Doral

APPENDIX 4D

ECOEDGE (2020c)- GROUNDWATER DEPENDENT ECOSYSTEMS ASSESSMENT

A Review and Impact Assessment of Potential Water Drawdowns on Groundwater Dependent Ecosystems at the Proposed Yalyalup Mineral Sands Project

Prepared for Doral Mineral Sands
May 2020

Ecoedge

PO Box 9179 Picton WA 6229
0484 771 825 | enquiries@ecoedge.com.au

Version	Origin	Review	Review date	Release approval	Issue date
V1	M. Portman, R. Smith	R. Smith	10/11/2019		
V2	R. Smith	M. Portman, C. Spencer	15/11/2019		
Final draft	R. Smith	D. Brace	17/11/2019	18/11/2019	
Final	C. Bovell	R. Smith, D. Brace	25/11/2019	Ecoedge	23/4/2020
Final V2	D. Bourke	R. Smith	15/5/2020	Ecoedge	19/5/2020

Contents

Table of Figures

Table of Tables

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.

Report for Benefit of Client

The report has been prepared for the benefit of the Client and for no other party. Ecoedge assumes no responsibility and will not be liable to any other person or organisation for or in relation to any matter dealt with or conclusions expressed in the report, or for any loss or damage suffered by any other person or organisation arising from matters dealt with or conclusions expressed in the report (including, without limitation, matters arising from any negligent act or omission of Ecoedge or for any loss or damage suffered by any other party relying on the matters dealt with or conclusions expressed in the report). Other parties should not rely upon the report or the accuracy or completeness of any conclusions, and should make their own enquiries and obtain independent advice in relation to such matters.

1 Introduction

Doral Mineral Sands Pty Ltd (Doral) is currently planning to construct and operate a mineral sand mine, known as the 'Yalyalup Mineral Sands Project' (the Proposal Area), approximately 11 km southeast of the Busselton townsite.

The Proposal is located on Retention Licence R70/0052, which covers an area of approximately 2,290 ha (Doral, 2019).

The Proposal has a total disturbance area of ~453.34 ha within a Development Envelope of 924.8ha, comprising of ~3.5ha of native vegetation, ~2.88 of planted non-endemic vegetation and ~446.95ha of cleared pasture. The Proposal Area contains ~37.81 ha of native vegetation, of which 6 ha is in Degraded or better condition (Ecoedge, 2019).

The expected mine life is approximately 4.5 – 5.5 years. Dewatering of groundwater inflows into the pit will be required to enable dry mining to occur (Doral, 2019). A drawdown of the groundwater table may impact vegetation dependent on ground water.

Ecoedge was engaged by Doral in October 2019 to conduct a review and impact assessment of modelled water drawdowns on Groundwater Dependent Ecosystems (GDEs) and other conservation values potentially adversely affected by the cone of drawdown to be used in the preparation of the Environmental Review Document (ERD) for submission to Environmental Protection Authority (EPA).

2 Limitations

Data and information used in the preparation of this report to assess and form conclusions in relation to potential impacts of water drawdowns at Yalyalup has been constrained by the following factors:

- There has been no field investigation of plant water-relations or ecophysiology within the Proposal Area.
- This report draws heavily on data from one flora and vegetation survey (Ecoedge, 2019), in which the identification of potential groundwater dependent ecosystems or groundwater dependent species specified was included in the scope.

3 Physical Setting

3.1 Climate

The Proposal Area experiences a Mediterranean climate type (Köppen classification Csb) characterised by hot, dry summers and cool wet winters. The average annual rainfall at Bureau of Meteorology (BOM) gauging station 9603 (Busselton Aero) which is located approximately 1.6 km from the Proposal Area is 685 mm/year. Most rainfall occurs from May to September, with minimal (<25 mm) rainfall in the summer months. Potential average annual evapotranspiration in the region is approximately 1200mm, which therefore is likely to exceed precipitation during summer months (Doral, 2019). Over the 8 years up to and including 2019 the Busselton Aerostation annual rainfall as a percentage of the long-term mean (685 mm) ranged from 83% (2012 and 2015) to 114% (2016).

3.2 Physiography

The Proposal Area is located approximately 11 km southeast of Busselton (**Figure 1**).

It is located within the southern part of the Perth Basin, an elongate north–south rift trough with a series of sub-basins, shelves, troughs, and ridges. The Perth Basin contains up to 15 km depth of sediments that mostly accumulated from the Early Permian to late Cretaceous, with a veneer of Neogene sediments (Freeman and Donaldson, 2006). The Proposal Area is wholly contained within the Bunbury Trough, a sub-basin containing a Permian–Cretaceous succession up to 11 km thick wedged between the Vasse Shelf and the Yilgarn Craton.

The Proposal Area is situated on the Swan Coastal Plain landform, 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 (Ecoedge, 2019). Elevation with the Proposal Area ranges from 20 mAHD[1] near the north western boundary, rising to about 32 m in the south east.

Approximately 90% of the proposed Yalyalup mine site is mapped as a wetland in the Department of Biodiversity, Conservation and Attractions (DBCA) Geomorphic Wetlands of the Swan Coastal Plain dataset (DBCA, 2019), all of which has been assessed as being in the 'Multiple Use' management category, which is described as wetlands with few ecological attributes and functions remaining. The majority of the wetland area within the Project Area (77%) is mapped as Palusplain (i.e. seasonally waterlogged flat), with small areas of Sumpland (i.e. seasonally inundated basin, 3%) and floodplain (seasonally inundated flats, 17%).

[1] Metres above the Australian Height Datum (mAHD).

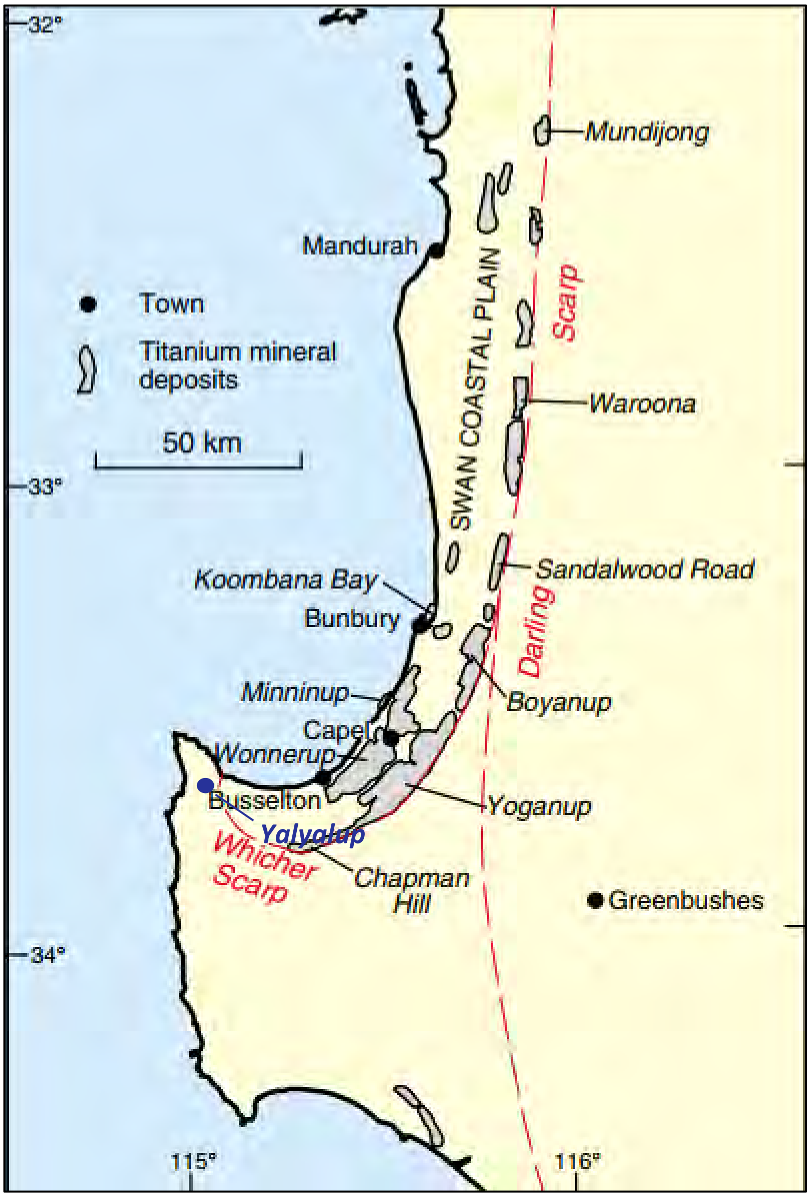


Figure 1. Location of the Proposal Area in a regional context (adapted from Freeman and Donaldson, 2006, p. 15).

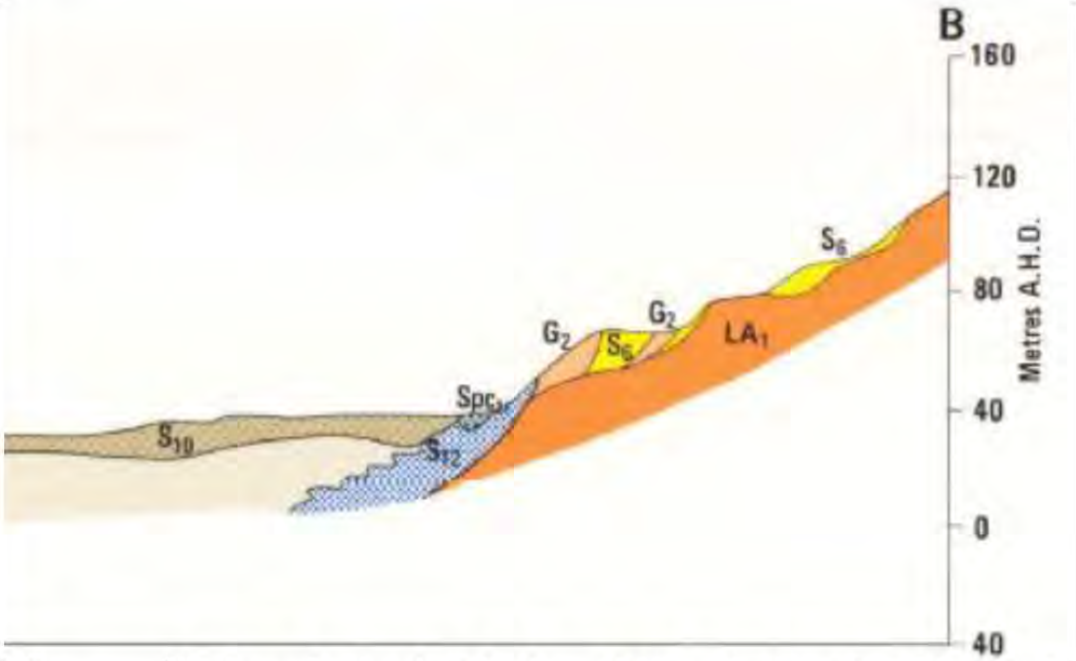
3.3 Geology

The Proposal Area is situated on the Yoganup strandline, (stratigraphically equivalent to the Yoganup Formation), which is a wedge of sand with discontinuous concentrations of heavy minerals stretching across the coastal plain from the base of the Whicher and Darling Scarps and thinning towards the coast (Freeman and Donaldson, 2006).

The Yoganup Formation (represented by 'S12' in **Figure 2**) is one of the superficial deposits in a sedimentary sequence that ranges from the Bassendean Sands (early to middle Pleistocene) at the top to Jurassic Era formations, including the units 1 to 4 of the Yarragadee Formation at depths of over -900 mAHD in the vicinity of the Proposal Area (AQ2, 2019). The sequence of these formations is presented in **Table 1**.

Drilling conducted by Doral to establish the size and distribution of the mineral sands resource has provided information of the depth of the various geological layers under the Proposal Area.

Sufficient data was obtained to gain some understanding of the geology above the Leederville Formation with regard to potential effects on natural values of groundwater drawdown (**Figure 3**).



S10	Sand over silt and sandy silt. Sand is very light grey at surface, yellow at depth, fine to medium grained sub-rounded quartz, local concentrations of heavy minerals, local development of coffee rock, moderately well sorted, of aolian origin
Spc	Clayey peaty sand. Grey to black with variable organic content.
S12	Sand. Yellow, fine to medium grained, sub-angular to rounded quartz with some feldspar, local local concentrations of heavy minerals, well sorted, overlying boulder and cobble conglomerates, of alluvial and marine origin.
G2	Gravel. Brown and reddish brown, ferrunginous, pisolitic, occasionally cemented in a clay silt matrix, moderately sorted, of colluvial origin.
S6	Sand. Light grey, fine to coarse, angular to sub-rounded quartz with some feldspar, moderately sorted, loose, of elluvial origin modified by colluvial processes
LA1	Laterite. Massive and cemented, occasionally vesicular, up to 4m thick. Sometimes overlain by a ferruginous gravel set in a clay-sand matrix.

Figure 2. Cross-section of the geology from the Swan Coastal Plain to the Whicher Scarp near Busselton (From Bellford, 1987).

Table 1. Generalised regional and local stratigraphic sequence and hydrogeology of the Proposal Area (from AQ2, 2019).

