



Appendix I

Groundwater impact assessment





Balranald Groundwater Impact Assessment

In support of Modification No.1

Prepared for Iluka Resources Limited
April 2022





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Balranald Groundwater Impact Assessment

In support of Modification No.1

Report Number

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Client

Iluka Resources Limited

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Table of Contents

1	Introduction	1
1.1	Project background	1
1.2	Description of modification	3
1.3	2015 EIS assessment summary	5
1.4	Other studies	8
2	Groundwater regulations and policy	10
2.1	Assessment requirements	10
2.2	Groundwater management	10
3	Existing environment	15
3.1	Geology	15
3.2	Hydrology	17
3.3	Hydrogeology	17
3.4	Groundwater levels and flow direction	19
3.5	Groundwater quality	27
3.6	Ecosystems that rely on groundwater	28
3.7	Third party use	30
4	Conceptualisation and water affecting activities	34
4.1	Conceptual models	34
4.2	Risk assessment approach	48
4.3	Monitoring regime	56
5	MOD1 assessment	60
5.1	Proposed approach	60
5.2	Mine plan and schedule	60
5.3	Model domain, features and stresses	60
5.4	Risk and comparative assessment summary	62
5.5	Groundwater quantity assessment	75
5.6	Groundwater quality assessment	84
5.7	Predictive uncertainty analysis	91
6	Summary	92
	References	94

Appendices

Appendix A Groundwater Modelling Report

Tables

Table 1.1	Water balance (average rainfall year)	6
Table 2.1	Requirements for water sharing (Western Murray Porous Rock Groundwater Source)	12
Table 3.2	MOD1 modelled aquifer hydraulic properties	21
Table 3.3	Olney Formation bores in the vicinity of the Project	30
Table 4.1	Minimal impact criteria for “less productive” porous and fractured rock water sources	49
Table 4.2	Direct effects of water affecting activities and potential effects	51
Table 4.3	Indirect groundwater effects	54
Table 4.4	Previous underground mining trial/s monitoring bore network	57
Table 4.5	T3 activity monitoring network	59
Table 5.1	Direct groundwater-affecting activities risk assessment	64
Table 5.2	Indirect groundwater effects risk assessment	72

Figures

Figure 1.1	Regional setting and EIS approved Balranald project area (SSD-5285)	2
Figure 1.2	Proposed modification study area and conceptual site layout	4
Figure 1.3	Predicted 2015 EIS mine dewatering rates and in-pit potentiometric surface over time (after Jacobs 2015)	7
Figure 1.4	T3 activity within the Balranald Mine project footprint	9
Figure 2.1	Groundwater Water Sharing Plan (WSP) boundaries	13
Figure 2.2	Western Murray Porous Rock Groundwater Source Provisions	14
Figure 3.1	Aquifer systems of the Murray Basin (after Evans and Kellett, 1989 and Brown and Stephenson, 1991)	16
Figure 3.2	Conceptualised hydrostratigraphy in the T3 bulk sampling activity area	18
Figure 3.3	Shepparton Formation (unstressed) potentiometric surface (m AHD)	22
Figure 3.4	Loxton Parilla Sands Formation (unstressed) potentiometric surface (m AHD)	23
Figure 3.5	Olney Formation (unstressed) potentiometric surface (m AHD)	24
Figure 3.6	Balranald monitoring GME network	25
Figure 3.7	Selected long term hydrographs	26
Figure 3.8	Piper diagram – comparative assessment of regional groundwater quality to T3 bores in the vicinity of the MOD1 footprint	28

Figure 3.9	GDE distribution	31
Figure 3.10	GDE class (after CDM Smith 2015)	32
Figure 3.11	Landowner bores and formation screened	33
Figure 4.1	Hydrostratigraphy and pre-mining conditions	37
Figure 4.2	Hydrostratigraphy and mining phase conditions	38
Figure 4.3	Hydrostratigraphy and slimes backfilling phase conditions	39
Figure 4.4	Hydrostratigraphy and post-mining conditions	40
Figure 4.5	Groundwater-affecting mining activities conceptual model	45
Figure 4.6	Geochemical conceptual model	46
Figure 4.7	PAX source conceptual model	47
Figure 5.1	MOD1 mine plan and slimes injection layout	63
Figure 5.2	MOD1 modelled drawdown in the Olney Formation at the end of mining	77
Figure 5.3	2015 EIS modelled drawdown in the Shepparton Formation at the end-of-mining (Jacobs 2015)	78
Figure 5.4	2015 EIS modelled drawdown in the LPS1 at the end-of-mining (Jacobs 2015)	79
Figure 5.5	MOD1 modelled drawdown at the water table during mining	80
Figure 5.6	MOD1 modelled drawdown in LPS1 lower shore/LPS2 foreshore during mining	81
Figure 5.7	Modelled hydrographs at third party Olney bores	83
Figure 5.8	Modelled hydrographs at selected terrestrial GDE sites	84
Figure 5.9	Modelled PAX concentration in the Shepparton Formation during mining	87
Figure 5.10	Modelled PAX concentration in LPS1 lower shore/LPS2 foreshore during mining	88
Figure 5.11	Modelled PAX concentration in Shepparton Formation post mining	89
Figure 5.12	Modelled PAX concentration in LPS1 lower shore/LPS2 foreshore post mining	90

1 Introduction

EMM Consulting Pty Limited (EMM) was commissioned by Iluka Resources Limited (Iluka) to undertake a groundwater impact assessment (GIA) of the proposed modification (MOD1) to the approved Balranald Mineral Sands Project (the Balranald Project) in south-western New South Wales (NSW).

The purpose of this GIA is to provide a comparison of predicted environmental impacts of the proposed modification against the predicted impacts of the approved project. The report structure is as follows:

- A summary of the project history and currently approved project (Chapter 1).
- Define groundwater licensing requirements in accordance with revised impact predictions and the relevant legislation updated since the EIS (Chapter 2).
- Summarise the existing environment, with a focus on updated data collected, given the continued monitoring that has occurred since submission of the EIS (Chapter 3).
- Description of the conceptual model from both a groundwater quantity and quality perspective (Chapter 4), and a framework outlining the direct and indirect water affecting activities, potentially induced by MOD1.
- Assessment of potential impacts of MOD1 on groundwater sources and identified receptors (including bores), using the results of the numerical groundwater modelling and geochemical modelling (Chapter 5).

This report will support a modification report which will be submitted to the NSW Department of Planning and Environment (DPE) under the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act).

1.1 Project background

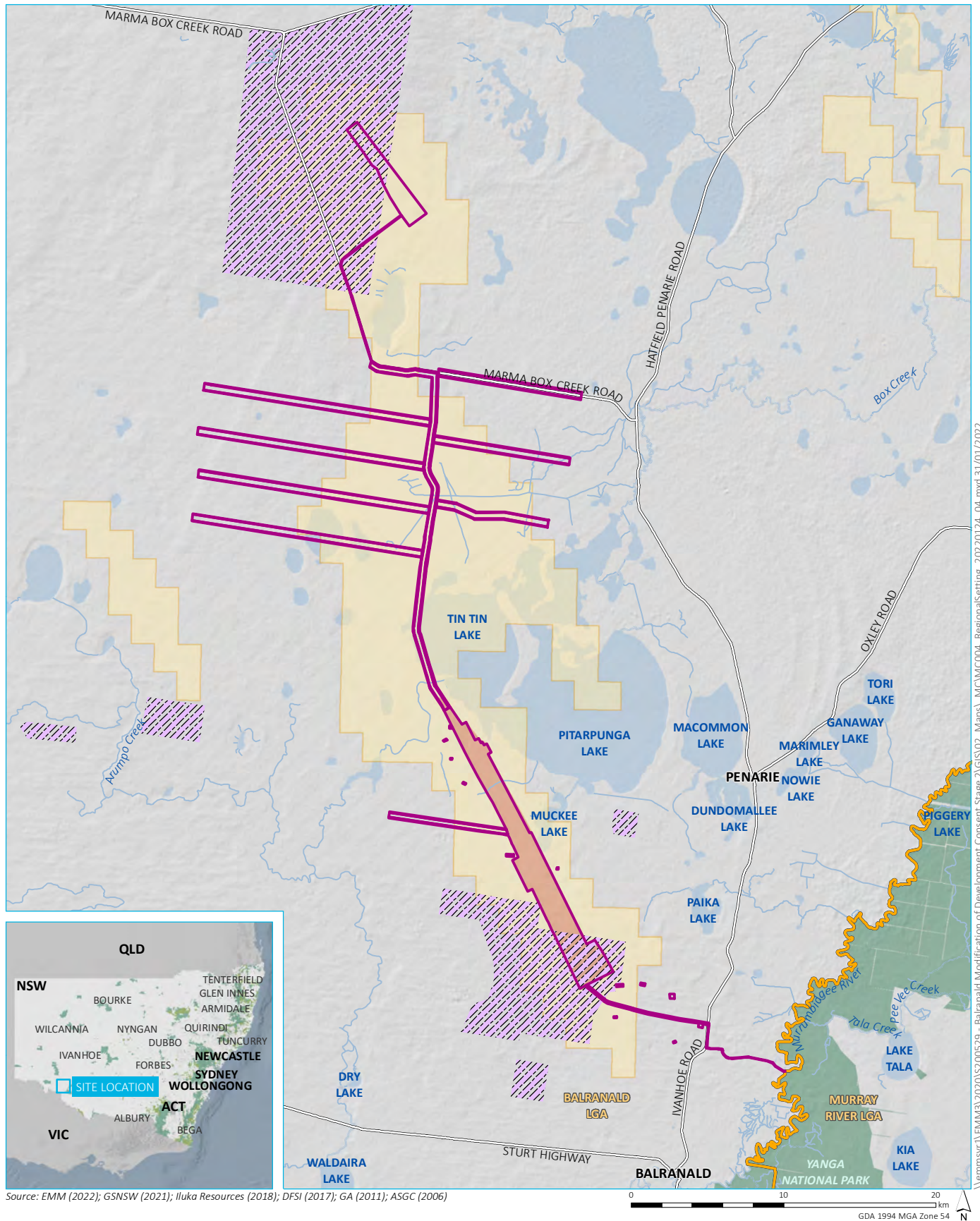
Iluka have approval to develop a mineral sands mine in south-western (NSW), known as the Balranald Project. It includes construction, mining, primary processing, and rehabilitation of two linear mineral sand deposits, known as the West Balranald and Nepean deposits, located approximately 12 kilometres (km) and 66 km north-west of the town of Balranald (Balranald town), respectively.

An environmental impact statement (EIS) was prepared and submitted in 2015 to accompany a State significant development (SSD-5285) application under Part 4 of the EP&A Act for an open cut, truck and shovel mining method. Development consent was granted by DPIE under Part 4 of the EP&A Act on 5 April 2016. The Balranald Project (also referred to as the 2015 EIS from hereon in) also included undertaking a bulk sampling activity at the West Balranald mine to test the removal of ore using underground mining methods.

The regional setting and approved EIS project area are shown on Figure 1.1.

Since development consent was granted in April 2016, Iluka has undertaken the approved bulk sampling activity involving the extraction of mineralised material or ore, from depth within the approved disturbance area of the West Balranald mine.

The outcome of the bulk sampling activities confirmed the effectiveness of the underground mining method, validated key elements of the mining unit design and have been used to help guide the proposed modification to inform the potential suitability (ie commerciality and reduced environmental impacts) of underground mining as an alternative method for resource extraction for the Project.



KEY

- EIS Approved Balranald Project Area (SSD-5285)
- Exploration Licence (EL7450)
- Mining Lease (ML1736)
- Southern Mallee Conservation Area (2015)
- Major road
- Watercourse/drainage line
- Waterbody
- NPWS reserve

Local government area

INSET KEY

- NPWS reserve
- State forest

Regional setting and EIS approved Balranald project area (SSD-5285)

Balranald Mineral Sands Project
Balranald groundwater comparative impact assessment
Figure 1.1

1.2 Description of modification

The proposed MOD1 would involve:

- continuing underground mining within a portion of the approved disturbance footprint of the West Balranald deposit pursuant to the consent (ie mining area); and
- development of approved mineral processing infrastructure within a proposed new area of disturbance (ie surface infrastructure).

The construction of infrastructure would be undertaken to support the construction and operation for proposed underground mining, including mineral processing infrastructure, access roads, upgrade of external roads and intersections, gravel extraction, monitoring infrastructure, accommodation facility, road transport of ore offsite for downstream processing and other infrastructure as required.

The underground mining process would involve:

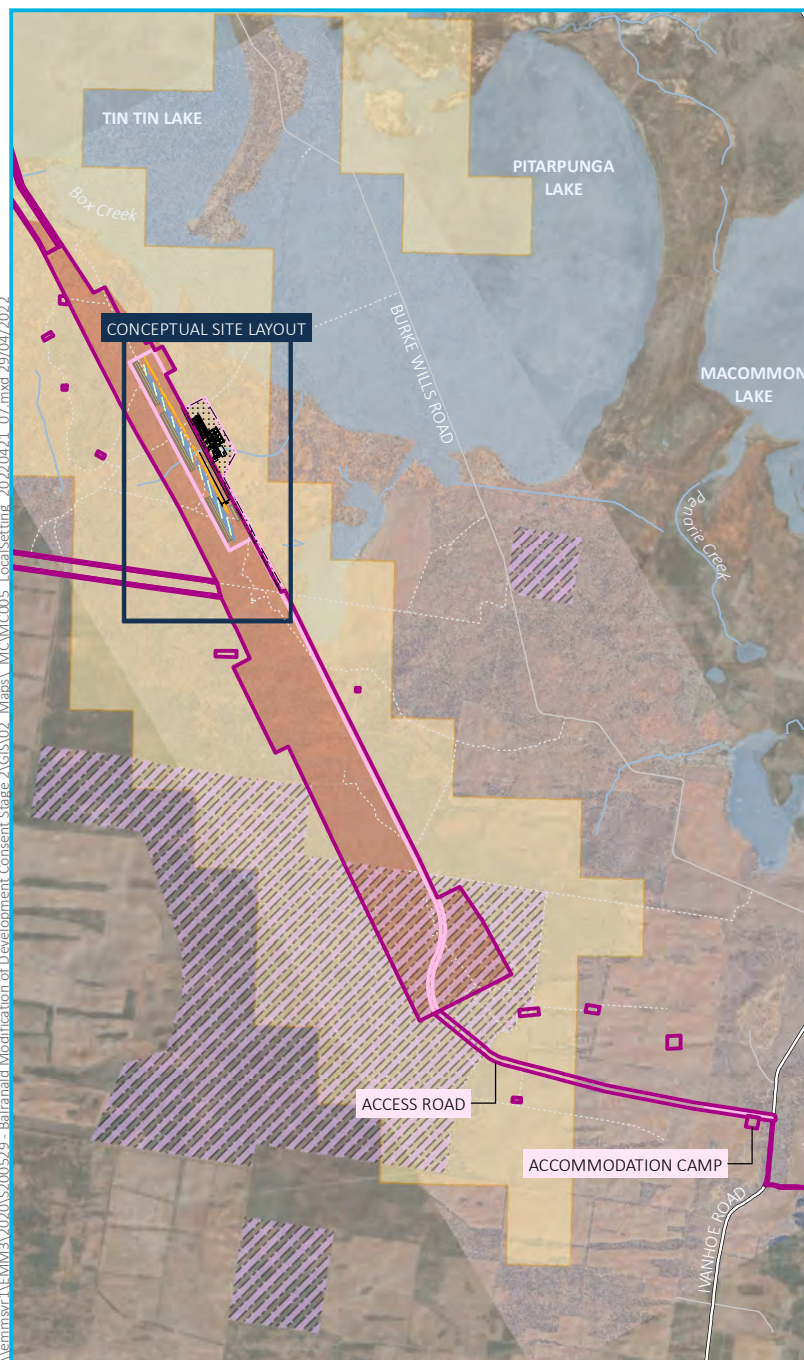
- clearing the footprint directly above the mining area – the area will be stripped of topsoil, subsoil, and non-saline overburden to a nominal depth of 2 metres (m);
- surface emplacement of treated sand tails and overburden/subsoil ahead of mining into the space created by the above stripping;
- underground mining of the ore;
- processing of the mined ore to separate the heavy mineral concentrate (HMC) from sand tails, sand fines and oversize;
- stockpiling of the HMC;
- backfilling of sand fines (slimes) underground;
- replacement of subsoil and topsoil for rehabilitation and final landform; and
- environmental monitoring activities (including groundwater, geochemistry, subsidence, air quality and noise).

Ore is expected to be produced and processed at a rate no greater than approved under the development consent. The processing plant on site will produce a HMC to generate two primary product streams; magnetic HMC and non-magnetic HMC.

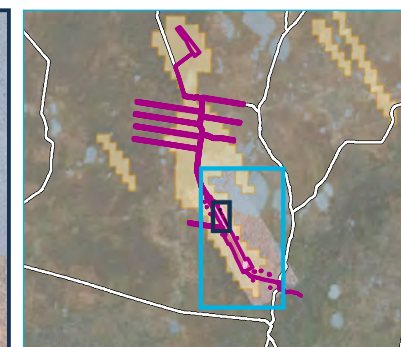
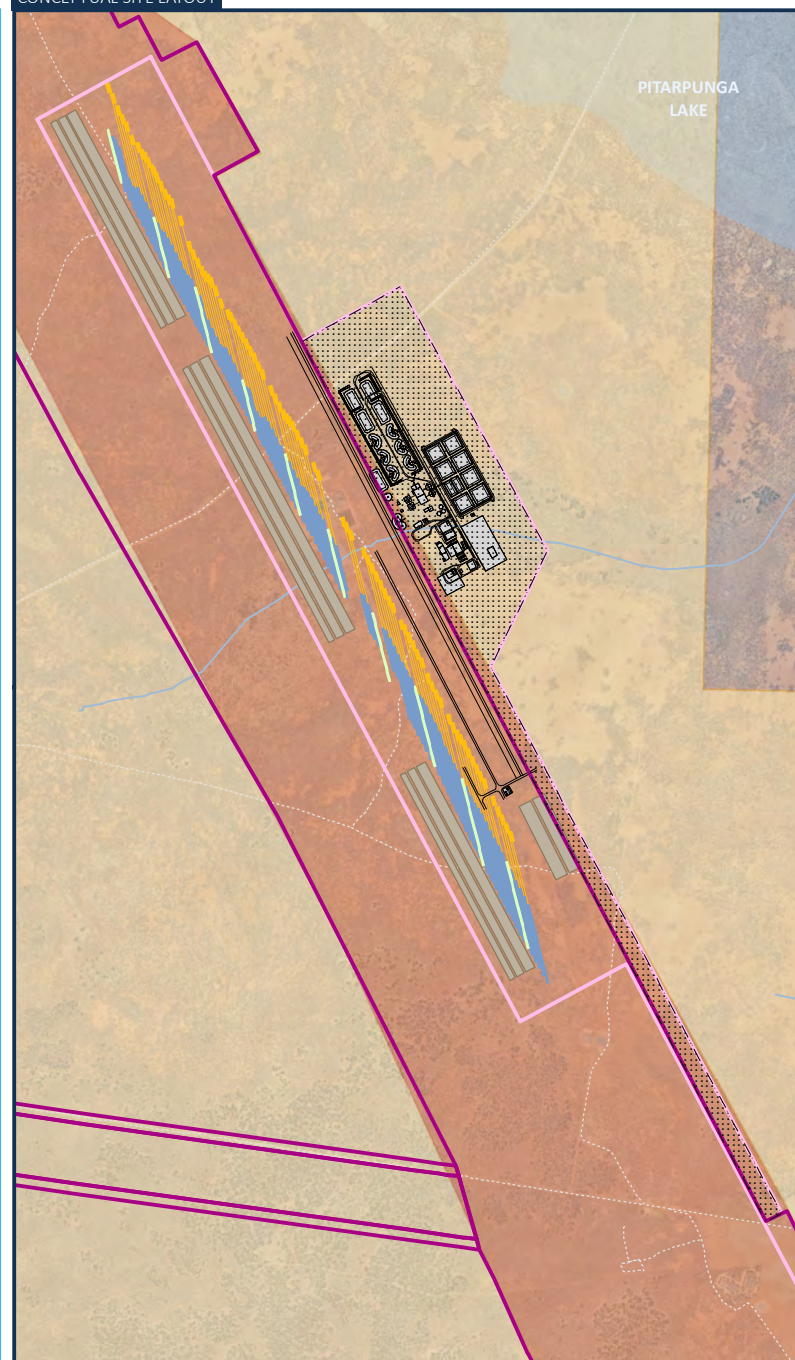
The product would be stockpiled and transported off-site for downstream processing with underground mining operations to be undertaken for a period of 6 years.

The proposed modification and conceptual layout are shown in Figure 1.2.

\\lemmsvr1\EMM3\2020\5200529 - Balranald Modification of Development Consent Stage 2\GIS\02 Maps\ MCM\CM005 LocalSetting_20220421_07.mxd 29/04/2022



CONCEPTUAL SITE LAYOUT



KEY

- EIS Approved Balranald Project Area (SSD-5285)
- Proposed modification study area
- Proposed modification extension to Balranald Project Area boundary
- Processing area infrastructure
- Subsoil stockpile
- Drill pad and string to underground stope
- Underground stope
- Underground pillar
- Major road
- Minor road
- Existing track
- Watercourse/drainage line
- Waterbody
- Southern Mallee Conservation Area (2015)
- Exploration Licence (EL7450)
- Mining Lease (ML1736)

Proposed modification study area and conceptual site layout

Balranald Mineral Sands Project
Balranald groundwater comparative impact assessment
Figure 1.2



Source: EMM (2022); Iluka Resources (2021); ESRI (2021); DFSI (2017); GA (2011)

0 0.5 1 km
GDA 1994 MGA Zone 54

1.3 2015 EIS assessment summary

An EIS was prepared by EMM in 2015 for Iluka, which included the assessment of construction, mining, primary processing, and rehabilitation of two linear mineral sand deposits, known as the West Balranald and Nepean deposits.

From a hydrogeological perspective, the Balranald Project requires perimeter pit dewatering bores to progressively dewater the open cut mining areas to allow for dry mining activities to occur. This water is then pumped north to a network of injection borefields for the return of hypersaline groundwater to the Loxton Parilla Sands aquifer. Within each borefield, infrastructure is generally located in two 50 m wide corridors (approximately 350 m apart) and typically comprises of:

- a network of pipelines with a graded windrow on either side;
- access roads for vehicle access during construction and operation;
- rows of injection bores, with bores spaced at approximately 100 m intervals; and
- a series of water storage dams to store water during bore development.

A water balance model was prepared that encompassed the mine affected water management system, hypersaline groundwater and reinjection volumes for pre-mining, and years one, four and eight of the conceptual mine plan (EMM 2015). This is presented in Table 1.1 and indicates marginal net change in total site water inventory during the operational phase. Dewatering and injection volumes dominated the water balance with the average dewatering rates being modelled at 746 litres per second (L/s) and 100 L/s for the West Balranald and Nepean deposits respectively. The modelled predicted potentiometric surface below the pit, along with the dewatering rates over the life of mine for the West Balranald deposit are shown on Figure 1.3. Dewatering rates progressively increased over time due to the gentle deepening of the ore zone as the mine progressed northward.

Table 1.1 Water balance (average rainfall year)

Component	Construction (total*)	Year 1 ML/ yr (operational)	Year 4 ML/yr (operational)	Year 8 ML/yr (operational)
<i>Inflows to water management system</i>				
Groundwater inflow to pit	-	1,577	1,577	0
Catchment runoff	-	34.9	32.5	37.7
Direct rainfall on water storages	-	11.2	12.1	4.8
Dewatering borefield	-	19,532	22,421	1,239
Hypersaline water supply to processing plant	-	-	-	841
Water supply bores – Olney Formation	300	-	-	-
Total inflows	300	21,155	24,043	2,123
<i>Outflows from water management system</i>				
Net site water management system	-	1,558	1,553	27.3
Uncontrolled releases	-	0	0	0
Evaporation	-	68	71	27.7
Reinjection	-	19,532	22,418	2,065
Total outflows	-	21,158	24,042	2,120
Net change in total site water inventory	-300	-3	1	3

Notes: Taken from Jacobs 2015 and WRM 2015.

*Total water usage has been provided for three years as the rate of abstraction is variable during this period.

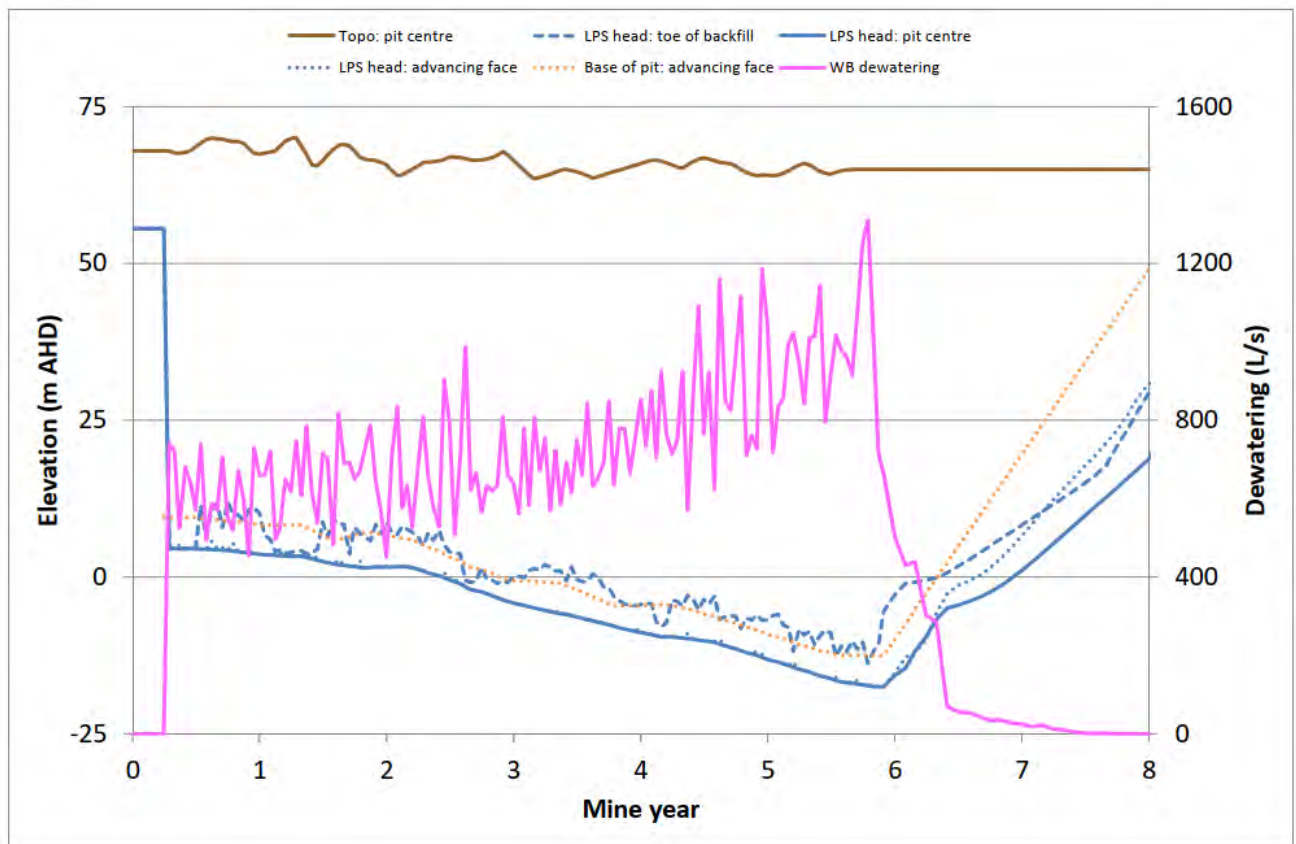


Figure 1.3 Predicted 2015 EIS mine dewatering rates and in-pit potentiometric surface over time (after Jacobs 2015)

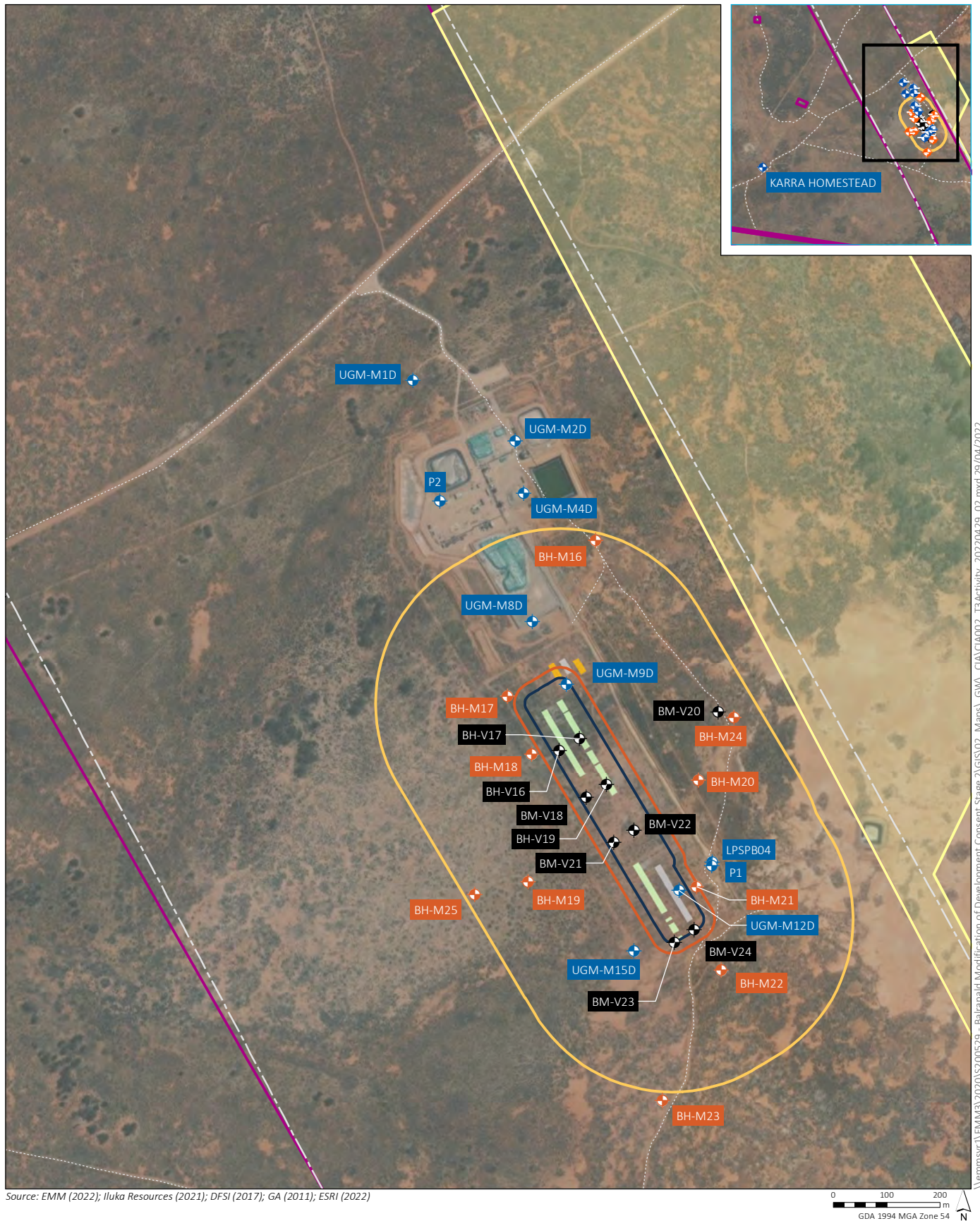
1.4 Other studies

There have been three bulk sampling activities undertaken at the Balranald Project that included groundwater investigations related to the underground mining method, which was used to extract ore from selected mining zones, called stopes. The site layout plan reflecting all historical mined stopes and the trial process plant during the third activity (T3), is shown on Figure 1.4.

The three bulk sampling activities are summarised below:

- T1 – the first activity involved selective in-situ removal of mineral ore from Stopes 1 and 2.
- T2 – the second activity commenced in Q2-2016 and extracted approximately 6,400 tonnes (t) of ore from three stopes (referred to as Stopes 1B, 3 and 4) and backfilled approximately 700 t of mining by product. Iluka placed the activity site into care and maintenance during 2017 and 2018 to review the mining and environmental monitoring outcomes. The T2 activity demonstrated that the mining process had minor hydraulic responses in comparison to re-injection simulated as part of the 2015 EIS, which forms part of the backfill process. Accordingly, the T3 numerical simulations, developed prior to the third and final activity, focused primarily on the responses during backfilling.
- T3 - the third and final activity is located within the disturbance footprint of the West Balranald mine (Figure 1.4), T3 involved the selective in-situ removal of the remaining 93,600 t of ore from Stopes 4 and 6. One of the objectives of T3 was to further validate the groundwater and subsidence impact prediction models.

A Groundwater Management Plan (GMP) was prepared to manage potential groundwater risks associated with the T3 activity and considered all the requirements under SSD-5285 and matters raised by the former Department of Industry in their letter to Iluka dated 3 May 2018 (Ref: OUT18/6975). The groundwater data collected during T3 provided an important data set for updating the numerical model, which is the primary tool used to assess impacts from a groundwater perspective.



KEY

- | | |
|---|---|
| EIS Approved Balranald Project Area (SSD-5285) | Restricted area |
| Proposed modification extension to Balranald Project Area boundary | Mining zone boundary |
| ● T3 bore | Transition zone boundary |
| ● T3 VWP | Mining Lease 1736 |
| ● Existing bore | Slope 1, Slope 2 (T1) |
| --- Existing track | Slope 1B, Slope 4 (T2) |
| | Slope 4, Slope 6 (T3) |

T3 activity within the Balranald Mine project footprint

Balranald Mineral Sands Project
Balranald groundwater comparative impact assessment
Figure 1.4

2 Groundwater regulations and policy

2.1 Assessment requirements

Consistent with the groundwater assessment completed as part of the EIS (EMM 2015), this assessment has been prepared following the appropriate guidelines, policies and industry requirements, including consultation with stakeholders such as relevant government agencies.

Legislation, guidelines and policies considered include:

- *Water Management Act 2000* (WMA);
- *Protection of the Environment Operations Act 1997* (POEO Act);
- *NSW Aquifer Interference Policy* (AIP; DPI Water 2012);
- relevant water sharing plans (WSPs);
- NSW State Groundwater Policy Framework Document (DLWC 1997);
- *Australian Groundwater Modelling Guidelines* (Barnett et al 2012);
- *Australia and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZG 2018); and
- the Risk assessment guidelines for groundwater dependent ecosystems (GDEs) (Serov et al 2012).

The minimal impact considerations outlined in the AIP have been used to assess the potential impacts to groundwater resources and associated receptors resulting from the MOD1. This is discussed further in Section 4.2.1.

The regulatory and policy context for the assessment was described in the EIS groundwater assessment (EMM 2015) and has not been reproduced here.

2.2 Groundwater management

Water sharing plans (WSPs) provide a legislative basis with the aim to ensure sustainable and integrated management of water resources in NSW by providing clear arrangements for activities that affect water quality and quantity. The plans set management rules for water access licences (WALs), water allocation accounts, dealings in licences and water allocations, water supply works approvals, and the extraction of water. WSPs also define the water management rules which apply to the trading of water and granting of access licenses. WSPs typically have a longevity of 10 years and are then updated (unless extended).

The Balranald Project lies within the Western Murray Porous Rock Groundwater Source which is managed by the *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources Order 2020* (MDB Porous Rock WSP) (Figure 2.1). This WSP has been revised since the 2015 EIS and came into force as of July 2020.

The Western Murray Porous Rock Groundwater Source is an aquifer in the far west of NSW, extending from the south of Broken Hill southward to the State's border and to the west of the Lower Lachlan, Lower Murrumbidgee, and Lower Murray Groundwater Sources and westward to the NSW/SA border. The WSP extends from the boundary with the Adelaide and Kanmantoo Fold Belts in the north to the Murray River in the south. To the east, the groundwater source is constrained by the boundary between the Kanmantoo and Lachlan Fold Belts. The groundwater source incorporates the alluvial Renmark Group and Calivil Formation in the east (as described by Kellett 1991) which grade into the Murray Group Limestone and Loxton-Parilla Sands to the south-west.

Section 4(6) of this WSP states that:

6) Subject to subclause (7), the waters in the Western Murray Porous Rock Groundwater Source comprise all water contained within:

- (a) all rocks of Tertiary and Quaternary age within the outcropped and buried areas; and
- (b) all alluvial sediments within the outcropped areas.

The Western Murray Porous Rock Groundwater Source has a long-term average annual extraction limit (LTAAEL) of 226,000 megalitres per year (ML/year). When assessed in January 2022, the NSW Water register reported that there were 23 WALs with a total entitlement of 35,944 share components in this groundwater source (Table 2.1).

The MDB Porous Rock WSP sets the annual groundwater recharge volumes for each identified groundwater source and the volumes of water available for sharing, otherwise known as the Long Term Annual Average Extraction Limit (LTAAEL). Provisions are made for environmental water allocations, basic landholder rights, domestic and stock rights and native title rights. The statistics for the Western Murray Porous Rock Groundwater Source 2022/2023 availability are presented in Table 2.1, and an overview of water availability is provided in Figure 2.2.

As shown in Table 2.1 and Figure 2.2, there is a significant amount of unallocated water (163,309 ML/yr) within the Western Murray Porous Rock Groundwater Source of the MDB Porous Rock WSP.

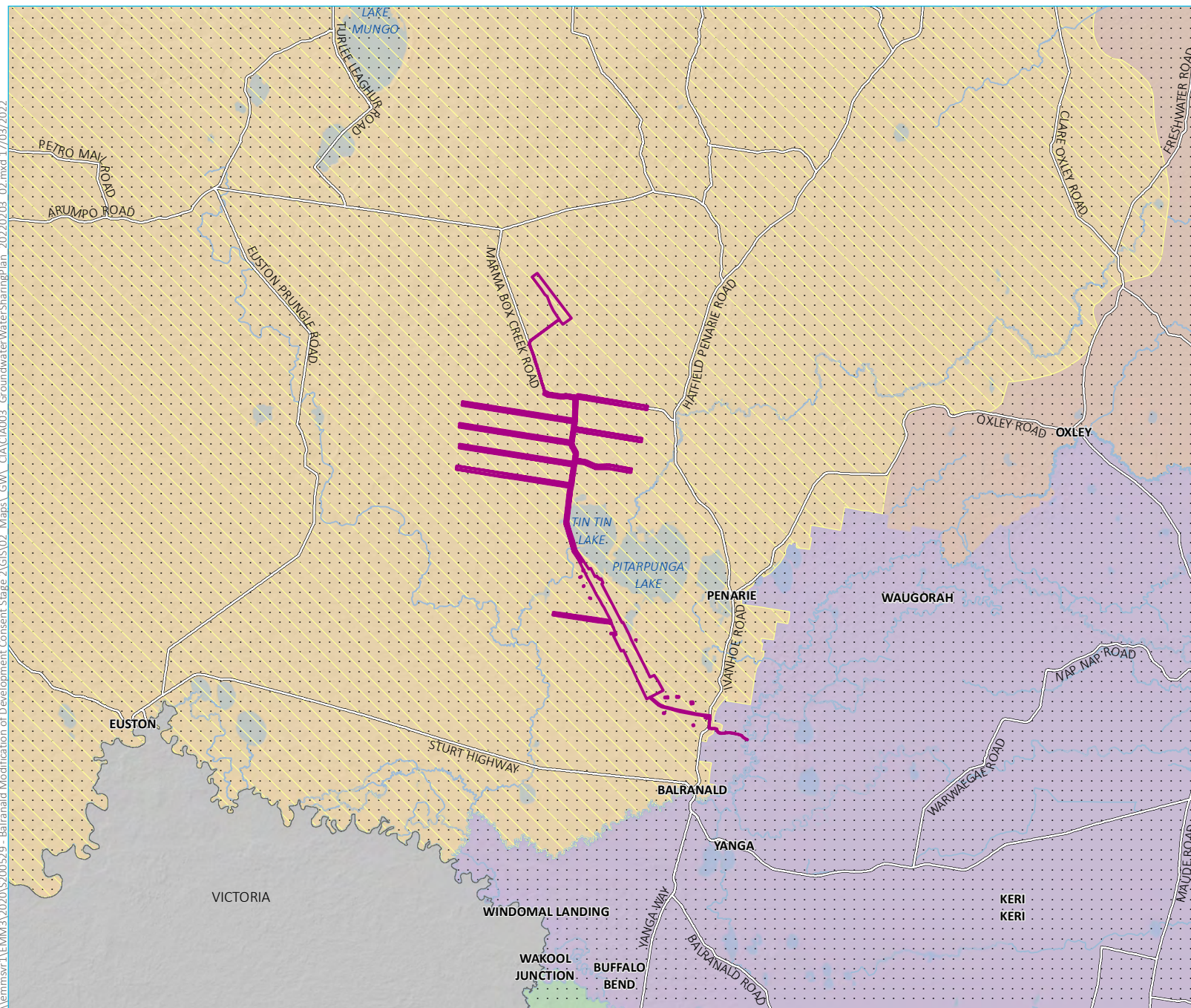
Table 2.1 Requirements for water sharing (Western Murray Porous Rock Groundwater Source)

Water requirements	No. of water access licences (WALs) ¹	Total share component (ML/yr) made available in 2022/2023
Requirements for Basic Landholder Rights (BLR)		
Basic rights (domestic and stock) ²	0	26,747
Native title ²	0	Not defined volumetrically
Requirements for water under access licences		
Aquifer	15	21,534
Local water utility	2	0
Local water utility (domestic and commercial)	3	425
Salinity and watertable management	3	13,985
Total	23	35,944
LTAEL ²		226,000
Available water (calculated LTAEL-BLR-Access licences)		163,309

1. Data based on a search of the NSW Water Register (accessed January 2022).

2. This value is listed in the MDB Porous Rock WSP, and assuming 1 unit share is equal to 1 ML.

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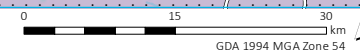
- KEY**
- EIS Approved Balranald Project Area (SSD-5285)
 - Major road
 - Named watercourse
 - Named waterbody
 - Groundwater source**
 - Western Murray Porous Rock Groundwater Source
 - Water sharing plan boundary**
 - Lachlan Alluvial Groundwater Sources 2020
 - Murray Alluvial Groundwater Sources 2020
 - Murrumbidgee Alluvial Groundwater Sources 2020
 - NSW Murray Darling Basin Porous Rock Groundwater Sources 2020
 - NSW Murray Darling Basin Fractured Rock Groundwater Sources 2020

Groundwater Water Sharing Plan (WSP) boundaries

Balranald Mineral Sands Project
Balranald groundwater comparative
impact assessment
Figure 2.1



Source: EMM (2022); GSNW (2021); Iluka Resources (2021); DPIE (2021); DPI (2020); DFSI (2017); GA (2011); ASGC (2006)



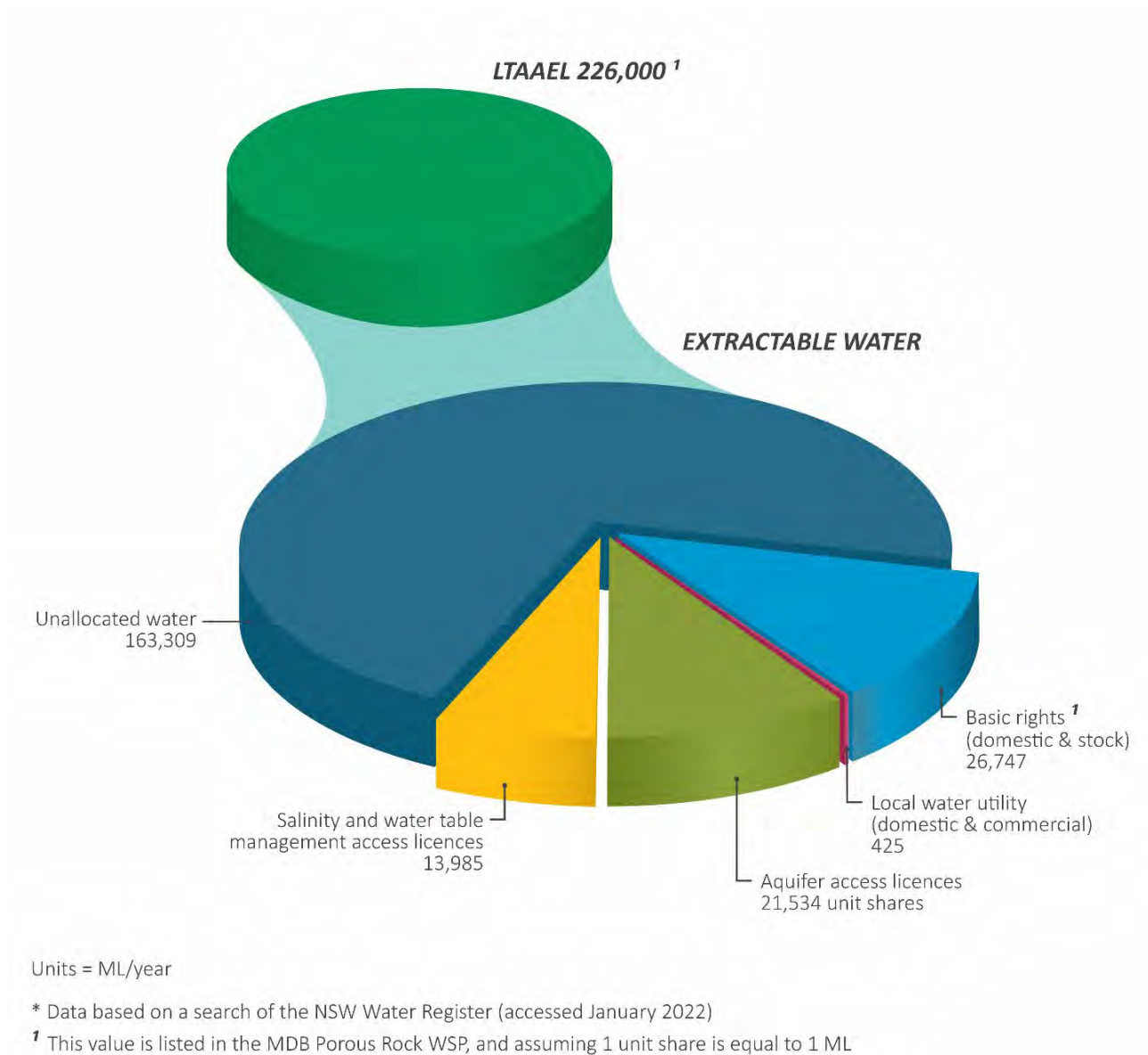


Figure 2.2 Western Murray Porous Rock Groundwater Source Provisions

3 Existing environment

3.1 Geology

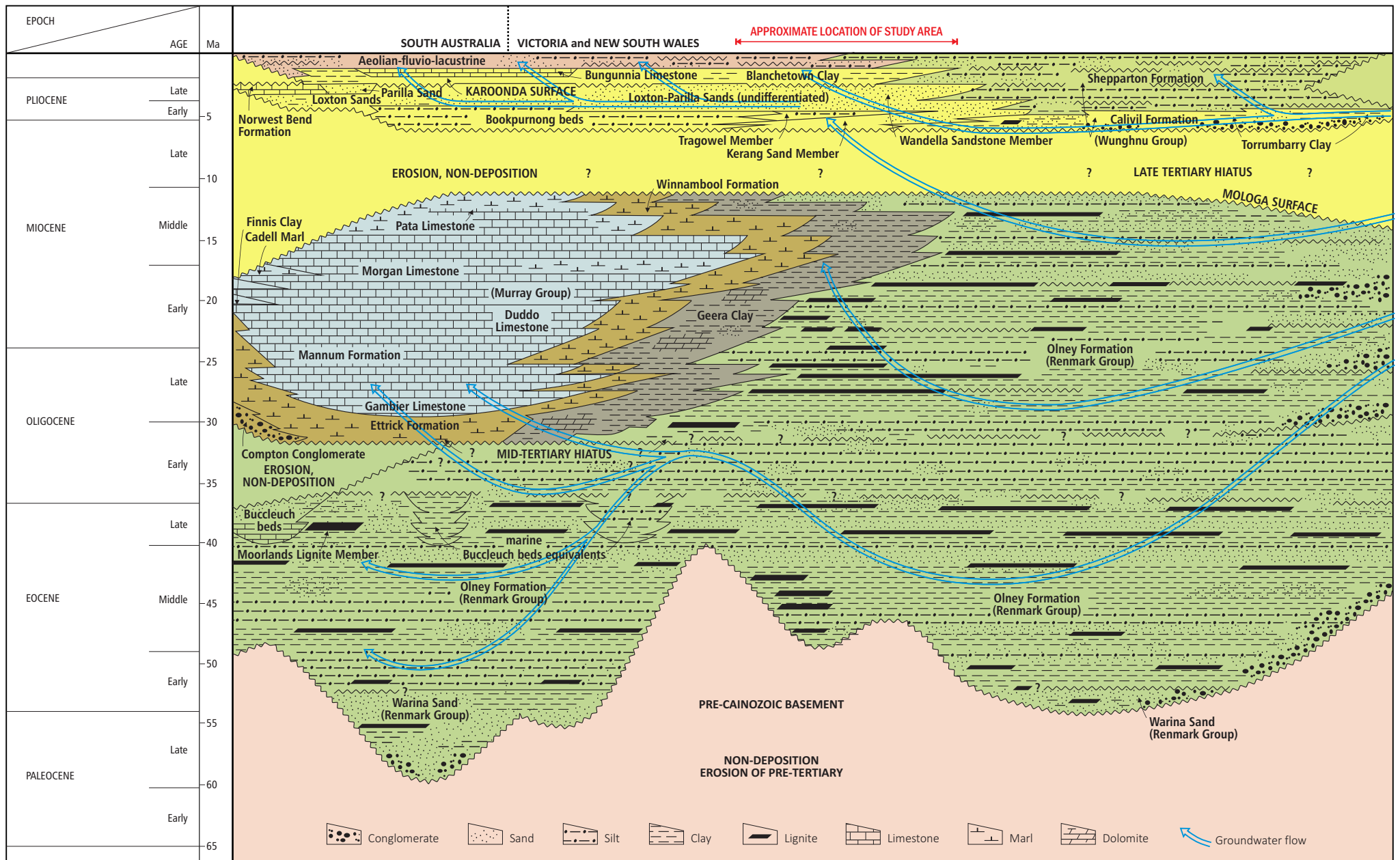
The Balranald Project is located in the centre of alluvial sediments of the Murray Basin, within the central west of the Riverine Plain. Subregions within the Murray Basin are defined by surface geomorphology and the presence of the Ivanhoe Block and associated structures. Within the project area the basal unit of the Murray Basin, which directly overlies the basement rocks (comprising Proterozoic and Palaeozoic rocks), is the Olney Formation; a geological unit deposited during the Paleogene to the mid-Miocene periods. The Olney Formation sediments are predominantly continental, but marginal marine units such as the Geera Clay, interfinger through the middle sequence to the east of the project area.

In the eastern end of the Murray Basin, the Olney Formation is overlain by the Calivil Formation which is in turn overlain by the Shepparton Formation. In the west, the Olney Formation is overlain by the Loxton-Parilla Sands Formation which is in turn overlain by aeolian sands of the Shepparton Formation. The Calivil Formation laterally interfingers and grades into the Loxton-Parilla Sands at the eastern edge of the Riverine Plain. The regional stratigraphy system of the Murray Basin is conceptually shown on Figure 3.1.

Within the project area, the combined thickness of the Murray Basin sediments ranges from 250 m to 290 m, with the local geology summarised in Table 3.1. The Shepparton Formation and Loxton-Parilla Sands range in thickness between 60 m to 100 m, while the Geera Clay and Olney Formation have a combined thickness of 190 m. The basement structure has significant influence on the geologic structure of both the overlying geology and associated groundwater flow in the project area (Kellett 1991 and 1994).

Table 3.1 Local geology at Balranald (from oldest to youngest)

Age	Group	Unit	Lithology
Pre-Tertiary		Basement rock	
Eocene to Early Oligocene	Lower Renmark Group	Olney Formation	Unconsolidated to poorly consolidated, blue-grey/dark-brown carbonaceous sand and silt.
Oligocene to Middle Miocene	Middle Renmark Group	Olney Formation	Unconsolidated to poorly consolidated, dark-grey, blue, or black carbonaceous clay or silty sand. Commonly pyritic and ligneous.
Late Oligocene to Middle Miocene	Murray Group	Geera Clay	Poorly consolidated, plastic to friable, dark greenish-grey or black silt and clay. Potentially glauconitic, pyritic, calcareous, carbonaceous, or fossiliferous. Local sandy and dolomitic hardbands.
Middle Miocene	Upper Renmark Group	Olney Formation	Unconsolidated to poorly consolidated, brown-grey, carbonaceous, medium to fine sand with interbedded silt. Micaceous and pyritic.
Late Miocene to Early Pliocene	Wunghnu Group	Calivil Formation	Interbedded clay, silty clay, silt and fine to coarse-grained quartz sand, reef quartz and metasediment gravel. Minor ligneous clay.
Late Miocene to Pliocene		Loxton-Parilla Sands	Unconsolidated to weakly cemented, yellow-brown, fine to coarse, well to poorly-sorted, quartz sand and sandstone. Minor clay and silt.
Quaternary (Holocene)		Floodplain Sediments: (Coonambidgal Formation)	Exists within the Murray River floodplain. Unconsolidated, grey, brown, micaceous silty clay, silt, polymictic sand and gravel.



Aquifer systems of the Murray Basin (after Evans and Kellett, 1989 and Brown and Stephenson, 1991)

3.2 Hydrology

On a regional scale, the Murrumbidgee and Murray rivers are the major permanent surface water features in the vicinity of the Balranald Project area. The Lachlan River terminates at the Great Cumbung Swamp, approximately 48 km east of the Balranald Project, a major permanent surface water feature in areas upstream of Balranald. The Murrumbidgee and Murray rivers provide key water resources for large populations within the Murray Darling Basin including town water supplies, agriculture and the environment. The Murrumbidgee River occurs about 10 km south of the Balranald Project, and flows in a south-westerly direction, to its confluence with the Murray River about 40 km to the south-west of the Balranald township.

Locally, the main surface water feature within the Balranald Project area is Box Creek, which is an ephemeral watercourse (and does not intercept the watertable) and a tributary of the Murray River. Almost all of the Balranald Project is located within the Box Creek catchment, however the creek only flows during and immediately following heavy local rainfall or large flooding events. Flow has only occurred in Box Creek on occasions in the last 60 years (WRM, 2015). Permanent surface water flows are confined to the major rivers and their associated backwaters outside of the Balranald Project area.

3.3 Hydrogeology

The three main aquifer units in the immediate vicinity of the Balranald Project area are:

- the Shepparton Formation (SFM);
- the ore-hosting Loxton-Parilla Sands (LPS); and
- the Lower Renmark Group Formation (also known as the Olney Formation; Brown and Stephenson, 1991).

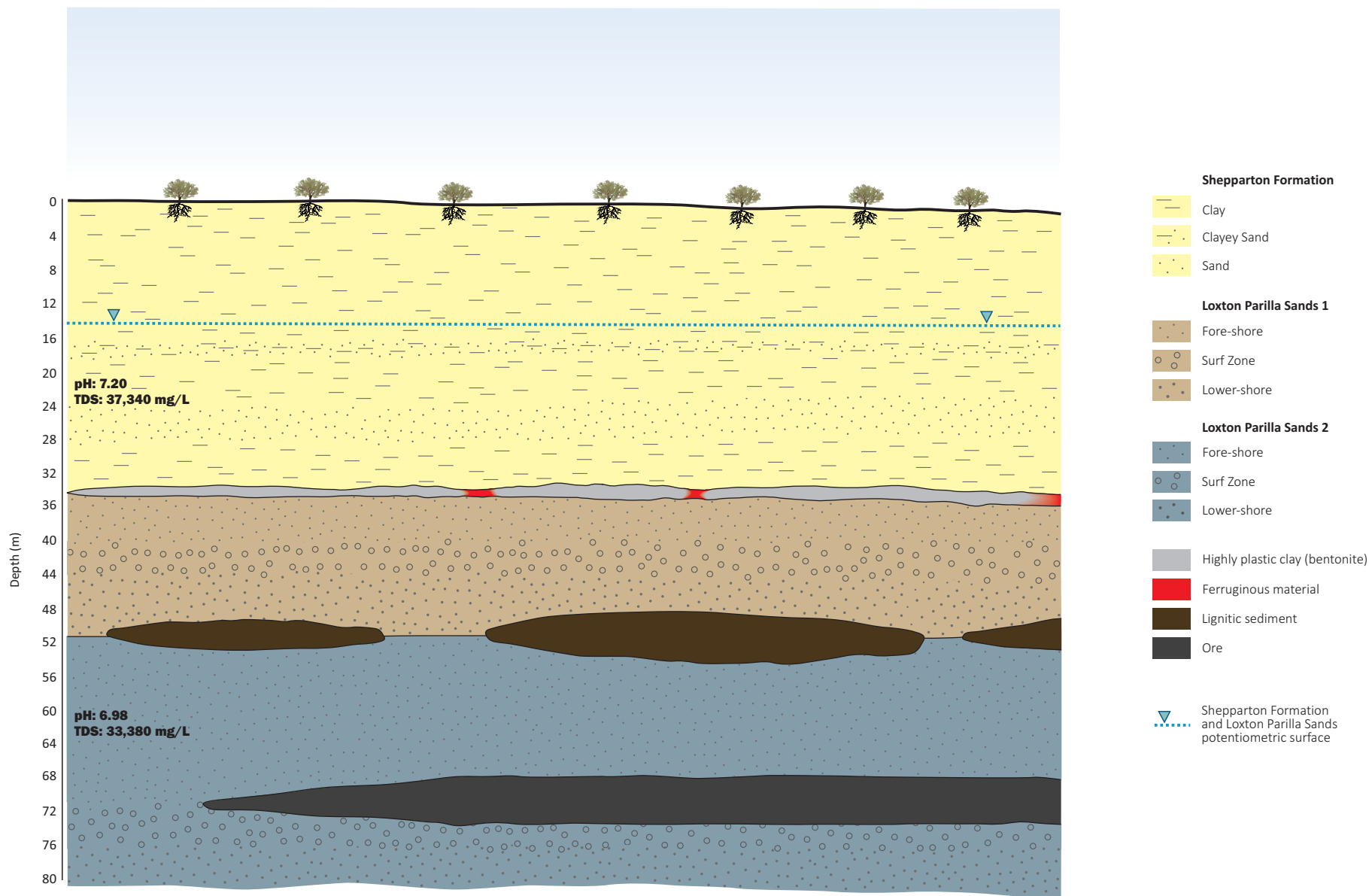
A conceptualised stratigraphic representation of the system in the area of the T3 bulk sampling activity is shown on Figure 3.2.

The Shepparton Formation consists of a thick layer of unconsolidated to poorly consolidated clayey sand and silty clays with interbedded sand lenses. This unit is highly variable across the West Balranald deposit and drilling has defined two dense clay layers (locally up to 4 m to 6 m thick). Moderately to strongly iron cemented rock layers are also present within the sand dominant lenses between the clay layers. The thickness of the unit varies from approximately 19 m at the northern end to more than 36 m through central and southern areas of the West Balranald deposit. The unit strikes in a northwest–southeast direction.

The upper Loxton-Parilla Sands marine sequence (referred to as LPS1) varies in thickness along the strike of the deposit from 16–20 m in the north to more than 60 m at the southern end. The sequence typically consists of three upper beach facies: foreshore, surf zone and lower shore; the different facies have varying horizontal hydraulic conductivities. A marine transgression marks the boundary between the LPS1 and the lower (older) marine sequence. The lower marine sequence (LPS2) is host to the West Balranald deposit and also consists of three facies (foreshore, surf zone and lower shore), with the mineral sands deposit typically lying within the foreshore facies of LPS2. Explorative drilling along the length of the West Balranald deposit confirmed the presence of confining Geera Clay along the strike of the West Balranald mine below the LPS2.

Within other geologic units, sediments are observed to be heterogeneous in nature and can act as localised and temporal aquifers. The Olney Formation is the regionally extensive early-Tertiary lacustrine system, specifically underlying the wider Balranald Project, and consists of the Upper, Middle and Lower Renmark Group.

The Palaeozoic rocks of the Lachlan Fold Belt underlie the Murray Basin sediments and form the basement to the basin. The basement contains structures such as ridges and troughs that have influenced deposition of the sediments and therefore also influence the hydrogeology of the Murray Basin.



Conceptualised hydrostratigraphy in the T3 bulk sampling activity area

3.4 Groundwater levels and flow direction

3.4.1 Horizontal groundwater pressures

Regional groundwater level measurements taken during 2014 and part of previous detailed feasibility studies (prior to any large-scale site activities), have been used to develop plan-view unstressed potentiometric surfaces. These surfaces for the following main aquifers of interest as follows:

- Figure 3.3 - SFM unstressed (ie natural conditions) potentiometric surface shown on a 0.5 m interval.
- Figure 3.4 - LPS unstressed potentiometric surface shown on a 0.5 m interval.
- Figure 3.5 - Olney Formation unstressed potentiometric surface shown on a 1 m interval.

The contours have been developed using surveyed bore collars associated with previous Balranald field programs and the quarterly baseline data collection program. In summary, the potentiometric surfaces suggest:

- The potentiometric surfaces for the SFM and LPS are near identical under natural/unstressed conditions, with the SFM hosting the watertable across the West Balranald deposit (also refer to Figure 3.2). At Nepean, the watertable is hosted within the LPS.
- Local groundwater occurring at elevations greater than 52 mAHD prevail at the southern end of the West Balranald deposit. Groundwater levels between 48 and 49 mAHD dominate further north.
- The local groundwater flow direction is from the south-east to the north-west.
- Groundwater heads recorded within the Olney Formation range from 63 mAHD at the southern end of the West Balranald deposit, to 57 mAHD to the west. The prevailing groundwater flow direction in this unit is from east to west, and consistent with the historical groundwater maps produced by Kellett (1989, 1994).

On a regional scale, the Ivanhoe Block impedes westerly throughflow in the Riverine Plain as the regional aquifer either thins out over the rising basement block or is truncated by it. At the boundary of the Ivanhoe Block flow lines in the deeper aquifers are deflected north and south, and flow lines in the shallower aquifers on top of the ridge line are forced to converge. The Geera Clay also forms a hydraulic barrier to lateral flow in the middle Olney Formation, forcing westerly groundwater flow lines in the middle and upper Olney Formation to converge.

Iluka undertake groundwater monitoring events (GMEs) across the Balranald site on a six-monthly frequency. The Balranald bore network targeted for the GMEs is shown on Figure 3.6, and includes a selection of Iluka-installed bores, third party bores and government bores. A selection of hydrographs (measured during unstressed conditions (ie not during bulk sampling activities) across the site are shown in Figure 3.7. Time series for all hydrographs measured between 2016 and early 2021 are provided within the modelling report (Appendix A).

3.4.2 Vertical groundwater pressures

Kellett (1991 and 1994) indicates artesian conditions in the east of the study area and URS (2012) reports a measured head at West Balranald (WB3 P1 screening the Olney Formation), 3.1 m above the ground surface. Iluka have identified two artesian third party bores (HD1 and T02) that are screened within the Olney Formation (and suspect artesian conditions at T03), in the vicinity of the West Balranald deposit.

A strong vertical upwards gradient is pronounced at GW036866 (40 km north of Balranald) and GW036674 (68 km north of Balranald) where there is approximately 9 m and 5 m difference, respectively, in potentiometric head pressure between the Loxton-Parilla Sands, and the Geera Clay and Olney Formation. It is likely that the Geera Clay prevents artesian pressures in the Olney Formation from equilibrating with the shallower units. Upward vertical head gradients are consistent with the monitoring sites being at the discharge end of the Balranald trough and near where basement rises, causing upward groundwater flow.

Groundwater density differences associated with variable groundwater salinity may contribute to groundwater flow patterns. On the vertical scale, the potentiometric heads at depth may represent higher equivalent freshwater head, although due to the relative homogeneity in groundwater salinity within hydrostratigraphic units it is likely that density does not have a significant impact on horizontal groundwater flows (WRM, 2015).

Although heads in the Shepparton Formation and Loxton-Parilla Sands are similar, the results of pumping and injection trials during the 2014 site activities related to the previous EIS submission (EMM, 2015), indicate that the two units are poorly connected (Iluka 2015) and that significant head differences may be created when water is extracted from or injected into one or other of these units. This is likely to be associated with the clay lens observed throughout the Shepparton Formation, particularly near its base.

3.4.3 Groundwater hydrograph responses

A selection of long-term hydrographs are shown in Figure 3.7. The responses indicate consistent steady water levels across Balranald, with very little seasonal variation or trend in any direction. Water levels in the Shepparton Formation (SF series) and Loxton-Parilla Sands (LPS series) are similar, with all six bores showing groundwater levels between 50–55 mAHD. The groundwater pressures within the Olney Formation (OF series) are noticeably higher, ranging between 58–62 mAHD. The Olney Formation has artesian pressure at Balranald, with the Geera Clay acting as a thick confining layer between the Olney Formation and the shallower aquifers.

3.4.4 Hydraulic conductivity and properties

Hydraulic conductivity in the Shepparton Formation is highly variable, due to the heterogeneous nature of this Formation with sand and clay lenses throughout. Continual lateral flow through the units of this formation is not common. A range of bulk hydraulic conductivity is observed in the Loxton-Parilla Sands, and this is due to the differences in the hydraulic conductivities of the surf and offshore zones. The stratification in this unit is likely to cause considerable vertical anisotropy in hydraulic conductivity values (WRM, 2015).

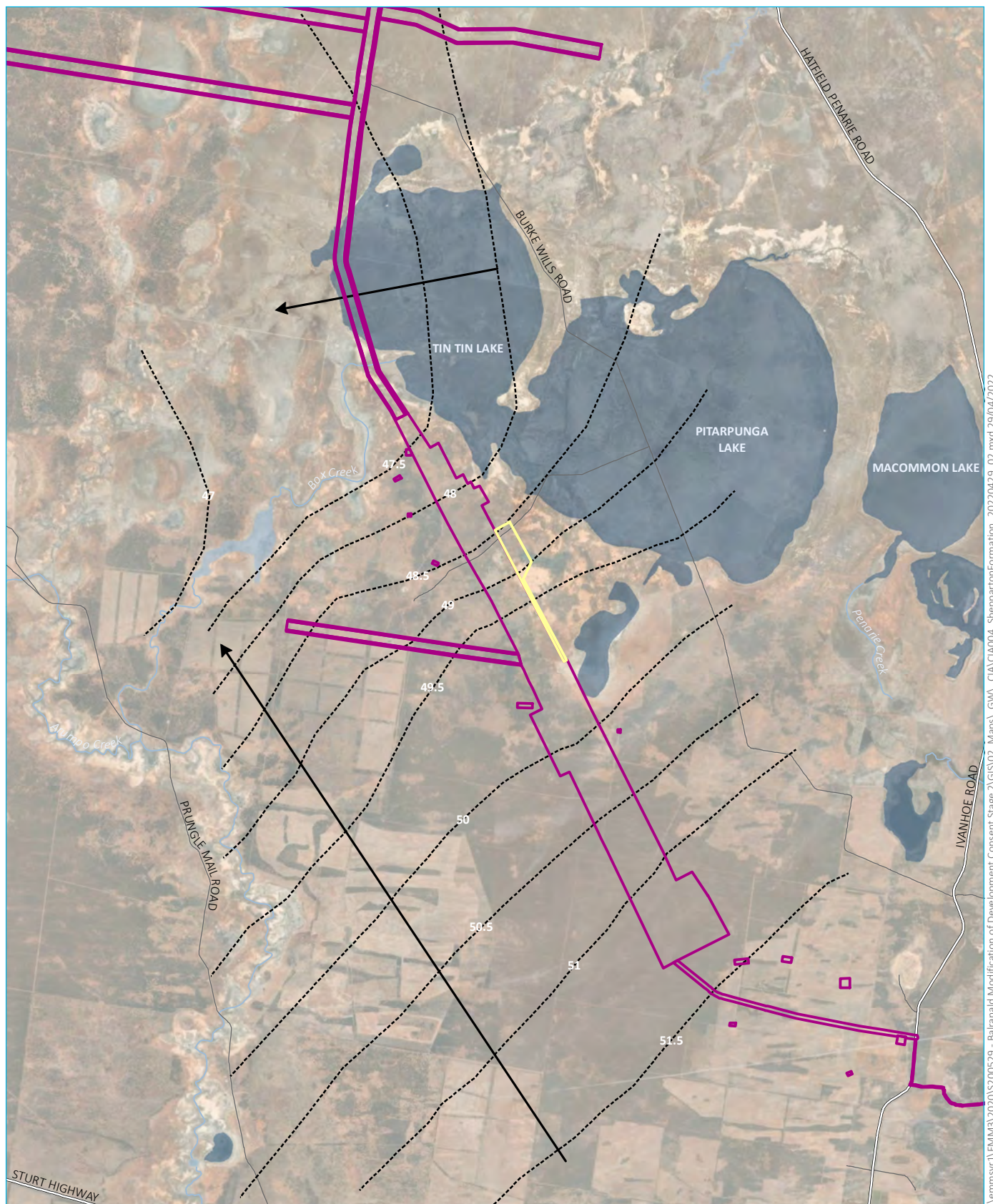
Horizontal hydraulic conductivity in the Olney Formation decreases proportionally with distance from the eastern to western Riverine Plain (Kellet 1994). Typically, the vertical hydraulic conductivity is at least an order of magnitude lower than horizontal hydraulic conductivity (Evans and Kellet 1989).

The hydraulic properties in the MOD1 numerical groundwater model (discussed further in Section 5.3) are presented in Table 3.2. The anisotropy in the Loxton-Parilla Sands is represented by five layers, from shallow to deep: LPS1 foreshore, LPS1 surf zone, LPS1 lower shore + LPS2 foreshore, LPS2 surf zone and LPS2 lower shore. The Shepparton Formation is modelled with two layers and of the same hydraulic properties. The calibrated modelled aquifer properties are consistent with the parameters derived from historic hydrogeological field assessments (Iluka 2015).

Table 3.2 **MOD1 modelled aquifer hydraulic properties**

Formation	Kh (m/d) ¹	Kv (m/d) ²	Sy ³	Ss (m ⁻¹) ⁴
Shepparton Formation	1	0.001	0.15	3 x 10 ⁻⁵
LPS1 foreshore	0.9	0.001	0.15	3 x 10 ⁻⁵
LPS1 surf zone	16-24	0.1	0.15	3 x 10 ⁻⁵
LPS1 lower shore/LPS2 foreshore	0.9	0.001	0.15	3 x 10 ⁻⁵
LPS2 surf zone	10-40	0.1	0.15	3 x 10 ⁻⁵
LPS2 lower shore	0.9	0.001-0.13	0.15	3 x 10 ⁻⁵
Geera Clay	0.0001	0.00001	0.15	3 x 10 ⁻⁵
Olney Formation	3	0.3	0.15	3 x 10 ⁻⁵

Notes: 1. Horizontal hydraulic conductivity.
 2. Vertical hydraulic conductivity.
 3. Specific yield.
 4. Specific storage.



