Central Queensland Coal Project

Appendix 10d – Groundwater Dependent Ecosystem Assessment

Central Queensland Coal

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Groundwater Dependent Ecosystem Assessment

Central Queensland Coal Project

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Prepared by 3d Environmental

for

Ecological Australia Pty Ltd / Central Queensland Coal Ltd

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Client: Ecological Australia / Central Queensland Coal Ltd

Purpose: Groundwater dependent ecosystem assessment for Surat Basin Acreage Development Area

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Revision 1	18 May 2020	David Stanton	First Draft GDE Assessment Report
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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	Vegetation 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
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.
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).
Obligate phreatophyte	A plant that is completed dependent on access to groundwater for survival
Percolation	The downward movement of water through the soil due to gravity and hydraulic forces.
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.
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
Soil water 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	An isotope that does not undergo radioactive decay.
Standard Wilting Point	The minimum LWP or corresponding soil moisture potential that can be tolerated before a 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).
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.
Water Table	The upper surface of the saturated zone in the ground, where all the pore space is filled with water.
Wetting front	The boundary of soil wet by water from rainfall and dry soil as the water moves downward in the unsaturated zone.

Executive Summary

Central Queensland Coal Pty Ltd and Fairway Coal Pty Ltd are joint proponents of the Central Queensland Coal Project which is located 130km north of Rockhampton and 25km north of Marlborough. The Project will operate within Mining Lease (ML) 80187 and ML 700022 and adjacent to Mineral Development Licence (MDL) 468 and Exploration Permit for Coal (EPC) 1029 and will consist of two open cut operations that will be mined using a truck and shovel.

Multiple lines of evidence including analysis of leaf water potential, core drilling, soil moisture potential and stable isotope analysis of twig xylem, soil moisture, surface water and groundwater have been applied in this assessment with a primary aim of Identifing if vegetation within and surrounding the project area is likely to access and utilise groundwater for transpiration, either permanently or intermittently, consistent with the definition of a groundwater dependent ecosystem (GDE).

Five GDE assessment areas were assessed across two assessment events in August 2018 within riparian vegetation mapped as GDEs in publicly available mapping databases. The assessment areas, and results of the assessment are summarised below:

- Wetland 1 GDE Assessment Area
  - The Wetland 1 GDE investigation area is a relatively unique landform element with no obvious inflow or outflow conduits and a localised catchment area. Extremely high LWP readings coupled with evidence from SMP measurements taken down borehole indicate that the woodland of broad-leaved paperbark at the Wetland 1 GDE investigation area are utilising a saturated source of moisture perched at 8mbgl. The saturated zone is most likely maintained by percolation of surface water from the wetland through the overlying clay pan along fracture zones in basement rock. Water seeking tree roots from the broad-leaved paperbark have been able to follow the percolating groundwater downward along the fracture plains with the saturated zone providing a source of moisture to sustain the woodland vegetation during drought periods. Based on this information, Wetland 1 GDE investigation area does represent a terrestrial GDE although the groundwater source is likely to be localised and not laterally extensive.
- Wetland 2 GDE Assessment Area
  - The Wetland 2 GDE investigation area is an internally drained surface water feature that has linkage to surface water flow paths that become more obvious to the east of the Bruce Highway. Mature canopy trees surrounding the wetland depression were in a state of water deficit at the time of assessment, all demonstrating LWP's that were at or approaching standard wilting point. Downhole SMP measurements indicate trees are utilising of soil moisture from the top 2 to 4m of the soil profile. This soil moisture would only be recharged following infiltration of seasonal rainfall or breach of the swamp depression during flooding. A borehole drilled to 15mbgl at

the assessment locality did not intersect any saturated zones in the soil, nor any aquifer and it is considered groundwater resources are below the maximum rooting depth of mature trees in the vicinity. The Wetland 2 GDE assessment area is inferred to not represent either an aquatic or terrestrial GDE.

- Vine Thicket GDE Assessment Area
    - Assessment of LWP, downhole SMP and stable isotopes of soil moisture, xylem and groundwater all suggest that vine thicket trees are accessing a source of soil moisture in the unsaturated zone, above the alluvial unconformity with the Styx Coal Measures. This is further supported by physical observations from boreholes which show a maximum rooting depth of approximately 6mbgl for vine thicket trees. Emergent red gum which are often associated with the riparian fringe and scattered through the vine thicket patch do possess LWP's that are consistent with access to a non-saline saturated source of moisture. Evidence from drill core indicates that these trees are utilising moisture within narrow coal seams in weathered portions of the Styx Coal Measures immediately below the alluvial unconformity at a depth of approximately 9mbgl. Recharge of this moisture would be facilitated by stream hi-flow periods which would result in lateral movement of floodwater into the stream banks and allow gradual baseflow return to the stream during dryer periods. The overlap of stable isotope signatures between soil and groundwater samples indicate a common derivation, most likely imparted by floodwater that has a stable isotope signature close to meteoric values. While the vine thicket component of this assessment locality is inferred to not represent a GDE, the riparian fringes and associated emergent red gum are likely to represent a terrestrial GDE that is dependent on groundwater contained within the shallow coal measures and the associated alluvial unconformity. The Tooloombah Creek watercourse would also likely represent an aquatic GDE based on an inferred linkage between surface water and groundwater baseflow. Further impact assessment is required to determine if potential project related impacts to baseflow mechanisms will result from mine void development.

- Tooloombah Creek and Deep Creek GDE Assessment Areas
    - Both Tooloombah Creek and Deep Creek GDE investigation areas consistently show that red gum on the upper terraces are accessing a saturated moisture source and similar to the Vine Thicket GDE assessment site, this water is inferred to be held at or near the alluvial unconformity with the weathered Styx Coal Measures. Weeping paperbark are inferred to utilise a different water harvesting strategy that relies on access to surface water in stream pools and held in fluvial sands rather than employing a sinker root with capacity to access deeper water sources. Like the Vine Thicket GDE investigation site, red gum associated with the riparian fringes are likely to be utilising groundwater and hence the system would represent a terrestrial GDE. The potential for baseflow of groundwater into both drainage systems suggests that these watercourses would be consistent with the definition of an aquatic GDE and weeping paperbark would still fit the definition of groundwater dependent vegetation as they are reliant on baseflow discharge. Further assessment of the

potential risk The Project poses to aquatic GDEs is required.

Preliminary conceptual models of ecohydrological function have been developed for three assessment areas assessed to be GDEs in this study, to assist the assessment of potential project impacts and develop mitigation strategies. This assessment provides an initial characterisation of the sources of water utilised by riparian vegetation mapped as GDE’s within the Central Queensland Coal Project Area. To account for climatic variables that influence the source of water utilised by trees, the collection of biophysical and isotopic data over an extended time frame that accounts for seasonal variation may be required to fully characterise plant/water relations on a seasonal basis.

Contents

Figures

1. Introduction

Central Queensland Coal Pty Ltd and Fairway Coal Pty Ltd are joint proponents of the Central Queensland Coal Project, herein referred to as 'The Project'. The Project is located 130km north of Rockhampton and 25km north of Marlborough, operating within Mining Lease (ML) 80187 and ML 700022 and adjacent to Mineral Development Licence (MDL) 468 and Exploration Permit for Coal (EPC) 1029. The Project, which is in the Styx Basin, consists of two open cut operations that will be mined using a truck and shovel (Central Queensland Coal Project Supplementary EIS, 2018). The location of The Project and the impact footprint are shown in **Figure 1**.

A component of the environmental approvals process requires an assessment of the groundwater dependence of ecosystems within the area of potential impact. Requirements for assessment are driven at a federal level by the 'water trigger' under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) which states that water resources in relation to coal seam gas and large coal mining developments are a matter of national environmental significance (MNES). Ecosystems which depend on groundwater resources for survival are also captured by the water trigger and require assessment as part of the Environmental Impact Statement (EIS) process.

This assessment provides a summary and analysis of data collected during an initial stage of site based GDE investigation, completed in two events in August 2018, within the area potentially impacted by groundwater drawdown surrounding the proposed mining void. The assessment utilises multiple lines of evidence including assessment of leaf water potential (LWP), soil moisture potential (SMP) and stable isotope analysis of twig xylem, soil moisture, surface water and groundwater.

1.1 Aims and Objectives

The aim of the investigation is to identify at a preliminary level the source of water utilised by trees for transpiration within areas identified as potential GDEs within the area of potential groundwater drawdown. Sources of water may include surface water, soil moisture, groundwater, or any combination of these. Objectives of the assessment are to:

- Identify if vegetation within and surrounding the project area is likely to access and utilise groundwater for transpiration, either permanently or intermittently, consistent with classification of a groundwater dependent ecosystem (GDE).
- Determine the source and nature of moisture utilised by GDEs.
- Identify the degree of dependence of vegetation communities on groundwater for survival and sustenance through periods of drought.

1.2 Site Setting and Hydrogeological Context

The Project footprint centres on a region of roughly 15km^2 within the Styx Basin, an early Cretaceous sag basin with less than 1000m depth of siliciclastic sediments and coal measures. The area underlying the mining footprint is occupied by a broad undulating plain formed on Pleistocene age alluvium (Qpa) representing older flood plain alluvium on higher terraces. Based on geological cross sections provided by CDM Smith (2017), the Pleistocene alluvium is up to 20m thick and is incised by the major drainage features of Deep and Tooloombah Creeks. These creeks define the mining void limits to the east and north respectively and are associated with younger Quaternary age alluvial deposits including fluvial sand (DNRME 2018) (see **Figure 2**).

Legend

🟨 Project Footprint

Figure 1. Location of Assessment Area

Client

Ecological Australia /
Central Queensland Coal

0 12.5 25 50
Kilometres

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Kenmore, Qld 4069
Mobile: 0447 822 119
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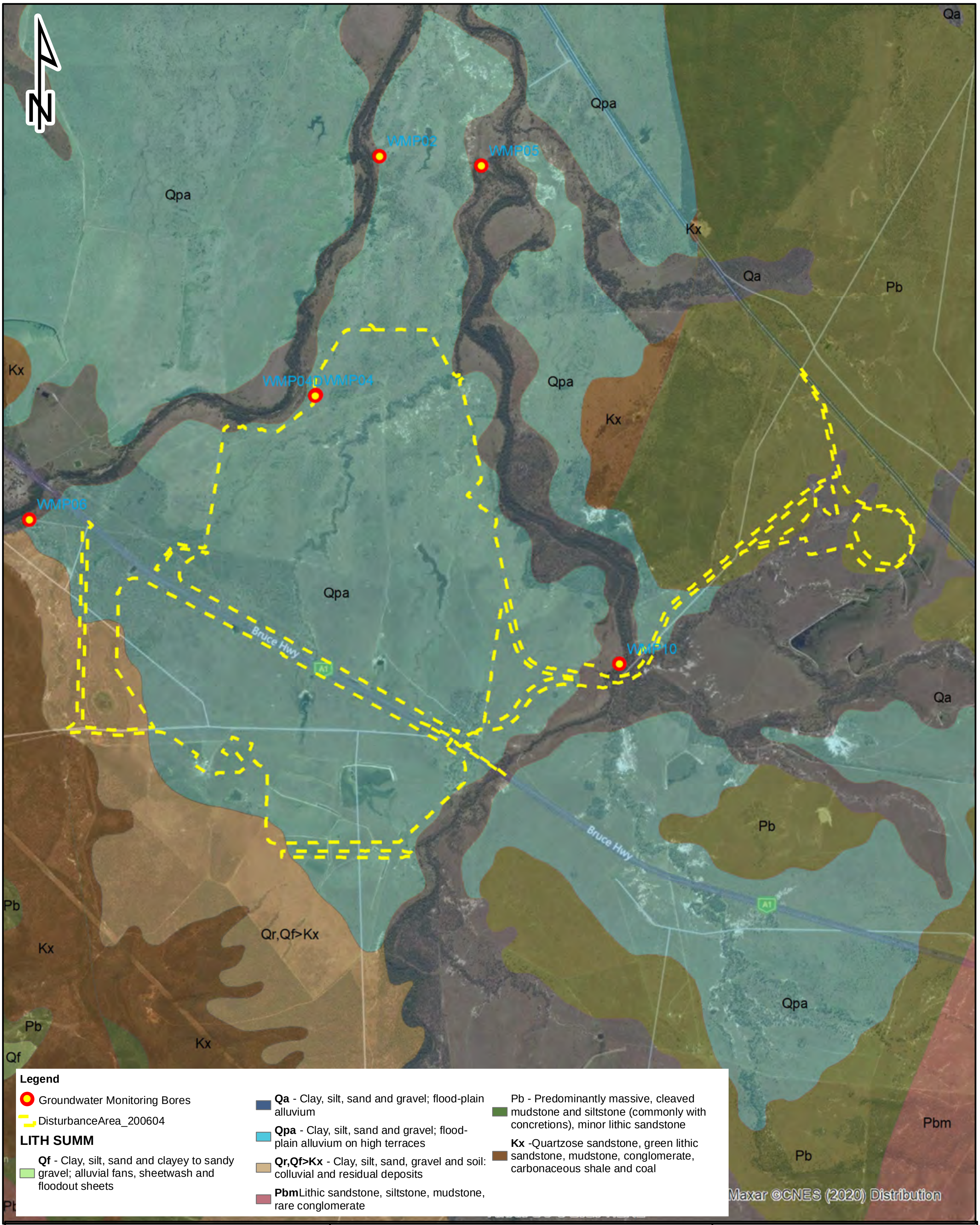

Source: Detailed Surface Geology Queensland (DNRM 2018)

Figure 2. Surface geology in relation to the proposed project footprint

Client **Ecological Australia / Central Queensland Coal**

0 0.75 1.5 3
Kilometres

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Underlying the alluvial deposits are the Styx Coal Measures which form a sequence of coarse to medium grained sandstones interbedded with coal seams. The sandstone overburden and interburden are generally considered aquitards with the coal measures providing some aquifer forming potential on account of their higher permeability (Independent Expert Scientific Committee [IESC] 2018).

Groundwater is generally formed at the interface between alluvium and the Styx Coal Measures with saline groundwater (EC2567 to 47700 µS/cm) recorded at depths of up to 17.3 metres below ground level (mbgl) adjacent to riparian areas (see **Figure 2**) where GDEs are predicted to occur. A summary of alluvial bores and associated standing water level (SWL) and salinity is provided in **Table 1**.

Table 1. Details of groundwater monitoring bores adjacent to riparian areas.

Bore ID	Location	Slotted interval (mbgl)	Groundwater level metres (median)	EC (median)	No. samples	Time period
WMP13	Styx River	12.7 - 19.7	14.2	47,700	46	Jan 18 to Nov 19
WMP05	Deep Creek	9 - 12	7.4	2,567	45	Nov 17 to Dec 19
WMP21D	Deep Creek	14 -20	14.7	39,600	5	Sep 19 to Dec 19
WMP10	Deep Creek	12 - 18	10.2	17,900	47	Nov 17 to Dec 19
WMP8	Deep Creek	10 - 16	10.1	27,100	47	Nov 17 to Dec 17
WMP02	Tooloombah Creek	12 - 18	16.9	16,917	51	Dec 17 to Dec 19
WMP12	Tooloombah Creek	11 - 17	16.4	5,270	9	Nov 17 to Apr 18
WMP04	Tooloombah Creek	12 - 18	11.4	16,000	48	Nov 17 to Dec 19
WMP06	Tooloombah Creek	12 - 18	17.3	5,295	52	Dec 17 to Dec 19
WMP28	Tooloombah Creek	8.9 – 11.9	-	6,085	4	Sep 19 to Dec 19

1.3 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 on Coal Seam Gas and Large Coal Mining Development (IESC). 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).
> - Ecosystems dependent on subsurface presence of groundwater (terrestrial GDEs).
> - Subterranean ecosystems (caves).

Ecosystems dependent on surface expression of groundwater are extended to spring fed streams and rivers otherwise defined as aquatic GDE's.

1.4 Groundwater Definition Used in this 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. 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:

- Water within wetting fronts, being the boundary between soil that is wet through the downward percolation of rainfall, or leakage from stream, lake or other surface sources of water and the dryer soil/rock in the unsaturated zone through which it is passing.
- Ephemeral zones of near saturation created when the infiltration rate approaches the saturated hydraulic conductivity of a subsurface soil horizon or geological layer.

1.5 Ecohydrological Function of Characteristic Tree Species

Eucalypts: The GDE investigation area and surrounds are characterised by the presence of forest red gum *(Eucalyptus tereticornis*) typically on river banks and levees; poplar gum (*Eucalyptus platyphylla),* swamp mahogany (*Lophostemon suaveolens),* Moreton Bay ash (*Corymbia tessellaris),* Clarkson's bloodwood (*Corymbia clarksoniana)* on more elevated alluvial terraces; and poplar box *(Eucalyptus populnea),* and ironbark (*Eucalyptus crebra)* on elevated upper terraces at greatest distance from the stream channel.

River red gum (*Eucalyptus camaldulensis)* 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) although the species is not known to occur in the assessment area. For this assessment, the physiological attributes of *Eucalyptus tereticornis* and *Eucalyptus camaldulensis* are assumed to be similar as the species inhabit a similar ecological niche. *Eucalyptus tereticornis* is however a more adaptable species, occupying dry hill slopes in some localities and it would be expected that *Eucalyptus tereticornis* would be more tolerant of changes to hydrological regime than *Eucalyptus camaldulensis* which is a riparian specialist. The water requirements of river red gum are obtained from three main sources being groundwater, rainfall, and river flooding. Flooding enables the species to survive in semi-arid areas (ANBG 2004). Stands of river red gum are intimately associated with the surface-flooding regime of associated watercourses and related groundwater flow. The high-water use of river red gums contributes to maintaining water tables at depth (Mensforth et al 1994; Lamontagne et al 2005). River red gum are considered partially opportunistic in their use of water and are considered a facultative phreatophyte, shifting between a combination of surface soil moisture and groundwater during periods of high rainfall, then shifting to exclusive use of groundwater during drier periods. They are likely to achieve this shift through inactivation of surface roots during drier periods with increased reliance on deeper tap roots when surface water is unavailable. Doody et al. (2015) demonstrated that soil moisture alone can sustain the health of *Eucalyptus camaldulensis* through periods of drought 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). Kath et al (2014) predicted a 'stand condition threshold response' to groundwater drawdown which predicted a rooting depth of between 12.1 - 22.6 mbgl for river red gum and Reardon-Smith (2011) concluded rooting depths of 13 – 16 mbgl based on observations of severe dieback in riparian habitats on the Upper Condamine floodplain. Similarly, 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. From excavations in 20 year-old plantation forests of *Eucalytpus tereticornis,* Kallarackal and Somen (1998) found that roots were traceable to depths of 9.3 mbgl and Jones et al (2020) found maximum rooting depths of 8.1m in river red gum in a broad study area in the Great Artesian Basin. In conclusion, maximum rooting depth of 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).

All eucalyptus species are potential users of groundwater (Cook et al, 2007) although few studies demonstrating this dependence exist. Fensham and Fairfax (2007) consider both ironbark and poplar box to possess shallow rooting systems with limited investment in deep root architecture, rendering them susceptible to droughting. Due to the location of these species on the more elevated Pleistocene clay plain, it is considered unlikely that they would be utilising groundwater to any significant degree. Root penetration of these species would be further hindered by the heavy clay substrate which provides an unsuitable medium for development of the deep tap root system necessary for penetration to the groundwater table (Dupuy et al 2005). Soils with low hydraulic conductivities, such as clays, also greatly limit the ability of trees to utilise groundwater (Feikema 2010).

For the remaining species, O'Grady et al (2006b) concluded the following in a study on groundwater usage of trees on a tropical floodplain savannah:

1. Poplar gum and swamp mahogany both utilised soil moisture from the top 5m of the soil profile in preference to groundwater, even when the groundwater table was 4 – 7mbgl. These species are unlikely to be dependent on groundwater although its use when the water table is at shallow depths cannot be discounted.
2. Clarkson's bloodwood was demonstrated to utilise groundwater usage when the water table was at 10mbgl indicating the potential for the species to develop a deep sinker root. Clarkson's bloodwood should be considered a known facultative phreatophyte.
3. Moreton Bay ash demonstrated groundwater usage when the water table was at 4mbgl, although it is not known whether the species has capacity to utilise deeper groundwater sources. Moreton Bay ash should be considered a facultative phreatophyte although may

have similar water use strategies to poplar gum, with limited capacity to utilise deeper groundwater sources.

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. However, given evidence exposed in stream cuttings in the Surat Basin, it is apparent that Brigalow can develop deeper rooting systems when the site substrate is suitable and has capacity to utilise groundwater held in coal seams. This scenario would most likely occur where brigalow occupies fractured basement rock exposures where brigalow roots could follow water percolating downward along fracture planes (preferential flow in groundwater recharge), rather than massive clay soil profiles where soil moisture infiltration would be extremely slow, uniform and diffuse (piston flow).

Figure 3. Exposure of coal seam on a drainage line in the Surat Basin with densely matted tree roots. This seam is at approximately 6m depth from soil surface and the tree roots are traced downward from the overlying brigalow forest.

Semi-evergreen Vine Thicket: There is only a single mappable occurrence of semi-evergreen vine thicket in the project area. This habitat is mapped as regional ecosystem (RE) 11.3.11 and occurs on an alluvial bench that is elevated (approximately 10m) well above the flood channel of Tooloombah

Creek. Dry vine forest species maintain drought tolerance through a number of physical and physiological adaptions including leaf fall (deciduousness) at progressively lower LWP, lower leaf surface area (LSA) reflecting a greater degree of sclerophylly (Eamus 1999, Lamont et al 2002) and stomata closure at low LWP (Smith et al 1997). It is also identified that dry rainforest plants have capacity to increase drought tolerance through higher vertical leaf angles resulting in lower LSA exposed to the sun during the hottest part of the day (Cowan 1981). Bowman (2000) identifies that the extremely low LWP typical of brigalow, which often grows in association with dry rainforest species, indicates that dry rainforest trees have capacity to survive extremely dry edaphic conditions and Curren et al (2009) reports LWP for *Eleodendron australe* (a vine forest species occurring on site) at an extremely low -8.3Mpa at stomatal closure. There is no indication in any literature that the distribution of dry vine thicket is reliant on more mesic soil conditions or requiring access to groundwater for persistence in dry climatic regimes.

Melaleuca species: Fringing weeping paperbark, including both *Melaleuca leucadendra* and *Melaleuca fluviatilis*) are almost ubiquitous species in riparian vegetation along tropical watercourses, occurring on the riparian fringe of both Toolombah and Deep Creek. Despite a widespread occurrence, their ecology is poorly understood. They are generally considered phreatophytes although O'Grady et al (2006a) determined that river water was the predominant source of water for melaleuca's fringing the Daly River in northern Australia. O'Grady (2006b) also suggest that highly variable stable isotope signatures of weeping paperbark fringing a tropical watercourse indicated variable and opportunistic water usage from variable sources.

