3D Environmental
Landscape & Vegetation Science

Lake Vermont Meadowbrook Project

Groundwater Dependent Ecosystem Assessment

Prepared by 3d Environmental

For

AARC Environmental Solutions / Bowen Basin Coal Pty Ltd

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Project Manager: David Stanton
Client: AARC Environmental Solutions
Purpose: Groundwater dependent ecosystem assessment for the Meadowbrook_Lake Vermont Project

Draft	Date Issued	Issued By.	Purpose
Rev 1	13 December 2021	David Stanton	Initial draft GDE assessment.
Rev 2	21 February 2022	David Stanton	Updated GDE assessment report following provision of Groundwater Impact Assessment Report.
Rev 3	22 March 2022	David Stanton	Final GDE report following review by AARC
Rev 4	19 June 2022	David Stanton	Updates to report and risk assessment following provision of an updated groundwater model.

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Executive Summary

Bowen Basin Coal Pty Ltd proposes to develop the Lake Vermont Meadowbrook Project, approximately 25km northeast of the township of Dysart and 160km southwest of Mackay, on tenure that immediately adjoins the northern boundary of the existing Lake Vermont Mine. The Project centred on MDL429 and MDL303 will use underground longwall mining and a small open cut to recover the resource which is primarily hard coking coal and pulverised injection coal for export.

Large coal mining developments have the potential to alter natural groundwater regimes and impact groundwater quality and an assessment of potential impacts on ecosystems that are reliant on a groundwater resource (groundwater dependent ecosystems or GDEs) is required as a component of a broader impact assessment. Multiple lines of evidence including measurement of LWP, SMP, stable isotopes and physical observation have been applied to assess for the presence of and characterise the ecological function of GDEs within areas potentially subject to mining influence. Based on the results of the field survey and associated data analysis, it is concluded that two types of GDEs are present within the Project Area being:

1. Type 1 GDEs: Includes drainage features with developed alluvial landforms that host variable groundwater volumes and are seasonally recharged via surface flows and flooding. This includes Phillips Creek, Boomerang Creek, and the Isaac River.
2. Type 2 GDEs: This represents a conceptualised perched groundwater lens that lies below GDE Assessment Site 3 (a mapped as an HES wetland). Percolation of groundwater through the alluvial soils occurs when surface water is recharged, and the infiltrating surface water is captured above an aquitard at the alluvial unconformity. Tree roots of river red gum and coolibah are utilising this freshwater lens, which possibly only remains viable for several months following rainfall. The perched freshwater lens is inferred to be >6m below the base of the wetland.

Water held in the regional Tertiary aquifer and coal seams is mostly an unsuitable resource to support GDEs due to high levels salinity, and a potentiometric surface that is generally below maximum tree rooting depth for the eucalypt and melaleuca species that define the Type 1 GDEs and Type 2 GDE systems.

Groundwater drawdown associated with development of the underground mining infrastructure and mining void development will result in drawdown within the Tertiary groundwater system, with modelling indicating >20m of drawdown is propagated beneath reaches of Boomerang and Phillips Creeks. Drawdown in the Tertiary may result in more rapid drainage in the perched alluvial groundwater systems which characterise both drainage features, focused on areas where drawdown intensity is greatest and where sandier alluvial soils promote increased rates of surface water percolation and drainage.

Drawdown in the Tertiary groundwater system of between 2m and 5m is propagated beneath HES Wetland 8 (Type 2 GDE) in the eastern portion of the drawdown impact footprint. Other wetland features within the area of drawdown impact, including HES wetlands, are assessed to be surface features perched on clay aquitards, and will not be influenced by groundwater drawdown related impacts.

Based on risk assessment protocols described in Doody et al (2019) and the Queensland guideline '*Groundwater dependent ecosystems: EIS information guideline* (DES 2022), all GDE areas identified within this assessment are considered 'High Value' ecological receptors due to their attributions which support prescribed environmental matters, both MNES and MSES. Despite this 'High Value', and with application of management measures which include ongoing groundwater monitoring, general operational measures consistent with the Project EA and development of a Project GDEMMP, the risk of impact to GDEs occurring within the influence of the Project is assessed as 'Low' to 'Insignificant' for the following reasons:

1. The recharge of sandy lenses is controlled by surface flows and surface water infiltration into the soil profile. There will be no significant impact to either surface flow or flood regimes which act to recharge the groundwater source which supports GDEs.
2. The groundwater perched in the alluvial systems is subject to natural fluctuations in volume in response to changing seasonal conditions and may dry for significant periods.
3. Tree species which characterise the riparian GDE areas (Type 1 GDEs), particularly river red gum which is a known facultative phreatophyte, are resilient and have capacity to adapt to the possible minor reductions in soil moisture availability that may propagate in areas of predicted drawdown.

For Type 2 GDEs (HES Wetland 8), groundwater drawdown in the Tertiary sediments may result in more rapid drying of the groundwater lens that is conceptualised to support the GDE system and the unmitigated risk of impact is assessed to be 'Moderate'. With application of appropriate management measures, including development and implementation of a Project GDEMMP, the risk of impact to Type 2 GDEs is assessed as 'Low'.

Based on this risk assessment, there is also no predicted significant residual impact to any prescribed environmental matters under relevant state or federal legislation that may be associated with GDEs in the vicinity of the Project area.

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Glossary

Alluvial aquifer	An aquifer comprising unconsolidated sediments deposited by flowing water usually occurring beneath or adjacent to the channel of a river.
Aquifer	A geological formation or structure that stores or transmits water to wells or springs. Aquifers typically supply economic volumes of groundwater
Aquatic GDE	Ecosystem supported by surface expression of groundwater (e.g. spring fed watercourses and associated fringing vegetation).
Base flow	Streamflow derived from groundwater seepage into a stream.
Capillary fringe	The unsaturated zone above the water table containing water in direct contact with the water table though at pressures that are less than atmospheric. Water is usually held by soil pores against gravity by capillary tension.
Confined aquifer	A layer of soil or rock below the land surface that is saturated with water with impermeable material above and below providing confining layers with the water in the aquifer under pressure.
Edaphic	Relating to properties of soil or substrate including its physical and chemical properties and controls those factors impose on living organisms.
Evapotranspiration	The movement of water from the landscape to the atmosphere including the sum of evaporation from the lands surface and transpiration from vegetation through stomata
Evaporative enrichment (of stable isotopes).	In a surface water body subject to evaporation, the d2H/d18O values of a water sample collected after a period of strong evaporation will be higher (more enriched in the heavier isotope) than the values obtained from water collected during an earlier sampling event. This reflects the progressive evaporation of water and loss of the lighter isotope under local conditions (assuming that there is not additional water inflow).
Facultative phreatophyte	A plant that occasionally or seasonally utilises groundwater to maintain high transpiration rates, usually when other water sources aren't available.
Fractured rock aquifer	An aquifer in which water flows through and is stored in fractures in the rock caused by folding and faulting.
Fluvial	Relating to processes produced by or found in rivers
Groundwater	Those areas in the sub-surface where all soil or rock interstitial porosity is saturated with water. Includes the saturated zone and the capillary fringe.
Water table	The upper surface of the saturated zone in the ground, where all the pore space is filled with water.
Groundwater dependent ecosystems (GDE)	Natural ecosystems which require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services (Richardson et al. 2011)
Infiltration	Passage of water into the soil by forces of gravity and capillarity, dependent on the properties of the soil and moisture content.
Leaf water potential (LWP)	The total potential for water in a leaf, consisting of the balance between osmotic potential (exerted from solutes), turgor pressure (hydrostatic

	pressure) and matric potential (the pressure exerted by the walls of capillaries and colloids in the cell wall).
Leaf area index (LAI)	The ratio of total one-sided area of leaves on a plant divided by the area of the canopy when projected vertically on to the ground.
Local Meteoric Water Line (LMWL)	Describes the relationship between hydrogen and oxygen isotope (Oxygen-18 and Deuterium) ratios in local natural meteoric waters. LMWL is usually developed from precipitation data collected from either a single location or a set of locations within a "localised" area of interest (USGS, 2018) and results are reported as the amount-weighted average d2H/d18O composition of water in rainfall. LMWL's define a constant relationship between d2H/d18O in local rainfall, and deviations from this relationship are imparted by stable isotope fractionation causally linked to evaporative processes (evaporative enrichment). Further information can be obtained from USGS (2004) and Crosbie et al (2012).
Matric potential	The capacity of soil to release water, dependant on the attraction of water in the matrix to soil particles. Matric potential is always a negative value.
Obligate phreatophyte	A plant that is completely dependent on access to groundwater for survival
Osmotic potential	The lowering of free energy of water in a system due to the presence of solute particles.
Percolation	The downward movement of water through the soil due to gravity and hydraulic forces.
Perched groundwater system	A groundwater system or aquifer that sits above the regional aquifer due to a capture of infiltrating moisture on a discontinuous aquitard.
Permeability	A materials ability to allow a substance to pass through it, such as the ability of soil or rocks to conduct water under the influence of gravity and hydraulic forces.
Permanent wilting point	The water content of the soil at which a plant can no longer extract water and leaves will wilt and die. Usually -1.5 Mpa (-217 psi). Generally applied to crops although Australian flora typically have much larger stress thresholds.
Phreatic zone	The zone of sub-surface saturation separated from the unsaturated zone in unconfined aquifers by the water table.
Phreatophyte	Plants whose roots extend downward to the water table to obtain groundwater or water within the capillary fringe
Piston flow	The movement of a water front through the soil uniformly downwards to the aquifer, with the same velocity, negligible dispersion, pushing older water deeper into the soil profile.
Preferential flow	Movement of surface water rapidly from surface to aquifer along preferential flow paths, bypassing older moisture in the upper soil profile.
Soil moisture potential (SMP)	A measure of the difference between the free energy state of soil water and that of pure water. Essentially a measure of the energy required to extract moisture from soil.
Stable isotope	A stable isotope is an isotope that does not undergo radioactive decay. Oxygen has three different isotopes: The ^{16}O is the most common stable isotope of oxygen and ^{18}O is present in the atmosphere in amounts that are

	measurable. The masses of ^{16}O and ^{18}O are different enough that these isotopes are separated (or fractionated) by the process of evaporation leading to enrichment of the heavier (^{18}O) isotope. Hydrogen has two naturally occurring stable isotopes being ^{1}H (protium) and ^{2}H (deuterium) which also fractionate during evaporation, although the higher energy state of hydrogen means that the ratio between ^{1}H and ^{2}H is much more sensitive to fractionation. Further information can be obtained from USGS (2004) and Singer (2014).
Standard Wilting Point	The minimum LWP or corresponding soil moisture potential that can be tolerated before a crop plant wilts in response to negative water supply. This is accepted at -15 bars or -1.5 MPa (or -217.55 PSI)
Specific Yield	The ratio of the volume of water that a saturated rock or soil will yield by gravity to the total volume of the rock or soil.
Surface water	Movement of water above the earths' surface as runoff or in streams
Transpiration	The process of water loss from leaves, through stomata, to the atmosphere.
Terrestrial GDE	Terrestrial vegetation supported by sub-surface expression of groundwater (i.e. tree has roots in the capillary fringe of groundwater table).
Unconfined aquifer	An aquifer whose upper surface is at atmospheric pressure, producing a water table, which can rise and fall in response to recharge by rainfall
Vadose zone	The unsaturated zone, above the water table in unconfined aquifers
Water Potential	The free energy potential of water as applied to soils, leaves plants and the atmosphere.
Wetting front	The boundary of soil wet by water from rainfall and dry soil as the water moves downward in the unsaturated zone.

1.0 Introduction

1.1 Project Background

Bowen Basin Coal Pty Ltd (the 'Proponent') proposes to develop the Lake Vermont Meadowbrook Project (referred to as 'the Project') on tenure that immediately adjoins the northern boundary of the existing Lake Vermont Mine. The Project lies approximately 25 kilometres (km) northeast of the township of Dysart and 160 km southwest of Mackay (**Figure 1**) and will use underground longwall mining to recover the resource which is primarily hard coking coal and pulverised injection coal for export. The proposed Project area lies within Mineral Development Licence (MDL) 429 and MDL303 and is presented in Figure 1. The primary purpose of the development is to extend the life of the existing Lake Vermont Mine, at existing (approved) production levels up to 12 million tonnes per annum (Mtpa) of run of mine (ROM) coal, supplementing the future decline in production from the existing open-cut mining operation with output from an adjoining underground operation and a satellite pit. The proposed mine layout is provided in **Figure 2** with the principal components of the proposed mining operation being:

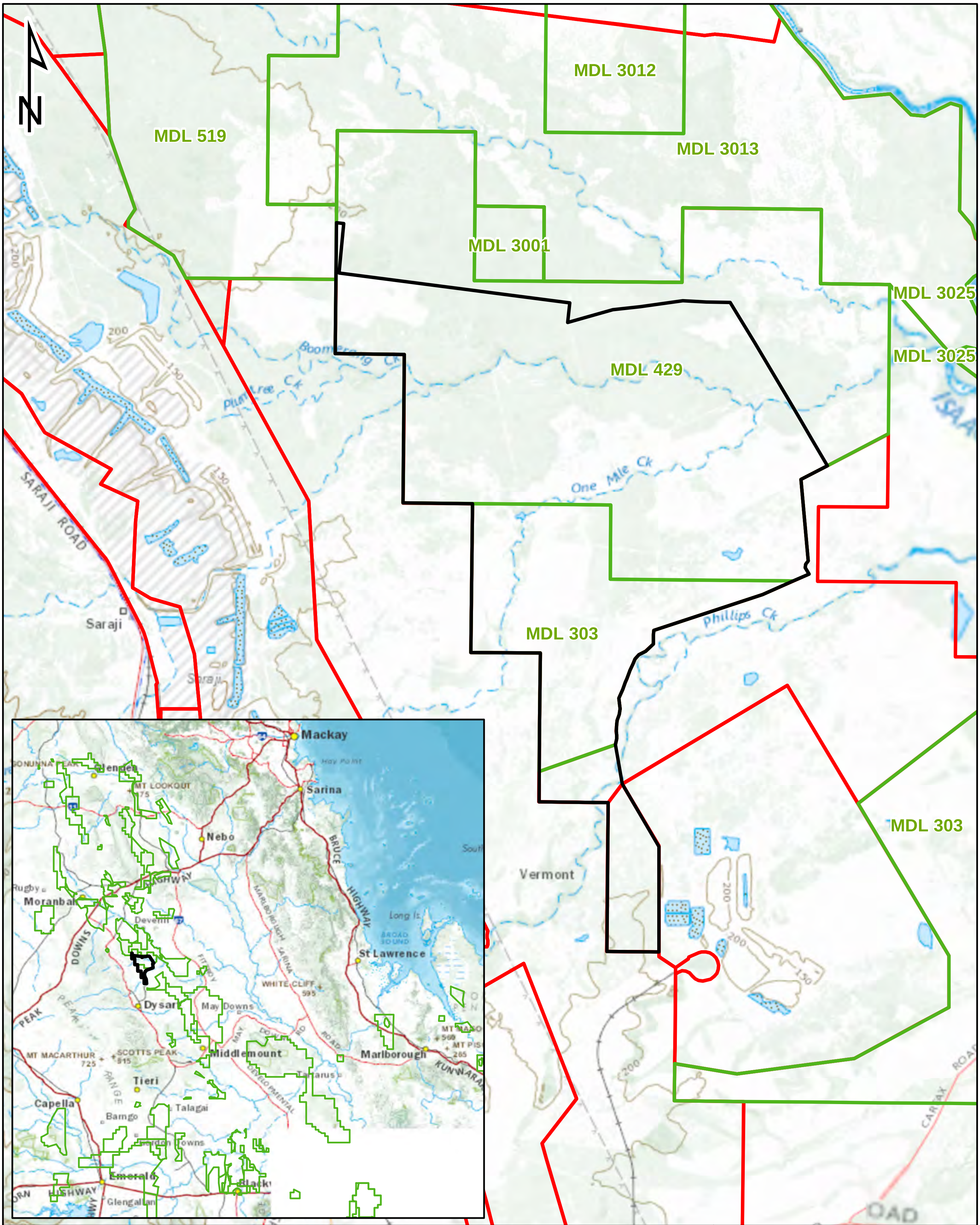
- Underground longwall mining of the Leichardt Lower Seam and Vermont Lower Seam.
- An open cut pit.
- Development of a new infrastructure corridor to link the new mining area to existing infrastructure at the Lake Vermont Mine.
- Development of a Mine Infrastructure Area (MIA).
- Construction of a drift and shafts to provide access to underground operations.
- Development of other supporting infrastructure and associated activities.

Large coal mining developments have the potential to alter natural groundwater regimes and impact groundwater quality. Therefore, an assessment of potential impacts on ecosystems that are reliant on groundwater resources is required. These ecosystems are captured under the general term of groundwater dependent ecosystems (GDEs). This report provides an assessment of the presence of GDEs within the Project area and surrounds and includes an assessment of potential Project related impacts to GDEs.

1.2 Project Objectives

Objectives of the GDE assessment are to:

- Identify if vegetation within and surrounding the Project area accesses and utilises groundwater for transpiration, either permanently or intermittently, consistent with classification of a GDE.
- Determine the source and nature of aquifers utilised by GDEs, if any.
- Identify the degree of dependence of vegetation communities on groundwater for survival and sustenance through periods of drought.
- Provide an assessment of potential Project impacts on identified GDEs.



Legend

- Project Outline
- Mineral development licence
- Mining_leases

Figure 1. Regional location of assessment area.

Client AARC Environmental Solutions

0 1.25 2.5 3.75 5
Kilometers

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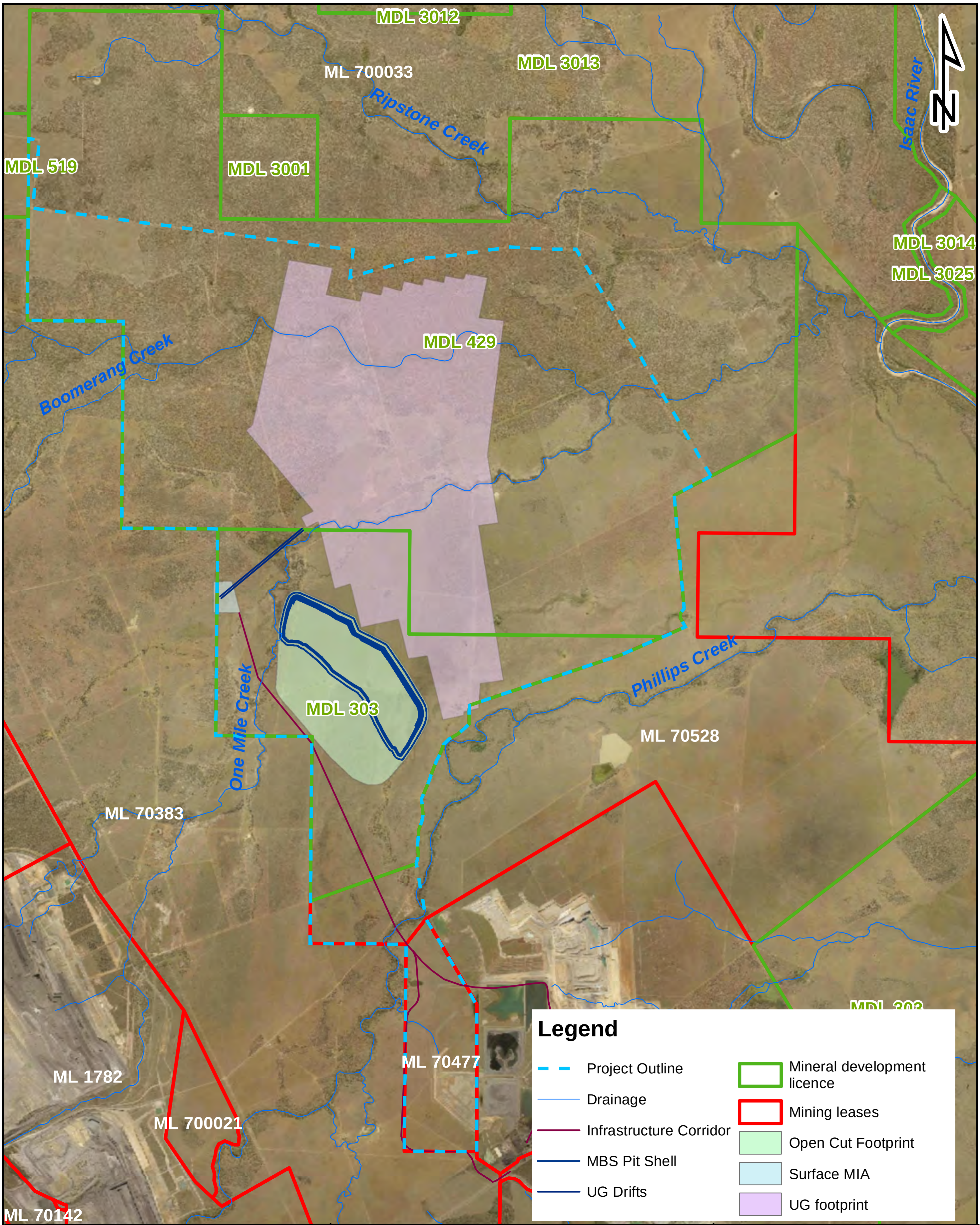

Figure 2. Proposed Mine Layout

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0 1.25 2.5 3.75 5
Kilometers

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1.3 Relevant Legislation

The Project will be assessed under the bilateral agreement between the Commonwealth and the State of Queensland using the Environmental Impact Statement (EIS) process prescribed under the Environmental Protection Act 1994 (EP Act), and it is intended that this assessment satisfies both state and federal requirements. General principles under relevant state and federal regulatory mechanisms are described below.

1.3.1 Queensland Legislation

Environmental Protection Act 1994: Under regulatory provisions of the Environmental Protection Act 1994 (EP Act), a site-specific Environmental Authority (EA) will be required under Section 125 of the EP Act with an EIS forming part of the EA application process. A component of the EIS is the requirement to address MNES that relate to water dependent assets under the EPBC Act.

1.3.2 Federal Legislation

Environment Protection and Biodiversity Conservation Act 1999: The Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) provides for the protection of environmental values, prescribed under the Act as Matters of National Environmental Significance (MNES). Any action that will or may cause a significant impact on MNES is subject to assessment under the EPBC Act. In June 2013, the EPBC Act was amended to capture water resources as MNES. Under the amendment, water resources include groundwater and surface water, and organisms and ecosystems that depend on it to maintain ecological function and condition. These ecosystems are otherwise termed GDEs and are captured under the water trigger.

The regulatory guideline *Significant impact guidelines 1.3: Coal seam gas and large coal mining developments – impacts on water resources (DoEE 2013a)* identify a 'significant impact' as 'an impact which is important, notable, or of consequence, having regard to its context or intensity'. In this regard, the uncertainties that are associated with the nature and significance of impacts to GDEs are addressed in this assessment.

1.4 GDE Definition Used for Assessment

The definition of a GDE applied to this assessment is consistent with the definition provided in the guidance document *Modelling water-related ecological responses to coal seam gas extraction and coal mining* prepared by Commonwealth of Australia (2015) on the advice from the Independent Expert Scientific Committee (IESC) on Coal Seam Gas and Large Coal Mining Development and IESC 2018a. This definition is described below:

> *Groundwater dependent ecosystems (GDEs): Natural ecosystems which require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements to maintain their communities of plants and animals, ecological processes and ecosystem services (Richardson et al. 2011). The broad types of GDE are (*from *Eamus et al. 2006a and 2006b):*
>
> - Ecosystems dependent on surface expression of groundwater (springs, and spring fed streams and rivers, otherwise defined as aquatic GDE's).
> - Ecosystems dependent on subsurface presence of groundwater (terrestrial GDEs).

- Subterranean ecosystems (caves as well as sub-terranean species including stygofauna).

1.5 Groundwater Definition Used for Assessment

Eamus (2006a) defines groundwater (when related to GDEs) as;

> *'all water in the saturated sub-surface; water that flows or seeps downwards and saturates soil or rock, supplying springs and wells, water stored underground in rock crevices and in the pores of material'.*

For this assessment of GDEs, the term groundwater refers to those areas in the sub-surface where all soil or rock interstitial porosity is saturated with water including the associated capillary fringe. It is assumed that in the overlying unsaturated zone, water may be present in varying amounts over time although saturation is rarely reached during infiltration or percolation of rainfall, stream water or other surface sources of groundwater recharge moving under gravity. The definition of groundwater excludes wetting fronts being the wetted area of soil underlying permanent surface water bodies and ephemeral zones of saturation created when the infiltration rate approaches the hydraulic conductivity of a subsurface horizon. The down-gradient migration of infiltrating water is merely slowed rather than halted.

1.6 Climatic Considerations

The annual rainfall at Booroondarra (BOM Recording Station 35109; Lat: 22.82° S / 148.49° E), 29km to the south of Dysart, being the nearest reliable recording station with public rainfall records is presented in **Figure 3**. The data indicates variable though typically below average rainfall for nearly all months through 2019 with an extremely dry period between March and November 2020, before returning to wet conditions in December 2020. While the first quarter of 2021 received above average rainfall with an extremely wet March (194.4mm), April to June returned to dry conditions before becoming wet in July where 56.4mm was recorded in the month preceding the survey, which is twice the average rainfall for that month. No significant rainfall was recorded in the four weeks preceding the survey which was completed across 6 days from 15th to 20th August (2021).

Plant growth in the region is strongly limited by moisture rather than temperature (Hutchinson et al. 1992) which is reflected in the evapotranspiration rates for the 2019 – 2020 period (from Silo 2020) with data for all months indicating evapotranspiration as being considerably higher than rainfall except in February 2020. Annual evapotranspiration rates tend to peak in December/January and are typically at their lowest in June / July (**Figure 4**) (BOM 2020a).

The region has experienced several significant drought events which is likely to have affected both surface flows and recharge of groundwater systems. **Figure 5** demonstrates the major climatic cycles in terms of Cumulative Rainfall Departure (CRD) (Weber and Stewart 2004), representing a cumulative departure of monthly rainfall from the long-term mean monthly rainfall (January 1990 to August 2021) from point data at Booroondarra (SILO 2021) (consistent with the location of BOM Recording Station 35109). Strongly decreasing rainfall trends between 1990 to 1996; and 2000 to 2007 representing major drought periods are strongly evident. Following a period of relatively stable / average rainfall conditions occurring between 2013 to 2017, the current trend is for decreasing rainfall with below average conditions experienced post 2017 indicating a longer-term regime of ecological water deficit preceded the assessment. It is noted however that following extremely high rainfall in March 2021, there has been an up-kick in the CRD curve indicating a possible return to wetter climatic conditions. The analysis of cumulative rainfall departure is relevant to this assessment as shallow water tables generally follow similar trends, with rising water tables and increased occupation of surface waters coincident with increasing trends in the CRD curve.

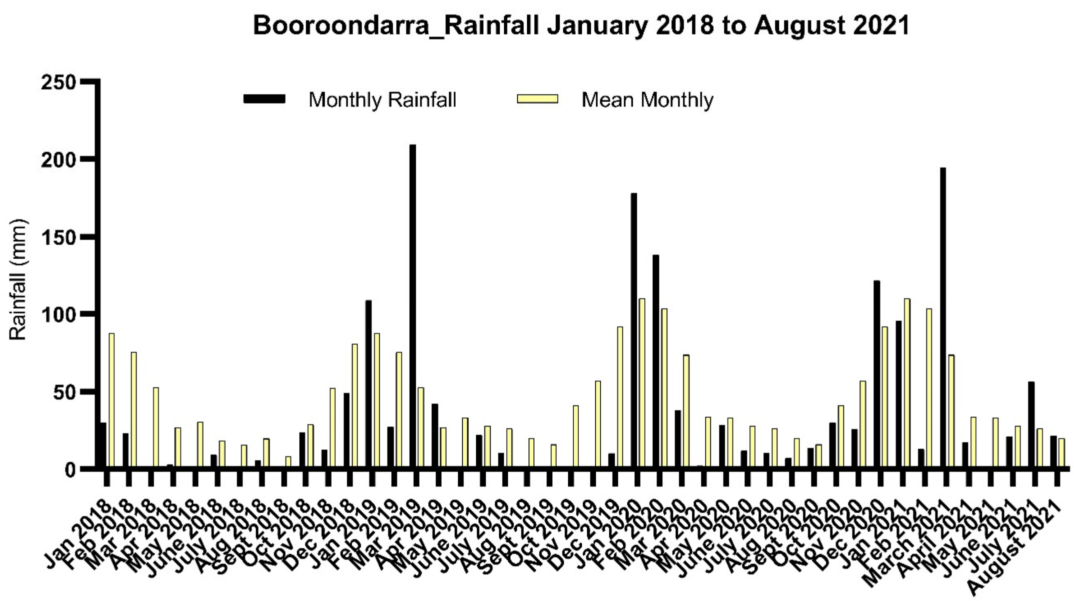


Figure 3. Rainfall for the period from January 2019 to August 2021 from Booroondarra Recording Station (Station No, 35109).

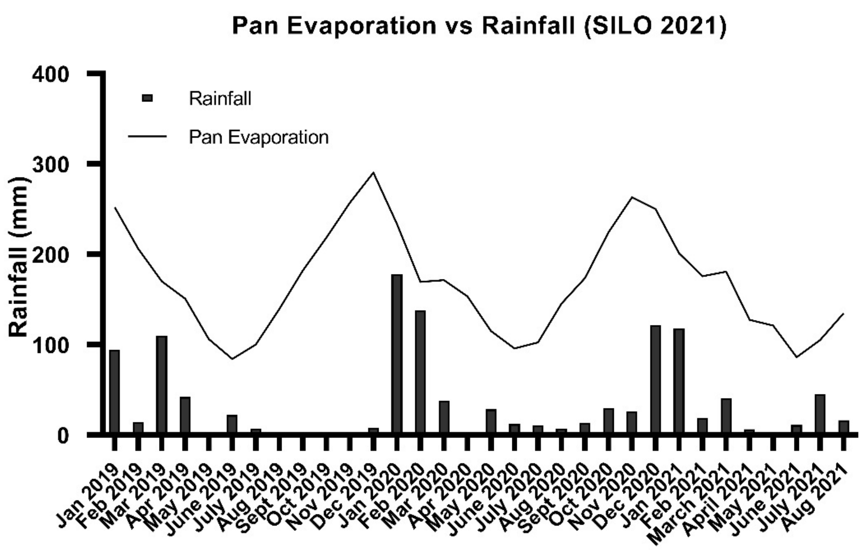


Figure 4. Evapotranspiration compared to rainfall for January 2019 to August 2021 from SILO (2021).

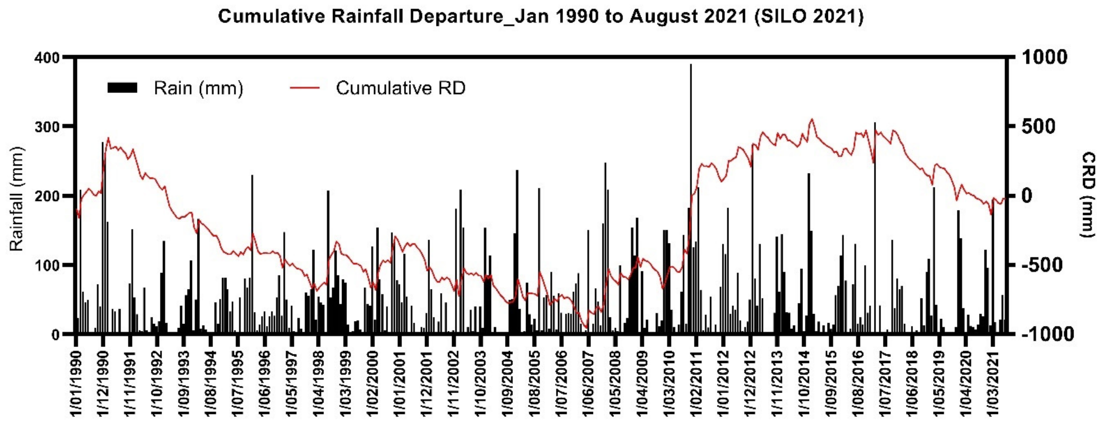


Figure 5. Cumulative Rainfall Departure demonstrating major and minor climatic fluctuations from SILO (2021).

2.0 Ecohydrological Setting

The following section details existing knowledge on the site as it relates to hydrogeology, ecology and mapped GDEs.

2.1 Hydrogeological Setting

The Project is in the central part of the Permo-Triassic aged Bowen Basin, a broad sedimentary basin formed in the Permian / Triassic period with a variable cover of Quaternary and Tertiary period sediment and basic volcanic rocks (basalts). The surface geology is summarised from DNRME (2020), as shown in **Figure 6**, with further descriptions provided in the following sections.

2.1.1 Geomorphic Setting

The Project area forms a landscape of gently undulating plains interrupted by narrow drainage features and scattered wetlands. The broad rises are formed by thick sequences of Pleistocene to Tertiary age cracking clay and residual silts and loams to the north of Phillip Creek, and sandier residuals on broad Tertiary rises to the south. The well-developed floodplain deposits of the Isaac River intrude marginally into the north-eastern portion of the Project Area attenuated upstream along Boomerang and Ripstone Creeks, where a complex system of floodplain wetlands has developed at the confluence. All creek systems in the Project Area, including the Isaac River to the east are strongly seasonal, flowing only after high intensity rainfall events with surface flows disappearing quickly into the streambed sands as surface flows recede.

2.1.2 Geological characteristics

Cainozoic Sediments: Cainozoic sediments which include Quaternary and Tertiary age alluvial sands, clayey sands and clays occur across the entire Project area, with variable thickness that ranges from 2 to 80m, and an average thickness of 26m (Minserve 2017). The Cainozoic sediments mainly comprise alluvial sands, clayey sands and clays, with a basal layer in some locations of sand and gravel. JBT (2022) notes that the thickness of the Cainozoic sediments increases from 35m-45m to the south of Boomerang Creek to more than 60m to the north. While significant Quaternary age alluvium is not mapped within MDL429 in available surface geology mapping (DNRM 2020) (see **Figure 6** for reference), a thick sequence of Quaternary Age alluvium is associated with the Isaac River floodplain in the eastern portion of the tenement, and this attenuates upstream along the Tributaries of Ripstone Creek and Phillips Creek in available surface geology mapping (DNRM 2020). JBT (2022) also observes that significant Quaternary age alluvium is associated with Boomerang Creek, estimated to be up to 14m thick although conclude that it is difficult to discern from the thicker sequences of Tertiary sediments as both units have a sandy structure.

Triassic and Permian Sedimentary Rocks: Solid geology comprises,

1. the upper unit of the Triassic Age Rewan Group
2. the late Permian Rangal Coal Measures
3. the underlying late Permian Fort Cooper Coal Measures forming the basal group.

The economic coal seams are hosted in the Rangal Coal Measures which has two prominent coal seams which dip gently to the northeast, including the Leichhardt Lower (LHL) seam with an average thickness of 2.9 meters, and the Vermont Lower (VL) seam with an average thickness of 5.8m. The economic coal seams sup-crop into the Tertiary sediments at the location of the proposed Meadowbrook open cut pit, though dips deeply to the north-east where they will be subject to proposed underground mining operations.

2.1.3 Groundwater Standing Water Levels and Water Quality

Standing water levels (SWLs) in the Tertiary overburden measured between October 2020 and May 2021 range from 13.36 metres below ground level (mbgl) in W14_MB1 to 26.63mbgl at W1_MB1. Potentiometric surfaces in the coal seams are more variable, though range from 17.46mbgl at W6_MB2 to 37.28mbgl at W10_MB2. The monitoring bores installed into the alluvium (W3_MB1 and W4_MB1) adjacent to Boomerang Creek had SWL's that ranged from 7.9 mbgl to 11.03mbgl, though neither monitoring well expressed sufficient groundwater to provide for consistent geochemical sampling or to be considered a significant aquifer. For all monitoring bores, SWLs were generally seasonally consistent and showed no strong response to the heavy rainfall events that occurred in December 2020, or March 2021 which suggests limited hydraulic conductivity in the overlying strata, and no indication of preferential flow / recharge. The exception might be W14_MB1 where groundwater levels rose by 1.3m between January 2021 and May 2021, suggesting some preferential response to surface recharge (see **Section 2.1.4**).

For monitoring bores installed in the alluvium, hydrochemical sampling was completed at W4_MB1 in October 2020, indicating salinity of 17 219 µS/cm, although no further successful geochemical sampling was completed at either W3_MB1 or W4_MB1 during the sampling period due to a lack of groundwater. Measured salinity in W14_MB (on Boomerang Creek), screened in the Tertiary sediments just below the inferred base of the alluvium, is consistently <1000 µS/cm and represents the least saline groundwater at the site. Measured salinity of groundwater from other monitoring bores screened in Tertiary sediments ranges from 11 400 µS/cm in W3_MB2 to 39 506 µS/cm in W9_MB1 (one sampling event) with some variability between monitoring bores, and within bores during the sampling period. Salinity values in the coal seams are comparable, with highest values recorded in W9_MB3 (37845 to 41565 µS/cm) and lowest levels of salinity recorded in W6_MB2 (12 370 to 21981 µS/cm). JBL (2022) attributes the salinity in the Tertiary sediments to a groundwater unit that is variably saturated, does not contain continuous lateral flow paths, with groundwater accumulating in low points at the base of the Tertiary sediments and limited hydraulic connection with the underlying sediments.

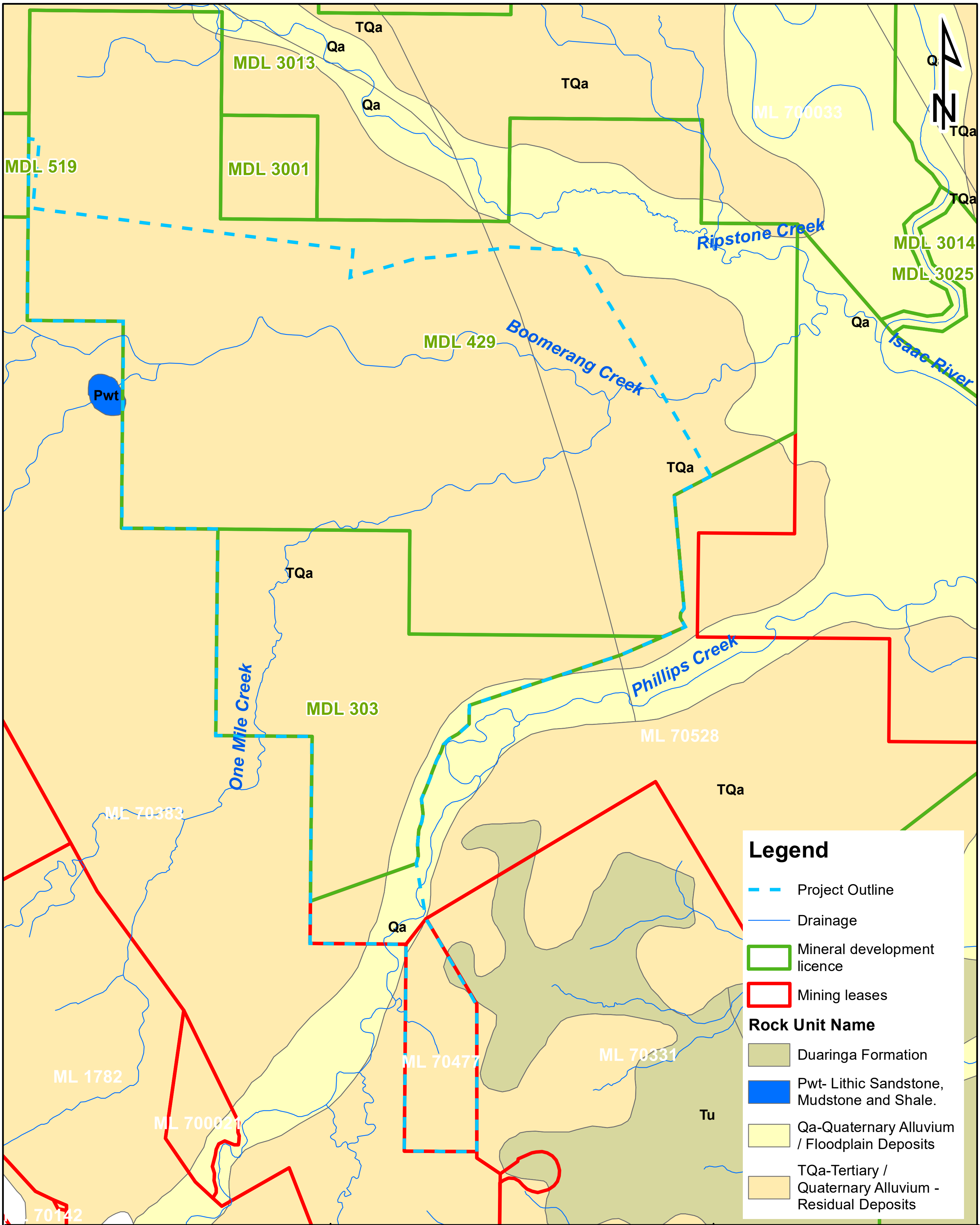
SWLs and salinity values recorded from monitoring bores in the Project Area over an eight-month monitoring period are provided in **Table 1**, with the locations of monitoring bores relative to MDL boundaries shown in **Figure 7**.

