority Four species require monitoring every 5-10 years. Under the *WC Act*, Threatened Flora are ranked according to their level of threat using IUCN Red List categories and criteria of Extinct (EX), Critically Endangered (CE), Endangered (EN) or Vulnerable (VU). **Table 6** presents the categories of Declared Rare and Priority Flora as defined by the *WC Act* (DPaW 2014a).

Table 6. Definitions of Declared Rare and Priority List flora (DPaW, 2014a).

Conservation code	Category
T	Threatened flora is flora that has been declared to be 'likely to become extinct or is rare, or otherwise in need of special protection', pursuant to section 23F(2) of the *Wildlife Conservation Act 1950*. The assessment of the conservation status of these species is based on their national extent and ranked according to their level of threat using IUCN Red List categories and criteria (CR, EN, VU, EX). A species that is listed as Threatened and assessed as 'Critically Endangered' would therefore have its status written as T (CR).
R	Taxa which have been adequately searched for and are deemed to be in the wild either rare, in danger of extinction, or otherwise in need of special protection and have been gazetted as such.
P1	Taxa which are known from one or a few (generally <5) populations which are under threat, either due to small population size, or being on lands under immediate threat. Such taxa are under consideration for declaration as 'rare flora', but are in urgent need of further survey.
P2	Taxa which are known from one or a few (generally <5) populations, at least some of which are not believed to be under immediate threat. Such taxa are under consideration for declaration as 'rare flora', but are in urgent need of further survey.
P3	Taxa which are known from several populations, and the taxa are not believed to be under immediate threat (i.e. not currently endangered), either due to the number of known populations (generally >5), or known populations being large, and either widespread or protected. Such taxa are under consideration for declaration as 'rare flora', but are in need of further survey.
P4	Taxa which are considered to have been adequately surveyed and which, whilst being rare (in Australia), are not currently threatened by any identifiable factors. These taxa require monitoring every 5-10 years.

Under the *EPBC Act,* a species may be listed in one of six categories; the definitions of these categories are summarised in **Table 7** (DotE, 2015c).

Threatened or Priority flora occurring within 10 km of the Project Area generated from a Naturemap data search (DPaW, 2014c) are listed in **Table 8.** Taxa listed under the *EPBC Act* (based on results of the Protected Matters Search Tool query (DotE, 2014b)) are also listed, and included in **Appendix 1**.

Table 7. Categories of Threatened Species under the *EPBC Act* (DotE, 2015c).

Category	Definition
Extinct (Ex)	A native species is eligible to be included in the ***extinct*** category at a particular time if, at that time, there is no reasonable doubt that the last member of the species has died.
Extinct in the Wild (ExW)	A native species is eligible to be included in the extinct in the wild category at a particular time if, at that time (a) it is known only to survive in cultivation, in captivity or as a naturalised population well outside its past range; or (b) it has not been recorded in its known and/or expected habitat, at appropriate seasons, anywhere in its past range, despite exhaustive surveys over a time frame appropriate to its life cycle and form.
Critically Endangered (CE)	A native species is eligible to be included in the critically endangered category at a particular time if, at that time, it is facing an extremely high risk of extinction in the wild in the immediate future, as determined in accordance with the prescribed criteria.
Endangered (E)	A native species is eligible to be included in the endangered category at a particular time if, at that time (a) it is not critically endangered; and (b) it is facing a very high risk of extinction in the wild in the near future, as determined in accordance with the prescribed criteria.
Vulnerable (V)	A native species is eligible to be included in the vulnerable category at a particular time if, at that time (a) it is not critically endangered or endangered; and (b) it is facing a high risk of extinction in the wild in the medium term future, as determined in accordance with the prescribed criteria.
Conservation Dependent (CD)	A native species is eligible to be included in the conservation dependent category at a particular time if, at that time, the species is the focus of a specific conservation program, the cessation of which would result in the species becoming vulnerable, endangered or critically endangered within a period of 5 years.

Table 8. List of Declared Rare and Priority List flora known to occur within 10 km of the Project Area (DPaW, 2015c; DotE, 2015b).

Species	Cons Status*	Flowering	Description and Habitat	Likelihood of Occurrence
Brachyscias verecundus	T (CE)		Annual (or ephemeral), herb, 0.012-0.022 m high, entirely glabrous. Fl. white/cream. In a moss sward. On a granite outcrop.	Low
Caladenia procera	T (CE)	Sep-Oct	Tuberous, perennial, herb, 0.35-0.9 m high. Fl. yellow. Rich clay loam. Alluvial loamy flats, jarrah/marri/peppermint woodland, dense heath, sedges.	Low
Andersonia gracilis	T (E)	Sep to Nov	Slender erect or open straggly shrub, 0.1-0.5(-1) m high. Fl. white-pink-purple. White/grey sand, sandy clay, gravelly loam. Winter-wet areas, near swamps.	Moderate
Banksia nivea subsp. *uliginosa*	T (E)	Aug-Sep	Dense, erect, non-lignotuberous shrub, 0.2–1.5 m high. Fl. yellow, brown. Sandy clay, gravel.	Moderate
Caladenia huegelii	T (E)	Sep-Oct	Tuberous, perennial, herb, 0.25-0.6 m high. Fl. green, cream, red. Grey or brown sand, clay loam.	Low
Centrolepis caespitosa	T (E)	Oct - Dec	Tufted annual, herb (forming a rounded cushion up to 25 mm across). White sand, clay. Salt flats, wet areas.	Moderate
Darwinia whicherensis	T (E)	Oct - Nov	Erect low shrub to 30 cm, flowers green, outer red. Winter-wet area of shrubland over shallow red clay over ironstone	Moderate
Drakaea elastica	T (E)	Oct-Nov	Tuberous, perennial, herb, 0.12-0.3 m high. Fl. red, green, yellow. White or grey sand. Low-lying situations adjoining winter-wet swamps	Low
Gastrolobium papilio	T (E)	Oct-Dec	Tangled, clumped shrub, to 1.5 m high. Fl. cream-red. Sandy clay over ironstone and laterite. Flat plains.	Low
Grevillea maccutcheonii	T (E)	Mar/May or Dec	Densely branched shrub, to 2 m high. Fl. green & red. Shallow soils over laterite, clay. Seasonally inundated sites.	Moderate
Lambertia echinata subsp. *occidentalis*	T (E)	Feb/May-Jun/Oct	Prickly, much-branched, non-lignotuberous shrub, to 3 m high. Fl. Yellow. White sandy soils over laterite, orange/brown-red clay over ironstone.	Low
Petrophile latericola	T (E)	Nov	Multi-stemmed shrub, 0.4-1.5 m high. Fl. yellow. Red lateritic clay. Winter-wet flats.	Moderate

Species	Cons Status*	Flowering	Habitat	Likelihood of Occurrence
Synaphea stenoloba	T (E)	Aug-Oct	Caespitose shrub, 0.3–0.45 m high. Fl. yellow. Sandy or sandy clay soils. Winter-wet flats, granite. Shrublands and woodlands on loamy soils.	Low
Verticordia plumosa var. *vassensis*	T (E)	Sep-Feb	Shrub, 0.3–1 m high. Fl. pink, Sep–Feb. White/grey sand. Winter-wet flats	Moderate
Banksia squarrosa subsp. *argillacea*	T (V)	Jun-Nov	Erect, open, non-lignotuberous shrub, 1.2–4 m high. Fl. yellow. White/grey sand, gravelly clay or loam. Winter-wet flats, clay flats.	High
Chamelaucium sp. S Coastal Plain (R.D.Royce 4872)	T (V)	Aug-Oct	Winter-wet areas, loams and ironstone.	Moderate
Diuris micrantha	T (V)	Sep-Oct	Tuberous, perennial, herb, 0.3–0.6 m high. Fl. yellow, brown. Brown loamy clay. Winter-wet swamps, in shallow water.	Moderate
Drakaea micrantha	T (V)	Sep-Oct	Tuberous, perennial, herb, 0.15–0.3 m high. Fl. red, yellow. White-grey sand.	Low
Grevillea elongata	T (V)	Oct	Shrub, 1.5-2 m high. Fl. white-cream. Gravelly clay, sandy clay, sand. Road verges, swamps, creek banks	Moderate
Hemigenia ramosissima	T	Nov–Dec or Jan	Slender shrub, to 0.5 m high. Fl. blue-purple. Lateritic soils, clay. Granite outcrops.	Low
Verticordia plumosa var. *ananeotes*	T	Nov-Dec	Erect, sparsely branched shrub, 0.3-0.5 m high. Fl. pink-purple/white. Sandy loam. Seasonally inundated plains.	Moderate
Gastrolobium sp. Yoongarillup (S.Dilkes s.n. 1/9/1969)	P1	Aug-Oct	Erect, perennial shrub; 0.5 m high, 1.0 m wide; flowers yellow/orange. Jarrah-Marri forest, white sand, gravel	Low
Andersonia ferricola	P1	Oct	Shrub, 0.2-0.5 m high. Fl. purple. White sand or red-brown loam over ironstone. Seasonally wet flats	Moderate
Loxocarya striata subsp. *implexa*	P1	Jul-Dec	Winter-wet flats	Moderate
Stylidium ferricola	P1	…	Caespitose perennial, herb, 0.09-0.15 m high. Shallow red-brown clay loam over ironstone. Seasonally wet poorly-drained slopes.	Moderate

Species	Cons Status*	Flowering	Habitat	Likelihood of Occurrence
Actinotus whicheranus	P2	Dec or Jan-Mar	Erect, slender perennial, herb, with flowering branches to 0.4 m high. Fl. white. White sand pockets over laterite.	Moderate
Amperea micrantha	P2	Oct-Nov	Low, spreading, bushy perennial, herb, 0.1–0.3 m high. Fl. brown. Sandy soils	Low
Calytrix sp. Tutunup (G.J. Keighery & N. Gibson 2953)	P2	Oct	Slender, spreading shrub, to 3 m high. Fl. white. Yellow-grey clayey loam, red clayey loam, laterite, ironstone. Slopes and flats, winter-wet areas, grazed paddocks.	Moderate
Gratiola pedunculata	P2	Sep-Nov	Erect to decumbent perennial herb 13–50 cm high. Damp areas.	Low
Leucopogon sp. Busselton (D. Cooper 243)	P2	Aug-Sep	Slender, erect shrub to 70 cm; flowers white. *Pericalymma ellipticum* wet shrubland, Marri-Jarrah woodland.	Low
Blennospora doliiformis	P3	Oct-Nov	Erect annual, herb, to 0.15 m high. Fl. yellow. Grey or red clay soils over ironstone. Seasonally-wet flats.	Moderate
Boronia capitata subsp. *gracilis*	P3	Jun-Nov	Slender shrub, 0.3-0.6(-3) m high, branches pilose. Fl. pink. White/grey or black sand. Winter-wet swamps,	Moderate
Boronia tetragona	P3	Oct-Dec	Perennial, herb, 0.3–0.7 m high, leaves sessile, entire, with papillate margins, branches quadrangular, sepals ciliate. Fl. pink, red. Black/white sand, laterite, brown sandy loam. Winter-wet flats, swamps, open woodland.	Moderate
Chordifex gracilior	P3	Sep-Dec	Rhizomatous, erect perennial, herb, 0.3-0.5 m high. Fl. brown, Sep to Dec. Peaty sand. Swamps.	Moderate
Conospermum paniculatum	P3	Jul-Nov	Spreading, open shrub, 0.3-1.25 m high. Fl. blue, white. Sandy or clayey soils. Swampy areas, plains, slopes.	Low
Grevillea brachystylis subsp. *brachystylis*	P3	Aug-Nov	Much-branched, prostrate or decumbent, non-lignotuberous shrub, 0.2-0.5 m high, to 3 m wide. Fl. red. Black sand, sandy clay. Swampy situations.	Moderate
Grevillea bronwenae	P3	Jun-Dec	Slender, erect shrub, 0.5–1.6 m high. Fl. red. Grey sand over laterite, lateritic loam. Hillslopes.	Moderate
Hakea oldfieldii	P3	Aug-Oct	Open, straggling shrub, up to 2.5 m high. Fl. white, cream, yellow. Red clay or sand over laterite. Seasonally wet flats.	High

Species	Cons Status*	Flowering	Habitat	Likelihood of Occurrence
Isopogon formosus subsp. *dasylepis*	P3	Jun-Dec	Low, bushy or slender, upright, non-lignotuberous shrub, 0.2–2 m high. Fl. pink, purple, red. Sand, sandy clay, gravelly sandy soils over laterite. Often swampy areas.	High
Lasiopetalum laxiflorum	P3	Sep-Oct	Jarrah forest, lateritic soils	Low
Loxocarya magna	P3	Sep or Nov	Rhizomatous, perennial, herb (sedge-like), 0.5-1.5 m high. Sand, loam, clay, ironstone. Seasonally inundated or damp habitats.	High
Pithocarpa corymbulosa	P3	Jan-Apr	Erect to scrambling perennial, herb, 0.5-1 m high. Fl. white. Gravelly or sandy loam. Amongst granite outcrops.	Low
Schoenus pennisetis	P3	Aug-Sep	Tufted annual, grass-like or herb (sedge), 0.05-0.15 m high. Fl. purple-black. Grey or peaty sand, sandy clay. Swamps, winter-wet depressions.	Moderate
Stylidium longitubum	P3	Oct-Dec	Erect annual (ephemeral), herb, 0.05-0.12 m high. Fl. Pink. Sandy clay, clay. Seasonal wetlands.	Moderate
Verticordia attenuata	P3	Dec-May	Shrub, 0.4–1 m high. Fl. pink. White or grey sand. Winter-wet depressions	Moderate
Acacia flagelliformis	P4	May-Sep	Rush-like, erect or sprawling shrub, 0.3-0.75(-1.6) m high. Fl. yellow. Sandy soils. Winter-wet areas.	Moderate
Acacia semitrullata	P4	May-Oct	Slender, erect, pungent shrub, (0.1-)0.2-0.7(-1.5) m high. Fl. cream, white. White/grey sand, sometimes over laterite, clay. Sandplains, swampy areas.	Moderate
Banksia meisneri subsp. *ascendens*	P4	Apr-Sep	Shrub, 0.5-2 m high, leaves ascending, 8-15 mm long. Fl. yellow-orange-brown. White or grey sand. Swampy flats.	Moderate
Calothamnus quadrifidus subsp. *teretifolius*	P4	Nov-Dec	Erect, compact, perennial shrub 1.7 m high x 1 m wide. Fl. Red. Seeds held. Fruit exposed.	High
Chamelaucium sp. Yoongarillup (G.J. Keighery 3635)	P4	Jul-Oct	Non-lignotuberous shrub, to 2.5 m high. Fl. cream, yellow. Jarrah-marri forest. Loams, sandy clays. Riverbanks, lower slopes, below laterite breakaways.	Low
Franklandia triaristata	P4	Aug-Oct	Erect, lignotuberous shrub, 0.2-1 m high. Fl. white, cream, yellow, brown, purple. White or grey sand.	Low

Species	Cons Status*	Flowering	Habitat	Likelihood of Occurrence
Ornduffia submersa	P4	Sep-Oct	Tuberous emergent aquatic perennial dwarf shrub, height to 35 cm; flowers white; leaves floating on surface of water. Clay-based ponds and swamps (semi-aquatic)	Moderate
Pultenaea skinneri	P4	Jul-Sep	Slender shrub, 1-2 m high. Fl. yellow, orange, red. Sandy or clayey soils. Winter-wet depressions.	Low

*The *WC Act* Conservation Status is shown; *EPBC Act* status is in brackets.

Many of the species listed in **Table 8** could potentially occur within the Project Area, based on an assessment of their preferred habitats. The great majority of the species listed in **Table 8** would have either been flowering at the time of survey or could be identified in the field without flowers.

1.7 Ecological Linkages

Information for this section is taken from Molloy *et al*. (2009) and their report on the South West Regional Ecological Linkages (SWREL) Project.

Ecological linkages are defined as:

"*A series of (both contiguous and non-contiguous) patches which, by virtue of their proximity to each other, act as stepping stones of habitat which facilitate the maintenance of ecological processes and the movement of organisms within, and across, a landscape*."

Regional ecological linkages link protected patches of regional significance by retaining the best (condition) patches available as stepping stones for flora and fauna between regionally significant areas. This increases the long-term viability of all the constituent areas.

The SWREL report is the result of collaboration between the Western Australian Local Government Association's *South West Biodiversity Project* and the then Department of Environment and Conservation's *Swan Bioplan* to provide a tool for the identification of ecological linkages and guidance for the protection of linkages through planning policy documents.

Molloy *et al.* (2009) assessed and assigned 'proximity values' to all patches of remnant native vegetation as a way of indicating their distance from the nearest regional ecological linkage axis line. These values are defined in **Figure 5.** It should be noted however, that the proximity value of a patch of remnant vegetation to an ecological linkage is not intended to replace the need to consider the other biodiversity conservation values of that patch of remnant vegetation.

Molloy *et al.* (2009) identify a regional ecological linkage axis line running through the western half of Project Area, along the Sabina River (**Figure 6**). Vegetation within this portion of the Project Area directly forms part of a regional ecological linkage.

While there is no statutory basis for regional ecological linkages identified through the SWREL project, the importance of ecological linkages has been recognised as an environmental policy consideration in EPA and Planning policy over the last decade (EPA, 2009 and references therein). In its statement regarding the SWREL Project, the EPA stated that even though Ecological Linkages are just one measure of the conservation values of a patch of remnant vegetation it expected that:

In preparing plans and proposals for development, consideration will be given to both the site-specific biodiversity conservation values of patches of native vegetation, as well as the landscape function and core linkage significance of a patch in supporting the maintenance of ecological linkage (EPA, 2009).

1a: with an edge touching or <100m from a linkage

1b: with an edge touching or <100m from a natural area selected in 1a

1c: with an edge touching or <100m from a natural area selected in 1b

2a: with an edge touching or <500m from a linkage

2b: with an edge touching or <500m from a natural area selected in 2a

2c: with an edge touching or <500m from a natural area selected in 2b

3a: with an edge touching or <1000m from a linkage

3b: with an edge touching or <1000m from a natural area selected in 3a

3c: with an edge touching or <1000m from a natural area selected in 3b

Figure 5. Linkage proximity values assigned to patches of remnant vegetation within a landscape (from Molloy et al., 2009).
Note: in Figure 5, ‘linkage’ refers to the linkage axis line.

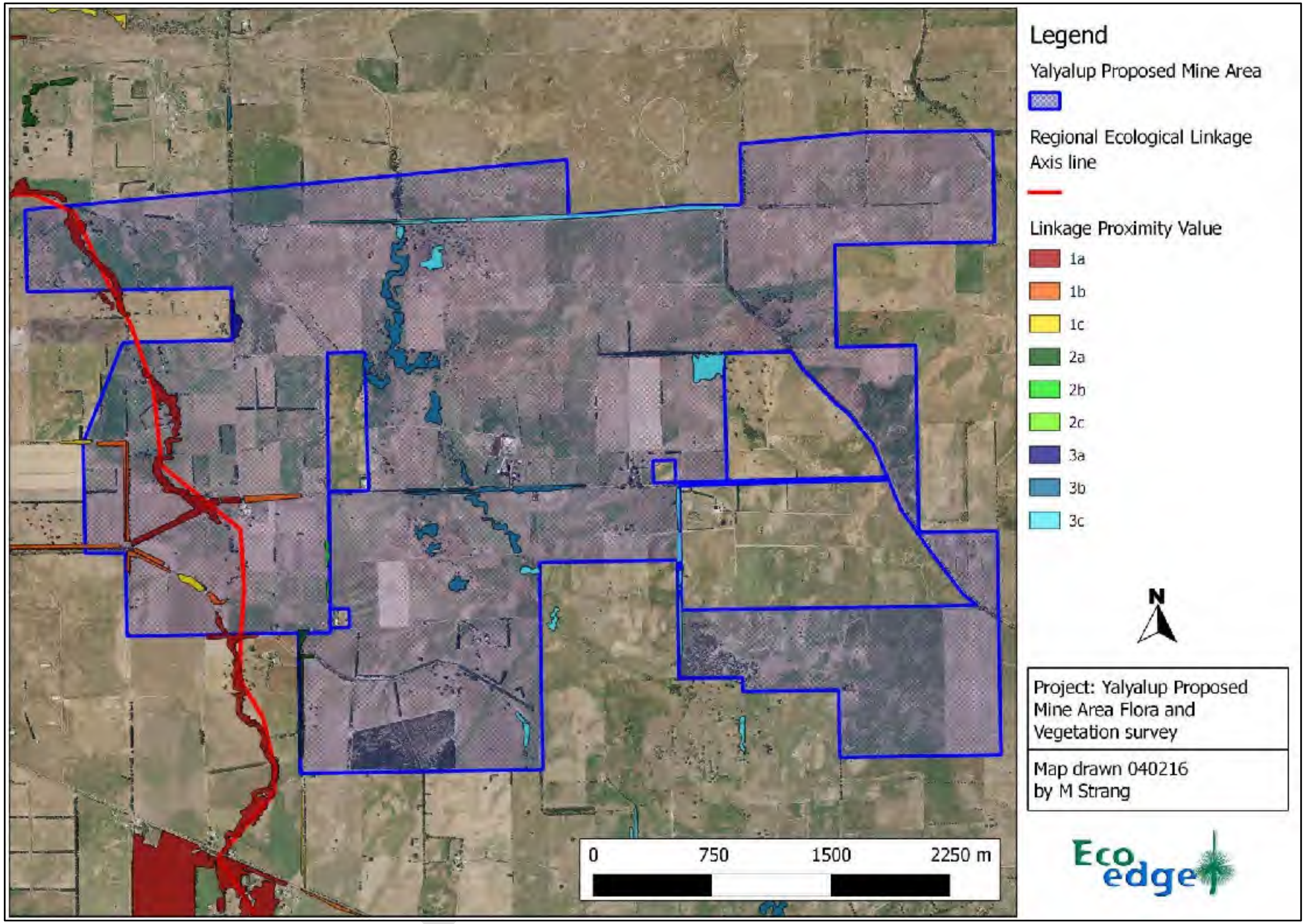

Figure 6. A Regional Ecological Linkage passes directly through the Project Area.

1.8 Environmentally Sensitive Areas

Environmentally sensitive areas are protected under the Environmental Protection (Clearing of Native Vegetation) Regulations 2004 and are selected for their environmental values at state or national levels (Government of Western Australia, 2005). They include;

- Defined wetlands and riparian vegetation within 50m;
- Areas covered by Threatened Ecological Communities;
- Area of vegetation within 50m of Declared Rare Flora;
- Bush Forever sites; and
- Declared World Heritage property sites.

Four Environmentally Sensitive Areas have been mapped by DPaW within the Project Area, related to occurrences of Declared Rare Flora (

) (DPaW, 2014). One of these is mapped as occurring in the middle of a paddock; this is a projection issue as the actual location is along the McGibbon Track.

1.9 Wetlands

80-90% of the Project Area is mapped as a wetland in the Geomorphic Wetlands of the Swan Coastal Plain dataset (Department of Environment and Conservation, 2008), all of which has been assessed as being in the ‘Multiple Use’ management category, which is described as Wetlands with few important ecological attributes and functions remaining (**Figure 8**). The majority of the wetland area within the Project Area is mapped as Palusplain (seasonally waterlogged flat), with small areas of Sumpland (seasonally inundated basin) and floodplain (seasonally inundated flats).

There are no wetlands of environmental significance in the Project Area, however it is likely that some areas of vegetation are Groundwater Dependent Ecosystems (GDEs) (refer to Section 1.4).

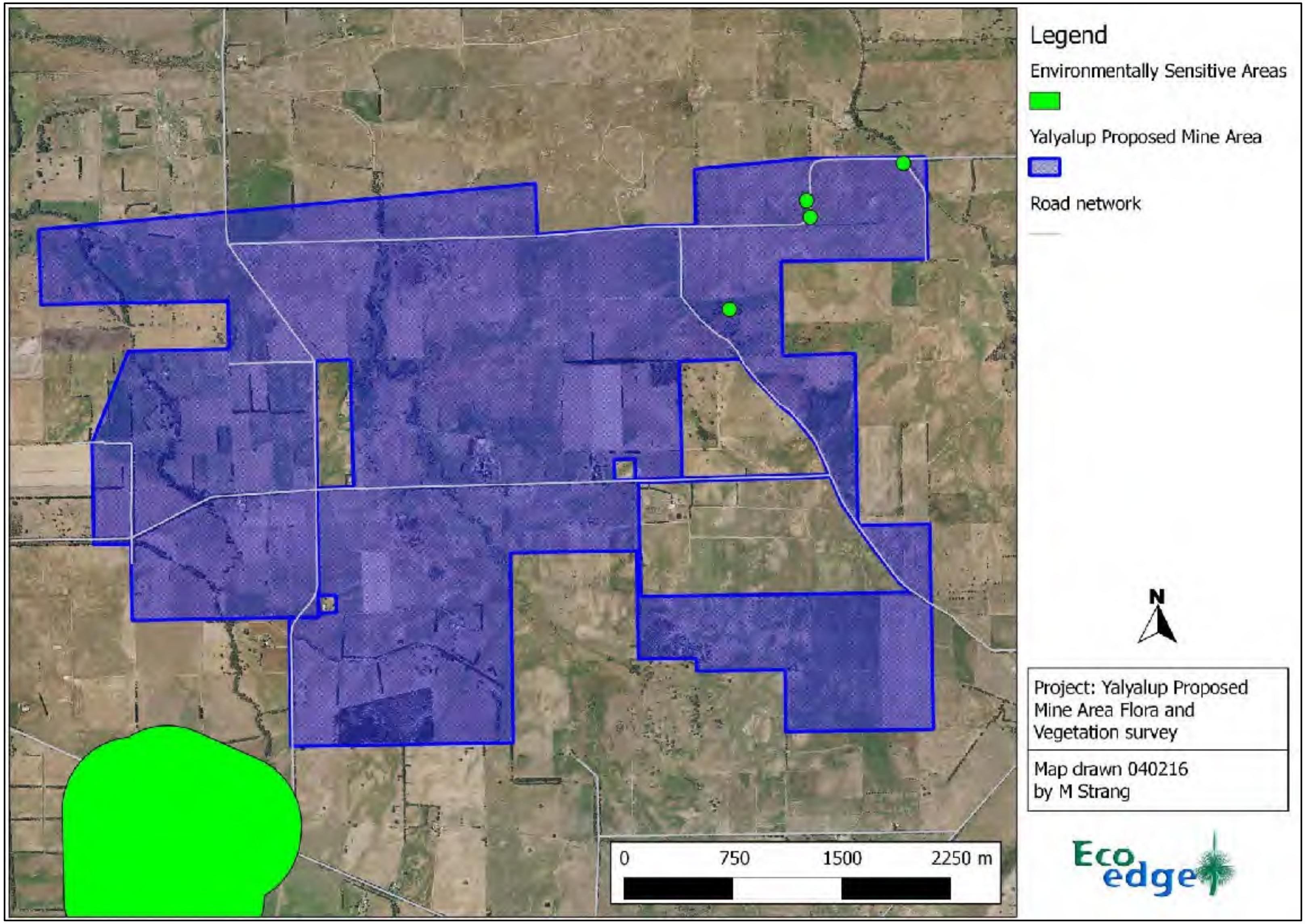

Figure 7. Environmentally Sensitive Areas within and near to the Project Area (DPaW, 2014)

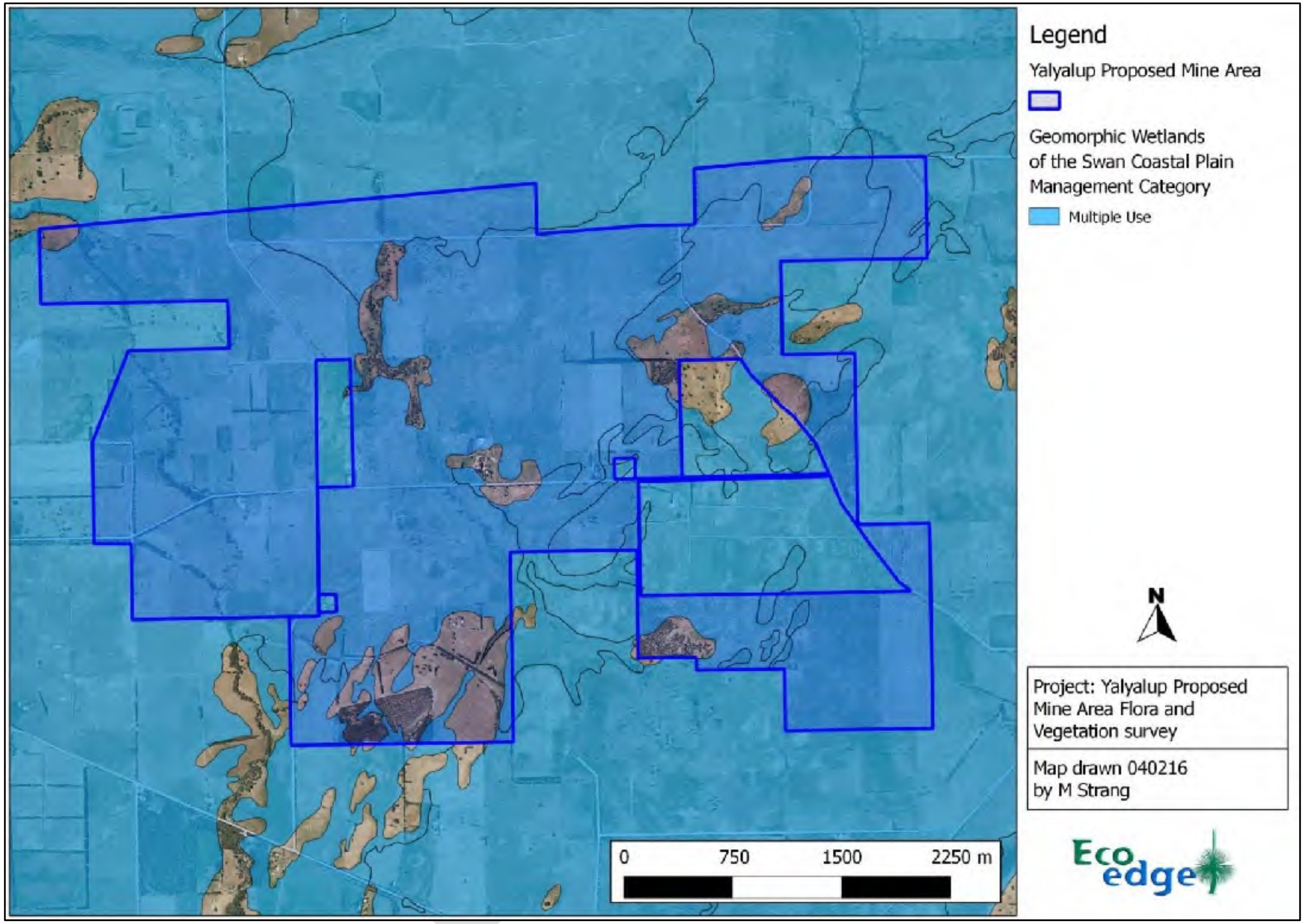

Figure 8. Geomorphic wetlands within and around the Project Area.

2 Methods

2.1 Desktop Study

Data from the NatureMap (DPaW, 2015c) and Protected Matters Search Tool (DotE, 2015b) reports was used to establish the list of DRF and Priority flora to target during the survey, as well as providing a list of what other plant taxa might be encountered during the survey.

Vegetation condition was assessed against the method of Keighery (1994) (**Table 9**).

Table 9. Vegetation condition ratings according to Keighery (1994).

Score	Description
Pristine (1)	Pristine or nearly so, no obvious signs of disturbance.
Excellent (2)	Vegetation structure intact, disturbance affecting individual species and weeds are non-aggressive species.
Very Good (3)	Vegetation structure altered, obvious signs of disturbance. For example, disturbance to vegetation structure caused by repeated fires, the presence of some more aggressive weeds, dieback, logging and grazing.
Good (4)	Vegetation structure significantly altered by very obvious signs of multiple disturbances. Retains basic vegetation structure or ability to regenerate it. For example, disturbance to vegetation structure caused by very frequent fires, the presence of some very aggressive weeds at high density, partial clearing, dieback and grazing.
Degraded (5)	Basic vegetation structure severely impacted by disturbance. Scope for regeneration but not to a state approaching good condition without intensive management. For example, disturbance to vegetation structure caused by frequent fires, the presence of very aggressive weeds, partial clearing, dieback and grazing.
Completely Degraded (6)	The structure of the vegetation is no longer intact and the area is completely or almost completely without native species. These areas are often described as 'parkland cleared' with the flora comprising weed or crop species with isolated native trees or shrubs.

2.2 Field survey

The field assessment was carried out on The field assessment was carried out on 16th September, 13th and 14th October 2015 and 18th February 2016. All areas of remnant native vegetation within the Project Area were visited on foot or by vehicle and data on plant species composition and vegetation condition was collected at 105 sites.

During the visits to the study area, a comprehensive list of native and many non-native vascular flora was compiled. Taxa not able to be identified with certainty in the field were photographed for later identification. Taxonomy and conservation status was checked against the WA Herbarium Census of WA Plants Database (WACENSUS) (DPaW, 2015d). The Declared Rare Flora and Priority Flora known to occur within a 10 km distance of the study area (**Table 8**) was targeted during the search.

Vegetation condition and vegetation units were mapped using aerial photography and notes taken during the survey.

2.3 Survey limitations

Potential limitations with regard to the assessment are addressed in **Table 10**.

Table 10. Limitations with regard to assessment adequacy and accuracy.

Aspect	Constraint	Comment
Scope	No	The survey scope was prepared in consultation with the client and was designed to comply with EPA requirements.
Climatic and seasonal effects	Moderate	Rainfall for the wet season in the South West (1st April – 30th November) was very much below average. This would have resulted in a lower proportion of some annual species germinating, less growth in some annually-renewed species and earlier 'dying-off' of annual and annually-renewed taxa.
Proportion of flora identified	Negligible	The survey was carried out in mid-September and mid-October which experience has shown to be within the main flowering season for plants on the southern Swan Coastal Plain. It is estimated that 95%+ of native species were identified.
Availability of contextual information	Negligible	Comprehensive regional surveys of remnant vegetation, as well as more localised surveys, have been carried out in the southern Swan Coastal Plain.
Completeness of the survey	Negligible	Vegetation within the Project Area was thoroughly search on foot. Further assessments outside the spring season would add to the completeness of the species list but probably only marginally affect the conclusions presented.
Skill and knowledge of the botanists	Negligible	The senior field botanist conducting the survey has had extensive experience in botanical survey in south west Australia over a period of 25 years.

3 Results

3.1 Flora

One hundred and forty-nine taxa of vascular plants were identified as a result of the survey, of which 57 taxa (38%) were introduced species (**Appendix 2**). The relatively low number of native species found within the approximately 78 ha of native vegetation in the Project Area is a result of many years of degradation of the small fragments of native bush. The largest single area of native vegetation within the Project Area is only 6.5 ha and this has been subject to many years of livestock grazing as a consequence of which all native species have been removed from the understorey.

The Fabaceae with 23 taxa (including 10 introduced species), Proteaceae with 16 taxa, Myrtaceae with 16 taxa (2 introduced species) and Poaceae, with 15 taxa (14 introduced species) were the dominant genera.

3.2 Rare Flora

Two taxa of Declared Rare Flora (*Banksia squarrosa* subsp. *argillacea*, *Verticordia plumosa* var. *vassensis*) and two Priority flora (*Loxocarya magna* and *Calothamnus quadrifidus* subsp. *teretifolius*) were found within the Project Area (**Table 11**, **Figure 9**).

Several other DRF and Priority species previously known from the Project Area were not able to be located:

- *Chamelaucium* sp. S coastal plain (R.D.Royce 4872) (DRF) (40+ plants in 1997) previously occurred within a small area of ironstone vegetation near the junction of Princefield Road and Coopers Road but this population is now possibly extinct due to burning and grazing of the small remnant (which is situated on a road and drainage reserve).
- *Banksia nivea* subsp. *uliginosa* (DRF) (6 plants in 2003) previously occurred on the verge of Princefield Road 875 m west of Coopers Road (Williams *et al*., 2001), but this also no longer extant. The road verge shows signs of having been mowed.
- One plant of *Verticordia plumosa* var. *vassensis* (DRF) on the verge of Princefield Road 4.3 km west of Ludlow-Hithergreen Road in 1996. This plant was not able to be found during the present survey.
- *Isopogon formosus* subsp. *dasylepis* (P3) had previously been known from 200 m N along McGibbon Track from Wonnerup-East road. This plant was not able to be found during the present survey.

3.2.1 *Banksia squarrosa* subsp. *argillacea*

Banksia squarrosa subsp. *argillacea* is a Declared Rare Flora listed as Endangered under the *WC Act* (with the status of "Vulnerable. *B. squarrosa* subsp. *argillacea* is also listed as

Endangered under the *EPBC Act*. There are 63 records for *B. squarrosa* subsp. *argillacea* in Department of Parks and Wildlife databases (DPaW, 2015d), most of which relate to occurrences in "Busselton Ironstone" vegetation on the Swan Coastal Plain south of Busselton, however there are several known populations in State forest on the Blackwood Plateau.

The population of *B. squarrosa* subsp. *argillacea* within the Project Area occurs on McGibbon Track within a small occurrence of Busselton Ironstone vegetation ('Shrublands on southern Swan Coastal Plain Ironstones', (SWAFCT10b, **Table 5**)) (**Figure 10**), approximately 810 m south of the junction with Princefield Road. Fourteen plants were present in the population in 1998 and 2003, when its condition was rated as "poor" (DotE, 2015e). Weeds, dieback, track maintenance and mining were given as the principle threats to the population. The population has declined by 5 plants since 2003, and most of the plants are old and partly collapsed. Track maintenance remains a threat – the track was graded in February 2016 with some resulting damage to the ironstone shrubland vegetation.

Table 11. Locations of Declared Rare Flora and Priority Flora within the Project Area.

Taxon	Category	Location	Number
Banksia squarrosa subsp. *argillacea*	T (E)	358859.9 E, 6271063.6 N	9
Verticordia plumosa var. *vassensis*	T (E)	359494.7 E, 6271807.4 N	*c*. 30
Loxocarya magna	P3	358859.9 E, 6271063.6 N 360140.3 E, 6272231.5 N	*c*. 32 4
Calothamnus quadrifidus subsp. *teretifolius*	P4	(1) 358860.7 E, 6271063.6 N (2) 359096.7 E, 6270788.1 N (2) 360140.9 E, 6272230.7 N (3) 360095.2 E, 6272257.8 N	70 1 *c*. 40 29

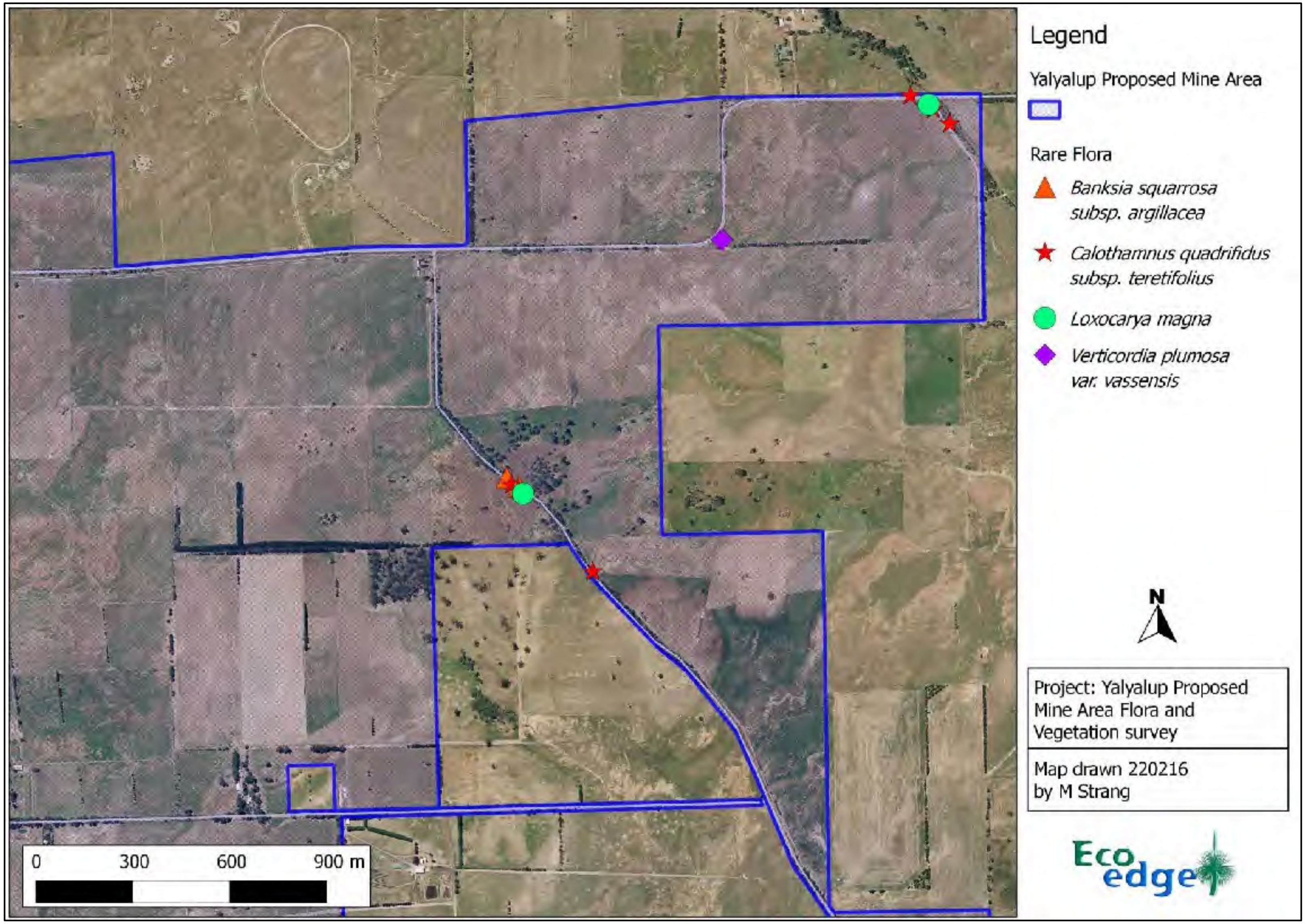

Figure 9. Locations of Rare and Priority flora within the Project Area.

Figure 10. Busselton Ironstone shrubland on McGibbon Track.
The yellow-flowered shrub and the left is *Banksia squarrosa* subsp. *argillacea*- the shrub in the foreground and on the right side of the track is *Calothamnus quadrifidus* subsp. *teretifolius.*

3.2.2 *Verticordia plumosa* var. *vassensis*

Verticordia plumosa var. *vassensis* is listed as Endangered under the *EPBC Act* and is Declared Rare Flora under the *WC Act*. There are 97 records for *V. plumosa* var. *vassensis* in Department of Parks and Wildlife databases, most of which relate to locations on the Swan Coastal Plain south of Busselton, with an east-west range of 30 km. The species occurs in winter-wet flats and depressions, on a variety of sands and swampy clay soil within low heaths containing *Hypocalymma* sp., *Pericalymma elliptica*, *Isopogon formosus* and *Kingia australis* (Williams *et al*., 2001) (**Figure 11**).

The population of *V. plumosa* var. *vassensis* within the Project Area is situated on the verge of Princefield Road 2.1 km west of Ludlow-Hithergreen Road. The population size was estimated at 200+ plants in 1996, and 100+ in 2006 (Williams *et al*., 2001; DotE, 2016f). The population size is not easy to estimate because the plants are situated within an area of think wet shrubland, but is has probably declined somewhat since 2006.

Figure 11. *Verticordia plumosa* var. *vassensis* on Princefield Road.

3.2.3 Loxocarya magna

This species is confined to ironstone plant communities of the Scott River and Busselton Plains, and is represented by 70 records in Department of Parks and Wildlife databases. Within the Project Area it is present within the area of Busselton Ironstone on McGibbon Track and also near the junction of Coopers Road and Princefield Road (**Figure 12**).

Figure 12. *Loxocarya magna* on McGibbon Track.

3.2.4 *Calothamnus quadrifidus* subsp. *teretifolius*

Calothamnus quadrifidus subsp. *teretifolius* is mostly confined to fragmented remnants of Busselton Ironstones plant community on the Swan Coastal Plain south of Busselton. It is represented by 69 records in Department of Parks and Wildlife databases. Within the Project Area it is found on the small area of Busselton Ironstone at the junction of Coopers Road and Princefield Road, and on McGibbon Track. All populations contain mainly old plants and many of those at the junction of Coopers Road and Princefield Road have recently been severely pruned back by cattle grazing (**Figure 13**).