Age	Formation	Stratigraphy	Thickness (m)	Lithology	Hydrogeology
Quaternary - late Tertiary	Superficial	Bassendean Sand	0.5-3	Fine to medium sub-rounded quartz sand	Superficial aquifer
		Guildford Formation	2-5	Clay and sandy clay with occasional discontinuous sand lenses	Local aquiclude
		Yoganup Formation	2-5	Leached and ferruginized beach sand conglomerate and clay. Local laterite.	Superficial aquifer
UNCONFORMITY					
Cretaceous	Leederville	Mowen Member	1-10	Clay and silty clay, with thin interbedded silt, clayey sand and fine-grained sand	Regional aquitard; local Leederville aquifer (when significant sand is present)
		Vasse Member	50-100	Fine to medium grained quartz sandstone and interbedded shale.	Leederville aquifer
UNCONFORMITY					
Mid-late Jurassic	Yarragadee	Unit 1	0-50	Medium to coarse grained, weakly consolidated sandstone, minor siltstone and shales	Yarragadee aquifer
		Unit 2	0-250		
		Unit 3	200-500		
		Unit 4	0-100		

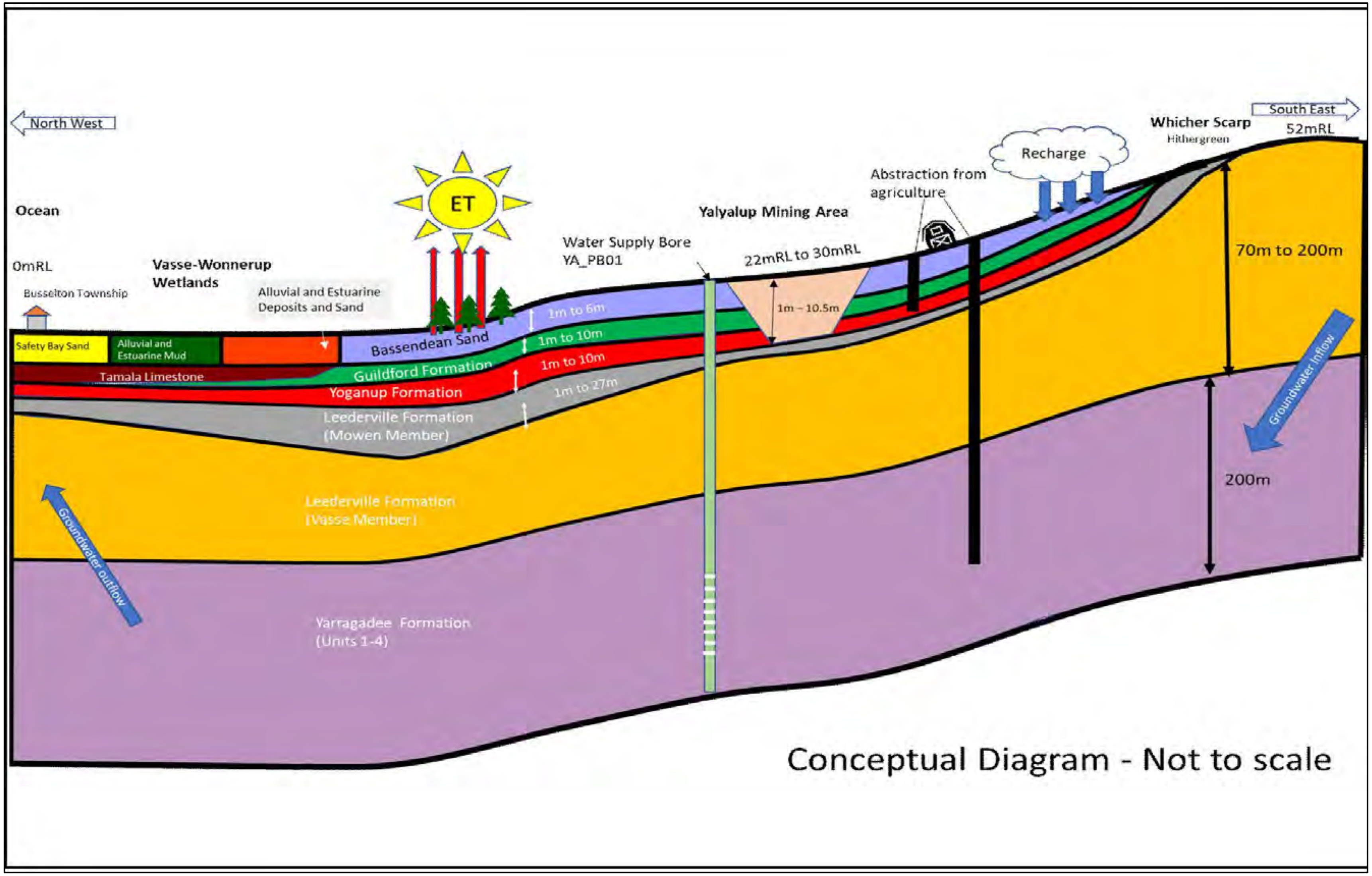


Figure 3. Cross section through the Project Area at Yalyalup (AQ2, 2019).

3.4 Hydrogeology of the Project Area

AQ2 (2019) carried out hydrogeological investigations and modelling for the Proposal Area and recognised three aquifers occurring locally (**Table 2**).

Table 2. Aquifers local to the Yalyalup Proposal Area.

Name	Description for the Proposal Area
Superficial Aquifer	The Bassendean Sand, Guildford Formation and Yoganup Formation form an unconfined Superficial aquifer, with a maximum saturated aquifer thickness of 9 m. The Yoganup Formation forms the main portion of the aquifer, while the Bassendean Sand is generally only saturated in the wet season.
Leederville Aquifer (incorporating the Mowen Member aquitard)	A multi-layered confined aquifer system, comprising discontinuous interbedded sequences of sand, clayey sand, silt and shale. Generally, comprises the Vasse Member of the Leederville Formation. The Mowen, which overlies the Vasse Member, is commonly considered as an aquitard due to its clayey nature. At the eastern portion of the modelled study area, the Mowen Member is likely to be very thin or has a greater sand content, resulting in the Leederville aquifer directly underlying the Superficial aquifer.
Yarragadee Aquifer	A confined Yarragadee aquifer below and confined by the Leederville formation.

The Superficial Aquifer, which is reported to underlie all of the proposed Pit Area (AQ2, 2019) is a shallow, transmissive aquifer that occurs on the surface of the Swan and Scott coastal plains. The groundwater within the Superficial Aquifer is often found close to the surface and therefore many of the wetlands and vegetation complexes found on the Superficial Aquifer on the coastal plains are groundwater dependent (Hyde, 2006). Changes in the water regime within this aquifer (such as through pumping) can affect the values of the dependent ecosystems, so it is important to map and assess the values of and risk to GDEs in the areas of future abstraction from the Superficial Aquifer on the coastal plains (Hyde, 2006; Del Borello, 2008).

Doral used this mineral drilling data collected from between 2012 to early 2018 to interpret and contour the base elevation of the Superficial Formation within the mining area, including the contours of the base elevations of each Superficial Formation unit (AQ2, 2019).

Doral has drilled and installed 12 monitoring bores (i.e. YA_MB01S to YA_MB12S) across the proposed Yalyalup site, with 6 bores being installed in December 2017 and the remaining 6 bores in June 2018 (**Figure 4**). All these monitoring bores were drilled to the base of the Superficial Formation (i.e. Yoganup Formation) and screened across the all Superficial Formation units.

Monitoring bores YA_MB01S, YA_MB07S, YA_MB08S and YA_MB09S are located near to mapped GDEs of high conservation value. Doral intends to install four additional shallow monitoring bores (GDE 1-4) along the McGibbon Track.

A north-south section at approximately 358,600 m E adjacent to the northern end of McGibbon Track showing the location of the shallow dunal ore and the deeper Yoganup Strand ore pits (**Figure 5**). Monitoring bore MB08S is shown in **Figure 4**.

Fluctuations in the depth to water (metres below ground level) for the bores at Yalyalup is shown in **Figure 5**. Bore SCPD28A, where depth to water table rises to the ground surface in some years is at the junction of Princefield Road and McGibbon Track. Depth to groundwater maps for August 2018 and September 2019 are presented in **Appendix 1.**

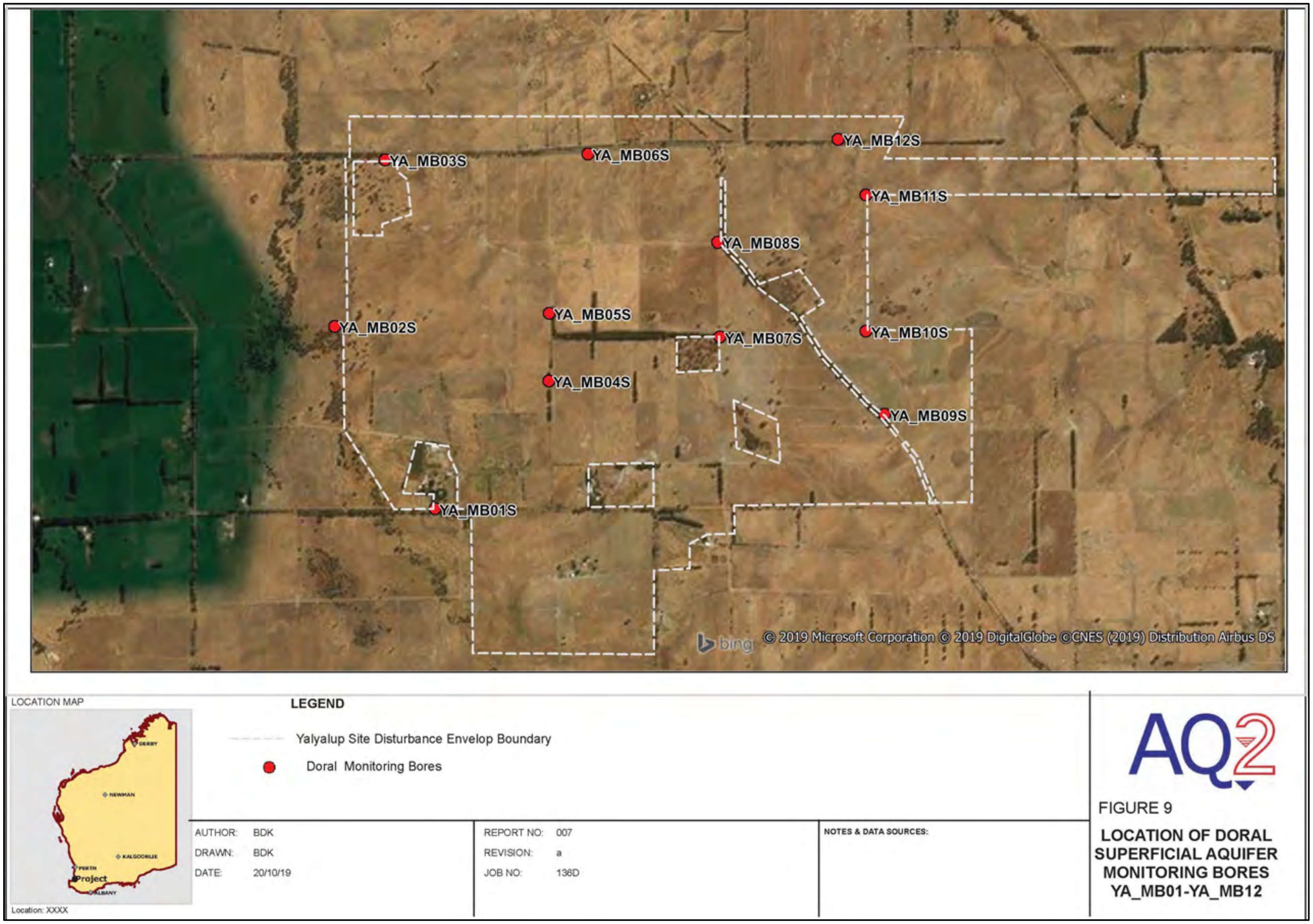


Figure 4. Monitoring bores installed within the Proposal Area (Doral, 2019).

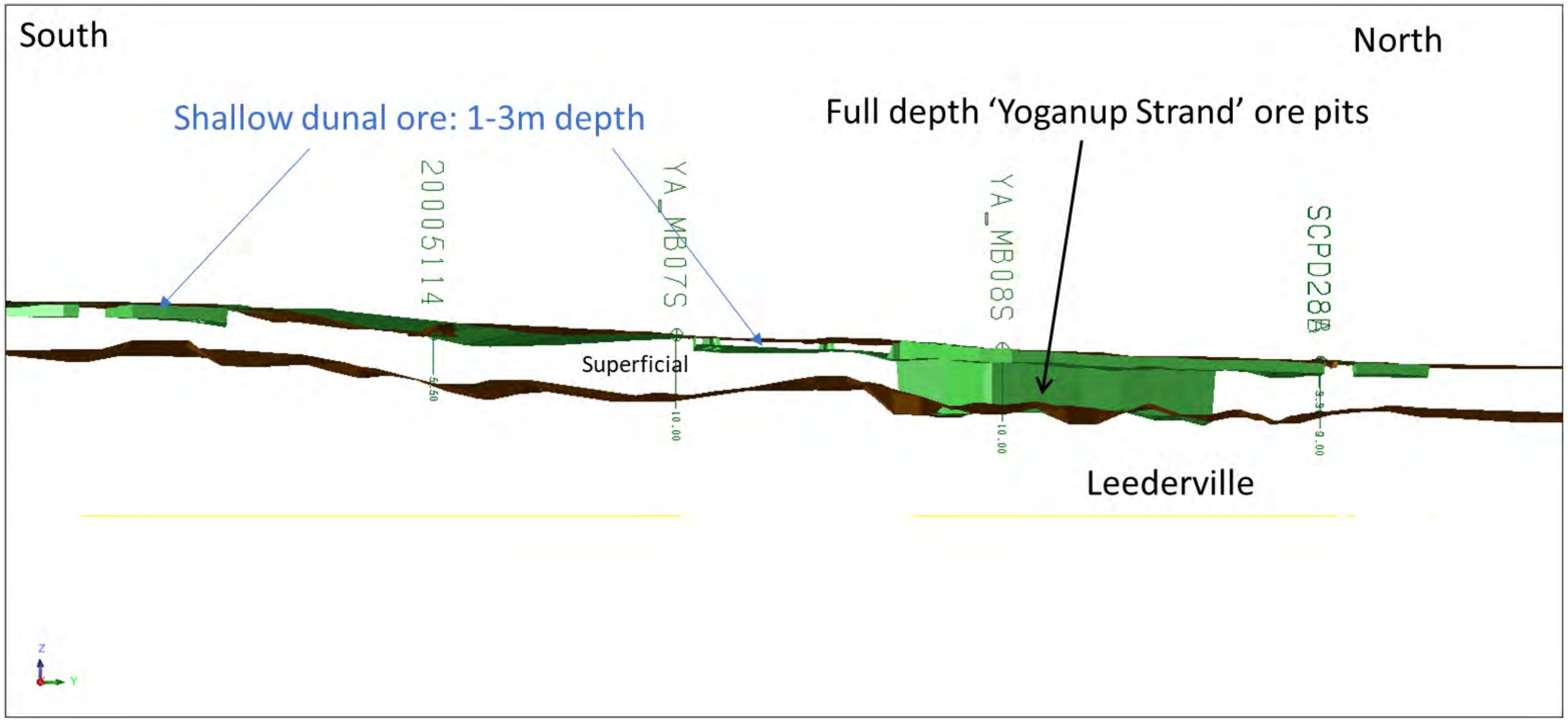


Figure 5. A north-south section at the northern end of McGibbon Track showing the location of the shallow dunal ore and the deeper Yoganup Strand ore pits.

