Groundwater Dependent Ecosystem (GDE) Management and Monitoring Plan

Isaac Plains East Extension Project

Prepared for **Stanmore IP Coal** *by*

3d Environmental

Revision 5 – 22 September 2020

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Project Manager: David Stanton

Client: Stanmore IP Coal Pty Ltd

Purpose: Groundwater dependent ecosystem assessment for Isaac Plains East Extension project

Draft	Date Issued	Issued By.	Purpose
Revision 1	24 August 2020	David Stanton	First Draft GDEMMP
Revision 2	10 September 2020	David Stanton	Second Draft GDEMMP following Stanmore review.
Revision 3	19 September 2020	David Stanton	Third draft following threshold assessments
Revision 4	22 September 2020	David Stanton	Final edits and adjustments
Revision 5	22 September 2020	David Stanton	Updates to decision tree

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List of Abbreviations

Abbreviation	Description
DAWE	Department of Agriculture Water and Environment (Commonwealth)
DES	Department of Environment and Science (Qld)
DoEE	Department of Environment and Energy (Commonwealth)
DSITI	Department of Science, Information, Technology and Innovation (Qld)
EA	Environmental Authority **EPML00932713** – Isaac Plains Mine
EIS	Environmental Impact Statement
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth)
EPBC Approval	Approval granted by the Commonwealth under the EPBC Act
EP Act (Water)	Environmental Protection Act (Qld) 1994
ESCP	Erosion and Sediment Control Plan
EWR	Environmental Water Requirement
GDE	Groundwater Dependent Ecosystem
GDEMMP	Groundwater Dependent Ecosystem Monitoring and Management Plan
GMMP	Groundwater Management and Monitoring Plan
IP	Isaac Plains
IPC	Isaac Plains Complex
IPE	Isaac Plains East
IPEE	Isaac Plains East Extension
LAI	Leaf Area Index
LWP	Leaf Water Potential
ML	Mining Lease
MNES	Matters of National Environmental Significance, as defined under the EPBC Act.
NDVI	Normalised Difference Vegetation Index
PER	Public Environment Report
REMP	Receiving Environment Monitoring Program
SMP	Soil Moisture Potential
WMP	Water Management Plan

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
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.
Perched groundwater system	A groundwater system or aquifer that sit above the regional aquifer due to a capture of infiltrating moisture on a discontinuous aquitard.
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
Obligate phreatophyte	A plant that is completed dependent on access to groundwater for survival
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.
Water table	The upper surface of the saturated zone in the ground, where all the pore space is filled with water.
Groundwater dependent ecosystems (GDE)	Natural ecosystems which require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services (Richardson et al. 2011)
Infiltration	Passage of water into the soil by forces of gravity and capillarity, dependent on the properties of the soil and moisture content.
Leaf water potential (LWP)	The total potential for water in a leaf, consisting of the balance between osmotic potential (exerted from solutes), turgor pressure (hydrostatic pressure) and matric potential (the pressure exerted by the walls of capillaries and colloids in the cell wall).
Leaf area index (LAI)	The ratio of total one-sided area of leaves on a plant divided by the area of the canopy when projected vertically on to the ground.
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.
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.
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.

1.0 Introduction

1.1 Background

3d Environmental has been engaged by Stanmore IP Coal Pty Ltd (IP Coal) to develop a Groundwater Dependent Ecosystem (GDE) Management and Monitoring Plan (GDEMMP) for the Isaac Plains East Extension (IPEE), which is an extension to the existing Isaac Plains East (IPE) coal mine. IP Coal is the operator of the Isaac Plains Complex (IPC), located approximately 5 – 7 km from Moranbah in Central Queensland (**Figure 1**). The IPC produces metallurgical coal used in the production of steel on State approved mining leases (ML) 70342, ML 700016, ML 700017, ML 700018, and ML 700019. In 2018 approval was received from State and Commonwealth agencies for mining on ML 700016, ML 700017, ML 700018 and ML 700019 (as part of the IPE Project). However, the Commonwealth approval for the IPE mining area limited the allowable disturbance area for mining activities, and the Extension area is outside the Commonwealth approved mining area. The State approved mining in the Extension area in February 2020. A new Referral under the Environment Protection and Biodiversity Act 1999 (EPBC) was lodged on 01 October 2019 for extension activities (EPBC 2019/8548). On 31 January 2020 the Referral was listed as a Controlled Action with the following controlling provisions:

- Listed threatened species and communities (sections 18 & 18A); and
- Water resources/trigger (sections 24D & 24E).

The Department of Agriculture, Water and Environment (DAWE) determined that the Referral for the Extension would be assessed by Public Environment Report (PER) and the project is currently being assessed via this process.

As a component of the PER, a GDE assessment was undertaken by 3d Environment which verified GDEs within the area that may potentially be impacted by the Extension (3d Environmental, 2020). This GDEMMP has been developed to monitor and manage potential impacts of mining activities, if any, on GDEs .

1.2 Purpose of the Management Plan

This GDEMMP has been prepared to manage the environmental impacts of the Extension on GDEs through the development of consistently applied monitoring actions, analysis and reporting of data trends. Corrective actions (mitigations) are described and should be implemented when statistically significant impacts on GDE function caused by mining activity are detected. The plan is to be used as a reference for management actions prior to construction, during construction and operation, extending though stages of project decommission and post operation.

1.3 Objectives

Objectives of this GDEMMP are described as follows:

1. Characterise GDEs in the Extension area in terms of ecological function, interaction with surface water and interaction with groundwater as presented in 3d Environmental (2020).
2. Provide a detailed synopsis of the potential risks to GDE integrity posed by mining activities associated with the Extension.
3. Identify biophysical parameters that can be applied to the monitoring of GDE function that can be repeated objectively and consistently throughout the life of the mining project to measure GDE health.
4. Describe the most appropriate actions to measure changes to biophysical function of GDEs that may indicate a decline in GDE health, and provide a statistically robust framework that

can demonstrate whether impacts to GDEs are associated with mining activities rather than natural variation.

5. Develop triggers that may be used to initiate the application of corrective actions, which can be refined over time as baseline data is collected.
6. Develop a suite of corrective actions that may be applied to ameliorate impacts to GDEs and prevent or repair declining GDE health.

1.4 Relevant Legislation

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

The regulatory guideline *Significant impact guidelines 1.3: Coal seam gas and large coal mining developments – impacts on water resources (DoEE 2013a)* identify a 'significant impact' as 'an impact which is important, notable, or of consequence, having regard to its context or intensity'. The assessment of the significance of impacts to GDEs as a result of the IPE Project is currently being undertaken through the Public Environment Report (PER) process under the EPBC Act.

Within the state approval process, an EA amendment application for the Extension was submitted to the Queensland Department of Environment and Science (DES) in September 2019 in accordance with the requirements of the EP Act. The EA amendment was granted on 26 February 2020, inclusive of the Extension activities. Therefore, at State level the necessary approval under the EP Act has been secured to progress the Extension activities.

1.5 Relationship with other plans and management controls

This GDEMMP interacts with the following plans which directly aim to avoid and minimise impact to MNES:

1. **Groundwater Monitoring and Management Plan (GMMP)** (KCB 2019): Identifies monitoring, management, and mitigation with respect to approved impacts to groundwater resources, which includes impacts to GDEs.
2. **Isaac Plains Complex REMP Design Document (C&R Consulting 2019):** Monitors, identifies and describes any impacts to aquatic ecology and surface water quality values from discharges associated with approved mining activities.
3. **Isaac Plains Complex Erosion and Sediment Control Plan (ESCP) (C&R Consulting, 2018):** Provides actions and processes to manage sediment dispersal, which may impact GDEs when associated with surface water flows.
4. **Isaac Plains Complex Water Management Plan (WMP) (WRM Water & Environment, 2018):** The WMP includes a study of potential contaminants, a water balance model, a description of the site water management system, measures to manage and prevent saline and acid rock drainage, contingency procedures for emergencies and a monitoring and review program for the effectiveness of the WMP.

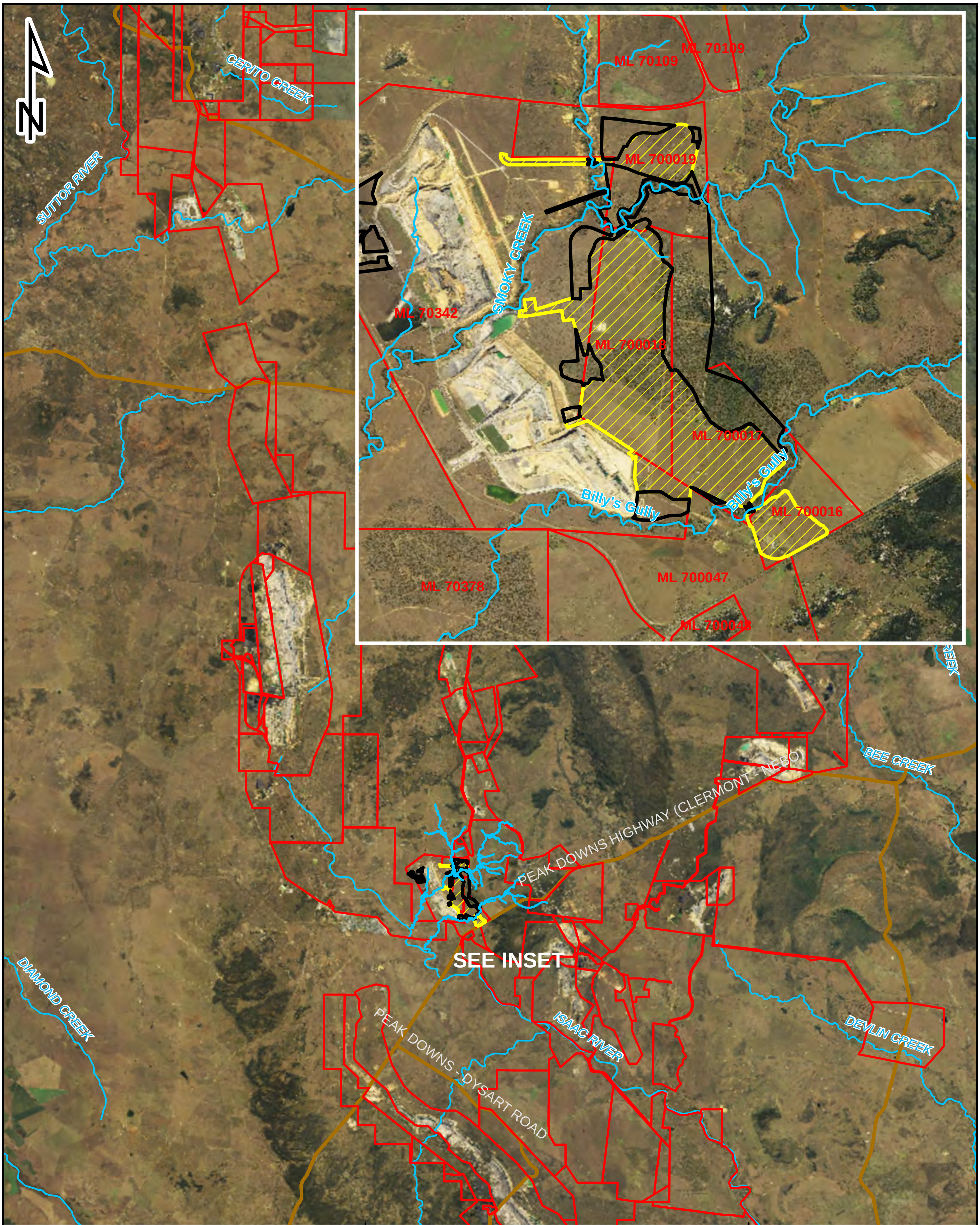
5. **Isaac Plains East Extension – MNES Significant Species Management Plan** (Base Consulting Group, 2020): Identifies koala (vulnerable), greater glider (vulnerable), ornamental snake (Vulnerable) and squatter pigeon (vulnerable) that may be incur impacts through degradation of regional ecosystem 11.3.25, which is associated with the alluvial system of Billy's Gully.
6. **Isaac Plains East Project – EPBC Act Riparian Baseline Monitoring:** Satisfies condition 10 of the IPE approval, which requires, ecological surveys be undertaken required to determine the extent (in hectares) and habitat condition for four EPBC Act listed threatened species in the riparian area.
7. **Environmental Authority (EA) no EPML00932713** – Provides conditions of approval under the Queensland Environmental Protection Act for all mining activities on ML 70342, ML 700016, ML 700017, ML 700018, and ML 700019, inclusive or trigger levels for water quality and contaminant release which are relevant for management of groundwater resources under the EPBC Act.

1.6 Structure of this Document

As the GDEMMP intends to compile knowledge on the ecohydrological function of relevant GDEs, scope has been made to update monitoring requirements including methods, timing and interval as the knowledge base increases with each subsequent monitoring survey. A summary of the key components of this GDEMMP is provided below:

- Section 2: A contextual description of the project in relation to mining layout and timeframes.
- Section 3: A general description of the existing environment to contextualise hydrogeological and ecological setting as presented in 3d Environmental (2020).
- Section 4: Provides a summary for what are considered the major risks to GDE health imposed by the IPEE Project, as presented in 3d Environmental (2020).
- Section 5: A summary of how the biotic impacts to GDEs may manifest in the environment.
- Section 6: The general approach to the monitoring program.
- Section 7: An overview of monitoring techniques and their application.
- Section 8: A summary of reporting requirements for each monitoring event as well as preparation of a baseline synopsis.
- Section 9: Approach to determining trigger thresholds for which impacts to GDEs are investigated and corrective actions applied where appropriate.
- Section 10: A discussion identifying potential corrective actions that may be applied to ameliorate impacts to GDEs that have been created by mining activities.

The Appendix also provides a summary of monitoring methods, monitoring timing and raw data from prior GDE surveys.



Legend

- IPE Pit Extension
- Approved IPE Outline
- Mining leases

Figure 1. Project location

Stanmore IP Coal Pty Ltd

0 7.5 15 22.5 30
Kilometers

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2.0 Project Description and Timing

2.1 Proposed Activities

The Extension activities will occur in areas outside of existing and approved activities, as shown in **Figure 2** and **Figure 3** (from the IPC Project Description, Reach Environmental 2020), and comprise:

- extension of the open cut mine pits at IPE Pit 2, 3 and 4 (extends into Pit 4N)
- area for overburden dumping around IPE Pit 2, 3, 4 and 5
- levee between Pit 4 and Smoky Creek
- haul roads, including a new crossing of Smoky Creek and a powerline corridor
- water management infrastructure, being sediment dams and clean water diversions
- areas for topsoil stockpiles
- areas for laydowns
- modular extension to the CHPP
- additional ROM coal stockpile area
- water management infrastructure around the CHPP area, being clean water diversion drains.

The disturbance area of the Extension is 466 ha, which includes buffer zones around infrastructure locations to allow operational flexibility and includes some areas between the Extension's infrastructure and activities which may be fragmented, but not directly disturbed. This footprint therefore provides a conservative estimate (over-estimate) of the actual likely footprint of the Extension area.

2.2 Mining Schedule

Plans for staged mining at IPE and the Extension area have been prepared for 2021, 2024 and 2028 as provided in **Appendix A**. Activities for stage plans are described below:

- 2021 shows areas in which clearing, grubbing, topsoil removal and pre-stripping of overburden are proposed beyond the current Commonwealth IPE approved area.
- 2024, where coal mining has moved into the Extension areas and progressive rehabilitation has commenced on dump areas at IPE.
- 2028, being the final year of open cut mining operations, with progressive rehabilitation of dump areas at IPE well advanced).
- The final landform, as approved by DES in the Rehabilitation Management Plan required under IPC's EA, and showing residual void areas and rehabilitated dump and infrastructure areas (**Appendix A**).

Under the IPE approved action, the final landform would have comprised residual voids near the eastern extent of the IPE approved action area. The final landform, as approved for IPE and as proposed for the Extension show that the Extension areas result in a similar residual void configuration but further to the east and deeper.

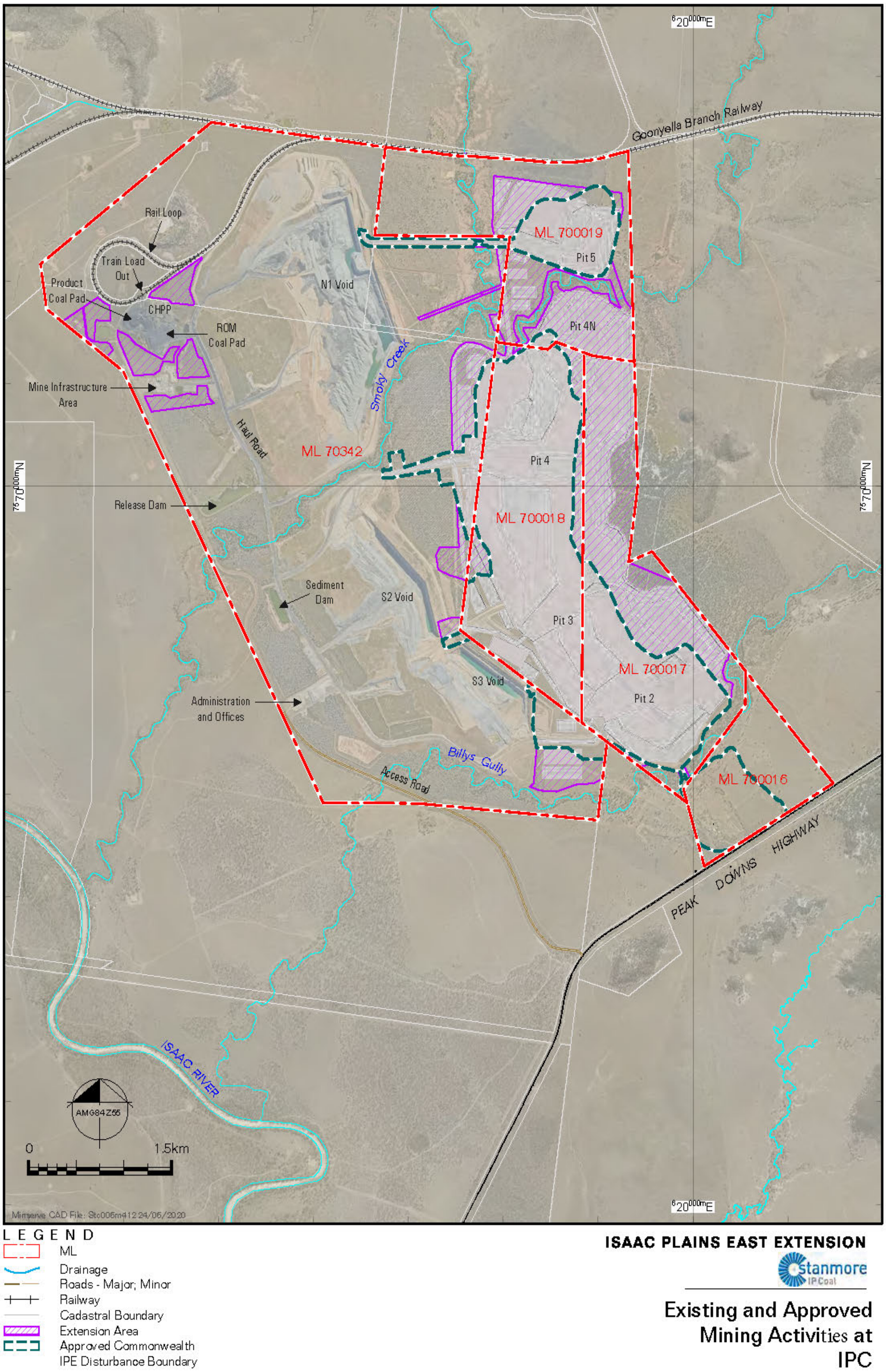


Figure 2. Existing and approved activities at IPC including the Extension Area (Reach Environmental 2020).

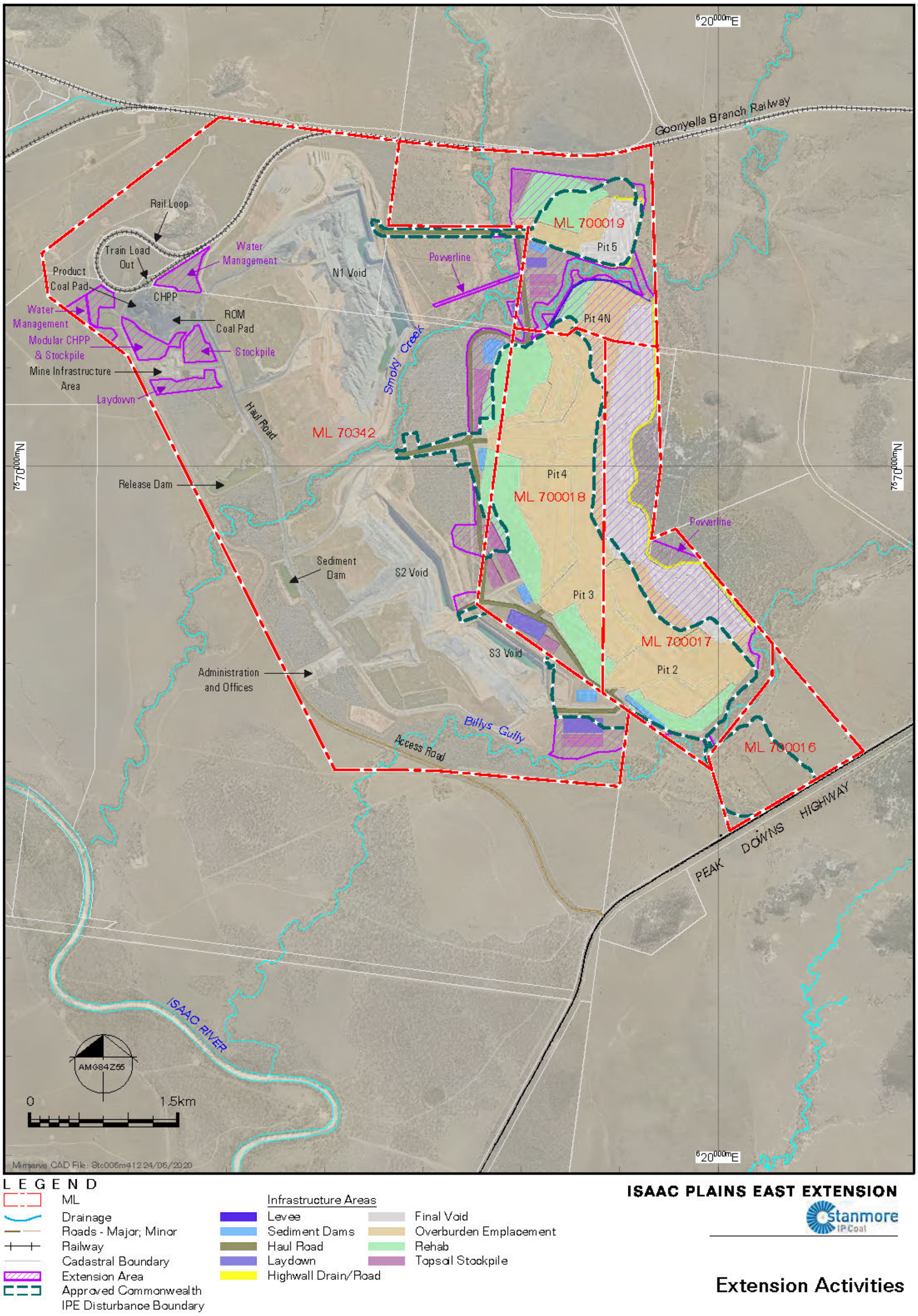


Figure 3. Activities associated with IPEE (Reach Environmental 2020).

