3D Environmental
Landscape & Vegetation Science

Baralaba South Project

Groundwater Dependent Ecosystem Assessment

Prepared by 3D Environmental

For

Baralaba South Pty Ltd

Final_04 December 2023

Project No. 2020_235
Project Manager: David Stanton
Client: Baralaba South
Purpose: Groundwater dependent ecosystem assessment for Baralaba South Project

Draft	**Date Issued**	**Issued By.**	**Purpose**
Rev 1	15 Jan 2021	David Stanton	Initial draft GDE assessment.
Rev 2	26 March 2021	David Stanton	Review following comments from AARC project manager.
Rev 3	29 March 2021	David Stanton	Final draft issue following additional AARC comments
Rev 4	31 March 2021	David Stanton	Final draft 2 after Mt Ramsay Coal Company Review
Rev 5	26 November 2023	David Stanton	Revised Impact Assessment Report based on changes to the mining void and associated impacts on groundwater.
Rev 6_Final	30 November 2023	David Stanton	Updated following review from AARC and Watershed HydroGeo
Final	04 December 2023	David Stanton	Final version following client review.

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Executive Summary

Baralaba South Pty Ltd (The Proponent) proposes to develop the Baralaba South Project (the Project) 8 km south of Baralaba and 115 km west of Rockhampton. The Project will be an open cut mine for the extraction of metallurgical coal for export of low volatile pulverised coal injection (PCI) for use in the steel production industry. The mining activity is proposed to be undertaken within the area MLA 700057, which covers a total of 2214 ha.

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 resources (groundwater dependent ecosystems or GDEs). This report provides an assessment of the presence of GDEs within the Project area and includes an assessment of potential Project related impacts to GDEs.

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 area on groundwater. The results indicate that water held in the regional alluvial aquifer is mostly an unsuitable resource to support GDEs due to high levels of salinity, and considerable depth to the water table (>10m). Exceptions occur directly adjacent to a stream channel where bank recharge with fresh surface water can occur, and channel incision decreases the depth to the groundwater table. The assessment identified that groundwater dependency within MLA 700057 and adjacent areas associated with the Dawson River flood plain is controlled by small discontinuous lenses of sand that are distributed sporadically throughout the heavy clay soils that otherwise characterise the flood plain sediments. GDEs identified, which include those at GDE Area 1, GDE Area 6 and GDE Area 9 are all associated with overland flow paths of the main Dawson River channel, which would act to increase infiltration into the soil profile due to prolonged ponding of surface water. The sandy lenses support shallow, fresh and seasonal groundwater resources that are perched above and disconnected from the regional groundwater table.

Recharge of the sandy lenses occurs during surface water infiltration, which is associated with overbank flow and intense rainfall events, and seasonality will depend on climatic factors including transpiration rates and flood interval. GDEs will occur wherever floodplain vegetation utilises water held within the sandy lenses as either a seasonal or permanent groundwater source and sandy intervals that form below the channel of the Dawson River are likely to have a high level of permanency.

While it is not possible to precisely define the extent of groundwater dependent vegetation due to the sporadic nature of the sandy lenses, this assessment indicates that they are discrete, restricted in extent, generally discontinuous and more likely to coincide with overland flow paths and flood channels. Areas confirmed not to represent GDEs includes a HES wetland (wetland of High Ecological Significance under the EP Act), the boundary of which partially overlaps with MLA 700057, and the predominant extent of coolibah woodland that occupies upper terraces of the Dawson River flood plain.

Groundwater modelling completed for the Baralaba South Project indicates Groundwater drawdown associated with mining void development is not predicted to impact the ecological function of GDEs

both inside and outside the MLA which utilise and rely upon the perched seasonal groundwater resources. Drawdown will interact with the saline basal colluvial groundwater system with depressurisation and drainage of the system toward the mining void with some possible increased leakage from Banana Creek to the underlying sediments, which is considered negligible. Groundwater drawdown will only be propagated beneath Banana Creek during periods when the alluvium is saturated and would only induce leakage of surface water when the watercourse is flowing, and a saturated connection exists between the alluvial groundwater table and surface water in the creek. In this instance, the impact of drawdown and the induced leakage would likely be negligible in comparison to the rate of groundwater recharge. There will be no interaction between the perched discontinuous sandy lenses which seasonally support vegetation groundwater dependence and the drawdown in the deeper alluvial / colluvial groundwater system due to the physical separation of these units, and the lack of hydraulic connection. Because of these factors, there are no identified causal pathways for impact which have capacity to alter GDE function and cause ecological harm.

Management measures to limit impact to potential GDEs in vicinity of the Project assessment area include general operational measures such the development and implementation of a WMS, ESCP and REMP. Specific measures to monitor GDE health in areas of predicted groundwater drawdown will also be required to validate the GDE impact assessment and increase confidence in the ecohydrological conceptual models developed within this impact assessment report. This should encompass the development of a Project GDEMMP, which should be maintained for a period that is sufficient to confirm GDE function and provide increased certainty to the outcomes of this assessment, nominally over a baseline assessment period of two-years. Ongoing measures to detect any changes to GDE health may be required based on the baseline assessment outcomes. With implementation of management measures, consistent with project approval conditions, it is considered that the risk to GDE's posed by mine development is insignificant.

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Glossary

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

	pressure) and matric potential (the pressure exerted by the walls of capillaries and colloids in the cell wall).
Leaf area index (LAI)	The ratio of total one-sided area of leaves on a plant divided by the area of the canopy when projected vertically on to the ground.
Local Meteoric Water Line (LMWL)	Describes the relationship between hydrogen and oxygen isotope (Oxygen-18 and Deuterium) ratios in local natural meteoric waters. LMWL is usually developed from precipitation data collected from either a single location or a set of locations within a "localised" area of interest (USGS, 2018) and results are reported as the amount-weighted average d2H/d18O composition of water in rainfall. LMWL's define a constant relationship between d2H/d18O in local rainfall, and deviations from this relationship are imparted by stable isotope fractionation causally linked to evaporative processes (evaporative enrichment). Further information can be obtained from USGS (2004) and Crosbie et al (2012).
Matric potential	The capacity of soil to release water, dependant on the attraction of water in the matrix to soil particles. Matric potential is always a negative value.
Obligate phreatophyte	A plant that is completely dependent on access to groundwater for survival
Osmotic potential	The lowering of free energy of water in a system due to the presence of solute particles.
Percolation	The downward movement of water through the soil due to gravity and hydraulic forces.
Perched groundwater system	A groundwater system or aquifer that sit 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	A measure of the difference between the free energy state of soil water and that of pure water. Essentially a measure of the energy required to extract moisture from soil.
Stable isotope	A stable isotope is an isotope that does not undergo radioactive decay. Oxygen has three different isotopes: The ^{16}O is the most common stable isotope of oxygen and ^{18}O is present in the atmosphere in amounts that are

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

1.0 Introduction

1.1 Project Background

Baralaba South Pty Ltd (the 'Proponent') proposes to develop the Baralaba South Project (referred to as 'the Project' or 'BSP') 8 km south of Baralaba and 115 km west of Rockhampton in the lower Bowen Basin region of Central Queensland (**Figure 1**). The Project is a proposed open cut mine for the extraction of metallurgical coal for export of low volatile pulverised coal injection (PCI) for use in the steel production industry. The mining activity is proposed to be undertaken within Mining Lease Application (MLA) 700057, which covers a total of 2214 ha, of which Mineral Development Licence (MDL) 352 has been granted over a large portion of the existing tenement.

Overburden and interburden will be disposed of in both in-pit and out-of-pit spoil dumps located on-site and contiguous with the pit excavation. The open cut pits behind the advancing operations will be progressively backfilled and rehabilitated to minimize risks to the environment. A conventional Coal Handling and Preparation Plant (CHPP) will be constructed at the Project site for coal washing. Dry disposal of tailings and reject material is proposed within the spoil. Processed wastewater will be recovered for recycling through the plant. The main activities associated with the project area include:

- a greenfield open-cut coal mine to be developed within the MLA area, including:
  - a Coal Handling Preparation Plant (CHPP).
  - a mining infrastructure area, including workshops, administration buildings, fuel and chemical storage facilities, warehouse, and hardstand areas.
  - ROM coal and product coal stockpile pads.
  - topsoil stockpiles, laydown areas and borrow pit areas.
  - haul roads and internal roads.
  - water management infrastructure.
  - backfilling of mine voids with waste rock behind the advancing open cut mining operations and the placement of waste rock in out-of-pit emplacements adjacent to the pit extents.
  - dewatering of CHPP rejects and disposal on-site within mine voids behind the advancing open cut mining operation.
  - other associated minor infrastructure, plant, equipment, and activities; and
  - exploration activities.
- product coal road transport approximately 40 km to the existing train load-out facility east of Moura; and
- product coal rail transport to the Port of Gladstone for export to international markets.

The Project would employ up to 268 construction employees and up to approximately 521 employees during peak mining operations. Construction of the BSP is proposed to commence in 2029, with operations commencing in 2030 ("Year 1"), and the end of active mining ("Year 23") in 2052 as shown in **Figure 2**.

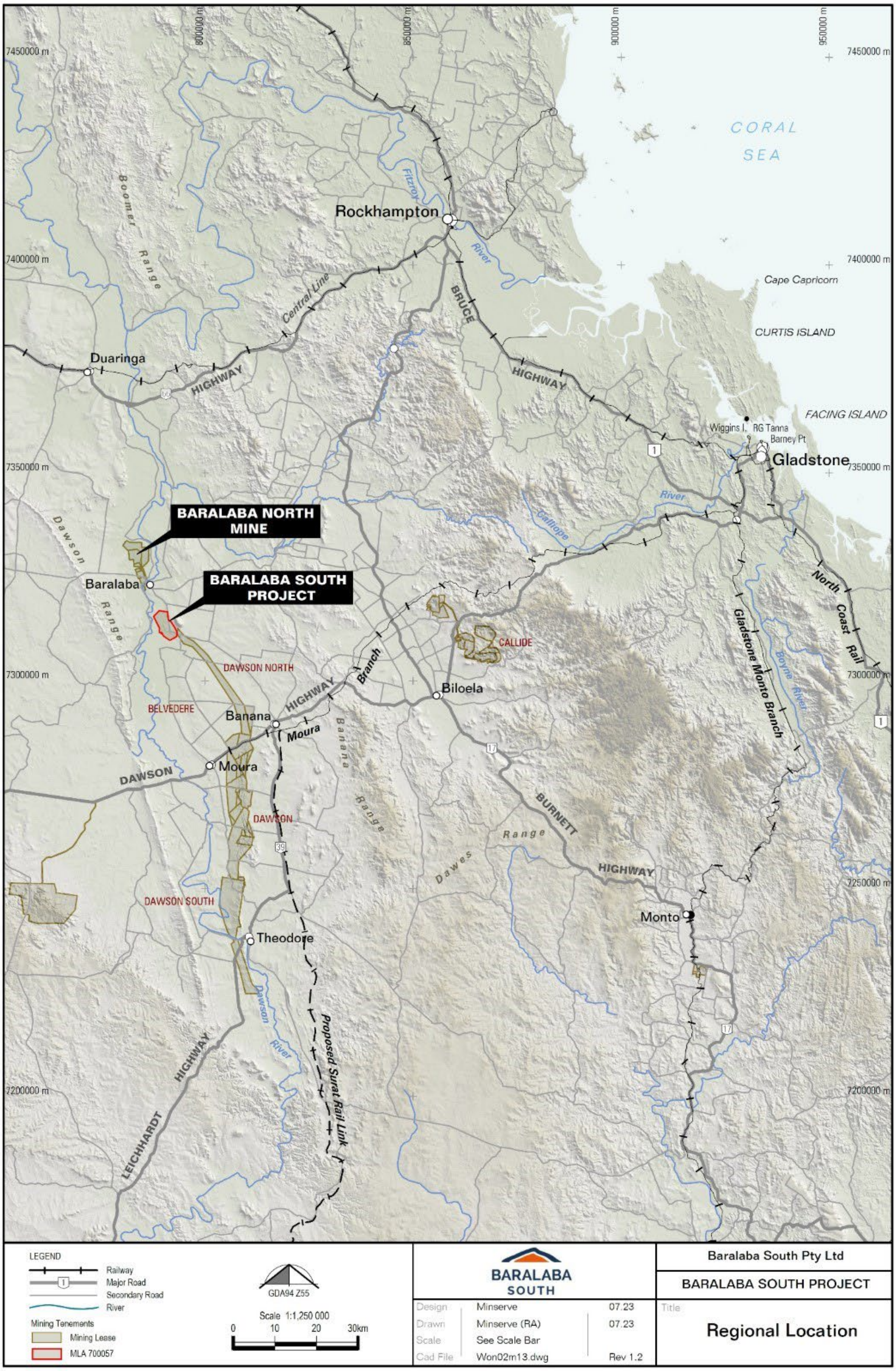


Figure 1. Regional location of the Baralaba South Project.

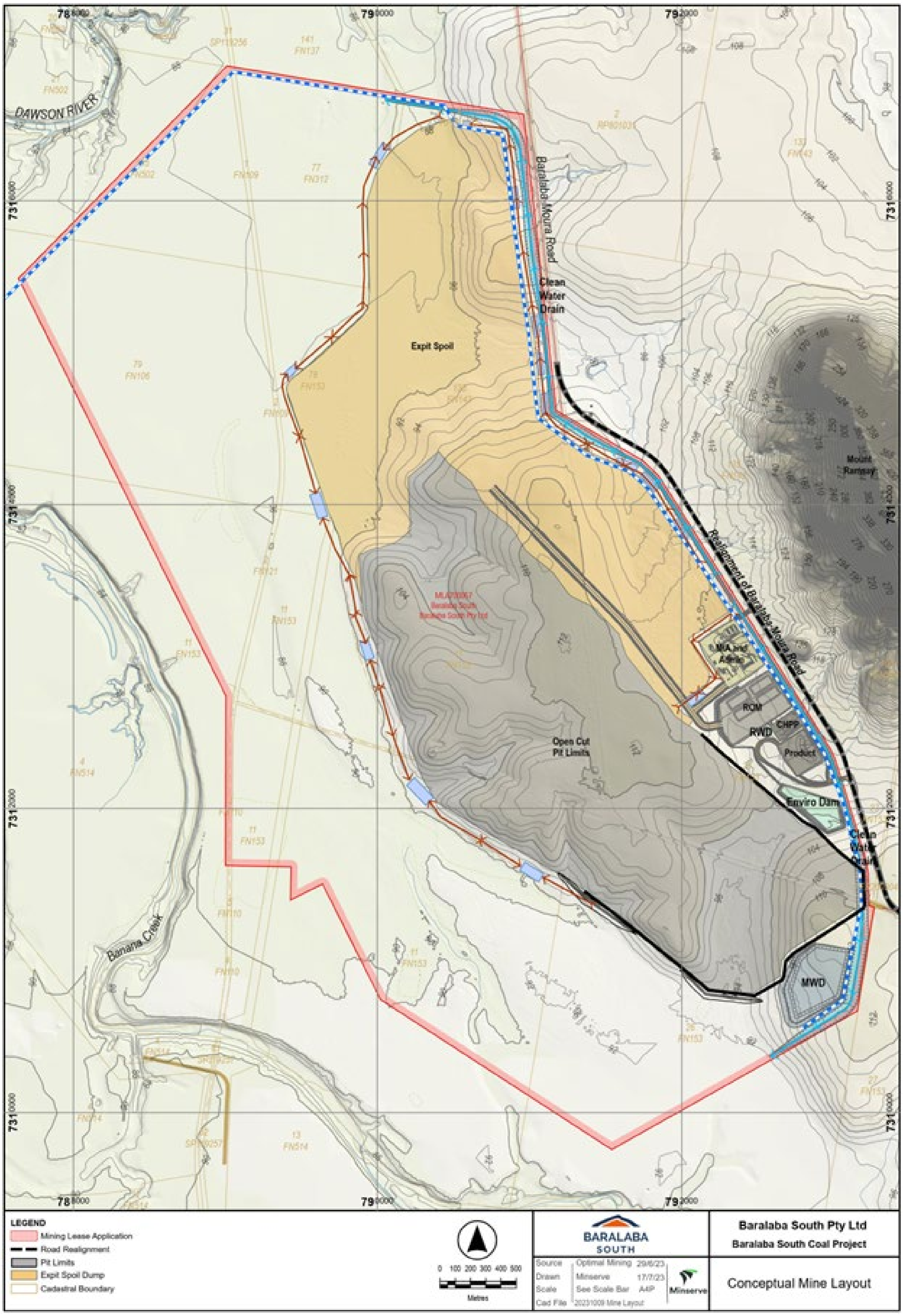


Figure 2. Project facilities and infrastructure.

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

1.2 Project Objectives

Objectives of the GDE assessment are to:

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

1.3 Relevant Legislation

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

1.3.1 Queensland Legislation

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

1.3.2 Federal Legislation

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

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

1.4 GDE Definition Used for Assessment

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

> *Groundwater dependent ecosystems (GDEs): Natural ecosystems which require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services (Richardson et al. 2011). The broad types of GDE are (*from *Eamus et al. 2006a and 2006b):*

- Ecosystems dependent on surface expression of groundwater (springs, and spring fed streams and rivers, otherwise defined as aquatic GDE's).
- Ecosystems dependent on subsurface presence of groundwater (terrestrial GDEs).
- Subterranean ecosystems (caves as well as sub-terranean species including stygofauna).

1.5 Groundwater Definition Used for Assessment

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

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

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

1.6 Climatic Considerations

The annual rainfall at Belvedere (Recording Station 39201; Lat: 24.33° S / 149.86° E), 3km to the south of MLA700057 which is the nearest reliable recording station is presented in **Figure 3**. The data indicates below average rainfall for nearly all months through 2019 (except for March 2019) with a total rainfall of 397.0mm for the year, being slightly more than half the long-term annual average of 671.5mm (BOM 2020a). February 2020, four months preceding the survey, was very wet with 185mm falling for the month compared to the long-term monthly average of 110.2mm. In

March 2020 rainfall was slightly higher than the long-term average. Following this period of higher-than-average precipitation, the three months preceding the survey (April to July 2020) experienced below average rainfall. A minor rainfall event of 4mm occurred in the week preceding the survey which was completed across 5 days from 10th to 14th August (2020).

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

The region has experienced several significant drought events which is likely to have affected both surface flows and recharge of groundwater systems. **Figure 5** demonstrates the major climatic cycles in terms of Cumulative Rainfall Departure (CRD) (Weber and Stewart 2004), representing a cumulative departure of monthly rainfall from the long-term mean monthly rainfall (1990 to 2020) from point data at Baralaba (SILO 2020). Strongly decreasing rainfall trends between 1990 to 1996; and 2000 to 2007 representing major drought periods are strongly evident. Following a period of relatively stable / average rainfall conditions occurring between 2013 to 2017, the current trend is for decreasing rainfall with below average conditions experienced post 2017 indicating a longer-term regime of ecological water deficit preceded the assessment. The analysis of cumulative rainfall departure is relevant to this assessment as shallow water tables generally follow similar trends, with rising water tables during upward precipitation trends.

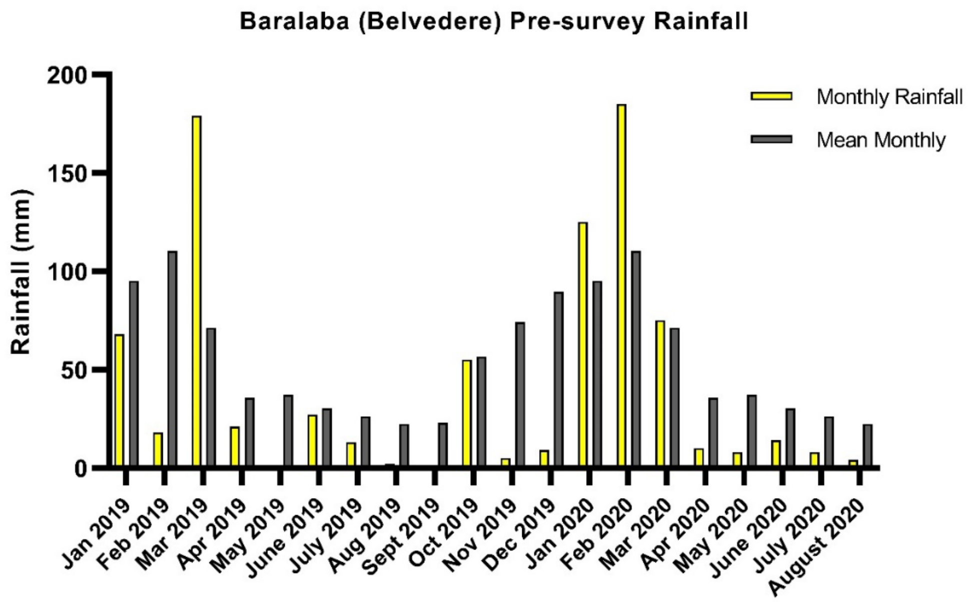


Figure 3. Rainfall for the period from January 2019 to August 2020 from Belvedere Recording Station (Station No, 39201).

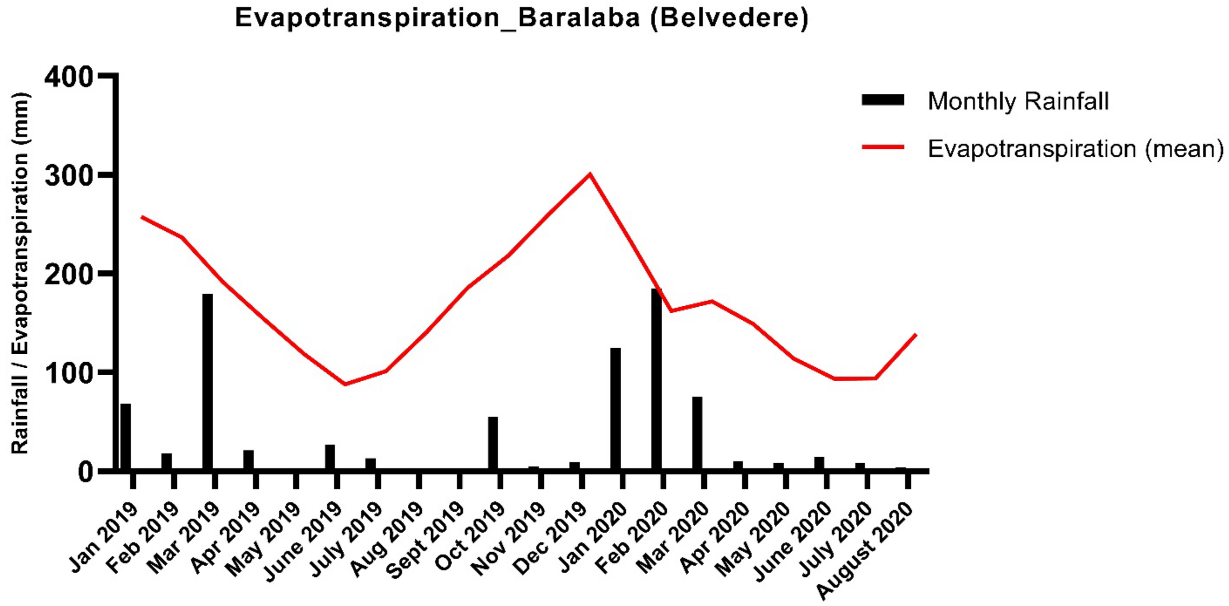


Figure 4. Evapotranspiration compared to rainfall for January 2019 to August 2020 from the Belvedere recording station with evapotranspiration data from SILO (2020).

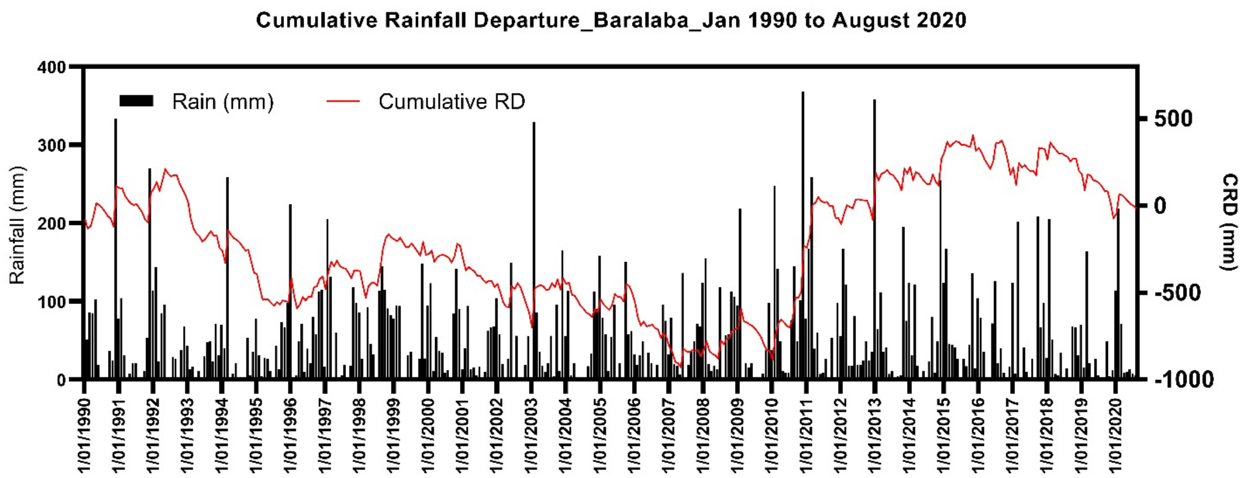


Figure 5. Cumulative Rainfall Departure demonstrating major and minor climatic fluctuations for the Baralaba grid calculated from SILO (2020).

2.0 Ecohydrological Setting

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

2.1 Hydrogeological Setting

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

2.1.1 Geomorphic Setting

The assessment area is centred on the broad flood plain of the Dawson River, a major tributary of the Fitzroy River. The Dawson River is incised to a depth of 10 – 15m below the broader floodplain with the tributary of Banana Creek incised to depths of 5 to 10m. The floodplain is formed by heavy clay soils, which have been largely cleared of woody vegetation to facilitate grazing and other agricultural activity. The flood plain and associated heavy clay soils extend for up to 4km east of the Dawson River channel and form a flat to gently undulating plain which is crossed by several open flood depressions and overflow drainage channels which are activated during overbank flow events. The clay soils which characterise the flood plain are overlapped with colluvial deposits which are shed from more elevated ranges, including Mt Ramsay, to the east of the MLA.

2.1.2 Geological characteristics

Quaternary Alluvial Deposits: Quaternary age alluvial deposits are associated with the major drainage features of the Dawson River and Banana Creek which occur to the west and south of the proposed mining area. The characteristics and extent of the Quaternary sediments are described in Watershed HydroGeo (2023) as follows:

- The Quaternary sediments consist of alluvial and colluvial sands and gravel, soil, and clay. Available information indicates that the alluvium is heterogeneously distributed, but often comprises distinct layers of surficial clays, thick sands/gravels, and basal sandy clays.
- The sediments thicken beneath and immediately adjacent the Dawson River, and are typically about 15 m thick. The thickness of Quaternary sediments along Banana Creek are expected to be less than the Dawson River with an even lesser veneer of alluvium/colluvium across parts of MLA 700057.

Quaternary / Tertiary Colluvium: Colluvium is poorly sorted, unconsolidated detrital material (typically sand, gravel and cobble) which is transported from higher elevations under the influence of gravity, typically accumulating on footslopes. A broad apron of colluvium is shown in DNRME (2020) as forming a broad expanse around the base of Mt Ramsay, intruding into the eastern portion of MLA 700057. The colluvial boundary overlaps and intergrades with Quaternary alluvial deposits which fringe the Dawson River.

Permian Coal Measures: The Permian Baralaba coal measures subcrop (into the Quaternary alluvium) along a narrow corridor that trends north-north-west. There is no surface outcrop of the coal measures within MLA 700057, being buried beneath thick sequences of Quaternary alluvium and Tertiary-Quaternary colluvium**.** The base of the Baralaba coal measures is marked by the sub-unit Kaloola member containing minor coal horizons, which in turn is underlain by the Gyranda formation, which outcrops in the east of the MLA at the base of Mt Ramsay.

