# Appendix B2. Assessment of Potential Groundwater Dependent Ecosystems

OZ Minerals Exploration Pty Ltd

# West Musgrave Project Pre-feasibility Study – APPENDIX A
# Assessment of potential GDEs in the West Musgrave Project area

18 March 2020

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March 18, 2020
Project Number: 1000103.1000

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Environmental and Approvals Lead – West Musgrave

OZ Minerals
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Dear Justin

RE: West Musgrave Project pre-feasibility study – Attachment A Groundwater dependent ecosystem baseline report

CDM Smith Australia Pty Ltd is pleased to present the accompanying report outlining the results of an assessment of potential groundwater dependent ecosystems in the West Musgrave Project landscape. The report provides the following:

- Details of the physical setting where groundwater dependent ecosystems might exist, which is in addition to information and data presented in the surface water and groundwater baseline reports, including landscape and soils, and water sources
- Identification of potential GDEs and their location in the landscape based on an extensive literature review
- Conceptualisation of groundwater use by potential GDE's to provide context for their level of sensitivity to altered groundwater conditions arising from mine water affecting activities (which is assessed in the Groundwater effects assessment report, OZL ref. WM-5100-ENV-REP-0007)

We trust the report meets your expectations. If you have any questions, please do not hesitate to call.

Sincerely,

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cc:

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# Glossary of terms and abbreviations

## Terms

| | |
|---|---|
| Aquifer | A saturated or partially saturated hydrostratigraphic unit that is sufficiently permeable to transmit useful quantities of water |
| Aquifer (confined) | A fully saturated aquifer that is overlain by a confining (low permeability) hydrostratigraphic unit, and where the groundwater pressure is higher than the base of the confining unit |
| Aquifer (unconfined) | An aquifer whose upper water surface (water table) is at atmospheric pressure, sometimes referred to as a water table aquifer |
| Aquitard | A layer in the geological profile that separates two aquifers and restricts the flow between them, in unconsolidated (regolith) aquifers it is generally clay |
| Baseflow | The portion of stream flow derived from groundwater discharge |
| Basement | Lowest or basal rock unit occurring within a region, comprising rock |
| Capillary fringe | The zone immediately above the water table, where water is drawn upward by capillary action |
| Capillary rise | The ability of a liquid to flow in narrow spaces without the assistance of, or even in opposition to, external forces like gravity |
| Claypan | A dense, compact, slowly permeable layer in the subsoil having a much higher clay content than the overlying material, from which it is separated by a sharply defined boundary |
| Colluvial slopes | Accumulation of colluvium (loose unconsolidated sediments) as gently sloping aprons or fans, either at the base of or within gullies and hollows within hillslopes |
| Discharge | The volume of water that passes a given location within a given period of time, can be expressed as cubic metres per second, cubic metres per day or megalitres per day |
| Drained upper limit (field capacity) | The amount of water a soil can hold against gravity |
| Drawdown | The distance between the static water level and the surface of the water table in response to the taking of groundwater, e.g. via pumping |
| Ecological function | Any process or set of processes that can change (over time) an ecological system |
| Ecological services | The services and benefits that humans derive from ecological systems, including oxygen production, carbon stores and water purification |
| Ecosystem | Term used to describe species in an environment and their relationship with one another and the non-living (abiotic) community |
| Ecosystem composition | The variety of living things found within an ecosystem |
| Ecosystem (health) condition | The state of ecological systems, which includes their physical, chemical, and biological characteristics and the processes and interactions that connect them |
| Ecosystem resilience | Resilience relates to the capacity of an ecosystem that is adversely affected by a disturbance to recover to its prior condition (e.g. for leaves to recommence normal rates of photosynthesis) |
| Ecosystem resistance | Resistance relates to the capacity of an ecosystem to resist/adapt to change (e.g. by eco-physiological means such as increasing leaf water potentials to overcome the effect of water table drawdown, or reducing canopy area to minimise transpiration rates) |

| | |
|---|---|
| Ecosystem services | Fundamental characteristic of ecosystems related to conditions and processes necessary for maintaining ecosystem integrity, which implies intact abiotic components (e.g. soils and water), biodiversity and resilience to natural successional cycles (e.g. fire, flooding, predation). Ecosystem function will include such processes as decomposition, nutrient cycling and production. It is generally considered that maintenance of biodiversity is integral to ecosystem function. The term is sometimes used interchangeably with *ecosystem condition* |
| Environmental value | Values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health |
| Environmental water requirement | Water regime needed to maintain a particular composition, structure and level of ecological function and ecosystem service provision |
| Ephemeral | Lasting only a short time; short lived; transitory |
| Evapotranspiration | The process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants |
| Facultative groundwater dependent ecosystem | Facultative GDEs require access to groundwater in some landscapes, but in other landscapes can utilise alternate sources of water to maintain ecosystem function, i.e. access to groundwater is not critical in determining ecosystem occurrence in the landscape (compare with obligate GDE) |
| Flowpath | Any route for groundwater movement, extending from a recharge (intake) zone to a discharge (output) zone such as a shallow stream |
| Groundwater | The water contained in interconnected pores, gaps or fractures located below the water table in an unconfined aquifer or located in a confined aquifer. |
| Groundwater dependant ecosystem | Natural ecosystems that require access to groundwater to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services |
| Groundwater discharge | The movement of groundwater from the subsurface to the surface |
| Hydraulic gradient | The rate of change in total head per unit distance in a given direction. The direction of gradient is that yielding the maximum rate of decrease in head |
| Indicator species | An organism or a plant that serves as a measure of the environmental conditions that exist in a given locale |
| Obligate groundwater dependent ecosystem | Obligate GDEs are ecosystems that rely on groundwater for maintenance of some part or all of their ecosystem function. This reliance can be continual, seasonal or episodic (compare with Facultative GDE), and access to groundwater is crucial in determining ecosystem occurrence in the landscape |
| Outcrop hills | Visible exposure of bedrock or ancient superficial deposits on the surface of the Earth |
| Outwash plains | A broad, sloping landform built of coalesced deposits of outwash |
| Palaeochannel | A landform occurring within an inactive river or stream system that has been inset into a palaeovalley and infilled by younger sediments, the deepest part of which may be infilled with relatively coarse clastic materials, depending on the depositional environment (see thalweg and palaeovalley) |
| Palaeoriver | An inactive, ancient river or stream system, an infilled and buried palaeoriver is referred to as a palaeochannel |
| Palaeovalley | An ancient valley that may have hosted one or more palaeoriver systems, now partially or completely buried by fine to coarse sediments, e.g. the Kadgo Palaeovalley |

| | |
|---|---|
| Phreatophytes | Plant that draws water from the capillary fringe and saturated zone (i.e. below water table) to maintain vigour and function |
| Permanent wilting point | The minimal amount of water in the soil that the plant requires not to wilt |
| Plant Available Water Capacity | The soil water content between an upper limit, termed field capacity (FC), and a lower limit or the permanent wilting point (PWP) |
| Plant uptake | The amount of nutrients taken into a plant by root and foliar uptake |
| Priority Flora | The system by which Western Australia's conservation flora are given a priority |
| Riparian vegetation | Vegetation found in the riparian zone, considered to be distinct from *terrestrial vegetation* |
| Riparian zone | Riparian zones border creeks, rivers, lakes, wetlands or other bodies of water, often, there is close interaction of surface water and groundwater within riparian zones. |
| Rockhole | Weathered depression in basement outcrop that may or may not hold water arising from rainfall runoff |
| Riparian vegetation | Vegetation found in the riparian zone |
| Riparian zone | Riparian zones are narrow strips of land that border creeks, rivers, lakes, wetlands or other bodies of water. Often, there is close interaction of surface water and groundwater within riparian zones |
| River baseflow system | Streams that are fed by groundwater baseflow |
| Rockhole | Surface water feature formed in rocky outcrop |
| Rooting depth | The soil depth from which a fully grown plant can easily extract most of the water needed for transpiration |
| Runoff | The part of the water cycle that flows over land as surface water instead of being absorbed into groundwater or evaporating |
| Saturated zone | The zone in which the voids in the rock or soil are filled with water. Sometimes referred to as the 'phreatic' zone |
| Seep | A source of water at the ground surface supplied by groundwater discharge |
| Sheet flow | Relatively high-frequency, low-magnitude overland flow occurring in a continuous sheet and is restricted to laminar flow conditions |
| Soil moisture | Water occurring in the pore spaces between the soil particles in the unsaturated zone from which water is discharged by the transpiration of plants or by evaporation from the soil |
| Soil water | Any water held in the soil as a vapour, liquid or solid |
| Soil water reservoir/ storage | The total amount of water that is stored in the soil above the water table and capillary fringe, can change with time depending on evapotranspiration and frequency of precipitation events |
| Spring | A source of water at the ground surface supplied by groundwater discharge |
| Stable isotope | An isotope that does not undergo radioactive decay |
| Stable water isotope ratio | The ratio of the concentrations of the comparatively rare, stable 18O isotope and the comparatively abundant, stable 16O isotope in water molecules in a given body of water |
| Stomatal control | A physiological mechanism of plants for the reduction of water loss |
| Stratum | A distinct height class of plants in a vegetation association |

| | |
|---|---|
| Stygofauna | Any fauna that live in groundwater systems or aquifers, such as pore spaces, caves, fissures and vughs |
| Subterranean ecosystem | An ecosystem dependent on water held in aquifers (e.g. stygofauna) or inundated caves, also referred to as 'aquifer and cave ecosystems' |
| Surface expression of groundwater | Groundwater that has been discharged to the surface, such as baseflow or spring flow |
| Swale | A low or hollow place, especially a marshy depression between ridges |
| Terrestrial vegetation | Vegetation that grows on, in or from land, considered different to *riparian vegetation* |
| Thalweg | A line connecting the deepest sections of a palaeochannel, not usually discernible from the surface |
| Threatened Flora | Flora which are vulnerable to endangerment in the near future |
| Transpiration | The process by which water absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface, principally from the leaves |
| Troglofauna | Terrestrial animals living in caves and other air-filled subterranean spaces |
| Unconfined aquifer | A water table aquifer |
| Unsaturated zone | The zone between land surface and the water table within which the moisture content is less than saturation (except in the capillary fringe) and pressure is less than atmospheric. Sometimes referred to as the vadose zone |
| Vadose zone | Unsaturated zone |
| Vadophytic | Reliant on soil water reservoir for maintenance of ecosystem function |
| Vadophyte | A plant which is vadophytic |
| Vegetation associations | A grouping of plant species, or a plant community, that recurs across the landscape; Structural form and dominant species |
| Vegetation complex | Structural and floristic description linked to geomorphology |
| Water affecting activity | A development activity that has the potential to alter the water environment from the baseline and may therefore have an effect on dependent EVs |
| Water holding properties | Properties that control a medium's ability to retain water, such as texture, composition and organic matter content |
| Water regime | The prevailing pattern of water flow over a given time of a freshwater ecosystem. More specifically, it refers to the duration and timing of flooding resulting from surface water (overland flow), precipitation, and ground water inflow |
| Water table | The surface between the unsaturated and saturated zones of the subsurface at which the hydrostatic pressure is equal to that of the atmosphere |
| Wetland | A distinct ecosystem that is inundated by water, either permanently or seasonally, where oxygen-free processes prevail |

## Abbreviations

| | |
|---|---|
| AHD | Australian Height Datum |
| bgl | Below ground level |
| DEM | Digital elevation model |
| DTW | Depth to (ground)water |

| | |
|---|---|
| EWR | Environmental Water Requirement |
| GDE | Groundwater dependent ecosystem |
| JAXA | Japan Aerospace Exploration Agency |
| PAWC | Plant available water capacity |
| SILO | Scientific Information for Land Owners |
| WAA | Water affecting activity |
| WMP | West Musgrave Project |

# Units of measure

| | |
|---|---|
| mAHD | Metres Australian Height Datum |
| mbgl | metres below ground level |

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# Section 1 Introduction

OZ Minerals Exploration Pty Ltd (OZL) has entered into a Joint Venture (JV) with Cassini Resources Limited (CZI) to develop the West Musgrave Project (WMP or 'the Project'), which is located in the remote east of Western Australia (around 1,300 km northeast of Perth), near the South Australian and Northern Territory borders (Figure 1). The Project will involve the mining and processing of the Nebo-Babel Ni-Cu-PGE sulfide deposits (Figure 1).

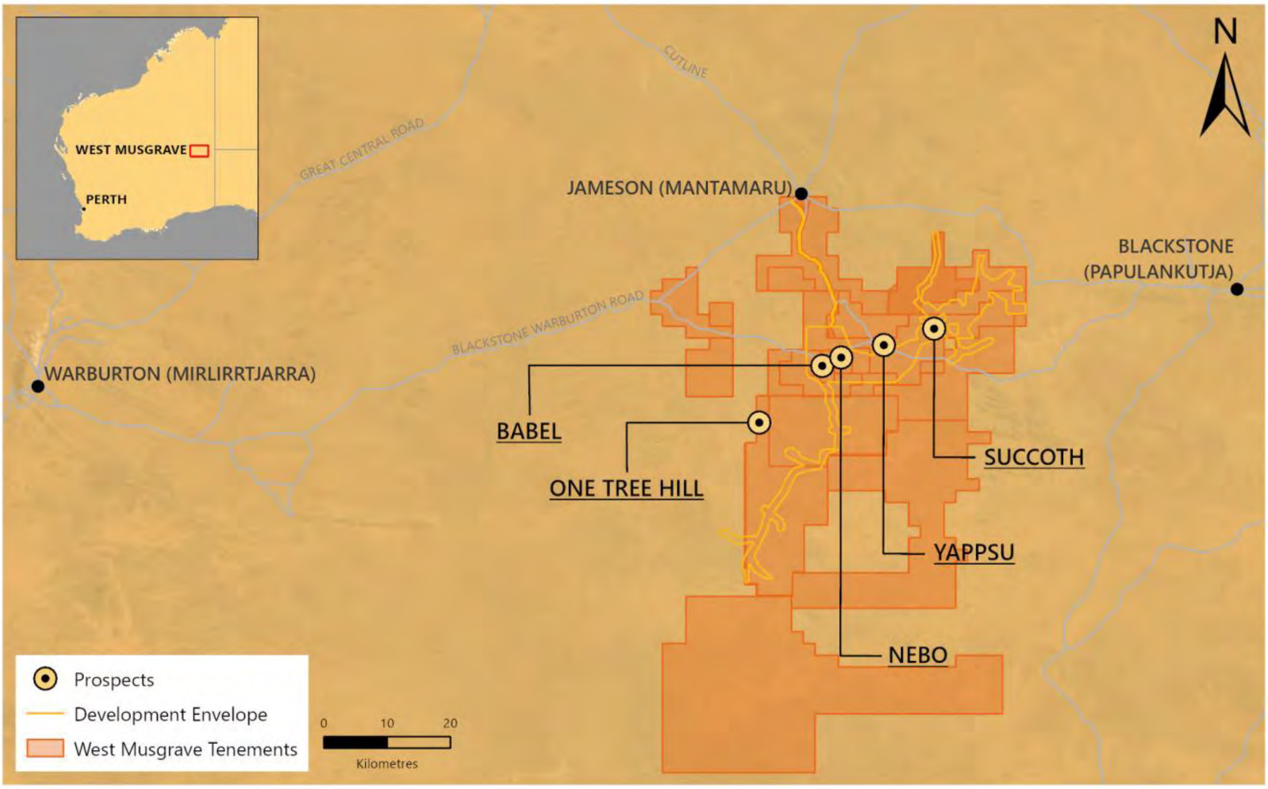



**Figure 1** **WMP locality plan** (Source: OZL)

This report presents a desktop assessment of the potential for groundwater dependent ecosystems (GDEs) to occur within the Project area, and provides the basis from which to assess the potential effects to GDEs arising from changes in groundwater conditions due to the proposed development activities (OZL ref. WM-5100-ENV-REP-0007).

# Section 2 Physical setting

## 2.1 Overview

A detailed description of climate and topography of the broader Project area is presented in the surface water baseline report (WM-5100-ENV-REP-0002). A detailed description of the geological and hydrogeological setting of the Project area is presented in the groundwater baseline report (WM-5100-ENV-REP-0003).

The discussion presented below provides specific context around the sources of water available to sustain ecosystems in the Project area.

## 2.2 Climate

Mean rainfall for the Project area is likely to range between 100 and 200 mm/y (BoM, 2010), with most rainfall likely to occur during the summer and autumn months (averaging around 100 mm and more than 50 mm, respectively) in association with cyclonic depressions moving across the continent from the northwest. Rainfall during winter and spring months can be expected to range between 25 and 50 mm, respectively, on average.

Figure 2 shows long-term average monthly rainfall and evaporation data for the Project area from SILO (Ref. WM-5100-ENV-REP-0002). Figure 3 shows estimated annual rainfall for the period 1889 through to 2014 and cumulative deviation from mean (CDFM) rainfall for the same period. The figure shows rainfall can be regarded as low (average of 181 mm, consistent with BoM's estimate of between 100 to 200 mm/y), and extremely variable. Importantly, there appears to be multi-decadal rainfall variability within the Project area, with the period from 1974 to the present likely being significantly wetter than earlier years (Figure 3).

The mean annual pan evaporation rate for the Project area ranges between 3,200 and 3,600 mm/y (BoM, 2006) averaging around 14 mm/d during warmer months and around 5 mm/d during cooler periods of the typical year. Figure 2 shows that average monthly evaporation rates greatly exceed average rainfall rates across all months of the year. This is an important factor, as it drives a considerably large annual soil water deficit, which might impact on plant available water.

## 2.3 Geology, landforms and soils

The geology of the Project area comprises Quaternary sandplains and dunefields (Tile, 2006), over Tertiary and Neoproterozoic sediments of the Officer Basin and Proterozoic rocks of the Musgrave Province, which have been incised by palaeochannels hosted within the Kadgo Palaeovalley .

The landscape is characterised by sand dunes, particularly in the northeast, small scale calcrete ridges to the south, and low relief rocky outcrop hills and associated outwash plains to the east, west and north of the Project area (Figure 5).

The landscape is covered by varying thicknesses of red siliceous sand, becoming silty or clayey in low-lying areas (Western Botanical, 2020), where internally draining claypans are common (Figure 4). Micro-relief calcareous soils overlying calcrete deposits are also common while colluvial slopes and outwashes occur adjacent to elevated areas, where they occur.

Given the arid environment, the water holding capacity of soils (which is controlled by texture, bulk density and organic matter content) will be an important consideration for plant water use patterns. Typically, it would be expected sandplains and dunefields will have a relatively lower water holding capacity than the clayey and silty soils that might be associated with claypans. In the Project area, the source of water held within the vadose (unsaturated) zone will be a combination of rainfall that infiltrates to replenish the soil water reservoir and water rising up from the water table in response to water potential gradients established between the soil water reservoir (due to plant uptake) and the capillary fringe.

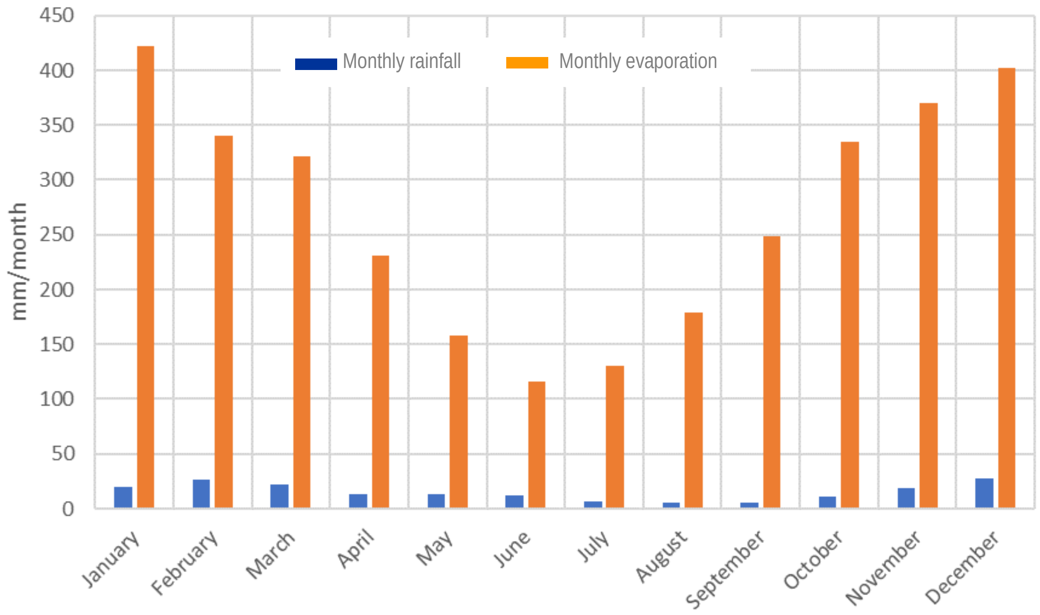



**Figure 2** **Average monthly evaporation versus rainfall**

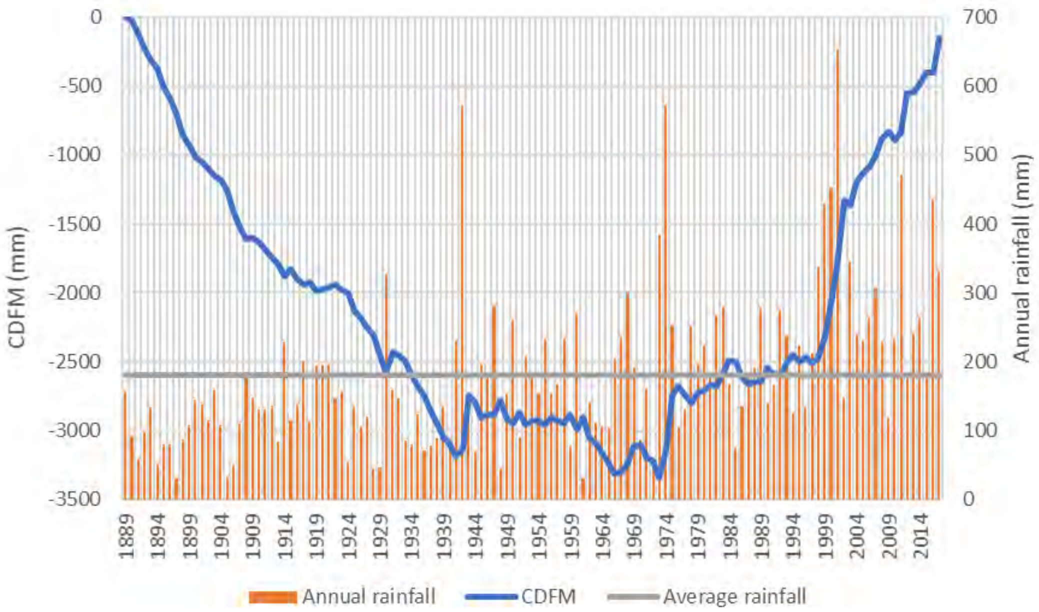
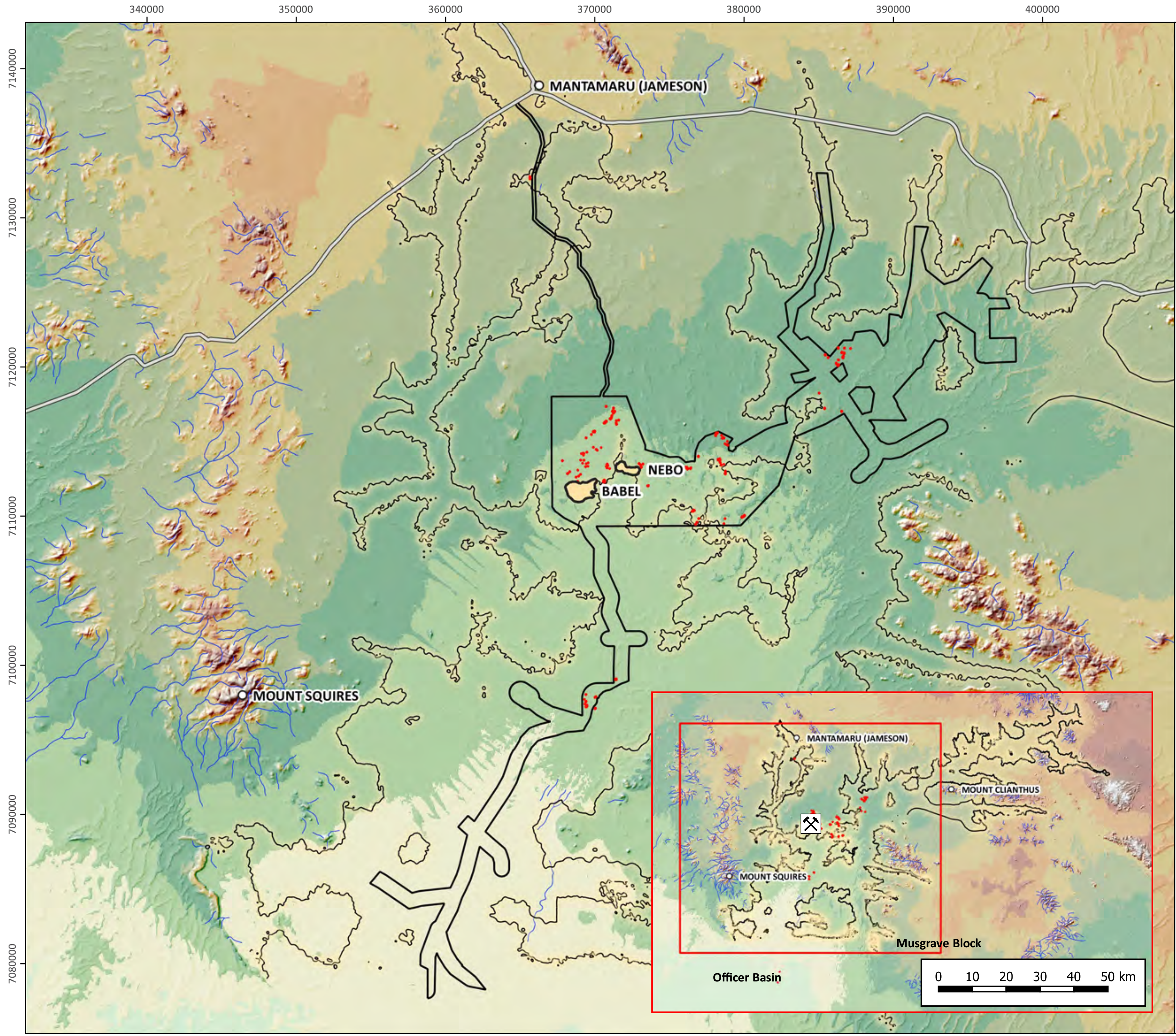