3.0 Existing Environment

A description of the existing environment including general setting surface water flow, hydrogeology and interplays with GDEs are described in **Section 3**.

3.1 Site Setting

The IPE extension is located within the Northern Bowen Basin subregion of the Brigalow Belt Bioregion in central Queensland. The Brigalow Belt North Bioregion is an ecologically complex area characterised by clay soils interspersed with Tertiary plateaus, sand plains, basalt plains and some more expansive ranges formed on sandstone and granite. Vegetation is typically dominated by forests and woodlands of *Acacia harpophylla* (Brigalow), *Acacia shirleyi* (lancewood) eucalyptus woodlands and grassland habitats.

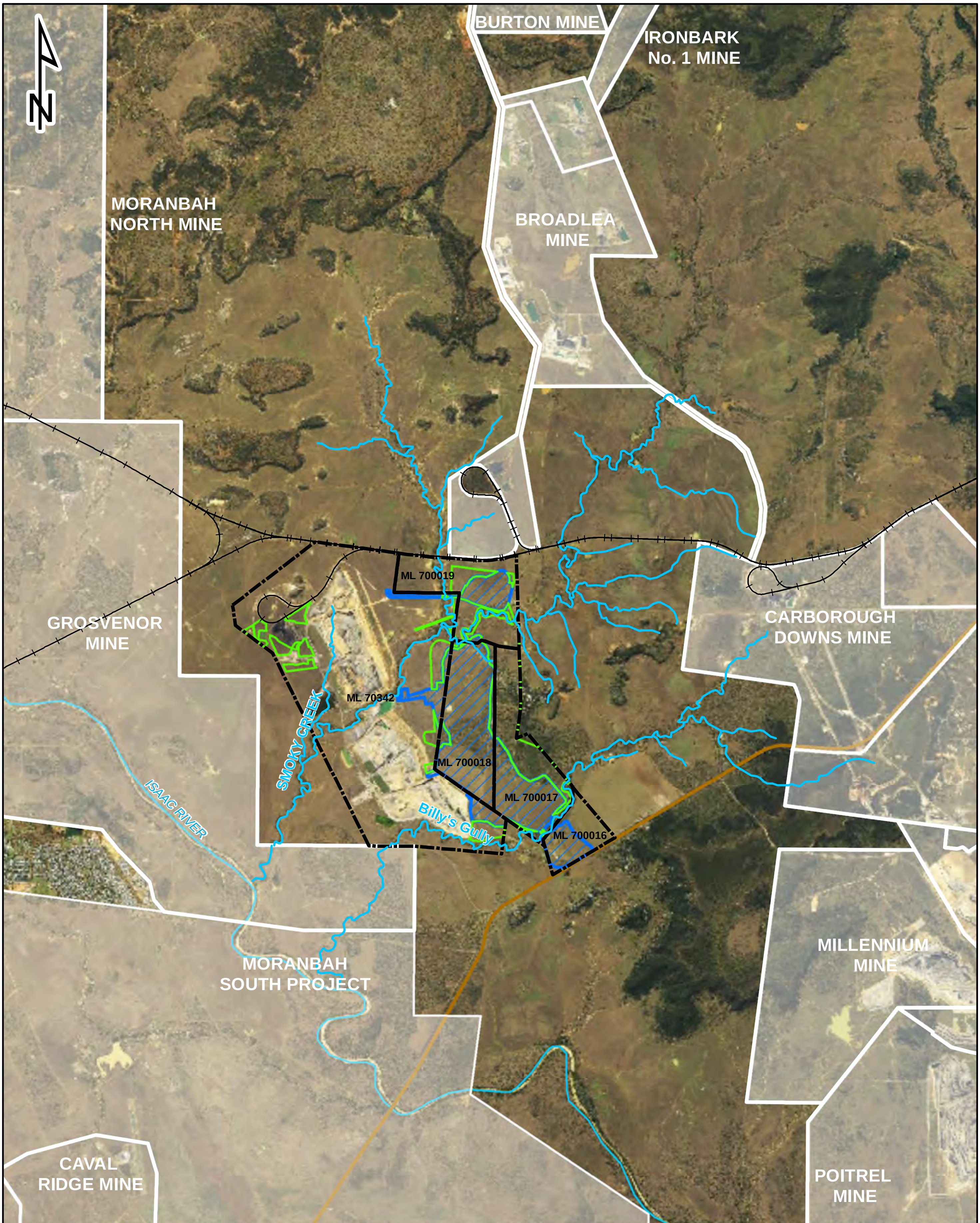
The region surrounding the IPE mining area has been extensively cleared of native vegetation to accommodate pastoral activities, except for topographically rugged areas and drainage lines where intact vegetation has generally been retained. Riparian vegetation associated with the larger watercourses is generally continuous, though largely restricted to channel margins with attenuations along minor tributaries and occasionally buffered by broader areas of floodplain woodland. Coal mining has been a more recent activity in the region, emerging in the 1970's as a major industrial activity. The Project description for the Extension project (Reach Environmental 2020) identified several coal mines and projects approved in the region including:

- the Grosvenor Mine adjacent to the IPC;
- the Moranbah North Mine located northwest;
- the Burton, Broadlea and Ironbark No. 1 Mines located north;
- Carborough Downs Mine located east;
- Millennium and Poitrel Mines located southeast; and,
- the Moranbah South Project and Caval Ridge Mine located southwest.

Other non-approved projects that are in the process of being developed include:

- the Winchester South Project, located approximately 20 km south, to be developed by
- Whitehaven Coal;
- Olive Downs Project, located approximately 30 - 40 km south, to be developed by Pembroke
- Resources;
- Isaac Downs Project, located approximately 5– 10 km south, to be developed by Stanmore IP
- South Pty Ltd; and,
- Eagle Downs Project located approximately 20 km southeast, to be developed by South32.

The location of coal mining operations that fringe the IPE MLs is shown in **Figure 4**.



Legend

- Isaac Plains Complex Mining Lease
- IPE Pit Extension
- Approved IPE Outline

Figure 4. Isaac Plains Complex adjacent mining activity.

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3.2 Climatic considerations

The region is sub-tropical with average temperatures recorded in Moranbah of between 21.1°C and 34.8°C in the summer months, and 8.9°C and 25.2 °C in the winter months. The long-term average rainfall (30 years of data between January 1990 and December 2019) from the Moranbah Water Treatment Plant is 590.4mm (SILO 2020) with a pronounced wet season. Approximately 75% of the annual rainfall is recorded between November and March, inclusive (BoM 2020). Plant growth in the region is strongly limited by moisture rather than temperature (Hutchinson et al. 1992) which is reflected in the evapotranspiration rates at the Moranbah Airport for the 2019 – 2020 period being considerably higher than rainfall for all months (except for the wettest months). Between January 2015 and December 2019, the largest offset between rainfall and evapotranspiration occurred between October to December during the build-up to summer storms (**Figure 5**) (data from SILO 2020).

The region has experienced several significant drought events, many of which have resulted in tree dieback. The early to mid-1990's drought, the worst on record for north Queensland, and the millennium drought from 2000 through to 2007 both resulted in substantial dieback of native woodland habitats, typically affecting ironbark woodlands and most severely on basaltic substrates (Fensham and Holman 1999; Fensham et al 2009). **Figure 6** demonstrates the major climatic cycles in terms of Cumulative Rainfall Departure (CRD) (Weber and Stewart 2004), representing a cumulative departure of monthly rainfall from the long term mean monthly rainfall (1990 to 2020) at the Moranbah Water Treatment Plant (SILO 2020). Strongly decreasing rainfall trends between 1990 to 1996; and 2000 to 2007 representing major drought periods are strongly evident, interspersed with periods of above average rainfall between January 1998 and January 2001, January 2010 and July 2012, and January 2016 to March 2017, which were considerably wetter than average conditions.

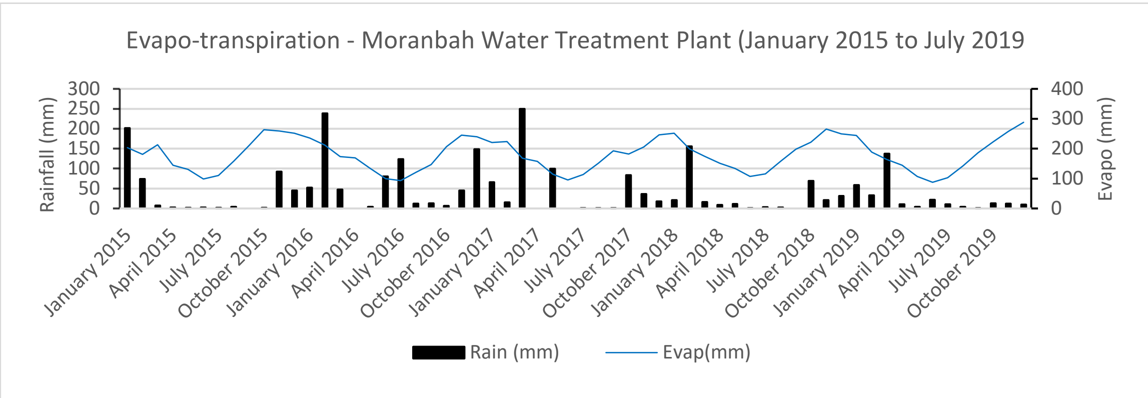


Figure 5. Evapotranspiration trends on a seasonal basis for Moranbah Water Treatment Plant.

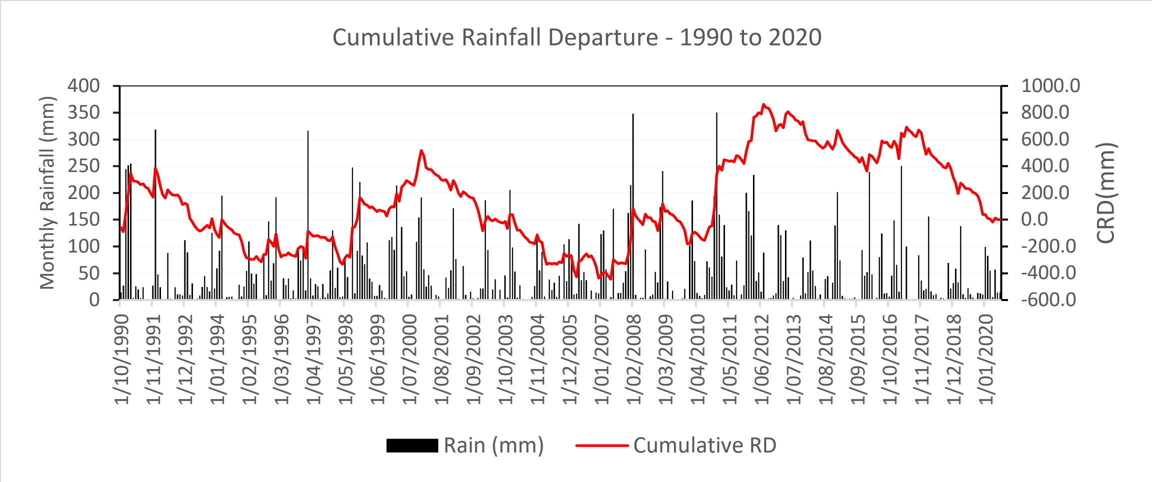


Figure 6. Cumulative rainfall departure calculated for the Moranbah Water Treatment Plant.

3.3 Topography and Drainage

The topography is relatively suppressed in the west, gently rising from 240m AHD with slopes <2° to a low plateau east of the Extension at 300m AHD. The plateau splits the drainage of Billy's Gully and Smoky Creek, with the former passing south of the existing IPE mine. Smoky Creek and its northern tributary converge and then dissect the existing Isaac Plains Mine. Both watercourse features flow toward the south-west, joining with the Isaac River approximately 4km to the west of the IP mining lease. Billy's Gully and Smoky Creek are ephemeral watercourses, characterised by short duration flows, though Smoky Creek holds surface water in discontinuous pools for longer periods than Billy's Gully which consistently demonstrates a dry sandy channel. Both drainage lines form part of the Isaac River sub-catchment, which flows into the Fitzroy River draining to the coast near Rockhampton.

3.4 Surface Water Flows

The characteristics of surface flows associated with Billy's Gully have been described in detail by WRM (2020) in the surface water report prepared for the IPEE PER. This information is summarised below. Further description is also provided for Smoky Creek (a non-GDE drainage system), which is the dominant drainage feature in the IPEE area to provide site context.

3.4.1 Billy's Gully

Billy's Gully is a minor order 3 tributary of the Isaac River with a total catchment area of 67.5 km^2. Billy's Gully drains into the Isaac River about 2.5 km to the south east of Smoky Creek and 3.0 km upstream from the Isaac River crossing on the Peak Downs Highway. The entire catchment of Billy's Gully is characterised by gentle slopes limited to upper values of 5% and a lower channel draining at a slope of approximately 0.3%. The Carborough Downs coal mine is in the upper catchment of the watercourse. There are three flow gauging stations on Billy's Gully being:

- 332402 Billy's Gully DS flow gauge which commenced readings on 06/06/2013.
- 332403 Billy's Gully US IPM (unknown).
- 332401 Smoky Creek US IPE (unknown).

The location of the Billy's Gully catchment and flow gauging stations is shown on **Figure 7**.

At the Billy's Gully DS (332402), flows were recorded on 0.2% of the days between July 2013 and June 2020 and the water levels recorded in Billy's Gully are consistently lower than those recorded in Smoky Creek. A maximum water level of 12.6 mGH was recorded at the Billy's Gully DS gauge in February 2016 (flow depth of around 2.6 m at the gauge).

3.4.2 Smoky Creek

Smoky Creek is a minor tributary of the Isaac River with a total catchment area of 164.9km^2 that drains between the N1 pit and S2 pit. It is formed by the main Smoky Creek Channel, which is an order 4 tributary, and the un-named 'Northern Tributary' which is an order 3 watercourse. The lower reaches of Smoky Creek are relatively flat (0.2% slope) and the main channel of the creek is highly sinuous. The channel sediments are mobile and there is considerable erosion of the outside bends of meanders. There are three flow gauges on Smoky Creek used to measure surface flows being:

- 332400 Smoky Creek Downstream (DS) flow gauge which commenced readings on 24/09/2013.
- 332401 Smoky Creek Upstream (US) IPM which commenced readings on 08/04/2019.
- 332401 Smoky Creek Upstream (US) IPE which commenced readings on 01/08/2018.

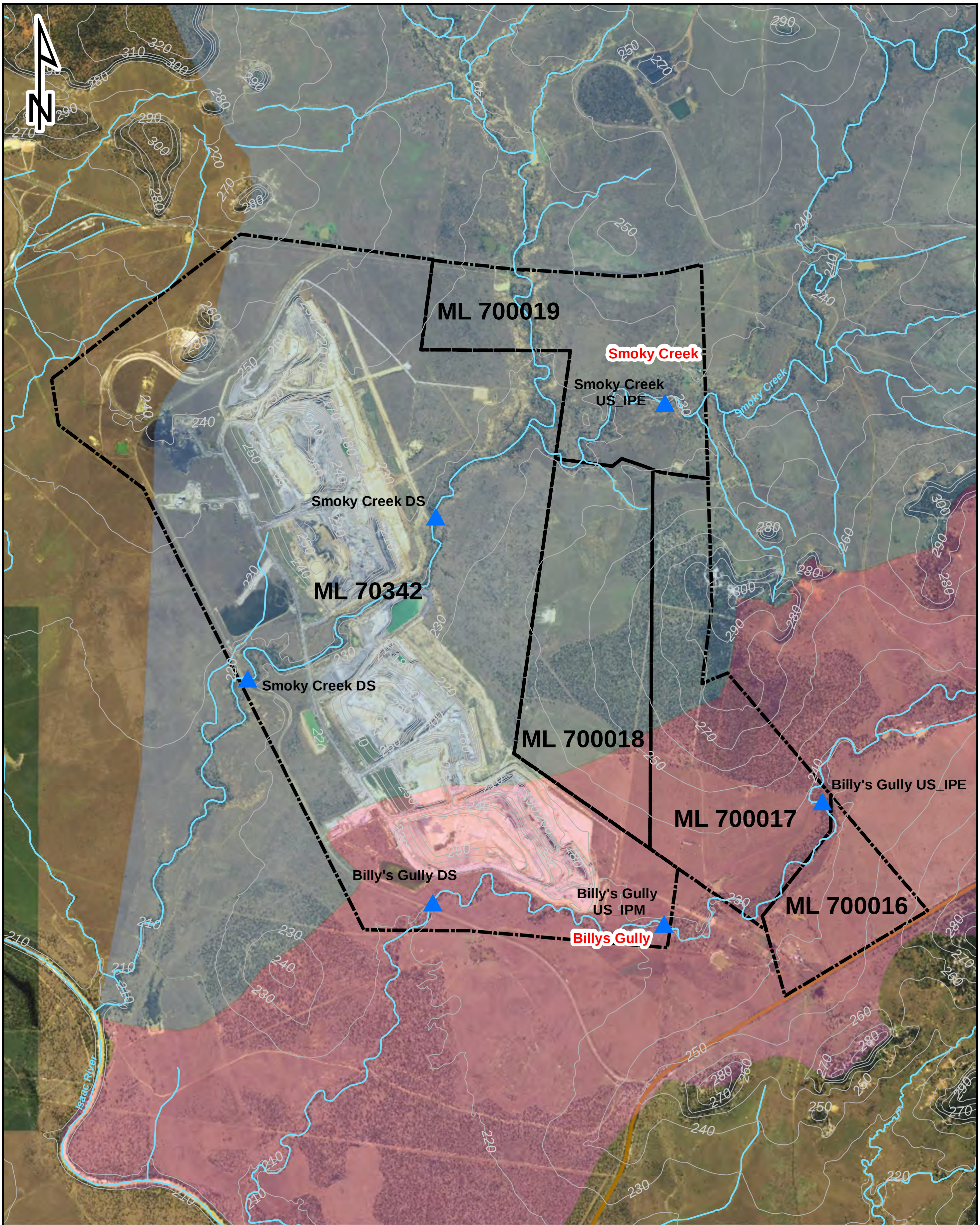
At Smoky Creek DS (gauge no. 332400), flows were recorded on approximately 15% of the days. The maximum water level recorded at Smoky Creek DS was 18.2 mGH in February 2016 (flow depth of around 7.8 m at the gauge) (see **Figure 8**). Smoky Creek drains through the project area between the proposed Pit 4/4N and Pit 5 mining areas. The location of the Smoky Creek catchment and flow gauges is shown on **Figure 7**.

3.4.3 Water Quality

Routine water quality samples for the upstream and downstream Smoky Creek monitoring points are summarised as follows:

- Typical EC values in Smoky Creek (combined upstream and downstream) vary from 144 µS/cm (20th percentile) to 447 µS/cm (80th percentile), with a median value of 231 µS/cm from 2016 to 2020;
- pH is slightly alkaline;
- Typical TSS values in Smoky Creek vary from 96 mg/L (20th percentile) to 1,070 mg/L (20th percentile), with a median value of 292 mg/L from 2016 to 2020; and
- All metal toxicants, except for aluminium and copper, are lower than the default water quality objectives for aquatic ecosystem protection (for slightly to moderately disturbed level of protection).

There is limited water quality sampling data available for Billy's Gully due to its highly ephemeral nature (i.e. flows were recorded on approximately only 0.2% of the days) (see **Figure 8**). However, 15 months of surface flow monitoring between 18/11/2010 and 21/03/2012 indicates that the salinity of surface waters range from 271 to 840 µs/cm.



Legend

- Stream Gauge
- Isaac Plains Complex Mining Lease
- Billys Gully
- Smoky Creek

Figure 7. Catchments, drainage and topography and stream gauging stations in the locality of the IPEE project.

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0 0.75 1.5 2.25 3
Kilometers

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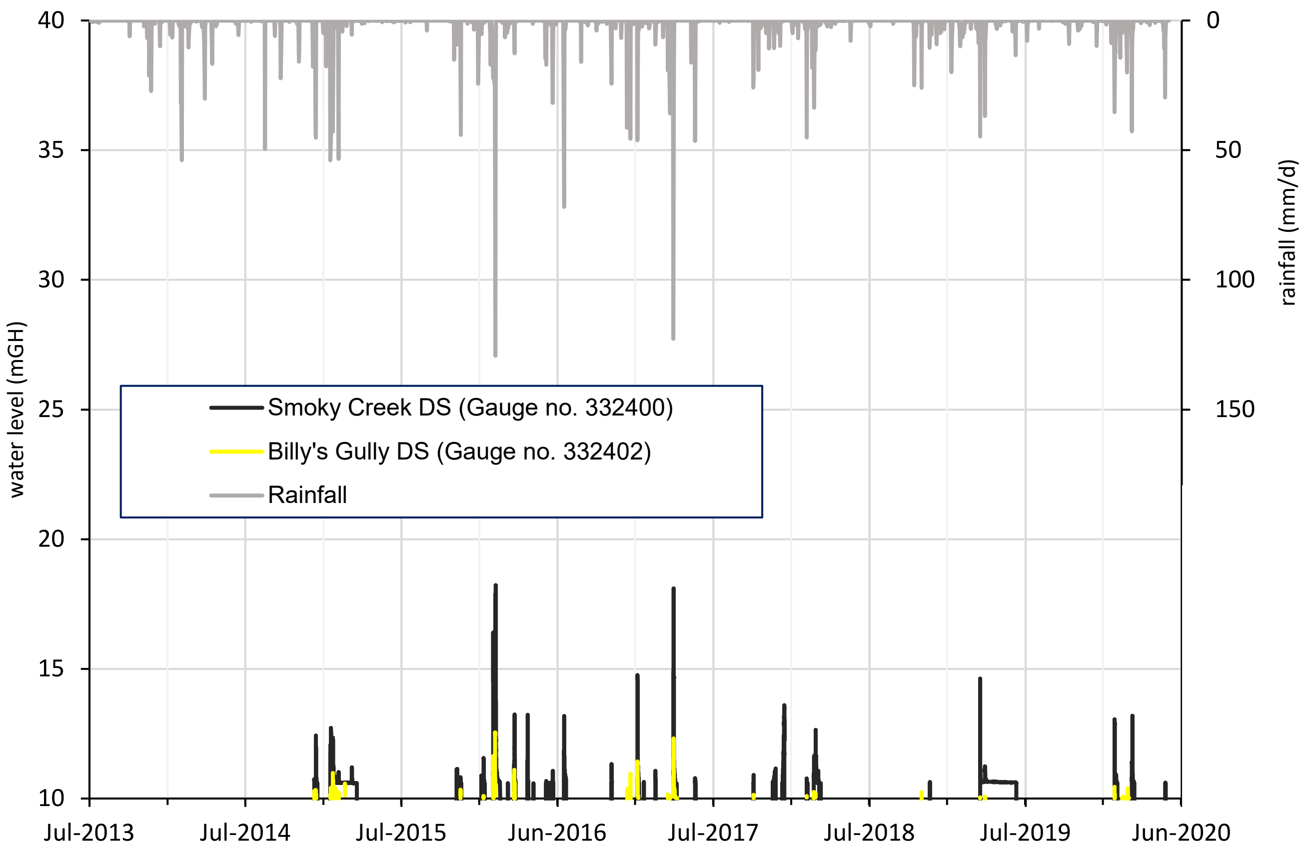


Figure 8. Stream flows and rainfall from Smoky Creek and Billy's Gully DS gauges (from WRM 2020).

