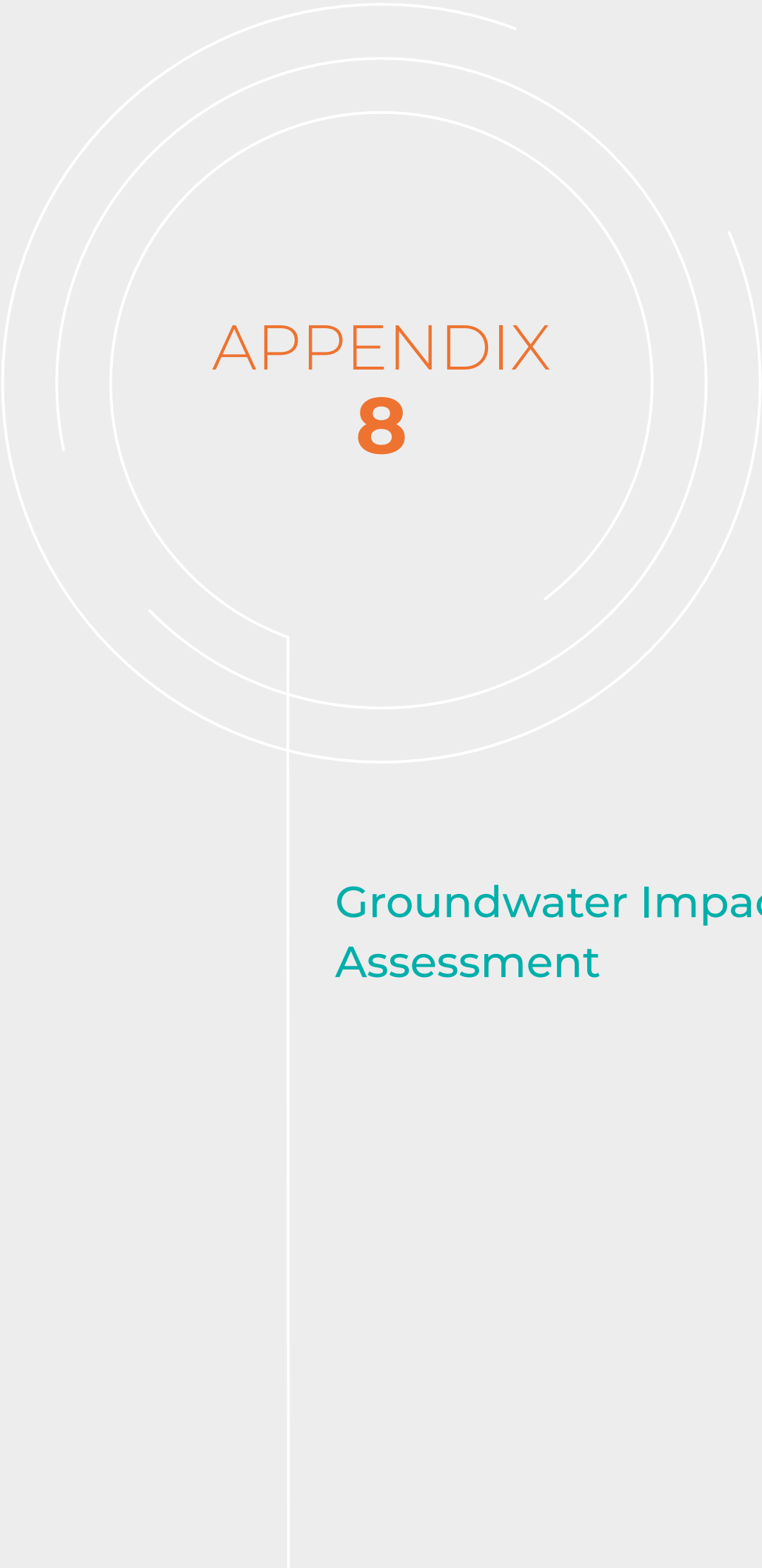




APPENDIX 8

Groundwater Impact Assessment



Australasian
Groundwater
& Environmental
Consultants

Report on

Ulan Coal Mines Modification 6 (MOD6) Groundwater Impact Assessment

Prepared for
Ulan Coal Mine Complex

Project No. G1985G
November 2022

ageconsultants.com.au

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Australasian Groundwater and Environmental Consultants Pty Ltd

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Ulan Coal Mines Modification 6 (MOD 6)

Groundwater Impact Assessment

1 Introduction

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) has been engaged by Ulan Coal Mines Pty Limited (UCMPL) to review and update the Groundwater Impact Assessment (GIA) for the Ulan Coal Complex (UCC) for a proposed modification discussed in the overview below.

1.1 Proposed Modification overview

UCMPL operates the UCC, which is 100% owned and managed by Glencore Coal Assets Australia Pty Ltd (GCAA). The UCC is in the central west of New South Wales near the town of Ulan, which is approximately 38 km north-northeast of Mudgee (refer to Figure 1.1). The mine operates under Project Approval (PA) 08_0184, approved under Part 3A of the *Environmental Planning & Assessment Act (1979)* (EP&A Act) on 15 November 2010 (PA 08_0184). The UCC also operates under Environment Protection Licence (EPL) 394.

UCMPL is proposing to modify PA 08_0184 to facilitate extensions to several longwall panels at Ulan West and Ulan Underground Operations. The proposed modification is MOD6 as shown on Figure 1.2 and comprises:

- extension of Ulan Underground longwall (LW) panels LWW9 to LWW11 to the west
- widening of Ulan Underground LWW11 by approximately 30 metres
- extension of Ulan West LW9 to LW12 to the north.

UCMPL is also proposing some minor changes to surface infrastructure to support underground mining activities including provision of:

- three ventilation shafts and associated infrastructure corridors
- five dewatering bores and associated infrastructure corridors
- an alternate access track
- an infrastructure corridor and service borehole (to deliver gravel and other construction materials and to provide access and power to the underground mine) to the south-west of Ulan West.

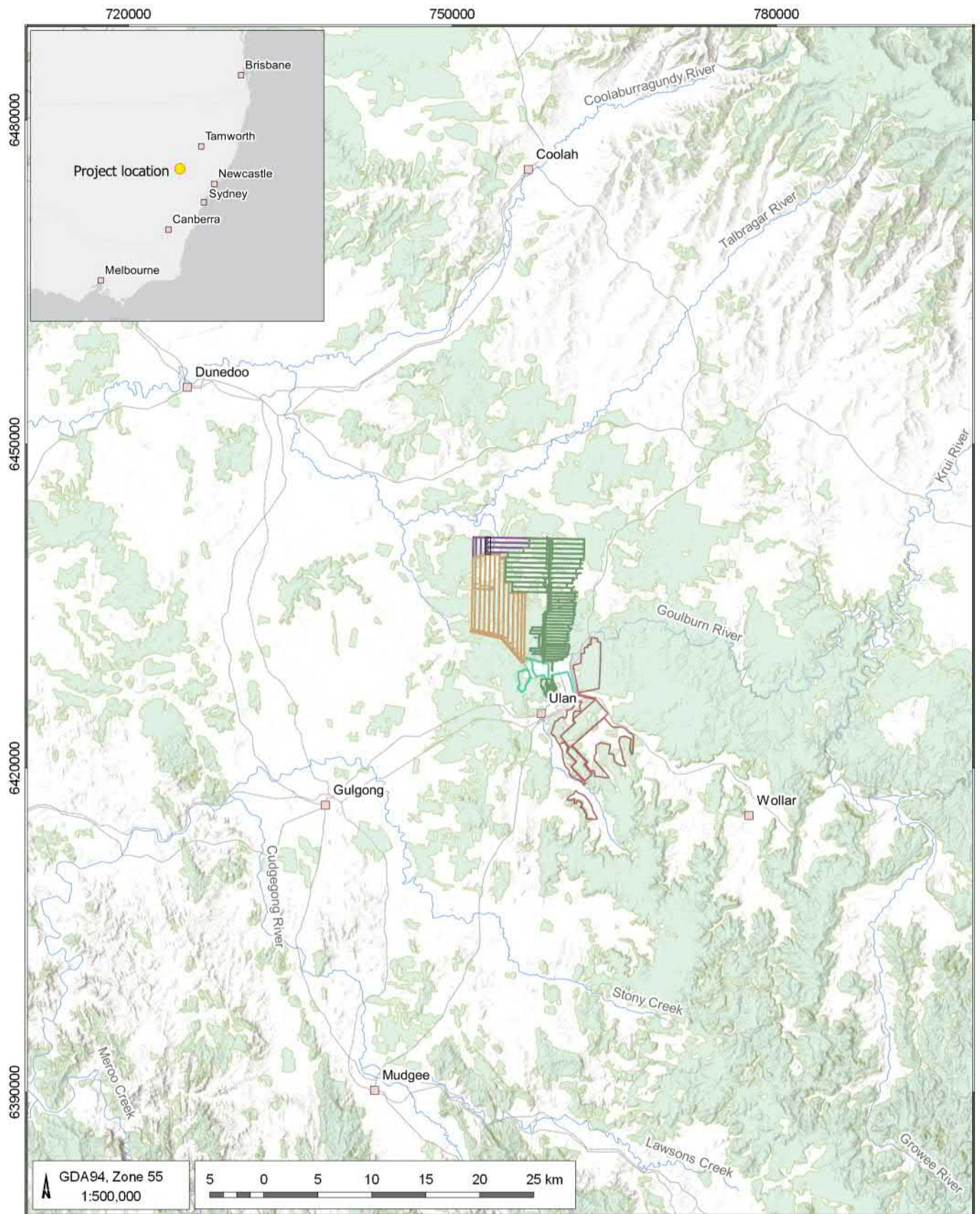
No changes are proposed to coal handling and preparation facilities, water management systems, offices or ancillary facilities is proposed as a result of MOD6.T

The NSW Department of Planning and Environment (DPE) has indicated the required approval path for the proposed modification is under section 4.55(2) of the *Environmental Planning and Assessment Act 1979* (EP&A Act).

UCMPL has referred the proposed modification to the Commonwealth Department of Climate Change, Energy, the Environment and Water (DCCEEW) under the *Environment Protection and Biodiversity Conservation Act (1999)* (EPBC Act), updates on status will be provided during consultation with stakeholders about the modification.

The UCC operation is situated in a rural area, primarily surrounded by rural landholdings, native bushland and primary industries including agriculture, forestry, mining, and extractive industries. Grazing is widespread throughout the region. The valley floors support agricultural activities including sheep and cattle grazing. There is a reliance on groundwater in the area for stock watering.

Areas to the south and south-west of the UCC operation are dominated by rural residential landholdings. The approved Moolarben Coal Mine (MCM) is located adjacent to the southern and eastern boundaries of the UCC (Figure 1.1) and comprises underground and open cut mining operations. The approved Wilpinjong Coal Mine is an open cut operation, located approximately seven kilometres to the south-east near the village of Wollar.



LEGEND

- | | |
|---|--|
| Populated place | Ulan West Mine Plan |
| Drainage | Ulan Underground Mine Plan |
| Road | Proposed longwall panel |
| Rail | |
| Ulan - Underground | |
| Moolarben mine area | |
| Ulan open cut | |
| Vegetation | |
| Flexibility area | |

Ulan MOD6 GIA (G1985G)

Site location



AGE

DATE
11/08/2022

FIGURE No:
1.1

1.2 Objectives and scope of work

The objective of the groundwater impact assessment is to assess the impact of the proposed modification on the groundwater regime, in consideration of the requirements of NSW and Federal Government legislation and policies. To assess the groundwater impacts associated with the proposed modification, AGE has undertaken the following scope:

- utilise and build on the 2015 MOD3 groundwater assessment by Mackie Environmental Research (MER, 2016) and the MOD4 assessment by AGE (2018);
- describe the existing hydrogeological environment;
- apply the groundwater model to inform the impact assessment in terms of:
 - regional groundwater levels in aquifers and aquitards during and post mining;
 - rates of baseflow to surface waters in particularly the Talbragar River;
 - potential for groundwater quality changes during and post mining; and
 - take of water under applicable water sharing plans.
- assess the potential for impacts upon water dependent assets via causal pathways including:
 - potential groundwater dependent ecosystems (GDE) and defining the characteristics of the Mona Creek valley sediment; and
 - third party water users (i.e. private bores).
- compare predicted impacts against the requirements of the:
 - NSW Aquifer Interference Policy (2012) (AIP); and
 - Significant impact guidelines developed by the Federal Government for the EPBC Act.
- assess risks to groundwater systems and appropriate mitigation, management, and monitoring measures.

1.3 Mining – current and proposed

The UCC has a history of open-cut and underground mining dating back to the 1920's. Currently, underground mining is active within Ulan Underground (previously referred to as Ulan Underground No. 3) and Ulan West Underground mining areas.

Longwall mining commenced at Ulan Underground in 1986 and progressed in a northerly direction. During 2020/2021, mining was active within Ulan Underground in longwall panels LWW5, LWW6 and LWW7, and headings development commenced for LWW8 and LW30 (Figure 1.2).

Mining commenced at Ulan West Underground in 2012 and is progressing in a westerly direction with operations approved until 2033. During 2020/2021, mining was active within the Ulan West Underground in longwall panel LW5 and commenced in LW6. Headings were also developed in LW7 and LW8.

Open cut mining occurred within the East Pit until 2008. East Pit has been (and is currently) used for tailings storage since the 1990's and is approved for continued use until 2033. Tailings were also deposited within the Rail Loop tailings dam (inactive), and South 5 Tailings Dam (rehabilitated) until around 2011. Coarse rejects are stored in the Barrier Pit. Mining at the Waratah Open Cut, on the western side of the operations commenced in 2012 and was suspended in 2016. The current approval allows further mining in West Pit until 2031. Open cut mining at the UCC is currently in care and maintenance.

There are several water storage dams across the UCC, including North West Sediment Dam (NWSD), Bobadeen Dam and Rowans Dam which receive mine water pumped from underground workings. Water is treated from Bobadeen and NWSD, with the water utilised on site and/or released from two licensed discharge points on Ulan Creek.

The currently approved mine plan and schedule are described in Ulan Continued Operations Project – Modification 4 Longwall Optimisation Project (MOD4) dated January 2018. MOD4 involved the extension of a number of longwall panels, similar to the current proposed modification being assessed. MOD4 was assessed and deemed not to be a significant impact when referred the Commonwealth Government in 2018, and therefore was not a controlled action.

Modification 5 was a minor, administrative modification under section 4.55(1) of the *Environmental Planning and Assessment Act 1979* to amend a misdescription of the approved Figures provided in Appendix 2 to 7 of Project Approval 08_0184.

The Proposed Modification extends the existing longwall panels in sections of both the Ulan West Underground and the Ulan Underground operations, in addition to widening LWW11 within the Ulan Underground. The proposed conceptual underground mine plan is shown in Figure 1.2.

There is an area within EL 7542 which may be accessed by either Ulan West Underground or Ulan Underground depending on timing of operations and mining conditions. The area referred to as the 'Flexibility Area' is shown on Figure 1.2. The coal in the Flexibility Area may be accessed by either a northern extension of Ulan West Underground LW9 or a western extension of Ulan Underground LWW9, 10 and 11 (refer to Figure 1.2). The underlined fields in Table 1.1 and Table 1.2 show the proposed commencement and completion date changes for MOD6. . In relation to potential groundwater impacts, the mining of the flexibility area via Ulan West Underground LW9 is the more conservative approach. Accordingly, this assessment has modelled mining of the flexibility area via Ulan West Underground LW9 in order to assess the worst case scenario for MOD6. The extensions cover an area of approximately 745 ha, which represents an increase of approximately 7.3 % compared to the total mine area of 10,165 ha (refer Figure 1.2).

Table 1.1 Panel commencement dates, Ulan West

Longwall Panel	Mod Extension		Approved Mine Plan	
	Longwall commencement date	Longwall completion date	Longwall commencement date	Longwall completion date
LW07	No Change	-	Jul 2022	Apr 2024
LW08a	No change	-	May 2024	Feb 2025
LW08b	No Change	-	Mar 2025	Jan 2026
LW09a	Mar 2026	<u>Apr 2027</u>	Mar 2026	Dec 2026
LW09b	<u>May 2027</u>	<u>May 2028</u>	Jan 2027	Dec 2027
LW10a	<u>Jun 2028</u>	<u>Jul 2029</u>	Jan 2028	Oct 2028
LW10b	<u>Aug 2029</u>	<u>Jul 2030</u>	Nov 2028	Oct 2029
LW11a	<u>Aug 2030</u>	<u>Sept 2031</u>	Nov 2029	Jul 2030
LW11b	<u>Oct 2031</u>	<u>Sept 2032</u>	Aug 2030	Jul 2031
LW12a	<u>Oct 2032</u>	<u>Aug 2033</u>	Aug 2031	Jan 2032
LW12b	<u>Sept 2033</u>	<u>Aug 2034</u>	Feb 2032	Jan 2033

Source: UCMPL, per email (19 November 2020).

Table 1.2 Panel commencement dates, Ulan Underground

Longwall Panel	Mod Extension		Approved Mine Plan	
	Longwall commencement date	Longwall completion date	Longwall commencement date	Longwall completion date
LW30	No change	-	Jul 2022	Jul 2023
LWW8	No Change	-	Aug 2023	Aug 2024
LW31	No Change	-	Sept 2024	Sept 2025
LWW9	<u>Nov 2025</u>	<u>May 2027</u>	Jan 2026	Sept 2026
LW32	<u>June 2027</u>	<u>Feb 2028</u>	Oct 2026	Jul 2027
LWW10	<u>Mar 2028</u>	<u>Aug 2029</u>	Sept 2027	April 2028
LW33	<u>Nov 2029</u>	<u>Oct 2030</u>	May 2028	Feb 2029
LWW11	<u>Nov 2030</u>	<u>Feb 2032</u>	Mar 2029	Sept 2029

1.4 Report Structure

This report is structured as follows:

- Section 1 – Introduction: provides an overview of the proposed modification, scope of the report and objectives.
- Section 2 – Regulatory framework: describes the NSW and Commonwealth regulatory framework relating to groundwater that is relevant to the proposed modification.
- Section 3 – Environmental setting: describes the environmental setting of the proposed modification including the climate, terrain, land uses and other environmental features.
- Section 4 – Geological setting: describes the regional geology and local stratigraphy.
- Section 5 – Hydrogeology: describes the existing local groundwater regime within the proposed modification area and surrounds.
- Section 6 – Numerical groundwater model: describes the application of modelling to predict the impacts associated with the proposed modification.
- Section 7 – Groundwater model predictions: presents the numerical model predictions during mining and for the post mining recovery phase.
- Section 8 – Impact assessment: describes the predicted impacts of the proposed modification on the groundwater regime and water dependent assets.
- Section 9 – Uncertainty analysis: summarises the uncertainty and sensitivity analysis undertaken on the numerical groundwater model, including details about the purpose and methodology of the assessment.
- Section 10 – Groundwater Monitoring and Management Plan: describes the proposed measures for mitigation, management and monitoring of the groundwater regime and potential impacts.
- Appendix A provides a detailed description of the numerical modelling undertaken for the proposed modification, including details on model construction, and calibration.
- Appendix A 2 provides a list of the UCC monitoring bores.
- Appendix B provides a summary for comparison of the groundwater impact predictions for the approved and MOD6 mine plans against the requirements under the AIP as well as the Independent Expert Scientific Committee (IESC) guidelines and where they are addressed within the report.
- Appendix C provides details of the independent review comments received, and recommendations adopted in the final Groundwater Impact Assessment report.

2 Regulatory framework

This Section outlines the regulatory framework of relevance to the proposed modification. The following legislation, policies and guidelines are relevant for groundwater:

- NSW Government:
 - *Water Management Act 2000* (WM Act), and the associated Water Sharing Plans (WSPs);
 - NSW Aquifer Interference Policy (AIP);
 - Strategic Regional Land Use Policy (2012); and
 - *Protection of the Environment Operations Act (1997)*.
- Commonwealth Government:
 - EPBC Act guidelines including:
 - Significant impact guidelines (DoE, 2013).
 - Independent Expert Scientific Committee information guidelines for coal seam gas (CSG) and large coal mining development proposals (IESC, 2018).
 - IESC Explanatory Note on Uncertainty Analysis in Groundwater Modelling (Middlemis & Peeters, 2018).
 - Assessing Groundwater Dependent Ecosystems (Doody *et al.*, 2019).

The following sections identify the relevant NSW Government legislative instruments, regulations and policies that are applicable to the management of groundwater at the proposed modification. This section also presents information on the licenses (water access and environmental) currently held by UCMPL.

2.1 *Water Management Act 2000*

The WM Act manages NSW water resources via the regulation of access rights through water licensing and approvals. The WM Act is administered by the DPE-Water and Natural Resources Access Regulator (NRAR) via the following means:

- Water Access Licence (WAL): which allows the holder access to a maximum volume or share component that may be drawn from a particular water source. A WAL may also specify a category and the conditions under which water may be taken from a particular water source;
- water use approval: which authorises the particular use of water taken under a WAL; and
- water work approval: which states the nature, type and location of infrastructure by which water may be taken from a water source.

2.1.1 *Water Sharing Plans (WSP)*

NSW WSPs establish rules for sharing water between the environmental needs of the river or aquifer and water users, and between different types of water use such as town supply, rural domestic supply, stock watering, industry and irrigation.

DPE-Water is progressively developing WSPs for rivers and groundwater systems across NSW following the introduction of the WM Act. The purposes of these plans are to protect the health of rivers and groundwater, while also providing water users with perpetual access licences, equitable conditions, and increased opportunities to trade water through separation of land and water rights.

UCMPL currently holds licenses to extract groundwater from water sources in the area to accommodate existing mining operations.

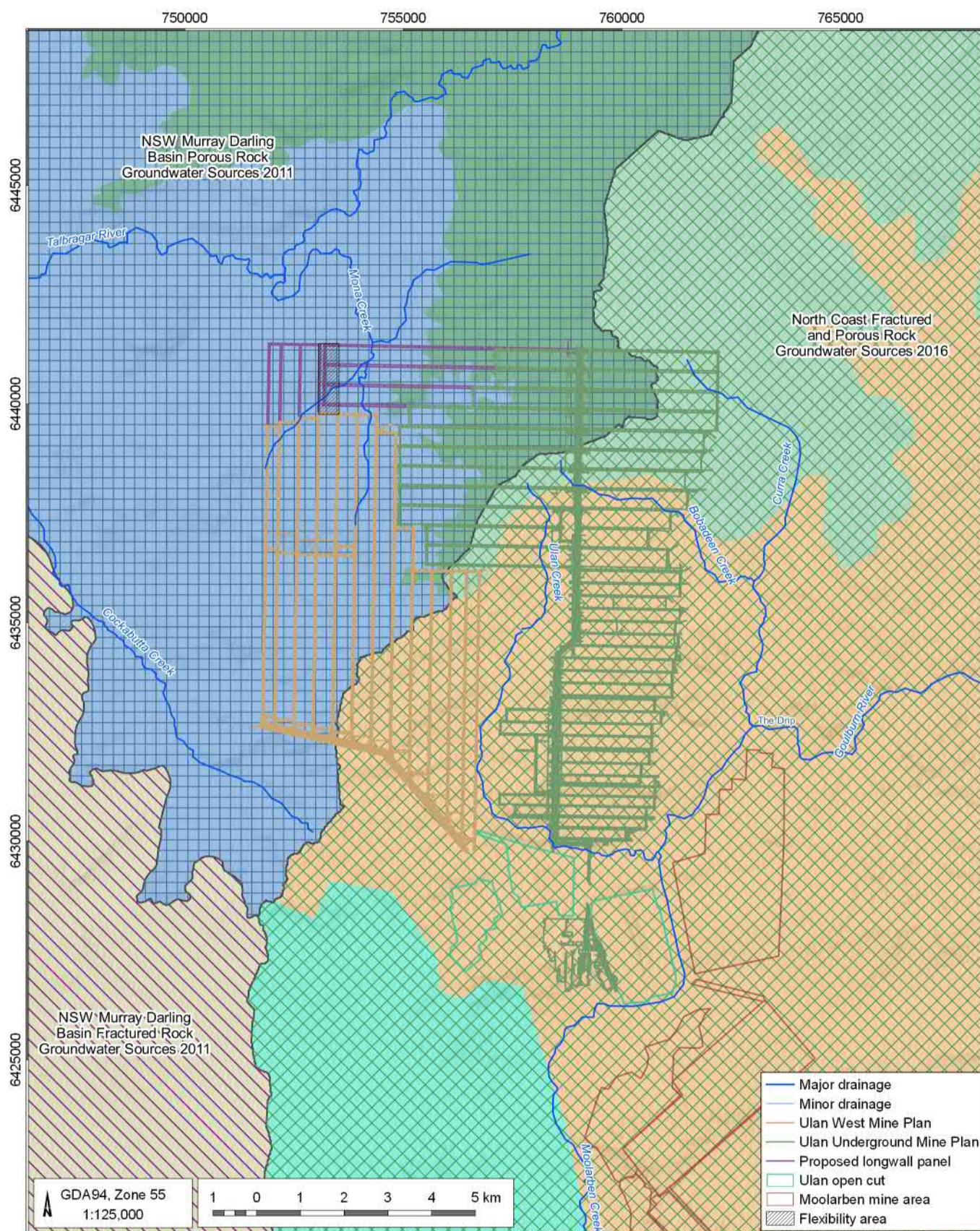
These water sources are:

- **Direct¹** water take from water sources associated with the Permian sediments:
 - *North Coast Fractured and Porous Rock Groundwater Sources 2016* – Sydney Basin – North Coast Groundwater Source; and
 - *NSW Murray Darling Basin Porous Rock Groundwater Sources 2020* – Sydney Basin Murray Darling Basin (MDB) (Other) Management Zone.
- **Indirect²** water take through:
 - *North Coast Fractured and Porous Rock Groundwater Sources 2016* – Oxley Basin Coast Groundwater Source;
 - *Hunter Unregulated and Alluvial Water Sources 2009* – Upper Goulburn River Water Source;
 - *NSW Murray Darling Basin Porous Rock Groundwater Sources 2020* – Sydney Basin MDB (Macquarie Oxley) Management Zone;
 - *Macquarie Bogan Unregulated Rivers Water Sources 2012* – Upper Talbragar River Water Source; and
 - *Macquarie – Castlereagh Groundwater Sources Order 2020* – Talbragar Alluvial Groundwater Source.

The extent of these water sources is presented in Figure 2.1.

¹ Also referred to as 'incidental water' as defined in the Aquifer Interference Policy 2012 as "Water that is taken by an aquifer interference activity that is incidental to the activity; including water that is encountered within and extracted from mine workings, tunnels, basements or other aquifer interference structures that must be dewatered to maintain access, serviceability and/or safe operating conditions. This water is not actually required to be used as part of the process of carrying out that activity".

² sometimes referred to as 'passive water take' as water losses from a groundwater system occur indirectly due to an adjacent activity.



LEGEND

- NSW Murray Darling Basin Porous Rock Groundwater Sources 2011
- Sydney Basin MDB (Macquarie Oxley) Management Zone
- Sydney Basin MDB (Other) Management Zone
- North Coast Fractured and Porous Rock Groundwater Sources 2016
 - Oxley Basin Coast Groundwater Source
 - Sydney Basin (Fractured Rock) - North Coast Groundwater Source
 - Sydney Basin (Porous Rock) - North Coast Groundwater Source
- NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011
- Lachlan Fold Belt MDB Groundwater Source

Ulan MOD6 GIA (G1985G)

Water Sharing Plan areas and subordinate management units relevant to the Project



AGE

DATE
11/08/2022

FIGURE No:
2.1

2.1.2 Water licensing

Proponents of aquifer interference activities are required to provide predictions of the volume of water to be taken from a water source(s) as a result of the activity. These predictions need to occur prior to approval. After approval and during operations, these volumes need to be measured wherever possible (or predicted from modelling results through comparison with extractions from mine workings) and reported in annual returns or environmental management reports. The water user must hold sufficient share component and water allocation to account for the take of water from the relevant water source when the take occurs (refer Section 8.1). Also refer to Appendix B for comparison tables of the groundwater impact predictions for the approved and MOD6 mine plans against the requirements under the AIP.

The AIP states that a water licence is required for the aquifer interference activity regardless of whether water is taken directly for consumptive use or incidentally. In the case of the mining and the proposed modification, the take of water occurs incidentally during the mining process. This incidental take of groundwater can induce flow from adjacent groundwater sources or connected surface water, which constitutes a passive take of water under the AIP. In all cases, separate access licences are required to account for the take from all individual water sources (refer Section 8.1 for predicted takes).

Table 2.1 below summarises the current licencing and the predicted peak take from the approved mine operations for all the water sources predicted to be directly and indirectly impacted by the UCC.

The UCC groundwater model was recently upgraded and recalibrated. An additional layer was included in the groundwater model to represent the Jurassic aquifer that intermittently overlies the Triassic lithology in the area. The upgraded model was used to identify nominal incidental water takes from the Jurassic Aquifer which will need to be accounted for by licencing allocation. UCMPL already holds allocation within the *North Coast Fractured and Porous Rock Groundwater Sources 2016 – Oxley Basin Coast Groundwater Source* and will achieve allocation within the *North Coast Fractured and Porous Rock Groundwater Sources 2016 – Oxley Basin Coast Groundwater Source* within the 2022 Water Year. Table 2.2 lists the licence number for each allocation.

Table 2.1 Summary of current licencing at Ulan and modelled peak take during operations

Catchment	Water Sharing Plan (WSP), Water Source and Applicable Management Zone	Licence (Units)	Modelled Peak (ML/year)
Goulburn Catchment	Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016 – Sydney Basin – North Coast Groundwater Source	0*	5222
	Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016 – Oxley Basin Coast Groundwater Source	7060*	12.1
	Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009 – Upper Goulburn River Water Source	600	122.6
Talbragar Catchment	Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2020 – Sydney Basin MDB (Other) Management Zone	6950	5604
	Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources Order 2020 – Sydney Basin MDB (Macquarie Oxley) Management Zone	0**	8.55
	Water Sharing Plan for the Macquarie Bogan Unregulated Rivers Water Sources 2012 - Upper Talbragar River Water Source and Water Sharing Plan for the Macquarie - Castlereagh Groundwater Sources Order 2020 - Talbragar Alluvial Groundwater Source	80	29.6

Notes: * Approximately 7000 units were incorrectly assigned at the time of issuing. UCMPL are undertaking consultation with NRAR to resolve this issue at the time of writing.

** Upgraded groundwater model (July 2021) identified take from source where this was not previously identified. UCMPL are seeking to obtain allocation in this source, commencing this water year (2022).

Table 2.2 Water Access Licences (WAL) for groundwater extraction

Licence number	Water Sharing Plan	Water Source	Allocation (units)	Extraction
WAL41492	North Coast Fractured and Porous Rock Groundwater Sources 2016	Oxley Basin Coast Groundwater Source	7060	Incidental take
WAL37192	NSW MDB Porous Rock Groundwater Sources 2020	Sydney Basin MDB Groundwater Source	704	Passive take until implementation of LW6 Infrastructure
WAL41906	NSW MDB Porous Rock Groundwater Sources 2020	Sydney Basin MDB Groundwater Source	2215	Passive take until implementation of LW6 Infrastructure
WAL42900	NSW MDB Porous Rock Groundwater Sources 2020	Sydney Basin MDB Groundwater Source	4031	Passive take until implementation of LW6 Infrastructure
WAL41817	Macquarie Bogan Unregulated Rivers Water Sources 2012	Upper Talbragar River Water Source	50	Passive take – Baseflow loss offset
WAL34921	Macquarie-Castlereagh Groundwater Sources 2020	Talbragar Alluvial Groundwater Source	30	Passive take – Baseflow loss offset
WAL19047	Hunter unregulated and alluvial water sources 2009	Upper Goulburn River Water Source	600	Riparian rights, water harvesting and passive take offset for baseflow losses

2.2 State groundwater policy

2.2.1 Aquifer Interference Policy (AIP)

The AIP describes minimal impact considerations for aquifer interference activities which are a series of acceptable thresholds for water level and quality changes. The minimal impact consideration thresholds depend upon whether the water source is highly productive or less productive and whether the water source is alluvial or porous/fractured rock in nature.

A “highly productive” groundwater source is defined by the AIP as a groundwater source which has been declared in regulations and datasets, based on the following criteria:

- has a Total Dissolved Solids (TDS) concentration less than 1,500 milligrams per litre (mg/L); and
- contains water supply works that can yield water at a rate greater than 5 litres per second.

Highly productive groundwater sources are further grouped by geology into alluvial, coastal sands, porous rock, and fractured rock. “Less productive” groundwater sources are all other aquifers that do not satisfy the “highly productive” criteria for yield and water quality.

The AIP requires that impacts on highly and less productive water sources need to be assessed and accounted for. In 2012, the then NSW Crown Lands and Water Division produced a map of groundwater productivity across NSW, showing those areas classified as either highly or less productive. The groundwater productivity map has been produced based on regional scale geological maps.

The groundwater productivity map is shown in Figure 2.2 and indicates that the Pilliga Sandstone formation (Jurassic sediments) has been classified as highly productive. Despite being mapped as highly productive, near the UCC the Pilliga Sandstone formation is less productive than in other areas. The Pilliga Sandstone formation is regarded as less important in the proposed modification area due to its hydrogeological characteristics which have been characterised during previous assessments. The Jurassic sediments comprise the Pilliga Sandstone and Purlewaugh Siltstone. Regionally the Pilliga Sandstone comprises cross-bedded sequences of ferruginous, coarse grained quartzose sandstone, conglomerates, claystone and shale. The Pilliga Sandstone is relatively permeable and can form an aquifer where it is present. However, where these sediments exist across the mine area, they are mainly unsaturated. The unit is generally utilised to the east and south of the mine area.

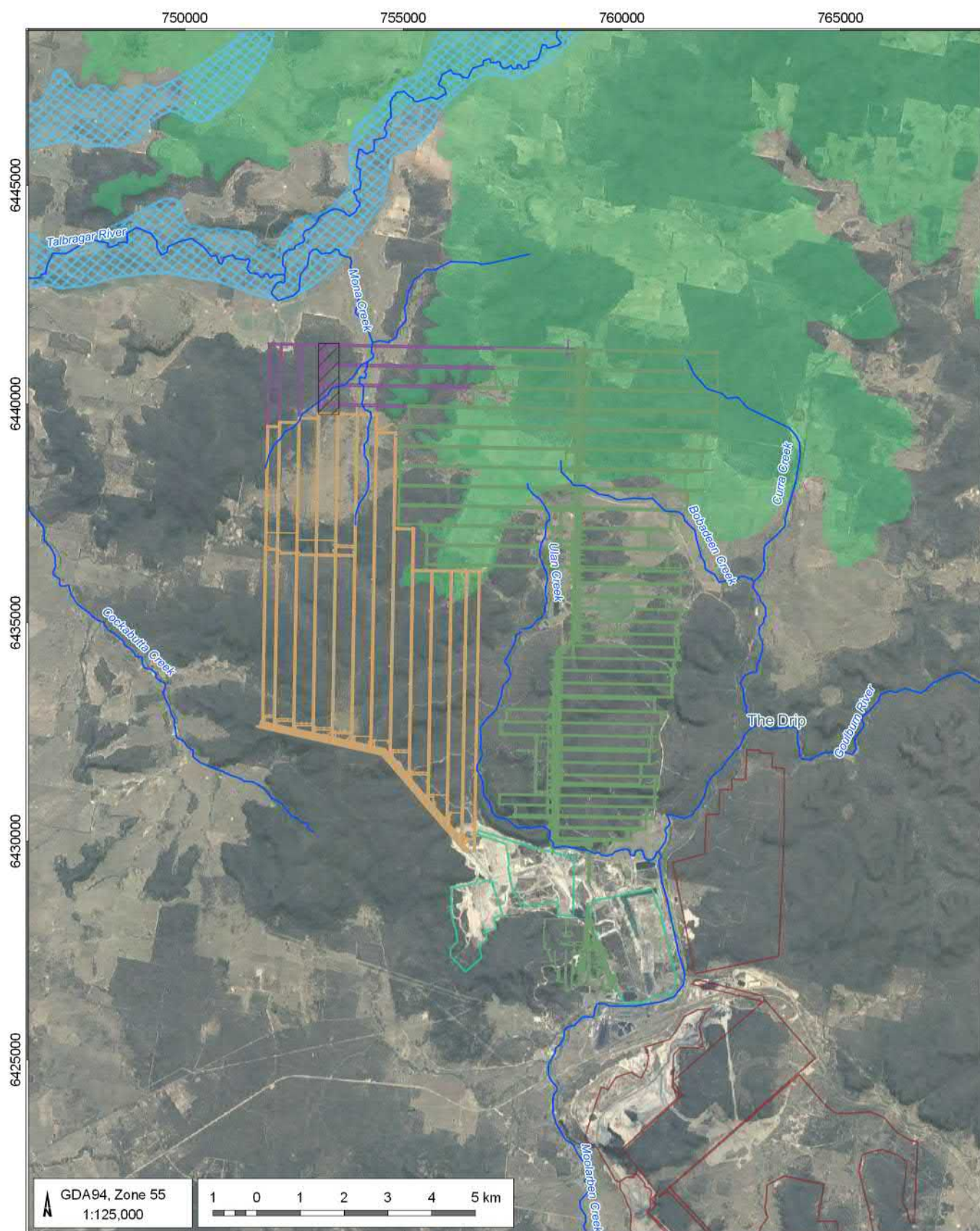
The most significant alluvial groundwater systems in the area are associated with tributaries of the Talbragar and Goulburn Rivers. The tributary most relevant to the proposed modification is Mona Creek. The sediments in the valley of Mona Creek were identified as alluvium in broad scale geological mapping, however more detailed characterisation work carried out (refer to Section 5.1.1.1) for the proposed modification has identified that these sediments are colluvial in nature.

The hydrogeological characteristics of Triassic and Permian age sedimentary rocks (porous and fractured rock) are discussed in more detail in Sections 4 and 5 and mainly categorised as “less productive” (DPIE, 2012).

The minimal impact considerations are a series of threshold levels defining minimal impact on groundwater sources, connected water sources, GDEs, culturally significant sites and water users. The thresholds specify water table and groundwater pressure drawdown as well as groundwater and surface water quality changes. Section 7 presents predicted impacts from the proposed modification and compares these with the AIP thresholds.

2.2.2 NSW Strategic Regional Land Use Policy

Under the EP&A Act, the Strategic Regional Land Use Policy requires any State significant mining development requiring a new mining lease to assess potential impacts on Biophysical Strategic Agricultural Land (BSAL). BSAL is land with high quality soil and water resources capable of sustaining high levels of productivity. BSAL is identified on regional mapping along parts of the Talbragar River (Figure 2.2). A site verification process was undertaken for the proposed modification which indicated that there is no BSAL located within areas subject to a new mining lease application.



LEGEND

- Major drainage
- Minor drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolanben mine area
- ▨ Biophysical Strategic Agricultural Land
- ▨ Porous rock - other porous rock - Highly productive groundwater source
- ▨ Flexibility area

Ulan MOD6 GIA (G1985G)

Highly Productive groundwater (DPI Water) and Biophysical Strategic Agricultural Land



AGE

DATE
11/08/2022

FIGURE No:
2.2

2.3 Commonwealth Environment Protection and Biodiversity Conservation Act 1999

As indicated previously in Section 1, UCMPL will refer the proposed modification to the Commonwealth for consideration under the EPBC Act.

The Commonwealth Guidelines (2013) state that a 'significant impact' is an impact which is:

"...important, notable, or of consequence, having regard to its context or intensity, whether or not an action is likely to have a significant impact depends upon the sensitivity, value and quality of the water resource which is impacted, and upon the intensity, duration, magnitude and geographic extent of the impacts.

An action is likely to have a significant impact on a water resource if there is a real or not remote chance or possibility that it will directly or indirectly result in a change to:

- the hydrology of a water resource,*
- the water quality of a water resource.*

that is of sufficient scale or intensity as to reduce the current or future utility of the water resource for third party users, including environmental and other public benefit outcomes, or to create a material risk of such reduction in utility occurring."

The Commonwealth guidelines summarised provide guidance on how to determine whether a project will significantly impact the groundwater regime. A significant impact is considered to occur when there is a substantial change to the hydrology or water quality in a water resource. The aspects of a water resource that must be considered are summarised in Section B 2 and Appendix B.

2.3.1 IESC Guidelines

As indicated above in Section 2.3, the EPBC Act is administered by the Commonwealth DCCEEW to protect national environmental assets (Matters of National Environmental Significance [MNES]). A 2013 amendment to the EPBC Act, identified impacts on water resources as the result of large coal mining development as being MNES (the 'water trigger'). The IESC is a statutory body established under the EPBC Act to provide scientific advice to the Commonwealth Environment Minister and relevant State ministers on the impacts on water resources. Guidelines have been developed in order to assist the IESC in reviewing CSG or large coal mining development proposals. A summary of the IESC guidelines and where they are addressed within the report is included in Appendix B.

3 Environmental setting

3.1 Location

The UCC is situated in the central west of New South Wales. It is located in the Mid-Western Regional Council (MWRC) Local Government Area (LGA) near the village of Ulan; approximately 38 kilometres north-northeast of Mudgee and 19 kilometres northeast of Gulgong (Figure 1.1). UCMPL operates the mine on behalf of GCAA.

3.2 Climate

3.2.1 Rainfall

The climate in the vicinity of the proposed modification area is typical of temperate regions and is characterised by hot dry summers dominated by thunderstorms, and cold winters with frequent frosts. Rainfall data collected from Scientific Information for Landowners (SILO) data³ was obtained for Ulan Station (Station No. 062036) and the Wollar Station (Station No. 062032). The average monthly rainfall is presented in Table 3.1.

Table 3.1 Average monthly rainfall (mm)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Station 1*	76.8	75.1	60.1	40.9	43.7	43.6	47.5	45.5	45.4	63.6	64.4	73.0	679.6
Station 2**	66.3	62.9	54.3	39.1	37.7	43.8	42.3	41.0	41.2	51.9	56.1	60.9	597.5

Notes: * Ulan Station, 62036 (1906-2021).

