# SARAJI EAST MINING LEASE PROJECT

Environmental Impact Statement

## Appendix D-2

Groundwater Dependent Ecosystems Report

BHP Mitsubishi Alliance

# Saraji East Mining Lease Project

## Groundwater Dependent Ecosystem Assessment

Prepared by 3d Environmental

*For*

*Aecom Australia Pty Ltd*

Revision 3_ Final Draft_July 2023

**Project No.** 2021_242

**Project Manager:** David Stanton
**Client:** GHD Pty Ltd / Arrow Energy
**Purpose: Groundwater Dependent Ecosystem (GDE) assessment for the Saraji East Mining Lease Project**

| Draft | Date Issued | Issued By. | Purpose |
|---|---|---|---|
| Rev 1 | 20 August 2022 | David Stanton | Preliminary draft GDE assessment prior to finalisation of impact assessment components. |
| Rev 2 | 22 Nov 2022 | David Stanton | Second draft GDE assessment following provision of additional technical reports. |
| Rev 2 | 15 July 2023 | David Stanton | Final draft GDE assessment report following BHP review and incorporation of information from the Mine Water System report. |
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## Executive Summary

BM Alliance Coal Operations Pty Ltd (BMA) is finalising environmental approvals for the Saraji East Mining Lease Project (the Project), located approximately 30 kilometres (km) north of Dysart and approximately 167 km southwest of Mackay in Queensland. The Project will include a greenfield underground single-seam mine operation and associated project infrastructure within EPC837, which is directly to the east of Saraji's existing mining operations. Extraction of up to seven million tonnes per annum of metallurgical product coal for the export market over a life of 25 to 30 years is proposed.

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 the dependence of vegetation in the SEMLP on GDEs. Based on the results of the field survey, it is concluded that TGDEs are present on Phillips Creek which passes through the central portion of EPC837. TGDEs identified on Hughes Creek mapped in association with the contiguous Lake Vermont - Meadowbrook Project are also mapped as intruding marginally into EPC837. These TGDEs host variable groundwater volumes and are seasonally recharged via surface flows and flooding.

While there is no specific impediment to tree water use of Tertiary or Permian aquifer based on known salinity values, water held in these aquifers is an unsuitable resource to support GDEs due to a potentiometric surface that is generally >17mbgl, which is significantly below the maximum rooting depth of facultative phreatophytes associated with the major drainage channels in the Project Site. However, groundwater hosted in these units may be closer to the surface where deeply incised creek channels occur, as on Phillips Creek where depth of channel incision is >8m, and to a lesser extent on Hughes and Boomerang Creeks where channel incisions are shallower. In these localities, the Tertiary aquifers may be linked to a seasonal groundwater system hosted in creek alluvium, particularly on Phillips Creek where fringing alluvial deposits are well developed. Due to this potential for linkage, and the presence of perched groundwater intersected in river sands during auger sampling, the riparian habitats that fringe Phillips Creek (typically RE11.3.25) have been mapped as a TGDE. While TGDEs were not identified in sampling completed on other drainage features assessed in the Project Site, GDE assessments undertaken on the contiguous Lake Vermont tenement (MDL429) to the east identified Hughes Creek as a TGDE which is likely to intrude into the Project Site from the east. In relation to GDEs within the boundaries of the SEMLP, the following points are considered relevant:

1. Field data indicates that Phillips creek is highly likely to function as a TGDE where groundwater dependence varies on a seasonal basis. The highest degree of groundwater usage would occur post seasonal flooding events which recharge groundwater in associated alluvial deposits. There is no indication that Phillips Creek represents an AGDE. The mapping of a TGDE on Phillips Creek is consistent with the Lake Vermont - Meadowbrook GDE assessment completed on the contiguous tenements to the east (3d Environmental 2022).

2. Vegetation on Tertiary plains, typically RE11.5.3 and 11.4.9, has limited potential for groundwater dependency, due to both the shallow rooted nature of the dominant poplar box and brigalow and the significant depth to the groundwater table.
3. Vegetation fringing One Mile Creek and adjacent woodland does not meet the hydrological criteria for a TGDE with field assessment confirming that moisture requirements of vegetation are being supported within the unsaturated portion of the soil profile.
4. Vegetation fringing One Mile Creek and adjacent woodlands do not meet the ecological or hydrological criteria for a TGDE with moisture requirements of riparian being supported in the unsaturated portion of the soil profile.
5. Vegetation fringing Hughes Creek within EPC837 does not meet the hydrological or ecological criteria for a TGDE, although a TGDE intrusion may extend into the Project Site from the east, mapped in conjunction with the contiguous Lake Vermont - Meadowbrook Project. The transition of Hughes Creek into a TGDE is most likely associated with a thickening and widening of creek alluvium eastward toward the Isaac River where there is greater capacity for storage of perched groundwater. Within the Project Site, the alluvial landform hosting Hughes, Boomerang and Plum Tree Creeks is extremely shallow, with outcropping sedimentary basement evident in some channel exposures.
6. The Boomerang Creek wetland (assessed at Site 13) is a surface feature and there is no indication of any hydrological linkage between surface waters and groundwater. The Boomerang Creek wetland does not meet the hydrological or ecological criteria for either a TGDE or AGDE.

Impacts of drawdown in the Tertiary groundwater system may be propagated into creek alluvium wherever areas of enhanced potential for downward drainage occur, most likely through sandy sediments with increased hydraulic conductivity or increased density of preferential flow paths. Drawdown impacts have potential to manifest along reaches of Hughes Creek where modelled groundwater drawdown extends well to the east of EPC837 into contiguous Lake Vermont tenements. There are no predicted impacts associated with TGDEs on Phillips Creek as groundwater drawdown does not propagate below the stream channel or fringing riparian habitats.

The major features of TGDEs associated with Hughes Creek that ameliorate impacts are considered to be:

1. There is no evidence from monitoring data that groundwater hosted in Permian coal seams or Tertiary sediments has capacity to propagate upward to interact with alluvial groundwater sources and support GDEs.
2. The groundwater system perched in alluvium that supports TGDEs on Hughes Creek is recharged by surface flows and flooding, providing the dominant driver to support riparian ecological function. Surface flow volumes will be subject to only minor impact because of subsidence, and minor impacts to sediment volumes affecting the channel bedform.
3. Perched groundwater in the alluvium is discontinuous along the length of the creek channel (3d Environmental 2022) and riparian trees associated with the watercourse feature are facultative phreatophytes which have capacity to utilise moisture from multiple sources including soil moisture, surface water and groundwater to support transpiration

Management measures to limit the impact to potential GDEs in vicinity of the Saraji East Mining Lease Project include general operational measures such those encompassed in the Project WMS and ongoing monitoring through the existing REMP. It is also recommended that additional ecological baseline data collection, GDE management and mitigation measures be developed through development of a GDE monitoring program to provide for ongoing management and detection of change that can be linked to mining operations, complementing any GDE management measures that are implemented for the Lake Vermont – Meadowbrook project contiguous to the east.

With implementation of management measures, 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 to Insignificant'. 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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## Glossary

| | |
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| 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 |
| AGDE | 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 |

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| | 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 |

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| | 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. |
| TGDE | 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

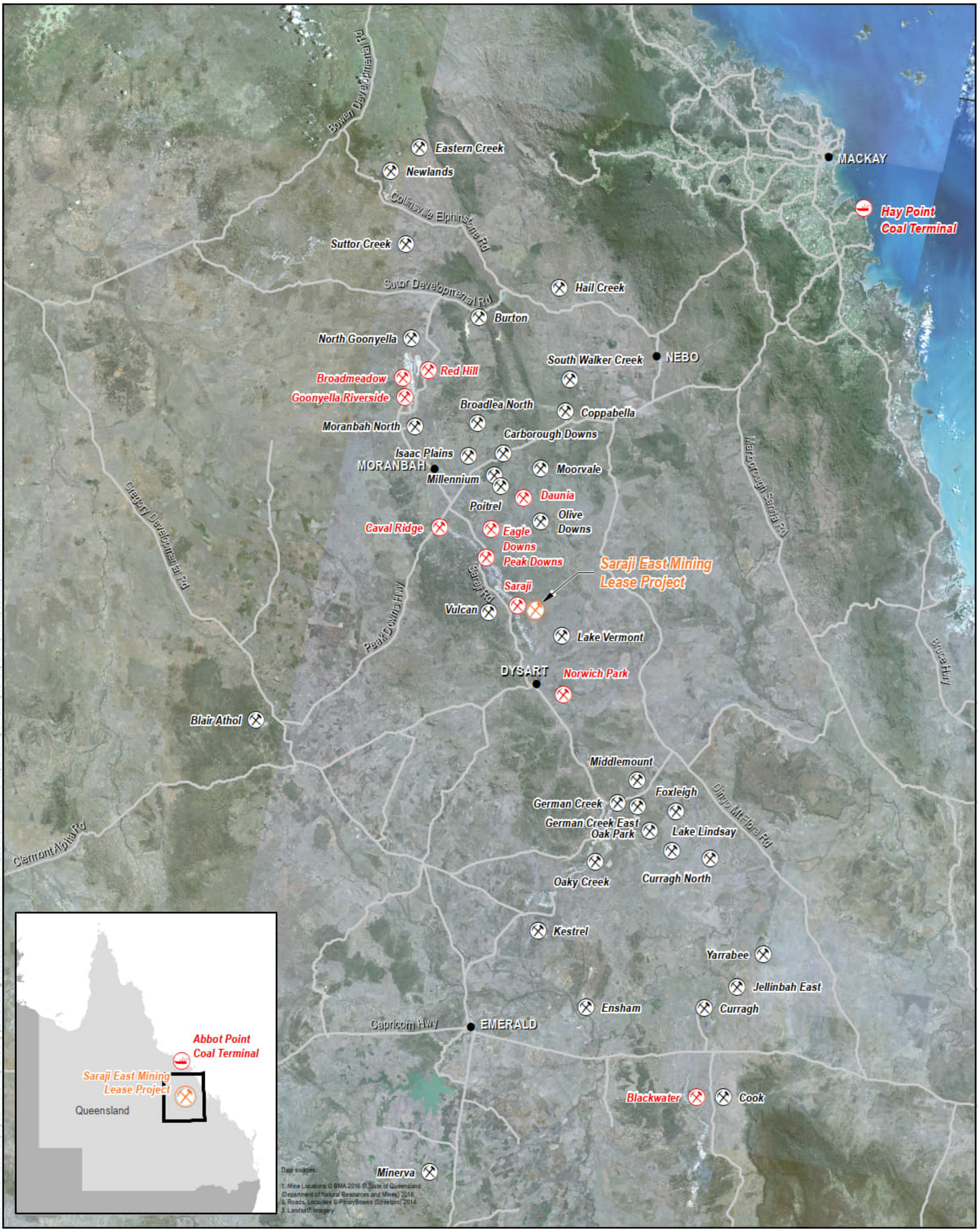
BM Alliance Coal Operations Pty Ltd (BMA) is seeking approval to develop the Saraji East Mining Lease Project (the Project) involving a greenfield single-seam underground mine and supporting infrastructure on Mining Lease Application (MLA) 70383 and MLA 70459 adjacent to, and accessed through the existing open cut mine void within Mining Lease (ML) 1775.

The Project is located approximately 30 kilometres (km) north of Dysart and approximately 170 km southwest of Mackay in Queensland, approximately 30 kilometres (km) north of Dysart and approximately 170 km southwest of Mackay, within the Isaac Regional Council (IRC) area (**Figure 1**). Approximately 11,427 hectares of existing resource tenure is occupied in the Project Site including: Exploration Permit – Coal (EPC) 837 and EPC 2103 and overlapping MLA 70383 and MLA 70459. To minimise new disturbance, the Project is designed to make use of existing approved infrastructure and previously disturbed areas on the adjacent Saraji Mine (ML 1775 and ML 70142). Where necessary, existing infrastructure will be upgraded or new Project infrastructure will be preferentially located to minimise disturbance and operational efficiency of Project access, service connections, coal processing and rail loading (**Figure 2**).

With an optimised underground mine layout, the Project will supply over 110 million tonnes of high quality coking coal and pulverised coal injection coal products for the export market over a 20-year production schedule. In addition to economic benefits of royalties and taxes paid to the Queensland Government, the Project will support regional prosperity through direct and indirect employment opportunities and investment in strategic infrastructure and service needs in the region.
The Project will be authorised by a standalone Project Environmental Authority (EA). Consequential Project interactions with the existing authorised Saraji Mine activities (e.g., accepting mine water or waste) will be authorised by minor amendment to the existing Saraji Mine EA Permit: EPML 00862313.

The EA will impose environmental management conditions on the proposed mining activities on the relevant ML and outline the environmental management requirements that BMA must comply with related to regulated structures, water and waste management, monitoring and reporting.
Where supporting infrastructure extends beyond mining tenure, subsequent negotiation with relevant authorities and legislative approvals will be undertaken where required. The Project Site is located on Mining Lease Application (MLA) 70383 and MLA 70459 which are adjacent to, and east of the existing Saraji open cut mine void that is within Mining Lease (ML) 1775 and is directly to the east of the Lake Vermont Meadowbrook mining project for which underground mining development is proposed on MDL429 and MDL303 (Jellinbah 2023; 3d Environmental 2022) (**Figure 3**).

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 Site and surrounds and includes an assessment of potential Project related impacts to GDEs.




**LEGEND**

- Saraji East Mining Lease Project
- BMA Coal Terminal
- BMA Mine
- Other Mine
- Locality
- Major Road

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**Figure 1**

**Regional Context**

**Environmental Impact Statement**
**Saraji East Mining Lease Project**

0 5 10 20
Kilometres

Scale: 1:1,500,000 (when printed at A4)

Projection: Map Grid of Australia - Zone 55 (GDA94)

BMA
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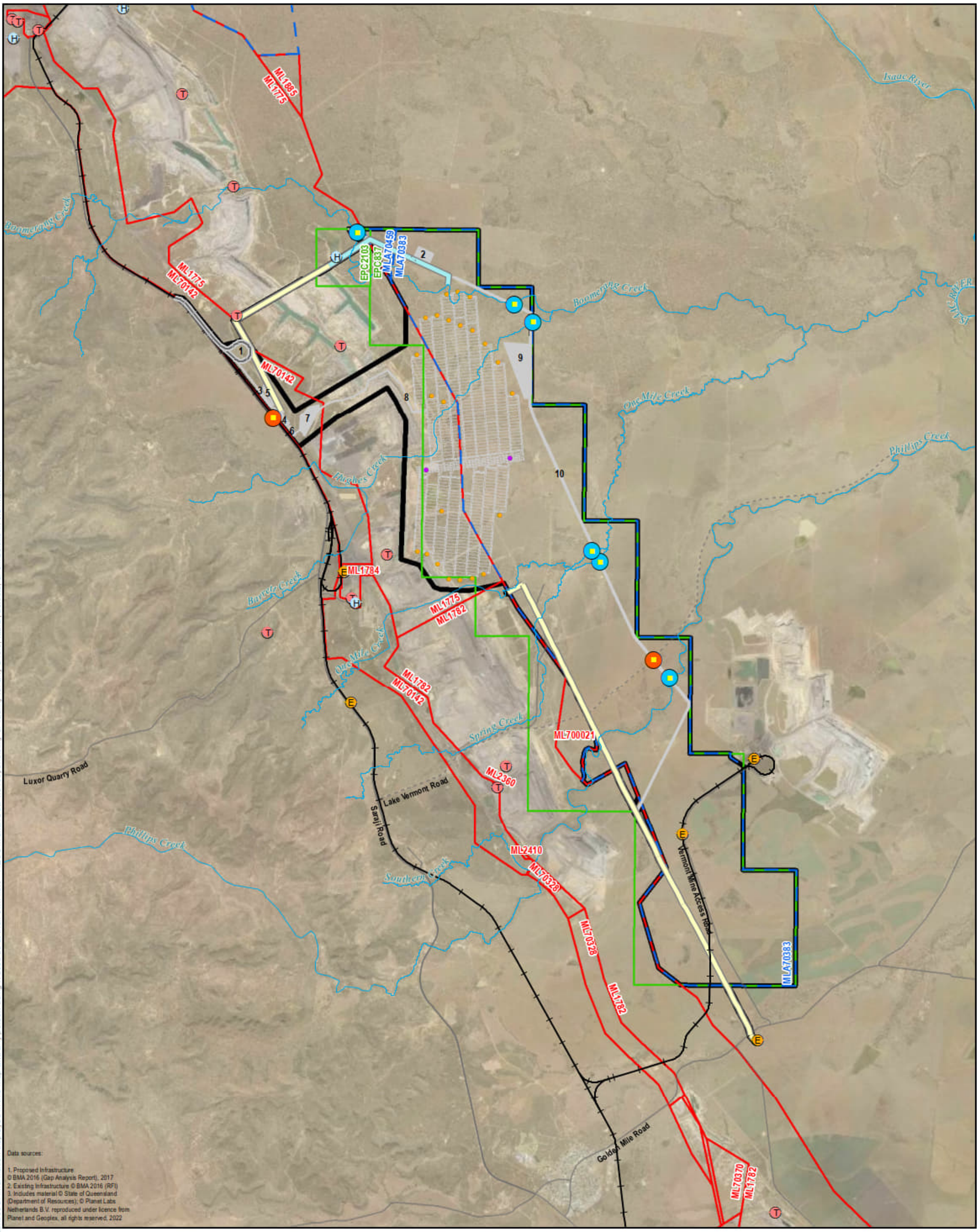
DATE: 21/07/2023 VERSION: 3






**LEGEND**

- Project Site
- Exploration Permit Coal (EPC)
- Mining Lease (ML)
- Mining Lease Application (MLA)
- Underground Mine Layout
- Surface Infrastructure
- Watercourse
- Existing Railway
- Private Access Road
- Public Road
- Rail Loop
- 66kV Powerline
- Pipeline
- Entry/Access point
- Watercourse crossing
- Substation
- Helipad
- Telecommunications Tower
- Flare
- Vent

**Surface Infrastructure**

1 Rail Loading Balloon Loop
2 Process Water Dam
3 Product Stockpiles
4 CHPP
5 Raw Water Dam
6 ROM Pad
7 Future MIA
8 Conveyor
9 Construction Village
10 Transport and Infrastructure Corridor

N

**Figure 2**
**Project Layout**

**Environmental Impact Statement**
**Saraji East Mining Lease Project**

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Kilometres

Scale: 1:158,094 (when printed at A4)
Projection: Map Grid of Australia - Zone 55 (GDA94)

BMA
BHP Mitsubishi Alliance

DATE: 11/07/2023 VERSION: 6

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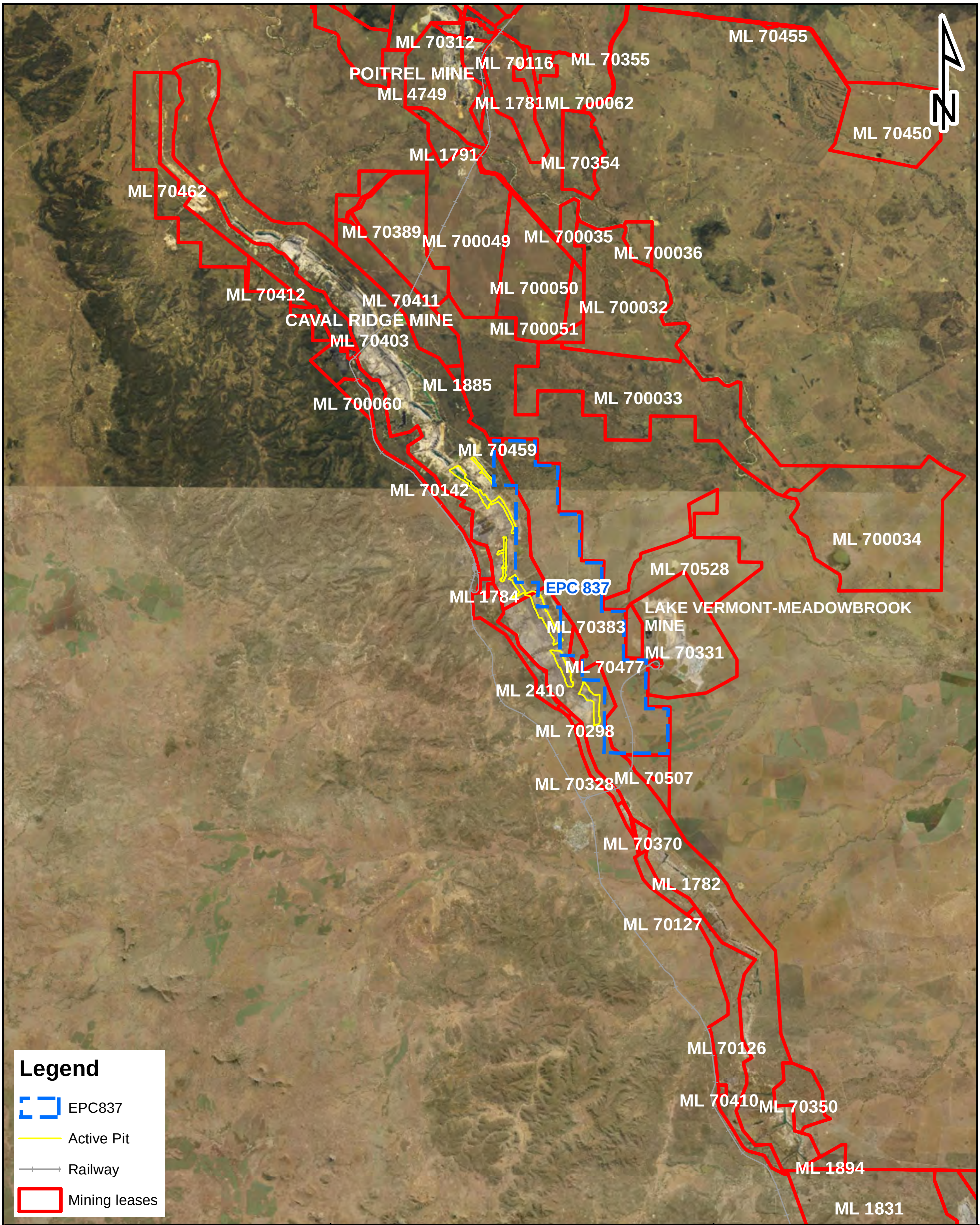




**Figure 3.** Mining Tenements associated with the Saraji East Mining Lease Project.

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## 1.2 Project Objectives

Objectives of the GDE assessment are to:

- Identify if vegetation within and surrounding the Project Site 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 and cumulative impacts on any identified GDEs.

This GDE study excludes the assessment of stygofauna assemblages which is captured in another scope.

## 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 4**. 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 compared to a long-term average of 73.7mm), April to June returned to dry conditions before becoming wet in July 2021 where 56.4mm was recorded in the month. A significant rainfall event occurred in November 2021 where 150.6mm was received, which is three times the average monthly rainfall, resulting in postponement of the planned field survey until drier conditions returned. All months between December 2021 and March 2022 received significantly below average rainfall, enabling successful implementation of the field survey across a 6-day period from 7$^{th}$ to 12$^{th}$ of March 2022. Conditions during the period were extremely hot and humid with maximum temperatures ranging from 39.6°C (9th May) and 31.3°C (12th May) and relative humidity (3pm) ranging from 22% (7th) to 52% (11th). While the 2-week period preceding the survey was dry, 19.4mm of rainfall was received on 10th and 11th of March toward the completion of the survey (see **Figure 5**).

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 – 2022 period (from Silo 2022) with data for all months indicating evapotranspiration as being considerably higher than rainfall. Annual evapotranspiration rates tend to peak in December/January and are typically at their lowest in June / July (**Figure 6**).

The region has experienced several significant drought events which is likely to have affected both surface flows and recharge of groundwater systems. **Figure 7** 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 between January 1990 to March 2022). Long term rainfall data was collected at Booroondarra (-22.82 / 148.49) (SILO 2022), 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 a slight upward inflection of the mass curve coincided with increased rainfall in November 2021, 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 strongly increasing trends in the CRD curve.

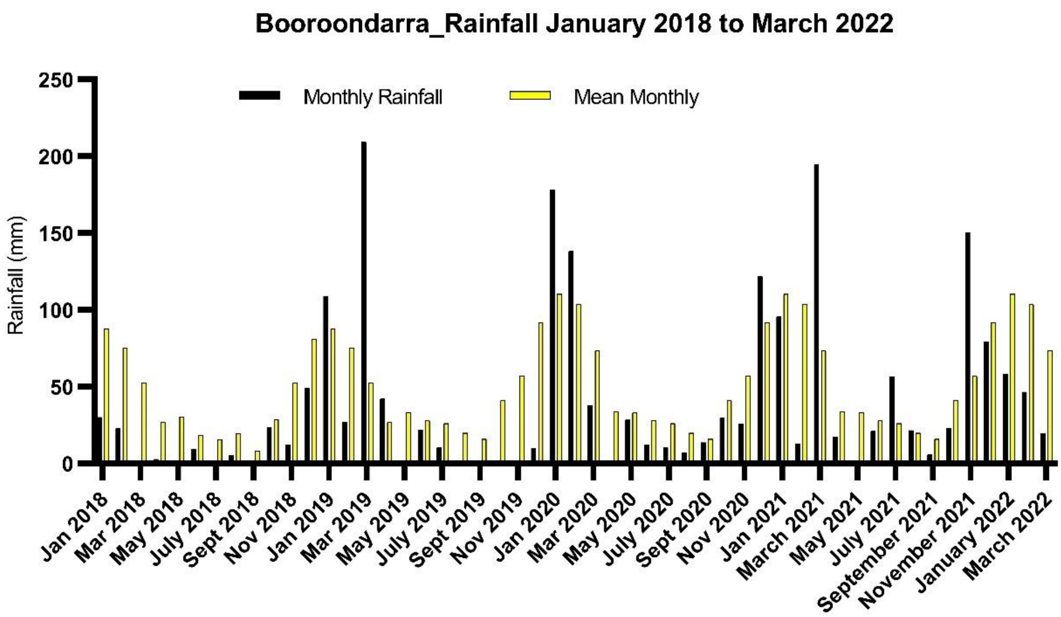



**Figure 4.** Rainfall for the period from January 2019 to March 2022 from Booroondarra Recording Station (Station No, 35109).

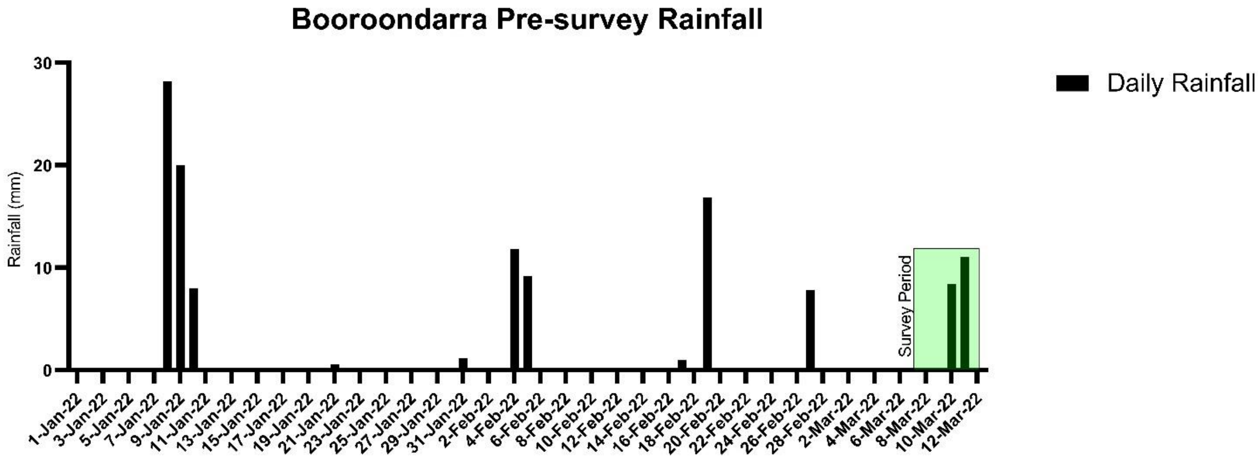



**Figure 5.** Daily rainfall for the 10 weeks prior to field survey, indication rainfall on 10th and 11th March, coinciding with the field survey.

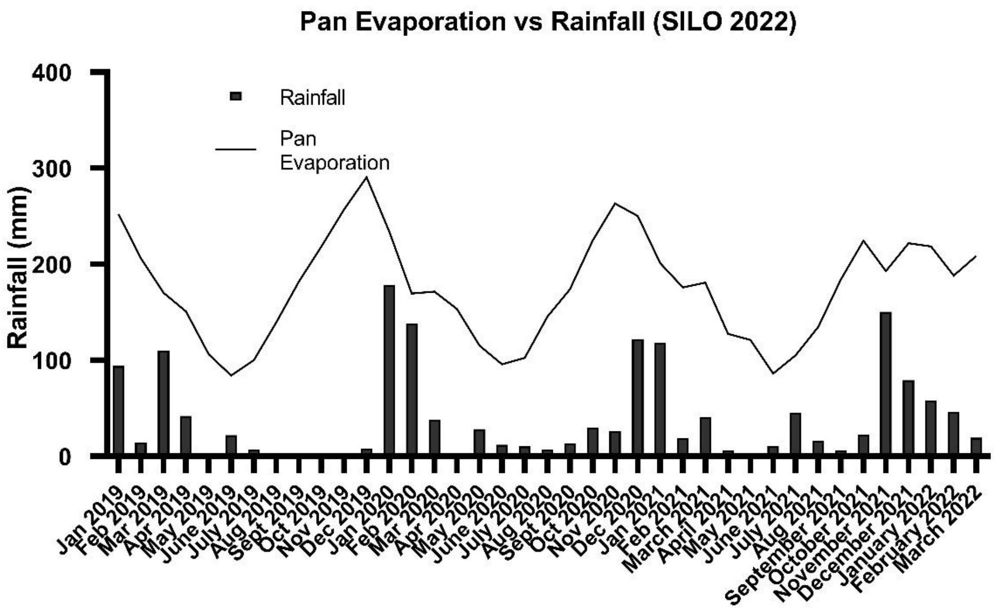



**Figure 6.** Evapotranspiration compared to rainfall for January 2019 to March 2022 from SILO (2022).

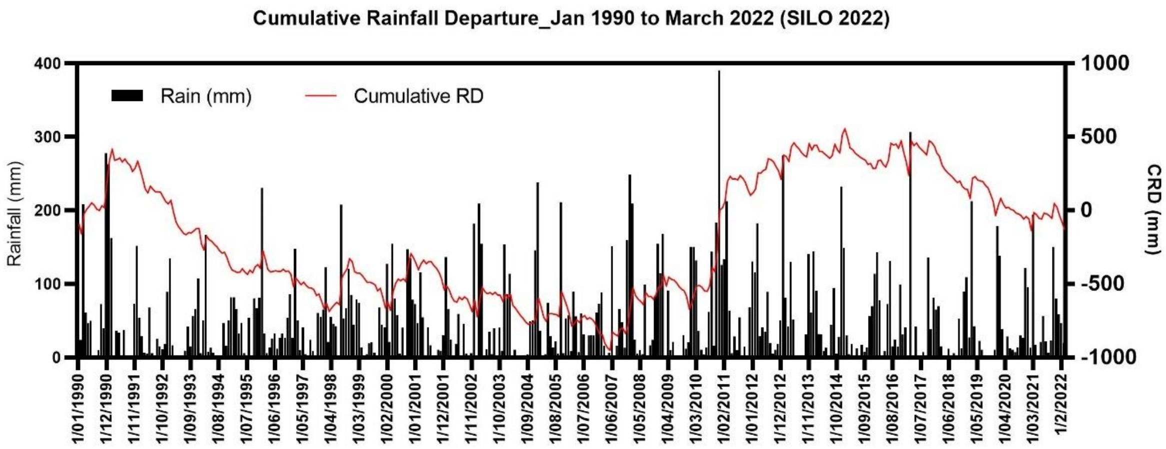



**Figure 7.** Cumulative Rainfall Departure demonstrating major and minor climatic fluctuations with a slight upward inflection of the mass curve at the end of 2021 suggesting return to wetter climatic conditions (from SILO 2022).

# 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 8**, with further descriptions provided in the following sections.

### *2.1.1 Geomorphic Setting*

The Project Site 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. All creek systems in the Project Site, 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. All drainage systems flow toward the east as tributaries of the Isaac River. Plumtree Creek, the smallest of the tributary's merges with Boomerang Creek prior to merging with Hughes Creek which is the largest of the three tributaries in the north of the Project Site. One Mile Creek also passes through the central portion of the Project Site, joining with Hughes Creek several kilometres to the east prior to merging with Isaac River. These creeks all have sandy drainage channels incised into Tertiary sediments with minor slivers of alluvium in outwash areas and flood pockets. In the south, Philips Creek is the largest tributary system flowing to the Isaac, with a well-formed sandy channel which is deeply incised into the surrounding Tertiary plain, with more extensive development of floodplain alluvium than the Isaac tributaries to the north.

### 2.1.2 Geological characteristics

Surface Geology from DNRM (2018) is presented in **Figure 8**, with further discussion of surface geology characteristics provided in following sections.

**Cainozoic Sediments:** Cainozoic sediments which include Quaternary and Tertiary age alluvial sands, clayey sands and clays occur across the entire Project Site with variable thickness. The Cainozoic sediments mainly comprise alluvial sands, clayey sands and clays, with a basal layer of sand and gravel in some locations. The only significant occurrence of Quaternary age alluvium (Qa) is mapped as a 250m wide corridor along Phillips Creek, which passes in a NE/SW direction across EPC837, joining with the well-developed alluvial sediments of the Isaac River floodplain over 15km to the east. Quaternary sediments surrounding the Project Site have been reported to have a maximum thickness of 25 m at Phillips Creek (AGE, 2007).

Tertiary (TQa) sediments within the Project Site comprise dominantly of 'tight' clay which overlies a discontinuous basal unit of sand and gravel. Aecom (2019) suggest that the Tertiary sediments reach a maxi thickness of approximately 45m across the underground mine footprint whilst AGE (2011) suggest that the Tertiary sediments are up to 57 m thick in the western portion of the Saraji Mine. The Tertiary sequence unconformably overlies the Permian sediments. Characteristics of the Tertiary sediments include:

1. A Tertiary clay unit that forms a predominantly clay matrix mixed with thin sand intervals, which is the dominant Tertiary lithology present across the Project Site. The Tertiary sediments have weathered in at least three periods of laterisation with associated mottling and concretionary structure (AGE, 2011).
2. A basal sand and gravel sequence is associated with the base of the Tertiary sediments. This unit which is locally discontinuous is formed by coarse to medium sands and fine gravels with a maximum sequence thickness of approximately three metres where present (Aecom 2019).

The early Tertiary age Duaringa Formation (Qr) is mapped towards the south and north of the underground mining footprint, comprising mudstone and siltstone (i.e., low permeability argillaceous strata).

**Triassic and Permian Sedimentary Rocks:** Solid geology comprises the late Permian Fort Cooper Coal Measures and underlying Moranbah Coal Measure as the major coal bearing units, comprising sandstone, siltstone, claystone, mudstone and coal. Aecom (2019) describes several coal seams of economic interest occurring in the Moranbah Coal Measures which include the P seam, Harrow Creek Upper (H16) seam, Harrow Creek Lower (H15 and H19) seams, Dysart Upper (D52) seam and Dysart Lower (D14, D24) seam. The coal seam of economic interest to this project is the Dysart Lower (D14 / D24) seam, which is positioned 35 m below the Dysart Upper seam (D52), and the 7m thick D24 seam where the depth of cover ranges from 120 m in the west to a maximum of 780 m at eastern limit of MLA 70838.

#### 2.1.3 Groundwater Standing Water Levels and Water Quality

**Alluvial sediments:** Aecom (2019) consider the Quaternary alluvium associated with Phillips Creek to have limited potential as a groundwater resource because:

- Several DNRME bores drilled near Phillips Creek do not intersect groundwater, or the drilling results indicate limited or no sustainable groundwater resources associated with the alluvium.
- Phillips Creek is ephemeral and does not provide a permanent recharge source to the alluvium.

Only one bore (MB32) which was constructed in the alluvial sediments of Phillips Creek (located to the west of the Saraji Mine) has been reported to contain water during groundwater monitoring. In August 2020, MB32 had a standing water level (SWL) of 13.2 metres below ground level (mbgl) although SWLs of 7.5mbgl have previously been reported. Four other holes were drilled in alluvium in August in 2019 (MB19SRM01A_HY, MB20SRM01A_PZ, MB20SRM04A_PZ and MB20SRM05A_PZ). While shallow groundwater was intersected in MB19SRM01A_HY (SWL of 8.87mbgl) and MB20SRM04A_PZ (SWL of 9.12mbgl), the other monitoring wells installed in alluvium remained dry on development.