Cretaceous Intrusives: A late Cretaceous intrusion of trachyte forms the base of Mt Ramsay on its western flank, outside the MLA area.

2.1.3 Hydraulic characteristics

The major groundwater bearing units in the assessment area are the Quaternary alluvium, and the Baralaba coal measures, with the Quaternary / Tertiary colluvium considered to be largely unsaturated. HydroSimulations (2021) describes the hydrogeological regimes associated with the various lithologies in the assessment area. Information from this assessment, coupled with more recent ground water quality data, is summarised below:

Quaternary Alluvium

- The hydraulic properties of alluvium are variable due to the heterogeneous distribution of sediments (i.e., fine clays to coarse gravels). Hydraulic testing of the alluvial monitoring bores conducted by SKM (2014) reported average hydraulic conductivity of 2.1 m/day, and localised readings ranging between 1 x 10^{-4} m/day to 13 m/day.
- Possible recharge boundary effects were observed likely due to the influence of the higher Dawson River stage within 500 m of bore A-PB1 and the adjacent alluvial monitoring bore (A-OB2) recorded a minor (6 cm) water level response to pumping at A-PB1, despite being only 17.5 m away.
- Other nearby bores screened in the Permian coal measures (P-PB1 and P-VWP2 [Sensor 2]) showed no visible response within the alluvium for the duration of the test, indicating limited connectivity.

The results of pumping tests in 2014 and 2018 support the concept that *"the alluvium is made up of a series of sand/gravel lenses that are limited in both horizontal and vertical extent and separated from other lenses by significantly less permeable clays"* (Watershed HydroGeo, 2023).).

Permian Coal Measures and Interburden

Groundwater in the Permian coal measures occurs preferentially in the coal seams due to the open nature of the cleats while interburden units (i.e., material between coal seams) are generally considered an aquitard. Pump testing undertaken by SKM (2014) indicate:

- There is negligible vertical leakage through the aquitard units (interburden) and limited connectivity of the pumped Permian coal measures to the Dawson River and the adjacent shallow alluvial monitoring bores did not show any response to pumping in the Permian coal measures.

- The hydraulic properties of the coal measures can be influenced locally by weathering (particularly at the subcrop level) and as is typically observed in coal seams, the secondary porosity (cleats), however the results demonstrated strong consistency from the repeated tests.

2.1.4 Groundwater Recharge, Standing Water Levels and Water Quality

Based on stable isotope sampling results, (Watershed HydroGeo, 2023) indicate that groundwater monitoring bores closer to the Dawson River (i.e., AOB2) are more readily charged by rainfall than bores sampled at distance from the river (A-OB4 and A-OB8) which have more distinctive stable isotope signatures. The Neville Hewitt Weir, which has a full storage level (FSL) at approximately 79m AHD, maintains the Dawson River stage at a higher elevation than the majority of the groundwater levels observed around Baralaba. This recharge mechanism was identified by the results (i.e. relatively swift recovery) of the pumping tests conducted on site (Watershed HydroGeo, 2023). Isotope analysis of the groundwater at OB1 (Permian bore) also indicated the alluvium is readily recharged by rainfall.

Standing water levels (SWLs) in the alluvium measured in March 2020 range from 8.2 metres below ground level (mbgl) at monitoring bore A-OB11, which is on the fringe of the Neville Hewitt Weir inundation area to 22.3 mbgl at A-OB7 which is over a km east of the channel of Banana Creek. In general, monitoring bores closer to the Dawson River (A-OB1, A-OB2, A-OB7) have much higher SWLs than those monitoring bores further from the river. A map of monitoring bores utilised in this assessment is shown in **Figure 7** with a summary of SWL provided in **Table 1**.

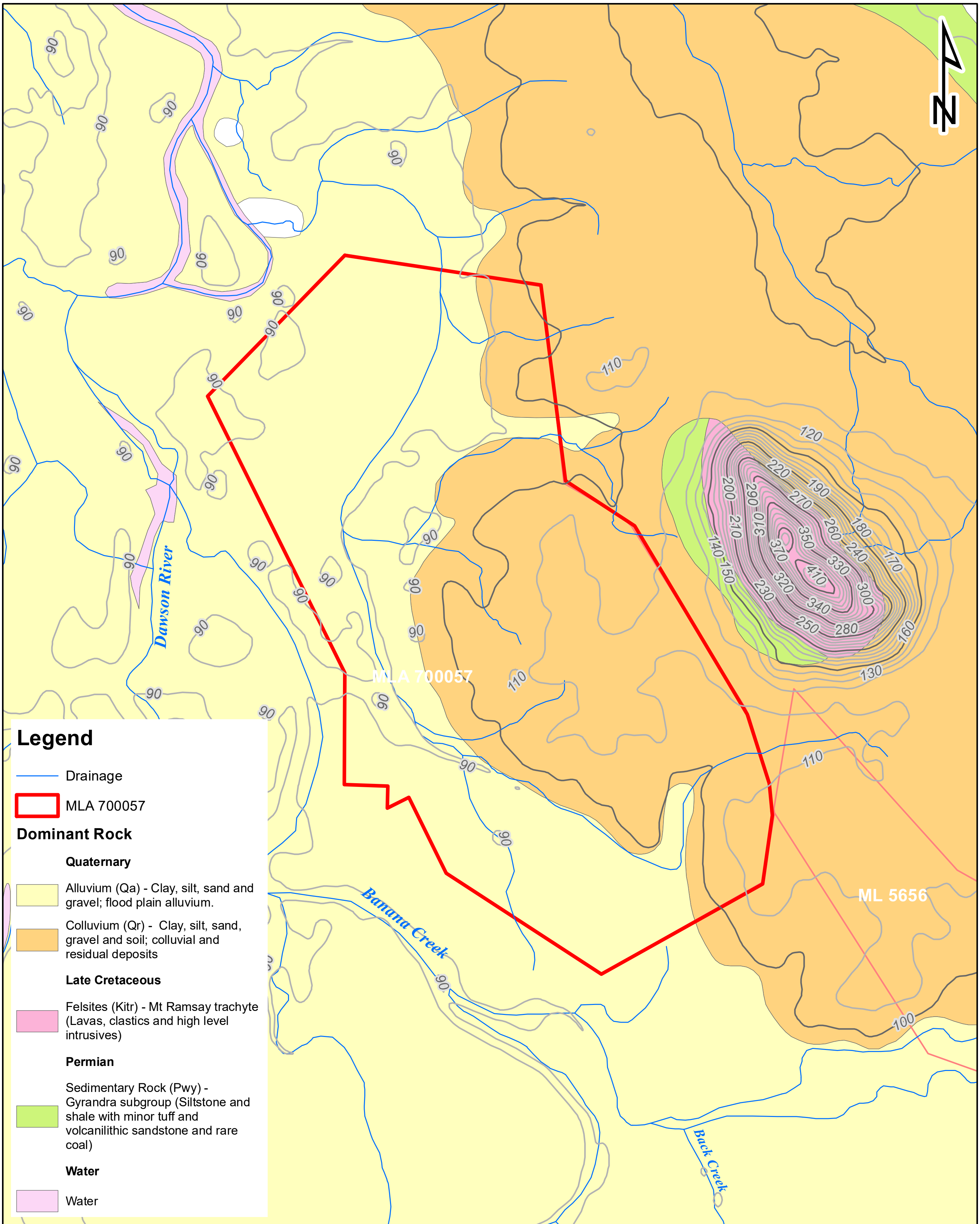
Measured salinity from groundwater in the alluvial aquifer is also generally lower at monitoring bores closer to the Dawson River channel than those further from the river. Salinity at A-OB1 on the fringes of the inundation area created by the Neville Hewitt Weir recorded a range of values from 466 to 700 µS/cm and A-OB4 (over a km from the Dawson River) recorded a range from 31 759 to 40 022 µS/cm over a three- year monitoring period (2017-2020). Salinity values in the Baralaba Coal Measures also vary considerably between monitoring bores ranging from 23 666 µS/cm at P-OB5 (June 2018) to 40 297 µS/cm at P-OB4 (October 2018). The range of salinity values recorded from monitoring bores in the Project area and surrounds over a three-year monitoring period from December 2017 to March 2020 is provided in **Table 1,** with additional information provided in the groundwater modelling report prepared by Watershed HydrGeo (2023).

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

								Salinity µS/cm								
BORE ID	**Formation**	**Easting**	**Northing**	**Elevation**	**Drilled Bore Depth**	**Screened Interval - Alluvium**	**SWL MBGL#**	**Dec-17**	**Mar-18**	**Jun-18**	**Oct-18**	**Feb-19**	**May-19**	**Aug-19**	**Nov-19**	**Mar-20**
A-PB1	Alluvium	787806	7314088	88.4	27	11.5-23.5	12.9	-	646	630	610	720	711	615	648	-
A-PB2	Alluvium	791931	7309808	91.5	29	11.5-23.5	Dry									
A-OB1	**Alluvium**	**787440**	**7314586**	**88.9**	**29**	**10 to 22**	**13.0**	**570**	**466**	**486**	**493**	**586**	**700**	**606**	**644**	**-**
A-OB2	Alluvium	787802	7314105	88.3	20	11.5-17.5	13.0	657	617	686	565	583	831	843	911	-
A-OB3	Alluvium	788393	7314309	87.9	30	12 to 30	12.7	-	561	593	490	-	-	-	-	-
A-OB4	**Alluvium**	**789290**	**7314733**	**87.5**	**17**	**8 to 17**	**12.7**	**37011**	**35920**	**37557**	**40022**	**37150**	**36385**	**36423**	**31759**	
A-OB6	Alluvium	791402	7309557	91.4	29	9 to 18	Dry	-	-	-	-	-	-	-	-	-
A-OB7	**Alluvium**	**791935**	**7309829**	**91.7**	**26**	**11 to 26**	**22.3**	**15681**	**16809**	**16637**	**18390**	**20122**	**19487**	**19657**	**18058**	**-**
A-OB8[+]	Alluvium	792501	7310136	91.4	23	10 to 22	19.3	26260	25877	26914	27752	28071	28197	27752	25754	28536
A-OB10	**Alluvium**	**789247**	**7313094**	**87.5**	**23**	**8 to 20**	**13.8**	**31708**	**36433**	**38097**	**38786**	**37303**	**35894**	**34430**	**29887**	**32507**
A-OB11	**Alluvium**	**787270**	**7313771**	**86.2**	**17**	**9 to 15**	**8.2**	**425**	**405**	**434**	**377**	**440**	**481**	**452**	**351**	**-**
A-OB12	Alluvium	787220	7313767	87.2	18	9.6-15.6	9.0	381	354	328	323	430	526	456	306	-
P-PB1	**Interburden**	**787805**	**7314101**	**88.3**	**185**	**136-178**	**14.3**	**-**	**15950**	**16296**	**18453**	**15763**	**15574**	**15303**	**13721**	**-**
P-OB3	**Interburden**	**789939**	**7312422**	**89.6**	**59**	**29-59**	**15.2**	**34107**	**33141**	**34154**	**37120**	**33042**	**32548**	**32169**	**28835**	**32386**
P-OB1	Baralaba Coal Measures	788477	7316388	87.4	60	30-60	12.9	29785	30324	31390	33260	34270	34234	33794	30700	-
P-OB4	**Baralaba Coal Measures**	**789205**	**7314695**	**87.1**	**205**	**75-78**	**12.4**	**37088**	**36356**	**37492**	**40297**	**36546**	**36131**	**35942**	**31702**	**-**
P-OB5	Baralaba Coal Measures	792626	7310218	91.4	204	66 - 69	13.6	24664	27225	23666	34100	29073	28889	28641	25455	-
P-OB2	Dryandra Formation	793140	7311758	105.3	60	30-60	24.3	-	19480	19503	21075	19085	19000	18964	16669	18797

Bold = specimen submitted for stable isotope sampling.

Average of measurements between December 2017 and March 2020



Source: Detailed Surface Geology Queensland (DNRM 2020)

Figure 6. Surface geology in the assessment area

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0 0.8 1.6 2.4 3.2

Kilometers

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Legend

- Groundwater Bores
- Drainage
- MLA 700057

Figure 7. Groundwater monitoring bores in the assessment area

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2.2 Site Ecology and Ecohydrological Function of Characteristic Tree Species

2.2.1 Regional Ecosystems

Field validated Regional Ecosystem (RE) mapping completed by Ecological Survey & Management (EcoSM, 2021), provided in **Figure 8**, for the Project defines a number of regional ecosystems, typically dominated by eucalypt woodland and open forest habitats. This includes:

- RE 11.3.3 and RE11.3.3a being a woodland and open forest dominated by coolibah (*Eucalyptus coolabah)* fringing drainage channels and upper river terraces, typically on heavier clay soils. Includes some areas of wetland.
- RE 11.3.25, dominated by river red gum (*Eucalyptus camaldulensis)* with scattered Moreton Bay ash (*Corymbia tessellaris*), Clarkson's bloodwood (*Corymbia clarksoniana*) and river oak (*Casuarina cunninghamia*). Typically forms the immediate fringe of the larger drainage lines.
- RE 11.3.4, being an open forest and woodland dominated by forest red gum (*Eucalyptus tereticornis)* with scattered Moreton Bay ash (*Corymbia tessellaris)* and Clarkson's bloodwood *(Corymbia clarksoniana)* associated with loamy flood plains on upper alluvial terraces.
- RE11.3.1, being an open woodland dominated by brigalow (*Acacia harpophylla)* associated with heavy clay soils on upper river terraces.
- RE11.5.9, typically dominated by narrow leaf ironbark (*Eucalyptus crebra*) with scattered poplar box occurring on older residual plains and jump-ups.

Regional ecosystems are also associated with some elevated areas on granite including dry vine thicket (RE11.12.4), ironbark woodlands (RE11.12.1) and brigalow communities associated with fine grained sedimentary rocks (RE11.9.1), although these areas are assessed as having limited potential for groundwater dependency.

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

2.2.2 Mapped Groundwater Dependent Ecosystems

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

- **Aquatic** ecosystems that rely on the surface expression of groundwater–this includes surface water ecosystems which may have a groundwater component, such as rivers, wetlands, and springs. Marine and estuarine ecosystems can also be groundwater dependent, but these are not mapped in the GDE Atlas. None are mapped by BOM in the vicinity of BSP.
- **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). None are mapped by BOM in the vicinity of BSP.

The BOM GDE mapping layer has been compiled with national scale datasets and rules to describe the potential for groundwater interaction, and within the assessment area corresponds directly with GDE and potential aquifer mapping produced by the Department of Environment and Science (DES) (2020). Due to the limited ground verification, the dataset requires site specific GDE assessment. The mapping of GDEs over the Project area and surrounds, as produced by BOM (2020b) is provided in **Figure 9**. In general, this assessment shows 'Low Potential' for 'Terrestrial' GDEs associated with riparian vegetation and watercourses.

There are no springs mapped within proximity to the assessment area. It is noted that updates to the mapping presented in the GDE Atlas were incorporated in August 2020 (around the time of field assessment) which resulted in the significant changes to GDE mapping across the assessment area. The version applied in this assessment utilises data from the most recent BOM release.

2.2.3 Groundwater Dependent Species

Eucalypts: Coolibah (*Eucalyptus coolabah*) and River Red Gum (*Eucalyptus camaldulensis)* are the most prevalent eucalypt species in the assessment area. Coolibah is the dominant canopy tree in RE11.3.3 with River Red Gum being more prevalent in RE11.3.25 which occupies the riparian fringe of the Dawson River and the lower reaches of Banana Creek.

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

The species is considered opportunistic in its water use, sourcing water according to osmotic and matric water potential and source reliability (Thorburn et al., 1993; Mensforth et al., 1994; Holland et al., 2006; Doody et al., 2009) with the water requirements obtained from three main sources being groundwater, rainfall, and river flooding. Flooding enables the species to survive in semi-arid areas (ANBG 2004) where stands are intimately associated with the surface-flooding regime of watercourses and related groundwater flow. River red gums are considered a facultative 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. River red gum will often use saline groundwater in preference to fresh surface water, probably because it represents a more reliable supply (Colloff 2014). 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.

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

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

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

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

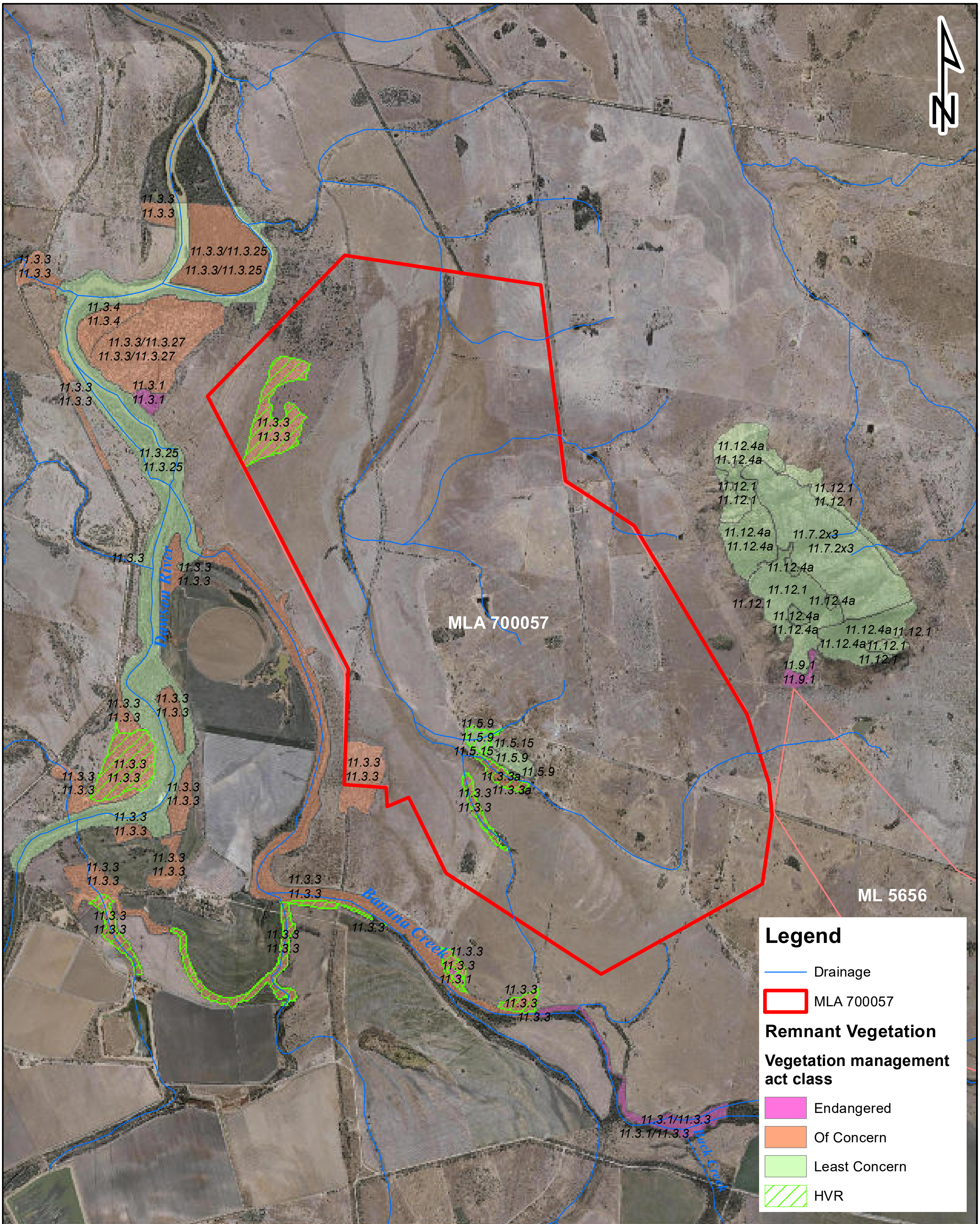
The heavy clay that characterises the Dawson River flood plain in the assessment area presents a physical limitation on tree root penetration. Clay substrates are an unsuitable medium for development of a deep tap root system that would be necessary to penetrate to the groundwater table (Dupuy et al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

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

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

2.2.4 Other Significant Habitats

Vegetation mapped in government databases also includes a wetland listed as a 'Great Barrier Reef wetland of high ecological significance (HES)' under the Environmental Protection Regulation 2008. The location of this feature is indicated in **Figure 10**. Ecological assessment of this feature has been completed in the Terrestrial Ecology Impact Assessment Report (Ecological Survey & Management 2021) and the Aquatic Ecology Assessment Report (Ecological Service Professionals 2021), the latter describing the habitat as having 'connectivity to other wetland habitats being rare and the wetland would not provide long lasting (aquatic) habitat'. The wetland area is not mapped in the most recent release of the BOM GDE Atlas as a potential GDE, although has been considered for assessment in the GDE field sampling program.



Source: Ecological Survey and Management (2021)

Figure 8. Field validated regional ecosystems mapping in the assessment area provided by Ecological Survey and Management (2021)

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Kilometers

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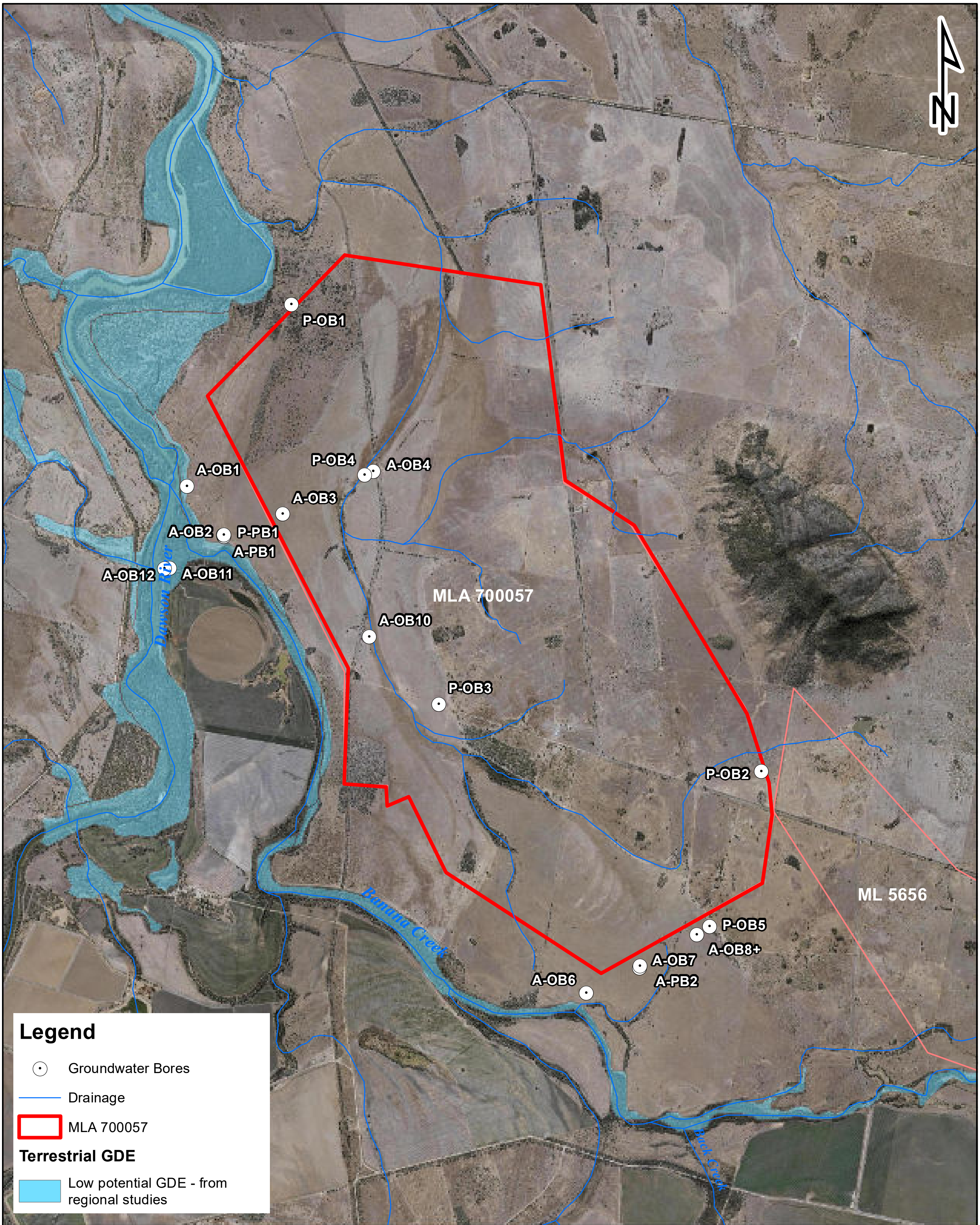

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Source: BOM GDE Atlas (2020).

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

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0 0.8 1.6 2.4 3.2 Kilometers

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Source: HES Wetland Mapping Dataset (DES 2020).

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

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3.0 Methods

The field assessment was completed over a five-day period (excluding travel) from 10 August to 14 August 2020. Field conditions were fine and dry. Weather conditions during the survey were cool to warm, with an estimated maximum daily temperature from 24°C to 29°C. No rainfall was recorded during the field assessment. Minor rainfall was recorded 2 days beforehand (4 mm) on the 8th August, although this is not expected to have influenced the results to any significant degree. The following sections provide an overview of methods used to assess groundwater dependence of vegetation within the Project area and surrounds. It describes site selection, assessment of leaf water potential (LWP), use of soil auger holes to assess soil moisture potential (SMP) and analysis of stable isotope composition in a manner that is consistent with Jones et al (2020) and supplemented with methodology from Richardson et al (2011), IESC (2018b) and Eamus (2009).

3.1 Site Selection

The survey focused on areas mapped as potential GDEs in the GDE Atlas (BOM 2020) which are largely associated with woody vegetation which forms on the frontage of the Dawson River. Additional areas of woody vegetation were targeted where it was considered, from overview of aerial imagery, that potential for vegetation groundwater dependence exists. This includes areas of woody vegetation associated with overflow drainage channels and depressions which are not represented in current GDE or RE mapping databases. The mapped HES wetland (see Section **2.2.4**) was also targeted for assessment (**Figure 10**). In total, 12 sites were chosen for targeted GDE assessment, to provide representative coverage of the major vegetation types and landform elements that are most likely to be groundwater dependent. The purpose of each of the twelve chosen sites is provided in **Table 2** with localities provided in **Figure 11**. Due to the necessity to sample multiple sites pre-dawn, the subject sites also needed to be relatively accessible with minimal foot traverse to ensure sampling objectives could be met. An additional site (GDE Area 13) was also inspected during the assessment, being a dry vine thicket on Mt Ramsay, although was not targeted for biophysical or stable isotope sampling due to lack of any evidence for potential groundwater utilisation.

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

GDE Assessment Area	Location / Geomorphic Position	Purpose of Assessment
Area 1	Channel overflow on the Dawson River flood plain that passes through MLA 700057 providing a link between Banana Creek and the Dawson River. Isolated area of woody vegetation fringing the broadest portion of the overflow channel.	Representation of woody vegetation on the Dawson River flood plain that is associated with an overflow flood channel, not currently mapped as a GDE in existing databases.
Area 2	Isolated area of woody vegetation that is associated with the Dawson River flood plain at distance (>1km) from the river.	Assessment of a small area of mature non-remnant vegetation associated with the Dawson River flood plain, not currently mapped as a GDE in existing databases.