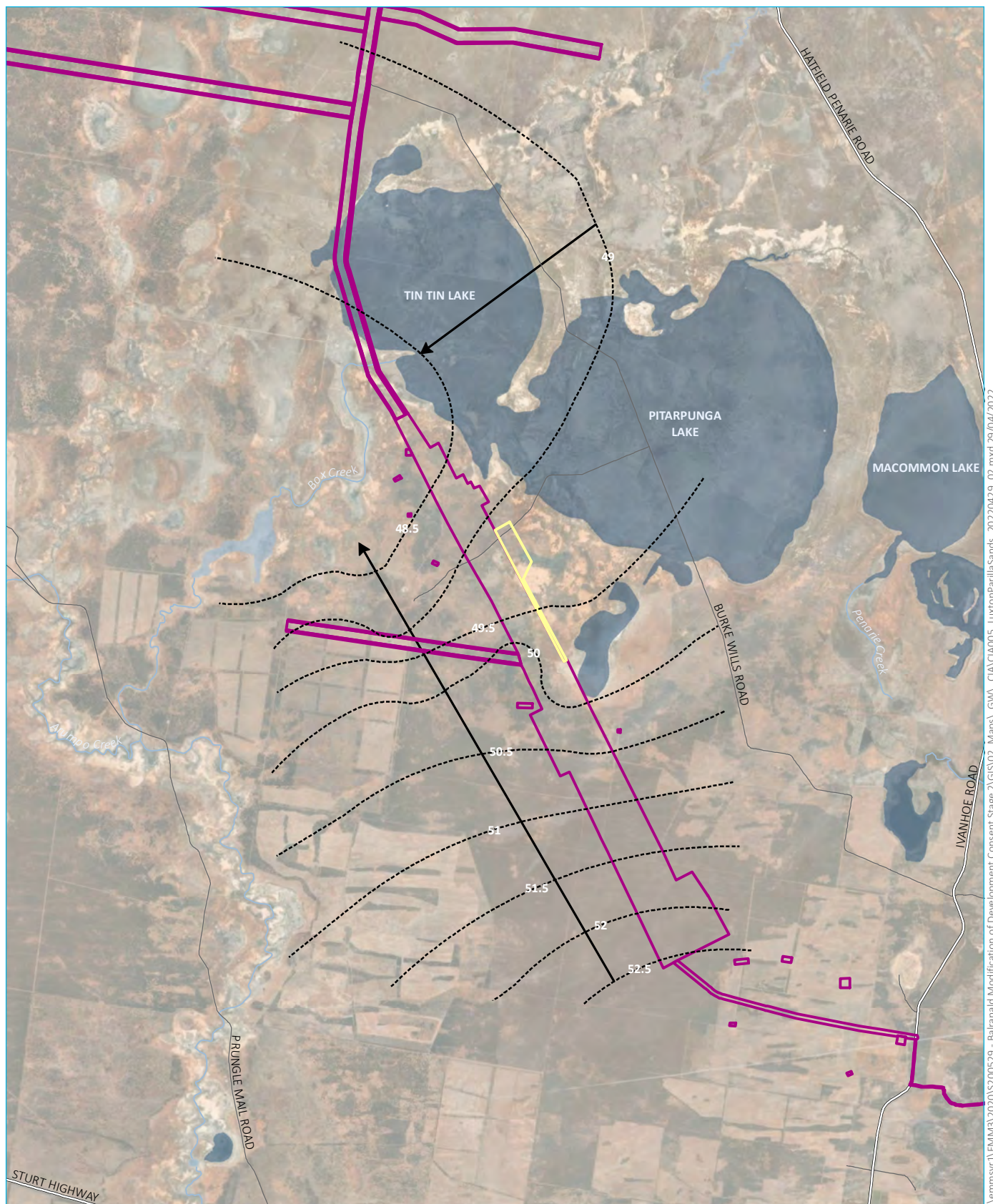
Source: EMM (2022); Iluka Resources (2021); ESRI (2021); DFSI (2017); GA (2011)

KEY

- EIS Approved Balranald Project Area (SSD-5285)
- Proposed modification extension to Balranald Project Area boundary
- Flow line
- Shepparton Formation (m AHD)
- Major road
- Minor road
- Named watercourse
- Ephemeral lake
- Perennial lake

Shepparton Formation (unstressed)
potentiometric surface (m AHD)

Balranald Mineral Sands Project
Balranald groundwater comparative impact assessment
Figure 3.3



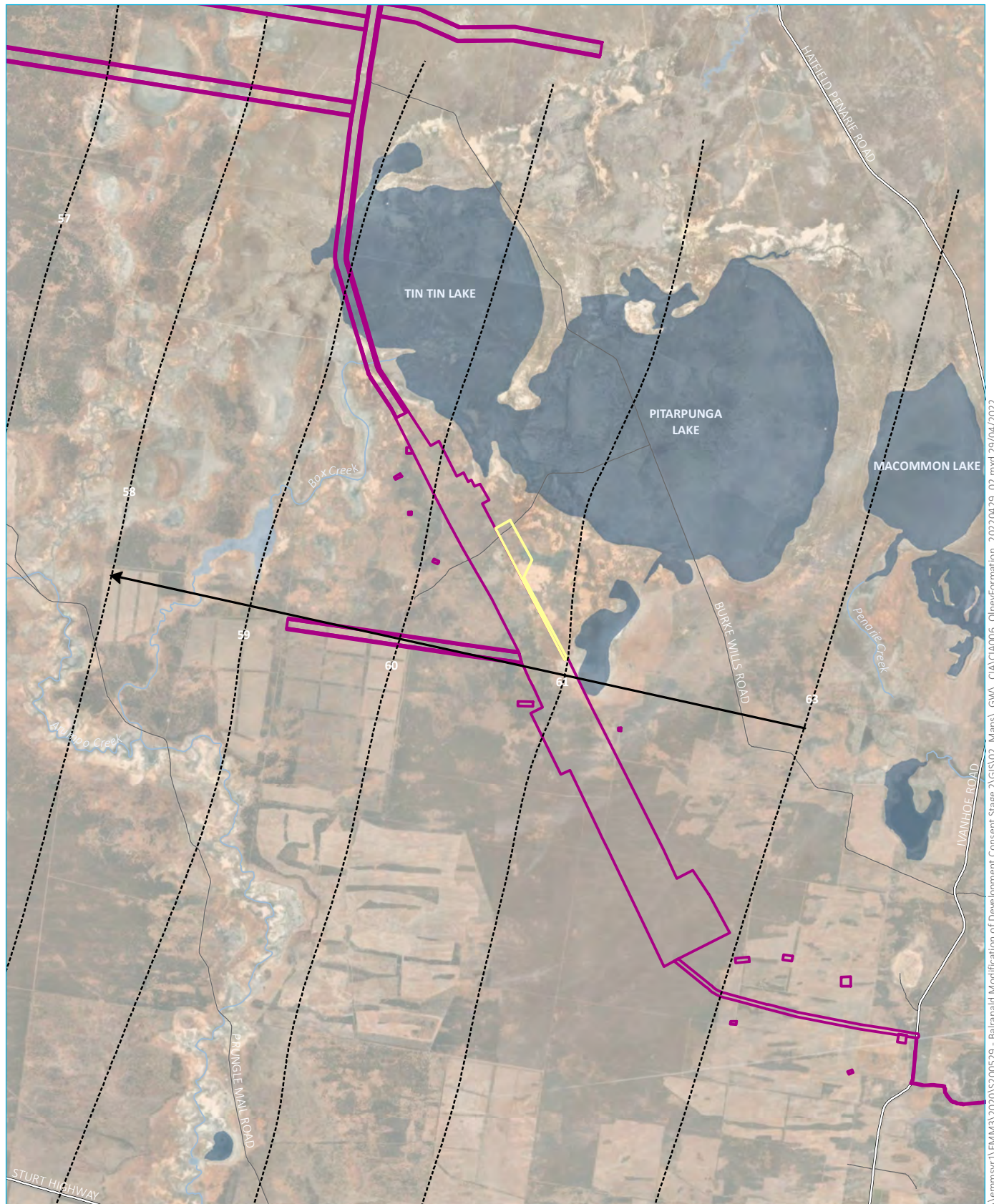
Source: EMM (2022); Iluka Resources (2021); ESRI (2021); DFSI (2017); GA (2011)

KEY

- EIS Approved Balranald Project Area (SSD-5285)
- Proposed modification extension to Balranald Project Area boundary
- Flow line
- Loxton Parilla Sands (m AHD)
- Major road
- Minor road
- Named watercourse
- Ephemeral lake
- Perennial lake

Loxton Parilla Sands Formation (unstressed)
potentiometric surface (m AHD)

Balranald Mineral Sands Project
Balranald groundwater comparative impact assessment
Figure 3.4



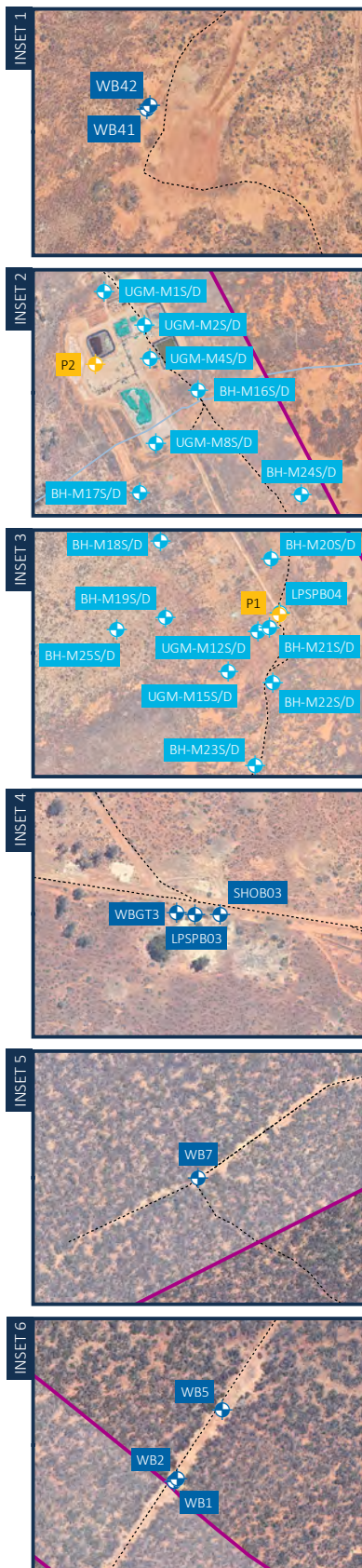
Source: EMM (2022); Iluka Resources (2021); ESRI (2021); DFSI (2017); GA (2011)

KEY

- EIS Approved Balranald Project Area (SSD-5285)
- Proposed modification extension to Balranald Project Area boundary
- Flow line
- Potentiometric surface (m AHD)
- Major road
- Minor road
- Named watercourse
- Ephemeral lake
- Perennial lake

Olney Formation (unstressed)
potentiometric surface (m AHD)

Balranald Mineral Sands Project
Balranald groundwater comparative impact assessment
Figure 3.5



Source: EMM (2022); Iluka Resources (2021); DFSI (2017)



KEY

■ EIS Approved Balranald Project Area (SSD-5285)

— Major road

— Minor road

..... Vehicular track

— Watercourse/drainage line

■ Waterbody

Groundwater bore

◆ Monitoring bore

◆ Regional monitoring bore

◆ Production bore

◆ Third-party bore

Balranald monitoring network (GME and T3 network)

Balranald Mineral Sands Project
Balranald groundwater comparative impact assessment
Figure 3.6

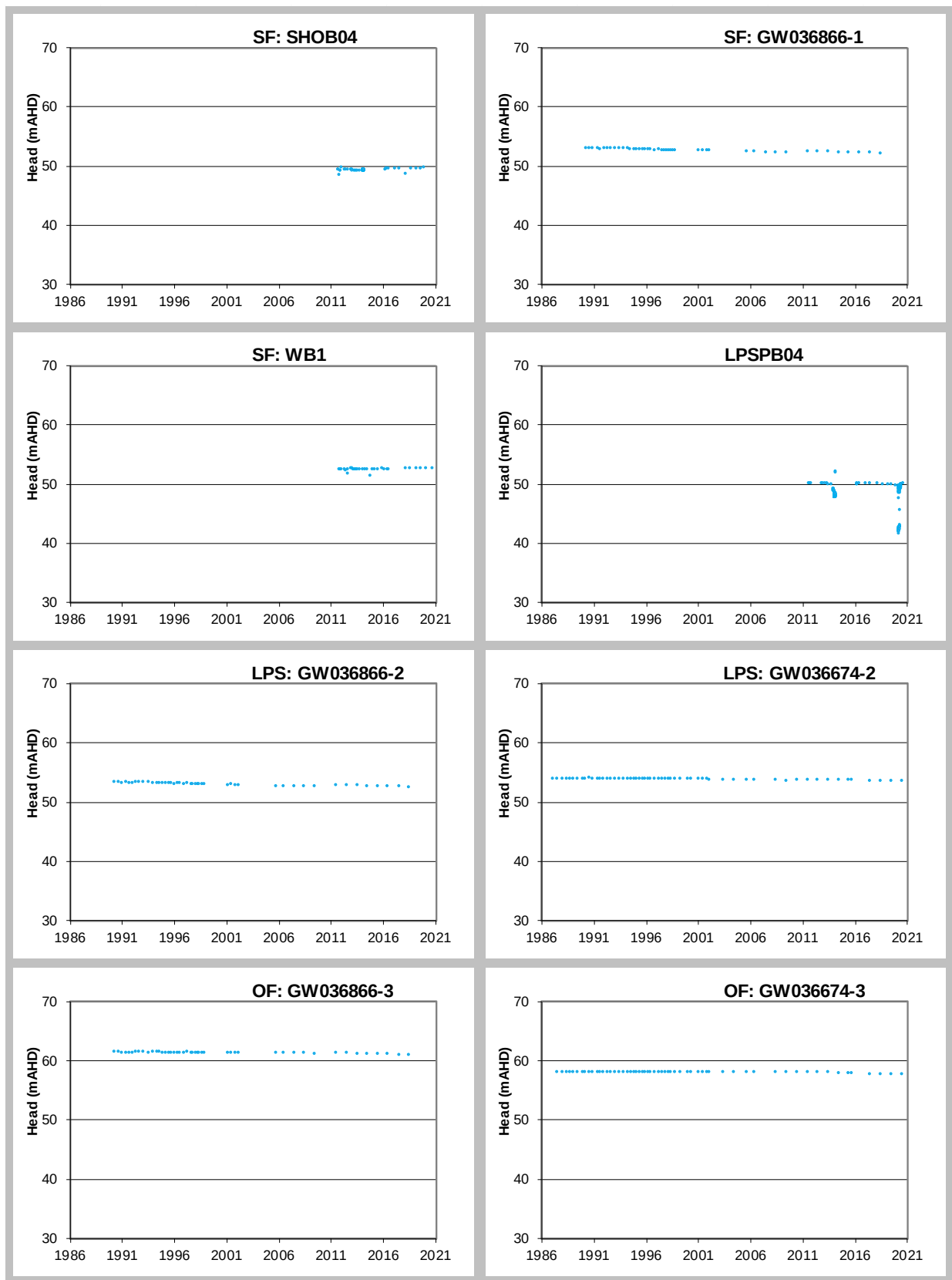


Figure 3.7 Selected long term hydrographs

3.5 Groundwater quality

Groundwater chemistry reports were collected from Earth Systems (2015), LWC (2017) and Iluka (2015a) to inform the T3 Groundwater Management Plan. This information provided a summary of the groundwater quality at the Balranald Project:

- The Shepparton Aquifer is characterised as saline to hypersaline (Median TDS = 39,650 mg/L), with total dissolved solids (TDS) ranging between 19,700 and 57,200 milligrams per litre (mg/L), and is deemed unsuitable for irrigation and stock and domestic purposes (ANZG, 2018). The median pH is neutral (7.13), but ranges between 3.85 and 8.1, whilst the redox (oxidation-reduction potential) is considered denitrifying to oxidising (-2 to 253 millivolts (mV); Stumm and Morgan, 1981).
- The LPS Aquifer is characterised as saline to hypersaline (Median TDS = 33,000 mg/L), with TDS ranging from between 8,870 and 48,200 mg/L and is deemed unsuitable for irrigation. Certain bores are identified as a tolerable drinking source for sheep (ANZG, 2018); however these bores are located adjacent to the Murrumbidgee River and, similar to the Shepparton Formation, may be influenced by proximity to the comparatively fresher, losing Murrumbidgee River. The median pH is neutral (7.16), but ranges between 6.19 and 8.40, whilst the redox condition is considered denitrifying to moderately reducing (-6 to 193 mV).
- Within the Balranald Project area, the Geera Clay has no representative chemical analyses, and no monitoring locations are discretely screened within the Formation. Pore-water samples extracted from the Geera Clay in bores drilled near Piangil in northern Victoria yielded TDS concentrations of approximately 200,000 mg/L (Evans 2014) and electrical conductivity (EC) concentrations in two bores in the area yielded salinities of ~37,000 microsiemens per centimetre ($\mu\text{S}/\text{cm}$), comparative with the Middle Renmark Group, which inter-fingers with the Geera Clay.
- Brackish to saline groundwater is observed in the Lower Renmark Group Aquifer (Median TDS = 4,349 mg/L), with TDS ranging between 2,490 and 10,265 mg/L and is deemed suitable for irrigation of salt tolerant crops and as a tolerable drinking source for most stock purposes (ANZG, 2018). The median pH is circum-neutral (7.50), but ranges between 5.70 and 9.63, whilst the redox condition is considered denitrifying to slightly reducing (-1 to 254 mV).

A Piper diagram comparing the groundwaters from samples obtained in the vicinity of the MOD1 footprint during the T3 trial to groundwater sampled from regional bores (outside of the T3 project area), grouped by aquifer, is presented in Figure 3.8. This Piper diagram shows that all of the groundwater samples are sodium chloride type, and there is little difference between the T3 bores and regional bore signatures.

Samples obtained from bores screening the LRG have a lower proportion of sulphate than those that are screening in the SFM and LPS aquifers. It is noted that none of the T3 bores monitored for groundwater quality are screened in the LRG and therefore only regional samples are available for this aquifer.

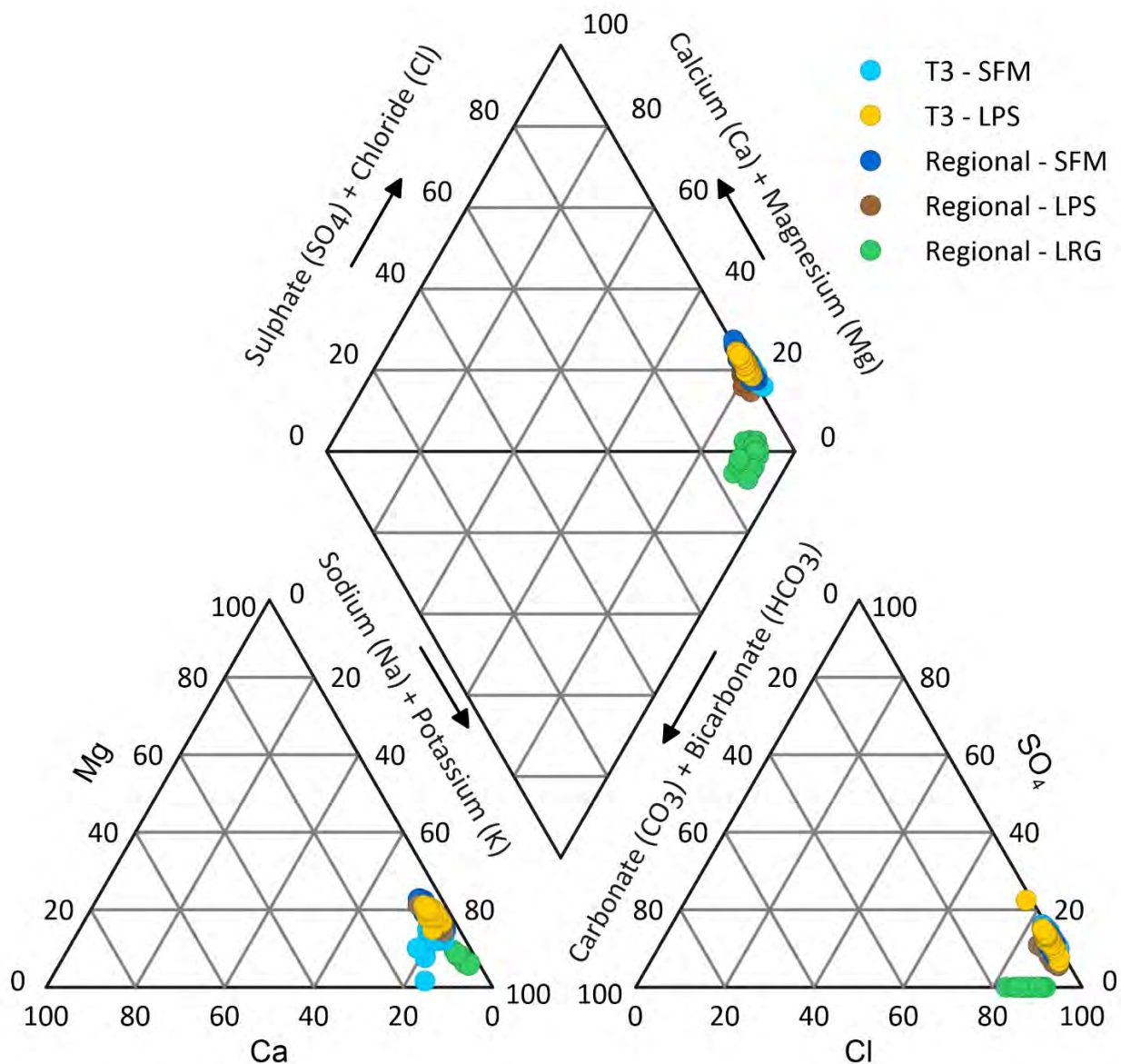


Figure 3.8 Piper diagram – comparative assessment of regional groundwater quality to T3 bores in the vicinity of the MOD1 footprint

3.6 Ecosystems that rely on groundwater

3.6.1 High priority groundwater dependent ecosystems

NSW WSPs include schedules with lists of high priority groundwater dependent ecosystems (GDEs) which are required to be assessed using the minimal impact criteria outlined in the AIP (AIP; DPI Water 2012). Groundwater WSPs were previously reviewed for reference to GDEs and only the Lower Murrumbidgee Groundwater Sources, a water source within the Murrumbidgee Alluvial Groundwater Sources 2020, identified high priority GDEs. There were no high priority GDEs identified in the Western Murray Porous Rock Groundwater Source of the MDB Porous Rock WSP (WRM 2015).

3.6.2 Ecosystems that potentially rely on groundwater

The baseline investigations (SKM 2011), undertaken as part of the PFS, identified the occurrence of ecosystems that potentially rely on groundwater in the vicinity of the Balranald Project area. This investigation mapped and characterised ecosystems that potentially rely on groundwater into two broad categories:

- wetlands and vegetation associated with the Murrumbidgee, Lachlan and Murray River Floodplain environments, as per the Lower Murrumbidgee Groundwater WSP for the vegetation to the south and west of the Murrumbidgee River; and
- vegetation (primarily Black Box woodland) outside the floodplain and permanent streams, in topographic depressions where the watertable may be shallow enough and not too saline.

The study found that potential groundwater reliance associated with both of these environments is likely to be only opportunistic. Groundwater use of vegetation in the region is influenced by two main factors: the depth of the watertable and groundwater salinity. The ecosystems that potentially rely on groundwater associated with the floodplain environments include the high value River Red Gum forests and the Great Cumbung Swamp. The Black Box woodlands away from the floodplain are less significant assets in terms of their ecological value, but they provide locally valuable shade and shelter for fauna (and stock) in a landscape sparsely populated by trees (WRM, 2015).

Rainfall and the periodic flooding of the Murrumbidgee River are more likely sources of water for vegetation (URS 2012). Thus, floodplain environments are considered to have a low susceptibility to altered groundwater conditions due to the close presence of the Murrumbidgee River, a regular flow regulated water source. Further from floodplains, vegetation may have a greater reliance on groundwater as there are no permanent water sources in these environments.

In 2014, an investigation was undertaken to establish where the Black Box vegetation was accessing water from the Shepparton Formation (CDM Smith 2015). This study found that rainfall and episodic surface water (irregular flooding and/or pooling from heavy rainfall) provided the dominant water source for Black Box, although there was some potential for these trees to use groundwater opportunistically to supplement their water needs. Previous studies have shown Black Box to be a hardy, resilient species capable of sustaining droughts and quite saline conditions (up to 60,000 $\mu\text{S}/\text{cm}$). The River Red Gum is more tolerate to water logging than the Black Box community.

The spatial distribution of ecosystems that rely on groundwater, updated from the baseline investigation to include the areas of Black Box that were mapped in 2014 by CDM Smith (EMM 2015), and is shown on Figure 3.9.

3.6.3 GDE assessment sites

CDM-Smith developed a GDE classification system based of inferred groundwater salinity and depth to water. Class 1 and Class 2 GDEs are ecosystems that are more likely to rely on the presence of groundwater, compared to Class 5 which do not rely on groundwater. The classification system applied in a spatial sense using available coverages of groundwater depth and salinity (CDM-Smith, 2015) is shown on Figure 3.10. Figure 3.10 also shows the location of previously nominated hydrographs whereby potential changes in groundwater levels were assessed during the 2015 EIS using the previous EIS model developed by Jacobs (Jacobs, 2015). The sites that are largely associated with Class 2, Class 3 and 4 GDEs relate to the Murrumbidgee floodplain, Black Box communities, Box Creek and other vegetation communities where the depth to groundwater may be shallow.

3.7 Third party use

3.7.1 Landowner bores

Several landholders in the area rely on groundwater, sourced from the brackish Lower Renmark Group Aquifer (part of the Olney Formation), for stock, irrigation, and domestic use. These landholder bores are located throughout the Balranald Project area and shown in Figure 3.11.

The only aquifer with beneficial use is the Olney Formation due to its brackish salinity. This water is used for livestock drinking purposes. Within the Balranald Project vicinity, bores that could be impacted by mine related activities are summarised in Table 3.3.

Table 3.3 Olney Formation bores in the vicinity of the Project

Local name	Easting	Northing
HD1	726012	6185773
T01	722791	6201029
T02	729721	6195973
T03	732061	6189404
Karra Homestead	720430	6188310

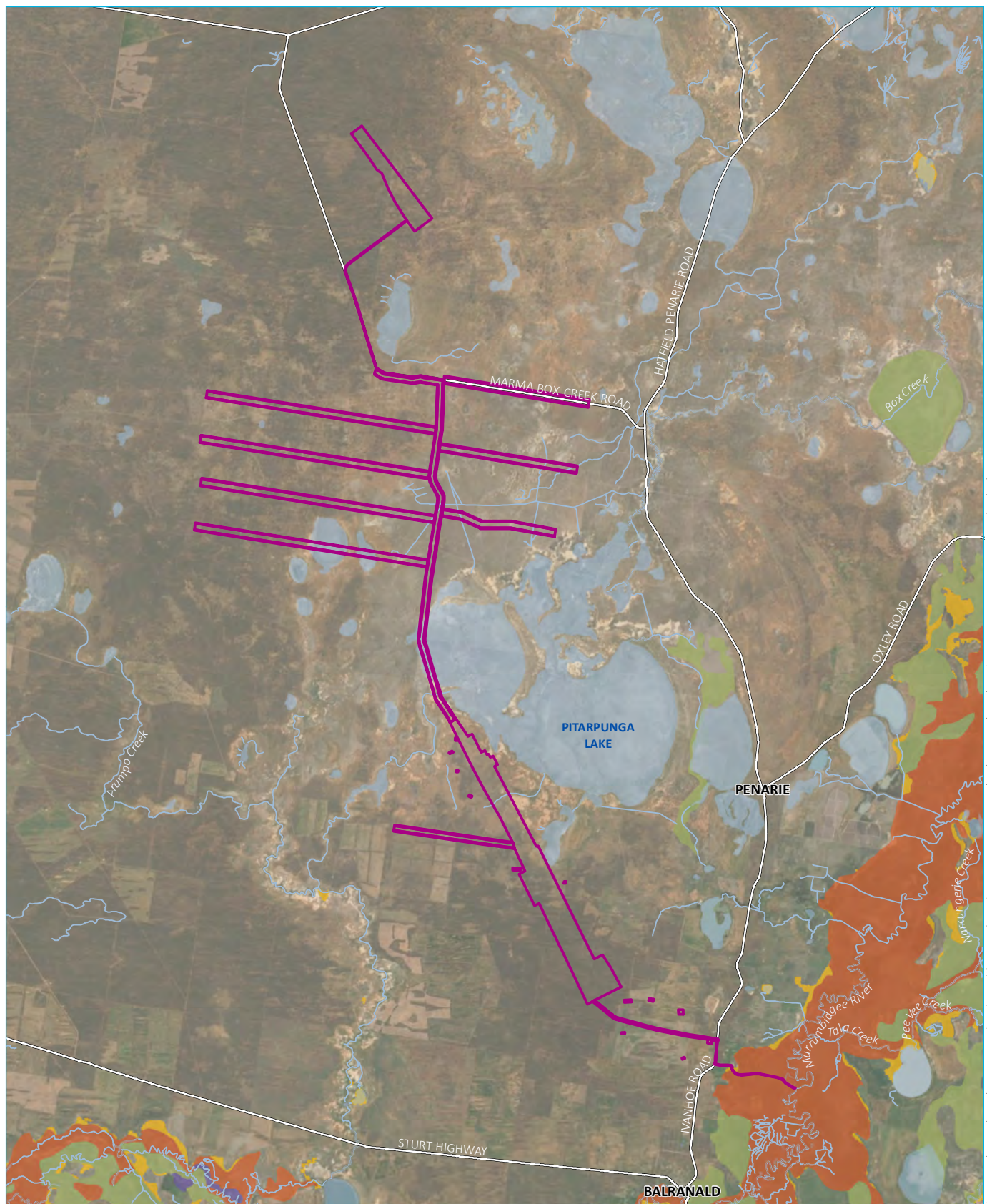
3.7.2 Atlas Campaspe Mine

Tronox's Atlas Campaspe Mine is located approximately 20 km north of Iluka's Nepean deposit and will comprise of extracting ore from two parallel deposits from the LPS. Water effecting activities on site include mine dewatering of two open cut mines and supplementary water supply from the LPS. The mine received development consent under the EP&A Act on the 6 June 2014. Previous assessments undertaken by EMM (EMM 2015), considered the interactions between the Balranald and Atlas-Campaspe mines to be negligible from a hydrogeological perspective.

Since receiving the original development consent, Tronox identified opportunities to expand their operations. On 22 July 2019, Tronox lodged the modification application for Atlas-Campaspe MOD1, which seeks approval for:

- increase mineral concentrate production;
- increase road and rail haulage;
- change the layout of and access to the Ivanhoe Rail Facility;
- add or change supporting infrastructure at the mine;
- extract groundwater for dust suppression at the Ivanhoe Rail Facility; and
- use local roads to access the mine.

The modification resulted in no changes to the project life, ore production rate, mining method or workforce size. There is no change to the disturbance area at the mine site, however there is a proposed variation to the disturbance area at the Ivanhoe Rail Facility, leading to a net reduction in vegetation clearance of 12 hectares (ha). The modification was approved on the 17 December 2019, and the mine is currently under construction.



Source: EMM (2022); Iluka Resources (2021); ESRI (2021); BOM (2017); DFSI (2017); GA (2011)

KEY

 EIS Approved Balranald Project Area (SSD-5285)

Major road

Watercourse/drainage line

Waterbody

Groundwater dependent ecosystem

Black Box woodland

Floodplain wetlands

Lignum and Chenopodium shrub land

Riverine Forest

GDE distribution

Balranald Mineral Sands Project
Balranald groundwater comparative impact assessment
Figure 3.9

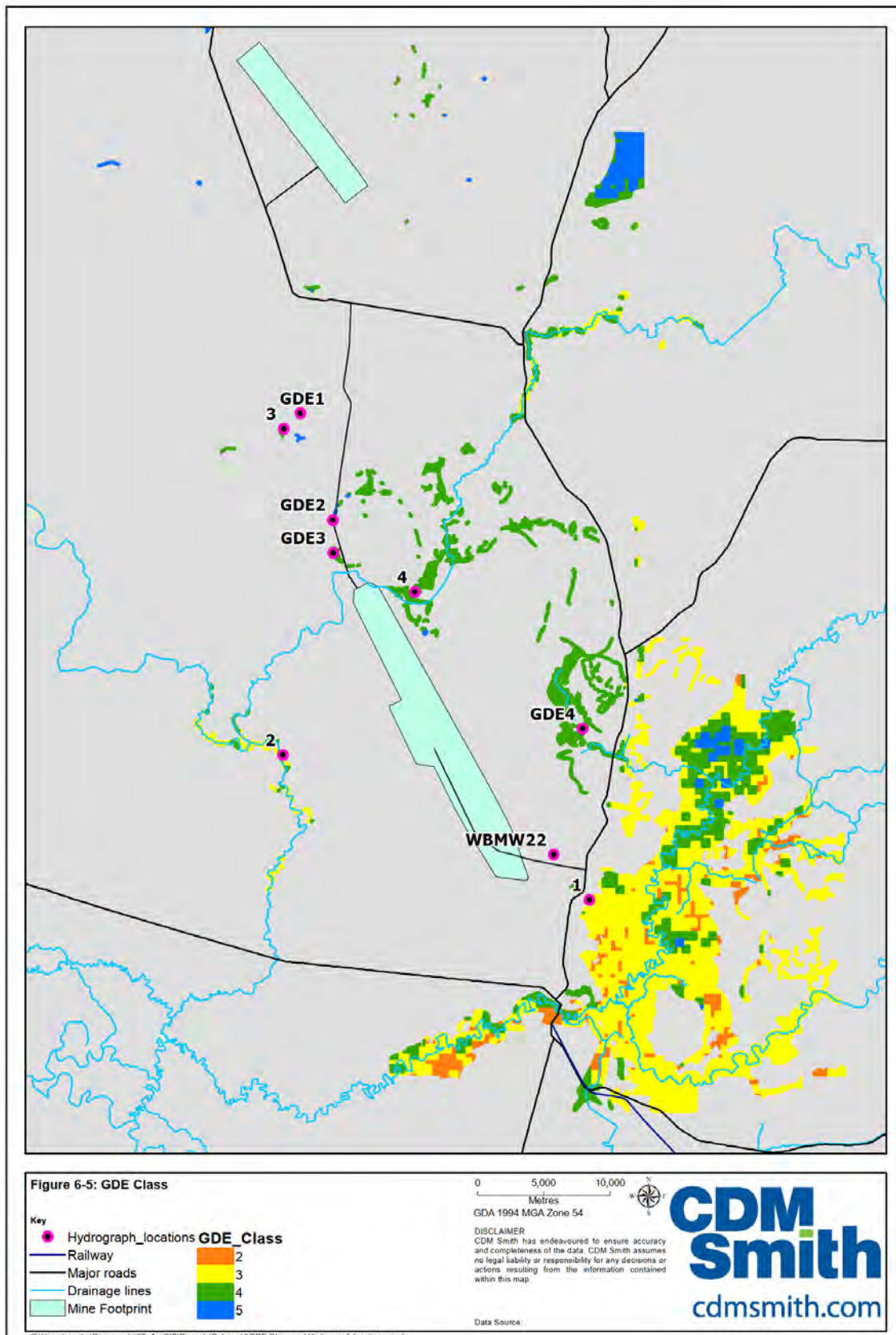


Figure 3.10 GDE class (after CDM Smith 2015)

4 Conceptualisation and water affecting activities

4.1 Conceptual models

A series of conceptual models have been developed to support previous studies and this groundwater comparative impact assessment (GIA) as follows:

- The underground mining process and how it interacts with the surrounding aquifer water pressures, quality and integrity (Section 4.1.1).
- The overall conceptual model including groundwater stresses, sources and sinks likely to develop during progressive mine development and rehabilitation including both surface and underground activities (Section 4.1.2).
- A focused geochemical conceptual model, which identifies potential sources of acid mine drainage (AMD) and processing chemicals that may impact groundwater quality (Section 4.1.3).

4.1.1 Underground mining process

The local stratigraphy shown below provides a conceptualised interpretation based on logging data acquired during hydrogeological studies (Iluka 2015 and 2016b) and data collected during the installation of monitoring infrastructure to support the T2 bulk sampling activity during 2016. The T3 assessment undertaken by EMM (EMM 2021), analysed the groundwater level and quality data collected during the T3 activity.

A summary of the hydrogeological conceptualisation related to the underground mining process and what effect it had on the surrounding aquifers is discussed below.

i Pre-mining

Figure 4.1 shows the pre-mining conceptual model, with the following attributes:

- The ore is hosted within the LPS aquifer, generally located below the LPS1 package and within the LPS2 package.
- High grade ore targets, predominantly consisting of ilmenite, are approximately 5 m thick and are located approximately 70 metres below ground level (mBGL).
- The watertable is hosted within the SFM aquifer at approximately 14 mBGL. The LPS potentiometric surface is also measured at around 14 mBGL, and thus the LPS is confined at the Site.
- The water pH of the LPS and SFM aquifers is approximately neutral, with mean pre-mining pH measurements of 6.98 and 7.20 respectively. The groundwater in these aquifers is saline, with the LPS and SFM having mean EC values of 51,000 and 56,000 $\mu\text{S}/\text{cm}$ respectively.

ii During mining

Figure 4.2 shows the mining conceptual model, with the following attributes:

- Increased pressure within the LPS aquifer may occur during the mining phase as a consequence of injecting high-pressure water into the mine stope to facilitate the mining process. The subsequent recovery is likely to be rapid due to the confining nature and high transmissivity of the LPS aquifer.
- Pressure impacts within the SFM aquifer should remain insignificant if a sufficient aquitard exists between the SFM and the underlying LPS. However, pressure increases within the SFM could occur in areas where a hydraulic connection occurs between the SFM and underlying LPS aquifer. This could occur in the absence of a basal bentonite unit at the base of the SFM.
- Subsidence events are not unexpected, with predictions of systemic subsidence across the mining zone. To date, there have been no long-term impacts on groundwater quality or groundwater levels in the area as part of the three assessment trials. If the ground surface subsides more than the maximum levels predicted, it is possible this may impact the natural groundwater level. The similarity in groundwater quality between the SFM and LPS aquifers suggest that any water quality impacts to the SFM aquifer (from the LPS aquifer) will be difficult to discern. It is possible that localised mounding within the SFM could mobilise salts within the unsaturated zone, however this risk would be minimised with final landform rehabilitation using non saline overburden, thus reducing salt store at the subsidence locations.
- Groundwater quality is not expected to be significantly affected by mining. The main source of potential contamination during mining would be drilling muds. LWC (2017a) reviewed the drilling mud mixture and concluded that the substances used are environmentally benign and unlikely to cause any significant change to groundwater quality.

iii Backfilling

Figure 4.3 shows the backfilling conceptual model, with the following attributes:

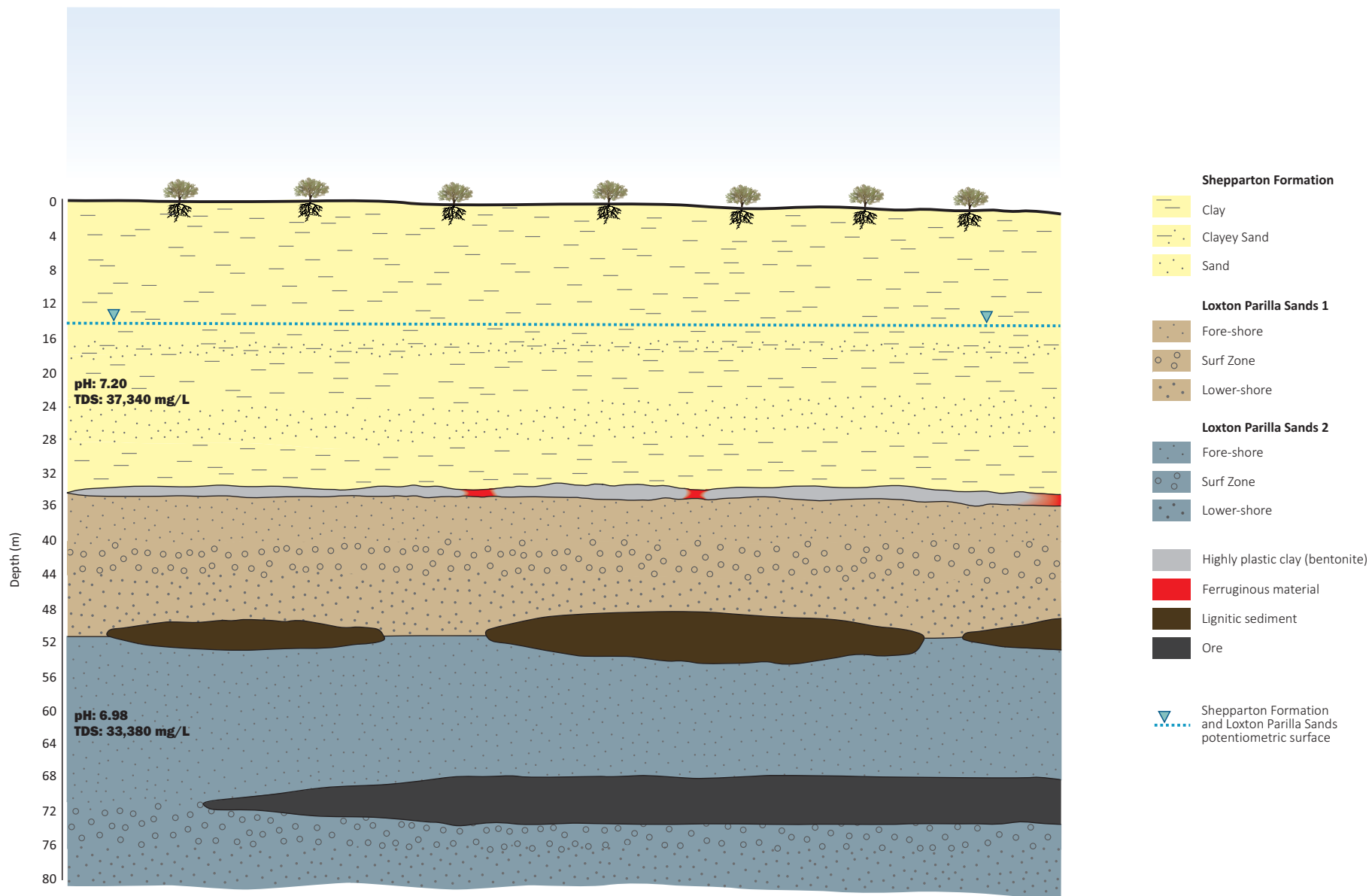
- Backfilling activities may result in significant pressure responses within the LPS aquifer, a consequence of injecting tailings into the mined cavity initially, with pressure impacts propagating throughout the aquifer thereafter. Pressure build-up is dependent on the stope dimensions, stope continuity and aquifer transmissivity. These parameters may vary between stopes or along the strike.
- Backfilling activities should not result in significant pressure responses within the SFM aquifer if a sufficient aquitard exists between the SFM and LPS aquifers in the trial area. This is generally represented by multiple clay horizons within the SFM itself, and commonly by a highly plastic clay located at the base of the SFM which represents naturally occurring bentonite along with the occasional ferricrete.
- Pressure impacts (both drawdown to supply process water and mounding due to mining/backfilling) are expected to be rapid, due to the confining and semi-confining nature of the LPS and SFM aquifers respectively.
- Some subsidence events are expected, with predictions of systemic subsidence across the mining zone. Some local subsidence may occur directly above the stopes. It is anticipated that a combination of successful backfill and strategic sand tailings placement will reduce potential impacts from subsidence.

- Reactive sulfide minerals within the extracted material may oxidise and generate acid and metalliferous drainage while stockpiled and exposed to atmospheric conditions. If reinjected without management or treatment, the pH of the groundwater system could be reduced leading to the mobilisation of metals. Aerated injected slurry or water could also react with in-situ sulfides within the aquifer itself. Other risks associated with chemical additives are discussed in Section 4.1.3.

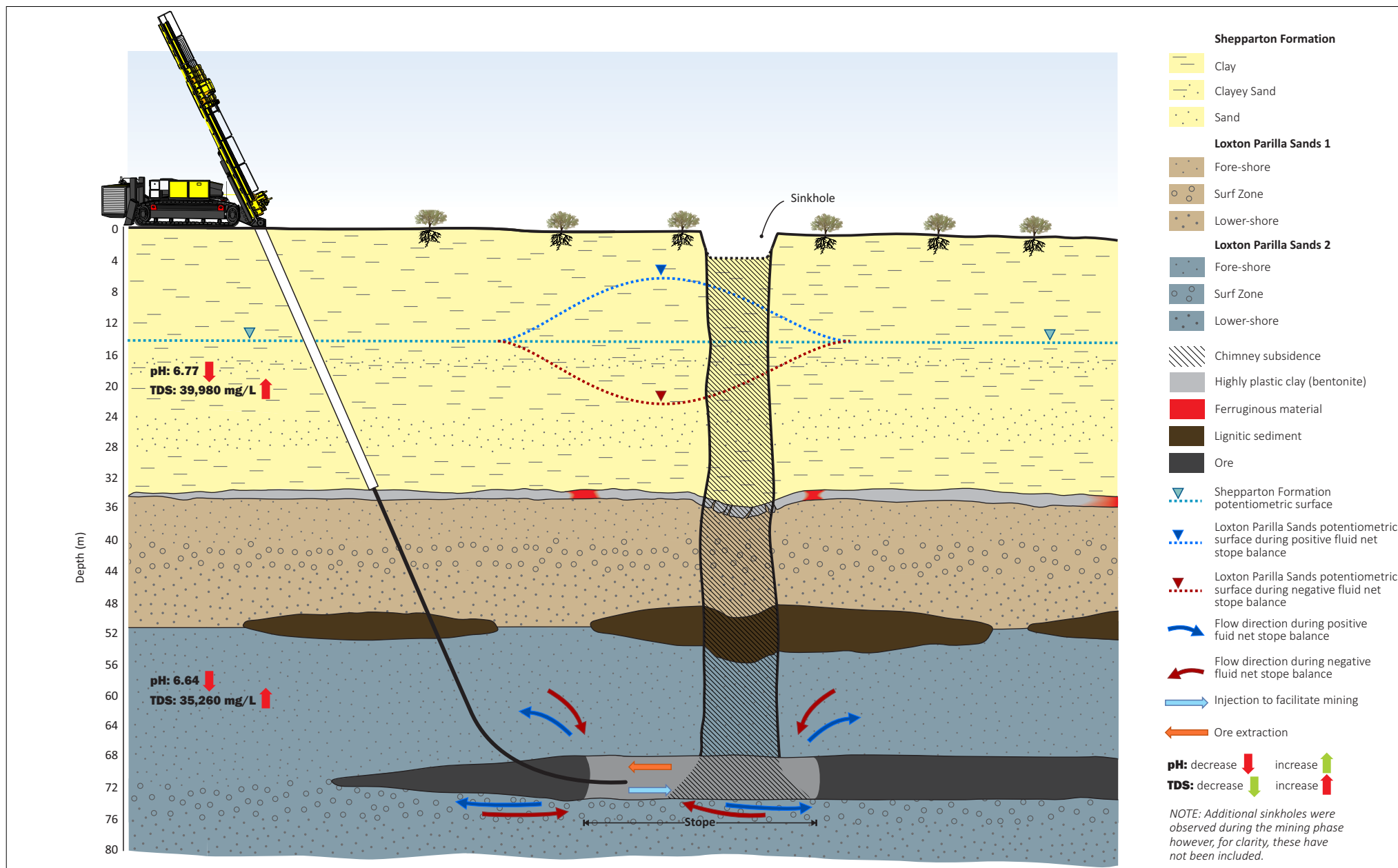
iv Post-mining

Figure 4.4 shows the post-mining conceptual model, with the following attributes:

- The post mining pressure impacts within the LPS aquifer are expected to recover to, or close to, the pre-mining groundwater pressure levels. Depending on the variability and level of backfilling achieved and thus the in-situ material density of the final stopes, final LPS groundwater pressures in close proximity to the stopes may be more subdued than the pre-mining levels. This would be caused by an area of the LPS which would exhibit higher transmissivities and porosity, compared to its pre-mining state.
- Large scale subsidence events are not unexpected beyond the stope footprint, with predictions of systemic subsidence across the mining zone. It is anticipated that successful backfill will reduce future potential subsidence. In the event of localised subsidence, Iluka will backfill the surface expression with benign material.
- Post-mining, any changes to groundwater quality that occurred in and adjacent to the stopes during backfilling are expected to return to baseline conditions over time as the aquifer recovers and mixes with more regional groundwater.



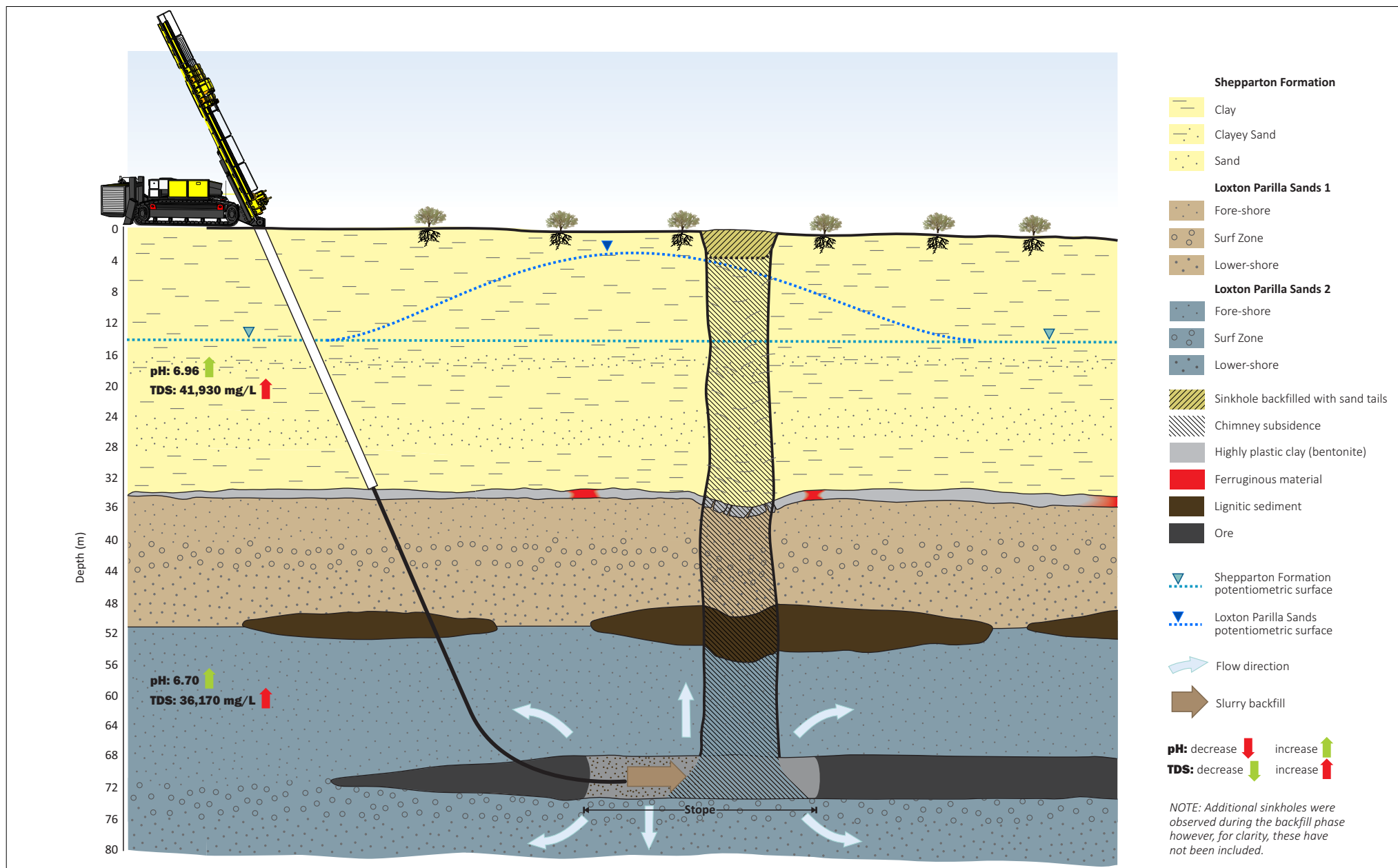
Hydrostratigraphy and pre-mining conditions



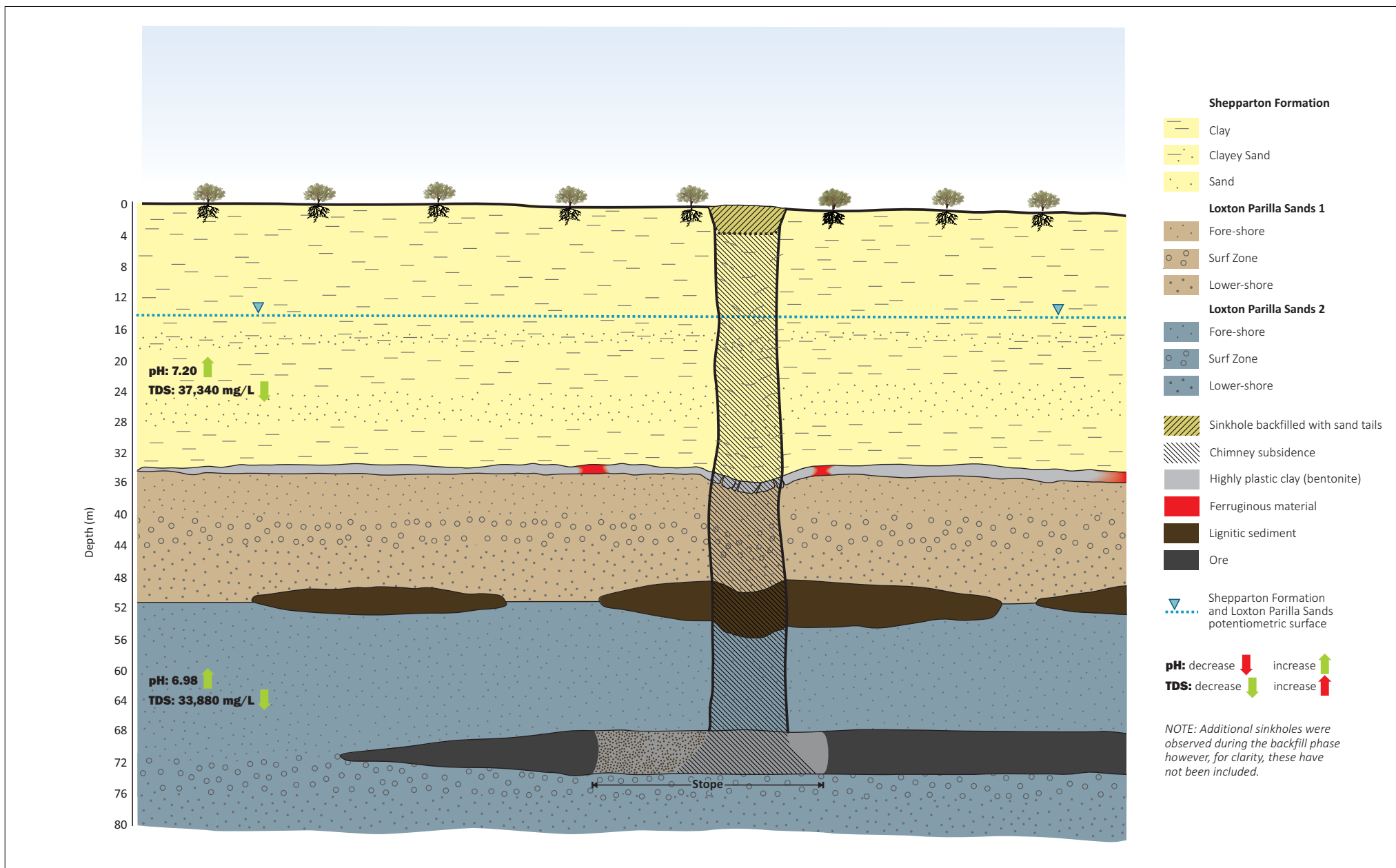
Hydrostratigraphy and mining phase conditions

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 Balranald Groundwater Comparative Impact Assessment

Figure 4.2



Hydrostratigraphy and slimes backfilling phase conditions



Hydrostratigraphy and post-mining conditions

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Figure 4.4

4.1.2 Water affecting activities and stressors

The conceptual model related to how the groundwater affecting activities interact with the surrounding environment as a result of the proposed modification is summarised in Figure 4.5. The main features include:

- Groundwater supply bores shown to the left of the figure. One production bore will target the LPS, which will direct saline water to the process water dam (PWD) to support mining and processing activities. Another two production bores will target the deeper Olney Formation to supply brackish water to the floatation dam and workshop. These activities have the potential to cause drawdown within the targeted aquifers. Drawdown within the LPS may encourage water associated with injected slimes to migrate towards the production bores and indirectly take from the overlying Shepparton Formation, which could cause watertable drawdown. Drawdown within the Olney Formation could cause induced saline water migrating downwards from the overlying Geera Clay and drawdown to nearby third-party bores.
- Seepage from sand tails is assumed to occur for approximately 10 days and located one mine panel¹ or approximately 155 m ahead of active mining. Emplacement of sand tails in advance of the mining front is aimed to induce subsidence. Seepage from sand tails may cause watertable mounding and migration of seepage water, emanating away from tailing emplacement areas.
- Mining the stopes is estimated to cause four meters of subsidence. Subsidence can cause increased hydraulic conductivity within the units and may manifest as depressions or 'sink holes' at land surface.
- The slimes fraction of the tailings will be reinjected into the previously mined stopes. Slimes injection will occur across five stopes simultaneously and will occur approximately 52 m behind the active mining stope. Slime injection may cause increased groundwater pressure to occur initially in the LPS, which may cause the injected water and any solutes to emanate away from the stopes being backfilled. If hydraulic connectivity has been increased due to subsidence, groundwater pressure could also increase in the overlying SFM, potentially causing watertable mounding.
- The mining and backfilling process will have insignificant impact on the underlying Geera Clay and Olney Formation, the latter only being affected by brackish water supply.

More detail related to the contamination sources and the potential direct effects on the surrounding environment is discussed in Section 4.1.3.

¹ One mine panel approximately includes 10 mine stopes

4.1.3 Geochemistry and processing

Iluka engaged Earth Systems to undertake geochemical testing of ore, products and mining by-products. The geochemical assessment is underway and geochemical and water quality impact assessments will be provided when the testing has been completed. A conceptual geochemical model of the groundwater system and potential sources of contamination that may affect groundwater quality is presented in Figure 4.6. The geochemical conceptual model is based on interim results and interpretations provided by Earth Systems (2020, 2021a, b, c, 2022). Key concepts that relate to water quality and geochemistry include:

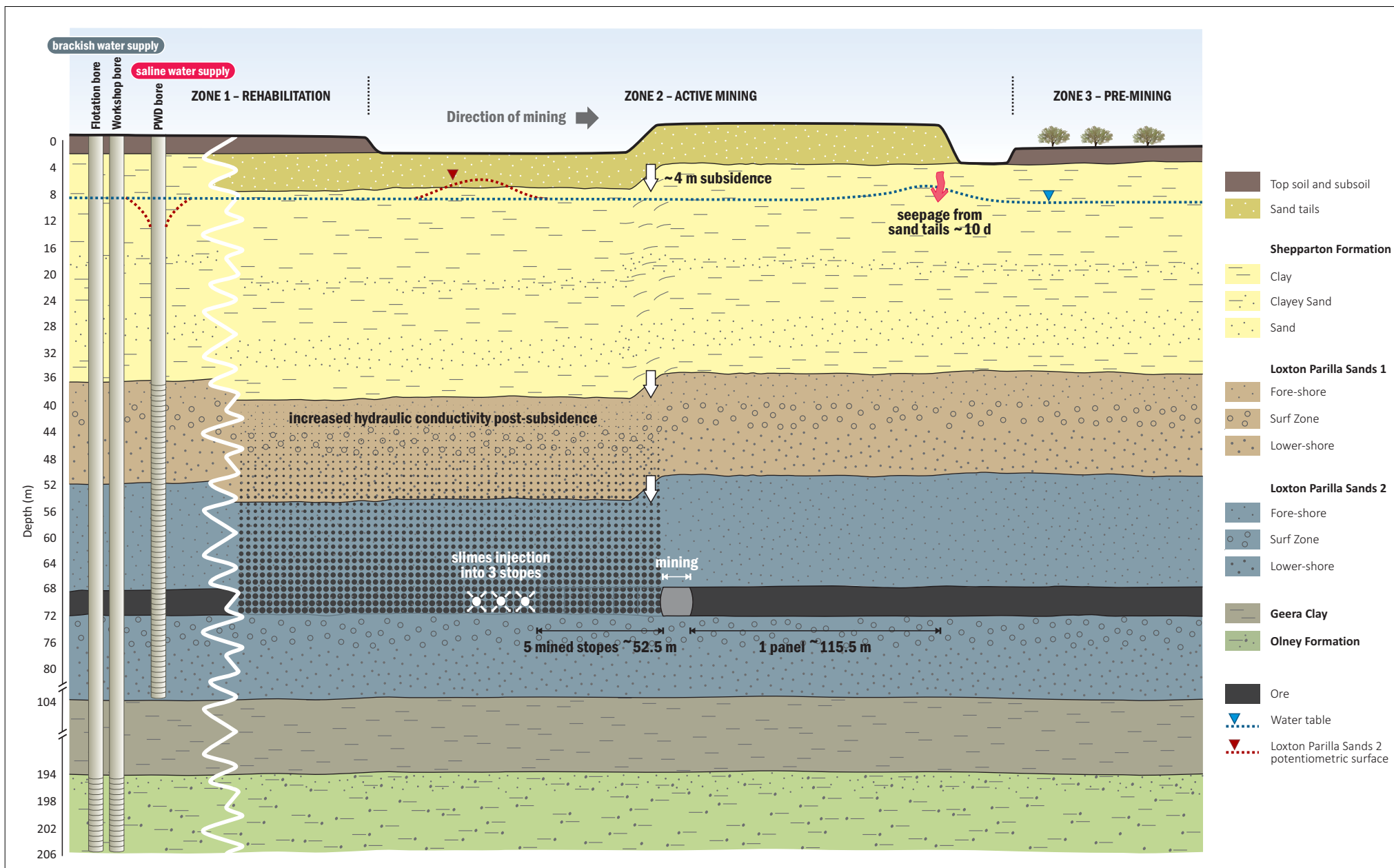
- Groundwater in the SFM and LPS aquifers is saline to hypersaline and has near neutral pH. Due to the high salinity, the water is not suitable for human consumption, irrigation or stock watering.
- Groundwater will be sourced from the saline LPS aquifer and from the brackish Olney Formation aquifer. Groundwater in the Olney Formation is less saline than groundwater in the LPS aquifer, and injecting water originating from the deeper formation into the LPS aquifer is not considered to pose a risk to water quality.
- Oxidation of reducing minerals such as pyrite does not occur naturally in the SFM and LPS aquifers because the dissolved oxygen concentration is limited, and the groundwater is not in contact with oxygen in the atmosphere.
- The ore contains sulfide minerals which may oxidise when brought to surface during mining. Oxidation of sulfide minerals generates acidic water and liberates heavy metals. This process is referred to as AMD, which will be minimised by the addition of limestone to de-slimes ore, products and by-products that contain sulfide minerals.
- Process chemicals will be added during ore processing to remove sulfides and other waste products, and to concentrate magnetic and non-magnetic saleable products. Potassium amyl xanthate (PAX) are expected to last a few days in the natural environment (NICNAS 1995) and they are not expected to bioaccumulate (Earth Systems 2021 b, c, 2022b).
- A portion of the PAX will biodegrade in storage dams and tanks and some PAX will sorb to surfaces of solids. It is currently assumed that 50% of the PAX will sorb to fine-grained tailings and recent monitoring indicates that half of the PAX degrades in less than eight weeks. Further testing on PAX sorption and degradation will be conducted.
- Ore processing separates saleable products from oversized material, sand tails and fine sand tails. The by-products and saleable products will temporarily be stored in stockpiles. Sulfide minerals from the ore will primarily be concentrated in the sand fines fraction but some other by-products will contain some sulfides. Sulfidic waste products will be amended with lime to prevent or minimise water quality impacts due to AMD (Earth Systems 2020, 2022a).
- Sand tails will be amended with lime and permanently placed above the mined stopes to counteract subsidence and recontour the land surface.

- Floatation tails and sand fines will be mixed with supernatant water from the PAX dams in the hydraulic backfill (HBF) tank and will be re-injected into the ore body. Sulfides will be concentrated in the waste during the floatation process and will be returned to the LPS and are not expected to further oxidise because of the limited dissolved oxygen. Some AMD will be generated during temporary storage of waste above ground, including existing fines from trial mining. Sand fines and floatation tails not directly re-injected will be amended with limestone sand to neutralise generated acidity. Sorption of PAX to fine-grained tailings and degradation in storage ponds and tanks will reduce the PAX concentration. Once injected into the LPS aquifer, PAX will also sorb to aquifer solids and will continue to degrade which will reduce the mobility of PAX and will consume PAX from the groundwater. Groundwater abstraction from the PWD bore will likely induce some drawdown towards the bore which may cause the PAX containing groundwater to migrate in the direction of the PWD bore.

The following sources of potential water quality impacts have been identified. The sources are labelled A to E within Figure 4.6 and the two most relevant sources are presented in Figure 4.7:

- Re-injection of tails and supernatant water introduces PAX and returns sulfide minerals to the LPS aquifer. Sulfide minerals originate from the ore and are considered to be stable once re-injected because of the low concentration of dissolved oxygen in the LPS aquifer. However, AMD would be generated if sand fines, and floatation tails are stored above ground and become unsaturated. The material would need to be amended with limestone sand to prevent injecting acidified slurry into the aquifer. The PAX concentration of the re-injected slurry is estimated to be 110 mg/L but further testing is being conducted to more accurately estimate the PAX concentration (Earth Systems 2022). Some of the re-injected PAX will sorb to surfaces on aquifer solids which will slow down the transport of PAX with groundwater. PAX is also expected to biodegrade in the aquifer and the concentration will decrease over time. The degradation rate in the aquifer is not known. Groundwater modelling (Appendix A) was conducted assuming that half of the PAX concentration degrades within 12 weeks based on observed degradation rates above ground, but PAX sorption to aquifer solids was conservatively not included in the model. Biodegradation of PAX will likely consume oxygen in the aquifer and may result in reducing conditions, ie absence of oxygen. Reducing conditions may cause some native metal(loid)s (eg iron, manganese, arsenic) to dissolve and become mobile. Those metal(loid)s are expected to precipitate when the oxygen depleted groundwater mixes with background groundwater. The residual risk of AMD release into groundwater from tailings from the mining trial and from new mining by-products has been rated as moderate (Earth Systems 2022a).
- Wet sand tails will contain some PAX, which may seep into the ground. The PAX concentration and volume of seepage will be less compared to the re-injected tails and supernatant water, and is considered a lesser source of PAX. The PAX concentration in the seepage water is estimated to be 5 mg/L (Earth Systems, personal communication, 21 December 2021), however a more recently revised floatation circuit design includes a filter belt which will prevent PAX coming in contact with the sand tails (Iluka, 2022). The sand tails contain sulfide minerals which will react with oxygen and generate acidity during temporary stockpiling and permanent placement above ground. The sand tails will be amended with lime to prevent acidification and reduce seepage of AMD to groundwater. The residual risk of AMD generation from mining by-product stockpiles has been rated as moderate (Earth Systems 2022a).
- Water in ore stockpiles, which will contain low concentrations of sulfide minerals, can potentially seep into the ground. The water content of the ore will be low, however, runoff from de-slimed stockpiled ore may affect surface water and groundwater quality. De-slimed ore will be stored on a low permeability pad comprising limestone, surface water drainage controls will be implemented, and the ore will be blended with sufficient quantity of limestone sand to neutralise AMD generated following dewatering. The residual risk to surface water and groundwater quality due to runoff or seepage from de-slimed ore has been rated as moderate (Earth Systems 2022a).

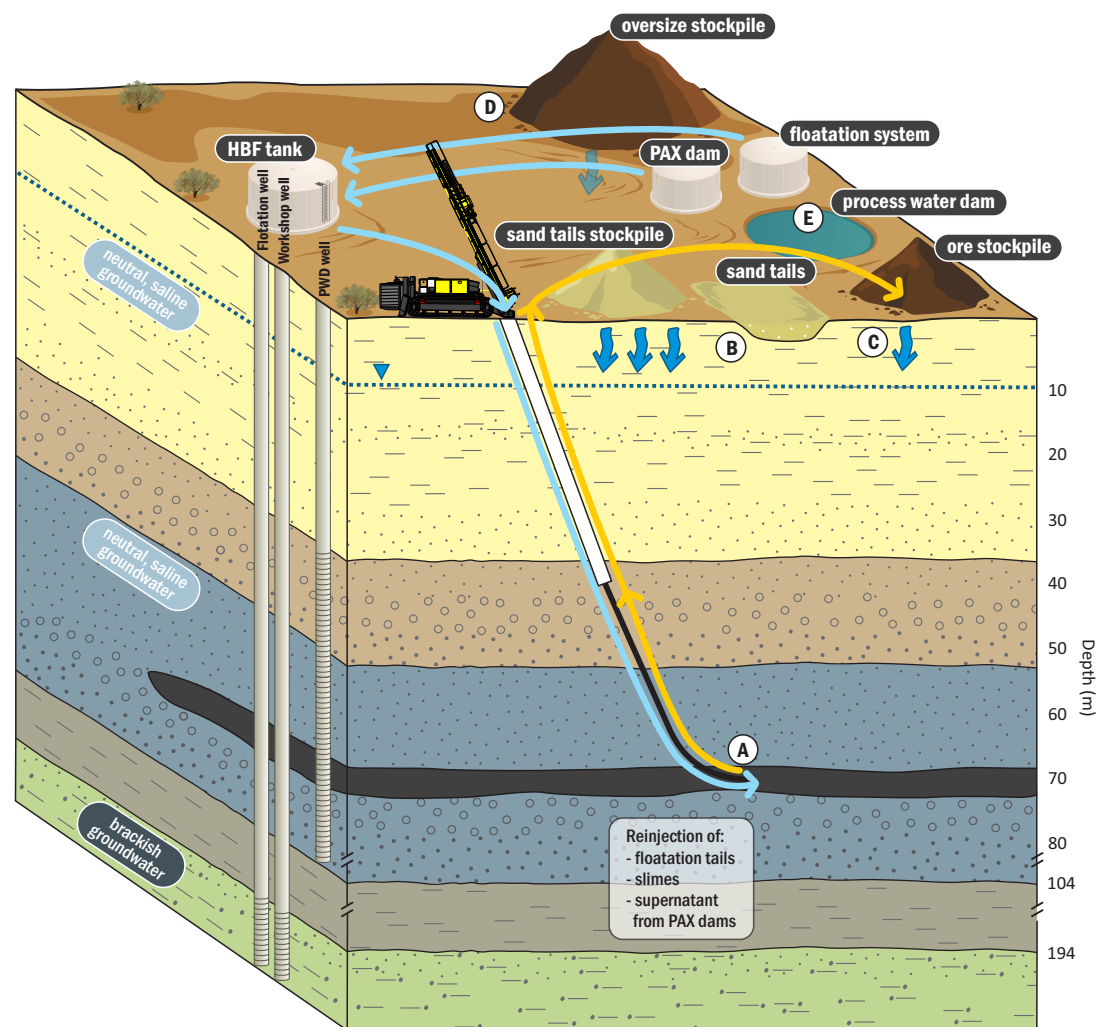
- The oversized material stockpile may contain some sulfides and some seepage may occur. The material will be amended with lime as needed to neutralise generated acidity. Risk to groundwater quality is considered low.
- Seepage may occur from the Process Water Dam, Fines Storage Dam, Dropout Dam and PAX Dams during mining. The process water may be affected by AMD and water in the PAX dam will contain process chemicals. The dams will be lined to prevent seepage and a monitoring program will be developed. The residual risk of seepage from the dams and from any sand fines or floatation tails that may not be backfilled by the HBF process was rated as high (Earth Systems 2022a, b). However, during the most recent mining trial, the pH of the process water was maintained neutral by addition of lime and it is unlikely that sand fines or floatation tails will remain above ground at the end of mining. The residual risk rating assuming that process control and slurry re-injection implemented during the mining trial will be achieved during mining, is therefore considered less, ie low.



Groundwater-affecting mining activities conceptual model

Iluka Resources
Balranald Groundwater Comparative Impact Assessment

Figure 4.5



Potential sources of water quality impacts

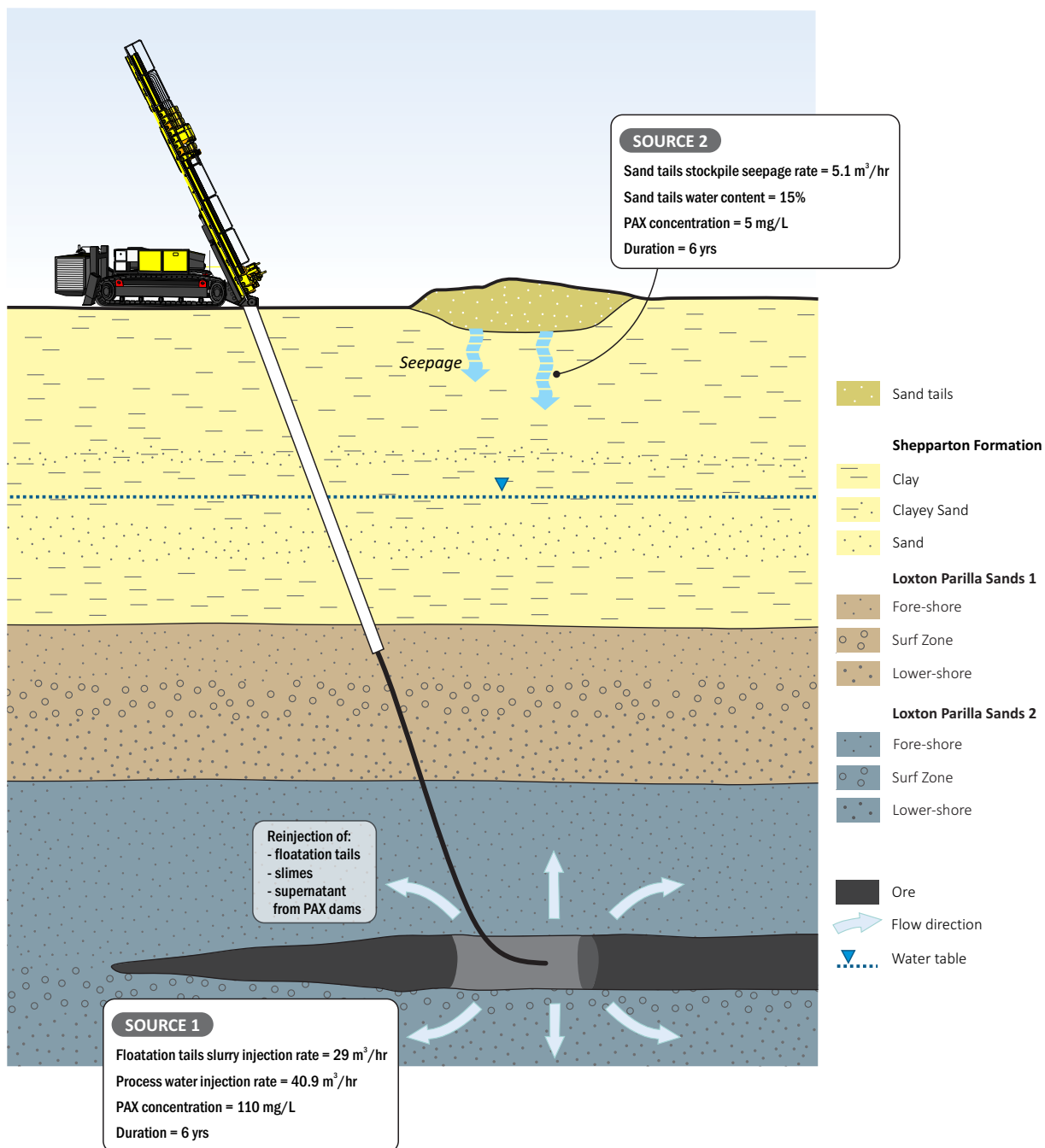
- (A) Reinjection of tails and water that contains PAX and sulfides. If by-products become acidic during temporary storage above ground, AMD would be generated and the material would need to be amended with limestone sand prior to injection.
- (B) Seepage of water containing PAX and AMD from sand tails temporarily stockpiled and permanently placed above mined stopes. Sand tails contain sulfide and will generate acidity that will need to be neutralised by amendment with limestone sand.
- (C) Potential AMD seepage and runoff from sulfide containing de-slimed stockpiled ore.
- (D) Potential AMD seepage from oversize stockpile. Addition of lime will neutralise AMD.
- (E) Potentially AMD affected water stored in various process and storage dams may seep into underlying groundwater should liners be compromised.



