APPENDIX H

Groundwater dependent ecosystem assessment

Evolution MINING

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Co-authored by

3D Environmental
Landscape & Vegetation Science

Cowal Gold Operations - Open Pit Continuation Project

Response to Submissions: Groundwater Dependent Ecosystems Assessment

Prepared for Evolution Mining Pty Limited

January 2024

Cowal Gold Operations - Open Pit Continuation Project

Response to Submissions: Groundwater Dependent Ecosystems Assessment

Evolution Mining Pty Limited

J190417 RP56

January 2024

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15 January 2024

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Executive Summary

Evolution Mining Pty Limited (Evolution) is proposing to extend open pit mining operations at its existing Cowal Gold Operations (CGO) open pit and underground gold mine through the Open Pit Continuation Project (the Project). The Project is classified as a State Significant Development (SSD) and planning approval is required under Part 4 of the *NSW Environmental Planning and Assessment Act 1979* (EP&A Act) and the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) for the Project.

As a requirement of the SSD application, an Environmental Impact Statement (EIS) was prepared to address Secretary's Environmental Assessment Requirements (SEARs) issued by the NSW Department of Planning, Housing and Infrastructure (DPHI) (formally the Department of Planning and Environment). Based on groundwater modelling, the EIS identified a likelihood of groundwater drawdown greater than natural water table fluctuations in areas with mapped high priority groundwater dependent ecosystems (GDEs) to the north of the Project. This GDE Assessment was completed to supplement the Project EIS and address recommendations provided by NSW Department of Climate Change, Energy, the Environment and Water (DCCEEW - formally DPE Water) and NSW Biodiversity Conservation Division (BCD).

This assessment involved detailed field-based investigations and ecohydrological conceptualisations to identify characteristics of GDEs, in particular, River Red Gum (*Eucalyptus camaldulensis*). This species was focused on given it is the dominant canopy species of the plant communities where potential drawdown impacts were identified in the EIS. Specifically, the study tested the potential reliance River Red Gums on groundwater sources, which are expected to be impacted by groundwater drawdown associated with the Project. Note that Black Gum (*Eucalyptus largiflorens*) were also studied where encountered, but are rare adjacent to Lake Cowal.

This assessment was undertaken following the well-established methods and assessments outlined in the GDE toolbox (Richardson S, et al, 2011) and IESC guidelines (2019, 2023). Methods applied include measurement of Leaf Area Index (LAI), Leaf Water Potential (LWP), and Soil Moisture Potential (SMP), along with soil salinity measurements, lithological logging, and root architecture observations inferred from completed auger holes. Data produced from the field-based investigations were used to develop ecohydrological conceptual models and complete a risk assessment for the Project. The key findings of the assessment are as follows:

- Most trees fringing Lake Cowal and within the predicted groundwater drawdown impact zone are in good health, as indicated by moderate to high LWP values, LAI values above the water stress threshold, and SMP values that suggest reliable and shallow water sources are accessible.
- Potential for health stress by water logging was identified for River Red Gum closest to the Project, where a perched groundwater system was supported by recent, high lake levels. This was evident through field observations, high LWP values, and low LAI values falling below health thresholds.
- River Red Gum communities (and Black Gum where measured) appear to draw moisture from soil water within the shallow vadose zone, predominantly between depths from surface to 1.5 metres below ground level (mbgl). This represents the zone where soil moisture is most consistently available across all seasons, as supported by both LWP and SMP measurements.
- LWP measured in River Red Gum and Black Gum across all locations surveyed here suggested that these trees have no reliance on the permanent groundwater source hosted in the Upper Cowra Formation.
- Salinity measurements of the groundwater within the unconfined Upper Cowra Formation are also inhospitable for River Red Gum and Black Gum (i.e. salinity measures were up to 43,700 micro-siemens per centimetre [µS/cm]), which provides additional evidence that these trees do not use this groundwater source.

- Groundwater drawdown associated with the Project is not expected to impact River Red Gum communities since they appear to be dependent on water within the vadose zone or shallow perched system only. That is, as these vegetation communities are not accessing groundwater within the Upper Cowal Formation, any drawdown of groundwater associated with that formation is not expected to impact these potential GDEs.

- Further, although excavation has the potential to affect the shallow systems supporting the perched aquifer under Lake Cowal, these perched systems seem to be associated with local lake sediments and are not at risk of excavation due to the mining activities, unless located within or immediately adjacent to the open cut mining operations.

- In conclusion, aquifer drawdown associated with the development of the Project is not expected to impact River Red Gum communities due to the absence of pathways between groundwater sources, being either the vadose zone or the shallow perched system, and the water effecting activities at the mine site.

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1 Introduction

1.1 Background

Evolution Mining Pty Limited (Evolution) is the owner and operator of Cowal Gold Operations (CGO), an existing open pit and underground gold mine located approximately 38 kilometres (km) north-east of West Wyalong, in the central west region of New South Wales (NSW). CGO is located on the traditional lands of the Wiradjuri People and is immediately adjacent to the western foreshore of Lake Cowal, which is an ephemeral waterbody.

CGO was first approved in 1999, and open pit mining operations commenced in 2005. Underground mining operations were approved in 2021 and commenced in 2023. Evolution is seeking approval for further open pit mining operations at CGO through the Open Pit Continuation Project (the Project). The Project primarily seeks to continue the open pit operations by approximately 10 years to 2036 and extend the total mine life by approximately two years to 2042.

The Project is classified as a State Significant Development (SSD) (SSD-42917792). Planning approval is required under Part 4 of the *NSW Environmental Planning and Assessment Act 1979* (EP&A Act) and the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) for the Project. As a requirement of the SSD application, an Environmental Impact Statement (EIS) was prepared to address the Secretary's Environmental Assessment Requirements (SEARs) issued by the NSW Department of Planning, Housing and Infrastructure (DPHI), formally the Department of Planning and Environment (DPE).

In response to the SEARs, a *Groundwater Impact Assessment* (EMM 2023a) was prepared for the Project and included in the EIS (refer Appendix H of the EIS), which identified a likelihood of groundwater drawdown greater than natural water table fluctuations in areas with mapped high priority groundwater dependent ecosystems (GDEs) to the north of the Project area. The study area for the GDE assessment is the groundwater model domain defined in the *Groundwater Impact Assessment* (EMM 2023a; hereafter groundwater study area), and is shown in Figure 1.1 and Figure 1.2.

A *Biodiversity Development Assessment Report* (EMM 2023b) was also prepared to meet the SEARs (refer Appendix J of the EIS), which identified two potential high priority GDEs through a desktop assessment that drew upon State Vegetation Mapping and groundwater modelling by EMM (2023a). The two potential high priority GDEs were plant community types (PCT): PCT 249 - River Red Gum (*Eucalyptus camaldulensis*) swampy woodland wetland on cowals (lakes) and associated flood channels in central NSW, and PCT 10 River Red Gum - Black Box (*Eucalyptus largiflorens*) woodland wetland of the semi-arid (warm) climatic zone (mainly Riverina Bioregion and Murray Darling Depression Bioregion).

The *Groundwater Impact Assessment* (EMM 2023a) focused on cumulative variation in the water table, as required by the Aquifer Interference Policy (AIP) (see Section 1.2). The *Biodiversity Development Assessment Report* (EMM 2023b) focused on incremental drawdown, since this allowed assessment of the actual impact of only the Project. For this reason, this study is framed in relation to both cumulative and incremental drawdown on GDEs to meet the requirements for both reports.

Submissions to the EIS were received and included agency advice recommendations for groundwater impact and biodiversity management, to action prior to Project approval. This GDE Assessment has been prepared to supplement the EIS as part of a Submissions Report, and address the recommendations outlined in the following sections. Relevant feedback from NSW Department of Climate Change, Energy, the Environment and Water (NSW DCCEEW) and NSW Biodiversity Conservation Division (BCD), which presented the need for this additional GDE assessment, are provided in Sections 1.2 and 1.3 below.

1.2 NSW Department of Climate Change, Energy, the Environment and Water recommendations prior to EIS approval

The submission from NSW DCCEEW was provided on 1 August 2023. The recommendation associated with this study and outlined in Section 2.9 of the document is summarised as follows.

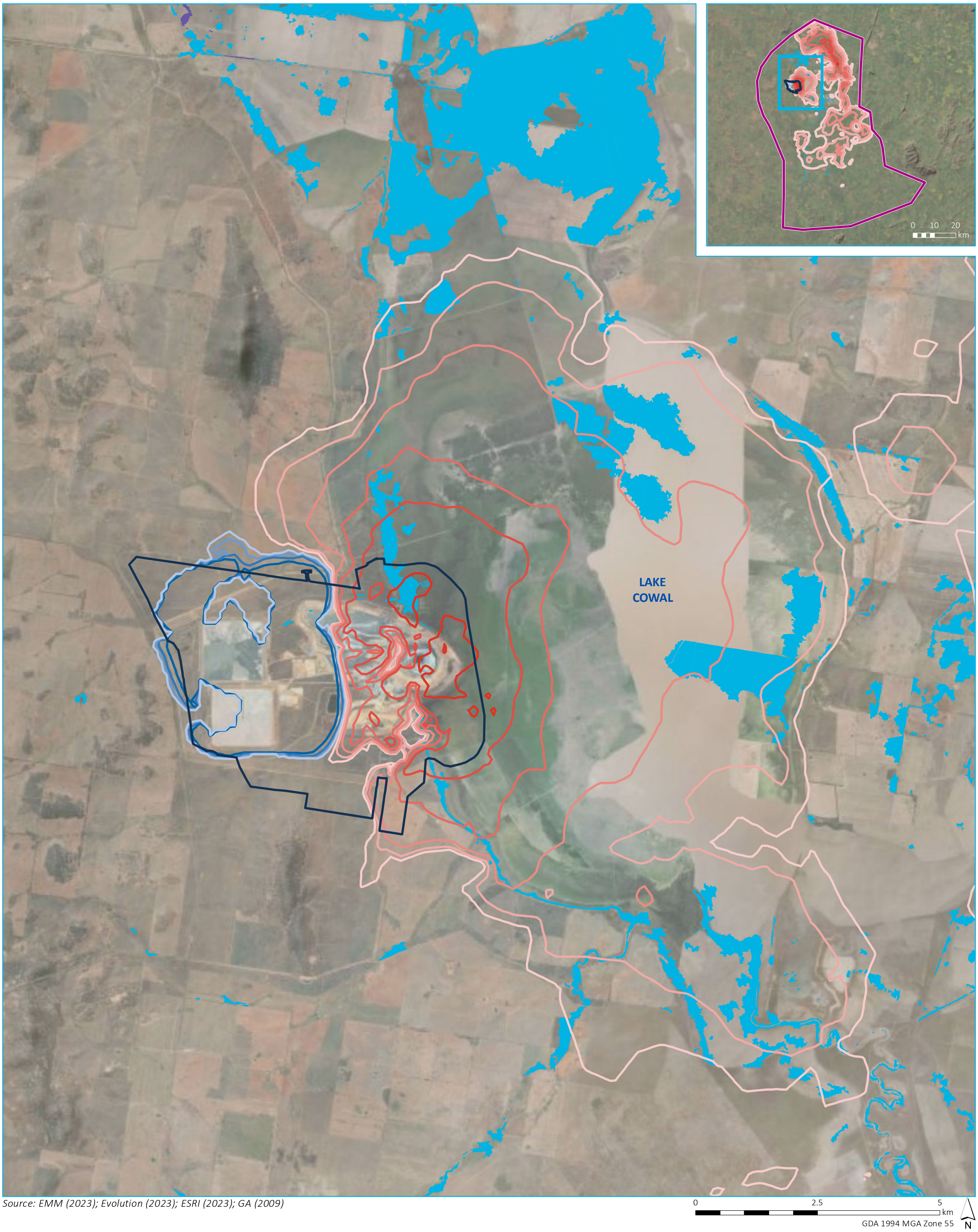
- Complete appropriate studies to address the requirement of the Level 2 AIP minimal impact considerations for predicted impacts on GDEs of more than 10% of cumulative variation in the water table (this equates to 0.5 metres (m)). These cumulative drawdown impacts, detailed in Section 6.4.3 of the *Groundwater Impact Assessment* (EMM 2023a), exceed the stipulated threshold, necessitating studies to ensure Ministerial satisfaction regarding the long-term viability of dependent ecosystems.

1.3 NSW Biodiversity Conservation Division recommendations prior to EIS approval

The submission from NSW BCD was provided on 28 July 2023. The recommendation associated was to:

- provide a commitment to assess long-term health of PCTs with a high risk of drawdown impacts and further define a TARP for impacts to GDEs, in consultation with BCD.

However, as agreed with BCD, it was decided that since the original assessment in the BDAR was desktop based only, if the proposed GDE data (i.e. pre-dawn leaf water potential Leaf Area Index measurement, soil logging / lithological descriptions and sampling and measure of Soil Moisture Potential) collected for PCTs 10 and 249 indicate that they are not GDEs, monitoring would not be required (as per email correspondence by L. Maloney, Senior Conservation Planning Officer – South West; 17 October 2023). This report presents the results of data collected to test if PCTs 10 and 249 are GDEs to identify whether adaptive management (i.e. monitoring and association trigger, action response plan) are required.