2.1.4 Groundwater Recharge and Discharge

JBL (2022) identifies that groundwater recharge occurs predominantly via rainfall and downward seepage from ephemeral creeks following creek flow with direct recharge into the Tertiary and Quaternary groundwater units. Groundwater associated with coal seams is preferentially recharged where the coal seams sub-crop beneath Tertiary / Quaternary overburden, notably where Phillips Creek flows over the sub-crop area. Preferential recharge is also interpreted to be occurring in the vicinity of Boomerang Creek near W14-MB1. While all creeks the Project area are ephemeral, larger watercourses in topographically lower areas, particularly to the east of the Project area where the Isaac River is deeply incised into alluvium, may receive groundwater baseflow.

2.1.5 Hydraulic characteristics

JBL (2022) identifies variable hydraulic conductivity throughout the range of lithologies within the Project area though the highest average conductivity occurs in the Tertiary overburden (4.31E-01) and the Permian coal measures shallower than 130mbgl. Tertiary overburden in vicinity of Meadowbrook (near the proposed open cut) has a distinctly higher hydraulic conductivity than further to the north on account of its sandier nature. The Lowest average hydraulic conductivity occurs in the Rewan Group (1.59E-02) and for the coal seams, Permian interburden and Rewan Group sediments, hydraulic conductivity decreases with depth. Hydraulic conductivity within the Quaternary Alluvium is extremely variable on account of structure which ranges from sandy clays to sands, with an average hydraulic conductivity of Quaternary alluvium at 2.66E-02 with highest conductivity in the vicinity of W14_MB1 on account of the sandy nature of sediments, which is consistent with the low levels of salinity and higher recharge rates reported from this monitoring bore.



Source: Detailed Surface Geology Qld 1:100 000 (DNRM 2018

Figure 6. Surface geology in the assessment area

Client: **AARC Environmental Solutions**

0 1.25 2.5 3.75 5
Kilometers

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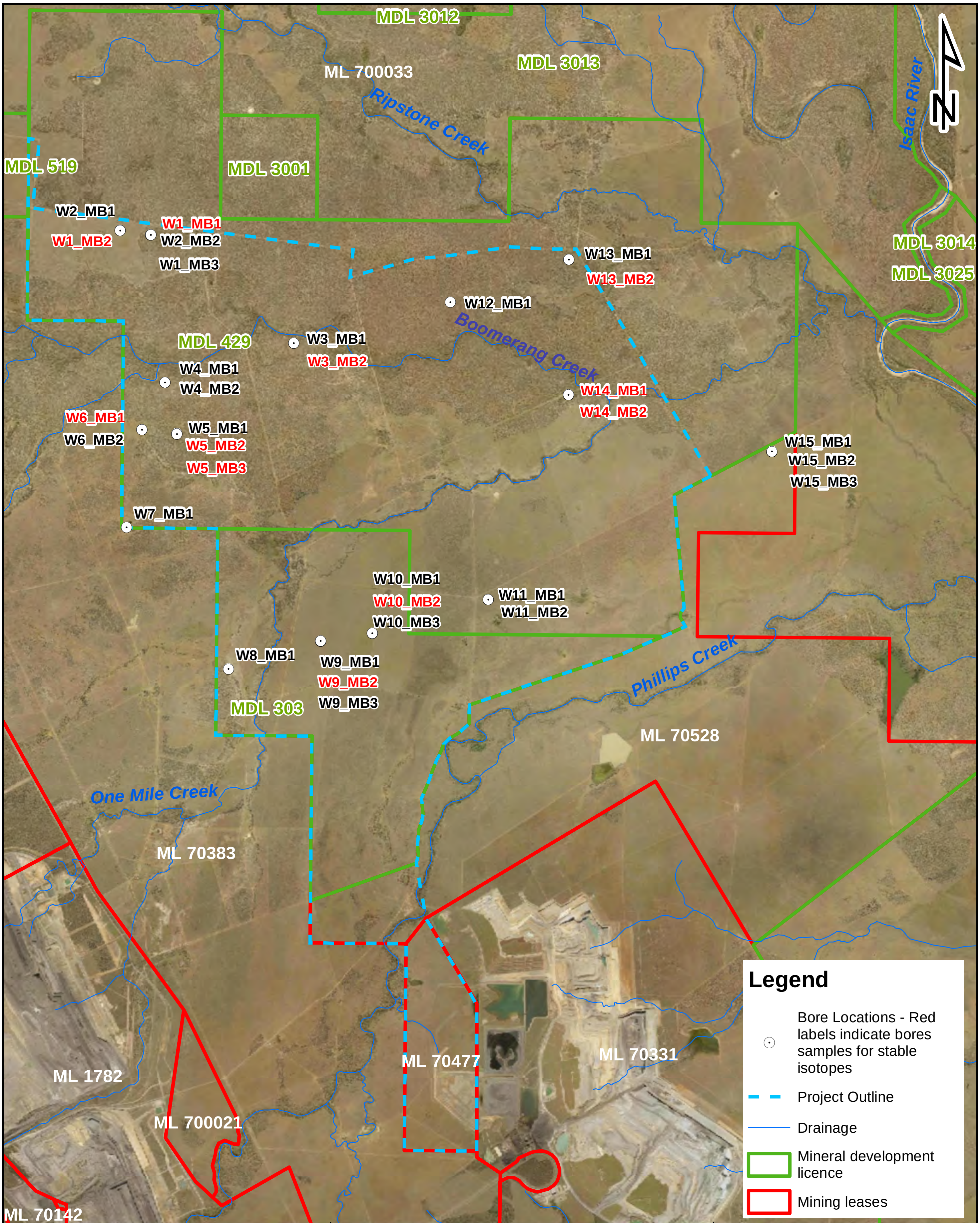

Figure 7. Groundwater monitoring bores in the Projec Area

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Kilometers

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Table 1. Details of groundwater monitoring bores used to inform assessment.

BORE ID	**Formation**	**Easting**	**Northing**	**Elevation (m)**	**Drilled Bore Depth (m)**	**Screened Interval – Alluvium (m)**	**SWL MBGL# Range 21 Oct 2020 to 25 May 2021***	**Salinity µS/cm (Field)**							
								20/Oct/2020	**09/Dec/2020**	**04/Jan/2021**	**26/Jan/2021**	**16/Feb/2021**	**24/Mar/2021**	**14/Apr/2021**	**25/May/2021**
Tertiary Sediments															
W1_MB1	**Tertiary sediments**	**637914**	**7531373**	**187.09**	**45.5**	**43.6 – 45.1**	**26.46 – 26.63**	**37668**	**8817**	**17339**	**27524**	**24171**	**27160**	**24503**	**23665**
W2_MB1	Tertiary sediments	637368	7531452	187.92	42	34- 40	25.61 – 25.78	38079	12004	19500	25411	26933	29328	26882	27320
W3_MB2	**Tertiary sediments**	**640468**	**7529435**	**176.20**	**41**	**35 - 41**	**17.8 – 18.18**	**11685**	**11400**	**15749**	**17618**	**12118**	**19463**	**18547**	**7311**
W9_MB1	Tertiary sediments	640953	7524117	177.46	22	19 - 22	21.40 – 22.20	39506	No Data	No Data	No Data	No Data	No Data	No Data	No Data
W12_MB1	Tertiary sediments	643268	7530165	166.80	60	54 - 60	19.78 – 20.05	20531	21685	23609	22395	23249	22982	21757	20716
W15_MB1	Tertiary sediments	649009	7527504	177.50	23	17 - 23	17.43 – 17.45	26224	No Data	No Data	No Data	No Data	No Data	No Data	No Data
W14_MB1	**Tertiary sediments**	**645373**	**7528515**	**166.80**	**20**	**15.6 - 18.6**	**13.36 – 14.66**	**23476**	**491**	No Data	**1202**	**1099**	**999**	**963**	**842**
Quaternaru Alluvium															
W3_MB1	Quaternary alluvium	640470	7529435	176.80	12	9 - 12	**7.96 – 8.32**	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
W4_MB1	Quaternary alluvium	638172	7528735	179.00	12	9 - 12	**10.41 – 11.03**	17219	No Data	No Data	No Data	No Data	No Data	No Data	No Data
Coal Seams and Permian Overburden															
W1_MB2	Leichhardt Lower Seam	637916	7531372	187.06	84	81.75-83.24	25.64 – 26.09	36574	38882	37952	37541	37860	37109	35670	36131
W1_MB3	Vermont Seam	637919	7531372	187.18	124	122.5 - 124	**25.93 – 26.17**	No Data	36478	39283	38115	39149	39256	37221	35390
W2_MB2	**Girrah 1 Seam**	**637370**	**7531452**	**187.93**	**110**	**104-110**	**25.54 – 25.77**	**2121**	**39511**	**36823**	**39221**	No Data	**39487**	**38558**	**38612**
W4_MB2	Permian overburden	638169	7528735	179.25	60	54 - 60	17.8 – 18.18	No Data	16549	19458	20112	18918	No Data	18797	17802
W5_MB1	Rewan Group	638387	7527823	181.15	50	44 - 50	**19.94 – 20.18**	22477	22528	23363	23500	22776	22511	18810	22009
W5_MB2	**Leichhardt Lower Seam**	**638385**	**7527820**	**181.16**	**71**	**69.5 - 71**	**19.12 – 19.21**	**23193**	**24671**	**24045**	**24204**	**24424**	**24430**	**24304**	**23710**
W5_MB3	**Vermont Seam**	**638384**	**7527817**	**181.14**	**113**	**111.5 - 113**	**21.05 – 21.13**	**21254**	**22396**	**23023**	**23271**	**23421**	**23085**	**23039**	**21711**

BORE ID	Formation	Easting	Northing	Elevation (m)	Drilled Bore Depth (m)	Screened Interval – Alluvium (m)	SWL MBGL# Range 21 Oct 2020 to 25 May 2021*	Salinity µS/cm (Field)							
								20/Oct/2020	09/Dec/2020	04/Jan/2021	26/Jan/2021	16/Feb/2021	24/Mar/2021	14/Apr/2021	25/May/2021
W6_MB1	**Permian overburden**	**637758**	**7527892**	**179.85**	**56**	**50 - 56**	**17.41 – 23.07**	**20364**	**14486**	**14692**	**15060**	**15425**	**15334**	**15624**	**15880**
W6_MB2	Girrah 1 Seam	637761	7527893	179.95	77	75.5 - 77	**16.86 – 17.16**	12370	21918	21832	21890	21981	21717	21660	**21338**
W7_MB1	Permian overburden	637484	7526145	180.69	60	54 - 60	18.46 – 18.57	36274	36074	38050	38549	38394	37650	37956	37239
W8_MB1	Girrah 1 Seam	639306	7523618	177.67	60	54 - 60	**20.26 – 20.31**	39697	**42701**	43787	44481	44002	42829	43685	43118
W9_MB2	**Vermont Upper Seam**	**640953**	**7524119**	**177.42**	**44.8**	**42.5 - 44**	**29.53 – 30.03**	**15157**	**29837**	**37232**	**30962**	**29343**	**36653**	**36281**	**37763**
W9_MB3	Vermont Lower Seam	640952	7524121	177.42	71	64.5 – 70.5	28.35 – 28.62	No Data	41294	41209	41565	40284	39695	40094	37845
W10_MB 1	Rewan Group	641869	7524259	177.00	28	22- 28	28.05 – 28.06	34333		29730	29511	29942	29608	28821	28089
W10_MB 2	**Vermont Upper Seam**	**641869**	**7524259**	**177.00**	**91**	**88.5 - 90**	**36.42 – 36.68**	**24428**	**31021**	**29730**	**29511**	**29942**	**29608**	**28821**	**28089**
W10_MB 3	Vermont Lower Seam	641869	7524261	177.00	119.65	116.65 - 119	32.59 – 32.73	No Data	36153	36162	35025	34495	35413	35784	33815
W11_MB 1	Rewan Group	643941	7524860	174.42	120	114 - 120	32.67 -	33018	23743	23667	23911	23870	23898	24120	24298
W11_MB 2	Leichhardt Seam	643943	7524861	174.27	139	133.5 - 135	29.71 – 29.58	21523	33485	32985	32238	33570	33207	33091	31212
W13_MB 1	Vermont Lower Seam	645381	7530927	166.80	46.5	43.5 – 46.5	17.53 – 17.65	25814	31953	31931	31822	31830	31918	31985	31113
W13_MB 2	**Girrah 1 Seam**	**645379**	**7530927**	**166.80**	**88**	**82 - 88**	**17.98 – 18.06**	**30841**	**23021**	**24124**	**26487**	**27675**	**27590**	**22984**	No Data
W14_MB 2	**Permian Coal Seam**	**645375**	**7528515**	**167.80**	**68**	**65 - 68**	**18.15 – 18.3**	**178.8**	**24285**	**23904**	**23957**	**24130**	**23614**	**23514**	**23356**
W15_MB 2	Vermont Upper Seam	649009	7527504	177.50	60	58.5 - 60	17.34 – 17.42	25030	25096	24697	25329	25105	25540	25427	25281
W15_MB 3	Vermont Lower Seam	649009	7527504	177.50	105	102 - 105	17.26 – 17.49	No Data	27914	27973	27821	27993	29243	29472	28570

Bold = specimen submitted for stable isotope sampling.

Average of measurements between December 2017 and March 2020

*Calculated from Top of Casing (TOC) minus casing stick-up.

2.2 Site Ecology and Ecohydrological Function of Characteristic Tree Species

2.2.1 Regional Ecosystems

Regional Ecosystem (RE) mapping from DNRM (V12.0 2021) is provided in **Figure 8**, which defines several regional ecosystems, typically dominated by eucalypt woodland and open forest habitats. This includes:

- RE 11.3.1, being an open forest of brigalow (*Acacia harpophylla)* associated with flood plain alluvium. The ecosystem is listed as a Threatened Ecological Community (Endangered) under the federal EPBC Act and is Endangered under the Queensland VM Act.
- RE 11.3.2, dominated by poplar box (*Eucalyptus populnea)* with a grassy understory on flood plain alluvium. The ecosystems is listed as a Threatened Ecological Community (Endangered) under the federal EPBC Act and is Of Concern under the Queensland VM Act.
- RE 11.3.3 and RE11.3.3a being a woodland and open forest dominated by coolibah (*Eucalyptus coolabah)* fringing drainage channels and upper river terraces, typically on heavier clay soils. Includes some areas of wetland.
- RE 11.3.25, dominated by river red gum (*Eucalyptus camaldulensis)* with scattered Moreton Bay ash (*Corymbia tessellaris*), Clarkson's bloodwood (*Corymbia clarksoniana*) and river oak (*Casuarina cunninghamia*). Typically forms the immediate fringe of the larger drainage lines.
- RE 11.3.27, being freshwater wetlands with variable vegetation including open water with or without aquatic species and fringing sedgelands and eucalypt woodlands. Occurs in a variety of situations including lakes, billabongs, oxbows and depressions on floodplains.
- RE 11.3.37, *Eucalyptus coolabah* with *Eucalyptus camaldulensis* woodland to low woodland on alluvial plains fringing major watercourses.
- RE11.4.9, being an open forest of brigalow (*Acacia harpophylla)* associated with clay soils on elevated Cainozoic plains. The ecosystem is listed as a Threatened Ecological Community (Endangered) under the federal EPBC Act and is Endangered under the Queensland VM Act.
- 11.5.3, dominated by poplar box (*Eucalyptus populnea)* with Clarkson's bloodwood on Cainozoic / Tertiary age residual soils.
- RE11.5.9, typically dominated by narrow leaf ironbark (*Eucalyptus crebra*) with scattered poplar box occurring on older residual plains and jump-ups.
- 11.5.17. *Eucalyptus tereticornis* woodland in depressions on Cainozoic sand plains and remnant surfaces. The ecosystem is listed as Endangered under the Queensland VM Act.

The dominant species within the major regional ecosystems and their potential capacity to utilise groundwater are discussed in **Section 2.2.3**.

2.2.2 Mapped Groundwater Dependent Ecosystems

The mapping of GDEs has been completed at a national level by the Bureau of Meteorology (BOM) which has produced the GDE Atlas (BOM 2020b) which identifies the following GDEs types, consistent with the definition of a GDE applied in this assessment.

- **Aquatic** ecosystems that rely on the surface expression of groundwater–this includes surface water ecosystems which may have a groundwater component, such as rivers, wetlands, and springs. Marine and estuarine ecosystems can also be groundwater dependent, but these are not mapped in the GDE Atlas.

- **Terrestrial** ecosystems that rely on the subsurface presence of groundwater–this includes all vegetation ecosystems.
- **Subterranean** ecosystems–this includes cave and aquifer ecosystems (including stygofauna).

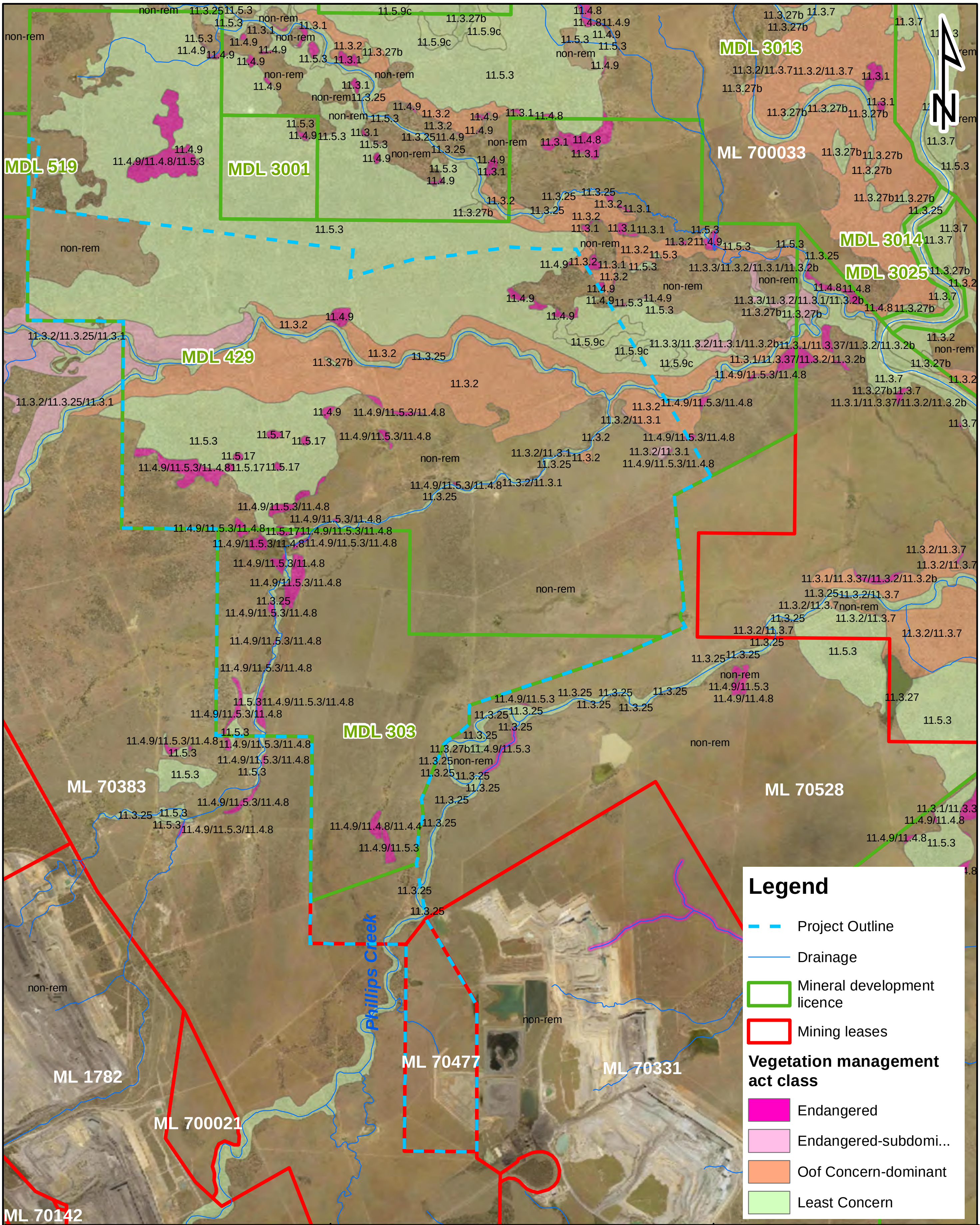
The BOM GDE mapping layer has been compiled with national scale datasets and rules to describe the potential for groundwater interaction, and within the assessment area corresponds directly with GDE and potential aquifer mapping produced by the Department of Environment and Science (DES) (2020). Due to the limited ground verification, the dataset requires site specific GDE assessment. The mapping of GDEs over the Project area and surrounds, as produced by BOM (2020b) is provided in **Figure 9**. In general, this assessment shows 'Low Potential' for Terrestrial GDEs associated with elevated residual plains (typically RE11.5.3), 'High Potential' and 'Moderate Potential' for Terrestrial GDEs associated with floodplain alluvium (typically RE11.3.2 and RE11.3.3 and RE11.3.25) vegetation and watercourses. There are no springs mapped within proximity to the assessment area, although the Isaac River (east of MDL439) and Phillip Creek (on the southern fringe of MDL439) are mapped as 'High Potential' Aquatic GDEs, and the other larger creeks (Boomerang and Ripstone) are mapped as 'Moderate Potential' Aquatic GDEs. There are also numerous floodplain wetlands including RE11.3.27 and RE11.5.17 scattered across the tenement which are mapped as 'Moderate Potential' Aquatic GDEs.

2.2.3 Groundwater Dependent Species

Eucalypts: Coolibah (*Eucalyptus coolabah*) and River Red Gum (*Eucalyptus camaldulensis)* are the most prevalent eucalypt species in the assessment area. Coolibah is the dominant canopy tree in RE11.3.3 with River Red Gum being more prevalent in RE11.3.25, the defining ecosystem on both major and minor drainage features.

River red gum: River red gum is a well-studied species known to have deep sinker roots, hypothesised to grow down towards zones of higher water supply (Bren et al., 1986). River red gum is adapted to arid and semi-arid environments and will go through alternate phases of shedding and regaining its crown, depending on the availability of water. It is adapted to do so over time and across the flood frequency classes. River red gum have the capacity to self-regulate and adjust their transpiration rates to match the average flood return interval (Colloff 2014). The species maintains a strong capacity for genetic selection to increase the capacity of the species to survive drought stress. Trees less able to survive drought tend to die off, hence the genes that are associated with drought tolerance traits become more common in the remaining population.

The species is considered opportunistic in its water use, sourcing water according to osmotic and matric water potential and source reliability (Thorburn et al., 1993; Mensforth et al., 1994; Holland et al., 2006; Doody et al., 2009) with the water requirements obtained from three main sources being groundwater, rainfall, and river flooding. Flooding enables the species to survive in semi-arid areas (ANBG 2004) where stands are intimately associated with the surface-flooding regime of watercourses and related groundwater flow. River red gums are considered a facultative



Source: Vegetation Management Regional Ecosystems Version 12.0 (DNRM 2022)

Figure 8. Regional ecosystems in the Project

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0 1.25 2.5 3.75 5

Kilometers

Scale 1:90,000	**Drawn By** DG	**Checked** DS	**File Path**	**Date** 25-Mar-22	A4

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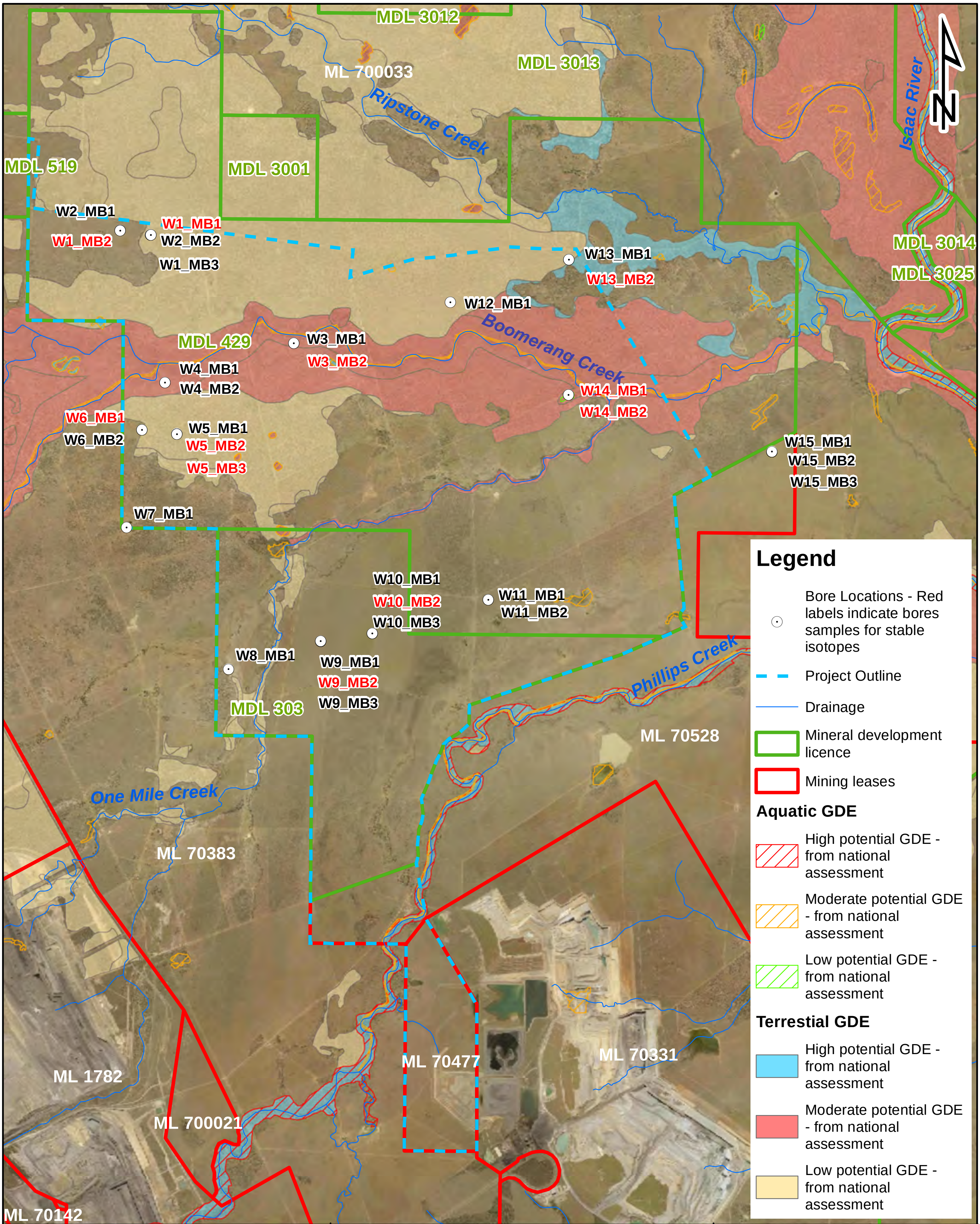

Source: BOM GDE Atlas (2020).

Figure 9. Mapped potential GDEs from the Commonwealth assessment (BOM 2020)

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Kilometers

Scale 1:90,000	Drawn By DG	Checked DS	File Path	Date 25-Mar-22	A4

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phreatophyte, shifting between a combination of surface soil moisture and groundwater during periods of high rainfall, then shifting to exclusive use of groundwater during drier periods. They are likely to achieve this shift through inactivation of surface roots during drier periods with increased reliance on deeper tap roots when surface water is unavailable. Doody et al. (2015) demonstrated that soil moisture alone can sustain the health of *Eucalyptus camaldulensis* through periods of drought for up to six years before significant decline in tree health is noted.

River red gum have capacity to utilise saline groundwater in preference to fresh surface water, probably because it represents a more reliable supply (Colloff 2014) although salinity tolerances are likely to vary on a site-by-site basis and there is no clear threshold. Eamus (2006b) identifies river red gum as being a relatively salt-tolerant species, growing well in soil salinities up to 1 500 µS/cm with Mensforth (1994) suggesting that river red gum will continue to utilise groundwater with salinity as high as 40 000 µS/cm in the absence of a fresh source of soil moisture. Based on the authors personal observation, exposure of the tree rooting zone to a shallow (<3mbgl) saline groundwater table at 30 000 µS/cm can result in wholesale dieback of a previously well-developed river red gum riparian forest, with only scattered river red gum saplings living on the immediate river bank.

The maximum potential rooting depth of river red gum is subject to considerable conjecture in current literature, although it is widely accepted that the species has capacity to access deep groundwater sources (Eamus et al 2006a). Horner et al. (2009) found rooting depths at 12–15mbgl based on observed mortality in plantation river red gum forests on the Murray River Floodplain. Jones et al (2020) found maximum rooting depths of 8.1mbgl in river red gum in a broad study area in the Great Artesian Basin. In conclusion, maximum rooting depth of river red gum is likely to be variable, dependent on site geology and depth to saturation with the capillary fringe being the general depth at which root penetration will be arrested (Eamus et al 2006b). For this assessment, the physiological attributes of river red gum and forest red gum are assumed to be similar as the species can inhabit and mix within a similar ecological niche. Forest red gum is however a more adaptable species, occupying dry hill slopes in some localities and it would be expected to be more tolerant of changes to hydrological regime than *Eucalyptus camaldulensis* which is a riparian specialist.

River red gum has a number of traits that enable the species to be relatively resilient to all but the most extreme ecological change as listed:

1. The species is adapted to arid and semi-arid environments, and is opportunistic in its water use, sourcing water according to osmotic and matric water potential and source reliability (Thorburn et al., 1993; Mensforth et al., 1994; Holland et al., 2006; Doody et al., 2009).
2. The species has capacity to survive high levels of water deficit with the major sources of water utilised for transpiration include:
    a. Groundwater including fresh to moderately saline aquifers.
    b. Surface water held in river pools,
    c. Soil moisture in the unsaturated zone, including infiltration of moisture from lateral bank recharge, overbank flooding and rainfall which also act to recharge groundwater (Doody et al 2020).
3. River red gum will often use saline groundwater in preference to fresh surface water, probably because it represents a more reliable supply (Colloff 2014).

4. River red gum also has a capacity for genetic selection to increase capacity for the species to survive drought stress. Trees less able to survive drought tend to die off, hence the genes that are associated with drought tolerance traits become more common in the remaining population.
5. River red gum will go through alternate phases of shedding and regaining its crown, depending on the availability of water and it is adapted to do so and over time and across the flood frequency classes. Trees have capacity to self-regulate and adjust their transpiration rates to match the average flood return interval (Collof 2014).

Coolibah: *Eucalyptus coolabah* favours sites with heavier clay soils, typically close to drainage lines and requires flooding for regeneration (Roberts 1993). There are few studies that attempt to detail the moisture sources and usage strategies of *Eucalyptus coolabah.* Costelloe et al (2008) suggest that coolibah avoids using saline groundwater via the following mechanisms:

1. Growing at sites that maximise the frequency of soil moisture replenishment (i.e. on drainage lines and overflow channels).
2. Having extremely low transpiration rates.
3. Strong capacity to extract moisture from soils with extremely low osmotic / matric potentials.

Costelloe et al (2008) concluded that coolibah avoided using hypersaline groundwater (71 000 mg / L [Cl] or 70290 µS / cm), instead favouring the use of low salinity soil moisture in the vadose zone above the groundwater table. Coolibah can however continue to extract moisture at Cl concentrations up to 30 000 mg / L (27 800 µS/cm) in soils where matric potential in the upper soil profile is extremely low due to a combination of extreme drying coupled with a clayey substrate.

The heavy clay that characterises many areas dominated by coolibah in the Project Area assessment area would present a physical limitation on tree root penetration. Clay substrates are an unsuitable medium for development of a deep tap root system that would be necessary to penetrate to the groundwater table (Dupuy et al 2005) and soils with low hydraulic conductivities, such as clays, greatly limit the ability of trees to utilise groundwater (Feikema 2010). Hence it is not expected that coolibah would have the same capacity to develop the deeper tap roots that characterise river red gum, and maximum rooting depth would be considerably shallower, most likely considerably less than 10m.

Other Eucalyptus Species: All eucalyptus species are potential users of groundwater (Cook et al 2007) although few studies demonstrating this dependence exist. Fensham and Fairfax (2007) consider both poplar box and narrow-leaved ironbark to possess a shallow rooting system with limited investment in deep root architecture, rendering them susceptible to droughting. Poplar box is more typically associated with upper terraces that are elevated above the river channel requiring a deeper rooting system to access groundwater. Narrow leaf ironbark generally occupies more elevated portions of the landscape, away from drainage lines where depth to groundwater would be greatest. For the remaining species, O'Grady et al (2006b) concluded the following when studying groundwater usage of trees on a tropical floodplain savannah:

1. Clarkson's bloodwood utilised groundwater when the water table was at 10mbgl indicating the potential for the species to develop a deep sinker root. Clarkson's bloodwood should be considered a facultative phreatophyte. It is likely that Clarkson's bloodwood occurring on the banks of ephemeral watercourses will utilise groundwater if it is within reach of rooting depth and not saline.
2. Moreton Bay ash demonstrated groundwater usage when the water table was at 4mbgl, although it is not known whether the species has capacity to utilise deeper groundwater sources. Moreton Bay ash should be considered a facultative phreatophyte.

Both Moreton Bay ash and Clarkson's bloodwood are scattered throughout the frontages of Boomerang and Phillip Creek's as minor components of RE11.3.25 and RE11.3.2.

For Dawson Gum (*Eucalyptus cambageana),* the general association of the species with heavy clay soils and brigalow suggests that there will be limited development of deeper sinker roots. It is expected that species ecology will be closer to coolibah than river red gum with the associated heavy clay presenting a physical limitation on tree root penetration.

Brigalow: Brigalow (*Acacia harpophylla)* habitats and individual trees regularly occur adjacent to the floodplain of the major drainage systems and generally occupy heavy clay soils (vertosols) with well-developed gilgai microtopography in the upper soil profile (0.6m to surface) where the bulk of nutrient recycling occurs. The subsoil components are however typically strongly cohesive clays with high levels of salinity, sodicity, acidity and phytotoxic concentrations of chloride which may reduce the effective rooting depth in these soils (Dang et al 2012). Johnson et al (2016) describe brigalow as 'a clonal species with stems arising from horizontal roots which draw resources from a substantial area around the plant'. The concentration of the brigalow root mass in the upper soil profile enables the species to sucker profusely from horizontal roots after physical disturbance and limits the capacity for other woody species to compete for moisture and nutrients. Brigalow's shallow rooting habitat is evident with the tendency of mature trees to topple because of churning in the upper soil profile with fallen trees universally exposing a well-developed lateral root system with little evidence for development of deeper sinker roots that would have capacity to propagate to deeper groundwater tables. Brigalow is not considered to represent groundwater dependent vegetation.

River oak: The water use strategy of river oak (*Casuarina cunninghamiana)* appears dependent on its position relative to a watercourse. O'Grady et al (2006b) determined river oak mainly utilised river water when adjacent to a stream channel, which is its most common topographic position. There has been no demonstration that river oak has capacity to utilise deeper groundwater sources. River Oak is not considered to be groundwater dependent in the Project area.

Weeping tea-tree: There is limited information on the water use strategies of the larger paperbark species in literature. Two studies (O'Grady et al 2006, O'Grady et al 2005) indicate *Melaleuca argentea* and *Melaleuca leucadendra* directly utilise surface water, although their capacity to utilise water from deeper aquifers when surface water is not available is unknown. Based on observations of matted tree roots concentrated in wet sands within river channel deposits, it is expected that weeping tea-tree will utilise mostly surface water with capacity to utilise residual moisture in river channel deposits as surface water recedes. There is no evidence for development of deeper sinker roots in weeping tea tree with significant investment in spreading lateral roots adapted to utilising shallow moisture sources.

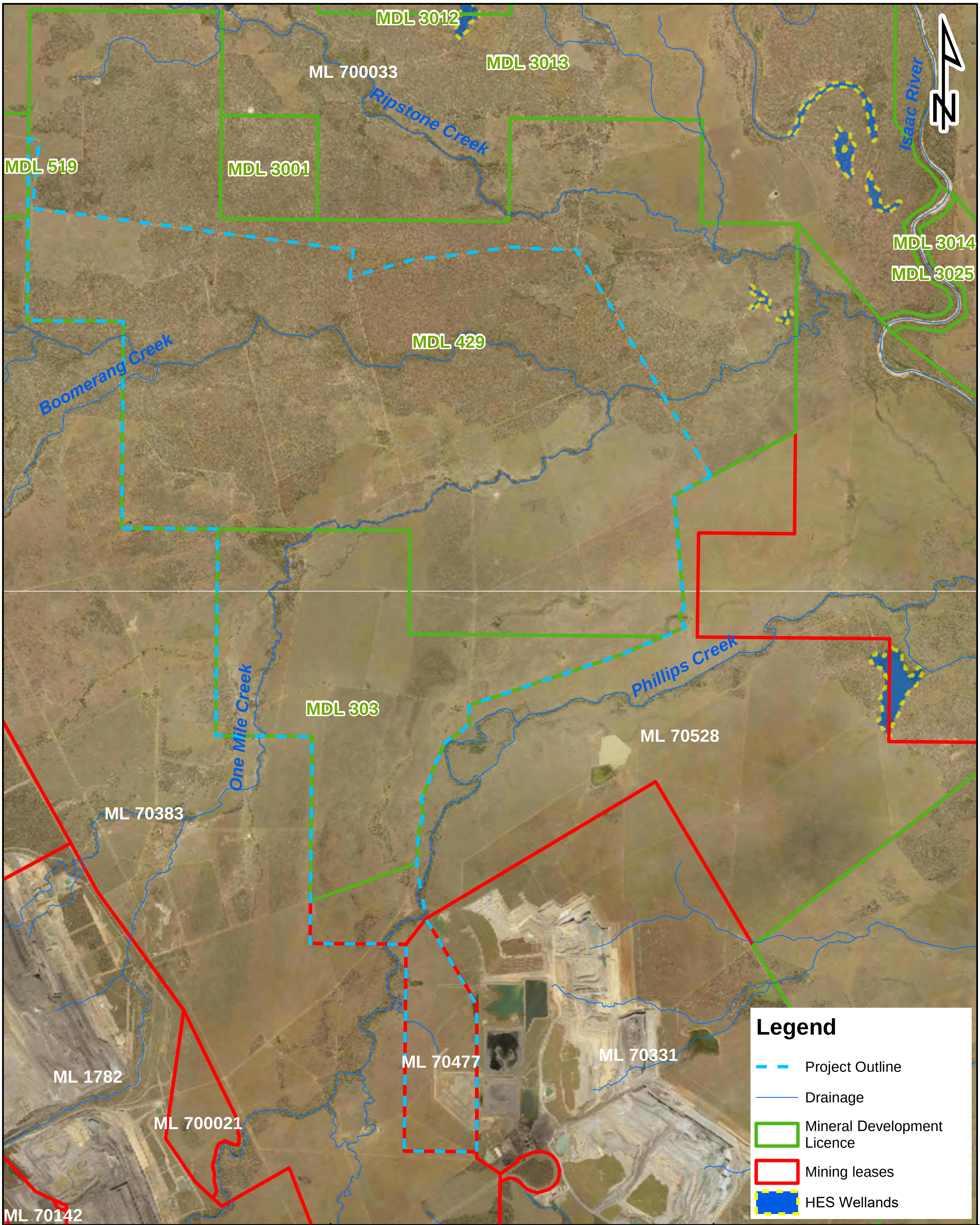
2.2.4 Summary - Depth of Tree Rooting and Salinity Tolerances

As described in previous sections, tree rooting depth is a difficult parameter to predict and measure as it depends on several factors including tree species, substrate, edaphic conditions, as well as depth to groundwater. Tree root penetration is typically arrested at the capillary fringe (Eamus et al 2006b). DNRME (2013) considers 20m to represent the maximum potential rooting depth of river red gum, although this would likely only occur under optimal conditions with favourable soil types. As previously discussed, other authors have suggested much shallower maximum rooting depths including Jones et al (2020) at 8.1mbgl based on physical observation and Horner et al. (2009) at 12–15mbgl. Due to the tendency of coolibah to occupy sites with heavy clay soils, maximum rooting depth of this species is likely to be considerably shallower.