3.5 Hydrogeological Setting

The project mining area is in the north-west extent of the Bowen Basin, a broad sedimentary basin formed in the Permian / Triassic period with a variable cover of Tertiary period sediment and basic volcanic rocks (basalts). The surface geology, shown in **Figure 9**, is summarised from KCB (2020) as below:

- Quaternary age alluvial deposits associated with Billy's Gully.
- Surface deposits of Quaternary age colluvium (Qr), Tertiary age alluvium (TQa) and Tertiary age sediments of the Suttor Formation (Ts); all of which show similar lithological characteristics and therefore are grouped together as the Tertiary sediments.
- Tertiary age basalt (Tb) outcropping the northern and eastern portions of the IPEE area.
- Triassic age lithic sandstone and conglomerate of the Rewan Group.
- Permian period sedimentary rocks of the Rangal Coal Measures (Rr) which includes the Leichardt Coal Seam mined at IPE and the deeper Fort Cooper Coal Measures (Pwt).

Field assessments by KCB (2020) indicate that there are limited Quaternary alluvial deposits associated with Smoky Creek, comprising fluvial deposits on the channel floor. Field investigations completed as part of the GDE field survey identified thin (~2 m), localised deposits of sandy alluvium within and adjacent to the drainage channel of Billy's Gully.

KCB (2020) described the hydrogeological regimes associated with the various lithologies in the assessment area. Information from this assessment is summarised below:

3.5.1 Quaternary Alluvium

Quaternary alluvium occurs within, and adjacent to, the water course of Billy's Gully as identified during field studies conducted by 3d Environmental (2020). The Billy's Gully flood plain is approximately 150 m wide with alluvial deposits to 2m deep. The alluvium comprises coarse sands with minor clays and intermittent lenses of gravel. The lithology underlying the alluvium comprises highly plastic clay with mottled clay features and some weathered sandstone. Both of these lithologies are representative of Tertiary age weathered residual bedrock and colluvium.

Field investigation completed in March 2020 (3D Environmental) identified a shallow saturated layer at the base of the alluvium drawing water to a depth of approximately 20 cm and this is perched on low permeability Tertiary sediments. As the field assessment was undertaken in the wet season following significant rainfall, it is inferred that the saturated sands drain quickly through subsurface flow or transpiration and saturation is likely to be ephemeral.

The water level in the alluvium (230.3 mAHD) is ~8 m higher than the water level in the underlying Tertiary Sediments (MB4b) (see Appendix III); indicating that the alluvium is not in hydraulic connection with the Tertiary Sediments and not in connection with the regional groundwater system. For this reason, the perched alluvial system was not simulated in the numerical groundwater model completed by KCB (2020).

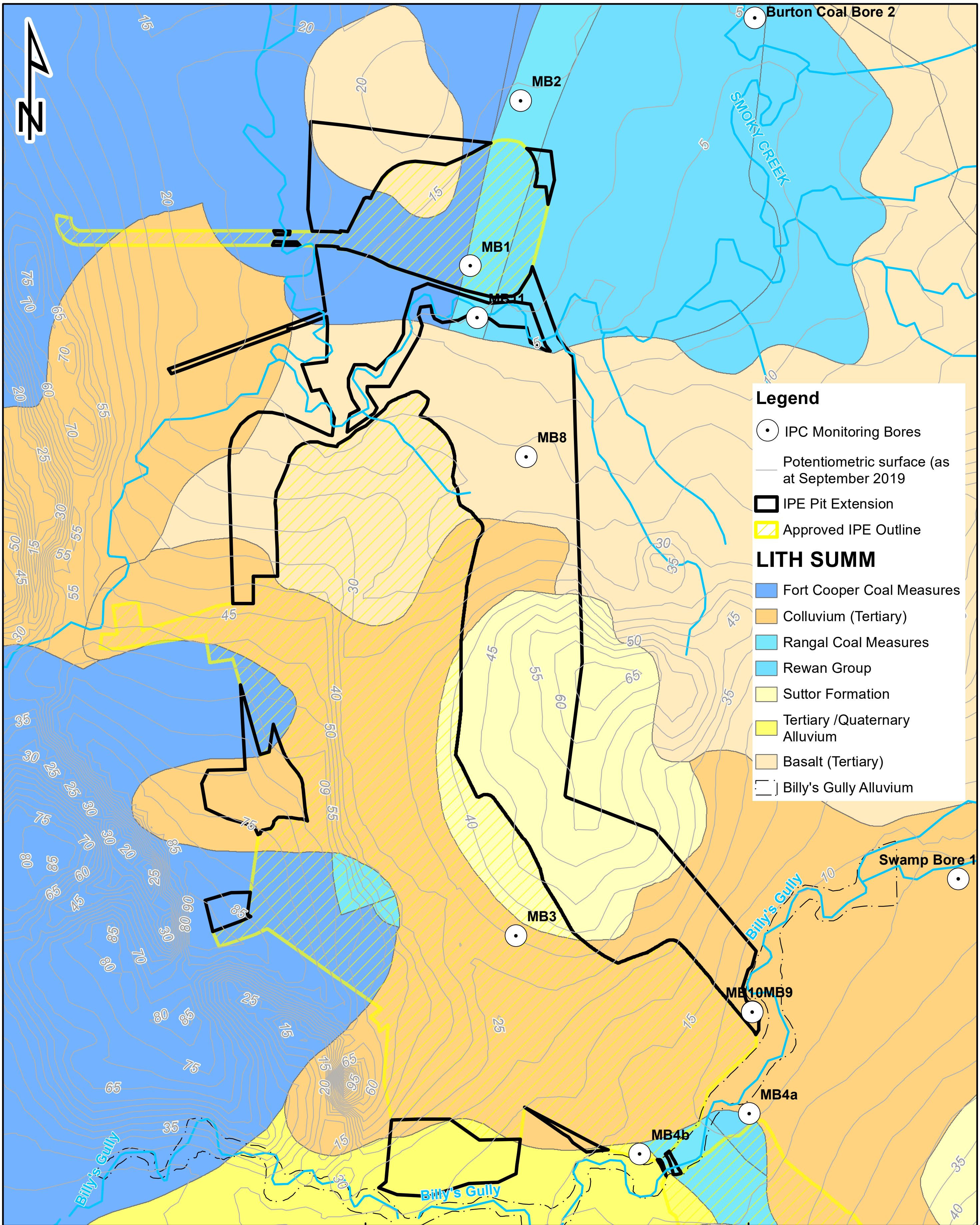
3.5.2 Tertiary Sediments

The Tertiary sediments comprise a heterogeneous profile of deeply weathered semi-consolidated sandstone, mudstone and clays and other minor sediments that are widely distributed over the project mining area and its surrounds forming undulating sandy plains.

Tertiary sediments have been extensively weathered resulting in the formation of a heterogeneous layer of residual soils and weathered clays. The Tertiary sediments form a blanket of low porosity sediments that are up to 10 m thick in the project area although the low primary porosity of these sediments result in limited capacity for groundwater storage and movement. The Tertiary sediments are recharged by direct infiltration from rainfall and by the groundwater regime where they are hydraulically connected to the water table. Groundwater quality in the Tertiary sediments can be extremely saline (e.g. EC 51660 µS/cm at MB4a), reflecting the degree of weathering and the long residence time in this formation.

3.5.3 Tertiary Basalt

Fresh Tertiary basalt forms the main water bearing unit in the project area although the basalt is also associated with low permeability basaltic clays. Basalt exposures in the Project Area are on the margins of the regional basalt flow and are relatively massive compared to thicker, more vesicular portions of the flow to the east. Basalt outcrops are typically dry or with a saturated profile of <5 m, although the saturated thickness of the basalt increases to over 50 m further to the east of the Extension. The basalt aquifer is recharged directly by rainfall or infiltration from overlying Tertiary sediments where they form overburden. Associated groundwater is typically moderately saline (e.g. 2653 µS/cm at MB10).



Source: KCB (2019)

Figure 9. Surface geology, groundwater monitoring network and potentiometric surface.

Stanmore IP Coal Pty Ltd

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Kilometers

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3.5.4 Rewan Group

The Triassic age Rewan Group is a thinly interbedded sequence of siltstone, claystone and minor fine-grained sandstone uniformly saturated at depth, becoming unsaturated where it outcrops above the regional water table east of the mining project. The Rewan Group is a regional aquitard, acting as a confining unit overlying Permian sediment with saturation and groundwater movement associated with fracturing. Recharge occurs via direct rainfall infiltration where the unit outcrops, or from seepage from overlying basalts or Tertiary sediments. The groundwater is moderately saline with an average salinity of 5795 µS/cm for Burton Coal Bore 2 and 8933 µS/cm for Swamp Bore 2 respectively.

3.5.5 Permian Sediments

The Permian sediments of the Rangal Coal Measures, Fort Cooper Coal Measures and Moranbah Coal Measures comprise alternating layers of fine to medium grained sandstone and siltstone which are hydraulically tight, meaning the coal seams are the main water bearing structures. The coal seams are typically saturated throughout their full thickness. The salinity of the groundwater associated with the Permian sediments is saline (e.g. MB5 average salinity reading of 24214 µS/cm).

3.5.6 Potentiometric surface and monitoring network

The potentiometric surface produced from available groundwater bores in relation to surface geology and the groundwater monitoring bore network has been shown in **Figure 9** (adapted from KCB 2020). The potentiometric surface occurs as close as 5 to 10 metres below ground level (mbgl) in the north-eastern reach of Smoky Creek (see MB1, MB11 and Burton Coal Bore 2) and in the upper portions of Billy's Gully (see MB9, MG10 and Swamp Bore 1) to over 40mbgl in the central eastern portion of the IPEE area (see MB3). A summary of groundwater monitoring bores, total depth, standing water level (SWL), target formation and salinity is provided in **Table 1**. Data was drawn from a range of sources including KCB (2020) and C&R Consulting (2019) and recent groundwater monitoring data supplied from Stanmore IP Coal Pty Ltd.

Table 1. Details of registered water monitoring bores used to inform assessment.

DNRM Reg. Bore Name	Easting (GDA94- Zone 55K)	Northing (GDA94 – Zone 55K)	Surface RL (mAHD)	Screened Aquifer	Screen Depth (mbgl)	Total Depth (mbTOC)	Recorded SWL (mbgl)	Salinity (µS/cm)
Burton Coal Bore 2	620383.37	7573599.08	240.79	Rewan Group	30.3 – 34.6	35.5	13.37[1]	5795[1]
Swamp Bore 1	621517.97	7568789.72	244.989	Rewan Group	24.0 – 55.1	59.37	9.5[1]	8933[1]
MB1	618792.84	7572213.92	236.376	Rangal Coal Measures	22.5 - 28.5	28.9	15.54[1]	3742[1]
MB2	619073.87	7573137.24	242.669	Rangal Coal Measures	48.7 - 51.7	52.3	15.98[1]	7871[1]
MB3	619047.16	7568472.75	252.971	Rangal Coal Measures	49.64 – 52.64	53.15	-27.95[1]	21543[1]
MB4a	620351.36	7567478.64	237.598	Tertiary sediments	7.80 – 10.80	11.34	10.02[2]	51660[2]
MB4b	619739.67	7567253.00	233.925	Tertiary sediments	8.50 – 11.50	11.84	9.41[1]	31167[1]
MB5	618507.00	7570878.00	235.7-	Rangal Coal Measures	36.4 – 39.3	39.4	-	24214[1]

DNRM Reg. Bore Name	Easting (GDA94-Zone 55K)	Northing (GDA94 – Zone 55K)	Surface RL (mAHD)	Screened Aquifer	Screen Depth (mbgl)	Total Depth (mbTOC)	Recorded SWL (mbgl)	Salinity (µS/cm)
MB8	619105.16	7571148.56	245.916	Rangal Coal Measures	117.3 – 120.3	126.3	24[1]	12013[1]
MB9	620368.48	7568048.86	239.495	Basalt & Rangal Coal Measures	77.50 – 80.50	80.57	12.73[1]	10725[1]
MB10	620368.24	7568045.82	239.495	Tertiary Basalt	21.30 – 27.30	27.44	11.28[1]	2653[1]
MB11	618831.91	7571923.52	232.302	Quaternary - Undefined	3.00 – 4.00	4.53	Dry[1]	NA

[1]From KCB (2020); [2]C&R Consulting (2019)

3.6 Groundwater Dependent Ecosystems and other Riparian Vegetation

A comprehensive assessment of the nature, distribution and ecohydrological function of GDEs was undertaken across the IPEE assessment area by 3d Environmental in March 2020. The assessment included multiple field and laboratory techniques to infer use of groundwater by vegetation communities. Multiple lines of evidence to suggest groundwater use included measurement of leaf water potential (LWP), soil moisture potential (SMP) and stable isotope analysis supported by geomorphology observation.

Groundwater dependent ecosystems are defined as:

> *'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 assessment identified that riparian vegetation associated with the alluvial floodplain of Billy's Gully provided the only representation of vegetation in the assessment area that would meet the definition of a GDE. The larger drainage feature of Smoky Creek is not considered to represent a GDE, and riparian vegetation utilises moisture held in the unsaturated portion of the soil profile above the phreatic zone. The ecohydrological function of the Billy's Gully GDE system is described below.

3.6.1 Billy's Gully GDE system

The terrestrial ecology assessment for the IPEE project (EcoSM 2020) identified riparian vegetation on Billy's Gully as regional ecosystem 11.3.25 under Queensland's *Vegetation Management Act 1999*. Typical canopy trees associated with this vegetation include Queensland blue gum (*Eucalyptus tereticornis),* Moreton Bay ash (*Corymbia tessellaris),* Poplar box (*Eucalyptus populnea)* and Dallachy's bloodwood (*Corymbia dallachiana).* Queensland blue gum was most common adjacent to the channel and become less frequent in marginal areas of the flood plain. Ground cover is typically exotic, formed by green panic (*Panicum maximus var trichoglume).* From the GDE Assessment completed by 3d Environmental (2020), the following features relevant to ecohydrology are noted:

1. Billy's Gully is an ephemeral drainage system that has developed on a flood plain characterised by coarse sandy alluvial soils overlying a basement of Tertiary sediments.
2. The thick sandy deposits provide a favourable substrate for the capture and storage of surface water and the sands and clayey sands of the flood plain host a saturated zone perched above low-permeability clays and sediments. This shallow unconfined groundwater table is likely to be seasonally variable though retaining sufficient moisture through seasonally dry periods to sustain robust riparian vegetation.

3. The perched groundwater system demonstrates a slight enrichment of stable isotopes when compared to overlying alluvial sediments. This indicates downward displacement of surface moisture through infiltration of younger surface flows, with mixing of flow events occurring at the zone of saturation. The isotopic signatures obtained from xylem samples are consistent with the perched groundwater system suggesting that trees are utilising water from within the saturated zone. This observation is supported by data from biophysical measurements of LWP and SMP.
4. The saturated alluvial profile would likely facilitate some shallow infiltration into underlying Tertiary clays which may provide diffuse recharge to the Tertiary sediments. The high salinity of the Tertiary groundwater system however indicates that recharge from the perched groundwater system is insignificant. There is no evidence of strong hydraulic connectivity with groundwater in the underlying Tertiary sediments. The relative height difference between the top of the Tertiary groundwater system and the base of the perched groundwater (approximately 8m), coupled with the low hydraulic conductivity of the Tertiary sediments (approximately 7.0×10^{-4} to 0.04 m/d from KCB 2020) precludes any recharge of the perched groundwater system by baseflow.
5. From all evidence, Billy's Gully is considered to represent a GDE reliant on a shallow seasonal perched groundwater system sustained by surface water infiltration.

The location of the Billy's Gully GDE system, coinciding with the field verified alluvial floodplain, is shown in **Figure 9**. A north-south section through Billy's Gully provided in **Figure 10**, demonstrates the sandy alluvium that defines the flood plain, which is drained by a sparse system of shallowly incised anastomosing sandy channels. Based on consistency of landform, tree size and species dispersal, the sandy alluvial sediments are expected to be relatively uniform over large areas. During the wet season, the anastomosing drainage channels are activated with surface flow and bank overflow. This occurs during the wet season when the sandy alluvium is totally saturated, or surface runoff exceeds infiltration during intense storm events (**Figure 11**). There may be some minor infiltration into the Tertiary sediments that confine the flood plain margins. The landform associated with Billy's Gully relies on its own local catchment and surface flows to replenish the perched groundwater system.

Billy's Gully is considered a GDE that is reliant on a shallow perched aquifer, possibly with some deeper roots penetrating into the surface of the moist Tertiary clays for anchorage and a source of soil moisture utilised as the perched groundwater system dries. As the landform that hosts the perched groundwater system will not be directly impacted by the mine footprint and there is limited connectivity to the Tertiary sediments due to low hydraulic conductivity, the groundwater hydrology in this alluvial system is not expected to be impacted by drawdown associated with mine pit development.

3.6.2 Ecohydrological function of characteristic tree species

The following provides a characterisation of the groundwater dependence and known ecohydrological function of the major canopy species associated with Billy's Gully. The purpose of the characterisation is to identify those species most likely to exhibit groundwater dependence to allow monitoring and corrective actions to be appropriately targeted.

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 has only an occasional occurrence on Smoky Creek. 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 it would be more tolerant of changes to hydrological regime than *Eucalyptus camaldulensis* which is a riparian specialist. Malik and Sharma (2004) found that *Eucalyptus tereticornis* also has a strong capacity to extract moisture from the shallow soil profile (0 – 150cm).

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). 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

Figure 10. Conceptual model of the Billy's Gully GDE system in the dry season.

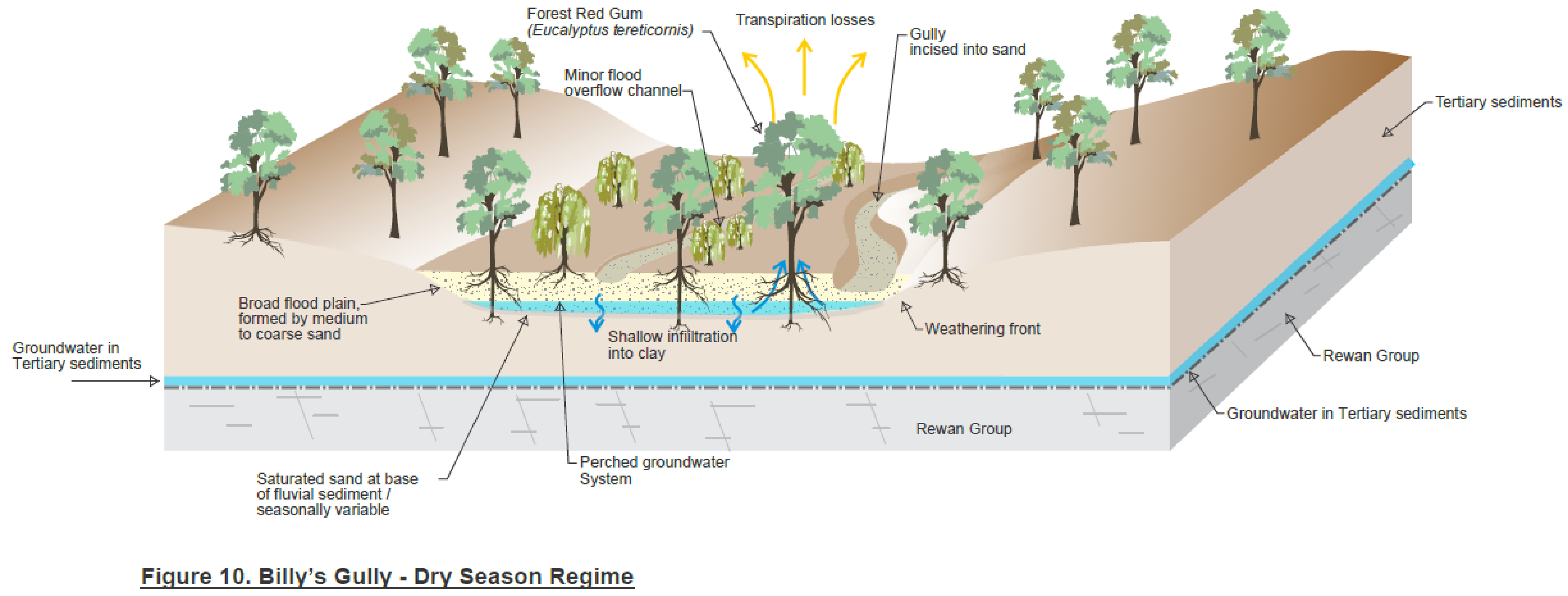
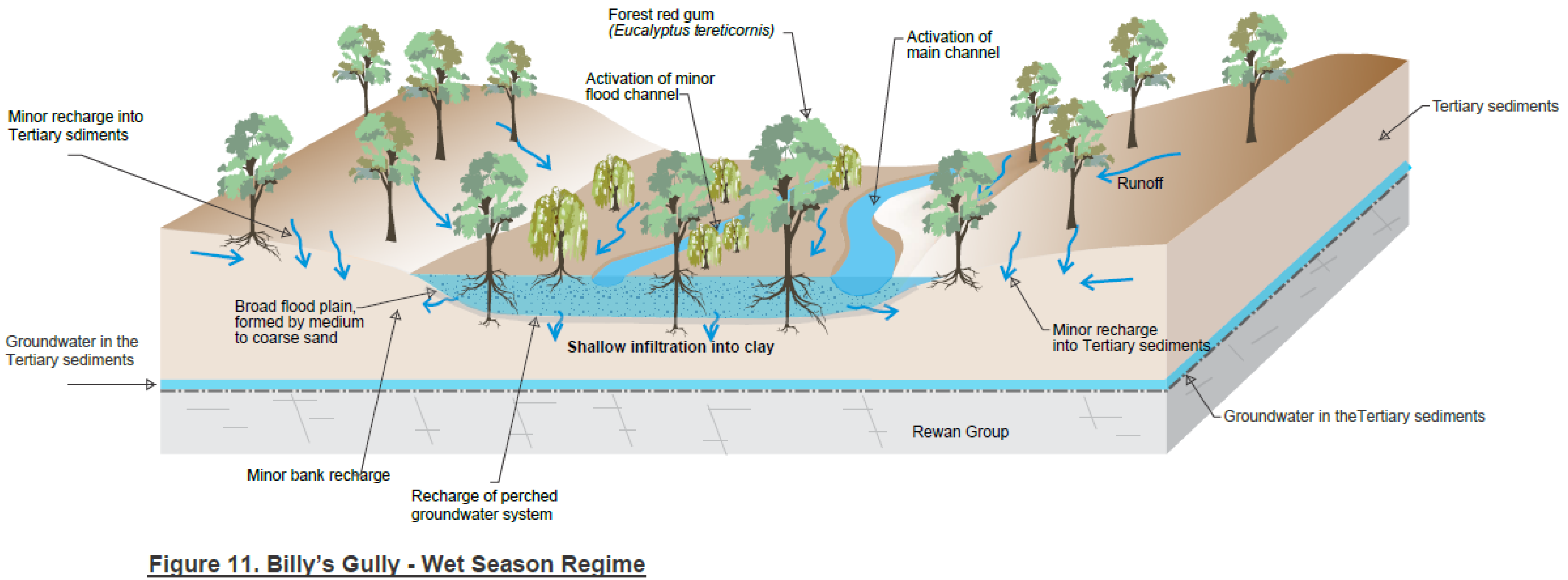


Figure 11. Conceptual model of the Billy's Gully GDE system in the wet season showing groundwater recharge mechanisms.