Source: EMM (2023); Evolution (2023); ESRI (2023); GA (2009)

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KEY

Groundwater study area (see inset)

Additional disturbance area

PCTs with potential groundwater dependence

PCT 10

PCT 249

Cumulative drawdown (m)
(end of mining)

-5
-2
-1
-0.5

0.5
1
2
5
10
25

Cumulative groundwater drawdown and PCTs with potential groundwater dependence

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Figure 1.1

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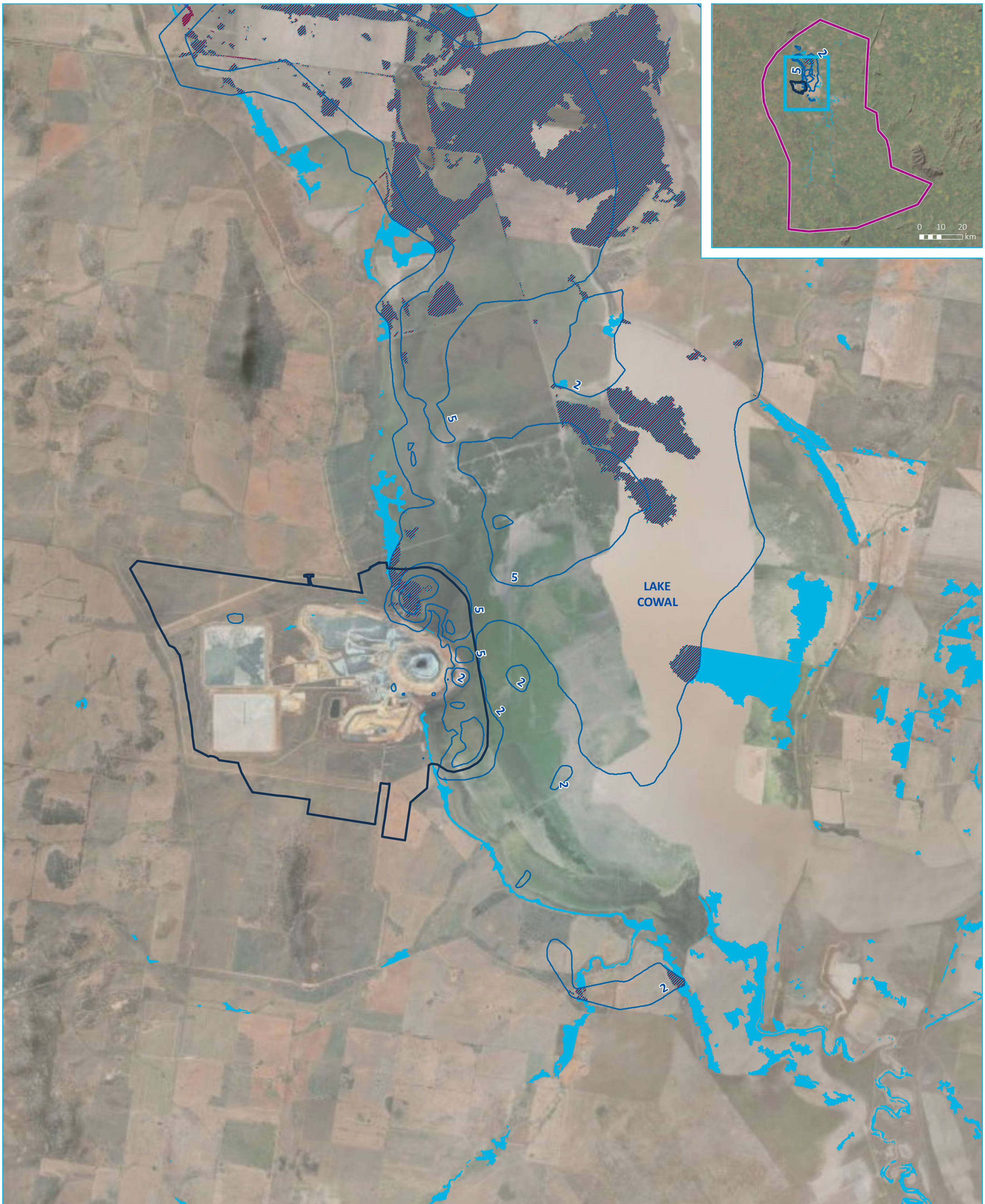

\\emmsvr1\EMM\Jobs\2019\J190417 - CGO Open Cut Expansion Project\GIS\02_Maps_GDEA\GDEA002_IncrementalDrawdownAndPotentialGDEs_20231221_01.mxd 21/12/2023

Source: EMM (2023); Evolution (2023); ESRI (2023); GA (2009)

0 2.5 5 km
GDA 1994 MGA Zone 55
N

KEY

- Groundwater study area (see inset)
- Additional disturbance area
- Incremental groundwater drawdown level contour (m BGL)
- Potential impacts with incremental drawdown of > 2 m

PCTs with potential groundwater dependence

- PCT 10
- PCT 249

Incremental groundwater drawdown and PCTs with potential groundwater dependence

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Groundwater Dependent Ecosystems Assessment
Figure 1.2

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1.4 Scope of work

To address the recommendations outlined in Sections 1.2 and 1.3, this assessment aims to provide a detailed field-based investigation to characterise the nature of GDEs associated with the Project which may be subject to impact as a result of groundwater drawdown.

This assessment was undertaken following the well-established methods and assessments outlined in the GDE toolbox (Richardson S. et al. 2011) and IESC guidelines (2019, 2023), and include:

- assessment of four mature River Red Gum trees for pre-dawn leaf water potential (LWP) at nine locations, with priority to the north of the Project. This northern location was targeted since this is where incremental drawdown impacts were predicted by the BDAR. This data assists in understanding tree water status and ability to access soil moisture
- Leaf Area Index (LAI) measurements at each site to understand vegetation structure and health
- construction of three auger holes to refusal or groundwater interception (max depth achieved 4.6 metres below ground level (mbgl)) to investigate the geological and hydrological characteristics underlying the area, including root architecture
- soil logging / lithological descriptions and sampling at approximately 0.5 m intervals for measurement of Soil Moisture Potential (SMP), also referred to as matric potential, to inform moisture availability down the soil profile
- interpretation of data produced from the field-based investigation alongside scientific literature and expert advice to develop an understanding of links between the key water effecting activities on the groundwater system, associated GDEs, and potential casual pathways
- develop ecohydrological conceptual models to visually represent conclusions drawn from data interpretation and provide the basis for the risk assessment
- complete a risk assessment for the PCTs using the information gathered from this GDE Assessment.

1.5 Authorship

This report was compiled by Alexandra Kiss (EMM Hydrogeologist) with the support of David Stanton (3D Environmental Principal Landscape Ecologist). David Stanton has 27 years of experience in resource mapping, landscape-scale ecological assessments, and GDE monitoring and analysis. David has co-authored several technical papers on issues relating to landscape ecology inclusive of GDE assessments. His expertise has been utilised by sectors including mining, infrastructure, government, and indigenous organisations. David Stanton authored several key sections of this report, notably contributing to the methodology and framework upon which this study is based. The report was reviewed by Joel Georgiou (EMM Associate Director) and Hayden Beck (EMM Associate Ecologist). Field work was completed by Alexandra Kiss and David Stanton.

2 Ecological and climatic context

2.1 River Red Gum ecology

The River Red Gum is a well-studied species known to have deep sinker roots, hypothesised to grow down towards zones of higher water supply (Bren et al., 1986). It is adapted to arid and semi-arid environments and will go through alternate phases of shedding and regaining its crown, depending on the availability of water. This species has the capacity to self-regulate and adjust their transpiration rates across the flood frequency classes (Collof 2014), while maintaining a strong capacity for genetic selection to increase capacity to survive prolonged drought conditions. Trees less able to survive drought tend to die off, hence the genes that are associated with drought tolerance traits become more common in the remaining population.

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

The River Red Gum is considered a facultative phreatophyte, shifting between a combination of soil moisture within the vadose zone and groundwater during periods of higher rainfall, then shifting to exclusive use of groundwater during drier periods. They are likely to achieve this shift through inactivation of surface roots during drier periods with increased reliance on deeper tap roots when surface water is unavailable. River Red Gums will often use saline groundwater in preference to fresh surface water under circumstances when the reliability of fresh surface water is low (Colloff 2014), and provided that the saline water is suitable (see Section 3.6). Doody et al. (2015) demonstrated that soil moisture alone can sustain the health of a River Red Gum through periods of drought up to six years before significant decline in tree health is observed.

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. 2006). Horner et al. (2009) found rooting depths at 12–15 mbgl based on observed mortality in plantation River Red Gum forests on the Murray River Floodplain. Jones et al. (2020) found maximum rooting depths of 8.1 mbgl in River Red Gum in a broad study area in the Great Artesian Basin. In conclusion, maximum rooting depth of River Red Gum is likely to be variable, dependent on-site geology and depth to saturation with the capillary fringe being the general depth at which root penetration will be arrested (Eamus et al. 2006).

2.2 Study period climatic conditions

This assessment was conducted over a three-day period (excluding travel) between 16 to 18 November 2023. Maximum temperatures at the Burcher Post Office Recording Station (BOM station 50010 approximately 30 km north-west of the Project) for this period ranged from 29.2°C to 32.0°C with relative humidity from 20.2% to 23.3%. Pre-survey rainfall for the 6-month period prior to the field assessment is shown in Figure 2.1. A significant rainfall event occurred on 5 October 2023 (24 mm rainfall), with a wet weather period persisting just prior to the assessment.

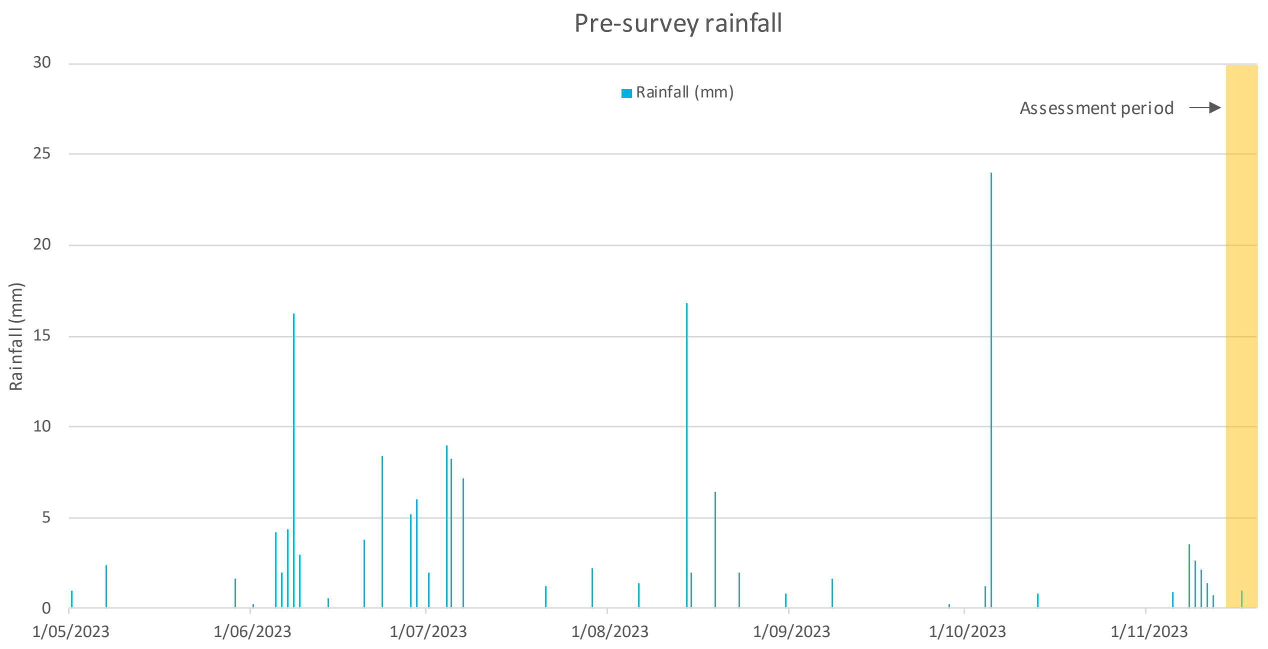


Figure 2.1 Pre-survey rainfall measured at the Burcher Post Office (BOM station 50010)

2.3 Cumulative rainfall departure

In many hydrogeological settings, precipitation is the largest component of the water budget such that variation in precipitation should be expected to contribute substantially to variation in groundwater levels (Smail et al. 2019), at least in the shallower aquifer systems. Cumulative rainfall departure (CRD) is a metric applied to temporal rainfall data and is identified as one of several methods that can be applied to predict groundwater volumes in unconfined aquifers (Emelyanova et al. 2013; Mondal and Ajaykumar 2022; Şen 2019; Xu and Van Tonder 2001). The calculation determines the mean value of the rainfall over a selected period, subtracts mean values from each data point to determine the departure from the mean, and accumulates this departure to produce a resultant curve (rainfall mass curve). The calculation requires a time point to be established for the start of the period, at which the CRD will be set at zero, meaning that absolute CRD values are only relevant to the selected period. While this is considered a major limitation of the method (Weber and Stewart 2004), the slope of the curve is considered the critical indicator of rainfall trends (McCallum et al. 2009).

Analysis of SILO rainfall data (SILO 2023) indicates the field assessment follows a strong wetting trend that has been occurring from January 2020, followed by a slight fall in the CRD curve prior to the field assessment (Figure 2.2). CRD is considered an important metric in the assessment of groundwater related assets as shallow groundwater tables tend to follow similar trends to the curve; it is anticipated that groundwater in the area will be adequately recharged and would have followed an upward groundwater level trend since 2021, in the absence of any anthropogenic influence.

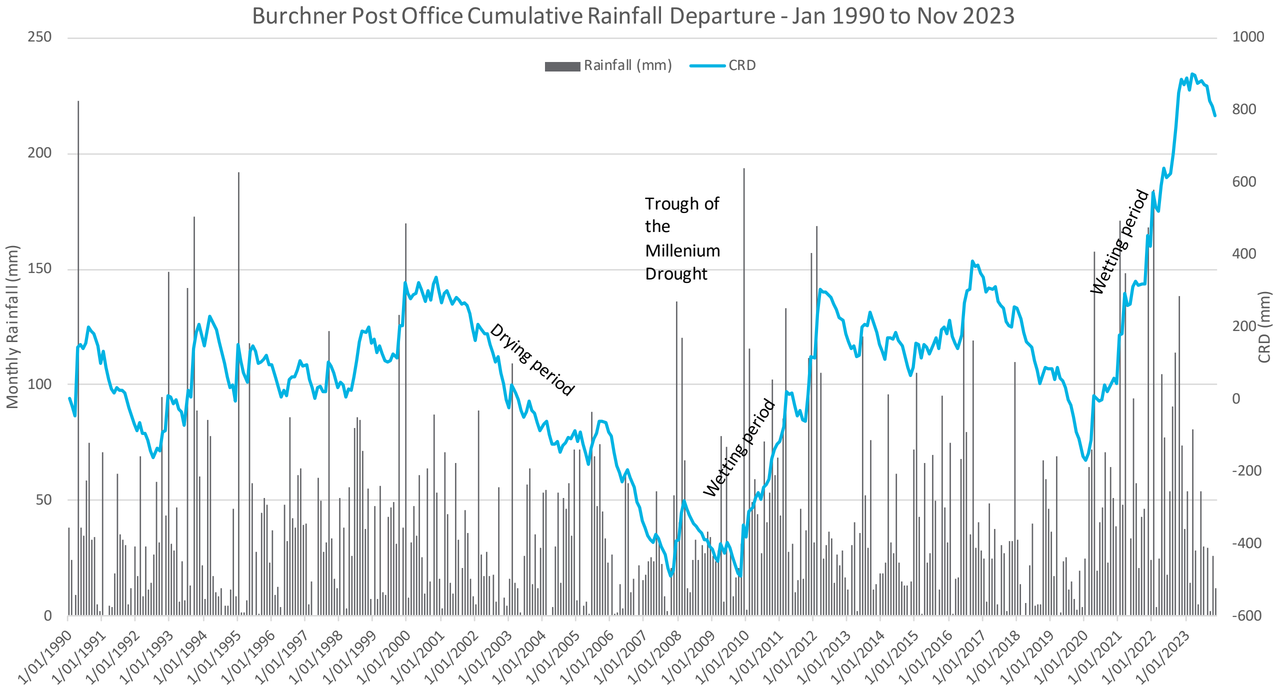


Figure 2.2 **Cumulative Rainfall Departure at the Burcher Post Office (BOM station 50010)**

In the context of the dramatic spike in CRD, tree dieback caused by water logging of the soil profile becomes an increasing risk. If oxygen requirements of the roots and soil biota are not reduced during flooding, oxygen rapidly becomes depleted and anoxia results (Ackeroyd 1998; Davison 1988). Anoxia causes changes in plant metabolic and physiological processes which lead to a decline in tree growth and survival (Kozlowski, 1984) with the first response to anoxic conditions being stomatal closure (Ladiges and Kelso 1977; Heinrich 1990; McEvoy 1992; Marcar 1993). Under conditions with lower permeability and low matric potentials (i.e. clays which tightly bind moisture), clay soils will sustain saturation and anoxic conditions for longer periods than sandier soils, leading to a decline in tree growth and survival (Kozlowski 1984). This effect would mean soil saturated from flooding events would not be available as a moisture source and would also leave trees susceptible to increased stress if soil conditions rapidly dry, leading to dieback. Significant River Red Gum dieback was observed at the Project where trees were submerged within the lake waters, with some dieback / stress still observed on the fringe of the lake.