Based on evidence from published literature and the authors personal observation, it is unlikely that the terrestrial woody vegetation that characterises the Project Area would have capacity to utilise groundwater that has salinity greater than 30 000 µS/cm, instead relying on whatever fresh moisture that can be extracted from the vadose zone. It is also unlikely that any tree would invest in the development of a deep root system to tap water from a saline water table, where the benefits in terms of increased water availability would be very marginal.

2.2.5 Other Significant Habitats

Vegetation mapped in government databases also includes two wetland areas mapped as 'Great Barrier Reef wetland of high ecological significance (HES)' under the Environmental Protection Regulation 2008. Within MDL429, HES wetlands occur at the confluence of Boomerang and Ripstone Creeks where the outwash of alluvium interacts with the Isaac River Flood Plain. The HES wetland areas are mapped as 'Moderate Potential Aquatic GDEs' in the BOM GDE Atlas (see **Section 2.2.2, Figure 9**) with the location shown in **Figure 10**.



Source: Matters of State Environmental Significance - High Ecological Significance Wetland (DES 2020)

Figure 10. High Ecological Significance (HES) wetlands under the EP Act.

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3.0 Methods

The field assessment was completed over a five-day period (excluding travel) from 15 August to 19 August 2021. Field conditions were fine and dry. Weather conditions during the survey were cool to warm, with an estimated maximum daily temperature from 24°C to 29°C. No rainfall was recorded during the field assessment or in the 4 weeks prior to the assessment, although 56.4 mm was recorded in early July, which would have recharged surface flows and wetlands as well as soil moisture in the upper soil profile. The following sections provide an overview of methods used to assess groundwater dependence of vegetation within the Project area and surrounds. It describes site selection, assessment of leaf water potential (LWP), use of soil auger holes to assess soil moisture potential (SMP) and analysis of stable isotope composition in a manner that is consistent with Jones et al (2020) and supplemented with methodology from Richardson et al (2011), IESC (2018b), Doody (2019) and Eamus (2009).

3.1 Site Selection

The survey focused on areas mapped as potential Aquatic and Terrestrial GDEs in the GDE Atlas (BOM 2020b) which are associated with woody vegetation occupying creek channels, floodplain vegetation and vegetation associated with residual surfaces. The mapped HES wetlands (see **Section 2.2.5**) were also targeted for assessment (**Figure 10**). In total, 18 sites were chosen for targeted GDE assessment, to provide representative coverage of the major vegetation types and landform elements that are most likely to be groundwater dependent. The purpose of each of the chosen sites is provided in **Table 2** with localities provided in **Figure 11**. Due to the necessity to sample multiple sites pre-dawn, the subject sites also needed to be relatively accessible with minimal foot traverse to ensure sampling objectives could be met, and sampling of some sites was assisted with the use of an ATV buggy. GDE Assessment Site 12 could not be sampled during the survey due to difficult access constraints and was removed from the sampling itinerary.

Table 2. Summary of the assessment localities targeted during field assessment.

GDE Assessment Site*	Location / Geomorphic Position	Purpose of Assessment
Site 1	Isaac River flood plain and channel to the east of MDL439 including the immediate channel and upper alluvial terraces.	The assessment aimed to sample woody vegetation associated with the Isaac River channel and associated flood plain. The Isaac River flood channel is mapped as a 'High Potential' Terrestrial and Aquatic GDE in the GDE Atlas (BOM 2020b). Associated floodplain vegetation is mapped as a 'Moderate Potential' Terrestrial GDE, dominated by poplar box (RE11.3.2).
Site 2 and Site 3	Fringes of two connected floodplain wetlands that form on a well-developed alluvial floodplain at the confluence of Boomerang Creek and Ripstone Creek.	The assessment aimed to sample floodplain wetlands (RE11.3.27) which are mapped as 'Moderate Potential' Aquatic and 'High Potential' Terrestrial GDEs (BOM 2020). There is an imperative to determine the water sources utilised by riparian vegetation and determine whether there is

GDE Assessment Site*	Location / Geomorphic Position	Purpose of Assessment
		any surface water / groundwater interaction. Both sites are mapped as HES Wetlands under the Qld Environmental Protection Regulation 2008.
Site 4, Site 5 and Site 6	All sites are located on the channel and immediate riparian margins of Ripstone Creek in the northern portion of the assessment area.	The assessment aims to sample riparian vegetation, including vegetation fringing the immediate drainage channel and associated floodplain woodlands along Ripstone Creek. The GDE assessment sites are located within an area mapped as a 'High Potential' Terrestrial GDE (BOM 2020) with the dominant vegetation mapped as RE11.3.2 in V12 RE mapping.
Site 7	Site 7 is located approximately 350m from the channel of Boomerang Creek, on an elevated residual plain.	The assessment aims to sample the water sources utilised by poplar box dominant woodland on residual land surfaces, currently mapped as RE11.5.3 in V12 RE mapping and as a 'Low Potential' Terrestrial GDE in BOM (2020b).
Site 8, Site 9, Site 16	All sites are located on the channel and immediate riparian margins of Boomerang Creek, focusing on vegetation fringing the stream channel and the adjacent alluvial terraces.	The assessment aims to sample riparian vegetation, including vegetation fringing the immediate drainage channel and associated floodplain woodlands of Boomerang Creek. The GDE assessment sites are located within an area mapped as a 'Moderate Potential' Terrestrial GDE with the immediate channel mapped as a 'Moderate Potential' Aquatic GDE (BOM 2020). The dominant vegetation as the site is RE11.3.2 on the fringes and RE11.3.25 within the stream channel based on V12 RE mapping.
Site 10	GDE Assessment Site 10 is located on a floodplain wetland feature with sampling focused on fringing riparian vegetation and the associated surface water body.	The assessment aims to determine the water sources utilised by riparian vegetation fringing the wetland feature, as well as determine whether there is any surface water / groundwater interaction. The wetland feature is mapped as RE11.3.27 and is represented as a 'Moderate Potential' Aquatic GDE and 'Moderate Potential' Terrestrial GDE in the GDE Atlas(BOM 2020b).

GDE Assessment Site*	Location / Geomorphic Position	Purpose of Assessment
Site 11	Site 11 is located approximately 350m from the channel of Boomerang Creek, on an elevated residual plain.	The assessment aims to sample the water sources utilised by poplar box dominant woodland on residual land surfaces, currently mapped as RE11.5.3 (in V12 RE mapping) and as a 'Low Potential' Terrestrial GDE in BOM (2020b).
Site 13	Site 13 is in the northern portion of the tenement on a broad drainage depression that drains into Ripstone Creek. The site is located to sample vegetation in the central portion of the drainage depression.	The assessment at GDE Assessment Site 13 aims to sample vegetation mapped as RE11.4.8 (Brigalow and Dawson Gum) which is currently mapped as a 'High Potential' Terrestrial GDE om the GDE Atlas (BOM 2020b).
Site 14 and Site 15	GDE Assessment Site 14 and Site15 are positioned on, and within wetland depressions across a broad residual land surface in the western portion of MDL439.	GDE assessment sites are located to assess the water sources utilised by trees associated with wetland depressions currently mapped as RE11.5.17 (V12 RE mapping). Both localities are mapped as 'Moderate Potential' Aquatic and Terrestrial GDEs by BOM (2020b).
Site 17	The assessment locality is on One-Mile Creek, which is a minor tributary of Boomerang Creek. The site is positioned to assess riparian vegetation positioned within and adjacent to the drainage channel.	Site 17 is located within a narrow riparian fringe currently mapped as RE11.3.25 in V12 RE mapping. The riparian habitats of One-Mile Creek are mapped as a 'Moderate Potential' Terrestrial GDE in the GDE Atlas (BOM 2020b).
Site 18	Located outside MDL439, adjacent to the southern boundary on Phillip Creek. The locality includes both the riparian margins of the creek and vegetation on the high terrace.	The assessment aims to sample riparian vegetation, including vegetation fringing the immediate drainage channel and associated vegetation on the higher terraces of Phillips Creek. The GDE assessment sites are located within an area mapped as a 'High Potential' Aquatic and 'High Potential' Terrestrial GDE. The dominant vegetation is mapped as RE11.3.25 within the stream channel in V12 RE mapping.

*Note GDE Site 12 was not assessed due to access constraints

3.2 Leaf Water Potential

Leaf Water Potential (LWP) is defined as the amount of work that must be done per unit quantity of water to transport that water from the moisture held in soil to leaf stomata. LWP consists of the balance between osmotic potential, turgor pressure and matric potential. It is a function of soil water availability, evaporative demand, and soil conductivity.

LWP was measured pre-dawn (prior to sunrise) as per standard protocol. Due to a lack of transpiration, LWP will equilibrate with the wettest portion of the soil that contains a significant amount of root material. Pre-dawn, LWP will shift to a lower status as soil dries out on a seasonal basis (Eamus 2006a). Measurement of LWP pre-dawn thus gives an indication of the water availability to trees at each assessment site and provides an indication as to whether trees are tapping saturated zones of the soil profile where water is freely accessible, or utilising moisture that is more tightly bound to soil particles.

Survey localities were visited pre-dawn (first light to pre-sunrise) and leaves were collected from the canopy with the aid of a 9m extension pole fitted with a lopping head. Leaves were collected from seven to ten mature canopy trees, within each assessment site along a stretch of stream frontage that was amenable to traverse in low light conditions. Collected branches were double bagged in black plastic to avoid moisture loss and sun exposure and LWP was measured on-site within half an hour of harvest. Suitable leaf material was trimmed with a fine blade and inserted into an appropriate grommet for sealing within a Model 3115 Plant Water Status Console (Soil Moisture Equipment Corp, 2007). The chamber was sealed and gradually pressurised with nitrogen until the first drop of leaf water emerged from the petiole. Two readings were taken at each GDE site to calculate an average with a third taken where significant differences between reading was noted. Readings were taken in pounds per square inch (PSI) which is converted to a negative value in millipascals (MPa) for direct comparison to Soil Moisture Potential (SMP) measurements. In total, 64 trees were assessed for LWP across the 17 assessment sites, with the location of these trees detailed in **Section 4.2**. For purposes of representation, the following categories have been applied as a measure of relative water availability:

1. Extremely High: LWP >-0.276 MPa
2. Very High: LWP <-0.276 to -0.580 MPa
3. High: LWP <-0.580 to -0.896 MPa
4. Moderate: LWP <-0.896 to -1.21 MPa
5. Low: LWP <-1.21 to -1.72 MPa
6. Very Low: LWP <1.72 to -2.21 MPa
7. Extremely Low: LWP <-2.21 MPa

While the defining values of these categories are arbitrary in nature, they are intended to provide an indication of the likely degree and nature of groundwater dependence or interaction. The 'Extremely High' category would indicate the potential for interaction with an extremely fresh source of groundwater, with the degree of groundwater interaction decreasing through to the 'Moderate' category which may indicate either utilisation of soil moisture from the vadose zone or interaction with saline groundwater. Categories of 'Low' to 'Extremely Low' are considered unlikely to be utilising groundwater to any degree, regardless of salinity.

3.3 Soil Moisture Potential

A hand auger was utilised to collect shallow soil samples at regular depths down the soil profile at selected sites, as well as opportunistic sampling of groundwater where it was intersected. Selection of sites for auger placement considered:

1. Whether LWP measurements indicated a higher degree of water availability in the soil profile than other assessment localities, suggesting that shallow groundwater or a soil zone of higher matric potential[1] exists at depth (i.e., a sand lens may be present in the soil profile).
2. The representativeness of a particular chosen site to provide information that is applicable to other assessment localities.

At each site chosen for auger sampling, the aim was to collect soil samples to the maximum depth of the auger of penetration, with penetration often arrested by coarse gravel / cobble substrates, large tree roots, or refusal at relatively shallow depths in the soil profile due to a high density of root material. Within each auger hole, the following observations were taken at regular depth intervals or where changes to soil structure were apparent:

1. Soil structure, colour, and texture.
2. Presence of root matter.
3. Soil moisture / water and areas of saturation.

Soil sampling was undertaken at regular intervals down the soil profile for analysis of stable isotopes of oxygen (δ18O) and deuterium (δ2H) and duplicate samples were retained for analysis of SMP. Samples collection was generally spaced at 0.5m intervals down the auger profile with additional samples taken where changes in soil structure / texture, moisture content or zones of tree roots were detected. As the samples were collected, they were immediately sealed in airtight plastic vials and placed on ice.

SMP, which includes the matric (water availability) and osmotic (saltiness) potential, is a measure of the energy required to extract moisture from soil. Water only has capacity to move down a hydraulic gradient from soil to root (Gardner 1960). Areas in the soil profile that have a SMP that is less negative than measured pre-dawn LWP will be accessible as a source of moisture. It is widely agreed in ecohydrology and plant physiology fields, that large, mature trees are unable to extract moisture from regions in the soil profile where the total SMP is significantly below LWP measured in pre-dawn leaf material (Feikema et al. 2010, Lamontagne et al. 2005, Thorburn et al. 1994, Mensforth et al. 1994, Holland et al 2009 and Doody et al. 2015). For crops, the maximum suction roots can apply to a soil/rock before a plant wilts due to negative water supply is approximately -15 bars or -1.5 MPa (or -217.55 psi). This wilting point is considered relatively consistent between all plant species (Mackenzie et al, 2004), although many Australian plants have adapted to conditions of low water availability and can persist strongly in soil conditions where soils moisture potential is below standard wilting point (Eamus 2006a). As a general measure however, where measured LWP is below standard wilting point, it indicates plant water deficit, and the tree is unlikely to be supported by a saturated water source unless highly saline.

The measurement of SMP was completed in the laboratory by a portable Dew Point Potentiometer (WP4C) (Meter Group Inc, 2017). The WP4C meter uses the chilled mirror dew point technique with

[1] Matric potential is the portion of the water potential that can be attributed to the attraction of the soil matrix for water.

the sample equilibrated within the headspace of a sealed chamber that contains a mirror and a means of detecting condensation on the mirror. Soil moisture potential samples were measured in megapascal pressure units (MPa). A single 7 ml soil sample was inserted into the WP4C meter using a plastic measuring tray with a stainless-steel base.

3.4 Xylem Stable Isotope Sampling and Analyses

Trees may utilise water from a range of sources including the phreatic zone (saturated zone), the vadose zone (unsaturated zone) and surface water. The stable isotopes of water, oxygen 18 (18O) and deuterium (2H) are useful tools to help define the predominant source of water used by terrestrial vegetation. The method relies on a comparison between the stable isotope ratios of water contained in plant xylem (from a twig or xylem core) with stable isotope ratios found in the various sources of water including a shallow groundwater table, potential sub-artesian aquifer water sources or shallow soil moisture. Methods used to assess stable isotopes are detailed below.

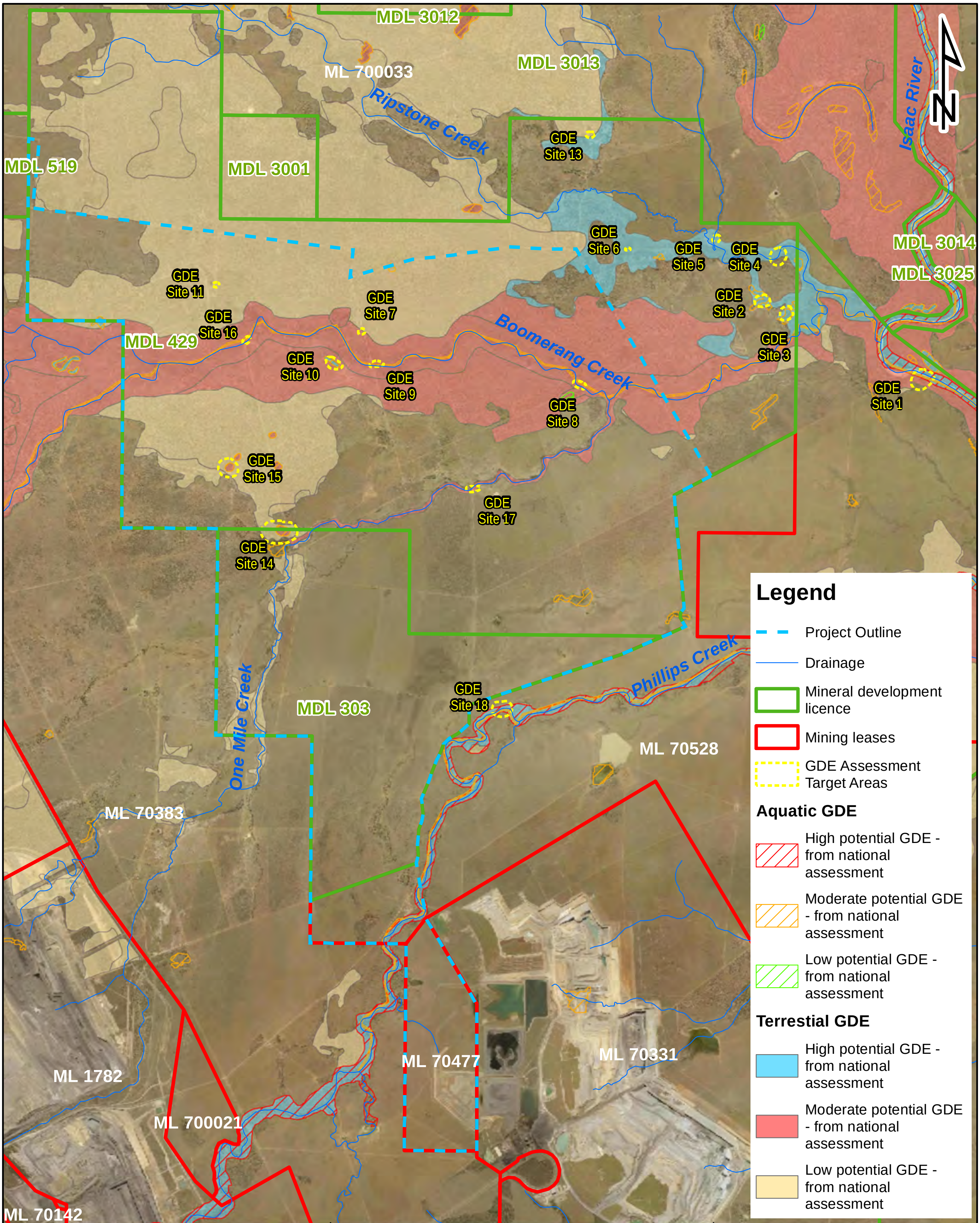
3.4.1 Soil Moisture Isotopes

Sampling was undertaken at regular intervals in auger holes to capture isotopic signatures from a range of potential plant moisture sources from the upper soil surface to the top of the phreatic zone in shallow water tables. The sampling intervals for soil moisture isotope analyses was dependent on auger yield and soil variation although in general, the initial soil sample was taken within the top 20cm of the soil profile and subsequent samples were taken at 0.5m intervals down the soil profile to the end of hole, mirroring the interval for SMP. Approximately 200mg of soil was collected for isotope analysis, sealed in airtight plastic sampling containers, double sleaved in click-seal plastic bags and placed on ice for storage prior to dispatch to Australian National University (ANU) Stable Isotope Laboratory for analysis where they were snap frozen until analysis was complete.

3.4.2 Xylem Water Isotopes

Twigs were collected from the outer canopy branches of target trees used to sample LWP. The following sampling procedure was applied:

1. Outer branches of trees of the GDE target tree were harvested for twig material. Two duplicate samples were prepared from each branch for analysis.
2. The position of trees subject to assessment were marked with a GPS and structural measurements were recorded including height and diameter at breast height (dbh).
3. Outer branches from each tree were harvested with an extendable aluminium pole.
4. Stem material approximately 5cm in length was sourced with stainless-steel secateurs.
5. Bark was immediately removed, and stems were sealed in wide mouth sample containers with leakproof polypropylene closure (approx. 125ml volume) and immediately labelled with the tree number and placed in an iced storage vessel prior to dispatch to the ANU Stable Isotope Laboratory.
6. Upon receipt of samples at the ANU Stable Isotope Laboratory, samples were snap frozen (-18°C) until analysis.
7. For all twigs, samples were taken from xylem as close to the centre of twig as possible. For both xylem and soil samples, extracted water was analysed using a Picarro L2140i cavity ring-down spectrometer.



Source: BOM GDE Atlas (2020).

Figure 11. GDE areas targeted for field assessment.

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For xylem water analysis, multiple samples were taken from a single branch sample at all sampling localities. From each branch sampled, the twig samples returning the lowest degree of isotopic enrichment was used as the reference. This is because there may be considerable partitioning of isotope ratios across a twig cross-section (moving from the xylem to phloem) and it is not always possible to sample the same region of a twig consistently when multiple samples are submitted for analysis. There is also potential for fractionation of stable isotope values, particularly 2H, during movement of water through the xylem from roots to leaves (Evaristo et al 2017, Petit and Froend 2018). As fractionation will likely result in isotopic enrichment rather than depletion, the least enriched sample from each tree is considered most likely to be representative of the soil moisture or groundwater source.

3.4.3 Groundwater Monitoring Bore Sampling

To compare the isotopic signature of groundwater to that of vegetation, groundwater samples from selected developed monitoring bores were collected and despatched to ANU for analysis of stable isotopes of oxygen and deuterium. Monitoring bores where groundwater was sampled for stable isotope analysis have been indicated in **Table 1** (**Section2.1.4**).

3.5 Data Reconciliation and Interpretation

Data interpretation followed a structured approach in which multiple lines of evidence were filtered to provide an assessment of groundwater dependence. The biophysical measurement of LWP formed assessment, followed by the adjunct comparison with SMP, with stable isotope data used to provide supplementary evidence where ambiguity remained. Further context to the approach is provided below. In addition, an overview of depth to groundwater table and groundwater salinity was completed as a final filter, to determine the accessibility of groundwater and suitability as a source of moisture to support transpiration at each assessment locality.

Step 1. LWP: An initial comparison was undertaken to identify individual trees with LWP measurements within the expected range for known terrestrial GDEs subject to various salinity regimes, assuming complete saturation of sediments in the groundwater table and minimal influence of soil matric potential is applied. This data is drawn from a range of published sources including Jones et al (2020), Holland et al (2009) and Mensforth et al (1994):

- Expected LWP for trees in equilibrium with a fresh to brackish saturated source of moisture (EC<1500 µS/cm) = >-0.2MPa.
- Expected LWP for trees in equilibrium with a moderately saline soil moisture source (EC>1500 to 10 000 µS /cm) =<-0.2MPa to >-0.55MPa.
- Expected LWP for trees in equilibrium with a saline soil moisture source (EC>10 000 to 30 000 µS /cm) = <-0.55MPa to >-1.4MPa.

It is noted that where groundwater regimes exhibit varying salinity regimes, this greatly increases the complexity and uncertainty of LWP assessments, meaning much greater reliance must be placed on other analytical tools such as stable isotopes. However, trees that demonstrate LWP values that are considerably more negative than expected ranges for the local groundwater salinity regimes were assumed not to exhibit any significant degree of groundwater dependence. From the range of groundwater salinities recorded from monitoring bores, sites with average LWP <-1.5 MPa (standard wilting point) were not subject to further scrutiny, other than for comparative purposes. Groundwater with salinity > 30 000 µS /cm is considered an unsuitable source of moisture for most trees and unlikely to be utilised to any significant degree.

Step 2. SMP: For trees where LWP was within the expected range of values for GDE's under specific local salinity regimes, an assessment of SMP from auger profiles was undertaken to identify the likelihood that moisture for transpiration was being supplied from the upper soil profile, or whether deeper sources of moisture must be inferred. As described in **Section 3.4**, water only has capacity to move down a hydraulic gradient from soil to root meaning that only those portions of the soil profile that have a SMP that is less negative than measured pre-dawn LWP will be accessible as a source of moisture (Gardner 1960). This does not provide an absolute assessment of groundwater dependence though identifies potential sources of moisture to provide context to assessment of stable isotopes (Step 3). It is noted that SMP data is not available at all sites, increasing the reliance on stable isotopes during data reconciliation.

Step 3. Stable Isotope Signatures: For trees that demonstrate potential groundwater dependence from LWP measurements, stable isotope signatures from the xylem samples were compared to signatures from groundwater, surface water from residual and permanent pools, and soil moisture (where this data was available) to provide a fingerprint for the source of moisture being utilised.

Where three lines of evidence indicated utilisation of a groundwater source, the tree was generally accepted as being groundwater dependent. Where ambiguity remained in the assessment, additional features were considered including site specific geology, geomorphology, soil physical properties, groundwater salinity and depth to water table at the location to inform the final assessment of groundwater dependence for any tree or site.

3.6 Limitations and Other Information Relevant to the Assessment

This assessment provides a snapshot of eco-hydrological process at each of the 17 GDE assessment localities identified during pre-survey desktop assessment and sampled during field survey. Specific limitations include:

1. Climatic conditions preceding the assessment were dry, although significant rainfall in the month preceding the survey (July 2021) would have recharged moisture in the shallow soil profile, potentially creating some surface flow in the major creeks, and recharged wetland habitats. Where ambiguity in biophysical measurements were apparent, stable isotope signatures were relied upon to differentiate groundwater from other soil moisture sources.
2. Access was limited in some localities due to requirements for considerable foot traverse, which was not possible due to sampling timing interval constraints. Generally, areas requiring greater than 500m of foot traverse from the nearest access point could not be sampled efficiently within the pre-dawn sampling window. Site 12 on the western portion of Boomerang Creek was the only planned site not sampled during the assessment, although due to a considerable number of alternative sites downstream on Boomerang Creek, removal had little consequence for the overall assessment or data interpretation.
3. Due to the intensive nature of the data collection, representative areas were chosen for GDE sampling which were used as a basis for extrapolation over broader areas considered to present similar ecohydrological function. The data collection process aimed to inform

conceptualisation of the types of GDEs present on the site and their general distribution, so an informed risk assessment could be completed.

4. The ecological processes and hydrogeological conditions encountered within the Project area are complex and transient. Interpretations and conceptualisations presented here are based upon multiple lines of evidence and represent what the author considers is the most appropriate interpretation of the data. Continued refinement of the presented conceptual models may result from further data collection on a seasonal basis, although it is not considered essential to inform the GDE Risk assessment.

4.0 Results

Survey results are divided into individual sections dealing with LWP, SMP and stable isotope assessment in a manner consistent with the data reconciliation process detailed in **Section 3.6**. In **Section 5.0** (Discussion), interpretation of the results considers a combination of all parameters and places that interpretation into a conceptual site model (CSM).

4.1 Leaf Water Potential Measurements

A summary of LWP sampling results for all trees, including locations of sampled trees relative to waterways is provided in **Appendix A.** Representation of average LWP results for all assessment sites is shown in **Figure 12** with a breakdown of LWP for individual trees shown in **Figure 13. Figure 14** provides a spatial representation of average water availability per site with spatial details for each GDE area shown in **Appendix B**. Summary of the results is provided in **Table 3** which also provides notes on site ecology and RE. Based on **Table 3,** the only GDE assessment areas that have likelihood of representing GDEs are GDE Site 1, GDE Site 2, GDE Site 3 and GDE Site 9, GDE Site 10, GDE Site 16 and GDE Site 18. There is some potential that trees from GDE Site 4, GDE Site 6 and GDE Site 8 have LWP values that be indicative of saline groundwater usage. Other localities present LWP values that are too low for the local groundwater salinity regime or are associated with groundwater salinity that is too high to represent a viable source of moisture for transpiration.

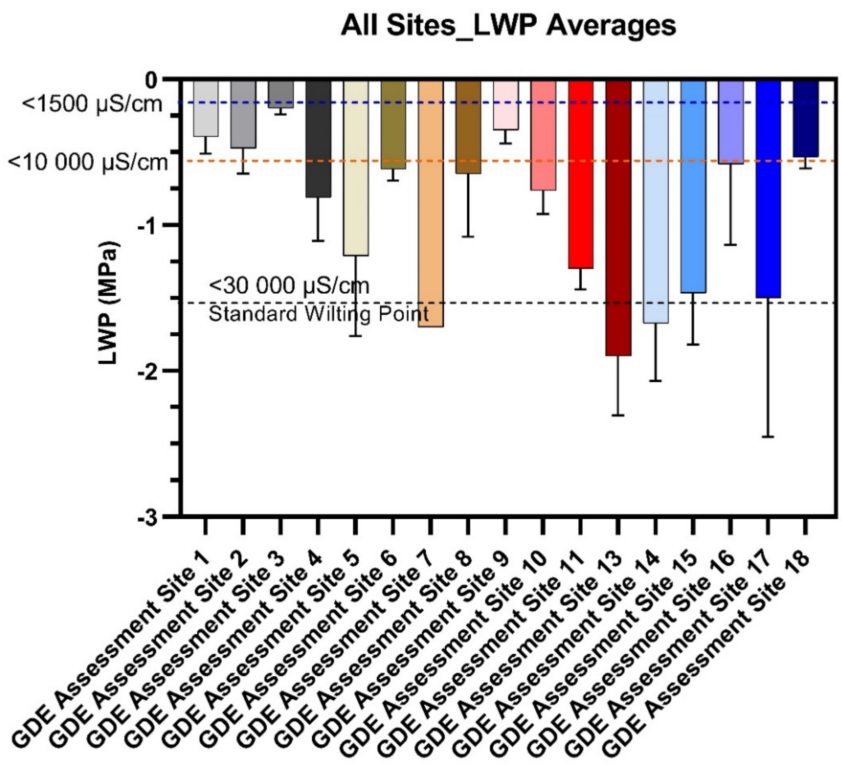


Figure 12. Average LWP readings for all GDE Assessment Areas. The blue line (>-0.2MPa) indicates typical LWPs for trees in equilibrium with a non-saline saturated source of soil moisture; the orange line (>-0.55MPa) indicating typical values for trees in equilibrium with a moderately saline soil moisture source (EC 10 000 µS/cm) and the black line indicative of trees in equilibrium with saline source of moisture at 30 000 µS/cm coinciding with Standard Wilting Point (<-1.5MPa).

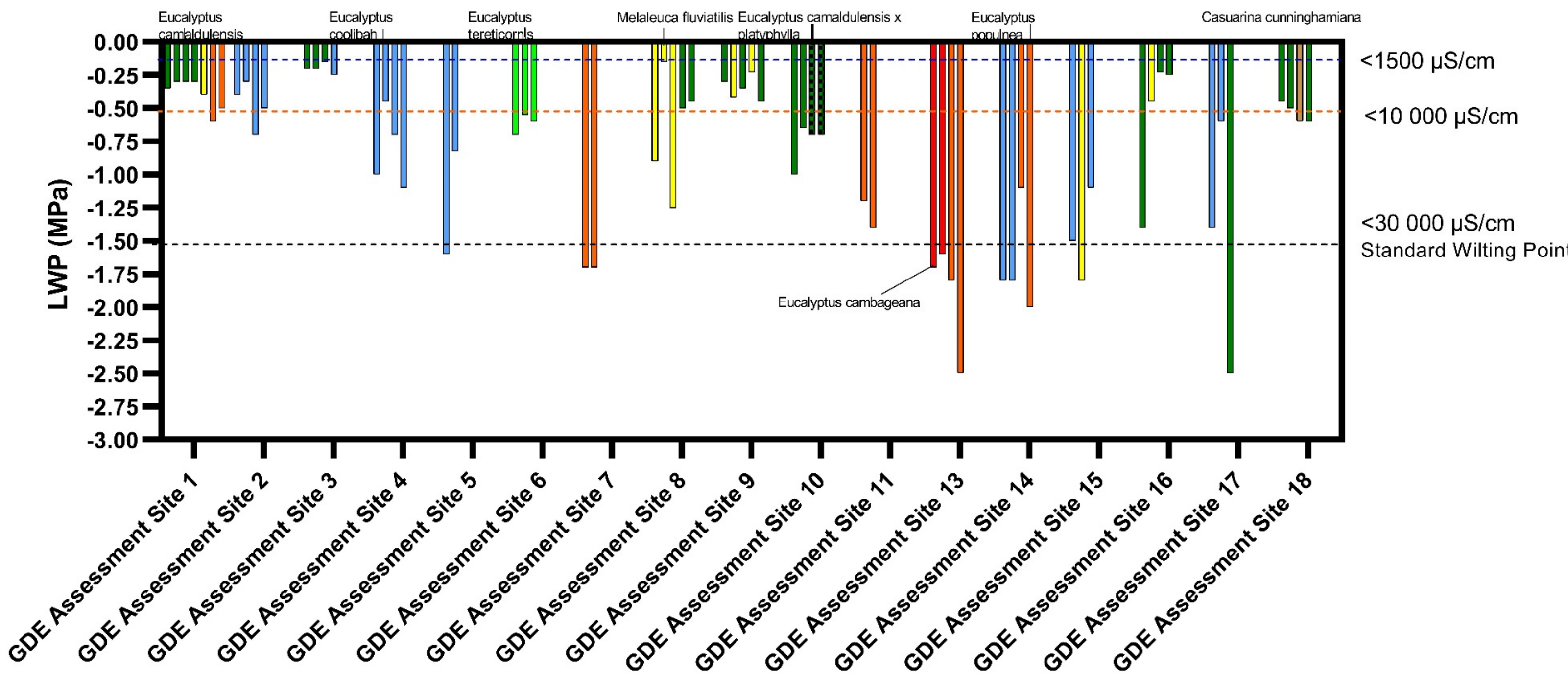


Figure 13. LWP results for individual trees per species at each of the 12 GDE assessment areas.

Table 3. Summary details and results of LWP assessment for each sampling area.

Site	Average LWP (MPa)	Water Availability	Comments
Sites that indicate extremely to very high water availability / Possible near-saturated source of fresh soil moisture of groundwater			
GDE Site 1	-0.39 MPa	Very High	GDE Site 1 represents well developed riparian open forest typical of RE11.3.25, dominated by river red gum and weeping tea tree, fringing the major watercourse of the Isaac River. The upper alluvial terrace forms at 12m above the sandy channel floor and is occupied by a well-developed woodland of poplar box, representative of RE11.3.2. The average LWP is very high (-0.39MPa) indicative of extremely high water availability, with the LWP highest near the river channel (-0.3MPa for Tree 2, 3, 4), decreasing onto the top of the upper Terrace where Tree 6 presents a LWP of -0.6MPa. The data indicates trees on the lower terrace are accessing a zone of high moisture availability, potentially indicative of fresh groundwater with a salinity not significantly higher than 1500 µS/cm, with water availability decreasing as depth to groundwater increases and soil texture becomes loamier. The nearest groundwater monitoring bore is W15_MB2 which is installed into the base of the Tertiary aquifer, has a SWL of -17mbgl, and a salinity of approximately 25000 µS/cm. This suggests that groundwater from the regional Tertiary aquifer is not being utilised, and groundwater is from a localised fresh source associated with the Isaac River. Groundwater sampled in the riverbed aquifer demonstrated a salinity of 195 µS/cm which presents a more likely source of groundwater utilisation. Groundwater dependency of vegetation associated with the Isaac River is discussed in 3d Environmental (2020).
GDE Site 2	-0.475	Very High	GDE Assessment Site 2 is located at a HES wetland. The feature had surface water at the time of the assessment (**Photograph 1**), with the waterbody fringed by a well-developed woodland of coolibah (RE11.3.3) with trees extending surface roots toward the waterbody margins. While the average LWP is very high (-0.475), there is no pattern with the highest LWP returned from Tree 2 (-0.3), which is furthest (15m) from the margin of the waterbody and the lowest in Tree 3 at 10m from the waterbody. Salinity of surface water was measured at 179 µS/cm which would be consistent with recent rainfall. While the high LWP values recorded at this locality could be attributed as groundwater usage, it is more likely to be related to

Site	Average LWP (MPa)	Water Availability	Comments
			variable utilisation of fresh surface water with further information from stable isotopes required.
GDE Site 3	-0.2	Extremely High	GDE Site 3 represents a palustrine wetland, being a circular waterbody fringed by brigalow and coolibah woodland with large specimens of river red gum and coolibah occupying wetlands central portion (**Photograph 2**). The wetland was dry at the time of assessment although scattered patches of water chestnut (*Eleocharis dulcis)* are indicative of recently wet conditions. The average LWP values returned at this assessment site are extremely high (-0.2MPa), the highest of all GDE assessment sites. As there is no surface water present, the extremely high LWP values are attributed to a source of fresh water at depth in the soil profile. Based on extremely high LWP values and lack of available surface water, GDE Assessment Site 3 is considered likely to be a GDE that is utilising a localised source of fresh perched groundwater that is couched in the alluvium.
GDE Site 9	-0.35	Very High	GDE Assessment Site 9 is similar to Site 8, with both being located on Boomerang Creek. LWPs range from -0.23MPa to -0.45MPa, indicative of very high to extremely high moisture availability, suggesting that a fresh source of moisture / groundwater is being utilised for transpiration. The likely source of this would be from moisture / perched groundwater couched in the riverbed sand and inner alluvial terraces. There is no indication that trees are utilising a deeper source of groundwater in the Tertiary aquifer.
GDE Site 16	-0.58	Very High	LWPs at GDE Site 16 range from extremely high (-0.23 MPa for Tree 3) to low (-1.4MPa for Tree 2). Both Tree 2 and Tree 3 are located directly on the margins of the sandy channel, which indicates the variable nature of moisture availability in the river sand, which is subject to depletion through transpiration. The LWPs at GDE Assessment Site 16 (**Photograph 4**) are indicative of the variable nature of moisture availability within the narrow sliver of alluvium / river sand that forms the channel and inner terraces of Boomerang Creek. There is no indication that trees are utilising a deeper source of groundwater in the Tertiary aquifer. Further information is provided in sections relating to stable isotopes and SMP.
GDE Site 18	-0.54	Very High	LWPs at GDE Site 18 are relatively consistent, ranging from high (-0.45 MPa for Tree 1) to low (-0.6MPa for Tree 4). While Tree 1 is directly on the channel margins, Tree 4 is high on the upper terrace, which would explain the lower LWP. The high LWPs are indicative of moisture availability within the narrow sliver of alluvium / river sand that forms

Site	Average LWP (MPa)	Water Availability	Comments
			the channel and inner terraces of Phillips Creek. There is no indication from LWP values those trees are utilising a deeper source of groundwater in the Tertiary aquifer. Further information is provided in sections relating to stable isotopes and SMP.
Sites that indicate high to moderate water availability – Likely to be extracting moisture from the vadose zone or possible utilisation of saline groundwater			
GDE Site 4	-0.8125	Moderate	GDE Site 4 is located on the channel of Ripstone Creek (**Photograph 3**), a seasonal watercourse which was dry at the time of assessment. The site is characterised by 15m wide channel incised to depths of up to 5m into a clay loam floodplain with *Eucalyptus coolibah* being the dominant tree. Generalised extrapolations from W13_MB2 (3.5km west) would suggest SWL of -17mbgl, and a salinity of approximately 25000 µS/cm in the coal seams, which would be too deep for utilisation by coolibah due to relatively shallow root morphology. There is no evidence from LWP measurements that trees are utilising a fresh groundwater source in the alluvium, and it is considered most likely that are sourcing soil moisture in the vadose zone to support transpiration. Stable isotopes analysis will add confidence to this assessment.
GDE Site 6	-0.6166	High	GDE Site 6 is located on a channel overflow of Ripstone Creek, occupying a broad depression with forest red gum (*Eucalyptus tereticornis)* occupying the central portion of the depression. There was no surface water in the drainage feature at the time of the assessment. The highest LWP at the assessment locality was -0.55MPa with the lowest at -0.70MPa. The LWP is not sufficiently high to suggest utilisation of a source of fresh groundwater perched in alluvium and it is most likely that trees are utilising soil moisture in the vadose zone. Stable isotopes will add further confidence to this assessment.
GDE Site 8	-0.65	High	LWPs at GDE Site 8 are variable, ranging from extremely high -0.15MPa (weeping tea tree - Tree 2) to -1.25MPa (weeping tea tree - Tree 3). Both Tree 2 and Tree 3 are located directly on the margins of the sandy channel, which indicates the variable nature of moisture availability in the river sand, which is subject to depletion through transpiration. The two river-red gum sampled (Tree 4 - 0.45MPa and Tree 5 – 0.5MPa) located on the inner terrace would be expected to have lower LWP values than the weeping tee tree due to their higher geomorphic position. The LWPs at GDE Assessment Site 8 are indicative of the variable nature of moisture availability within the narrow sliver of alluvium / river sand that forms the channel and

Site	Average LWP (MPa)	Water Availability	Comments
			inner terraces of Boomerang Creek. There is no indication that trees are utilising a deeper source of groundwater in the Tertiary aquifer.
GDE Site 10	~~-0.76~~	~~High~~	GDE Assessment Site 10 (**Photograph 3**), representing a wetland perched on the Tertiary surface, presents a high average LWP (-0.76) with a range of values from -0.65MPa to -1.0MPa. The nearest groundwater monitoring bore (W3_MB2) is 800m northwest and indicates the groundwater table in Tertiary sediments is at 18mbgl, with a salinity of approximately 11 000 µS/cm. While the salinity is in the range of tolerance for most eucalyptus species, the considerable depth to the groundwater resource is a considerable impediment to tree utilisation. It is most likely that the high LWPs are derived from soil moisture in the vadose zone rather than a saline groundwater source. Analysis of stable isotope will assist characterisation of the sites water relations. It is noted that salinity of surface water at the wetland was 127 µS/cm, suggesting that it is derived from recent rainfall.
Sites that indicate low to very low water availability – Unlikely to be utilising groundwater to any degree			
GDE Site 7	-1.7	Low	LWP at assessment Site 7 is extremely low suggesting extremely limited moisture availability in the soil profile. Based on data from monitoring bore W3_MB2, groundwater in the Tertiary sediments is >18mbgl and highly saline, indicating that it is not an available source of groundwater for transpiration. Trees at this locality are not utilising groundwater.
GDE Site 5	-1.2125	Low	GDE Site 5 is located on the channel of Ripstone Creek presenting a similar channel and floodplain ecology, geomorphology to GDE Site 4. Only two coolibah trees were sampled for LWP at the site, presenting moderate LWP values ranging from -0.8125 to -1.6MPa. Based on the relatively shallow rooting morphology of coolibah, and considerable depth to the regional saline groundwater table, it is most likely that trees are utilising soil moisture in the vadose zone rather than a groundwater / saturated moisture source.
GDE Site 11	-1.3	Low	LWP at assessment Site 11 is Low suggesting limited moisture availability in the soil profile. Based on data from monitoring bore W1_MB2 (approx. 1.5km to the north-west), groundwater in the Tertiary sediments is >25mbgl and highly saline (approximately 25 000 µS/cm). This indicates that it is not an available source of groundwater for transpiration. Trees at this locality are not utilising groundwater.