Note: ore extraction and reinjection happens at different times

Geochemical conceptual model

Iluka Resources
 Balranald Groundwater Comparative Impact Assessment
 Figure 4.6



PAX source conceptual model

4.2 Risk assessment approach

4.2.1 AIP assessment criteria

The predicted impacts of the activities affecting groundwater resources (and associated receptors) have been assessed against the minimal impact thresholds defined in the AIP. Impacts to groundwater are assessed via the consideration of high priority GDEs, high priority culturally significant sites, and third-party bores. This assessment has not changed since submission of the EIS (EMM 2015).

The minimal impact criteria is defined to establish principles for assessing impact to water table levels, water pressure levels and water quality across a range of different groundwater system types. The AIP classifies groundwater into 'highly productive' or 'less productive' based on the yield (>5 L/s for high yielding) and water quality (<1,500 mg/L total dissolved solids for high yielding). Thresholds are set in the AIP for the different groundwater classifications for the different minimal impact criteria. The applicable minimal impact considerations are detailed in Table 4.1.

The groundwater in the vicinity of the Balranald Project is classified as 'less productive', based on the very high salinity levels. The categories of less productive groundwater include alluvial, and porous rock and fractured rock.

Table 4.1 Minimal impact criteria for “less productive” porous and fractured rock water sources

Impact level	Watertable	Water pressure	Water quality
Level 1 impact (ie less than minimal)	Less than or equal to 10% cumulative variation in the water table, allowing for typical climatic ‘post-water sharing plan’ variations, 40 m from any: a) high priority groundwater dependent ecosystem; or b) high priority culturally significant site. Listed in the schedule of the relevant water sharing plan. A maximum of a 2 m decline cumulatively at any water supply work.	A cumulative pressure head decline of not more than a 2 m decline, at any water supply work.	Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.
Level 2 impact (ie greater than minimal)	If more than 10% cumulative variation in the water table, allowing for typical climatic ‘post-water sharing plan’ variations, 40 m from any: a) high priority groundwater dependent ecosystem; or b) high priority culturally significant site. Listed in the schedule of the relevant water sharing plan if appropriate studies demonstrate to the Minister’s satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site. If more than a 2 m decline cumulatively at any water supply work, then make good provisions should apply.	If the predicted pressure head decline is greater than requirement 1 above, then appropriate studies are required to demonstrate to the Minister’s satisfaction that the decline will not prevent the long-term viability of the affected water supply works unless make good provisions apply.	If condition 1 is not met then appropriate studies will need to demonstrate to the Minister’s satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.

Source: AIP DPI Water 2012.

Notes: ‘Post-WSP’– refers to the period after the first WSP in the water source begins, including the highest pressure head (allowing for typical climatic variations) within the first year after the first WSP begins.

‘Appropriate studies’ on the potential impacts of watertable changes greater than 10% are to include an identification of the extent and location of the asset, the predicted range of watertable changes at the asset due to the activity, the groundwater interaction processes that affect the asset, the reliance of the asset on groundwater, the condition and resilience of the asset in relation to watertable changes and the long-term state of the asset due to these changes.

All cumulative impacts are to be based on the combined impacts of all ‘post-WSP’ activities within the water source.

4.2.2 Direct and indirect assessment approach

The National Water Commission (NWC) mining risk framework (NWC 2010) has been adopted for the groundwater risk assessment. The framework uses a source-pathway-analysis that describes how water-affecting activities might impact on sensitive groundwater receptors. For an effect to occur to a sensitive water receptor, a pathway must exist between a water-affecting activity and a receptor. Risks are characterised by making an informed decision as to the potential for adverse effects to impact sensitive groundwater receptors as a result of project-related activities, while also considering the AIP.

The impact assessment quantifies the risk from water-affecting activities and involves assessing the potential consequences arising from the water-affecting activities in terms of direct effects (ie altered water resource condition, Section 4.2.3) and of possible indirect effects at identified receptors (Section 4.2.4). The risk assessment also provides a basis for communicating risks and consequences and identifying the management approach that may be necessary to eliminate or reduce risk. Results of both existing and new monitoring data will be used to review the management measures and approach over the life of mine (LOM).

4.2.3 Direct effects of underground mining on groundwater

Direct effects encompass changes to the water resource, extending to both water quality or ‘physical’ (ie storage, groundwater flow paths, levels and pressure) as a result of an activity or change to the existing environment. Direct effects arising through MOD1 are summarised in Table 4.2.

4.2.4 Indirect effects of underground mining on groundwater

Indirect effects typically occur as a response to direct effects, commonly impacting a sensitive receptor (ie GDE, third party bore). The assessment of potential receptor exposure to adverse changes in the groundwater regime (quantity, quality, groundwater and surface water interactions, and physical disruption of aquifers) requires:

- knowledge of the location of sensitive receptors within the landscape, particularly in relation to the location and area of influence of water affecting activities;
- an understanding of the receptor’s reliance on groundwater (eg depth to watertable, groundwater flux to baseflow-fed streams, groundwater quality to meet beneficial purposes); and
- an understanding of the spatial and temporal scale of direct groundwater effects at the location of sensitive receptors.

The indirect effects arising through MOD1 are summarised in Table 4.3.

Table 4.2 **Direct effects of water affecting activities and potential effects**

Water affecting activity	Potential effect	Project Phase		
		Construction	Operation	Rehabilitation and Closure
Groundwater quantity				
Saline water supply for mining, sourced from the LPS aquifer	Watertable drawdown, aquifer depressurisation, changed groundwater flow paths, migration of reinjected slime water towards production bores, local induced flows, indirect take from the overlying Shepparton Formation.	✓	✓	
Brackish water supply, sourced from the Olney Formation	Induced saline water from the overlying Geera Clay, drawdown on third party bores.	✓	✓	
Mining and ore extraction	Under or over pressurisation of the stopes, increasing hydraulic gradients towards or away from the active mining area.		✓	
Reinjection of fine tailings into stopes	Groundwater pressure increase within the LPS and/or watertable mounding in the SFM. This may be exacerbated due to subsidence.		✓	
Re-emplacement of sand tailings to surface	Seepage causing watertable mounding.		✓	
Water storage in engineered impoundments	Seepage causing watertable mounding.	✓	✓	
Stockpiling- ore and tails	Seepage causing watertable mounding.		✓	
Permanent changes to natural surface topography	Altered flow directions, increased recharge due to rainfall runoff in areas of subsidence.		✓	

Table 4.2 **Direct effects of water affecting activities and potential effects**

Water affecting activity	Potential effect	Project Phase		
		Construction	Operation	Rehabilitation and Closure
Groundwater quality				
Reinjection of flotation tails, fine sands and supernatant from PAX dam, which may have undergone oxidation during processing and temporary storage.	Introduction of PAX to LPS aquifer, PAX migration with groundwater flow, localised dissolution of native metals present in aquifer solids and returning sulfide minerals to LPS aquifer. Potential for sulfides to have oxidised and generated acidity which is injected with the tails to the aquifer.		✓	✓
Reinjection of water, which is a combination of LPS aquifer and Olney Formation source water, could lower the beneficial use of the LPS aquifer by changing the salinity.	Reinjected water into the LPS aquifer, is originally sourced from both the LPS aquifer and the Olney Formation. Mixing of these two water types could affect the beneficial use of the LPS aquifer.		✓	✓
Re-emplacement of sand tailings to surface	Seepage and runoff of PAX to groundwater, AMD which may generate acid and metal enriched seepage water.		✓	
Stockpiling- ore and tails	Seepage of PAX from tails, AMD which may generate acid and metal enriched seepage from tails.		✓	
Seepage from process and storage dams	Compromised liners resulting in infiltration of process water potentially introducing AMD and PAX to the groundwater.		✓	
Recirculation of groundwater caused by saline water supply sourced from the LPS	If the drawdown of the LPS production bores encroaches the area of active tailings and supernatant water re-injection, the re-injected water would migrate towards the saline water supply bore. Water being pumped for water supply may contain PAX and increased heavy metals concentrations.		✓	
Surface water-groundwater interaction				
Groundwater supply	Altered baseflow to local watercourses, increased leakage from watercourse to groundwater, induced inflows of different water quality.	✓	✓	

Table 4.2 Direct effects of water affecting activities and potential effects

Water affecting activity	Potential effect	Project Phase		
		Construction	Operation	Rehabilitation and Closure
Aquifer disruption				
Development of mine stope voids and backfill.	Removal of part of the aquifer in and around the ore zone, change in aquifer properties due to backfill, change in groundwater flow paths, subsidence creating enhanced connection between groundwater sources.		✓	

Table 4.3 **Indirect groundwater effects**

Indirect effect	Impacted environmental value	Potential effect (source-pathway-receptor)
Groundwater quantity	Aquatic ecosystems	Aquatic ecosystems are largely associated with both the Murrumbidgee and Murray Rivers. Possible effects could be reduced baseflow due to mine water supply, especially in the southern areas of the mine, reducing flow in the river particularly during dry periods.
	Terrestrial ecosystems with potential groundwater dependency	Terrestrial vegetation includes: • Those associated with the Murrumbidgee, Lachlan, and Murray River Floodplain environments. • Primarily Black Box woodland located outside the floodplain and permanent streams, in topographic depressions. Possible effects could be watertable drawdown due to mine water supply, exceeding rooting depths, however the risk would reduce away from the mine where the aquitard remains intact between the LPS and overlying SFM, which hosts the watertable. Mounding could also occur causing water logging in areas of tailings seepage and sand fine injection.
	Third party bores	The groundwater quality within the Shepparton Formation and Loxton Parilla Sands is unsuitable for potable consumption or irrigation. Thus, bores that are screened across the deeper Olney Formation, which is brackish, represent the only bores which may have their beneficial use (livestock purposes) impacted by the mine. Groundwater from the Olney Formation is being sourced for the mine's floatation plant and other miscellaneous uses.
	Tronox's Atlas Campaspe Mine	Potential for pressure changes at the mine stope and water supply bores to impact mining operations at the Atlas Campaspe mine. The distance between the Balranald mine and the Atlas Campaspe mine may negate any significant interaction and the previous assessment made during the 2015 EIS is likely to still apply.

Table 4.3 **Indirect groundwater effects**

Indirect effect	Impacted environmental value	Potential effect (source-pathway-receptor)
Groundwater quality	Aquatic ecosystems	Aquatic ecosystems are largely associated with both the Murrumbidgee and Murray Rivers. Possible effects could be induced mounding (especially during stope backfill and sand emplacement periods) mobilising heavy metals and PAX towards these receiving environments, especially in the southern areas of the mine.
	Terrestrial ecosystems with potential groundwater dependency	Local terrestrial vegetation could be affected by tailings seepage, inducing saline groundwater and potential other contaminants to migrate towards the surface. The risk is associated with seepage originating from sand tailing emplacement and other stockpiles (ore and tailings).
	Third party bores	Local groundwater quality within the Shepparton Formation and Loxton Parilla Sands in the vicinity of the mine may be effected by PAX and AMD. However, this is unlikely to impact the beneficial use of either system. In addition, PAX is expected to degrade in the aquifer and mining by-products will be amended with lime, as required to maintain near neutral pH. Thus, the risk is likely negligible.
	Tronox's Atlas Campaspe Mine	Any impact to groundwater quality is likely to be local to the Balranald Project area and the distance between the Balranald and Atlas-Campaspe mines is likely to preclude any pathway for interference effects and thus accumulative impacts.
Aquifer disruption	Aquatic and terrestrial ecosystems located in close proximity to mine	Risks associated with aquifer disruptions are caused by changes in groundwater levels, gradients, and thus solute fluxes, which could impact on local ecosystems. Given the disruption of the aquifers caused by mining and backfilling occurs over a limited time and area, and takes place within the Loxton Parilla Sands, which is disconnected from local ecosystems, the risk is considered negligible. Subsidence may cause increased hydraulic connection between the deeper Loxton Parilla Sands and the shallower Shepparton Formation. However, subsidence events are likely to only disrupt local flow and quality momentarily and on a local scale in close proximity to the mining stopes.

4.3 Monitoring regime

In 2013, Iluka Resources Limited (Iluka) undertook a broad and comprehensive two-year groundwater monitoring program of quarterly monitoring events (comprised of 8 monitoring events) to obtain baseline groundwater quality (prior to the first trial (T1)). This program was undertaken according to regulators requirements and has been previously discussed in Section 3.4.1. However, during this time, other detailed investigations were undertaken to add to the understanding of potential impacts to groundwater following the commencement of the mining activity.

Baseline groundwater monitoring continued in 2016 (during T2), although chemical analysis was decreased to target analytes that indicated potential geochemical changes to the aquifer systems that may be affected by mining. As part of the T2 program of work, Iluka initiated a Groundwater Operating and Management Strategy (GOMS) and installed a significant number of groundwater monitoring bores (in the Shepparton and Loxton Parilla Sands Formation) around the T2 bulk sampling area. Sampling was undertaken fortnightly, with a total of nine groundwater monitoring events. Automated loggers continuously monitored pH, temperature, salinity and redox potential. On 10 June 2016, the EPA issued an EPL 20795 that ensured that there was ongoing monitoring of a range of analytes from selected bores.

Two groundwater monitoring programs were undertaken in 2017 (July and December) to satisfy Iluka's internal requirements and in 2018 and 2019, Land and Water Consulting (LWC) was engaged by Iluka to undertake a groundwater monitoring program to obtain suitable and representative baseline and pre-T3 activities water quality data from the Balranald Project area. These programs targeted the monitoring bores that were installed as part of the T2 trial and also regional monitoring bores that are located around the perimeter of the West Balranald deposit.

When baseline monitoring began in 2013, the groundwater monitoring network consisted of Iluka-installed bores, third-party bores and government bores near the project area. Following T2, a number of near-mining bores (UGM bores) were added to the baseline network. Table 4.4 describes the current baseline monitoring network where twice-yearly sampling is ongoing.

In 2019, EMM prepared and submitted a revised Groundwater Management Plan (GMP) to regulators. The previous Balranald bore network, including near-mining monitoring bores, regional monitoring bores, third party bores and process water abstraction bores is listed in Table 4.4. To meet the monitoring objectives for the T3 trial, additional monitoring bores were installed and are outlined in Table 4.5. Continued and progressive monitoring will be undertaken during the life of mine and the GMP will be updated accordingly.

Table 4.4 Previous underground mining trial/s monitoring bore network

Bore ID	Licence number	Easting	Northing	SFM screen interval (mBGL ¹)	LPS screen interval (mBGL)	Category
UGM-M1	60BL216700	723166	6189938	15–18	71–77	near mining
UGM-M2	60BL216700	723332	6189842	25–28	68–71	near mining
UGM-M4	60BL216700	723348	6189745	24–27	71–77	near mining
UGM-M5	60BL216700	723478	6189409	26–29	66–72	near mining
UGM-M6	60BL216700	723373	6189400	20–23	68–71	near mining
UGM-M7	60BL216700	723425	6189454	29–32	74–77	near mining
UGM-M8	60BL216700	723364	6189505	26–29	66–72	near mining
UGM-M10	60BL216700	723380	6189381	30–33	71–77	near mining
UGM-M11	60BL216720	723591	6189038	15–18	74–77	near mining
UGM-M12	60BL216720	723609	6189009	15–18	74–77	near mining
UGM-M13	60BL216720	723630	6188974	15–18	74–77	near mining
UGM-M14	60BL216720	723649	6188941	15–18	71–77	near mining
UGM-M15	60BL216720	723555	6188886	15–18	74–77	near mining
GW036673 (1)	n/a	711680	6189281	32–37	n/a	regional
GW036866 (1/2)	n/a	734900	6203463	21–27	52–58	regional
SHOB03	60BL216540	724911	6186351	17–23	n/a	regional
SHOB04	60BL216539	723695	6189033	16–22	n/a	regional
WB41	60BL216632	720596	6194488	n/a	35–77	regional
WB42	60BL216625	720599	6194491	23–27	n/a	regional
WBG73	n/a	724880	6186352	n/a	76–82	regional
WBG74	n/a	723703	6189063	n/a	76–82	regional
LPSPB03	60BL216540	724893	6186351	n/a	62–72	regional
LPSPB04	60BL216539	723702	6189053	n/a	58–70	regional
WB1	60BL216637	730399	6175412	22–28	n/a	regional
WB2	60BL216621	730402	6175415	n/a	52–100	regional
WB5	60BL216646	730450	6175489	n/a	96–102	regional
WB7	60BL216621	729924	6176754	15–31	n/a	regional
HD1	n/a	726021	6185781	n/a	225–235 (LRG)	third-party
T01	n/a	722791	6201032	n/a	208–216 (LRG)	third-party
T02	n/a	729728	6195981	n/a	176.5–185 (LRG)	third-party
T03	n/a	732044	6189404	n/a	204–210 (LRG)	third-party

Table 4.4 **Previous underground mining trial/s monitoring bore network**

Bore ID	Licence number	Easting	Northing	SFM screen interval (mBGL ¹)	LPS screen interval (mBGL)	Category
Karra Homestead Bore	60WA583109	720430	6188310	n/a	218.3–230.3 (LRG)	third-party/ process water
P2	60WA583169	723191	6189730	n/a	57–81	process water

- 1. mBGL: Metres below ground level.
- 2. SFM: Shepparton Formation Aquifer.
- 3. LPS: Loxton-Parrilla Sands Aquifer.
- 4. LRG: Lower Renmark Group Aquifer.

Table 4.5 T3 activity monitoring network

Bore ID	Easting (m)	Northing (m)	Status	Screen	SSTL zone
UGM-M01	723217	6189938	existing	SFM/LPS	3 (background)
UGM-M02	723332	6189842	existing	SFM/LPS	3 (background)
UGM-M04	723348	6189745	existing	SFM/LPS	3 (background)
UGM-M06	723373	6189400	existing	SFM/LPS	2 (transition)
UGM-M12	723639	6189000	existing	SFM/LPS	1 (mining)
UGM-M15	723555	6188886	existing	SFM/LPS	2 (transition)
LPSPB04	723702	6189053	existing	LPS	2 (transition)
BH-M16	723484	6189656	new	SFM/LPS	3 (background)
BH-M17	723318	6189364	new	SFM/LPS	2 (transition)
BH-M18	723363	6189255	new	SFM/LPS	2 (transition)
BH-M19	723377	6189038	new	SFM/LPS	2 (transition)
BH-M20	723676	6189207	new	SFM/LPS	2 (transition)
BH-M21	723672	6189008	new	SFM/LPS	2 (transition)
BH-M22	723682	6188854	new	SFM/LPS	2 (transition)
BH-M23	723631	6188619	new	SFM/LPS	3 (background)
BH-M24	723779	6189359	new	SFM/LPS	3 (background)
BH-M25	723238	6189003	new	SFM/LPS	3 (background)
VWP16	723414	6189262	new	SFM	1 (mining)
VWP17	723453	6189284	new	SFM	1 (mining)
VWP18	723466	6189175	new	SFM	1 (mining)
VWP19	723504	6189198	new	SFM	1 (mining)
VWP20	723713	6189335	new	SFM	1 (mining)
VWP21	723517	6189090	new	SFM	1 (mining)
VWP22	723555	6189112	new	SFM	1 (mining)
VWP23	723631	6188902	new	SFM	1 (mining)
VWP24	723668	6188926	new	SFM	2 (transition)
HBF4-FE1	723630	6188994	new	Stope	1 (mining)
HBF5-MP1	723551	6189121	new	Stope	1 (mining)
HBF6-MP1	723450	6189216	new	Stope	1 (mining)
HBF5- North	723399	6189356	New	Stope	1 (mining)
HBF6- North	723381	6189345	new	Stope	1 (mining)

1. SFM: Shepparton Formation Aquifer.

2. LPS: Loxton-Parilla Sands Aquifer.

5 MOD1 assessment

5.1 Proposed approach

Iluka proposes to modify their existing mineral sands West Balranald mine in south-western NSW. As part of the Modification of consent (MOD1), this chapter contains a comparative assessment of the current development (as originally approved, referred to as 2015 EIS) to that of the modified development (referred to as MOD 1). A major deliverable of the assessment contains an updated version of the numerical groundwater model (previously referred to as BAL2.0). The updated model and mine schedule is briefly discussed below, and the results used to inform the comparative assessment are shown in Section 5.5 through to Section 5.7. The complete modelling report is included as Appendix A.

5.2 Mine plan and schedule

The modelled mine plan (including location and timing of stopes to be mined), groundwater supply bores and slimes injection locations are presented in Figure 5.1. The modelled mine plan and schedule exhibits the following characteristics:

- Mine direction progresses from south to north.
- The mine plan is made up of individual stopes, that are 10 m wide, with a 1 m gap between stopes. For modelling purposes however, the stopes are set as adjacent cells 10.5 m wide instead with no gap.
- Stope length varies from 300–450 m, with an average of about 350 m.
- Every 10 mined stopes are grouped into a panel, and between each panel is one stope that is not mined, referred to as a pillar.
- The mining duration of each panel is based on a schedule provided by Iluka, and each stope in a given panel is assumed to take the same amount of time, which varies over the mine life between 15–30 days.
- Wet sand tails (the courser fraction) from mining are deposited onto a stope that is 10 stopes, or one mining panel (average of 115.5 m) ahead of the current mining progress.
- Sand fines (or slimes) blended with water to create a slurry are injected simultaneously into three previously mined stopes, that are between five to seven stopes behind the current mining progress.
- The sand fines are injected with a target injection rate of 90 m³/h of water plus solids into the three combined stopes for six hours per day, equating to an average rate of 180 m³/d at each stope.
- Water is supplied from one bore in the LPS and two bores in the Olney Formation over the duration of mining.

5.3 Model domain, features and stresses

The 'BAL3.0' groundwater model that has been developed for MOD1, is an update to the 'BAL2.0' model that was used to support the 2015 EIS. The updated model has been developed to take advantage of modern modelling software and the current best practice methodologies, and to include the additional data gathered during the T3 trial to inform the predicted outcomes of MOD1. A summary of the groundwater modelling is presented below. For the full details regarding the groundwater model, refer to Appendix A.

5.3.1 Modelling techniques

The BAL3.0 groundwater model uses the updated modelling code MODFLOW-USG (Panday et al 2017), instead of MODFLOW-Surfact (HGL 2014), which was used in BAL2.0. This update allows for a major efficiency gain, primarily with the use of a Voronoi polygon mesh to discretise the model domain, rather than the previous rectangular grid.

The Voronoi polygon mesh allows the previously separate local-scale transient calibration models, employed at 'TN5', 'TN1', 'Nanda', 'Upson Downs' and the 'Long Term Trial' (LTT) site to be merged into BAL3.0, as well as not requiring another local-scale model for the T3 trial, which was conducted in 2020.

The BAL3.0 model upgrade also contains solute transport modelling for PAX that is present in the sand tails and injected sand fines. MODFLOW-USG allowed for this to be included with minimal issues. Previously, solute transport was modelled in the BAL1.1 model in 2012, but this was not included in BAL2.0.

5.3.2 Boundary conditions and model features

Excluding the T3 trial, many of the features and boundary conditions used in BAL3.0 have been directly translated from those used in BAL2.0 as follows:

- The model domain is identical.
- Rainfall recharge is assigned uniformly at a constant rate of 0.0365 mm/yr.
- Evapotranspiration is modelled with a maximum rate of 2,000 mm/yr, decreasing linearly to 0 mm/yr at a depth of 3 m below the ground surface.
- Groundwater abstraction and injection related to the various trials were included from the local-scale models.
- The river levels for the Murray and Murrumbidgee Rivers were modelled with a linear interpolation between gauge levels and river bottom elevation set 4 m below the river stage.
- The general head boundary condition values assigned at the model borders were retained for BAL3.0.

Some of the model features updated from BAL2.0 to better represent reality are given below:

- To assist modelling the Murrumbidgee and Murray Rivers in BAL3.0, the Voronoi mesh allowed river cells sized at approximately 100 by 100 m to be created that follow the river channel. This is a major improvement over the rivers in the BAL2.0 model, which were largely located in regional grid cells measuring 500 by 500 m and poorly aligned to the river locations.
- Hydraulic conductivity for several formations in BAL2.0 varied spatially based on results from the local-scale calibration models and this was represented by several zones of different conductivity. In BAL3.0, the zones have been replaced by a continuous field for hydraulic conductivity, interpolated to the values determined by the trials.
- The T3 trial was included in BAL3.0, allowing the model to be calibrated for similar groundwater stresses that will apply to MOD1.

The MOD1 also contains solute transport to simulate PAX within the injected sand fines. The modelling assessment assumed the following, based on Earth Systems (personal communication, 21 December 2021):

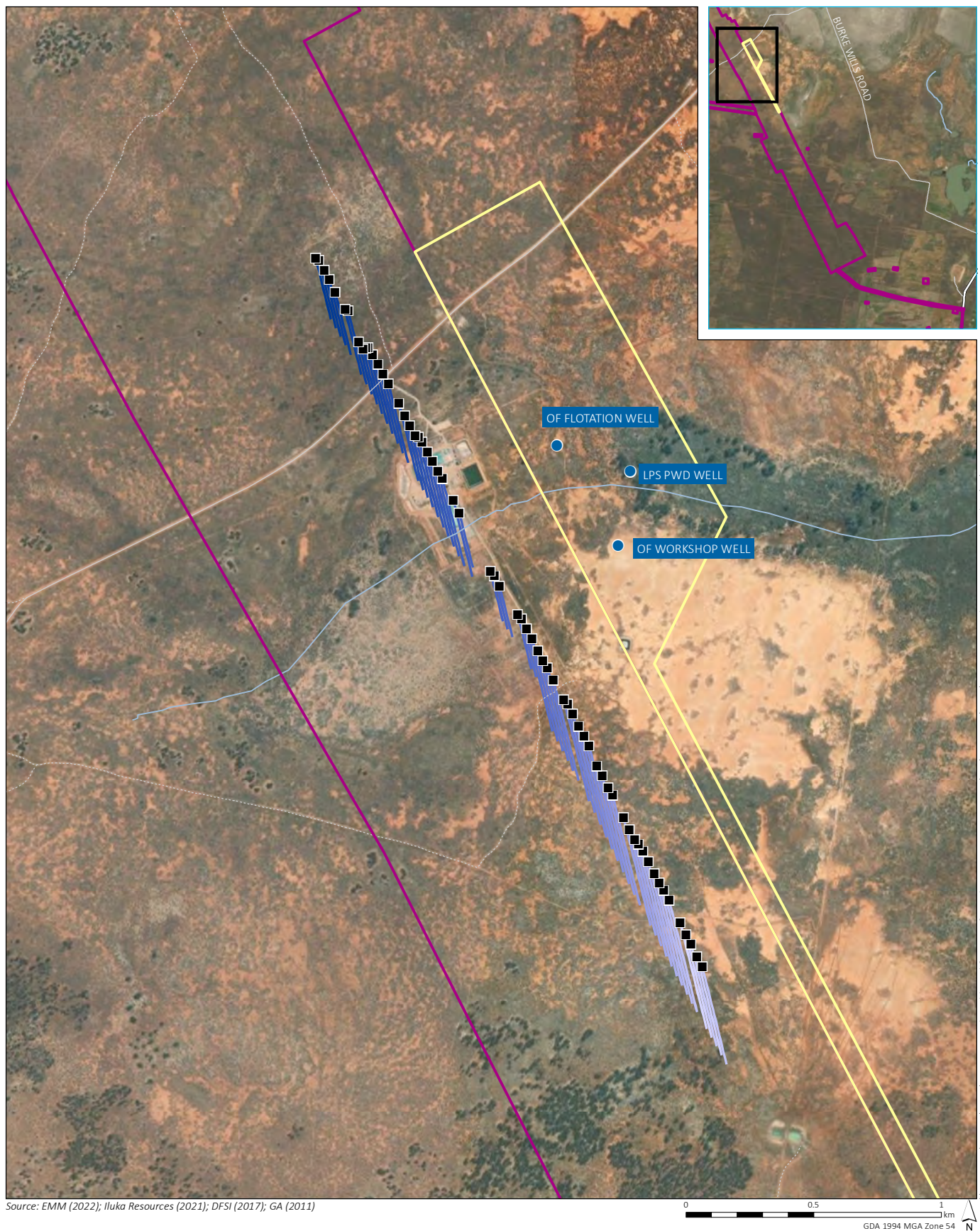
- Seepage water from the sand tails is modelled with a concentration of 5 mg of PAX per litre at a rate of 5.1 m³/h (Earth Systems 2021b). This is assumed to be applied over an entire stope, with the time taken for the volume of water emplaced above an individual model cell calculated to be, on average, 14 days.
- The injected slimes have been modelled with an injection rate of 90 m³/h into three stopes simultaneously for six hours per day, with a concentration of 110 mg of PAX per litre of water.
- First order decomposition of PAX in the groundwater model is simulated with a half-life of 12 weeks.

5.4 Risk and comparative assessment summary

The comparative assessment between the previously approved project (2015 EIS), informed through BAL2.0, and MOD1, informed through BAL3.0, have been summarised within the following tables:

- Table 5.1 – Risk assessment undertaken for the direct groundwater-affecting activities.
- Table 5.2 – Risk assessment undertaken for the indirect impact to sensitive receivers caused by groundwater-affecting activities.

The risk assessment is supported by the modelling results summarised in Sections 5.5 and 5.6 which discuss both the groundwater modelling pressures (quantity) and quality results respectively. Previous modelling results associated with the 2015 EIS undertaken by Jacobs (Jacobs, 2015) have also been included to facilitate the comparative assessment. Section 5.7 summarises the predictive uncertainty assessment undertaken using the updated MOD1 model to ensure consistency with best practise guidelines.



KEY

 EIS Approved Balranald Project Area (SSD-5285)

 Proposed modification extension to Balranald Project Area boundary

● Mine water supply well

■ Slime injection point

— Minor road

--- Vehicular track

— Watercourse/drainage line

Mine progression



MOD1 mine plan and slimes injection layout

Balranald Mineral Sands Project
Balranald groundwater comparative impact assessment
Figure 5.1

Table 5.1 **Direct groundwater-affecting activities risk assessment**

Water affecting activity	Potential risk/effect	MOD1 Assessment with mitigation actions/controls	MOD1 residual risk	Comparison to previous 2015 EIS
Groundwater Quantity				
Saline water supply for mining, sourced from the LPS aquifer	Watertable drawdown, aquifer depressurisation, changed groundwater flow paths, local induced flows, indirect take from the overlying Shepparton Formation.	12 L/s is continuously sourced from the LPS, and 12 L/s sourced from the Olney Formation. Water supply will be managed via an approved groundwater management plan (GMP) to ensure groundwater levels are not impacted at GDEs and/or third party bores within the Olney Formation. In addition, the Geera Clay acts as competent barrier between the more saline LPS and Olney Formation and thus intermixing is deemed insignificant.	The residual risk is considered minimal and less than the Level 1 impact defined by the AIP.	Total rate for the MOD 1 is 24 L/s compared to 4.8 L/s for the 2015 EIS. The MOD1 production bores pump for the life of mine compared to the 2015 EIS, which pump for only 3 years during construction. Impacts are larger in the MOD1 within the Olney Formation but are significantly smaller in the LPS due to no mine dewatering being required. In summary: • MOD1 impact > 2015 EIS for Olney Formation. • MOD1 impact < 2015 EIS for LPS.
Brackish water supply, sourced from the Olney Formation	Induced saline water from the overlong Geera Clay, drawdown on third party bores.			
Mining and ore extraction	Under or over pressurisation of the stopes, increasing hydraulic gradients towards or away from the active mining area.	The ore is to be extracted under net-zero stope pressure conditions. These conditions will be monitored via a central control room. Any fluctuations from these conditions will have minimal effect on the pressures throughout the aquifer during the mining process. Monitoring bores will be continuously monitored and assessed as part of the GMP.	The residual risk is considered minimal and less than the Level 1 impact defined by the AIP.	The 2015 EIS induced large dewatering and injection volumes resulting in changes greater than 70m along the ore body, and greater than 5 m at the injection borefield. For MOD1, the groundwater pressure changes will be insignificant due to net-zero stope pressure conditions during the mining phase. In summary: • MOD1 impact << 2015 EIS related to the LPS and Shepparton Formation groundwater pressures during mining.

Table 5.1 **Direct groundwater-affecting activities risk assessment**

Water affecting activity	Potential risk/effect	MOD1 Assessment with mitigation actions/controls	MOD1 residual risk	Comparison to previous 2015 EIS
Reinjection of sand fines into stopes	Groundwater pressure increase within the LPS and/or watertable mounding in the SFM.	The updated model shows mounding pressures would not extend more than few hundred metres from the point of injection. The groundwater will not migrate to third party bores or ecosystems or create pressures which would affect the integrity of the LPS. Groundwater pressures will be monitored via VVPs and using traditional monitoring bores in line with the approved GMP.	The residual risk is considered minimal and less than the Level 1 impact defined by the AIP.	Re-injection of sand fines was not part of the mining method proposed in the 2015 EIS. However predicted mounding caused by the injection of surplus water into the borefield is larger both in magnitude and extent compared to the increased groundwater pressures predicted for MOD1. In summary: MOD1 impact << 2015 EIS related to the groundwater pressure increases during reinjection periods.
Re-emplacment of sand tailings to surface	Seepage causing watertable mounding, impacting on surrounding infrastructure, buildings and local vegetation.	Mounding caused by seepage from sand tailings is minimal and has no significant impact on water table mounding on a local or regional scale.	The residual risk is considered minimal and less than the Level 1 impact defined by the AIP.	Sand tails were intended to be co-disposed with sand fines in the mining method proposed in the 2015 EIS. Disposal of sand tails above stopes avoids constructing a waste storage facility.
Water storage in engineered impoundments		Water will be stored in lined engineered structures. Any seepage will be monitored and mitigated via the GMP.		Water will still be stored within engineered impoundments. The proposed underground mine method presents no material difference in water quantity risks.
Stockpiling- ore and tails		Seepage volume will be limited, with the majority of seeped water captured and recycled towards sedimentation dams and/or the PWD.		In summary: MOD1 and 2015 EIS impacts related to seepage across the mine site remain unchanged.

Table 5.1 **Direct groundwater-affecting activities risk assessment**

Water affecting activity	Potential risk/effect	MOD1 Assessment with mitigation actions/controls	MOD1 residual risk	Comparison to previous 2015 EIS
Permanent changes to natural surface topography	Altered flow directions, increased recharge due to rainfall runoff in areas of subsidence.	Subsidence both planned and unexpected will be managed via Iluka's subsidence management plan. Some subsidence events are expected, with predictions of systemic subsidence across the mining zone. Some local subsidence may occur directly above the stopes. It is anticipated that a combination of successful backfill and strategic sand tailings placement will reduce potential impacts from subsidence and the final landform will meet Iluka's rehabilitation objectives.	Residual risk will be low and any subsidence will be managed in accordance with Iluka's subsidence management plan to meet final landform objectives.	Given the new MOD1 does not require any removal of overburden and thus less works required to recontour the final landform, the risk associated with permanent changes to the natural surface topography is considered lower for MOD1 in comparison to the 2015 EIS. In summary: • MOD1 impact < 2015 EIS related to the permanent changes to natural surface topography.

Table 5.1 **Direct groundwater-affecting activities risk assessment**

Water affecting activity	Potential risk/effect	MOD1 Assessment with mitigation actions/controls	MOD1 residual risk	Comparison to previous 2015 EIS
Groundwater Quality				
Reinjection of flotation tails, fine sands and supernatant from PAX dam, which may have undergone oxidation during processing and temporary storage	Introduction of PAX and potentially AMD to LPS aquifer, PAX and acid migration with groundwater flow, localised dissolution of native metals present in aquifer solids and returning sulfide minerals to LPS aquifer. Potential for sulfides to have oxidised and generate acidity which is injected with the tails into the LPS aquifer.	Groundwater modelling results show that re-injected water that contains PAX will extend approximately 500 m east from the point of injection assuming that PAX does not degrade, and the groundwater will not migrate to third party bores or aquatic ecosystems. The PAX is expected to degrade in the aquifer resulting in decreasing concentration over time. Potential dissolution of metals will be localised to the PAX plume and will reverse when mixing with ambient groundwater. Floatation tails and sand fines will be amended with lime as needed to neutralise acidity. Oxygen is limited in the groundwater and sulfide oxidation is unlikely to occur in the aquifer. Further testing on PAX degradation and sorption will be conducted. The results will refine PAX concentration in re-injected water and improve future fate and transport modelling. Groundwater monitoring will be undertaken during and post-operations to measure PAX concentration in groundwater in accordance with the GMP.	The localised PAX and increase in heavy metals concentrations do not affect the groundwater beneficial use category. No nearby receptors will be affected. The impact will be temporally limited because PAX degrades in the aquifer and the pH of the re-injected slurry will be monitored. While the risks were rated as 'medium', the proposed monitoring and reagent amendment, as necessary, is considered to reduce the residual risk to low.	Re-injection of mining by-products is considered a lesser long-term environmental impact compared to managing by-products above ground. Dewatering, which was proposed in the original mining method would have resulted in AMD generation in-situ. Sulfide minerals are not expected to oxidise once returned to the aquifer.

Table 5.1 **Direct groundwater-affecting activities risk assessment**

Water affecting activity	Potential risk/effect	MOD1 Assessment with mitigation actions/controls	MOD1 residual risk	Comparison to previous 2015 EIS
Reinjection of water, which is a combination of LPS and Olney source water, could lower the beneficial use of the LPS aquifer by changing the salinity.	Reinjected water into the LPS aquifer, is originally sourced from both the LPS aquifer and the Olney Formation. Mixing of these two water types could affect the beneficial use of the LPS aquifer.	The LPS aquifer has an approximate TDS of 33,000 mg/L at the project site and is the source aquifer to supply the Process Water Dam. The Olney Formation has an approximate TDS of 4,300 mg/L and is used for the floatation system. Based on the assumed pumping rates, a mixed water quality with a TDS of ~23,500 mg/L would potentially report to the HBF tank prior to reinjection into the LPS, assuming no other dissolution processes occur. The injected water therefore is likely be of better quality than the ambient groundwater quality of the LPS. The LPS aquifer has no beneficial use and even if freshening was to occur, the water quality still exceeds the ANZECC/ARMCAZ 2000 guideline for livestock.	Residual risk is low.	
Re-emplacment of sand tailings to surface	Seepage of PAX to groundwater, AMD which may generate acid and metal enriched seepage water.	Results of geochemical testing will be used to design lime dosing rate. Amending sand tailings with lime will neutralise generated acid. Groundwater modelling indicates minor PAX impacts due to seepage. Recent changes to the process design, however, practically removes the risk of PAX seepage from sand tailings. Groundwater modelling is very conservative.	Residual risk to groundwater quality was rated as moderate (Earth Systems 2022a) but is considered low due to reagent amendment as necessary.	Sand tails were intended to be co-disposed with sand fines in the mining method proposed in the 2015 EIS. Disposal of sand tails above stopes avoids constructing a dedicated waste storage facility, however, sand tails would generate acidity if not amended with lime. The risk of generating AMD will be mitigated by addition of lime sand. The proposed underground mine method presents no material difference in water quality risks.

Table 5.1 **Direct groundwater-affecting activities risk assessment**

Water affecting activity	Potential risk/effect	MOD1 Assessment with mitigation actions/controls	MOD1 residual risk	Comparison to previous 2015 EIS
Stockpiling- ore and tails	Seepage and runoff of PAX from tails, AMD which may generate acid and metal enriched seepage from ore and tails.	The PAX concentration in tails is expected to be low (5 mg/L) and the seepage water volume is limited. PAX will be removed by sorption and degradation during seepage through the vadose zone. Potential impacts to groundwater will therefore be minimal and temporally and spatially limited. The risk for AMD during temporary storage of ore and tails is moderate, but tails will be amended with lime to prevent and neutralise AMD. Fine sand tails will contain the greatest concentration of sulfide minerals. These tails will be stored and maintained water saturated in a lined and engineered pond prior to reinjection.	Residual risk to groundwater quality was rated as moderate (Earth Systems 2022a, b) but is considered to be low due to proposed process controls.	The underground mining method presents no material change to water quality risk due to stockpiling of ore compared to the mining method proposed in the 2015 EIS. Stockpiling of tails will be temporary, whereas permanent above ground disposal of tails was proposed in 2015. Pyrite will be removed in the floatation process and less acid is anticipated to be generated during the underground mining method compared to the method proposed in the 2015 EIS. The proposed underground mine method is therefore considered to reduce the risk to water quality due to stockpiling of tails.
Seepage from process and storage dams	Compromised liners resulting in seepage of process water, potentially introducing AMD and PAX to the groundwater.	Process water quality will be monitored, and the water will be amended, as needed, to maintain neutral pH. A seepage monitoring plan will be provided in the groundwater monitoring program.	Water quality risks have been rated as low to medium (Earth Systems 2022a), however, water quality monitoring and reagent amendment to the process circuit achieved during the mining trial indicates that the residual risk is low.	The proposed underground mine method presents no material difference in water quality risks.

Table 5.1 **Direct groundwater-affecting activities risk assessment**

Water affecting activity	Potential risk/effect	MOD1 Assessment with mitigation actions/controls	MOD1 residual risk	Comparison to previous 2015 EIS
Recirculation of groundwater caused by saline water supply sourced from the LPS	If the drawdown of the LPS production bores encroaches the area of active tailings and supernatant water re-injection, the re-injected water would migrate towards the saline water supply bore. Water abstracted for water supply may contain PAX and increased heavy metals concentrations.	Groundwater modelling results indicate that PAX impacted groundwater will not reach the PWD bore. Should some PAX reach the bore, contrary to the groundwater modelling predictions, the water will be used for ore processing which will include addition of PAX. Water recirculation will not result in material spreading of PAX containing groundwater. The migration and degradation of PAX will be monitored during operations as outlined in the GMP.	Recirculation of groundwater will not lower the beneficial use category of groundwater and does not pose a realistic risk to groundwater quality.	Recirculation of groundwater was not an identified risk in the mining method described in the 2015 EIS. However, water recirculation is not considered to pose a realistic risk to groundwater quality.
Surface water-groundwater interaction				
Groundwater supply	Altered baseflow to local watercourses, increased leakage from watercourse to groundwater, induced inflows of different water quality.	Modelling shows no impact at any surface water features. The rivers within the study domain exist outside of the drawdown and mounding extent caused by both the mining and water supply activities.	The residual risk is considered minimal and less than the Level 1 impact defined by the AIP.	The previous 2015 EIS model showed small fluctuations associated with river leakage volumes with the predicted drawdown not reaching the Murray and Murrumbidgee Rivers. In summary: • MOD1 impact is considered on par or smaller than the 2015 EIS related impacts to surface water features.

Table 5.1 **Direct groundwater-affecting activities risk assessment**

Water affecting activity	Potential risk/effect	MOD1 Assessment with mitigation actions/controls	MOD1 residual risk	Comparison to previous 2015 EIS
Aquifer disruption				
Development of mine stope voids and backfill.	Removal of part of the aquifer in and around the ore zone, change in aquifer properties due to backfill, change in groundwater flow paths, subsidence creating enhanced connection between groundwater sources.	The model simulated change in aquifer properties above the stopes to simulate responses measured during the T3 trial. The local changes to aquifer properties had no lasting effect on groundwater levels or flow irrespective of the stope developments and preceding subsidence events, as indicated by the measured aquifer responses detailed in the T3 hydrogeological assessment report (EMM, 2021) and the post mining simulations (Appendix A).	The risk associated with long term changes to groundwater pressure, flow paths and connection between aquifer sources is considered low. Very local connection between the LPS and overlying Shepparton Formation may temporally exist during subsidence events.	The approved EIS is a truck and shovel operation which required the removal of all overburden above the ore zone. In the northern areas of the deposit, this can present 70 m of overburden material required to be removed and rehabilitated. For the MOD1, removal of material is only planned at the stopes, with backfill of sand fines to occur soon after. The 2015 EIS also included a final void in the northern section of the mine footprint which may have had an effect on local rainfall runoff and groundwater flow directions, whereas no void will be created for MOD1. In summary: • The MOD1 impact associated with any voids is considered < 2015 EIS.

Table 5.2 Indirect groundwater effects risk assessment

Impacted environmental value	Potential risk/effect	MOD1 Assessment with mitigation actions/controls	Residual risk	Comparison to previous 2015 EIS
Groundwater Quantity				
Aquatic ecosystems	Aquatic ecosystems are largely associated with both the Murrumbidgee and Murray Rivers.	Modelling shows no impact at any aquatic surface water features. The rivers within the study domain exist outside of the drawdown and mounding extent caused by both the mining and water supply activities.	The residual risk is considered minimal and less than the Level 1 impact defined by the AIP.	The previous 2015 EIS model showed small fluctuations associated with river leakage volumes with the predicted drawdown not reaching the Murray and Murrumbidgee Rivers. In summary: MOD1 impact is considered on par or smaller than the 2015 EIS related impacts to surface water and aquatic ecosystems.
Terrestrial ecosystems with potential groundwater dependency	Water table drawdown caused by water supply or mounding/water logging caused by sand tailing seepage, sand fine reinjection or seepage from various sources across the mine site.	The largest change to the water table was modelled at a Black Box community, located northeast of the mine. The modelled drawdown was < 0.1 m and presents no risk to the type of terrestrial ecosystems mapped in this region.	The residual risk is considered minimal and less than the Level 1 impact defined by the AIP.	The GDE assessment was undertaken by CDM-Smith. Low impacts were identified for terrestrial vegetation however a moderate risk rating was assigned to some vegetation associated with the predicted mounding caused by the injection borefield. In summary: MOD1 impact < 2015 EIS related to risk impacts associated with terrestrial ecosystems.
Third party bores	Bores that are screened across the deeper Olney Formation, which is brackish, represent the only bores which may have their beneficial use or pumping pressure impacted by the mine, due to the mine directly sourcing 12 L/s from this aquifer.	Maximum drawdown is observed at the Karra Homestead bore, which is located in close proximity to the mine site. At all bores, drawdown is less than then the 2 m decline threshold defined by the AIP for minimal impact.	The residual risk is considered minimal and less than the Level 1 impact defined by the AIP.	Slightly more drawdown is simulated at third party bores located in the Olney Formation for MOD1, compared to the 2015 EIS. In summary: MOD1 impact > 2015 EIS related to risk impacts associated with third party bores, however the risk is still defined as low.

Table 5.2 Indirect groundwater effects risk assessment

Impacted environmental value	Potential risk/effect	MOD1 Assessment with mitigation actions/controls	Residual risk	Comparison to previous 2015 EIS
Tronox's Atlas Campaspe Mine	Potential for pressure changes at the mine stope and water supply bores to impact mining operations at the Atlas Campaspe mine	The distance between the Balranald mine and the Atlas Campaspe mine negates any significant interaction. Modelled drawdown and mounding effects are localised to the mine workings and disturbance footprint.	The residual risk is considered minimal and less than the Level 1 impact defined by the AIP.	The 2015 EIS concluded that no accumulative impact at the Atlas Campaspe Mine will be expected from the Balranald Project. The MOD1 predictions simulate smaller effects to groundwater pressures, reducing the risk even further. In summary: • MOD1 impact < 2015 EIS related to risk impacts at the Atlas Campaspe Mine.
Groundwater Quality				
Aquatic ecosystems	Aquatic ecosystems are largely associated with both the Murrumbidgee and Murray Rivers. Possible effects could be induced mounding (especially during stope backfill and sand emplacement periods) mobilising heavy metals and PAX towards these receiving environments, especially in the southern areas of the mine.	The presence of PAX in groundwater and potential mobilisation of heavy metals due to AMD and PAX degradation would be limited spatially to approximately 500 m from point of re-injection. The PAX will degrade in the aquifer and mobilised metals will re-sorb to mineral surfaces or precipitate in minerals when the groundwater mixes with ambient groundwater. The groundwater migrates slowly, and PAX and metals will not reach aquatic ecosystems.	The risk to aquatic ecosystems is considered negligible.	The proposed underground mining method does not pose an increased risk to aquatic ecosystems.
Terrestrial ecosystems with potential groundwater dependency	Local groundwater quality within the Shepparton Formation and Loxton Parilla Sands in the vicinity of the mine may be affected by PAX which could impact terrestrial ecosystems.	Due to very limited mounding predicted along the mine path commensurate with the low reliance the local vegetation species has on the presence of groundwater, the presence of PAX or metal laden groundwater is unlikely to cause any impact.	The risk to terrestrial ecosystems is considered negligible.	The proposed underground mining method does not pose an increased risk to terrestrial ecosystems.

Table 5.2 Indirect groundwater effects risk assessment

Impacted environmental value	Potential risk/effect	MOD1 Assessment with mitigation actions/controls	Residual risk	Comparison to previous 2015 EIS
Third party bores	Local groundwater quality within the Shepparton Formation and Loxton Parilla Sands in the vicinity of the mine may be affected by PAX. However, any third-party bores located within these water sources are unsuitable for human drinking, livestock drinking and irrigation.	Third party bores that are in use are screened in the Olney Formation. PAX containing water will be reinjected into the LPS aquifer which is separated from the Olney Formation by the thick Geera Clay, which acts as an aquiclude in this area. In addition, the nearest third party bore is spatially located beyond the extent of PAX influenced groundwater within the LPS aquifer.	The risk to third party bore is considered negligible.	The proposed underground mining method does not pose increased risk to water quality at third party bores.
Tronox's Atlas Campaspe Mine	Potential for groundwater quality to be affected at the Atlas Campaspe mine.	The model predicts that PAX containing water could migrate 500 m from the Balranald mine, and the Atlas Campaspe mine is 55 km away from the Balranald deposit.	The risk to the mine is considered negligible	The 2015 EIS methodology did not include the use of PAX, so this impact was not relevant.
Aquifer disruption				
Aquatic and terrestrial ecosystems located in close proximity to mine	Risks associated with aquifer disruptions are caused by changes in groundwater levels, gradients, and thus solute fluxes, which could impact on local ecosystems. Subsidence may cause increased hydraulic connection between the deeper Loxton Parilla Sands and the shallower Shepparton Formation.	Given the disruption of the aquifers caused by mining and backfilling occurs over a limited time and area, and takes place within the Loxton Parilla Sands, which is disconnected from local ecosystems, the risk is considered negligible. Groundwater modelling post closure also shows that groundwater levels and flow directions quickly re-establish to near-pre mining conditions (Appendix A). Subsidence events are likely to only disrupt local flow and quality momentarily and on a local scale in close proximity to the mining stopes.	The risk to local ecosystems in close proximity of the mine is considered negligible.	The proposed underground mining method does not pose increased risk to water quality at local aquatic and terrestrial ecosystems.

5.5 Groundwater quantity assessment

5.5.1 Water supply

MOD1 has water supplied from three bores. The process water is supplied from a bore screened across the whole LPS group and located adjacent to the PWD. This bore pumps at an average rate of 12 L/s continuously, starting three months prior to the commencement of mining to initially fill the PWD and finishing at the conclusion of slimes reinjection; leaving the PWD full at the completion of mining.

The two other bores are screened in the deeper, less saline, Olney Formation. One is located adjacent to the process plant to provide water to the flotation plant during mining and the other is located near the vehicle wash/workshop area for dust suppression and vehicle cleaning. The bores have a combined average extraction rate of 12 L/s, and this is modelled by each bore pumping at 6 L/s with the same timing as the main LPS aquifer production bore.

The previously approved project predicted to have a surplus of water due to the large dewatering requirements and thus only required water during the mine construction phase. Three bores were proposed to be installed within the Olney Formation with a pumping capacity of 2.4 L/s. The maximum rate pumped at any one time was 4.8 L/s. At the end of the construction period, a localised drawdown impact of 0.2 m was modelled, which was constrained to a small area within the West Balranald disturbance footprint.

The predicted drawdown pressure response in the Olney Formation is larger for MOD1 as shown in Figure 5.2, with a drawdown of more than 0.2 m extending for 15 km from the Balranald Project area. A maximum drawdown of just over 4 m is predicted at the two Olney water supply bores, and a drawdown impact of greater than 2 m is localised to the site and does not reach any third party bores.

The modelled drawdown within the LPS is discussed in Section 5.5.2 below.

5.5.2 Groundwater drawdown

Modelled drawdown associated with the 2015 EIS are shown at the end of mining for the Shepparton Formation and LPS within Figure 5.3 and Figure 5.4, respectively. By comparison, a series of modelled drawdown plots for mine years 1, 2, 3 and at the end of mining for MOD1 is shown in Figure 5.5 and Figure 5.6 for the Shepparton Formation and LPS, respectively. Within these figures, a positive value represents drawdown, and a negative value represents mounding above pre-mining conditions. In summary, the results indicate that:

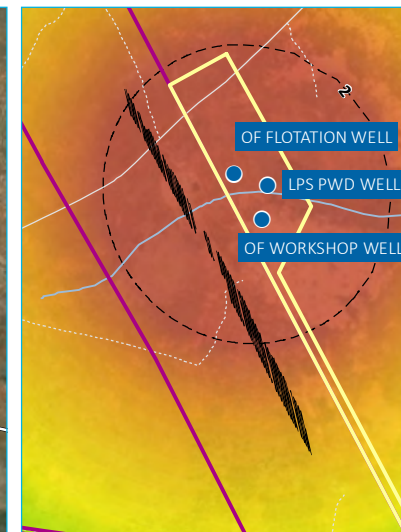
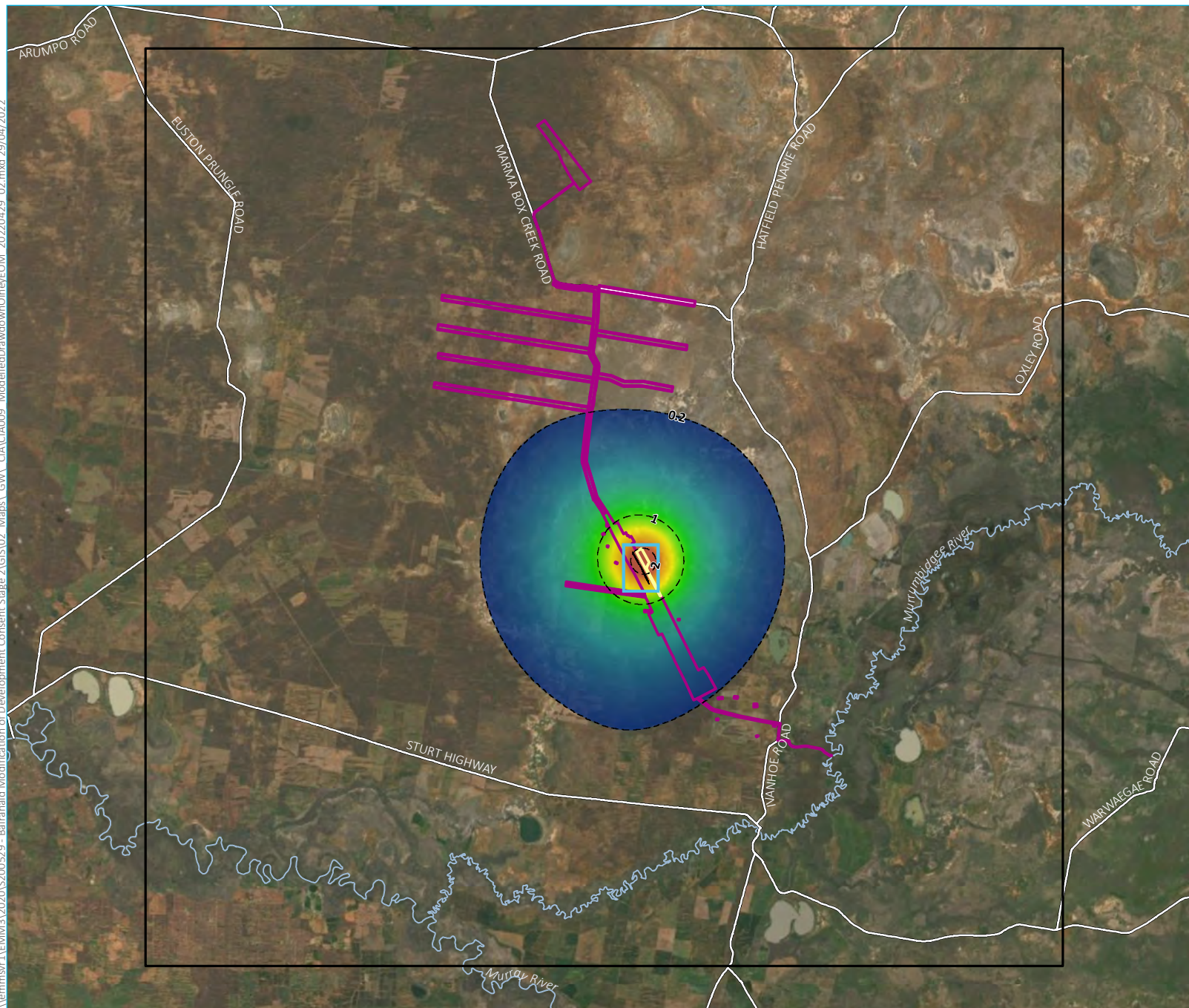
- Drawdown extends along the entire ore body strike at the end of mining for both the Shepparton Formation (Figure 5.3) and the LPS (Figure 5.4) for the previous 2015 EIS. The 0.2 m drawdown contour extends 10 km and 15 km laterally from the ore deposit for the Shepparton Formation and the LPS, respectively.
- By comparison, the 0.2 m drawdown contour extends no more than a few hundred meters within the Shepparton Formation (Figure 5.5) and no more than 2 km within the LPS (Figure 5.6).

Since the underground mining method is intended to be pressure neutral at the active mining stope, with the volume of sand-water slurry removed balanced by the volume of injected process water, the mining process is not modelled explicitly. Therefore, the modelled drawdown is purely attributed to the water supply requirements.

5.5.3 Groundwater mounding

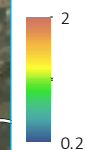
Referring to the same set of figures referenced above, the comparisons related to groundwater mounding indicate:

- Large scale mounding was predicted for the 2015 EIS, associated with the off-path TSF, north of the West Balranald deposit. Peak injection rates were simulated at 1300 L/s.
- For the 2015 EIS, modelled maximum mounding above pre-mining levels were greater than 5 m for the LPS and around 2 m for the Shepparton Formation in the area of the off-path injection borefield. These pressure limits were set to minimise impact to vegetation through water table rise and salinisation. The 0.2 m mounding contour extended around 15 km from the centre of the borefield in all directions by the end of mining.
- The predicted mounding for MOD1 is constrained to the stresses applied to the system during the reinjection of sand fines into the mined stopes, since it is assumed that the stopes are maintaining a net zero stope pressure. Mounding within the LPS is expected to be less than 1 m in the vicinity of the stopes, and not extend beyond a few hundred meters based on the 0.2 m mounding contour during mining. The mounding at the water table is predicted to be even smaller in magnitude.
- Mounding caused by seepage from sand emplacement at the surface has also been simulated in BAL3.0. Water is expected to drain from the deposited sand tails at up to 5.1 cubic metres per hour (m³/hr) for a period of around 10 days (Earth Systems 2021b). This will elevate recharge, above the natural rate due to rainfall, to the groundwater system. This is expected, as simulated by the model, to produce localised and insignificant mounding of the water table in the Shepparton Formation.



KEY

- EIS Approved Balranald Project Area (SSD-5285)
- Proposed modification extension to Balranald Project Area boundary
- Model domain
- MOD1 stope
- Mine water supply well
- Major road
- Named watercourse
- Drawdown (m)
- Modelled drawdown (m)



MOD1 modelled drawdown
in the Olney Formation at
the end of mining

Balranald Mineral Sands Project
Balranald groundwater comparative
impact assessment
Figure 5.2

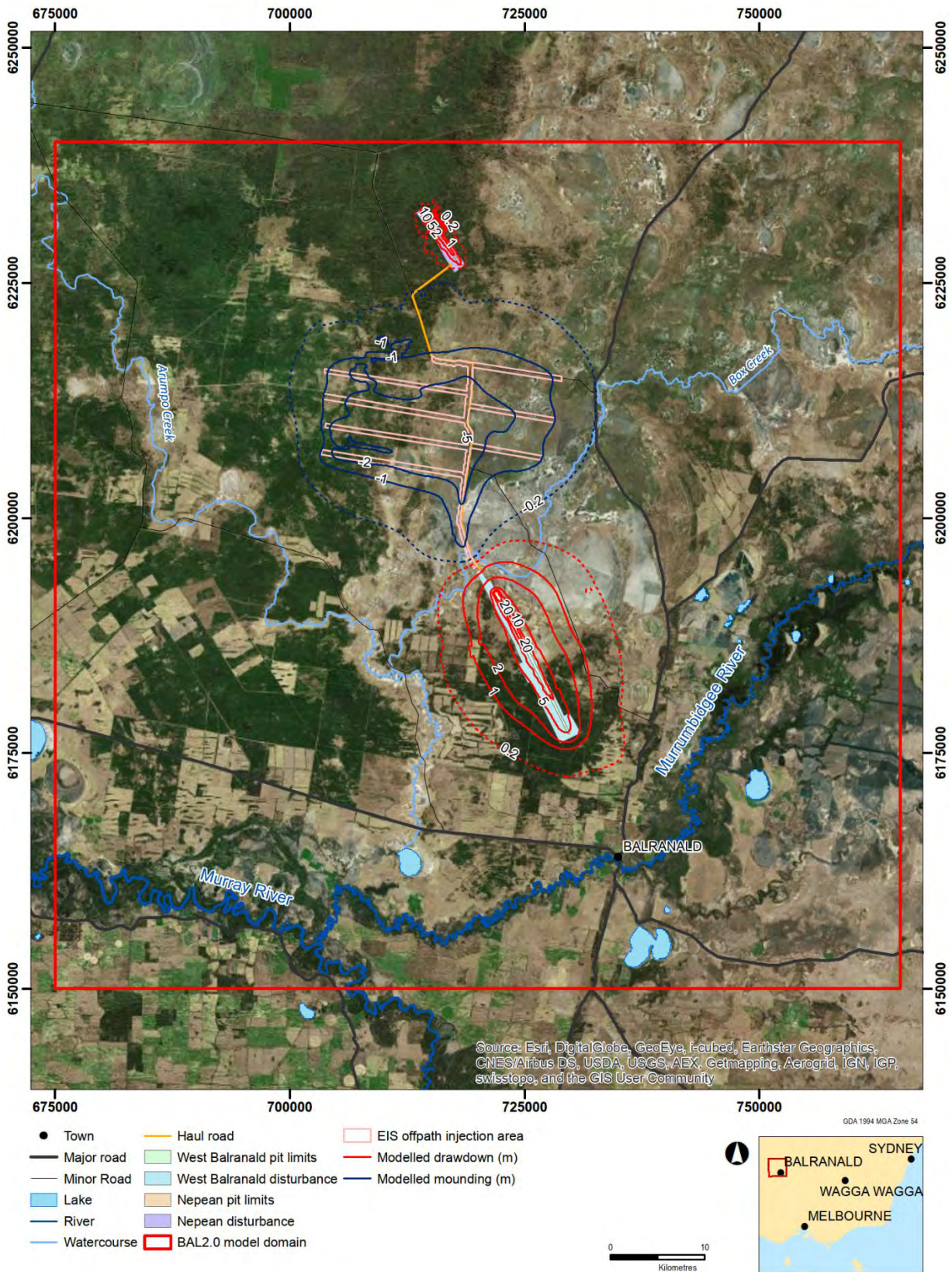


Figure 5.3 2015 EIS modelled drawdown in the Shepparton Formation at the end-of-mining (Jacobs 2015)

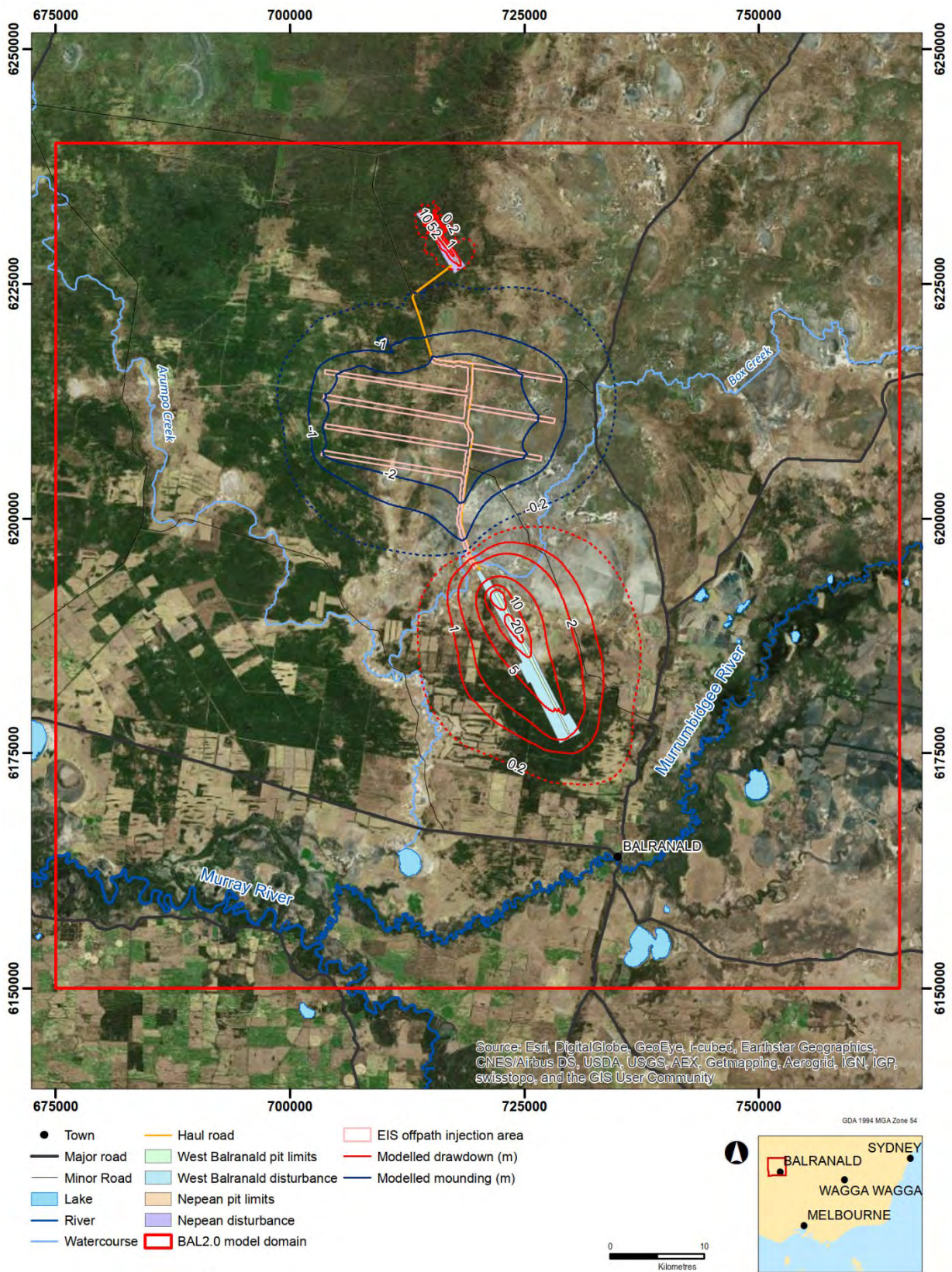


Figure 5.4 2015 EIS modelled drawdown in the LPS1 at the end-of-mining (Jacobs 2015)

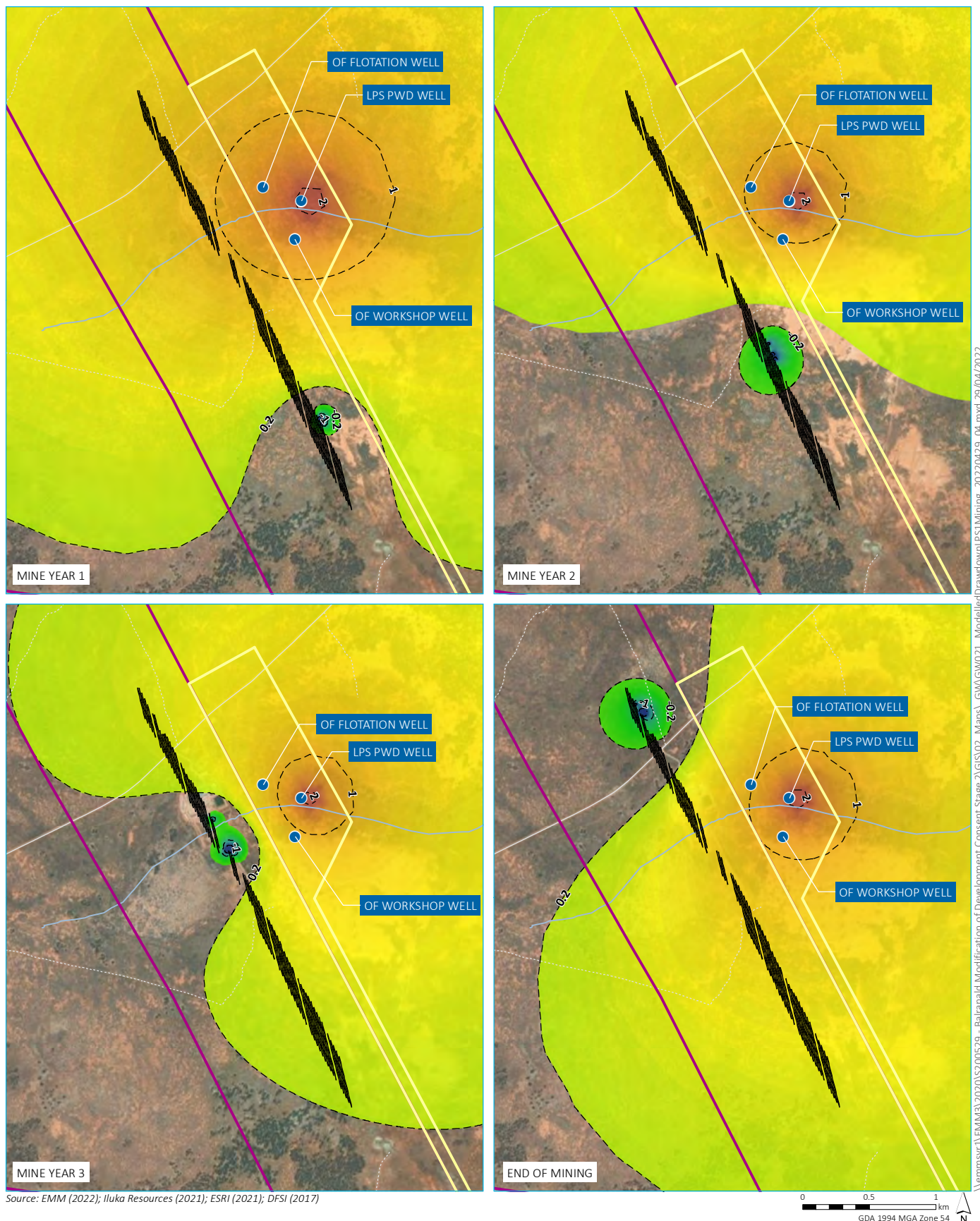


KEY

- EIS Approved Balranald Project Area (SSD-5285)
- Proposed modification extension to Balranald Project Area boundary
- MOD1 stope
- Mine water supply well
- Drawdown (m)
- Minor road
- Vehicular track
- Watercourse/drainage line
- Modelled drawdown (m)
- >2
- <-2

MOD1 modelled drawdown at the water table during mining

Balranald Mineral Sands Project
Balranald groundwater comparative impact assessment
Figure 5.5



KEY

- EIS Approved Balranald Project Area (SSD-5285)
- Proposed modification extension to Balranald Project Area boundary
- MOD1 stope
- Mine water supply well
- Drawdown (m)
- Minor road
- Vehicular track
- Watercourse/drainage line
- Modelled drawdown (m)
- >2
- <-2

Modelled drawdown in LPS1 lower shore/LPS2 foreshore during mining

Balranald Mineral Sands Project
Balranald groundwater comparative impact assessment
Figure 5.6

5.5.4 Sensitive receivers

i Third party bores

Figure 5.7 shows the modelled responses at the third-party Olney bores over the mining period. Maximum drawdown is observed at the Karra Homestead bore, which is located in close proximity to the mine site. As distance increases away from the mine site, drawdown responses decrease as observed at the other bores. In comparison to the 2015 EIS, the updated modelled responses show a greater drawdown response due to more makeup water being required from the Olney Formation. However, at all bores, drawdown is still less than the 2 m decline threshold defined by the AIP for minimal impact.

ii Aquatic ecosystems

Aquatic ecosystems are represented in the model using MODFLOW's river package to simulate both the Murray and Murrumbidgee Rivers. For both the 2015 EIS and MOD1 models, the water balance indicates that the rivers are dominantly a losing system within the model domain. The previous 2015 EIS model showed fluctuations associated with river leakage volumes with the predicted drawdown not reaching the Murray and Murrumbidgee Rivers. The MOD1 model shows significantly smaller drawdown and mounding effects on the groundwater system and thus any impacts to the rivers and associated aquatic ecosystems would be smaller again, in comparison to the 2015 EIS.

iii Terrestrial ecosystems

Modelled hydrographs were assessed at the nominated GDE sites, with the largest drawdown responses shown in Figure 5.8, which is associated with location number 4 (GDE8) shown in Figure 3.10. At this location, potential GDEs are associated primarily with Black Box trees along Box Creek, located directly north-east of the West Balranald footprint. Previous studies conducted by CDM-Smith (CDM Smith, 2015) indicated that Black Box were found to be a hardy, resilient species requiring fresh water from rainfall and periodic inundation for the bulk of its water needs. There was some evidence of Black Box using groundwater opportunistically to supplement its water needs during dry periods; however, the use of groundwater is likely to be negligible in hypersaline conditions (ie when groundwater salinity exceeds 35,000 mg/L). The GDE class and impact assessment framework developed for the project indicated that Blackbox in this region is likely a Class 4 GDE, which has a 'low' level of dependence on the occurrence of groundwater. In addition, drawdowns of up to 5 m may have a 'low' impact on GDE health. Given the modelled drawdown for MOD1 shows drawdown less than 0.1 m at this location, the risk to terrestrial impacts is considered low to insignificant.

iv Atlas Campaspe Mine

Both the previous 2015 EIS (Figure 5.3 and Figure 5.4) and MOD1 modelling results (Figure 5.5 and Figure 5.6) show insignificant drawdown and mounding effects north of the Balranald mining area. On this basis, groundwater affecting activities will have no interaction with the mining activities at the Atlas Campaspe Mine, located approximately 20 km north of Iluka's Nepean deposit.