2.4 Hydrogeological setting and conceptualisation

Within the saturated zone (i.e. below the water table), the Cenozoic alluvial sediments support alluvial groundwater systems. Groundwater flows through pore spaces within the sediments, with hydraulic conductivity increasing proportionally to sediment grain size (Freeze 1979). The surficial sediments facilitate vertical infiltration from rainfall recharge and surface water however, recharge is limited by the extent and thickness of the Lacustrine Clay.

The alluvial sequence within the paleochannel area is split into three groundwater systems, based on varying hydrogeological properties (i.e. yield, water quality, and confinement) and depositional periods and environments. Conceptual hydrogeological sections were developed as part of the *Groundwater Impact Assessment* (EMM 2023a) developed for the Project with Figure 2.3 showing a regional east-west cross-section through the paleochannel and the mine site. This figure clearly shows the main alluvial groundwater systems as follows:

- Upper Cowra groundwater system, an unconfined, phreatic groundwater system supporting the water table (where present). This sequence generally occurs from ground surface to an average depth of approximately 45 m to 50 m over most of the groundwater study area, with an average depth to groundwater of approximately 7 m (Evolution, 2022c). The Upper Cowra groundwater system is rarely utilised for water supply, generally providing low yields (<1 litres per second (L/s), (Lampayan, 2001)) of saline (~39,000 micro-siemens per centimetre [µS/cm]) groundwater (Evolution, 2022b).

- Lower Cowra groundwater system, an unconfined/confined groundwater system (Bilge, 2012) underlying the Upper Cowra groundwater system. Yield from the Lower Cowra groundwater system is highly dependent on intercepting extensive sand and gravel lenses within the formation. Groundwater from the Lower Cowra system can provide up to 40 L/s of saline (~22,500 µS/cm) groundwater (Evolution, 2022b).

- Lachlan groundwater system, a confined groundwater system underlying the Lower Cowra groundwater system which does not extend to the proposed mining areas. This sequence generally occurs over an average depth interval of around 90 m to 120 m within the Bland Creek Palaeochannel (Evolution, 2022c). The Lachlan groundwater system has been reported to provide up to 200 L/s (Lampayan, 2001) of brackish (~2,600 µS/cm, (Evolution, 2022b)) groundwater. Vertical head differences between the Lachlan and Lower Cowra formation, especially in areas near pumping centres, indicates the presence of large vertical anisotropy, likely attributed to multiple clay layers observed in the Cowra Formation.

The AIP defines water sources as being either ‘highly productive’ or ‘less productive’ based on levels of salinity and average yields from bores (DPI, 2012). As the AIP applies productive categories at the groundwater source scale, all three alluvial groundwater systems are collectively considered part of the Upper Lachlan Alluvial Groundwater Source, which is a ‘highly productive’ groundwater system.

Referring to the *Groundwater Impact Assessment* (EMM 2023a), other main aspects of the hydrogeological conceptualisation include:

- irrigation and rainfall are the main recharge mechanisms. Locally, groundwater systems are recharged by the Lachlan River, irrigation channels, and intermittently from the Lachlan River floodway during flooding

- the main flow direction is downwards from the palaeochannel sediments to the underlying fractured rock system. Groundwater then continues to flow west and discharges outside of the groundwater study area

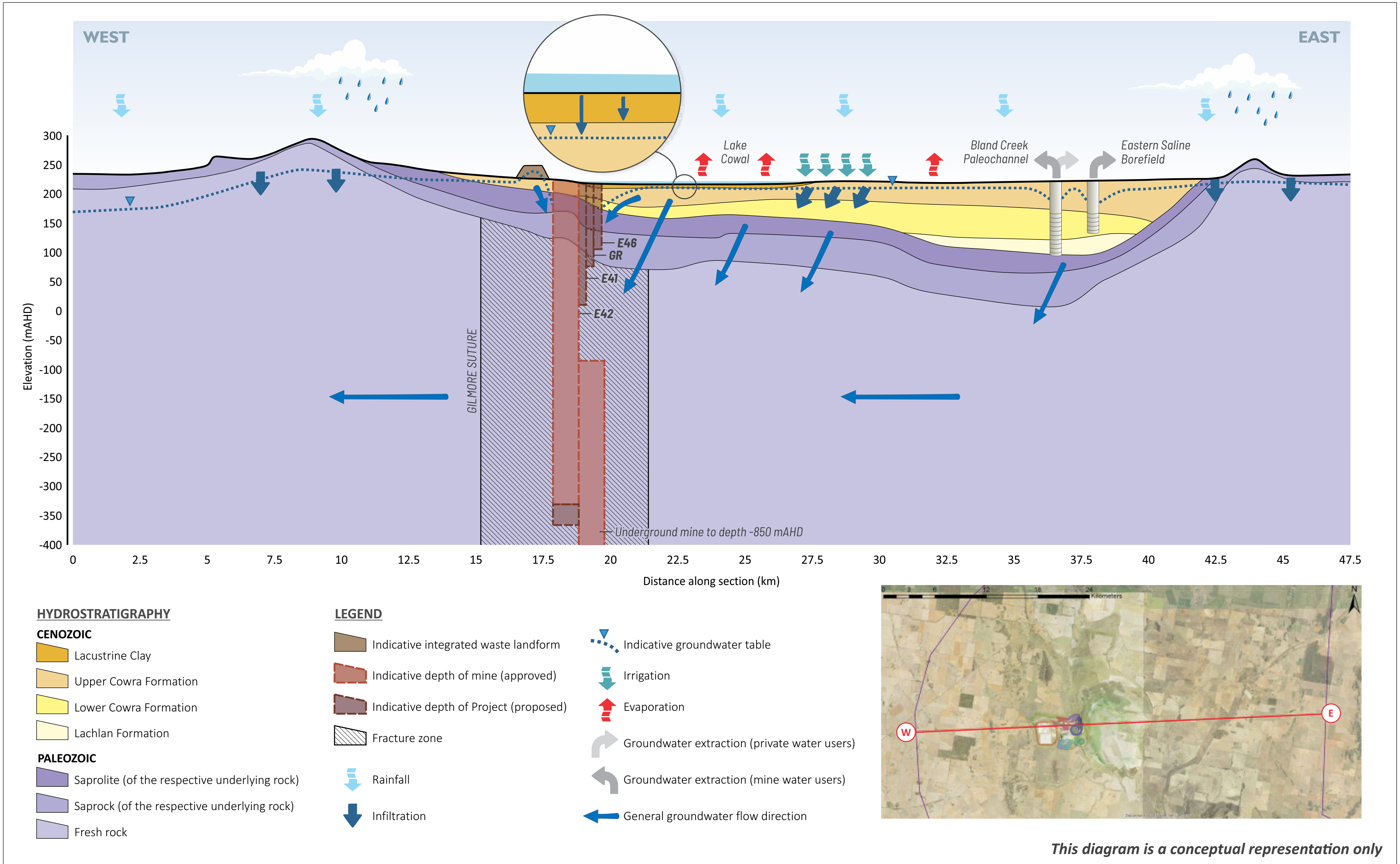
- evapotranspiration is the main discharge mechanism from the shallow groundwater system, especially during wetter periods when the lakes are full

- minor seepage occurs from these lakes; however recharge is limited by the low hydraulic conductivity of the Lacustrine Clay, deposited directly beneath the lakes

- inflow of groundwater from the Upper Cowra, Lower Cowra, and fractured rock groundwater system flows into Pit E42, causing local drawdown

- tailings deposition and waste rock emplacements induce local groundwater mounds beneath these facilities.

Directly relevant to this study, the drawdown likelihood at the PCTs of interest are associated with the Upper Cowra and the Lower Cowra groundwater systems, as these systems are required to be dewatered, at least locally, as part of the opencut mining process. There is no mine related drawdown in the Lachlan formation due to the absence of this system around the mine (EMM 2023a).



Conceptual hydrogeological section – east to west

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Figure 2.3

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3 Applied methods

Methods applied during the field assessment include measurement of Leaf Area Index (LAI), Leaf Water Potential (LWP), and Soil Moisture Potential (SMP) along with soil salinity measurements, lithological logging, and root architecture observations inferred from completed auger holes.

3.1 Selection of representative sites

The groundwater study area contains a naturally complex mosaic of woodlands across the alluvial plain, with most vegetation largely cleared / disturbed by agriculture. The assignment of native vegetation communities to their PCTs was informed by discussions with the NSW BCD.

The survey focused on areas mapped as potential drawdown impact areas, informed by predictions from the groundwater numerical model. In total, nine sites were chosen for targeted GDE assessment, with soil / auger sampling completed at three of the sites. Table 3.1 summaries the methods applied at each site. Sample locations in relation to cumulative groundwater drawdown, as assessed by the *Groundwater Impact Assessment* (EMM 2023a) is shown in Figure 3.1. Sample locations in relation to incremental groundwater drawdown, as assessed by the *Biodiversity Development Assessment Report* (EMM 2023b) are shown in Figure 3.2.

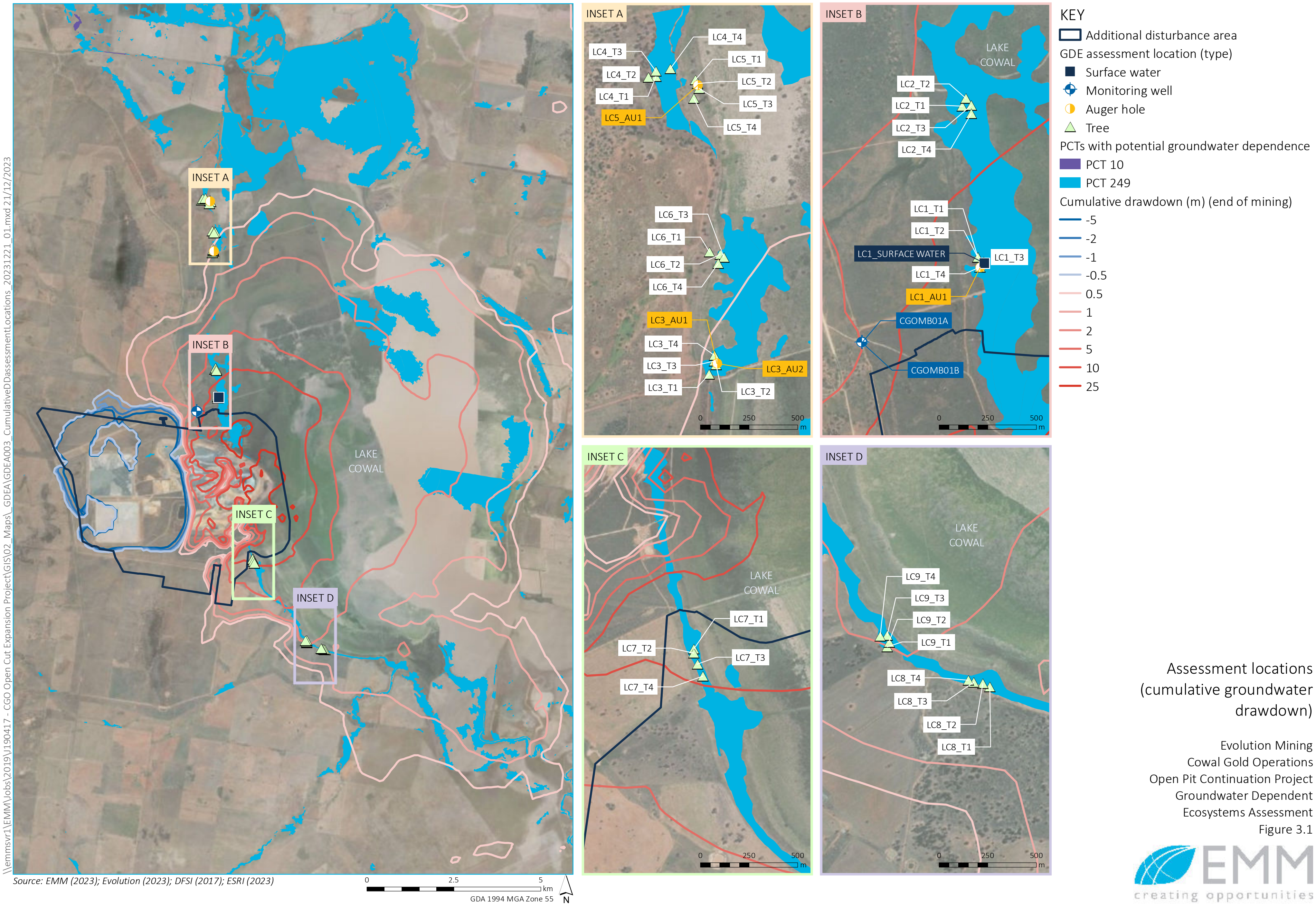
The overwhelming majority of PCTs in the area were of the River Red Gum species (PCT 249), with exception to a small community of River Box (PCT 10) far north of the area (LC4). One River Box tree was sampled during the assessment.