GDE Assessment Area	Location / Geomorphic Position	Purpose of Assessment
Area 3	Restricted area of mature woody vegetation associated with a drainage depression that is located on the interface between the flood plain and the broader area of colluvial sediments.	Representation of woody vegetation associated with drainage depression / swamp not currently represented in GDE or RE mapping databases.
Area 4	On the upper terrace of the Dawson River flood plain ½ km from the river channel. Intact, remnant woody vegetation.	Representation of HES wetland near the boundary of MLA 700057.
Area 5	Upper inundation level of the Neville Hewitt Weir on Banana Creek, 1 km from the junction of the Dawson River. Intact, remnant riparian vegetation currently mapped as a GDE in BOM GDE Atlas.	Assess interaction of remnant riparian vegetation fringing areas of permanent inundation on Banana Creek. Assess the degree of groundwater utilisation of remnant riparian vegetation currently mapped as a GDE in the BOM GDE Atlas.
Area 6, Area 7, Area 8	3km, 5km and 7km upstream respectively from the inundation area associated with the Neville Hewitt Weir on Banana Creek. Intact, remnant riparian vegetation currently mapped as a GDE in BOM GDE Atlas.	Assess interaction between remnant riparian vegetation and groundwater associated with areas above permanent inundation on Banana Creek.
Area 9	Fringes the area of permanent inundation on the Dawson River formed by the Neville Hewitt Weir. Associated with a broad fringe on intact / remnant riparian vegetation that fringes the corridor of the Dawson River. Currently mapped as a GDE in the BOM GDE Atlas.	Assess the interaction between groundwater and remnant riparian vegetation fringing areas of permanent inundation on the Dawson River.
Area 10	Fringes the area of permanent inundation on the Dawson River formed by the Neville Hewitt Weir. Associated with a broad fringe on intact / remnant riparian vegetation that fringes the corridor of the Dawson River. Currently mapped as a GDE in the BOM GDE Atlas.	Assess interaction between groundwater and remnant riparian vegetation adjacent to a channel overflow 100m from the main Dawson River channel.
Area 11	Assessment locality fringes the area of permanent inundation on the Dawson River formed by the Neville Hewitt Weir. Associated with a broad fringe of intact /	Assess the interaction between groundwater and remnant riparian vegetation fringing areas of permanent inundation on the Dawson River.

GDE Assessment Area	Location / Geomorphic Position	Purpose of Assessment
	remnant riparian vegetation that fringes the corridor of the Dawson River. Currently mapped as a GDE in the BOM GDE Atlas.	
Area 12	Assessment locality is associated with a broad expanse of intact / remnant riparian vegetation that fringes the Dawson River, 1 km from the main Dawson River channel. Currently mapped as a GDE in the BOM GDE Atlas.	Assess the interaction between groundwater and remnant vegetation at distance from the Dawson River channel.
Area 13	Assessment locality on the footslopes of Mt Ramsay on acid intrusive rocks (trachyte). Mapped as a potential GDE in earlier versions of the BOM GDE Atlas though excluded from the most recent iteration.	Assess potential for groundwater interaction on the footslopes of Mt Ramsay, associated with acid volcanic intrusives.

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 7.5m extension pole fitted with a lopping head. Leaves were collected from seven to ten mature canopy trees, within each assessment site along a stretch of stream frontage that was amenable to traverse in low light conditions. Collected branches were double bagged in black plastic to avoid moisture loss and sun exposure and LWP was measured on-site within half an hour of harvest. Suitable leaf material was trimmed with a fine blade and inserted into an appropriate grommet for sealing within a Model 3115 Plant Water Status Console (Soil Moisture Equipment Corp, 2007). The chamber was sealed and gradually pressurised with nitrogen until the first drop of leaf water emerged from the petiole. Two readings were taken at each GDE site to calculate an average with a third taken where significant differences between reading was noted. Readings were taken in pounds per square inch (PSI) which is converted to a negative value in millipascals (MPa) for direct comparison to Soil Moisture Potential (SMP) measurements. In total, 50 trees were assessed for LWP across the 12 assessment sites, with the location of these trees detailed in **Section 4.2**.

3.3 Soil Moisture Potential

A hand auger drilled to a maximum depth of 4.80 mbgl was utilised to collect shallow soil samples at regular depths down the soil profile at four selected representative sites. Selection of sites for auger placement considered:

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

At each site chosen for auger sampling, the aim was to collect soil samples to the maximum depth of the auger (4.8m) although the auger could not penetrate to maximum depth in some localities due to dense clays or coarse gravel substrates, or refusal occurred at relatively shallow depths in the soil profile due to a high propensity of root material. Within each auger hole, the following observations were taken at regular depth intervals or where changes to soil structure were apparent:

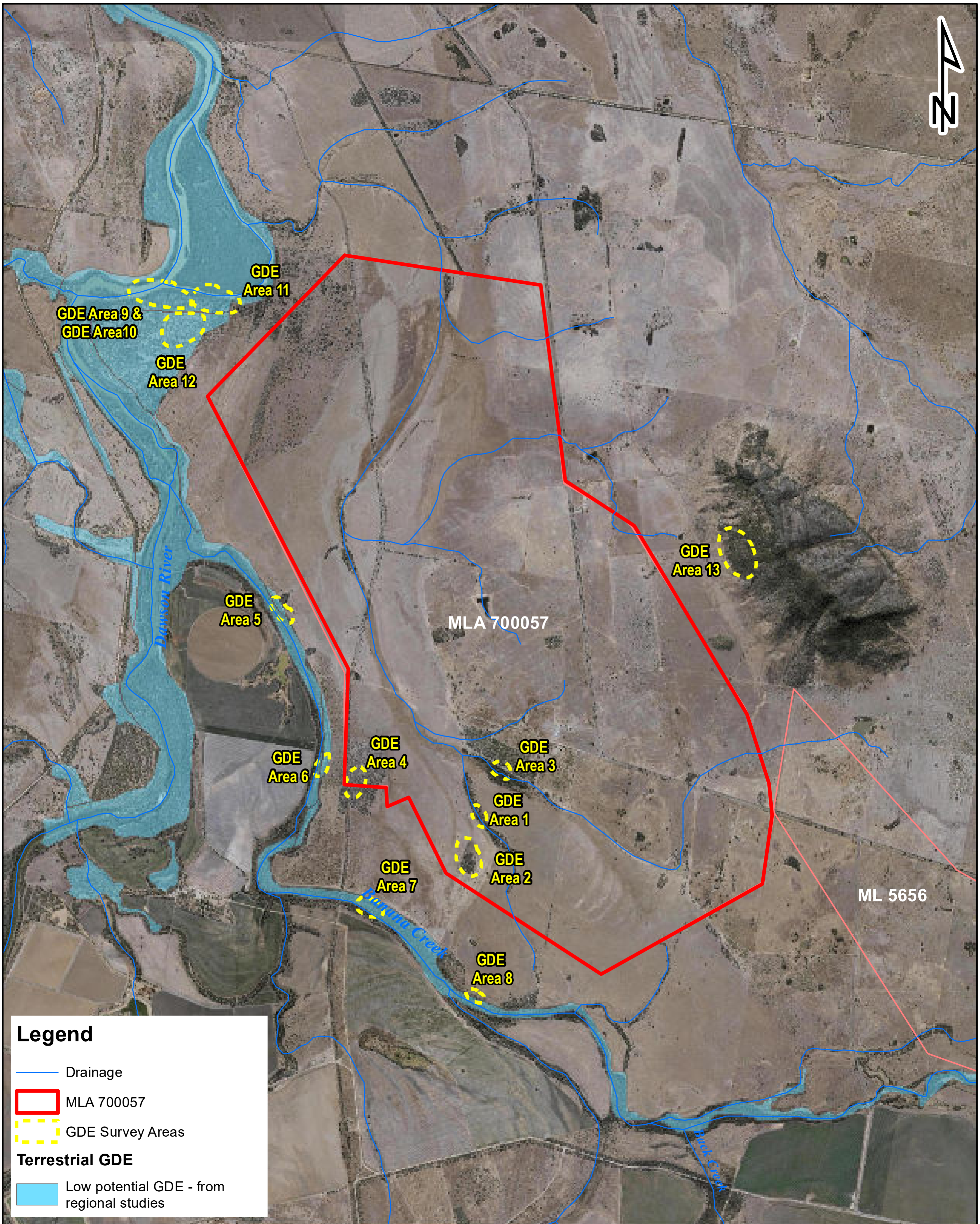
1. Soil structure, colour, and texture.
2. Presence of root matter.
3. Soil moisture / water and areas of saturation.

Soil sampling was undertaken at regular intervals down the soil profile for analysis of stable isotopes of oxygen (δ18O) and deuterium (δ2H) and duplicate samples were retained for analysis of SMP.

Samples collected during soil auger sampling were analysed for SMP at regular intervals of 0.2 mbgl, 0.5 mbgl and at 0.5 mbgl to 1.0 mbgl to the end of hole. As samples were collected, they were immediately sealed in airtight plastic vials and placed on ice.

SMP, which includes the matric (water availability) and osmotic (saltiness) potential, is a measure of the energy required to extract moisture from soil. Water only has capacity to move down a hydraulic gradient from soil to root (Gardner 1960). Areas in the soil profile that have a SMP that is less negative than measured pre-dawn LWP will be accessible as a source of moisture. It is widely agreed in ecohydrology and plant physiology fields, that large, mature trees are unable to extract moisture from regions in the soil profile where the total SMP is significantly below LWP measured in pre-dawn leaf material (Feikema et al. 2010, Lamontagne et al. 2005, Thorburn et al. 1994, Mensforth et al. 1994, Holland et al 2009 and Doody et al. 2015).

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



Source: BOM GDE Atlas (2020).

Figure 11. GDE areas targeted for field assessment.

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0 0.8 1.6 2.4 3.2 Kilometers

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For crops, the maximum suction roots can apply to a soil/rock before a plant wilts due to negative water supply is approximately -15 bars or -1.5 MPa (or -217.55 psi). This wilting point is considered relatively consistent between all plant species (Mackenzie et al, 2004), although many Australian plants have adapted to conditions of low water availability and can persist strongly in soil conditions where soils moisture potential is below standard wilting point (Eamus 2006a). As a general measure however, where measured LWP is below standard wilting point, it indicates plant water deficit, and the tree is unlikely to be supported by a saturated water source unless highly saline.

The measurement of SMP was completed in the laboratory by a portable Dew Point Potentiometer (WP4C) (Meter Group Inc, 2017). The WP4C meter uses the chilled mirror dew point technique with the sample equilibrated within the headspace of a sealed chamber that contains a mirror and a means of detecting condensation on the mirror. Soil moisture potential samples were measured in megapascal pressure units (MPa). A single 7 ml soil sample was inserted into the WP4C meter using a plastic measuring tray with a stainless-steel base.

3.4 Xylem Stable Isotope Sampling and Analyses

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

3.4.1 Soil Moisture Isotopes

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

3.4.2 Xylem Water Isotopes

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

1. Outer branches of trees of the GDE target tree were harvested for twig material. Two duplicate samples were prepared from each branch for analysis.
2. The position of trees subject to assessment were marked with a GPS and structural measurements were recorded including height and diameter at breast height (dbh).
3. Outer branches from each tree were harvested with an extendable aluminium pole.

4. Stem material approximately 5cm in length was sourced using clean 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 Groundwater Monitoring Bore Sampling

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

3.5 Data Reconciliation and Interpretation

Data interpretation followed a structured approach in which multiple lines of evidence were filtered to provide an assessment of groundwater dependence. The biophysical measurement of LWP formed the primary 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.

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

- Expected LWP for trees in equilibrium with a fresh to brackish saturated source of moisture (EC<1500 µS/cm) = >-0.2MPa.

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

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

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

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

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

3.6 Limitations and Other Information Relevant to the Assessment

This assessment provides a snapshot of eco-hydrological process at each of the 13 GDE assessment localities identified during pre-survey desktop assessment and field reconnaissance. Specific limitations include:

1. Climatic conditions preceding the assessment were dry, although preceding wet season rainfall events (in February and March 2020) would have saturated shallow portions of the soil profile with residual wetness being present in some soil horizons. Where ambiguity in biophysical measurements were apparent, stable isotope signatures were relied upon to differentiate groundwater from other soil moisture sources.

2. Access was limited in some localities due to requirements for considerable foot traverse, which was not possible due to sampling timing interval constraints. Generally areas requiring greater than 1km 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. It is noted that not all potential groundwater sources have been sampled for stable isotope composition. Where perched / ephemeral groundwater systems are suggested, it is assumed that stable isotope composition is comparative to the regional groundwater table. This is considered acceptable as all groundwater sources are derived from a mix of infiltrated surface water that has been subject to varying degrees of evaporation.
5. The ecological processes and hydrogeological conditions encountered within the Project area are complex and transient. Interpretations and conceptualisations presented here are based upon multiple lines of evidence and represent what the author considers is the most appropriate interpretation of the data. However continued refinement of the presented conceptual models may result from further data collection.

4 Results

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

4.1 Leaf Water Potential Measurements

A summary of LWP sampling results for all trees, including locations of sampled trees relative to waterways is provided in **Appendix A.** Representation of average LWP results for all assessment sites is shown in **Figure 12** with a breakdown of LWP for individual trees shown in **Figure 13. Figure 14** provides a spatial representation of average water availability per site with spatial details for each GDE area shown in **Figure 15** to **Figure 18**. Summary of the results is provided in **Table 3** which also provides notes on site ecology and regional ecosystem. Based on the summary provided in **Table 3,** the only GDE assessment areas that are likely to represent GDEs are GDE Area 1, GDE Area 6, GDE Area 9 and GDE Area 10, although GDE Area 5, GDE Area 7 and GDE Area 8 may be indicative of saline groundwater usage . Other localities present LWP values that are too low for the local groundwater salinity regime or are associated with groundwater salinity that is too high to represent a viable source of moisture for transpiration.

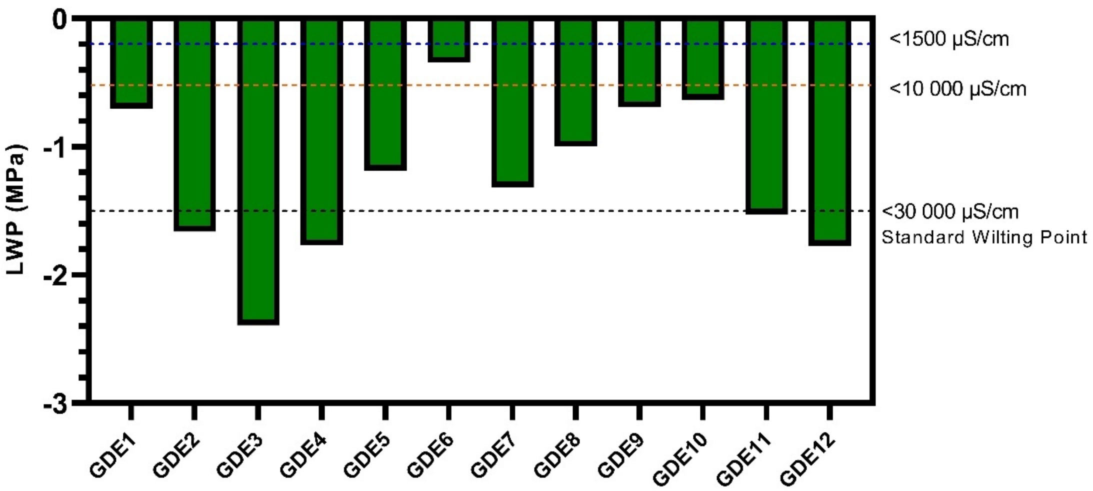

Figure 12. Average LWP readings for all GDE Assessment Areas. The blue line (>-0.2MPa) indicates typical LWPs for trees in equilibrium with a non-saline saturated source of soil moisture; the orange line (>-0.55MPa) indicating typical values for trees in equilibrium with a moderately saline soil moisture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

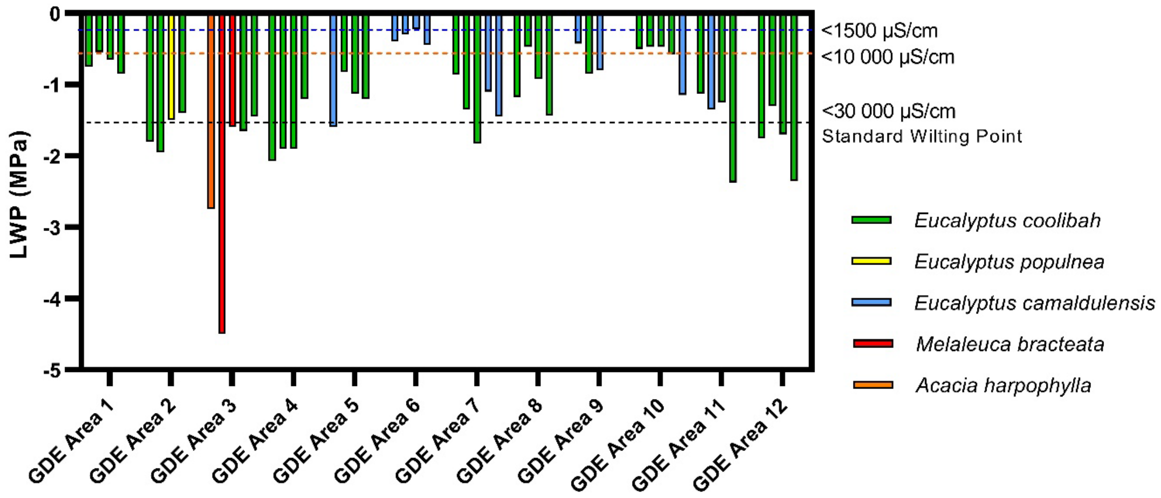

Figure 13. LWP results for individual trees per species at each of the 12 GDE assessment areas.

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

Site	**Average LWP**	**Water Availability**	**Comments**
Sites that indicate high water availability / Possible saturated source of soil moisture			
GDE Area 1	-0.7 MPa	High	Wetland habitat RE11.3.3 with dominant coolibah. LWP values range from -0.55 to -0.75 MPa with the highest values associated with Tree 2 (Photograph 1) in the central portion of the wetland. Nearest groundwater monitoring bore (P-OB3 with SWL at 15.2 mbgl) indicates groundwater salinity range from 34000 to 37000 µS/cm suggesting that trees are accessing a lower salinity moisture source that is disconnected from the regional alluvial groundwater table.
GDE Area 6	-0.34	Very High	Represented in EcoSM (2021) as RE11.3.3 (coolabah dominant) although vegetation is locally dominated by river red gum at this location. LWP values range from -0.225 to -0.45 MPa. All sampled trees are located within or adjacent to the main channel of Banana Creek above the zone of permanent inundation. Nearest groundwater monitoring bore (A-OB2 with SWL 13 mbgl) indicates groundwater salinity range from 600 to 900 µS/cm which is consistent with the high LWP values recorded at this locality.
GDE Area 9	-0.69	High	Located on the margins of the Neville Hewitt Weir inundation area with Tree 1 (river red gum) located on the waters edge (-0.425 MPa) and other trees located higher on the levee having lower LWP (-0.85 MPa). There are no groundwater monitoring bores near this assessment area although groundwater would be influenced by direct infiltration of fresh surface water from the weir inundation area and would be expected to be fresh. While Tree 1 is likely to be utilising surface water, other trees present LWPs that are too low for the expected groundwater salinity regime.

Site	Average LWP	Water Availability	Comments
GDE Area 10	-0.63	High	Located on shallow overflow depression running parallel and 100m from the main river channel. Tree 1 to Tree 4 are all coolibah with LWP values above -0.5MPa suggesting trees are utilising a readily available source of fresh to brackish soil moisture / groundwater. Tree 5, a large river red gum, presented a considerably lower LWP (-1.01 MPa) which skewed the average value. There are no groundwater monitoring bores near this assessment area although the groundwater regime is expected to be fresh due to the influence of infiltrating surface water from the weir inundation area.
Sites where there may be utilisation of a moderately saline to saline saturated moisture source			
GDE Area 5	-1.19	Moderate	Represented in EcoSM (2021) as RE11.3.3 (coolabah dominant) although vegetation is locally dominated by river red gum. LWP values range from -0.825 to -1.6 MPa with the highest recorded value from Tree 1 (river red gum) which was closest to the zone of inundation. Nearest groundwater monitoring bore (A-OB2 with SWL 13 mbgl) indicates groundwater is fresh with a salinity range from 600 to 900 µS/cm. LWP values recorded at this locality are considerably more negative than would be expected if trees were utilising groundwater in this salinity range.
GDE Area 7	-1.31	Low	Riparian open forest RE11.3.3 on a lower river terrace with a narrow fringe locally dominated by river red gumon the channel of Banana Creek. LWP values range from -0.86 to -1.8MPa with no distinction between coolibah on the flood plain to river red gum on the channel. Nearest groundwater monitoring bore A-OB6 is dry suggesting there is limited potential for tree / groundwater interaction consistent with the 'Low' LWP.
GDE Area 8	-1.0	Moderate	Riparian open forest RE11.3.3 on a lower river terrace. LWP values range from -0.47 to -1.44 MPa, Nearest groundwater monitoring bore A-OB6 is dry suggesting there is limited potential for tree / groundwater interaction in this locality. Tree 1 (-0.47 MPa) has a considerably higher LWP than all other trees suggesting an extremely localised edaphic control, possibly in the form of a restricted lens of soil with high matric potential.
Sites that indicate unlikely utilisation of a saturated moisture source, saline or otherwise			
GDE Area 2	-1.66	Very Low	Open forest RE11.3.3 on an upper terrace of the Dawson River flood plain on heavy clay. Nearest groundwater monitoring bore (P-OB3 with SWL at 15.2 mbgl) indicates groundwater salinity range from 34000 to 37000 µS/cm. Due to high salinity and depth to groundwater, coupled with evidence from low

Site	Average LWP	Water Availability	Comments
			LWP values, it is highly unlikely that trees are utilising groundwater in this locality.
GDE Area 3	-2.39	Extremely Low	Wetland habitat RE11.3.3a on a distal portion of the upper terrace of the Dawson River flood plain on heavy clay. Nearest groundwater monitoring bore (P-OB3 with SWL at 15.2 mbgl) indicates groundwater salinity range from 34000 to 37000 µS/cm. Due to high salinity and depth to groundwater, coupled with evidence from low LWP values, it is highly unlikely that trees are utilising groundwater in this locality.
GDE Area 4	-1.77	Very Low	HES Wetland habitat RE11.3.3 on an upper terrace of the Dawson River flood plain. Nearest groundwater monitoring bore (P-OB3 with SWL at 15.2 mbgl) indicates groundwater salinity range from 34000 to 37000 µS/cm. Due to high salinity and depth to groundwater, coupled with evidence from low LWP values, it is highly unlikely that trees are utilising groundwater in this locality.
GDE Area 11	-1.52	Very Low	On the direct margins of the Neville Hewitt Weir inundation area representing RE11.3.3. LWP values range from -1.13 to 2.37. At this location, there is no indication that trees are utilising a saturated moisture source derived from infiltrated surface water, despite being adjacent to the river channel.
GDE Area 12	-1.77	Very Low	On a secondary terrace of the Dawson River flood plain 1km from the Neville Hewitt Weir inundation area with vegetation representing RE11.3.3. LWP values range from -1.3 to -2.37 MPa. There are no groundwater monitoring bores installed in the alluvium near this assessment area. The use of saline groundwater at this locality is considered unlikely.

Photograph 1. Large coolibah (Tree 2) subject to sampling at GDE Area 1.

Photograph 2. Large river red gum (Tree 3) sampled at GDE Area 6.

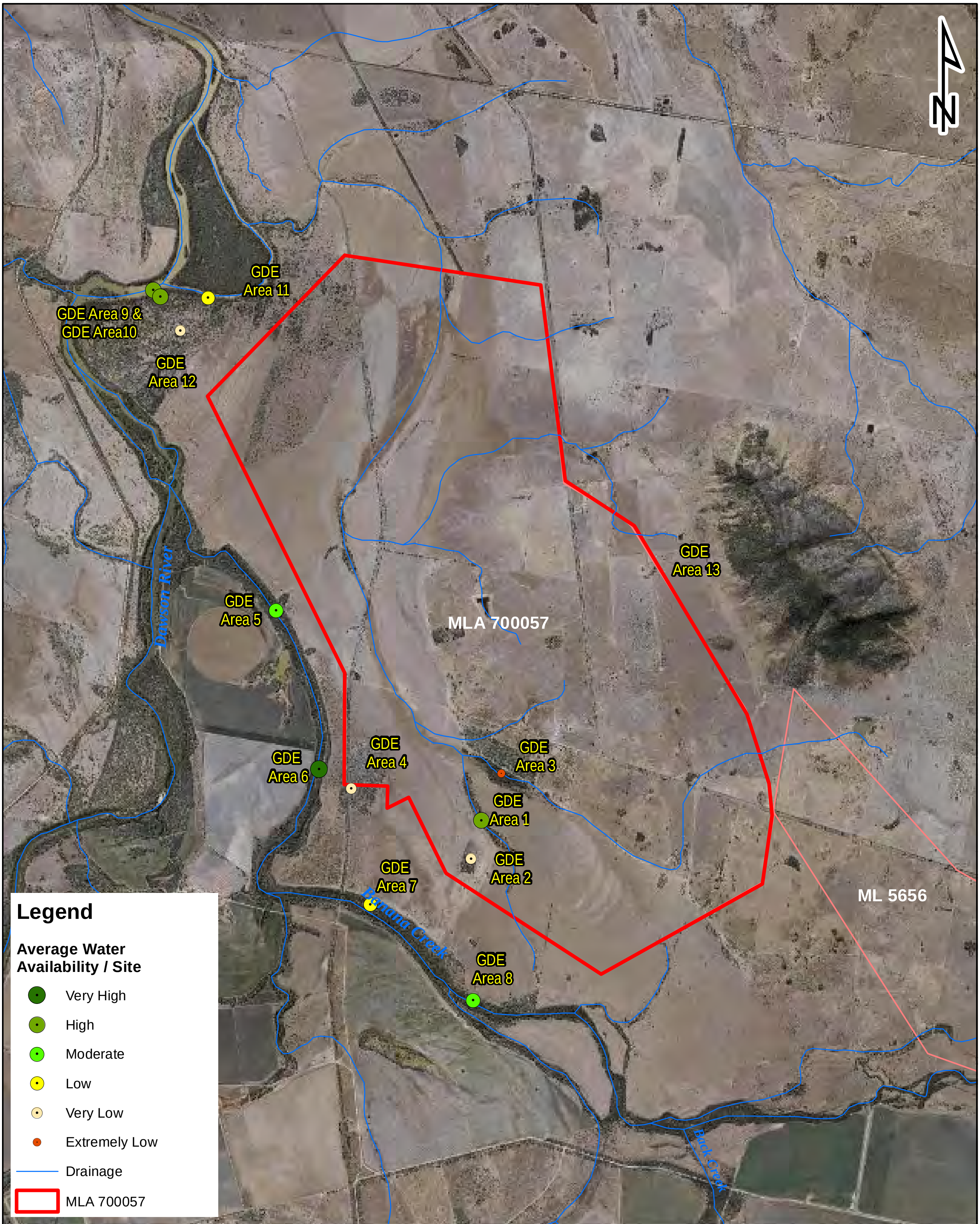

Figure 14. Spatial representation of average LWP values for sampling sites in the assessment area

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Kilometers

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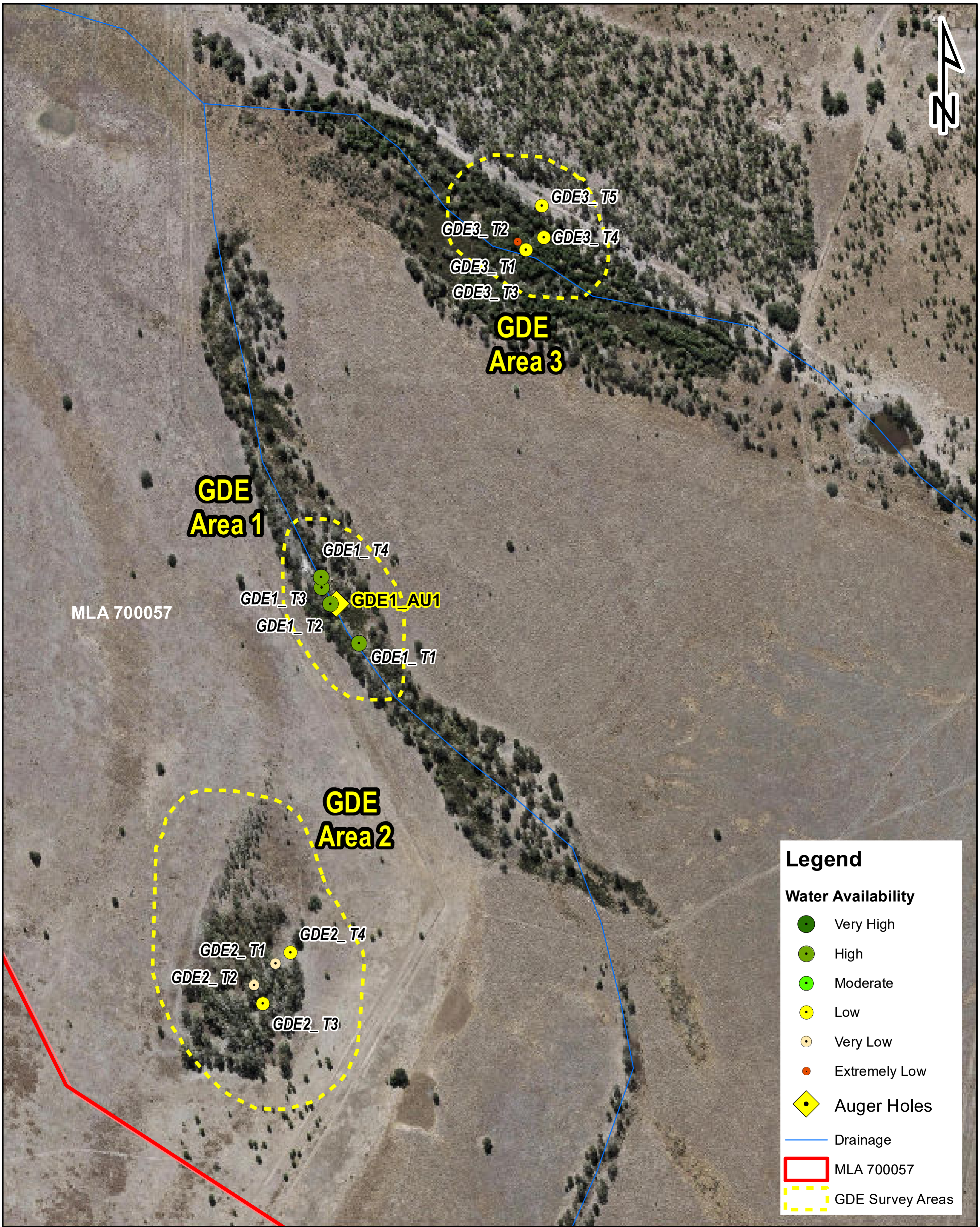

Figure 15. Sampling detail at GDE Area 1, GDE Area 2 and GDE Area 3.