** Wollar Station, 62032 (1901-2021).

The average total annual rainfall is 679.6 mm at Ulan and 597.5 mm at Wollar. Table 3.1 shows that rainfall is slightly higher in summer, but relatively uniform throughout the year. Recent rainfall years have been put into historical context using the Cumulative Rainfall Departure (CRD) method (Bredenkamp, *et al.* 1995). This method is a summation of the monthly departure of rainfall from the long-term average monthly rainfall. A rising trend in the CRD plot indicates periods of above average rainfall, whilst a falling slope indicates periods when rainfall is below average. The CRD in Figure 3.1 was calculated from the Ulan and Wollar stations from March 2000 to March 2021. The CRD indicates that the Millennium Drought continued until 2007, when rainfall generally began to increase again over time until around 2013. A severe drought period followed until early 2020, after which generally above average rainfall has occurred to the present. Figure 3.1 also shows an overview of the variability in rainfall patterns by presenting the monthly recorded rainfall. The maximum recorded monthly rainfall is 240 mm and the minimum zero mm; annual maximum rainfall for the period is 1240 mm and the minimum 325 mm. Total rainfall at the site during 2020 was 1,089.8 mm, the highest annual rainfall since 2010.

In the context of a groundwater assessment, above average CRD may represent periods of above average recharge to groundwater systems and, correspondingly, below average CRD indicates potentially lower than average recharge. This can often correspond to naturally increasing or decreasing trends in groundwater levels in these systems. This is particularly evident in unconfined aquifer systems, or recharge areas of semi-confined or confined systems.

³ Rainfall data is collected by BoM at station 62036 however there are significant gaps in this dataset. In order to obtain longer term climate information, rainfall data was sourced from the Scientific Information for Land Owners (SILO) database. SILO is operated by the Queensland Department of Environment and Science, with data contributions from BoM. The SILO generates a climate dataset via interpolation between neighboring BoM stations to produce a continuous daily time series. The SILO dataset was for latitude -32.25 and longitude 149.70 from 1889 to present.

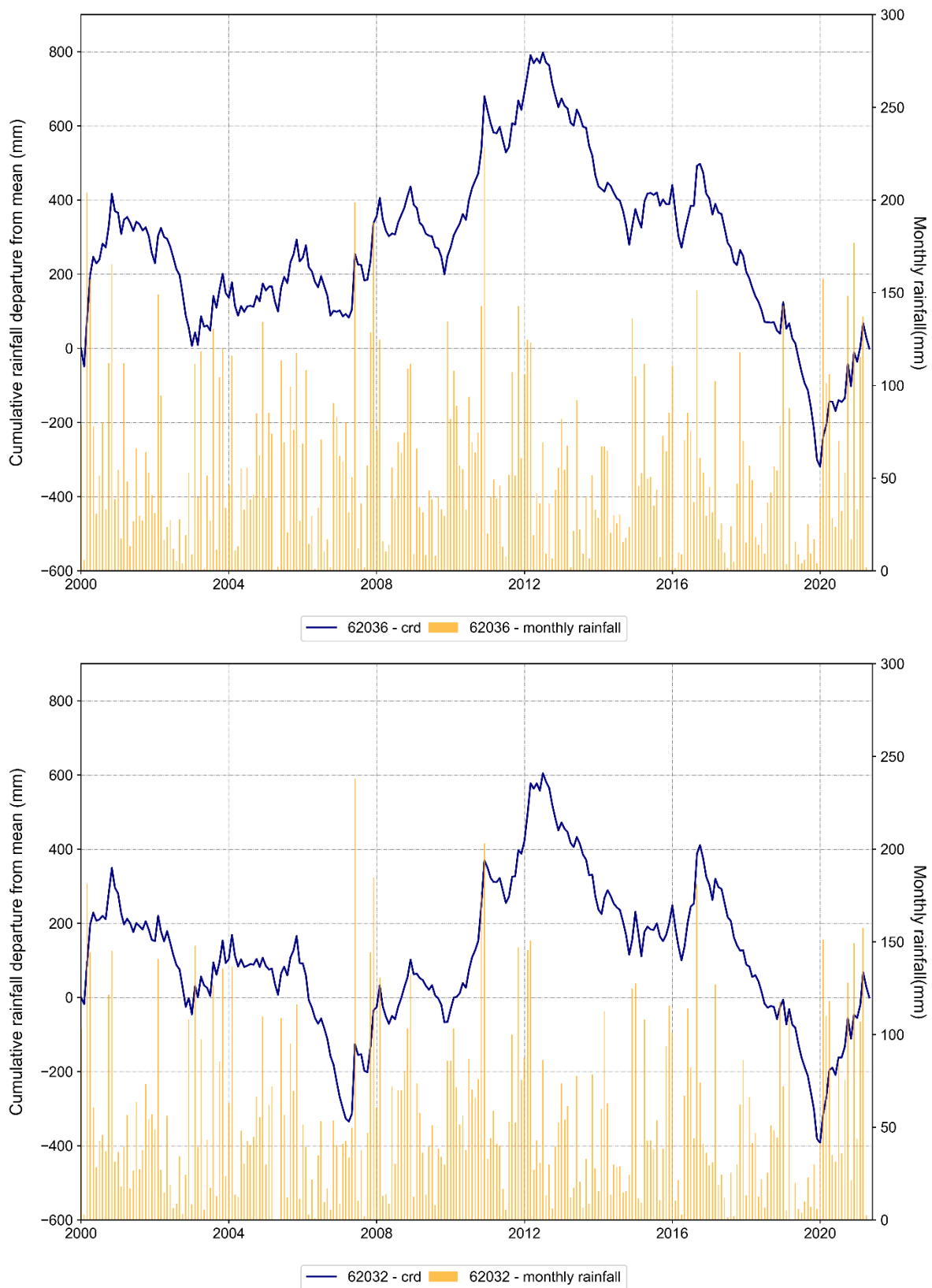


Figure 3.1 Cumulative Rainfall Departure and monthly rainfall (SILO) (Ulan and Wollar Stations)

3.2.2 Evaporation

Evaporation data was obtained from Ulan Station 062036 and Wollar Station 062032. A summary of the monthly averages are presented in Table 3.2. A summary of SILO average monthly rainfall and pan evaporation is shown on Figure 3.2 for the Ulan Station. Figure 3.2 indicates that groundwater recharge is unlikely to be high due to the high evaporation rates relative to rainfall. Recharge rates depend on a range of factors including soil type, geology, topography, vegetation and dominant land use. Despite the high average evaporation rates, recharge will occur sporadically when rainfall activity promotes saturation of the soil profile, and evaporation is insufficient to remove the soil moisture. During these periods there is potential for deep drainage to underlying groundwater systems.

Table 3.2 Monthly average pan evaporation data for the Ulan station

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Station 1*	228.2	179.4	155.6	103.3	64.8	44.3	49.7	72.0	105.0	150.8	184.9	227.7	1565.7
Station 2**	223.7	175.6	152.3	102.5	65.2	45.5	51.9	74.1	106.2	150.9	182.7	224.7	1555.3

Notes: * Ulan Station, 62036 (1906-2021).

** Wollar Station 62032 (1901-2021).

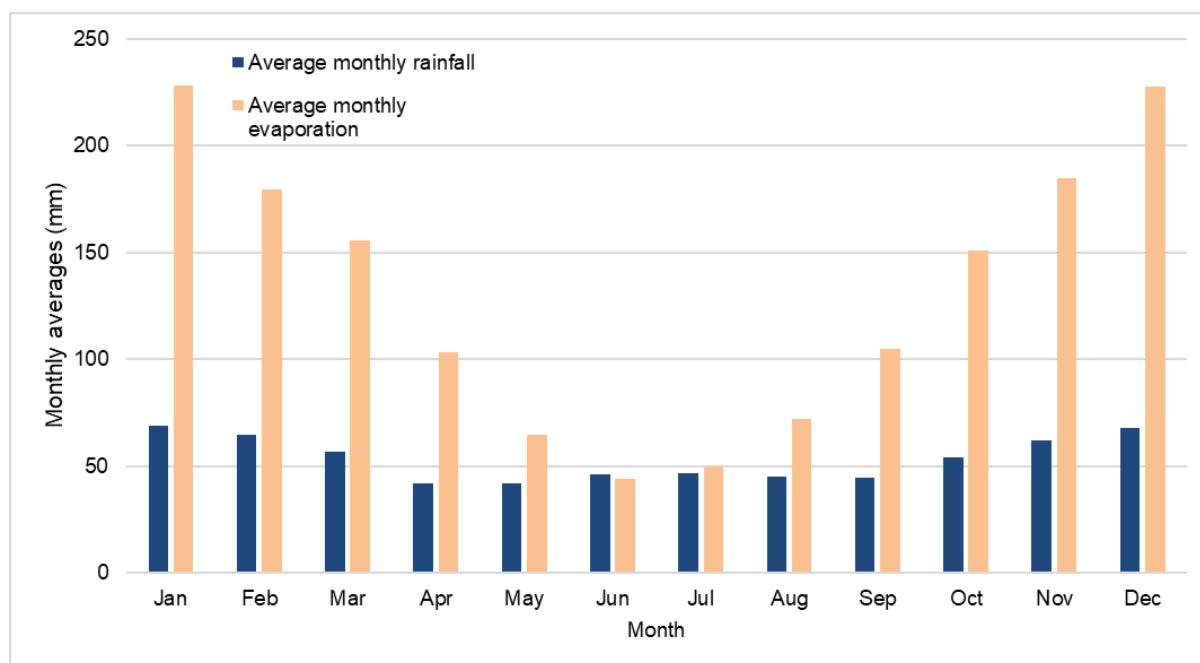


Figure 3.2 Monthly average SILO rainfall and pan evaporation (Ulan Station)

3.3 Terrain and Drainage

The UCC is located at the headwaters of both the Goulburn River system and the Talbragar River system. Figure 3.4 shows the regional river systems and topographical setting of the UCC and the proposed modification footprint. The catchments for these river systems are separated by the Great Dividing Range, with the Goulburn River system draining east into the Hunter River Catchment, and the Talbragar River system draining west to the Macquarie River Catchment and the Murray-Darling Basin. All the tributaries within the UCC boundary draining to the Goulburn River and Talbragar River are ephemeral by nature.

The proposed modification area lies within the Mona Creek catchment. The Mona Creek catchment is part of the Talbragar River system. An image taken of the dry Mona Creek bed is shown in Photo 3.1. Mona Creek is an ephemeral creek system, with flows only occurring during storm events or after prolonged rainfall. The Mona Creek catchment area is approximately 4720 ha (Umwelt, 2009). Groundwater interaction with surface drainage was modelled using the river package of the modelling software applied, U.S. Geological Survey modular finite-difference flow model (MODFLOW) and is discussed in more detail in Appendix A.



Photo 3.1 Mona Creek (17/01/2019)

3.3.1 River water quality

3.3.1.1 Talbragar River

The Talbragar River is monitored by WaterNSW on a daily basis in the river channel at Elong Elong about 50 km west of the mine lease boundary. While this location is beyond the area of interest, it does provide a useful indicator of regional water quality. Results over the period 2000 to 2007 (WaterNSW database, 2021) indicate that Electrical Conductivity (EC) has an average value of around 1500 $\mu\text{S}/\text{cm}$ but falls significantly (for short periods of time) during intense rainfall events and can increase steadily to 2000 $\mu\text{S}/\text{cm}$ during prolonged dry periods (Figure 3.3).

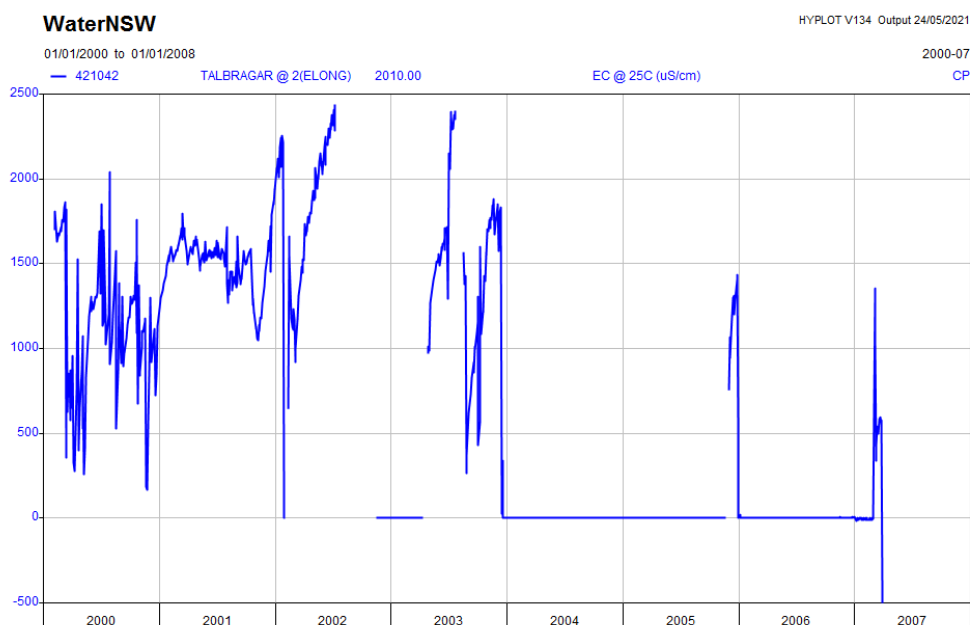


Figure 3.3 WaterNSW EC plot for river station 421042, Talbragar river at Elong Elong

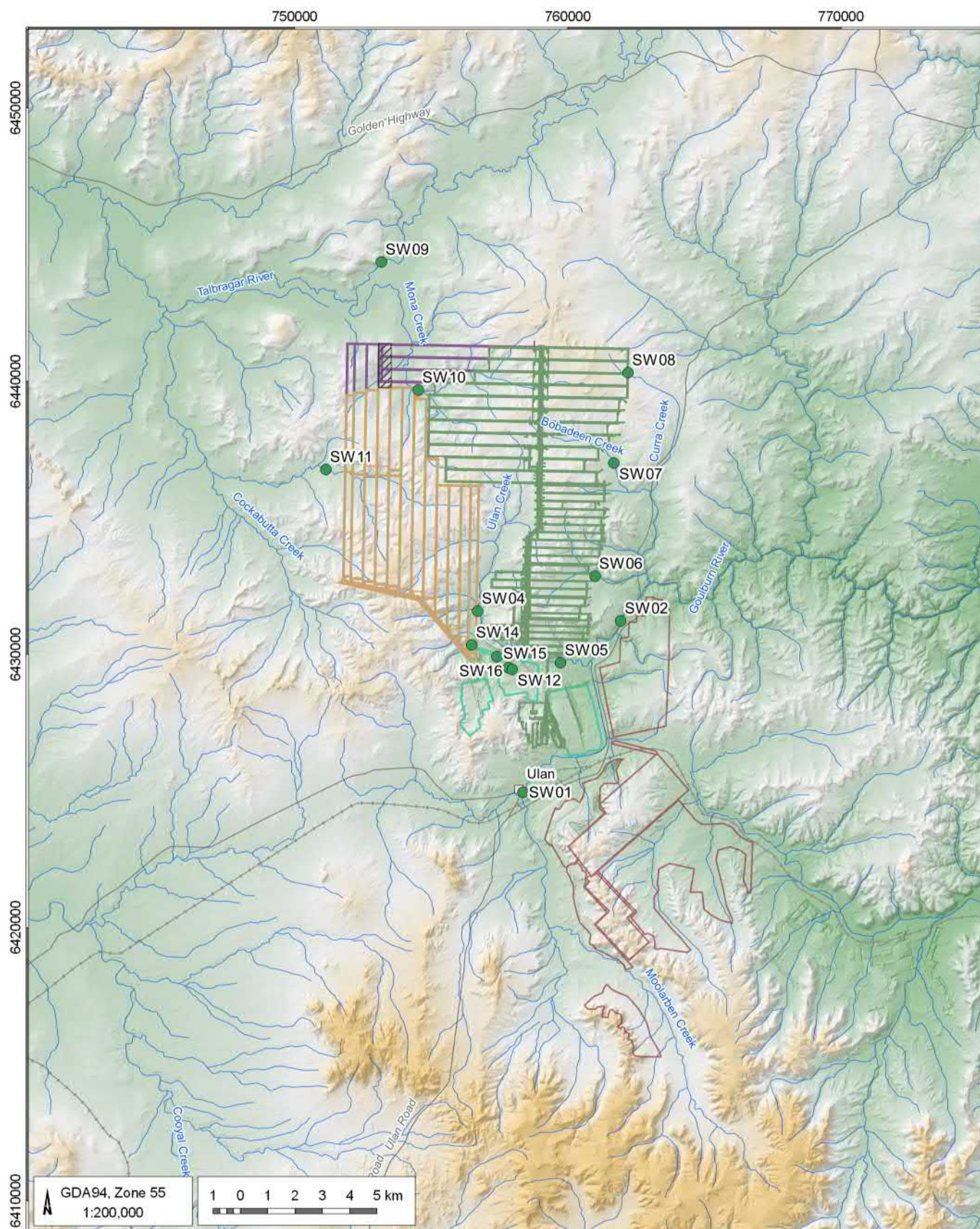
The Talbragar River (SW09, Figure 3.4) is sampled by UCMPL (UCMPL, 2021a) as part of the surface water monitoring program. Since sampling commenced in 2011, 52 samples have been collected from the Talbragar River to the north of the proposed modification, upstream of the confluence with Mona Creek. The EC measurements for the available data set ranges between 145 and 1680 $\mu\text{S}/\text{cm}$, while pH levels range between 6.7 and 9.3 and TDS between 182 and 968 mg/l.

3.3.1.2 Mona Creek

The tributary most relevant to the proposed modification is Mona Creek. Water quality sampling for Mona Creek (SW10, Figure 3.4) commenced in 2011 (UCMPL, 2021a), however fewer samples have been collected compared with the Talbragar River, as Mona Creek flows less often. Twenty two samples have been collected in total from Mona Creek. Analysis of the samples indicates a range of EC measurements between 30 and 955 $\mu\text{S}/\text{cm}$, while recorded pH levels range between 6.1 and 7.5 and TDS between 64 and 674 mg/l.

3.3.1.3 Cockabutta Creek

Water quality sampling for Cockabutta Creek (SW11, Figure 3.4) also commenced in 2011 (UCMPL, 2021a). Twenty samples have been collected from the creek since monitoring commenced. Analysis of samples indicates the range of EC measurements is between 80 and 192 $\mu\text{S}/\text{cm}$, while recorded pH levels range between 4.9 and 7.1 and TDS between 69 and 203 mg/l.



LEGEND

- Populated place
- Surface water monitoring locations
- Road
- Rail
- Major surface drainage
- Minor surface drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area

Flexibility area

Elevation (mAHD)

- 300
- 400
- 500
- 600
- 700

Ulan MOD6 GIA (G1985G)

Terrain and drainage



AGE

DATE
11/08/2022

FIGURE No:
3.4

4 Geological Setting

The UCC is situated at the western edge of the Sydney Basin, and at the southern end of the Gunnedah Sub-basin. The stratigraphic sequence across the mine area comprises Permian Illawarra Coal Measures, Triassic Narrabeen Group and both Jurassic Pilliga sandstone and Purlewaugh siltstone (Table 4.1 and Figure 4.1.). Tertiary volcanics and Quaternary sediments are also present in localised areas around the site. The overall geological understanding of the site has not changed since the 2009 numerical model development (MER, 2009), although a more recent geological model obtained from UCMPL was used to define the base of the Ulan Seam across the UCC (AGE 2018).

The Permian and Triassic strata are stratified and dip gently towards the north-east at less than two degrees. Each of the key geological units and their hydrogeological characteristics are discussed further below.

Table 4.1 Summary of site stratigraphy

Age	Unit	Description
Quaternary	-	Alluvium/colluvium – comprising soil, silt, clay, sand and gravel
Tertiary	- Liverpool Range Volcanics	Alluvium (palaeochannels) Weathered basalts
Jurassic	Pilliga sandstone Purlewaugh Siltstone	Coarse grained quartzose sandstone, lithic sandstone, conglomerates, claystone and shale
Triassic	Wollar Sandstone (Narrabeen Group equivalent)	Quartzose and lithic sandstone, conglomerates and claystone
Permian	Illawarra Coal Measures	Interbedded claystones, siltstones, sandstones (fine to coarse grained), conglomerate and coal seams

4.1 Quaternary and Tertiary alluvium/colluvium

Quaternary alluvium and sediments are restricted to areas along creeks, including Mona Creek, Ulan Creek, Bobadeen Creek and Cockabutta Creek. The alluvium comprises fine to coarse grained sands and gravels within a silt/clay matrix. Thicker sequences (up to ~ 20 m) of alluvium are present at the confluence of Ulan Creek and the Goulburn River, and approximately 750 metres to the northwest of the proposed modification in areas adjacent to the Talbragar River (refer to Section 5.1.2). Away from these thicker sequences, colluvium is present at the margins of the alluvium, and in some of the tributaries feeding into the alluvium.

As the proposed modification will progress longwall mining under the Mona Creek, the unconsolidated sediments in the valley have been assessed through additional studies. These studies have involved drilling and assessment of sediment particle size distribution. This work concluded that the sediments are colluvium in origin, with minor pockets of disconnected sand lenses which may form short term water storages after recharge events (refer to Section 5.1.1.1). Alluvium has been mapped for Cockabutta Creek, approximately 1.7 kilometres to the west of the approved mining, at its closest point.

4.2 Tertiary volcanics

The tertiary basalts are part of an extensive lava field, which extends from northern Queensland to Victoria. The basalts unconformably overlie and intrude all pre-Cretaceous rocks. Sills and plugs have caused contact metamorphism in the country rocks and erosion has reduced these rocks into peneplains, plateaus and valley fills. Only small outcrops of basaltic intrusions are present to the south and southeast of the proposed modification area as presented in Figure 4.1 as “Tb”. North of the UCC the tertiary basalts become more extensive as part of the Liverpool Range Volcanics formation and provide a cap over the Jurassic and Triassic sediments.

4.3 Jurassic sediments

The Jurassic sediments are present at the northern limits of the UCC. The Jurassic sediments comprise the Pilliga Sandstone and Purlewaugh Siltstone. The Pilliga Sandstone comprises cross-bedded sequences of ferruginous, coarse grained quartzose sandstone, conglomerates, claystone and shale. The Pilliga Sandstone is relatively permeable and forms a groundwater aquifer where it is present. Where these sediments exist across the mine area, they are unsaturated, with the aquifer widely utilised only to the east and north of the mine area.

The underlying Purlewaugh Siltstone comprises siltstone, mudstone and fine to medium grained lithic sandstone. The Purlewaugh Siltstone is a low permeability unit that likely forms an aquitard (MER, 2009). At the UCC the Jurassic sediments are largely unsaturated. The lower permeability of this formation allows the overlying Pilliga Sandstone to form a perched groundwater system where saturation occurs.

4.4 Triassic Wollar Sandstone (Narrabeen Group)

The Triassic aged Wollar Sandstone, which is equivalent to the Narrabeen Group, is present across the UCC. The unit thickens towards the north, and ranges between 10 m and 120 m thick across the UCC. The Wollar Sandstone comprises two depositional units, a shallower quartzose unit and the deeper lithic unit. The quartzose unit comprises a thick sequence (up to approximately 90 m) of cream to yellow, cross-bedded porous sandstone, conglomerates and claystone. The lithic unit is thinner (up to approximately 35 m) and comprises light grey/green, poorly sorted sandstone.

The Wollar Sandstone is largely a stratified/bedded unit with variable hydraulic properties. As documented for the Narrabeen Group, the coarser grained sandstone units can form aquifers and claystone units can form aquitards (Australian Government, 2016). At the UCC the Triassic sediments are variably saturated.

4.5 Permian Illawarra Coal Measures

The Permian aged Illawarra Coal Measures are present across the UCC and are around 145 m thick. The coal measures conformably underlie the Triassic Wollar Sandstone and comprise interbedded claystones, siltstones, sandstones (fine to coarse grained) and coal seams. The coal seams include the Middle River, Moolarben, Glen Davis, Irondale and Ulan Seams. The Ulan Seam is the main economic seam at site, is around 10 m thick and occurs approximately 90 m below the base of Triassic. Underlying the Ulan Seam is the Marrangaroo Conglomerate, which comprises weakly cemented conglomerates and medium to coarse grained sandstones. A stratigraphic column showing increased detail for the coal resources is provided as Figure 4.2 (UCMPL, 2017).

Groundwater storage and movement occurs within the coal seam cleats and fissures. Other sediments in the coal overburden and interburden sequence are relatively impermeable and form aquitards. Some Permian sandstones yield minor groundwater, although in the mined section of the coal measures, these are rare.

The Permian strata is therefore categorised into the following hydrogeological units:

- hydrogeologically “tight” and hence very low yielding to essentially dry (when drilling) sandstone and siltstone that comprise the majority of the Permian interburden/overburden; and
- low to moderately permeable coal seams which are the prime water bearing strata within the Permian sequence.

The Permian coal measures are confined to semi-confined within the region. However, the coal measures are depressurised locally due to historic and current mining activities.

4.6 Structural geology

A north to north-east trending fault (Spring Gully Fault) is present on the eastern extent of the UCC (Figure 4.1). The fault is near vertical, with an approximate 8 m (up to approximately 10 m maximum) displacement in the Permian and Triassic sediments.

Two north-east trending faults are also mapped east of Spring Gully Fault, and a northwest trending fault is present west of Ulan West Underground, near Broken Back Creek. The nature of these faults is largely unknown, with only minor observations of the Spring Gully Fault gained through mining adjacent to it.

The Spring Gully fault has been drawn on Figure 5.22 based on details provided by Glencore Geologists. The Curra Creek and Green Hills faults were not depicted on cross sections, due to a paucity of data, specifically relating to exploration borehole spacing near these features.

A spring gully fault assessment was completed by McElroy Bryan Geological Services (MBGS, 2011) and determined that there was only one place in the mine workings where the Spring Gully Fault was intersected with any confidence. The location was associated with a cavity of at least 10 metres where intersected, and associated with a very soft clay. The clay was described to be similar in nature to a cement slurry flowing out along the floor of the mine workings. MBGS reported that at LW 15 to 22, there was a general practice of mining as far as possible east, but not as far as to intersect the Spring Gully Fault. As a consequence, broken ground was often intersected, but it was concluded that the Spring Gully Fault had not been intersected. MBGS also reported that the eastern extent of longwall development has been well west of the Spring Gully Fault. Accordingly, no observations relating to the variability of groundwater ingress due to the Spring Gully Fault are available.

MBGS (2011) concluded that the northern extent of the Spring Gully Fault has been interpreted to finish just south of the eastern extremity of LW 25. AGE notes this coincides roughly with the location of Bobadeen Creek.

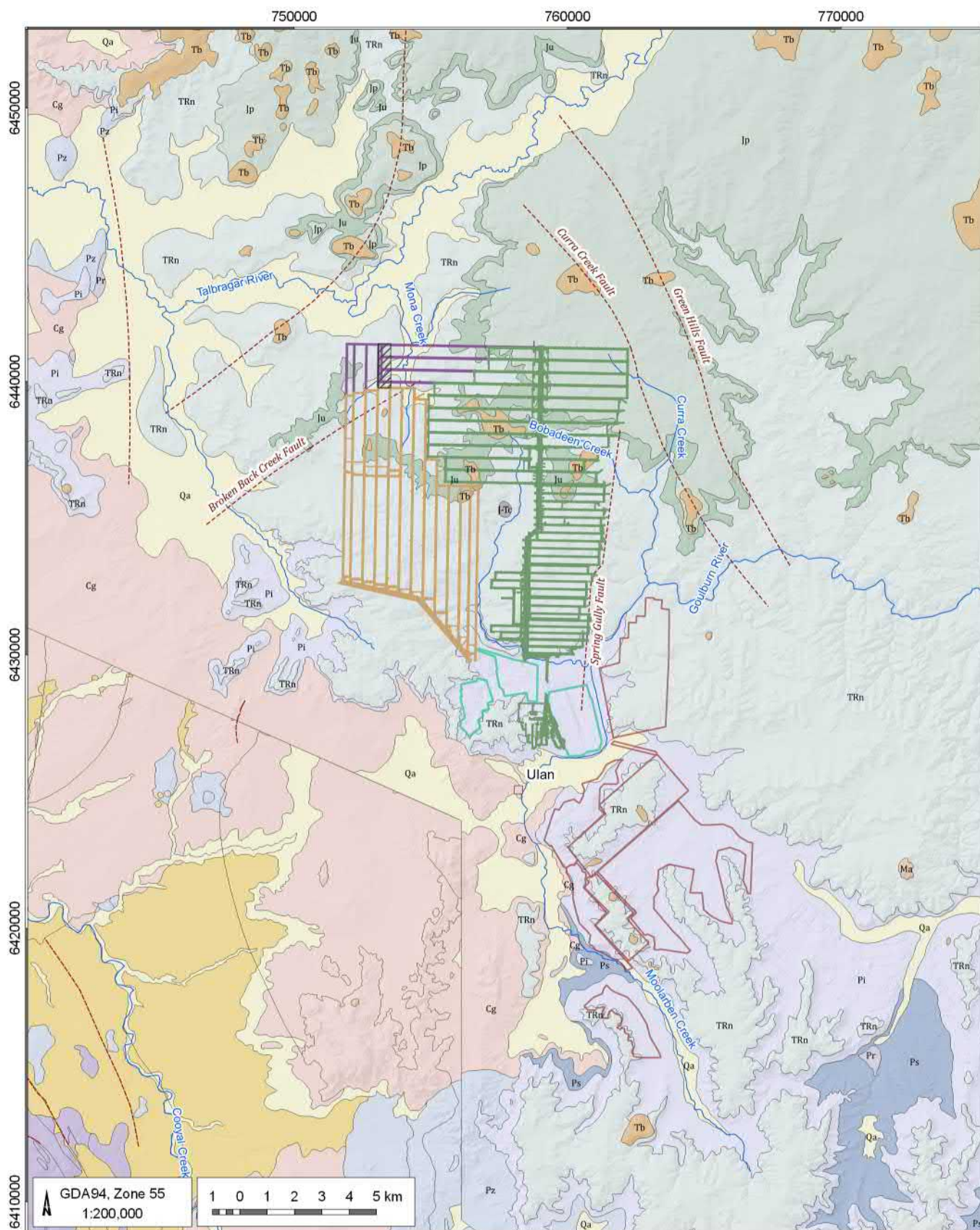
Table 4.2 provides details of monitoring bores located in proximity of the Spring Gully Fault. See Figure 5.23 for the location of these bores. From Table 4.2 (and Figure 5.23) it is clear that most of the UCC groundwater monitoring which occurs in proximity to the Spring Gully Fault, occurs to the west of the fault. A comparison of groundwater levels from PZ08C and R755A show only a minor head difference (of approximately 6.5 m) within the Triassic sediments, however these bores are both north of Bobadeen creek and the inferred extent of the fault.

To the south, groundwater monitoring data from EAST07 shows that pressures within the Ulan Seam have continued to decline throughout the monitoring record, which suggests that the fault is not an effective barrier for groundwater flow.

Table 4.2 Groundwater monitoring bores adjacent Spring Gully Fault

Bore ID	Comment	Unit Monitored	Date	RSWL (mAHD)
PZ08B	West of Fault	Permian	27/03/2018	304.10
PZ08C	East of Fault	Triassic	6/12/2018	396.22
R755A	West of Fault	Triassic	6/12/2018	389.64
MG22	West of Fault	Ulan Seam	23/02/2018	242.79
MG21	West of Fault	Ulan Seam	18/10/2017	240.63
PZ04A	East of Fault	Triassic	6/12/2018	397.95
EAST18	West of Fault	Ulan Seam	19/12/2018	253.88
EAST15	West of Fault	Ulan Seam	15/11/2018	267.95
EAST10	West of Fault ??	Ulan Seam	19/12/2018	285.68
EAST09	West of Fault ??	Ulan Seam	19/12/2018	302.87
EAST07	East of Fault ??	Ulan Seam	19/12/2018	302.99

Given the relatively minor vertical displacement and coupled with the lack of hydrogeological observations made with respect to the Spring Gully Fault, AGE has assumed that the faults do not represent a significant barrier to groundwater flow and hence have not been modelled explicitly as discrete features.



LEGEND

- Populated place
- Major surface drainage
- Fault
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- Flexibility area

Western Coalfield (north) Regional Geology (1:100k)

- Qa - Quaternary alluvium
- Tb - Tertiary basalts
- J-Tc - Jura-Tertiary volcanics
- Ip - Pilliga Sandstone
- Ju - Purlawaugh Formation
- Ma - Late triassic intrusions, phonolite
- TRn - Narrabeen Group
- Pi - Illawarra Coal Measures
- Ps - Shoalhaven Group
- Pr - Rylstone Volcanics
- Cg - Carboniferous granite
- Pz - Undifferentiated Palaeozoic

Ulan MOD6 GIA (G1985G)

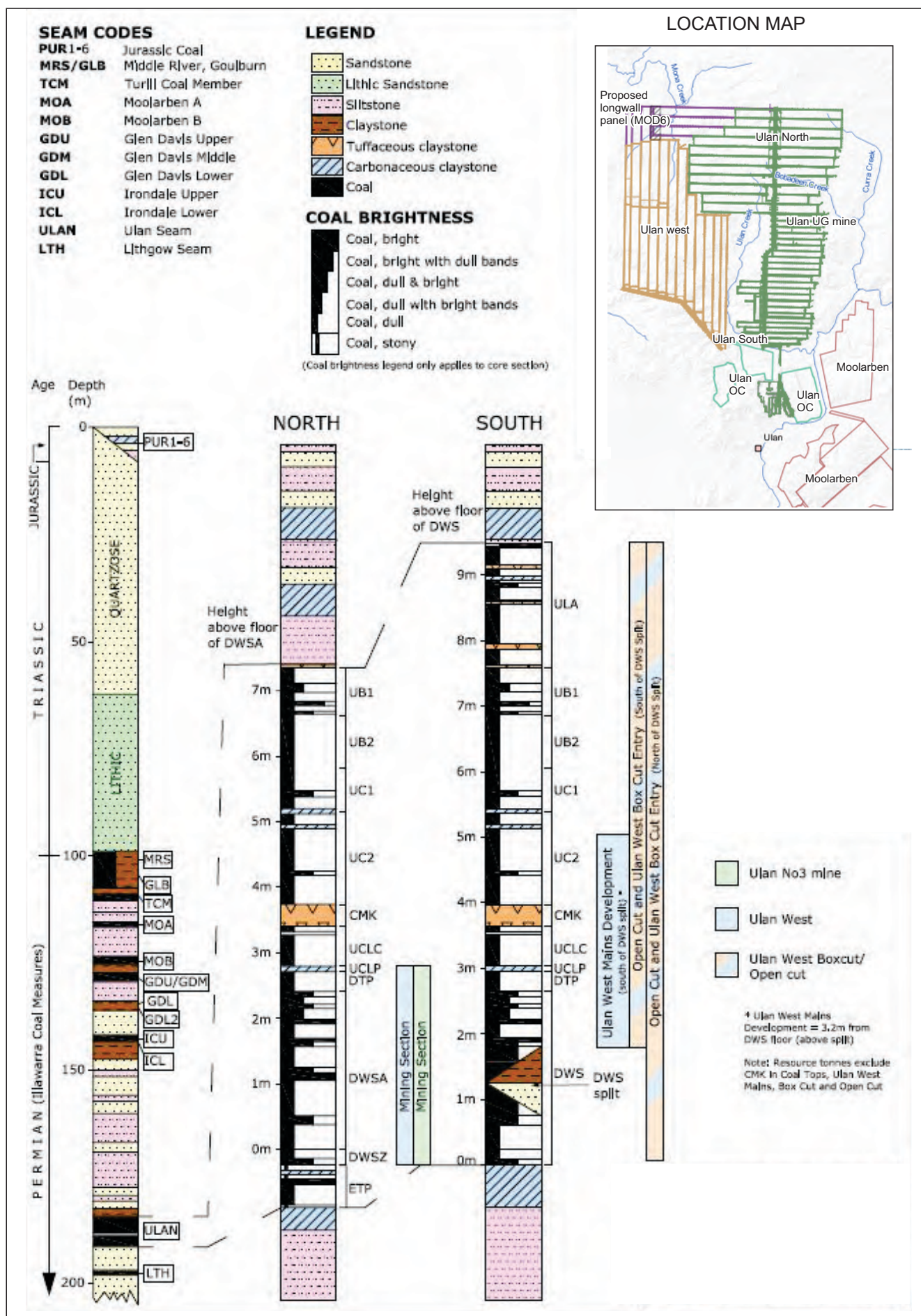
Site Geology



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FIGURE No:
4.1



Typical stratigraphic column at Ulan (UCMPL, 2017)

Figure 4.2

Ulan MOD6 GIA (G1985G)

5 Hydrogeology

5.1 Hydrostratigraphic units

The hydrostratigraphic units occurring at the UCC have been described through various groundwater investigations, the most recent being prepared by AGE (2018) as part of the MOD4 application. The primary hydrostratigraphic units in the region are:

- unconsolidated alluvial sediments occurring along the creek lines;
- shallow regolith and near surface weathered rock profiles; and
- Triassic, Jurassic and Permian formations.

5.1.1 Unconsolidated alluvium

The most significant alluvial groundwater systems in the area surrounding the UCC are associated with tributaries of the Talbragar and Goulburn Rivers. Alluvial sediments can be broadly classified as either shallow Quaternary valley fill sediments (substantive along the Talbragar River and relatively minor along other drainages west of the Great Divide), or deeper Tertiary sediments (noted particularly in the Moolarben area east of the divide). Quaternary (and Recent) alluvium east of the divide is more localised (MER, 2009).

According to MER, 2009, the alluvium tends to be a mixed sequence of sands, silts and clays as determined from a small number of bores identified as part of a regional bore census undertaken by UCMLP. Groundwater contained within these sediments occurs at depths of 10m or so, with estimated saturated thicknesses of alluvium of the order of 20 to 25m. Minor occurrences in the upper reaches of Mona Creek and Broken Back Creek, were drilled in late 2008 and piezometers were installed as part of the UCMLP regional groundwater monitoring program. Results have shown the alluvium to be thin (less than 5m) and comprised of sandy, silty deposits with limited saturated thickness. Most test holes were dry.

As indicated earlier in Sections 3.3 and 4.1, the tributary most relevant to the proposed modification is Mona Creek. The sediments in the valley of Mona Creek are identified as alluvium in broad scale geological mapping, however more detailed characterisation work carried out for the proposed modification has identified that these sediments are colluvial in nature (refer to Section 5.1.1.1). The sediments within the Mona Creek valley are spatially limited, and relatively clay bound with more permeable zones formed in lenses that are not well spatially interconnected. The characteristics of the Mona Creek sediments is discussed in more details below in Section 5.1.1.1.

5.1.1.1 Mona Creek sediment assessment

Part of the proposed longwall extensions are situated underneath the Mona Creek area. As mentioned above, additional work was completed by AGE (AGE 2020a) to assess the potential for the proposed modification to significantly impact on groundwater resources associated with Mona Creek. Multiple lines of evidence were used to assess the nature and extent of the groundwater system present within the unconsolidated sediments that occur along the alignment of Mona Creek. These included regional geological mapping, site inspection, geophysics, sediment analyses, and monitoring bore installation. The outcome of the assessment is summarised below.

NSW government has published geological maps of the area at 1:100,000 scale that show the occurrence of Cenozoic deposits. The mapping subdivides the deposits into alluvial and colluvial sediments and is reproduced on Figure 5.1. The mapping indicates the Talbragar River and the Mona Creek flood plains are dominated by alluvial sediments. Figure 5.1 also shows the spatial extents of highly productive alluvium as defined in the AIP (DPI-Water, 2012a), approximately 7.7 kilometres to the West of the approved mining area, as depicted in the map produced by DPI-Water (2012b). Highly productive alluvium is alluvium with yields of greater than 5 L/sec and with a salinity of less than 1,500 mg/L. The figure shows that Mona Creek and the adjacent section of the Talbragar River is not classified as a highly productive groundwater source. Further to this, the Mona Creek area is not considered to be BSAL (Office of Environment & Heritage, 2013).

In 2015, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) published maps indicating potential thicknesses of regolith across Australia. Regolith is the zone of unconsolidated rock that forms from the weathering of rock outcrops. Because of its similar unconsolidated nature, zones of alluvium can often be detected in the CSIRO regolith maps. Figure 5.2 shows the estimated thickness of regolith along Talbragar River, Mona Creek and associated tributaries. On Figure 5.2, the 15 m regolith thickness was considered to be the best approximation of the potential limit of the sedimentary sequence in Mona Creek prior to additional data collection. Analysis of the data set shows that the regolith is up to 23 m thick in the northern parts of Mona Creek, close to the confluence with the Talbragar River. Typical thicknesses of regolith identified in the CSIRO Mapping range between 7 m and 19 m in the Mona Creek area.

Long term observations and understanding of the Mona Creek alluvium is that there is limited groundwater supply, and that it is highly reliant on rainfall recharge for opportunistic take. Mackie Environmental Research (MER, 2015) in the 2015 MOD3 report described alluvium associated with Mona Creek as “relatively minor and commonly less than 5 m thick”. This was based on some test pits that were either dry or only damp.

A geophysical survey of the sediments within the Mona Creek valley was undertaken in August 2019. Ultramag used Deep Ground Penetrating radio RADAR (DGPR) to visualise the subsurface sediments to a depth of approximately 50 m. The dataset obtained by Ultramag Geophysics identified a number of anomalies that have been interpreted to represent possible paleo-channels, faults and joints, and the Triassic sandstone contact. The location of the features identified through the DGPR survey are shown on Figure 5.3 including the presence of a thin paleo-channel within the Mona Creek valley. The location of the Triassic sandstone subcrop represents the sides of the Mona Creek valley that are covered with colluvial material derived from the Triassic sandstone ridges and cliffs that lie adjacent the creek. The geophysical survey also identified possible locations of structural features (joints and/or faults) within the Triassic Sandstone which are also shown in Figure 5.3.

The paleochannel defined through the DGPR survey was identified as a target for the installation of groundwater monitoring bores. Monitoring bores were installed at three sites along the paleochannel with paired bores installed at each site (a total of 6 bores). The location of the bores is shown on Figure 5.3 at sites MCMB01, MCMB03 and MCMB04.