Sampling of surface water and groundwater was completed, using a bailer for groundwater collection from established groundwater monitoring bores and from the base of auger holes where groundwater was intersected, for in-situ water quality measurements.

Table 3.1 Summary of the assessment locations targeted during field assessment

Assessment site[1]	Location / geomorphic position	LWP	LAI	Auger / SMP
LC1	West of Lake Cowal, north of the Project	4 trees	4 trees	4.0m auger hole and associated soil samples Groundwater and surface water sampled
LC2	West of Lake Cowal, north of the Project	4 trees	4 trees	Not sampled
LC3	West of Lake Cowal, north of the Project	4 trees	4 trees	2.5m auger hole and associated soil samples
LC4	West of Lake Cowal, north of the Project	4 trees	4 trees	Not sampled
LC5	West of Lake Cowal, north of the Project	4 trees	4 trees	4.6m auger hole and associated soil samples Groundwater sampled
LC6	West of Lake Cowal, north of the Project	4 trees	4 trees	Not sampled
LC7	West of Lake Cowal, south of the Project	4 trees	4 trees	Not sampled
LC8	West of Lake Cowal, south of the Project	4 trees	4 trees	Not sampled
LC9	West of Lake Cowal, south of the Project	4 trees	4 trees	Not sampled

1. LC = Lake Cowal



Assessment locations (cumulative groundwater drawdown)

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Figure 3.1

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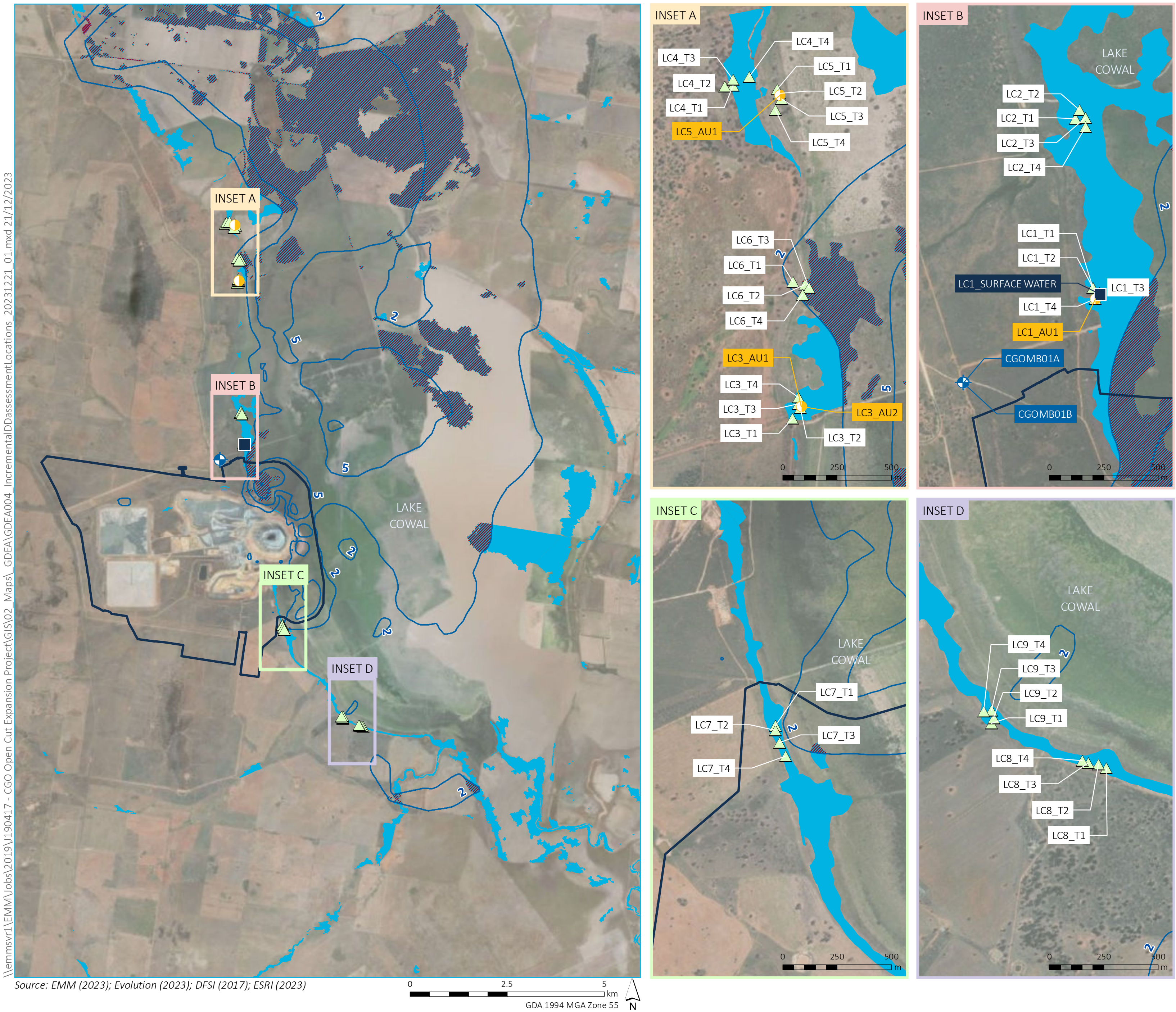
Source: EMM (2023); Evolution (2023); DFSI (2017); ESRI (2023)



Source: EMM (2023); Evolution (2023); DFSI (2017); ESRI (2023)

KEY
- Additional disturbance area
- Incremental groundwater drawdown level contour (m BGL)
- Potential impacts with incremental drawdown of > 2 m

GDE assessment location (type)
- Surface water
- Monitoring well
- Auger hole
- Tree

PCTs with potential groundwater dependence
- PCT 10
- PCT 249

Assessment locations (incremental groundwater drawdown)

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Figure 3.2

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3.2 Leaf Water Potential

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

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

Survey localities were visited pre-dawn (first light to pre-sunrise), and leaves were collected from the canopy with the aid of a 9m extension pole fitted with a lopping head, where required. Leaves were collected from four mature canopy trees within each assessment site in localities that were within several hundred metres from a vehicle track to assist collection of samples in low light within a limited sampling window. Collected branches were double bagged in reflective plastic to avoid moisture loss and sun exposure and LWP was measured on-site within half an hour of harvest. Suitable leaf material was trimmed with a fine blade and inserted into an appropriate grommet for sealing within a Model 3115 Plant Water Status Console (Soil Moisture Equipment Corp 2007). The chamber was sealed and gradually pressurised with nitrogen until the first drop of leaf water emerged from the petiole. Readings were taken in pounds per square inch (PSI) which is converted to a negative value in millipascals (mPa) for direct comparison to SMP measurements. In total, 36 trees were assessed for LWP across the nine assessment sites, with the location of these trees detailed in Table 3.1.

The following categories have been applied as a measure of relative water availability:

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

While the defining values of these categories are arbitrary in nature, they are intended to provide an indication of the likely degree and nature of groundwater dependence or interaction. The 'Extremely High' category would indicate the potential for interaction with an extremely fresh source of groundwater, with the degree of groundwater interaction decreasing through to the 'Moderate' category which may indicate either utilisation of soil moisture from the vadose zone or interaction with saline groundwater. Categories of 'Low' to 'Extremely Low' are considered unlikely to be utilising groundwater to any degree, regardless of salinity. It should also be stressed that soil moisture in the 'Extremely High' category can also be supplied directly from unsaturated portions of the soil profile depending on moisture availability, which can be assessed by measuring SMP.

3.3 Leaf Area Index

LAI is defined as the one-sided leaf area divided by the total ground area, or alternatively the likelihood that light transmitted from above a canopy will reach the ground without being intercepted by foliage. The main application of LAI is a measure of vegetation productivity or health, being a useful parameter to measure changes in canopy condition against an established baseline. Gap Fraction indicates how much of the sky is visible from beneath the plant canopy. Gap Fraction LAI measures gap fraction through a range of zenith divisions, incorporating measurement of leaf angle to allow calculation of the total one-sided leaf area. Gap Fraction LAI will range from 0 to >1 where multiple overlapping foliage covers exist.

The utility of LAI measurement is that it represents the earliest detectable measurement of a trees' response to reduced water availability and stress. Eamus et al. (2009) provides a conceptual assessment of the major stressors that contribute to declining GDE health with reduced water availability being the major determinate. Flow-on effects from reduced water availability are outlined in Figure 3.3. The initial reaction to reduced water availability would be limitation of stomatal opening (to limit transpiration losses) followed by decreased plant growth, loss of foliage cover and a reduced LAI. Ultimately, physiological responses would lead to tree senescence and conversion of a diverse, functioning habitat to a simplified system with reduced ecological value (Doody et al. 2009). As outlined in Figure 3.3, the time taken for the first measurable impacts caused by reduced water availability to manifest may take months. As a result, habitat conversion due to dieback of the original canopy for instance, could take many years.

LAI varies on a seasonal basis dependent on water availability, generally within the space of weeks to months, with the highest values lagging moisture recharge events. Doody et al. (2015) documented typical annual LAI variation in the range of 14% to 35%, with LAI = 0.5 identified as a potential threshold, indicative of critical water stress beyond which riparian vegetation health rapidly declines. While this value is taken from River Red Gum forest on the Murray River, it provides an indicative measurement of vegetation health at any given assessment locality, from which a more site-specific LAI threshold can be adapted if required.

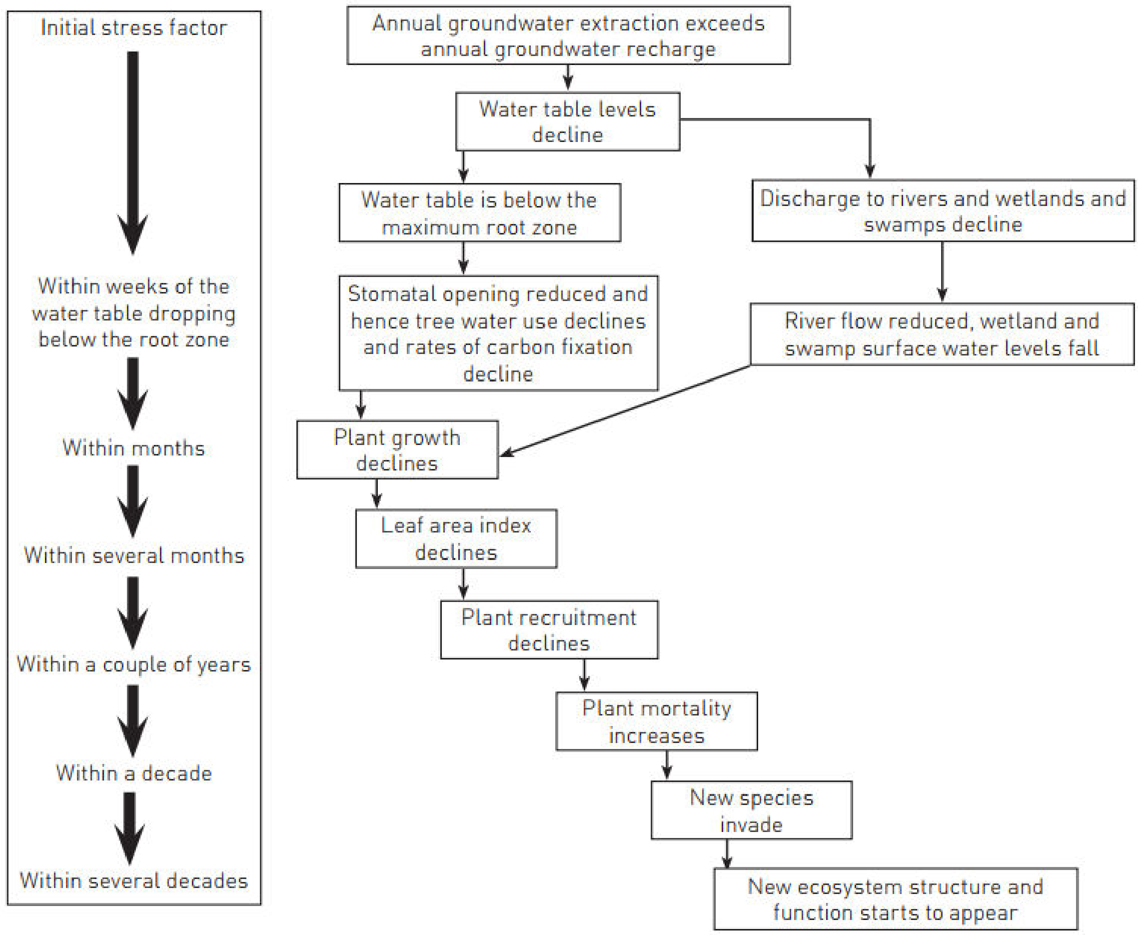

Figure 3.3 Schematic outline of the response of plants and communities of plants to reduced availability of groundwater from Eamus (2009)

3.4 Auger sampling and Soil Moisture Potential

A hand auger was utilised to collect shallow soil samples at regular depths down the soil profile at selected sites, as well as opportunistic sampling of groundwater where it was intersected. Sites for auger placement were spread spatially across the potential drawdown impact zones to represent variability and diversity of soil types, hydrological conditions, and ecological characteristics across the area.

At each site chosen for auger sampling, the aim was to collect soil samples to the maximum depth of the auger of penetration, with penetration often arrested by coarse gravel / cobble substrates or large tree roots. Within each auger hole, the following observations were taken at regular depth intervals or where changes to soil structure were apparent:

- soil structure, colour, and texture
- presence of root matter
- soil moisture / water and areas of saturation.

Soil sampling was undertaken at regular intervals down the soil profile to analyse for SMP. Sample collection was generally spaced at 0.5 m intervals down the auger profile with additional samples taken where changes in soil structure / texture, moisture content, or zones of tree roots were detected. As the samples were collected, they were immediately sealed in airtight plastic vials and placed on ice, for later measurement for SMP.

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

The measurement of SMP was completed with a portable Dew Point Potentiometer (WP4C) (Meter Group Inc 2021). 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. A single 7 ml soil sample was inserted into the WP4C meter using a stainless-steel measuring tray. SMP samples were measured in megapascal pressure units (MPa).

3.5 Salinity measurements

Soil salinity measurements were completed in field with a Teros 12 soil water, EC, and temperature probe which relies on insertion of 3 x 50 mm stainless steel sensor needles into the soil sample. For soil surface samples, stainless steel needles were inserted directly into the substrate meaning measurements are directly relevant to the top 50 mm of the soil profile. For soil cores, measurement of soil salinity was made with placement of the sensors directly into the soil core through cut-aways in the auger head. This enabled soil salinity to be measured at a minimum of 50 mm downhole intervals. Measurement of soil salinity requires insertion into the substrate to the full depth of the 3 x 50 mm needle sensors and could not be undertaken accurately when soil cores were broken, resulting in some significant information gaps.