Figure 13. Calothamnus quadrifidus subsp. teretifolius on McGibbon Track.

3.3 Declared Plants

Two weeds found within the Project Area, *Asparagus asparagoides** and *Zantedeschia aethiopica**, are listed as Pest Plants by the Department of Agriculture and Food (DAF, 2014). Both are in the C3 (management) category for the whole of the State. *A. asparagoides** (Bridal Creeper) was only found in four locations, but *Z. aethiopica** (Arum Lily) is widespread within the Project Area, particularly along creeklines (Figure 14).

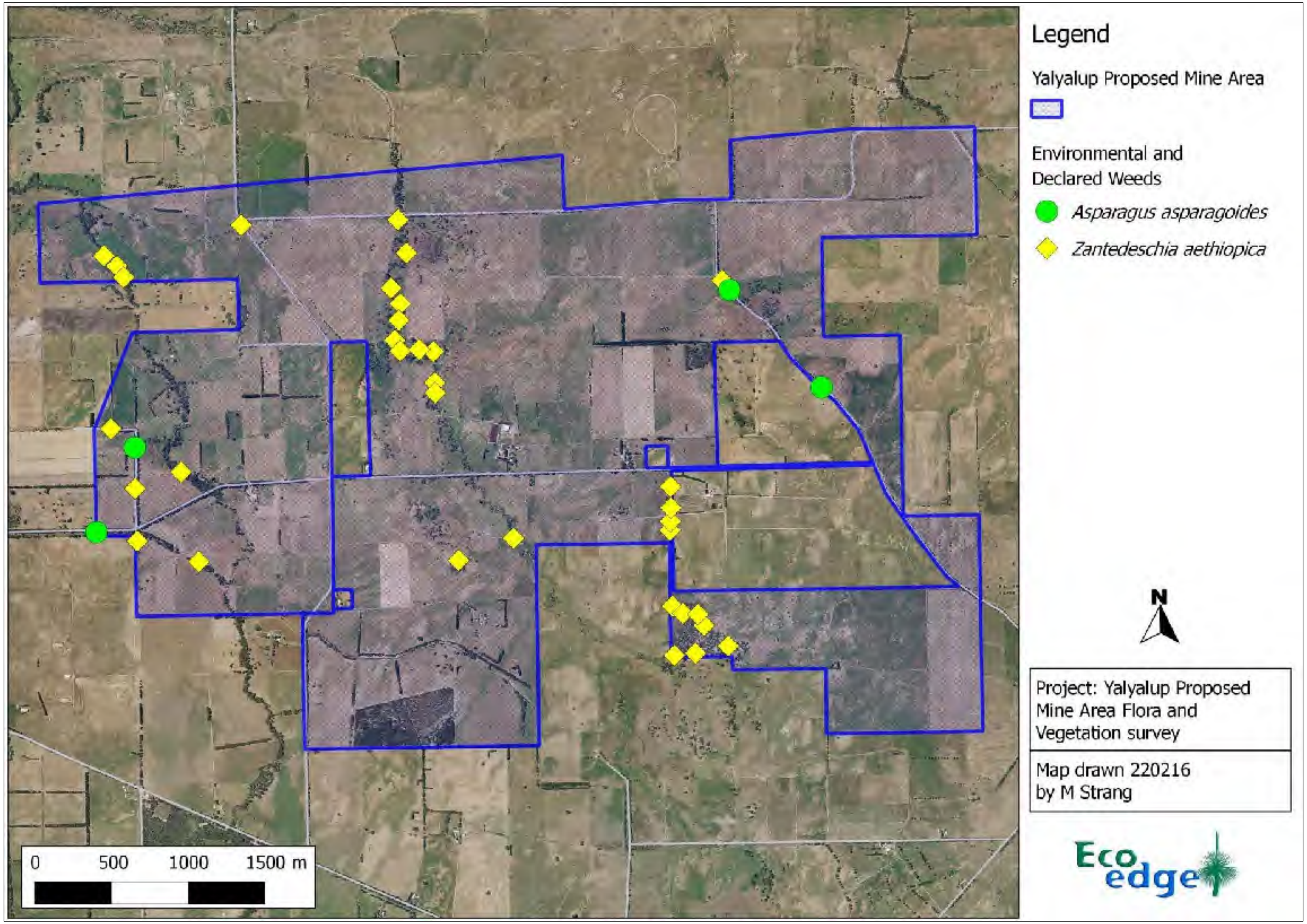

Figure 14. Location of environmental and declared weeds within the Project Area.

3.4 Vegetation Units

To enable the mapping of field survey results at a useable scale, the Project Area has been divided into four quadrants, as is shown in **Figure 15**.

Eight vegetation units were recognised in the Project Area – they are described (with comments on their conservation status) in **Table 12** and mapped in **Figures 15 – 18**. Photographs of the vegetation units are provided in **Appendix 4**. Most areas of remnant native vegetation within the Project Area were in Degraded or Completely Degraded condition and consequently had low species diversity. Because of this it was generally only possible to separate vegetation types based on overstorey composition and to a lesser extent soil type.

3.4.1 Vegetation Units A1 and A2

Vegetation Unit A1 appears to be a degraded form of SWAFCT01b (Southern *Corymbia calophylla* woodlands on heavy soils) (Gibson et al., 1994), which is listed as a threatened ecological community by the Department of Parks and Wildlife, with the threat status of "Vulnerable". It is generally dominated by both *Corymbia calophylla* and *Eucalyptus marginata* where it occurs on grey sands, but on heavier soils *C. calophylla* predominates, sometimes co-occurring with *E. rudis*. On farmland there are no other native species present, however on road verges, particularly along McGibbon Track the smaller trees *Agonis flexuosa*, *Banksia attenuata*, *B. grandis*, *Nuytsia floribunda*, *Persoonia longifolia* or *Xylomelum occidentale* may be present as a mid-storey layer. The shrub-layer is usually dominated by *Xanthorrhoea preissii*.

The only area of Vegetation Unit A1 of sufficient size and in good enough condition to be inferred as an occurrence of the TEC SWAFCT01b is on McGibbon Track.

Vegetation Unit A2, which only occurs on McGibbon Track, has characteristics of both SWAFCT01b (because of the overstorey of *C. calophylla*) and SWAFCT02 (Southern wet shrublands), however, the predominance of wetland-adapted species characteristic of SWAFCT02, such as *Acacia saligna*, *Banksia littoralis*, *Melaleuca rhaphiophylla* and *Hakea ceratophylla* make it, floristically, much closer to SWAFCT02 which is listed as Endangered by the Department of Parks and Wildlife. Consequently, the occurrence of Unit A2 at the northern end of McGibbon Track is inferred to be an occurrence of the threatened ecological community SWAFCT02.

3.4.2 Vegetation Units B1 and B2

Both vegetation units B1 and B2 are associated with the "Abba Wet Ironstone Flats" (Awi) soil-landscape mapping unit of Tille and Lantzke (1990), which are described as "winter wet flats and slight depressions with shallow red brown sands and loams over ironstone (i.e. bog iron ore soils)".

Vegetation Unit B1 is recognised as a threatened ecological community, this being "SWAFCT10b - Shrublands on southern Swan Coastal Plain Ironstones (Busselton area)" (Gibson *et al*., 1994; Meissner and English, 2005). The "Busselton Ironstones" are listed as Critically Endangered by the Department of Parks and Wildlife. The community is also listed as Endangered under the *EPBC Act.*

The largest occurrence of Vegetation Unit B1, that on McGibbon Track (0.34 ha) is recognised as an occurrence of Busselton Ironstones community (Webb, 2004) but, unaccountably, is yet to be added to the DPaW threatened communities database[2]. The McGibbon Track occurrence of Vegetation Unit B1 is illustrated in **Figure 10**, above. The occurrence of unit B1 on McGibbon Track consists mainly of "over-mature" shrubs of species such as *Acacia saligna*, *Banksia squarrosa* subsp. *argillacea*, *Calothamnus quadrifidus* subsp. *teretifolius* and *Hakea ceratophylla*, with much of the ground-layer consisting of annual weeds, however there were two native herbaceous species present in low numbers, viz. *Drosera glanduligera* and *Sowerbaea laxiflora*. The occurrence of Busselton Ironstones community on McGibbon Track appears to belong to community type 1 or 2 of Gibson *et al*. (2000) which typically have a high representation of native herbaceous taxa.

Other, smaller, occurrences of Vegetation Unit B1 are situated on Princefield Road, but these are severely degraded and consist of only a few typical Busselton Ironstone community species.

Vegetation Unit B2 appears to be a severely degraded form of the previous community, recognisable by the presence of massive ironstone and lateritic boulders at or near the soil surface. Generally, the only native species still present are the trees *Eucalyptus rudis* which is also present within Unit B1 on McGibbon Track, and sometimes *Melaleuca rhaphiophylla*.

3.4.3 Vegetation Units C1, C2 and C3

Vegetation Unit C1 is associated with the winter streams that flow northwards through the western half of the Project Area and which empty into the Sabina River. Riverine vegetation was not covered by the survey reported in Gibson *et al*. (1994), but Webb *at al*. (2008) discuss the plant communities of riverine areas of the Busselton (or Abba) Plain. Unit C1 appears to belong to the "Riverine Jindong Plant Communities", associated as it is with the loams of the Jindong soil-landscape subsystem (Tille and Lantzke, 1990). All of Unit C1 was rated as being in "Completely Degraded" condition.

Both vegetation units C2 and C3 are restricted to a single occurrence. Vegetation Unit C2, which consists of the small tree *Melaleuca preissiana* over pasture, occurs on an area of the "Abba deep sandy rises" (ABd) mapping unit in the south east of the Project Area. Generally the ABd unit consists of pale deep sands (Tille and Lantzke, 1990), however Vegetation Unit

[2] A. Webb, DPaW, Bunbury, *pers. comm*. 22/02/2016.

C2 occurs in a seasonally-wet, shallow depression, perhaps associated with a lens of clay near to the surface. Unit C2 is all in "Completely Degraded" condition.

Vegetation Unit C3 is comprised a few small patches of wet shrubland on the "Abba Wet Flats" soil-landscape mapping unit, in "Degraded/Good" or "Good" condition, on the verge at the western end of Princefield Road. It has similarities to the "SWAFCT09 - Dense shrublands on clay flats" threatened ecological community. However, the occurrence is considered to be too small and badly degraded to be inferred as an example of the TEC.

3.4.4 Vegetation Unit D

Vegetation Unit D is comprised predominantly of *Agonis flexuosa*, with scattered *Banksia attenuata* over pasture and is situated on an area of the "Abba deep sandy rises" (ABd) mapping unit in the south east of the Project Area. Originally it would have resembled the SWAFCT21b (Southern *Banksia attenuata* woodlands) floristic community type (Gibson *et al*., 1994), which is a Priority 3 ecological community, but has been completely degraded by livestock grazing.

Table 12. Description of Vegetation Units occurring in the Project Area.

Vegetation Unit	Description	Comments
A1	Woodland of *Corymbia calophylla* and *Eucalyptus marginata*, with scattered *Agonis flexuosa*, *Banksia attenuata*, *B. grandis*, *Melaleuca preissiana*, *Nuytsia floribunda*, *Persoonia longifolia* or *Xylomelum occidentale* over *Xanthorrhoea preissii* over weeds on grey-brown or grey loamy sand or sand (on farmland usually only *C. calophylla* and *E. marginata* are present).	"SWAFCT01b – Southern *Corymbia calophylla* woodlands on heavy soils" (TEC). Mostly in Degraded or Completely Degraded Condition.
A2	Woodland of *Corymbia calophylla* (sometimes with *Eucalyptus marginata* or *E. rudis*) with scattered *Melaleuca preissiana* or *Banksia littoralis* over open shrubland that may include *Acacia extensa*, *A. saligna*, *Hakea ceratophylla*, *H. lissocarpha*, *H. prostrata*, *H. varia*, *Kingia australis*, *Melaleuca viminea* and *Xanthorrhoea preissii* over weeds on seasonally wet grey loamy sand.	Similar to "SWAFCT02 - Southern wet shrublands". (TEC), which may have an overstorey of *C. calophylla*, *M. preissiana* or *B. littoralis*. At the northern end of McGibbon Track this unit is in Good condition.
B1	Tall shrubland of *Acacia saligna*, *Banksia squarrosa* subsp. *argillacea*, *Calothamnus quadrifidus* subsp. *teretifolius*, *Hakea oldfieldii* and *Kunzea micrantha* (with scattered emergent *Eucalyptus rudis*) over scattered native herbs including *Drosera glanduligera* and *Sowerbaea laxiflora*, the sedge *Loxocarya magna*, and weeds on shallow red sandy clay on massive ironstone.	"SWAFCT10b - Shrublands on southern Swan Coastal Plain Ironstones (Busselton area)". Except on McGibbon Track where it is classed as Good condition the small fragments of this unit are Degraded/Good or Degraded condition.
B2	Woodland of *Eucalyptus rudis* and (in some areas) *Melaleuca rhaphiophylla* over weeds on massive ironstone.	"SWAFCT10b - Shrublands on southern Swan Coastal Plain Ironstones (Busselton area)". Completely Degraded areas of B1 with only the overstorey remaining.
C1	Woodland of *Eucalyptus rudis* (and sometimes *Corymbia calophylla*) over scattered *Agonis flexuosa* and *Melaleuca rhaphiophylla* over weeds on grey-brown clayey loams in drainage lines.	Riverine Jindong Plant Communities (Webb *et al*., 2008). All in Completely Degraded condition.
C2	Open woodland of *Melaleuca preissiana* over weeds on seasonally wet brown clay-loam.	"SWAFCT04 - *Melaleuca preissiana* damplands". Small area on farmland – Completely Degraded
C3	Tall Open Shrubland that may include *Acacia saligna*, *Jacksonia furcellata*, *Kingia australis*, *Melaleuca osullivanii*, *M. preissiana*, *M. viminea* and *Xanthorrhoea preissii* on seasonally wet grey-brown sandy loam.	"SWAFCT09 - Dense shrublands on clay flats". (TEC). A small area in Degraded/Good or Good condition on the verge of Princefield Road.
D	Woodland of *Agonis flexuosa* with scattered *Banksia attenuata* over weeds on grey sand on low dunes.	"SWAFCT21b - Southern *Banksia attenuata* woodlands" (PEC). Situated on farmland – all in Completely Degraded condition.

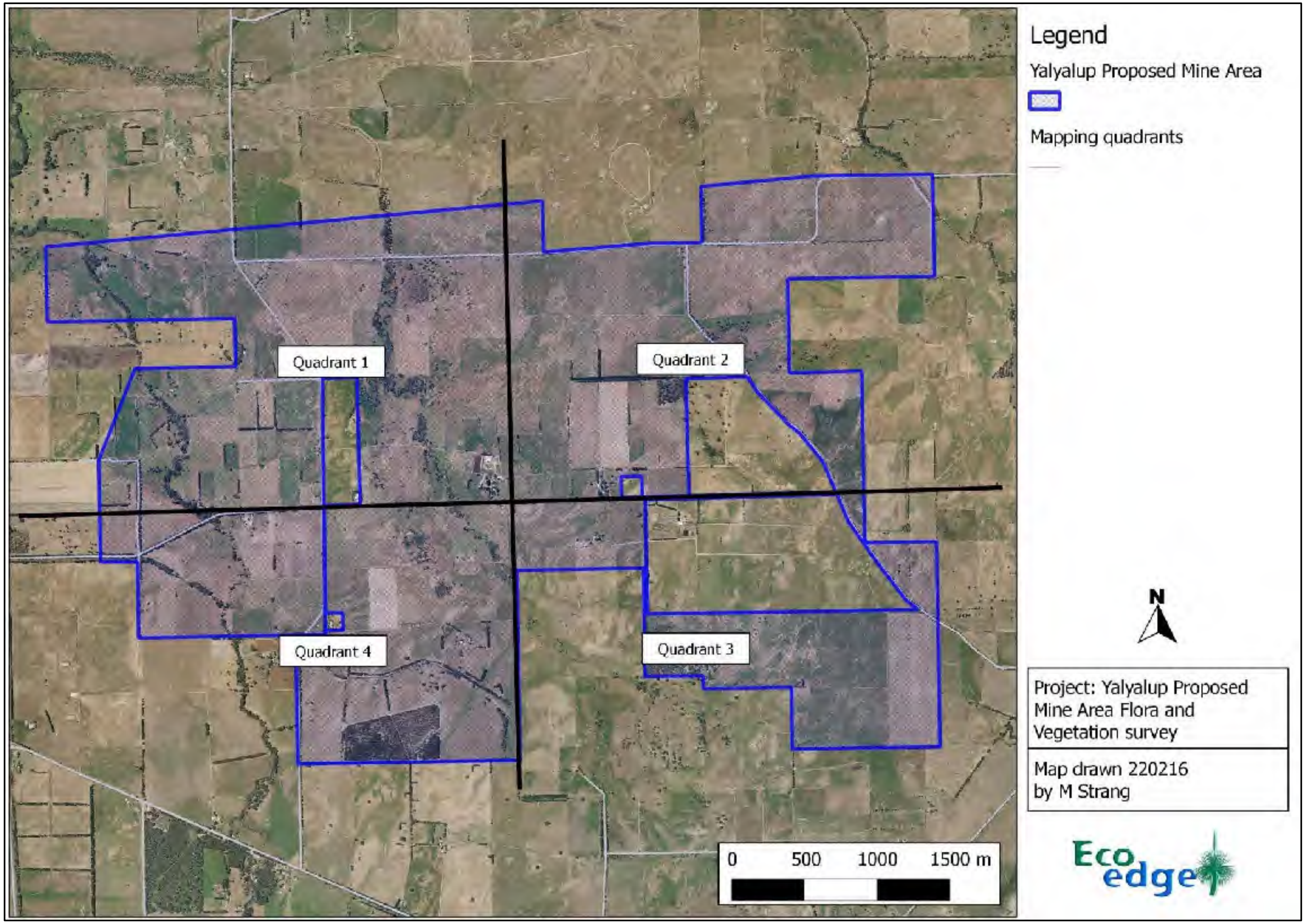

Figure 15. The Project Area has been divided into four quadrants for mapping purposes.

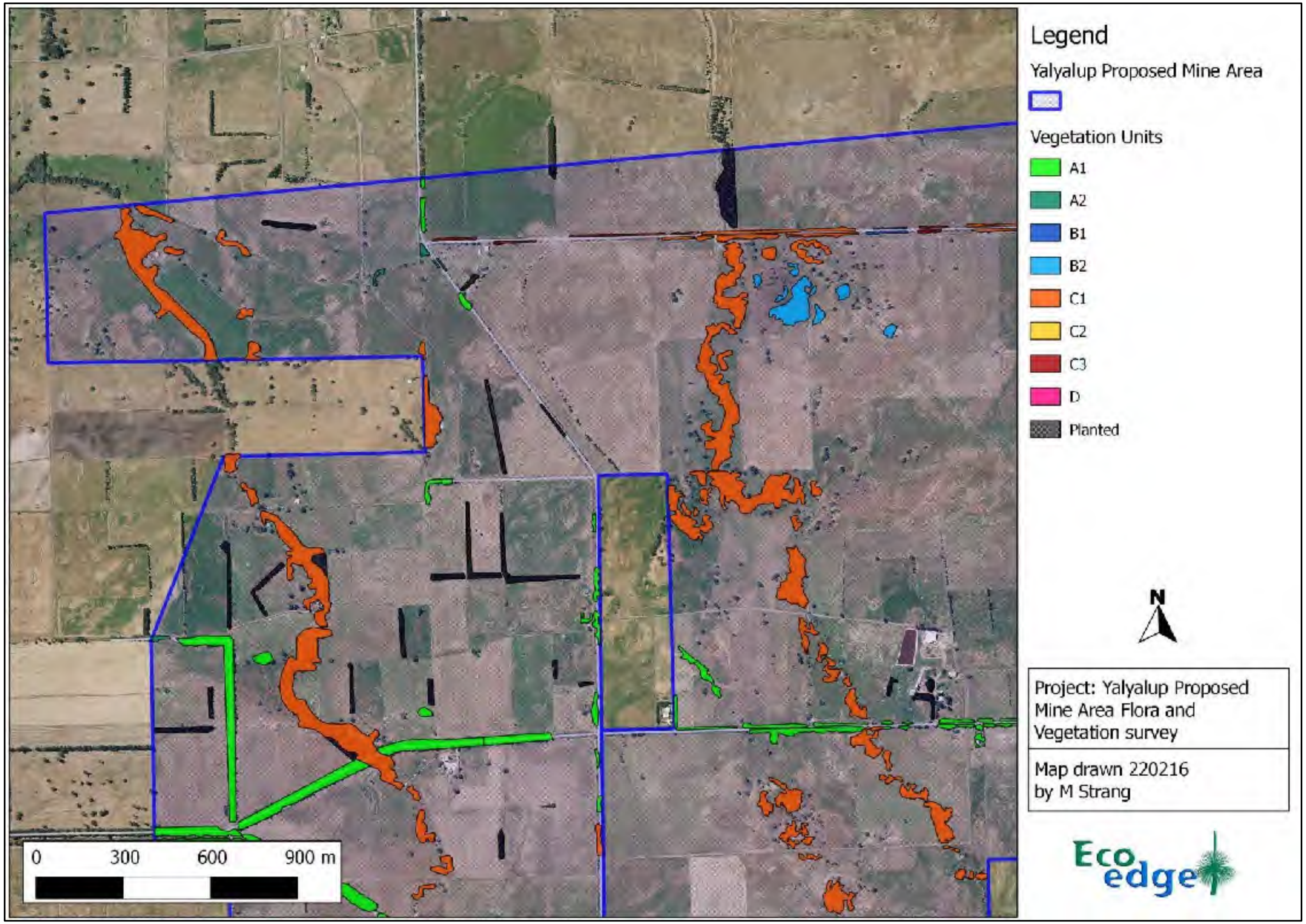

Figure 16. Vegetation units mapped within quadrant 1 of the Project Area.

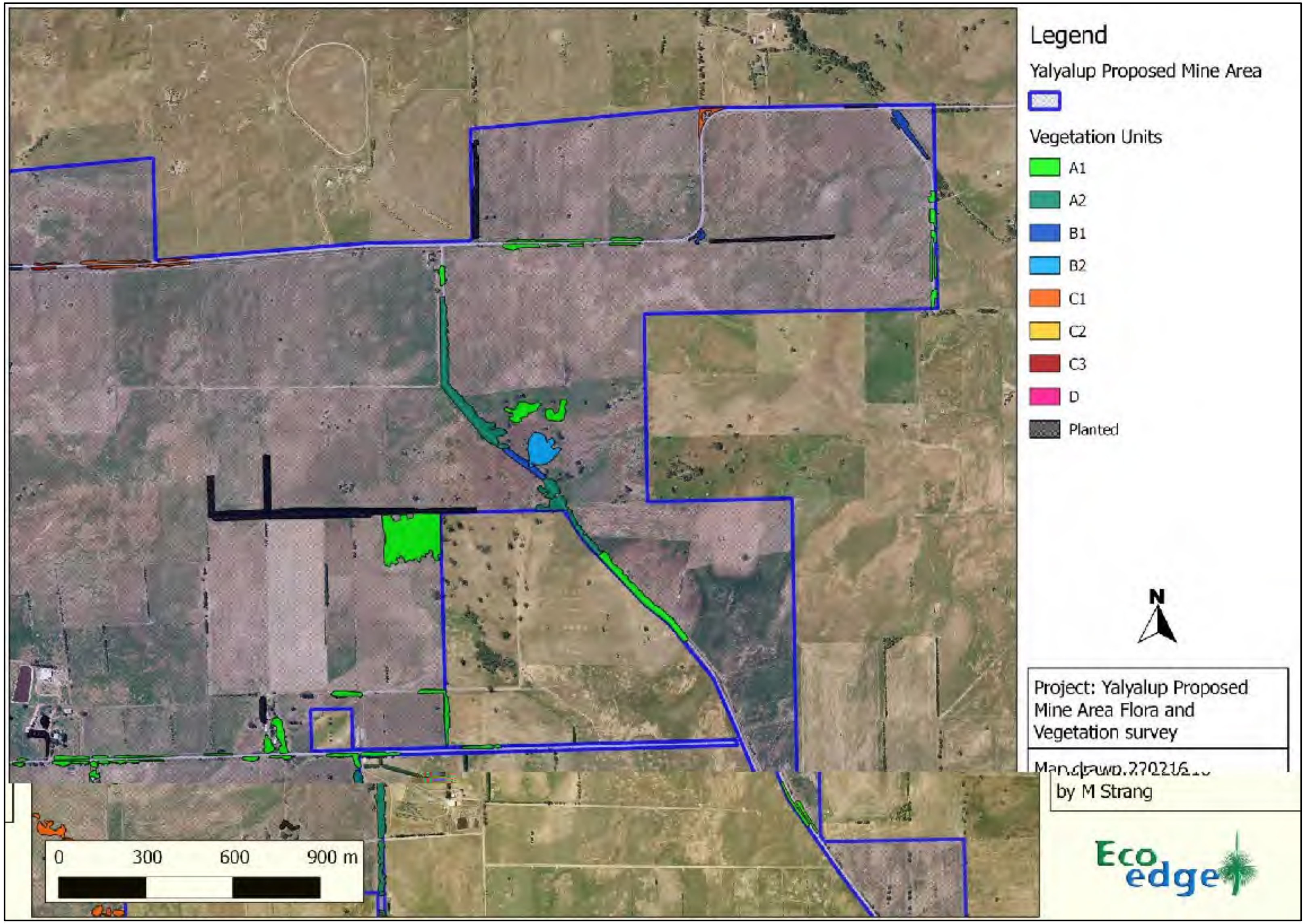

Figure 17. Vegetation units mapped within quadrant 2 of the Project Area.

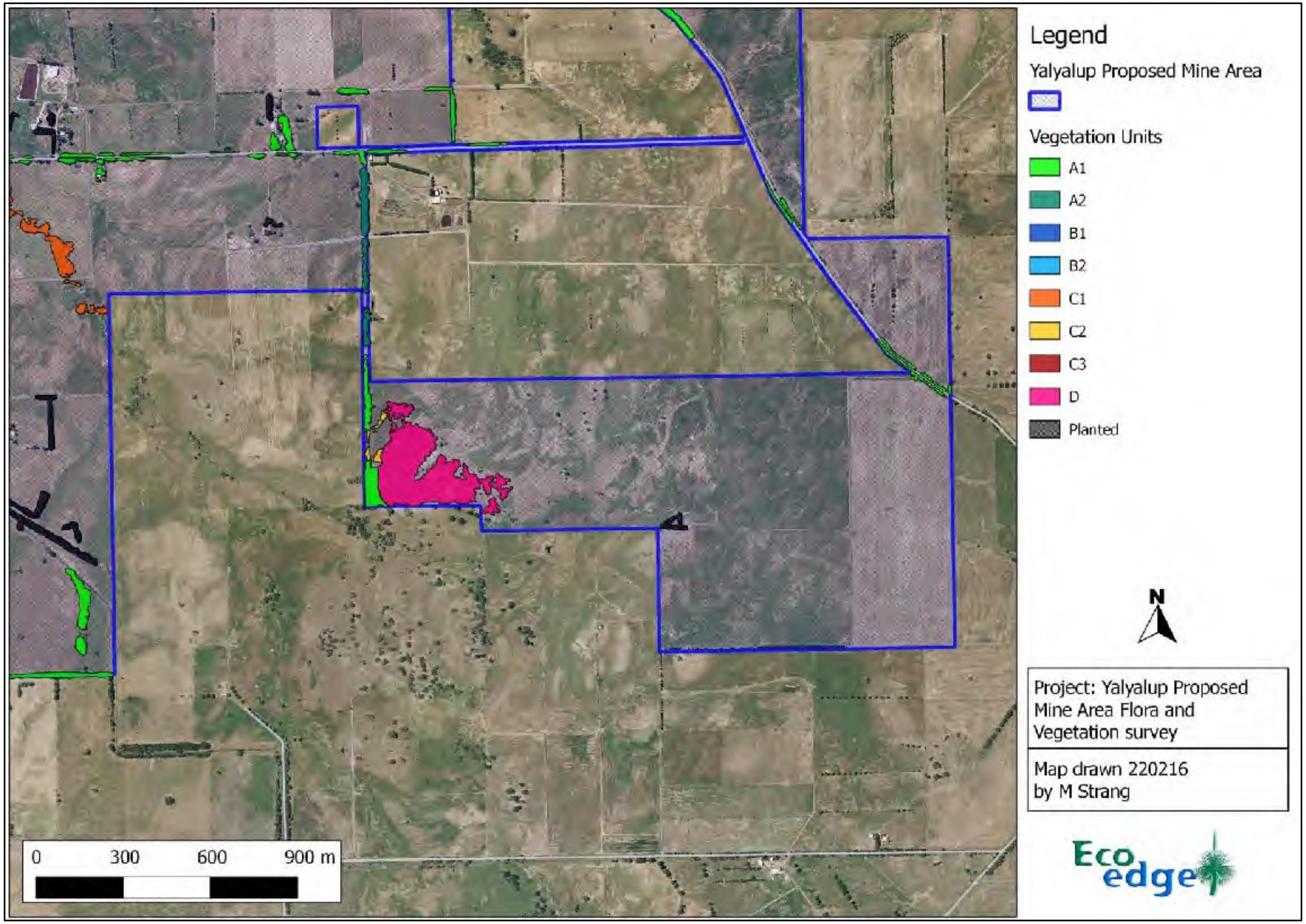

Figure 18. Vegetation units mapped within quadrant 3 of the Project Area.

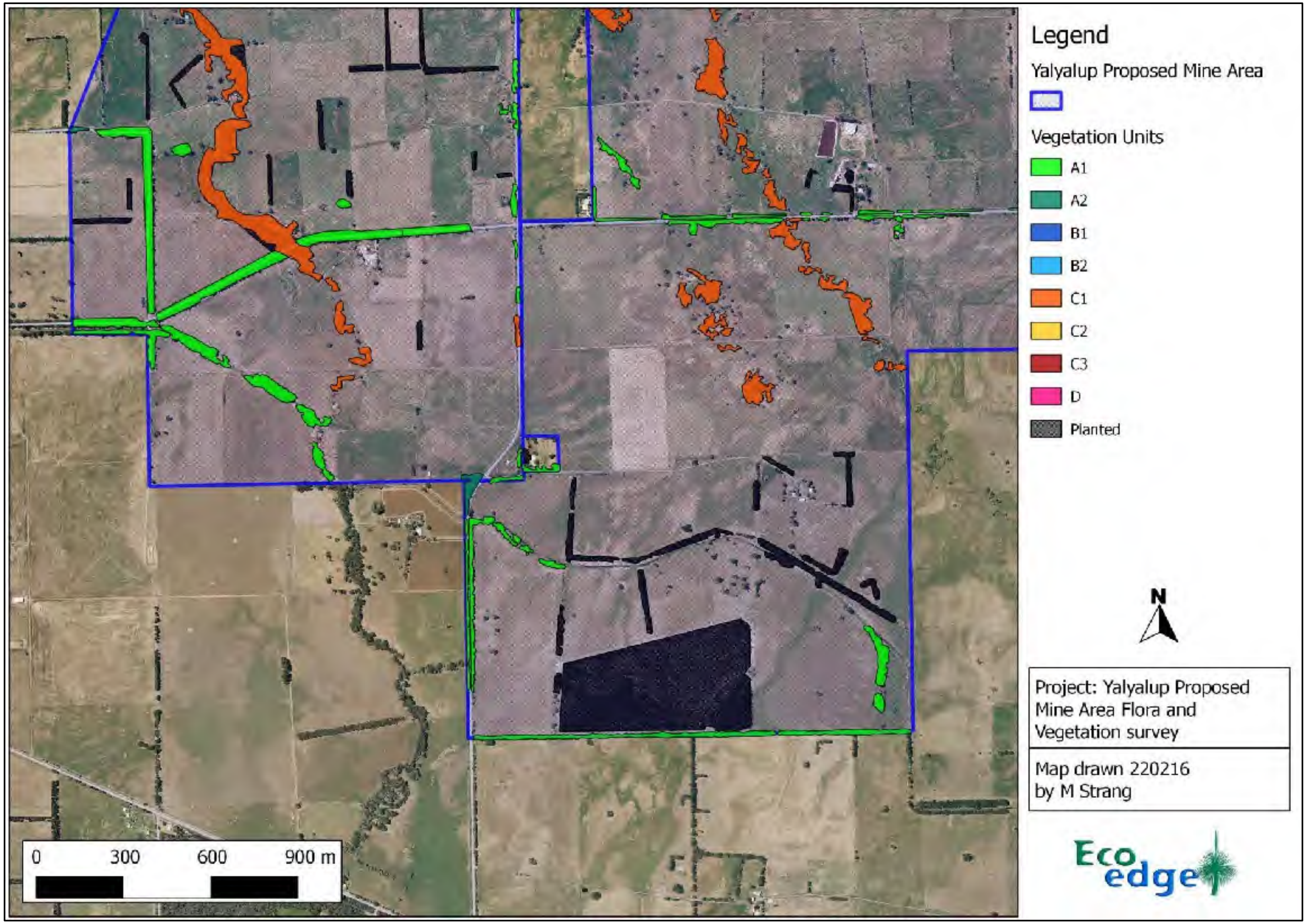

Figure 19. Vegetation units mapped within quadrant 4 of the Project Area.

3.5 Vegetation Condition

Vegetation condition within the Project Area is summarised in **Table 13** and mapped in **Figures 19 – 22**. Most remnant native vegetation in the Project Area, and all remnant vegetation on farmland, is in "Completely Degraded" condition. The only vegetation deemed to be in "Good" condition is at the northern end of McGibbon Track and a small area on Princefield Road. A few other small areas were rated as "Degraded/Good" condition on McGibbon Track, Princefield Road and Yalyalup Road.

The main reasons for the generally poor condition of remnant native vegetation in the Project Area are the small size of the remnants that are not on farmland, and the fact that all of the remnants on farmland have been grazed for many years.

Small fragments remaining after land clearing are subject to new disturbance regimes, invasive species, disease, increased nutrient loads, and changes in physical edge effects, including changes in wind, temperature, light and humidity (Lindenmayer, 2007; pp. 236-237). In this altered environment native species, particularly herbaceous taxa, are usually out-competed by agricultural weeds. Long-term grazing of native vegetation by livestock has been shown to cause eventual replacement of the native shrub and herbaceous components by exotic annual grasses and forbs (e.g. Pettit, *et al*., 1998).

Table 13. Summary of Vegetation Condition in the Project Area.

Condition Score	Ha	%
Good	2.5	3.2
Degraded/Good	3.3	4.2
Degraded	7.8	9.9
Completely Degraded	64.5	82.7
Total	78.0	100.0

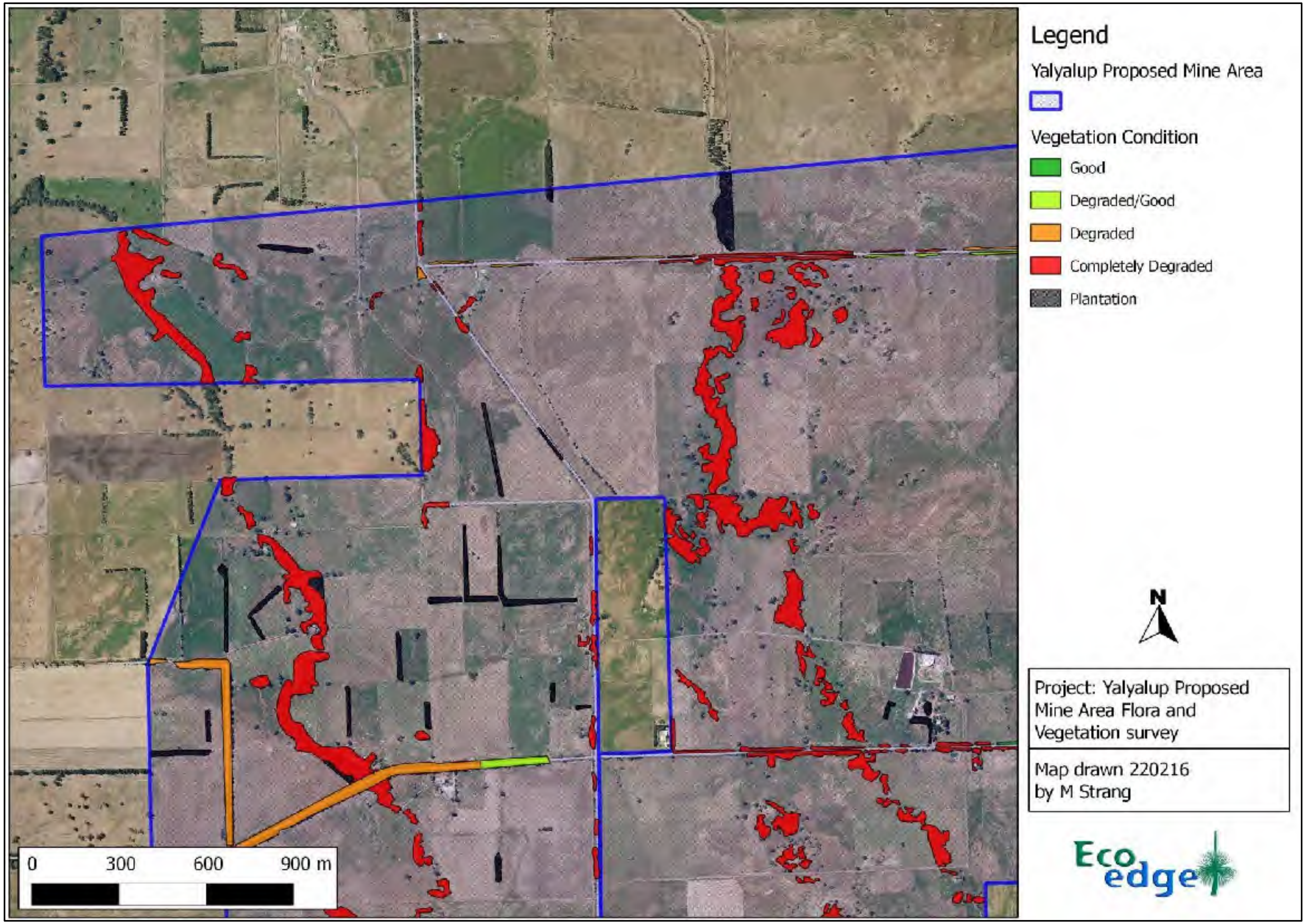

Figure 20. Condition of vegetation in quadrant 1 of the Project Area.

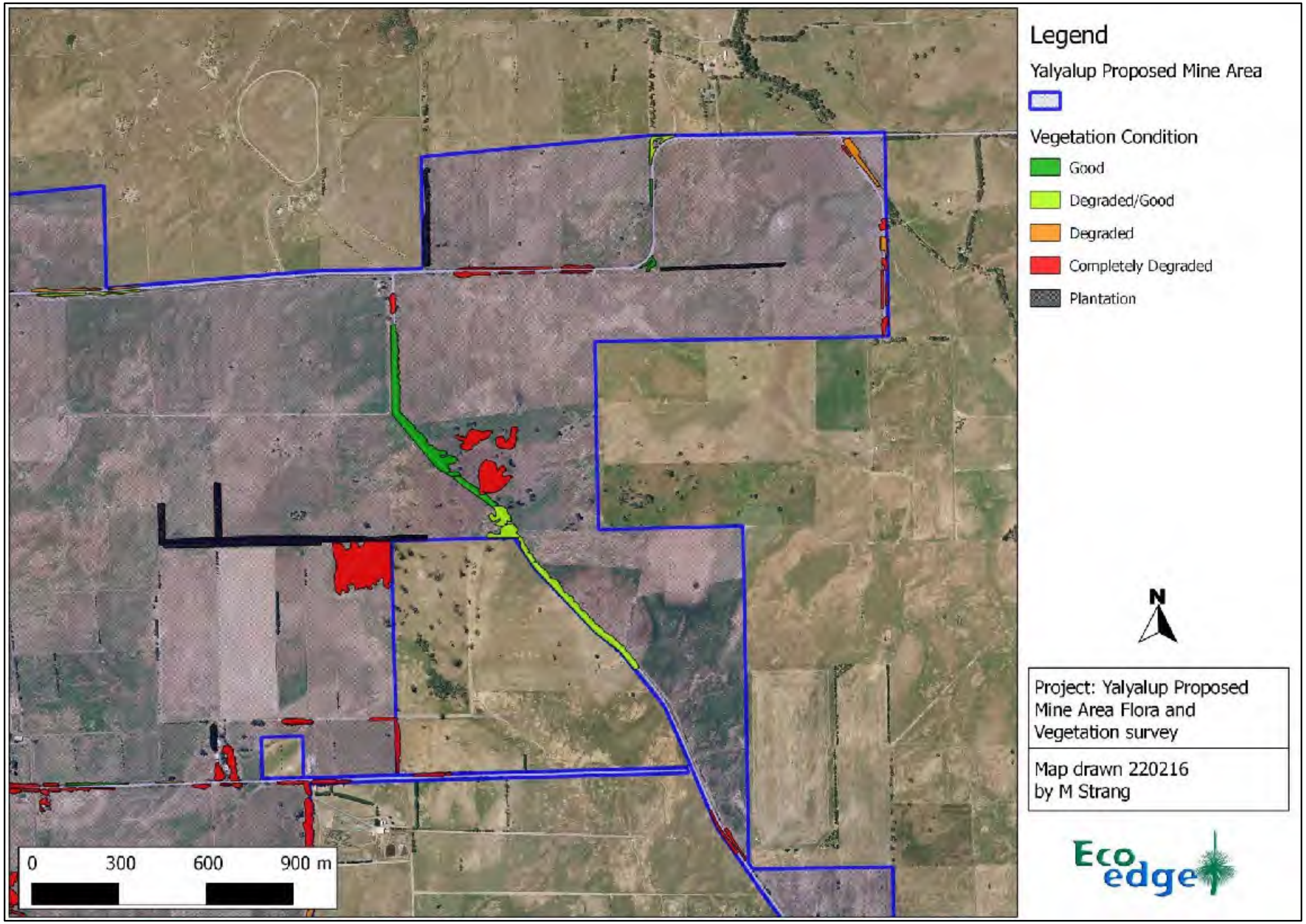

Figure 21. Condition of vegetation in quadrant 2 of the Project Area.

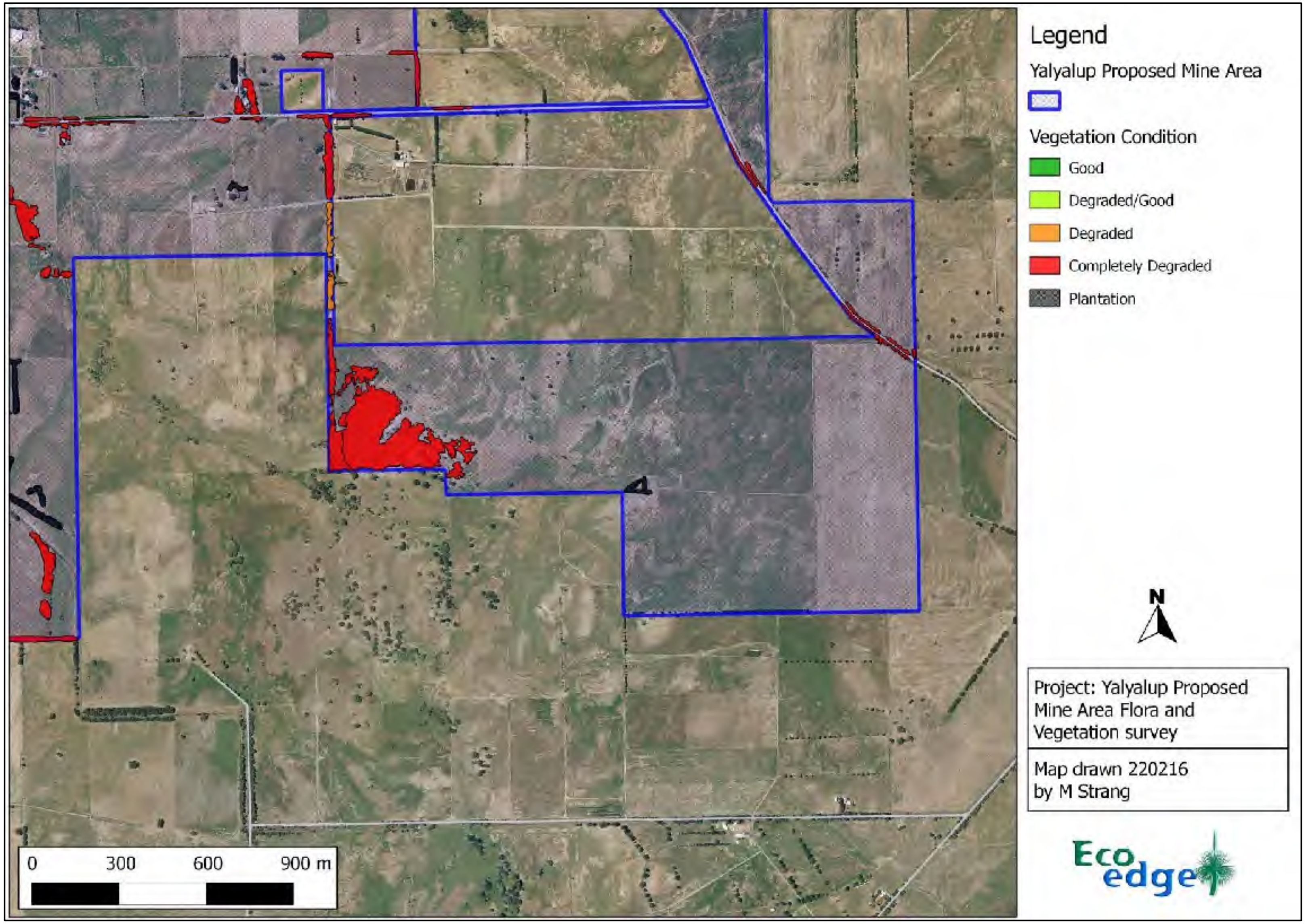

Figure 22. Condition of vegetation in quadrant 3 of the Project Area.