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 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. These species are more typically associated with elevated terraces associated with the Tertiary sediments away from alluvial areas and stream channels and 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 substrates 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 when studying groundwater usage of trees on a tropical floodplain savannah:

1. Clarkson's bloodwood utilised groundwater when the water table was at 10 mbgl indicating the potential for the species to develop a deep sinker root. Clarkson's bloodwood should be considered a facultative phreatophyte. It is likely that Clarkson's bloodwood occurring on the floodplain of Billy's Gully will utilise perched groundwater when it is available.
2. Moreton Bay ash demonstrated groundwater usage when the water table was at 4 mbgl, although it is not known whether the species has capacity to utilise deeper groundwater sources. Moreton Bay ash should be considered a facultative phreatophyte and the closely related Dallachy's bloodwood (*Corymbia dallachiana)* should be considered to possess similar water utilisation strategies.

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.

Melaleuca species: Fringing *Melaleuca bracteata* are almost ubiquitous with heavy clay soils, particularly soils derived from basalt and associated drainage lines. This suggests a root mass concentrated in the upper soil profile where the bulk of nutrient cycling occurs. While many melaleuca species are considered to be facultative phreatophytes, *Melaleuca bracteata* is thought to obtain its moisture requirements entirely from the soil (Soonthornvipat, 2018).

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

4.0 Major Risks to GDE Function

The GDE Toolbox, developed by Richardson et al (2011), provides a starting point for investigating potential impacts to GDEs exposed to development through the following mechanisms:

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

There will be no direct clearing of vegetation associated with the GDE system at Billy's Gully during IPEE development, operation and decommission, other than the widening of the crossing. Widening of the existing road crossing will result in the clearing of 0.6 ha of riparian vegetation (RE11.3.25 from EcoSM, 2020), however offsets are proposed for this clearing associated with the Extension, with offsets also required for the original crossing for the IPE Project under the Commonwealth approval for IPE. A risk assessment for each potential impact pathway was undertaken as a component of the IPEE GDE assessment report. The methods and results of the risk assessment are fully described in 3d Environmental (2020) and a summary provided in **Table 2.** The pathways with highest risk of impact to GDEs at IPEE are associated with shallow perched groundwater systems with surface flows, representative of the GDE characteristics of Billy's Gully.

Table 2. Potential pathways for impact to the Billy's Gully GDE system with an assessment of the unmitigated risk of impact.

Impact Mechanism	Context	Unmitigated Risk	Mitigation Measures	Mitigated Risk
1. A total or partial loss or reduction in the volume or pressure of the aquifer being utilised by GDEs.	The perched groundwater system supporting the Billy's Gully GDE system and underlying groundwater system associated with the Tertiary sediments do not show evidence of hydraulic linkage.	Low[1]	• Monitoring of groundwater and vegetation communities to detect changes in aquifer pressure and application of mitigation strategies.	Low
2. A change in the magnitude and timing of volume fluctuations in the aquifer being utilised by GDEs[1].	Volume fluctuations in the perched groundwater system are regulated by surface flows. Changes to flow regimes associated with IPEE development are not expected due to the limited catchment excision. Haul road construction with not alter the hydrology or lateral connectivity of the perched groundwater system.	Moderate[2]	• Water Management System • Erosion and Sediment Control plan. • Monitoring of groundwater and vegetation communities to detect changes in aquifer pressure and application of mitigation strategies. • Engineering solutions are provided for construction of the Haul Road crossing on Billy's Gully to ensure the lateral connectivity of the perched groundwater table is not disrupted.	Low
3. Changes to the interaction between surface flows and aquifers being utilised by a GDE.	Flooding volume and frequency will not be significantly impacted by the IPEE development	Moderate[2]	• Water Management System • Erosion and Sediment Control plan. • Monitoring of groundwater and vegetation communities to detect changes in aquifer pressure and application of mitigation strategies.	Low
4. Change in chemical composition of an aquifer detrimentally impacting the health of a GDE[1].	No controlled releases of mine water planned for Billy's Gully. Uncontrolled releases of mine water not predicted for Billy's Gully.	Moderate[2]	• Water Management System • Erosion and Sediment Control plan. • Monitoring of groundwater and vegetation communities to detect changes in aquifer pressure and application of mitigation strategies.	Low

[1]Low - Moderate (loss <25% of keystone trees) within ecosystem although impact contained on mining lease. Reversible in 1 to 5 years with rehabilitation.
[2]Moderate - Significant impact on ecosystem (loss >25% of keystone trees) although impact is contained on mining lease and is reversible with rehabilitation.

5.0 Biophysical Response to Reduced Water Availability / Quality

Eamus et al (2009) provides a conceptual assessment of the major stressors that contribute to declining GDE health. Reduced water availability is the major determinate of GDE health and the flow-on effects of this are outlined in **Figure 12**. The potential impact pathway for the GDE system at Billy's Gully may arise from reduced groundwater recharge because of reduced surface flows, rather than groundwater abstraction. Reduced surface flows and a subsequent reduction in recharge is a low risk (**Section 4.0**) (noting, that the GDE assessment identified that surface flows will have very minor change in flow duration or catchment excision), however is an important consideration. Similarly, increasing salinity levels within the groundwater table would result in stomatal closure, reduction in Leaf Area Index (LAI) and longer-term plant mortality. These adverse physiological responses would ultimately result in the conversion of a diverse, functioning habitat to a simplified system with reduced ecological value (Doody et al 2009). As described in **Figure 12**, the time taken for the first measurable impacts to manifest may take months. As a result, habitat conversion due to dieback of the original canopy for instance, could take many years. Therefore, annual monitoring using the most sensitive indicator is an important measure to detect measurable changes. Many of the physical responses of vegetation to reduced water availability can also occur as a result of natural seasonal variation and hence any monitoring program must have capacity to distinguish what is natural variation from impacts that result from anthropogenic interference.

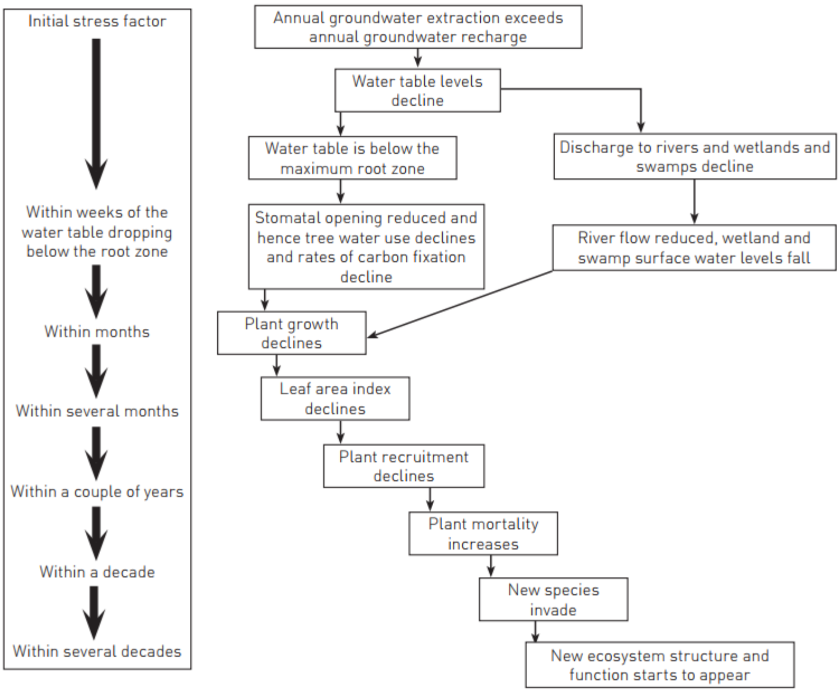


Figure 12. Schematic outline of the response of plants and communities of plants to reduced availability of groundwater from Eamus (2009).

6.0 Approach to Monitoring and Management Program

6.1 Overview

This document provides a framework for the management and monitoring of GDEs in the IPEE area, developed specifically for the Billy's Gully GDE system. A sequential approach to monitoring and management has been applied which allows for adaptive implementation of monitoring and management protocols reliant on results of prior assessment activities. The major components of the GDEMMP include provision to:

- Apply monitoring and assessment techniques that support development of an environmental baseline for GDE function prior, commencing prior to Extension operations, including an upstream control site for monitoring.
- Produce a statistically robust multi-parameter dataset that can be used to validate perturbations in GDE function that fall beyond thresholds of natural seasonal variation.
- Allow a flexible approach to monitoring which is subject to ongoing review and allows methods to be adapted based on results of lead-up monitoring and data analysis.
- Utilise this baseline data to establish an appropriate ecological trigger threshold, applied to indicate requirement for further investigation or corrective action.
- Develop a comprehensive suite of management actions and corrective measures which can be applied if a breach of trigger threshold is identified.

The sequential approach above is consistent with the GDE Toolbox approach (Richardson 2011a and 2011b) which recommends a sequential assessment, as outlined below:

- Stage 1 – GDE location, classification and basic conceptualisation. The focus of Stage 1 is to gain a baseline understanding of where potential GDEs exist including classification of GDE type and ecohydrological function.
- Stage 2 – Characterisation of groundwater reliance. Stage 2 assessment builds on conceptual information provided in Stage 1 to characterise the degree of reliance of the GDE on groundwater.
- Stage 3 – Characterisation of ecological response to change: During Stage 3 assessment, knowledge of baseline ecohydrological function is utilised to describe and quantify likely changes to biophysical function and health of GDEs if impacts to groundwater regimes are manifested.

The GDE characterisation undertaken by 3d Environmental (2020) as a component of the PER process meets the requirements of Stage 1, the outcomes of which are described in accordance with conceptual models in **Section 3.6**. Ongoing adjustment of the ecohydrological models for Billy's Gully may be required as the monitoring program develops, and baseline data is collected and analysed.

Stage 2 and Stage 3 of the monitoring program will rely on collection of temporal data to support characterisation of baseline ecohydrological function. Seasonal monitoring events will allow for baseline data to be acquired to predict trends in GDE function and identify impacts that extend beyond the range of natural variation.

6.2 Approach

The monitoring and management program has been separated into two stages:

- The initial 2 years, for which thresholds have been defined (see **Section 9**).
- The period after 2 years, comprising the remainder of operations and the post mining period, which will utilise data collected in the initial two years to re-assess the thresholds.

The process for establishing thresholds is described in **Section 9**, involving data from the impact site (being the Billy's Gully GDE system adjacent to the IPEE) and a control site. The thresholds for impact are linked to vegetation health and provide a comparison between the control and impact site. Should the thresholds be exceeded, this will trigger an investigation that will make use of other monitoring data (See **Section 9.2**) on the eco-physical function of vegetation a, groundwater and surface water to determine the cause of a threshold exceedance. If the Extension is found to be cause of the threshold exceedance, then mitigation measures (see **Section 10**) will be implemented and the effect of mitigation measures monitored. If mitigation measures are not effective, habitat quality data from the riparian monitoring program will be used to assess whether there has been a significant residual impact to habitat for listed species that are likely to occur (EcoSM, 2020). The riparian monitoring program is described in Chapter 5 of the public environment report (PER) for the Extension.

The initial two year of assessment specifically aims to establish thresholds for monitoring and impact assessment, including provision of a dataset to support investigative action. For the subsequent period after 2 years, the process remains the same; however, the thresholds may be amended to reflect alternative parameters for monitoring and / or the threshold values attached to those parameters.

7.0 Monitoring and Analysis Techniques

The GDE Toolbox – Part 2 (Richardson 2011b) provides a suite of technically robust tools to identify GDEs and determine their ecological water requirements. These tools are based on established methods repeated in studies within Australia and abroad, many of which are published in peer-reviewed scientific journals. Many of these tools were applied in the GDE assessment (3d Environmental 2020) and for the purpose of data continuity and baseline characterisation, will be recommended for inclusion as a component of ongoing monitoring. **Table 3** provides a list of tools used in the GDE assessment and describes their purpose and ongoing relevance to monitoring. Several additional methods adapted from the GDE Toolbox have also been included, being recommended components of an ongoing monitoring program. Technical details of recommended assessment methods are detailed in **Appendix B.**

Table 3. Assessment methods that may be applied during GDE monitoring.

Assessment Method	Utilised in IPEE GDE Assessment	GDE Toolbox Method No.	Method Description	Primary Utility
Conceptual modelling	Yes	Tool 2	Aims to conceptualise the interactions between biotic factors (e.g. trees) and abiotic (e.g. soil, surface water and groundwater). Conceptualisation formalises the understanding of the major components of a GDE system and allows impact pathways to be contextualised.	Conceptualisation and informing monitoring program design and implementation.
Leaf water potential	Yes	Tool 3	LWP provides the primary biophysical measure of tree water availability and defines a continuum between the relationship of soil, water and plant. Trees associated with high water availability will have a high (least negative) LWP. LWP provides an indication of which trees have access to a saturated or near saturated water source, although does not identify the nature of the source (i.e. groundwater, saturated pockets in the soil, surface water from stream pools).	Site based assessment with some application for seasonal monitoring to identify plant water deficits. Used in conjunction with Leaf Area Index (LAI).
Stable Isotopes of water in plants	Yes	Tool 4	The stable isotopic signature (2H and 18O) of the dominant water source for a tree will be imparted on its hydraulic architecture, typically measured in twigs. The stable isotope signature in twigs may be directly analogous to a single water source if that source provides a predominant contribution to a trees water requirement. It may also be a combination of a number or sources, requiring a mixing model to be employed to calculate relative contributions of each water source.	Identifies plant water sources. Ongoing monitoring application during baseline development to demonstrate seasonal variations in plant water sources.
Leaf Area Index	No	Tool 1, Tool 2	Leaf Area Index (LAI) is a ratio of the total leaf area within a canopy to the ground area covered by the canopy. It is a measure of canopy vigour and the rationale applied is that plants with access to permanent sources of water (i.e. groundwater) will have greater vigour and LAI than vegetation that has only periodic access to groundwater resources (e.g. Zolfagher 2014). LAI is likely to vary on a seasonal basis if the sustaining	Has an applicable monitoring application which may be used in conjunction with remote sensing for longer term monitoring.

Assessment Method	Utilised in IPEE GDE Assessment	GDE Toolbox Method No.	Method Description	Primary Utility
			source of moisture is variable, or the groundwater is only seasonally utilised.	
Remote sensing	No	Tool No 1	Assessment utilises the Normalised Difference Vegetation Index (NDVI) as a measure of canopy health and vigour, that can be directly correlated to LAI. It is a widely accepted method and with advances in satellite technology, has the capacity to assess the health of individual trees rather than landscapes.	Application for long-term monitoring once baseline conditions have been established.
Site based groundwater monitoring	Yes – for data from regional groundwater units. Site- specific shallow bores in Billy's Gully alluvium proposed.	Tool No 10, 13	Local installation of groundwater monitoring bores targeted to monitor the groundwater source which the GDE is utilising.	Long term monitoring applications as a basis to draw correlations with biotic assessment parameters (e.g. LAI).
Surface Water Monitoring	Ongoing monitoring under the site WMP and ESCP.	Tool No 10	Ongoing monitoring of surface water flows and quality from dedicated monitoring points (see Section 2.4).	Long term monitoring applications to draw correlations between surface flows and recharge of unconfined alluvial aquifers on Billy's Gully.

7.1 Site Selection and Application

Table 4 provides the recommended data collection requirements for each of the chosen monitoring parameters. Parameters to be applied include LAI, LWP, NDVI image capture, stable isotope assessment of twig xylem, soil, surface water and groundwater from the Billy's Gully GDE system, including an associated control site located upstream at -21.9778 / 148.1796. The control site is approximately 1.7 km upstream of the IPEE, directly west of the Broadlea Road crossing. Further information on each of these monitoring parameters is provided in the Appendix as detailed below:

1. LWP and SMP provided in **Appendix B1**
2. Stable Isotope analysis in **Appendix B2**
3. Measurement of field-based LAI in **Appendix B3**
4. NDVI assessment in **Appendix B4**
5. Groundwater monitoring bores in **Appendix B5.**

The location of trees for LWP and stable isotope sampling, shown in relation to proposed shallow groundwater monitoring bores and habitat quality sites from EcoSM (2018) is provided in **Figure 13**. A summary of all trees that were sampled for LWP and stable isotopes during development of the PER report is provided in **Appendix E** for future reference.

Table 4. Recommended GDE sampling program

Sampling Method	Sampling Locality	Sampling Intensity
LAI	Billy's Gully	Ten capture points in the GDE assessment area including: a) Three sites associated with groundwater monitoring bores BGMB1, BGMB3, BGMB4. b) Co-location of additional sites with habitat quality Monitoring Site 1, Monitoring Site 2 and Monitoring Site 3 as proposed for the Billy's Gully riparian monitoring program.
	Billy's Gully Control	Ten capture points in the riparian ecosystem associated with Control Site 1 on Billy's Gully.
LWP	Billy's Gully	Sampling for LWP will be completed for: a) Ten trees (10) sampled at Billy's Gully by 3d Environmental 2020. Details of these trees are provided **Appendix E** (IP4_T1a, IP4_T1 to IP4_T9). b) A selection of three canopy (3) trees in the vicinity of GDE monitoring bore BGMB3. c) A selection of three canopy trees in the vicinity of GDE monitoring bore BGMB4. Sampling is to focus on red gum (*Eucalyptus tereticornis / camaldulensis)* which is a known facultative phreatophyte.
	Billy's Gully Control	A selection of ten trees will be sampled at a Control Site 1 on Billy's Gully upstream. Sampling is to focus on red gum (*Eucalyptus tereticornis / camaldulensis)* which is a known facultative phreatophyte.
Stable Isotopes	All localities	The program aims to sample selected trees for stable isotopes which are broadly representative of the range of LWP readings at each assessment site. This will include trees with the highest LWP readings, trees with the lowest LWP readings and a range of values between the two end points. Stable isotope sampling will be applied to: a) Twigs from representative trees

Sampling Method	Sampling Locality	Sampling Intensity
		b) Surface water. c) Groundwater from alluvial monitoring bores collected during routine sampling events. d) Soil samples where a particular need arises, including explanation of unusually high or low LWP measurements.
NDVI Capture	Approximately 100km2 capture to cover the relevant parts of Isaac Plains and Isaac Plains East MLs (ML700019, 700018, 700017, 700016, ML70342) plus the control site.	Minimum quality requirements would be fresh capture WorldView 2 and GeoEye-1 (0.5m Resolution 4-8 band Pan) imagery to coincide with the timing of field survey events. Finer resolution imagery from the WorldView 3 and WorldView 4 satellites (0.3m resolution, 4 -16 band multispectral) is also available and may be recommended dependant on any supplementary imagery requirements considered beneficial by Stanmore IP Coal.
Groundwater Monitoring Bores	Monitoring bores are to be installed as a component of the GDEMMP in the Billy's Gully alluvium.	Three monitoring bores include: a) BGMB1[1] (-21.99536, 148.16267) installed to base of alluvium at 3.5m depth with a screened depth of 3.0 to 3.5m. b) BGMB3[1] (-21.98686, 148.16662) installed to base of alluvium at 4.5m with a screened depth of 3.5m to 4.5m. c) BGMB4[1] (-21.99597, 148.16008) installed to base of alluvium at 3.0m with a screened depth of 2.5m to 3.0m. The location of GDE monitoring bores is intended to coincide with the location of Monitoring Site 1, Monitoring Site 2 (HQ17) and Monitoring Site 3 (HQ18) from the riparian monitoring program (EcoSM 2016) (see **Figure 13** and **Appendix C**). Lithology logs from the shallow auger holes is provided in **Appendix B5**.

[1] Temporary monitoring bore name.