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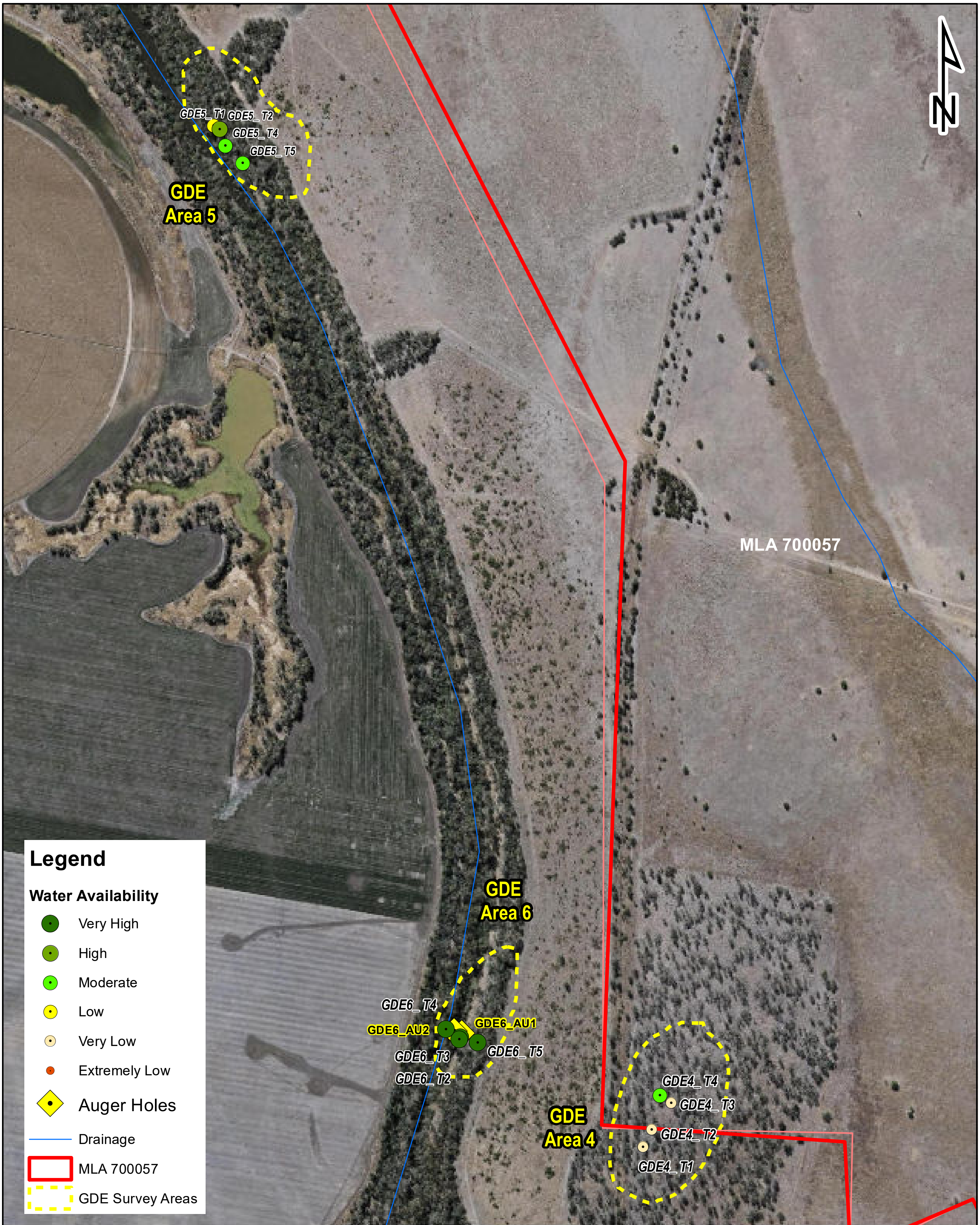

Figure 16. Sampling detail at GDE Area 4, GDE Area 5 and GDE Area 6

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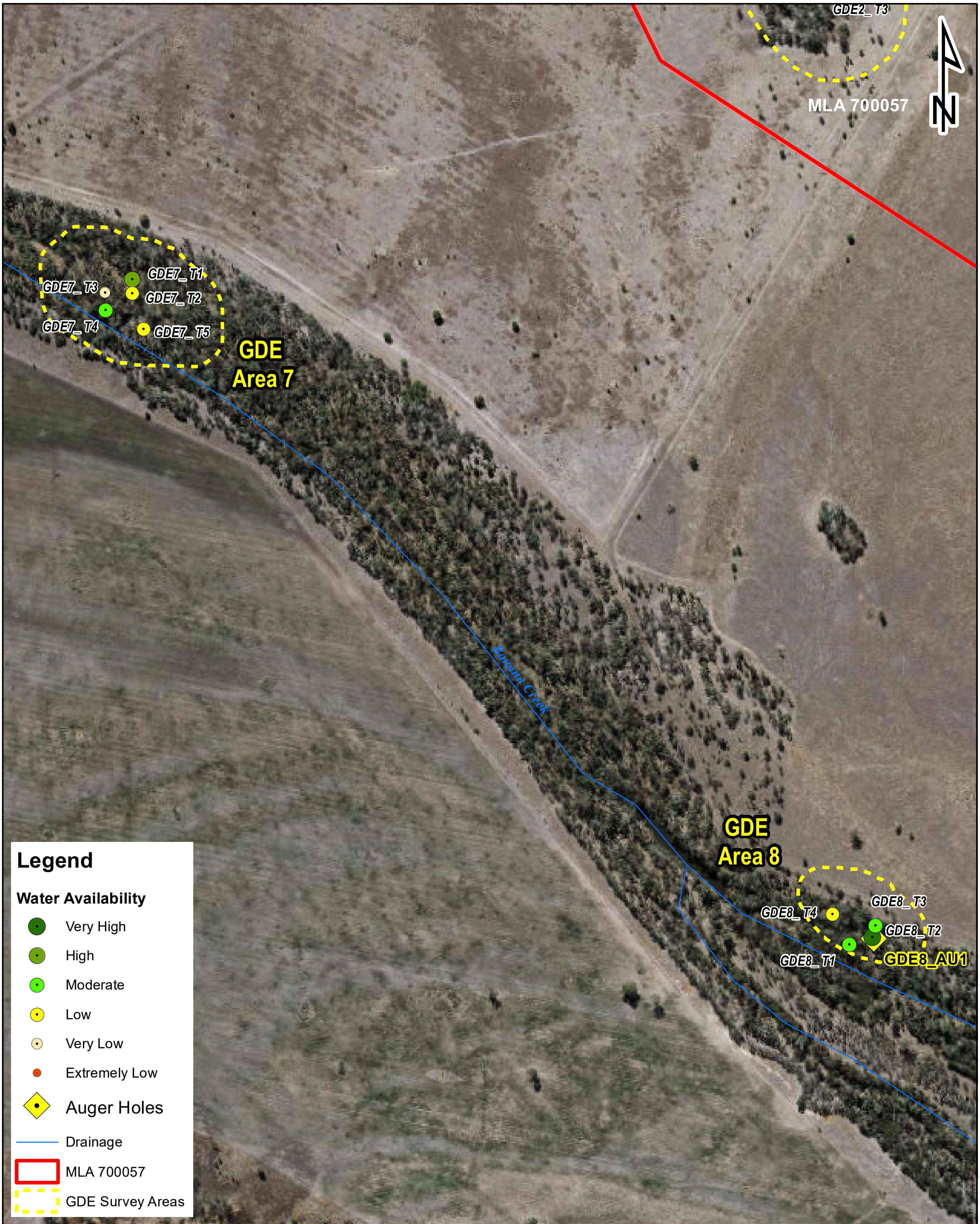

Figure 17. Sampling detail at GDE Area 7, GDE Area 8.

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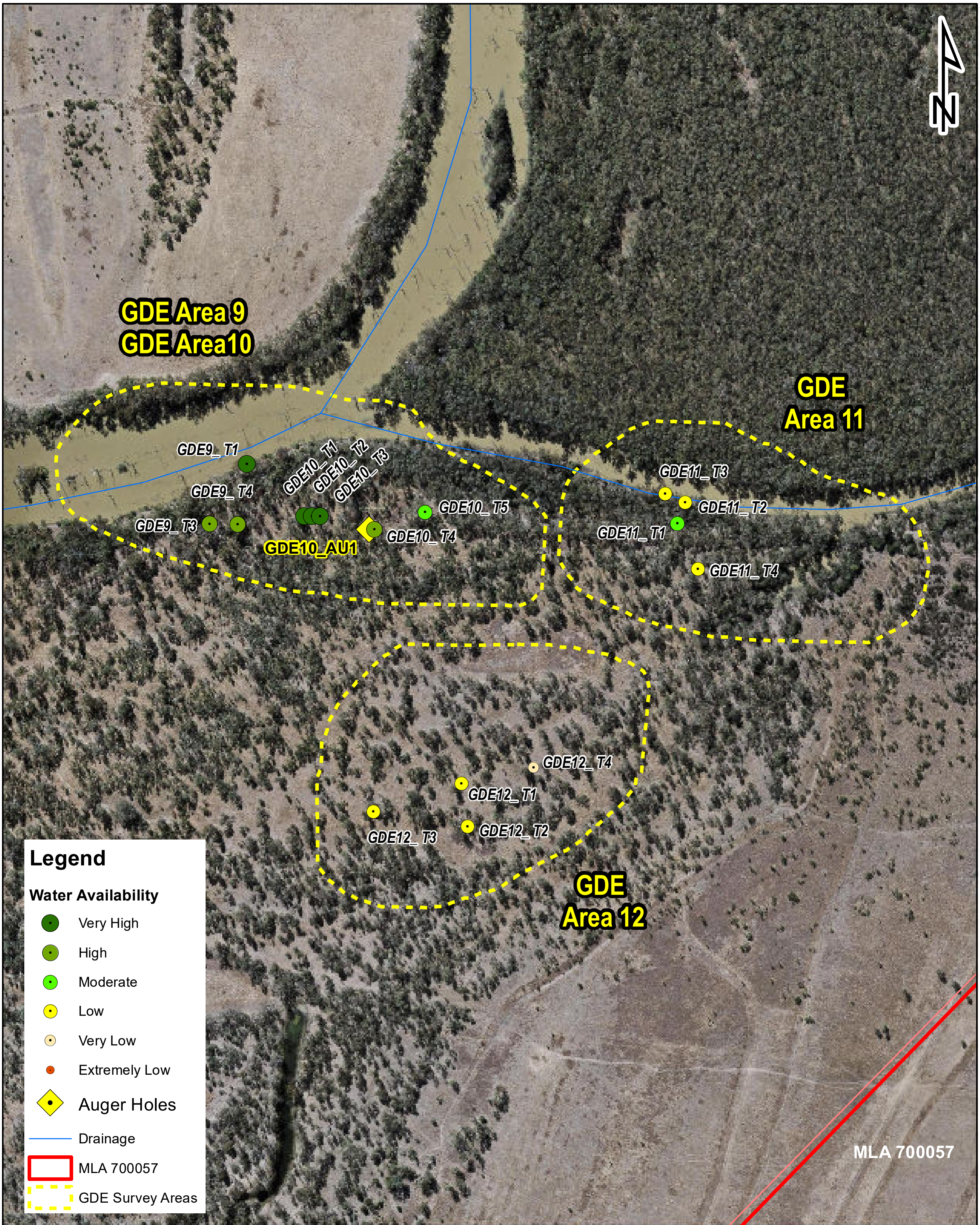

Figure 18. Sampling detail at GDE 9, GDE Area 10, GDE Area 11, GDE Area 12.

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4.2 Hand Auger Profiling and Soil Moisture Potential

Summary profile data for sites where an auger was completed are provided in **Appendix B** which provide an indication of soil structure, texture, and moisture content. As per **Section 3.4**, the purpose of the SMP testing is to identify, for those trees where LWP measurement indicate potential groundwater usage, whether sufficient moisture is available in the upper unsaturated portion of the soil profile (i.e vadose zone) to explain LWP measurements. The location for auger holes was selected during the field survey to cover sites where potential groundwater dependence was indicated or were considered representative of a particular habitat or landform. From **Section 4.1**, this includes the following:

1. GDE Area 1 where the auger hole was placed next to Tree 2 which had the lowest LWP value of all trees (-0.55MPa in coolibah).
2. GDE Area 6 where the auger hole was placed next to Tree 2 which presented a LWP value of -0.25 MPa (*Eucalyptus camaldulensis*).
3. GDE Area 8 adjacent to Tree 2 (coolibah) which returned a LWP of -0.475 MPa. GDE Area 8 was considered representative of the broader extent of RE11.3.3 that fringed Banana Creek.
4. GDE Area 10 adjacent to Tree 2 (coolibah) which returned a LWP of -0.475 MPa.

Two auger holes were placed at GDE Area 6 as penetration of auger hole AU1 was arrested by coarse gravel at 1.3 mbgl and auger hole AU2 was placed nearby to provide continuous soil profile data. Penetration of AU2 was arrested by a coarse gravel band at 3.3 mbgl while at GDE Area 8, penetration was arrested at 3.3 mbgl due to extremely compacted and cohesive clays. Augers at both GDE Area 1 and GDE Area 10 were placed to the maximum depth of the auger (4.8 m).

4.2.1 Soil Moisture Potential in GDE Area 1

Soil moisture data in GDE Area 1 is presented in **Figure 19**. The data demonstrates that the entire depth of the 4.8m soil profile has an SMP that is much lower (more negative) than the recorded LWPs at the locality, despite the presence of coarse tree roots recorded at 4.5 mbgl (**Photograph 3**). The results infer that the source of moisture utilised by trees is below the depth of the auger hole and the upper 4.8m of the soil profile was not a significant source of soil moisture for trees at the time of the assessment. Soil moisture is being supplied at a deeper level in the soil profile from a source with higher matric potential (i.e., sandier soil structure).

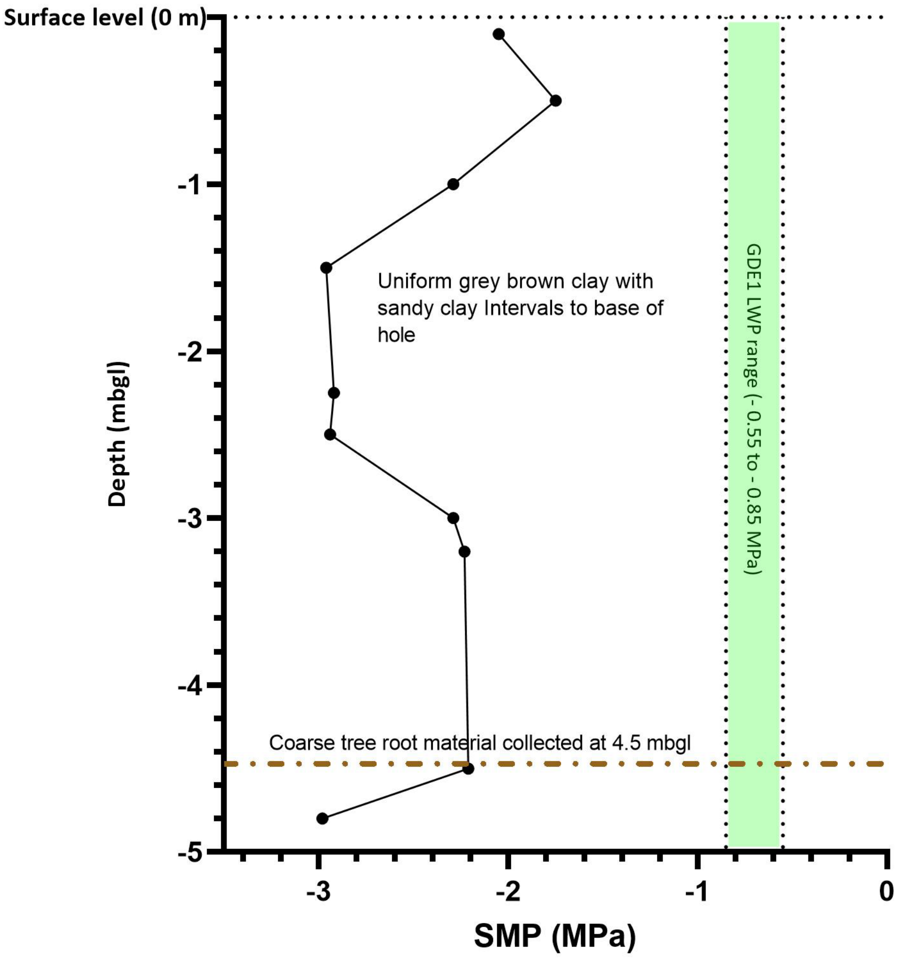

Figure 19. SMP relative to depth (mbgl) for Auger Hole 1 (AU1) at GDE Area 1.

Photograph 3. Coarse (5mm thick) tree roots recorded in AU1 from GDE Area 1 at 4.5m depth.

4.2.2 Soil Moisture Potential in GDE Area 6

Soil moisture data in GDE Area 6 is presented in **Figure 20**. Like GDE Area 1, SMP becomes increasingly more negative down profile and there is no portion of the profile with SMP values that correlate to measured LWP values for the sampled trees. Due to the high LWP values demonstrated at this locality, it is reasonable to infer that the source of moisture utilised by trees is below the depth of the auger hole and the upper 3.3m of the soil profile does not provide a significant source of soil moisture for trees at this locality.

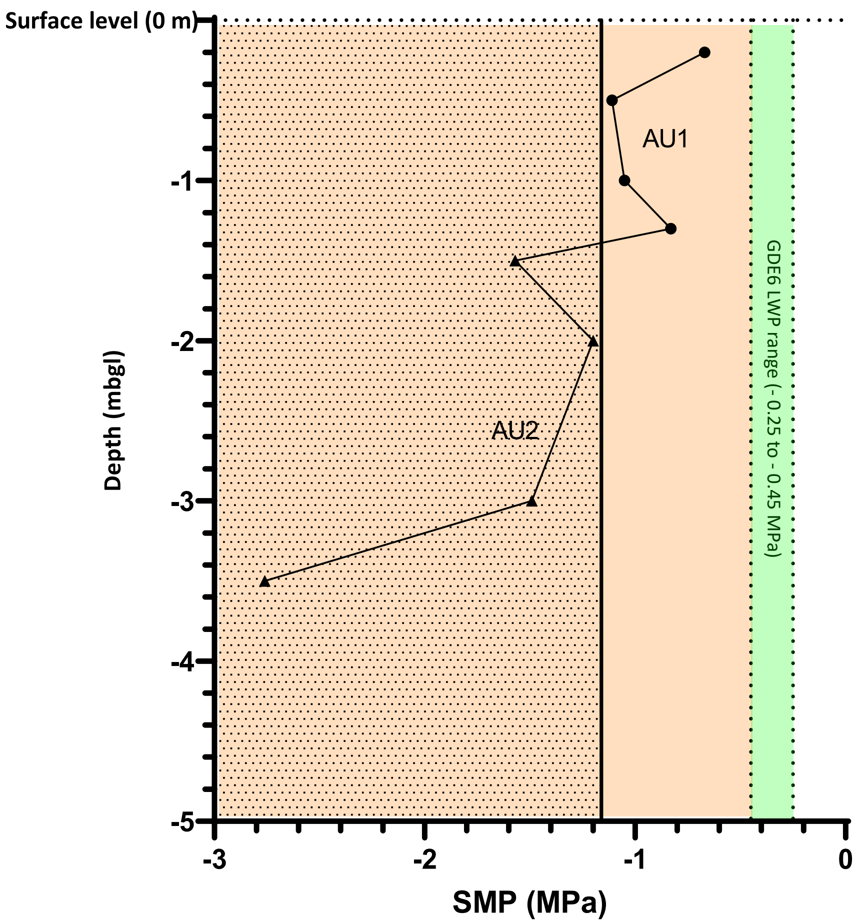

Figure 20. SMP relative to depth (mbgl) for Auger Hole 1 (AU1) and 2 (AU) at GDE Area 6 indicating more negative SMP values at depth in the soil profile, compared to high LWP values recorded at the site.

4.2.3 Soil Moisture Potential in GDE Area 8

While the LWP results recorded for GDE Area 8 are much more negative than the other sites where auger holes were placed, Tree 2 (LWP -4.75 MPa) provides some indication that a zone of higher matric potential / soil moisture availability is present in the soil profile. The SMP profile provided in **Figure 21** indicates that this zone of high moisture availability is mostly below the depth of the auger hole (3.3m), most likely a sandy lens. The sandy lens is however most likely discrete and discontinuous and all other trees at this site have elevated LWPs indicating a non-saturated source of soil moisture. In all cases however, the predominant source of soil moisture is below 3.3 mbgl.

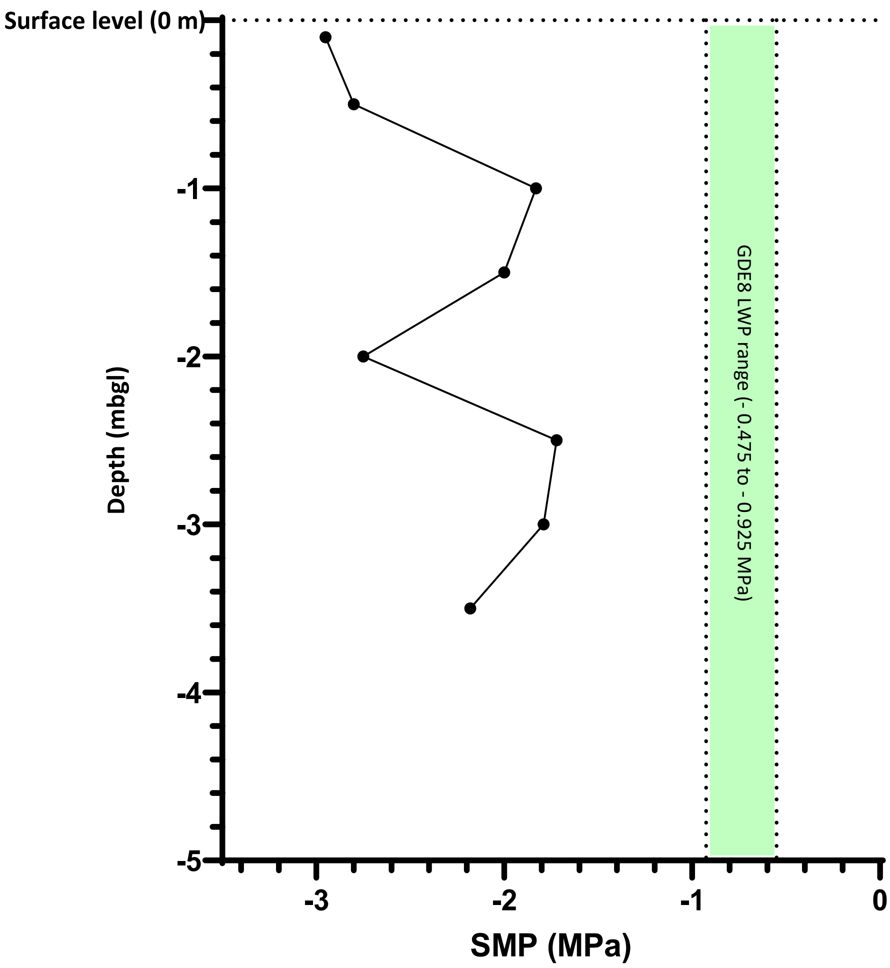

Figure 21. SMP relative to depth (mbgl) for Auger Hole 1 (AU1) at GDE Area 8 indicating range of LWP values recorded at the site.

4.2.4 Soil Moisture Potential in GDE Area 10

At GDE Area 10, an interval of fine to medium unconsolidated sand was intersected at 3.5 mbgl and was continuous to the base of the profile at 4.8m (see **Figure 22** and **Photograph 4**). Overlying the unconsolidated sandy horizon is a uniform sandy clay which presents a sharp transition to the sand. LWP measurements (excluding the river red gum – Tree 5) are consistent with the moisture availability (SMP) from the sandy layer at 4.8 mbgl, suggesting that this depth in the soil profile and below is the predominant moisture source for trees at this locality. While there was no free water intersected during development of the auger profile, sediment in the sandy horizon became increasingly moist downhole and it is possible that free water is present at the base of the unconsolidated sand. It is also noted in **Figure 21** that tree roots have been identified at the base of the sandy clay (3.6m) which suggests that the sandy horizon is occasionally completely saturated, most likely following flood recharge including infiltration associated with overland flow.

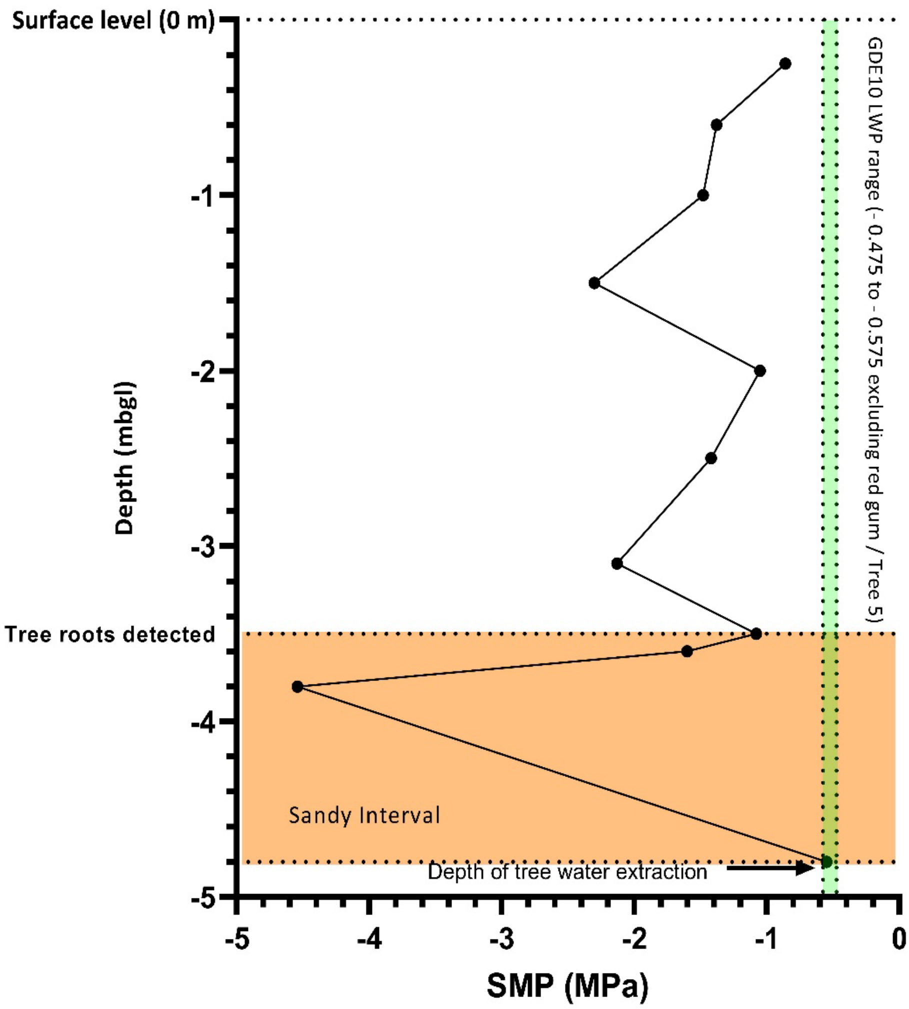

Figure 22. SMP relative to depth (mbgl) for Auger Hole 1 (AU1) at GDE Area 10 showing intersection with LWP values at 4.8 mbgl.