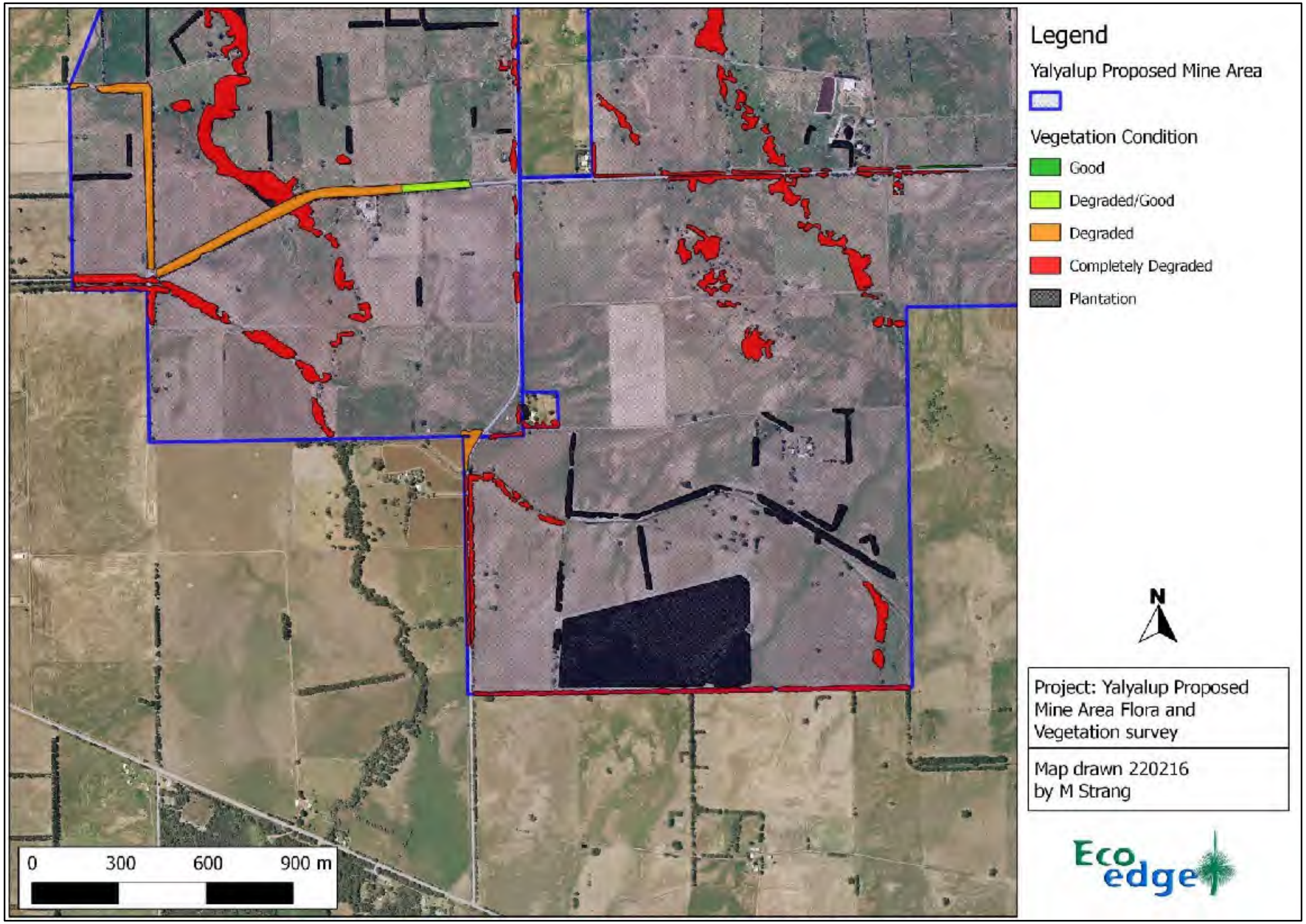

Figure 23. Condition of vegetation in quadrant 4 of the Project Area.

3.6 Groundwater Dependant Ecosystems in the Project Area

In the absence of detailed information on soil-type and depth to groundwater distribution within the Project Area, only general comments can be made with regard to the presence of likely GDEs or phreatophytic[3] vegetation. The discussion below is based on the recorded plant species recorded and vegetation units derived during the present study, as well as general observations on soil type and distribution.

Classification schemes for assessing the dependence of vegetation on groundwater or the phreatophytic class of the vegetation have been developed, such as that by Froend and Zencich (2001). A similar classification scheme was employed in a GDE assessment for a proposed mine-site at DMS's Burekup operations by Soil Water Consultants (SWC) (2007). The steps in making the assessment are set out by SWC:

1. Identify the soil profile and aquifer systems underlying each of the vegetation communities;
2. Assess the root distribution of the vegetation and the interaction with groundwater;
3. Determine the likely groundwater dependence of the vegetation based on the properties of the soils, the root distribution of the vegetation, and the location of groundwater;
4. Determine the risk that mining and groundwater dewatering may have on the growth and survival of the vegetation.

Individual plant species associated with potential GDEs are assessed with regard to their degree of reliance on groundwater as opposed to water stored in the soil profile above the groundwater.

Most of the vegetation units present within the Project Area contain species that are associated with wetland vegetation and potentially phreatophytic. *Eucalyptus rudis*, *Melaleuca rhaphiophylla*, *M. preissiana* and *Banksia littoralis*, one or more of which are present in all but one of the Project Area vegetation units, are known to be groundwater dependent (obligate phreatophytes) on the Swan Coastal Plain (Water Corporation, 2005). However, *Banksia attenuata*, which is typically found on deep sands well above the water-table (and is found in Vegetation Unit D), may also be partially phreatophytic (facultative phreatophytes) (Canham, *et al*., 2009).

In conclusion, it is likely that much of the native vegetation within the Project Area is at least partially phreatophytic and that most of the vegetation units are potential GDEs. Detailed

[3] A "phreatophyte" is a plant often with deep roots, that is mostly or entirely dependent on water from a permanent ground supply.

tudies similar to those carried out at the Burekup minesite by SWC (2007) will be needed to pinpoint the vegetation most at risk from potential water-drawdown due to mining.

4 Conclusions

A spring flora and vegetation survey of 78 ha of remnant vegetation within the Project Area at Yalyalup resulted in the following primary findings:

Native flora richness is relatively low (92 taxa in total), with a high proportion of introduced species (38%).

Floristically, the most important part of the Project Area is the remnant vegetation along McGibbon Track, which has 50% of the total number of native species identified in the Project Area represented in its 5.1 ha of remnant vegetation.

Two taxa of Declared Rare Flora (*Banksia squarrosa* subsp. *argillacea*, *Verticordia plumosa* var. *vassensis*) and two Priority flora (*Loxocarya magna* and *Calothamnus quadrifidus* subsp. *teretifolius*) were found within the Project Area – three of these being found within the ironstone vegetation on McGibbon Track.

Of the eight vegetation units identified in the Project Area, an occurrence of one of them (Unit B1 on McGibbon Track) has previously been identified as an example of the Critically Endangered ecological community SWAFCT10b ("Shrublands on southern Swan Coastal Plain Ironstones (Busselton area)").

Two small areas of Vegetation unit B2 are also inferred to be occurrences of SWAFCT10b, although one of these, located at the corner of Coopers Road, is being degraded and is in urgent need of improved management.

Two vegetation units dominated by *Corymbia calophylla* are inferred to be occurrences of the threatened communities SWAFCT01b (Southern *Corymbia calophylla* woodlands on heavy soils) – Vegetation unit A1, and SWAFCT02 (Southern wet shrublands) – Vegetation unit A2.

Some of the other Vegetation units identified in the Project Area are similar to several other threatened or priority ecological communities. However, the small size or degraded condition of these remnants probably precludes them from being recognised as new occurrences of these communities.

Most remnant vegetation in the Project Area is in "Degraded" or "Completely Degraded" condition, with only a relatively small percentage (5.8%) rated as "Degraded/Good" or "Good" condition – most of this is on McGibbon Track. All remnant vegetation on farmland is in "Completely Degraded" condition.

It is likely that much of the remnant vegetation within the Project Area is groundwater dependent to some extent. Almost all vegetation units have wetland species in their overstorey that have been shown to be at least partially phreatophytic. However, detailed studies of hydrology and soils within the Project Area are required to quantify and qualify the degree of groundwater dependence of the vegetation.

5 Recommendations

- That the McGibbon Track vegetation is recognised as the most important nature conservation asset within the Project Area and due attention is given to improving its management and protecting it from any potential negative effects from mining the adjacent land,

- That efforts be made to further protect and manage the nature conservation values of the area of Busselton Ironstone at the corner of Princefield Road and Coopers Road,

- That the possibility of carrying out revegetation of areas of private property adjacent to and within the Busselton Ironstone occurrence on McGibbon Track using locally sourced seed be considered,

- That further fencing of riverine vegetation be carried out to protect remaining native vegetation, reduce erosion and to ensure the value and integrity of the Regional Ecological Linkage is maintained in this largely cleared landscape.

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Appendix 1. Protected Matters Search Tool Report

Appendix 2. List of vascular flora found within the Project Area at Yalyalup.

FAMILY	SPECIES NAME	NATURALISED	CONSV_CODE
Alliaceae	*Allium triquetrum*	*	
Anacardiaceae	*Schinus terebinthifolius*	*	
Anarthriaceae	*Anarthria laevis*		
	Lyginia imberbis		
Araceae	*Lemna disperma*		
	Zantedeschia aethiopica	*	
Asparagaceae	*Asparagus asparagoides*	*	
	Sowerbaea laxiflora		
Asteraceae	*Arctotheca calendula*	*	
	Cotula coronopifolia	*	
	Cotula turbinata	*	
	Hypochaeris glabra	*	
	Sonchus asper	*	
	Sonchus oleraceus	*	
Boraginaceae	*Echium plantagineum*	*	
Casuarinaceae	*Allocasuarina humilis*		
	Allocasuarina thuyoides		
Centrolepidaceae	*Aphelia cyperoides*		
Colchicaceae	*Burchardia multiflora*		
Crassulaceae	*Crassula colorata*		
Cucurbitaceae	*Citrullus lanatus*		
Cyperaceae	*Caustis dioica*		
	Cyathochaeta avenacea		
	Isolepis stellata		
	Lepidosperma gladiatum		
	Lepidosperma leptostachyum		
	Lepidosperma longitudinale		
	Lepidosperma pubisquameum		
	Lepidosperma squamatum		
	Mesomelaena tetragona		
	Schoenus rigens		
Dasypogonaceae	*Kingia australis*		
	Lomandra hermaphrodita		
Dennstaedtiaceae	*Pteridium esculentum*		
Dilleniaceae	*Hibbertia amplexicaulis*		
	Hibbertia hypericoides		
	Hibbertia racemosa		
	Hibbertia vaginata		
Droseraceae	*Drosera glanduligera*		
Ericaceae	*Leucopogon australis*		
	Leucopogon capitellatus		
Fabaceae	*Acacia applanata*		
	Acacia extensa		

FAMILY	SPECIES NAME	NATURALISED	CONSV_CODE
Fabaceae	*Acacia incurva*		
	Acacia longifolia	*	
	Acacia paradoxa	*	
	Acacia pulchella		
	Acacia saligna		
	Callistachys lanceolata		
	Daviesia preissii		
	Gastrolobium capitatum		
	Gastrolobium praemorsum		
	Jacksonia furcellata		
	Kennedia coccinea		
	Kennedia prostrata		
	Lotus subbiflorus	*	
	Lupinus cosentinii	*	
	Trifolium arvense	*	
	Trifolium campestre	*	
	Trifolium dubium	*	
	Trifolium hirtum	*	
	Trifolium repens	*	
	Vicia sativa	*	
	Viminaria juncea		
Geraniaceae	*Erodium botrys*	*	
	Erodium cicutarium	*	
	Pelargonium capitatum	*	
Haemodoraceae	*Anigozanthos viridis*		
	Conostylis setigera		
	Haemodorum spicatum		
Hemerocallidaceae	*Caesia micrantha*		
Iridaceae	*Romulea rosea*	*	
	Sparaxis bulbifera	*	
	Watsonia meriana	*	
Juncaceae	*Juncus holoschoenus*		
	Juncus microcephalus	*	
	Juncus pallidus		
Loranthaceae	*Nuytsia floribunda*		
Lythraceae	*Lythrum hyssopifolia*	*	
Malvaceae	*Malva multiflora*	*	
Myrtaceae	*Agonis flexuosa*		
	Astartea scoparia		
	Astartea zephyra		
	Calothamnus quadrifidus subsp. *teretifolius*		4
	Corymbia calophylla		
	Eucalyptus marginata		
	Eucalyptus melliodora	*	

FAMILY	SPECIES NAME	NATURALISED	CONSV_CODE
Myrtaceae	*Eucalyptus rudis*		
	Hypocalymma angustifolium		
	Kunzea micrantha subsp. *micrantha*		
	Leptospermum laevigatum	*	
	Melaleuca osullivanii		
	Melaleuca preissiana		
	Melaleuca rhaphiophylla		
	Melaleuca viminea		
	Verticordia plumosa var. vassensis		DRF
Oleaceae	*Olea europaea*	*	
Oxalidaceae	*Oxalis pes-caprae*	*	
Papaveraceae	*Fumaria capreolata*	*	
Poaceae	*Aira caryophyllea*	*	
	Austrostipa campylachne		
	Avena fatua	*	
	Briza maxima	*	
	Bromus diandrus	*	
	Cenchrus clandestinus	*	
	Cynodon dactylon	*	
	Desmazeria rigida	*	
	Ehrharta longiflora	*	
	Eragrostis curvula	*	
	Holcus lanatus	*	
	Hordeum leporinum	*	
	Lolium perenne	*	
	Lolium rigidum	*	
	Poa annua	*	
Polygonaceae	*Acetosella vulgaris*	*	
	Polygonum arenastrum	*	
	Rumex brownii	*	
	Rumex crispus	*	
	Rumex obtusifolius	*	
	Rumex pulcher	*	
Proteaceae	*Adenanthos meisneri*		
	Banksia attenuata		
	Banksia dallanneyi		
	Banksia grandis		
	Banksia littoralis		
	Banksia squarrosa subsp. *argillacea*		DRF
	Hakea ceratophylla		
	Hakea lasianthoides		
	Hakea lissocarpha		
	Hakea prostrata		
	Hakea ruscifolia		
	Hakea varia		

FAMILY	SPECIES NAME	NATURALISED	CONSV_CODE
Proteaceae	*Persoonia elliptica*		
	Persoonia longifolia		
	Stirlingia latifolia		
	Xylomelum occidentale		
Ranunculaceae	*Ranunculus muricatus*	*	
Restionaceae	*Chordifex laxus*		
	Desmocladus flexuosus		
	Hypolaena pubescens		
	Loxocarya magna		3
	Lyginia barbata		
	Lyginia imberbis		
	Meeboldina coangustata		
	Meeboldina roycei		
	Stenotalis ramosissima		
Rubiaceae	*Opercularia hispidula*		
Solanaceae	*Solanum nigrum*	*	
Xanthorrhoeaceae	*Xanthorrhoea preissii*		

Appendix 3. List of vascular flora found in the vicinity of the ironstone vegetation on McGibbon Track prior to 2007 by Andrew Webb of DPaW, Bunbury.

FAMILY	SPECIES	CONSV_CODE
Anarthriaceae	*Anarthria laevis*	
Asparagaceae	*Lomandra purpurea*	
	Lomandra sonderi	
	Thysanotus sparteus	
Casuarinaceae	*Allocasuarina thuyoides*	
Cyperaceae	*Caustis dioica*	
	Cyathochaeta avenacea	
	Lepidosperma aff. *resinosum*	
	Lepidosperma longitudinale	
	Lepidosperma squamatum	
	Lepidosperma tenue	
	Mesomelaena tetragona	
	Schoenus rigens	
	Tetraria capillaris	
Dasypogonaceae	*Kingia australis*	
Dilleniaceae	*Hibbertia hypericoides*	
	Hibbertia racemosa	
Ericaceae	*Leucopogon australis*	
	Leucopogon sp.	
Fabaceae	*Acacia applanata*	
	Acacia extensa	
	Acacia flagelliformis	4
	Acacia pulchella	
	Acacia saligna	
	Daviesia preissii	
	Gastrolobium praemorsum	
	Hovea trisperma var. *grandiflora*	
	Kennedia coccinea	
	Viminaria juncea	
Haemodoraceae	*Conostylis serrulata*	
	Haemodorum spicatum	
Hemerocallidaceae	*Agrostocrinum scabrum*	
Iridaceae	*Patersonia occidentalis*	
	Patersonia umbrosa	
Loranthaceae	*Nuytsia floribunda*	
Malvaceae	*Thomasia grandiflora*	
Myrtaceae	*Calothamnus quadrifidus* subsp. *teretifolius*	4
	Corymbia calophylla	
	Eucalyptus marginata	
	Eucalyptus rudis	
	Hypocalymma angustifolium	
	Hypocalymma robustum	

FAMILY	SPECIES	CONSV_CODE
Myrtaceae	*Kunzea micrantha*	
	Melaleuca preissiana	
	Melaleuca uncinata	
	Regelia ciliata	
Proteaceae	*Adenanthos meisneri*	
	Banksia dallanneyi	
	Banksia grandis	
	Banksia littoralis	
	Banksia squarrosa subsp. argillacea	DRF
	Hakea ceratophylla	
	Hakea oldfieldii	3
	Hakea prostrata	
	Hakea ruscifolia	
	Hakea varia	
	Isopogon formosus subsp. *dasylepis*	3
	Persoonia elliptica	
	Xylomelum occidentale	
Restionaceae	*Chordifex laxus*	
	Hypolaena exsulca	
	Hypolaena pubescens	
	Loxocarya magna	3
	Stenotalis ramosissima	
	Tremulina tremula	
Thymelaeaceae	*Pimelea* sp.	
Xanthorrhoeaceae	*Xanthorrhoea preissii*	

Appendix 4. Photographs of Vegetation Units within the Project Area

Vegetation Unit A1

Woodland of *Corymbia calophylla* and *Eucalyptus marginata*, with scattered *Agonis flexuosa*, *Banksia attenuata*, *B. grandis*, *Melaleuca preissiana*, *Nuytsia floribunda*, *Persoonia longifolia* or *Xylomelum occidentale* over *Xanthorrhoea preissii* over weeds on grey-brown or grey loamy sand or sand (on farmland usually only *C. calophylla* and *E. marginata* are present).

Vegetation Unit A2

Woodland of *Corymbia calophylla* (sometimes with *Eucalyptus marginata* or *E. rudis*) with scattered *Melaleuca preissiana* or *Banksia littoralis* over open shrubland that may include *Acacia extensa*, *A. saligna*, *Hakea ceratophylla*, *H. lissocarpha*, *H. prostrata*, *H. varia*, *Kingia australis*, *Melaleuca viminea* and *Xanthorrhoea preissii* over weeds on seasonally wet grey loamy sand.

Vegetation Unit B1

Tall shrubland of *Acacia saligna*, *Banksia squarrosa* subsp. *argillacea*, *Calothamnus quadrifidus* subsp. *teretifolius*, *Hakea oldfieldii* and *Kunzea micrantha* (with scattered emergent *Eucalyptus rudis*) over scattered native herbs including *Drosera glanduligera* and *Sowerbaea laxiflora*, the sedge *Loxocarya magna*, and weeds on shallow red sandy clay on massive ironstone.

Vegetation Unit B2

Woodland of *Eucalyptus rudis* and (in some areas) *Melaleuca rhaphiophylla* over weeds on massive ironstone.

Vegetation Unit C1

Woodland of *Eucalyptus rudis* (and sometimes *Corymbia calophylla*) over scattered *Agonis flexuosa* and *Melaleuca rhaphiophylla* over weeds on grey-brown clayey loams in drainage lines.

Vegetation Unit C2

Open woodland of *Melaleuca preissiana* over weeds on seasonally wet brown clay-loam.

Vegetation Unit C3

Tall Open Shrubland that may include *Acacia saligna*, *Jacksonia furcellata*, *Kingia australis*, *Melaleuca osullivanii*, *M. preissiana*, *M. viminea* and *Xanthorrhoea preissii* on seasonally wet grey-brown sandy loam.

Vegetation Unit D

Woodland of *Agonis flexuosa* with scattered *Banksia attenuata* over weeds on grey sand on low dunes.

APPENDIX 2: INITIAL HYDROGEOLOGICAL ASSESSMENT

Initial Hydrogeological Assessment: Proposed Yalyalup Mineral Sands Mine

Doral Mineral Sands Pty Ltd

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Report No. DMS532-r3145-r1_170915

EXECUTIVE SUMMARY

Conclusions

HydroSolutions Pty Ltd has undertaken an Initial Hydrogeological Desk Assessment for the proposed Yalyalup Mineral Sand Mine, on behalf of Doral Mineral Sands Pty Ltd. The objectives of the current work were to:

- Determine background information with regard to the surface water and groundwater systems at the Site and in its vicinity
- Perform a preliminary (Level 1) assessment of the impact of mine dewatering on the surface water and groundwater systems
- Identify any other potential impacts on the groundwater environment, including on any Groundwater Dependent Ecosystems (GDEs), Acid Sulfate Soils (ASS), and conservation wetlands and waters.

The Site is underlain by approximately 12-15 m of superficial Quaternary formations, with economic mineralisation occurring within the Bassendean Sand and discontinuous lenses of Yoganup Formation at depth.

Groundwater is present at the Site within a multi-aquifer system, including the unconfined superficial aquifer, with an approximate saturated thickness of 12-14m, and the underlying confined Leederville and Yarragadee Aquifers. Groundwater within the Leederville aquifer is confined by a thick clay sequence. Mining is planned to take place of the superficial formation only. Groundwater flow in the superficial aquifer occurs to the northwest with an approximate hydraulic gradient of 0.0037. Hydraulic conductivities in the superficial formations are expected to range between 0.5-30 m/d. Groundwater in the superficial and Leederville aquifers is generally fresh to transitional.

The Sabina and Abba rivers are located within 1 km of the Site; however the Site is located wholly within the Sabina River catchment, and below the Sabina River Diversion drain. Local farm drains on-Site have inverts of <1 to c1.5m, and discharge into the Sabina River approximately 2km to the north of the Site. Preliminary examination of DWER hydrographs and recent groundwater level monitoring by Doral, suggest that groundwater discharge is unlikely to be a significant proportion of stream or drain flow, which is dominated by rainfall run-off. The Sabina and Abba Rivers are registered as Aboriginal Heritage sites with the Western Australian Department of Planning, Lands and Heritage, and both discharge to the Vasse-Wonnerup wetlands at the coast. The Site is not in a proclaimed area for surface water management.

Potential terrestrial Groundwater Dependent Ecosystems (GDEs) occur within 5 km of the Site, mainly concentrated near the Sabina River. A detailed flora and fauna study by Ecoedge, 2016, concluded that further detailed studies on-Site may be required to identify at-risk GDEs. Aquatic GDEs within 5 km of the Site are all categorised as “Multiple Use”, and therefore of lower environmental significance. Highly-significant conservation wetlands comprising the RAMSAR-listed Vasse-Wonnerup Wetlands Reserve, are located 7.5 km to the northwest, but will not be impacted by dewatering activities at the Site.

A total of 64 licensed abstractions occur within 5 km of the Site, almost all of which abstract from the Leederville Aquifer, which is not expected to be impacted by mining operations. Approximately 26 (unlicensed) bores abstracting from the superficial aquifer occur on-Site.

A radius of influence has been estimated using several analytical methods to extend between 95 to 1,083m from the Site, based on the quoted range of hydraulic conductivities. A Tier 1 analytical model of groundwater drawdown due to mine dewatering was used to estimate the abstraction needed spatially for the dry extraction of ore based on the initial mine plan for each segment. In most cases the modelled discharge was less than or comparable with the initial estimates, with the discharge for Q3 2026 (the largest single segment) being approximately 7,850m^3/d. The effective radius of influence given by the model was between c850m and c1200m.

Estimated drawdowns of 1m are predicted to occur at between c560 to 670m, and of approximately 5m at between c90 and c300m distance from the mined segment. Bores abstracting from the superficial aquifer potentially impacted by the drawdown estimate include private bores for livestock, irrigation and domestic purposes, and monitoring bores for the Department of Water and Environmental Regulation (DWER). Several of these bores were observed to be disused at mid-2017. It is emphasised, however that these are initial estimates of drawdown only; these estimates will be revised as more site-specific data become available from site investigations, from additional modelling, and as the mining plan is further developed. Other groundwater users, including those abstracting from the Leederville Aquifer, are not expected to be impacted by dewatering.

Possible mitigation measures may include:

- Survey of existing superficial groundwater usage, including existing abstraction equipment, bore construction, yield, existing groundwater quality and end-usage requirements with respect to required yield and quality;
- Provision of an alternative water supply from dewatering operations, or;
- Re-scheduling of planned dewatering periods to high water table (i.e. winter ‘wet’ high rainfall) months.

An initial assessment of published Acid Sulfate Soil maps indicates that local shallow soils are in the Moderate to Low category. However, more detailed assessment of on-Site soils has been undertaken by Doral and consultants ABEC; it is understood by HydroSolutions that field tests from on-Site bores indicate a significant proportion of samples may be characterised as Potential Acid Sulfate Soils, and that net acidity above the DER 2015a criterion triggers the requirement to develop an Acid Sulfate Soils Management Plan (ASSMP). In addition, the estimated extent and duration of dewatering operations are likely to trigger the need for Dewatering Management Level 2 as stipulated in DER June 2015b.

The estimated extent of drawdown is not sufficient to impact any of the publically identified wetland GDEs in the vicinity, but may have an impact on local terrestrial GDEs; further assessment to identify any high-value GDEs on site is warranted. Possible mitigation measures may include:

- Further studies to identify high conservation value GDEs;
- Provision of monitoring bores within the unsaturated zone adjacent to conservation value GDEs to establish the seasonal variations in soil moisture profile and hence periods of potential stress
- As required, provision of reticulated irrigation to maintain any high conservation GDEs that may be under stress;
- Possible changes to the mining plan to:
    - Reduce the mining operational areas to minimise/ limit the dewatering requirement.
    - Avoid areas that may impact on any high-value GDEs identified.
    - Re-scheduling of the location/ timing and duration of dewatering operations to periods of high water table elevation following winter rainfall.

Any existing groundwater discharge to local field drains is only likely to occur during groundwater high periods following winter recharge, and is therefore unlikely to be a significant proportion of surface water flow, on which basis dewatering operations are unlikely to impact significantly on the existing surface water flow regime. Initial estimates of dewatering indicate that local rivers will not be affected.

The mining operation is intended to be a 'closed system', with no discharges occurring to the surface water environment, except when on-Site storage is full. However, incidental (clean) stormwater occurring on undisturbed land will be discharged to the existing local drainage system.

Possible mitigation measures may include:

- Minimisation of the extent, duration and area of diversion of over-land flow/ surface water run-off from the mining footprint.
- Stormwater falling onto disturbed areas will be added to the site water usage. However, clean incidental stormwater occurring on undisturbed areas unaffected by mining operations will flow off-Site into existing surface water courses.
- Application under RIWI, 1914 for a permit from DWER to authorise interference or obstruction of the bed and banks of a watercourse or wetland at the point of discharge, for emergency discharges.
- Prevention/ minimisation of erosion at the point of discharge.
- Prevention of sediment release.
- Baseline surface water quality monitoring throughout the operational mining period, to verify that minimal or no impact is occurring.

Recommendations

The following recommendations are made:

- Local bores should be resurveyed to verify their locations and elevations in order to provide future accurate groundwater measurement.
- Survey of existing superficial groundwater usage, including existing abstraction equipment, bore construction, yield, existing groundwater quality and end-usage requirements with respect to required yield and quality, so that appropriate mitigation measures can be developed.
- Monitoring programs should be developed for groundwater and surface water to ensure that they are consistent with and provide suitable data for identified project objectives.
- Monitoring of groundwater bores should continue for an assessment of local spatial and seasonal variations in the water table, and to provide a baseline for surface and groundwater quality, particularly when surface water courses are flowing.
- Surface water monitoring should continue to provide baseline data, and to ensure that no unacceptable impacts are occurring.
- Hydrogeological investigation is required, to provide site-specific data to support a probable H3 level of assessment for a groundwater license application, and to provide data for ASS management requirements
- A Tier 3 calibrated numerical model should be constructed for the Site, to provide a more comprehensive and reliable estimate of groundwater impacts, and as required under a probable H3 level of assessment.
- Further groundwater investigations are warranted to support a groundwater license application for process water abstraction from the Yarragadee aquifer.
- Further investigation of terrestrial GDEs on Site should be performed, based on the derived water table and detailed topography of the Site, concentrating on the eastern and north-eastern sides of the project area, in order to identify any high-conservation GDEs present on site warranting preservation so that appropriate mitigation measures can be developed.

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Abbreviations

^oC	Degrees centigrade	GIL	Groundwater Investigation Level (NEPM 2013)	PHs	Saturation pH
ABC	Ambient Background Concentration	GL	Giga litre=1x10^{9}litres=1x10^{6}m^3	PID	Photo-ionisation detector
ABS	Acrylonitrile butadiene styrene	GME	Groundwater Monitoring Event	PO_4	Phosphorous
ACL	Added Contaminant Limit	GSWA	Geological Survey of Western Australia	POS	Public open space
ACM	Asbestos containing material	ha	Hectare	'ppm'	Parts per million=mg/L
AF	Asbestos fines, includes free fibres, fibre bundles & small (<7mm) ACM fragments	HCO_3	Bicarbonate	PSH	Phase separated hydrocarbon
Ag	Silver	Hg	Mercury	PVC	Poly vinyl chloride
'agd66/84'	Australian Geodetic Datum	HILA	Residential with garden/ accessible soil (home grown produce <10% fruit & vegetable intake, no poultry. Includes children day-care centres, preschool & primary schools)	PWL	Pumping water level
AGL	Above ground level	HILB	Residential with minimal opportunities for soil access, includes dwelling with fully & permanently paved yard space such as high-rise apartment and flats	'q'	Recharge term (m^3/d/m^2)
AHD	Australian Height Datum	HILC	Public open space such as parks, playgrounds, playing fields, secondary schools & footpaths, excluding undeveloped POS (e.g. urban bushland & reserves).	Q	Discharge (or throughflow)
AMG	Australian Map Grid	HILD	Commercial/ industrial , such as shops, offices, factories & industrial sites	QA/QC	Quality assurance/ control
Al	Aluminium	HSL	Health screening levels for petroleum hydrocarbon compounds (NEPM 2013)	RBCA	Risk based corrective action
AMG	Australian map grid	Hu	Hazen units (colour)	Rn	Radon
Anion	A negatively charged ion	H_2S	Hydrogen sulfide	Redox	Simultaneous (chemical) reduction and oxidation
ANZECC	Australian and New Zealand Environment and Conservation Council	'i'	Hydraulic gradient (dimensionless)	RPD	Relative percentage difference
ARMCANZ	Agriculture and Resource Management Council of Australia and new Zealand	ID	Inside diameter	RIWI	Rights in Water & Irrigation Act, 1914
As	Arsenic	IL	Investigation Level	RL	Relative level
AS	Australian Standard	IWG	Irrigation Water Guidelines	SAR	Sodium absorption ratio
AST	Above ground storage tank	'k'	Permeability/ Hydraulic conductivity (m/d)	Se	Selenium
AUSRIVAS	Australian river assessment scheme	K	Potassium	SG	Specific gravity
b	Saturated thickness	Kg	Kilogram	Si	Silicon
B	Boron	LOEC	Lowest observed effect concentration	Sn	Tin
Ba	Barium	LOR	Limit of Reporting	SO_4	Sulfate
BaP	Benzo(a)pyrene	LNAPL	Light non-aqueous phase liquid	Sr	Strontium
Be	Beryllium	LTV	Long-term value	STV	Short-term Value
BOD	Biological oxygen demand	MAH	Monocyclic aromatic hydrocarbons (BTEX)	SSTL	Site-specific target level
BQ	Head loss attributable to laminar flow	'mAHD'	Metres Australian Height Datum, (Mean Sea Level+ 0.026m; Low Water Mark Fremantle+ 0.756m)	sVOC	Semi-volatile organic compound
BTEX	Benzene, toluene, ethylbenzene, xylene	'm^3/a'	Cubic metres per annum	SWL	Static or standing water level
Ca	Calcium	mBD	Metres below datum	Sy	Specific yield
$CaCO_3$	Calcium Carbonate	'mBGL'	Metres below ground level	T	Transmissivity (m^2/d)
Cation	A positively charged ion	'mBTOC'	Metres below top of casing	TEF	Toxic equivalent factor for dioxin & d-like compounds
Cd	Cadmium	'm/d'	Metres per day	TEQ	Toxic equivalency compared to BaP
CEC	Cation exchange capacity	'm^3/d'	Cubic metres per day	2,4-D	2,4 dichlorophenoxyacetic acid
Cl	Chloride	Mg	Magnesium	2,4,5-T	2,4,5-trichlorphenoxyacetic acid
Co	Cobalt	'mg/Kg'	Milligrams per kilogram (equivalent parts per million at SG=1)	TDS	Total dissolved solids
Cn	Cyanide	'mg/L'	Milligrams per litre=PPM	THM	Trihalomethane
CoC	Contaminant of Concern	'μg/L'	Microgram's per litre	TIT	Triple interceptor trap
CoCust	Chain of Custody	'μS/cm'	Micro-Siemens per centimetre	TKN	Total Kjeldahl nitrogen
COD	Chemical oxygen demand	'μS/m'	Micro-Siemens per metre	Tl	Thallium
CQ^2	Head loss attributable to turbulent flow	ML	Mega litre=1x10^{6}litres=1000m^3	TN	Total nitrogen
Cr	Chromium	Mn	Manganese	TOC	Total organic carbon
Csat	The concentration at which the soil porewater phase cannot dissolve any further hydrocarbons	Mo	Molybdenum	TON	Total oxidised nitrogen
CSIRO	Commonwealth Scientific and Industrial Research Organization	'mRL'	Metres relative level		
Cu	Copper	Mtpa	Million tonnes per annum	TP	Total phosphorous
DBCA	Department of Biodiversity, Conservation and Attractions (formerly DPAW)			TPH	Total Petroleum Hydrocarbons
DDT	Dichlorodiphenyltrichloroethane	MWG	Marine water guideline	TRH	Total recoverable hydrocarbons
DDE	Dichlorodiphenyldichloroethylene	Na	Sodium	U	Uranium
DEC	Department of Environment and Conservation	NAPL	Non aqueous phase liquid		
DMP	Department of Minerals & Petroleum (now DMIRS)	NATA	National Association of testing Authorities of Australia	UST	Underground storage tank
DMIRS	Department of Mines, Industry Regulation and Safety			V	Vanadium
DNAPL	Dense non-aqueous phase liquid	NEPC	National Environmental Health Council	VCH	Volatile chlorinated Hydrocarbons
DO	Dissolved oxygen	NEPM	National Environmental Protection Measure	VOC	Volatile organic compound
DOC	Dissolved organic carbon			VOCC	Volatile organic chlorinated compounds
DoH	Department of Health	NHMRC	National Health and Medical Research Council	Volatile	A chemical with Henrys Law Constant>1x10^{-5}atm/m^3/mol & vapour pressure >1mm Hg at room temperature NJDEP 2005 quoted in NSW 2010
DoW	Department of Water (now DWER)	NH_3	Ammonia	'w'	Aquifer width perpendicular to flow direction
DPAW	(former) Department of Parks and	NH_4	Ammonium	WA EPA	Western Australian Environmental

	Wildlife (now DBCA)				Protection Authority
dS/m	Deci-Siemens per metre (soil salinity)	Ni	Nickel	WDE	Water Dependent Ecosystems
DWER	Department of Water and Environmental Regulation	NL	Not limiting; hydrocarbon concentration is at Csat, i.e. the soil cannot dissolve any more chemical, & the soil vapour concentration at equilibrium could not exceed the maximum allowable vapour risk (NEPM 2013)	WQPG	Water Quality Protection Guidelines
DWG	Drinking Water Guidelines	NO_2	Nitrite	WQPN	Water Quality Protection Notes
EC	Electrical conductivity	NO_3	Nitrate	Zn	Zinc
E. Coli	Escherichia coli	NOx	Oxidised nitrogen		
Eh	Redox potential	NTU	Nephelometric Turbidity Unit (turbidity)		
EIA	Environmental Impact Assessment	O_2	Oxygen		
EIL	Ecological Investigation Level	OC/OP	Organo chlorine/ organo phosphate compound		
EPA	Environmental Protection Authority	OD	Outside diameter		
ESL	Ecological screening level (NEPM 2013)	ORP	Oxidation Reduction Potential		
F1	TPH C6-C10-sum BTEX (NEPM 2013)	OH&S	Occupational Health and Safety		
F2	TPH >C10-C16-napththalene	O/W	Oil/ water		
F3	TPH >C16-C34	P	Phosphorous		
F4	TPH >C34-C40	PAH	Polycyclic aromatic hydrocarbons		
FA	Friable asbestos, include severely weathered ACM, insulation products & woven asbestos, degraded A that can be broken by hand	Pb	Lead		
Fe	Iron	PCB	Polychlorinated biphenyls		
FRP	Filterable reactive phosphorous	pCoC	Potential contaminant of concern		
FWG	Fresh water guideline	PER	Public Environmental Review		
'gda94'	Geodetic Datum of Australia 1994	'pH'	Intensity of acidic or basic character of a solution, (-log of hydrogen ion concentration of a solution)		

1. Introduction

HydroSolutions Pty Ltd (HydroSolutions) was commissioned on 30th June 2017 to undertake an Initial Hydrogeological Desk Assessment for the proposed Yalyalup Mineral Sand Mine (the Site), on behalf of Doral Mineral Sands Pty Ltd (Doral, the Client). The site location is shown on Figure 1. Boundaries for the Site are provisional, based on current information supplied by Doral with regard to their preliminary forecasted mining plan.

Doral proposes to develop its Yalyalup prospect as a future mineral sands mining operation. Mineral sand deposits are present at depth within the superficial deposits which overlie the regional Leederville Formation. Groundwater is present within the superficial formation and the underlying Leederville Formation. Doral proposes to dewater the superficial aquifer beneath the site for the dry extraction of ore.

Doral wishes to undertake an initial desk assessment of the surface water and groundwater regimes at the site to form part of a referral document to the former Environmental Protection Agency (now DWER) for the proposed development, for the key environmental factors relating to the water theme, as defined in EPA 2016, specifically:

- Hydrological Processes, and;
- Inland Waters Environmental Quality.

1.1 Objectives

The objectives of the study were to:

- Determine background information with regard to the surface water and groundwater systems at the Site and in its vicinity
- Perform a preliminary assessment of the impact of mine dewatering on the surface water and groundwater systems
- Identify any other potential impacts on the groundwater environment, including on any Groundwater Dependent Ecosystems (GDEs), Acid Sulfate Soils (ASS), and conservation wetlands and waters.

1.2 Acknowledgments

HydroSolutions wishes to acknowledge the help and assistance of personnel from the following organisations in the preparation of this report:

- Doral Mineral Sands:
    - Craig Bovell
    - Drew Walton
    - Dente Williamson
- ABEC Environmental Consulting: Damon Bourke

2. Scope of Work

The scope of work was developed based on HydroSolutions proposal of 30th June 2017, and is summarised as follows:

- Liaison with Doral:
    - Receive details of the proposed scope and timing of the mine development
    - Monitoring & use data available for on-site bores
    - Other data previously collated
- Collation and review of all readily available published data relating to surface & groundwater for the site area, including the following:
    - Department of Water & Environmental Regulation (DWER) data:
        - Windata Base (surface water & groundwater monitoring data, including flow, quality, geology, bore construction data etc.)
        - Licensing database (licensed abstractions)
        - Acid sulfate soil (ASS) risk, given the need to dewater and the presence of possible ASS (“PASS”)
    - Geological Survey of Western Australia: published geological data (maps, reports etc.)
    - Australian Wetlands Database
    - Department of Mines, Industry Regulation and Safety (DMIRS): mining tenements
    - Landgate:
        - Cadastral data
        - Digital elevation models (if required and not available from Doral)
        - Aerial photographs (ortho-rectified)
    - Bureau of Meteorology:
        - Monthly and Long Term Average (LTA) rainfall and evapotranspiration data
    - Liaison with Regulators:
        - DWER:
            - Available hydrological/ groundwater reports for the area
            - Concerns with respect to surface water quality and flows (Sabina and Abba rivers/ other ephemeral watercourses)
            - Discussion of any concerns wrt possible impacts from the mine development
            - Landuse impacts/ (any) contamination issues/ impacts on water courses etc.
- Preparation of a report which is consistent with the requirements of EPA, 2016, to be suitable as a referral document, but <u>at an initial, desktop level of detail</u>, given the current lack of site-specific data or mining development details available.

3. Environmental Principles and Factors

Table 1: EP Act principles

Principle	Consideration
The precautionary principle *Where there are threats of serious or irreversible damage, lack of scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.* *In application of this precautionary principle, decisions should be guided by:* *1) Careful consideration to avoid, where practicable, serious or irreversible damage to the environment; and* 2) *An assessment of the risk-weighted consequences of various options*	The development is a mineral sands mining operation of approximately 6-years in duration. Dewatering is temporary, and occurs in limited stages, giving an opportunity to revise dewatering practices over time. Partially saturated overburden will be used to rehabilitate the mine and the local aquifer, resulting in minimal impact and discharges to the water environment. The groundwater system is expected to completely recover. Water returns from the process may have a low (i.e. acidic) pH, and will be neutralized as-needed prior to infill. This material will also have added lime as-needed to control possible acid generation from Potential Acid Sulfate Soils within the tailings and mine void
The principle of intergenerational equity *The present generation should ensure that the health, diversity and productivity of the environment is maintained and enhanced for the benefit of future generations*	The mine development will occur over approximately 6-years. On the cessation of temporary dewatering, the mining void will be infilled with sand tailings with entrained water. The superficial aquifer will be recharged by incidental rainfall, and over time, the former groundwater regime will be re-established. No long-term environmental impairment is expected. Rehabilitation of the previously worked area/s will occur progressively throughout the active mining period. At the end of active mining, the mine footprint will be rehabilitated to allow re-establishment of similar pre-existing agricultural activities.
The principle of the conservation of biological diversity and ecological integrity *Conservation of biological diversity and ecological integrity should be a fundamental consideration*	The site contains groundwater dependent ecosystems (GDEs); these will be further studied and monitored, and mitigation measures will be employed as-needed for their maintenance during the active mining period. The former groundwater regime is expected to be re-established over time by recharge from incidental rainfall. The current fresh groundwater quality is not expected to be affected, through reinstatement of the temporary void by infill using sand tailings with entrained water and the existing geological overburden material which forms the current aquifer units.
Principles relating to improved valuation, pricing and incentive mechanisms *1) Environmental factors should be included in the valuation of assets and services* *2) The polluter pays principles – those who*	During mining, mitigation measures with regard to impacts on water users and the environment are expected to be incorporated into the mining plans. At the end of active mining, the mine footprint

generate pollution and waste should bear the cost of containment, avoidance and abatement. 3) *The users of goods and services should pay prices based on the full life-cycle costs of providing goods and services, including the use of natural resources and assets and the ultimate disposal of any waste.* *Environmental goals, having been established, should be pursued in the most cost effective way, by establishing incentive structure, including market mechanisms, which enable those best placed to maximise benefits and/or minimise costs to develop their own solution and responses to environmental problems*	will be rehabilitated to allow re-establishment of similar pre-existing agricultural activities.
The principle of waste minimisation *All reasonable and practicable measures should be taken to minimise the generation of waste and its discharge into the environment*	The mine development is not expected to produce any waste materials. Geological overburden will be stored temporarily within two or more Solar Evaporation Ponds (SEPs); this material will be relocated within the temporary voids by progressive infilling. Abstracted groundwater will be re-used within the mineral processing plant, and sand tailings with entrained water will be used to infill the void created by the previous mineral extraction campaign. Stormwater falling onto disturbed areas will be added to the site water usage. However, clean incidental stormwater occurring on undisturbed areas unaffected by mining operations will flow off-Site into existing surface water courses. Any suspended sediment loads in discharge water will be controlled. At the end of active mining, the mine footprint will be rehabilitated to allow re-establishment of similar pre-existing agricultural activities.