Standing water levels (SWLs) in the Tertiary overburden range from 12.15mbgl in MB37 (upgradient from the mining operation) to 28.2mbgl at MB34. Potentiometric surfaces in the coal seams are more variable, ranging from 6.27mbgl at MB31 (5km to the west of the Saraji Mine September 2016) to 38.8mbgl in MB20SRM07P_PZ to the south-west of Hakea Pit. SWLs showed considerable seasonal variation for some monitoring bores, particularly MB31 where SWLs ranged from 6.27mbgl (August 2020) to 21.2mbgl (November 2020) without any significant rainfall trigger to prompt the response. Strong seasonal variation was also observed for some wells installed in the Tertiary sediments with MB34 recording a SWLs of 28. 4mbgl in November 2020 rising to 25.54mbgl in February 2021, following significant rainfall in December 2020.

For monitoring bores installed in the alluvium, hydrochemical sampling indicates salinity ranging from 873 µS/cm to 20438 µS/cm in MB19SRM01A_HY and MB20SRM04A_PZ respectively, both sampled in August 2019. Monitoring bores installed into Tertiary sediments indicate a similar large range of values with waters ranging from a brackish 1546 µS/cm at MB35 (August 2020) to a saline 30756 µS/cm at MB34 (August 2020). Salinity levels reported for groundwater in monitoring wells installed into the Permian coal measures are consistently fresher than groundwater hosted in either the alluvium or Tertiary sediments, with a range of values reported from 969 µS/cm (MB20SRM02T_PZ) to 9864 µS/cm at MB39.

SWLs and salinity values recorded from monitoring bores in the Project Site over a period from March 2020 to April 2021 are provided in **Table 1**, with the locations of monitoring bores relative to MDL boundaries shown in **Figure 9**.

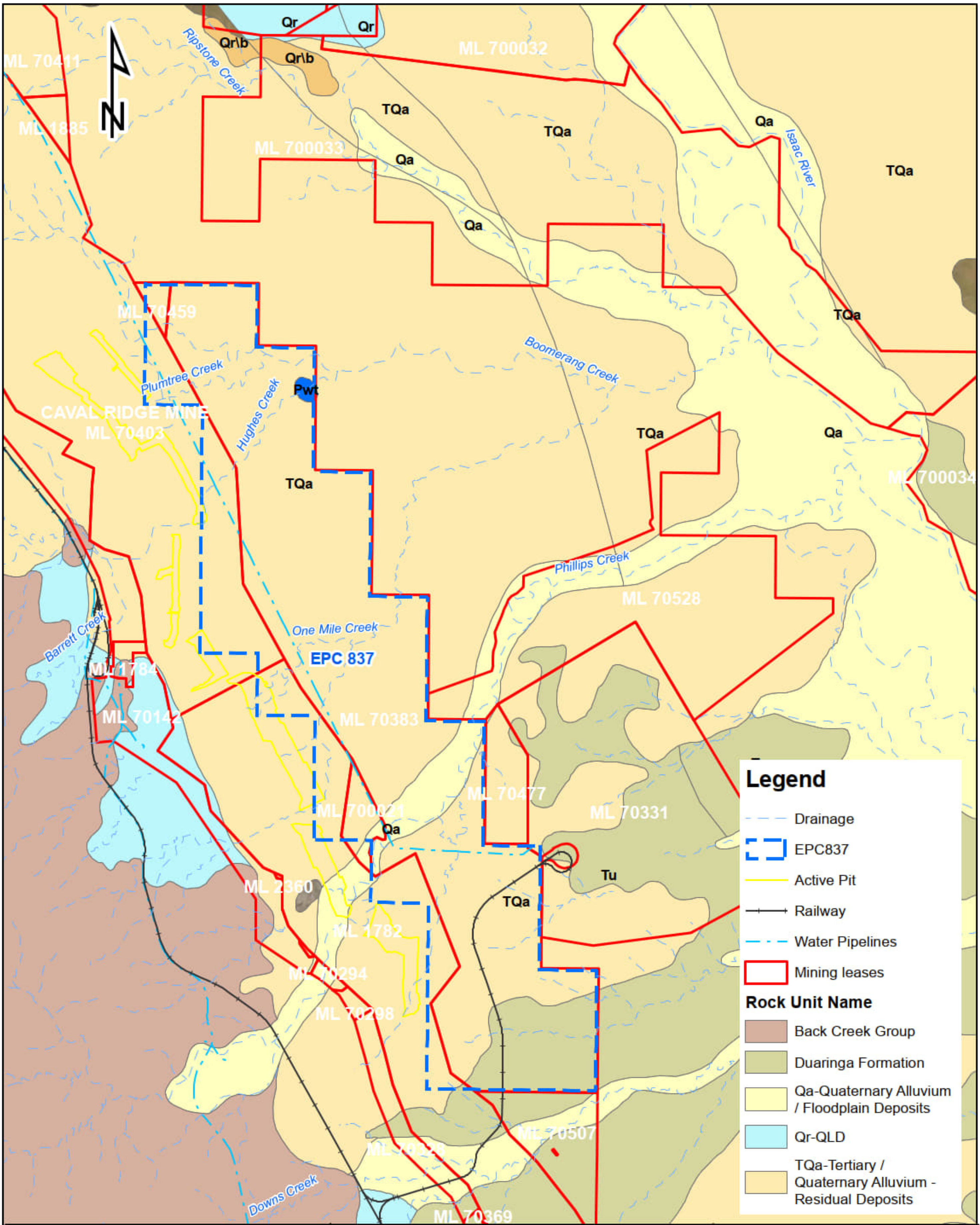
#### 2.1.4 Groundwater Recharge and Discharge

Aecom (2019) identifies that recharge occurs from infiltration from the rainfall and creek flow into the Tertiary and Permian aquifer sub-crop areas, although differences in groundwater levels measured in the Tertiary and deeper Permian aquifers indicate that there is limited hydraulic connection between these two groundwater systems. Minor leakage from overlying aquifers into Permian coal seems may occur but is not evident based on groundwater level data. The low salinities (<2500 µS/cm) associated with monitoring bores MB32 (alluvium) and MB35 (underlying Tertiary interburden), both located on the Phillips Creek floodplain, suggest these bores are likely receive recharge from streamflow and from the overlying alluvium in the case of MB35.

### *2.1.5 Hydraulic characteristics*

Variable hydraulic conductivity will occur throughout the range of lithologies within the Project Site due to considerable variation in regolith and basement rock structure. Further information on hydraulic conductivities will be available following finalisation of the revised groundwater modelling report, although for the intermediary purposes of this assessment, hydraulic values from the Lake Vermont Project (JBL 2022) are considered indicative with the following properties identified:

- Hydraulic conductivity within the Quaternary Alluvium is extremely variable on account of structure which ranges from sandy clays to river-bed sands, with an average hydraulic conductivity of Quaternary alluvium at 2.66E-02.
- The highest average conductivity occurs in the Tertiary overburden (4.31E-01) and the Permian coal sures shallower than 130mbgl.
- For Permian coal measures, hydraulic conductivity decreases with depth with the lowest average hydraulic conductivity identified in Permian interburden (1.59E-02).




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

**Figure 8.** Surface geology from DNRM (2020)

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GraveDyard Gully

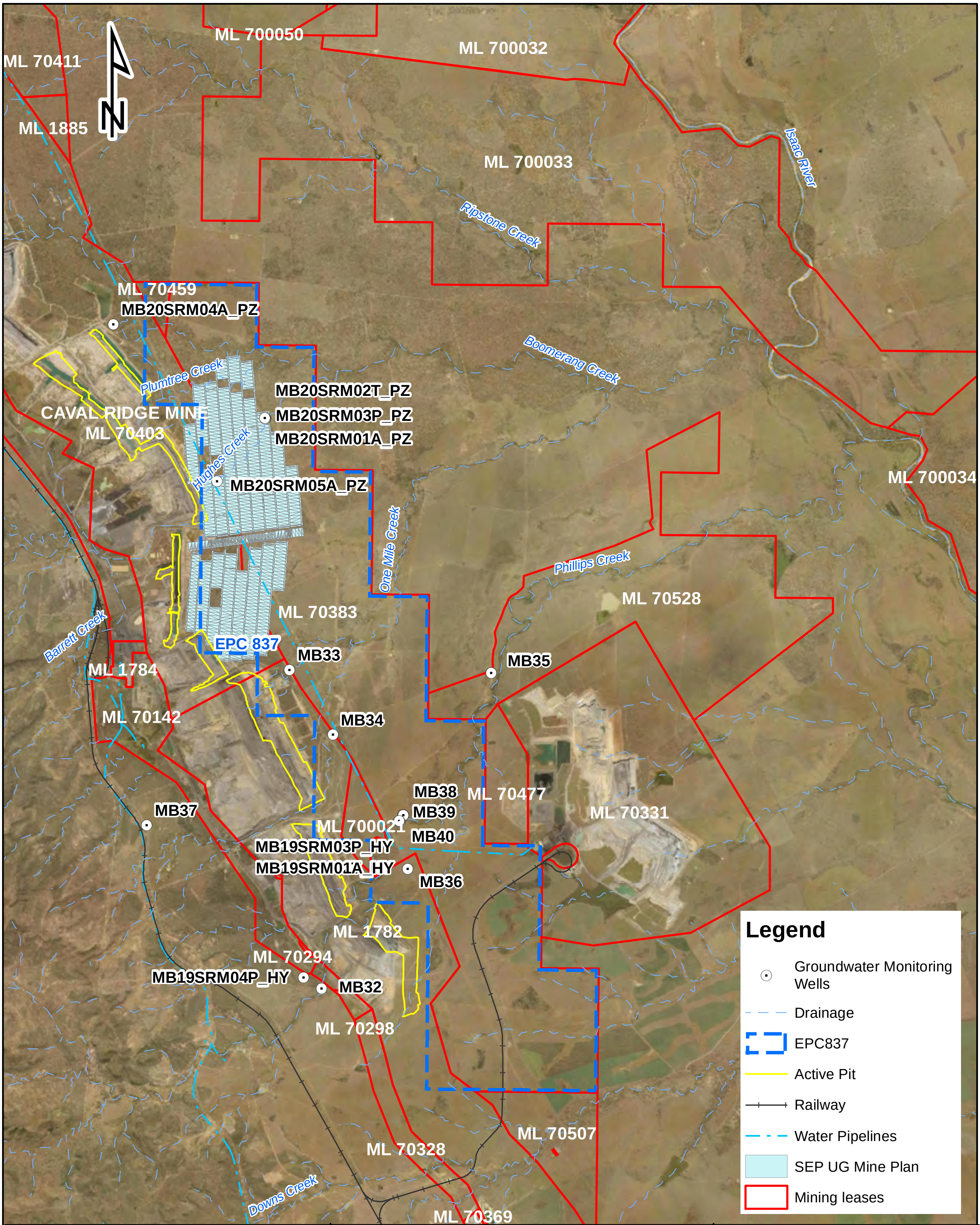


**Figure 9.** Groundwater monitoring bores in the assessment area

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

| Planned Bore ID | Location | E (AGD84) | N (AGD84) | Elevation (AHD) | Cased Depth (mbgl) | Screened Interval (mbgl) | Monitored Aquifer | SWL Average MGBL | Saliinity Range (when available) |
|---|---|---|---|---|---|---|---|---|---|
| **Monitoring Bores in Alluvium** | | | | | | | | | |
| MB32 | Phillips Creek | 637595 | 7510716 | 208.13 | 19.52 | - | Alluvium | 7.45 to 13.22 | 1400 |
| MB38 | Phillips Creek | 640032 | 7515860 | - | 8.5 | - | Alluvium | Dry | Dry |
| MB19SRM01A_HY | East of Grevillea Pit. Co-located with MB19SRM02T and MB19SRM03P | 639919 | 7515681 | 186.416** | 8.5 | 5.5 - 8.5 | Alluvium | 8.78# | 873# |
| MB20SRM01A_PZ | East of Bauhinia Pit, collocated with MB20SRM02T and MB20SRM03P | 635922 | 7527665 | 186.416** | 10.5 | 7.2 - 10.2 | Alluvium | Dry | Dry |
| MB20SRM04A_PZ | North of Jacaranda Pit | 631397 | 7530470 | 194.949** | 12 | 6.5 - 9.5 | Alluvium | 9.12# | 20438# |
| MB20SRM05A_PZ | East of Bauhinia Pit | 634476 | 7525798 | 191.428 | 24 | 6.5 - 9.5 | Alluvium | Dry# | Dry# |
| **Monitoring Bores in Tertiary Sediments and Permian Overburden** | | | | | | | | | |
| MB33 | One Mile Creek | 636640 | 7520199 | 194.11 | 37.5 | - | Tertiary Interburden / Permian Overburden | 18.45 to 21.34 | 24865 |
| MB34 | One Mile Creek tributary | 637926 | 7518269 | 195.61 | 107 | - | Tertiary Interburden / Permian Overburden | 22.97 to 28.2 | 30756 |
| MB35 | Phillips Creek | 642646 | 7520110 | 185.28 | 34.5 | - | Tertiary Interburden | 17.02 to 20.3 | 1546 |

| Planned Bore ID | Location | E (AGD84) | N (AGD84) | Elevation (AHD) | Cased Depth (mbgl) | Screened Interval (mbgl) | Monitored Aquifer | SWL Average MGBL | Saliinity Range (when available) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | / Permian Overburden | | |
| MB36 | Lake Vermont Property | 640150 | 7514283 | 196.93 | 32 | - | Tertiary Interburden / Permian Overburden | 17.45 to 18.45 | 7177 |
| MB37 | Up-gradient of mining | 632389 | 7515571 | 234.66 | 42.5 | - | Tertiary Interburden / Permian Overburden | 12.15 to 13.18 | 15444 |
| MB40 | Phillips Creek | 640026 | 7515867 | - | 21 | - | Tertiary | 18.03 | 2230 |
| MB19SRM02T_HY | East of Grevillea Pit. Co-located MB19SRM01A and MB19SRM03P | 639913 | 7515688 | 194.337** | 27 | 14.0 - 20.0 | Tertiary | 17.36# | 969# |
| **Permian Coal Seams** | | | | | | | | | |
| MB31 | Saraji Station | 625942 | 7522560 | 225.04 | 44.23 | - | Permian | 6.27 to 21.20 | 6327 |
| MB39 | Phillips Creek | 640018 | 7515876 | - | 91.5 | - | Permian | 17.81 | 9864 |
| MB19SRM03P_HY | East of Grevillea Pit. Co-located with MB19SRM01A and MB19SRM02T | 639904 | 7515697 | 194.298** | 91.5 | 84.35 - 90.5 | Permian | 17.04# | 1445# |
| MB19SRM04P_HY | Phillips Creek co-located with MB32 | 637059.895 | 7511041.1 | 207.87 | 42.3 | 36 - 42 | Permian | 19.93 to 19.96# | 6190# |
| MB20SRM02T_PZ | East of Bauhinia Pit, collocated with MB20SRM01A and MB20SRM03P | 635914 | 7527670 | 186.611** | 36.5 | 27.5 - 36.5 | Permian | 17.36# | 969# |
| MB20SRM03P_PZ | East of Bauhinia Pit, collocated with MB20SRM01A and MB20SRM02T | 635907 | 7527677 | 185.867 | 242.7 | 231 - 237 | Permian | 17.06# | 8595# |

| Planned Bore ID | Location | E (AGD84) | N (AGD84) | Elevation (AHD) | Cased Depth (mbgl) | Screened Interval (mbgl) | Monitored Aquifer | SWL Average MGBL | Saliinity Range (when available) |
|---|---|---|---|---|---|---|---|---|---|
| MB20SRM07P_PZ | South of Hakea Pit | 641362 | 7507960 | 208.12 | 177 | 165.0 - 171.0 | Permian | 38.01# | 5596# |

# Value on well development August 2020

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## 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) for the Project Site and surrounds is provided in **Figure 10**, 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 (TEC)(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 TEC(Endangered) under the federal EPBC Act and is Of Concern under the Queensland VM Act.
- RE 11.3.3 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. The ecosystem is listed as Of Concern under the Queensland VM Act
- 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. The ecosystem is listed as a Least Concern under the Queensland VM Act.
- 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.
- RE11.4.8, representing an open forest of Dawson gum (*Eucalyptus cambageana)* and brigalow (*Acacia harpophylla),* often with an associated vine thicket sub-canopy. The habitat is associated with clay soils on elevated Cainozoic plains and is listed as a Threatened Ecological Community (Endangered) under the federal EPBC Act and is Endangered under the Queensland VM Act.
- 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.
- RE11.4.13 representing a woodland of mountain coolabah (*Eucalyptus coolibah*) and Dallachy's bloodwood (*Corymbia dallachiana)* associated with clay soils derived from basalt. The ecosystem is listed as a Least Concern under the Queensland VM Act.
- 11.5.3, dominated by poplar box (*Eucalyptus populnea)* with Clarkson's bloodwood on Cainozoic / Tertiary age residual soils. The ecosystem is listed as a Least Concern under the Queensland VM Act.
- RE11.5.9, typically dominated by narrow leaf ironbark (*Eucalyptus crebra*) with scattered poplar box occurring on older residual plains and jump-ups. The ecosystem is listed as a Least Concern under the Queensland VM Act.
- 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.

- 11.9.2, representing a woodland of *Eucalyptus melanophloia* and/or *E. orgadophila* on fine grained sedimentary rocks. The ecosystem is listed as a Least Concern 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.

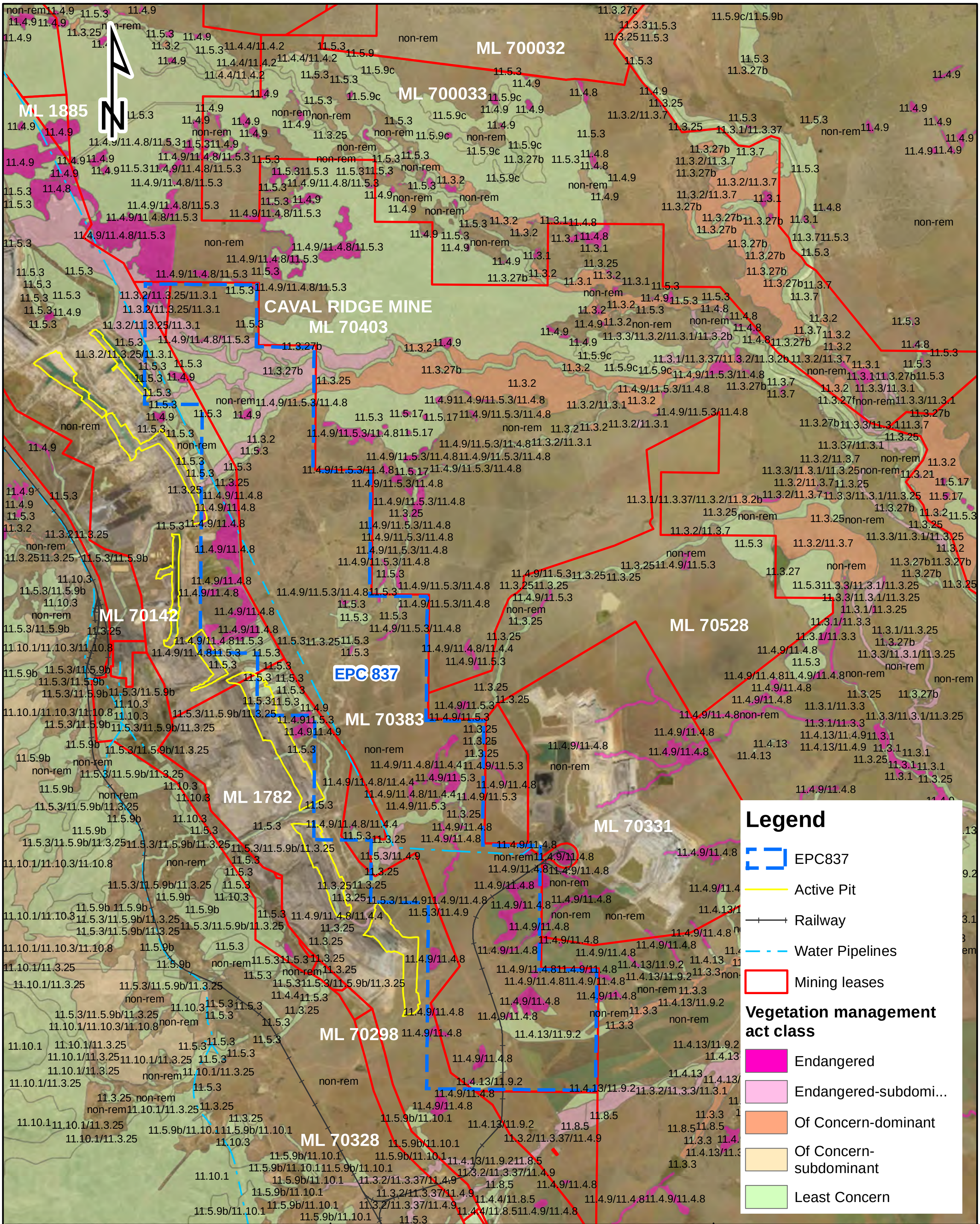
- **Aquatic** ecosystems that rely on the surface expression of groundwater–this includes surface water ecosystems which may have a groundwater component, such as rivers, wetlands, and springs. Marine and estuarine ecosystems can also be groundwater dependent, but these are not mapped in the GDE Atlas.
- **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 Site and surrounds, as produced by BOM (2020b) is provided in **Figure 11**. In general, this assessment shows 'Low Potential' for Terrestrial GDEs (TGDEs) associated with elevated residual plains (typically RE11.5.3), 'High Potential' and 'Moderate Potential' for TGDEs associated with floodplain alluvium (typically RE11.3.2 and RE11.3.25). There are no springs mapped within proximity to the assessment area, although Phillips Creek passing through the central portion of EPC837 is mapped as a 'High Potential' Aquatic GDE (AGDE), and the larger creeks such as Boomerang are mapped as 'Moderate Potential' AGDEs. A large floodplain wetland mapped as RE11.3.27 on the Floodplain of Boomerang Creek is also mapped as a 'Moderate Potential' AGDE. There are no Subterranean GDEs mapped within the assessment area or region.

### *2.2.3 Groundwater Dependent Species*

**Eucalypts:** Coolibah (*Eucalyptus coolabah*) and Forest Red Gum (*Eucalyptus tereticornis)* 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.

***Forest / River red gum:*** For this assessment, the physiological attributes of river red gum (*Eucalyptus camaldulensis)* and forest red gum *(Eucalyptus tereticornis)* are assumed to have similar ecological attributes as the two species can inhabit and mix within a similar ecological niche. Forest red gum which is predominant species in the Project Site, is however a more adaptable species, occupying

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

**Figure 10.** Field validated Regional ecosystems

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Kilometers

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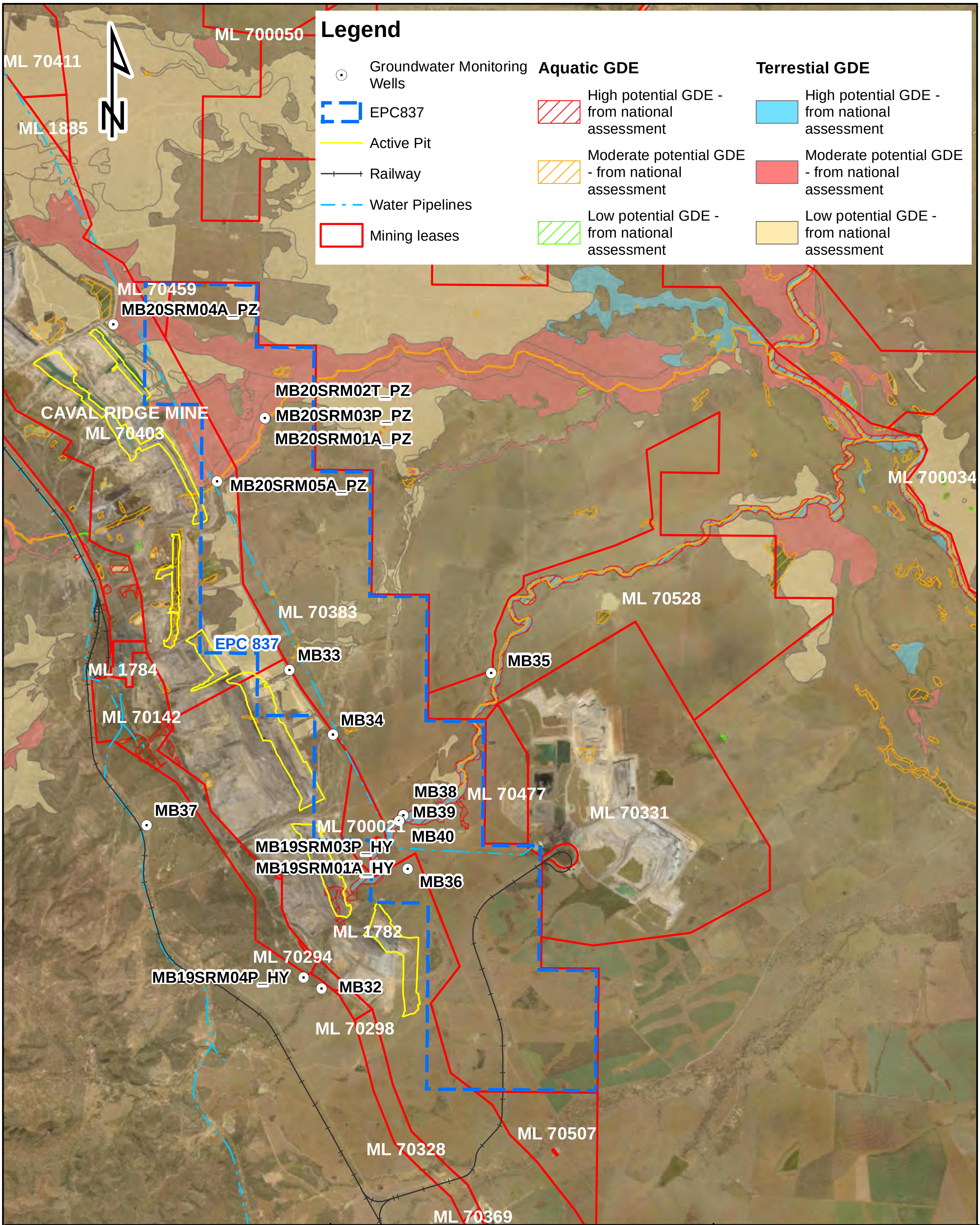


Source: BOM GDE Atlas (2020).

**Figure 11.** Mapped potential GDEs from the Commonwealth assessment (BOM 2020)

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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 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). The species 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 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 riverbank where they are buffered by fresher surface flows.

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).

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:

- Growing at sites that maximise the frequency of soil moisture replenishment (i.e. on drainage lines and overflow channels).
- Having extremely low transpiration rates.
- 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 Site 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 poplar box, narrow-leaf ironbark (*Eucalyptus crebra)* and silver leaf ironbark (*Eucalyptus melanophloia)* 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) ,* and mountain coolabah (*Eucalyptus orgadophila)* 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 in this assessment due to its elevated position on Cainozoic plains and associated with clay soils.

***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 Site.

***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 and moisture unencumbered by salinity. 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 Site 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 Habitat Values*

As per **Figure 12**, there are no 'Great Barrier Reef wetland of high ecological significance (HES)' under the Environmental Protection Regulation 2008 mapped within the Project Site, although these habitats occur further to the north and east of the project, many associated with the floodplain of the Isaac River. Many areas mapped as potential GDEs, including REs and floodplain ecosystems associated with the major riparian corridors of Phillips, Boomerang and One-Mile Creeks (typically RE11.3.25 and RE11.3.2) are mapped as Essential Habitat for Koala (*Phascolarctos cinereus – Endangered under the EPBC Act)* and Ornamental Snake (*Dennisonia maculata – Vulnerable EPBC Act).*

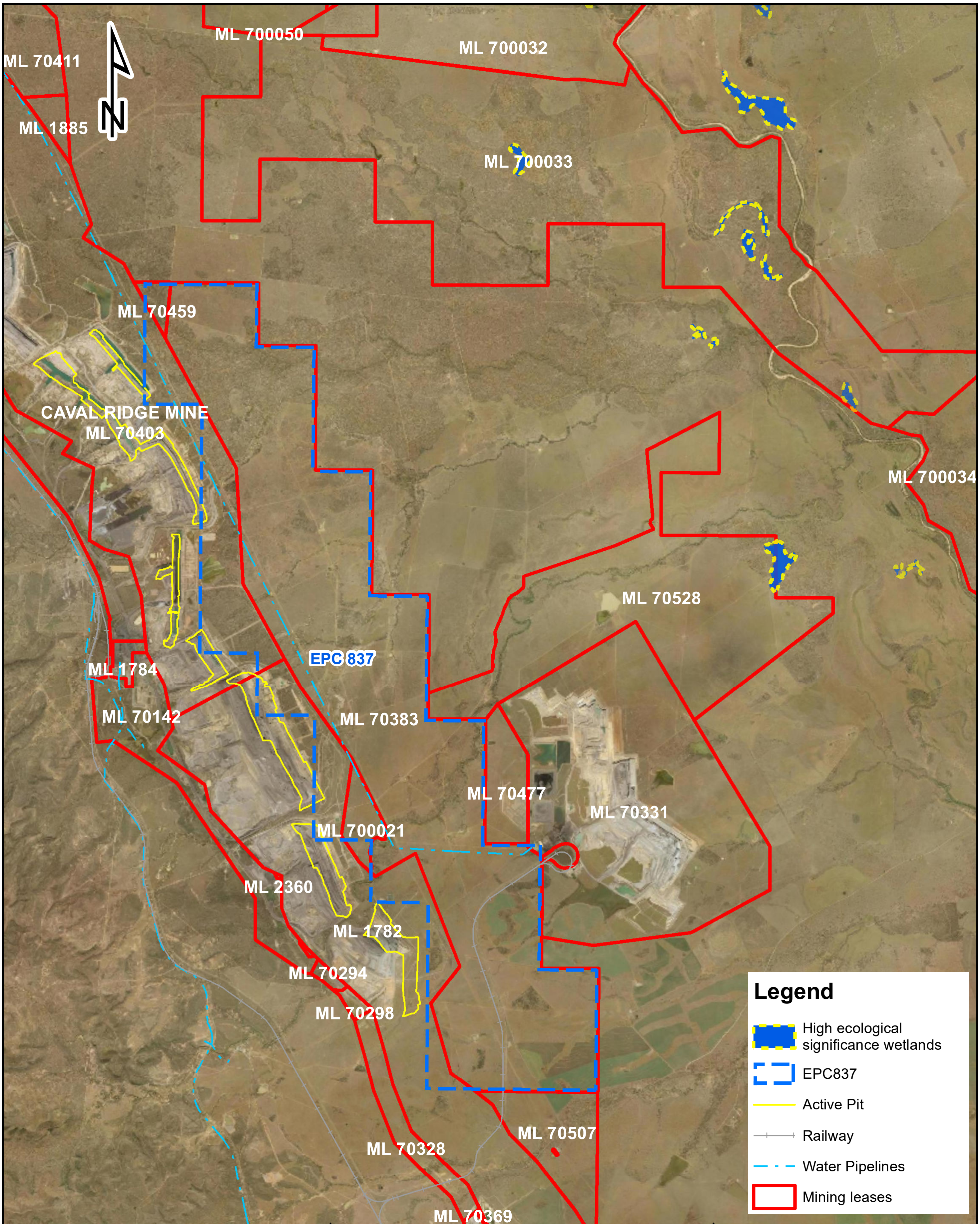


**Figure 12.** High Ecological Significance (HES) wetlands under the EP Act.

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# 3.0 Methods

The field assessment was completed over a six-day period from 7th to 12th August 2020. As described in **Section 1.6**, field conditions were hot and humid with a daily temperature range from 23°C to 39°C with some heavy showers reported at the end of the survey window. The following sections provide an overview of methods used to assess groundwater dependence of vegetation within the Project Site 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 TGDEs in the GDE Atlas (BOM 2020b) which are associated with woody vegetation occupying creek channels, floodplain vegetation and vegetation associated with residual surfaces. In total, 13 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 13**. 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.

It should also be noted that emphasis for survey was placed on those habitats which are mapped as 'High Potential' GDEs in the BOM GDE Atlas, with the rationale being that Low Potential GDEs would not demonstrate groundwater dependence if High Potential areas were confirmed not to be groundwater dependent.

For the ease of data interpretation, assessment sites were sub-divided in distinct creek catchments or localities with specific landform affinities. These include:

1. Phillips Creek
2. Tertiary residuals
3. One Mile Creek
4. Hughes Creek
5. Boomerang Creek
6. Boomerang Creek Wetland

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

| Assessment Site* | Location / Geomorphic Position | Purpose of Assessment |
|---|---|---|
| Site 1 and Site 5 (Tertiary residuals) | Both sites are Located on residual soils above the upper flood level of Phillips Creek. Both sites are approximately 400m from the Phillip Creek main channel. | The assessment aimed to sample woody vegetation associated with elevated terraces associated with, and above the flood plain of Phillips Creek. While Phillips Creek is mapped as a 'high potential' aquatic and TGDE, vegetation at the location of both GDE Site 1 and GDE Site 5 is mapped as a 'Low Potential' TGDE in the GDE Atlas (BOM 2020b) and represented as |

| Assessment Site* | Location / Geomorphic Position | Purpose of Assessment |
|---|---|---|
| | | RE11.5.3 / 11.4.9 in certified regional ecosystem mapping, being habitats dominated by *Eucalyptus populnea* / *Acacia harpophylla* dominant. |
| Site 2, Site 3 and Site 4 (Phillips Creek) | All sites are located on the main channel and fringing embankment of Phillips Creek. | The assessment aims to sample riparian vegetation, including vegetation fringing the immediate drainage channel and associated floodplain woodlands of Phillips Creek. The GDE assessment sites are located within an area mapped as a 'High Potential' TGDE with the immediate channel mapped as a 'High Potential' AGDE (BOM 2020). The dominant vegetation associated with Phillip Creek is RE11.3.25, dominated by *Eucalyptus tereticornis* and *Casuarina cunninghamiana* which are known facultative phreatophytes. |
| Site 6 and Site 7 (One Mile Creek) | Both Site 6 and Site 7 are located on the upper reaches and tributary channels of One Mile Creek, which is a minor Order 3 watercourse passing through the central portion of EPC837. | The assessment aims to sample riparian vegetation and vegetation associated with the broader flood plain of One Mile Creek. The GDE assessment sites are located within an area mapped as a 'Low Potential' TGDE (BOM 2020) with the dominant vegetation mapped as RE11.3.25 (Site 6) and 11.5.3 (Site 7). |
| Site 8, Site 9 (Hughes Creek) | All sites are located on the channel and immediate riparian margins of Hughes 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 Hughes Creek. The GDE assessment sites are located within an area mapped as a 'Moderate Potential' TGDE with the immediate channel mapped as a 'Moderate Potential' TGDE and 'Moderate Potential' AGDE (BOM 2020). The dominant vegetation associated with these sites is RE11.3.25 on the stream channel, merging with RE11.3.1 and RE11.3.2 on the upper flood plain terraces. |
| Site 10, Site 11 and Site 12 (Boomerang Creek) | Site 10, Site 11 and Site 12 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. All three GDE assessment sites are located within an area mapped as a 'Moderate Potential' TGDE with the immediate channel mapped as a |

| Assessment Site* | Location / Geomorphic Position | Purpose of Assessment |
|---|---|---|
| | | 'Moderate Potential' TGDE and 'Moderate Potential' AGDE (BOM 2020). The dominant vegetation associated with these sites is RE11.3.25 on the stream channel, merging with RE11.3.1 and RE11.3.2 on the upper flood plain terraces. |
| Site 13 (Boomerang Creek Wetland) | Site 13 is in the northern portion of EPC837, located as an overflow flood channel on the floodplain of Boomerang Creek. | The assessment aimed to sample floodplain wetlands (RE11.3.27) which is mapped as 'Moderate Potential' Aquatic and 'High Potential' TGDEs (BOM 2020). There is an imperative to determine the water sources utilised by riparian vegetation and determine whether there is any surface water / groundwater interaction. |

## 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 three to five mature canopy trees within each assessment site in localities that were within several hundred metres from a vehicle track to assist collection of samples in low light within a limited sampling window. 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, 52 trees were assessed for LWP across the 13 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 and later measurement of SMP.

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

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 regardless of groundwater salinity.

Soils were sampled at regular intervals down a soil profile for measurement of SMP, with sampling interval dependent the degree of structural and lithological heterogeneity. The measurement of SMP was completed in the laboratory with a portable Dew Point Potentiometer (WP4C) (Meter Group Inc, 2017). The WP4C meter uses the chilled mirror dew point technique with 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.

### *1.4.1 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.

Soil intervals selected for stable isotope analysis include intervals where tree roots were recorded, intervals that were particularly moist, or at the base of the auger hole high soil moisture / groundwater was recorded. In some localities, isotopic sampling of complete profiles was undertaken to aid data interpretation.

#### *1.4.2 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.

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.