Photograph 4. Medium sand intersected in a horizon below 3.5m at GDE Area 10.

4.3 Stable Isotope Sampling and Analyses

Figure 23 shows stable isotope values ($\delta^{18}O$ and $\delta^{2}H$) for all values including soil, surface water from the Neville Hewitt Weir inundation area (at GDE Area 11) and residual stream pools in Banana Creek (at GDE Area 6), selected groundwater samples (as per **Table 1**) and twig xylem water analysed during the assessment. The main groupings have been circled to better indicate the inter-relationship between the groups and highlight areas of dataset overlap. The scatter shows:

1. Broad isotopic overlap between soil and all other sample types, with soil presenting the greatest spread of isotopic values. Stable isotope signatures of twig xylem samples generally overlap with the more isotopically enriched soil samples (see 'evaporative enrichment' in glossary) and isotopic signatures from twigs are generally distinct from groundwater (noting some overlap between the groups). This indicates that trees sampled at most localities are consistently utilising moisture from shallow evaporatively enriched moisture sources rather than isotopically depleted groundwater.
2. Some twig (xylem) samples demonstrate minor overlap with groundwater samples which suggests that there may be some usage of groundwater occurring for some trees.
3. A relatively tight range of values and linear trend is demonstrated between groundwater samples from the alluvium and coal seams and surface water from the Neville Hewitt Weir (sampled at GDE Area 11) indicating that these are likely to be linked through common hydrogeochemical evolutionary processes (i.e., surface water from the weir is contributing significantly to recharge of groundwater in both the coal seams and the alluvial aquifer).
4. An additional surface water sample taken from a residual pool at GDE Area 6 shows significantly enriched isotopic values that are the result of strong evaporation. The evaporative trend, which is the offset below the LMWL is indicated by the blue arrow. The surface water at GDE Area 6 was not connected to the surface water body associated with the Neville Hewitt Weir inundation area at the time of the assessment and has hence been subject to concentrated evaporative enrichment (due to small and restricted water volumes).

The broad scatter of isotopic values in the soil and twig samples with significant overlap is expected. This scatter would be imparted by infiltration of surface water, with varying degrees of isotopic enrichment, into the soil profile. Infiltrating surface water would include direct infiltration of unfractionated rainfall with variable isotopic composition (dependent on the season and type of rainfall event[2]), evaporatively enriched surface waters, with subsequent uptake by trees from various depths within the soil profile. Note that **Figure 23**, and all subsequent stable isotope biplots include the Local Meteoric Water Line (LMWL) for Rockhampton from Crosbie et al (2012). The LMWL provides a reference to identify evaporative processes, which will generally result in δ isotope values that plot below the LMWL. The scatter of stable isotope values above the LMWL for soil samples is likely due to ^{2}H fractionation as a result of long soil residence time and associated interaction with soil particles and vapour fractions in the unsaturated portion of the soil profile prior to update by trees. Hydrogen stable isotopes have a higher energy state than those of oxygen and

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

have a much stronger tendency to fractionate by processes other than evaporation (Singer et al 2014, Evaristo 2017). The scatter of isotope values above the LMWL provides strong evidence that corresponding trees are not utilising significant quantities of groundwater and are reliant on moisture derived from the unsaturated portion of the soil profile. Raw data for all isotopic samples is provided in **Appendix D**. Stable isotope results for individual assessment areas is provided in subsequent sections.

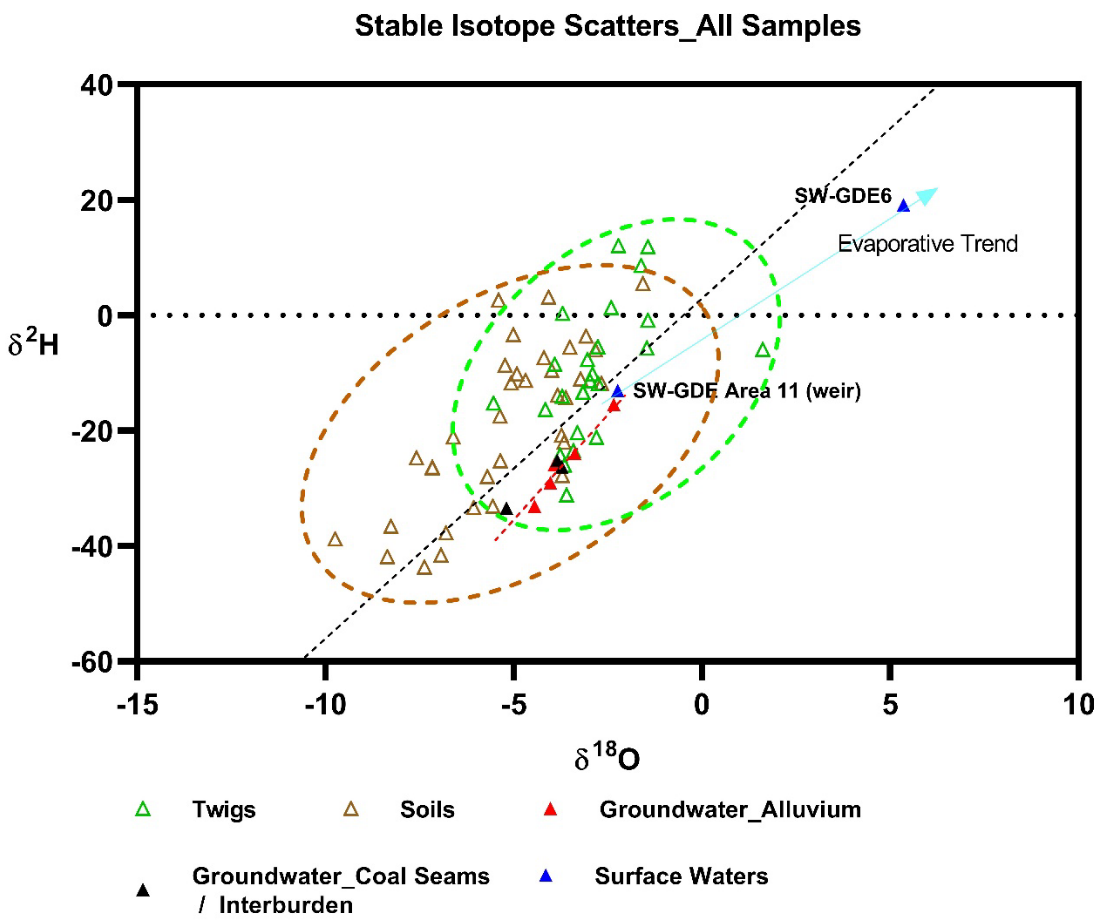

Figure 23. Stable isotope scatters for all data with the LMWL for Rockhampton indicated by black dashed line and linear trend of groundwater samples with red line. Note that the surface water sample from the weir inundation area (GDE Area 11) sits on the trendline for groundwater samples suggesting a common hydro-geochemical and evolutionary linkage.

4.3.1 GDE Area 1, GDE Area 6, GDE Area 9 and GDE Area 10

From **Section 4.1** (**Table 3**), assessment areas indicating potential for utilisation of a source of fresh saturated soil moisture / groundwater are GDE Area 1, GDE Area 6, GDE Area 9 and GDE Area 10. Biplots showing the isotopic composition of soils, twigs, groundwater, and surface water from these assessment areas is shown in **Figures 24** to **Figure 28**.

For **GDE Area 1** (**Figure 24**), isotopic signatures for the twig samples show direct overlap with isotopic composition of the groundwater samples, with no overlap with soil samples. This suggests that groundwater is being used by trees to sustain transpiration at this locality. Due to the high salinity of regional alluvial groundwater table measured in nearby monitoring wells (>30 000 µS/cm), it is anticipated that the groundwater source is from a sandy horizon at depth in the soil profile that is perched above the regional groundwater table and recharged from surface water held seasonally in the drainage depression. This interpretation is consistent with interpretation of the soil moisture data (**Section 4.2.1**) which indicates trees at this locality are utilising moisture from a soil horizon below the depth penetrated by the auger hole. As per **Section 3.7**, the assessment assumes that groundwater held in the perched aquifer presents the same or similar isotopic values to the regional alluvial groundwater table.

For **GDE Area 6** (**Figure 25**), there is broad overlap between stable isotope composition of twigs, soils, groundwater, and surface water. Two of the twig samples (T2 and T4) lie directly on the LMWL suggesting that these trees are utilising a saturated moisture source that has been subject to limited evaporation. This would most likely occur as a result of direct infiltration of unfractionated surface water, occurring as rapid infiltration following rainfall recharge, into the alluvial groundwater table. From **Section 4.3.2**, the source of moisture utilised by trees is below the depth of penetration from the auger profile (3.3 mbgl) and is most likely attributed to a sandy horizon below the river channel. It is expected that groundwater within this horizon may have some hydraulic connection to the regional groundwater table, although would be low salinity due to recharge from fresh surface waters. Note the scatter of soil moisture samples with many sitting above the LMWL suggesting ^{2}H fractionation has occurred because of slow infiltration and long residence times in the upper soil profile.

There are no soil samples for **GDE Area 9** though scatter of twigs, surface water and groundwater samples provide sufficient basis for assessment (see **Figure 26**). Tree 1, which was directly on the margins of the inundation zone, is inferred to be utilising surface water that has undergone significant evaporative enrichment on the margins of the surface water body prior to infiltration into the soil profile. Consistent with the very high LWP values recorded for Tree 1 (see **Section 4.1**), the soils providing moisture are saturated due to surface water infiltration, though are not linked to the groundwater table. Tree 3 has an isotopic signature that has greater isotopic similarity to the groundwater samples, although the slight displacement above the groundwater trendline and LMWL suggests that there is utilisation of moisture from the unsaturated portion of the soil profile (i.e., groundwater is not being utilised). This is consistent with the LWP of Tree 3 (-0.8 MPa from Section 4.1) which does not suggest direct utilisation of a fresh groundwater source.

At GDE Area 10 (**Figure 27**), there is direct overlap between the stable isotope composition of groundwater and twig xylem, particularly for Tree 3. Considering the high LWP values for trees in this assessment area (see **Section 4.1**), it is likely that trees are utilising a source of fresh groundwater / soil moisture from a zone possessing high matric potential. From **Section 4.2.4**, this would correspond with the horizon of unconsolidated sand that was intersected in the auger hole. While free water was not confirmed in the sandy horizon during the auger profiling, it is likely to be subject to direct recharge from infiltration of surface water, particularly during flood events when overflow channels are actively channelling floodwaters. All three lines of evidence (LWP, SMP and stable isotopes) suggest groundwater utilisation is occurring that this assessment locality.

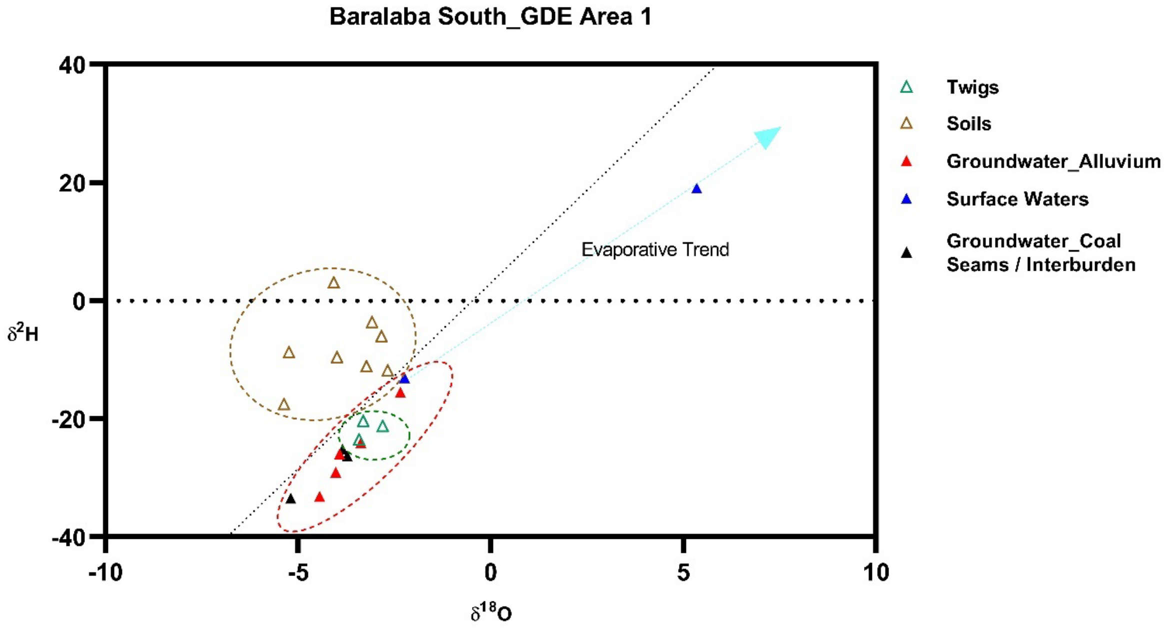

Figure 24. Stable isotope scatters for samples from GDE Area 1 with the LMWL for Rockhampton indicated by black line and isotope clusters indicated by the brown dashed line (soils), red dashed line (groundwater) and green dashed line (twigs). Twig samples overlap with isotopic composition of groundwater rather than soils.

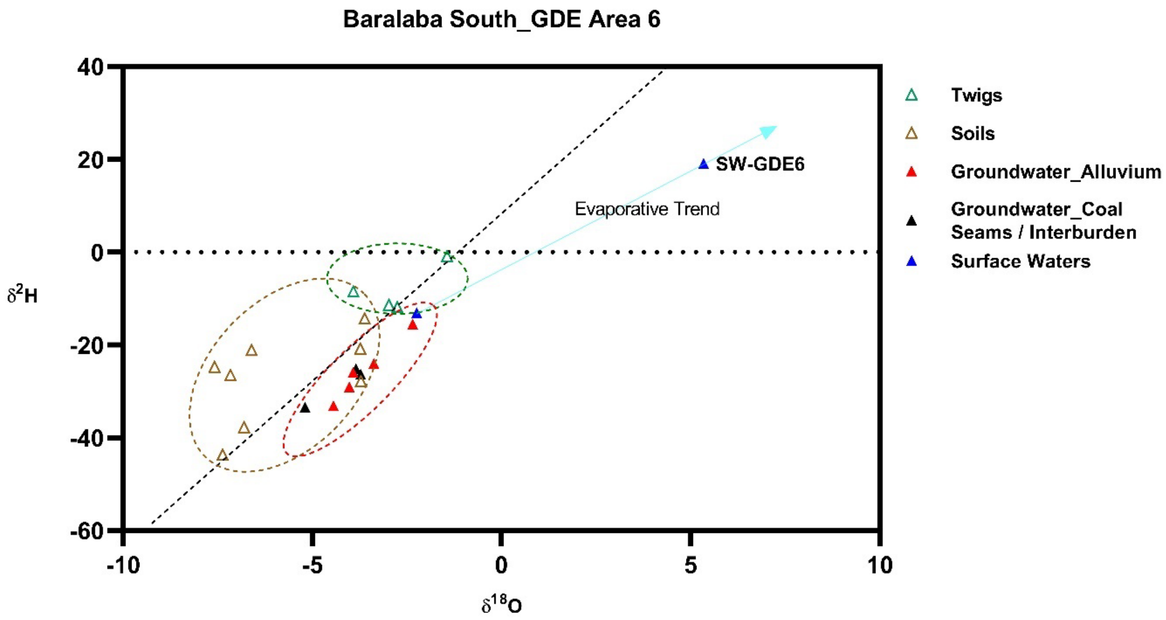

Figure 25. Stable isotope scatters for samples from GDE Area 6 with the LMWL for Rockhampton indicated by black line and isotope clusters indicated by the brown dashed line (soils), red dashed line (groundwater) and green dashed line (twigs). Twig samples T2 and T4 line directly on the LMWL (black dashed line) indicating a water source that has been subject to limited evaporation.

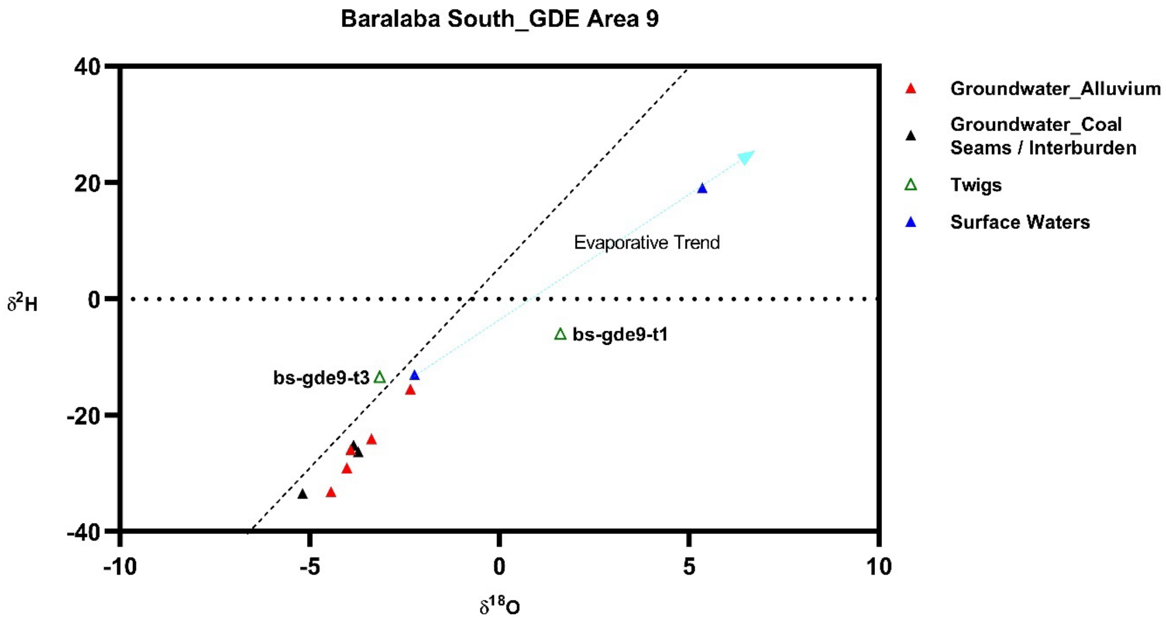

Figure 26. Stable isotope scatters for samples from GDE Area 9 with the LMWL for Rockhampton indicated by black line. While the stable isotope values for Tree 3 indicate similarities with groundwater, evidence from LWP measurements (Section 4.1) suggest the xylem moisture is not from a saturated source (i.e., most likely a soil moisture source). The significant enrichment of stable isotope values for Tree 1 suggests utilisation of an evaporatively enriched source of moisture rather than groundwater, consistent with the high LWP values (Section 4.1).

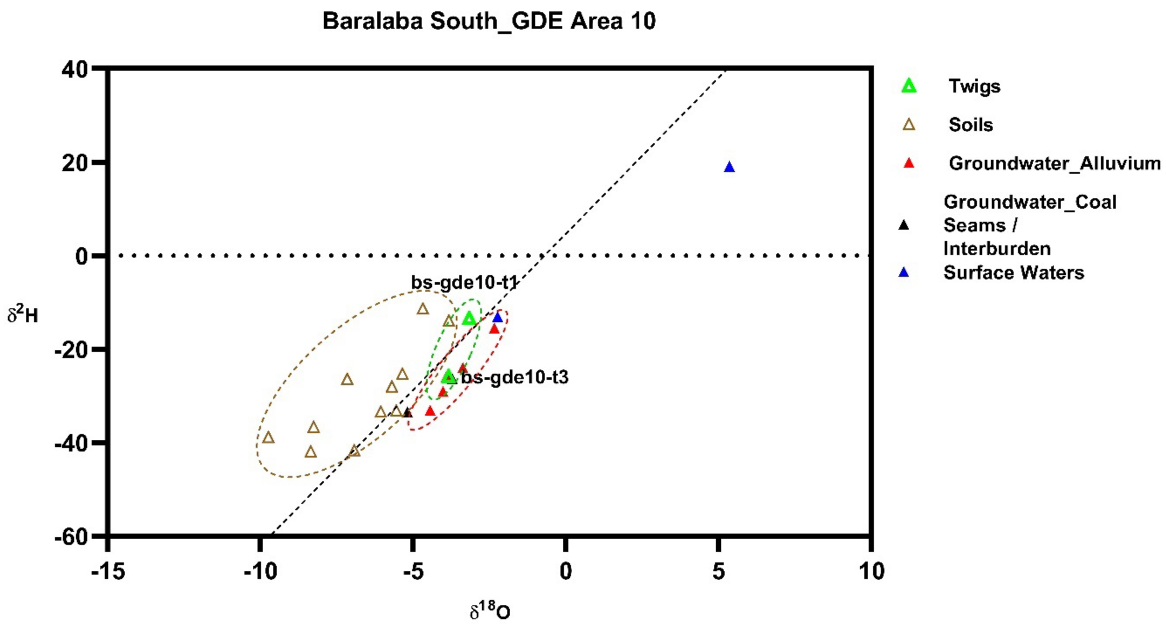

Figure 27. Stable isotope scatters for samples from GDE Area 10 with the LMWL for Rockhampton indicated by black dashed line and isotope clusters indicated by the brown dashed line (soils), red dashed line (groundwater) and green dashed line (twigs). Both Tree 1 and Tree 3 show isotopic similarity to groundwater samples with Tree 3 showing direct overlap.

4.3.2 GDE Area 5, GDE Area 7, and GDE Area 8

As per **Table 3** (LWP results in **Section 4.1**) GDE Area 5, 7 and 8 were assessed as presenting LWP values that may be indicative of trees potentially utilising a saline source of groundwater. The stable isotope results presented in **Figure 28, Figure 29** and **Figure 30** all demonstrate xylem stable isotope analyses that are offset from groundwater values, lying above the LMWL. As explained in **Section 4.3**, the scatter of samples above the LMWL is likely to be due to ^{2}H fractionation resulting from long residence time in the unsaturated portion of the soil profile prior to update by trees, and presents clear evidence than none of these sites are utilising even saline groundwater to any significant degree. The strong overlap between soil and twig isotope values for GDE Area 8 (**Figure 30**) provides further evidence that trees are extracting soil moisture from the vadose zone at this locality.

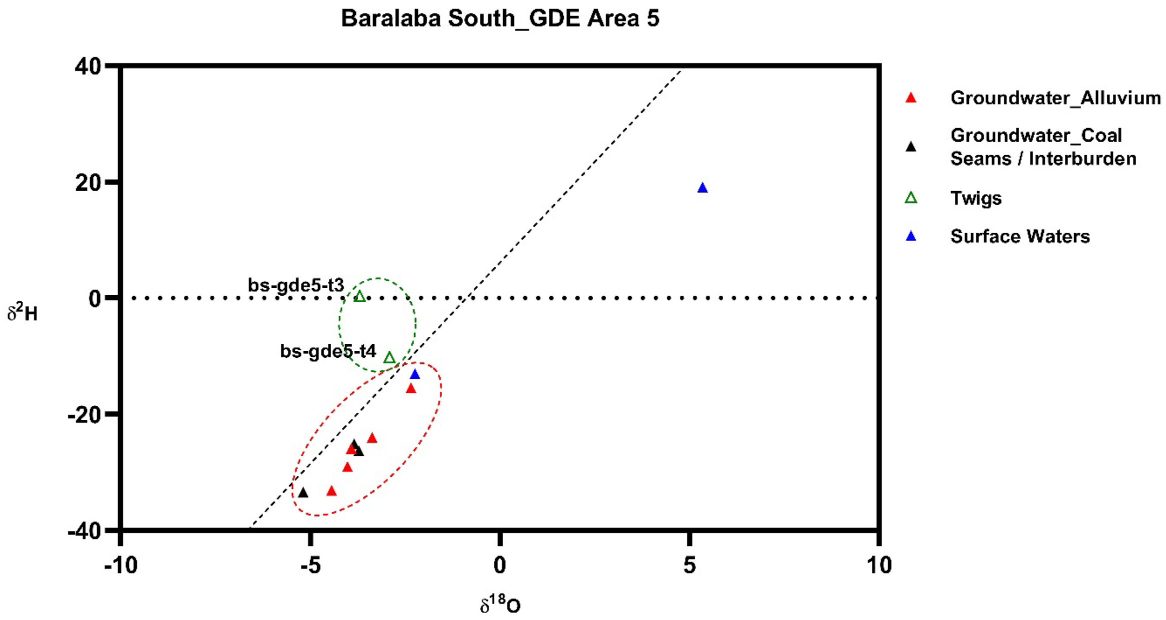

Figure 28. Stable isotope scatters for samples from GDE Area 5 with the LMWL for Rockhampton indicated by black line and isotope clusters indicated by the red dashed line (groundwater) and green dashed line (twigs) demonstrating lack of overlap, and position of twig samples above the LMWL.

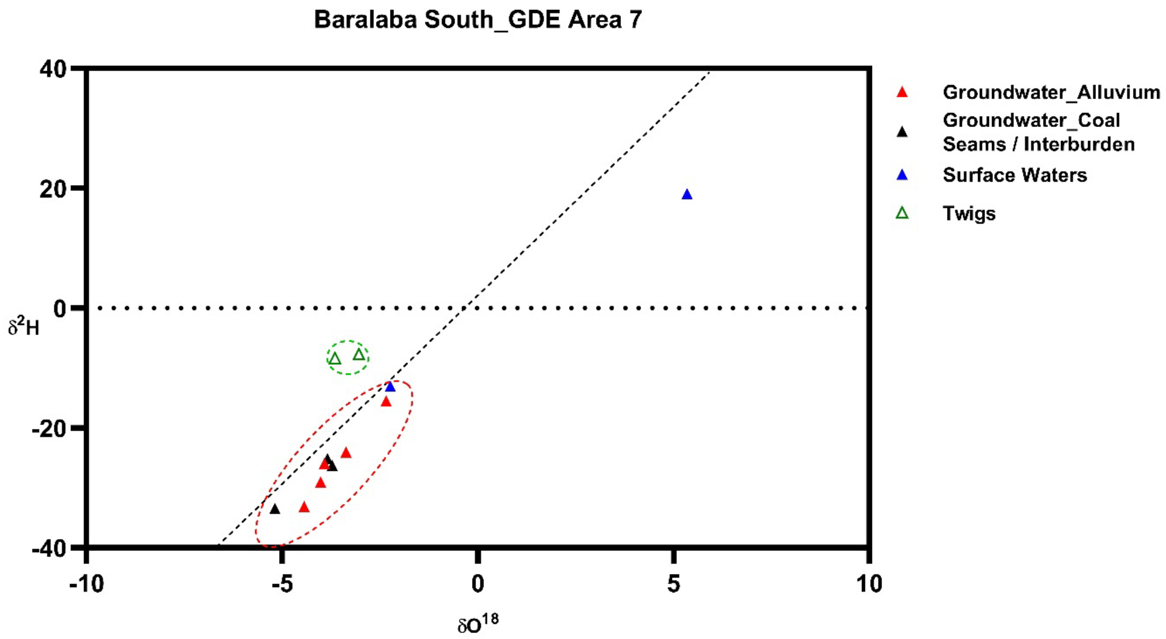

Figure 29. Stable isotope scatters for samples from GDE Area 7 with the LMWL for Rockhampton indicated by black line and isotope clusters indicated by the red dashed line (groundwater) and green dashed line (twigs) demonstrating lack of overlap.