For broad-leaved paperbark (*Melaleuca viridiflora*) which has scattered occurrence in drainage depressions surrounding the assessment area, Cook et al (2007) suggest a capacity to utilise moisture from the upper 0.5m of the soil profile plus deeper usage of moisture below 7m, likely to represent groundwater. O'Grady et al (2006b) demonstrated that broad-leaved paperback could utilise groundwater from a water table at 10mbgl. This suggests considerable species adaptability with a dimorphic root system capable of utilising moisture from multiple sources and depths dependent on seasonal availability.

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. A scenario where rivers water was derived partially from baseflow would however render such trees as groundwater dependent.

2. Methods

This study utilised a combination of published recommended methods (e.g. Eamus et al. 2006; Richardson 2011: Eamus et al. 2015) and additional methods tailored to investigate shallow sources of moisture and groundwater present in the shallow subsurface (upper 10 m), and likely vegetation interactions with these water sources. Adopted methods included

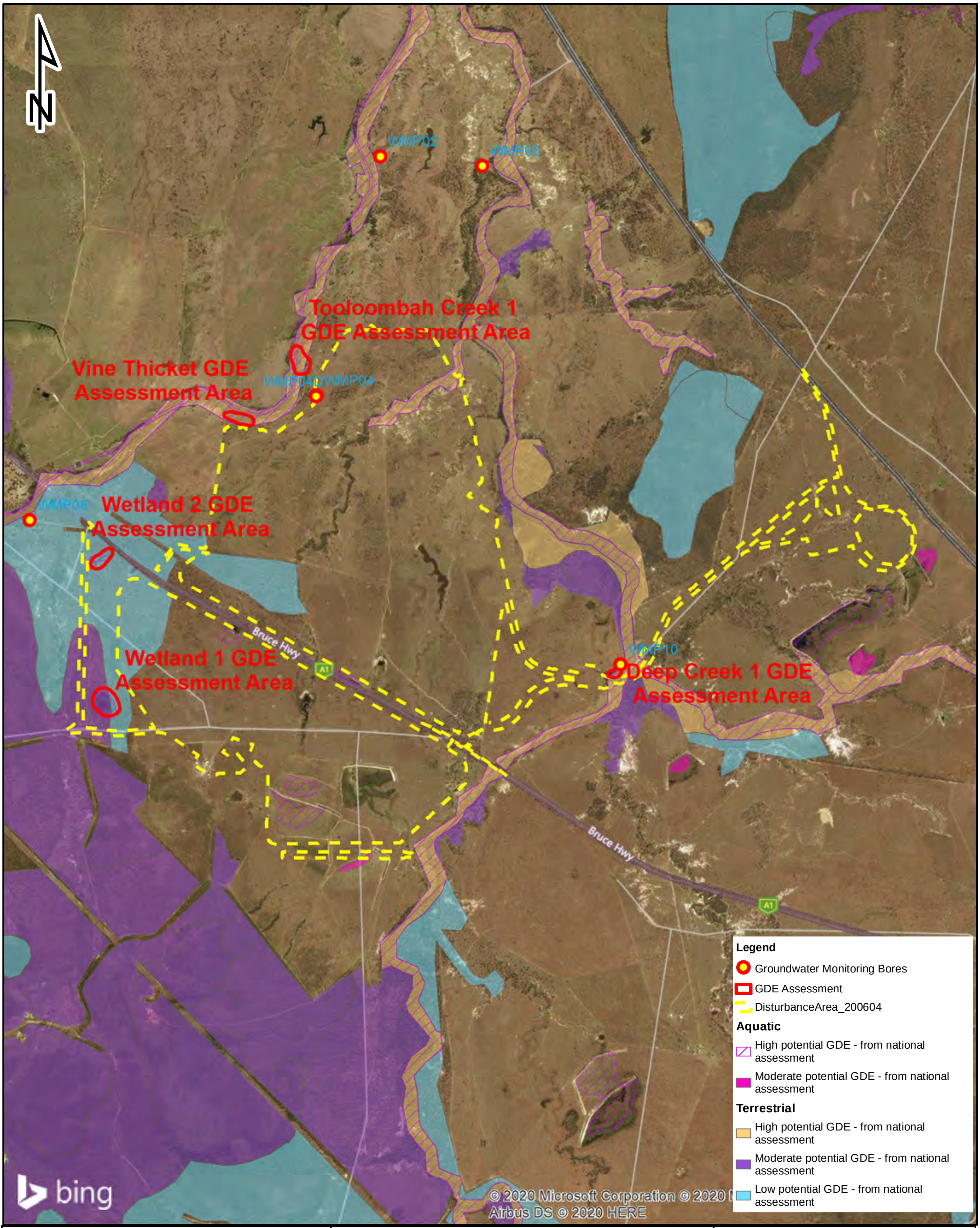
1. Utilisation of drill core to provide evidence for tree rooting depth and characterise the local hydrogeological conditions;
2. Soil moisture potential (SMP) measurement;
3. Leaf water potential (LWP) measurement;
4. Stable isotope analysis of xylem water, soil moisture, surface water and groundwater.

Detailed assessment methods were focused around target trees species which were chosen to be representative of the potential phreatophytes at each site including red gum, vine thicket species and melaleuca species. Not all methods were applied at each GDE assessment site dependent on the specific purpose of the assessment and timing.

2.1 Site Selection

GDE assessment localities were pre-chosen to be representative of a variety of specific eco-hydrological regimes within the area of potential impact with all sites coinciding with areas mapped as either terrestrial or aquatic GDE's in the GDE Atlas (BOM 2017). Five sites were chosen for assessment being Wetland 1 GDE assessment area, Wetland 2 GDE assessment area, Vine Thicket GDE assessment area, Tooloombah Creek GDE assessment area and Deep Creek GDE assessment area, with locations shown in **Figure 4** relative to mapped GDEs. Summaries of each assessment site are provided below:

Wetland 1 GDE assessment area: The Wetland 1 GDE assessment area is listed as a 'Great Barrier Reef wetland of high ecological significance (HES)' under the *Environmental Protection Regulation 2008* and is also a listed wetland under theVegetation Management Act (1999). . It is identified in the BoM GDE Atlas as a 'high potential' aquatic GDE and 'moderate potential' terrestrial GDE characterised by coastal/ sub-coastal non-floodplain tree swamps (melaleuca and eucalypt). Physical characteristics of Wetland 1 indicate a circular, internally drained depression, which was dry at the time of survey exposing a clay pan with constituent vegetation forming a woodland of broad-leaved paperbark (*Melaleuca viridiflora)* (12 to 18m tall at 30% canopy cover) with a single red gum (*Eucalyptus tereticornis)* located in the central portion of the swamp. Wetland 1 is unusual as it is entirely enclosed by low sandstone rises with no drainage outflow, meaning the catchment is highly localised. The characteristics of Wetland 1 are shown in **Figure 5**.



Source: BOM GDE Atlas available at:
http://www.bom.gov.au/water/groundwater/gde/map.shtml

Figure 4. Groundwater Dependent Ecosystems from national assessment.

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Figure 5. Vegetative structure of Wetland 1 in August 2018 when swamp was dry (left) and general shape physiography from google earth demonstrating the lack of a drainage outlet (2017). The red line indicates position of cross section (see **Section 4.1**)

Wetland 2 GDE assessment area: The Wetland 2 GDE assessment area is listed as a 'wetland of general ecological significance' under the *Environmental Protection Regulation 2008* and is also identified in the BoM GDE Atlas as a 'high potential' aquatic GDE and 'low potential' terrestrial GDE on a coastal/sub-coastal floodplain swamp which is reliant on surface expression of groundwater. Wetland 2 forms a narrow internally draining depression with characteristic aquatic macrophytes fringed by red gum and ironbark. There is no obvious thickening of riparian vegetation on the wetland margins with the occurrence of red gum on the swamp fringes the only feature that distinguishes vegetation from the broader surrounding woodland. Drainage linkages are obscure although it feeds a more visible drainage depression to the east side of the Bruce Highway (see **Figure 6**).

Figure 6. Wetland 2 from the ground in August 2018 and from the air in 2017 from Google Earth.

Vine Thicket GDE assessment area: The Vine Thicket GDE assessment area is located on the southern bank of Tooloombah Creek where it occupies an alluvial terrace, bound to the north by the main channel of Tooloombah Creek and to the south by a weakly incised flood overflow channel. The alluvial terrace that hosts the vine thicket sits approximately 10m above the channel floor of Tooloombah Creek and 5m below the broader Pleistocene alluvial terrace. The thicket forms a low mix of vine forest shrubs and trees including crow's ash (*Flindersia australis*), *Coatesia paniculata, Siphonodon australis,* narrow leaved bottle tree (*Brachychiton rupestris*), celerywood (*Polyscias* *elegans*) with a canopy at 7 – 10m and emergent red gum reaching 35m. Red gum typically occur on the lower portions of the terrace closer to the channel of Tooloombah Creek. Occasional brigalow trees occupy the landward fringe of the vine thicket (see **Figure 7**).

Figure 7. Emergent narrow leaved bottle tree in the Vine Thicket GDE assessment area within the vine thicket (left) and the vine thicket patch on Tooloomba Creek adjacent to a permanent waterhole. The red line indicates position of cross section (see **Section 4.3**)

Tooloombah Creek GDE assessment area: The Tooloombah Creek GDE assessment area is located on a relatively straight reach of Tooloombah Creek approximately 1km downstream from the Vine Thicket GDE assessment area. The channel of Tooloombah Creek at this locality is formed by a cobble to gravel sized bedload mixed with areas of coarse sand. The channel, which had no visible pools of surface water at the time of assessment, anastomoses around sinuous instream gravel bars. The vegetation is much less mesic than the vine forest GDE assessment site with a sparse mix of red gum, weeping paperbark (*Melaleuca fluviatilis)* and river oak (*Casuarina cunninghamii)* with an understory of bottle brush (*Melaleuca viminalis).* Red gum occur at some distance from the creek line on the upper terraces and these distal trees were included in the sampling program (**Figure 8**).

Figure 8. Gravel and cobble deposits on the channel floor of Tooloombah Creek (left) with channel form from Google Earth (2017) on the right.

Deep Creek GDE assessment area: The Deep Creek GDE assessment area is located on Deep Creek immediately upstream from the confluence of Barrack Creek. At this locality, Deep Creek is incised to a depth of approximately 10 – 12m below the upper surface of the surrounding Pleistocene alluvial plain. Tall red gum to 35m fringe the margins of the alluvial terrace and a mid-dense sub-canopy of weeping paperbark (*Melaleuca leucadendra*) hug the inner terrace adjacent to the stream channel. The stream channel is narrow, and at the time of assessment was formed by a string of disconnected pools interspersed with sandy channel bars (**Figure 9**).

Figure 9. Narrow sandy channel at the Deep Creek GDE assessment area (left), immediately upstream from the confluence of Barrack Creek (right). Red line indicates position of cross section (**see Section 4.5**).

2.2 Timing and seasonality

The sampling was undertaken over two periods with an initial assessment undertaken between 6th and 11th August 2018 with a subsequent assessment undertaken between 28th and 31st August 2018.

The annual rainfall for Rockhampton Airport, the nearest reliable recording station to The Project for 2016 and 2017 was 963.2 and 832.2mm respectively, slightly above the long-term average rainfall of 806mm. The early part of 2018 commenced with an extremely wet January and February with 382mm falling, well above the long-term average of 272mm for those months. Subsequent months of March to July were extremely dry with 97.4mm falling compared to the long-term average of 260mm (see **Figure 10**) (BOM 2020a). The uncharacteristically dry period in the months preceding survey provided optimal time for the assessment of groundwater dependence. Plant growth in the region is strongly limited by moisture rather than temperature (Hutchinson et al. 1992) which is reflected in the evapotranspiration rates at the Rockhampton Airport being considerably higher than rainfall for all months with the exception of January and February, with a large offset between rainfall and transpiration occurring between March and August as a result of extremely dry conditions (**Figure 11**) (BOM 2020b).

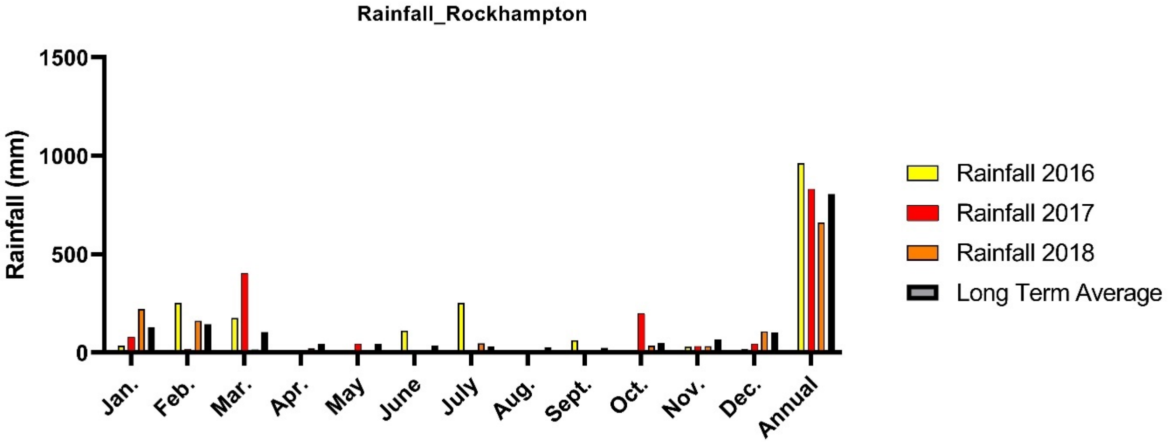


Figure 10. Long term rainfall from the Rockhampton Airport for 2016, 2017 and 2018 (BOM 2020a).

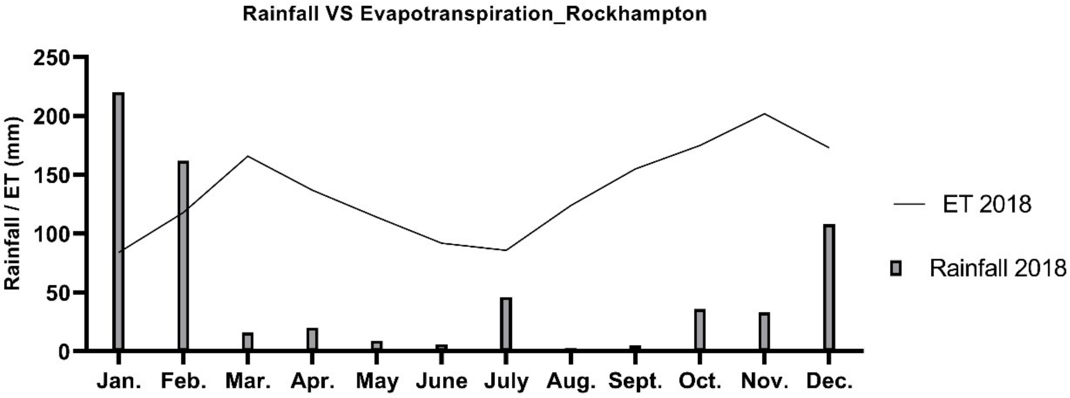


Figure 11. Rainfall records 2018 compared to evapotranspiration for the same period (BOM 2020b).

2.3 Geological Coring

Geological coring and sampling was completed utilising a combination of 50mm push tube coring and Reverse Circulation (RC) dependent on lithology. The geotechnical rig used for push tubing did not have capacity for deep RC drilling into basement rock so upon refusal, the geotechnical rig was substituted with a larger exploration rig and a 100mm drill bit. Push tubing returned continuous core although was only useful in unconsolidated alluvial sediments and saprolite with refusal occurring whenever competent basement rock was intersected. RC drilling was generally continued to a total depth of 15m, which is the inferred maximum rooting depth for eucalypt species, or the first water strike. All holes were drilled dry to full depth where possible to avoid sample contamination although this was not possible in all cases. Use of air in RC drilling likely dried soils in the return process which would have influenced both SMP and stable isotope sampling results. Six holes were drilled in total which were located as close as possible to sampled trees, across three of the sites. A summary of drilling undertaken is provided in **Table 2**.

Table 2. Summary of drill coring undertaken at GDE assessment sites.

Hole ID	Drilling method	Refusal (mbgl)	Total depth	Comments
Wetland 1 GDE Assessment Area				
BH1	Direct push	1.4	5.0	Push tubing through clay profile to 1.4m then drilled in RC mode to 5m with water. Drilled in rotary mode from 1.4 to 5 m with applied water.
BH2	Direct push	0.35	5.0	Drilled in rotary mode from 0.35 to 5 m with applied water and not sampled.
BH3	RC		15	RC drilled without water. First narrow water strike at 8m with aquifer intersected at 13.5 m resulting in a loss of chip return.
Wetland 2 GDE Assessment Area				
BH4	Direct push	4.2	4.2	Push tube to 4.2 m at base of alluvium. Hole was moved to BH5 and RC drilling was continued.
BH5	Direct push/RC	4.2	14.5	RC from 4.2 to 14.5 mbgl, dry to total depth
Vine Thicket GDE Assessment Area				
BH6	Direct push	9.85	9.85	Refusal in Styx coal measures in saprolite.

The coring was undertaken in part to intersect root material under the premise that root material would spread laterally and thicken upon intersection with the capillary fringe or where significant soil moisture or groundwater was present (Eamus et al 2006, Petit and Froend 2018, Orellana, et al 2012), and thus would be most concentrated in the zone of predominant moisture uptake. Therefore, while it is acknowledged that deeper roots may exist below the maximum observed root depth in drill core, the most likely depth of interception would be at the depth where tree roots are most concentrated within the zone of predominant moisture uptake. A positive observation of root material in drill core allows a robust assessment that tree roots must be at least as deep as the depth of root material observed, without speculation associated with the less absolute data sets. The drill coring also facilitated sampling and measurement of SMP, which could be directly correlated with LWP, to determine the region within the soil profile where maximum tree water/ moisture utilisation was occurring.

2.4 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 and is a function of soil water availability, evaporative demand and soil conductivity. LWP was measured pre-dawn (prior to sunrise) as per standard protocol (Eamus 2006a, Richardson 2011). 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 pre-dawn LWP 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 in soils. From experience, trees that has been proven to be utilising shallow, non-saline saturate sources of moisture typically have LWP of > -0.5 MPa (Jones et al 2019) although increasing salinity of the moisture source will result in more negative moisture potentials.

Survey localities were visited pre-dawn and leaves were collected from the canopy with the aid of a 7.5m extension pole fitted with a lopping head. Canopy leaves were collected from up to seven canopy trees at each GDE assessment with fewer samples collected at GDE sites where ecological variation was limited. Collected branches were harvested for suitable leaf material which 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. Three (3) readings were taken at each GDE site to calculate an average. Readings were taken in pounds per square inch (PSI) which is converted to a negative value in MPa as a standard unit of measurement.

2.5 Soil Moisture Potential

Returned drilling cores were sampled for the analysis of soil moisture potential at regular intervals with an aim to collect samples at 0.2 mbgl, 0.5 mbgl after which samples were collected at 1.0 m intervals to the end of hole. In core extracted from push tubing, samples were cut from the central portion of the core to minimise the risk of contamination from clay smearing, introduced drilling water (if used), or excessive drying. For RC drill chips, samples were collected at 1m intervals in similar fashion to drill core. Two samples were taken from each interval with approximately 200 mm sections of soil collected. Samples were then immediately sealed in airtight plastic vials and placed on ice. For each interval sampled, one sample was dispatched to the Australian National University (ANU) Stable Isotope Laboratory (Farquhar Laboratory) for the analysis of the naturally occurring stable isotopes of hydrogen and oxygen within soil moisture. The second sample was retained for the measurement of laboratory tested soil moisture potential.

Soil moisture potential, which includes the matric and osmotic potential, is a measure of the energy required to extract moisture from soil. 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 soil moisture potential is significantly below leaf water potential measured in pre-dawn leaf material (Feikema et al. 2010, Lamontagne et al. 2005, Thorburn et al. 1994, Mensforth et al. 1994 and Doody et al. 2015).

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

2.6 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 ($\delta^{18}O$) and deuterium (δ^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.

2.6.1 Soil Moisture Isotopes

Sampling for stable isotopes in returned soil core and RC chips was undertaken at the same intervals described for measurement of soil moisture potential (see **Section 2.5**) 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. 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 ANU Stable Isotope Laboratory for analysis where they were snap frozen until analysis was complete.

2.6.2 Surface Water and Groundwater Sampling

Surface water from pools in both Tooloombah and Deep Creeks were sampled as part of the supplementary EIS studies undertaken by CDM Smith (CDM Smith 2018), and these results have been utilised in this assessment. Sampling for stable isotopes in surface pools was undertaken between 16th and 18th July 2018 with six grab water samples collected from Tooloombah Creek surface water and another three from Deep Creek. In addition, CDM Smith (2018) collected groundwater samples from six monitoring wells close to the surface water sampling points, using a low-flow groundwater sampling pump.

2.6.3 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 equivalent approximately 5cm in length was sourced using clean stainless-steel secateurs.
5. From one sample, bark was immediately removed while retained on another, 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.
8. Bark samples were also analysed for their stable isotope signature, though only to act as a comparison and control for xylem samples. Bark samples were not used to assess potential groundwater sources due to the strong likelihood that bark would be affected by evaporative enrichment.

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 result in isotopic enrichment rather than depletion, the least enriched sample from each tree is considered most likely to be representative of the true value of water within xylem vessels.

2.7 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. This data is drawn from a range of published sources including Jones et al (2020), Holland et al (2006) 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 25 000 µS /cm) = <-0.55MPa to >-1.4MPa.

Trees that demonstrated LWP values that were more negative than expected ranges for the local groundwater salinity regime were assumed not to be groundwater dependent and not subject to additional scrutiny, other than for comparative purposes.

Step 2. SMP: For trees where LWP was within the expected range of values for GDE's under specific local salinity regimes, comparison with SMP values from the soil profile was undertaken to identify the likelihood that moisture for transpiration was being supplied from the unsaturated zone, or whether deeper sources of moisture / groundwater must be inferred. As described in **Section 2.5**, 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). The comparison of LWP and SMP provides an indication of those portions or the soil profile that are available to the plant for moisture uptake and provides context to assessment of stable isotopes (Step 3).

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 in available soil core, groundwater, and surface water from pools in creek lines to provide a fingerprint for the most likely source of moisture being utilised.

Generally, where SMP aligned with LWP in suggesting groundwater was being utilised, it was generally accepted that the tree is groundwater dependent. Biophysical measurements are less prone to sources of error through sampling and storage than geochemical methods (i.e. stable isotopes) and have been relied on heavily in this assessment. 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.