#### *1.4.3 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.

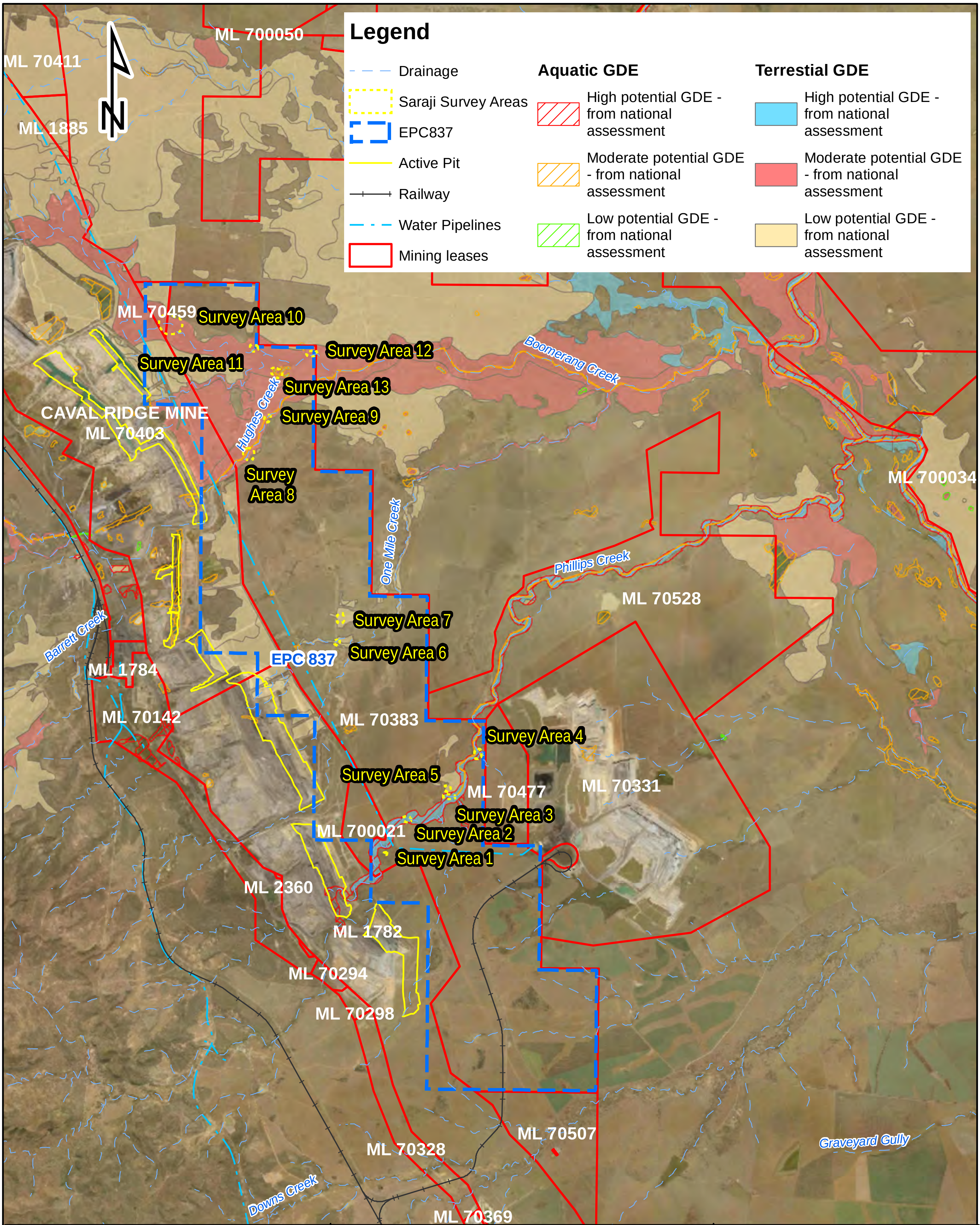
***Step 1. LWP:*** An initial comparison was undertaken to identify individual trees with LWP measurements within the expected range for known TGDEs subject to various salinity regimes, assuming complete saturation of sediments in the groundwater table and minimal influence of soil matric potential is 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 >-1.5MPa.

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 by vegetation.

***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.




Source: BOM GDE Atlas (2020).

**Figure 13.** GDE areas targeted for field assessment.

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### 3.6 Limitations and Other Information Relevant to the Assessment

This assessment provides a snapshot of eco-hydrological process at each of the 13 GDE assessment localities identified during pre-survey desktop assessment and sampled during field survey and does not assume tree moisture sources are uniform across a broader range of climatic variations. Additional information of relevance to the assessment is summarised below.

1. Considerable information has been drawn from the recently completed GDE assessment for the Lake Vermont - Meadowbrook Project (3d Environmental 2022) which forms a contiguous boundary with the Saraji Project to the east.
2. Climatic conditions preceding the assessment were dry and hot, although significant rainfall was received in the early summer months of 2021 which may have recharged the shallow perched water tables associated alluvial drainage features. Where ambiguity from biophysical measurements is apparent (e.g., LWP and SMP), stable isotope signatures were relied upon to differentiate groundwater from other moisture sources utilised by trees.
3. Access was limited in some localities due to requirements for considerable foot traverse, which was not possible due to timing constraints associated with a limited sampling window for LWP. 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.
4. 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.
5. A recommended component of the GDE assessment is to provide an assessment of GDE habitat condition. While notes are provided on habitat condition in this assessment, the assessment aim is to specifically identify which areas represent GDEs, which requires data interpretation which cannot be completed while in the field. GDE condition assessment is best completed once GDE areas are identified, through application of the Queensland Biocondition Methodology (Eyre et al 2015), typically as part of the terrestrial ecology scope.
6. The ecological processes and hydrogeological conditions encountered within the Project Site 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 14** with a breakdown of LWP for individual trees shown in **Figure 15. Figure 16** 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, regional ecosystem, and condition. Based on the assessment in **Table 3,** potential for groundwater utilisation can be categorised into the following categories:

1. Sites that have LWPs indicating Very High water availability, and potential for utilisation of fresh groundwater based on data from relevant monitoring bores. This includes Phillips Creek Sites (Site 2, 3 and 4) and the Boomerang Creek Wetland Site (Site 13). Further investigation of SMP and stable isotopes will be necessary at these sites to determine the nature and degree of groundwater dependence.
2. Sites that have LWPs indicating High to Moderate water availability although data from groundwater monitoring bores suggests that groundwater is unlikely to be accessible (i.e., >15mbgl). This includes One Mile Creek (Site 6 and Site 7), Hughes Creek (Site 8, Site 9). Further investigation of SMP and stable isotopes will be necessary at these sites.
3. Sites that have LWPs indicating Moderate to Low water availability and limited capacity for groundwater usage, which is supported by monitoring data from nearest groundwater monitoring bores. This includes Boomerang Creek sites (Site 10, Site 11 and Site 12).
4. Sites that have LWP that indicates Low water availability and no indication that groundwater is being used to any degree. This includes site associated with Tertiary residual landforms including Site 1 and Site 5.

Based on LWP data, Phillips Creek, and the Boomerang Creek Wetland site (Site 2, Site 3, Site 4 and Site 13) have the highest potential for groundwater utilisation within the Project Site warranting additional scrutiny of stable isotope values. SMP and stable isotope data from all sites will however be interrogated due to the potential for presence of saline groundwater, which complicates LWP assessments. Due to recent rainfall (late November 2021) which would have increased availability of soil moisture in the shallow profile, it is considered extremely unlikely that any tree would have been reliant on saline water sources (e.g., groundwater >20 000 µS/cm) at the time of assessment.

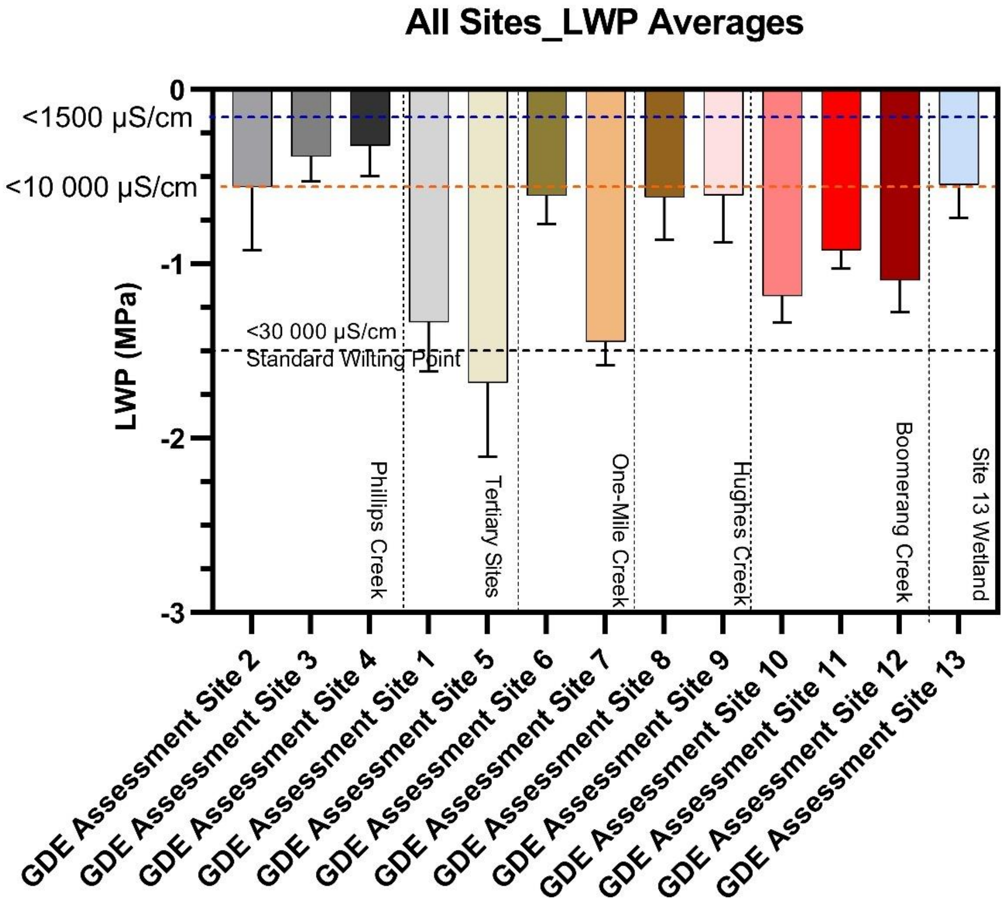



**Figure 14.** Average LWP readings for all GDE Assessment Areas. The blue line (>-0.2MPa) indicates expected LWPs for trees in equilibrium with a non-saline saturated source of soil moisture; the orange line (>-0.55MPa) indicating expected values for trees in equilibrium with a moderately saline soil moisture source (EC 10 000 µS/cm) and the black line indicating expected values of trees in equilibrium with saline source of moisture at 30 000 µS/cm coinciding with Standard Wilting Point (<-1.5MPa).

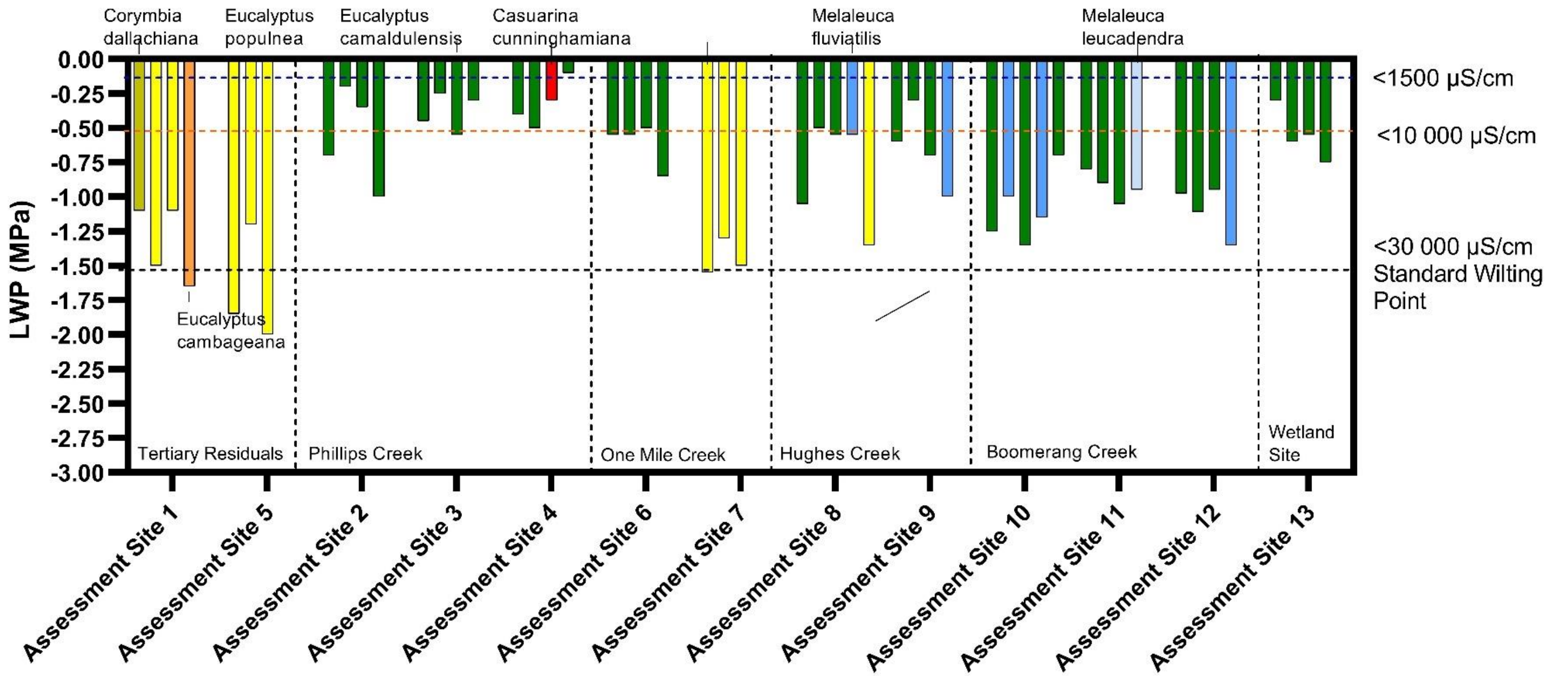



**Figure 15.** LWP results for individual trees per species at each of the 12 GDE assessment areas.

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

| Site | Average LWP (MPa) | Water Availability | Comments |
|---|---|---|---|
| **Phillips Creek Sites** | | | |
| Site 2, Site 3, Site 4 | -0.32 to -0.56 MPa | Very High | The riparian frontage of Phillips Creek represents well developed riparian open forest typical of RE11.3.25 dominated by river red gum (see **Photograph 1**). The upper alluvial terrace forms at 8 – 10 m above the sandy channel floor and is occupied by a well-developed woodland of river red gum on alluvium (RE11.3.4) merging with poplar box woodland (RE11.5.3) with increasing distance from the creek channel. Riparian canopy and sub-canopy vegetation is entirely intact though groundcover is dominated by exotic grasses (mostly Green Panic – *Panicum maximum var. trichoglume*). Heavily grazed.<br><br>Three sites (GDES Site 2, GDE Site 3 and GDE Site 4) with very high average LWPs of 0.56, 0.38 and 0.32MPa respectively all demonstrate similar pattern of water usage. The highest individual LWPs are recorded for trees low on the inner bank adjacent to the river channel, with trees higher on the river terrace demonstrating decreased water availability. Tree 2 at Site 2 and Tree 4 at Site 4 demonstrate the highest LWPs of any trees assessed during the survey (-0.2 and -0.1MPa respectively) indicative of utilisation of a fresh near-saturated to saturated source of groundwater or soil moisture. Tree 4 at Site 2 is located high on the river terrace (>8m above the river channel) and presents a much lower LWP (-1.0MPa) indicating trees are utilising moisture bound in soil.<br><br>Relevant groundwater monitoring bores are MB35 and MB38. MB35 is screened at the base of the Tertiary sediments with groundwater depth at 17.0 mbgl and a salinity of approximately 1500 µS/cm. MB35 is screened in the alluvium and has been dry since installation. Due to stream incision of up to 10m into the alluvial sediments which would bring groundwater to within 7m from the base of the stream channel, meaning this groundwater could possibly be accessible to trees on the lower terrace.<br><br>The data for these sites indicates trees on the lower terrace are accessing a zone of high moisture availability, potentially indicative of fresh groundwater, with trees higher on the terrace utilising soil moisture. |
| **Sites Associated with Tertiary Residuals** | | | |

| Site | Average LWP (MPa) | Water Availability | Comments |
|---|---|---|---|
| Site 1, Site 5. | -1.33 to -1.68MPa | Low | Both sites are located on the outer flood plain of Phillips creek above the current flood level. Vegetation is typically occupied by RE11.5.3, dominated by shallow rooted *Eucalyptus populnea*. Intact native canopy vegetation with some drought dieback. Mixed native / exotic groundcovers with evidence for grazing. Average LWPs for both sites are 'Low' with Site 5 possessing an average LWP that is lower than standard wilting point.<br><br>Relevant groundwater monitoring bores are MB35 and MB40 both screened at the base of the Tertiary sediments. These monitoring wells indicate groundwater depths >17mbgl which would be beyond the maximum rooting depth of the dominant shallow rooted *Eucalyptus populnea*.<br><br>The data indicates habitats of the residual landforms are unlikely to be utilising groundwater to any degree. |
| **Sites Associated with One Mile Creek** | | | |
| Site 6, Site 7 | -0.61 to -1.45MPa | High to Low | GDE Site 6 represents a shallow drainage channel with a clayey floodplain largely occupied by river red gum on the narrow channel (RE11.3.25) to woodlands dominated by poplar box on the outer flood plain. Intact native canopy vegetation with some drought dieback. Mixed native / exotic groundcovers with evidence for grazing. LWPs for red gum sampled at the locality range from -0.5 to -0.85 MPa indicating high water availability in the subsoil. Further information is required on sub-soil conditions to determine whether moisture in the shallow soil profile is supporting transpiration of woodland canopy trees.<br><br>GDE Site 7 is largely dominated by shallow rooted poplar box and with a Low LWP of -1.45MPa, there is no indication that vegetation at this locality is accessing groundwater, being solely reliant of moisture bound in clay. |
| **Sites Associated with Hughes Creek** | | | |
| Site 8, Site 9 | -0.61 and -0.62MPa | High | Hughes creek at the site of assessment Site 8 has a channel incised to depths of 5m into the residual land surface with the immediate channel occupied by forest red gum and weeping tea tree (RE11.3.25) and poplar box woodland on the upper river terrace (RE11.3.2). Strong evidence of drought dieback on riparian margins and heavy grazing on riverbanks. Weathered Permian sandstone outcrop is visible exposed in the sandy channel at Site 8 (see **Photograph 2**). Site 9 has a deeper soil profile and better developed and preserved riparian vegetation. |

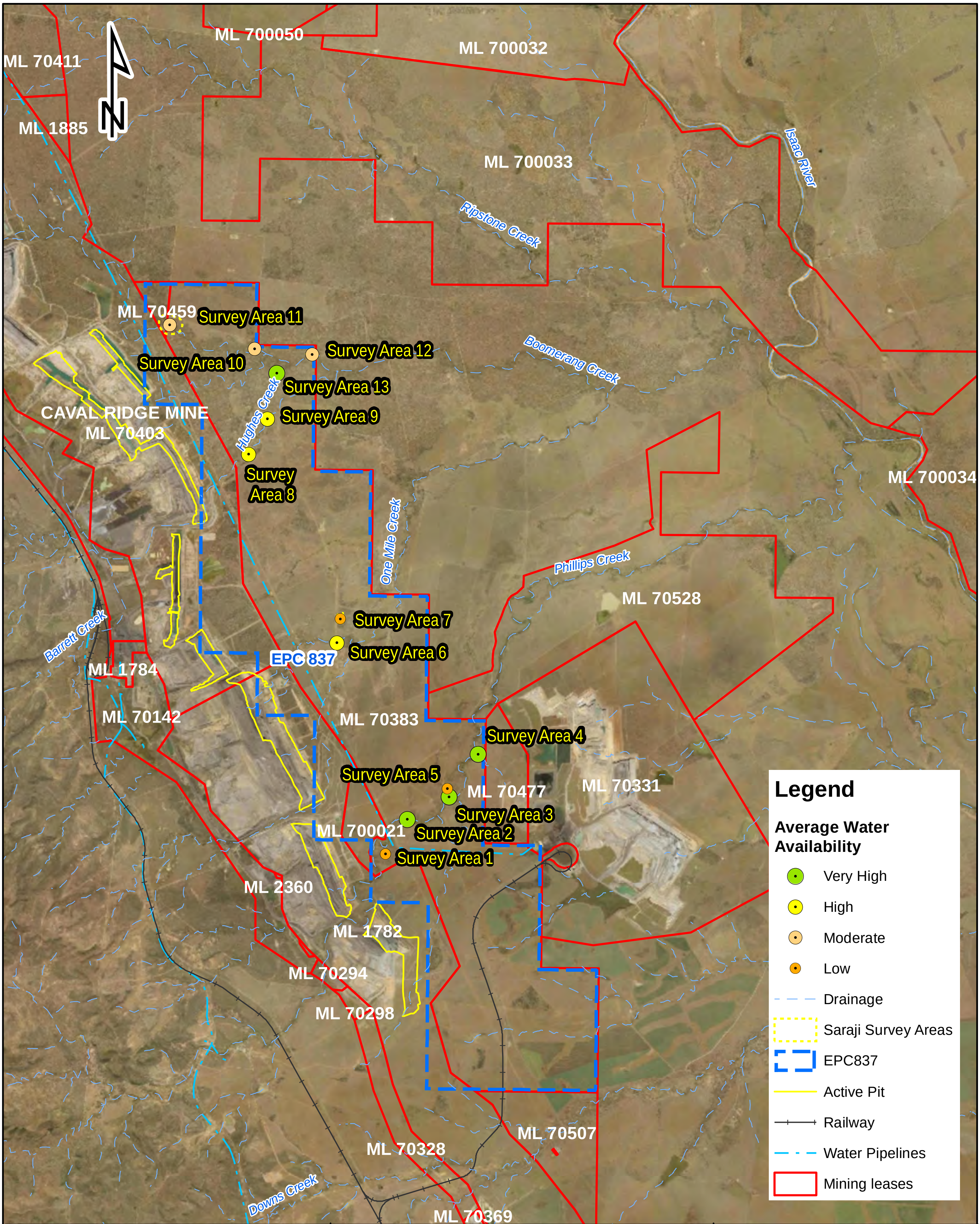
| Site | Average LWP (MPa) | Water Availability | Comments |
|---|---|---|---|
| | | | Both sites demonstrate 'High LWPs' that indicate either high soil moisture availability in the shallow soil profile, or the possible utilisation of a source of brackish to slightly saline groundwater at >10 000µS/cm.<br><br>Considering the lack of flood plain alluvium developed at these sites and considerable depth to groundwater indicated in wells installed into Tertiary and Permian sediments (>17mbgl at MB20SRM01A_PZ and MB19SRM03P_HY) and dryness of bores installed into alluvium (MB19SRM03P_HY, MB20SRM05A_PZ) it is considered unlikely that groundwater is being utilised by riparian vegetation on Hughes Creek at these localities. |
| **Sites Associated with Boomerang Creek** | | | |
| Site 10,<br><br>Site 11,<br><br>Site 12 | -0.93 to -1.20 | Moderate | Boomerang Creek is an ephemeral sandy drainage channel fringed by riparian vegetation dominated by river red gum and weeping tea-tree (RE11.3.25).<br><br>All sites present average LWPs that are Moderate, indicating an unlikelihood that trees would be utilising groundwater to any significant degree, unless saline (>20 000µS/cm).<br><br>Considering the lack of flood plain alluvium developed at these sites and considerable depth to groundwater indicated in wells installed into Tertiary and Permian sediments (>17mbgl at MB20SRM01A_PZ and MB19SRM03P_HY) and dryness of bores installed into alluvium (MB19SRM03P_HY, MB20SRM05A_PZ) it is considered unlikely that groundwater is being utilised by riparian vegetation at these locations on One Mile Creek. |
| **Boomerang Creek Wetland Site** | | | |
| GDE Site 13 | -0.55 | Very High | GDE Assessment Site 13 (**Photograph 3**) represents an overflow wetland associated with older alluvial flood plain deposits with the wetland fringed by large forest red gum. with a range of values from -0.3 to -0.7MPa. Surface water was present at the time of assessment presenting salinity of 1 554 µS/cm and fringing trees were perched on an older terrace approximately 1.5m above the level of surface water. While the canopy of forest red gum is intact and relatively healthy, the wetland margins have been heavily grazed and trampled, occupied mostly by exotic species. |

| Site | Average LWP (MPa) | Water Availability | Comments |
|---|---|---|---|
| | | | The very high LWP values indicate trees have access to a readily available, although unsaturated source of soil moisture, or possibly groundwater of brackish to moderate salinity (5 000 to 10 000µS/cm).<br><br>The nearest monitoring bores installed into Tertiary and Permian sediments indicate groundwater at >17mbgl at MB20SRM01A_PZ and MB19SRM03P_HY,) and dryness of bores installed into alluvium MB19SRM03P_HY, MB20SRM05A_PZ.<br><br>If groundwater is the source of the high LWP values, it is likely to be a restricted shallow perched system that is localised in the area adjacent to the wetland.<br><br>Further analysis of stable isotopes and SMP will be required to adequately determine groundwater dependence. |

**Photograph 1.** Phillips Creek at Site 3, showing sandy channel fringed by well-developed riparian woodland dominated by river red gum and scattered river oak (RE11.3.25).

**Photograph 2.** Outcropping weathered sedimentary rock exposed in the channel of Hughes Creek at Site 8, likely to be late Permian / Triassic age, with limited development of riparian vegetation.

**Photograph 3.** Overflow wetland on the floodplain of Boomerang Creek, assessed at Site 13.




| | | |
|---|---|---|
| Mpa | Extremely High | >-0.276 |
| 0.580 MPa | Very High | <-0.276 to - |
| 96 MPa | High | <-0.580 to -0.8 |
| Pa | Moderate | <-0.896 to -1.21 M |
| | Low | <-1.21 to -1.72 MPa |
| | Very Low | <1.72 to -2.21 Mpa |
| | Extremely Low | <-2.21 Mpa |

**Figure 16.** Spatial representation of average LWP values for sampling sites in the assessment area

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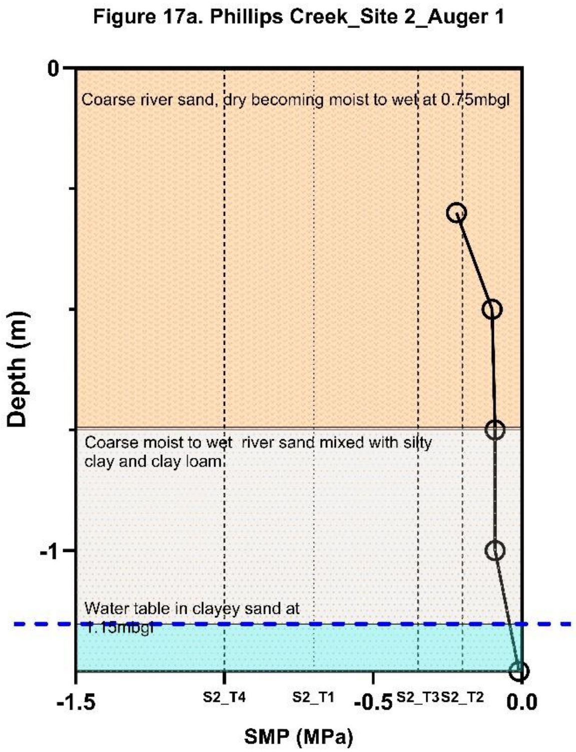
## 4.2 Hand Auger Profiling and Soil Moisture Potential

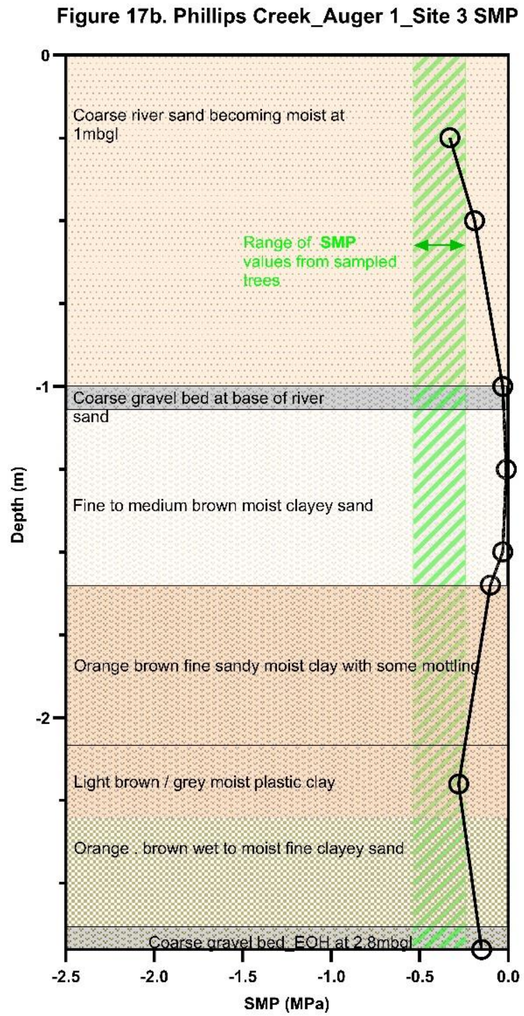
As per **Section 3.4**, the purpose of the SMP testing is to identify, for those assessment areas / trees where LWP measurement indicate potential groundwater usage, whether sufficient moisture is available in the upper unsaturated portion of the soil profile (i.e., vadose zone) to explain LWP measurements or whether utilisation of groundwater can be inferred. The location for auger holes was selected during the field survey to cover sites where potential groundwater dependence was indicated by LWP values, or assessment sites were considered representative of a particular habitat or landform. In total, 10 auger holes were installed including:

- **Phillips Creek Sites**
  - GDE Site 2 where the auger hole was placed in the central portion of the sandy channel of Phillips Creek to a depth of 1.3mbgl. Groundwater was intersected at 1.15mbgl and a sample retained for stable isotope analysis. Salinity of the groundwater was 376µS/cm. SMP values indicate extremely high SMP down the entire soil profile, considerably higher than LWP values recorded at the location except for Tree 2 which suggests trees are utilising moisture from soil held in the creek banks rather than the channel sands (see **Figure 17a**).
  - GDE Site 3 where the auger hole was placed in the central portion of the sandy channel of Phillips Creek to a depth of 2.75mbgl. Coarse river sand was recorded to a depth of 1mbgl with a basal interval of gravel, passing downhole into heterogenous profile comprising clayey sand, sandy clay and minor plastic clay. The auger hole remained dry to the depth of a coarse gravel bed which prevented deeper auger penetration. The range of LWPs recorded at the site overlap with soils at 2.2mbgl and at 0.25mbgl. This indicates sufficient moisture is held in the unsaturated (at the time of assessment) portion of the soil profile to account for the range of LWPs recorded (see **Figure 17b**).
  - GDE Site 4 where the auger hole was placed in the sandy channel of Phillips Creek to a depth of 1.6mbgl with further penetration arrested by competent basement rock. Soil data indicates a heterogeneous soil profile with 30cm of coarse river sand passing into a coarse gravel interval from 0.3 to 0.5mbgl. The gravel interval had a dense matting of fine tree roots at its base, indicating utilisation of moisture from this interval by riparian vegetation. Below this depth, the soil profile varies from clayey sand to sandy clay to the intersection of basement rock with some iron mottling indicating fluctuations in a transient groundwater table. The auger hole remained dry to the depth of decomposed basement rock, although the range of LWPs recorded at the site overlap with soils at 0.3 to 0.5mbgl and from 1.2 to 1.3mbgl. This indicates sufficient moisture is held in the unsaturated portion of the soil profile at the time of assessment to account for the range of LWPs recorded (see **Figure 17c**).
- **One Mile Creek**
  - A single auger hole was placed at Site 6 in the central portion of the drainage depression which penetrated to a depth of 2.6mbgl. Soil texture down the profile is relatively uniform with clayey sand in the top 2.0m of the soil profile, passing into clay between 2.0 and 2.5mbgl with gravelly sand at the base of the hole. Iron mottling occurs from the top of the profile to the base likely indicating transient zones of soil saturation. The data indicates that LWPs recorded at Site 6 are relatively consistent with

SMPs down the entire soil profile with overlap between 1.0mbgl and 1.6mbgl with some fine tree roots are recorded. There is no indication that groundwater is being utilised by trees at Site 6 based on data compiled during auger profiling (see **Figure 18**).

- **Hughes Creek**
  - The soil profile at Site 8 was too shallow to accommodate an auger, with competent basement rock intersected at 0.3mbgl. A single auger hole was placed at Site 9 in the sandy channel of Hughes Creek which penetrated to a depth of 2.5mbgl, with deeper penetration arrested by dense plastic clay. The auger was dry to the full depth of the soil profile, which comprised 50cm of coarse river sand, grading into clayey sand and gravelly clay to a depth of 2mbgl. Tree roots were recorded at 2.0mbgl above a zone of strongly mottled gravelly clay indicating a region of tree moisture utilisation. LWP values of individual trees plotted against downhole SMP suggest a zone of tree moisture extraction could occur between 1.25mbgl and the base of the auger (see **Figure 19**). While the soil profile in the river could be seasonally saturated, the shallow depth to basement rock would mean that transient water stored in river sand would drain quickly.
- **Boomerang Creek**
  - Three auger holes were placed in the Boomerang Creek channel at Site 10 (1.6mbgl), Site 11 (2.75mbgl) and Site 12 (2.5mbgl). All auger holes were placed into the channel of Boomerang Creek and were dry to full depth. Augers at both Site 10 and Site 11 intersected sedimentary basement rock at shallow depths (1.6mbgl and 2.75mbgl respectively) while Site 12 was abandoned at 2.5mbgl due to hole collapse in loose dry sand. For all holes, downhole SMP overlaps with recorded LWP values for the almost the complete depth of the soil profile. This indicates that soil moisture in the unsaturated zone can adequately account for the range of LWPs recorded at all sites. Auger and downhole SMP profiles are presented in **Figure 20a** to **Figure 20c**.
- **Boomerang Creek Wetland Site**
  - A single auger hole to total depth of 4mbgl was placed on the inner bank of the Boomerang Creek wetland. The auger was placed at approximately 1m above surface water level meaning that the auger penetrated to significant depth (3m) below the wetland surface. The auger was dry to total depth and intersected brown silty loam soils to a depth of 1.5mbgl, before passing into an interval of very dry (-2.45MPa at 2.5mbgl) fine sand between 1.5 and 2.8mbgl. The base of this interval was marked by a 25cm thick interval of moist, mottled clayey sand with tree roots recorded at 3.0mbgl, and additional tree roots intersected at 3.75mbgl above weathered sedimentary basement rock. Zones of tree moisture utilisation are most likely to be occurring at the soil surface, at 2.8mbgl and below 3.75mbgl where SMP and LWP measurements overlap (see **Figure 21**).



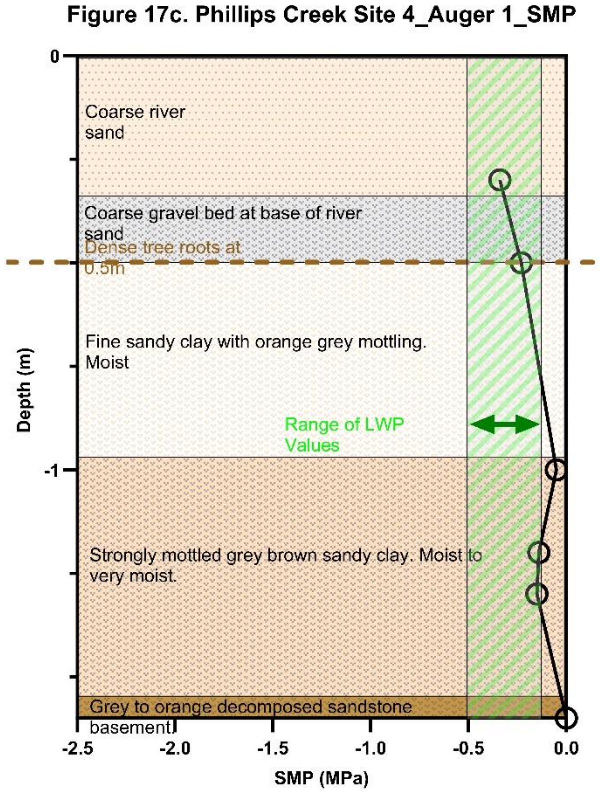




**Figure 17.** Figure 17a, Figure 17b and Figure 17c showing soil auger and downhole SMP profiles for Site 2, Site 3 and Site 4 on Phillips Creek.

**Figure 18.** Soil auger and downhole SMP profile for Site 6 on One Mile Creek, showing zone of overland between LWP and SMP values.