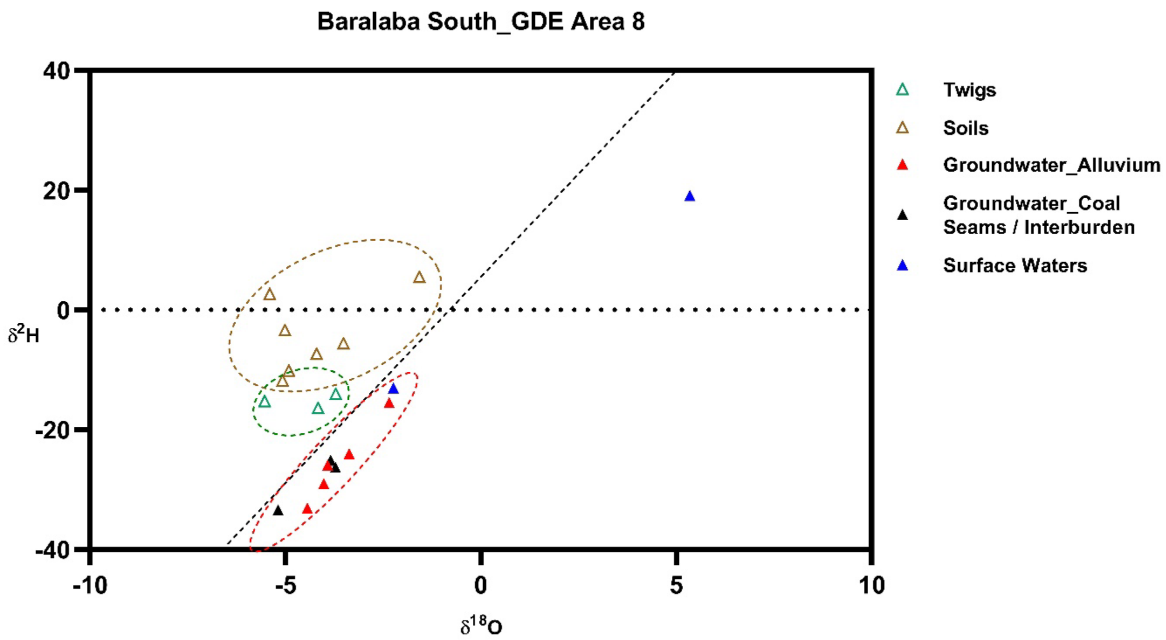

Figure 30. Stable isotope scatters for samples from GDE Area 8 with the LMWL for Rockhampton indicated by black line and isotope clusters indicated by the red dashed line (groundwater) and green dashed line (twigs). isotopic overlap is demonstrated between the twig and soil samples suggesting trees are predominantly utilising soil moisture from the unsaturated zone.

4.3.3 Other Assessment Areas

As per **Table 3** (LWP results in **Section 4.1**) GDE Areas 2, 3, 4 and GDE Area 11 were assessed as not representing GDEs based on the highly negative LWP values of trees at these localities. The stable isotope results presented in **Figure 31 to Figure 34** all demonstrate xylem stable isotope results that are offset from groundwater values, generally sitting above the LMWL, supporting evidence from LWP sampling that these assessment localities are not utilising groundwater and are not GDEs. The results highlight that despite some sampling localities being directly adjacent to a large surface water body created by the Neville Hewitt Weir (i.e., GDE Area 11), this does not necessarily imply that trees are utlising groundwater, nor do they have access to an alternative source of saturated soil moisture. Note that twigs were not sampled for stable isotopes for GDE Area 12 due to the extremely high LWP values returned during field assessment.

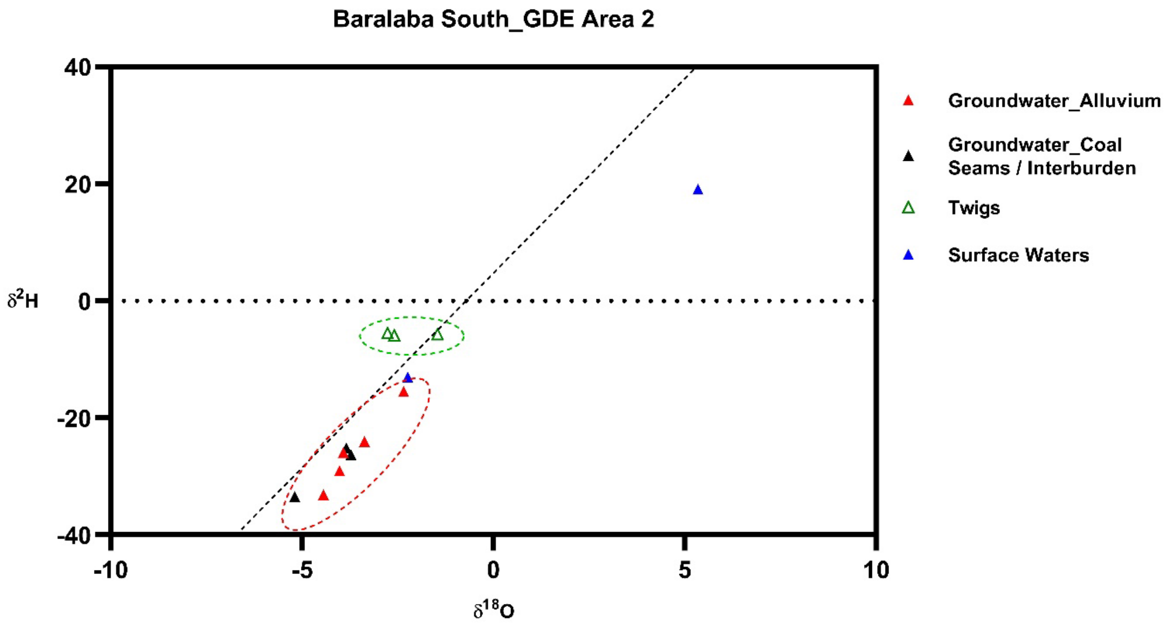

Figure 31. Stable isotope scatters for samples from GDE Area 2 with the LMWL for Rockhampton indicated by black line and isotope clusters indicated by the red dashed line (groundwater) and green dashed line (twigs) demonstrating lack of overlap.

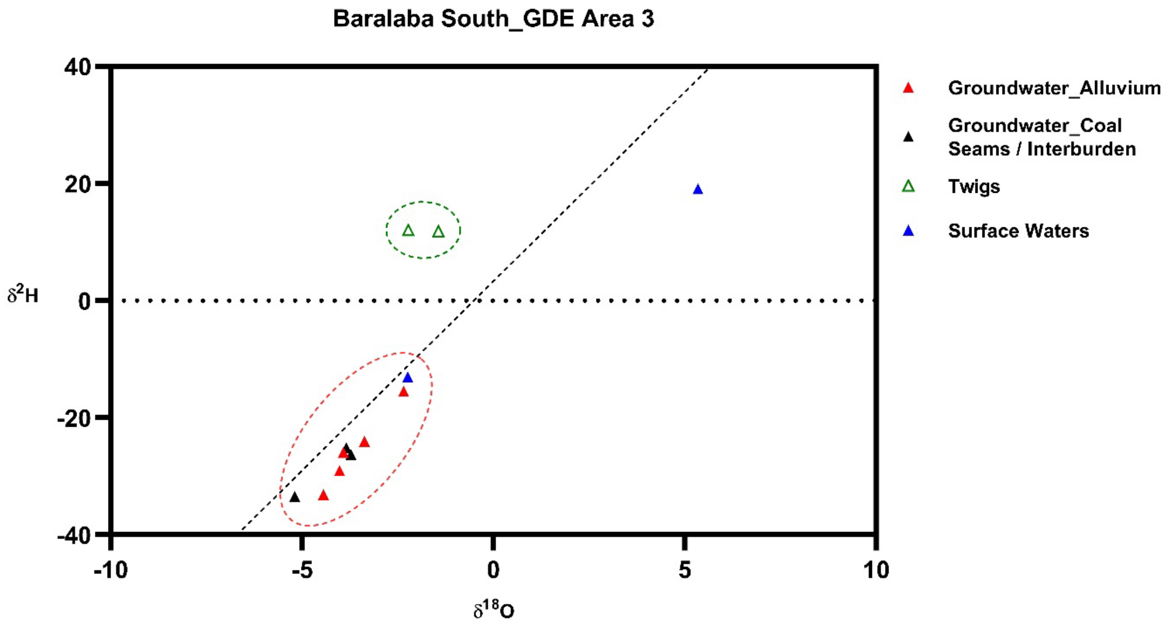

Figure 32. Stable isotope scatters for samples from GDE Area 3 with the LMWL for Rockhampton indicated by black line and isotope clusters indicated by the red dashed line (groundwater) and green dashed line (twigs) demonstrating lack of overlap.

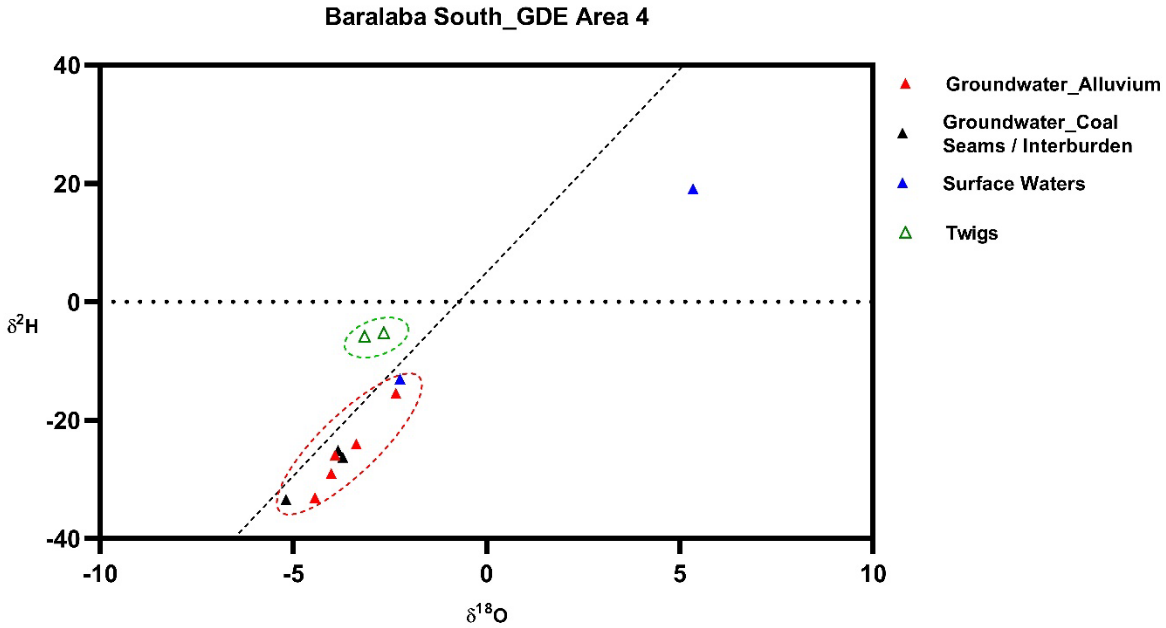

Figure 33. Stable isotope scatters for samples from GDE Area 4 with the LMWL for Rockhampton indicated by black line and isotope clusters indicated by the red dashed line (groundwater) and green dashed line (twigs) demonstrating lack of overlap.

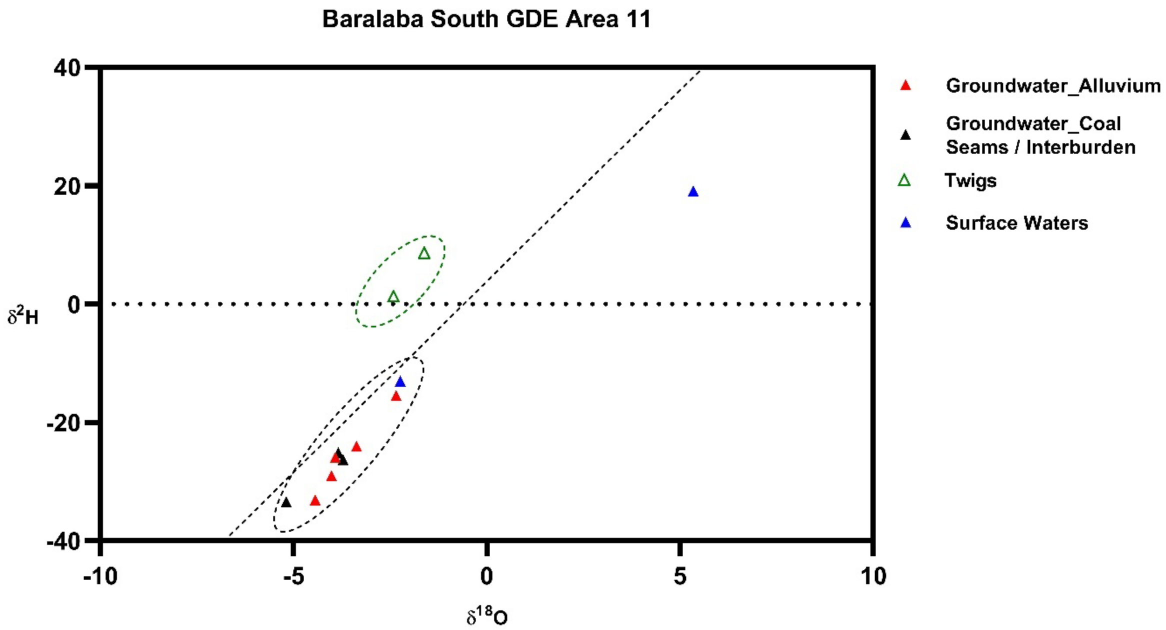

Figure 34. Stable isotope scatters for samples from GDE Area 11 with the LMWL for Rockhampton indicated by black line and isotope clusters indicated by the red dashed line (groundwater) and green dashed line (twigs) demonstrating lack of overlap.

5.0 Discussion and Conceptual Site Models (CSMs)

5.1 Suitability of Groundwater Resources to Support GDEs

Interburden in the Permian sediments (Baralaba coal measures) are low permeability units generally considered to be an aquitard, with groundwater largely restricted to the coal seams where it occurs in cleats and secondary fractures. The Baralaba coal measures sub-crop in a narrow north-west trending corridor into thick sequences of Quaternary alluvium. While the potentiometric surface of the coal seams ranges from 12.9 to 24.3 mbgl, which is roughly comparable to groundwater levels measured in the alluvium (8.2 to 24.3 mbgl), Watershed HydroGeo (2023) concluded, through analysis of stable isotopes that the alluvium is more readily recharged by rainfall. Several alluvial bores in the region have also been recorded as dry. The reported limited connectivity of the Permian coal measures, and adjacent shallow alluvial monitoring bores also suggests there is limited potential for upward propagation of groundwater into the alluvium. Hence recharge is predominantly from rainfall and associated surface runoff, or bank recharge following overbank flooding events.

Despite the limited connectivity between the coal measures and the alluvium, groundwater salinity in the two units can be comparable with both aquifers demonstrating salinities above 30 000 µS/cm in some bores, indicative of long residence times with groundwater in the alluvium, which only freshen where monitoring bores are located close to the major drainage channels. Salinity plays a significant role in determining the suitability of groundwater to support ecological processes, including its capacity to support terrestrial GDEs. Costelloe et al (2008) concluded that coolibah, the dominant tree across the Dawson River flood plain, extending into the lower river terraces and channels, can continue to extract moisture at salinity levels up to 27 800 u µS/cm in soils where matric potential in the upper soil profile is extremely low (attributed to a combination of extreme drying coupled with a clayey substrate). Hence while the salinity of groundwater recorded in the alluvium does not preclude its utilisation by coolibah across the flood plain, there is unlikely to be any significant investment in deep root architecture when groundwater quality at depth provides only an extremely marginal moisture resource.

Typical depths to the water table across the flood plain (from **Section 2.1.4, Table 1**) range from 12.7 to 22.3 mbgl which is close to the inferred threshold depth beyond which tree roots / groundwater interaction is unlikely to occur (DNRM 2013) with Doody et al (2019) suggesting that vegetation will only consistently utilise groundwater where it occurs at depths of <10m below the land surface. Due to a combination of saline groundwater which has limited utility as a moisture resource, and heavy clay soils which present a barrier to tree root penetration (as per Dupuy et al 2005), plus significant depth (i.e., <10 mbgl) to the alluvial groundwater table, it would be extremely unlikely that trees would invest the energy to penetrate tree roots to the groundwater table. It is only closer to the river channel where groundwater is closer to the surface and relatively fresh (monitoring bore A-OB11 and AOB12 being at 8.2 and 9.0 mbgl and salinity is <500 µS/cm) where it would be expected that tree roots might penetrate to the groundwater table and utilise groundwater resources.

The immediate river channel also comprises a much more significant proportion of river red gum which is known to have deeper sinker roots which penetrate to depths of at least 15m (Horner 2009) and are much more likely to demonstrate groundwater dependence / utilisation than coolibah which is adapted to heavier clay soils and hence would be expected to have a shallower and laterally expansive tree root system.

5.2 Nature of Groundwater Dependency in the Assessment Area and Conceptual Models

Examination of the LWP measurements indicates considerable variability between assessment areas. From stable isotope analysis (**Section 4.3**), it is concluded that only three sites present strong evidence of groundwater utilisation being:

1. GDE Area 1, which is formed by a seasonally activated flood depression which joins the Dawson River in the norther portion of the assessment area. This is a relatively restricted (approximately 7.2 ha) linear area of riparian vegetation that is classified as RE11.3.3 (high value regrowth) under Queensland's Vegetation Management Act (1999) by Ecological Survey & Management (2021). Despite the classification of HVR, mature remnant tree still occur within this ecosystem and tree root systems would be expected to be well developed, as evidenced by rooting material being intersected in an auger hole at 4.5 mbgl. The ecohydrological characteristics of this site indicate relatively low soil matric potentials in the upper 4.8m of the soil profile. With evidence provided by high LWP values, the strongly negative SMP results provide physical evidence of a sandy lens at depth where soil matric potential is significantly higher. This sand is inferred to be a seasonal aquifer that is perched above the more saline regional groundwater table. Stable isotope analysis of twig samples indicates strong similarity to groundwater water samples providing three lines of evidence supporting this locality as being groundwater dependent.
2. GDE Area 6, on the main channel of Banana Creek, provides evidence for a zone of high water availability below an upper soil profile characterised by thick plastic clay with low matric potential. The zone of high water availability is inferred to be a sandy interval lying directly beneath the river channel, below the depth sampled by the auger hole (installed to 3.3 mbgl). Based on LWP measurements, the sandy interval is saturated or near saturated and would be directly recharged during river flow. It is expected that any sandy interval would be centred along the river channel and would subtend the river terraces laterally in discontinuous pockets. This assessment is supported by stable isotope analysis which indicates the water source utilised by trees is of similar isotopic composition to surface water in the Neville Hewitt weir, consistent with groundwater recharge associated with channel flow.
3. GDE Area 10, which presents as a flood overflow channel on the upper alluvial terrace of the Dawson River flood plain. The overflow channel is proximal to and flows parallel to the Dawson River (Neville Hewitt Weir inundation area). The high LWP values are attributed to a sandy soil horizon, with low matric potential and inferred seasonal saturation, that was intersected during auger profiling. Groundwater dependence is confirmed by overlap of stable isotope signatures extracted from twigs with the isotopic composition of groundwater samples.

All sites assessed as GDEs are attributed to sandy intervals in the soil profile which, in the case of GDE Area 1 and GDE Area 10, would be recharged during overbank flow events where overflow channels distribute floodwaters across the flood plain. The period of saturation in the sandy intervals would be seasonal, dependent on the period between flood events and climatic regimes which influence transpiration rates. For these GDE Areas, it is also likely that the sandy horizon is perched above, and hydraulically disconnected from the regional alluvial aquifer. For GDE Area 6, saturation of the sandy profile would more likely be permanent or near permanent due to direct recharge via with surface water held in the stream channel.

For all these assessment areas, it is noted that adjacent assessment areas (GDE Area 2, 3, 4, 5, 7, 8, 9, 11 and 12 which includes assessment localities adjacent to the river channel as well as those occurring on higher alluvial terraces) do not demonstrate any indication of groundwater dependency. This is particularly notable in GDE Area 10 where three adjacent sites (GDE Area 11, GDE Area 12 and GDE Area 9 to a lesser extent as per **Figure 18**) all demonstrate LWP results indicative of relative water deficit suggesting moisture utilisation from hydraulically tight clays in the vadose zone, despite some of these sites being directly adjacent to the river channel (GDE Area 9 and 11). From this evidence it can be concluded that:

1. Groundwater dependency of vegetation across the floodplain is linked to the hydraulic capacity of substrates in the deeper soil profile with sandy lenses / interbeds hosting groundwater on a seasonal basis. Where these sandy lenses interact with mature flood plain vegetation, seasonal groundwater dependence is implied.
2. The sandy interbeds in the soil profile have a restricted and discontinuous distribution beneath the flood plain surface and there is no evidence of hydraulic connectivity between sandy lenses.
3. Riparian vegetation that occupies major riverine channels does not necessary imply groundwater dependence and there are extensive areas, both within and fringing the channels of Dawson River and Banana Creek, that are reliant on soil moisture held by clays in the vadose zone alone (e.g., GDE Area 5, GDE Area 7, GDE Area 8, GDE Area 9 and GDE Area 11).

The potential occurrence of these localised perched groundwater systems is referenced in Section 8.7.3 of HydroSimulations (2021), consistent with the findings of SLR (2019) and WaterShed HydroGeo (2023) who have concluded that:

"… the alluvium is made up of a series of sand/gravel lenses that are limited in both horizontal and vertical extent and separated from other lenses by significantly less permeable clays".

It is not possible to infer the exact extent and location of these discontinuous sandy lenses based on the spatial scale of sampling undertaken during this assessment. Importantly however, it can be inferred that they are discontinuous and not extensive. The inferred distribution of vegetation that is likely to be reliant on seasonal groundwater resources held in sandy lenses, as identified during field sampling, is shown in **Figure 35.** This significantly reduces the mapped extent of potentially groundwater dependent vegetation represented by BOM (2020). The area of potentially groundwater dependent vegetation excludes the HES wetland based on information gathered during this assessment.

A conceptual model of the Dawson River flood plain which illustrates the ecohydrological function of vegetation in relation to sandy lenses, seasonal bank and aquifer recharge during post-wet season, wet season, and dry season flow scenarios on Boomerang Creek is shown in the GDE impact conceptualisation (Section **Figure 37, Figure 38** and **Figure 39**) with the location of the cross section shown in **Figure 35**.

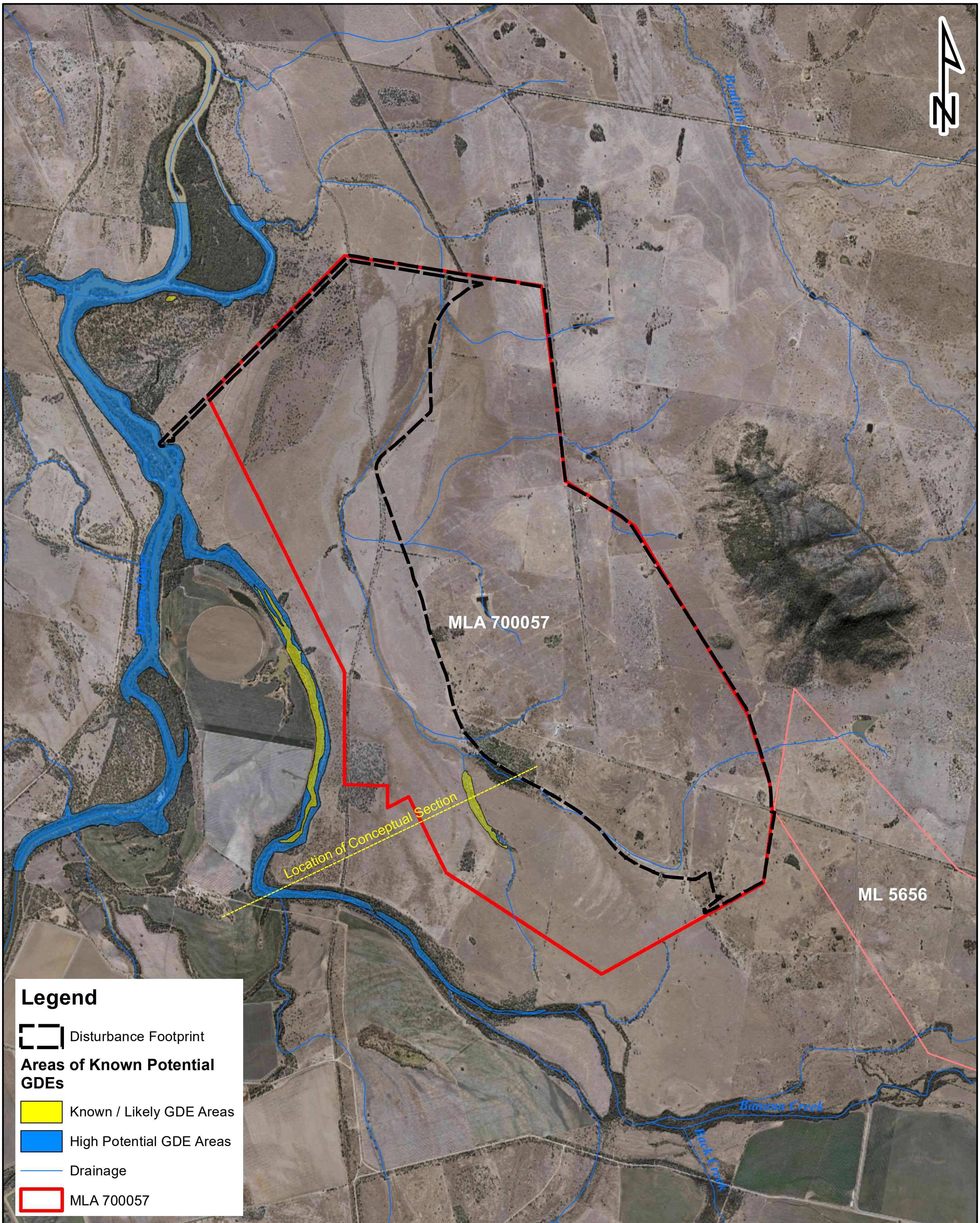

Figure 35. Location of known and high potential groundwater dependent vegetation based on evidence from field assessment.

Client
Mt Ramsay Coal Company

0 0.8 1.6 2.4 3.2
Kilometers

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

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6.0 Assessment of Impacts to GDEs

Section 6.1 provides a summary of the conceptual understanding of the Dawson River flood plain and its capacity to support GDEs. Potential impact mechanisms and their relevance to GDEs within the assessment area, discussed in **Section 6.2**. Potential measures for impact mitigation and management are provided in **Section 6.4** and a risk assessment has been undertaken in **Section 6.5** consistent with the approach identified in the IESC summary guide – assessing groundwater dependent ecosystems (IESC 2018c).