The Teros 12 measures volumetric moisture content (VMC) and bulk salinity of the soil sample and in conjunction with soil temperature (°C), enabled conversion into plant available EC or pore moisture EC (an indicator of solute concentration in the soil pores) for a more meaningful ecological application. Conversion was completed using the algorithm developed by Hillhorst (2020) ($\sigma p= (\varepsilon p\ \sigma b) / (\varepsilon b - \varepsilon \sigma b=0)$) which calculates soil dielectric permeability to accommodate a correction for soil temperature. For general reference, soil salinity was subsequently grouped into broad classification units for which the widely adopted classification of Gartley (2010) was applied, with floristic descriptions adapted from Agriculture Victoria (2020):

1. Non-saline soils (<2 dS/m): Vegetation is unaffected.
2. Slightly saline soils (2–4 dS/m): Salt sensitive plants show a reduction in number and salt tolerant species increase.
3. Moderately saline (4–8 dS/m): Salt tolerant plants tend to dominate and salt sensitive plants are affected. Small bare areas may appear.
4. Highly saline (8–16 dS/m): Salt tolerant plants including halophytes dominate and large bare areas appear.
5. Extremely saline (>16 dS/m): Only halophytes survive amongst extensive areas of bare scald.

The major application of the salinity data is to identify the contribution that soil salinity makes to soil samples with particularly negative SMP values.

Water salinity measurements, among other parameters, were completed in field with a TPS WS water quality meter. Water quality measurements were taken where groundwater was intercepted in auger holes, boreholes, and surface water.

3.6 Data reconciliation and interpretation

The biophysical measurement of LWP provided an initial assessment parameter, which was then directly compared to downhole SMP measurements to determine the likelihood of groundwater dependence and likely zone of water uptake by the root system. LWP values for trees with rooting zones in equilibrium with a source of fresh groundwater will typically present LWP values >-2 MPa with the likelihood of groundwater dependence decreasing as the LWPs become increasingly negative. Groundwater salinity complicates the interpretation of LWP measurements due to influence of a negative osmotic force. Generally, groundwater dependence is ruled out where LWP values fall below -1.5 MPa; this would be equivalent to the osmotic force generated by groundwater with salinity >30,000 µS/cm which is considered an unsuitable source of moisture for most trees.

For trees presenting LWP values >-1.5 MPa, assessment of downhole SMP from soil auger sampling determines the likelihood that moisture for transpiration is being supplied from the upper soil profile, as opposed to deeper groundwater sources. As described in Section 3.4, water only has capacity to move down a hydraulic gradient from soil to root meaning that only those portions of the soil profile that have a SMP that is equal to or less negative than measured pre-dawn LWP will be accessible as a source of moisture from the vadose zone for water to move into the plant (Gardner 1960).

4 Results

Complete tabulated LWP, LAI, and SMP results for all leaf and soil samples, water quality measurements, and field observations are provided in Attachment A with a summary of the results presented below.

4.1 Leaf Water Potential

The LWP statistical values for the nine assessment sites are shown in Figure 4.1 as box and whisker plots, with the average, median, 25th, 75th, minimum, and maximum values shown. Extremely High to Very Low LWP values, as outlined in Section 3.2, have been plotted on the figure also to aid in interpretation.

The majority (69%) of trees have Moderate to Extremely High LWP values. The highest average LWP values are measured from the location closest to the Project and just north of the current E42 pit (LC1 avg. -0.625 Mpa), with the lowest values recorded from the location south of the Project (LC9 avg. -1.3125 Mpa).

There is variability contained within individual assessment sites, with most locations ranging across four moisture potential categories. Three trees have LWP values that fall within the Very Low moisture availability category and have a plant water deficit (LC4_T2, LC6_T1, LC8_T2), inclusive of the one Black Box tree assessed (LC4_T2). One tree has an LWP value that falls within the Extremely High category (LC2_T2). No trees have LWP values within the Extremely Low moisture availability category.

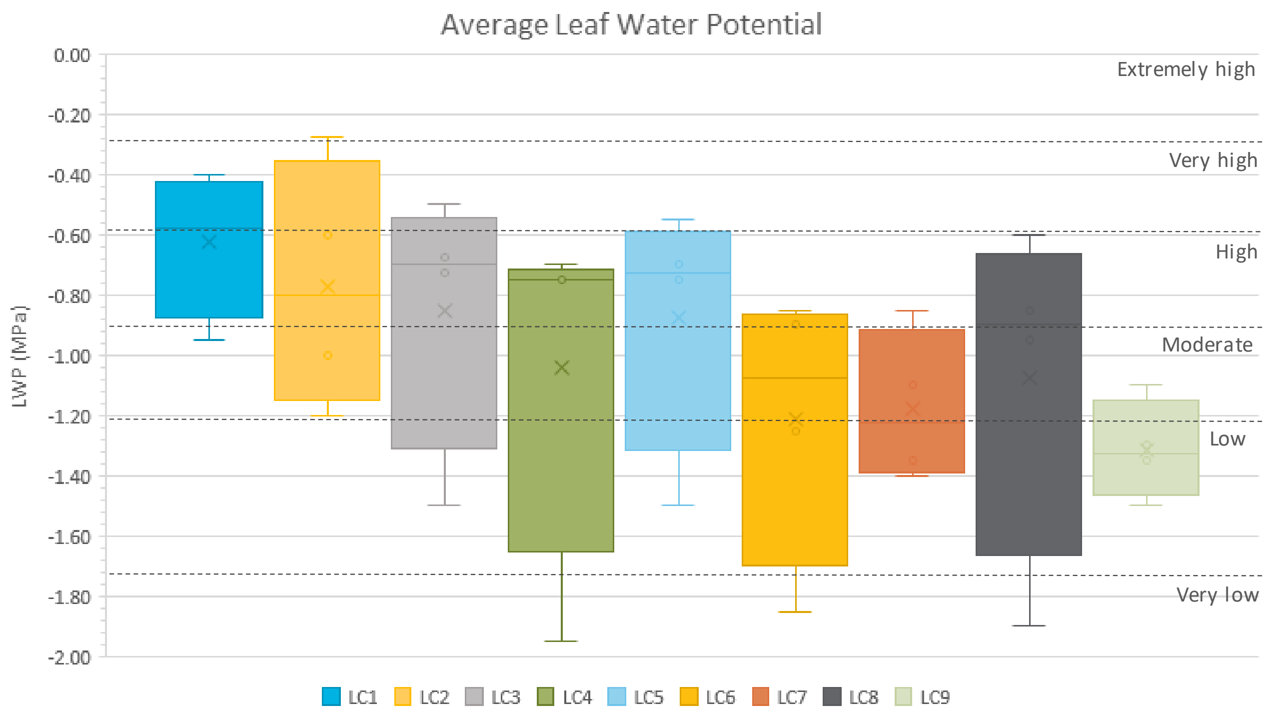

Figure 4.1 Statistical LWP values for assessment sites

4.2 Leaf Area Index

LAI values measured for individual trees from the nine assessment sites (which are colour coded per site) are shown in Figure 4.2. The threshold LAI value indicative of tree stress, as defined by Doody et al. (2015), is less than 0.5; all but five trees had LAI values above 0.5 which indicates relatively good health. The exceptions include two trees from LC1 (with one tree just above the threshold), one tree from LC2, and two trees from LC3; these locations are closest to, and north of, the Project, and have significantly lower LAI values than locations further north (LC4 and LC5).

These values are in accordance with field observations that trees fringing the lake are generally in good health, with trees from LC1, LC2, and LC3 observing more leaf shed. The reduced LAI is likely a response to high lake levels and associated soil saturation in the months prior; as shown in Figure 3.3, it may take weeks to months for a response in LAI to be measurable. The high LWP values indicate good growing conditions at the time of assessment, and LAI is likely to increase as the soil profile continues to dry.

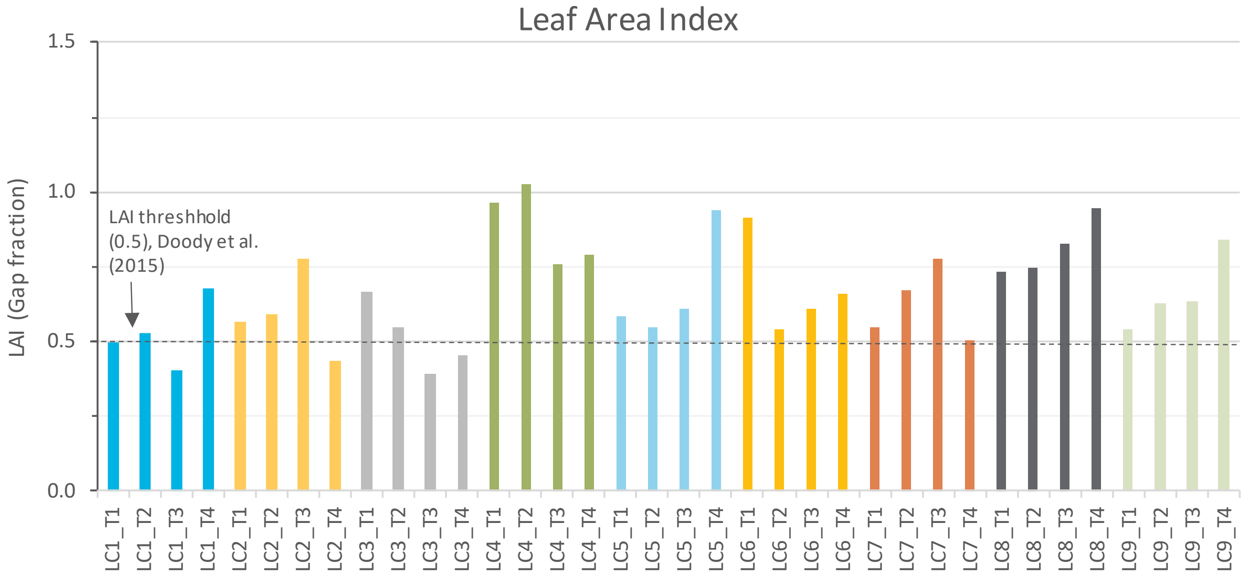

Figure 4.2 Leaf Area Index values for individual trees across the assessment sites

4.3 Auger sampling and Soil Moisture Potential

As per Section 3.4 and Section 3.6, the purpose of the auger sampling and SMP measurements is to identify whether sufficient moisture is available in the upper unsaturated portion of the soil profile (i.e. vadose zone) to support the LWP measurements or suggest the utilisation of deeper groundwater sources (below the depth of auger sampling and towards the capillary fringe zone).

Three soil auger holes were sampled during the assessment at locations LC1, LC3, and LC5. A summary of auger location and depth is shown in Table 4.1. Auger holes are discussed in the following sections, and logs are provided to show representation of the major elements of the soil profile including location of major soil intervals and the depth of groundwater, if intersected. Soil samples were collected at each significant change in soil texture and soil moisture. SMP was measured for each soil sample and the results of these analyses are plotted directly on the auger lithological profiles along with the range of LWPs measured at each assessment site. Standing water at the base of each auger hole was bailed where possible, with a sample collected for measurement of field salinity.

Table 4.1 Location and depth of auger holes sampled during assessment

Auger hole	Latitude	Longitude	Auger lithology	Total auger depth (m)
LC1_AU1	-33.6155162	147.3999217	East of Lake Cowal, north of the Project. Upper Cowra Formation – alluvium Cenozoic sediments.	4.0
LC3_AU1	-33.5773281	147.3984450	East of Lake Cowal, north of the Project. Upper Cowra Formation – alluvium Cenozoic sediments. Hit base of alluvium at interface of Palaeozoic bed rock.	2.5
LC3_AU2	-33.5773280	147.3984536	East of Lake Cowal, north of the Project. Upper Cowra Formation – alluvium Cenozoic sediments. Hit base of alluvium at interface of Palaeozoic bed rock.	2.2
LC5_AU1	-33.5644184	147.3973392	East of Lake Cowal, north of the Project. Upper Cowra Formation – alluvium Cenozoic sediments.	4.6

4.3.1 Site LC1

The location of Auger LC1 AU1 (Figure 3.1) was placed close to active mining (approximately 2.3 km north of the Project), near mature trees measured for LWP and LAI (adjacent to LC1 T4). Figure 4.3 summarises the LC1 AU1 lithological and SMP profile while also highlighting the range in LWPs measured at this site and observations of the presence of groundwater. Results are discussed below.

The hole penetrated to a depth of 4.0 mbgl intersecting 35 cm of loamy soil before passing through heavy alluvial / lacustrine clays. A thin layer of gravelly clay was intercepted between 1.25 and 1.5 mbgl, and a thin clayey sand layer was intercepted at approximately 3.1 mbgl. A perched groundwater system was discovered within the sand layer at 3.1 mbgl. The static water level of the groundwater rose to 1.5 mbgl overnight, inferring that this system is hydraulically connected to Lake Cowal, with the water level rise due to hydrostatic loading associated with the high lake surface water levels. Orange and red mottling was observed down the soil profile, with extensive mottling at 3.6 mbgl, indicating seasonal variation of the system.

SMP values are highest (least negative) from surface to 1.7 mbgl, and the range of LWP values recorded from the four River Red Gum are accounted in the shallow soil profile. Tree roots were observed from surface to below the perched groundwater table (observed to 3.6 mbgl), ranging from fine to coarse (Photograph 4.1), with very fine and some dead roots at 3.6 mbgl. Where salinity measurements were possible, the soil profile ranged from 1,093 µS/cm (pore space salinity at 0.5 mbgl) to 4,333 µS/cm (pore space salinity at 3.8 mbgl). These soils are considered non-saline to moderately-saline. Salinity of the groundwater bailed from the hole was 2,500 µS/cm.

As discussed previously, Site LC1 has the least negative LWPs, with statistics previously discussed in Section 4.1 and the range shown in Figure 4.3 allowing for a direct comparison to the measured SMP, lithology, and groundwater presence, if any. The LWPs range between high and moderate water availability, indicating that the plants may be using water sourced from soil moisture from the vadose zone or interaction with saline groundwater. However, when LWP range is compared to the SMP profile, SMP and LWP value intersect between surface and 1.7 mbgl, implying a preferred zone of moisture uptake in this depth range at the time of assessment. Below 1.7 mbgl, SMP is considerably more negative than LWP values and it is inferred that soil moisture is not available for plant use below this depth. This zone is also above both the perched water table and inferred regional water table, further showing the plants are relying on soil water from the vadose zone and not from a permanent groundwater source.