**Figure 3** **Annual rainfall and CDFM at West Musgrave**




## Figure 4

### Project physical setting



DATA SOURCES
Cassini Resources, 2018
OZ Minerals, 2019

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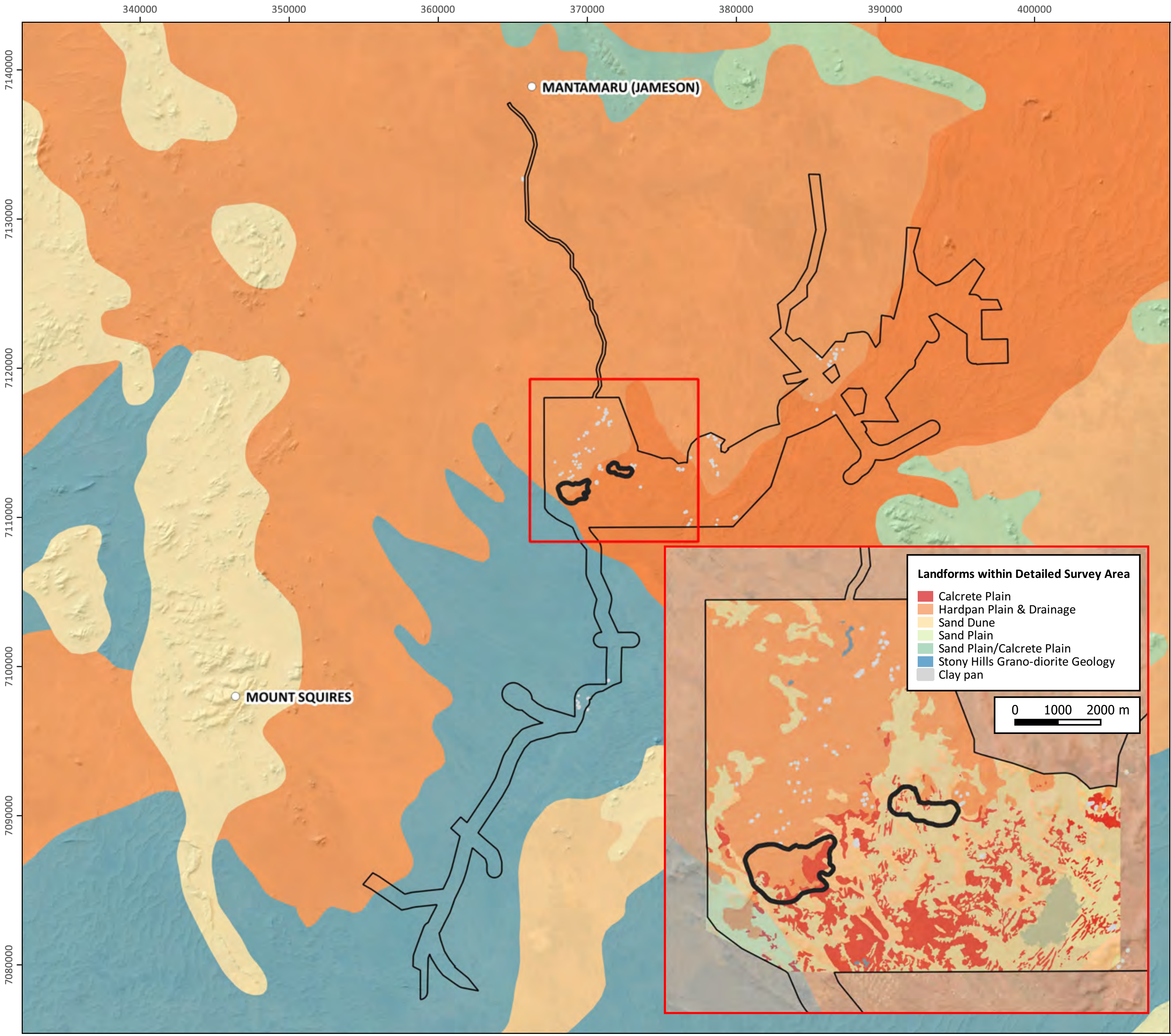


# Figure 5

## Landform systems

- Proposed mine pit
- Development envelope

**Landscape**

- Extensive plains with numerous dunes which are often short and of irregular shape and orientation
- Outwash plains and dissected fan and terrace formations flanking ranges of sedimentary and some metamorphic, volcanic, and granitic rocks
- Outwash plains subjacent to ranges of basic igneous rocks; some low hills of basic rocks occur in the unit; occasional dunes
- Plains with occasional short dunes, and hilly areas with rock outcrops
- Ranges and hills mainly on granitic rocks; rock outcrop is extensive
- Steep hills and ranges on basic rocks; rock outcrop common; some gorges; small pediments and plains
- Steep hills and ranges on sedimentary and some metamorphic, volcanic, and granitic rocks; bare rock outcrop is common; some gorges
- Very gently undulating plain traversed by longitudinal dunes
- Clay pan

DATA SOURCES
DMIRS, 2018
OZ Minerals, 2019

Inset map: Western Botanical, 2020

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## 2.4 Vegetation associations

Three phases of field vegetation and flora surveys have been undertaken (2014/2015, 2018 and 2019; Western Botanical, 2020) over the development envelope, and these have identified 38 different vegetation associations in total (extending from Jameson in the north to the Officer Basin in the south), 29 of which occur within the development envelope (Figure 1) and 33 of which occur with the numerical model domain that is described in the Project groundwater modelling report (OZL ref. WM-5100-WTR-REP-0034). The distribution of these associations is presented in Figure 6, showing there is reasonable affinity to landform systems (Figure 5), i.e.:

- Calcrete Plains landforms host a number of grassland associations and *Corymbia opaca* woodlands
- Hardpan Plain and Drainage landforms host a number of woodland, shrubland and grassland associations
- Clay Pan Playa host annual grasses and herbs
- Sand Dune landforms host shrubland associations
- Sand Plains landforms host a number of woodland, shrubland and (Spinifex) grassland associations
- Stoney Hill landforms host a number of shrubland associations

No Threatened Flora that are listed under the Western Australian Biodiversity Conservation Act (2016) or the Commonwealth EPBC Act have been observed in the Project area, although a number of Priority Flora species have been identified (Western Botanical, 2020), which are listed in Table 1.

**Table 1 Priority vegetation species list (Western Botanical, 2020)**

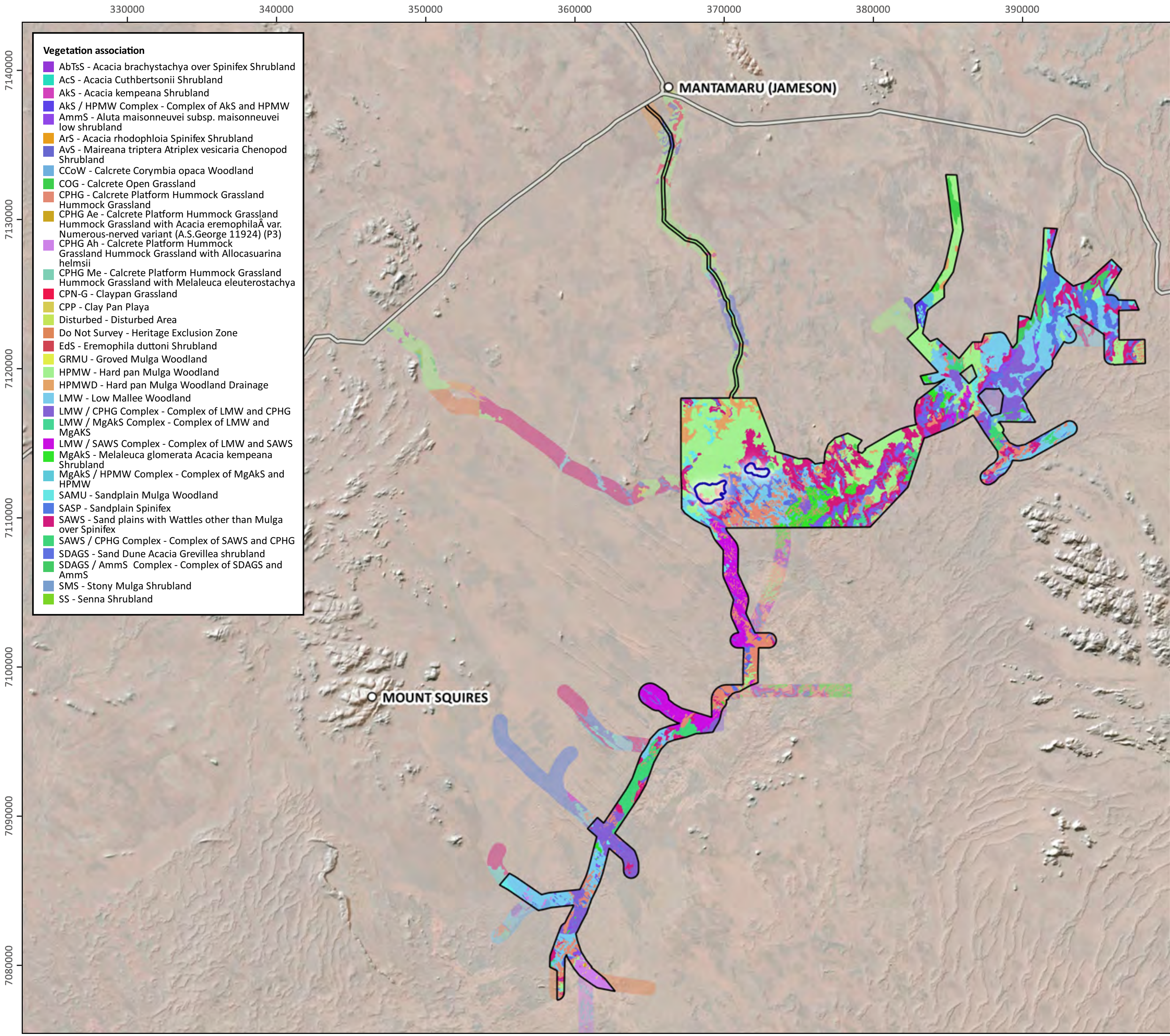
| Priority 1 | Priority 3 |
|---|---|
| *Aenictophyton anomalum* | *Acacia eremophila* |
| *Indigofera warburtonensis* | *Amaranthus centralis* |
| | *Aristida jerichoensis var. subspinulifera* |
| | *Chrysocephalum apiculatum* subsp. *ramosum* |
| | *Eragrostis* spp. |
| | *Goodenia asteriscus* |
| | *Stackhousia clementii* |
| | *Tephrosia* sp. |

## 2.5 Water-related habitats

### 2.5.1 Aquatic

The Project area is characterised by poorly defined surface water catchments and disconnected ephemeral drainage lines (Figure 4). There are no permanent or semi-permanent water courses present in the landscape. The 'normal' condition of the Project area catchments is dry. Runoff and ponding of rainfall is not often seen observed in the Project area following a rainfall event. This suggests one of three effects:

- Rainfall runoff is limited due to high evaporation rates, or
- Rainfall runoff is limited due to rapid infiltration (consistent with the presence of micro-relief calcareous soils), or
- Rainfall runoff is limited due to a combination of high evaporation rates and rapid infiltration




# Figure 6

## Surveyed vegetation communities (Western Botanical, 2020)

Road
Proposed mine pit
Development envelope

DATA SOURCES
Cassini Resources, 2018
OZ Minerals, 2019
Western Botanical, 2020

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However, when sufficient rainfall occurs to generate runoff, sheet flow is the dominant form of runoff observed. There are some areas where rainfall-runoff will collect and flow after intense rainfall events, particularly where there are successions of interconnected low-lying terrains that often terminate in clay pans. Groundwater baseflow to streams is not a feature of the landscape.

Rainfall samples report very low salinity (around 30 µS/cm) and groundwater is typically fresh to slightly brackish (generally ranging from 750 to 3,000 µS/cm). Groundwater from all aquifers across the Project area report elevated levels of nitrate.

The presence of aquatic habitats that have some reliance on groundwater requires surface water interaction with groundwater, which means:

- The water table surface has to cut (window at) the land surface or intersect water courses above the bed level, and this is not observed in the Project area or more broadly
- Aquifers have artesian pressures resulting in groundwater discharge to the surface via diffuse upward leakage or fractures / fissures, and again this is not observed in the Project area or more broadly

### 2.5.2 Subterranean

Aquifers provide a habitat for stygofauna, and troglofauna are present above the water table. These fauna are adapted to conditions of stable temperature and limited sunlight, oxygen and nutrients.

Stygofauna are commonly found in aquifers having relatively large (mm or greater) pore spaces, e.g. within alluvial, karst and some fractured rock systems. They are typically most abundant in fresh to brackish shallow aquifers where nutrients and oxygen are more readily available, and their presence generally decreases with depth and distance along groundwater flow paths (Hose et al, 2015).

Troglofauna likely have limited sensitivity (if any) to changes in groundwater levels, other than where this might impact on subsurface humidity levels. However, rainfall infiltration is likely important for these types of ecosystems to meet environmental water requirements (EWRs), which makes them more reliant on maintaining surface water regimes as close as possible to the baseline rather than groundwater regimes.

### 2.5.3 Terrestrial

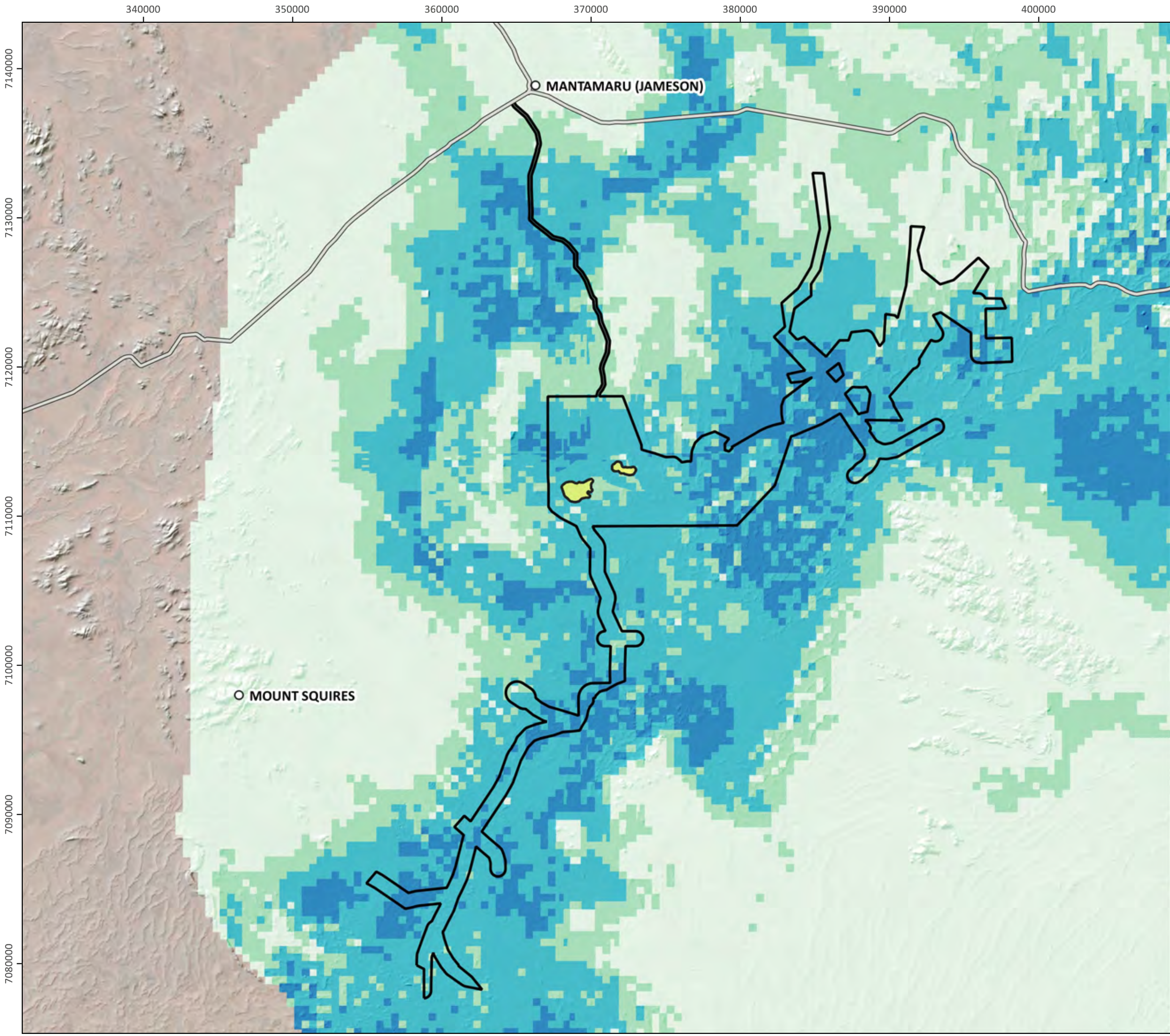
Where the water table is shallow enough to be accessed by plant roots or allow capillary rise to near the surface, groundwater discharge will occur through evapotranspiration processes.

It is anticipated that, due to the lack of any evidence of wetlands connected to the groundwater, the presence of any above ground surface GDEs will be dominated by terrestrial vegetation that have access to groundwater via root development, and it follows that tall tree species with larger canopy areas are more likely to have deeper, more extensive rooting systems than smaller tree species.

An important component of mapping potential terrestrial GDEs is plant available water capacity (PAWC), i.e. the total amount of water in the vadose zone (also termed the soil water reservoir) that can be stored and released to plants. PAWC is controlled by the water holding properties of the soil, including the thickness of the vadose zone. For an individual plant, PAWC is the amount of water held between the drained upper limit (field capacity) of the soil and the permanent wilting point (which varies between plant species based on their ability to extract tightly held soil moisture in dry soils), summed over the rooting depth. Rooting depths depend on many factors including soil structure, antecedent conditions over the life of the plant and the quality of available soil moisture over time. These typically vary between species but can show significant variation between different species populations, depending on location and climate.

Infiltrating rainwater will likely be the dominant source of soil water, and it follows that this will vary seasonally depending on rainfall conditions (timing, amount and intensity). Rooting depth is an important factor in controlling PAWC, it will vary between plant species and may be limited by physical (e.g. hardpans) and chemical (e.g. high/low pH, salinity and elevated boron) constraints in the subsoil, all of which can prevent root access to deeper soil water reserves.

The depth of the vadose zone (i.e. depth to the water table and capillary fringe) generally ranges between 3 and 8 m below ground level in the Project area (m bgl; OZL ref. WM-5100-ENV-REP-0003). Figure 7 presents a plan showing the modelled steady-state depth to water table (OZL ref. WM-5100-WTR-REP-0034) across the Project area. In areas where the water table is shallow (i.e. the soil water reservoir is restricted by depth), there may be times when larger, perennial vegetation species require access to groundwater, e.g. during extended periods of drought.




# Figure 7

## Modelled depth to groundwater

Road

Proposed mine pit

Development envelope

**Modelled depth to groundwater (mbgl)**

- < 2
- 2 - 5
- 5 - 10
- 10 - 15
- < 15

DATA SOURCES
Cassini Resources, 2018
OZ Minerals, 2019

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# Section 3 Groundwater Dependent Ecosystems

## 3.1 Overview

All ecosystems rely on a water regime that is sufficient to maintain a particular composition, structure and level of ecological function and ecosystem service provision. This water regime is known as the EWR. Groundwater dependent ecosystems (GDEs) depend on groundwater (i.e. water occurring below the water table including the capillary fringe) to at least some extent consistently or on occasion to meet their EWRs. The EWR can be related to surface water flow, depth to water table and/or water quality, and can vary spatially and temporally (Richardson et al., 2011a).

Groundwater often forms an important component of EWRs for ecosystems in arid environments where extended dry periods are experienced, and when surface water and soil water is scarce (Eamus et al., 2006). GDEs may be dependent on groundwater to meet their EWR at all times (e.g. stygofauna) or only part of the time, for example a few months every year during the dry season when the soil water reservoir is depleted. The dependence becomes apparent when the supply of groundwater is removed for a sufficient length of time that might give rise to changes in plant function, ecosystem condition, composition and distribution (Eamus, 2009). These changes will be constrained to some degree by ecosystem resilience (capacity to recover once the water regime returns to 'normal') and resistance (capacity to adapt to change).

Obligate GDEs are those GDEs where component species require access to groundwater at some stage in their lifecycle to maintain ecological function and ecosystem services, i.e. access to groundwater (as well as other factors) defines the ecosystems presence in the landscape. Facultative GDEs are those GDEs where access to groundwater does not necessarily define their presence in a landscape, i.e. depending on location, component species may use no groundwater to meet all of their EWRs. Not all component species (flora or fauna) within an ecosystem need to be groundwater users in order for an ecosystem to be classified as a GDE. However, if the species that requires access to groundwater (i.e. the 'indicator species') are removed or impacted (e.g. due to long-term drought, anthropogenic effects, pests, weeds or fire) other component non-GDE species may be impacted such that ecosystem function breaks down.