4. DWER Objectives

The former Environmental Protection Authority (now DWER) defines its objectives and focus on the protection of Inland Waters and Hydrological Processes in its Statement of Environmental Principles, Factors and Objectives (EPA, 2016).

Environmental values considered of significance for Hydrological Processes include:

- In-situ values of water dependent ecosystems and associated recreational, cultural and aesthetic values
- Extractive values including consumptive use for public water supplies, agriculture and industry

Of the in-situ values, the EPA focus is on impacts to environmentally significant water dependent ecosystems (also considered of significance for Inland Waters), which include:

- Conservation wetlands and poorly-represented wetlands;
- Wild and scenic rivers;
- Natural springs and pools, particularly in arid areas;
- Ecosystems supporting conservation of significant flora and fauna communities;
- Ecosystems which support significant amenity, recreation and cultural values.

Specific issues highlighted in EPA, 2016, include:

- Changes in water regimes in the South West, as a result of reduced rainfall and recharge;
- Surplus discharge to creeks and wetlands, resulting in alteration of hydrological regimes and destabilisation and erosion of banks – maximum alternative use of excess water is preferred;
- Reduced water quality due to diffuse source impacts;
- Appropriate creation of mine pit lakes, particularly in arid areas and where there is a risk of poor quality lake water;
- Appropriate siting, containment, design, monitoring and management of waste and tailings structures;
- Aquifer-recharge water quality.

5. Policy and Guidance

Doral wishes to undertake an initial desk assessment of the surface water and groundwater regimes at the site to form part of a referral document to DWER for the proposed development, for the key environmental factors relating to the water theme, as defined in EPA 2016, specifically:

- Hydrological Processes, and;
- Inland Waters Environmental Quality.

5.1 Hydrological Processes

"The EPA's objective for the factor '*Hydrological Processes*' (EPA, 2016) is: "*To maintain the hydrological regimes of groundwater and surface water so that environmental values are protected*".

Consideration of the following issues et. al. is relevant:

- (Identification of) environmental values which are potentially impacted
- Significance of those potential impacts in the location, regional and cumulative impacts
- (Initial) Prediction of environmental impacts
- The risks to environmental values
- Impacts to environmentally significant groundwater dependent ecosystems (GDEs)
- Surplus water discharge
- Monitoring requirements
- Mitigation of impacts.
- Closure & rehabilitation.

5.2 Inland Waters Environmental Quality

"The EPA's objective for the factor '*Inland Waters Environmental Quality*' (EPA, 2016) is: "*To maintain the quality of groundwater and surface water so that the environmental values are protected*".

Consideration of the following issues et. al. is relevant:

- (Any potential for) reduced groundwater & surface water quality
- (Identification of) environmental values which are potentially impacted
- Use of tailings storage facilities
- How waste discharge is minimised
- How use of the land or water may impact on water quality and environmental values
- (Any) Impacts on ecosystem health related to water.

6. Receiving Environment

6.1 Regional Setting

The Site is located on the Swan Coastal Plain, approximately 10km east-southeast from the town of Busselton and the coast at Geographe Bay. The Swan Coastal Plain in this area slopes gently to the northwest from maximum elevations of approximately 50 mAHD at the base of the Whicher Scarp, to the Vasse-Wonnerup wetlands system and the coastline (Figure 1).

The Site slopes gently northwest from elevations of approximately 30 mAHD in the south-eastern corner to around 22 mAHD in the northwest. It is generally comprised of farmland and contains three continuous farm drains running southeast/northwest through the area (Figure 2). The surrounding environment is also farmland and the Site area is zoned under City of Busselton planning as agricultural.

The Abba River lies approximately 700m beyond the northeast corner of the Site and the Sabina River lies approximately 900m beyond the southwest corner. These rivers drain to the Vasse-Wonnerup wetlands to the northwest of the Site, which are Department of Water and Environmental Regulation (DWER) Conservation Wetlands and registered RAMSAR protected wetlands.

6.2 Climate & Rainfall

Meteorological data has been sourced from the Bureau of Meteorology Station 9603 (Busselton Aero). The Busselton area has a mean maximum temperature of 17^{o} C in winter months and a mean maximum temperature of 29^{o} C in the summer, and has experienced a generally warming trend over the past 20 years.

Annual mean rainfall for the previous 10 years (2007-2017) is 677mm, which is substantially lower than the long-term average (LTA) for Busselton of 811mm. The majority of precipitation occurs between the months of May and September, with minimal rainfall (<25mm) in the summer months. Potential average annual evapotranspiration in the region is approximately 1200mm, which therefore is likely to exceed precipitation during summer months.

6.3 Geology

The Site is included on the published 1:50,000 Environmental Geology Series map for Busselton (Belford, 1987). The Site is shown as being underlain by Pliocene to Quaternary sands and silts, which comprise the superficial formations. Identified units within the superficial formations include the Bassendean Sand (Bsnd), principally an aeolian quartz sand; the Guildford Formation (Gfm), which in the area is dominated by interbedded sandy silt, representative of alluvial and estuarine deposits; and the Yoganup Formation (Yog), a fine to medium quartz sand, which (together with the Bsnd) contains the heavy minerals identified for mining and is of a nearshore/beach facies. The total depth of the superficial formations at the Site is approximately 12-15m.

The superficial formations are unconformably underlain by the Leederville Formation of early Cretaceous age, comprising interbedded sands, silts and clays, and which is indicated to be up to 500m thick in the region and at least 100m thick in the area of the Site (Hirschberg, 1989, Baddock et al, 2005). The uppermost member of the Leederville Formation in the Busselton area is the Vasse Member, which is composed of highly stratified and discontinuous interbedded clayey sands, which are dominated by substantial clay layers at the Site.

At depth a further sequence of Mesozoic sedimentary formations unconformably underlie the Leederville Formation, comprising the Yarragadee Formation, a fluvial sandstone; the Cockleshell Gully Formation, a fluvial sand and silt/shale; the Lesueur Sandstone, a terrestrial sand and conglomerate; and the Sue Coal Measures. This sequence measures at least 3000m in thickness in the Busselton area, and rest unconformably on Archaean and Proterozoic metamorphosed basement (Baddock et al, 2005).

Lithological sequences of the superficial formations at the Site obtained by the Client indicate that the Bassendean Sand is approximately 0-3m thick, the Guildford Formation is approximately 2-6 m thick, and the Yoganup Formation is discontinuous across the Site, with lenses of 3-5 m thickness striking in an east-northeast/west-southwest orientation at depth.

6.4 Hydrogeology

Groundwater is present in the area within a multi-layered aquifer system. The superficial deposits contain an unconfined aquifer with saturated thicknesses of generally less than 10m, whereas the Leederville and Yarragadee Formations contain multiple regional-scale confined and semi-confined aquifers.

6.4.1 Superficial Aquifer

Unconfined groundwater in the superficial formations occurs at approximately 1-3mBGL, with a consequent saturated thickness of approximately 10-14 m, based on water levels obtained from local bores by Doral during their monitoring round in May-June 2017 and ongoing monitoring. Seasonal variation in the water table, derived from existing DWER hydrographs in the area, is in the range of approximately 1-2m. A water table based on Doral measurements is shown on Figure 3, although this is a preliminary estimate, pending re-surveying of these bores. Given the age and usage history of many of these private bores, their construction, current condition and the reliability of their elevation information may render them insufficient for monitoring purposes.

Regional groundwater flow is expected to occur to the northwest in the Site vicinity, and this is borne out by Figure 3, which also indicates an hydraulic gradient within the superficial aquifer of approximately 0.0037. The ultimate discharge point is likely to be Geographe Bay and the Vasse – Wonnerup wetlands at approximately 7km to the northwest. Recharge occurs by rainfall, although a large proportion of this infiltration is likely to be lost due to evapotranspiration due to the shallow water table.

The superficial formations are variable across the region and hydraulic conductivities are site-specific. However, in general, hydraulic conductivities have been estimated to be in the range of 0.5-50 m/d (Davidson, 1995; Hirschberg, 1989), with an average of 15m/d, partially dependent on the percentage sand content. HydroSolutions, 2014, pumping tests within the Bassendean Sand and sandy facies of the Guildford Formation in the Bunbury area indicated transmissivities of 483-731 m^2/d and corresponding hydraulic conductivities in the range of 23.3-32.5 m/d. The superficial aquifer is underlain by a clay-dominated aquitard unit, which also forms a confining layer for the underlying Leederville aquifer; the two aquifers are not expected to be in hydraulic continuity with each other in the site vicinity.

6.4.2 Leederville Aquifer

A major clay-dominated confining layer occurs at the top of the Leederville Formation across the region. The various sub-aquifers within the Leederville Formation are in hydrogeological continuity with each other generally. Hirschberg, 1989, reports that upward leakage occurs into the superficial aquifer from the confined aquifers in the vicinity of the Site, although later studies suggest that downward flows have also been occurring since that time, potentially due to ongoing regional abstraction from the Leederville Aquifer (Schafer et al, 2008). Based on the measured groundwater levels for the two aquifers shown on Figure 3 and Figure 4, there is generally a 2m or greater difference in equipotentials between the groundwater systems at the site, with lower elevations recorded within the Leederville. There are also some instances of upward hydraulic heads and artesian flows in the vicinity of the Site, including reportedly in one bore to the south of the Site (bore Lot 667_WM1). Groundwater flow in the Leederville Aquifer is generally towards the coast, with discharge into the subsurface saltwater wedge.

Water levels obtained from monitoring undertaken by Doral of local bores indicate a large variation in heads across the Site, with a range from 0.8 to 11.27mBGL (Figure 4) which is likely to reflect differences between static water levels (SWL) and pumping water levels (PWL) in bores with active abstractions. Considerable uncertainty is attached to the condition and elevation reference level of these bores, although we understand that Doral will re-survey the bores in late 2017. One bore (LOT667_WM1) was anecdotally reported to be experiencing artesian flow, to the south of the Site.

Pumping tests by Hirschberg, 1989, indicate that hydraulic conductivities for the Leederville Formation fall within the range of 2-7 m/d and storativities in the range of 0.9-2.7 x 10^{-4}.

6.4.3 Yarragadee Aquifer

The confined Yarragadee Aquifer underlies the Leederville Aquifer, and is also comprised of multiple connected sub-aquifers. There is a significant downward hydraulic gradient in the upper parts of the aquifer (Baddock et al, 2005). As well as downward leakage from the Leederville Aquifer, recharge to the aquifer is likely to occur mostly from the south and southeast where the formation outcrops, and groundwater flow is generally to the northwest towards the coast. Groundwater is freshest in the upper part of the flow system, and is brackish to saline in the lower part.

6.4.4 Groundwater Quality

Groundwater within the superficial aquifer is generally fresh to transitional, and in the vicinity of the Site total dissolved solids (TDS) is expected to be between 500-1,000mg/L (Hirschberg, 1989; Baddock et al. 2005). Groundwater within the Leederville Aquifer is generally fresh to transitional, with higher salinities observed in areas closest to the coast.

Doral have commenced limited groundwater monitoring in certain bores on-Site, and the results of sampling for the superficial aquifer have been collated and compared to relevant guidelines in Appendix 4. Bores exceeding these guidelines are as follows:

- Bores SCPD28A and 20005166 exceed the DWER Fresh Water Guidelines for:
    - Aluminium
    - Zinc
- Bore SCPD28A also exceeds the ANZECC (2000) Nutrient Guidelines for SW Australian Lowland Rivers ANZECC (2000) Nutrient Guidelines for South West Australian Lowland Rivers for:
    - Total Phosphorus
- All sampled bores exceed ANZECC (2000) Nutrient Guidelines for:
    - Total Nitrogen
- Bore TS012M exceeds the DWER Fresh Water Guidelines and the ANZECC (2000) Nutrient Guidelines for:
    - Ammonia (NH_3 as N)

Current initial values for Total Dissolved Solids (TDS) are within the limits for fresh water quality for bores 20005156 and TS012M (i.e. <1000 mg/L), but are transitional in bore SCPD28A (1800 mg/L). These samples represent near groundwater-low conditions, prior to the onset of winter rainfall, and therefore groundwater quality would be expected to improve during subsequent monitoring.

6.4.5 Groundwater Usage

Available data on licensed groundwater abstractions within a 5 km radius of the Site was obtained from DWER, and is reproduced in summary in Appendix 1. The locations of abstraction bores, including DWER groundwater monitoring locations, are shown on Figure 5.

A total of 64 licences are current, and 273 bores are listed. The majority of groundwater usage is stated to be for livestock and domestic/household use, although there are two major abstraction licenses by volume, at the Iluka Resources site to the southeast of the Site (6.5 GL/yr), and the Cable Sands (WA) Pty Ltd site to the north (3.9 GL/yr). Also within 5 km to the west are 3 licences for the City of Busselton. Categories of groundwater usage are shown on Figure 5.

All but two registered licences abstract from either the Leederville or the Yarragadee Aquifer systems. The other two licences for the Superficial Aquifer are for irrigation of City of Busselton reserves by the Vasse Highway, 5 km west of the Site; and for a private farm user 5 km east and up hydraulic gradient of the Site. All identified licences within the Site boundaries abstract from the Leederville Aquifer, although licensing of superficial aquifer abstractions are not always mandated by the DWER, and approximately 26 current and legacy landholder bores on-Site are screened within the superficial aquifer. These bores are listed in Appendix 2 and are also shown on Figure 3.

Information regarding on-Site groundwater abstractions from the superficial aquifer was obtained from observations made by Doral at mid-2017.

6.4.6 Groundwater Dependent Ecosystems

The National Water Commission, in conjunction with State and Territory water agencies, maintains a database of Groundwater Dependent Ecosystems (GDEs) for the purposes of environmental planning and ecosystems management. The database includes three categories: cave ecosystems, including stygofauna; terrestrial GDEs, such as terrestrial vegetation; and aquatic GDEs, such as wetlands and springs.

A search of the database over a 5 km radius from the Site indicated that no stygofaunal GDEs were present in the vicinity of the Site, but that the surrounding area contains marri, jarrah, wandoo, river gum and casuarina vegetation, identified in the database as “medium woodland” with moderate to high potential GDE status. The majority of these stands of vegetation are proximal to the Sabina River. A detailed study of native vegetation on Site has also been undertaken in the recent survey for Doral by Ecoedge (2016), which concluded that it is likely much of the native vegetation on Site are potential terrestrial GDEs, and that detailed further studies may be required to identify at-risk populations. This is compatible with observations that the water table is relatively shallow at several locations on Site. In the absence of detailed information on soil types, and specific groundwater dependence of on-Site vegetation, a reasonable initial assumption is that mapped vegetation present above a water table at <3 mBGL may be potential GDEs (the depth of 3 m is considered to be the normal limit for the evapotranspiration extinction depth in groundwater modelling). Figure 6 shows the stands of vegetation mapped by Ecoedge, 2016, as potential GDEs, and their location relative to the water table depth. Apart from an area in the central south, the entire Site is located above a water table shallower than 3 mBGL. Note that mapped vegetation in Figure 6 includes stands identified as “Degraded” or “Completely Degraded” by Ecoedge, 2016. However, Ecoedge, 2016, comment that the vegetation along the McGibbon Track is in “Good” and “Very Good” condition, and also includes rare and protected floral species and therefore has conservation value.

The database results for aquatic GDEs are shown on Figure 7. All identified GDEs are various forms of wetlands located across the coastal plains. The Western Australian Department of Biodiversity, Conservation and Attractions (DBCA, formerly DPaW) defines conservation and management categories for geomorphic wetlands on the Swan Coastal Plain, based on Hill et al., 1996, and these categories are also shown on Figure 7. These indicate that the area surrounding the site is generally designated as a palusplain, (i.e. flat, seasonally waterlogged wetlands) with isolated floodplain areas, damplands and sumplands (the latter two referring to groundwater-receiving seasonal depressions). All wetlands within 5 km of the Site have been categorised for management as “Multiple Use” which is defined as “wetlands with few remaining important attributes and functions”.

Three reserve areas in the Busselton-Capel groundwater subarea are under ecological monitoring due to the presence of high sensitivity GDEs (DoW, 2009). These have management triggers and responses attached to them by DWER (Del Borello, 2008). These are labelled “conservation” sumplands and floodplains, but are located approximately 6 km to either the northeast or southwest of the Site, and will not therefore be affected by the mine development.

The most significant aquatic GDE in the region is the Vasse-Wonnerup Wetlands Reserve, which is located approximately 7.5 km northwest of the Site and will not therefore be affected by the mine development. This is a Conservation Wetland, under the (former) DPaW geomorphic wetlands management scheme; a listed conservation wetland in the (federal) Department of Environment & Energy Australian Directory of Important Wetlands; and a registered International Wetland of Importance under the RAMSAR Convention, 1971. The Vasse-Wonnerup wetland receives surface water inflow from the Sabina, Abba, Vasse and Ludlow Rivers, as well as groundwater inflow from the local superficial aquifer.

6.5 Surface Water

6.5.1 Local Rivers

The Sabina and Abba Rivers are located within 1km of the Site to the southwest and northeast, respectively. The major drainage and catchment areas around the Site are shown on Figure 1. The Sabina River has a total catchment area of approximately 49km^2, while the Abba River has a total catchment area of approximately 261km^2. Both rivers flow generally to the northwest to feed into the Vasse-Wonnerup wetlands approximately 7.5km to the northwest (Figure 1). DWER gauging stations are situated 1.5km west of the Site at the Sabina River and 3.3km north of the Site at the Abba River. Data for Sabina River flows and stages are available for 2007-2010 and 2015-2016, and are included in Appendix 3. These indicate little variability in flow volumes generally over these periods, with maximum flows of approximately 2 m^3/s and minimal or no-flows for 3-4 months each summer – flows during the summer months are generally <0.03 m^3/s, and ceasing to flow in most years before February/March. The average annual discharge over the period of the DWER records is approximately 1.9 GL for the Sabina River and 16.6 GL for the Abba River.

Local surface water drainage around the site is shown on Figure 2. The Site area is likely to be located wholly within the Sabina River catchment area. However, the north-eastern corner may straddle the catchment divide with the Abba River, although no evidence of a marshy area apparently draining towards the Abba River depicted on topographic maps in this area was observed during a site visit on 27th July 2017, and the Princefield road drain is likely to divert run-off towards the western central drains (Watterdup drain (?)) and the Sabina River. Previous high rainfall had led to surface water run-off observed within the shallow field drains on the western and northern site perimeters, with flow observed to be occurring to the north and west respectively towards the tributary of the Sabina River.

Surface water discharge from the site occurs below the Sabina River Diversion drain (refer to Figure 1), and therefore flows directly into the Vasse-Wonnerup wetlands. Based on the Site area of approximately 1,061Ha, this represents approximately 21.7% of the Sabina catchment below the diversion.

While the Sabina River diversion drain is located to the west of the site, surface water flow from the site occurs northwards to drain into the Sabina River downflow of the diversion. The Sabina River Diversion drain joins the Vasse Diversion drain to the northwest of the site (refer to Figure 1), which was constructed in 1927 to divert approximately 60% of flow from the Sabina River and 90% of flow from the Vasse River away from the Lower Vasse River and the Vasse Wonnerup wetlands.

18 other DWER surface sampling locations have been identified within 5km of the Site, including that for the Sabina River diversion drain at Yoongarrilup; however no sampling data are on record for these sites.

The Whicher Area Surface Water Management Plan (DoW, 2009) does not list the Sabina or Abba Rivers as connected to the groundwater system (as opposed to the Capel or Margaret Rivers, for example). However, the shallow depth of unconfined groundwater at the Site could suggest the possibility of groundwater discharge occurring as baseflow as a component of flow in these rivers. However, hydrographs for both rivers (refer to Appendix 3) indicate clear cease to flow levels during a substantial part of the summer low-rainfall period, which suggests that there is limited or no groundwater contribution to surface water flow (i.e. as baseflow discharge) in the rivers. The surface water flow regime is therefore likely to be dominated by high-rainfall periods generating surface water run-off, rather than any substantial groundwater flow component.

The Sabina and Abba Rivers are registered as Aboriginal Heritage sites with the Western Australian Department of Planning, Lands and Heritage, under site ID numbers 17353 & 17354, although they are not listed protected areas.

The Site is not in a proclaimed area for surface water management (DoW, 2009).

6.5.2 On-Site Drainage

Three farm/ field drains exist on Site, one extending along the western boundary of the Site (‘Wonnerup Road South Drain’) and a further two located in the western-central parts of the Site (this may be known as the ‘Watterdup Creek”, although this has not been confirmed), which are adapted from ephemeral creeks (Figure 2). These flow generally towards the north and northwest, and join the Sabina River approximately 2km downstream at Wonnerup South Road. A discontinuous road-side drain is located along the northern boundary of the Site following Princefield Road; this flows to the west to join the creek draining to the north towards the Sabina River.

Inspection of the Site confirmed that these drains have maximum depths of <1 m across the Site. Given that some static groundwater levels on Site have been reported to be very shallow (i.e. 8 bores in the area contained water levels at <2 mBGL), it is possible that these drains are connected to groundwater periodically. However, it should be noted that groundwater levels in the vicinity of the drains are generally >2 mBGL except in the far southeast corner of the Site, and that any groundwater baseflow discharge to surface water flow in the drains would therefore be expected to be limited (or periodically absent).

Doral have allocated several surface water monitoring points along the drains, and commenced monitoring from July 2017 onwards; surface water flows were reported in 12 of 14 sites between July and August 2017, and were observed during the site visit of 27th July 2017 following recent rainfall.

A potential marshland on the north-eastern corner of the Site, identified from the 1:50,000 Environmental Geology Map (Bedford, 1987) was not apparent during the inspection of the Site.

6.5.3 Vasse-Wonnerup Wetlands

The Vasse-Wonnerup wetlands, approximately 7km to the northwest of the Site, receive inflow from the Vasse, Sabina, Abba and Ludlow rivers, a total catchment area of approximately 961km^2. The system is highly modified, with diversion of flow from several of the rivers, floodgates installed at the exit of both estuaries and high nutrient runoff is received from the catchment. '*The floodgates were installed in the early 1900s to mitigate flooding of adjoining agricultural land…during high river flows in winter and to prevent seawater inundation caused by storm surges. The gates effectively transformed the estuaries in to shallow, winter fresh/ summer saline lagoons, unique in Western Australia* (DER, September 2007). The wetlands are listed as a wetland of International importance under the Ramsar Convention. The high ecological values of the wetlands are coupled with extremely poor water quality in late summer that lead to fish kills and declines in visual amenity. The wetlands are managed for multiple purposes including water bird habitat, flood and storm surge mitigation, visual amenity and the prevention of fish kills (Geocatch, 2017).

The wetlands are reportedly '…*subject to poor water quality issues, with the floodgates acting to reduce flushing flows that may otherwise help to ameliorate high nutrient concentrations from catchment runoff, while excessive algal blooms, blooms of potentially toxic cyanobacteria and fish deaths are not uncommon* (and)… *increased salinisation of adjoining pastoral lands and death of colonising native vegetation*' DER, 2007.

6.5.4 On-Site Surface Water Quality

Doral has a dedicated surface water sampling system in place, and is currently commencing with baseline studies of flow and water quality at 14 locations in the farm drains and creeks on Site. The results of this sampling have been collated and compared to relevant guidelines in Appendix 4. Sites exceeding these guidelines are as follows:

- Site YALSW04 exceeds the ANZECC (2000) Nutrient Guidelines for South West Australian Lowland Rivers for:
  - Total Nitrogen
  - Ammonia (NH_3 as N)
- Sites YALSW04 and 07 exceed the DWER Fresh Water Guidelines for:
  - Aluminium

Sites YALSW05, 06, 07, 11 and 13 are all above the EC and/or TDS limits (1,470 µS/cm and 1000 mg/L respectively) for fresh water, although they are all in the transitional range, except YALSW07, which is brackish. This may not be unexpected in some surface locations, given that many locations were not experiencing any flow at the time of sampling, and since sampling occurred prior to the onset of winter rainfall, and therefore surface water quality would be expected to improve during subsequent monitoring.

7. Potential Impacts on the Water Environment

7.1 Proposed Development

Doral Mineral Sands is proposing to mine the superficial formations on Site, currently under the Department of Mines, Industry Regulation and Safety (DMIRS) (previously the Department of Mining and Petroleum) retention licence R70/52.

HydroSolutions understands that Doral wishes to extract mineral sands from two laterally discontinuous zones trending WSW to ENE of Yoganup Formation at depth, termed respectively the Northern and Southern segments, by progressively dewatering the superficial formations to their base, and removing the covering Bassendean and Guildford Formations. The Bassendean Sand is to be additionally mined for heavy minerals, and unused material from the excavated formations will be used to backfill the mining void and rehabilitate the land surface. The elongated geometry and substantial extent of the Yoganup Formation requires Doral to dewater and mine in a staged approach, with successive mining zones being approximately 150-250 m in diameter. The required total extent of mining and dewatering, including the staged mining zones, is shown on Figure 8 and Figure 9.

Initial tailings will be stored in a pre-mined ore zone located to the east of the Concentrator (refer to Figure 8). Two or more solar evaporation pond (SEPs) will be used to temporarily store geological overburden, prior to backfill of this material within the mining void. Mined segments will be sequentially backfilled concurrently with the commencement of the subsequent excavation. Abstracted water will be reused within the processing plant, and sand tailings with entrained water will be used to backfill the void created by the previous mineral extraction campaign. Fine material will be either included into the sand tailings for backfill into the pits, or transferred to one of three SEPs. Doral have indicated that abstracted water is conserved in the mining process as much as possible, the majority being used in processing or included in reinstatement material. Water returns from the process may have a low (i.e. acidic) pH, and will be treated as-needed prior to backfill.

The SEPs will also be used to store abstracted water, and incidental stormwater. Stormwater falling onto disturbed areas will be added to the site water usage. However, clean incidental stormwater occurring on undisturbed areas unaffected by mining operations will flow off-Site into existing surface water courses.

No significant waste materials or chemicals are expected to be generated from the mine development.

7.2 Dewatering Estimates

7.2.1 Radius of Influence Estimate

The radius of influence (Re) of dewatering has been approximated using the following simplifying assumptions:

- The superficial aquifer, comprising the Bassendean Sand (BS), the Guildford Formation (GFm), and the Yoganup Formation (Yog) acts as a single unconfined aquifer unit.
- Groundwater with the underlying Leederville Formation regional aquifer is confined beneath a thick, locally continuous clay-rich aquitard unit at its top, and hence there is no effective hydraulic continuity with the overlying superficial aquifer in the site vicinity.

- Groundwater flow in the superficial aquifer in the site vicinity occurs from southeast to northwest with a broadly uniform hydraulic gradient of approximately 0.0037.
- The water table is between 1-2mBGL across the site.
- The aquifer saturated thickness varies between 10-14m.
- The varying hydraulic properties of the superficial units may be approximated as a single unit with the following assumed range of 'average' properties:
    - Transmissivity (T) from 100 to 700m^2/d, consistent with a permeability of 10m/d (minimum) to 50m/d (maximum)
    - Storativity 0.1 (minimum) to 0.2 (maximum)
    - Recharge to groundwater occurs at approximately 5% of incidental rainfall, of between 677mm/a (last ten-year average - minimum) and 811mm/a (Long-term average – maximum).
- The range of abstraction (discharge) rate/s required was based on the Hazel solution for the assumed lower and upper end values assumed, as detailed in Section 7.2.2.

Re was estimated using several analytical solutions, including:

- Jacob, 1940, unconfined (short-term) approximation
- Kusakin (Chetoussov, 1949, Bear, 1979), unconfined approximation
- Sichardt, 1930
- CIRIA, Report C750, based on Sichardt approximation.

Re was estimated to be as follows:

- Minimum: range of estimates was 95m to 368m: average value 273m
- Maximum: range 178m to 1,083m: average value 751m

The assumptions, underlying equations and working estimates are provided in Appendix 6. For the purposes of the current initial study, Re was estimated at between approximately 260m and 720m, however one solution gave a figure greater than 1km, and hence 1.5km was adopted in the analytical modelling to estimate the drawdown extent.

7.2.2 Discharge Estimate

The discharge required to dewater each mineral segments was estimated based on the following simplifying assumptions:

- Assumptions as for the Re estimate (Section 7.2.1).
- The head (H) at Re for mineral segment was estimated based on the Re-low and Re-high estimates, assuming an approximate uniform hydraulic gradient of c 0.0037, to be:
    - H-low at Re-low (273m): 23.5mAHD for segment Q3-2026(S) (largest segment)
    - H-high at Re-high (751m): 24mAHD for Q3-2026 (a/a)
- The head (hw) at the proposed pit was estimated based on the observed Static Water Level (SWL) from the measured water table (refer to Figure 3) for the north-eastern half of the Northern Segment of the Yoganup subcrop as shown on Figure 10 to be:
    - SWL approximately 22mAHD for segment Q3-2026
    - hw-low (based on c13.5m drawdown)
    - hw-high (based on c15m of drawdown).

The discharge rate (Q) was estimated using two similar analytical solutions:

- Dupuit, 1863, radial inflow, incorporating recharge
- Hazel, 2009 (based on Dupuit, 1863)

The underlying equations, values assumed and estimates are included in Appendix 6. For each method, the lowest and highest combinations of assumed parameters were used to provide possible low and high-end estimates of the possible discharge rates, for the given assumptions. Both estimates provided broadly comparable values for segment Q3-2026(S), which is the largest individual segment, to provide the following range of discharge values adopted in the Re estimate:

- Dupuit:
    - Q-low~14,423m^3/d (based on Q3-2026(S) a/a)
    - Q-high~28,677m^3/d (for Q3-2026(S))
- Hazel:
    - Q-low~16,981m^3/d
    - Q-high~40,494m^3/d (for Q3-2026(S))

The range of estimated discharge values to dewater each mineral segment given by each method is included in Appendix 6.

It is emphasised however that these are initial estimates only, based on a large number of simplifying assumptions, in the current absence of site-specific hydrogeological and minesite development details. The discharge rates represent short-term volumetric estimates during the period of active drawdown, up to perhaps the first 91-days (I.e. one quarter) for each stage; once dry conditions are established, ongoing rates needed to maintain dry-working will be much lower. More detailed assessment of dewatering volumes will need to be established using numerical modelling, as more details for the site hydrogeology and the mining development become available.

7.2.3 Dewatering Impact Estimate

An analytical modelling solution was used to estimate the possible impact from dewatering operations at the Site and its immediate surrounds. A computer program ‘Unconmod’, developed by HydroSolutions was used to represent the superficial aquifer system. The model is based on the Theis, 1935, solution for drawdown in a confined aquifer, which can be applied to unconfined aquifers by incorporating the Jacob, 1940, solution for the reduced saturated thickness due to dewatering, which may be expressed as:

$s' = s - (s^2/2.D)$

where:

s’ = corrected drawdown
s = observed drawdown
D = original saturated aquifer thickness.

The model is based on a uniform 20 by 20 grid; the grid dimensions were established over the area of the Northern and Southern segments of the Yoganup subcrop, and extending to the assumed Re value (c1500m) beyond this area in order to estimate the full extent of the dewatering impact, by incorporating a grid spacing of 300mx300m.

The mineral segment dimensions, perimeter lengths and areas are given in Appendix 6, together with the model nodes representing each segment.

For each segment, discharge nodes and rates were varied to achieve the target drawdown as far as possible within the limitations of the 300m model grid. The drawdown are based on the 91-day time period after the commencement of dewatering, which is assumed to begin at the start of each quarter, and hence represents the dewatering achieved at the end of the quarter. The modelled drawdowns achieved are shown for each segment on figures in Appendix 6; the modelled discharge rates are also compared with the estimated discharge rates given by the Dupuit and

Hazel methods. In most cases, the modelled discharge is less than or comparable with the estimated values.

It is emphasised, however that the dewatering solutions are initial estimates only, based on a number of simplifying assumptions:

- A simplified, uniform, homogeneous aquifer.
- The lower end of hydraulic values were assumed to be representative, due to the preponderance of clay or clayey-sand in the lithological sequence; Kh=10m/d, storativity 0.1, in the current absence of any site-specific hydraulic parameters.
- Model nodes were assumed to be usable as discharge points; in reality, dewatering points will need to be located around the perimeter of each dewatering segment.
- The analytical dewatering model is not able to incorporate the effects of recharge or of sequential backfilling of the mining void post dewatering.

The model outputs are therefore initial estimates only. A time-variant, calibrated numerical hydraulic model will be required in the future to more accurately predict the extent of drawdown due to the mining operations.

The year-on-year combined drawdown extents, obtained by amalgamating each quarterly dewatering estimate, are shown on Figure 10 to Figure 15 for each mining year from 2021 to 2026.

7.3 Potential Impacts on Surrounding Groundwater Users

On the basis of preliminary mining plans, Tier 1 analytical modelling of drawdown has indicated that a radius of influence for dewatering may be in the order of c850m and c1200m. Drawdown would therefore be expected to impact the local bores accessing the superficial aquifer within this perimeter, as shown on Figure 10 to Figure 15. The degree of impact is related to the distance from the operationally dewatered area (i.e. mine void); with water table level reductions estimated to be in the order of 1m at approximately 560 to 670m, and of 5m at approximately 90 to 300m distances from the segment being mined at any one time (refer to Figure 10 to Figure 15). It is emphasised, however that these are initial estimates of drawdown only, which are based on the assumptions listed in Section 7.2; these estimates will be revised as more site-specific data become available from site investigations, and as the mining plan is further developed.

Superficial aquifer bores expected to be impacted by dewatering operations are shown within the drawdown areas on Figure 10 to Figure 15. Some of these bores are maintained by local landowners for livestock, irrigation and domestic purposes, and by DWER for monitoring purposes. Bores identified as likely to experience water level reductions are shown in Table 2. Data on whether the bores are currently in use was provided by Doral, based on on-Site observations for mid-2017.

It is understood from Doral that some pits may be less than 10m deep, in which case future modelling will indicate a reduced discharge and therefore radius of impact due to a reduced dewatering requirement in these areas.

Table 2: Superficial bores with potentially reduced groundwater levels

Year	Estimated drawdown (m)	Bore name	Easting (GDA94)	Northing (GDA94)	Ownership	Usage
2021	0.1-1	20005165	357282	6270170	Private, lot 843	Disused
		20005167	356360	6270395	Private	Disused,
		20005168	355790	6271295	Private, lot 971	
2022	0.1-1	20005169	356737	6271639	Private, lot 229	
		20005101	358052	6272283	Private, lot 104	
		20005114	358644	6270521	Private, lot 1426	Disused
		20005165	357282	6270170	Private, lot 843	Disused
2023	0.1-1	20005101	358052	6272283	Private, lot 104	
		20005115	357995	6269748	Private, lot 668	Disused
		TS012S	358329.55	6270016.58	Private, lot 1426	Disused
		20005111	358054	6270091	Private, lot 758	Disused
		20005114	358644	6270521	Private, lot 1426	Disused
	1-5	20005167	356360	6270395	Private.	Anecdotally due for decommission
		20005171	356627	6269888	Private, lot 421.	Disused
		LOT421_BORE2	356993	6269791	Private, lot 421	
		20005165	357282	6270170	Private, lot 843	Disused
		20005166	357402	6269919	Private, lot 421	
	5-10	SCPD28A	358612	6271752	Department of Water	
2024	0.1-1	20005171	356627	6269888	Private, lot 421.	Disused
		20005167	356360	6270395	Private.	Anecdotally due for decommission
		20005169	356737	6271639	Private, lot 229	
		SCPD28A	358612	6271752	Department of Water	
		20005114	358644	6270521	Private, lot 1426	Disused
		20005115	357995	6269748	Private, lot 668	Disused
		TS012M	358329.71	6270015.68	Private, lot 1426	Disused
		20005111	358054	6270091	Private, lot 758	Disused
		LOT421_BORE2	356993	6269791	Private, lot 421	
	1-5	20005114	358644	6270521	Private, lot 1426	Disused
		LOT1464_WELL	359520	6270925	Private, lot 1464	Disused
		20005101	358052	6272283	Private, lot 104	
2025	0.1-1	20005114	358644	6270521	Private, lot 1426	Disused
		LOT1464_WELL	359520	6270925	Private, lot 1464	Disused
		20005101	358052	6272283	Private, lot 104	
	1-5	None				
	5-10	SCPD28A	358612	6271752	Department of Water	
2026	0.1-1	20005165	357282	6270170	Private, lot 843	Disused
		20005166	357402	6269919	Private, lot 421	
		TS012S	358329.55	6270016.58	Private, lot 1426	Disused
		20005115	357995	6269748	Private, lot 668	Disused
		20005111	358054	6270091	Private, lot 758	Disused
		LOT1464_WELL	359520	6270925	Private, lot 1464	Disused
		20005101	358052	6272283	Private, lot 104	
	1-5	SCPD28A	358612	6271752	Department of Water	
		20005114	358644	6270521	Private, lot 1426	Disused

Assessment of potential impacts is discussed in Section 8.1.

7.4 Acid Sulfate Soil Potential

The Department of Water and Environmental Regulation (DWER) currently considers assessment and management of Acid Sulfate Soils (ASS) as a priority, given their prevalence in Western Australia. Dewatering operations in areas of ASS have the potential to decrease environmental and groundwater quality values due to the concentration of acidic leachate from these soils.

An initial assessment of the Acid Sulfate Soil (ASS) potential was undertaken using the DWER-maintained ASS risk database for the Swan Coastal Plain. The majority of shallow soils within the estimated radius of influence of drawdown for the Site are categorised by the DWER as Moderate to Low risk. One area to the northwest, where the west-central creek/drain on-Site joins the Sabina River (Figure 2), is categorised as Class I High risk. Dewatering of this area would trigger further assessment with DWER; however, this area does not fall within the estimated area of impact by the dewatering operations.

Further detailed assessment is currently being undertaken by Damon Bourke of ABEC Environmental Consulting; it is understood by HydroSolutions that field tests on-Site indicate a significant proportion of samples may be characterised as Potential Acid Sulfate Soils (PASS), with 65% of laboratory tested samples exceeding the Net Acidity (NA) action criterion of 0.03% Chromium Reduced Sulfur (Scr), although only 16 of 34 (47%) samples exceeded the criterion from materials within the proposed pit voids.

Initial assessment of the impacts relating to ASS is discussed in Section 8.2.

7.5 Potential Impact of Dewatering on GDEs

The radius of influence for dewatering is not sufficiently extensive to impact any of the wetland GDEs identified in section 6.4.6 (apart from the general palusplain surrounding the entire region), and those within 5 km of the Site are designated Multiple Use on the WA Geomorphic Wetlands register and are therefore of lower environmental significance. The high value conservation area at the Vasse-Wonnerup Wetlands Reserve, and the three conservation reserves under ecological monitoring by DoW, are not considered to be within range of dewatering operations. There are no other known natural springs or pools in the vicinity, nor any other environmentally sensitive hydrological environments.

The estimated extent of drawdown of mining operations may reduce the local water table sufficiently to potentially impact local stands of terrestrial GDEs.

Initial assessment of impacts on local GDEs is discussed in Section 8.3.

7.6 Potential Impact of Dewatering on Surface Water Courses

The expected radius of influence of dewatering includes the identified surface drains on Site but does not extend to the Sabina River. However, as stated in section 6.5, it is considered that the superficial aquifer has only limited connection via discharge to the local field drains only during periods of high water table elevation (i.e. winter ‘wet’ high rainfall) months, which typically occurs during October, or around 3-months following winter rainfall occurring as groundwater recharge. As such, groundwater discharge to the local field drains is unlikely to be a significant proportion of the total surface water flow volume, which occurs predominately as surface water run-off from the surrounding land surface.

Initial assessment of impacts on local surface water courses are discussed in Section 8.4.

7.7 Potential Discharges to Surface Water Courses

HydroSolutions understands from Doral that the mining operation is intended to be a 'closed system', with no off-Site water discharge occurring until on-Site water storages are full, at which time discharge will occur through a licensed or pre-agreed 'emergency discharge' location'; "*All discharges must be of a similar or better water quality than the existing agricultural run-off*". Abstracted groundwater from dewatering operations will be reused within the mineral processing plant, and ultimately tailings with entrained process water will be used to progressively backfill the mining void. Water storage will occur within the solar evaporation ponds (refer to Figure 8) prior to re-use during mineral processing, where some loss by evaporation will occur, prior to backfill.

Stormwater falling onto disturbed areas will be added to the site water usage. However, clean incidental stormwater occurring on undisturbed areas unaffected by mining operations will flow off-Site into existing surface water courses. Excess stormwater may be discharged to the existing local drainage system. Any stormwater discharge has the potential to reach the Sabina River downstream under substantial flows, particularly via the creeks/drains on the western side of the Site.

Initial assessment of the impacts relating to potential discharge to surface water courses are discussed in Section 8.4.

8. Assessment of Impacts

8.1 Impacts on Surrounding Groundwater Users

Estimated drawdowns of the magnitude identified in Table 2 (i.e. greater than 0.1 m) may have the potential to affect certain identified bores, particularly where existing bores currently have marginal yields, or where existing pumping equipment is inadequate to cope with even a minimal decrease in the standing water level (SWL) or pumping water level (PWL). Data on whether the bores are currently in use was provided by Doral, based on on-Site observations for mid-2017; many of the bores which may be affected by reduced groundwater levels due to dewatering operations were apparently no longer is use at mid-2017. Bores still in use which are required for domestic use or irrigation may therefore require mitigation planning. Potential mitigation for local groundwater users affected by the development is discussed in Section 9.1.

Assuming that the aquitard layer of the Leederville Formation remains intact at the Site, dewatering is not expected to impact groundwater within the Leederville Aquifer, nor therefore any of those groundwater users accessing this resource.

8.2 Acid Sulfate Soils

It is understood by HydroSolutions that field tests from on-Site bores indicate a significant proportion of samples may be characterised as Potential Acid Sulfate Soils (PASS), with 65% of laboratory tested samples exceeding the Net Acidity (NA) action criterion of 0.03% Chromium Reduced Sulfur (Scr), although only 16 of 34 (47%) samples exceeded the criterion from materials within the proposed pit voids, however this exceeds action criteria specified in DER, June 2015a.

In addition, the estimated extent and duration of dewatering operations are likely to trigger the need for Dewatering Management as stipulated in DER June 2015b.

Possible actions and mitigation measures are considered in Section 9.2.

8.3 Impacts on GDEs

A drawdown of up to 1 m may be expected to occur within approximately 560 to 670m of pumping. Ecoedge, 2016, commented that the majority of native vegetation within the study area may be groundwater dependent, and stands of vegetation mapped by Ecoedge, 2016, fall within the above-mentioned drawdown area (as shown on Figure 10 to Figure 15). Any GDEs in this area considered to be of high environmental value may therefore require consideration of mitigation measures.

There is no expected impact on high value wetland GDEs (refer to Section 7.5).

Possible actions and mitigation measures are considered in Section 9.3.

8.4 Impacts on Surface Water Courses

It was commented in Section 7.6 that existing groundwater discharge as baseflow is unlikely to be a significant proportion of surface water flow within existing field drains locally around the mining development area. On which basis dewatering operations are unlikely to impact significantly on the existing surface water flow regime.

Initial Doral sampling of surface water chemistry indicates that on-Site surface water is fresh to transitional in quality, with the exception of one sampling location (YALSW07), which was in the brackish range. However sampling occurred prior to the onset of winter rainfall, and therefore surface water quality would be expected to improve during subsequent monitoring.

Any incidental stormwater occurring to undisturbed areas will also be fresh and unaffected by the mining operation. As such, any discharges of clean stormwater will not have any detrimental impact on the existing surface water quality local to the Site, and hence on water quality within the Sabina River, since it will represent existing run-off quality from the pre-development site.