The Superficial Aquifer

The Superficial Aquifer (which includes the Yoganup Formation as its oldest member) is an unconfined aquifer (up to 20 m thick) that overlies the Mowen Member of the Leederville Formation within the Proposal Area (CSIRO, 2009). The upper surface of the Superficial Aquifer is the local water table, which fluctuates seasonally by an amount that depends on the hydraulic conductivity of the soil and the direction of groundwater flow. The water table is generally at its highest level in spring and lowest in late autumn. The Mowen Member of the Leederville Formation is generally considered as an aquitard, however at the Yalyalup site the Mowen Member is thin resulting in the prediction of a small indirect upward leakage of water from the Leederville aquifer from below the pit floor (AQ2, 2019).

There are a number of factors that influence the rate and magnitude of recharge and discharge of the Superficial Aquifer and so control the level of the water table. The Superficial Aquifer on the Swan Coastal Plain is primarily recharged by rainfall and discharges into the ocean as well as into streams, drains, wetlands, and into the underlying Leederville or Yarragadee aquifers (CSIRO, 2009). The rate and magnitude of groundwater recharge by rainfall is dependent on rainfall patterns, land use cover (vegetation cover) and depth to the water table.

The processes of vertical rainfall infiltration and horizontal groundwater flow determine the level of the water table. The water table rises when rainfall infiltration exceeds the flow of groundwater in the winter months and declines over the summer drought period when the horizontal flow of groundwater exceeds the amount of recharge. In addition to horizontal flow, groundwater discharge also occurs through evapotranspiration of water by plants and groundwater abstraction in impacted areas. The influence of evapotranspiration on groundwater levels is greatest in habitats with a shallow depth to groundwater, and during periods when there is little recharge (Shafer *et al*., 2008; Gao *et al*., 2017).

4 Hydrogeological Investigations and Modelling for the Project Area

4.1 Investigations by AQ2

Hydrosolutions (2017) were engaged by Doral to conduct an initial hydrogeological desktop assessment for the Proposal. In regards to their assessment of potential drawdown on GDEs, Hydrosolutions stated that the estimated extent of drawdown is not sufficient to impact any of the publicly identified wetland GDEs in the vicinity, but may have an impact on local terrestrial GDEs; and recommended further assessment to identify any high-value GDEs on site.

In 2019, Doral engaged AQ2 to conduct a groundwater investigation at Yalyalup to obtain a baseline hydrogeological characterisation of the site as an input to the environmental approval process. The focus of the work was to establish a hydrogeological framework to develop a conceptual model and to build a numerical groundwater flow model of the study area incorporating the Proposal Area. The numerical model was then used to predict the likely drawdown, and pit inflows associated with the proposed mining activities (AQ2, 2019).

The investigation by AQ2 comprised four components;

- A desktop literature review of all available geological and hydrogeological data and previous work, including the Initial Hydrogeological Desktop Assessment report (Hydrosolutions, 2017).
- Field programmes, including the establishment of a site groundwater monitoring network, groundwater and surface water monitoring and hydraulic testing.
- The development of a conceptual hydrogeological model and
- The development of a calibrated numerical groundwater model of the mine site and surrounding area.

4.1.1 AQ2's model

AQ2 completed predictions of groundwater inflow to the Proposal Area for the mine plan provided by Doral in May 2019, which included quarterly pit progressions for a period of 3.5 years. This plan shows mining starting in Quarter 3 (July) 2021 and finishing in Quarter 4 (December) 2024, with mining progressing to a depth of between 0.35 m and 10.5 m below ground surface and covering a total mined area of up to 260 ha. The extent of the mining area is shown in **Figure 6**.

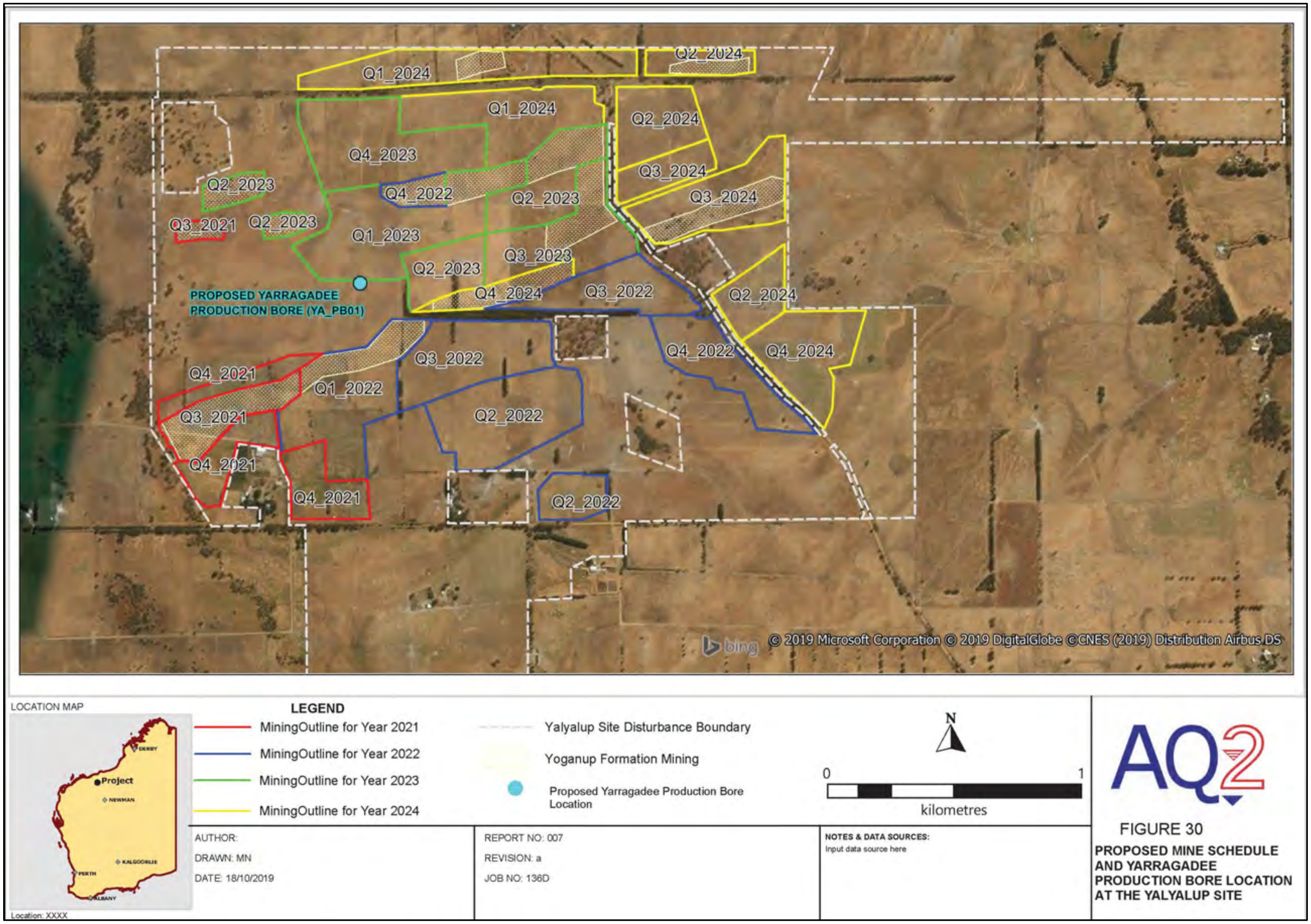


Figure 6. Proposed Yalyalup mining plan (AQ2, 2019).

Operational prediction models were run for a set of wet and dry climatic conditions. Based on the rainfall data sets used for model calibration, a set of "wet" rainfall and associated recharge conditions was included in model predictions using the measured monthly rainfall from July 1997 to December 2000. Similarly, a set of "dry" rainfall and associated recharge conditions was included in model predictions based on measured rainfall from July 2003 to December 2007.

Groundwater inflows and outflows and evaporative losses were included in model predictions consistent with the model calibration.

4.1.2 Summary of model predictions

To provide a clear indication of predicted drawdowns across the Proposal Area in relation to the proposed temporal and spatial progress of mining, several model outputs have been prepared by AQ2 (refer to figures 75 to 103 in AQ2, 2019). Composite maps for both wet and dry scenarios are presented in **Figure 7** and **Figure 8**.

The following general observations were made by AQ2 regarding predicted drawdown:

- Maximum drawdown is predicted in the immediate mining area and is similar for both climatic cases.
- The total maximum drawdown predicted over the life of the mine varies with mining depth.
- The extent of predicted drawdown shown (0.1 m contour) is generally limited to the Potential Disturbance Envelope.
- The maximum distance that drawdown of 0.1 m extends outside of the perimeter of the mine area is 700 m to the north, 250 m to the south, 300 m to the east and 450 m to the west, at various times during the mine life for the dry climate scenario.
- For the wet climate scenario, the maximum distance that drawdown of 0.1 m extends outside of the perimeter of mine area is 600 m to the north, 20 m to the south, 300 m to the east and 400 m to the west, at various times during the mine life for the wet climate scenario.

In summary, groundwater drawdowns in the Superficial aquifer and the underlying Leederville aquifer due to the open pit dewatering have been predicted by the numerical model.

These drawdowns are predicted to be localised in the immediate area of the active mining (pits), temporary in duration (water levels are predicted to recover as the mine pit is progressively tailed and rehabilitated), and relatively small, with a maximum drawdown of 10.5 m predicted at the end of mining in Q2 of 2023. The cone of depression of 0.1 m generally lies within the proposed mining disturbance envelop and only marginally extends past this area (up to 700 m for the dry scenario and 600 m for the wet scenario).

Some small drawdowns (up to 0.4 m) are predicted in the Leederville aquifer due to dewatering of the overlying Superficial aquifer. The Mowen Member of the Leederville Formation is generally considered as an aquitard, however at the Yalyalup site the Mowen Member is thin and may result in small indirect upward leakage of water from the Leederville aquifer from below the pit floor. Based on the results of groundwater modelling, the drawdowns in the Leederville aquifer are predicted to be local and likely to extend laterally, but not vertically (owing to clayey layers within the sand). The drawdown of 0.1 m is estimated to extend no more than 1.2 km for both wet and dry scenario (i.e. Q3 of 2023) from the active mining area and only marginally extending past the proposed mining disturbance envelope boundaries (i.e. up to 700 m).

With regard to water supply wells, drawdown from water supply pumping is predicted at a maximum value of close to 2 m in the Yarragadee aquifer, and less than 1 m in the overlying Leederville aquifer, for both wet and dry climatic conditions. It is noted that these predicted drawdowns are not water table drawdowns, but pressure changes. Pumping from the Yarragadee aquifer is not predicted to have any impact on the shallow (superficial) water table.

AQ2 conclude that is unlikely that short-term dewatering at the proposed Yalyalup mine will have any adverse impacts on the water supply potentials of the Superficial and Leederville aquifer systems.