2.8 Limitations and Other Information Relevant to the Assessment

This assessment provides a snapshot of eco-hydrological processes at the five pre-determined GDE assessment localities. Desktop information considered relevant to the field assessment includes the following information:

1. Climatic conditions preceding the assessment were extremely dry with no rainfall in the four months prior to the survey. Extremely dry conditions are ideal for assessment of potential groundwater usage by vegetation. During dry conditions, the soil profile usually contains limited moisture availability, necessitating usage of groundwater, if available, over soil moisture.

2. The ecological processes and hydrogeological conditions encountered within the Project area are complex and transient. Interpretations presented here are based upon multiple lines of evidence. However, sources of uncertainty remain, and other interpretations are possible. The GDE assessment undertaken here provides a snapshot of the ecohydrological conditions at the time of assessment and temporal data will be required to assess longer term trends in plant / water use and interaction.
3. The use of RC drilling may have influenced results of both the stable isotope and SMP sampling from drilling chips due to the drying effect of air used to blast the sample out of the borehole. This effect would be manifest as an enrichment of stable isotopic signatures from soils and a reduced (more negative) SMP. Soils that return a high SMP from RC chips are likely to be representative of true values, though where SMP is much lower than the range sampled in soil core, the samples were considered suspect and not reliable for interpretative purposes.
4. Not all GDE assessment methods were applied at each individual GDE assessment site and application was dependent on access constraints, specific purpose, and timing. LWP measurement was the only analytical technique applied in the earlier survey event (6 – 11 August), completed in conjunction with ecological biocondition assessments, which allowed more specific planning to be undertaken for the subsequent assessment. A summary of sampling techniques applied at each GDE assessment site is provided in **Table 3**.

Table 3. Sampling timing and methods applied at each GDE assessment area.

GDE Site	Date of Sampling	Leaf Water Potential	Drill Coring	Soil Moisture Potential	Stable Isotope Analysis
Wetland 1 GDE assessment area.	11 Aug 2018; 28 August 2018	Yes	Yes	Yes	Yes
Wetland 2 GDE assessment area.	29 August 2018	Yes	Yes	Yes	Yes
Vine Thicket GDE assessment area.	12 August 2018; 30 August 2018	Yes	Yes	Yes	Yes
Tooloombah Creek GDE assessment area	9 August 2018	Yes	No	No	No
Deep Creek GDE assessment aite	10 August 2018	Yes	No	No	No

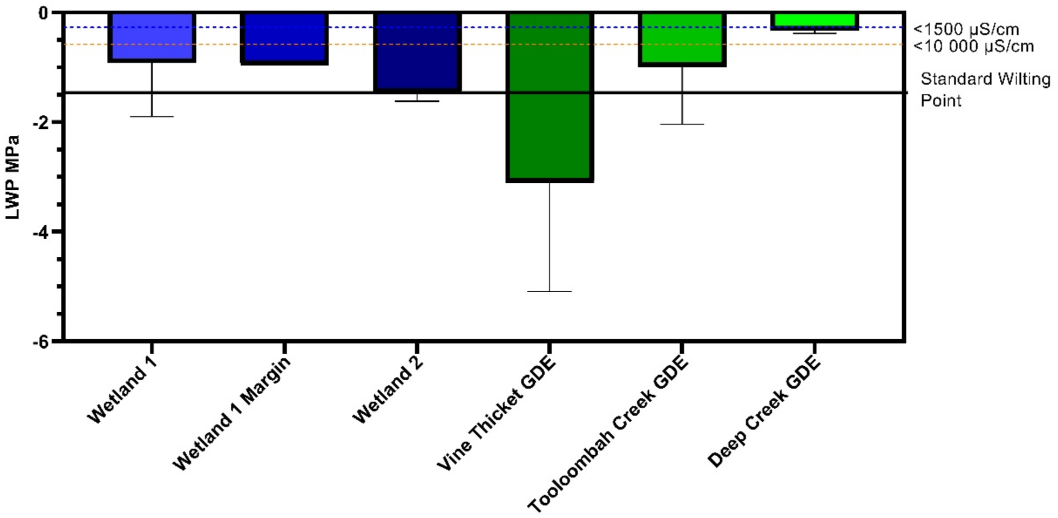
3. Assessment Results

An initial comparison of LWP and stable isotope results between all assessment areas is presented followed by an assessment of the five GDE assessment areas individually. SMP is not compared in the overall assessment as it relates strongly to LWP and is best compared on that basis for an individual GDE assessment area.

3.1 Leaf Water Potential

The average LWP for all GDE assessment sites is presented in **Figure 12a** with individual values for trees at each site presented in **Figure 12b**. A spatial representation of the average water availability for trees at each locality is provided in **Figure 13** with expanded detail provided within individual GDE assessment site results and summary data for all trees assessed is provided in **Appendix A**. Wetland 2 and the Vine Thicket GDE assessment site demonstrate the lowest (most negative) average LWP with the highest average LWP at the Deep Creek GDE assessment site. Detail for individual sites shown in Figure 12b indicates that there is considerable variability in LWP for trees at each site. For example, Wetland 1 has three trees that have extremely high LWP and a single tree with extremely low (negative) LWP while the Vine Thicket GDE assessment site has a single tree with extremely high LWP and the majority of trees having strongly negative values that fall well below standard wilting point. This suggests that there is variation in the source of moisture being utilised by trees at each GDE assessment site responding to the specific physiology of individuals species as well as site conditions which include topography, soil type, distance from and height above the stream channel.

Figure 12a. Average Leaf Water Potential Styx All Sites



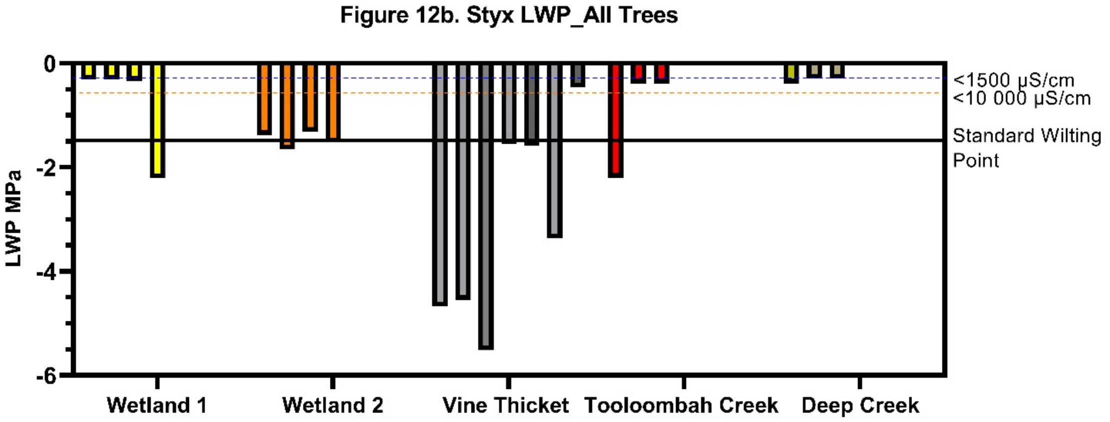


Figure 12. Figure 12a showing average LWP for all trees at each GDE assessment area and Figure 12b showing LWP for individual trees. The blue line (>-0.2MPa) indicates typical LWPs for trees in equilibrium with a non-saline saturated source of soil moisture; the orange line (>-0.55MPa) indicating typical values for trees in equilibrium with a moderately saline soil moisture source (EC 10 000 µS/cm) and the black line indicates Standard Wilting Point (<-1.5MPa) being the point when trees are in state of considerable water deficit.

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3.2 Stable Isotope Values for all Data

Figure 14 shows stable isotope values (δ18O and δ2H) for all values including soil, surface water, groundwater and twig xylem water analysed during the assessment. Groundwater and surface water results have been obtained from CDM Smith (2018). The scatter shows broad isotopic overlap between soil samples and groundwater samples with twigs generally enriched above the soil and groundwater and surface water samples having the most consistently enriched isotopic composition of all samples except for a few soil samples. One groundwater sample (WMP06) has an isotopic signature that is strongly enriched above other groundwater samples and surface water sample DE3 is depleted relative to other surface water samples. Water samples (**Figure 7b**) show a strong separation between highly enriched surface water samples and groundwater samples with some overlap between groundwater sample WMP06 and surface water sample DE3. The groundwater samples all fall close to the local meteoric water line (LMWL) for Rockhampton from Crosbie et al (2012) while surface water samples lie on a trend that falls south indicative of evaporative enrichment. Raw data for all isotopic samples is provided in **Appendix D**.

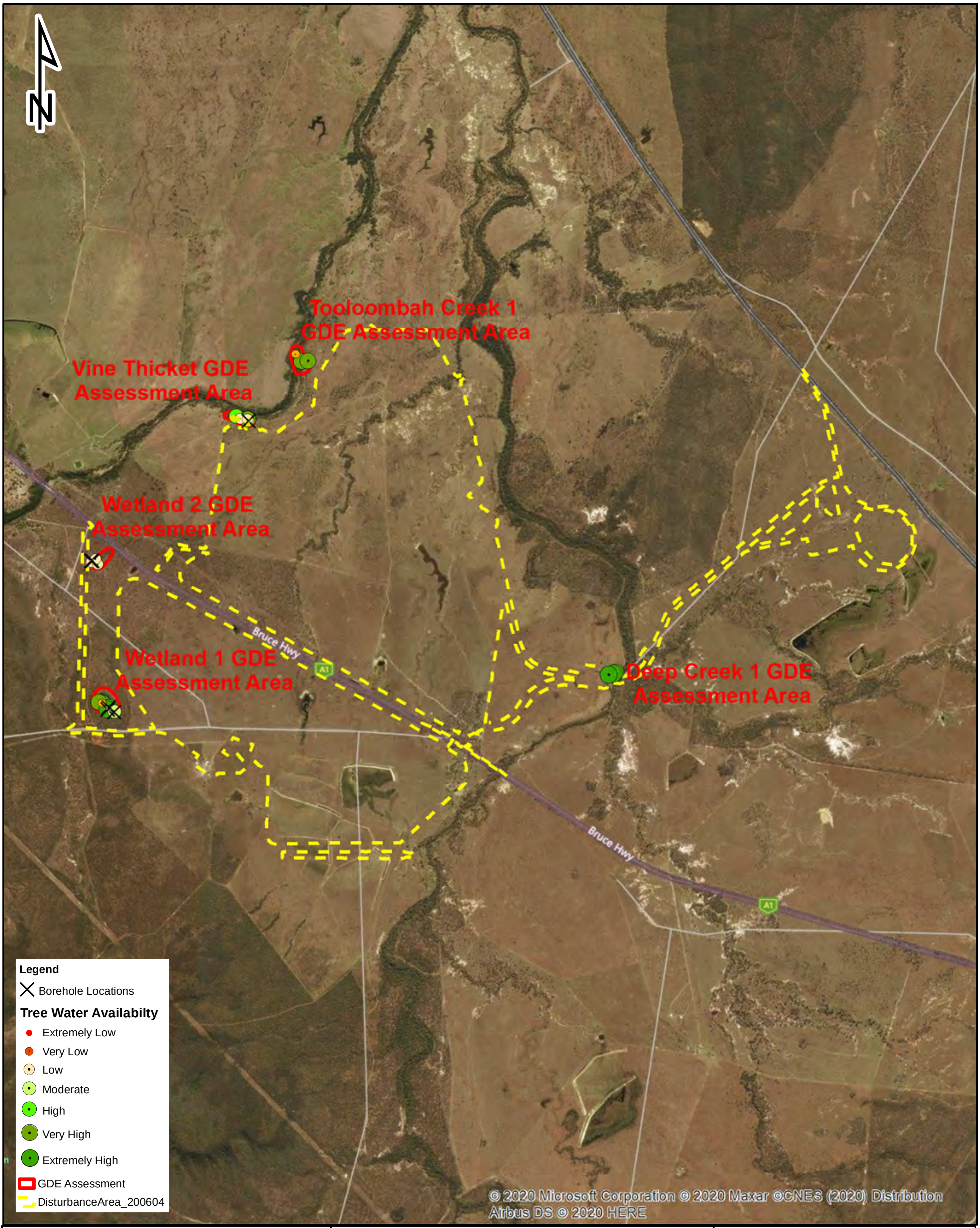

Figure 3. Tree water availability across all GDE assessment areas

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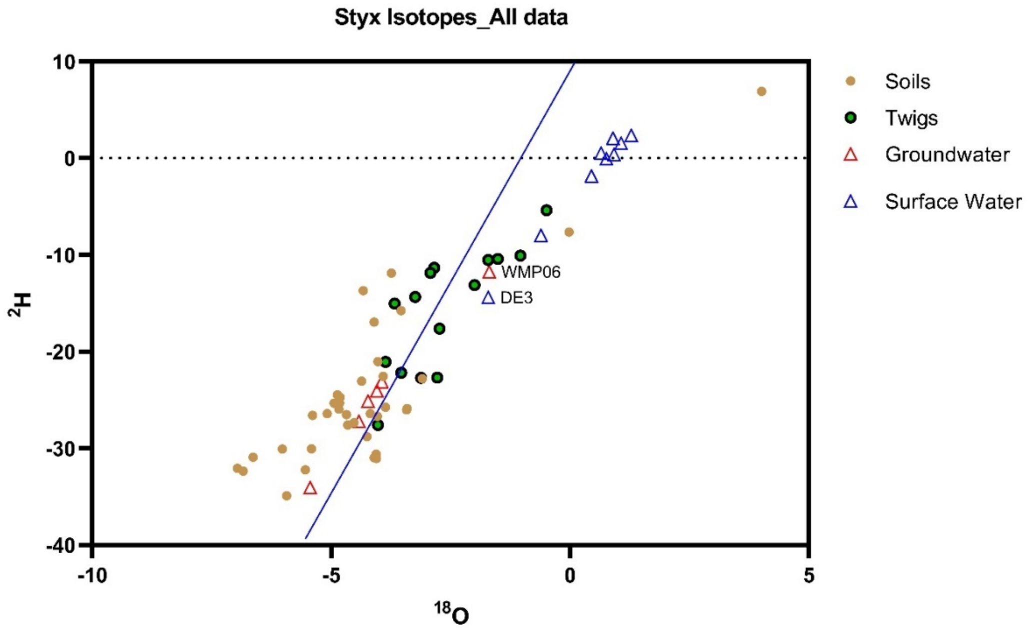

Figure 14. Stable isotope biplot for all soils, twigs xylem, surface water and groundwater from all GDE assessment sites. The blue line represents the LMWL Local Meteoric Water Line (LMWL) from Rockhampton, the closest published LMWL to the assessment area (Crosbie et al, 2012).

3.3 Wetland 1 GDE Assessment Area

Assessment parameters including LWP, SMP, isotopes of soil, surface water, groundwater and twig xylem water for the Wetland 1 GDE assessment area are presented in **Section 3.3**. Spatial details of sampling at the assessment area are shown in **Figure 15**.

3.3.1 Leaf Water Potential

Figure 16 shows LWP for individual trees at Wetland 1 GDE assessment area including repeat samples of the single red gum in the central portion of the wetland. It is apparent that the red gum is utilising a different water source to the melaleuca trees with a strongly negative LWP which is well below standard wilting point on both sampling events (11 August and 28 August 2018). In comparison, the melaleucas demonstrate extremely high LWP readings, generally around -0.3MPa, indicative of their access to a saturated, non-saline source of moisture. A summary of all trees sampled for LWP is provided in **Appendix A**.

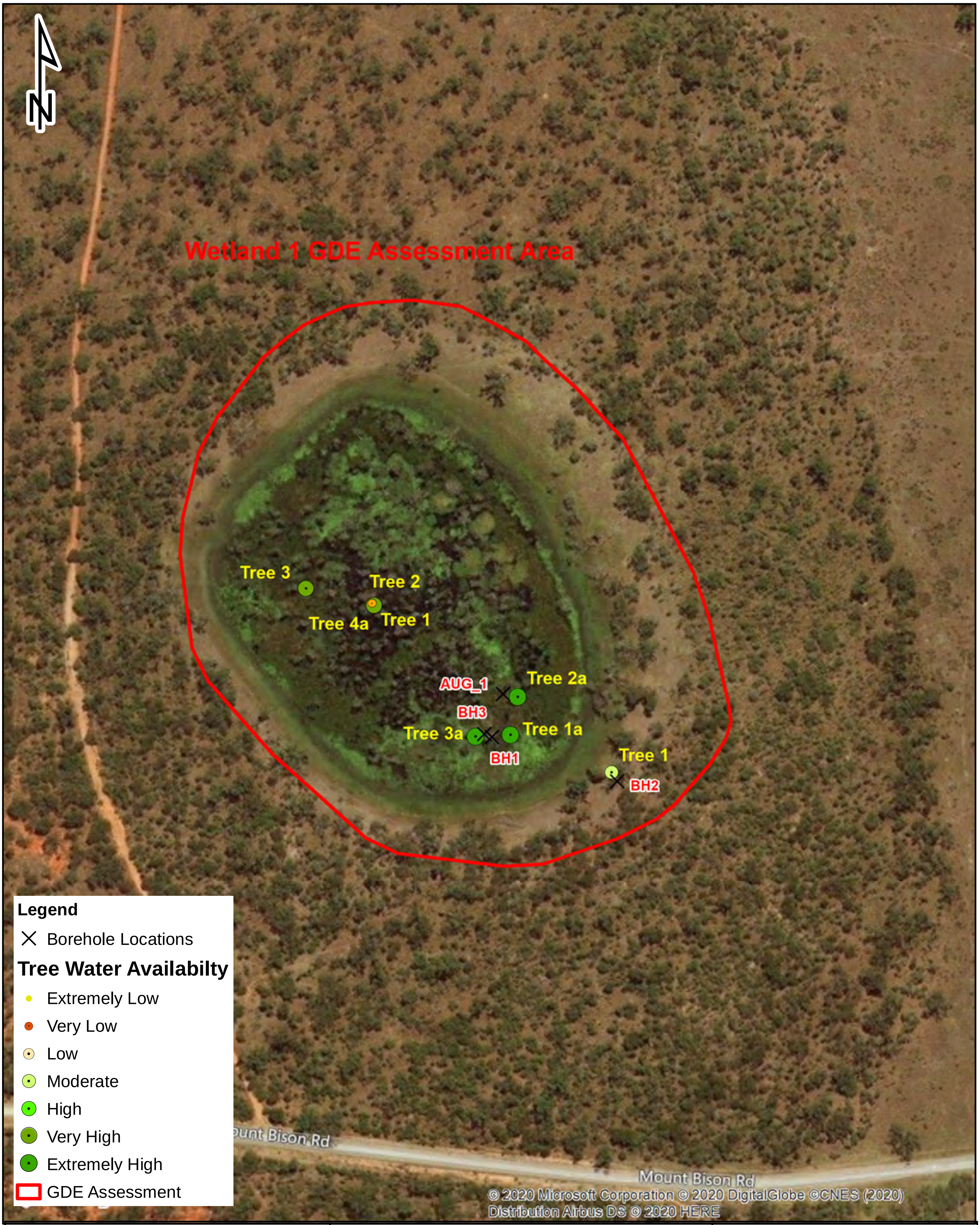

Figure 15. Tree water availability in Wetland 1 GDE assessment area

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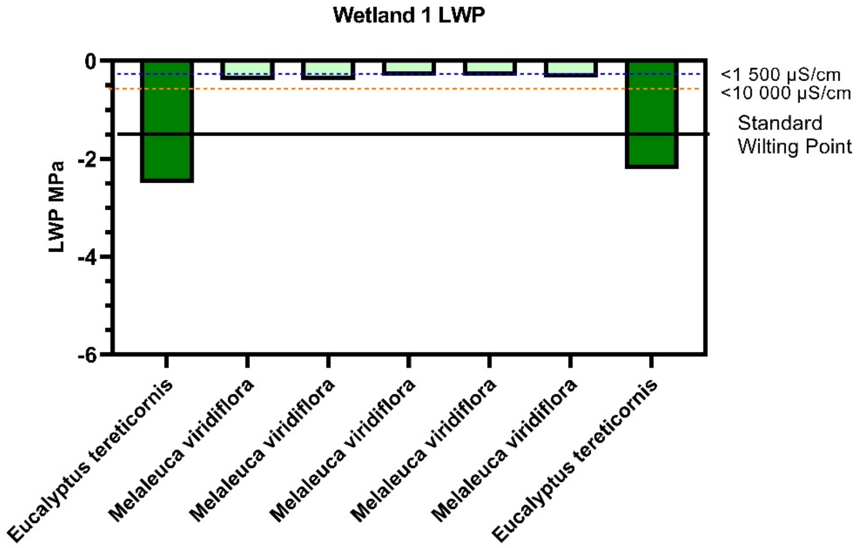

Figure 16. Leaf Water Potential for all GDE assessment areas. Black line indicates Standard Wilting Point (-1.5MPa).

3.3.2 Soil Moisture Potential

SMP down the combined borehole profile from BH1 and BH3 is shown **in Figure 17.** LWP for all trees is also shown with the average LWP of melaleuca trees indicated by the green line to the left (at -0.3 MPa) and the red gum indicated by the brown line at approximately -2.2 MPa. The LWP of the red gum corresponds to the SMP of the upper clay profile, a grey vertosol which extends to 1.3m depth below the surface of the wetland. This suggests that red gum is utilising moisture from this upper part of the clay pan where SMP is low. LWP from the melaleuca however corresponds to the SMP recorded from a narrow, saturated zone that was intersected at 8 mbgl in BH3. A second water strike at 13.5 mbgl was a more substantial aquifer that rose to 10 mbgl overnight, either under hydrostatic pressure or fed from the saturated zone above. A summary of geology from drilling of BH4 and BH5 is provided in **Appendix B** for reference.

3.3.3 Stable Isotope Analysis

Results of the stable isotope analyses are shown in **Figures 18,** indicates extremely strong isotopic enrichment in the upper 0.1m of the clay soil profile which would be typical of a clay pan that has been subject to strong evaporative enrichment of the overlying surface water. The isotopic signature of the melaleuca twigs overlaps those of the upper clay profile (0.2 to 1.0 mbgl) while the isotopic values obtained from the red gum twigs (T4a) indicate much stronger isotopic enrichment, suggesting the tree is accessing moisture from evaporatively enriched surface of the clay pan. It is noted that below 1m depth, isotopic values recorded in RC chips overlap broadly with isotopic values measured in groundwater samples. Interestingly, the isotopic signature of the melaleuca tree xylem (T1a, T2a, T3a) sits close to the LMWL (defined in blue) suggested limited evaporation while the red gum falls well south of the LMWL indicating the moisture sources it is utilising have been subject to considerable evaporative enrichment. Analytical analyses from stable isotope sampling is provided in **Appendix C**.