Possible actions and mitigation measures are considered in Section 9.4.

8.5 Tailings Management

Doral has stipulated that SEPs will be designed to be self-contained and water conserving as much as practicable.

9. Mitigation

9.1 Affected Groundwater Users

Bores listed in Table 2 may require mitigation measures to prevent substantial drawdown of water levels and reduced yields for local users; these could include the following:

- Survey of existing superficial groundwater usage, including existing abstraction equipment, bore construction, yield, existing groundwater quality and end-usage requirements with respect to required yield and quality;
- Provision of an alternative water supply from dewatering operations, or;
- Re-scheduling of planned dewatering periods to high water table (i.e. winter 'wet' high rainfall) months.
- Users of the Leederville aquifer are not expected to be affected by the development.

9.2 Acid Sulfate Soils

A separate ASS report has been prepared by ABEC Consultants (ABEC, 2017); while this report has not been reviewed by HydroSolutions, it is apparent that, on the basis of soils within the pit (i.e. to be disturbed) exceeding the Net Acidity (NA) criterion, that the potential drawdown of the water table at certain locations may create an ASS risk. Please refer to ABEC, 2017, for further details.

Net acidity (NA) above the DER criterion triggers the requirement to develop an Acid Sulfate Soils Management Plan (ASSMP).

In addition, the initial assessment of the cone of depression due to dewatering operations indicates that drawdowns of more than 0.1m may extend between approximately 1,060 and 1,210 m from the operationally dewatered area (refer to Figure 10 to Figure 15) and be maintained for c. 91-days (i.e. one-quarter) based on the initial mining plan, on which basis Dewatering Management Level 2 (DER, June 2015b) would be required. It is emphasised, however, that these are initial estimates of drawdown only, which are based on the assumptions listed in Section 7.2; these estimates will be revised as more site-specific data become available from site investigations, and as the mining plan is further developed. Site-specific investigation will be required to provide suitable soil quality, hydrological, monitoring, hydraulic and groundwater quality data to support the development of an ASSMP.

Further discussion may be found in ABEC, 2017.

9.3 Affected GDEs

Ecoedge, 2016, recommend that a detailed survey of local phreatophytic vegetation be undertaken to establish the nature of any impacts on potential GDEs. Ecoedge, 2016, also recommend that the vegetation of the McGibbon track area, running through the east side of the Site (Figure 2), be considered a conservation asset, and this area coincides with the highest likelihood of terrestrial GDEs due to its relatively shallower water table (<2 mBGL).

Possible mitigation measures for any GDEs that may be potentially impacted by the development may include et al:

- Further studies to identify high conservation value GDEs;
- Provision of monitoring bores within the unsaturated zone adjacent to conservation value GDEs to establish the seasonal variations in soil moisture profile and hence periods of potential stress
- As required, provision of reticulated irrigation to maintain any high conservation GDEs that may be under stress;
- Possible changes to the mining plan to:
  - Reduce the mining operational areas to minimise/ limit the dewatering requirement.
  - Avoid areas that may impact on any high-value GDEs identified.
  - Re-scheduling of the location/ timing and duration of dewatering operations to periods of high water table elevation following winter rainfall.

9.4 Impacts on Surface Water Courses

Possible mitigation measures may include the following, et al:

- Minimisation of the extent, duration and area of diversion of over-land flow/ surface water run-off from the mining footprint.
- Stormwater falling onto disturbed areas will be added to the site water usage. However, clean incidental stormwater occurring on undisturbed areas unaffected by mining operations will flow off-Site into existing surface water courses.
- Application under RIWI, 1914 for a permit from DWER to authorise interference or obstruction of the bed and banks of a watercourse or wetland at the point of discharge, for emergency discharges.
-
- Prevention/ minimisation of erosion at the point of discharge.
- Prevention of sediment release.
- Baseline surface water quality monitoring throughout the operational mining period, to verify that minimal or no impact is occurring.

9.5 Monitoring

Monitoring programs should be established with the objectives of:

- Defining baseline conditions existing prior to mine development.
- Identifying any impacts and to establish their degree and significance during the development and operational phases.
- Post development/ closure period, to establish recovery and identify any long-term impacts from mining.
- Surface Water:
  - Monitoring of rainfall events.
  - Monitoring surface water flow.
  - Monitoring surface water quality, to identify compliance with applicable guideline values and to identify any exceedances.
  - (Of) Discharge water, volumes, quality, and discharge periods to establish and demonstrate that no unacceptable impact is occurring/ has occurred.
- Groundwater:
  - Establish bore location and datum level by survey.
  - Groundwater levels, within the superficial aquifer, to establish the extent of impact in the water table and on any affected groundwater users.
  - Groundwater quality, to establish pre-development conditions, to identify any impacts attributable to the development, and any impacts arising from disturbance of acid sulfate soil (ASS) materials and prolonged dewatering operations.

- To provide historical data, to allow calibration of numerical (i.e. predictive) modelling.

9.6 Investigation

9.6.1 Hydrogeological Investigation

Hydrogeological investigations are required to provide site-specific hydraulic and chemical data, to support the development and applications for abstraction licensing from the DoW. Based on the initial estimate of discharge required for dewatering in each water year (i.e. July to June) given in Appendix 6, the potential for unacceptable impacts to occur on other groundwater users and GDEs, and the existing fresh groundwater (refer to Appendix 3), it is likely that an H3 level of assessment will be required by the DoW (DoW, 2009b) to support an application for a groundwater abstraction license. On which basis, a desk study, a bore investigation, and a numerical model will be needed, including:

- Elements of the current study are compatible with the requirements of an H3 desk study; although this will need to be compiled and data revised as additional investigation results become available.
- Provision of one or more large diameter production bores that may be used for potential dewatering purposes, completed within the superficial aquifer. Ideally these would be 10 to 12" internal diameter to accommodate estimated flow rates, fully-penetrating of the superficial aquifer sequence to be dewatered, and be located adjacent to monitoring bores to provide observation readings. This will also provide an opportunity to obtain formation-specific aquifer materials for physical and chemical testing, including Particle size-distribution (PSD) to assist with bore design/ ASS assessment etc.
- Test-pumping program to provide site-specific hydraulic data for the aquifer, as input to the numerical groundwater model, including:
    - Step-testing: bore efficiency and performance, specific capacity etc.
    - Constant rate test: provision of site-specific hydraulic data, including permeability/ transmissivity and storage values
    - Recovery data: confirmation of hydraulic parameters.
- Groundwater analysis: to establish pre-development groundwater quality against which to define short-medium impacts and any long-term (post development) effects.
- Assessment of the adequacy of the existing groundwater monitoring network, and potential need to supplement/ replace with additional monitoring bores, at varying distance from and at different locations around the dewatering area. Doral has developed an initial monitoring bore location plan, which is shown on Figure 16.
- Supplemental small-scale hydraulic testing of existing and any new monitoring bores to provide additional data on hydraulic properties and their spatial variability.
- Numerical modelling is discussed in Section 9.7.

9.6.2 ASS Investigation

This is not addressed in any detail in the current study, as it is assumed that it will be addressed in ABEC, 2017.

9.7 Numerical Modelling

A groundwater numerical model will need to be developed in order to:

- More accurately represent the hydraulic properties of the aquifer/ formation materials and their spatial variability.
- Represent temporally variable parameters, including:
    - Rainfall;

  - Evaporation.
- Represent changes to the mining plan with regard to timing, duration and location of dewatering.
- Allow calibration of the model against available monitoring data, to enhance confidence in and the reliability of predictive scenarios.
- Inclusion of the recovery in groundwater levels post active dewatering, and to include progressive reinstatement of the mining void with tailings and entrained water from the processing plant.
- More accurately assess potential impacts on high value GDEs and impacted users of the groundwater resource.
- To comply with the likely requirements for an H3 level of assessment by DoW, to support a groundwater abstraction license application.
- To assist in the development of an ASS Dewatering Management Level 2 plan (DER, June 2015b).

9.8 License Application

An application for a groundwater abstraction license to DWER will be required, and will need to be in place prior to the commencement of dewatering operations. In our experience, DWER may take up to six-months or more from application to grant a license; this must be factored into the overall time planning for the development.

It is likely that an Operating Strategy (OS) will be required, given the volumes and duration of the groundwater abstraction, and since there are likely to be impacts on identified groundwater users and also GDEs associated with the mine development. Similarly, the time to prepare an OS and to obtain DWER approval will need to be factored into the mine plans.

Similar comments are also applicable to the proposed Yarragadee abstraction for processing supply.

10. Predicted Outcome

The mine development is currently at an initial planning stage, and the current report represents only part of an overall initial referral document to DWER. Predicted outcomes are likely to change as the plan is further developed or amended, and in light of results obtained from further studies. Therefore, only an initial outline of possible outcomes is provided:

- The development is referred to DWER, which advises on the scope of assessment & reporting required to support development approval
- Further studies are progressed and additional site-specific data becomes available, including et al:
    - Groundwater investigation
    - Numerical modelling
    - ASSMP
    - Monitoring programs are instigated.
    - Mitigation measures as required for affected superficial groundwater users and GDEs are developed.
- DWER approval is granted.
- Mine plan is amended and finalised.
- Application for a Groundwater License (GWL) to abstract groundwater for temporary dewatering purposes is made to DWER together with an Operating Strategy (OS) as required.
- DWER grants approval to the GWL and OS.
- The mine is developed.
- Clean stormwater on undisturbed areas is discharged to existing surface water courses.
- Groundwater is dewatered temporarily.
- The mining void is progressively backfilled with sand tailings and entrained water neutralised as required for any acidity associated with mineral processing, and amended with lime to offset possible ASS effects.
- Groundwater levels recover within the reinstated aquifer after the cessation of dewatering due to infill and natural rainfall recharge.
- Backfill of the mining void with pre-existing geological overburden is expected to return the aquifer to a similar pre-development condition, broadly reinstating previous unconfined flow conditions, groundwater quality and discharge characteristics.
- 1 or 2 remaining water bodies may be created adjacent to natural or man-made surface drainage. "*These lakes will be small in area, and be located where groundwater and surface-water flows maintain the surface water at a similar level to adjacent groundwater levels*."
- No impact is predicted from dewatering operations within the superficial aquifer on local groundwater users abstracting from the Leederville aquifer, which is confined and hydraulically separated from the superficial aquifer.
- The land surface is progressively rehabilitated to the pre-mining topography.
- Reinstatement of mine area progressively during active mining, with rehabilitation of the land and return to pre-existing land uses (agricultural).

This will need to be revised as the project develops further.

11. Conclusions and Recommendations

11.1 Conclusions

HydroSolutions Pty Ltd has undertaken an Initial Hydrogeological Desk Assessment for the proposed Yalyalup Mineral Sand Mine, on behalf of Doral Mineral Sands Pty Ltd. The objectives of the current work were to:

- Determine background information with regard to the surface water and groundwater systems at the Site and in its vicinity
- Perform a preliminary (Level 1) assessment of the impact of mine dewatering on the surface water and groundwater systems
- Identify any other potential impacts on the groundwater environment, including on any Groundwater Dependent Ecosystems (GDEs), Acid Sulfate Soils (ASS), and conservation wetlands and waters.

The Site is underlain by approximately 12-15 m of superficial Quaternary formations, comprising Bassendean Sand (Bsnd), Guildford Formation & at depth discontinuous lenses of Yoganup Formation (Yog); economic mineralisation occurs within the Bsnd & Yog, comprising the mining targets. Superficial formations are unconformably underlain by the Cretaceous Leederville Formation.

Groundwater is present at the Site within a multi-aquifer system, including the unconfined superficial aquifer, with an approximate saturated thickness of 12-14m, and the underlying confined Leederville and Yarragadee Aquifers. Groundwater within the Leederville aquifer is confined by a thick clay sequence, and is hydraulically separated from the superficial aquifer. Mining is planned to take place in the superficial formation only. It is understood that Doral proposes to abstract groundwater from the Yarragadee as a partial source of water supply for mineral processing at Yalyalup, with the remainder to be provided from dewatering discharge.

Groundwater flow in the superficial aquifer occurs to the northwest with an approximate hydraulic gradient of 0.0037. Hydraulic conductivities in the superficial formations are expected to range between 0.5-30 m/d. Groundwater in the superficial and Leederville aquifers is generally fresh to transitional.

The Sabina and Abba rivers are located within 1 km of the Site, but the site is wholly located within the Sabina river catchment area. The Sabina River discharges approximately 1.9 GL per year to the Vasse-Wonnerup wetlands and inlet at the coast, and has maximum flows of c2 m^3/s during winter months, reducing to no flow conditions (i.e. ephemeral) in most years during the summer months. Preliminary examination of published hydrographs and recent groundwater level monitoring by Doral, indicate that groundwater discharge is unlikely to be a significant proportion of stream flow, which is dominated by rainfall run-off. The Sabina and Abba Rivers are registered as Aboriginal Heritage sites with the Western Australian Department of Planning, Lands and Heritage.

Three local farm drains, some adapted from ephemeral creeks, occur on-Site with inverts of <1 to c1.5m below ground surface. Observed groundwater levels of between 1-3mBGL indicate that the field drains may be perched above the water table, but may intersect some groundwater flow during the post winter groundwater-high. The drains discharge via the western central drain into the Sabina River approximately 2 km downstream northwards of the Site, and below the Sabina River diversion drain.

A marshland on the north-eastern corner of the Site shown on published maps was not apparent during inspection of the Site. The Site is not in a proclaimed area for surface water management.

Various areas of potential terrestrial Groundwater Dependent Ecosystems (GDEs) occur within 5 km of the Site, mainly concentrated near the Sabina River. A detailed flora and fauna study by Ecoedge, 2016, concluded that further detailed studies on-Site may be required to identify at-risk GDEs, and the most likely vegetation areas to be dependent on groundwater occur on the eastern and north-eastern parts of the Site. Aquatic GDEs within 5 km of the Site are all categorised as “Multiple Use”, and therefore of lower environmental significance. Highly-significant conservation wetlands comprising the RAMSAR-listed Vasse-Wonnerup Wetlands Reserve, are located 7.5 km to the northwest, and will therefore not be impacted by dewatering activities at the Site.

A total of 64 licensed abstractions occur within 5 km of the Site, almost all of which abstract from the Leederville Aquifer, which is not expected to be impacted by mining operations. Approximately 26 (unlicensed) bores abstracting from the superficial aquifer occur on-Site.

A radius of influence, approximated as the 0.1m drawdown and estimated using several analytical methods, may extend between 95 to 1,083m from the Site, based on the quoted range of hydraulic conductivities. Initial estimates of discharge rates were made using two analytical methods to achieve dry-working in proposed quarterly mining segments. A Tier 1 analytical model of groundwater drawdown due to mine dewatering was used to estimate the abstraction needed spatially for the dry extraction of ore based on the initial mine plan for each segment. In most cases the modelled discharge was less than or comparable with the initial estimates, with the discharge for Q3 2026 (the largest single segment) being approximately 7,850m^3/d. The effective radius of influence given by the model was between c850m and c1200m, assuming the lower end of quoted hydraulic conductivities (c10m/d), based on the preponderance of clayey sands observed within the on-site sequence.

Estimated drawdowns of 1m are predicted to occur at between c560m to c670m, and of approximately 5m at between c90m and c300m distance from the mined segment. Bores abstracting from the superficial aquifer potentially impacted by the drawdown estimate are tabulated, including private bores for livestock, irrigation and domestic purposes, and monitoring bores undertaken by Department of Water and Environmental Regulation (DWER). Several of these bores were observed to be disused at mid-2017. It is emphasised, however that these are initial estimates of drawdown only, and will be revised as more site-specific data become available from site investigations, from additional modelling, and as the mining plan is further developed.

Possible mitigation measures may include:

- Survey of existing superficial groundwater usage, including existing abstraction equipment, bore construction, yield, existing groundwater quality and end-usage requirements with respect to required yield and quality;
- Provision of an alternative water supply from dewatering operations, or;
- Re-scheduling of planned dewatering periods to high water table (i.e. winter ‘wet’ high rainfall) months.

Other groundwater users, including those abstracting from the Leederville Aquifer, are not expected to be impacted by dewatering.

An initial assessment of published Acid Sulfate Soil (ASS) maps indicate that local shallow soils are in the Moderate to Low category, and therefore dewatering operations would not necessarily trigger further assessment by DWER. However, more detailed assessment of on-Site soils has been undertaken by Doral and consultants ABEC; it is understood by HydroSolutions that field tests from on-Site bores indicate a significant proportion of samples may be characterised as Potential Acid Sulfate Soils (PASS), although only 16 of 34 (47%) samples exceeded the criterion from materials within the proposed pit voids; Net acidity (NA) above the DER criterion triggers the requirement to develop an Acid Sulfate Soils Management Plan (ASSMP) (DER, June 2015a). In addition, the estimated extent and duration of dewatering operations are likely to trigger the need for Dewatering Management Level 2 as stipulated in DER June 2015b. Further measures are considered in ABEC, 2017.

The estimated extent of drawdown is not sufficient to impact any of the publically identified wetland GDEs in the vicinity, but may have an impact on local terrestrial GDEs on-Site; further assessment to identify any high-value GDEs on-Site is warranted. Possible mitigation measures may include:

- Further studies to identify high conservation value GDEs;
- Provision of monitoring bores within the unsaturated zone adjacent to conservation value GDEs to establish the seasonal variations in soil moisture profile and hence periods of potential stress
- As required, provision of reticulated irrigation to maintain any high conservation GDEs that may be under stress;
- Possible changes to the mining plan to:
    - Reduce the mining operational areas to minimise/ limit the dewatering requirement.
    - Avoid areas that may impact on any high-value GDEs identified.
    - Re-scheduling of the location/ timing and duration of dewatering operations to periods of high water table elevation following winter rainfall.

Dewatering may affect surface water flows within local field drains, however existing groundwater discharge is only likely to occur during groundwater high periods following winter recharge, and is therefore unlikely to be a significant proportion of surface water flow, on which basis dewatering operations are unlikely to impact significantly on the existing surface water flow regime. Initial estimates of dewatering indicate that local rivers will not be affected.

The mining operation is intended to be a ‘closed system’, with no off-Site water discharge occurring until on-Site water storages are full, at which time discharge will occur through a licensed or pre-agreed ‘emergency discharge’ location’. Stormwater falling onto disturbed areas will be added to the site water usage. However, clean incidental stormwater occurring on undisturbed areas unaffected by mining operations will flow off-Site into existing surface water courses.

Possible mitigation measures may include:

- Minimisation of the extent, duration and area of diversion of over-land flow/ surface water run-off from the mining footprint.
- Stormwater falling onto disturbed areas will be added to the site water usage. However, clean incidental stormwater occurring on undisturbed areas unaffected by mining operations will flow off-Site into existing surface water courses.
- Application under RIWI, 1914 for a permit from DWER to authorise interference or obstruction of the bed and banks of a watercourse or wetland at the point of discharge, for emergency discharges.
- Prevention/ minimisation of erosion at the point of discharge.
- Prevention of sediment release.
- Baseline surface water quality monitoring throughout the operational mining period, to verify that minimal or no impact is occurring.

11.2 Recommendations

The following recommendations are made:

- Local bores should be resurveyed to verify their locations and elevations in order to provide future accurate groundwater measurement.
- Survey of existing superficial groundwater usage, including existing abstraction equipment, bore construction, yield, existing groundwater quality and end-usage requirements with respect to required yield and quality, so that appropriate mitigation measures can be developed.
- Monitoring programs should be developed for groundwater and surface water to ensure that they are consistent with and provide suitable data for identified project objectives.
- Monitoring of groundwater bores should continue for an assessment of local spatial and seasonal variations in the water table, and to provide a baseline for surface and groundwater quality, particularly when surface water courses are flowing.
- Surface water monitoring should continue to provide baseline data, and to ensure that no unacceptable impacts are occurring.
- Hydrogeological investigation is required, to provide site-specific data, to support a probable H3 level of assessment for a groundwater license application, and to provide data for ASS management requirements
- A Tier 3 calibrated numerical model should be constructed for the Site, to provide a more comprehensive and reliable estimate of groundwater impacts, and as required under a probable H3 level of assessment.
- Further groundwater investigations are warranted to support a groundwater license application for process water abstraction from the Yarragadee aquifer.
- Further investigation of terrestrial GDEs on Site should be performed, based on the derived water table and detailed topography of the Site, concentrating on the eastern and north-eastern sides of the project area, in order to identify any high-conservation GDEs present on site warranting preservation so that appropriate mitigation measures can be developed.

12. Limitations

HydroSolutions Pty Ltd (the Consultant) has prepared this report for the Client, in accordance with generally accepted consulting practice and the Consultants' Terms of Business. No other warranty, either expressed or implied, is made as to the professional advice included in this report. The Consultant disclaims any responsibility in respect of any matters outside the scope of the terms of agreement with the Client. In preparing this report, the Consultant has relied upon and presumed accurate, certain information provided by the Client or third parties. Unless otherwise stated in the report, the Consultant has not attempted to verify the accuracy or completeness of any such information.

This report is intended for the use of the Client only. It is not intended for use by third parties, nor is it to be relied upon for any purpose other than the use for which it was commissioned. It may or may not contain sufficient information for the purposes of other parties or for other uses. The Consultant accepts no responsibility to third parties to whom this report or any part thereof is made known. A third party relies upon the report at its own risk. It is recommended that any plans and specifications prepared by others and relating to the content of this report or amendments to the original plans and specification be reviewed by HydroSolutions Pty Ltd to verify that the intent of our recommendations is properly reflected in the design.

Whilst to the best of our knowledge information contained in this report is accurate at the date of issue, subsurface conditions, including contaminant concentrations, can change over time. This should be borne in mind if the report is used after a protracted delay. There are always some variations in subsurface conditions across a site that cannot be fully defined by investigation. Hence it is unlikely that the measurements and values obtained from sampling and testing during the investigation will represent the extremes of conditions that exist within the site. In accordance with standard practice, the assessment carried out is site specific. Consequently, the assessment does not address environmental liabilities that may or may not pertain to other properties either currently or previously owned or operated by the client, or to other off-site environmental liabilities.

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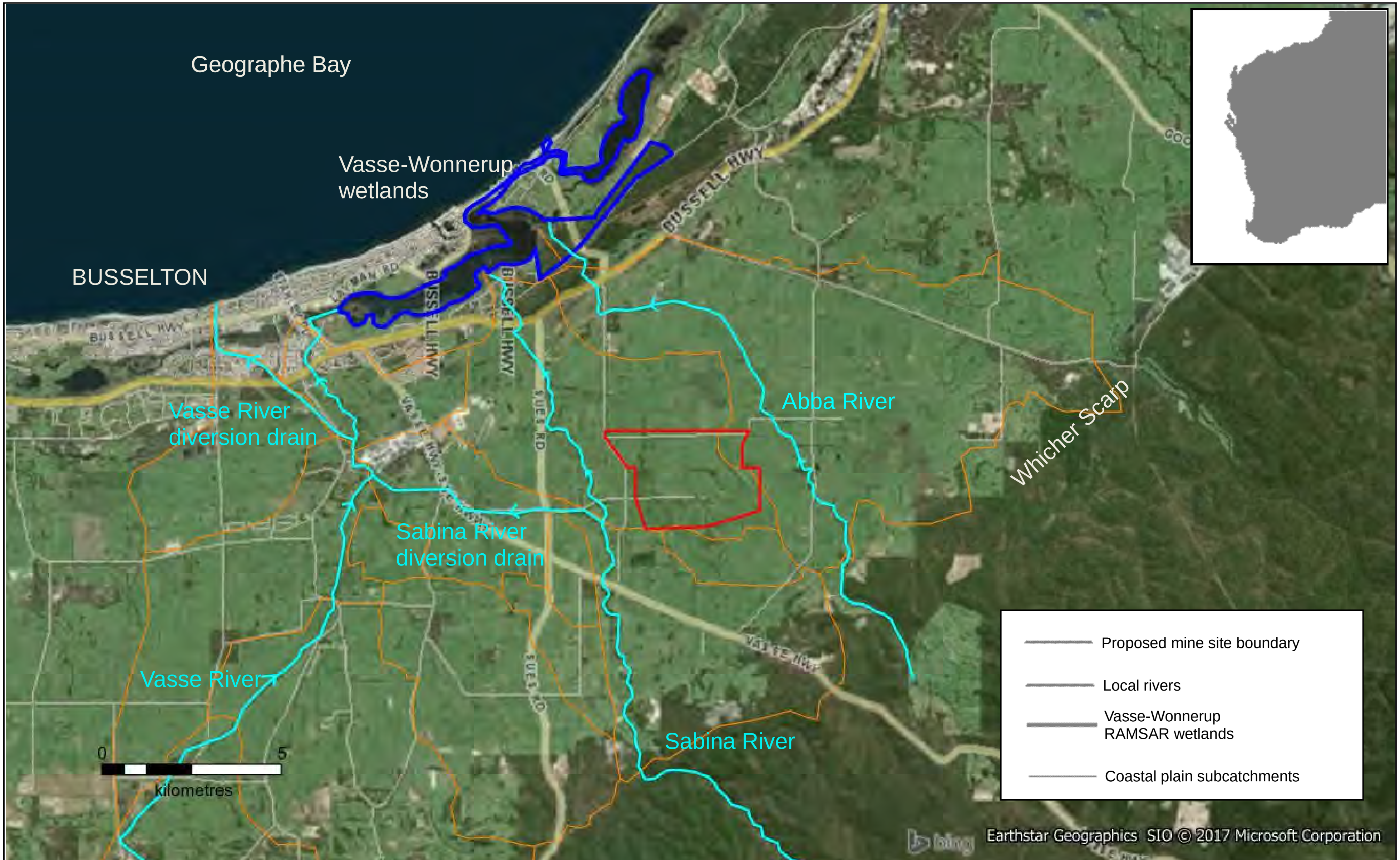

HYDROSOLUTIONS PTY LTD

CLIENT:	Doral Mineral Sands	SCALE:	As shown
PROJECT:	DMS532	DRAWN:	AK
FIGURE:	1: Site Location and major drainage	DATE:	August 2017
		FILE:	DMS532-r3145-F1

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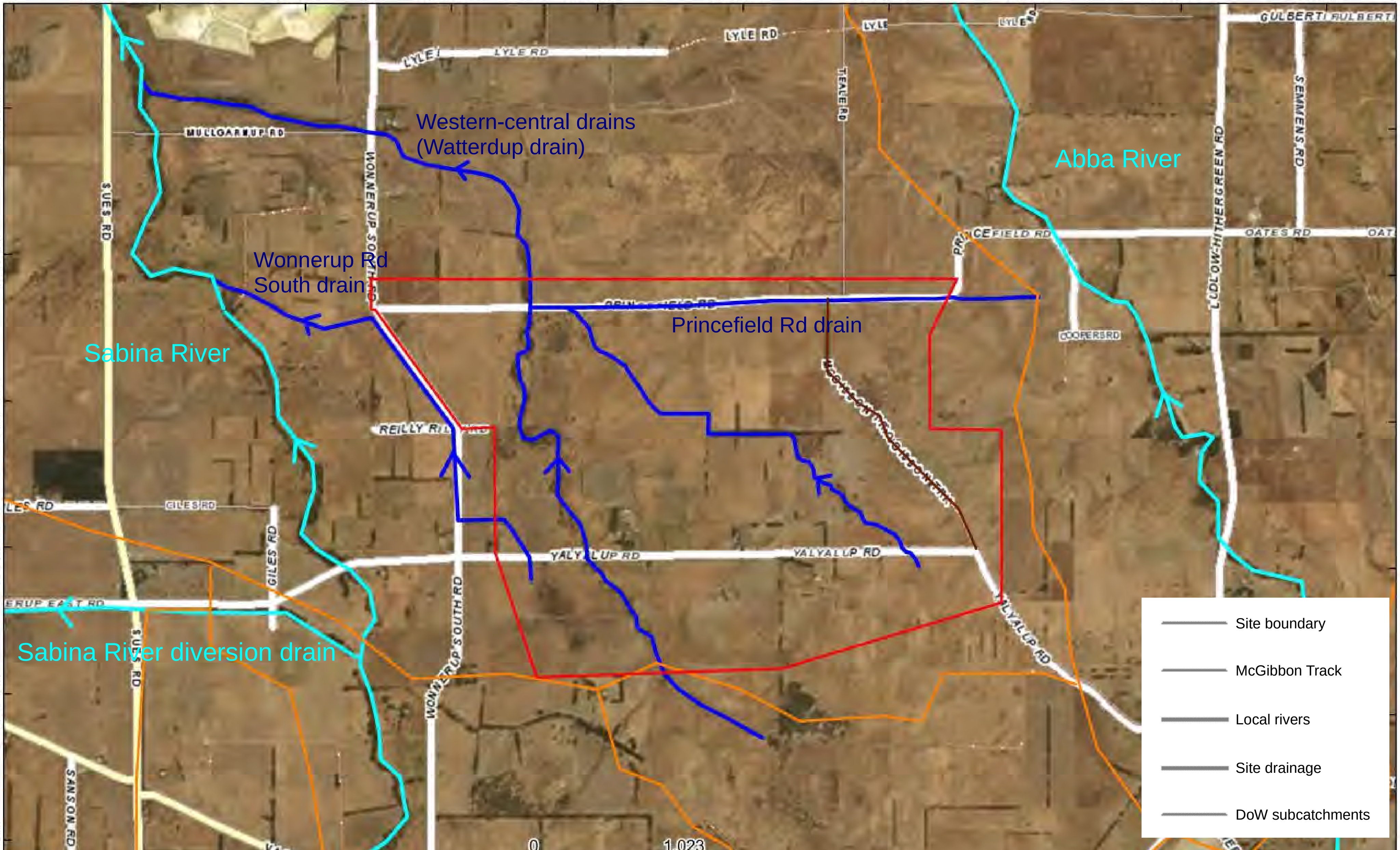
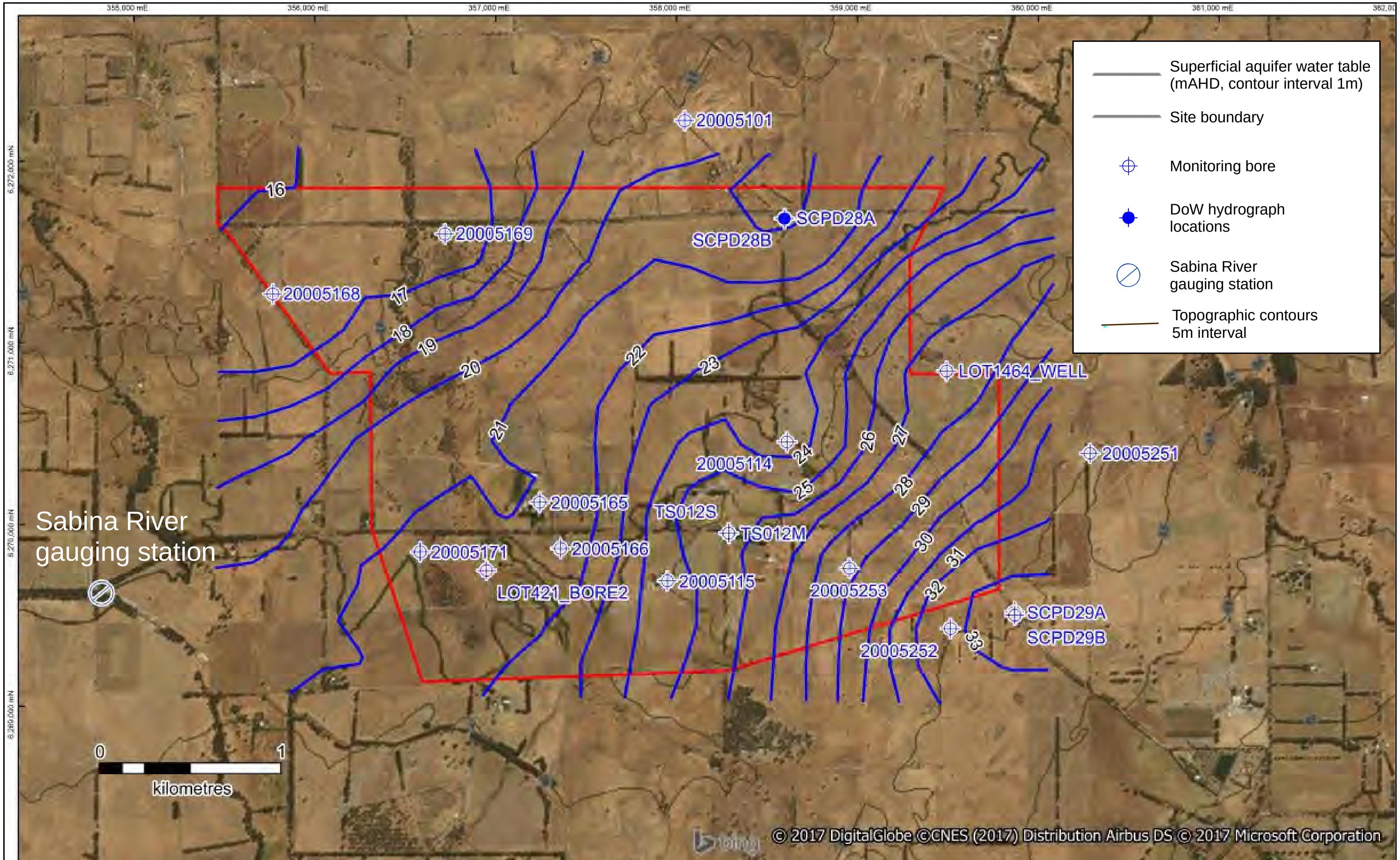


HYDROSOLUTIONS PTY LTD

CLIENT:	Doral Mineral Sands	SCALE:	As shown
PROJECT:	DMS532	DRAWN:	AK
FIGURE:	2: Site Layout	DATE:	August 2017
		FILE:	DMS532-r3145-F2



HYDROSOLUTIONS PTY LTD

CLIENT: Doral Mineral Sands

PROJECT: DMS532

FIGURE: 3: Provisional water table, June 2017

SCALE: As shown

DRAWN: AK

DATE: August 2017

FILE: DMS532-r3145-F3

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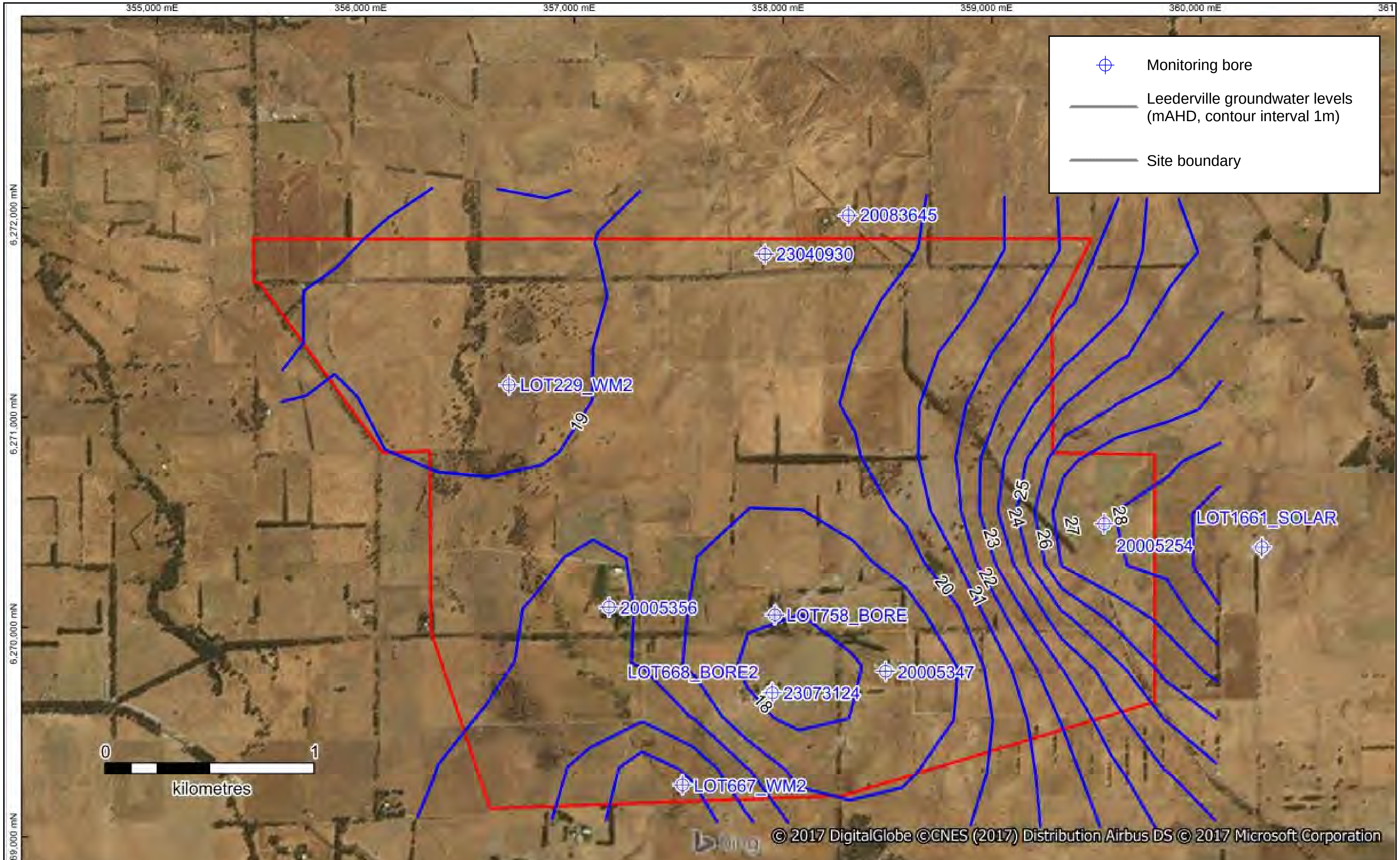

HYDROSOLUTIONS PTY LTD

CLIENT: Doral Mineral Sands

PROJECT: DMS532

FIGURE: 4: Provisional groundwater levels, Leederville Aquifer June 2017

SCALE: As shown

DRAWN: AK

DATE: August 2017

FILE: DMS532-r3145-F4

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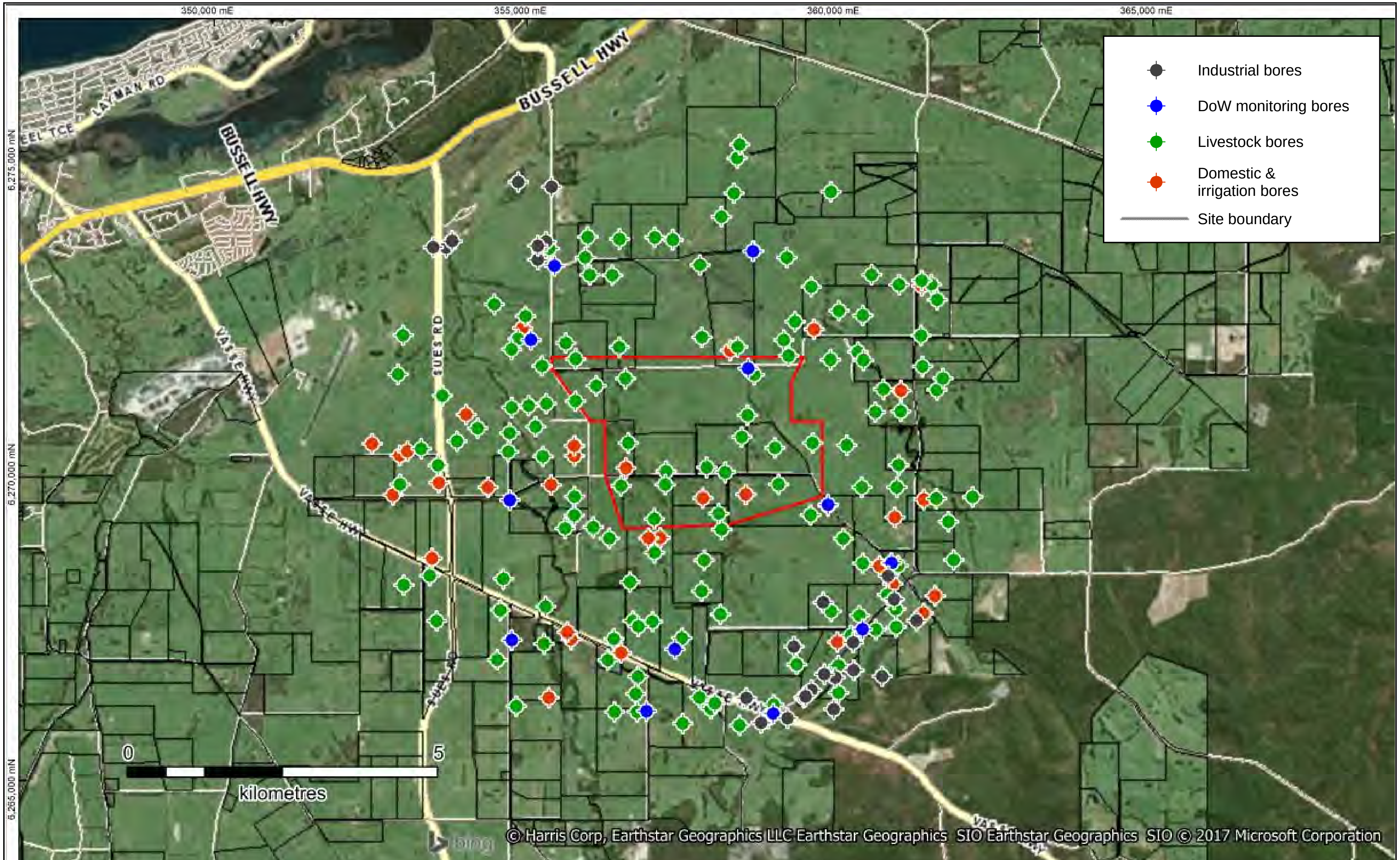


HYDROSOLUTIONS PTY LTD

CLIENT: Doral Mineral Sands

PROJECT: DMS532

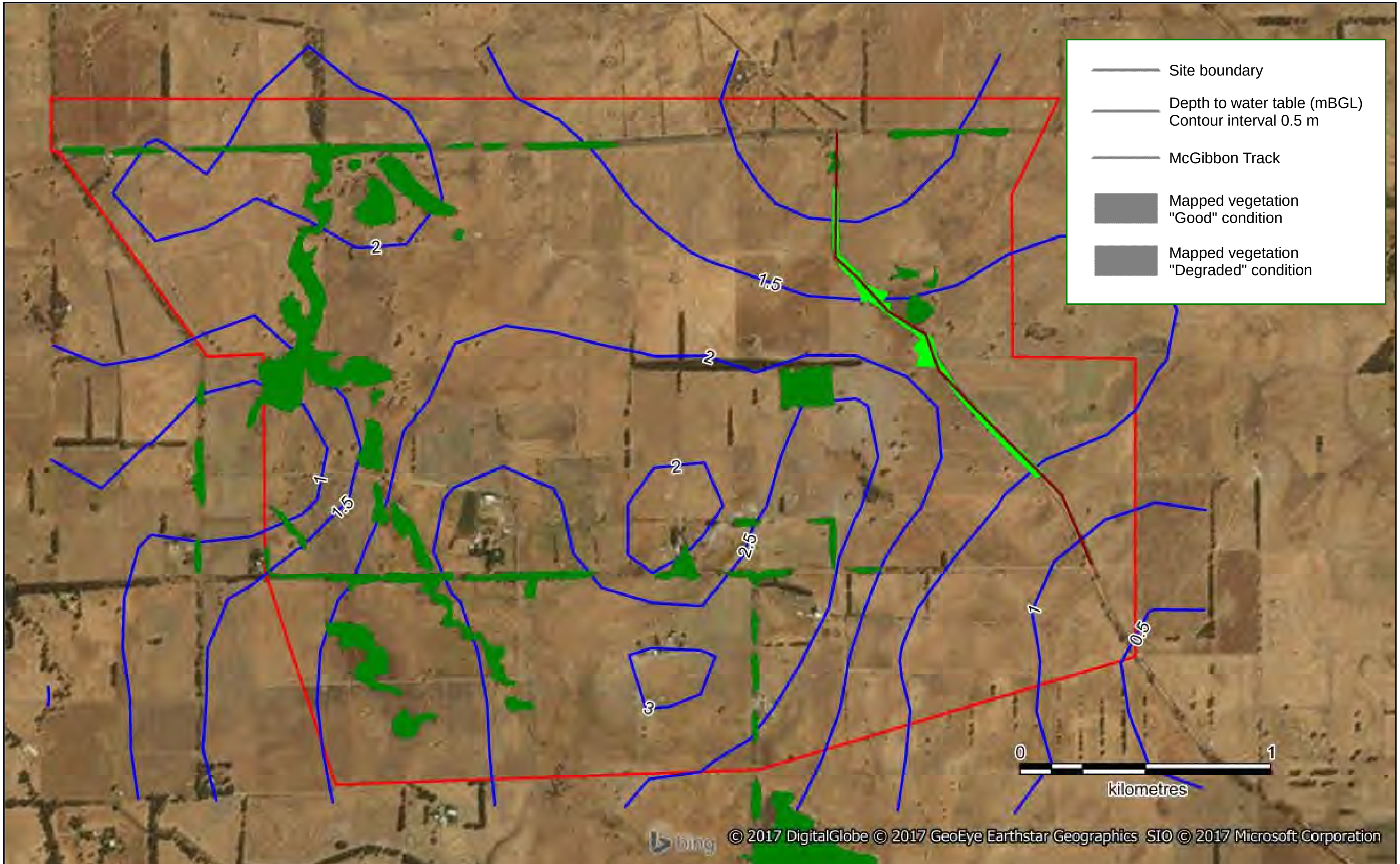
FIGURE: 5: Abstraction bores within 5 km