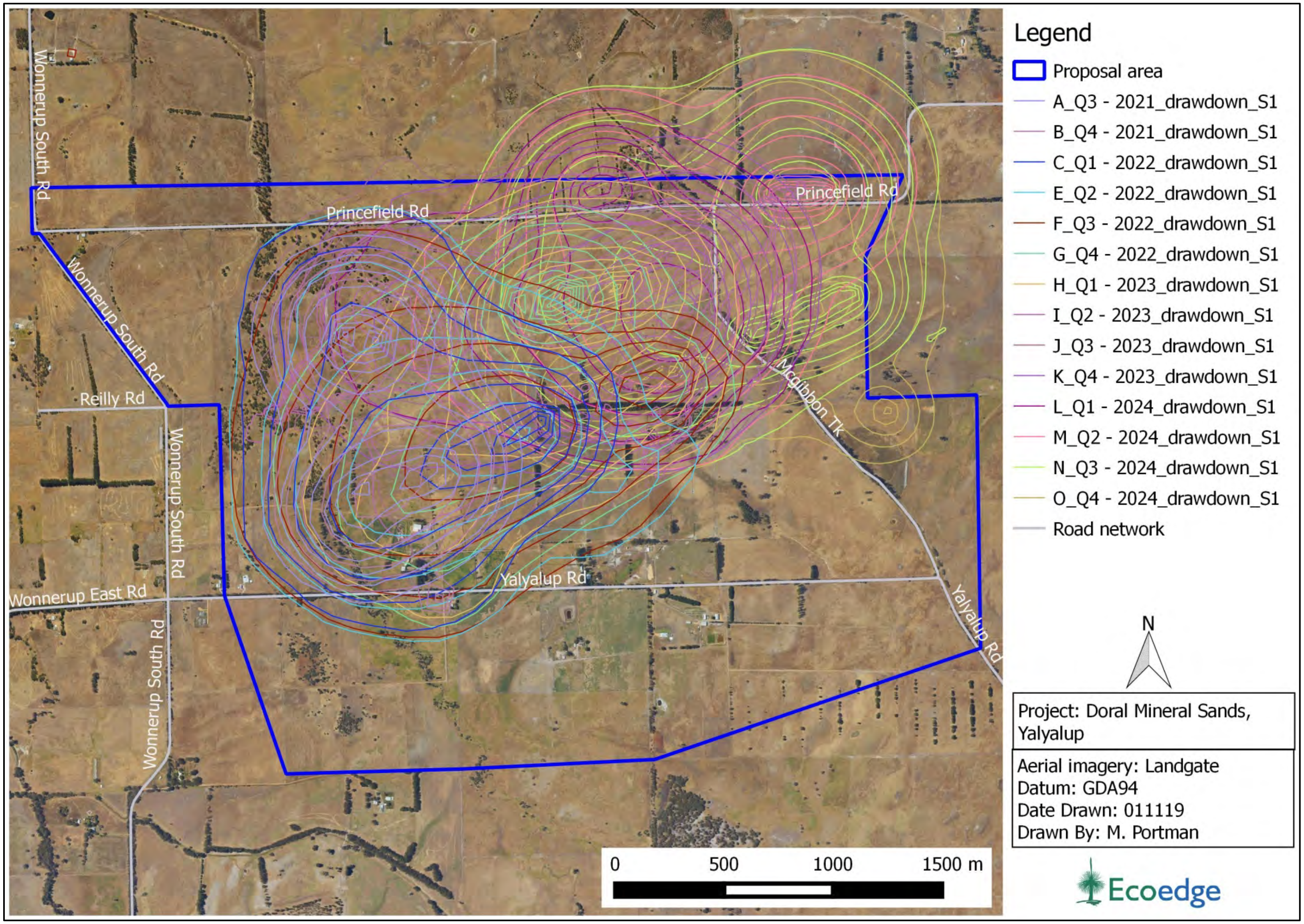


Figure 7. Potential dry scenario induced drawdowns. The outermost mapped drawdown level is 0.1 metres (AQ2, 2019).

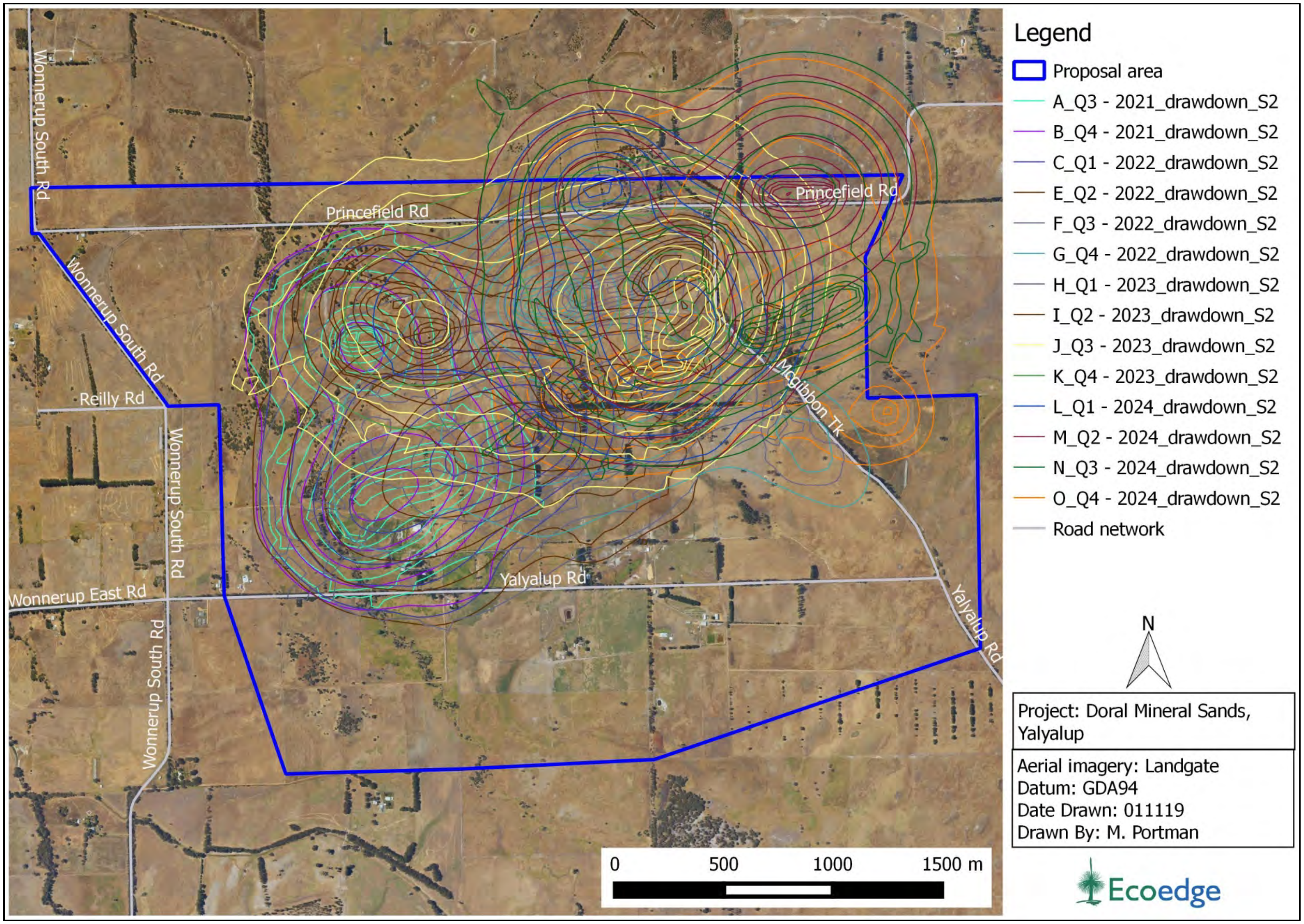


Figure 8. Potential wet scenario induced drawdowns. The outermost mapped drawdown level is 0.1 metres (AQ2, 2019).

5 Groundwater Dependent Ecosystems

5.1 Definition

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). The same publication ('Australian Groundwater-Dependent Ecosystems Toolbox'), defines groundwater as subsurface water located in the zone of saturation in pores, fractures in rocks and cavities.

For the purposes of defining ecosystem dependence on groundwater, groundwater is defined as "*…that water which has been below ground and would be unavailable to plants and animals were it to be extracted by pumping*" (Hatton and Evans, 1998).

Types of groundwater dependent ecosystems may include (Richardson *et al*., 2011):

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 water table is within the root zone of the plants, either permanently or episodically.

Groundwater dependent, or phreatophytic vegetation, depends on the subsurface presence of groundwater, often accessed via the capillary fringe or vadose zone (i.e. the subsurface water just above the water table in a zone that is not completely saturated). The soil water in this zone is readily available to plant roots. As water is removed by transpiration it is continually replenished from the water table through capillary rise. Phreatophytes are therefore plants that meet their water requirements by water uptake from the groundwater or its capillary fringe (Kuginis *et al*., 2012).

5.2 Identifying Groundwater Dependent Ecosystems

Type 3 GDEs (ecosystems dependent on subsurface presence of groundwater, as defined in **Section 5.1**) 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).

6 Potential Groundwater Dependent Ecosystems and Species with Potential Impacts of Groundwater Drawdown at Yalyalup

6.1 Groundwater Dependant Vegetation Units

Vegetation Units[2] within the Proposal Area were described and mapped by Ecoedge (2016, 2017, 2019). Three of these vegetation units are considered to be GDEs (A2, B1, and C3), and another unit, A1, while probably not a GDE, has groundwater-dependant trees within it. Three no longer intact communities[3] (B2, C1, C2), are dominated by phreatophytic species (**Table 3**). All the GDEs identified in Table 3 (as well as SWAFCT01b; unit A1) are listed as Threatened Ecological Communities under the Western Australian *Biodiversity Conservation Act 2016* (BC Act). Two of them (SWAFCT09 and SWAFCT10b) are also listed as threatened under the Federal *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The small area of SWAFCT09 (unit C3) on Princefield Road is a degraded occurrence of the "Claypans of the Swan Coastal Plain" TEC (DPaW, 2015), and vegetation unit B1 is an occurrence of "Shrublands on southern Swan Coastal Plain ironstones" TEC (Meissner and English, 2005). Research into the hydrology and plant water relations of the GDEs occurring in the Yalyalup Proposal Area will be discussed below. The locations of the GDEs are shown in **Figure 11**, and denoted by areas A, B, and C.[4]

6.1.1 Local and Regional Conservation Significance of the GDEs at Yalyalup

There is no readily available information on the conservation significance of these TECs (SWAFCT01b, SWAFCT02, SWAFCT09 and SWAFCT10b) at a local or regional level. However, SWAFCT01b, SWAFCT02 and SWAFCT10b are only found on the Swan Coastal Plain south of Capel so their local threat status and conservation significance would be the same as their State-wide level.

6.1.2 Claypan Communities (vegetation unit C3)

Hydrology studies of the Brixton Street wetlands (which include claypan GDEs) has recently been summarised (Bourke, 2017). There is some evidence that there is limited or no hydrological connection between claypan vegetation and groundwater in claypan wetlands and that the vegetation relies primarily on rainfall (V & C Semenuik, 2001[5]; Chow *et al*., 2010). However, widespread clearing, that has occurred within the Proposal Area combined with the

---

[2] The term "vegetation unit" is used rather than "plant community" because some of the vegetation units are considered to be no longer a functioning native ecosystem.

[3] These vegetation units are classed as "Completely Degraded" and while having one or more of the original overstorey species, are devoid of native species in the understorey.

[4] These GDE Area codes do not relate to the vegetation unit codes.

[5] Cited in DPaW, 2015

fact that most of the native vegetation occurs as narrow remnants would have led to substantial changes in local hydrology. The replacement of native vegetation by agricultural crops and pastures has disturbed the water cycle that existed prior to European settlement and greatly increased the amount of water leaking beyond the root zone of introduced species and contributing to groundwater systems (Eberbach, 2003).

6.1.3 Southern Wet Shrublands (vegetation unit A2)

Southern wet shrublands (SWAFCT02) (which are listed as “Endangered” under State legislation) are shrublands or open woodlands occurring on seasonally inundated sandy-clay soils. Because their subsoil has higher permeability than claypan communities they are more typically a GDE. There appears to have been no research conducted into the hydrology of this community. However, the response of the dominant small trees such as *Melaleuca preissiana* and *Banksia littoralis* in this community is probably similar to that of the same species occurring in the sandier wetlands of the Gnangara Mound near Perth (Groom *et al*., 2001). In the study conducted by Groom *et al.,* both taxa were shown to be dependent on groundwater, and *B. littoralis* in particular had showed a decline in distribution resulting from declining rainfall and increased water abstraction.

The geology log for water-monitoring bore MB08S, which is adjacent to the Southern Wet Shrublands at the northern end of McGibbon Track, records grey sand to 1 m and then a relatively impervious layer of clayey-sand over sandy clay (with ironstone gravel) to 3 m.

6.1.4 Shrublands on Southern Swan Coastal Plain Ironstones (vegetation unit B1)

The ironstone soils near Busselton are associated with shallow seasonal inundation with fresh water. This inundation may occur due to ponding of rainfall as a consequence of the impermeable nature of the surface outcrops of ironstone and the associated heavy soils. In addition, groundwater levels in the community come very close to or may reach the surface in the wetter months (Tille and Lantzke 1990; Smith, 1994).

The geology log for bore MB03S which was drilled into an ironstone outcrop on Princefield Road within the Proposal Area records about 4 metres of massive ironstone over sandy-clay at 5 m and clay at 6 m. The record for the drilling of bore MB11S provides another glimpse of the geology of the ironstone formation in the Proposal Area. Here 0.7 m of grey sand overlies 2.1 m of massive ironstone overlying about 3 m of clayey sand.

The specialised root-growth adaptations of several ironstone endemic shrubs have been the subject of research in recent years (e.g. Williams, 2007; Poot and Lambers, 2008; Poot *et al.*, 2008). Seedlings of ironstone endemics were shown to direct much more of their growth into their root systems than more widespread congeners. Ironstone endemics also favoured root growth in deeper layers of the substrate which appears to be related to their need to produce roots capable of penetrating vertical cracks or fissures in the laterite, to access water at deeper levels as the water-table retreats during the summer drought.

Vegetation unit B1 on McGibbon Track contains the threatened species *Banksia squarrosa* subsp. *argillacea* plus several other ironstone endemics that are classified as priority species.

Another occurrence of Unit B1 is situated at the corner on Princefield Road 890 m east of McGibbon Track (Area C on **Figure 11)**. This small area of vegetation is comprised almost entirely of *Astartea scoparia* with a few shrubs of the threatened *Verticordia plumosa* subsp. *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).

Table 3. Summary Information on vegetation units and their GDE Status in the Yalyalup Proposal Area.

Vegetation Unit	Description	Comments	GDE Characteristics
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. Only areas mapped as Degraded/Good or Good are considered to be an occurrence of SWAFCT01b.	Probably not a GDE, though *Melaleuca preissiana* is known to be phreatophytic.[6]
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. Only areas mapped as Degraded/Good or Good are considered to be an occurrence of SWAFCT02.	A GDE. In addition to the phreatophytic small trees *M. preissiana* and *Banksia littoralis*[7] there are several other known groundwater-dependant taxa such as *Eucalyptus rudis* and *Hakea varia.*[8]
B1	Tall shrubland of *Acacia saligna*, *Banksia squarrosa* subsp. *argillacea*, *Calothamnus quadrifidus* subsp. *teretifolius*, *Hakea oldfieldii*	"SWAFCT10b - Shrublands on southern Swan Coastal Plain Ironstones (Busselton area)" (TEC).	A GDE. Many of the shrubs growing in the ironstone community have specialised root morphologies that

[6] Froend R. H., Drake P. L. (2006) Defining phreatophyte response to reduced water availability: preliminary investigations on the use of xylem cavitation vulnerability in Banksia woodland species. *Australian Journal of Botany* 54, 173-179.
[7] Groom, P.K. & Froend, Ray & Mattiske, E.M. & Gurner, R.P. (2001). Long-term changes in vigour and distribution of Banksia and Melaleuca overstorey species on the Swan Coastal Plain. Journal of the Royal Society of Western Australia 84, 63-69.
[8] Tauss, C. and Weston, A.S. (2010). The flora, vegetation and wetlands of the Maddington-Kenwick Strategic Employment Area. A survey of the rural lands in the vicinity of the Greater Brixton Street Wetlands. Report to the City of Gosnells, W.A.