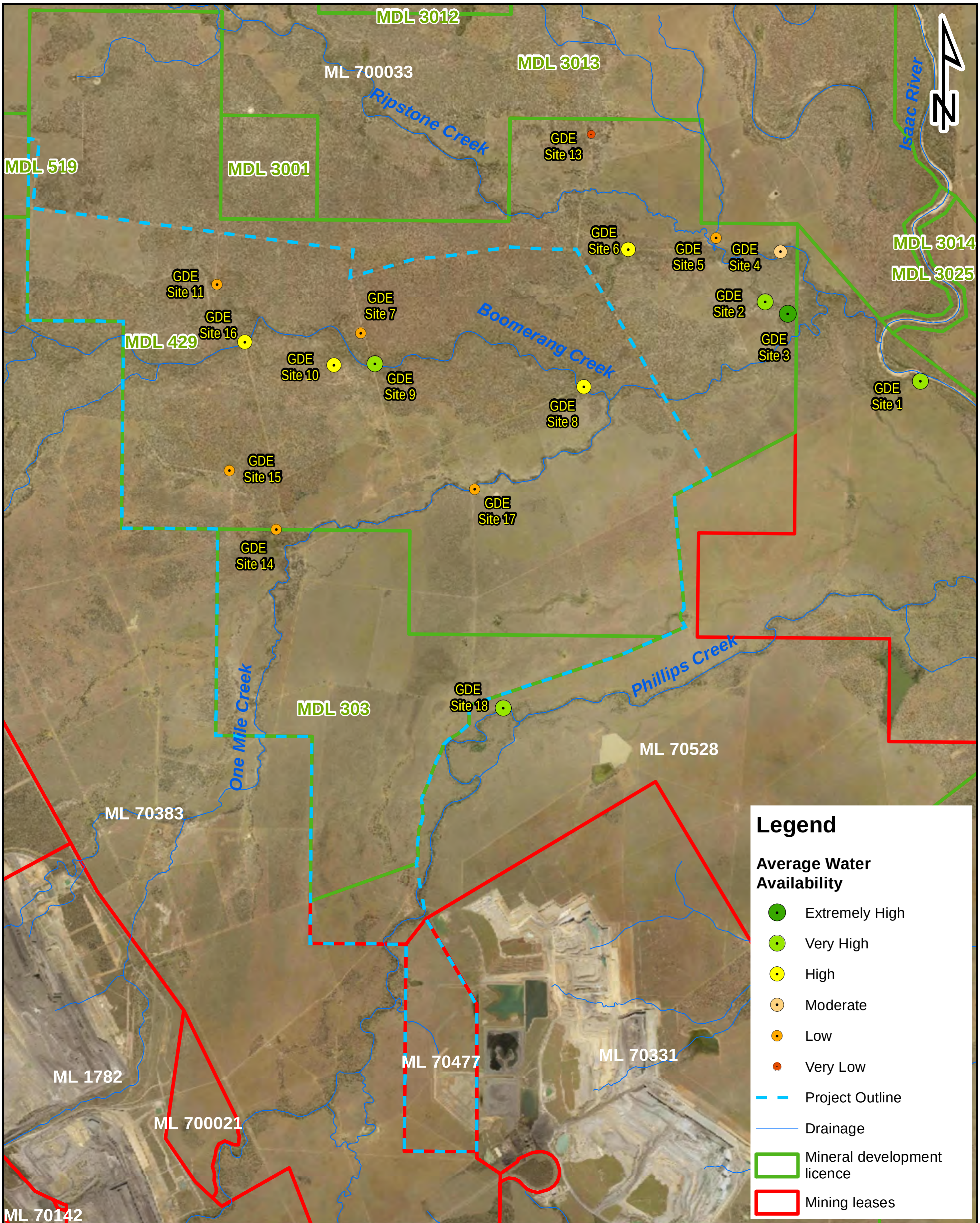
Site	Average LWP (MPa)	Water Availability	Comments
GDE Site 13	-1.9	Very low	LWP values from the two Dawson Gum and two poplar box sampled indicate extremely low LWP ranging from -1.7 to -2.5MPa. Data from W13_MB2 indicates groundwater in the Tertiary sediments is 18mbgl and saline (approximately 25 000 µS/cm) indicating that it is likely to be inaccessible and unsuitable as a moisture source for tree transpiration. The extremely low LWP values reflect the moisture content of the heavy clay soils from which trees at the site are extracting moisture. No groundwater is being utilised by vegetation at this locality.
GDE Site 14	-1.8	Very Low	LWP values range from -1.1MPa to -2.5MPa in measured trees fringing a small drainage channel and wetland depression. Considering the known shallow rooting depth for poplar box and most likely coolibah, it is unlikely that trees are accessing deeper groundwater sources and the low LWP values reflect the moisture content of the heavy clay soils from which trees at the site are extracting moisture. There is no indication of groundwater utilisation at this locality and while small surface pools (476 µS/cm) are present in proximity to some trees, extremely low LWPs are indicative of moisture extraction from a clay soil profile rather than utilisation of either surface water or groundwater.
GDE Site 15	-1.65	Low	GDE Assessment Site 15, representing a wetland perched on the Tertiary surface, presents an extremely low average LWP (--1.65) with LWP values ranging from -1.1MPa to -2.1MPa. Considering the known shallow rooting depth for poplar box and most likely coolibah, it is unlikely that trees are accessing deeper groundwater sources and the low LWP values reflect the moisture content of the heavy clay soils from which trees at the site are extracting moisture. There is no indication of groundwater utilisation at this locality. Salinity of surface waters within a watercourse at the assessment locality was measured at 495 µS/cm and it is also considered unlikely that trees are utilising surface water to any significant degree.
GDE Site 17	-1.5	Low	Extremely variable LWP values ranging from -0.5MPa to -2.5MPa suggests small pockets of high moisture availability are present in the soil profile, though not laterally extensive. Overall, LWP values are too low to be indicative of groundwater utilisation.

Photograph 1. HES wetland at GDE Site 2, fringed by coolibah (RE11.3.3). Surface water is extremely fresh (179 µS/cm).

Photograph 2. Large coolibah (Tree 4) subject to sampling at GDE Assessment Site 3, with patches of water chestnut indicative of recent surface water.

Photograph 3. Wetland at GDE Assessment Site 10, lined by river red gum.

Photograph 4. Sandy channel lined by river red gum and weeping tea tree at GDE Assessment Site 16 (Boomerang Creek).



Extremely High	>-0.276 Mpa
Very High	<-0.276 to -0.580 MPa
High	<-0.580 to -0.896 MPa
Moderate	<-0.896 to -1.21 MPa
Low	<-1.21 to -1.72 MPa
Very Low	<1.72 to -2.21 Mpa
Extremely Low	<-2.21 Mpa

Figure 14. Spatial representation of average LWP values for sampling sites in the assessment area

Client
AARC Environmental Solutions

0 1.25 2.5 3.75 5
Kilometers

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4.2 Hand Auger Profiling and Soil Moisture Potential

As per **Section 3.4**, the purpose of the SMP testing is to identify, for those trees where LWP measurement indicate potential groundwater usage, whether sufficient moisture is available in the upper unsaturated portion of the soil profile (i.e., vadose zone) to explain LWP measurements. The location for auger holes was selected during the field survey to cover sites where potential groundwater dependence was indicated or were considered representative of a particular habitat or landform. In total, six auger holes were installed including:

1. GDE Site 3 where the auger hole was placed next to Tree 2 in the central portion of the wetland, where all trees demonstrated extremely high LWP. The auger penetrated to a depth of 6.1mbgl.
2. GDE Site 8 where the auger was installed in the river sand next to Tree 2 (LWP – 0.25) to a depth of 1.7mbgl. Penetration was arrested by dense matted tree roots from weeping tea tree at the base of the river sand.
3. A single auger hole at GDE Site 10, installed to a depth of 2.25mbgl where penetration was arrested by dense clay.
4. Two auger holes at GDE Site 16. One hole was installed on the terrace above the stream channel to a depth of 5.3mbgl, and the other was installed in the channel sand to a depth of 2.3mbgl. Both holes penetrated to the depth of the water table in river alluvium and groundwater was sampled for stable isotope analysis.
5. A single auger hole at GDE Site 18 installed in the river channel sand near Tree 1 to a depth of 2.3mbgl. Auger penetration was arrested at a coarse gravel band at the base the river channel sand.

4.2.1 Soil Moisture Potential in GDE Assessment Site 3

Soil moisture data in GDE Site 3 (HES wetland) is presented in **Figure 15,** providing a lithological summary matched to measured SMP. The data demonstrates that the entire depth of the 6.3m soil profile comprises a massive silty loam derived from floodplain alluvium. The downhole profile demonstrates an SMP that is much lower (more negative) than the recorded LWPs from trees at the site. The presence of fine tree roots to near the full depth of soil profile indicates that that there are no preferential zones from which trees are extracting soil moisture in the profile. Based on an extremely high LWP from trees at this locality, it can be inferred that soil moisture is being extracted from a region in the soil profile that is deeper than 6.3mbgl. This region would possess soils with high matric potential (i.e., sandier soil structure) which would be expected to hold perched groundwater at the base of the alluvium on a seasonal basis.

4.2.2 Soil Moisture Potential in GDE Assessment Site 8

Soil moisture data in GDE Site 8 is presented in **Figure 16** showing an auger profile placed entirely in river sand with bands of matted tree root material throughout. While the data shows SMP becomes increasingly positive down profile to the base of the hole, the range of SMP values encompasses the full range of LWP values from trees sampled at the site. Therefore, the range of LWP values can be readily accounted for by moisture available in the local soil profile, rather than a deeper groundwater source. The extremely high LWP recorded in Tree 2 is most likely obtained from the base of the soil profile (i.e., 1.7mbgl) where SMP and LWP for Tree 2 correspond.

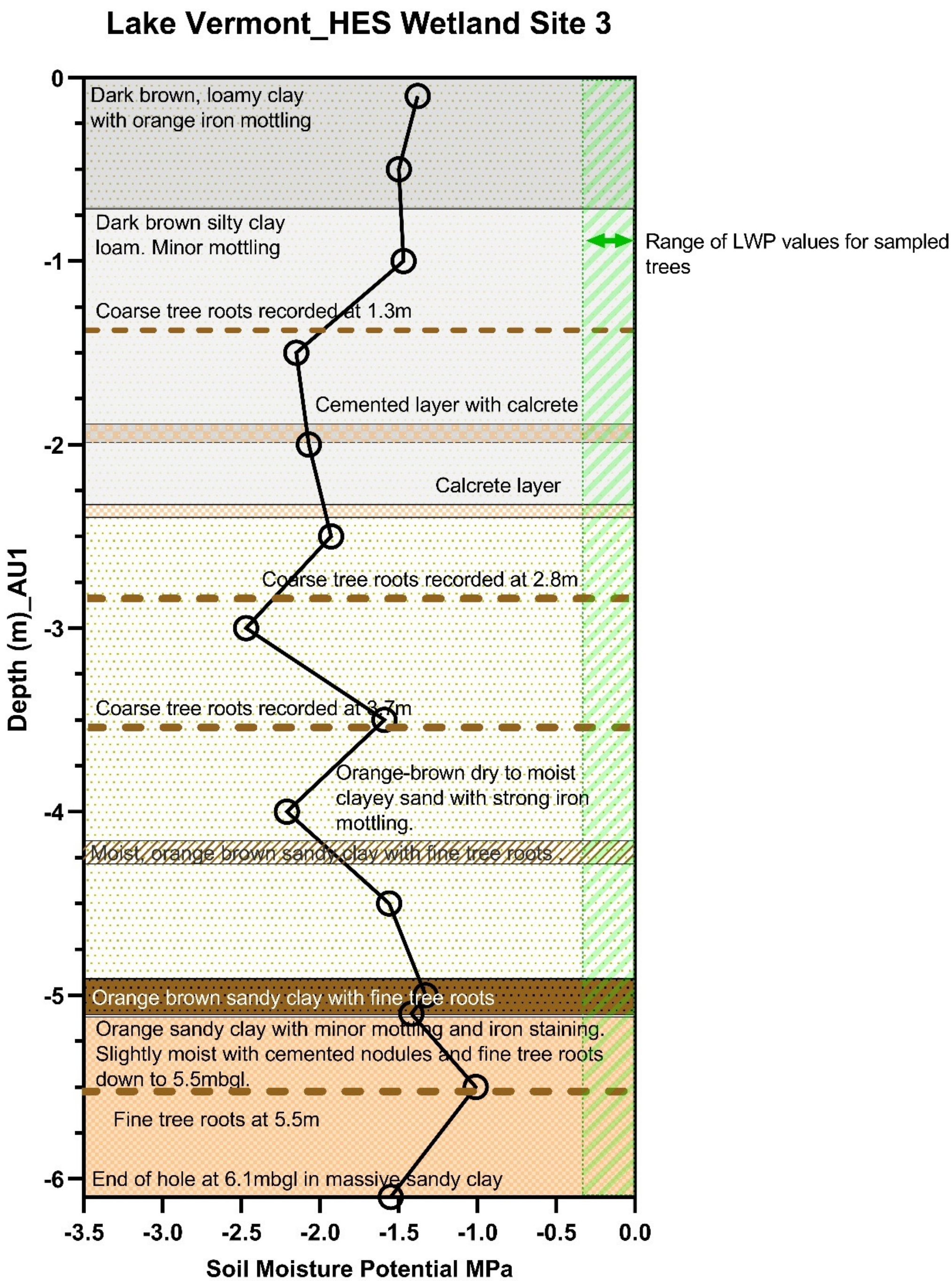


Figure 15. SMP relative to depth (mbgl) for Auger Hole 1 (AU1) at GDE Site 3.

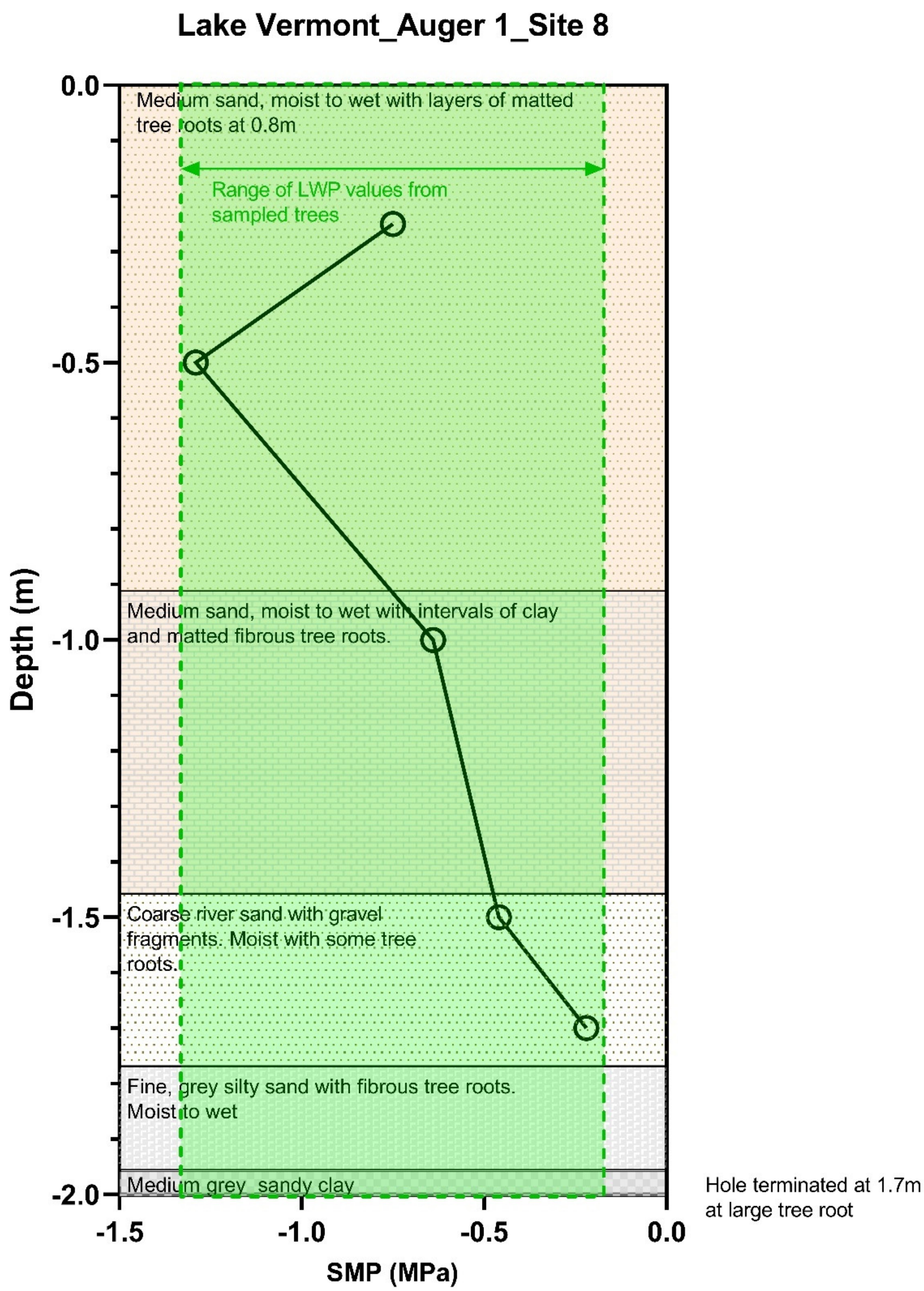


Figure 16. SMP relative to depth (mbgl) for Auger Hole 1 (AU1) and 2 (AU) at GDE Site 8 indicating LWP values can be readily accounted for in measured SMP.

4.2.3 Soil Moisture Potential in GDE Assessment Site 10

There is clear indication from **Figure 17**, that the range of LWP values from trees adjacent to the wetland at GDE Assessment Site 10 can be readily accounted for in the upper soil profile, at depths below 1.5mbgl where SMP matches the range of measured LWP values. It is noted that tree roots are recorded at 1.5mbgl, and abundant ironstone mottling is evident in the soil profile below depths of 1.75mbgl, indicating strong seasonal variation of moisture content.

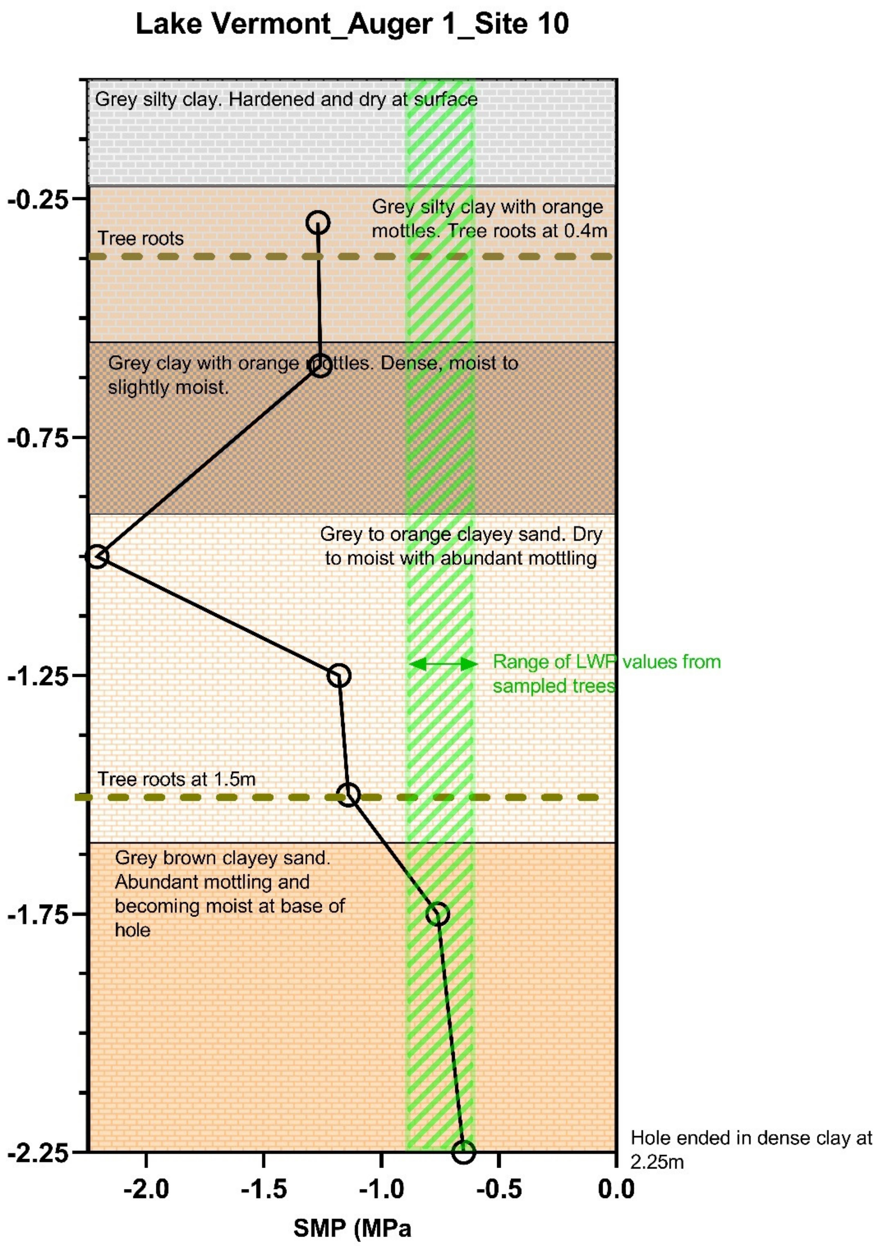


Figure 17. SMP relative to depth (mbgl) for Auger Hole 1 (AU1) at GDE Site 10 indicating the range of LWP values recorded at the site, corresponding the LWP values below 1.5mbgl.

4.2.4 Soil Moisture Potential in GDE Site 16

Lithological summaries and SMP profiles for the two auger holes installed at GDE Site 16 are shown in **Figure 18** and Figure 19. Auger hole 1 (**Figure 18**) is installed into sand in the river channel and shows an increase in SMP with depth in the soil profile, becoming close to zero at the surface of the groundwater table (salinity measured at 415 µS/cm). For Auger Hole 2 (**Figure 19**) which was installed on the terrace above the river channel, LWP values are equivalent to SMP values at depths below 3.5mbgl, suggesting that this is the region of the soil profile below which trees are accessing moisture for transpiration. It is notes that a saturated zone was intersected at 5mbgl from which small quantities of groundwater were drawn and sampled for water quality (376 µS/cm) and stable isotopes. Based on evidence from Auger 2, trees at GDE Site 16 are utilising a saturated source of soil moisture, representing a seasonal groundwater table that is couched in river sand and alluvium, and perched above the regional groundwater table in the Tertiary sediments.

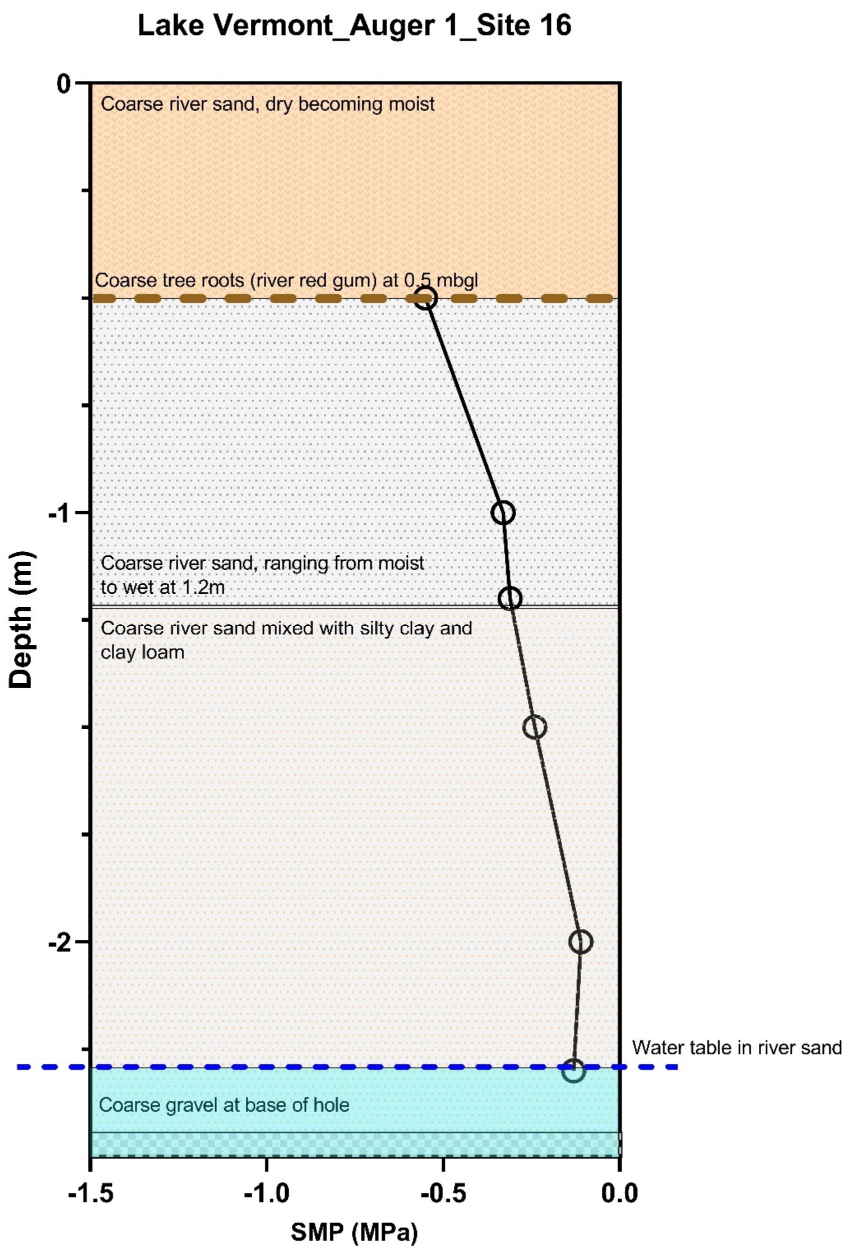


Figure 18. SMP relative to depth (mbgl) for Auger Hole 1 (AU1) at GDE Site 16 installed into the river channel. Groundwater is intersected at 2.20 mbgl.

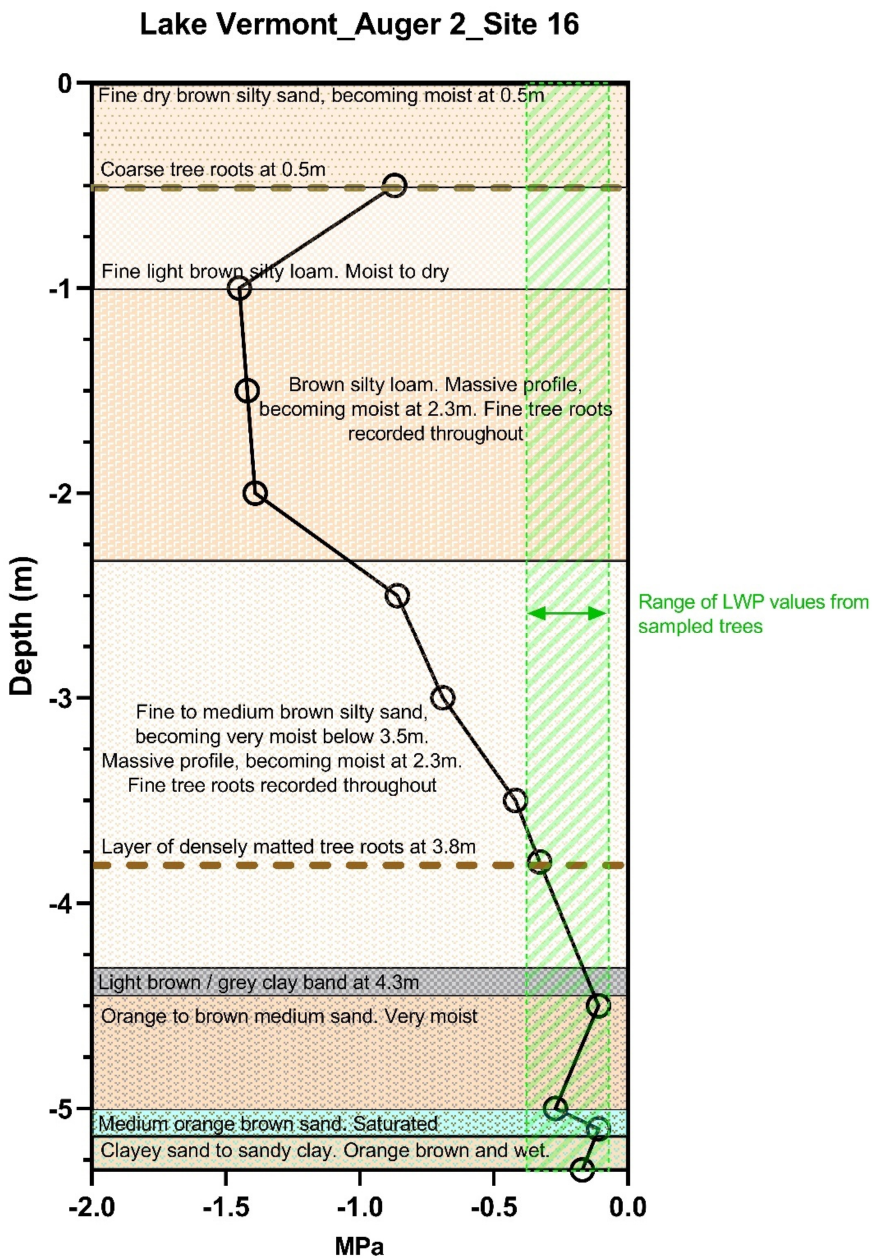


Figure 19. Downhole lithological summary and SMP profile for Auger 2 at GDE Site 16. SMP corresponds to LWP values below 3.5mbgl, with a narrow saturated zone intersected at 5mhgl.

4.2.5 Soil Moisture Potential in GDE Site 18

Lithological summaries and SMP for Auger hole 1 installed into sand in the river channel at GDE Site 18 is shown in **Figure 20**. The data shows SMP becomes increasingly positive down profile to the base of the hole with increasing soil moisture content. The range of LWP values recorded at Site 18 corresponds to depths between 0.7 mbgl and 2.0 mbgl and suggest LWP values can be readily accounted for by moisture content in the streambed sediments. The auger was terminated at a band of coarse gravel, most likely saturated, with saturation in the river sand varying on a seasonal basis.

Trees closer to the river channel (e.g., Tree 1 and Tree 2) would have greatest capacity to utilise groundwater in the river channel sands.

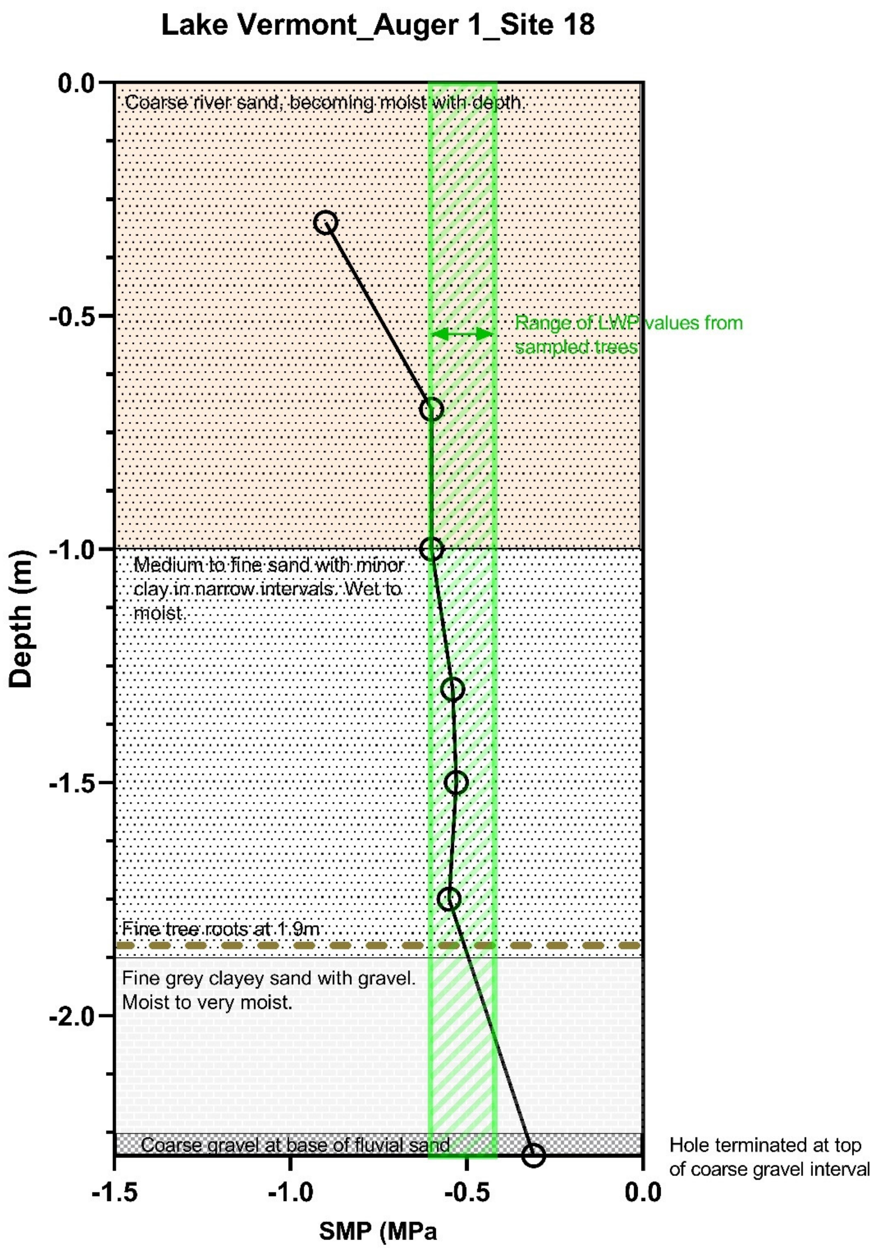


Figure 20. Soil lithology and SMP profile for Auger 1 at Site 18, showing LWP values correspond to SMP between 0.7 mbgl and 2.1 mbgl.

4.3 Stable Isotope Sampling and Analyses

Figure 21 shows stable isotope values ($\delta^{18}O$ and $\delta^{2}H$) for all values including soil, surface water from the wetland areas (GDE Site 2, GDE Site 10), selected groundwater samples (as per **Table 1**) and twig xylem water analysed during the assessment. Note that **Figure 21**, and all subsequent stable isotope biplots include the Local Meteoric Water Line (LMWL) for Rockhampton from Crosbie et al (2012). The LMWL provides a reference to identify evaporative processes, which will generally result in $\delta^{18}O$ isotope values that plot below the LMWL. The scatter shows:

1. A broad cluster of isotope values derived from soil samples lies mostly above the LMWL (black triangles).
2. A broad scatter of isotope samples from twigs (green triangles) which shows the greatest spread and range of all groups.
3. Two samples of groundwater from shallow alluvium collected during auger sampling as a component of this study.
4. Surface water samples (blue bullets) which are strongly enriched above other groups.
5. Two evaporative trends are indicated, from the surface water samples (blue arrow) representing waters from a common source (rainfall) which have been subject to differing degrees of evaporation. There is also an evaporative trend shown between some twig samples (green arrow), indicating trees that are utilising waters from a common source with vary degrees of evaporative enrichment.

The broad scatter of isotopic values in the soil and twig samples with significant overlap would be imparted by infiltration of surface water, with varying degrees of isotopic enrichment, into the soil profile. Infiltrating surface water would include direct infiltration of unfractionated rainfall with variable isotopic composition (dependent on the season and type of rainfall event[2]) and evaporatively enriched surface waters. It is noted that groundwater samples from the Tertiary and coal seam aquifers sit relatively tightly along the LMWL, which indicates limited isotopic change from the rainfall source, through limited evaporation and short residence time in the soil profile. This might suggest that recharge of these aquifers occurs through preferential flow (i.e., rapid recharge along faults and fractures) rather than slow infiltration through the soil profile which would promote fractionation. The two groundwater samples from shallow alluvium align with soil samples rather than regional groundwater samples from the Tertiary sediments and coal seams suggesting significant interaction with soils.

The scatter of stable isotope values above and below the LMWL for soil samples is likely due to ^{2}H fractionation because of long soil residence time and associated interaction with soil particles in the unsaturated portion of the soil profile prior to update by trees. Hydrogen stable isotopes have a higher energy state than those of oxygen and have a much stronger tendency to fractionate by processes other than evaporation (Singer et al 2014, Evaristo 2017). The scatter of isotope values both above and below the LMWL in twigs provides strong evidence that most trees are not utilising significant quantities of groundwater and are reliant on moisture derived from the unsaturated

[2] The isotopic composition of rainfall will vary dependent on season and the type of rainfall event. It is common for storm events to be enriched in the heavier stable isotopes at the beginning of the event and become progressively depleted with ongoing precipitation. The isotopic composition of winter rain is also typically lighter (lower in heavier isotope fractions) than summer rain (USGS, 2004).

portion of the soil profile. Raw data for all isotopic samples is provided in **Appendix D**. Stable isotope results for individual assessment areas is provided in subsequent sections.