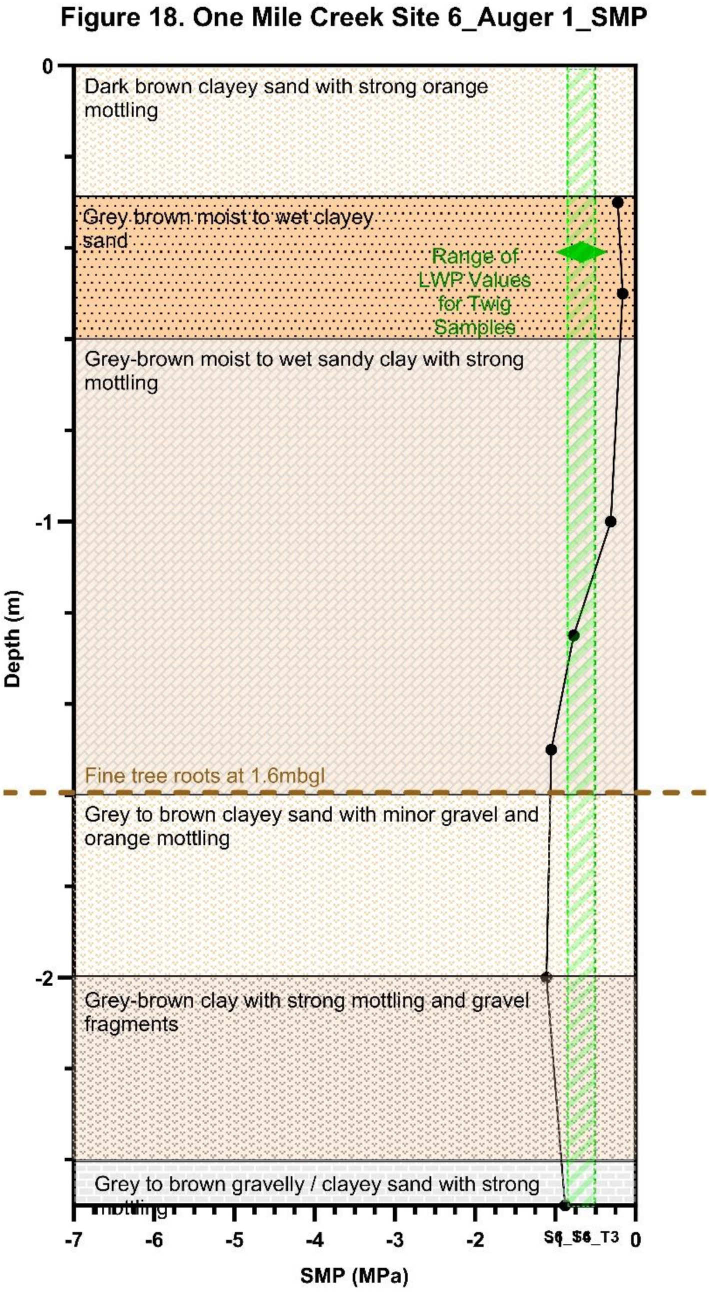


**Figure 19.** Figure 19 demonstrating auger soil and downhole SMP profile of Site 9 on Hughes Creek. The broad overlap between LWP values and SMP below depths of 1.2mbgl is notable.

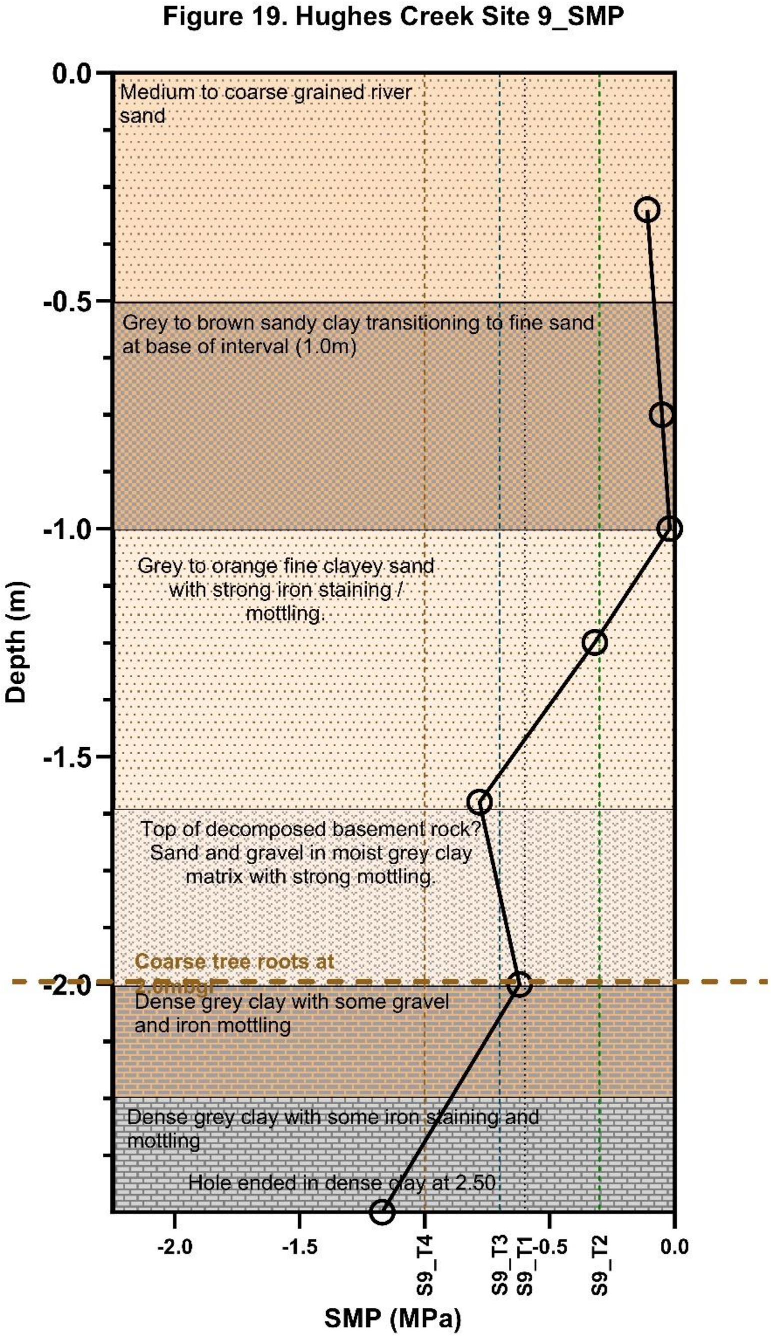


**Figure 20.** Auger holes placed at Boomerang Creek including Site 10 (Figure 20a), Site 11 (Figure 20b) and Site 12 (Figure 20c) demonstrating relationship between LWP values and SMP.

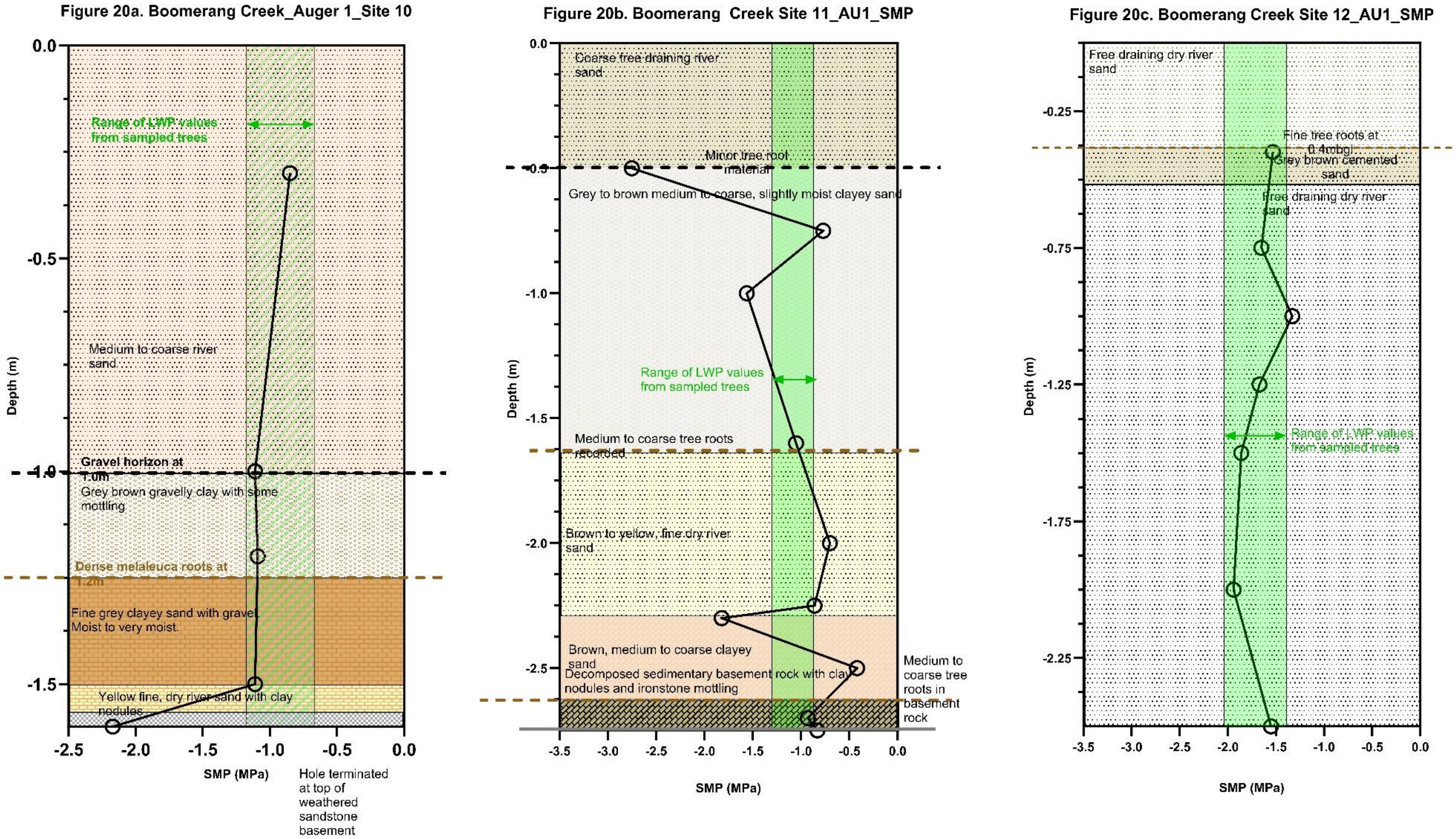
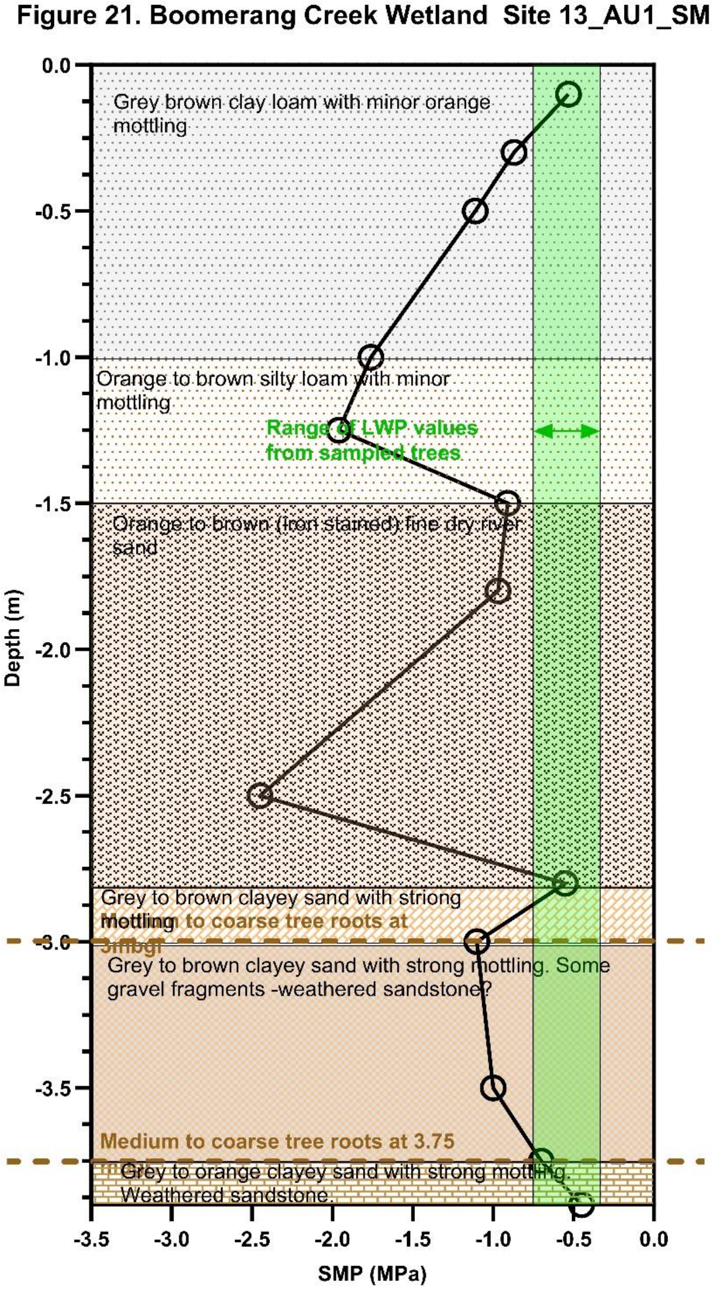


**Figure 21.** Boomerang Creek Wetland Site 13 demonstrating overlap between LWP and SMP values at 2.8 and below 3.5mbgl.



## 4.3 Stable Isotope Sampling and Analyses

### *4.3.1 General trends*

**Figure 22** 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 and twig xylem water analysed during the assessment. Data interpretation is supported by incorporation of isotopic data from rainfall collected in the Bowen Basin between 2008 and 2021 (including data from Crosbie et al 2012), applied to construct a best available Local Meteoric Water Line (LMWL) using simple linear regression. The constructed LMWL defines a slope of 6.852 and d-excess of 9.776 (Y = 6.852*X + 9.776) which is very similar to the Global Meteoric Water Line which defines a slope of 8 and d-excess of 10 (Craig, 1961). While construction is based on a limited number of samples (5 in total), the lack of sample scatter along the trendline increases confidence that the calculated LMWL provides a suitable reference. Data utilised in construction of the LMWL, along with raw data from the stable isotope assessment is provided in **Appendix D**. The LMWL provides a reference to identify evaporative processes, which will generally result in $\delta^{18}O$ isotope values that plot below the LMWL trend. The scatter shows:

1. A broad cluster of isotope values derived from soil samples (black triangles) that includes values that lie both above and below the LMWL with a trendline defining a slope of Y = 4.434*X + 0.6401
2. A broad scatter of isotope samples from twigs (green triangles) which shows the greatest spread and range of all groups, although samples lie below the LMWL suggesting that all samples have been subject to evaporative enrichment to some degree. The trendline formed by xylem samples forms a slope defined by Y = 4.081*X - 8.113.
3. A sample of groundwater (S2_AU1_GW) from shallow alluvium collected during auger sampling as a component of this study (Phillips Creek Site 2). This sample lies in the centre of a tight cluster of groundwater samples collected from Saraji groundwater monitoring bores (MB34, MB35, MB40 and PZ00c), supplemented with groundwater data from Lake Vermont Project (trendline defined by Y = 4.733*X - 6.952).
4. Three surface water samples (blue bullets) which are generally enriched above other groups, with surface water from Site 13 (Boomerang Creek wetland) being the most enriched of all samples.

The broad scatter of isotopic values in the soil samples is likely due to incorporation of pre-existing soil moisture into rainfall as it infiltrates the unsaturated portion of the soil profile. 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) which would contribute greatly to the isotopic scatter demonstrated by soils. The offset between trendlines defined by soil samples and twig xylem is typical of the offset expected to occur through fractionation of deuterium during transpiration (de La Casa et al, 2021; Dr Hilary Stuart-Williams, ANU pers. com.).

The tight cluster of groundwater samples, which includes groundwater from Tertiary sediments, Permian coal seams, alluvium (including S2_AU1_GW collected at Site 2 during current sampling) suggests some hydrological linkage between the groundwater sources. This would indicate groundwater recharge for most sources is facilitated by preferential flow (through cracks and fractures) rather than slow infiltration through the soil profile (piston flow). Infiltrating surface water would include direct infiltration of unfractionated rainfall with variable isotopic composition (dependent on the season and timing of precipitation in the rainfall event[2]) and possibly more evaporatively enriched surface waters.

As a summary, the broad scatter of both twigs and xylem samples, consistent offset between data trendlines when compared to the relatively tight cluster of groundwater samples provides evidence to suggest that most trees sampled (if not all) are not utilising any significant quantity of groundwater, being reliant instead on moisture derived from the unsaturated portion of the soil profile. Further analysis of data for individual sites is presented in following sections.

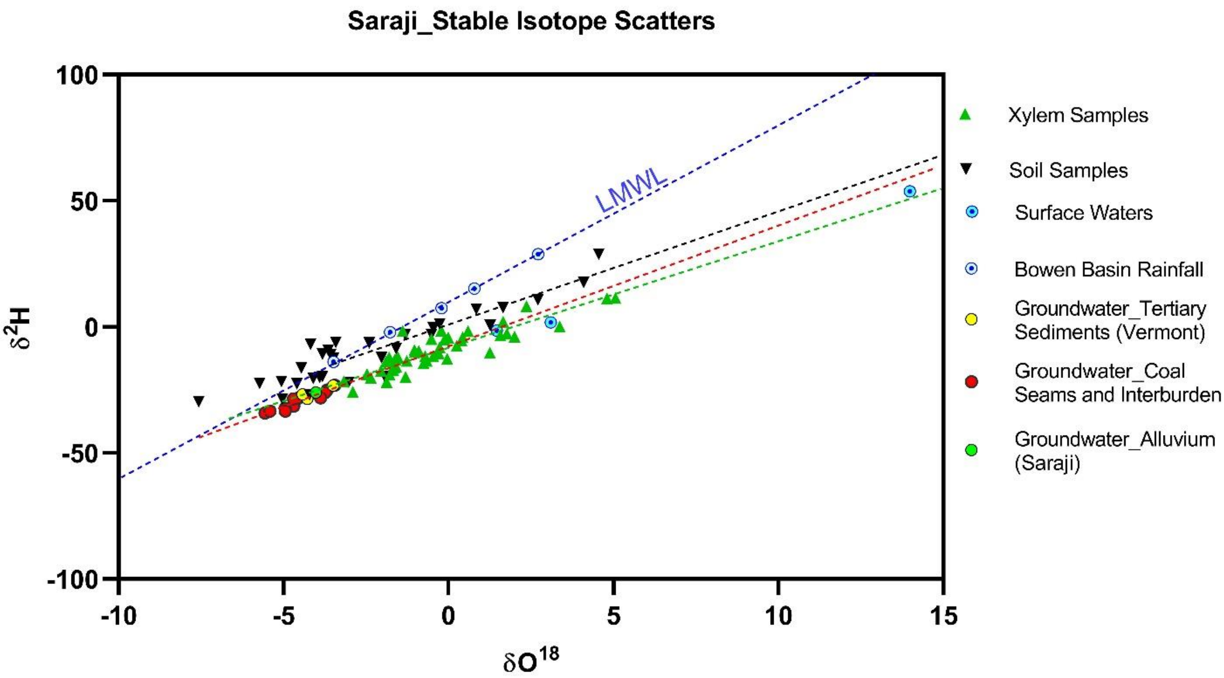



**Figure 22.** Stable isotope scatters for all data with the LMWL indicated by blue dashed line, cluster of groundwater samples from the Tertiary, Permian coal seam and alluvial aquifers with associated trendline (red, yellow and green circles and red dashed trendline), and trendlines defined by the scatter of twig xylem samples (green triangles and dashed green trendline) and soil samples (black triangles and black dashed line).

### *4.3.2 Deuterium Excess*

Deuterium excess (or d-excess), defined by d (‰) = δH2- 8* δO18 (Dansgaard, 1964), is a metric commonly used in climatological studies for tracing past and present precipitation processes. D-excess is a measure of the relative proportions of $^{18}O$ and $^{2}H$ contained in water and can be visually depicted as an index of deviation from the global meteoric water line (MWL; d=10) in δ18O versus δ2H space (Froehlich and Gibson 2002). The metric also has application in identifying water compositions subject to varying degrees of evaporative enrichment, indicated by d-excess values

[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).

falling below the range of 8 to 10, which are the typical values of primary meteoric water. D-excess > 10 indicates recycling of previously evaporated water vapour, or previously evaporated moisture when contained in soils. D-excess value for all samples is shown in **Figure 23**, which indicates:

1. Rainfall samples within the general range expected of primary meteoric water.
2. An expected broad scatter of soil values indicating exposure to both moisture recycling and evaporative processes.
3. A broad spread of xylem moisture values with most samples universally subject to some degree of evaporative enrichment ranging from minor to extreme.
4. A narrow range of groundwater values which range from primary meteoric values to those indicative of minor degrees of evaporative enrichment.
5. Strong deuterium enrichment of surface water samples

The data supports recharge of groundwater sources by preferential flow paths, which would limit the degree to which isotopic fractionation could occur. The data identifies that only one tree at Phillips Creek Site 2 (S2_T1) is utilising moisture representative of primary meteoric / rainfall values and all other trees are utilising moisture that has evolved considerably through evaporation. The data also supports the limited degree to which sampled trees are utilising groundwater.

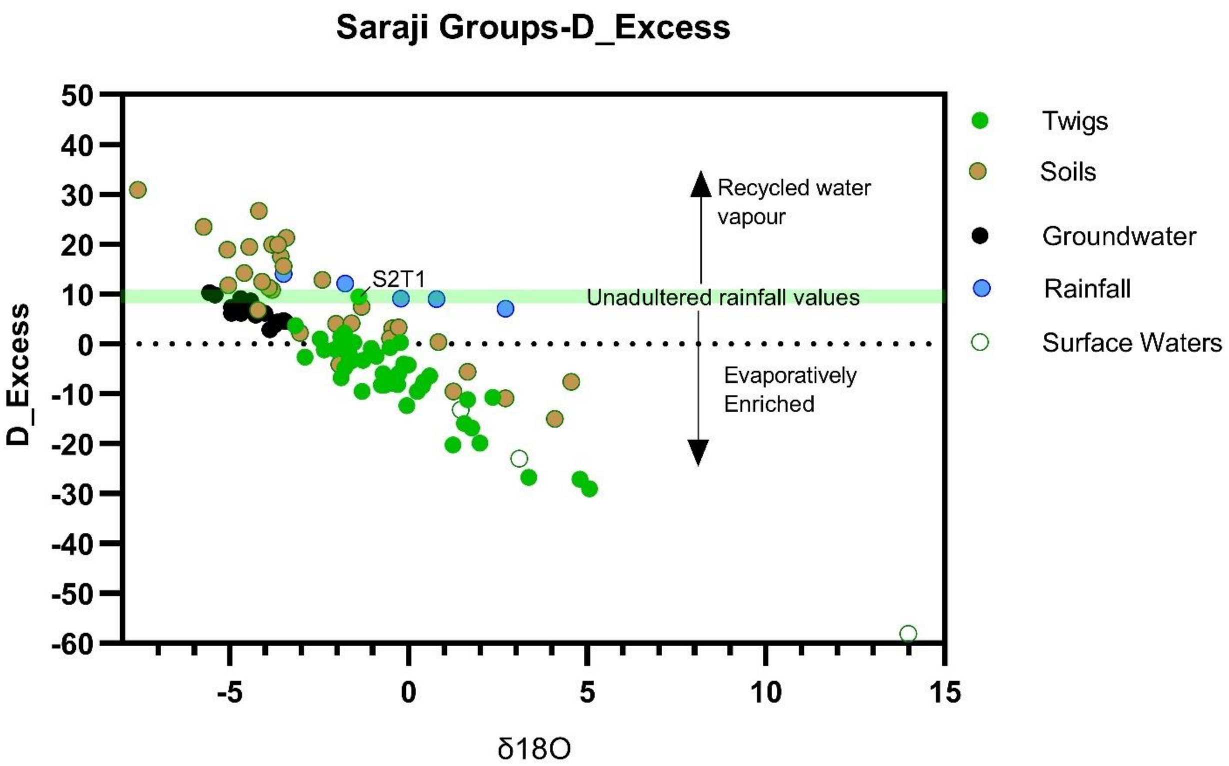



**Figure 23.** D_excess calculated for isotopic values reported for twigs, soils, groundwater, surface water and rainfall indicating the broad scatter of values for twigs and soils.

### *4.3.3 Line Conditioned Excess for Individual Assessment Sites*

To further define the isotopic differences in the various moisture pools used by potentially groundwater dependent vegetation, line conditioned excess ('lc-excess' or 'precipitation offset) was calculated using the LMWL as a reference. Line conditioned excess describes the differences in stable isotope composition of various moisture pools compared to local precipitation (Landwehr & Coplen, 2006; Evaristo et al 2015., Petit and Froend 2018) through application of the following equation:

lc-excess* = [δ2H − a δ18O – b]/S

Where a and b are the slope and intercept of the LMWL, and S is the standard deviation of both δ2H and δ18O values. Local precipitation has a lc-excess =0, and evaporation of moisture on the land surface results in lc-excess values that variably fall below this dependent on the degree of evapotranspiration they have been subjected to (Evaristo et al 2015). In contrast, those values that have lc-excess values >0 have accumulated deuterium as part of their evolutionary process. Data from each of the GDE assessment sites is provided in a box and whisker plot shown in **Figure 24**. Lc-excess data should not be considered an absolute indicator of groundwater usage, though indicates the evolution various moisture sources away from their meteoric origin. Trees that have strongly negative lc-excess value are utilising moisture that has undergone large degrees of evaporative enrichment while trees with higher (less negative lc-excess values) are utilising moisture that has evolved little from its primary meteoric source, which is isotopically variable along the LMWL in time and space.

The data indicates groundwater values, including the groundwater sample collected during auger sampling at Site 2, form a relatively narrow range of values that is slightly offset below the LMWL indicating the effect of minor evaporation. Consistent with d-excess calculations, the data confirms that groundwater isotopic ratios have been derived from rainfall which has not had a significant surface residence time and has infiltrated the soil profile relatively rapidly through preferential flow paths. For nearly all sites, there is clear separation between the range of values reported for twig xylem and groundwater, and lc-excess values reported for soil samples (brown) are clearly separated from twig xylem (green) and are generally closer to primary meteoric values than groundwater. The data suggests that at most localities, trees are not reliant of groundwater and are predominantly utilising moisture sources that are heavily compartmentalised in the soil profile (Evaristo, et. al., 2015; Evaristo et. al., 2016), and not captured within he limited resolution of site-based soil sampling. Site 2 on Phillips Creek represents the only monitoring locality where there is any significant overlap between lc-excess values for twig xylem, soil and groundwater, which strongly suggests that riparian vegetation is utilising moisture that is hydrologically linked to perched groundwater couched in the river sand, which is derived directly from rainfall or surface flows which have not been subject to significant evaporative enrichment.

Riparian vegetation at Site 7 may be utilising surface water to some degree indicated by the overlap between xylem and surface water samples. Similarly, twig xylem at the wetland Site 13 has a large negative precipitation offset, that likely indicates some of the extremely evaporatively enriched wetland surface water (precipitation offset of -45.1) is interacting with the zone of tree moisture uptake.

Sites where there is some overlap in lc-excess values between twig xylem samples and groundwater include Site 1 (Tertiary plain) and Site 10 (Boomerang Creek). LWP values at these sites (discussed in **Section 4.1**) are however strongly negative, indicating trees are unlikely to be utilising groundwater and highlights the importance of considering multiple datasets to assist data interpretation.

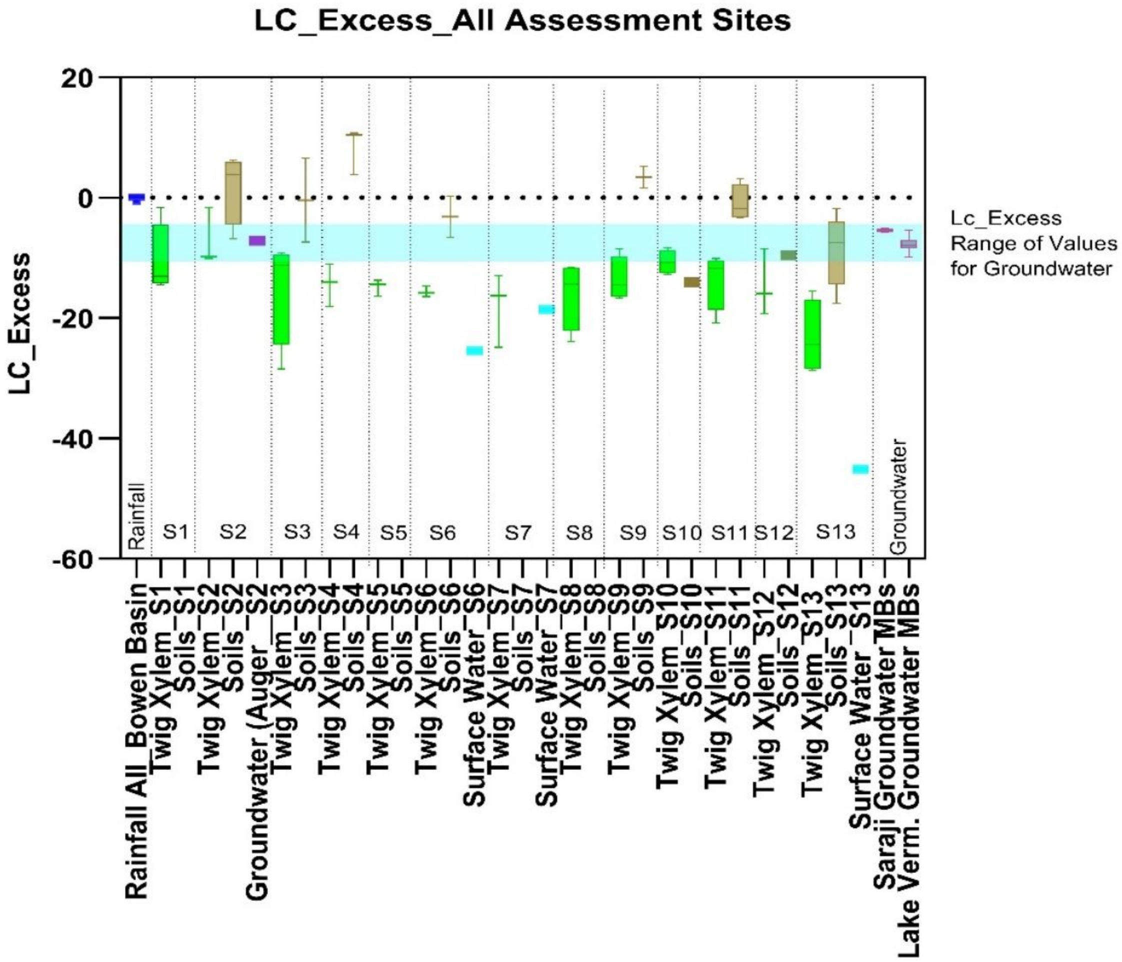



**Figure 24.** Box and whisker plot defining Lc-excess values for rainfall (dark blue), twig xylem (green), soils (brown), surface waters (light blue) and groundwater (purple) for each GDE assessment site. The range of Lc-excess values of groundwater is indicated by the light blue shading.

#### *4.3.4 Phillips Creek Sites (Site 2, Site 3, Site 4)*

The isotopic samples for twigs and soil for sites on Phillips Creek (Site 1, Site 2, Site 3) 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 tight cluster formed by groundwater samples from the regional aquifers (coal seams and Tertiary sediments) and the single groundwater sample collected from alluvium during field survey. Although the data shows no overlap between groundwater and twig samples, there is minor overlap with the deepest soil sample from Site 3 (S3_AU1_2.7), which is the only sample in the soil cluster that falls below the LMWL, and Site 2_T1 appears to be utilising unaltered meteoric waters which is consistent with lc-excess calculations. When the isotopic scatter is reduced by excluding $^{2}H$ values, overlap between δO18 values returned from twigs and the deepest soil sample at Site 3 is strongly apparent, supporting the interpretation that trees are utilising moisture from a range of depths in the unsaturated portion of the soil profile including utilisation of deeper soil moisture sources including groundwater perched in river sand (see **Figure 26**). This interpretation is consistent with results of SMP sampling discussed in **Section 3.6**. Representation of downhole soil stable isotope sampling for Site 2 and Site 3 are provided in **Appendix E**.

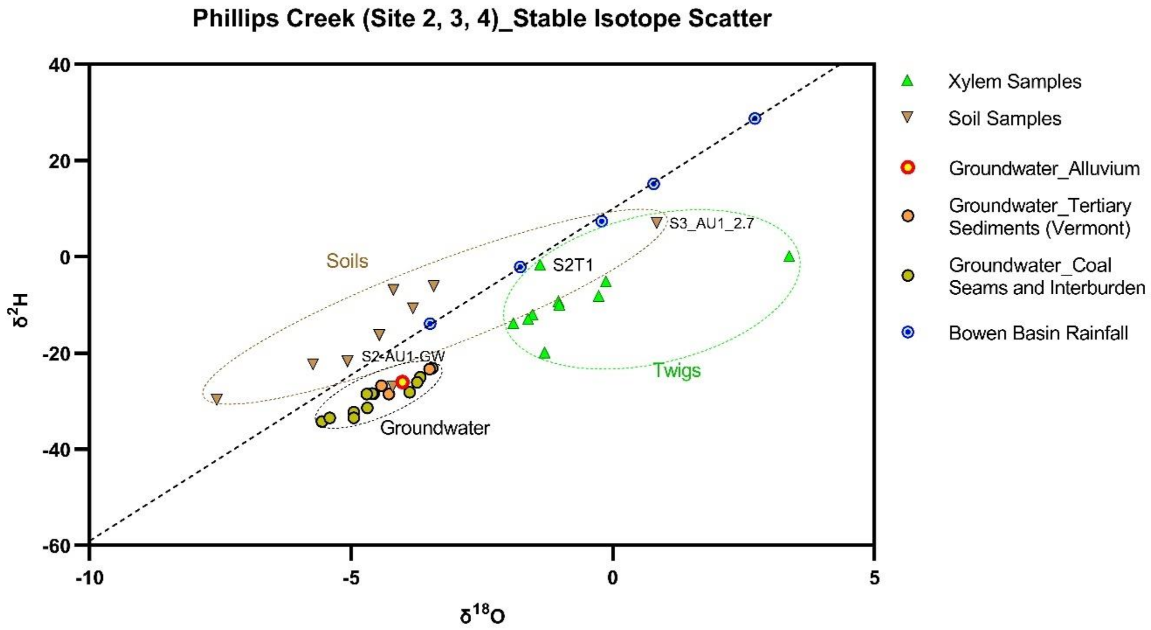



**Figure 25.** Stable isotope scatter from soils, twigs, groundwater and surface water from Phillips Creek Site 2, Site 3 and Site 4 compared to groundwater from coal seams, Tertiary aquifers, and alluvial sources. LMWL is indicated by the dashed line.

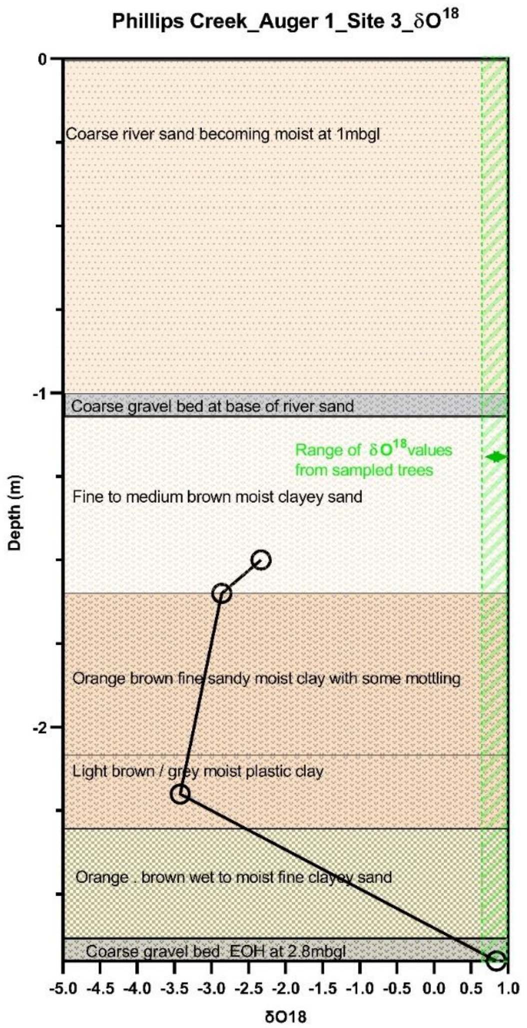



**Figure 26.** Downhole δO18 profile for Auger 1 at GDE Site 3, showing general offset in δO18 values between twigs and soils with a zone of overlap at 2.5mbgl.

