



APPENDIX 10 – GROUNDWATER DEPENDENT ECOSYSTEM ASSESSMENT

**NEW LENTON COAL PTY LTD
NEW LENTON COAL PROJECT**

New Lenton Project Groundwater Dependent Ecosystem Assessment

Prepared by 3d Environmental

For

Bowen Coking Coal Ltd

Revision 4_ Final _14 December 2023

Project No: 2022_249
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Client: Bowen Coking Coal



3D Environmental
Landscape & Vegetation Science

Purpose: Groundwater Dependent Ecosystem (GDE) assessment for the New Lenton Project

Draft	Date Issued	Issued By.	Purpose
Rev 1	12 June 2023	David Stanton	Preliminary draft GDE assessment prior to finalisation of impact assessment components
Rev 2	27 October 2023	David Stanton	Revised draft incorporating impact assessment
Rev 3	03 December 2023	David Stanton	Revised Impact Assessment Report after review by SLR and Richard Oldham
Rev 4	14 December 2023	David Stanton	Updates following final review by SLR and Richard Oldham

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Executive Summary

New Lenton Coal Pty Ltd (NLC), a wholly owned subsidiary of Bowen Coking Coal Pty Ltd (BCC) proposes to develop the New Lenton Project (the Project), an open cut mining operation in the Bowen Basin of central Queensland, approximately 120 km south-west of Mackay and 50 km north of Moranbah. The Project's mining leases (MLs) adjoins the western boundary of the Burton Mine. NLC will develop open cut coal mining pits on ML70337, ML700053 and ML700054 in joint venture with MPC Lenton Pty Ltd, known as the Lenton Joint Venture. Lenton Joint Venture hold the operating Burton Mine MLs (ML70109 and ML70260) which adjoins the New Lenton MLs. New Lenton MLs and Burton Mine MLs are subject to separate, existing State approved Environmental Authorities (EAs).

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 leaf water potential, soil moisture potential, stable isotopes and physical observation have been applied to assess the dependence of vegetation in the Project study area. Based on the results of the field survey, it is concluded that riparian vegetation fringing the Isaac River floodplain and associated flood plain alluvium presents the only terrestrial GDE (TGDE) identified within the Project study area. The Isaac River flows adjacent to the eastern portion of the Project disturbance area. Groundwater usage by vegetation away from the river margins decreases with distance from the river. On older elevated alluvial terraces and regolith, groundwater usage is restricted by the shallow rooting depth of vegetation, significant depth to the groundwater table (>10mbgl, particularly in the regolith), and high levels of groundwater salinity. Uncertainties in the GDE assessment relate to the degree of connectivity between the seasonally variable perched groundwater unit and the basal alluvial groundwater unit, and whether riparian vegetation has developed deeper, dimorphic root systems which have capacity to utilise shallow groundwater in the perched system, switching to the basal alluvial groundwater unit when the perched groundwater is depleted. Based on current knowledge, there is no indication of any connectivity between the perched and basal alluvial groundwater units, although this linkage will be further explored during implementation of a Project GDEMMP.

Direct clearing within the disturbance footprint will impact 2.21ha of mapped TGDEs adjacent the Isaac River. Outside of this clearing, the most likely pathway for impact to TGDEs will be through depressurisation / dewatering of the basal alluvial groundwater unit which may result in faster drying of the soil profile, and possibly reduced seasonal persistence of the perched groundwater unit. The magnitude of impact will depend on the degree of connectivity between the seasonally variable perched and the basal alluvial groundwater units. Based on current understanding, connectivity between the perched and basal groundwater units is extremely limited to non-existent and risk to GDE function is further ameliorated by several factors which include:

1. Tree species which characterise the riparian GDE areas, particularly forest red gum (*Eucalyptus tereticornis*), are resilient and have capacity to adapt to the possible minor reductions in soil moisture availability that may propagate above areas of groundwater drawdown.

2. The groundwater perched in the seasonally variable perched groundwater unit that supports GDEs is subject to natural volume fluctuations in response to changing seasonal conditions and may dry for significant periods, meaning dependent vegetation will be adapted to variable degrees of moisture availability.

GDE 'Risk Zones' have been identified across the Project study area based on the potential for Project related activities to impact GDE function. The risk zones are defined as:

- Areas where intense drawdown of groundwater (10m to 12m) interacts with mapped TGDEs on the Isaac River (Risk Zone 1-Highest Risk).
- Areas where high levels of groundwater drawdown (>5m to <10m) interacts with mapped TGDEs on the Isaac River (Risk Zone 2).
- Areas where moderate levels of groundwater drawdown (2m to 5m) interacts with mapped TGDEs on the Isaac River (Risk Zone 3).
- Areas where low levels of groundwater drawdown (<2m) interacts with TGDEs mapped on the Isaac River (Risk Zone 4 – Lowest Risk).

Mapped GDEs outside the area of groundwater drawdown are not considered to be at risk from Project development.

Outside the 2.21ha of GDEs proposed for clearing on the Isaac River, the assessment of unmitigated risk to GDE function ranges from Moderate to Low dependant on the magnitude of predicted groundwater drawdown in the basal alluvial groundwater unit. Coal seams and elevated residual terraces away from Isaac River do not support groundwater resources that are accessible to terrestrial vegetation.

Management measures to limit ecological impact to GDEs in the vicinity of the Project study area include general operational measures such those encompassed in the existing New Lenton EA, including a water management system and a receiving environment monitoring program (REMP). To detect impacts to the health and function of TGDEs associated with Project development, a groundwater dependent ecosystem monitoring and management plan (GDEMMP) will be prepared which accommodates for uncertainties in ecological response of GDEs to disturbance. The GDEMMP will provide methods for the early detection of impacts through development of trigger thresholds of ecological condition and proposes mitigations to be applied should decline in ecological condition be linked to project related mining operations.

With implementation of the GDEMMP, it is considered that the risk to GDEs from drawdown posed by mine development ranges from 'Low' (Risk Zone 1) to Insignificant (Risk Zone 4). Implementation of the GDEMMP will ensure that impacts to GDEs will be detected early to allow mitigations to be applied, reducing the risk that significant residual impacts are experienced by either matters of national environmental significance (MNES) or matters of state environmental significance (MSES), and ecological offsets can be applied in the future should significant residual impacts be detected.

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Glossary

Alluvial aquifer	An aquifer comprising unconsolidated sediments deposited by flowing water usually occurring beneath or adjacent to the channel of a river.
Aquifer	A geological formation or structure that stores or transmits water to wells or springs. Aquifers typically supply economic volumes of groundwater
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

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

	measurable. The masses of ^{16}O and ^{18}O are different enough that these isotopes are separated (or fractionated) by the process of evaporation leading to enrichment of the heavier (^{18}O) isotope. Hydrogen has two naturally occurring stable isotopes being ^1H (protium) and ^2H (deuterium) which also fractionate during evaporation, although the higher energy state of hydrogen means that the ratio between ^1H and ^2H 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 earth's 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

New Lenton Coal Pty Ltd (NLC), a wholly owned subsidiary of Bowen Coking Coal Ltd (BCC), is seeking approval to develop the New Lenton Coal Project (the Project) in the Bowen Basin of central Queensland, approximately 120 km south-west of Mackay and 50 km north of Moranbah within the Isaac Regional Council (IRC) local government area (LGA) (see **Figure 1**). NLC is proposing to develop open cut coal mining pits on mining lease (ML) 70337, ML700053 and ML700054 (the New Lenton MLs), in joint venture with MPC Lenton Pty Ltd (MPC), known as the Lenton Joint Venture (LJV). The LJV hold the operating Burton Mine MLs (ML70109 and ML70260) which adjoins the New Lenton MLs and are subject to an existing State approved Environmental Authority (EA). The nearest mining activities to the west are North Goonyella and Red Hill mines which are approximately 15 km west and separated from the Project by the Burton Range. The nearest mining activity to the east is Hail Creek Mine which is approximately 25 km east and separated from the Project by the Carborough Range (**Figure 2**).

Approximately 1.9 million tonnes per annum (Mtpa) of metallurgical run of mine (ROM) coal will be mined at the Project over a period of 18 years with a total of approximately 30 Mt over the life of the mine. In some years, including during ramp up phases, less than 1.9 Mtpa ROM coal will be mined. Overburden will be placed in in-pit and out of pit waste rock dumps, with a final void remaining at the end of mine life. Supporting infrastructure includes a mine infrastructure area (MIA), haul roads, realignment of a public road and water management infrastructure (refer to **Figure 3**). ROM coal will be hauled to Burton Mine for washing in Burton Mine's coal handling and processing plant (CHPP). Product coal will be hauled to Burton Mine's train load out (TLO) facility and railed to Dalrymple Bay Coal Terminal (DBCT). Rejects from washing of Project ROM coal will be stored within Burton Mine's existing co-disposal areas within old mine voids.

1.2 Project Activities

The proposed Project activities are shown in **Figure 3**, and comprise:

- 2 mining pits, East Pit and West Pit
- In-pit and out of pit overburden dumps
- Mine Infrastructure Area (MIA).
- haul roads, including haul road connection with the Burton Mine haul roads and a bed level crossing of the Isaac River
- Sutor Developmental Road (a public road) realignment, with a new bridge over the Isaac River
- mine affected water dams
- sediment dams
- clean water diversion drains
- mine affected water pipeline connecting with pipelines at Burton Mine
- diversion of Ti-Tree Creek and a levee along the diversion of Ti-Tree Creek
- levees along the Isaac River
- general infrastructure and construction working area.

The Project's proposed disturbance area, as shown in **Figure 3**, totals 886 ha, and includes sufficient area for construction working room for infrastructure and general mining activities.

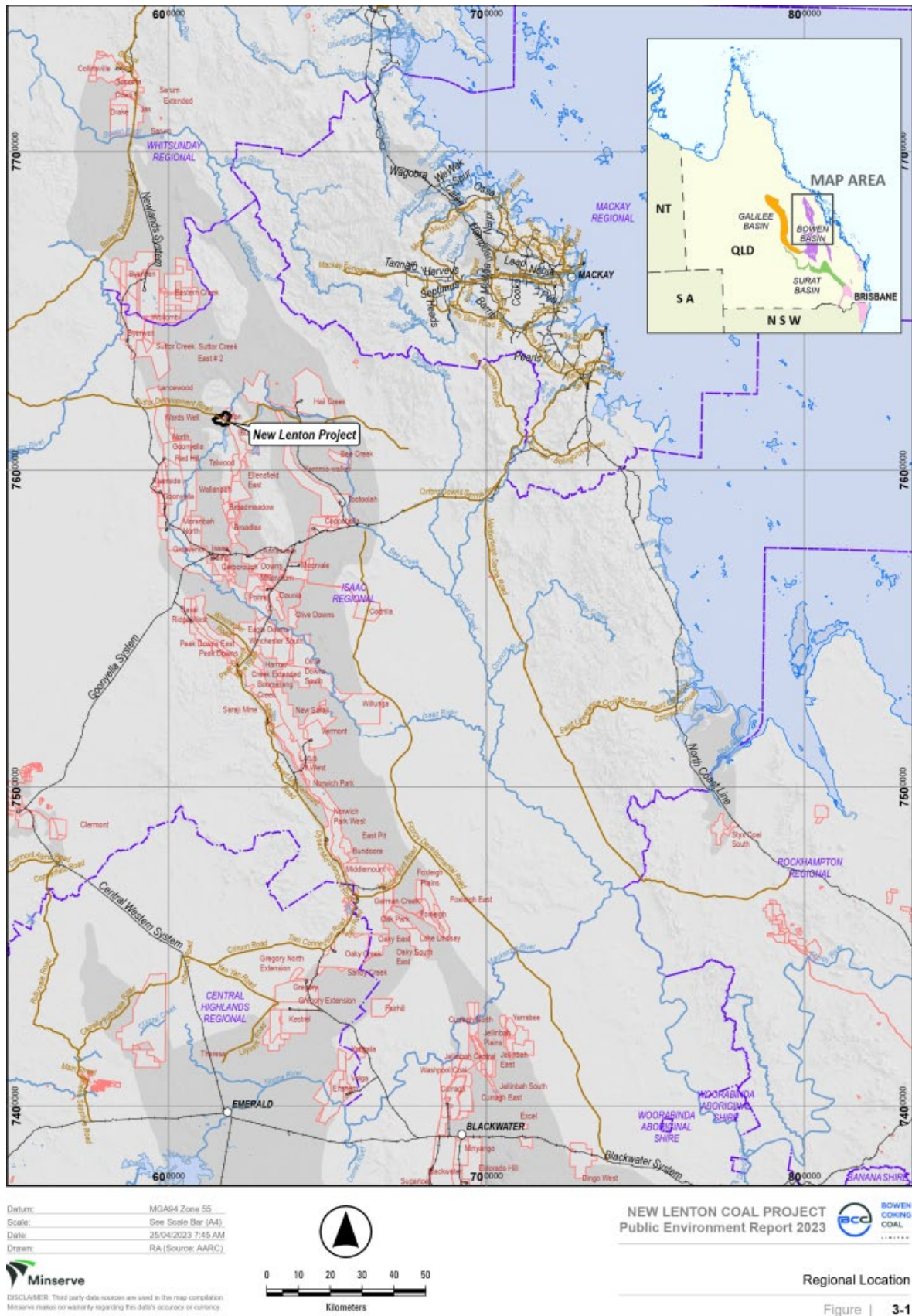


Figure 1. Regional Project location.

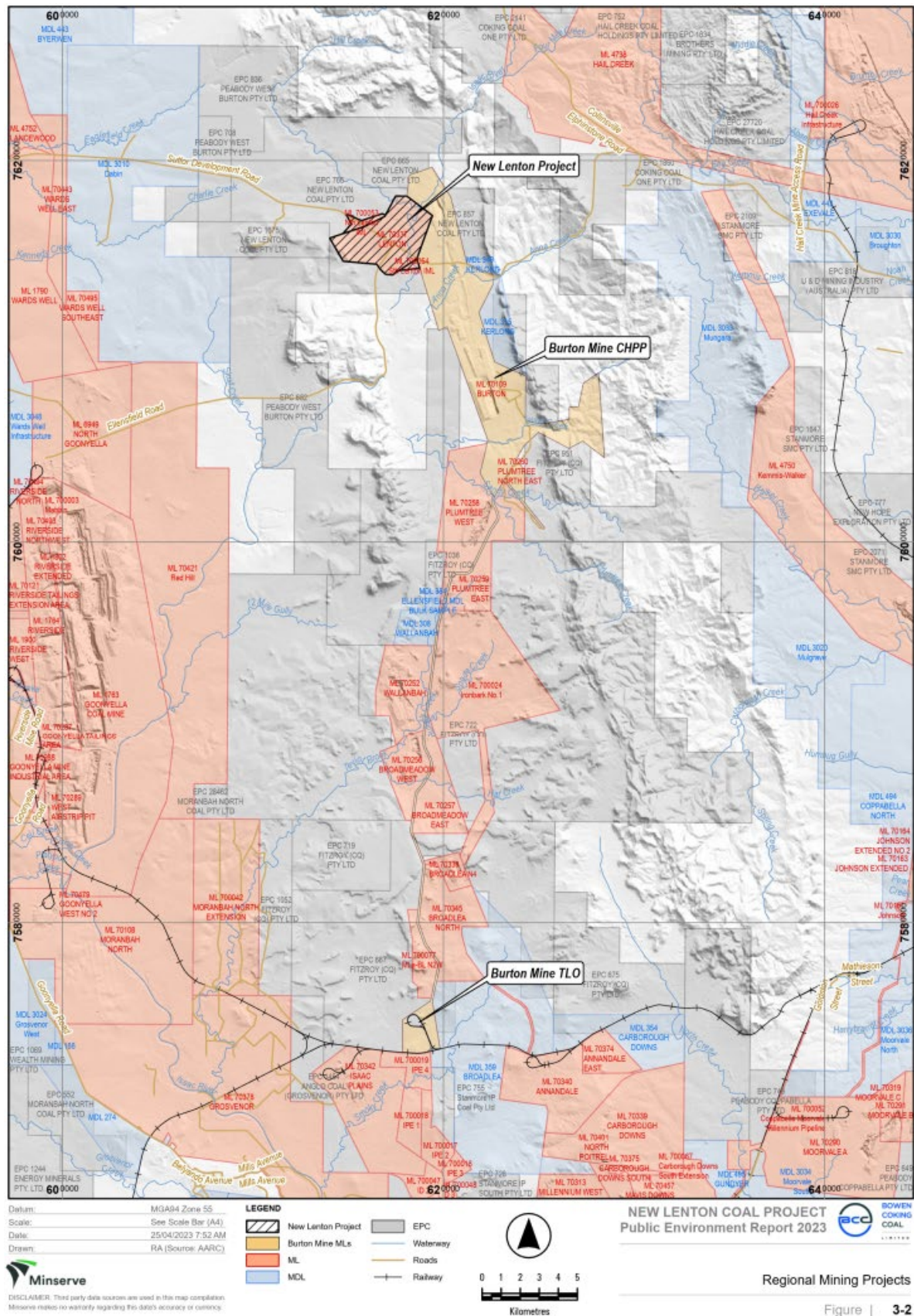


Figure 2. Regional mining projects in relation to the New Lenton Project.

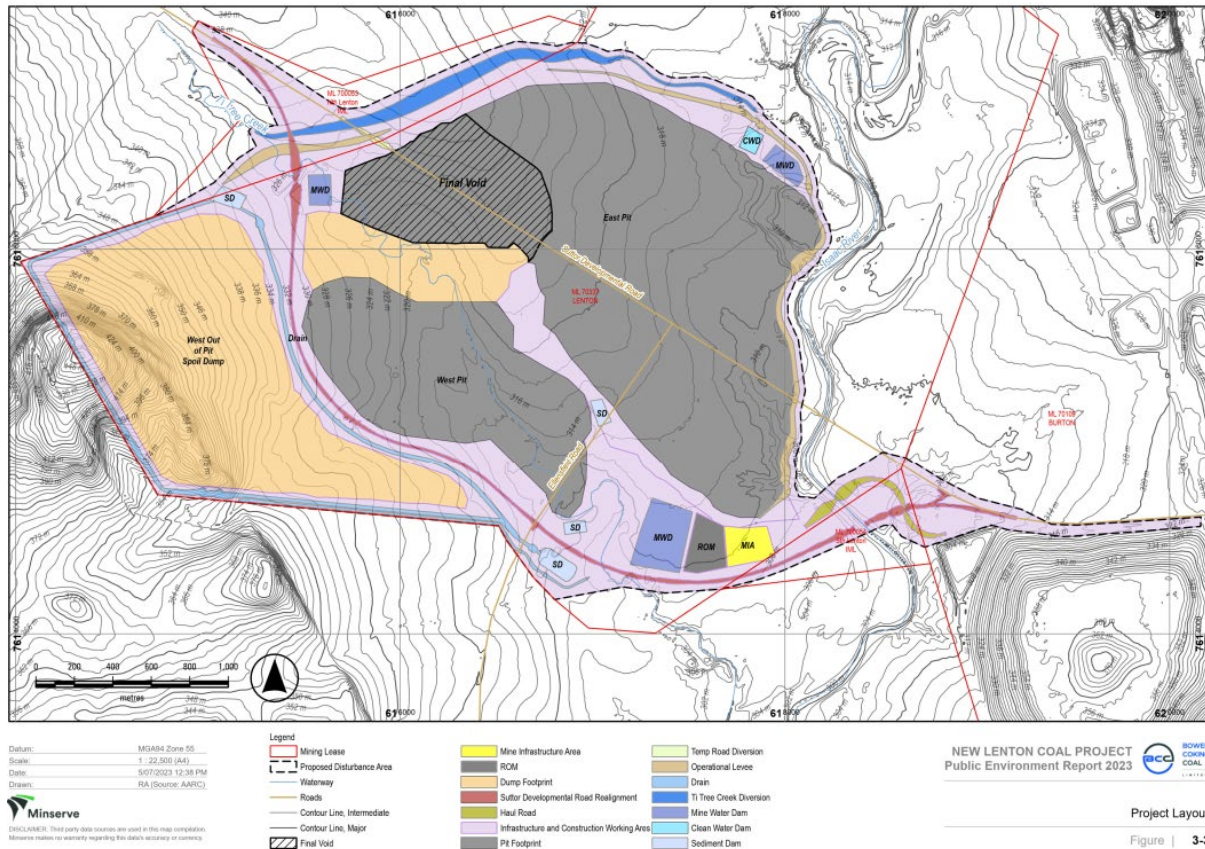


Figure 3. Project layout.

1.3 Project Objectives

Large coal mining developments have the potential to alter natural groundwater regimes and impact groundwater quality. Therefore, an assessment of potential impacts of the Project 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 study area, which includes the Project Site (i.e., proposed disturbance area) and surrounding areas that are potentially influenced by Project development.

Objectives of the GDE assessment are to:

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

1.4 Relevant Legislation and the Assessment Process

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 (the 'water trigger'). 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.

Following referral of the Project for assessment under the EPBC Act, the then Department of Agriculture, Water, and the Environment (DAWE) (now the Department of Climate Change, Energy, the Environment and Water (DCCEEW)) made a decision that Project development is a 'controlled action' with the controlling provisions being:

- Listed threatened species and communities (sections 18 & 18A)
- A water resource, in relation to coal seam gas development and large coal mining development (sections 24D & 24E).

DAWE determined that the Referral for the Project would be assessed by public environment report (PER).

1.5 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).*

1.6 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.

1.7 Climatic Considerations and Survey Timing

The nearest reliable public meteorological recording station to the Project Site is at the Moranbah Airport which is 79km to the south and within a drier climatic region. To provide context to local climatic conditions, point data from the SILO database (SILO 2023) was extracted for the Burton Mine (-21.55° / 148.15°) with rainfall records for the previous three years presented in **Figure 4**. The data indicates variable though typically average to below average rainfall for nearly all months through to November 2020 before turning to extremely wet conditions in December 2020. Extremely high rainfall was reported in November and December 2021, with unseasonal extreme rainfall in May 2022 and July 2022. Except for December, the months of September 2022 through to January 2023 all received strongly above average rainfall, with rainfall volumes only moderating in February 2023. A climatically dry period which commenced on February 8th facilitated completion of a field survey over a 6-day period from 20th to 25th February 2023, with only minor rainfall was reported early in the field survey (see **Figure 5**). Temperatures at the Moranbah Airport remained moderate during the field assessment, with a maximum temperature ranging from 25.8°C (20th February) and 31.8°C (25th February) and relative humidity (3pm) ranging from 70% (20th) to 38% (25th).

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 2020 – 2023 period with data indicating evapotranspiration is generally considerably higher than rainfall (SILO 2023). Exceptions to this occurred in May 2022, July 2022, and January 2023 where rainfall exceeded evapotranspiration, resulting in increased penetration of rainfall into the soil profile and recharge of shallow unconfined groundwater tables. 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 February 2023 (SILO 2023). 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 between 2013 to October 2017, rainfall volumes

declined up to August 2021, followed by a strong upward trajectory in rainfall volume to the period of field assessment (February 2023). 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.

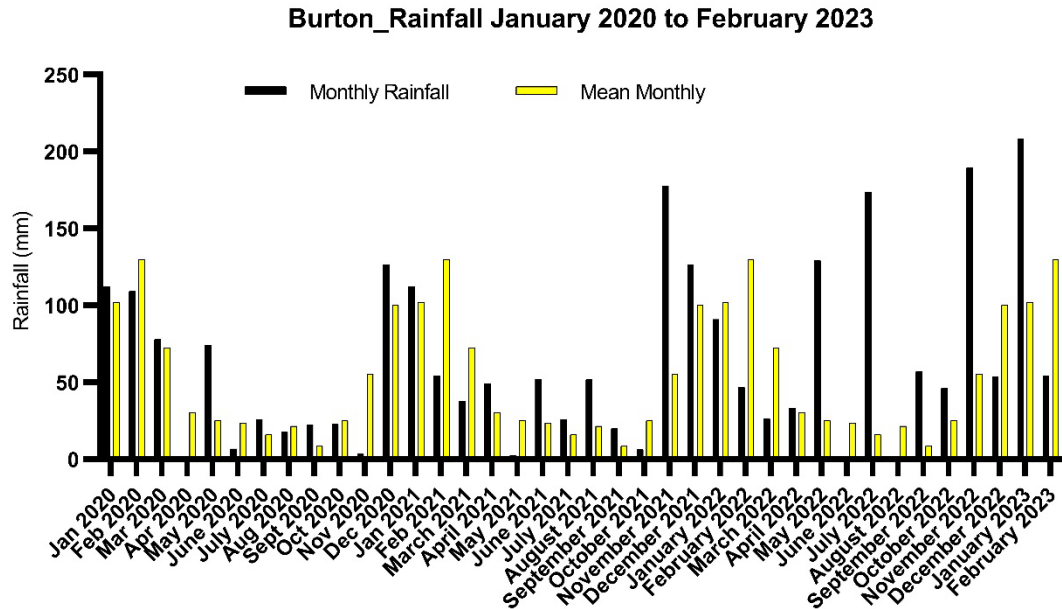


Figure 4. Rainfall for the period from January 2020 to February 2023 for Burton (-21.55° / 148.15°).

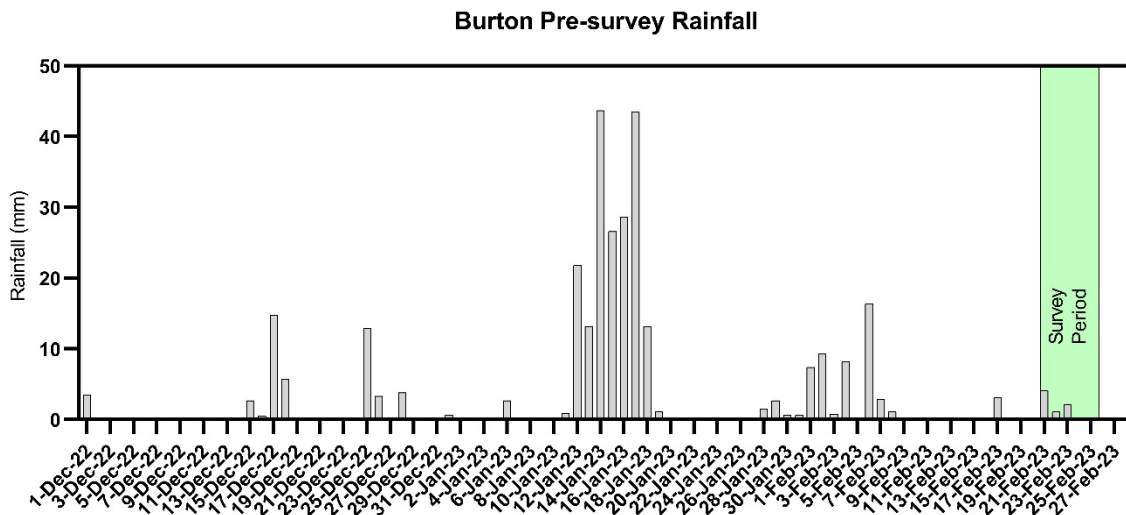


Figure 5. Daily rainfall for 3 months prior to field survey, with an intense rainfall event in January 2023, and a dry period between 8th February and survey commencement.

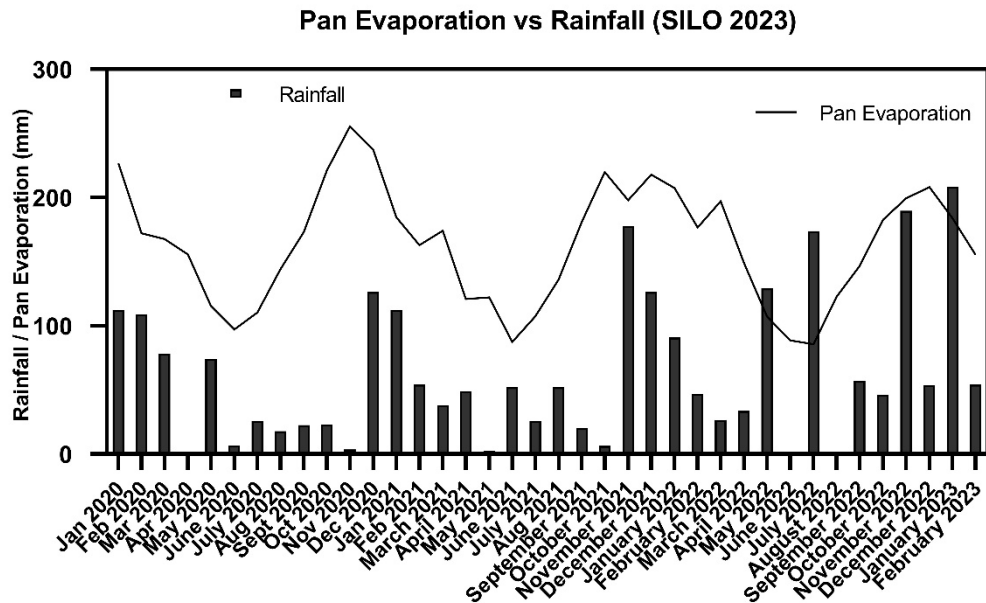


Figure 6. Evapotranspiration compared to rainfall for January 2020 to February 2023 (from SILO 2023).

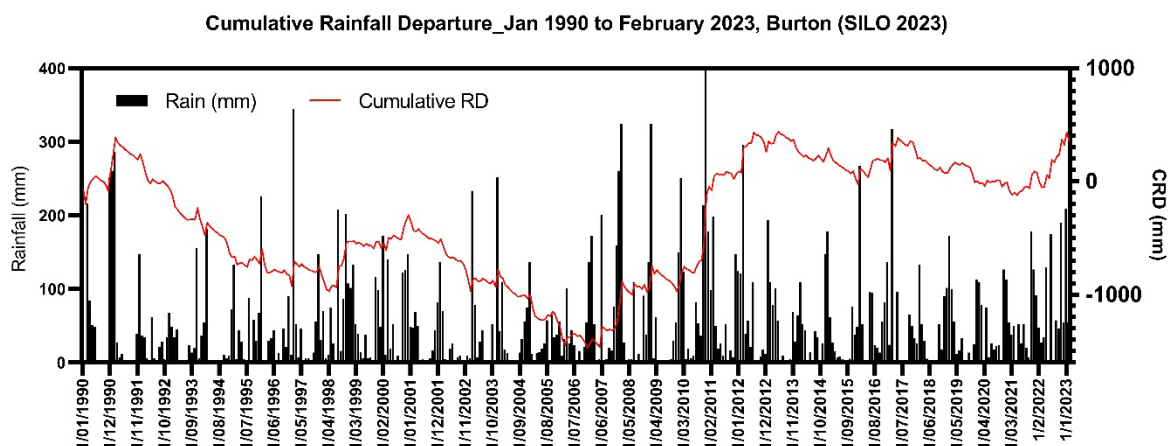


Figure 7. Cumulative Rainfall Departure demonstrating major and minor climatic fluctuations with a strong upward trajectory in rainfall volume from August 2021 to the period of field assessment (February 2023) (from SILO 2023).

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 Site 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*

Gently undulating plains interrupted by narrow drainage features which drain toward the south characterise the Project Site. The broad rises are formed by a variable cover of Pleistocene to Tertiary age cracking clay and residual silts and loams. Watercourses flow into the Isaac River, the largest drainage feature in the region which drains to the south. The Isaac River is the only watercourse with any significant development of a floodplain and associated alluvium. All watercourses flowing through the New Lenton Project study area are highly ephemeral in nature, flowing only after high intensity rainfall events. For the larger watercourse features, including the Isaac River and Hill Creek in the north of the Project Site, surface flows disappear quickly into the streambed sands as flows recede.

The Project study area is bound to the east by the Kerlong Range, which runs in north south orientation to the east of the Burton Mine, the Burton Range with passes to the south-east, and the Denham Range to the north which are all formed on the Triassic age Clematis Sandstone.

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, predominantly Quaternary age alluvial sands, clayey sands and clays, and some Tertiary sediments occur across the entire Project Site with variable thickness. The most significant occurrence of Quaternary age alluvium (Qa) is associated with the Isaac River where it is mapped as up to 1km wide, with thickness ranging from <10m to 21m (SLR 2023), attenuating along the major tributaries of Ti-Tree and Hill Creek. SLR (2023) suggests coarser grained alluvial sediments are largely restricted to the area of the river meander belt close to the existing Isaac River channel, with most of the near surface (0 – 20 m depth) mapped alluvium more likely dominated by clay and weathered sediments rather than sand and gravel deposits. Regolith, comprising weathered Triassic to Permian age bedrock mixed with Quaternary age colluvium and residual soils occur across most of the Project study area and surrounds, with the depth of weathering highly variable, ranging from 10m to 50m, although averaging 25m (SLR 2023). SLR (2023) also reports sequences of Tertiary age flow basalt flows outcropping in the north-western portion of the Project study area, although not being sufficiently extensive to be mapped as an individual geological unit.

Triassic Sedimentary Rocks: The Rewan Formation (Rr), being formed by arenitic mudstone, siltstone and some lithic sandstone, occurs over a broad portion of the Project study area and surrounds, with surface outcrop hidden by regolith cover. The Rewan Formation forms a thickness of up to 440m within the Project study area although structural controls result in reduced thickness towards the east (SLR 2023). The Rewan Formation is overlain by the medium to coarse grained cross bedded sandstones of the Triassic age Clematis Group. The Clematis group outcrops to the north (Denham Range), east (Kerlong Range and Carborough Range) and west (Burton Range) of the Project study area, with the Burton Range intruding into the south-western boundary of ML 70337 (SLR 2023).

Permian Sedimentary Rocks: The Rangal Coal Measures are the uppermost unit of coal-bearing strata in the Bowen Basin and the primary resource target within ML 70337 (SLR 2023). Thickness of coal seams is up to 8m for the Burton Rider and Leichardt / Vermont sequence with coal seams separated by an average of 20 to 25 m of sandstone, siltstone and mudstone interburden. The Rangal Coal measures are underlain by the Fort Cooper Coal Measures, separated by an average thickness of approximately 99 m of interburden, and mapped as outcropping in the south of ML70337 (DNRM 2018). The Burton Rider and Leichardt / Vermont sequence subcrop below regolith / alluvium in the south of ML 70337 and along an alignment running roughly parallel to and west of the Isaac River (GHD 2019; SLR 2023).

2.1.3 Hydrogeological Setting

Four main hydrostratigraphic units are identified in proximity to the Project Site being 1) Quaternary alluvial aquifers associated with the creeks and the Isaac River; 2) Regolith (weathered bedrock); 3) Tertiary basalt aquifers; and 4) Permian fractured rock aquifers (SLR 2023).

Data from borehole logs indicates that the alluvium is mostly dry with potentially water bearing coarse grained sediments largely restricted to the meander belt of the Isaac River close to the main sandy river channel (SLR 2023). Recharge of the alluvium naturally occurs via diffuse infiltration of rainfall and leakage of surface water from creeks following rainfall and surface flow. Groundwater levels within river alluvium in the south of the New Lenton MLs are permanently and artificially elevated due to the Burton Gorge Dam, which has resulted in increased (artificial) groundwater recharge via seepage of surface water directly into riverbank alluvium in pooled surface water behind the dam wall, which extends for approximately 2.5 km north of the dam wall towards the Project Site. Recharge of groundwater in the alluvium is estimated at 0.2 mm to 2.0 mm/year which equates to a recharge rate between 0.04 % and 1.7 % of long-term average annual rainfall. Hydraulic testing of monitoring bores installed in the alluvium indicates horizontal hydraulic conductivity ranging from 0.01 to 0.3 m/d (SLR 2023).