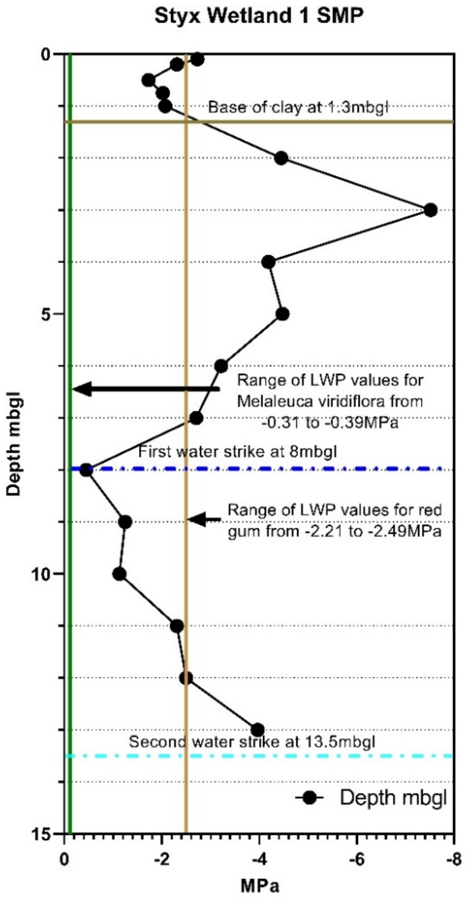

Figure 17. Downhole SMP for BH1 and BH3 showing position of the clay pan plus LWP for both the melaleuca and red gum which occupy the wetland.

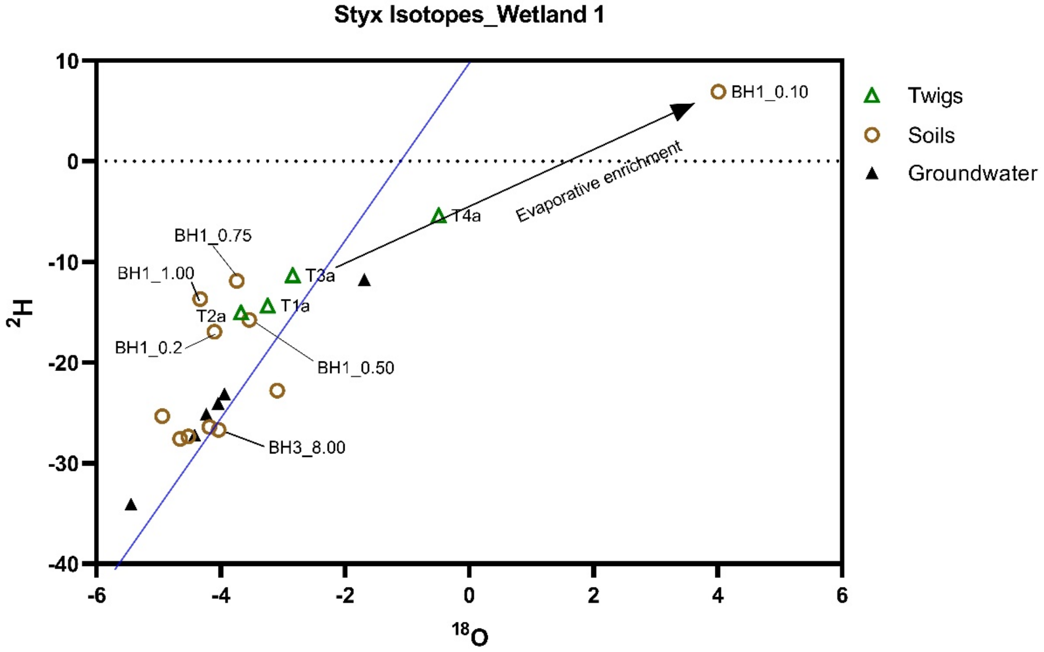

Figure 18. Biplot of stable isotope values for Wetland 1 comparing local groundwater values with isotopic signatures of soils and twig xylem. Blue line represents the LMWL.

3.4 Wetland 2 GDE Assessment Area

Assessment of the Wetland 2 GDE assessment area included measurement of LWP, SMP plus stable isotope analysis of water extracted from soil and twig xylem. The results of this assessment are presented in **Section 3.4**. Spatial detail of sampling points is provided in **Figure 19**.

3.4.1 Leaf Water Potential

Figure 20 shows LWP for the four individual trees that were sampled adjacent to Wetland 2. All trees were mature specimens of red gum or ironbark that are <10m from the wetland margins. The LWP for individual trees is relatively consistent, between -1.3 and -1.7MPa, suggesting that all plants are subject to some degree of water deficit, despite being adjacent to a surface water body that held water at the time of assessment. A summary of trees assessed at Wetland 2 is provided in **Appendix A**.

3.4.2 Soil Moisture Potential

Downhole SMP prepared from samples analysed from BH4 and BH5 is shown in **Figure 21.** The highest available soil moisture is evident at 2 to 3mbgl, falling off sharply below 4mbgl. LWP measurements correlate to SMP in the upper 3m of the soil profile. Based on strongly negative SMP values below 4m, there is no indication that trees could be accessing moisture from deeper than 4m. It should be noted the summary log from BH5 (see **Appendix B** and **Appendix C**) that the hole was dry to termination at 14.5mbgl with no saturated zone or aquifer intersected.

3.4.3 Stable Isotope Analysis

Results of the stable isotope analyses are shown in **Figures 22,** indicating relatively depleted isotopic signatures for the upper 4m of the soil profile, relatively consistent with the isotopic signature of local groundwater samples. Samples returned from RC drilling form a cluster that is isotopically enriched when compared to core samples, with a strong evaporative trend evident. This suggests that the drying effect of the RC drilling process has resulted in evaporative enrichment of the RC samples and caution should be applied to their use for interpretive purposes. There is also an evaporative trend apparent in the xylem samples with Tree 4 (*Eucalyptus tereticornis)* plotting on the LMWL and other trees offset below. Analytical results for stable isotopes are provided in **Appendix D**.

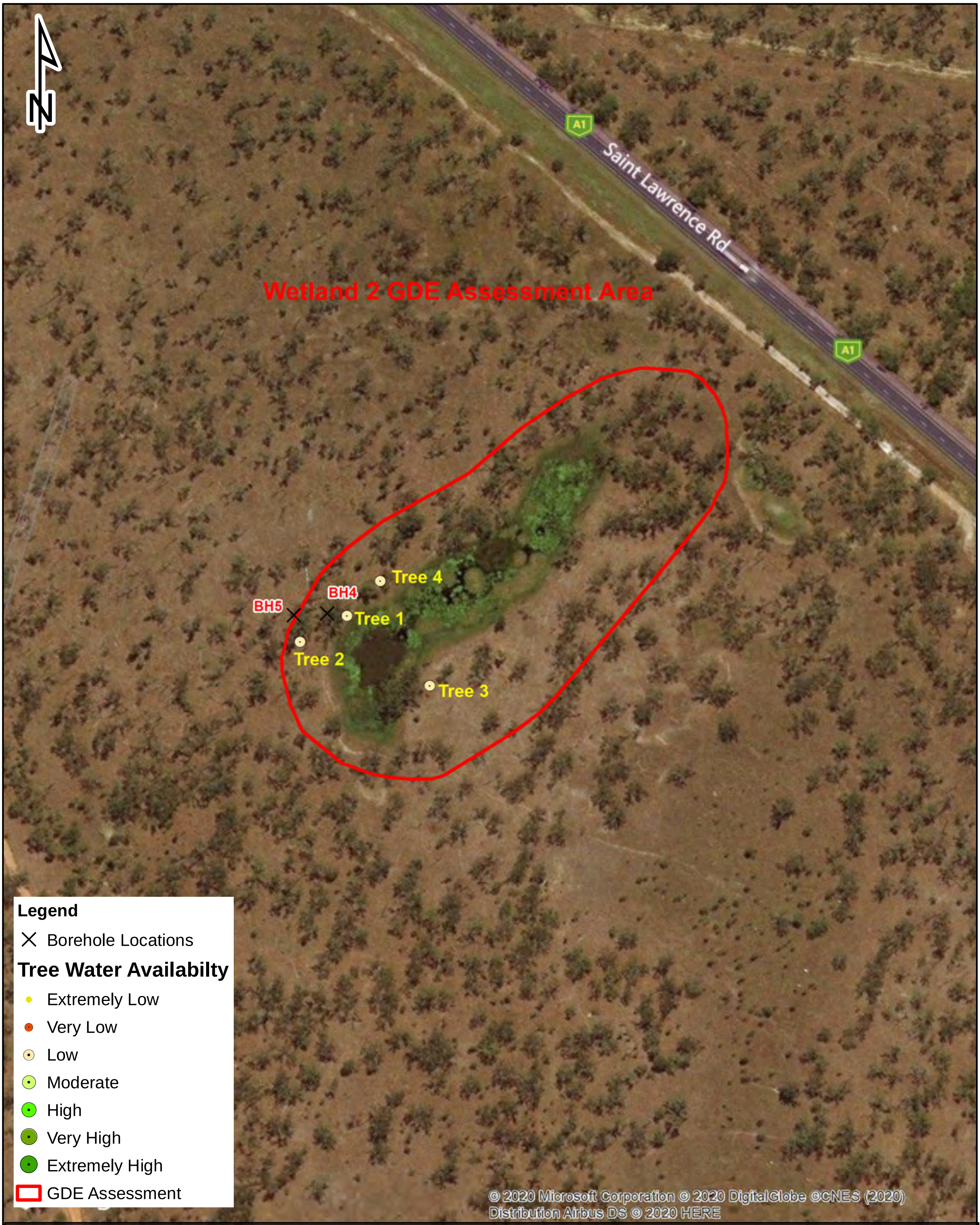

Figure 19. Tree water availability in Wetland 2 GDE assessment area

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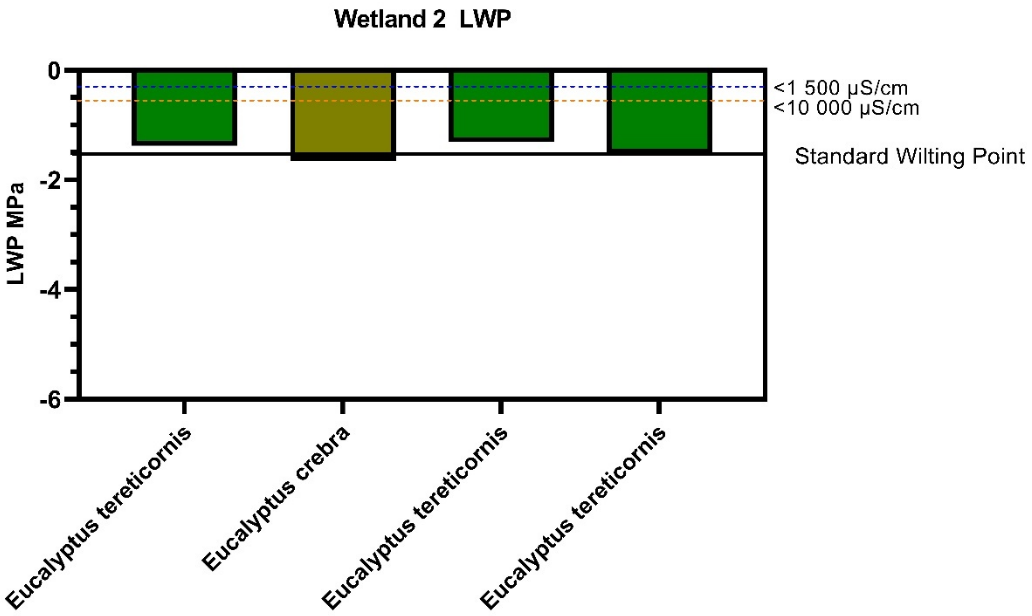

Figure 20. Leaf Water Potential for the Wetland 2 GDE assessment site showing relative consistency between all sampled trees. All trees have LWP more negative than would be expected for trees utilising a saline groundwater source.

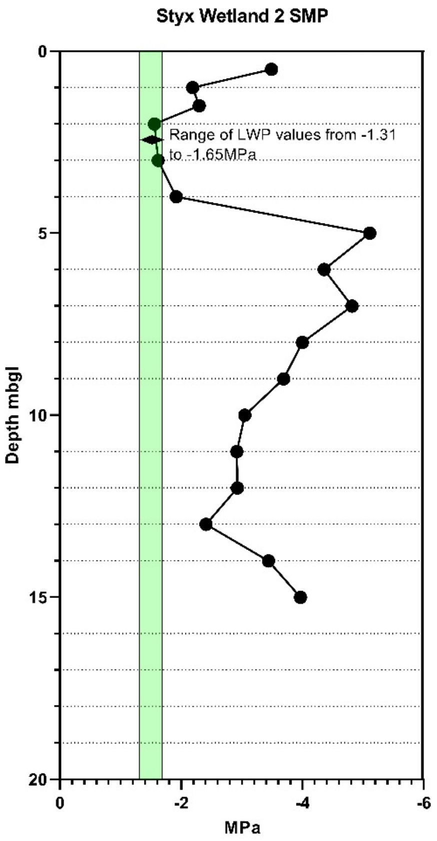

Figure 21. Downhole SMP for Wetland 2 constructed from BH4 and BH5. Note BH5 was dry to end of hole at 15m.

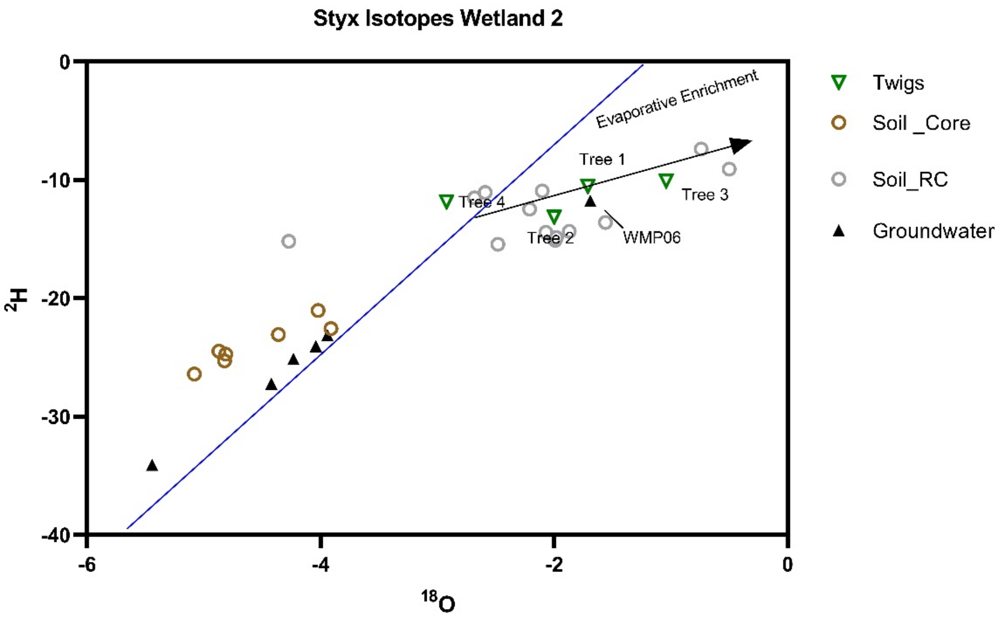

Figure 22. Stable isotope biplot for Wetland 2 showing LMWL in blue and evaporative trend for both the RC samples and twig xylem samples.

3.5 Vine Thicket GDE Assessment Area

Assessment parameters including LWP, isotopes of soil, surface water and twig xylem water for the Vine Thicket GDE assessment area are presented in **Section 3.5**. Additional features of relevance including local geomorphological controls and physical features identified within individual sections are also considered with spatial details of sampling undertaken at the site provided in **Figure 23**.

3.5.1 Leaf Water Potential

Figure 24 shows LWP for individual trees at the Vine Thicket GDE assessment area. It is noted that all vine thicket species (those excluding eucalypts) have LWP that is close to or more negative than standard wilting point m (-1.6 to -5.9MPa). This indicates that vine thicket trees are is a state of water deficit / stress. Comparatively, the two red gums (*Eucalyptus tereticornis)* have a much higher LWP (>-0.3MPa) than all vine forest species which indicates that water is being utilised from different sources. The strongly negative LWP values for vine thicket species indicate a moisture source that is relatively dry compared to the red gum which is utilising moisture from a source that is close to saturation (see **Appendix A** for tree details).

3.5.2 Soil Moisture Potential

Downhole SMP prepared from samples analysed from BH6 are shown in **Figure 25**. Significant points to note are that the deepest recorded roots of a vine forest species in BH6 are at 6.1mbgl from *Coatesia paniculata,* a specimen near which BH6 was positioned. Coatesia is easy to identify through vegetative features due to its strongly yellow sub-rhytidome layer which is evident in both bark and root samples (see **Figure 26**). The deepest root material of red gum was recorded at 9.5mbgl with matted roots observed to be penetrating along a coal seam (see **Figure 27**). It is fairly evident that coal seams provide a favourable substrate for tree root penetration on account of their permeable nature. The interface between Styx Coal Measures and alluvium in BH6 was at 8.6mbgl which would mean that Tooloombah Creek would be incised at least to the depth of alluvial unconformity. LWP values for vine thicket species range from -1.5 to -5.59 MPa which is corresponds to SMP's between depths of 2 and 8mbgl in alluvium. SMP's measured in the Styx Coal Measures are considerably higher (-0.81MPa measured in coal seams) which aligns with the much higher LWP measured in red gum. There may have been some loss of moisture from the coal seams during the drilling process which may have pushed the coals seams to slightly more negative SMP values when analysed.

3.5.3 Stable Isotope Analysis

Results of the stable isotope analyses for the Vine Thicket GDE investigation area is shown in **Figure 28**. It is apparent from the biplot that there is a broad overlap in isotopic signatures between soil samples (from BH6), groundwater and twigs although as a group, soils demonstrate the most isotopically depleted signatures, groundwater sits in the middle and twigs generally more enriched. Surface water samples lie on an isotopically enriched evaporative trend that is distinct from groundwater and soils. The single red gum sample that was analysed for xylem isotopes (T7a) sits in the middle of the broad cluster and appears indistinct from the twig samples obtained from vine thicket species. The general overlap between soils and groundwater indicate a common derivation or influence that is relatively close to their meteoric source.

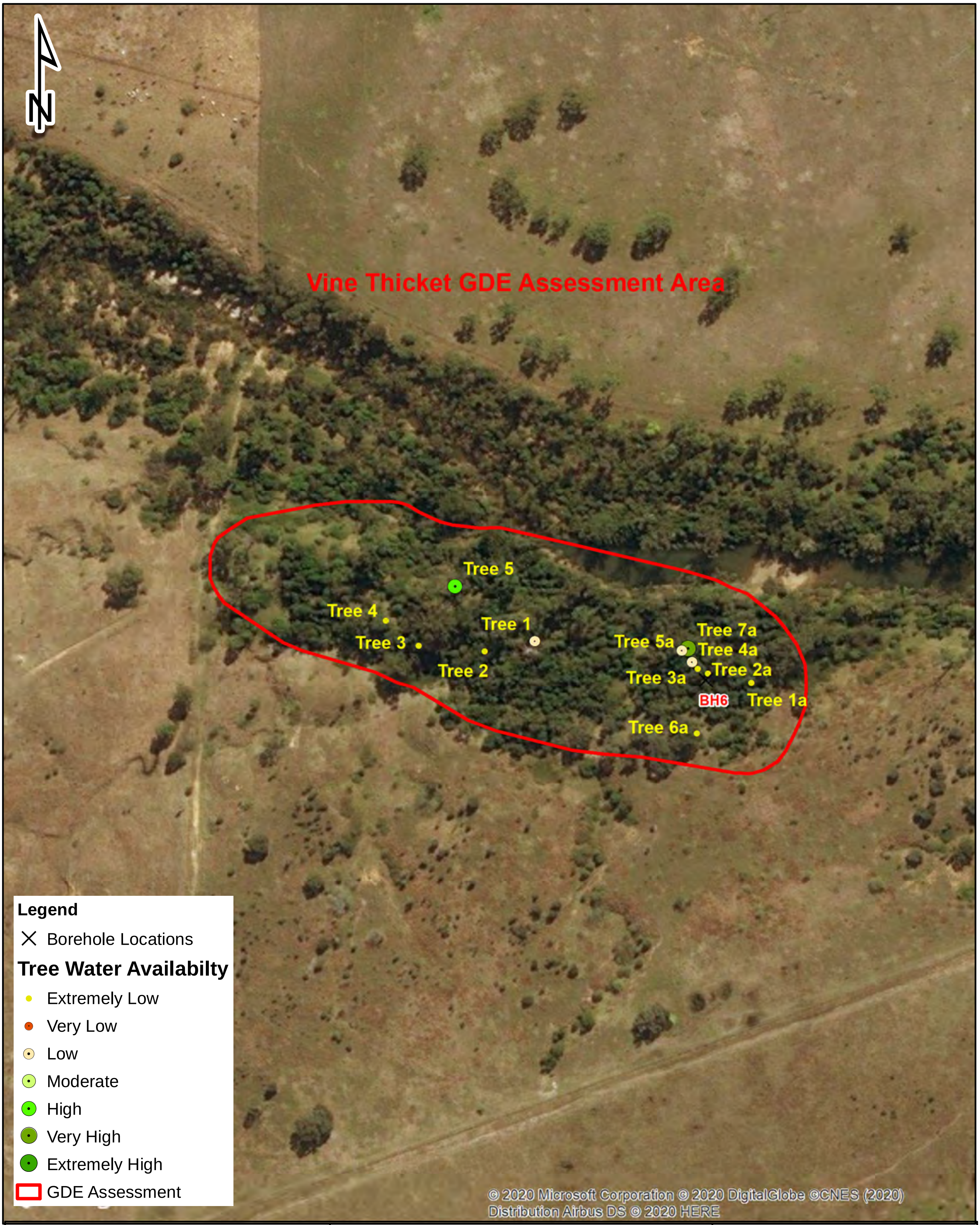

Figure 23. Tree water availability in Vine Thicket GDE assessment area

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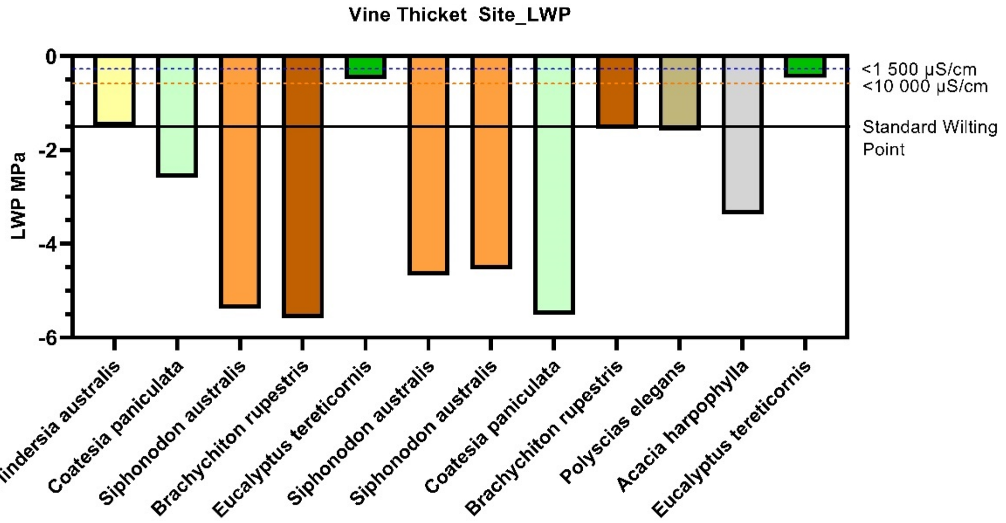

Figure 24. Leaf Water Potential for the Vine Thicket GDE assessment site demonstrating extremely low (negative LWP) for vine thicket species and relatively high LWP for the two sampled *Eucalyptus tereticornis,* approaching expected values for trees utilising a non-saline saturated source of moisture.