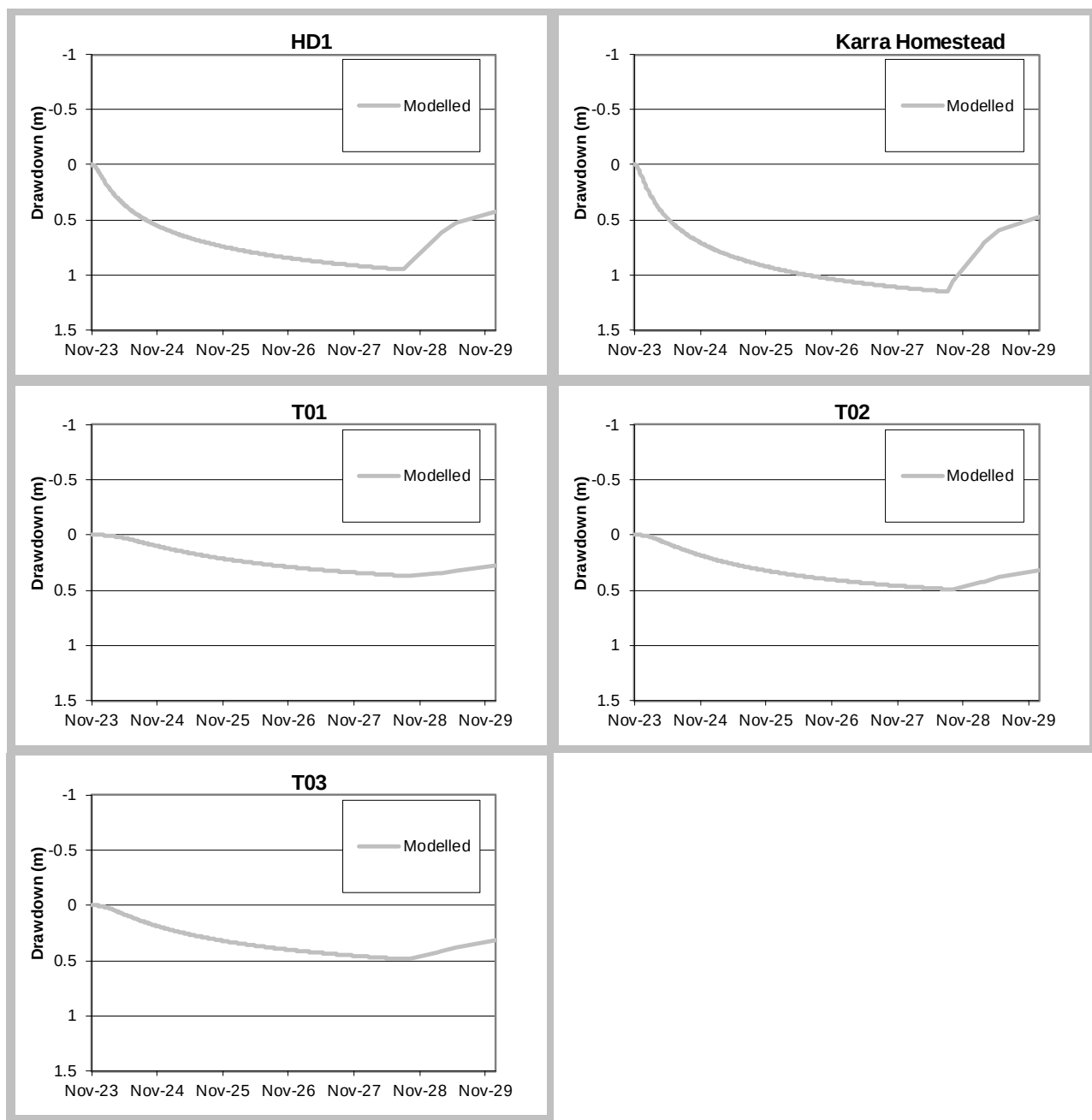


Figure 5.7 Modelled hydrographs at third party Olney bores

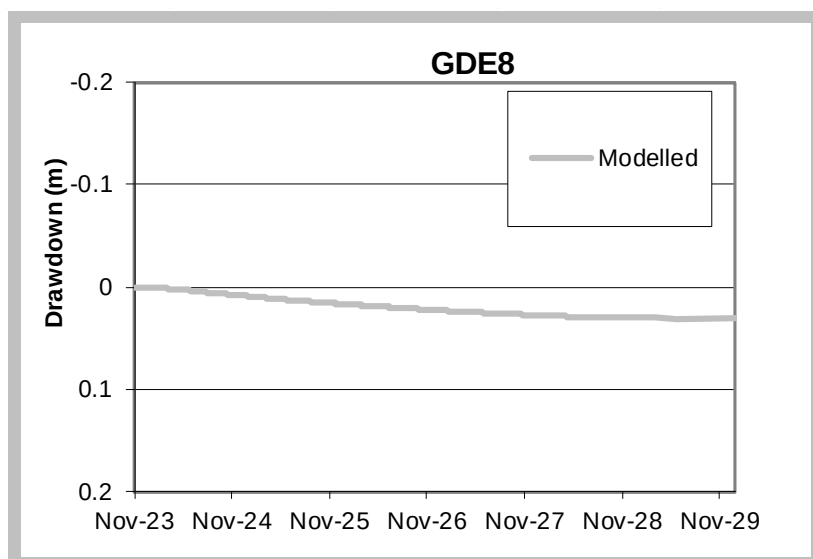


Figure 5.8 Modelled hydrographs at selected terrestrial GDE sites

5.6 Groundwater quality assessment

Groundwater in the LPS aquifer is too saline to be used for human consumption, stock watering or irrigation. Geochemical testing and water quality assessments are, however, being conducted to assess potential groundwater quality impacts (Earth Systems 2020, 2021a, b, c, 2022a). Two potential risks to water quality have been identified:

1. geochemical oxidation of sulfide minerals in ore, products and mining by-products which may generate AMD; and
2. reinjection of process water, fine sand tailings and floatation tails which have become acidic and contain process chemicals, in particular PAX.

5.6.1 Acid mine drainage

The mining method presented in the 2015 EIS proposed co-disposal of fine sand tails and sand tails above ground. In the underground mining method, sulfide minerals will be concentrated within the fine sand tails and floatation tails which will be reinjected into the LPS aquifer. The ore in the LPS aquifer naturally contains sulfides but the neutral pH of the aquifer indicates that in-situ oxidation is not occurring. The geochemical conditions in the LPS aquifer are therefore not conducive to further oxidation of sulfide minerals and AMD is not expected to occur once the fine sand tails have been reinjected into the aquifer. During processing and storage, tailings will be maintained water saturated to reduce sulfide oxidation and the water quality will be monitored. The pH will be adjusted if required prior to re-injection into the aquifer.

Mining by-products will contain some sulfide minerals which may generate AMD during storage or permanent placement above ground. For instance, sand tails will be placed above mined stopes to raise the ground surface following expected subsidence and ground settlement, and oversized material will be used for road construction. To minimise the risk of AMD generation and to neutralise potentially generated acid, these materials will be amended with lime sand. Geochemical testing has been performed on these materials and lime dosing will be designed to neutralise acidity. After implementation of AMD mitigation techniques, the presence of sulfide minerals in ore and mining by-products is not considered to pose risk to groundwater quality.

The underground mining method eliminates the need for long-term above ground storage of fine sand tails and dewatering, which would have generated acidity in-situ, will not be required. The revised mining method is therefore not considered to increase the AMD risk to groundwater quality in comparison to the method proposed in the 2015 EIS.

5.6.2 Process chemicals

The below ground mining method will include injection of process chemicals into the LPS aquifer. Re-injection of process water was not included in the mining method presented in the 2015 EIS. Of the process chemicals, PAX will be present at the greatest concentration in the slurry that will be re-injected into the mined stopes. Additionally, other chemicals used in the processing are less harmful to human health and the environment and PAX is therefore the only processing chemical discussed herein (Earth Systems 2022b). This chemical is commonly used in mining processing and has been shown to break down in water storage dams and in mining process circuits. PAX is expected to break down in the aquifer once injected and the PAX concentration in groundwater will decrease over time. The rate of degradation assessment has conservatively used a half-life of 12 weeks.

Investigations are currently ongoing to determine the PAX concentration of the water to be re-injected. A conservative approach has been adopted for estimating the PAX concentration. The PAX concentration was initially estimated by Earth Systems to be 550 mg/L in 2017 and the estimate was refined at the end of 2021 to 110 mg/L (Earth Systems 2021c). Laboratory bench-scale testing, however, reported PAX concentrations from 9 mg/L to 94 mg/L, and further testing is being conducted to determine a more realistic PAX concentration in process water that will be used in the HBF process (Earth Systems 2022b). Laboratory tests are also being conducted to estimate the degree of sorption to tailings and the rate of degradation prior to injection. The tests had not been completed at the time of writing.

A groundwater fate and transport model was developed to simulate the transport and migration of PAX if it were to be re-injected at 110 mg/L, with an assumed half-life of 12 weeks. When the PAX was assumed to degrade and break down to innocuous products, the model results showed that PAX impacted groundwater did not extend to the project boundary during mining. In the model, the PAX concentration and the spatial extent of the PAX plume decreased over time post injection and further decreased at the cessation of mining. The modelled PAX concentration in the SFM and LPS during mining are presented in Figure 5.9 to Figure 5.10.

Figure 5.11 and Figure 5.12 show the modelled PAX concentrations post mining for the SFM and LPS respectively. By three years post mining, almost no PAX remains above the 0.0005 mg/L environmental threshold within the SFM and by 10 years post mining, there is predicted to be none. Within the LPS, by three years post mining, the modelled plume is noticeably smaller compared to the mining phase, and ten years post mining it is almost completely reduced to below the trigger of 0.0005 mg/L. It is worth noting the plume is predicted to get close to the LPS saline water supply well during mining. Over the entire 100 year post mining period, the simulated PAX plume does not migrate further than 1,000 m from the injection point, and thus the groundwater beneficial use category will not be affected by the mining activities. The potential impacts to groundwater quality is therefore considered minimal.

An alternative model was developed to simulate the migration of PAX assuming that PAX would not degrade in the aquifer. The results of this highly conservative model indicated that the PAX impacted groundwater would only migrate 1,000 m to the west of the injection point 100 years following injection. Both models conservatively assumed that PAX would not sorb to aquifer surfaces, which is highly likely to occur and would further reduce the concentration and extent of PAX in groundwater. Groundwater modelling therefore show that PAX injected into the LPS aquifer will not spread in the aquifer. Further details of the groundwater fate and transport modelling is provided in Appendix A.

The groundwater in the LPS aquifer is too saline to be used for domestic or agricultural purposes, and thus third-party bores near the mining area are installed in the deeper Olney Formation, which is hydraulically separated from the LPS formation where PAX will be injected. Third party bores are also located spatially beyond any potential PAX plume, and the risk for PAX to reach third party bores is considered negligible. Tronox's Atlas-Campaspe mine, which is currently being constructed, is located approximately 55 km from the Balranald mine and the proposed underground mining does not pose risk to groundwater quality at the Atlas-Campaspe mine.

There are no aquatic ecosystems within the area affected by PAX injection to the LPS, and PAX impacted groundwater will not migrate and discharge to ecosystems associated with the Murray and Murrumbidgee Rivers. The risk to aquatic ecosystems is therefore considered negligible.

As discussed in Section 4.3, a GMP has been developed and includes required monitoring of potential groundwater quality impacts during and following mining. The GMP will be updated prior to MOD1 commencement.



KEY

 EIS Approved Balranald Project Area (SSD-5285)

 Proposed modification extension to Balranald Project Area boundary

 MOD1 stope

● Mine water supply well

— Minor road

--- Vehicular track

— Watercourse/drainage line

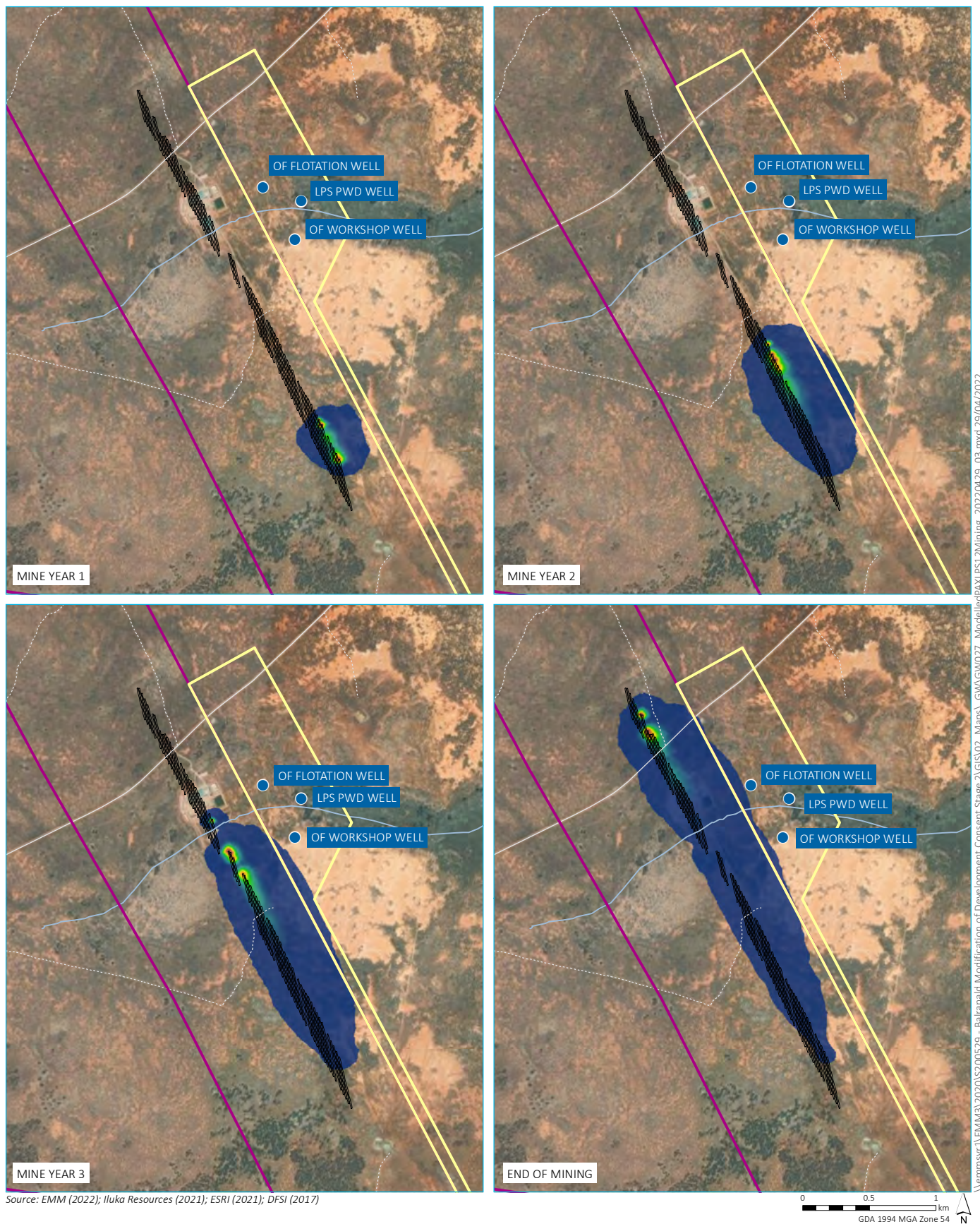
Modelled PAX (mg/L)

100

0.0005

Modelled PAX concentration in the Shepparton Formation during mining

Balranald Mineral Sands Project
Balranald groundwater comparative impact assessment
Figure 5.9



KEY

 EIS Approved Balranald Project Area (SSD-5285)

 Proposed modification extension to Balranald Project Area boundary

 MOD1 slope

● Mine water supply well

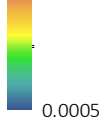
— Minor road

--- Vehicular track

— Watercourse/drainage line

Modelled PAX (mg/L)

100



0.0005

Modelled PAX concentration in LPS1 lower shore/LPS2 foreshore during mining

Balranald Mineral Sands Project
Balranald groundwater comparative impact assessment
Figure 5.10



Source: EMM (2022); Iluka Resources (2021); ESRI (2021); DFSI (2017)

KEY

 EIS Approved Balranald Project Area (SSD-5285)

 Proposed modification extension to Balranald Project Area boundary

 MOD1 stope

● Mine water supply well

— Minor road

--- Vehicular track

— Watercourse/drainage line

Modelled PAX (mg/L)

100

0.0005

0.0005

0.0005

0.0005

0.0005

0.0005

0.0005

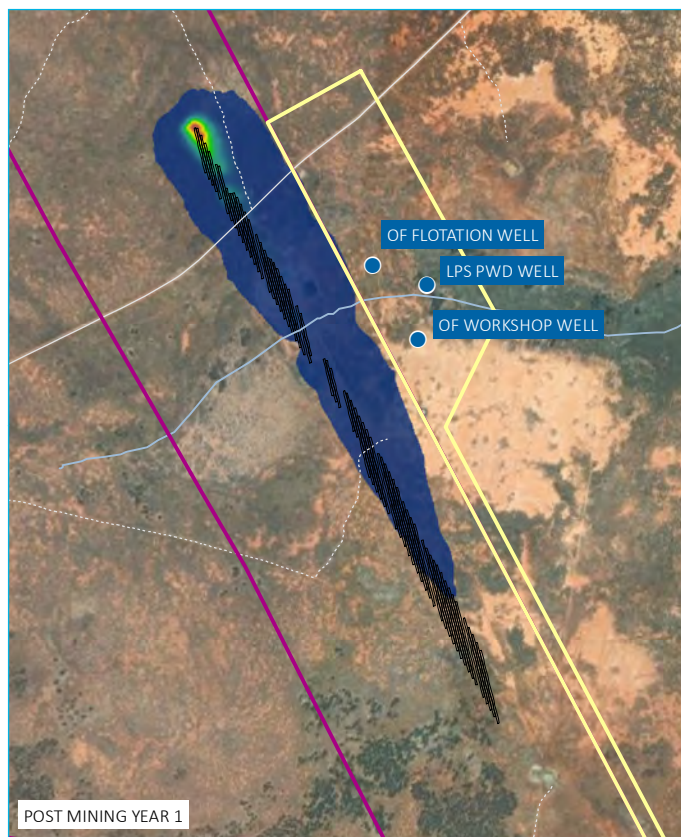
0.0005

0.0005

0.0005

Modelled PAX concentration in the Shepparton Formation post mining

Balranald Mineral Sands Project
Balranald groundwater comparative impact assessment
Figure 5.11



Source: EMM (2022); Iluka Resources (2021); ESRI (2021); DFSI (2017)

KEY

 EIS Approved Balranald Project Area (SSD-5285)

 Proposed modification extension to Balranald Project Area boundary

 MOD1 stope

● Mine water supply well

— Minor road

--- Vehicular track

— Watercourse/drainage line

Modelled PAX (mg/L)

100

0.0005

0.0005

0.0005

0.0005

0.0005

0.0005

0.0005

0.0005

0.0005

0.0005

0.0005

Modelled PAX concentration in LPS1 lower shore/LPS2 foreshore post mining

Balranald Mineral Sands Project
Balranald groundwater comparative impact assessment
Figure 5.12

5.7 Predictive uncertainty analysis

5.7.1 Modelled scenarios

In the previous 2015 EIS modelling, two predictive uncertainty scenarios were modelled with multipliers to the base case hydraulic conductivity and storage parameters to assess a range of plausible impacts. These two uncertainty scenarios called 'high dewatering (HDW)' and 'low dewatering (LDW)' represent scenarios with plausible maximum drawdown/dewatering volumes and mounding/injection volumes.

The previous two 2015 EIS scenario definitions have also been run for the MOD1 model and have been renamed to alternative parameters (Alt par) 1 and 2 respectively, since varied dewatering rates does not form part of the MOD1 assessment.

An additional uncertainty scenario was also run where the injected PAX does not decay, to show where a more conservative solute could travel to if the half-life is longer than the assumed 12 weeks.

5.7.2 Uncertainty results

The two hydraulic uncertainty scenarios produced results that are reasonably similar to the base case. Alt par 1 shows less drawdown and mounding impact overall compared to the base case, and Alt par 2 shows more drawdown and mounding, but it does not cause the drawdown to reach any environmental receptors.

For the no-decay scenario PAX did not reach any environmental receptors.

There is a low chance that PAX could reach the process water bore screened within the LPS, which would have a minor consequence since this water is only used for flotation and is treated with PAX anyway.

6 Summary

A groundwater impact assessment has been undertaken for the proposed modification (MOD1) to the approved Balranald Mineral Sands Project in south-western New South Wales. The purpose of this GIA is to assess predicted environmental impacts of the proposed modification against the predicted impacts of the approved project, undertaken previously by EMM in 2015. Both direct and indirect risks were assessed between the two project definitions, and the framework outlined by the *Australian Interference Policy* (AIP, 2012) provided the main framework to assess the level of impact.

The previously approved project consisted of a linear open cut pit, which required perimeter pit dewatering bores to progressively dewater the mine to allow dry mining activities to occur. The water was then planned to be pumped north to a network of injection borefields for the return of hypersaline groundwater to the Loxton Parilla Sands aquifer. At the peak, modelled dewatering and injection volumes reached around 1,300 L/s with dewatering and mounding contours emanating around 15 km from the center of the mine pit and injection borefield respectively.

The proposed MOD1 involves underground mining of the ore from areas called stopes. The stopes are then backfilled using sand fines and the courser sand tails are replaced on the surface and form part of the final landform. No removal of overburden is required, and thus mine dewatering and disposal of surplus water does not form part of the MOD1 definition. An additional activity associated with the MOD1 involves process chemicals, which will be added during ore processing to remove sulfides and other waste products, and to concentrate magnetic and non-magnetic saleable products. Some of the process water and residual process chemicals will be reinjected when backfilling the stopes.

The GIA details potential impacts associated with MOD1 are smaller than those presented in the 2015 EIS for the following identified risks:

- Drawdown associated with water supply from the LPS.
- Changes to the Shepparton Formation and LPS groundwater pressures during mining.
- Mounding effects during the reinjection phase.
- Reduced risk associated with altered hydrogeological conditions associated with mine voids.
- Reduced risk associated with permanent changes to natural topography.
- Reduced risk to terrestrial vegetation health.
- Reduced risk associated with interaction with the Atlas Campaspe Mine.
- No risk of AMD seepage from final above ground storage fine sand tails.

The GIA details potential impacts associated with MOD1 that are larger than those presented in the 2015 EIS for the following identified risks:

- Drawdown associated with water supply from the Olney Formation.
- There is a low probability that injected process water and residual process chemicals may reach the process water supply bore.
- There is a low risk that lime amendment will not be effective at neutralising AMD generated in the sand tails to be placed above the mined stopes.

The GIA suggests that impacts between the 2015 EIS and MOD1 are no different for the following identified risks:

- seepage from sand tailings, ore stockpiles and engineered impoundments from a quantity perspective;
- groundwater supply effect on surface water systems and other aquatic ecosystems;
- potential AMD seepage from temporary stockpiles; and
- reinjection of process water and residual process chemicals will not affect the groundwater beneficial use category, however, groundwater in close proximity to the mining stopes will contain PAX during and for a several years after mining.

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Appendix A

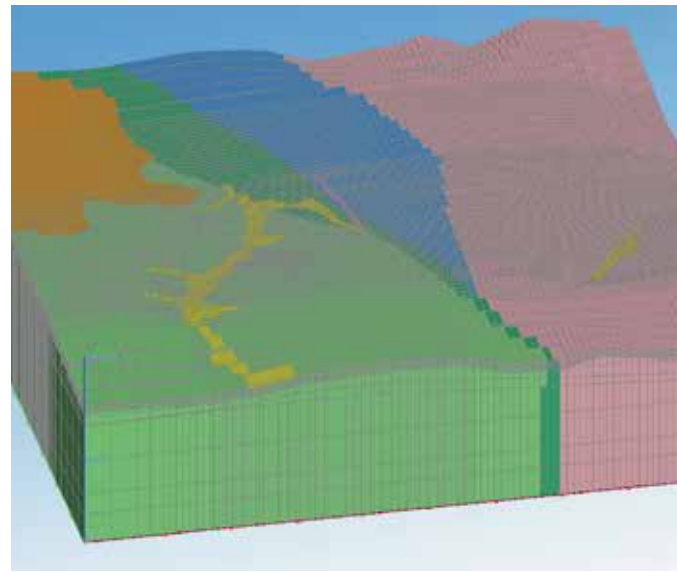
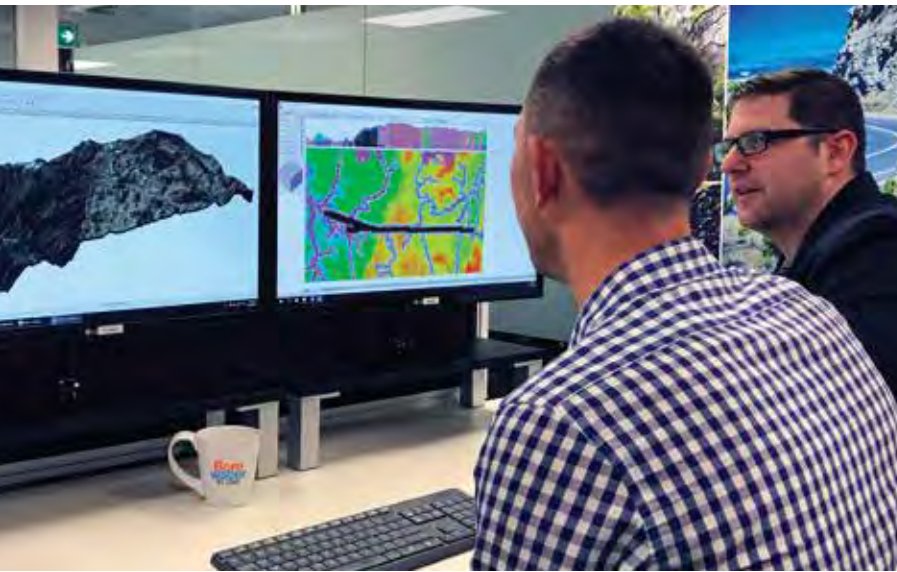
Groundwater Modelling Report





Balranald Mineral Sands Project MOD1 Groundwater Modelling

Prepared for Iluka Resources Limited
April 2022





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Balranald Mineral Sands Project MOD1 Groundwater Modelling

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Client

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Executive Summary

Iluka proposes to develop a mineral sands mine in south-western (NSW), known as the Balranald Project. It includes construction, mining, primary processing and rehabilitation of two linear mineral sand deposits, known as the West Balranald and Nepean deposits, located approximately 12 kilometres (km) and 66 km north-west of the Balranald township, respectively.

Since development consent was granted in April 2016, Iluka has undertaken an approved bulk sampling activity, via an underground mining method, involving the extraction of mineralised material (ore) from depth within the approved disturbance area of the West Balranald mine.

The proposed Balranald Project Modification (MOD1) would involve continuing the underground mining trial wholly within a portion of the approved disturbance footprint of the West Balranald mine pursuant to the development consent (SSD-5285), including development of mineral processing infrastructure and a portion of the access road within a proposed new area of disturbance under Part 4 of the EP&A Act.

An updated numerical groundwater model, referred to as 'BAL3.0', has been developed based on the existing 'BAL2.0' groundwater model used to support the groundwater assessment for the EIS (Jacobs 2015). The updated model was used to conduct predictive modelling of the proposed MOD1 groundwater-affecting activities. This modelling supports, and will be appended to, the groundwater assessment for MOD1.

Specific updates to the model include modernisation of the modelling software from MODFLOW-Surfact (HGL 2014) to MODFLOW-USG (Panday et al 2017). The graphical user interface used to build and host the model and to process some of the results, was updated from Groundwater Vistas 6 (ESI 2014) to Groundwater Vistas 7 (ESI 2017). Substantial numerical efficiency has been gained by the use of a Voronoi polygon mesh, rather than the previous rectangular grid, to discretise the model domain. This method provides a more efficient method to incorporate spatial detail where needed and larger model cells elsewhere. The update to MODFLOW-USG also enabled pinching out and deactivating of model cells where hydrostratigraphic units are absent, whereas previously these had to be simply represented as very thin layers. These substantial gains in numerical efficiency enabled the previously separate local-scale models, used for transient calibration, to be merged with the regional predictive model used to support impact assessment.

Predictive modelling and uncertainty analysis have been carried out to simulate potential effects resulting from the following MOD1 groundwater-affecting activities:

- Alteration of aquifer properties with time as a result of creation of subsurface voids and associated subsidence.
- Injection of sand fines into mined stope voids.
- Seepage from sand tailings emplaced at surface.
- Saline groundwater supply abstraction from the Loxton-Parilla Sands aquifer.
- Brackish water supply abstraction from the deeper Olney Formation.
- Addition of potassium amyl xanthate (PAX) solute into the groundwater system via injection of sand fines and seepage from sand tailings.

Model updates, performance and the results of predictive modelling are documented in this report and form the quantitative basis for the associated MOD1 groundwater assessment, to which this report is appended.

The updated modelling was independently reviewed by Hugh Middlemis of HydroGeoLogic. The review found that the model was developed consistent with best practice, that a Class 2 model confidence classification (its targeted Class) is well justified and was that it is suitable for predicting the impacts associated with the mining activities proposed in MOD1.

Table of Contents

Executive Summary	ES.1
1 Introduction	1
1.1 Project background	1
1.2 Description of modification	3
1.3 Groundwater-affecting activities	5
1.4 Previous modelling	8
1.5 Modelling objectives	8
1.6 Model confidence classification	9
2 Model design	11
2.1 Software	11
2.2 Domain and spatial discretisation	11
2.3 Temporal discretisation and numerical solution	13
2.4 Boundary conditions	14
3 History-matching	17
3.1 Approach	17
3.2 Performance	23
3.3 Water balance	27
3.4 Calibrated hydraulic properties	28
3.5 Sensitivity	28
4 Predictive modelling	30
4.1 Scenario definition and representation	30
4.2 Uncertainty analysis	33
4.3 Results	34
5 Summary	57
References	58

Appendices

Appendix A Independent review

Appendix B Modelled hydraulic property distributions

Appendix C Modelled steady state hydraulic head distributions

Appendix D Hydrographs: history-matching

Appendix E Hydrographs: mining prediction, T3 trial wells

Tables

Table 2.1	Model layers	13
Table 3.1	SRMS errors for BAL2.0 local-scale models and BAL3.0	23
Table 3.2	Modelled pre-development steady state water balance	27
Table 3.3	Base case calibrated hydraulic property values	29
Table 4.1	Modelled timing of mining stopes and panels	32

Figures

Figure 1.1	Regional setting and EIS approved Balranald project area (SSD-5285)	2
Figure 1.2	Proposed modification and conceptual site layout	4
Figure 1.3	Groundwater-affecting mining activities conceptual model	7
Figure 2.1	Model domain, Voronoi mesh and previous local-scale models	12
Figure 2.2	History-matching stress periods	14
Figure 2.3	Regional boundary conditions	15
Figure 3.1	T3 stopes, abstraction and injection locations	19
Figure 3.2	Modelled groundwater abstraction (-ve) and injection (+ve): TN5, TN1, Nanda, Upson Downs and T3	20
Figure 3.3	Modelled groundwater abstraction (-ve) and injection (+ve): LTT	21
Figure 3.4	Modelled groundwater abstraction (-ve) and injection (+ve): LTT	22
Figure 3.5	Modelled steady state watertable	24
Figure 3.6	Scatter plot of steady state hydraulic head	25
Figure 3.7	Scatter plots of drawdown for localised tests and trials: TN5 and TN1	25
Figure 3.8	Scatter plots of drawdown for localised tests and trials: Nanda, Upson Downs, LTT and T3	26
Figure 3.9	Modelled pre-development steady state water balance	27
Figure 3.10	Modelled transient water balance over the history-matching period	28
Figure 4.1	MOD1 mine plan and slimes injection layout	31
Figure 4.2	Modelled drawdown at the water table during mining	35
Figure 4.3	Modelled drawdown at the water table post mining	36
Figure 4.4	Modelled drawdown in LPS1 lower shore/LPS2 foreshore during mining	37
Figure 4.5	Modelled drawdown in LPS1 lower shore/LPS2 foreshore post mining	38

Figure 4.6	Modelled drawdown in Olney Formation during mining	39
Figure 4.7	Modelled drawdown in Olney Formation post mining	40
Figure 4.8	Modelled drawdown at the water table: uncertainty analysis	41
Figure 4.9	Modelled drawdown in LPS1 lower shore/LPS2 foreshore: uncertainty analysis	42
Figure 4.10	Modelled drawdown in Olney Formation: uncertainty analysis	43
Figure 4.11	Modelled hydrographs at 500 m chainage intervals along the West Balranald deposit	44
Figure 4.12	Modelled hydrographs at third party wells	45
Figure 4.13	Locations of potential GDEs (after CDM Smith 2015)	46
Figure 4.14	Modelled hydrographs at GDEs	47
Figure 4.15	Modelled PAX concentration in the Shepparton Formation during mining	49
Figure 4.16	Modelled PAX concentration in the Shepparton Formation post mining	50
Figure 4.17	Modelled PAX concentration in LPS1 lower shore/LPS2 foreshore during mining	51
Figure 4.18	Modelled PAX concentration in LPS1 lower shore/LPS2 foreshore post mining	52
Figure 4.19	Modelled PAX concentration in the Shepparton Formation during mining: no decay	53
Figure 4.20	Modelled PAX concentration in the Shepparton Formation post mining: no decay	54
Figure 4.21	Modelled PAX concentration in LPS1 lower shore/LPS2 foreshore during mining: no decay	55
Figure 4.22	Modelled PAX concentration in LPS1 lower shore/LPS2 foreshore post mining: no decay	56

1 Introduction

EMM Consulting Pty Limited (EMM) was commissioned by Iluka Resources Limited (Iluka) to undertake a groundwater comparative impact assessment (GCIA) of the proposed modification (MOD1) to the approved Balranald Mineral Sands Project (the Balranald Project) in south-western New South Wales (NSW).

The groundwater assessment will support a modification report which will be submitted to the NSW Department of Planning, Infrastructure and Environment (DPIE) under the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act).

This groundwater modelling report forms a supporting appendix to the groundwater comparative impact assessment. Further details on conceptualisation of the groundwater system, supporting data and the MOD1 project can be found there or, with the exception of the latter, in the groundwater assessment (Jacobs 2015) of the approved development.

1.1 Project background

Iluka have approval to develop a mineral sands mine in south-western (NSW), known as the Balranald Project. It includes construction, mining, primary processing and rehabilitation of two linear mineral sand deposits, known as the West Balranald and Nepean deposits, located approximately 12 kilometres (km) and 66 km north-west of the town of Balranald (Balranald town), respectively.

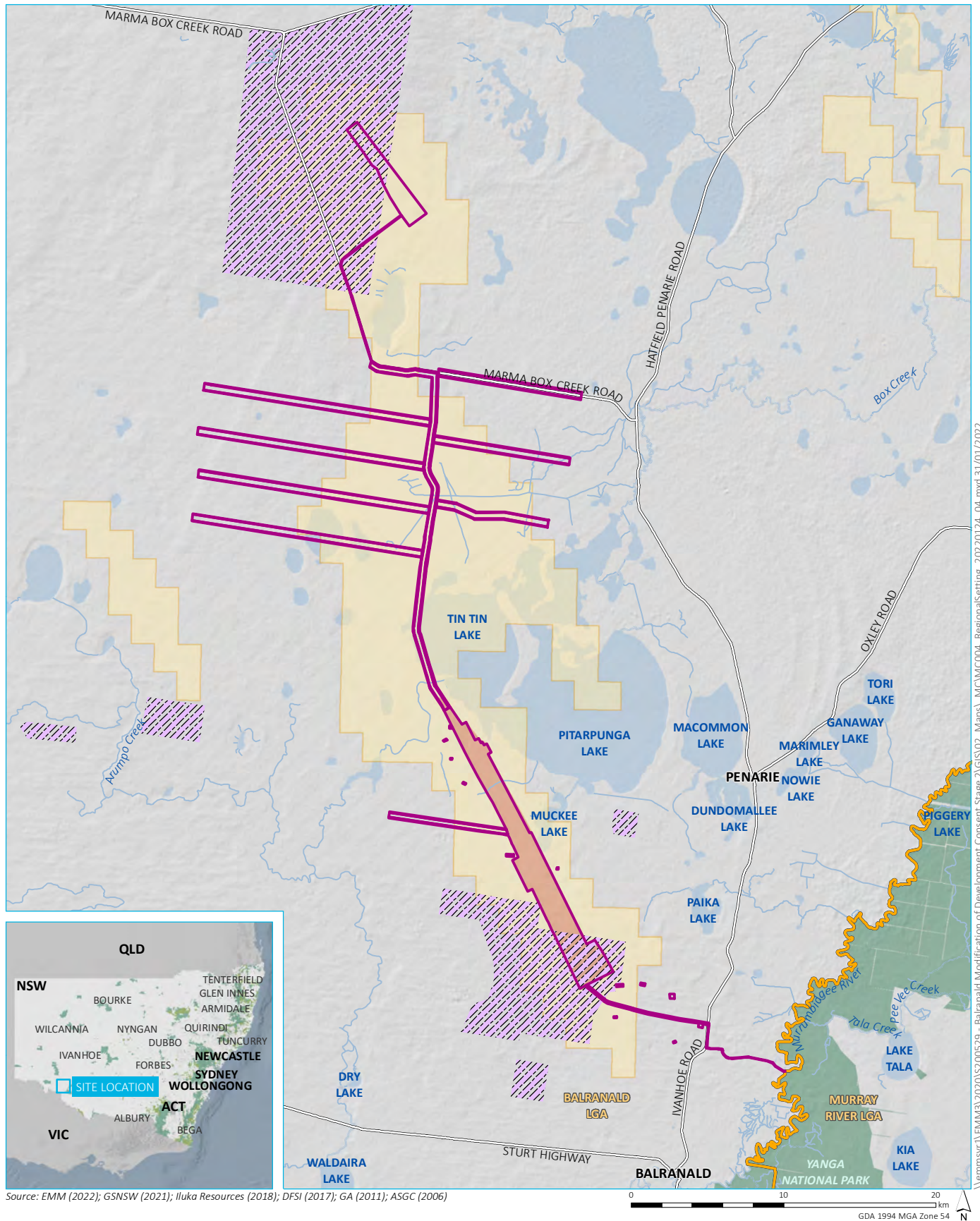
An environmental impact statement (EIS) was prepared and submitted in 2015 to accompany a State significant development (SSD-5285) application under Part 4 of the EP&A Act for an open cut, truck and shovel mining method. Development consent was granted by DPIE under Part 4 of the EP&A Act on 5 April 2016. The Balranald Project also included undertaking a bulk sampling activity at the West Balranald mine to test the removal of ore using underground mining methods.

The regional setting and approved EIS project area are shown on Figure 1.1.

Since development consent was granted in April 2016, Iluka has undertaken the approved bulk sampling activity involving the extraction of mineralised material or ore, from depth within the approved disturbance area of the West Balranald mine.

The outcomes of the bulk sampling activities confirmed the effectiveness of the underground mining method, validated key elements of the mining unit design and have been used to help guide the proposed modification to inform the potential suitability (ie commerciality and reduced environmental impacts) of underground mining as an alternative method for resource extraction for the Project.

Further details on the background of the Balranald Project can be found in Chapter 2 of the modification report.



KEY

- EIS Approved Balranald Project Area (SSD-5285)
- Exploration Licence (EL7450)
- Mining Lease (ML1736)
- Southern Mallee Conservation Area (2015)
- Major road
- Watercourse/drainage line
- Waterbody
- NPWS reserve

- Local government area
- NPWS reserve
- State forest

INSET KEY

Regional setting and EIS approved
Balranald project area (SSD-5285)

Balranald Mineral Sands Project
Balranald groundwater comparative impact assessment
Figure 1.1

1.2 Description of modification

The proposed MOD1 would involve continuing the underground mining trial wholly within a portion of the approved disturbance footprint of the West Balranald mine pursuant to the development consent (SSD-5285) and development of mineral processing infrastructure and a portion of the access road within a proposed new area of disturbance under Part 4 of the EP&A Act.

The construction of infrastructure would be undertaken to support the construction and operation for proposed underground mining, including mineral processing infrastructure, access roads, upgrade of external roads and intersections, gravel extraction, monitoring infrastructure, accommodation facility, road transport of ore offsite for downstream processing and other infrastructure as required.

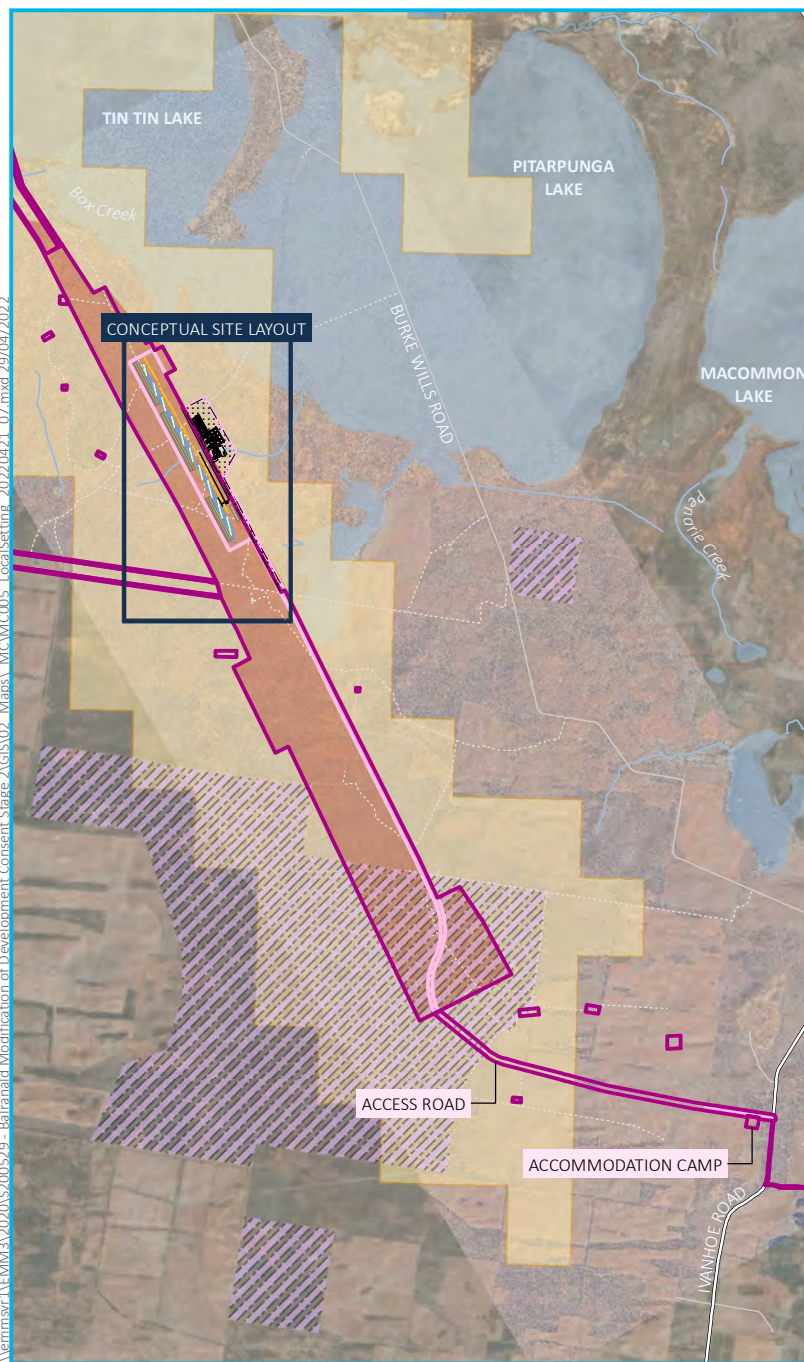
The underground mining process would involve:

- clearing the footprint directly above the mining area – the area will be stripped of topsoil, subsoil and non-saline overburden to a nominal depth of 2 metres (m);
- surface placement of treated sand tails and overburden/subsoil ahead of mining into the space created by the above stripping;
- underground mining of the ore;
- processing of the mined ore to separate the heavy mineral concentrate (HMC) from sand tails, sand fines and oversize;
- stockpiling of the HMC;
- backfilling of sand fines underground;
- replacement of subsoil and topsoil for rehabilitation and final landform; and
- environmental monitoring activities (including groundwater, geochemistry, subsidence, air quality and noise).

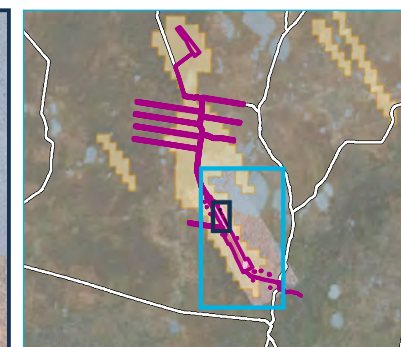
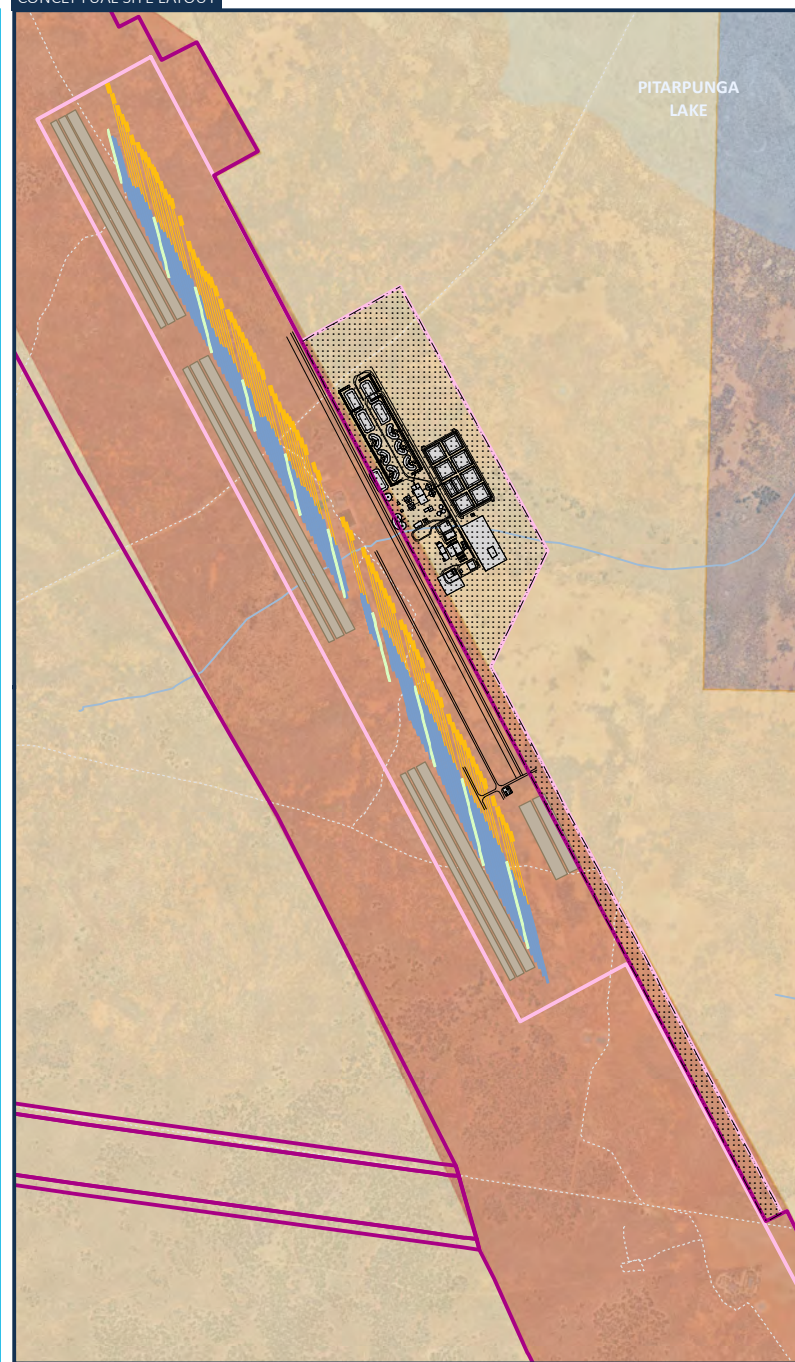
Ore is expected to be produced and processed at a rate no greater than approved under the development consent. The processing plant on site will produce a HMC to generate two primary product streams; magnetic HMC and non-magnetic HMC.

The product would be stockpiled and transported off-site for downstream processing with underground mining operations to be undertaken for a period of 6 years.

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CONCEPTUAL SITE LAYOUT



KEY

- EIS Approved Balranald Project Area (SSD-5285)
- Proposed modification study area
- Proposed modification extension to Balranald Project Area boundary
- Processing area infrastructure
- Subsoil stockpile
- Drill pad and string to underground stope
- Underground stope
- Underground pillar
- Major road
- Minor road
- Existing track
- Watercourse/drainage line
- Waterbody
- Southern Mallee Conservation Area (2015)
- Exploration Licence (EL7450)
- Mining Lease (ML1736)

Proposed modification study area and conceptual site layout

Balranald Mineral Sands Project
Balranald groundwater comparative impact assessment
Figure 1.2



Source: EMM (2022); Iluka Resources (2021); ESRI (2021); DFSI (2017); GA (2011)

0 0.5 1 km
GDA 1994 MGA Zone 54

1.3 Groundwater-affecting activities

Figure 1.3 illustrates the groundwater-affecting activities associated with MOD1, which are then of relevance to the groundwater modelling. Process water dams are proposed to be lined, and therefore will not seep water into the ground, and all other process water is similarly contained. The proposed groundwater-affecting activities, and associated processes, are discussed in the following sections.

1.3.1 Groundwater supply

Iluka proposes to install a well in the LPS aquifer, adjacent to the process water dam, to provide saline groundwater supply for the project. The well will be pumped at an average rate of 12 L/s, commencing three months prior to commencement of mining (ie end of October 2023) and will cease at the conclusion of slimes injection.

Additionally, Iluka proposes to install two wells in the deeper Olney Formation, adjacent to the process plant, to provide brackish groundwater supply to the flotation plant during mining and the vehicle wash/workshop area during construction (October 2022 – October 2023) and operation. The Olney bores will have a combined average abstraction rate of 12 L/s.

1.3.2 Underground mining

The underground mining method, implemented via directional drilling, provides a means to extract ore without having to remove, transport, store and reinstate overburden material. Process water will be injected at a high velocity into the aquifer, down the directional drill hole, producing a sand-water slurry that is extracted up the drill hole. This process is intended to be pressure neutral at the active mining stope, thereby requiring that the volume of sand-water slurry removed be balanced by the volume of injected process water.

Previous mining trials at the site have demonstrated that the underground voids created by the mining process can lead to subsidence of overlying unconsolidated sediments. Subsidence of 4 m (Mine Advice 2021) is expected to occur, which will likely result in increased vertical connection between the depth of ore, overlying sediments and the watertable hosted by the Shepparton Formation. Whilst mining is intended to be pressure neutral, previous trials at the site have indicated that subsidence events can create a short term, localised pressure wave in the groundwater system following collapse of overlying sediment into the mined void.

1.3.3 Seepage from sand tails

Following stripping a depth of approximately 2 m of topsoil and subsoil, sand tails will be deposited ten stopes, or one mining panel (average of 115.5 m long), ahead of the active mining stope (see Figure 1.3). Water is expected to drain from the deposited sand tails at up to 5.1 m³/hr for a period of around 10 days. This will elevate recharge, above the natural rate due to rainfall, to the groundwater system. This is expected to produce localised mounding of the water table in the Shepparton Formation.

Iluka has a stockpile of sand tails from previous mining trials. These will be deposited on the first ten stopes prior to commencement of MOD1 mining. Subsequently, the sand tails from MOD1 mining will be used for this process.

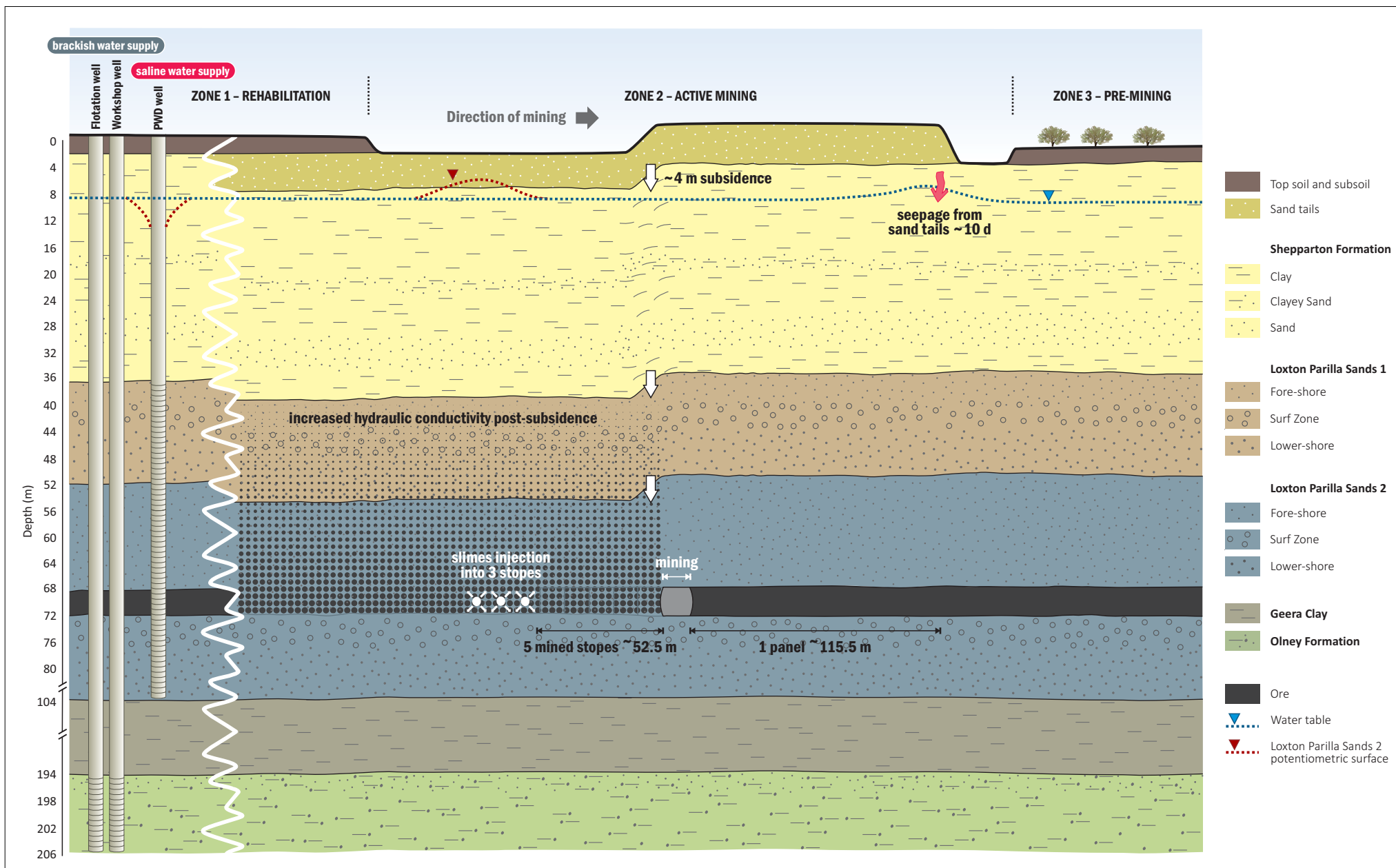
Seepage will be of a different water quality from natural recharge to the groundwater system. Potassium amyl xanthate (PAX) has been identified as the key solute of interest (Earth Systems 2021a) for the groundwater impact assessment. PAX is used to remove sulfides and other waste products from the processed ore.

1.3.4 Injection of slimes

Iluka proposes to inject waste sand fines (slimes) into mined stopes from the end closest to the directional drilling rig. Injection will occur simultaneously into three stopes with the closest being located five stopes (average of 52.5 m) behind the active mining stope, and the other two immediately behind that stope. Iluka is targeting injection of 90 m³/hr of water and slimes into the three stopes (combined) for six hours per day, equating to an average rate of 180 m³/d at each stope.

Injection will progressively follow the mining of stopes, maintaining the desired spacing. Consequently, no injection will occur during mining of the first five stopes. Injection will continue after mining is completed until the remaining five stopes have each been injected into.

As is the case for seepage from sand tails, water injected with slimes will have a different composition from natural groundwater and PAX has been identified as the key solute of interest (Earth Systems 2021a) for the groundwater impact assessment.



Groundwater-affecting mining activities

Iluka Resources
Balranald Project MOD1 groundwater modelling
Figure 1.3

1.4 Previous modelling

Over several years, numerical groundwater modelling has been conducted at various stages of the Balranald Project. Key stages of modelling are documented as follows:

- Modelling to support the pre-feasibility studies of the West Balranald and Nepean deposits (SKM 2013a).
- Modelling of a proposed dewatering and injection trial (SKM 2013b).
- Groundwater Assessment, in support of the approved EIS (Jacobs 2015a).
- Modelling of a proposed borehole mining trial (Jacobs 2015b).
- Groundwater Assessment for an alternative open cut mining method (Jacobs 2015c).
- Modelling of tailings slurry injection during a proposed borehole mining trial (Jacobs 2016).
- Modelling of the proposed T3 underground mining trial (EMM 2019).

The current modelling builds upon the modelling conducted in support of the EIS (Jacobs 2015a) and adds knowledge gained from ongoing monitoring and mining and injection trials since its submission.

1.5 Modelling objectives

The broad objective of the groundwater modelling is to provide quantitative input to the GCIA. Specific objectives are to:

- predict regional drawdown and/or mounding at the watertable and in key aquifers;
- predict drawdown and/or mounding impacts at groundwater dependent ecosystems (GDEs) and third party wells;
- predict changes in groundwater fluxes and fluxes between surface water and groundwater systems;
- predict potential migration of solute introduced into the groundwater system as a result of mining activities; and
- to provide a platform for future validation and/or modelling of modified activities.

1.6 Model confidence classification

The Confidence Level Classification is a cornerstone of the Australian Groundwater Modelling Guidelines (Barnett et al. 2012). It is used to indicate the reliability of model predictions and is based on a number of criteria related to the available data with which the model is conceptualised and calibrated, the manner and accuracy of history-matching and the manner in which the predictions are formulated. The Guidelines provide advice as to the model confidence level class that are suitable (there are three classes of model defined) for different types of modelling investigation and different types of hydrogeological settings. For the EIS, a Class 2 model was considered appropriate and the likewise for the current Modification. Accordingly, the model aims to achieve this confidence level. A Class 2 model has a sound conceptual hydrogeological model based on a good compilation of data to describe the hydrostratigraphy, recharge and discharge features and groundwater flow directions. It produces typically good matches to historical data but with stresses smaller in magnitude and/or duration than those the model will be used to simulate in predictions. It will often be history-matched only to measured hydraulic head data and not to measured groundwater flows and/or chemistry.

Historical data are available in the form of regional and local hydraulic heads as well as local head and drawdown data during small and medium scale (compared to the stresses in predictions) aquifer pumping and injection tests and mining trials.

Flow data are not available to quantify regional groundwater fluxes including surface water-groundwater interaction. There is not a great deal of knowledge regarding the interaction between the groundwater system in the study area and the Murrumbidgee and Murray Rivers, except for the understanding that both rivers are generally losing in the vicinity of Balranald. This limits the ability to represent spatially detailed surface-groundwater interaction in the model, although it is expected that the model provides a good regional-scale representation of the overall interaction between the rivers and the groundwater system. The project proposed under the Modification is expected to greatly reduce changes to groundwater pressures and fluxes and, accordingly, impacts at and near the rivers are expected to be insignificant.

Whilst BOM (2022) provides monitoring data for rainfall and evaporation, the spatial distribution of these across varying landuse types, and the components of these that impact groundwater, are not measured directly. Some studies (Allison and Hughes, 1983; Budd et al., 1990; SKM 2013c) do provide estimates of groundwater recharge but, because these are point-based estimates, they provide a guide rather than a quantity that can be used as a rigid input to a regional numerical groundwater flow model. However, recharge and groundwater evapotranspiration fluxes within the mining area are expected to be relatively small in comparison to the water supply and injection activities of the Project and, hence, the inability to accurately quantify these processes is not a significant weakness in the modelling methodology.

Key features of the available data, history-matching approach and the predictions that limit the modelling from attaining a higher (Class 3) confidence level classification include the following (common limitations applying to mining project models):

- the length of predictions (years) is significantly longer than the length of individual stresses in the history-matching dataset (weeks), although the total duration over which historical stresses have been applied now spans years;
- the area subject to abstraction and injection stresses in predictions is significantly larger than those in history-matching;
- the regional extent of some key stratigraphic units is not well understood (eg thickness and eastern extent of the Geera Clay, extent of the thick region of surf zone sediments targeted by the off-path injection wellfield proposed in the EIS);
- hydraulic properties of injected and subsided material are not well understood; and

- history-matching is to heads/drawdown only; no measurements of groundwater flow are available (to help constrain surface water-groundwater interaction simulations) although pumping and injection flows are represented explicitly in the model.

A review of the model and its associated documentation in this report was carried out by Hugh Middlemis of HydroGeoLogic. A copy of the review is presented in Appendix A. The review found that the model was developed consistent with best practice, that a Class 2 model confidence classification (its targeted Class) is well justified and was that it is suitable for predicting the impacts associated with the mining activities proposed in MOD1.

2 Model design

2.1 Software

The model is built in the Groundwater Vistas 7 (ESI 2017) graphical user interface and run using the MODFLOW-USG Transport (Panday et al 2017) numerical modelling code. These represent updates to more modern, flexible and efficient software than Groundwater Vistas 6 (ESI 2014) and MODFLOW-SURFACT 4 (HGL 2014) used in the previous EIS modelling.

2.2 Domain and spatial discretisation

To maintain consistency, the BAL2.0 model domain from the EIS modelling was maintained for the BAL3.0 updated model. The domain measures 90 km east-west by 90 km north-south, encompassing locations of all groundwater-affecting activities proposed in both the EIS and MOD1, as well as extending to the Murray and Murrumbidgee Rivers, potential GDEs and nearby third party wells. It also encompasses the local-scale models used for transient calibration of properties in the previous BAL2.0 model. The BAL3.0 model domain and features are illustrated in Figure 2.1.

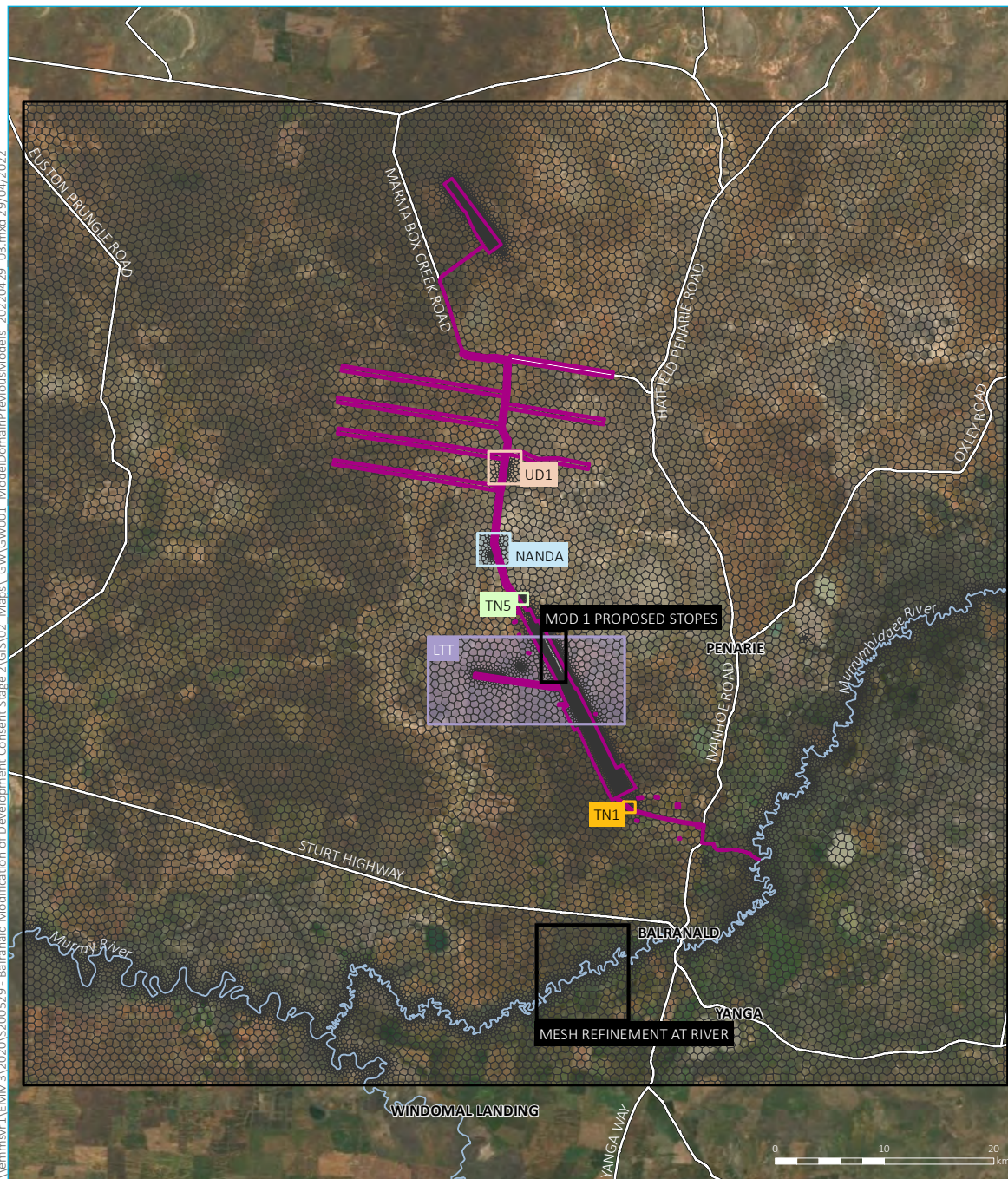
2.2.1 Mesh

A substantial update to the numerical efficiency of the model was achieved by replacing the previous rectangular mesh with a Voronoi polygon mesh (Figure 2.1), which is an advanced feature available as a result of the update in software to MODFLOW-USG. The highly flexible Voronoi polygon mesh was employed to provide refinement of model cells around the mining stopes proposed as part of MOD1, the major rivers and groundwater abstraction and injection locations, including those where production and injection tests and trials have been undertaken. This efficient meshing methodology enabled integration of the previously separate local-scale transient calibration models at their fine mesh scale, employed at 'TN5', 'TN1', 'Nanda', 'Upson Downs' and the 'Long Term Trial' (LTT) site, into the regional scale impact prediction model that was previously only calibrated in steady state mode.

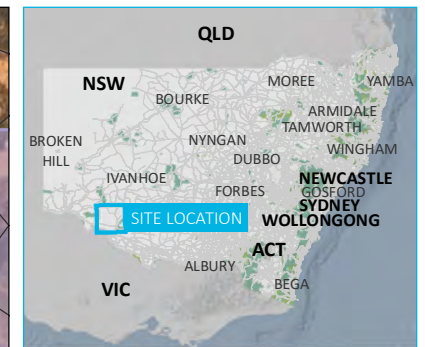
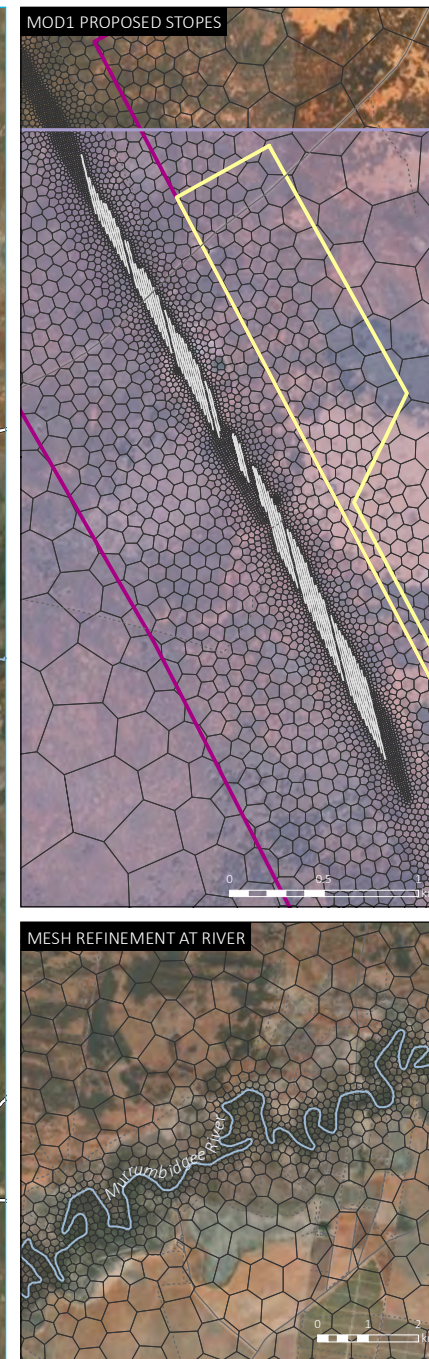
Regionally, model nodes are spaced 1,000 m apart except for along model boundaries where spacing reduces to 500 m. Along the Murrumbidgee and Murray Rivers, model cells are refined to 100 m spacing between nodes. The mesh is refined to 10.5 m spacing and utilises square cells aligned with the footprint of the mining stopes proposed in MOD1, enabling representation of mining activities on a stope-by-by basis. For the remainder of the West Balranald and Nepean deposit areas, outside the portion of the West Balranald deposit proposed to be mined in MOD1, cell spacings of 50 m are employed. Additionally, cells are refined to 0.25 m at injection and abstraction wells used for history-matching.

This meshing advance results in a reduction from 223,200 cells per layer in BAL2.0 to 50,936 for BAL3.0. Across nine model layers, and with pinching out and deactivation of some cells (discussed further below), this equates to a reduction in total active model cells from 2,008,800 in BAL2.0 to 431,166 in BAL3.0, whilst providing greater refinement in key areas of interest and allowing for much faster run times, which is helpful for predictive uncertainty analysis.

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Source: EMM (2021); Iluka Resources (2021); DFSI (2017); GA (2011); ASGC (2006)



- KEY**
- EIS Approved Balranald Project Area (SSD-5285)
 - Proposed modification extension to Balranald Project Area boundary
 - Model domain
 - BAL3.0 mesh
 - MOD1 proposed stope
- Existing environment**
- Major road
 - Named watercourse
- Local-scale model domains**
- LTT
 - NANDA
 - TN1
 - TN5
 - UD1
- INSET KEY**
- Major road
 - NPWS reserve
 - State forest

Model domain Voronoi mesh and previous local-scale models

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 2.1



GDA 1994 MGA Zone 54

2.2.2 Layers

The nine model layers employed in the existing BAL2.0 model were maintained in the BAL3.0 model update, as outlined in Table 2.1.