SCALE: As shown

DRAWN: AK

DATE: August 2017

FILE: DMS532-r3145-F5



HYDROSOLUTIONS PTY LTD

CLIENT: Doral Mineral Sands
PROJECT: DMS532
FIGURE: 6: Potential terrestrial GDEs

SCALE: As above
DRAWN: AK
DATE: August 2017
FILE: DMS532-r3145-F6

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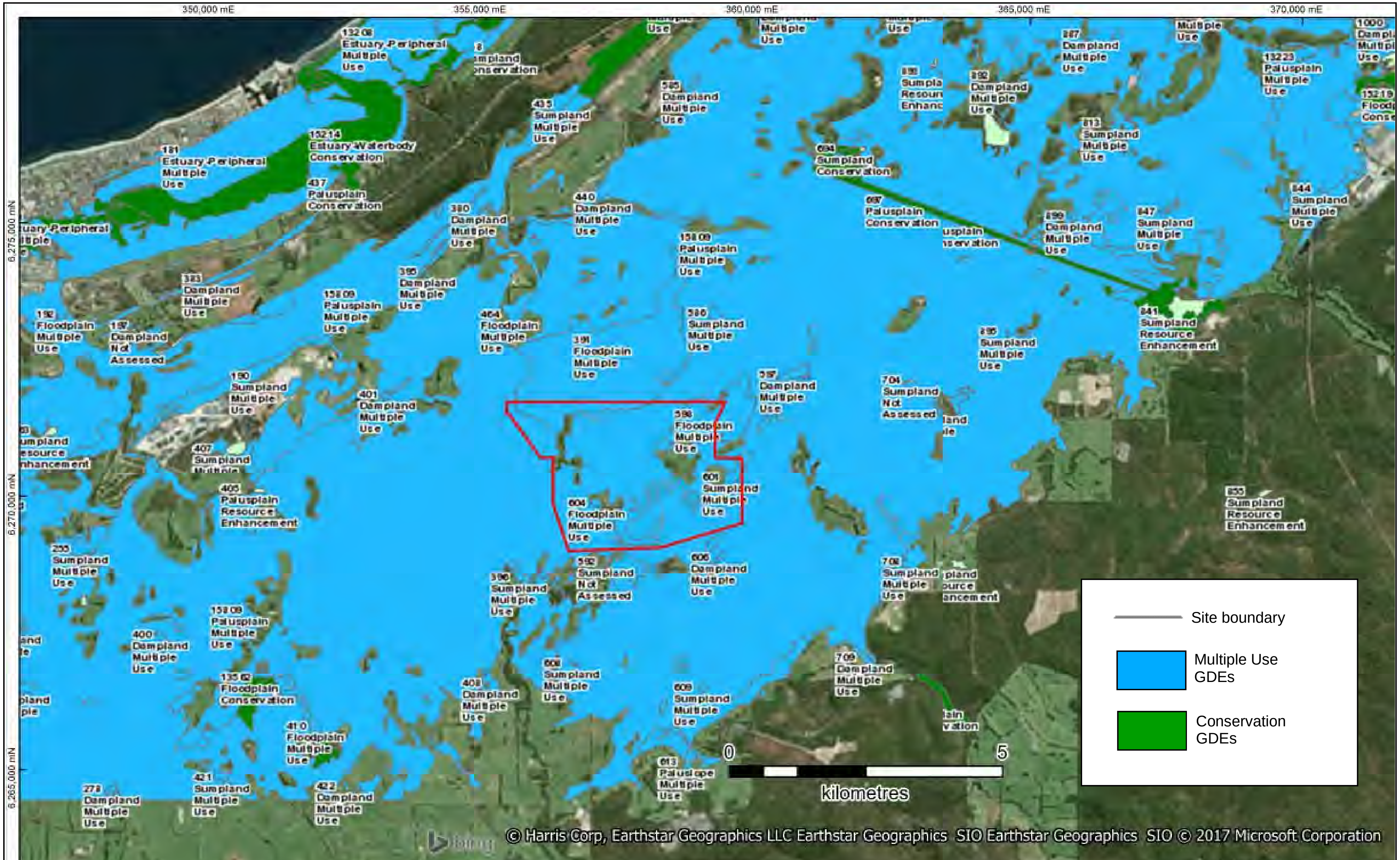
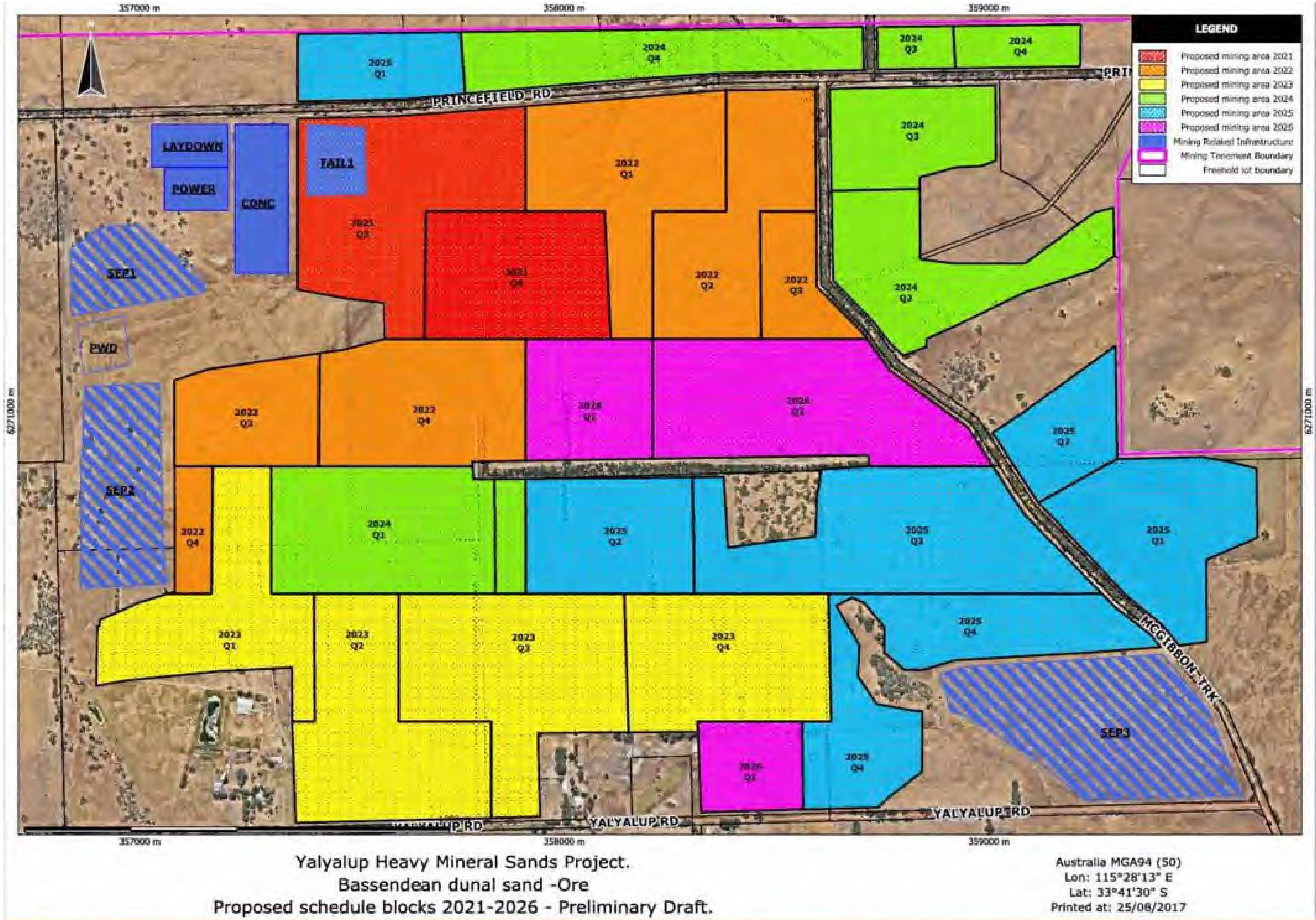


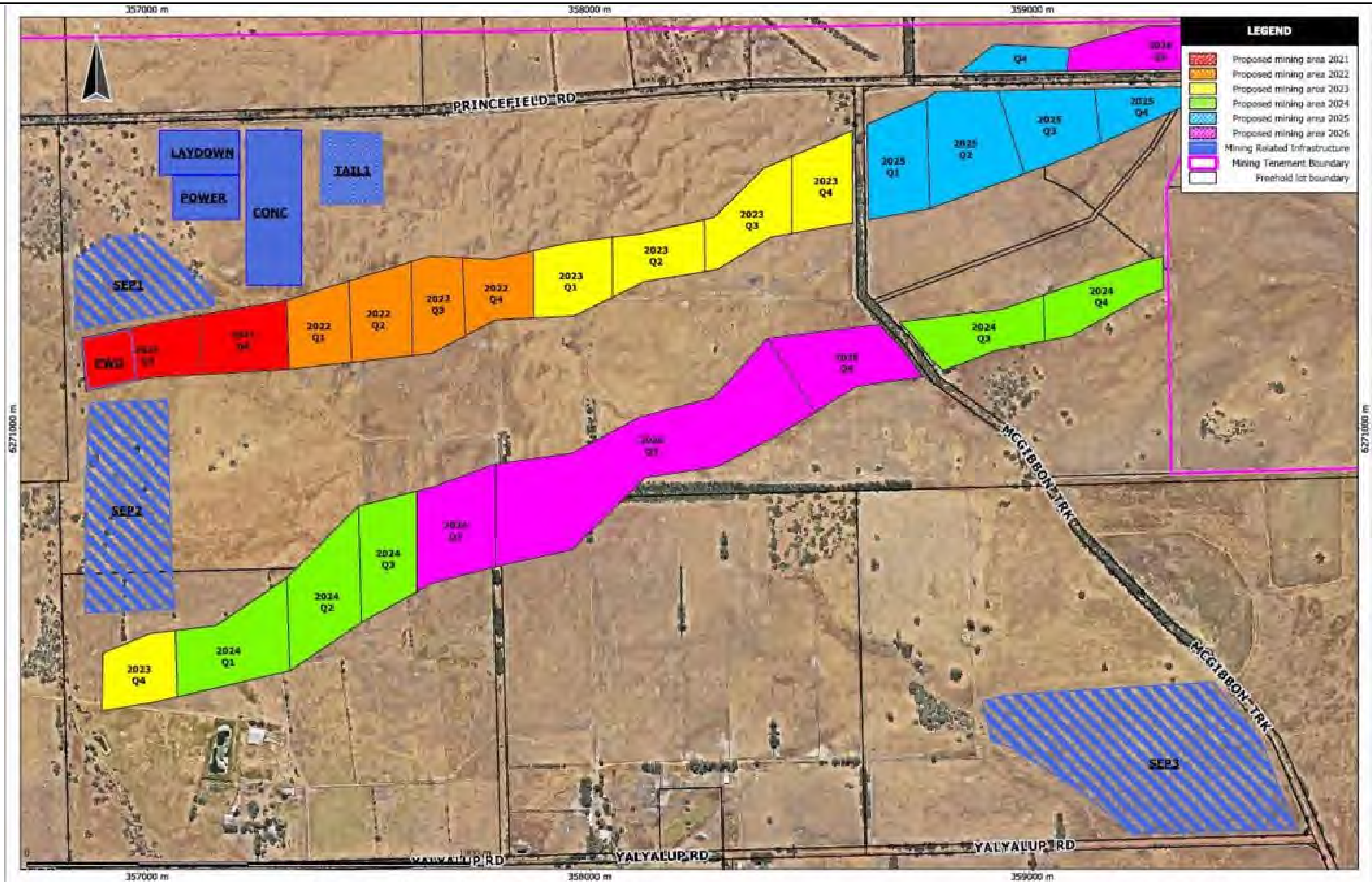
HYDROSOLUTIONS PTY LTD

CLIENT:	Doral Mineral Sands	SCALE:	As shown
PROJECT:	DMS532	DRAWN:	AK
FIGURE:	7: Aquatic groundwater dependent ecosystems within 5 km	DATE:	August 2017
		FILE:	DMS532-r3145-F7



HYDROSOLUTIONS PTY LTD

CLIENT:	Doral Mineral Sands	SCALE:	As shown
PROJECT:	DMS532	DRAWN:	After Doral Mineral Sands
FIGURE:	8: Surface layout of proposed mine	DATE:	August 2017
		FILE:	DMS532-r3145-F8



Yalyalup Heavy Mineral Sands Project.
Guildford Clay Overburden and Yoganup Strand Ore
Proposed schedule blocks 2021-2026 - Preliminary Draft.

Australia MGA94 (50)
Lon: 115°28'13" E
Lat: 33°41'30" S
Printed at: 25/08/2017

HYDROSOLUTIONS PTY LTD

CLIENT:	Doral Mineral Sands	SCALE:	As shown
PROJECT:	DMS532	DRAWN:	After Doral Mineral Sands
FIGURE:	9: Yoganup Fmn mining at depth	DATE:	August 2017
		FILE:	DMS532-r3145-F9

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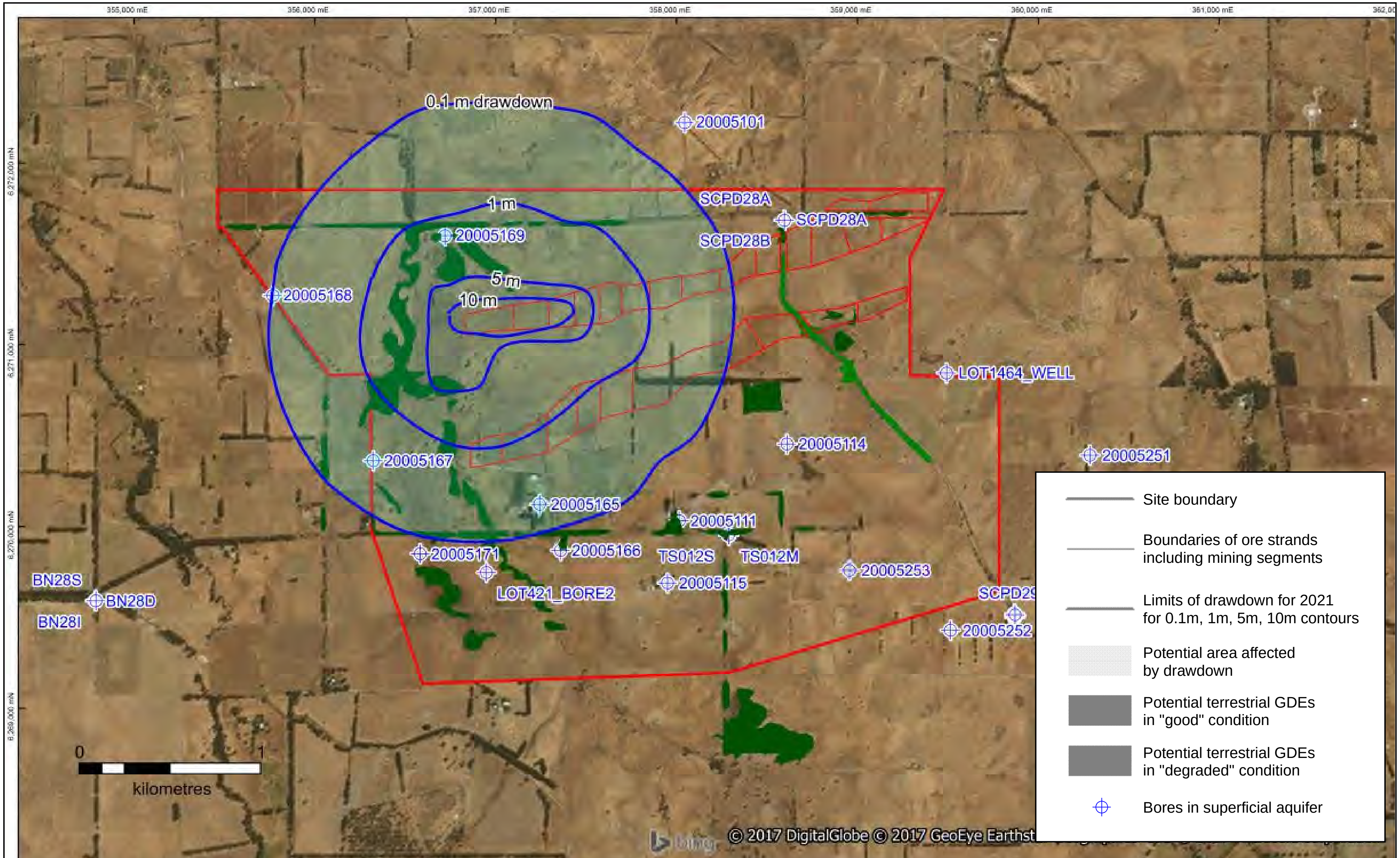

HYDROSOLUTIONS PTY LTD

CLIENT:	Doral Mineral Sands	SCALE:	As shown
PROJECT:	DMS532	DRAWN:	AK
FIGURE:	10: Dewatering estimate, 2021	DATE:	August 2017
		FILE:	DMS532-r3145-F10

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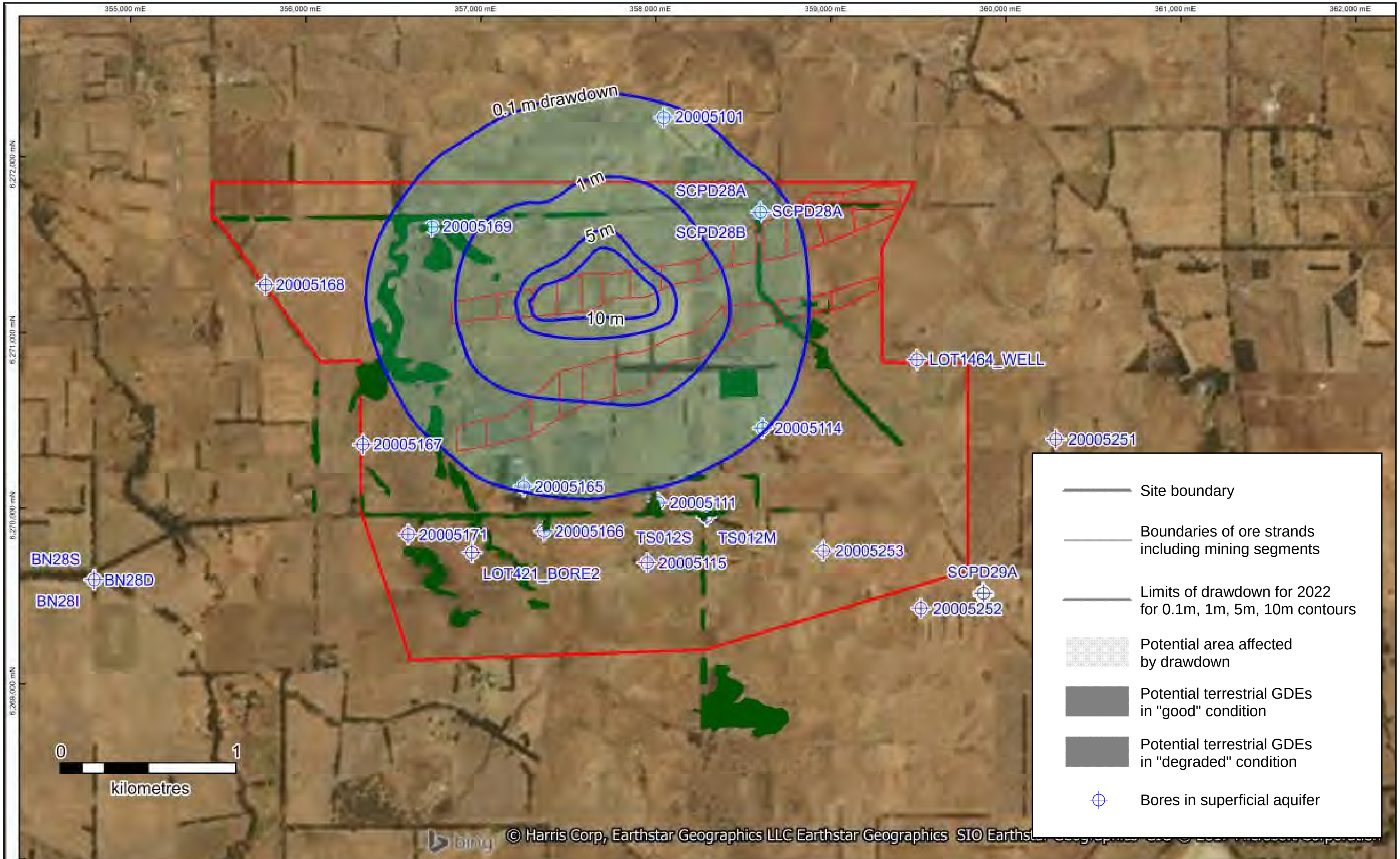

HYDROSOLUTIONS PTY LTD

		SCALE:	As shown
CLIENT:	Doral Mineral Sands	DRAWN:	AK
PROJECT:	DMS532	DATE:	August 2017
FIGURE:	11: Dewatering estimate, 2022	FILE:	DMS532-r3145-F11

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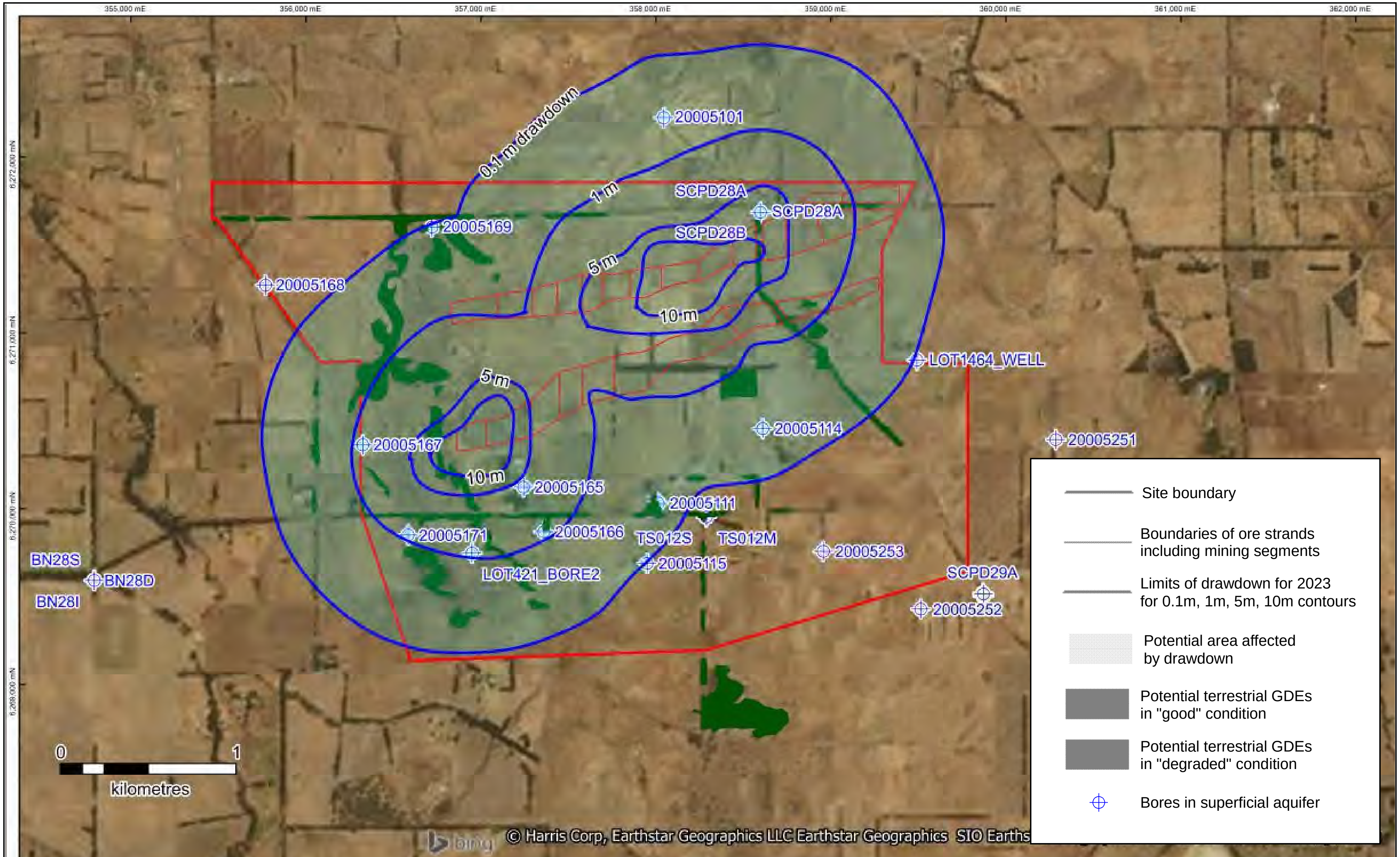

HYDROSOLUTIONS PTY LTD

CLIENT: Doral Mineral Sands

PROJECT: DMS532

FIGURE: 12: Dewatering estimate, 2023

SCALE: As shown

DRAWN: AK

DATE: August 2017

FILE: DMS532-r3145-F12

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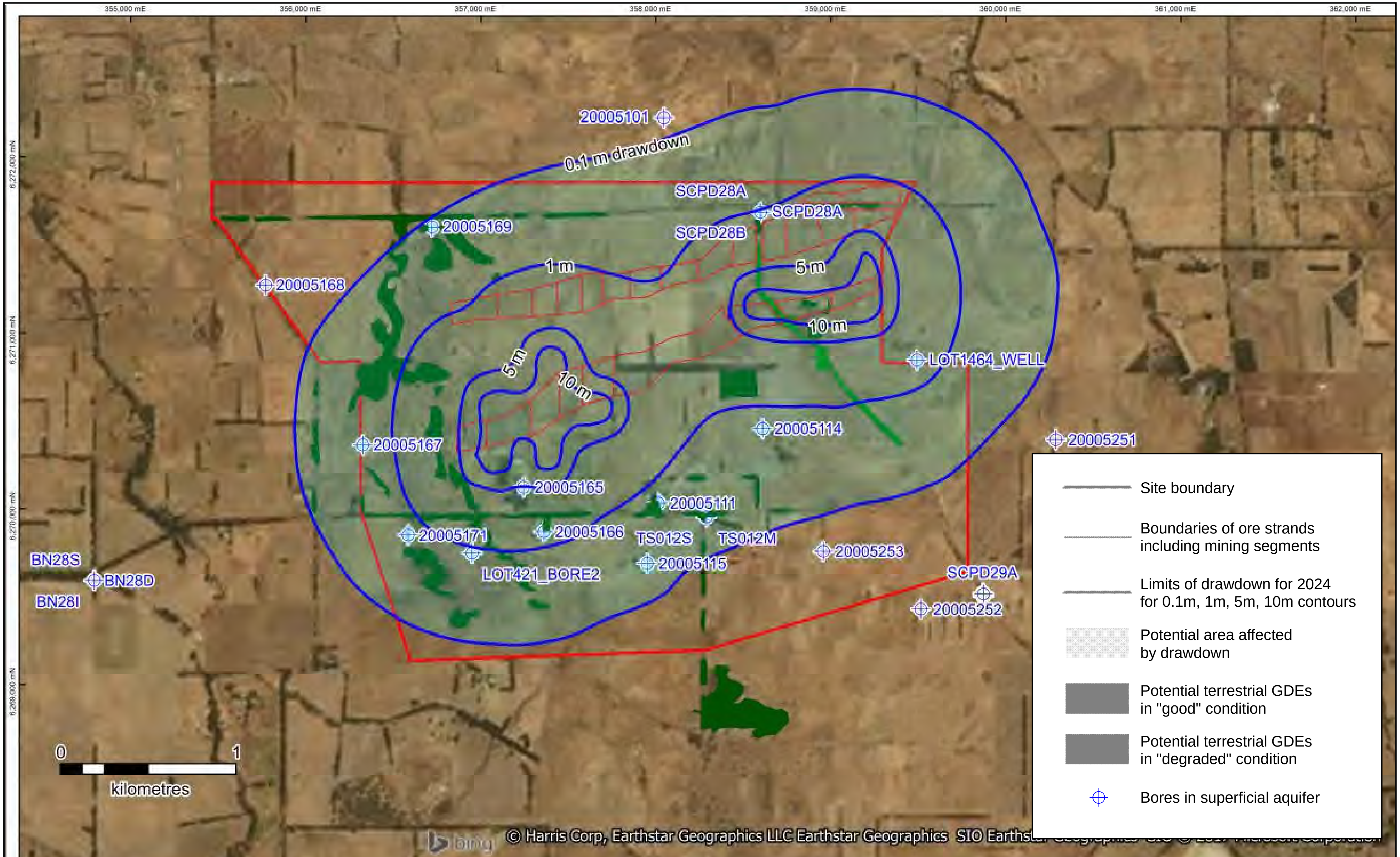

HYDROSOLUTIONS PTY LTD

CLIENT:	Doral Mineral Sands	SCALE:	As shown
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FIGURE:	13: Dewatering estimate, 2024	DATE:	August 2017
		FILE:	DMS532-r3145-F13

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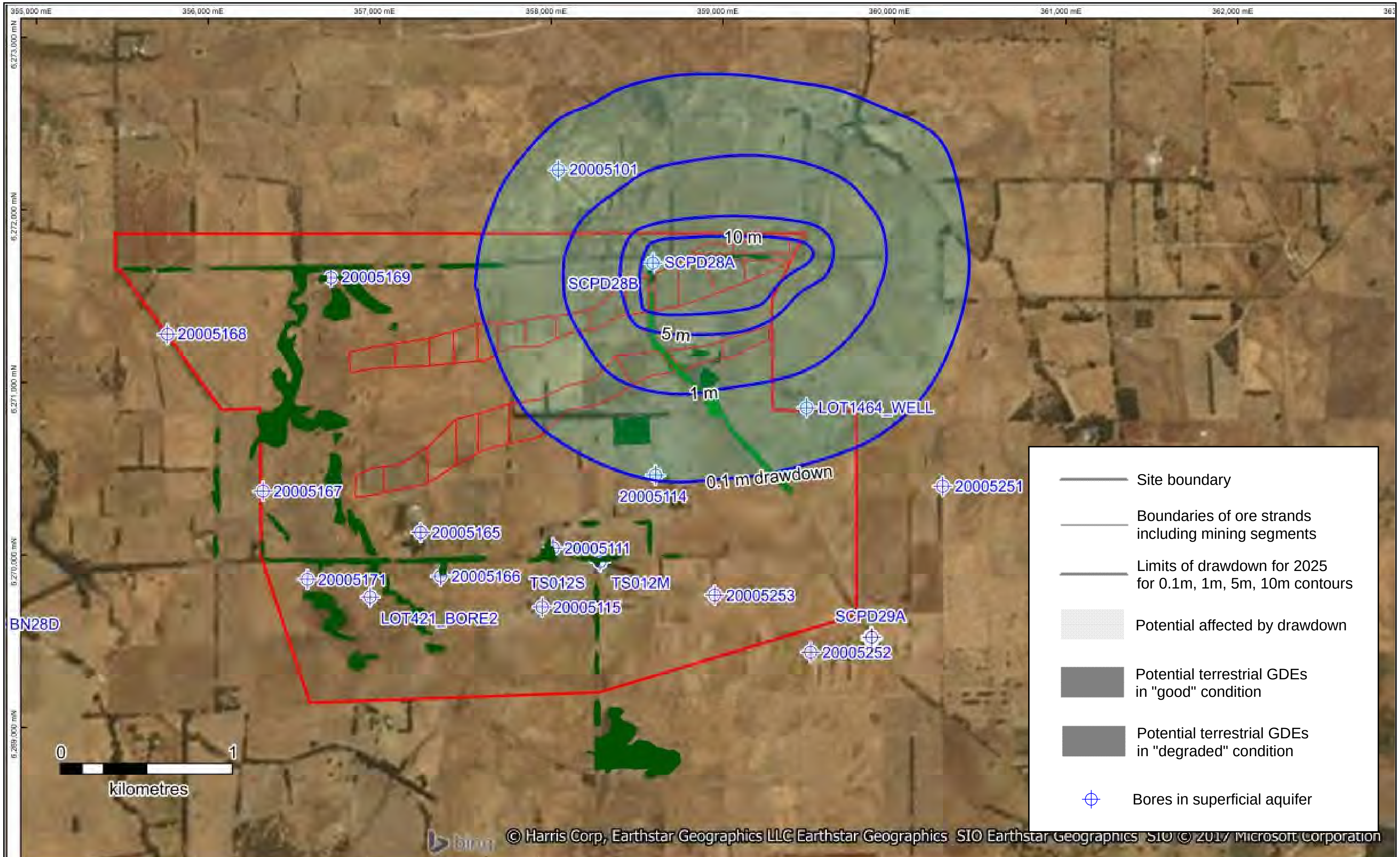


HYDROSOLUTIONS PTY LTD

CLIENT: Doral Mineral Sands

PROJECT: DMS532

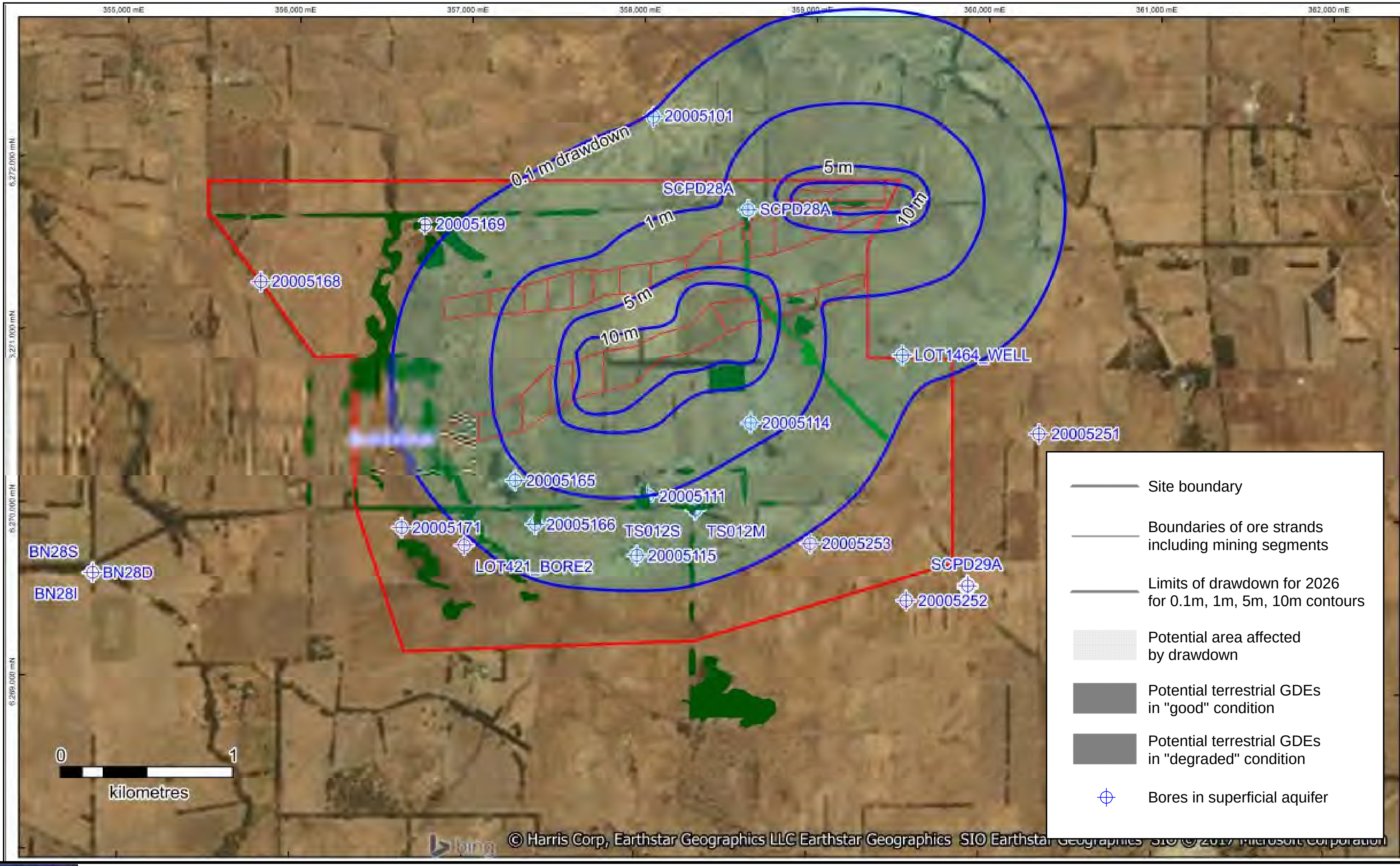
FIGURE: 14: Dewatering estimate, 2025

SCALE: As shown

DRAWN: AK

DATE: August 2017

FILE: DMS532-r3145-F14



HYDROSOLUTIONS PTY LTD

CLIENT:	Doral Mineral Sands	SCALE:	As shown
PROJECT:	DMS532	DRAWN:	AK
FIGURE:	15: Dewatering estimate, 2026	DATE:	August 2017
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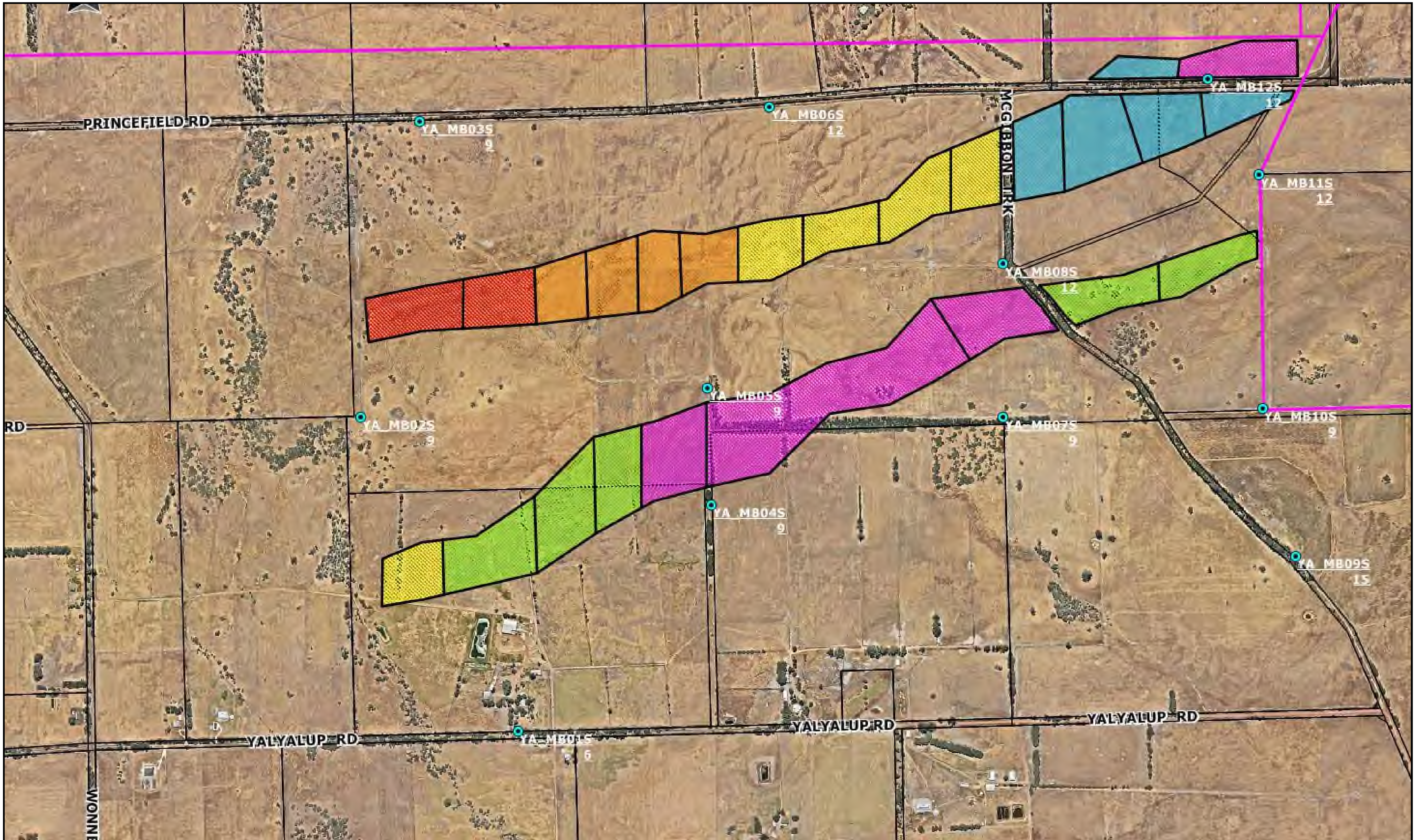

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CLIENT:	Doral Mineral Sands Ltd	DRAWN:	SRJ (data supplied by Doral)
PROJECT:	DMS532	DATE:	September 2017
FIGURE:	16: Initial proposed monitoring bore locations	FILE:	HD-DMS532-r3145-F16

KEY

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Appendix 1: Licensed Groundwater Abstractions