7.2 Interactions with Established Monitoring Programs and Parameters

Monitoring of surface water quality and environmental flows will continue to form a component of the IPC mine site (including the Extension) surface water management system. Monitoring of upstream, onsite and downstream flow depths and water quality on Billy's Gully extending to the Isaac River will continue in accordance with the IPC EA (which includes the Extension) and the IPC REMP Design Document (C&R, 2019), allowing for early detection of any impacts and employment of appropriate corrective actions. Surface flow and water quality datasets will be used, in conjunction with other parameters, to inform the baseline characterisation of the Billy's Gully GDE system and assess project impacts. The riparian habitat quality monitoring program (EcoSM 2018) that is in action for Smoky Creek has been extended to cover Billy's Gully, with habitat quality monitoring to be completed every two years post wet season. The program includes three monitoring sites in the Billy's Gully GDE area of potential impact, plus a control site co-located with the GDE control site (Control Site 1) 1.7km upstream from the IPEE boundary. The location of the proposed riparian habitat quality monitoring sites is shown in **Appendix C.**

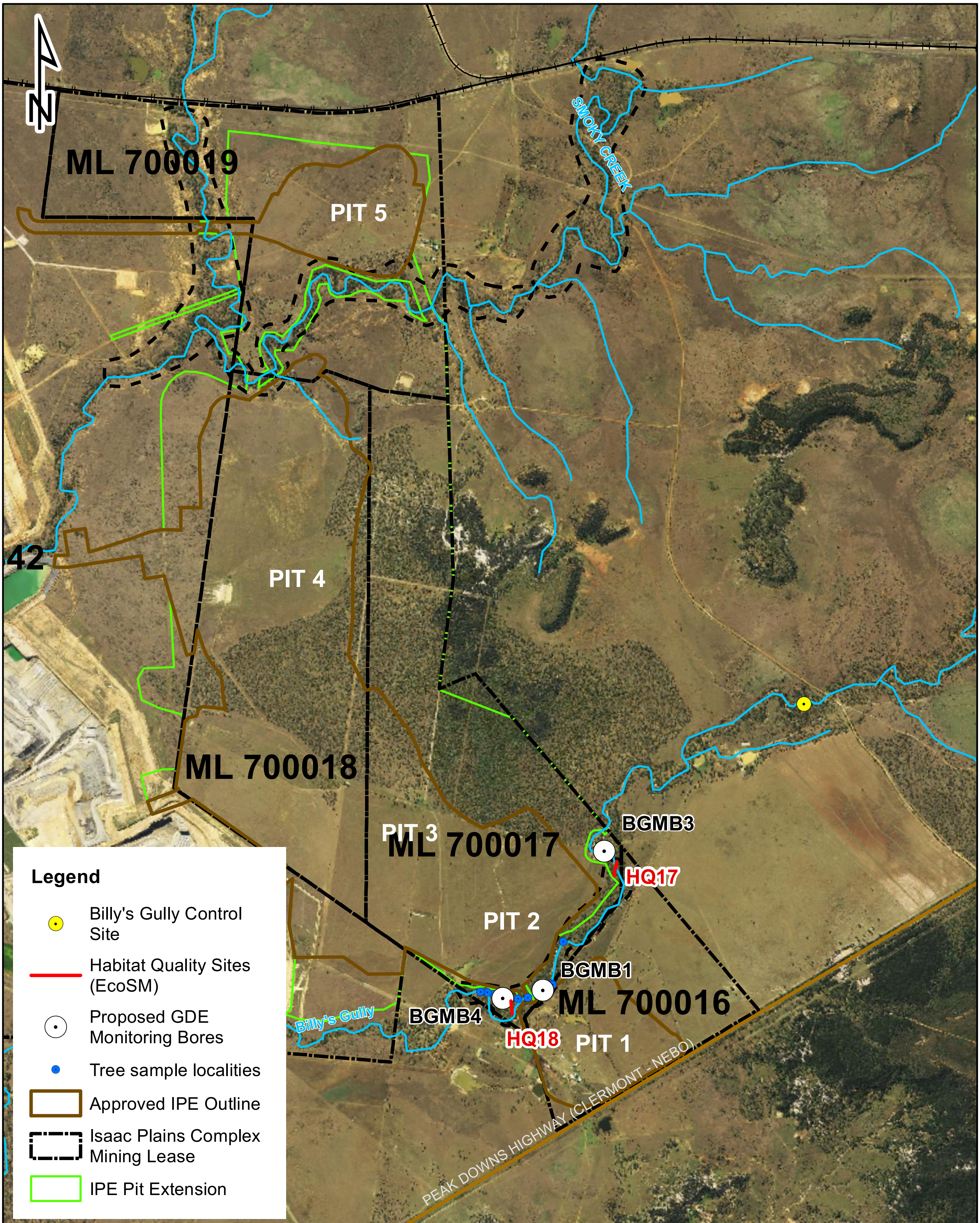


Figure 13. Assessment locations relevant to GDE monitoring.

Client

Stanmore IP South Pty Ltd

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Kilometers

3d Environmental

LANDSCAPE AND VEGETATION SCIENCE

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7.3 Detection of Trends and Statistical Analysis

The BACI (Before After / Control Impact) provides a statistically robust survey design to test for environmental change in response to disturbance. The method takes single impact site and a single control site (outside the impact area) before and after the management or impact is incurred to detect environmental change. Monitoring controls can be augmented with regional data collected during NDVI capture on a temporal basis. In this context, image capture should be extended east along Billy's Gully and Smoky Creek to augment the analysis of locally collected data and ensure habitats associated with the proposed control site are captured.

Statistical analysis will need to consider interactions between multiple datasets to establish baseline conditions and allow identification of statistically significant deviations from these conditions that may be associated with IPE Extension activities. The most critical interactions will be between biotic health (typically measured in LAI, LWP and NDVI) and abiotic factors such as groundwater levels and salinity. Statistical tests applied to analysis of data will depend on whether datasets are normally distributed and may include bivariate analysis of two datasets (e.g. NDVI and LAI) applying a Pearson or Spearman Correlation. 'T-tests' will be applied to identify significant differences in mean values between sampling localities. More complex statistical analysis may be applied if investigative actions are required including multivariate analysis of variance (PERMANOVA) to interacting datasets.

The overriding purpose of the data collection and subsequent statistical analysis is to provide representation of natural variation in the system applied to both biotic factors and abiotic controls and allow appropriate trigger thresholds to be proposed, which are further discussed in **Section 9.0**.

8.0 Reporting, Periodic Review, Timing and Objectives

General program: This GDEMMP proposes methods that will result in collection of baseline ecological and biophysical data that will facilitate increased understanding of the ecohydrological function of the Billy's Gully GDE system. During compilation and analysis of monitoring data, information gaps or data trends may be identified that indicate a need to update the GDEMMP approach and methods. To accommodate this requirement:

1. Reporting will be prepared at the completion of each monitoring event which describes:
    a. Methods employed.
    b. Factors that may have influenced data and monitoring results
    c. Data trends for each of the parameters measured.
    d. Information gaps which may influence the assessment.
    e. Correlations between datasets which characterise ecological function.
    f. Trends which appear abnormal or indicative of unexplained / un-natural decrease in ecological function, warranting further investigation or corrective action.
2. Bi-annual monitoring (four events covering two wet seasons and two dry seasons) should be undertaken for a two-year period.
3. At the completion of four monitoring events (excluding the original GDE assessment associated with the PER), a consolidated report will be prepared which provides a synopsis of the data collected, including correlations between parameters and statistical analysis (where possible) of baseline ecological function.

The aim of the four-event baseline characterisation is to determine the range of natural seasonal variation in the measured parameters, particularly LWP and LAI which are fundamental indicators of plant stress. These parameters can be correlated to the NDVI signature, allowing future monitoring to be undertaken remotely at an 'on demand' basis, supplemented with field assessment if a significant departure from baseline condition is detected. Reporting and review requirements have been incorporated into a proposed two-year monitoring schedule as per **Appendix D**.

Ongoing monitoring following baseline: Following completion of the two-year (four-event) baseline. program in March 22, NDVI will be captured on an annual basis during the height of dry season (nominally October / November) to support ongoing monitoring of GDE health. NDVI threshold values will be calculated from correlations to LAI established during the baseline assessment, and annually checked for statistically significant threshold exceedance events that affect the impact site, in the absence of similar affects at the control site. Annual capture of NDVI data will be completed until completion of mining operations, as described below.

Monitoring completion: A monitoring event that includes field assessment of monitoring parameters should be undertaken to coincide with completion of mining at the IPEE. This event will include:

1. A comparison to the baseline GDE dataset to identify any significant departure from pre-impact conditions.
2. Provision of a summary memorandum detailing ecological condition of the Billy's Gully GDE system and recommendations for future monitoring requirements.

Providing there has been no significant decline in ecological condition that can be attributed to mining operations, follow up survey periods should be:

1. Two years from completion of mining operations, timed to coincide with the driest portion of the year (typically September to November).
2. Four years following completion of mining operations, timed to coincide with the driest portion of the year.
3. A final survey event at six years following completion of the mining operation.

Based on correlations drawn between LAI and NDVI during baseline characterisation, completion of post mining monitoring through capture of remotely sensed data should be feasible.

9.0 Triggers for Investigative Action and Supporting Parameters

While groundwater associated with the alluvial flood plain is a major abiotic control on the ecohydrological function of the Billy's Gully GDE system, it is the actual health of the vegetation that defines GDE habitat values. In the absence of long-term groundwater monitoring data to characterise seasonal variation and persistence of the alluvial groundwater system, it is pertinent that vegetative indices be utilised to provide a baseline for ecological health and define trigger thresholds to direct when investigative actions are required. The indices used to define trigger thresholds, including potential parameters applied during investigative action are described in following sections. The management framework is intended to be adaptive, with future capacity for update dependent on the ongoing results of the baseline assessment, and any information gaps identified.

9.1 Vegetative Indices

Section 5.0 (**Figure 12**) identifies a decrease in LAI as an initial indicator of vegetative stress. LAI is a precursor to more intensive impacts to habitat values including canopy dieback and conversion to an alternative ecological state over a longer time frame. LAI varies on a seasonal basis dependent on water availability, generally within the space of weeks to months, with the highest values lagging slightly behind moisture recharge events. Doody et al (2015) document typical annual LAI variation in the range of 14% to 35%, with LAI = 0.5 (i.e. 50% foliage to canopy ratio) identified as a potential threshold, indicative of critical water stress beyond which vegetation health rapidly declines. This value is however taken from river red gum forest on the Murray River and may not be directly applicable to the Billy's Gully GDE system due to the vastly different climatic regimes and hydrological controls. The process for thresholds based on LAI applies the following principles:

1. Collection of time series data of LAI from control and impact sites for a period of two years to establish a baseline.
2. Identifying appropriate thresholds which may be applied as a trigger for investigation and provide a mechanism to review the appropriateness of the derived trigger.
3. Statistical analysis of time series data to characterise seasonal differences in assessment parameters at control and impact sites to identify if a threshold breach occurs.

Where a threshold breach occurs, appropriate baseline data from a range of biotic and abiotic parameter will be available to provide a sound basis for investigation. **Figure 14** details the process and decision framework from initial data collection through to corrective actions in the case that a threshold breach can be linked to mining activity. The initial two years of the assessment cover wet and dry season surveys, to provide a baseline against which future vegetation condition trends can be assessed. The two-year baseline assessment and decision-making process are as follows:

1. Establish suitable impact and control sites on Billy's Gully and collect and capture LAI and supporting biophysical data (LWP and NDVI) in an initial dry season assessment event (November 2020). The proposed location of the impact and control sites has been previously identified in **Section 7.1** and **Table 4**.
2. Establish an appropriate trigger threshold value based on the percentile method detailed in DSITI (2017). The proposed process for establishment of the investigative trigger thresholds is:
    a. Collect LAI data from a minimum of 10 permanently located monitoring points at both the impact site and control site in the initial dry season GDE assessment.
    b. Undertake statistical analysis (t-test) to compare dataset means and ensure the appropriateness of the control site for comparative purposes.
    c. If a significant difference is detected between the mean values of control and impact datasets in the initial assessment, the location of the control site will be re-evaluated.
    d. Assuming suitability of the control site, set the lower of the 10^{th} percentile (or LAI of 0.5 as per Doody et al 2015, whatever value is lowest) as a trigger value for investigative action.
3. Collect seasonal data (post wet season in March to April 2021) to provide a baseline which incorporates seasonal variation.

4. Complete a follow up dry season assessment (October to November 2021). Assess appropriateness of applied thresholds and assess data for significant differences in means (t-test) to identify if a threshold breach occurs.
5. Undertake a final wet season assessment to complete the baseline data collection phase.

At each stage, decision pathways are provided when threshold breaches are identified, including requirements for investigative action and corrective measures where causal factors can be linked to mining activity. Corrective actions, including potential requirement for biodiversity offsets in a worst-case scenario, are discussed in **Section 10**.

Following the two-year baseline assessment, statistical correlation between various assessment parameters will be drawn, particularly the relationship between LAI and NDVI to allow ongoing monitoring to be completed remotely, and trigger thresholds to be adapted. The full suite of parameters collected during the baseline assessment period, with their relevance, intended application in both the baseline assessment and longer-term monitoring program is provided in **Table 5.** Supporting parameters are further discussed in **Section 9.2**. The process that occurs after the two-year baseline assessment will follow the same process as shown in the flowchart in **Figure 14.** Instead of using LAI as a threshold parameter however, NDVI is proposed for use; with the relevant parameter threshold value to be established using the baseline data collected in the previous two years. NDVI will be measured in the dry season at impact and control sites to determine if the threshold is exceeded and, if exceeded, trigger the flow chart process for investigation, mitigation (corrective action) and offsets.

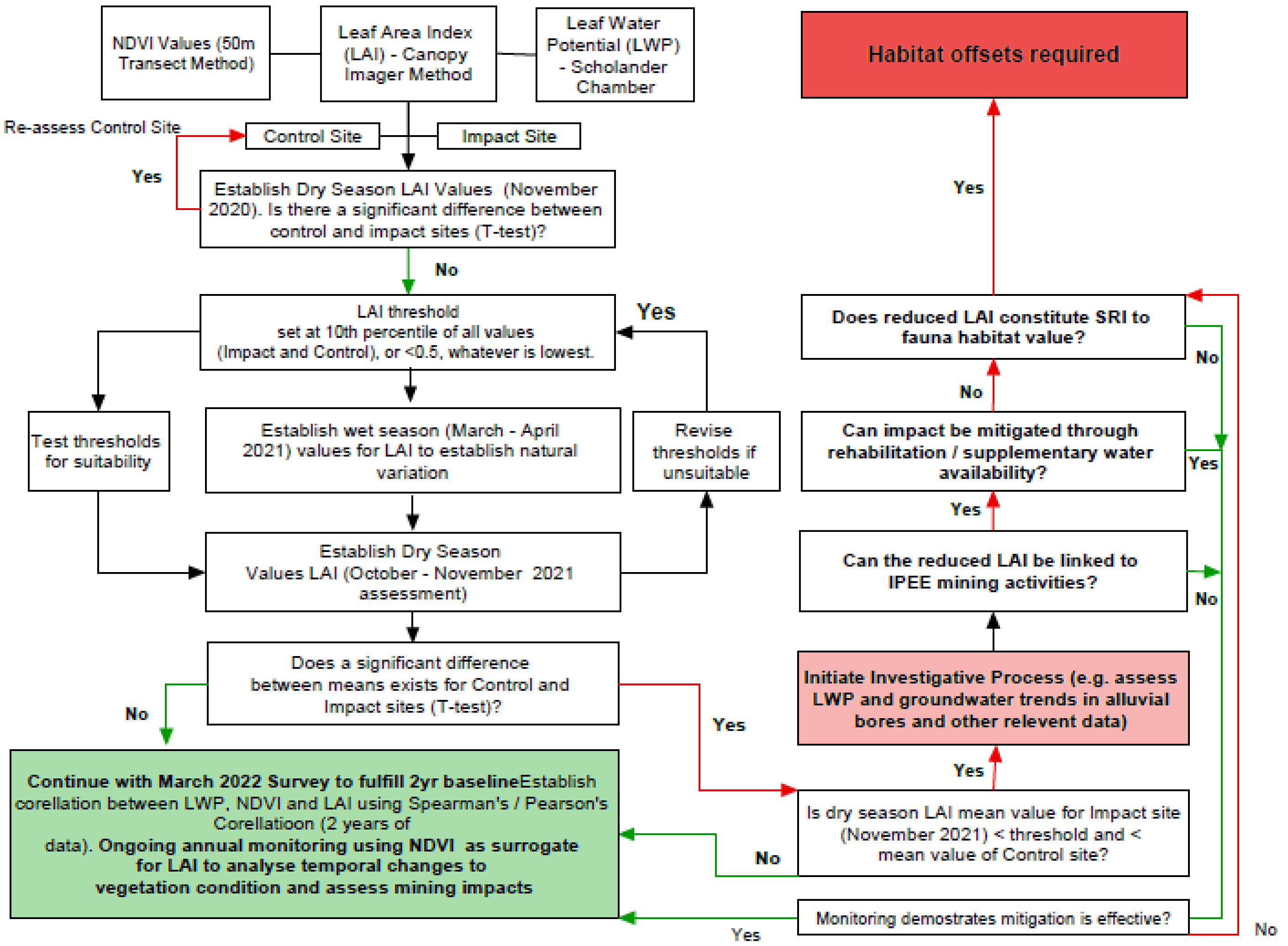

Figure 14. Decision process for application of investigative and corrective actions when trigger thresholds are exceeded for the initial 2-year baseline assessment.

9.2 Supporting Parameters

Supporting parameters are those that will be measured to provide a component of the baseline dataset and will be drawn on to support both the longer-term monitoring program and provide input into investigative action if required. Specifically, these supporting parameters will include LWP, stable isotopes, NDVI and groundwater monitoring in the alluvial aquifer.

9.2.1 Leaf water potential

LWP provides the primary biophysical measure of tree water availability and defines a continuum between the relationship of soil, water, and plant. LWP typically demonstrates a strong positive correlation to LAI and where this relationship breaks down, indicates factors other than water availability may be influencing the relationship (e.g. insect defoliation). LWP measurements established during the two-year baseline will be a fundamental consideration for any future investigative action.

9.2.2 Normalised Difference Vegetation Index

NDVI is a measure of vegetation vigour, including a combination of greenness and biomass, which has a direct positive correlation to LAI. A correlation between field-based measurements of LAI and NDVI will be established over the 2-year baseline period, to allow GDE monitoring to be undertaken remotely at a landscape scale on an annual basis. Upon completion of the two- year baseline, trigger threshold values for investigative action will be calculated based on the correlation between LAI and NDVI, and it is proposed that ongoing annual monitoring will utilise high resolution NDVI as a surrogate for field-based LAI measurements. Further information on the NDVI process is provided in **Appendix B4**.

9.2.3 Stable isotopes

The primary role of stable isotope investigations is to inform how sources of moisture utilised by trees vary on a seasonal basis. The dataset will be used to identify endpoints where vegetation is utilising groundwater alone, shifting in status to primary utilisation of soil moisture in the unsaturated zone. While stable isotope analysis provides insight into site ecological function, allowing risks to GDE function to be characterised, its relevance to ongoing monitoring diminishes once a baseline dataset is established as it is not an indicator of plant health. Stable isotope analyses might be may be applied beyond baseline dataset collection to support investigative actions, allowing status shifts in seasonal water utilisation to be identified.

9.2.4 Groundwater levels and quality

There is no baseline characterisation of the groundwater fluctuations or quality for the Billy's Gully alluvium as construction of the proposed alluvial monitoring bores (BCMB1, BGMB3, BGMB4) is not complete. As the monitoring bores are likely to be seasonally wet, the imperatives of groundwater monitoring at the alluvial bores will be to:

1. Confirm linkages between recharge of the alluvial aquifer and surface flows.
2. Establish the period of saturation, including saturated thickness of the alluvial aquifer and lags in recharge following surface water flows.
3. Identify natural groundwater quality parameters to provide a baseline dataset for comparison to water quality of surface flows.
4. Identify the degree to which the alluvial aquifer is utilised by vegetation (typically through analysis of stable isotopes) on a seasonal basis.

5. Identify ecological response to aquifer recharge including correlations between alluvial aquifer recharge, LAI, LWP, NDVI and climate data.

The baseline dataset for groundwater levels and water quality in the Billy's Gully alluvial aquifer will be developed during the two-year baseline characterisation. Water levels and water quality will be directly correlated to LAI to determine the relationship between groundwater and vegetation health. While Eamus (2006) defines 1500 µS/cm as a measure where salinity becomes toxic to red gum, any impact to the seasonality and water quality of the alluvial aquifer will be directly imparted on LAI and supporting vegetative parameters. Establishing threshold values for water levels and quality in a seasonally variable aquifer will not be meaningful in the absence of longer-term groundwater datasets where seasonality and aquifer recharge rates can be ascertained. Hence thresholds for investigative action that relate to water levels and quality are not proposed in this GDEMMP, which otherwise relies on vegetation indices which are the primary values which define GDE health and any related impacts. Never-the-less data from groundwater monitoring will provide input into investigative action if required.

Table 5. Assessment parameters, application, and analysis.

Data collection method	Purpose	Analysis methods / metrics
Primary Parameter		
LAI	Primary parameter used to measure plant stress and vegetation response to decreasing groundwater.	Threshold to be set at the lower of the 10th percentile for all LAI data from the initial dry season survey of Billy's Gully and control site (or 0.5 from Doody et al 2015), triggered when: 1. T-test indicates significant differences between means of control and impact sites, and; 2. Impact site has a lower mean LAI value. The initial establishment of the trigger threshold will be undertaken in the dry season 2020 and relies on initial means between impact and control sites to be comparable.
Supporting Parameters		
LWP	A measurement of water availability to trees, which will provide an important correlate with LAI and a baseline dataset to support a future requirement for investigative action. Supporting data which can be used to determine if any future LAI threshold trigger events are related to plant water availability.	1. Pearson / Spearman's correlation to establish statistical relation between LAI and LWP as a basis for inclusion in investigative action, if required. 2. Application of a T-test to identify if significant differences between means of control and impact sites exist during the initial dry season assessment.
NDVI	A remotely sensed measurement of vegetation productivity that describes the greenness and the relative density / health of forest biomass.	Confirming the relationship between NDVI and LAI through application of Pearson's / Spearman's correlation. Longer term application to remotely monitor GDE health at completion of the 2yr baseline assessment.

Data collection method	Purpose	Analysis methods / metrics
Stable Isotopes of twig xylem, soil, groundwater and surface water.	Application as a tracer to identify the predominant sources of water utilised by trees. Useful to determine how tree / water interaction varies on a seasonal basis as groundwater levels fluctuate. Most applicable in the baseline characterisation phase though may be useful supporting information if investigative actions are initiated.	Biplot comparisons of stable isotope values (δ18O and δ2H) of tree xylem, groundwater and soil moisture to identify phase shifts.
Groundwater monitoring data	The purpose of monitoring groundwater in the alluvium at Billy's Gully is to: 1. Confirm linkages between recharge of the alluvial aquifer and surface flows. 2. Establish the period of saturation and seasonality. 3. Determine natural groundwater quality parameters. 4. Allow ecological response to aquifer recharge to be identified / quantified.	1. Installation of pressure transducers in the three alluvial monitoring bores to collect information on groundwater levels, fluctuation trends and water level response to rainfall. 2. Water quality measurement associated with routine water sampling schedules. 3. Analysis of water levels and water quality against vegetative indices including LAI and LWP through correlation testing (Pearson / Spearman's).