#### 4.3.5 Tertiary Residuals (Site 1 and Site 5)

Lack of evidence for groundwater utilisation from LWP measurements in Site 1 and Site 5, located on Tertiary residual surfaces meant soil sampling was not completed. Isotopic data from twig samples and groundwater samples is presented in **Figure 27** demonstrating some separation between the cluster of values defined by groundwater from the cluster defining the twig samples. Consistent with results from LWP sampling, there is no indication for any utilisation of groundwater by trees at this locality. The similarity between precipitation offset of twigs at Site 1 and groundwater previously described in **Section 4.3.3** indicates trees are utilising soil moisture derived from precipitation which has been subject to a similar degree of evaporative evolution to groundwater. Soil moisture is however isotopically heavier than groundwater due to differences in rainfall sources.

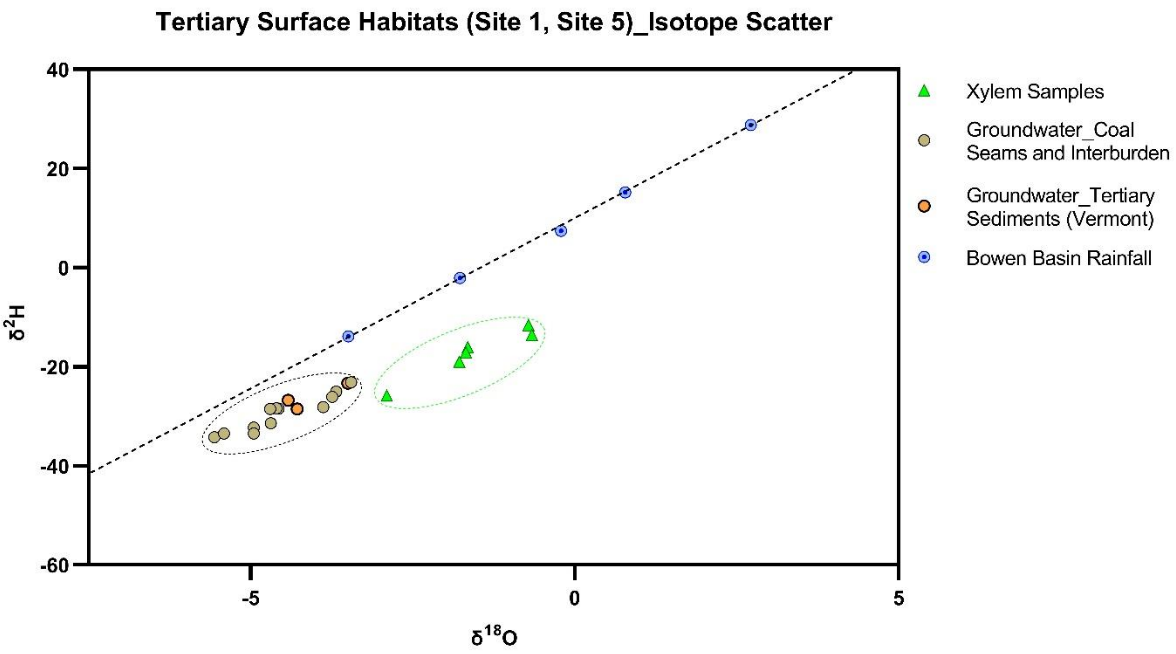



**Figure 27.** Stable isotope scatter plot for groundwater and twig samples from sites on Tertiary residuals (Site 1 and Site 5).

#### 4.3.6 One Mile Creek (Site 6 and Site 7)

Stable isotope results from Site 6 and Site 7 are provided in **Figure 28**, showing a clear separation of clusters forming the regional groundwater values and twig xylem samples. Soils, twigs, and surface water samples can all be placed into a single broad cluster which indicates some hydrological linkage may occur between the three datasets. There is no indication of any groundwater interaction at either Site 6 or Site 7 and there is no indication that trees at either of these sites represent a TGDE. This is consistent with the results of the LWP and SMP sampling completed at these sites (**Section 4.1** and **Section 4.2**). Downhole δO18 profiling for One Mile Creek is provided in **Appendix B**.

#### 4.3.7 Hughes Creek (Site 8 and Site 9)

Stable isotope results from Hughes Creek Site 8 and Site 9 are shown in **Figure 29**. The data shows clear separation of the clusters which form the regional groundwater values and twig xylem samples. Limited isotopic sampling of soils was undertaken at these localities although a lack of overlap between twigs and samples from deeper portions of the soil profile suggest shallower soil moisture sources are being utilised. There is no indication of any groundwater interaction at either Site 8 or Site 9 and there is no indication that these sites represent TGDEs. This is consistent with the results of the LWP and SMP sampling completed at these sites (**Section 4.1** and **Section 4.2**). Downhole δO18 profiling for Hughes Creek Site 9 is provided in **Appendix E**.

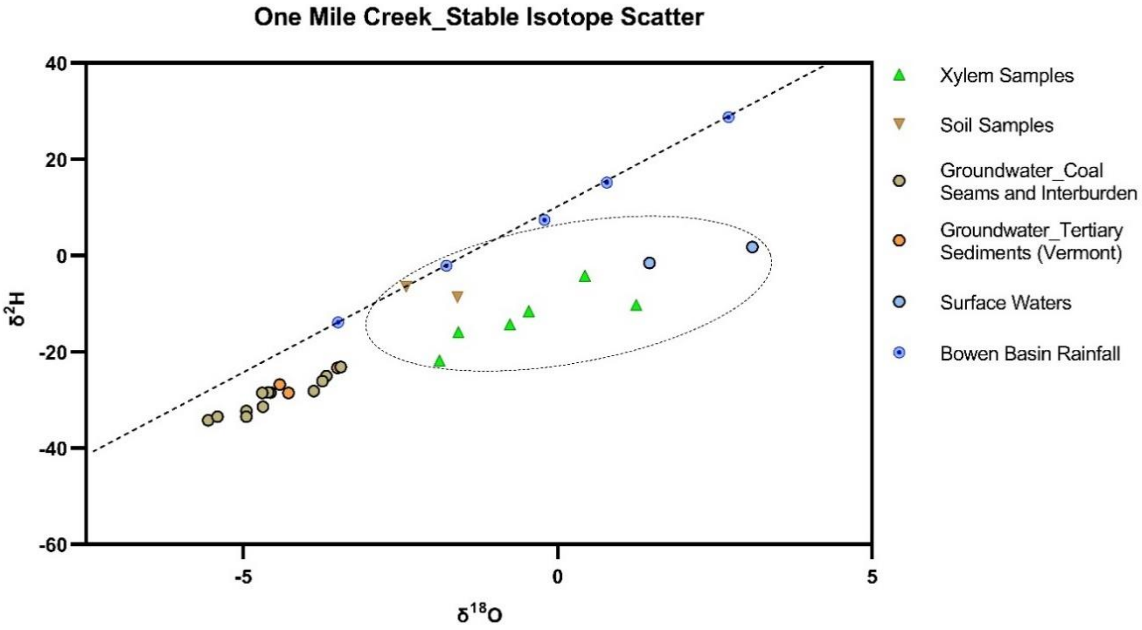



**Figure 28.** Stable isotope scatters for Site 6 and Site 7 (One Mile Creek) with the LMWL indicated by black dashed line. The separation of clusters formed by groundwater samples with a broad cluster defined by xylem samples, soil samples and surface water samples is notable.

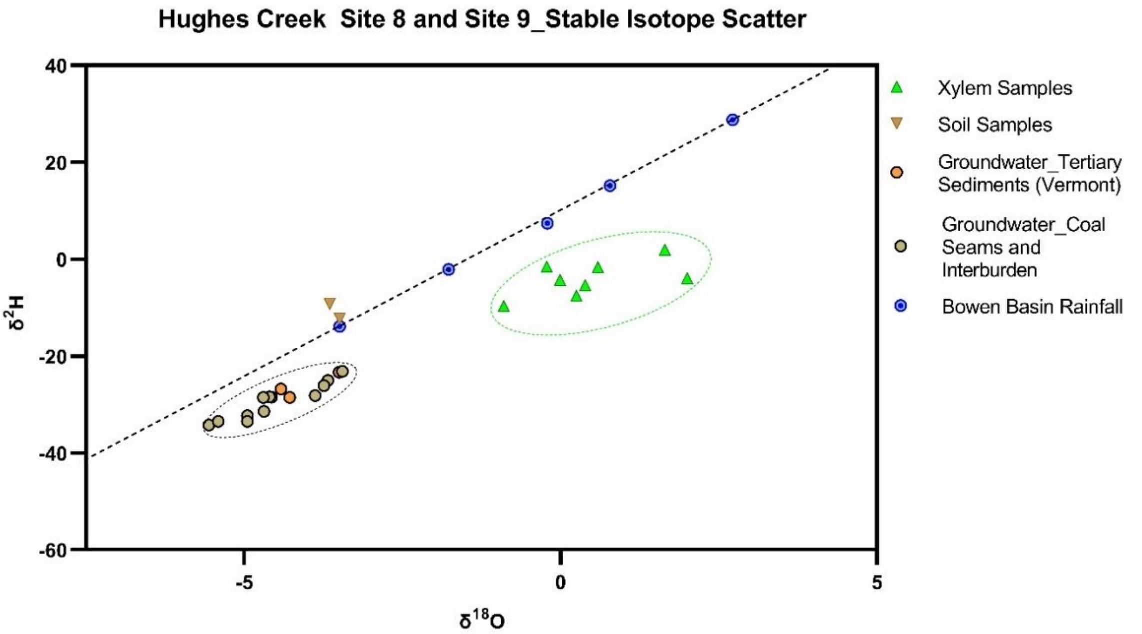



**Figure 29.** Stable isotope scatters for Site 8 and Site 9 (Hughes Creek) with the LMWL indicated by black dashed line. The separation of the cluster formed by groundwater samples and the cluster defined by xylem samples is clearly apparent.

#### *4.3.8 Boomerang Creek (Site 10, Site 11 and Site 12)*

Stable isotope results from Boomerang Creek Site 10, Site 11 and Site 13 are shown in **Figure 30**. The data shows a broad scatter of isotopically enriched twig samples, which are separated from the cluster formed by groundwater, though soil samples overlap with both twigs and groundwater. Downhole δO18 profiling for Hughes Creek Sites (provided in **Appendix E**) provides limited indication of moisture utilisation from any consistent region of the soil profile and it is expected that trees are utilising moisture opportunistically from soil horizons where it is locally most available. Consistent with results of the LWP and SMP sampling, there is no indication that trees are utilising groundwater to any degree at sites located on Boomerang Creek.

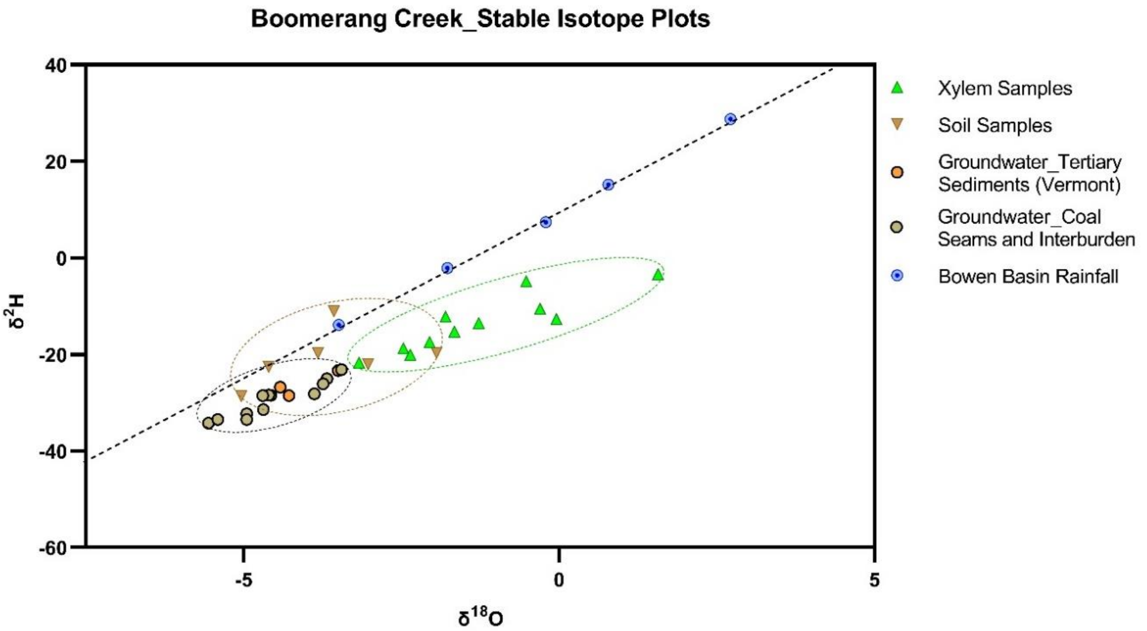



**Figure 30.** Stable isotope scatters for samples from Site 10, Site 11 and Site 12 with the LMWL indicated by black dashed line showing separation of twig xylem and groundwater clusters and overlap with soil samples.

#### *4.3.9 Boomerang Creek Wetland (Site 13)*

Stable isotope results from the Boomerang Creek wetland (Site 13) are shown in **Figure 31**, showing clear separation of the clusters which form groundwater from twig xylem samples. There is also clear overlap between twig xylem and soil samples, and extreme evaporative enrichment of the surface water sample, with twigs and surface water falling on a similar evaporative trendline. **Figure 32** provides a downhole δO18 profile for the auger completed at the locality, demonstrating overlap between twig xylem and soil stable isotope values in the upper 1.5m of the soil profile. There is also extreme isotopic enrichment of moisture values in some soil horizons suggesting interaction with evaporatively enriched surface waters. Tree roots recorded at 3.0 and 3.7mbgl suggest a dimorphic root system where trees can vary the portion of the soil profile from which moisture is being extracted dependant on seasonal availability. For the Boomerang Creek wetland site, there is no indication that trees are utilising groundwater to any degree and transpiration is supported by moisture sourced from unsaturated regions of the soil profile, which vary dependent on seasonal availability. Furthermore, the extreme isotopic enrichment of the surface water sample indicates a clear lack of exchange between groundwaters and surface water, excluding the site as an AGDE.

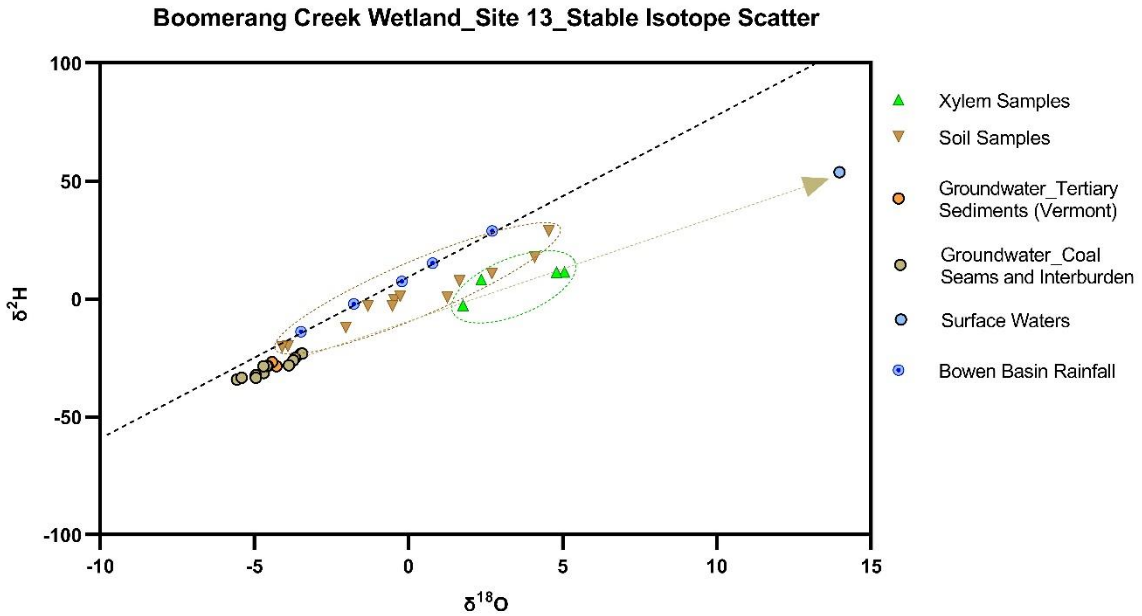



**Figure 31.** Stable isotope biplot for Boomerang Creek Wetland Site 13 comparing groundwater, twig xylem, soil and surface water isotopic samples with LMWL indicated by black dashed line. Clear separation of stable isotope values of twigs and groundwater with overlap of soil samples is clearly indicated.

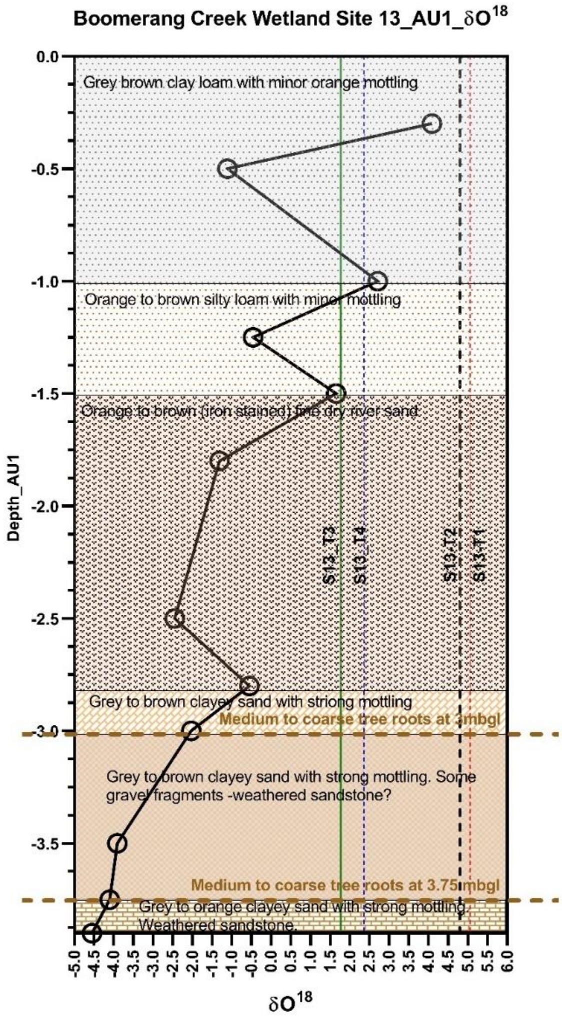



**Figure 32.** Downhole stable isotope profile for auger S13_AU1, showing overlap between stable isotope values of twig xylem and soils in the upper 1.5m of the soil profile.

# 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 Site is a consistent lack of well-developed alluvial deposits, with only thin slivers attenuating along the larger drainage lines of Phillips Creeks. 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 17.4 to 38.01 mbgl (excluding MB31 which is up-gradient from the Saraji operation), roughly comparable to groundwater levels measured in the Tertiary sediments which range from 17.02 to 28.2 mbgl (excluding MB37 which is also up gradient). SWLs for monitoring bores installed in the alluvium range from 7.45 to 13.2mbgl, although most monitoring bores are dry. Based on differences in 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.

Salinity of the groundwater units is highly variable, ranging from 873 µS/cm to 20 438 µS/cm in groundwater held in alluvial sediments, 1546 µS/cm to 30756 µS/cm within the Tertiary groundwater systems, and 969 µS/cm to 9864 µS/cm in the Permian coal seams. The relatively fresh nature of the Tertiary groundwater system at the Philips Creek monitoring bore (1546 µS/cm at MB35) does indicate groundwater recharge is likely to be occurring from downward infiltration of rainfall or flood surface waters. Riparian vegetation on Phillips Creek will be seasonally utilising this downward percolating groundwater that forms the hydraulic linkage between alluvial and Tertiary groundwater systems. There is also a clear indication from groundwater sampled in Phillips Creek Site 2 auger hole (S2_AU1) that perched groundwater occurs in the Phillips Creek alluvium, which has capacity to provide a source of seasonal groundwater to support TGDE function, and that this will be discontinuous along the creek channel. Auger sampling also suggests that there are no other drainage systems in the Project Site with similar capacity to host shallow groundwater in well-developed alluvial deposits.

Salinity plays a significant role in determining the suitability of groundwater to support ecological processes, including its capacity to support TGDEs. The salinity of groundwater recorded in most monitoring bores installed in Tertiary sediments, alluvium and Permian coal seams does not preclude its utilisation by terrestrial vegetation (except maybe for MB34 at 30756s µS/cm) and groundwater utilisation by vegetation will be limited by groundwater depth rather than salinity. There will however unlikely be any significant investment in deep root architecture when groundwater quality at depth provides only an extremely marginal moisture resource due to salinity constraints. 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 the depth of the groundwater resource and salinity in some localities, 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 channel of Phillips Creek with deeper channel incision, where groundwater perched in alluvium may be closer to the surface, and sufficiently fresh to stimulate penetration of tree roots to the depth of the water table. The larger drainage channels also comprise a more significant proportion or forest red gum which is known to have deeper sinker roots which penetrate to depths of at least 15m (Horner 2009). Forest red gum is much more likely to demonstrate groundwater dependence / utilisation than poplar box which is the dominant species across residual land surfaces, and shallow rooted Melaleucas which fringe both Hughes and Boomerang Creeks.

## 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**), the following conclusion have been regarding groundwater dependence of vegetation in the assessment area:

1. Phillips Creek has capacity to support groundwater dependent vegetation in the assessment area. The narrow strip of alluvium associated with Phillips Creek has capacity to host variable quantities of fresh groundwater, both in riverbed sands and the fringing alluvial terraces, on a seasonal basis. Phillips creek represents a TGDE where groundwater dependence varies on a seasonal basis with greatest groundwater usage occurring post seasonal flood recharge events. There is no indication that Phillips Creek represents an AGDE, consistent with the assessment completed for the Lake Vermont Project (3d Environmental 2022).
2. Vegetation on Tertiary plains, typically RE11.5.3, has limited potential for groundwater dependency, due to both the shallow rooted nature of the dominant poplar box and brigalow and the significant depth to the groundwater table. This lack of groundwater dependency is confirmed in LWP and stable isotope analysis.
3. The One Mile Creek catchment contains both forest red gum habitats fringing narrow drainage lines (RE11.3.25) as well as fringing poplar box woodlands (RE11.5.3). While LWP values indicate high water availability, auger profiling and associated SMP measurement indicate high LWP values can be accommodated by moisture in the upper 2.5m of the soil profile, which is further supported by stable isotope analysis. Vegetation fringing One Mile Creek and the adjacent woodland does not meet the hydrological criteria for a TGDE.
4. Hughes Creek has a shallow veneer of sand over weathered Permian sedimentary rocks which are exposed in the stream channel, with depth of alluvium increasing downstream. There is no shallow groundwater reported in the alluvium along Hughes Creek and SMP measurements from Site 9 (S9_AU1) indicate that the high moisture availability evident in LWPs can readily be accommodated in the upper 2.5m (unsaturated portion) of the soil profile. This assessment is further supported by stable isotope values reported from twig samples. Vegetation fringing Hughes Creek and adjacent woodlands do not meet the ecological or hydrological criteria for a TGDE at the localities sampled. However, GDE assessments completed for the Lake Vermont Project (3d Environmental 2022a) indicate that downstream, alluvium thickens, and perched groundwater is seasonally present at the base of the creek alluvium. Therefore, downstream from Site 9 toward the Isaac River as the creek alluvium thickens, there is increased capacity to host perched groundwater and the Hughes Creek riparian system transitions into a TGDE. There is no precise location on Hughes Creek that indicates where the TGDE starts, and it is likely to be transitional over several hundred meters to kilometres.

5. Boomerang Creek has relatively low LWP values which suggests an unlikelihood that riparian vegetation is utilising groundwater to any significant degree. SMP measurements indicate moisture requirements of riparian vegetation can be met in the upper 2.5m of the soil profile, further supported by the enriched nature of twig xylem stable isotope values. Vegetation fringing Boomerang Creek within EPC837 does not meet the hydrological or ecological criteria for a TGDE. A small TGDE intrusion extends into EPC837 from the east, identified from GDE assessments completed in conjunction with the Lake Vermont - Meadowbrook Project (3d Environmental 2022). This transition to a TGDE on Boomerang Creek toward the east accompanies a downstream thickening and widening of the alluvial landform.
6. The Boomerang Creek wetland assessed at Site 13 is a surface feature and there is no indication of any hydrological linkage between surface waters and groundwater. High LWP values reported from riparian vegetation at the wetland can be accommodated in the upper 4.0m of the soil profile, and stable isotope values of twigs suggest utilisation of evaporatively enriched moisture from either surface water or the upper soil profile. Vegetation fringing the Boomerang Creek wetland does not meet the hydrological or ecological criteria for either a TGDE or AGDE.

The watercourse associated with Phillips Creek defines a narrow flood channel flanked by discontinuous alluvial terraces confined between gentle Tertiary rises and plains. Groundwater is perched discontinuously in fluvial sands beneath the sandy creek bed and residual, isotopically variable surface water from seasonal flows extends as groundwater laterally into the adjacent alluvial terraces. This confined alluvial system which includes both the direct drainage channel, and the associated alluvial terraces hosts s 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 groundwater system. In this sense, these narrow alluvial aquifers are considered seasonal features with riparian trees demonstrating facultative dependence on the groundwater resource, with a shift to utilisation of soil moisture when groundwater reserves are depleted. The seasonally variable alluvial groundwater system defined by Phillips Creek is hydraulically connected to groundwater couched in the Tertiary sediments through preferential flow and seepage.

Recharge of the Phillips Creek alluvial groundwater system occurs 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 seepage / baseflow. The mapping of a TGDE on Phillips Creek is consistent with the Lake Vermont - Meadowbrook GDE assessment (3d Environmental 2022) with spatial representation of the extent of TGDEs in EPC837 shown in **Figure 33**, extending eastward toward the Isaac River. The inferred position for the transition of Hughes Creek to a TGDE is also indicated, intruding slightly into the Project Site from the east with a more extensive downstream TGDE expression. It should be noted that east of The Project site, the characterisation and mapping of TGDEs was completed as a component of the Lake Vermont -Meadowbrook project (3d Environmental 2022), which has allowed from a more comprehensive understanding of the potential impacts to GDEs occurring outside The Project area, particularly downstream along watercourses where TGDEs have been identified.

A hydro-ecological conceptualisation of Phillips Creek at Site 2 is shown in **Figure 34,** which is consistent with the conceptualisation developed for downstream reaches of Hughes Creek where the creek system is confirmed to be a TGDE in the Lake Vermont Project GDE Assessment (3d Environmental 2022a).

**Figure 35** also presents a hydro-ecological conceptualisation for the surface expression wetland at Site 13 (Boomerang Creek Wetland). Based on stable isotope analysis of soils, twigs and surface waters, this wetland and associated smaller floodplain wetlands are surface water features which are recharge by rainfall and overbank flow during flooding, 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.

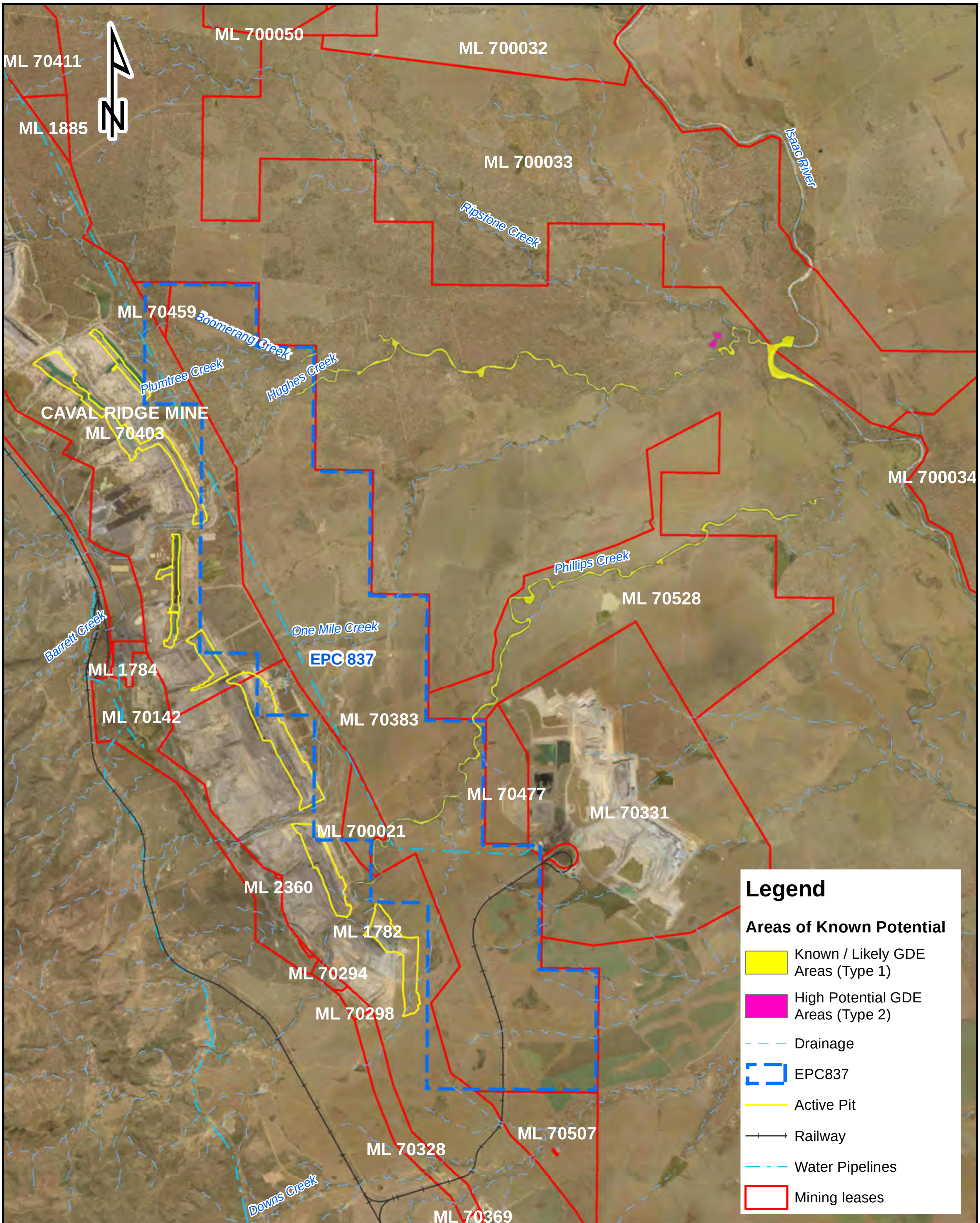



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**Figure 33.** Location of GDE areas based on field evidence including data from the Lake Vermont Project

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**Figure 34a. Phillips Creek - Terrestrial GDE - Dry Season**

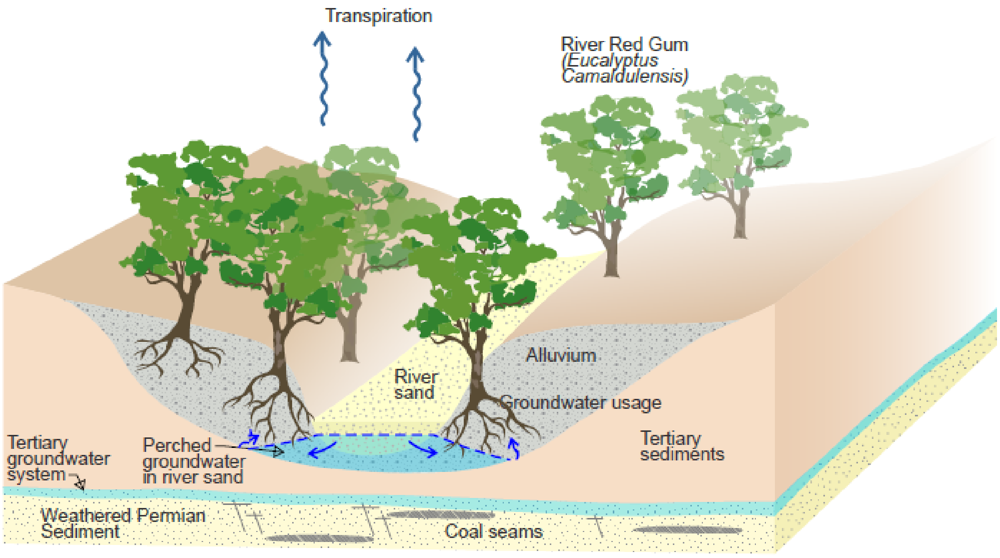
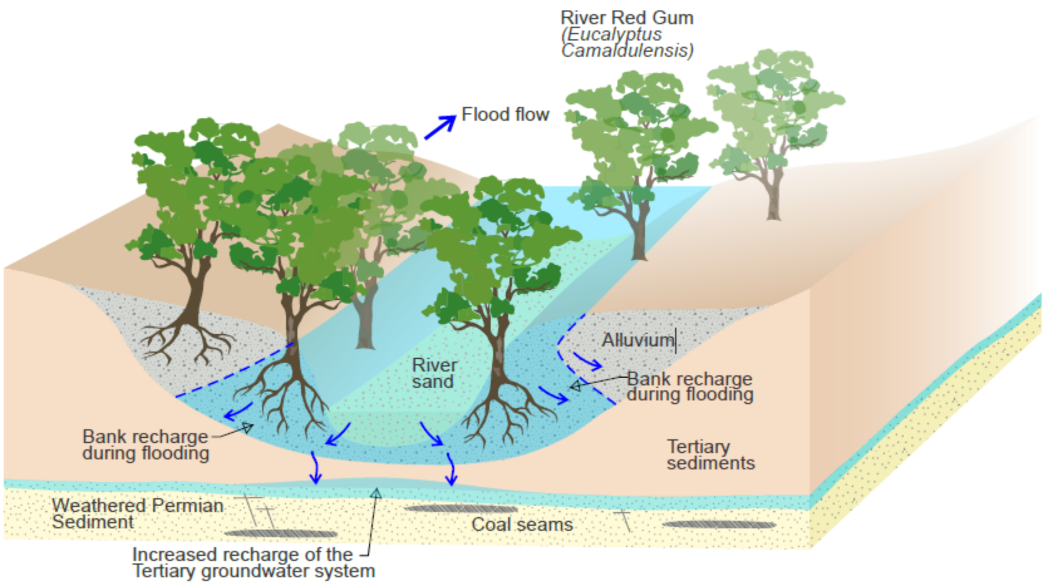



**Figure 34b. Phillips Creek - Terrestrial GDE - Wet Season Flood**



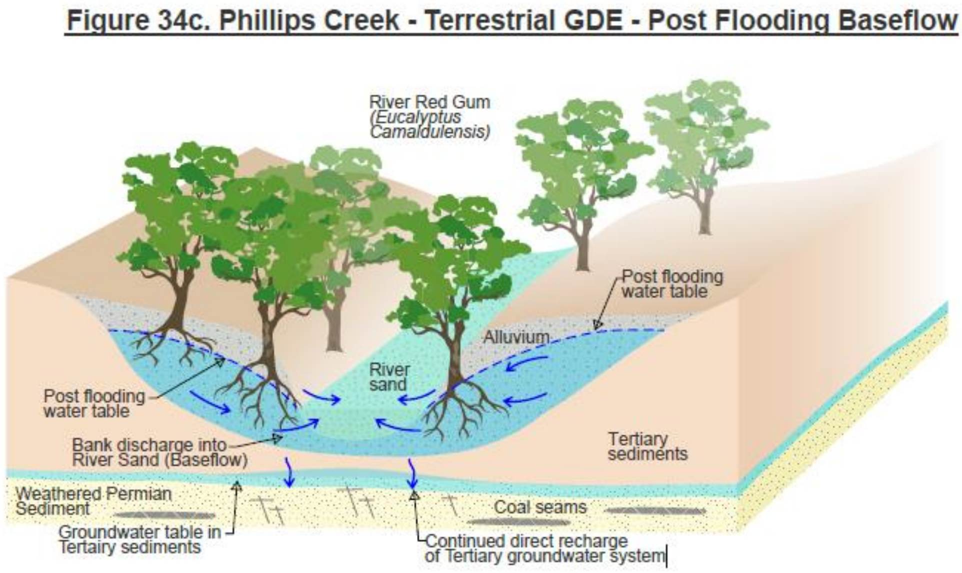



**Figure 34.** Hydro-ecological conceptualisation of the Phillips Creek TGDE system, based on data collected at Site 2, Site 3 and Site 4. Figure 34a shows dry season ecological function with Figure 34b showing wet season recharge of the perched alluvial groundwater table, followed by post flooding baseflow (Figure 34c). The alluvial groundwater system is hydraulically disconnected from the regional Tertiary groundwater system.