Vegetation Unit	Description	Comments	GDE Characteristics
	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.	Except on McGibbon Track where it is classed as Good condition the small fragments of this unit are Degraded/Good or Degraded condition and are not considered to represent an occurrence of SWAFCT10b.	enable access to stored moisture sources in the underlying rock.[9] *V. plumosa* var. *vassensis* population on Princefield Road (Area C).
B2	Woodland of *Eucalyptus rudis* and (in some areas) *Melaleuca rhaphiophylla* over weeds on massive ironstone.	Degraded "SWAFCT10b - Shrublands on southern Swan Coastal Plain Ironstones (Busselton area)" (not considered to be a TEC). Completely Degraded areas of B1 with only the overstorey remaining.	Not an intact community, however both *Eucalyptus rudis* and *Melaleuca rhaphiophylla* are groundwater dependant.
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.	Not an intact community, however both *Eucalyptus rudis* and *Melaleuca rhaphiophylla* are groundwater dependant.
C2	Open woodland of *Melaleuca preissiana* over weeds on seasonally wet brown clay-loam.	"SWAFCT04 - *Melaleuca preissiana* damplands". Small area on farmland – Completely Degraded	Not an intact community, however *Melaleuca preissiana* is known to be phreatophytic.
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.	A small area in Degraded/Good or Good condition on the verge of Princefield Road. Considered to be too small and badly degraded to be inferred as an example of "SWAFCT09 - Dense shrublands on clay flats" (TEC).	Probably a GDE, depending on the permeability of the subsoil. Species such as *M. preissiana* and *M. viminea* would be accessing groundwater for part of the year.

[9] Poot, P., & Lambers, H. (2008). Shallow-soil endemics: adaptive advantages and constraints of a specialized root-system morphology. New Phytologist 178, 371-381.

6.1.5 Threatened and Priority Flora

The surveys by Ecoedge (2016, 2017, 2019) identified populations of several threatened and priority flora growing within and adjacent to the Yalyalup Proposal Area (**Table 4**; **Figure 9**). All of this threatened and priority flora is associated with TECs and GDEs. Several of the populations (for instance the *Banksia nivea* subsp. *uliginosa*[10] on Princefield Road) have not been seen in recent years. All populations were checked, or searched for in 2019 (Ecoedge, 2019). Some of these taxa are dominants or co-dominants within plant communities (for instance *C. quadrifidus* subsp. *teretifolius* and *B. squarrosa* subsp. *argillacea* in the Busselton ironstone on McGibbon Track). They are threatened to the degree the community they occur in with regard to potential drawdown of groundwater.

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 (Area C on **Figure 11**). The population size was estimated at 200+ plants in 1996, and 100+ in 2006 (Williams *et al*., 2001; DotEE, 2016f) and about 30 in 2019 (Ecoedge 2019).

TAXON	NUMBER	WA Conservation status	LOCATION
Acacia flagelliformis	13	P4	Princefield Road
	9	P4	McGibbon Track
Banksia squarrosa subsp. *argillacea*	9	T	McGibbon Track
Calothamnus quadrifidus subsp. *teretifolius*	62	P4	McGibbon Track
	12	P4	Cooper's Road Drain Reserve
Grevillea brachystylis subsp. *brachystylis*	2	P3	Princefield Road
Loxocarya magna	42	P3	McGibbon Track
	1	P3	Cooper's Road Drain Reserve
	3	P3	Princefield Road
Verticordia plumosa var. *vassensis*	c. 30	T	Princefield Road

Table 4. Threatened and Priority flora occurring in the Yalyalup Proposal Area.

[10] Formerly *Dryandra nivea* subsp. *uliginosa*.

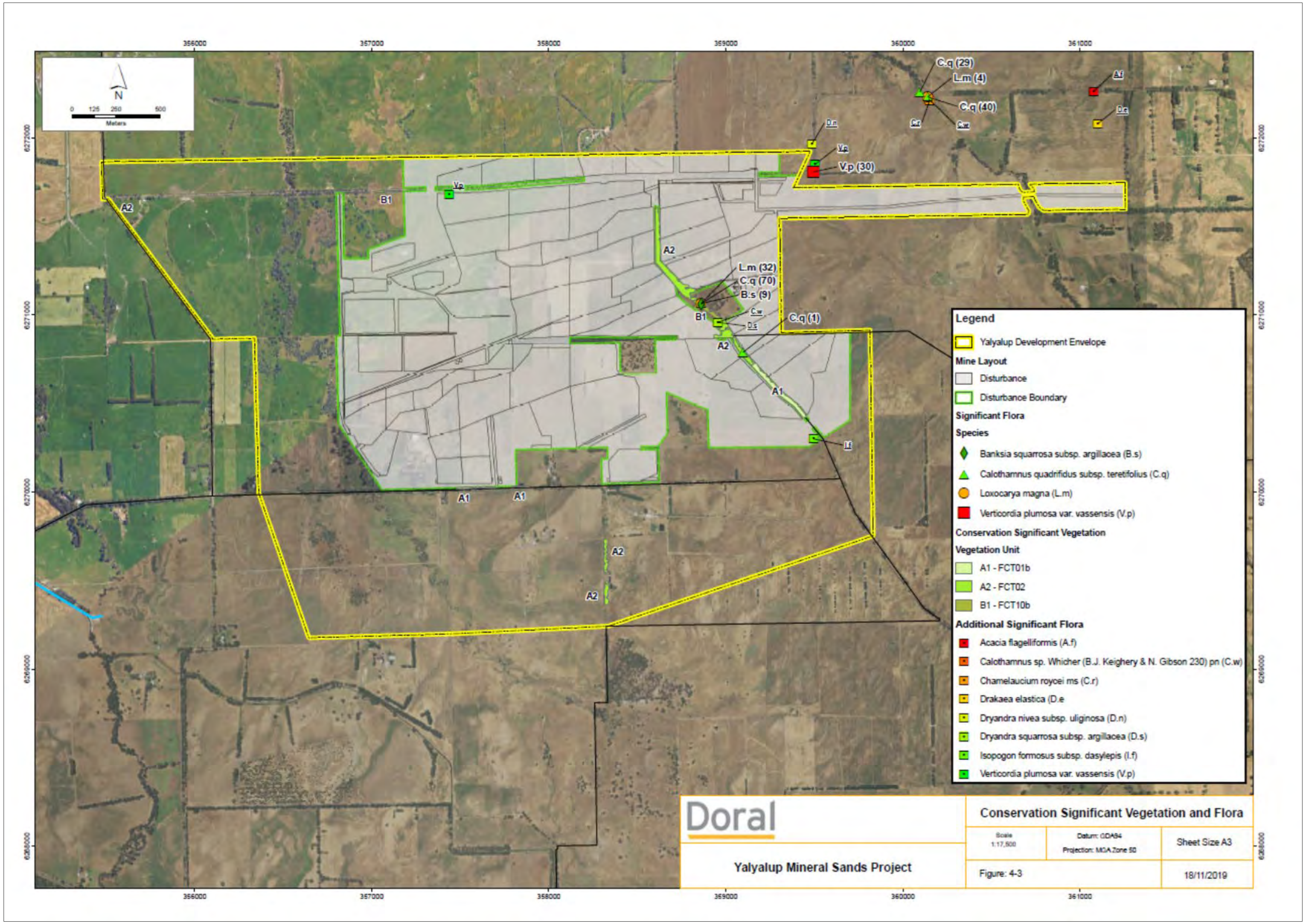


Figure 9. Threatened and Priority Flora within and adjacent to the Yalyalup Proposal Area. Note: Not all of these populations have been sighted in recent years.

6.2 Superficial Groundwater Level Fluctuations within the GDEs at Yalyalup

Two bores (MB07S and MB10S) that occur near to the northern end of McGibbon Track where areas of vegetation units A2 (Southern Wet Shrublands) and B1 (Ironstone Shrublands) are situated have substantial records of water levels. Water table depths between December 2017 and October 2019 are shown in **Figure 10** for these bores: MB07S, MB10S and another one (20005169) which is located just south of Princefield Road near small areas of vegetation units B1 and C3 on the road verge. The location of these bores is shown in **Figure 11**.

The geology at MB07S is sand over clayey sand at 1 m then clay at 2 m and at MB10S it is clayey sand to 2 m then sand then clayey sand again at 3 m.

Water level data for MB08S, which is situated adjacent to McGibbon Track (and the Southern Wet Shrublands community) is only available for June and October 2019, when the depth below ground surface was 1.68 m and 0.94 m, respectively.

It can be seen in **Figure 10** that:

- Highest water level elevations were recorded in August or September and lowest in May or June;
- The seasonal water level variations for these bores were between 1.7 and 2.5 m;
- Variations in water levels are generally correlated with the seasonal rainfall pattern.

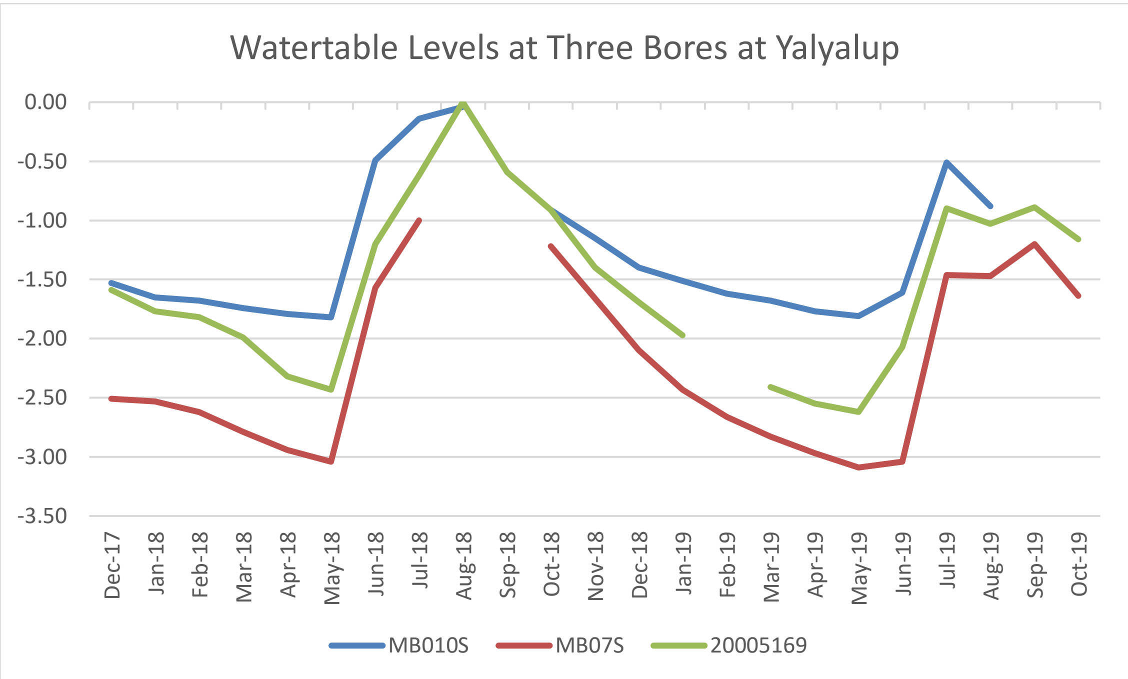


Figure 10. Depth to the water table for three bores near McGibbon Track, Yalyalup Proposal Area

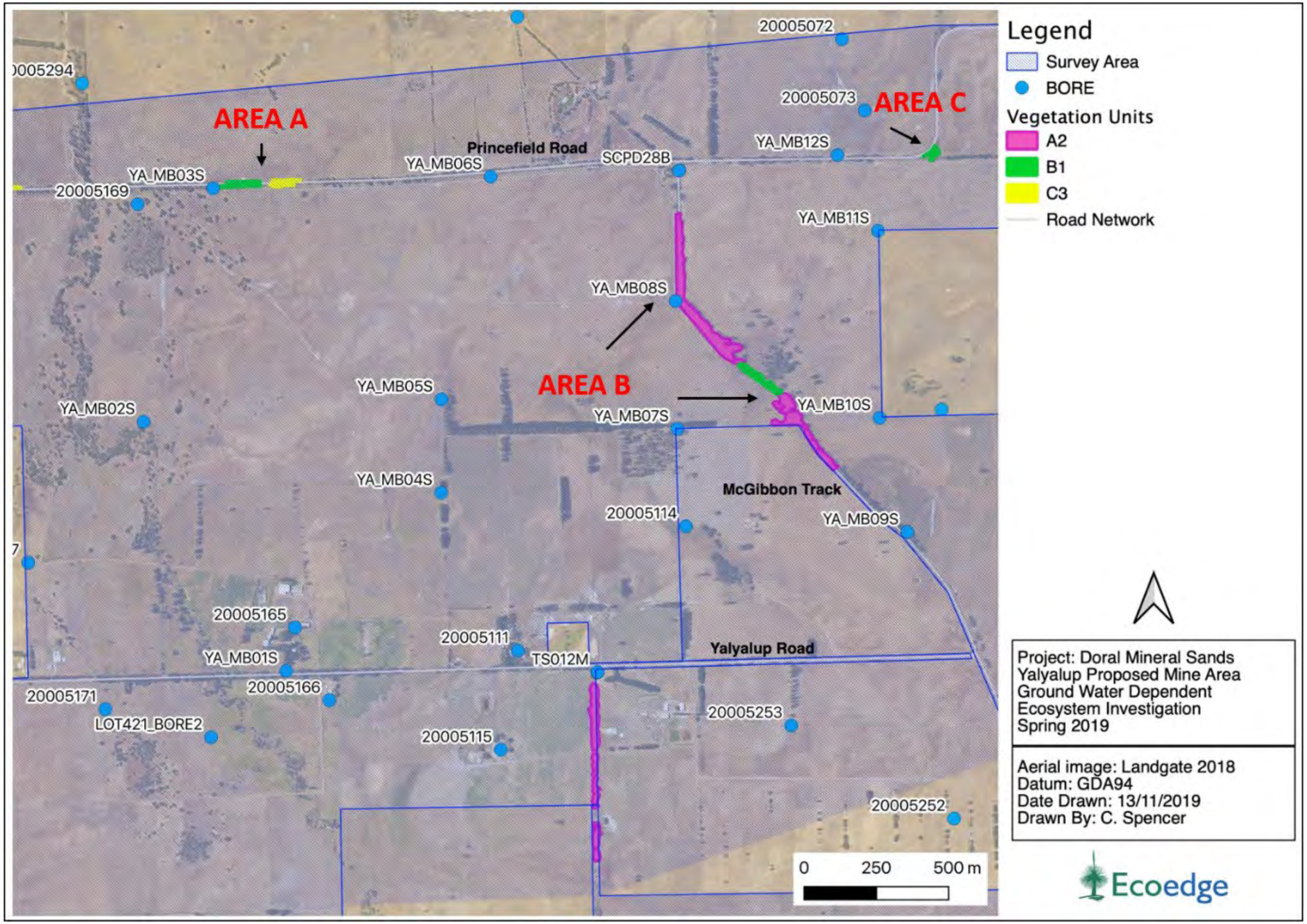


Figure 11. Locations of water level bores (Superficial aquifer) in relations to GDEs in the Yalyalup Proposal Area.