Table 2.1 **Model layers**

Model layer	Hydrostratigraphic unit/s	Abbreviation
1	Shepparton Formation (shallow)	SF (shallow)
2	Shepparton Formation (deep)	SF (deep)
3	Loxton-Parilla Sands 1 foreshore	LPS1FS
4	Loxton-Parilla Sands 1 surf zone	LPS1SZ
5	Loxton-Parilla Sands 1 lower shore/ Loxton-Parilla Sands 2 foreshore (contains the ore)	LPS1LS/LPS2FS
6	Loxton-Parilla Sands 2 surf zone	LPS2SZ
7	Loxton-Parilla Sands 2 lower shore	LPS2LS
8	Geera Clay	GC
9	Olney Formation	OF

Surfaces for the tops and bottoms of model layers were broadly unchanged, with the following exceptions:

- The top of model layer 1 (Shepparton Formation), previously based on a Shuttle Radar Topography Mission (SRTM) digital elevation model, was updated with a 5 m LiDAR DEM, resampled directly at model nodes.
- Where layers previously employed a nominal minimum thickness of 0.1 m (because the previous MODFLOW-SURFACT code cannot handle pinching out of layers), model layer surfaces were adjusted to pinch out completely according to the mapping, and the relevant nodes were deactivated, thus reducing model computational and storage burdens.

2.3 Temporal discretisation and numerical solution

Stress periods from the previously separate local-scale transient calibration models, employed at 'TN5', 'TN1', 'Nanda', 'Upson Downs' and the 'Long Term Trial' (LTT) site, were merged into a continuous series spanning their duration. Additional stress periods were appended to incorporate the T3 mining trial. An initial steady state stress period was implemented to obtain stable, internally consistent, hydraulic conditions prior to commencement of simulation of the historical tests and trials.

A total of 64 stress periods of variable durations were employed to discretise the history-matching period, spanning from 10 October 2011 to 1 December 2020. The timing of stress periods is illustrated in Figure 2.2.

MODFLOW-USG's adaptive time-stepping (ATS) package was used to efficiently discretise stress periods into timesteps. Numerical solution was achieved using the SMS solver employing head change closure criteria of 10^{-3} m (outer) and 10^{-5} m (inner).

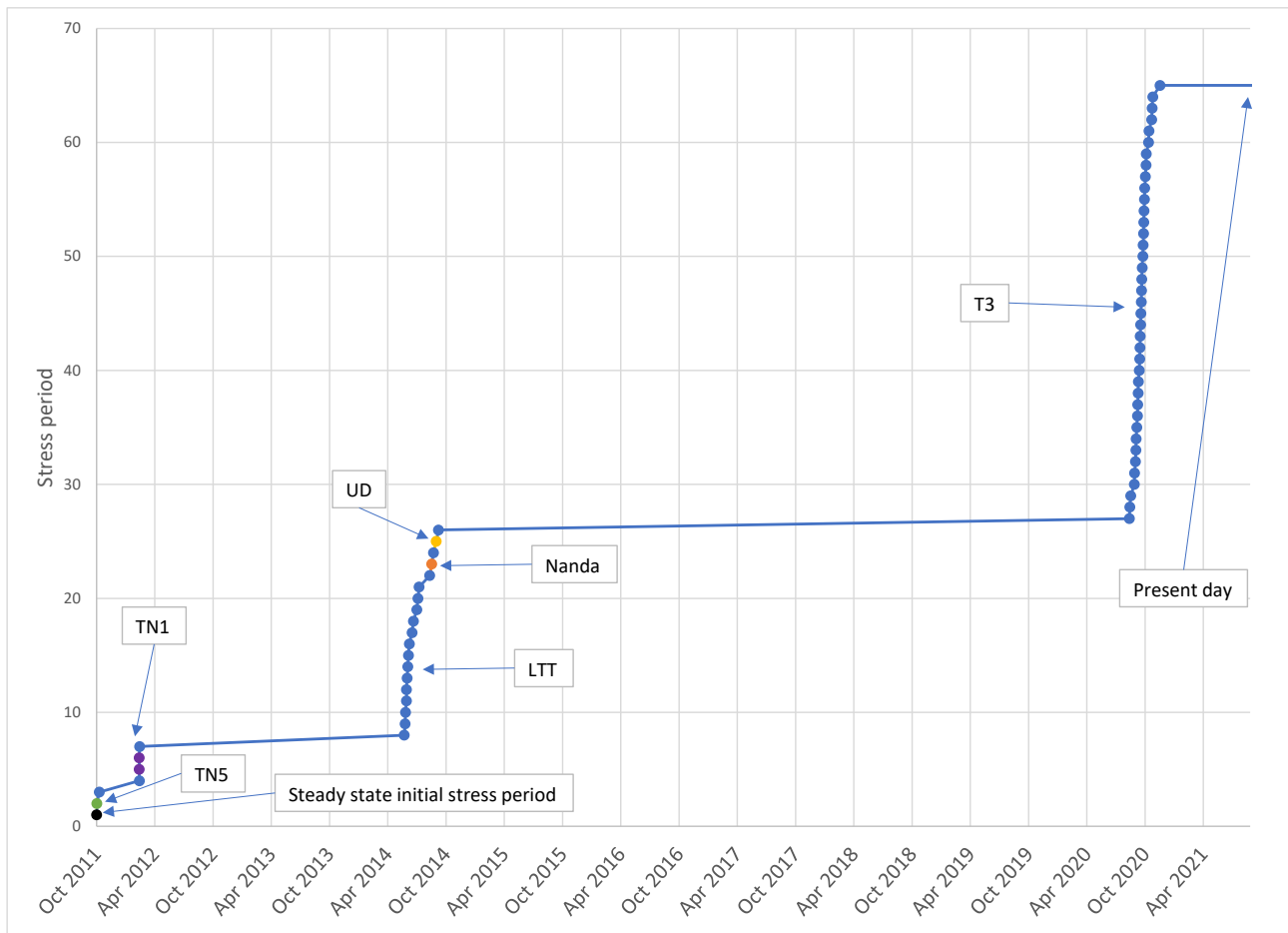


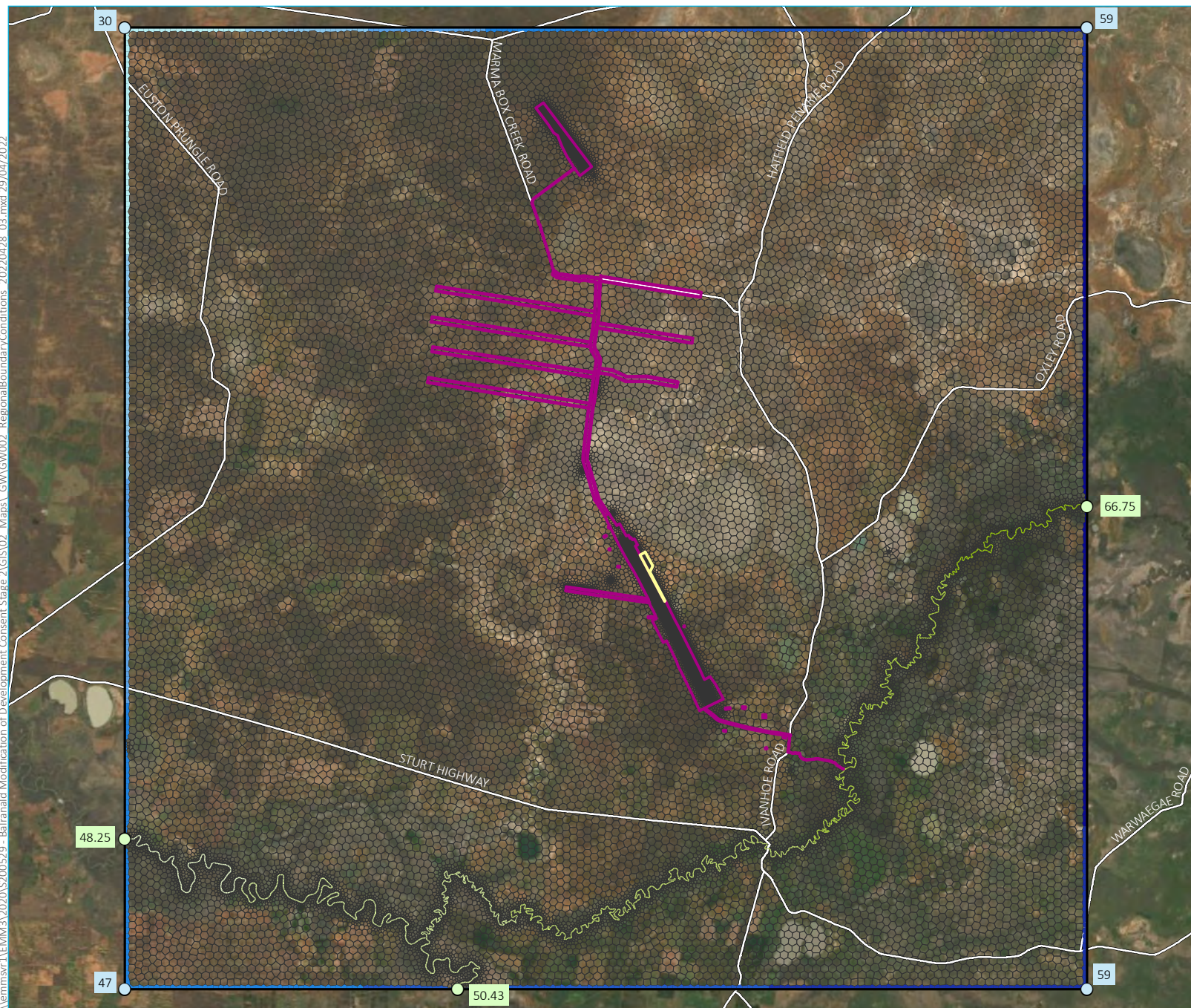
Figure 2.2 History-matching stress periods

2.4 Boundary conditions

2.4.1 Regional groundwater flow

As in the existing BAL2.0 model, General Head Boundary (GHB) conditions were assigned around the model edges to simulate regional groundwater flow into and out of the model domain (see Figure 2.3). Heads assigned to the GHBs were interpolated between inferred hydraulic heads at the model edges as per the BAL2.0 model. Conductance values were maintained, based on a layers' average horizontal hydraulic conductivity and thickness and assuming a distance of 5 km to a location outside the model domain where no head changes would be experienced as a result of stresses simulated within the model domain.

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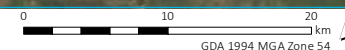
- KEY**
- █ EIS Approved Balranald Project Area (SSD-5285)
 - █ Proposed modification extension to Balranald Project Area boundary
 - █ Model domain
 - ▭ BAL3.0 mesh
 - Major road
 - Boundary point
 - General head boundary
 - River boundary
 - General head boundary condition (mAHd)
 - 30 - 35
 - 35 - 40
 - 40 - 45
 - 45 - 50
 - 50 - 55
 - 55 - 60
 - > 60
 - River boundary condition (mAHd)
 - < 50
 - 50 - 55
 - 55 - 60
 - 60 - 65
 - > 65

Regional boundary conditions

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 2.3



Source: EMM (2021); Iluka Resources (2021); DFSI (2017); GA (2011)



2.4.2 Recharge and evapotranspiration

Rainfall recharge was modelled as per the BAL2.0 model using the Recharge (RCH) package and was assigned uniformly across the model domain at a constant rate of 0.0365 mm/yr. This rate is more consistent with estimates of recharge under Mallee vegetation (estimated to be less than 0.1 mm/yr by Allison and Hughes, 1983 and Budd et al., 1990) than for cleared and cropped land (estimated to be 3 mm/yr by Allison and Hughes, 1983 and between 3 mm/yr and 10 mm/yr by Budd et al., 1990). The calibration process of the existing BAL2.0 model indicated that diffuse recharge must be relatively low because adoption of higher recharge rates resulted in poorer calibration to “steady state” regional hydraulic head observations.

Evapotranspiration from groundwater was modelled using the depth-dependent Evapotranspiration (EVT) package, as in BAL2.0. A maximum evapotranspiration rate of 2,000 mm/yr (measured pan evaporation at Mildura Airport is 2,192 mm/yr), applicable where/when the water table is at or above the ground surface, was applied uniformly across the model domain. Modelled evapotranspiration decreases linearly with increasing depth to the water table up to an ‘extinction depth’, set 3 m below ground surface. Below the 3 m extinction depth, modelled evapotranspiration from groundwater is zero.

2.4.3 Rivers

As in the BAL2.0 model, the River (RIV) package was used to simulate the Murrumbidgee and Murray Rivers in model layer 1. River stage was assigned using linear interpolation between gauges and river bottom elevation was set 4 m below river stage.

2.4.4 Groundwater abstraction and injection

Groundwater abstraction from, and injection into, wells utilised during the trials and tests over the transient history-matching period were represented with the Well (WEL) package. More detail is provided in Chapter 3.

2.4.5 Mining activities

Besides abstraction and injection, the only other mining-related water-affecting activity that has occurred at the site to date is trialling of the underground mining of stopes. The underground mining process is intended to be pressure neutral. Hence, the injection of process water and extraction of sand-water slurry is not modelled. However, the increase in vertical hydraulic conductivity, associated with subsidence, is modelled using the Time-Variant Materials (TVM) package. Further details are provided in the history-matching and predictive modelling sections.

3 History-matching

3.1 Approach

Given the existing regional BAL2.0 modelling platform as a starting point, the approach taken to history-matching was as follows:

- Following the rebuild with new mesh, layering options and using interpolated property distributions (rather than the zones of homogeneous property values in the BAL2.0 model), run the model in steady state and transient modes to validate performance against the existing steady state and transient history-matching data used for the EIS, plus extended regional monitoring data.
- With new data from the latest underground mining trial (termed 'T3'), carry out a focused calibration of TVM package properties such that an acceptable match to the T3 dataset was achieved. More emphasis was placed on matching later drawdown/mounding responses for two reasons. First, at commencement of the trial non-metered groundwater abstraction that occurred prior to the trial was still evident. Second, experience was gained balancing inflows and outflows as the trial progressed. Consequently, earlier periods of the trial are likely to incorporate hydraulic stresses (flow imbalances) that are not simulated but affect the measured drawdown/mounding responses.

3.1.1 Targets

The monitoring data from tests and trials conducted over more than nine years at the project area were combined into a single dataset for use in the new model, rather than using the separate local-scale models adopted to calibrate the BAL2.0 model for the EIS.

3.1.2 Parameterisation

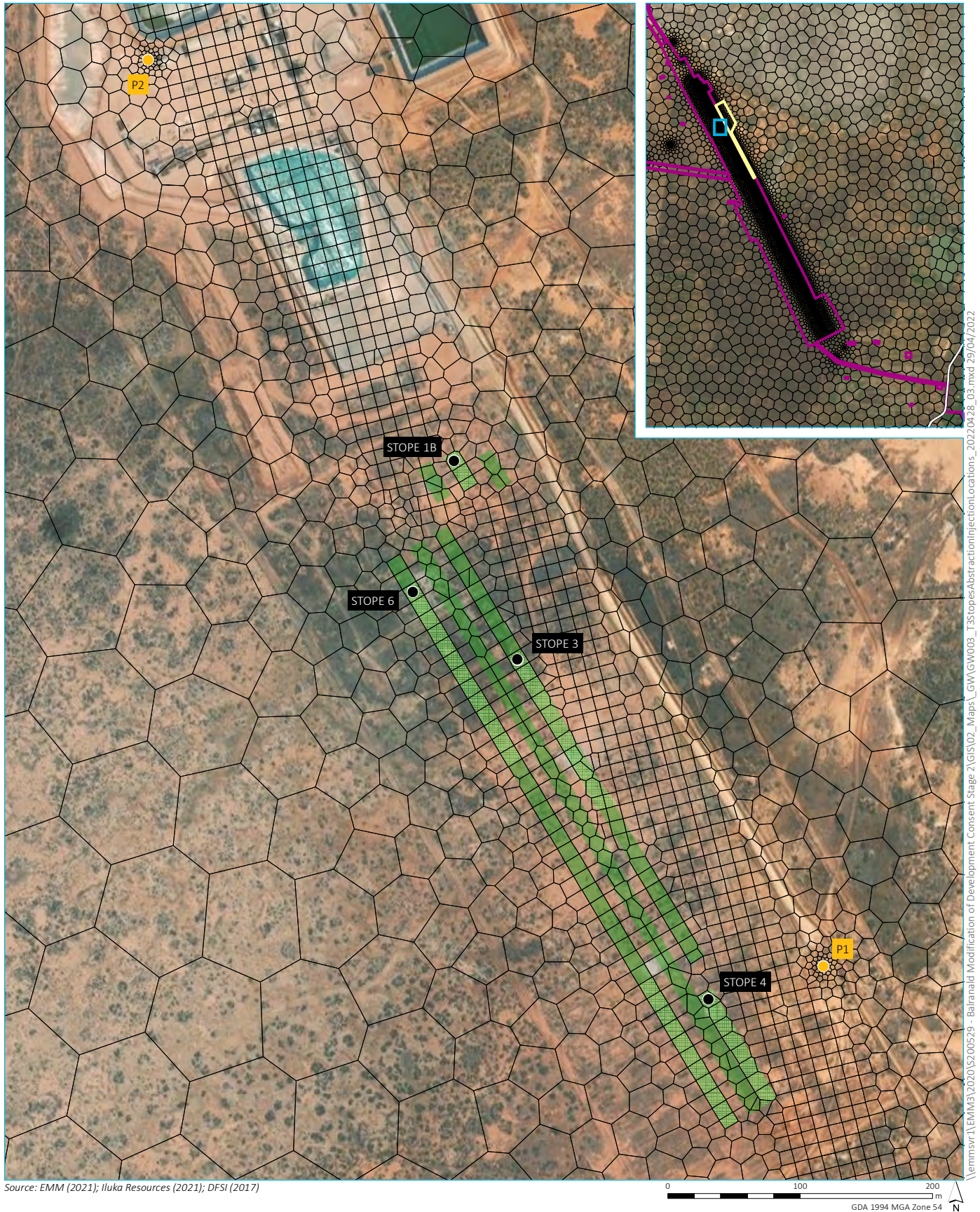
Rather than the approach of zones of piecewise constancy (adopted in the BAL2.0 model) where BAL2.0 calibrated property values differed from one local-scale test/trial to another, the properties were interpolated across the model domain using the calibrated values at each of the test/trial sites with values added at the model edges to avoid extrapolation to unreasonable values. Where properties were consistent between all local-scale calibration models, uniform properties were assigned to that layer in BAL3.0. Resulting distributions of aquifer property values are presented in Appendix B.

3.1.3 Stresses

The data from pumping and injection tests and trials used to calibrate the BAL2.0 model were combined to construct input to the Well package. Further details on those field activities are provided in Jacobs (2015a).

New data, since the EIS, were available from the T3 underground mining trial and were used specifically to help inform the changes to hydraulic properties arising from underground mining and associated subsidence (represented by the TVM package). Details of the trial, including mining-related activities, hydraulic and geochemical responses, are documented in EMM (2021). The T3 trial site layout is illustrated in Figure 3.1, showing the locations of the planned stopes, the sections of stopes that were mined, the slimes injection points and the two groundwater supply wells, along with the BAL3.0 model mesh.

Measured groundwater abstraction and injection rates, and the associated modelled rates, for the full set of tests and trials (TN5, TN1, LTT, Nanda, Upson Downs and T3) are presented in Figure 3.2 to Figure 3.4. Prior to the T3 trial, groundwater was abstracted from the aquifer. This was not metered and, at commencement of the trial, there was residual drawdown evident.



KEY

- EIS Approved Balranald Project Area (SSD-5285)
- Proposed modification extension to Balranald Project Area boundary
- Well
- Injection point
- Major road (refer to inset)
- T3 stope footprint
- T3 stope - mined
- BAL3.0 mesh

T3 stopes, abstraction and injection locations

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 3.1

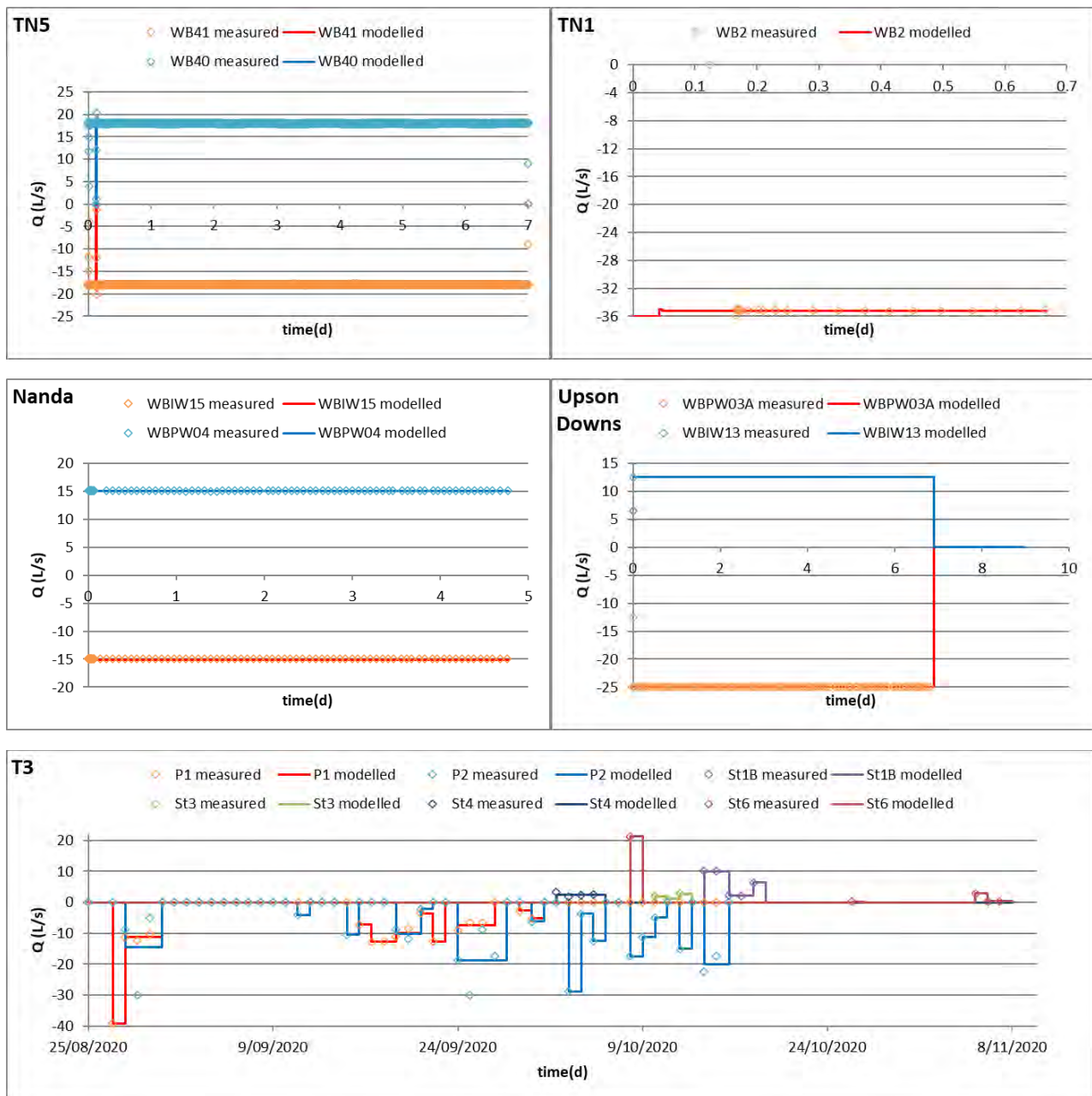


Figure 3.2 Modelled groundwater abstraction (-ve) and injection (+ve): TN5, TN1, Nanda, Upson Downs and T3

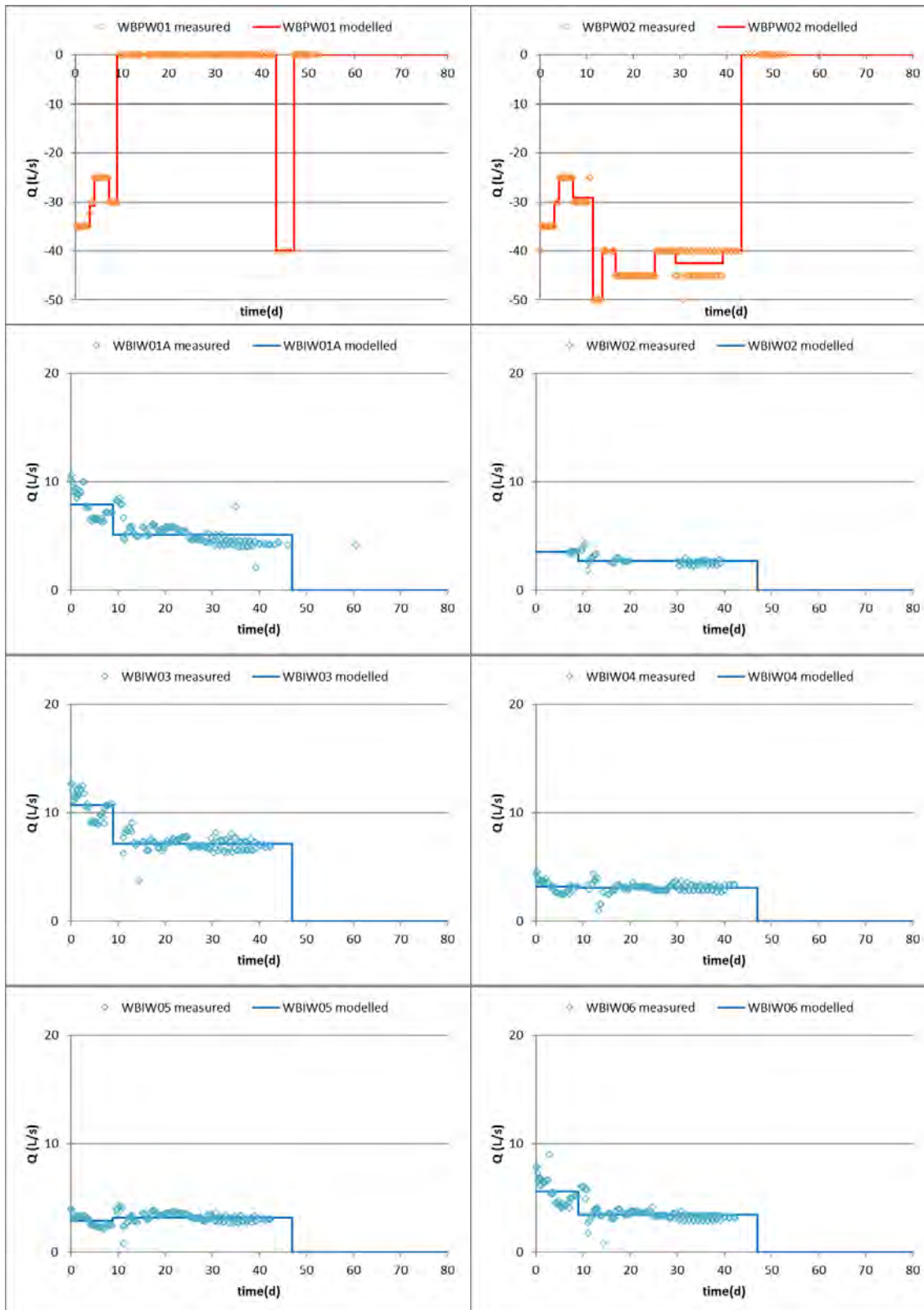


Figure 3.3 Modelled groundwater abstraction (-ve) and injection (+ve): LTT

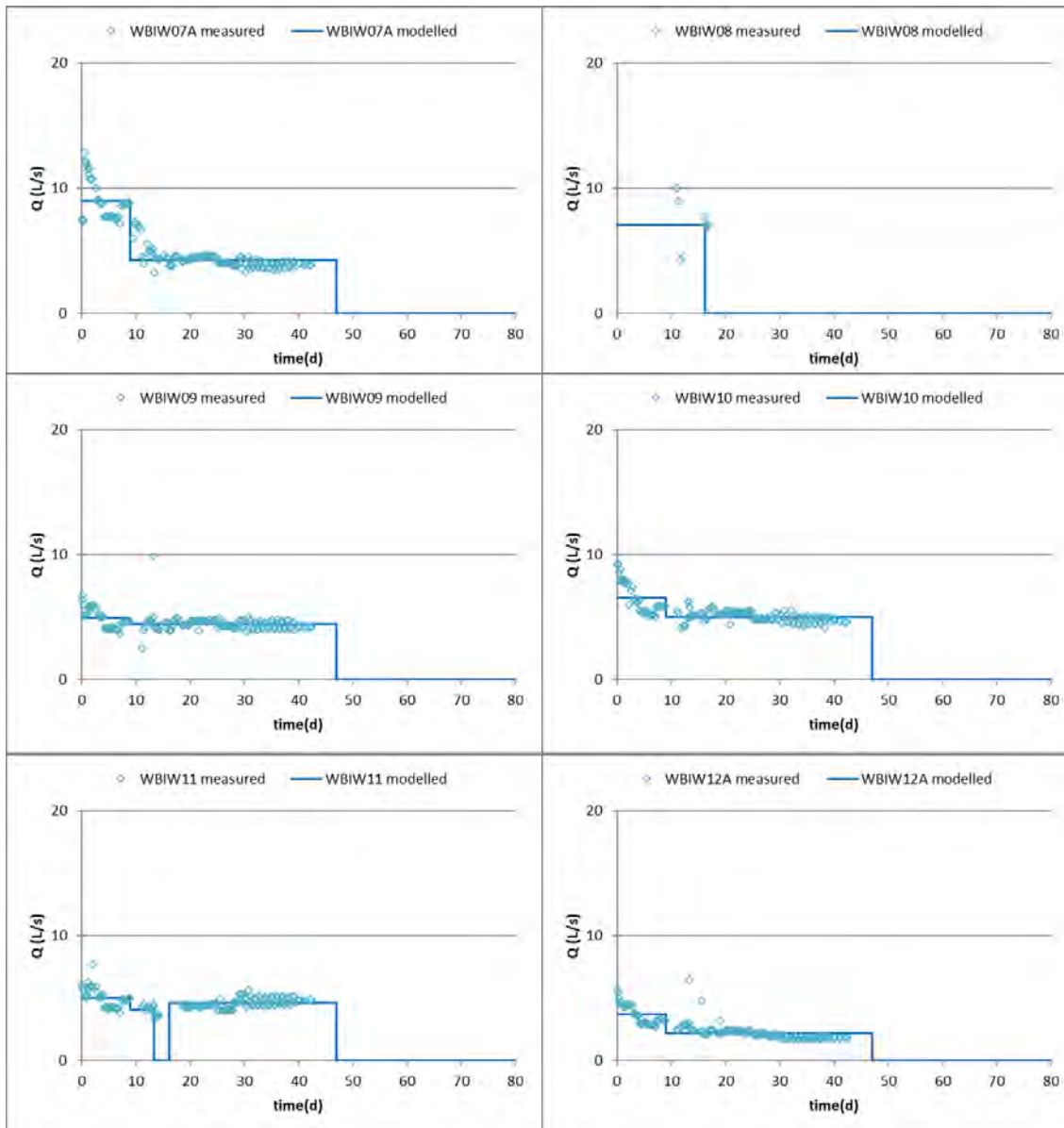


Figure 3.4 Modelled groundwater abstraction (-ve) and injection (+ve): LTT

3.2 Performance

3.2.1 Steady state

The modelled steady state water table is illustrated in Figure 3.5. Modelled steady state hydraulic head in each of the nine model layers is presented in Appendix C. Contours of hydraulic head are generally in good agreement with measured values and the previous BAL2.0 model. The modelled water table contours indicate groundwater flowing from east to west and towards the north-west corner of the model, with leakage from the Murrumbidgee and Murray Rivers causing contours to deviate locally.

Figure 3.6 presents a scatter plot of modelled versus measured steady state hydraulic head, along with the plot from the BAL2.0 EIS model. The corresponding Scaled Root Mean Squared (SRMS) error equates to 11.3%, compared to 11.2% achieved by the BAL2.0 model.

3.2.2 Transient

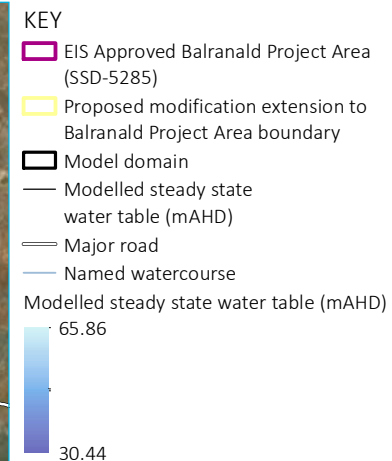
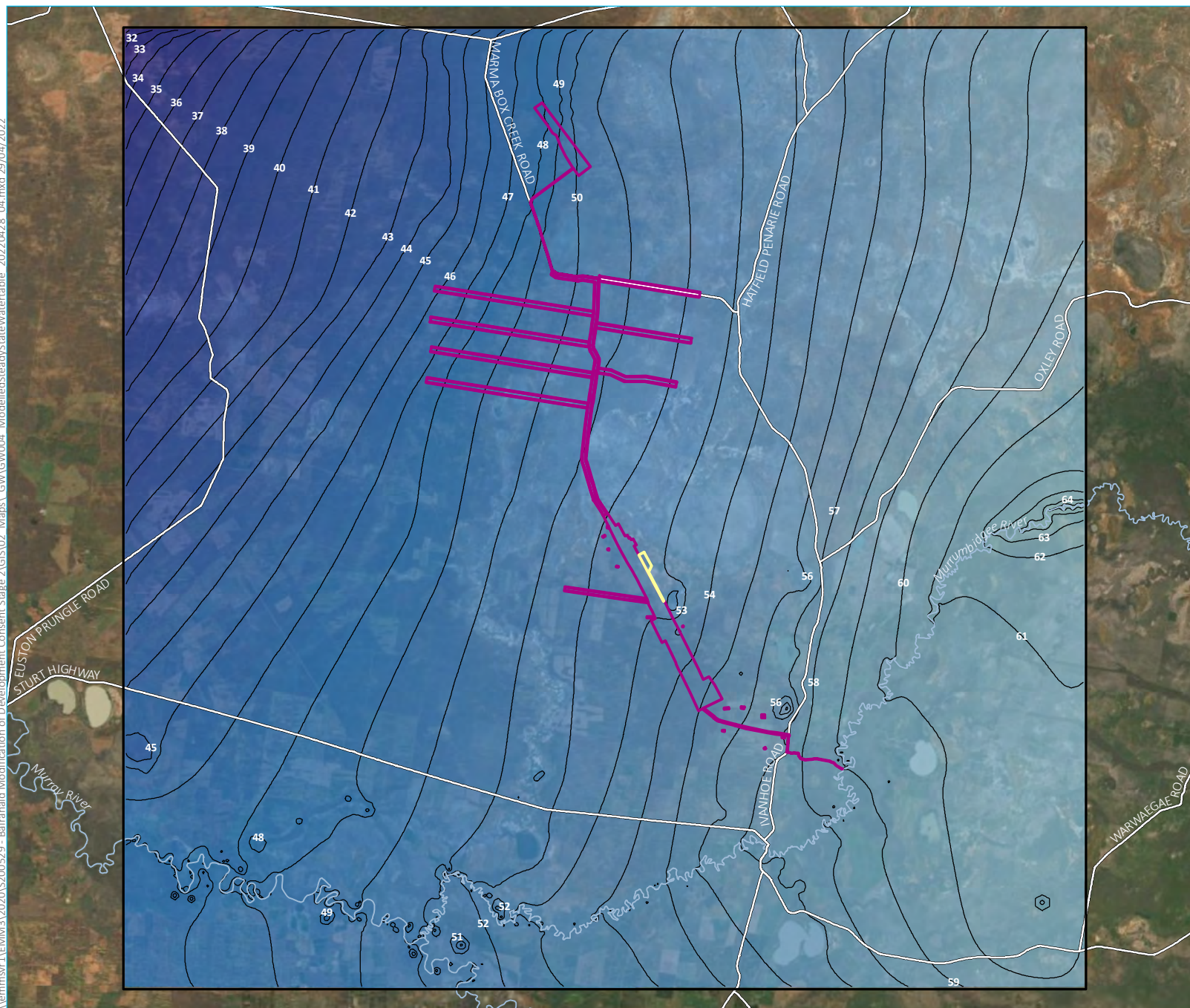
Scatter plots of modelled versus measured drawdown for the localised tests and trials are presented in Figure 3.7 to Figure 3.8. Results for sites used to calibrate BAL2.0 are similar to results for that model (see Table 3.1) with some statistical improvements and some declines. Despite an apparent moderate degree of scatter in the plot for the T3 underground mining trial, caused by several outliers, the majority of data are clustered (many on top of each other) around the one-to-one line. As mentioned earlier, emphasis was placed on matching later time T3 responses even if at the expense of matching responses from earlier time.

Modelled and measured hydrographs for each of the localised tests and trials are presented in Appendix D. Where available/relevant, corresponding modelled hydrographs from the EIS modelling (Jacobs 2015a) are provided for comparison. For completeness, hydrographs for abstraction and injection wells, which are not included in the history-matching dataset, are also presented.

Table 3.1 SRMS errors for BAL2.0 local-scale models and BAL3.0

Test/trial	BAL2.0 local-scale model	BAL3.0
TN5	13.2%	12.04%
TN1	7.6%	9.93%
LTT	8.4%	9.25%
Nanda	7.5%	9.76%
Upson Downs	11.8%	8.96%
T3	n/a	4.49%

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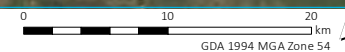


Modelled steady state water table

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 3.5



Source: EMM (2021); DFSI (2017); GA (2011)



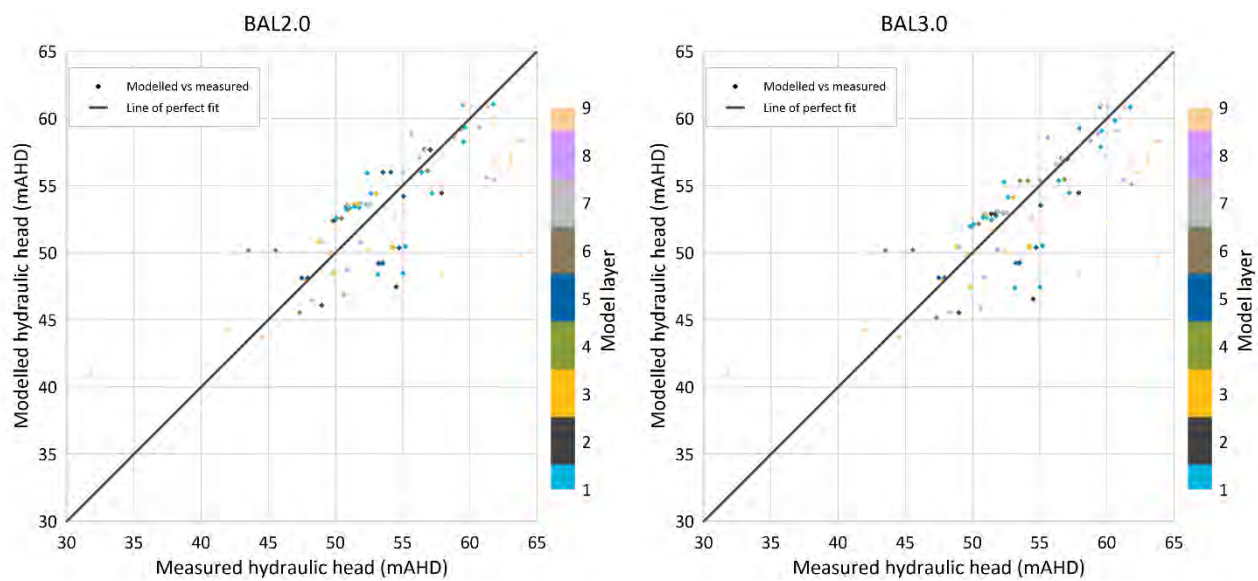


Figure 3.6 Scatter plot of steady state hydraulic head

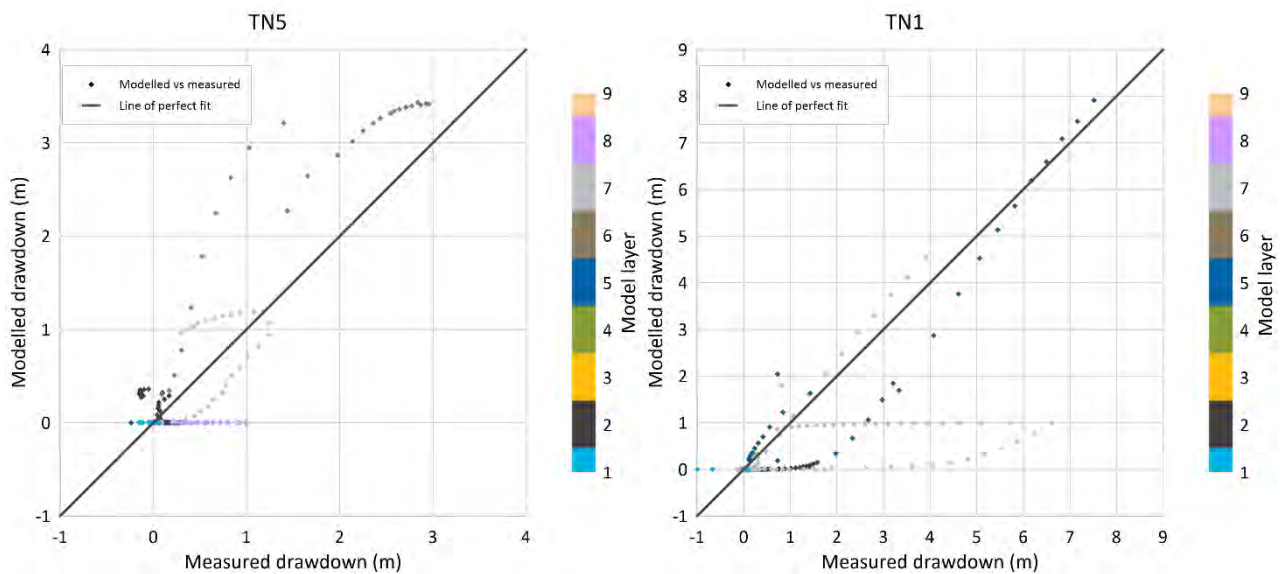


Figure 3.7 Scatter plots of drawdown for localised tests and trials: TN5 and TN1

Note: negative drawdown equates to mounding, or an increase, of hydraulic head

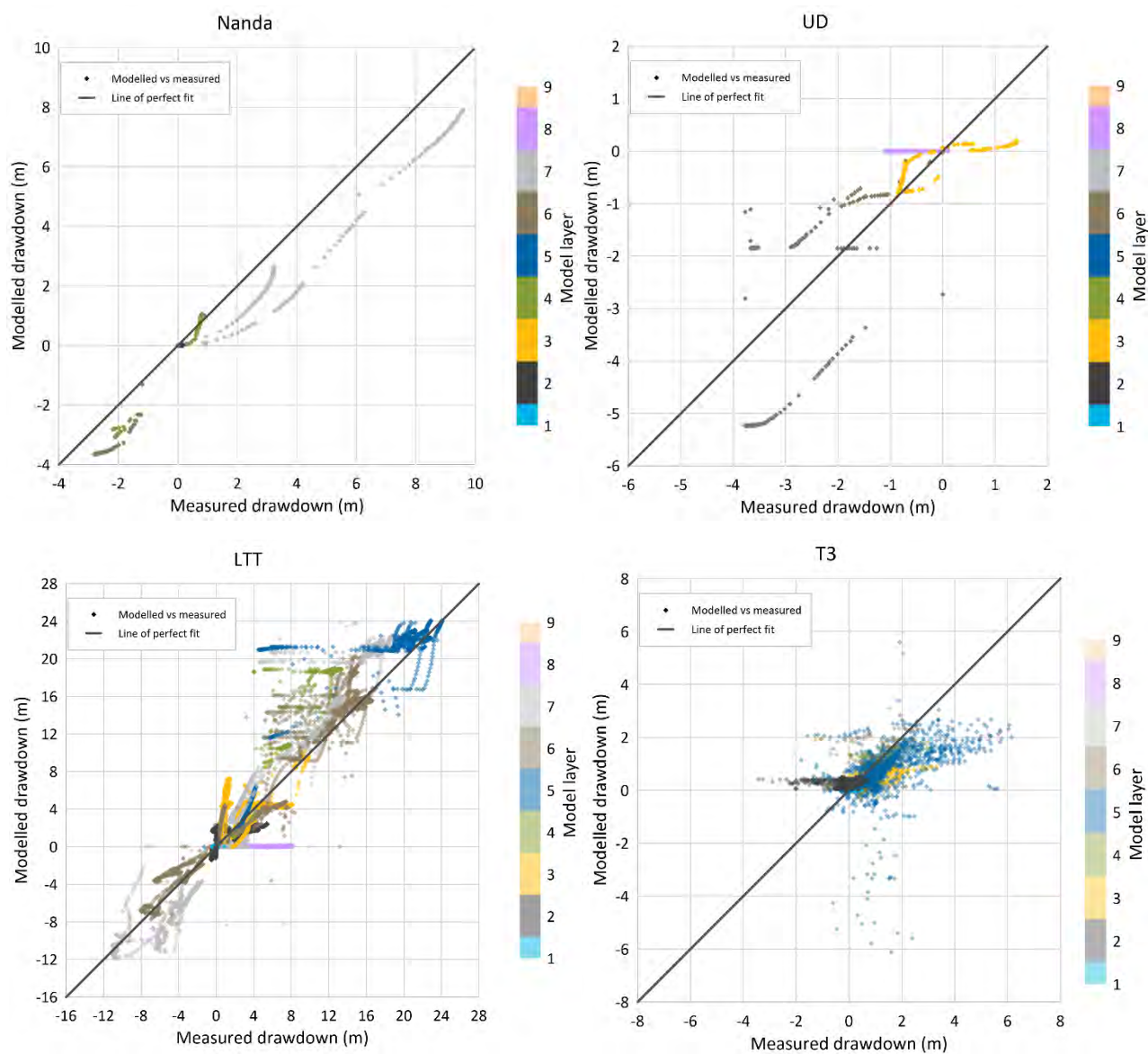


Figure 3.8 Scatter plots of drawdown for localised tests and trials: Nanda, Upson Downs, LTT and T3

Note: negative drawdown equates to mounding, or an increase, of hydraulic head

3.3 Water balance

The modelled pre-development steady state water balance is presented in Table 3.2 and Figure 3.9. The modelled inflow and outflow components balance each other, confirming an accurate numerical solution. Consistent with the BAL2.0 model, that largest inflow and outflow components are regional throughflow (via the GHBs assigned around the model edges). Leakage from the modelled rivers is the next largest inflow component (consistent with the conceptualisation of a largely losing river system) with recharge from rainfall constituting a relatively minor contribution. Evapotranspiration is the second largest outflow component and baseflow to the modelled rivers is almost zero.

There are some notable changes from the BAL2.0 modelled water balance. Leakage from rivers is considerably larger than in the previous model and is balanced by an increase in modelled evapotranspiration. This results from implementation of a refined mesh, now 100 m cells along the rivers versus 500 m in the BAL2.0 model. This refinement, combined with an update to a LiDAR DEM, gives the model a better ability to represent the topographic lows around the river floodplain. These areas of topographic low result in localised high evapotranspiration from groundwater, which is modelled using a depth-dependent function. The lowered topography and elevated evapotranspiration lower the water table either side of the losing river channel driving an increase in leakage from the river to the groundwater system.

Table 3.2 Modelled pre-development steady state water balance

Component	In (ML/yr)	Out (ML/yr)
Rainfall recharge	296	-
Evapotranspiration	-	5,858
River leakage	5,925	25
Regional throughflow	7,676	8,014
TOTAL	13,897	13,897

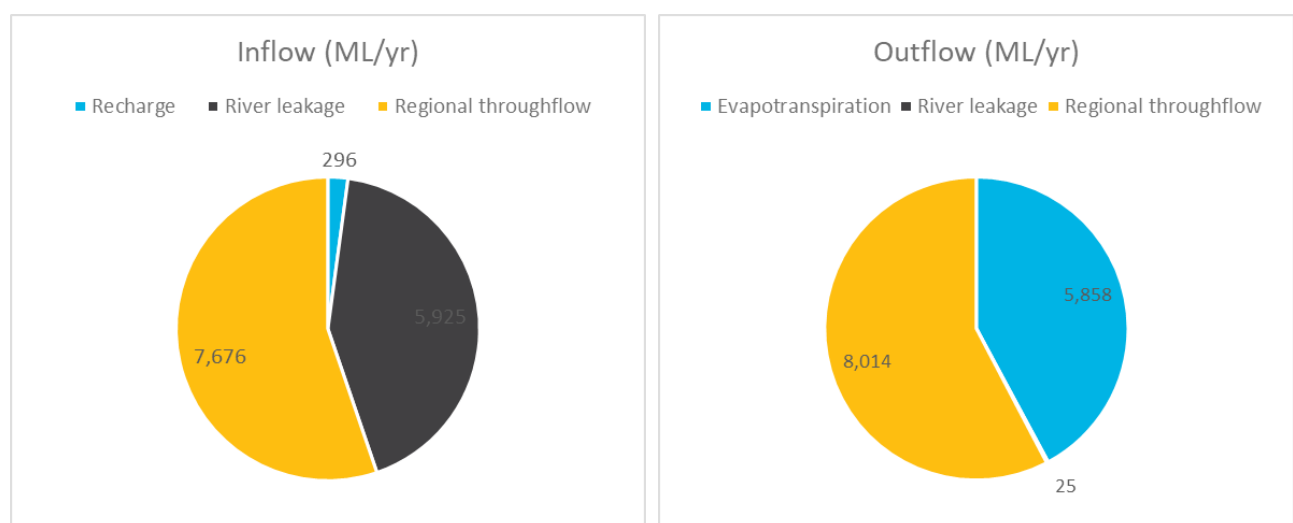


Figure 3.9 Modelled pre-development steady state water balance

The transient modelled water balance over the history-matching period is presented in Figure 3.10. Responses to the historical tests and trials (including the historical pumping test trials and the recent T3 trial) are clearly evident and, importantly, the model simulates the groundwater system repeatedly returning to stable conditions. Of note is that the modelled regional inflow and outflow, river leakage and evapotranspiration fluxes display no evidence of significant deviation during the tests/trials, with the abstraction and injection stresses and variation of aquifer properties having only localised storage inflow/outflow responses.

The modelled water balance error (difference between totals of modelled inflows and outflows) is far less than 1% at all output times, indicating a very accurate numerical solution for the duration of the simulation period and is well inside the guidance outlined in the *Australian Groundwater Modelling Guidelines* (Barnett et al 2012).

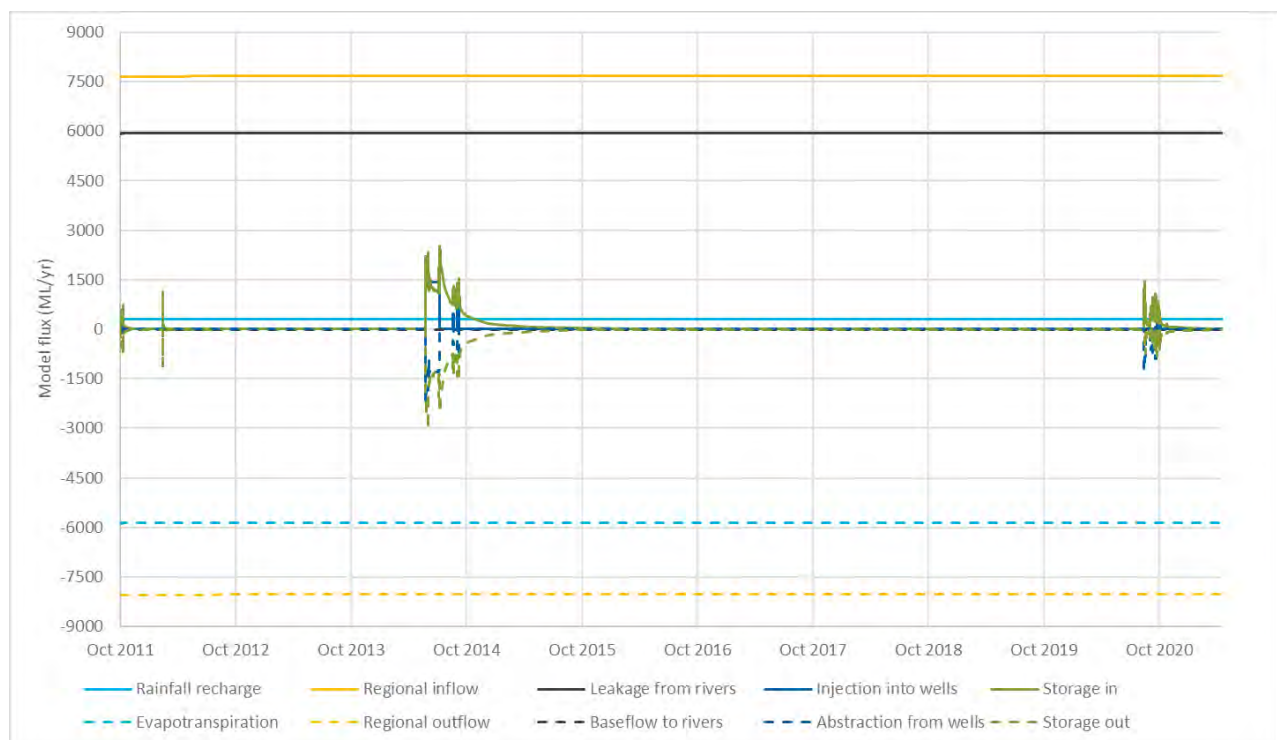


Figure 3.10 Modelled transient water balance over the history-matching period

3.4 Calibrated hydraulic properties

The adopted base case calibrated hydraulic properties are presented in Table 3.3. These values were assigned at specific points and interpolated across the model domain in layers where homogeneous values were not adopted. Modelled distributions of hydraulic properties, where heterogeneity is represented, are presented in Appendix B.

3.5 Sensitivity

Given the similarity of model results from the BAL2.0 local-scale and BAL3.0 models at the sites used to calibrate the BAL2.0 model, calibration sensitivity analysis at these locations (used to populate the broader model domain) was not repeated.

Table 3.3 **Base case calibrated hydraulic property values**

Model layer	HSU	TN1		TN5		Nanda		Upson Downs		LTT		In/above stopes	
		Kh (m/d)	Kv (m/d)	Kh (m/d)	Kv (m/d)	Kh (m/d)	Kv (m/d)	Kh (m/d)	Kv (m/d)	Kh (m/d)	Kv (m/d)	Kh (m/d)	Kv (m/d)
1	SF (shallow)	1	0.001	1	0.001	1	0.001	1	0.001	1	0.001	Unchanged	
2	SF (deep)	1	0.001	1	0.001	1	0.001	1	0.005	1	0.001	Unchanged	
3	LPS1FS	0.9	0.001	0.9	0.001	0.9	0.001	0.9	0.001	0.9	0.001	Unchanged	
4	LPS1SZ	20	0.1	24	0.1	20	0.1	20	0.1	16	0.1	Unchanged	10
5	LPS1LS-LPS2FS	0.9	0.001	0.9	0.001	0.9	0.001	0.9	0.001	0.9	0.001	Unchanged	1
6	LPS2SZ	20	0.1	24	0.1	10 (south) 40 (north)	0.1	17	0.1	16	0.1	Unchanged	
7	LPS2LS	0.13	0.001	0.012	0.001	0.9	0.001	0.9	0.001	0.9	0.001	Unchanged	
8	GC	0.0001	0.00001	0.0001	0.00001	0.0001	0.00001	0.0001	0.00001	0.0001	0.00001	Unchanged	
9	OF	3	0.3	3	0.3	3	0.3	3	0.3	3	0.3	Unchanged	

Note: The parameter values above are assigned at the centre of the localised test/trial sites and interpolated across the model domain, except for at Nanda where two localised values are assigned.

4 Predictive modelling

4.1 Scenario definition and representation

A predictive scenario was constructed to simulate the groundwater-affecting activities proposed in MOD1. The modelled mine plan (including location and timing of stopes to be mined), groundwater supply wells and slimes injection locations are presented in Figure 4.1.

4.1.1 Groundwater supply

The Well package was used to simulate saline groundwater supply from the LPS aquifer, from the 'PWD Well' located adjacent the process water dam. Groundwater abstraction was modelled at a rate of 12 L/s, commencing three months prior to commencement of mining (ie end of October 2023) and ceasing at the conclusion of slimes injection.

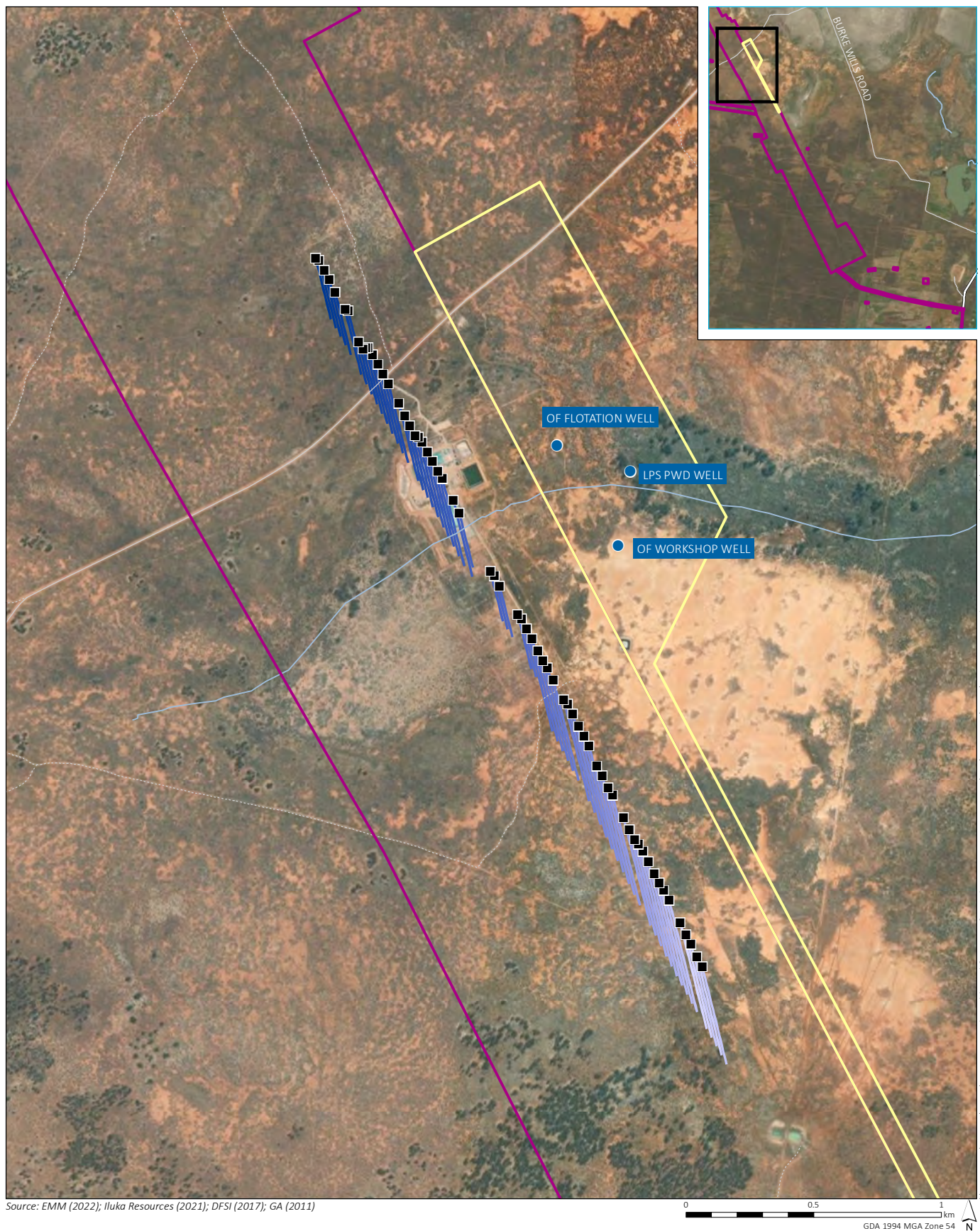
The Well package was also used to simulate brackish groundwater supply from two wells, 'Flotation Well' and 'Workshop Well', to be screened in the deeper Olney Formation, adjacent to the process plant, to provide brackish groundwater supply to the flotation plant during mining and the vehicle wash/workshop area during construction (October 2022 – October 2023) and operation. The Olney Fm bores were each assigned an abstraction rate of 6 L/s.

4.1.2 Underground mining

Since the underground mining method is intended to be pressure neutral at the active mining stope, with the volume of sand-water slurry removed balanced by the volume of injected process water, the mining process is not modelled explicitly.

Previous mining trials at the site have demonstrated that the underground voids created by the mining process can lead to subsidence of overlying unconsolidated sediments. Approximately 4 m of subsidence is expected to occur over the footprint of the area to be mined in MOD1 (Mine Advice 2021). Monitoring of hydraulic head during the T3 trial, and history-matching to these data, indicate that this process creates an increased vertical connection between the aquifer at the stope depth and the shallower sediments. Therefore, the TVM package was employed to assign increased vertical hydraulic conductivity, at the values derived from the history-matching process, to the LPS1 SZ and LPS1LS-LPS2FS model layers over the footprint of stopes immediately following mining of each stope. The increased vertical hydraulic conductivity values were then maintained for the remainder of the predictive simulation.

The location and timing of mining of stopes is illustrated in Figure 4.1. Mining was modelled as proceeding one stope at a time, progressively moving from south to north along the West Balranald deposit. For modelling purposes, the time taken to mine each stope was based on the advised total time to mine each panel divided by the number of stopes in the panel. Hence, the model assumes a constant average 'mining speed' per panel. A summary of timing of modelled stope mining is presented in Table 4.1.



KEY

— EIS Approved Balranald Project Area (SSD-5285)

— Proposed modification extension to Balranald Project Area boundary

● Mine water supply well

■ Slime injection point

— Minor road

--- Vehicular track

— Watercourse/drainage line

Mine progression

— Start

— Finish

MOD1 mine plan and slimes injection layout

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 4.1

Table 4.1 **Modelled timing of mining stopes and panels**

Panel number	Number of stopes	Mining start	Mining end	Mining duration (d/stope)
1	10	1 Feb 2024	1 Jan 2025	33.5
2	10	1 Jan 2025	1 Oct 2025	27.3
3	8	1 Oct 2025	1 Apr 2026	22.75
4a	5	1 Apr 2026	1 Jul 2026	18.2
4b	10	1 Jul 2026	1 Feb 2027	21.5
5	10	1 Feb 2027	1 Aug 2027	18.1
6	10	1 Aug 2027	1 Jan 2028	15.3

4.1.3 Seepage from sand tails

Following stripping a depth of approximately 2 m of topsoil and subsoil, sand tails will be deposited ten stopes, or one mining panel (average of 115.5 m), ahead of the active mining stope. Water is expected to drain from the deposited sand tails for a period of around 10 days (Earth Systems 2021b), over which time recharge to the groundwater system will be elevated above the natural rate due to rainfall.

Fifty-eight dry tonnes per hour of sand tails are continuously produced during mining. The moisture content of the sand tails is expected to be 15% by mass (Earth Systems 2021b). Model cells representing the stopes are 10.5 m by 10.5 m squares, and the sand tails are expected to be emplaced 1.5–2 m high (1.75 m is assumed as an average for modelling). Therefore, 192.9 m³ of wet sand tails, with an assumed density of 1800 kg/m³, will be emplaced above each model cell. This equals 347.3 tonnes of moist sand or, at 15% water content by mass, 52.1 kL of water per cell. The model assumes that the sand tails drain completely to the groundwater system. This is a conservative approach given that some moisture will be retained by the sand or will evaporate.

Given a maximum total drainage rate of 5.1 m³/h (Earth Systems 2021b), assumed to apply over an entire stope, the time taken for the volume of water emplaced above an individual model cell was calculated to be, on average, 14 days. Given that this duration is less than the shortest stress period employed in the predictive scenario (see Table 3.1), seepage from sand tails was assigned only to the single stress period in which sand tails were emplaced at surface at a given location. To maintain consistency with the mine water balance, seepage rates assigned via the Recharge (RCH) package were pro-rated per stope based on the duration of the stress period in which tailings were emplaced at that location.

Iluka has a stockpile of sand tails from previous mining trials. These will be deposited on the first ten stopes prior to commencement of MOD1 mining. Subsequently, tails from the MOD1 mining process will be used.

Seepage will be of a different water quality from natural recharge to the groundwater system. PAX has been identified as the key solute of interest (Earth Systems 2021a) for the groundwater comparative impact assessment.

4.1.4 Injection of slimes

Injection of slimes was simulated using the Well package. Injection was simulated to occur simultaneously into three stopes with the closest being located five stopes (average of 52.5 m) behind the active mining stope, and the other two immediately behind that stope. Iluka is targeting injection of 90 m³/hr of water and slimes into the three stopes (combined) for six hours per day, equating to an average rate of 180 m³/d at each stope.

Injection locations progressively followed the mining of stopes, maintaining the defined spacing. Consequently, no injection was modelled during mining of the first five stopes. Injection was modelled to continue after mining is completed until the remaining five stopes had each been injected into.

As is the case for seepage from sand tails, water injected with slimes will have a different composition from natural groundwater and PAX has been identified as the key solute of interest (Earth Systems 2021a) for the groundwater comparative impact assessment.

4.1.5 PAX transport

Earth Systems (2021a) identified PAX as the key solute of interest with regard to potential groundwater impacts from MOD1 activities. Two sources of PAX entering the groundwater system were modelled: 1) seepage from sand tails emplaced at surface ahead of mining and 2) within the slimes injected into the LPS following mining. Earth Systems (2021a) advised 5 mg/L be assumed for seepage from sand tails emplaced at surface and 110 mg/L be assumed for injected slimes.

Earth Systems (2021b) indicated that, from laboratory testing limited to a duration of four weeks, the half-life of PAX in surface water (under oxidising conditions) was greater than eight weeks and recommended a nominal half-life of 12 weeks be assumed for decay in groundwater.

The transport functionality of MODFLOW-USG Transport was employed to simulate PAX entering the groundwater system at the concentrations outlined above at the times, and for the durations, in which the relevant sources were modelled. First order decay with a 12 week half-life was adopted. Based on earlier solute transport modelling carried out for the Balranald Project (SKM 2013a), a porosity of 15% and nominal dispersivity values of 100 m (horizontal) and 10 m (vertical) were adopted. Those values, although quite arbitrary, were originally chosen according to the relationship with the scale of the total transport as described in Schulze-Makuch (2005).

4.2 Uncertainty analysis

Two broad areas were identified as contributing factors to predictive uncertainty: hydraulic properties (controlling propagation of drawdown and mounding) and PAX solute behaviour in groundwater (specific to PAX migration). In order to address the potential uncertainty associated with these factors, additional predictions were made using alternative parameterisations specifically targeting anticipated end member values controlling modelled potential outcomes.

To address hydraulic uncertainty, the two alternative hydraulic parameterisations from the EIS modelling were adopted. In the EIS these related to 'high dewatering and injection' (from hereon referred to as alt par 1) and 'low dewatering and injection' (from hereon referred to as alt par 2) realisations.

To address uncertainty associated with transport of PAX in the groundwater system an alternative scenario was simulated, in which PAX never decays. Besides decay, both modelled porosity and dispersivity values will affect solute transport results. Qualitatively, higher dispersivity values will spread solute further, but at lower concentrations. Lower modelled porosity will spread solute faster/further, however the porosity of sand is unlikely to be much lower than the adopted value.

By simulating these three anticipated extreme end-member scenarios, in addition to the base case, the modelling aims to provide predictions that can be used to bookend areas of potential impacts in the comparative impact assessment. This is consistent with recent guidance on uncertainty analysis (Middlemis and Peeters 2018); paraphrasing: if a parameterisation aimed at maximising predicted impact does not result in an unacceptable outcome, then the argument can be made that any less-extreme parameterisation would also result in an acceptable outcome.

4.3 Results

4.3.1 Drawdown/mounding

Base case predictions of drawdown at the water table during and post mining are presented in Figure 4.2 and Figure 4.3. No drawdown is predicted at the water table. Localised mounding (ie negative drawdown) from sand tails seepage dissipates soon after the active tailing area advances, leaving little drawdown and mounding post mining.

Base case predictions of drawdown in the LPS1 lower shore/LPS2 foreshore during and post mining are presented in Figure 4.4 and Figure 4.5. Drawdown as a result of saline groundwater abstraction from the PWD Well is evident in a localised area east of the deposit at all times during mining. A small area, entirely within the proposed MOD1 disturbance area, of mounding at slimes injection locations can be seen to move northward along the deposit through the duration of mining. Post mining, both drawdown and mounding dissipate rapidly to below 0.2 m.

Base case predictions of drawdown in the Olney Formation during and post mining are presented in Figure 4.6 and Figure 4.7. Drawdown from the two brackish water supply wells is predicted to extend outward into the surrounding aquifer, with the 2 m drawdown contour extending a short distance beyond some parts of the MOD1 disturbance area. Post mining, the drawdown recovers rapidly, due to the confined nature of the aquifer, with no drawdown greater than 1 m remaining after only one year.

Results of the alternative hydraulic parameterisations are presented in Figure 4.8 to Figure 4.10 for the water table, LPS1LS/LPS2FS and Olney Formation. Results demonstrate that, in all three aquifers, the base case and two alternative parameterisations result in localised impacts with only relatively small changes in hydraulic head propagation beyond the proposed MOD1 disturbance area.

Modelled hydrographs at selected chainages, 500 m apart, along the West Balranald deposit (chainage zero is at the far southern end, outside the area proposed for MOD1 mining) are presented in Figure 4.11. Comparison of hydrographs at different chainages illustrates the timing of seepage from sand tails (ahead of mining) impacting the water table, followed by a spike in the LPS1LS/LPS2FS due to slimes injection. An overlying drawdown impact is observed at varying magnitudes depending on proximity of the monitoring points to the saline water supply from PWD Well, screened across the LPS.

Modelled hydrographs at nominal third party wells are presented in Figure 4.12. Across the base case and two alternative hydraulic parameterisations, drawdown never reaches 1.5 m.

Locations of potential GDEs identified in the EIS are illustrated in Figure 4.13. Corresponding modelled hydrographs are presented in Figure 4.14. These demonstrate only very small drawdown magnitudes, with the maximum being around 5 cm.

Predicted hydrographs at Iluka monitoring wells associated with the T3 trial are presented in Appendix E.