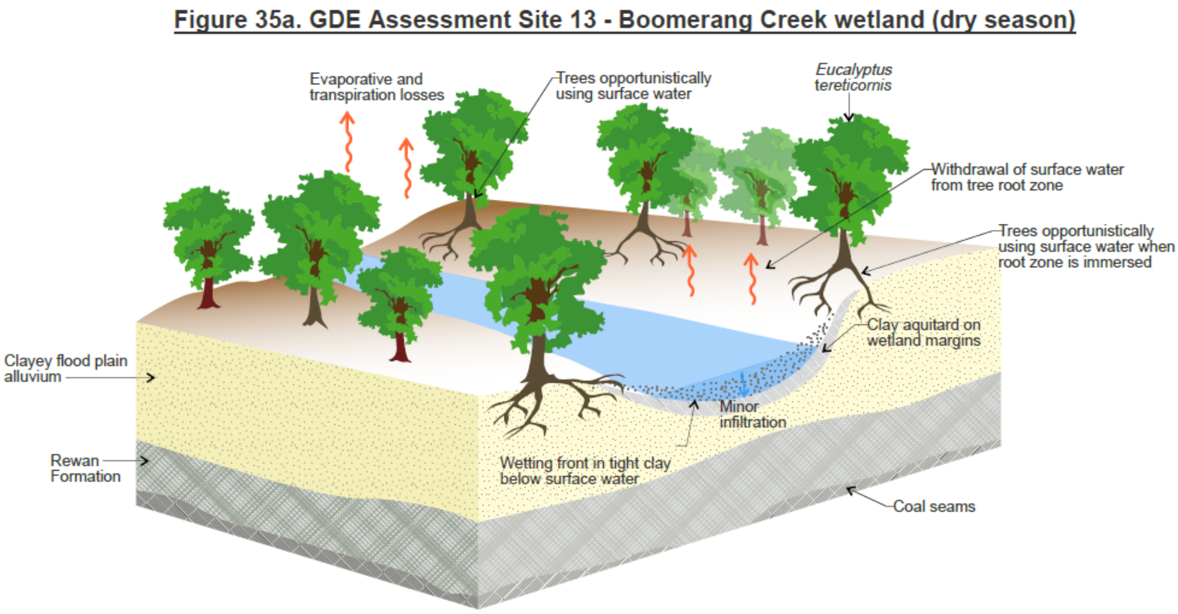


Figure 35b. GDE Assessment Site 13 - Boomerang Creek wetland (wet season)

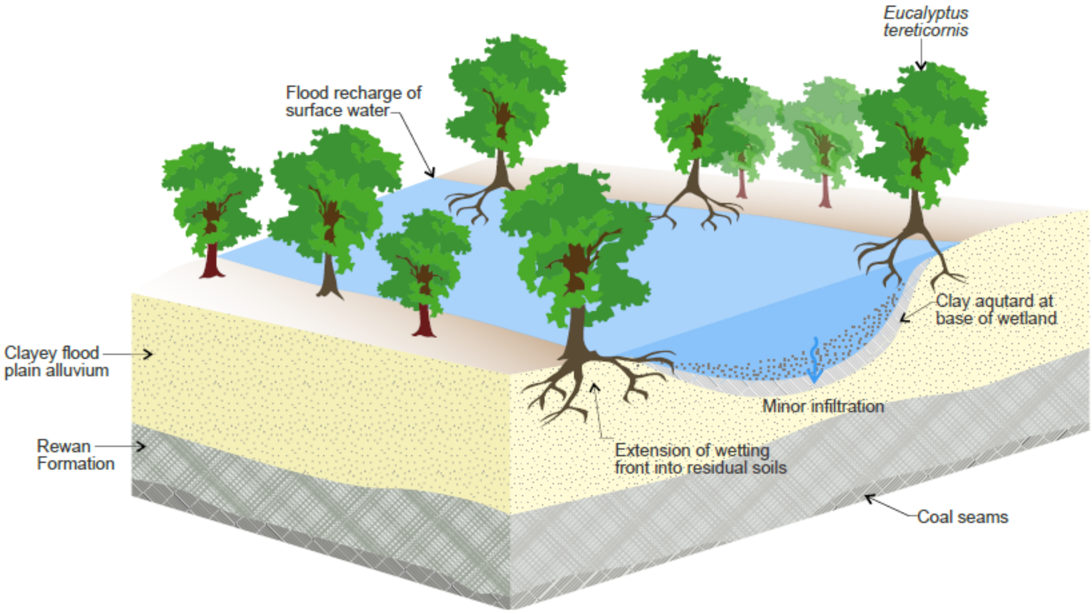



**Figure 35.** Hydro-ecological conceptualisation of the wetland feature at GDE Assessment Site 2 (and Site 10) showing dry season (Figure 35a) and wet season (Figure 35b). The surface water is perched on a clay aquitard which prevents infiltration.

# 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 are discussed in **Section 6.2**. Measure 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 associated GDEs identified in this report being:

1. A riparian TGDE is associated with the narrow belts of alluvium associated with the incised drainage lines of Phillips Creek in the south of EPC837. TGDEs on Phillips Creek are supported by fresh groundwater that is hosted in recent river alluvium, typically fluvial sands.
2. Riparian TGDEs also extend from the east along Hughes Creek to intrude into the margins of Project Site, although the four sites assessed along Hughes and Boomerang Creeks during this assessment are not considered to represent TGDEs. It is likely that Hughes Creek transitions to a TGDE downstream toward the east, outside the boundary of EPC837 where the alluvium associated with the channel and floodplain thicken and become wider.
3. There is some hydrological linkage between groundwater in the alluvium associated with both Phillips Creek and Hughes Creek and the regional groundwater system associated with Tertiary sediments, and possibly Permian Coal seams. This hydrological linkage is associated with downward percolation of surface flows which recharges the Tertiary and Permian groundwater systems following seasonal flooding and surface flows.
4. There is no identified surface expression of regional groundwater tables in the assessment area and wetland features are recharged by rainfall events and associated overbank 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.

While direct clearing is a tangible impact, other mechanisms of impact that affect GDEs through groundwater drawdown or interference with the natural groundwater regime are more difficult to predict and quantify. In most cases, the severity and extent of impact incurred to GDEs through interference with natural groundwater regimes can only be ascertained with dedicated longer-term monitoring which considers both the groundwater and ecological aspects of GDE function.

#### *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 eastwards into EPC837 underneath the catchment area of Boomerang / Hughes Creek where GDEs were not identified.

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

The predicted groundwater drawdown (>2m) associated with development of the SEMLP is provided in **Figure 36** which shows the predicted maximum extent of Project related drawdown in Tertiary and alluvial sediments associated with proposed underground and open cut mining operations (from SLR Groundwater Model 2022). Based on groundwater drawdown shown in models provided in **Figure 36**, there is no interaction between modelled groundwater drawdown and the TGDE identified on Phillips Creek.

**Figure 36** indicates that groundwater drawdown in the Tertiary sediments does extend up to 4km east of the Project Site outside ML70383 (contiguous with MDL429 from the Lake Vermont Mine) with groundwater drawdown of between 2 to 5m extending 1.6km to the east of the Project Site drawdown of 1-2m a further 1.4km below Hughes Creek. Based on groundwater information in the Lake Vermont - Meadowbrook GDE assessment report (3d Environmental 2022), the alluvium that hosts GDEs fringing Hughes Creek may be connected to the Tertiary groundwater system through downward infiltration and leakage of perched groundwater, and enhanced infiltration from the perched aquifer may be associated with sandy alluvial sediments or preferential flow-paths.

Impacts of drawdown in the Tertiary groundwater system may be propagated into alluvium wherever areas of enhanced potential for downward drainage occur, most likely through sandy sediments with increased hydraulic conductivity or increased density of preferential flow paths. Impacts could manifest in isolated pockets of groundwater within the Quaternary alluvium that is not captured at model scale, or where seasonal groundwater within the alluvium would have enhanced potential for downward infiltration due to a lower groundwater level within the underlying Tertiary sediments.

The impact of any increased drawdown in the alluvium is predicted to be minor to insignificant because:

1. The alluvial groundwater system associated with Hughes Creek is discontinuous along the length of the creek channel (3d Environmental 2022) and riparian trees associated with the watercourse feature 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 TGDEs on Phillips Creek is recharged by surface flows and flooding which provides the dominant driver to support riparian ecological function.

### *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 TGDEs on Hughes Creek are regulated by surface flows rather than upward propagation of groundwater from regional aquifers. Surface flows have a direct influence on groundwater volume fluctuations and are more fully discussed in **Section 6.2.4**. There may be an increased rate of drainage / drying and reduction in the volume of the alluvial groundwater system that supports TGDEs wherever increased surface infiltration coincides with areas of drawdown in either the Tertiary or alluvial sediments. The combined impact of groundwater drawdown with potential for reduced surface flow volumes (discussed in **Section 6.2.4)** has potential to reduce the volume of perched aquifers supporting TGDEs. Potential for impact occurs on reaches of Hughes Creek downstream from the Project Site to the east of MLA70383. Any impact would however be subtle as associated groundwater dependent species including forest red gum and weeping tea tree are adapted to periods of seasonal wetting and drying and can utilise a range of moisture sources dependent on availability (see **Section 2.2.3**). Any impact is most likely to manifest during periods of prolonged drought where the perched groundwater table remains depressed (or totally depleted) for extended periods.

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

Alluvium (2022) identifies that the longitudinal profile of Hughes Creek for approximately 4.9 km of the waterway will be affected by six subsided panels with a diversion on Hughes Creek contributing to approximately 1.75 km of the affected reach. Subsidence will also affect upstream reaches of Plumtree and Boomerang Creeks, with subsidence occurring sometime between 2026 and 2028 upstream from the confluence of Hughes and Boomerang Creek. While subsidence areas are outside the mapped TGDE extent on Hughes Creek, there remains the capacity for alteration to downstream surface flows and associated sediment transport which may impact the integrity of mapped TGDEs. Alluvium (2022) identifies the potential impacts of the SEMLP as follows:

- Residual pools will occur in parts of the landscape post-subsidence (without erosion or management intervention, which is not modelled) and will account for the attenuation and reduction in flow volume leaving the Project Site.
- Downstream of the mine plan, Hughes and Boomerang Creek will potentially be subject to bedload starvation for a period, which would elevate the risk of channel and bank erosion.
- Erosion would persist until the bedload overwhelms the subsidence void upstream. The response of Hughes Creek is likely to produce some impact downstream of the mine footprint through to Boomerang Creek confluence for a period of years to possibly decades.

There is therefore potential for these impacts to be propagated downstream from the Project Site to impact mapped TGDEs associated with Hughes Creek, leading to destabilisation of the supporting bedform, and reduced surface flows potentially reducing capacity for recharge of groundwater perched in the alluvium. There has already been a considerable excision of the combined catchments of Hughes, Boomerang and Plumtree Creek during development of the Saraji Mine, and potential loss or alteration of the catchment area through subsidence is additional to prior impacts.

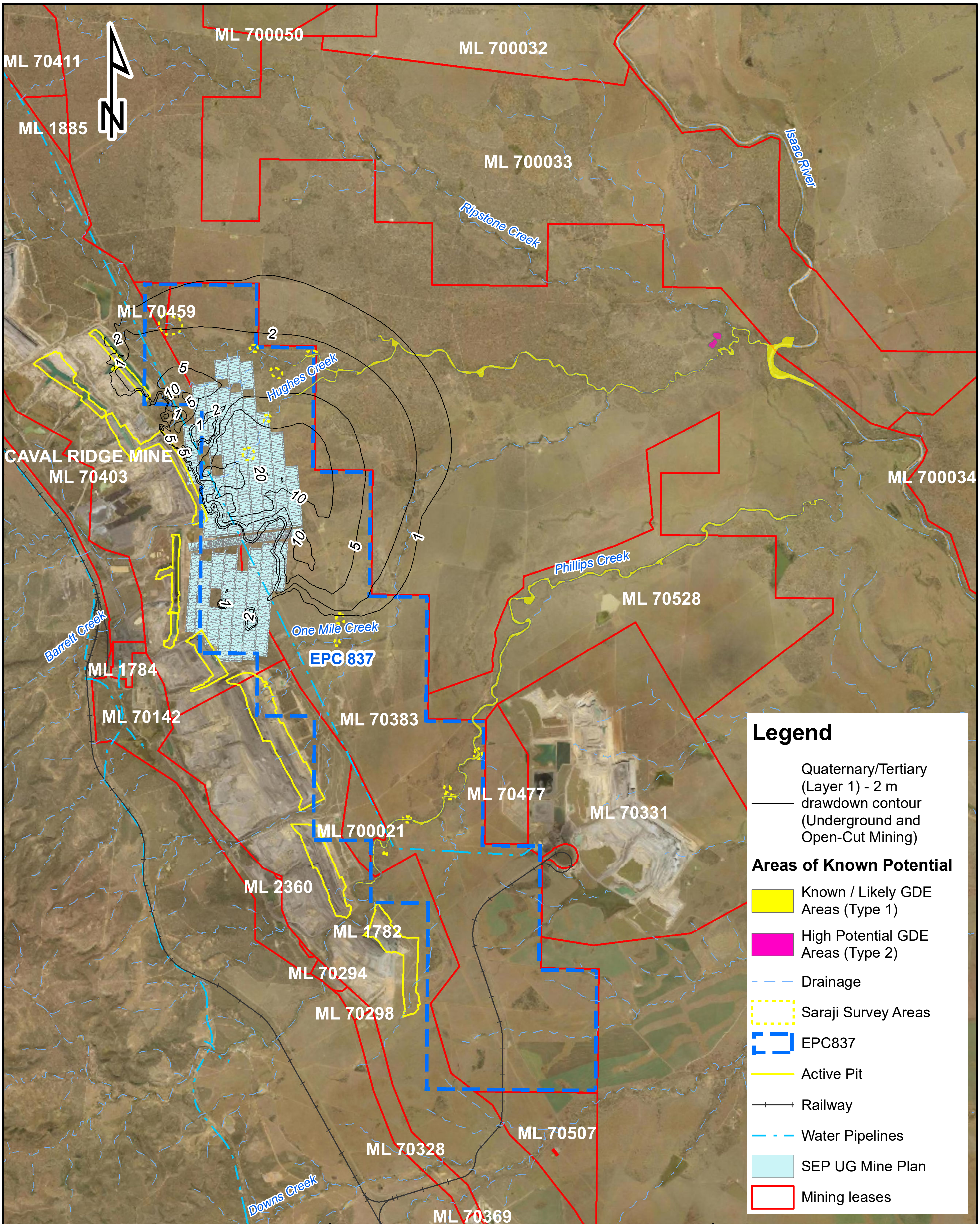



**Figure 35.** Location of field verified GDE areas relative to predicted groundwater drawdown in Tertiary sediments.

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

A Water Management System has been developed for the Project which proposes mine affected water (MAW) storages including a Process Water Dam (PWD), collection dams for each of the Project process areas, and a Raw Water Dam (RWD) (Aecom 2023). A probabilistic Water Balance Model (WBM) was developed to assess the proposed WMS system's performance in a range of current and projected climatic conditions and water storage capacities were assigned to each structure to ensure that;

- Uncontrolled releases of MAW to the receiving environment are minimised
- The regulated structures accommodate the extreme storm storage and design storage allowance volumes.

BMA will be seeking authority and licence conditions to conduct the controlled release of MAW from the PWD, with an indicative location for controlled release of MAW on Boomerang Creek adjacent to the proposed PWD. A simple dilution assessment demonstrated that the water quality objectives for downstream waterways are achievable, and managed releases that comply with predefined conditions reduces the likelihood that uncontrolled releases, which may potentially lead to significant downstream ecological impacts, will not occur.

Rock spoil is also expected to generate low salinity rainfall runoff and seepage 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 detail 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 controlled releases, it is considered that there is low risk of impact to the quality of alluvial groundwater systems which support GDEs.

### 6.3 Cumulative Impacts

The Lake Vermont - Meadowbrook Project is centred on MDL429 and MDL303 which are tenements to the immediate east of MLA70387. Modelled drawdown associated with this project will result in drawdown within the Tertiary groundwater system, with modelling indicating >20m of drawdown is propagated beneath reaches of Hughes and Phillips Creeks where TGDEs have been identified and mapped. The risk that the Lake Vermont - Meadowbrook Project poses to TGDEs has been assessed as 'Low' to 'Insignificant' (3d Environmental 2022).

The interaction of modelled drawdown on Tertiary and alluvial groundwater systems has potential to compound potential impacts associated with both the Lake Vermont and Saraji East projects. Based on groundwater modelling from the Lake Vermont Project (JBT 2022), groundwater drawdown in the alluvium and Tertiary sediments will directly interact with drawdown modelled for the Project (SLR 2022). In conjunction with the potential for reduced flow volumes along Hughes Creek due to mining related subsidence, the interaction between the two projects will increase the risk of impact to mapped GDEs associated with Hughes Creek east of EPC837.

## 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, largely due to:

1. The resilience of facultative phreatophytes that typify GDEs and their capacity to utilise moisture from a range of sources including groundwater, soil moisture and surface water.
2. The alluvial groundwater system that supports TGDEs is supported and recharged by surface flows, which will not be significantly 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*

A project WMS has been developed (Aecom 2023) which will be operational during all stages of the Project. Implementation of the MWS will be directly applicable to management of impacts to GDEs that may occur due to uncontrolled release of MAW, with potential to impact the chemical integrity of the perched groundwater system which supports TGDEs on Hughes Creek to the east of the Project site. Specific objectives of the WMS relevant to the management of impact to GDEs will be:

- **Segregation of waters based on source and integrity**. Passively divert clean runoff beyond the mine WMS MAW dams (and other mine infrastructure), such that non-MAW runoff remains undisturbed and does not increase volumes of MAW in storage.
- **Minimise volumes of MAW generated and stored onsite:** Potential volumes of MAW generated onsite will be minimised wherever possible and stored volumes of MAW will be preferentially sourced to satisfy those Project water demands for which reuse of MAW is suitable.
- **Containment and release of MAW:** A conservative approach has been taken towards controlled and uncontrolled releases of MAW from the Project using historical climate data and under a set of assumed operational rules, ensuring storage capacities are sufficient to minimise uncontrolled discharge of MAW to the environment.
- **Water Transfer System:** The water transfer network provides the ability to move MAW from the various collection dams to the PWD, as well as the subsequent transfer of MAW to the various consumptive demand points.

**REMP:** Local receiving watercourses represent a ‘slightly to moderately disturbed’ (SMD) aquatic habitat. Receiving environment water quality data collected as part of BMA’s receiving environment monitoring program (REMP) indicates water quality is above the guideline for most parameters (Aecom 2023). Ongoing monitoring of water quality to the receiving environment under the REMP will be continued throughout the operation of the mining project.

### *6.4.2 Groundwater monitoring*

A comprehensive groundwater monitoring network including monitoring bores screened in major groundwater units including the regional Tertiary and Coal Seam aquifers, and alluvial groundwater systems will be maintained for the duration of the Project. 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 TGDEs on Hughes Creek, off lease to the east of EPC837 where impact to mapped TGDEs may potentially be propagated. This will need to complement any GDE monitoring that is undertaken on Hughes Creek under approval conditions for the Lake Vermont - Meadowbrook project. This baseline data collection would form the basis of a 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 TGDEs associated with Hughes Creek downstream and to the east of EPC837 where groundwater drawdown in the Tertiary and Quaternary sediments is predicted and reduced surface flows may occur because of mining related subsidence.
2. 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.
3. 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.

The purpose of the baseline data collection is to provide a basis for detection of future declines in ecological condition of GDEs subject to monitoring that can be linked to mining related activities. 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) detect 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 TGDE areas 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. For example, RE11.3.25 associated with Phillips Creek is classified Essential Habitat for threatened wildlife listed under either the NC Act or other prescribed environmental matters under the EPBC Act. The corridor of Hughes Creek is mapped as Essential Habitat for Koala, which is 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. 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 operations associated with the SEMLP.

**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. |

| Magnitude | Description |
|---|---|
| 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 the Saraji East Project under a dedicated WMS (Aecom 2023). |
| 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 | Insignificant | Insignificant |
| 2. A total or partial loss or reduction in the volume or pressure of the aquifer being utilised by TGDEs. | 3 | Moderate | Moderate | The alluvial groundwater system that supports TGDEs on Hughes Creek to the east of ML70383 is perched above regional aquifers associated with Tertiary sediments and coal seams. Loss of aquifer pressure in the Tertiary aquifer underlying Hughes Creek may increase downward drainage from creek alluvium into Tertiary sediments resulting in some reduction in volume of the perched aquifer that supports TGDEs. The adaptability of the dominant riparian species to ecological change (see **Section 2.2.3**) would suggest that these impacts will be 'Low' in areas where an aquifer drawdown response is predicted. | 5, 6, 7 | 2 | Low | Low |
| 3. A change in the magnitude and timing of volume fluctuations in the aquifer being utilised by GDEs. | 3 | Low | Low | Volume fluctuations in the perched groundwater system are regulated by surface flows and local surface water infiltration which may be affected by subsidence and reduced surface flows. | 5, 6, 7 | 2 | Low | Low |
| 4. Changes to the interaction between surface flows and | 3 | Moderate | Low | Surface flow volumes in Hughes Creek may be reduced | 5, 6, 7 | 1 | Low | Insignificant |

| Impact Pathway | Pre-mitigated Risk | | | Comments | Management /Mitigation Measures* | Residual Risk Ranking | | |
|---|---|---|---|---|---|---|---|---|
| | Likelihood | Consequence | Risk | | | Likelihood | Consequence | Risk |
| aquifers being utilised by a GDE. | | | | in areas supporting TGDEs to the east of EPC837 due to mining related subsidence. Furthermore, the integrity of the perched groundwater system that supports TGDEs on Hughes Creek may also be compromised by periodically reduced sediment supply resulting in erosion. | | | | |
| 5. 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 if appropriate management measures are applied. | 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 SEMLP on GDEs. Based on the results of the field survey, it is concluded that TGDEs are present on Phillips Creek which passes through the central portion of EPC837. TGDEs identified on Hughes Creek mapped in association with the contiguous Lake Vermont - Meadowbrook Project are also mapped as intruding marginally into EPC837. These TGDEs host variable groundwater volumes and are seasonally recharged via surface flows and flooding.

While there is no specific impediment to tree water use of Tertiary or Permian aquifer based on known salinity values, water held in these aquifers is an unsuitable resource to support GDEs due to a potentiometric surface that is generally >17mbgl, which is significantly below the maximum rooting depth of facultative phreatophytes associated with the major drainage channels in the Project Site. However, groundwater hosted in these units may be closer to the surface where deeply incised creek channels occur, as on Phillips Creek where depth of channel incision is >8m, and to a lesser extent on Hughes and Boomerang Creeks where channel incisions are shallower. In these localities, the Tertiary aquifers may be linked to seasonal groundwater systems hosted in creek alluvium through diffuse seepage and preferential flow, particularly on Phillips Creek where fringing alluvial deposits are well developed. Due to this potential for hydraulic linkage, and the presence of perched groundwater intersected in river sands during auger sampling, the riparian habitats that fringe Phillips Creek (typically RE11.3.25) have been mapped as a TGDE. While TGDEs were not identified in sampling completed on other drainage features assessed in the Project Site, GDE assessments undertaken on the contiguous Lake Vermont tenement (MDL429) to the east identified Hughes Creek as a TGDE which is likely to intrude into the Project Site from the east. In relation to GDEs within the boundaries of the SEMLP, the following points are considered relevant:

1. Field data indicates that Phillips creek is highly likely to function as a TGDE where groundwater dependence varies on a seasonal basis. The highest degree of groundwater usage would occur post seasonal flooding events which recharge groundwater in associated alluvial deposits. There is no indication that Phillips Creek represents an AGDE. The mapping of a TGDE on Phillips Creek is consistent with the Lake Vermont - Meadowbrook GDE assessment completed on contiguous tenements to the east (3d Environmental 2022).
2. Vegetation on Tertiary plains, typically RE11.5.3 and 11.4.9, has limited potential for groundwater dependency, due to both the shallow rooted nature of the dominant poplar box and brigalow and the significant depth to the groundwater table.
3. Vegetation fringing One Mile Creek and adjacent woodland does not meet the hydrological criteria for a TGDE with field assessment confirming that moisture requirements of vegetation are being supported within the unsaturated portion of the soil profile.
4. Vegetation fringing One Mile Creek and adjacent woodlands do not meet the ecological or hydrological criteria for a TGDE with moisture requirements of riparian being supported in the unsaturated portion of the soil profile.
5. Vegetation fringing Hughes Creek within EPC837 does not meet the hydrological or ecological criteria for a TGDE, although a TGDE intrusion may extend into the Project Site from the east, mapped in conjunction with the contiguous Lake Vermont - Meadowbrook

Project. The transition of Hughes Creek into a TGDE is most likely associated with a thickening and widening of creek alluvium eastward toward the Isaac River where there is greater capacity for storage of perched groundwater. Within the Project Site, the alluvial landform hosting Hughes, Boomerang and Plum Tree Creeks is extremely shallow, with outcropping sedimentary basement rock evident in some channel exposures.

6. The Boomerang Creek wetland (assessed at Site 13) is a surface feature and there is no indication of any hydrological linkage between surface waters and groundwater. The Boomerang Creek wetland does not meet the hydrological or ecological criteria for either a TGDE or AGDE.

Impacts of drawdown in the Tertiary groundwater system may be propagated into creek alluvium wherever areas of enhanced potential for downward drainage occur, most likely through sandy sediments with increased hydraulic conductivity or increased density of preferential flow paths. These impacts could manifest in isolated pockets of groundwater within the Quaternary alluvium 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. These potential drawdown impacts have potential to manifest along reaches of Hughes Creek where modelled groundwater drawdown extends well to the east of EPC837 into contiguous Lake Vermont mining tenements. There are no predicted impacts associated with TGDEs on Phillips Creek as groundwater drawdown does not propagate below the stream channel.

The major features of TGDEs associated with Hughes Creek that ameliorate impacts are listed below:

1. There is no evidence from monitoring data that groundwater hosted in Permian coal seams or Tertiary sediments has capacity to propagate upward to interact with alluvial groundwater sources and support GDEs.
2. The groundwater system perched in alluvium that supports TGDEs on Hughes Creek is recharged by surface flows and flooding, providing the dominant driver to support riparian ecological function. Surface flow volumes will be subject to only minor impact because of subsidence, and minor impacts to sediment volumes affecting the channel bedform.
3. Perched groundwater in the alluvium is discontinuous along the length of the creek channel (3d Environmental 2022) and riparian trees associated with the watercourse feature are facultative phreatophytes which have capacity to utilise moisture from multiple sources including soil moisture, surface water and groundwater to support transpiration

Management measures to limit the impact to potential GDEs in vicinity of the Saraji East Mining Lease Project include general operational measures including the WMS and groundwater monitoring program to cover the additional operations. It is also recommended that additional ecological baseline data collection, GDE management and mitigation measures be developed through development of a GDEMMP monitoring program. The monitoring program will need to provide the basis for ongoing management and detection of change that can be linked to mining operations, noting that impacts extend into the tenements of the Lake Vermont-Meadowbrook project, requiring a co-operative approach to implementation of monitoring protocols.

With implementation of management measures, 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 to Insignificant'. 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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# Appendices

## Appendix A – Tree LWP Measurements and Details

| Latitude | Longitude | Time | Tree Number | Species | Height (m) | DBH (cm) | Location relative to watercourse | LWP Sample Time | Xylem Sample Time | LWP (Mpa) | Moisture Availability |
|---|---|---|---|---|---|---|---|---|---|---|---|
| -22.3261 | 148.2915 | 2022-03-09T22:19:55Z | S10_T1 | Eucalyptus camaldulensis | 27 | 83 | 1.5m above and 4m from sandy channel | 5:32 | 10:25 | -1.25 | Low |
| -22.326 | 148.292 | 2022-03-09T22:25:28Z | S10_T2 | Melaleuca fluviatilis | 18 | 40 | On small sandy rise / island in stream channel | 5:39 | 10:29 | -1 | Moderate |
| -22.3262 | 148.2928 | 2022-03-09T22:31:54Z | S10_T3 | Eucalyptus camaldulensis | 25 | 90 | >2.5m above stream channel on T2 terrace. 7m from edge of sandy channel | 5:42 | 10:36 | -1.35 | Low |
| -22.3263 | 148.2929 | 2022-03-09T22:35:37Z | S10_T4 | Melaleuca fluviatilis | 18 | 50 | In central portion of sandy stream channel | 5:45 | 10:41 | -1.15 | Moderate |
| -22.3265 | 148.293 | 2022-03-09T22:37:52Z | S10_T5 | Eucalyptus camaldulensis | 23 | 70 | 3 above and 10m away from sandy stream channel | 5:49 | 10:47 | -0.7 | High |
| -22.3325 | 148.317 | 2022-03-09T23:38:22Z | S11_T1 | Eucalyptus camaldulensis | 20 | 60 | In sandy creek channel | 5:58 | 11:12 | -0.8 | High |
| -22.3328 | 148.3161 | 2022-03-09T23:50:03Z | S11_T2 | Eucalyptus camaldulensis | 25 | 60 | 25m from main creek channel on T2 terrace | 6:01 | 11:16 | -0.9 | Moderate |
| -22.3323 | 148.3158 | 2022-03-09T23:58:45Z | S11_T3 | Eucalyptus camaldulensis | 20 | 70 | In secondary channel 80m from main creek channel | 6:05 | 11:19 | -1.05 | Moderate |
| -22.333 | 148.3164 | 2022-03-10T00:55:55Z | S11_T4 | Melaleuca leucadendra | 25 | 75 | Directly adjacent to main creek channel on inner bench | 6:08 | 11:25 | -0.95 | Moderate |
| -22.334 | 148.334 | 2022-03-10T01:46:56Z | S12_T4 | Eucalyptus camaldulensis | 20 | 115 | In sandy creek channel | 12:11 | 12:15 | -0.975 | Moderate |
| -22.3343 | 148.3325 | 2022-03-10T01:34:36Z | S12_T1 | Eucalyptus camaldulensis | 21 | 85 | In sandy creek channel | 6:16 | 11:55 | -1.11 | Moderate |
| -22.3343 | 148.3327 | 2022-03-10T01:39:09Z | S12_T2 | Melaleuca fluviatilis | 20 | 100 | In sandy creek channel | 6:21 | 11:59 | -0.95 | Moderate |

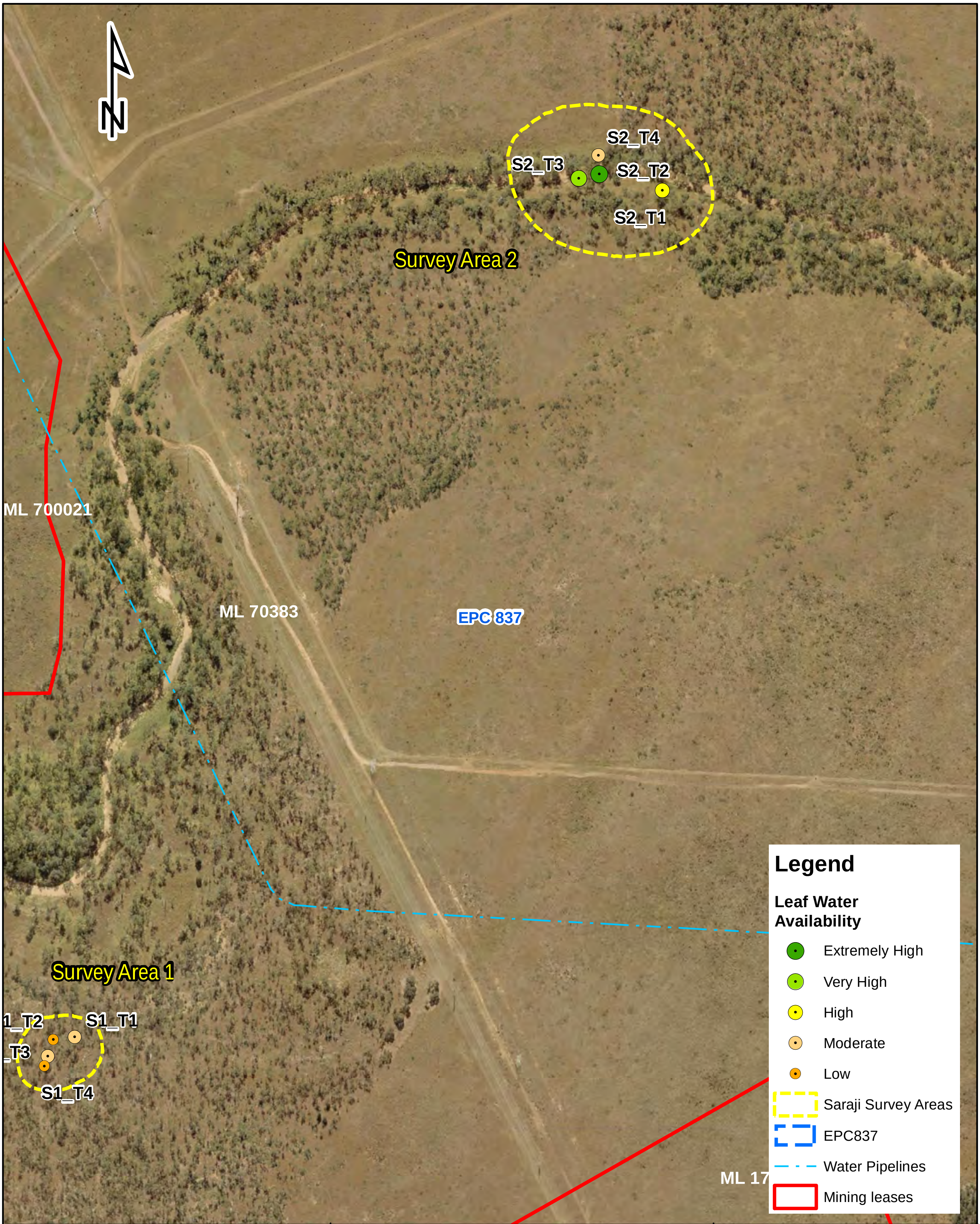
| Latitude | Longitude | Time | Tree Number | Species | Height (m) | DBH (cm) | Location relative to watercourse | LWP Sample Time | Xylem Sample Time | LWP (Mpa) | Moisture Availability |
|---|---|---|---|---|---|---|---|---|---|---|---|
| -22.334 | 148.3334 | 2022-03-10T01:42:41Z | S12_T3 | Melaleuca fluviatilis | 23 | 100 | In sandy creek channel | 6:24 | 12:06 | -1.35 | Low |
| -22.3393 | 148.3227 | 2022-03-10T02:47:41Z | S13_T3 | Eucalyptus camaldulensis | 30 | 120 | 4m from edge of surface water inside sloping upper bank of waterhole | 6:45 | 12:41 | -0.3 | Very High |
| -22.3387 | 148.3226 | 2022-03-10T03:06:20Z | S13_T1 | Eucalyptus camaldulensis | 28 | 80 | 5m from edge of surface water on top of terrace above waterbody | 6:37 | 12:33 | -0.6 | High |
| -22.339 | 148.3225 | 2022-03-10T03:10:19Z | S13_T2 | Eucalyptus camaldulensis | 30 | 120 | 4m from edge of surface water inside sloping upper bank of waterhole | 6:41 | 12:38 | -0.55 | Very High |
| -22.3396 | 148.3229 | 2022-03-10T03:10:19Z | S13_T4 | Eucalyptus camaldulensis | 23 | 116 | 5m from edge of surface water on top of terrace above waterbody | 6:45 | 12:41 | -0.75 | High |
| -22.4679 | 148.3559 | 2022-03-07T20:50:13Z | S1_T1 | Corymbia dallachiana | 15 | 50 | Broad residual plain not associated with watercourse | 5:21 | 15:15 | -1.1 | Moderate |
| -22.468 | 148.3557 | 2022-03-07T20:52:08Z | S1_T2 | Eucalyptus populnea | 18 | 50 | Broad residual plain not associated with watercourse | 5:26 | 15:18 | -1.5 | Low |
| -22.4682 | 148.3556 | 2022-03-07T20:56:50Z | S1_T3 | Eucalyptus populnea | 15 | 45 | Broad residual plain not associated with watercourse | 5:28 | 15:23 | -1.1 | Moderate |
| -22.4683 | 148.3556 | 2022-03-07T20:59:13Z | S1_T4 | Eucalyptus cambageana | 18 | 60 | Broad residual plain not associated with watercourse | 5:32 | 15:27 | -1.65 | Low |
| -22.4589 | 148.3626 | 2022-03-07T21:44:52Z | S2_T1 | Eucalyptus camaldulensis | 30 | 95 | On T2 terrace 8m above stream channel | 5:45 | 15:33 | -0.7 | High |
| -22.4588 | 148.3618 | 2022-03-07T21:53:12Z | S2_T2 | Eucalyptus camaldulensis | 25 | 100 | At base of inner bench immediately adjacent to sandy channl | 5:51 | 15:41 | -0.2 | Extremely High |
| -22.4588 | 148.3616 | 2022-03-07T21:54:17Z | S2_T3 | Eucalyptus camaldulensis | 25 | 70 | 3m up inner bench immediately adjacent to stream channel | 5:57 | 15:41 | -0.35 | Very High |
| -22.4586 | 148.3618 | 2022-03-07T22:06:42Z | S2_T4 | Eucalyptus camaldulensis | 30 | 90 | Mid way up inner terrace 6m above sandy channel | 6:01 | 15:46 | -1 | Moderate |