Tertiary age basalts are not considered a significant hydro stratigraphic unit in the Project Site due to its restricted spatial extent. Hydraulic testing at one Project monitoring bore installed into this unit indicates horizontal hydraulic conductivity is a relatively low 1.7×10^{-3} m/d (SLR 2023) (GW20), i.e., not in the range that would be considered as a reasonable aquifer.

Weathered Triassic and Permian strata form a blanket of regolith which overlies fresh Permian bedrock, with regolith hosting groundwater at various locations across the Project Site. Hydraulic testing indicates the horizontal hydraulic conductivity of regolith ranges between 1.2 m/d and 4.6 m/d, although these values are likely to be at the high end of expected hydraulic conductivities across the Site. Groundwater hosted in regolith is recharged through infiltration of rainfall and surface water leakage from drainage features following rainfall and surface flows, with estimates of recharge being at 0.2 mm to 2.9 mm/year, equating to 0.04 % and 0.49 % of long-term average annual rainfall (SLR 2023).

The Triassic Rewan Formation forms the dominant outcrop lithology across the Project study area, though is considered a major regional aquitard which limits hydraulic connectivity between shallow groundwater systems (hosted in regolith or alluvium) and the underlying Permian coal measures.

There is limited groundwater occurrence within the Rewan Formation itself, although minor volumes may be associated with localised fracturing and weathered horizons (SLR 2023).

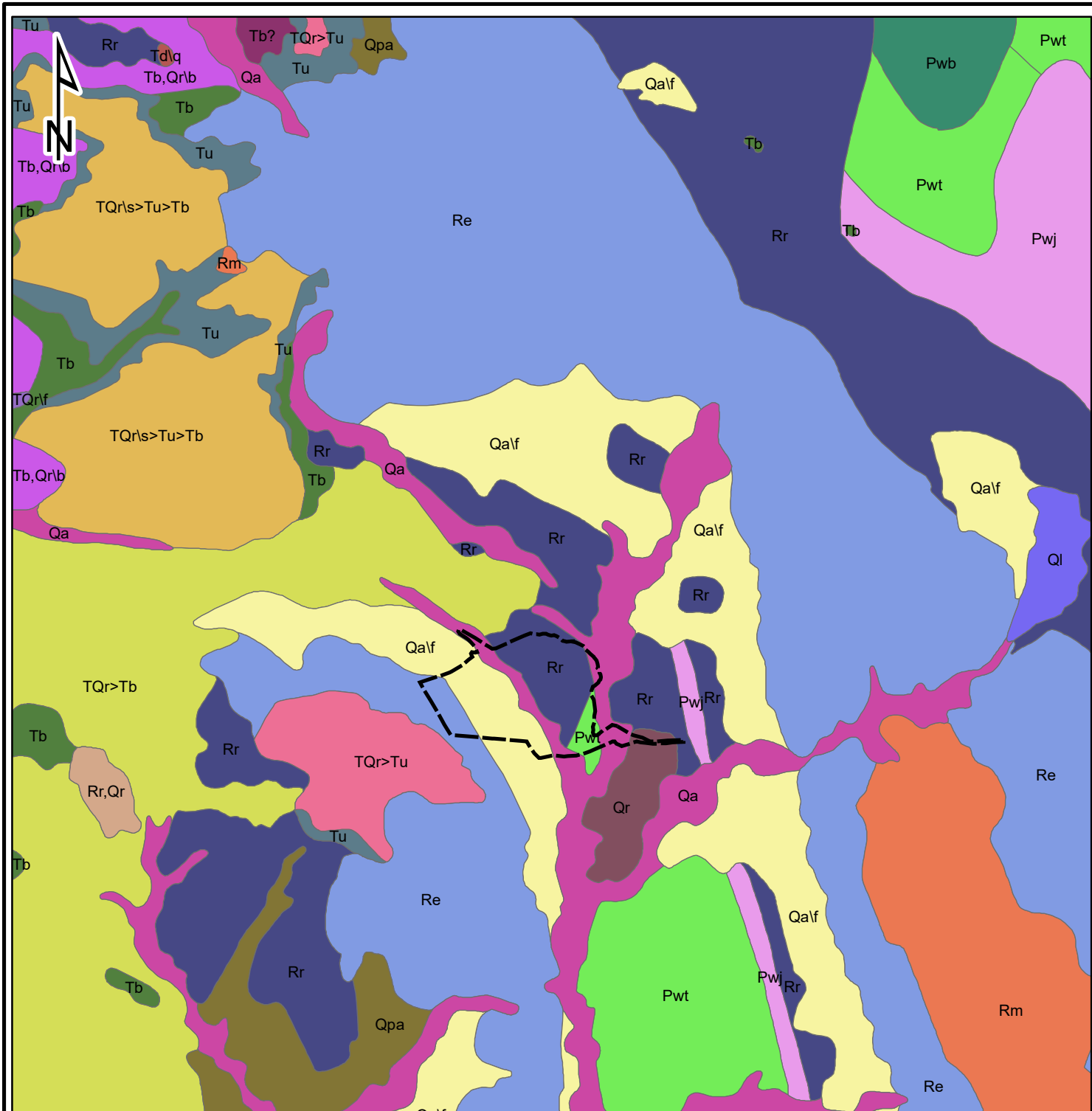
Groundwater is present in both the Permian Rangal and the Fort Cooper Coal Measures where it is preferentially hosted in coal seams along fractures and cleats, with interburden acting as low hydraulic conductivity confining units where groundwater does not occur. The coal measures are conceptualised to comprise multiple discreet aquifers within coal seams, that are interbedded with aquitards formed by overburden, interburden, and underburden (SLR 2023). Hydraulic testing indicates that the horizontal hydraulic conductivity of the coal seams is relatively low with values ranging between 0.001 m/d and 0.02 m/d, with hydraulic conductivity decreasing with depth, down dip and away from the Project Site (SLR 2023). Recharge to the coal measures is interpreted to predominantly occur along areas of subcrop via diffuse vertical flow from overlying lithologies such as regolith. Rainfall recharge to the coal measures is estimated at 0.1 to 3.9 mm/year, which equates to a recharge rate of 0.02 to 0.7 % of long-term average annual rainfall (SLR 2023).

2.1.4 Groundwater Standing Water Levels and Water Quality

Table 1 provides a summary of standing water levels (SWLs) and water quality (EC) for Project groundwater bores subject to ongoing monitoring, with monitoring bore locations shown in **Figure 9**. SWLs of monitoring bores installed within the basal parts of the alluvium range from 5.26 metres below top of casing (mbtc) in GW07 to 14.04 mbtc in GW19_37a, noting that on average top of casing 'stick-up' is 60cm above ground level. GW07 is located on the flood terrace of the Isaac River where surface water backs upstream behind the Burton Gorge dam impoundment, and hence groundwater levels are likely to be artificially shallow in the alluvium at this location. There is only limited seasonal variation in standing water levels for monitoring bores installed in the basal parts of the alluvium, typically not more than 0.5m, as indicated in **Table 1**. Water quality in the alluvium is fresh to saline, ranging from 1980 $\mu\text{S}/\text{cm}$ in GW17_37a (24 March 2020) to 15360 $\mu\text{S}/\text{cm}$ in GW06 (24 March 2020), indicating sporadic/isolated groundwater presence that is not well hydraulically connected throughout the alluvial extent, and areas of preferential freshwater recharge.

SWLs in the regolith are generally slightly deeper and more saline than reported for the alluvium, ranging from 7.67 mbtc in GW31b (28/03/22) to 16.49 mbtc in GW19 (28/03/22) with salinity values ranging from 2130 $\mu\text{S}/\text{cm}$ in GW31b (24/03/2020) to 16990 $\mu\text{S}/\text{cm}$ in GW19_41b (24/03/2020). The highly variable salinity again indicates sporadic/isolated groundwater presence that is not well hydraulically connected throughout the extent of regolith, and also areas of preferential freshwater recharge.

SWLs for Permian coal seams are as shallow as 13.4 mbtc in GW04 (09/05/19) installed in the Burton Rider Seam, with the deepest reported SWL of 35.68 mbtc in GW10 (09/05/19) installed in the Leichardt / Vermont Seam. Groundwater salinity values are highly variable, ranging from 3770 $\mu\text{S}/\text{cm}$ in GW11 (09/05/19) to 16800 $\mu\text{S}/\text{cm}$ in GW30b (8/11/22). The highly variable salinity again indicates groundwater is not well hydraulically connected throughout the extent of the coal measures.



Legend

Proposed Disturbance Boundary	Qa-QLD (Qa)	Qr's-QLD, Qf-QLD (Qr's, Qf)	TQR-QLD>Sutor Formation (TQR>Tu)	Tb-QLD, Qr'b-QLD (Tb, Qr'b)
LEGEND	Qalf-QLD (Qalf)	Rangal Coal Measures (Pwj)	TQR-QLD>Tb-QLD (TQR>Tb)	Tb?-QLD (Tb?)
Clematis Group (Re)	Ql-QLD (Ql)	Rewan Group (Rr)	TQRf-QLD (TQRf)	Tdlq-QLD (Tdlq)
Fort Cooper Coal Measures (Pwt)	Qpa-QLD (Qpa)	Rewan Group, Qr-QLD (Rr, Qr)	TQR's-QLD>Sutor Formation>Tb-QLD (TQR's>Tu>Tb)	
Moolayember Formation (Rm)	Qr-QLD (Qr)	Sutor Formation (Tu)	Tb-QLD (Tb)	
Moranbah Coal Measures (Pwb)	Qr'b-QLD (Qr'b)	TQa-QLD (TQa)		

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

Figure 8. Surface geology in the assessment area

Client

Bowen Coking Coal Ltd

0 2,000 4,000 6,000 8,000

Metres

Scale 1:130,000

Drawn By DG

Checked DS

File Path

Date

04-Jun-23

A4



3D Environmental
Landscape & Vegetation Science

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

Bore ID	E (AGD84)	N (AGD84)	Monitored Aquifer	Period of Monitoring	SWL Range (mbtc)**	Salinity Range (µS/cm)
Monitoring Bores Installed in Alluvium						
GW06	618097	7616723	Alluvium	20/02/2014 to 21/12/2022	10.848 (31/07/17) to 11.80 (31/12/19)	2859.38 (20/02/2014) to 15360 (24/03/2020)
GW07	617640	7613075	Alluvium	20/02/2014 to 21/12/2022	4.15 (15/05/14) to 6.82 (04/12/19)	4656.25 (04/12/2019) to 7421.88 (01/012/2017)
GW08	616926	7613720	Alluvium	09/05/2019 and 21/12/2022	11.5 (09/05/19) to Dry (21/12/22)	Not measured
GW09	617525	7614070	Alluvium	15/02/2014 to 21/12/2022	9.303 (15/02/14) to 16.96 (09/05/19) to Dry (12/12/22)	1401.55 (20/02/2014) to 3000 (01/04/2015)
GW19_37A	618032	7615770	Alluvium	17/12/2019 to 27/03/2023	10.008 (18/03/20) to 13.173 (25/12/21)	1980 (24/03/2020) to 2500 (08/11/2022)
Monitoring Bores Installed in Regolith						
GW19_33	618661.4	7617347	Alluvium/Regolith	17/12/2019 to 27/03/2023	11.036 (7/01/22) to 6.9642 (29/07/22)	7540 (17/12/2019) to 4860 (24/03/2020)
GW01	617299	7618210	Regolith	01/05/2014 to 21/12/2022	7.932 (15/02/14) to 12.75 (04/12/19) to Dry (21/12/19)	5718.75 (01/03/2017) to 7156.25 (01/04/2015)
GW19	612323	7620097	Regolith	1/05/2014 to 28/03/2023	22.301 (09/05/19) to 23.284 (16/02/14)	3109.38 (13/06/2014) to 3328.63 (01/05/2014)
GW30c	618094	7617368	Regolith	01/06/2018 to 27/03/2023	14.625 (31/05/18) to 14.69 (21/12/23)	7440 (01/05/2018) to 14700 (08/01/2022)
GW31b	617621	7617680	Regolith	01/06/2018 to 27/03/2023	11.483 (31/05/18) to 14.960 (23/04/23)	2125 (01/06/2018) to 2620 (08/11/2022)
GW19_36a	617984.7	7615809	Regolith	17/12/2019 to 27/03/2023	12.28 (31/12/19) to 14.63 (21/12/22)	NA
GW19_41B	617850.6	7615909	Regolith	17/12/2019 to 27/03/2023	14.51 (17/12/19) to 15.68 (21/12/22)	16640 (17/12/2019) to 16990 (24/03/2020)
Monitoring Bores Installed in Permian Coal Seams						
GW04	617876	7615892	Burton Rider Seam/weathered sandstone	01/05/2014 to 21/12/2022	12.157 (20/07/17) to 13.4 (9/05/19)	7210 (09/05/2019) to 21093.8 (20/02/2014)
GW30b	618088	7617382	Burton Rider Seam	1/06/2018 to 27/03/2023	14.91 (31/05/18) to 16.73 (3/12/19)	15660 (09/05/2019) to 16800 (08/11/2022)
GW27a	617885	7614847	Girrah Seam	1/06/2018 to 26/03/2023	14.824 (31/07/18) to 19.00 (3/12/19) to Dry (14/05/23)	5860 (09/05/2019) to 6120 (24/03/2020)
GW10	616032	7617014	Leichhardt/Vermont Seam	1/05/2014 to 21/12/2022	35.15 (21/12/22) to 36.35 (15/04/15)	2062.5 (01/05/2014) to 5860 (24/03/2020)
GW11	616294	7616680	Leichhardt/Vermont Seam	1/05/2014 to 27/03/2023	30.484 (31/05/17) to 31.48 (27/03/23)	3156.25 (01/12/2017) to 5000 (01/05/2014)
GW13	616881	7615480	Leichhardt/Vermont Seam	1/05/2014 to 29/03/2023	20.787 (23/03/17) to 22.108 (08/03/22)	10187.5 (01/03/2017) to 12200 (08/01/2022)
GW28a	617192	7616641	Leichhardt/Vermont Seam	1/06/2018 to 27/03/2023	16.22 (21/12/22) to 19.68 (4/12/19)	4500 (01/06/2018) to 5210 (24/03/2020)
GW30a	618084	7617395	Leichhardt/Vermont Seam	01/06/2018 to 27/03/2023	14.855 (31/05/18) to 16.57 (4/12/19)	13510 (09/05/2019) to 13980 (24/03/2020)
GW31a	617623	7617680	Leichhardt/Vermont Seam	1/06/2018 to 29/03/2023	14.772 (31/01/19) to 16.0249 (12/05/23)	4093.75 (01/06/2018) to 4810 (4/12/2019)

Bore ID	E (AGD84)	N (AGD84)	Monitored Aquifer	Period of Monitoring	SWL Range (mbtc)**	Salinity Range (µS/cm)
LEN486	615734	7615593	Leichhardt/Vermont Seam	1/05/2014 to 27/03/2023	27.389 (31/03/17) to 29.650 (13/05/23)	8210 (01/03/2017) to 15320 (24/03/2020)
GW19_40	617774.6	7615977	Leichhardt/Vermont Seam	17/12/2019 to 27/03/2023	13.359 (21/08/19) to 14.63 (21/12/22)	7400 (17/12/2019) to 6120 (24/03/2020)
GW19_41A	617840.8	7615916	Leichhardt/Vermont Seam	17/12/2019 to 27/03/23	13.56 (17/12/2019) to 14.04 (21/12/22)	4900 (17/12/2019) to 4230 (24/03/2020)
GW29a	618081	7616561	Underburden	9/05/2019 to 27/03/2023	12.325 (06/05/20) to 12.9606 (5/07/18)	8900 (09/05/2019) to 8660 (24/03/2020)
Monitoring Bores Installed in Basalt						
GW20	612676	7618392	Basalt	20/02/2014 to 28/03/2023	7.82(16/02/14) to 10.969 (21/07/17)	1010.94 (20/02/2014) to 1178.13 (01/05/2015)

**Calculated from Top of Casing (TOC)

2.2 Site Ecology and Ecohydrological Function of Characteristic Tree Species

2.2.1 Regional Ecosystems

Regional Ecosystem (RE) mapping produced for the Project study area (AARC 2023) is provided in **Figure 10**, which defines several regional ecosystems, typically dominated by eucalypt woodland and open forest habitats. This includes:

- RE 11.3.2, dominated by poplar box (*Eucalyptus populnea*) with a grassy understory on flood plain alluvium. The ecosystem has potential to be listed as a threatened ecological community (TEC) (Endangered)¹ under the EPBC Act and is Of Concern under the Queensland *Vegetation Management Act 1999* (VM Act).
- RE 11.3.4 being a woodland and open forest dominated by forest red gum (*Eucalyptus tereticornis*) woodland to open forest with other tree species potentially including Moreton Bay ash (*Corymbia tessellaris*), Clarkson's bloodwood (*Corymbia clarksoniana*), silver leaf ironbark (*Eucalyptus melanophloia*), Poplar gum (*Eucalyptus platyphylla*), narrow-leaf ironbark (*Eucalyptus crebra*) and swamp mahogany (*Lophostemon suaveolens*) may be locally common. RE11.3.4 fringes drainage channels and upper river terraces, typically on heavier clay soils. The ecosystem is listed as Of Concern under the Queensland VM Act.
- RE 11.3.7, being a woodland to open woodland dominated by Clarkson's bloodwood, Moreton Bay ash and Dallachy's bloodwood formed on quaternary alluvial deposits. The ecosystem is listed as Least Concern under the Queensland VM Act.
- RE 11.3.25, dominated by forest red gum or river red gum with scattered Moreton Bay ash, Clarkson's bloodwood and river oak (*Casuarina cunninghamia*). The ecosystem typically forms the immediate fringe of the larger drainage lines and is listed as a Least Concern under the Queensland VM Act.
- RE 11.3.36, dominated by narrow leaf ironbark, poplar box and / or silver leaf ironbark woodland with a grassy ground layer. The habitat occurs on Cainozoic alluvial plains, typically on older floodplain complexes and river terraces. The ecosystem is listed as a Least Concern under the Queensland VM Act.
- RE 11.8.5, being an open woodland dominated by mountain coolabah (*Eucalyptus orgadophila*) on weathered basal plains. The ecosystem is listed as Least Concern under the Queensland VM Act. The ecosystem is listed as a Least Concern under the Queensland VM Act.
- RE 11.9.1, being a woodland to open forest dominated by brigalow (*Acacia harpophylla*) mixed with Dawson gum (*Eucalyptus cambageana*) on fine-grained sedimentary rocks. The ecosystem is listed as Endangered under the Queensland VM Act and is potentially also a TEC (Endangered) under the EPBC Act.
- RE 11.9.7 / 11.9.7a, forming a shrubby woodland dominated by poplar box and false sandalwood (*Eremophila mitchellii*) on fine-grained sedimentary rocks. The ecosystem is listed as Of Concern under the Queensland VM Act.
- RE11.9.10, being an open forest dominated by poplar box with a secondary tree layer of brigalow and sometimes belah (*Casuarina cristata*) on fine-grained sedimentary rocks. The ecosystem is listed as Of Concern under the Queensland VM Act.

¹ Habitat condition thresholds are applicable.

- RE11.10.3, representing an open forest of lancewood (*Acacia shirleyi*) or bendee (*Acacia catenulata*) forest on coarse-grained sedimentary rocks, typically crests and scarps. The ecosystem is listed as a Least Concern under the Queensland VM Act.
- RE11.10.4a, being a woodland with dominant narrow leaf ironbark, Clarkson's bloodwood and/or lancewood on crests, scarps and upper slopes of ranges formed from medium to coarse-grained sediments with shallow soils. 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 potential 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 study area, as produced by BOM (2020b) is provided in **Figure 11**. In general, this assessment shows 'Low Potential' and 'Moderate Potential' for Terrestrial GDEs (TGDEs) associated with habitats on elevated / older flood plain deposits and foothills away from the Isaac River with typical REs including RE11.3.2, RE11.3.4, RE11.3.7 and RE11.9.7 to a lesser extent. 'High Potential' for TGDEs is associated with the major drainage features (excluding Ti-Tree Creek) where the vegetation is typically occupied by RE11.3.25. The larger watercourses including the Isaac River, Hill Creek, and un-named tributary streams in the north of the Project study area are consistently mapped as 'High Potential' for TGDEs and as 'High Potential' Aquatic GDEs, implying groundwater is discharging into these watercourses as baseflow.

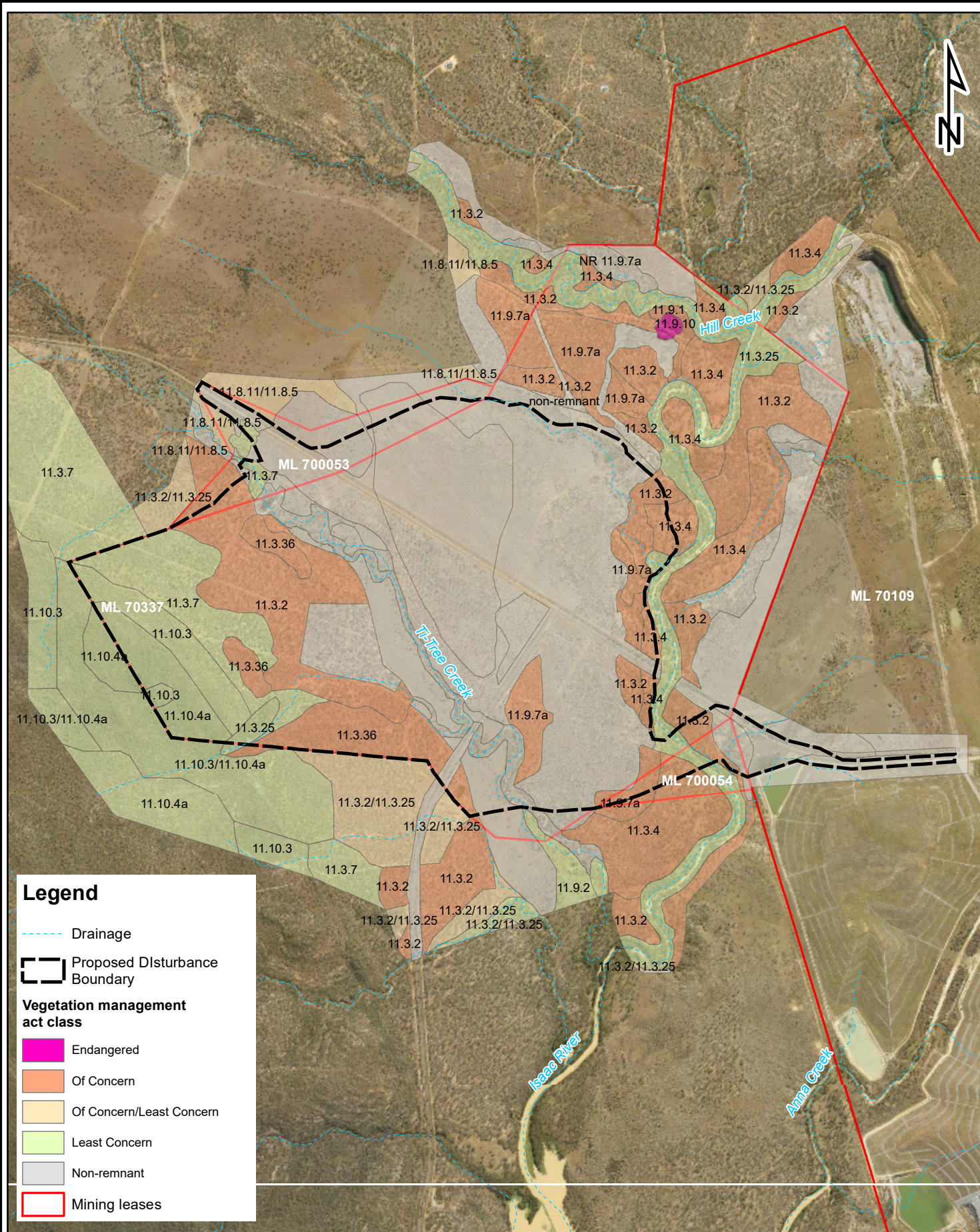
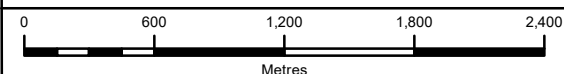


Figure 10. Field Verified Regional Ecosystems in the Project Area



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Scale 1:34,941

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2.2.3 Groundwater Dependent Species

Eucalypts: Forest red gum (*Eucalyptus tereticornis*), river red gum (*Eucalyptus camaldulensis*), poplar box, Clarkson's bloodwood, Moreton Bay ash, narrow leaf ironbark and silver leaf ironbark are the most prevalent eucalypt species in the study area. Forest red gum is the dominant riparian tree along creek and river frontages where it is associated with RE11.3.25, mixing with lesser proportions of river red gum. Moreton Bay ash and Clarkson's bloodwood become more abundant with increasing distance from the river. Poplar box occupies older, more elevated alluvial features typically as a dominant tree in RE11.3.2, with narrow leaf ironbark and silver leaf ironbark occupying habitats associated with footslopes on colluvium / basement rock outcrop or where alluvium thins significantly.

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 the predominant species on the Isaac River within the study area, is however a more adaptable species, occupying dry hill slopes in some localities and it would be expected to be more tolerant of changes to hydrological regime than *Eucalyptus camaldulensis* which is a riparian specialist.

River red gum 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 $\mu\text{S}/\text{cm}$ with Mensforth (1994) suggesting that river red gum will continue to utilise groundwater with salinity as high as 40 000 $\mu\text{S}/\text{cm}$ 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 $\mu\text{S}/\text{cm}$ 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).

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 Isaac River and minor tributaries as components of RE11.3.25 and RE11.3.4.

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 poplar box than river red gum with the associated heavy clay presenting a physical limitation on tree root penetration.

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

River oak: The water use strategy of river oak (*Casuarina cunninghamiana*) appears dependent on its position relative to a watercourse. O’Grady et al (2006b) determined river oak mainly utilised river water when adjacent to a stream channel, which is its most common topographic position. There has been no demonstration that river oak has capacity to utilise deeper groundwater sources, although is considered a facultative phreatophyte within and surrounding the Project study area.

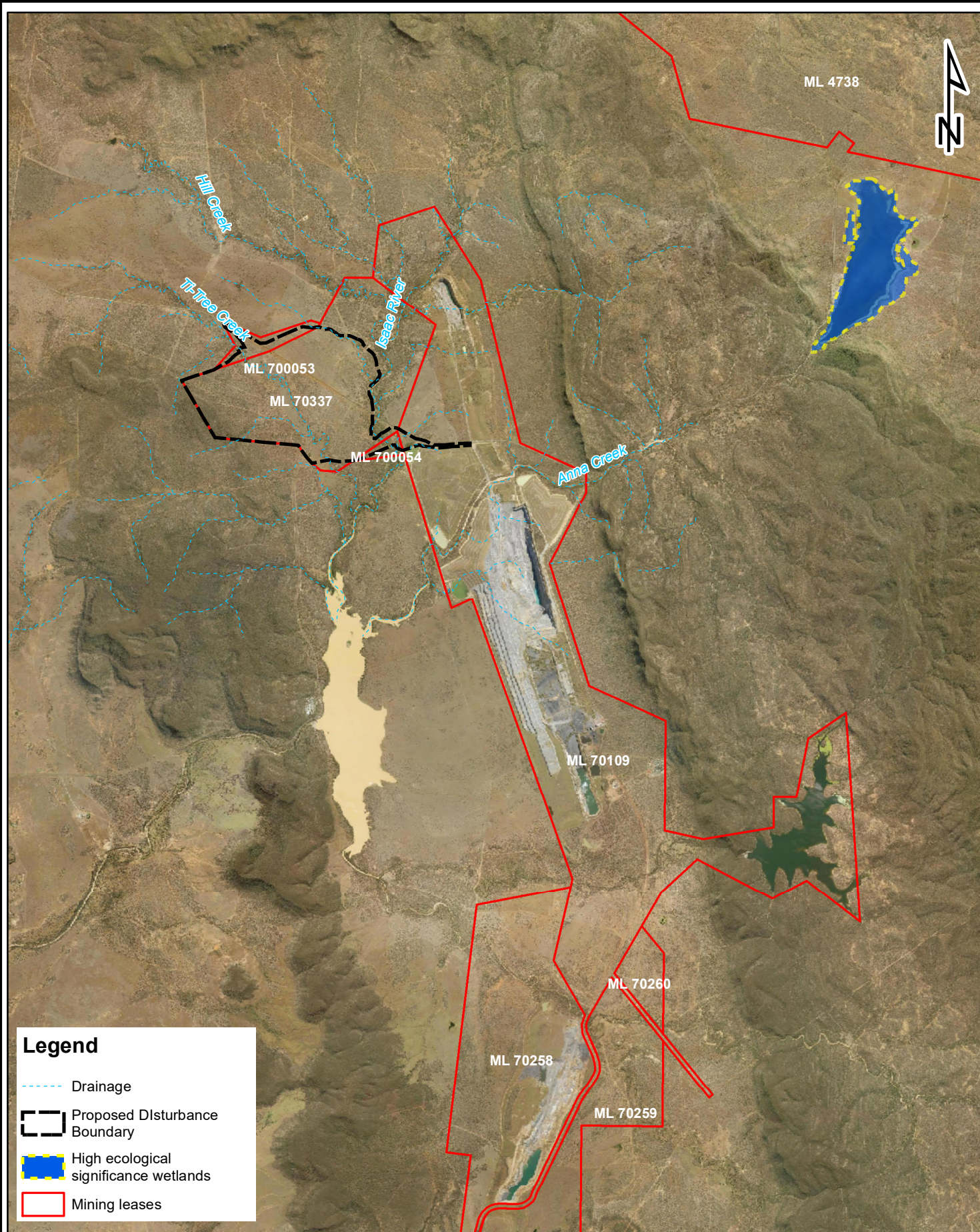
2.2.4 Summary - Depth of Tree Rooting and Salinity Tolerances

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 and Doody et al (2019) suggests that vegetation will only consistently utilise groundwater where it occurs at depths of <10m below the land surface. Based on these observations, it is unlikely that forest or river red gum would be utilising a groundwater table deeper than 15 mbgl, and for other species including poplar box and narrow-leaf ironbark, the groundwater depth threshold would be considerably shallower (<10m).

Based on evidence from published literature (Costelloe et al 2008; Thorburn et al. 1994, Mensforth et al. 1994) and the authors personal observation, it is unlikely that the terrestrial woody vegetation that characterises the study area would have capacity to utilise groundwater that has salinity greater than 30 000 $\mu\text{S}/\text{cm}$, 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 study area, with Lake Elphinstone approximately 10 km east and upstream of the Project providing the only local wetland representation.



Legend

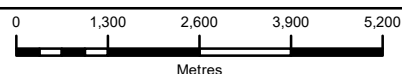
- Drainage
- Proposed Disturbance Boundary
- High ecological significance wetlands
- Mining leases

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

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

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3.0 Methods

The field assessment was completed over a six-day period from 20th to 25th February 2023. As described in **Section 1.6**, field conditions were moderate and followed an extremely wet period where over 500mm of rainfall were recorded from November 2022, with some minor showers occurring in the days leading up to the assessment. The following sections provide an overview of methods used to assess groundwater dependence of vegetation within the study area. 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 older residual surfaces. In total, 13 sites were chosen for targeted GDE assessment, to provide representative coverage of the major vegetation types, landform elements and drainage systems that are most likely to demonstrate groundwater dependence. 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, although field sampling included Moderate and Low Potential areas also, as well as areas where no groundwater dependence was indicated, particularly Ti-Tree Creek where a drainage diversion is planned.

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

1. The Isaac River
2. Ti-Tree Creek
3. Hill Creek and other Northern Tributary Streams
4. Older residual landforms.

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

Assessment Site*	Location / Geomorphic Position	Purpose of Assessment
Site 1, Site 2, Site 6, Site 7 and Site 13 (Isaac River)	All sites are Located on the main channel of the Isaac River with sampling extending from the inner riparian margins adjacent to the channel to more elevated river terraces at distance from the river.	The assessment at these localities aims to assess the moisture status of woody vegetation associated with immediate flood terraces of the Isaac River, as well as undertake shallow auger sampling both in the river channel and on the adjacent floodplain to test for the presence of a shallow / perched groundwater table above the regional alluvial water table, and sample general edaphic conditions. All sites

Assessment Site*	Location / Geomorphic Position	Purpose of Assessment
		are located within polygons mapped as High Potential TGDEs and AGDEs in the GDE Atlas. All sites are located within areas identified as RE11.3.25 in mapping produced by AARC (2023).
Site 4, Site 5 and Site 8 (Ti-Tree Creek)	All sites are located on the main channel and fringing embankments of Ti-Tree Creek.	The assessment aims to sample riparian vegetation, including vegetation fringing the immediate drainage channel and associated floodplain woodlands of Ti-Tree Creek. The assessment also aims to confirm general edaphic conditions and identify if associated vegetation is supported by a shallow groundwater system. Vegetation at Site 4 and Site 5 are identified as non-remnant vegetation (AARC 2023) and neither of the locations are classified as GDEs in the GDE Atlas (BOM 2020a). Site 8 is identified as a High Potential TGDE and AGDE with attributed values attenuating upstream from the Ti-Tree Creek junction with the Isaac River.
Site 11, Site 12 (Hill Creek and un-named tributary watercourse).	Site 11 and Site 12 are located on the immediate stream banks of Hill Creek and an un-named tributary in the northern region of ML70037.	The assessment aims to assess the moisture status and water sources of riparian vegetation fringing the immediate drainage channels of tributary streams and associated floodplain in the northern region of ML70037. Both are mapped within RE11.3.25 (AARC 2023) and located within areas mapped as both High Potential TGDEs and AGDEs in the GDE Atlas.
Site 3, Site 9 and Site 10 (Older elevated alluvial and residual surfaces)	Site 3 and Site 10 are located on older residual landforms over 500 from the channel of the Isaac River. Site 9 occurs on an older colluvial slope at the break of slope at the base of the Burton Range.	Site 9 aims to determine the moisture status of vegetation on the footslope of the Burton Range, mapped as a Moderate Potential TGDE in the GDE Atlas. RE Mapping completed by AARC (2023) indicates Site 9 is located on the interface between RE11.10.3 and RE11.3.7. Site 3 and Site 10 have been positioned to assess the moisture status of woodland vegetation associated with other alluvial / residual terraces. Both sites are identified as Low Potential TGDEs in the GDE Atlas, and Site 3 is identified as RE11.3.2 in mapping produced by AARC (2023). Site 10 is located outside the area covered by project based RE mapping.

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 potential² 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 ($\delta^{18}\text{O}$) and deuterium ($\delta^2\text{H}$) 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.

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

² Matric potential is the portion of the water potential that can be attributed to the attraction of the soil matrix for water.

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 stainless-steel measuring tray.