At MCMB01 two bores were drilled targeting the near surface sediments and underlying Triassic sandstone. The deeper of these two bores was MCMB01B and was drilled to 30.95 metres below ground level. This bore did not intersect any significant water bearing sediments until around 30 m depth, which was below the base of weathering (at 23 m) and within the Triassic sandstone (indicative of the regional water table in this area). There was some dampness noted in the first 5 m of drilling, but this discontinued with depth.

At MCMB01, the shallow bore was drilled to a depth of 6.3 m, just metres away from the deep bore. This bore did encounter shallow groundwater. Prior to bore development the standing water level was measured to be less than a metre below ground level. More recent water level measurements have occurred at 2 mbgl. It is understood that this bore intersects some shallow sediments which may have been recharged due to the preceding rainfall, and has formed an ephemeral perched water table. It is also understood that during the development of this bore (where water is pumped out of the borehole) the water level was very slow to recover. Recovery was so slow that a post drilling standing water level could not be obtained in the time allocated. These observations are consistent with the intersected strata, consisting of a layered sequence of shallow sand and clay lenses, with the shallow system effectively isolated and not connected to a broader / more pervasive alluvium (where recovery would have readily occurred).

Perched water tables were also detected at the two other sites drilled, where the shallow monitoring bores recorded a water level higher than the deeper bores. Perching was less pronounced at MCMB04 where difficulty drilling and constructing the deeper bore may be impacting on the measured water levels. Drill logs indicate that the unconsolidated sediments comprise clay-bound sands and gravels. Site MCMB04 is close to the Talbragar alluvium, and is the only site to be logged as alluvium, showing 2.5 to 3 m of sand matrix with poorly sorted gravels and weathered igneous fragments.

In August 2020, UCMPL staff collected samples of unconsolidated sediments occurring along Mona Creek to allow measurements of particle size distribution at various depths. The purpose of the sediment distribution analysis was to determine if the sediments could be classified as alluvial or colluvial based on particle size distribution. Alluvial sediments are commonly defined as sediment that has been deposited by river flow or flood waters, at some distance from its source. This results in sediments that have been generally well sorted into sand and gravel fractions in riverbeds, and finer silt and clay fractions where overbank flood waters settle. Colluvium (in contrast) is sediment that has been transported by rain-wash and / or slope creep, and tends to collect at the base of slopes and / or in surface depressions. As the sediment has travelled shorter distances (compared with alluvium) and is less subject to the physical abrasion from flowing water, the sediment is generally poorly sorted, with a wider range of sediment grain size.

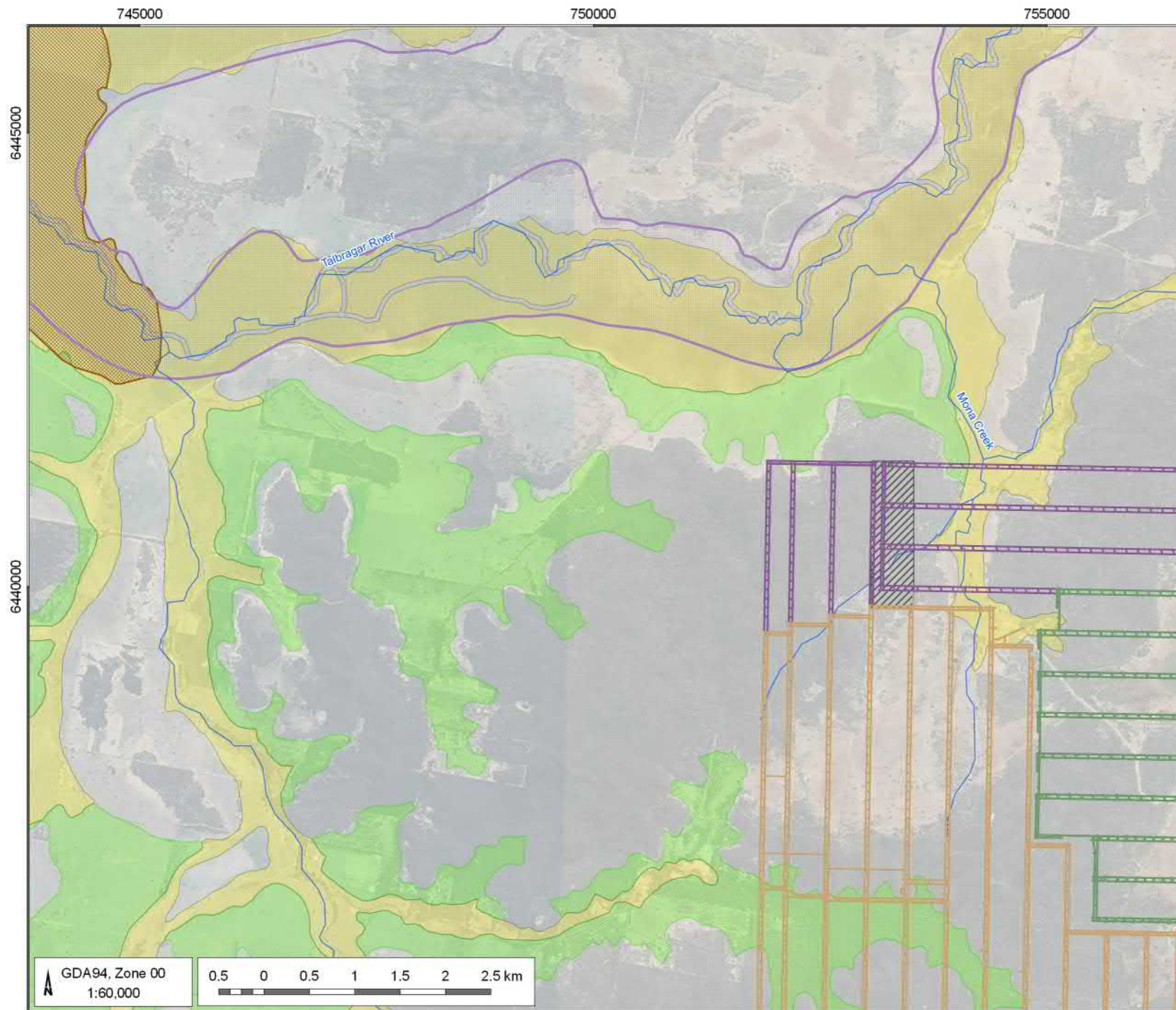
Where alluvial sediments are sorted into thick assemblages of porous and permeable sand and gravel fractions, they can form productive groundwater systems. In contrast, the permeability and porosity of colluvial sediments is commonly reduced by the presence of fine-grained sediments within the matrix. The NSW Aquifer Interference Policy (AIP) identifies alluvial sediments as potentially forming productive groundwater sources. No such classification exists for colluvial sediments.

A total of 196 sediment samples were collected along transects that traversed the Mona Creek valley. The samples were sent to a laboratory for particle size distribution analysis. Statistical analysis of these results identified that 23 were 'very poorly sorted', while the remaining 173 samples were 'extremely poorly sorted'. Based on this analysis, all collected samples can be considered as colluvium origin.

Drilling investigations and geophysics indicate the presence of a thin and shallow alluvial paleochannel occurring within the Mona Creek valley. The alluvial material is characterised by poorly sorted clay, silt and sand sediments. Outside this thin sinuous paleochannel, the sediments are thinner and overly the sandstone bedrock. The sediments are characterised by poor sorting, more indicative of a colluvial origin (from surrounding slopes). Where more permeable sands and gravels occur, these are expected to form laterally disconnected lenses. Where sands and gravels occur with poor sorting, they are often clay bound. Recent drilling indicates that water levels associated with the valley sediments are perched higher and disconnected from the regional water table associated with the underlying Triassic Sandstone.

The limited permeability and porosity within the Mona Creek valley sediments results in the sediments forming localised perched groundwater lenses on top of the underlying lower permeability bedrock. The silt and clay bound nature of the Mona Creek valley sediments means localised perched groundwater lenses are ephemeral and slowly drain into the underlying bedrock, and downgradient (to the north) over time. Any areas of cleaner sands and gravel are not well connected. Poor lateral continuity means that connectivity with persistent pools in the creek will be highly variable.

A Local landholder noted that historically, shallow groundwater was accessed in dry times by digging into the Mona Creek valley sediments (*pers. comm* Geoff Mitchell - landowner). Where unconsolidated sediments are present within the Mona Creek valley, the area has been cleared, and is used for grazing purposes. Therefore, there is not expected to be any groundwater dependent vegetation occurring in the area.



LEGEND

- Populated place
- Major surface drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- Flexibility area

BSAL land

Groundwater productivity (AIP 2012)

Alluvial - Highly Productive Zone

NSW seamless geology (1:100k)

Alluvial valley deposits

Colluvial and residual deposits

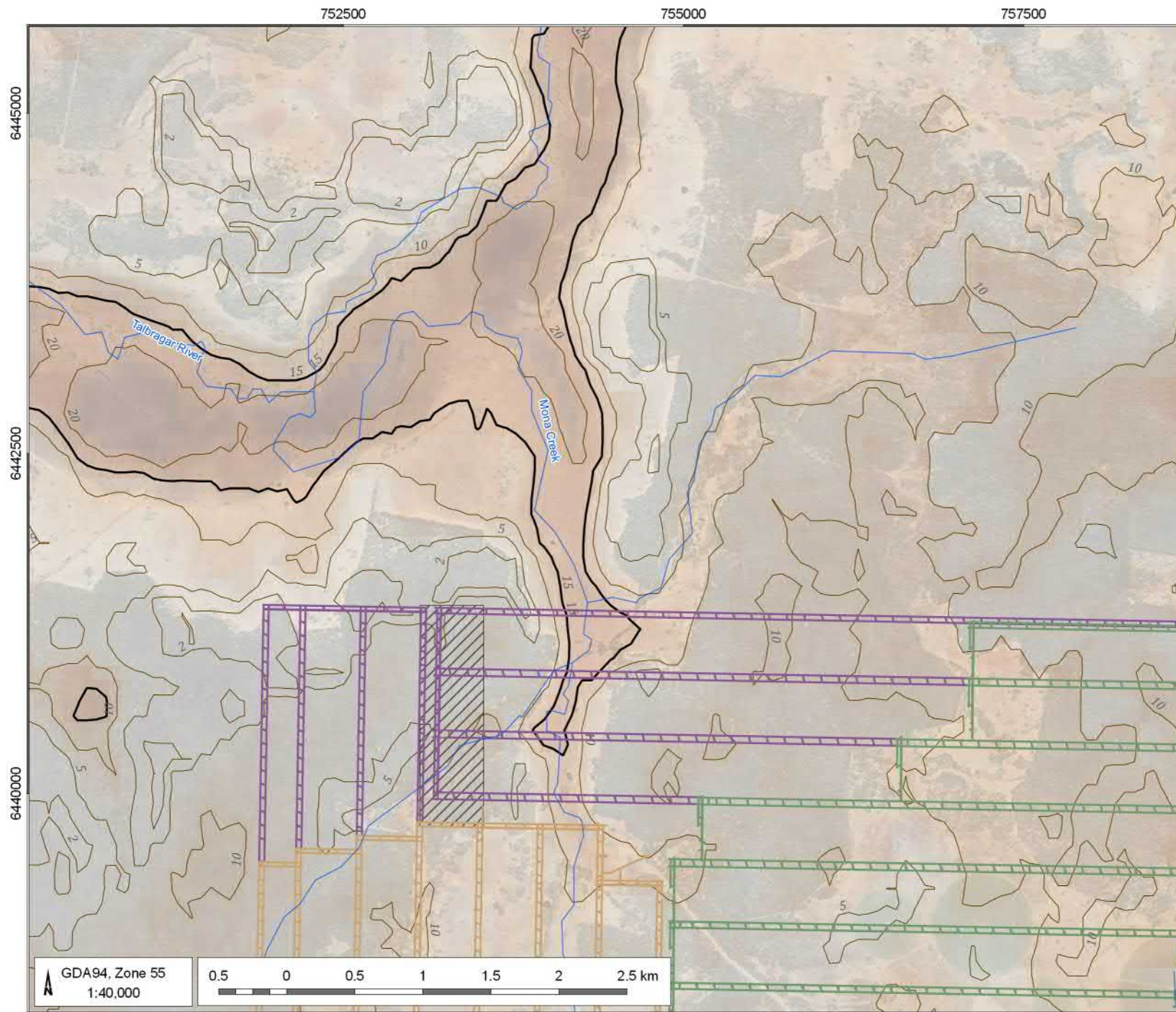
Ulan MOD6 GIA (G1985G)

Geological mapping and legislative boundaries



DATE
11/08/2022

FIGURE No:
5.1



LEGEND

- Populated place
- Major surface drainage
- Regolith depth - greater than 15 m
- Regolith depth contour (m)
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- Flexibility area

Regolith depth (m)

- 1
- 2
- 5
- 10
- 12
- 15
- 20
- 22
- 25

Data Sources:

CSIRO Depth of Regolith Release 2. V5
(Wilford et. al. 2015)

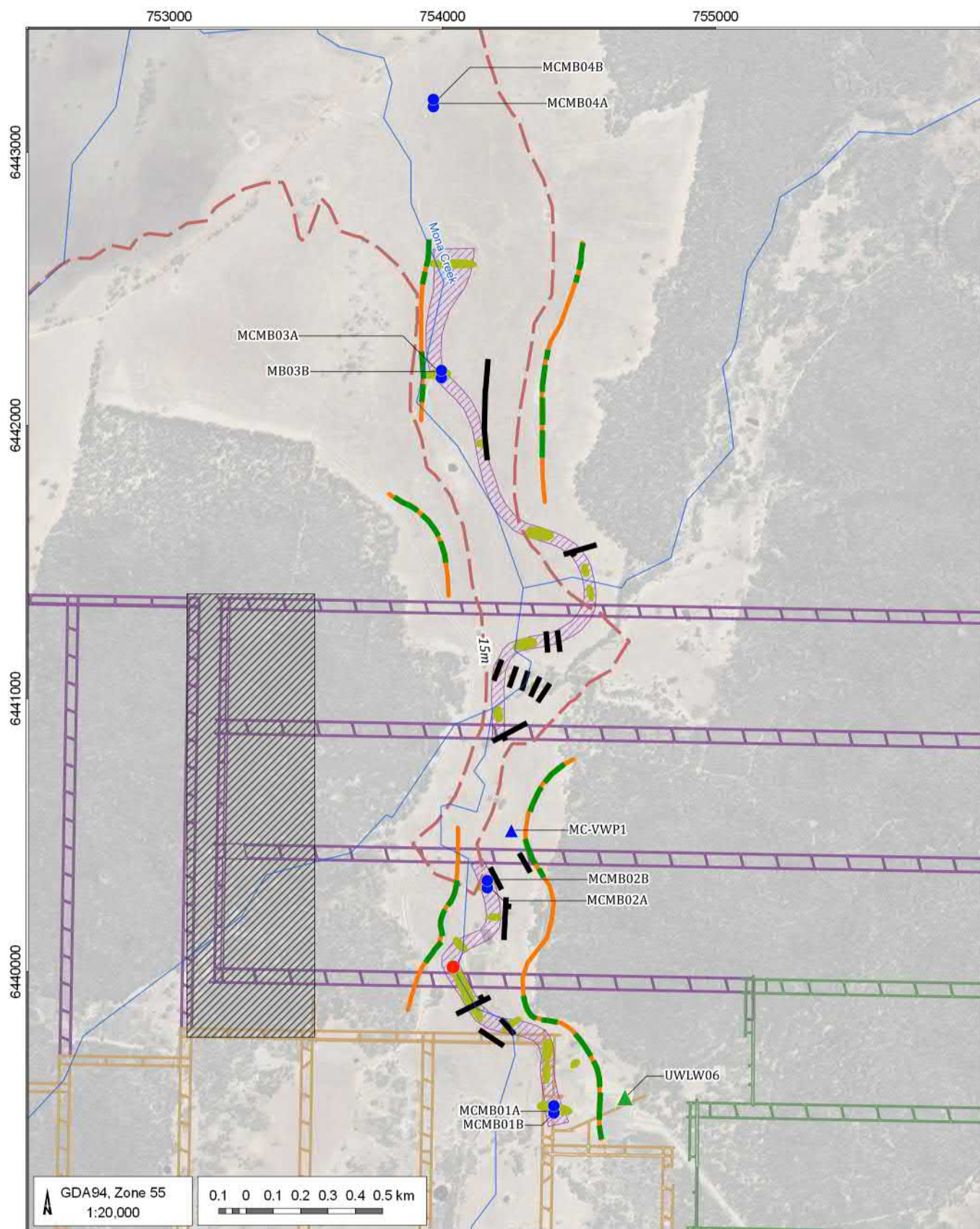
Ulan MOD6 GIA (G1985G)

Depth of regolith, Mona Creek Area (CSIRO)



DATE
11/08/2022

FIGURE No:
5.2



LEGEND

- Populated place
- Major surface drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- Monna Creek Paleo-channel
- Alluvial channel - DPGR
- Flexibility area

- Depth of regolith - greater than 15 m contour
- Inferred fault or joint (Triassic sandstone)
- Triassic sandstone - DPGR survey
- Triassic sandstone - AGE
- Landholder test bore
- Monna Creek Monitoring Bores
- Monna Creek VWP
- Pleuger monitoring network bore

Ulan MOD6 GIA (G1985G)

DPGR survey and monitoring bore locations



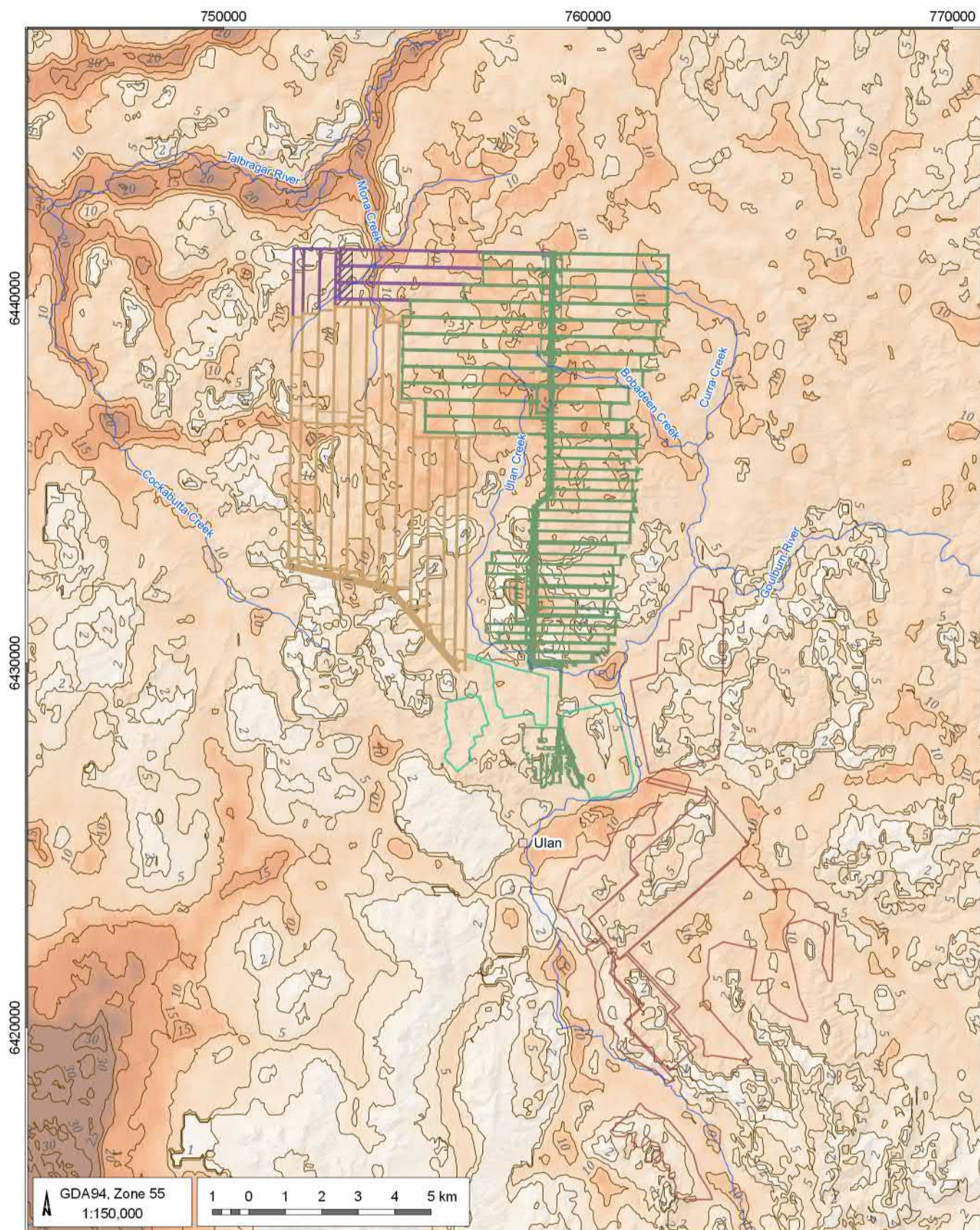
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FIGURE No:
5.3

5.1.2 Shallow regolith and weathered rock

As shown in Figure 4.1, beyond the areas mapped as Quaternary alluvium, the dominant surface cover material consists of undifferentiated colluvium and residual soils (or regolith). The shallow regolith and weathered rock profile can host unconfined groundwater during extended wet periods when the recharge rate exceeds the rate of downward movement or lateral flow. In situ weathering of consolidated strata at outcrop is also an important process in most Australian landscapes. The regolith material, which is typically clay dominated, forms a cap over the underlying 'fresh' strata. Whilst regolith material is typically not shown on geological maps, its thickness has been estimated by the CSIRO (Wilford et al., 2015) who have developed a depth of regolith product, which estimates the thickness of the Quaternary cover (i.e. alluvium, colluvium and regolith) across the whole of Australia. Reference to this CSIRO dataset suggests that the depth of regolith over consolidated formations in the area varies between 5 to 15 m below the ground, but can be as deep as 20 m towards the major creek lines north of the proposed modification area. Figure 5.4 shows the estimated thickness of regolith specific to the Mona Creek area, while Figure 5.4 shows the regional regolith mapping. The regolith cover (where present within the proposed modification area) is thought to be relatively thin and dominated by low permeability clay strata which are the result of weathering and decomposition of the underlying consolidated strata.



LEGEND

- Populated place
- Major surface drainage
- Regional depth contour (m)
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- Flexibility area

Regolith depth (m)

- 1
- 2
- 5
- 10
- 15
- 20
- 25

Ulan MOD6 GIA (G1985G)

Depth of regolith, Regional Mapping (CSIRO)



AGE

DATE
11/08/2022

FIGURE No:
5.4

5.1.3 Deeper hard rock groundwater systems

The bedrock comprises a sequence of Jurassic, Triassic and Permian age sedimentary rocks. Historical reporting has sometimes referred to these units as the deeper hard rock groundwater systems. The coal seams targeted by mining occur within the Permian coal measures, and are overlain by Triassic and Jurassic units. These form unconfined, semi-confined and confined groundwater systems where groundwater is held predominantly as interstitial storage. The Triassic and Jurassic sandstones are more porous and permeable; compared with the underlying Permian coal measures. Within the coal measures, the coal seams are the most permeable layers with the non-coal interburden being relatively impermeable (MER 2015).

The Ulan Seam is identified as the main water bearing zone within the Permian strata as the nature of the coal (containing cleats and/or being fractured) allows the lateral movement of water more freely than the other Permian units (MER 2015). MER (2015) states that *“historical mining at Ulan has caused depressurisation of the Seam of more than 10 km beyond mining areas. This seam depressurisation has induced some vertical leakage and pressure losses within adjacent strata in these distant strata. However, non-coal strata [in the Ulan Seam roof] appear to act as an aquitard, effectively inhibiting downward leakage”* (MER 2015).

Water yields to bores installed within both the weathered and deeper hard rock groundwater systems within the UCC have been low. There has been extensive depressurisation of the deeper hard rock groundwater systems within and surrounding the UCC, as a result of approved mining operations. The depressurisation from mining is demonstrated in Figure 5.6 to Figure 5.8, which show depressurisation in Permian monitoring due to mine dewatering, partial dewatering in the Triassic due to increased drainage in the fracture zone, and unaffected / perched water levels in the Jurassic monitoring data.

5.2 Hydraulic properties

The hydraulic properties that govern groundwater storage and flow across the broader region vary considerably between the unconsolidated Quaternary alluvial systems and the confined hard rock Permian groundwater system associated with the coal measures. The hydraulic properties of the hydrostratigraphic units associated with the proposed modification are summarised in the sections below.

5.2.1 Hydraulic properties of alluvium and colluvium

Measured hydraulic conductivities of alluvium associated with the Goulburn River range from 0.01 to 10 m/day (MER, 2009). Hydraulic properties of the alluvial deposits along the Talbragar River, have not been measured, however, since the materials comprise a similarly mixed assemblage of clays, silts, sands and gravels, the horizontal hydraulic conductivity range is expected to range from 0.01 to 50 m/day with an effective porosity between 1% and 20%. The vertical conductivity range is expected to be lower. With the proportion of clays and silts being substantially higher in the Mona Creek colluvium, the horizontal hydraulic conductivity range is expected to range from 0.1 to 5 m/day with a specific yield between 0.1% and 6%. The vertical conductivity range is expected to be lower.

5.2.2 Hydraulic properties of hard rock strata

Hydraulic testing has been conducted by UCMPL in the hard rock strata within the UCC as part of regional hydrogeological evaluations over a number of years (MER, 2009). Test procedures have historically comprised conventional packer injection type testing and test pumping. Laboratory measurements on strata core have been conducted to establish an expected range in matrix hydraulic conductivities, together with bulk and effective porosities. Other measurements that have contributed to the hydraulic properties knowledge base include parameters relating to geomechanical properties – sonic velocity, unconfined compressive strength and Young's modulus.

Testing of the Ulan Seam and other strata has also been undertaken in the Moolarben area (Moolarben, 2006) as part of environmental impact assessment studies. This information has been used to supplement UCMPL data and indicates that the permeability and storativity of the Permian coal measures is variable. Permeability is generally higher in the coal seams, but is occasionally enhanced in the interburden sediments (generally sandstone, siltstone and mudstone) due to localised fracturing. The Ulan Seam is termed an aquifer by virtue of its relatively higher permeability when compared to the interburden sediments.

The interburden sandstones, siltstones and mudstones are of significantly lower permeability than the Ulan Seam (by one or more orders of magnitude) and they generally act as aquitards. The hydraulic conductivity reported in this work range between 4×10^{-3} to a maximum outlier of 11 m/day, with the median 2.9×10^{-1} m/day.

MER (2009) reports on packer testing that was been completed at eight exploration borehole locations. Testing was conducted using either a single packer drill stem assembly (e.g. borehole DDH242) or a straddle packer assembly with test intervals varying from 3 m to 6 m. Test procedure comprised measurement of the rate of clean water injection to test intervals over a range of injection pressures. Laboratory tests were conducted on selected core from two exploration holes; DDH242 in longwall panel LW24 in the UG3 area, and DDH340 in LW-UW8 in the Ulan West area. These tests were undertaken in order to provide improved estimates of intergranular matrix conductivity, and to examine the ratio of vertical to horizontal conductivity (anisotropy). Total porosity and effective porosity were also determined for selected samples. A summary of the data is provided in Table 5.1.

Table 5.1 Summary of core measurements by formation

Strata	Kv (LN) m/day	Effective Porosity (%)
Jurassic sandstones	2.15×10^{-3}	
Triassic quartzose sandstones	5.62×10^{-2}	6.1 to 16.9
Triassic lithic sandstones	2.66×10^{-4}	1.5 to 12.8
Permian sandstones	8.03×10^{-6}	0.3
Permian siltstones	4.13×10^{-7}	
Permian shales	1.98×10^{-7}	

Notes: Kv = vertical hydraulic conductivity.
LN = mean for log normal distribution.

Source: MER, 2009.

MER (2015) summarised the data derived from the processing of geophysical logs for bore DDH242 and other boreholes:

- Jurassic strata tend to exhibit variable but lower conductivities and higher anisotropies than the underlying Triassic quartzose sandstones;
- most of the Triassic quartzose samples submitted for laboratory analyses exhibit relatively high conductivities (near to or above $1.0\text{E-}02$ m/day) consistent with a medium grained porous and sometimes friable sandstone. Calculated conductivities from wireline logs correlate closely to measured conductivities;
- Triassic lithic sandstones are evidently less permeable than the Triassic quartzose sandstones with the upper 10 to 15 m exhibiting quite low conductivities; and
- Permian non-coal strata are the least conductive rocks being mostly below $1.0\text{E-}5$ m/day for sandstone-siltstone core samples.

Specific storage estimates ranging from $1.69\text{E-}06$ to $5.13\text{E-}06$ 1/m have been calculated for a modulus range from 3.1 to 17.7 GPa. Higher specific storage values may be associated with weaker porous Triassic sandstones and the coal seams. Aquifer properties applied for the proposed modification are discussed in more detail in the numerical groundwater model report captured in Appendix A.

5.3 Groundwater Monitoring and Monitoring bores

Routine groundwater monitoring is undertaken at the UCC as part of the conditions of PA 08_0184. The groundwater monitoring program is outlined in the Ulan Groundwater Monitoring Program (GWMP) that was updated in May 2019. The GWMP incorporates monitoring in accordance with the conditions of approval at the UCC, and on properties adjacent to the UCC.

The monitoring bore network at the UCC has been installed over a number of different campaigns since 1997. General construction details for the UCC groundwater monitoring network are listed in Appendix A 2, and locations are shown in Figure 5.5. The UCC has three main monitoring networks, the North Monitoring Network (NMN), Bobadeen Monitoring Network (BMN) and Pleuger Monitoring Network (PMN).

The NMN is the largest network, currently comprising 41 monitoring standpipes at 18 locations, as well as 11 vibrating wire piezometer (VWP) locations with a total of 43 sensors in operation. The currently monitored NMN intersects all key hydrogeological units, as presented in Table 5.2.

Table 5.2 NMN active network target lithology

Lithology	PVC standpipes	VWP sensors	No.
Mona Creek colluvial sediments	MCMB01A, MCMB03A, MCMB04A	-	3
Tertiary basalt	R752	-	1
Jurassic sediments	PZ09D, PZ10B, PZ14C, PZ26D, PZ28B	R894_119, PZ29_018 EX03_28, EX03_48, EX03_90, EX06_8, EX06_27, EX09_33, EX09_50, EX09_87	15
Triassic sediments	PZ01A, PZ04A, PZ06C, PZ07C, PZ08C, PZ09C, PZ10A, PZ11B, PZ12C, PZ14B, PZ24B, PZ26C, PZ28A, R755A, MCMB01B, MCMB03B, MCMB04B	DDH266_084, DDH270_76, DDH336_42, DDH336_62, DDH336_82, DDH336_102, EX03_160, EX03_201, EX06_55, EX06_70, EX06_94, EX06_120, EX09_126, EX09_209, DDH598_30, DDH598_54, R894_219, R894_255, TAL1_028, TAL1_045, UW2_050, PZ29_050, PZ29_072, PZ29_090, PZ29_122	42
Permian coal measures	PZ06B, PZ08B	TAL1_061, TAL1_097, TAL2_050, TAL2_090, TAL2_110, UW1_022, UW1_035, UW1_051, UW2_090, UW3_040, UW3_060, UW3_075, UW4_041, UW4_063, UW4_087, DDH336_122, DDH336_146, DDH336_167, PZ29_143, PZ29_183, DDH598_68, DDH598_119, DDH598_152, EX03_242, EX06_185, EX09_261	28
Permian coal seam (Ulan Seam)	PZ06B, PZ07B, PZ09B, PZ11A, PZ12B, PZ14A, PZ24A, PZ26B	DDH266_189, DDH336_183, TAL1_140, TAL2_128, UW1_061, UW2_110, UW3_098, UW4_122, PZ29_243, EX03_297, EX06_226, EX09_301	20
Permian coal measures beneath Ulan Seam	PZ06A, PZ07A, PZ09A, PZ12A, PZ26A	DDH266_192, DDH270_171	7
No.	41	73	114

Notes: R753A is included in the GWMP but no data is available for this bore.

DDH270 and DDH271 are in the GWMP but have not been functioning since 2014.

The BMN comprises nine open standpipes (IMW01 to IMW09) that intersect unconsolidated sediments within the upper catchments of Mona Creek, Ulan Creek, and Spring Gully Creek (in the vicinity of the Bobadeen Irrigation Scheme). IMW01 to IMW09 are shallow bores, which were installed primarily to monitor for evidence of groundwater mounding associated with the Bobadeen Irrigation Scheme, a Glencore owned asset. The BMN is not used for monitoring the impacts from mining.

The PMN comprises seven active mine dewatering bores (E20, MG22, MG26, MG27, MG28 and MG29 and UW TG1), as well as six decommissioned dewatering stations that are used for monitoring (East 7, East 9, East 10, East 15, East 18 and MG21).

Private landholder bores (PB bores) are also monitored, where access is granted. Little is known about the construction of the PB bores; however available details are presented in Appendix A 2. The location of the PB bores are presented in Figure 5.5.

5.4 Water levels

5.4.1 Groundwater occurrence and flow directions

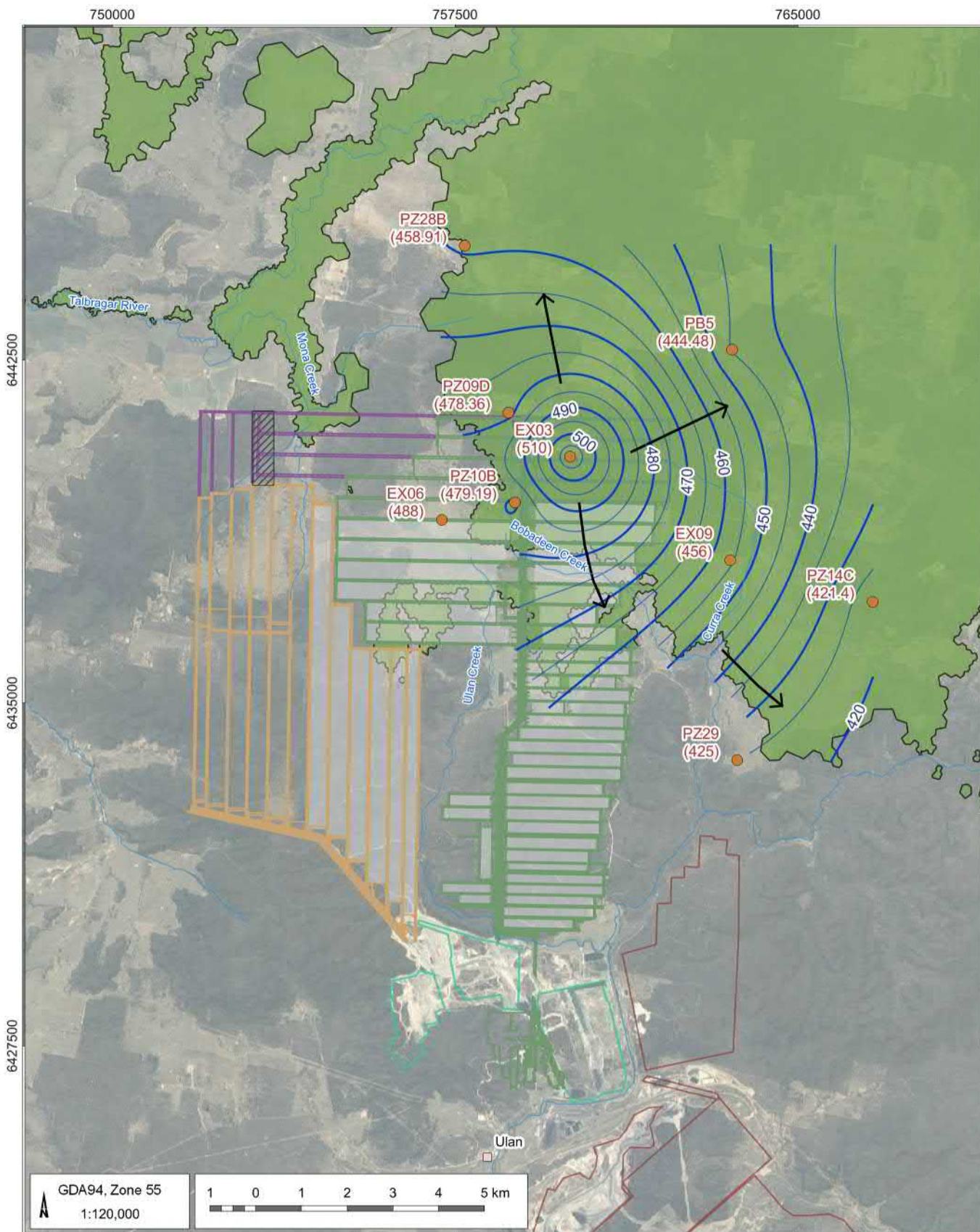
Groundwater within the Alluvium / Colluvium, Jurassic, Triassic and Permian strata in the area is held predominantly in the pore space of the hydro-stratigraphic units, as storage. This storage is a result of infiltration of rainwater from the surface. The Jurassic and Triassic sandstone and conglomerate units are more porous and permeable than the Permian units, which tend to consist of finer grained sediments. There is a secondary permeability associated with fracturing and jointing of the units. Secondary permeability has the potential to promote vertical connectivity between hydro-stratigraphic units that are generally separated hydraulically. As indicated in Section 5.1.3, the Ulan Seam is identified as the main water bearing zone within the Permian strata.

Groundwater level data for the various hydro-stratigraphic units was reviewed and groundwater flow directions were derived. The interpolated groundwater level data for the Jurassic sediments are shown in Figure 5.6 and based on the 2020 annual groundwater review data (AGE, 2021a). The water level varies significantly, from well above the mine footprint, down to water levels in the northwest that are consistent with the underlying layers. It is considered that the water levels measured in PZ10B and PZ09D above the mine footprint (and most likely PZ28B), are perched and disconnected from the regional water table. This conclusion has been reached based on:

- water level and response observed in R894_119 and PZ14C being consistent with the underlying Triassic formation water levels; and
- PZ10B, PZ09D located directly above the mine footprint record water levels significantly different (~90 m higher) than the underlying Triassic groundwater levels which suggests that any vertical fracturing from longwall mining does not extend as high as the Jurassic sediments in these locations.

The groundwater flow direction for the Triassic units (as shown in Figure 5.7) indicate confined conditions compared to the Jurassic units. This supports the conceptual model relating to the stratified nature of the Triassic sediments, and the presence of 'aquitards' still holds. Figure 5.7 shows that groundwater within the Triassic units in the mine area flow towards active mining (PZ08C). However, east of the mine area, the hydraulic gradient is gentler, with groundwater flowing south-east towards the Goulburn River.

Groundwater contours of the Ulan Seam are presented in Figure 5.8. Figure 5.8 shows groundwater depressurisation within the Permian coal measures, and flow towards the main active underground mine area.