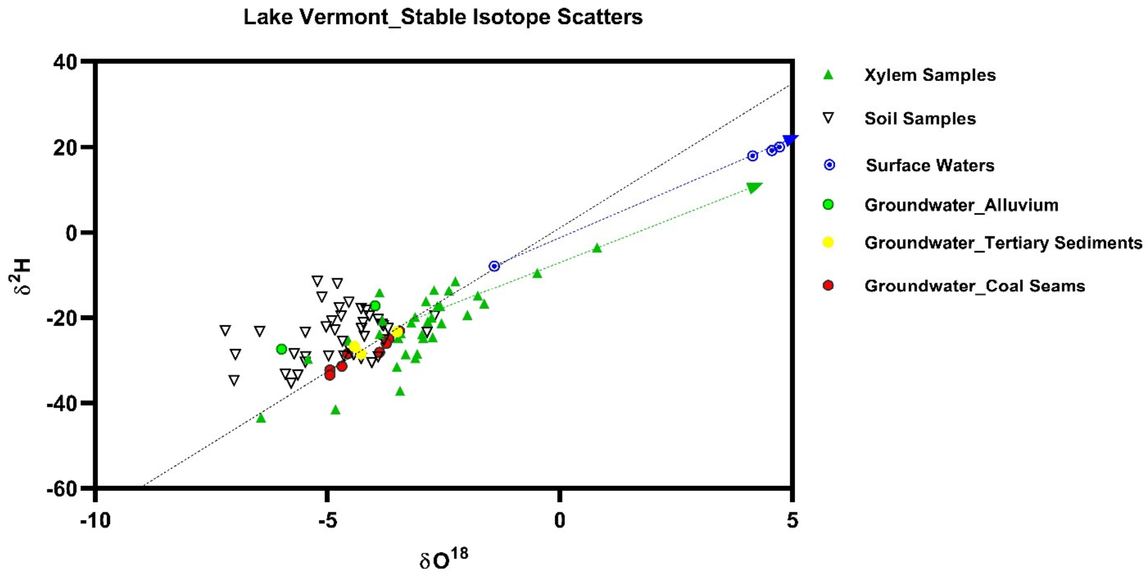


Figure 21. Stable isotope scatters for all data with the LMWL for Rockhampton indicated by black dashed line, cluster of groundwater samples from the Tertiary and coal seam aquifers along the LMWL, scatter of isotopic values for twigs and soils and evaporative trendlines for surface waters (blue arrow) and twig samples (green line).

4.3.1 GDE Assessment Site 1 – Isaac River

Stable isotope samples from the Isaac River (GDE Site 1) are shown in **Figure 22** as a biplot relative to groundwater samples from the Tertiary sediments and coal seams. The data shows a strong scatter of isotopic samples from twigs below the LMWL, the single groundwater sample extracted from the riverbed sand demonstrates relative isotopic depletion (though sitting above the LMWL), and an enriched sample from surface water from a pool in the river. The scatter of xylem samples indicates that trees are utilising moisture from various sources including soil moisture and potentially groundwater from the alluvium, although there is unlikely to be a common groundwater source for all trees.

4.3.2 GDE Assessment Site 2 and GDE Assessment Site 3 (HES Wetlands)

Isotopic samples from the two HES wetland sites (GDE Site 1 and GDE Site 2) are shown as a biplot in **Figure 23** relative to groundwater samples from the Tertiary sediments and coal seams. The data shows a relatively tight scatter of isotopic samples from soils at GDE Site 1 above the LMWL and relative enrichment of the twig samples from GDE Site 2 compared to GDE Site 3. The twig samples from GDE Site 2 lie on the same evaporative trend as the highly enriched surface water sample from the same wetland. This provides strong evidence that:

1. The wetland at GDE Site 2 is a surface feature only that is recharged by rainfall, consistent with the low salinity (179 µS/cm) of the surface water. There is no indication of any

groundwater interaction and GDE Site 2 is not an Aquatic GDE as represented in BOM (2020b).

2. The trees are utilising soil moisture that has been recharged by the surface water when the wetland was at various stages of bank-full, with the most enriched samples from xylem likely to be from trees that are directly utilising surface water. There is no indication of groundwater usage at this locality and the GDE Site 2 is not a Terrestrial GDE.

For GDE Site 3, a downhole δO18 plot has been constructed from soil samples collected during auger profiling as shown in **Figure 24**. The plot shows that the δO18 values of twigs and soils overlap at approximately 5mbgl, although for nearly the entire profile, there is a considerable offset between twigs and soils. While this might indicate tree moisture extraction for a zone in the soil profile at 5mbgl, biophysical measurements of SMP suggest that this is unlikely (see **Section 4.2.1**), further supported by the presence of tree roots recorded at 5.5mbgl. The most likely interpretation is that the zone of predominant moisture uptake (based on the δO18 overlap) is below the depth of the soil auger hole (6.1mbgl) in a seasonally recharged alluvial groundwater table that lies below the wetland.

4.3.3 GDE Assessment Site 8, Site 9, Site 16 - Boomerang Creek

The isotopic samples for twigs and soil for all sites on Boomerang Creek have been combined on a single biplot shown in **Figure 25**. The data shows twig samples form a broad scatter which is generally enriched above both the soil samples and the groundwater samples from the regional aquifers (coal seams and Tertiary sediments). There is general overlap between the twig samples and the groundwater sample from the shallow alluvium at GDE Site 16 (collected during auger sampling) which suggests groundwater from the alluvium may support transpiration in some trees. While there is some overlap between twigs and regional groundwater sources, evidence from LWP and SMP analysis (**Section 4.1** and **Section 4.2**) suggests that these sources are not being utilised by any trees at these localities.

When the isotopic scatter is reduced by excluding ^{2}H values, the correlations become more apparent and there is similarity between δO18 values returned from twigs and the alluvial groundwater sample collected during auger profiling (see **Figure 26**). The slight enrichment in δO18 values in twigs over the groundwater samples would be consistent with minor isotopic fractionation occurring as water moves through xylem vessels, as per Evaristo et al (2017) and Petit and Froend (2018). Overall, the data from the three assessment sites on Boomerang Creek provides evidence that trees are utilising groundwater that is perched in the river sand alluvium and creek terraces when it is available, though this is supplemented with soil moisture for those trees occupying sites where the alluvial groundwater has been locally depleted.

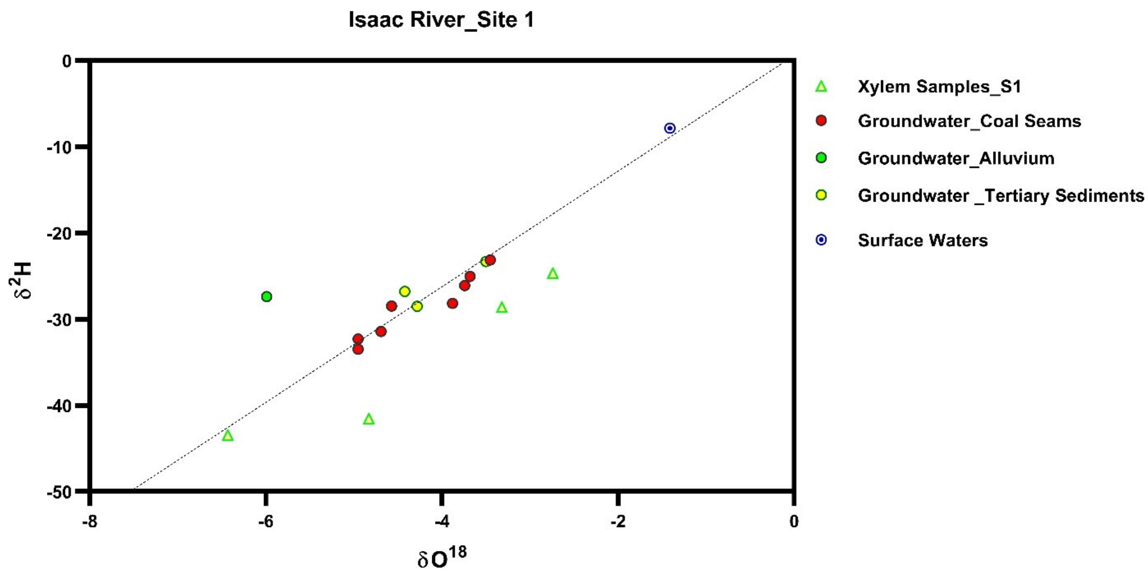


Figure 22. Stable isotope scatter from soils, twigs, groundwater and surface water from Isaac River GDE Site 1 compared to groundwater from coal seams and Tertiary aquifers. LMWL for Rockhampton is indicated.

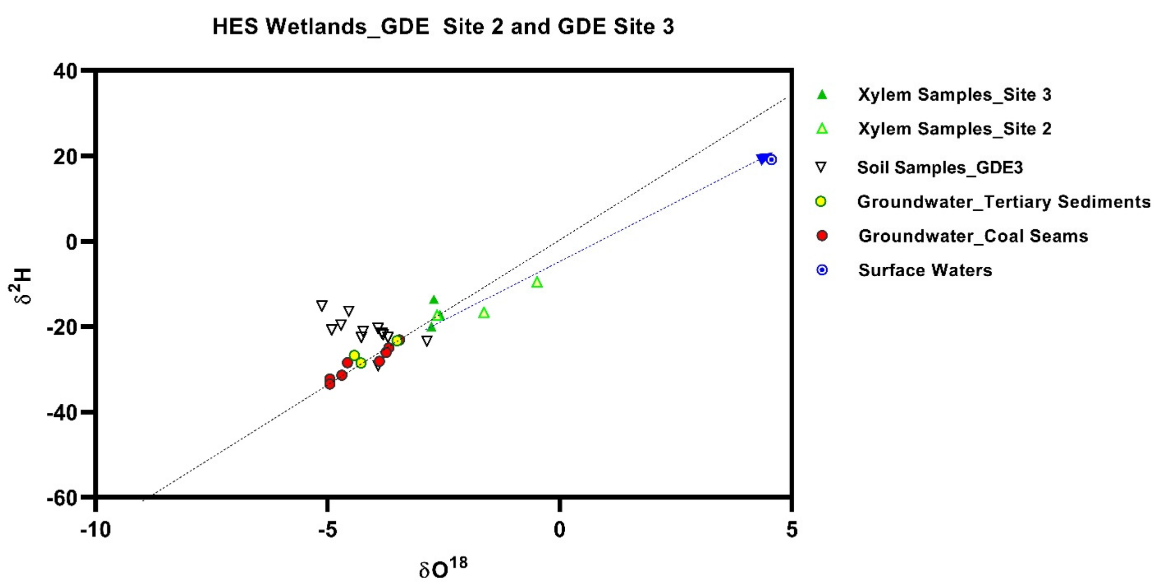


Figure 23. Stable isotope biplot from GDE Site 2 and GDE Site 3 (both HES wetlands) compared to regional groundwater samples and surface water. The evaporative trendline for twigs and surface waters is shown by the blue arrow.

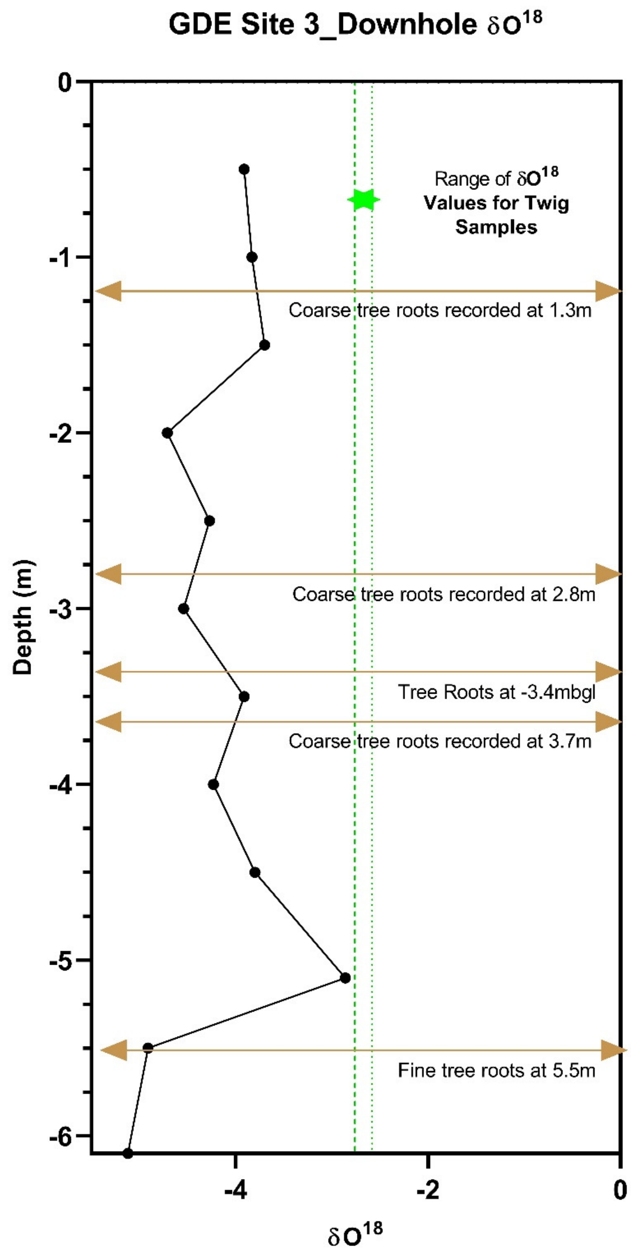


Figure 24. Downhole δO18 profile for Auger 1 at GDE Site 3, showing general offset in δO18 values between twigs and soils with a zone of overlap at 5.5mbgl.

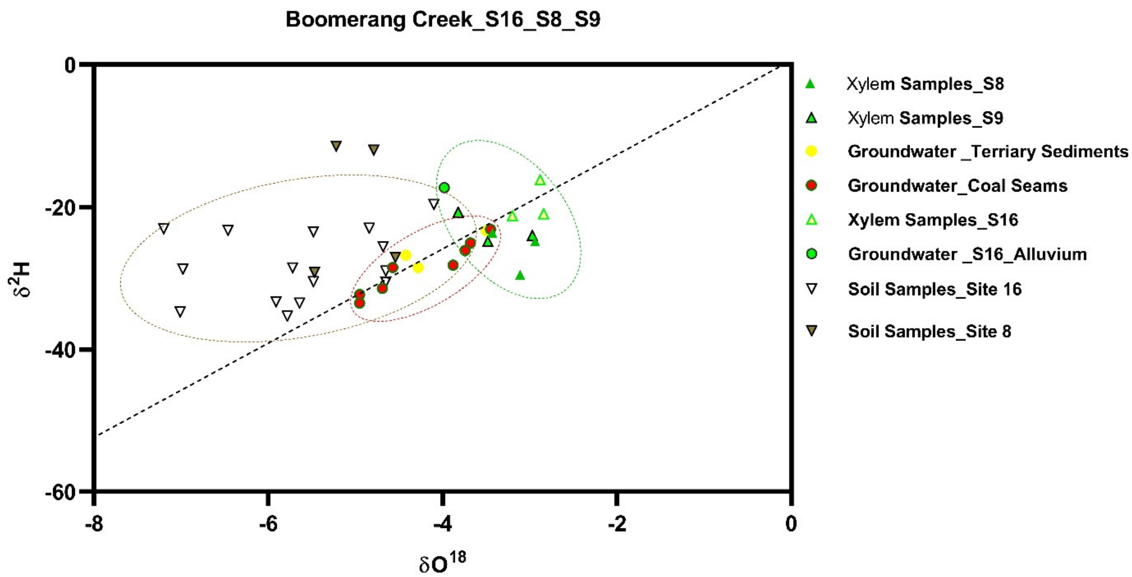


Figure 25. Stable isotope scatters for samples Boomerang Creek GDE Site 8, 9 and 16 showing general enrichment of the twig samples over soil and regional groundwater samples.

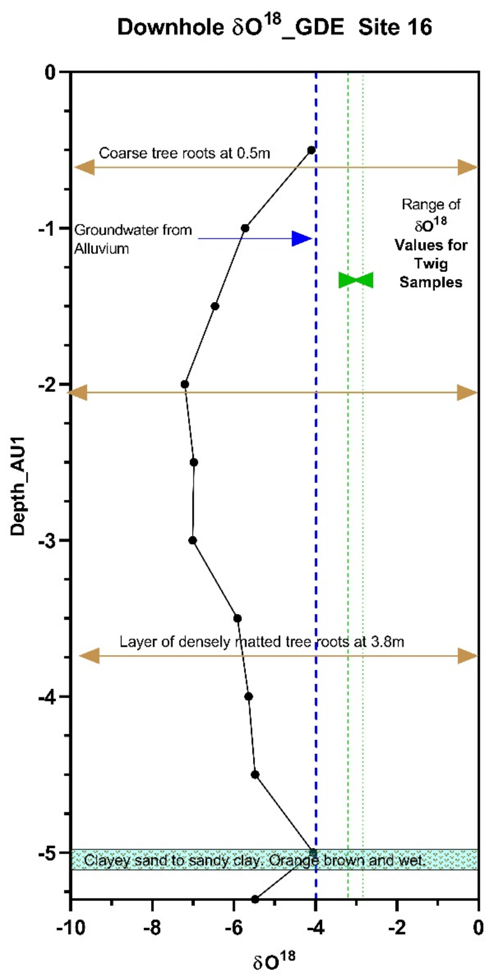


Figure 26. Downhole δO18 profile for Auger 2 at GDE Site 16, showing similarity in isotopic values returned for twigs and the alluvial groundwater sample.

4.3.4 GDE Assessment Site 18 – Phillips Creek

Stable isotope results from Phillips Creek GDE Assessment Site 18 are ambiguous, with xylem samples overlapping both soil samples from auger profiling as well as stable isotope composition of regional groundwater samples from the Tertiary and coal seam aquifers (see **Figure 27**). From **Section 4.1** and Section **4.2.5**, LWP values are consistent with utilisation of a source of fresh soil moisture / groundwater, and the LWPs can readily be accounted for by moisture availability in the upper soil profile. As trees will utilise the moisture source that requires the least energy to transport, it is more likely that they would be persisting on soil moisture in the upper profile than investing energy into deep root architecture to utilise saline groundwater of questionable utility to support tree function. Construction of a downhole δO18 profile for Auger 1 (see Figure 28) also clearly indicates that δO18 values in the upper soil profile overlap consistently with twig samples, giving greater confidence to the assumption that riparian trees on Phillips Creek are utilising moisture from the upper soil profile, which would include seasonally recharged fresh groundwater couched in the riverbed fluvial sediments.

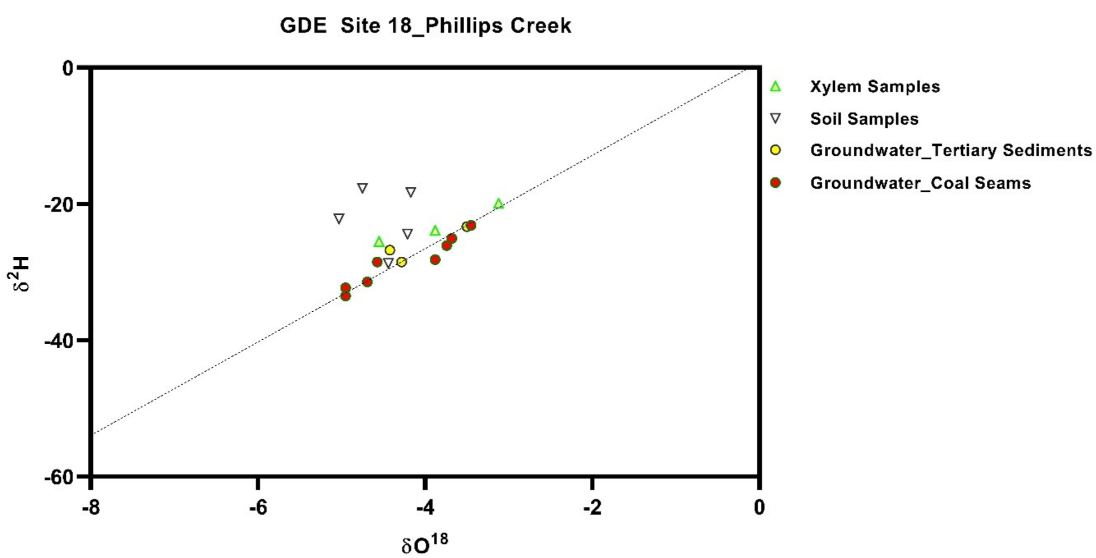


Figure 27. Stable isotope scatters for samples from GDE Site 18 (Phillips Creek) with the LMWL for Rockhampton indicated by black line. The overlap between xylem samples, soil samples and regional groundwater samples is notable.

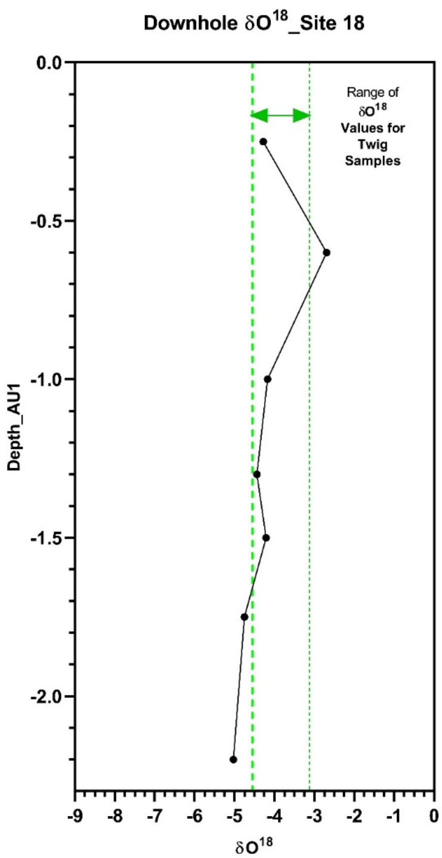


Figure 28. Downhole δO18 profile for GDE Site 18 (Phillips Creek) demonstrating overlap between δO18 of twigs and soil moisture samples extracted from soil auger samples.

4.3.5 GDE Assessment Site 10

Stable isotope results from GDE Assessment Site 10 are shown in **Figure 29**. The data shows a relatively tight scatter of isotopic samples from soils that overlap with the isotopic composition of the regional groundwater samples. The enrichment of the twig samples over soils is notable, and the twig samples lie on the same evaporative trend as the highly enriched surface water sample. This provides strong evidence that the wetland at GDE Site 10 is a surface feature only that is recharged by rainfall, consistent with the low salinity (127 µS/cm) of the surface water. There is no indication of any surface water / groundwater interaction and GDE Site 2 is not an Aquatic GDE as represented in BOM (2020b). There is also clear evidence that soil moisture that has been recharged by the surface water when the wetland was at various stages of bank-full, with the most enriched samples from xylem likely to be from trees that are directly utilising surface water. There is no indication of groundwater usage at this locality and the GDE Site 10 does not represent a Terrestrial GDE.

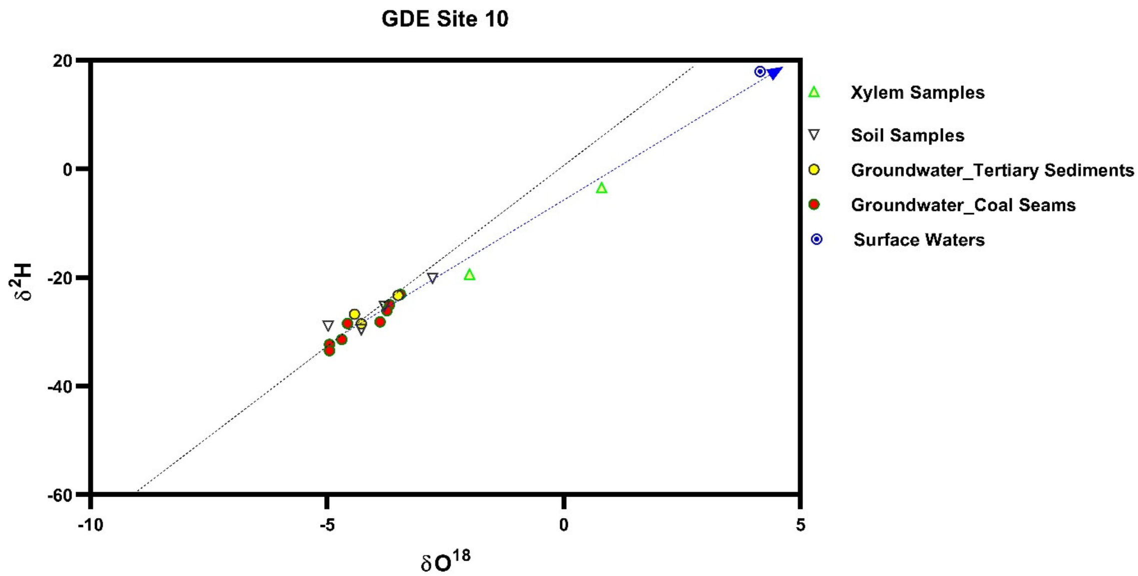


Figure 29. Stable isotope scatters for samples from GDE Site 10 with the LMWL for Rockhampton indicated by black dashed line and an evaporative trend which is indicated by the blue arrow, along which xylem samples fall.

4.3.6 GDE Assessment Site 14 and GDE Assessment Site 15

Stable isotope results from GDE Assessment Site 14 and Site 15 are shown in **Figure 30**. The data shows clear separation of the clusters which form the regional groundwater and twig xylems samples. There is also extreme evaporative enrichment of the surface water sample collected from GDE Site 14, which clearly indicates evaporative enrichment of a recent rainfall source. There is no indication of any groundwater interaction at either GDE Site 14 or GDE Site 15 and there is no indication that trees at either of these sites represent a Terrestrial GDE, consistent with the results of the LWP sampling (**Section 4.1**).

4.3.7 GDE Assessment Site 4, GDE Assessment Site 5 and GDE Assessment Site 6 – Ripstone Creek.

Stable isotope results from Ripstone Creek GDE Sites 4, 5 and 6 are shown on **Figure 31**. The results indicate considerable scattering and fractionation of twig xylem samples, and no consistent alignment with stable isotopic composition of the regional groundwater samples. This would suggest, in alignment with results of the LWP sampling, that trees are not tapping the regional groundwater table, and transpiration is being supported by moisture held in the unsaturated portion of the upper soil profile.

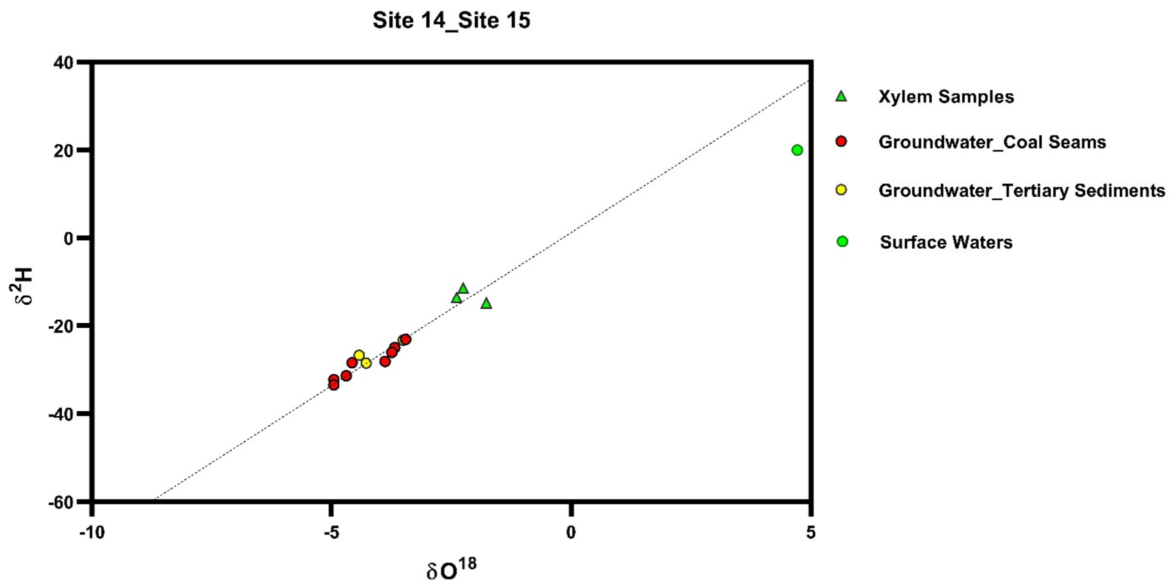


Figure 30. Stable isotope scatters for samples from GDE Site 14 and GDE Site 15 with the LMWL for Rockhampton indicated by black line. The clear separation in values between twigs and groundwater samples is evident.

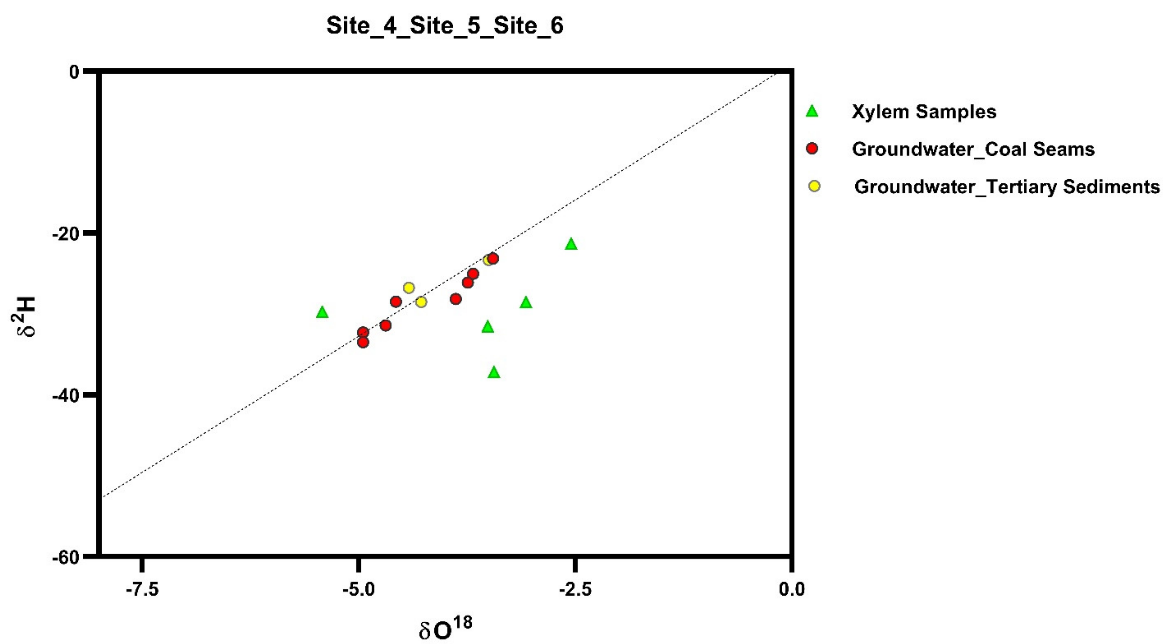


Figure 31. Stable isotope biplot from GDE Assessment Sites 4, 5 and 6 on Ripstone Creek, with the scatter lacking correlation with regional groundwater samples.

4.3.8 Other Assessment Areas

There was no isotopic sampling completed at GDE Assessment Site 7, GDE Assessment Site 11, or GDE assessment Site 17 as it was considered that LWP sampling and analysis was sufficient to conclude that no groundwater dependence exists at any of these assessment localities.

5.0 Discussion and Conceptual Site Models (CSMs)

5.1 Suitability of Groundwater Resources to Support GDEs

The most significant control on groundwater dependence with the Project Area is a consistent lack of well-developed alluvial deposits, with only thin slivers attenuating along the larger drainage lines of Boomerang and Phillips Creeks, before they join with the more extensive alluvial deposits of the Isaac River floodplain east of MDL429. The lack of significant alluvium means that away from the drainage channels, groundwater is confined to the base of the Tertiary sediments, as well as coal seams.

The potentiometric surface of the coal seams ranges from 16 to 26 mbgl, roughly comparable to groundwater levels measured in the Tertiary sediments (13.3 to 26.6 mbgl) with the monitoring bores installed in the alluvium ranging from 8mbgl to 11mbgl, although these are typically dry. Based on potentiometric surface alone, there is limited potential for upward propagation of groundwater into the alluvium reinforcing the likelihood that recharge of groundwater in the alluvium will be predominantly from rainfall and associated surface runoff, or bank recharge following overbank flooding events.

Apart from small areas where the coal seams sub-crop into the Tertiary sediments below Phillips Creek and preferential recharge of the coal seams occurs, there is limited connectivity between the Tertiary sediments and Permian coal seams. Despite this lack of connectivity, salinity of the two units can be comparable with both aquifers demonstrating salinities above 30 000 µS/cm in some bores, with more typical values ranging from 11 000 to 26 000 µS/cm. This can be compared to the low salinity (376 µS/cm) of groundwater that was sampled in the alluvium at Boomerang Creek (GDE Site 16) during this assessment, supporting the interpretation of a complete lack of interaction between groundwater contained in creek alluvium, and the underlying aquifers in the Tertiary sediments and coal seams.

Salinity plays a significant role in determining the suitability of groundwater to support ecological processes, including its capacity to support terrestrial GDEs. Costelloe et al (2008) concluded that coolibah, a dominant tree in some localities, particularly along Ripstone Creek, can continue to extract moisture at salinity levels up to 27 800 µS/cm in soils where matric potential in the upper soil profile is extremely low, and river red gum can utilise groundwater with salinity up to 30 000 µS/cm. Hence while the salinity of groundwater recorded in the Tertiary sediments and coal seams does not preclude its utilisation by either coolibah or river red gum, it is at the end point of tolerance for most trees, and there is unlikely to be any significant investment in deep root architecture when groundwater quality at depth provides only an extremely marginal moisture resource. Typical depths to the water table across the Tertiary landform are close to the inferred threshold depth beyond which tree roots / groundwater interaction is unlikely to occur (DNRM 2013) with Doody et al (2019) suggesting that vegetation will only consistently utilise groundwater where it occurs at depths of <10m below the land surface. Due to a combination of saline groundwater which has limited utility as a moisture resource, heavy clay soils which present a barrier to tree root penetration (as per Dupuy et al 2005), plus significant depth (i.e., >10 mbgl) to the groundwater table in Tertiary landforms, it would be extremely unlikely that trees would invest energy to propagate tree roots into the Tertiary groundwater table. It is only closer to the larger drainage channels of Boomerang and Phillips Creek, plus the Isaac River, where groundwater perched in alluvium may be closer to the surface, and sufficiently fresh to stimulate penetration of tree roots to depths sufficient to allow utilisation of the seasonal groundwater resources in the alluvium. The larger drainage channels also comprise a more significant proportion or river red gum which is known to have deeper sinker roots which penetrate to depths of at least 15m (Horner 2009) and are much more likely to demonstrate groundwater dependence / utilisation than either coolibah or poplar box which is the dominant species across residual land surfaces.

5.2 Nature of Groundwater Dependency and Conceptual Models

Examination of LWP measurements indicates considerable variability between assessment areas. From analysis of the biophysical parameters of LWP and SMP, coupled with analysis of stable isotope signatures from twigs, soils, surface water and groundwater (**Section 4.0**), it is concluded that only a few sites present any strong evidence of groundwater utilisation, being:

1. GDE Assessment Area 1 on the Isaac River, with groundwater dependence highest in vegetation closest to the sandy channel, decreasing with distance from the channel and with height onto the higher alluvial terraces. Comprehensive assessment of groundwater dependence on the Isaac River was completed by 3d Environmental (2020). It was concluded that geomorphology and geology provide a significant control on the groundwater dependence of vegetation along the river and those portions of the river frontage with capacity to develop the thickest sequences of alluvium having the greatest degree of groundwater dependence. Furthermore, groundwater dependence is controlled by the proximity of vegetation to the river channel and height of associated alluvial terraces on which the fringing vegetation is perched. It was also concluded that groundwater dependence of riparian vegetation was influenced by flooding and bank recharge, with utilisation of saline regional aquifers relatively insignificant (3d Environmental 2020).
2. The narrow strips of alluvium associated with the channels of Boomerang and Phillips Creek present another GDE system hosting variable quantities of fresh groundwater, both in riverbed sands and the fringing alluvial terraces. These watercourses define narrow flood channels flanked by discontinuous alluvial terraces which are confined between gentle Tertiary rises and plains. Groundwater is perched in fluvial sands beneath the sandy creek bed where residual, isotopically variable surface water from seasonal flows extends laterally into the adjacent alluvial terraces. This confined alluvial system defines a restricted and laterally variable perched water table that is accessible to the tree roots of riparian vegetation. The alluvial groundwater features may dry during extended drought periods, accelerated by evapotranspiration, which acts to deplete the alluvial aquifer. In this sense, these narrow alluvial aquifers are considered seasonal features with riparian trees demonstrating facultative dependence on the groundwater resource, utilising soil moisture when groundwater reserves are depleted. The alluvial groundwater systems are also disconnected from the deeper, saline regional aquifers in the Tertiary sediments and coal seams. While there may be some diffuse leakage occurring from the perched alluvial system into the Tertiary aquifer, this leakage is relatively minor, evidenced from the generally high and temporally consistent salinity of the Tertiary aquifer. The groundwater couched in the narrow alluvium fringes is recharged during flood events where overbank flow pushes water laterally into the riverbanks and adjacent terraces. Lateral infiltration of surface flows into the alluvial terraces continues until the level of the surface water drops below the level of

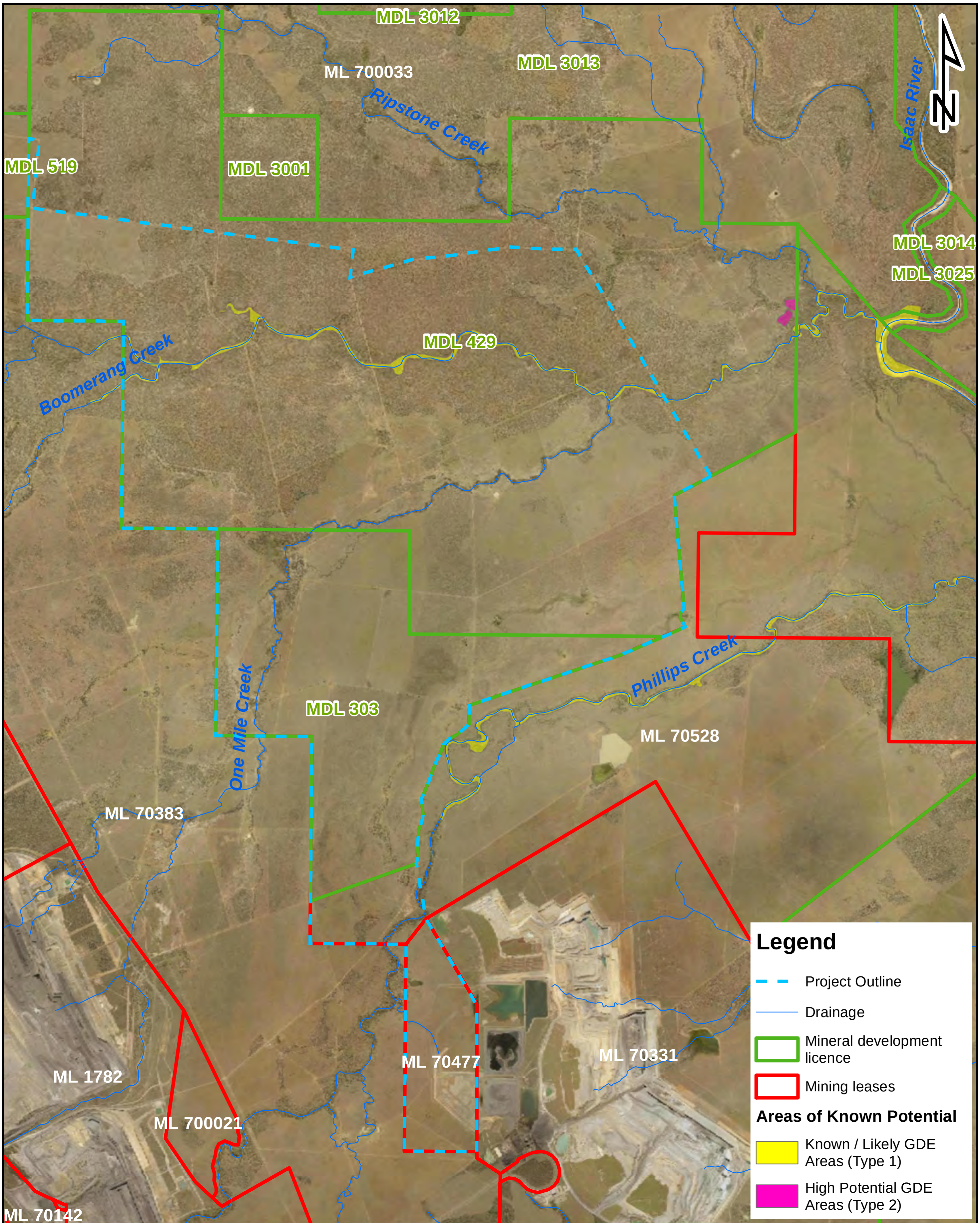
the recharged alluvial water table, after which recharged water may return to the river channel as low volume baseflow.