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

3.4.1 Soil Moisture Isotopes

Sampling was undertaken at regular intervals in auger holes to capture isotopic signatures from a range of potential plant moisture sources from the upper soil surface to the top of the phreatic zone in shallow water tables. The sampling intervals for soil moisture isotope analyses was dependent on auger yield and soil variation although in general, the initial soil sample was taken within the top 20cm of the soil profile and subsequent samples were taken at 0.5m intervals down the soil profile to the end of hole, mirroring the interval for SMP. Approximately 200mg of soil was collected for isotope analysis, sealed in airtight plastic sampling containers, double sleeved 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 where high soil moisture / groundwater was recorded. In some localities, isotopic sampling of complete profiles was undertaken to aid data interpretation.

3.4.2 Xylem Water Isotopes

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

1. Outer branches of trees of the GDE target tree were harvested for twig material. Two duplicate samples were prepared from each branch for analysis.
2. The position of trees subject to assessment were marked with a GPS and structural measurements were recorded including height and diameter at breast height (dbh).
3. Outer branches from each tree were harvested with an extendable aluminium pole.
4. Stem material approximately 5cm in length was sourced with stainless-steel secateurs.
5. Bark was immediately removed, and stems were sealed in wide mouth sample containers with leakproof polypropylene closure (approx. 125ml volume) and

immediately labelled with the tree number and placed in an iced storage vessel prior to dispatch to the ANU Stable Isotope Laboratory.

6. Upon receipt of samples at the ANU Stable Isotope Laboratory, samples were snap frozen (-18°C) until analysis.
7. For all twigs, samples were taken from xylem as close to the centre of twig as possible. For both xylem and soil samples, extracted water was analysed using a Picarro L2140i cavity ring-down spectrometer.

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

3.4.3 Water Sampling

To compare the isotopic signature of groundwater to that of vegetation, water samples were collected from various sources including:

1. Selected developed monitoring bores.
2. Shallow groundwater intercepted in soil augers.
3. Developed groundwater monitoring bores.

All samples were dispatched to ANU for analysis of stable isotope composition.

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):

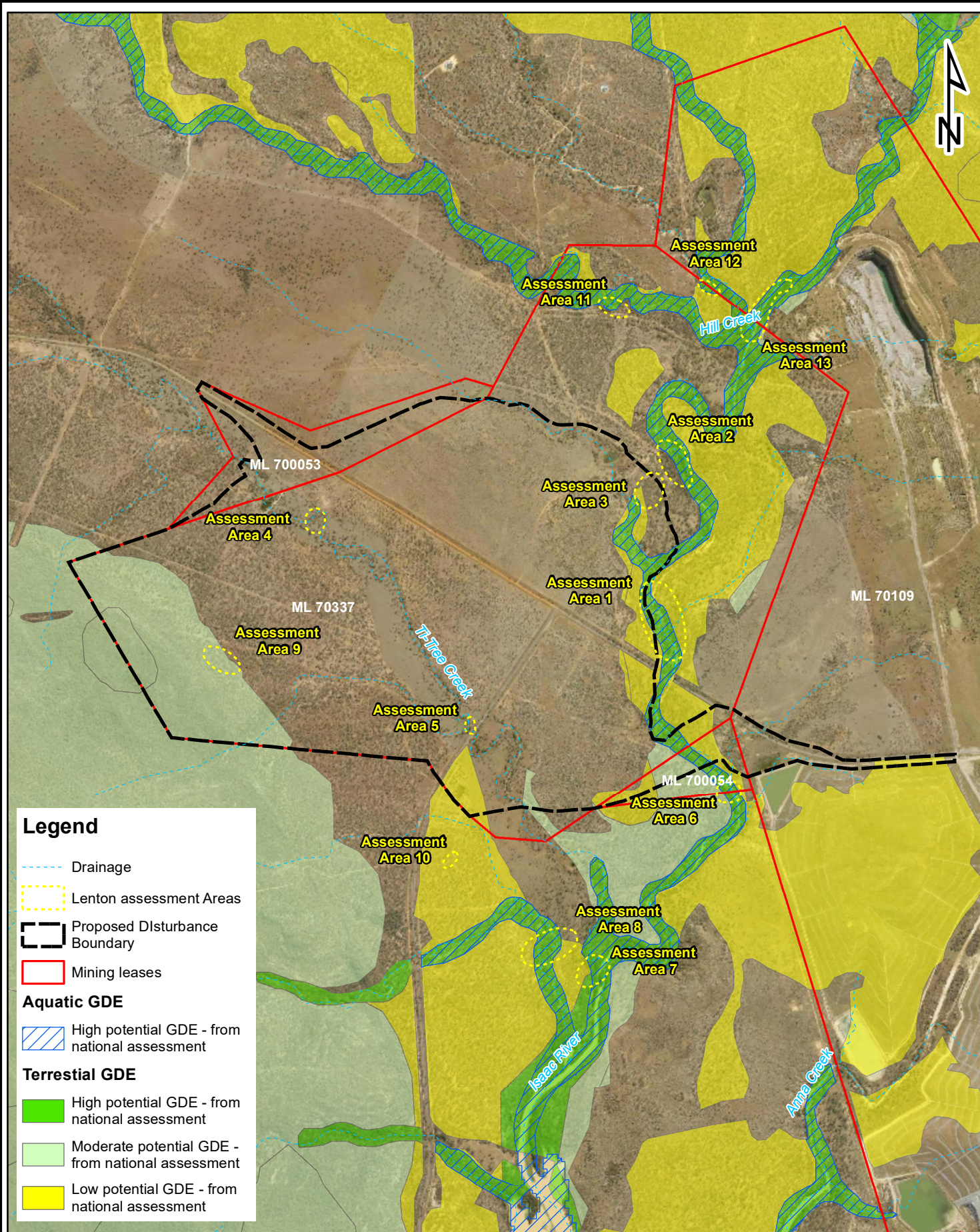
- Expected LWP for trees in equilibrium with a fresh to brackish saturated source of moisture ($\text{EC} < 1500 \mu\text{S}/\text{cm}$) = $> -0.2\text{MPa}$.

- Expected LWP for trees in equilibrium with a moderately saline soil moisture source (EC>1500 to 10 000 $\mu\text{S/cm}$) = <-0.2MPa to >-0.55MPa.
- Expected LWP for trees in equilibrium with a saline soil moisture source (EC>10 000 to 30 000 $\mu\text{S/cm}$) = <-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 $\mu\text{S/cm}$ is considered an unsuitable source of moisture for most trees and unlikely to be utilised to any significant degree by vegetation.

Step 2. Soil Augering and SMP: Soil augering is useful for a) direct observation of soil physical properties including depth to bedrock; b) physical observation of distribution of tree roots down within the soil profile; c) identification and sampling of shallow groundwater tables; and d) measurement of soil biophysical properties including SMP. For trees where LWP was within the expected range of values for GDE's under specific local salinity regimes, soil augering was undertaken to allow direct observation of the physical features of the soil profile, as well as facilitate measurement of SMP 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).

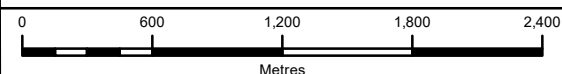
Figure 13. GDE areas targeted for field assessment.



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3.6 Review of Historical Imagery

Development of the northern extent of a mine pit at Burton Mine, where it directly abuts the riparian fringe of the Isaac River, commenced in 2003. To facilitate a temporal assessment of vegetation condition and gain an understanding of the potential impacts of groundwater drawdown associated with mining adjacent to this northern extent of the mining operation at Burton Mine, a sequence of aerial imagery was acquired covering a period of approximately 30 years within images well before mining commenced (1987), immediately prior to pit construction (2000), immediately post construction of the northern void (2004) and 16 year post construction of this pit (2018). The imagery had variable spatial resolution, dependent on data source and was assessed directly on the screen for features including land management practices, presence of dead trees and stags and general canopy continuity and condition. Imagery that was integral to the assessment included:

1. QAP8554 Harrybrandt, July 1987 Black and White (Run 2 -134) (1:24, 900).
2. QAP5480 Harrybrandt, July 2000 Colour (Run 1 -189) (1:40, 000).
3. QAP6117 Harrybrandt, June 2004 Colour (Run 2 -031) (1:40, 000).
4. Digital aerial imagery for Queensland Globe, September 2018. Approximate spatial resolution is 0.15m.

Consideration was given to acquisition of NDVI imagery to allow a quantitative assessment of canopy vigour to be made. However, lack of resolution of earlier imagery (e.g. Landsat has a 30m pixel size) was considered problematic and in riparian habitats examined on the ground, the understory retained relatively intact and vigorous condition. This would have confused the NDVI signature in those areas where the canopy is dead or losing vigour.

3.7 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. Climatic conditions preceding the assessment were extremely wet, despite a two-week period prior to the field assessment when the weather dried. Wet ground conditions are not amenable to direct assessment of groundwater usage by vegetation during drought periods, though it does provide an opportunity to assess where shallow tables accumulate in the subsurface following moisture recharge, as well as provide valuable information on the sources of water used by trees on a seasonal basis, which is important to contextualise the potential for ecological impact associated with groundwater drawdown.
2. 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.
3. Due to the intensive nature of the data collection, representative areas were chosen for GDE sampling which were used as a basis for extrapolation over broader areas considered to present similar ecohydrological function. The data collection process aimed to inform conceptualisation of the types of GDEs present on the Site and their general distribution, so an informed risk assessment could be completed.

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

4.0 Results

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

4.1 Leaf Water Potential Measurements

A summary of LWP sampling results for all trees, including locations of sampled trees relative to waterways is provided in **Appendix A**. Representation of average LWP results for all assessment sites is shown in **Figure 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 Extremely High and Very High water availability and demonstrate potential for utilisation of fresh groundwater based on data from relevant monitoring bores. This includes all Isaac River sites (Site 1, Site 2, Site 6, Site 7 and Site 13) as well as Site 8 on Ti-Tree Creek (near the junction with Isaac River). Site 11 and Site 12 on northern tributaries also fall within this category. Further investigation of SMP and stable isotopes will be necessary at these sites to determine the nature and degree of any 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 Site 5 from Ti-Tree Creek, which will require investigation of stable isotope values and groundwater levels from nearby monitoring bores.
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 all sites on older alluvial and residual surfaces (Site 3, Site 9 and Site 10) as well as Site 4 from Ti-Tree Creek. These sites are unlikely to be utilising groundwater to any extent.

Based on LWP data, sites associated with the Isaac River (Site 1, Site 2, Site 6, Site 7 and Site 13) have the highest potential for groundwater utilisation within the study area, although data from individual trees shown in **Figure 15** suggest considerable variation in water availability for trees within individual sites, suggesting water availability varies with topographic position and distance to the river channel. Due to the high rainfall volumes received prior to the assessment, which would have increased availability of soil moisture in the shallow profile, it is considered extremely unlikely that any tree at any of the assessment sites would have been reliant on saline water sources (e.g., groundwater >20 000 $\mu\text{S}/\text{cm}$) at the time of assessment.

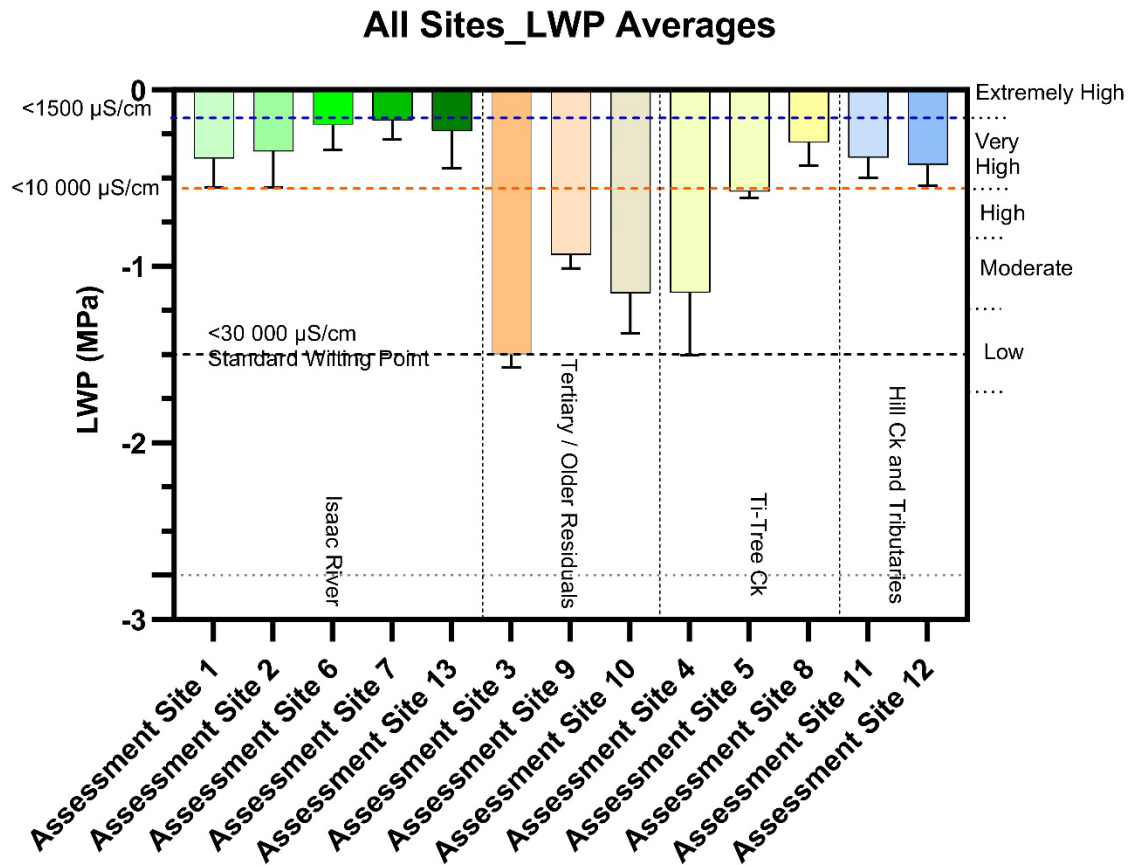


Figure 14. Average LWP readings for all GDE Assessment Areas. The blue line ($> -0.2 \text{ MPa}$) indicates expected LWPs for trees in equilibrium with a non-saline saturated source of soil moisture; the orange line ($> -0.55 \text{ MPa}$) indicating potential values for trees in equilibrium with a moderately saline soil moisture source (EC 10 000 $\mu\text{S/cm}$). Standard Wilting Point is indicated ($< -1.5 \text{ MPa}$). Low to moderate moisture availability for sites associated with older residuals indicates an unlikelihood that trees associated with these sites will be utilising groundwater to any degree.

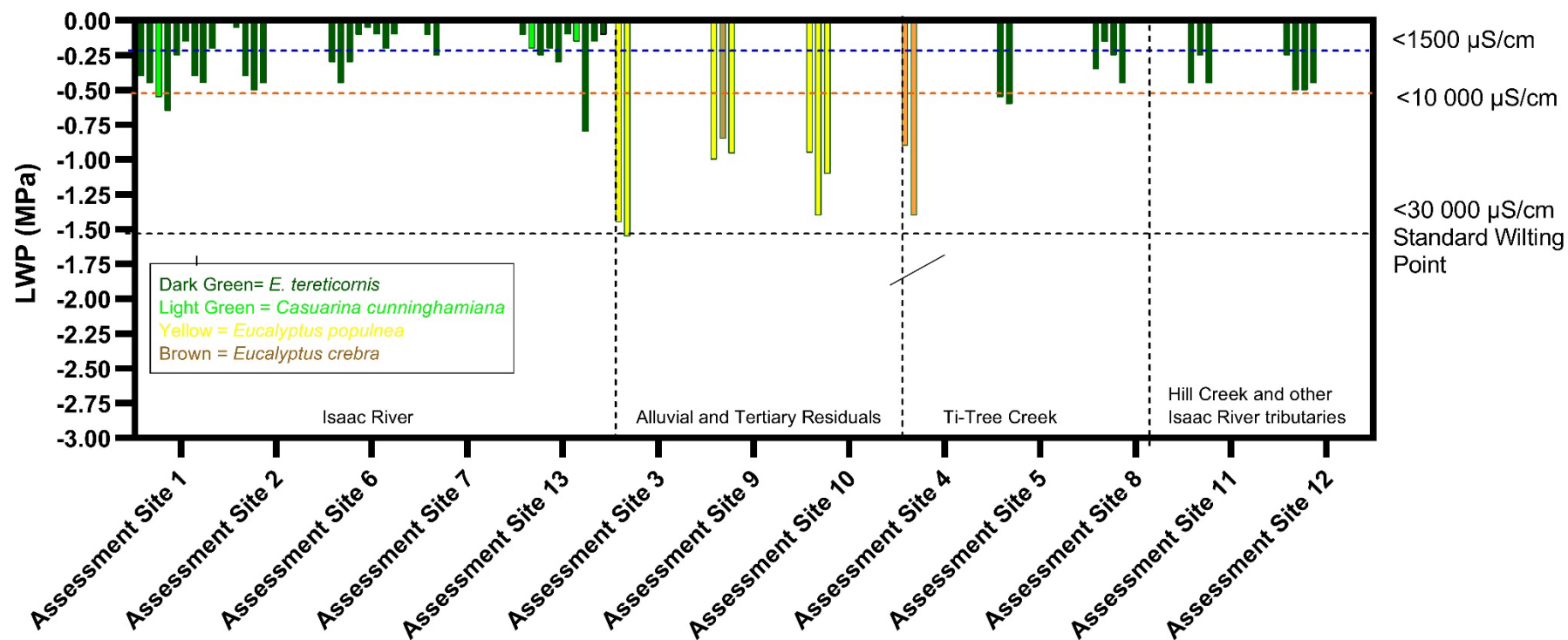


Figure 15. LWP results for individual trees per species at each of the 13 GDE assessment sites, showing considerable variation in moisture values between trees at individual sampling locations.

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

Site	Average LWP (MPa)	Water Availability	Comments
Isaac River Sites			
Site 1, Site 2, Site 6, Site 7, Site 13	-0.32MPa to -0.175 MPa	Extremely to Very High	The riparian frontage of Isaac River represents well developed riparian open forest typical of RE11.3.25 dominated by forest red gum, river oak, and minor river red gum (see Photograph 1 at Site 1). The lower alluvial terrace forms at approximately 5m above the sandy channel floor where RE11.3.25 merges with 11.3.4 moving away from the river, before rising to an older more elevated terrace occupied by poplar box woodland (RE11.3.2). Riparian canopy and sub-canopy vegetation is entirely intact though groundcover is dominated by exotic grasses (mostly Green Panic – <i>Panicum maximum</i> var. <i>trichoglume</i> and buffel grass (<i>Cenchrus ciliaris</i> away from the river frontage). Five sites (Site 1, Site 2, Site 6, Site 7 and Site 13) with 33 trees in total (including 3 river oak) were sampled for LWP with average LWPs ranging from -0.39 MPa (Site 1) to -0.175MPa (Site 7). There is no consistent pattern to the LWP values with trees directly adjacent to the channel often presenting similar or more negative LWP values than trees at greater distance. Site 6 is an exception where the three trees at greatest distance from the river channel presented the most negative LWP values (Tree 1, Tree 2 and Tree 3), representing drier soil conditions with increasing distance from the river. Relevant groundwater monitoring bores are GW06, GW07, GW09, GW19_37a, GW19_33 screened within the alluvium all indicate groundwater depths at <15.0 mbgl and salinity values generally below 10 000 µS/cm. Due to incision of the Isaac River into its banks from flooding to depths of up to 10m, groundwater would be well within tree rooting depth, particularly for trees adjacent to the river channel. The data for these sites indicates than many trees at the Isaac River sites are likely to be accessing groundwater. Groundwater usage is however not ubiquitous with some trees continuing to rely on soil moisture, particularly those at greatest distance and height above the river channel.
Trees Associated with Older Alluvial and Tertiary Residuals			
Site 3, Site 9, Site 10.	-1.5 MPa, -0.958MPa, -1.15 MPa	Low	All sites are elevated above flood level of the Isaac River and tributaries. Sites are occupied by RE11.3.2 and 11.10.3

Site	Average LWP (MPa)	Water Availability	Comments
			which comprise shallow rooted <i>Eucalyptus populnea</i> and <i>Eucalyptus crebra</i> (Photograph 2). Average LWPs for both sites are 'Low' to 'Moderate'. Relevant groundwater monitoring bores include those screened in regolith (GW19_33, GW01, GW19, GW30c, GW31b, GW19_36, GW19_41b) which are at greater distance from the river than monitoring bores installed in alluvium. Groundwater levels in these monitoring bores are typically below 10mbgl, which is below the rooting depth of the predominant vegetation. The data indicates woodland habitats on the older alluvial and residual landforms are unlikely to be utilising groundwater to any degree.
Sites Associated with Ti-Tree Creek			
Site 4, Site 5, Site 8	-1.15MPa, -0.575MPa and - 0.3MPa.	High to Low	Site 4 and Site 5 are located on Ti-Tree Creek where the feature is represented by shallow drainage channel with a clayey floodplain. Basement outcrop (fine grained sedimentary rocks) is present in the channel at Site 4, with the floodplain mantled by a blanket of black vertosols, where the vegetation is dominated by shallow rooted mountain coolabah (<i>Eucalyptus orgadophila</i>). LWP values at this site are strongly negative (average value of -1.15MPa) and there is no evidence for groundwater utilisation considering the depth to groundwater at the nearest monitoring bore (GW28a) exceeds 15m. Vegetation at Site 5 is reduced to a narrow fringe of forest red gum along the creek channel. LWP values are higher than reported for Site 4 (average of -0.575MPa) although not sufficiently elevated to indicate utilisation of a shallow groundwater table. Groundwater at the nearest monitoring bore (GW13) is >20mbgl and saline (see Table 1) meaning that LWP values are likely imparted by soil moisture. Site 8 is located on Ti-Tree Creek (Photograph 3), approximately 500m from its junction with the Isaac River. LWP values are elevated (-0.3MPa average) suggesting potential utilisation of groundwater. The nearest relevant monitoring bore (GW09) is dry, indicating that the LWP values may be imparted by the soil profile. Additional interrogation of soil and isotopic data is required to determine likelihood of groundwater dependence.
Sites Associated with Northern Tributaries			

Site	Average LWP (MPa)	Water Availability	Comments
Site 11, Site 12	-0.39 and - 0.45MPa	High	Site 11 and Site 12 are located on Hill Creek and an unnamed tributary creek respectively. Both drainage systems are characterised by sandy channels incised into loamy alluvial / residual sediments with forest red gum forming the dominant canopy species (RE11.3.25). LWP values at both sites are Very High (-0.38MPa and -0.45MPa respectively) suggesting potential for groundwater utilisation. The nearest groundwater monitoring bore (GW28a) is installed into the Leichardt / Vermont Coal Seam and has a potentiometric level at >15mbgl. There are no nearby bores screened in regolith. As LWP values indicate potential for groundwater utilisation, further assessment of soil moisture and stable isotopes will be required to provide a more informed assessment of vegetation moisture sources.



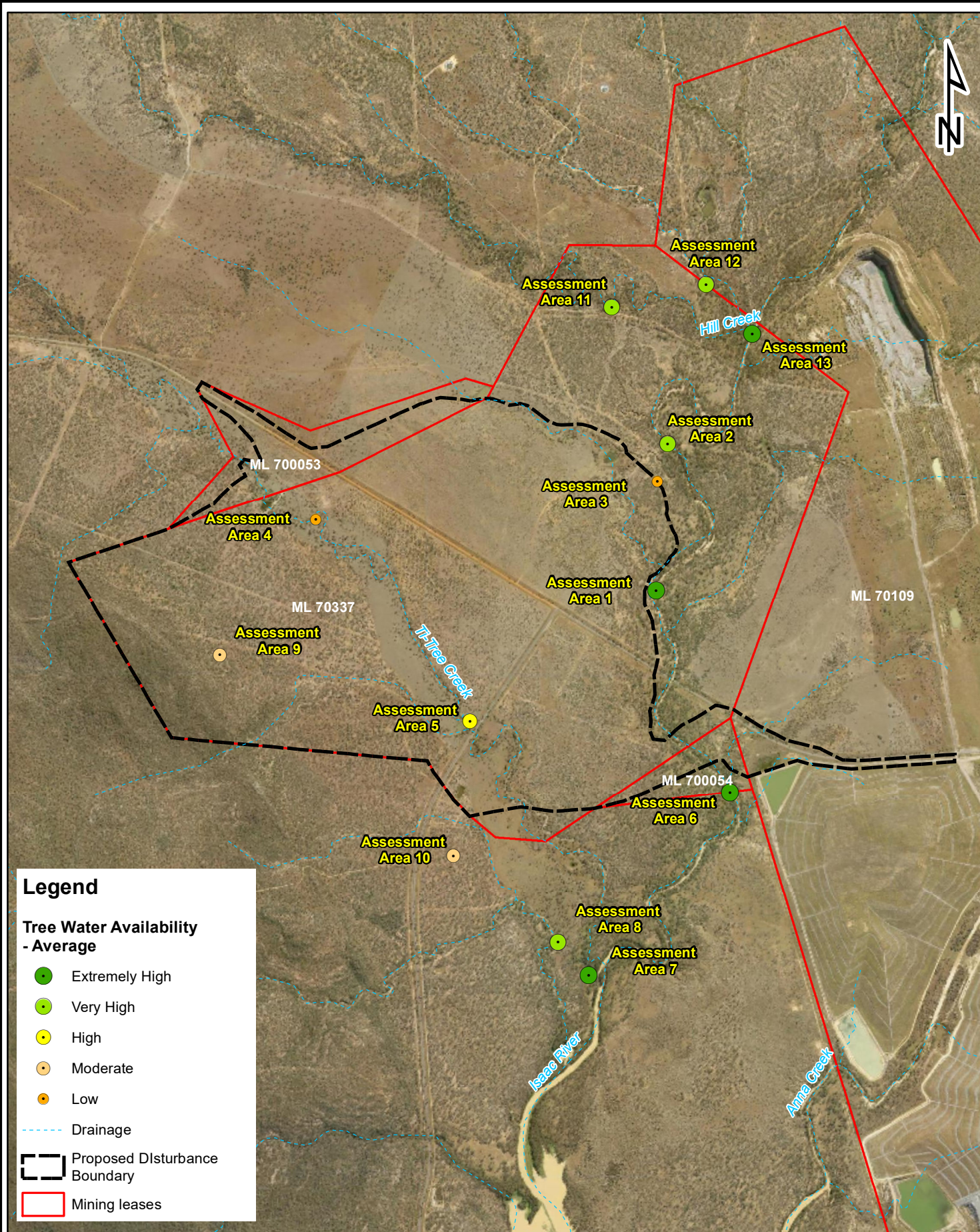
Photograph 1. Site 1 on the Isaac River, looking to the north toward sampled tree S1_T8 in the river channel on the east, and S1_T7 in for photograph foreground.



Photograph 2. Site 10, located on an older alluvial / residual plane approximately 500m west of the Isaac River. The dominant tree is poplar box (*Eucalyptus populnea*).



Photograph 3. The narrow sandy channel of Ti-Tree Creek at Site 8, with Tree 1 (S8_T1) on the right.

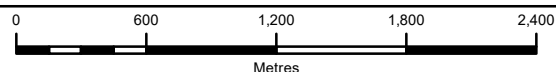


Extremely High	> -0.276 Mpa
Very High	< -0.276 to -0.580 Mpa
High	< -0.580 to -0.896 Mpa
Moderate	< -0.896 to -1.21 Mpa
Low	< -1.21 to -1.72 Mpa
Very Low	< -1.72 to 2.21 Mpa
Extremely Low	< -2.21 Mpa

Figure 16. Average LWP values for GDE assessment sites.

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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 sites were considered representative of a particular habitat or landform. In total, 8 auger holes were installed with the results summarised below, and locations shown in **Appendix C** relative to LWP values and raw data from SMP readings provided in **Appendix D**.

- **Isaac River Sites**

- **Site 1:** Two auger holes were installed at Site 1, with a single auger placed in the sandy river channel to identify and sample (if present) any shallow water table couched in the river sand. A second auger hole was installed on the lower river terrace, approximately 3m above and 5m from the margins of the river channel to gain an understanding of soil conditions within the tree rooting zone (near S1_T7). At auger 1 (S1_AU1), groundwater was intersected at 0.7 mbgl (**Figure 17**) and a sample of extremely fresh water ($296\mu\text{S}/\text{cm}$) was collected for isotopic analysis. For auger 2 (S1_AU2), the hole was installed to a depth of 3.7 mbgl, which is 50cm below the water table which was intersected at 3.2 mbgl. The soil profile comprised a layered mix of medium to coarse sand, minor clayey sand, with groundwater hosted in coarse river sand and gravel. Due to hole collapse back to the depth of the water table, a groundwater sample could not be collected from Site 1_AU2. **Figure 17b** demonstrates that downhole SMP increased consistently from -0.32MPa at the top of the hole to '0' at the base, consistent with the intersection of fresh groundwater. The high LWP values reported for trees at Site 1 can readily be explained by utilisation of shallow groundwater within the tree root zone, as well as high moisture availability in the unsaturated portion of the soil profile for those trees with more negative LWP values.
- **Site 6:** Two auger holes were installed at Site 6, including a single auger placed in the sandy river channel, and a second deeper auger hole installed on the lower river terrace, approximately 3m above and 10m from the river channel margins. Auger 2 was placed to sample soil conditions within the tree rooting zone adjacent to tree 7 (S6_T7). Fresh groundwater ($285\mu\text{S}/\text{cm}$) was intersected at 1.0 mbgl in auger 1 with the groundwater table associated with a matting of fibrous tree roots (**Figure 18**). Auger 2 (S6_AU2) was placed to a depth of 3.2 mbgl with fresh groundwater ($285\mu\text{S}/\text{cm}$) intersected at 3.0 mbgl. Like S1_AU1, the soil profile comprised a layered mix of medium to coarse sand, some minor clayey sand, with the groundwater table hosted in coarse river sand and gravel. Tree roots were recorded at two depths with a dense matting of coarse tree roots recorded above a wet sandy clay interval at 2.5 mbgl (see **Figure 18b**). **Figure 18b** indicates that downhole SMP is consistently high in the entire soil profile ($> -0.21\text{ MPa}$) and the high LWP values reported for trees at Site 6 can accounted for by utilisation of a combination of both shallow groundwater and readily available soil moisture in the unsaturated portion of the profile, depending on distance from the river and topographic position.

- Site 13: As per Site 1 and Site 6, two auger holes were installed at Site 13, including an auger placed in the sandy river channel, and a second auger hole installed on the river terrace approximately 10m from and 4m above the river channel. Auger 2 was placed to sample soil conditions within the tree rooting of Tree 2 (S13_T2). Both augers intersected a fresh groundwater table at 1.3 mbgl in auger 1 (317 $\mu\text{S}/\text{cm}$) and 4.0m in auger 2 (365 $\mu\text{S}/\text{cm}$) (**Figure 19**) hosted in coarse river sand. Auger 6 presented a slightly more heterogenous soil profile than Site 1 and Site 6, with a coarse gravel layer intersected at 2.5 mbgl, and intervals of moist to wet fine to medium sand intermixed with wet sandy clay. A notable feature of auger 2 is the intersection of coarse tree roots at several intervals down the soil profile, including at 3.8mbgl, which is immediately above the water table (most likely within the capillary fringe), which confirms groundwater utilisation. **Figure 19b** indicates that downhole SMP is consistently high in the entire soil profile (> -0.17 MPa) and the high LWP values reported for most trees at Site 13 can be accounted for by utilisation of either shallow groundwater, or readily available soil moisture in the unsaturated portion of the soil profile for trees that present slightly more negative LWP values.
- **Ti-Tree Creek**
 - A single auger hole was placed at Site 8 in the narrow sandy channel of Ti-Tree Creek. The auger remained dry to the full depth of the hole, which was completed in heavy grey clay (and associated gravel band) at 2.45 mbgl. The auger hole intersected a heterogenous mix of fine sand, clayey sand and sandy clay with a moist to wet clay interval intersected between 1.8 and 2.0 mbgl with an associated band of coarse tree roots sitting immediately above (**Figure 20**). The data indicates that the LWP values reported for sampled trees at Site 8 can be readily accounted for with moisture in the soil profile, demonstrated by the intersection of downhole SMP and LWP values. At the time of assessment, trees at Site 8 were reliant on soil moisture to support transpiration and there is no evidence of perched groundwater at this locality.
- **Northern Tributaries**
 - A single auger hole was placed at Site 12 in an un-named tributary of the Isaac River. The auger intersected 1.5m of moist sand and clayey sand before hitting a thin gravel interval, passing into a mottled clayey sand that was competent / impenetrable at 1.8mbgl suggesting the auger has intersected weathered sandstone basement. No groundwater was intersected. The profile shown in **Figure 21** indicates LWPs measured at Site 12 are consistent with SMPs, implying that moisture sources at the site can be accounted for in the unsaturated portion of the soil profile.

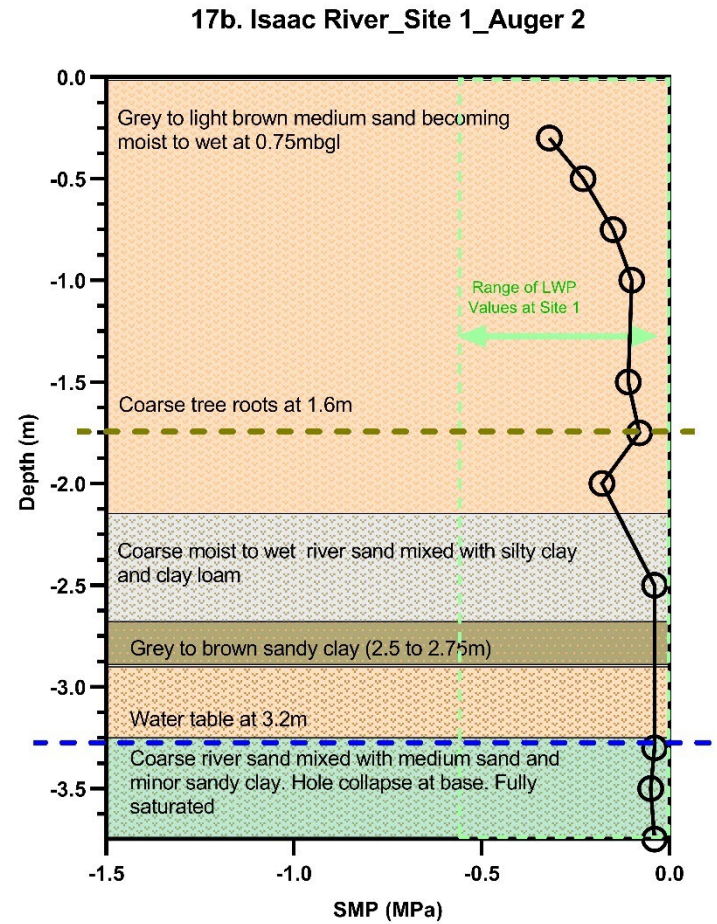
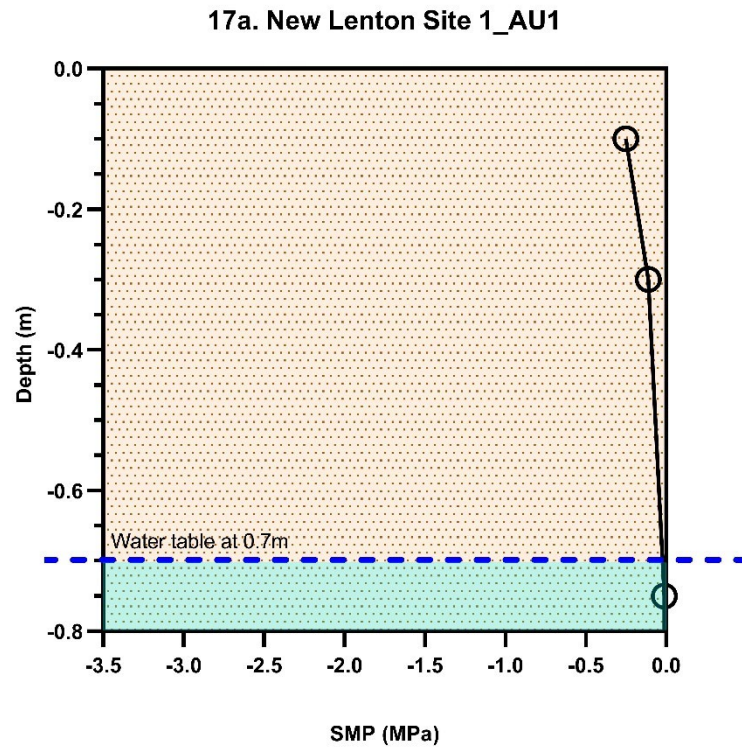


Figure 17. Soil auger and downhole SMP profiles for Site 1, Auger 1 (17a on left) in the river sand and Auger 2 (17b on right) on the lower terrace noting position of the water table at both auger locations.