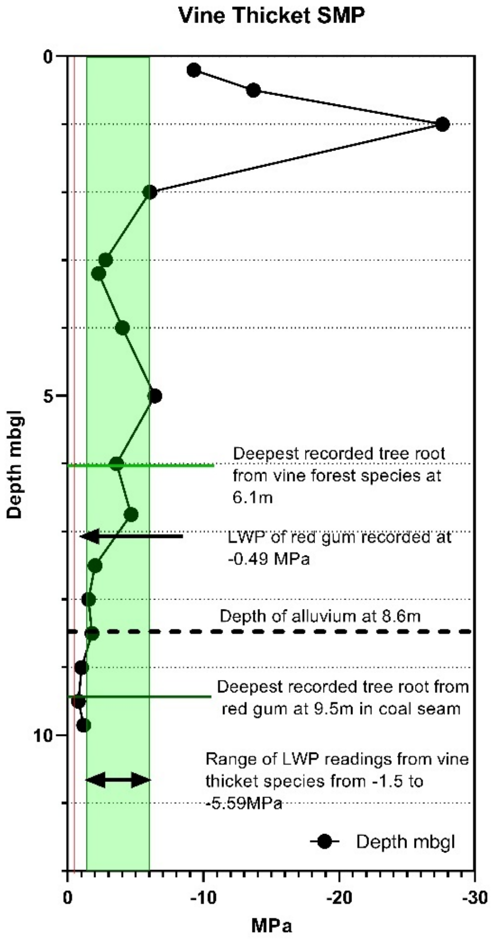

Figure 25. Downhole SMP for BH6 at the Vine Thicket GDE assessment area. The red line indicates LWP measured in red gum with the shaded green area the range of LWP recorded for vine thicket species, corresponding to largely to SMP's in the alluvium.

Figure 26. A tree root of *Coatesia paniculata* recorded at 6.1mbgl in BH6 with distinctive yellow colouration.

Figure 27. Matted roots of red gum penetrating along a coal seam at 9.5mbgl.

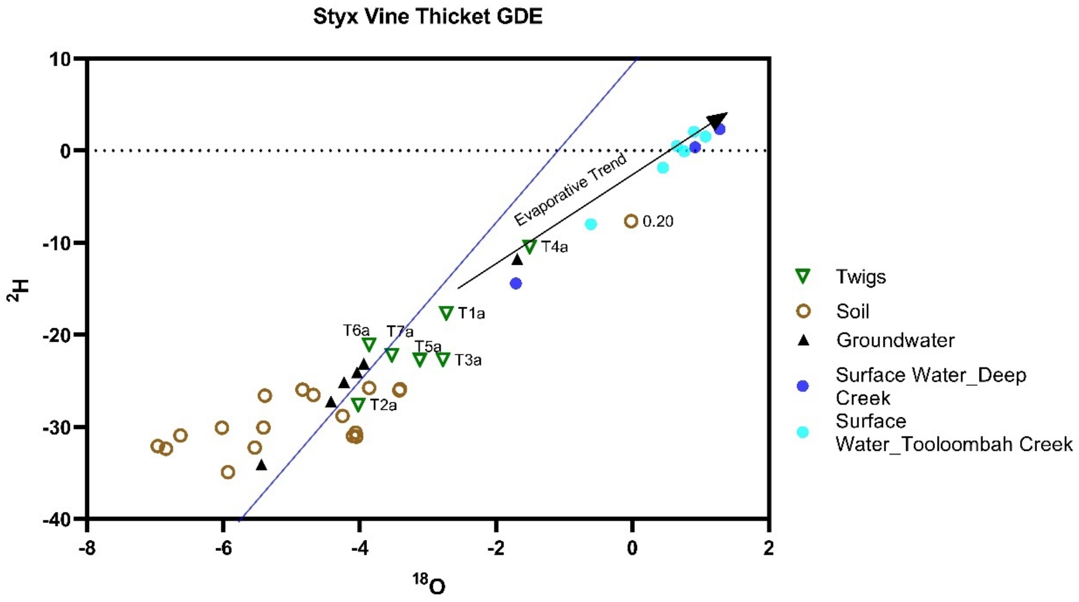

Figure 28. Stable isotope biplots for the Vine Thicket GDE investigation area. Isotopic signatures of surface water samples are plotted due to the proximity of the assessment area to a permanent pool on Tooloombah Creek.

3.6 Tooloombah and Deep Creek GDE Assessment Areas.

The Tooloombah and Deep Creek GDE assessment areas were targeted in the initial phase of field assessment between the 8th and 11th August, completed in conjunction with ecological biocondition surveys. For this reason, LWP was the only parameter assessed meaning inferences and similarities need to be drawn from more detailed GDE assessment localities. Details of sampling localities are shown in **Figure 29** and **Figure 30**.

3.6.1 Leaf Water Potential

LWP for the Tooloombah Creek and Deep Creek GDE assessment sites are shown in **Figure 31** and **Figure 32** respectively. LWP for two redgum measured on Tooloombah Creek are extremely high (both at -0.39MPa) indicating root access to a saturated or near saturated source of moisture. In contrast, LWP for the single weeping paperbark (*Melaleuca fluviatilis)* is considerably more negative (-2.2MPa), well below standard wilting point, indicative of considerable water deficit. It should be noted that the weeping paperbark specimen was located directly on the inner stream bank adjacent to a fluvial gravel bar, though the creek was dry at the locality at the time of survey.

For the Deep Creek GDE assessment site (**Figure 32**), all trees are accessing a saturated or near saturated water source with LWP values ranging from -0.3 to -0.39 MPa. Compared to Tooloombah Creek, the two measured weeping paperbark specimens, which have a similar position on the inner creek bank, have extremely high LWPs (note *Melaleuca leucadendra* compared to *Melaleuca fluviatilis*). At the Deep Creek site, the stream channel is extremely sandy and there were interconnected pools present at the time of assessment which would provide considerable moisture nourishment to both the stream banks and channel deposits.

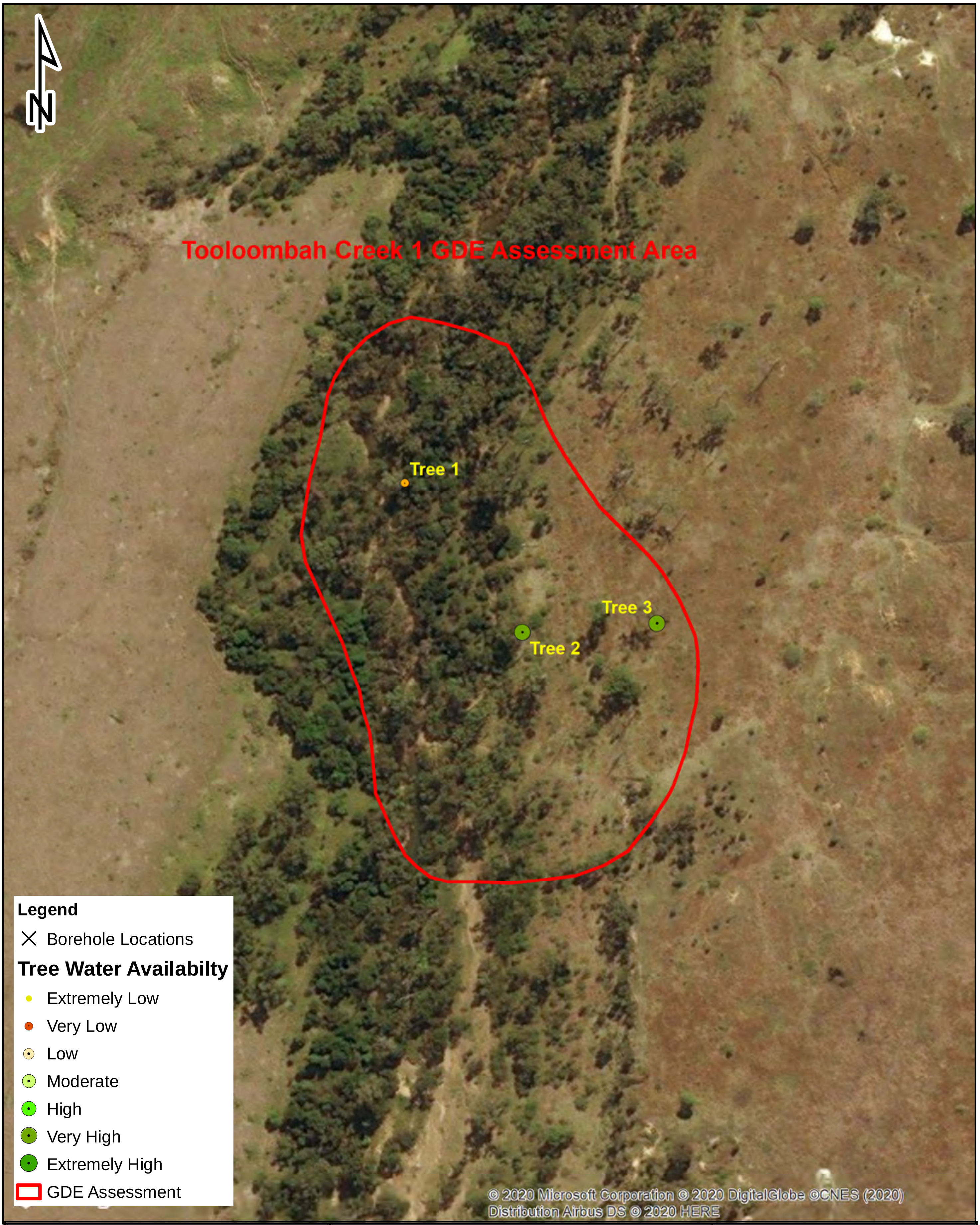

Figure 29. Tree water availability in Tooloombah Creek 1 GDE assessment area

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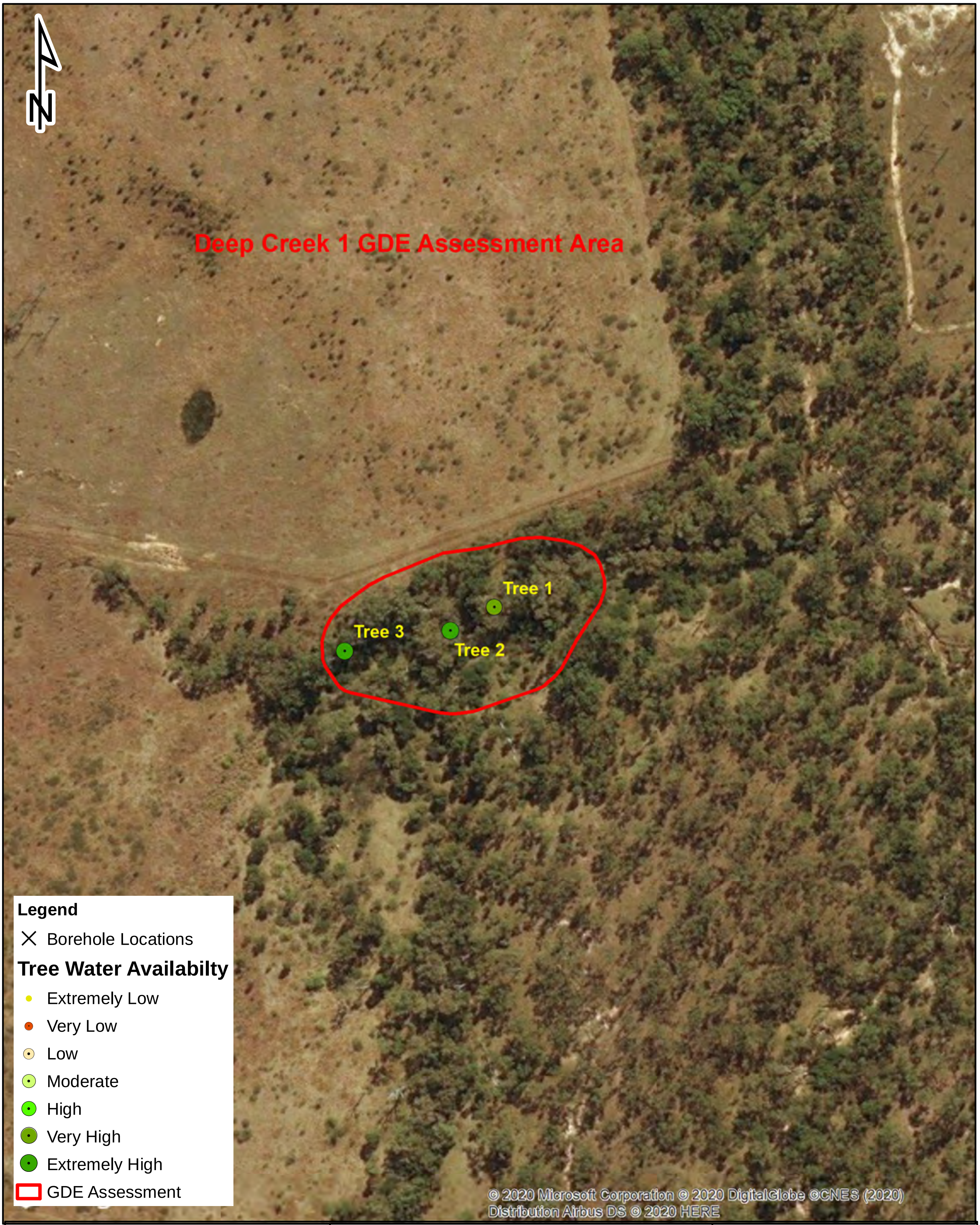

Figure 32. Tree water availability in Deep Creek 1 GDE assessment area

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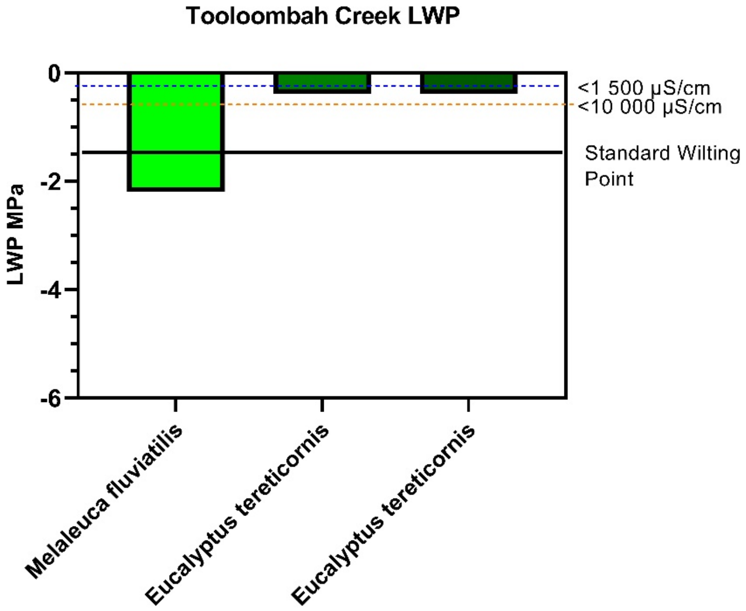

Figure 31. LWP for three trees measured at the Tooloombah Creek GDE assessment area with *Melaleuca fluviatilis* demonstrating significant water stress.

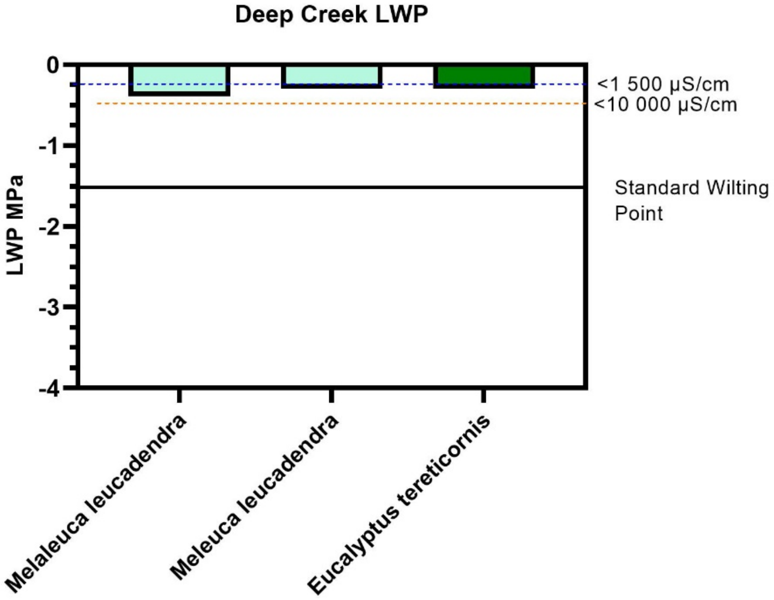

Figure 32. LWP for three trees measured on Deep Creek with all trees demonstrating utilisation of a saturated source of moisture.

4. Discussion

This assessment provides an initial characterisation of the sources of water utilised by riparian vegetation mapped as GDE's within the Central Queensland Coal Project Area. To account for climatic variables (e.g. rainfall and temperature) that influence the source of water utilised by trees, the collection of biophysical and isotopic data over an extended time frame that accounts for seasonal variation may be required to fully characterise plant/water relations and determine seasonal vegetation dependence on groundwater. The one-off sampling event undertaken during this study may not provide enough temporal context to allow tree / water interactions to be interpreted with confidence at all GDE assessment sites. However, some inferences can be drawn which are useful to initial characterisation and assessment of potential project related impacts.

For ease of reference, the discussion has been divided into GDE assessment areas to allow integration of results from LWP, stable isotope assessments and other notable features. Where appropriate, and where assessment areas have been identified as likely GDEs, preliminary conceptual models have been developed to contextualise the current understanding of tree / groundwater relations and provide a basis for further refinement.

4.1 Wetland 1 GDE Assessment Area

The Wetland 1 GDE assessment area is unusual in a local context as it represents a localised catchment area with no outflow. Therefore, the only pathway for captured surface water is either evapotranspiration or percolation into the soil and subsoil. The comparison of SMP and LWP data provides the most powerful interpretive tool for assessment of plant / water interactions in this case. The narrow saturated layer recorded at 8mbgl during the drilling of BH3 corresponds precisely with the LWP recorded in all samples of broad-leaved paperbark that were analysed at the site. There are no options for a saturated source of soil moisture that is shallower in the profile under the dry conditions at the time of survey. As discussed in **Section 1.5,** broad-leaved paperbark can develop a dimorphic root system which has capacity to utilise shallow sources of moisture in the upper soil profile when available, though switch to deeper sources of groundwater when surface conditions dry out. This dynamic is strongly supported by the propensity of fine tree roots recorded in the upper 1.3m of BH1 within the perched clay pan (see **Appendix B**). Infiltration of water would likely occur when the swamp holds ponded surface water with percolation downward to the first aquitard inferred from the BH3 to be at 8mbgl. Initial infiltration of surface water would be by diffuse flow in the upper clay profile and then along preferential flow pathways in fractured basement rock to the aquitard. The water seeking root system of the broad-leaved paperbark would have capacity to follow downward percolating water along fracture plains in weathered basement rock to the depth of the first saturated water source. While a deeper aquifer was intersected at 13.5mbgl, there would be no impetus for the tree roots to penetrate deeper than the initial zone of saturation. The conceptualisation of vegetation / groundwater relations in wet and dry seasonal conditions are presented in **Figure 33a** and **Figure 33b**. In comparison to the broad-leaved paperbark, the single red gum that occupies the central portion of the swamp is utilising moisture and nutrients from the upper clay pan only, as indicated by the close match between the SMP in the clay profile (-1.73 to - 2.7MPa) and the LWP measured in the tree (up to -2.49MPa). Persistence of this tree would be reliant on seasonal replenishment of moisture in the clay pan rather than utilisation of a deeper groundwater source.

The stable isotope signatures of both soil and twig xylem does raise a few questions and it may require sampling over several seasons before the patterns in isotopic signatures in tree xylem become apparent. There is noted strong enrichment of isotope values in twigs from the broad-leaved paperbark over the those of the soil from their postulated source of water at 8mbgl. The trend for isotopic enrichment is not readily explained although in some cases, the size of the offset between isotopic values of groundwater and twigs provides the greatest insight into plant water relations and this offset is likely to vary seasonally. There is some expected enrichment of stable isotope values with movement of water through tree xylem (Petit and Froend 2018) and recent studies indicate that soil / stem isotopic offsets may be caused by water isotope heterogeneities within the soil pores, which would be masked under drier conditions due to evaporative enrichment. Hence the closer the plant is to its permanent wilting point, the closer the isotopic signatures of the soil moisture and xylem moisture will be. Plants with access to a saturated water source may demonstrate the largest offset in isotopic composition of twigs and xylem of all (Barbeta et al 2020[1]).