KEY

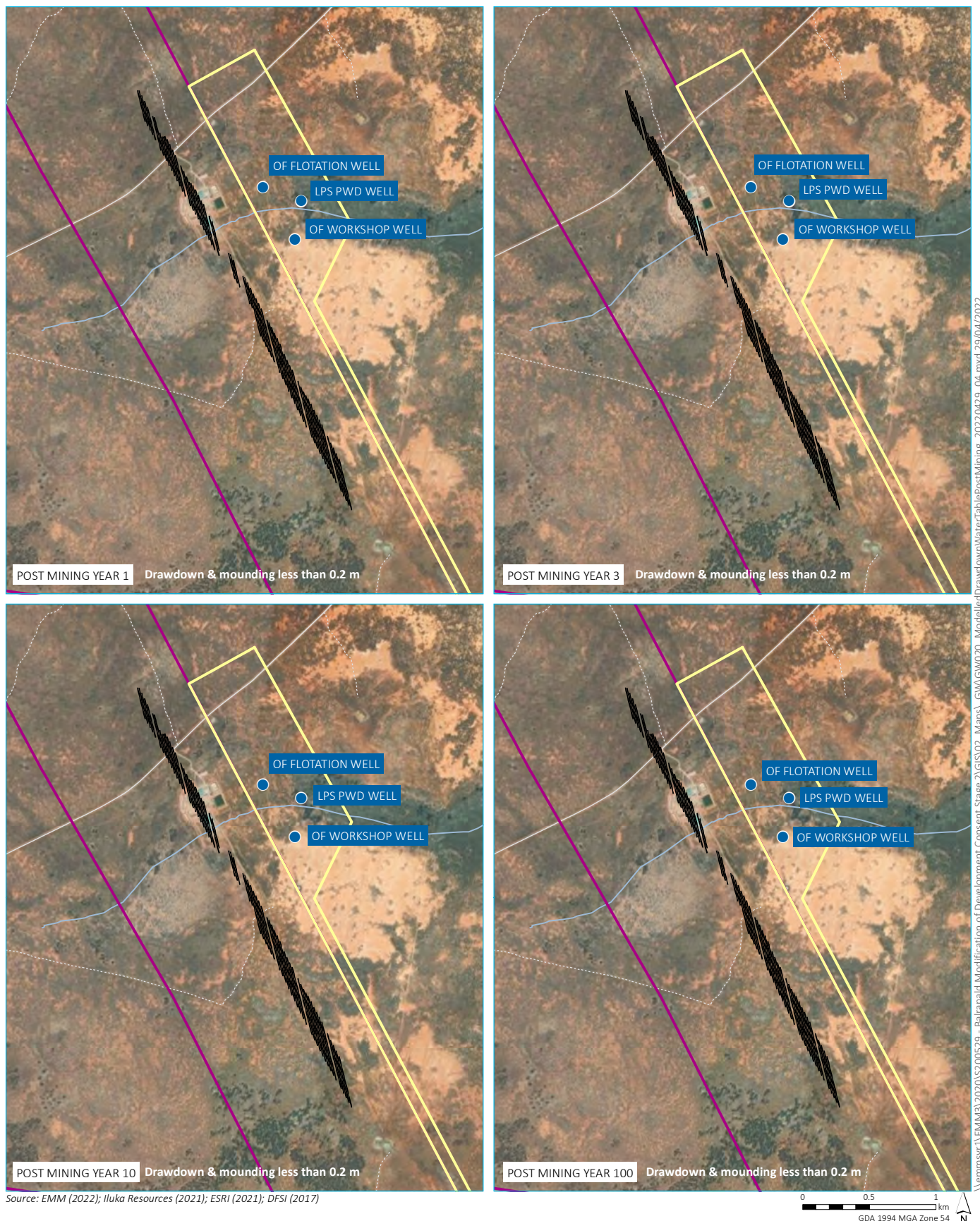
- EIS Approved Balranald Project Area (SSD-5285)
 - Proposed modification extension to Balranald Project Area boundary
 - MOD1 stope
 - Mine water supply well
 - Drawdown (m)
 - Minor road
 - Vehicular track
 - Watercourse/drainage line
- Modelled drawdown (m)
- >2

<-2

Modelled drawdown at the water table during mining

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 4.2





KEY

 EIS Approved Balranald Project Area (SSD-5285)

 Proposed modification extension to Balranald Project Area boundary

MOD1 stope

● Third party well

— Minor road

--- Vehicular track

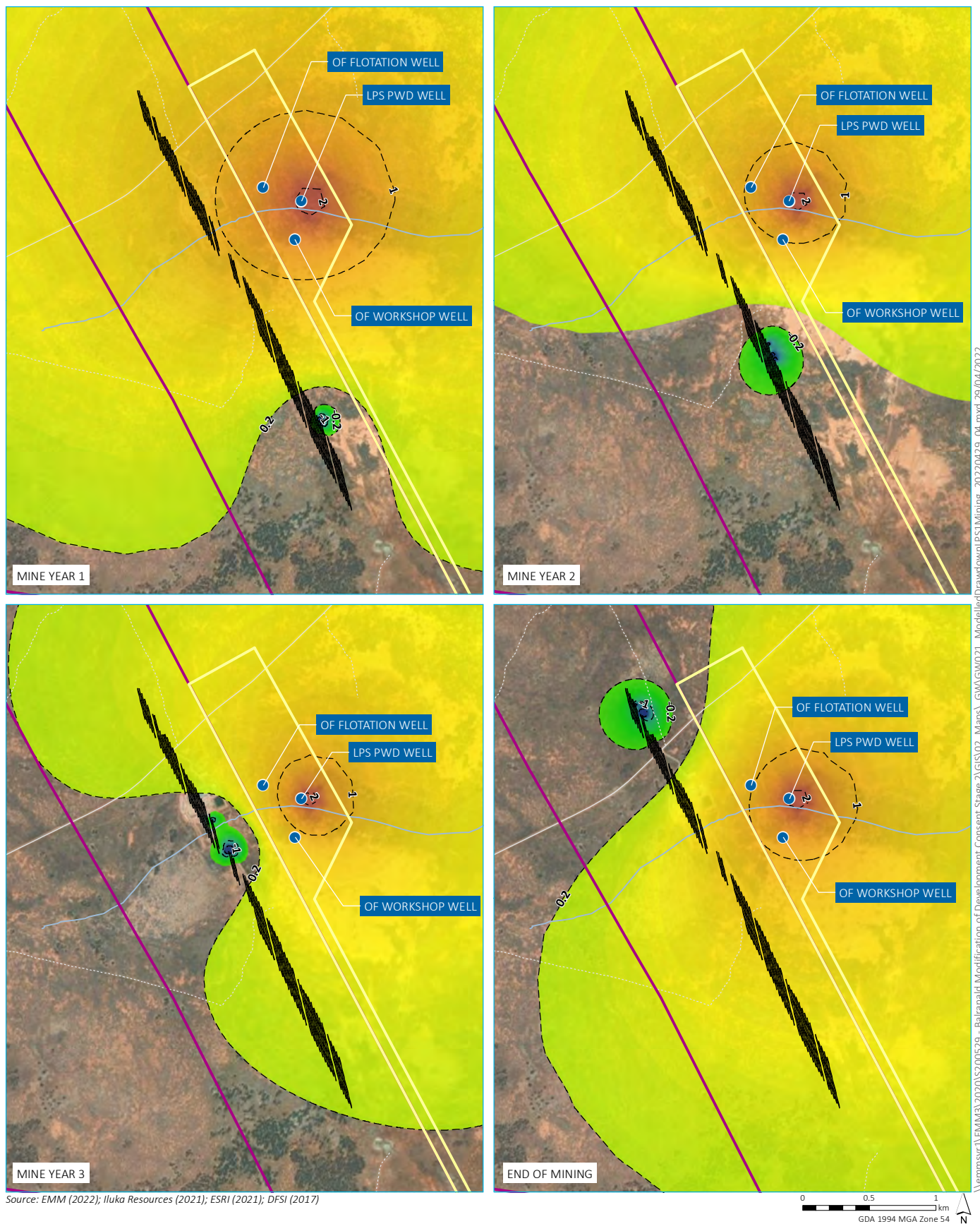
— Watercourse/drainage line

Modelled drawdown (m)



Modelled drawdown at the water table post mining

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 4.3



KEY

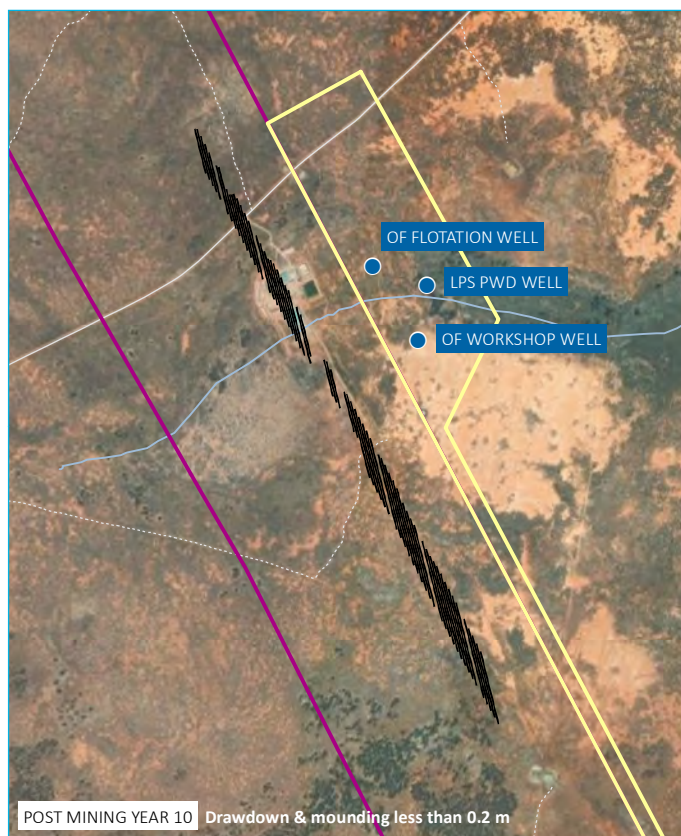
- EIS Approved Balranald Project Area (SSD-5285)
 - Proposed modification extension to Balranald Project Area boundary
 - MOD1 stope
 - Mine water supply well
 - Drawdown (m)
 - Minor road
 - Vehicular track
 - Watercourse/drainage line
- Modelled drawdown (m)
- >2

<-2

Modelled drawdown in LPS1 lower shore/LPS2 foreshore during mining

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 4.4





Source: EMM (2022); Iluka Resources (2021); ESRI (2021); DFSI (2017)

KEY

 EIS Approved Balranald Project Area (SSD-5285)

 Proposed modification extension to Balranald Project Area boundary

MOD1 stope

● Third party well

— Minor road

- - - Vehicular track

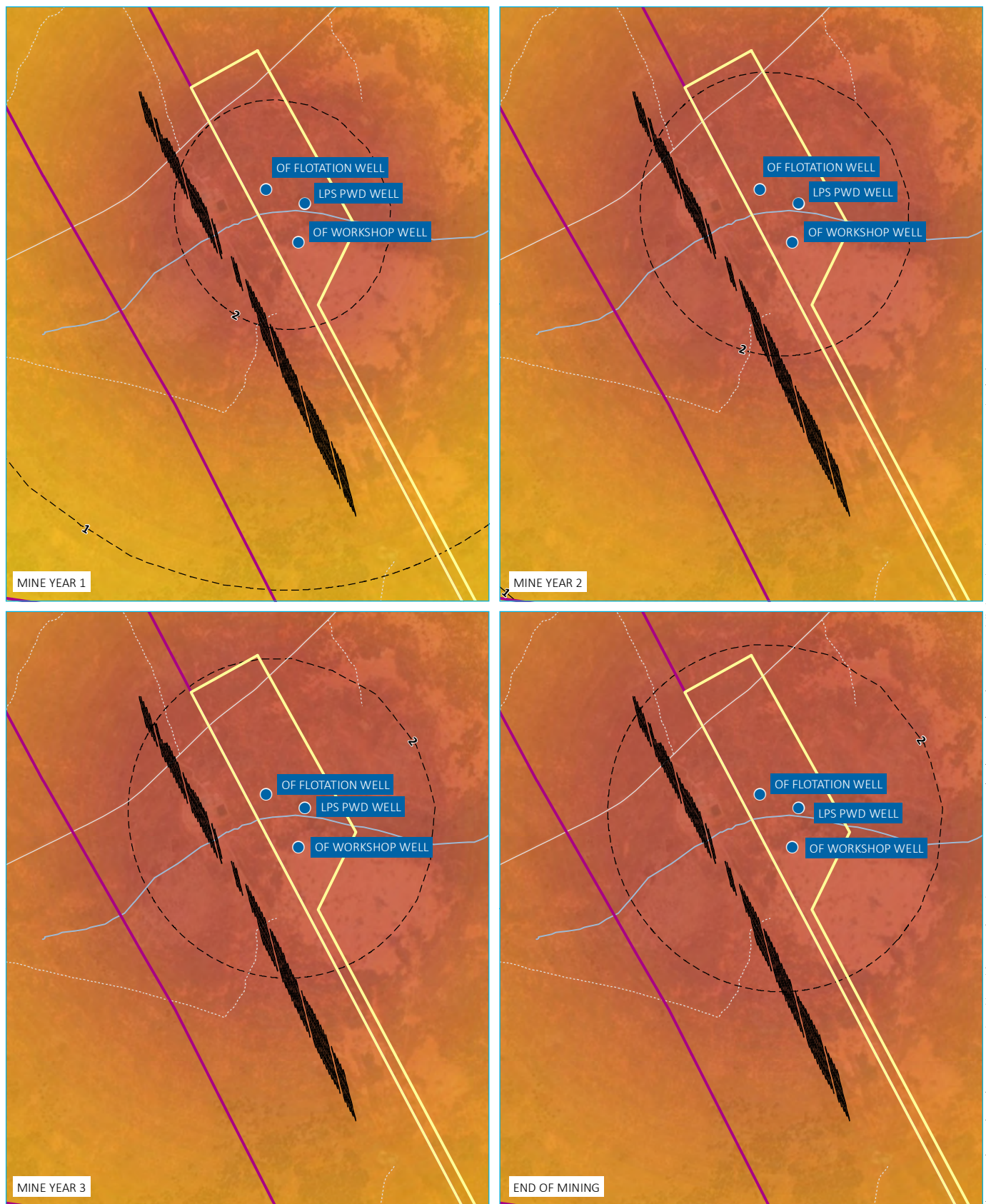
— Watercourse/drainage line

Modelled drawdown (m)



Modelled drawdown in LPS1 lower shore/LPS2 foreshore post mining

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 4.5



Source: EMM (2022); Iluka Resources (2021); ESRI (2021); DFSI (2017)

KEY

 EIS Approved Balranald Project Area (SSD-5285)

 Proposed modification extension to Balranald Project Area boundary

MOD1 stope

● Third party well

Drawdown (m)

Minor road

Vehicular track

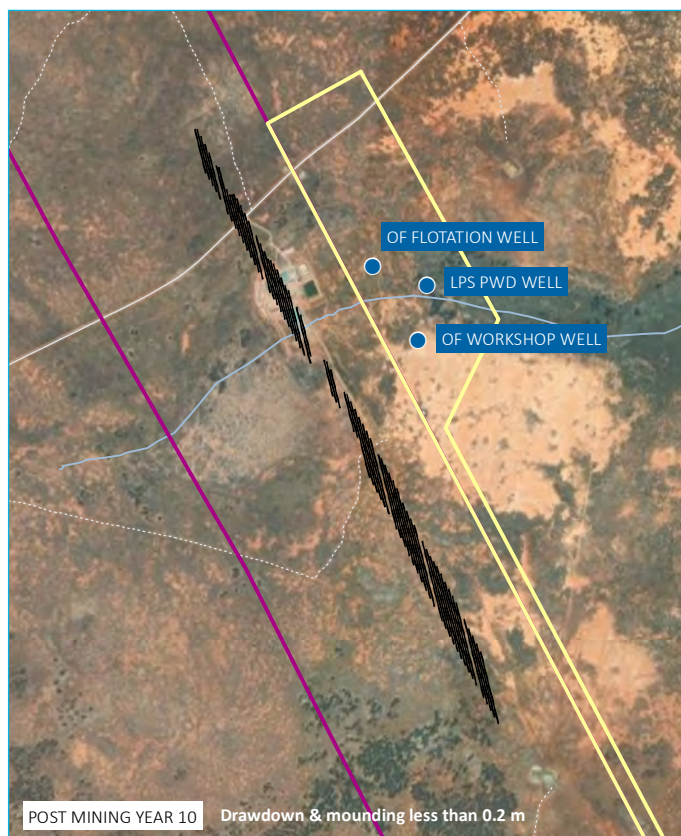
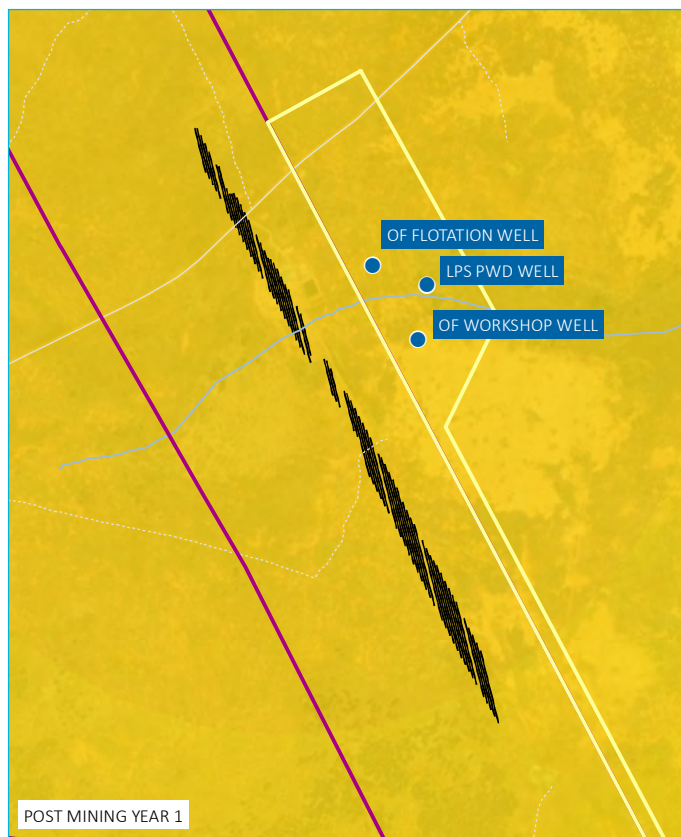
— Watercourse/drainage line

Modelled drawdown (m)



Modelled drawdown in Olney Formation during mining

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 4.6



Source: EMM (2022); Iluka Resources (2021); ESRI (2021); DFSI (2017)

KEY

 EIS Approved Balranald Project Area (SSD-5285)

 Proposed modification extension to Balranald Project Area boundary

MOD1 stope

● Third party well

— Minor road

--- Vehicular track

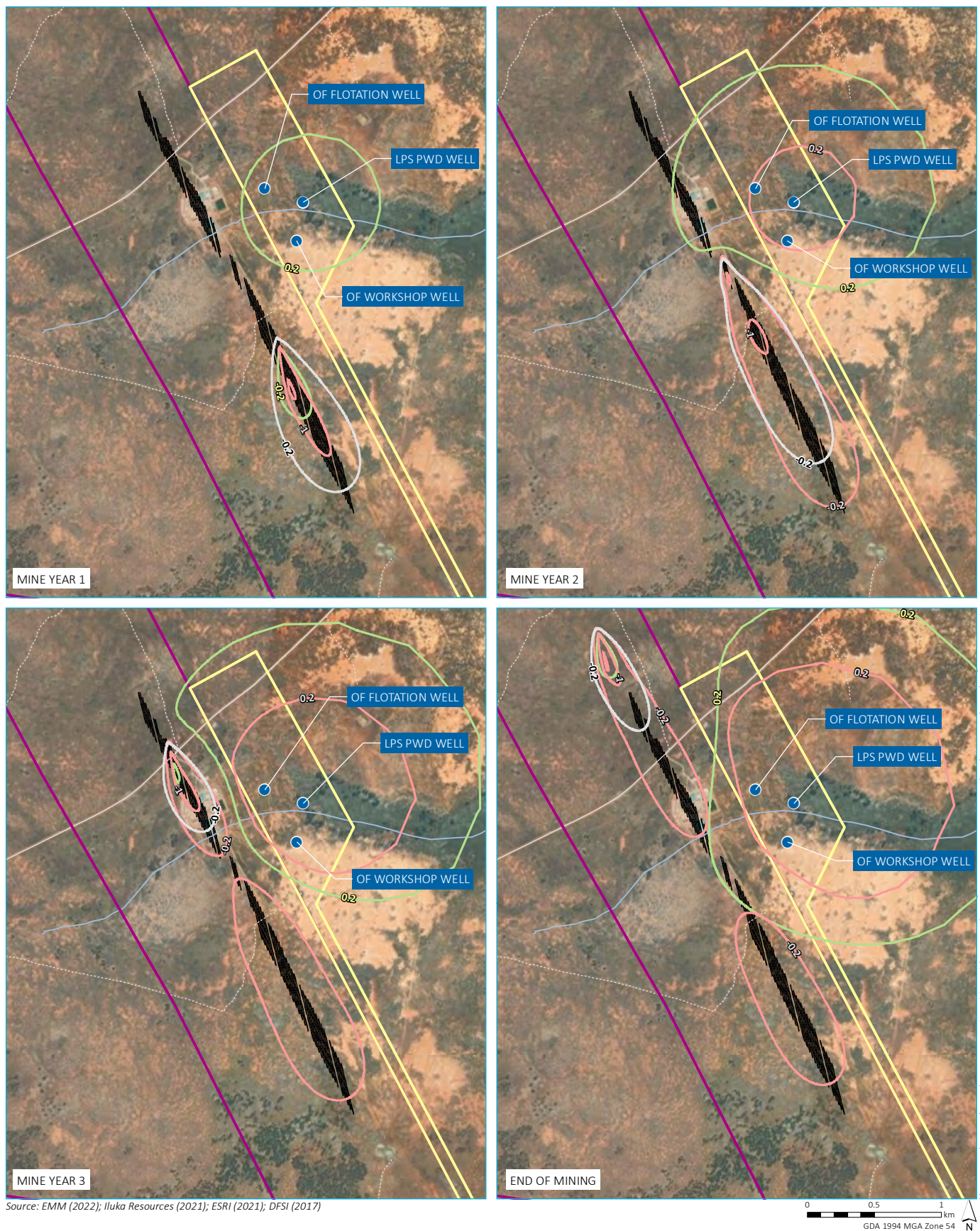
— Watercourse/drainage line

Modelled drawdown (m)



Modelled drawdown in Olney Formation post mining

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 4.7

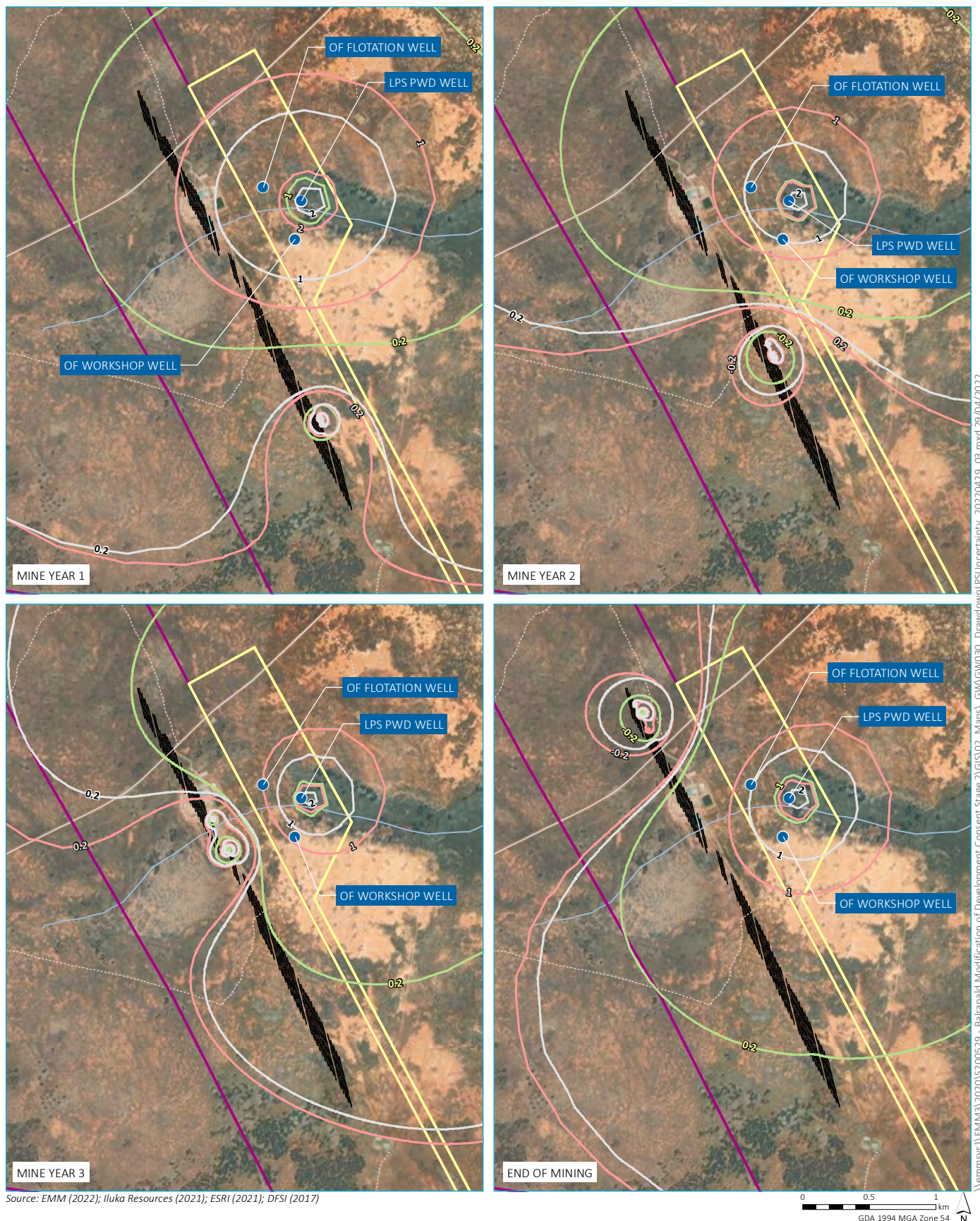


KEY

- EIS Approved Balranald Project Area (SSD-5285)
- Proposed modification extension to Balranald Project Area boundary
- MOD1 stope
- Third party well
- Minor road
- Vehicular track
- Watercourse/drainage line
- Modelled drawdown (m) Alternative parameters 1
- Alternative parameters 2
- Base case

Drawdown at the water table:
uncertainty analysis

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 4.8



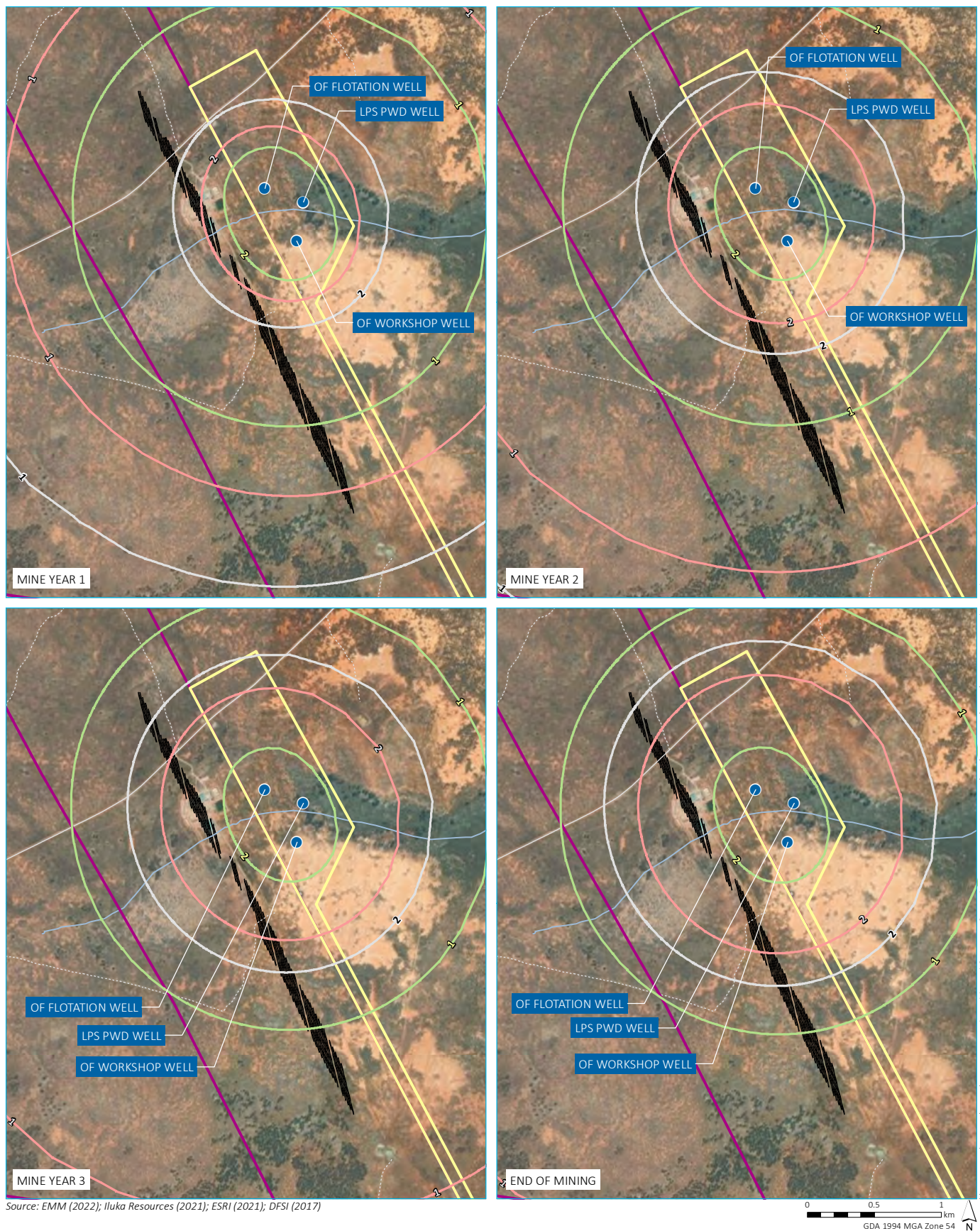
KEY

- EIS Approved Balranald Project Area (SSD-5285)
- Proposed modification extension to Balranald Project Area boundary
- MOD1 slope
- Third party well
- Minor road
- Vehicular track
- Watercourse/drainage line
- Modelled drawdown (m)
 - Alternative parameters 1
 - Alternative parameters 2
 - Base case

Modelled drawdown in LPS1 lower shore/LPS2 foreshore: uncertainty analysis

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 4.9





KEY

- | | |
|---|--|
| EIS Approved Balranald Project Area (SSD-5285) | Modelled drawdown (m) |
| Proposed modification extension to Balranald Project Area boundary | Alternative parameters 1 |
| MOD1 stope | Alternative parameters 2 |
| ● Third party well | Base case |
| — Minor road | |
| --- Vehicular track | |
| — Watercourse/drainage line | |

Drawdown in Olney Formation:
uncertainty analysis

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 4.10

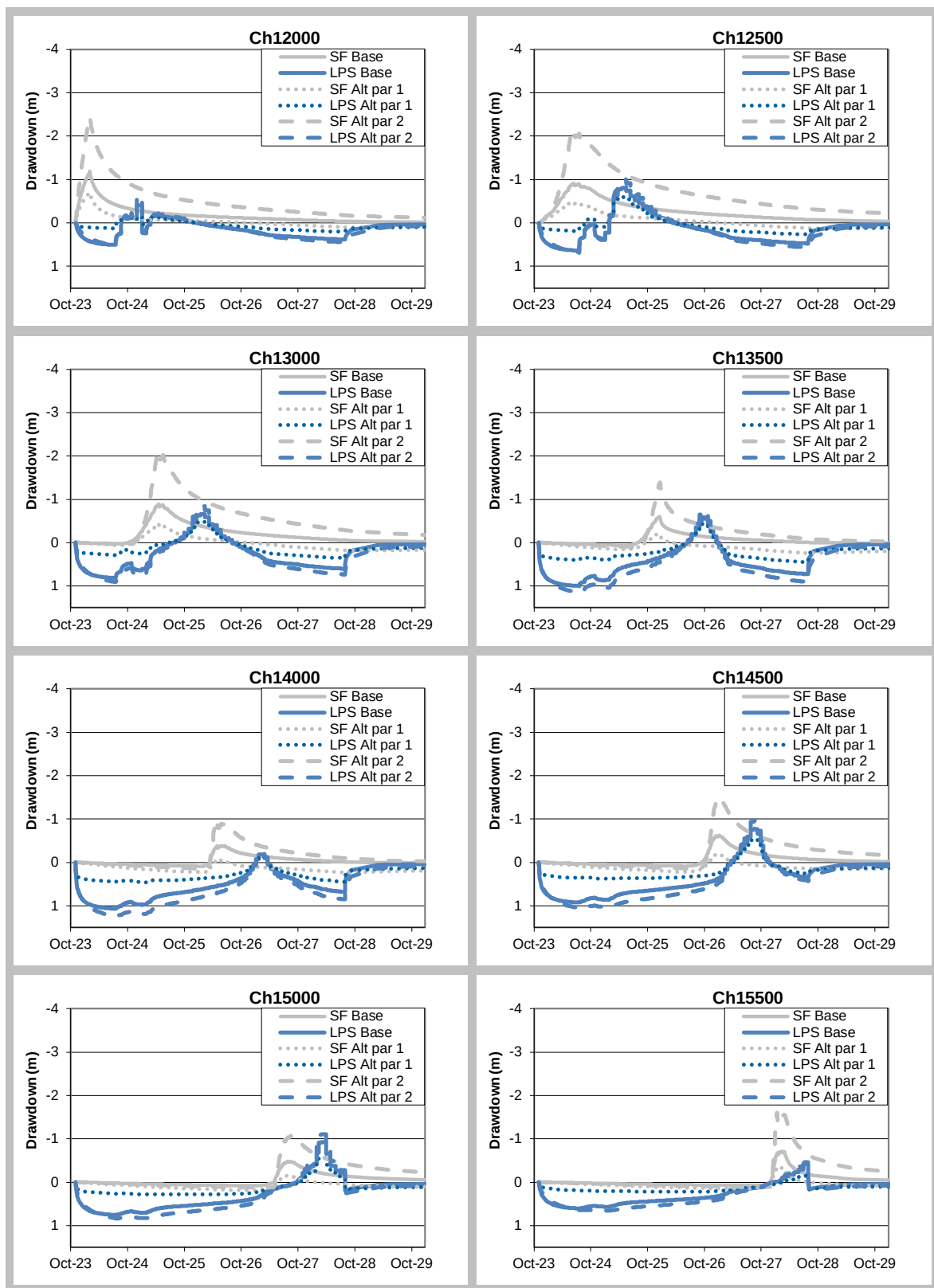


Figure 4.11 Modelled hydrographs at 500 m chainage intervals along the West Balranald deposit

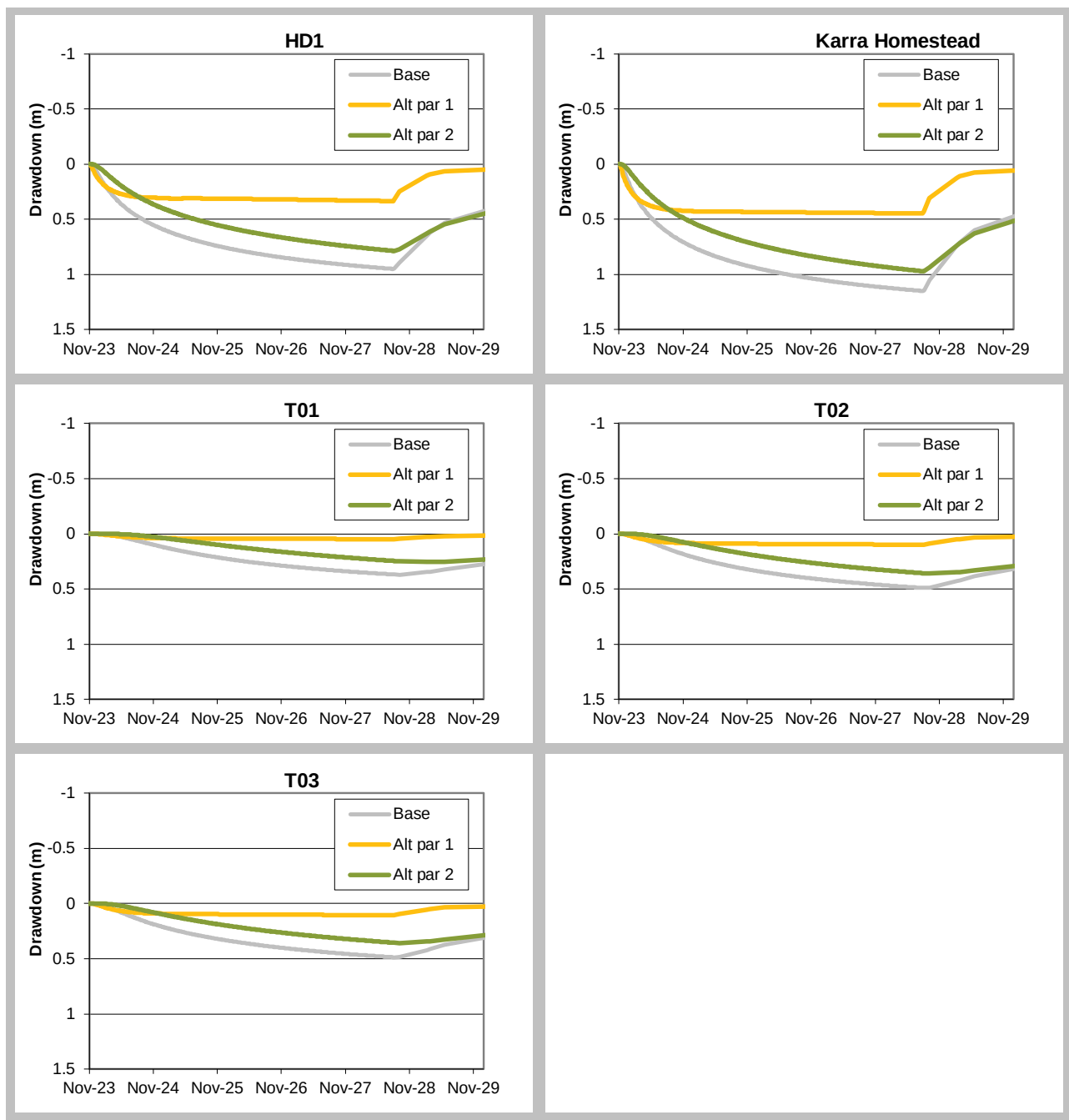


Figure 4.12 Modelled hydrographs at third party wells

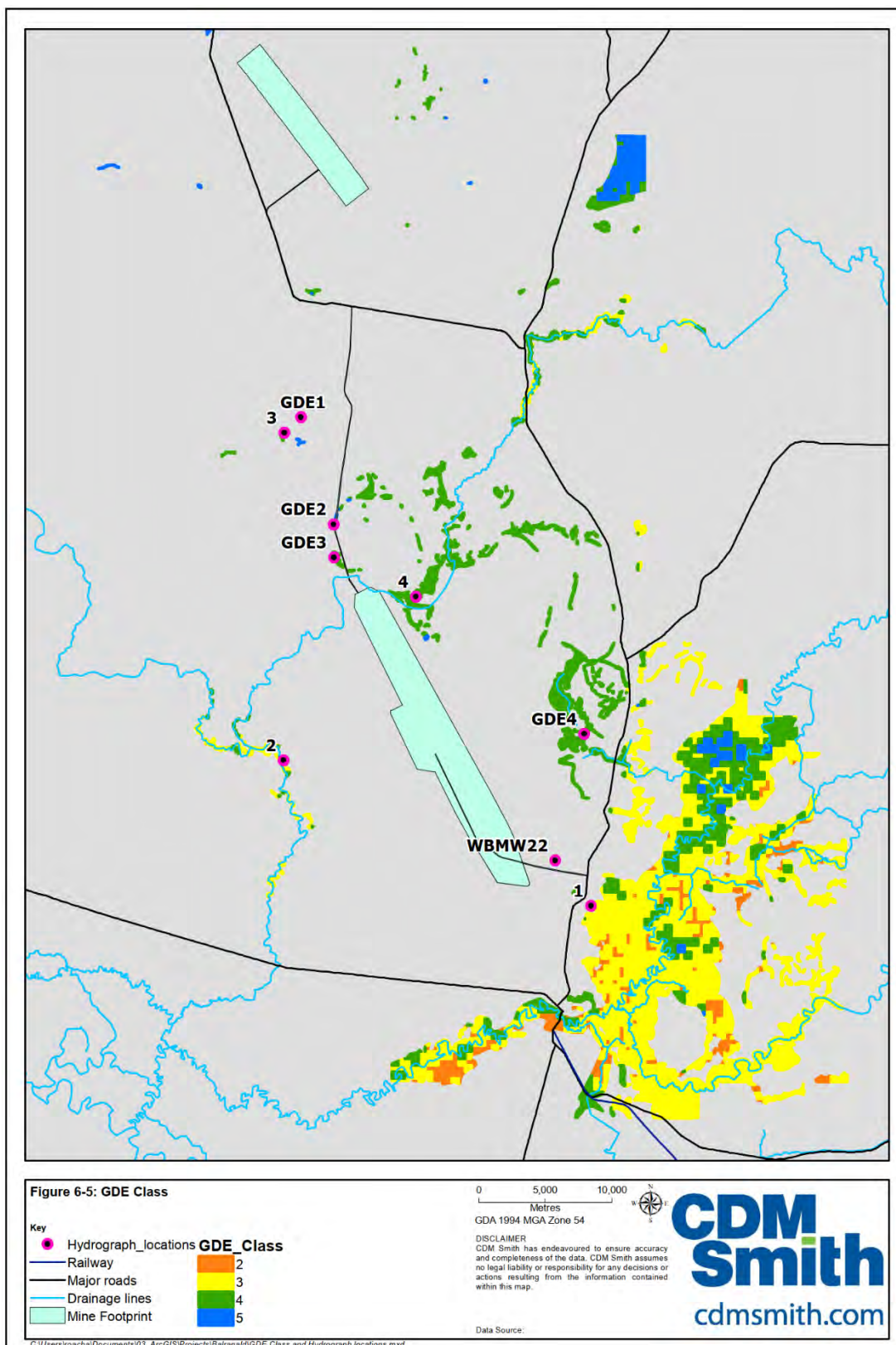


Figure 4.13 Locations of potential GDEs (after CDM Smith 2015)

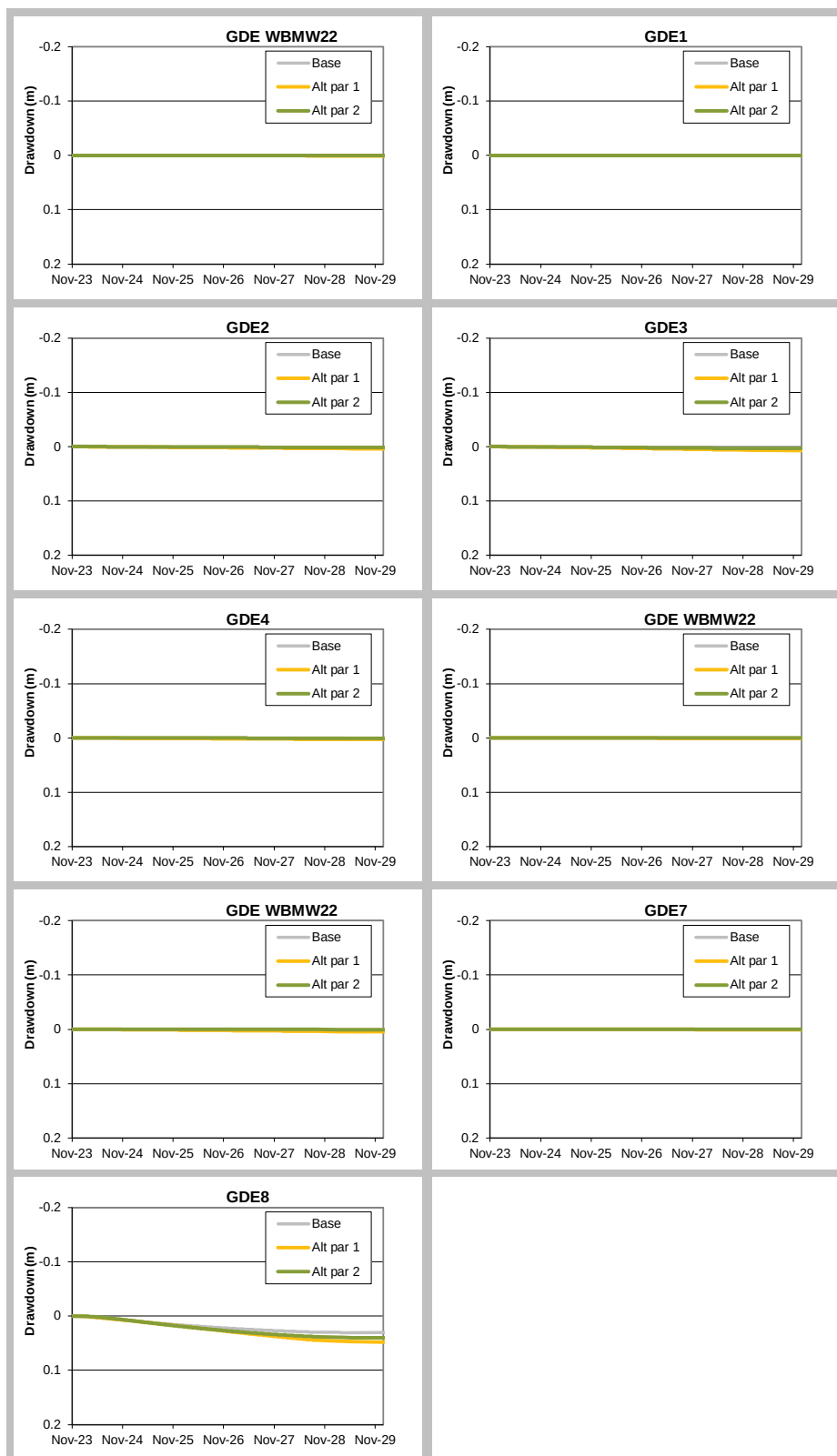


Figure 4.14 **Modelled hydrographs at GDEs**

4.3.2 PAX transport

Modelled PAX concentration in the Shepparton Formation during and post mining is presented in Figure 4.15 and Figure 4.16 respectively. These demonstrate development of a plume of PAX below the emplaced sand tails, at concentrations above the 0.0005 mg/L low reliability trigger for aquatic ecosystem protection (ANZECC and ARMCANZ 2000). However, as the active emplacement area moves forward, ahead of the active mining area, decay of PAX soon results in the PAX concentration dropping below the threshold. The result is a moving plume, not because of migration of PAX in groundwater, but because of movement of the source and relatively rapid decay of PAX once in the groundwater system. By three years post mining, almost no PAX remains above 0.0005 mg/L and by 10 years post mining there is predicted to be none.

Modelled PAX concentration in the LPS1LS/LPS2FS during and post mining is presented in Figure 4.17 and Figure 4.18 respectively. A larger plume with higher peak concentration is predicted in the LPS than the Shepparton Formation. This is a result of a modelled source concentration of 110 mg/L in the injected slimes rather than the 5 mg/L modelled for seepage from sand tails at surface. However, a similar outcome is predicted with a relatively rapid decay meaning PAX remains above the freshwater threshold value of 0.0005 mg/L for around four years in a given location, resulting in a progressive movement of the modelled plume along the deposit, in line with the progressive injection of slimes behind mining. By three years post mining, the modelled plume is noticeably smaller and ten years post mining it is almost completely reduced to below the trigger of 0.0005 mg/L. It is worth noting the plume is predicted to get close to the LPS saline water supply well during mining.

Results of the simulation run to address uncertainty in the decay rate of PAX are presented in Figure 4.19 and Figure 4.20 for the Shepparton Formation and Figure 4.21 and Figure 4.22 for the LPS1LS/LPS2FS. In both aquifers, results illustrate a non-decaying plume would remain at higher concentrations for longer and, therefore, over a larger area above the 0.0005 mg/L trigger than for the modelled base case half-life of 12 weeks. However, in the Shepparton Formation this plume is entirely constrained to within the proposed MOD1 disturbance area and in the LPS1LS/LPS2FS, it remains mostly within this area. Importantly, even 100 years after cessation of mining, a non-decaying plume displays little evidence of migration due to the very low regional hydraulic gradient.



KEY

 EIS Approved Balranald Project Area (SSD-5285)

 Proposed modification extension to Balranald Project Area boundary

 MOD1 stope

● Mine water supply well

— Minor road

--- Vehicular track

— Watercourse/drainage line

Modelled PAX (mg/L)

100

0.0005

Modelled PAX concentration in the Shepparton Formation during mining

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 4.15



Source: EMM (2022); Iluka Resources (2021); ESRI (2021); DFSI (2017)

KEY

 EIS Approved Balranald Project Area (SSD-5285)

 Proposed modification extension to Balranald Project Area boundary

 MOD1 stope

● Mine water supply well

— Minor road

--- Vehicular track

— Watercourse/drainage line

Modelled PAX (mg/L)

100

0.0005

0.0005

0.0005

0.0005

0.0005

0.0005

0.0005

0.0005

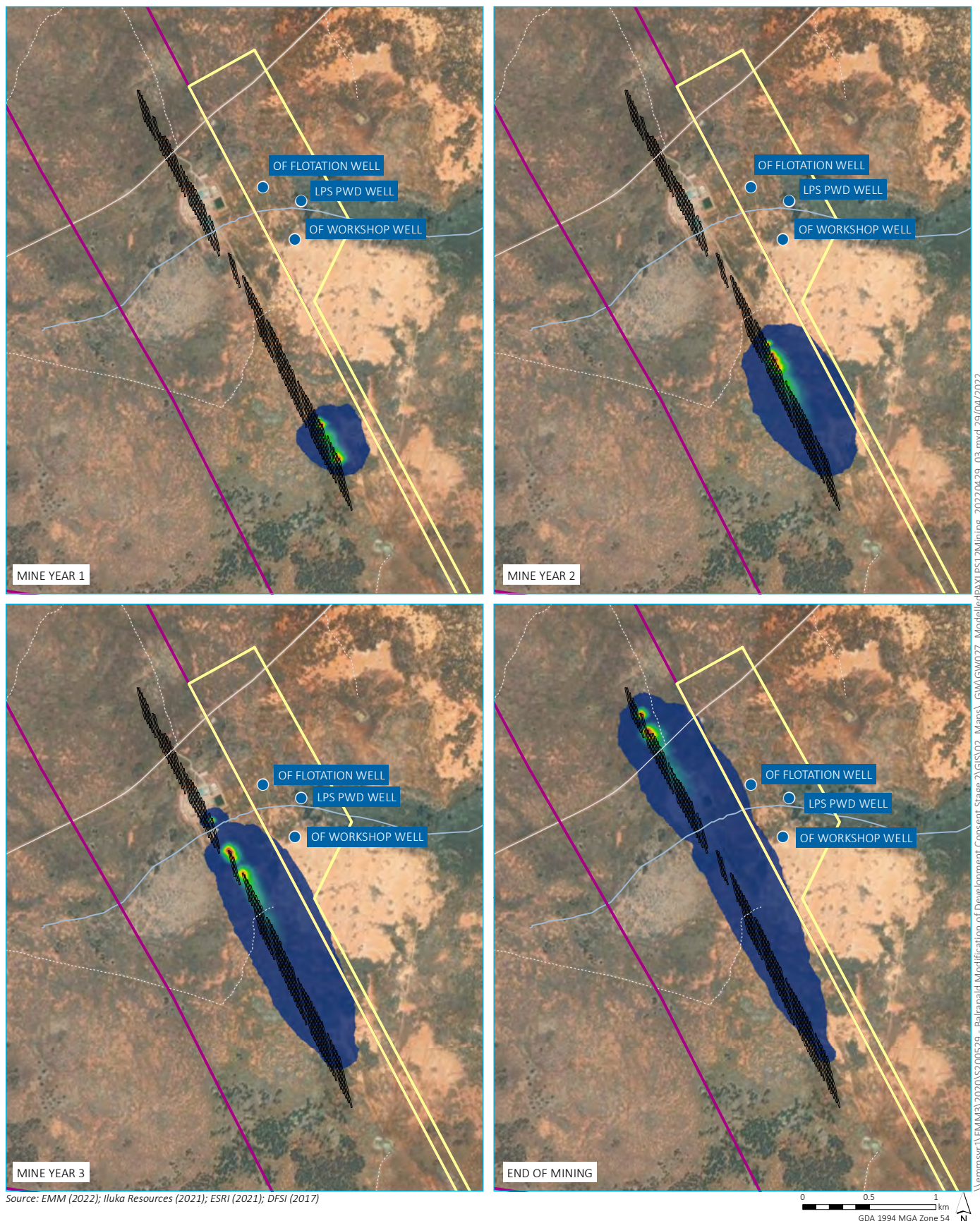
0.0005

0.0005

0.0005

Modelled PAX concentration in the Shepparton Formation post mining

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 4.16



KEY

 EIS Approved Balranald Project Area (SSD-5285)

 Proposed modification extension to Balranald Project Area boundary

 MOD1 stope

● Mine water supply well

— Minor road

--- Vehicular track

— Watercourse/drainage line

Modelled PAX (mg/L)

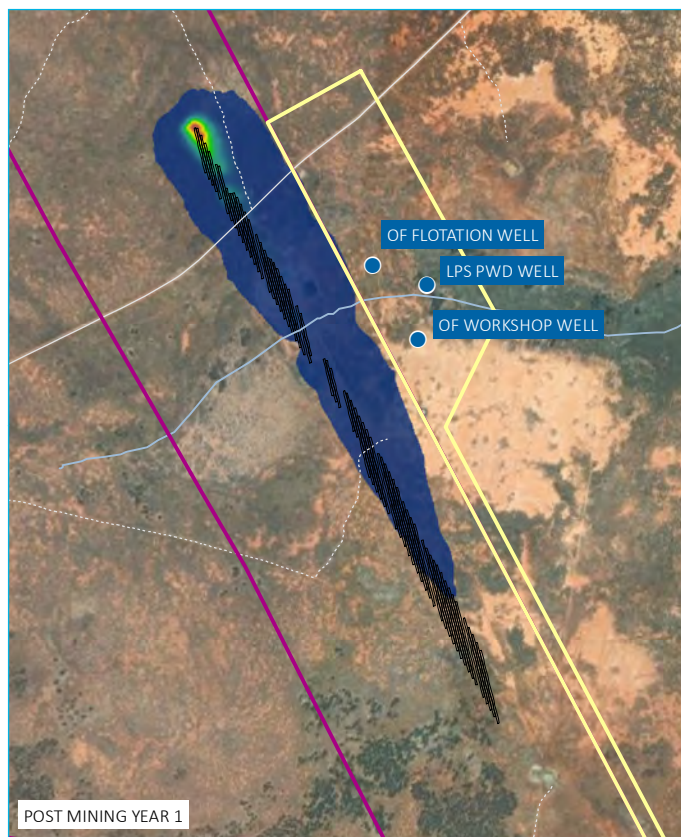
100

0.0005

Modelled PAX concentration in LPS1 lower shore/LPS2 foreshore during mining

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 4.17





Source: EMM (2022); Iluka Resources (2021); ESRI (2021); DFSI (2017)

KEY

 EIS Approved Balranald Project Area (SSD-5285)

 Proposed modification extension to Balranald Project Area boundary

 MOD1 stope

● Mine water supply well

— Minor road

--- Vehicular track

— Watercourse/drainage line

Modelled PAX (mg/L)

100

0.0005

0.0005

0.0005

0.0005

0.0005

0.0005

0.0005

0.0005

0.0005

0.0005

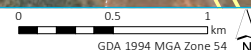
0.0005

Modelled PAX concentration in LPS1 lower shore/LPS2 foreshore post mining

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 4.18



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KEY

 EIS Approved Balranald Project Area (SSD-5285)

 Proposed modification extension to Balranald Project Area boundary

 MOD1 stope

● Third party well

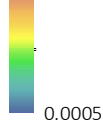
— Minor road

--- Vehicular track

— Watercourse/drainage line

Modelled PAX (mg/L)

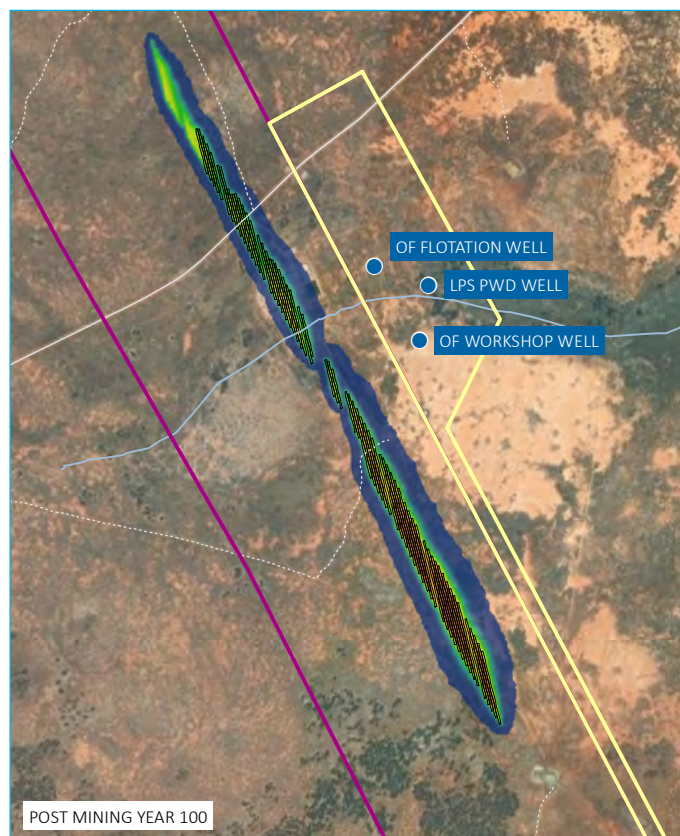
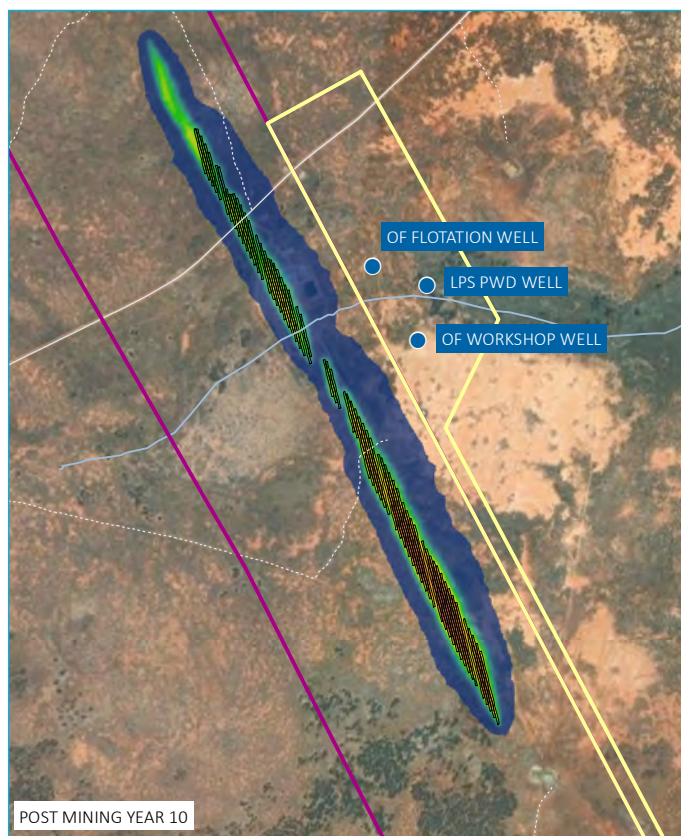
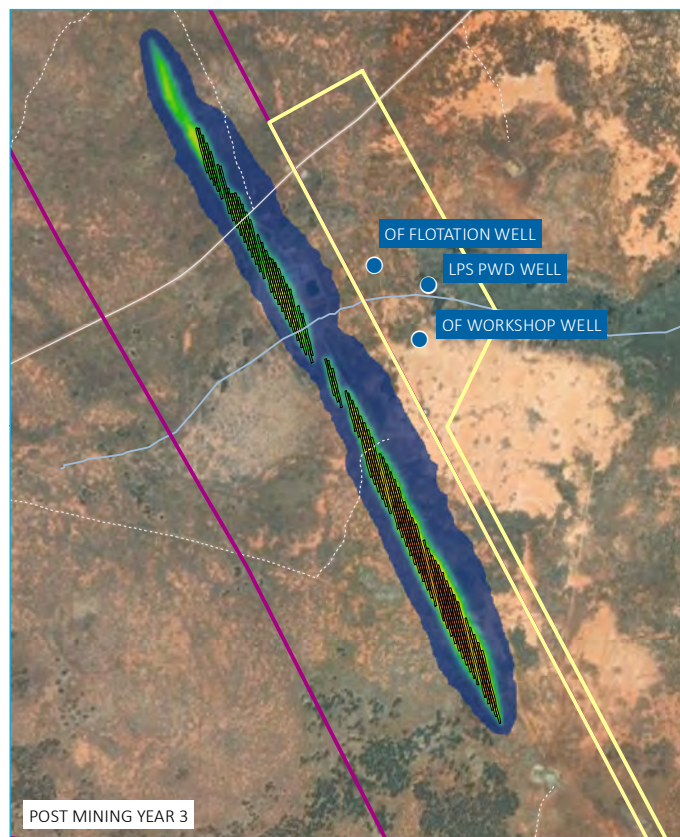
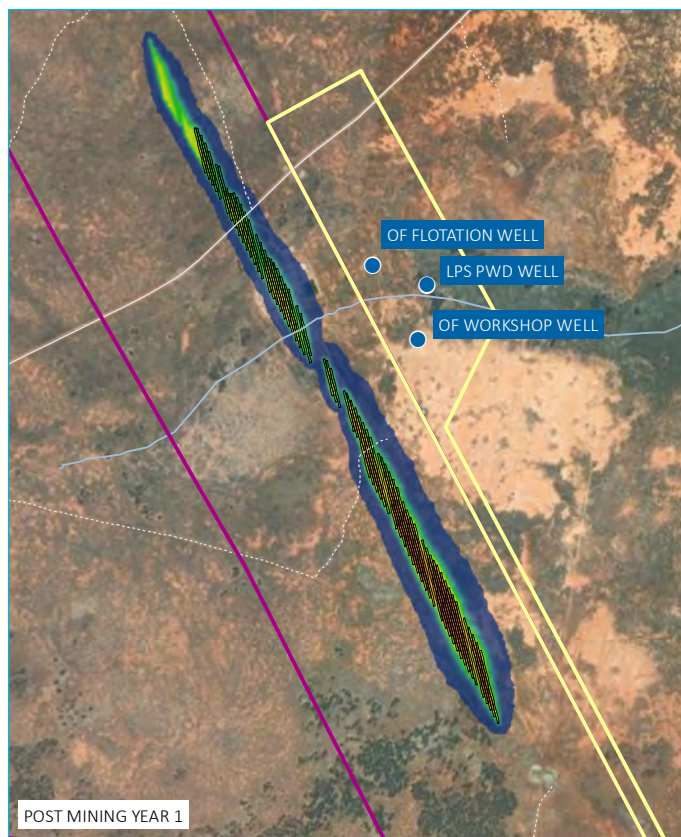
100



0.0005

Modelled PAX concentration in the Shepparton Formation during mining:
No decay

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 4.19



Source: EMM (2022); Iluka Resources (2021); ESRI (2021); DFSI (2017)

KEY

 EIS Approved Balranald Project Area (SSD-5285)

 Proposed modification extension to Balranald Project Area boundary

 MOD1 stope

● Third party well

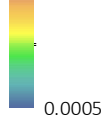
— Minor road

--- Vehicular track

— Watercourse/drainage line

Modelled PAX (mg/L)

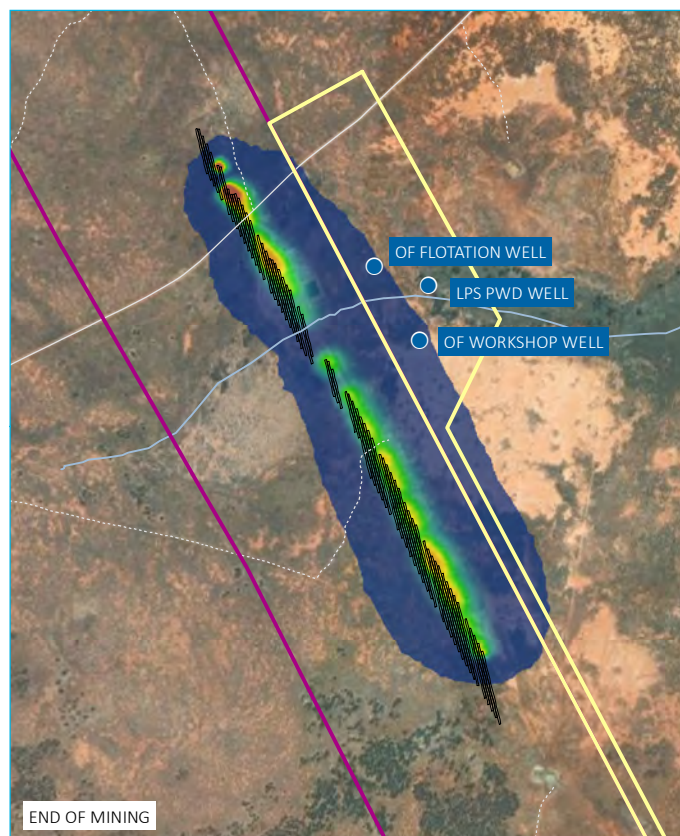
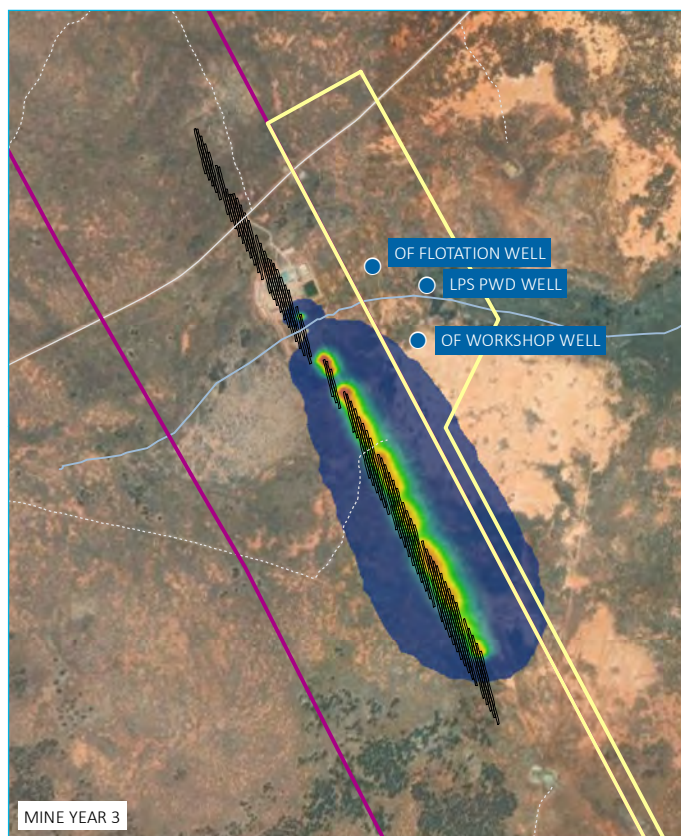
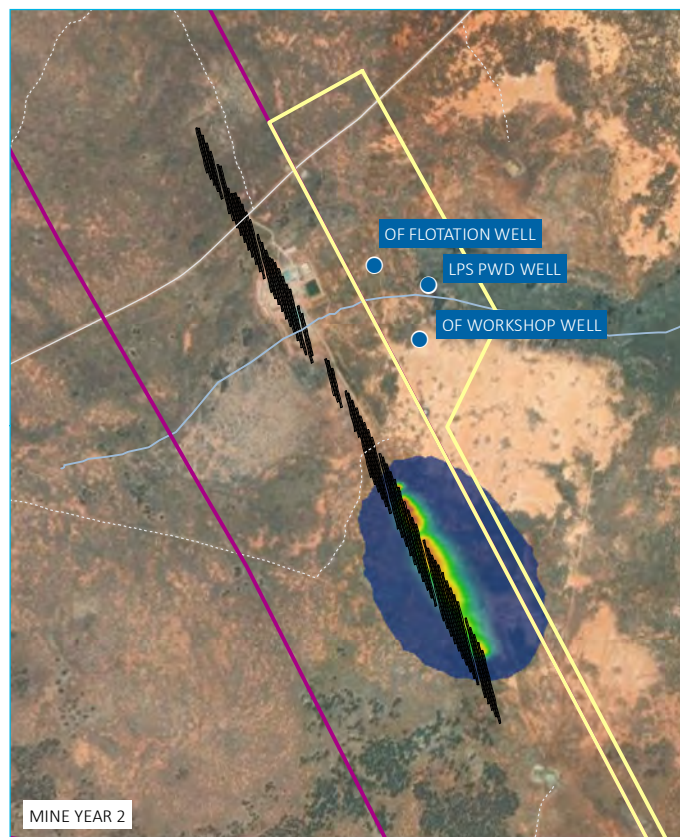
100



0.0005

Modelled PAX concentration in the Shepparton Formation post mining:
No decay

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 4.20



Source: EMM (2022); Iluka Resources (2021); ESRI (2021); DFSI (2017)

KEY

 EIS Approved Balranald Project Area (SSD-5285)

 Proposed modification extension to Balranald Project Area boundary

 MOD1 stope

● Third party well

— Minor road

--- Vehicular track

— Watercourse/drainage line

Modelled PAX (mg/L)

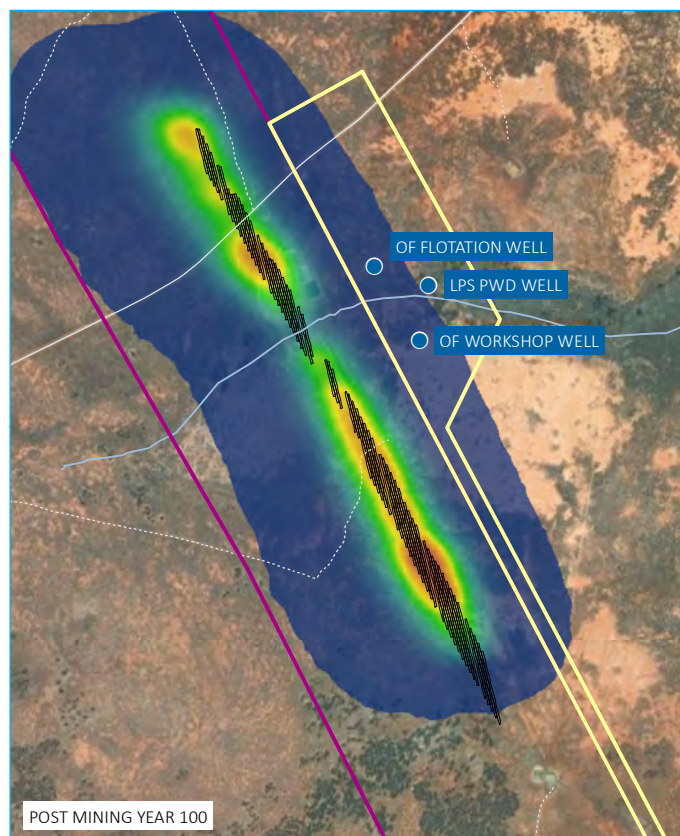
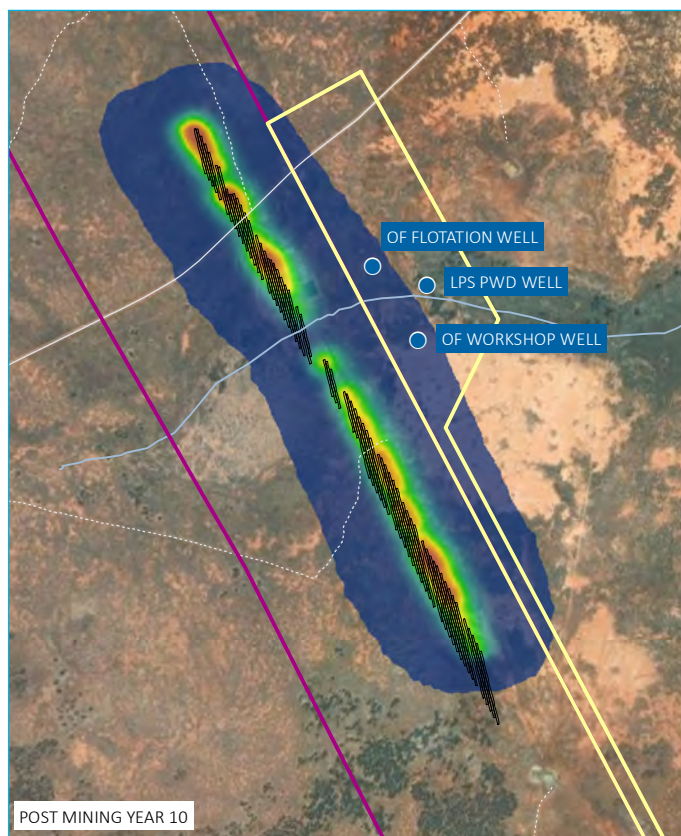
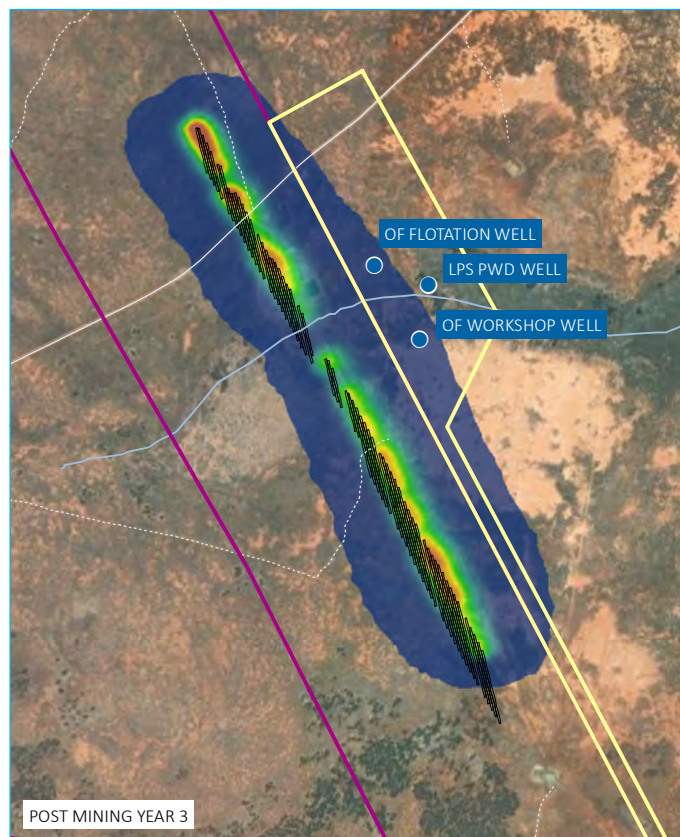
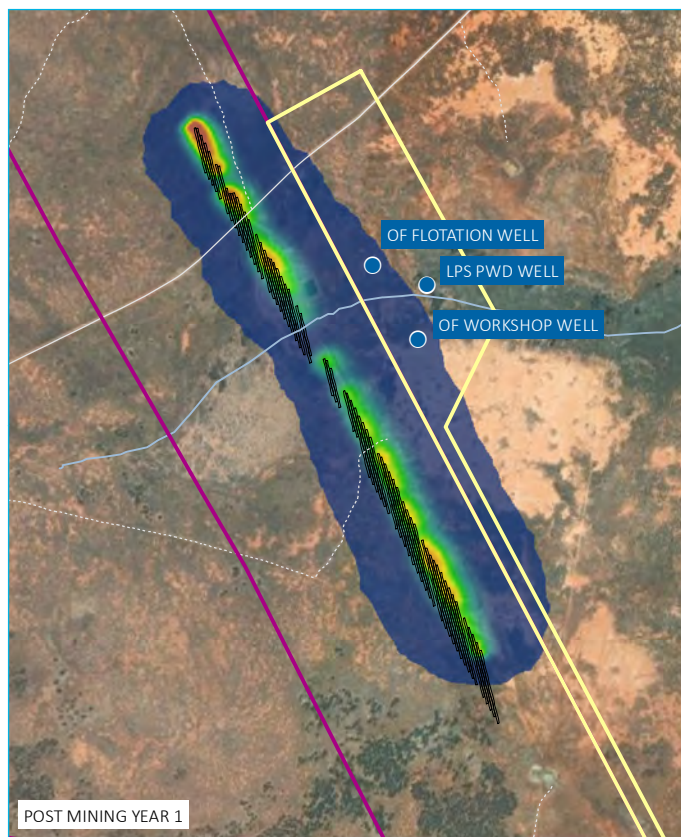
100

0.0005



Modelled PAX concentration
LPS1/2 during mining:
No decay

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure 4.21



Source: EMM (2022); Iluka Resources (2021); ESRI (2021); DFSI (2017)

KEY

 EIS Approved Balranald Project Area (SSD-5285)

 Proposed modification extension to Balranald Project Area boundary

 MOD1 stope

● Third party well

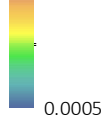
— Minor road

--- Vehicular track

— Watercourse/drainage line

Modelled PAX (mg/L)

100



0.0005

Modelled PAX concentration

LPS1/2 post mining:

No decay

Balranald Mineral Sands Project

MOD1 groundwater modelling

Figure 4.22

5 Summary

The existing BAL2.0 numerical groundwater model has been updated, making use of software advances since the previous model was developed, and tailored to making predictions of proposed groundwater-affecting activities associated with the MOD1 project. The updated model provides a platform for future validation and any further development of the project.