LEGEND

- Populated place
- Major surface drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- Panels mined / being mined in 2020
- Modelled Jurassic Extent
- ▨ Flexibility area

- Monitoring bore (groundwater level, mAHD)
- Flow direction
- Groundwater level contours (mAHD)**
- Major contour
- Minor minor

Ulan MOD6 GIA (G1985G)

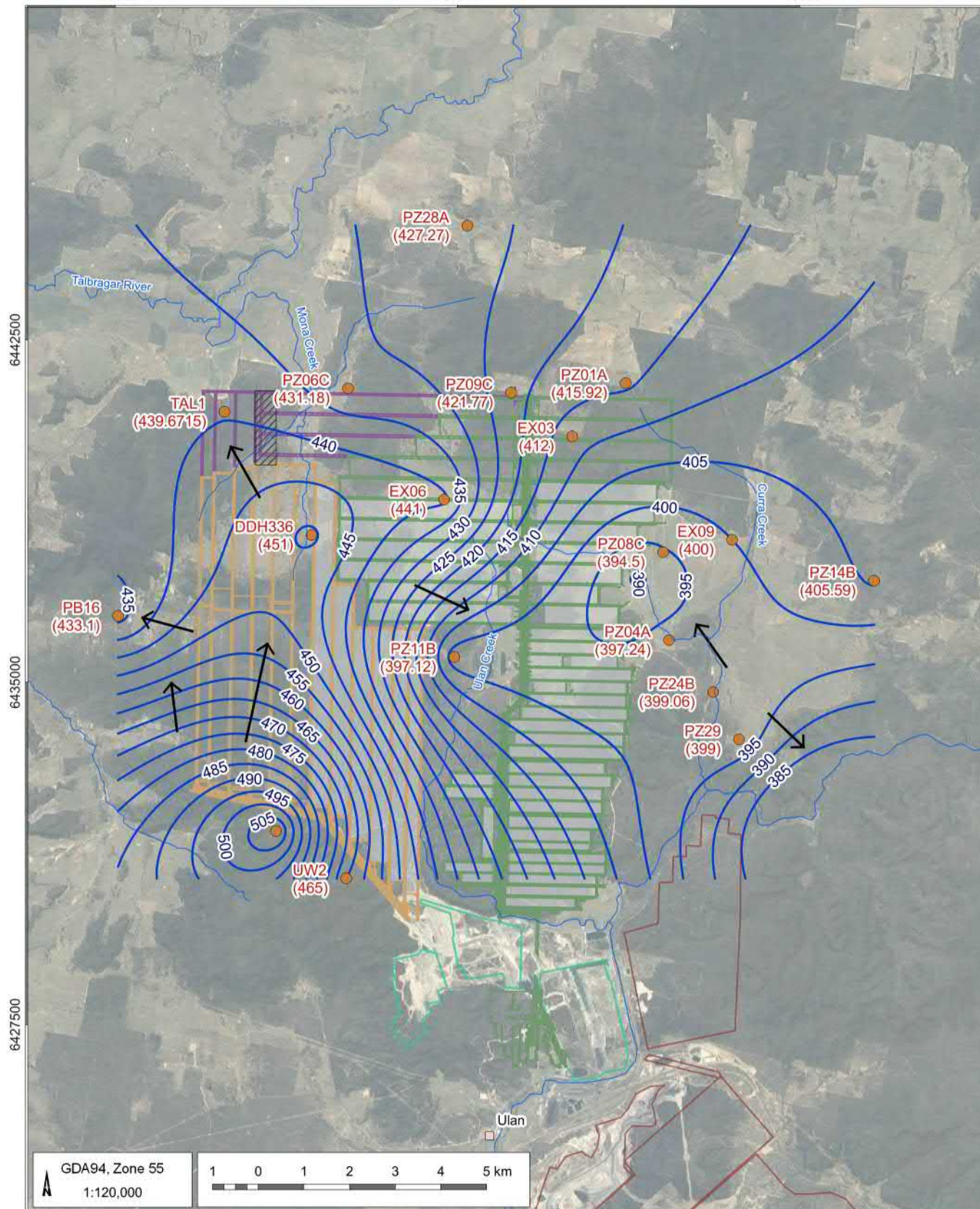
2020 Interpolated groundwater contours – Jurassic formations



AGE

DATE
09/09/2022

FIGURE No:
5.6



LEGEND

- Populated place
- Major surface drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- Panels mined / being mined in 2020
- Flexibility area

- Monitoring bore (groundwater level, mAHd)
- Groundwater level contours (mAHd)
- Flow direction

Ulan MOD6 GIA (G1985G)

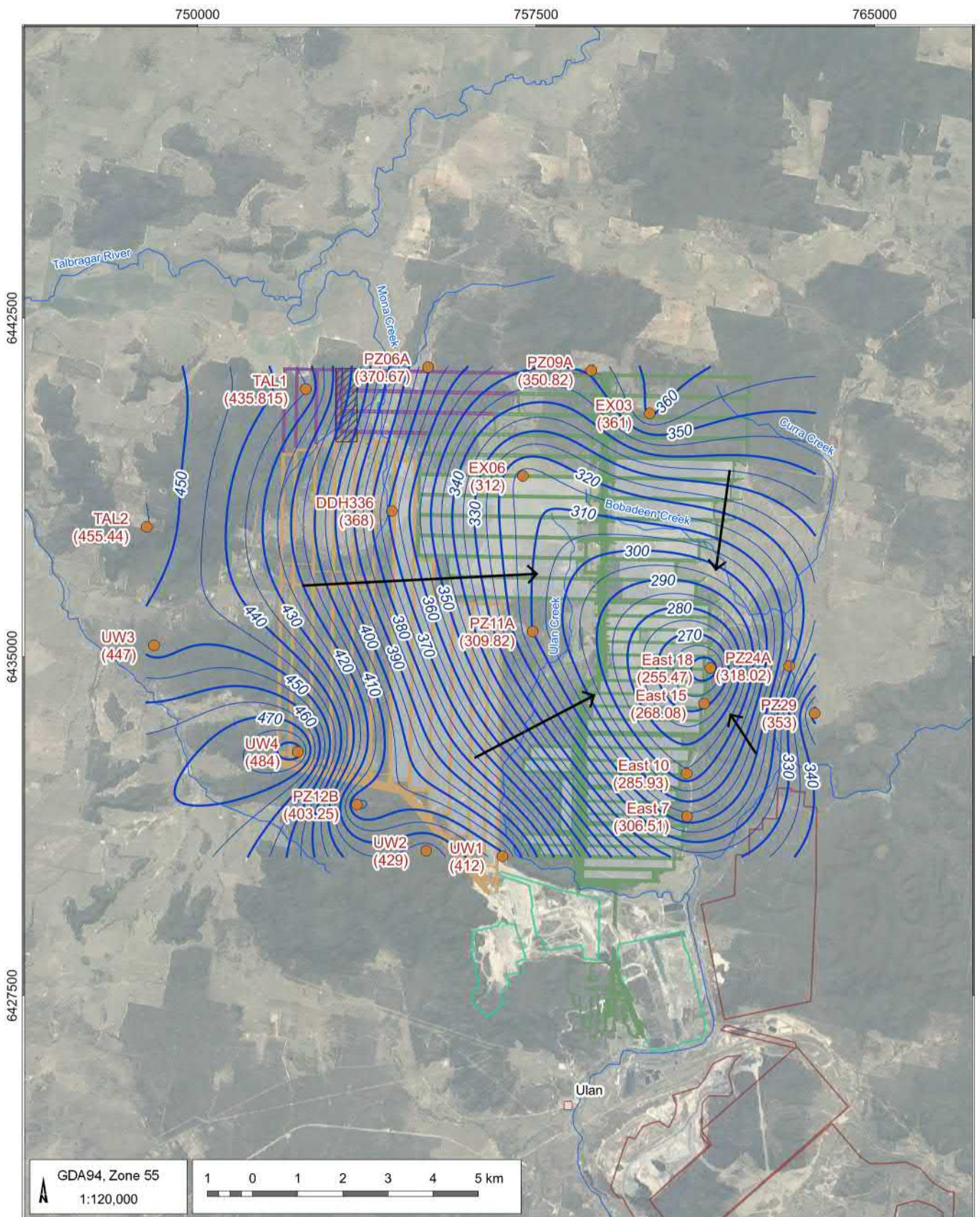
**Interpolated groundwater contours –
Triassic formations**



AGE

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09/09/2022

FIGURE No:
5.7



LEGEND

- Populated place
- Major surface drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- Panels mined / being mined in 2020
- ▨ Flexibility area

- Monitoring bore (groundwater level, mAHD)
- Flow direction
- Groundwater level contours (mAHD)**
 - Major contour
 - Minor contour

Ulan MOD6 GIA (G1985G)

2020 Interpolated groundwater contours – Permian formations



AGE

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09/09/2022

FIGURE No:
5.8

5.4.2 Hydrographs

5.4.2.1 Jurassic

It is evident from the hydrograph representing the Jurassic sediments in Figure 5.9 that generally stable groundwater levels occur, which supports the conclusion that these aquifer systems are perched and are not impacted by mining in the underlying strata. The four monitoring bore hydrographs shown were selected because they represent typical responses from the Jurassic sediments.

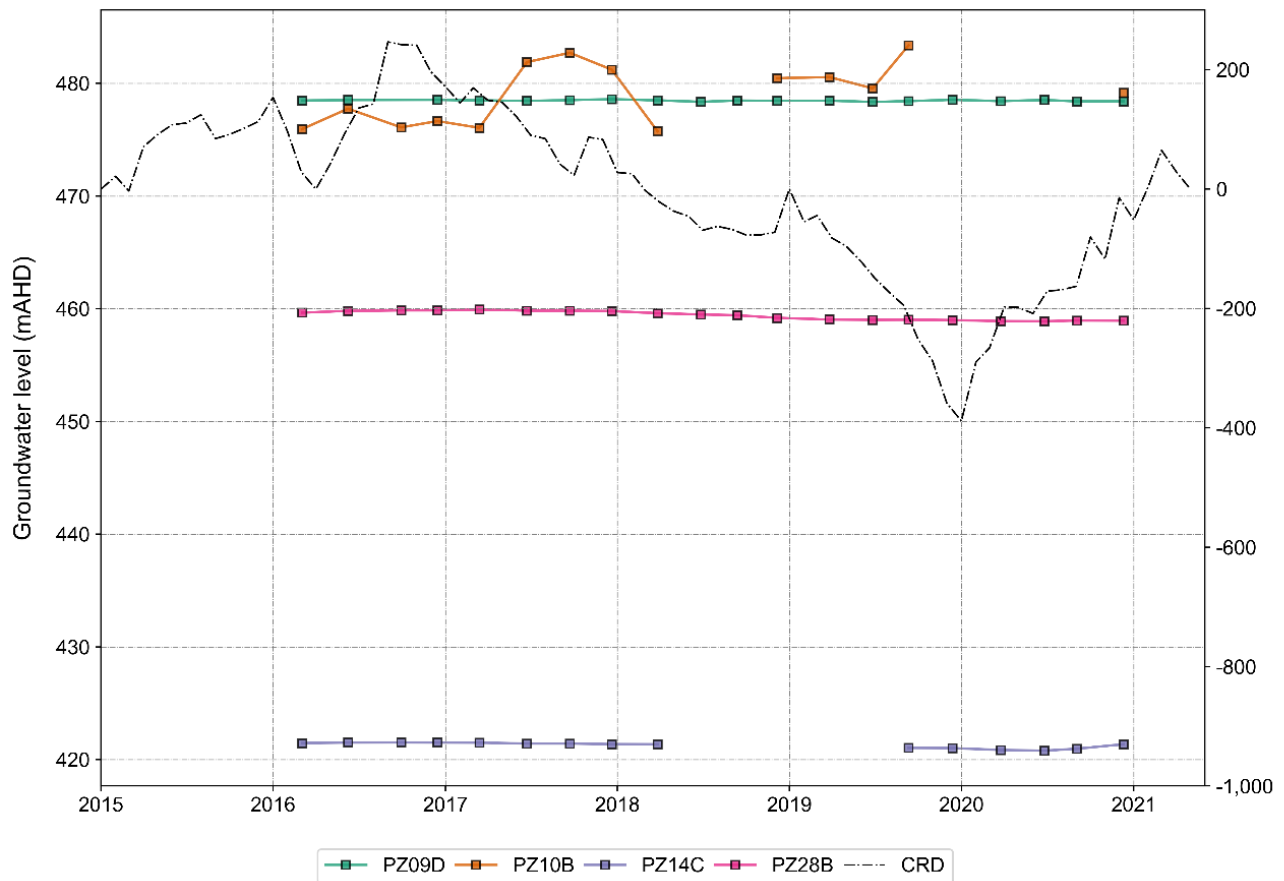


Figure 5.9 Jurassic monitoring bores hydrographs

5.4.2.2 Triassic

The Triassic sediments directly overlie the Permian coal measures, which include those currently being mined. Figure 5.10 presents the hydrograph of groundwater level measurements at NMN monitoring bores screened in this stratigraphy. The monitoring well PZ28A is remote from mining and has a stable groundwater level. Groundwater level declines of less than 2 metres were recorded over the period 2016 to 2021 at PZ01A, PZ06C and PZ09C.

Groundwater levels at PZ07C, located directly above the northern section of the underground mine have declined slowly since installation, becoming dry in 2020. Groundwater levels at PZ04A and PZ08C, east of the mine footprint have recorded a declining trend due to mining. The monitoring bore hydrographs shown were selected because they represent the typical range in responses from the Triassic sediments.

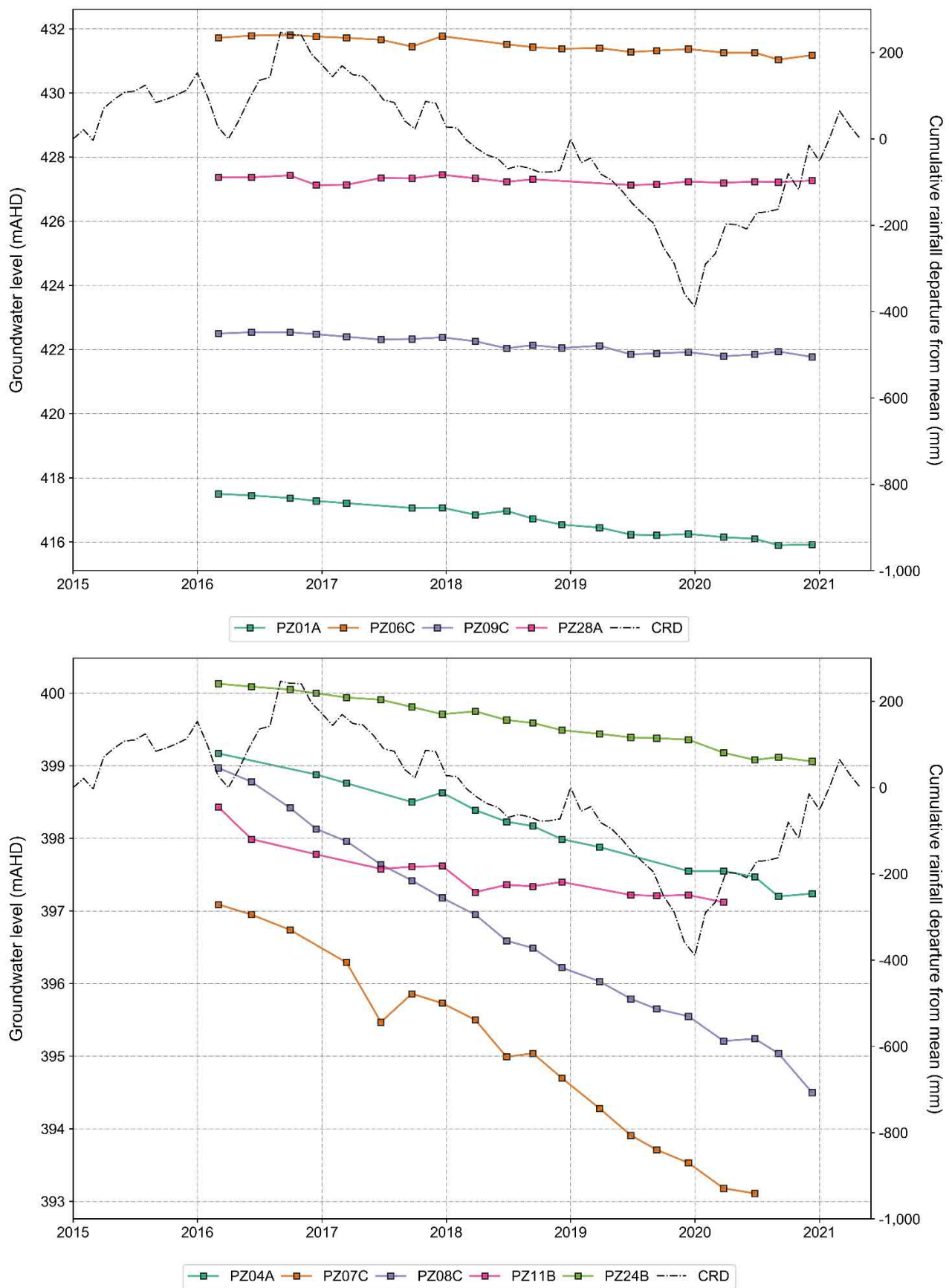


Figure 5.10 Triassic monitoring bores hydrographs

5.4.2.3 Permian coal measures

Figure 5.11 presents the Permian coal measures hydrograph for monitoring bores intersecting the Ulan Seam and the underlying Permian coal measures. Declines in groundwater levels are evident at PZ06A, PZ06B, PZ09A, PZ12B and PZ24A. Declining groundwater levels in this stratigraphic unit are expected as the process of underground mining reduces groundwater pressures within the target coal seam (Ulan Seam) and hydraulically connected layers (Permian coal measures).

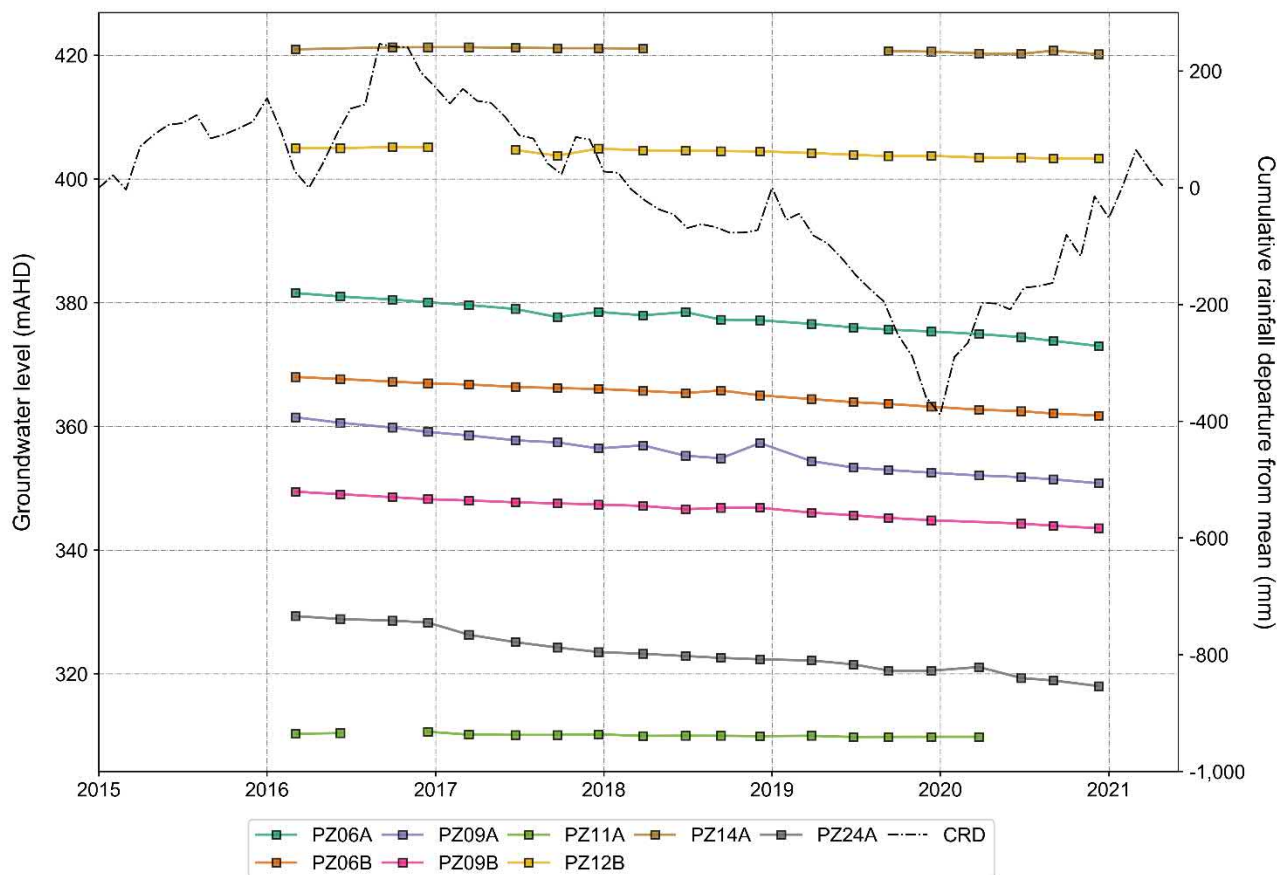


Figure 5.11 Permian coal measures monitoring bores hydrograph

5.4.3 Porewater pressure (VWPs)

Porewater pressure is monitored in a number of VWP sensor arrays installed in the vicinity of the UCC. The VWP sensor arrays are installed in a single borehole to measure changes in groundwater pressure over time at a specific depth. Hydrographs for observed porewater pressures are presented below for VWP DDH336. These observations and observations from other VWPs as discussed in the 2020 groundwater review (AGE 2021a) were considered during the recalibration of the numerical groundwater model discussed in Appendix A.

DDH336 is located within the mine footprint and equipped with eight sensors. The top sensor (in the Triassic strata) has been generally stable, fluctuating slightly since installation in 2009. Sensors in the Triassic sediments below 62 m experienced an overall pressure head decline (refer to Figure 5.12). Porewater pressures in the Permian sensors indicates a declining trend. Given that mining in LWW6 recently progressed past DDH336, full depressurisation would be expected at this location.

The Ulan seam is monitored by the sensor at 183 m depth. This is likely to have been impacted by earlier mining and depressurisation of the seam. As mining has progressed closer, the sensor at 167 m depth has also responded to mining, and this has reversed the gradient which was upwards to the sensor at 146 m depth.

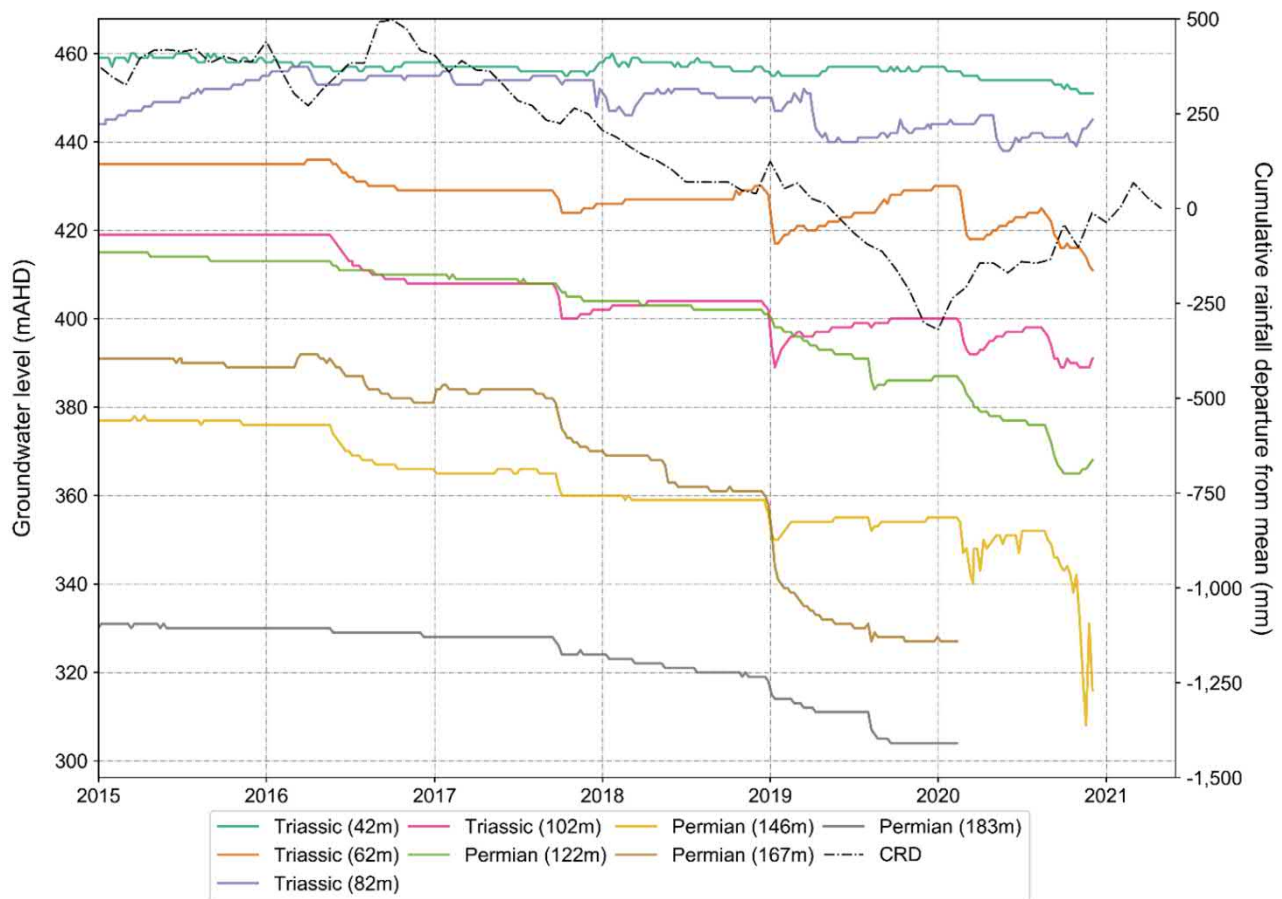


Figure 5.12 DDH336 VWP hydrograph

5.4.4 Mona Creek

The VWP MC-VWP1 was installed during late 2019 and is located in the northern area of the site along Mona Creek. The VWP array includes five sensors: Wollar sandstone (30 m), Narrabeen conglomerate (54 m), Middle River coal (68 m), Irondale coal (119 m) and Ulan Seam (152 m). Since installation, levels have declined in four of the five sensors in the range of 4 to 7 m equivalent pressure head. The exception to this is the Irondale coal sensor which has been relatively stable. Mining commenced in Ulan Underground LWV6, approximately 1.5 kilometres southeast of MC-VWP1, in February 2020. Mining of Ulan West LW6, approximately 1 kilometre south of MC-VWP1, commenced in August 2020 and also coincided with direct groundwater extraction from the Ulan West LW6 dewatering infrastructure, approximately 800 metres south of MC-VWP1). Figure 5.13 presents the hydrograph for MC-VWP1.

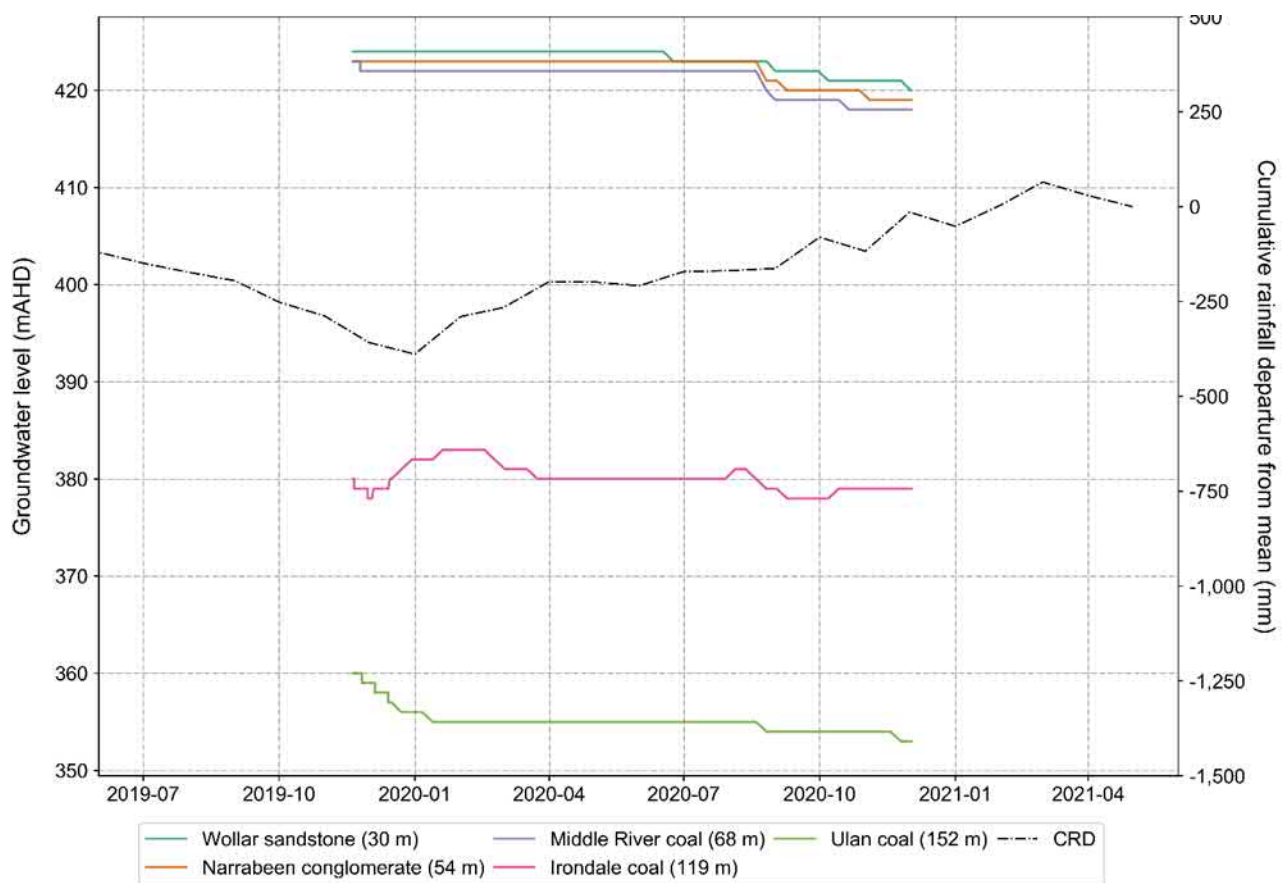


Figure 5.13 MC-VWP1 hydrographs

5.5 Groundwater quality and beneficial use

5.5.1 Salinity and pH

This section describes the water quality and beneficial use of groundwater within the different hydrostratigraphic units.

Salinity is the key constraint to groundwater use and can be described by TDS concentrations. TDS concentrations are commonly classified on a scale ranging from fresh to extremely saline. Food and Agriculture Organization of the United Nations ('FAO') (2013) provide a useful set of categories for assessing salinity based on TDS concentrations as follows:

- Fresh water: <500 mg/L (approximately 750 $\mu\text{S/cm}$).
- Brackish (slightly saline): 500 to 1,500 mg/L (approximately 750 to 2,250 $\mu\text{S/cm}$).
- Moderately saline: 1,500 to 7,000 mg/L (approximately 2,250 to 10,500 $\mu\text{S/cm}$).
- Saline: 7,000 to 15,000 mg/L (approximately 10,500 to 22,400 $\mu\text{S/cm}$).
- Highly saline: 15,000 to 35,000 mg/L (approximately 22,400 to 55,250 $\mu\text{S/cm}$).
- Brine: >35,000 mg/L (approximately 55,250 $\mu\text{S/cm}$).

Groundwater quality monitoring at the UCC is undertaken in accordance with the GWMP. As outlined within the GWMP for the NMN, field water quality parameters are tested on a biannual basis. Water samples from the bores are also tested for Major Cations and Anions, TDS, Reactive Silica, 17 Dissolved Metals and constituents of Ammonia including Nitrate and Nitrite on an annual basis. Physical parameters (EC and pH) were summarised historically in the MOD3 reporting (MER, 2015) and presented below in Table 5.3. Overall, the groundwaters associated with the Jurassic sediments are more saline than the coal seam waters.

Analysis of two groundwater samples collected from the recently installed groundwater bores targeting the alluvial water associated with Mona Creek (MCMB03A and MCMB04A) and 3 samples that were collected from private bores located within the Talbragar Alluvium (sampled in December 2020) indicate that groundwater pH measured in the alluvium is within the range 4.8 to 7.5 with EC ranging from 1080 to 3400.

Table 5.3 NMN field water quality data statistics - 2020

		Jurassic sediments	Triassic sediments	Permian coal measures
EC ($\mu\text{S/cm}$)	Historic average (standard deviation)	2,175 (804)	613 (466)	1,040 (398)
pH (pH unit)	Historic average (10% deviation range)	7.6 (1.1)	8.0 (1.9)	8.1 (1.3)

The variation in EC ($\mu\text{S/cm}$) across the geological units can be seen from the EC vs time graphs presented for the Jurassic, Triassic and Permian coal measures in Figure 5.14, Figure 5.15 and Figure 5.16 respectively.

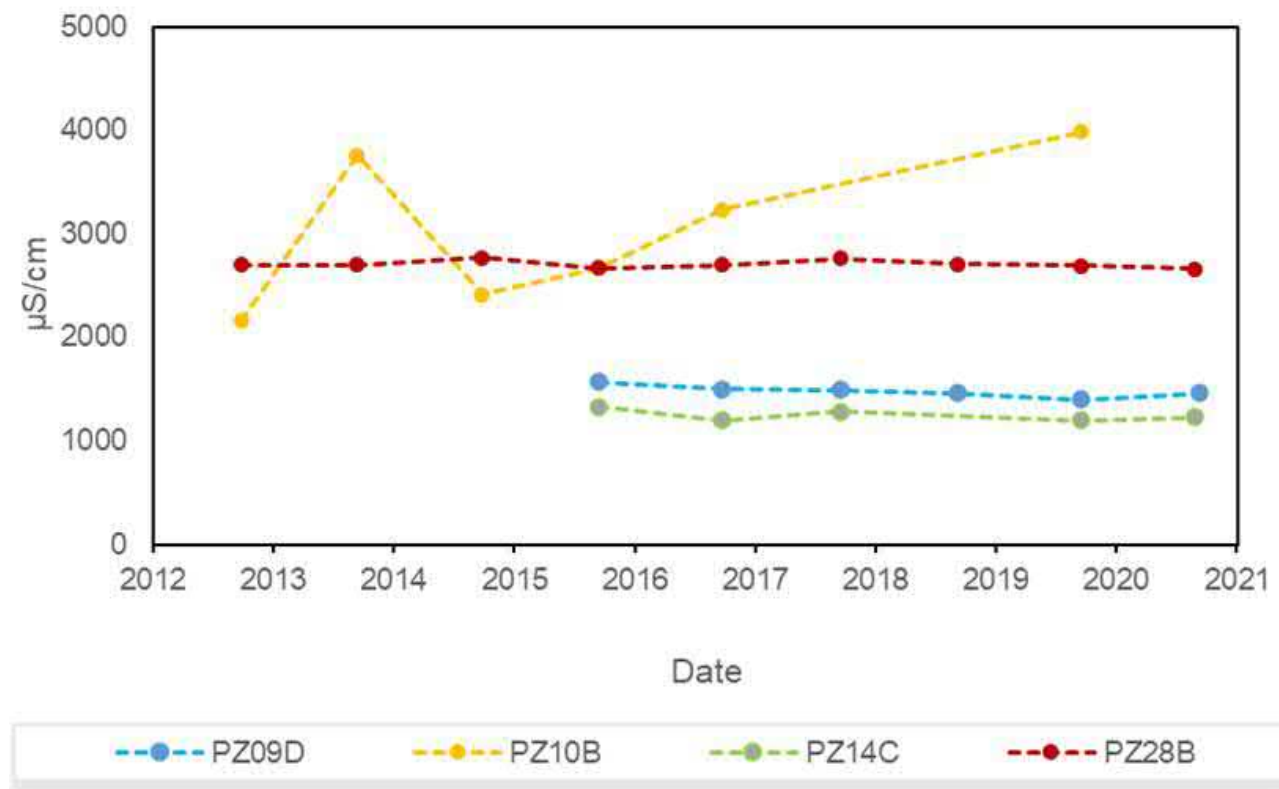


Figure 5.14 Jurassic EC

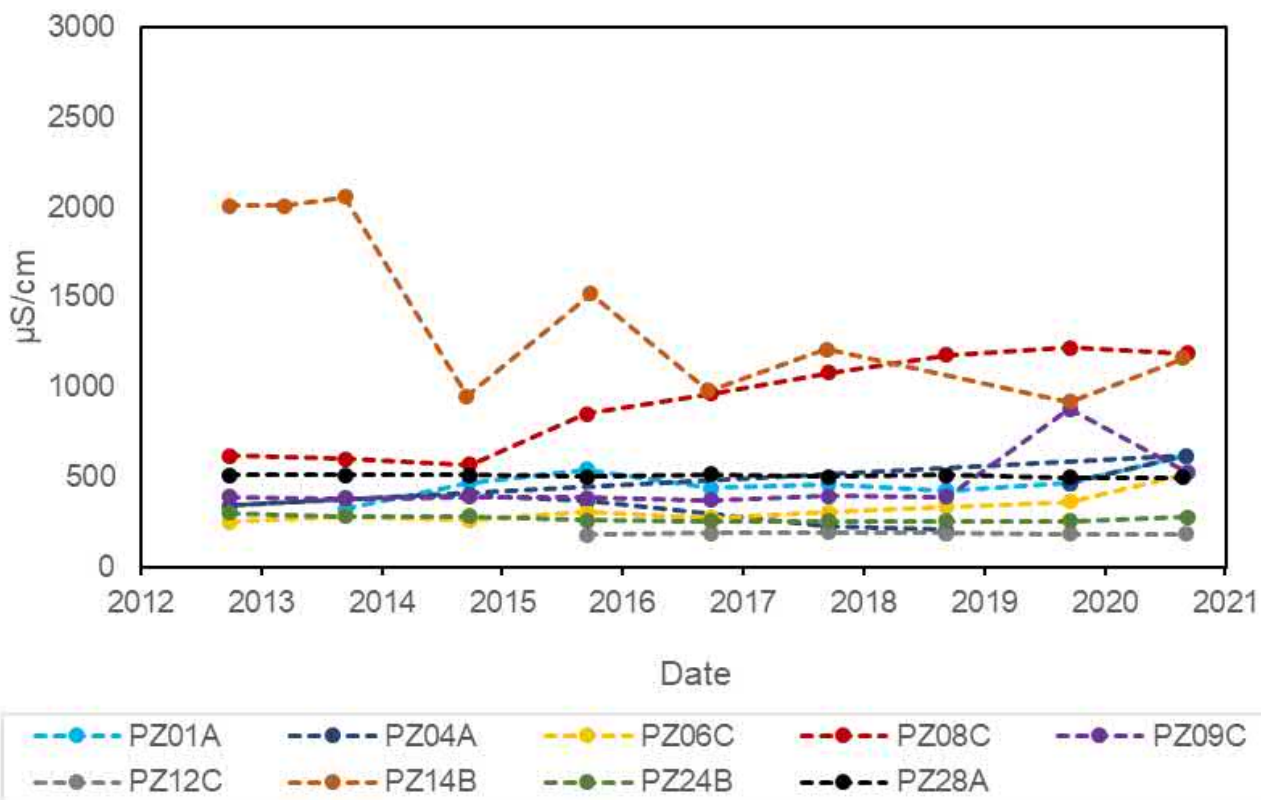


Figure 5.15 Triassic EC

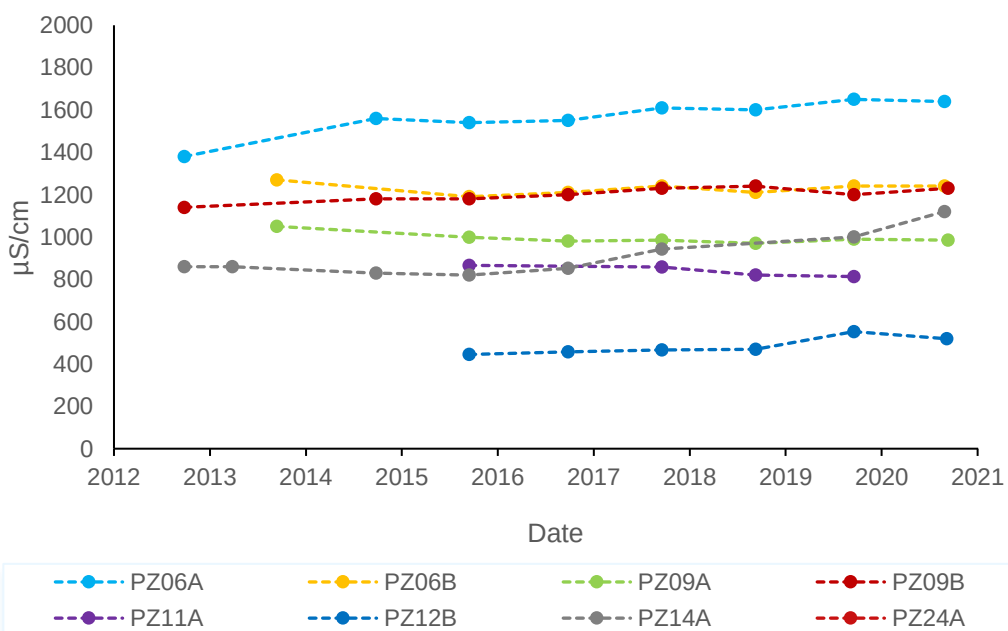


Figure 5.16 Permian coal measures EC

5.5.2 Beneficial Use

As noted, salinity is the key restriction on beneficial use of groundwater in the local region. Data collected from groundwater bores at the UCC falls between the brackish and moderately saline classification. This means that much of this groundwater (moderately saline) is unsuitable for more sensitive uses such as human consumption and irrigation without additional treatment. The data indicates that the Triassic groundwater generally has salinity levels that could be tolerated by stock or used to irrigate salt tolerant crops.

5.5.3 Major ions and alkalinity

Data from historical water quality sampling indicates that different formations (Jurassic, Triassic, Permian, and in particular the Ulan Seam) have distinctive water types as presented in Table 5.4. The proportions of the major anions and cations were used to determine the hydro-chemical facies of the groundwaters sampled and are shown on the Piper diagram in Figure 5.17. It can be concluded that the water types for the different geological units are fairly similar with some minor Sulphate (SO_4) type waters evident within the Jurassic, Permian coal measures and Ulan Seam. The different signatures for shallow and deep waters reflect dynamic evapotranspiration acting preferentially on shallow groundwater. Groundwater within the Triassic is likely chloride dominant, due to increased groundwater recharge rates.

Table 5.4 Ionic species relevance for formations

Formation	Cations	Anions
Jurassic	Na>Mg>Ca	Cl > HCO_3 >> SO_4
Triassic	Na>Mg,Ca	HCO_3 , Cl
Permian	Na>Mg,Ca	HCO_3 , Cl>> SO_4
Ulan Seam	Na>Mg,Ca	HCO_3 >Cl>> SO_4

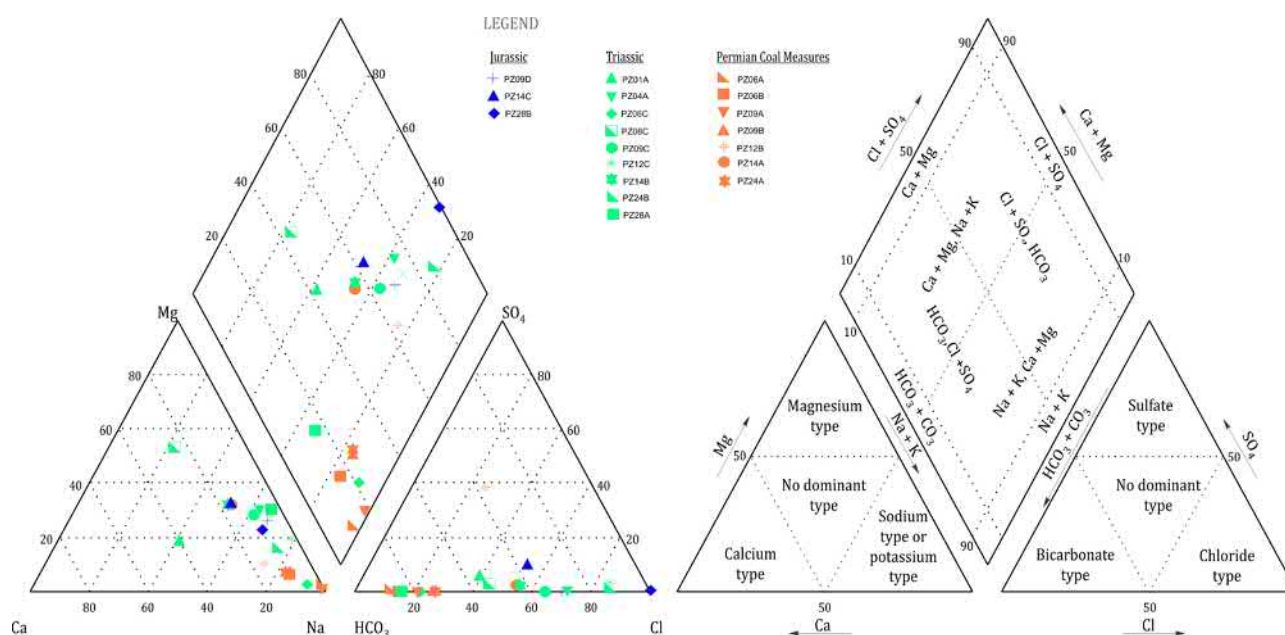


Figure 5.17 NMN Piper plot

5.5.4 Metals

Metals and metalloids are trace elements that naturally occur in the Earth's crust. Trace elements are considered essential for many organisms in low quantities, however harmful if in high uptake. Inherently, the presence of trace elements in the subsurface results in the suspension and dissolution of these species in groundwater. The Australian Drinking Water Guidelines (NHMRC, 2011) and ANZECC & ARMCANZ (2000) water quality guidelines outline standard concentrations that indicate when trace elements become harmful to humans or some organisms in water. A total of 19 NMN bores were sampled and analysed for dissolved metals (Silver (Ag), Aluminium (Al), Arsenic (As), Boron (B), Barium (Ba), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Mercury (Hg), Lithium (Li), Manganese (Mn), Nickel (Ni), Lead (Pb), Antimony (Sb), Selenium (Se), Strontium (Sr) and Zinc (Zn)).