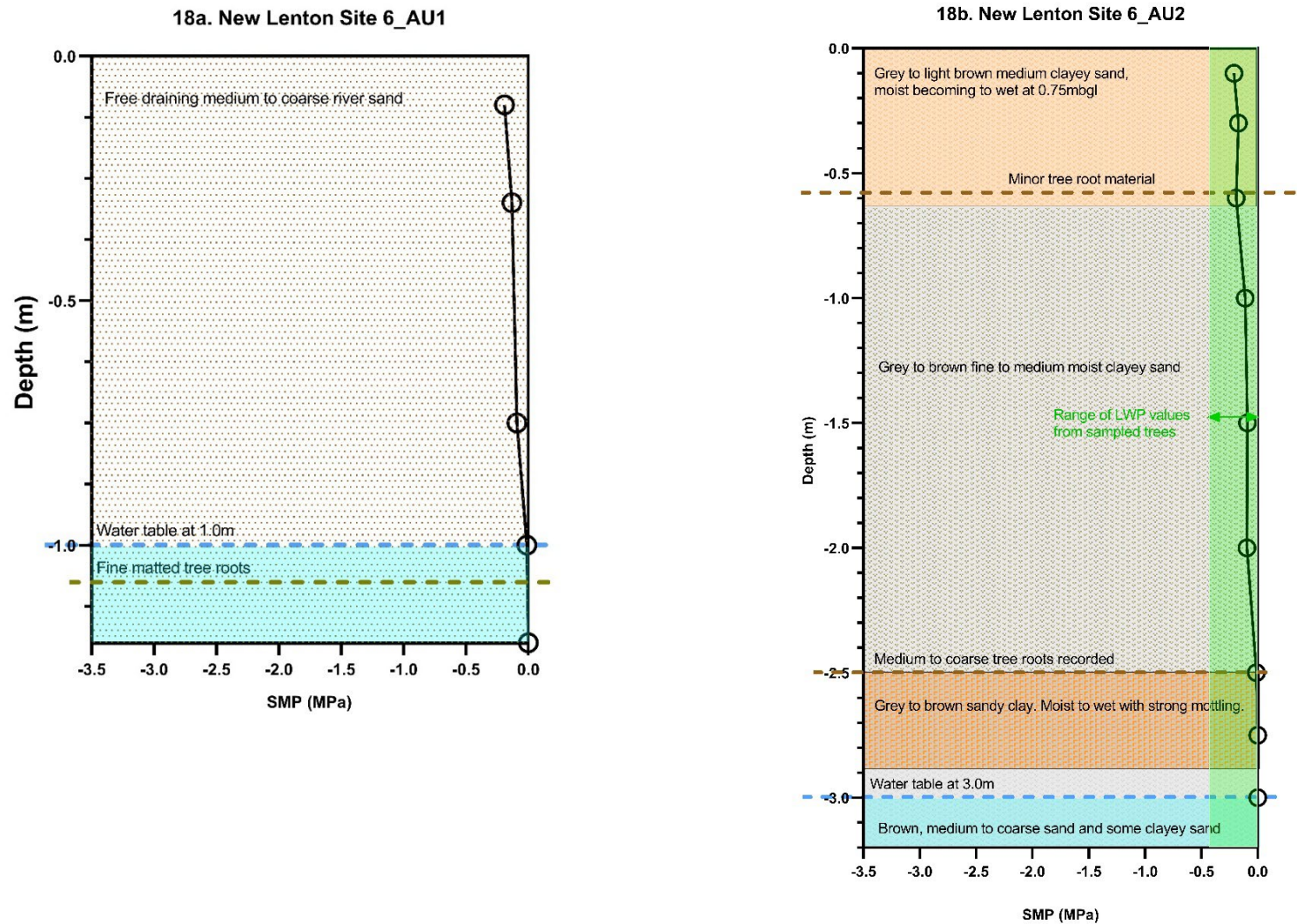


Figure 18. Soil auger and downhole SMP profiles for Site 6 on the Isaac River, showing the location of groundwater table which was intersected at both auger 1 (S6_AU1) and auger 2 (S6_AU2) higher on the alluvial terrace.

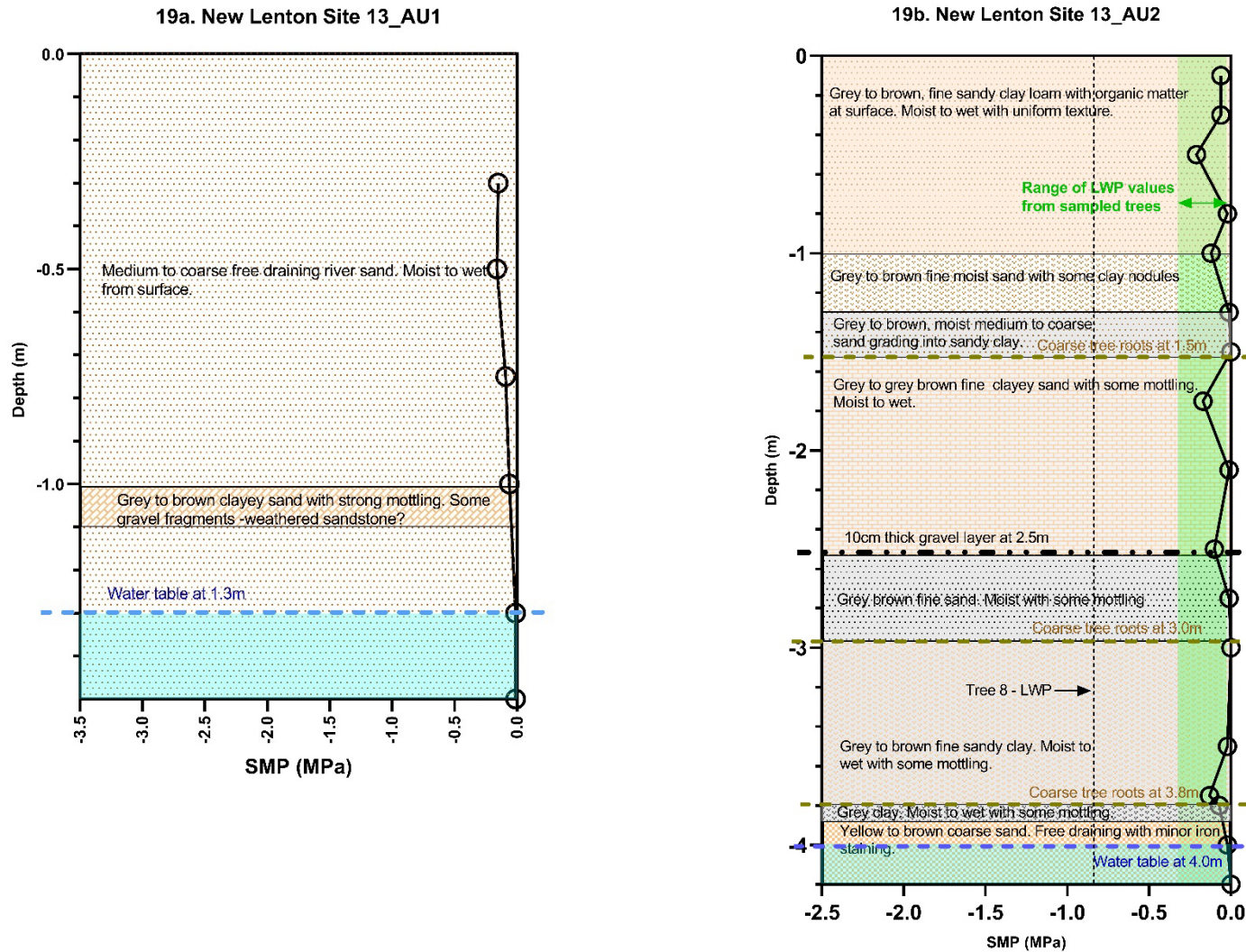


Figure 19. Soil auger and downhole SMP profile for Site13 on Isaac River, demonstrating the location of the sampled groundwater table and presence of tree roots immediately above this water table in auger 2 (S13_AU2).



Photograph 4. Coarse tree roots intersected at 3.8mbgl at Site 13 auger 2 (S13_AU2), located immediately above the water table.

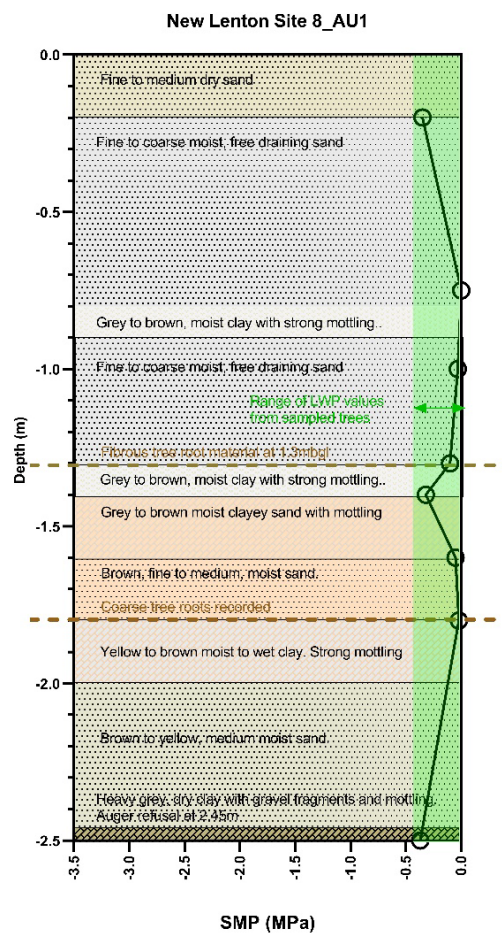


Figure 20. Soil and downhole SMP profile for Site 8, demonstrating the intersection of SMP values with LWP values reported for sampled trees and lack of perched groundwater.

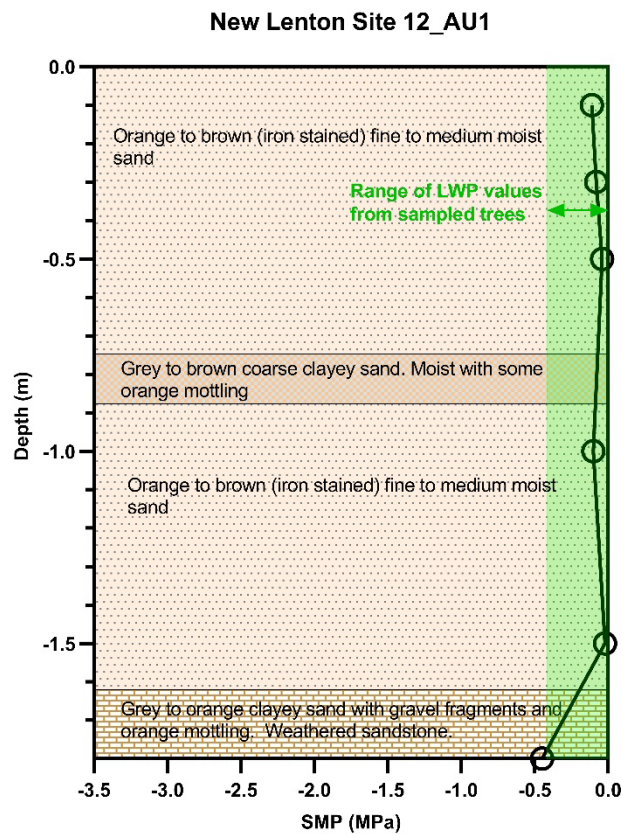


Figure 21. Soil and downhole SMP profile for Site 12, demonstrating the intersection of SMP values with LWP values reported for sampled trees and lack of perched groundwater.

4.3 Stable Isotope Sampling and Analyses

4.3.1 General trends

Figure 22 shows stable isotope values ($\delta^{18}\text{O}$ and $\delta^2\text{H}$) for all values including soil, surface water from the Isaac River (Site 2, Site 7), selected groundwater samples and twig xylem water analysed during the assessment. Sites located on older alluvial / residual area (Site 3, Site 9, Site 10) are not included in the isotopic analysis due to LWPs that indicated limited potential for groundwater utilisation. 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). 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 E** with location of groundwater and surface water samples, and soil auger locations shown in **Appendix C**. The LMWL provides a reference to identify evaporative processes, which will generally result in $\delta^{18}\text{O}$ isotope values that plot below the LMWL trend. The scatter shows:

1. A broad spread 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 $Y = 6.870 * X + 1.812$. Soil samples show the greatest spread of all groupings.
2. A much tighter cluster of xylem isotope values that fall within the isotopically heavier (enriched in heavy isotopic fractions) range of values reported for soils. The trendline formed by xylem samples forms a slope defined by $Y = 4.450 * X - 11.08$ which would indicate minor isotopic fractionation from the moisture source through to the xylem.
3. A tight cluster of isotopic values for groundwater samples with samples from the shallow auger holes overlapping samples from monitoring bores installed in the alluvium, coal seams and regolith. The isotopic values of groundwater samples overlap relatively tightly with values reported for tree xylem.
4. Two surface water samples from the Isaac River (blue bullets) with the sample from Site 2 (SW_S2) overlapping with groundwater samples and the sample taken downstream from the impoundment (SW_S7) showing significant evaporative enrichment. The overlap of the sample from Site 2 with groundwater samples likely indicates surface water in this location represents a water table window in the river sand.

The tight cluster of isotopic values for groundwater from all sources suggests a common hydrological linkage between groundwaters regardless of the host aquifer, with leakage from the seasonably variable shallow perched water table systems feeding deeper aquifers in the regolith and coal seams. Of note is the relatively tight isotopic cluster of groundwater samples in comparison to values reported for soils. Soils demonstrate a much greater spread of values with many samples presenting significantly lighter isotopic composition. This likely reflects groundwater recharge for deeper aquifers has occurred through preferential flow (from surface to groundwater through cracks and fractures) rather than slow infiltration through the soil profile.

In summary, the strong overlap between isotopic values for xylem and groundwater samples suggests that groundwater was being utilised by at least some trees at the time of assessment, and more detailed interrogation is required to differentiate groundwater and soil moisture sources. More detailed analysis is presented in following sections.

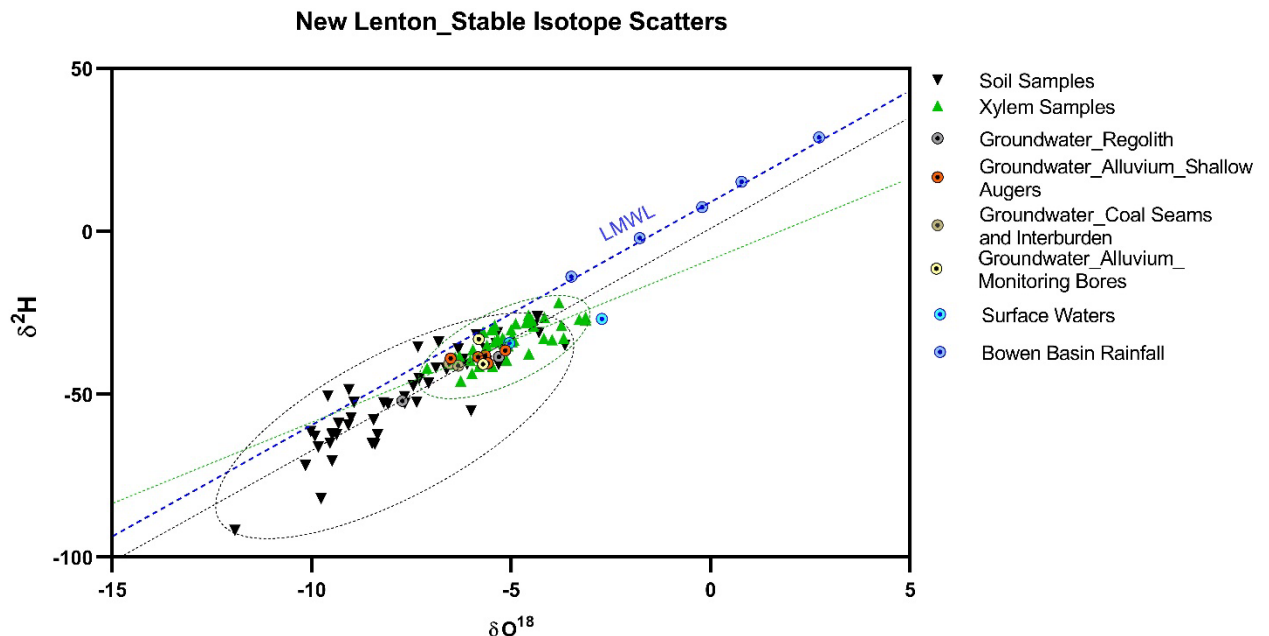


Figure 22. Stable isotope scatters for all data with the LMWL indicated by blue dashed line. Strong overlap between xylem (green dashed line), groundwater samples and soil moisture sources is indicated.

4.3.2 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:

$$lc\text{-}excess^* = [\delta^2H - a \delta^{18}O - b]/S$$

Where a and b are the slope and intercept of the LMWL, and S is the standard deviation of both δ^2H and $\delta^{18}O$ 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 23**. Lc-excess data should not be considered an absolute indicator of groundwater usage, though indicates the evolution of 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 lc-excess data indicates groundwater from all sources forms a relatively narrow range of values that is slightly offset below the LMWL, indicating the effect of minor evaporation prior to infiltration into the soil profile. For nearly all sites, there is significant overlap between lc-excess values for groundwater, soils, and tree xylem. Site 6 (Isaac River) has the greatest spread of soil lc-excess values with a much narrower range of xylem values, while Site 13 has the narrowest spread of soil values which are almost directly comparable to xylem. For Site 12, there is only very minor overlap between xylem and soils, although xylem values overlap significantly with groundwater values. This data suggests that trees are either utilising groundwater directly or are utilising moisture sources that are heavily compartmentalised in the soil profile (Evaristo, et. al., 2015; Evaristo et. al., 2016). The lc-excess values presented in **Figure 23** indicate a continuum in the interaction between groundwater, soil moisture and tree xylem at the time of assessment. This would be influenced by high levels of rainfall in the preceding months which would act to confound isotopic signatures of the soils, with the high levels of moisture retained in the soil profile continuing to contribute to recharge of shallow groundwater tables. The interaction observed in the isotopic datasets also highlights the importance of applying multiple parameters to inform levels of groundwater utilisation dependence.

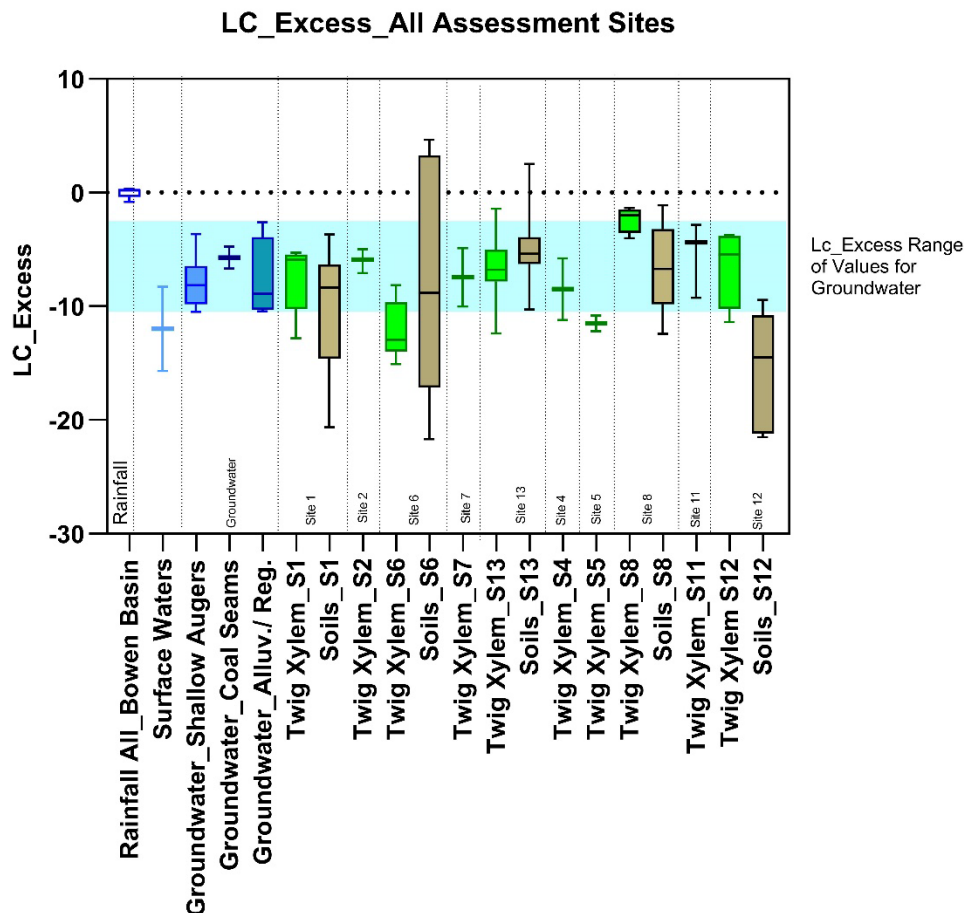


Figure 23. Box and whisker plot defining Lc-excess values for rainfall (dark blue), twig xylem (green), soils (brown), surface waters (light blue) and groundwater (purple) for each GDE assessment site. The range of Lc-excess values of groundwater is indicated by the light blue shading.

4.3.3 Isaac River Sites (Site 1, Site 2, Site 6, Site 7, Site 13)

The isotopic samples for twigs and soil for sites on Isaac River have been combined on a single biplot shown in **Figure 24**. The data shows the tight cluster of groundwater samples from alluvium (both monitoring bore and auger), regolith and coal seams which falls nearly within the centre of the cluster formed by twigs (green dashed line) and overlap with the more enriched (heavier) samples collected from soil profiles. In combination with high LWP / SMP values (**Section 4.1** and **Section 4.2**) and the physical presence of perched water, this indicates that the perched water is a significant input into the tree water requirements these sites including Site 1, Site 2, Site 6, Site 7 and Site 13. When the isotopic scatter is reduced by excluding ^2H values (noting the higher energy state of ^2H resulting in greater scatter), overlap between δO^{18} values returned from twig xylem and the shallow groundwater becomes strongly apparent in the soil profiles from Site 1, Site 6 and Site 13, supporting the interpretation that trees are on the Isaac River were utilising the perched groundwater at the time of assessment. This interpretation is consistent with results of LWP and SMP sampling discussed in **Section 4.1** and **Section 4.2**. Representation of downhole soil stable isotope sampling for Site 1, Site 6 and Site 13 is provided in **Figure 25**, **Figure 26** and **Figure 27** respectively.

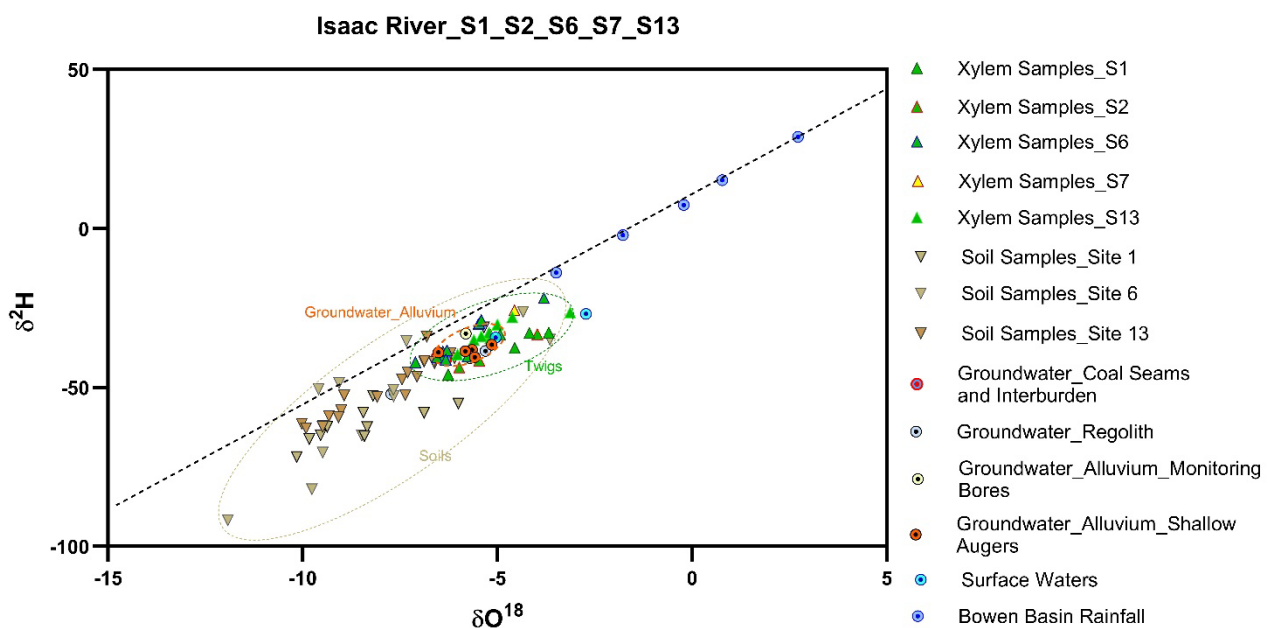


Figure 24. Stable isotope scatter from soils, twigs, groundwater and surface water from Isaac River Site 1, Site 2, Site 6, Site 7 and Site 13 compared to groundwater from coal seams, regolith, and alluvial groundwater sources. LMWL is indicated by the dashed line.

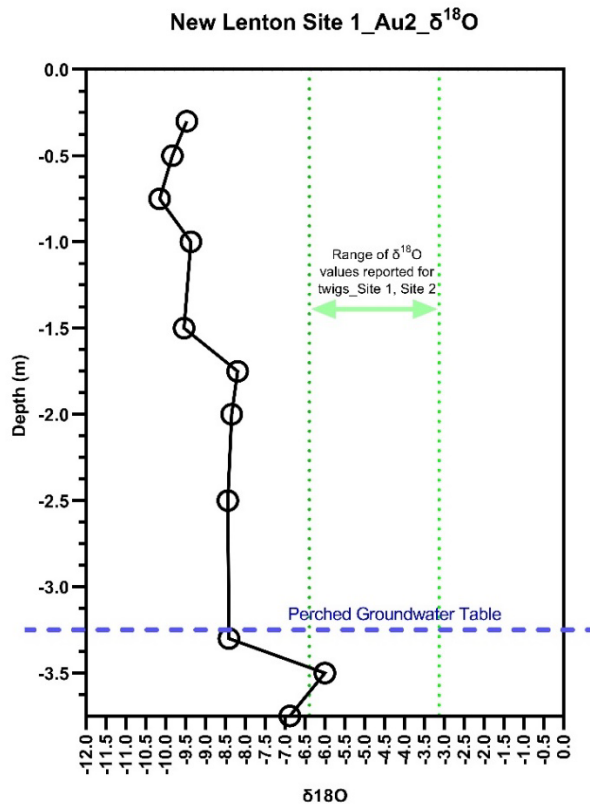


Figure 25. Downhole δO18 profile for Auger 2 at Site 1, showing overlap between δO18 values for twigs and groundwater at the position of the perched groundwater table (3.2mbgl).

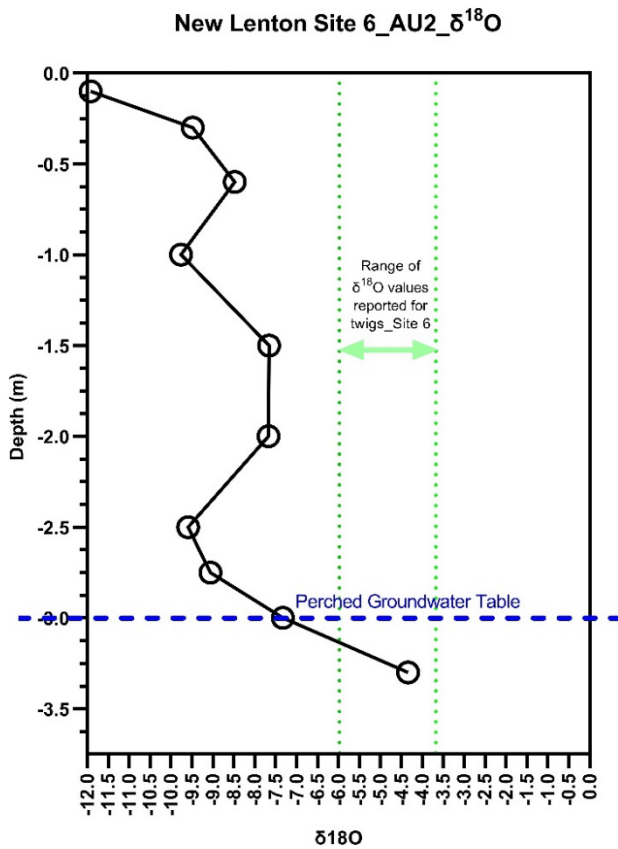


Figure 26. Downhole δO18 profile for Auger 2 at Site 6, showing overlap between δO18 values for twigs and groundwater at the position of the perched groundwater table (3.0 mbgl).

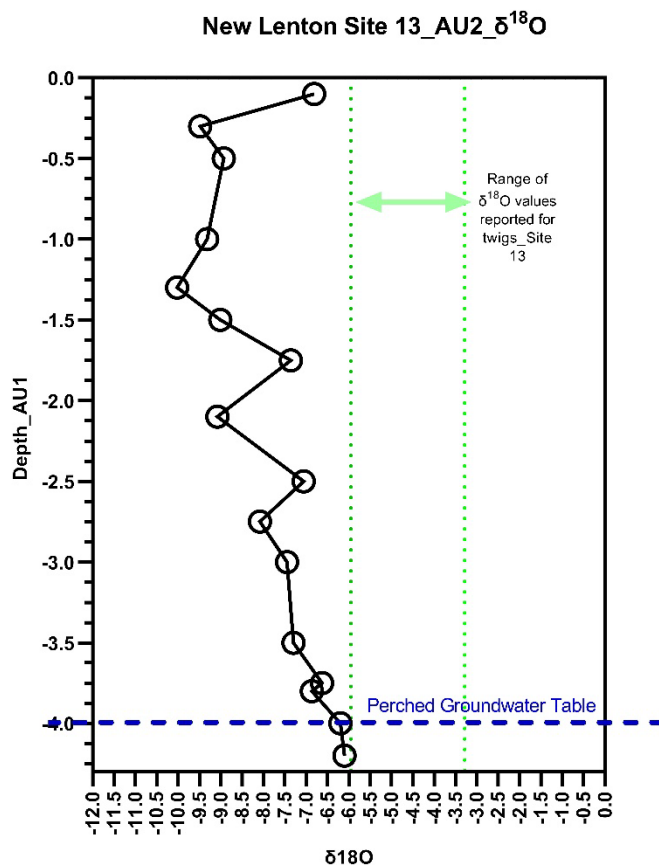


Figure 27. Downhole $\delta\text{O}18$ profile for Auger 2 at Site 13, showing migration of $\delta\text{O}18$ values for twigs toward the composition of groundwater at the position of the perched groundwater table (4.0 mbgl).

4.3.4 Ti-Tree Creek (Site 4, Site 5, Site 8)

Isotopic data from twig samples, soil samples and groundwater samples for Ti-Tree Creek is shown in **Figure 28**. There is overlap between twig xylem and soil moisture samples from Site 8 (S8_AU1), and relatively tight cluster of twig xylem values for Site 4, Site 5 and Site 8. The weak overlap between groundwater and soil samples is expected considering the demonstrated evolutionary continuum between these moisture sources. The downhole $\delta\text{O}18$ values auger S8_AU show increasing isotopic depletion down the profile to the base of the hole, with intersection between the isotopic values of twig xylem and soil moisture occurring below 1.5mbgl (**Figure 29**). This data indicates trees are utilising moisture from unsaturated regions of the soil profile mostly below 1.5mbgl, consistent with observed lack of perched groundwater. The relative consistency of xylem isotope values between Site 4, Site 5, and Site 8 suggests that trees at all three sites on Ti-Tree Creek are similarly using moisture from unsaturated regions of the soil profile. This interpretation is supported by LWP and SMP measurement (**Section 4.1** and **Section 4.2**) and there is no evidence that groundwater is being utilised to any degree by vegetation on Ti-Tree Creek at the time of assessment.

4.3.5 Northern Tributary Streams (Site 11, Site 12)

Isotopic data from twig samples, soil samples and groundwater samples for Site 11 (Hill Creek) and Site 12 (un-named tributary stream) is shown in **Figure 30**. The data demonstrates clear separation between xylem isotope values and groundwater in Site 11 indicating groundwater is unlikely being utilised at this sampling locality. For Site 12, there is consistent overlap between xylem isotope

values, groundwater, and soil moisture. Like Site 8, this could be expected considering the demonstrated evolutionary continuum between soil moisture and groundwater these datasets. The downhole $\delta\text{O}18$ values for this dataset (**Figure 31**) shows a clear overlap between stable isotope value for twig xylem and soils below 1.0 mbgl, demonstrating that stable isotope values can clearly be accounted for by soil moisture alone. This interpretation is consistent with the results of LWP and SMP analysis completed in **Section 4.1** and **Section 4.2** and there is no strong evidence that trees are utilising groundwater at this assessment site.