Figure 33a - Wetland 1, Dry Season Scenario

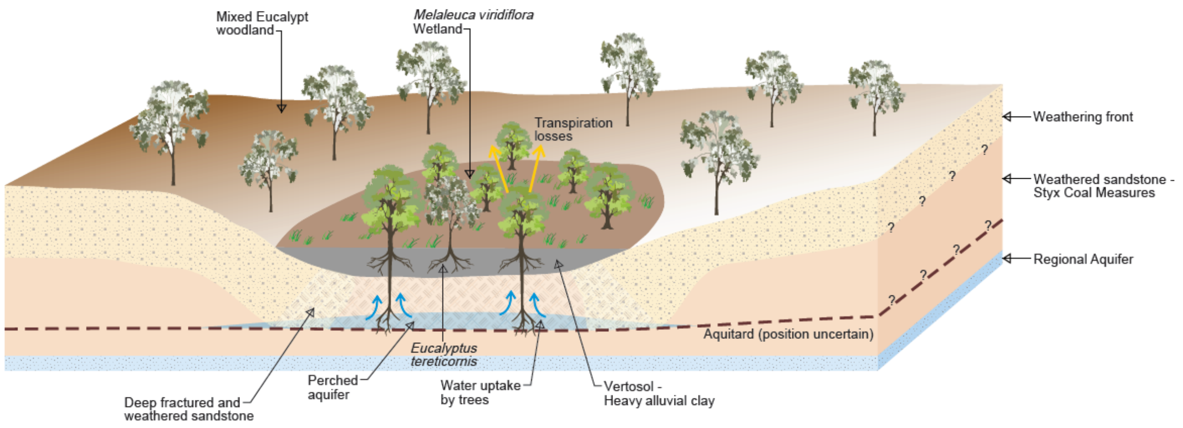

Figure 33b. Wetland 1 - Wet Season Scenario

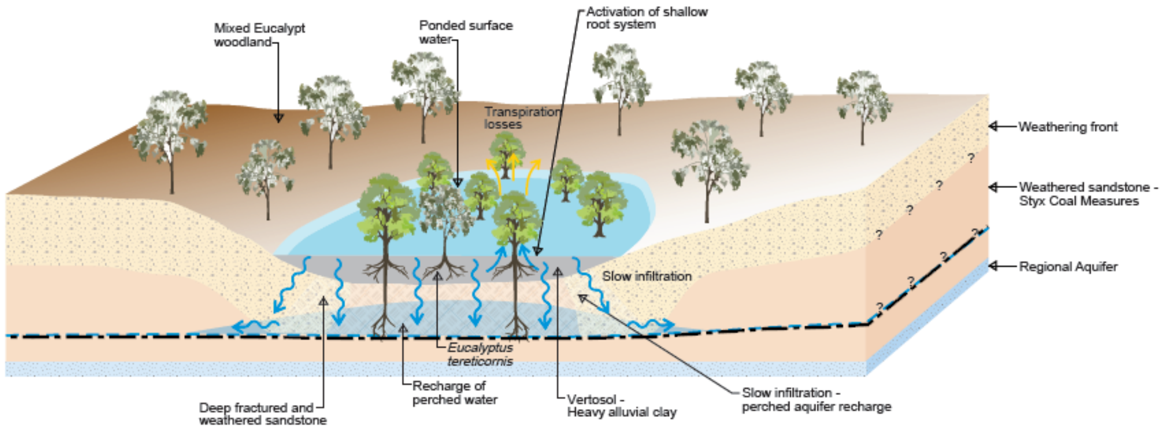

Figure 33. Conceptual ecohydrological model of the Wetland 1 GDE assessment area demonstrating plant / water relations in both dry season (Figure 33a) and wet season (Figure 33b) scenarios. The location of the cross section is indicated in **Figure 5, Section 2.1**.

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[1] Advance manuscript accepted for publication in March 2020

4.2 Wetland 2 GDE Assessment Area

Mature trees at the Wetland 2 GDE assessment area provide no indication of groundwater use or use of any other saturated water source. A combination of LWP and SMP assessment provides clear evidence that trees are utilising soil moisture in the interval from 2 to 4mbgl. This is supported by a lack of a groundwater intersection in BH5 which was drilled to 15mbgl, near the expected maximum rooting depth for red gum and much deeper than the expected rooting depth of ironbark. Like Wetland 1, the degree of separation between stable isotope signatures of twigs and soil is problematic and would require ongoing seasonal monitoring to decipher. However, in the context of this assessment, all lines of evidence indicate Wetland 2 is a surface drainage feature with no connectivity to deeper groundwater sources. Trees on the fringe of Wetland 2 are sustained by soil moisture which is recharged during rainfall with deeper percolation of surface moisture occurring when the wetland depression breaches during flooding. Wetland 2 should not be considered a GDE and no conceptual model has been developed.

4.3 Vine Thicket GDE Assessment Area

Obtaining continuous soil core from 0 to 10mbgl in BH6 greatly increased confidence in the assessment of vegetation groundwater dependence at this locality. There is clearly a separation in water sources utilised by the vine thicket trees and the much taller red gum which characterise the adjacent riparian woodland and form scattered emergents above the vine thicket canopy.

All assessment parameters, including an overlap of xylem and soil isotope signatures, plus matching of LWP and SMP measurements between twig xylem and alluvial soils in the upper 8m of BH6 suggest that vine thicket species are accessing soil moisture in the unsaturated zone, from the thick deposits of alluvium, at the time of the assessment. These indications are supported by physical evidence from drill core where the maximum observed rooting depth of the vine forest tree *Coatesia paniculata* was recorded at 6.1mbgl, consistent with evidence from biophysical measurements and isotopes. As the assessment was undertaken after a prolonged dry spell, there is no indication that groundwater would be utilised on a seasonal basis in this locality. The continued maintenance of soil moisture would be reliant on seasonal rainfall and flood rises in Tooloombah Creek which would facilitate lateral infiltration of flood water into the stream banks. The capacity for moisture recharge would be enhanced by the flood overflow channel which would hold surface water for periods following overbank flow at a level above the stream channel and extend the capacity for surface water infiltration.

In contrast, the emergent red gum is from all indications, utilising a saturated source of soil moisture that is held in saprolite, and associated thin weathered coal seams below the alluvium / Styx Coal Measures unconformity. In the absence of precise survey, the alluvial / Styx Coal Measures unconformity corresponds roughly to the position of the incised depth of the Tooloombah Creek channel, a position which would facilitate recharge of surface water into the creek banks and along the unconformity during periods of creek hi-flow. Notable is the general overlap between isotopic signatures of groundwater and soil moisture at this assessment locality suggesting soil moisture and groundwater held in stream banks are derived from a common source. The similarity in isotopic composition also suggests that surface water infiltration into the soil profile is via a slow moving wetting front whereby new water pushes older water deeper into the profile (termed ‘piston flow’) as described in Zimmerman et al (2010) and Cheng et al (2014). This mechanism of infiltration imparts isotopic heterogeneity in the soil profile, controlled by changes in soil permeability, while the derived groundwater would generally be enriched above meteoric values.

The preliminary conceptual model for this system is presented in **Figure 34a** (dry season), **Figure 34b** (wet season) and **Figure 34c** (drought). This model demonstrates:

1. The separation of moisture sources for red gum and vine thicket;
2. The recharge of groundwater into stream banks during flood events creating a bulge in the groundwater table adjacent to the stream, and;
3. Gentle baseflow from the along the alluvial unconformity back into the Tooloombah Creek surface water, which may sustain streamflow during drier periods.

There is also a distinct possibility that residual pools in Tooloombah Creek provide a meagre recharge to alluvial groundwater reserves during drought.

The question of salinity remains problematic to the model and from **Table 1** (**Section 1.3**), groundwater salinities in alluvial bores that range from 2567 to an extremely saline 47700 µS/cm. Eamus et al (2006b) identifies river red gum as being a relatively salt-tolerant species, growing well in soil salinities of almost 1,500 µS/cm. In addition, Mensforth et al. (1994) identified that river red gum will continue to utilise groundwater with salinity as high as 40,000 µS/cm in the absence of a fresh source of soil moisture, although higher levels of tree stress will be apparent. Hence, while the upper salinity levels in alluvial aquifer do not necessarily preclude its utilisation by deep rooted trees, LWP will be much lower under high salinity regimes. There is however no indication that red gum trees were being stressed by salinity at the time of the assessment and LWPs of >-3 MPa indicated trees are close to equilibrium with a non-saline (<1,500 µS/cm) saturated source of moisture. For those areas underlain by more saline groundwater, increasing groundwater salinity will decrease the degree and likelihood of its utilisation by groundwater dependent vegetation.

There is also evidence from AgTEM surveys (Allen 2019) showing that electrical conductivity decreases significantly on the margins of major watercourses, possibly reflecting lower groundwater salinity on the fringes of watercourses or possibly a lens of freshwater sitting over the top of saline groundwater. This scenario is supported by measurements of LWP from red gum on the alluvial fringe undertaken during this assessment, which show no signs of osmotic stress that would be expected with utilisation of saline groundwater.

Figure 34a. Tooloombah Creek Vine Thicket Dry Season Scenario

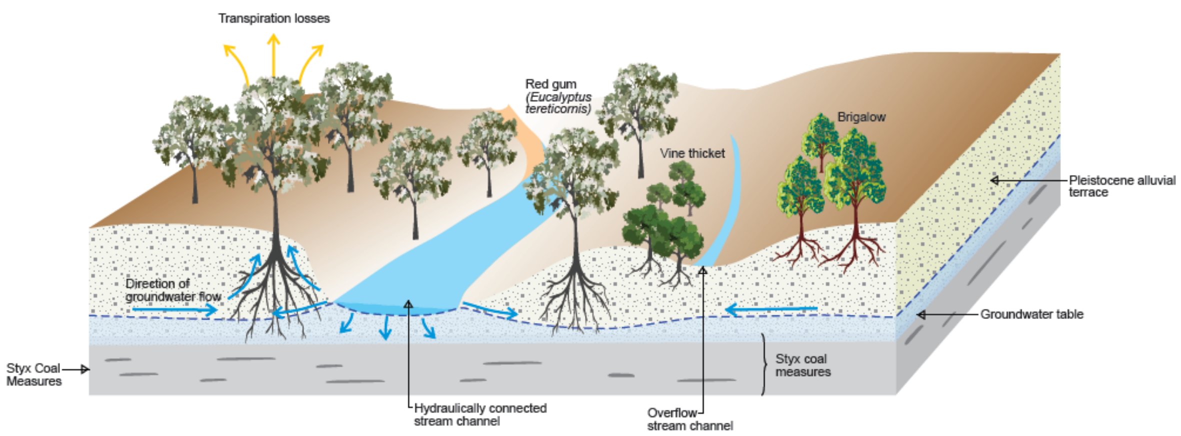

Figure 34b. Tooloombah Creek Wet Season Scenario

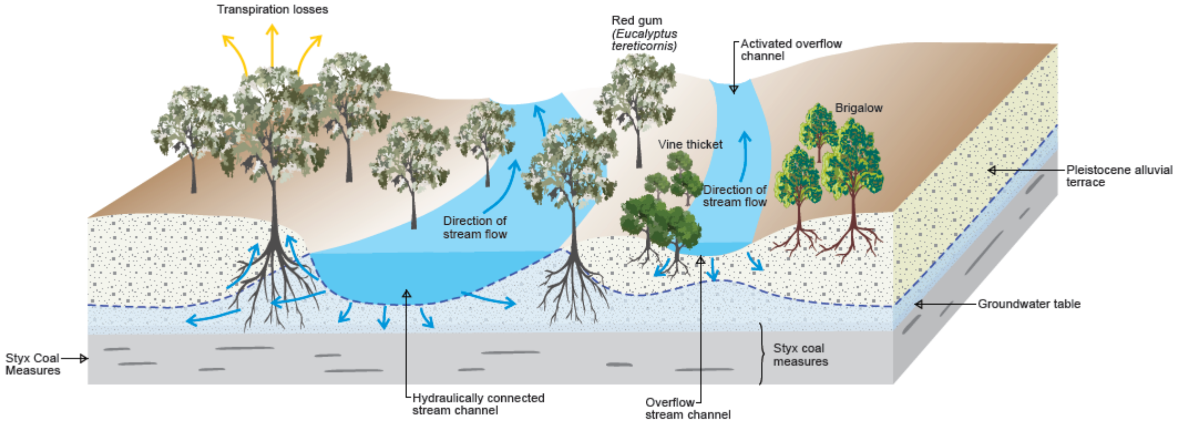

Figure 34c. Tooloombah Creek Drought Scenario

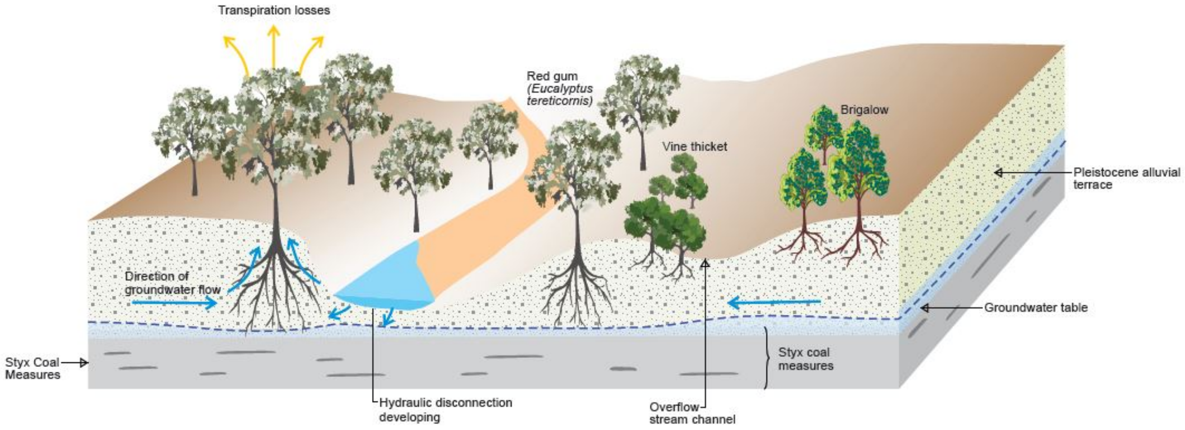

Figure 34. Conceptual ecohydrological model for the Vine Thicket GDE assessment site. Figure 34a shows the modelled ecohydrological regime during a typical average dry season scenario; Figure 34b through a period of creek hi-flow with stream bank recharge, and: Figure 34c shows the modelled ecohydrological function during a drought period. The location of the cross section is indicated in **Figure 7, Section 2.1**

4.4 Tooloombah Creek GDE Assessment Area

To a large part, the Tooloomba Creek GDE assessment area mirrors the ecological function of the Vine Thicket GDE site except that it lacks the well-developed alluvial terrace supporting the vine thicket vegetation. Although drill coring, SMP measurements and isotope analysis were not undertaken, the availability of deeper moisture sources to fringing red gum forests are strongly apparent from LWP measurements and it is anticipated that these red gum are utilising a similar saturated water source held at the Styx Coal Measures / Alluvial unconformity. Interestingly, the large specimen of weeping paperbark that was sampled, being the tree closest to the stream channel, showed considerable water stress. LWP measurements for this tree are well below those of the more distal red gum and well below standard wilting point. This highlights the differing water harvesting strategies employed between red gum and weeping paperbark with the paperbark adapted to harvest surface water during stream flow with a root system that binds the upper soil profile on the stream banks. It seems apparent that the weeping paperbark, being a riparian fringe specialist, lacks the sinker roots that would enable it to harvest deeper sources of saturated soil moisture.

Based on the presence of red gum, the Tooloombah Creek frontage at this location would likely meet the definition of a GDE, although the level of groundwater dependence of riparian vegetation varies between species. The modelled groundwater usage is best represented by the conceptual model developed for the Vine Thicket GDE assessment area without the vine thicket, with the water harvesting strategies of the fringing weeping paperbark represented in the conceptual model developed for Deep Creek. A scenario where river water was derived partially from baseflow would however render any trees reliant on the harvesting of surface water as demonstrating groundwater dependence to some degree.

4.5 Deep Creek GDE Assessment Area

The frontage of Deep Creek differs from Tooloombah Creek, possessing a much narrower channel incision with thick deposits of coarse sand rather than gravel and rock bars. There is also a reasonably well- developed inner terrace that is occupied by frequent weeping paperbark with tree roots that bind the stream banks and extend into the stream channel.

At the time of assessment, based on LWP measurements, all trees assessed including red gum and weeping paperbark were accessing a saturated water source. The stream channel was formed by a series of disconnected pools interspersed with deep sand bars which would also have capacity to hold significant reserves of water. The weeping paperbark were clearly utilising this surface water source and tree root were observed extending into the surface pools.

The single sampled red gum was located high on the upper terrace approximately 10m above and at least 20m from the stream channel. The extremely high LWP measured for this tree (-0.3MPa) indicates its utilisation of a saturated, non-saline source of moisture. Based on data and observations collected at other GDE assessment localities, this saturated source of groundwater would lie at the base of the alluvial unconformity. The depth of this unconformity isn’t as tightly constrained as the Vine Thicket GDE assessment area as it lacks the physical evidence derived from drill core. It is however anticipated that the unconformity would lie at a similar physical position at a level that approximates the depth of the stream channel incision.

The preliminary conceptual model shown in **Figure 35** presents a similar regime to Tooloombah Creek with dry season baseflow returning to the stream channel. The baseflow would help maintain water reserves in the sandy channel and surface pools, prolonging their persistence and extending the availability of the saturated water source to the fringing weeping paperbark (Figure 35a).

Wet season hi-flows would facilitate a recharge of the alluvial aquifer with lateral flow into the stream banks and levees, creating a bulge in the groundwater lens adjacent to the stream channel (Figure 35b). This bulge would prolong discharge of groundwater into the stream channel well after hi-flows had passed and may also facilitate lateral movement of groundwater back along the alluvial unconformity. This lateral water movement would assist regulation of groundwater salinity levels and maintain health of the fringing red gum.

The movement of groundwater during drought periods is a little more difficult to predict though it is possible that any persisting pools in the stream channel would lose surface water to provide meagre recharge to the alluvial aquifer (Figure 35c). The risk of increased salinity might only manifest after an extended drought, when surface pools had thoroughly dried and net groundwater flow along the alluvial unconformity was predominantly toward the stream channel.

Figure 35a. Deep Creek - Dry Season Scenario

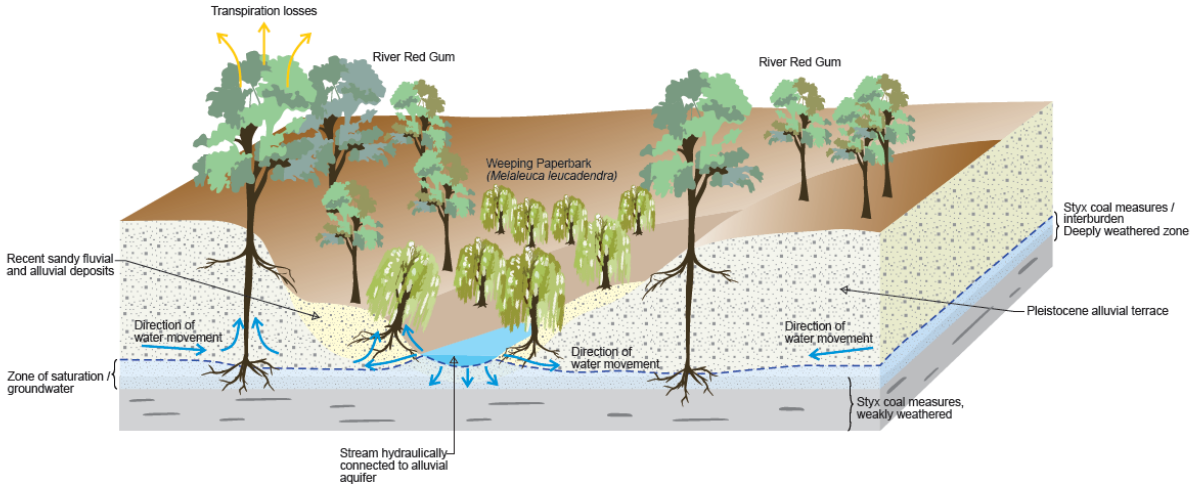

Figure 35b. Deep Creek Flood Scenario

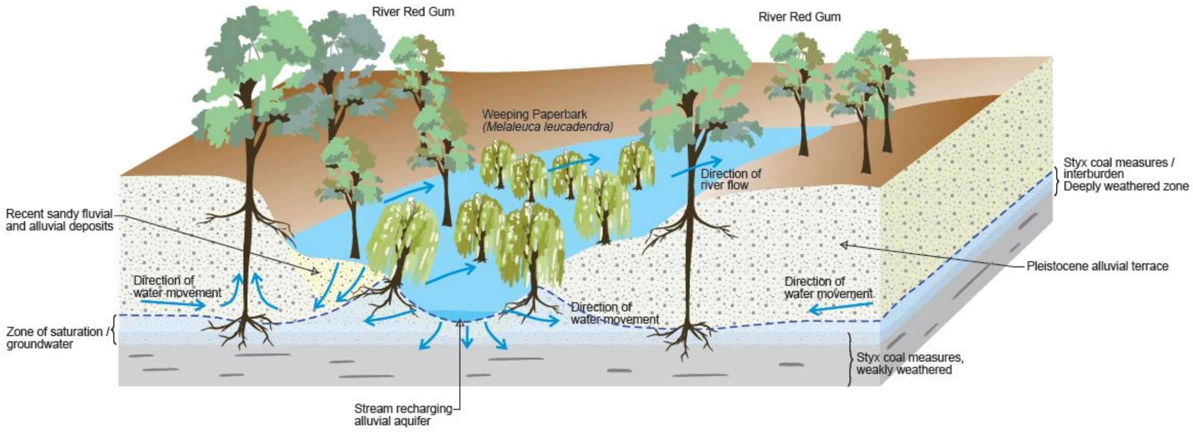

Figure 35c. Deep Creek Drought Scenario

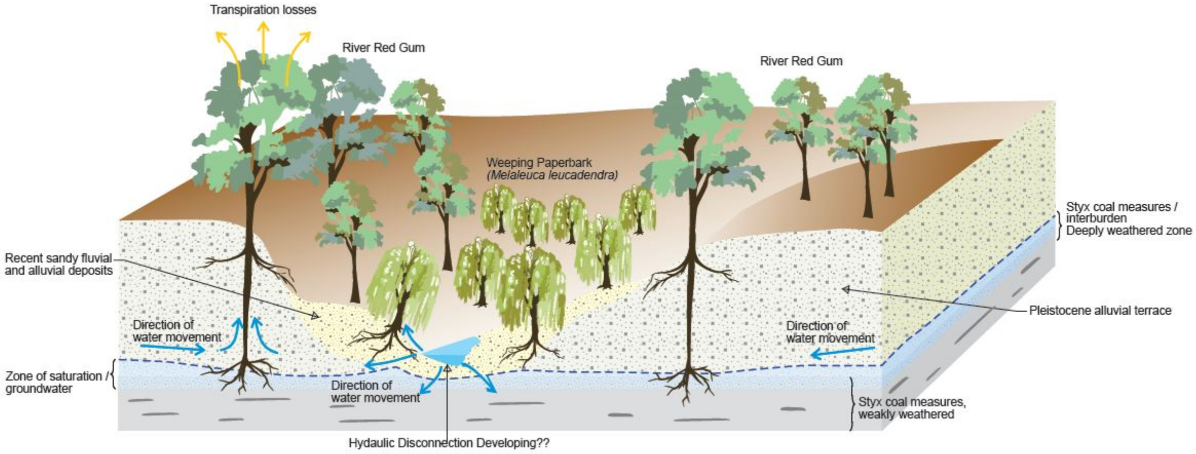

Figure 35. Conceptual ecohydrological model for Deep Creek GDE assessment area showing dry season scenario (Figure 35a), wet season scenario (Figure 35b) and drought scenario (Figure 35c). The location of the cross section is indicated in **Figure 9, Section 2.1**