The Australian GDE toolbox (Richardson et al., 2011) provides a framework to assist with the identification of GDEs and the management of their EWRs. The toolbox adopts the approach of Eamus et al. (2006) by classifying GDEs based on the role groundwater plays in maintaining biodiversity and ecological function. Three types of GDEs are defined by the GDE toolbox:

- Type 1 - Subterranean ecosystems, also referred to as 'aquifer and cave ecosystems'
  Dependent on water held in aquifers (e.g. stygofauna) or inundated caves, these ecosystems are typically common within karst aquifer systems, sedimentary aquifers and fractured rock groundwater environments
- Type 2 - Ecosystems dependent on the surface expression of groundwater, also referred to as 'aquatic ecosystems'
  Surface expression of groundwater provides water that can support aquatic biodiversity through access to habitat (especially when surface run-off is low or non-existent), as well as regulation of water quality and temperature, include wetlands, lakes, seeps, springs, and river baseflow systems
- Type 3 - Ecosystems dependent on subsurface presence of groundwater, also referred to as terrestrial ecosystems
  Dependent on groundwater either seasonally, episodically or permanently to prevent water stress and avoid adverse threat to their condition, these ecosystems can exist wherever the water table and capillary fringe (semi-saturated zone of soil above the water table) are within the root zone of the plants, either permanently or episodically, includes terrestrial and riparian vegetation

## 3.2 Assessment approach

### 3.2.1 Available data sources

The Project area is located within an arid and remote region of Australia that remains relatively undeveloped and under studied compared to other relatively remote environments, e.g. Ti-Tree Basin (NT), Pilbara (WA) and the Goldfields (WA). This has resulted in a paucity of observational data and information from which to make a quantitative assessment of the presence and distribution of GDEs. The following data sources have been used to inform the assessment presented in this report:

- The National Atlas of GDEs (GDE Atlas; BoM, 2017)
  - Provides a national dataset pertaining to the presence of GDEs, and presents the current knowledge of ecosystems that may have some degree of reliance on groundwater across Australia
- A desktop survey and multiple phases of detailed flora and vegetation field surveys of the Project area from 2014 to 2020 (summarised in Western Botanical, 2020)
  - Provides a preliminary identification of a small number of plant species that may be dependent on groundwater
- Field surveys of the Project area, including communication with Traditional Owners (TOs)
- State and national surface water feature mapping (EPP wetlands, Ramsar wetlands, or Directory of Important Wetlands)
- State geological and landscape mapping
- Project baseline hydrologic and hydrogeologic data and conceptualisation, as described above in Section 2 and other Project references listed in Section 5
- Expert knowledge and experience of the extended GDE study team
- Publicly available literature, including VegMachine (https://vegmachine.net/), which is a web-based tool that summarises the long-term spatial and temporal changes in land cover using satellite imagery
- Published literature re: GDE research and studies completed for plant species identified in the Project area, including Project references listed in Section 5

### 3.2.2 Approach

The approach used to identify potential GDEs in the Project area is summarised in Figure 8 and more specifically for Type 1 GDEs in Figure 9. The following describes the steps undertaken:

- Stage 1 – Preliminary identification of potential GDEs
  - GDE Atlas
    - Given the scarcity of site-specific data and broad resolution of available national scale data, the usefulness of GDE Atlas data products are considered preliminary / indicative for the Project area
  - Local scale field surveys
    - First pass knowledge gleaned from the GDE Atlas and other broad scale datasets is refined based on more detailed/local scale desktop and field assessments, including baseline hydrological and hydrogeological data collection, and surface water, vegetation and flora surveys
    - Sampling of groundwater from dedicated bores for the presence of stygofauna (results are reported in Bennelongia, 2020)

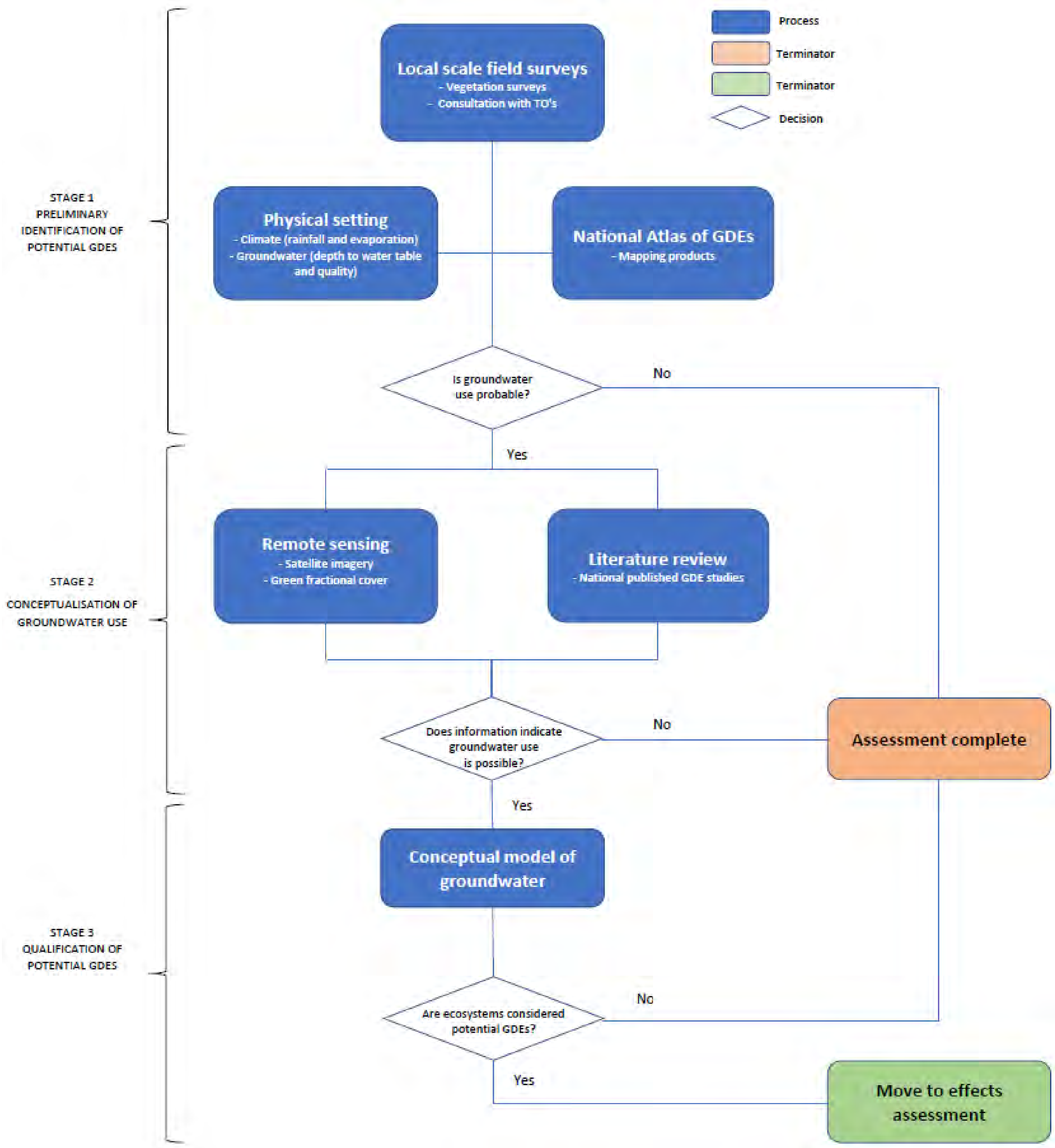



**Figure 8** Assessment approach for identifying potential Type 2 and Type 3 GDEs

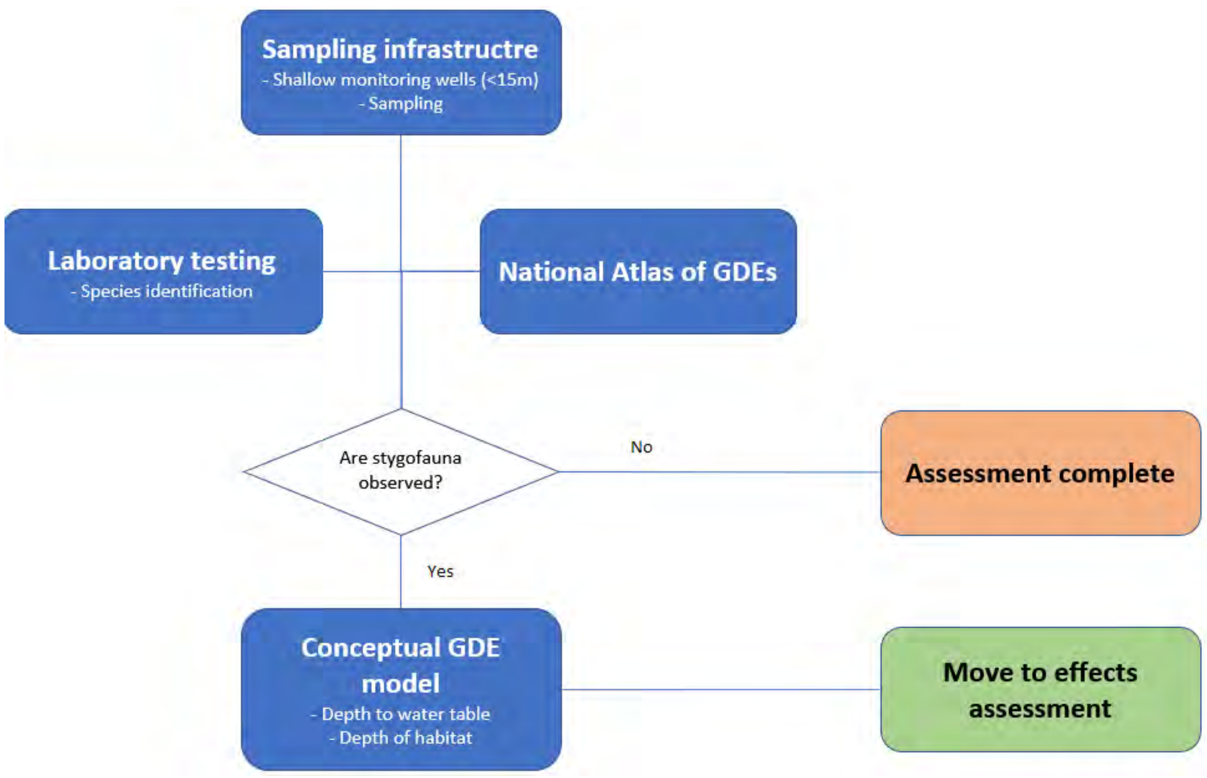



**Figure 9** Assessment approach for identifying potential Type 1 GDEs

- Stage 2 – Conceptualisation of groundwater use
  - Literature review of relevant publicly available GDE research and studies has been completed (see Attachment A), including consultation with persons considered to have expert knowledge of the Project area and/or other similar regions (e.g. Angus Duguid, NT Department of Environment and Natural Resources), which is considered an important data source in data-limited regions (Richardson et al., 2011a)
  - Development of a conceptualisation of the interactions between potential GDEs (Types 1, 2 and 3) and groundwater, including interpretation of remote sensing data and hydrogeological trends analysis
- Stage 3 – Qualification of potential GDEs
  - Qualification of potential GDEs and their capacity to resist altered groundwater condition whilst maintaining their EWRs, based on their presence in the landscape
  - Mapping the spatial distribution of potential GDEs that forms the basis for undertaking an assessment of possible effects that might arise in response to the proposed development (OZL ref. WM-5100-ENV-REP-0007)

## 3.3 Stage 1: Preliminary identification of potential GDEs

### 3.3.1 GDE Atlas review

Interrogation of the GDE Atlas indicates:

- No information exists re: stygofauna ecosystems (Type 1 GDEs) in the Project area
- No aquatic ecosystems (Type 2 GDEs) likely to occur within the Project area
- Terrestrial ecosystems (Type 3 GDEs) likely exist in the Project area (Figure 10) but the potential for their presence is mostly identified as low, with moderate potential for GDEs to occur more than 20 km to the west and northwest (near Jameson), no high potential terrestrial GDEs have been mapped by the GDE Atlas

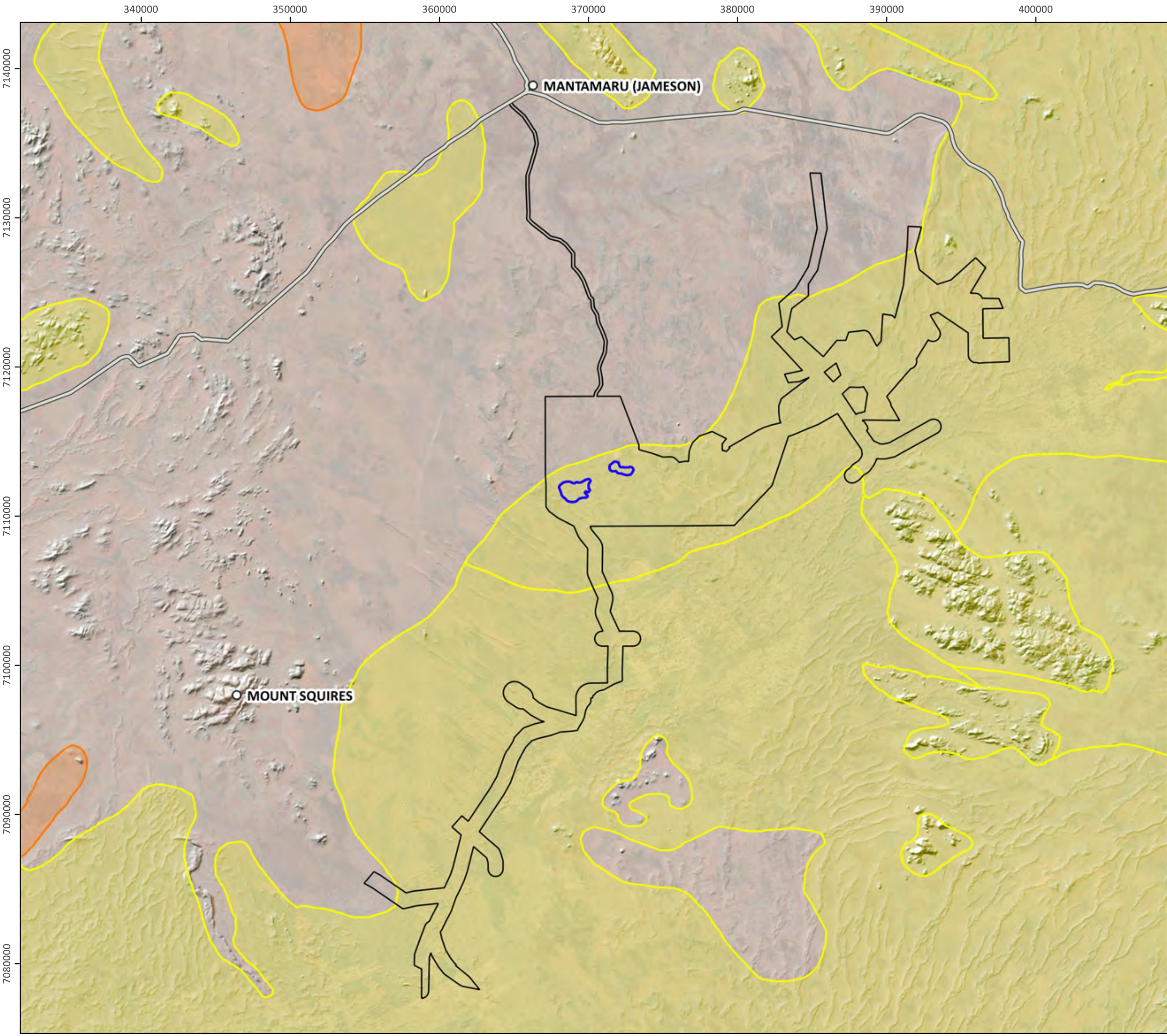
### 3.3.2 Local scale field surveys

#### Stygofauna survey (Type 1 GDEs)

As at January 2020, a total of 202 samples have been collected from 100 dedicated bores for analysis of the presence of stygofauna (Figure 11, see OZL Ref. WM-5100-WTR-REP-0014 for completion details). These bores are located across the Project area (Babel pit, Nebo pit, Northern Borefield investigation area and Southern Borefield investigation area; Bennelongia, 2020). Stygofauna specimens have been collected, where present, via net hauls during field surveys. 30 different species of stygofauna have been identified in the laboratory from 63 of 100 sampled bores. Major groups recorded include annelid worms, amphipods, a protojanirid isopod, syncarids, cyclopoid copepods, harpacticoid copepods, ostracods and nematodes. Species have been identified in the following locations

- In and around the proposed Babel pit (basement habitat)
- In and around the Nebo pit (palaeovalley sediment and calcrete habitat)
- In The Northern and Southern Borefield investigation areas (palaeovalley sediment and calcrete habitat)

In a broader context of stygal communities documented in the Yilgarn, the community observed across the Project area is not notably rich. However, only a small number of species have been recorded in more than one of the sampled areas, no single species has been recorded in all four sampled areas and none of the species have been identified outside the area covered by the survey. Figure 11 presents a locality plan showing sample locations and locations where stygofauna have been recorded.




## Figure 10

**Potential GDEs in the Project area identified in the GDE atlas**

Road
Proposed mine pit
Development envelope

**Potential GDE - identified via GDE Atlas**

Moderate potential Type 3 GDE
Low potential Type 3 GDE

DATA SOURCES
BoM, 2017
Cassini Resources, 2018
OZ Minerals, 2019

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Map Projection: GDA2020 / MGA Zone 52

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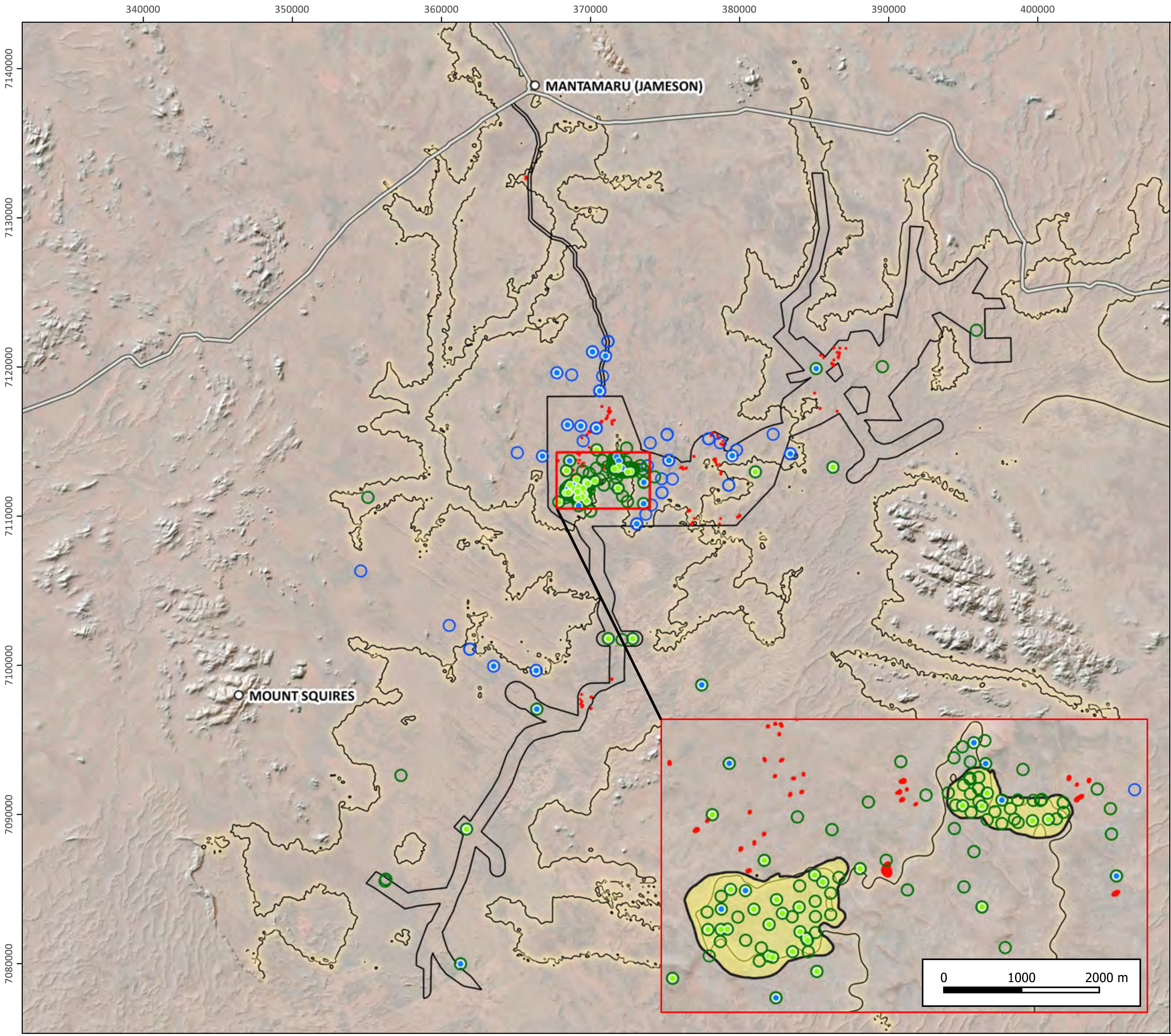


# Figure 11

## Identified stygofauna locations from sampled bores

- Road
- Proposed mine pit
- Development envelope
- AEM Palaeovalley extent (20m depth)
- Clay pan
- Subterranean fauna sample site (installed 2018)
- Subterranean fauna sample site (installed 2019)
- Identified stygofauna (2018)
- Identified stygofauna (2019)

DATA SOURCES
Cassini Resources, 2018
OZ Minerals, 2019
Bennelongia, 2020

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Based on initial findings and the potential for Project mine water affecting activities (WAAs) to impact on stygofauna habitat, the stygofauna survey area has been expanded to encompass more of the proposed mine development envelope to assist in developing a more detailed understanding of species distribution and physical constraints on distribution.

### Wetlands and springs (potential Type 2 GDEs)

OZL has consulted with Traditional Owners (TOs) to understand whether there are springs located within the Project area or the broader landscape. The TOs have not identified any springs, but have indicated there are a number of rockholes in the region that are associated with basement outcrops. Two of these occur within the proposed mine development envelope and one occurs within 25 km of the proposed mine. Table 2 presents key observational data for the rockholes and Plate 1 shows the position of 'Rockhole 2' in the landscape. The rockholes have cultural significance and, for this reason, their locations are unable to be presented in this report.

**Table 2 Key observational data for rockholes in the Project area**

| Rockhole [1] | Ground elev. [2] | Water table elev. [3] | Comment |
|---|---|---|---|
| 1 | 483.3 | 472.3 | • Occurs within proposed mine development envelope<br>• Approx. 11 m above water table<br>• Dry 'basin' with desiccated grasses |
| 2 | 480.4 | 474.9 | • Occurs within proposed mine development envelope<br>• Approx. 5.5 m above water table<br>• Dry 'basin' |
| 3 | 516.5 | 492.2 | • Occurs within 25 km of proposed mine<br>• Approx. 24.3 m above water table<br>• Dry cleft |

Notes: 1. Name and co-ordinates of rockholes cannot be provided for cultural reasons
2. Sourced from JAXA DEM (mAHD)
3. Predicted by calibrated groundwater model (mAHD)


**Plate 1 Rockhole 2 occurring on weathered granitic outcrop**

The evidence shows it is very unlikely the rockholes interact with groundwater, i.e. they:

- Appear to be ephemeral (i.e. all inspected rockholes were dry at the time they were observed by OZL personnel)
- Occur on weathered basement outcrops that are typically slightly more elevated than the surrounding landscape and some metres above the water table, as inferred from the model predicted water table surface (see OZL ref. WM-5100-WTR-REP-0034) and Japan Aerospace Exploration Agency (JAXA) AW3D30 digital elevation model (DEM; OZL ref. WM-5100-ENV-REP-0002)
- Are all located such that weathered outcrop surfaces form small surface water catchments that drain to the rockholes following rainfall events

There is no evidence of permanent or semi-permanent wetlands in the Project area that might be reliant on groundwater to maintain EWRs, i.e. where the water table might intersect the land surface or artesian pressures might result in discharge to the land surface via fissures or faults (OZL ref. WM-5100-ENV-REP-0002 and WM-5100-ENV-REP-0003).

### Flora and vegetation survey (potential Type 3 GDEs)

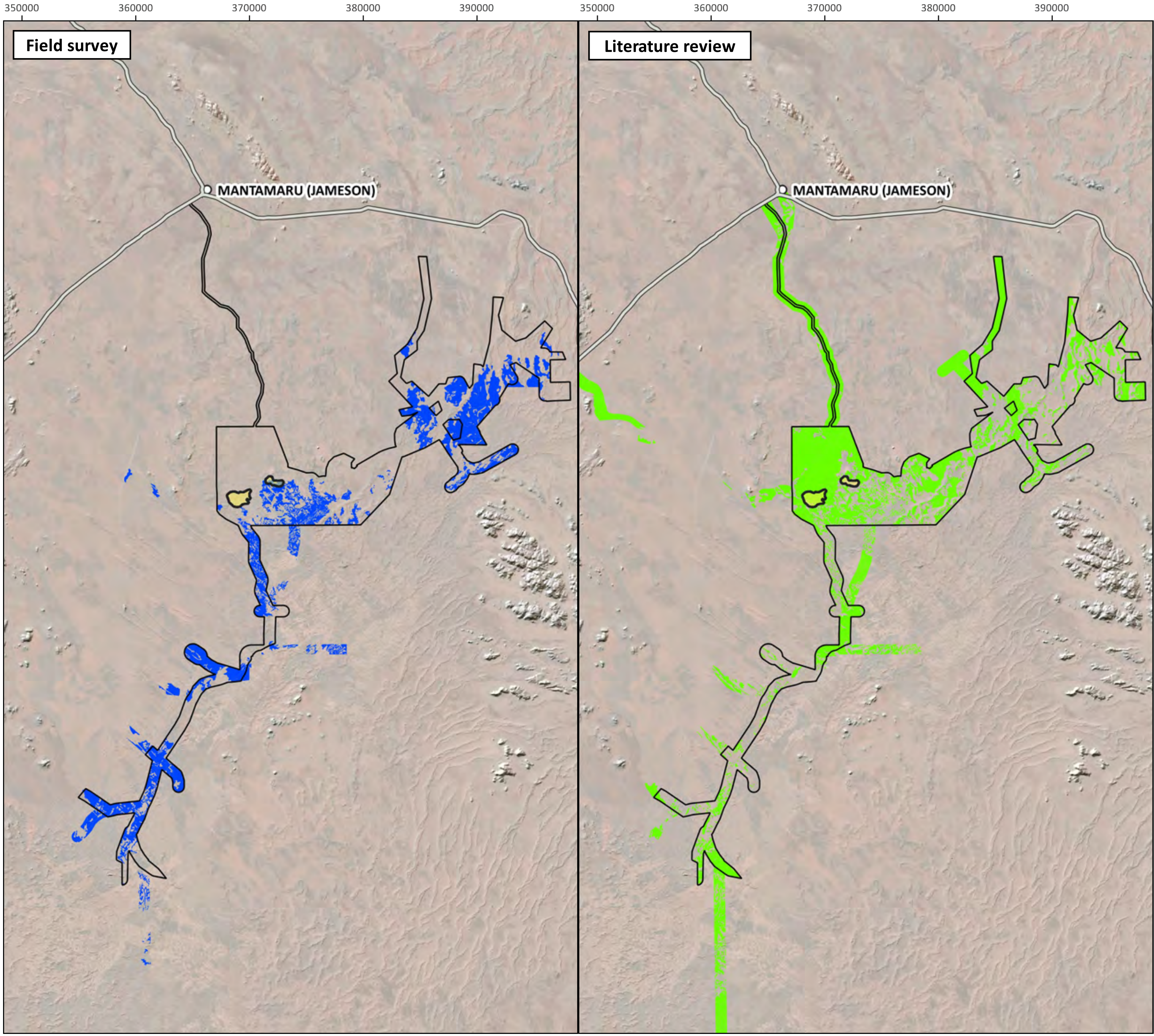
Consistent with the lack of surface water features in the Project area (Section 2.5.1; also see OZL ref. WM-5100-ENV-REP-0002), no riparian ecosystems have been identified. However, the Western Botanical (2020) survey, described in Section 2.4 with results presented in Figure 6, has identified three vegetation associations as potential GDEs based on their position in the landscape and knowledge of indicator species that are known to be phreatophytes (groundwater users) as opposed to species that are known to typically be shallow rooted and vadophytic (soil water users).

The Type 3 assessment presented here is based primarily on the following key assumptions - (i) vegetation associations represent identifiable ecosystems, and (ii) if dominant plant species within any vegetation association are known, or considered, to be phreatophytic then the vegetation association is identified as a potential GDE.