10.0 Potential Corrective Actions and Adaptive Management

Corrective actions that halt or reverse impacts to GDEs are not well developed in literature and the suggested measures will require trials to determine / confirm their effectiveness. As a starting point, where impacts to GDEs are identified that can be related to mining activities, corrective actions should be taken to ameliorate the source of impact. Where severe, these could include potentially limiting expansion of mining in the area that is contributing to impact whilst further investigation occurs. Corrective actions may include engineering solutions or re-design of surface water and sediment controls.

As the Billy's Gully GDE system is reliant on recharge from surface flows, the most relevant corrective actions will involve surface water management and enhancing its capacity to recharge the shallow alluvial aquifer. Possible mechanism might involve:

1. Minimise mine water catchments that would otherwise report to Billy's Gully
2. Maximising the diversion of clean water from clean water diversions to Billy's Gully. Infiltration may be enhanced by placement of temporary bunding to slow surface water flow.
3. Pumping sediment water from sediment ponds to Billy's Gully if water quality can meets standards to sustain ecosystem health, with salinity being a key driver.
4. Redirect any sediment dam overflows to Billy's Gully upstream of impact, if possible.
5. Direct injection of water, including sediment water that meets water quality objectives, into the rooting zone of trees where impacts are detected to provide site specific amelioration of impacts through increased water availability and /or dilution of groundwater salinity.

These techniques can be trialled in localised areas, most beneficially during a period of extended drought and seasonally dry conditions where impacts on LWP and LAI are likely to be most measurable. The release of water into Billy's Gully must be undertaken in compliance with the EA conditions for surface water release.

While there have been few case studies that have applied direct injection into the root zone, Behrens et al (2009) investigated direct injection of fresh water into a saline aquifer on the Murray and found that while the trial resulted in temporary freshening of the capillary fringe, it had limited influence on tree condition as the radial extent of freshening (approximately 10 m) did not intersect with the root zone of salinity stressed trees. Therefore, application of this technique is likely to be practical for localised areas where impacts are detected in scattered trees or scattered groups of trees rather than application in broader scale impact mitigation.

Forest red gum (*Eucalyptus tereticornis)* is one of the dominant groundwater dependent species occupying the Billy's Gully floodplain and is also the species that is most likely to demonstrate groundwater reliance. The species is ecologically adaptable, occurring on dry hillslopes as well as floodplains and is a significant plantation species. Malik and Sharma (2004) found that the species has a strong capacity to extract moisture from the shallow soil profile (0 – 150cm) in the 426mm rainfall belt and Kallarackel and Somen (1997) identified that growth rates are not necessarily limited by water deficit. Trials using locally sourced forest red gum seedlings should be undertaken to determine:

1. If infill planting of forest red gum in canopy gaps has capacity to ameliorate impacts caused by potential tree dieback.
2. Whether trees that have been planted in dry soil regimes have greater capacity to withstand environmental stressors than older established trees that have adapted over long periods to specific ecological water requirements (EWRs).

It is recommended that small scale trials commence upon approval of the Extension, through planting of forest red gum seedlings into existing canopy gaps on Billy's Gully. This will require some maintenance through drier periods until seedlings have established. Trials do not need to be extensive and should focus on the capacity of the species to survive, through planting of scattered trees into existing canopy gaps. Plantings should be checked for disease and loss of vigour:

1. At least weekly for the first month including any watering requirements to aid establishment.
2. Monthly for the next 5 months, and;
3. Annually following the initial six months, in conjunction with the annual GDE monitoring program.

Where injection of fresh water into the tree root zone is applied as a management measure, the following approach to confirming the effectiveness of the measures should be considered:

4. Measurement of pre-impact LWP and LAI of trees where treatment is applied. Pre-impact canopy health can also be measured using NDVI imagery captured prior to treatment.
5. Repeat measurements for LAI and LWP to be taken at 1month, three months and six months following treatment to measure vegetative response.
6. Ongoing annual monitoring of crown health of individual trees using high resolution NDVI in accordance with annual monitoring program post baseline assessment.

In the absence of positive results from either of these trials, and degradation of GDE habitat on Billy's Gully that can be directly attributed to mining activity, despite implementation of mitigation measures, biodiversity offsets can be considered. Disturbance thresholds for habitat to listed species (identified as likely to occur by EcoSM, 2020) that trigger a requirement for biodiversity offsets should consider the following criteria to determine whether a significant impact has been incurred:

1. Death of dominant canopy trees, to the extent that habitat is converted from remnant to non-remnant vegetation cover as per definition under Queensland's Vegetation Management Act (1999) (i.e. loss of 50% of the original constituent trees or canopy cover).

2. *Loss of foraging resources* to the extent that a significant residual impact is incurred to a threatened species listed under the EPBC Act (as identified by EscoSM, 2020).

Relevant EPBC Act listed species are identified in the *Isaac Plains East Extension – Terrestrial Ecology Impact Assessment* and assessment of the significance of impact should be guided by the proposed habitat quality assessment

The decision-making process which determines the level of action required has been provided in **Figure 14**, which indicates ecological offset as a final measure applied to compensate habitat loss. The management framework is intended to be adaptive, with future capacity for update dependent on the ongoing results of the baseline assessment, and any information gaps identified.

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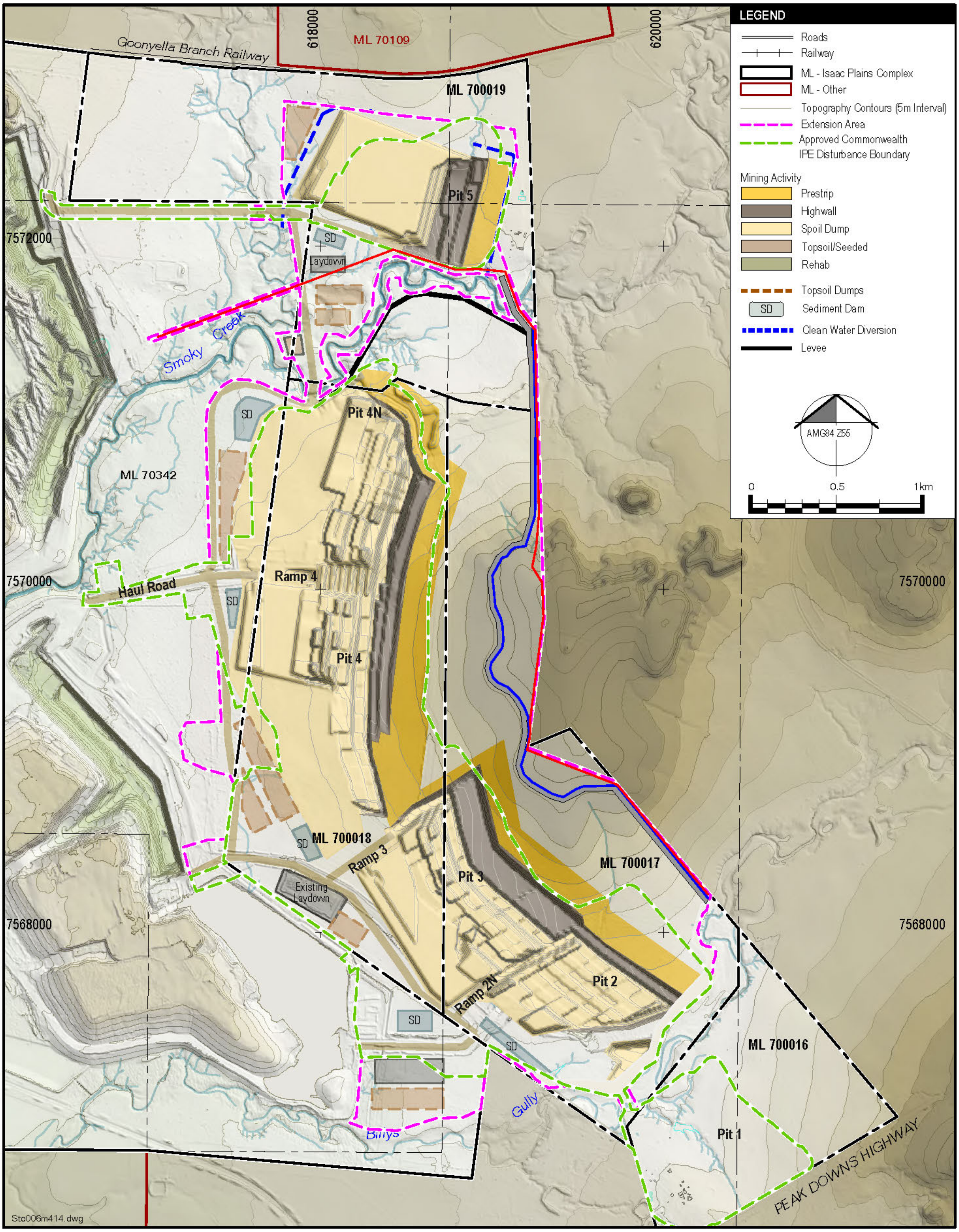
12.0 Appendices

Appendix A. Project Schedule and Timing

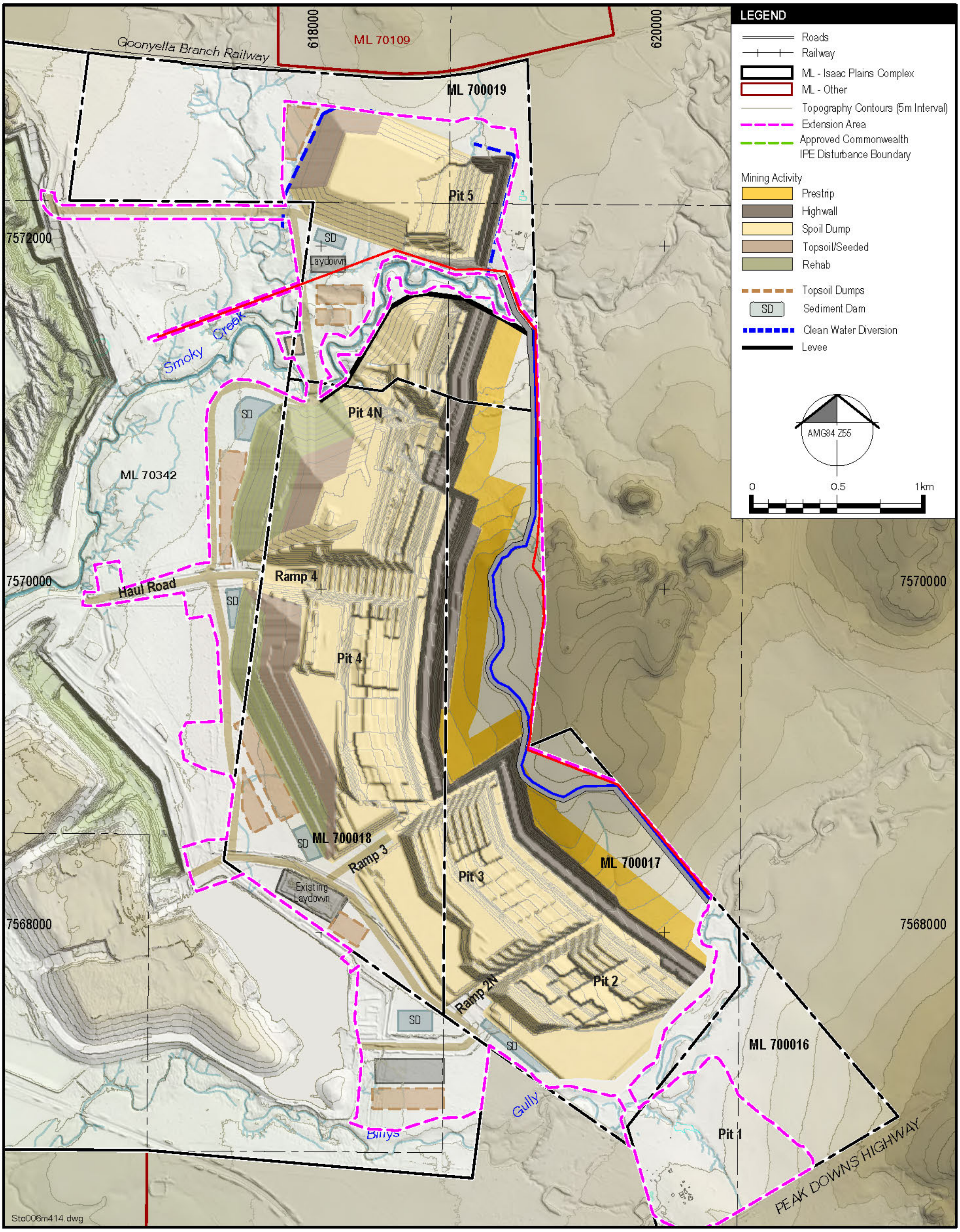


ISAAC PLAINS EAST EXTENSION

Stanmore IP Coal

Mine Stage Plan 2021

Figure 3-14

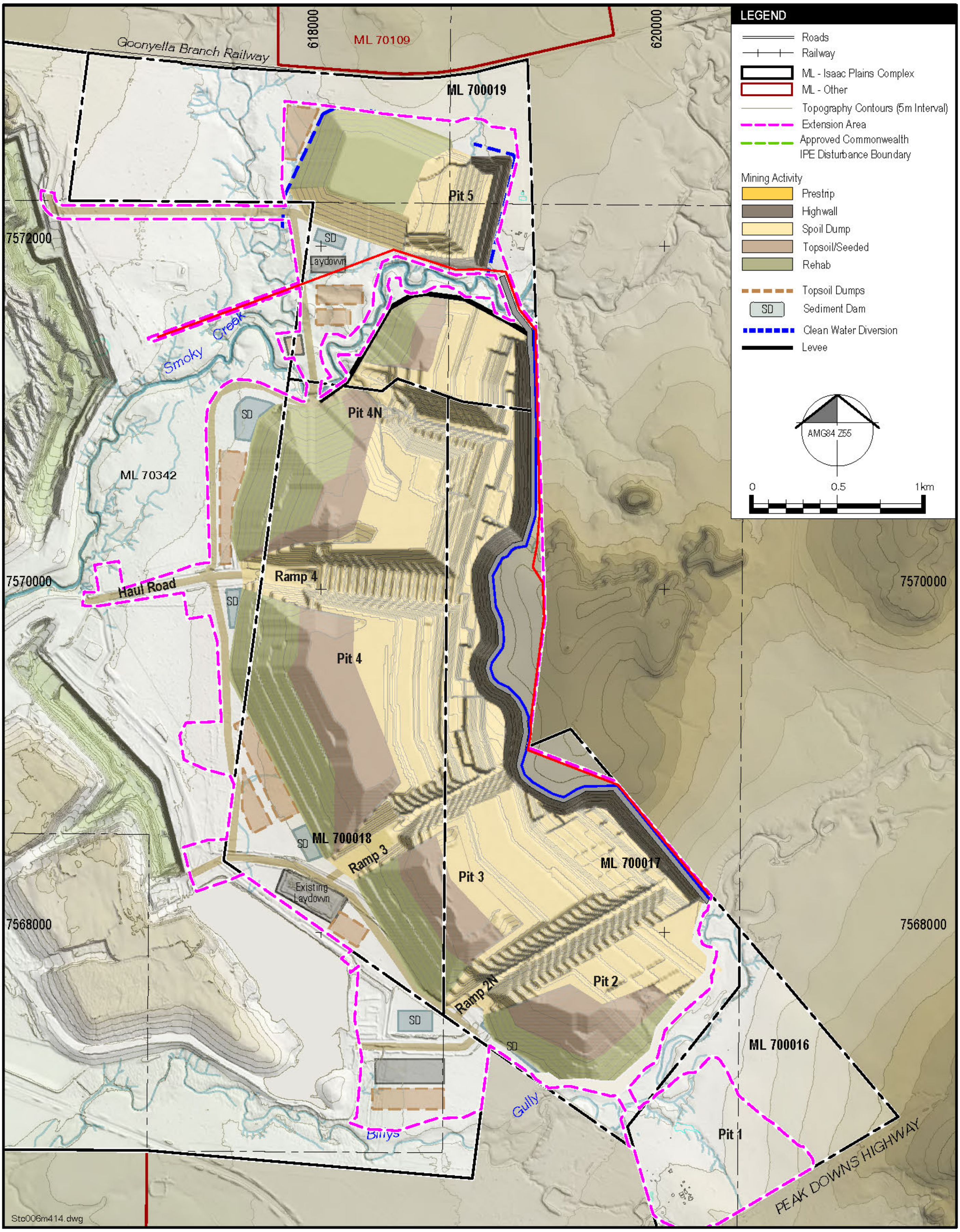


ISAAC PLAINS EAST EXTENSION

Stanmore IP Coal

Mine Stage Plan 2024

Figure 3-15

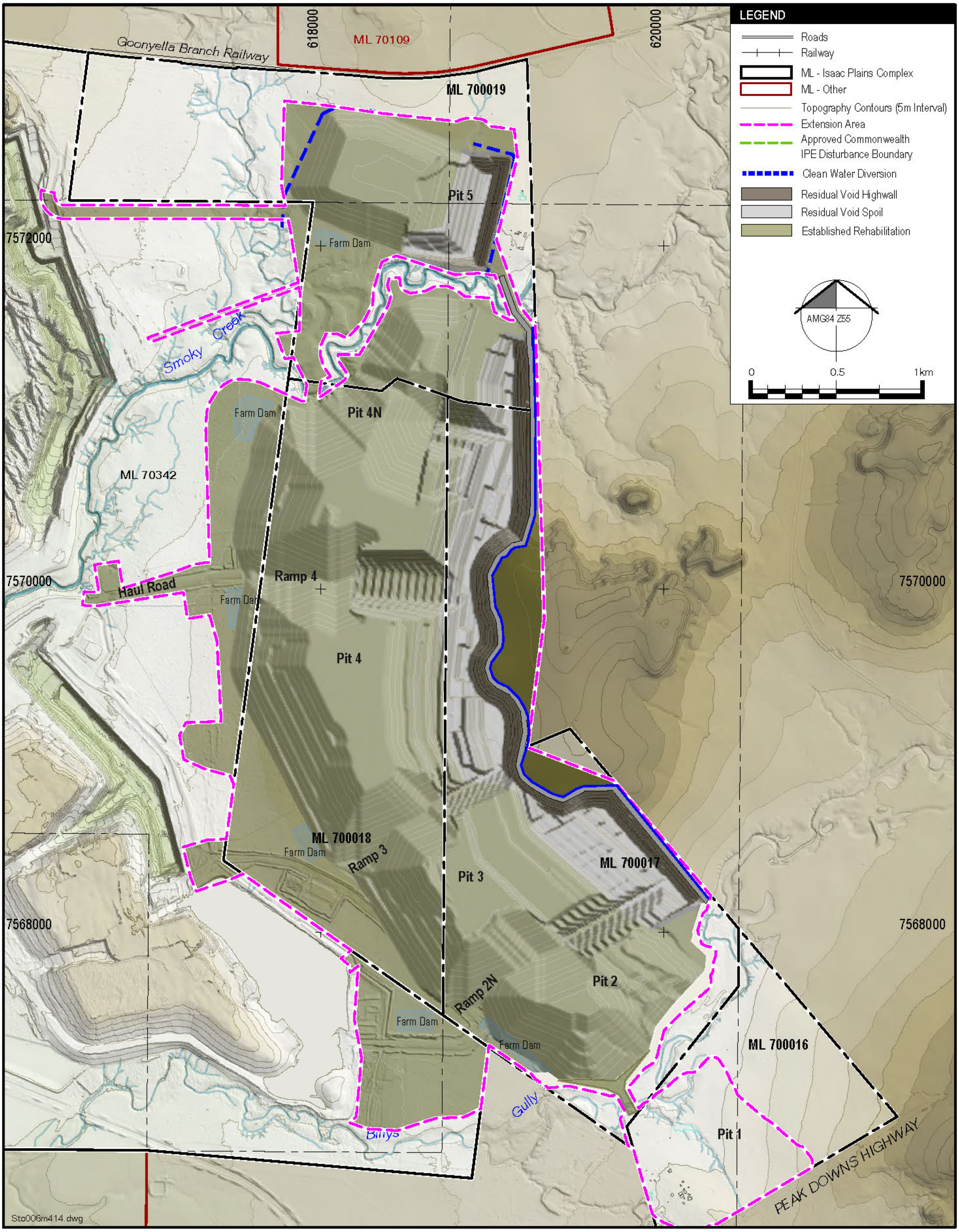


ISAAC PLAINS EAST EXTENSION

Stanmore IP Coal

Mine Stage Plan 2028

Figure 3.16



ISAAC PLAINS EAST EXTENSION

Stanmore IP Coal

IPE Extension Final Landform

Figure 3.17

Appendix B. Sampling Methods

B1. Leaf / Soil Moisture Potential

The measurement of leaf moisture potential will be targeted to specifically assess the interactions between tree roots and soil moisture / groundwater. These measurements will only be undertaken at the all chosen localities on selected trees (as per **Section 7.1.2**) placed specifically to assess for these interactions.

Rationale

Leaf water potential is the total potential for water in a leaf consisting of the balance between osmotic potential, turgor pressure and matric potential. It 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. It is a function of soil water availability, evaporative demand, and soil conductivity.

Measurement of leaf water potential is undertaken by collecting leaf samples at pre-dawn and using a Scholander pressure chamber (pressure bomb) to measure the pressure required to force water from the stem of the leaf. The results of the leaf water potential measurement are then compared to either the soil moisture potential at the same site collected at regular vertical intervals by drilling down to the water table and using a dewpoint potential meter.

It is assumed that trees will be using water from a source that requires the least energy (lowest water potential) to lift water from the soil, through plant xylem to the leaf for transpiration. This will be dependent to a large part on recent rainfall as well as the specific physical attributes of the soil that holds the rooting material. Heavy clays for example, may have a relatively high water content, although this water is hard to extract due to the cohesive forces of the fine particles which hold water very tightly. Clays will thus have a lower water potential than sand which has large pore spaces between the grains and much lower cohesive forces.

It is must also be recognised that trees at the chosen monitoring sites may not be accessing water from one specific source exclusively. Moisture from several horizons within the soil profile may be contributing to tree water requirements, and the predominant source of water may vary on a seasonal basis. To maximise the likelihood of identifying trees that are predominantly using groundwater, it is important that assessments be undertaken in the seasonally driest part of the year.

Methodology

Leaf water potential needs to be measured pre-dawn (prior to sunrise). The basis of this requirement is that pre-dawn measurement provides an estimate of the water potential of the wettest part of the soil profile that contains a significant amount of root matter (Eamus et al 2006a). It is assumed that pre-dawn leaf water potential will equilibrate overnight to the portion of the soil profile that has the highest water potential. Hence contemporaneous measurement of both pre-dawn leaf water potential from a canopy tree at a chosen monitoring locality and soil water potential from selected depth intervals down a co-located borehole will provide an indication of the predominant source of water (soil moisture or groundwater) being utilised by trees at the time of survey.