Generally monitoring data for the monitored bores recorded concentrations below the limit of reporting for the dissolved metals Sb, Cd, Pb, Hg, Se, Ba, Li, As, Cr, Cu, Sr and Ag. Analysis indicates that Mn, Fe, Al, Zn and Ni concentrations fluctuate in some bores periodically. Annual groundwater reviews are conducted and the details pertaining to groundwater quality trends are discussed in these reports as explained in Section 10.

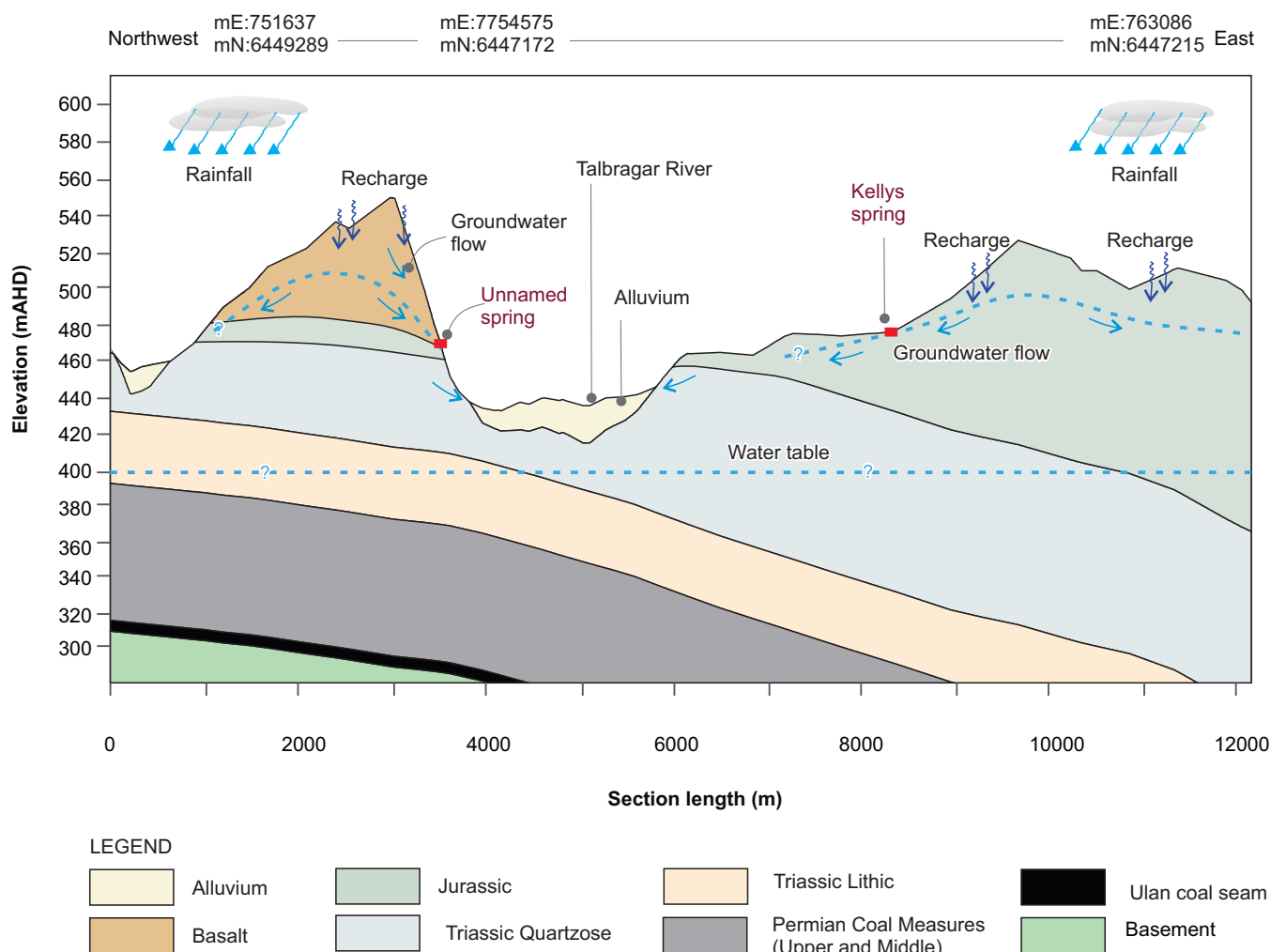
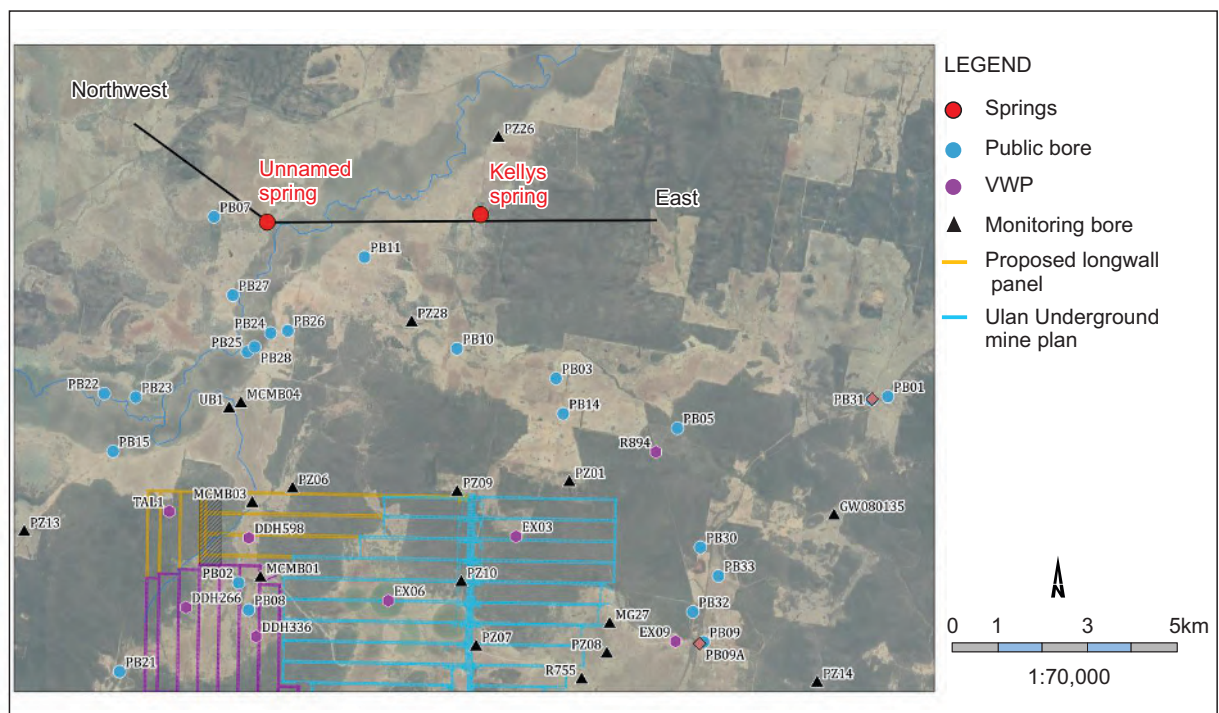
5.6 Groundwater dependent assets

5.6.1 Groundwater dependent ecosystems

Ecological surveys undertaken in the modification area have assessed the potential for groundwater dependent ecosystems (GDEs) and no significant GDEs were identified (Umwelt 2021).

Two Springs were identified approximately 6 km north of UCC. One 'unnamed' spring occurs north of the Talbragar alluvium and interpretation from geological mapping suggests that the spring is associated with discharge from a nearby and isolated basalt cap, and is therefore a recharge fed spring. The other spring is called 'Kelly's Spring'. This is located in an area where the Jurassic Pilliga formation is outcropping and is therefore a recharge fed spring associated with the perching of groundwater in the Jurassic formation in this area. The nature of these springs is demonstrated in the conceptual model provided in Figure 5.18.

No high priority GDEs have been identified in NSW Government Water Sharing Plans covering the UCC.



Spring Conceptual Model Cross Section

Figure 5.18

Ulan MOD6 GIA (G1985G)



The *Groundwater Dependent Ecosystem Atlas* (GDE Atlas) was developed by the Commonwealth Bureau of Meteorology (BoM) as a national dataset of Australian GDEs to inform groundwater planning and management (BOM, 2019). The Atlas contains information about three types of ecosystems defined in the Australian Groundwater-Dependent Ecosystems Toolbox.

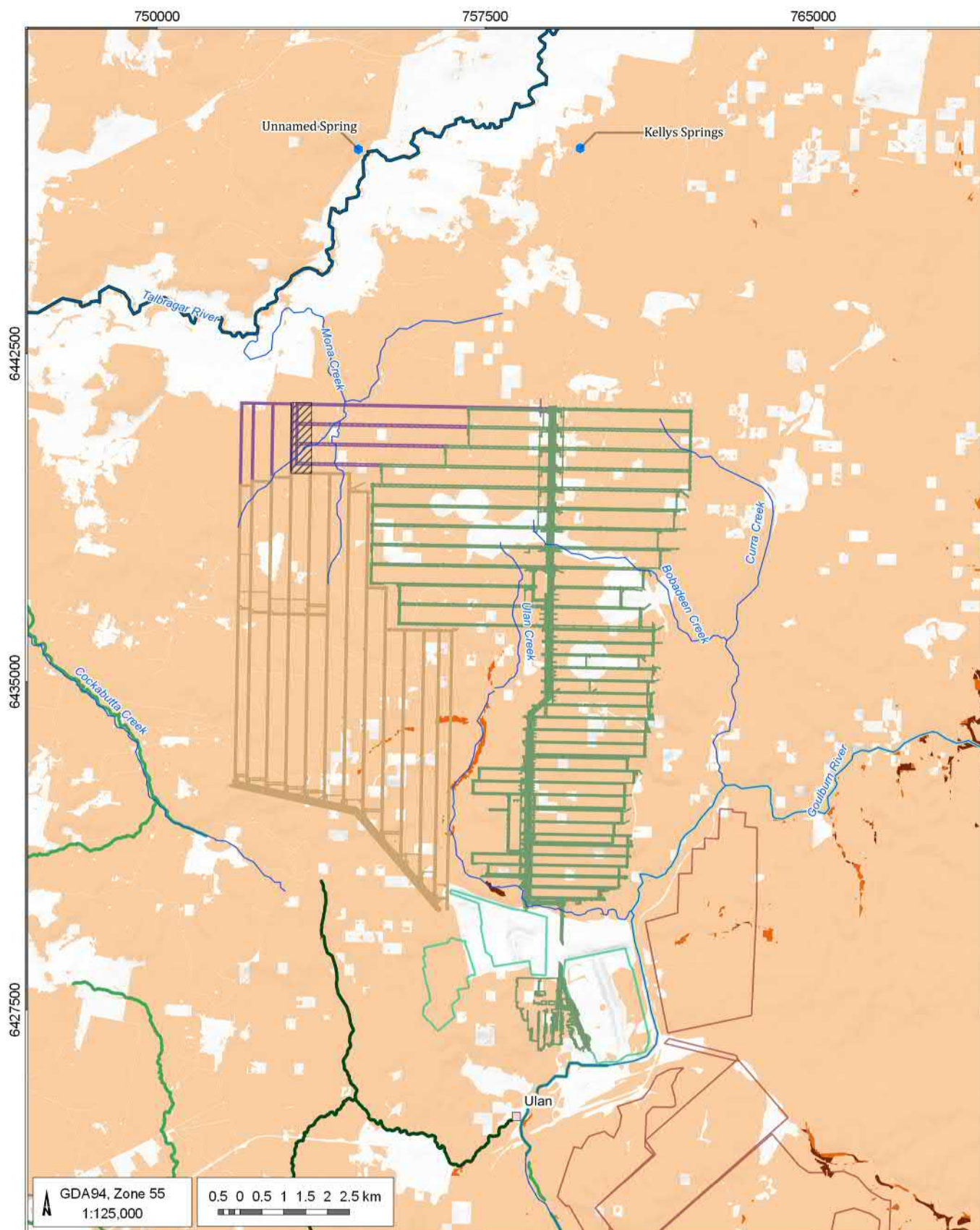
GDEs derived in the GDE Atlas are mapped according to the following classifications:

- high potential for groundwater interaction;
- moderate potential for groundwater interaction; and
- low potential for groundwater interaction.

Figure 5.19 shows the potential GDE's identified by the BoM GDE mapping (BoM, 2019) within and surrounding the UCC area. This shows that much of the surrounding land that is still treed has been mapped as a "low potential terrestrial" GDE and appears to be based heavily upon the extent of this existing treed vegetation within this area. Mapped areas of potential GDEs include:

- Terrestrial vegetation mapped as a low potential GDE that is "marginally more likely to access an additional source of water than rely solely on rainfall";
- Aquatic wetland/riverine habitat within watercourses associated with surface drainages, which is mapped as a moderate potential GDE "that is more likely to rely solely on rainfall and is therefore not considered inflow dependent"; and
- Aquatic wetland/riverine habitat within watercourses associated with Talbragar River, which is mapped as a high potential GDE that is "marginally more likely to access an additional source of water than rely solely on rainfall".

Information on the depth to groundwater within and around the UCC footprint is available from monitoring bores. The depth to groundwater for these bores range between 0.5 mbgl to 80 mbgl (unaffected by mining), with an average depth of 15 mbgl. The average depth to the water table may make it difficult for some vegetation in the potential terrestrial GDE category to access groundwater. The variation in depth to groundwater can be inferred from Figure 5.22 and Figure 5.24



LEGEND

- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- Flexibility area
- Mapped Spring

Terrestrial GDE

- High potential GDE
- Moderate potential GDE
- Low potential GDE

Aquatic GDE

- High potential GDE
- Moderate potential GDE
- Low potential GDE

Ulan MOD6 GIA (G1985G)

GDE mapping around the Ulan Coal mine Complex



AGE

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12/08/2022

FIGURE No:
5.19

5.6.1.1 The Drip

The Drip is a natural feature that hosts a localised GDE of vegetation growing on the sandstone cliff face. The Drip is located approximately 2 km east of the UCC longwall footprint as shown on Figure 5.21. It appears that the Drip is formed by perched localised groundwater discharge that is sustained by rainfall recharge to the Triassic Quartzose sandstone units that overlie the Illawarra Coal Measures. Depressurisation of the Triassic strata has already occurred at UCC due to mining at the UCC. However as indicated below through monitoring data for VWP (PZ29), it appears likely that the aquifer system associated with the Drip is isolated from the broader Triassic layers (AGE, 2019 and AGE, 2021a). The Drip is located over 10 km from the proposed modification underground mining area and is on the opposite side of the UCC. As such, the proposed modification will not impact The Drip. Numerical modelling completed for the proposed modification supports this statement.

The Drip is located within a Triassic sandstone gorge along the Goulburn River and is recognised for its cultural significance and potential to sustain groundwater dependent ecosystems. The Drip is located to the east of Ulan, on the northern side of the Goulburn River. Due to the incised nature of the gorge, it acts as a discharge area for the Triassic sandstone. The Triassic sandstone has an unconfined water table aquifer across most of the area and is semi-confined where overlain by the Jurassic sandstone. Previous studies (AGE, 2019) have conceptualised that the weathered sequences near the cliff face act as shallow perched groundwater systems. Photo 5.1 shows an aerial photograph of The Drip marked with elevations of the discharge zone. In the area adjacent and to the north of The Drip, Triassic groundwater levels show that groundwater is hosted at different levels within the Triassic sandstone units (also illustrated by cross-section in Figure 5.22). These are likely to be separate groundwater hydraulic units within a greater aquifer. The Triassic water levels have been impacted by mining over UCC; however, at and north of The Drip, the groundwater levels appear to only be minimally impacted by the 2019 dry conditions. Data from key groundwater monitoring locations are shown on Figure 5.21. The data from these bores were used to conceptualise the cross-section included as Figure 5.22 and recent porewater pressure data for VWP (PZ29) are discussed below.

A VWP (PZ29) was installed 1.3 km north of The Drip for the purpose of assessing groundwater gradients and trends around The Drip (refer to Figure 5.21). The time-series data from the VWP is presented in Figure 5.20. The porewater pressure trends have been stable for three years, are consistent with natural variation, and indicate that there is no mining related drawdown in the Triassic sediments at this location. Consistent with previous groundwater model predictions, there is minor drawdown in the Ulan Seam (PZ29-243, Figure 5.20) due to active mining and dewatering of that seam.

The groundwater quality also shows that these separate units are potentially recharged locally giving rise to groundwater of varying quality and chemistry. The water discharging at The Drip is magnesium dominant, whereas groundwater from other Triassic monitoring locations is sodium dominant. Overall, The Drip water quality exhibits a different proportion of major ions (different water type) compared to the Triassic sediments elsewhere. This, along with the high calcium and bicarbonate concentration suggest that the Drip seep has a local recharge source.



Photo 5.1 The Drip with discharge elevation markers

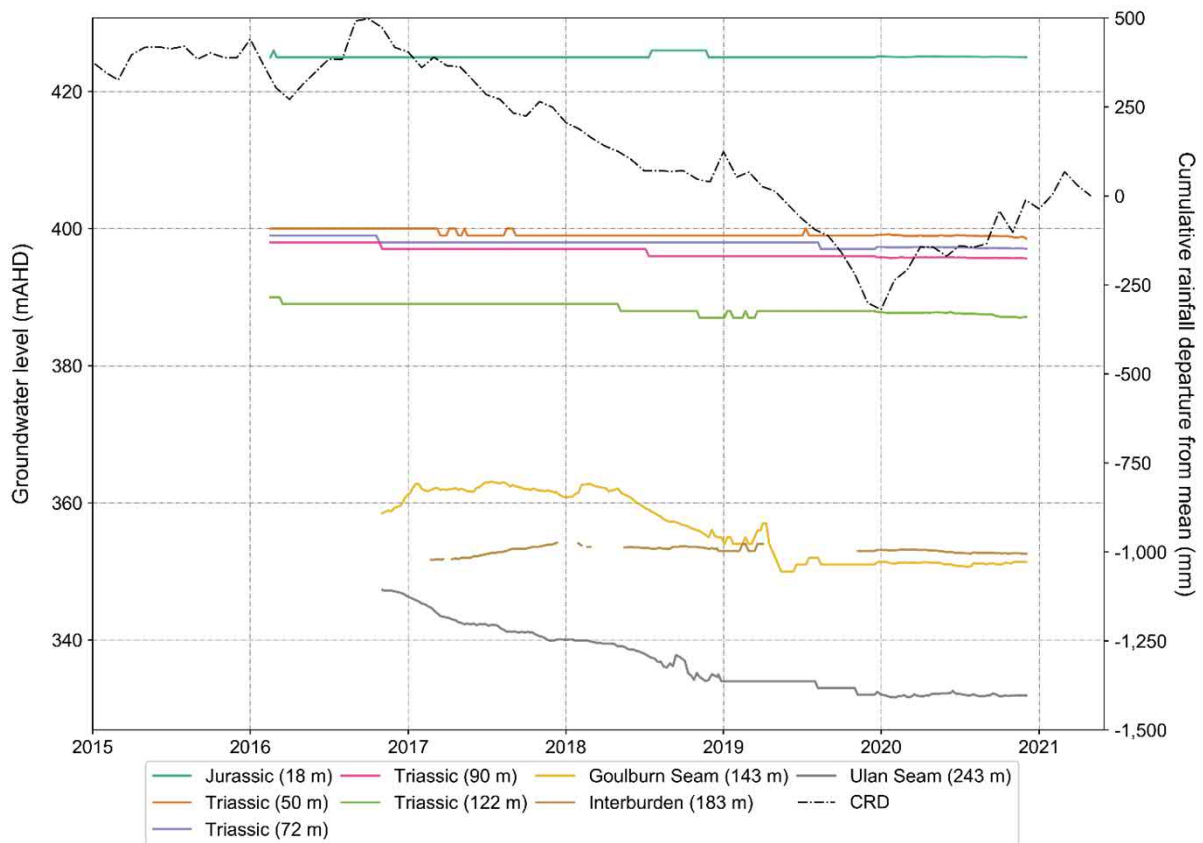
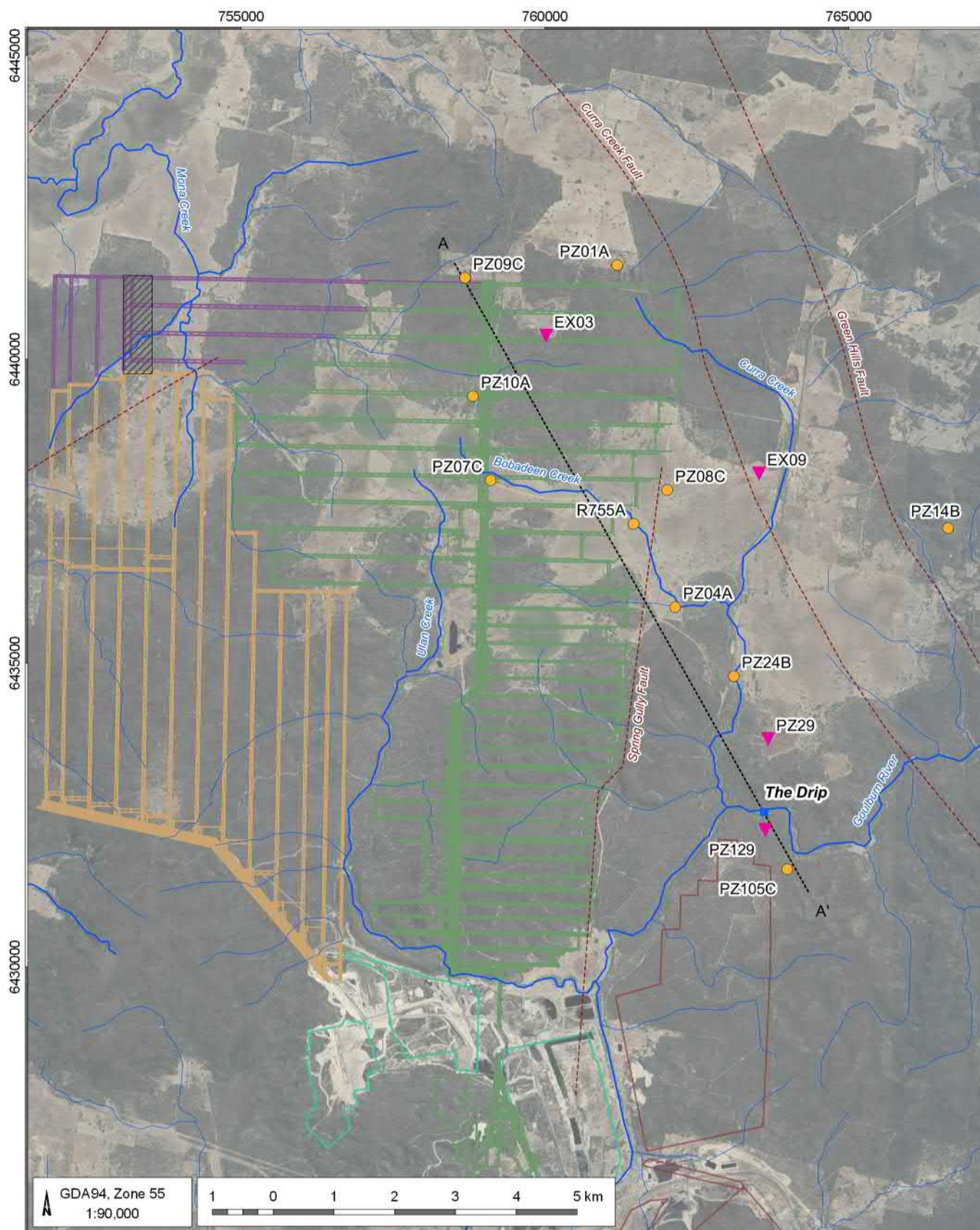


Figure 5.20 PZ29 hydrograph response



LEGEND

- Major drainage
- Minor drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Cross section location
- Fault
- Ulan open cut
- Moolarben mine area
- ▨ Flexibility area

- Monitoring bore
- ▼ Vibrating wire piezometer

Ulan MOD6 GIA (G1985G)

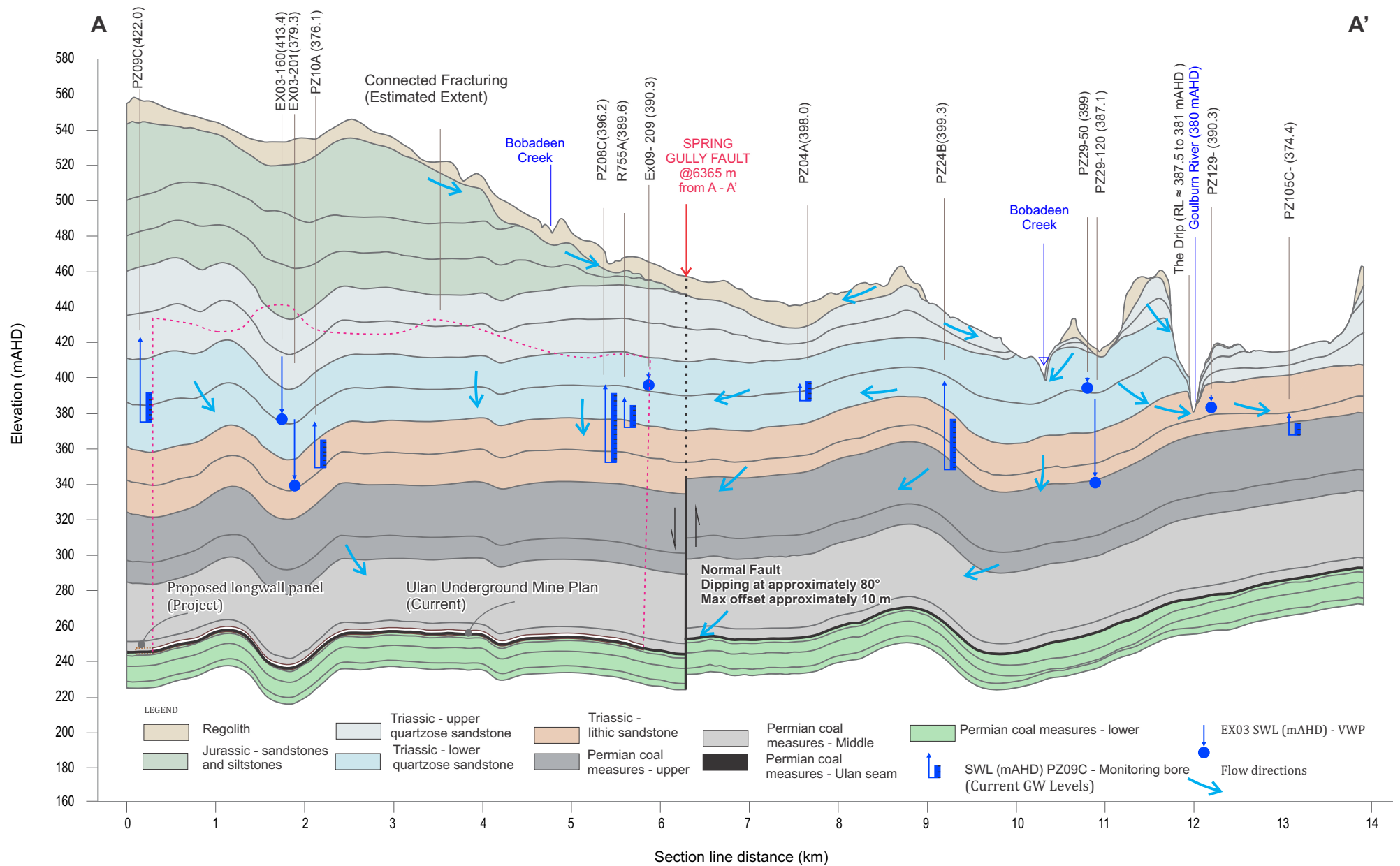
Location of key bores and cross-section location



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12/08/2022

FIGURE No:
5.21



Geological cross section (A - A') – The Drip and surrounds

Figure - 5.22

Ulan MOD6 GIA (G1985G)

5.6.2 Private water users

The UCC groundwater monitoring program includes 44 private bores; refer to Appendix A 2 for the list of bores. These bores vary in condition and are subject to varying degrees of use. The majority of bores are screened in the Triassic overburden units that comprise the sandstone aquifer that provides better quality groundwater, and as a result, the Triassic water table aquifer is a focus of the groundwater impact assessment. However, this unit is known to have a saturated thickness of three metres or less of low permeability sandstone across the mine area. This suggests that bore yields will likely be very low; as such the value of this water resource is minimal. The private bores that are likely to be impacted by two or more metres drawdown by the cumulative approved mining, and as a result of the proposed modification are listed and discussed in Section 8 and Appendix A. Several private bores use the alluvial water within the Talbragar River Alluvium, to the north of the proposed modification area. The yields for these bores have not been assessed but they are assumed to have at least moderate yields. These bores are not predicted to be impacted.

5.7 Recharge and discharge

Water inflows into the underground mine are likely to be sourced predominantly from the deep hardrock aquifers. Recharge to groundwater is sustained by rainfall infiltration, with estimates of recharge to deep hardrock strata varying from 0 to 2 percent of annual rainfall (MER, 2009). This estimate is commensurate with chloride mass balance estimates which AGE have completed for neighbouring mines. Recharge to the groundwater systems generally occurs in areas where the regolith is well developed or where alluvial deposits have accumulated. The Goulburn River and Talbragar River act as regional drainage sinks. The calibrated rate of recharge for each geological unit is discussed in detail in Appendix A. Mapped recharge distribution zones, which equate to the locations where various geologies outcrop and where recharge could be received are also presented in Appendix A (Section A.4.3.1).

Groundwater contribution to the adjoining surface water systems is through “*minor contributions of baseflows from slightly deeper hardrock systems (as upward leakage possibly via springs) and are more likely to dominate during the extended dry periods when flows are frequently less than 0.5 ML/day*” (MER 2009). Historical streamflow records indicate a long-term average flow rate in the Goulburn River at Ulan (just upstream of the mine) of around 2 ML/day, although the gauge data also indicates significant variation due to climate. The historical gauging also indicates that prior to mining, the river experienced very low to “ceased to flow” conditions, usually in extended dry periods. While contributions from groundwater discharge are not sufficient to maintain surface flows during extended dry periods, they may assist in extending persistence of refugial pools.

5.8 Conceptual Model

A conceptual (hydrogeological) model is a descriptive representation of a groundwater system that incorporates an interpretation of the geological and hydrological conditions (Anderson and Woessner 1992). It consolidates the current understanding of the key processes of the groundwater system, including the influence of stresses, and assists in the understanding of possible future changes. This section describes the processes that control and influence the storage and movement of groundwater in the hydrogeological systems occurring in vicinity to the proposed modification as derived from the information presented in the previous sections. The hydrogeological conceptual model applied for the initial groundwater impact assessment and sequential modifications remains the foundation for the numerical groundwater model conceptualisation and impact assessment. The hydrogeological conceptual model was verified with new available data obtained from additional site assessments and from the routine water monitoring program. Accordingly, changes were also made to the numerical groundwater model, and these are discussed in Appendix A. A series of cross sections were developed to further support the conceptual model based on recent data and are discussed in more detail below.

Three aquifer systems occur at the UCC, namely:

- the alluvial aquifers associated with tributaries of the Talbragar and Goulburn Rivers. The unconsolidated (colluvial) system most relevant to this review is that associated with Mona Creek (north of Ulan West);
- shallow regolith and near surface weathered rock profiles; and
- Jurassic, Triassic and Permian formations.

The completed work and observations, undertaken for the Mona Creek sedimentary system (refer to Section 5.1.1.1), indicate that there is limited groundwater supply, and it is highly reliant on rainfall recharge for opportunistic take. As discussed previously, the lithological description was redefined for the Mona Creek sediments from alluvium to colluvium based on the recent and detailed work undertaken.

The regolith cover, where present within the proposed modification area, is relatively thin and dominated by low permeability clay strata which are the result of weathering and decomposition of the underlying consolidated strata. This unit can host unconfined groundwater during extended wet periods when the recharge rate exceeds the rate of downward or lateral flow.

The Jurassic and Triassic sandstone and conglomerate units are more porous and permeable than the Permian units, which tend to consist of finer grained lithology. There is a secondary permeability associated with fracturing and jointing of the units. This has the potential to promote vertical connectivity between hydro-stratigraphic units that are generally separated hydraulically. The Ulan Seam is identified as the main water bearing zone within the Permian strata, as the nature of the coal (being fractured and/or with cleating) allows the horizontal movement of water more freely than the other Permian units (MER 2015).

These groundwater units and the depressurisation from current mine operations are presented conceptually below in a series of cross-sections in Figure 5.24, Figure 5.25 and Figure 5.26. The cross-section locations are depicted in Figure 5.23. To support the hydrogeological conceptualisation a series of additional hydrographs are shown in Figure 5.27 to Figure 5.29.

To conceptually illustrate the observed impacts from current mining, the cross-section shown in Figure 5.24 was developed and traverses through the currently active mining area, as well as through the area where mining is planned under the proposed modification (see Figure 5.23 for cross section alignment). Superimposed on the cross section are adjacent monitoring points and their more recent observed water levels. At the Ulan Seam currently being mined, the observed water level is at a similar elevation as the coal seam (see EX06 and PZ07) and indicates the dewatered nature of the formation where mining has occurred. Outside of the mined area, other coal seam measurements show some depressurisation, reducing as distance increases away from the mined part of the seam. Measurements in lower parts of the Triassic above the mined area show moderate levels of drawdown (PZ10 and PZ07), while measurements from higher in the Triassic and Jurassic formations appear unaffected (EX06 and PZ10). Away from the mining area, the Triassic formations show very little influence from mining.

As indicated on the cross section (Figure 5.24), subsidence does not instantly vertically connect and drain the overlying strata to the surface. Connected fractures extend into the lower lithic part of the Triassic formation, and in some areas will extend into the quartzose Triassic formation. The lack of any observed reduction in water levels in the Jurassic formations (refer to Section 5.4) supports the hypothesis that vertical fracturing does not extend to these strata (where present) and that aquitards below the Jurassic aquifers remain intact and are unaffected by longwall mining in the Ulan Seam. These observations have guided the application of empirical formulas (the formula developed by Ditton-Merrick was applied) to determine the height of continuous fracturing within this assessment. The depth to this zone is shown on Figure 5.30 and discussed in more detail in Section A 4.6.4.3 in Appendix A. This figure shows that the zone of continuous / connected fracturing has / will reach the surface in the southern extents of the approved mine plan (where the depth shown is 0 m in Figure 5.30). The potential for seam to surface fracturing is not changed as a result of the proposed modification. The section shown in Figure 5.24 depicts a conceptualisation of the currently active mining area, and also the area where mining is planned under the proposed modification (see Figure 5.23 for cross section alignment). Superimposed on the cross section are adjacent monitoring points and their more recent observed water levels. Measurements from VWP TAL1 (DDH544), in upper (28 m) and lower (45 m) parts of the Triassic show relatively stable groundwater levels, while deeper Permian monitoring at this location shows some decline due to recent nearby mining. The recovery monitored in the 97 m deep instrument is believed to be an issue with the sensor.

The predicted minimum depth to the top of fracturing from the proposed modification in the area where the Mona Creek colluvium is present, will be 15.8 m and is situated at the northern edge of the MOD6 panels. This aligns closely with the location of MCMB03A which indicates colluvium to a depth of 13 m. The base of the colluvium is therefore close to the estimated top of fracturing, so this shallow bore combined with the nearby deeper bore (MCMB03B which extends to a depth of 30 m) will provide valuable monitoring of potential impacts. Outside of the Mona Creek valley the depth to the top of fracturing is predicted to be 20 to 50 m across the proposed modification panels.

Transient groundwater levels (refer to Section 5.4) demonstrate limited impact to shallow formations and increased mine related impacts with depth. The two bores presented below (Figure 5.28 and Figure 5.29) are located at the northern end of the approved and proposed longwall panels. Prior to mining, the regional water table for the Triassic and Permian units across the site varied from 400 mAHD to 450 mAHD with the Jurassic units exhibiting perched (> 450 mAHD) water tables in more elevated topography. At the start of mining, depressurisation of the Ulan Seam has propagated within the seam and has also had impacts on the adjacent Permian strata. Monitoring of the Ulan Seam water levels in bores nearby to the mine have recorded a gradual decline (as shown in Figure 5.28 and Figure 5.29). Water levels in the overlying Triassic strata have not responded to this decline at distance from the mine, nor in the Jurassic strata, which is expected given the perched nature of the groundwater occurrence in that formation. Monitoring of Triassic water levels above the mine has shown declines in water levels as fracturing from longwall mining increases vertical connection between the Triassic and the dewatered Ulan Seam. However, the horizontal propagation in the Triassic is not as fast as observed in the Permian, and is observed in the hydrographs below. This indicates that depressurisation effects from mining in the Triassic occurs to be driven primarily by goaf fracture effects, with lower rates of horizontal movement towards these depressurised areas. Any vertical movement of water from the Triassic to the Permian in areas away from the fracture zone towards the depressurised Permian strata below appears to be minimal to negligible.

The conceptual section shown in Figure 5.25 graphically illustrates the main hydrogeological features and processes associated with the proposed modification, including recharge, discharge, and groundwater flow directions. The interpolated groundwater contours from monitoring bores and VWP in the Jurassic sediments show that groundwater elevation is a subdued version of topography, and that groundwater flows towards adjacent watercourses. The contours developed from monitoring bores in the Triassic sediments show depressed groundwater levels nearby to the mine, with groundwater also flowing south-east towards the Goulburn River. The contours developed from monitoring bores in the Permian coal measures indicate that groundwater is flowing towards the underground mine and drawdown is occurring within the Ulan Seam towards the active mine area, as predicted within the EA for the approved project.

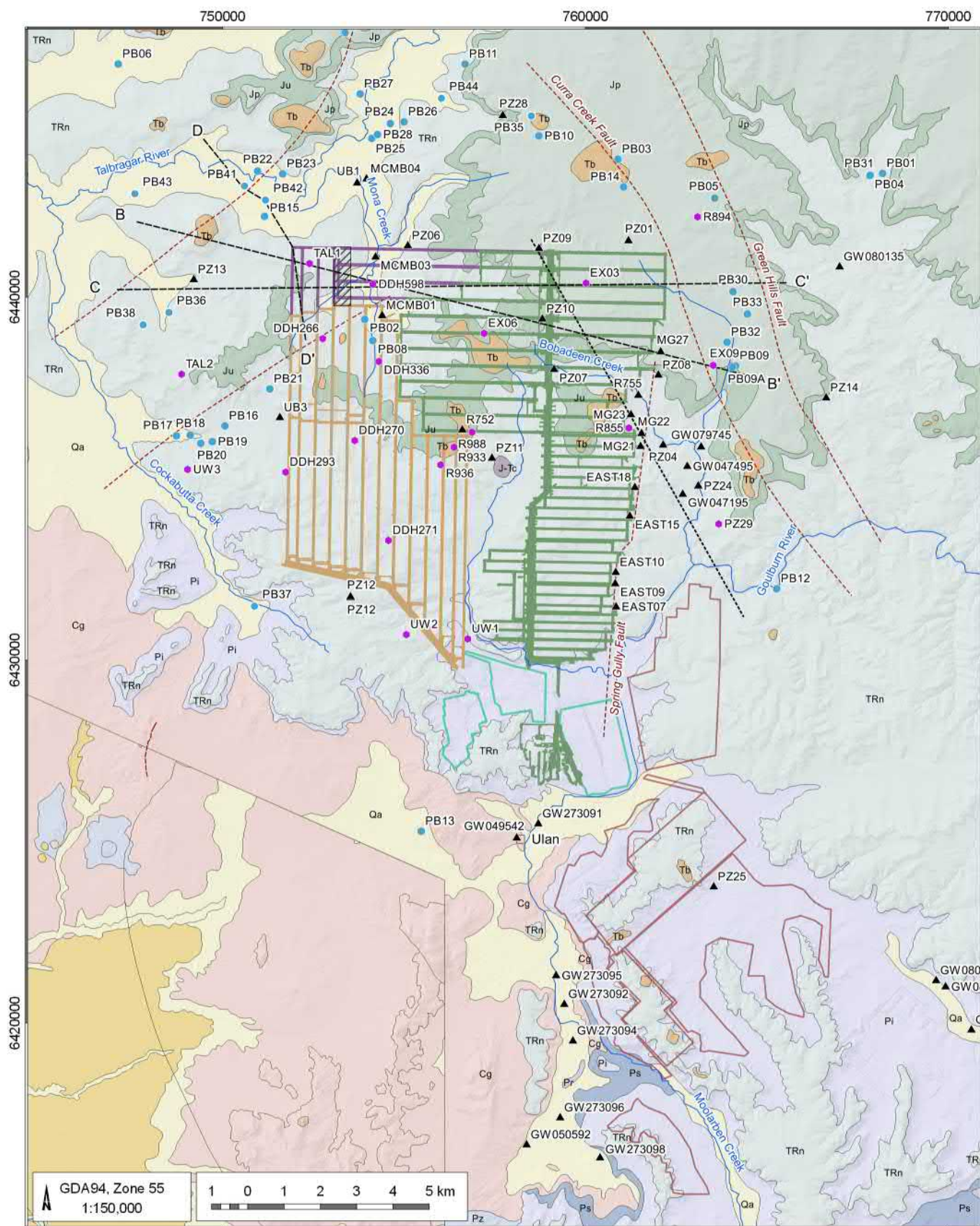
The cross-section shown in Figure 5.26 was developed to conceptually illustrate the Talbragar alluvial groundwater levels north of the proposed modification. Groundwater levels measured in two private bores considered to be drawing from the Talbragar Alluvium, PB41 and PB42, are around 10 mbgl.