6.1 Summary of Findings Relevant to Impact Assessment

The assessment of impacts to GDEs is based on the findings of the extent and distribution of GDEs identified in this report, and groundwater impact assessment reports completed by SLR (2019) and Watershed HydroGeo (2023). In summary:

1. The Dawson River is deeply incised into a broad flood plain that is predominantly formed by clay and sandy clay, although discontinuous lenses of sand may occur throughout the clay.
2. An aquifer occurs at the base of the flood plain alluvium which is generally saline (>30,000 µS/cm), freshening closer to the major drainage channels due to the influence of bank recharge during flooding. The depth of the alluvial aquifer is typically >12 mbgl, shallowing to approximately 8 mbgl closer to the river channel.
3. The potentiometric surface of the aquifer associated with the Baralaba coal measures is at similar levels to that of the alluvial aquifer, though the coal seams sub-crop over a restricted area and there is negligible (or no) vertical leakage and limited connectivity between the coal measures and the alluvium.
4. Due to the depth and salinity of the alluvial aquifer across the broader flood plain, coupled with the heavy clay soils that pose an impediment to deep tap root penetration, it is considered unlikely that the coolibah woodlands which dominate remnant vegetation on the floodplain have capacity to utilise the regional alluvial aquifer. This includes coolibah woodlands on the upper alluvial terraces extending across the HES wetland.
5. Discontinuous sand lenses hosted within the clay alluvium provide a greater capacity for water storage than the dominant clay, and these lenses may provide a seasonal source of groundwater utilised by coolibah, that is recharged during seasonal flood events. These sandy lenses are conceptualised as being perched above and disconnected from the regional alluvial aquifer with no, or limited hydraulic connectivity between lenses. It is not possible to accurately map the extent of these sandy lenses due to the necessary point specific nature of the field assessment. It is however possible to discount their occurrence in areas where GDE sampling is undertaken, and from the field assessment, these sandy lenses are inferred to be restricted spatially and discontinuous.
6. Sandy lenses appear to be restricted to localities directly below the river channel, or where overflow flood channels traverse the floodplain creating flood depressions. It is important to note that not all areas associated with the flood channels of either the Dawson River, or Banana Creek are considered groundwater dependent.
7. Sandy intervals that may be associated with the soil profile below major river channels are likely to be permanently saturated due to hydraulic connectivity with surface flows, and

these also provide a source of moisture for groundwater dependent species including river red gum which occupy inner benches on major drainage channels. Like the sandy lenses that are conceptualised as having a localised occurrence beneath the flood plain, there is no evidence that sandy intervals below the drainage channel have any extensive medial or lateral continuity.

6.2 Potential Impacts to GDEs

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

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

These potential changes can result in:

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

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

6.2.1 Direct clearing

No direct clearing of field verified GDE areas will occur during any stage of project development.

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

The predicted extent and magnitude of groundwater drawdown associated with development of the mining void is shown in **Figure 36**. The model results from Watershed HydroGeo (2023) show the predicted maximum extent of Project-related drawdown in alluvium and colluvium. Both these units host a saline basal groundwater unit, as well as shallower discontinuous perched groundwater lenses in the alluvium. The drawdown area extends beneath the channel of Banana Creek, where ‘known and likely GDEs’ occur (although these mapped by BOM as having ‘low potential for groundwater dependence). However, there is no interaction with potential GDE areas mapped in association with the Dawson River channel.

Drawdown will interact with the saline basal colluvial groundwater system with depressurisation and drainage of the system toward the mining void. There may also be some increased leakage from Banana Creek to the underlying sediments, which Watershed HydroGeo (2023) considers negligible due to a conservative model stimulation based on a fixed head / consistent source of water, noting that Banana Creek flows only irregularly, as discussed in the flood modelling report (Engeny, 2023).

Groundwater drawdown will only be propagated beneath Banana Creek during periods when the alluvium (or colluvium, as it is mapped by the Qld government geology mapping) is saturated and would only induce leakage of surface flow from this watercourse when the watercourse is flowing, and a saturated connection exists between the alluvial groundwater table and surface water in the creek. In this instance, the impact of drawdown and the induced leakage would likely be negligible in comparison to the rate of groundwater recharge. There will be no interaction between the perched discontinuous sandy lenses which seasonally support vegetation groundwater dependence and the drawdown in the deeper colluvial groundwater unit due to the physical separation of these units, and the lack of hydraulic connection.

Ecohydrological conceptualisations are provided in **Figure 37** (post wet season), **Figure 38** (wet season / flooding) and **Figure 39** (dry season) based on the detail provided in **Section 5.2**. The conceptualisations show the subtle nature of drawdown in the alluvial groundwater table through drainage into the mining void, and lack of any interaction with the discontinuous sandy lenses in the alluvium which seasonally host perched groundwater. The conceptualisations illustrate the lack of any causal pathway for impact to GDEs which rely upon seasonal replenishment of perched groundwater hosted in sandy lenses, which are disconnected from the regional alluvial groundwater table.

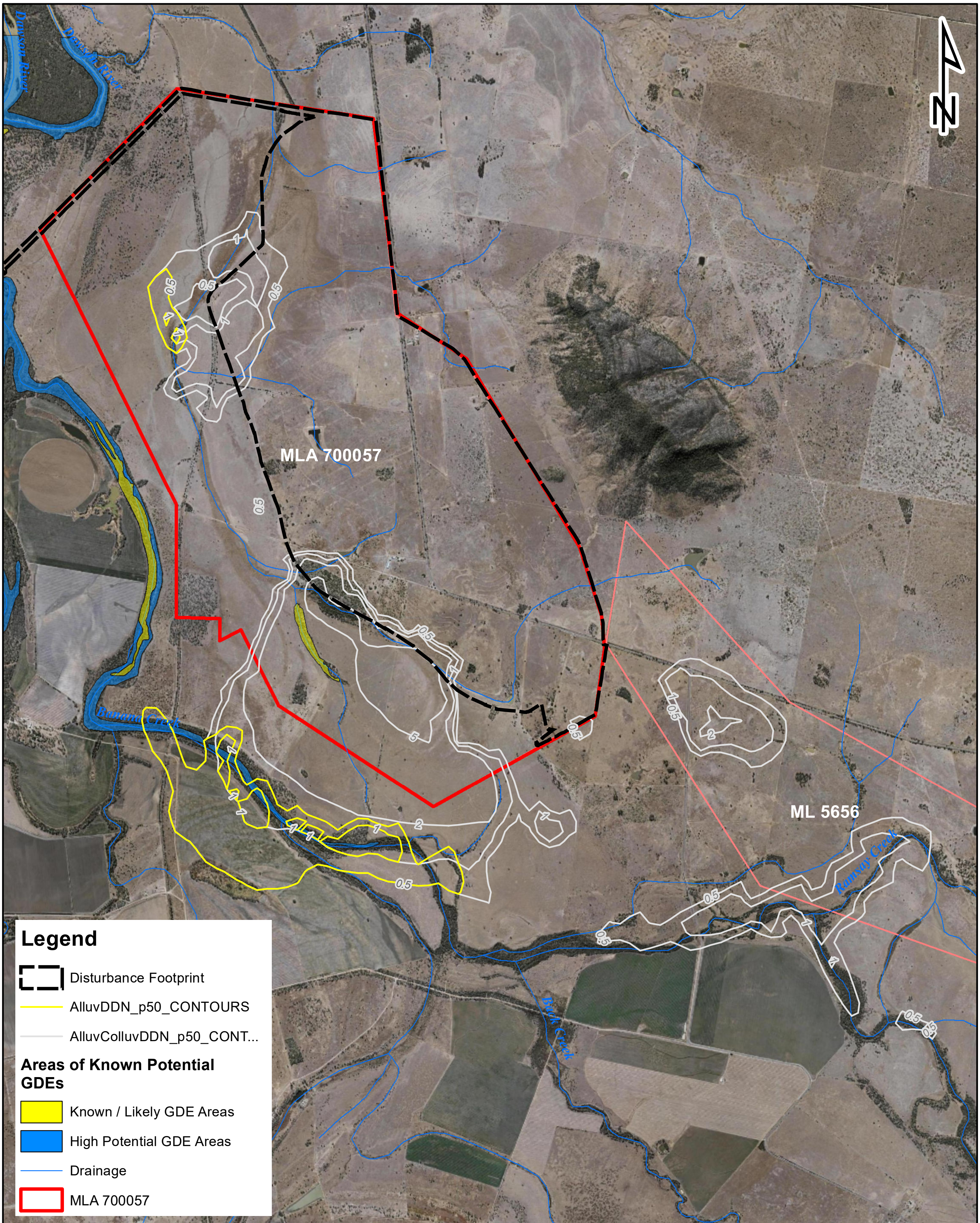

Figure 36. Location of GDE areas relative to predicted groundwater drawdown in alluvium and colluvium (from Watershed GeoHydro 2023).

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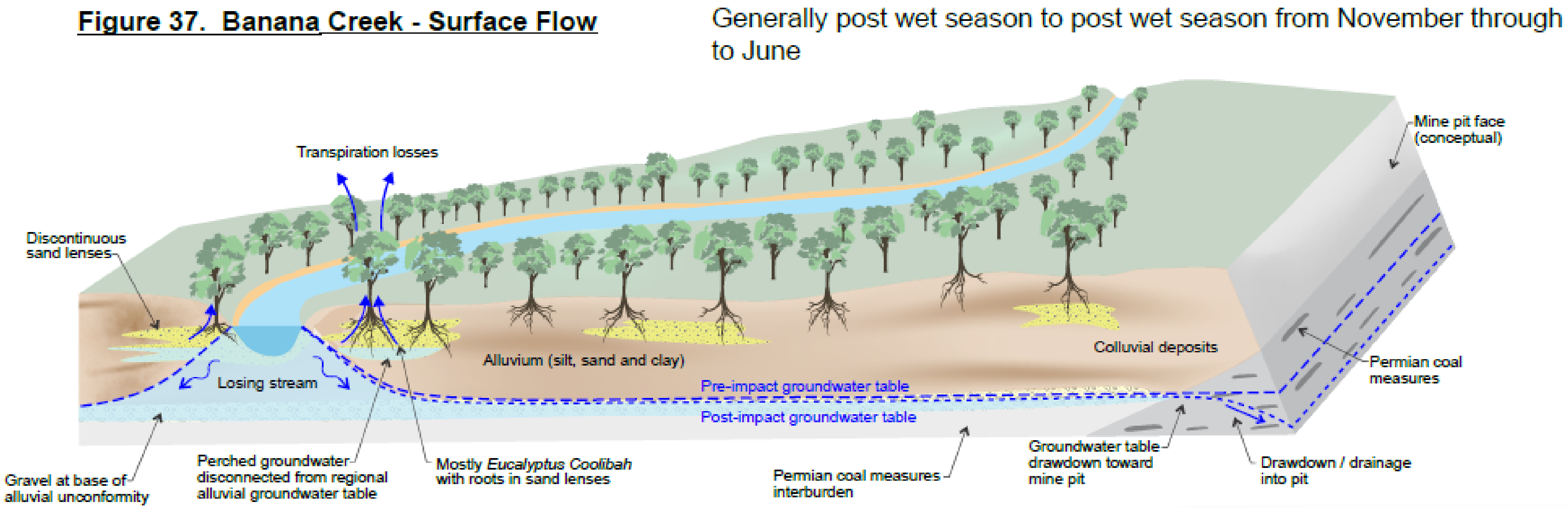

Figure 37. Conceptual model of the Dawson River flood plain at its confluence with Banana Creek, illustrating inferred distribution of sandy lenses within the clay alluvium in a post wet-season flow scenario, showing minor drawdown in the alluvial groundwater table, and discontinuous nature of the hydraulically disconnected sandy lenses in the alluvium. The cross-section location is shown in **Figure 35** indicating its position on Banana Creek, within the area of predicted groundwater drawdown.

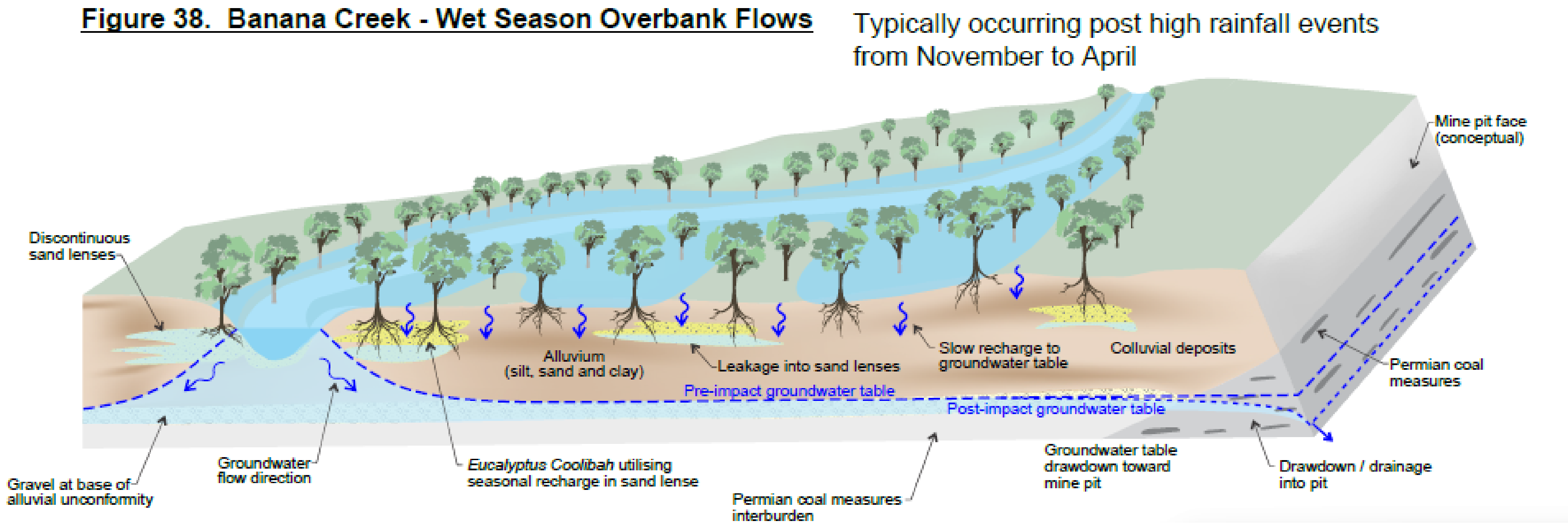

Figure 38. Conceptual model of the Dawson River flood plain at the confluence of Banana Creek during flooding / overbank flow illustrating the inferred recharge of sandy lenses in the alluvium through infiltration of flood water and surface flow. The model illustrates pre and post impact position of the groundwater table, noting only minor drawdown of the groundwater table near the mining pit face.

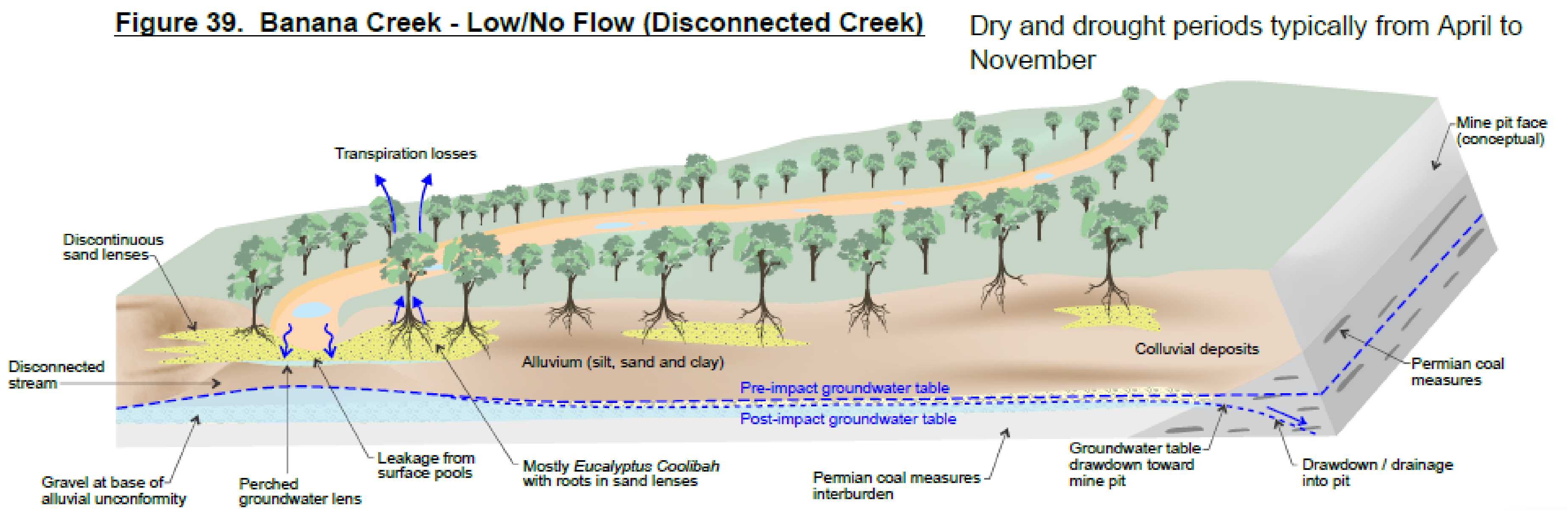

Figure 39. Conceptual model of the Dawson River flood plain at the confluence of Banana Creek in the late dry season (no flow) showing disconnect between the alluvial groundwater table and surface water bodies. Minor leakage from residual surface water pools into the groundwater table is occurring through unsaturated processes. The position of the pre-impact and pos-impact groundwater table in the alluvium is shown showing the subtle impact of groundwater drawdown.

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

Volume fluctuations in both the regional alluvial aquifer and perched aquifers associated with sandy lenses are regulated by surface flows rather than upward propagation of groundwater from the coal seams. The interaction between surface flows and the perched groundwater system is elaborated further in **Section 6.2.4**.

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

The Neville Hewitt Weir has artificially raised surface water levels both in the Dawson River channel as well as attenuating the impoundment upstream along Banana Creek. This has most likely influenced the capacity of the Dawson River to recharge the alluvial groundwater system, providing sustained bank recharge rather than recharge on a seasonal basis. In this regard, potential GDEs that are associated with the Dawson River channel, in areas fringing the weir inundation area exist in a modified hydro-ecological environment. The flood impact assessment report prepared by Engeny (2023b) indicates:

1. There is negligible change to peak flow rates at the Beckers gauging station downstream of the Project for all flood events up to the 1% AEP event, and there is no change in the flood peak travel time from the Bindaree (130374A) gauging station to the Beckers (130322A) gauging station for all flood events up to the 1% AEP event.
2. In summary, the changes in flow velocity up to and including the 1% AEP event are predicted to be within 0.1 m/s to 0.3 m/s adjacent to the northern out-of-pit dump and will be contained within the MLA boundary. There are negligible changes to peak flood velocity outside of the Project's MLA boundary.
3. Inundation duration is unchanged for flood events up to and including the 1% AEP.

Negligible change to surface flows in the Dawson River and Banana Creek are predicted in the project surface water modelling (Engeny 2023b) and It is highly unlikely that changes to flood behaviour will be detrimental to the health of GDEs occurring on frontages of either Dawson River or Banana Creek and their associated floodplain.

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

The potential for impact to the groundwater quality is discussed in detail by Watershed Hydrogeo (2023). The disconnected sandy lenses which support GDEs on a seasonal basis are underlain by partially confined groundwater systems associated with the regional alluvial aquifer and the Permian sediments / coal measures. The potential for saline water from these groundwater units to contaminate any fresh perched groundwater system is negligible as there is no risk of upward propagation of saline groundwater under hydrostatic pressure (Watershed HydroGeo 2023).

The Project would use waters that drain into the open cut pit where they are pumped into holding dams where it would be incorporated into the mine water balance. Changes to water quality, either in Permo-Triassic strata subject to groundwater drawdown impacts or the hosted within younger colluvium and alluvium groundwater units, are not predicted. The hydraulic sink formed by the mining pit will minimise the migration of saline groundwater from within the mining pit toward sensitive ecosystems including GDEs fringing Banana Creek and the Dawson River. Consequently, there would be negligible impacts on surface water quality in downstream waters due to interaction with groundwater (Watershed HydroGeo, 2023).

Rock spoil is expected to be non-acid forming (NAF) and have a negligible risk of developing acidic conditions (Terrenus Earth Sciences, 2023). The spoil is also expected to generate low salinity rainfall runoff and seepage which will be captured by sediment dams. Uncontrolled release of seepage is not expected to occur from site and recovered seepage flows will be managed in accordance with a mine Water Management Plan (WMP). It is not expected that seepage from waste rock dumps will cause any additional impacts to water quality in the receiving waterway (Engeny 2023a).

Based on the low salinity of runoff and seepage, and the management of mine affected water storages and sediment dams under the mine WMP, it is considered that there is low risk of impact to the water quality of alluvial aquifers which support GDEs.

6.3 Cumulative Impacts

In relation to overlapping groundwater drawdown, Watershed HydroGeo (2023) conclude that there is unlikely to be any interaction between the Project and the Baralaba North Mine (except at depth, within the coal measures), or any other mining tenure in the vicinity and thus the predicted (water table) groundwater drawdown impacts would be equivalent to those modelled for the Project alone. Hence at a cumulative level, any potential drawdown impacts on GDEs would not propagate beyond the drawdown contours presented in **Figure 36**.

6.4 Mitigation, Management and Monitoring Measures

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

1. The lack of any significant utilisation of groundwater held in aquifers associated with the Permian coal seams or the regional alluvial aquifer.
2. The localised and discontinuous sand lenses that support GDE Areas are not hydraulically connected either between individual sandy lenses, or with the regional alluvial groundwater table.

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

6.4.1 General operational measures

Under a Project Environmental Authority, a mine Water Management System (WMS) will be operational during all stages of mine development, with the primary objective of minimising environmental harm. Implementation of the WMS and associated Erosion and Sediment Control Plan (ESCP) and Receiving Environment Monitoring Program (REMP) will be directly applicable to management of potential impacts to GDEs that occur in within the influence of mining operations. Specifics of each management plan are detailed below.

WMS: If approved, a mine Water Management System (WMS) should be developed for the Project integrating water management procedures for surface water including mine affected water (MAW), and groundwater. Specific objectives under a WMS that are relevant to the management of impact to GDEs will be to:

- Minimise capture of clean surface water from external catchments via catchment diversion.
- Maximise recycle and reuse of first mine affected water, then sediment runoff, for site demands including processing and dust suppression.
- Preferential supply of water demands from site water storages over external raw water supply and surface water harvesting.
- Minimise and manage controlled releases of water to receiving waterways, with a single release point is proposed for the Dawson River.
- Prevent uncontrolled release of mine affected water to receiving waterways in 95% of years.

ESCP: Sediment water containment (runoff from spoil and Project disturbance areas) will be managed in accordance with a site ESCP which will be define a number of sediment control requirements for the site which will be maintained through all stages of the mine development (Engeny 2023a) . These are:

- Limiting disturbance to prevent sediment runoff generation.
- Erosion control measures such as revegetation and rehabilitation, aimed to prevent soil erosion from disturbed areas.
- Documenting soil types and disturbed catchment areas on the site and their potential for sediment generation.
- Design and management of drainage control measures to prevent erosion from concentrated flows and manage the flow of both clean water and sediment runoff.
- Erosion and sediment control requirements associated with temporary disturbance and construction activities.
- Design and management of sediment dams including dewatering and desilting requirements and the use of suitable construction materials.
- Water quality testing of sediment dams to assess their performance and inform continual improvements of the erosion and sediment control system.

Application of the ESCP will ensure sediment runoff from the MIA and spoil is managed within the WMS, limiting potential for uncontrolled release into the environment.

REMP: The REMP will be developed to monitor, identify and describe any impacts to the environmental values, water quality and flows within the receiving environment (Engeny 2023a). 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. Implementation of the REMP will have capacity to identify any impacts to water quality in the receiving environment of the Dawson River, which may have detrimental impact to GDE function.

6.4.2 Groundwater monitoring

The groundwater monitoring program is described in Watershed HydroGeo (2023) which is summarised in the following section. The comprehensive groundwater monitoring network, that was developed in 2012, comprising fifteen (15) standpipe groundwater monitoring bores and three (3) standpipe production bores, will be maintained for the duration of the Project. The primary purpose of the groundwater monitoring network will be to enable the natural groundwater fluctuations to be detected and distinguished from groundwater level impacts caused by depressurisation of aquifers caused by the proposed mining activities. Specific details of the groundwater monitoring program taken from Watershed HydroGeo (2023) include:

- Maintenance of the existing groundwater monitoring network at the BSP with regular reviews to detect changes in groundwater levels and quality because of mining and improve knowledge of aquifer definition and interactions.
- installation of three proposed shallow alluvial holes to improve coverage of monitoring for the Project design, with:
  - one near the HES wetland (despite its likely 'perched' nature);
  - one to the south or south-east of the BSP site near to Banana Creek (i.e. along the strike of the coal measures); and
  - an alluvium site near P-OB1.
- water level and flow monitoring be conducted at the private landholder bore (i.e. Ross bore) if access is permissible by the landholder. Potential drawdown effects are predicted at this bore, this will provide early indication of any changes to predictions as well as identification of influence of local bore usage on groundwater trends.
- derivation and progressive development of groundwater level and quality triggers for the BSP, and inclusion in the Environmental Authority.
- Groundwater quality monitoring continue to be undertaken on a quarterly basis which will include manual measurement of water levels and download of logger level data, as well as representative sampling and field analysis applied to the pH and EC which are of specific relevance to GDE health:
- Monitoring and estimation of groundwater inflow to the developing pit through annual review of pit dewatering/pumping records and site water balance model, catchment (rainfall runoff), coal moisture and evaporation considerations to partition groundwater inflow/seepage rates.

6.4.3 GDE Baseline Data Collection and Monitoring

Consistent with the intent of the groundwater monitoring program, it is recommended that additional baseline data be collected to further characterise the seasonal ecohydrological function and baseline condition of GDEs on Banana Creek, that may be subject to impact related to groundwater drawdown, particularly where the drawdown footprint intersects mapped GDEs. The baseline data collection would form a component of a project Groundwater Dependent Ecosystem Monitoring and Management Plan (GDEMMP) that would provide protocols for collection of baseline ecological data and monitoring parameters that are useful to measure changes to GDE health. Measured parameters should include:

1. Measures of Leaf Area Index (LAI)
2. Pre-dawn Leaf water potential (LWP)
3. Remotely sensed data suitable for monitoring of vegetation health including NDVI.

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

6.5 Risk Assessment

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

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

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

Although there is no direct causal pathway identified that may result in impact to GDEs in the vicinity of the Project, ongoing monitoring of groundwater levels and quality and surface water quality, as described in **Section 6.4** will provide a management measure that is sufficiently robust to underpin detection of potential changes to GDE function that may be attributed to mine related groundwater drawdown or contamination.

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

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

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

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

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

Table 6. Matrix applied in the risk assessment.

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

Table 7. List of relevant mitigations and management actions.