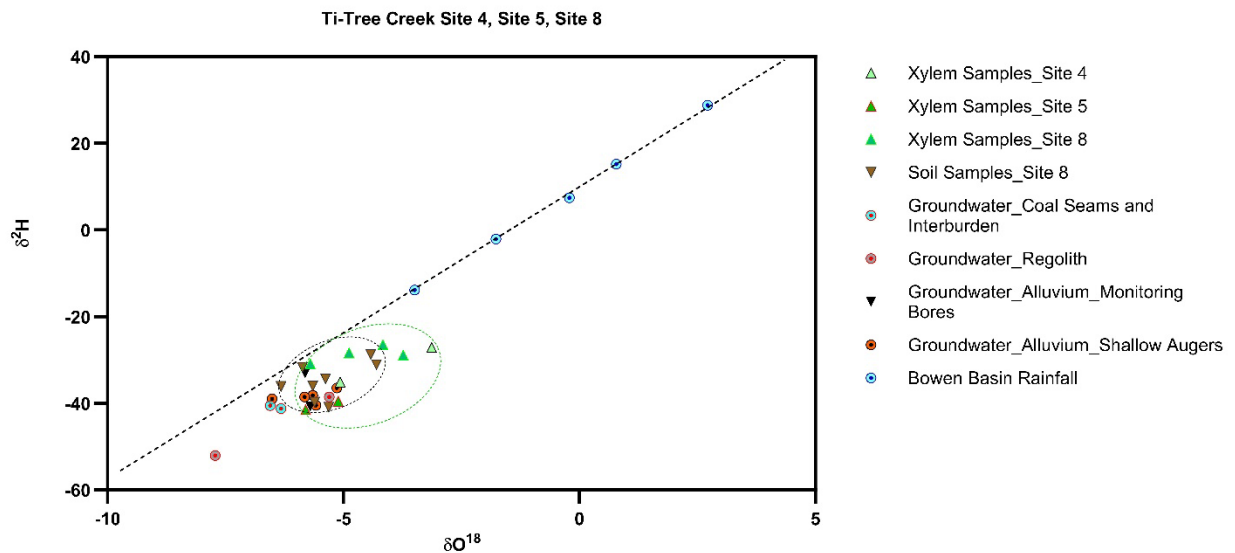


Figure 28. Stable isotope scatter plot for groundwater and twig samples from sites on Ti-Tree Creek (Site 4, Site 5, Site 8).

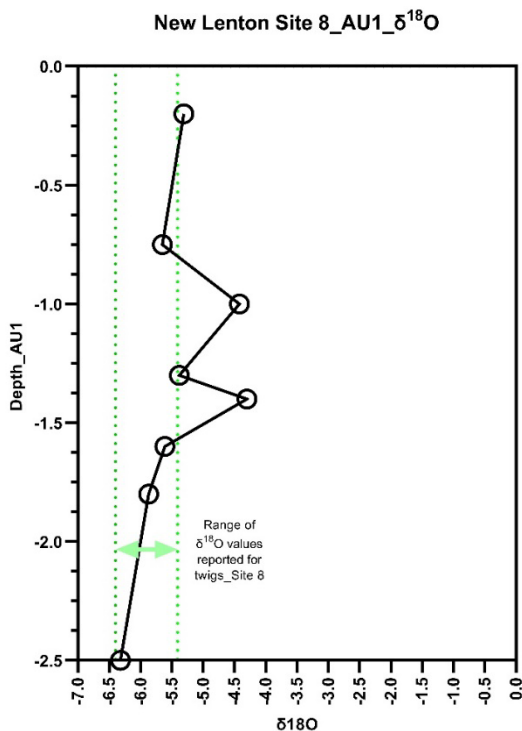


Figure 29. Downhole $\delta\text{O}18$ profile for Auger 1 at Site 8, showing strongest overlap between $\delta\text{O}18$ values for twigs and soil moisture occurs below 1.5 mbgl.

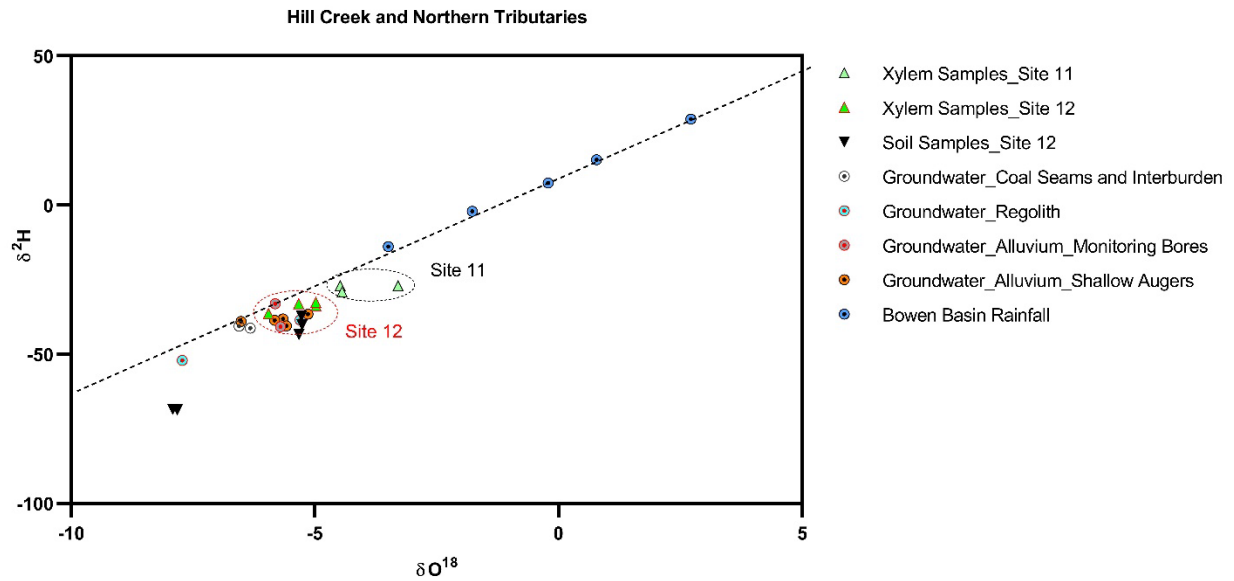


Figure 30. Stable isotope values for twig xylem at Site 11 (Hill Creek) and Site 12 (un-named tributary) compared to groundwater samples from a range of sources and soil moisture samples from Site 12 (S12_AU1).

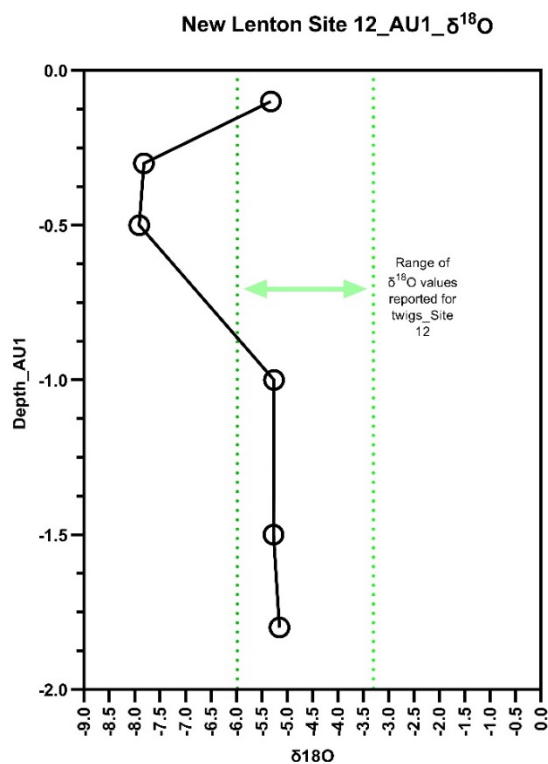


Figure 31. Downhole $\delta\text{O}18$ profile for Auger 1 at Site 12, showing significant overlap between $\delta\text{O}18$ values for twigs and soil moisture below 1.0 mbgl.

4.4 Temporal Analysis of Aerial Imagery

Historical imagery was reviewed to identify any impact to riparian vegetation structure or condition on the Isaac River, that could possibly be linked to construction of the northern Burton Mine void where this was closest to the river in the north, close to Assessment Area 13. The assessment could not confirm any detectable change to vegetation health and condition on imagery that was captured prior to mining void (1987 and 2000), spanning construction (2000 to 2004), and 16 years post construction based on recent imagery viewed in Queensland Globe (approximately 2018). Imagery from these pre to post mining stages is provided in **Figure 32** to **Figure 35**, providing no evidence of mining related changes to vegetation structure and condition spanning the 30 years of imagery. This provides evidence that historical open cut mining in the vicinity of the Isaac River, adjacent to the Project, has not resulted in drawdown of groundwater that has impacted vegetation structure and condition. Therefore it could be expected that open cut mining associated with the Project will not result in drawdown of groundwater that will impact vegetation structure and condition.

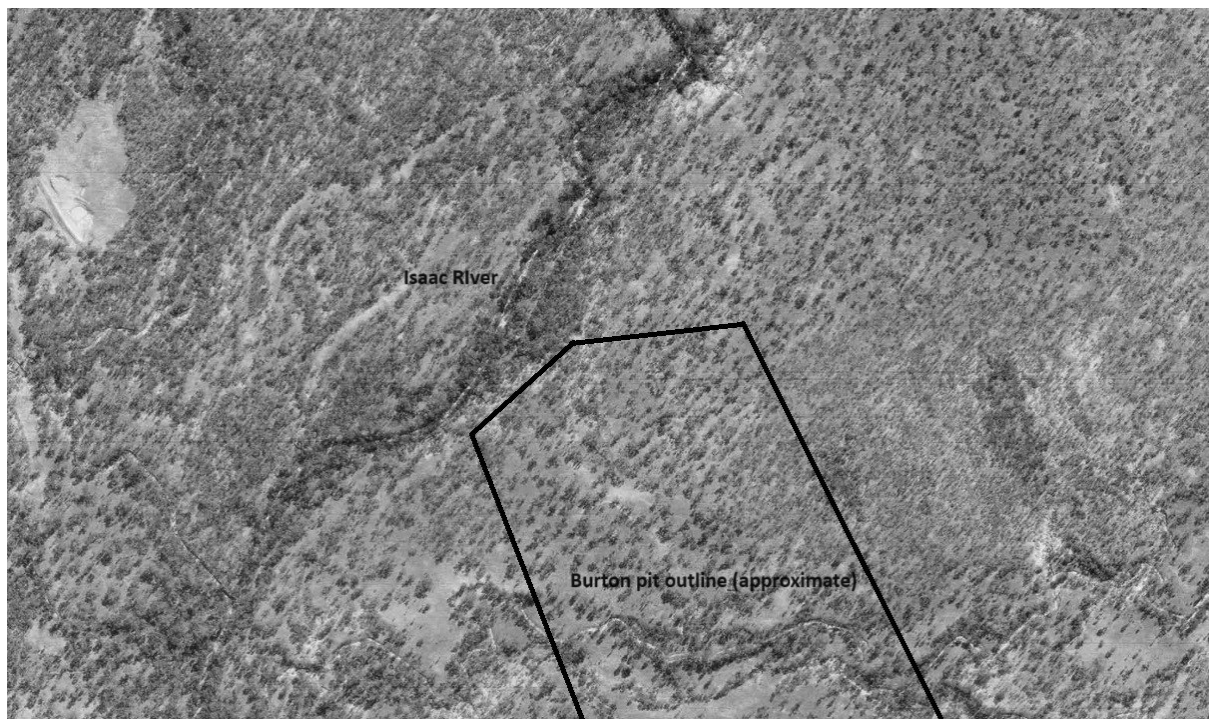


Figure 32. Intact pre-mining riparian vegetation on the Isaac River prior to construction of the mining void from imagery captured in July 1987.



Figure 33. Intact pre-mining riparian vegetation on this Isaac River prior to construction of the mining void from imagery captured in July 2000.



Figure 34. Construction of the Burton Mine void (northern extent) indicated in 2003 imagery, with intact riparian vegetation on the Isaac River immediately north of the pit.

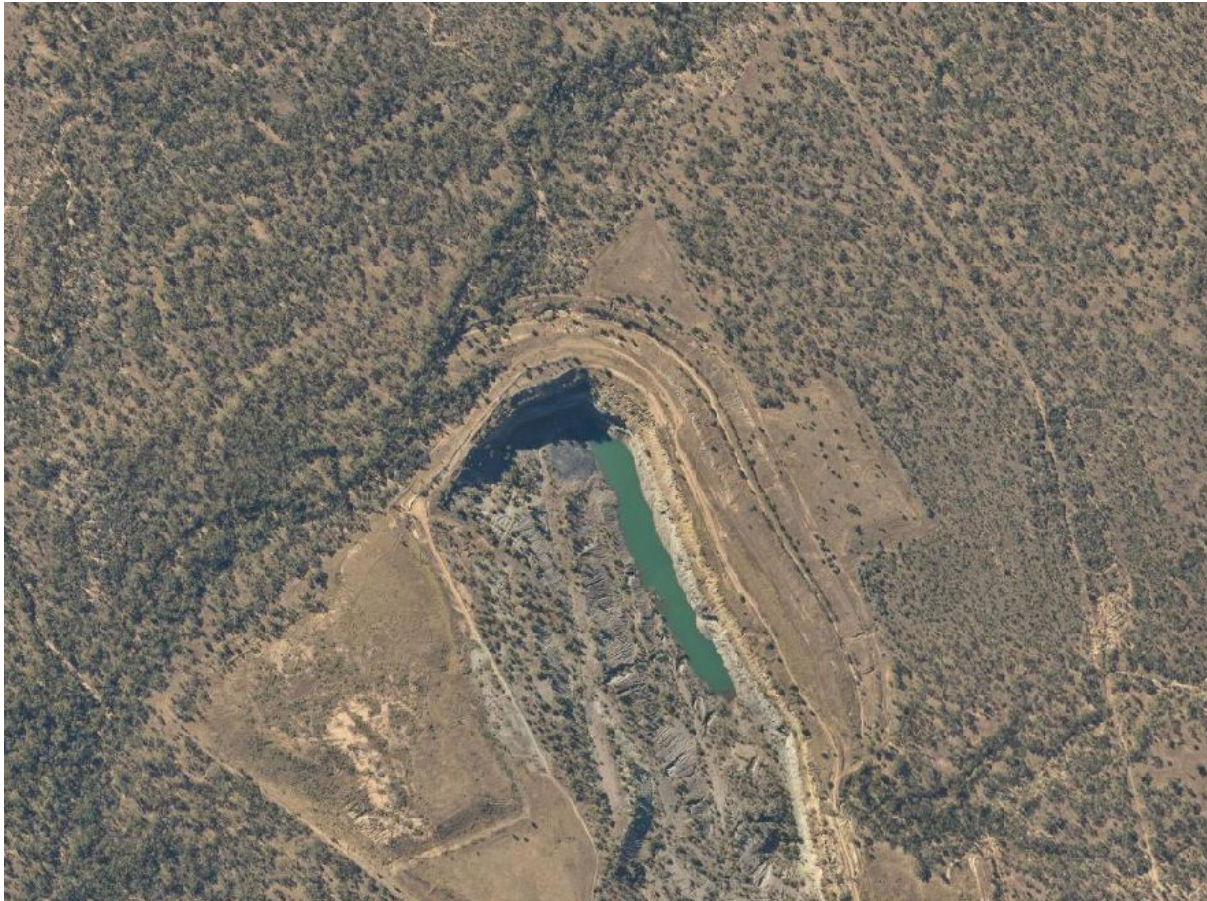


Figure 35. Current extent and condition of riparian vegetation on the Isaac River fringing the northern extent of the Burton Mine void. No evidence of structural change to riparian vegetation is indicated in recent imagery (2018).

5.0 Discussion and Conceptual Site Models (CSMs)

5.1 Suitability of Groundwater Resources to Support GDEs

The most significant control on groundwater dependence across the study area is a lack of well-developed alluvial deposits, except for the relatively narrow Isaac River floodplain and thin slivers of alluvium attenuating upstream along the larger tributary streams. Auger sampling on tributary streams at Site 8 and Site 12 suggest alluvium thins rapidly away from the Isaac River with only a thin mantle of residual soils retained over regolith. The lack of significant alluvium away from the Isaac River means that away from the drainage channels, groundwater is confined to the base of the regolith, as well as coal seams.

Depth to groundwater in the Permian coal seams ranges from 13.4 mbgl in the Burton Rider Seam (GW04) to approximately 35 mbgl in the Fort Cooper Coal Measures (GW27a), with groundwater in the regolith significantly shallower at 9.7 mbgl in GW31b. Depth to groundwater for monitoring bores installed in the alluvium range from 5.3 to 14.0 mbgl. Potential TGDEs on residual landforms (i.e., away from the Isaac River alluvium) are largely dominated by shallow rooted poplar box and narrow leaf ironbark meaning that even at the shallowest groundwater levels of approximately 10m, tree roots will not have capacity to penetrate to these depths. Groundwater salinity in the regolith ranges from brackish (2130 $\mu\text{S}/\text{cm}$ at GW31b) to moderately saline (16990 $\mu\text{S}/\text{cm}$ at GW19_41B). While even the upper salinity levels do not preclude its utilisation by terrestrial vegetation, there is 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. Groundwater depth in the alluvial monitoring bores is typically much more amenable to vegetation utilisation with depths as shallow as 5.4 mbgl, which is well within the rooting depth of riparian vegetation. Salinity levels as high as 15360 $\mu\text{S}/\text{cm}$ have however been reported in the alluvium (GW06), which would present only a marginal source of moisture for transpiration when all other moisture sources had been depleted. There is also physical evidence from auger profiling for a shallow perched water table in the alluvium that sits consistently at depths of up to 4 mbgl on the riverbanks at the time of the field assessment, which presented a highly suitable source of moisture to support riparian vegetation. This water is extremely fresh (<300 $\mu\text{S}/\text{cm}$), which suggests:

- recent and rapid recharge in response to rainfall and recent river flows (i.e. in response to the very recent wetter than normal climatic conditions); and
- hydraulic separation from the deeper regional alluvial groundwater table hosted in the basal alluvial sediments, that reports much higher salinities (3770 $\mu\text{S}/\text{cm}$ to 16800 $\mu\text{S}/\text{cm}$, see Section 2.1.4).

This seasonal recharge would also mean that the perched water would be susceptible to depletion during dryer periods, facilitated in part by evapotranspiration, i.e., the identified shallow perched water table would be highly seasonally variable. The lateral extent of this perched water would be controlled by the presence of a coarse river sand layer, which would be expected to thin with distance from the Isaac River. This implies that trees closest to the river would have the greatest degree of groundwater dependence and this dependence would decrease with distance from the river as the perched groundwater table pinches out towards the margins of the floodplain. The perched groundwater unit is inferred to be supported by a clay horizon which restricts downward leakage. Groundwater level monitoring data from bores where saturation was recorded in the basal alluvial sediments show that the basal alluvial groundwater was hydraulically disconnected from

both the shallow seasonally variable perched alluvial groundwater table and the Isaac River channel, with the river channel losing to the underlying groundwater system and forming the “perched water” resting on shallow clay horizons in some areas as it seeps down. However, data from some monitoring bores suggests groundwater levels in the basal groundwater unit may temporarily rise to similar depths as the perched groundwater during extremely wet periods, which may facilitate a temporary hydraulic connection if intervening clays have sufficient permeability. For example, average monthly groundwater levels from GW19-33, installed into the basal alluvial unit, shows a statistically significant weak positive correlation with CRD ($r=0.3349$, $p=0.03$) indicating responsiveness to rainfall (**Figure 36**). During an extremely wet period in July and August 2022, the basal alluvial groundwater table rose to 6.34 mbgl on 28th July 2022 with an average monthly groundwater level at 6.8 mbgl for August 2022. This is 2.3m below the groundwater level reported in the perched alluvial system at nearby auger S13_AU2 during the field assessment (4.0 mbgl), suggesting the degree of hydraulic separation can reduce (but noting levels in GW19-33 did not ever reach the perched water level recorded in S13_AU2). The separation between perched and basal alluvial groundwater systems could also be slightly less than indicated during this period, given that the location of S13_AU2 is up to 1m lower in elevation than the position of GW19-33.

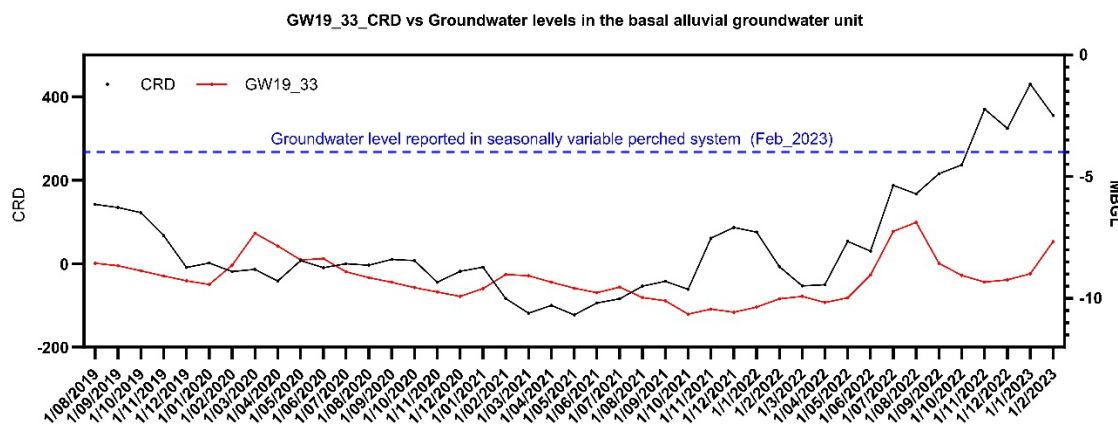


Figure 36. Comparison between CRD and groundwater levels in alluvial monitoring bore GW19-33, with comparison to groundwater levels reported in the perched system for S13_AU2 nearby.

5.2 Nature of Groundwater Dependency and Conceptual Models

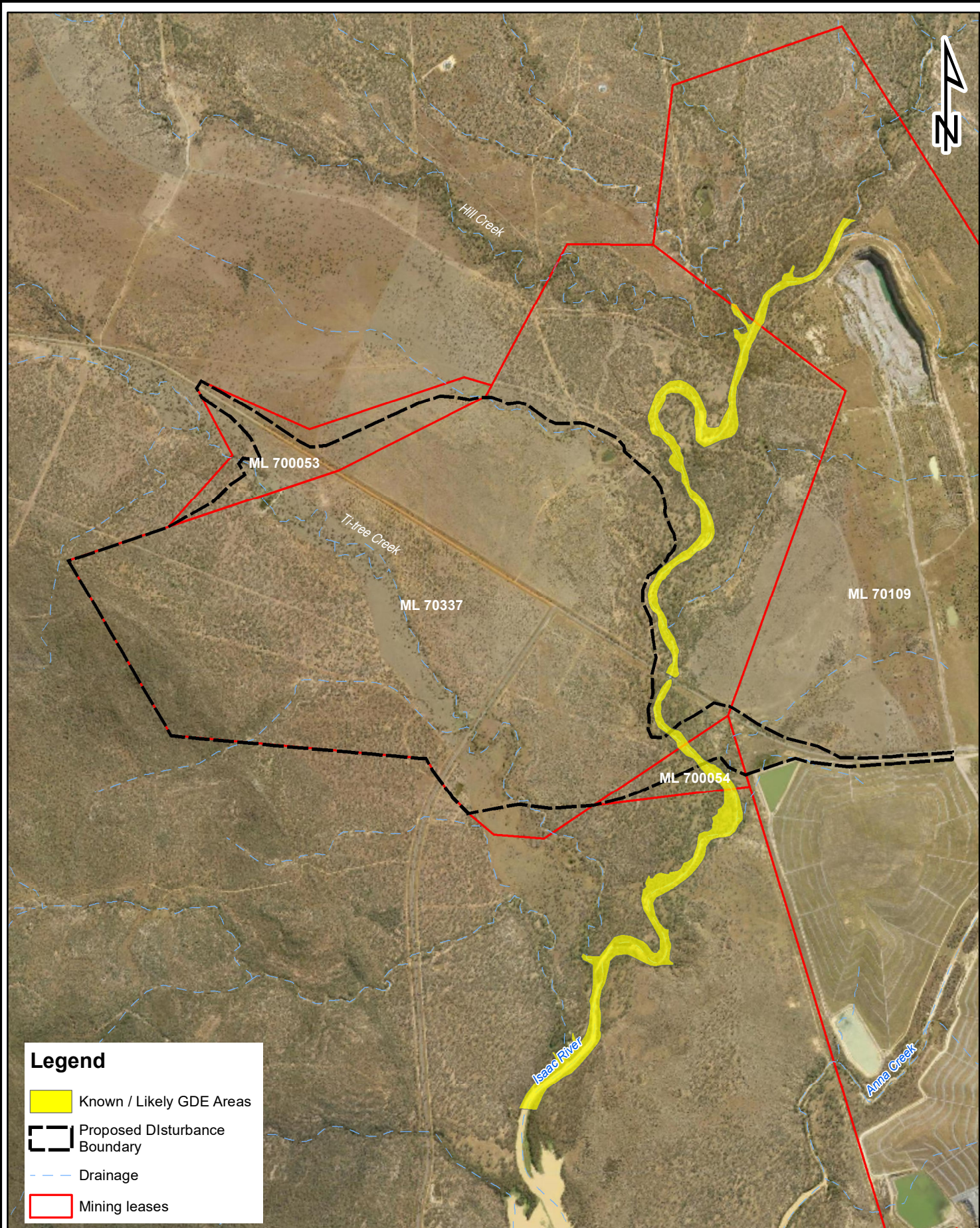
The results provided in **Section 4** indicate that the riparian vegetation associated with the Isaac River floodplain and alluvium presents the only TGDE identified during the assessment. Groundwater usage by vegetation away from the river margins decreases with distance; and away from well-developed alluvial sediments, groundwater usage is restricted by the shallow rooting depth of vegetation, depth to the groundwater table (particularly in the regolith), and groundwater salinity levels.

Within the assessment area, the alluvial floodplain of the Isaac River forms a narrow sandy flood channel flanked by discontinuous upper and lower alluvial terraces with are confined between gentle rises in regolith mantled by residual sediments. At the time of assessment, groundwater was perched in fluvial sands beneath the sandy creek bed, and these coarse river sands and associated groundwater extended as a unit laterally, subtending the riverbanks were intersected and sampled

in shallow auger holes. The perched water that is recorded beneath the river terraces supports well developed riparian vegetation that fringes the river, typically comprising RE11.3.25.

The GDE field assessment was completed at the tail of an extended period of climatic wetting, and the perched alluvial groundwater features may dry during extended drought periods, accelerated by evapotranspiration. In this sense, these perched, and most likely discontinuous alluvial aquifers are likely to be seasonal features with riparian trees demonstrating facultative dependence on the groundwater resource, with a shift to utilisation of soil moisture when the seasonally variable perched water is depleted. Water levels from hand augering show that the seasonally variable perched water table may have only limited separation with the basal alluvial aquifer during wet periods (approximately 2.3m in July 2022), although this separation will become much greater during dryer periods when the perched system is diminished. Vertical hydraulic gradients exist within the alluvium that would facilitate the shallow perched water to leak downwards to the deeper basal alluvial groundwater unit in the absence of an intervening barrier. However, the clay layers within the alluvial profile that exist above the basal alluvial groundwater unit and upon which the perched water sits (SLR, 2023) would significantly inhibit the degree to which this downwards seepage occurs, and it is the low permeability of these clay layers that allows the seasonally variable perched groundwater unit to exist.

Recharge of the Isaac River 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 temporarily discharge back into the river channel as low volume seepage / baseflow in the short-term, during which time the Isaac River is likely to be consistent with the definition of an AGDE. The inferred spatial extent of TGDE (and possibly seasonal AGDEs) on the Isaac River floodplain is presented in **Figure 37**. Based on this assessment, TGDEs are only defined in well-developed riparian vegetation that fringes the Isaac River, and TGDEs are not attenuated any significant distance upstream along tributary watercourses. A hydro-ecological conceptualisation of Isaac River at Site 1 is shown in **Figure 38**, demonstrates the inferred extent of the seasonally perched water table and its hydraulic relationship to deeper regional scale aquifer systems. The models also demonstrate seasonal groundwater recharge and discharge mechanisms across the three seasonal period. The wet season model (**Figure 38b**) also demonstrates the variable response in the basal alluvial groundwater table in response to recharge, with inferred bulging. Based on field data, as illustrated in the conceptual models, there is no evidence that groundwater in the coal seams, or regolith supports any GDEs in the New Lenton Project area.



Legend

- Known / Likely GDE Areas
- Proposed Disturbance Boundary
- Drainage
- Mining leases

Figure 37. Location of Known GDE Areas based on evidence from field assessment.

Client Bowen Coking Coal Ltd			
0 600 1,200 1,800 2,400 Metres			

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

Figure 38a. Isaac River Floodplain and Tributary - Dry Season

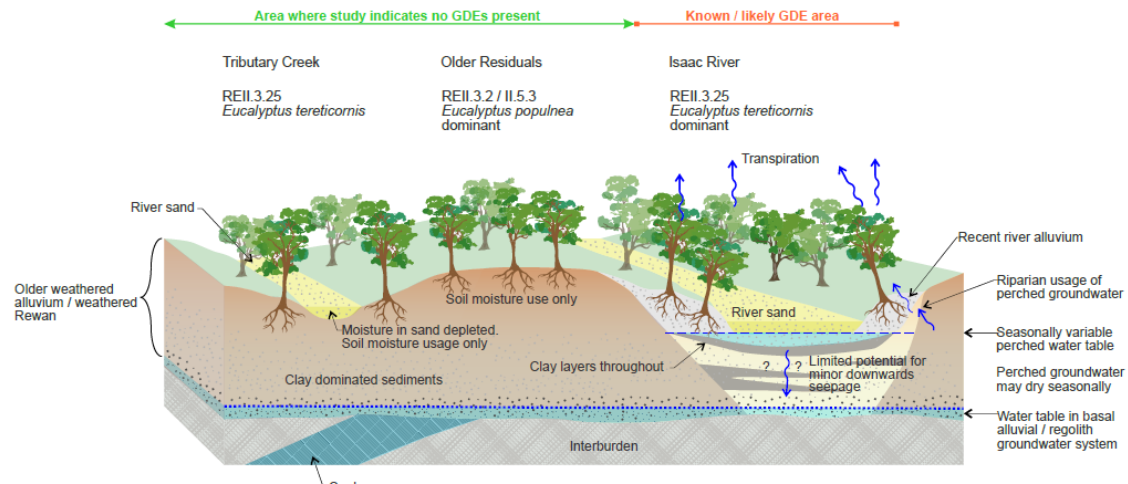


Figure 38b. Isaac River Floodplain and Tributary - Wet Season

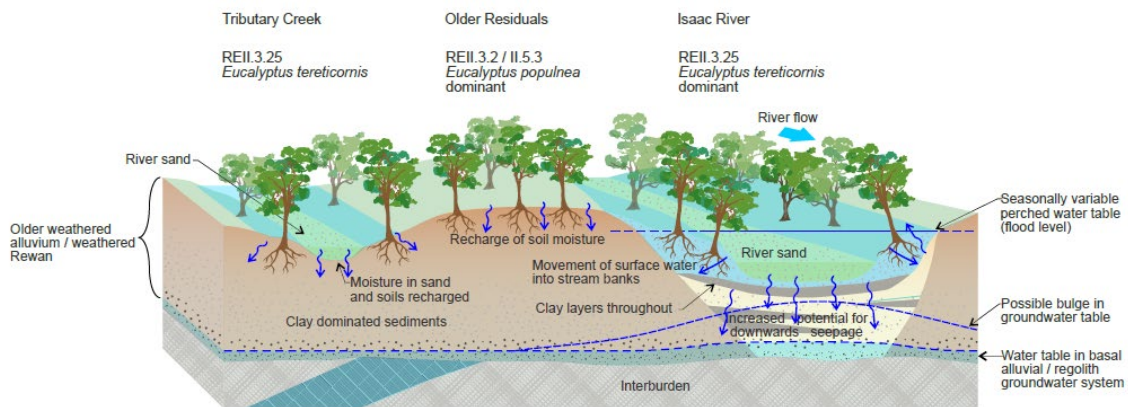


Figure 38c. Isaac River Floodplain and Tributary - Post Wet Season Baseflow Regime

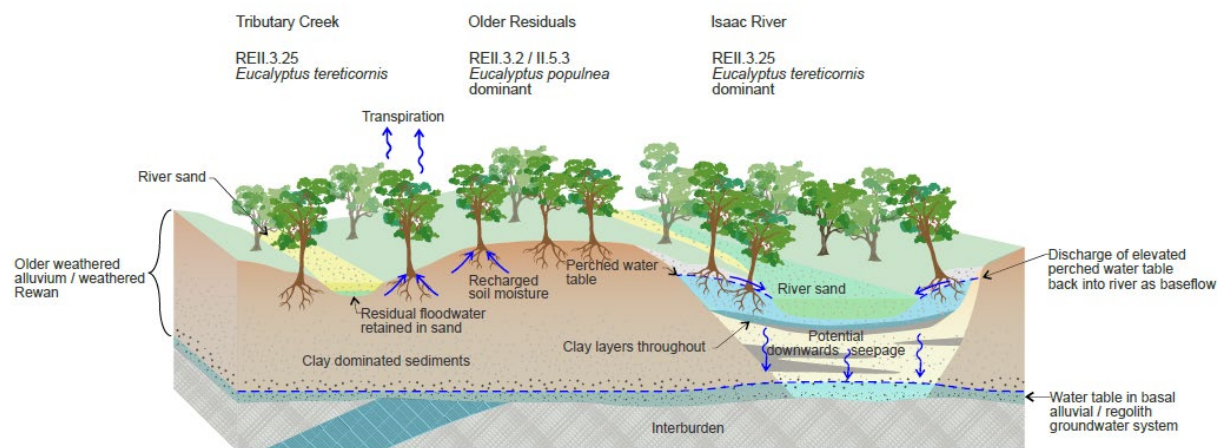


Figure 38. Hydro-ecological conceptualisation of the Isaac River TGDE system, based on data collected at Site 1, Site 6 and Site 13. Figure 38a shows dry season ecological function with Figure 38b showing wet season recharge of the perched alluvial groundwater table, followed by post flooding baseflow (Figure 38c).

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

Data from LWP measurement, soil augering and SMP measurements, as well as stable isotope assessment demonstrates the following:

1. Data from the Isaac River Sites (Site 1, Site 2, Site 6, Site 7, Site 13) demonstrate that riparian vegetation was utilising groundwater from a shallow seasonally variable perched water table at the time of assessment. This water table was hosted in river sand but resting on alluvial clay, above the deeper basal alluvial groundwater unit. This interpretation is consistent between all assessment parameters including LWP, SMP, stable isotopes and including direct observation of a perched water table intersected during shallow soil augering.
2. For sites on older alluvial / residual landforms (Site 3, Site 9 and Site 10), any significant utilisation of groundwater has been excluded by the strongly negative LWP values and considerable depth to groundwater resources, below the rooting depth of relatively shallow rooted poplar box and ironbark.
3. For sites on Ti-Tree Creek, use of groundwater at Site 4 is excluded by strongly negative LWP values. For Site 5 and Site 8, LWP values are considerably higher, although these high LWP values can be accounted for in the shallow soil profile, as suggested by both SMP and downhole stable isotope analysis. This is also in agreement with the lack intersection of a perched shallow water table at Site 8 (S8_AU1). There is no indication that vegetation at Site 5 and Site 8 are utilising groundwater to any degree.
4. Data from northern tributary streams, including Site 11 (Hill Creek) and Site 12 (un-named tributary) suggests soils account for the moisture being utilised by riparian vegetation at these localities, in agreement with soil auger profiling which did not identify a perched water table. Soil moisture is being supplied in the shallow portion of the soil profile (>1 mbgl) directly above the contact between the unconsolidated soil profile and regolith.