Department of Water Licensed Abstractions within 5 km of the Site				
Licence Number	**Name**	**Licence Address**	**Abstraction (kL)**	**Aquifer**
		WITHIN PROJECT AREA		
156606	Shorelands Pastoral Co	Lot 971 On Plan 137479 Volume/Folio 1778/575 Lot 971 Wonnerup South Rd Abba River	2220	Leederville
67672	Macleay, Peter Hervey	Lot 843 On Plan 134692 Volume/Folio 1841/682 Lot 843 Yalyalup Rd Abba River	9500	Leederville
178017	Macleay, Peter Hervey	Sussex Location 758 and being the whole of the land comprised in Certificate of Title Volume 1170 Folio 957	1500	Leederville
50966	Paperbark Farm	Lot 1426 On Plan 140184 Volume/Folio 1155/672 Lot 1426 Yalyalup Rd Yoongarillup; Sussex Location 667 and being the whole of the land comprised in Certificate of Title Volume 866 Folio 114	14500	Leederville
177828	Boardman, Darryl Fredric	Lot 3773 On Plan 140318 Volume/Folio 1319/491 Lot 3773 Yalyalup Rd Hithergreen; Lot 1816 On Plan 201688 Volume/Folio 1908/731 Lot 1816 LudlowHithergreen Rd Hithergreen; Lot 3882 On Plan 140318 Volume/Folio 1150/505 Lot 3882 Yalyalup Rd Hithergreen; Lot 2 on Diagram 65503 Certificate of Title Volume/Folio 1655/450	200000	Leederville
174905	Slade Parkin Pty Ltd	Sussex Location 668 and being the whole of the land comprised in Certificate of Title Volume 976 Folio 149	1800	Leederville
180362	Stefani, Jeremy	Lot 421 On Plan 113233 Volume/Folio 1332/290 Lot 421 Yoongarillup	100000	Leederville
94291	Hester, Kimberley McBride	104, PRINCEFIELD RD, ABBA RIVER; 103 PRINCEFIELD ROAD, ABBA RIVER	3100	Leederville
		WITHIN 5KM SOUTH		
107623	Brand, Adrian Ralph	Portion of Sussex Location 552	2850	Leederville
95377	Copeland, Anthony Hedley	220, WONNERUP SOUTH RD, YOONGARILLUP; Lot 221 On Plan 301730 Volume/Folio 1366/703 Lot 221 Wonnerup South Rd Yoongarillup	3000	Leederville
182032	O'Neill, Timothy John	Lot 2 On Diagram 25972 Volume/Folio 1242/52 Lot 2 Sidebottom Rd Hithergreen; Lot 1825 On Plan 201688 Volume/Folio 425/151a Lot 1825 Sidebottom Rd Hithergreen; Lot 1821 On Plan 201688 Volume/Folio 1242/52 Lot 1821 Sidebottom Rd Hithergreen; Lot 1826 On Plan 201688 Volume/Folio 425/150a Lot 1826 LudlowHithergreen Rd Hithergreen; Lot 1827 On Plan 201688 Volume/Folio 425/151a Lot 1827 LudlowHithergreen Rd Hithergreen; Lot 1 On Diagram 25972 Volume/Folio 1930/253 Lot 1 Sidebottom Rd Hithergreen; Lot 1819 On Plan 201688 Volume/Folio 1930/252 Lot 1819; Lot 681 On Plan 130373 Volume/Folio 1811/128 Lot 681 Avery Rd Hithergreen; Lot 581 On Plan 128032 Volume/Folio 1298/570 Lot 581 Avery Rd Yoongarillup	30000	Leederville
164407	Trigwell, Wayne	Lot 832 On Plan 134092 Volume/Folio 1547/573 Lot 832 Vasse Hwy Yoongarillup	3200	Leederville
106573	Trigwell, Wayne	677, , YOONGARILLUP	1150	Leederville
175045	Iluka Resources	Lot 7 On Plan 29159 Volume/Folio 2584/377 Lot 7 LudlowHithergreen Rd Hithergreen; Lot 6 On Plan 29159 Volume/Folio 2584/376 Lot 6 LudlowHithergreen Rd Hithergreen	1500	Leederville
161847	Iluka Resources	M70/401,M70/1052,M70/414,M70/415,M70/403,M70/672,M70/467, M70/1107 YOGANUP; M70/959 North Capel Leases, M70/278, M70/295, M70/914, M70/279, M70/257, M70/970 North Capel Operations, M70/1082, M70/990, M70/978, M70/962, M70/386, M70/1083, M70/1128, M70/1117; M70/612 Tutunup South; State Forest 12 Lot 1589 Bussell Hwy Ludlow M70/63 Capel Wetlands; Lot 2 On Diagram 90768 Volume/Folio 2204/99 Lot 2 Jenkin Rd Capel Dry Mill; M70/63 South Capel; Lot 7 On Diagram 45177 Volume/Folio 1365/874 Lot 7 Capel S.R Plant; Lot 6 On Plan 14174 Volume/Folio 2054/896 Lot 6 Bussell Hwy Capel S.R Plant; Lot 4453 On Plan 254024 Volume/Folio 1063/762 Lot 4453 Matthews Rd Capel S.R Plant; M70/401,M70/1052,M70/414,M70/415,M70/403,M70/672,M70/467, M70/1107 YOGANUP; Lot 3739 On Plan 140795 Volume/Folio 1215/949 Lot 3739 Capel River Yoganup; M70/611, M70/612, M70/1261 Tutunup South; Lot 3345, Capel; Wellington Loc 3719 North Capel Minesite; 10, MANGLES RD, STRATHAM	6500000	Yarragadee
167315	Iluka	M70/1261 Tutunup South; M70/611; M70/612	1040000	Superficial

	Resources			
99745	Woodward, James	Lot 2047 On Plan 203006 Volume/Folio 1859/383 Lot 2047 Vasse Hwy Hithergreen	4000	Leederville
176760	Jasper Farms Holdings	Lot 798 On Plan 225726 Volume/Folio 1179/461 Lot 798 Sabina River; Lot 3 On Diagram 33452 Volume/Folio 2788/642 Lot 3 Ruabon Rd Ruabon; Lot 4 On Diagram 33452 Volume/Folio 2788/643 Lot 4 Wonnerup South Rd Ruabon; Lot 21 On Plan 402137 Volume/Folio 2848/399 Lot 21 Lot 22 On Plan 402137 Volume/Folio 2848/400 Lot 22 Lot 20 On Plan 402137 Volume/Folio 2848/398 Lot 20	624000	Leederville
99166	Piggott, Mervyn Ronald	Lot 110 On Plan 24758 Volume/Folio 2651/375 Lot 110 Yoongarillup Rd Yoongarillup; Lot 111 On Plan 24758 Volume/Folio 2651/376 Lot 111 Yoongarillup Rd Yoongarillup	3000	Leederville
159521	Blythe, Richard Roland	Lot 10 On Plan 21593 Volume/Folio 2107/927 Lot 10 Vasse Hwy Yoongarillup	1500	Leederville
52395	Sunderland, Christine Elsie	Lot 401 On Plan 108109 Volume/Folio 2107/928 Lot 401 Vasse Hwy Yoongarillup	8500	Leederville
61294	Williamson, Ross	Lot 839 On Plan 137478 Volume/Folio 1919/497 Lot 839 Myrtle Vale Yoongarillup	18000	Leederville
63214	Avery, Ian Lawrence	Sussex Location 929 comprised in Certificate of Title Volume 2103 Folio 799	3000	Leederville
63254	KD Power Pastoral CO Pty Ltd	Lot 2059 On Plan 203008 Volume/Folio 1748/961 Lot 2059 Payne Rd Chapman Hill; Lot 2308 P203027; Lot 289 P100990 & Lot 1134 P254255; Lot 1 On Diagram 58865 Volume/Folio 1571/400 Lot 1 Yoongarillup; Lot 2062 & 2061 P203008; Lot 1472 On Plan 153366 Volume/Folio 1452/526 Lot 1472 Vasse Hwy Yoongarillup; Lot 2060 On Plan 203008 Volume/Folio 1748/962 Lot 2060 Payne Rd Chapman Hill; Lot 2306 On Plan 203027 Volume/Folio 1579/49 Lot 2306 Doyle Rd Ambergate; Lot 2309 On Plan 203027 Volume/Folio 1579/50 Lot 2309 Doyle Rd Ambergate; Lot 2310 On Plan 203027 Volume/Folio 1579/51 Lot 2310 Doyle Rd Ambergate; Lot 2061 On Plan 203008 Volume/Folio 1748/959 Lot 2061 Payne Rd Chapman Hill; Lot 1134 On Plan 254255 Volume/Folio 1596/465 Lot 1134 Vasse Hwy Yoongarillup	20500	Leederville
WITHIN 5KM EAST				
98218	Johnson, Peter Michael	Lot 1813 On Plan 201688 Volume/Folio 1977/276 Lot 1813 Palmer Rd Hithergreen; Lot 1811 On Plan 201688 Volume/Folio 1977/276 Lot 1811 Palmer Rd Hithergreen; Lot 1812 On Plan 201688 Volume/Folio 1977/276 Lot 1812 Hithergreen Lot 1812 On Plan 201688	40000	Yarragadee
155670	Johnson, Darryl Joseph	Lot 3913 On Plan 166159 Volume/Folio 1222/800 Lot 3913 Hithergreen; Lot 3913 On Plan 166159 Volume/Folio 1222/800 Lot 3913 Palmer Rd Hithergreen	1500	Leederville
172434	Johnson, Todd Anthony	Lot 1810 on PLAN 201688 Certificate of Title Volume/Folio 1245/211 Williamson Road, Hithergreen	28000	Leederville
172933	Kemp, Maureen	Lot 958 On Plan 81564 Volume/Folio 2227/988 Lot 958 Hithergreen; Lot 1157 On Plan 82059 Volume/Folio 1398/906 Lot 1157 Banksia Rd Hithergreen; Lot 141 On Plan 33018 Volume/Folio 2227/986 Lot 141 LudlowHithergreen Rd Hithergreen; Lot 142 On Plan 33018 Volume/Folio 2227/987 Lot 142 LudlowHithergreen Rd Hithergreen	3000	Leederville
155719	Clifford, Peter Malcolm	Lot 52 On Diagram 92432 Volume/Folio 2121/211 Lot 52 Yalyalup Rd Hithergreen	1500	Leederville
97098	Graeme Baesjou	Portion of Sussex Location 1817 and being Lot 51 on Diagram 92432.	39100	Leederville
174021	Slee, Ian Sydney	Lot 1661 On Plan 153335 Volume/Folio 1198/657 Lot 1661 Yalyalup Rd Hithergreen	1000	Leederville
169309	Oates, Jamie Allen	Lot 63 On Plan 49002 Volume/Folio 2631/292 Lot 63 Ruabon; Lot 62 On Plan 49002 Volume/Folio 2631/291 Lot 62 Ruabon; Lot 652 On Plan 130367 Volume/Folio 1143/326 Lot 652 LudlowHithergreen Rd Abba River	32000	Leederville
179889	Buchan, John	Lot 81 On Plan 70426 Volume/Folio 2813/618 Lot 81	1500	Leederville
63163	O'Neill, Timothy John	Sussex Locations 1800, 1801 and 3195 being the whole of land comprised on Certificate of Title Volume 1406 Folio 684; Lot 1800 On Plan 201688 Volume/Folio 1406/684 Lot 1800 Banksia Rd Hithergreen; Lot 1799 On Plan 201688 Volume/Folio 1402/959 Lot	30000	Swan Superficial

		1799 Banksia Rd Hithergreen		
49903	Oates, Rodney Allen	Lot 100 On Plan 40387 Volume/Folio 2573/953 Lot 100 Abba River; LOT 1762 ON PLAN 201682; Lot 1763 On Plan 201682 Volume/Folio 2193/631 Lot 1763 Oates Rd Abba River; Lot 1764 On Plan 201682 Volume/Folio 1344/338 Lot 1764 Oates Rd Abba River	41000	Leederville
180513	Cox, Stephen John	Lot 4 On Diagram 70962 Volume/Folio 1813/679 Lot 4 Semmens Rd Abba River	1500	Leederville
162993	Harbeck, Christopher Ian	Lot 60 LudlowHithergreen Rd, Ludlow Lot 61 on Plan 49002 Volume/Folio 2631/290	1500	Leederville
177482	Croxford, Clive Desmond	Volume/Folio 1245/670 Lot 1757 Gulberti Rd Ruabon	12000	Leederville
180898	Ealing, Berendina Johanna Maria	Lot 1759 On Plan 201682 Volume/Folio 1547/195 Lot 1759 Abba River	4500	Leederville
168061	Wright, Mark Alistair	Lot 1758 On Plan 201682 Volume/Folio 1547/194 Lot 1758 Gulberti Rd Ruabon	40000	Leederville
168024	Tutunup Pty Ltd	Lot 74 On Plan 57221 Volume/Folio 2675/290 Lot 74 Tutunup Rd Tutunup	900	Leederville
WITHIN 5KM WEST				
181194	Kimbolton Greyman Pty Ltd	Lot 200 On Plan 301787 Volume/Folio 2116/919 Lot 200 Yalyalup Rd Abba River	18400	Leederville
49902	Oates, Peter James	Lot 1976 On Plan 153063 Volume/Folio 1231/696 Lot 1976 Giles Rd Yalyalup; Lot 1975 On Plan 201694 Volume/Folio 1536/487 Lot 1975 Yalyalup; Lot 1978 On Plan 201694 Volume/Folio 1231/697 Lot 1978 Wonnerup East Rd Yalyalup; Lot 1 On Diagram 31020 Volume/Folio 1292/783 Lot 1 Yalyalup; Lot 1977 On Plan 201694 Volume/Folio 2050/147 Lot 1977 Yalyalup	27000	Leederville
164408	Craigie, Mary	Lot 3 On Diagram 42927 Volume/Folio 1324/234 Lot 3 Wonnerup East Rd Yalyalup	1000	Leederville
183817	Oates, Peter James	LOT 1370 ON PLAN 251516; Lot 8 On Plan 232754 Volume/Folio 2130/620 Lot 8	60000	Leederville
150672	City of Busselton	Reserve 34260 (Heseltine Park); Reserve 30 (McBride Park); Reserve 37236 (Herron Place); Lot 340 Vasse Highway Busselton (Busselton Airport); Reserve 31975 (Wilmot Park); Reserve 28734 (Alexander / Hovea); Old Broadwater Farm Reserve 48279	46200	Swan Superficial
150671	City of Busselton	Busselton Cemetery Reserve 9298 LR3137/416; Sir Stewart Bovell Park Lot 20 Vasse Highway, Bovell Volume/Folio 1390/368; Lou Weston Lot 4539 King St, West Busselton Volume/Folio LR3004/329; Crown Reserve 38558 Lot 3001 on Plan 43542 Marine Terrace Busselton; Reserve 8485 (Barnard Park Central); Old Broadwater Farm Reserve 48279; Dolphin Park Lot 428 Butcherbird Pl, West Busselton Volume/Folio LR3144/886; Reserve for Recreation & Drainage Cnr Walpole Loop & Paterson Dr, Yalyalup Lot 8001 on Deposited Plan 400177; Barnard Park Cnr Marine Tce and Milne St, Busselton LR3166/953; Marine Tce Lot 503 on Plan 402933 Volume/Folio LR3166/951; Signal Park Lot 400 on Plan 185938 Volume/Folio LR3148/672; Lot 418 On Plan 189088 Volume/Folio Lr3004/735 Lot 418; Lot 556 On Plan 408338 Volume/Folio Lr3167/352 Lot 556 Lot 500 On Plan 402933 Volume/Folio Lr3166/948 Lot 500 Foreshore Pde Busselton; Foreshore Lot 556 on Plan 408338 Volume/Folio LR3167/352; Churchill Park Lot 556 on Plan 408338 Volume/Folio LR3167/352; Carey St Lot 507 on Plan 402933 Volume/Folio LR 3166/955	483777	Leederville
157168	East Busselton Estate Pty Ltd	Lot 204 On Plan 32475 Volume/Folio 2223/979 Lot 204 Airport Dr Yalyalup; Water can only be used on 'POS Areas' as described in "Provence POS Irrigation Strategy Rev B" plan as submitted to the Department of Water on 15 July 2010 and for the maintenance of the Almond Parkway Lake; Lot 9032 On Plan 406716 Volume/Folio 2891/698 Lot 9032 Cable Sands Rd Yalyalup; Lot 9030 On Plan 405433 Volume/Folio 2901/289 Lot 9030; Lot 8001 On Plan 59382 Volume/Folio Lr3155/224 Lot 8001; Lot 8002 On Plan 59382 Volume/Folio Lr3155/287 Lot 8002; Lot 8004 On Plan 62834 Volume/Folio Lr3158/810 Lot 8004 Seguret Pwy Yalyalup; Lot 8003 On Plan 62834 Volume/Folio Lr3158/809 Lot 8003 Thyme Pass Yalyalup; Lot 9030 On Plan 405433 Volume/Folio 2901/289 Lot	168300	Yarragadee

		9030		
159609	Suncove Asset Pty Ltd	Lot 3160 On Plan 153066 Volume/Folio 2182/85 Lot 3160 Yalyalup	1500	Leederville
167410	Rea, David John	Lot 3161 On Plan 153066 Volume/Folio 2181/475 Lot 3161 Yalyalup	1400	Leederville
157265	Worrall, Trevor	Lot 300 on Plan 27743 Volume/Folio 2219/393 Lot 300 Sues Rd Yalyalup	1500	Leederville
63018	Gow, David	Lot 370 On Plan 106350 Volume/Folio 1940/801 Lot 370 Wonnerup East Rd Yalyalup	6000	Leederville
174360	Craigie, Cyril	Lot 302 On Plan 27796 Volume/Folio 2219/395 Lot 302 Giles Rd Yalyalup	1000	Leederville
		WITHIN 5KM NORTH		
161841	Cable Sands (WA) Pty Ltd	M70/86 Ludlow; G70/83, G70/191 North Shore, Bunbury; M70/899, M70/895 Gwindinup Mine Site; Lot 100 On Plan 65306 Volume/Folio 2731/156 Lot 100 Wonnerup South Rd Yalyalup Wonnerup; M70/360 Wonnerup North; M70/569 Wonnerup North; M70/785 Wonnerup South	3900000	Yarragadee
168831	Rival Pty Ltd	Lot 424 on Plan 113235 comprised in Certificate of Title Volume 1070 Folio 780; Lot 107 On Plan 246012 Volume/Folio 1434/392 Lot 107 Lyle Rd Abba River; Lot 1 On Plan 37025 Volume/Folio 2582/842 Lot 1 Lyle Rd Ruabon; Lot 1323 On Plan 140114 Volume/Folio 992/95 Lot 1323 Lyle Rd Abba River; 1270, , RUABON; Lot 101 On Diagram 99536 Volume/Folio 2188/677 Lot 101	63700	Leederville
110289	Hodge, Robert	125, WONNERUP SOUTH RD, ABBA RIVER	1500	Leederville
58886	Avery, Trevor William	Lot 4 On Diagram 47033 Volume/Folio 1406/302 Lot 4 Wonnerup South Rd Yalyalup	2500	Leederville
156423	Clayton, John Rodney	Lot 6 On Diagram 68068 Volume/Folio 1700/495 Lot 6 Wonnerup South Rd Ruabon	400000	Yarragadee
110434	Manning, Ross Harry	Lot 3819 On Plan 153196 Volume/Folio 2069/595 Lot 3819 Bussell Hwy Yalyalup	640000	Yarragadee
176760	Jasper Farms Holdings Pty Ltd	Lot 798 On Plan 225726 Volume/Folio 1179/461 Lot 798 Sabina River; Lot 3 On Diagram 33452 Volume/Folio 2788/642 Lot 3 Ruabon Rd Ruabon; Lot 4 On Diagram 33452 Volume/Folio 2788/643 Lot 4 Wonnerup South Rd Ruabon; Lot 21 On Plan 402137 Volume/Folio 2848/399 Lot 21 Lot 22 On Plan 402137 Volume/Folio 2848/400 Lot 22 Lot 20 On Plan 402137 Volume/Folio 2848/398 Lot 20	624000	Leederville
169471	Teale, John Edward	Lot 1831 On Plan 201682 Volume/Folio 2600/290 Lot 1831 Ruabon	1700	Leederville
110298	Johnson, Todd Anthony	835, , RUABON; Lot 847 On Plan 134123 Volume/Folio 1229/220 Lot 847 Ruabon	37000	Yarragadee
156776	D'Opera, Steven Michael	Lot 822 On Plan 134122 Volume/Folio 1349/119 Lot 822 Ruabon	34500	Yarragadee
179187	Cowper, Kenneth	Lot 60 On Plan 72086 Volume/Folio 2797/474 Lot 60 Bussell Hwy Ruabon	1500	Leederville
178880	Earl, Peter Colin	Lot 61 On Plan 72086 Volume/Folio 2797/475 Lot 61 Bussell Hwy Ruabon	1500	Leederville

Appendix 2: On-Site Bores

Known On-Site Bores				
Bore name	Easting	Northing	Elevation (mAHD)	Depth (mBGL)
SCREENED IN SUPERFICIAL AQUIFER				
20005101	358052	6272283	20.5	3.6
20005111	358054	6270091	25	6.5
20005114	358644	6270521	25	5.5
20005115	357995	6269748	28	8.54
20005165	357282	6270170	23.5	3.7
20005166	357402	6269919	23.8	4.3
20005167	356360	6270395	22	4.88
20005168	355790	6271295	17.8	7.93
20005169	356737	6271639	18.1	3.8
20005171	356627	6269888	23	6.2
20005251	360319	6270483	33.4	4.2
20005252	359563	6269510	34.8	4
20005253	359000	6269832	30.5	3.4
LOT1464_WELL	359520	6270925	29	4.2
LOT421_BORE2	356993	6269791	23.2	6
SCPD28A	358612	6271752	21.2	9
SCPD28B	358612	6271751	21.2	3.3
SCPD29A	359916	6269605	34.8	9.5
SCPD29B	359917	6269588	34.8	2.6
TS012M	358329.71	6270015.68	29.24	9
TS012S	358329.55	6270016.58	29.33	5.5
SCPD28A	358612	6271752	21.2	9
SCPD28B	358612	6271751	21.2	3.3
SCPD29A	359916	6269605	34.8	9.5
SCPD29B	359917	6269588	34.8	2.6
BN28S	354837.67	6269602.36	24.67	6.7
BN29S	359917.89	6269600.79	33.39	9
SCREENED IN LEEDERVILLE AQUIFER				
20005254	359572	6270576	30	17
20005347	358537	6269856	28.5	67.6
20005356	357207	6270142	23.5	16.5
20083645	358326	6272028	20.5	42
23040930	357928	6271837	19.8	48
23073124	357993	6269748	28	69
LOT1661_SOLAR	360330	6270474	33.4	20.45
LOT1661_WM1	359864	6269833	33	28.6
LOT200_BORE	356347	6270064	22.25	70
LOT229_WM2	356712	6271194	19.2	16
LOT3773_WM	359644	6270317	31	Unknown
LOT421_BORE1	357323	6269971	25	48
LOT552_BORE	356220	6269870	23	70
LOT667_WM1	358311	6269190	29	11
LOT667_WM2	357571	6269300	26	16.8

LOT668_BORE2	357996	6269745	28	25.3
LOT758_BORE	358002	6270118	25.5	30
LOT1293_WM1	357467	6271303	20	Unknown
LOT1293_WM2	357950	6271185	22	Unknown
LOT3752_WM1	358812	6271744	22	Unknown
LOT3752_WM2	359035	6271304	25	Unknown
LOT421_BORE2	356993	6269791	26	6
BN28D	354837.52	6269603.73	24.66	101.75
BN28I	354835.76	6269602.4	24.55	31.5
BN29D	359918.96	6269598.28	34.8	101.75
BN29I	359918.67	6269599.69	33.6	23.5

Appendix 3: Groundwater Quality

Wellhead Parameters

Bore Name	Date Measured	Plumbed depth of bore	Electrical Conductivity	Salinity	pH	Redox Potential	Temperature
		mBD	µS/cm OR mS/cm	g/L	pH units	+/- mV	˚C
SCPD28A (DoW)	*27/06/2017*		3250	1630	6.25		15.2
20005166	*29/06/2017*		1750	870	6.20	105	15.40
TS012M	*29/06/2017*		1120	560	5.86	93	17
Statistics							
Minimum	-	-	*810*	*410*	*5.86*	*52*	*15.2*
Maximum	(NEPM 2013 Sch B4, S3.4.4, No value>250% of Tier 1 SV)	-	*4530*	*2260*	*7.65*	*217*	*17*
N (No. values)	-	-	*10*	*10*	*10*	*4*	*3*
Mean	-	-	*2201*	*1100*	*6.63*	*116.75*	*15.87*
Median	-	-	*1985*	*990*	*6.68*	*99*	*15.40*
Std Dev	(NEPM 2013 SchB4 S3.4.4 SD<50% of Tier 1 SV)	-	*1099.60*	*548.84*	*0.50*	*70.58*	*0.99*
95% UCL	-	-	2882.53	1440.17	6.94	185.92	16.98
DER (2014) Fresh Water Guidelines (FWG)		FWG	-	-	6.5 - 8.5	-	-
DER 2014 Marine Water Guidelines (MWG)		MWG	-	-	8.0 - 8.4	-	-
ANZECC (2000) FWG Low Reliability Trigger Values (µg/L)		FWG-LRTV	-	-	-	-	-
DER (2014) Short-term Irrigation Water (IWG-STV)		IWG-STV	-	-	-	-	-
DER (2014) Long-term Irrigation Water (IWG-LTV)		IWG-LTV	<12.2mS, crop varies T4.2.5	-	6.0-8.5 gw 6.0-9.0 sw	-	-
DoH (2014) Contaminated Sites Ground & Surface Water Chemical Screening Guidelines (Domestic Non-potable Groundwater (NPUG) use		NPUG	-	-	-	-	-

Notes

DER (2014). Assessment Levels for Water: Marine Water Guideline (MWG) / Fresh Water Guideline (FWG)

DER (2014). Assessment Levels for Water: Drinking Water Health Value (HV) / Aesthetic Value (AV)
DER (2014). Assessment Levels for Water: Short-term Irrigation Water Guideline (ST-IWG) / Long-term Irrigation Water Guideline (LT-IWG)
Department of Health (2014). Contaminated Sites Ground & Surface Water Chemical Screening Guidelines, Domestic non-potable groundwater use (NPUG)

Groundwater Analytical Results
Standard Water Quality Parameters Including Major Ions

Sample ID	Sample information	Date of sampling	Laboratory	Laboratory Batch No.	pH (Lab)	EC (Lab)	Water type	Major Ions: TDS	Major Ions: Alkalinity	Major Ions: Chloride (Cl)	Major Ions: Sulphate (SO_4)	Nutrients: Ammonia (as NH_3-N at pH 8)	Nutrients: Total Nitrogen	Nutrients: Total Phosphorus
Units					-	uS/cm	-	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
SCPD28A (DoW)		*27-Jun-17*			6.6	3160	*Brackish*	1800		940	120			0.42
20005166		*29-Jun-17*			6.6	1730	*Transitional*	1000	64	380	160	<0.01	4.9	<0.005
TS012M		*29-Jun-17*			6.3	1090	*Fresh*	610	87	230	80	1.8	4.6	0.012
Statistics														
Minimum	-	-	-	-	*6.3*	*743*	-	*420*	*50*	*150*	*77*	*0.01*	*1.1*	*0.01*
Maximum	(NEPM 2013 Sch B4, S3.4.4, No value>250% of Tier 1 SV)				*8.3*	*4590*	-	*2700*	*250*	*1200*	*450*	*1.8*	*4.9*	*0.42*
N (No. values)	-	-	-	-	*5*	*5*	-	*5*	*4*	*5*	*5*	*3*	*3*	*4*
Mean	-	-	-	-	*7.02*	*2262.60*	-	*1306*	*112*	*580*	*177*	*0.64*	*3.53*	*0.12*
Median	-	-	-	-	*6.60*	*1730*	-	*1000*	*75*	*380*	*120*	*0.10*	*4.60*	*0.02*
Std Dev	(NEPM 2013 SchB4 S3.4.4 SD<50% of Tier 1 SV)				*0.80*	*1596.09*	-	*942*	*92*	*464*	*156*	*1.01*	*2.11*	*0.20*
95% UCL	-	-	-	-	7.73	3661.60	-	2131	203	986	314	1.78	5.92	0.32
FWG, DER (2014) Fresh Water Guidelines, DER 2014 & ANZECC (2000) (mg/L)				FWG	6.5 - 8.5	-	-	-	-	-	-	0.9	2 (1)	0.2 (0.1)
MWG, Marine Water Guidelines (MWG) from DER 2014 & ANZECC (2000) (mg/L)				MWG	8.0 - 8.4	-	-	-	-	-	-	0.91	-	-
IWG-STV, Short-term Irrigation Water (mg/L), DER(2014)				IWG-STV	-	-	-	-	-	-	-	-	25-125	0.8-12
IWG-LTV, Long-term Irrigation Water, DER (2014) (mg/L)				IWG-LTV	6.0-8.5 gw 6.0-9.0 sw	<12.2mS, crop varies T4.2.5	-	<8300 crop varies T4.2.5	-	crop varies T4.2.6	-	-	5	0.05
NPUG, Domestic Non-potable groundwater use, DER (2014) from DoH (2014) (mg/L)				NPUG	-	-	-	-	-	250	1000	0.41	-	-

Notes

DER (2014). Assessment Levels for Water: Marine Water Guideline (MWG), Fresh water Guideline (FWG)
Australian and New Zealand Environment Conservation Council, 2000. Australian Water Quality Guidelines for Fresh and Marine Waters. National Water Quality Management Strategy. Trigger values for slightly-moderately disturbed systems.
DER (2014). Assessment Levels for Water: Short-term Irrigation Water Guideline (ST-IWG) / Long-term Irrigation Water Guideline

Nutrients

Sample ID	Sample information	Date of sampling	Laboratory	Laboratory Batch No.	Phosphate as PO4-P	Total Phosphorous	Total Nitrogen	Nitrate NO3-N	Ammonia NH3-N
Units						mg/L	mg/L	mg/l	mg/L
SCPD28A (DoW)		*27-Jun-17*			<0.005	0.42	2.5	0.07	
20005166		*29-Jun-17*			<0.005	<0.005	4.9	<0.01	<0.01
TS012M		*29-Jun-17*			<0.005	0.012	4.6		1.8
Statistics									
Minimum	-	-	-	-		*0.01*	*1.1*	*0.07*	*0.01*
Maximum	(NEPM 2013 Sch B4, S3.4.4, No value>250% of Tier 1 SV)					*0.42*	*4.9*	*0.07*	*1.8*
N (No. values)	-	-	-	-		*4*	*5*	*1*	*3*
Mean	-	-	-	-		*0.12*	*3.20*	*0.07*	*0.64*
Median	-	-	-	-		*0.02*	*2.90*	*0.07*	*0.10*
Std Dev	(NEPM 2013 SchB4 S3.4.4 SD<50% of Tier 1 SV)					*0.20*	*1.57*	-	*1.01*
95% UCL	-	-	-	-		0.32	4.57	-	1.78
ANZECC 2000 South West Australia						-	-	-	-
Upland River				SWUp Rvr		0.02	0.45	200	0.06352706
Lowland River				SWLow Rvr		0.065	1.2	150	0.084708236
Freshwater Lakes and Reservoirs				SWFLake&Res		0.01	0.35	10	0.010590588
Wetlands				SWWetland		0.06	1.5	100	0.042354118
Estuaries				SWEstuary		0.03	0.75	45	0.042354118
Marine Inshore				SWMarineInS		0.02	0.23	5	0.00106-0.0106
Marine Offshore				SWMarine OffS		0.02	0.23	5	0.0063

Groundwater Analytical Results - Heavy

Sample ID	Sample information	Date of sampling	Laboratory	Laboratory Batch No.	pH (laboratory)	Aluminium (Al)	Arsenic (As)	Cadmium Total (Cd)	Chromium Total (Cr)	Iron (Fe)	Manganese (Mn)	Nickel (Ni)	Selenium (Se)	Zinc (Zn)
					Heavy Metals									
Units					-	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
SCPD28A (DoW)		*27-Jun-17*			*6.6*	68	0.0009	<0.0001	0.0007	52	0.14	0.003	<0.0002	0.72
20005166		*29-Jun-17*			*6.6*	0.067	0.0001	<0.0001	0.0001	0.12	0.0055	<0.0005	<0.0002	0.023
TS012M		*29-Jun-17*			*6.3*	0.02	<0.0001	<0.0001	<0.0001	0.71	0.015	<0.0005	<0.0002	0.001
Statistics														
Minimum	-	-	-	-	*6.3*	*0.02*	*0.0001*	*0*	*0.0001*	*0.067*	*0.0031*	*0.003*	*0.0003*	*0.001*
Maximum	(NEPM 2013 Sch B4, S3.4.4, No value>250% of Tier 1 SV)				*8.3*	*68*	*0.0009*	*0*	*0.0007*	*52*	*0.14*	*0.003*	*0.0003*	*0.72*
N (No. values)	-	-	-	-	*5*	*5*	*4*	*0*	*2*	*5*	*5*	*1*	*1*	*4*
Mean	-	-	-	-	*7.02*	*13.68*	*0.00*	-	*0.00*	*10.61*	*0.03*	*0.00*	*0.00*	*0.19*
Median	-	-	-	-	*6.60*	*0.15*	*0.00*	-	*0.00*	*0.15*	*0.01*	*0.00*	*0.00*	*0.01*
Std Dev	(NEPM 2013 SchB4 S3.4.4 SD<50% of Tier 1 SV)				*0.80*	*30.37*	*0.00*	-	*0.00*	*23.14*	*0.06*	-	-	*0.36*
95% UCL	-	-	-	-	7.73	40.30	0.00	-	0.00	30.89	0.09	-	-	0.54
FWG, DER (2014) Fresh Water Guidelines, DER 2014 & ANZECC (2000) (mg/L)				FWG	6.5-8.5	0.055	0.024 As(III) \0.013 As(V)	0.0002	-	-	1.9	0.011	0.011	0.008
ANZECC (2000) FWG Low Reliability Trigger Values (mg/L)				FWG-LRTV	-	-	-	-	-	0.3	-	-	-	-
MWG, Marine Water Guidelines (MWG) from DER 2014 & ANZECC (2000) (mg/L)				MWG	8-8.4	-	-	0.0055	-	-	-	0.07	-	0.015
MWG LRTV, ANZECC (2000) MWG Low Reliability Trigger Values (mg/L)				MWG-LRTV	-	0.5	0.0023 As(III) 0.0045 As(V)	-	-	-	0.08	-	0.003	-
IWG-STV, Short-term Irrigation Water (mg/L), DER(2014)				IWG-STV	-	20	2	0.05	1	10	10	2	0.05	5
IWG-LTV, Long-term Irrigation Water, DER (2014) (mg/L)				IWG-LTV	-	5	0.1	0.01	0.1	0.2	0.2	0.2	0.02	2
NPUG, Domestic Non-potable groundwater use, DER (2014) from DoH (2014) (mg/L)				NPUG	-	0.2	0.1	0.02	-	0.3	5	0.2	0.1	3
RIVM (2001) Dutch Ground Water Intervention Value (mg/L)				IV	-	-	0.06	0.006	0.03	-	-	0.075	-	0.8

Notes

DER (2014). Assessment Levels for Water: Marine Water Guideline (MWG) / Fresh Water Guideline (FWG)

Australian and New Zealand Environment Conservation Council, 2000. Australian Water Quality Guidelines for Fresh and Marine Waters. National Water Quality Management Strategy. Trigger values for slightly-moderately disturbed systems.

DER (2014). Assessment Levels for Water: Drinking Water Health Value (HV) / Aesthetic Value (AV)

NHMRC, NRMMC (2011) Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy. National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra.

DER (2014). Assessment Levels for Water: Short-term Irrigation Water Guideline (ST-IWG) / Long-term Irrigation Water Guideline (LT-IWG)

Exceeds several GLs

<LOR

Appendix 4: Surface Water Quality

In Situ Parameters

Bore Name	Date Measured	Plumbed depth of bore	Electrical Conductivity	Salinity	pH	Redox Potential	Temperature
		mBD	µS/cm OR mS/cm	g/L	pH units	+/- mV	˚C
YALSW04	*27/06/2017*		810	410	6.70	52	
YALSW05	*18/07/2017*		2560	1280	6.65		
YALSW06	*18/07/2017*		2620	1310	6.35		
YALSW07	*29/06/2017*		4530	2260	7.65	217	
YALSW08	*18/07/2017*		1400	700	6.71		
YALSW11	*18/07/2017*		2060	1030	6.92		
YALSW13	*18/07/2017*		1910	950	6.98		
Spare							

Statistics

Minimum	-	-	*810*	*410*	*5.86*	*52*	*15.2*
Maximum	(NEPM 2013 Sch B4, S3.4.4, No value>250% of Tier 1 SV)	-	*4530*	*2260*	*7.65*	*217*	*17*
N (No. values)	-	-	*10*	*10*	*10*	*4*	*3*
Mean	-	-	*2201*	*1100*	*6.63*	*116.75*	*15.87*
Median	-	-	*1985*	*990*	*6.68*	*99*	*15.40*
Std Dev	(NEPM 2013 SchB4 S3.4.4 SD<50% of Tier 1 SV)	-	*1099.60*	*548.84*	*0.50*	*70.58*	*0.99*
95% UCL	-	-	2882.53	1440.17	6.94	185.92	16.98
DER (2014) Fresh Water Guidelines (FWG)		FWG	-	-	6.5 - 8.5	-	-
DER 2014 Marine Water Guidelines (MWG)		MWG	-	-	8.0 - 8.4	-	-
ANZECC (2000) FWG Low Reliability Trigger Values (µg/L)		FWG-LRTV	-	-	-	-	-
DER (2014) Short-term Irrigation Water (IWG-STV)		IWG-STV	-	-	-	-	-
DER (2014) Long-term Irrigation Water (IWG-LTV)		IWG-LTV	<12.2mS, crop varies T4.2.5	-	6.0-8.5 gw 6.0-9.0 sw	-	-
DoH (2014) Contaminated Sites Ground & Surface Water Chemical Screening Guidelines (Domestic Non-potable Groundwater (NPUG) use		NPUG	-	-	-	-	-

Notes

DER (2014). Assessment Levels for Water: Marine Water Guideline (MWG) / Fresh Water Guideline (FWG)
DER (2014). Assessment Levels for Water: Drinking Water Health Value (HV) / Aesthetic Value (AV)
DER (2014). Assessment Levels for Water: Short-term Irrigation Water Guideline (ST-IWG) / Long-term Irrigation Water Guideline (LT-IWG)
Department of Health (2014). Contaminated Sites Ground & Surface Water Chemical Screening Guidelines, Domestic non-potable groundwater use (NPUG)

Analytical Results
Standard Water Quality Parameters Incluc

								Major Ions				Nutrients		
Sample ID	**Sample information**	**Date of sampling**	**Laboratory**	**Laboratory Batch No.**	**pH (Lab)**	**EC (Lab)**	**Water type**	**TDS**	**Alkalinity**	**Chloride (Cl)**	**Sulphate (SO_4)**	**Ammonia (as NH_3-N at pH 8)**	**Total Nitrogen**	**Total Phosphorus**
Units					-	uS/cm	-	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg /L
YALSW04		*27-Jun-17*			7.3	743	*Fresh*	420	50	150	77	0.1		0.01
YALSW07		*29-Jun-17*			8.3	4590	*Brackis h*	2700	250	1200	450	0.01	1.1	0.03 3
Statistics														
Minimum	-	-	-	-	*6.3*	*743*	-	*420*	*50*	*150*	*77*	*0.01*	*1.1*	*0.01*
Maximum	(NEPM 2013 Sch B4, S3.4.4, No value>250% of Tier 1 SV)				*8.3*	*4590*	-	*2700*	*250*	*1200*	*450*	*1.8*	*4.9*	*0.42*
N (No. values)	-	-	-	-	*5*	*5*	-	*5*	*4*	*5*	*5*	*3*	*3*	*4*
Mean	-	-	-	-	*7.02*	*2262.60*	-	*1306*	*112.75*	*580*	*177.40*	*0.64*	*3.53*	*0.12*
Median	-	-	-	-	*6.60*	*1730*	-	*1000*	*75.50*	*380*	*120*	*0.10*	*4.60*	*0.02*
Std Dev	(NEPM 2013 SchB4 S3.4.4 SD<50% of Tier 1 SV)				*0.80*	*1596.09*	-	*942.11*	*92.76*	*464.06*	*156.11*	*1.01*	*2.11*	*0.20*
95% UCL	-	-	-	-	7.73	3661.60	-	2131.7 8	203.66	986.76	314.23	1.78	5.92	0.32
FWG, DER (2014) Fresh Water Guidelines, DER 2014 & ANZECC (2000) (mg/L)				FWG	6.5 - 8.5	-	-	-	-	-	-	0.9	2 (1)	0.2 (0. 1)
MWG, Marine Water Guidelines (MWG) from DER 2014 & ANZECC (2000) (mg/L)				MWG	8.0 - 8.4	-	-	-	-	-	-	0.91	-	-
IWG-STV, Short-term Irrigation Water (mg/L), DER(2014)				IWG-STV	-	-	-	-	-	-	-	-	25-125	0.8 -12
IWG-LTV, Long-term Irrigation Water, DER (2014) (mg/L)				IWG-LTV	6.0-8.5 gw 6.0-9.0 sw	<12.2mS , crop varies T4.2.5	-	<8300 crop varies T4.2.5	-	crop varies T4.2.6	-	-	5	0.0 5

Notes

DER (2014). Assessment Levels for Water: Marine
Water Guideline (MWG), Fresh water Guideline (FWG)
Australian and New Zealand Environment Conservation Council, 2000. Australian Water Quality Guidelines for Fresh and Marine Waters. National Water Quality Management Strategy. Trigger values for slightly-moderately disturbed systems.
DER (2014). Assessment Levels for Water: Drinking
Water Health Value (HV) / Aesthetic Value (AV)
NHMRC, NRMMC (2014) V3 Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy. National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra.
DER (2014). Assessment Levels for Water: Short-term Irrigation Water
Guideline (ST-IWG) / Long-term Irrigation Water Guideline (LT-IWG)

Nutrients

Sample ID	Sample information	Date of sampling	Laboratory	Laboratory Batch No.	Phosphate as PO4-P	Total Phosphorous	Total Nitrogen	Nitrate NO3-N	Ammonia NH3-N
Units						mg/L	mg/L	mg/l	mg/L
YALSW04		*27-Jun-17*				0.01	2.9		0.1
YALSW07		*29-Jun-17*			0.01	0.033	1.1		0.01
Statistics									
Minimum	-	-	-	-		*0.01*	*1.1*	*0.07*	*0.01*
Maximum	(NEPM 2013 Sch B4, S3.4.4, No value>250% of Tier 1 SV)					*0.42*	*4.9*	*0.07*	*1.8*
N (No. values)	-	-	-	-		*4*	*5*	*1*	*3*
Mean	-	-	-	-		*0.12*	*3.20*	*0.07*	*0.64*
Median	-	-	-	-		*0.02*	*2.90*	*0.07*	*0.10*
Std Dev	(NEPM 2013 SchB4 S3.4.4 SD<50% of Tier 1 SV)					*0.20*	*1.57*	-	*1.01*
95% UCL	-	-	-	-		0.32	4.57	-	1.78
ANZECC 2000 South West Australia						-	-	-	-
Upland River				SWUp Rvr		0.02	0.45	200	0.06352706
Lowland River				SWLow Rvr		0.065	1.2	150	0.084708236
Freshwater Lakes and Reservoirs				SWFLake &Res		0.01	0.35	10	0.010590588
Wetlands				SWWetland		0.06	1.5	100	0.042354118
Estuaries				SWEstuary		0.03	0.75	45	0.042354118
Marine Inshore				SWMarineInS		0.02	0.23	5	0.00106-0.0106
Marine Offshore				SWMarine OffS		0.02	0.23	5	0.0063

Heavy Metals (mg/L)

Sample ID	Sample information	Date of sampling	Laboratory	Laboratory Batch No.	pH (laboratory)	Aluminium (Al)	Arsenic (As)	Cadmium Total (Cd)	Chromium Total (Cr)	Iron (Fe)	Manganese (Mn)	Nickel (Ni)	Selenium (Se)	Zinc (Zn)
Units					-	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
YALSW04		*27-Jun-17*			*7.3*	0.15	0.0002	<0.0001	<0.0001	0.15	0.006	<0.0005	0.0003	0.003
YALSW07		*29-Jun-17*			*8.3*	0.16	0.0003	<0.0001	<0.0001	0.067	0.0031	<0.0005	<0.0002	<0.001
Statistics														
Minimum	-	-	-	-	*6.3*	*0.02*	*0.0001*	*0*	*0.0001*	*0.067*	*0.0031*	*0.003*	*0.0003*	*0.001*
Maximum	(NEPM 2013 Sch B4, S3.4.4, No value>250% of Tier 1 SV)				*8.3*	*68*	*0.0009*	*0*	*0.0007*	*52*	*0.14*	*0.003*	*0.0003*	*0.72*
N (No. values)	-	-	-	-	*5*	*5*	*4*	*0*	*2*	*5*	*5*	*1*	*1*	*4*
Mean	-	-	-	-	*7.02*	*13.68*	*0.00*	-	*0.00*	*10.61*	*0.03*	*0.00*	*0.00*	*0.19*
Median	-	-	-	-	*6.60*	*0.15*	*0.00*	-	*0.00*	*0.15*	*0.01*	*0.00*	*0.00*	*0.01*
Std Dev	(NEPM 2013 SchB4 S3.4.4 SD<50% of Tier 1 SV)				*0.80*	*30.37*	*0.00*	-	*0.00*	*23.14*	*0.06*	-	-	*0.36*
95% UCL	-	-	-	-	7.73	40.30	0.00	-	0.00	30.89	0.09	-	-	0.54
FWG, DER (2014) Fresh Water Guidelines, DER 2014 & ANZECC (2000) (mg/L)				FWG	6.5-8.5	0.055	0.024 As(III) \0.013 As(V)	0.0002	-	-	1.9	0.011	0.011	0.008
ANZECC (2000) FWG Low Reliability Trigger Values (mg/L)				FWG-LRTV	-	-	-	-	-	0.3	-	-	-	-
MWG, Marine Water Guidelines (MWG) from DER 2014 & ANZECC (2000) (mg/L)				MWG	8-8.4	-	-	0.0055	-	-	-	0.07	-	0.015
MWG LRTV, ANZECC (2000) MWG Low Reliability Trigger Values (mg/L)				MWG-LRTV	-	0.5	0.0023 As(III) 0.0045 As(V)	-	-	-	0.08	-	0.003	-
IWG-LTV, Long-term Irrigation Water, DER (2014) (mg/L)				IWG-LTV	-	5	0.1	0.01	0.1	0.2	0.2	0.2	0.02	2
NPUG, Domestic Non-potable groundwater use, DER (2014) from DoH (2014) (mg/L)				NPUG	-	0.2	0.1	0.02	-	0.3	5	0.2	0.1	3
RIVM (2001) Dutch Ground Water Intervention Value (mg/L)				IV	-	-	0.06	0.006	0.03	-	-	0.075	-	0.8

Notes

DER (2014). Assessment Levels for Water: Marine Water Guideline (MWG) / Fresh Water Guideline (FWG)
Australian and New Zealand Environment Conservation Council, 2000. Australian Water Quality Guidelines for Fresh and Marine Waters. National Water Quality Management Strategy. Trigger values for slightly-moderately disturbed systems.
DER (2014). Assessment Levels for Water: Drinking Water Health Value (HV) / Aesthetic Value (AV)
NHMRC, NRMMC (2011) Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy. National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra.