3. GDE Assessment Area 3 (HES wetland) represents a broad dish shaped depression that is connected to overflow channels of Ripstone Creek via broad interconnected drainage depressions. It is notable that while this wetland was dry at the time of assessment, other wetland features in the local area including the wetland feature at GDE Assessment Site 2 (another HES wetland) held abundant surface water residual from heavy rainfall in the month prior. The comparison of SMP and LWP data provides the most powerful interpretive tool for assessment of plant / water interactions in this case and at GDE Assessment Site 3, the LWP values indicate that trees were utilising a saturated source of fresh water, while the soil profile that was examined through auger sampling to 6.1mbgl remained extremely dry to its total depth. Hence there is necessity to conceptualise a source of shallow groundwater or high moisture availability, most likely hosted in sandy alluvium with high matric potential, that is below the depth penetrated during auger sampling. Recharge of this localised perched groundwater system would occur when the swamp holds ponded surface water with percolation downward to the first aquitard, inferred to be positioned at the unconformity between the alluvial sediments and underlying geological formation (either the Rewan Group country rock or Tertiary residuals). Initial infiltration of surface water would likely be by diffuse flow in the upper clay profile and then along preferential flow pathways that occur as gaps or cracks in the soil profile, acting to increase surface water infiltration.

Based on this information there are two types of GDEs present within MDL429 being:

1. Type 1 GDEs: Includes drainage features with developed alluvial landforms that host variable groundwater volumes and are seasonally recharged via surface flows and flooding. This includes Phillips Creek, Boomerang Creek, and the Isaac River.
2. Type 2 GDE: This represents the conceptualised perched groundwater lens that lies below GDE Assessment Site 3, which is mapped as an HES wetland. Percolation of groundwater through the alluvial soils occurs when surface water is recharged, and the infiltrating surface water is captured above an aquitard at the alluvial unconformity. Tree roots of river red gum and coolibah are utilising this freshwater lens, which possibly only remains viable for several months following rainfall. The perched freshwater lens is inferred to be >6m below the surface based on detail from soil auger sampling.

The location of Type 1 and Type 2 GDE features is shown in **Figure 32,** which shows their occurrence associated with Philips Creek, Boomerang Creek, the Isaac River and the HES wetland at GDE Assessment Site 3. Hydro-ecological conceptualisations of these features is shown in **Figure 33** for Type 1 GDEs and **Figure 34** for Type 2 GDEs. A hydro-ecological conceptualisation is also developed for surface expression wetlands that were sampled at GDE Assessment Site 2 and GDE Assessment Site 10 in **Figure 35**. Based on stable isotope analysis of soils, twigs and surface waters, these wetland features are primarily surface water features, recharged by rainfall, with fringing riparian vegetation utilising soil moisture associated with the surface water recharge or direct utilisation of surface water. There is no inferred utilisation of a deeper groundwater table, and the wetlands are not terrestrial GDEs.



Source: BOM GDE Atlas (2020).

Extremely High	>-0.276 Mpa
Very High	<-0.276 to -0.580 MPa
High	<-0.580 to -0.896 MPa
Moderate	<-0.896 to -1.21 MPa
Low	<-1.21 to -1.72 MPa
Very Low	<1.72 to -2.21 Mpa
Extremely Low	<-2.21 Mpa

Figure 32. Location of GDE Type 1 and GDE Type 2 areas based on evidence from field assignment.

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0 1.25 2.5 3.75 5
Kilometers

3D Environmental
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Kenmore, Qld 4069
Mobile: 0447 822 119
www.3denvironmental.com.au

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Figure 33a. Type 1 GDE - Boomerang Creek GDE Site 16 (Dry Season Scenario)

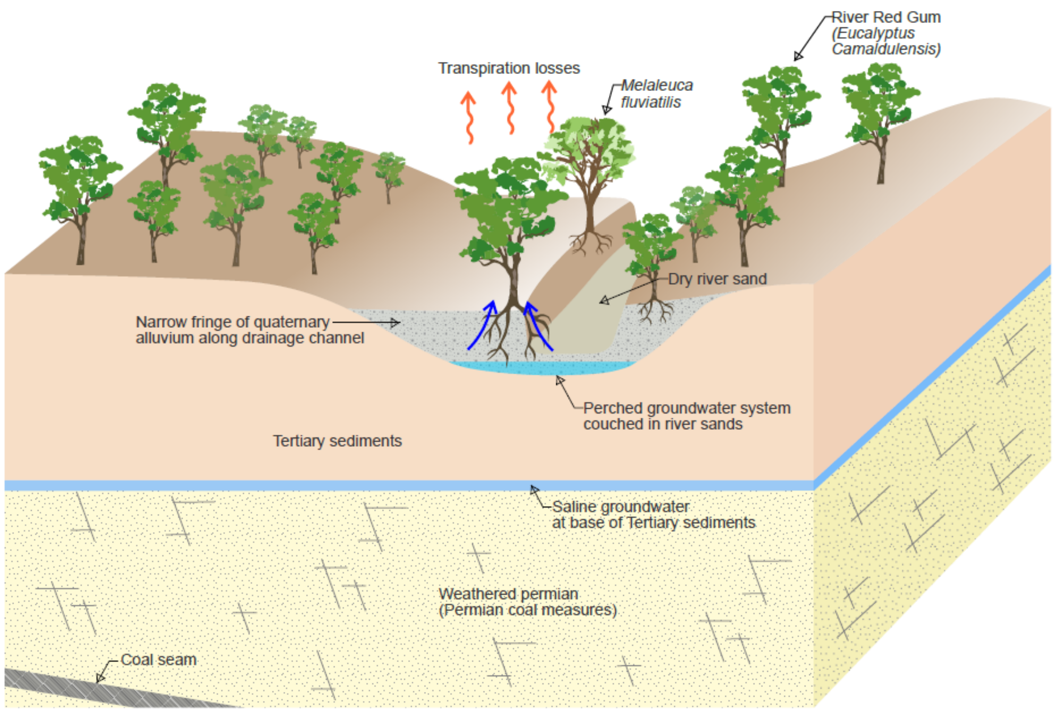


Figure 33b. Type 1 GDE - Boomerang Creek GDE Site 16 (Flooding Regime)

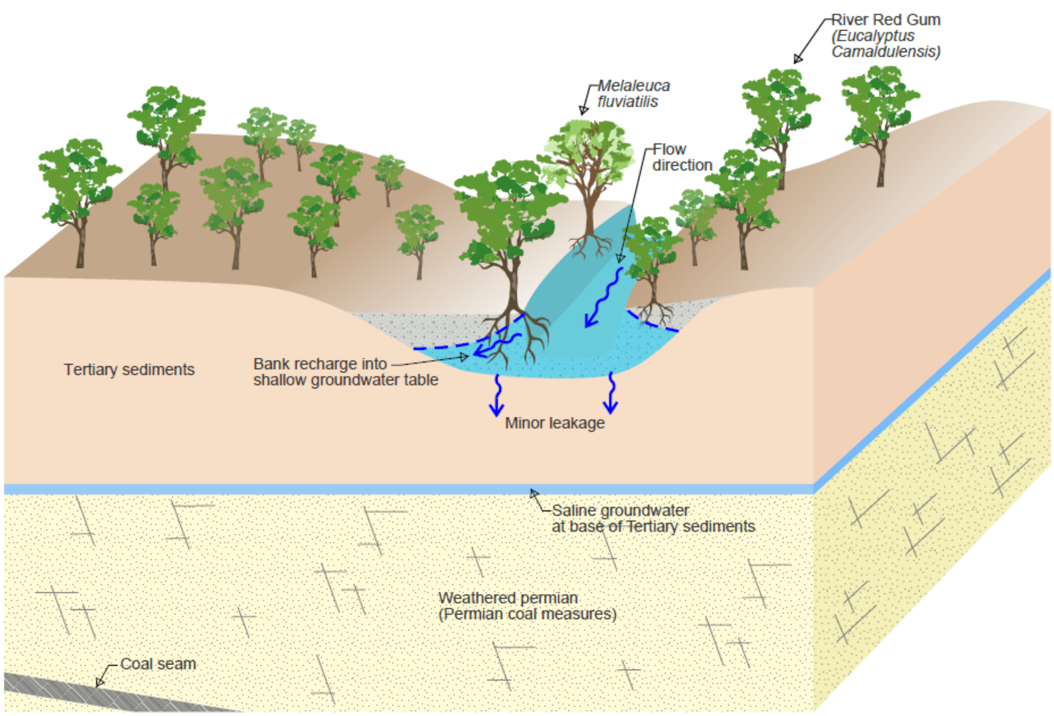


Figure 33. Hydro-ecological conceptualisation of Type 1 GDEs, based on GDE Assessment Site 16 on Boomerang Creek. Figure 33a shows dry season ecological function with Figure 33b showing wet season recharge of the perched alluvial groundwater table. The alluvial groundwater system is hydraulically disconnected from the regional Tertiary groundwater system.

Figure 34a. Type 2 GDE- GDE Assessment Site 3 (Dry Season)

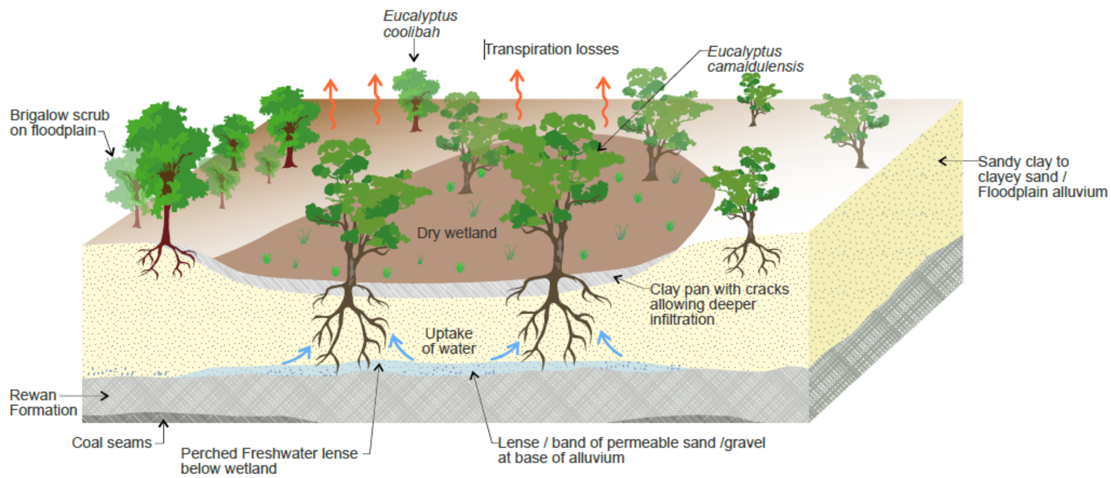


Figure 34b. Type 2 GDE - GDE Assessment Site 3 (Wet Season).

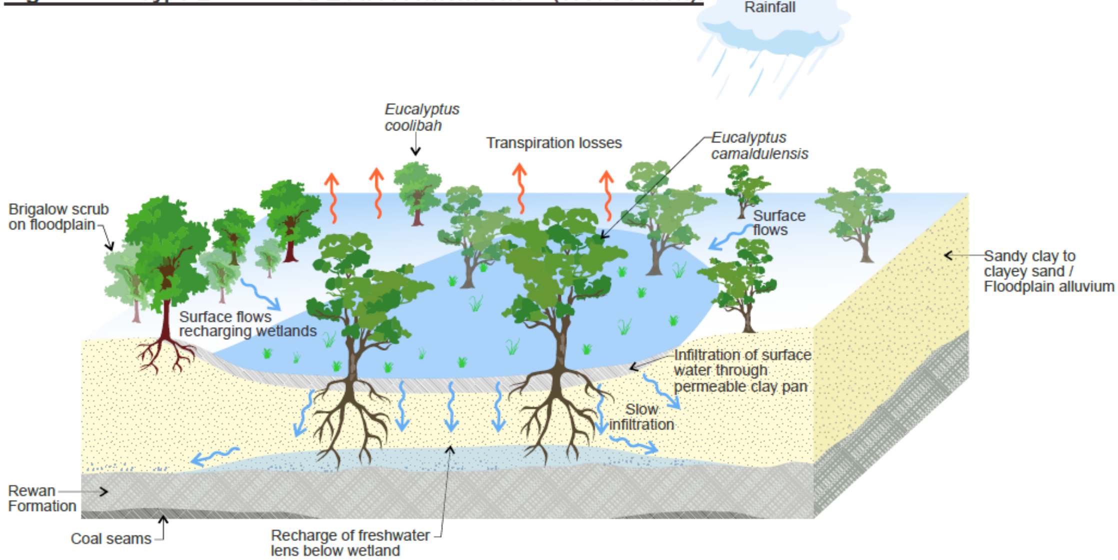


Figure 34. Type 2 GDE system based on eco-hydrological understanding of the wetland feature at GDE Assessment Site 2. Figure 34a shows a dry season system with Figure 34b showing wet season recharge of the seasonal groundwater lens.

Figure 35a. GDE Assessment Site 2 (and Site 10) wetland feature (dry season)

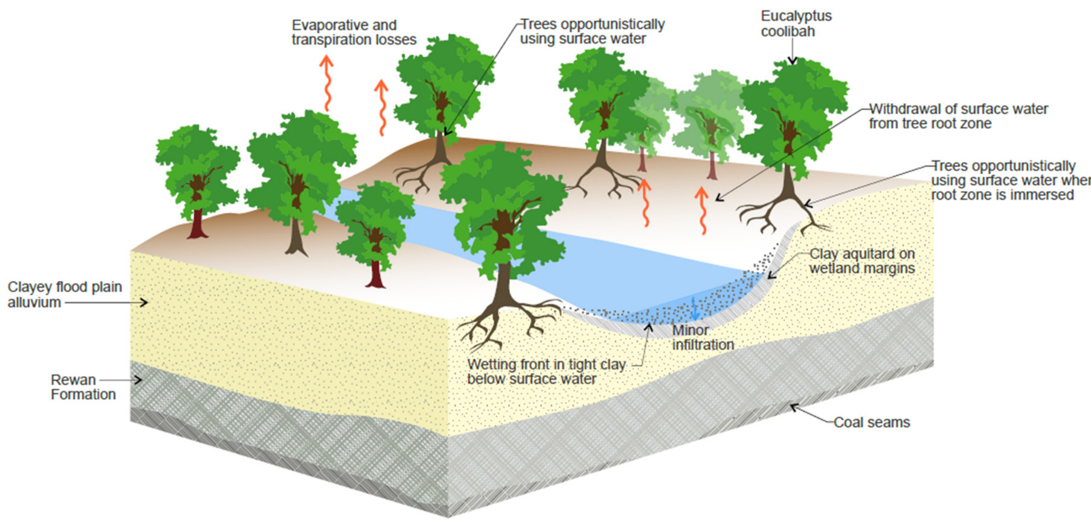


Figure 35b. GDE Assessment Site 2 (and Site 10) wetland feature (wet season)

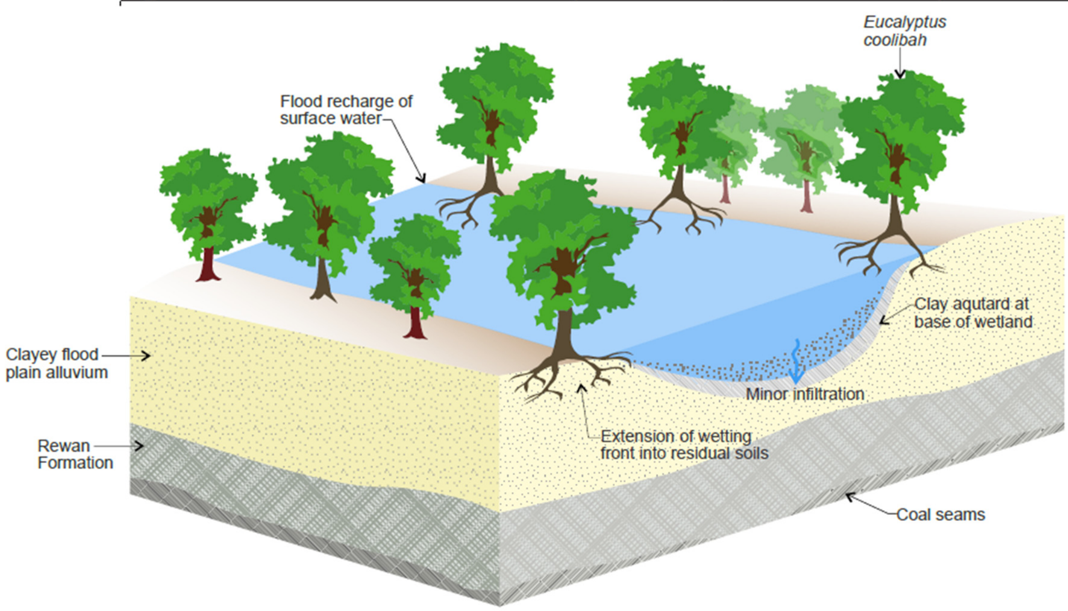


Figure 35. Hydro-ecological conceptualisation of the wetland feature at GDE Assessment Site 2 (and Site 10) showing dry season (Figure 35a) and wet season (Figure 35b). The surface water is perched on a clay aquitard which prevents infiltration.

6.0 Assessment of Impacts to GDEs

Section 6.1 provides a summary of the hydro-ecological conceptual understanding of the GDE types within the potential impact area of the Project. Potential impact mechanisms and their relevance to GDEs within the assessment area, discussed in **Section 6.2**. Potential measures for impact mitigation and management are provided in **Section 6.4** and a risk assessment has been undertaken in **Section 6.5** consistent with the approach identified in the IESC summary guide – assessing groundwater dependent ecosystems (IESC 2019).

6.1 Summary of Findings Relevant to Impact Assessment

The assessment of impacts to GDEs is based on the findings of the extent and distribution of groundwater and GDEs identified in this report being:

1. There are two types of GDE system identified within MDL429, being Type 1 GDEs and Type 2 GDEs systems.
2. Type 1 GDEs systems are associated with the narrow belts of alluvium that are associated with larger incised drainage lines of Boomerang and Phillips Creek, extending eastward to the Isaac River. Type 1 GDE systems are:
    a. Supported by fresh groundwater that is couched in recent river alluvium.
    b. Seasonal by nature with groundwater reserves being recharged during bank-to-bank flow events, with depletion occurring during dry periods under the influence of evapotranspiration
    c. Disconnected from the regional aquifer at the base of the Tertiary.
3. Type 2 GDE systems which are supported by a lens of fresh groundwater that lies at depth below the surface wetland system at GDE Assessment Site 3. This system:
    a. Is mapped as a HES wetland under the Environmental Protection Regulation 2008.
    b. Relies on infiltration and deeper percolation of surface waters to significant depth below the wetland surface to recharge a localised groundwater lens or zone of high water availability.
    c. The groundwater lens is tapped by large trees that occupy the central portion of the wetland and is likely to be seasonally variable and depleted by extended periods of strong evapotranspiration without recharge.
    d. Disconnected from the regional aquifer at the base of the Tertiary / within coal seams.

The regional aquifers which occur at the base of the Tertiary sediments and within coal seams are an unsuitable source of moisture to support ecological function due to salinity and considerable depth below the land surface. There is no identified surface expression of regional groundwater tables in the assessment area and wetland features are recharged by rainfall events and associated overland flow.

6.2 Potential Impacts to GDEs

The GDE Toolbox (Richardson et al 2011), provides a starting point for investigating potential impacts on GDEs through the following impact mechanisms:

1. A total or partial loss or reduction in the volume or pressure of the aquifer being utilised by GDEs.
2. A change in the magnitude and timing of volume fluctuations in the aquifer being utilised by GDEs.
3. Changes to the interaction between surface flows and aquifers being utilised by a GDE.
4. Change in chemical composition of an aquifer detrimentally impacting the health of a GDE.

These potential changes can result in:

1. Loss of canopy vigour leading to senescence of groundwater dependent vegetation.
2. Changes to sub-canopy and groundcover because of increased light penetration through the canopy of senescing vegetation.
3. Change in species composition with replacement of species not adapted to changing ecological parameters with species that have greater capacity to absorb change.

Direct clearing of a GDE system is also an additional impact which needs to be considered in the context of the Project.

6.2.1 Direct clearing

There will be no direct clearing of GDEs associated with the Project. The lack of surface disturbance is facilitated by underground extension of the mine northwards into MDL429. The proposed open pit does not impact on riparian habitats of either Boomerang or Phillips Creek where GDEs are mapped as occurring.

6.2.2 Partial or total loss or reduction in pressure of the aquifer being utilised by GDEs

The predicted groundwater drawdown associated with development of the Project, is provided in **Figure 36** which shows the predicted maximum extent of Project related drawdown in Tertiary sediments and alluvium at completion of the Project. Based on conceptual models provided in **Figure 34** and **Figure 35**, the perched alluvial groundwater system that supports both Type 1 and Type 2 GDEs is disconnected from the deeper groundwater system associated with the Tertiary sediments and Permian coal seams which are subject to drawdown or reduction of pressure. Except in the circumstances where there is enhanced potential for infiltration due to overlying sandy alluvial sediments, drawdown in the Tertiary groundwater systems should have no to limited impact to the perched groundwater systems that are supporting either Type 1 or Type 2 GDEs.

The groundwater impact model prepared by JBT (2022) predicts almost no depressurisation in the Quaternary alluvium due to its dryness. There is however an area of alluvium near groundwater monitoring bore W14_MB1 that has been differentiated, where seasonally saturated sandy alluvium extends to depths of 18mbgl, which is coincident with an area of drawdown in the alluvium shown in **Figure 36**. The modelled maximum extent of drawdown of 2m is attenuates along the lower reaches of Ripstone, Boomerang and Philips Creek during mining phases of the project, though is highly localised near W14_MB1 on Boomerang Creek where 5m of drawdown is modelled. The drawdown in alluvial sediments diminishes completely in post mining phases. More broadly across the assessment area where alluvium has not been differentiated, depressurisation of the Tertiary groundwater system is applied to infer where drawdown related impact to the Quaternary alluvium could occur. Impacts of drawdown in the Tertiary groundwater system on shallower alluvial / perched groundwater sources would most likely be through and enhanced potential for downward drainage from the Quaternary alluvium to the underlying Tertiary sediments. This could occur either to isolated pockets of water within the Quaternary alluvium that is not captured at model scale, or where seasonal water within the alluvium would have enhanced potential for downward flow due to a lower groundwater level within the underlying Tertiary sediments (JBT 2022). It is possible that increased rates of groundwater drainage / drying could occur on Boomerang or Phillips Creek (Type 1 GDEs) where the GDE system is intersected by drawdown contours in either the alluvium or Tertiary sediments, or in any wetland where significant infiltration of surface water occurs into underlying Quaternary alluvium or Tertiary sediments (Type 2 GDEs). **Figure 36** shows groundwater depressurisation and drawdown in the Tertiary sediments of >5m (and up to 50m) over extensive portions of Boomerang Creek and Philips Creek, with both drainage systems representing Type 1 GDEs. The impact of this predicted drawdown on ecological function of Type 1 GDEs is predicted to be insignificant because:

1. The alluvial groundwater system associated with Type 1 GDEs is discontinuous along the length of the creek channel and riparian trees are facultative phreatophytes which have capacity to utilise moisture from multiple sources including soil moisture, surface water and groundwater to support transpiration.
2. The alluvial groundwater system that supports Type 1 GDEs is recharged by surface flows and flooding which provides the dominant driver to support riparian ecological function.

JBT (2022) further discusses the impact of drawdown in the Tertiary sediments on the integrity of HES wetlands in the vicinity of the Project Area, numbering HES wetlands from 1 to 10 (see **Figure 37**), noting that the area of predicted drawdown (1m contour) propagates to the east of HES Wetland 8 and HES Wetland 9. The following relevant points are noted:

1. HES Wetland No 9 corresponds to GDE Assessment Site 2 (from this assessment) and is a surface feature only with limited infiltration of perched surface water through a clay aquitard into the underlying sediments (GDE conceptual model from **Figure 35**).
2. HES Wetland No 8, corresponding the GDE Assessment Site 3 (Type 2 GDE, **Figure 34**) lies between the 2m and 5m drawdown layers. The impact of this drawdown on the fresh lens of groundwater that is conceptualised to be seasonally present below this wetland feature is uncertain. The drawdown could potentially result in more rapid drying of the groundwater lens and reduced availability of groundwater extending into dryer periods. Ongoing monitoring will be required to detect if any ecological impact to this wetland feature is incurred (see **Section 6.4.3**).
3. HES Wetland No 10 was not investigated during field inspection although aerial imagery identifies a broad depression which is well vegetated in its central portion with tall eucalypts (most likely river red gum). Whether HES Wetland No 10 is a surface feature, or its hydro-ecological function is analogous to Type 2 GDE (**Figure 34**) is uncertain. Its location lies between the 5m and 10m drawdown contours suggesting that similar impacts to HES Wetland No 8 may be expected if it is attributed with similar ecohydrological function. It is noted that HES Wetland 10 is within the footprint of the approved Olive Downs project, is subject to clearing, and will be appropriately offset under the Olive Project Biodiversity Offset Strategy (Pembroke Resources 2019).

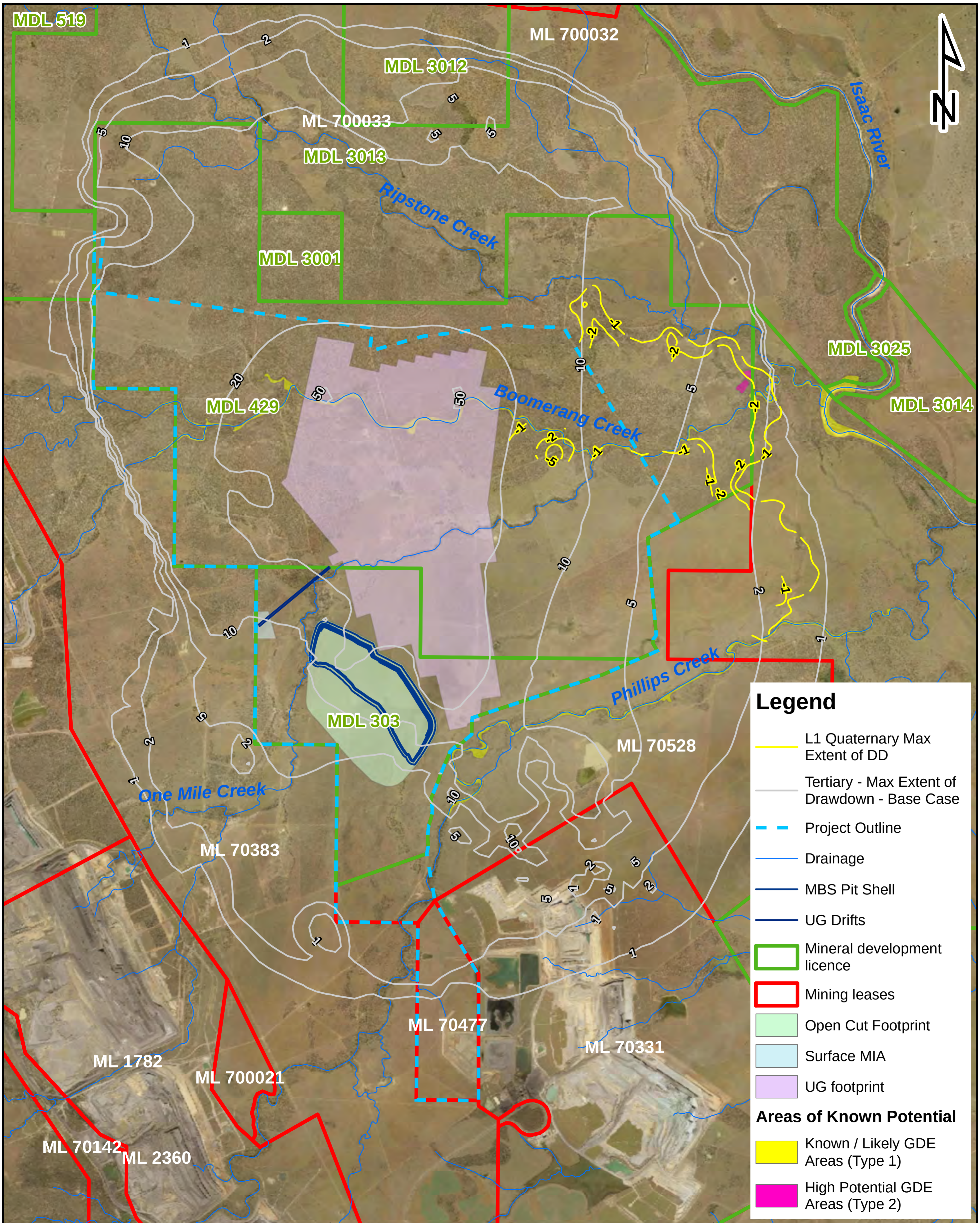
All other wetland features occurring across the area of predicted drawdown in the Tertiary sediments are interpreted to be surface features with limited infiltration of surface water into underlying sediments and no inferred hydraulic linkage between surface waters and groundwater.

6.2.3 Change in the magnitude and timing of volume fluctuations in the aquifer being utilised by GDEs

Volume fluctuations in the perched alluvial groundwater system that support both Type 1 and Type 2 GDEs are regulated by surface flows rather than upward propagation of groundwater from regional aquifers. As described in **Section 6.2.4**, surface flows will not be impacted by the Project and volume fluctuations in the alluvial aquifer that supports Type 1 GDEs will remain dependent on seasonal surface flows and rainfall. The alluvial groundwater system that supports Type 1 GDEs on Phillips and Boomerang Creek's has limited hydraulic connectivity with the Tertiary groundwater system, except in some pockets where increased surface water infiltration may occur. While it is not possible to precisely delineate these pockets, JBT (2022) identifies an area on Boomerang Creek (near W14_MB1) as being an area of increased surface infiltration where the alluvium may be seasonally saturated (as shown in **Figure 36)**. There may be increased potential for drying in this area and more rapid reduction in the volume of groundwater in the alluvium that supports GDEs following surface recharge events. There is also an increased risk of drying and reduction in the volume of the groundwater systems supporting GDEs where increased surface infiltration coincides with the most intense drawdown in either the Tertiary or alluvial sediments (JBT 2022). It is noted in **Figure 36** that reaches of Boomerang and Phillips Creek are subject to drawdown in the Tertiary groundwater system of >5m. The impact that drawdown on these watercourse reaches will have on groundwater volumes and timing of groundwater fluctuations will be subtle as neither the physical integrity of the groundwater systems that supports these GDEs, or the surface flows that recharge shallow groundwater will be impacted. Impact to volume fluctuations associated with drawdown to aquifers that support GDEs are unlikely to cause significant / notable impacts to GDE function because:

1. Surface flows which are the primary sources of aquifer recharge will not be impacted (see **Section 6.2.4**).
2. Groundwater dependent species including river red gum, coolabah and weeping tea tree which are associated with Type 1 and Type 2 GDEs are facultative phreatophytes which are adapted to periods of seasonal wetting and drying (see **Section 2.2.3**).

For Type 2 GDEs (HES Wetland 8), this GDE system is similarly located within an area subject to >2m drawdown in the Tertiary sediments (maximum extent). As this wetland feature is recharged with surface water, the timing of volume fluctuations in the conceptualised groundwater lens supporting this GDE system will not be impacted. Drawdown may however contribute to marginally increased rates of drying and drainage in the perched groundwater lens.



Source: BOM GDE Atlas (2020).

Figure 36. Location of Known and High Potential GDE areas relative to predicted groundwater drawdown

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Kilometers

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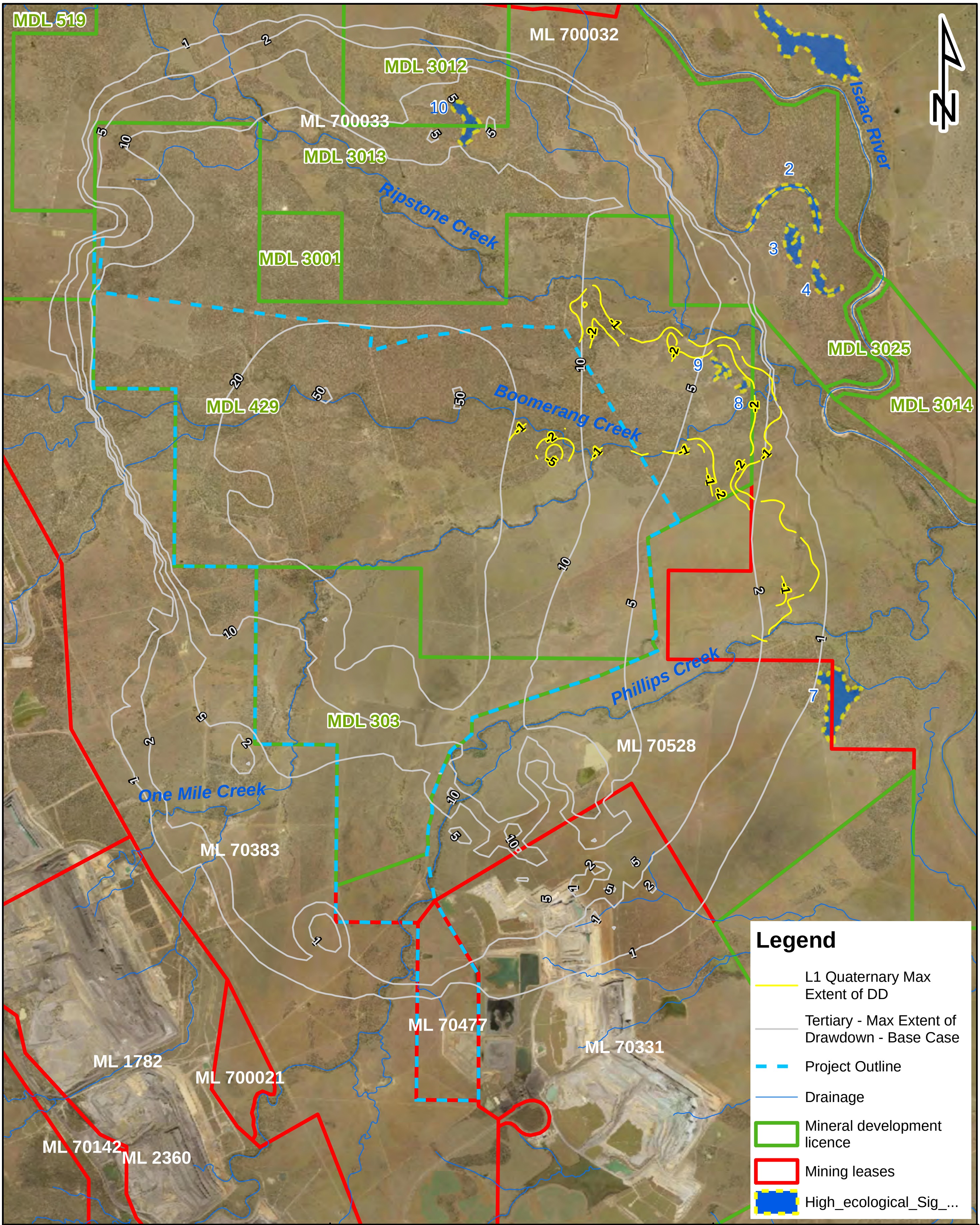

Source: Matters of State Environmental Significance - High Ecological Significance Wetland (DES 2020)

Figure 37. HES wetlands in relation to maximum drawdown in Tertiary.

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6.2.4 Changes to the interaction between surface flows and aquifers being utilised by a GDE

There is no impact proposed to surface flows associated with this Project and seasonal flow regimes will not be interrupted. This is critical as both Type 1 and Type 2 GDEs are solely reliant on surface flows for groundwater recharge. As there is no alteration to surface flow regime, impacts to the ecohydrological function of Type 1 GDEs are not predicted. Similarly, there will be no impact to the catchment areas of the potentially impacted Type 2 GDE (Wetland 8 from JBT 2022 as per **Figure 37**) meaning surface recharge of this GDE systems will be unaffected. The hydrogeological function of Wetland 10 (from JBT 2022) has not been assessed in the field, although clearing of this feature will be managed under the Biodiversity Offset Strategy for the Olive Downs EIS.

6.2.5 Change in chemical composition of an aquifer detrimentally impacting the health of a GDE

Groundwater predictive modelling by JBT (2022) identifies that that the development of a permanent cone of depression will direct groundwater flow towards the underground void. Therefore, the risk of the Meadowbrook Project impacting on regional water quality (via outflow to the groundwater system) is assessed to be low.

The discontinuous groundwater system which supports Type 1 GDEs and potentially Type 2 GDEs is underlain by partially confined groundwater systems associated with the regional Tertiary aquifer and aquifers associated with the Permian sediments / coal measures. The potential for saline water from these groundwater units to contaminate any fresh perched groundwater system is negligible as based on current potentiometric surfaces, there is no risk of upward propagation of saline groundwater into the seasonal alluvial groundwater system which supports GDEs.

The mine would facilitate drainage of groundwater directly into the mining void where this leakage would be pumped into holding Dams that currently service the existing Lake Vermont mining operation. There will be no additional release points associated with the Project and discharge of saline water into the receiving environment which supports GDEs will not occur.

Rock spoil is also expected to generate low salinity rainfall runoff and seepage (JBT 2022) which will be captured by sediment dams. Uncontrolled release of seepage is not expected to occur from site and recovered seepage flows will be managed in accordance with an implemented mine Water Management System (WMS). Further information on these management systems is provided in the mitigations chapter of this report (see **Section 6.4.1**).

With implemented mitigations (as per **Section 6.4.1**), based on the low salinity of runoff and seepage, and the management of mine affected water storages and sediment dams under the mine WMS, it is considered that there is low risk of impact to the water quality of alluvial groundwater systems which support GDEs.

6.3 Cumulative Impacts

An Initial Advice Statement (IAS) has been developed for the Saraji East Extension Project (BMA 2017) with an EIS study currently being completed. The Project is located directly downstream of the

Saraji Mine and Boomerang Creek plus the tributary of Boomerang Creek, has been diverted upstream of the existing Saraji Mine. The IAS lists the following potential impacts:

- Changes to surface drainage including flow paths, flow velocities and flood inundation areas
- Runoff from disturbed areas such as MIAs and stockpiles impacting on downstream water quality and quantity
- Mine-affected water from processing and underground mining
- Surface water quality impacts from the discharge of mine affected water, stormwater with elevated suspended sediment loads or other contaminants
- Reduced downstream flows due to reduction in the contributing catchment because of the open cut pit and/or mine dewatering

All of these have potential to contribute to the cumulative ecological impacts of the Project on Type 1 GDE systems associated with Boomerang Creek. A Mine Water Management System will be developed for the Project with an aim to minimise impact to surface flow volumes and minimise controlled and uncontrolled releases of mine affected water. Further information on the potential impact to GDEs will be forthcoming when the EIS is fully developed.

Furthermore, JBT (2022) has modelled cumulative drawdown contours for the Tertiary sediments associated with a full range of interacting mining projects which indicate an additional 2 to 10 m of drawdown beneath Boomerang Creek and an additional 2 to 15 m of drawdown beneath Ripstone Creek. While Ripstone Creek is not considered to be a GDE based on the results of this assessment, the cumulative impact to the Tertiary groundwater system below Boomerang Creek must be considered in impact predictions.

6.4 Mitigation, Management and Monitoring Measures

Section 6.2 identifies that the risk of impact to GDEs from groundwater drawdown, changes to surface water flows, flooding, and water quality is considered low on account of:

1. Groundwater held in aquifers associated with the Tertiary and Permian coal seams that will be subject to impacts by development of the Project does not support the function of any GDEs within the vicinity of the Project.
2. The alluvial groundwater system that supports Type 1 GDEs ecosystems is supported and recharged by surface flows, which will not be impacted by the development of the Project.