| Latitude | Longitude | Time | Tree Number | Species | Height (m) | DBH (cm) | Location relative to watercourse | LWP Sample Time | Xylem Sample Time | LWP (Mpa) | Moisture Availability |
|---|---|---|---|---|---|---|---|---|---|---|---|
| -22.4524 | 148.3728 | 2022-03-08T00:01:39Z | S3_T1 | Eucalyptus camaldulensis | 25 | 105 | 7m above channel floor on upper terrace of creek | 6:15 | 16:02 | -0.45 | Very High |
| -22.4527 | 148.3736 | 2022-03-08T00:09:48Z | S3_T2 | Eucalyptus camaldulensis | 25 | 90 | 8m above channel floor on upper terrace of creek | 6:19 | 16:06 | -0.25 | Extremely High |
| -22.453 | 148.3737 | 2022-03-08T00:09:48Z | S3_T3 | Eucalyptus camaldulensis | 23 | 80 | Top of T2 terrace 12m above channel floor | 6:23 | 16:11 | -0.55 | Very High |
| -22.4526 | 148.3754 | 2022-03-08T00:19:00Z | S3_T4 | Eucalyptus camaldulensis | 30 | 190 | 1m above  channel floor inside inner bench | 6:29 | 16:15 | -0.3 | Very High |
| -22.4417 | 148.3823 | 2022-03-08T02:26:10Z | S4_T1 | Eucalyptus camaldulensis | 25 | 90 | 5m above channel floor on T2 Terrace | 6:01 | 12:15 | -0.4 | Very High |
| -22.4415 | 148.3823 | 2022-03-08T02:29:05Z | S4_T2 | Eucalyptus camaldulensis | 25 | 135 | 7m above channel floor on upper terrace of creek | 6:05 | 12:19 | -0.5 | Very High |
| -22.4408 | 148.3828 | 2022-03-08T02:32:24Z | S4_T3 | Casuarina cunninghamiana | 18 | 70 | Directly adjacent to main sandy creek channel on inner bench | 6:11 | 12:21 | -0.3 | Very High |
| -22.4402 | 148.3822 | 2022-03-08T02:41:09Z | S4_T4 | Eucalytptus camaldulensis | 25 | 100 | On inner bench directly adjacent to sandy creek channel | 6:15 | 12:25 | -0.1 | Extremely High |
| -22.4505 | 148.3734 | 2022-03-08T03:59:28Z | S5_T1 | Eucalyptus populnea | 12 | 55 | Broad residual plain not associated with watercourse | 6:45 | 13:18 | -1.85 | Very Low |
| -22.4503 | 148.3739 | 2022-03-08T04:09:01Z | S5_T2 | Eucalyptus populnea | 16 | 50 | Broad residual plain not associated with watercourse | 6:55 | 13:23 | -1.2 | Low |
| -22.4507 | 148.3736 | 2022-03-08T04:13:45Z | S5_T3 | Eucalyptus populnea | 15 | 50 | Broad residual plain not associated with watercourse | 6:49 | 13:27 | -2 | Very Low |
| -22.4116 | 148.3413 | 2022-03-08T23:22:34Z | S6_T1 | Eucalytptus camaldulensis | 18 | 65 | Loamy clays- shallow alluvium associated with ephemeral watercourse | 5:51 | 10:47 | -0.55 | Very High |
| -22.4114 | 148.3415 | 2022-03-08T22:39:34Z | S6_T2 | Eucalytptus camaldulensis | 22 | 60 | Loamy clays- shallow alluvium associated with ephemeral watercourse | 5:55 | 10:52 | -0.55 | Very High |

| Latitude | Longitude | Time | Tree Number | Species | Height (m) | DBH (cm) | Location relative to watercourse | LWP Sample Time | Xylem Sample Time | LWP (Mpa) | Moisture Availability |
|---|---|---|---|---|---|---|---|---|---|---|---|
| -22.4116 | 148.3412 | 2022-03-08T22:42:40Z | S6_T3 | Eucalytptus camaldulensis | 23 | 65 | Loamy clays- shallow alluvium associated with ephemeral watercourse | 5:59 | 10:55 | -0.5 | Very High |
| -22.4114 | 148.341 | 2022-03-08T22:45:41Z | S6_T4 | Eucalytptus camaldulensis | 27 | 90 | Loamy clays- shallow alluvium associated with ephemeral watercourse | 6:03 | 10:59 | -0.85 | High |
| -22.4051 | 148.3419 | 2022-03-08T23:41:38Z | S7_T1 | Eucalyptus populnea | 17 | 45 | Loamy clays- shallow alluvium associated with ephemeral watercourse | 6:11 | 11:10 | -1.55 | Low |
| -22.405 | 148.3422 | 2022-03-08T23:45:11Z | S7_T2 | Eucalyptus populnea | 20 | 65 | Loamy clays- shallow alluvium associated with ephemeral watercourse | 6:13 | 11:15 | -1.3 | Low |
| -22.4052 | 148.3423 | 2022-03-08T23:51:07Z | S7_T3 | Eucalyptus populnea | 22 | 50 | Loamy clays- shallow alluvium associated with ephemeral watercourse | 6:15 | 11:19 | -1.5 | Low |
| -22.3614 | 148.3151 | 2022-03-09T00:43:47Z | S8_T1 | Eucalyptus camaldulensis | 18 | 60 | Low instream sandy island with exposure of decomposed sandstone in the creek bed | 6:23 | 11:39 | -1.05 | Moderate |
| -22.361 | 148.3152 | 2022-03-09T00:48:53Z | S8_T2 | Eucalyptus camaldulensis | 15 | 60 | On lower margins of creek bank 1m above stream channel | 6:27 | 11:44 | -0.5 | Very High |
| -22.3605 | 148.3154 | 2022-03-09T00:53:32Z | S8_T3 | Eucalyptus camaldulensis | 18 | 70 | 2m above sandy channel on inner stream terrace. Tree is very stressed. | 6:31 | 11:49 | -0.55 | Very High |
| -22.3601 | 148.3153 | 2022-03-09T01:01:18Z | S8_T4 | Melaleuca fluviatilis | 18 | 50 | Low bank directly adjacent to sandy creek channel. Bedrock exposure in creek | 6:35 | 11:54 | -0.55 | Very High |
| -22.3603 | 148.3151 | 2022-03-09T01:12:45Z | S8_T5 | Eucalyptus populnea | 17 | 55 | Top of T2 terrace 10m above channel floor | 6:41 | 11:59 | -1.35 | Low |
| -22.3519 | 148.3203 | 2022-03-09T01:46:22Z | S9_T1 | Eucalyptus camaldulensis | 25 | 80 | Inner terrace 5m from drainage line and 2m above sandy drainage channel | 6:45 | 12:13 | -0.6 | High |
| -22.3516 | 148.3206 | 2022-03-09T01:55:02Z | S9_T2 | Eucalyptus camaldulensis | 25 | 90 | T1 terrace 15m from river channel | 6:48 | 12:17 | -0.3 | Very High |
| -22.3514 | 148.3208 | 2022-03-09T02:01:37Z | S9_T3 | Eucalyptus camaldulensis | 28 | 80 | Edge of T2 terrace 10m from margins of sandy channel and 5m above channel floor | 6:51 | 12:23 | -0.7 | High |

| Latitude | Longitude | Time | Tree Number | Species | Height (m) | DBH (cm) | Location relative to watercourse | LWP Sample Time | Xylem Sample Time | LWP (Mpa) | Moisture Availability |
|---|---|---|---|---|---|---|---|---|---|---|---|
| -22.3514 | 148.3204 | 2022-03-09T20:33:52Z | S9_T4 | Melaleuca fluviatilis | 16 | 65 | Inner bank of creek immediately adjacent to sandy drainage channel | 6:54 | 12:27 | -1 | Moderate |

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




**Appendix B1.** Sampling detail at Survey Area 1 and Survey Area 2

Client
Aecom Aust. Pty Ltd

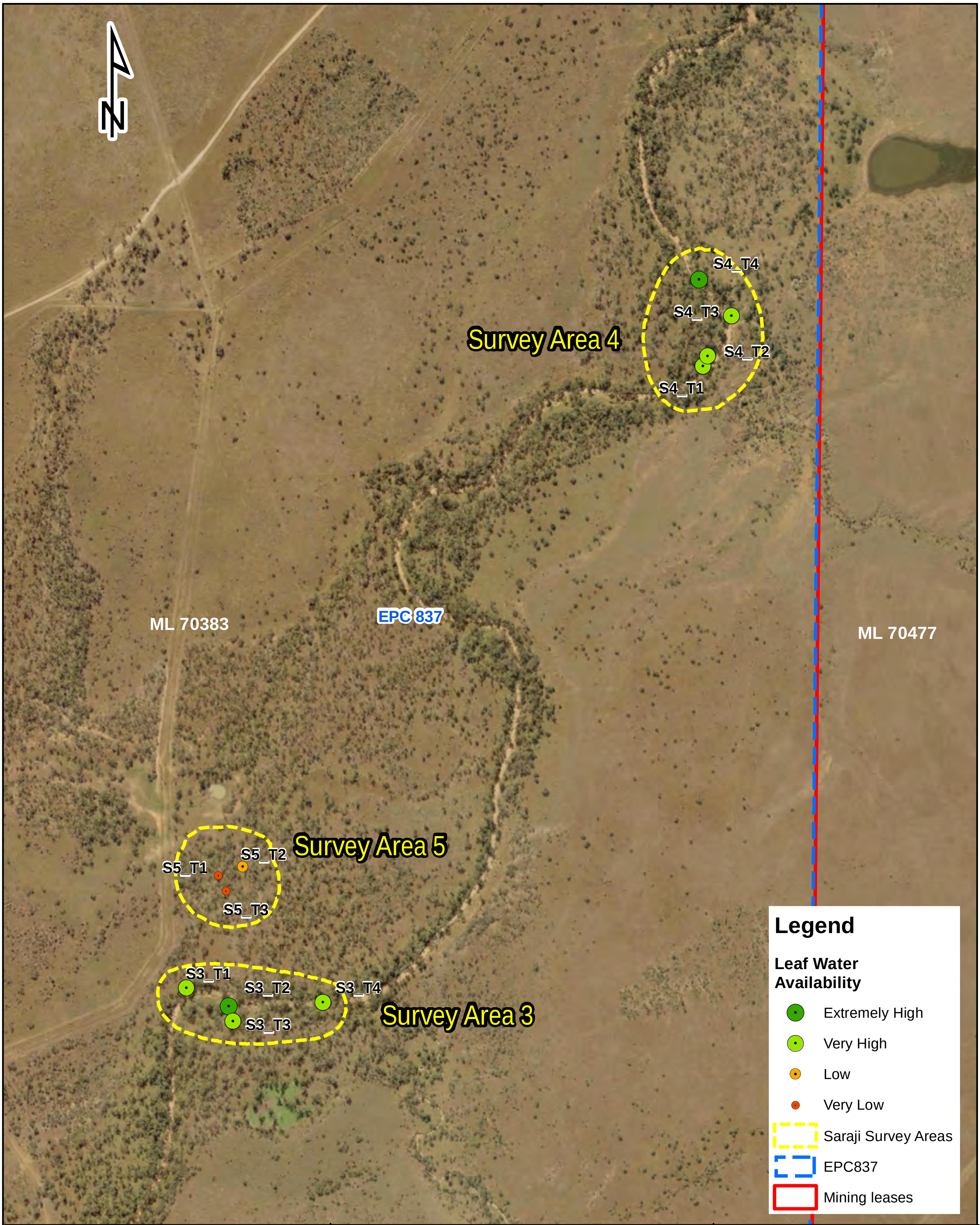
0 0.1 0.2 0.3 0.4
Kilometers

3D Environmental
Landscape & Vegetation Science

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

| Scale | Drawn By | Checked | File Path | Date | |
|---|---|---|---|---|---|
| 1:5,917 | DG | DS | | 11/08/2022 | A4 |

D:\Backup C Drive 26519\3D Environmental\Saraji\Saraji_Map_9822.mxd




**Appendix B2.** Sampling detail at Survey Area 3, Survey Area 4 and Survey Area 5

Client
Aecom Aust. Pty Ltd

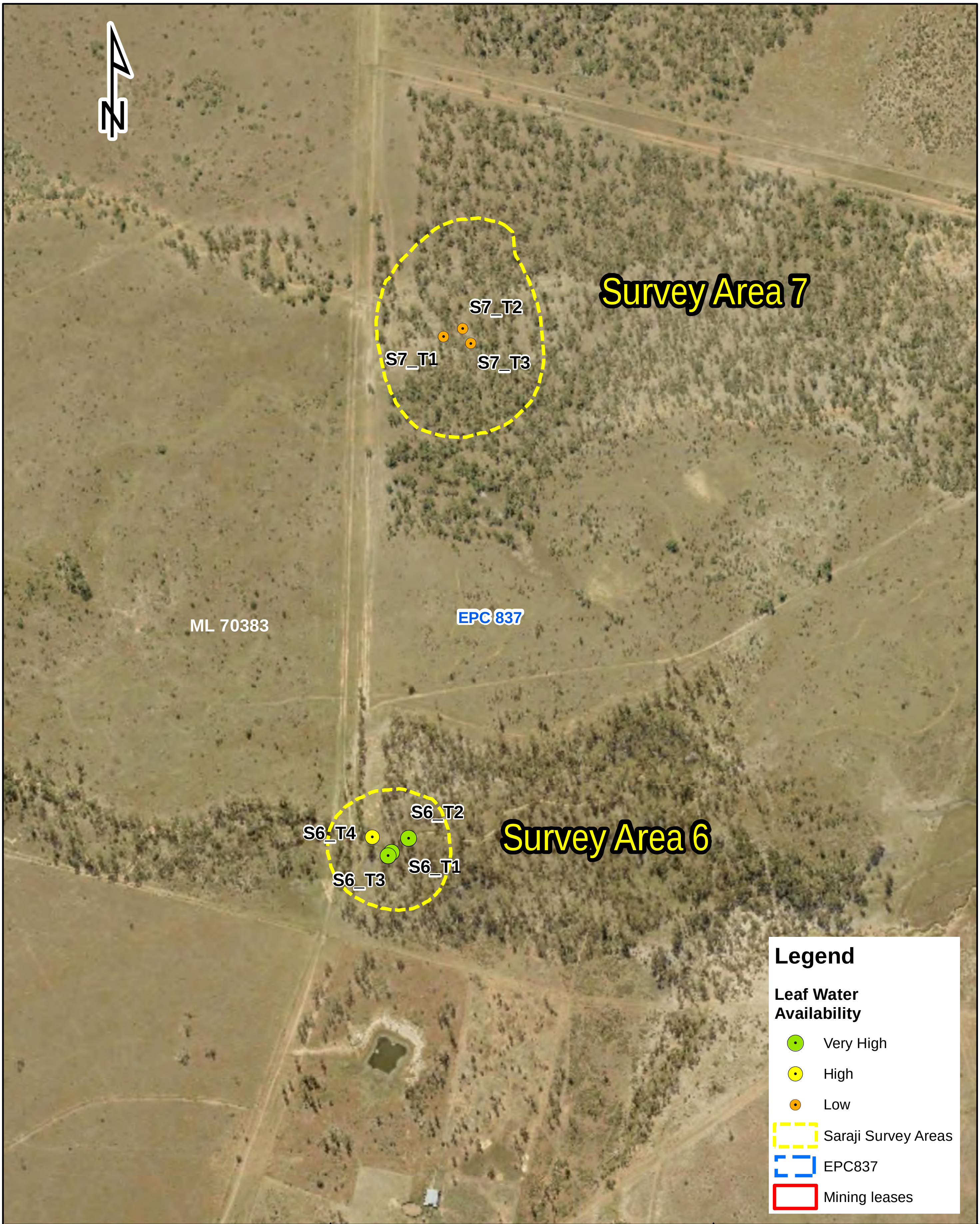
0 0.1 0.2 0.3 0.4
Kilometers

3D Environmental
Landscape & Vegetation Science

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

| Scale 1:9,582 | Drawn By DG | Checked DS | File Path | Date 11/08/2022 | A4 |
|---|---|---|---|---|---|

D:\Backup C Drive 265193D Environmental\Saraji\Saraji_Map_9822.mxd




**Appendix B3.** Sampling detail at Survey Area 6 and Survey Area 7

Client

**Aecom Aust. Pty Ltd**

0 0.1 0.2 0.3 0.4

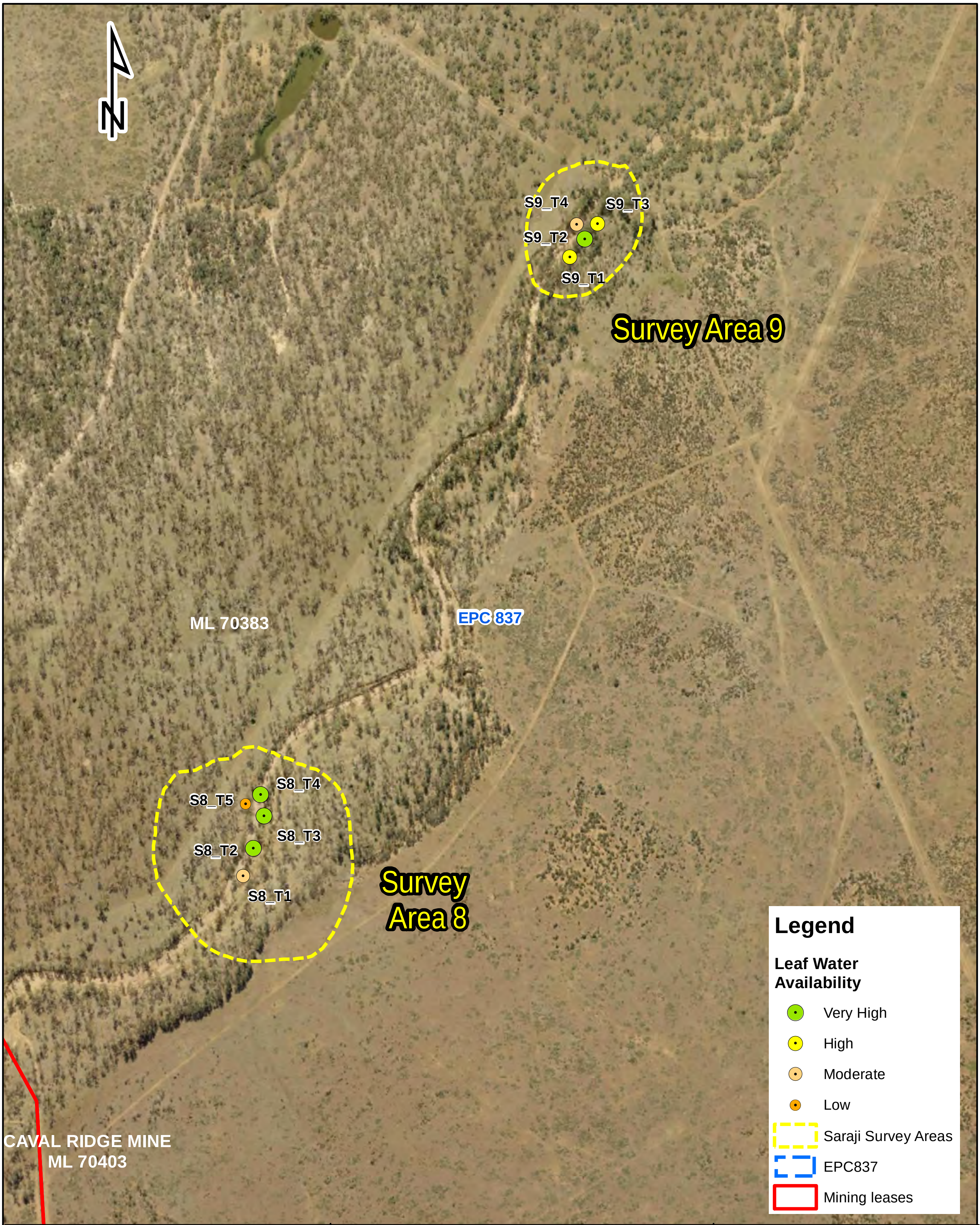
Kilometers

3D Environmental
Landscape & Vegetation Science

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

| Scale 1:7,005 | Drawn By DG | Checked DS | File Path | Date 11/08/2022 | A4 |
|---|---|---|---|---|---|

D:\Backup C Drive 26519\3D Environmental\Saraji\Saraji_Map_9822.mxd




**Appendix B4.** Sampling detail at Survey Area 8 and Survey Area 9

Client
**Aecom Aust. Pty Ltd**

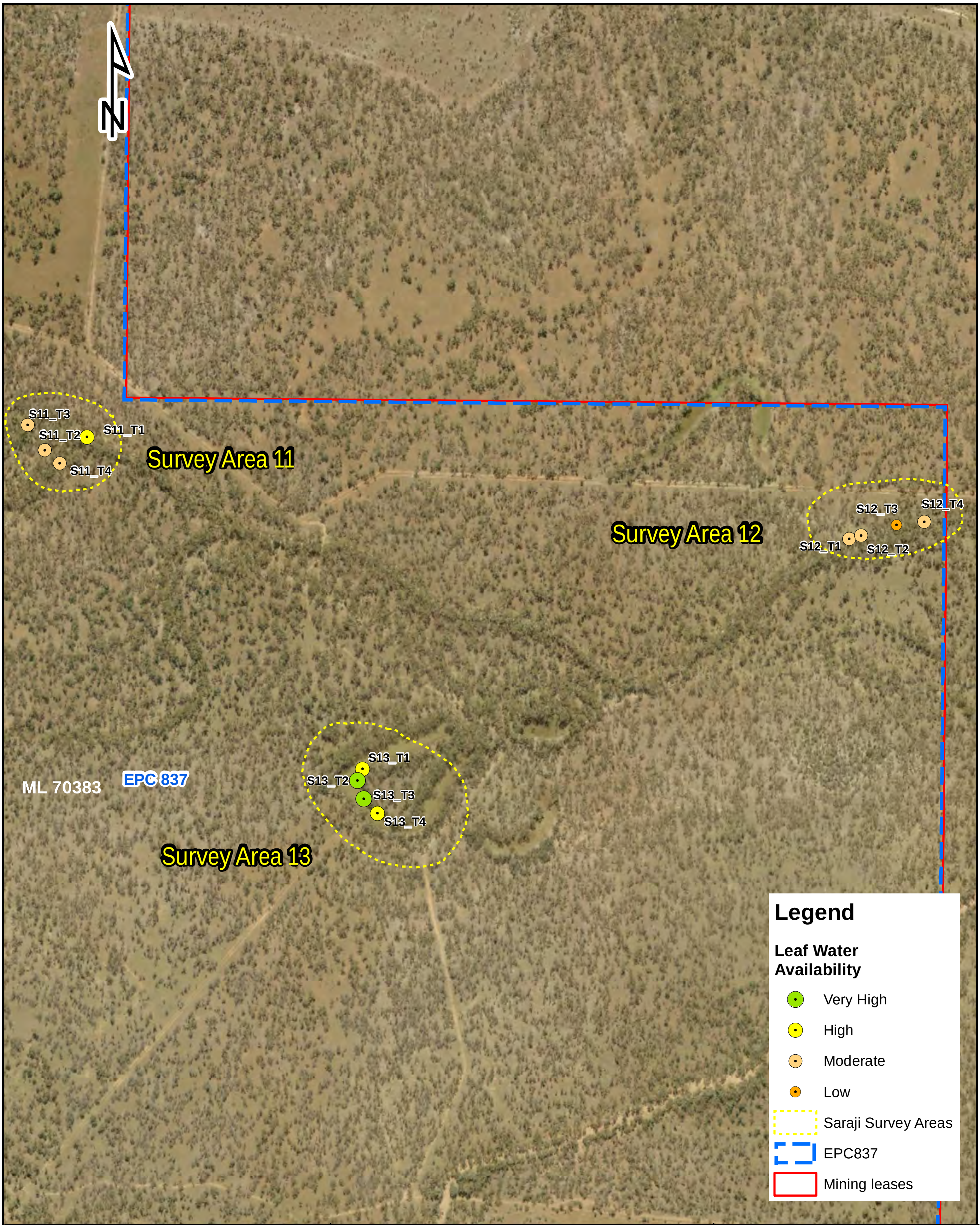
0 0.1 0.2 0.3 0.4
Kilometers

3D Environmental
Landscape & Vegetation Science

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

| Scale 1:8,515 | Drawn By DG | Checked DS | File Path | Date 11/08/2022 | A4 |
|---|---|---|---|---|---|

D:\Backup C Drive 26519\3D Environmental\Saraji\Saraji_Map_9822.mxd




**Appendix B5.** Sampling detail at Survey Area 11, Survey Area 12 and Survey Area 13

Client

**Aecom Aust. Pty Ltd**

0 0.18 0.36 0.54 0.72

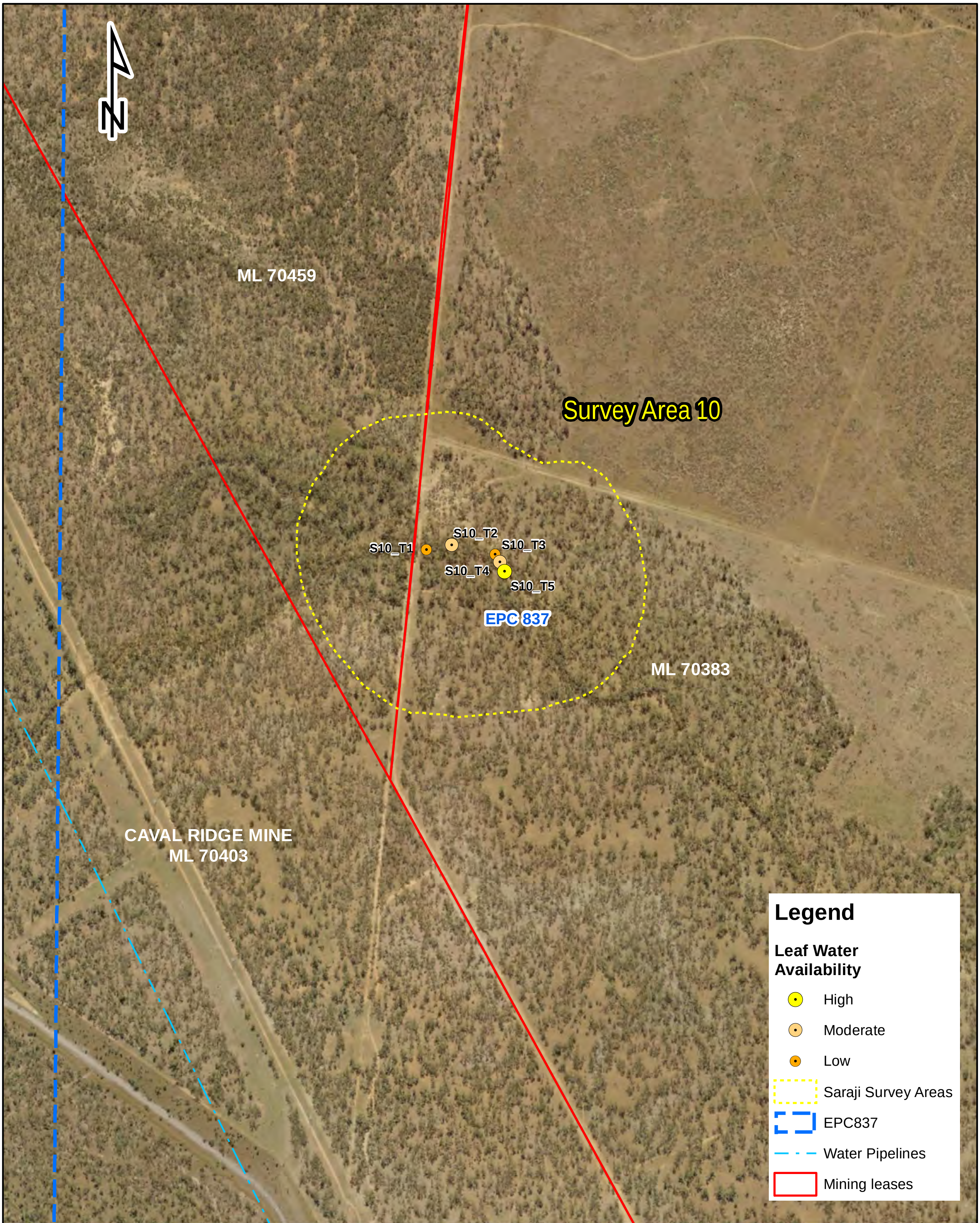
Kilometers

3D Environmental
Landscape & Vegetation Science

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

| Scale | Drawn By | Checked | File Path | Date | |
|---|---|---|---|---|---|
| 1:10,542 | DG | DS | | 15/08/2022 | A4 |

D:\Backup C Drive 26519\3D Environmental\Saraji\Saraji_Map_9822.mxd




**Appendix B6.** Sampling detail at Survey Area 10

3D Environmental
Landscape & Vegetation Science

**Client**

**Aecom Aust. Pty Ltd**


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


0 0.18 0.36 0.54 0.72
Kilometers

| | | | | |
|---|---|---|---|---|
| **Scale** 1:9,986 | **Drawn By** DG | **Checked** DS | **File Path** | **Date** 15/08/2022 | A4 |

D:\Backup C Drive 26519\3D Environmental\Saraji\Saraji_Map_9822.mxd

## Appendix C – Soil Moisture Potential Raw Data

| Sample | Type | Project | Date Sampled | SMP (Mpa) |
|---|---|---|---|---|
| S10_AU1_1.6 | Soil | Saraji | 13.03.22 | -2.17 |
| S10_AU1_1.2 | Soil | Saraji | 13.03.22 | -1.09 |
| S10_AU1_1.5 | Soil | Saraji | 13.03.22 | -1.11 |
| S11_AU1_0.5 | Soil | Saraji | 13.03.22 | -2.75 |
| S11_AU1_0.75 | Soil | Saraji | 09.03.22 | -0.77 |
| S11_AU1_1.0 | Soil | Saraji | 13.03.22 | -1.56 |
| S11_AU1_1.6 | Soil | Saraji | 13.03.22 | -1.05 |
| S11_AU1_2.0 | Soil | Saraji | 13.03.22 | -0.7 |
| S11_AU1_2.25 | Soil | Saraji | 13.03.22 | -0.86 |
| S11_AU1_2.30 | Soil | Saraji | 13.03.22 | -1.82 |
| S11_AU1_2.5 | Soil | Saraji | 13.03.22 | -0.42 |
| S11_AU1_2.70 | Soil | Saraji | 13.03.22 | -0.93 |
| S11_AU1_2.75 | Soil | Saraji | 13.03.22 | -0.83 |
| S12_AU1_0.4 | Soil | Saraji | 13.03.22 | -1.14 |
| S12_AU1_1.0 | Soil | Saraji | 13.03.22 | -1.67 |
| S12_AU1_1.5 | Soil | Saraji | 13.03.22 | -1.86 |
| S12_AU1_2.2 | Soil | Saraji | 13.03.22 | -1.94 |
| S13_AU1_0.3 | Soil | Saraji | 12.03.22 | -0.87 |
| S13_AU1_0.5 | Soil | Saraji | 12.03.22 | -1.11 |
| S13_AU1_1.0 | Soil | Saraji | 12.03.22 | -1.76 |
| S13_AU1_1.25 | Soil | Saraji | 12.03.22 | -1.96 |
| S13_AU1_1.5 | Soil | Saraji | 12.03.22 | -0.91 |
| S13_AU1_1.8 | Soil | Saraji | 12.03.22 | -0.97 |
| S13_AU1_2.0 | Soil | Saraji | 12.03.22 | -1.02 |
| S13_AU1_2.5 | Soil | Saraji | 12.03.22 | -2.45 |
| S13_AU1_2.75 | Soil | Saraji | 12.03.22 | -0.55 |
| S13_AU1_3.0 | Soil | Saraji | 12.03.22 | -1.1 |
| S13_AU1_3.5 | Soil | Saraji | 12.03.22 | -1 |
| S13_AU1_3.7 | Soil | Saraji | 12.03.22 | -0.7 |
| S2_AU1_0.3 | Soil | Saraji | 09.03.22 | -0.22 |
| S2_Bank Seepage | Soil | Saraji | 09.03.22 | -0.01 |
| S2-AU1_0.5 | Soil | Saraji | 09.03.22 | -0.01 |
| S2-AU1_1.0 | Soil | Saraji | 09.03.22 | -0.09 |
| S2-AU1_1.1 | Soil | Saraji | 09.03.22 | -0.05 |
| S2-AU1_1.25 | Soil | Saraji | 09.03.22 | -0.01 |
| S3_AU1_1.5 | Soil | Saraji | 09.03.22 | -0.03 |
| S3_AU1_1.6 | Soil | Saraji | 09.03.22 | -0.1 |
| S3_AU1_2.2 | Soil | Saraji | 09.03.22 | -0.28 |
| S3_AU1_2.7 | Soil | Saraji | 09.03.22 | -0.15 |
| S4_AU1_1.0 | Soil | Saraji | 09.03.22 | -0.05 |
| S4_AU1_1.2 | Soil | Saraji | 09.03.22 | -0.14 |
| S4_AU1_1.3 | Soil | Saraji | 09.03.22 | -0.15 |
| S4_AU1_1.6 | Soil | Saraji | 09.03.22 | 0 |
| S6_AU1_0.5 | Soil | Saraji | 09.03.22 | -0.12 |

| | | | | |
|---|---|---|---|---|
| S6_AU1_0.5 | Soil | Saraji | 09.03.22 | -0.16 |
| S6_AU1_1.0 | Soil | Saraji | 09.03.22 | -0.31 |
| S6_AU1_1.25 | Soil | Saraji | 09.03.22 | -0.77 |
| S6_AU1_1.5 | Soil | Saraji | 09.03.22 | -1.01 |
| S6_AU1_2.0 | Soil | Saraji | 09.03.22 | -1.11 |
| S6_AU1_2.4 | Soil | Saraji | 09.03.22 | -0.88 |
| S8_AU1_0.3 | Soil | Saraji | 09.03.22 | -0.27 |
| S9_AU1_0.75 | Soil | Saraji | 18.11.21 | -0.05 |
| S9_AU1_1.0 | Soil | Saraji | 18.11.21 | -0.02 |
| S9_AU1_1.25 | Soil | Saraji | 18.11.21 | -0.32 |
| S9_AU1_1.6 | Soil | Saraji | 18.11.21 | -0.78 |
| S9_AU1_2.0 | Soil | Saraji | 18.11.21 | -0.62 |
| S9_AU1_2.5 | Soil | Saraji | 19.11.21 | -1.17 |

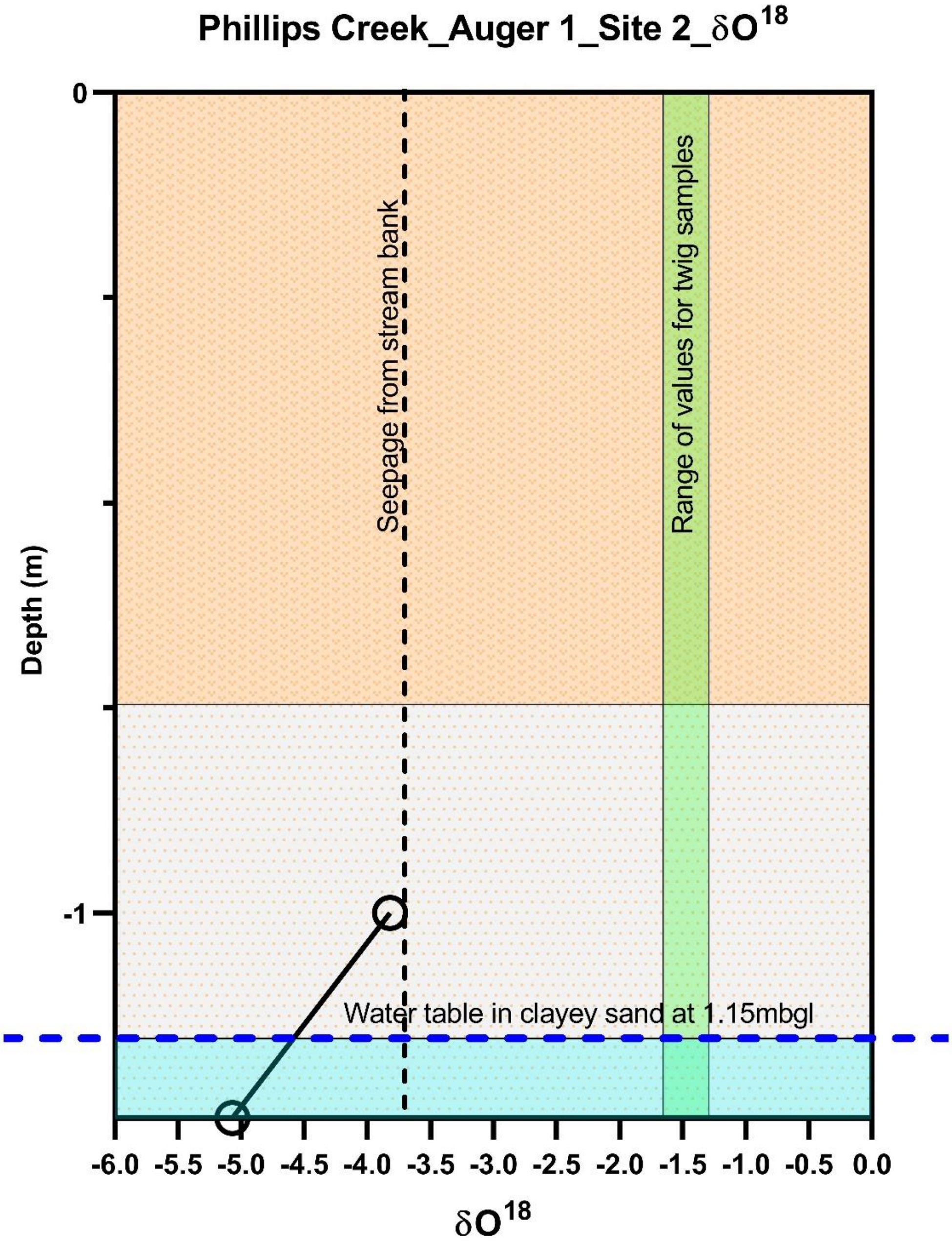
## Appendix D– Stable Isotope Analytical Results