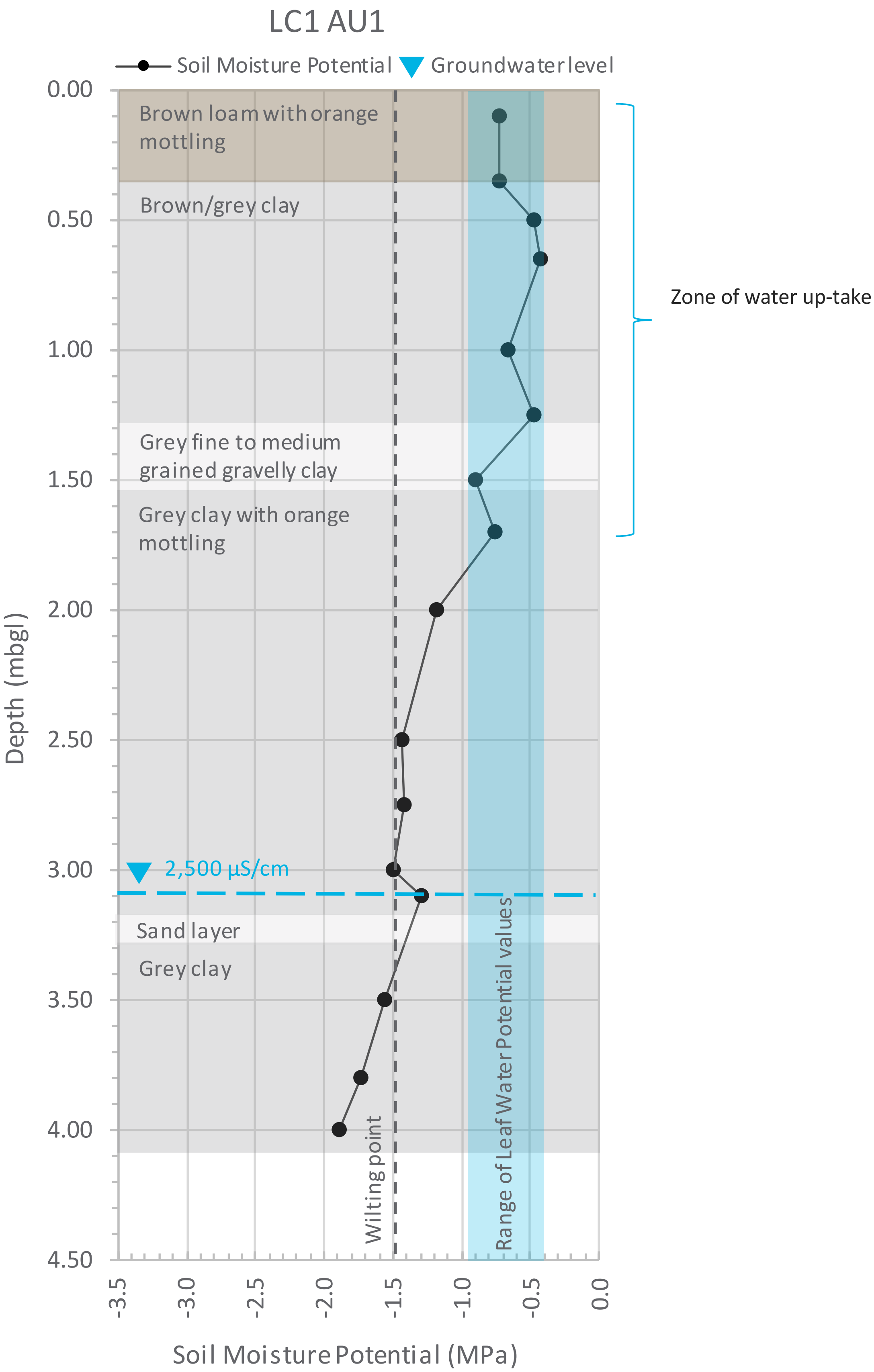

Figure 4.3 Soil auger AU1 profile from site LC1

Photograph 4.1 Coarse roots from LC1_AU1 at 1.7 mbgl

4.3.2 Site LC3

The location of Auger LC3 AU1 (Figure 3.1) was located approximately 6.5 km north of the Project, near mature tree measured for LWP and LAI (adjacent to LC3 T2). Figure 4.4 summarises the LC3 AU1 lithological and SMP profile while also highlighting the range in LWPs measured at this site and observations of the presence of groundwater, if encountered. Results are discussed below.

The auger hole penetrated to refusal at 2.5 mbgl; a second hole was drilled (AU2) approximately 2 m adjacent to AU1 in an attempt to penetrate deeper into the soil. AU2 hit refusal at 2.2 mbgl. AU1 intersected 0.5 m of loamy soil before passing through heavy alluvial / lacustrine clays. An extensively red and orange mottled zone was observed at 1.5 mbgl, with clayey sands and gravels following to approximately 2.4 mbgl. Basement rock was intercepted at the end of LC3 AU1 and LC3 AU2.

Referring to Figure 4.4, SMP values are highest (least negative) within the clay layer from 0.75 to 1.3 mbgl and become increasingly negative with depth. Based on the intersects between SMP and LWP values, the indicated zone of moisture uptake at the time of assessment for the four River Red Gum's is from surface to 1.3 mbgl. Filamentous roots were observed at 1.4 mbgl, and no groundwater was observed in this hole. Where salinity measurements were possible, the soil profile ranged from 3,946 µS/cm (pore space salinity at 0.75 mbgl) to 5,275 µS/cm (pore space salinity at 1.3 mbgl). These soils are considered slightly-saline to moderately-saline. Measurements could not be completed at deeper levels in the soil profile due to the broken and blocky nature of the auger spoils.

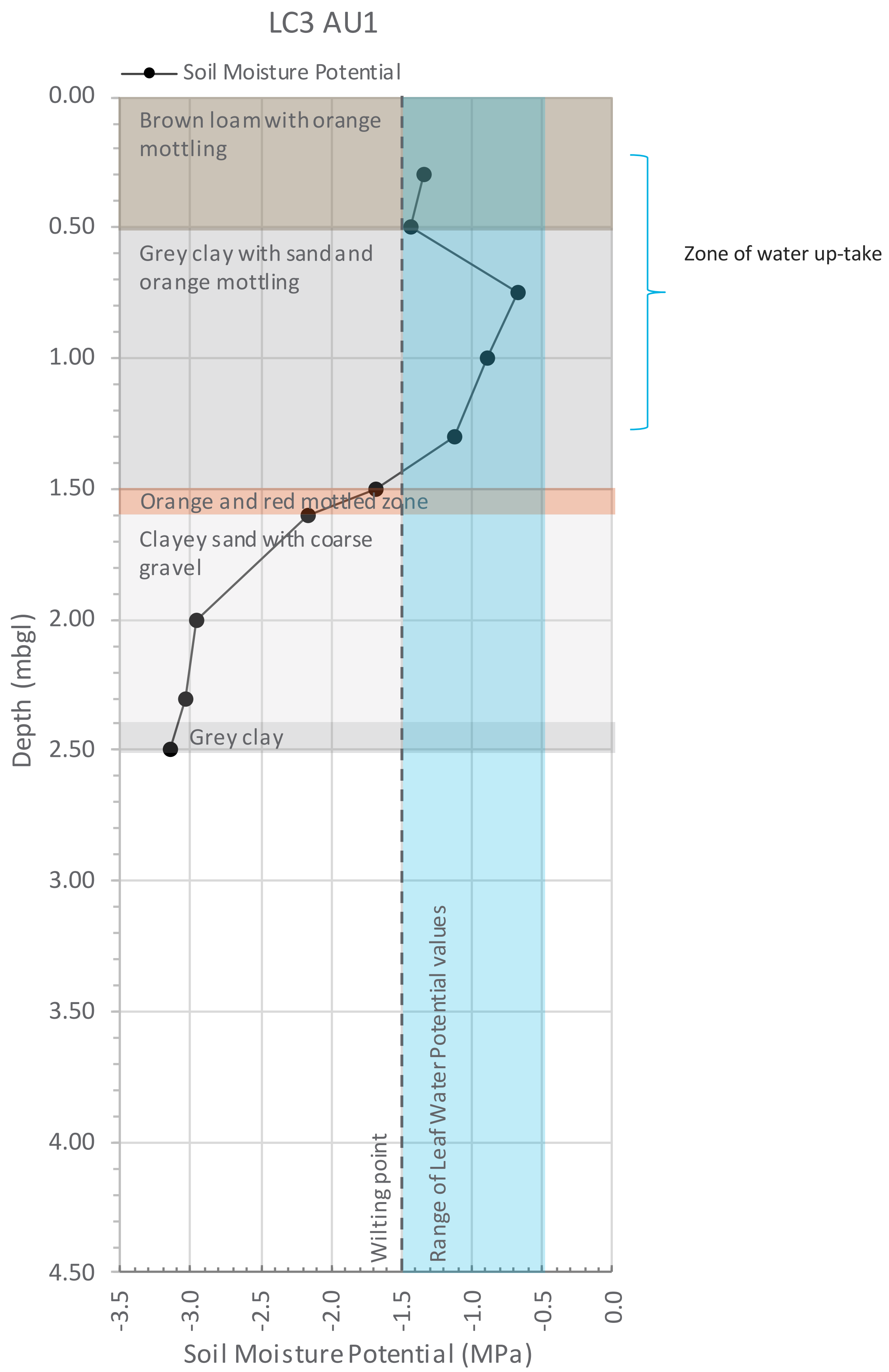

Figure 4.4 Soil auger AU1 profile from site LC3

4.3.3 Site LC5

Auger LC5 AU1 (Figure 3.1) was placed furthest north of the Project (approximately 7.9 km north of the Project), excluding the most northernly site LC4, which sits further inland. AU1 was placed near mature trees measured for LWP and LAI (between LC5_T2 and LC5_T3) and is considered representative of the PCTs located within the BDAR that identified potential incremental drawdown impacts on GDEs (EMM 2023b). Figure 4.5 summarises the LC5 AU1 lithological and SMP profile while also highlighting the range in LWPs measured at this site and observations of the presence of groundwater, if encountered. Results are discussed below.

The hole penetrated to a depth of 4.6 mbgl intersecting 0.8 m of loamy soil before passing through heavy alluvial / lacustrine clays to 4.2 mbgl. Crystaline gypsum was observed within the clay at 3.7 mbgl (Photograph 4.2). Gypsum is a mobile compound of moderate solubility (Mackenzie et al. 2004) that is typically associated with soils of low rainfall areas, where it accumulates through dissolution at a depth regulated by soil drainage capacity. Red mottling was present from 4.0 mbgl. Groundwater was intercepted within a red gravel lens (inferred to be hematite rich) between 4.2 and 4.4 mbgl (Photograph 4.3).

SMP values observed at this site were lower than other sites (all values <-1.0 Mpa), meaning soil moisture has lower availability at this site due either to lower matric potentials (i.e. higher clay content) or lower osmotic potentials (i.e. salinity), or a combination of both. The highest (least negative) values occurred within the clay between 0.8 and 1.2 mbgl. Based on the intersects between SMP and LWP values, the indicated zone of moisture uptake at the time of assessment for the four River Red Gum's is from 0.5 to 1.5 mbgl.

Tree roots were observed up to 3.2 mbgl, with coarser roots observed in this area compared to the other two sites suggesting perhaps, that some uptake of water may occur at deeper depths on occasion, although this is not supported by the LWP and SMP data. Carbon staining with an organic odour was observed around tree roots at 1.2 mbgl. Where salinity measurements were possible, the soil profile ranged from 8,376 µS/cm (pore space salinity at 2.5 mbgl) to 8,580 µS/cm (pore space salinity at 4.0 mbgl). These soils are considered moderately-saline to highly-saline; the higher salinity values correspond to the lower SMP values observed at this site. Salinity of the groundwater bailed from the hole was 43,700 µS/cm; this groundwater is considered an unsuitable source of moisture for trees, (>30,000 µS/cm) as discussed in Section 3.6. The salinity is also characteristic of the regional groundwater system, hosted either within the Upper Cowra or basement rock, west of the BCP.

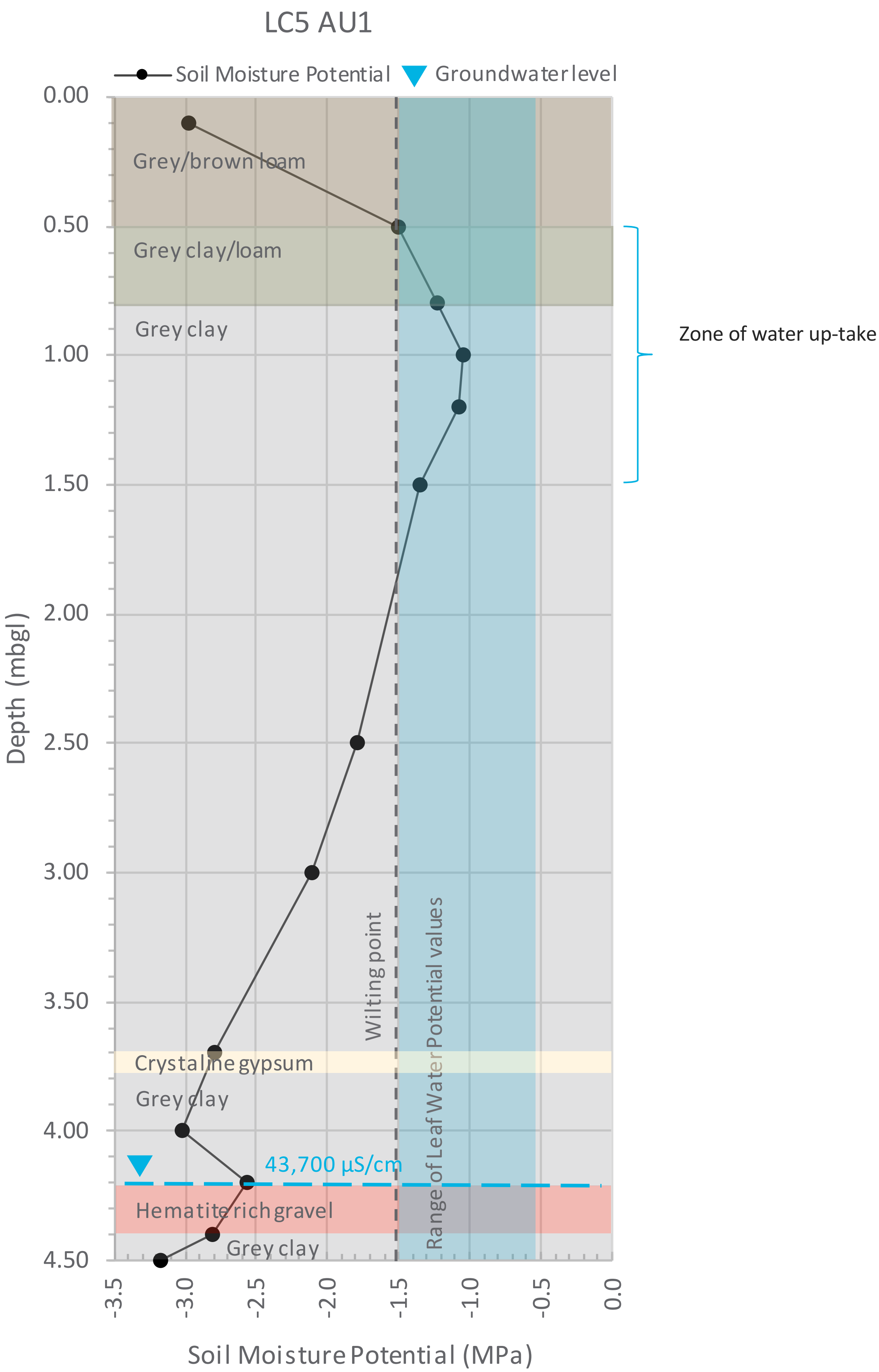

Figure 4.5 **Soil auger AU1 profile from site LC5**

Photograph 4.2 Gypsum from LC5_AU1 at 3.7 mbgl

Photograph 4.3 Hematite rich wet gravel from LC5_AU1 at 4.2 mbgl

4.4 Water quality sampling

Salinity (EC (µS/cm)) measurements for groundwater encountered in auger holes, groundwater from two established groundwater bores, and one surface water sample from Lake Cowal are summarised in Table 4.2.