Predictions have been made regarding potential drawdown and mounding of groundwater, resulting from groundwater supply, seepage from tailings and injection of slimes, as well as predictions of potential migration of PAX within the groundwater system. These model predictions support the MOD1 groundwater comparative impact assessment.

The model and predictions were independently reviewed by Hugh Middlemis of HydroGeoLogic. The review found that the model was developed consistent with best practice, that a Class 2 model confidence classification (its targeted Class) is well justified and was that it is suitable for predicting the impacts associated with the mining activities proposed in MOD1.

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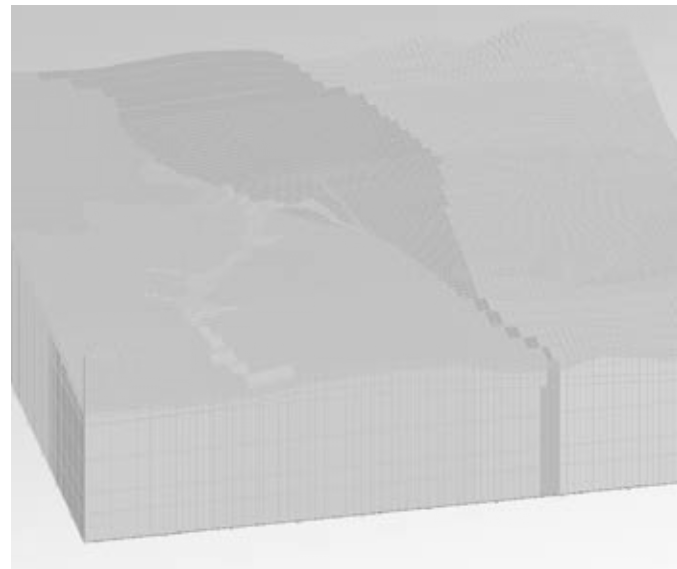
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Appendix A

Independent review



INDEPENDENT PEER REVIEW STATEMENT

ATTENTION:	Dr Doug Weatherill, Associate Groundwater Modeller, EMM Consulting	
FROM:	Hugh Middlemis, Principal Groundwater Engineer, HydroGeoLogic Pty Ltd	
REFERENCES:	6 April 2022	Balranald Mineral Sands Project MOD1 Groundwater Modelling
SUBJECT:	Independent Peer Review of Balranald MOD1 Groundwater Model 'BAL3.0'	

1. SUMMARY

This brief statement summarises the outcomes of a peer review of the 'BAL3.0' modelling conducted for the groundwater comparative impact assessment (GCIA) of the Balranald Mineral Sands Project Modification 'MOD1' project. MOD1 involves an innovative directional borehole underground mining method via pressure-neutral injection of process water and extraction of a sand-water slurry. While the pressure-neutral mining process itself is not simulated in the BAL3.0 model, the injection of sand fines into the stope voids is simulated, along with the subsidence induced changes to vertical hydraulic conductivity.

This peer review was conducted by Hugh Middlemis in March/April 2022 in accordance with the best practice principles of the Australian Groundwater Modelling Guideline ('AGMG'; Barnett et al. 2012). The peer review outcomes are summarised using the AGMG compliance summary checklist (after Table 9-1 of Barnett et al. 2012), presented as Table 1 below, with further discussion on some details outlined later.

The main evidentiary basis for this peer review was the report on the 'BAL3.0' model version that was developed specifically for the Balranald MOD1 project (EMM 2022), upgrading the BAL2 model (EMM 2015) that was also reviewed by Hugh Middlemis, confirming that it has been developed consistent with best practice groundwater modelling guidelines and is fit for the purpose of mining project impact assessment (HydroGeoLogic 2015a,b). The BAL2 model formed the quantitative basis for the groundwater assessment component of the 2015 environmental impact statement that resulted in project approval for SSD-5285. It is understood that the MOD1 changes require a groundwater comparative impact assessment (GCIA) to be conducted, with upper and lower range ('end-member') parameter values applied to BAL3.0 simulations, demonstrating that MOD1 groundwater effects are (much) less than the 2015 project approval assessment.

The BAL3.0 model purpose is to provide the quantitative basis for the GCIA by simulating the effects from MOD1 groundwater-affecting activities:

- injection of sand fines ('slimes') into the underground stope voids
- seepage from sand tailings emplaced at surface
- temporal changes to aquifer vertical hydraulic conductivity to represent subsidence due to mining
- groundwater supply pumping from the saline Loxton-Parilla Sands aquifer and the deeper brackish Olney Formation aquifer
- solute transport of PAX solute (potassium amyl xanthate) from tails deposition and fine sands injection.

The BAL3.0 groundwater modelling has been conducted consistent with best practice methods and a Class 2 model confidence level is well justified, confirming its fitness for mining project impact assessment and groundwater management purposes.

2. Model Design and Calibration

The BAL2.0 hydrogeochemically-constrained conceptual hydrogeological model (Jacobs 2015, figure 2.28) has been retained for BAL3.0, along with the numerical model domain, layer structure and boundary conditions from the BAL2 model (Figure 1). These aspects have previously been peer reviewed (Middlemis 2015a,b) and found to be fit for purpose.

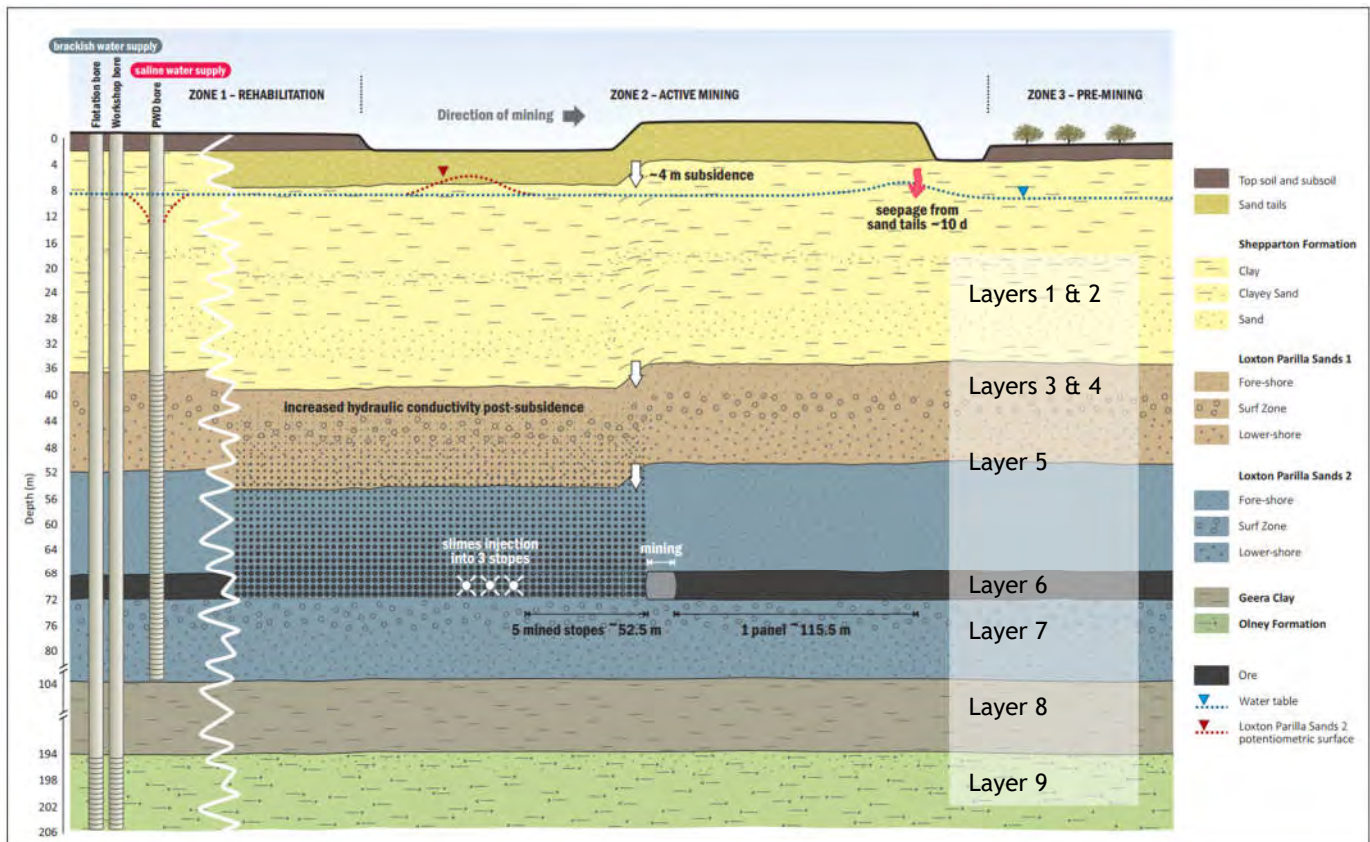


Figure 1 - BAL3.0 conceptual model, with layers indicated schematically (after EMM 2022 Figure 1.3)

The numerical modelling package has been upgraded for BAL3.0, from the Modflow-Surfact used for BAL2 to the latest and industry-leading Modflow-USG (fulfilling a recommendation from the previous peer reviews; Middlemis 2015a,b).

The previous rectangular grid has been upgraded to a well-designed Voronoi polygon mesh with cell sizes of about 1000 m regionally, reducing to 100 m near rivers, 50 m across the lease areas outside the MOD1 area, 10.5 m within the MOD1 area and 0.25 m at abstraction and injection wells used for history-matching. The new mesh allows for the integration within the BAL3.0 model of the previous local scale models at the various test/trial sites (TN5, TN1, LTT, Nanda, Upson Downs, T3), and for the actual pinching out of aquifer layers rather than the 'thin dummy layer' approach applied previously.

The numerical solution parameters were carefully designed in terms of the temporal discretisation for the various tests/trials, including using adaptive time-stepping, to carefully represent the underground mining process, along with the advanced Modflow-USG SMS solver and sub-millimetre head change criteria. The water balance documentation provides evidence of accurate simulations (EMM 2022, section 3.3). The calibrated aquifer parameter values are consistent with the known regional property values and the values from the site-specific testing conducted since 2009 (Jacobs 2015; EMM 2022).

The previous SRTM topography dataset has been updated with more accurate LiDAR data and a 5 metre DEM that was re-sampled directly at the model nodes. This significantly improves the simulation of dynamic surface-groundwater interactions (eg. depth-dependent evapotranspiration, river-aquifer exchanges).

The BAL3.0 steady state model calibration performance was benchmarked to the BAL2 model in terms of the scaled RMS value (11.3% for BAL3.0 and 11.2% for BAL2; EMM 2022, Figure 3.6). It is noted that the steady state calibration is designed simply to establish the initial conditions for the transient simulations.

Although the steady state calibration scaled RMS value slightly exceeds the nominal 10% criterion (Barnett et al. 2012), the steady state performance is acceptable for the stated purpose (noting also that the transient calibration scaled RMS performance is less than the preferred 5% criterion).

The BAL3.0 transient model calibration to data at the various test/trial site data (TN5, TN1, LTT, Nanda, Upson Downs) is very similar to that for BAL2 (EMM 2022, Table 3.1). The time series matches are also very similar to BAL2, improved in some cases, although poor matches apply to data from some pumping or injection bores, which is a common model limitation and the justifications provided are adequately explained. The transient calibration has a justified emphasis on matching later time data from the T3

The T3 trial of the innovative directional borehole underground mining method in 2020 provided site-specific data on groundwater responses and associated subsidence effects expected for MOD1, including the injection of fine sands to underground stopes and seepage from sand tails at the surface. This has allowed calibration of the BAL3.0 time-varying materials (TVM) changes, notably increased vertical hydraulic conductivity for LPS in layers 4 and 5 (see EMM 2022, Table 3.3), and confirmation of the model fitness for purpose and performance for MOD1 effects. There is reportedly no evidence of change to the horizontal hydraulic conductivity parameters due to the mining process and the associated injection of fine sands to the underground stopes. For the T3 trial, the BAL3.0 transient model scaled RMS is 4.5% (EMM 2022, Table 3.1), with mostly very good time series matches. Some early time data from the T3 test was reasonably removed from the calibration assessment at some bores, because the T3 test procedure had not yet achieved the reliable methods of ensuring pressure-neutral conditions that were subsequently assured.

These improvements mean that the BAL3.0 model is now suitable for regional and local scale investigations of traditional mining or innovative underground mining effects, with greatly improved run times that will facilitate efficient uncertainty analysis. Overall, the model calibration performance is sound and the BAL3.0 model is fit for the intended purposes.

3. Solute Transport and End-member Sensitivity Analysis

The BAL3.0 base case predictions (indicative of ‘most likely’ effects) have a focus on the propagation of piezometric levels (drawdown and mounding), and comparison with the previous BAL2 assessment (ie. as required for the MOD1 groundwater comparative impact assessment). This is supported by the solute transport simulations of PAX migration associated with seepage from the sand tails deposited at the surface and the sand fines injected to the underground stopes. The key solute transport parameters were adequately justified in terms of the first order decay half-life (12 weeks), dispersivity (100m horizontal and 10m vertical) and porosity (15%).

Predictive uncertainty was evaluated via alternative parameter or ‘alt-par’ simulations that applied end-member values to represent high throughput (alt par 1) and low throughput (alt par 2), where throughput refers to dewatering and injection, and with a third very conservative scenario of solute transport without first-order decay. The report adequately justifies the base case and the three extreme ‘alt-par’ scenarios as providing predictions that bookend the MOD1 effects in terms of the comparative groundwater impact assessment, consistent with recent guidance on uncertainty analysis (Middlemis and Peeters, 2018). The qualitative uncertainty analysis narrative (EMM 2022, sections 4.2, 4.3.2) is also insightful.

The prediction scenarios show a small-range variability in results, and comparatively much less than the previous BAL2 impact assessment (Jacobs 2015).

4. Model Confidence Level Classification

The AGMG sets out a model confidence classification schema that aims to describe the resources applied to the modelling and accordingly evaluate the degree of confidence in model predictions. The evaluation is based on considerations of the hydrogeological conceptual model and the data available, especially aquifer responses to hydrological stresses, as well as the model design, construction and performance. It is expected that any model will have attributes that fall into more than one ‘class’, with the overall ‘confidence level’ indicated from the weight of criteria that are met.

This review conducted an independent assessment of the model confidence level, consistent with the AGMG and applying the refinements outlined in the IESC uncertainty guidance (Middlemis and Peeters 2018). A Class 2 model confidence level is well justified, confirming its fitness for purpose.

Yours sincerely,

HydroGeoLogic Pty Ltd



Hugh Middlemis

(Principal Groundwater Engineer)

5. References

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- Middlemis H. (2015b). Balranald Project Groundwater Model Review (BAL2.1, May 2015). Prepared for Iluka Resources Limited.
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- Middlemis H, Merrick N, Ross J, and Rozlapa K. (2001). Groundwater Flow Modelling Guideline. Prepared for Murray–Darling Basin Commission by Aquaterra, January 2001. www.mdba.gov.au/sites/default/files/archived/mdbc-GW-reports/2175_GW_flow_modelling_guideline.pdf

6. Declaration

For the record, the reviewer, Hugh Middlemis, is an independent modelling specialist with a bachelor degree in engineering and a masters in hydrogeology, and more than 40 years' Australian and international experience. Hugh established HydroGeoLogic as an independent consultancy in 2013, with core business including independent peer reviews for government and catchment management authorities, mining companies and consulting firms, and contributing to expert panels and providing expert witness services.

Hugh was principal author of the first Australian groundwater modelling guidelines (Middlemis et al. 2001) that formed the basis for the latest guidelines (Barnett et al. 2012) and was awarded a Churchill Fellowship in 2004 to benchmark groundwater modelling best practice. He is principal author on two guidance reports on modelling uncertainty (Middlemis and Peeters 2018 (update in prep. 2022); and Middlemis et al. 2019).

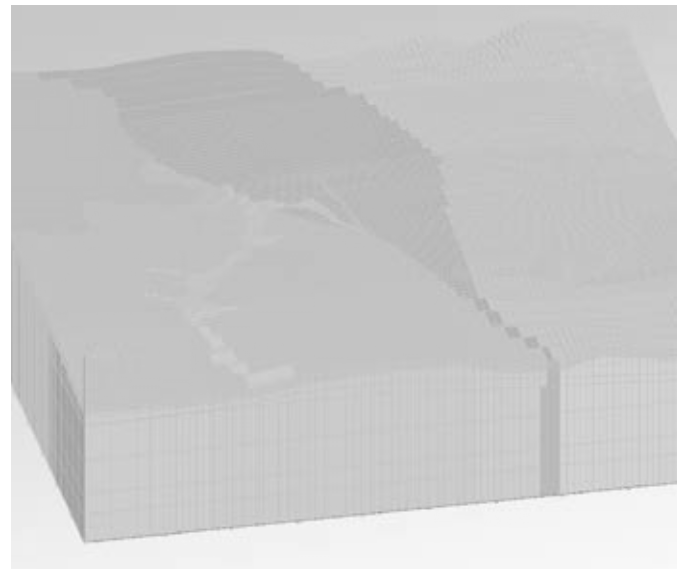
We assert no conflict of interest in relation to this work. The peer reviewer, Hugh Middlemis, has not worked directly on the Balranald Mineral Sands Project, nor for Iluka Resources, nor for EMM Consulting, other than as an independent reviewer.

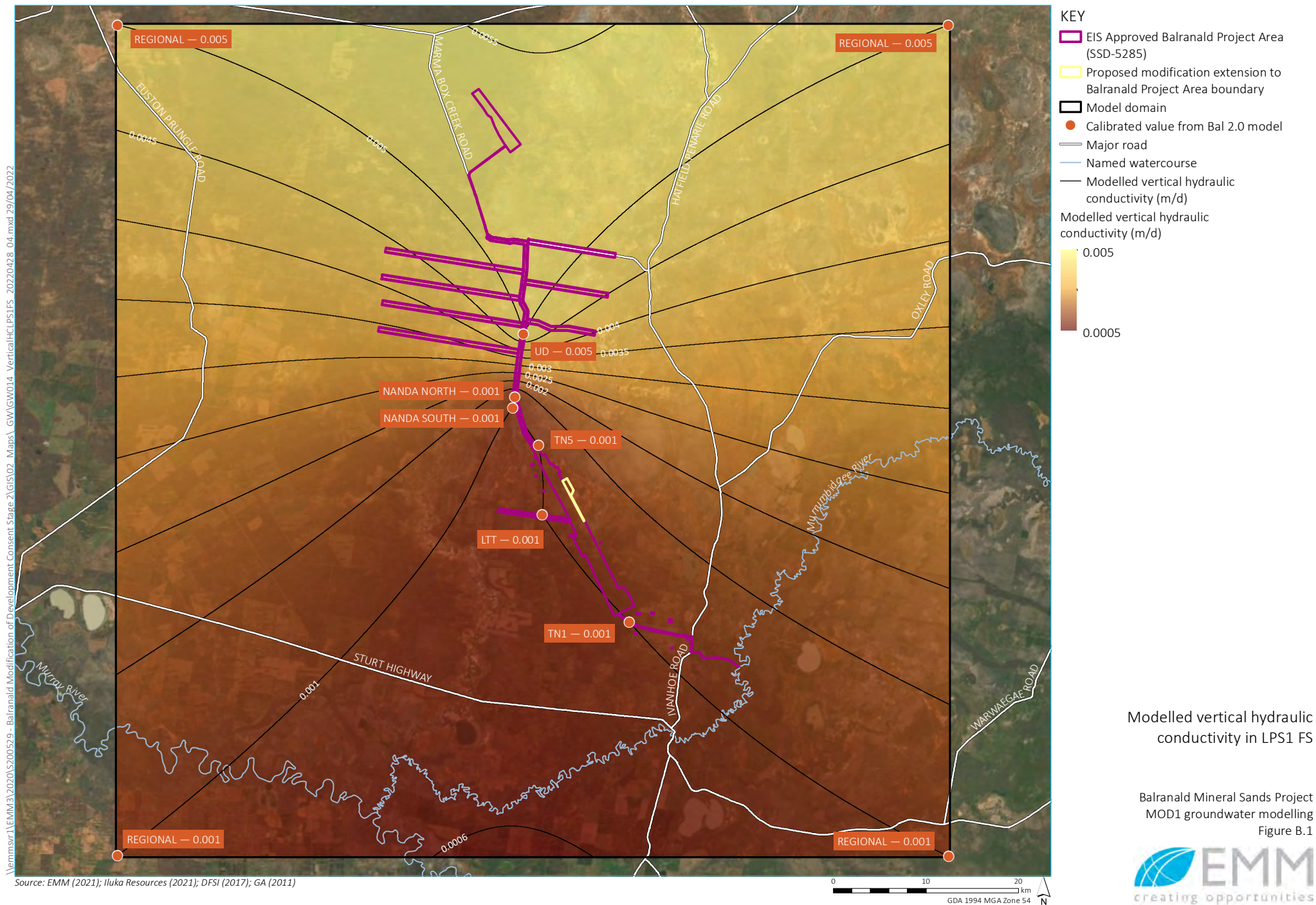
We note that the peer reviewer's son (Roger Middlemis) has worked for EMM Consulting since March 2019 as an environmental engineer in their Adelaide office, and we understand that he did contribute to the groundwater modelling and reporting tasks.



Appendix B

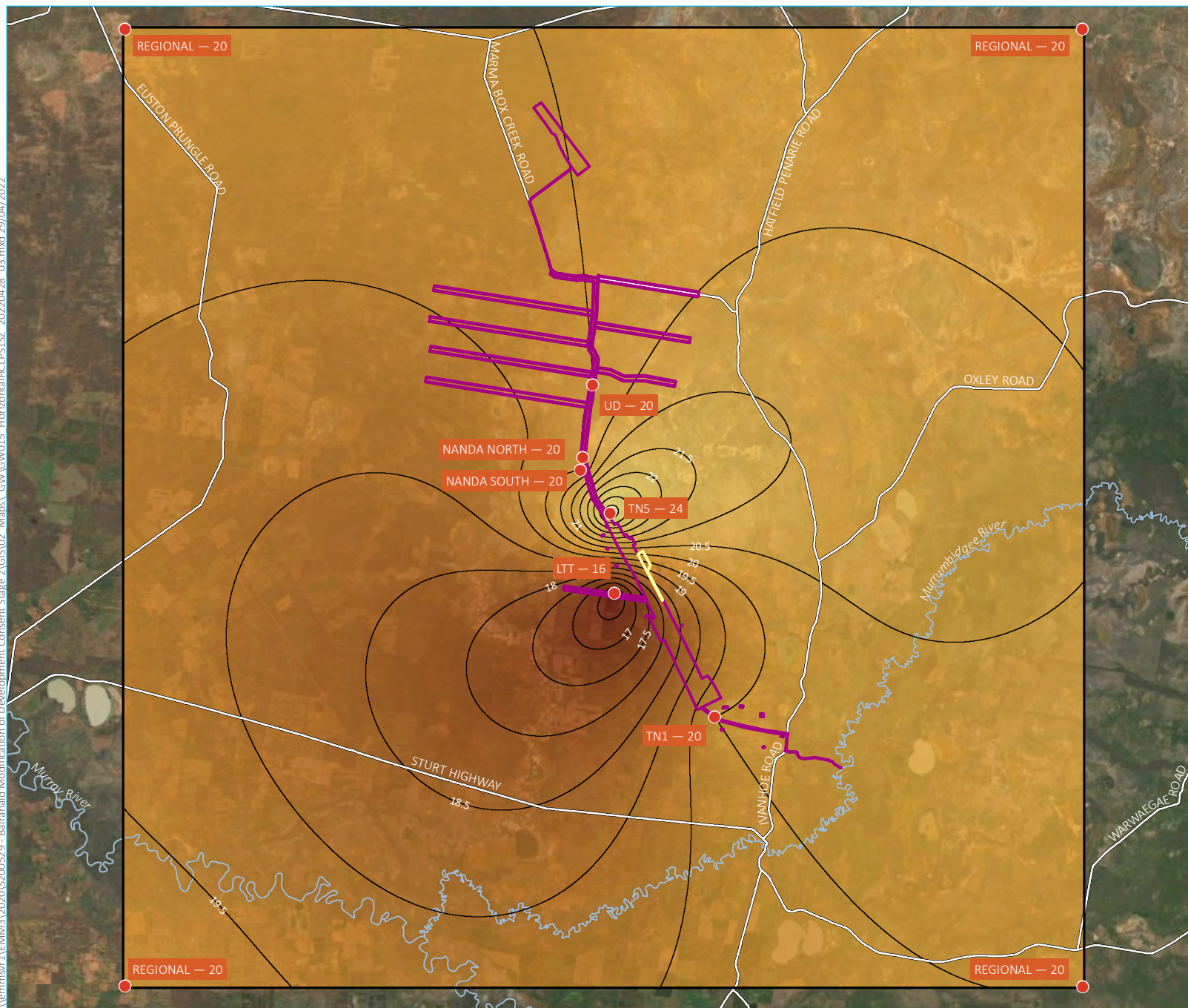
Modelled hydraulic property distributions





Source: EMM (2021); Iluka Resources (2021); DFSI (2017); GA (2011)

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- KEY**
- EIS Approved Balranald Project Area (SSD-5285)
 - Proposed modification extension to Balranald Project Area boundary
 - Model domain
 - Calibrated value from Bal 2.0 model
 - Major road
 - Named watercourse
 - Modelled vertical hydraulic conductivity (m/d)
 - Modelled horizontal hydraulic conductivity (m/d)

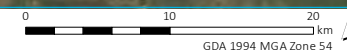


Modelled horizontal hydraulic conductivity in LPS1 SZ

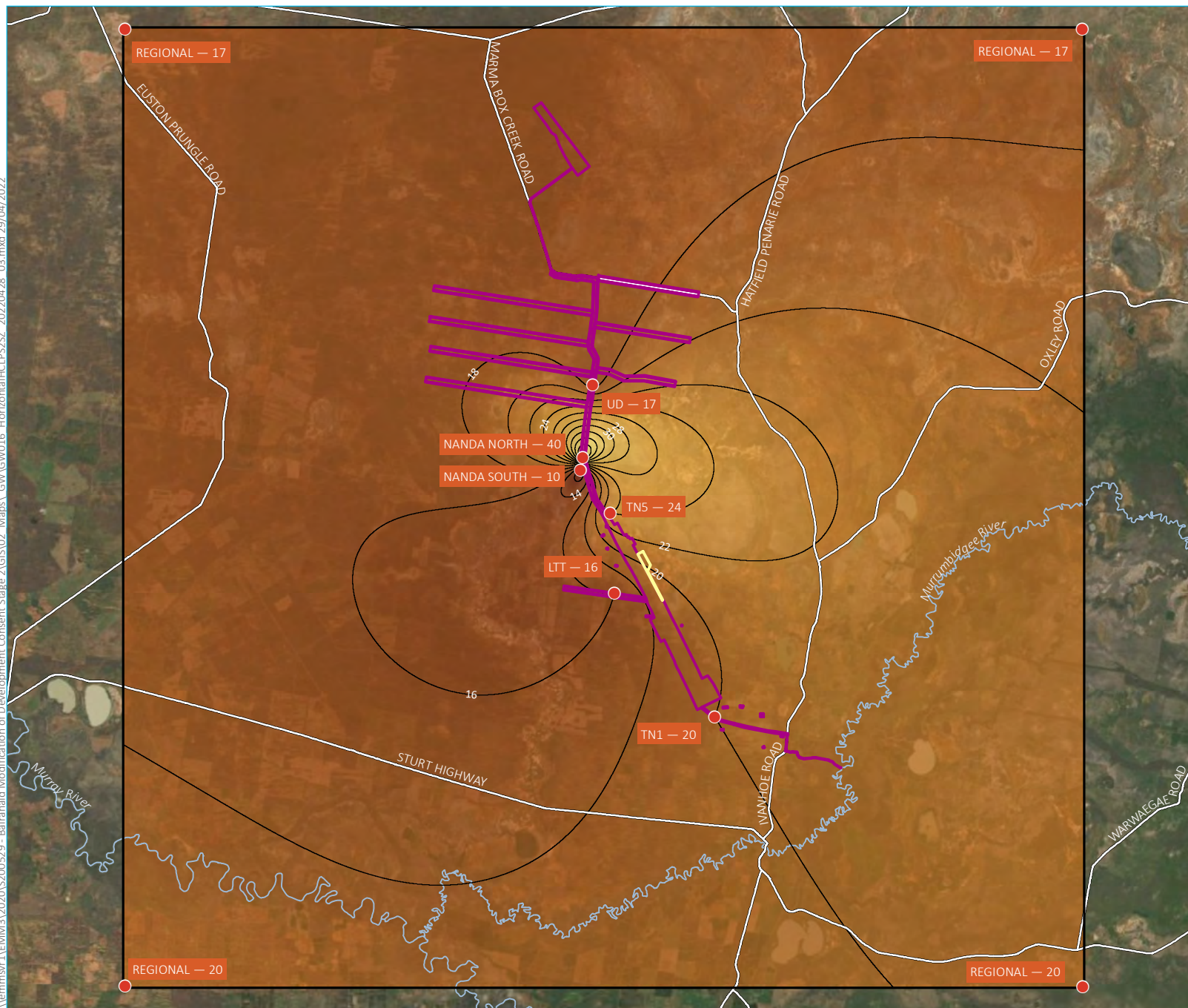
Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure B.2



Source: EMM (2021); Iluka Resources (2021); DFSI (2017); GA (2011)



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- KEY**
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 - Proposed modification extension to Balranald Project Area boundary
 - Model domain
 - Calibrated value from Bal 2.0 model
 - Major road
 - Named watercourse
 - Modelled vertical hydraulic conductivity (m/d)
 - Modelled horizontal hydraulic conductivity (m/d)

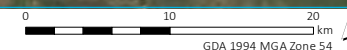


Modelled horizontal hydraulic conductivity in LPS2 SZ

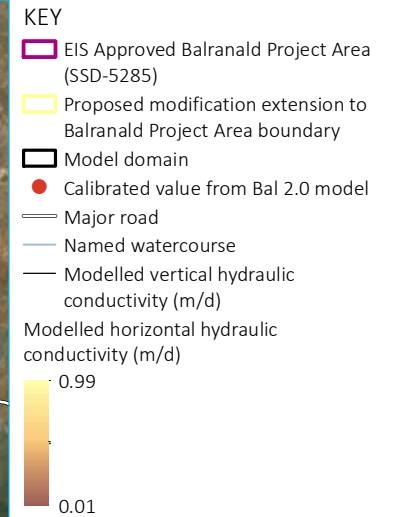
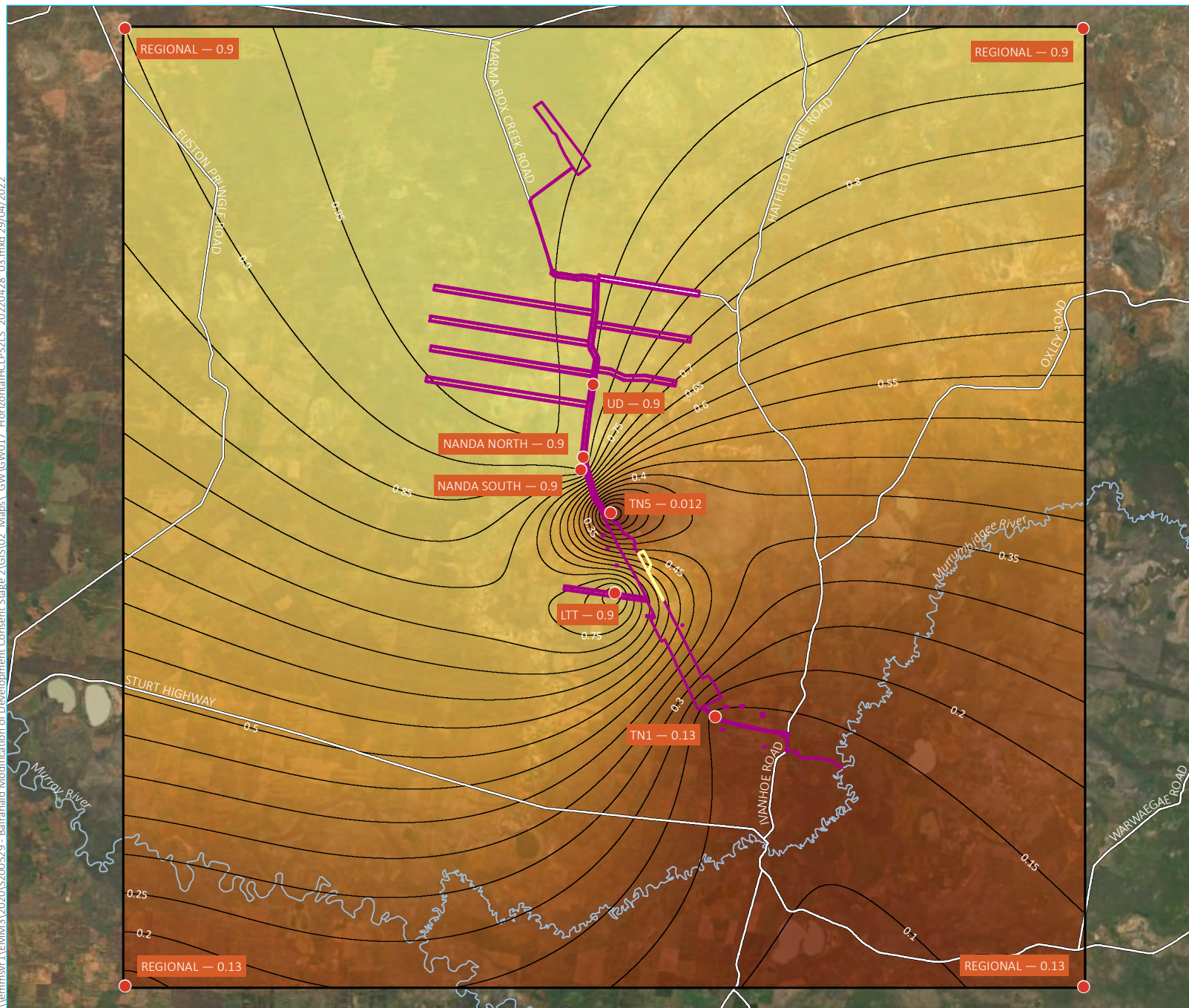
Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure B.3



Source: EMM (2021); Iluka Resources (2021); DFSI (2017); GA (2011)



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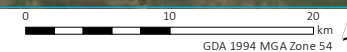


Modelled horizontal hydraulic conductivity in LPS2 LS

Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure B.4



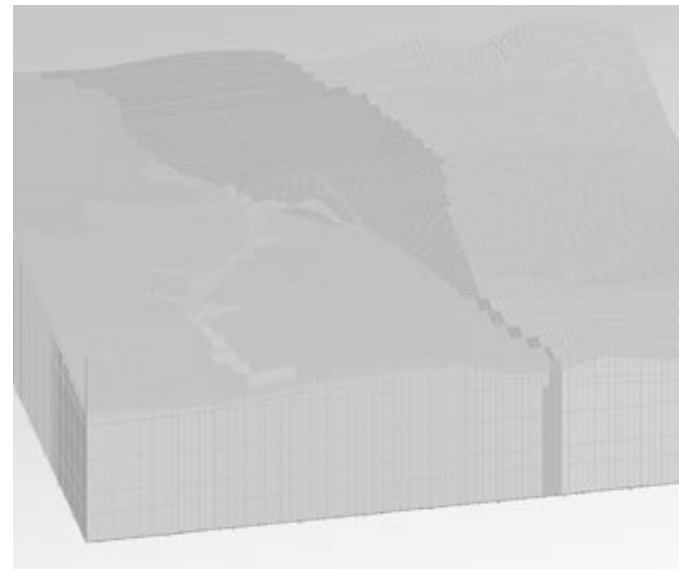
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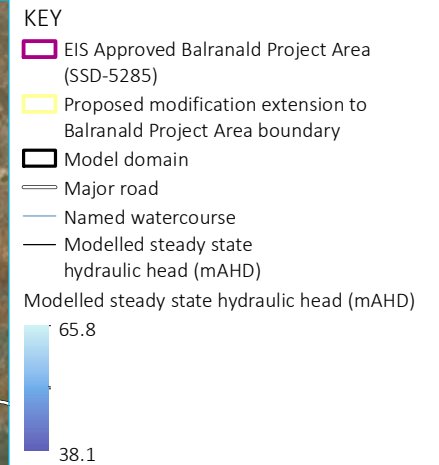
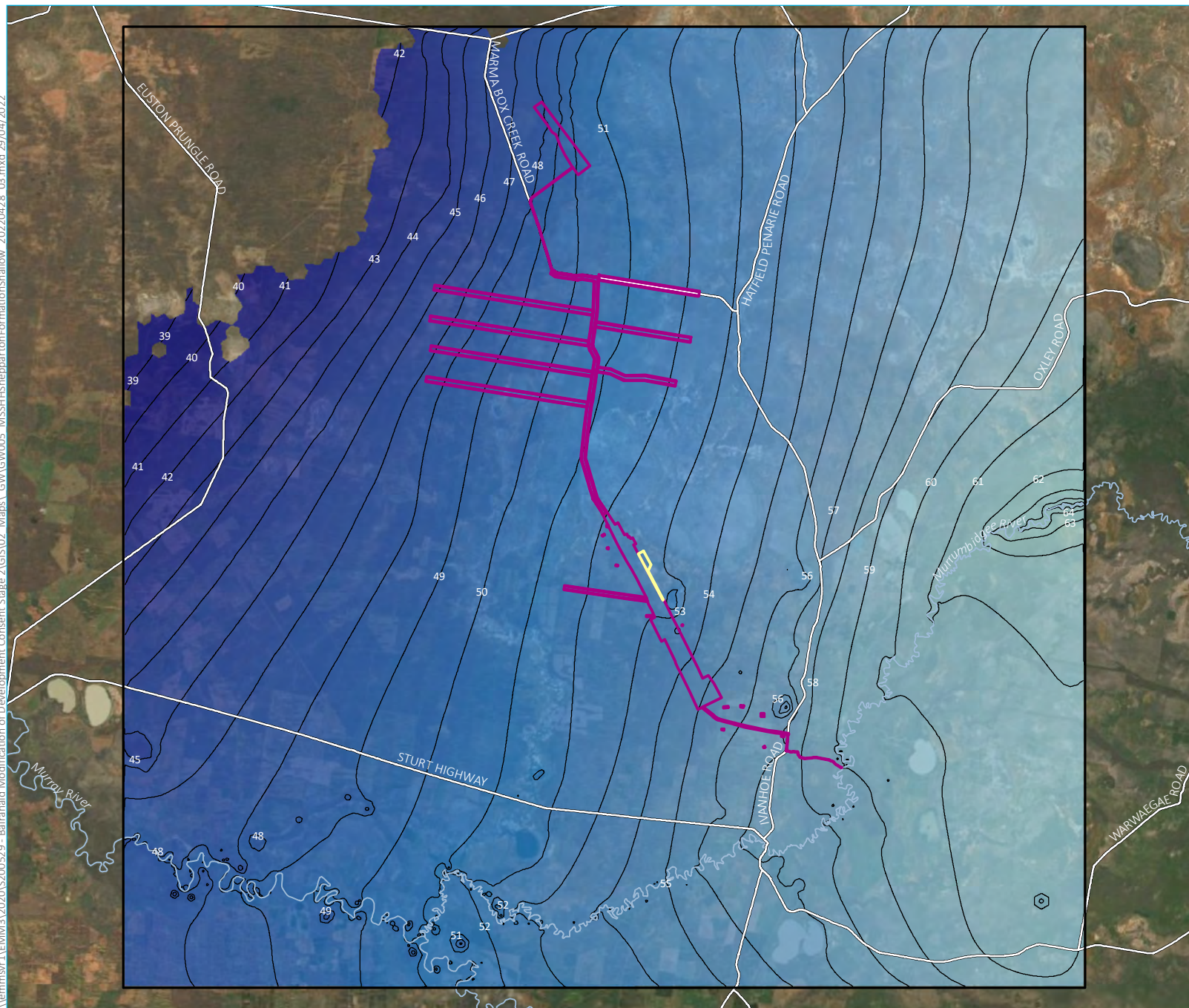


Appendix C

Modelled steady state hydraulic head distribution



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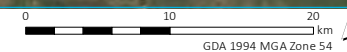


Modelled steady state hydraulic head in the Shepparton Formation (shallow)

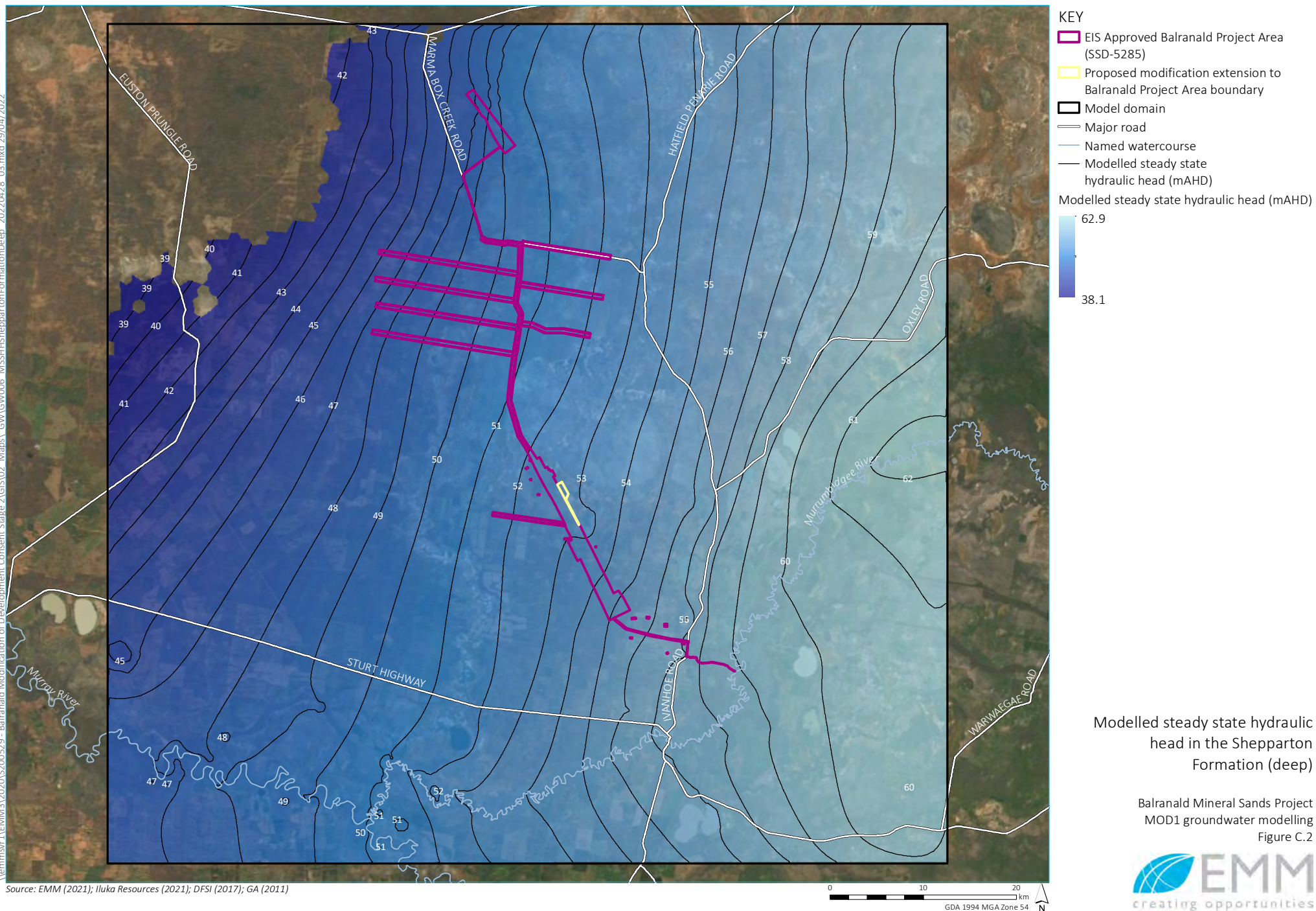
Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure C.1



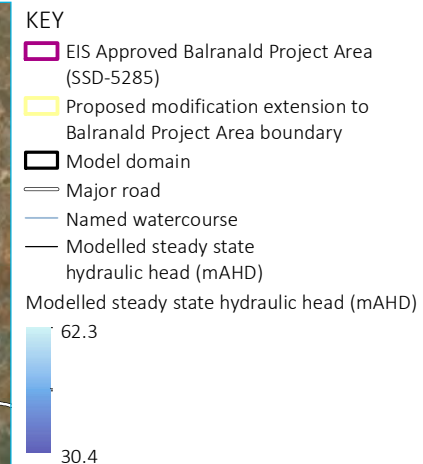
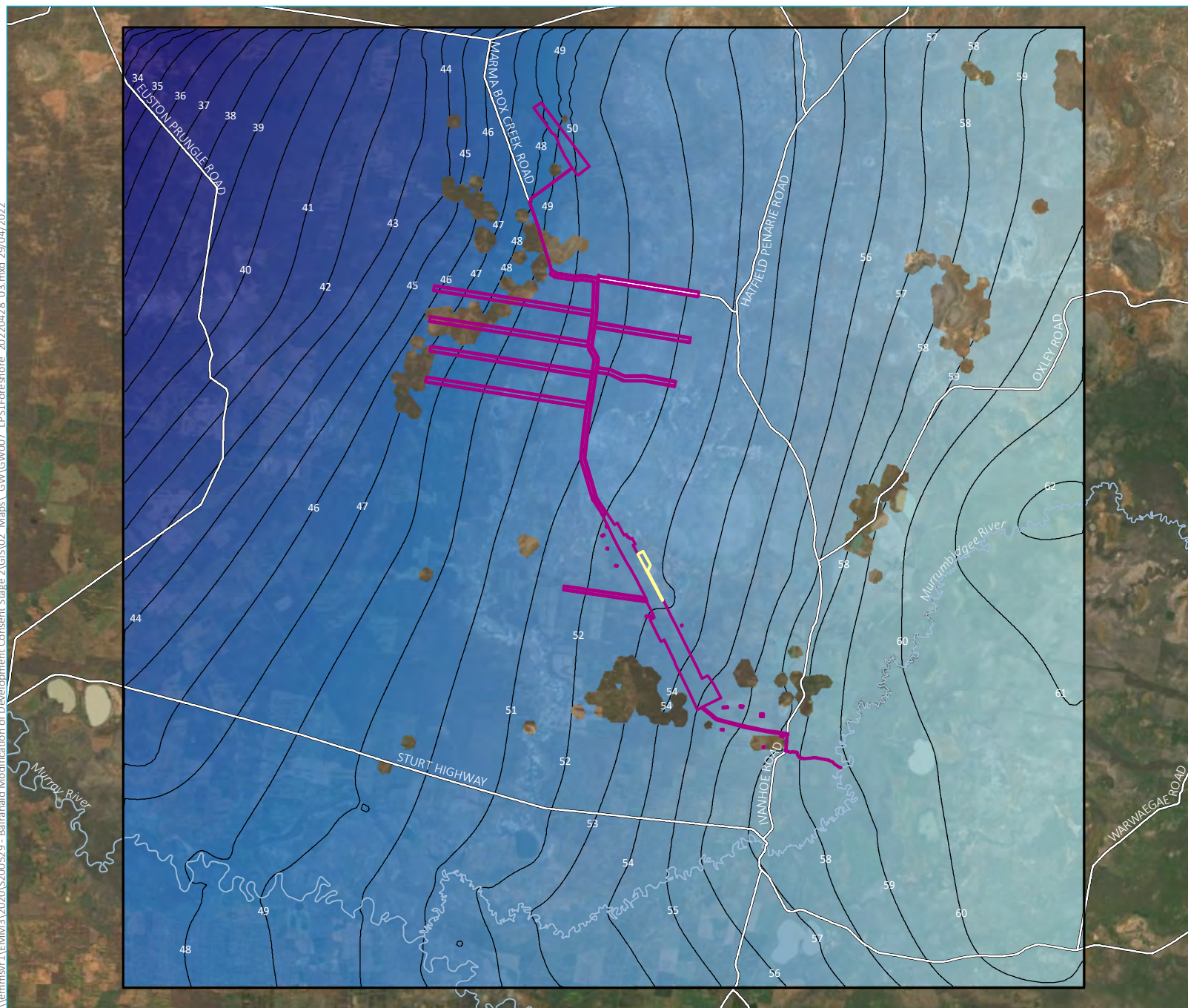
Source: EMM (2021); Iluka Resources (2021); DFSI (2017); GA (2011)



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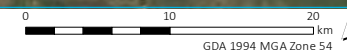


Modelled steady state hydraulic head in LPS1 foreshore

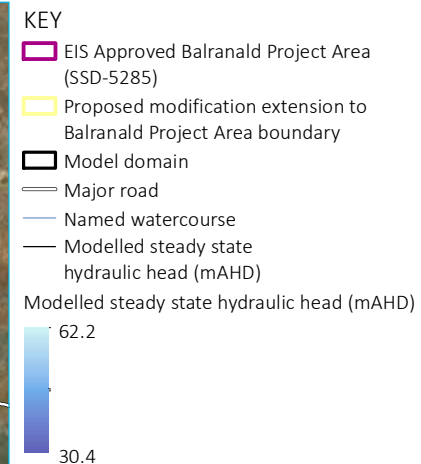
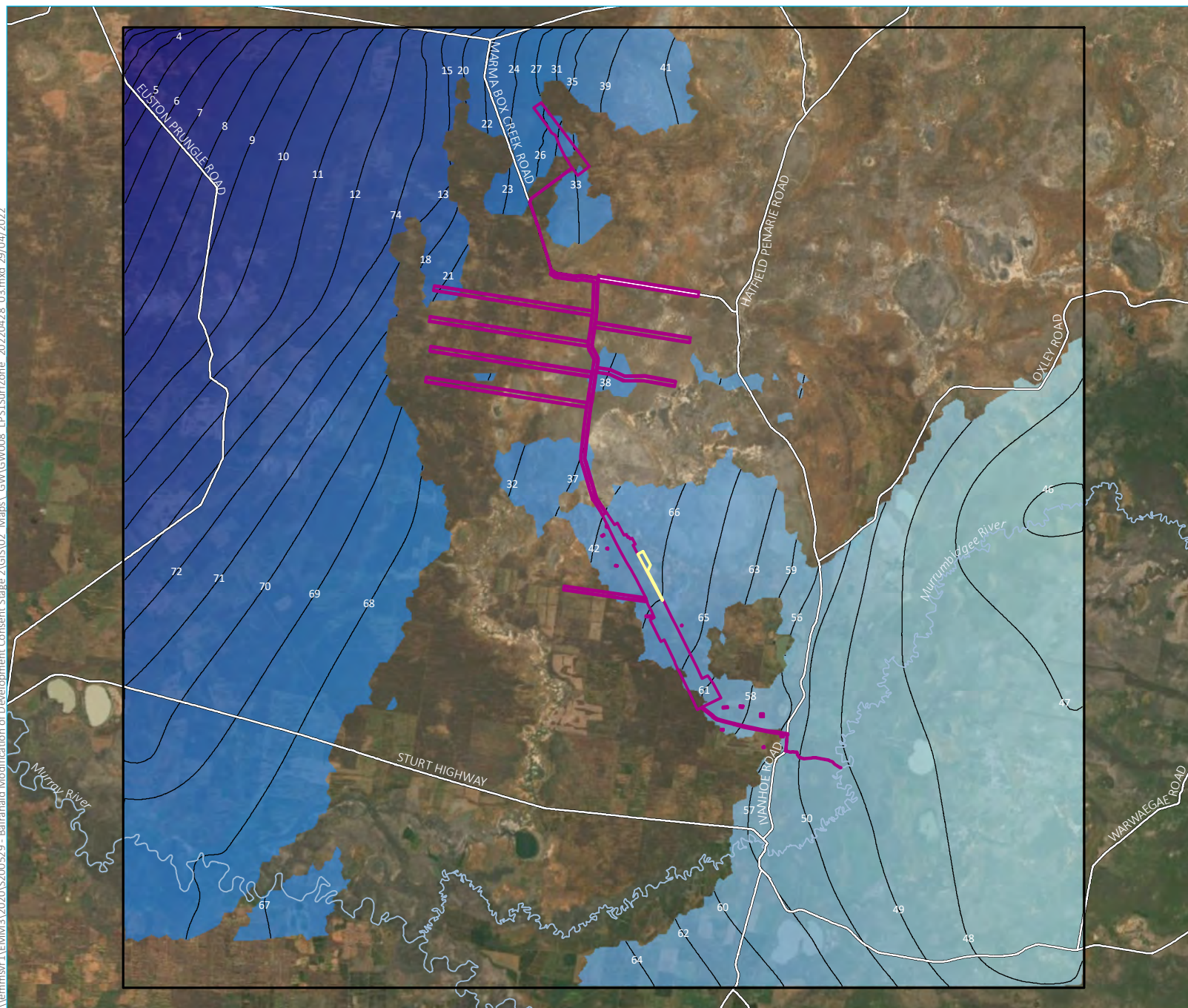
Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure C.3



Source: EMM (2021); Iluka Resources (2021); DFSI (2017); GA (2011)



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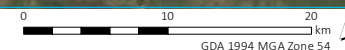


Modelled steady state hydraulic head in LPS1 surf zone

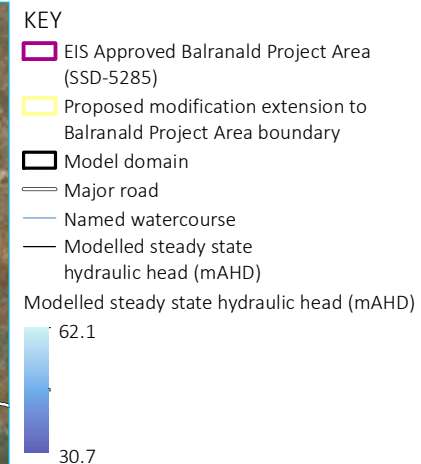
Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure C.4



Source: EMM (2021); Iluka Resources (2021); DFSI (2017); GA (2011)



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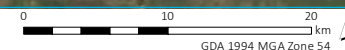


Modelled steady state
hydraulic head in LPS1 lower
shore / LPS2 foreshore

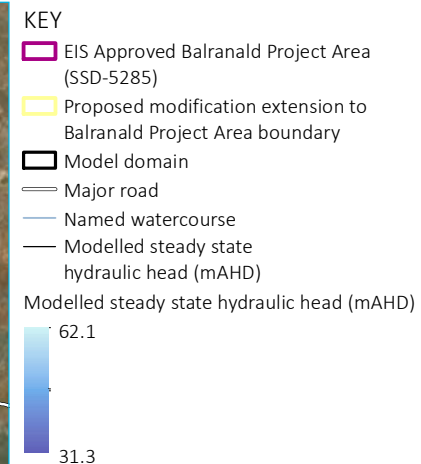
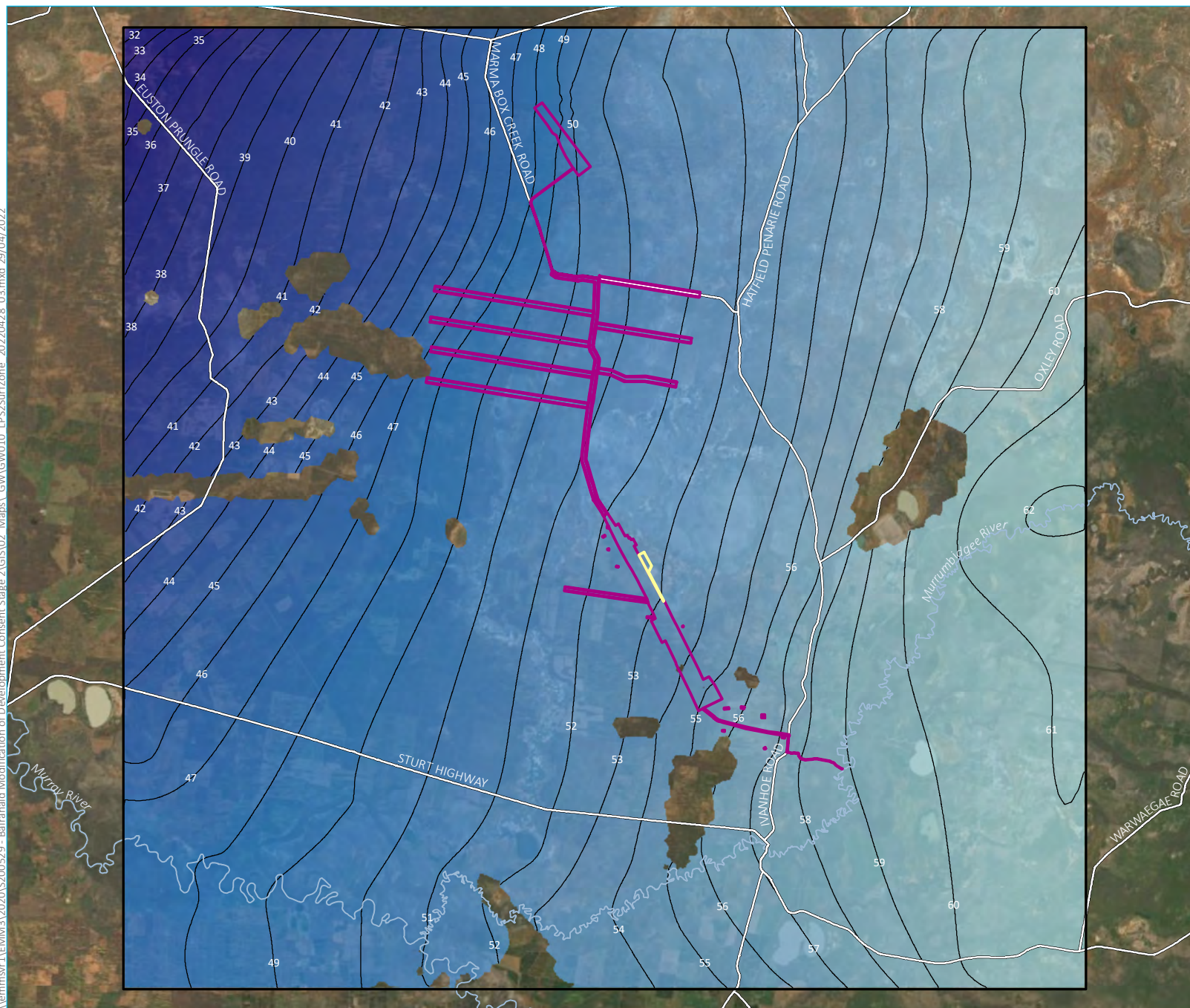
Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure C.5



Source: EMM (2021); Iluka Resources (2021); DFSI (2017); GA (2011)



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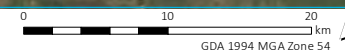


Modelled steady state hydraulic head in LPS2 surf zone

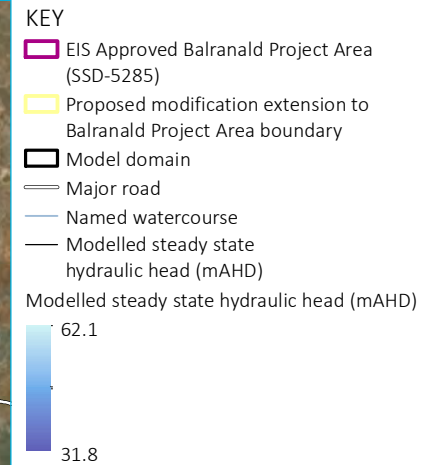
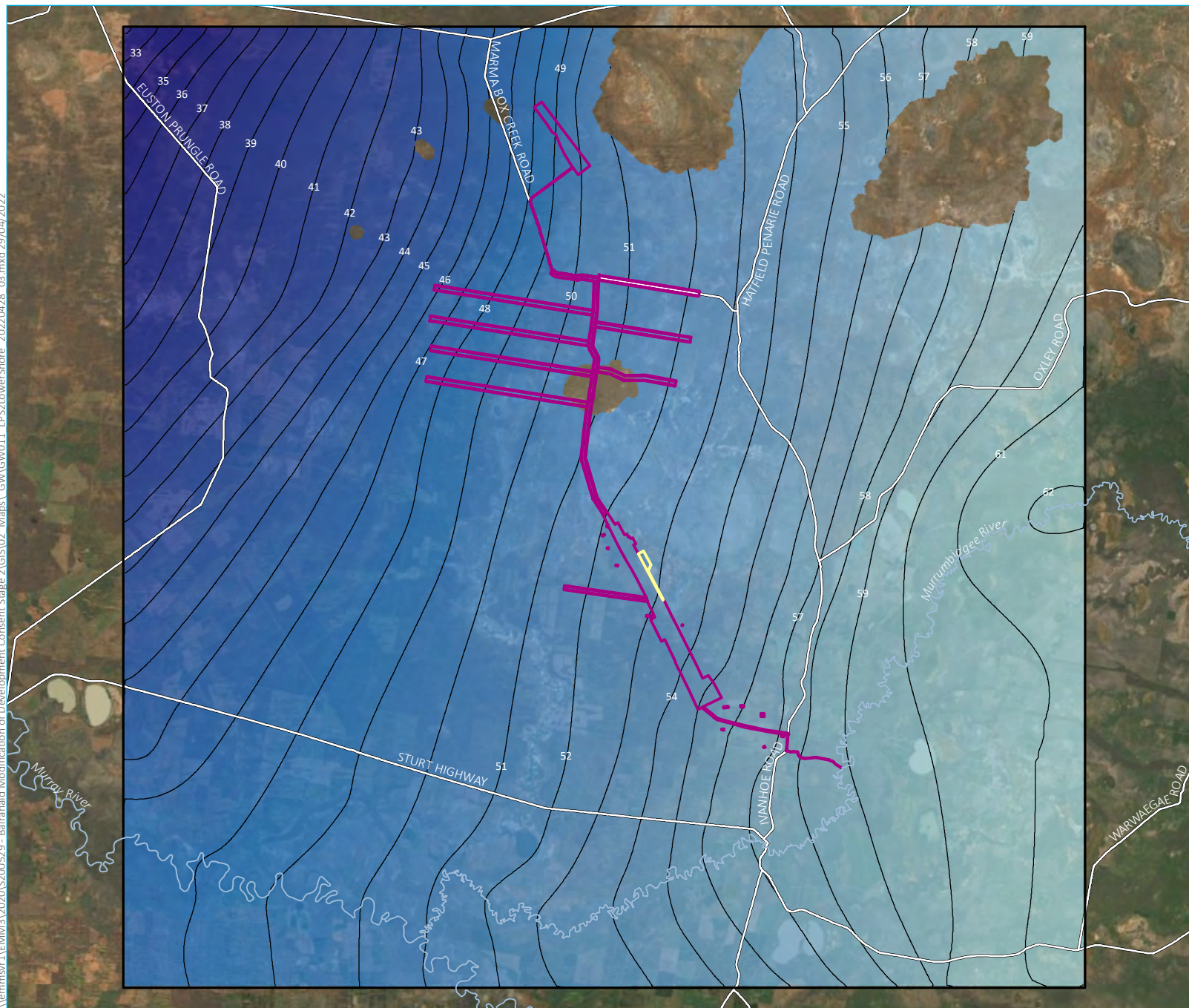
Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure C.6



Source: EMM (2021); Iluka Resources (2021); DFSI (2017); GA (2011)



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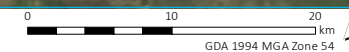


Modelled steady state hydraulic head in LPS2 lower shore

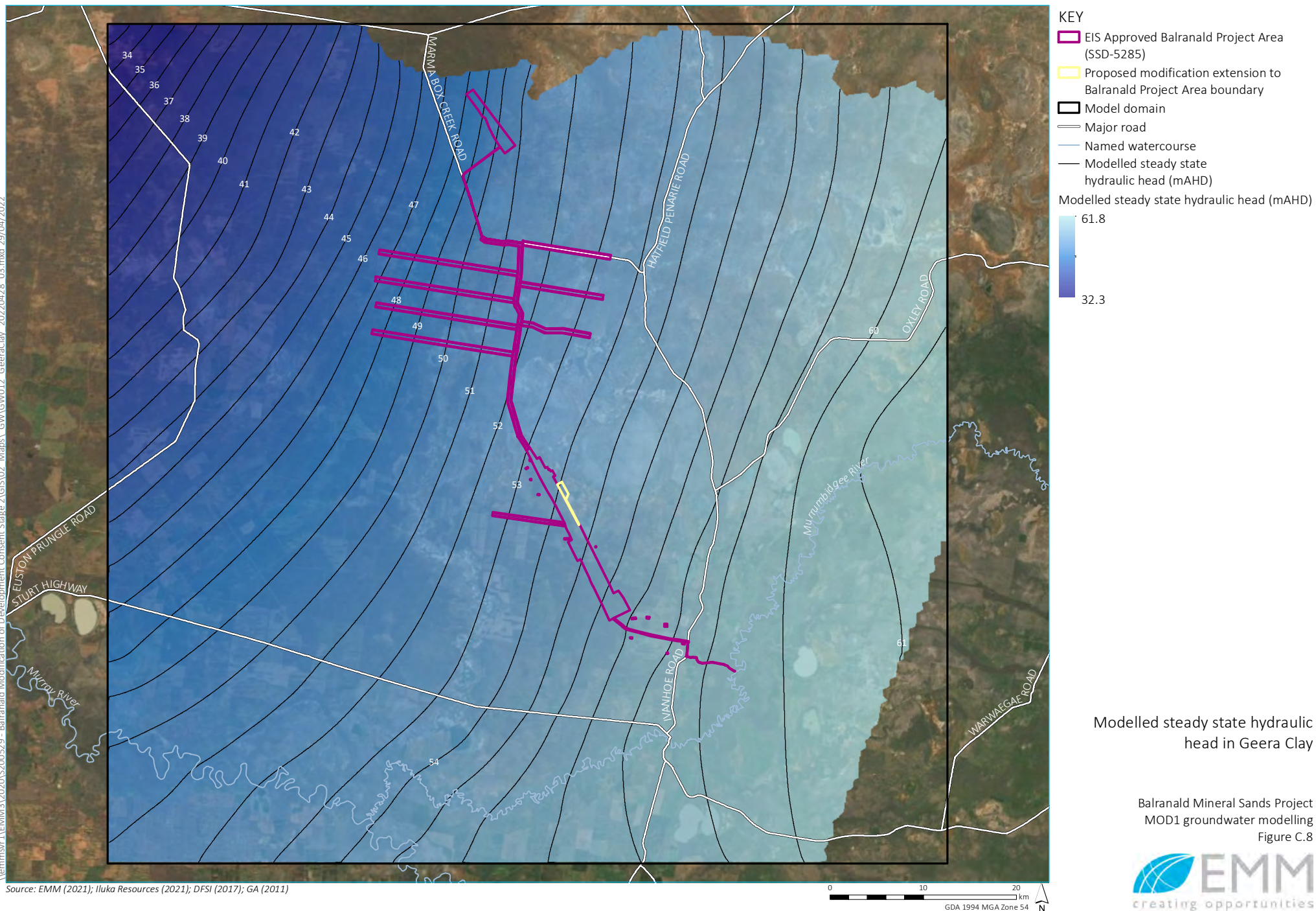
Balranald Mineral Sands Project
MOD1 groundwater modelling
Figure C.7