There are also the following uncertainties that are relevant to impact assessment:

5. The seasonality and persistence of the perched groundwater system that was supporting GDEs at the time of the assessment, and whether any connectivity between the perched groundwater system and the deeper basal alluvial groundwater unit exists, noting the current lack of evidence for a hydraulic linkage as reported in SLR (2023).
6. Whether riparian vegetation that was utilising groundwater hosted in the seasonally variable perched groundwater system has developed a dimorphic root system that has capacity to utilise the seasonally variable perched system when present, shifting to utilisation of the deeper basal alluvial groundwater unit when the perched system is depleted.

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 utilised by GDEs.
2. A change in the magnitude and timing of volume fluctuations in the aquifer 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.

There may be a common linkage between these mechanisms, such that changes to surface flows (3) may lead to changes in aquifer volumes (1) as well as changes to the timing of aquifer fluctuations. Other mechanisms also exist including direct clearing of GDEs, destabilisation of aquifer confining layers leading to groundwater leakage. The manifestation of these impacts varies dependant on the type and nature of the GDE system, though typically results in:

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

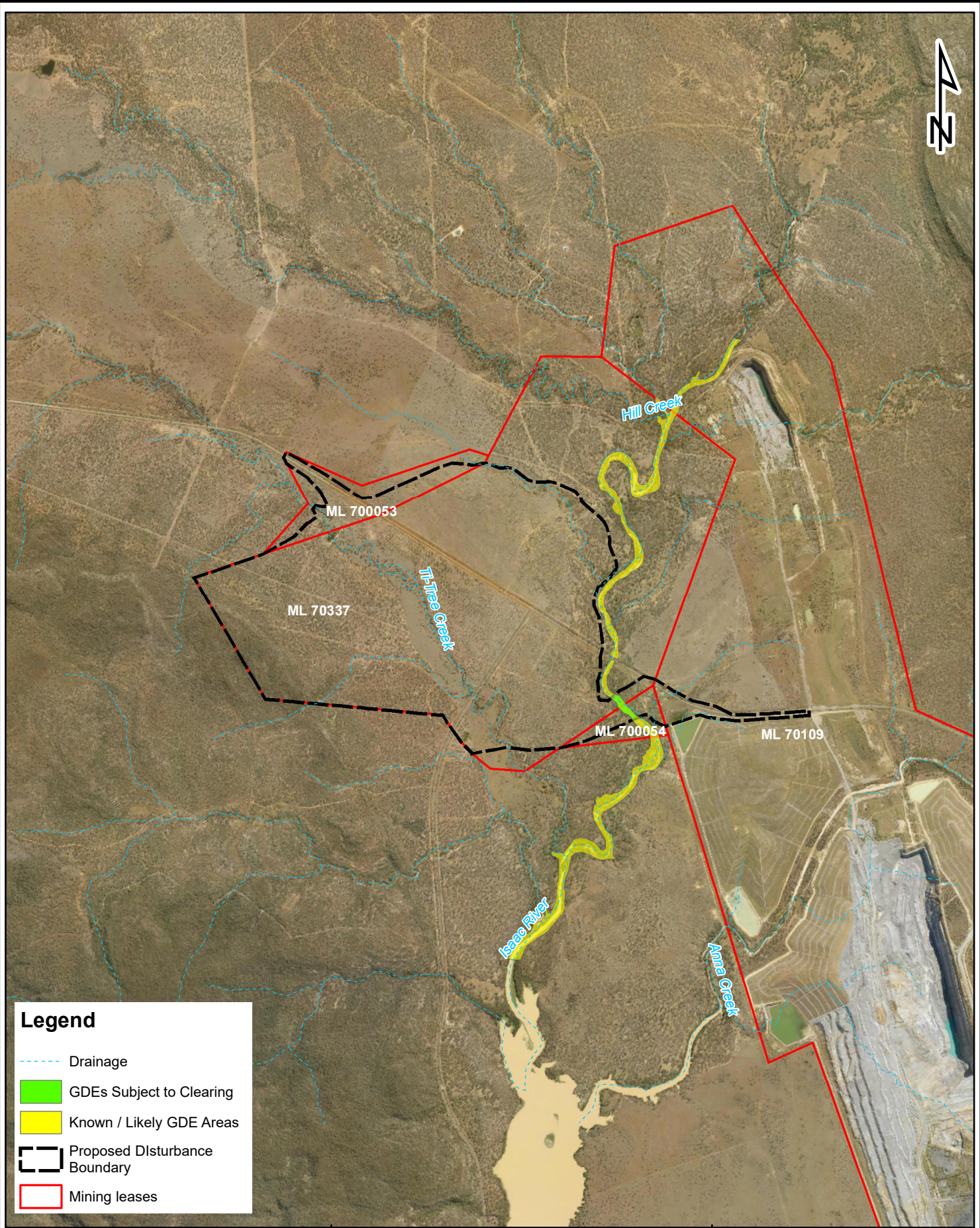
Direct clearing of a GDE system is also an additional impact which needs to be considered in the context of the Project. The major impact mechanisms, and potential impacts to groundwater vegetation in the study area are discussed in the following sections.

6.2.1 Direct clearing

A total of 2.21ha of mapped known / likely GDEs is within the Project footprint, associated with the two crossings of the Isaac River. Clearing impacts are associated with the riparian frontage of the Isaac River, where groundwater from the river sand sub-tends the riverbanks. The location of GDE clearing is shown in **Figure 39**, affecting RE11.3.25.

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

Modelled groundwater drawdown associated with the Project, is provided in **Figure 40** which shows the predicted maximum extent of Project related drawdown in the alluvium at completion of mining with maximum (end of mining) drawdown of 11.46m focused within a restricted area that overlaps GDEs on the Isaac River (10m drawdown contour). Conceptual models provided in **Figure 38** demonstrate that the seasonally variable perched groundwater system that was supporting GDEs at the time of the assessment is disconnected from the deeper basal alluvial / regolith aquifer system during drier climatic periods. The integrity of the perching layer will not be affected by development of the mining pit, although pronounced groundwater drawdown will occur in the basal alluvial groundwater system which will drain into the pit. The impact of this drawdown on the seasonally variable perched groundwater system is predicted to be subtle, and no impact is predicted if clay layers are sufficiently tight to limit infiltration. During wet season surface flows, there may be enhanced hydraulic connection between the perched and basal groundwater systems, driven through lateral penetration of surface flows into riverbanks and increased downward leakage. As recharge of both the perched and basal groundwater systems is driven by surface flows, there is unlikely to be any significant change in groundwater regimes while recharge is occurring.

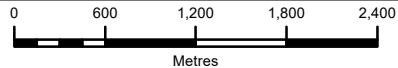


Legend

-  Drainage
-  GDEs Subject to Clearing
-  Known / Likely GDE Areas
-  Proposed Disturbance Boundary
-  Mining leases

Figure 39. Terrestrial GDE areas subject to direct clearing

Client
Bowen Basin Coking Coal

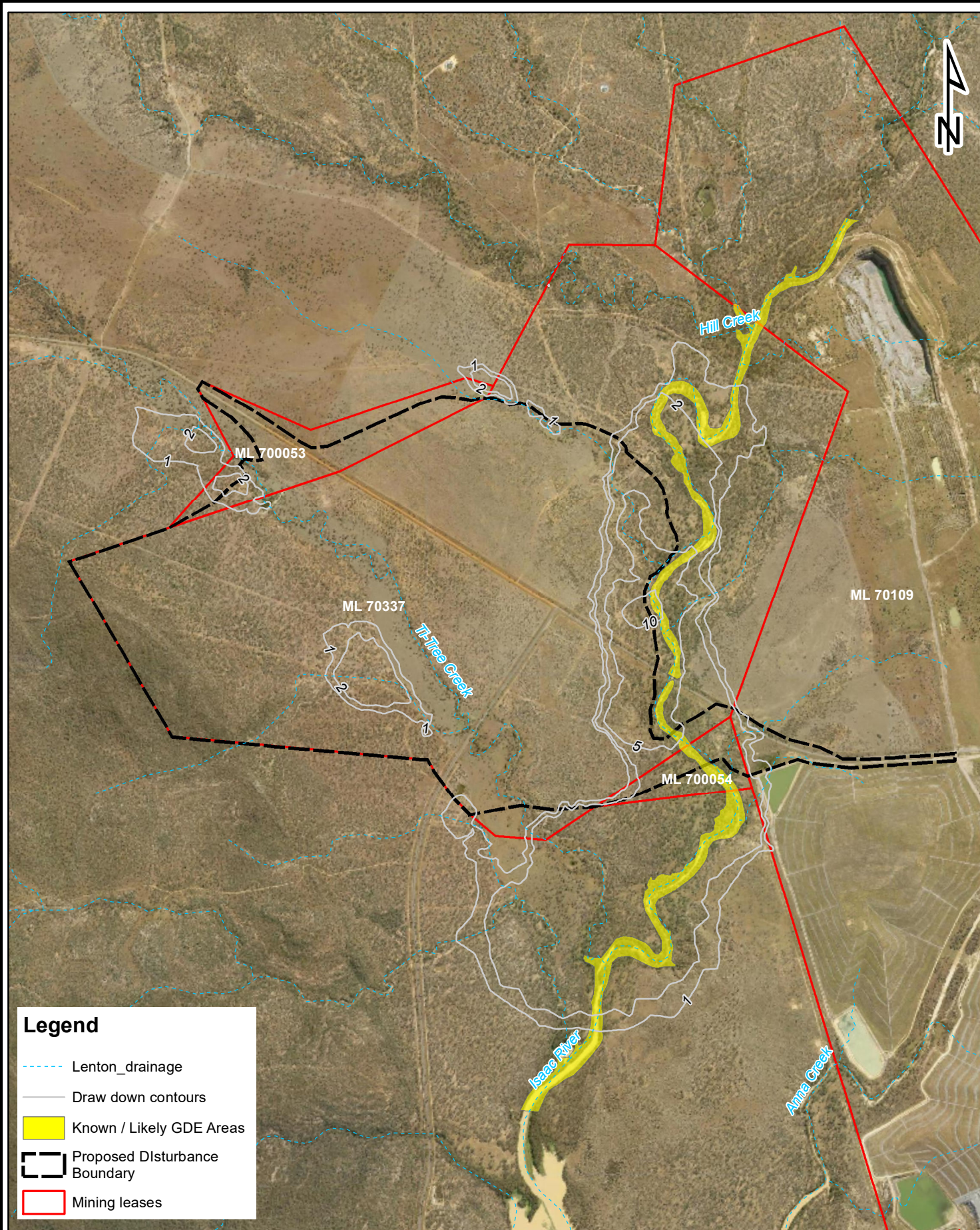


Scale 1:50,000 Drawn By DG Checked DS File Path



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Mobile: 0447 822 119
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Date 04-Dec-23 A4



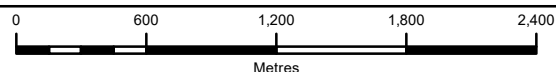
Legend

- Lenton_drainage
- Draw down contours
- Known / Likely GDE Areas
- Proposed Disturbance Boundary
- Mining leases

Figure 40. Groundwater drawdown in the alluvium relative to confirmed TGDE's.

Client

Bowen Basin Coking Coal



Scale 1:34,941

Drawn By DG

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File Path



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Date
04-Dec-23

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6.2.3 Changes to the interaction between surface flows and aquifers being utilised by a GDE / and associated change in the magnitude and timing of volume fluctuations in the aquifer being utilised by GDEs.

Volume fluctuations in the basal alluvial groundwater unit are correlated to rainfall, which drives diffuse recharge and leakage of surface water along creeks and drainage lines following episodic rainfall events (SLR 2023). Episodic surface water flows in the Isaac River are a significant driver of groundwater recharge, with sustained recharge after surface water has receded into the river sand. **Figure 41** demonstrates the correlation between surface flow events in the Isaac River and groundwater levels in GW19_33 during a period of continuous monitoring between August 2019 and January 2023. The data demonstrates an immediate rise in groundwater levels following a flow event in January 2020 followed by an extended period of consistent decline through to December 2020 in the absence of surface flows. There is also a slight rise in the groundwater table in January 2021 following surface flow, and an extended rise following significant surface flows in December 2021 and January 2022, however with substantial lag evident.

Flood modelling by WRM (2023) indicates limited changes for surface flow conditions along the Isaac River frontage, with 10cm to 50cm increase in surface water levels where the Isaac River flows directly adjacent to the mine levee wall in a 2% AEP flood scenario (**Figure 42**). Further upstream and downstream there is a change in surface water levels of between 1cm and 10cm in the Isaac River during a 2% AEP flood scenario. Ti-Tree Creek will continue to discharge to the Isaac River via the Ti-Tree Creek diversion. The minor changes to surface flow levels are not of sufficient magnitude to affect groundwater recharge, and there is no mechanism that could influence surface flow timing.

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

Groundwater predictive modelling by SLR (2023) identifies a permanent cone of depression around the mining void into which groundwater flows will be directed. This will facilitate drainage of groundwater directly into the mining void where this discharge will be captured within the mine water management system during mining. Post mining a residual void lake will form that will be a long-term groundwater sink. The potential for saline water from mine water collected from, or remaining within, the void to contaminate any fresh perched groundwater system is negligible and there is no risk of upward propagation of saline groundwater into the seasonal alluvial groundwater system which supports GDEs.

Geochemical assessment of the overburden indicates that any generated runoff will be moderately alkaline and fresh, non-acid forming with low sulphur content, and low concentrations of soluble metals. Overburden spoil will generate low salinity rainfall runoff and seepage which will be captured by sediment dams. Following rehabilitation of overburden dumps, runoff quality will be similar to existing runoff from undisturbed catchments in the Project study area. 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. With the water management system controls proposed for mine water and sediment water (during and post mining) it is unlikely that there will be a risk of contamination of surface water flows, which are a major contributor to groundwater recharge.

With implemented mitigations (as per **Section 6.5**), it is considered that there is negligible risk of impact to the water quality of the seasonally variable perched alluvial groundwater unit that support GDEs.

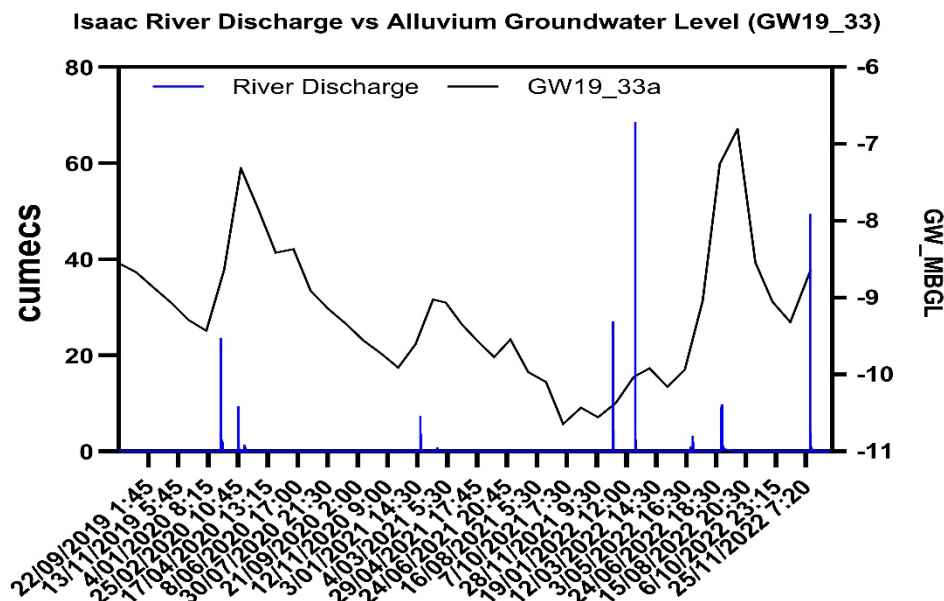


Figure 41. Surface flows in the Isaac River (Isaac River 1056) compared to groundwater levels in the basal alluvial groundwater unit (GW19_33).

6.3 Conceptualisation of Potential Impacts to GDEs

The most likely impact pathway will be through depressurisation / dewatering of the basal alluvial groundwater unit which may result in faster drying of the soil profile, and seasonal persistence of the perched groundwater system may be slightly reduced, if the permeability of the intervening clays is sufficient to allow downwards movement from the perched water to the basal alluvial system. A dry season conceptualisation of the impact scenario is provided in **Figure 43**, which illustrates drainage of the basal alluvial groundwater unit into the mining void and associated drawdown of the groundwater table. The model also indicates the position of the wet season bulge in the groundwater table resulting from wet season recharge, and the potential for enhanced drying in the soil profile leading to slightly reduced residence time for the perched system. While this represents the most likely impact pathway, the magnitude of impact will depend on if there is any degree of connectivity between the seasonally variable perched and the basal alluvial groundwater units including the effectiveness of the hydraulic barrier effect of any intervening clay horizons that support perching, and whether any vegetation associated with the mapped TGDE areas on the Isaac River have developed deeper rooting systems which have penetrated to the basal alluvial unit.

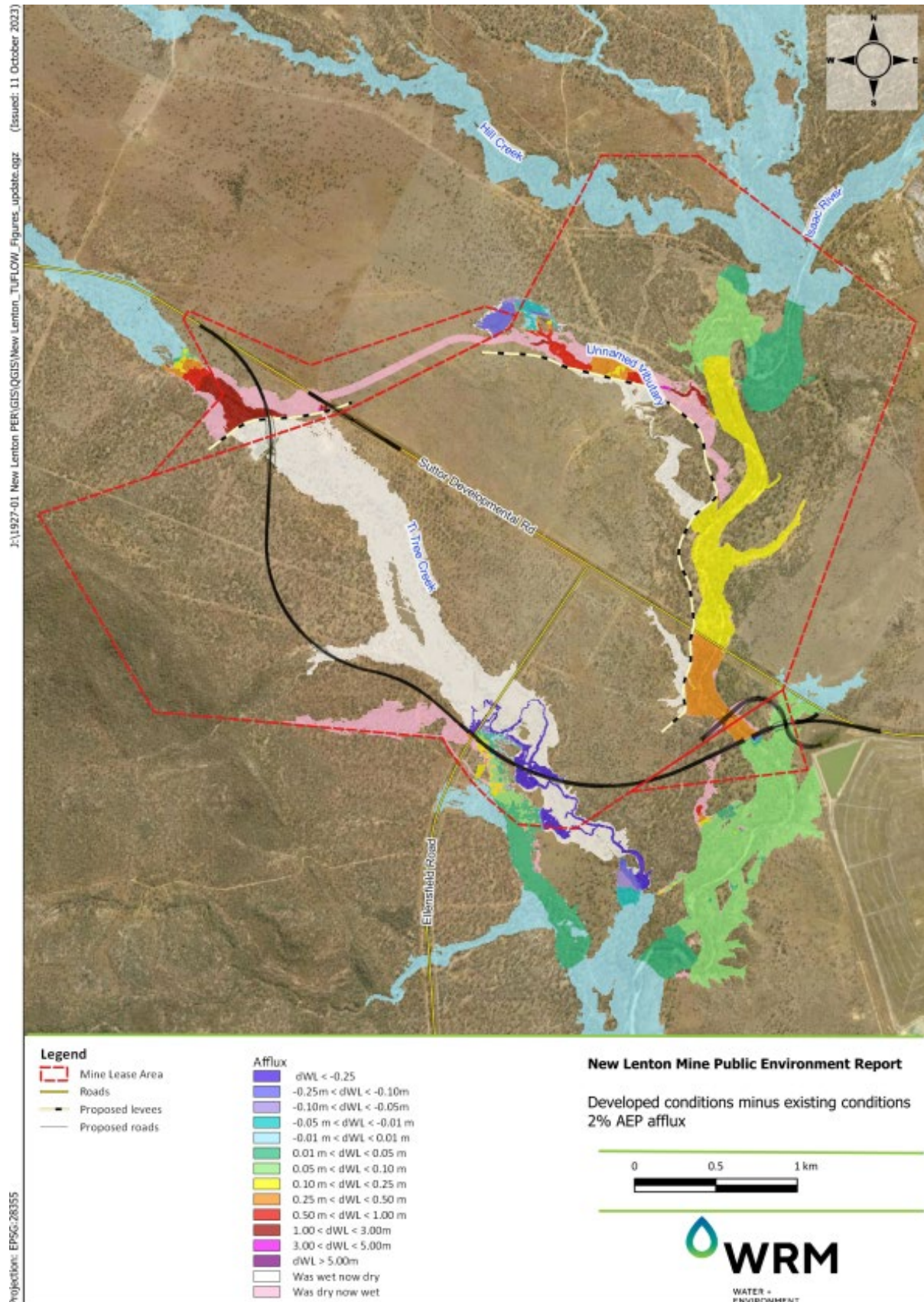


Figure 42. Modelled changes to surface flows at the Project study area because of mine development (from WRM 2023).

Figure 43. Isaac River and floodplain post mining GDE impact conceptualisation

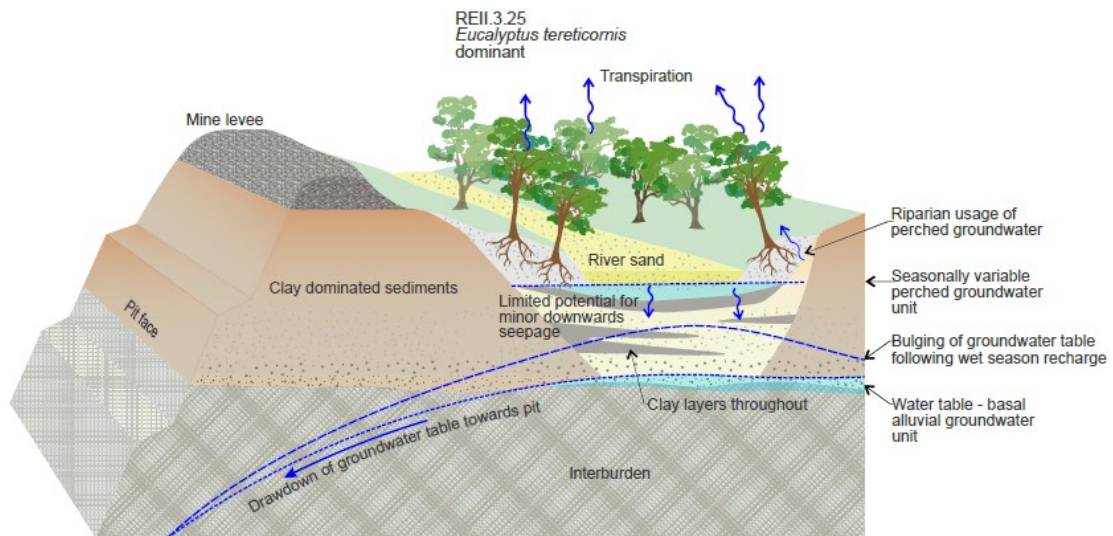


Figure 43. Conceptualisation of the most likely pathway for impact to GDEs on the Isaac River associated with drawdown of the basal alluvial groundwater table with drainage into the mining void, and potential for increased drying of the seasonally variable perched groundwater unit.

6.4 Cumulative Impacts

The proposed Project will add to a number of mines that currently directly adjoin frontage of the Isaac River including, from north to south;

1. Burton Mine, recently purchase by Bowen Coking Coal, which operated for 16yrs prior to a hiatus in production in 2016. Burton Mine operates on ML70109 with the most northern portion of the mining pit directly fringing the Isaac River approximately 600m north of ML70337, and 300m north-east of tree S13_T8, assessed as a component of the New Lenton GDE assessment.
2. Goonyella Riverside Mine Complex, operated by BM Alliance, includes the Goonyella Riverside Mine and the Red Hill Underground Mine and is approximately 20km downstream from the New Lenton Project. The Isaac River was diverted during development of the Goonyella mine and the straightened watercourse has been rehabilitated.
3. Isaac Downs Mine, owned and operated by Stanmore Resources, is approximately 60km downstream from the Project. The mine commenced operation in July 2021, removing overburden from the east bank of the Isaac River, and is currently operating under an approved Groundwater Dependent Ecosystem Monitoring and Management Plan (3d Environmental 2020).
4. Poitrel Mine, purchased by Stanmore Resources in May 2022 from BM Alliance has been extracting coal since 2006. The mine directly fringes 3.2km on the east bank of the Isaac River, approximately 65km south to the New Lenton Project.

While these mining operations all have potential to impact GDEs on the Isaac River and associated local catchment, impacts have not been reported for existing mining operations, with Isaac Downs Mine being subject to longer term GDE Monitoring. Except for Burton Mine, all other mines are too

far downstream to experience cumulative impacts on GDEs adjacent the New Lenton Project. Time series aerial photography examined for northern extent of the Burton mining operation could not detect any noticeable changes to riparian vegetation structure or condition on the Isaac River fringing the most northern extent of the pit, consistent with observations made during the field assessment at Assessment Site 13. Therefore, this indicates minimal potential for cumulative impacts to TGDEs associated with groundwater drawdown from the existing Burton Mine.

Groundwater modelling (SLR 2023) demonstrates that in the area of predicted incremental drawdown in the alluvium, the predicted cumulative drawdown shows negligible increase in drawdown magnitude between the incremental and cumulative predictions (i.e. Burton Mine doesn't exacerbate the Project predicted drawdown), although Burton Mine contributes its own drawdown to the north in the Isaac River. There is no predicted increase in the magnitude of groundwater drawdown for the New Lenton Project as a result of the existing Burton Mine operations, which is further discussed in **Section 6.6** of the groundwater modelling report (SLR 2023).

6.5 Mitigation, Management and Monitoring Measures

Section 6.2 identifies that the most significant risk of impact to GDEs is associated with drawdown of the basal alluvial groundwater unit during mine development, which may provide a minor control on the rate of drying and persistence of the seasonally variable perched groundwater system.

Ameliorating factors that act to decrease the risk of impact to GDEs are that:

1. There is no evidence that groundwater hosted in the Permian coal seams that are subject to mining impacts support the GDEs within the study area.
2. The seasonally variable perched groundwater system that supports TGDEs on the frontage of the Isaac River is supported and recharged by surface flows. The impact of the Project on surface flows is extremely marginal.

While a risk assessment is dealt with more comprehensively in **Section 6.6**, general operational measures that will minimise risk of impact to GDEs are provided in **Section 6.5.2**.

6.5.1 Reduction to the footprint of direct clearing

Figure 44 shows the current Suttor Developmental Road crossing of the Isaac River, with riparian vegetation flanking the crossing that is like upstream and downstream reaches. The realigned Suttor Developmental Road is expected to be similar following rehabilitation of the construction corridor. The bed level haul road crossing will be decommissioned and rehabilitated following mining, leading to the reestablishment of RE11.3.25. During construction, management measures will be applied that will reduce or mitigate impacts including minimising the construction width of the crossings and rehabilitating the construction corridor.



Figure 44. The maximum potential disturbance footprint for proposed road crossings on the Isaac River, demonstrated at the location of the existing river crossing on the Suttor Development Road.

6.5.2 General operational measures

The New Lenton MLs are subject to an existing State approved EA. Infrastructure at the existing Burton Mine will support the development of the Project, thereby reducing the Project's impacts by not duplicating existing infrastructure. The water management systems at Burton Mine and the Project will be integrated and mine affected water will be piped from the Project to the Burton CHPP was use in coal washing. The Project will have the ability to source raw water or mine affected water from Burton Mine to meet site demands (e.g., dust suppression) and the integration of the water management systems will allow for balancing of water supply and demand.

Under the EA, the water management system (WMS) will be operational during all stages of the Project, with the primary objective of minimising environmental harm. Implementation of the WMS and associated erosion and sediment control plan (ESCP) and receiving environment monitoring program (REMP) will be directly applicable to management of potential impacts to GDEs. Specifics of each management plan are detailed below.

WMS: The water management plan for the Project has been integrated with the approved water management system for Burton Mine (WRM, 2023), rather than developed as an independent system. This allows for balancing of mine affected water across the Project and Burton Mine and minimises the potential for uncontrolled releases of mine affected water (MAW). Specific

components of the WMS that are relevant to the management of impact to GDEs are described below.

- Capture of clean surface water will be minimised through diversions around the mining area.
- Mine affected water generated at the Project comprises pit water, groundwater seepage or runoff from areas disturbed by mining activities, and groundwater from dewatering activities. While controlled release of mine affected water is permitted under the EA, limits have been placed on the volumes and quality of mine affected water that can be released subject to flows in receiving waters, designed to protect downstream environmental values.
- Sediment water comprises rainfall runoff from catchments which discharge through release points associated with erosion and sediment control (ESC) structures. Water captured in sediment dams will be preferentially used for dust suppression.
- Water demands will be managed through maximising the recycle and reuse of first mine affected water, then sediment runoff, for site demands including processing and dust suppression.
- The water demands from site water storages will be preferentially used over external raw water supply and surface water harvesting.
- Controlled releases to the receiving environment will be minimised and managed to reduce the risk of impact. Uncontrolled releases of mine affected water to receiving waterways are not predicted to occur.

REMP: A REMP will be developed to monitor and record the effects of mining activities on the receiving environment. The receiving environment, for purposes of the REMP, would incorporate the waters of the Isaac River and connected watercourses within 15 km downstream of Project release points. The REMP will be developed in to comply with EA conditions with an intent to monitor, identify and describe any impacts to the environmental values, water quality and flows within the receiving environment. Annual monitoring, reporting and analysis of long-term trends and potential impacts will be undertaken, and outcomes will inform further mitigation and remediation of existing mitigation measures as required.

6.5.3 Groundwater monitoring

A comprehensive groundwater monitoring network, including monitoring bores installed within all the major groundwater units including the regional Tertiary and Coal Seam aquifers, and alluvial groundwater systems will be maintained for the duration of the Project. There will be a requirement for additional monitoring bores to replace those that are removed in association with development of the Project footprint. The primary purpose of the groundwater monitoring network will be to enable the natural groundwater fluctuations to be detected and distinguished from groundwater level impacts associated with de-watering of aquifers impacted by the Project. Additional monitoring bores will be recommended as part of a GDEMMP to provide more specific information on the degree of hydraulic interaction between the seasonally variable perched groundwater unit, and the basal alluvial groundwater unit to inform the management of potential impacts to GDEs.

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.

6.5.4 GDE Baseline Data Collection and Monitoring

The purpose of the baseline data collection is to provide a basis for detection of future declines in ecological condition that can be linked to detected changes in groundwater levels and physio-chemical indicators resultant from the mining operation. In addition, the GDEMMP will aim to address any uncertainties identified in field assessment including:

1. The seasonality and persistence of the perched groundwater system that was supporting GDEs at the time of the assessment.
2. If there is any degree of connectivity between the perched groundwater system and the deeper basal alluvial groundwater system, undertaken in conjunction with the groundwater monitoring program.
3. Whether groundwater usage is restricted to the seasonally variable perched groundwater unit, or deeper dimorphic root systems have developed enabling utilisation of the basal alluvial groundwater unit when the perched groundwater unit dries.

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 GDEs potentially impacted by the Project. While groundwater is an abiotic control on the ecohydrological function of GDEs, it is the ecological attributes and condition of terrestrial vegetation that defines GDE habitat values. Therefore, the monitoring of GDE function and condition should be based on vegetation indices to provide a baseline for ecological health and define trigger thresholds for initiation of investigative action. The indices best applied to define trigger thresholds, including potential parameters applied during investigative actions are described in **Table 4** and include Leaf Area Index (LAI), LWP, NDVI and temporal assessment of stable isotopes in twig xylem, water, and soils.

LAI is a precursor to more intensive impacts to habitat values including canopy dieback and conversion to an alternative ecological state that may manifest over a longer time frame. LAI varies on a seasonal basis dependent on water availability, generally within the space of weeks to months, with the highest values lagging slightly behind moisture recharge events. Doody et al (2015) document typical annual LAI variation in the range of 14% to 35%, with LAI = 0.5 (i.e., 50% foliage to canopy ratio) identified as a potential threshold, indicative of critical water stress beyond which vegetation health rapidly declines. This value is taken from river red gum forest on the Murray River and it may not have similar applicability to the GDEs at New Lenton. However, the LAI threshold can be adapted based on the results of pre-impact monitoring assessments. The process for thresholds based on LAI applies the following principles:

1. Collection of time series data of LAI from control and impact sites for a period of two years to establish and test thresholds applied to vegetation indices.
2. Identifying appropriate thresholds which will be applied as a trigger for investigation and provide a mechanism to review the appropriateness of the derived trigger.

3. Statistical analysis of time series data to characterise seasonal differences in assessment parameters at control and impact sites to identify if a threshold breach occurs.

Data collection will be site based to provide data collection across all identified GDE risk zones as described in **Section 6.6**.

The application of a threshold value for LAI intends to provide an ‘early warning’ which will trigger a requirement for investigation to identify causal factors. This will allow mitigations to be applied to restore vegetation health if a threshold breach is linked to mining activities. NDVI may similarly be utilised to define a trigger threshold where it can be correlated to field measured LAI, supported by a suitable period of data collection. Where a threshold breach occurs, appropriate baseline data from a range of biotic and abiotic parameter will be available to provide a sound basis for investigation.

Figure 45 details the process and decision framework proposed for the GDEMMP, from initial data collection through to corrective actions in the case that a threshold breach can be linked to mining activity. The initial two years of the assessment covers wet and dry season surveys, to provide a baseline against which future vegetation condition trends can be assessed. The two-year baseline assessment and decision-making process are as follows:

1. Establish the proposed monitoring sites to capture LAI and supporting biophysical data (LWP and NDVI) at the proposed monitoring area in an initial GDE monitoring event prior to construction of the mine.
2. Establish an appropriate trigger threshold value based on the percentile method detailed in DSITI (2017). The proposed process for establishment of the investigative trigger thresholds is:
 - a. Collect LAI data from the proposed impact and control sites (as per **Table 4**) at permanently located monitoring points in the initial GDE assessment.
 - b. Undertake statistical analysis (t-test) to compare dataset means and ensure the appropriateness of the control site for comparative purposes.
 - c. If a significant difference is detected between the mean values of control and impact datasets in the initial assessment, the location of the control site will be re-evaluated.
 - d. Assuming suitability of the control site, set the lower of the 10th percentile (or LAI of 0.5 as per Doody et al 2015, whatever value is lowest) as a trigger value for investigative action.
3. Collect seasonal data from a follow up assessment to provide an initial (1 year) baseline dataset which considers seasonal variation.
4. Undertake an additional two monitoring events in the following year to complete the two-year baseline dataset. This will allow the appropriateness of applied thresholds to be tested and provide sufficient data to test for significant differences in means (t-test) to identify if a threshold breach occurs.

At each stage, decision pathways are provided when threshold breaches are identified, including requirements for investigative action and corrective measures where causal factors can be linked to mining activity. Following the two-year baseline assessment, statistical correlation between various assessment parameters will be drawn, particularly the relationship between LAI and NDVI to allow ongoing monitoring to be completed remotely on an annual basis if necessary, and trigger thresholds to be adapted.

Table 4. Assessment parameters, application, and analysis.