Table 4.2 Salinity measurements for water sources on site

Location / bore ID	Source	EC (µS/cm)
LC1 SW	Surface water – Lake Cowal	588
LC1 AU1	Groundwater – perched system (3.1 mbgl)	2,500
LC5 AU1	Groundwater – hematite rich gravel layer (4.2 mbgl)	43,700
CGOMB01A	Groundwater – screened in Upper Cowra Formation (29–35 mbgl)	38,500
CGOMB01B	Groundwater – screened in Lake Cowal Volcanics (100–106 mbgl)	39,200

As discussed in Section 3.6 and Section 4.3.3, groundwater with salinity values over 30,000 µS/cm is considered unsustainable as a source of moisture for trees. Therefore, the PCTs will not be utilising the groundwater in the gravel layer at 4.2 mbgl, the groundwater within the Upper Cowra Formation, or the groundwater in the Lake Cowal Volcanics, due to the highly saline conditions.

The salinity values measured from the perched water system and Lake Cowal further shows that the lake serves as a source for the perched system. As water percolates through the soil, it accumulates salts, thereby elevating the salinity levels from the fresh lake water conditions as seen at assessment site LC1.

5 Ecohydrological conceptualisation and risk assessment

5.1 Ecohydrological conceptualisation

Ecohydrological conceptualisation involves identifying and describing the processes that control or influence the movement and storage of groundwater in a hydrogeological system, providing information on how a project may impact surface water bodies that depend on groundwater (Merz 2012). The development of site-specific conceptualisations are an essential part of a site assessment and present critical links between a source, receptor, pathways, and potential associated impacts (NEMP 2013).

Based on the information gathered from the soil logs, LWP and SMP measurements, field observations, geological knowledge of the area, and supporting scientific literature, ecohydrological conceptualisations have been created to inform the source – pathway – receptor connection for the potential GDEs, which also informs the risk assessment (see Section 5.2).

Figure 5.1 and Figure 5.2 visually represent site assessment locations LC1 and LC5 respectively, identifying the current state (i.e. high lake level setting) and predicting changes from seasonal changes to groundwater. The following section identifies the main features of the conceptual models.

5.1.1 LC1 site

- Where the perched groundwater is present (location LC1), during the wet season, there is less leaf density (lower LAI) in the River Red Gum, due to over saturation of the soil profile and potential water logging.
- Despite the perched groundwater availability, the dominant zone of moisture uptake in LC1 is from the vadose zone, which is occurring quite shallow within the soil profile as indicated by the LWP and SMP values.
- The perched water system is sourced by Lake Cowal; changes to lake levels effect the perched groundwater levels through this hydraulic connection and is shown as bank storage in Figure 5.1.
- During the dry season, as the vadose zone dries and the lake water retreats, trees focus root activation on roots established deeper in the soil profile where residual moisture may exist from the perched system during the wet season.
- The regional water table is likely several meters deep and is generally within the depths that phreatophytes such as River Red Gums can access. However, the salinities are >40,000 µS/cm and is considered unsustainable as a source of moisture for trees.
- Leaf density will improve during the dry season as water logging potential is reduced.

5.1.2 LC5 site

- Within this area, there is no perched groundwater system and plant water is supplied from moisture within the vadose zone all year-round.
- Lake leakage would occur, assisting with moisture conditions within the vadose zone.
- Similar to the LC1 site, River Red Gum tree roots favour the vadose zone, and are not utilising the unconfined Upper Cowra groundwater system even though this permanent source of water is within this species root depth range.

- Using the vadose zone as a source of water, the River Red Gums are generally healthy with all trees having a LAI >0.5.
- At this location, the regional groundwater system, most likely associated with the western fringes of the Upper Cowra system, is shallow and saline.
- Similar to the LC1 site, the Upper Cowra groundwater system is unsuitable for use across both locations due to high salinity values and assumed highly negative SMP values.

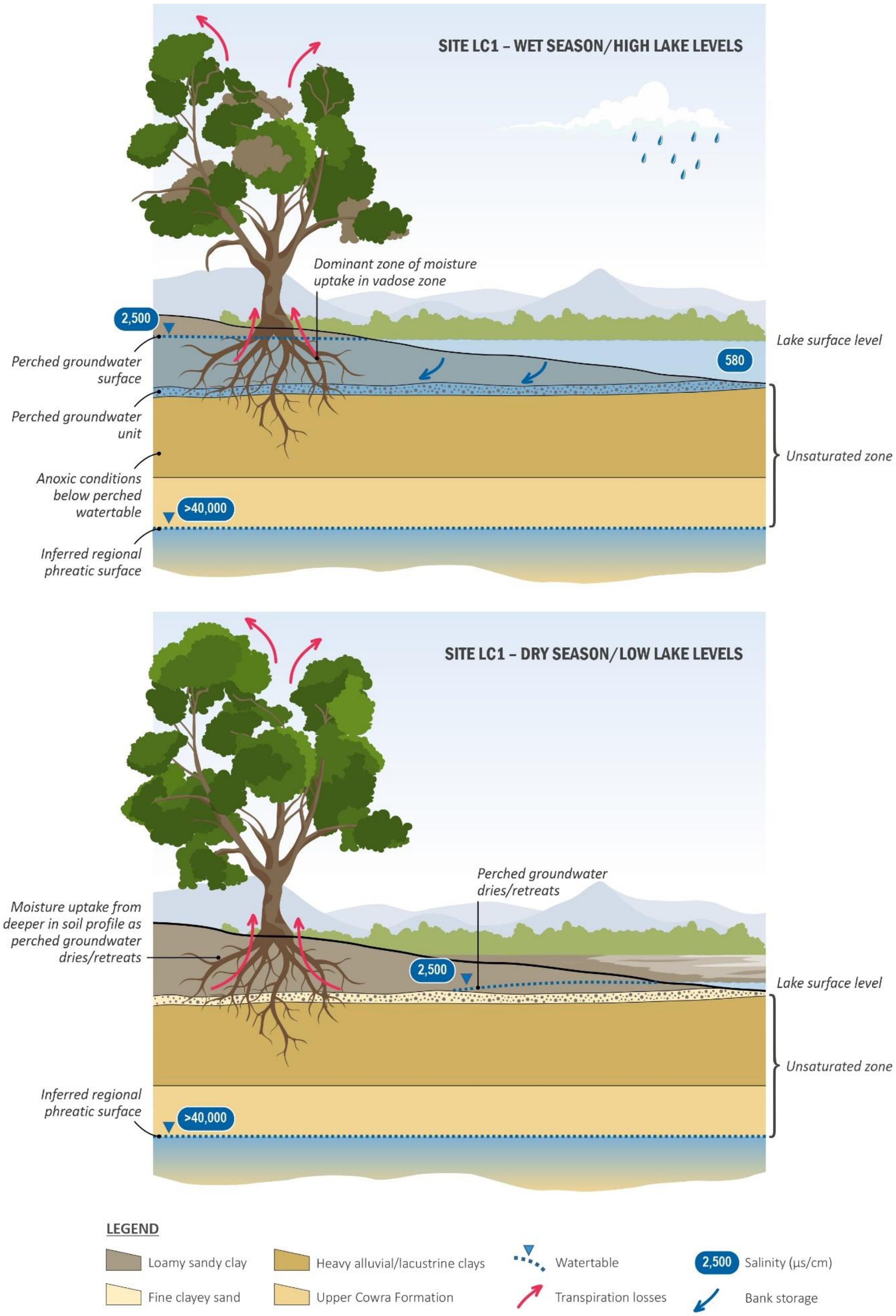

Figure 5.1 Site LC1 ecohydrological conceptual model

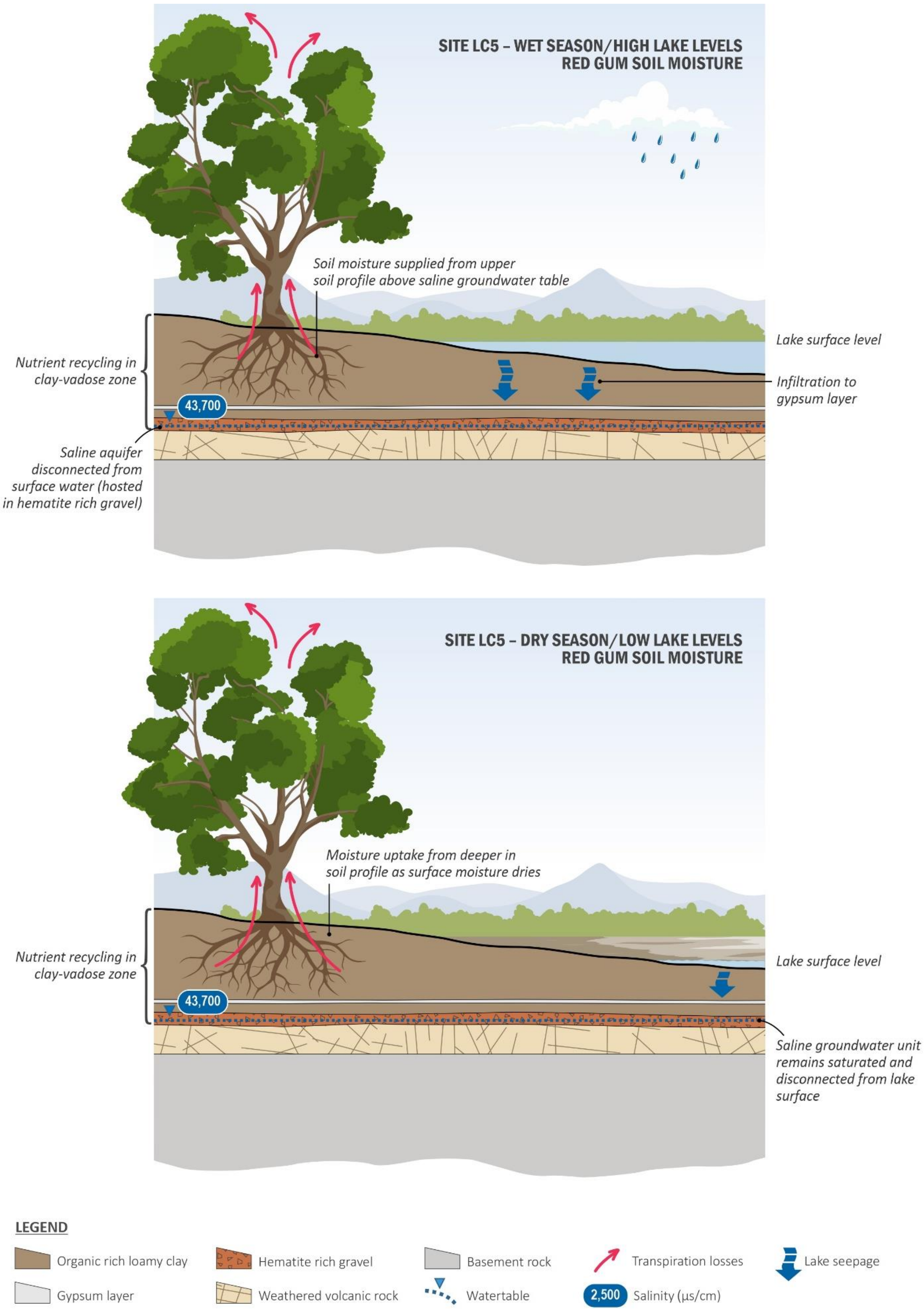

Figure 5.2 Site LC5 ecohydrological conceptual model

5.2 Risk assessment

Many activities associated with mining exploration, development, and operations have the potential to impact GDEs. The magnitudes and types of impact expected for a GDE are determined largely by the connection between the GDE and the mining activities. This connection is referred to as the causal pathway of connection, defined as a logical chain of events. It consists of four main conduits (IESC 2019):

1. subsurface depressurisation and dewatering
2. subsurface physical flow paths
3. surface water drainage
4. operational water management.

Relevant to this study is the impact associated with dewatering around groundwater-dependent terrestrial vegetation (terrestrial GDEs), which reduces the availability of water to established vegetation root networks, impairing the condition of the vegetation community. The response of vegetation to water stress may take years to become obvious, although some vegetation communities die back almost immediately (IESC 2019).