Recharge to groundwater is sustained by rainfall infiltration with estimates of recharge to deep hardrock strata varying from 0 to 2 percent of annual rainfall.

Landholders predominantly extract groundwater from the Triassic formation, and to a lesser degree from the alluvium, Jurassic and Permian coal measures aquifers in the region. Most bores/wells are situated near drainages where recharge to regolith and shallow weathered bedrock is expected to be enhanced.

Groundwater quality across the hydrostratigraphic units is highly variable, and can be classified as brackish to moderately saline. The best groundwater quality is observed within the alluvial aquifers and in other aquifers at locations close to the point at which recharge occurs, but still variable in quality based on location. Groundwater within the regolith, unweathered bedrock and Permian coal measures is variable but can be suitable for stock and domestic purposes, where salinities are lowest.

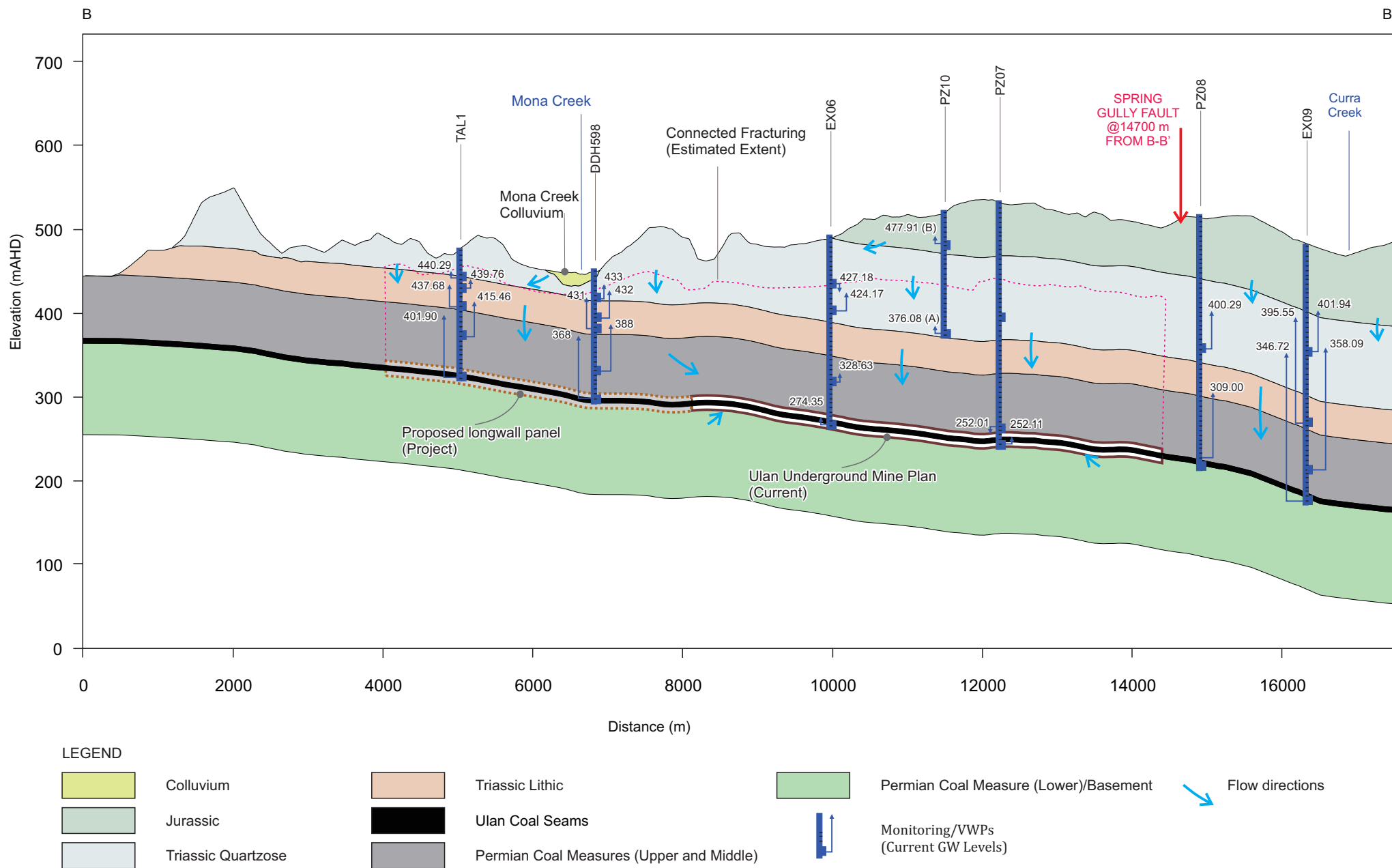
As indicated, hydrogeological conceptual models are collections of hypotheses describing the contemporary understanding of groundwater systems. However, it is important to note that hydrogeological conceptual models contain, to a certain degree, a level of uncertainty and it is important to discuss and analyse this in detail. For this reason, an uncertainty analysis was undertaken and is discussed in more detail in the numerical modelling sections captured in Section 9.

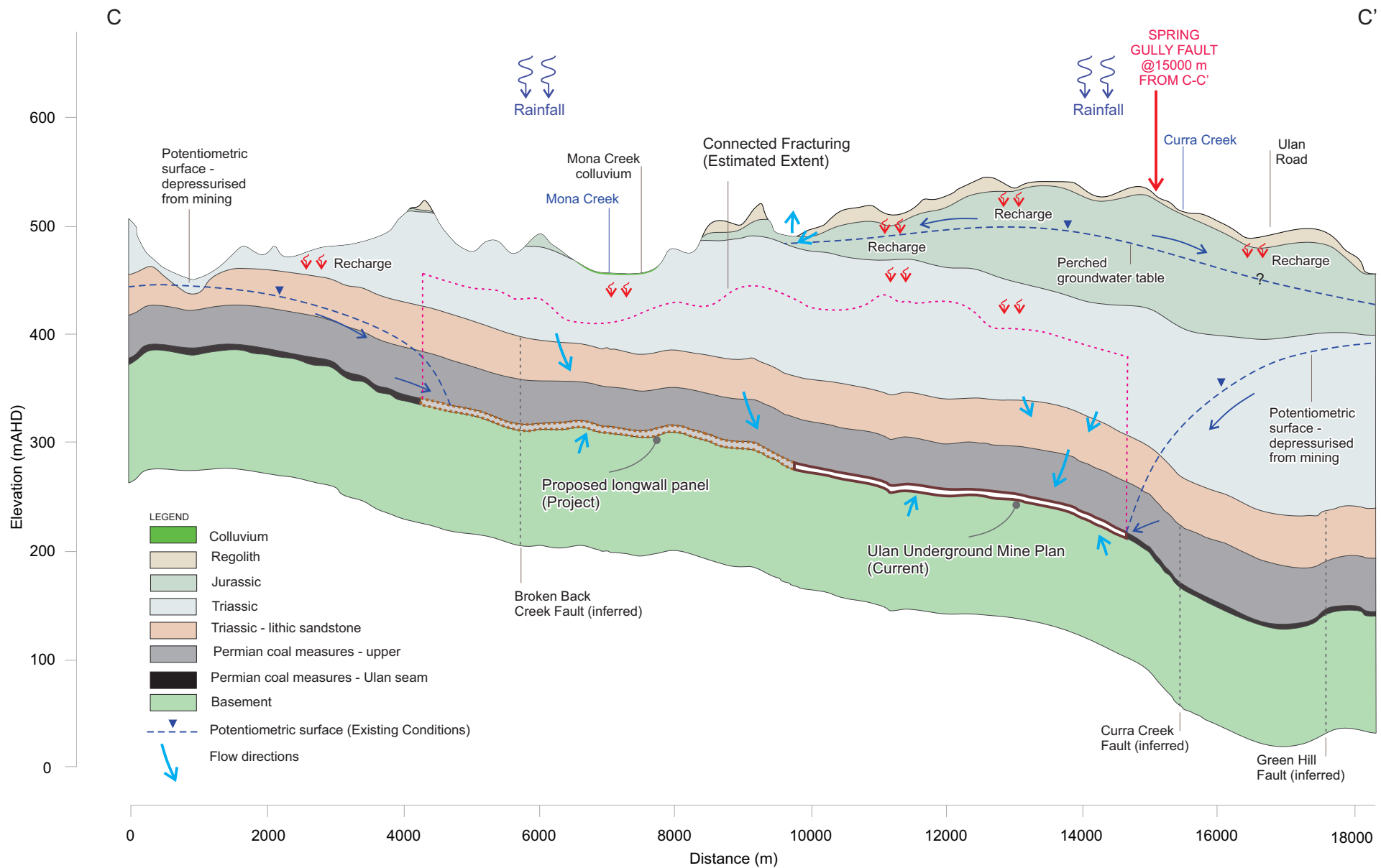


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5.23



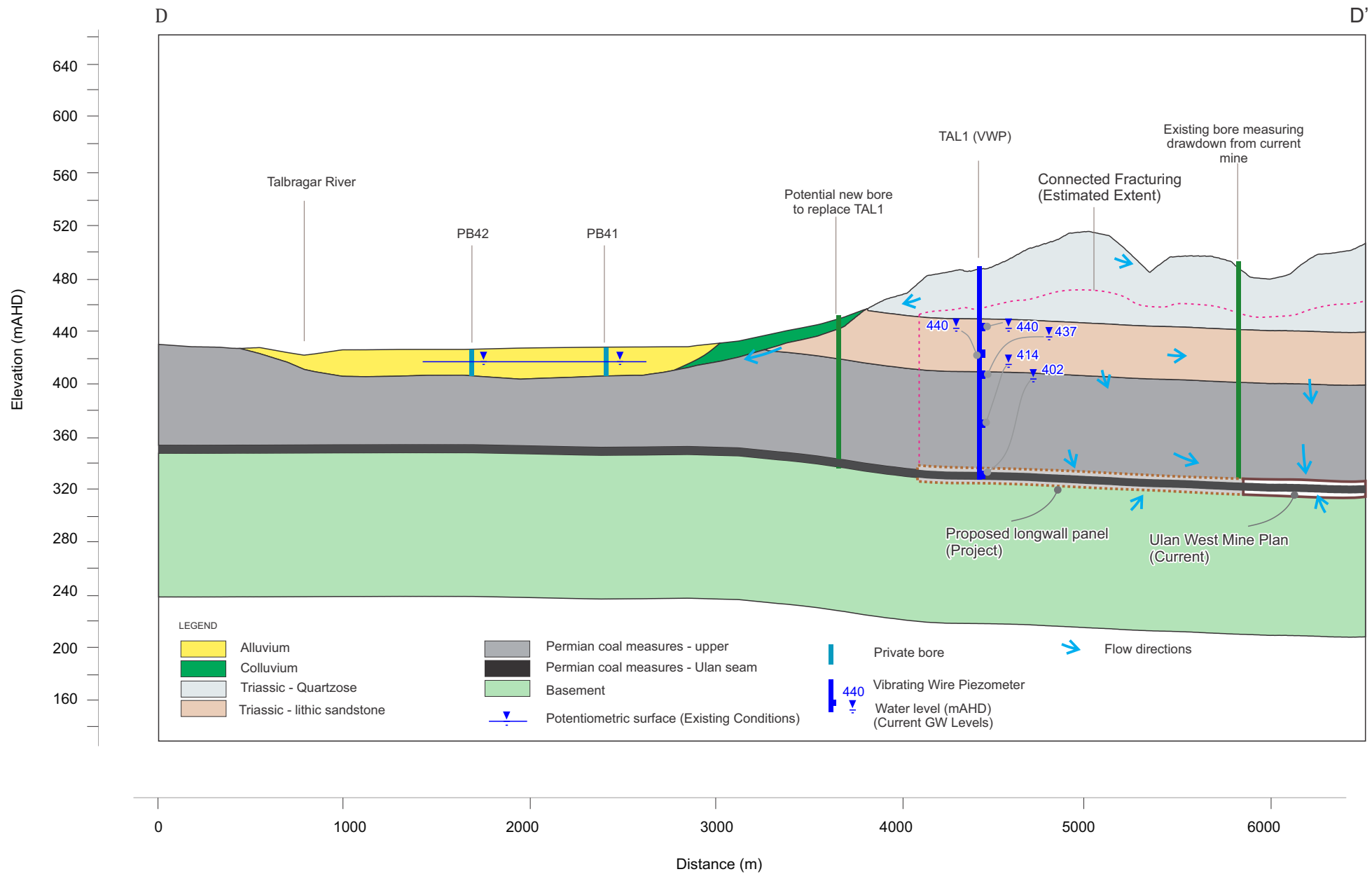


Hydrogeological conceptual cross section (C - C')

Figure - 5.25

Ulan MOD6 GIA (G1985G)





Hydrogeological conceptual cross section (D - D')

Figure - 5.26

Ulan MOD6 GIA (G1985G)

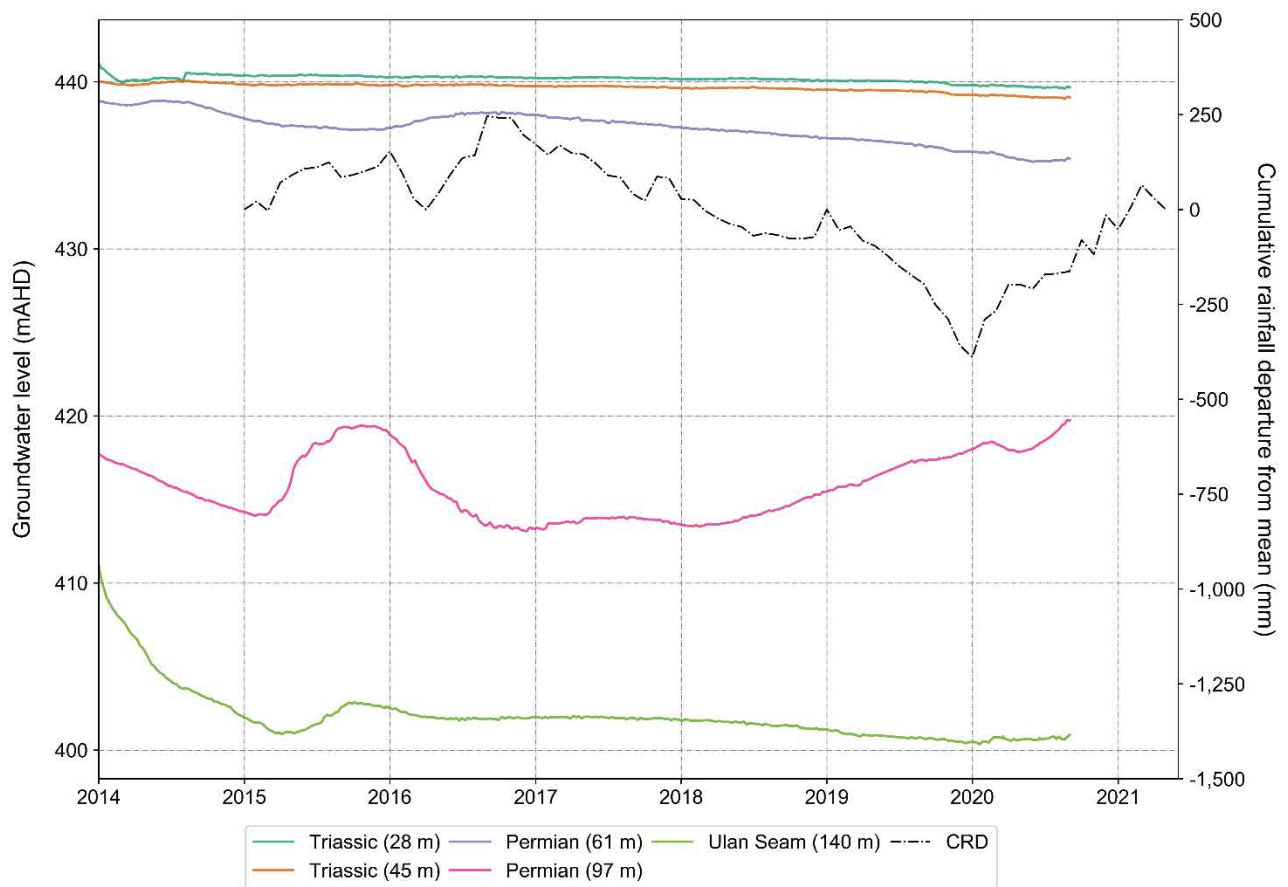


Figure 5.27 VWP DDH544 (TAL-1) hydrograph

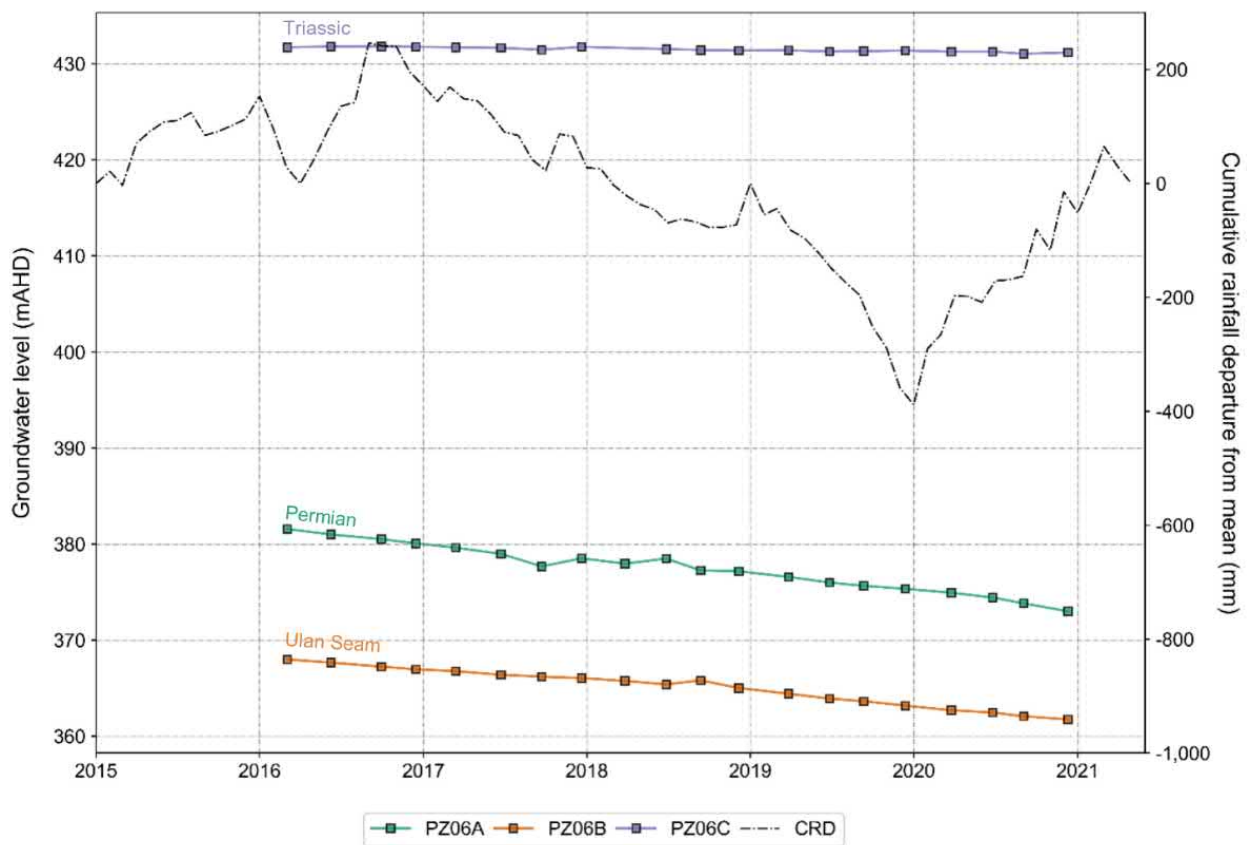


Figure 5.28 Hydrographs of recent measurements for PZ06

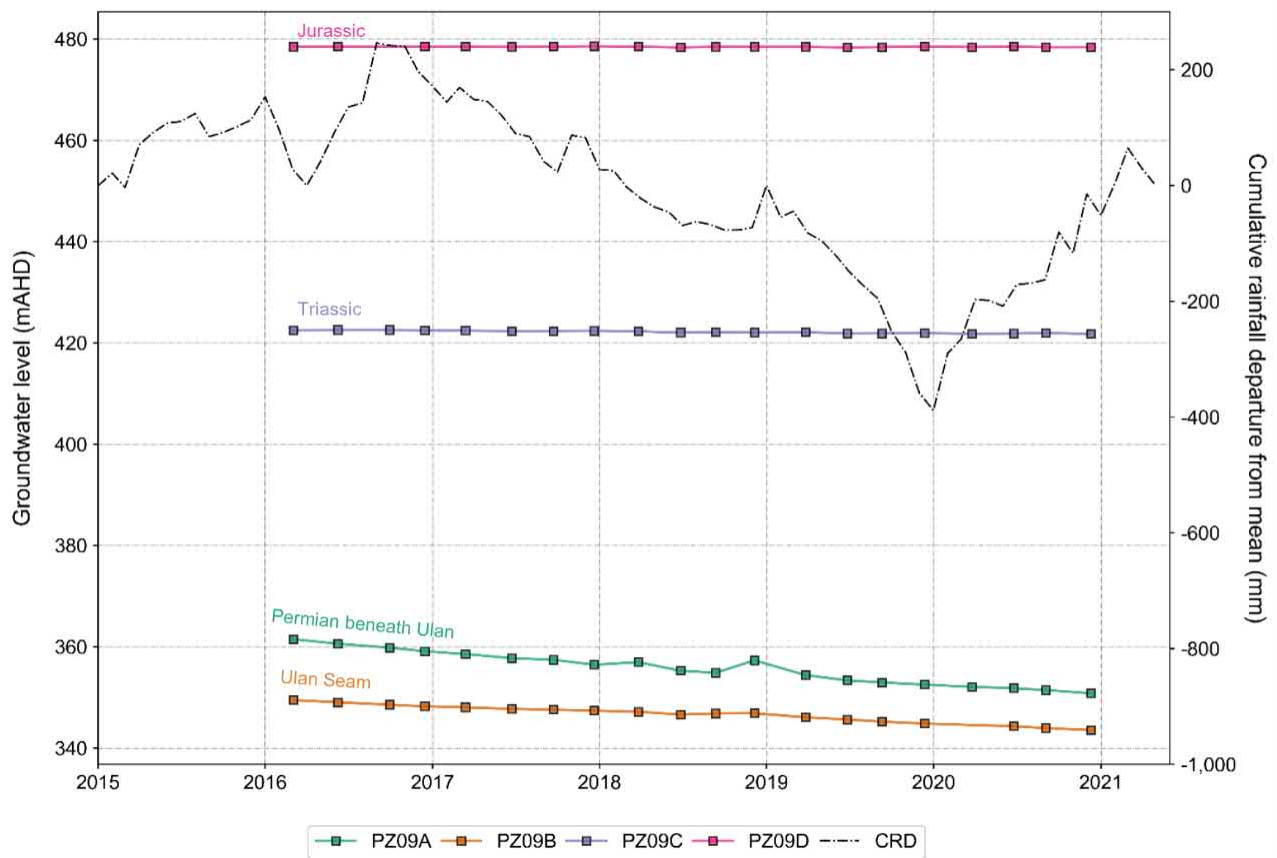
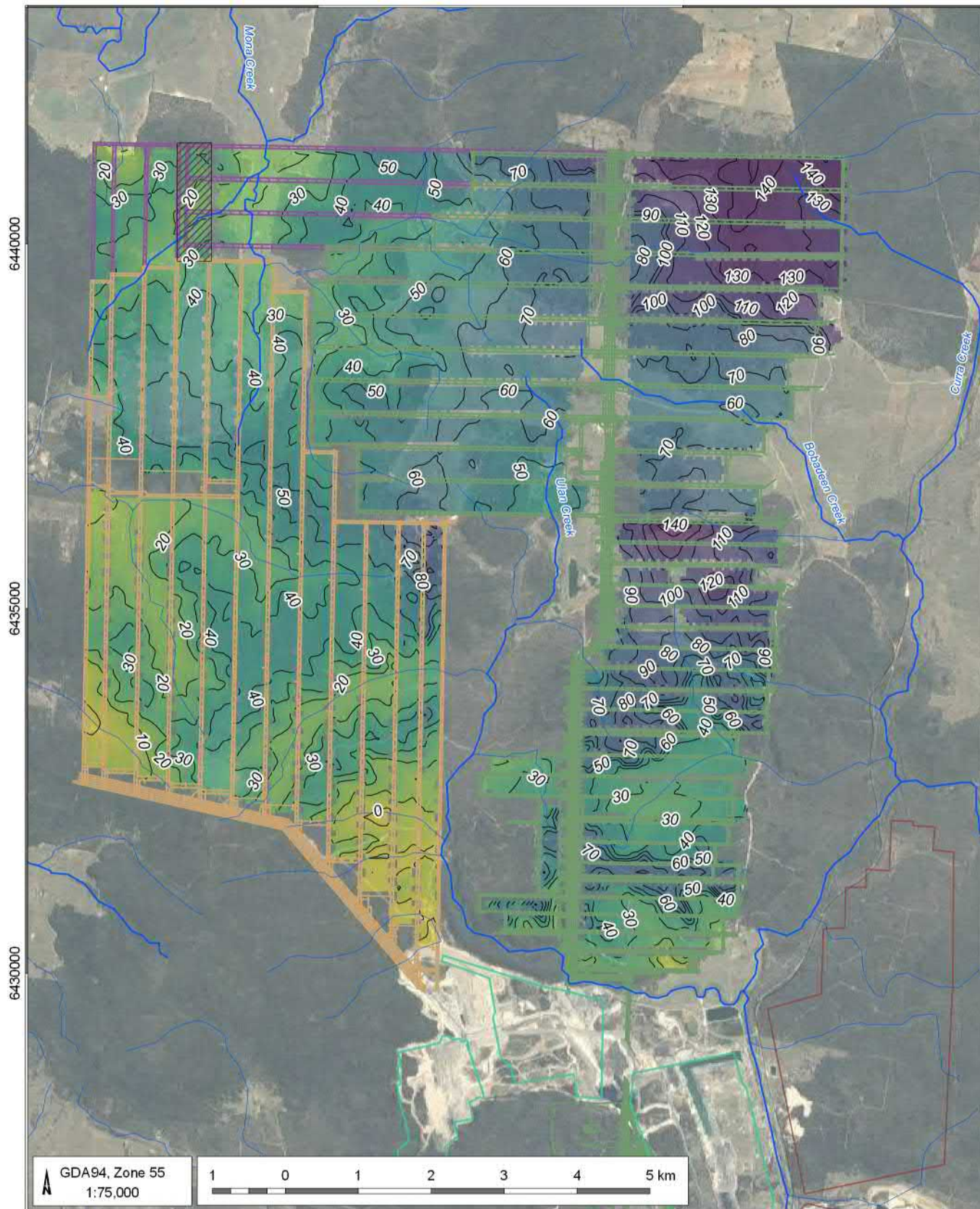


Figure 5.29 Hydrographs of recent measurements for PZ09

755000

760000



LEGEND

- Major drainage
- Minor drainage
- Depth to top of connected fracturing contour (m)
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- ▨ Flexibility area

Depth to top of connected fracturing (m)

- 0
- 10
- 20
- 30
- 40
- 50
- 60
- 80
- 100
- 120
- 140

Ulan MOD6 GIA (G1985G)

Estimated depth to top of connected fracturing



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5.30

5.9 Potential impact causal pathways

For the purposes of Bioregional Assessments, causal pathways are defined as ‘the logical chains of events – either planned or unplanned – that link coal resource development and potential impacts on water resources and water dependent assets’ (Dawes et al, 2018). Water dependent assets can be impacted by changes to quantity, quality or timing of surface water or groundwater or both. Water dependent assets in the vicinity of the proposed modification were described in Section 5.6.

The identification of causal pathways between the proposed modification specifically, as well as the current approved mine workings and the water-dependent assets is an important part of the impact assessment process. Causal pathways are initiated by an activity associated with the coal resource development. In the case of the proposed modification, this is the extension of mining of coal from the existing approved UCC area, and it is the incremental increase in potential impacts that requires assessment. Assessment of the potential for impacts upon water dependent assets via causal pathways for the proposed modification is discussed in more detail in the impact assessment in Section 8.

There are four main causal pathway groups associated with coal mining (refer to Figure 5.31), although there is commonly overlap or linkage between them, Henderson et al. (2016):

- ‘A - subsurface depressurisation and dewatering’;
- ‘B - subsurface physical flow paths’;
- ‘C - surface water drainage’; and
- ‘D - operational water management’.

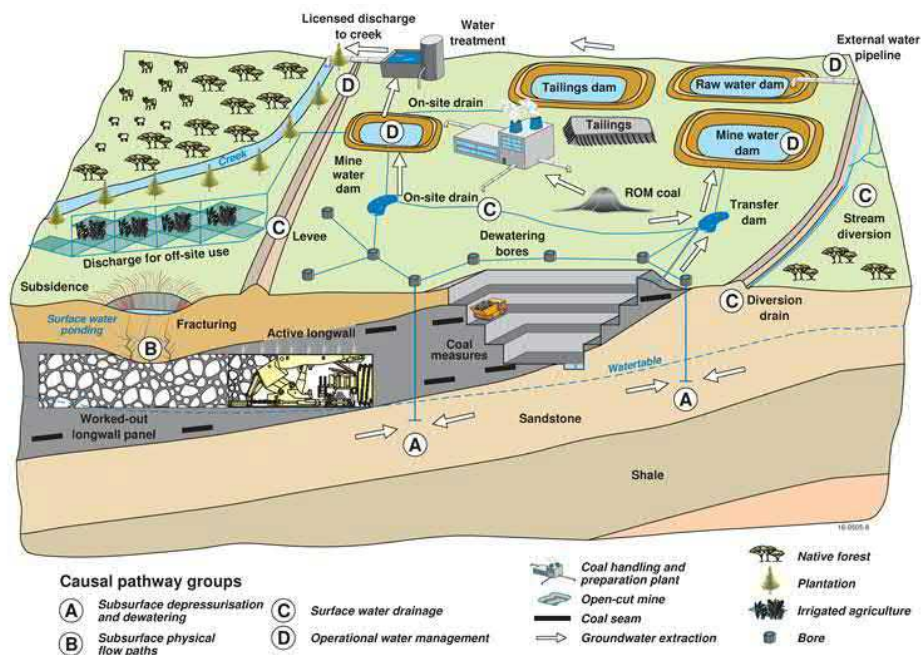


Figure 5.31 Conceptual diagram of the generic causal pathway groups defined in bioregional assessments that are associated with open-cut and underground coal mines (Henderson et al., 2016).

This report focusses on those causal groups primarily related to groundwater, that is ‘subsurface depressurisation and dewatering’, and ‘subsurface physical flow paths’. ‘Surface water drainage’ is also briefly discussed in relation to groundwater-surface water interactions.

The 'subsurface depressurisation and dewatering' group of causal pathways occurs when coal mines intentionally dewater the subsurface so that open-cut and underground mining operations can occur safely. This depressurisation can occur prior to mining extending into an area and/or as part of active mining operations where groundwater inflows are pumped away from active mining areas. The pre-existing hydraulic gradients are disrupted, usually causing changes to groundwater levels and pressures, and occasionally altering groundwater quality. Pumping from conventional bores extracting groundwater to support mining activities is also part of this causal group. However, the scale of the effects from conventional bores is typically less than those associated with underground mine dewatering which will be part of the proposed modification. Groundwater extraction for underground mine development can indirectly affect non-target strata in situations where direct hydraulic connections exist. The connections could be diffuse, such as connections between adjacent geological layers, or more focussed via structures such as faults. The proposed development (the modification) only involves the extension of the underground longwall panels, and no additional open cut mining will occur.

The UCC and surrounding region has had significant disturbance of groundwater levels from historical mining. Subsurface depressurisation from historic and recent mining is evident in the groundwater level records of bores screened in the Permian coal measures at UCC. Moolarben to the south and Wilpinjong Mine to the south-east both also show mine related drawdown in their groundwater level monitoring data. The lower layers show the greatest drawdown response to adjacent mining, which is not reflected in the bores screened in the upper strata as discussed in Section 5.8.

As discussed in Section 5.4.3, porewater pressure is monitored in a number of VWP sensor arrays installed in the vicinity of the UCC. The VWP sensor arrays are installed in a single borehole to measure changes in groundwater pressure over time at specific depths. Details of the sensor depths are provided in the GWMP. DDH336 is an example of such an installation, and is located within the mine footprint and discussed in Section 5.4.3.

As discussed in Section 5.8, and illustrated through the cross-section provided in Figure 5.24, it is evident that groundwater levels in lower parts of the Triassic (above the mined area) show moderate levels of drawdown (PZ10A and PZ07), while measurements recorded from higher in the Triassic and Jurassic formations show that groundwater levels appear to be mainly unaffected (EX06 and PZ10B). Away from the mining area, the Triassic formations show very little influence from mining.

Groundwater components that are potentially relevant to mining associated with the proposed modification are summarised in Table 5.5. The table outlines the most likely pathways, impact causes, impact modes and activities to generate the impacts. The potential hydrological effects on the groundwater system are noted in the final column. Those components that are most likely to produce the greatest changes to the groundwater system, or which have been identified as occurring within the proposed modification area are highlighted bold. The proposed modification specific groundwater impact assessment is discussed in Section 8. The most likely potential causal pathways identified have been considered when designing the numerical groundwater model to ensure that they are suitably represented.

Table 5.5 Potential causal pathways with a groundwater component for the proposed modification

Pathway	Cause	Mode and activity	Hydrological effect
Aquifers – Groundwater conditions post mining	Inevitable, deliberate	Artificial point of recharge, enhanced aquifer interconnectivity, groundwater source/sink – post closure groundwater inflow into mine workings Groundwater extraction from groundwater supply bores	Quality, Direction, Pressure, Volume/quantity Pressure
Groundwater pumping enabling underground coal mining	Longwall coal extraction (underground) Development of underground mine panels	Deliberate aquifer dewatering (groundwater pumping) for underground mine development and coal production	Groundwater level Groundwater flow Groundwater pressure Groundwater quantity/volume
Subsurface fracturing above underground longwall panels	Coal extraction from longwall panels	Creation of new subsurface fractures, and modification of existing fracture networks	Groundwater pressure Groundwater flow Groundwater quality Groundwater quantity/volume Surface water flow

Note: **Bold** highlighting indicates those causes and activities that are likely to cause the greatest changes for the proposed modification.

Source: After Henderson et al. (2016).

6 Numerical Groundwater Model

A 3D numerical groundwater flow model was developed using the Unstructured Grid Version of MODFLOW (MODFLOW-USG) to predict the impacts from the proposed modification. The objective of the modelling was to compare the impacts of the approved UCC and the proposed modification on the groundwater regime and the identified water dependent assets. A detailed description of the numerical model development is provided in Appendix A. The model extent is illustrated in Figure 6.1.

The model was divided into 19 layers comprising up to a maximum of 44,652 cells in each model layer with the dimension of the cells varying. The following Voronoi cell dimensions were adopted for key detail areas of the model domain:

- cells covering the mine areas ~ 125 m x 125 m cells;
- cells around the Drip ~ 25 m x 25 m; and
- cells representing stream and river locations ~ 200 m x 200 m although more refined around the Drip.

The model mesh is shown in Figure 6.1 which shows how the cell size varies across the model domain. This also shows the truncation of the model domain in the southeast.

As described in Appendix A, water entering or leaving the model domain is simulated through the actions of boundary conditions. The model boundary conditions were applied across the model grid and refer to any stresses applied to the model domain that influence the flow of groundwater within the model domain. The conceptual model indicates that the stresses on the groundwater system include diffuse recharge from rainfall, and stream leakage, and discharge from mine dewatering and baseflow to streams.

The model domain is surrounded by “no flow” boundaries. A “no flow” boundary does not allow any exchange of water between the model domain and the surrounding areas. The boundaries are set at a distance of around 40 km to the north and east from the proposed mining operation, and 20 km to the south and west, which is considered sufficient distance to avoid the boundary having an impact on the development of the cone of depression around the mine. The base of the model was also assumed to be a “no flow” boundary.

Layer 1 represents the alluvium associated with the Talbragar River, colluvium associated with Mona Creek, regolith and weathered bedrock. Updated topography data (sourced from the ELVIS database⁴) was used to derive the surface of the system and improved drainage line elevations. The updated topography data represents a significant improvement over the ground surface adopted in the previous model. Further to this, previous models assigned a nominal thickness of 20 m to layer 1. In this model update, data from the regolith thickness dataset from CSIRO⁵ has been used to support the structure of the shallow regolith and alluvium. The rest of the model layers are described as follows:

- Layer 2 represents the Tertiary basalt;
- Layers 3, and 4 represent the Pilliga and Purlewaugh Jurassic strata;
- Layers 5 to 8 represent the Triassic quartzose sandstone;
- Layer 7 is the main layer where discharge from the Drip is occurring;
- Layers 9 and 10 represent the Triassic lithic sandstone unit;
- Layers 11 to 18 represent Permian coal measures;
- The Ulan Seam is represented as a discrete layer (i.e. layer 16) within the Permian strata; and
- Layer 19 represents the bedrock strata.

⁴ ELVIS - Elevation and Depth - Foundation Spatial Data - <https://elevation.fsdf.org.au/>

⁵ CSIRO Soil and Landscape Grid of Australia (<http://www.clw.csiro.au/aclep/soilandlandscapegrid/index.html>), viewed Dec 2015.

An advantage of MODFLOW-USG is that the relationship between geological layers can be more accurately represented than previous versions of MODFLOW. For instance, where the Ulan Seam subcrops to the southwest, it is usually just below the surface geology and the opportunity for connection to surface layers is present. In a small number of discrete locations, the Ulan Seam subcrops directly beneath the Talbragar alluvium and its tributaries. MODFLOW-USG allows for this connection to be represented discretely.

Historic and the proposed mine dewatering is simulated using the MODFLOW-USG Drain package. Overall, the drain package removes water out of the model when the water level in the model cell is above the defined drain elevation. When the head is below the defined drain elevation, the drain becomes inactive.

The effects of the subsidence of material into the mined void/goaf, and the formation of a fracture zone above the mined panel were represented in the model by changing aquifer parameters. If the distance between the coal seam roof and the vertical centre of the model layer was within the expected extent of continuous cracking, then it was assumed that fracturing extends through the model layer to potentially form a pathway for vertical groundwater flow. Groundwater can flow through the fracture zone to the workings of the Ulan Seam based on the applied changes in vertical and horizontal hydraulic conductivity. In reality, the fracture network reduces in size and frequency with distance above the longwall mining area and the requisite model implementation is discussed in more detail in Appendix A.

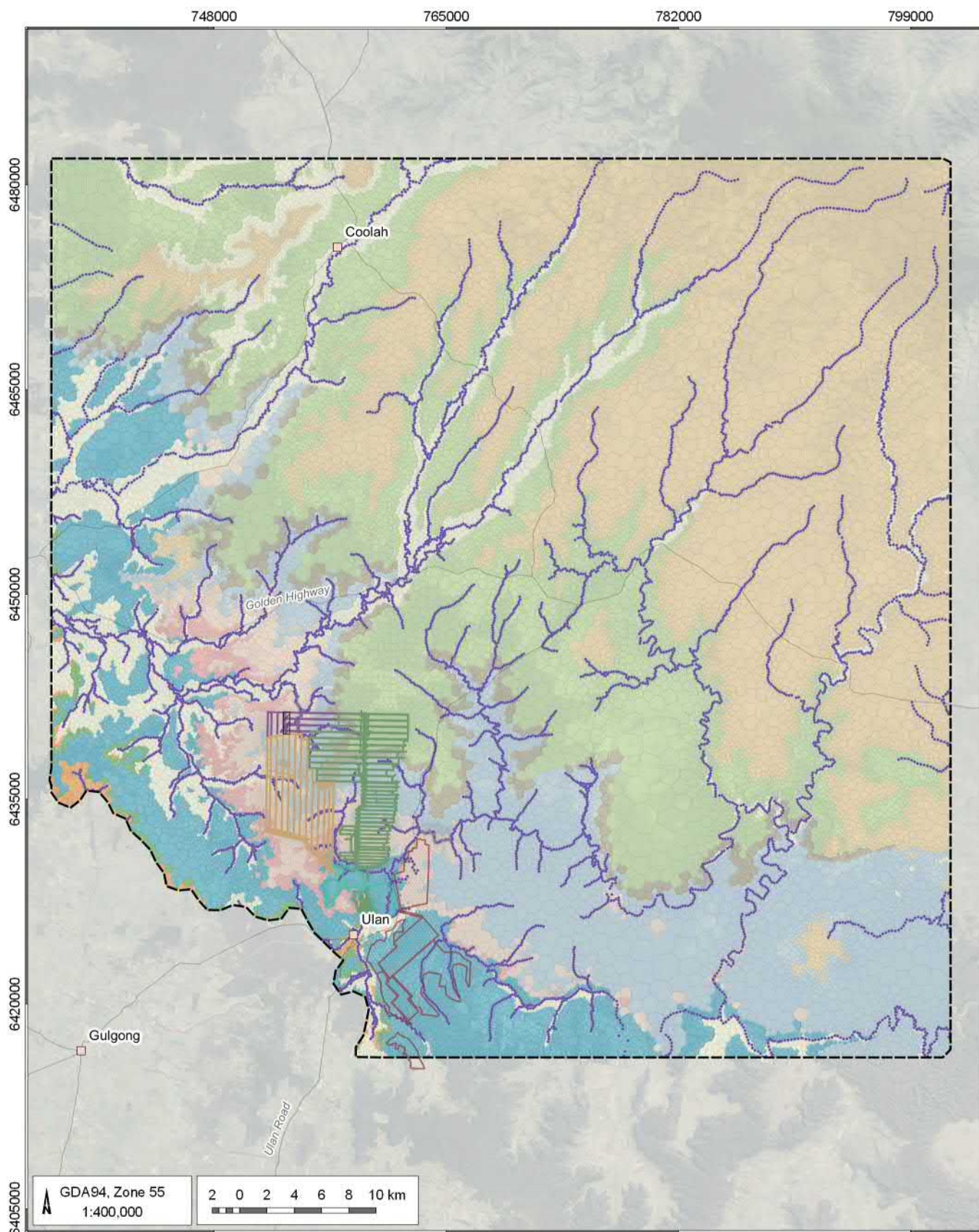
The model was constructed to allow for the simulation of both historical and future approved mining at the Ulan mine, with the historical period allowing for comparison between observed and model predicted groundwater level and flow behaviour. The model starts with the generation of a pre-mining steady state condition, before progressing to transient model conditions. The transient model is divided into quarterly time steps, which simulate the groundwater changes from January 1984 to 2034, with the calibration period covering 1984 to 2019.