The three potential GDEs identified by Western Botanical are:

- Calcrete *Corymbia opaca* Open Woodlands (CCoW)
  This association covers around 1% of the greater survey area, and comprises open Woodland with an upper stratum of scattered *C. opaca trees* with a height of 8 to 12 m, which form dense vegetation stands in places that are represented by two or three trees within an area of around 50 $m^2$, and *Eucalyptus intertexta* (6 to 7 m high), over *Acacia ligulata* (2 m high), *A. kempeana* (3 m high), *M. glomerata* (3 m high), *Hakea lorea* subsp. *lorea* (5 m high) and a ground stratum of hummock grassland
- *Melaleuca glomerata* and *A. kempeana* Shrubland (MgAkS)
  This association covers around 3% of the greater survey area, and comprises very open woodland with occasional *E. intertext*a and *C. opaca* (4 to 8 m high), a Shrubland mid stratum dominated by *M. glomerata* (4 m high), *A. kempeana* (2 to 3 m high), *H. lorea* subsp. *lorea (3 to 4 m high)*, *A. ligulate* (2 to 3 m high) and *Eremophila longifolia* (2 m high), and a ground stratum of open hummock grassland
- Low Mallee Woodlands (LMW)
  This association covers around 12% of the greater survey area, and comprises open Mallee woodland to Mallee woodland dominated by *E. oxymitra* (2 to 5 m high) and *E. gamphylla* (2 to 8 m high) and a sparse Shrubland mid stratum dominated by *A. ligulata* (2 to 5 m high), *A. melleodora* (2 to 3 m high), *Grevillea eriostachya* (3 m high) and *Hannafordia bissillii* subsp. *bissillii* (1 m high), and a ground stratum of hummock grassland

These vegetation associations have been observed across dune swales between calcrete platforms, often as a complex with Calcrete Platform Hummock Grassland Complex (CPHG). Figure 12 shows their spatial distribution.




## Figure 12

**Identified potential GDEs: field survey and literature review**

- Road
- Proposed mine pit
- Development envelope
- Potential GDE - identified via field survey (Western Botanical, 2020)
- Potential GDE - Identified via literature review

DATA SOURCES
Cassini Resources, 2018
OZ Minerals, 2019
Western Botanical, 2020

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## 3.4 Stage 2: Conceptualisation of groundwater use

### 3.4.1 Literature review

A literature review has been undertaken to confirm Western Botanical's findings and to identify potential groundwater dependent vegetation from the list of 'dominant' vegetation species observed in each of the vegetation associations identified within the mine development area (as outlined in Western Botanical, 2020). Only dominant species with a typical observed height of greater than 1m have been included in the literature review, as trees above this height are more likely to have a rooting system that can extend to more the a few metres and access the water table (Zolfhager, 2013 and Zolfhager *et al.*, 2017). Attachment A provides the literature review results, and the following presents a summary:

- Studies in the Ti Tree Basin, located near Alice Springs in the Northern Territory (i.e. an arid area within a similar geographical and climatic setting) indicate plant abundance (density) and growth form is linked to groundwater depth, with larger plants occurring in areas where a shallow groundwater exists and shrubs generally occurring in areas where groundwater is deeper (Cook and Eamus, 2018)
- Studies in the Ti Tree Basin demonstrate groundwater use in *C. opaca* where the water table is between 8 and 15 m bgl and in some cases up to 20 m bgl (Cook and Eamus, 2018)
- Studies in arid and semi-arid Australia indicate a typical groundwater use threshold of around 10 m bgl for overstory trees (Rumman et al., 2017 and Zolfhager, 2013) and note significant differences in woodland ecosystem structure and function where the water table is in excess of 10 m bgl compared to areas with shallower water tables (Cook and Eamus, 2018)
- Western Botanical's identification of potential GDEs is supported, but several other potential groundwater indicator species are present in the Project area as shown in Table 3, and in Figure 12 and Figure 13
- In regard to identified Priority Flora species listed in Section 2.4, the literature review has not identified any Priority Flora species as being potentially groundwater dependent

### 3.4.2 Conceptualisations of groundwater use

#### Overview

The following conceptualisations of GDEs within the Project area relies on the available information and results of field studies described in Section 3.3, as well as information sourced from the literature and study team experience.

#### Type 1 GDEs – Stygofauna ecosystems

There are two key habitats for stygofauna in the Project area – (i) saturated Kadgo palaeovalley sediments and calcretes, and (ii) saturated fractured rock (gabbronorite and gneiss). Figure 14 presents a conceptualisation of stygofauna occurrence. Stygofauna habitat comprises saturated pore space or open fractures, which will be vertically constrained by:

- Clayey sequences (in sedimentary environments) and depth of weathering (in hardrock environments)
- Bioavailability of nutrients, carbon and oxygen, which typically results in decreasing abundance and diversity with depth below the water table (Hose et al, 2015)

#### Type 2 GDEs- Aquatic ecosystems

Figure 15 presents a conceptualisation of rockholes in the Project Area, based on observations presented in Section 3.3.2. The conceptualisation shows the rockholes are not reliant on groundwater.

**Table 3 Surveyed vegetation and inferred potential for groundwater use from literature review[1],[2]**

| Landform system | Sub-unit description | Vegetation associations | Vegetation association code | Dominant species [3] |
|---|---|---|---|---|
| Calcrete Plain | Calcrete Plain:<br>Level to undulating plains of paleo-groundwater Calcrete overlain by varying depths of Aeolian sand | Calcrete *Corymbia opaca* Woodland | CCoW | *Corymbia opaca*<br>*Eucalyptus intertexta*<br>*Acacia ligulata*<br>*Acacia kempeana*<br>*Hakea lorea* subsp. *Lorea*<br>*Melaleuca glomerata* |
| | | Calcrete Open Grassland | COG | *Acacia kempeana*<br>*Acacia tetragonophylla*<br>*Acacia victoriae* subsp. *victoriae* |
| | | Calcrete Platform Hummock Grassland | CPHG | *Hakea lorea* subsp. *lorea*<br>*Acacia tetragonophylla*<br>*Acacia ligulata* |
| | | Calcrete Platform Hummock Grassland with *Acacia eremophila* var. Numerous-nerved variant (A.S. George 11924 | CPHG Ae | *Hakea lorea* subsp. *lorea*<br>*Acacia eremophila* var.<br>*Acacia prainii* |
| | | Calcrete Platform Hummock Grassland with *Allocasuarina helmsii* | CPHG Ah | *Hakea lorea* subsp. *lorea*<br>*Eucalyptus oxymitra*<br>*Acacia ligulata*<br>*Allocasuarina helmsii* |
| | | Calcrete Platform Hummock Grassland with *Melaleuca eleuterostachya* | CPHG Me | *Hakea lorea* subsp. *lorea*<br>*Acacia ligulata*<br>*Melaleuca eleuterostachya* |
| | | CPHG / LMW COMPLEX | LMW/ CPHG Complex | See LMW and CPHG |
| | | CPHG / SAWS COMPLEX | SAWS/CPHG Complex | See SAWS and CPHG |
| Hardpan Plain & Drainage | Plains:<br>red clayey sand hardpan plains, subject to sheet flow | Hardpan Mulga Woodland | HPMW | *Acacia ayersiana* (narrow phyllode variant)<br>*Acacia aneura*<br>*Acacia aptaneura*<br>*Hakea lorea* subsp. *Lorea*<br>*Senna artemisioides* subsp. *Artemisioides* |
| | | Hardpan Mulga Woodland Drainage | HPMWD | *Acacia aptaneura*<br>*Acacia ayersiana* (narrow phyllode variant)<br>*Acacia aneura*<br>*Eremophila latrobei* subsp. *Glabra*<br>*Teucrium teucriiflorum*<br>*Acacia tetragonophylla* |
| | | Mulga Grove | GRMU | *Acacia aptaneura*<br>*Hakea lorea* subsp. *lorea* |
| | | *Eremophila duttonii* Shrubland | EdS | *Eremophila duttonii*<br>*Rhagodia drummondii* |
| | | Hardpan Chenopod Shrubland | Avs | no upper story (all less than 0.5m) |
| | Clay Pans:<br>(a) Small ephemerally inundated clay pans with hard setting clay soils supporting annual grasses and herbaceous vegetation; or<br>(b) Extensive clay pans with medium to heavy clay soils supporting perennial grasses | Claypan Playa | CPP | *Acacia tetragonophylla*<br>*Acacia pteraneura*<br>*Eremophila longifolia*<br>*Acacia victoriae* subsp. *victoriae* |
| | | Claypan Grassland | CPN-G | *Aristida latifolia* |

**Table 4** **Surveyed vegetation and inferred potential for groundwater use [1],[2]** (cont.)

| Landform system | Sub-unit description | Vegetation associations | Vegetation association code | Dominant species [3] |
|---|---|---|---|---|
| Sand Dune | Sand dunes with fine red Aeolian sand, 2 to 20m relief | *Aluta maisonneuvei* subsp. *maisonneuvei* low shrubland | AmmS | *Aluta maisonneuvei* subsp. *maisonneuvei* |
| | | Sand Dune *Acacia - Grevillea* shrubland | SDAGS | *Acacia ligulata* |
| | | | | *Acacia maitlandii* |
| | | | | *Grevillea stenobotrya* |
| | | | | *Grevillea juncifolia* subsp. *juncifolia* |
| | | | | *Dodonaea viscosa* subsp. *angustissimus* |
| | | | | *Acacia melleodora* |
| | | | | *Aluta maisonneuvei* subsp. *maisonneuvei* |
| | | SDAGS/AmmS COMPLEX | SDAGS/AmmS COMPLEX | See SDAGS and AmmS |
| Sand Plain | Aeolian medium red silty sand plains, often with hardpan or underlying calcrete | Sandplains with Wattles other than Mulga | SAWS | *Acacia ligulata* |
| | | | | *Acacia walkeri* |
| | | | | *Acacia abrupta* |
| | | | | *Acacia pachyacra* |
| | | | | *Acacia melleodora* |
| | | | | *Acacia pruinocarpa* |
| | | | | *Acacia sericophylla* |
| | | | | *Grevillea eriostachya* |
| | | | | *Eremophila forrestii* |
| | | Sandplain Spinifex | SASP | *Triodia schinzii* |
| | | Sandplain Mulga | SAMU | *Acacia aneura* |
| | | | | *Acacia ayersiana* |
| | | | | *Hakea lorea* subsp. *lorea* |
| | | | | *Eremophila longifolia* |
| | | | | *Acacia ligulata* |
| | | Low Mallee Woodland | LMW | *Eucalyptus oxymitra* |
| | | | | *Eucalyptus gamophylla* |
| | | | | *Acacia ligulata* |
| | | | | *Acacia melleodora* |
| | | | | *Grevillea eriostachya* |
| | | | | *Hannafordia bissillii* subsp. *bissillii* |
| | | LMW/SAWS COMPLEX | LMW/SAWS Complex | See LMW and SAWS |
| | | LMW/MgAkS COMPLEX | LMW/MgAkS Complex | See LMW and MgAkS |
| | | *Melaleuca glomerata* Shrubland with *Acacia kempeana* | MgAks | *Eucalyptus intertexta* |
| | | | | *Corymbia Opaca* |
| | | | | *Acacia kempeana* |
| | | | | *Melaleuca glomerata* |
| | | | | *Hakea lorea* subsp. *lorea* |
| | | | | *Acacia ligulata* |
| | | | | *Eremophila longifolia* |
| | | MgAks/HPMW Complex | MgAks/HPMW Complex | See MgAks and HPMW |
| | | *Acacia brachystachya* over Spinifex Shrubland | AbTsS | *Acacia brachystachya* |
| | | | | *Eremophila longifolia* |
| | | | | *Acacia pachyacra* |
| | | | | *Triodia schinzii* |

**Table 4 Surveyed vegetation and inferred potential for groundwater use [1],[2]** (cont.)

| Landform system | Sub-unit description | Vegetation associations | Vegetation association code | Dominant species [3] |
|---|---|---|---|---|
| Sand Plain (cont.) | Aeolian medium red silty sand plains, often with hardpan or underlying calcrete (cont.) | *Acacia rhodophloia* over Spinifex Shrubland | ArS | *Acacia rhodophloia* |
| | | | | *Acacia ligulata* |
| | | | | *Grevillea eriostachya* |
| | | | | *Aluta maisonneuvei* subsp. *maisonneuvei* |
| Stony Hills | Granodiorite Geology:<br>Foot slopes and outwash plains at the base of small to medium sized outcrops of grano-diorite | Stony Mulga Shrubland | SMS | *Acacia ayersiana* (narrow phyllode variant) |
| | | | | *Acacia aptaneura* |
| | | | | *Eremophila latrobei* subsp. *glabra* |
| | | | | *Senna artemisioides* subsp. *artemisioides* |
| | | | | *Eremophila hughesii* subsp. *hughesii* |
| | | Senna Shrubland | SS | *Hakea lorea* subsp. *lorea* |
| | | | | *Acacia pruinocarpa* |
| | | | | *Acacia ayersiana* (narrow phyllode variant) |
| | | | | *Senna artemisioides* subsp. *helmsii* |
| | | | | *Senna* sp. *Billabong* |
| | | *Acacia kempeana* Shrubland | AkS | *Acacia kempeana* |
| | | | | *Acacia tetragonophylla* |
| | | | | *Senna artemisioides* subsp. *artemisioides* |
| | | | | *Rhagodia eremaea* |
| | | | | *Eremophila serrulata* |
| | | | | *Eremophila longifolia* |
| | | AkS/HPMW Complex | AkS/HPMW Complex | See AkS and HPMW |
| | | *Acacia cuthbertsonii* Shrubland | AcS | *Acacia cuthbertsonii* |
| | | | | *Acacia ayersiana* (narrow phyllode variant) |
| | | | | *Eremophila latrobei* subsp. *glabra* |
| | | | | *Senna artemisioides* subsp. *helmsii* |
| | | | | *Eremophila latrobei* subsp. *glabra* |

Notes:
1. From Western Botanical, 2020
2. Does not include associations/complexes that occur outside model domain (and, hence, outside the possible area of Project impact)
3. Dominant species considered to be those >1m in upper and mid stratum, as per Western Botanical, 2020

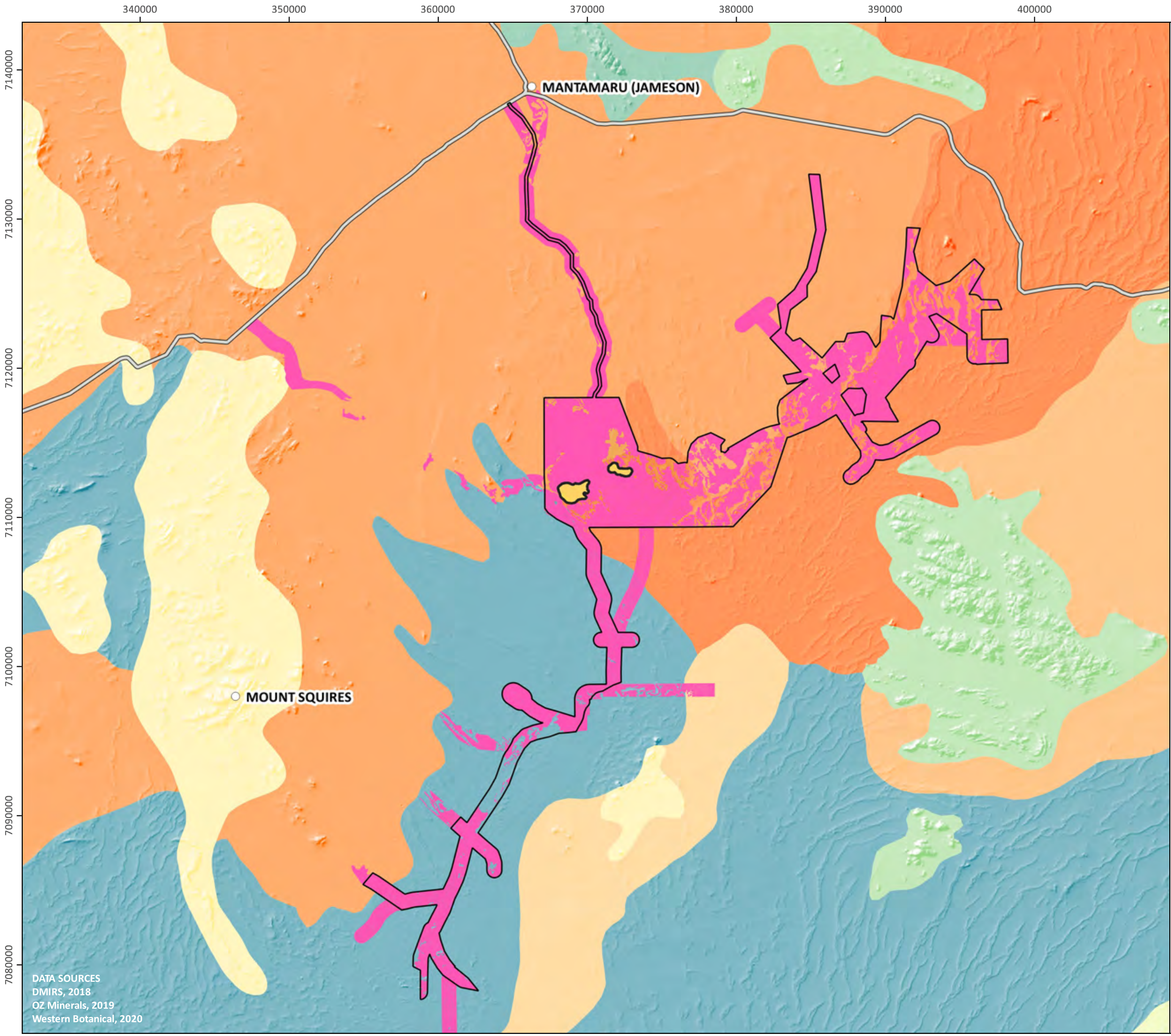
Key:

**Vegetation association – Identified potential GDE**

- Identified by field survey
- Identified by literature review

**Dominant species – Identified potential groundwater user**

- Unlikely
- Possible
- No information identified




# Figure 13

## Preliminary identified potential terrestrial GDEs within the Project development over landform systems

- Road
- Proposed mine pit
- Development envelope
- Identified potential GDEs

**Landscape**

- Extensive plains with numerous dunes which are often short and of irregular shape and orientation
- Outwash plains and dissected fan and terrace formations flanking ranges of sedimentary and some metamorphic, volcanic, and granitic rocks
- Outwash plains subjacent to ranges of basic igneous rocks; some low hills of basic rocks occur in the unit; occasional dunes
- Plains with occasional short dunes, and hilly areas with rock outcrops
- Ranges and hills mainly on granitic rocks; rock outcrop is extensive
- Steep hills and ranges on basic rocks; rock outcrop common; some gorges; small pediments and plains
- Steep hills and ranges on sedimentary and some metamorphic, volcanic, and granitic rocks; bare rock outcrop is common; some gorges
- Very gently undulating plain traversed by longitudinal dunes



Date Published: 12 Mar 2020
Project Number: 1000103
Client: OZ Minerals/Cassini Resources
Drawn: ETEROVICZ
Map Projection: GDA2020 / MGA Zone 52

N

0 5000 10000 m

1:350000

CDM Smith

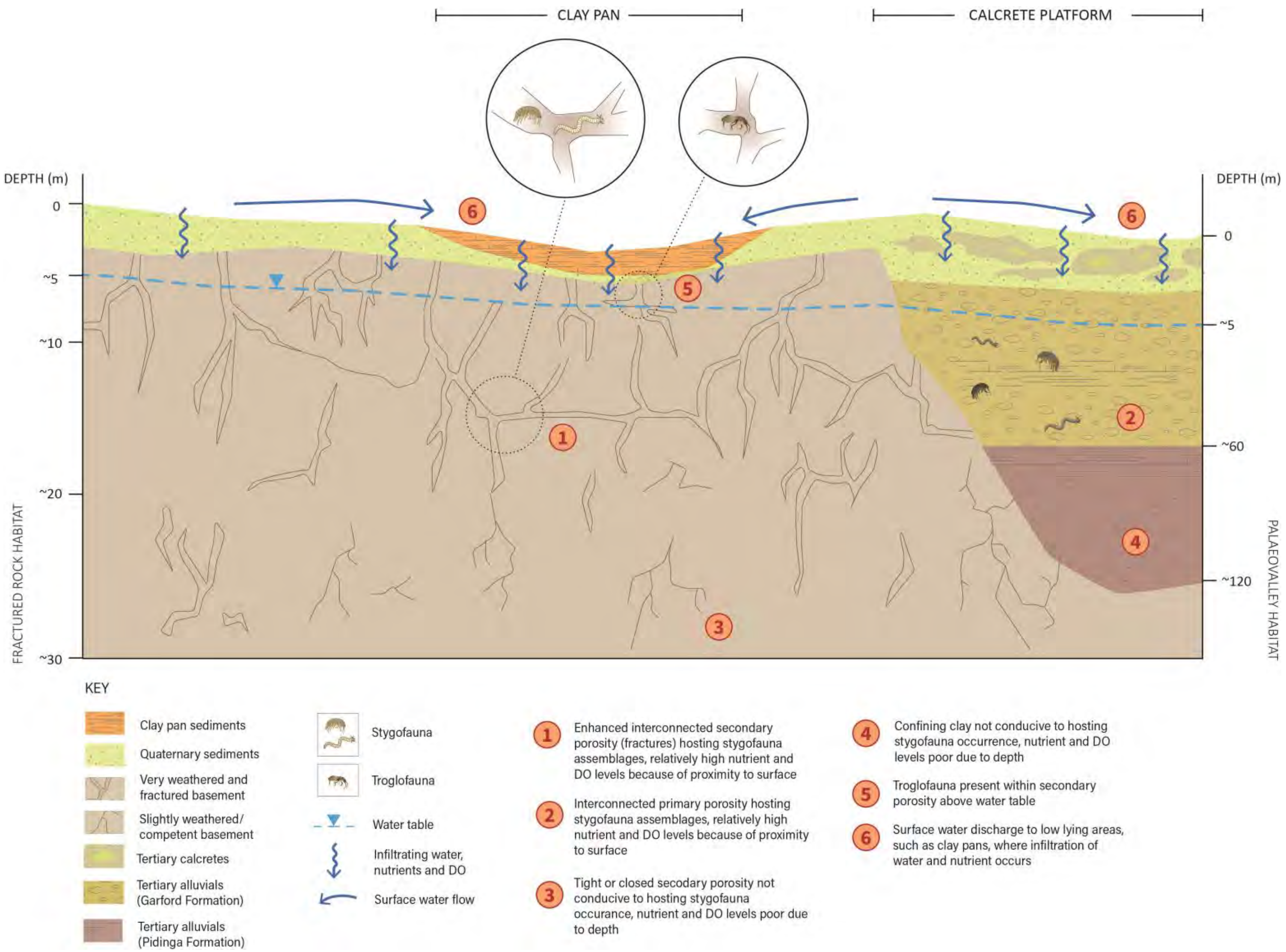



**Figure 14 Conceptualisation of stygofauna occurrence**

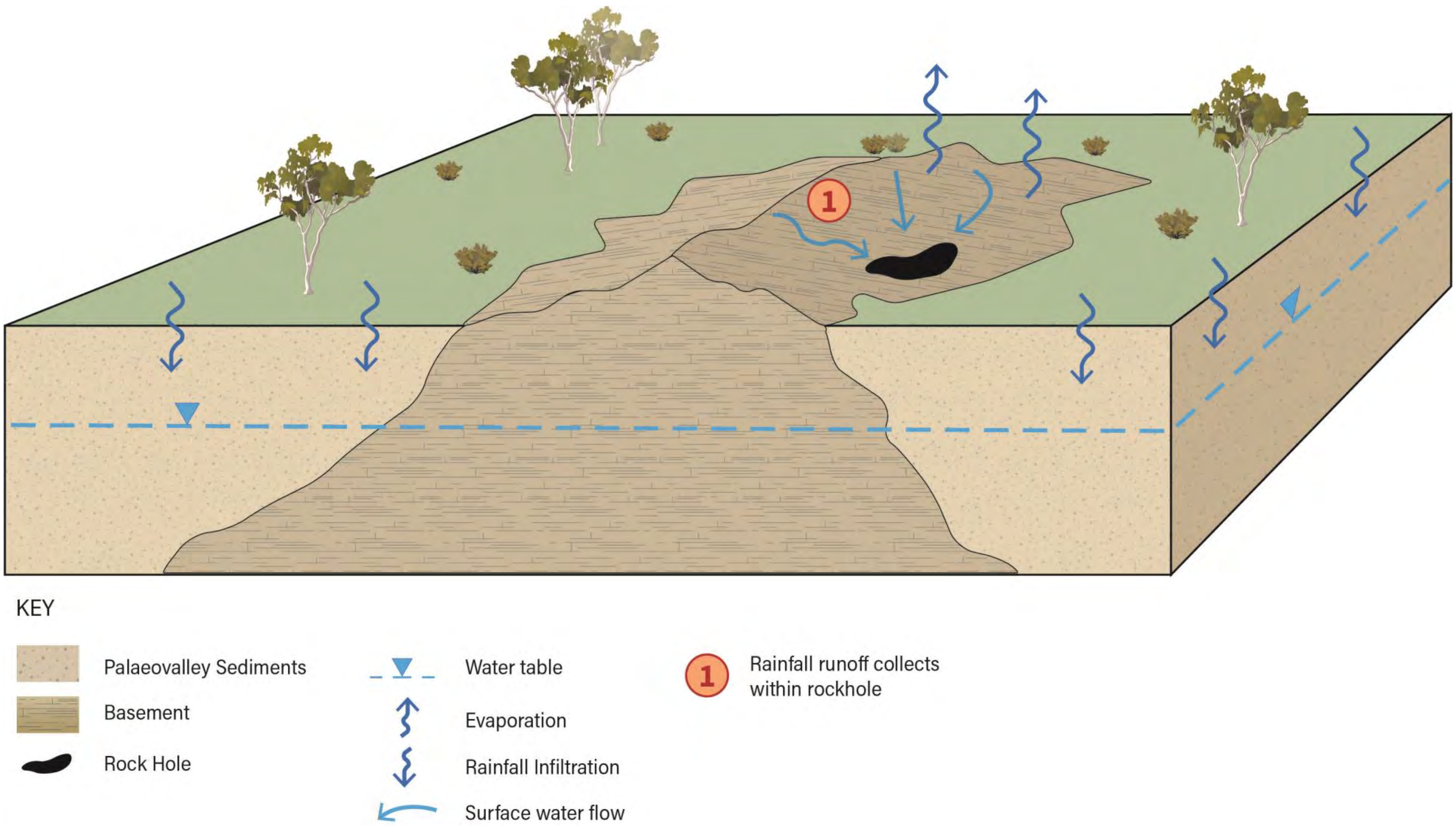



**Figure 15 Conceptualisation of rockholes**

### Type 3 GDEs- Terrestrial ecosystems

Vegetation associations present in the Project area that are not identified as potential GDEs (as described in Stage 1 of the assessment, refer Section 3.3) can generally be described as:

- Annual (ephemeral) and perennial grasses, shrubs and small trees associated with clay pans and hardpans that likely have their EWRs met via inundation following rainfall events that are of sufficient intensity or duration to generate runoff and recharge of the soil water reservoir
- Shrublands on sandplains and stony hills, including species of Acacia, Grevillea and hummock grasses, that typically demonstrate (resistance) attributes allowing them to cope with low soil moisture levels (e.g. stomatal control and the ability to generate very negative plant water potentials)

Figure 13 presents vegetation associations present in the Project area that have been identified as potential GDEs (as described in Stage 1 of the assessment, refer Section 3.3) over landform systems, whilst Figure 16 presents identified potential GDEs over model predicted depth to groundwater (see OZL ref. WM-5100-WTR-REP-0034) and Figure 17 shows the spatial distribution of the maximum height of dominant species within the different vegetation associations (as a proxy for estimating the rooting depth of these species, which may be a conservative assumption based on a study conducted by Jochen Shenk and Jackson, 2002).