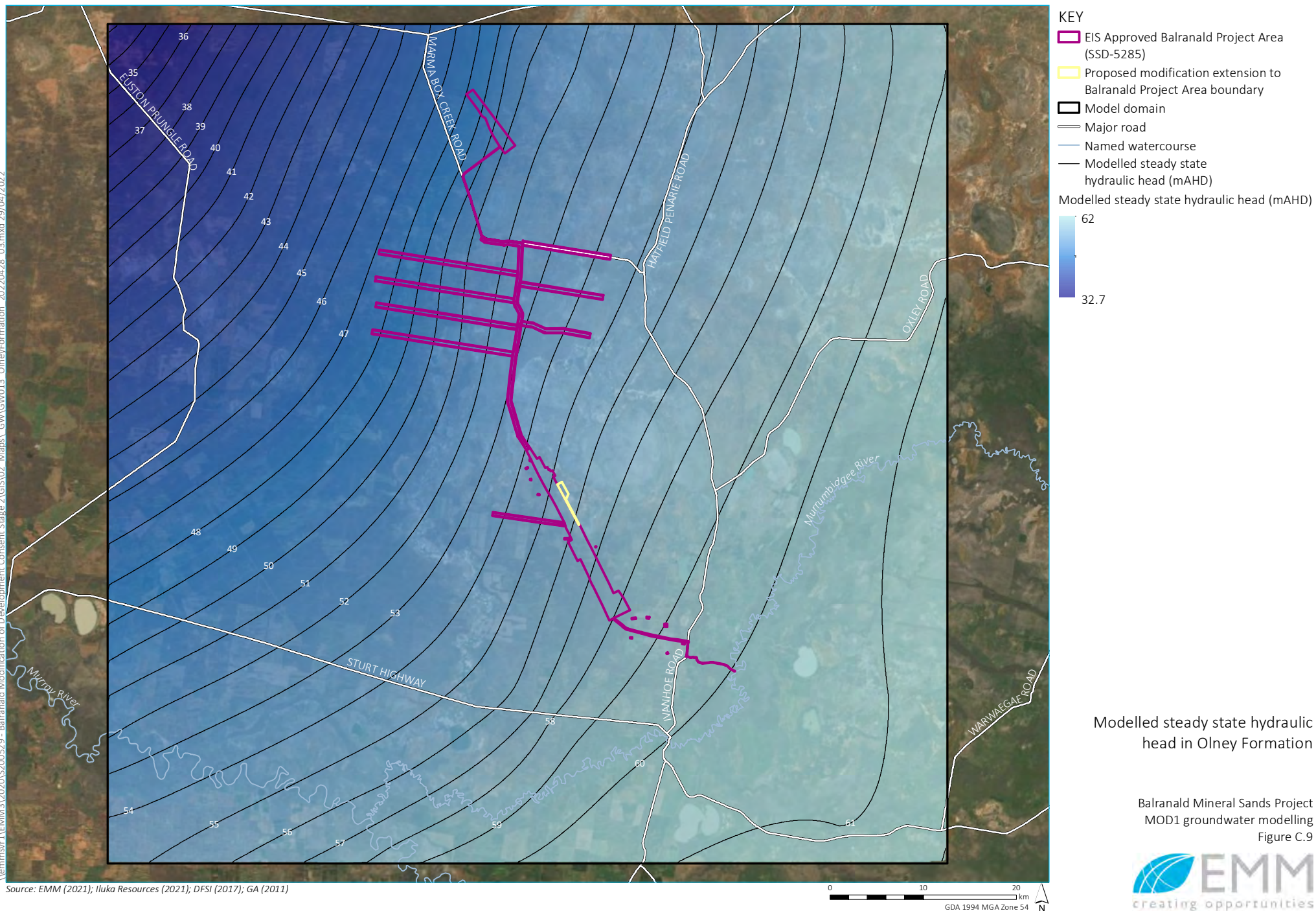
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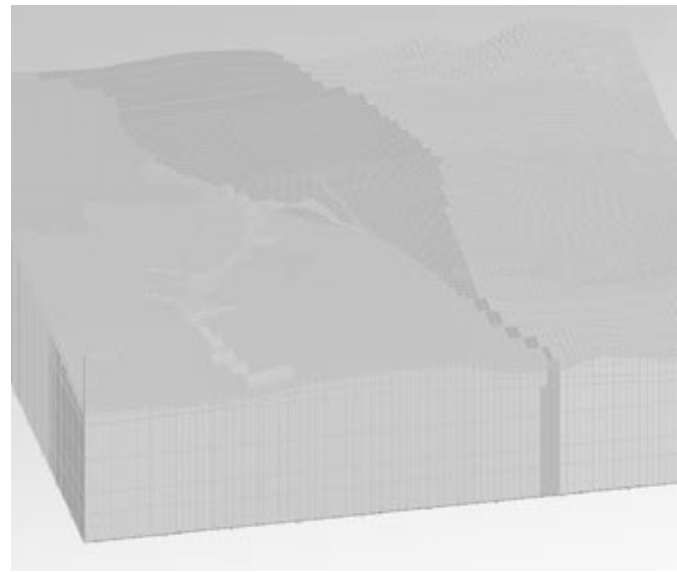
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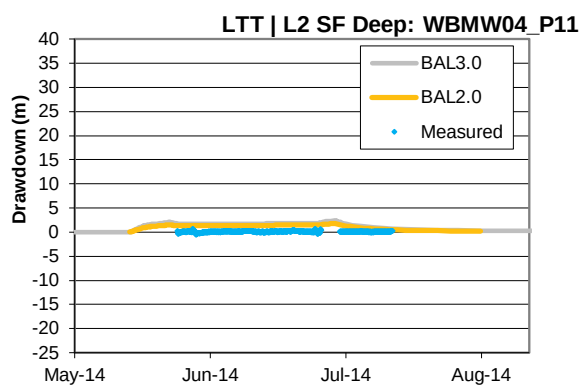
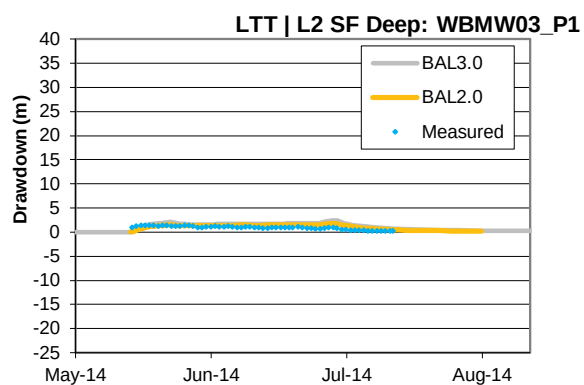
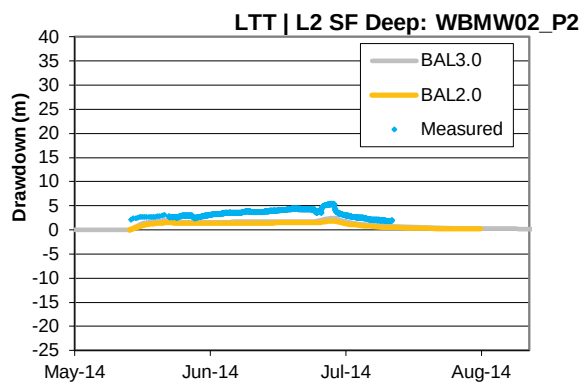
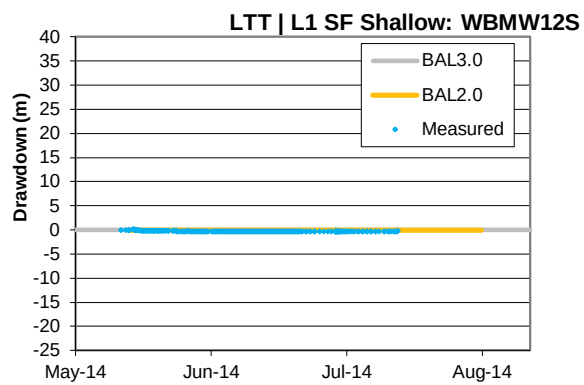
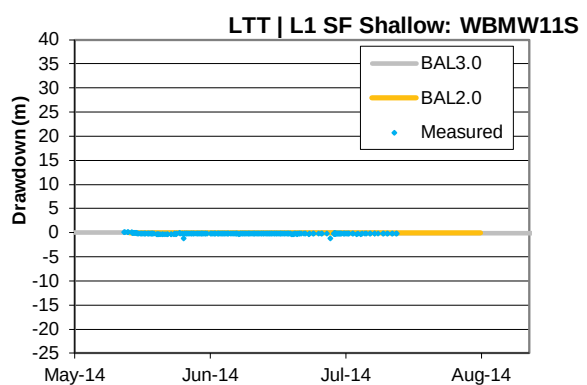
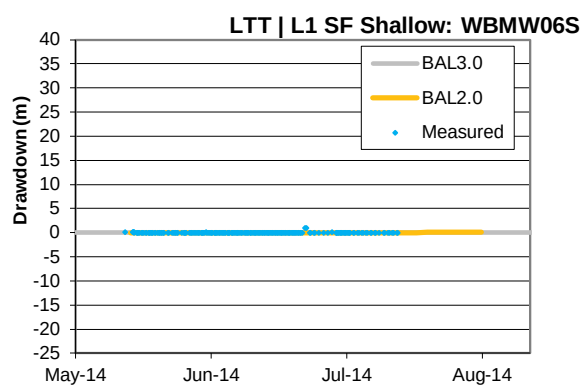
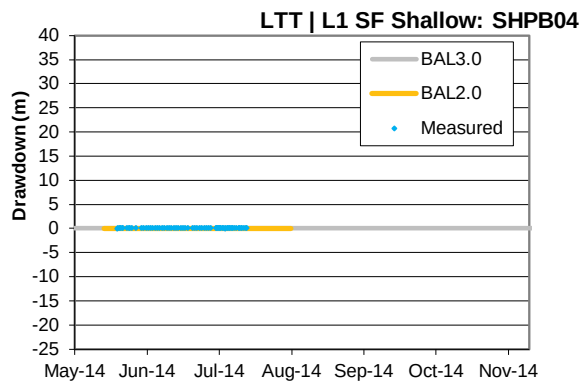
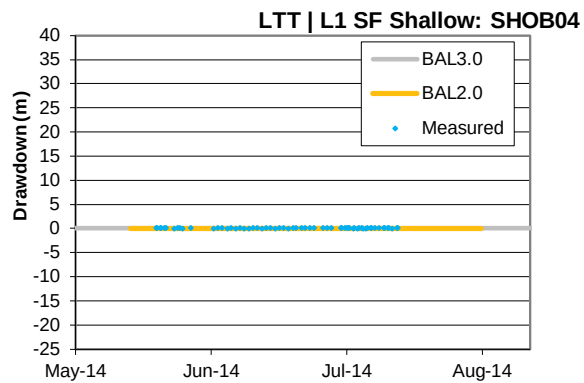


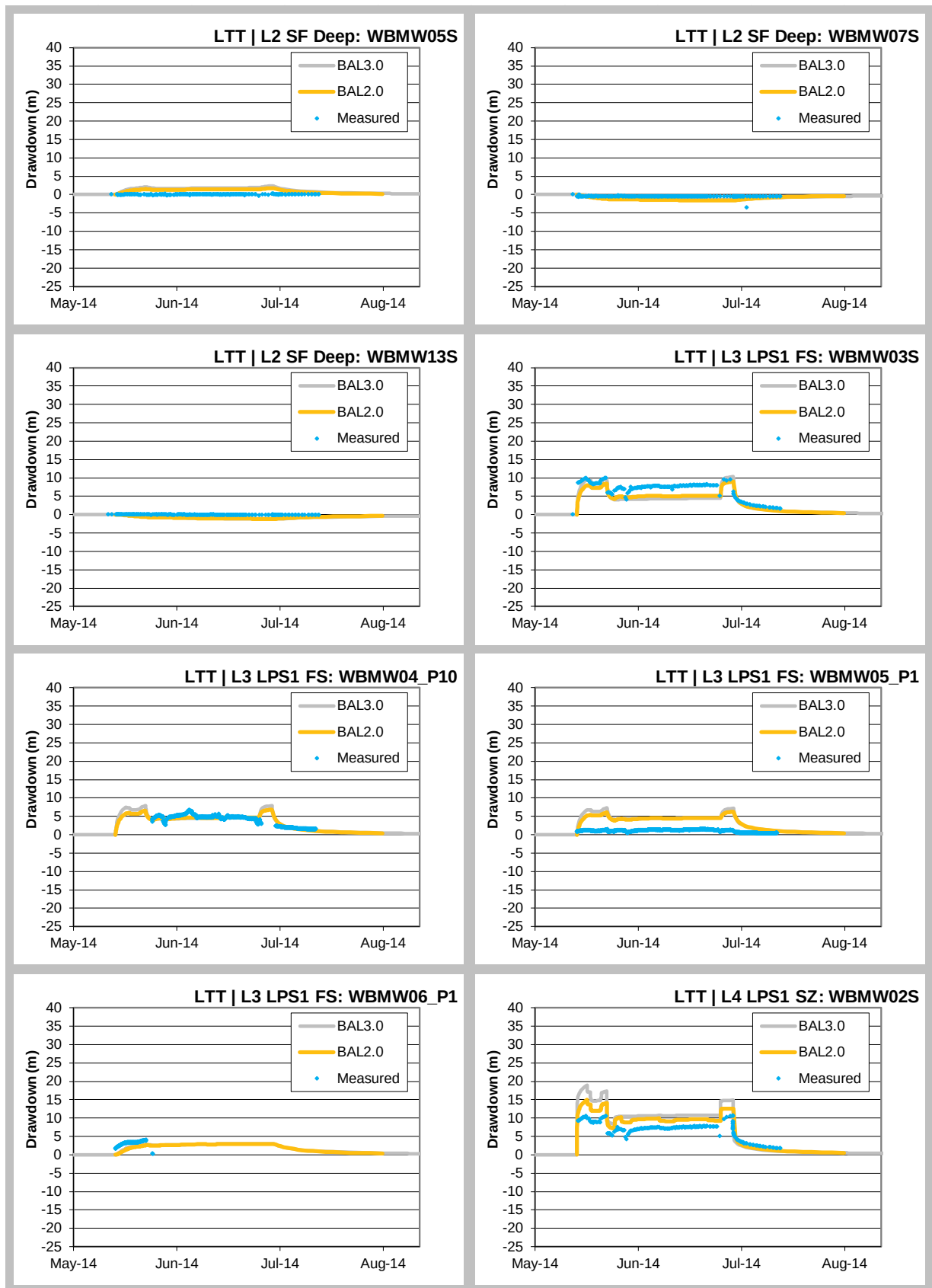
Appendix D

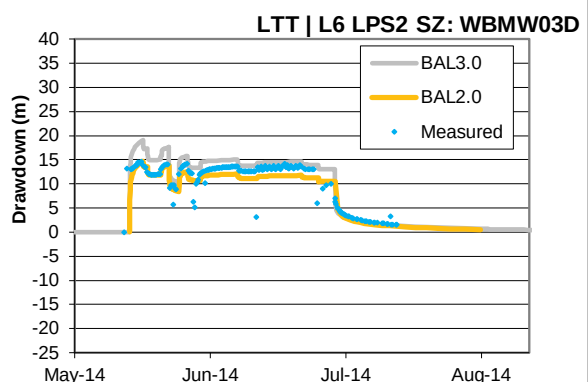
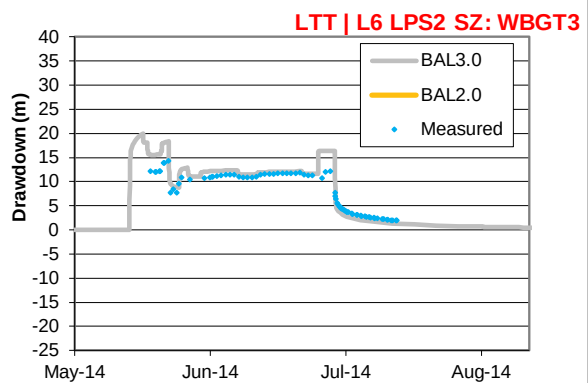
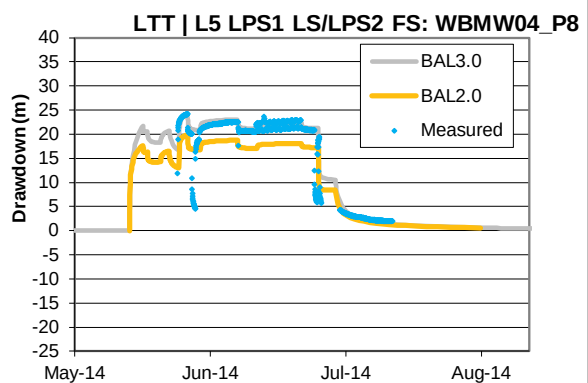
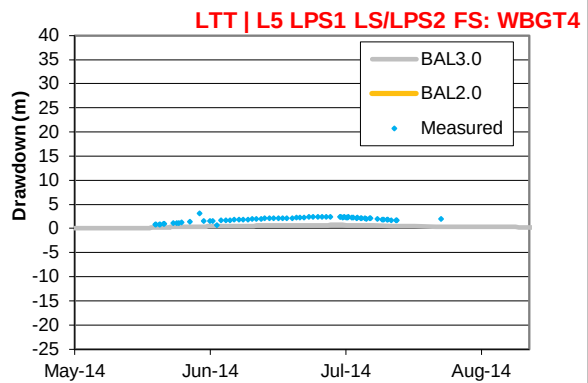
Hydrographs: history matching

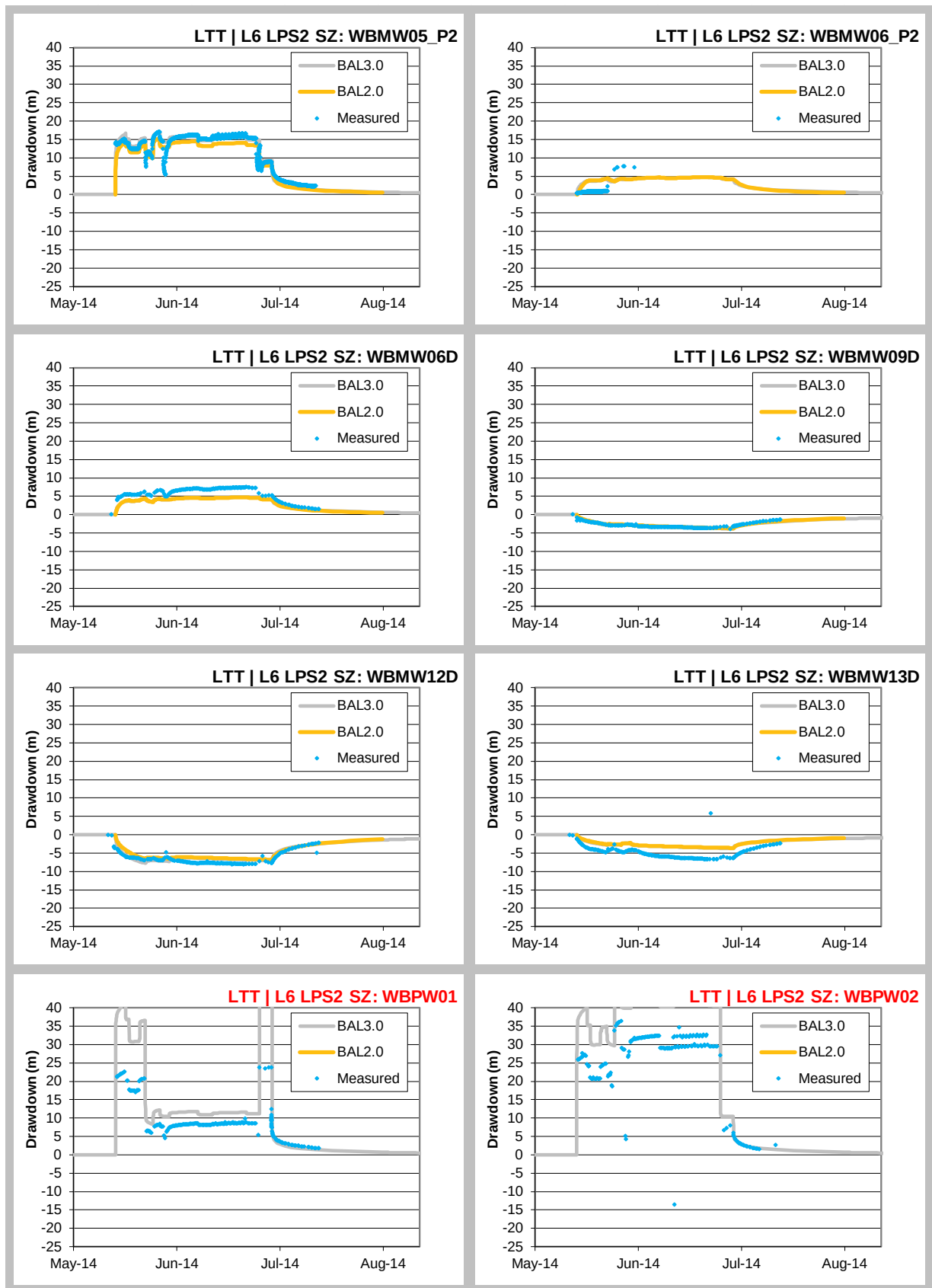


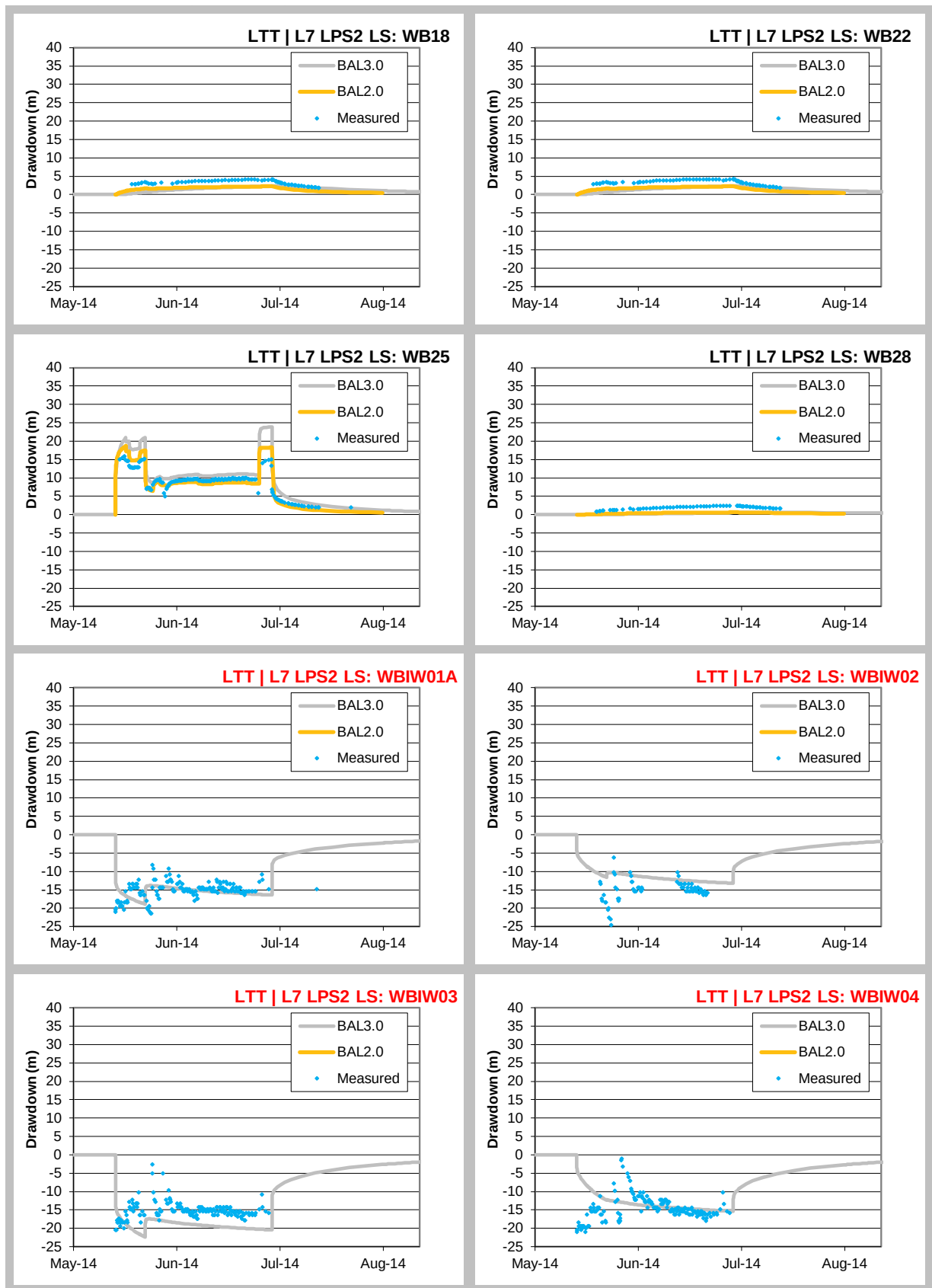
Note, a well name shown in **red text** indicates the well is not included in the history-matching dataset, as it is used for abstraction or injection and cannot be expected to be matched closely as flow dynamics within wells and their surrounding gravel packs are not modelled. They are presented here for completeness as measurements of head/drawdown were available.

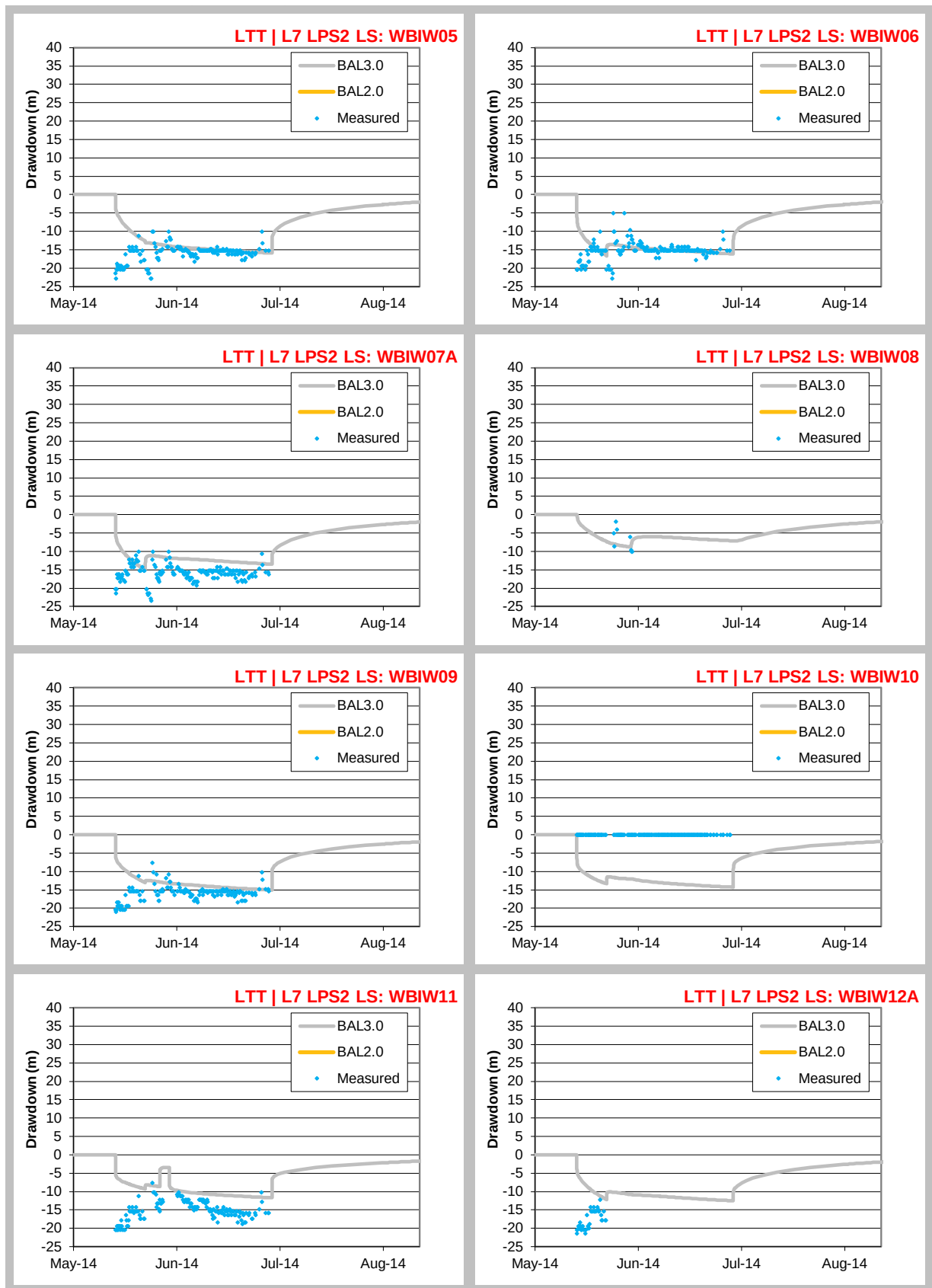


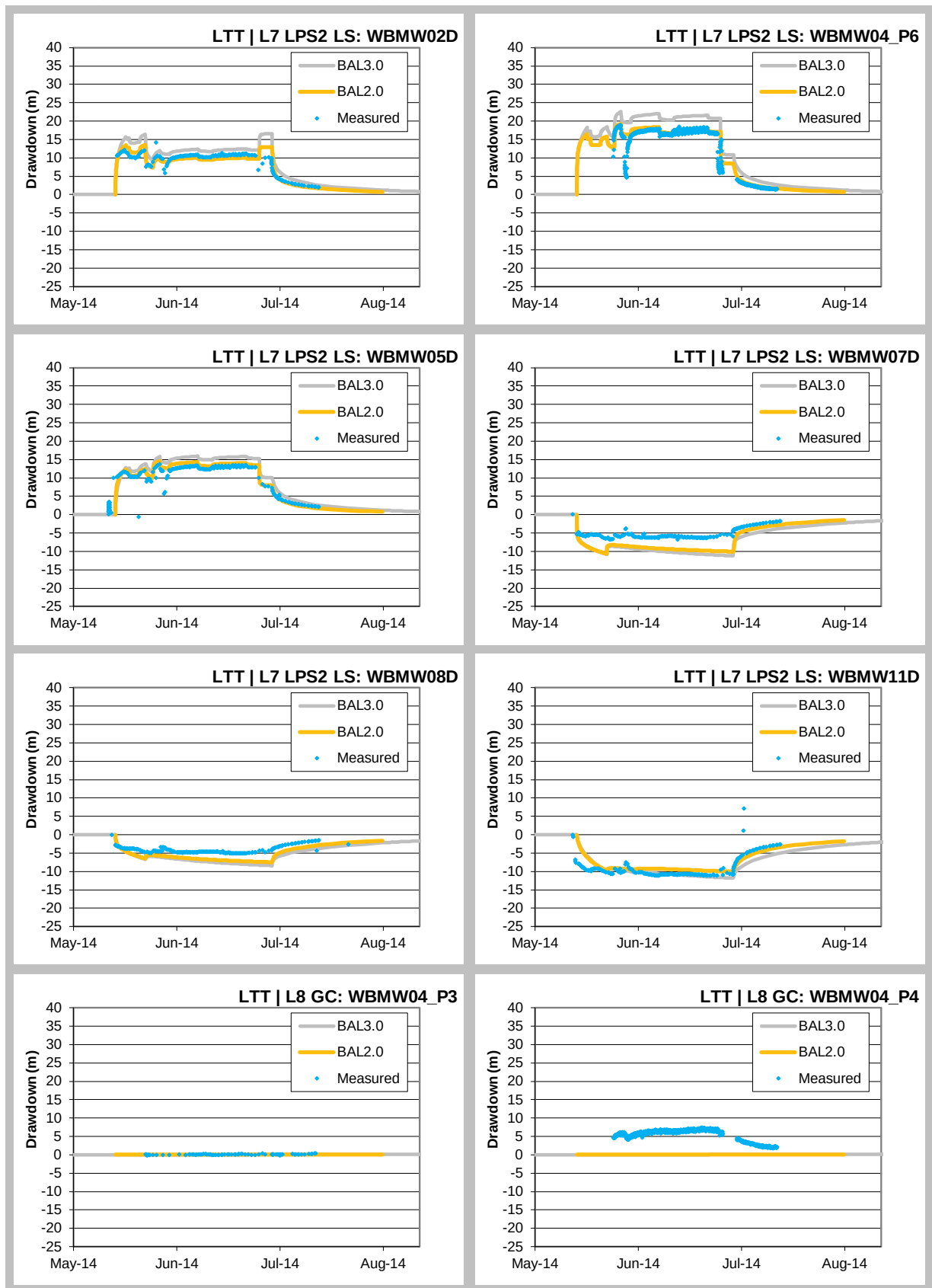


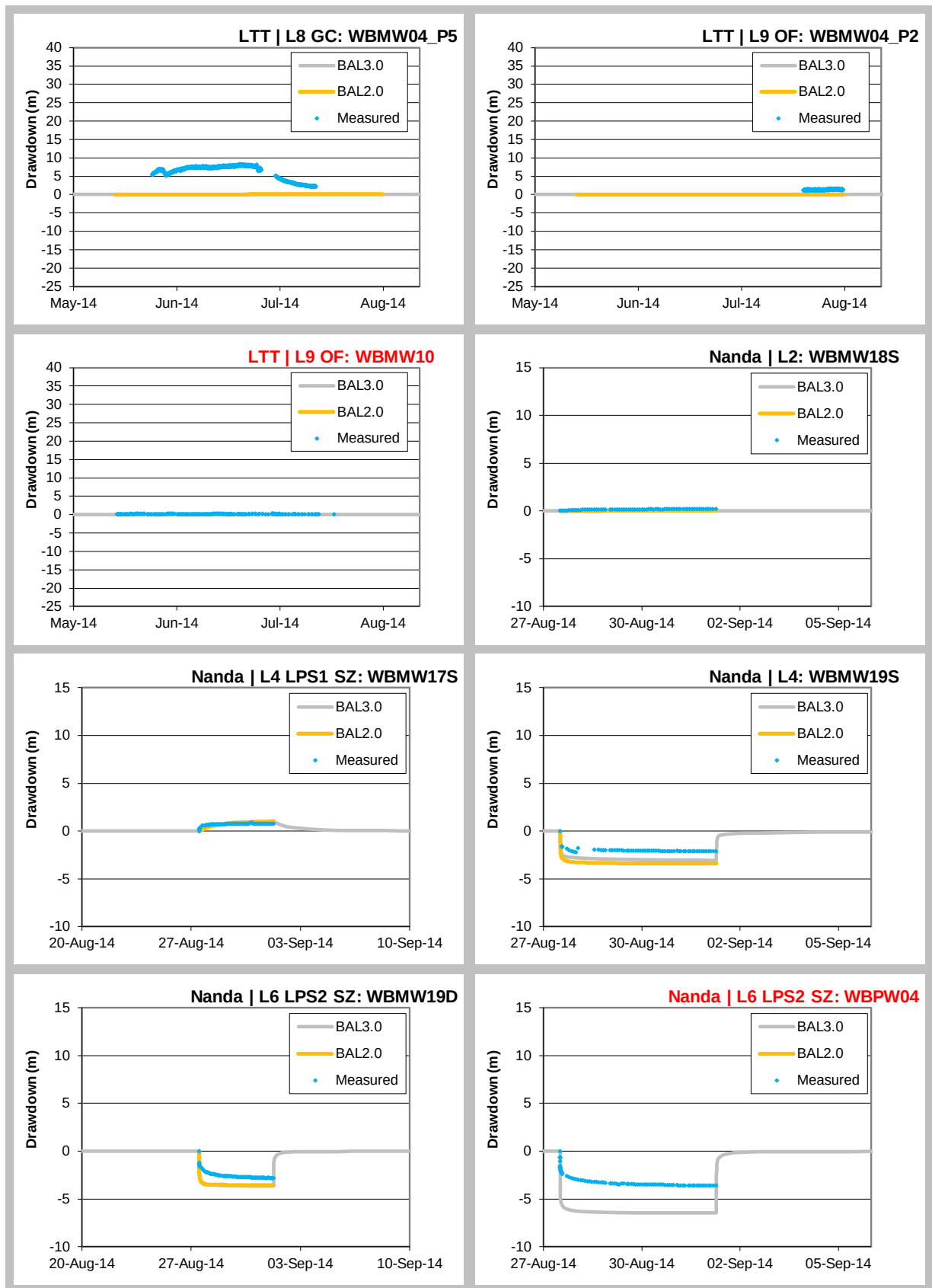


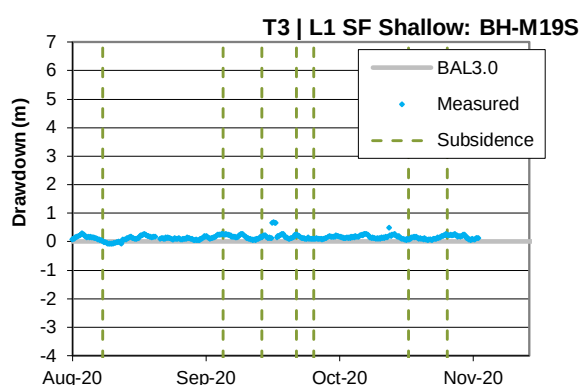
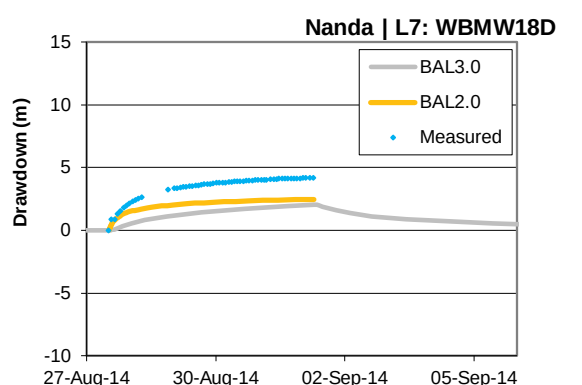
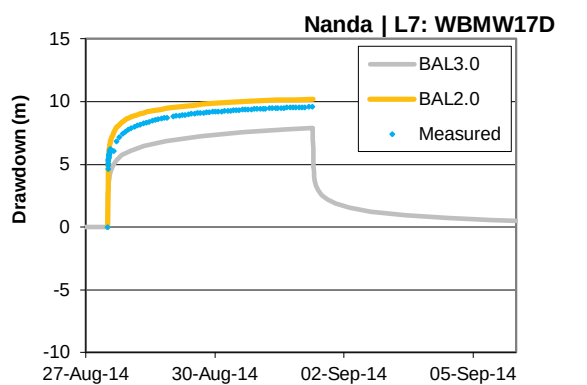
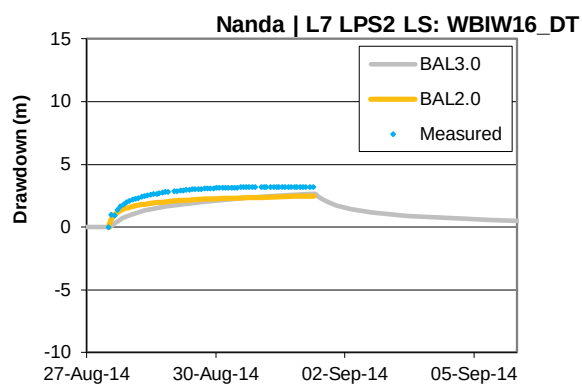
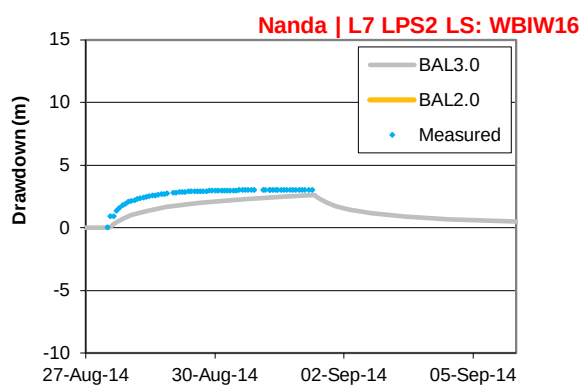
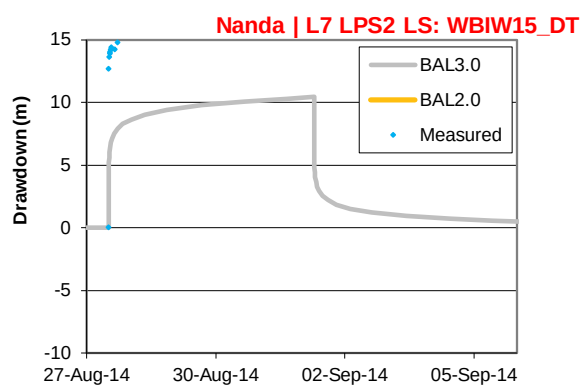
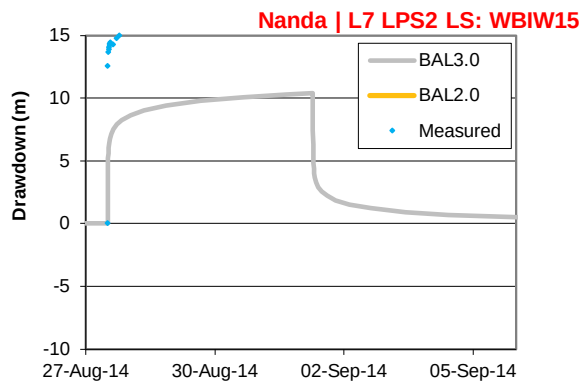
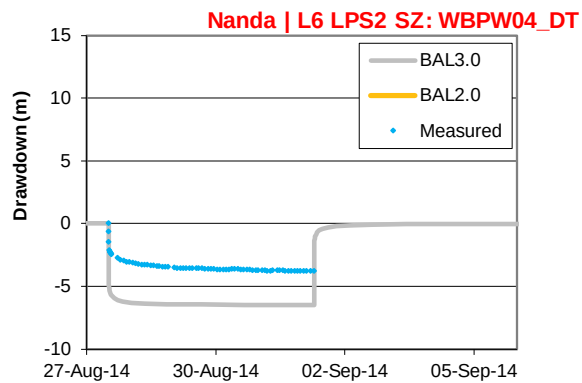


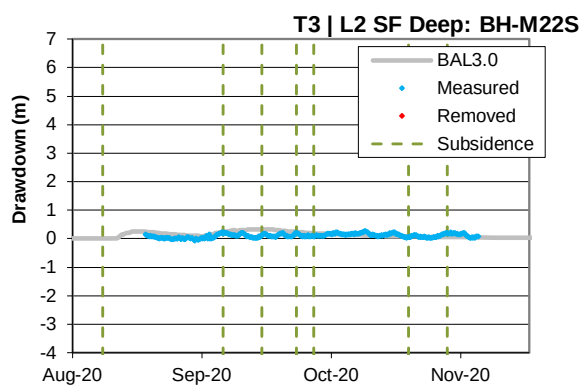
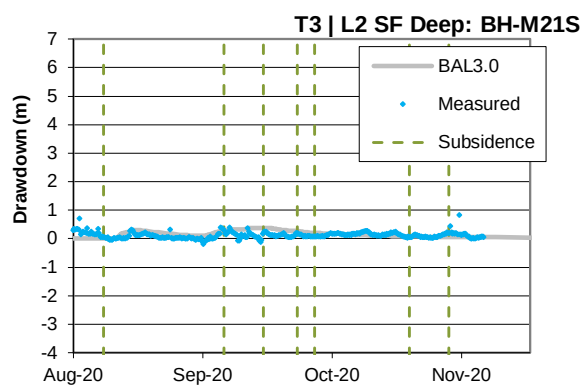
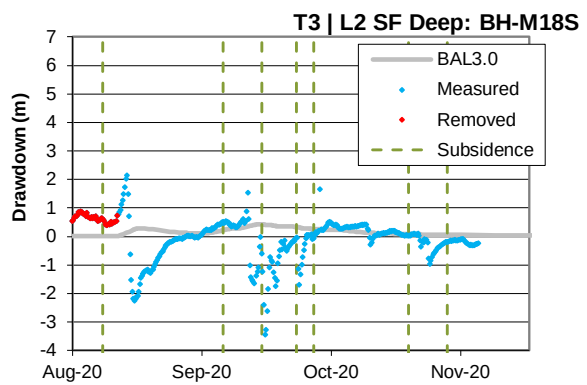
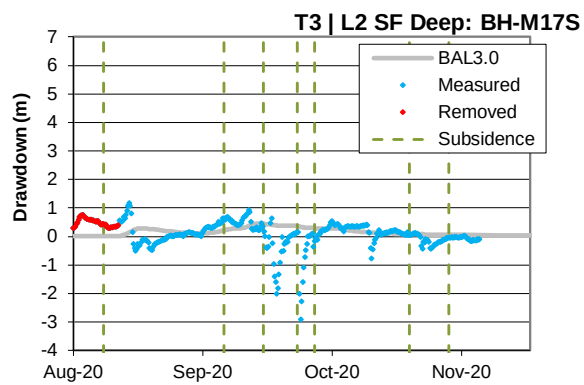
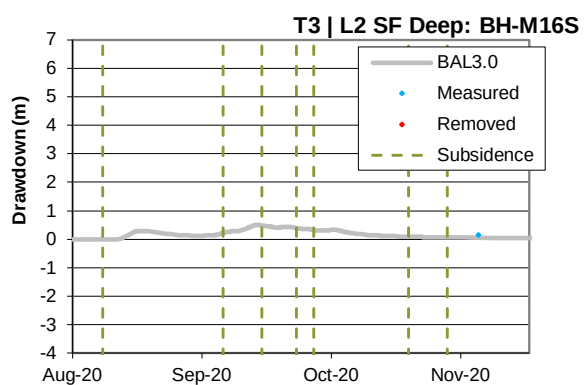
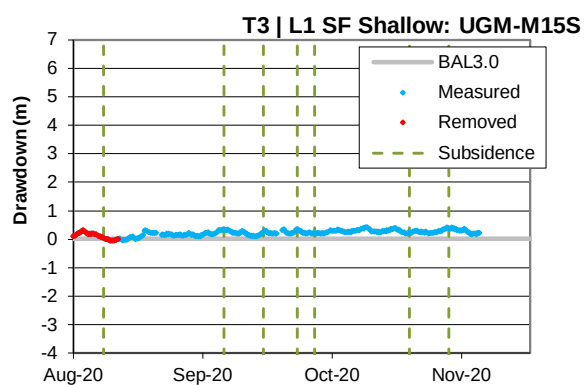
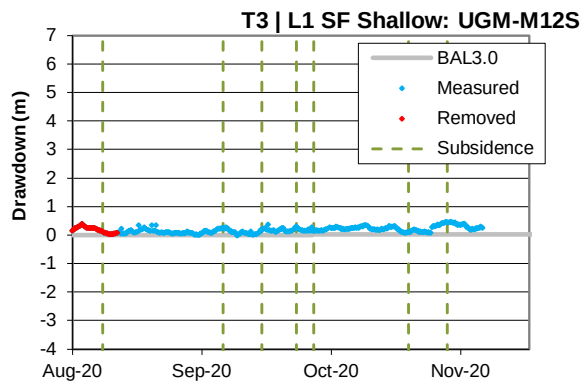
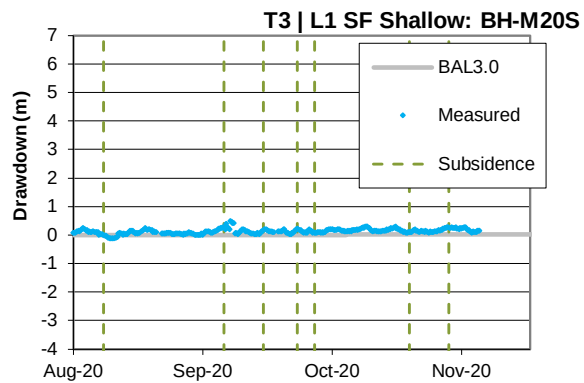


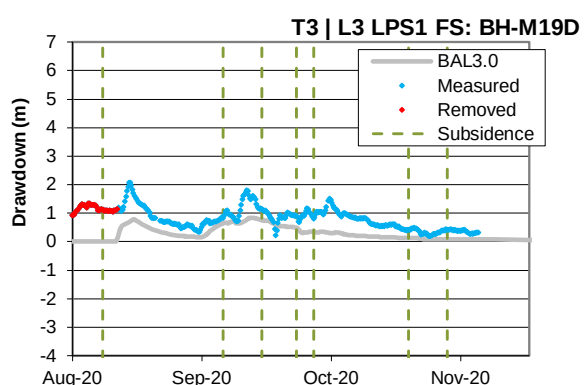
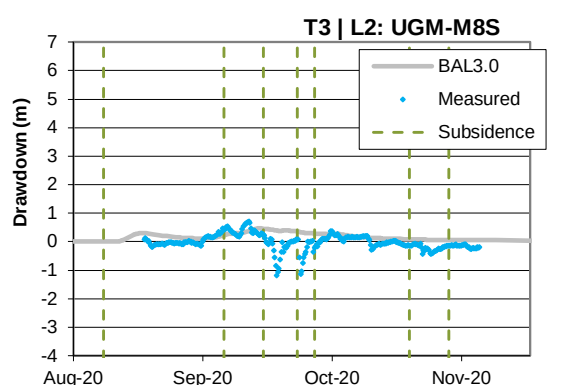
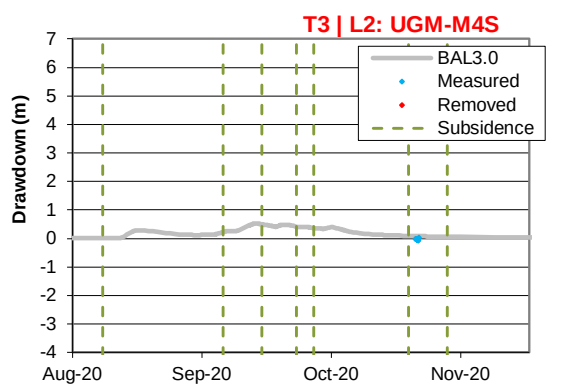
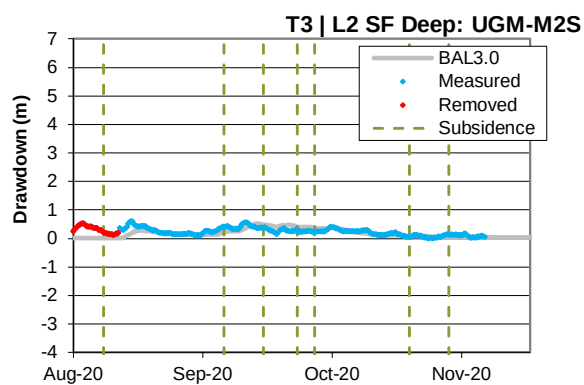
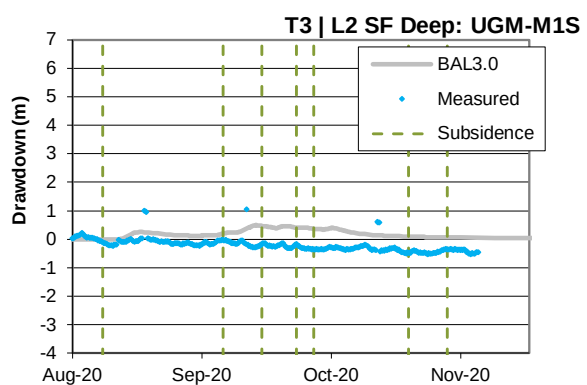
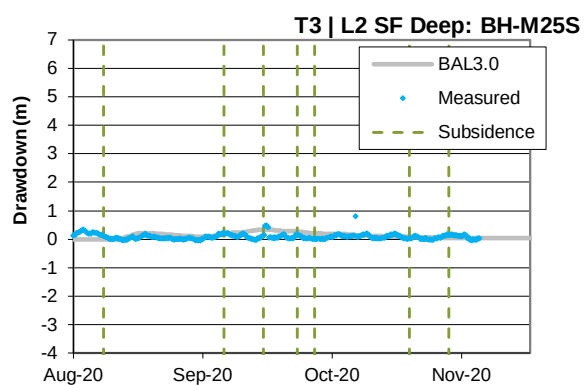
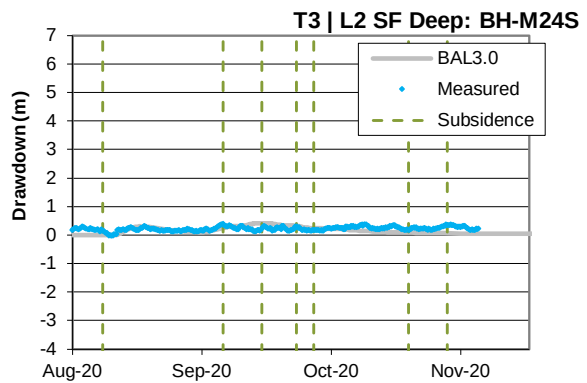
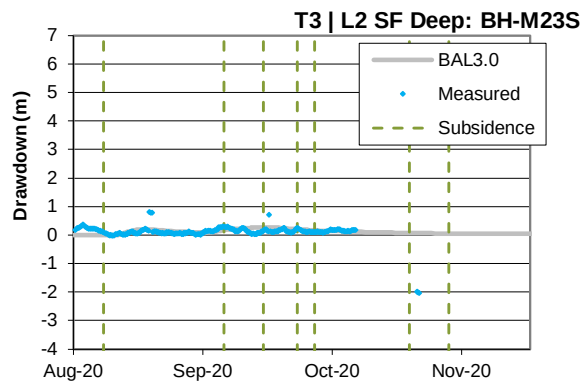


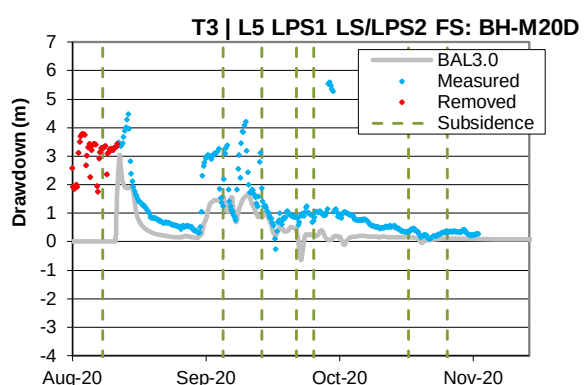
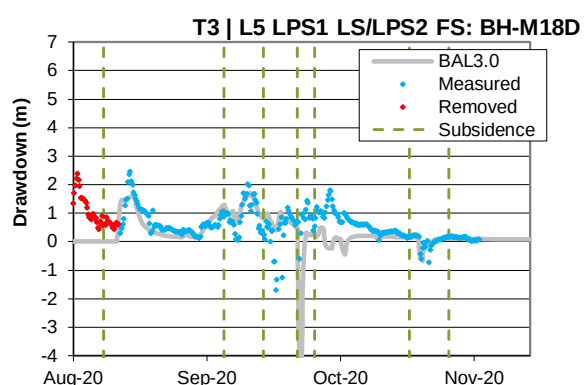
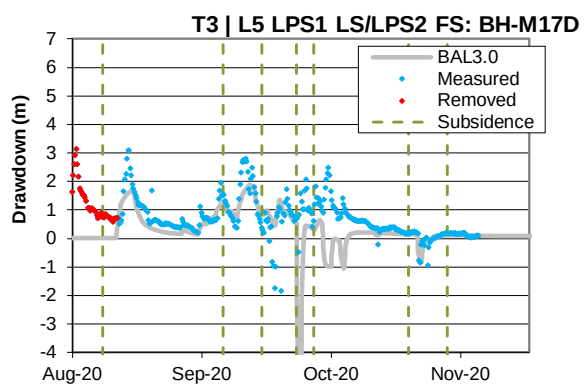
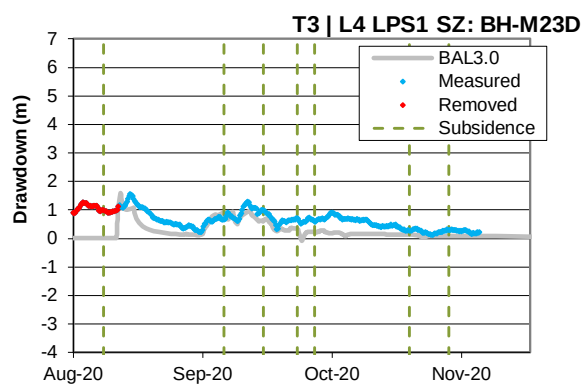
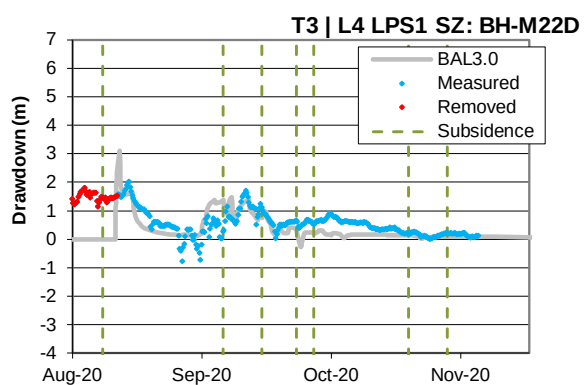
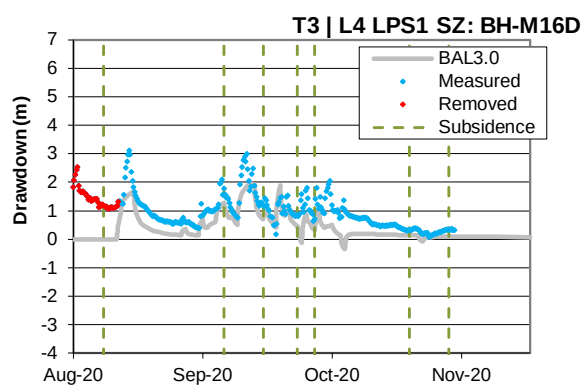
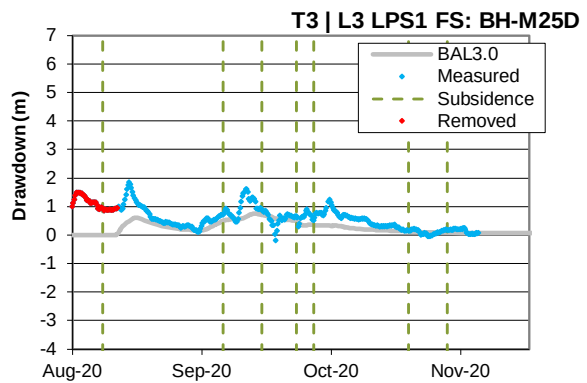
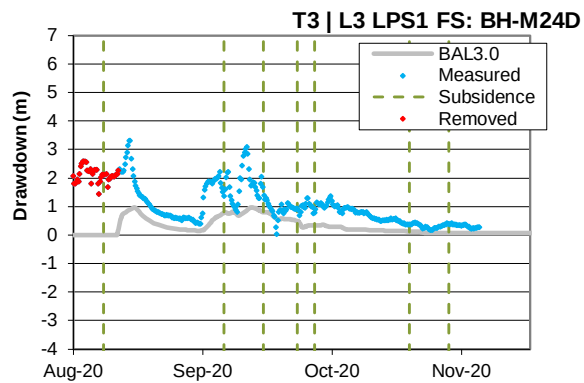


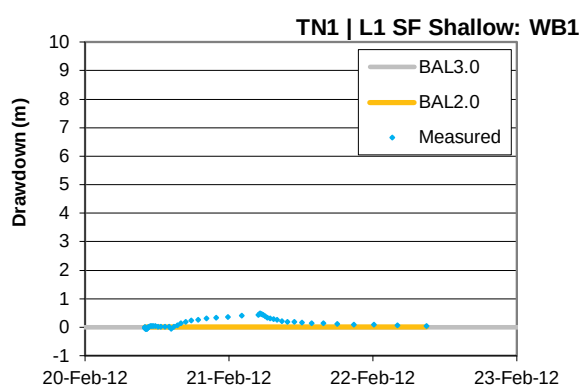
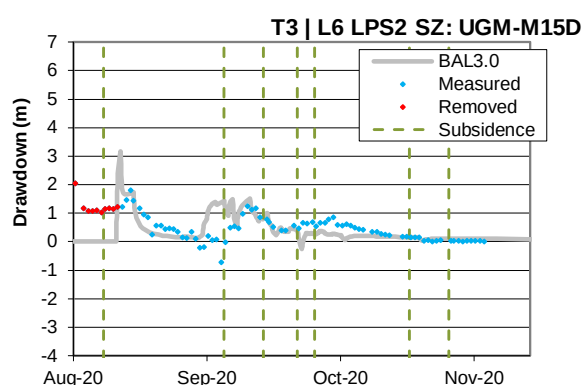
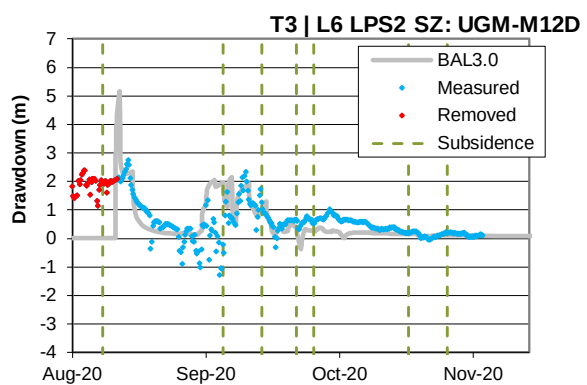
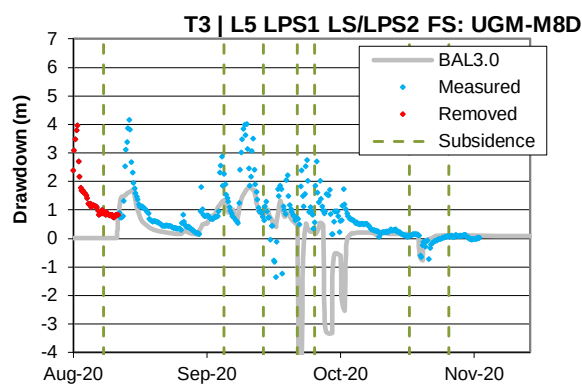
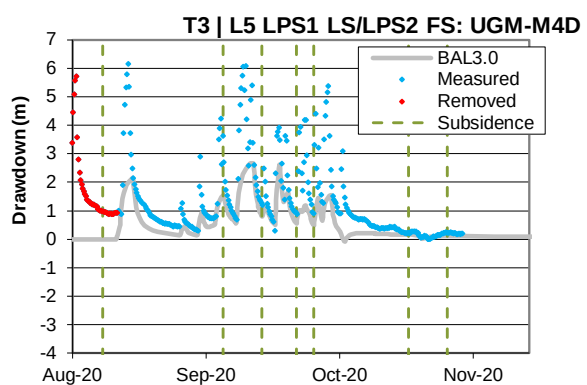
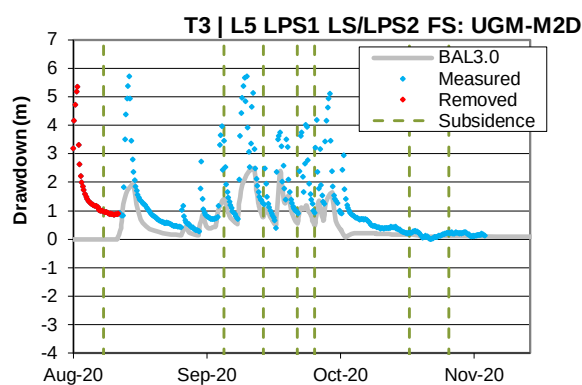
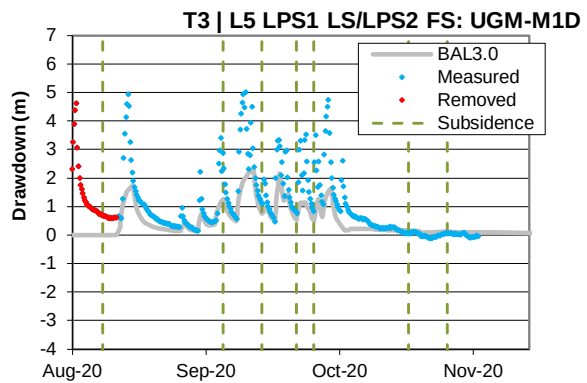
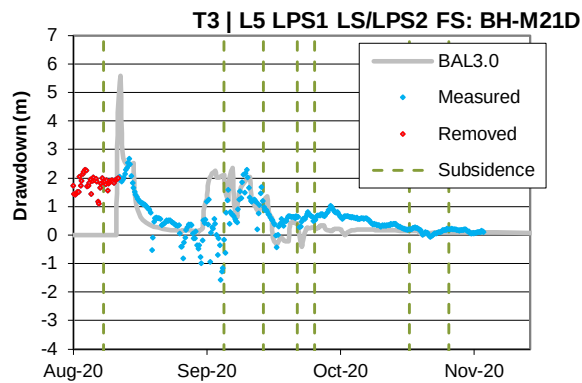


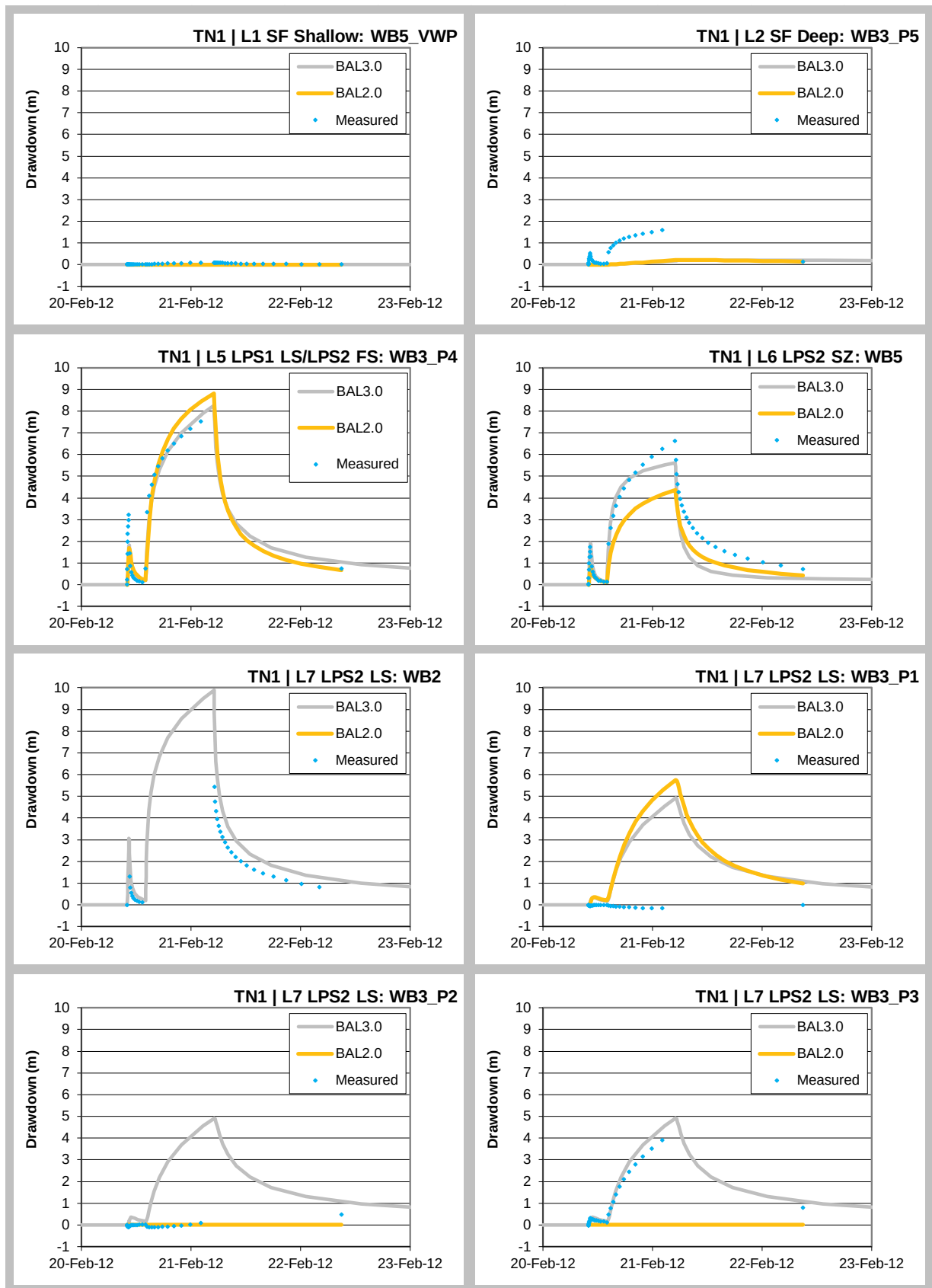


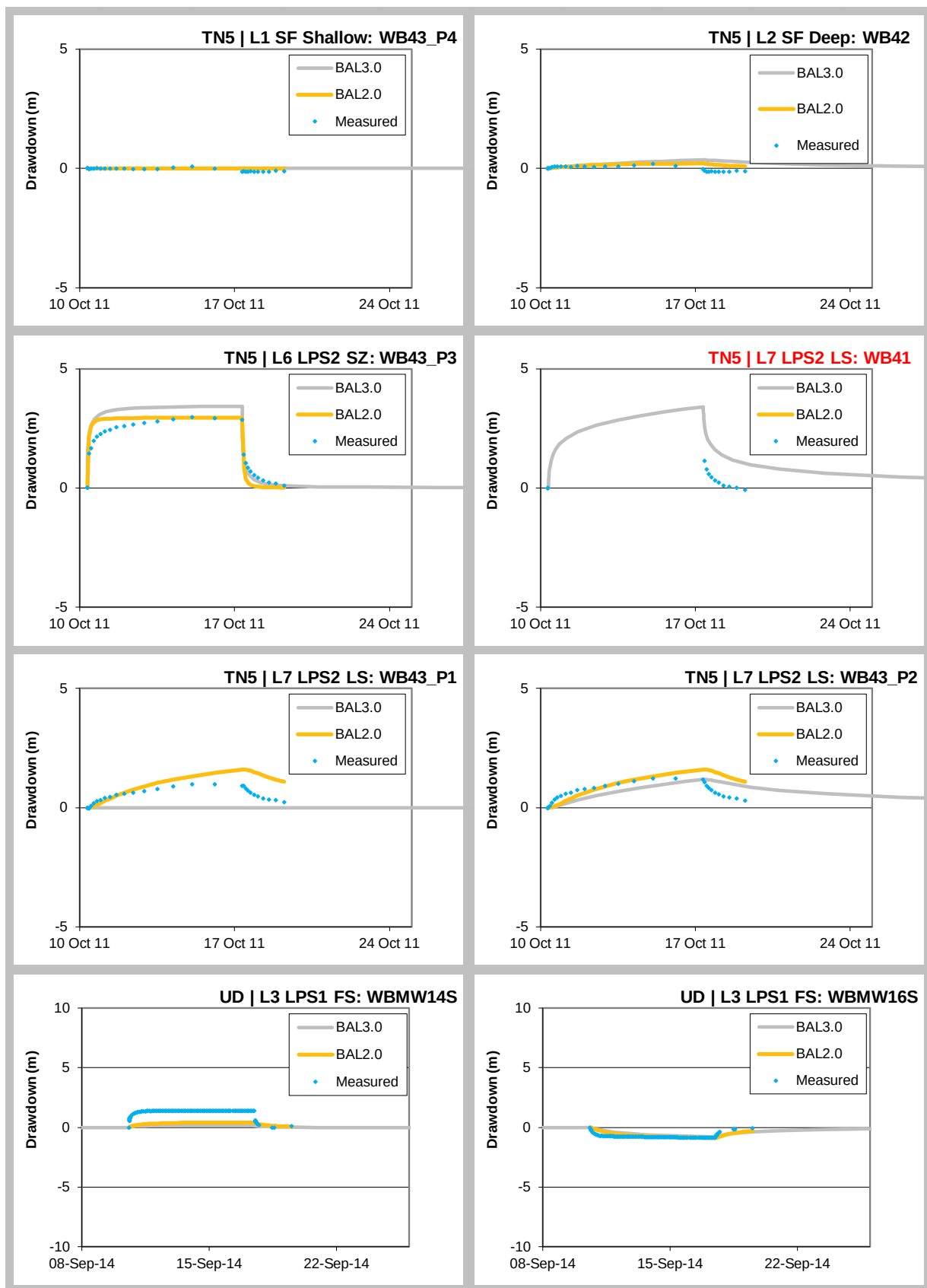


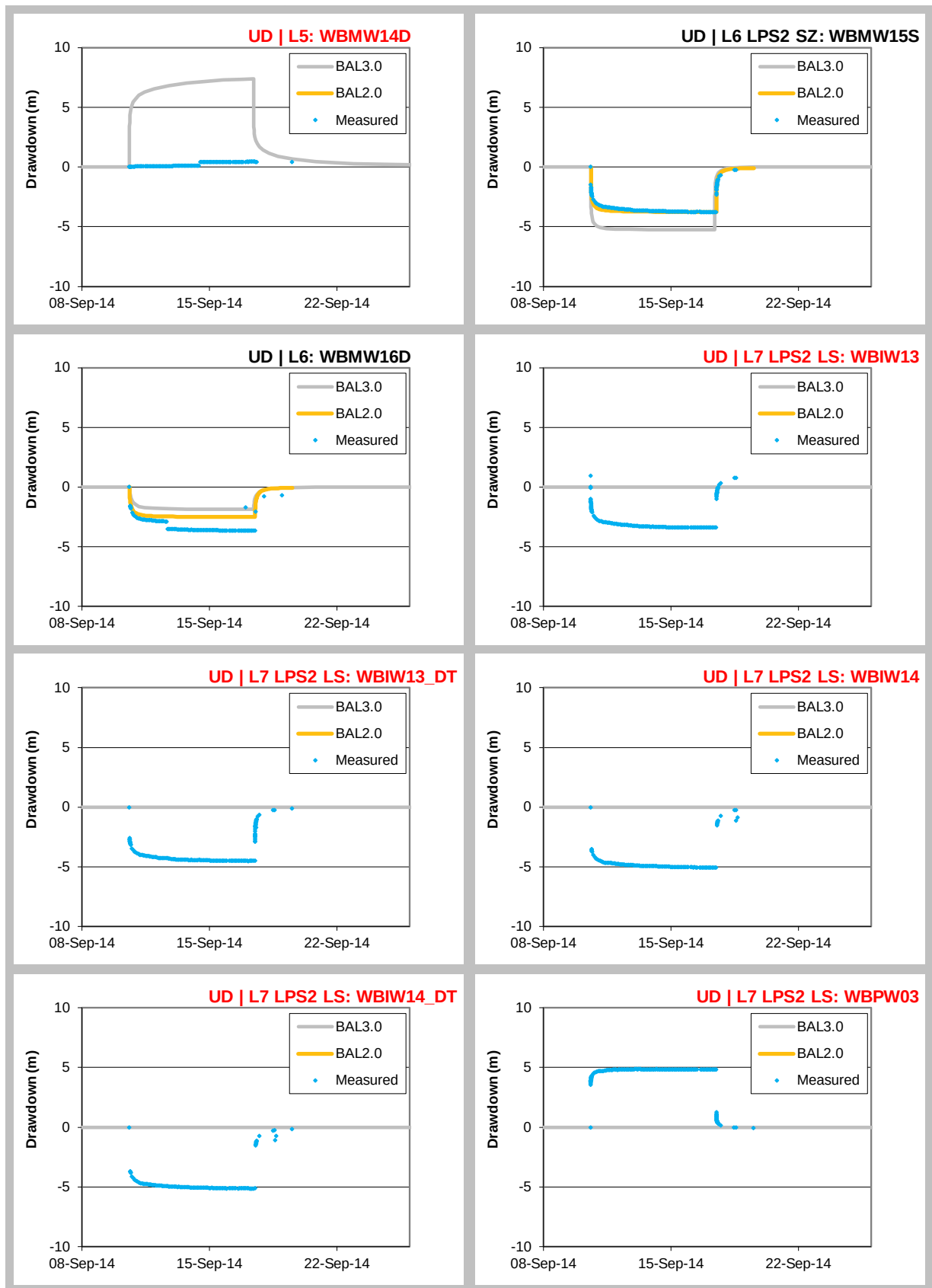


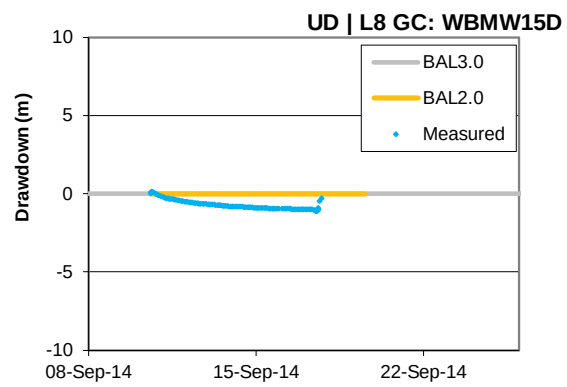














Appendix E

Hydrographs: mining prediction, T3 trial wells