5. Conclusions

Based on measurement of LWP and SMP, supplemented with analysis of stable isotope signatures extracted from soil, twigs, surface water and groundwater, the following conclusion are reached regarding the water usage of riparian vegetation at each of the representative GDE assessment sites:

1. The Wetland 1 GDE investigation area is a relatively unique landform element with no obvious inflow or outflow conduits and a localised catchment area. Extremely high LWP readings coupled with evidence from SMP measurements taken down borehole indicate that the woodland of broad-leaved paperbark at the Wetland 1 GDE investigation area are utilising a saturated source of moisture perched at 8mbgl. The saturated zone is most likely maintained by percolation of surface water from the wetland through the overlying clay pan along fracture zones in basement rock. Water seeking tree roots from the broad-leaved paperbark have been able to follow the percolating groundwater downward along the fracture plains with the saturated zone providing a source of moisture to sustain the woodland vegetation during drought periods. There would be no impetus for tree roots to penetrate deeper than the saturated zone at 8mbgl and it is unlikely that they would be tapping the deeper aquifer intersected at 13.5mbgl. Based on this information, Wetland 1 GDE investigation area does represent a terrestrial GDE although the groundwater source is likely to be localised and not laterally extensive.
2. The Wetland 2 GDE investigation area is an internally drained surface water feature that his linkage to surface water flow paths that become more obvious to the east of the Bruce Highway. Mature canopy trees surrounding the wetland depression were in a state of water deficit at the time of assessment, all demonstrating LWP's that were at or approaching standard wilting point. Downhole SMP measurements indicate trees are utilising of soil moisture from the top 2 to 4m of the soil profile. This soil moisture would only be recharged following infiltration of seasonal rainfall or breach of the swamp depression during flooding. A borehole drilled to 15mbgl at the assessment locality did not intersect any saturated zones in the soil, nor any aquifer and it is considered groundwater resources are below the maximum rooting depth of mature trees in the vicinity. The Wetland 2 GDE assessment area is inferred to not represent either an aquatic or terrestrial GDE.
3. At the locality of the Vine Thicket GDE investigation area, the channel of Tooloombah Creek broadens with the development of an internal alluvial terrace and channel overflow path that hosts a well-developed vine thicket community. Assessment of LWP, downhole SMP and stable isotopes of soil moisture, xylem and groundwater all suggest that vine thicket trees are accessing a source of soil moisture in the unsaturated zone, above the alluvial unconformity with the Styx Coal Measures. This is further supported by physical observations from boreholes which show a maximum rooting depth of approximately 6mbgl for vine thicket trees. Emergent red gum which are often associated with the riparian fringe do however possess LWP that demonstrates access to a non-saline saturated source of moisture. Evidence from drill core indicates that these trees are utilising moisture within narrow coal seams in weathered portions of the Styx Coal Measures immediately below the alluvial unconformity at a depth of approximately 9mbgl. Recharge of this moisture would be facilitated by stream hi-flow periods which would result in lateral movement of floodwater into the stream banks and allow gradual baseflow return to the stream during dryer periods. The overlap of stable isotope signatures between soil and groundwater

samples indicate a common derivation, most likely imparted by floodwater that has a stable isotope signature close to meteoric values, with mixing of isotopic signatures during infiltration of surface water into the soil. While the vine thicket component of this assessment locality is inferred to not represent a GDE, the riparian fringes and associated emergent red gum is likely to represent a terrestrial GDE that is dependent on groundwater contained within the shallow coal measures and the associated alluvial unconformity. The Tooloombah Creek watercourse would also likely represent an aquatic GDE based on an inferred linkage between surface water pools to groundwater via baseflow. Baseflow is sustained by bank recharge during surface flows and flooding and the impact of mining void development on baseflow mechanisms needs to be explored during impact assessment.

4. Both Tooloombah Creek and Deep Creek GDE investigation sites demonstrate that red gum on both lower and upper terraces are accessing a saturated moisture source and similar to the Vine Thicket GDE assessment site, this water is inferred to be held at or near the alluvial unconformity with the weathered Styx Coal Measures. Weeping paperbark however appear to utilise a different water harvesting strategy that relies on access to surface water in stream pools and fluvial sands rather than employing a sinker root with capacity to access deeper water sources. Like the Vine Thicket GDE investigation site, red gum associated with the riparian fringe are the likely to be utilising groundwater and hence the system would represent a terrestrial GDE. The potential for baseflow of groundwater into both drainage systems suggests that these watercourses would be consistent with the definition of an aquatic GDE and hence weeping paperbark would still fit the definition of groundwater dependent vegetation. Further assessment of baseflow mechanisms, recharge rates and discharge rates is required to assess the impact of mine void development on the aquatic GDE system.

A summary of assessment parameters and a likelihood that an assessment site represents a GDE is provided below in **Table 4**.

Table 4. Assessment of vegetation groundwater dependence and likelihood of site being representative of a GDE.

GDE Assessment Area	LWP and SMP Measurements	Stable Isotope Analysis	Other Features	Assessment of Groundwater Dependence	Likelihood of Site Representing a GDE
Wetland 1 GDE Assessment Area	• All broad-leaved paperbark have extremely High LWP (typically -0.31 to -0.39MPa) which indicates near equilibration with a saturated non-saline water source. Downhole SMP measurements indicate that the source of water is likely to coincide with a saturated zone at 8mbgl. • The single red gum in the central portion of the wetland has an extremely negative LWP suggesting that it is utilising moisture from the upper clay pan.	Stable isotope signatures of twig xylem moisture in all tree samples is enriched above soil samples indicating that the moisture source utilised by trees has been subject to evaporative enrichment. The reason for this enrichment is not clear following a one-off sampling event.	Broad-leaved paperbark are known to have capacity to develop a dimorphic root system with capacity to utilise multiple water sources dependent on availability. This is consistent with matted tree roots in the upper clay pan accessing water when the surface soils are moist with deeper sinker roots accessing deeper groundwater when the swamp is dry.	• Broad-leaved paperbark trees are inferred to be phreatophytes with dependence on groundwater reserves during periods of drought. • Red gum in this locality does not show indications that it is tapping a deeper groundwater source and all lines of evidence suggest reliance on moisture that is tightly held in the upper clay pan.	**Likely:** The Wetland 1 GDE assessment area is dependent on groundwater resources to sustain ecological function during periods when the wetland surface is dry. This site represents a terrestrial GDE.
Wetland 2 GDE Assessment Area	• LWP for all trees ranges from -1.3 to -1.6MPa which indicates that availability of moisture was low at the time of assessment. • Downhole SMP measurements indicate tree moisture is being accessed from 2 to 4mbgl in the upper soil profile.	• Stable isotope signature of twig xylem moisture in all tree samples are enriched above soil samples from the upper 4m of the soil profile indicating some degree of evaporative enrichment. Like Wetland 1, the reason for this isotopic enrichment of twigs over soil	BH6 was drilled to 15m, near the maximum anticipated rooting depth of eucalypt trees with no groundwater intercepted.	• Comparison of LWP and SMP results suggests trees are accessing moisture from the upper soil profile. • Stable isotope signatures indicate strong enrichment of twig xylem over local groundwater sources indicating that there is no common linkage. • Groundwater is below the likely maximum rooting	**Unlikely:** During an extended dry period, trees are utilising soil moisture and groundwater is not accessible.

GDE Assessment Area	LWP and SMP Measurements	Stable Isotope Analysis	Other Features	Assessment of Groundwater Dependence	Likelihood of Site Representing a GDE
		samples is not clear following a one-off sampling event.		depth of trees at the assessment locality.	
Vine Thicket GDE Assessment Area	• LWP for all vine thicket trees ranges from -1.49 to -5.59 MPa indicative of significant water deficit. LWP corresponds to SMP measurements in the unsaturated zone within alluvial soils. • LWP measurements from red gum trees that were emergent at the site were -0.49 and -0.46MPa which indicates equilibration with a saturated or near saturated non-saline source of moisture. • Downhole SMP measurements indicate a correlation between LWP in the red gum and SMP at 9.5mbgl within weathered Styx Coal Measures.	• Stable isotope values of twigs for both vine thicket trees and red gum, soils and groundwater all show some degree of overlap suggesting a common provenance. • Stable isotope signatures of groundwater and soils are likely to be influenced by recharge during flood events with floodwater that has undergone limited evaporative enrichment.	• Deepest tree roots from vine thicket species were observed at 6mbgl in drill core supporting the findings of the LWP and SMP assessment. • Deepest tree roots observed for red gum were at 9.5mbgl which is consistent with measurement for LWP and SMP.	• LWP of vine thicket trees does not indicate any reliance on a saturated groundwater source and this is supported by data from downhole SMP measurements. • LWP for emergent red gum suggests equilibrium with a saturated moisture source and correlation with SMP measurements suggests water is being accessed from coal seams at 9.5mbgl. • The utilisation of water held in the Styx Coal Measures is supported by observations of tree root material held in coal seams retrieved from borehole samples.	**Vine Thicket - Unlikely:** All indications are that vine thicket trees and shrubs are utilising soil moisture over groundwater. **Red Gum – Likely:** LWP, SMP, stable isotope analysis all suggest red gum are utilising a saturated source of moisture within the weathered interface between the Styx Coal Measures and alluvium. This site is likely to represent both a terrestrial (red gum) and aquatic (creek) GDE.

GDE Assessment Area	LWP and SMP Measurements	Stable Isotope Analysis	Other Features	Assessment of Groundwater Dependence	Likelihood of Site Representing a GDE
• Tooloombah Creek and Deep Creek GDE assessment area	• LWP for red gum indicates equilibrium with a saturated source of soil moisture. • LWP for weeping paperbark at Tooloombah Creek indicates considerable water deficit and stress despite proximity to creek channel. • LWP for red gum and weeping paperbark at the Deep Creek GDE assessment site indicates utilisation of a saturated water source for both species.	• Not undertaken	• Not undertaken	• Tooloombah Creek and Deep Creek GDE assessment areas both demonstrate reliance of red gums on a saturated source of soil moisture. Similar to the vine thicket GDE investigation site, this source of moisture is inferred to be at the interface between the weathered Styx Coal Measures and the alluvial unconformity. There is inferred reliance of red gum of groundwater and potential baseflow from groundwater into drainage for sustained periods following flooding. • Weeping paperbark is inferred to have seasonal reliance on surface water flows although due to likelihood of sustained baseflow, would still be considered groundwater dependent vegetation.	**Likely:** Based on LWP measurements and observed similarities to the Vine Thicket GDE assessment site, Deep Creek and Tooloombah Creek sites are both considered to represent terrestrial and aquatic GDEs.

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7. Appendices

Appendix A. Tree Sampling / Twig Summary

Date	Location	Tree No.	South	East	Species	Girth (DBH) (cm)	Height (m)	Topographic Location	Surface Soil Structure	Water Potential (MPa)	Tree Water Availability	Notes
Vine Thicket GDE Assessment Area												
10.08.18	Tooloombah Creek	Tree 1	-22.6831	149.6484	*Findersia australis*	40	18	Top of T2 Terrace	fine silty sand	-1.49	Low	
10.08.18	Tooloombah Creek	Tree 2	-22.6832	149.6481	*Coatesia paniculata*	25	12	Top of T2 Terrace	fine silty sand	-2.59	Extremely Low	
10.08.18	Tooloombah Creek	Tree 3	-22.6832	149.6478	*Siphonodon australis*	40	15	Top of T2 Terrace	fine silty sand	-5.39	Extremely Low	
10.08.18	Tooloombah Creek	Tree 4	-22.6830	149.6476	*Brachychiton rupestris*	150	23	Top of T2 Terrace	fine silty sand	-5.59	Extremely Low	
10.08.18	Tooloombah Creek	Tree 5	-22.6829	149.6480	*Eucalyptus tereticornis*	120	26	Outer margins of lower / T1 Terrace	fine silty sand	-0.49	High	
29.08.18	Tooloombah Creek	Tree 1a	-22.6833	149.6494	*Siphonodon australis*	25	13	Top of T2 Terrace	fine silty sand	-4.68	Extremely Low	
29.08.18	Tooloombah Creek	Tree 2a	-22.6833	149.6492	*Siphonodon australis*	35	13	Top of T2 Terrace	fine silty sand	-4.55	Extremely Low	

Date	Location	Tree No.	South	East	Species	Girth (DBH) (cm)	Height (m)	Topographic Location	Surface Soil Structure	Water Potential (MPa)	Tree Water Availability	Notes
29.08.18	Tooloombah Creek	Tree 3a	-22.6832	149.6492	*Coatesia paniculata*	35	12	Top of T2 Terrace	Fine silty sand	-5.52	Extremely Low	
29.08.18	Tooloombah Creek	Tree 4a	-22.6832	149.6491	*Brachychiton rupestris*	100	14	Top of T2 Terrace	fine silty sand	-1.55	Low	
29.08.18	Tooloombah Creek	Tree 5a	-22.6832	149.6491	*Polyscias elegans*	30	13	Top of T2 Terrace	fine silty sand	-1.58	Low	
29.08.18	Tooloombah Creek	Tree 6a	-22.6835	149.6492	*Acacia harpophylla*	50	17	Mid-way up slope between T1 and T2 Terrace	Silty sand	-3.37	Extremely Low	Up slope from vine thicket habitat on the margins of the T3 Terrace.
29.08.18	Tooloombah Creek	Tree 7a	-22.6832	149.6491	*Eucalyptus tereticornis*	85	25	Part way downslope, approximately 3m below top of T2 terrace.	Silty sand	-0.46	Very High	Part of riparian fringing habitat RE11.3.25
Wetland 2 GDE Assessment Area												
30.08.18	Wetland 2	Tree 1	-22.6961	149.6345	*Eucalyptus tereticornis*	100	24	5m from margins of wetland	Silt and clay	-1.38	Low	
30.08.18	Wetland 2	Tree 2	-22.6962	149.6343	*Eucalyptus crebra*	45	21	5m from margins of wetland	Silt and clay	-1.65	Low	
30.08.18	Wetland 2	Tree 3	-22.6964	149.6349	*Eucalyptus tereticornis*	70	24	3m from margins of wetland	Silt and clay	-1.31	Low	
30.08.18	Wetland 2	Tree 4	-22.6959	149.6346	*Eucalyptus tereticornis*	70	24	3m from margins of wetland	Silt and clay	-1.52	Low	
Wetland 1 GDE Assessment Area												

Date	Location	Tree No.	South	East	Species	Girth (DBH) (cm)	Height (m)	Topographic Location	Surface Soil Structure	Water Potential (MPa)	Tree Water Availability	Notes
11.08.18	Wetland 1	Tree 1	-22.7088	149.6355	*Eucalyptus tereticornis*	40	18	Central region of wetland.	Heavy clay with hummocky surface microtopography	-2.49	Very Low	Wetland habitat totally dry at time of survey and ground cover sedges and forbs desiccated. Only representation of red gum in the wetland
11.08.18	Wetland 1	Tree 2	-22.7088	149.6355	*Melaleuca viridiflora*	35	17	Central region of wetland adjacent to single red gum	Heavy clay with hummocky surface microtopography	-0.39	Very High	Wetland habitat totally dry at time of survey and ground cover sedges and forbs desiccated
11.08.18	Wetland 1	Tree 3	-22.7087	149.6352	*Melaleuca viridiflora*	30	16	Mid-central portion of wetland	Heavy clay with hummocky surface microtopography	-0.39	Very High	Wetland habitat totally dry at time of survey and ground cover sedges and forbs desiccated
30.08.18	Wetland 1	Tree 1a	-22.7094	149.6362	*Melaleuca viridiflora*	38	17	Central region of wetland.	Heavy clay with hummocky surface microtopography	-0.31	Extremely High	Very strong dew on the date of sample
30.08.18	Wetland 1	Tree 2a	-22.7092	149.6362	*Melaleuca viridiflora*	32	16	Central region of wetland.	Heavy clay with hummocky surface microtopography	-0.31	Extremely High	Very strong dew on the date of sample
30.08.18	Wetland 1	Tree 3a	-22.7094	149.6360	*Melaleuca viridiflora*	34	16	Central region of wetland.	Heavy clay with hummocky surface microtopography	-0.34	Extremely High	Very strong dew on the date of sample
30.08.18	Wetland 1	Tree 4a	-22.7088	149.6355	*Eucalyptus tereticornis*	40	18	Central region of wetland.	Heavy clay with hummocky surface microtopography	-2.21	Very Low	Very strong dew on the date of sample
30.08.18	Margins of Wetland 1	Tree 1	-22.7096	149.6367	*Eucalyptus acmenoides*	75	19	Margins of wetland above clay pan	Fine to medium silty sand	-0.96	Moderate	Very strong dew on the date of sample. Limited soil moisture information due to difficult drilling conditions
Tooloombah Creek GDE Assessment Area												

Date	Location	Tree No.	South	East	Species	Girth (DBH) (cm)	Height (m)	Topographic Location	Surface Soil Structure	Water Potential (MPa)	Tree Water Availability	Notes
06.08.18	Tooloombah Creek	Tree 1	-22.6773	149.6536	*Melaleuca fluviatilis*	130	25	Top of inner bench that forms drainage channel	Silty river sand	-2.2	Very Low	Tree is located on the top of bank on inner stream bench. No surface water along reach associated reach of creek.
06.08.18	Tooloombah Creek	Tree 2	-22.6779	149.6542	*Eucalyptus tereticornis*	100	22	Mid position on second (T2) river terrace	Silty sand /loam	-0.39	Very High	Mid position on T2 river terrace
06.08.18	Tooloombah Creek	Tree 3	-22.6779	149.6548	*Eucalyptus tereticornis*	90	23	Outer position on second (T2) river terrace at base of T3 terrace	Silty sand /loam	-0.39	Very High	
Deep Creek GDE Assessment Area												
07.08.18	Deep Creek	Tree 1	-22.7053	149.6851	*Melaleuca leucadendra*	80	23	Lower river terrace adjacent to stream channel	Silty sand / loam	-0.39	Very High	Surface water in pools in stream channel
07.08.18	Deep Creek	Tree 2	-22.7054	149.6848	*Meleuca leucadendra*	100	25	Lower river terrace adjacent to stream channel	Silty sand / loam	-0.3	Extremely High	Surface water in pools in stream channel
07.08.18	Deep Creek	Tree 3	-22.7055	149.6843	*Eucalyptus tereticornis*	140	35	Upper river terrace on breakaway	Silty loam	-0.3	Extremely High	Large canopy tree that has been damaged by fire. Sample taken from flow branch developed from epicormic growth.

Appendix B. Soil Auger Summary

BH 1 _ Location		**-22.709418**	**149.636083**					
BH2_Location		**-22.70962**	**149.63673**					
BH3_Location		**-22.70943**	**149.63612**					
Auger 1		**-22.709237**	**149.63617**					
BH1_Depth		**4.2m**						
BH2_Depth		**4.0m**						
BH3_Depth		**14.0m**						
Auger 1_Depth		**1.3m**						
Date		**28-Aug-18**						
Explanation:								
BH1 was drilled dry using push tubing down to a depth of 1.4 where a hard band of calcrete was intersected and push tubing failed. Drilling continued from 1.4m to 4.2m using percussion and water injection to characterise geology. Sampling was not completed below 1.4 m due to contamination. refusal using push tubing. Drill hole 5 was drilled dry with an RC rig to 15m depth to point of maximum likely rooting depth.								
BH2 was drilled on the margins of the wetland in a position elevated above the clay pan. The push tubing failed at 45 cm due to hard basement rock. Drilling continued to a depth of 4.0m using rotary percussion and water injection to characterise geology. Sampling was not undertaken due to contamination.								
BH3 was drilled dry using rotary percussion and air injection for sampling. The specific purpose was to sample geology and gain an understanding of local hydrogeology. As no water was utilised during drilling, it was possible to identify water strike and allow sampling to proceed. Moisture was intersected in a narrow interval at around 8m depth with an aquifer intersected at 13.5m.								
Auger 1- was sampled with a hand auger to gain a better understanding of shallow geology. Failure at 1.4m when calcrete band was was encountered. Not sampled.								
Note: Aquifer strike at 13.5mbgl. Bore was dipped on 30th August and water had risen to 10.5mbgl. Possibly from artesian pressure or seepage from moist zone intersected at 8.0m.								