Measurement of Leaf Water Potential

Leaf water potential is measured pre-dawn (prior to 5.30 am in summer) using a Plant Water Potential Gauge (originally referred to as the Scholander pressure chamber or 'Pressure Bomb'). Measurement of leaf water potential requires:

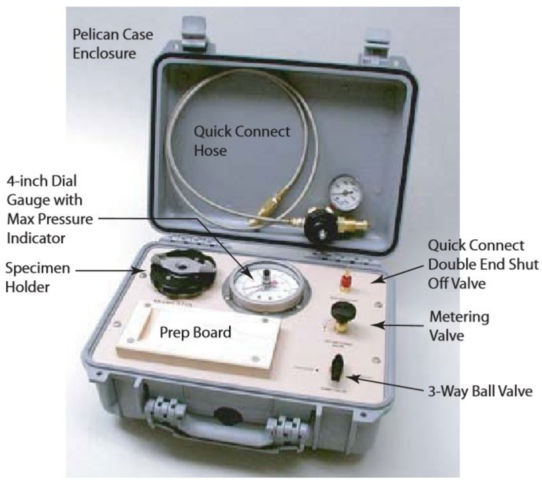
1. Collection of leaves from an accessible part of the tree crown.
2. Preparing of leaf material for insertion into the pressure bomb.
3. Measurement of Leaf Water Potential using the pressure bomb.

Collection of Leaf Material: Leaf material is to be collected from the highest accessible portion of the tree crown using an extension pole and attached lopper head (see **Section 8.5.2.2**). Leaf material should be selected that is disease free (as far as practical) and vigorous, preferably with indications of new leaf growth at the growing tips.

Preparation of Leaf Material: A representative sample of healthy leaf is removed from the collected material with sufficient leaf stem (petiole) to allow it to protrude outside the water potential meter (typically 1 to 2 cm). The stem is cut square with a sharp blade and immediately inserted into the water potential metre with the grommet sealed.

Use of the Plant Water Potential Gauge: The preferred Plant Water Potential gauge is the Model 3115 Plant Water Status Console due to its compactness and portability. The device is manufactured in USA (Soil Moisture Equipment Corp.) and distributed in Australia by ICT International (Armidale). The device fits into a 16 x 13 x 7inch Pelican Case and weighs approximately 11kgs which includes the compressed gas cylinder.

Additional Safety and Operational Measures: The Model 3115 console is accompanied with a detailed unit operation manual which describes in detail the required operational procedures. The unit operates on a compressed gas cylinder which should be professionally refilled with compressed N_2. As pressure is applied to the chamber, there is potential for the leaf petiole to be forcefully ejected from the chamber. Hence safety glasses will be required during unit operation.



A1. Model 3115 Plant Water Status Console with parts description.

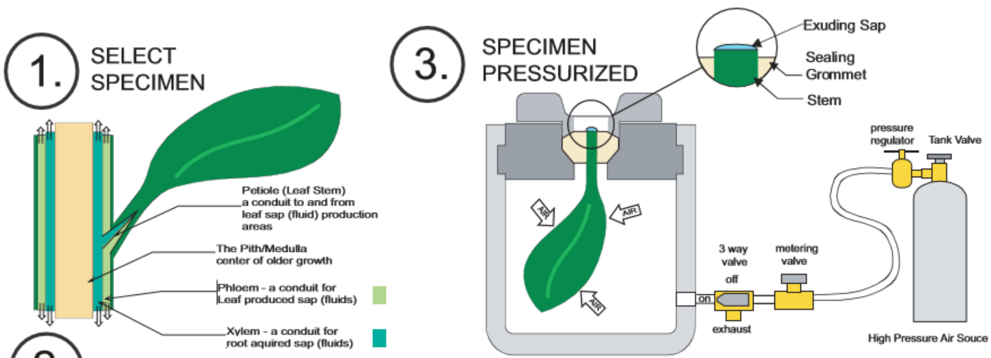
The Water Potential gauge measures leaf or stem water status by the following method:

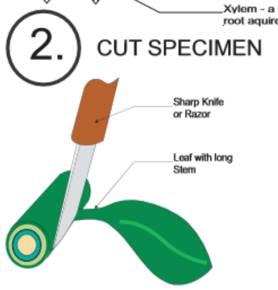
1. A leaf or stem is collected from the tree that is targeted for assessment.

2. The petiole (leaf stem) is cut and placed in the pressure chamber with the cut stem protruding from the chamber at atmospheric pressure.
3. The vessel is sealed around the petiole and pressure applied via an external gas cylinder.
4. The protruding stem is observed and pressure readings recorded at the first point that water is noted to be exuding from the leaf.
5. The positive pressure applied to the leaf that forced water from the leaf stem is measured. This is the leaf water potential.

The process as supplied by Soil Moisture Equipment Corp (2006) is provided in **A2** below.

Step 1: Select a representative sample specimen of the plant with sufficient length to fit into the pressure vessel.





Step 2: Cut the stem close to the plant stalk with a sharp knife or razor.
Step 3: Put the cut leaf into the pressure vessel as quickly as possible to prevent changes from to dehydration, evaporation, etc. Pressurize the vessel and look for exudation of sap from the petiole. At the first indication of exuding sap, stop pressurization and note the pressure at which sap appeared on the cut surface.

A2. Diagrammatic illustration of the use of the Pressure Bomb as per Soil Moisture Equipment Corp. (2006).

Measurement of Soil Water Potential

Soil moisture potential should be measured, utilising a soil auger, in specific cases where results of LWP analysis require additional explanation. This would occur primarily as result of unexpectedly high, or unexpectedly low LWP measurements that cannot be contextualised based on seasonal conditions. The same sampling protocols applied to soil sampling for stable isotopes should be applied to assessment of soil moisture potential. This includes:

1. An initial soil sample taken within the top 10cm of the soil profile.
2. Subsequent sampling at 0.5m intervals down borehole to the top of the Permian basements.
3. Additional measurements taken whenever there is a noted change is soil texture within the soil core (i.e change from clay to sandy clay / loam).

Sampling should be undertaken with a portable hand auger with a maximum expected depth of 5m (BGMB3 is 4.5m depth).

The most convenient method of measuring soil moisture potential is with a portable Dew Point PotentiaMeter which enables measurement to be taken directly on site. Portable devices such as the WP4C uses the chilled mirror dew point technique to measure water potential with the sample being equilibrated with the headspace of a sealed chamber that contains a mirror and a means of detecting condensation on the mirror.

A3. The WP4C Dew Point PotentiaMeter available for hire from ICT International Pty Ltd.

The following protocols are to be followed:

1. A 7ml soil sample is inserted into the sample draw of the potentiaMeter in a 15ml stainless steel sample cup.
2. A soil sample takes between 10 -15mins to analyse.
3. Faster settings (fast mode) should be used for samples with limited water holding capacity such as sand.

The WPC4 unit will require 12V power inverter that plugs into the 12V port of a vehicle if measurements are to be taken in the field. Alternatively, samples can be collected in a sealed sample bag (with air removed) and measurements taken in an office or other areas where there is a reliable power source. The inverter should have a continuous output of at least 140 Watts.

Outputs

The water potential assessments of both leaf (target tree at site) and soil (from soil core) will provided the following data outputs:

1. Pre-dawn leaf water potential measurements of canopy / sub-canopy leaf samples taken with the Pressure Bomb (3115 unit). The output unit will be provided in MPA.
2. Soil moisture potential taken with the portable WPC4 Potentiometer at standard intervals along the drillhole core. The unit output will be measured in MPA consistent with leaf moisture potential. The intervals for measurement will be:
    a. Top 10cm of the soil profile.
    b. At 0.5m intervals from the soil surface to the top of the phreatic zones.
    c. Where noticeable changes in soil texture or moisture content are noted during examination of the core.

The interval for measurement is purposefully coincident with the interval applied to soil sampling for stable isotopes. This will allow for more ready comparison of the results between differing sampling methods and applications.

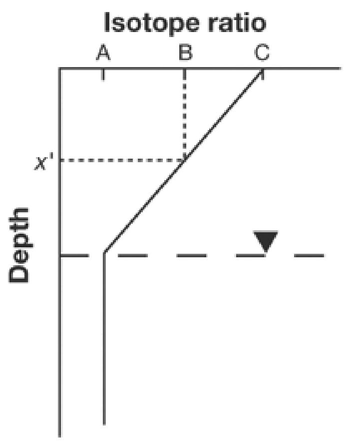
B2. Stable Isotope Analysis

The overarching aim of stable isotope analysis is to determine the degree to which trees utilise groundwater on either a permanent or seasonal basis. It will be applied during the initial phase of the baseline assessment to determine seasonal sources of moisture usage by selected trees, to be phased out once baseline water utilisation patterns are established (minimum of 2 years).

Rationale

Trees may utilise water from a range of sources including the phreatic zone, the vadose zone and surface water and the stable isotopes of water, oxygen 18 (18O) and deuterium (2H) may be a useful tool 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 concentrations in the various sources of water including potential artesian water sources, and shallow soil moisture. The heavier isotopes of 18O and 2H fractionate differently to the lighter isotopes equivalents (16O and 1H). Rainfall has a typically large δ18O and δ2H as it is formed through the process of condensation which concentrates heavier isotopes. Surface water may have an extremely high δ18O if it is subject to a period of strong evaporation, whilst isotopic composition of groundwater will vary dependent on the input source, although tends to be relatively stable as it is not exposed to processes of fractionation.

The isotopic signature of water measured in a trees xylem may result from a combination of sources with varying signatures. As per **A4** from Eamus et al (2006a) below, if an isotopic signature of 'A' is recorded, then water is being sourced from the phreatic zone, and for 'C' at the surface. If an isotopic signature of 'B' is recorded, this may represent water sourced from the middle of the vadose zone (at depth x), or may be a combination of water from a deeper phreatic source (A) or a shallow source (B). Hence there is potential for considerable uncertainty when mixed isotopic signatures occur and it may be necessary to apply a linear mixing model to aid the interpretation (as per Thorburn et al, 1993).



A4. Schematic representation of isotope ratios within soil and groundwater and application in identifying plant water sources (from Eamus et al. 2006a).

For a robust application of stable isotopes signatures obtained from plant xylem and soil pore spaces, the following general protocols should be observed:

1. Sampling of plant and soil material will need to be completed during a single sampling event to ensure the results are directly comparable.
2. Sampling of plant xylem material would be completed most effectively from twigs as leaves have tendency to concentrate isotopic concentrations during the process of transpiration and evaporation and hence should not be used. Twigs should be sampled during periods of active transpiration.
3. Persistence of groundwater dependency is best completed following a period of extended drought / dry conditions to maximise the potential that plants are utilising groundwater sources.
4. Sampling of soil pore water should be undertaken at consistent intervals throughout the vadose zone (the unsaturated zone above the groundwater table) down to the groundwater table. Soil samples are to be collected to the depth of the saturated zone or consolidated bedrock (whichever comes first). Sampling needs to extended beyond the saturated zone to consolidated bedrock in the case that a perched aquifer is identified.

Methodology

Sampling of Soil Pore Water for Stable Isotopes

Method: Soil sampling is to be undertaken at regular intervals along a retrieved soil core to capture signatures for possible isotopic end points (ground water and surface water) and a range of potential plant moisture sources within from the upper soil surface to the top of the phreatic zone. Mensforth et al (1994) completed soil sampling at 0.1m increments to 0.4m depth; 0.2m increments to 2m depth and 0.5m increments to the groundwater surface while others such as O'Grady et al (2006) applied sampling interval of 0.5m down the entire profile. The proposed sampling interval for this assessment is:

1. Initial soil sample taken within the top 10cm of the soil profile.
2. Subsequent soil sampled taken at 0.5m intervals down borehole to the top of the phreatic zone.
3. Additional soil samples take whenever there is a noted change is soil texture within the soil core (i.e change from clay to sandy clay / loam).

Soil sampling should be continued until either the unconfined groundwater table is intersected or the top of the Pleistocene surface halts auger penetration.

Soil sampling protocols: The following protocols for soil sampling are to be applied based on advice from ANU Stable Isotope Laboratory:

1. A minimum 50ml equivalent of soil is to be collected for each sample to be analysed.
2. Samples are to be immediately sealed to prevent evaporation in an airtight container (double bagging recommended).
3. Samples are to be labelled with the drill hole number and sampling depth / interval in a consistent format to aid data entry and recognition
4. Samples are to be kept on ice and transported to a freezer for temporary storage prior to dispatch to the laboratory (at the completion of each hole).
5. Frozen samples are to be dispatched in an a sealed (as airtight as possible) esky via overnight courier.

Equipment: The following equipment will be required by the site geologist / ecologist.

1. Stainless steel spatula for sample collection (paint scraper of putty knife sufficient).
2. Tape measure (15m extendable steel builders measure).
3. Sealable polypropylene containers (30 to 70ml adequate)
4. Permanent marking pens.
5. Esky for sample storage and dispatch.
6. A chest freezer will need to be accessed off site for storage.

Sampling of Xylem Water for Stable Isotopes

This will require twigs to be collected from the outer branches of mature Red Gum (or Poplar Box) trees that are the subject of the assessment. It is anticipated that up to 4 twig samples will be collected from individual trees directly adjacent to the assessment locality. At each site, the following sampling protocols should be observed:

1. Outer branches of up to four trees, including the central tree at the assessment locality plus three adjacent trees are to be harvested for twig material.
2. Trees subject to assessment are to be marked with a GPS.
3. Outer branches from each tree will be harvested using an extendable aluminium pole and lopping head. The longest commercially available extension pole is 7.5m giving a maximum reach of approximately 10m.
4. Stem material that is the equivalent to one joint length of the small finger should be sourced (based on advice from ANU). Hence collected branches should contain some stem diameters of at least 10mm.
5. Selected stems are to be cut into maximum 5cm lengths and the bark stripped. One to two stems of 10mm diameter stems will be sufficient although more material will be required for smaller diameter stems.
6. Stems are to be sealed in wide mouth sample containers with leakproof polypropylene closure.
7. Samples should be immediately labelled with the tree number and placed in an iced storage vessel before being transported to a freezer for temporary storage prior to dispatch to the laboratory (at the completion of each hole).
8. Frozen samples are to be dispatched in an a sealed (as airtight as possible) esky via overnight courier.

Equipment: The following equipment will be required by the site geologist / ecologist.

1. An extendable 7.5m aluminium pruning pole with an attached lopper head.
2. High quality secateurs for cutting stem material.
3. 125m wide mouth sample containers with a polypropylene seal cap (up to 16 required).
4. Permanent marking pens.
5. Esky for sample storage and dispatch. May be included with the frozen soil samples.
6. A chest freezer will need to be accessed off site for storage.

Groundwater sampling for stable isotopes

Method: Groundwater samples are to be collected from each groundwater monitoring bore using the low flow method. Groundwater sampling will follow methods described in the Geosciences Australia *Groundwater Sampling and Analysis – A Field Guide* (Sundaram, et al., 2009). Care should be taken not to oxygenate or agitate the sample during pumping or sample collection.

Samples for analysis of stable isotopes should be collected in laboratory prepared 28ml glass McCartney bottles or 15ml Vacutainers and kept cool during storage and transport.

Sample Despatch and personnel

Personnel: Samples are to be collected, bagged and stored by the supervising geologist / ecologist who will also be responsible for the sample dispatch to the receiving laboratory

Dispatch: Samples are to be dispatched directly to the ANU Stable Isotope Laboratory (address provided below).

Hilary Stuart-Williams
Stable Isotope Laboratory
Research School of Biology
R.N. Robertson Building (46)
The Australian National University Canberra ACT 0200 Australia

B3. Field Based Assessment of Leaf Area Index

Leaf Area Index (LAI) is a ratio of the total leaf area within a canopy to the ground area covered by the canopy. It is a measure of canopy vigour and the rationale applied is that plants with access to permanent sources of water (i.e. groundwater) will have greater vigour and hence LAI than vegetation that has only periodic access to groundwater resources (e.g. Zolfagher 2014). If a previous permanent groundwater resource is withdrawn (as might occur in a CSG operation), then leaf fall will occur, and LAI will decrease.

Measurement of LAI is typically completed with a hemispherical lens, is labour intensive and utilises specialised software to analyse foliage cover. The CI-110 Plant Canopy Analyzer provides a self-leveling, wide-angled lens to capture hemispherical photographs for the analysis of leaf area index (LAI) and gap fraction analysis and photosynthetically active radiation (PAR). This instrument is integrated with the corresponding software program, and a GPS, allowing for fast and simple analysis, with immediate data available on site including:

- Leaf area index (LAI)
- Leaf angle distribution
- Extinction coefficients
- PAR LAI

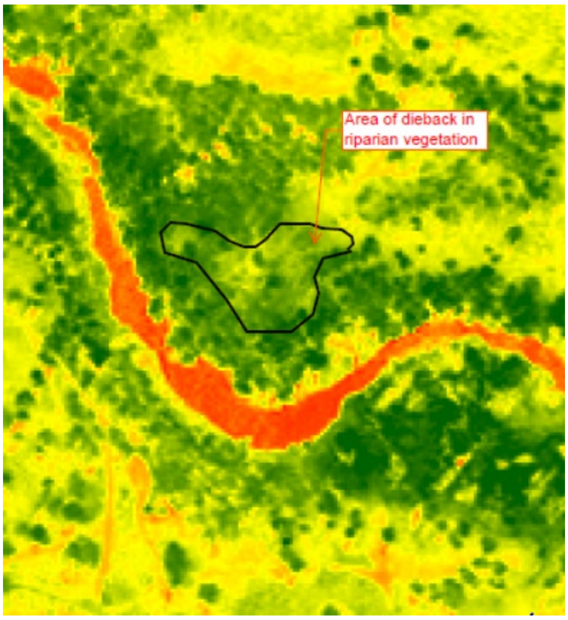
The units provides considerably greater accuracy in LAI measurement than standard hemispherical cameras and is time saving due to the immediate access of data.

The CI-110 Plant Canopy Analyzer is will be utilised during monitoring events which require calculation of LAI.

B4. Remote Sensing Methods

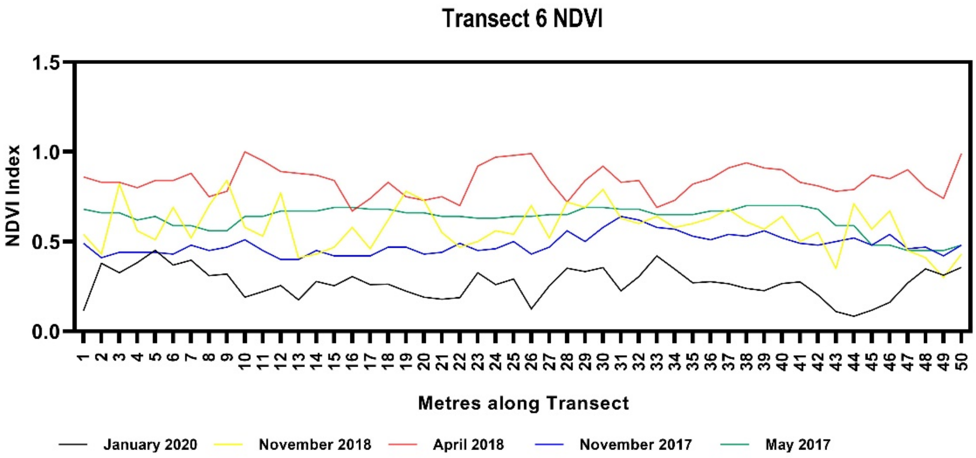
There are remote sensing based assessments used to calculate LAI (TERRA and AQUA satellites), although the spatial resolution of at 250 m x 250 m is not going be useful for the application, due to the fragmented nature of the landscape with large areas of clearing interspersed amongst native woodland.

Recent availability of high- resolution satellite imagery (WorldView-3/WorldView-2 and GeoEye-1; 0.5m Resolution 4-band Pan / WorldView 3 and WorldView 4 satellites; 0.3m resolution, 4 -16 band multispectral) provides an advanced capacity to monitor the health of individual trees if required. Assessment utilises the Normalised Difference Vegetation Index (NDVI) as a measure of canopy health and vigor. The strength of the assessment is that it enables the health of riparian (and other GDE) vegetation to be monitored across the entire landscape, rather than just a limited number of individual sites. The landscape-scale capability also has an ability to overcome issues surrounding a lack of site access and provides a long-term monitoring record of vegetation health that can be utilised as reference when a need arises. Capture can be undertaken reactively and can be tasked with a days' notice, providing weather, particularly cloud cover is amenable. An example of high resolution NDVI Imagery showing dieback in riparian vegetation is provided in **A7** (capture date May 2017).



A7. Healthy vegetation in bright green grading to bare ground and water in red. Area of recent canopy dieback is indicated (from Worldeye 1, 0.5m imagery).

Measurements of NDVI values at set intervals along permanently established transects also provides a quantifiable and easily rectifiable measure of vegetation productivity that can be undertaken on a seasonal basis. This would form a component of the baseline dataset against which trends in vegetation productivity and fluctuations in groundwater regime can be correlated to LAI. Figure A8 provides an example of a vegetation transect that that has been monitored for vegetation production for period of years, showing the strong decrease in vegetative productivity between May 2017 and January 2020.



A8. Seasonal variations in vegetation productivity, measured using NDVI, showing a decrease in vegetation health over a 2.5yr sampling period for a permanent monitoring transect in the Surat Basin.