Identified potential terrestrial GDEs can generally be described as associations comprising vegetation that:

- Have rooting systems capable of penetrating shallow calcrete profiles present in many locations
- Are located within dune systems, in deep sandy swales between outcropping calcretes
- Are located where the water table is accessible, e.g. within 10 to 15 m bgl, depending on the depth to which root systems can extend

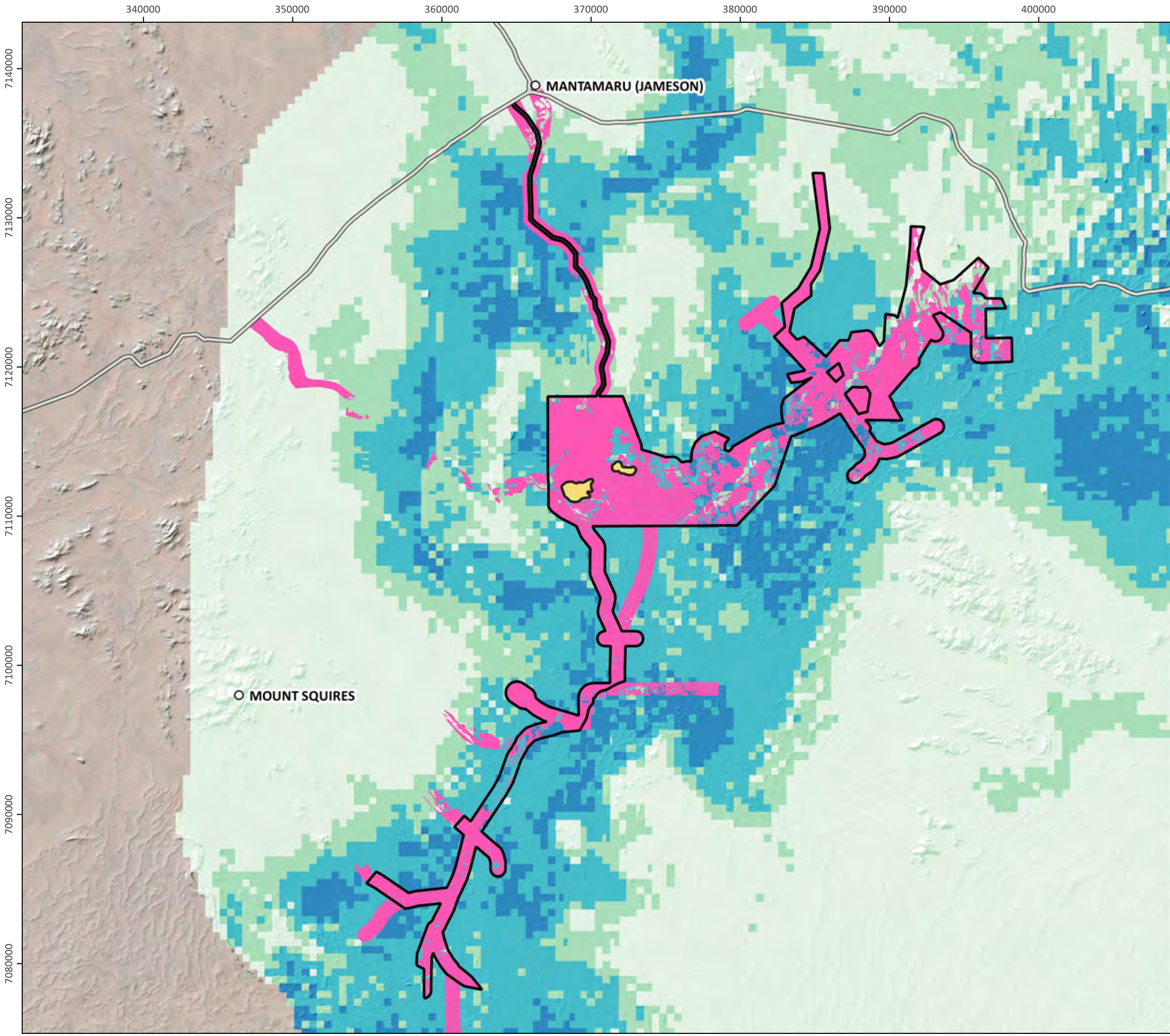
The identification of potential groundwater dependent terrestrial vegetation is supported by the following trends (as described in Attachment B), noting the temporal nature of possible groundwater reliance is not well understood given the lack of timeseries groundwater head data for the Project area:

- An increasing salinity trend along the regional flowpath, which suggests either evaporation from a shallow water table or evapotranspiration (i.e. plant transpiration and shallow groundwater evaporation) is occurring, assuming water-rock interactions do not account for the observed salinity increase and recharge conditions are relatively uniform across the Project area
- Although, there appears to be responsiveness of vegetation to rainfall across the Project area, there is also an apparent consistent base level green fractional cover that persists over a drying sequence of below-average rainfall years, suggesting sustained access to water (possibly from a sizable soil water reservoir or groundwater, or both)

## 3.5 Stage 3: Qualification of potential GDEs

### 3.5.1 Type 1 GDEs (stygofauna ecosystems)

Stygofauna are accepted as having obligate groundwater dependence but have the capacity to move vertically within an aquifer in response to changes in water table elevation. This capacity will be limited by a number of factors such as the vertical and lateral extent of interconnected (primary or secondary) porosity, the size of pore spaces to accommodate individual animals, and the depth to which sufficient nutrients, carbon and oxygen are available.




# Figure 16

## Preliminary identified potential terrestrial GDEs within the Project development envelope and modelled depth to groundwater

Road
Proposed mine pit
Development envelope
Identified potential GDE

**Modelled depth to groundwater (mbgl)**

< 2
2 - 5
5 - 10
10 - 15
< 15

DATA SOURCES
Cassini Resources, 2018
OZ Minerals, 2019
Western Botanical, 2020

DISCLAIMER
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Date Published: 12 Mar 2020
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Map Projection: GDA2020 / MGA Zone 52

N

0 5000 10000 m

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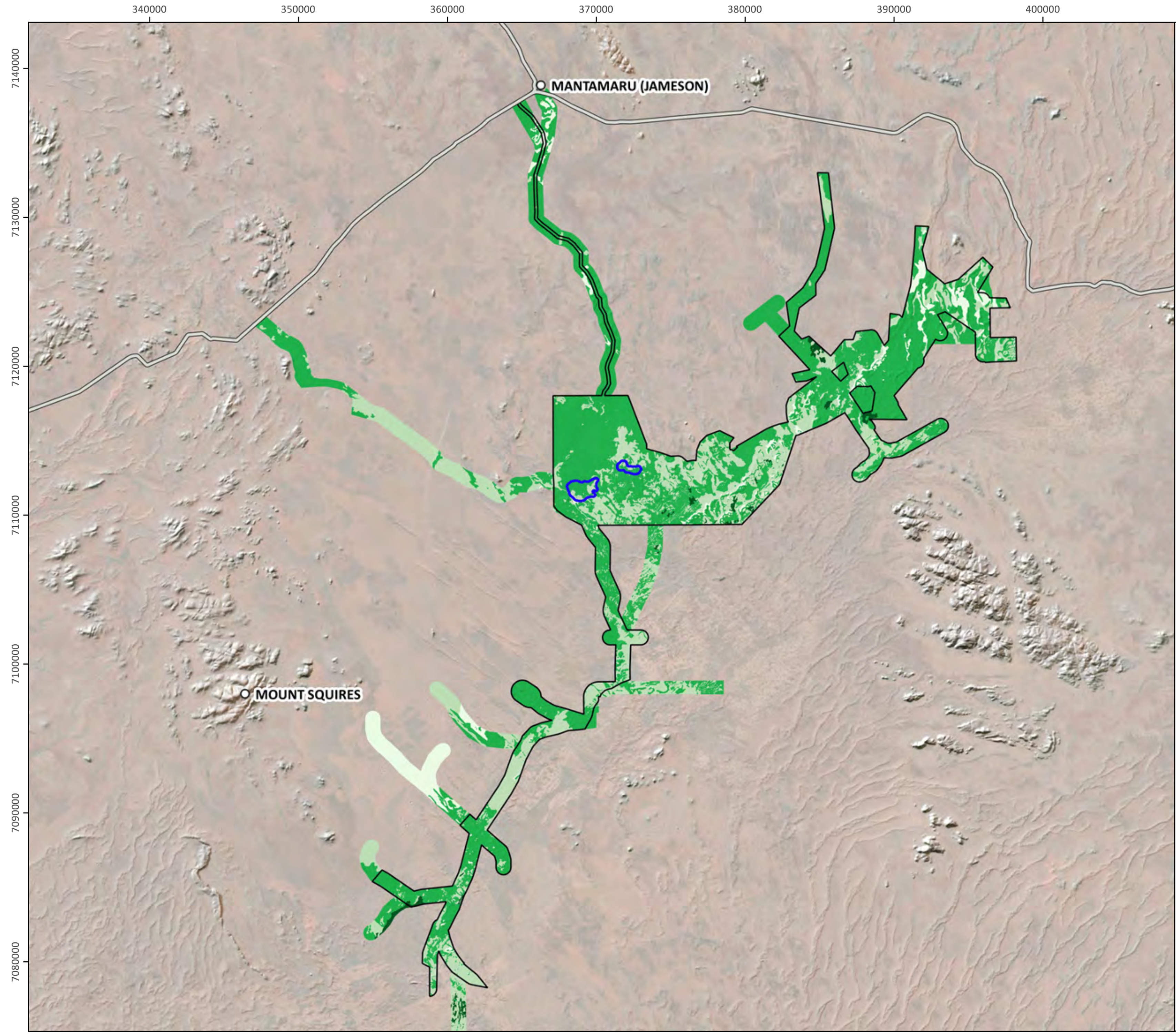


# Figure 17

## Maximum height of tallest dominant species in each mapped vegetation association within the Project development envelope

Road
Proposed mine pit
Development envelope

**Max height (m)**

< 2.0
2.0 - 5.0
5.0 - 10.0
> 10

DATA SOURCES
Cassini Resources, 2018
OZ Minerals, 2019
Western Botanical, 2020

DISCLAIMER
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Date Published: 13 Mar 2020
Project Number: 1000103
Client: OZ Minerals/Cassini Resources
Drawn: ETEROVICZ
Map Projection: GDA2020 / MGA Zone 52

N
0 5000 10000 m
1:350000

CDM Smith

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### 3.5.2 Type 3 GDEs (terrestrial ecosystems)

#### Classification of groundwater use

Based on the conceptualisation presented in Section 3.4.2, a qualitative assessment of the likelihood of groundwater use by terrestrial vegetation has been undertaken, with the following, sometimes conservative, assumptions:

- Vegetation species identified as 'dominant' within a vegetation association (according to Western Botanical 2020) are critically important components of the ecosystems active within the association, i.e. if this species were to be adversely impacted by reduced water access, ecosystem function would also be adversely impacted
- A relatively shallow vadose zone and an arid climate suggests the soil reservoir in some locations might be insufficient to meet EWRs, especially of larger perennial plant species (trees and shrubs; see Jochen Shenk and Jackson, 2002)
- Dominant plant species height and rooting depth are co-related, i.e. the taller a tree is the deeper its root system can extend (Jochen Shenk and Jackson, 2002)
- Water table drawdown in response to climate variability and anthropogenic activity (such as mine dewatering) is likely to have some impact on the capacity of groundwater dependent vegetation to meet EWRs
- Based on climate and hydrological setting, vegetation species in the Project area will demonstrate a degree of resistance (ability to control water loss) and / or resilience (the ability to recover ecosystem function) to cope with variable water access

The assessment considers groundwater use according to the matrix provided in Figure 18. The matrix classifies the likelihood or potential for groundwater to meet all or some of the EWRs of terrestrial vegetation associations (ecosystems) based on two variables – (i) vegetation height of dominant species in each vegetation association (identified through field surveys, as a proxy for potential rooting depth), and (ii) depth to groundwater (predicted by a numerical groundwater model, calibrated to field measurements; refer OZL ref. WM-5100-WTR-REP-0034 and Figure 19). Depending on an association's distribution across the landscape, it may be classified into more than one category of potential for groundwater use. The qualitative assessment considers the following:

- 'Low' likelihood of groundwater use occurs where the depth to groundwater is probably below the dominant plant species potential rooting depth, as indicated by the dominant species tree height
- 'Moderate' likelihood of groundwater use occurs where the depth to groundwater is *possibly within* the dominant plant species potential rooting depth, as indicated by the dominant species tree height
- 'High' likelihood of groundwater use occurs where the depth to groundwater is *probably within* the dominant plant species potential rooting depth, as indicated by the dominant species tree height

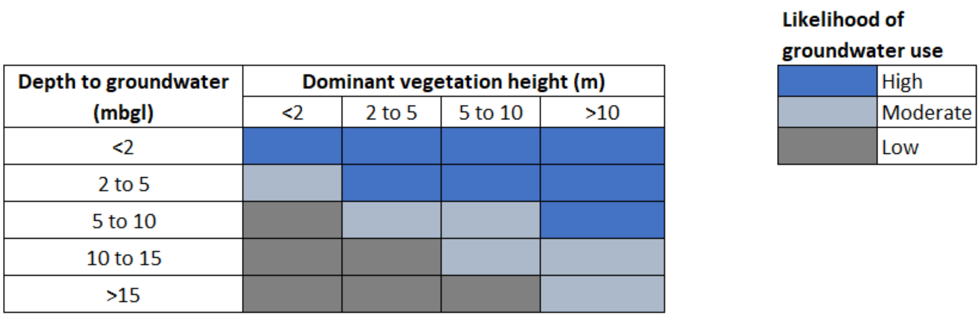



**Figure 18 Matrix for qualitative determination of vegetation groundwater use**

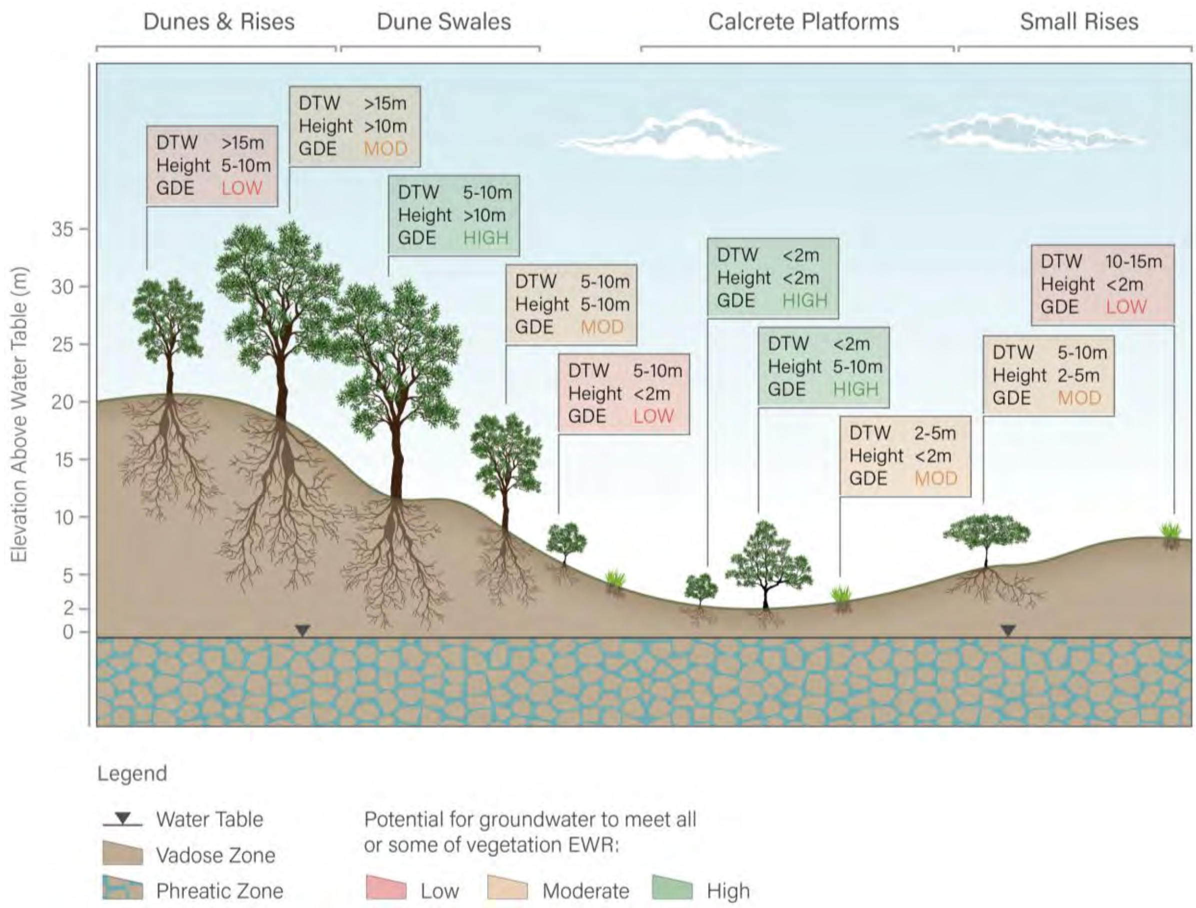



**Figure 19 Conceptualisation of potential groundwater use by terrestrial vegetation**

Table 4 lists each of the 38 identified vegetation associations that have been mapped within the entire surveyed area. Only 33 of the associations occur within the Project groundwater model domain (OZL ref. WM-5100-WTR-REP-0034), and these have been assessed on their likelihood of groundwater use based on the above approach:

- Four are mapped as low likelihood only (AcS, AvS, CPN-G, SS)
- Five are mapped as low-moderate likelihood (AmmS, ArS, SASP, SDAS/AmmS, SMS)
- 16 associations are mapped as low-moderate-high likelihood (AbTsS, AkS, COG, CPHG, CPHG Ah, CPP, GRMU, HPMW, HMPWD, LMW, LMW/CPHG, LMW/SAWS, MgAkS, SAMU, SAWS, SAWS/CPHG)
- Two are mapped as moderate likelihood only (CPHG Ae, MgAkS/HPMW)
- Five are mapped as moderate-high likelihood (i.e. Complex of Aks and HPMW, CCoW, CPHG Me, Complex of LMW and MgAkS, Complex of SAWS and CPHG)
- One is mapped as high likelihood (i.e. *E. duttonii shrubland*; EdS)

**Table 4 Qualitative classification of identified vegetation association potential for groundwater use**

| Vegetation association | Likelihood of groundwater use based on depth to groundwater and dominant species height | | | Potential for groundwater use of dominant species based on literature review[1,2] |
|---|---|---|---|---|
| | High | Mod | Low | |
| *Acacia brachystachya* over Spinifex Shrubland (AbTsS) | ✓ | ✓ | ✓ | Unlikely/unknown |
| *A. cuthbertsonii* Shrubland (AcS) | × | × | ✓ | Unlikely/unknown |
| *A. kempeana* Shrubland (AkS) | ✓ | ✓ | ✓ | **Possible** |
| Complex of Aks and HPMW | ✓ | ✓ | × | Possible |
| Complex of AkS and SAMU | *Occurs outside model domain* | | | |
| *A. maisonneuvei* subsp. *maisonneuvei* low shrubland (AmmS) | × | ✓ | ✓ | Unknown |
| *A. rhodophloia* over Spinifex Shrubland (ArS) | × | ✓ | ✓ | Unlikely/unknown |
| Hardpan Chenopod Shrubland (AvS) | × | × | ✓ | Unknown |
| *Calcrete C. opaca* Open Woodlands (CCoW) | ✓ | ✓ | × | Possible |
| Calcrete Open Grassland (COG) | ✓ | ✓ | ✓ | **Possible** |
| Calcrete Platform Hummock Grassland (CPHG) | ✓ | ✓ | ✓ | **Possible** |
| Complex of CPHG and SaS | *Occurs outside model domain* | | | |
| CPHG Hummock Grassland with *A. eremophila* var. numerous-nerved variant (CPHG Ae) | × | ✓ | × | Possible |
| CPHG with *A. helmsii* (CPHG Ah) | ✓ | ✓ | ✓ | **Possible** |
| CPHG with *M. eleuterostachya* (CPHG Me) | ✓ | ✓ | × | Possible |
| Claypan Grassland (CPN-G) | × | × | ✓ | Unknown |
| Claypan Playa (CPP) | ✓ | ✓ | ✓ | **Possible** |
| *E. duttonii* Shrubland (EdS) | ✓ | × | × | Unknown |
| Mulga Grove (GRMU) | ✓ | ✓ | ✓ | **Possible** |
| Hardpan Mulga Woodland (HPMW) | ✓ | ✓ | ✓ | **Possible** |
| Hardpan Mulga Woodland Drainage (HPMWD) | ✓ | ✓ | ✓ | **Possible** |
| Low Mallee Woodland (LMW) | ✓ | ✓ | ✓ | **Possible** |
| Complex of LMW and CPHG | ✓ | ✓ | ✓ | **Possible** |
| Complex of LMW and MgAkS | ✓ | ✓ | × | Possible |
| Complex of LMW and SAWS | ✓ | ✓ | ✓ | **Possible** |
| *M. glomerata* Shrubland with *A. kempeana* (MgAkS) | ✓ | ✓ | ✓ | **Possible** |
| Complex of MgAkS and HPMW | × | ✓ | × | Possible |
| Sandplain *A. Dodonea* Shrubland (SADS) | *Occurs outside model domain* | | | |
| Sandplain Mulga Woodland (SAMU) | ✓ | ✓ | ✓ | **Possible** |
| *Senna artemisioides* subsp. *xartemisioides* Shrubland (SaS) | *Occurs outside model domain* | | | |
| Complex of SaS and SAWS | *Occurs outside model domain* | | | |
| Sandplain Spinifex (SASP) | × | ✓ | ✓ | Unknown |
| Sandplains with Wattles other than Mulga over Spinifex (SAWS) | ✓ | ✓ | ✓ | Unlikely/unknown |
| Complex of SAWS and CPHG | ✓ | ✓ | × | Possible |
| Sand Dune *A. Grevillea* shrubland (SDAGS) | ✓ | ✓ | ✓ | **Possible** |
| Complex of SDAGS and AmmS | × | ✓ | ✓ | Unknown |
| Stony Mulga Shrubland (SMS) | × | ✓ | ✓ | **Possible** |
| Senna Shrubland (SS) | × | × | ✓ | **Possible** |
| **Total** | **22** | **28** | **25** | - |

Notes: 1. Refer to Table 3

2. Bold text indicates a vegetation association that has been identified through the literature review to have possible dependence on groundwater however the qualitative assessment indicates it is likely to have some resistance as it is present in areas classified as having "Low" likelihood for groundwater use based on depth to groundwater and the dominant species tree height.