BH1_BH3								
Depth		**Geology**	**Organics/ Root Material**		**Additional Notes**	**Drilling Method**		
1 to 0.2m		**Silty clay:** Grey brown dry calywith 5% sand and ironstone gravel fragments. Minor yellow /orange mottling and ironstone staining. Minor organic content and root material, Very dry.	Fine matted root material in layers		Cracking clay at surface. Recent alluvium.	Push tubing - core to depth of 1.4m in BH1		
0.2 to 1.3m		**Plastic clay**: Grey / grey brown clay with yellow / orange mottling. Moist with minor fine root material.	Minor fine root material		Recent clay pan			
1.3 - 1.4m		**Calcrete??**: Hard, grey cemented layer.	No root material identified		Basement rock interface	Push tubing failure		

1.4 - 2.0m		**Sandstone**: Grey / white fine grained quartz rich arenite.	NA		Sandstone country rockk	Rotary percussion rig with air in BH3. Sampling commenced at 1.4m depth. Chips only		
2.0 to 3.0m		**Sandstone:** Grey / white fine grained quartz rich arenite. Ironstone gravel with some orange and red iron staining on sandstone grains and fracture surfaces.	NA		Sandstone country rock	Chips only		
3.4 to 4.0m		**Sandstone:** Fine to medium grained arkosic sandstone. Red iron staining (hematite) in matrix with orange (limonite) staining on fracture surfaces. Some ironstone gravel.	NA		Sandstone country rock	Chips only		

4.0 to 5.0m		**Sandstone:** Fine to medium grained arkosic sandstone. Red iron staining (hematite) in matrix with orange (limonite) staining on fracture surfaces. Some ironstone gravel.	NA		Sandstone country rock	Chips only		
5.0 to 6.0m		**Sandstone / gravelly sandstone:** Fine to medium grained sandstone with strong orange ironstone staining. Rounded gravel and pebble sized clasts of iron stained sandstone and ironstone.			Sandstone country rock	Chips only		

6.0 to 7.0m		**Sandstone / gravelly sandstone:** Fine to medium grained sandstone with strong orange ironstone staining. Some larger rounded quartz clasts and inclusions and coal lithic fragments.			Sandstone counrty rock	Chips only		
7.0 to 8.0m		**Sandstone / gravelly sandstone:** Fine to medium grained sandstone with strong orange staining. Some larger ironstone and rounded quartz clasts and inclusions. Clay beads present			Moisture indicated at 8.0	Chips only		

8.0 to 9.0m		**Sandstone / gravelly sandstone:** Fine to medium grained sandstone with strong orange and red staining. Arkosic sandstone lithics and ironstone gravel. Clay beads present				Chips only		
9.0 to 10.0m		**Sandstone / gravelly sandstone / clay:** Fine to medium grained sandstone. Strong orange limonite staining. Kaolin beads present within chips.				Chips only		

10.0 to 11.0m		**Decomposed / clayey silstone and minor sandstone:** Yellow brown ironstone staining on gravel fragments. Abundant orange kaolin beads present.				Chips only		
11.0 to 12m		**Decomposed / clayey silstone and minor sandstone:** Yellow brown ironstone staining on decomposed siltstone fragments. Abundant orange and dark brown kaolin beads present.				Chips only		

11.0 to 12m		**Decomposed / clayey silstone :** Yellow brown to dark grey-brown siltstone. Abundant dark brown and orange clay beading ironstone staining on decomposed siltstone fragments. Abundant orange and dark brown kaolin beads present.				Chips only		

12.0 to 13m		**Sandstone:** Fine to medium grained grey to white quartz arenite with minor limonite staining. Some white kaolin beading.				Chips only		
13.0 to 14m		**Sandstone:** Fine to medium grained grey to white quartz arenite with minor limonite staining. Some white kaolin beading.				Chips only	Aquifer strike at 13.5m	
14.0 to 14.5m		Limited chip return						

BH 4 _ Location	**-22.69611**	**149.63438**		
BH5_Location	**-22.69612**	**149.63422**		
BH4_Hole Depth	**4.2m**			
BH5_Hole Depth	**15m**			
Date	**30-Aug-18**			
Explanation: Drillhole 4 was drilled nearby to 4.2m depth to point of refusal using push tubing. Drill hole 5 was drilled dry with an RC rig to 15m depth to point of maximum likely rooting depth.				
BH4_BH5				
Depth	**Geology**	**Organics/ Root Material**	**Additional Notes**	**Drilling Method**
0 to 0.5m	**Sandy silt / clay:** Grey brown silt clay matrix with fine sand <20% total content. Orange brown mottling. Limited organic matter. Very dry.	Limited fine root material	Pleistocene age alluvium	Push tubing - core to deoth of 4.2m
0.5 - 1.0m	**Clayey sand**: Grey / brown clayey sand. 50% fine grained sand with clay matrix. Abundant yellow orange mottling. Very dry.	No root material identified	Pleistocene age alluvium	

1.0 - 2.0m	**Clayey sand**: Grey / brown clayey sand. 50% fine grained sand with clay matrix. Abundant yellow orange mottling.	No root material identified	Pleistocene age alluvium	
2.0 - 3.0m	**Clayey sand**: Grey / brown clayey sand. 50% fine grained sand with clay matrix. Abundant yellow orange mottling.	No root material identified	Pleistocene age alluvium	
3.05 - 3.41	**Clayey sand:** Grey brown with orange limonite mottles. some coarser rounded to sub-angular grains. Fine grained angular to sub-angular quartz / feldspar sand with 20% silty clay matrix	No root material identified	River alluvium. Core loss at 2.0 to 2.5m	
3.4 to 4.0m	**Clayey sand / sand:** Orange brown fine to medum grained quartz / feldspar sand. Weakly cemented with clay, <10% clay matrix. Brown with orange limonite mottling.	No root material identified	Pleistocene age alluvium	

4.0 to 4.2m	**Clayey Sand:** Dark grey / grey brown angular to subangular sand with 40% clay matrix. Strong orange brown (limonite) mottles. Weakly cemented with some moisture.	No root material identified	Pleistocene age alluvium	
4.2 to 5m	**Sand / Gravel:** Fine to medium grained sand and gravel with some lithic sandstone fragments. Possibly base of alluvium / top of Styx coal measures.	NA	Chips only	Rotary percussion with air at BH5. Sampled from 4.5m to EOH at 14.5m
5.0 to 6m	**Sand / Gravel:** Fine to medium grained sand and gravel with lithic sandstone fragments. Likely to be top of the Styx Coal Measures??	NA	Chips only	
6.0 to 7m	**Sandstone:** Fine to medium grained quartz arenite with strong red and orange iron staining on grain and fracture surfaces. Some rounded quartz clasts and fragments.		Chips only	

7.0 to 8m	**Sandstone:** Fine to medium grained quartz arenite with s orange iron staining on grain and fracture surfaces. Some ironstone gravel and clayey sandstone / silstone clasts mixed with coal fragments		Chips only	
8.0 to 9m	**Sandstone:** Grey brown, fine to medium grained sandstone with weathered clay matrix. Angular to sub-angular quartz grains with some yellow -orange ironstone staining. Coal fragments.		Chips only	
9.0 to 10m	**Sandstone:** Grey brown, fine to medium grained sandstone with weathered clay matrix. Some orange ironstone staining on grain surfaces and rounded ironstone gravel fragments.		Chips only	
10.0 to 11m	**Sandstone:** Grey brown, fine to medium grained sandstone with weathered clay matrix. Some orange ironstone staining on grain surfaces. Carbonaceous siltstone and coal fragments.		Chips only	

11.0 to 12m	**Sandstone:** Grey brown, fine to medium grained sandstone with weathered clay matrix. Some orange ironstone staining on grain surfaces. Minor ironstone gravel and fragments with some coal fragments.		Chips only	
12.0 to 13m	**Sandstone:** Grey brown, fine to medium grained sandstone with weathered clay matrix. Some orange ironstone staining on grain surfaces. Carbonaceous siltstone and coal fragments.		Chips only	
13.0 to 14m	**Sandstone:** Grey brown, fine to medium grained sandstone with weathered clay matrix. Some orange ironstone staining on grain surfaces. Coal fragments.		Chips only	
14.0 to 14.5m	**Sandstone:** Grey brown, fine to medium grained sandstone with weathered clay matrix. Some orange ironstone staining on grain surfaces. Coal fragments.		Chips only	

Note: Dry to end of hole. Hole was dipped on 30th August (2days after drilling) and remained dry.				

BH 6 _ Location	**-22.68333**	**149.64919**						
Hole Depth	**10m**							
Date	**29-Aug-18**							
Depth	**Geology**	**Organics/ Root Material**		**Additional Notes**				
0 to 0.2	**Sandy Silt.** Grey / brown fine grained sand. <20% organic matter. Dry,	Abundant fibrous root material		River Alluvium				
0.2 - 0.6m	**Sandy Silt**. Grey / brown. 30% fine grained sand with silt with <10% organic matter. Very dry.	Large yellow root 0.5cm diameter with some fibrous yellow root matter also evident.		River Alluvium				
0.6 - 1.00	**Sandy Silt.** Grey / brown with some fine yellow / orange mottling. 50% fine grained sand with silt. Very dry.	Some matted fine root material and occasional larger yellow roots to 1mm.		River Alluvium				
1.0 - 2.0	**Sandy Silt.** Brown to orange brown with some finer orange specs and mottling. 30 fine grained sand with silt. Very dry.	Minor matted fine root material. Larger dead tree root at 2.0m with orange colour.		River Alluvium				
2.0 to 3.0	**Silty Sand.** Orange -brown Fine to medium grained sand with some coarser rounded to sub-angular grains. 40% silty clay matrix	Large dead tree root at 2.5m. Strong yellow coloration		River alluvium. Core loss at 2.0 to 2.5m				

3.0 to 4.3	**Silty Sand.** Orange brown with some stronger bands with orange limonite mottling. 60% rounded to sub-angular quartz grains with 40% silty clay matrix, Very dry.	Fine yellow tree roots recorded at 3.8m		River alluvium				
4.3 to 4.5	**Clayey Sand.** Orange brown with 40% silty clay matrix with fine grained rounded to sub-angular quartz rich sand . Some orange brown (limonite) mottles.	Fine yellow tree roots recorded at 4.5m		River alluvium				
4.5 - 5.5	**Silty Sand.** Mottled grey to orange brown silty sand. Rounded to sub-angular quartz sand with 40% silty clay matrix, Very dry	Fine tree yellow tree roots recorded at 5.5m.		River alluvium				
5.5 to 6.3	**Silty / Clayey sand:** Grey brown fine to medium sand with 50% silty clay matrix. Orange brown limonite mottles and staining throughout. Dry.	Fine yellow tree roots recorded at 6.1m		River alluvium				

6.3 to 6.7	**Silty sand:** Orange / brown fine quarts and with 40% silty clay matrix. Abundant yellow brown limonite mottling and staining with orange coating on sand grains,	Large 0.5 cm tree root from river red gum (probably tree 7a) at 6.5m.		River alluvium				
6.7 to 7.5	**Silty / Clayey sand:** Orange grey mottled quartz / feldspar sand with fine angular to rounded grains. 40% silty clay matrix. Strong limonite mottling.	Large 0.5cm tree root from river red gum recorded at 7.5m		River alluvium				
7.5 to 7.8m	**Sility / Sandy clay:** Grey brown clay with stong orange mottling. 30% fine quartz sand with 70% silty clay matrix.			River alluvium				
7.8 to 8.6m	**Sandy clay:** Gey brown / orange clay. 40% sub-angular quartz / feldspar clay with 60% clay matrix. Cohesve texture with strong limonite mottling throughout.			Top of Styx coal measures at 8.6m				

8.6 to 9.1m	**Sandy clay (decomposed sandstone):** Brown grey tight sandy clay with lithic sandstone and coal fragments. 80% clay matrix with 20% angular to sub-angular quartz and feldspar sand. Strong limonite mottling,			Decomposed sandstone with coal fragments				
9.1 to 9.25m	Decomposed sandstone with coal lithics: Grey with orange / brown mottles. Medum angular quartz / feldspar sand fragments with tight clay matrix. Strong limonite coating on some fracture surfaces. Coal seams to 3cm thick in some intervals.			Decomposed sandstone with coal fragments				
9.25 to 9.65.	**Decomposed dirty / clayey coal seams in sandstone;** Mostly decomposed coal with interbeds of medium grained sandstone.	Matted fibrous tree roots in coal seam at 9.5m.		Decomposed sandstone with coal fragments				

9.65 to 9.85	**Coal:** Vitreous coal seams interbedded with decomposed clayet sandstone. Fine to medium grained decomposed clayey sandstone interbeds.			EOH due to drill rod refusal. Hole finished in coal measures.				

Appendix C. Soil Moisture Potential Results with Correlation to Leaf Water Potential

BH 1 and BH3_Wetland 1 GDE Assessment Area													
Sample Depth (m)	**Mpa**	**pF**	**Temp°C**	**Soil Moisture Potential (PSI)**	**Tree Root Material**	**Leaf Water Potential (PSI)**							**Notes**
						Tree 1	**Tree 2**	**Tree 3**	**Tree 1a**	**Tree 2a**	**Tree 3a**	**Tree 4a**	
0.1	-2.73	4.45	28.8	-396.0	Fine matted tree root material								Drilled from surface to 1m depth with push tubing. Core retrieved.
0.2	-2.31	4.45	28.8	-335.0	Fine matted tree root material								
0.5	-1.73	4.56	28.7	-250.9									
0.75	-2.02	4.32	28.7	-293.0									
1	-2.07	4.33	28.7	-300.2		-362						-320	
2	-4.45	4.66	28.8	-645.4									Drilled from 1m depth to 14m with Rotary Percussion and Air. Chips only at 1m intervals.
3	-7.52	4.89	28.7	-1090.7									
4	-4.19	4.64	28.7	-607.7									
5	-4.48	4.67	28.9	-649.8									
6	-3.22	4.52	28.8	-467.0									

BH 1 and BH3_Wetland 1 GDE Assessment Area													
7	-2.71	4.45	28.8	-393.1									
8	-0.45	3.67	28.7	-65.3			-58	-58	-45	-45	-50		Moisture strike noted by drillers and recorded in drill chips.
9	-1.25	4.11	28.7	-181.3									
10	-1.13	4.07	28.8	-163.9									
11	-2.31	4.38	28.7	-335.0									
12	-2.5	4.41	28.8	-362.6									
13	-3.97	4.61	28.9	-575.8									Aquifer hit at 13.5mbgl. Loss of drill chips with only dust retrieved
14	-9.97	5.01	28.8										
Tree Label	**Date of Survey**	**Species**		**Notes**									
Tree 1	9-Aug-18	Melaleuca viridiflora											
Tree 2	9-Aug-18	Melaleuca viridiflora											
Tree 3	9-Aug-18	Eucalyptus tereticornis		Same tree as Tree 4a sampled on 30 August 18									
Tree 1a	30-Aug-18	Melaleuca viridiflora		Heavy dew on leaves at time of sampling (may have influenced water potential measurements)									

BH 1 and BH3_Wetland 1 GDE Assessment Area													
Tree 2a	30-Aug-18	Melaleuca viridiflora		Heavy dew on leaves at time of sampling (may have influenced water potential measurements)									
Tree 3a	30-Aug-18	Melaleuca viridiflora		Heavy dew on leaves at time of sampling (may have influenced water potential measurements)									
Tree 4a	30-Aug-18	Eucalyptus tereticornis		See Tree 3									

BH4 and BH5_Wetland 2 GDE Assessment Area

Depth (m)	**Mpa**	**pF**	**Temp°C**	**Soil Moisture Potential (PSI)**	**Tree Root Material**	Tree Leaf Water Potential (PSI)				**Notes**
						Tree 1	**Tree 2**	**Tree 3**	**Tree 4**	
0.5	-3.49	4.56	28.7	-506.2						Heavy dew at time of survey may have affected leaf moisture potential
1	-2.19	4.36	28.8	-317.6						
1.5	-2.3	4.38	28.8	-333.6						
2	-1.56	3.95	28.8	-226.3		-200		-190		
3	-1.62	4.32	28.8	-235.0			-240		-220	
4	-1.92	4.3	28.7	-278.5						
5	-5.11	4.72	28.7	-741.1						Drilled dry from 4m depth to EOH with Rotary Percussion and Air. Chips only- no core.
6	-4.36	4.65	28.7	-632.4						
7	-4.82	4.7	28.7	-699.1						
8	-4	4.62	28.6	-580.2						
9	-3.69	4.58	28.7	-535.2						

10	-3.05	4.5	28.7	-442.4						
11	-2.92	4.48	28.8	-423.5						
12	-2.93	4.48	28.7	-425.0						
13	-2.41	4.4	28.8	-349.5						
14	-3.44	4.5	28.7	-498.9						
15	-3.97	4.61	28.7	-575.8						
Tree Label	**Date of Survey**	**Species**								
Tree 1	30-Aug-18	Eucalyptus tereticornis								
Tree 2	30-Aug-18	Eucalyptus crebra								
Tree 3	30-Aug-18	Eucalyptus tereticornis								
Tree 4	30-Aug-18	Eucalyptus tereticornis								

BH6 _Vine Thicket GDE Assessment Area																	
Depth	**Mpa**	**pF**	**Temp°C**	**Soil Moisture Potential (PSI)**	**Tree Root Material in Log**	**Tree Leaf Water Potential (PSI)**											
						Tree 1	**Tree 2**	**Tree 3**	**Tree 4**	**Tree 5**	**Tree 1a**	**Tree 2a**	**Tree 3a**	**Tree 4a**	**Tree 5a**	**Tree 6a**	**Tree 7**
0.2	-9.3	4.98	28.8	-1348.9	Abundant matted roots from Tree 2a												
0.5	-13.69	5.15	28.7	-1985.6	Abundant matted roots from Tree 2a												
1	-27.62	5.46	28.9	-4005.9	Abundant matted roots from Tree 2a												
2	-6.07	3.95	28.8	-880.4	Abundant matted roots from Tree 2a			-812					-800				
3	-2.81	4.32	28.8	-407.6	Abundant matted roots from Tree 2a											-480	
3.2	-2.29	4.37	28.8	-332.1	Abundant matted roots from Tree 2a		-377										
4	-4.04	4.62	28.8	-586.0	Abundant matted roots from Tree 2a												
5	-6.43	3.94	28.8	-932.6	Abundant matted roots from Tree 2a												
6	-3.61	4.57	28.5	-523.6	Abundant matted roots from Tree 2a												
6.75	-4.69	3.82	28.6	-680.2	Large root from E. tereticornis (Tree 7a)				-782		-680	-660					
7.5	-2.03	4.32	28.8	-294.4													
8	-1.55	4.2	28.8	-224.8		-217								-225	-235		

BH6 _Vine Thicket GDE Assessment Area																	
8.5	-1.8	4.03	28.8	-261.1													
9	-1.04	4.03	28.8	-150.8													
9.5	-0.81	4.18	28.8	-117.5													
9.85	-1.19	4.09	28.7	-172.6													
										-72							
	Zone of Inferred Vine Thicket Water Uptake																
Tree Label	**Date of Survey**	**Species**		**Notes**													
Tree 1	8-Aug-18	Flindersia australis															
Tree 2	8-Aug-18	Coatesia paniculata															
Tree 3	8-Aug-18	Siphonodon australis															
Tree 4	8-Aug-18	Brachychiton australis															
Tree 1a	29-Aug-18	Siphonodon australis															
Tree 2a	29-Aug-18	Siphonodon australis															
Tree 3a	29-Aug-18	Coatesia paniculata															
Tree 4a	29-Aug-18	Brachychiton rupestris															
Tree 5a	29-Aug-18	Polyscias elegans															
Tree 6a	29-Aug-18	Acacia harpophylla															

BH6 _Vine Thicket GDE Assessment Area																	
Tree 5	8-Aug-18	Eucalyptus camaldulensis		Tree from outside vine thicket community on lower terrace / bench													
Tree 7a	29-Aug-18	Eucalyptus camaldulensis		Tree from outside vine thicket community on lower terrace / bench													

Appendix D. Stable Isotope Analytical Results.

Corrected Soil Water						
Borehole	Depth (meters)	d2H	d18O			
BH1	0.10	6.90	4.01			
BH1	0.20	-16.94	-4.10			
BH1	0.50	-15.77	-3.54			
BH1	0.75	-11.90	-3.74			
BH1	1.00	-13.69	-4.33			
BH1	3.20	-25.33	-4.94			
BH3	2.00	-18.19	-3.38			
BH3	3.00	-21.96	-3.46			
BH3	4.00	-22.79	-3.09			
BH3	5.00	-27.58	-4.65			
BH3	6.00	-27.36	-4.52			
BH3	7.00	-26.42	-4.18			
BH3	8.00	-26.70	-4.03			
BH3	9.00	-23.40	-2.76		Suspect	Too Dry
BH3	10.00	-24.14	-3.07		Suspect	
BH3	11.00	-20.09	-1.36		Suspect	
BH3	12.00	-22.37	-2.79		Suspect	
BH3	13.00	-3.40	2.03		Suspect	
BH3	14.00	-4.08	2.32		Suspect	

BH4	0.50	-24.73	-4.81			
BH4	1.00	-25.30	-4.82			
BH4	1.00	-26.40	-5.08			
BH4	1.50	-24.47	-4.87			
BH4	2.00	-22.56	-3.91			
BH4	3.00	-23.07	-4.36			
BH4	4.00	-21.03	-4.02			
BH5	4.00	-11.53	-2.68	Suspect		Too Dry
BH5	5.00	-12.46	-2.21			
BH5	6.00	-11.05	-2.59			
BH5	7.00	-10.94	-2.1			
BH5	8.00	-14.44	-2.07			
BH5	9.00	-15.10	-1.99			
BH5	10.00	-15.19	-4.27			
BH5	11.00	-14.34	-1.87			
BH5	12.00	-13.60	-1.56			
BH5	13.00	-15.45	-2.48			
BH5	13.10	-14.87	-1.98			
BH5	14.00	-9.09	-0.5			
BH5	15.00	-7.39	-0.74			
BH6	0.20	-7.66	-0.02			
BH6	0.50	-26.51	-4.68			
BH6	1.00	-30.98	-4.10			
BH6	2.00	-34.90	-5.93			

BH6	3.20	-30.60	-4.06			
BH6	3.20	-31.04	-4.05			
BH6	4.00	-28.79	-4.25			
BH6	5.00	-30.08	-6.02			
BH6	6.00	-32.37	-6.84			
BH6	6.70	-32.07	-6.96			
BH6	7.50	-26.01	-3.42			
BH6	7.50	-25.90	-3.41			
BH6	8.00	-25.76	-3.86			
BH6	8.50	-25.95	-4.84			
BH6	9.00	-30.91	-6.63			
BH6	9.50	-30.05	-5.41			
BH6	9.50	-32.22	-5.54			
BH6	9.85	-26.59	-5.39			
Corrected Twig and Bark Water						
BH1	T3 bark	-13.19	-2.67			
BH1	T3 wood	-7.81	-2.73			
BH1	T3 wood	-11.34	-2.84			
BH1	T3/2 bark	-12.06	-2.00			
BH1	T3/2 bark	-16.45	-3.43			
BH1	T3/2 wood	-15.03	-3.67			
BH1	T1 bark	-11.91	-2.74			
BH1	T1 wood	-14.35	-3.24			
BH2	T1 bark	-5.60	-0.09			
BH2	T1 bark	-6.15	-0.26			
BH2	T1 wood	-5.39	-0.49			
BH2	T1 wood	-7.12	-0.41			

BH4	T3 bark	-12.30	-1.18			
BH4	T3 bark	-10.13	-0.26			
BH4	T3 bark	-9.61	-0.80			
BH4	T3 bark	-9.61	-0.80			
BH4	T3 Wood	-12.97	-0.93			
BH4	T3 Wood	-7.89	-0.50			
BH4	T3 Wood	-10.09	-1.04			
BH4	T3 Wood	-11.12	-0.10			
BH4	T4 bark	-11.84	-2.21			
BH4	T4 wood	-11.86	-2.92			
BH4	T1 Bark	-12.19	-1.52			
BH4	T1 wood	-10.53	-1.71			
BH4	T2 bark	-17.56	-2.80			
BH4	T2 wood	-13.13	-2.00			
BH6	T6 bark	-18.57	-3.16			
BH6	T6 bark	-15.86	-2.76			
BH6	T6 wood	-16.73	-2.52			
BH6	T6 wood	-17.54	-2.57			
BH6	T1 bark	-14.89	-1.88			
BH6	T1 wood	-19.52	-2.49			
BH6	T3 bark	-17.49	-2.11			
BH6	T3 wood	-19.34	-1.67			
New wood and bark						
BH6	T3 bark	-18.38	-2.95			
BH6	T3 wood	-22.70	-2.78			
BH6	T6 bark	-18.23	-3.36			

BH6	T6 wood	-21.07	-3.86			
BH6	T1 outer wood	-16.41	-2.37			
BH6	T1 wood	-17.64	-2.73			
BH6	T2 out wood	-23.45	-3.66			
BH6	T2 wood	-27.59	-4.02			
BH6	T5 bark	-22.32	-3.15			
BH6	T5 bark	-22.56	-3.27			
BH6	T5 wood	-22.73	-3.12			
BH6	T4 bark	-14.59	-2.13			
BH6	T4 wood	-10.43	-1.51			
BH6	T7 Bark	-23.40	-3.38			
BH6	T7 Wood	-22.19	-3.53			