6.3 Predicted Water Level Drawdowns

AQ2 have produced a series of predicted water level drawdowns within the superficial aquifer over the life of the mining project. This was done for a set of wet and dry climatic conditions (sub-section 5.1.2, above) (**Figure 12** and **Figure 13**). The following discussion will focus on those periods when the "dry climatic conditions" (late autumn) predicted drawdown will be at its maximum for the GDEs shown in **Figure 11**, above.

Figure 12 shows the projected drawdowns for Q2 (Apr-Jun) 2023 under a dry climate scenario. Under this scenario drawdown of 1 m would occur within 30 m of GDE Area A (and between 0.1 m and 0.25 m within the road verge vegetation), and of 7 m within 40 m of the northern part of GDE Area B. Within the vegetation on McGibbon Track in the northern part of Area B, drawdowns of between 3 m and 5 m are projected.

During Q3 2023, the contours of projected drawdown move further south and the central part of GDE Area B has 7 m projected drawdowns within 40 m of its boundary and 4 m – 5 m within the vegetation on McGibbon Track. In this quarter, however, the projected drawdowns at the ironstone shrubland part of GDE Area B are only 0.1 – 0.25 m. Predicted drawdowns in the central part of GDE Area B reduce to 1 m – 2 m by Q4 2023.

Mining moves to the east side of McGibbon Track in 2024 and in Q3, 2024 drawdowns within vegetation unit A2 (Wet Shrubland) within GDE Area B on McGibbon Track are predicted to be 3 m – 4 m, and within 20 m of the edge of the road reserve they are predicted to be 5 m (**Figure 13**). Water level drawdown within vegetation unit B2 (Ironstone Shrubland) is projected to be between 0.25 m and 1.5 m in Q3, 2024. In Q4, 2024, water level drawdowns will remain between 0.5 m and 2 m within the central part of GDE Area B, which includes the Ironstone Shrubland. Predicted drawdowns within the central part of GDE Area B are similar whether the "wet climate" or "dry climate" is chosen.

The predicted water level drawdowns under the dry climate scenario are no greater than 0.25 m for GDE Area C.

In summary; GDE Area B has predicted drawdowns in Superficial groundwater levels of up to 5 m for a period of up to 18 months within the central and northern part of this area.

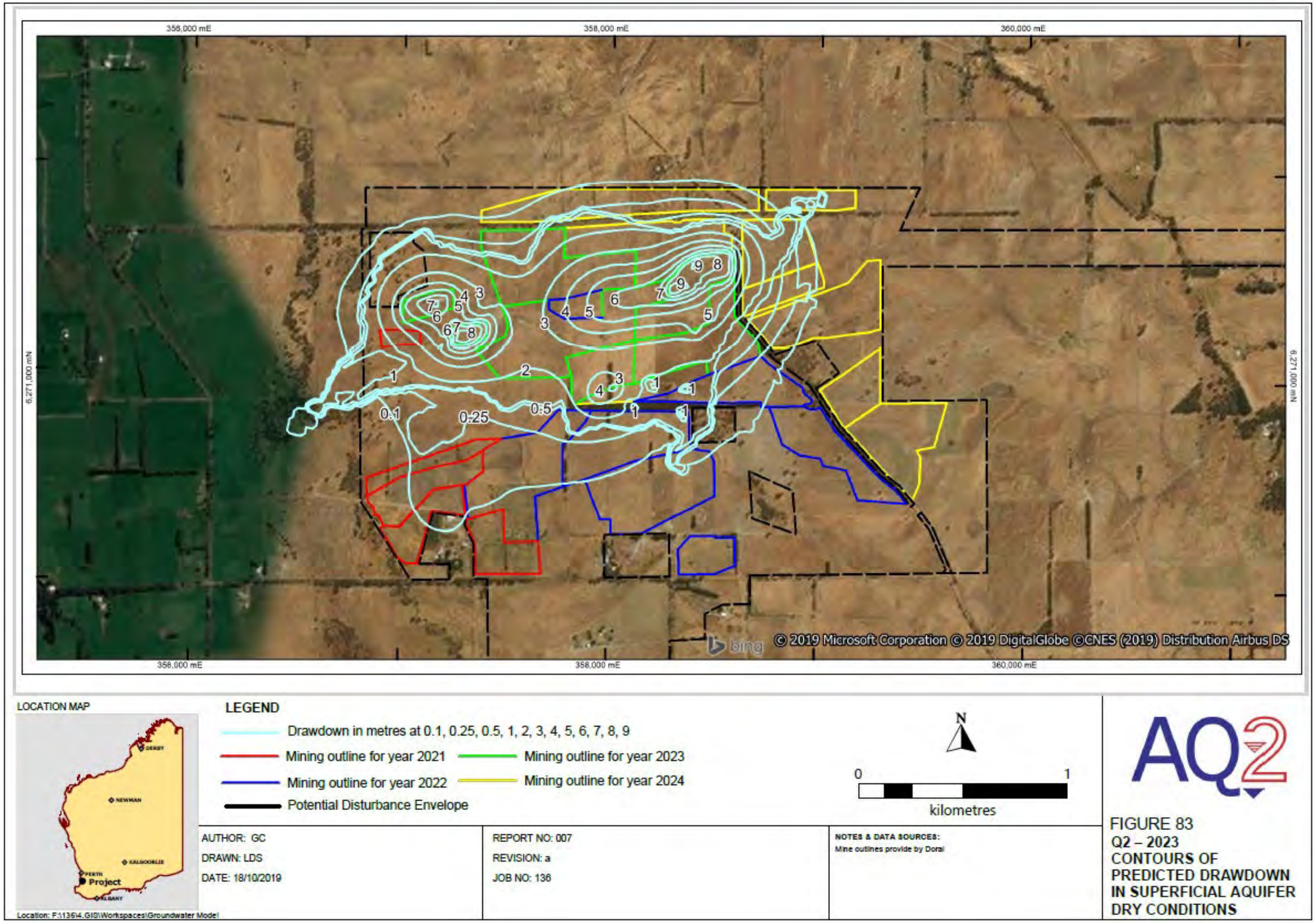


Figure 12. Predicted Superficial aquifer drawdowns under a "dry climate" scenario in quarter 2, 2023.

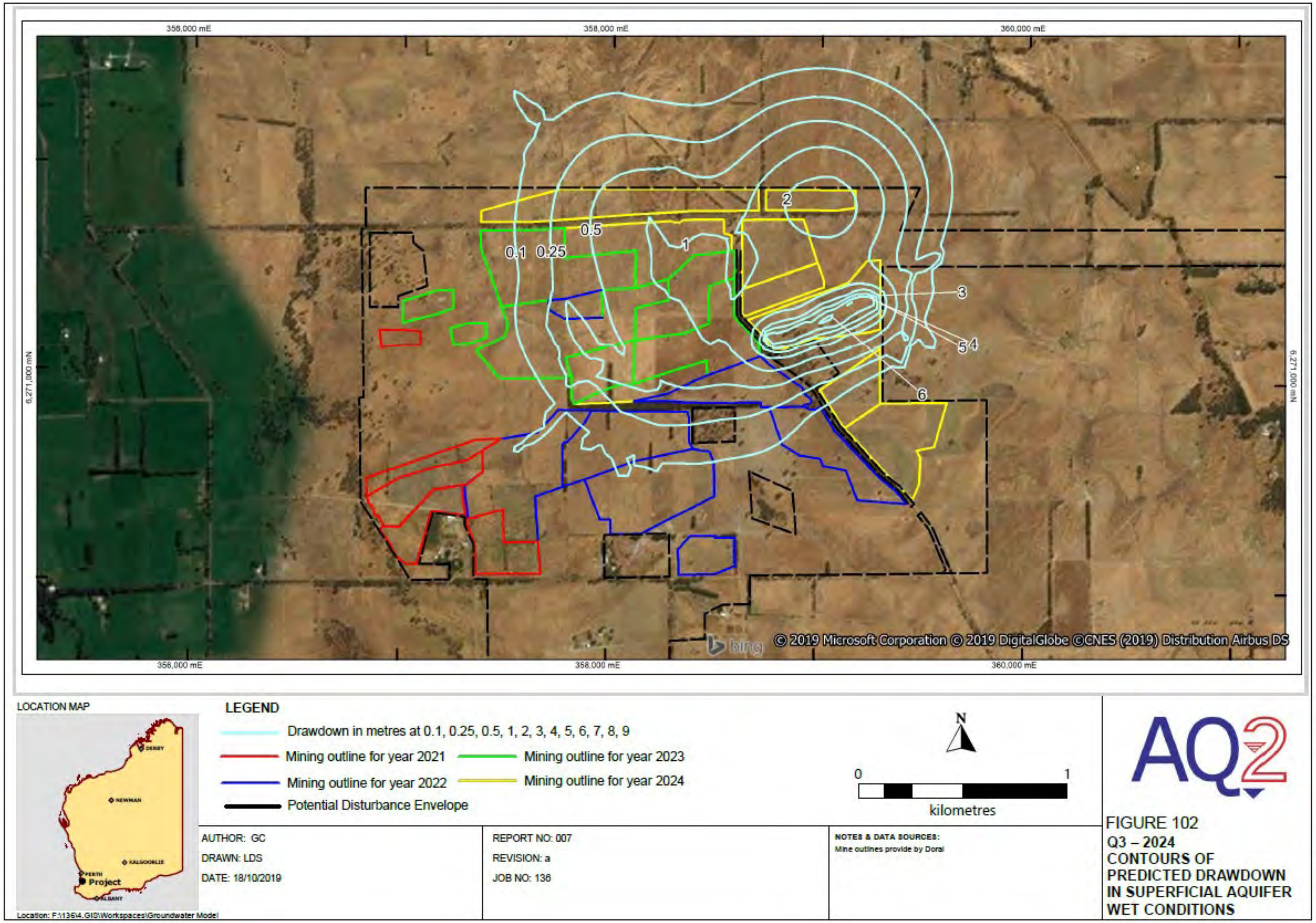


Figure 13. Predicted Superficial aquifer drawdowns under a “dry climate” scenario in quarter 3, 2024.

6.4 Theories of Plant and Vegetation Response to Groundwater Level Change

Trees and shrubs mostly access water from the upper unsaturated soil profile. However, in groundwater dependent ecosystems, the roots of plants adapted to these conditions also extract water from the capillary zone above the water table (Erasmus, 2009). This author goes on to describe the sequence of adaptions and responses of plants as groundwater availability declines:

> *"The response of vegetation to reduced availability of groundwater is incremental. Initially, following a decline in groundwater availability, plants show short-term adaptive responses, the most important of which is a reduced opening of the stomata on leaves. This occurs to reduce the amount of water required by the plant canopy, but it also reduces the rate of carbon fixation and hence growth is also reduced. If the decline in availability persists, the leaf area index of the site declines as trees lose their leaves in an effort to further reduce their water use. Growth is now very much reduced."*

A schematic depiction of the responses of plants and plant communities to declining groundwater levels is shown in **Figure 14**, below.