Using the observations drawn from the field assessments and the developed ecohydrological conceptualisations, the risk to the health and ecological function of GDEs associated with the Project are considered negligible due to the following:

- River Red Gums in the groundwater study area appear to predominantly utilise soil water within the shallow vadose zone, which is maintained by rainfall and / or a perched groundwater system fed by Lake Cowal.
- Given the River Red Gums are likely to have adapted to use soil water as their predominant water source, there is no causal pathway as mine dewatering effects depressurization within the Upper Cowra groundwater system and not the shallow vadose zone.
- Aquifer disruption, such as excavation of the shallow system supporting the identified perched system in the case of the Project, has the potential to deplete or change groundwater flow paths and volumes supporting ecosystem habits (DPE 2022). At Lake Cowal, these perched systems seem to be associated with local lake sediments and are not at risk of excavation due to the mining activities, unless located within or immediately adjacent to the open cut mining operations.
- Changes to River Red Gum health may occur with fluctuations of the lake and saturation / availability of the perched groundwater system. Over saturation can cause health stress, as can prolonged drought with the PCTs, however in general, River Red Gum are typically more resilient to drought conditions.

In summary, aquifer drawdown associated with the development of the Project is expected to have no impact on River Red Gums due to the absence of pathways between groundwater sources, being either the vadose zone or the shallow perched system, and the water effecting activities at the mine site.

6 Conclusions

This Groundwater Dependent Ecosystem Assessment has been completed through detailed field-based investigations and the creation of ecohydrological conceptualisations to identify characteristics of GDEs, in particular, River Red Gum trees. The study considered the potential reliance River Red Gums have on the presence of groundwater, that may be subject to impact caused by groundwater drawdown associated with the Project.

This assessment was completed to supplement the Project EIS and address recommendations provided by NSW DCCEEW (see Section 1.2), and NSW BCD (see Section 1.3).

The key conclusions drawn from this assessment are as follows.

- The majority of River Red Gum and Black Gum trees belonging to PCTs 10 and 249 fringing the lake and within the predicted groundwater drawdown impact zone are in good health, with moderate to high LWP values (Section 4.1), LAI values above the water stress threshold (Section 4.1), and reliable, shallow and accessible water sources shown by the SMP values (Section 4.3).

- Potential water logging causing health stress is inferred at locations with PCT 249 closest to the Project where a perched groundwater system is supported by recent high lake levels. This is evident through field observations, high LWP values, and low LAI values falling below health thresholds.

- The River Red Gum communities (i.e. PCTs 10 and 249) appear to draw moisture from soil water within the shallow vadose zone, predominantly between depths from surface to 1.5 mbgl. This represents the zone where soil moisture is most consistently available across all seasons, supported by both LWP and SMP measurements.

- There is no evidence from LWP measurement recorded in River Red Gum communities (i.e. PCTs 10 and 249) that trees have any reliance on the permanent groundwater source hosted in the Upper Cowra Formation.

- The salinity measurements of the groundwater within the unconfined Upper Cowra Formation confirm that River Red Gum (i.e. PCTs 10 and 249) near Lake Cowal are not utilising moisture from this source, as the highly saline conditions are unsustainable for use.

- Drawdown associated with the development of the Project is not expected to impact on River Red Gums (i.e. PCTs 10 and 249) due to the absence of casual pathways between the mine dewatering activities and these potential GDEs. This is because the Upper Cowal Formation is affected by mine dewatering, which the GDEs do not appear to be reliant upon.

- Any aquifer disruption, through excavation activities for example, have the potential to affect the shallow systems supporting the perched aquifer, however since these perched systems seem to be associated with local lake sediments, they are not at risk of excavation due to the mining activities, unless located within or immediately adjacent to the open cut mining operations.

- Based on a lack of expected impacts of groundwater drawdown on River Red Gum communities (i.e. PCT 10 and 249) by the Project, it is considered that adaptive management (i.e. ongoing monitoring and associated trigger, action response plans) are not considered necessary.

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Glossary

Term	Description
AIP	The Aquifer Interference Policy (2012) applies to all water effecting activities in NSW and clarifies the requirements for obtaining water licenses and establishes the assessment requirements on whether more than minimal impacts might occur to a key water-dependent asset based on defined thresholds.
BCP	Bland Creek Palaeochannel- the major alluvial groundwater system located directly east of the Project, which is a major groundwater source for stock and domestic, irrigation and industrial use.
BDAR	A Biodiversity Development Assessment Report (BDAR) is a report required under the BC Act which provides guidance on how a proponent can avoid and minimise potential biodiversity impacts and identifies the number and class of biodiversity credits that need to be offset to achieve a standard of 'no net loss' of biodiversity.
BoM	Bureau of Meteorology
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.
Casual pathway	A causal pathway is a logical chain of events – either planned or unplanned – that links activities associated with, for example resource development with potential impacts on groundwater resources and related assets and ecosystems.
CGO	Cowal Gold Operations Comprises both open pit and underground operations currently approved under DA14/98 and SSD-10367.
DPE	NSW Department of Planning and Environment
DPE Water	NSW Department of Planning and Environment - Water
EIS	Environmental impact statement
Evolution	Evolution Mining (Cowal) Pty Limited
GDE	Groundwater dependent ecosystem - Natural ecosystems that require access to groundwater to meet all or some of their water requirements on a permanent or intermittent basis so as to maintain their communities of plants and animals, ecological processes and ecosystem services.
IESC	Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development
IWL	Integrated waste landform
km	Kilometres
LAI	Leaf Area Index- The ratio between the total upper leaf surface area of vegetation and the surface area of ground over which the vegetation grows.
LWP	Leaf Water Potential - Measure of the water pressure of a leaf and hence the plant. A plant that is fully hydrated may exhibit a water potential close to zero. An alternative definition is 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.
m	Metres
mAHD	Metres Australian height datum
mbgl	Metres below ground level
mg/L	Milligrams per litre
mPa	Millipascal pressure unit

Term	Description
MPa	Megapascal pressure unit
phreatophyte	Plant that draws water from groundwater or the capillary zone to maintain vigour and function.
µS/cm	Micro siemens per centimetre which is a measurement of the conductivity / salinity of water.
NSW	New South Wales
Open pit mining operations	Includes the removal and placement of waste rock in WREs or backfilled into E46 pit, extraction of ore and ancillary activities.
PCT	Plant community types
The Project	The Project in its entirety, encompassing proposed open pit continuation project components and existing approved activities under DA14/98 and SSD-10367.
SEARs	Secretary's Environmental Assessment Requirements
SMP	Soil Moisture Potentials- also referred to as matric potential, which is a variable describing how strongly the water within a soil matrix is bound to the soil by capillary and other forces.
SSD	State significant development is a project of suitable size based on the scale, nature, location, and strategic importance of the development to the State.
TSF	Tailings storage facility
Underground mining operations	Includes the development of stopes and the extraction of ore via long hole stoping, the backfilling of stopes with cemented paste fill and ancillary activities.
WRE	Waste rock emplacement

Attachment A

Results tables

EMM
creating opportunities

Table A.1 Tree structural features, LAI, and LWP measurements

Location	Tree	Species	Date	Longitude	Latitude	Height (m)	DBH[1] (m)	LAI[2] (Gap Fraction)	LWP[3] (Mpa)
LC1	T1	Eucalyptus camaldulensis	11/16/2023	147.3998	-33.6151	12.0	0.8	0.4983332	-0.950
	T2	Eucalyptus camaldulensis	11/16/2023	147.3998	-33.6151	10.0	0.7	0.5281321	-0.400
	T3	Eucalyptus camaldulensis	11/16/2023	147.4001	-33.6153	15.0	1.0	0.4026171	-0.650
	T4	Eucalyptus camaldulensis	11/16/2023	147.3999	-33.6155	15.0	1.0	0.6792389	-0.500
LC2	T1	Eucalyptus camaldulensis	11/16/2023	147.3989	-33.6081	10.0	1.0	0.5638173	-0.600
	T2	Eucalyptus camaldulensis	11/16/2023	147.3991	-33.6077	18.0	1.0	0.5930309	-0.275
	T3	Eucalyptus camaldulensis	11/16/2023	147.3994	-33.608	12.0	1.0	0.7779334	-1.000
	T4	Eucalyptus camaldulensis	11/16/2023	147.3994	-33.6084	10.0	1.3	0.434088	-1.200
LC3	T1	Eucalyptus camaldulensis	11/16/2023	147.398	-33.5778	18.0	1.5	0.6659606	-0.725
	T2	Eucalyptus camaldulensis	11/16/2023	147.3984	-33.5774	10.0	0.8	0.5497048	-0.675
	T3	Eucalyptus camaldulensis	11/16/2023	147.3983	-33.5772	10.0	0.8	0.388775	-0.500
	T4	Eucalyptus camaldulensis	11/16/2023	147.3983	-33.577	12.0	0.9	0.4567404	-1.500
LC4	T1	Eucalyptus camaldulensis	11/17/2023	147.395	-33.564	18.0	1.0	0.9639407	-0.750
	T2	Eucalyptus largiflorens	11/17/2023	147.3946	-33.5641	25.0		1.026809	-1.950
	T3	Eucalyptus camaldulensis	11/17/2023	147.395	-33.5638	22.0	2.0	0.7580854	-0.750
	T4	Eucalyptus camaldulensis	11/17/2023	147.3958	-33.5637	20.0	0.9	0.7929075	-0.700
LC5	T1	Eucalyptus camaldulensis	11/17/2023	147.3972	-33.5642	10.0	1.3	0.5832847	-0.550
	T2	Eucalyptus camaldulensis	11/17/2023	147.3973	-33.5643	13.0	1.3	0.545092	-0.750
	T3	Eucalyptus camaldulensis	11/17/2023	147.3974	-33.5646	10.0	0.6	0.6091076	-0.700
	T4	Eucalyptus camaldulensis	11/17/2023	147.3971	-33.565	12.0	1.1	0.936277	-1.500
LC6	T1	Eucalyptus camaldulensis	11/17/2023	147.398	-33.5722	15.0	1.4	0.9161005	-1.850
	T2	Eucalyptus camaldulensis	11/17/2023	147.3986	-33.5723	10.0	1.0	0.538882	-1.250
	T3	Eucalyptus camaldulensis	11/17/2023	147.3988	-33.5724	16.0	1.0	0.6063815	-0.900
	T4	Eucalyptus camaldulensis	11/17/2023	147.3985	-33.5727	10.0	1.0	0.6591815	-0.850
LC7	T1	Eucalyptus camaldulensis	11/18/2023	147.4109	-33.6571	12.0	1.2	0.5502584	-1.350
	T2	Eucalyptus camaldulensis	11/18/2023	147.4109	-33.6573	12.0	1.0	0.6746465	-1.100
	T3	Eucalyptus camaldulensis	11/18/2023	147.4111	-33.6578	10.0	1.1	0.7802786	-1.400
	T4	Eucalyptus camaldulensis	11/18/2023	147.4114	-33.6583	12.0	1.1	0.50202	-0.850
LC8	T1	Eucalyptus camaldulensis	11/18/2023	147.4334	-33.6807	10.0	1.5	0.7315606	-0.600
	T2	Eucalyptus camaldulensis	11/18/2023	147.433	-33.6806	12.0	1.3	0.7473008	-1.900
	T3	Eucalyptus camaldulensis	11/18/2023	147.4325	-33.6805	15.0	1.2	0.8276427	-0.950

Table A.1 Tree structural features, LAI, and LWP measurements

Location	Tree	Species	Date	Longitude	Latitude	Height (m)	DBH[1] (m)	LAI[2] (Gap Fraction)	LWP[3] (Mpa)
	T4	Eucalyptus camaldulensis	11/18/2023	147.4322	-33.6804	12.0	1.2	0.9478559	-0.850
LC9	T1	Eucalyptus camaldulensis	11/18/2023	147.4277	-33.6789	12.0	1.5	0.5432719	-1.500
	T2	Eucalyptus camaldulensis	11/18/2023	147.4278	-33.6787	10.0	0.8	0.6287622	-1.350
	T3	Eucalyptus camaldulensis	11/18/2023	147.4277	-33.6784	10.0	1.0	0.6335232	-1.300
	T4	Eucalyptus camaldulensis	11/18/2023	147.4273	-33.6784	12.0	0.9	0.8393988	-1.100

1. DBH = Diameter breast height,
2. LAI = Leaf Area Index,
3. LWP = Leaf Water Potential

Table A.2 In-situ soil parameters and SMT measurements

Auger hole	Depth	EC (mS/cm)	Pore space EC (µS/cm)	VWC[1] (%)	pH	SMP[2] (Mpa)
LC1 AU1	0.10	-[3]	-	-	-	-0.72
	0.35	-	-	-	-	-0.72
	0.50	0.337	1,093	29.9	6.87	-0.48
	0.65	-	-	-	-	-0.43
	1.00	0.501	1,974	26	6.87	-0.67
	1.25	-	-	-	-	-0.48
	1.50	1.225	2,942	38.2	6.44	-0.9
	1.70	-	-	-	-	-0.66
	2.00	0.883	2,717	34.5	5.76	-1.19
	2.50	-	-	-	-	-1.44
	2.75	-	-	-	-	-1.42
	3.00	-	-	-	-	-1.5
	3.10	-	-	-	-	-1.3
	3.50	-	-	-	-	-1.56
	3.80	1.929	4,333	41.5	6.01	-1.67
	4.00	-	-	-	-	-1.89
LC3 AU1	0.30	-	-	-	-	-1.35
	0.50	-	-	-	-	-1.43
	0.75	1.617	3,946	39	6.53	-0.68

Table A.2 In-situ soil parameters and SMT measurements

Auger hole	Depth	EC (mS/cm)	Pore space EC (µS/cm)	VWC[1] (%)	pH	SMP[2] (Mpa)
	1.00	1.885	4,093	43	6.32	-0.89
	1.30	1.928	5,275	35.2	6.20	-1.13
	1.50	-	-	-	-	-1.68
	1.60	-	-	-	-	-2.17
	2.00	-	-	-	-	-2.96
	2.30	-	-	-	-	-3.04
	2.50	-	-	-	-	-3.15
LC5 AU1	0.10	-	-	-	-	-2.98
	0.50	-	-	-	-	-1.5
	0.80	-	-	-	-	-1.23
	1.00	-	-	-	-	-1.04
	1.20	-	-	-	-	-1.07
	1.50	-	-	-	-	-1.35
	2.00	2.006	6,237	31.6	6.39	-
	2.50	1.996	8,376	24.8	5.60	-1.79
	3.00	1.988	7,010	28.5	5.56	-2.11
	3.70	2.437	6,251	36.8	5.60	-2.79
	4.00	2.602	8,580	29.7	5.62	-3.02
	4.20	-	-	-	-	-2.57
	4.40	-	-	-	-	-2.81
	4.50	-	-	-	-	-3.18

1. VCM = Volumetric Moisture Content
2. SMT = Soil Moisture Potential
3. "-" = no measurement taken

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