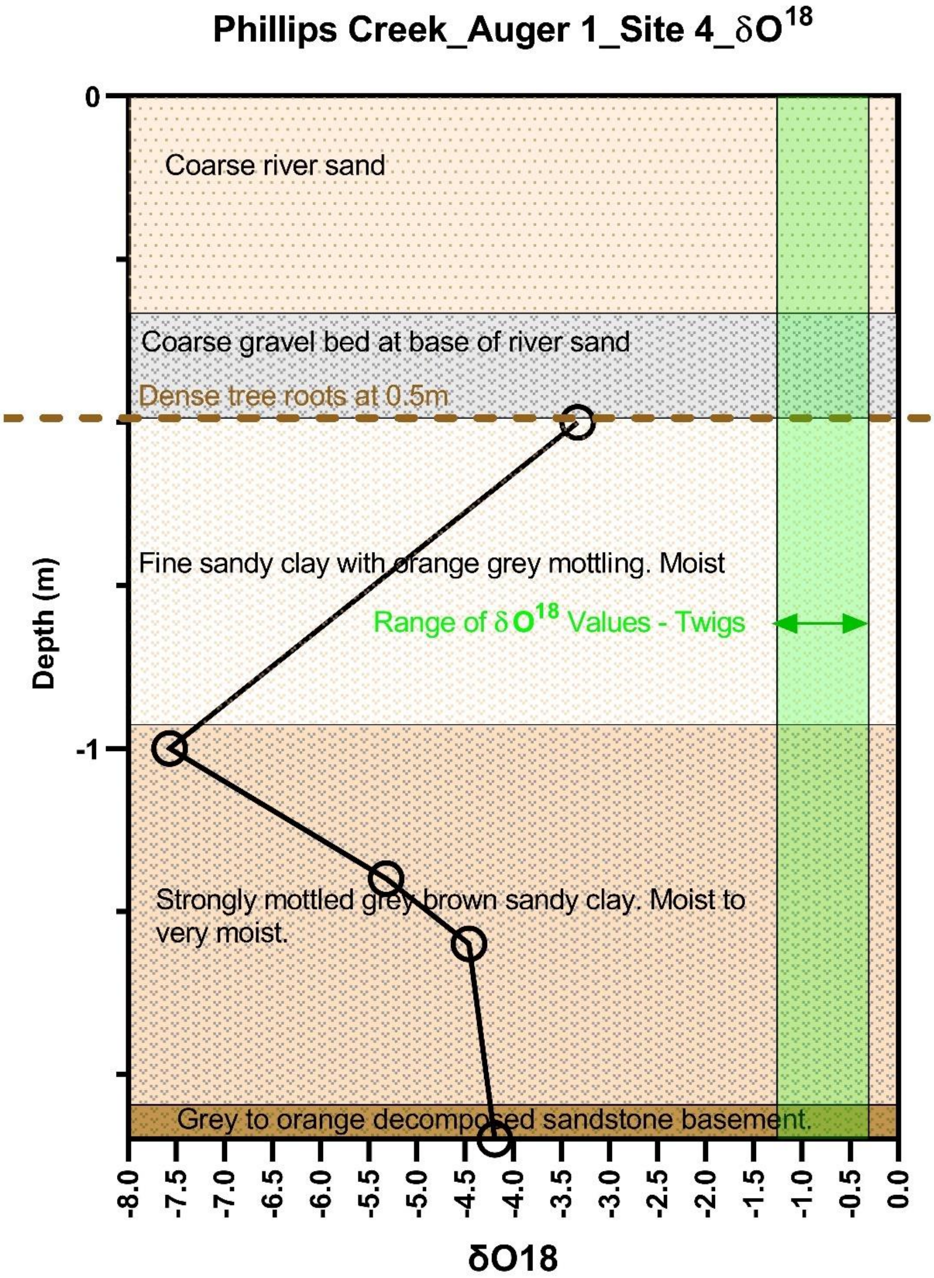
| Sample No. | Sample Type | $\delta^2H$ VSMOW | $\delta^{18}O$ VSMOW | D_Excess | LC_Excess |
|---|---|---|---|---|---|
| Soils | S10_AU1_1.5 | -1.94 | -19.64 | -4.12 | -14.02 |
| Soils | S11_AU1_2.25 | -4.6 | -22.57 | 14.23 | -0.72 |
| Soils | S11_AU1_2.5 | -3.57 | -11.07 | 17.49 | 3.14 |
| Soils | S11_AU1_2.7 | -3.82 | -19.72 | 10.84 | -2.89 |
| Soils | S11_AU1_2.75 b | -5.04 | -28.63 | 11.69 | -3.37 |
| Soils | S12_AU1_2.2 | -3.03 | -22.02 | 2.22 | -9.60 |
| Soils | S13_AU1_0.3 | 4.55 | 28.75 | -7.65 | -10.61 |
| Soils | S13_AU1_0.3 | 4.09 | 17.68 | -15.04 | -17.50 |
| Soils | S13_AU1_1.0 | 2.71 | 10.78 | -10.9 | -15.27 |
| Soils | S13_AU1_1.25 | -0.46 | -0.55 | 3.13 | -6.24 |
| Soils | S13_AU1_1.5 | 1.65 | 7.64 | -5.56 | -11.69 |
| Soils | S13_AU1_1.8 | -1.31 | -3.02 | 7.46 | -3.32 |
| Soils | S13_AU1_2.0 | -0.52 | -3.06 | 1.1 | -8.06 |
| Soils | S13_AU1_2.5 | -0.27 | 1.12 | 3.28 | -5.92 |
| Soils | S13_AU1_2.75 | 1.26 | 0.57 | -9.51 | -15.51 |
| Soils | S13_AU1_3.0 | -2.03 | -12.17 | 4.07 | -6.99 |
| Soils | S13_AU1_3.5 | -3.91 | -19.98 | 11.3 | -2.58 |
| Soils | S13_AU1_3.7 | -4.1 | -20.37 | 12.43 | -1.79 |
| Soils | S2 Bank Seep | -5.73 | -22.36 | 23.48 | 6.20 |
| Soils | S2_AU1_1.0 | -4.21 | -26.94 | 6.74 | -6.84 |
| Soils | S2_AU1_1.1 | -3.82 | -10.71 | 19.85 | 4.95 |
| Soils | S2_AU1_1.25 | -5.07 | -21.71 | 18.85 | 2.83 |
| Soils | S3_AU1_2.2 | -3.42 | -6.11 | 21.25 | 6.56 |
| Soils | S3_AU1_2.7 | 0.84 | 7.05 | 0.33 | -7.38 |
| Soils | S4_AU1_1.0 | -7.57 | -29.71 | 30.85 | 10.77 |
| Soils | S4_AU1_1.3 | -4.46 | -16.29 | 19.39 | 3.91 |
| Soils | S4_AU1_1.6 | -4.19 | -6.85 | 26.67 | 10.51 |
| Soils | S6_AU1_2.0 | -1.59 | -8.64 | 4.08 | -6.54 |
| Soils | S6_AU1_2.4 | -2.41 | -6.43 | 12.85 | 0.27 |
| Soils | S9_AU1_2.0 | -3.49 | -12.34 | 15.58 | 1.56 |
| Soils | S9_AU1_2.5 | -3.65 | -9.27 | 19.93 | 5.19 |
| Surface Water | S13 - SW 1 | 13.98 | 53.71 | -58.13 | -45.09 |
| Groundwater | S2-AU1-GW | -4.02 | -26.01 | 6.15 | -7.17 |
| Surface Water | S6 - SW 1 | 3.1 | 1.75 | -23.05 | -25.45 |
| Surface Water | S7 - SW 1 | 1.46 | -1.54 | -13.22 | -18.54 |
| Twigs | S10T1 | -2.36 | -20.11 | -1.23 | -11.93 |
| Twigs | S10T2 | -1.27 | -13.5 | -3.34 | -12.67 |
| Twigs | S10T4 | -1.8 | -12.21 | 2.19 | -8.39 |
| Twigs | S10T5 | -0.52 | -4.89 | -0.73 | -9.65 |
| Twigs | S11T1 | 1.57 | -3.38 | -15.94 | -20.79 |
| Twigs | S11T2 | -1.66 | -15.29 | -2.01 | -11.91 |

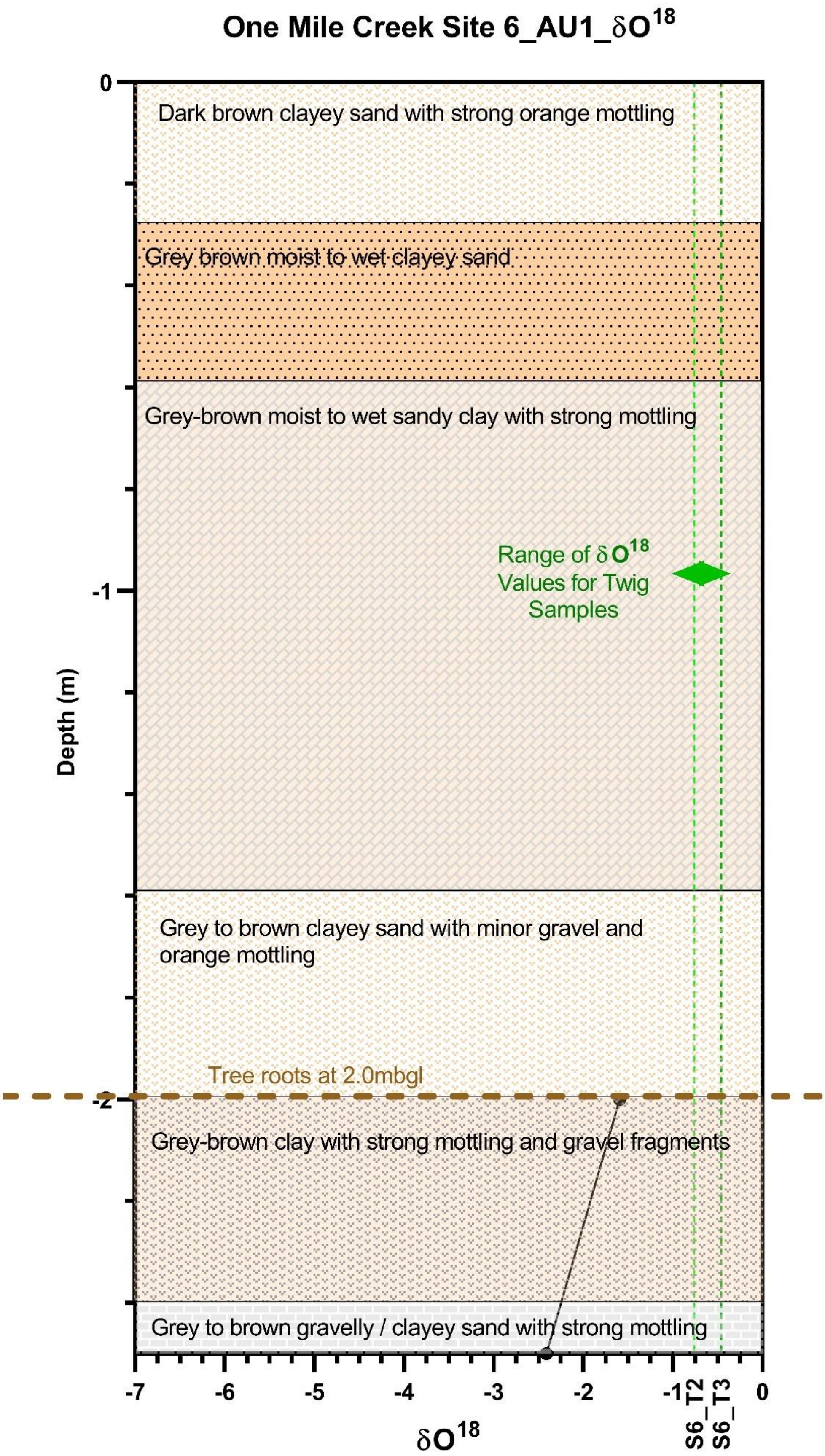
| Sample No. | Sample Type | $\delta^2H$ VSMOW | $\delta^{18}O$ VSMOW | D_Excess | LC_Excess |
|---|---|---|---|---|---|
| Twigs | S11T3 | -2.05 | -17.46 | -1.06 | -11.47 |
| Twigs | S11T4 | -2.47 | -18.75 | 1.01 | -10.09 |
| Twigs | S12T1 | -0.3 | -10.58 | -8.18 | -15.91 |
| Twigs | S12T2 | -3.17 | -21.69 | 3.67 | -8.47 |
| Twigs | S12T3 | -0.04 | -12.68 | -12.36 | -19.29 |
| Twigs | S13T1 | 5.06 | 11.41 | -29.07 | -28.73 |
| Twigs | S13T2 | 4.8 | 11.26 | -27.14 | -27.31 |
| Twigs | S13T3 | 1.77 | -2.73 | -16.89 | -21.42 |
| Twigs | S13T4 | 2.36 | 8.13 | -10.75 | -15.49 |
| Twigs | S1T1 | -1.65 | -16.1 | -2.9 | -12.67 |
| Twigs | S1T3 | -1.68 | -17.16 | -3.72 | -13.41 |
| Twigs | S1T4 | -1.78 | -19 | -4.76 | -14.42 |
| Twigs | S2T1 | -1.39 | -1.65 | 9.47 | -1.65 |
| Twigs | S2T3 | -1.53 | -12 | 0.24 | -9.82 |
| Twigs | S2T4 | -1.62 | -12.93 | 0.03 | -10.09 |
| Twigs | S3T1 | -1.04 | -9.24 | -0.92 | -10.34 |
| Twigs | S3T2 | 3.37 | 0.15 | -26.81 | -28.45 |
| Twigs | S3T3 | -0.13 | -5.12 | -4.08 | -12.18 |
| Twigs | S3T4 | -1.9 | -13.81 | 1.39 | -9.19 |
| Twigs | S4T1 | -1.3 | -19.9 | -9.5 | -18.06 |
| Twigs | S4T2 | -1.02 | -9.93 | -1.77 | -11.06 |
| Twigs | S4T4 | -0.27 | -8.12 | -5.96 | -13.95 |
| Twigs | S5T1 | -0.71 | -11.65 | -5.97 | -14.40 |
| Twigs | S5T2 | -0.66 | -13.54 | -8.26 | -16.34 |
| Twigs | S5T3 | -2.9 | -25.84 | -2.64 | -13.69 |
| Twigs | S6T2 | -0.76 | -14.35 | -8.27 | -16.45 |
| Twigs | S6T3 | -0.46 | -11.59 | -7.91 | -15.84 |
| Twigs | S6T4 | 0.43 | -4.15 | -7.59 | -14.67 |
| Twigs | S7T1 | 1.25 | -10.24 | -20.24 | -24.85 |
| Twigs | S7T2 | -1.58 | -15.96 | -3.32 | -12.97 |
| Twigs | S7T3 | -1.88 | -21.86 | -6.82 | -16.31 |
| Twigs | S8T1 | 0.25 | -7.55 | -9.55 | -16.56 |
| Twigs | S8T2 | -0.9 | -9.69 | -2.49 | -11.56 |
| Twigs | S8T3 | -0.01 | -4.29 | -4.21 | -12.17 |
| Twigs | S8T4 | 2 | -3.91 | -19.91 | -23.82 |
| Twigs | S9T1 | -0.22 | -1.52 | 0.24 | -8.51 |
| Twigs | S9T2 | 1.65 | 1.97 | -11.23 | -16.62 |
| Twigs | S9T3 | 0.59 | -1.7 | -6.42 | -13.49 |
| Twigs | S9T5 | 0.39 | -5.35 | -8.47 | -15.48 |
| Groundwater | W5-MB3 | -4.57 | -28.49 | 8.07 | -6.05 |
| Groundwater | W8-MB1 | -3.45 | -23.13 | 4.47 | -8.06 |
| Groundwater | W5-MB2 | -4.69 | -31.42 | 6.1 | -7.88 |
| Groundwater | W2-MB2 | -3.68 | -25.03 | 4.41 | -8.34 |
| Groundwater | W9-MB2 | -3.74 | -26.1 | 3.82 | -8.91 |

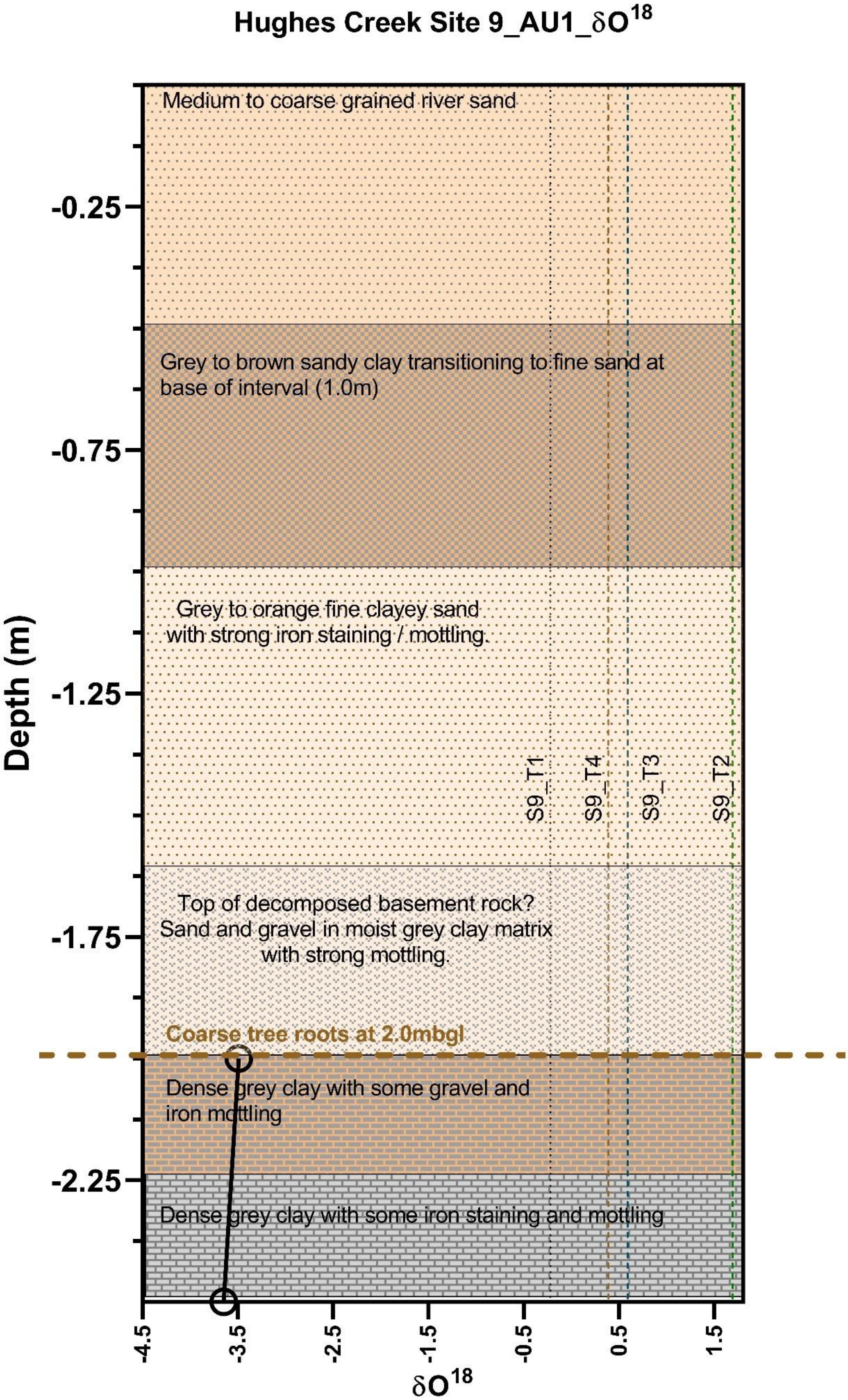
| Sample No. | Sample Type | δ²H VSMOW | δ¹⁸O VSMOW | D_Excess | LC_Excess |
|---|---|---|---|---|---|
| Groundwater | W10-MB2 | -3.88 | -28.16 | 2.88 | -9.87 |
| Groundwater | W14-MB2 | -4.95 | -32.3 | 7.3 | -7.09 |
| Groundwater | W13-MB2 | -4.95 | -33.5 | 6.1 | -8.14 |
| Groundwater | W3-MB2 | -4.28 | -28.51 | 5.73 | -7.79 |
| Groundwater | W14-MB1 | -4.42 | -26.77 | 8.59 | -5.44 |
| Groundwater | W1-MB1 | -3.5 | -23.32 | 4.68 | -7.93 |
| Groundwater | PZ00C | -4.6 | -28.39 | 8.41 | -5.78 |
| Groundwater | MB34 | -4.7 | -28.52 | 9.08 | -5.30 |
| Groundwater | MB35 | -5.56 | -34.21 | 10.27 | -5.12 |
| Groundwater | MB40 | -5.41 | -33.48 | 9.8 | -5.38 |
| Rainfall_Bowen Basin | RAIN MOR_171121_1806 | 0.78 | 15.2 | 8.96 | 0.07 |
| Rainfall_Bowen Basin | RAIN MOR_181121_0806 | 2.72 | 28.79 | 7.03 | 0.33 |
| Rainfall_Bowen Basin | Clermont Mar-Apr-08 | -1.77 | -2.1 | 12.06 | 0.22 |
| Rainfall_Bowen Basin | Clermont Mar-Apr-08 | -3.49 | -13.9 | 14.02 | 0.21 |
| Rainfall_Bowen Basin | RAIN MOR 19-11 | -0.21 | 7.39 | 9.07 | -0.82 |

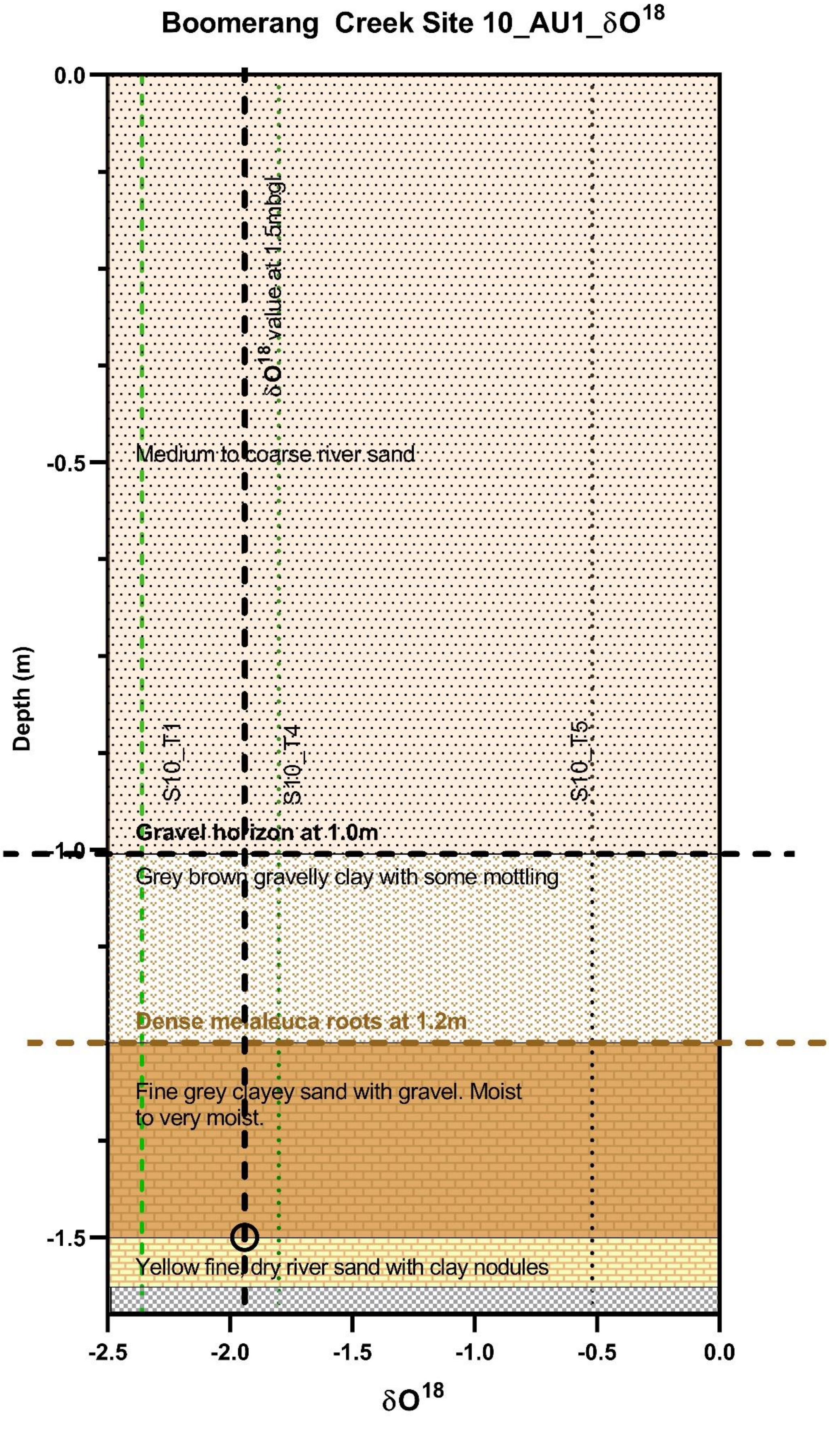
## Appendix E– Downhole δO18 Values for Auger Holes

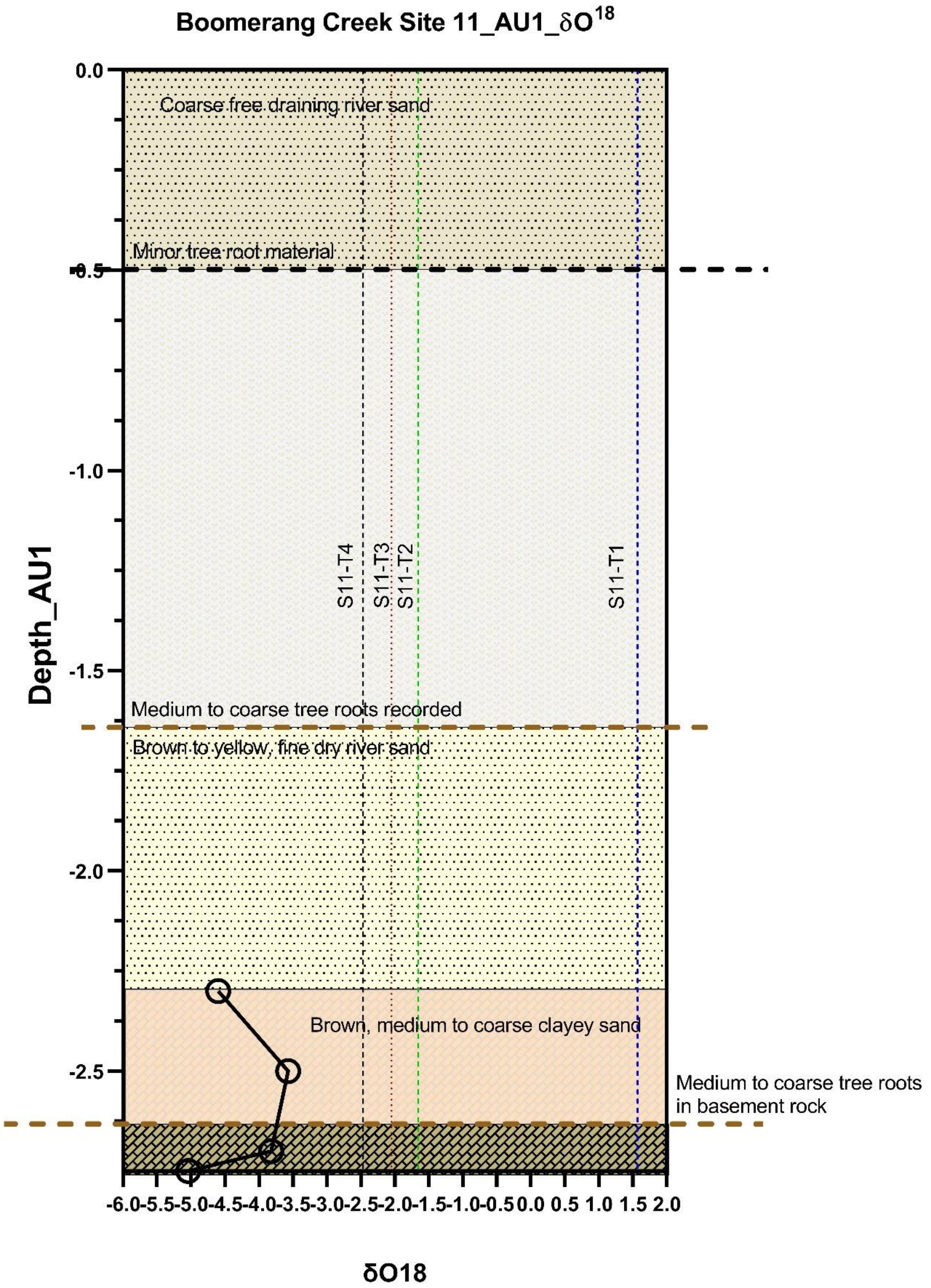


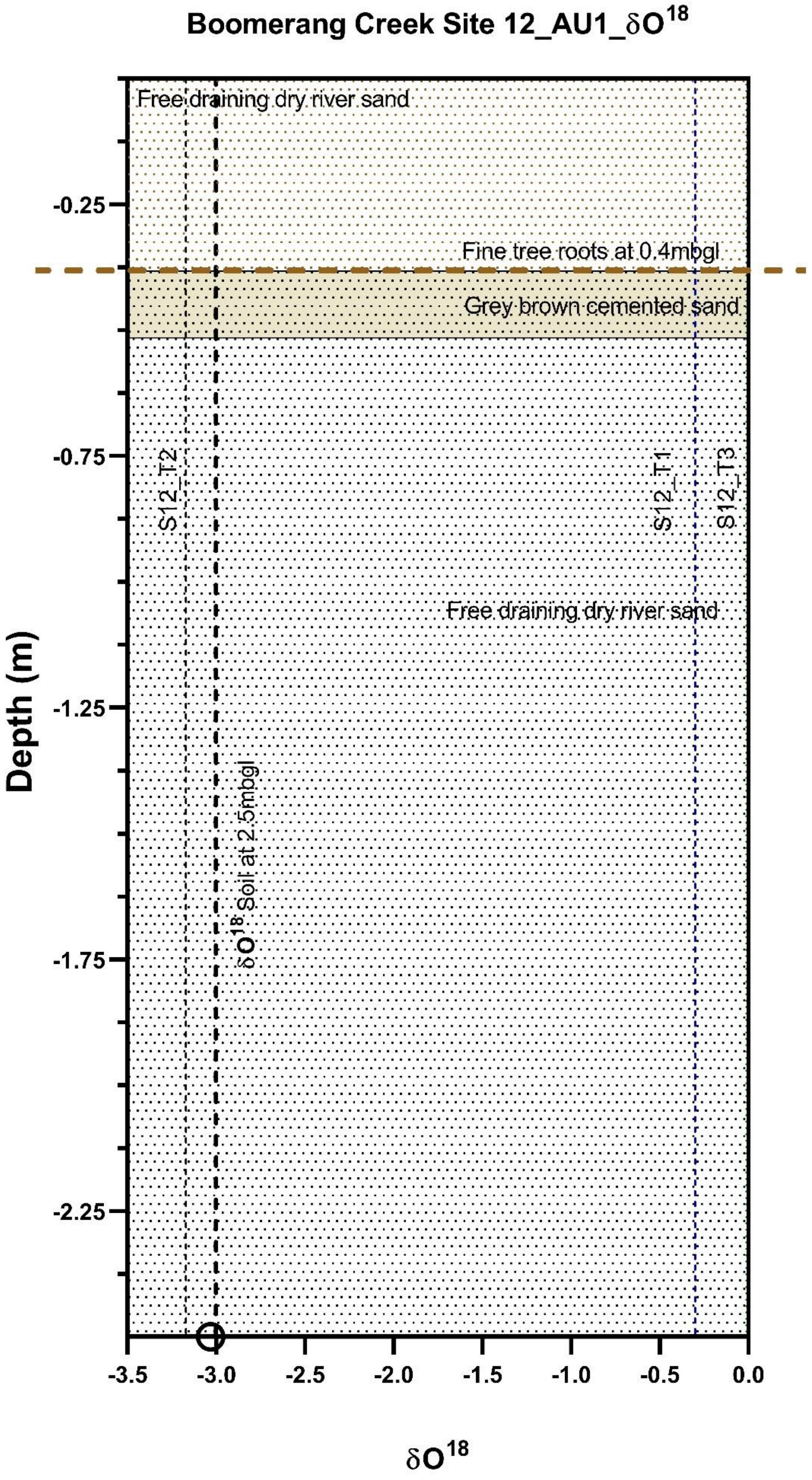

Phillips Creek_Auger 1_Site 4_δO18
Coarse river sand
Coarse gravel bed at base of river sand
Dense tree roots at 0.5m
Fine sandy clay with orange grey mottling. Moist
Range of δO18 Values - Twigs
Strongly mottled grey brown sandy clay. Moist to very moist.
Grey to orange decomposed sandstone basement.
Depth (m)
0
-1
-8.0 -7.5 -7.0 -6.5 -6.0 -5.5 -5.0 -4.5 -4.0 -3.5 -3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0.0
δO18


One Mile Creek Site 6_AU1_δO18
Dark brown clayey sand with strong orange mottling
Grey brown moist to wet clayey sand
Grey-brown moist to wet sandy clay with strong mottling
Range of δO18 Values for Twig Samples
Grey to brown clayey sand with minor gravel and orange mottling
Tree roots at 2.0mbgl
Grey-brown clay with strong mottling and gravel fragments
Grey to brown gravelly / clayey sand with strong mottling
Depth (m)
0
-1
-2
-7
-6
-5
-4
-3
-2
-1
0
S6_T2
S6_T3
δO18


Hughes Creek Site 9_AU1_δO18
Medium to coarse grained river sand
Grey to brown sandy clay transitioning to fine sand at base of interval (1.0m)
Grey to orange fine clayey sand with strong iron staining / mottling.
Top of decomposed basement rock? Sand and gravel in moist grey clay matrix with strong mottling.
Coarse tree roots at 2.0mbgl
Dense grey clay with some gravel and iron mottling
Dense grey clay with some iron staining and mottling
S9_T1
S9_T4
S9_T3
S9_T2
Depth (m)
-0.25
-0.75
-1.25
-1.75
-2.25
-4.5
-3.5
-2.5
-1.5
-0.5
0.5
1.5
δO18


Boomerang Creek Site 10_AU1_δO18
Depth (m)
0.0
-0.5
-1.0
-1.5
δO18 value at 1.5mbgl
Medium to coarse river sand
S10_T1
S10_T4
S10_T5
Gravel horizon at 1.0m
Grey brown gravelly clay with some mottling
Dense melaleuca roots at 1.2m
Fine grey clayey sand with gravel. Moist to very moist.
Yellow fine, dry river sand with clay nodules
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
δO18


Boomerang Creek Site 11_AU1_δO18
Depth_AU1
δO18
Coarse free draining river sand
Minor tree root material
Medium to coarse tree roots recorded
Brown to yellow, fine dry river sand
Brown, medium to coarse clayey sand
Medium to coarse tree roots in basement rock
S11-T4
S11-T3
S11-T2
S11-T1
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-6.0 -5.5 -5.0 -4.5 -4.0 -3.5 -3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0


Boomerang Creek Site 12_AU1_δO18
Free draining dry river sand
Fine tree roots at 0.4mbgl
Grey brown cemented sand
S12_T2
S12_T1
S12_T3
Free draining dry river sand
δO18 Soil at 2.5mbgl
Depth (m)
-0.25
-0.75
-1.25
-1.75
-2.25
-3.5
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
δO18