### Degree of ecosystem groundwater dependence

Any vegetation association that includes a dominant plant species that is considered to have some likelihood of using groundwater, even if only episodically or to meet a portion of its EWRs, is considered a potential GDE, and their reliance on groundwater can be either facultative (essentially opportunistic) or obligate (essentially absolute). A GDE's degree of dependence, or more importantly, resistance to altered groundwater condition (either quantity or quality), can be qualified based on its occurrence in the landscape (see Table 5):

- Where an association / ecosystem occurs *only* in areas where the soil water reservoir is not sufficient to support the EWRs of some or all component plant species at some stage in their lifecycle and groundwater access is required to meet EWRs (i.e. 'high' likelihood for groundwater use), it is classified as an obligate GDE, meaning
  - Access to groundwater is one of the factors that likely define the ecosystem's presence in the landscape
  - Plant resistance to altered groundwater availability is possibly diminished by relatively consistent access to water for meeting EWRs
  - An ecosystems ability to recover following re-established groundwater availability (resilience) is diminished by an extended period of not having consistent access to water for meeting EWRs
- Where an association / ecosystem occurs in areas with varying depths to the water table[1], ranging from less than a few metres (likely within plant root zones, i.e. 'moderate' to 'high' likelihood for groundwater use) to where the water table is beyond plant root zones ( i.e. 'low' likelihood for groundwater use), it is classified as a facultative GDE, meaning
  - Access to groundwater does not necessarily define the ecosystem's presence in the landscape
  - There is a likelihood the soil water reservoir is sufficient to meet plant EWRs in some areas where they occur
  - Plant resistance to altered soil water availability mitigates the need to access groundwater to meet EWRs until the soil water potentials cannot be overcome, at which point plants will switch to using groundwater
- Where an association is present in areas where the water table is deeper than 10 m and likely outside the plant root zone, (i.e. 'low' likelihood for groundwater use), even if also present in areas more conducive to groundwater use, it may be considered vadophytic meaning
  - Access to groundwater is unlikely to define an ecosystem's presence in the landscape
  - There is a likelihood the soil water reservoir is always sufficient to meet plant EWRs
  - Plant resistance to altered soil water availability is sufficient to meet plant EWRs as the soil water reservoir becomes depleted
  - Ecosystem ability to recover following re-established groundwater availability is likely because of reliance on soil water and seasonality of water availability

[1] Including the capillary fringe

**Table 5 Qualitative classification of identified vegetation associations degree of dependence**

| Vegetation association | Type of dependence | | |
|---|---|---|---|
| | Obligate | Facultative | Vadophytic |
| *Acacia brachystachya* over Spinifex Shrubland (AbTsS) | | | ✓ |
| *A. cuthbertsonii* Shrubland (AcS) | | | ✓ |
| *A. kempeana* Shrubland (AkS) | | | ✓ |
| Complex of Aks and HPMW | | ✓ | |
| *A. maisonneuvei* subsp. *maisonneuvei* low shrubland (AmmS) | | | ✓ |
| *A. rhodophloia* over Spinifex Shrubland (ArS) | | | ✓ |
| Hardpan Chenopod Shrubland (AvS) | | | ✓ |
| *Calcrete C. opaca* Open Woodlands (CCoW) | | ✓ | |
| Calcrete Open Grassland (COG) | | | ✓ |
| Calcrete Platform Hummock Grassland (CPHG) | | | ✓ |
| CPHG Hummock Grassland with *A. eremophila* var. Numerous-nerved variant (CPHG Ae) | | ✓ | |
| CPHG with *A. helmsii* (CPHG Ah) | | | ✓ |
| CPHG with *M. eleuterostachya* (CPHG Me) | | ✓ | × |
| Claypan Grassland (CPN-G) | | | ✓ |
| Claypan Playa (CPP) | | | ✓ |
| *E. duttonii* Shrubland (EdS) | ✓ | | |
| Mulga Grove (GRMU) | | | ✓ |
| Hardpan Mulga Woodland (HPMW) | | | ✓ |
| Hardpan Mulga Woodland Drainage (HPMWD) | | | ✓ |
| Low Mallee Woodland (LMW) | | | ✓ |
| Complex of LMW and CPHG | | | ✓ |
| Complex of LMW and MgAkS | | ✓ | |
| Complex of LMW and SAWS | | | ✓ |
| *M. glomerata* Shrubland with *A. kempeana* (MgAkS) | | | ✓ |
| Complex of MgAkS and HPMW | | ✓ | |
| Sandplain Mulga Woodland (SAMU) | | | ✓ |
| Sandplain Spinifex (SASP) | | | ✓ |
| Sandplains with Wattles other than Mulga over Spinifex (SAWS) | | | ✓ |
| Complex of SAWS and CPHG | | ✓ | |
| Sand Dune *A. Grevillea* shrubland (SDAGS) | | | ✓ |
| Complex of SDAGS and AmmS | | | ✓ |
| Stony Mulga Shrubland (SMS) | | | ✓ |
| Senna Shrubland (SS) | | | ✓ |
| **Total** (33 in total) | **1** | **7** | **25** |

Notes: Associations that occur only outside the numerical model domain are omitted from this table

Table 6 presents the potential GDEs within the Project area that have the potential to be affected by WAAs (development activities) and whether Priority listed plant species might occur within the ecosystems, noting the following:

- For the vegetation associations demonstrating potential facultative groundwater dependence
  - All have been identified from the literature as possible groundwater users (see Section 3.4.1)
  -
  - The dominant vegetation species occurring within these associations likely achieve their EWRs by primarily accessing the soil water reservoir, or by accessing both the soil water reservoir and the water table where it is accessible
- For the single vegetation association (*Eremophila duttonii* Shrubland) that demonstrates potential obligate groundwater dependence
  - Reference to *E. duttonii* in the available literature is absent (see Section 3.4.1)
  - No priority listed plant species identified within this vegetation association
  - The dominant vegetation species occurring within this association likely achieve their EWRs by accessing both soil water and the groundwater (at least seasonally)

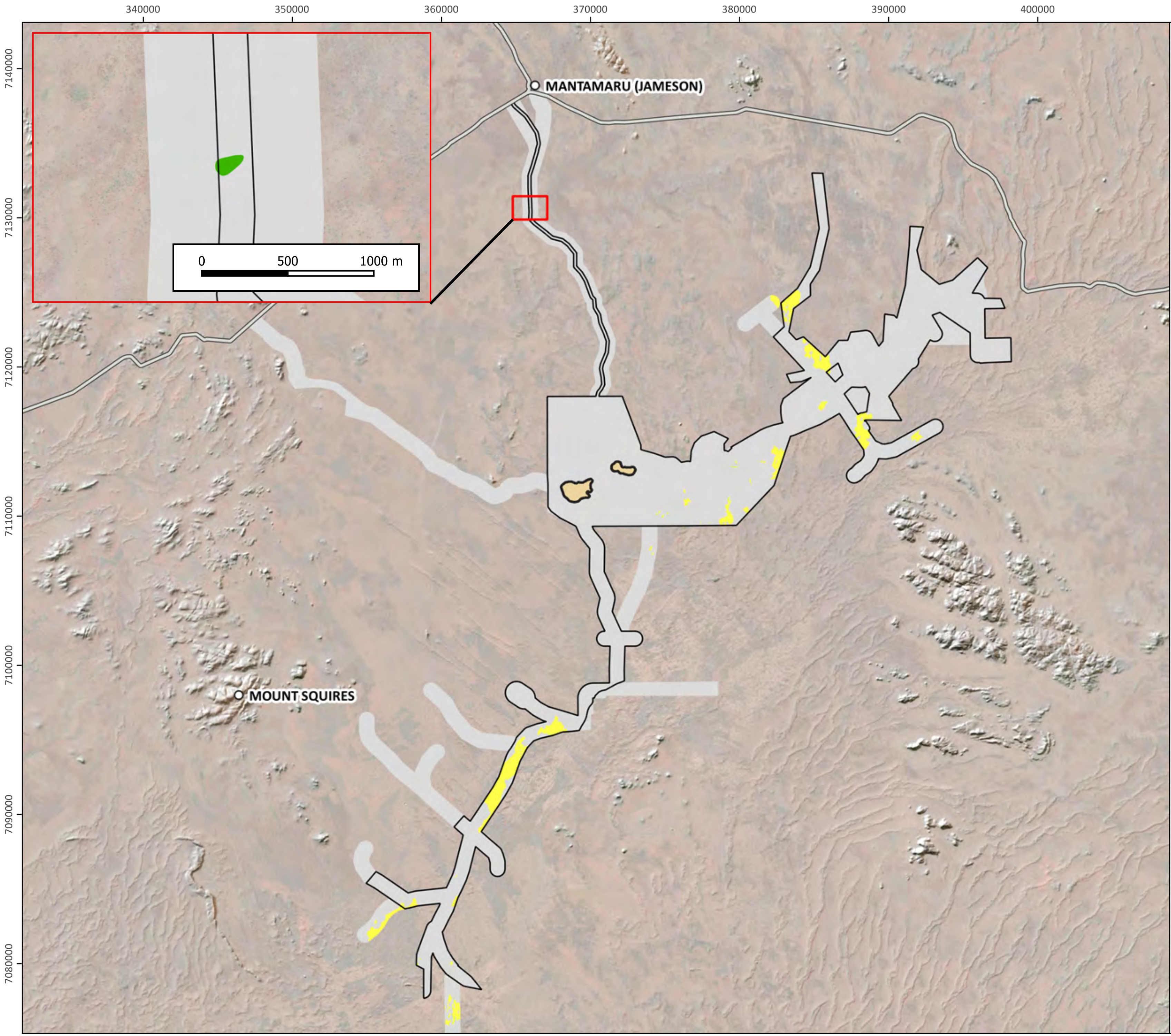
**Table 6 Potential terrestrial GDEs**

| Vegetation association | Likely form of dependence |
|---|---|
| *Eremophila duttoni* Shrubland (Eds) | Obligate |
| Complex of *A. kempeana* Shrubland (AkS) and Hardpan Mulga Woodland (HPMW) | Facultative |
| Calcrete *C. opaca* Woodland (CCoW) | |
| Calcrete Platform Hummock Grassland with *A. eremophila* (CPHG Ae) | |
| Calcrete Platform Hummock Grassland with *M. eleuterostachya* (CPHG Me) | |
| Complex of Low Mallee Woodland (LMW) and *M. glomerata* Shrubland with *A. kempeana* (MgAkS) | |
| Complex of *M. glomerata* Shrubland with *A. kempeana* (MgAkS) and Hardpan Mulga Woodland (HPMW) | |
| Complex of Sandplains with Wattles other than Mulga over Spinifex (SAWS) and Calcrete Platform Hummock Grassland (CPHG) | |

Notes: 1. Refer to Western Botanical (2020), Table 14
2. Priority 3 only, where identified
☒ Priority species absent
☑ One or more priority species present

25 of the 33 surveyed vegetation associations (i.e. within the groundwater model domain) are classified as probably vadophytic, predominantly achieving their EWRs by accessing the soil water reservoir. However, use of groundwater in areas where it is very shallow cannot be completely discounted.

Figure 20 presents the spatial distribution of the type of terrestrial vegetation groundwater dependence based on the qualitative analysis presented in Table 4 and in the above discussion. The figure shows the development envelope (and by association the broader Project area landscape) is dominated by vadophytic vegetation associations (i.e. ecosystems that will be relatively insensitive to altered groundwater condition), whereas vegetation associations having either a facultative or obligate dependence on groundwater cover a small portion of the development envelope.




# Figure 20

## Qualification of terrestrial vegetation groundwater dependence based on distribution across landscape

Road
Proposed mine pit
Development envelope

**Vegetation association groundwater dependence**

Obligate GDE
Facultative GDE
Vadophytic GDE

DATA SOURCES
Cassini Resources, 2018
OZ Minerals, 2019
Western Botanical, 2020

DISCLAIMER
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Drawn: ETEROVICZ
Map Projection: GDA2020 / MGA Zone 52

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# Section 4 Conclusions

### 4.1.1 Overview

The following observations support the preliminary identification of potential GDEs in the Project area:

- The Project area occurs within an arid climate zone where evaporation rates greatly exceed rainfall rates in every month of the average year
- Depths to water table are relatively shallow over much of the Project area (typically between 3 and 8 m bgl), meaning the PAWC for supporting larger vegetation species may be limited and sometimes insufficient to meet EWRs during prolonged drought periods, for example
- Rockholes that occur within the Project area appear to be formed above the water table, meaning there is little to no potential for interaction with groundwater or for Type 2 GDEs to occur in the landscape

A staged approach has been used to identify the presence of potential GDEs within and surrounding the Project area that may be affected by mining related activities.

### 4.1.2 Stage 1 assessment

Stage 1 of the assessment involved preliminary identification of potential GDEs via interrogation of the national scale GDE Atlas as well as local scale field surveys and indicated:

- Type 1 GDEs – Stygofauna ecosystems are present, with more apparent diversity in the area of the proposed mine pits compared to the borefield investigation areas
- Type 2 GDEs – Aquatic ecosystems (springs and wetlands) are not present in the landscape including rockholes, which, whilst occurring within the development envelope, are not reliant on groundwater
- Type 3 GDEs
  - Terrestrial ecosystems (vegetation) may be widely occurring in the Project area but, as noted in Section 2.4, none of the plant species that might be reliant on groundwater are Threatened Flora
  - Riparian ecosystems (vegetation) are not present in the Project area

### 4.1.3 Stage 2 assessment

Stage 2 of the assessment involved analysis and interpretation of available data to develop conceptualisations of the interactions between potential GDEs and groundwater. Key outcomes of the Stage 2 of the assessment are as follows:

- Type 1 GDEs – Stygofauna ecosystems
  - 30 species of stygofauna identified from 63 locations across the Project area
  - The presence of stygofauna inherently indicates groundwater use
  - Stygofauna habitat comprises saturated palaeovalley sediments and fractured basement
- Type 3 GDEs- Terrestrial ecosystems
  - Groundwater use by vegetation is potentially widespread across the Project area

### 4.1.4 Stage 3 assessment

Stage 3 of the assessment involved qualification of the capacity of potential GDEs identified in Stage 2 to resist altered groundwater condition whilst maintaining their EWRs, based on their presence in the landscape. Key outcomes of the qualification undertaken in Stage 3 of the assessment are as follows:

- Type 1 GDEs – Stygofauna ecosystems
  - Groundwater dependence is obligate, however stygofauna ecosystems have some tolerance or resistance to change in groundwater conditions owing to their capacity to move within an aquifer
  - Maintenance of a portion of habitat will be important in providing the ecosystem the opportunity to resist a change in groundwater condition and recover once mine WAA cease
- Type 3 GDEs- Terrestrial ecosystems
  - The spatial extent of vegetation associations that are considered likely to have some form of groundwater dependence is much less than those vegetation associations considered to be vadophytic (eight compared to 25 of the 33 associations occurring within the groundwater model domain)
  - One vegetation association (*E. duttoni* Shrubland), which is located at the northern end of the Jameson-WMP access road, is classified as probably being an obligate GDE, i.e. access to groundwater defines the ecosystem's presence in the landscape
  - Seven vegetation associations are classified as probably being facultative GDEs, i.e. access to groundwater does not necessarily define their presence in the landscape (Calcrete *C. opaca* Woodland, Calcrete Platform Hummock Grassland *A. eremophila* variant, Calcrete Platform Hummock Grassland *M. eleuterostachya* variant, Complex of Low Mallee Woodland and *M. glomerata A. kempeana* Shrubland, Complex of *M. glomerata A. kempeana* Shrubland and Hard pan Mulga Woodland, Complex of Sand plains with Wattles other than Mulga over Spinifex and Calcrete Platform Hummock Grassland, Complex of A. kempeana Shrubland and Hard pan Mulga Woodland)

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# Attachment A Literature review

## Summary of literature review: groundwater use by dominant species identified within the survey area

| Species | Possible groundwater use yes/no | Summary of literature review | References |
|---|---|---|---|
| *Acacia abrupta* | unlikely | Unlikely to be a groundwater user. | Pers comms, A. Duguid, Jan 2019 |
| *Acacia aneura* | unlikely | Mulga have shallow root system and routinely measure water potentials <-10MPa in arid areas, indicating severe water deficit and therefore little or no access to groundwater (Slatyer 1965, Pressland 1975).<br>Can extract water from very dry soils and is able to maintain very low rates of water use during extended drought to survive (Page & Grierson, 2010, as cited by RPS, 2015).<br>Typically known to be shallow rooted rainfall harvesters (Western Botanical, 2020). | Page, 2013 (Thesis)<br>RPS, 2015<br>Western Botanical (2020) |
| ***Acacia aptaneura*[1]** | **possible** | Identified as part of a potential GDE and is located where the water table generally <10 m bgl, but no evidence is provided to justify why it is considered a GDE.<br>Soil and leaf water potential data indicates water extraction to 8m depth (Cook and Eamus, 2018) indicating this species opportunistically uses groundwater where the water table is at or shallower than this depth, although it is typically reliant on soil moisture.<br>Typically known to be shallow rooted rainfall harvesters (Western Botanical, 2020). | Gold Road Resources Limited, 2016<br>Cook and Eamus, 2018<br>Western Botanical (2020) |
| *Acacia ayersiana* | unlikely | Unlikely to be a groundwater user.<br>Typically known to be shallow rooted rainfall harvesters (Western Botanical, 2020). | Pers comms, A. Duguid, Jan 2019<br>Western Botanical (2020) |
| *Acacia ayersiana (narrow phyllode variant)* | unlikely | Unlikely to be a groundwater user. | Pers comms, A. Duguid, Jan 2019 |
| *Acacia brachystachya* | unlikely | Unlikely to be a groundwater user. | Pers comms, A. Duguid, Jan 2019 |
| *Acacia cuthbertsonii* | unlikely | Unlikely to be a groundwater user. | Pers comms, A. Duguid, Jan 2019 |
| *Acacia eremophila var.* | unlikely | Unlikely to be a groundwater user. | Pers comms, A. Duguid, Jan 2019 |
| *Acacia kempeana* | unlikely | Unlikely to be a groundwater user. | Pers comms, A. Duguid, Jan 2019 |
| *Acacia ligulata* | unknown | Typically a riparian/floodplain species that 'responds to wet conditions'. Prefer lake edges, sandy soils. | DEWNR, 2015 |
| ***Acacia maitlandii*** | **yes** | Soil and leaf water potential data indicates water extraction to at least 6.5m. | Cook and Eamus, 2018 |
| ***Acacia melleodora*** | **yes** | Soil and leaf water potential data indicates water extraction to 12m depth . | Cook and Eamus, 2018 |
| *Acacia pachyacra* | unlikely | Unlikely to be a groundwater user. | Pers comms, A. Duguid, Jan 2019 |
| *Acacia prainii* | unknown | | |
| ***Acacia pruinocarpa*** | **possible** | Possible facultative (opportunistic) groundwater user. | Pers comms, A. Duguid, Jan 2019 |
| *Acacia pteraneura* | unlikely | Unlikely to be a groundwater user. | Pers comms, A. Duguid, Jan 2019 |
| *Acacia rhodophloia* | unlikely | Unlikely to be a groundwater user. | Pers comms, A. Duguid, Jan 2020 |
| *Acacia sericophylla* | unlikely | Unlikely to be a groundwater user. | Pers comms, A. Duguid, Jan 2019 |
| ***Acacia tetragonophylla*** | **possible** | Conflicting information:<br>Identified as part of a potential GDE and is located where the water table generally <10 m bgl, but no evidence is provided to justify why it is considered a GDE.<br>Unlikely to use groundwater (DEWNR, 2017) | Gold Road Resources Limited, 2016<br>DEWNR, 2017 |

| Species | Possible groundwater use yes/no | Summary of literature review | References |
|---|---|---|---|
| *Acacia victoriae* subsp. *victoriae* | unlikely | Unlikely to be a groundwater user. | Pers comms, A. Duguid, Jan 2019 |
| *Acacia walkeri* | unlikely | Unlikely to be a groundwater user. | Pers comms, A. Duguid, Jan 2019 |
| *Allocasuarina helmsii* | unknown | | |
| *Aluta maisonneuvei* subsp. *maisonneuvei* | unknown | Typical habitat- sand dunes, sandplains, high rocky sites | Western Australian Herbarium (1998–) |
| *Aristida latifolia* | unknown | | |
| ***Corymbia opaca*** | **yes** | Can access groundwater where water table depths are 8-12m and up to 20m in some cases.<br>Listed as a species that have been shown to access groundwater (Doody et al, 2018). | Cook and Eamus, 2018, GHD, 2017 (for Arafura Resources Limited)<br>Doody et al, 2018 |
| *Dodonaea viscosa* subsp. *angustissimus* | unknown | | |
| *Eremophila duttonii* | unknown | | |
| *Eremophila forrestii* | unknown | | |
| *Eremophila hughesii* subsp. *hughesii* | unknown | | |
| *Eremophila latrobei* subsp. *Glabra* | unknown | | |
| *Eremophila longifolia* | unknown | | |
| *Eremophila serrulata* | unknown | Typical habitat- red sand, sandy clay loam, gravelly soils; along creek lines, granite outcrops, hardpan flats. | Western Australian Herbarium (1998–) |
| ***Eucalyptus gamophylla*** | **possible** | Conflicting information:<br>Listed as a xerophytic species, representing no groundwater reliance (BHP, 2015).<br>Known to access deep groundwater (Western Botanical, 2020). | BHP, 2015<br>Western Botanical, 2020 |
| ***Eucalyptus intertexta*** | **yes** | Listed as a species that have been shown to access groundwater (Doody et al., 2018)<br>Known to access deep groundwater (Western Botanical, 2020) | Doody et al, 2018<br>Western Botanical, 2020 |
| ***Eucalyptus oxymitra*** | **yes** | Known to access deep groundwater (Western Botanical, 2020) | Western Botanical, 2020 |
| *Grevillea eriostachya* | unknown | Typical habitat- yellow or red sand, occasionally white or grey sand; sandhills, red sand dunes, sandplains. | Western Australian Herbarium (1998–) |
| *Grevillea juncifolia* subsp. *juncifolia* | unknown | Typical habitat- red or yellow sand, sandhills, flats. | Western Australian Herbarium (1998–) |
| *Grevillea stenobotrya* | unknown | Typical habitat- red sand; sand dunes | Western Australian Herbarium (1998–) |
| ***Hakea lorea subsp. Lorea*** | **yes** | Soil and leaf water potential data indicates water extraction to 5m. | Cook and Eamus, 2018 |

| Species | Possible groundwater use yes/no | Summary of literature review | References |
|---|---|---|---|
| *Hannafordia bissillii* subsp. *bissillii* | unknown | Typical habitat- red sand | Western Australian Herbarium (1998–) |
| *Melaleuca eleuterostachya* | unknown | Typical habitat- sandy or clayey soils, often over limestone; plains, low hills, moist depressions. | Western Australian Herbarium (1998–) |
| ***Melaleuca glomerata*** | **yes** | Opportunistic groundwater user.<br>Listed as a species that have been shown to access groundwater (Doody et al, 2018).<br>Typical habitat- red sand, clay, sandy loam; rocky river beds, shallow depressions, sandy flats.<br>Known to access deep water (Western Botanical, 2020) | Pers comms, A. Duguid, Jan 2019<br>Doody et al, 2018<br>Western Australian Herbarium (1998–)<br>Western Botanical, 2020 |
| *Rhagodia eremaea* | unknown | Typical habitat- sand, clayey or sandy loam, often stony soils, rocky hillsides, coastal areas over limestone, along rivers & creeks. | Western Australian Herbarium (1998–) |
| *Rhagodia drummondii* | unknown | | |
| *Senna artemisioides* subsp. *Artemisioides* | unknown | Variety of habitats. | Western Australian Herbarium (1998–) |
| *Senna artemisioides* subsp. *helmsii* | unknown | Variety of habitats. | Western Australian Herbarium (1998–) |
| *Teucrium teucriiflorum* | unknown | | |
| *Triodia schinzii* | unknown | Typical habitat- red sandy soils, sandplains, red sand dunes. | Western Australian Herbarium (1998–) |

Notes:

1. *Acacia aptaneura* previously called *Acacia aneura*

# Attachment B Supporting analysis for the identification of Type 3 GDEs

## Flowpath water quality trends

If groundwater is being widely used by vegetation across the Project area, it would be expected that the salinity of the groundwater along a regional flowpath would increase (i.e. reducing the volume of water but leaving the majority of salts has a concentration effect on the groundwater salinity). Groundwater generally flows in a south to southwestward direction (Figure B1) and so the northing of each groundwater salinity sample can be used to approximate the distance along a flowpath. Figure B2 shows that Flowpath A has an increasing salinity towards the south at a rate of approximately 50 µS/cm/km (i.e. approximately 2500 µS/cm over 50 km). A similar increasing trend is found using Chloride with a trend of approximately 30 mg/L/km along Flowpath A. This increase along the groundwater flowpath suggests that either evaporation or evapotranspiration is occurring (assuming water-rock interaction does not account for this much salinity increase and recharge conditions are relatively uniform across the Project area).

This relatively simple analysis could be strengthened using stable water isotope ratios of groundwater along the flowpath to support more definitive conclusions. If the increasing salinity and Chloride is caused partially or primarily from groundwater use by vegetation (i.e. GDEs), it would be expected that the water isotope ratios would remain relatively constant along the flowpath, while Chloride and/or salinity increases. This data is not available for the Project area.