While a risk assessment is dealt with more comprehensively in **Section 6.5**, general operational measures that will minimise risk of impact to GDEs are provided in **Section 6.4.1.**

6.4.1 General operational measures

The Project will operate under one Environmental Authority, with extension of the current EA for the existing Lake Vermont Mine extended to capture development components of the proposed Meadowbrook operations. Under the Project Environmental Authority, the existing Water Management System (WMS) will need to be operational during all stages of the Project, with the primary objective of minimising environmental harm. Implementation of the WMS and associated Erosion and Sediment Control Plan (ESCP) and Receiving Environment Monitoring Program (REMP) will be directly applicable to management of potential impacts to GDEs that occur in within the influence of the Project. Specifics of each management plan are detailed below.

WMS: Specific objectives under a WMS that are relevant to the management of impact to GDEs will be to:

- Minimise capture of clean surface water from external catchments via catchment diversion.
- Maximise recycle and reuse of first mine affected water, then sediment runoff, for site demands including processing and dust suppression.
- Preferential supply of water demands from site water storages over external raw water supply and surface water harvesting.
- Minimise and manage controlled releases of water to receiving waterways. No water release points are proposed with the Project, and all surplus water produced will be transferred to and managed within the existing Lake Vermont Mine operation.
- Prevent uncontrolled release of mine affected water to receiving waterways in 95% of years.

REMP: The Project will operate under one Environmental Authority with the existing REMP for the Lake Vermont operations extended to capture proposed components of the Meadowbrook Project. The intent of the existing REMP is to monitor, identify and describe any impacts to the environmental values, water quality and flows within the receiving environment. Annual monitoring, reporting and analysis of long-term trends and potential impacts will be undertaken, and outcomes will inform further mitigation and remediation of existing mitigation measures as required. Extension of the existing Lake Vermont REMP will ensure that there is capacity to identify any impacts to water quality in the receiving environments of the Boomerang and Phillips Creek and more broadly the Isaac River, which may have detrimental impact to GDE function.

6.4.2 Groundwater monitoring

A comprehensive groundwater monitoring network, including 15 nest monitoring bores screened within major groundwater units including the regional Tertiary and Coal Seam aquifers, and alluvial groundwater systems will be maintained for the duration of the Project. There will be a requirement for additional monitoring bores to replace those that are removed in association with development of the Project footprint. The primary purpose of the groundwater monitoring network will be to enable the natural groundwater fluctuations to be detected and distinguished from groundwater level impacts associated with de-watering of aquifers impacted by the proposed Project.

Groundwater monitoring will include groundwater levels as well as physio-chemical indicators (pH and EC), water quality parameters such as major ions and total alkalinity and hydro-geochemistry including dissolved metals.

6.4.3 GDE Baseline Data Collection and Monitoring

Consistent with the intent of the groundwater monitoring program, it is recommended that additional baseline data be collected to further characterise the seasonal ecohydrological function and baseline condition of Type 1 GDEs on both Boomerang and Phillips Creek, as well at the Type 2 Wetland (HES Wetland 8). This baseline data collection would form the basis of a project

Groundwater Dependent Ecosystem Monitoring and Management Plan (GDEMMP) which would provide protocols for:

1. Collection of baseline ecological condition data (Biocondition and Leaf Area Index) for type 1 GDEs over areas where groundwater drawdown in the Tertiary and Quaternary sediments is predicted.
2. Collection of baseline ecological condition data (Biocondition and Leaf Area Index) over HES Wetland 8 (GDE Type 2) where >2m of groundwater drawdown is modelled in the Tertiary sediments.
3. Collection of baseline ecological condition data in GDE areas where limited (<2m) and / or no groundwater drawdown is predicted to provide an ecological control.
4. Prescriptive methods for GDE monitoring over the life of the mine and post mining periods which are tailored to the assessed levels of ongoing risk to GDE function.
5. Mitigations and methods of adaptive management which can be implement if impacts to GDEs are detected which can be linked either directly or indirectly to mining operations associated with the Meadowbrook Project.

The purpose of the baseline data collection is to provide a basis for detection of future declines in ecological condition that can be linked to detected changes in groundwater levels and physio-chemical indicators that are resultant from the mining operation. The recommended period for baseline data collection would be two years, after which a review of requirements for ongoing monitoring can be undertaken, and methods tailored to the assessed level of risk to GDE function.

6.5 Risk Assessment

Drawing on information on GDE presence and function from previous sections, a risk assessment has been prepared which presents the likelihood of an impact occurring and the consequence associated with that impact. The significance of the risks is described below:

- ***High significance:*** Complete destruction of a GDE in terms of complete loss of keystone species and conversion to an alternate degraded ecological state. Impacts are irreversible and the only feasible option for mitigation is an environmental offset under relevant environmental policy.
- ***Moderate significance:*** Degradation of a GDE to an extent such that 25% or more keystone species are affected by the action. Impacts will be reversible only with mitigation.
- ***Low significance:*** Impacts are short in duration and reversible without mitigation required.
- ***Insignificant:*** Impacts are undetectable when assessed against a relevant ecological baseline.

The ranking applied to the assessment of likelihood including descriptor is provided in **Table 4**, descriptions of magnitude are applied in **Table 5** and the derived risk matrix is provided in **Table 6**. A list of applicable mitigations and management measures is provided in **Table 7,** although it should be noted that mitigations will only be applied if management measures (as developed in a project GDEMMP) detecti significant detrimental change to GDE health and function. The constructed risk assessment with a residual risk score is provided in **Table 8**. This assessment differs from the matrix supplied in Doody et al (2019) as it serves to identify the risk of impact and consequence in terms of habitat degradation in a GDE, without attributing any degree of sensitivity to the receptor. Based on risk assessment protocols described in Doody et al (2019) and the Queensland guideline '*Groundwater dependent ecosystems : EIS information guideline* (DES 2022) , all GDE areas (Type 1 GDEs and Type 2 GDEs) identified within this assessment are considered 'High Value' ecological receptors. This is due to the attribution of conservation values recognised as significant under relevant Qld legislation (e.g., RE11.3.3 which is classified as Of Concern under Queensland's Vegetation Management Act 1999), or their classification as Essential Habitat for threatened wildlife listed under either the NC Act or other prescribed environmental matters under the EPBC Act. Both the corridors of Phillips Creek and Boomerang Creek are mapped as Essential Habitat for Koala, listed as Endangered under the EPBC Act. These riparian corridors are also mapped as Matters of State Environmental Significance (MSES) in Queensland, which provides consistency with the intent of DES (2022).

Based on the risk assessment outcomes in **Table 8**, unmitigated risk to GDEs identified in this assessment are classified as 'Insignificant' to 'Low' risk for Type 1 GDEs and 'Moderate' risk for Type 2 GDEs. Residual risk ranking is 'Low' to 'Insignificant' following application of appropriate management measures, including mitigations if required. It should be noted that for all impact pathways, initial stages of GDE monitoring require active management (including monitoring) from which mitigations can be adapted if impacts to GDEs are identified which can be attributed either directly or indirectly to mining operations associated with the Meadowbrook Project.

Table 4. Descriptors and ranking for the likelihood of impact occurring.

Rank	Likelihood	Description
1	Highly unlikely	There is no precedent for this event in the industry and similar events have not previously occurred.
2	Unlikely	Impacts have been associated with previous industry actions although similar impact pathways are not identified for the Project.
3	Possible	Impact pathways are not clearly understood and impacts have been previously associated with a similar industry action
4	Likely	Impacts have previously been associated with the industry and a clear impact pathway exists.
5	Highly likely	A common event that is consistently associated with a similar industry action/ of an action that is proposed to occur.

Table 5. Descriptors of Impact Magnitude applied in the risk assessment.

Magnitude	Description
Negligible	No impact identifiable above baseline ecological conditions
Low	Plant stress linked to mining activity that results in the reduction in volume and duration of groundwater supporting a GDE system that does not result in more than 5% dieback of 'mature canopy trees'*. Impact localised and reversible with mitigation.
Moderate	Plant stress linked to mining activity that results in the reduction in volume and duration of groundwater supporting a GDE system that does not result in more than 25% dieback of mature canopy trees (defined as a canopy tree with DBH >60cm). Impact is reversible with mitigation.
High	Significant harm (loss of 25 to 50% of mature canopy trees). Impact is reversible although a significant lag in return to pre-disturbance condition occurs (lag>20yrs). Vegetation is converted from remnant to non-remnant status and significant impacts to habitat for protected fauna species occurs. Biodiversity offsets may be required.
Severe	Irreversible impact to > 50% 'mature canopy trees'* that cannot be mitigated. Vegetation is converted from remnant to non-remnant status and significant impacts to habitat for protected fauna species occurs. Biodiversity offsets will be required.

*A 'mature canopy tree' is defined for the purpose of this risk assessment as a tree that forms a component of the undisturbed canopy (T1 or upper structural layer) of a remnant vegetation community. In eucalyptus species, a mature canopy tree is often at the stage of maturity where significant habitat features may form including branch hollows.

Table 6. Matrix applied in the risk assessment.

		Likelihood				
		Highly Unlikely (1)	Unlikely (2)	Possible (3)	Likely (4)	Highly Likely (5)
Consequence	Severe	Insignificant	Low	High	High	High
	High	Insignificant	Low	Moderate	High	High
	Moderate	Insignificant	Low	Moderate	Moderate	Moderate
	Low	Insignificant	Low	Low	Low	Low
	Negligible	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant

Table 7. List of relevant mitigations and management actions.

Mitigation No	Mitigations	Management Actions
1	GDE Avoidance	-
2	Biodiversity Offsets	-
3	Habitat Augmentation	-
4	Injection of water into the tree root zone	-
5	-	Baseline data collection / Monitoring and development of a GDEMMP
6	-	Operation of Meadowbrook under the existing Lake Vermont EA including adoption of the Lake Vermont Water Management System.
7	-	Groundwater monitoring

Table 8. Risk assessment for potential impacts and residual risks scores.

Impact Pathway	Pre-mitigated Risk			**Comments**	Management /Mitigation Measures*	Residual Risk Ranking		
	Likelihood	Consequence	Risk			Likelihood	Consequence	Risk
1. Direct clearing of a GDE	1	Severe	Insignificant	No clearing of GDEs will be undertaken. Margins of GDE habitat should be flagged to ensure no disturbance zones are adhered to.	1	1	Negligible	Insignificant
2. A total or partial loss or reduction in the volume or pressure of the aquifer being utilised by **<u>Type 1 GDEs</u>**.	2	Moderate	Low	The alluvial groundwater system that supports Type 1 GDEs is perched above the regional aquifer associated with Tertiary sediments and coal seams. Loss of aquifer pressure resulting in up to 10m of drawdown is predicted for the Tertiary aquifer below on Boomerang Creek. This may increase downward drainage from creek alluvium into Tertiary sediments, with some resultant reduction in volume of the perched aquifer that supports Type 1 GDEs during periods of extended drying / drought. The adaptability of the dominant riparian species to ecological change (see **Section 2.2.3**) would suggest these impacts will be 'Low' in areas where aquifer drawdown response is greatest (i.e., >5m drawdown on Boomerang Creek) and the risk to GDE function will decrease as with decreasing levels of drawdown, becoming insignificant when 'end of mining' drawdown is <1m.	5, 6, 7	2	Moderate	Low
3. A total or partial loss or reduction in the volume or	3	Moderate	Moderate	Risk the ecohydrological function of Type 2 GDEs	5, 6, 7	2	Low	Low

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Impact Pathway	Pre-mitigated Risk			**Comments**	Management /Mitigation Measures*	Residual Risk Ranking		
	Likelihood	Consequence	Risk			Likelihood	Consequence	Risk
pressure of the aquifer being utilised by **Type 2 GDEs**.				requires further baseline data collection to adequately assess. Groundwater modelling indicates <5m of drawdown in Tertiary sediments associated with HES Wetland 8, which may result in more rapid drying and drainage of the groundwater lens is conceptualised to support GDE function. While recharge of the groundwater lens is via surface flow pathways, increased drainage and drawdown may reduce the persistence of the groundwater lens during seasonally dry periods resulting in declines in the health of terrestrial GDEs.				
4. A change in the magnitude and timing of volume fluctuations in the aquifer being utilised by GDEs.	2	Moderate	Low	Volume fluctuations in the perched groundwater system are regulated by surface flows and local surface water infiltration. These processes will not be impacted during mine development or operation. There will be no direct impact to the integrity of the perched groundwater systems that support Type 1 GDEs. A For Type 2 GDEs, increased drainage of perched groundwater may be result in more rapid drying and drainage of the supporting	5, 6, 7	1	Low	Insignificant

Impact Pathway	Pre-mitigated Risk			**Comments**	Management /Mitigation Measures*	Residual Risk Ranking		
	Likelihood	Consequence	Risk			Likelihood	Consequence	Risk
				groundwater lens, although the impact of this to ecohydrological function is considered to be 'Low'.				
5. Changes to the interaction between surface flows and aquifers being utilised by a GDE.	2	Low	Low	There will be no change to the period between, and timing of, floods or significant rainfall events. These stochastic events provide the dominant control on the fluctuations of groundwater which support GDEs.	5, 6, 7	1	Low	Insignificant
6. Change in chemical composition of an aquifer detrimentally impacting the health of a GDE[1].	2	Low	Low	Uncontrolled releases of mine water that has potential to impact the chemical composition of infiltrating surface waters will not occur during the life of the mine.	5, 6, 7	1	Low	Insignificant

*Management measures are applied in during implementation of a project GDEMMP, after which mitigations can be applied if significant impact GDE function and health is detected.

7.0 Conclusions

Multiple lines of evidence including measurement of LWP, SMP, stable isotopes and physical observation have been applied to assess the dependence of vegetation in the Meadowbrook Lake Vermont Project Area on groundwater. Based on the results of the field survey, it is concluded that two types of GDEs are present within the Project area being:

1. Type 1 GDEs: Includes drainage features with developed alluvial landforms that host variable groundwater volumes and are seasonally recharged via surface flows and flooding. This includes Phillips Creek, Boomerang Creek, and the Isaac River.
2. Type 2 GDEs: This represents a conceptualised perched groundwater lens that lies below GDE Assessment Site 3 (a mapped HES wetland). Percolation of groundwater through the alluvial soils occurs when surface water is recharged, and the infiltrating surface water is captured above an aquitard at the alluvial unconformity. Tree roots of river red gum and coolibah are utilising this freshwater lens, which possibly only remains viable for several months following rainfall. The perched freshwater lens is inferred to be >6m below the surface of the wetland.

Water held in the regional Tertiary aquifer and coal seams is mostly an unsuitable resource to support GDEs due to high levels of salinity, and a potentiometric surface that is generally below maximum tree rooting depth for the eucalypt and melaleuca species that define the Type 1 and Type 2 GDE Systems.

Groundwater drawdown associated with development of the underground mining infrastructure and mining void development will result in drawdown within the Tertiary groundwater system (and small areas of alluvium where this has been differentiated) with modelling indicating drawdown of the Tertiary groundwater system below reaches of Boomerang and Phillips Creek of >20m, and drawdown of between 2m and 5m below HES Wetland 8, which is identified as the only example of a Type 2 GDE within the Project area. Drawdown is not predicted to interact with the Isaac River on the eastern margin of MDL429. The risk of impact to GDEs due to depressurisation of the Tertiary groundwater system decreases away from the areas of the most intense drawdown. Increased capacity for infiltration and drainage is associated with sandier sediments (both alluvial and Tertiary) and, enhanced drying may occur where sandy alluvial soils that support Type 1 GDEs intersect areas of predicted groundwater drawdown. Risk of impact to GDEs increases commensurately with drawdown intensity and the hydraulic capacity of the soil to facilitate surface infiltration, although overall the risk the Project poses to GDE function is 'Low'. This is because:

1. The recharge of sandy lenses is controlled by surface flows and surface water infiltration into the soil profile. Natural flood and flow regimes will not be impacted.
2. The groundwater perched in the alluvial systems that support Type 1 and Type 2 GDEs is subject to natural fluctuations in volume in response to changing seasonal conditions and may dry for significant periods.
3. Tree species which characterise the riparian GDE areas (both Type 1 and Type 2 GDEs), particularly river red gum, are resilient and have capacity to adapt to the possible minor

reductions in soil moisture availability that may propagate above areas of predicted drawdown.

Management measures to limit the impact to potential GDEs in vicinity of the Project area include general operational measures such those encompassed in the existing Lake Vermont EA including extension of the existing WMS and REMP to cover Meadowbrook operations. It is also recommended that additional ecological baseline data collection, GDE management and mitigation measures be developed through development of a project GDEMMP, which would provide the basis for ongoing management and detection of change that can be linked to mining operations.

With implementation of management measures through a GDEMMP which includes development of suitable mitigations should impacts to GDEs be identified, it is considered that the risk to GDE's posed by mine development is 'Low'. There are also no significant residual impacts predicted to any prescribed environmental matters under relevant state or federal legislation including both MSES and MNES.

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8.0 References

3d Environmental (2020). Isaac Downs Project – Groundwater Dependent Ecosystem Assessment. Report prepared for Stanmore IP South Pty Ltd.

Australian National Botanic Gardens (ANBG)(2004). Water for a Healthy Country – Taxon Attribute Profile, *Eucalyptus camal*dulensis. Available at: https://www.anbg.gov.au/cpbr/WfHC/Eucalyptus-camaldulensis/index.html

BMA (2017). Initial Advise Statement – Saraji East Mining Project. Available at: Saraji East Mining Lease Project (www.qld.gov.au)

Bren, L.J. and Gibbs, N.L. (1986) Relationships between flood frequency, vegetation and topography in a river red gum forest. Australian Forest Research 16, 357-370.

Bureau of Meteorology (BoM) (2020a). Australian Government. www.bom.gov.au/climate/data/ accessed 27 September 2020.

Bureau of Meteorology (BOM)(2017). Groundwater Dependent Ecosystems Atlas; available at: http://www.bom.gov.au/water/groundwater/gde/map.shtml

Colloff M. (2014). Ecology and History of the River Red Gum. CSIRO Publishing. Collingwood, Victoria.

Commonwealth of Australia (2015), Modelling water-related ecological responses to coal seam gas extraction and coal mining, prepared by Auricht Projects and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for the Department of the Environment, Commonwealth of Australia'.

Costelloe, J., Payne, E., Woodrow, I., Irvine, E., Western, A., & Leaney, F. (2008). Water sources accessed by arid zone riparian trees in highly saline environments, Australia. Oecologia, 156(1), 43-52.

Crosbie RS, Morrow D, Cresswell RG, Leaney FW, Lamontagne S and Lefournour M (2012) New insights into the chemical and isotopic composition of rainfall across Australia. CSIRO Water for a Healthy Country Flagship, Australia

Dang Y.P, Dalal R.C., Mayer D.G., McDonald M. M., Routley R. R., Schwenke G. D., Buck S. R. S.R., Daniells I.G., Singh D. K, Manning W., and Ferguson N. (2008) High subsoil chloride concentrations reduce soil water extraction and crop yield on Vertosols in north-eastern Australia. Crop and Pasture Science 59.4 (2008): 321-330.

Department of Environment and Science (2022). Groundwater Dependent Ecosystems: EIS Information Guideline ESR / 2020 / 5301. Department of Environment and Science, Brisbane.

Department of Environment and Science (DES) (2020). Groundwater dependent ecosystems and potential aquifer mapping – Queensland.

Department of Natural Resources, Mines and Energy (DNRME 2018). Detailed surface geology – Queensland. Digital Database.

Doody TM, Hancock PJ, Pritchard JL (2019). Information Guidelines Explanatory Note: Assessing groundwater-dependent ecosystems. Report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy, Commonwealth of Australia 2019.

Doody, T., Colloff, M., Davies, M., Koul, V., Benyon, R., & Nagler, P. (2015). Quantifying water requirements of riparian river red gum (Eucalyptus camaldulensis) in the Murray–Darling Basin, Australia – implications for the management of environmental flows. Ecohydrology, 8(8), 1471-1487.

Doody, T. M., Holland K. L., Benyon R. G., and Jolly I. D. (2009). Effect of groundwater freshening on riparian vegetation water balance. Hydrological Processes 23.24: 3485-3499.

Dupuy L, Fourcaud T, Stokes A (2005). A numerical investigation into the influence of soil type and root architecture on tree anchorage. Plant Soil 278(1):119–134

Eamus, D (2009). Identifying groundwater dependent ecosystems – A guide for land and water managers. University of Technology, Sydney.

Eamus D., Hatton T., Cook P., Colvin C. (2006a). Ecohydrology. CSIRO Publishing, Collingwood, Australia.

Eamus D., Froend F., Loomes R., Hose G., Murray B., (2006b). A functional methodology for determining the groundwater regime needed to maintain the health of groundwater dependent vegetation. Australian Journal of Botany; 54, 97 -114.

Evaristo, J; McDonnell, J..; Clemens, J. Plant source water apportionment using stable isotopes: A comparison of simple linear, two-compartment mixing model approaches. Hydrological Processes , Volume 31 (21) – Oct 15, 2017.

Feikema, P., Morris, J., & Connell, L. (2010). The water balance and water sources of a Eucalyptus plantation over shallow saline groundwater. Plant and Soil, 332(1), 429-449.

Fensham R.J and Holman J.E (1999). Temporal and spatial patterns in drought-related tree dieback in Australian savanna. Journal of Applied Ecology, 36 1035 – 1050.

Fensham R. J and Fairfax R.J (2006), Drought-related tree death of savanna eucalypts: Species susceptibility, soil conditions and root architecture. Journal of Vegetation Science 18: 71-80

Fensham R. J, Fairfax R. J and Ward D (2009). Drought induced tree death in savanna. Global Change Biology Volume 15, Issue 2, 380-387

Gardner W. R. (1960). Dynamic aspects of water availability to plants. Soil Science, 89, 63 – 73.

Horner, G.J., Baker, P.J., Mac Nally, R., Cunningham, S.C., Thomson, J.R., Hamilton, F., 2009. Mortality of developing floodplain forests subjected to a drying climate and water extraction. Global Change Biol. 15, 2176–2186.

Hutchinson M. F., Nix H. A. & McMahon J. P. (1992) Climate constraints on cropping systems. Field Crop Systems, 18, 37–58.

Independent Expert Scientific Committee (IESC). 2018a. “Information Guidelines for Proponents Preparing Coal Seam Gas and Large Coal Mining Development Proposals.” Independent Expert Scientific Committee on Coal SeamGas and Large Coal Mining Developments. http://www.iesc.environment.gov.au/system/files/resources/012fa918-ee79-4131-9c8d-02c9b2de65cf/files/iesc-information-guidelines-may-2018.pdf.

Independent Expert Scientific Committed (IESC) 2019. Information Guidelines Explanatory Note – Assessing groundwater dependent ecosystems available at: http://www.iesc.environment.gov.au/system/files/resources/422b5f66-dfba-4e89-adda-b169fe408fe1/files/information-guidelines-explanatory-note-assessing-groundwater-dependent-ecosystems.pdf

JBT Consulting (2022). Meadowbrook Project Groundwater Assessment Report (Draft). Report prepared for Jellinbah Resources / AARC.

Johnson, R., McDonald, W., Fensham, R., McAlpine, C., & Lawes, M. (2016). Changes over 46 years in plant community structure in a cleared brigalow (Acacia harpophylla) forest. Austral Ecology, 41(6), 644-656

Jones C., Stanton D., Hamer N., Denner S., Singh K., Flook S., Dyring M. (2019). Field Investigations of Potential Terrestrial Groundwater Dependent Ecosystems within Australia’s Great Artesian Basin. Hydrogeology Journal. Springer Nature PP 4 - 27.

Lamontagne, S., Leaney, F., & Herczeg, A. (2005). Groundwater–surface water interactions in a large semi-arid floodplain: implications for salinity management. Hydrological Processes, 19(16), 3063-3080.

Mensforth, L., Thorburn, P., Tyerman, S., & Walker, G. (1994). Sources of water used by riparian Eucalyptus camaldulensis overlying highly saline groundwater. Oecologia, 100(1), 21-28.

O’Grady, A., Cook P. G., Howe P. P., and Werren G. G. (2006b). "Groundwater use by dominant tree species in tropical remnant vegetation communities." Australian Journal of Botany 54.2 (2006): 155-171.

Pembroke Resources (2020). Section 10 – Biodiversity Offset Strategy – All Stages. Available at: Olive Downs Project EIS documents | State Development, Infrastructure, Local Government and Planning

Petit N. E and Froend R. H (2018). How important is groundwater availability and stream perenniality to riparian and floodplain tree growth. Hydrological Process. Volume 32 (10) – Jan 15, 2018

Richardson S, et al 2011 Australian groundwater-dependent ecosystem toolbox part 1: assessment framework, Waterlines report, National Water Commission, Canberra

Roberts, J. (1993). Regeneration and growth of coolibah, Eucalyptus coolabah subsp. arida, a riparian tree, in the Cooper Creek region of South Australia. Austral Ecology, 18(3), 345-350.

Serov P, Kuginis L and Williams JP. 2012. *Risk assessment guidelines for groundwater dependent ecosystems, Volume 1—The conceptual framework.* NSW Department of Primary Industries, Office of Water, Sydney. Available [online]: http://archive.water.nsw.gov.au/__data/assets/pdf_file/0005/547682/gde_risk_assessment_guidelines_volume_1_final_accessible.pdf

Singer, M. B., Sargent, C. I., Piégay, H., Riquier, J., Wilson, R. J. S., & Evans, C. M. (2014). Floodplain ecohydrology: Climatic, anthropogenic, and local physical controls on partitioning of water sources to riparian trees. Water Resources Research, 50, 4490–4513.

SILO (2020) Climate data from the Data Drill -22.82 / 148.49, 1990 to 2020 available from: https://www.longpaddock.qld.gov.au/silo/point-data/

Soil Moisture Equipment Corp. (2006). Model 3115 – Portable Plant Water Status Console – Operation Manual.

Thorburn, P. J, and Walker G. R (1994) Variations in stream water uptake by Eucalyptus camaldulensis with differing access to stream water. Oecologia, 100, 293-301.

United States Geological Survey (2004). Resources on Isotopes, available at: USGS -- Isotope Tracers -- Resources

Weber K., and Stewart M., (2004). A Critical Analysis of the Cumulative Rainfall Departure Concept. Ground Water, 42(6)

Appendices

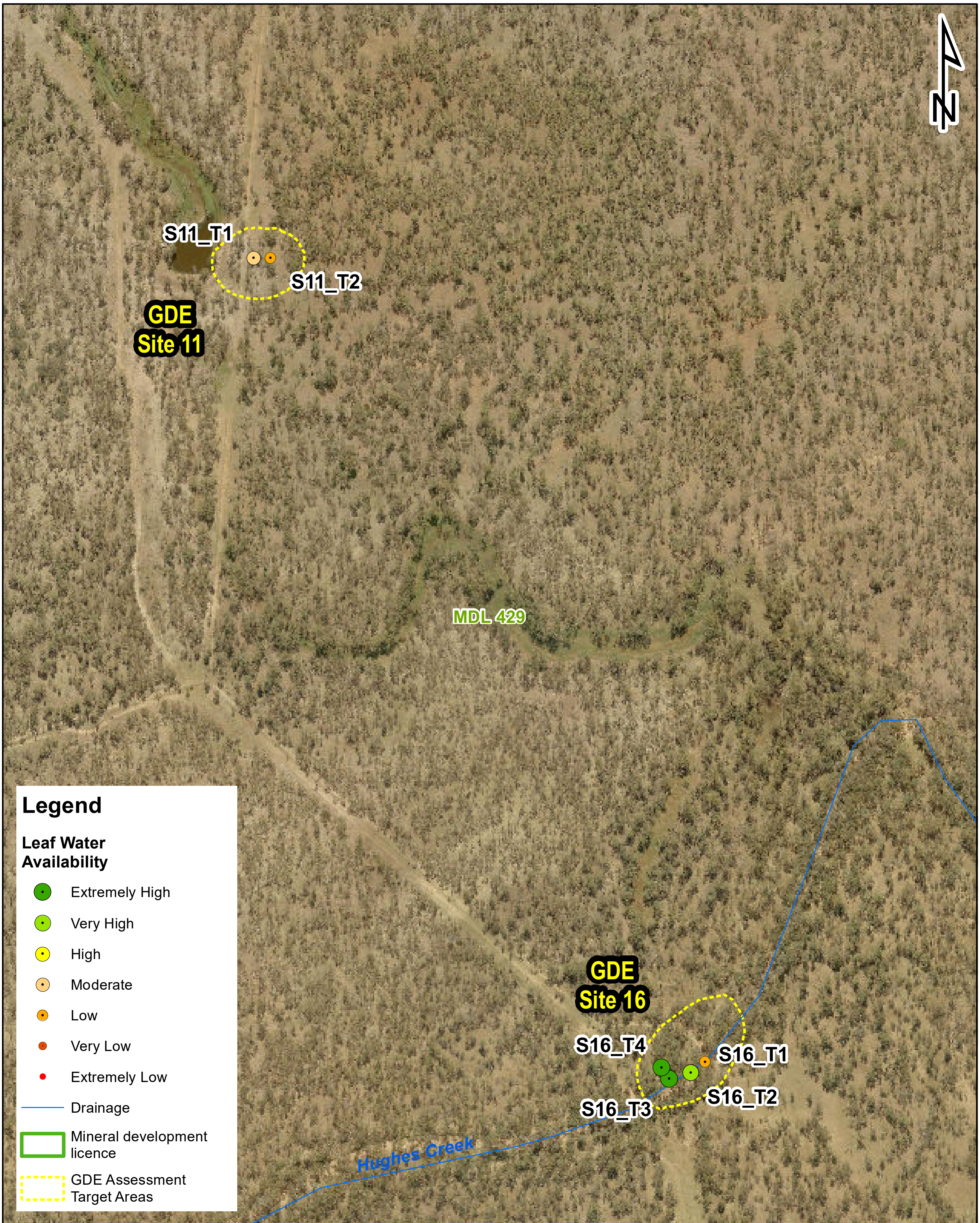
Appendix A – Tree LWP Measurements and Details

Site	Species	Tree Number	Y	X	DBH	Height	Position	LWP	Leaf Water Availability
1	*Eucalyptus camaldulensis*	S1_T1	-22.339651	148.472772	75	20	Mid inner terrace 25m from river channel, 12m above river channel	-0.35	Very High
1	*Eucalyptus camaldulensis*	S1_T2	-22.339784	148.472935	80	25	Top of T2 Terrace, 30m from river channel and 15m above river.	-0.3	Very High
1	*Eucalyptus camaldulensis*	S1_T3	-22.339692	148.473189	90	22	Mid terrace, 8m above channel floor	-0.3	Very High
1	*Eucalyptus camaldulensis*	S1_T4	-22.339778	148.473697	130	20	Inner Terrace, 7m above channel floor and 13m from river	-0.3	Very High
1	*Melaleuca fluviatilis*	S1_T5	-22.339695	148.473601	60	23	Base of inner bench, adjacent to to sandy channel	-0.4	Very High
1	*Eucalyptus populnea*	S1_T6	-22.340042	148.472594	50	18	Top of T2 terrace	-0.6	High
1	*Eucalyptus populnea*	S1_T7	-22.340288	148.472635	55	19	Top of T2 terrace	-0.5	Very High
2	*Eucalyptus coolibah*	S2_T1	-22.327688	148.445592	90	25	2m from edge of surface water body	-0.4	Very High
2	*Eucalyptus coolibah*	S2_T2	-22.327898	148.445586	75	21	15m from edge of surface water body	-0.3	Very High
2	*Eucalyptus coolibah*	S2_T3	-22.327875	148.445432	75	21	5m from edge of surface water body	-0.7	High
2	*Eucalyptus coolibah*	S2_T4	-22.327937	148.445	95	23	2m from edge of surface water body	-0.5	Very High
3	*Eucalyptus camaldulensis*	S3_T1	-22.329701	148.449498	65	23	Central portion of dry wetland depression	-0.2	Extremely High
3	*Eucalyptus camaldulensis*	S3_T2	-22.329659	148.449507	55	21	Central portion of dry wetland depression	-0.2	Extremely High
3	*Eucalyptus camaldulensis*	S3_T3	-22.329637	148.449565	60	23	Central portion of dry wetland depression	-0.15	Extremely High
3	*Eucalyptus coolibah*	S3_T4	-22.329664	148.450125	130	27	Outer eastern margins of dry wetland depression	-0.25	Extremely High
4	*Eucalyptus coolibah*	S4_T1	-22.319583	148.448165	135	24	3m from base of channel floor on inner bench	-1	Moderate
4	*Eucalyptus coolibah*	S4_T2	-22.320119	148.447901	60	18	20m from top of bank, 5m above channel floor. T1 terrace	-0.45	Very High
4	*Eucalyptus coolibah*	S4_T3	-22.320434	148.447868	55	19	In channel floor, dry creek bank.	-0.7	High
4	*Eucalyptus coolibah*	S4_T4	-22.320326	148.448093	85	21	Top of terrace, 4m above channel floor just inside inner bench.	-1.1	Moderate
5	*Eucalyptus coolibah*	S5_T1	-22.31732	148.437097	55	18	Dry drainage area. Limited development of riparian vegetation	-1.6	Low
5	*Eucalyptus coolibah*	S5_T2	-22.317472	148.43702	60	19	Dry drainage area. Limited development of riparian vegetation	-1.4	Low
6	*Eucalyptus tereticornis*	S6_T1	-22.319429	148.421966	60	24	Base of overflow depression	-0.7	Moderate

Site	Species	Tree Number	Y	X	DBH	Height	Position	LWP	Leaf Water Availability
6	*Eucalyptus tereticornis*	S6_T2	-22.319457	148.421796	60	20	Base of overflow depression	-0.55	Very High
6	*Eucalyptus tereticornis*	S6_T3	-22.319381	148.421514	60	15	Base of overflow depression	-0.6	High
7	*Eucalyptus populnea*	S7_T1	-22.333013	148.375616	55	19	Broad undulating loamy plain with no riparian vegetation development	-1.7	Low
7	*Eucalyptus populnea*	S7_T2	-22.333343	148.375621	60	18	Broad undulating loamy plain with no riparian vegetation development	-1.7	Low
8	*Melaleuca fluviatilis*	S8_T1	-22.341684	148.414374	110	23	Edge of channel on low terrace	-0.9	Moderate
8	*Melaleuca fluviatilis*	S8_T2	-22.341596	148.413636	60	23	Directly adjacent to sandy channel floor	-0.15	Extremely High
8	*Melaleuca fluviatilis*	S8_T3	-22.34108	148.413025	80	24	10m from channel floor, 5m above channel.	-1.25	Moderate
8	*Eucalyptus camaldulensis*	S8_T4	-22.341422	148.413685	90	23	15m from channel, 7m above channel floor	-0.5	Very High
8	*Eucalyptus camaldulensis*	S8_T5	-22.341431	148.413206	80	19	8m above channel floor on top of T1 terrace	-0.45	Very High
9	*Melaleuca fluviatilis*	S9_T1	-22.33833	148.378218	40	26	2m above channel floor on inner bench	-0.3	Very High
9	*Eucalyptus camaldulensis*	S9_T2	-22.338267	148.378731	100	25	Top of T1 terrace 10m from edge of bank	-0.42	Very High
9	*Eucalyptus camaldulensis*	S9_T3	-22.33836	148.379254	80	20	On direct margins of channel	-0.35	Very High
9	*Melaleuca fluviatilis*	S9_T4	-22.338251	148.378059	50	18	On direct margins of channel	-0.23	Extremely High
9	*Eucalyptus camaldulensis*	S9_T5	-22.338475	148.37751	65	20	Top of T1 terrace 20m from edge of bank	-0.45	Very High
10	*Eucalyptus camaldulensis*	S10_T1	-22.337614	148.370391	90	30	7m from edge of surface water body	-1	Moderate
10	*Eucalyptus camaldulensis*	S10_T2	-22.337832	148.370717	60	22	6m from edge of water body	-0.65	High
10	*Eucalyptus camaldulensis x platyphylla*	S10_T3	-22.338564	148.371307	80	20	In moist portions of the drainage depression	-0.7	High
10	*Eucalyptus camaldulensis x platyphylla*	S10_T4	-22.338568	148.370952	80	15	In moist portions of the drainage depression, 5m from surface water	-0.7	High
11	*Eucalyptus populnea*	S11_T1	-22.325715	148.350359	55	21	Broad undulating loamy plain with no riparian vegetation development	-1.2	Moderate
11	*Eucalyptus populnea*	S11_T2	-22.325711	148.350566	60	20	Broad undulating loamy plain with no riparian vegetation development	-1.4	Low
13	*Eucalyptus cambageana*	S13_T1	-22.300951	148.41519	80	25	Broad drainage depression with no defined channel or riparian vegetation	-1.7	Low
13	*Eucalyptus cambageana*	S13_T2	-22.301042	148.41494	75	23	Broad drainage depression with no defined channel or riparian vegetation	-1.6	Low

Site	Species	Tree Number	Y	X	DBH	Height	Position	LWP	Leaf Water Availability
13	*Eucalyptus populnea*	S13_T3	-22.300844	148.414804	55	21	Broad drainage depression with no defined channel or riparian vegetation	-1.8	Low
13	*Eucalyptus populnea*	S13_T4	-22.300797	148.415175	60	20	Broad drainage depression with no defined channel or riparian vegetation	-2.5	Extremely Low
14	*Eucalyptus coolibah*	S14_T1	-22.365217	148.361285	110	24	Margins of small drainage line in depression	-1.8	Very Low
14	*Eucalyptus coolibah*	S14_T2	-22.365084	148.361285	70	22	Margins of small drainage line in depression	-1.8	Very Low
14	*Eucalyptus populnea*	S14_T3	-22.365208	148.36117	60	19	Margins of small drainage line in depression	-1.1	Moderate
14	*Eucalyptus populnea*	S14_T4	-22.364758	148.361215	80	15	Margins of small drainage line in depression	-2	Very Low
15	*Eucalyptus coolibah*	S15_T1	-22.355737	148.352668	100	23	Margins of circular wetland depression	-1.5	Low
15	*Eucalyptus populnea*	S15_T2	-22.35568	148.353067	70	19	Out edges of wetland depression	-1.8	Very Low
15	*Eucalyptus coolibah*	S15_T3	-22.355508	148.353197	100	18	Inner portion of wetland depression, 80m from margins	-1.1	Moderate
16	*Eucalyptus camaldulensis*	S16_T1	-22.334779	148.355949	85	23	Inner bench immediately above sandy channel	-1.4	Low
16	*Melaleuca fluviatilis*	S16_T2	-22.334901	148.355777	65	20	Inner bench immediately above sandy channel	-0.45	Very High
16	*Eucalyptus camaldulensis*	S16_T3	-22.334973	148.355513	95	23	Top of T1 terrace 20m from river and 8m above channel	-0.23	Extremely High
16	*Eucalyptus camaldulensis*	S16_T4	-22.334847	148.355419	90	20	Mid way up T1 terrace 15m from river and 8m above channel	-0.25	Extremely High
17	*Eucalyptus coolibah*	S17_T1	-22.358121	148.396062	65	22	Top of T1 terrace 5m above clayey channel floor	-1.4	Low
17	*Eucalyptus coolibah*	S17_T2	-22.358154	148.395853	60	18	On low terrace instream, 3m above channel	-0.6	High
17	*Eucalyptus camaldulensis*	S17_T3	-22.358377	148.395573	65	17	Top of T1 terrace 5m above clayey channel floor	-2.5	Extremely Low
18	*Eucalyptus camaldulensis*	S18_T1	-22.394005	148.400023	110	26	Inner bench 2m above sandy channel	-0.45	Very High
18	*Casuarina cunninghamiana*	S18_T2	-22.393769	148.400738	50	23	Inner bench immediately above sandy channel	-0.5	Very High
18	*Eucalyptus camaldulensis*	S18_T3	-22.393615	148.400858	80	22	Top of T2 high terrace 10 -12m above sandy channel	-0.6	High
18	*Eucalyptus camaldulensis*	S18_T4	-22.393532	148.400928	75	19	Top of T2 high terrace 10 -12m above sandy channel	-0.6	High