Data collection method	Purpose	Analysis methods / metrics
Primary Parameter		
LAI	Primary parameter used to measure plant stress and vegetation response to decreasing groundwater.	Threshold to be set at the lower of the 10th percentile for all LAI data from the initial dry season survey (or 0.5 from Doody et al 2015, whichever is lower). A threshold response for investigative action will be triggered when: 1. The LAI at the impact site falls below the threshold value. 2. T-test indicates significant differences between means of control and impact sites, and 3. Impact site has a lower mean LAI value. The initial establishment of the trigger threshold will be undertaken in the first dry season assessment to be undertaken and relies on the means between impact and control sites to be comparable at the initial survey.
Supporting Parameters		
LWP	A measurement of water availability to trees, which will provide an important correlate with LAI and a baseline dataset to support a future requirement for investigative action. Supporting data which can be used to determine if any future LAI threshold trigger events are related to plant water availability.	1. Pearson / Spearman's correlation to establish if there is a statistical relationship between LAI and LWP as a basis for inclusion in investigative action, if required. 2. Application of a T-test to identify if significant differences between means of control and impact sites exist during the initial dry season assessment.
NDVI	A remotely sensed measurement of vegetation productivity that describes the greenness and the relative density / health of forest biomass.	Confirming the relationship between NDVI, LAI and LWP through application of Pearson's / Spearman's correlation. Longer term application to remotely monitor GDE health at completion of the 2yr intensive data collection period supplemented with field survey.
Stable Isotopes of twig xylem, soil, groundwater and surface water.	Application as a tracer to identify the predominant sources of water utilised by trees. Useful to determine how tree / water interaction varies on a seasonal basis as groundwater levels fluctuate. Most applicable in the baseline characterisation phase though may be useful supporting information if investigative actions are initiated.	Biplot comparisons of stable isotope values ($\delta^{18}\text{O}$ and $\delta^2\text{H}$) of tree xylem, groundwater and soil moisture to identify phase shifts. Calculation of Ic-excess as per Section 4.3.2 to identify how the water sources of trees varies along the frontage of the Isaac River.
Groundwater monitoring data	The groundwater monitoring program, focused on the monitoring of the alluvial and Tertiary groundwater systems for the purpose of GDE health will:	1. Water quality measurement associated with routine water sampling schedules. 2. Analysis of water levels and water quality in the perched groundwater system, and basal alluvial and

Data collection method	Purpose	Analysis methods / metrics
	1. Monitor linkages between recharge of the basal alluvial aquifer, the perched groundwater system, surface flows and rainfall. 2. Establish water quality values, and the influence of aquifer recharge events from various sources. 3. Assist identification of the degree to which the perched groundwater system and the basal alluvial and Tertiary groundwater systems is utilised by vegetation on a seasonal basis. 4. Identify ecological response to aquifer recharge including correlations between perched groundwater system recharge, the basal alluvial / Tertiary groundwater system recharge, LAI, LWP, NDVI and climate data. 5. Monitor and quantify the impacts of open cut mining development on drawdown in groundwater systems that support GDEs, in the case of New Lenton, being associated with flood plain alluvium on the frontage of the Isaac River.	Tertiary groundwater systems against vegetative indices including LAI and LWP through correlation testing (Pearson / Spearman's). 3. Pressure inducers (data loggers) installed into selected monitoring bores to continuously record water level changes.

The process that occurs after the two-year intensive data collection period will follow the same process as shown in the flowchart in **Figure 45**. Instead of using LAI as a threshold parameter however, NDVI may be applied if a suitable statistical correlation with LAI can be confirmed, although there will be a continued requirement for field assessment of both LAI and LWP completed every two years at a minimum as a control measure. Both NDVI and follow up field assessment will be completed in the dry season at impact and control sites to determine if the threshold is exceeded, and if exceeded, trigger the flow chart process for investigation, mitigation (corrective action) and offsets as required. The GDEMMP will also propose mitigations for remediation, should impacts to GDEs be detected, which may include:

1. Injection of water into the tree root zone for any trees that show significant signs of drought stress that can be linked to groundwater drawdown.
2. Infill planting where riparian tree death can be linked to groundwater drawdown.
3. Environmental offsets should other mitigations fail to limit decline in GDE condition.

The management framework is intended to be adaptive, with future capacity for update dependent on the ongoing results of the baseline assessment, and any information gaps identified. Data derived from the groundwater monitoring program, specifically water level and water quality data, will provide supporting information to be used in the case that vegetation threshold values are breached, and investigative actions are necessary.

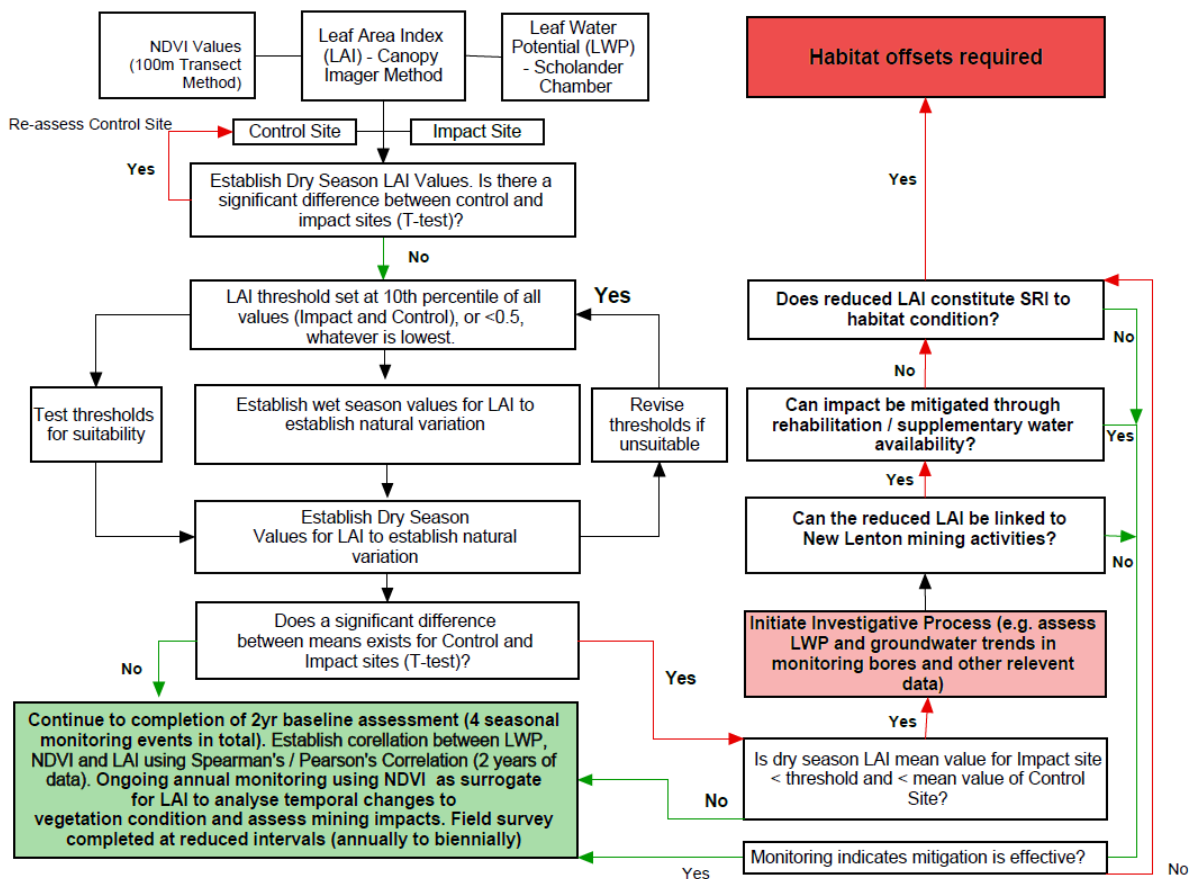


Figure 45. Decision process for application of investigative and corrective actions when trigger thresholds are exceeded for monitoring assessments after the initial 2-year baseline assessment.

6.6 Risk Assessment

To accommodate the assessment of Project related risks to GDEs, it is necessary to identify 'Risk Zones' recognising that the level of risk varies across the Project study area dependant on degree of perceived risk to identified GDEs relative to groundwater drawdown. Four risk zones are identified as described in **Table 4**, with spatial representation of Risk Zones provided in **Figure 45**.

Table 5. GDE Risk Zones based on degree of groundwater drawdown.

Rank	GDE Risk Zone	Likelihood of Unmitigated Impact	Description
1	Zone 1 – Highest Risk	Likely	10m to 12m drawdown in the basal alluvial groundwater unit focused on mapped GDEs associated with the Isaac River.
2	Zone 2 –	Possible	>5 to <10m groundwater drawdown in the basal alluvial groundwater unit focused on mapped GDEs associated with the Isaac River.
3	Zone3_	Unlikely	2m to 5m drawdown in the basal alluvial groundwater unit focused on mapped GDEs associated with the Isaac River.
4	Zone4_Lowest Risk	Not Expected	<2m drawdown in the basal alluvial groundwater unit focused on mapped GDEs associated with the Isaac River.

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 magnitude 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 6**, descriptions of magnitude are applied in **Table 7** and the derived risk matrix is provided in **Table 8**. A list of applicable mitigations and management measures is provided in **Table 9** although it should be noted that mitigations will only be applied, if management measures as developed within 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 10**. 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) the GDE 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 (classification as

Essential Habitat for threatened wildlife listed as per AARC 2023). The riparian corridor of the Isaac River is also mapped as a matter of state environmental significance (MSES) in Queensland, which provides consistency with the intent of DES (2022).

Based on the risk assessment outcomes in **Table 6**, outside direct clearing where the unmitigated risk is 'High', risk to GDEs identified in this assessment are classified as 'Moderate' to 'Low' risk for field verified GDEs dependent on location relative to drawdown. Residual risk ranking is 'Moderate' for direct clearing and 'Low' to 'Insignificant' for other impact mechanisms 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 that can be attributed either directly or indirectly to Project related mining operations.

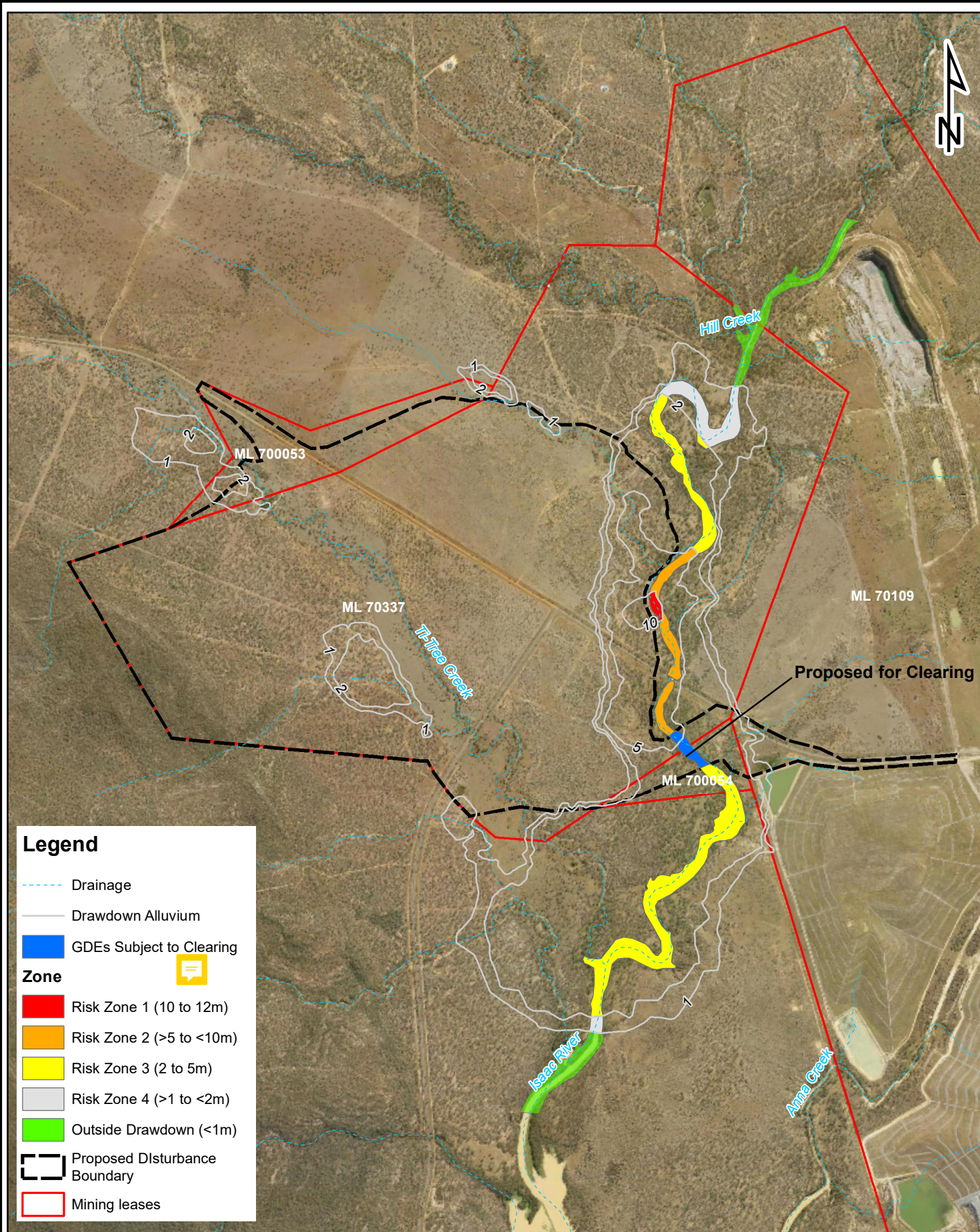
Table 6. Descriptors and ranking for the likelihood of impact occurring.

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

Table 7. Descriptors of Impact Magnitude applied in the risk assessment.

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

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



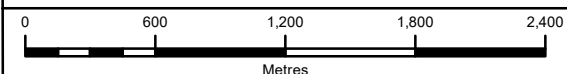
Legend

- Drainage
- Drawdown Alluvium
- GDEs Subject to Clearing
- Zone**
- Risk Zone 1 (10 to 12m)
- Risk Zone 2 (>5 to <10m)
- Risk Zone 3 (2 to 5m)
- Risk Zone 4 (>1 to <2m)
- Outside Drawdown (<1m)
- Proposed Disturbance Boundary
- Mining leases

Figure 46. GDE Impact Risk Zones relative to confirmed TGDEs

Client

Bowen Basin Coking Coal



Scale 1:34,941

Drawn By DG

Checked DS

File Path

Date

04-Dec-23

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Table 8. Matrix applied in the risk assessment.

Magnitude		Likelihood				
		Highly Unlikely (1)	Unlikely (2)	Possible (3)	Likely (4)	Highly Likely (5)
	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 9. List of relevant mitigations and management actions.

Mitigation No	Mitigations	Management Actions
1	GDE Avoidance, rehabilitation	-
2	Biodiversity Offsets	-
3	Habitat Augmentation	-
4	Injection of water into the tree root zone	-
5	-	Baseline data collection / Implementation of a Project GDEMMP.
6	-	Operation of New Lenton under the under the EA that includes a mine WMS, ESCP and REMP.
7	-	Groundwater monitoring

Table 10. Risk assessment for potential impacts and residual risks scores.

Risk Zone	Pre-mitigated Risk			Comments	Management /Mitigation Measures*	Residual Risk Ranking		
	Likelihood	Magnitude	Risk			Likelihood	Magnitude	Risk
1. Direct Clearing								
All Risk Zones	5	Severe	High	Potential clearing of up to 2.21 ha of identified terrestrial GDE, which may be reduced following mitigations provided in Section 6.5.1.	1	5	Moderate	Moderate
2. A total or partial loss or reduction in the volume or pressure of the aquifer being utilised by Terrestrial GDEs.								
Risk Zone 1 (Drawdown in the basal alluvial groundwater unit 10m to 12m)	4	Moderate	Moderate	The seasonally variable perched groundwater unit that supports GDEs on the Isaac River is perched above the basal alluvial groundwater unit, although the two groundwater units may interact during extremely wet climatic period following river flow and resultant groundwater recharge. Drawdown in the basal alluvial groundwater unit may result in more rapid drying of the perched unit decreasing its seasonal persistence and viability. The adaptability of the dominant riparian species to ecological change (see Section 2.2.3) would suggest these impacts will be ‘Low’ in areas where aquifer drawdown response is greatest (i.e., 10 -12m drawdown) and the risk to GDE function will decrease with decreasing drawdown magnitude.	5, 6, 7 and 2,3, 4 if significant impacts are identified.	3	Low	Low
Risk Zone 2 (Drawdown in the basal alluvial groundwater unit >5 to <10m)	3	Moderate	Moderate	Risk Zone 2 represents a reduction in the likelihood and magnitude of potential impacts to GDEs over Risk Zone 1. Groundwater	5, 6, 7 and 2,3, 4 if significant impacts are identified.	2	Low	Low

Risk Zone	Pre-mitigated Risk			Comments	Management /Mitigation Measures*	Residual Risk Ranking		
	Likelihood	Magnitude	Risk			Likelihood	Magnitude	Risk
				drawdown is reduced to >5m to <10m in the basal alluvial groundwater unit resulting in faster recharge during surface flow events. The influence of more rapid drying on the seasonally variable perched groundwater unit will be lessened.				
Risk Zone 3 and Risk Zone 4 (Drawdown in the basal alluvial aquifer <5m).	2	Low	Low	The effect of low-level drawdown on the basal alluvial groundwater unit will have insignificant impact on the seasonally variable perched groundwater unit and any riparian vegetation which is dependent on it.	5,6,7	2	Negligible	Insignificant
3. A change in the magnitude and timing of volume fluctuations in the aquifer being utilised by Terrestrial GDEs.								
All Risk Zones	Refer to 4 (below)			Volume fluctuations in both the seasonally variable perched groundwater unit and the basal alluvial groundwater unit are regulated by surface flows and local surface water infiltration which are assessed in 4 (below).	Refer to 4 (below)			
4. Changes to the interaction between surface flows and aquifers being utilised by Terrestrial GDEs.								
All Risk Zones	2	Low	Low	There will be insignificant impact on surface water flows and no resultant change to recharge of groundwater units in the alluvial groundwater units (both perched and basal).	5, 6, 7 and 2,3, 4 if significant impacts are identified.	1	Negligible	Insignificant
5. Change in chemical composition of an aquifer detrimentally impacting the health of a Terrestrial GDE.								

Risk Zone	Pre-mitigated Risk			Comments	Management /Mitigation Measures*	Residual Risk Ranking		
	Likelihood	Magnitude	Risk			Likelihood	Magnitude	Risk
All Risk Zones	3	Moderate	Moderate	Uncontrolled releases of mine water that have potential to impact the chemical composition of infiltrating surface waters will not occur during the life of the mine. WMS controls in place for mine water and sediment water. Post mining rehabilitation of disturbed areas.	1, 5, 6, 7	2	Negligible	Insignificant

*Management measures are applied 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 potentially affected by the New Lenton Project. Based on the results of the field survey, it is concluded that riparian vegetation associated with the Isaac River floodplain and alluvium presents the only TGDE identified within the Project study area. Groundwater usage by vegetation away from the river margins decreases with distance from the river. On older elevated alluvial terraces and regolith, groundwater usage is restricted by the shallow rooting depth of vegetation, significant depth to the groundwater table (>10mbgl, particularly in the regolith), and high levels of groundwater salinity. Uncertainties in the GDE assessment relate to if there is any degree of connectivity between the seasonally variable perched groundwater unit and the basal alluvial groundwater unit, and whether riparian vegetation has developed deeper, dimorphic root systems which have capacity to utilise shallow groundwater in the perched system, switching to the basal alluvial groundwater unit when the perched groundwater is depleted. Based on current knowledge, there is no indication of any hydraulic linkage between the perched and the basal alluvial groundwater unit

Direct clearing within the disturbance footprint will impact up to 2.21ha of mapped TGDEs on the Isaac River; however, these impacts will be mitigated by reducing construction width of linear infrastructure and rehabilitating construction disturbance. Outside of this clearing, the most likely pathway for impact to TGDEs will be through depressurisation / dewatering of the basal alluvial groundwater unit which may result in faster drying of the soil profile, and possibly reduced seasonal persistence of the perched groundwater unit if hydraulic linkage between these two units occurs. The magnitude of impact will also depend on the degree of connectivity (if any) between the seasonally variable perched and the basal alluvial groundwater units, and whether any vegetation associated with the mapped TGDE areas have developed deeper rooting systems which penetrate to the basal alluvial groundwater unit. Risk to GDE function is however ameliorated by several factors which include:

1. The limited to no hydraulic connectivity between the perched and basal alluvial groundwater systems based on the current understanding of the interactions between these two groundwater units.
2. Tree species which characterise the riparian GDE areas, particularly forest red gum (*Eucalyptus tereticornis*), are resilient and have capacity to adapt to the possible minor reductions in soil moisture availability that may propagate above areas of groundwater drawdown.
3. The groundwater hosted in the seasonally variable perched groundwater unit that supports GDEs is subject to natural volume fluctuations in response to changing seasonal conditions and may dry for significant periods. This means that dependent vegetation will be adapted to varying degrees of moisture availability.

GDE 'Risk Zones' have been identified across the Project study area based on the potential for Project related activities to impact GDE function. The risk zones are defined as:

- Areas where intense drawdown of groundwater (10m to 12m) interacts with mapped GDEs on the Isaac River (Risk Zone 1-Highest Risk).
- Areas where high levels of groundwater drawdown (>5m to <10m) interacts with mapped GDEs on the Isaac River (Risk Zone 2).
- Areas where moderate levels of groundwater drawdown (2m to 5m) interacts with mapped GDEs on the Isaac River (Risk Zone 3).
- Areas where low levels of groundwater drawdown (<2m) interacts with TGDEs mapped on the Isaac River (Risk Zone 4 – Lowest Risk).

Mapped TGDEs outside the area of groundwater drawdown in the alluvium are not considered to be at risk from Project development.

Outside the 2.21ha of GDEs proposed for clearing on the Isaac River, the assessment of unmitigated risk to GDE function associated within these areas indicates that levels of overall levels of risk range from 'Moderate' in Risk Zone 1 and Risk Zone 2 to 'Low' in Risk Zone 3, and Risk Zone 4.

Management measures to limit ecological impact to GDEs in vicinity of the Project disturbance area include general operational measures such those encompassed in the New Lenton EA, with implementation of the WMS, ESCP and REMP; and rehabilitation during and post mining. To detect impacts to the health and function of TGDEs associated with Project development, a GDEMMP will be prepared which accommodates for uncertainties in ecological response of GDEs to disturbance. This GDEMMP will provide methods for the early detection of impacts through development of trigger thresholds of ecological condition and proposes mitigations to be applied should decline in ecological condition be linked to Project related mining operations.

With implementation of the GDEMMP, it is considered that the risk to GDEs posed by mine development, other than the small area of direct clearing, ranges from 'Low' (Risk Zone 1) to Insignificant (Risk Zone 4). Implementation of the GDEMMP will ensure that impacts to GDEs will be detected early to allow mitigations to be applied, reducing the risk that significant residual impacts are experienced by either MSES or MNES, and ecological offsets can be applied should significant residual impacts be detected.

8.0 References

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Appendices

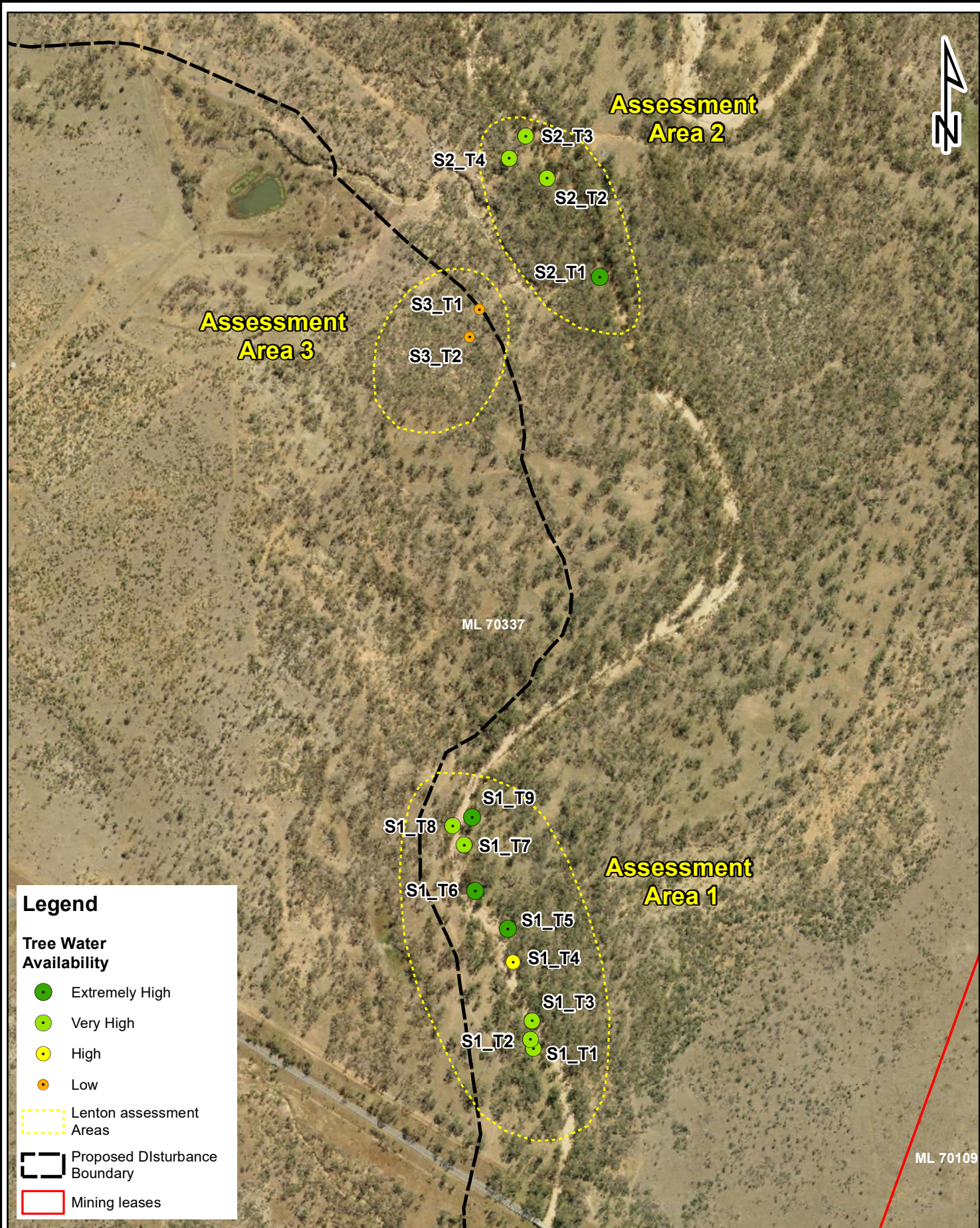
Appendix A – Tree LWP Measurements and Details

ID	Y	X	Tree Sample Point	Species	DBH (cm)	Height (m)	Geomorphic Position	LWP	Tree Water Availability
5	-21.5743	148.1268	S10_T1	Eucalyptus populnea	55	15	> 0.5km from river margins on elevated residual surface	-0.95	Moderate
6	-21.5741	148.127	S10_T2	Eucalyptus populnea	45	16	> 0.5km from river margins on elevated residual surface	-1.4	Low
7	-21.574	148.1271	S10_T3	Eucalyptus populnea	45	16	> 0.5km from river margins on elevated residual surface	-1.1	Moderate
8	-21.5395	148.1375	S11_T1	Eucalyptus tereticornis	100	18	On lower alluvial terrace of drainage line 5m from sandy channel	-0.45	Very High
9	-21.5396	148.1375	S11_T2	Eucalyptus tereticornis	100	17	2m above channel floor on inner bench	-0.25	Extremely High
10	-21.5396	148.1374	S11_T3	Eucalyptus tereticornis	50	17	5m above channel floor on upper terrace	-0.45	Very High
12	-21.5381	148.1437	S12_T1	Eucalyptus tereticornis	50	15	5m from river channel on lower alluvial terrace	-0.25	Extremely High
13	-21.5383	148.1437	S12_T2	Eucalyptus tereticornis	80	23	10m from river channel on lower alluvial terrace	-0.5	Very High
14	-21.5384	148.144	S12_T3	Eucalyptus tereticornis	80	20	3m above channel floor on inner bench of tributary creek	-0.5	Very High
15	-21.5383	148.144	S12_T4	Eucalyptus tereticornis	50	20	Inner bench 3m above sandy channel floor	-0.45	Very High
21	-21.5414	148.1463	S13_T1	Eucalyptus tereticornis	120	23	15m from river channel and 5m above channel floor	-0.1	Extremely High
17	-21.5412	148.1468	S13_T2	Casuarina cunninghamiana	80	23	Directly on river channel	-0.2	Extremely High
22	-21.5409	148.1472	S13_T3	Eucalyptus tereticornis	90	16	Top of upper terrace 5m above river channel	-0.25	Extremely High
23	-21.5405	148.147	S13_T4	Eucalyptus tereticornis	100	24	Top of upper terrace 8m above river channel	-0.2	Extremely High
24	-21.5403	148.1466	S13_T5	Eucalyptus tereticornis	120	25	3m above channel floor and 12m from channel margins	-0.3	Very High
25	-21.5383	148.1487	S13_T6	Eucalyptus tereticornis	80	16	2.5m above channel floor and 6m from sandy channel margins	-0.1	Extremely High
26	-21.5381	148.1486	S13_T7	Casuarina cunninghamiana	80	22	Directly on river channel floor	-0.15	Extremely High
27	-21.538	148.1492	S13_T8	Eucalyptus tereticornis	100	18	1m above channel floor and 3m from river channel margins	-0.8	High
28	-21.5382	148.149	S13_T9	Eucalyptus tereticornis	80	15	3.5m above river channel floor on inner bank of river	-0.15	Extremely High
20	-21.541	148.147	S13_T10	Eucalyptus tereticornis	55	16	2.5m above channel floor and 2.5m from sandy channel margins	-0.1	Extremely High
29	-21.5604	148.1414	S1_T1	Eucalyptus tereticornis	80	21	5m above river channel and 15m from channel margins	-0.4	Very High
30	-21.5603	148.1414	S1_T2	Eucalyptus tereticornis	95	22	5m above river channel and 10m from channel margins	-0.45	Very High
32	-21.5601	148.1414	S1_T3	Casuarina cunninghamiana	65	18	On margins of sandy channel	-0.55	Very High

ID	Y	X	Tree Sample Point	Species	DBH (cm)	Height (m)	Geomorphic Position	LWP	Tree Water Availability
33	-21.5593	148.1411	S1_T4	Casuarina cunninghamiana	73	23	On margins of sandy channel	-0.65	High
34	-21.5588	148.1411	S1_T5	Eucalyptus tereticornis	60	20	5m from margins of sandy channel and approximately 3m above channel floor	-0.25	Extremely High
35	-21.5583	148.1406	S1_T6	Eucalyptus tereticornis	100	24	2m from margins of sandy channel and approximately 3m above channel floor	-0.15	Extremely High
36	-21.5577	148.1404	S1_T7	Eucalyptus tereticornis	150	26	2m above channel floor directly adjacent to river	-0.4	Very High
37	-21.5574	148.1402	S1_T8	Eucalyptus tereticornis	90	27	On margins of sandy channel	-0.45	Very High
38	-21.5573	148.1405	S1_T9	Eucalyptus tereticornis	70	15	10m from river channel and 5m above channel floor	-0.2	Extremely High
39	-21.55	148.1423	S2_T1	Eucalyptus tereticornis	100	18	Lower alluvial terrace adjacent to the Isaac River. 5m from channel margin and 3m above channel floor	-0.05	Extremely High
40	-21.5487	148.1415	S2_T2	Eucalyptus tereticornis	55	17	Lower alluvial terrace adjacent to the Isaac River. 15m from channel margin and 4m above channel floor	-0.4	Very High
41	-21.5481	148.1412	S2_T3	Eucalyptus tereticornis	60	23	Lower alluvial terrace adjacent to the Isaac River. 5m from channel margin and 4m above channel floor	-0.5	Very High
42	-21.5484	148.141	S2_T4	Eucalyptus tereticornis	110	24	Margins of Tertiary residuals approximately 30m from river channel	-0.45	Very High
43	-21.5505	148.1406	S3_T1	Eucalyptus populnea	50	16	>250m from river margins on elevated residual surface	-1.45	Low
44	-21.5509	148.1404	S3_T2	Eucalyptus populnea	55	15	>250m from river margins on elevated residual surface	-1.55	Low
45	-21.5527	148.1177	S4_T1	Eucalyptus orgadophila	65	13	On margins of ephemeral gully on heavy clay soils	-0.9	Moderate
46	-21.553	148.1178	S4_T2	Eucalyptus orgadophila	70	15	On margins of ephemeral gully on heavy clay soils	-1.4	Low
47	-21.5659	148.1283	S5_T1	Eucalyptus tereticornis	65	15	Directly on margins of ephemeral drainage line	-0.55	Very High
48	-21.5656	148.1281	S5_T2	Eucalyptus tereticornis	70	16	Directly on margins of ephemeral drainage line	-0.6	High
51	-21.5697	148.1449	S6_T1	Eucalyptus tereticornis	70	22	>100m from main channel of Isaac River	-0.3	Very High
52	-21.5698	148.1449	S6_T2	Eucalyptus tereticornis	75	22	>100m from main channel of Isaac River	-0.45	Very High
53	-21.57	148.1448	S6_T3	Eucalyptus tereticornis	90	24	70m from main channel of Isaac River	-0.3	Very High
54	-21.5703	148.145	S6_T4	Eucalyptus tereticornis	75	21	60m from main channel of Isaac River	-0.1	Extremely High
55	-21.5699	148.1456	S6_T5	Eucalyptus tereticornis	130	24	30m from main channel of Isaac River on margins of T1 terrace	-0.05	Extremely High
56	-21.5698	148.1459	S6_T6	Eucalyptus tereticornis	140	30	On inner bench of river 4m above river channel	-0.1	Extremely High
57	-21.5696	148.1455	S6_T7	Eucalyptus tereticornis	110	23	3m from margins of the river channel on lower river terrace	-0.2	Extremely High
58	-21.5694	148.1451	S6_T8	Eucalyptus tereticornis	80	24	15m from river channel on margins of T1 terrace	-0.1	Extremely High

ID	Y	X	Tree Sample Point	Species	DBH (cm)	Height (m)	Geomorphic Position	LWP	Tree Water Availability
59	-21.581	148.1366	S7_T1	Eucalyptus tereticornis	80	26	20m from channel of Isaac River on lower T1 terrace	-0.1	Extremely High
60	-21.5814	148.1362	S7_T2	Eucalyptus populnea	80	23	50m from main channel of Isaac River on T1 terrace	-0.25	Extremely High
62	-21.5793	148.1341	S8_T1	Eucalyptus tereticornis	120	15	Directly on margins of ephemeral drainage line. Sandy channel	-0.35	Very High
63	-21.5793	148.1341	S8_T2	Eucalyptus tereticornis	70	23	15m from channel of ephemeral drainage line	-0.15	Extremely High
64	-21.5798	148.1333	S8_T3	Eucalyptus tereticornis	130	22	15m from channel of ephemeral drainage line	-0.25	Extremely High
65	-21.5798	148.1328	S8_T4	Eucalyptus tereticornis	80	20	Directly adjacent to overflow channel of ephemeral drainage line	-0.45	Very High
	-21.5613	148.1108	S9_T1	Eucalyptus populnea	50	15	Lower limits of colluvial slope	-0.85	Moderate
66	-21.5614	148.1112	S9_T2	Eucalyptus crebra	45	17	Lower limits of colluvial slope	- 0.95 5	Moderate
67	-21.5615	148.1114	S9_T3	Eucalyptus populnea	55	17	Lower limits of colluvial slope	- 0.95 5	Moderate