Mitigation No	Mitigations	Management Actions
1	GDE Avoidance	-
2	Biodiversity Offsets	-
3	-	Water Management System
4	-	Erosion and Sediment Control Plan
5	-	Groundwater monitoring
6	-	Groundwater Dependent Ecosystem Monitoring and Management Plan

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

Impact Pathway*	Pre-mitigated Risk			**Comments**	Mitigation and Management Measures	Residual Risk Ranking		
	Likelihood	Consequence	Risk			Likelihood	Consequence	Risk
1. Direct clearing of a GDE	5	Severe	Low	No clearing of GDEs will be undertaken in association with any stage of project development	1	1	Severe	Insignificant
2. A total or partial loss or reduction in the volume or pressure of the aquifer being utilised by GDEs.	2	Negligible	Insignificant	The sandy lenses that support GDEs on a seasonal basis are not hydraulicly connected between lenses and not connected to the regional alluvial aquifer or the aquifer supported by the Permian sediments / coal seams.	5, 6	1	Negligible	Insignificant
3. A change in the magnitude and timing of volume fluctuations in the aquifer being utilised by GDEs[1].	2	Negligible	Insignificant	Volume fluctuations in the perched groundwater system are regulated by surface flows and local surface water infiltration. These processes will not be impacted during mine development. While minoring drawdown is modelled within the alluvium underlying Banana Creek, this drawdown will only be propagated during periods where there is a hydraulic connection between surface flows and groundwater. In this instance, the impact of drawdown and the induced leakage would likely be negligible in comparison to the rate of groundwater recharge.	5, 6	1	Negligible	Insignificant

Impact Pathway*	Pre-mitigated Risk			**Comments**	Mitigation and Management Measures	Residual Risk Ranking		
	Likelihood	Consequence	Risk			Likelihood	Consequence	Risk
4. Changes to the interaction between surface flows and aquifers being utilised by a GDE.	2	Low	Low	No significant changes to surface flows on either Banana Creek or the Dawson River are predicted throughout the life of the mining operation.	3, 4, 5, 6	1	Low	Insignificant
5. Change in chemical composition of an aquifer detrimentally impacting the health of a GDE[1].	2	Low	Low	Uncontrolled releases of mine water that has potential to impact the chemical composition of infiltrating surface waters will not occur during the life of the mine.	3, 4, 5, 6	1	Low	Insignificant

1. Assumes freshwater aquifers / groundwater with EC<1500 µS/cm. Withdrawal of saline aquifers / groundwater may have a positive impact on vegetation / habitat condition of a GDE

7.0 Conclusions

Multiple lines of evidence including measurement of LWP, SMP, stable isotopes and physical observation have been applied to assess the dependence of vegetation in Baralaba South Project area on groundwater. Based on the results of the field survey, it is concluded that groundwater dependence within MLA 700057 and adjacent areas associated with the Dawson River flood plain is controlled by small discontinuous lenses of sand that are distributed sporadically throughout the heavy clay soils that otherwise characterise the flood plain sediments. GDEs identified, including GDE Area 1, GDE Area 6 and GDE Area 9 are all associated with overland flow paths on the floodplain or the main Dawson River channel, which would act to increase infiltration into the soil profile due to prolonged ponding of surface water. The sandy lenses support shallow, fresh and seasonal groundwater resources that are perched above and disconnected from the regional groundwater table. Water held in the regional alluvial aquifer is mostly an unsuitable resource to support GDEs due to high levels salinity, except where they occur directly adjacent to a stream channel and bank recharge where fresh surface water can occur. Recharge of the sandy lenses occurs during surface water infiltration, which is associated with overbank flow and intense rainfall events, and seasonality will depend on climatic factors including transpiration rates and flood interval. GDEs will occur wherever floodplain vegetation utilises water held within the sandy lenses as either a seasonal or permanent groundwater source. While it is not possible to precisely define the extent of groundwater dependent vegetation due to the sporadic nature of the sandy lenses, this assessment indicates that that they are discrete, restricted in extent, generally discontinuous and more likely to coincide with overland flow paths and flood channels. Areas confirmed not to represent a GDE include the HES wetland, the boundary of which partially overlaps with MLA 700057, and the predominant extent of coolibah woodland that occupies upper terraces of the Dawson River flood plain.

Groundwater modelling completed by Watershed HydroGeo (2023), drawing on data from prior modelling completed by SLR (2019) indicates Groundwater drawdown associated with mining void development is not predicted to impact the ecological function of GDEs outside the MLA, which utilise and rely upon the perched seasonal groundwater resources.

Drawdown will interact with the saline basal colluvial groundwater system with depressurisation and drainage of the system toward the mining void with some possible increased leakage from Banana Creek to the underlying sediments, which is considered negligible. Groundwater drawdown will only be propagated beneath Banana Creek during periods when the alluvium is saturated and would only induce leakage of surface water when the watercourse is flowing, and a saturated connection exists between the alluvial groundwater table and surface water in the creek. In this instance, the impact of drawdown and the induced leakage would likely be negligible in comparison to the rate of groundwater recharge. There will be no interaction between the perched discontinuous sandy lenses which seasonally support vegetation groundwater dependence and the drawdown in the deeper alluvial / colluvial groundwater system due to the physical separation of these units, and the lack of hydraulic connection. Because of these factors, there are no identified causal pathways for impact which have capacity to alter GDE function and cause ecological harm.

Management measures to limit impact to potential GDEs in vicinity of the Project assessment area include general operational measures such the development and implementation of a WMS, ESCP and REMP. Specific measures to monitor GDE health in areas of predicted groundwater drawdown will also be required to validate the GDE impact assessment and increase confidence in the ecohydrological conceptual models developed within this impact assessment report. This should encompass the development of a Project GDEMMP, which should be maintained for a period that is sufficient to confirm GDE function and provide increased certainty to the outcomes of this assessment, nominally over a baseline assessment period of two-years. Ongoing measures to detect any changes to GDE health may be required based on the baseline assessment outcomes. With implementation of management measures, consistent with project approval conditions, it is considered that the risk to GDE's posed by mine development is insignificant.

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Appendices

Appendix A – Tree LWP Measurements and Details

Site No	Tree No	X	Y	Species	DBH cm	Height m	Geomorphic position	LWP1 Mpa	LWP2 Mpa	LWP3 Mpa	Average two lowest	Water Availability
GDE3	T1	-24.2804	149.8621	Acacia harpophylla	40	12	Swampy drainage channel. Small terrace on loamy soil above wet, heavy clay overflow	-2.7	-2.8	-	-2.75	Extremely Low
GDE3	T2	-24.2803	149.8620	Melaleuca bracteata	20	8	Overflow drainage depression. Swampy clay soils	-4.5	-4.5	-	-4.5	Extremely Low
GDE3	T3	-24.2804	149.8621	Melaleuca bracteata	25	12	Overflow drainage depression. Swampy clay soils	-1.5	-1.7	-	-1.6	Low
GDE3	T4	-24.2802	149.8624	Eucalyptus coolabah	30	15	Overflow drainage depression. Swampy clay soils. Small terrace raised about 30cm above swampy plain	-1.6	-1.7	-	-1.65	Low
GDE3	T5	-24.2799	149.8623	Eucalyptus coolabah	49	22	Lower colluvial slopes on margins of swampy drainage depression	-1.45	-1.45	-	-1.45	Low
GDE2	T1	-24.2881	149.8594	Eucalyptus coolabah	40	18	Broad drainage depression on heavy clay loam soils	-2.3	-2.3	-1.9	-1.8	Very Low
GDE2	T2	-24.2883	149.8591	Eucalyptus coolabah	45	20	Broad drainage depression on heavy clay loam soils	-2	-1.9		-1.95	Very Low
GDE2	T3	-24.2885	149.8592	Eucalyptus populnea	40	20	Broad drainage depression on heavy clay loam soils	-1.5	-1.5		-1.5	Low
GDE2	T4	-24.2880	149.8596	Eucalyptus coolabah	50	24	Broad drainage depression on heavy clay loam soils	-1.3	-1.75	-1.5	-1.4	Low
GDE1	T1	-24.2846	149.8603	Eucalyptus coolabah	60	21	Broad linear drainage depression on heavy clay loams soils	-0.8	-0.7		-0.75	High
GDE1	T2	-24.2842	149.8599	Eucalyptus coolabah	130	21	Broad linear drainage depression on heavy clay loams soils	-0.55	-0.55		-0.55	High
GDE1	T3	-24.2840	149.8598	Eucalyptus coolabah	55	20	Broad linear drainage depression on heavy clay loams soils. Inner portion of depression	-0.7	-0.6		-0.65	High
GDE1	T4	-24.2839	149.8598	Eucalyptus coolabah	60	20	Broad linear drainage depression on heavy clay loams soils	-0.9	-0.8		-0.85	High
GDE4	T1	-24.2820	149.8475	Eucalyptus coolabah	40	18	Alluvial flood plain with loamy clay soils. Elevated 10m above channel and >100 from upper bank.	-1.9	-2.2		-2.075	Very Low
GDE4	T2	-24.2818	149.8477	Eucalyptus coolabah	48	16	Broad flood plain / drainage depression. Tree 25m from weakly incised drainage channel	-1.9	-1.9		-1.9	Very Low
GDE4	T3	-24.2813	149.8480	Eucalyptus coolabah	45	18	Broad flood plain / drainage depression. Tree 25m from weakly incised drainage channel	-1.9	-1.9		-1.9	Very Low
GDE4	T4	-24.2812	149.8478	Eucalyptus coolabah	55	22	Broad flood plain / drainage depression. Tree 25m from weakly incised drainage channel	-1.2	-1.2		-1.2	Moderate

Site No	Tree No	X	Y	Species	DBH cm	Height m	Geomorphic position	LWP1 Mpa	LWP2 Mpa	LWP3 Mpa	Average two lowest	Water Availability
GDE5	T1	-24.2663	149.8399	Eucalyptus camaldulensis	90	23	5m from margins of the flood channel on lower terrace. Adjacent to zone of permanent innundation.	-1.6	-1.6		-1.6	Low
GDE5	T2	-24.2663	149.8400	Eucalyptus coolabah	120	25	20m from margins of flood channel on gently sloping mid-terrace. 5m above permanently wet channel	-0.7	-0.95		-0.825	High
GDE5	T4	-24.2666	149.8401	Eucalyptus coolabah	80	23	20m from margins of flood channel on gently sloping mid-terrace. 5m above permanently wet channel	-1.2	-1.05		-1.125	Moderate
GDE5	T5	-24.2668	149.8404	Eucalyptus coolabah	160	30	25m from margins of flood channel on gently sloping mid-terrace. 7.5m above permanently wet channel	-1.1	-1.1		-1.2	Moderate
GDE6	T2	-24.2804	149.8444	Eucalyptus camaldulensis	120	23	5m from overflow channel of creek. Lower flood terrace.	-0.45	-0.35		-0.4	Very High
GDE6	T3	-24.2804	149.8444	Eucalyptus camaldulensis	160	35	Adjacent to overflow channel of creek. Lower flood terrace	-0.3	-0.3		-0.3	Very High
GDE6	T4	-24.2803	149.8441	Eucalyptus camaldulensis	180	35	Adjacent to overflow channel of creek. Lower flood terrace	-0.25	-0.2		-0.225	Very High
GDE6	T5	-24.2805	149.8447	Eucalyptus camaldulensis	150	23	Inner bench 2m above channel floor between overflow and main creek channel	-0.5	-0.4		-0.45	Very High
GDE7	T1	-24.2924	149.8496	Eucalyptus coolabah	110	23	Lower flood plain, on shallow overflow depression 80m from main channel.	-0.85	-0.87		-0.86	High
GDE7	T2	-24.2926	149.8496	Eucalyptus coolabah	120	23	Lower flood plain, 40m from main channel, 2m above channel floor	-1.3	-1.4		-1.35	Low
GDE7	T3	-24.2926	149.8492	Eucalyptus coolabah	110	26	Lower flood plain, 20m from main channel, 2m above channel floor	-1.8	-1.85		-1.825	Very Low
GDE7	T4	-24.2928	149.8493	Eucalyptus camaldulensis	110	28	On channel bank, 2m above flood channel.	-1.1	-1.1		-1.1	Moderate
GDE7	T5	-24.2930	149.8498	Eucalyptus camaldulensis	120	23	5m from channel bank, 2m above flood channel.	-1.4	-1.5		-1.45	Low
GDE8	T1	-24.3007	149.8599	Eucalyptus coolabah	130	27	10m from flood channel on lower terrace. 2m above channel floor.	-1.2	-1.15		-1.175	Moderate
GDE8	T2	-24.3006	149.8602	Eucalyptus coolabah	70	23	10m from flood channel, 5m above channel floor on slopeing inner terrace.	-0.5	-0.45		-0.475	Very High
GDE8	T3	-24.3005	149.8602	Eucalyptus coolabah	90	25	Mid way up to top of bank, 10m above channel floor and 20m from flood channel.	-0.95	-0.9		-0.925	Moderate
GDE8	T4	-24.3003	149.8596	Eucalyptus coolabah	100	28	Top of bank, 10m above channel floor and 20m from flood channel	-1.425	-1.425		-1.425	Low
GDE9	T1	-24.2378	149.8272	Eucalyptus camaldulensis	100	26	Lower terrace adjacent to flood channel. On zone of permanent saturation from impoundment	-0.45	-0.4		-0.425	Very High

Site No	Tree No	X	Y	Species	DBH cm	Height m	Geomorphic position	LWP1 Mpa	LWP2 Mpa	LWP3 Mpa	Average two lowest	Water Availability
GDE9	T3	-24.2385	149.8268	Eucalyptus coolabah	100	33	Secondary terrace, 60m from edge of channel and sloping down into shallow overflow channel	-0.8	-0.9		-0.85	High
GDE9	T4	-24.2385	149.8271	Eucalyptus camaldulensis	120	28	On secondary terrace, on the margins of shallow overflow channel.	-0.85	-0.75		-0.8	High
GDE10	T1	-24.2384	149.8279	Eucalyptus coolabah	70	26	Lower terrace, 5m above waterline and 80m from margins of the stream	-0.6	-0.4		-0.5	Very High
GDE10	T2	-24.2384	149.8280	Eucalyptus coolabah	60	23	Lower terrace, 5m above waterline and 80m from margins of the stream	-0.45	-0.5		-0.475	Very High
GDE10	T3	-24.2384	149.8281	Eucalyptus coolabah	60	27	Lower terrace, 5m above waterline and 80m from margins of the stream	-0.45	-0.5		-0.475	Very High
GDE10	T4	-24.2386	149.8288	Eucalyptus coolabah	110	30	In overflow channel, 5m above permanent water level and 100m from waterline	-0.5	-0.65		-0.575	High
GDE10	T5	-24.2383	149.8294	Eucalyptus camaldulensis	190	30	In overflow channel, 5m above permanent water level and 100m from waterline	-1.1	-1.2		-1.15	Moderate
GDE11	T1	-24.2384	149.8326	Eucalyptus coolabah	120	30	Margins of innundation, 3m above dam water edge, inner bank.	-1.4	-1.15		-1.1275	Moderate
GDE11	T2	-24.2382	149.8327	Eucalyptus camaldulensis	120	32	Margins of innundation, 2m above dam water edge, inner bank.	-1.4	-1.3		-1.35	Low
GDE11	T3	-24.2381	149.8324	Eucalyptus coolabah	80	25	30m from edge of water, margins of overflow flood channel	-1.2	-1.3		-1.25	Low
GDE11	T4	-24.2389	149.8329	Eucalyptus coolabah	100	25	120 from edge of water, on river flood plain. Heavy clay soils	-2.7	-2.75		-2.375	Low
GDE12	T1	-24.2414	149.8300	Eucalyptus coolabah	50	23	Broad flood plain on heavy clay soils, away from river channel	-1.8	-1.7		-1.75	Low
GDE12	T2	-24.2419	149.8301	Eucalyptus coolabah	90	25	Broad flood plain on heavy clay soils, away from river channel	-1.3	-1.3		-1.3	Low
GDE12	T3	-24.2418	149.8289	Eucalyptus coolabah	63	24	Broad flood plain on heavy clay soils, away from river channel	-1.6	-1.8		-1.7	Low
GDE12	T4	-24.2412	149.8309	Eucalyptus coolabah	70	25	Broad flood plain on heavy clay soils, away from river channel	-2.3	-2.4		-2.35	Very Low

Appendix B – Auger Hole Logs

Site No	Auger No	X	Y	Lithology	Position	Tree root depth	Depth metres
GDE1	AU1	-24.28421801	149.86001	0 - 0.1, heavy clay, grey brown, dry. Minor rooting material; 0.1 to 0.8, heavy dark clay with minor mottling and ironstone gravel in bands, dry to moist with minor root matter; 0.8 to 1.0, Heavy, dark clay with minor ironstone gravel and mottling; 1.0 - 1.3, Heavy clay, grey brown with root material, with drier interval with grey silty loam; 1.5 - 1.7, Hard silty sand, cemented with clay. Grey to grey brown; 1.7 - 2.5, Light grey, silty clay loam with week mottling. Cemented layers throughout; 2.5 - 3.0, sandy clay, dry to slighly moist with hard layer and week mottling with iron stains; 3.0 - 3.3, heavy grey brown clay, minor tree root matter present; 4.0 - 4.5 - heavy grey brown clay with minor mottling. Tree roots present, fine and evenly dispersed; 4.5 - 4.8 - Heavy clay, grey brown with minor iron staining and mottling. Think woody tree root material to 8mm recorded at 4.5. End of hole (EOH) at 4.8m in heavy clay.	Base of broad drainage depression.	0.1m, abundant fine root material; 1.3m with minor root matter to 25mm; 4.0 with minor fine root material; Thick tree root material recorded at 4.5m.	4.8
GDE6	AU1	-24.28032797	149.844408	0 - 0.2m, dark brown clayey sand, moist with mottling; 0.5 - 1.0, dark brown, slightly moist clayey sand with orange/ brown mottling and some gravel fragments. Minor calcrete; 1.0 - 1.3, Heavy grey brown clay with some mottling. Gravel band at base of hole and minor iron staining and mottling.	Margins of drainage channel on lower terrace.		1.3
GDE6	AU2	-24.28023803	149.844176	Start logging at 1.0m, gravelly clay, dark grey brown with mottling. Tree roots at 1.3m; 1.5 - 2.0m, very hard, dense black clay. Dry to moist; 2.0 - 3.0, dark grey sandy clay with ironstone nodules, gravel and charcoal fragments, moist. Tree root matter at 2.0m; 3.0 to 3.1, moist, sandy clay with gravel and ironstone nodules. EOH at 3.3m where hole encountered gravel bed.	Instream terrace elevated 1.5m above channel floor.	2.0 meters, minor tree root material to 25mm.	3

Site No	Auger No	X	Y	Lithology	Position	Tree root depth	Depth metres
GDE8	AU1	-24.30065601	149.860209	0 - 0.25, Sandy clay, dark brown and fine grained with fine tree roots present; 0.25 - 1.00, heavy dark brown / grey massive clay. Tree roots to 10mm intersected in profile; 1.0 - 1.8, dark grey brown, massive clay with minor mottling and iron staining; 1.8 - 2.6, massive, grey brown clay. Minor iron staining and some calcrete. Dry; 2.6 to 3.3, fine clayey sand, dark grey to brown with minor mottling. Some hardened intervals.	5 meters above channel floor on outer margins of the T1 terrace. 10m from drainage channel.	1.00m with 10mm thick tree roots	3.3
GDE10	AU1	-24.23855701	149.828753	0- 0.2m, moist friable silty / sandy loam, grey brown; 0.2 to 1.0, Dark grey brown, friable clayey / silty loam with some sand. Fine tree root material at 1.0m; 1.0 - 2.0m, friable dark grey, moist and uniform sandy clay; 2.0 - 3.3m, dark grey brown, dry to moist silty clay, minor mottling. Uniform texture throughout; 3.3 - 3.7m, orange brown sandy clay with minor orange mottling. Slightly moist with tree roots recorded at 3.5m; 3.7 - 4.2m, orange brown, well sorted fine clayey sand getting loose toward bottom of interval; 4.2 - 4.8m, loose fine, orange yellow sand, dry, becoming moist toward bottom of hole.	Base of overflow channel 3m from base of GDE10 Tree 4	Fine tree roots to 2.5mm at 1.0m; 10mm tree root at 2.0m; 2.5mm tree roots intersected at 3.0m.	4.8

Appendix C – Soil Moisture Potential Raw Data

Specimen Number	GDE Assessment Area	Type	Date Collected	SMP MPA
AU1-GDE1-0.1	GDE1	Soil	10-Aug-20	-2.05
AU1-GDE1-0.5	GDE1	Soil	10-Aug-20	-1.75
AU1-GDE1-1.0	GDE1	Soil	10-Aug-20	-2.29
AU1-GDE1-1.5	GDE1	Soil	10-Aug-20	-2.96
AU1-GDE1-2.25	GDE1	Soil	10-Aug-20	-2.92
AU1-GDE1-2.5	GDE1	Soil	10-Aug-20	-2.94
AU1-GDE1-3.0	GDE1	Soil	10-Aug-20	-2.29
AU1-GDE1-3.2	GDE1	Soil	10-Aug-20	-2.23
AU1-GDE1-4.5	GDE1	Soil	10-Aug-20	-2.21
AU1-GDE1-4.8	GDE1	Soil	10-Aug-20	-2.98
AU1-GDE10-0.25	GDE10	Soil	10-Aug-20	-0.86
AU1-GDE10-0.6	GDE10	Soil	10-Aug-20	-1.38
AU1-GDE10-1.0	GDE10	Soil	10-Aug-20	-1.48
AU1-GDE10-1.5	GDE10	Soil	10-Aug-20	-2.3
AU1-GDE10-2.0	GDE10	Soil	10-Aug-20	-1.05
AU1-GDE10-2.5	GDE10	Soil	10-Aug-20	-1.42
AU1-GDE10-3.1	GDE10	Soil	10-Aug-20	-2.13
AU1-GDE10-3.5	GDE10	Soil	10-Aug-20	-1.08
AU1-GDE10-3.8	GDE10	Soil	10-Aug-20	-4.54
AU1-GDE10-4.8	GDE10	Soil	10-Aug-20	-0.55
AU1-GDE10-3.6	GDE10	Soil	10-Aug-20	-1.6
AU1-GDE6-0.2	GDE6	Soil	10-Aug-20	-0.67
AU1-GDE6-0.5	GDE6	Soil	10-Aug-20	-1.11
AU1-GDE6-1.0	GDE6	Soil	10-Aug-20	-1.05
AU1-GDE6-1.3	GDE6	Soil	10-Aug-20	-0.83
AU2-GDE6-1.5	GDE6	Soil	10-Aug-20	-1.57
AU2-GDE6-2.0	GDE6	Soil	10-Aug-20	-1.2
AU2-GDE6-3.0	GDE6	Soil	10-Aug-20	-1.49
AU2-GDE6-3.5	GDE6	Soil	10-Aug-20	-2.76
AU1-GDE8-0.1	GDE8	Soil	10-Aug-20	-2.95
AU1-GDE8-0.5	GDE8	Soil	10-Aug-20	-2.8
AU1-GDE8-1.0	GDE8	Soil	10-Aug-20	-1.83
AU1-GDE8-1.5	GDE8	Soil	10-Aug-20	-2
AU1-GDE8-2.0	GDE8	Soil	10-Aug-20	-2.75
AU1-GDE8-2.5	GDE8	Soil	10-Aug-20	-1.72
AU1-GDE8-3.0	GDE8	Soil	10-Aug-20	-1.79
AU1-GDE8-3.5	GDE8	Soil	10-Aug-20	-2.18

Appendix D – Stable Isotope Analytical Results

Sample 2	Site	Material	Depth	$\delta^{2}H$	$\delta^{18}O$
au1-gd3e1-0.5	GDE3	soil	0.5	-11.79	-2.67
au1-gde1-0.5 b	GDE1	soil	0.55	5.98	-2.83
au1-gde10-0.25	GDE10	soil	0.25	-25.24	-5.35
au1-gde10-0.6	GDE10	soil	0.6	-13.88	-3.83
au1-gde10-1.0	GDE10	soil	1.0	-41.85	-8.35
au1-gde10-1.5	GDE10	soil	1.5	-33.13	-5.55
au1-gde10-2.0	GDE10	soil	2.0	-38.82	-9.74
au1-gde10-2.5	GDE10	soil	2.5	-11.32	-4.68
au1-gde10-3.1	GDE10	soil	3.1	-27.98	-5.70
au1-gde10-3.5	GDE10	soil	3.5	-26.34	-7.16
au1-gde10-3.6	GDE10	soil	3.6	-36.58	-8.26
au1-gde10-3.8	GDE10	soil	3.8	-41.59	-6.93
au1-gde10-4.8	GDE10	soil	4.8	-33.34	-6.06
au1-gde1-1.0	GDE1	soil	1.0	-9.54	-3.99
au1-gde1-1.0 a	GDE1	soil	1.1	-17.51	-5.36
au1-gde1-2.25	GDE1	soil	2.25	-8.69	-5.23
au1-gde1-2.5	GDE1	soil	2.5	3.12	-4.07
au1-gde1-3.0	GDE1	soil	3.0	-3.60	-3.08
au1-gde1-4.5	GDE1	soil	4.5	-11.07	-3.22
au1-gde1-4.8	GDE1	soil	4.8	-22.00	-3.66
au1-gde6-0.2	GDE6	soil	0.2	-24.76	-7.58
au1-gde6-0.5	GDE6	soil	0.5	-43.67	-7.37
au1-gde6-1.0	GDE6	soil	1.0	-20.80	-3.73
au1-gde6-1.3	GDE6	soil	1.3	-27.78	-3.71
au1-gde8-0.10	GDE8	soil	0.1	5.52	-1.57
au1-gde8-0.5	GDE8	soil	0.5	-10.16	-4.91
au1-gde8-1.5	GDE8	soil	1.5	-11.78	-5.07
au1-gde8-2.0	GDE8	soil	2.0	-3.40	-5.01
au1-gde8-2.5	GDE8	soil	2.5	-7.37	-4.20
au1-gde8-3.0	GDE8	soil	3.0	-5.58	-3.51
au1-gde8-3.5	GDE8	soil	3.5	2.64	-5.40
au2-gde6-1.5	GDE6	soil	1.5	-37.75	-6.80
au2-gde6-2.0	GDE6	soil	2.0	-14.32	-3.61
au2-gde6-3.0	GDE6	soil	3.0	-26.51	-7.16
au2-gde6-3.5	GDE6	soil	3.5	-21.12	-6.60
au1-gd3e1-0.5	GDE3	soil	0.5	-11.79	-2.67
au1-gde1-0.5 b	GDE1	soil	0.55	5.98	-2.83
au1-gde10-0.25	GDE10	soil	0.25	-25.24	-5.35
bs-gde10-t1	GDE10	twig	NA	-13.37	-3.16
bs-gde10-t3	GDE10	twig	NA	-25.80	-3.84
bs-gde11-t1	GDE11	twig	NA	1.28	-2.41

Sample 2	Site	Material	Depth	$\delta^{2}H$	$\delta^{18}O$
bs-gde11-t3	GDE11	twig	NA	8.64	-1.62
bs-gde1-t1	GDE1	twig	NA	-21.18	-2.80
bs-gde1-t2	GDE1	twig	NA	-20.36	-3.31
bs-gde1-t3	GDE1	twig	NA	-23.49	-3.41
bs-gde2-t2	GDE2	twig	NA	-5.68	-1.46
bs-gde2-t3	GDE2	twig	NA	-31.15	-3.59
bs-gde2-t4	GDE2	twig	NA	-5.50	-2.76
bs-gde3-t2	GDE3	twig	NA	11.85	-1.43
bs-gde3-t3	GDE3	twig	NA	12.04	-2.22
bs-gde4-t1	GDE4	twig	NA	-5.28	-2.66
bs-gde4-t4	GDE4	twig	NA	-5.84	-3.15
bs-gde5-t3	GDE5	twig	NA	0.33	-3.70
bs-gde5-t4	GDE5	twig	NA	-10.21	-2.91
bs-gde6-t2	GDE6	twig	NA	-0.90	-1.43
bs-gde6-t3	GDE6	twig	NA	-11.85	-2.75
bs-gde6-t4	GDE6	twig	NA	-11.39	-2.97
bs-gde6-t5	GDE6	twig	NA	-8.53	-3.91
bs-gde7-t1	GDE7	twig	NA	-7.70	-3.04
bs-gde7-t4	GDE7	twig	NA	-8.34	-3.65
bs-gde8-t2	GDE8	twig	NA	-15.26	-5.53
bs-gde8-t3	GDE8	twig	NA	-14.05	-3.71
bs-gde9-t1	GDE9	twig	NA	-5.96	1.61
bs-gde9-t4	GDE9	twig	NA	-13.37	-3.15
root-au1-gde8-2.5	GDE8	twig	NA	-16.39	-4.16
bs-gde10-t1	GDE10	twig	NA	-13.37	-3.16
bs-gde10-t3	GDE10	twig	NA	-25.80	-3.84
bs-gde11-t1	GDE11	twig	NA	1.28	-2.41
bs-gde11-t3	GDE11	twig	NA	8.64	-1.62
bs-gde1-t1	GDE1	twig	NA	-21.18	-2.80
bs-gde1-t2	GDE1	twig	NA	-20.36	-3.31
bs-gde1-t3	GDE1	twig	NA	-23.49	-3.41
bs-gde2-t2	GDE2	twig	NA	-5.68	-1.46
PPB1	NA	Groundwater	NA	-33.44	-5.19
SW-GDE6	NA	Surface Water	NA	19.11	5.35
SW-Dawson	NA	Surface Water	NA	-13.04	-2.24
AO B7	NA	Groundwater	NA	-29.02	-4.02
A0 B4	NA	Groundwater	NA	-24.02	-3.37
A0 B1	NA	Groundwater	NA	-25.91	-3.92
A0 B10	NA	Groundwater	NA	-33.12	-4.44
A0 B11	NA	Groundwater	NA	-15.50	-2.34
P0 B4	NA	Groundwater	NA	-25.15	-3.84
P0 B3	NA	Groundwater	NA	-26.30	-3.72