B5. Groundwater Monitoring Bores

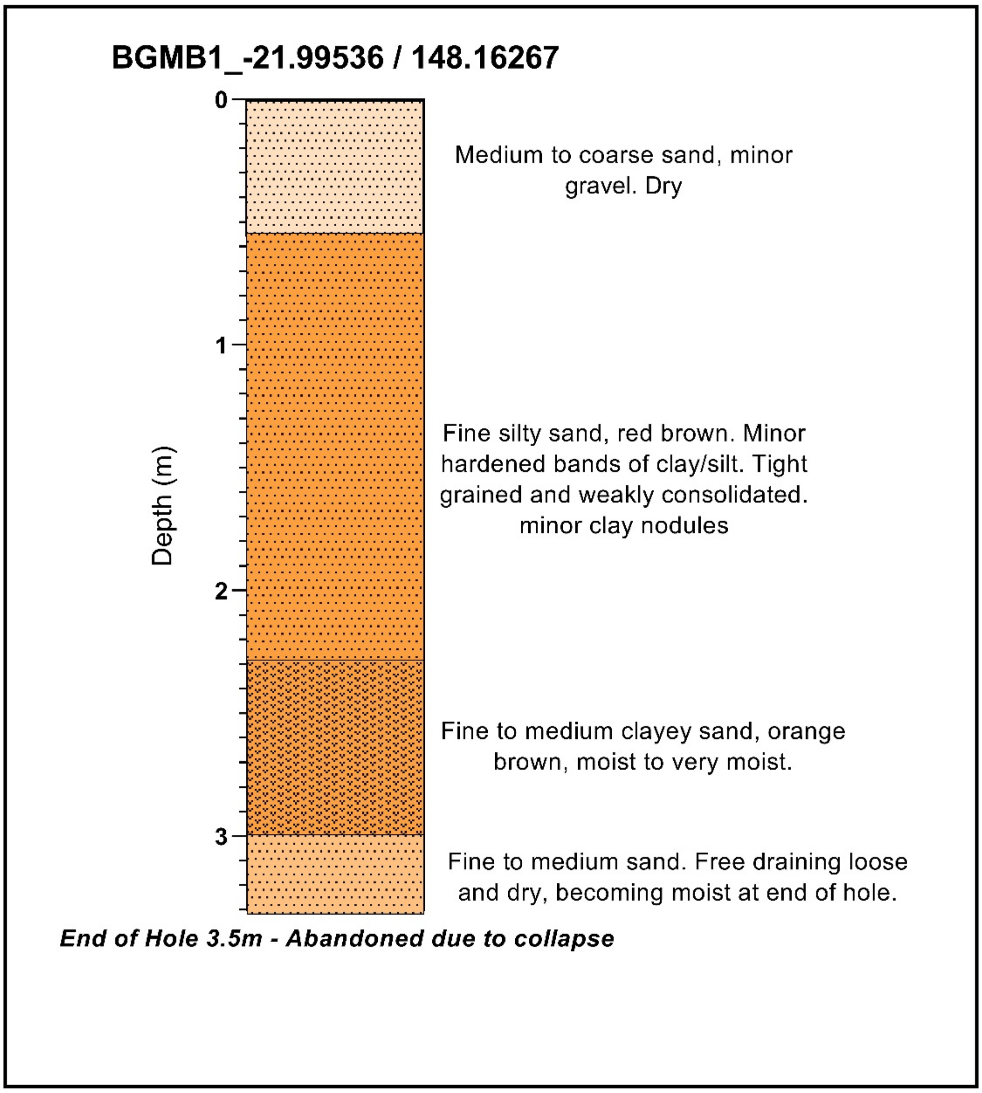
Drilling and construction of groundwater monitoring bores at a minimum of 3 selected localities and installation of pressure transducers to collect information on groundwater levels, fluctuation trends, water level response to rainfall and/or surface water recharge, hydrogeologic characteristics of shallow aquifers.

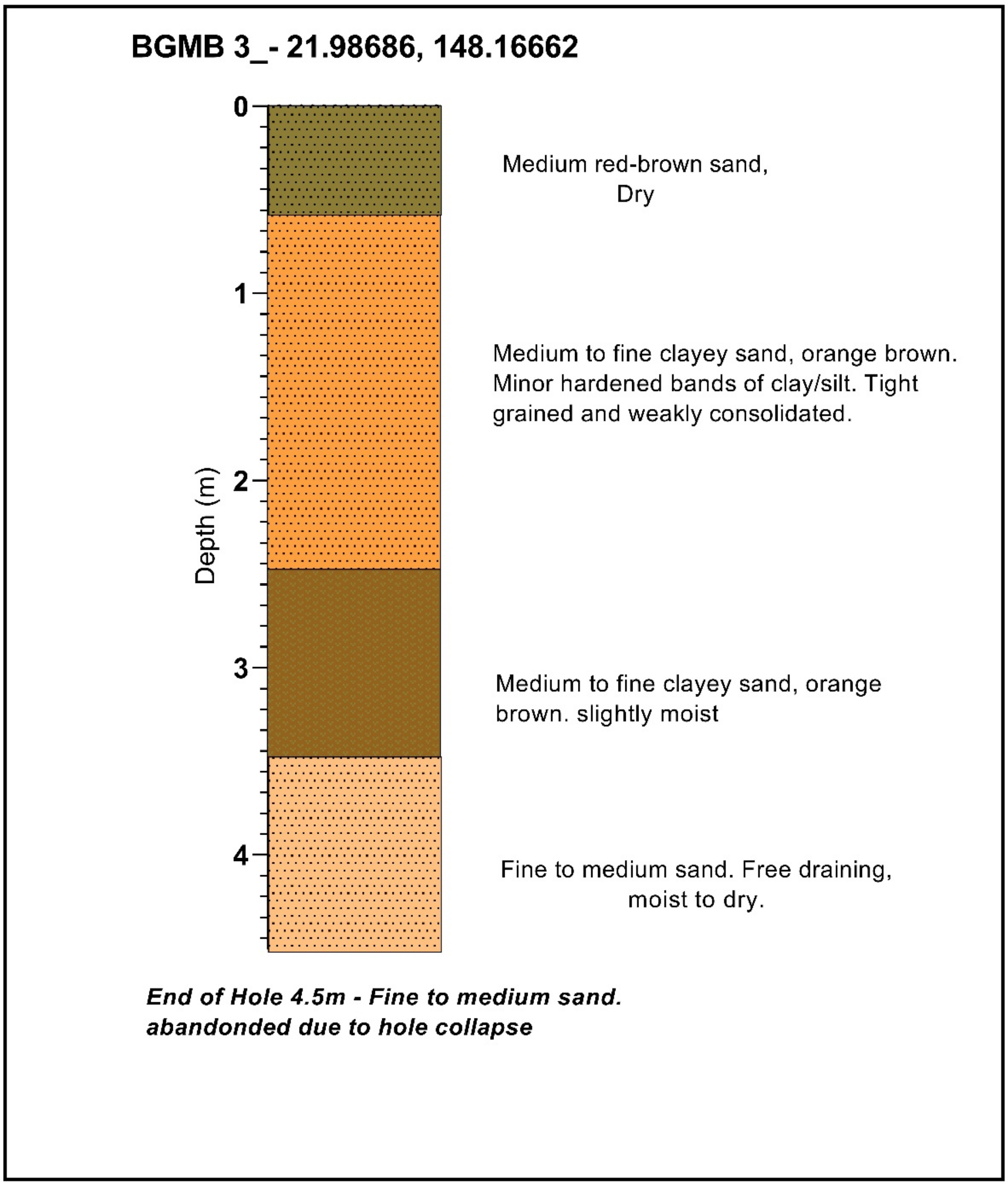
Installation of groundwater monitoring bores targeting shallow aquifers and screened across the water table, or level of the ephemeral water table will provide robust and site-specific data after a period of monitoring. To improve the robustness of this assessment method:

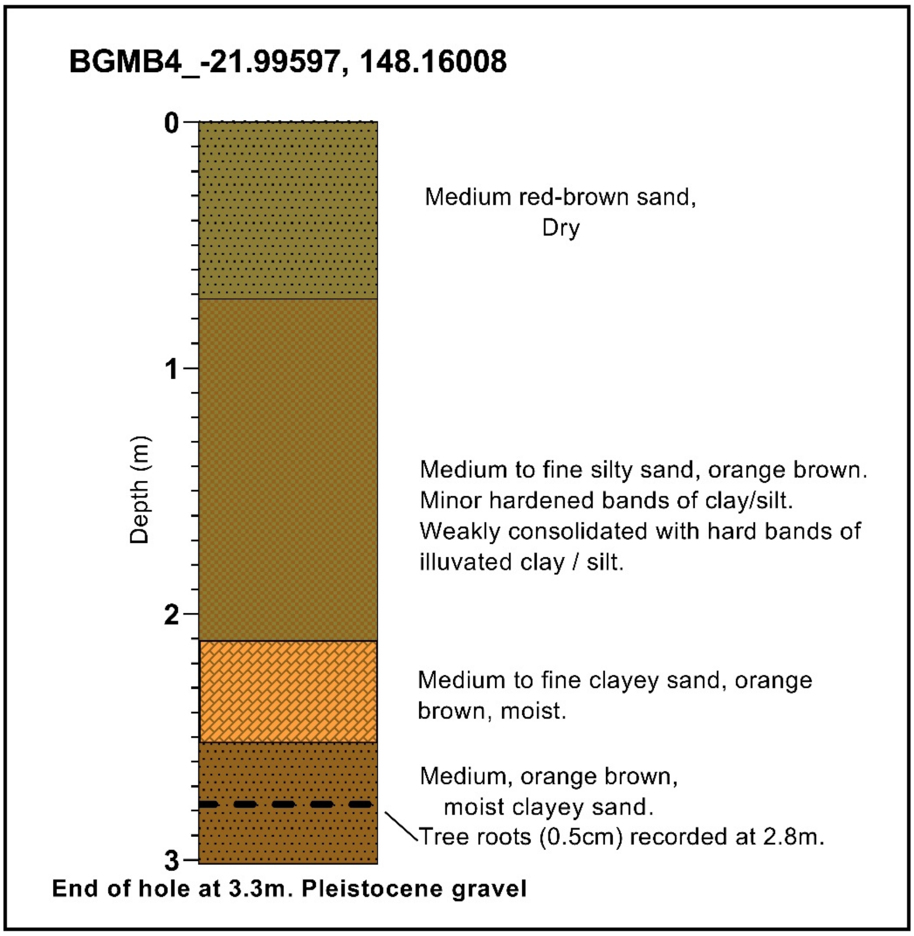
1. A barometric logger should be installed in the well, and weather recording stations should also be in proximity to assess daily and seasonal climate trends.
2. A survey should also be undertaken of ground level and top of monitoring bore casing levels at each monitoring site, preferably combined with levels of nearby surface water features and monitoring sites.

Diurnal changes in groundwater can provide an indication of groundwater use by vegetation accessing the capillary zone as identified by daily groundwater hydrographs. The method is only applicable in shallow unconfined aquifers. The seasonality of the unperched water table needs to be considered and there is likely to be a significant period when monitoring wells remains dry.

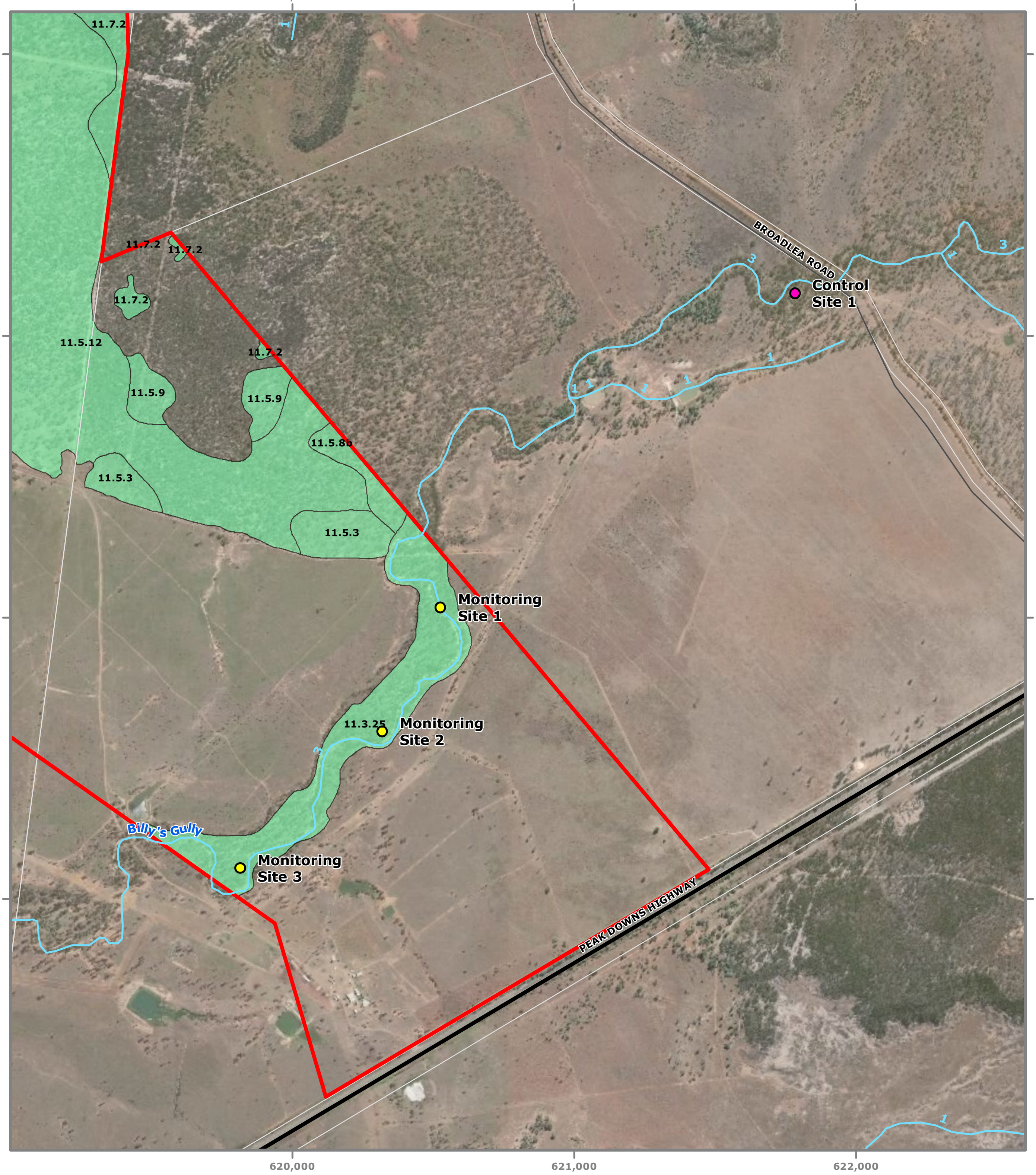
Logs from sites that were assessed for the suitability of groundwater monitoring bores in the Billy's Gully alluvium are provided.


BGMB1_-21.99536 / 148.16267
Depth (m)
0
1
2
3
Medium to coarse sand, minor gravel. Dry
Fine silty sand, red brown. Minor hardened bands of clay/silt. Tight grained and weakly consolidated. minor clay nodules
Fine to medium clayey sand, orange brown, moist to very moist.
Fine to medium sand. Free draining loose and dry, becoming moist at end of hole.
End of Hole 3.5m - Abandoned due to collapse


BGMB 3_- 21.98686, 148.16662
0
1
2
3
4
Depth (m)
Medium red-brown sand,
Dry
Medium to fine clayey sand, orange brown.
Minor hardened bands of clay/silt. Tight
grained and weakly consolidated.
Medium to fine clayey sand, orange
brown. slightly moist
Fine to medium sand. Free draining,
moist to dry.
End of Hole 4.5m - Fine to medium sand.
abandonded due to hole collapse


BGMB4_-21.99597, 148.16008
0
1
2
3
Depth (m)
Medium red-brown sand,
Dry
Medium to fine silty sand, orange brown.
Minor hardened bands of clay/silt.
Weakly consolidated with hard bands of
illuvated clay / silt.
Medium to fine clayey sand, orange
brown, moist.
Medium, orange brown,
moist clayey sand.
Tree roots (0.5cm) recorded at 2.8m.
End of hole at 3.3m. Pleistocene gravel

Appendix C. Proposed habitat quality monitoring sites proposed for the Billy's Gully GDE System.



Legend

Project Site

Highway

Street/Local Road

Vegetation Management Act Watercourse

Cadastral Boundary

Field-validated Vegetation Mapping

Remnant Vegetation

Least concern

Site Locations

Monitoring Site

Control Site

Figure 1 : Monitoring site locations

Isaac Plains East Project

Map Number: 20014_MPL_01_A
Date: 18 September 2020
Map Projection: GDA 1994 MGA Zone 55
Imagery: Digital Globe
Data: Roads, Watercourse, DCDB - (c)DNRM 2016

0 0.5 1
Kilometres

N

Appendix D. Suggested GDE Monitoring Program for Initial Two Years

Event	Timing	Areas for Monitoring	Parameters Measured	Additional Datasets / Techniques Recommended	Other Interacting Monitoring Datasets	Outputs
Monitoring Survey 1	Dry Season (October to December 2020)	• Billy's Gully GDE Assessment Area • Billy's Gully Control	• LWP • Stable isotopes (trees and selected auger sites if required). • Leaf Area Index	NDVI Imagery to coincide with the survey.	Groundwater monitoring data from shallow alluvium monitoring bores (water quality and data from pressure transducers). Rainfall and climate data from automated weather station.	GDE Monitoring Report- Monitoring Event 1.
Monitoring Survey 2	Wet Season (February to April 2021)	• Billy's Gully GDE Assessment Area • Billy's Gully Control	• LWP • Stable isotopes (trees and selected auger sites if required). • Leaf Area Index	NDVI Imagery to coincide with the survey	Groundwater monitoring data from shallow alluvium monitoring bores (water quality and data from pressure transducers). Rainfall and climate data from automated weather station.	GDE Monitoring Report- Monitoring Event 2.
Monitoring Survey 3	Dry Season (October to December 2021)	• Billy's Gully GDE Assessment Area • Billy's Gully Control	• LWP Stable Isotopes (Trees and Selected Auger Sites if required). • Leaf Area Index	NDVI Imagery to coincide with the survey	Groundwater monitoring data from shallow alluvium monitoring bores (water quality and data from pressure transducers). Rainfall and climate data from automated weather station.	GDE Monitoring Report- Monitoring Event 3.
Monitoring Survey 4	Wet Season (February to April 2022)	• Billy's Gully GDE Assessment Area • Billy's Gully Control	• LWP Stable Isotopes (Trees and Selected Auger Sites if required). • Leaf Area Index	NDVI Imagery to coincide with the survey	Groundwater monitoring data from shallow alluvium monitoring bores (water quality and data from pressure transducers). Rainfall and climate data from automated weather station.	GDE Monitoring Report- Monitoring Event 4.
2 Year GDE Monitoring Review						
2 Year Review - Baseline GDE Monitoring Assessment	At completion of Monitoring Survey 4	NA	NA	NA	NA	– Compilation of data from all surveys – Analysis of baseline ecohydrological function of

Event	Timing	Areas for Monitoring	Parameters Measured	Additional Datasets / Techniques Recommended	Other Interacting Monitoring Datasets	Outputs
						Billy's Gully GDE sites – Correlation between LAI and NDVI (plus other parameters) to provide a baseline for ongoing annual vegetation monitoring.

Appendix E. Raw Data from IPEE PER Assessment for Billy's Gully (LWP and Stable Isotopes)

Tree Number	Species	X	Y	Height (m)	DBH (cm)	LWP_Bar 1	LWP_Bar 2	LWP_Bar 3	LWP Mean Bar	LWP Mean MPa	Tree Water Availability	Notes
IP4_T1a	*Eucalyptus tereticornis*	-21.992389	148.164007	25	85	2	1.5		1.75	-0.175	Extremely High	On sandy flood plain adjacent to main drainage channel
IP4_T1	*Eucalyptus tereticornis*	-21.994953	148.163268	25	100	3	3		3	-0.3	Extremely High	On sandy flood plain adjacent to main drainage channel
IP4_T2	*Eucalyptus tereticornis*	-21.995026	148.163309	20	160	2	2		2	-0.2	Extremely High	On sandy flood plain adjacent to main drainage channel
IP4_T3	*Eucalyptus tereticornis*	-21.995529	148.162382	20	60	2	2		2	-0.2	Extremely High	On sandy flood plain adjacent to main drainage channel
IP4_T4	*Eucalyptus tereticornis*	-21.995801	148.161715	18	130	2	1.5		1.75	-0.175	Extremely High	On sandy flood plain adjacent to main drainage channel
IP4_T5	*Eucalyptus tereticornis*	-21.995883	148.161078	20	100	3	2		2.5	-0.25	Extremely High	On sandy flood plain adjacent to main drainage channel
IP4_T6	*Eucalyptus tereticornis*	-21.995791	148.159654	23	70	2	1.5		1.75	-0.175	Extremely High	On sandy flood plain adjacent to main drainage channel
IP4_T7	*Eucalyptus tereticornis*	-21.995607	148.159483	22	80	1.5	3	2	2.125	-0.2125	Extremely High	On sandy flood plain adjacent to main drainage channel
IP4_T8	*Eucalyptus tereticornis*	-21.995512	148.159073	20	70	2	2.5		2.25	-0.225	Extremely High	On sandy flood plain adjacent to main drainage channel
IP4_T9	*Eucalyptus tereticornis*	-21.995501	148.158623	25	55	2.5	3	3	2.75	-0.275	Extremely High	On sandy flood plain adjacent to main drainage channel

Sample 2	Site	Material	Depth	δ²H	δ¹⁸O
IP4_AU1_0.1	IP4	soil	0.1	-31.97	-4.26
IP4_AU1_0.5	IP4	soil	0.5	-45.74	-7.23
IP4_AU1_1.0	IP4	soil	1	-42.52	-6.67
ip4 au1 1.35	IP4	soil	1.35	-37.95	-6.02
IP4_AU1_1.6	IP4	soil	1.6	-35.91	-5.53
IP4_AU1_1.75	IP4	soil	1.75	-33.25	-4.70
IP4_AU1_2.0	IP4	soil	2	-38.29	-6.32
IP4_AU2_0.1	IP4	soil	0.1	-40.98	-6.53
IP4_AU2_0.5	IP4	soil	0.5	-43.38	-7.89
IP4_AU2_0.5	IP4	soil	0.5	-41.61	-7.01
IP4_AU2_0.75	IP4	soil	0.75	-37.41	-5.64
IP4_AU2_1.0	IP4	soil	1	-43.96	-7.12
IP4_AU2_1.35	IP4	soil	1.35	-41.80	-6.91
IP4_AU2_1.75	IP4	soil	1.75	-36.30	-5.38
IP4_AU2_2.25	IP4	soil	2.25	-43.55	-6.54
IP4_T1	IP4	twig	NA	-25.48	-3.85
IP4_T2	IP4	twig	NA	-27.44	-4.37
IP4_T3	IP4	twig	NA	-35.38	-4.91
IP4_T4	IP4	twig	NA	-41.84	-4.65
IP4_T5	IP4	twig	NA	-28.85	-4.81
IP4_T6	IP4	twig	NA	-31.55	-4.37
IP4_T7	IP4	twig	NA	-28.63	-3.96
IP4_T8	IP4	twig	NA	-23.32	-2.33
IP4_T9	IP4	twig	NA	-34.80	-4.52
IP4_T1a	IP4	twig	NA	-26.31	-4.22
MB2		Groundwater	NA	-29.49	-5.11
BCB2		Groundwater	NA	-27.07	-4.41
MB10		Groundwater	NA	-37.38	-6.29
SB1		Groundwater	NA	-32.31	-5.53
MB4b		Groundwater	NA	-32.54	-5.11
MB1		Groundwater	NA	-34.20	-4.82
MB4a		Groundwater	NA	-26.24	-3.84