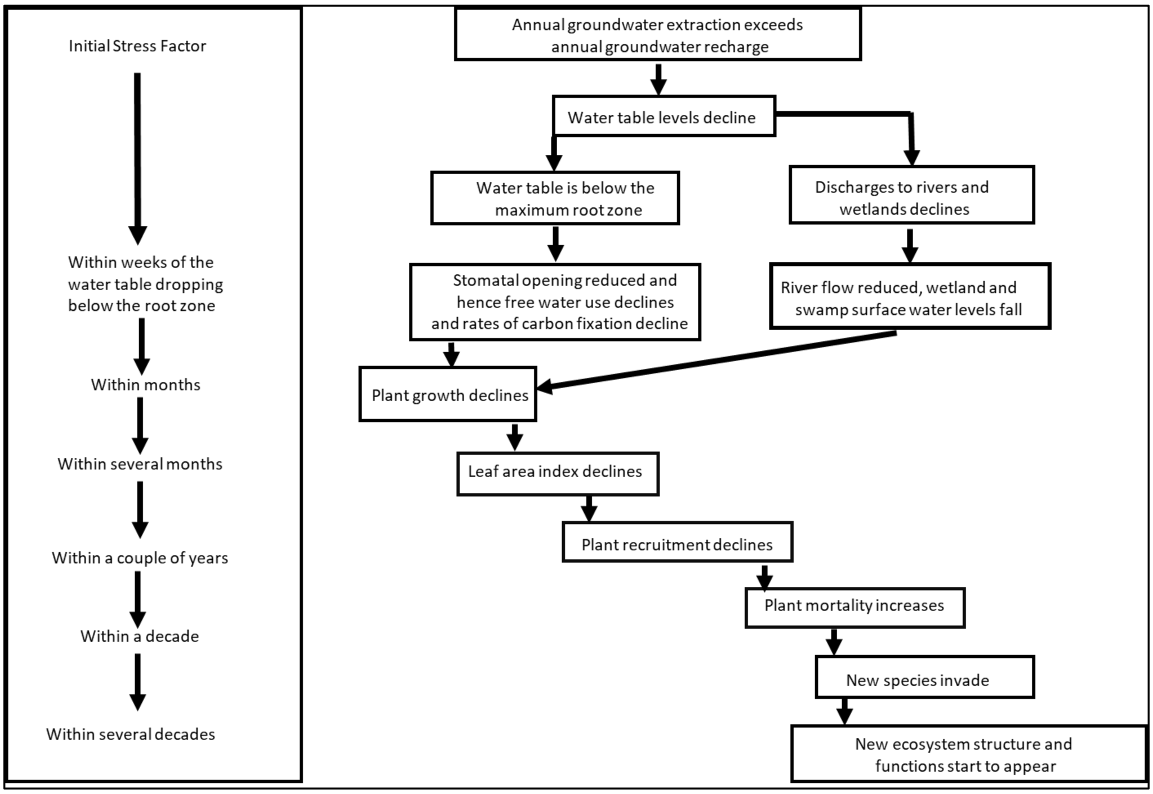


Figure 14. Schematic of the response of plants and communities of plants to reduced availability of groundwater (adapted from Erasmus, 2009).

Huang *et al*. (2019) present a model of plant responses to groundwater where they define "environmental groundwater depth", which can be defined as a mean depth or a range of groundwater depths, which satisfy the growth of natural vegetation, not under stress either because of lack of water or anoxia or soil salinisation. **Figure 15** displays a schematic definition of environmental groundwater depth (Huang *et al*., 2019);

> *'[Environmental groundwater depth] can be categorized as follows: desirable, acceptable, and unacceptable groundwater depth. Within the desirable range, the capillary fringe is near the vegetation root zone; vegetation grows well and changes in groundwater depth have slight influence on vegetation growth. Beyond the desirable range, a small variation in groundwater depth could significantly affect vegetation; the transition from healthy zone to lethal zone may be* linear *or* non-linear*, depending on the specific ecological and hydrological processes and their interactions. When the groundwater level is too low, capillary action cannot lift groundwater upward through the root zone of plants. This could cause soil desiccation, vegetation degradation, and land desertification.'*

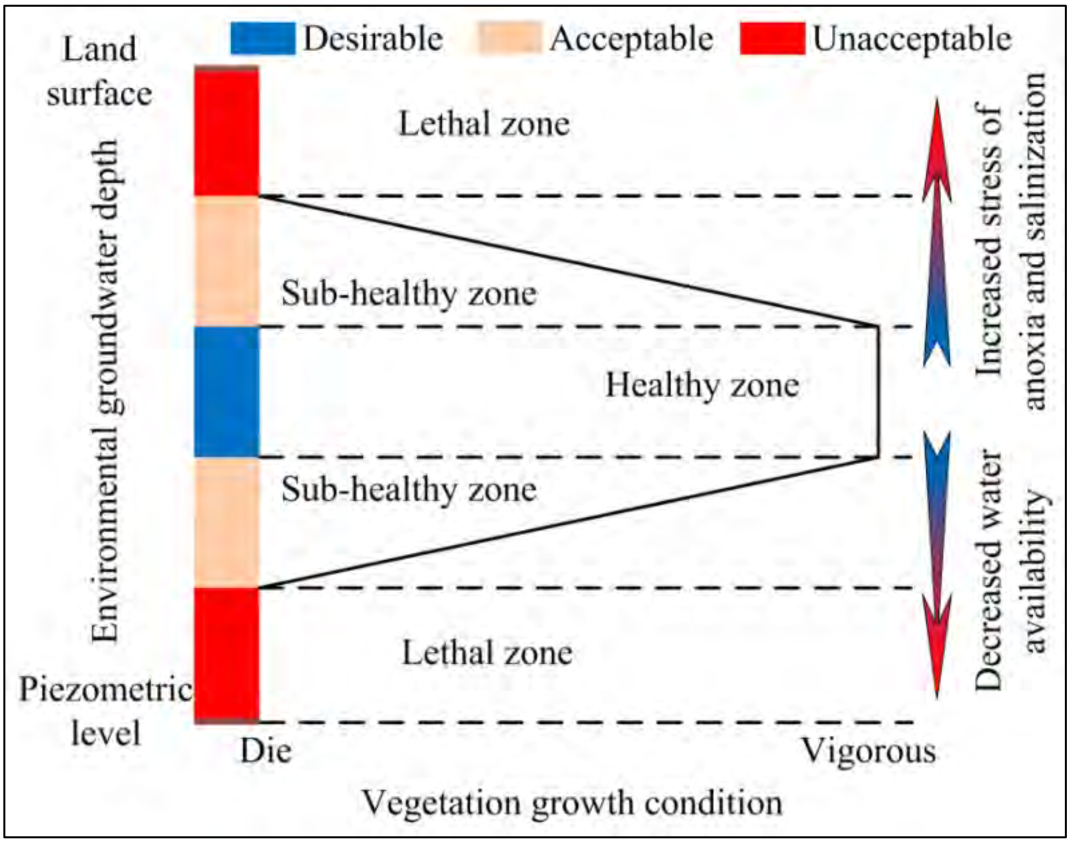


Figure 15. Schematic illustrating the concept of environmental groundwater depth.

The canopy condition response to groundwater decline was shown to be non-linear in the two Australian eucalypts, *Eucalyptus camaldulensis* and *E. populnea* (Kath, *et al*., 2014). Water depth thresholds were identified beyond which canopy condition declined abruptly. This may also prove to be the case with *E. rudis* (closely related to *E. camuldulensis*), which is widespread in the Yalyalup Proposal Area.

6.5 Studies into Responses of Vegetation to Groundwater Decline on the Gnangara Mound

Many studies into the response of tree and shrub species to relatively rapid groundwater decline (due to pumping) and long-term groundwater decline (due to declining average rainfall) have been carried on the Gnangara Mound north of Perth (Eamus *et al*., 2015). A study of *Banksia* woodland vegetation around a groundwater production bore demonstrated the differences in tree responses to rapid versus slow groundwater decline. At the start of the study the amplitude of seasonal fluctuation in groundwater level was about 2.5 m. Only two years after groundwater extraction commenced, groundwater levels declined by an additional 2.2 m during summer. The decline in watertable coupled with lower-than-average annual rainfall and a period of high summer temperatures resulted in extensive die back of *Banksia* species (a loss of between 20% and 80% of adults of overstorey species and up to 64% of adults of understorey species) within 200 m of the production bore. At the reference site no significant overstorey or understorey dieback occurred at the over the same period (Doody *et al*., 2018).

Research has shown that even phreatophytic plants may have only very limited root extension following water table decline (Canham, 2011). Phreatophytic *Banksia* seedlings experienced hydraulic failure during an experimental drawdown of up to 10 cm/day in the watertable, due to a rapid disconnection from the water table. If the water potential becomes more negative than what can be sustained by the plant, runaway embolisms can occur, leading to the complete desiccation of the plant and subsequently to cellular death (McDowell, *et al*., 2008).

Whereas there is no information available for responses by particular species to declining groundwater levels for the southern Swan Coastal Plain, data for the Gnangara Mound indicates that a drawdown of 2 m in groundwater levels can have a severe impact on the survival of the small phreatophytic tree *Banksia littoralis* (Groom *et al*., 2001).

In summary, plants and communities of plants have a desirable “environmental water depth” (healthy zone) in which vegetation growth is good. Below (or above) this zone vegetation health declines, and the vegetation responses to incremental further changes in groundwater level may be gradual (linear), or abrupt (non-linear). Mass deaths of plants may occur when a certain “tipping point” or threshold water level is reached that is beyond the plants’ capacity to adapt further.

6.5.1 Other Studies from Western Australia

A study on the Scott Coastal Plain and southern Blackwood Plateau sought to determine the ecological water requirements of a range of wetland and dryland habitats and species and their potential response to groundwater drawdown as a result of pumping from the Yarragadee aquifer (Froend and Loomes, 2006; Hyde, 2006). The authors of this report had previously derived four vegetation categories that have demonstrated phreatophytic (i.e.

groundwater dependent) behaviour; 0-3 m, 3-6 m, 6-10 m and 10 m+[11]). The greater the depth to groundwater, the lower the requirement for groundwater and the more tolerant vegetation is to water table decline, due to the corresponding increase in alternative water sources (i.e. the larger volume of unsaturated zone (with increasing depth) exploitable by the plant's root system). Wetland plant associations, by definition, are within areas of very shallow depth to groundwater and therefore their response to drawdown is equivalent to that of the 0-3 m phreatophyte category vegetation (Froend and Loomes, 2006).

A graphic showing "risk of impact" (ROI) for wetland vegetation is shown below in **Figure 16**. The ROI category for plant mortality runs from "Low" (no measurable mortality) to "Severe" (>50% reduction in species abundance).

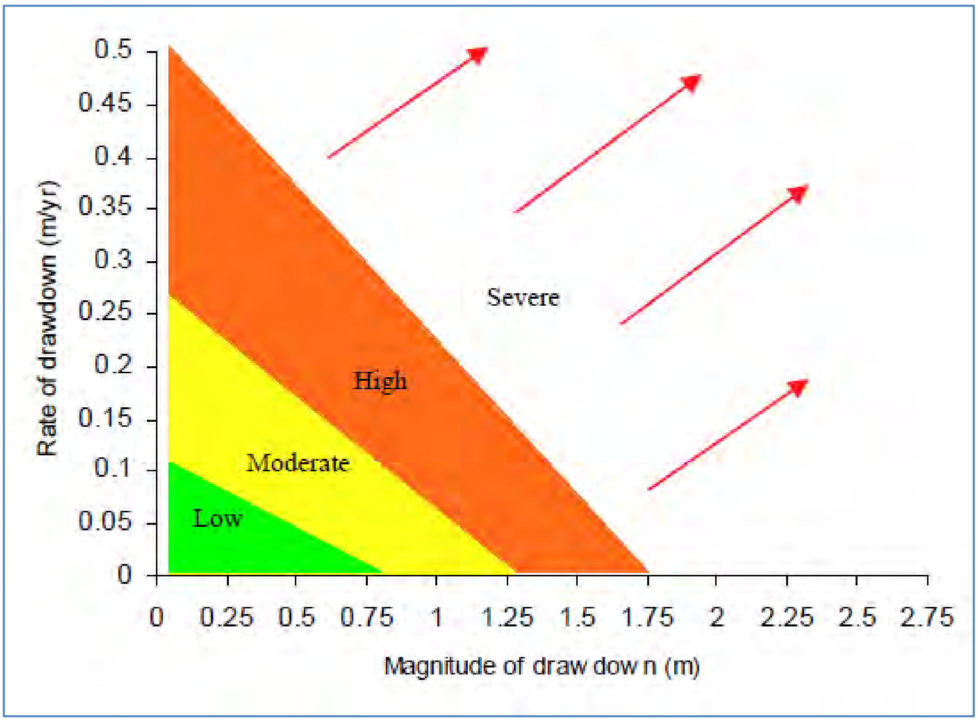


Figure 16 Historic water level change and ROI scores for wetlands (0-3 m groundwater depth category) (from Froend & Loomes, 2006).

[11] These groundwater depth categories were derived from sandy soils; clay horizons, as occurs at Yalyalup, may mitigate impacts of groundwater level decline.

6.6 Potential Effects of the Predicted Groundwater Drawdowns on GDEs at Yalyalup

Based on what is known about the hydrogeology and vegetation of the site, it is likely that the predicted water drawdowns for the central and northern part of GDE Area B at Yalyalup will be moderate to severe (**Figure 17**). The Wet Shrublands (vegetation unit A2) with predicted drawdowns of up to 5 m, and drawdowns of more than 2 m lasting for 3 – 6 months in 2023, is likely to be severely impacted. Small trees and medium- deep-rooted shrubs within this groundwater-dependent community, such as *Banksia littoralis*, *Melaleuca preissiana*, *Hakea ceratophylla* and *Xanthorrhoea preissii* are likely to suffer moderate-severe desiccation and death. *Banksia littoralis*, which is an important part of the overstorey, will possibly incur substantial mortality. The area of this vegetation unit potentially severely impacted by the projected water drawdowns is 1.8 ha.

Impact on the Ironstone shrubland (vegetation unit B1) is low-moderate, with the impact likely to be higher at the northern end of the shrubland occurrence. Maximum predicted drawdowns in the ironstone shrubland are predicted to be 1 m – 1.5 m in Q3 and Q4, 2024. Most of the shrubs growing in the ironstone community are relatively large and old, including the Endangered *Banksia squarrosa* subsp. *argillacea*. *V. plumosa* var. *vassensis* shrubs are found approximately 900m from Area B and predicted to be minimally impacted by the drawdowns. Bores MB12S and MB11S will be used to monitor water levels near Area C.