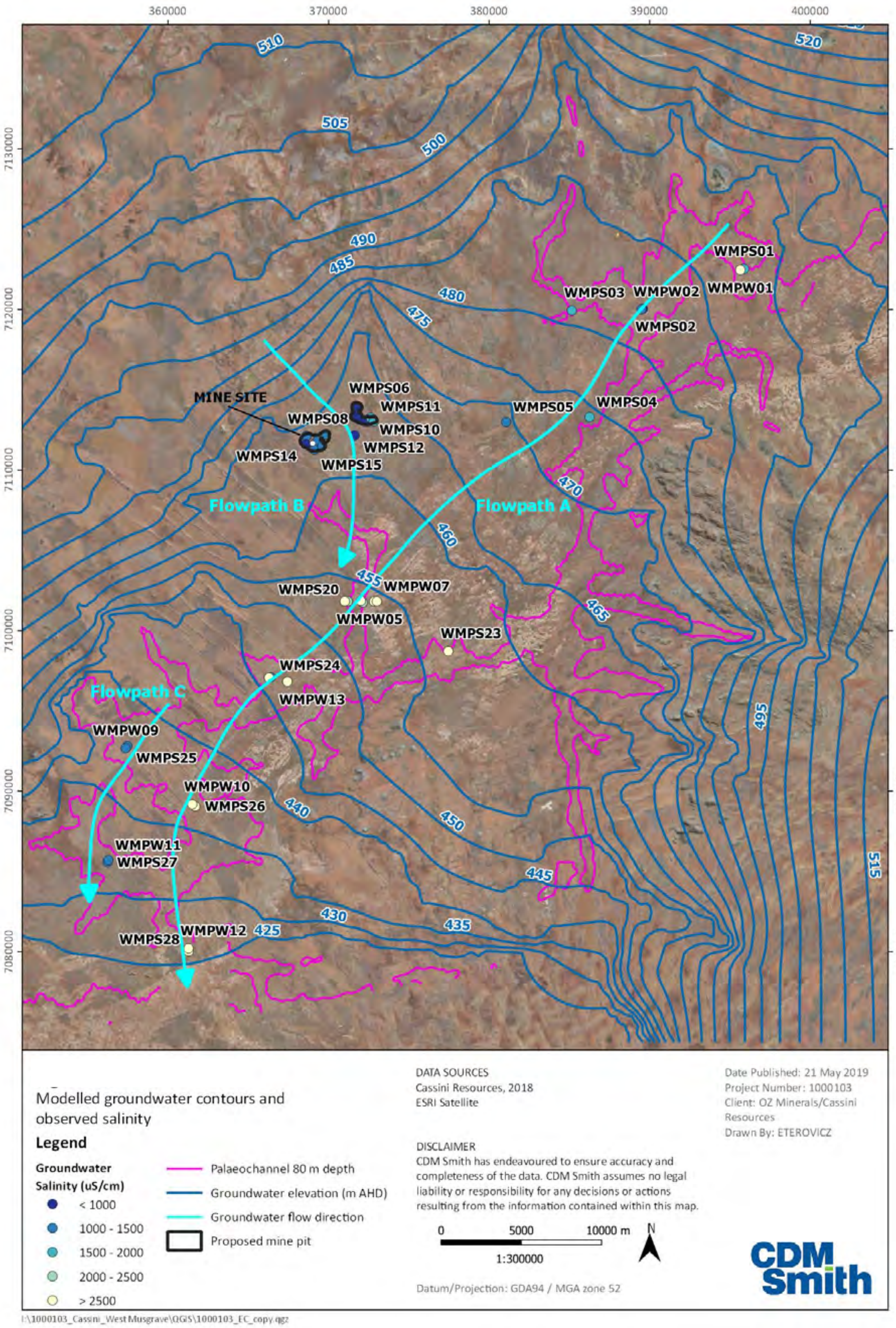


**Figure B1** **Distribution of groundwater salinity and modelled groundwater contours**

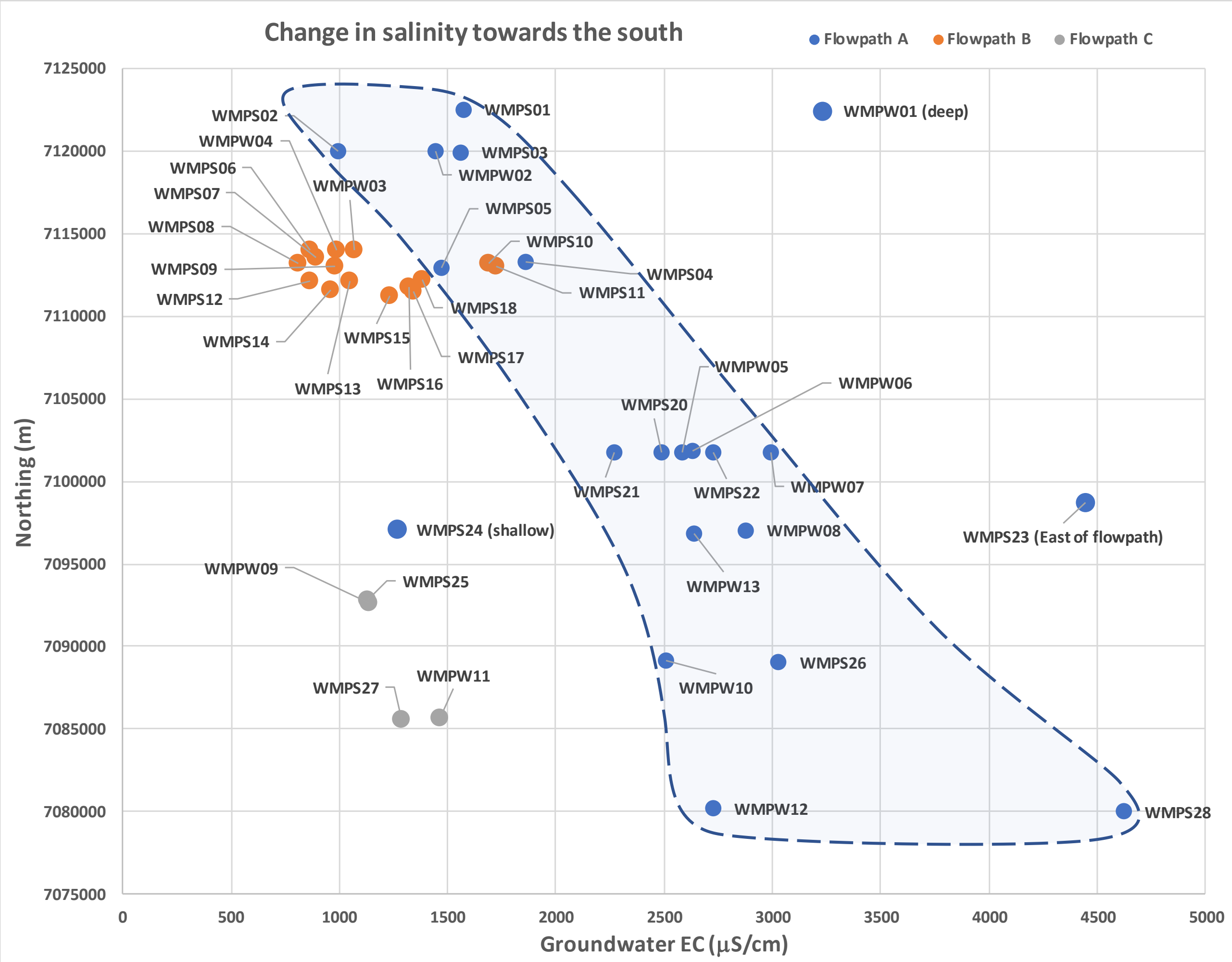


**Figure B2 Change in groundwater salinity towards the south**

## Analysis of VegMachine green fractional cover

The temporal nature of likely groundwater reliance by potential Type 3 GDEs is not well understood given the lack of timeseries groundwater head data associated with the Project.

VegMachine, a web-based tool that summarises the long-term spatial and temporal changes in land cover using satellite imagery, has been used to assist in identifying plant water use and the temporal nature of use. The data is sourced from Landsat image archive, which has been processed from 1988 – 2018 by the Queensland Department of Science, Information Technology and Innovation. A range of processed datasets are available, including fractional cover that is broken into three categories; green, non-green and bare. The green fractional cover represents greenness due to vegetation and can be used to infer actively transpiring vegetation and potentially groundwater use in some cases. For example, if a landscape is consistently green during extended periods of low rainfall where soil moisture is assumed to be insufficient for plant water demand. This would be observed over time as an elevated minimum green fractional that is consistently higher than other parts of the landscape.

Fourteen polygons of approximately 100x100 m area (1 Ha) were created using VegMachine covering a representative selection of the vegetation communities found in the Project area. Where possible these were linked with known depth to water and additional areas were also selected for relative comparisons where minimal or no vegetation was observed in satellite imagery (see Figure B3 for locations). The fractional cover data was extracted and processed in MS Excel. The timeseries green fractional cover is shown in Figure B4 and details of each polygon are summarised in Table B1. This table also shows a median green fractional cover ranking for three periods selected to align with the data sources from different satellites and/or the entire processed data record (i.e. LANDSAT-7 from April 1999 onwards and replaced by LANDSAT-8 in February 2013). It is assumed that the pixel configuration is constant over time and so results would be most consistent inclusive of these periods.

As expected, the vegetation communities within each of the polygons show a responsiveness in green fractional cover to rainfall with the newly available soil moisture. This responsiveness is likely due to the emergence of short-lived grasses in combination with enhanced growth periods of larger shrub and tree species. The increasing magnitude of monthly rainfall is correlated with an increased green fractional cover and there appears to be a threshold value between 30 and 50 mm/month (Figure B5) prior to considerable increases in green fractional cover for each vegetation community. A responsiveness to rainfall is also evident for the calcrete and outcrop areas, reflecting the ability of the vegetation types present in these locations to opportunistically utilise rainfall even in the apparent poor – absent soils.

Box and whisker plots for selected time periods show the variability of green fractional cover for each representative polygon (Figure B6, B7 and B8for 2013–2018, 2000–2012 and 1988–2018 time periods respectively) as a measure of variability in green fractional cover. These figures show the median as the middle line of each green box, which has upper and lower bounds of the 75$^{th}$ and 25$^{th}$ percentiles with the maximum and minimum values shown as the upper and lower error bars respectively. The vegetation communities are ordered based on their median value from left to right. The 2013–2018 period for example, shows the largest median green fractional cover is generally found in low Mallee woodland and Melaleuca shrubland polygons with the lowest median green fractional cover found in the calcrete hummock grasslands and outcrop polygons. The differences between the polygons with lower and higher green fractional cover can be accounted for by the vegetation community present that presumably has greater access to water (assuming this is the primary limiting factor in most cases – there may be others such as soil properties or limiting nutrients).

The persistence of green fractional cover from a relatively wet period through to a relatively dry period can give an indication of whether or not rainfall and shallow soil moisture is a limiting factor to greenness. Theoretically, a GDE would respond to rainfall and then show a decline in green fractional cover as soil stores are exhausted, while critically, also maintaining a higher green fractional cover compared to vegetation without access to groundwater.

To investigate the degree of this occurrence, the green fractional cover values from 2012 are directly compared with the values from 2015. These years are preceded by two above average and two below average rainfall years respectively, and the green fractional cover for the months of January, April, July and October are directly compared in Figure B9. The average of the four months is shown in the figure with error bars representing the variation. If the vegetation communities had similar access to water, the green fractional cover should be similar between years and the data should fall along the 1:1 line. However, the majority of vegetation communities are above this line showing that the green fractional cover has declined during the drying period. The largest declines are recorded for LMW_CPHG_WMPS26, SAWS_WMPS25, Deep_WT, LMW_SAWS_WMPS24 with average differences of 6, 5.7, 4.7 and 4 % green fractional cover respectively. These maintain an average median green cover fraction of > 12 % with the exception of LMW_CPHG_WMPS26. This suggests that this vegetation community in this particular polygon may have a less reliable water source.

It is important to note that this remote sensing approach may contain significant error due to the sparse nature of the vegetation in these landscapes. For example, in the LMW_CPHG_WMPS26 polygon there is one significant tree, around 23 low-lying shrubs and around a third of the ~100x100 m area is covered with hummock grasses (inferred from the May 2019 ESRI composite image). How the greenness of this vegetation is captured and represented by the 30x30 m LANDSAT pixels should be considered indicative given the sparsity of the cover. Specific plant water requirements and water sources can only be determined with a higher degree of confidence in this landscape, through site specific field investigations.

Additionally, the depth to groundwater may be a relevant factor in likelihood of specific vegetation types being able to access this as a source of water (provided it is of sufficient quality). The median green fractional cover of the selected representative polygons are compared with depth to groundwater in Figure B10. There is no clear relationship evident from this information and it is likely that the depth to groundwater (being so shallow across this site) is not a limiting factor for vegetation to access this water source. For example, SAWS_WMPS25 has a relatively high median green fractional cover and the deepest depth to groundwater (14.5 m bgl).

The assessment using VegMachine is unable to definitively identify GDEs in the landscape with a high degree of confidence. However, the relative likelihood of each selected representative polygon containing a GDE has been determined semi-quantitatively. This is based on the median green fractional cover for the period from 2012–2018 with thresholds of 10 and 15 %. Polygons with a median of < 10%, 10–15 % and > 15% were considered to have a low, moderate and high likelihood of containing GDEs respectively. This is considered to be a conservative approach and assumes that differences in the relatively low green fractional cover, are due to the presence or absence of sparsely distributed individual trees and/or shrubs that are able to access groundwater. To improve the confidence that can be placed on this categorisation, site specific field investigations would be required. This may involve the timeseries measurement of individual plant water use and both plant and water isotopic sampling in combination with depth profiles of soil moisture and hydrochemistry.

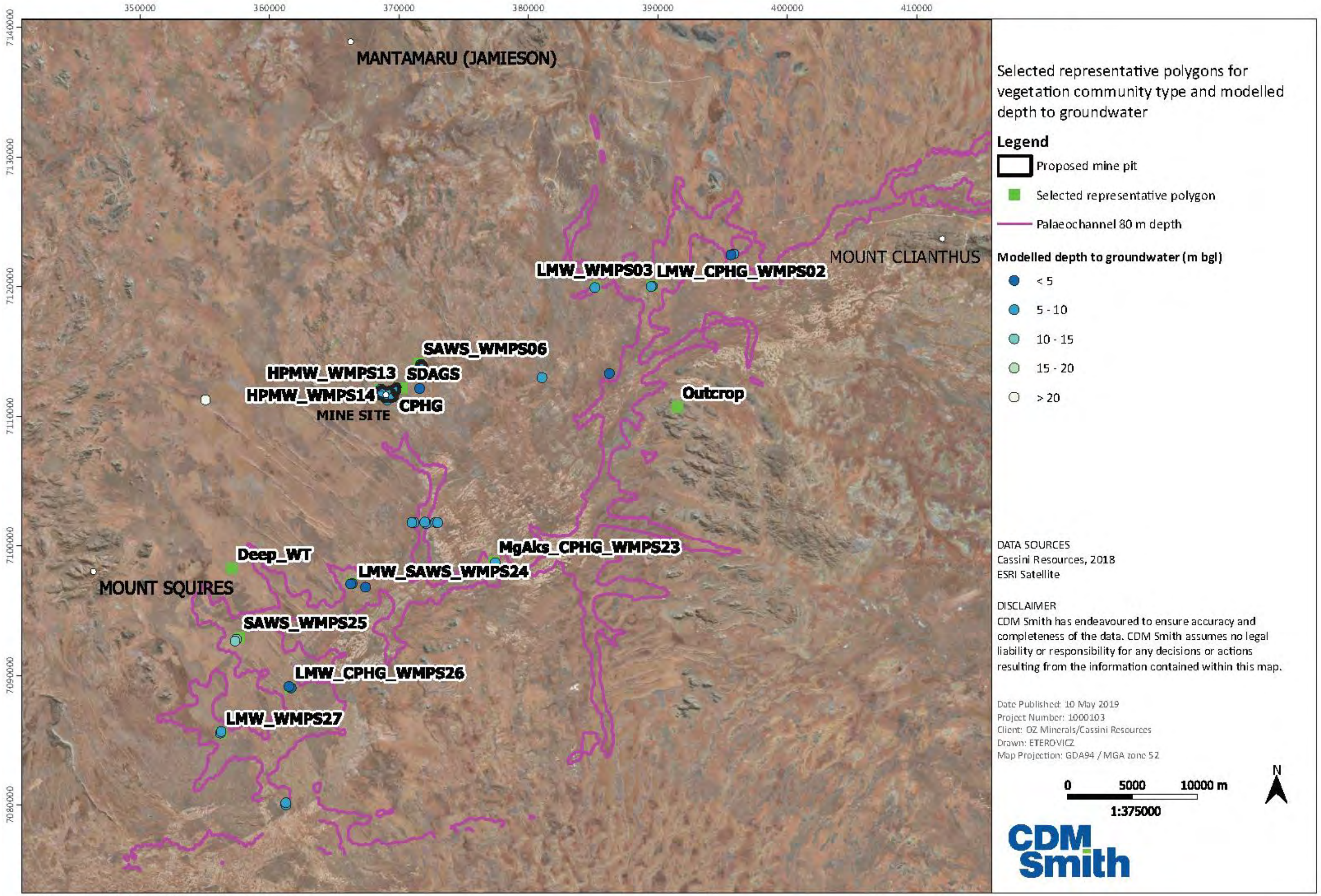


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**Figure B3 Location of representative polygons across the study area**

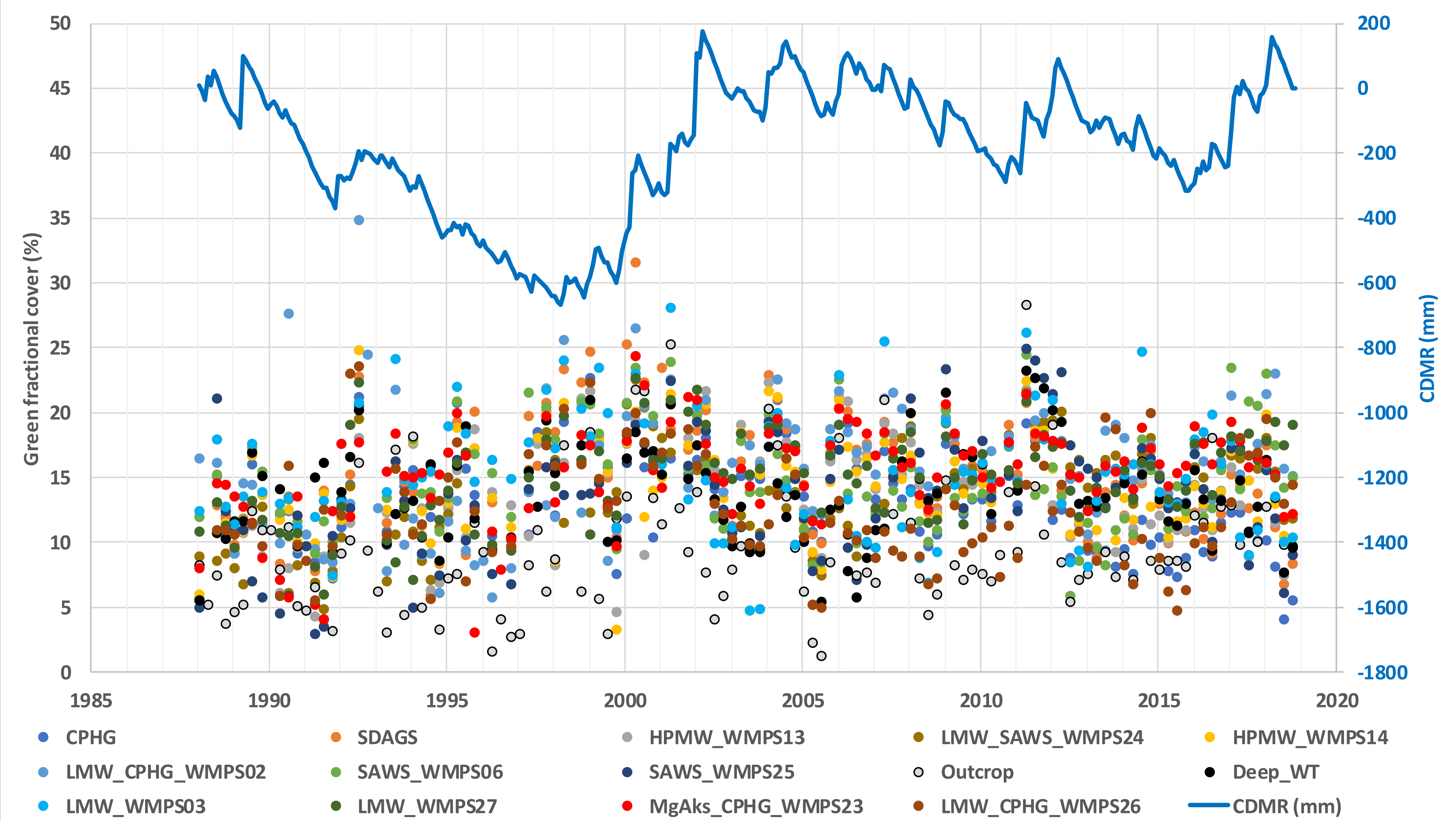


**Figure B4** **Time-series plot of green fractional cover for representative polygons**

**Table B1 Representative polygon details and ranking based on median green cover fraction**

| Location | Vegetation community | Identified potential GDE level[1] | 1988-2018 (median and relative rank) | 1999-2012 (median and relative rank) | 2013-2018 (median and relative rank) | Depth to water (m bgl) |
|---|---|---|---|---|---|---|
| LMW_CPHG_WMPS02 | Low mallee woodland and hummock grassland | Level 1 | 15.8 (1) | 18.1 (1) | 16 (1) | 5.00 |
| LMW_WMPS27 | Low mallee woodland | Level 1 | 15.2 (3) | 16.3 (4) | 16 (2) | 8.22 |
| MgAks_CPHG_WMPS23 | Melaleuca shrubland and calcrete with hummock grassland | Level 1 | 15.7 (2) | 17 (2) | 15.9 (3) | 6.39 |
| LMW_SAWS_WMPS24 | Low mallee woodland and sandplains with non-mulga acacias | Level 1 | 13.9 (8) | 14.6 (10) | 15.1 (4) | 4.10 |
| LMW_WMPS03 | Low mallee woodland | Level 1 | 14.9 (4) | 14.5 (11) | 15 (5) | 6.00 |
| SAWS_WMPS25 | Sandplains with non-mulga acacias | Unlikely | 13.7 (9) | 15.1 (7) | 14.2 (6) | 14.51 |
| SAWS_WMPS06 | Sandplains with non-mulga acacias | Unlikely | 13.9 (7) | 13.8 (12) | 14.1 (7) | 5.50 |
| Deep_WT | Not surveyed | - | 13.7 (10) | 14.9 (8) | 13.3 (8) | 13.3* |
| HPMW_WMPS14 | Hardpan mulga woodland | Level 2 | 14.1 (6) | 15.4 (6) | 12.9 (9) | 5.49 |
| SDAGS | Sand dune acacia – grevillea shrubland | Level 2 | 14.6 (5) | 16.9 (3) | 12.1 (10) | 6.26 |
| HPMW_WMPS13 | Hardpan mulga woodland | Level 2 | 13.7 (11) | 16.2 (5) | 11.2 (11) | 6.02 |
| LMW_CPHG_WMPS26 | Low mallee woodland and hummock grassland | Level 1 | 11.4 (13) | 11.4 (13) | 11.1 (12) | 4.17 |
| Outcrop | Not surveyed | - | 9 (14) | 9.4 (14) | 9.8 (13) | 7.9* |
| CPHG | Calcrete with hummock grassland | Level 2 | 12.3 (12) | 14.7 (9) | 9.3 (14) | 5.49 |

[1] Level 1= Identified in field survey (Western Botanical, 2020); Level 2: Identified through literature review, see Table 3.