The combined steady state and historical transient model was calibrated by adjusting aquifer parameters and recharge rates to produce the best match between the observed and simulated water levels, while also aligning to observed mine inflow and plausible baseflows. Automated parameterisation software (PEST, Doherty 2010) was used to determine optimal hydraulic parameters and recharge rates to achieve the best statistical calibration of the groundwater model to the observation dataset.

The root mean squared (RMS) error calculated for the calibrated model was 17.85 m. The total measured head change across the model domain was 449.41 m, with a scaled unweighted RMS (SRMS) error of 3.95%. This is significantly within the Australian Modelling Guidelines (Barnett, 2012) suggestion of SRMS error below 10%.

Following calibration, the model was used to predict potential changes in the alluvial water table and the Permian groundwater pressure (drawdown), as well as the volume of groundwater intercepted by the proposed modification. The numerical model was used to calculate the extent of groundwater level drawdown within each of the model layers through comparison of a null model run and a model run simulating the prediction of interest. This was done twice (i.e. three models required), firstly with the approved mine plan and then with the proposed modification mine plan. Extracting the predicted drawdown from both of these simulations and then calculating the difference between these drawdowns isolated the incremental change resulting from the proposed modification dewatering and fracturing.

The uncertainty of the model predictions, resulting from initial uncertainty in the assumptions and input parameters, was analysed. The analysis focussed on varying model parameters and design features that have the most influence on model predictions. The model parameters were adjusted within likely ranges to explore the range of uncertainty due to model parameter non-uniqueness. Appendix A provides a detailed discussion of the uncertainty analyses. Where possible, the uncertainty analysis followed the process recommended in the IESC's explanatory note on uncertainty analysis (Middlemis and Peeters, 2018).



LEGEND

- Populated place
- Road
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- Model domain
- Flexibility area

River cells

- River cell

Recharge zones

- 1 - Alluvium
- 2 - Basalt
- 3 - Jurassic (Piliga)
- 4 - Jurassic (Purlewaugh)
- 5 - Triassic (Quartzose - upper)
- 6 - Triassic (Quartzose - lower)
- 7 - Triassic (Lithic)
- 8 - Permian (above Ulan Seam)
- 9 - Permian (Ulan Seam)
- 10 - Permian (Lower) and Basement

Ulan MOG6 GIS (G1985G)

Model domain and recharge zones



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7 Groundwater model predictions

Predictive numerical modelling was undertaken to predict the impact of mining at the UCC on the groundwater regime. The objectives of the predictive modelling were to:

- predict groundwater inflow into the underground mine based on the approved mine plan;
- simulate and predict the extent and area of influence of mining on the shallow groundwater levels and deeper groundwater pressures; and
- predict the loss and/or water take from the water bearing units on site for licensing estimates, including losses to baseflow.

As outlined in Section 1.1, it is proposed that an area within EL 7542 may be accessed by either Ulan West Underground or Ulan Underground depending on timing of operations and mining conditions. Due to the proposed start time of mining in LW9 in the option where this panel is extended north being well before the same area would be mined by the alternate mine plan, this version of the option was taken forward in this assessment of MOD 6. This approach maximises the earlier drawdown at the northern boundary and therefore is most conservative in terms of drawdown extent with time. Apart from the timing, the impacts from either option will be essentially the same.

To make an assessment of the changes resulting from the proposed modification, a comparison was made between two models, one representing the situation without the change (the 'null' model) and one representing the alternate scenario. The difference between corresponding predictions from these two models defines the impact of the change.

To assess the changes due to the proposed modification at Ulan the following model situations or scenarios were created and used in various combinations to produce the range of required assessment items.

Table 7.1 Model setups used in the groundwater assessments

Model Setup	Model Description
1	No Mine model – simulates no mining in the model domain.
2	Only Moolarben - simulates the presence of Moolarben mine but excludes all Ulan mining. This can be used to isolate the Ulan only impacts from a cumulative model run.
3	Approved Mine – simulates the mine plan approved under MOD4. This model also simulates the Moolarben mine.
4	Modification Model – simulates the approved and additional proposed mining at Ulan and the mining at Moolarben.

All the predictions in the following sections are derived from combinations of these model setups.

The following sections describe the predictions for the approved mining simulation and the incremental change the proposed modification will have on the groundwater system.

7.1 Mine inflows

The extracted drain budget provides predicted mine inflows. This budget has been zoned to provide predictions of groundwater inflow to the underground mines at the UCC for the approved and proposed modification scenarios as shown in Figure 7.1. These results were taken directly from Model 3 and Model 4.

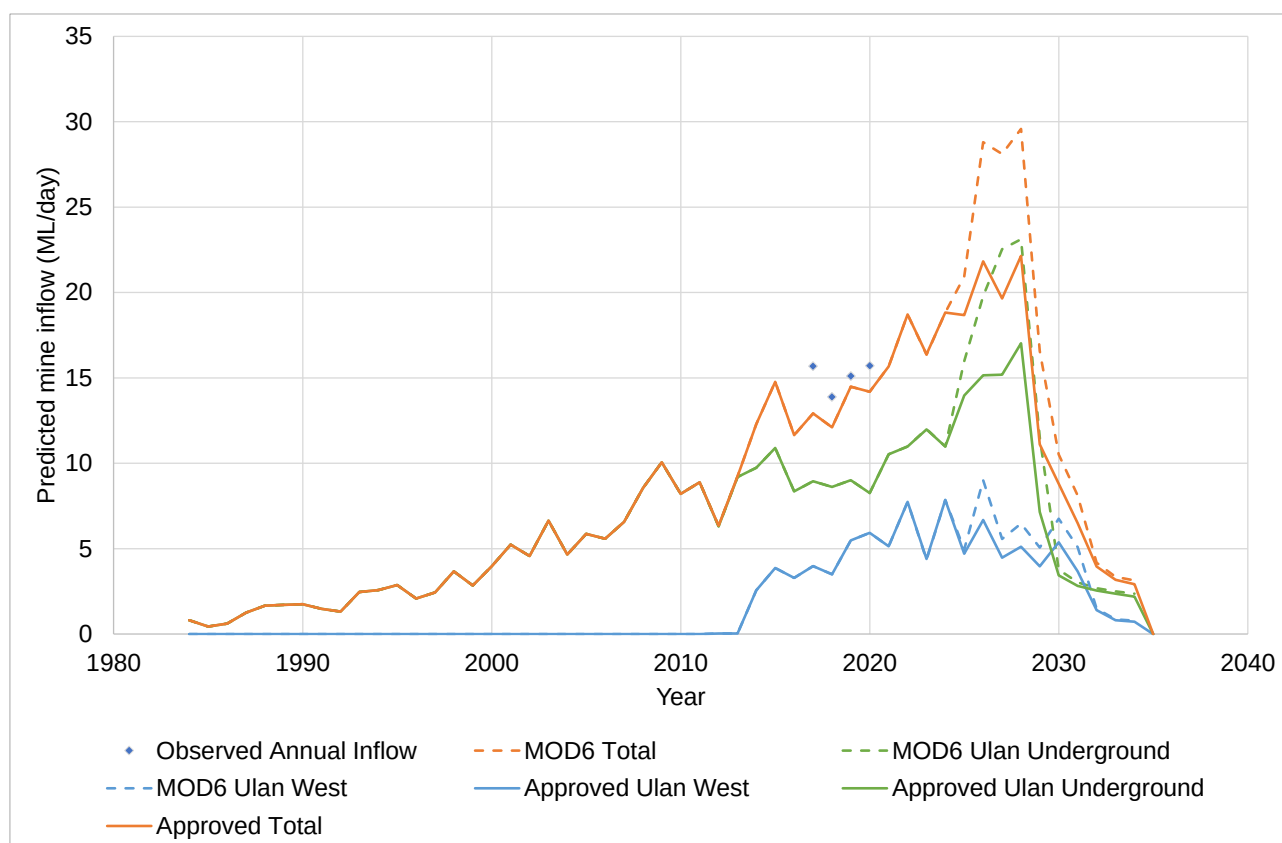


Figure 7.1 Predicted underground dewatering at Ulan for approved and for the proposed modification

During the period that the proposed modification is active, there is on average a 22% increase in mine inflow, which over the life of the mine is an 7.8% increase on the total inflow. This aligns to the increase in mine footprint of the proposed modification. The underground mine inflows have been measured at UCC and are in line with the volumes predicted by the numerical modelling as presented in Figure 7.1.

While there is an increase in the peak predicted dewatering from the approved to the proposed modification, this increase is predominantly sourced from the water stored in overlying formations. As fracturing occurs directly above the panels, this has no significant impact on already approved impacts away from the mine footprint.

7.2 Proposed modification - drawdown and depressurisation during mining

The extent of groundwater level drawdown/depressurisation is dependent on the properties of the coal seams, interburden units, and other surrounding hydrostratigraphic units. Groundwater level drawdown within the coal seam is greatest at the working coalface, and gradually reduces with distance from the mine.

The numerical model was used to predict the extent of groundwater level drawdown within each of the model layers through comparison of two model setups: a model simulating the approved mining (Model 3), and a model simulating the approved mining plus the changes due to the proposed modification (Model 4). Extracting the drawdown from comparing predicted heads from both of these simulations isolates the incremental change resulting from the proposed modification additional footprint. Figure 7.2 to Figure 7.5 presents the additional drawdown at the end of mining in model layers 1 (Alluvium/ colluvium), 7 (Triassic Quartzose), 10 (Triassic Lithic), and 16 (Ulan Seam) respectively, and represent the drawdown at the end of mining in 2035.

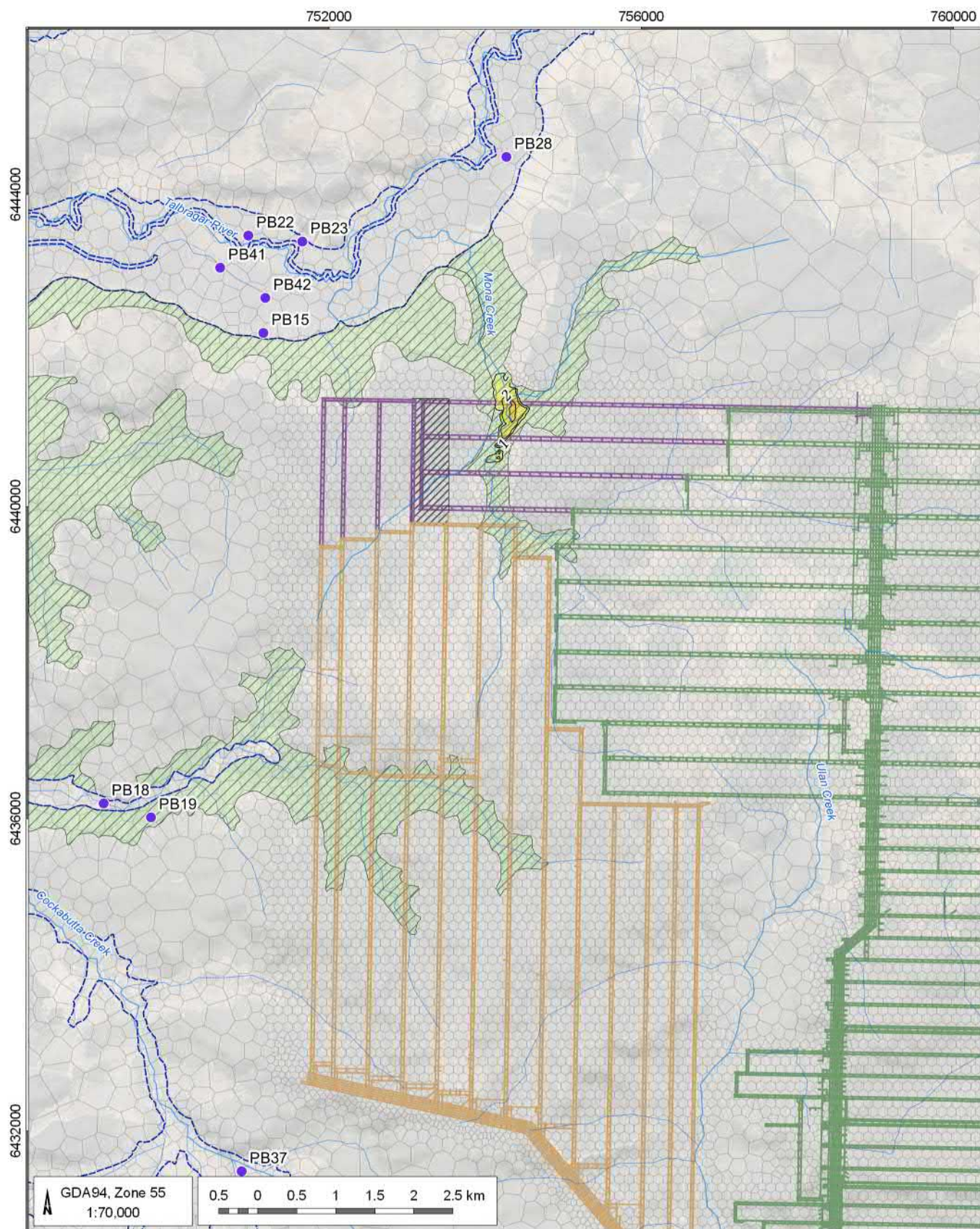
The additional drawdown contours for the Triassic formations do not extend under any saturated alluvium, however, the predicted drawdown contours do extend under and into areas of the colluvium associated with Mona Creek. This does result in additional drawdown in the Mona Creek valley sediments from the proposed modification, but this is contained within the colluvium of Mona Creek. The extent of predicted additional drawdown in Layer 1 does not extend north into the Talbragar alluvium. No changes to the impact on the Goulburn River alluvium are predicted from the proposed modification.

The model represents the Mona Creek sediments being vertically connected to the mining area through fracturing (noting the estimated fracture height is close to the base of the colluvium in this area). The predicted drawdown is considered conservative because the height of predicted fracturing is not expected to extend to the base of the colluvium. The height of fracturing has been estimated empirically using the Ditton-Merrick method, and this process (selecting appropriate input parameters) has been guided by an assessment of groundwater monitoring data observed at UCC. Through this process, AGE has been able to 'calibrate' the estimated height of fracturing, based on historical observations at the site, which have occurred in direct response to mining. As discussed in Section 5.1.1.1, the utility of the sediments associated with Mona Creek will not be significantly impacted by the proposed modification.

Drawdown is shown for both the quartzose (the more permeable part of the Triassic and most likely to be the source of water for private bores) and lithic sandstone formations of the Triassic age aquifers. Figure 7.3 shows that additional drawdown of the quartzose sandstone is limited in extent (compared with the underlying lithic sandstone, Figure 7.4) because a large component of the shallower quartzose aquifer are unsaturated prior to any mining. There is no drawdown predicted at the Drip due to Ulan, in either approved or proposed scenarios.

The elevation of the coal seam floor in the area covered by the proposed modification is higher, or 'up dip' of other mined areas within UCC. Mining in deeper areas has resulted in some depressurisation in the proposed modification footprint. This is evidenced by the additional coal seam drawdown maximising at just above 20 m (Figure 7.5).

In summary, the additional drawdown impact of mining is within the proposed modification footprint, because the areas surrounding UCC have already been impacted to a degree by the approved mining.



LEGEND

- Surface drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model mesh
- ▭ Alluvial
- ▨ Colluvial
- ▧ Flexibility area

Drawdown (m)

- 0
- 1
- 2
- 5
- 10
- 20
- Drawdown Contour
- Private bore

Ulan MOD6 GIA (1985G)

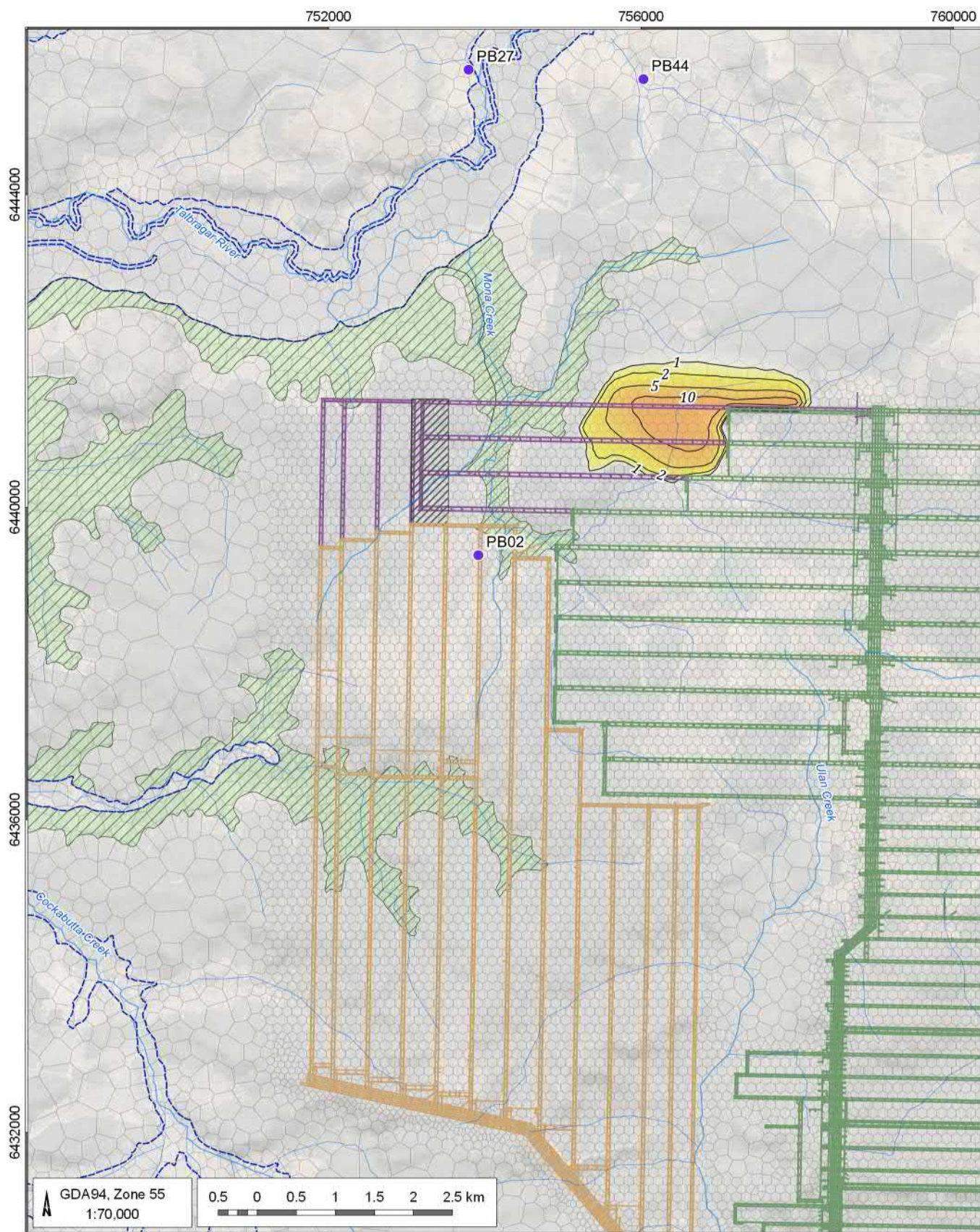
Additional drawdown in the alluvium / colluvium from proposed modification at 2035



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FIGURE No:
7.2



LEGEND

- Surface drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model mesh
- Alluvial
- Colluvial
- Flexibility area

Drawdown (m)

- 0
- 1
- 2
- 5
- 10
- 20
- 50
- Contour line
- Private bore

Ulan MOD6 GIA (1985G)

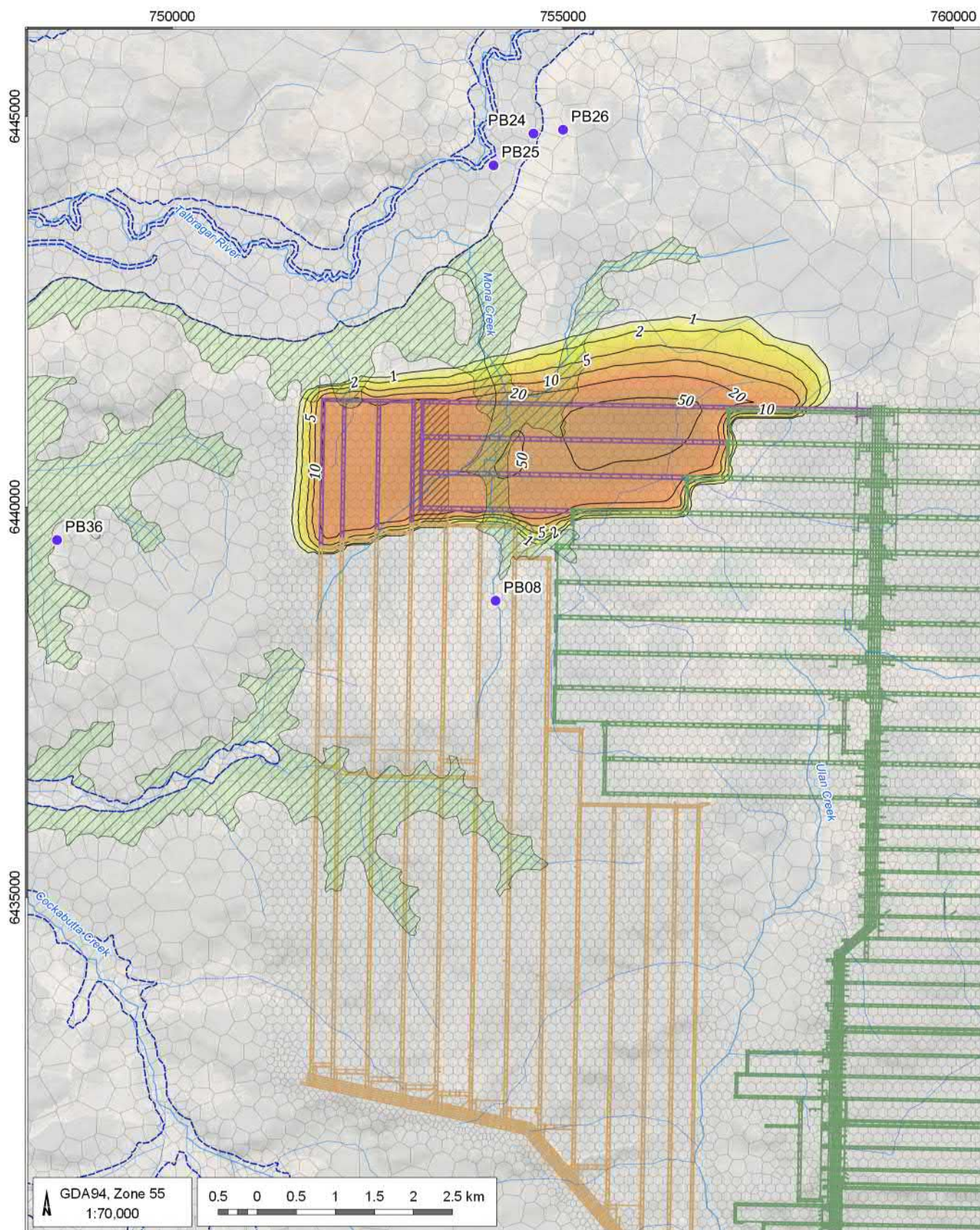
Additional drawdown in the Triassic (Quartzose) water table at 2035



AGE

DATE
12/08/2022

FIGURE No:
7.3



LEGEND

- Surface drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model mesh
- Alluvial
- Colluvial
- Flexibility area

Drawdown (m)

- 0
- 1
- 2
- 5
- 10
- 20
- 50
- 100
- Drawdown Contour
- Private bore

Ulan MOD6 GIA (1985G)

Additional drawdown in the Triassic (Lithic) from proposed modification at 2035



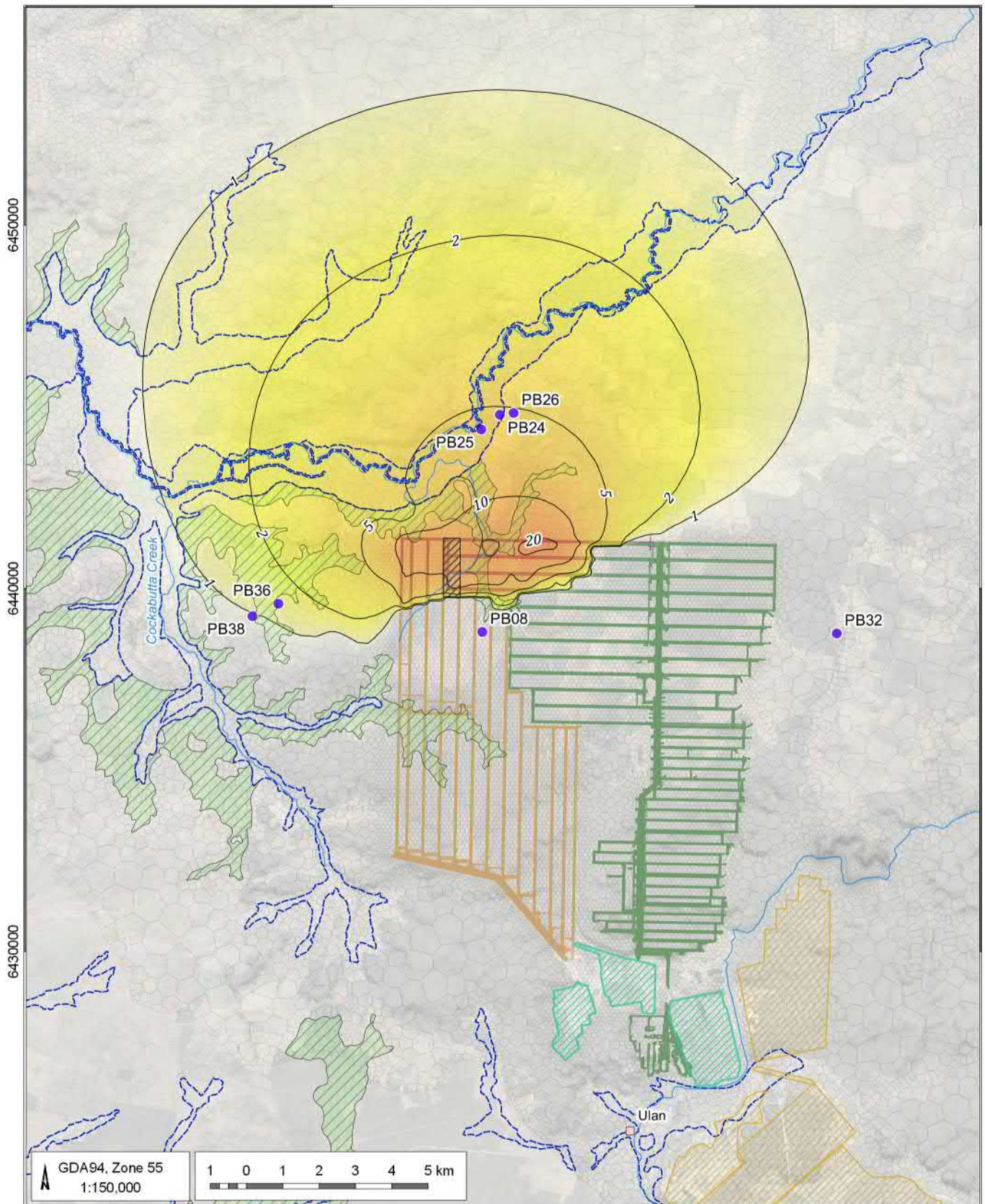
AGE

DATE
12/08/2022

FIGURE No:
7.4

750000

760000



LEGEND

- Populated place
 - Surface drainage
 - Ulan Underground Mine Plan
 - Ulan West Mine Plan
 - Proposed longwall panel
 - Moolarben mine area
 - Ulan open cut
 - Model mesh
 - Model domain
 - Alluvial
 - Colluvial
 - Flexibility area
 - Private bore
 - Additional drawdown contour (m)
- Additional drawdown (m)**
- 1
 - 2
 - 5
 - 10
 - 20
 - 50
 - 100

Ulan MOD6 GIA (1985G)

**Additional drawdown in the Ulan Seam
from proposed modification at 2035**



AGE

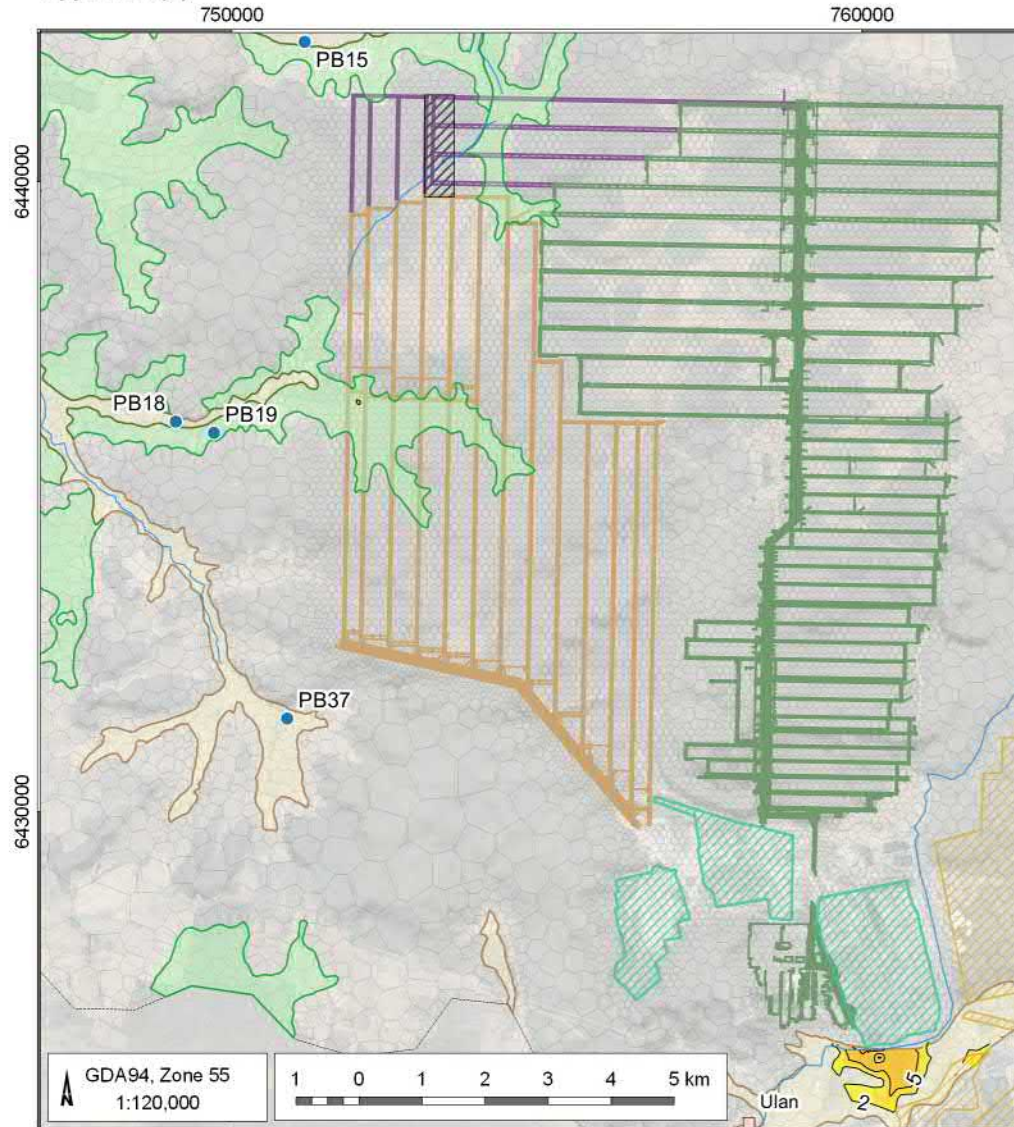
DATE
12/08/2022

FIGURE No:
7.5

7.3 Cumulative drawdown and depressurisation during mining

Figure 7.6 to Figure 7.9 show the predicted drawdown for the approved mining (Model 1 minus Model 3) and also for the proposed modification (Model 1 minus Model 4). It is evident from these figures that the predicted impacts for proposed modification are largely within or in line with the previously approved drawdown away from the proposed modification footprint.

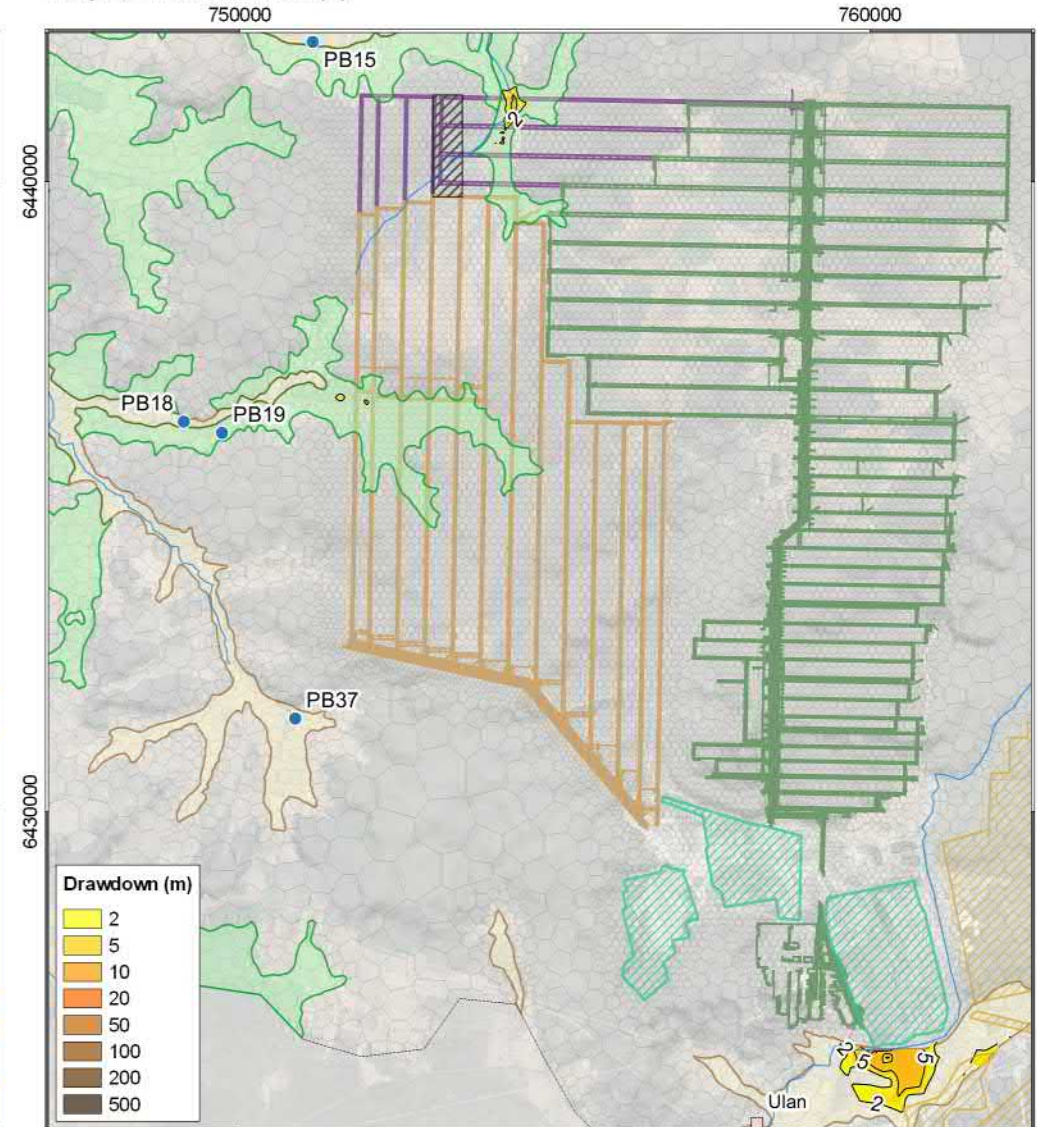
Approved (a)



LEGEND

- Populated place
- Surface drainage
- Drawdown contour (m)
- Ulan Underground Mine Plan
- Ulan West Mine Plan
- Proposed longwall panel
- Moolarben mine area
- Ulan open cut
- Alluvium
- Colluvium
- Model mesh
- Model domain
- Flexibility area

Proposed Modification (b)



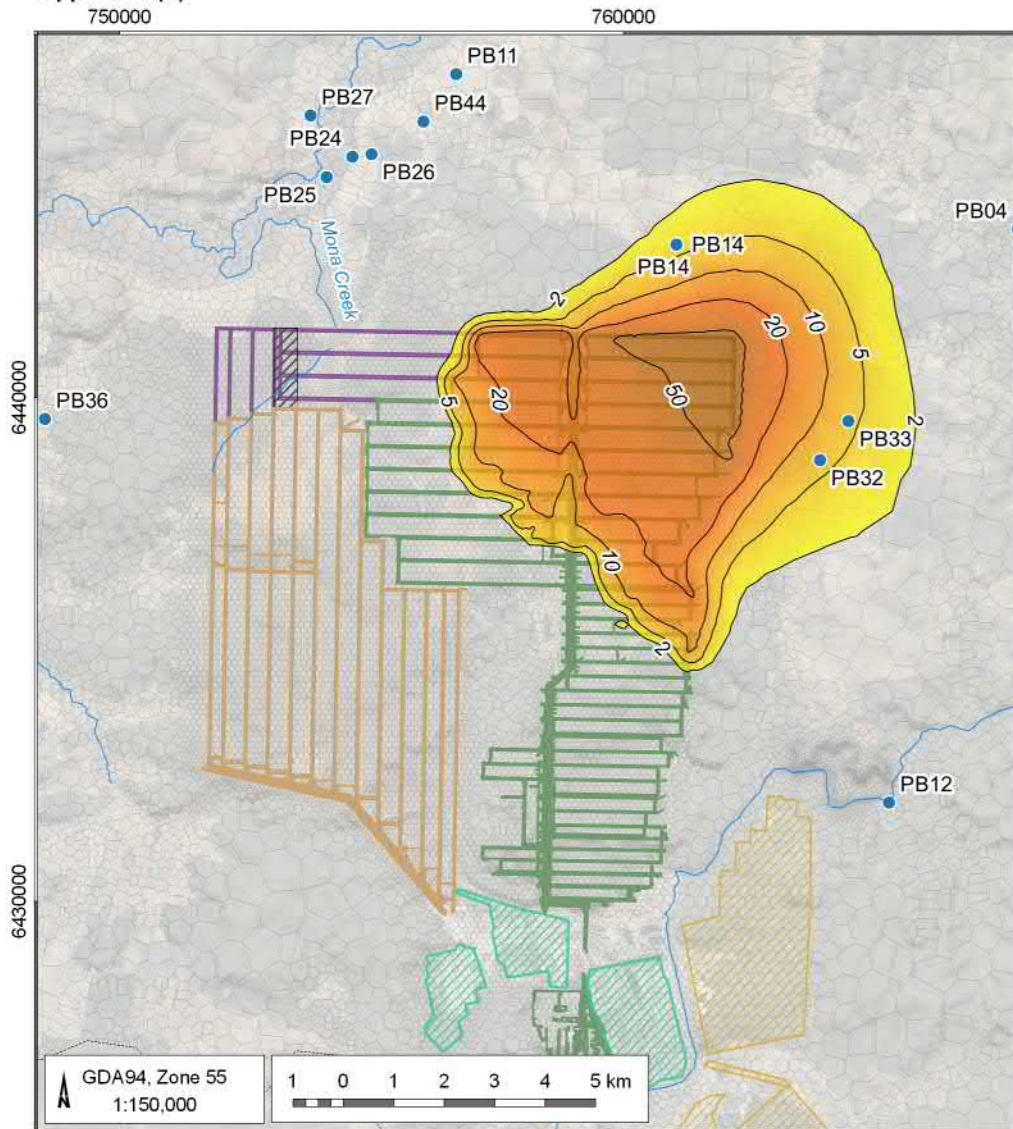
Ulan MOD6 GIA (1985G)

Predicted cumulative drawdown in the alluvium / colluvium for the (a) approved and (b) from the proposed modification at 2035