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



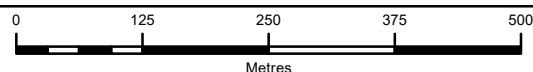
Extremely High	> - 0.276 mpa
Very High	< -0.276 to - 0.552 mpa
High	<-0.552 to -0.896 mpa
Moderate	<-0.896 to -1.24 mpa
Low	<-1.24 to -1.72 mpa
Very Low	<-1.72 to -2.21 mpa
Extremely Low	<-2.21 mpa

1:7,500

Appendix B1. Sampling detail at Assessment Area 1 to Assessment Area 3

Client

Bowen Basin Coking Coal



Scale

Drawn By DG

Checked DS

File Path

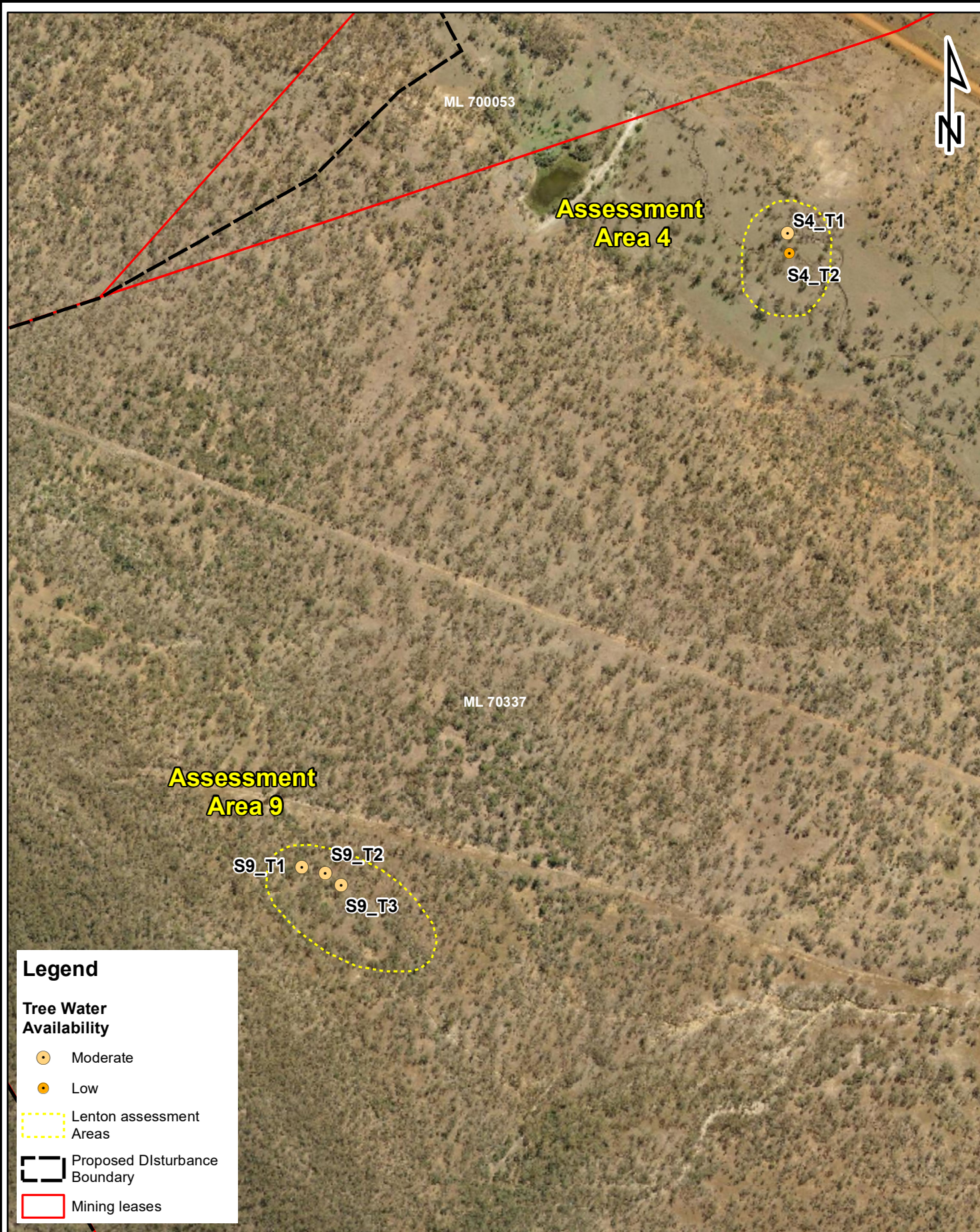


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Legend

Tree Water Availability

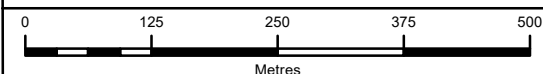
- Moderate
- Low
- Lenton assessment Areas
- Proposed Disturbance Boundary
- Mining leases

Extremely High	> - 0.276 mpa
Very High	< -0.276 to - 0.552 mpa
High	<-0.552 to -0.896 mpa
Moderate	<-0.896 to -1.24 mpa
Low	<-1.24 to -1.72 mpa
Very Low	<-1.72 to -2.21 mpa
Extremely Low	<-2.21 mpa

Appendix B2. Sampling detail at Assessment Area 4 and Assessment Area 9

Client

Bowen Basin Coking Coal



Scale 1:7,500

Drawn By DG

Checked DS

File Path



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Assessment Area 5

ML 70337

S5_T2

S5_T1

Legend

Tree Water Availability

-  Very High
-  High
-  Moderate
-  Low

 Lenton assessment Areas

 Proposed Disturbance Boundary

 Mining leases

S10_T2
S10_T1

S10_T3

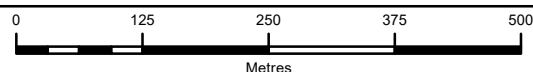
Assessment Area 10

Extremely High	> - 0.276 mpa
Very High	< -0.276 to - 0.552 mpa
High	<-0.552 to -0.896 mpa
Moderate	<-0.896 to -1.24 mpa
Low	<-1.24 to -1.72 mpa
Very Low	<-1.72 to -2.21 mpa
Extremely Low	<-2.21 mpa

Appendix B3. Sampling detail at Assessment Area 5 and Assesment Area 10

Client

Bowen Basin Coking Coal



Scale 1:7,500

Drawn By DG

Checked DS

File Path

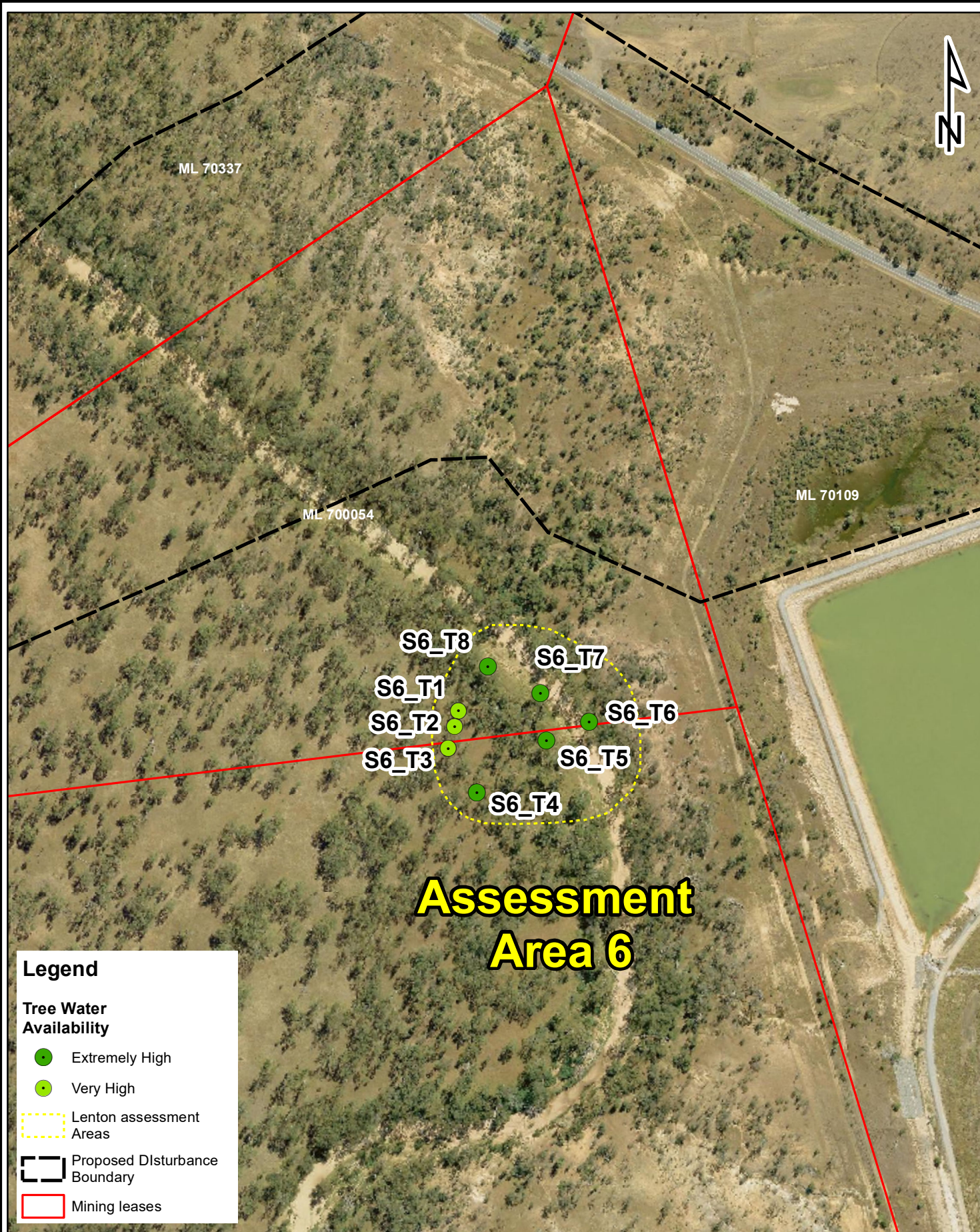


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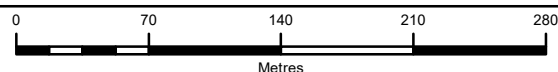


Extremely High	> - 0.276 mpa
Very High	< -0.276 to - 0.552 mpa
High	<-0.552 to -0.896 mpa
Moderate	<-0.896 to -1.24 mpa
Low	<-1.24 to -1.72 mpa
Very Low	<-1.72 to -2.21 mpa
Extremely Low	<-2.21 mpa

Appendix B4. Sampling detail at Assessment Area 6

Client

Bowen Basin Coking Coal



Scale 1:4,000

Drawn By DG

Checked DS

File Path



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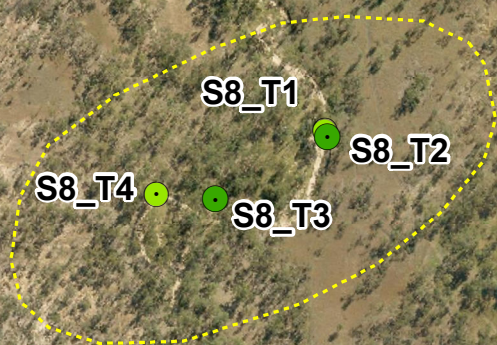
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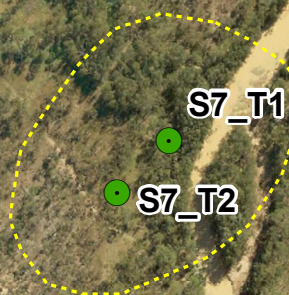
A4



Assessment Area 8



Assessment Area 7



Legend

Tree Water Availability

- Extremely High
- Very High

Lenton assessment Areas

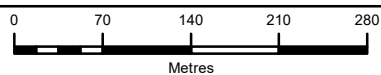
Mining leases

Extremely High	> - 0.276 mpa
Very High	< -0.276 to - 0.552 mpa
High	<-0.552 to -0.896 mpa
Moderate	<-0.896 to -1.24 mpa
Low	<-1.24 to -1.72 mpa
Very Low	<-1.72 to -2.21 mpa
Extremely Low	<-2.21 mpa

Appendix B5. Sampling detail at Assessment Area 7 and Assessment Area 8

Client

Bowen Basin Coking Coal



Scale 1:6,000

Drawn By DG

Checked DS

File Path

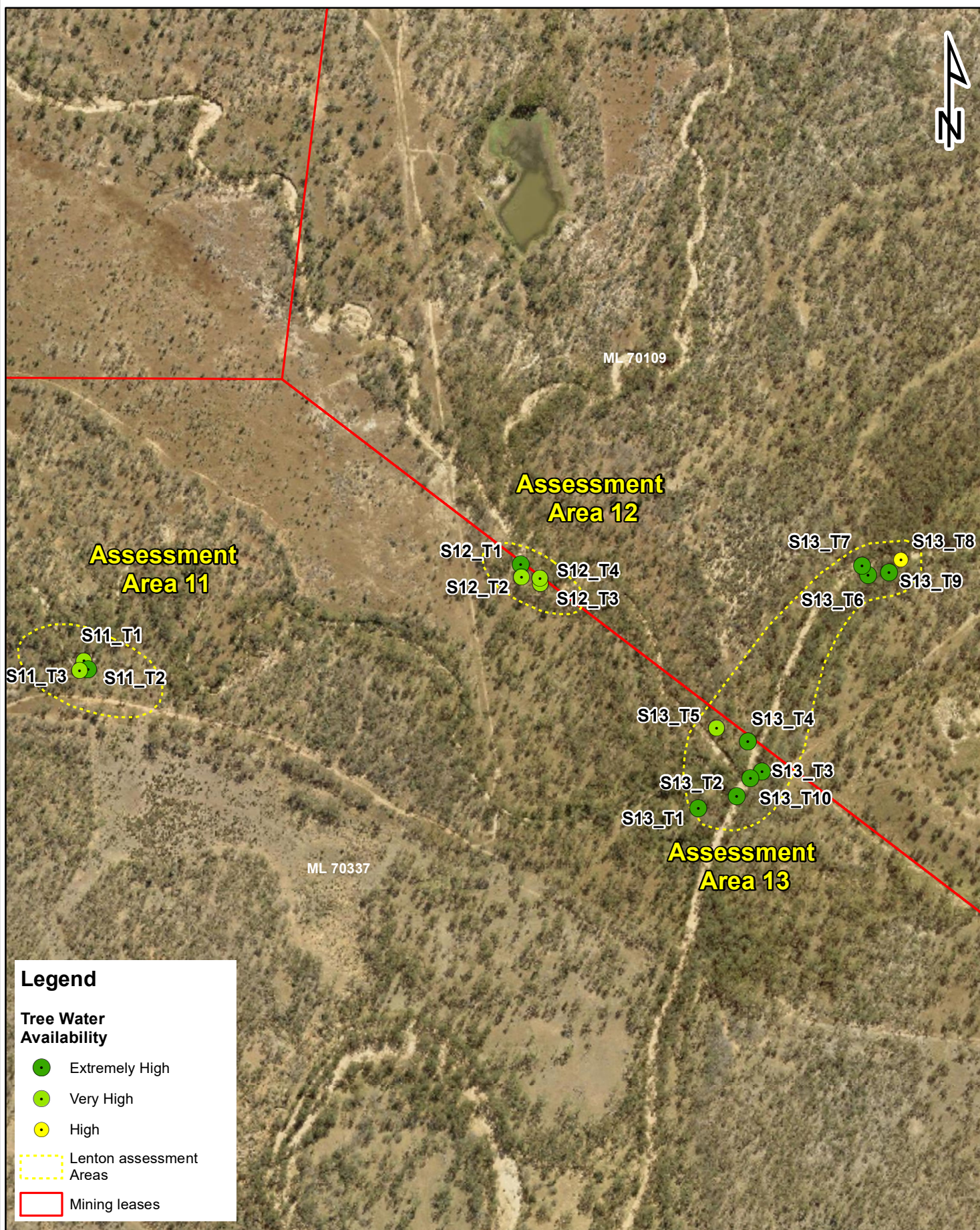


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Legend

Tree Water Availability

- Extremely High
- Very High
- High

 Lenton assessment Areas

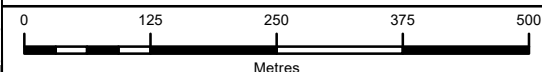
 Mining leases

Extremely High	> - 0.276 mpa
Very High	< -0.276 to - 0.552 mpa
High	<-0.552 to -0.896 mpa
Moderate	<-0.896 to -1.24 mpa
Low	<-1.24 to -1.72 mpa
Very Low	<-1.72 to -2.21 mpa
Extremely Low	<-2.21 mpa

Appendix B6. Sampling detail at Assessment Area 11 to Assessment Area 13

Client

Bowen Basin Coking Coal



Scale 1:7,500

Drawn By DG

Checked DS

File Path



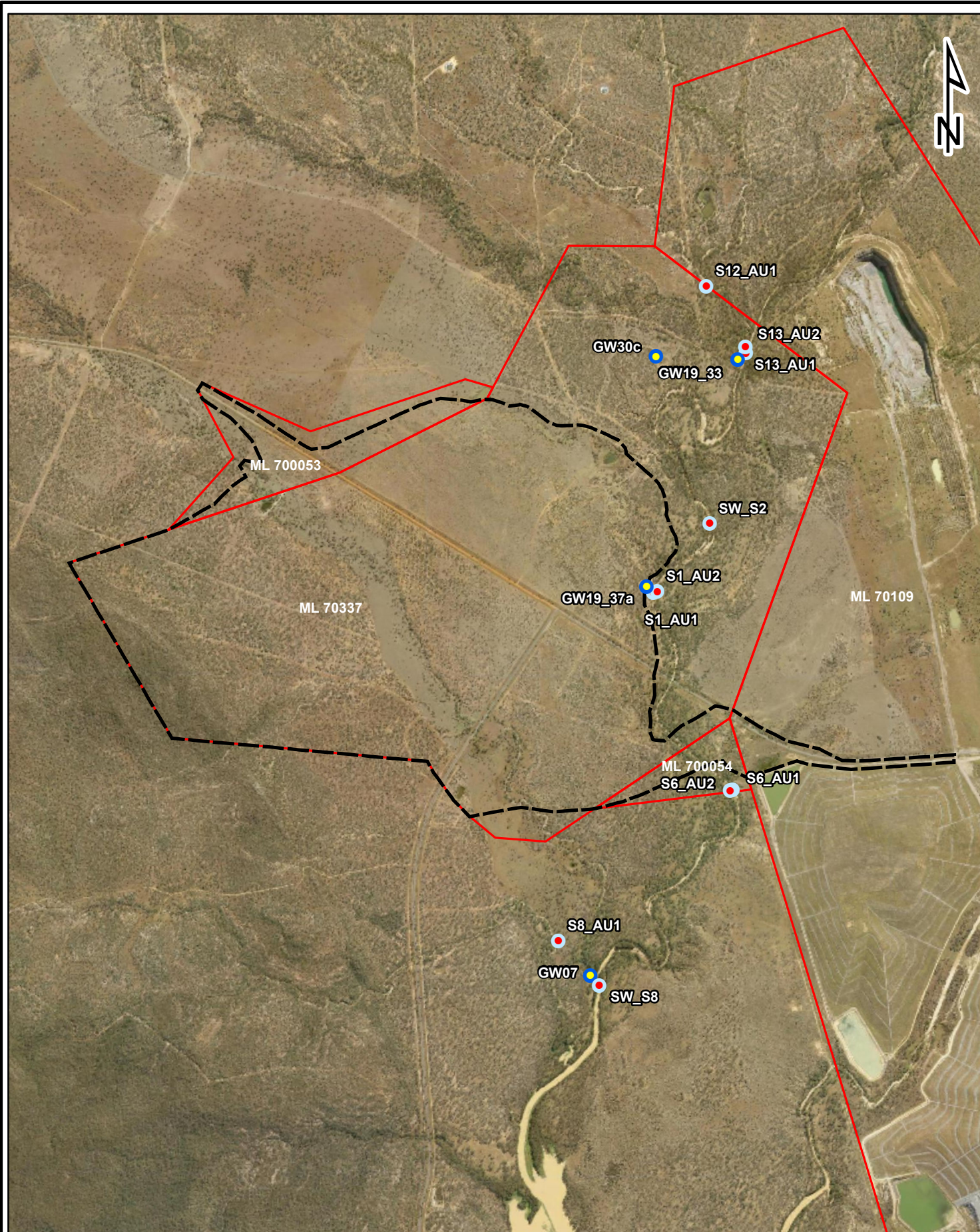
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Appendix C– Location of Soil Augers and Water Samples Analysed for Stable Isotope Composition.



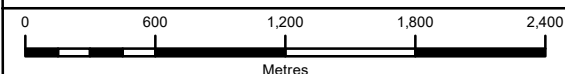
Legend

- Soil Auger
- Water sample
- Proposed Disturbance Boundary
- Mining leases

Appendix C. Location of soil augers and surface water sampling locations

Client

Bowen Basin Coking Coal



Scale 1:34,941

Drawn By DG

Checked DS

File Path



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Appendix D – Soil Moisture Potential Raw Data

Sample	Type	Project	Date Sampled	SMP
S1_AU1_0.6	Soil	New Lenton	21.02.23	-0.06
S1_AU2_0.3	Soil	New Lenton	21.02.23	-0.12
S1_AU2_0.5	Soil	New Lenton	21.02.23	0
S1_AU2_0.75	Soil	New Lenton	21.02.23	-0.02
S1_AU2_1.0	Soil	New Lenton	21.02.23	-0.02
S1_AU2_1.5	Soil	New Lenton	21.02.23	-0.03
S1_AU2_1.75	Soil	New Lenton	21.02.23	-0.08
S1_AU2_2.0	Soil	New Lenton	21.02.23	-0.18
S1_AU2_2.5	Soil	New Lenton	21.02.23	-0.04
S1_AU2_3.3	Soil	New Lenton	21.02.23	-0.04
S1_AU2_3.5	Soil	New Lenton	21.02.23	-0.05
S1_AU2_3.75	Soil	New Lenton	21.02.23	-0.09
S12_AU1_0.1	Soil	New Lenton	25.02.23	-0.11
S12_AU1_0.3	Soil	New Lenton	25.02.23	-0.08
S12_AU1_0.75	Soil	New Lenton	25.02.23	-0.04
S12_AU1_1.0	Soil	New Lenton	25.02.23	-0.1
S12_AU1_1.5	Soil	New Lenton	25.02.23	-0.02
S13_AU1_1.3	Soil	New Lenton	26.02.23	-0.01
S13_AU1_1.5	Soil	New Lenton	26.02.23	-0.04
S13_AU2_0.2	Soil	New Lenton	26.02.23	-0.06
S13_AU2_0.3	Soil	New Lenton	26.02.23	-0.06
S13_AU2_0.5	Soil	New Lenton	26.02.23	-0.21
S13_AU2_0.8	Soil	New Lenton	26.02.23	-0.02
S13_AU2_1.0	Soil	New Lenton	26.02.23	-0.12
S13_AU2_1.3	Soil	New Lenton	26.02.23	-0.01
S13_AU2_1.5	Soil	New Lenton	26.02.23	0
S13_AU2_1.75	Soil	New Lenton	26.02.23	-0.17
S13_AU2_2.1	Soil	New Lenton	26.02.23	-0.01
S13_AU2_2.5	Soil	New Lenton	26.02.23	-0.1
S13_AU2_2.7	Soil	New Lenton	26.02.23	-0.01
S13_AU2_3.0	Soil	New Lenton	26.02.23	0
S13_AU2_3.5	Soil	New Lenton	26.02.23	-0.02
S13_AU2_3.75	Soil	New Lenton	26.02.23	-0.13
S13_AU2_3.8	Soil	New Lenton	26.02.23	-0.07
S13_AU2_4.0	Soil	New Lenton	26.02.23	-0.02
S13_AU2_4.2	Soil	New Lenton	26.02.23	0
S6_AU1_1.2	Soil	New Lenton	24.02.23	-0.01
S6_AU2_0.1	Soil	New Lenton	24.02.23	-0.02
S6_AU2_0.3	Soil	New Lenton	24.02.23	-0.01
S6_AU2_0.6	Soil	New Lenton	24.02.23	0
S6_AU2_1.0	Soil	New Lenton	24.02.23	-0.07

Sample	Type	Project	Date Sampled	SMP
S6_AU2_1.5	Soil	New Lenton	24.02.23	-0.05
S6_AU2_2.0	Soil	New Lenton	24.02.23	-0.05
S6_AU2_2.5	Soil	New Lenton	24.02.23	-0.08
S6_AU2_2.75	Soil	New Lenton	24.02.23	0
S6_AU2_3.0	Soil	New Lenton	24.02.23	0
S6_AU2_3.3	Soil	New Lenton	24.02.23	0
S8_AU1_0.2	Soil	New Lenton	24.02.23	-0.35
S8_AU1_0.85	Soil	New Lenton	24.02.23	0
S8_AU1_1.0	Soil	New Lenton	24.02.23	-0.03
S8_AU1_1.3	Soil	New Lenton	24.02.23	-0.1
S8_AU1_1.4	Soil	New Lenton	24.02.23	-0.32
S8_AU1_1.6	Soil	New Lenton	24.02.23	-0.05
S8_AU1_1.8	Soil	New Lenton	24.02.23	-0.02
S8_AU1_2.5	Soil	New Lenton	24.02.23	-0.37

Appendix E – Stable Isotope Analytical Results

Sample Group	Site No	$\delta^{18}\text{O}$	$\delta^2\text{H}$	D_ Excess	LC_ Excess
Soils	S1_AU1_0.6	-5.34	-31.08	11.66293	-3.69
Soils	S1_AU2_0.3	-9.47	-62.20	13.57601	-6.15
Soils	S1_AU2_0.5	-9.83	-66.28	12.36747	-7.56
Soils	S1_AU2_0.75	-10.15	-71.88	9.307417	-10.54
Soils	S1_AU2_1.0	-9.37	-62.35	12.6359	-6.87
Soils	S1_AU2_1.5	-9.54	-64.98	11.35525	-8.15
Soils	S1_AU2_1.75	-8.19	-52.59	12.91652	-5.44
Soils	S1_AU2_2.0	-8.34	-62.50	4.202329	-13.17
Soils	S1_AU2_2.5	-8.44	-57.87	9.628459	-8.55
Soils	S1_AU2_3.3	-8.41	-65.25	2.068512	-15.10
Soils	S1_AU2_3.5	-6.00	-55.04	-7.0752	-20.64
Soils	S1_AU2_3.75	-6.88	-57.98	-2.96546	-17.94
Soils	S12_AU1_0.1	-5.32	-43.31	-0.76358	-14.47
Soils	S12_AU1_0.3	-7.82	-68.55	-5.98496	-21.51
Soils	S12_AU1_0.75	-7.91	-68.44	-5.14252	-20.87
Soils	S12_AU1_1.0	-5.26	-40.15	1.910076	-12.09
Soils	S12_AU1_1.5	-5.27	-37.19	4.949456	-9.46
Soils	S6_AU1_1.2	-3.65	-34.91	-5.74638	-17.14
Soils	S6_AU2_0.1	-11.92	-91.75	3.621768	-17.25
Soils	S6_AU2_0.3	-9.48	-70.45	5.40491	-13.27
Soils	S6_AU2_0.6	-8.48	-65.10	2.774185	-14.56
Soils	S6_AU2_1.0	-9.76	-82.00	-3.94035	-21.67
Soils	S6_AU2_1.5	-7.66	-52.82	8.428307	-8.81
Soils	S6_AU2_2.0	-7.67	-50.76	10.56962	-6.96
Soils	S6_AU2_2.5	-9.59	-50.55	26.13813	4.66
Soils	S6_AU2_2.75	-9.06	-48.58	23.93884	3.27
Soils	S6_AU2_3.0	-7.33	-35.43	23.24722	4.39
Soils	S6_AU2_3.2	-4.34	-26.23	8.52606	-5.42
Soils	S8_AU1_0.2	-5.31	-40.91	1.578652	-12.43
Soils	S8_AU1_0.85	-5.65	-35.98	9.226466	-6.12
Soils	S8_AU1_1.0	-4.42	-28.75	6.641228	-7.14
Soils	S8_AU1_1.3	-5.38	-34.37	8.682329	-6.32
Soils	S8_AU1_1.4	-4.30	-31.09	3.340316	-9.89
Soils	S8_AU1_1.6	-5.61	-39.74	5.144692	-9.63
Soils	S8_AU1_1.8	-5.87	-31.75	15.22362	-1.12
Soils	S8_AU1_2.5	-6.32	-36.12	14.45335	-2.24
Soils	S13_AU2_0.2	-6.81	-33.98	20.50164	2.53
Soils	S13_AU2_0.3	-9.48	-62.40	13.45137	-6.27
Soils	S13_AU2_0.5	-8.93	-52.50	18.95958	-0.93
Soils	S13_AU2_1.0	-9.32	-58.96	15.59203	-4.24
Soils	S13_AU2_1.3	-10.02	-61.48	18.66927	-2.27
Soils	S13_AU2_1.5	-9.01	-57.23	14.88004	-4.56

Sample Group	Site No	δ18O	δ2H	D_Excess	LC_Excess
Soils	S13_AU2_1.75	-7.36	-52.47	6.39712	-10.28
Soils	S13_AU2_2.1	-9.08	-59.34	13.32659	-5.98
Soils	S13_AU2_2.5	-7.06	-46.61	9.886528	-6.95
Soils	S13_AU2_2.7	-8.08	-52.95	11.71746	-6.38
Soils	S13_AU2_3.0	-7.45	-47.43	12.13664	-5.38
Soils	S13_AU2_3.5	-7.30	-45.29	13.14959	-4.36
Soils	S13_AU2_3.75	-6.63	-41.86	11.16084	-5.41
Soils	S13_AU2_3.8	-6.87	-41.59	13.37159	-3.73
Soils	S13_AU2_4.0	-6.20	-39.14	10.49154	-5.57
Soils	S13_AU2_4.2	-6.10	-40.75	8.069598	-7.58
Twigs	S1_T1	-3.13	-26.40	-1.37708	-12.82
Twigs	S1_T2	-4.61	-27.88	8.965068	-5.30
Twigs	S1_T4	-5.18	-34.53	6.915356	-7.66
Twigs	S1_T7	-5.60	-35.02	9.796524	-5.57
Twigs	S1_T9	-5.21	-32.76	8.94403	-5.93
Twigs	S2_T1	-6.39	-40.81	10.33588	-5.89
Twigs	S2_T2	-5.00	-30.23	9.766255	-5.00
Twigs	S2_T3	-6.02	-39.61	8.52147	-7.10
Twigs	S4_T1	-5.41	-33.92	9.332295	-5.78
Twigs	S4_T2	-6.26	-45.97	4.069367	-11.21
Twigs	S5_T1	-4.18	-32.90	0.571548	-12.18
Twigs	S5_T2	-5.98	-43.66	4.213092	-10.81
Twigs	S6_T1	-5.46	-41.52	2.164844	-12.07
Twigs	S6_T2	-3.97	-33.25	-1.46943	-13.74
Twigs	S6_T3	-3.68	-32.79	-3.34296	-15.08
Twigs	S6_T4	-4.93	-33.36	6.064157	-8.15
Twigs	S6_T5	-4.55	-37.55	-1.18487	-14.07
Twigs	S6_T6	-5.07	-35.11	5.440377	-8.83
Twigs	S6_T7	-3.13	-27.17	-2.14372	-13.49
Twigs	S6_T8	-5.11	-39.53	1.345107	-12.43
Twigs	S7_T1	-5.80	-41.51	4.909929	-10.02
Twigs	S7_T2	-3.80	-21.92	8.518862	-4.89
Twigs	S8_T1	-5.49	-30.19	13.70865	-2.06
Twigs	S8_T2	-5.46	-29.83	13.81325	-1.94
Twigs	S8_T3	-5.41	-28.87	14.44744	-1.34
Twigs	S8_T4	-6.40	-38.71	12.49283	-4.03
Twigs	S11_T1	-6.29	-38.34	11.95017	-4.38
Twigs	S11_T2	-5.76	-40.30	5.755124	-9.24
Twigs	S11_T3	-7.10	-42.14	14.6324	-2.86
Twigs	S12_T1	-5.17	-33.41	7.906418	-6.78
Twigs	S12_T2	-4.56	-25.75	10.75126	-3.71
Twigs	S12_T3	-4.88	-28.42	10.65988	-4.11
Twigs	S12_T4	-3.73	-28.88	0.976496	-11.38
Twigs	S13_T1	-5.70	-30.91	14.68374	-1.42

Sample Group	Site No	$\delta^{18}O$	δ^2H	D_Excess	LC_Excess
Twigs	S13_T2	-4.16	-26.53	6.765452	-6.77
Twigs	S13_T3	-4.48	-27.03	8.811604	-5.31
Twigs	S13_T4	-4.44	-29.13	6.38486	-7.38
Twigs	S13_T5	-3.29	-27.04	-0.70522	-12.40
Twigs	S13_T6	-5.33	-33.05	9.591356	-5.48
Twigs	S13_T7	-5.95	-36.38	11.18196	-4.71
Twigs	S13_T9	-4.97	-33.80	5.97166	-8.27
Twigs	S13_T10	-4.98	-32.65	7.205448	-7.21
Bowen Basin Rainfall	RAIN MOR_171121_1 806	0.78	15.2	8.96	0.07
Bowen Basin Rainfall	RAIN MOR_181121_0 806	2.72	28.79	7.03	0.33
Bowen Basin Rainfall	Clermont Mar-Apr-08	-1.77	-2.1	12.06	0.22
Bowen Basin Rainfall	Clermont Mar-Apr-08	-3.49	-13.9	14.02	0.21
Bowen Basin Rainfall	RAIN MOR 19-11	-0.21	7.39	9.07	-0.82
Surface Water	SW_Isaac_S8	-2.72	-26.91	-5.15	-15.69
Surface Water	SW_S2	-5.04	-34.3	6.02	-8.30
Groundwater_Alluvium_Auger	GWS1_AU1	-5.14	-36.51	4.61	-9.62
Groundwater_Alluvium_Auger	GWS13_AU1	-5.65	-38.17	7.03	-8.03
Groundwater_Alluvium_Auger	GWS13_AU2	-5.58	-40.5	4.14	-10.47
Groundwater_Alluvium_Auger	GW_S6_AU1	-6.51	-39.02	13.06	-3.64
Groundwater_Alluvium_Auger	GW_S6_AU2	-5.82	-38.58	7.98	-7.37
Groundwater_Coal Seams	GW19_40	-6.55	-40.56	11.84	-4.74
Groundwater_Coal Seams	GW30a	-6.32	-41.23	9.33	-6.70
Groundwater_Regolith	GW30c	-5.3	-38.56	3.84	-10.45
Groundwater_Regolith	GW19_33	-7.72	-52.09	9.67	-7.80
Groundwater_Alluvium_Monitoring Bore	GW19_37A	-5.7	-40.75	4.85	-9.97
Groundwater_Alluvium_Monitoring Bore	GW7	-5.81	-33.06	13.42	-2.63