Appendix B. LWP Values for Individual Trees as Each Assessment Locality



Appendix B1. Sampling detail at GDE Area 11 and GDE Area 16

Client: AARC Environmental Solutions

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Kilometers

3D Environmental
Landscape & Vegetation Science

Kenmore, Qld 4069
Mobile: 0447 822 119
www.3denvironmental.com.au

Scale	Drawn By	Checked	File Path	Date	
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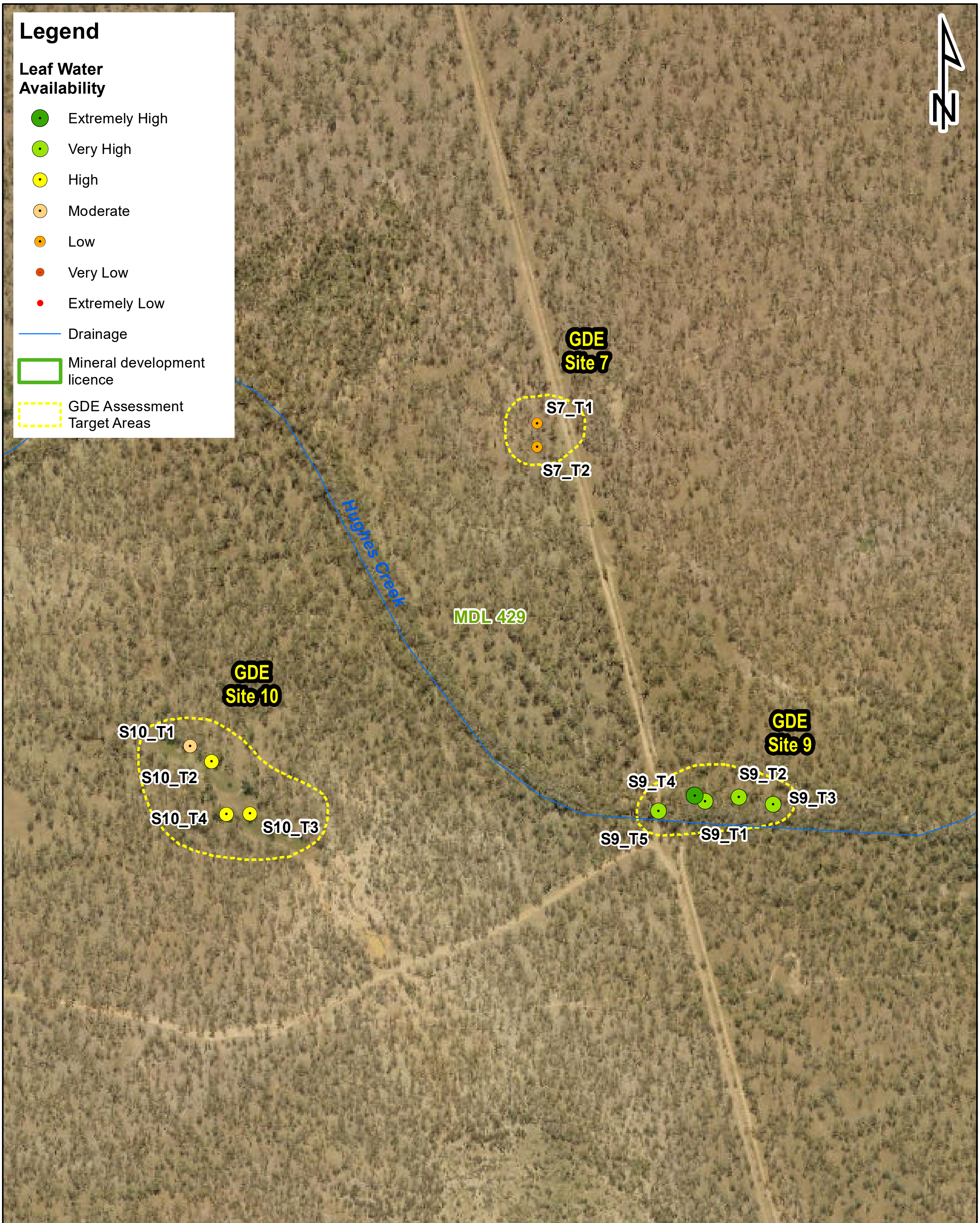

Appendix B2. Sampling detail at GDE Area 7, GDE Area 9 and GDE Area 10

Client
AARC Environmental Solutions

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Kilometers

3D Environmental
Landscape & Vegetation Science

Kenmore, Qld 4069
Mobile: 0447 822 119
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Scale 1:7,884	Drawn By DG	Checked DS	File Path	Date 10/12/2021	A4

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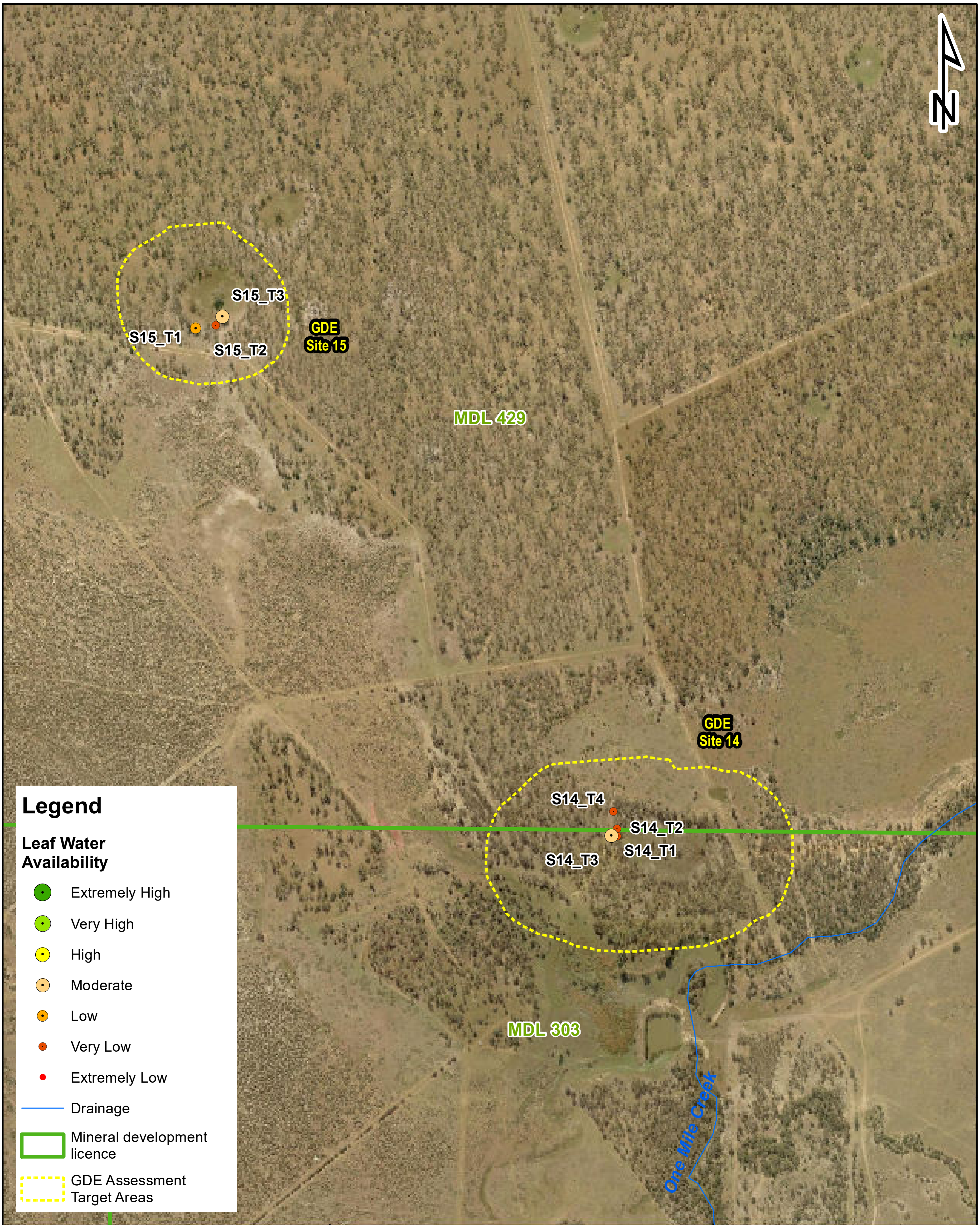

Figure 17. Sampling detail at GDE Area 14 and GDE Area 17.

Client: **AARC Environmental Solutions**

0 0.1 0.2 0.3 0.4
Kilometers

3D Environmental
Landscape & Vegetation Science

Kenmore, Qld 4069
Mobile: 0447 822 119
www.3denvironmental.com.au

Scale	Drawn By	Checked	File Path	Date	
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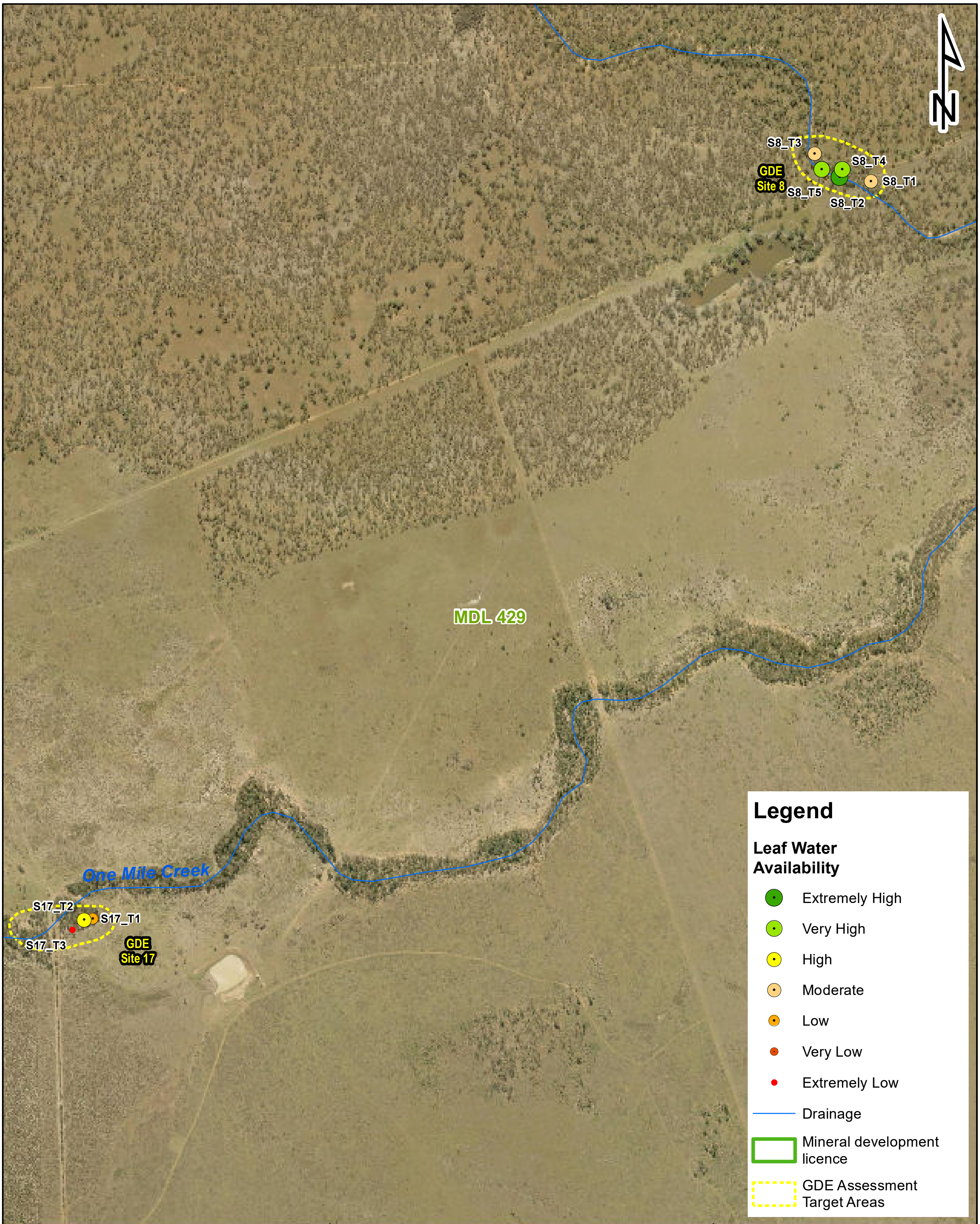

Appendix B4. Sampling detail at GDE 8 and GDE Area 17,

Client

AARC Environmental Solutions

0 0.1 0.2 0.3 0.4
Kilometers

3D Environmental
Landscape & Vegetation Science

Kenmore, Qld 4069
Mobile: 0447 822 119
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Scale	Drawn By	Checked	File Path	Date	
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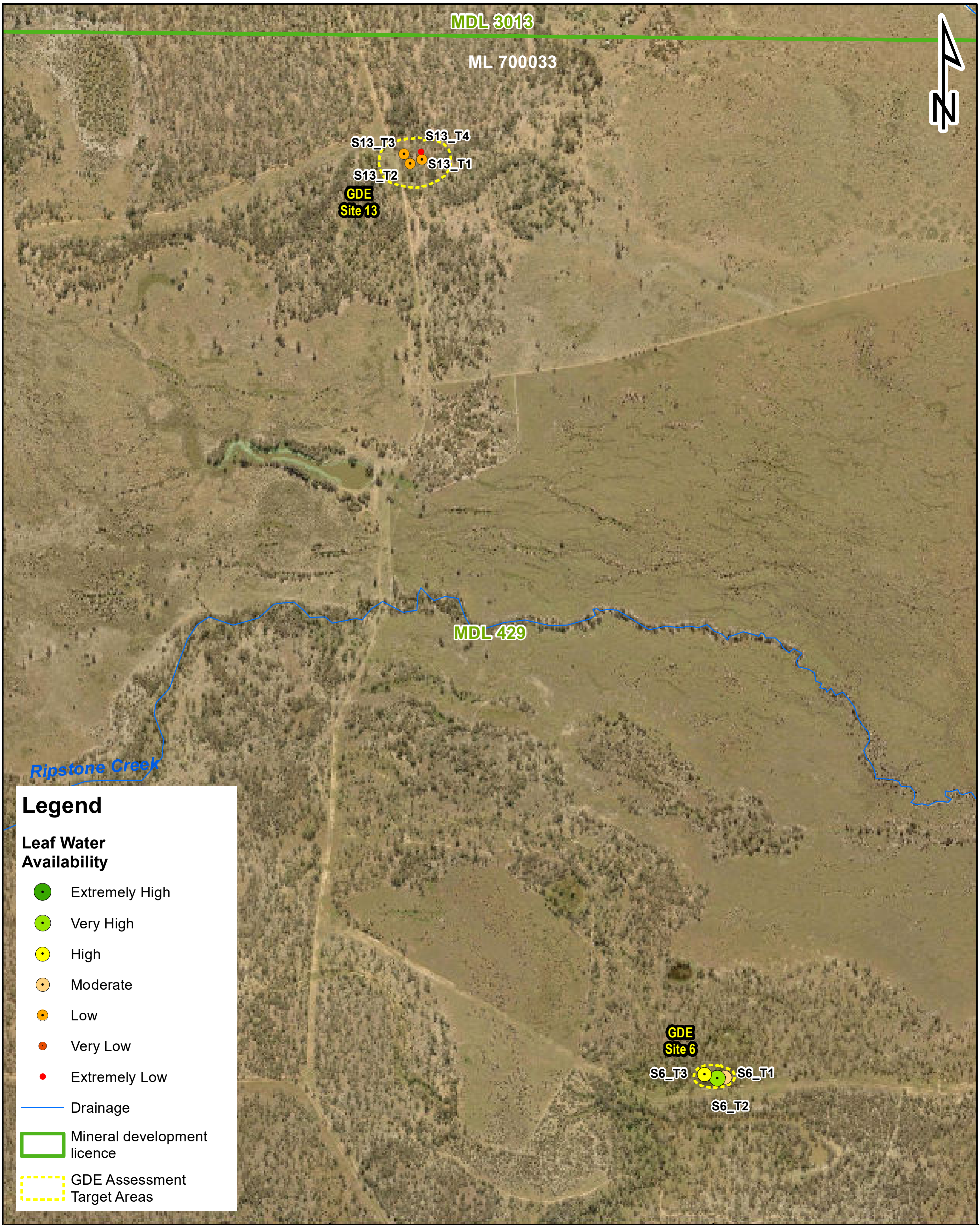

Appendix B5. Sampling detail at GDE 6 and GDE Area 13,

Client

AARC Environmental Solutions

0 0.1 0.2 0.3 0.4
Kilometers

3D Environmental
Landscape & Vegetation Science

Kenmore, Qld 4069
Mobile: 0447 822 119
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Scale 1:11,279	Drawn By DG	Checked DS	File Path	Date 10/12/2021	A4

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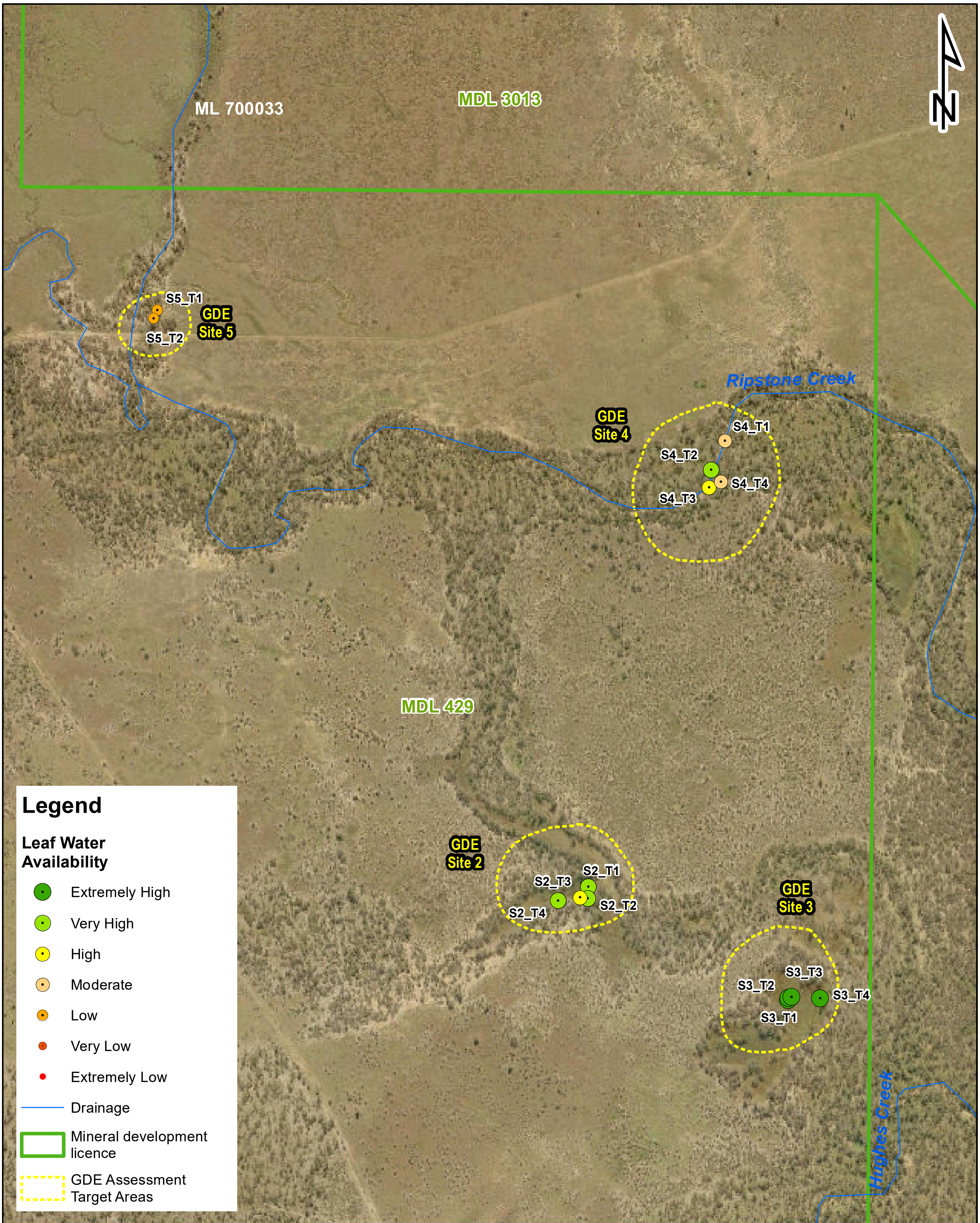

Appendix B6. Sampling detail at GDE 2 to GDE Area 5,

Client

AARC Environmental Solutions

0 0.1 0.2 0.3 0.4

Kilometers

3D Environmental

Landscape & Vegetation Science

Kenmore, Qld 4069
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Scale	1:10,108	Drawn By	DG	Checked	DS	File Path		Date	10/12/2021	A4

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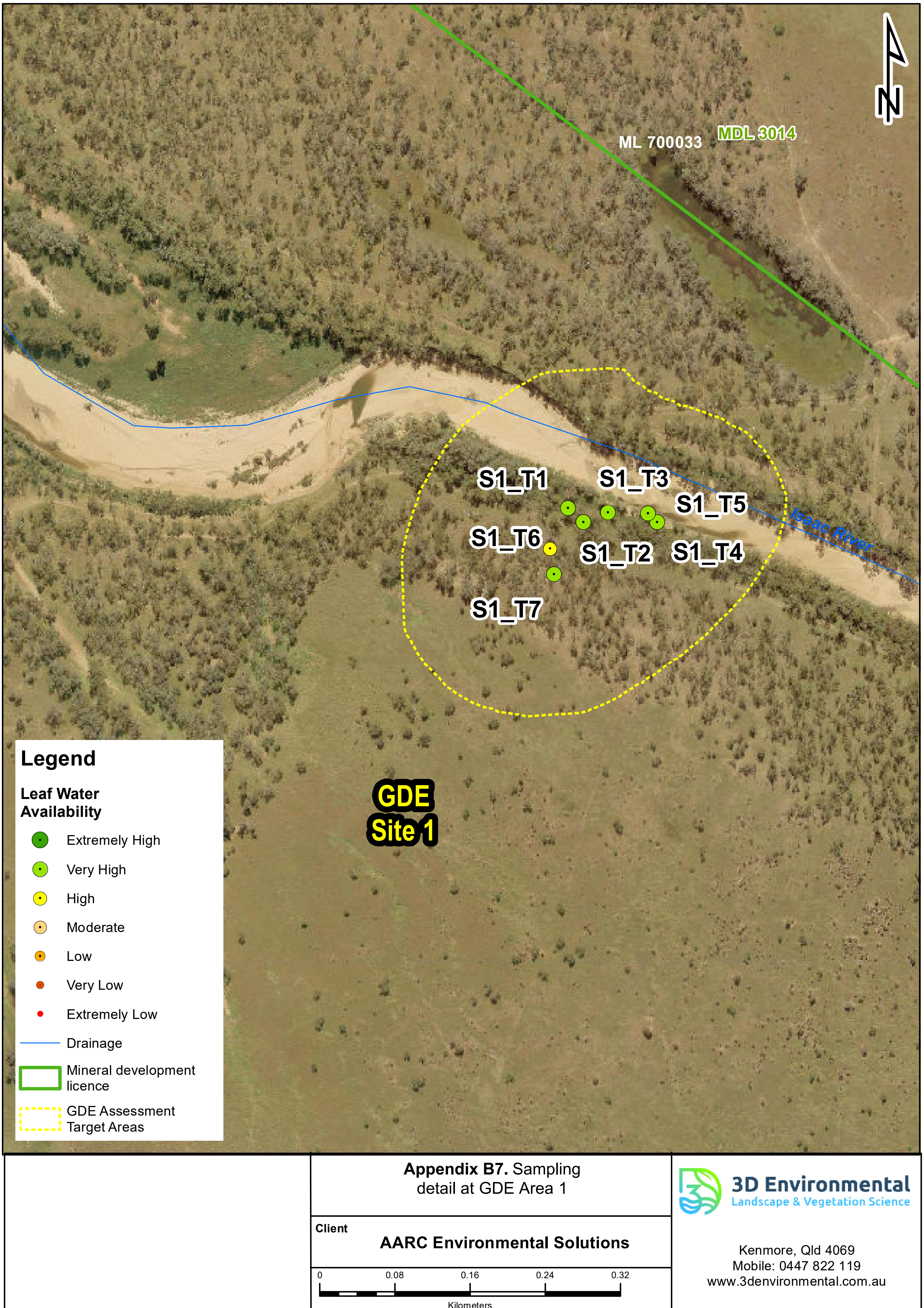

Appendix B7. Sampling detail at GDE Area 1

Client

AARC Environmental Solutions

3D Environmental
Landscape & Vegetation Science

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Mobile: 0447 822 119
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Scale 1:5,054	**Drawn By** DG	**Checked** DS	**File Path**	**Date** 10/12/2021	A4

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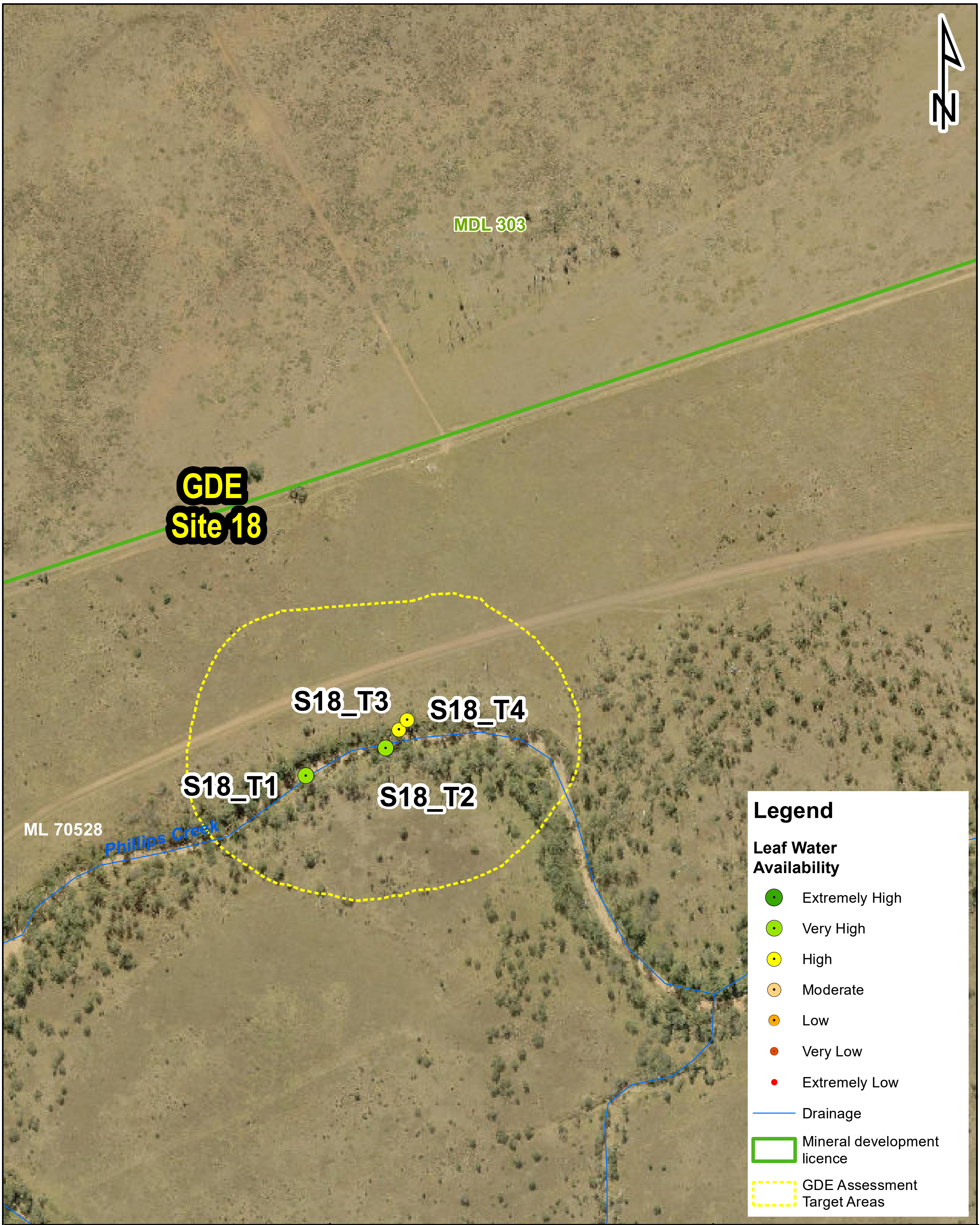

Appendix B8. Sampling detail at GDE Area 18

Client

AARC Environmental Solutions

0 0.08 0.16 0.24 0.32
Kilometers

Scale 1:4,650 | Drawn By DG | Checked DS | File Path | Date 10/12/2021 | A4

3D Environmental
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Appendix C – Soil Moisture Potential Raw Data

Specimen Number	GDE Assessment Area	Type	Date Collected	SMP MPA
S16_AU1_0.5	GDE Site 16	Soil	15 Aug-21	-0.55
S16_AU1_1.0	GDE Site 16	Soil	15 Aug-21	-0.33
S16_AU1_1.2	GDE Site 16	Soil	15 Aug-21	-0.31
S16_AU1_1.5	GDE Site 16	Soil	15 Aug-21	-0.24
S16_AU1_2.0	GDE Site 16	Soil	15 Aug-21	-0.11
S16_AU1_2.3	GDE Site 16	Soil	15 Aug-21	-0.13
S16_AU2_0.5	GDE Site 16	Soil	15 Aug-21	-0.87
S16_AU2_1.0	GDE Site 16	Soil	15 Aug-21	-1.45
S16_AU2_1.5	GDE Site 16	Soil	15 Aug-21	-1.42
S16_AU2_2.0	GDE Site 16	Soil	15 Aug-21	-1.39
S16_AU2_2.5	GDE Site 16	Soil	15 Aug-21	-0.86
S16_AU2_3.0	GDE Site 16	Soil	15 Aug-21	-0.69
S16_AU2_3.5	GDE Site 16	Soil	15 Aug-21	-0.42
S16_AU2_3.8	GDE Site 16	Soil	15 Aug-21	-0.33
S16_AU2_4.5	GDE Site 16	Soil	15 Aug-21	-0.11
S16_AU2_5.0	GDE Site 16	Soil	15 Aug-21	-0.27
S16_AU2_5.1	GDE Site 16	Soil	15 Aug-21	-0.11
S16_AU2_5.3	GDE Site 16	Soil	15 Aug-21	-0.17
S3_AU1_0.1	GDE Site 3	Soil	17 Aug-21	-1.38
S3_AU1_0.5	GDE Site 3	Soil	17 Aug-21	-1.5
S3_AU1_1.0	GDE Site 3	Soil	17 Aug-21	-1.47
S3_AU1_1.5	GDE Site 3	Soil	17 Aug-21	-2.15
S3_AU1_2.0	GDE Site 3	Soil	17 Aug-21	-2.07
S3_AU1_2.5	GDE Site 3	Soil	17 Aug-21	-1.93
S3_AU1_3.0	GDE Site 3	Soil	17 Aug-21	-2.47
S3_AU1_3.5	GDE Site 3	Soil	17 Aug-21	-1.59
S3_AU1_4.0	GDE Site 3	Soil	17 Aug-21	-2.21
S3_AU1_4.5	GDE Site 3	Soil	17 Aug-21	-1.56
S3_AU1_5.0	GDE Site 3	Soil	17 Aug-21	-1.33
S3_AU1_5.1	GDE Site 3	Soil	17 Aug-21	-1.42
S3_AU1_5.5	GDE Site 3	Soil	17 Aug-21	-1.01
S3_AU1_6.1	GDE Site 3	Soil	17 Aug-21	-1.55
S8_AU1_0.25	GDE Site 8	Soil	16 Aug 21	-0.75
S8_AU1_0.5	GDE Site 8	Soil	16 Aug 21	-1.29
S8_AU1_1.0	GDE Site 8	Soil	16 Aug 21	-0.64
S8_AU1_1.5	GDE Site 8	Soil	16 Aug 21	-0.46
S8_AU1_1.7	GDE Site 8	Soil	16 Aug 21	-0.22
S18_AU1_0.3	GDE Site 18	Soil	18 Aug-21	-0.9
S18_AU1_0.7	GDE Site 18	Soil	18 Aug-21	-0.6
S18_AU1_1.0	GDE Site 18	Soil	18 Aug-21	-0.6
S18_AU1_1.3	GDE Site 18	Soil	18 Aug-21	-0.54

Specimen Number	GDE Assessment Area	Type	Date Collected	SMP MPA
S18_AU1_1.5	GDE Site 18	Soil	18 Aug-21	-0.53
S18_AU1_1.75	GDE Site 18	Soil	18 Aug-21	-0.55
S18_AU1_2.2	GDE Site 18	Soil	18 Aug-21	-0.31
S10_AU1_0.3	GDE Site 10	Soil	16 Aug-21	-1.27
S10_AU1_0.6	GDE Site 10	Soil	16 Aug-21	-1.26
S10_AU1_1.0	GDE Site 10	Soil	16 Aug-21	-2.21
S10_AU1_1.25	GDE Site 10	Soil	16 Aug-21	-1.18
S10_AU1_1.5	GDE Site 10	Soil	16 Aug-21	-1.14
S10_AU1_1.75	GDE Site 10	Soil	16 Aug-21	-0.76
S10_AU1_2.25	GDE Site 10	Soil	16 Aug-21	-0.65
S10_AU1_0.3	GDE Site 10	Soil	16 Aug-21	-1.27

Appendix D– Stable Isotope Analytical Results

Sample 2	Site	Material	Depth	$\delta^{2}H$	$\delta^{18}O$
S1-AU1-1.2	S1	Soil	1.2	-27.38	-5.99
S3-AU1-0.5	S3	Soil	0.5	-20.44	-3.91
S3-AU1-1.0	S3	Soil	1.0	-21.58	-3.83
S3-AU1-1.5	S3	Soil	1.5	-22.56	-3.7
S3-AU1-2.0	S3	Soil	2.0	-19.69	-4.71
S3-AU1-2.5	S3	Soil	2.5	-22.57	-4.27
S3-AU1-3.0	S3	Soil	3.0	-16.45	-4.54
S3-AU1-3.5	S3	Soil	3.5	-29.21	-3.91
S3-AU1-4.0	S3	Soil	4.0	-21.18	-4.23
S3-AU1-4.5	S3	Soil	4.5	-21.99	-3.8
S3-AU1-5.1	S3	Soil	5.1	-23.47	-2.86
S3-AU1-5.5	S3	Soil	5.5	-20.84	-4.91
S3-AU1-6.1	S3	Soil	6.1	-15.26	-5.12
S8-AU-0.5	S8	Soil	0.5	-11.43	-5.22
S8-AU1-1.0	S8	Soil	1.0	-12.01	-4.79
S8-AU1-1.5	S8	Soil	1.5	-27.07	-4.54
S8-AU1-1.7	S8	Soil	1.7	-29.17	-5.47
S10-AU1-0.6	S10	Soil	0.6	-25.29	-3.79
S10-AU1-1.0	S10	Soil	1.0	-29.63	-4.28
S10-AU1-1.5	S10	Soil	1.5	-28.96	-4.98
S16-AU2-0.5	S16	Soil	0.5	-19.63	-4.1
S16-AU2-1.0	S16	Soil	1.0	-28.52	-5.72
S16-AU2-1.5	S16	Soil	1.5	-23.28	-6.46
S16-AU2-2.0	S16	Soil	2.0	-23.06	-7.2
S16-AU2-2.5	S16	Soil	2.5	-28.72	-6.98
S16-AU2-3.0	S16	Soil	3.0	-34.73	-7.01
S16-AU2-3.5	S16	Soil	3.5	-33.3	-5.91
S16-AU2-3.8	S16	Soil	3.8	-33.48	-5.64
S16-AU2-4.5	S16	Soil	4.5	-30.47	-5.48
S16-AU2-5.1	S16	Soil	5.1	-30.52	-4.05
S16-AU2-5.3	S16	Soil	5.3	-23.47	-5.48
S16-AU1-0.5	S16	Soil	0.5	-29	-4.65
S16-AU1-1.0	S16	Soil	1.0	-25.55	-4.68
S16-AU1-1.5	S16	Soil	1.5	-35.33	-5.78
S16-AU1-2.3	S16	Soil	2.3	-22.96	-4.84
S18-AU1-0.3	S18	Soil	0.3	-17.87	-4.28
S18-AU1-0.7	S18	Soil	0.7	-19.57	-2.69
S18-AU1-1.0	S18	Soil	1.0	-18.26	-4.17
S18-AU1-1.3	S18	Soil	1.3	-28.72	-4.44
S18-AU1-1.5	S18	Soil	1.5	-24.42	-4.21
S18-AU1-1.75	S18	Soil	1.75	-17.68	-4.75

Sample 2	Site	Material	Depth	$\delta^{2}H$	$\delta^{18}O$
S18-AU1-2.2	S18	Soil	2.2	-22.2	-5.03
S1_T1	S1	Xylem	NA	-43.45	-6.43
S1_T3	S1	Xylem	NA	-41.52	-4.83
S1_T4	S1	Xylem	NA	-28.61	-3.32
S1_T5	S1	Xylem	NA	-24.64	-2.74
S2_T1	S2	Xylem	NA	-16.69	-1.63
S2_T3	S2	Xylem	NA	-9.46	-0.49
S2_T4	S2	Xylem	NA	-17.38	-2.64
S3_T1	S3	Xylem	NA	-17.37	-2.64
S3_T2	S3	Xylem	NA	-20.04	-2.76
S3_T3	S3	Xylem	NA	-17.27	-2.58
S3_T4	S3	Xylem	NA	-13.56	-2.71
S4_T1	S4	Xylem	NA	-31.54	-3.51
S4_T3	S4	Xylem	NA	-29.75	-5.42
S5_T1	S5	Xylem	NA	-21.33	-2.55
S6_T1	S6	Xylem	NA	-28.56	-3.07
S6_T3	S6	Xylem	NA	-37.18	-3.44
S8_T1	S8	Xylem	NA	-24.8	-2.94
S8_T2	S8	Xylem	NA	-23.66	-3.43
S8_T4	S8	Xylem	NA	-29.51	-3.11
S9_T1	S9	Xylem	NA	-20.72	-3.82
S9_T2	S9	Xylem	NA	-23.99	-2.97
S9_T3	S0	Xylem	NA	-24.8	-3.48
S10_T1	S10	Xylem	NA	-3.47	0.8
S10_T2	S10	Xylem	NA	-19.41	-1.99
S14_T1	S14	Xylem	NA	-14.88	-1.77
S14_T4	S14	Xylem	NA	-13.61	-2.39
S15_T3	S15	Xylem	NA	-11.42	-2.25
S16_T2	S16	Xylem	NA	-16.17	-2.88
S16_T3	S16	Xylem	NA	-20.96	-2.84
S16_T4	S16	Xylem	NA	-21.19	-3.2
S17_T2	S17	Xylem	NA	-14.16	-3.88
S18_T1	S18	Xylem	NA	-25.49	-4.55
S18_T3	S18	Xylem	NA	-23.87	-3.88
S18_T4	S18	Xylem	NA	-19.88	-3.12
S1-SW1	S1	Surface Water	NA	-7.84	-1.41
S2-SW1	S2	Surface Water	NA	19.18	4.56
S10-SW1	S10	Surface Water	NA	17.92	4.15
S14_SW1	S14	Surface Water	NA	19.98	4.72
S16-AU1_GW	S16	Groundwater	NA	-17.28	-3.98
W3-MB2	NA	Groundwater	NA	-28.51	-4.28
W14-MB1	NA	Groundwater		-26.77	-4.42

Sample 2	Site	Material	Depth	⍰^{2}H	⍰^{18}O
W1-MB1	NA	Groundwater	NA	-23.32	-3.5
W5-MB3	NA	Groundwater	NA	-28.49	-4.57
W8-MB1	NA	Groundwater	NA	-23.13	-3.45
W5-MB2	NA	Groundwater	NA	-31.42	-4.69
W2-MB2	NA	Groundwater	NA	-25.03	-3.68
W9-MB2	NA	Groundwater	NA	-26.1	-3.74
W10-MB2	NA	Groundwater	NA	-28.16	-3.88
W14-MB2	NA	Groundwater	NA	-32.3	-4.95
W13-MB2	NA	Groundwater	NA	-33.5	-4.95