As such they are likely to have roots that have found their way through fractures in the ironstone to access groundwater as it retreats in late summer and autumn. There is a previous case of nearby mineral sands adversely impacting an ironstone community (at Tutunup; Meisner and English, 2005), although in this case the pit was closer to the community than will be the case at Yalyalup. There is a moderate probability that stress within shrubs growing in the ironstone vegetation will increase, and potentially some deaths will occur if drawdowns are greater than 1 m.

Effects on the GDE vegetation within Areas A and C are likely to be minimal based on the predicted drawdowns. However, it is likely that there will be increased stress and potentially mortality in individual trees in degraded vegetation that has not been mapped as a GDE, such as in the stand of *Eucalyptus rudis* on private property (Lot 3752) immediately east of the ironstone shrubland on McGibbon Track.

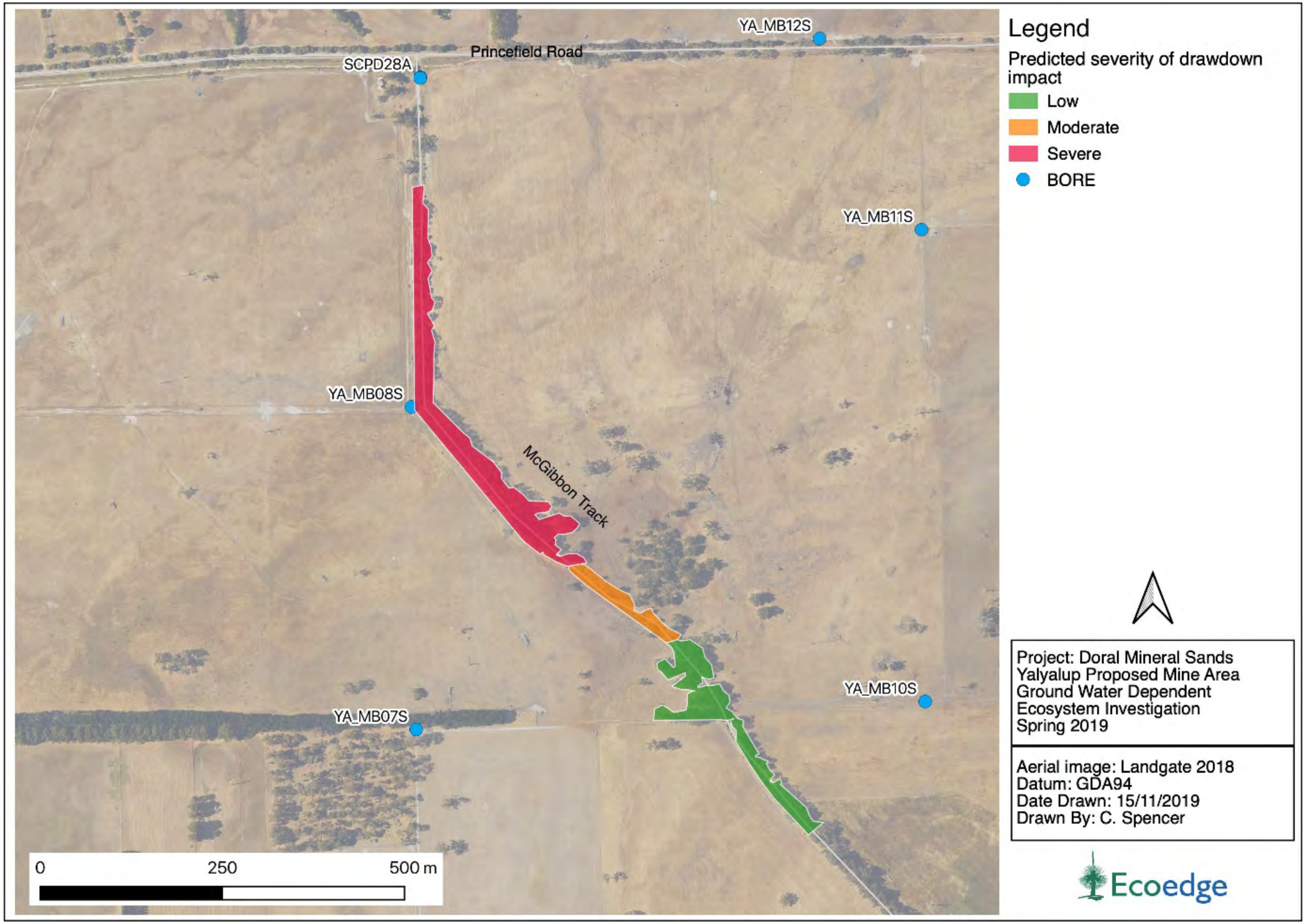


Figure 17 Predicted severity of impact on the GDEs in Area B at Yalyalup.

Conclusion

The greatest impact from the predicted water drawdowns is likely to occur in the central and northern two-thirds of GDE Area B, with the impact likely to be moderate to severe.

Based on the predicted drawdowns, effects on the GDE vegetation within Areas A and C are likely to be minimal, including the *V. plumosa* var. *vassensis* population on Princefield Road.

Impacts in phreatophytic species and or vegetation outside of Areas A, B and C, that due to their size have not been mapped as GDEs, are also likely to result from the predicted drawdowns.

7 References

AQ2 (2019). Yalyalup Mineral Sands Project: Hydrogeological Assessment. Prepared for Doral Mineral Sands.

Bellford, S.M. (1987). *Busselton Sheet No. 130. Environmental Geology Series (1: 50,000).* Geological Survey of Western Australia.

Bourke, L. (2017). Hydrological function of the Greater Brixton Street Wetlands: Data sourcing and review. Prepared for the Swan Region by the Wetlands Conservation Program, Science and Conservation Division, Department of Parks and Wildlife, Kensington, Western Australia

Bureau of Meteorology (BOM). (2019). *Average annual, monthly rainfall at Busselton Aero.* http://www.bom.gov.au/tmp/cdio/IDCJAC0001_009603.pdf Retrieved November 2019.

Canham, C. (2011). The response of *Banksia* roots to change in water table level in a Mediterranean-type environment. Retrieved from https://ro.ecu.edu.au/theses/389

Chow, W, Vogwill, R. and Forbes, M. (2010). Floristic values and hydrological threats to freshwater claypans in Drummond Nature Reserve, Western Australia. Australasian Plant Conservation: Journal of the Australian Network for Plant Conservation, Vol. 18, No. 4.

CSIRO (2009). *Groundwater yields in south-west Western Australia. A report to the Australian Government from the CSIRO South-West Western Australia Sustainable Yields Project.* CSIRO Water for a Healthy Country Flagship, Australia.

Del Borello, N. (2008). *Management triggers and responses for groundwater-dependent ecosystems in the South West groundwater areas*. Water resource allocation planning series, Report no. 31.

DBCA (2019) Geomorphic Wetlands Swan Coastal Plain (DBCA-019) data set, updated 12/07/2019, https://catalogue.data.wa.gov.au/dataset/geomorphic-wetlands-swan-coastal-plain

Doody, T.M., Hancock, P.J., Pritchard, J.L. (2018). *Assessing Groundwater-Dependent Ecosystems: IESC Information Guidelines Explanatory Note.* A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy.

Doral Mineral Sands Pty Ltd (2019). *Yalyalup Mineral Sands Project. Environmental Scoping Document*. Prepared by ABEC Environmental for Doral Mineral Sands Pty Ltd.

Doral Mineral Sands Pty Ltd (2017). *Yalyalup Mineral Sands Project. EP Act Supporting Document. Version 1 – October 2017*. Prepared by ABEC Environmental for Doral Mineral Sands Pty Ltd.

Department of Parks and Wildlife (2015). *Interim Recovery Plan 2015-2020 for Clay pans of the Swan Coastal Plain (Swan Coastal Plain community types 7, 8, 9 and 10a) and Clay pans with mid dense shrublands of Melaleuca lateritia over herbs.* Interim Recovery Plan No. 354. Perth.

Eamus D, Zolfaghar S, Villalobos-Vega R, Cleverly J, Huete A. (2015). *Groundwater-dependent ecosystems: recent insights, new techniques and an ecosystem-scale threshold response*. Hydrology and Earth Systems Science Sciences Discussions, 12, 4677-4754.

Eberbach, P.L. (2003). *The eco-hydrology of partly cleared, native ecosystems in southern Australia: a review*. Plant and Soil, vol. 257, 2, pp. 357–369.

Ecoedge (2016). *Report of a Level 1 Flora and Vegetation survey at the Yalyalup Proposed Mine Area*. Unpublished report to Doral Mineral Sands Pty Ltd.

Ecoedge (2017). *Report of a supplementary Level 1 Flora and Vegetation survey over part of the Yalyalup Proposed Mine Area*. Unpublished report to Doral Mineral Sands Pty Ltd.

Ecoedge (2019). *Report of a Level 1 Flora and Vegetation survey at the Yalyalup Proposed Mine Area. Revised May 2019.* Unpublished report to Doral Mineral Sands Pty Ltd.

Erasmus, D. (2009). Identifying groundwater dependent ecosystems; A guide for land and water managers. Land & Water Australia, Research Report, 1/6.

Freeman, M.J. and Donaldson, M.J. (2006). *Geology of the southern Perth Basin and Margaret River wine district, southwestern Western Australia — a field guide: Western Australia Geological Survey, Record 2006/20, 34p*.

Froend, R. H., and Loomes, R. C. (2006). *Determination of Ecological Water Requirements for Wetland and Terrestrial Vegetation - Southern Blackwood and Eastern Scott Coastal Plain*. A report to the Department of Water. Joondalup: (CEM report no. 2005-07). Centre for Ecosystem Management, ECU.

Gao, X., Huo, Z., Qu, Z., Xu, X., Huang, G. and Steenhuis, T. (2017). *Modeling contribution of shallow groundwater to evapotranspiration and yield of maize in an arid area*. Sci Rep 7, 43122. doi:10.1038/srep43122

Groom PK, Froend R, Mattiske EM, Gurner R (2001) *Long-term changes in vigour and distribution of Banksia and Melaleuca overstorey species on the Swan Coastal Plain*. Journal of the Royal Society of Western Australia 84, 63–69.

Hatton, T. and Evans, R. (1998). *Dependence of ecosystems on groundwater and its significance to Australia*. Occasional Paper No 12/98. Land and Water Resources Research and Development Corporation, Canberra.

Huang, F., Zhang, Y., Zhang, D., & Chen, X. (2019). *Environmental Groundwater Depth for Groundwater-Dependent Terrestrial Ecosystems in Arid/Semiarid Regions: A Review*. International journal of environmental research and public health, 16(5), 763. doi:10.3390/ijerph16050763

Hyde, N.L. (2006). *A summary of investigations into ecological water requirements of groundwater-dependent ecosystems in the South West groundwater areas.* Environmental Water Report 3, Department of Water, Perth.

Hydrosolutions (2017). *Initial Hydrogeological Assessment: Proposed Yalyalup Mineral Sands Mine.* Unpublished report to Doral Mineral Sands Pty Ltd.

Kath, J., Reardon-Smith, K., Brocque, A.F., Dyer, F., Dafny, E., Fritz, L., & Batterham, M. (2014). *Groundwater decline and tree change in floodplain landscapes: Identifying non-linear threshold responses in canopy condition*. Global Ecology and Conservation, Volume 2, December 2014, Pages 148-160.

Kuginis L., Byrne G., Serov P, Williams J.P., (2012). *Risk assessment guidelines for groundwater dependent ecosystems, Volume 3 – Identification of high probability groundwater dependent ecosystems on the coastal plains of NSW and their ecological value*. NSW Department of Primary Industries, Office of Water, Sydney.

McDowell, N., Pockman, W. T., Allen, C. D., Breshears, D. D., Cobb, N., Kolb, T., Plaut, J., Sperry, J., West, A., Williams, D.G., Yepez, E. A. (2008). *Mechanisms of plant survival and mortality during drought: why do some plants survive while others succumb to drought?* New Phytologist, 178: 719-739.

Meissner, R. and English, V. (2005). *Shrubland Association of Southern Swan Coastal Plain Ironstone (Busselton Area) (Southern Ironstone Association)*. Interim Recovery Plan 2005-2010. Department of Conservation and Land Management.

Playford, P.E. Cockbain, A.E. and Low. G.H. (1976). *Geology of the Perth basin, Western Australia*. Geological Survey of Western Australia.

Poot, P., and Lambers, H. (2008) *Shallow-soil endemics: adaptive advantages and constraints of a specialized root-system morphology*. New Phytologist 178, 371–381.

Poot Pi., Bakker, R., and Lambers H. (2008) *Adaptations to winter-wet ironstone soils: a comparison between rare ironstone Hakea (Proteaceae) species and their common congeners*. Australian Journal of Botany 56, 574-582.

Richardson, S., Irvine, E., Froend, R., P Boon, P., Barber, S., Bonneville, B. (2011). *Australian groundwater-dependent ecosystem toolbox part 1: assessment framework*, *Waterlines report*. National Water Commission, Canberra.

Serov P, Kuginis L, Williams J.P., (2012). *Risk assessment guidelines for groundwater dependent ecosystems, Volume 1 – The conceptual framework*. NSW Department of Primary Industries, Office of Water, Sydney.

Schafer, D.B., Johnson, S.L., and Kern, A.M. (2008). *Hydrogeology of the Leederville aquifer in the western Busselton-Capel Groundwater Area*, Department of Water, Hydrogeological Record Series, HG31.

Smith, R. S. (1994). *The ecology of two rare Chamelaucium species [Myrtaceae] from southwestern Australia*. Master of Philosophy thesis, Murdoch University, Western Australia, 205 pp.

Tille, P. J. and Lantzke, N. C. (1990). *Busselton - Margaret River - Augusta land capability study; methodology and results Volume 2 Appendices*. Technical Report 109. Division of Resource Management. Western Australian Department of Agriculture. Perth.

Williams, A.H. (2007). *An ecophysiological comparison of rare ironstone endemics and their common congeners*. PhD Thesis, University of Western Auastralia.

Appendix 1. Depth to Groundwater map for the Yalyalup Proposal Area