DER (2014). Assessment Levels for Water: Short-term Irrigation Water Guideline (ST-IWG) / Long-term Irrigation Water Guideline (LT-IWG)

Exceeds several GLs

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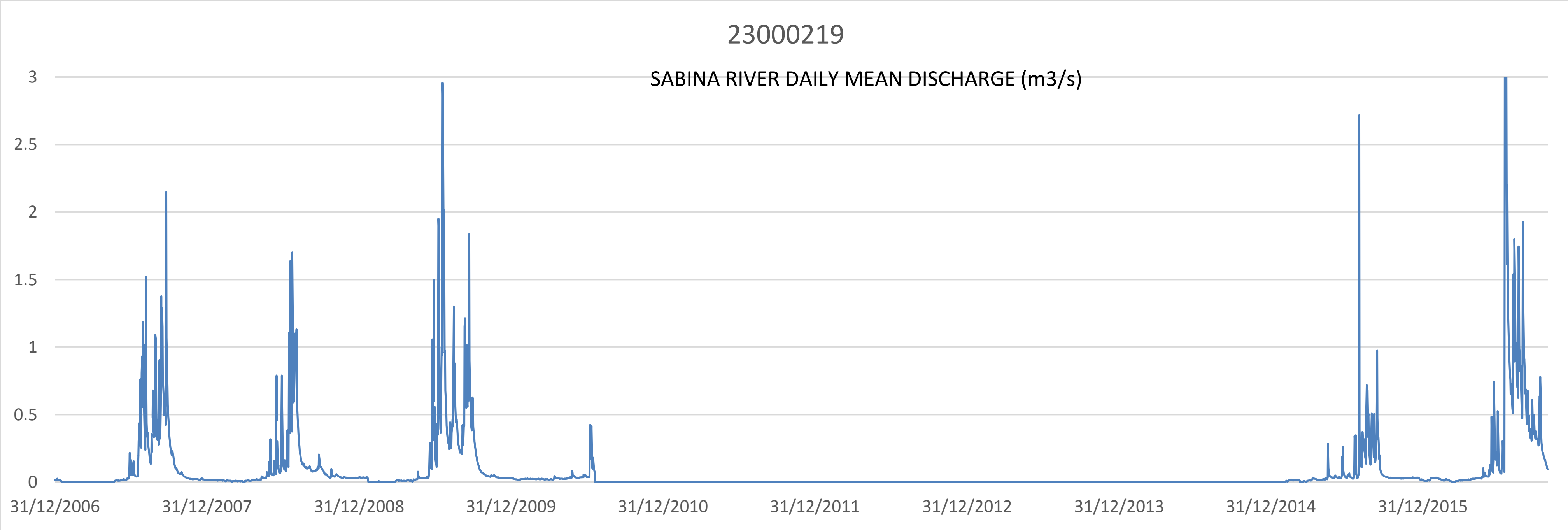
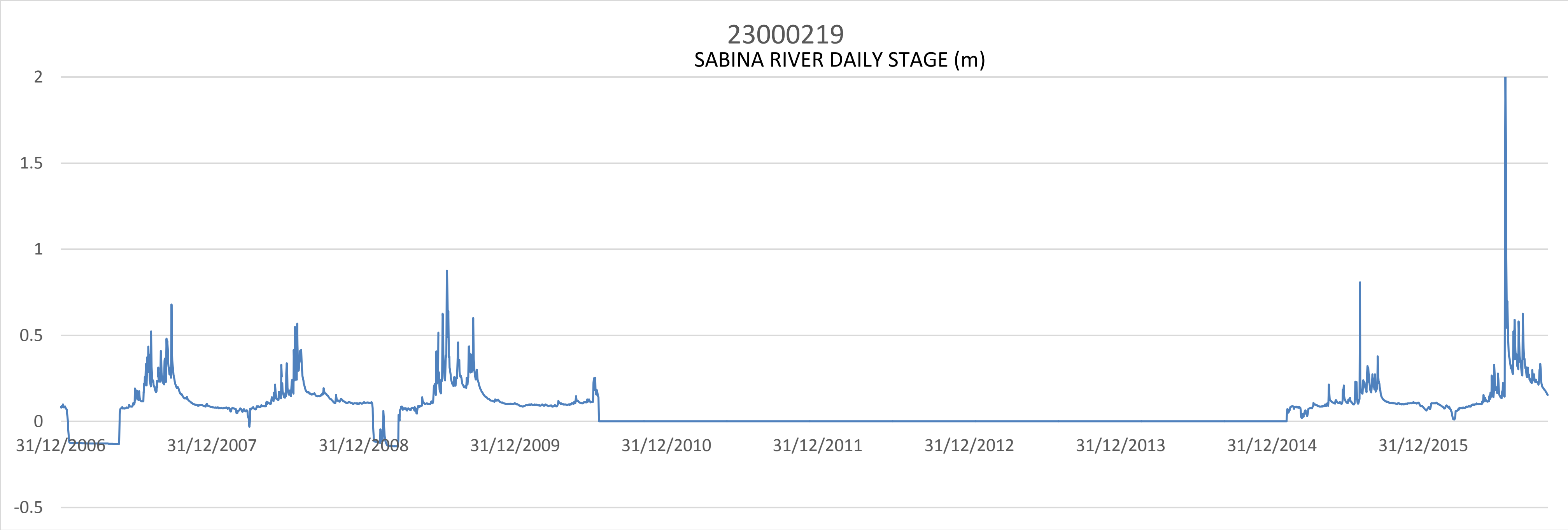
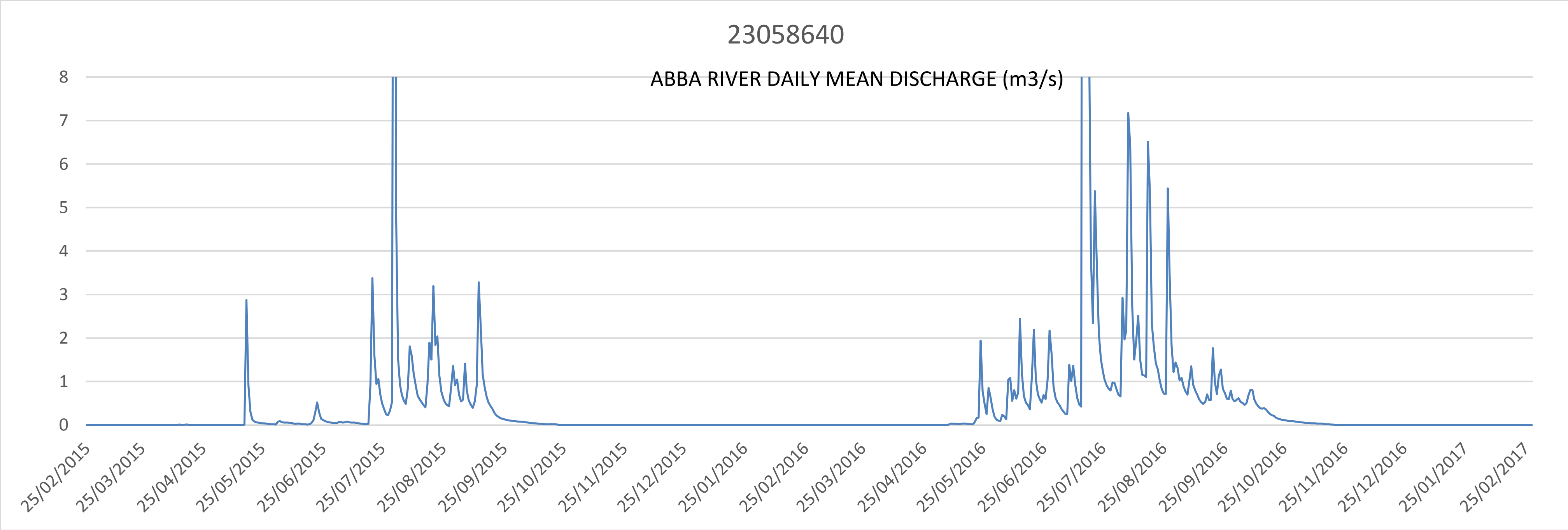
Appendix 5: River Stages and Flows


23000219
SABINA RIVER DAILY MEAN DISCHARGE (m3/s)
3
2.5
2
1.5
1
0.5
0
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015


23000219
SABINA RIVER DAILY STAGE (m)
2
1.5
1
0.5
0
-0.5
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015



23058640
ABBA RIVER DAILY MEAN DISCHARGE (m3/s)
8
7
6
5
4
3
2
1
0
25/02/2015
25/03/2015
25/04/2015
25/05/2015
25/06/2015
25/07/2015
25/08/2015
25/09/2015
25/10/2015
25/11/2015
25/12/2015
25/01/2016
25/02/2016
25/03/2016
25/04/2016
25/05/2016
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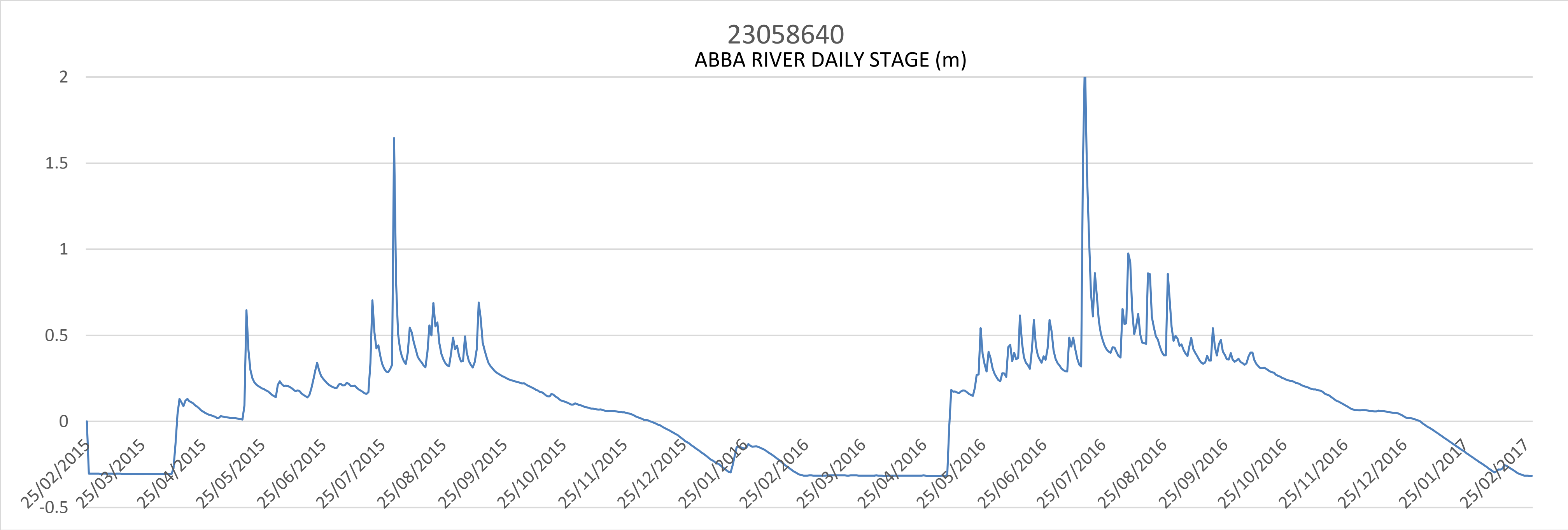
25/01/2017
25/02/2017



23058640
ABBA RIVER DAILY STAGE (m)
2
1.5
1
0.5
0
-0.5
25/02/2015
25/03/2015
25/04/2015
25/05/2015
25/06/2015
25/07/2015
25/08/2015
25/09/2015
25/10/2015
25/11/2015
25/12/2015
25/01/2016
25/02/2016
25/03/2016
25/04/2016
25/05/2016
25/06/2016
25/07/2016
25/08/2016
25/09/2016
25/10/2016
25/11/2016
25/12/2016
25/01/2017
25/02/2017

Appendix 6: Dewatering Initial Assessment

Estimate Radius of Influence (Re) from a pumping well, Unconfined Aquifer

password: unconfined

Parameter	Value	Units	Comment 1	Comment 2
SWL	**2**	mBTOC	Approximate average level, mBGL	Based on Q3 2026 (largest Yoganup strand, S segment, c677m by 195m, c13200m2, perimeter c1,744m)
Q=	**16981**	kL/day	From DupuitDewaterSolutionNEW.xls for given assumptions, based on Hazel solution, highest estimated discharge (Q), based on lower end estimates	
sw=	**13.5**	m	Lower end of range: Saturated thickness, range 10-14m, based on WT at 2mBGL, base of Yopanup 12-16mBGL	
rw	**0.157**	m	Radius of the pumped well (12"/ 314mm OD assumed)	
kD	**100**	m2/day	Upper end of range (assumed) for T, based on Kh=50m/d(max), and b=14m (man). Quoted literature range for Superficial Aquifer, 100-1,000m2/d (Davidson, 1995), upper value assumed to be too high, based on sandy clay sequence reported at site area.	
b:	**14**	m	Lower end of range: Saturated thickness, range 10-14m, based on WT at 2mBGL, base of Yopanup 12-16mBGL	
k	*7.1*	m/d	Permeability (from T and b)	
t=	**4**	days	<1-day (for Jacob unconfined estimate)	
S=	**0.1**	-	Lower end of range of quoted literature values: effective porosity for Superfical Aquifer 0.2 (Davidson 1995), HydroSolutions 2014, 0.010-0.1, Aquaterra 0.001	
H	**23.5**	mAHD	Head, mAHD, assumed at Re (c1km)	
Rainfall	**677**	mm/a	Lower end of range as LTA (Long term average 811mm/a, but 677mm/a over last 10 years)	
Percentage R as gw recharge	**5**	%	Assumed value	
q=	*1.07E-09*	m/s	vertical recharge	

Method:	Re (m)	Units	Comment
Jacob: Unconfined	***94.9***	m	s=2.3Q/4piTlog10(2.25Tt/r2S) At Re, then s=0, therefore log term =0, therefore 2.25Tt/r2S=1, therefore: Re=1.5*(kDt/ne)^0.5 (Unconfined aquifers) For t<1day
Kusakin (Unconfined) Bear, 1979	***264.1***	m	Re=575*sw*(b*k(m/s)^0.5
Sichardt, 1930	***368.2***	m	Re=3000*sw*k(m/s)^0.5
CIRIA, Report 750, based on Sichardt	***366.0***	m	Re~C.H.k^0.5, where C=1750, kh in m/s, H= head at Re
Minimum:	*94.9*	m	
Maximum:	*368.2*	m	
Mean:	*273.3*	m	

References:

Jacob, CE, 1940. On the flow of water in an elastic artesian aquifer. Trans. Amer. Geophys. Union, Vol. 21, Part 2, pp. 574-586

Kusakin (in Chetousov, 1949)

Bear, J., 1979. Hydraulics of groundwater. McGraw-Hill International, New York, 567 pp.

Sichart, K, 1930. Grundwasserabsenkung beio Fundierungsarbeiten, Springer, Berlin

https://www.der.wa.gov.au/your-environment/acid-sulfate-soils/66-cone-of-depression

Estimate Radius of Influence (Re) from a pumping well, Unconfined Aquifer

password: unconfined

Parameter	Value	Units	Comment	Comment 2
SWL	**2**	mBTOC	Approximate average level, mBGL	
Q=	**40494**	kL/day	From DupuitDewaterSolutionNEW.xls for given assumptions, based on Hazel solution, highest estimated discharge (Q), based on upper end estimate	Based on Q3 2026 (largest Yoganup strand, S segment, c677m by 195m, c13200m2, perimeter c1,744m)
sw=	**15**	m	Upper end of range: Saturated thickness, range 10-14m, based on WT at 2mBGL, base of Yopanup 12-16mBGL	
rw	**0.157**	m	Radius of the pumped well (12"/ 314mm OD assumed)	
kD	**700**	m2/day	Upper end of range (assumed) for T, based on Kh=50m/d(max), and b=14m (man). Quoted literature range for Superficial Aquifer, 100-1,000m2/d (Davidson, 1995), upper value assumed to be too high, based on sandy clay sequence reported at site area.	
b:	**14**	m	Upper end of range: Saturated thickness, range 10-14m, based on WT at 2mBGL, base of Yopanup 12-16mBGL	
k	*50.0*	m/d	Permeability (from T and b)	
t=	**4**	days	<1-day (for Jacob unconfined estimate)	
S=	**0.2**	-	Upper end of range of quoted literature values: effective porosity for Superfical Aquifer 0.2 (Davidson 1995), HydroSolutions 2014, 0.010-0.1, Aquaterra 0.001	
H	**24**	mAHD	Head, mAHD, assumed at Re (c1km)	
Rainfall	**811**	mm/a	Lower end of range as LTA (Long term average 811mm/a, but 677mm/a over last 10 years)	
Percentage R as gw recharge	**5**	%	Assumed value	
q=	*1.29E-09*	m/s	vertical recharge	

Method:	Re (m)	Units	Comment
Jacob: Unconfined	***177.5***	m	s=2.3Q/4piTlog10(2.25Tt/r2S) At Re, then s=0, therefore log term =0, therefore 2.25Tt/r2S=1, therefore: Re=1.5*(kDt/ne)^0.5 (Unconfined aquifers) For t<1day
Kusakin (Unconfined) Bear, 1979	***776.3***	m	Re=575*sw*(b*k(m/s)^0.5
Sichardt, 1930	***1,082.5***	m	Re=3000*sw*k(m/s)^0.5
CIRIA, Report 750, based on Sichardt	***968.3***	m	Re~C.H.k^0.5, where C=1750, kh in m/s, H= head at Re
Minimum:	*177.5*	m	
Maximum:	*1082.5*	m	
Mean:	*751.2*	m	

References:

Jacob, CE, 1940. On the flow of water in an elastic artesian aquifer. Trans. Amer. Geophys. Union, Vol. 21, Part 2, pp. 574-586

Kusakin (in Chetousov, 1949)

Bear, J., 1979. Hydraulics of groundwater. McGraw-Hill International, New York, 567 pp.

Sichart, K, 1930. Grundwasserabsenkung beio Fundierungsarbeiten, Springer, Berlin

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Dupuit Dewatering Solution, with Recharge, Inflow to a pit, Unconfined Aquifers

Land surface elevation (mAHD)			Water Table (Dip, mBGL)		
Low	High	Comment	Low	High	Comment
17	25	Low in NW corner, high in SE corner)	1	2	

Recharge to Groundwater			
Rainfall	677	mm/a	Assumed lower end value, based on Long term average 811mm/a, but 677mm/a over last 10 years
Percentage R as gw recharge	5	%	Assumed value
q=	*1.07E-09*	m/s	vertical recharge
q=	*9.27E-05*	m/d	

Anticipated radius of influence (Re)					
Permeability (m/d)	Comment	Drawdown (m)	Comment	Re (m)	Comment
10	Kh low	10	Dlow	262	Mean of Jacob, Kusakin, Sichardt & CIRIA (based on Sichardt) solutions for unconfined aquifers
50	Kh high	14	Dhigh	720	Mean of Jacob, Kusakin, Sichardt & CIRIA (based on Sichardt) solutions for unconfined aquifers

Approximate Check:

CIRIA Re~C.H.k^0.5, where C=1750, kh in m/s)		
H mAHD assumed	Comment	Re (m)
28	H-low	*527.2*
28	H-high	*1178.8*

Estimates of Discharge for required drawdown (Dupuit, Radial flow, with recharge: Q=-k(H^2-Ho^2)/2.L-q.L/2

Dewatering Area	Effective Width (m)	Effective Length (m)	Perimeter (m)	Measured Area (m2)	Permeability k (m/d)	Comment	Drawdown sw (H-hw) (m)	Comment	H at Ro assumed (mAHD)	Comment	hw (H-sw) (mAHD)	Comment	Ro (=Re) (m)	rw (m)	Discharge Q (m3/d/m width)	Q (L/s/m)	Total length of seepage face (e.g perimeter of pit) (m)	Discharge (total) Q m3/d	Q L/s	No. nodes	Q (per node) (m3/d)	Comment
1: Q3, 2021 (N)	140	116	512	16240	10	Kh-low	11.5	D-low	20.5	H-low	9	hw-high	273	1	6.2	0.1	512	3174.8	36.7	2	1587.4	
2: Q4 2021 (N)	181	130	622	23530	10	Kh-low	11.5	D-low	20.5	H-low	9	hw-high	273	1	6.2	0.1	622	3856.8	44.6	2	1928.4	
3: Q1 2022 (N)	133	150	566	19950	10	Kh-low	11.5	D-low	21.5	H-low	10	hw-high	273	1	6.6	0.1	566	3748.0	43.4	1	3748.0	
4: Q2 2022 (N)	130	178	616	23140	10	Kh-low	11.5	D-low	21.5	H-low	10	hw-high	273	1	6.6	0.1	616	4079.1	47.2	2	2039.6	
5: Q3 2022 (N)	109	178	574	19402	10	Kh-low	11.5	D-low	21.5	H-low	10	hw-high	273	1	6.6	0.1	574	3801.0	44.0	1	3801.0	
6: Q4 2022 (N)	147	150	594	22050	10	Kh-low	11.5	D-low	21.7	H-low	10.2	hw-high	273	1	6.7	0.1	594	3983.5	46.1	2	1991.7	
7: Q1 2023 (N0	168	130	596	21840	10	Kh-low	11.5	D-low	22	H-low	10.5	hw-high	273	1	6.8	0.1	596	4072.2	47.1	2	2036.1	
8: Q2 2023 (N)	192	113	610	21696	10	Kh-low	11.5	D-low	22	H-low	10.5	hw-high	273	1	6.8	0.1	610	4167.9	48.2	2	2083.9	
9: Q3 2023 (N)	209	130	678	27170	10	Kh-low	11.5	D-low	21	H-low	9.5	hw-high	273	1	6.4	0.1	678	4346.9	50.3	1	4346.9	
10a: Q4 2023 (N), 1of2	130	175	610	22750	10	Kh-low	11.5	D-low	21	H-low	9.5	hw-high	273	1	6.4	0.1	610	3910.9	45.3	1	3910.9	
10b: Q4 2023 (S), 2of2	157	127	568	19939	10	Kh-low	13.5	D-low	21	H-low	7.5	hw-high	273	1	7.0	0.1	568	3995.3	46.2	2	1997.7	
11: Q1 2024 (S)	246	164	820	40344	10	Kh-low	13.5	D-low	21.7	H-low	8.2	hw-high	273	1	7.4	0.1	820	6051.8	70.0	3	2017.3	
12: Q2 2024 (S)	195	215	820	41925	10	Kh-low	13.5	D-low	21.7	H-low	8.2	hw-high	273	1	7.4	0.1	820	6051.8	70.0	1	6051.8	
13a: Q3 2024 (S-sw), 1of2	123	222	690	27306	10	Kh-low	13.5	D-low	22.6	H-low	9.1	hw-high	273	1	7.8	0.1	690	5399.4	62.5	2	2699.7	
13b: Q3 2024 (S-ne)	260	113	746	29380	10	Kh-low	13.5	D-low	24.5	H-low	11	hw-high	273	1	8.8	0.1	746	6538.6	75.7	3	2179.5	
14: Q4 2024 (S)	263	82	690	21566	10	Kh-low	13.5	D-low	26.5	H-low	13	hw-high	273	1	9.8	0.1	690	6730.1	77.9	1	6730.1	
15: Q1 2025 (N)	130	209	678	27170	10	Kh-low	11.5	D-low	22	H-low	10.5	hw-high	273	1	6.8	0.1	678	4632.5	53.6	2	2316.2	
16: Q2 2025 (N)	178	202	760	35956	10	Kh-low	11.5	D-low	22	H-low	10.5	hw-high	273	1	6.8	0.1	760	5192.8	60.1	2	2596.4	
17: Q3 2025 (N)	185	144	658	26640	10	Kh-low	11.5	D-low	23	H-low	11.5	hw-high	273	1	7.3	0.1	658	4773.0	55.2	2	2386.5	
18a: Q4 2025 (N-ne), 1of2	277	55	664	15235	10	Kh-low	11.5	D-low	24	H-low	12.5	hw-high	273	1	7.7	0.1	664	5096.2	59.0	3	1698.7	
18b: Q4 2025 (N-nw), 2of2	188	72	520	13536	10	Kh-low	11.5	D-low	22.5	H-low	11	hw-high	273	1	7.0	0.1	520	3662.5	42.4	2	1831.2	
19: Q1 2026 (N)	328	68	792	22304	10	Kh-low	11.5	D-low	23.5	H-low	12	hw-high	273	1	7.5	0.1	792	5911.8	68.4	2	2955.9	
20: Q2 2026 (S)	174	209	766	36366	10	Kh-low	13.5	D-low	22.6	H-low	9.1	hw-high	273	1	7.8	0.1	766	5994.1	69.4	2	2997.1	
21: Q3 2026 (S)	677	195	1744	132015	10	Kh-low	13.5	D-low	23.5	H-low	10	hw-high	273	1	8.3	0.1	1744	14423.4	166.9	4	3605.9	
22: Q4 2026 (S)	229	157	772	35953	10	Kh-low	13.5	D-low	23.5	H-low	10	hw-high	273	1	8.3	0.1	772	6384.7	73.9	2	3192.3	
Spare			0	0							0	hw-high	273	1			0				#VALUE!	
High values			0	0							0						0				#VALUE!	
21: Q3 2026 (S)	677	195	1744	132015	50	Kh-high	15	D-high	24	H-high	9	hw-high	751	1	16.4	0.2	1744	28677.0	331.9	4	7169.2	Based on Q3 2026 (largest Yoganup strand, S segment, c677m by 195m, c13200m2, perimeter c1,744m), Hazel unconfined solution, for sw~13.5m
			0	0							0						0				#VALUE!	
			0	0							0						0				#VALUE!	
			0	0							0						0				#VALUE!	
			0	0							0						0				#VALUE!	
			0	0							0						0				#VALUE!	

Dewatering Solution, Hazel method, Inflow to a pit, Unconfined Aquifers

Q=pi.K(H^2-hw^2)/(2.3.log(Re/rw)+s.((x+y).K.(H^2-hw^2))/(2.Lo)

Estimates of Discharge for required drawdown, Inflow into a pit, unconfined aquifer (after Hazel, CP. 2009)

Dewatering Area	Effective Width	Effective Length	Perimeter	Measured Area	Permeability k	Comment	Drawdown sw (H-hw)	Comment	H at Ro assumed	Comment	hw (H-sw)	Comment	Ro (=Re)	rw	Discharge Q	Q	No. nodes	Q (per node)
	(m)	(m)	(m)	(m2)	(m/d)		(m)		(mAHD)		(mAHD)		(m)	(m)	(m3/d)	(L/s)		(m3/d)
1: Q3, 2021 (N)	140	116	512	16240	10	Kh-low	11.5	D-low	20.5	H-low	9	hw-high	273	1	5083.4	58.8	2	2541.7
2: Q4 2021 (N)	181	130	622	23530	10	Kh-low	11.5	D-low	20.5	H-low	9	hw-high	273	1	5766.8	66.7	2	2883.4
3: Q1 2022 (N)	133	150	566	19950	10	Kh-low	11.5	D-low	21.5	H-low	10	hw-high	273	1	5786.3	67.0	1	5786.3
4: Q2 2022 (N)	130	178	616	23140	10	Kh-low	11.5	D-low	21.5	H-low	10	hw-high	273	1	6118.0	70.8	2	3059.0
5: Q3 2022 (N)	109	178	574	19402	10	Kh-low	11.5	D-low	21.5	H-low	10	hw-high	273	1	5839.3	67.6	1	5839.3
6: Q4 2022 (N)	147	150	594	22050	10	Kh-low	11.5	D-low	21.7	H-low	10.2	hw-high	273	1	6047.9	70.0	2	3023.9
7: Q1 2023 (N0	168	130	596	21840	10	Kh-low	11.5	D-low	22	H-low	10.5	hw-high	273	1	6175.3	71.5	2	3087.7
8: Q2 2023 (N)	192	113	610	21696	10	Kh-low	11.5	D-low	22	H-low	10.5	hw-high	273	1	6271.1	72.6	2	3135.6
9: Q3 2023 (N)	209	130	678	27170	10	Kh-low	11.5	D-low	21	H-low	9.5	hw-high	273	1	6322.1	73.2	1	6322.1
10a: Q4 2023 (N), 1of2	130	175	610	22750	10	Kh-low	11.5	D-low	21	H-low	9.5	hw-high	273	1	5885.2	68.1	1	5885.2
10b: Q4 2023 (S), 2of2	157	127	568	19939	10	Kh-low	13.5	D-low	21	H-low	7.5	hw-high	273	1	6159.7	71.3	2	3079.9
11: Q1 2024 (S)	246	164	820	40344	10	Kh-low	13.5	D-low	21.7	H-low	8.2	hw-high	273	1	8325.3	96.4	3	2775.1
12: Q2 2024 (S)	195	215	820	41925	10	Kh-low	13.5	D-low	21.7	H-low	8.2	hw-high	273	1	8325.3	96.4	1	8325.3
13a: Q3 2024 (S-sw), 1of2	123	222	690	27306	10	Kh-low	13.5	D-low	22.6	H-low	9.1	hw-high	273	1	7807.6	90.4	2	3903.8
13b: Q3 2024 (S-ne)	260	113	746	29380	10	Kh-low	13.5	D-low	24.5	H-low	11	hw-high	273	1	9235.1	106.9	3	3078.4
14: Q4 2024 (S)	263	82	690	21566	10	Kh-low	13.5	D-low	26.5	H-low	13	hw-high	273	1	9728.7	112.6	1	9728.7
15: Q1 2025 (N)	130	209	678	27170	10	Kh-low	11.5	D-low	22	H-low	10.5	hw-high	273	1	6736.6	78.0	2	3368.3
16: Q2 2025 (N)	178	202	760	35956	10	Kh-low	11.5	D-low	22	H-low	10.5	hw-high	273	1	7297.9	84.5	2	3649.0
17: Q3 2025 (N)	185	144	658	26640	10	Kh-low	11.5	D-low	23	H-low	11.5	hw-high	273	1	7005.8	81.1	2	3502.9
18a: Q4 2025 (N-ne), 1of2	277	55	664	15235	10	Kh-low	11.5	D-low	24	H-low	12.5	hw-high	273	1	7458.1	86.3	3	2486.0
18b: Q4 2025 (N-nw), 2of2	188	72	520	13536	10	Kh-low	11.5	D-low	22.5	H-low	11	hw-high	273	1	5829.1	67.5	2	2914.5
19: Q1 2026 (N)	328	68	792	22304	10	Kh-low	11.5	D-low	23.5	H-low	12	hw-high	273	1	8210.8	95.0	2	4105.4
20: Q2 2026 (S)	174	209	766	36366	10	Kh-low	13.5	D-low	22.6	H-low	9.1	hw-high	273	1	8403.3	97.3	2	4201.6
21: Q3 2026 (S)	677	195	1744	132015	10	Kh-low	13.5	D-low	23.5	H-low	10	hw-high	273	1	16981.2	196.5	4	4245.3
22: Q4 2026 (S)	229	157	772	35953	10	Kh-low	13.5	D-low	23.5	H-low	10	hw-high	273	1	8930.1	103.4	2	4465.1
Spare			0	0	10	Kh-low	13.5	D-low		H-low	-13.5	hw-high	273	1	-1021.8	-11.8		#DIV/0!
High Values			0								0							#VALUE!
21: Q3 2026 (S)	677	195	1744	132015	50	Kh-high	15	D-high	24	H-high	9	hw-low	751	1	40493.8	468.7	2	20246.9
			0								0							#VALUE!
			0								0							#VALUE!

Assumed Lithological sequence in Analytical Model

Northern segment	Assumed thickness	Depth to base (mBGL)		Assumed thickness	Depth to base (mBGL)	Average depth to base (mBGL)	Dewatering (average) required to base (m)
Minimum values			**Maxium values**				
WT min (mBGL)	**1**	**1**	WT max (mBGL):	**2**	**2**	*1.5*	-
Saturated total aquifer (SBS, GFm, Yog Fm) minimum (m)	*11*	*12*	Saturated (total) aquifer (SBS, GFm, Yog Fm) maximum thickness (m):	*12*	*14*	*13*	*11.5*
Bassendean Sand (minimum thickness, n)	**0**	*0*	Bassendean Sand (maximum thickness, m)	**3**	*3*		
Guildford Formation (minimum thickness, m)	**2**	*2*	Guildford Formation (maximum thickness, m)	**4**	*7*		
Overburden (SBS & GFm) minimum thickness (m):	*2*	*4*	Overburden (SBS & GFm) maximum thickness (m):	*7*	*14*	*9*	*12*
Overburden (SBS & Gfm) minimum saturated thickness (m)	*1*	-	Overburden (SBS & Gfm) maximum saturated thickness (m)	*5*	-	-	-
Yoganup thickness minimum (m):	**3**	-	Yoganup thickness maximum (m):	**5**	-	-	-
Yoganup base minimum depth (mBGL):	**12**	*12*	Yoganup base maximum depth (mBGL):	**14**	*14*	*13*	*11.5*

Southern segment	Assumed thickness	Depth to base (mBGL)		Assumed thickness	Depth to base (mBGL)	Average depth to base (mBGL)	Dewatering (average) required to base (m)
Minimum values			**Maxium values**				
WT min (mBGL)	**1**	**1**	WT max (mBGL):	**2**	**2**	*1.5*	-
Saturated total aquifer (SBS, GFm, Yog Fm) minimum (m)	*13*	*14*	Saturated (total) aquifer (SBS, GFm, Yog Fm) maximum thickness (m):	*14*	*16*	*15*	*13.5*
Bassendean Sand (minimum thickness, n)	**0**	*0*	Bassendean Sand (maximum thickness, m)	**3**	*3*		
Guildford Formation (minimum thickness, m)	**2**	*2*	Guildford Formation (maximum thickness, m)	**4**	*7*		
Overburden (SBS & GFm) minimum thickness (m):	*2*	*4*	Overburden (SBS & GFm) maximum thickness (m):	*9*	*16*	*10*	*14*
Overburden (SBS & Gfm) minimum saturated thickness (m)	*1*	-	Overburden (SBS & Gfm) maximum saturated thickness (m)	*7*	-	-	-
Yoganup thickness minimum (m):	**3**	-	Yoganup thickness maximum (m):	**5**	-	-	-
Yoganup base minimum depth (mBGL):	**14**	*14*	Yoganup base maximum depth (mBGL):	**16**	*16*	*15*	*13.5*

Mineral segments

											Model nodes		
		Quarter	**x1m**	**x2m**	**y1m**	**y2m**	**Mean xm**	**Mean ym**	**Area (m2)**	**Perimeter (m)**	**I,j**	**No. nodes**	**Comment**
1	**1**	Sept (Q3) 2021 (N)	*129.941*	*150.458*	*109.424*	*123.102*	*140.1995*	*116.263*	*16300.01447*	*512.925*	(6,10), (6,11), (7,11)	**3**	
2	**2**	Dec (Q4) 2021 (N)	*184.653*	*177.814*	*123.102*	*136.78*	*181.2335*	*129.941*	*23549.66222*	*622.349*	(7,11), (8,11)	**2**	
3	**3**	March (Q1) 2022 (N)	*129.941*	*136.78*	*136.78*	*164.136*	*133.3605*	*150.458*	*20065.15411*	*567.637*	(8,11)	**1**	
4	**4**	June (Q2) 2022 (N)	*123.102*	*136.78*	*164.136*	*191.492*	*129.941*	*177.814*	*23105.32897*	*615.51*	(8,11), (9,11)	**2**	
5	**5**	September (Q3) 2022 (N)	*116.263*	*102.585*	*191.492*	*164.136*	*109.424*	*177.814*	*19457.11914*	*574.476*	(9,11), (9,12)	**2**	
6	**6**	December (Q4) 2022 (N)	*143.619*	*150.458*	*164.136*	*136.78*	*147.0385*	*150.458*	*22123.11863*	*594.993*	(9,11), (9,12), (10,11)	**3**	
7	**7**	March (Q1) 2023 (N)	*164.136*	*170.975*	*136.78*	*123.102*	*167.5555*	*129.941*	*21772.32923*	*594.993*	(9,11), (10,11), (10,12)	**3**	
8	**8**	June (Q2) 2023 (N)	*191.492*	*191.492*	*123.102*	*102.585*	*191.492*	*112.8435*	*21608.6275*	*608.671*	(10,11), (11,12)	**2**	
9	**9**	September (Q3) 2023 (N)	*191.492*	*225.687*	*102.585*	*157.297*	*208.5895*	*129.941*	*27104.32822*	*677.061*	(11,11), (11,12), (12,12)	**3**	
10	**10a**	December (Q4) 2023 (1os2-N)	*123.102*	*136.78*	*157.297*	*191.492*	*129.941*	*174.3945*	*22660.99572*	*608.671*	(11,12), (12,12), (12,13)	**3**	
11	**10b**	December (Q4) 2023 (2of2-S)	*157.297*	*157.297*	*116.263*	*136.78*	*157.297*	*126.5215*	*19901.45239*	*567.637*	(6,8), (7,8), (7,9)	**3**	
12	**11**	March (Q1) 2024 (S)	*239.365*	*253.043*	*136.78*	*191.492*	*246.204*	*164.136*	*40410.93974*	*820.68*	(7,8), (7,9), (8,9)	**3**	
13	**12**	June (Q2) 2024 (S)	*177.814*	*212.009*	*191.492*	*239.365*	*194.9115*	*215.4285*	*41989.49208*	*820.68*	(8,8), (8,9), (8,10)	**3**	
14	**13a**	September (Q3) 2024 (1of2-Ssw)	*129.941*	*116.263*	*239.365*	*205.17*	*123.102*	*222.2675*	*27361.57379*	*690.739*	(8,9), (8,10), (9,9)	**3**	
15	**13b**	September (Q3) 2024 (2of2-Sne)	*218.848*	*300.916*	*129.941*	*95.746*	*259.882*	*112.8435*	*29325.99447*	*745.451*	(12,11), (13,11), (14,11)	**3**	
16	**14**	December (Q4) 2024 (S)	*266.721*	*259.882*	*95.746*	*68.39*	*263.3015*	*82.068*	*21608.6275*	*690.739*	(13,11), (14,11), (14,12),	**3**	
17	**15**	March (Q1) 2025 (N)	*123.102*	*136.78*	*191.492*	*225.687*	*129.941*	*208.5895*	*27104.32822*	*677.061*	(12,12), (12,13), (13,12)	**3**	
18	**16**	June (Q2) 2025 (N)	*205.17*	*150.458*	*225.687*	*177.814*	*177.814*	*201.7505*	*35874.06341*	*759.129*	(12,12), (12,13), (13,12), (13,13	**4**	
19	**17**	September (Q3) (N)	*170.975*	*198.331*	*177.814*	*109.424*	*184.653*	*143.619*	*26519.67921*	*656.544*	(13,13), (14,12), (14,13)	**3**	
20	**18a**	December (Q4) 2025 (1of2, Nne	*280.399*	*273.56*	*109.424*	*0*	*276.9795*	*54.712*	*15154.1024*	*663.383*	(14,12), (14,13), (15,13)	**3**	
21	**18b**	December (Q4) 2025 (2of2, Nnw)	*218.848*	*157.297*	*95.746*	*47.873*	*188.0725*	*71.8095*	*13505.39219*	*519.764*	(13,13), (14,13)	**2**	
22	**19**	March (Q1) 2026 (N)	*328.272*	*328.272*	*47.873*	*88.907*	*328.272*	*68.39*	*22450.52208*	*793.324*	(13,13), (14,13), (15,13)	**3**	
23	**20**	June 2026 (S)	*170.975*	*177.814*	*205.17*	*212.009*	*174.3945*	*208.5895*	*36376.86156*	*765.968*	(9,9), (10,10)	**2**	
24	**21**	September 2026 (S)	*622.349*	*731.773*	*212.009*	*177.814*	*677.061*	*194.9115*	*131966.9751*	*1743.945*	(9,9), (10,10), (11,10), (11,11), (9,10), (12,10), (10,9)	**7**	
25	**22**	December 2026 (S)	*232.526*	*225.687*	*177.814*	*136.78*	*229.1065*	*157.297*	*36037.76513*	*772.807*	(11,11), (12,10), (12,11)	**3**	

Analytical Model Output

					Drawdown achieved at segment (m)			Modeled discharge (Qm)	Hazel estimated discharge (Qh)	Dupuit estimated discharge (Qd)	Modelled discharge estimate m3/d per quarter	m3/quarter	Water years (m3/a)
		Quarter	Drawdown target (m)	Days	low	High	Mean	(m3/d)	(m3/d)	(m3/d)	-	-	
1	**1**	Sept (Q3) 2021 (N)	11.5	91	10.6	11.2	*10.9*	5300	5100	3174	482300		July2021-June 2022
2	**2**	Dec (Q4) 2021 (N)	11.5	91	11.2	11.6	*11.4*	2800	5766	3856	254800	*991900*	
3	**3**	March (Q1) 2022 (N)	11.5	91	11.6	17.5	*14.55*	2800	5786	3748	254800		
4	**4**	June (Q2) 2022 (N)	11.5	91	9.4	14.5	*11.95*	4000	6118	4079	364000		
5	**5**	September (Q3) 2022 (N)	11.5	91	9.3	13.8	*11.55*	3200	5839	3801	291200	*1328600*	July 2022-June 2023
6	**6**	December (Q4) 2022 (N)	11.5	91	9.9	14.2	*12.05*	3800	6048	3084	345800		
7	**7**	March (Q1) 2023 (N)	11.5	91	10.5	13.1	*11.8*	3600	6175	4072	327600		
8	**8**	June (Q2) 2023 (N)	11.5	91	10.2	12.2	*11.2*	4600	6271	4188	418600		
9	**9**	September (Q3) 2023 (N)	11.5	91	10.5	12.2	*11.35*	5400	6322	4347	491400		
10	**10a**	December (Q4) 2023 (1os2-N)	11.5	91	10.1	12.8	*11.45*	3450	5885	3911	313950	*2170350*	July 2023-June 2024
11	**10b**	December (Q4) 2023 (2of2-S)	13.5		13.2	13.8	*13.5*	4800	6160	3995	436800		
12	**11**	March (Q1) 2024 (S)	13.5	91	11.8	14.7	*13.25*	5600	8325	6052	509600		
13	**12**	June (Q2) 2024 (S)	13.5	91	12.6	17.3	*14.95*	4500	8325	6052	409500		
14	**13a**	September (Q3) 2024 (1of2-Ssw)	13.5	91	12.3	13.9	*13.1*	4150	7808	5400	377650		
15	**13b**	September (Q3) 2024 (2of2-Sne)	13.5		12.7	15.6	*14.15*	4300	9235	6540	391300		
16	**14**	December (Q4) 2024 (S)	13.5	91	11.2	14.4	*12.8*	4600	9729	6730	418600	*1915550*	July 2024 to June 2025
17	**15**	March (Q1) 2025 (N)	11.5	91	10.1	12.4	*11.25*	3500	6737	4632	318500		
18	**16**	June (Q2) 2025 (N)	11.5	91	11.2	12.7	*11.95*	4000	7298	5193	364000		
19	**17**	September (Q3) (N)	11.5	91	10.9	12.1	*11.5*	3850	7006	4773	350350		
20	**18a**	December (Q4) 2025 (1of2, Nne	11.5	91	10.1	13.8	*11.95*	3200	7458	5096	291200	*1674400*	July 2025 to June 2026
21	**18b**	December (Q4) 2025 (2of2, Nnw)	11.5					3150	5829	3663	286650		
22	**19**	March (Q1) 2026 (N)	11.5	91	11.3	12.9	*12.1*	4200	8210	5912	382200		
23	**20**	Q2 June 2026 (S)	13.5	91	11.6	14	*12.8*	4700	8403	5994	427700	*1496950*	July 2026-June 2027
24	**21**	Q3 September 2026 (S)	13.5	91	12.6	14.2	*13.4*	7850	16981	14423	714350		
25	**22**	Q4 December 2026 (S)	13.5	91	12.6	14.5	*13.55*	3900	8930	6283	354900		
											-	-	
Maximum											***714350***	***2170350***	