*value from modelled depth to water

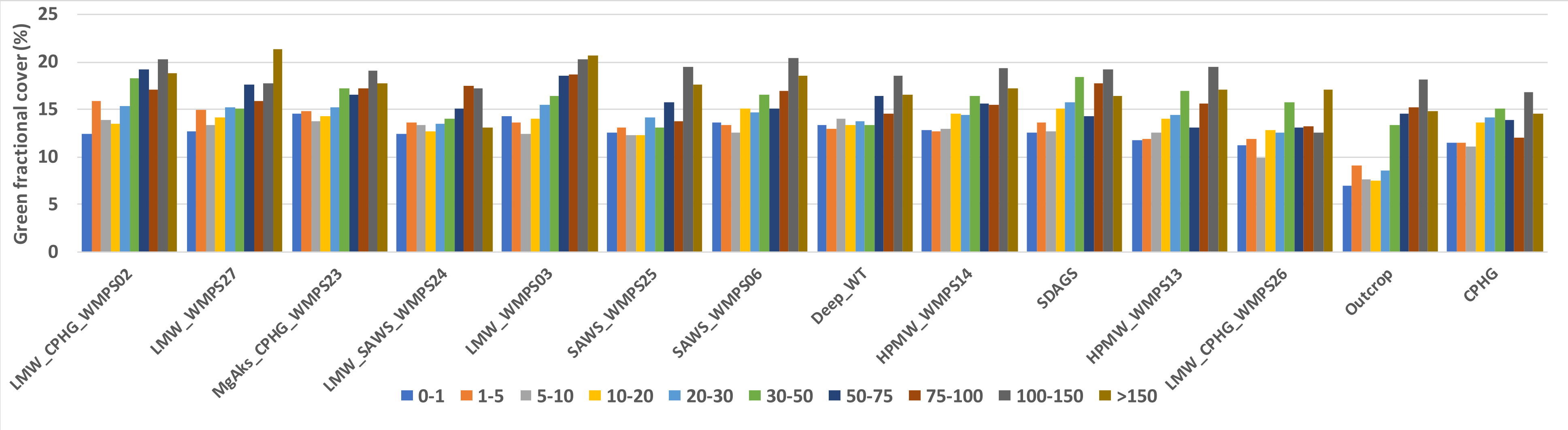


**Figure B5** **Relationship between green fractional cover and monthly rainfall totals (mm/month)**

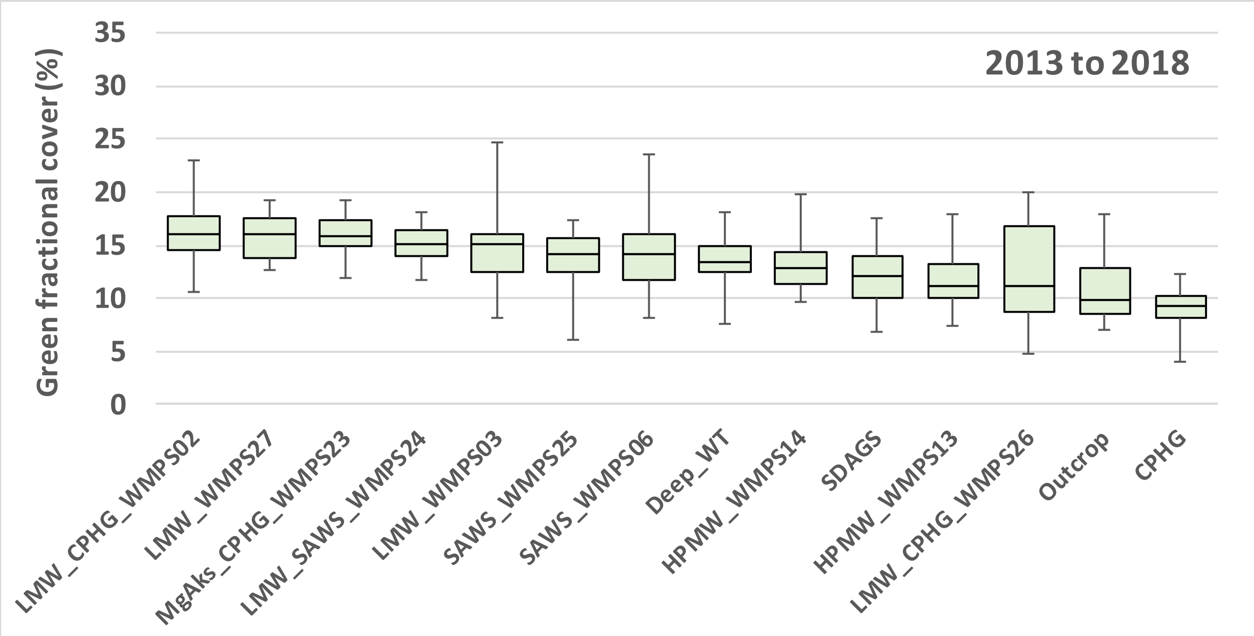


**Figure B6** Box and whisker plot of green fractional cover for representative polygons from 2013–2018

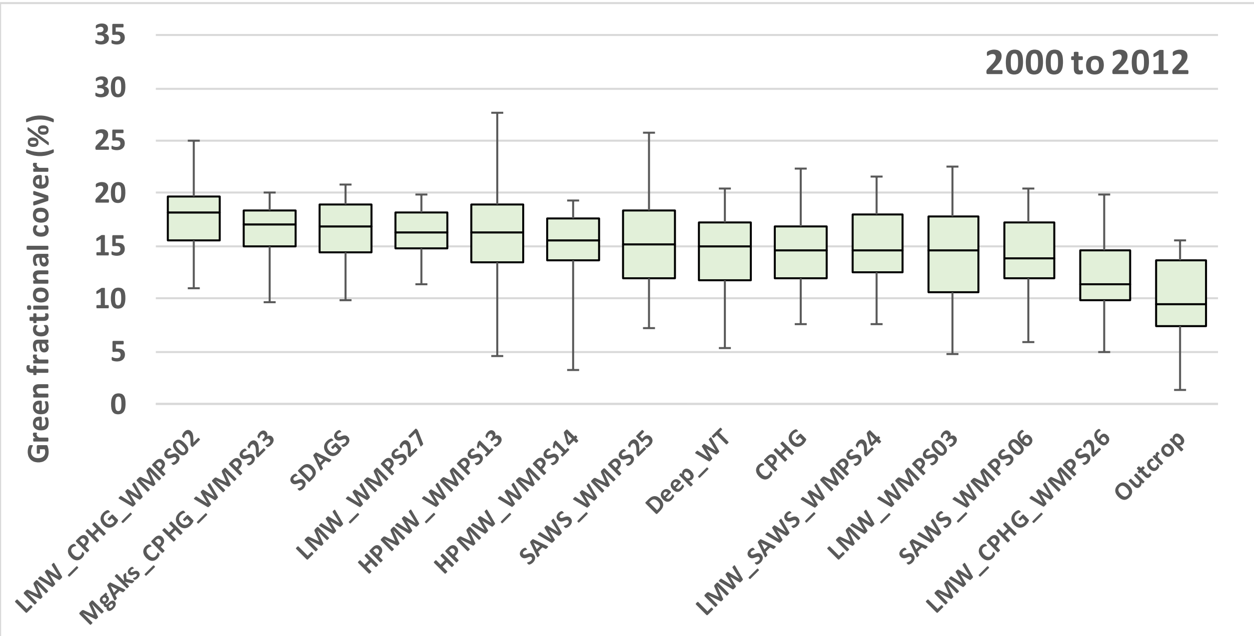


**Figure B7** Box and whisker plot of green fractional cover for representative polygons from 2000–2012

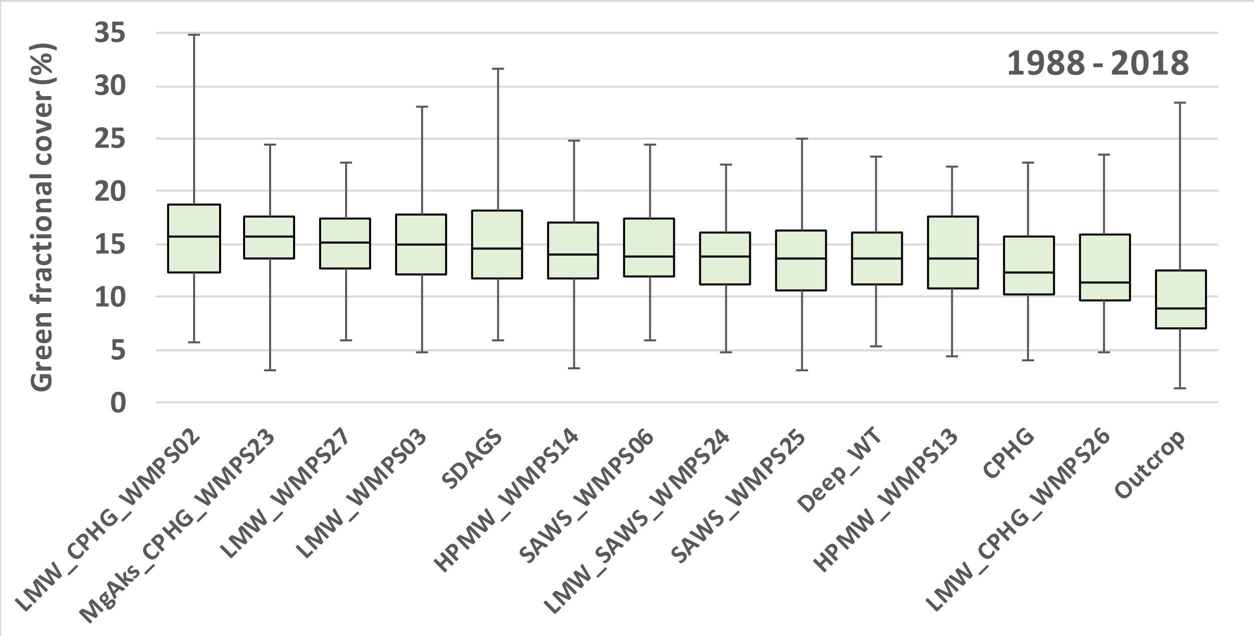


**Figure B8** Box and whisker plot of green fractional cover for representative polygons from 1988–2018

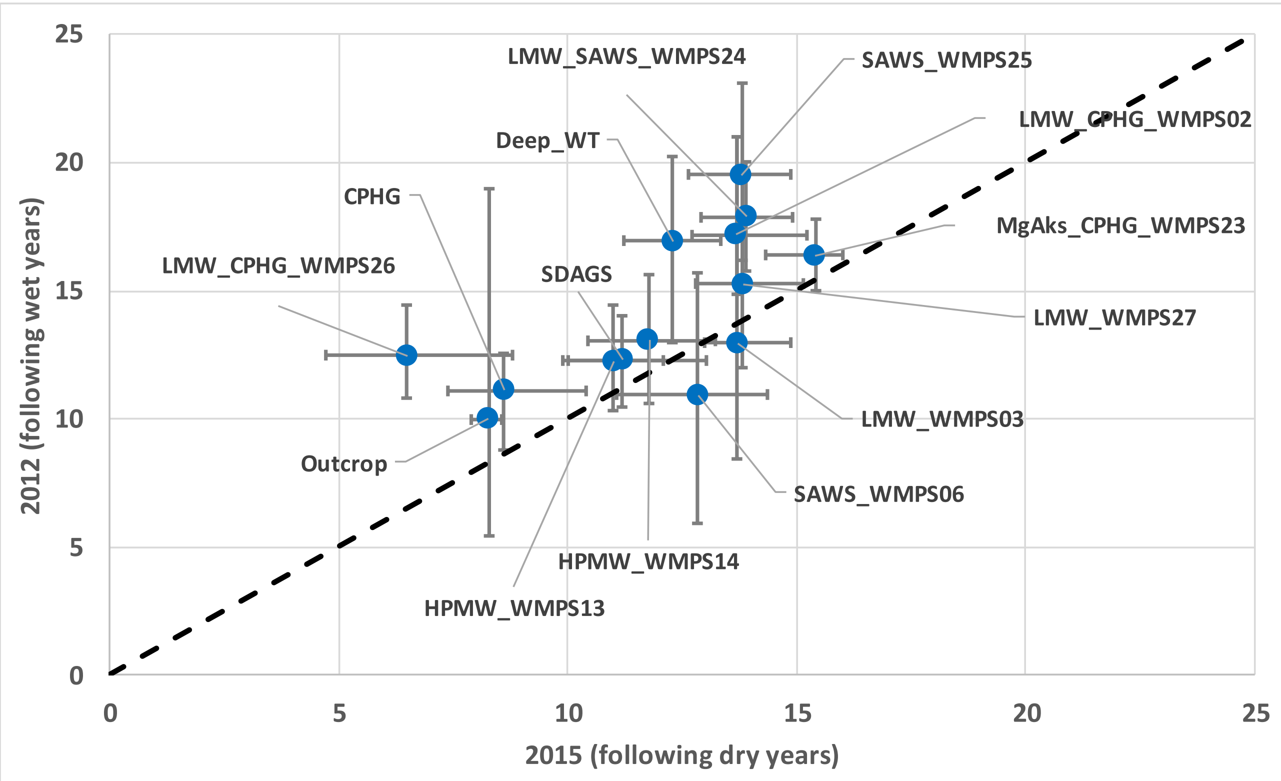


**Figure B9** Green fractional cover comparison between years following wetting and drying conditions

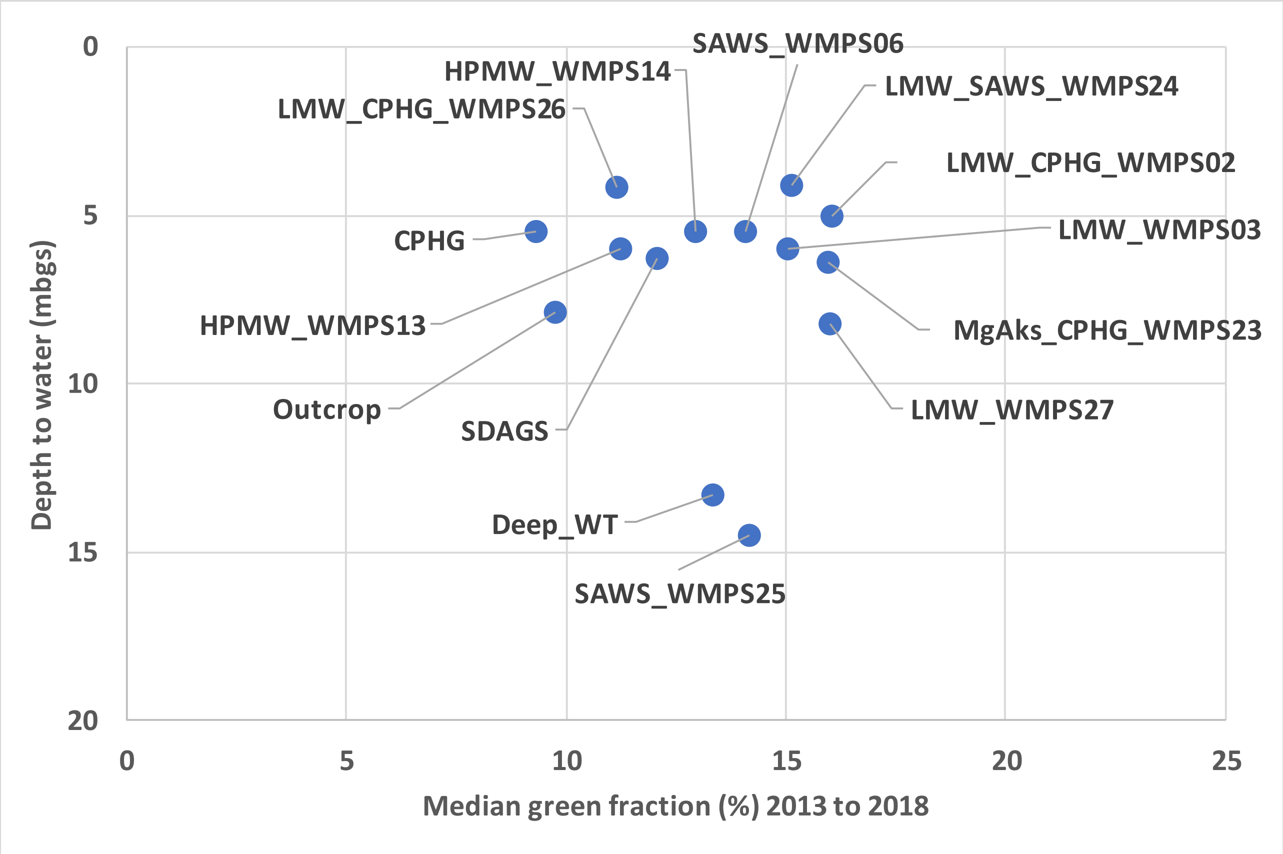


**Figure B10** **Relationship between depth to water and green fractional cover (2013–2018)**

# Addendum 1. Review of GDE Assessment

## Addendum to Appendix B2 – Letter reviewing methods and outcome of Appendix B2

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# Memo

| | | | |
|---|---|---|---|
| **To** | Justin Rowntree | **Company** | Oz Minerals |
| **From** | Duncan Storey / Shane Chalwell | **Job No.** | 314 |
| **Date** | 20/03/2021 | **Doc No.** | 020a |
| **Subject** | Groundwater Dependant Ecosystem Assessment | | |

## 1. BACKGROUND

Oz Minerals (OM) are developing the West Musgrave copper nickel project, in the interior of Western Australia. Prefeasibility studies and environmental approvals have been undertaken and OM are now completing a Definitive Feasibility Study and the environmental management plans that are required to comply with approval conditions. The project area is characterised by shallow groundwater levels and "desert" vegetation; 38 vegetation communities were identified predominantly comprising *Acacia sp* with a *Triodia sp* understorey. In some areas *Melaleuca glomerata* and scattered *Corymbia opaca* also occur within the *Acacia* spp. communities; *M.glomerata* and *C.opaca* have been associated with groundwater dependent ecosystems (GDE) elsewhere. Groundwater modelling has shown that groundwater levels will be drawn-down over parts of the project area, by the combined effects of dewatering and water supply abstraction. One of the environmental conditions requires that terrestrial vegetation will not be affected by drawdown, outside of the <2m groundwater level drawdown zone. To quantify groundwater-vegetation risks, a preliminary desk-top assessment to identify potentially groundwater dependent ecosystems in the project area, was undertaken by CDM Smith (March 2020). This study identified that: 1. the spatial extent of vadophytic vegetation is much greater than potentially phreatophytic vegetation; 2. notwithstanding, potential groundwater use by vegetation occurs in 8 of 35 vegetation communities identified in the project area; and 3. if it does occur, groundwater use is likely to be facultative rather than obligate.

Oz Minerals have asked AQ2 to undertake a review of the assessment of at-risk GDEs completed by CDM Smith. The memo presents a brief summary and review of the previous work and provides recommendations for field measurements to reduce uncertainty and risk in the GDE assessment.

## 2. GDE ASSESSMENT UNDERTAKEN

### 2.1 Vegetation Survey

Western Botanical (2020) identified three associations as potential GDEs within the West Musgrave Project area based on landscape position, species assemblage and the presence of species known to access deep water. These communities were:

- Calcrete *Corymbia opaca* Woodland (CCoW), which occurs over 455 ha of deep sandy swales. Dominant tree and shrub species include *Corymbia opaca, Eucalyptus intertexta, Melaleuca glomerata, Acacia kempeana,* and *Acacia ligulata*.

- *Melaleuca glomerata* with *Acacia kempeana* Shrubland (MgAkS), which occupies 911 ha in the surveyed area and occurs as stands within the broader *Triodia* hummock grasslands.

- Low Mallee Woodland (LMW), which occurs across 4400 ha on calcrete platforms with deep sandy soil and mainly consists of *Eucalyptus gamophylla* and *Eucalyptus oxymitra* patches within a *Triodia basedowii* grassland.

There is also an additional 1765 ha of potential GDE where these associations form as mosaics with other vegetation units.

Analysis by CDM Smith added more communities to the list of potential GDEs based on the height of dominant tree and shrub species and the depth to groundwater. In particular, communities that contain *Corymbia opaca, Eucalyptus intertexta, Melaleuca glomerata, Eremophila duttonii, Acacia maitlandii, Acacia melleodora, Eucalyptus gamophylla* and/or *Hakea lorea* are potential GDEs as these species have been identified as possible groundwater users.

## 2.2 GDE Assessment

CDM Smith undertook a desk-top identification of potential GDEs in the project area (March 2020). The work adopted a 3-staged approach, following the framework presented in the Australian GDE Toolbox (Richardson et al 2011) and involves the increasing focus on areas of potential GDE.

The study combined:

- Vegetation mapping and potentially phreatophytic species (as identified in published literature).
- Depth to groundwater (with shallow depth to groundwater (<2 mbgl) increasing the likelihood of groundwater use).
- Remote sensing data to assess the persistent greenness of each vegetation community.
- Changes in groundwater salinity along flow-lines that may indicate evapotranspirative concentration of salts in groundwater.

The review identified 8 vegetation communities that may use groundwater, within the study area. One of these 8 was defined as a likely obligate phreatophyte while the remainder were defined as potential facultative phreatophytic systems. The 8 vegetation communities covered a relatively small portion of the overall project area (which comprises 35 vegetation communities in total).

The obligate GDE related to the presence of *Eremophila duttonii* shrubland.

Three of the potential facultative GDEs are associated with the presence of calcrete in the substrate with varying keystone vegetation species (including *Corymbia opaca*). Two of the potential GDEs relate to the presence of *Melaleuca glomerata* and the remaining two relate to the presence of various *Acacia sp.*

## 2.3 Review and Comment

The desk-top assessment includes the following assumptions and / or limitations:

- The study focusses on the simple presence rather than abundance of potentially phreatophytic keystone species (which is appropriate from an ecological values perspective). The study assumes the presence of a potential phreatophytic species implies a potential GDE; no account is taken of species density. Species that are present a very low density (if they are keystone species) have the opportunity to develop extensive lateral roots and will have access to large volumes of soil water. In particular, it is noted that the *Corymbia opaca* woodland comprises only 2% tree cover which may allow extensive lateral tree roots. This means the desk top study is likely to be conservative (i.e., identified a larger area of GDE potential than may be the case).
- The determination of the potential for a species to use groundwater is based primarily on a detailed literature review as presented in Appendix A of the report (combined with project specific vegetation mapping). However, the basis of the listed conclusion by the studies in the appendix is not always clear nor is the application of any local context. This means the

desk top study is likely to be conservative (i.e., identified a larger area of GDE potential than may be the case).

- The desk top study notes the limitations of remote sensed data due to pixel size in the data set compared to the relative vegetation density. Over the observed data periods, all vegetation communities (both potentially GDE and non GDE) have relatively similar "greenness indices" (i.e., there is little differentiation). Also, the greenness index is generally higher in a wet period than a dry period. Overall, the greenness index assessment is not a strong diagnostic tool in this circumstance.

- The desk-top assessment does not consider potential causes of the increase in salinity through the project area, other than to note it is a potential indicator of evapotranspirative concentration (which is the case). The extent and scale of salinity increase is interesting though at odds with the extent that may be expected given the relatively small area of potential GDE and low-density vegetation within the potential GDE areas. This warrants further consideration.

- At desk-top level, the study could not consider the ecohydrological water balance and plant-available water. The study has identified areas of risk that require further investigation that will allow application of local context (such as vadose zone plant available water and vegetation density).

## 3. RECOMMENDATIONS

The following recommendations are made to add more confidence to important assumptions that have been used in the work and the assessment of probable GDEs:

- Key aspects of the conceptual ecohydrological model should be measured so that the water fluxes within the system can be quantified:

  - The actual density of trees that may use groundwater within each system should be quantified. This will involve measurements of stand basal area (SBA - trunk or stem ($m^2$) per unit area (ha)) in an appropriate quadrat sampling program.

  - The size of each stem should also be measured, and a size-class distribution (SCD) developed.

  - DBH / SCD / SBA should be recorded by species.

  - For each DBH measurement, sapwood should also be sampled through coring. This will allow a relationship between SBA and sapwood-area to be developed.

  - Pre-dawn and midday leaf water potential measurements should be collected from representative trees to gain an understanding of pre-dawn water status, hydraulic gradients that are driving transpiration, diurnal rehydration, and water stress. Based on the principle of nocturnal hydraulic equilibration between the root zone and soil matric pressure, pre-dawn leaf water potential can also provide an indication of plant water source.

  - Soil water, groundwater and plant xylem water samples should also be subject to isotopic analysis. The comparison of isotopic indicators will provide insight into the relative contribution of each water source to plant available water.

  - Hand-auguring within the potential GDE areas should be attempted to collect soil samples (although it is noted that the presence of hard-pans may limit auger penetration). Samples should be analysed for particle size distribution (including hydrometer analysis for the fines fraction) and moisture content; the latter should be achievable if the samples are weighed and sealed in the field and then oven-dried in the laboratory.

- Data loggers should be installed in groundwater monitoring bores close to potential GDEs and set for relatively high frequency monitoring (e.g., 10-minute intervals) over a diurnal cycle. A diurnal rise and fall in groundwater level can often be discerned where transpiration from the water table is occurring.

- Develop a quantified conceptual model based on analysis of the above data. Key aspects of this should include:

    - Estimates of stand-level transpiration based on SBA or sapwood area measurements, and published transpiration estimates for the relevant species.

    - Estimate of vadose zone hydraulic properties using pedogenic transfer functions and the soil PSD data. Properties should include matric pressure / moisture content relationships, capillary rise, and unsaturated hydraulic conductivity; the latter will influence the ability for significant water migration to support the capillary fringe or shallow PAW.

    - Estimates of tree water source and water status using the LWP and isotopic data.

    - LWP and isotope data combined with groundwater level data should be used to estimate likely root zones / root depths for the potentially phreatophytic species. In this regard it should be noted that: root systems cannot tolerate permanent saturation and so the persistent groundwater level represents a lower limit to the root depth. Also, the lower the pre-dawn leaf water potential, the drier (and further from the capillary fringe) the root zone is likely to be. Conservatively, if pre-dawn LWP is less than -0.5 MPa, then groundwater connection is very unlikely.

    - A representative rainfall sequence (with respect to frequency and magnitude) should be developed (or adopted from surface water studies that have been completed as part of the project).

- A Hydrus-based numerical ecohydrological model should be developed to simulate the conceptual model as developed above. The model should include the groundwater table as a lower boundary condition and incorporate high levels of root-compensation (which is a common desert phreatophyte adaptation). The prime water input to the model will be the representative rainfall sequence. The modelled "soil" should cover the range as determined from the hand-auguring exercise. The model should be calibrated against all observed and inferred characteristics of the system including:

    - Depth to groundwater and inferred rates of groundwater recharge.

    - Soil moisture content.

    - Transpiration rates.

    - Modelled matric pressure can be compared with observed pre-dawn leaf water potential and used to calibrate both water availability and root depth.

- For unsaturated zone ecohydrological modelling, it is often the case that the combination of model parameters that simulate the observed outcome is unique i.e., each input parameter can only vary through a small range before the model is no longer consistent with field observations. Thus, the model provides a good verification tool for the conceptual model.

- The combination of field data, quantified conceptual model and numerical model should be used to confirm the likelihood and extent of groundwater use for each potential GDE type.

- The model should also be used to simulate the rate and extent of groundwater drawdown that is predicted from associated groundwater modelling. If groundwater use is important to the systems, then rates of transpiration will decline as less groundwater is available. The decline can be correlated to both loss in areal extent (i.e. reduction in SBA) and loss in key species if the model simulates that key matric pressure thresholds are exceeded i.e. if the model simulates prolonged periods with matric pressure below the point at which a tree may lose turgor or suffer embolism, then that species may be at risk.

- In parallel, a review of groundwater salinity and the major ions that compose the groundwater should be undertaken to provide more insight on the increase in groundwater salinity from north to south through the project area. This should include available information on soil, shallow geology and vegetation cover to determine causative factors.

We trust this review meets with your immediate requirements and provides an indication of the next steps to increase confidence and quantification in the understanding of the groundwater-vegetation interaction at West Musgrave. Should you require any further information, please do not hesitate to contact us.

Regards

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Author: DGS (01/06/21)
Checked: DGS (01/06/21)
Reviewed: DGS (01/06/21)