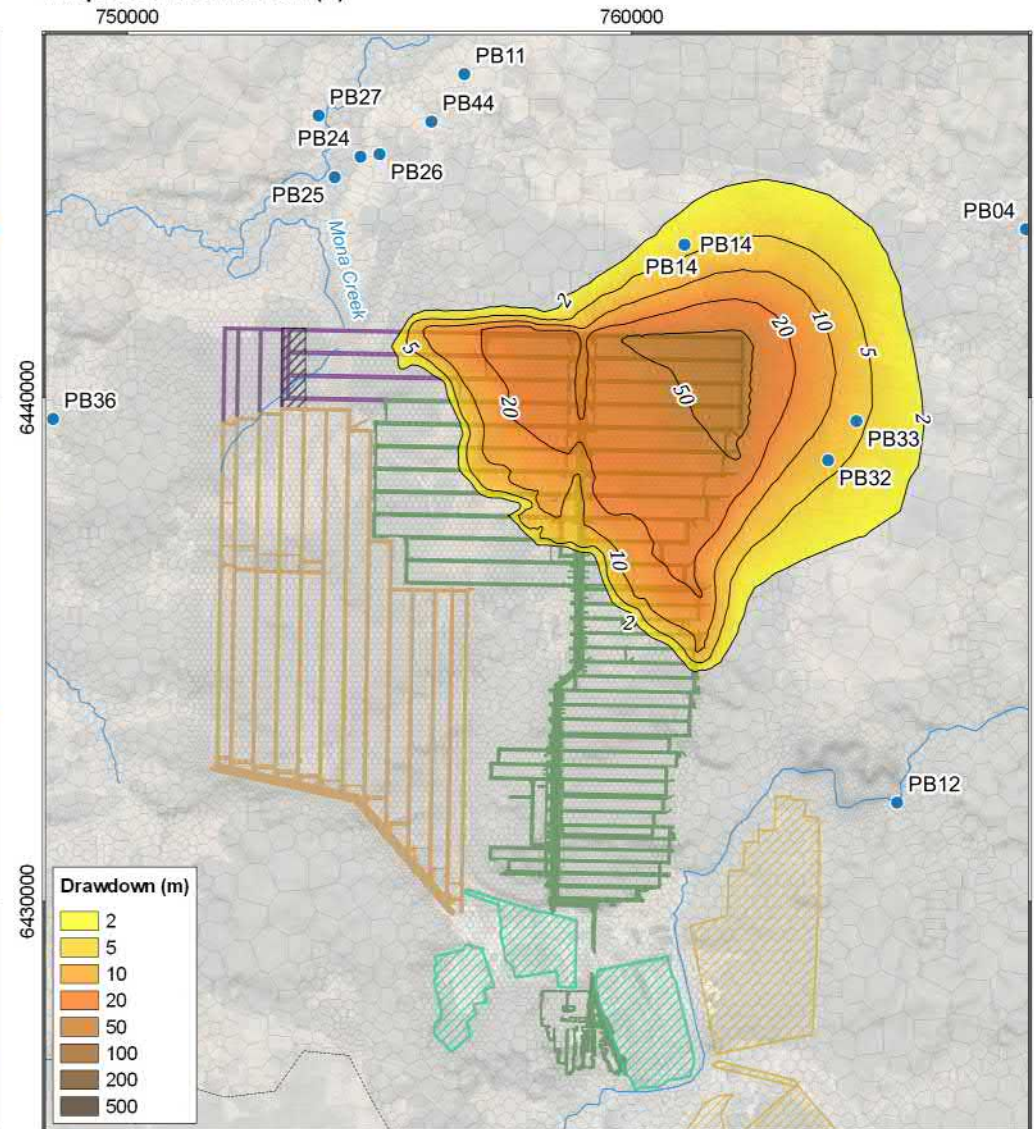
DATE
12/08/2022

FIGURE No:
7.6

Approved (a)



Proposed Modification (b)



LEGEND

- Populated place
- Surface drainage
- Drawdown contour (m)
- Ulan Underground Mine Plan
- Ulan West Mine Plan
- Proposed longwall panel
- Moolarben mine area
- Ulan open cut
- Model mesh
- Model domain



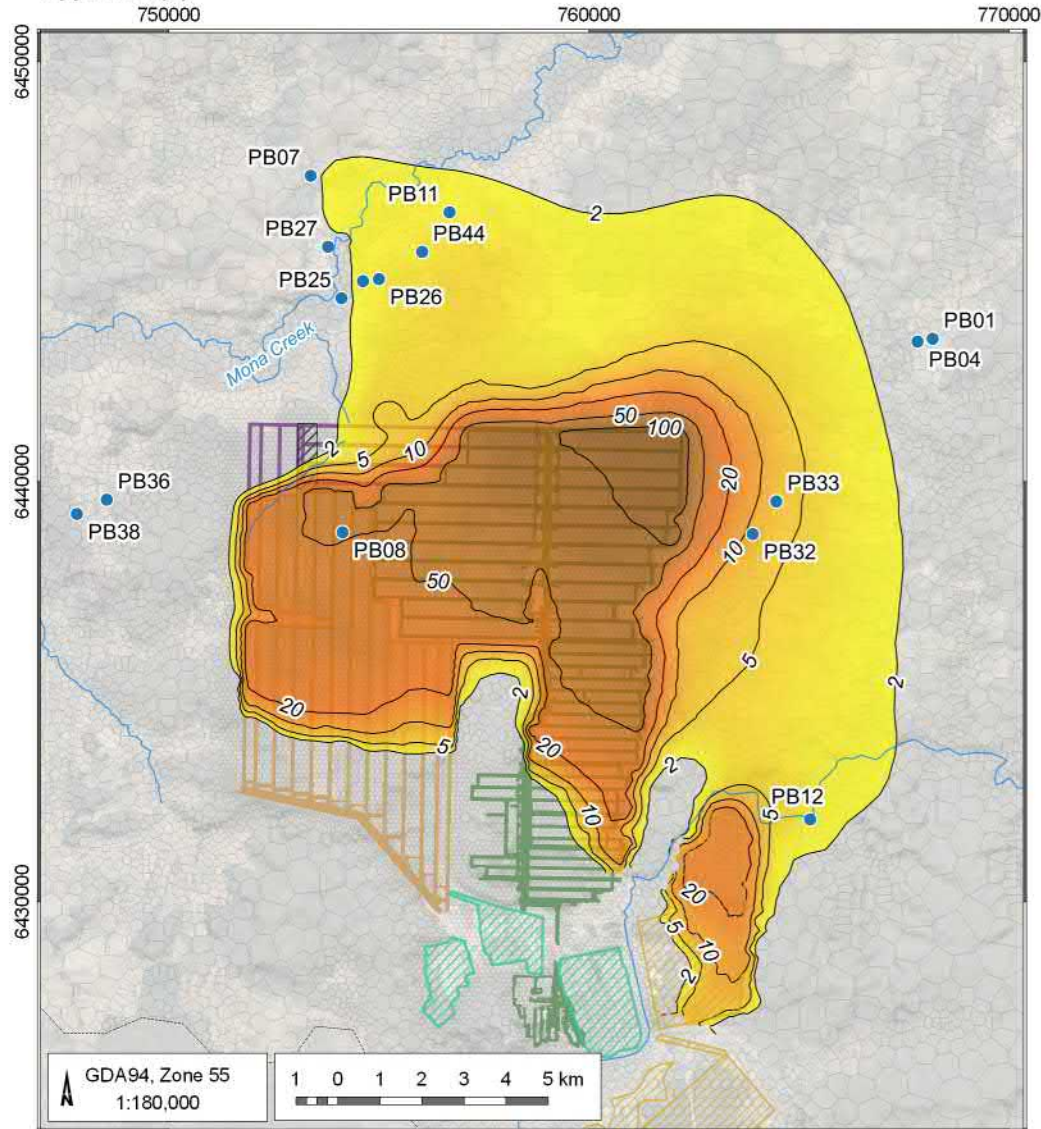
Ulan MOD6 GIA (1985G)

Predicted cumulative drawdown in the Quartzose Triassic sediments for the (a) approved and (b) from the proposed modification at 2035

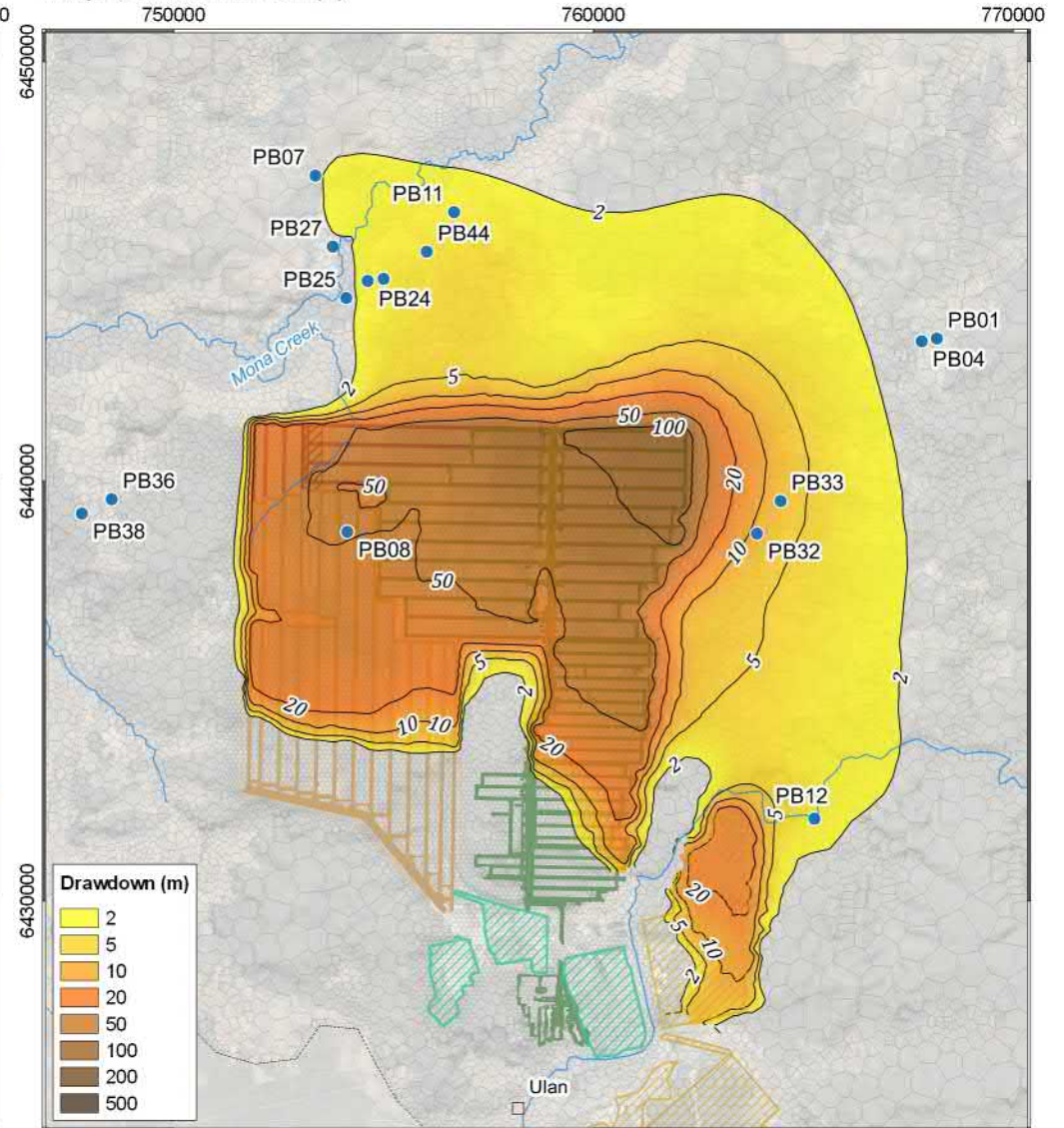
DATE
12/08/2022

FIGURE No:
7.7

Approved (a)



Proposed Modification (b)



LEGEND

- Populated place
- Surface drainage
- Drawdown contour (m)
- Ulan Underground Mine Plan
- Ulan West Mine Plan
- Proposed longwall panel
- Moolarben mine area
- Ulan open cut
- Model mesh
- Model domain
- Flexibility area



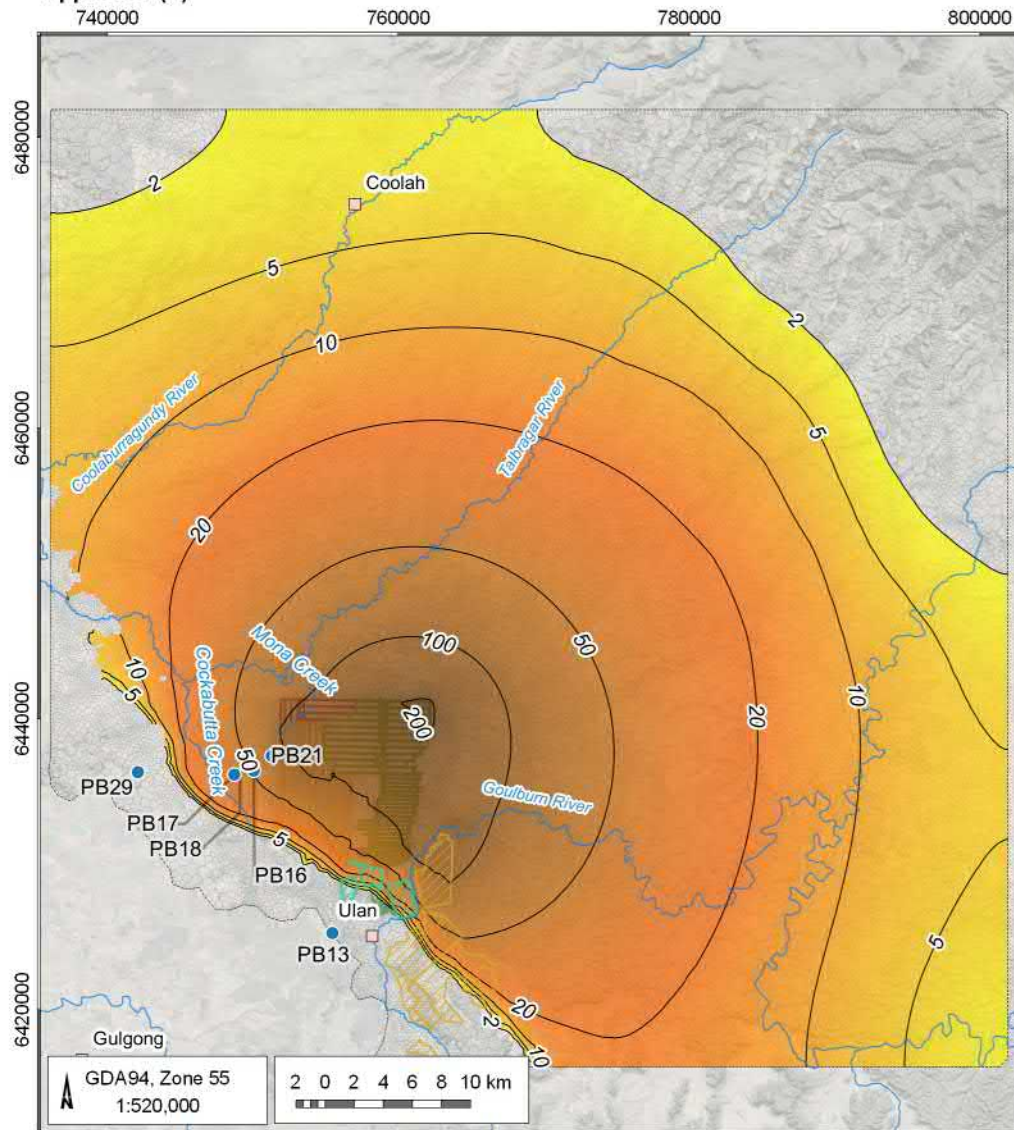
Ulan MOD6 GIA (1985G)

Predicted cumulative drawdown in the Lithic Triassic sediments for the (a) approved and (b) from the proposed modification at 2035

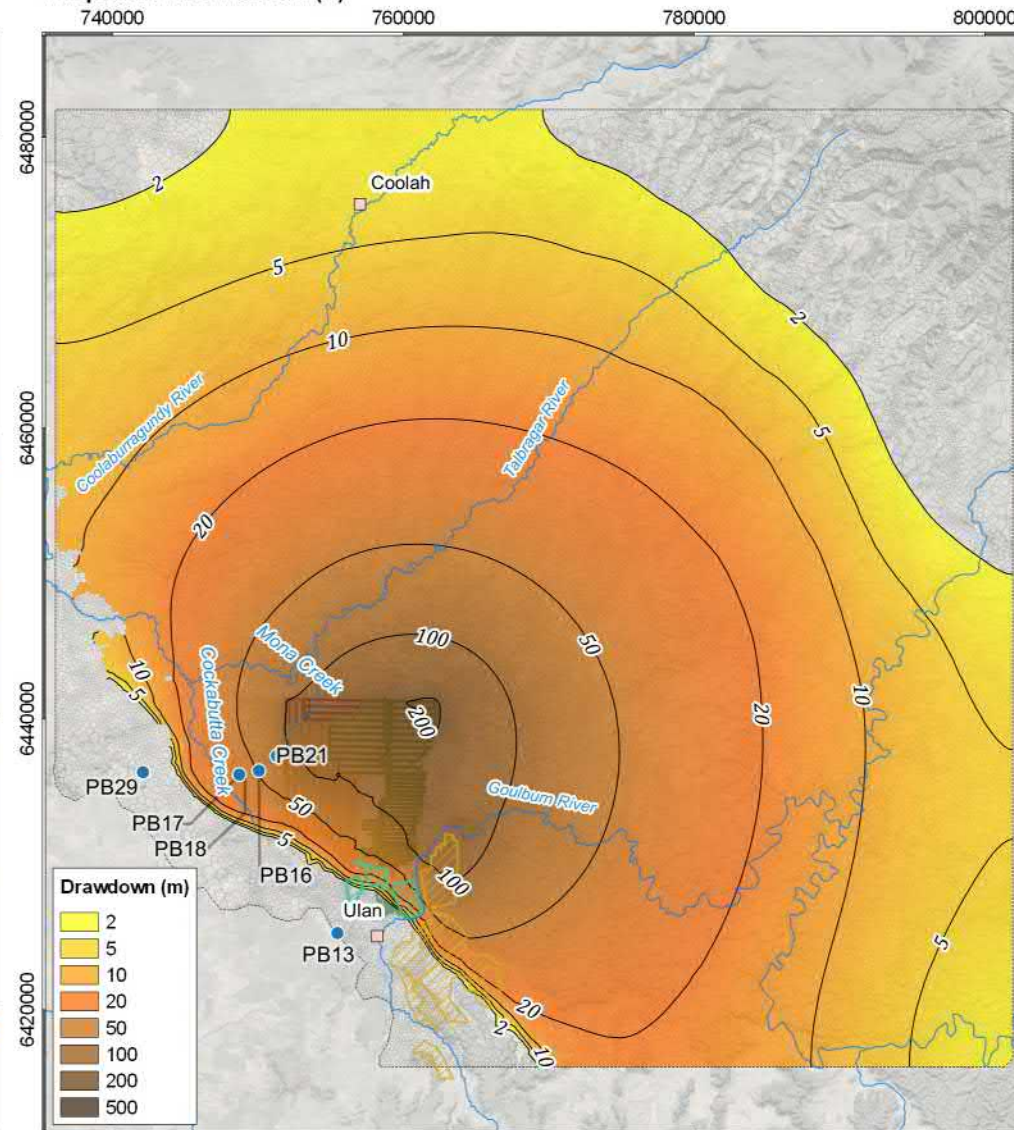
DATE
12/08/2022

FIGURE No:
7.8

Approved (a)



Proposed Modification (b)



LEGEND

- Populated place
- Surface drainage
- Drawdown contour (m)
- Ulan Underground Mine Plan
- Ulan West Mine Plan
- Proposed longwall panel
- Moolarben mine area
- Ulan open cut
- Model mesh
- Model domain
- Flexibility area



UCML – EPBC Referral - Groundwater Review
(G1985G)

Predicted cumulative drawdown in the Ulan Seam for the (a) approved and (b) from the proposed modification at 2035

DATE
12/08/2022

FIGURE No:
7.9

7.4 Post mining conditions

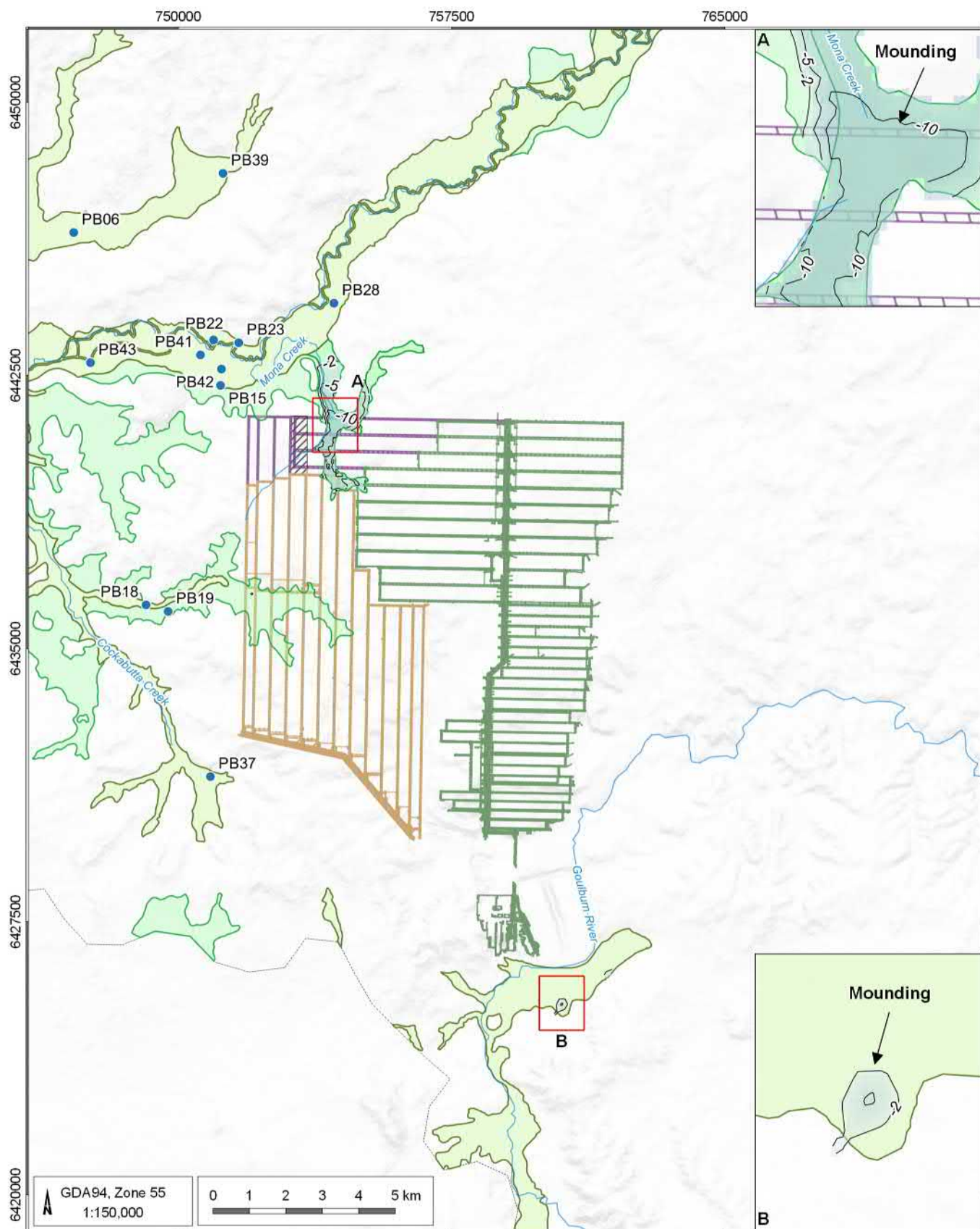
When mining finishes at Ulan West and Ulan Underground, the area around the existing portals in the open cut pits will be regraded to have the northern section of the current East Pit void extent remain a void and form the topographical low point of the area (noting that the western arm of East Pit void will be backfilled). The plan involves the water level in the void being maintained at an elevation of 359 mAHD.

In the period following the cessation of mining, the drawdown presented in previous sections will continue to propagate outwards until there is sufficient recovery of groundwater levels throughout the mined area. The rate at which the 2 m drawdown extent expands will reduce as the gradient back to the dewatered area decreases. Open cut pits that are backfilled with unconsolidated sediments (spoil) are areas where groundwater is expected to mound up due to an increase in groundwater recharge.

Eventually the groundwater system that surrounds Ulan mine will reach an equilibrium, however due to the changes in hydraulic properties due to fracturing above longwall panels, the recovered groundwater levels across the mine area will form a relatively uniform level. This is because the system is more connected than the pre-mining conditions. This means that some groundwater levels will be lower, and some groundwater levels will be higher than pre mining groundwater levels.

The predicted long term residual drawdowns (and mounding) have been derived from a steady state stress period in the groundwater model which represent the system state in an equilibrium. Figure 7.10 to Figure 7.14 show the cumulative residual post mining impacts, incorporating the approved Ulan mining plus the proposed modification and the neighbouring Moolarben mine (Model 1 minus Model 4). It was assumed that the mining at Moolarben ceased at the same time as Ulan and the model changes were applied to both sites to represent the post mining conditions.

Figure 7.10 shows the long-term residual mounding for the alluvium and colluvium. The colluvium associated with Mona Creek is expected to see up to a 10 m rise in water levels post mining. The figure also shows that there is mounding predicted in the mapped alluvium adjacent to Moolarben and this is probably the result of the high recharge into the adjacent spoil piles at Moolarben.



LEGEND

- Private bore
- Major drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Drawdown/Mounding contour (m)
- Alluvium
- Colluvium
- Model domain
- ▨ Flexibility area

Drawdown (m)

- 0
- 2
- 5
- 10
- 20
- 50
- 100
- 200
- 500

Mounding (m)

- -500
- -200
- -100
- -50
- -20
- -10
- -5
- -2
- 0

Ulan MOD6 GIA (G1985G)

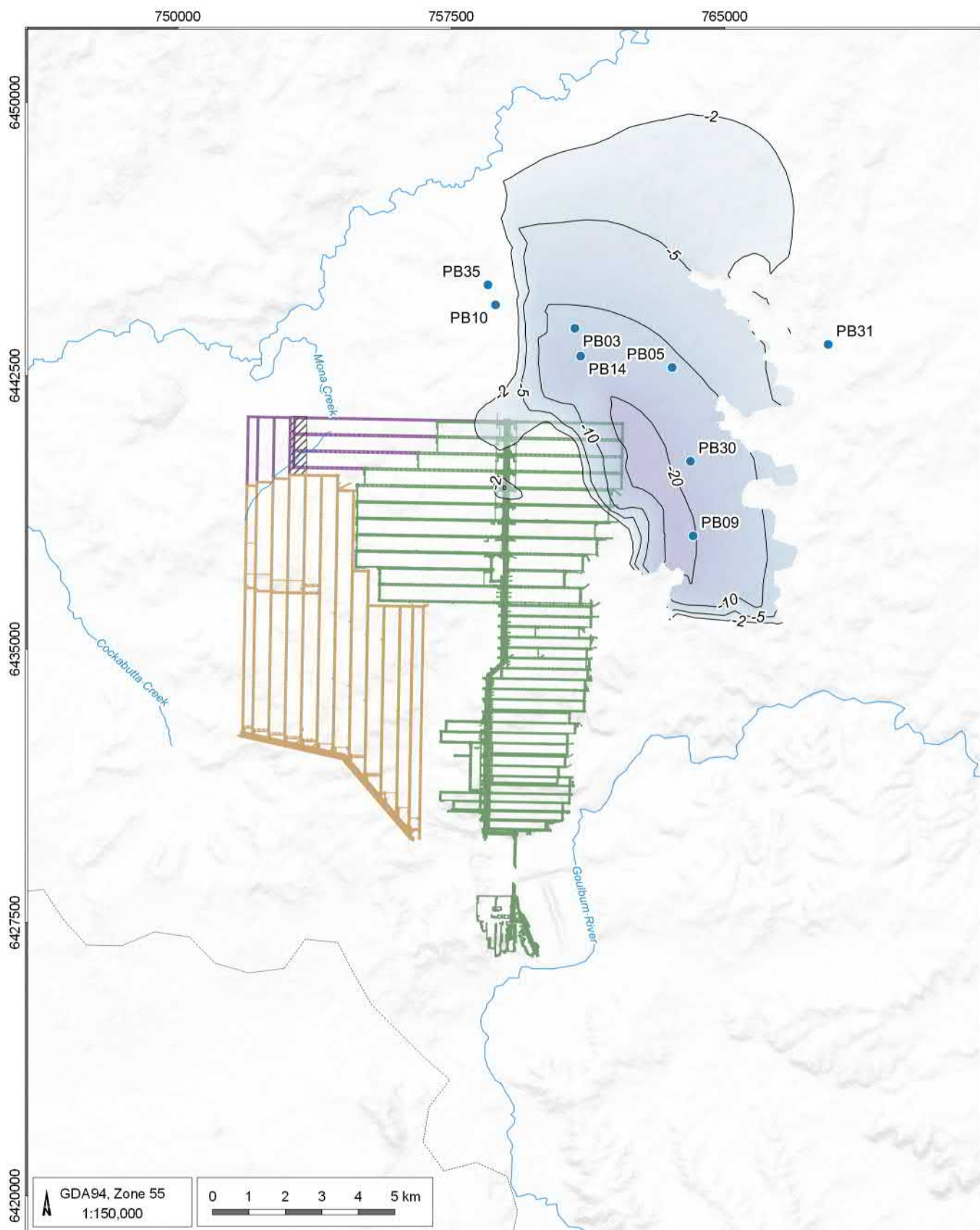
Predicted long term drawdown and mounding - alluvium / colluvium



AGE

DATE
03/11/2022

FIGURE No:
7.10



LEGEND

- Private bore
- Major drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Drawdown/Mounding contour (m)
- Model domain
- ▨ Flexibility area

Drawdown (m)

- 0
- 2
- 5
- 10
- 20
- 50
- 100
- 200
- 500

Mounding (m)

- 500
- 200
- 100
- 50
- 20
- 10
- 5
- 2
- 0

Ulan MOD6 GIA (G1985G)

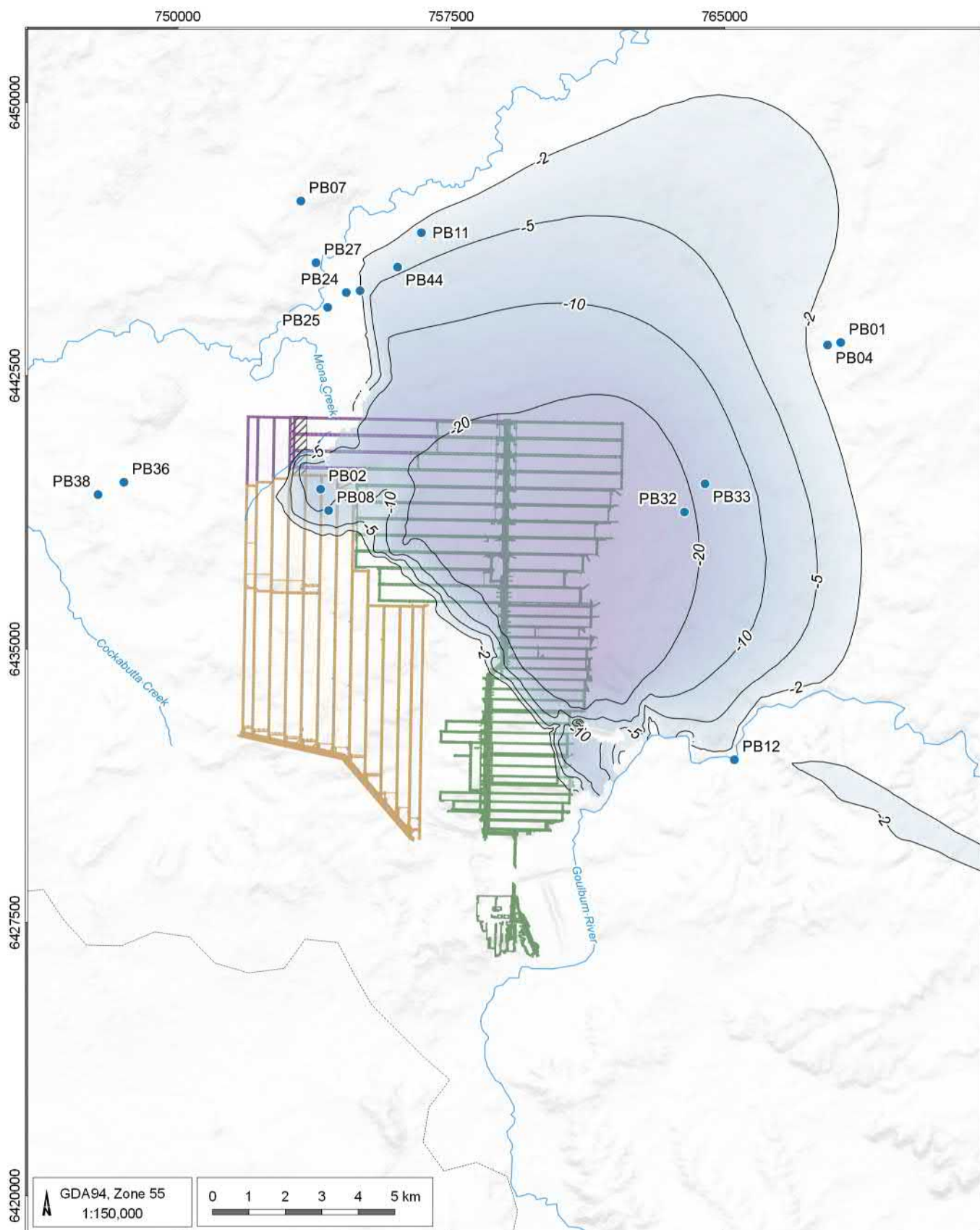
Predicted long term drawdown and mounding - Jurassic



AGE

DATE
03/11/2022

FIGURE No:
7.11



LEGEND

- Private bore
- Major drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Drawdown/Mounding contour (m)
- ▨ Model domain
- ▨ Flexibility area

Drawdown (m)

- 0
- 2
- 5
- 10
- 20
- 50
- 100
- 200
- 500

Mounding (m)

- 500
- 200
- 100
- 50
- 20
- 10
- 5
- 2
- 0

Ulan MOD6 GIA (G1985G)

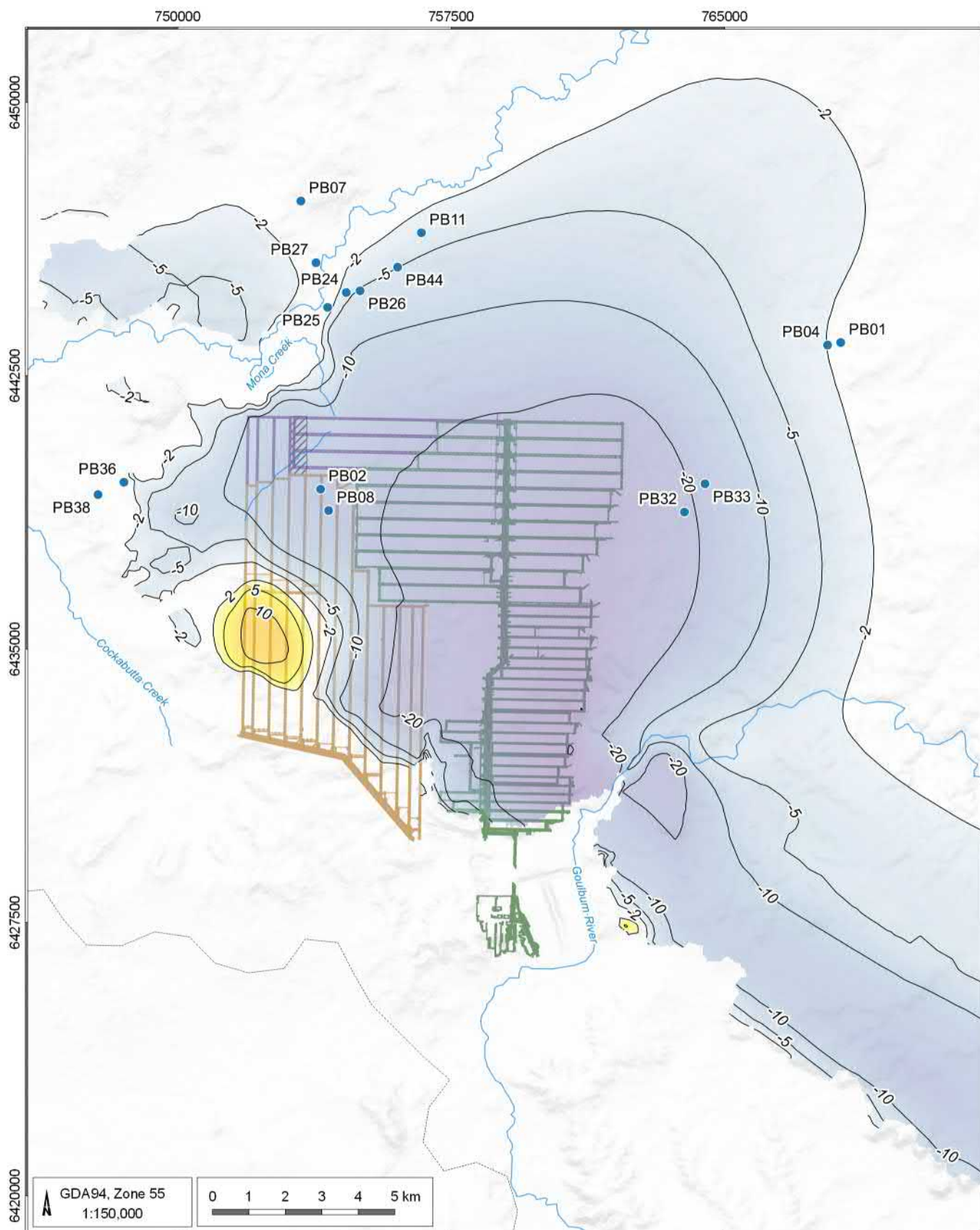
Predicted long term drawdown and mounding - Triassic (Quartzose)



AGE

DATE
03/11/2022

FIGURE No:
7.12



LEGEND

- Private bore
- Major drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Drawdown/Mounding contour (m)
- Model domain
- ▨ Flexibility area

Drawdown (m)

- 0
- 2
- 5
- 10
- 20
- 50
- 100
- 200
- 500

Mounding (m)

- 500
- 200
- 100
- 50
- 20
- 10
- 5
- 2
- 0

Ulan MOD6 GIA (G1985G)

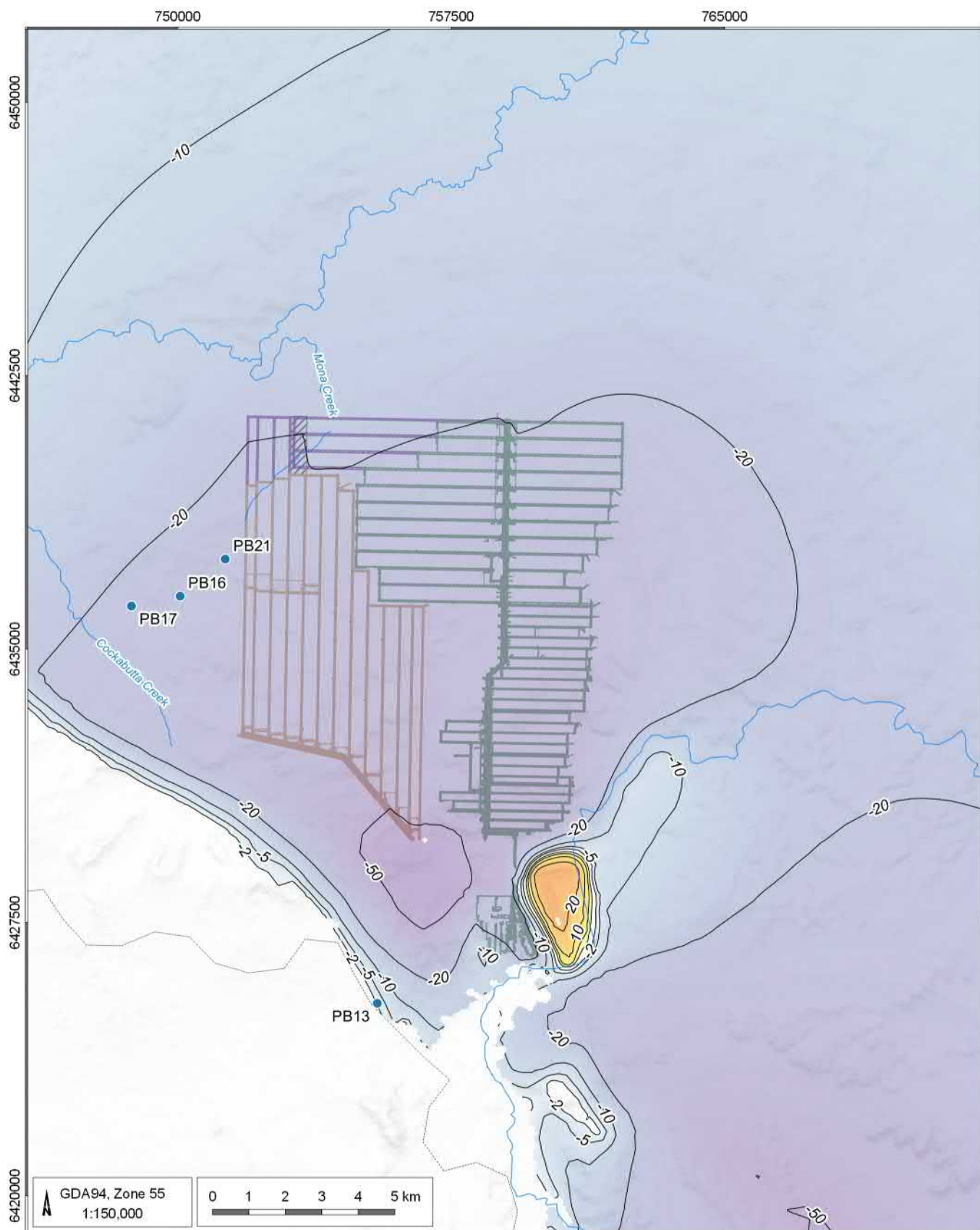
Predicted long term drawdown and mounding - Triassic (Lithic)



AGE

DATE
03/11/2022

FIGURE No:
7.13



LEGEND

- Private bore
- Major drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Drawdown/Mounding contour (m)
- Model domain
- ▨ Flexibility area

Drawdown (m)

- 0
- 2
- 5
- 10
- 20
- 50
- 100
- 200
- 500

Mounding (m)

- 500
- 200
- 100
- 50
- 20
- 10
- 5
- 2
- 0

Ulan MOD6 GIA (G1985G)

Predicted long term drawdown and mounding - Ulan Seam



AGE

DATE
03/11/2022

FIGURE No:
7.14

8 Groundwater Impact Assessment

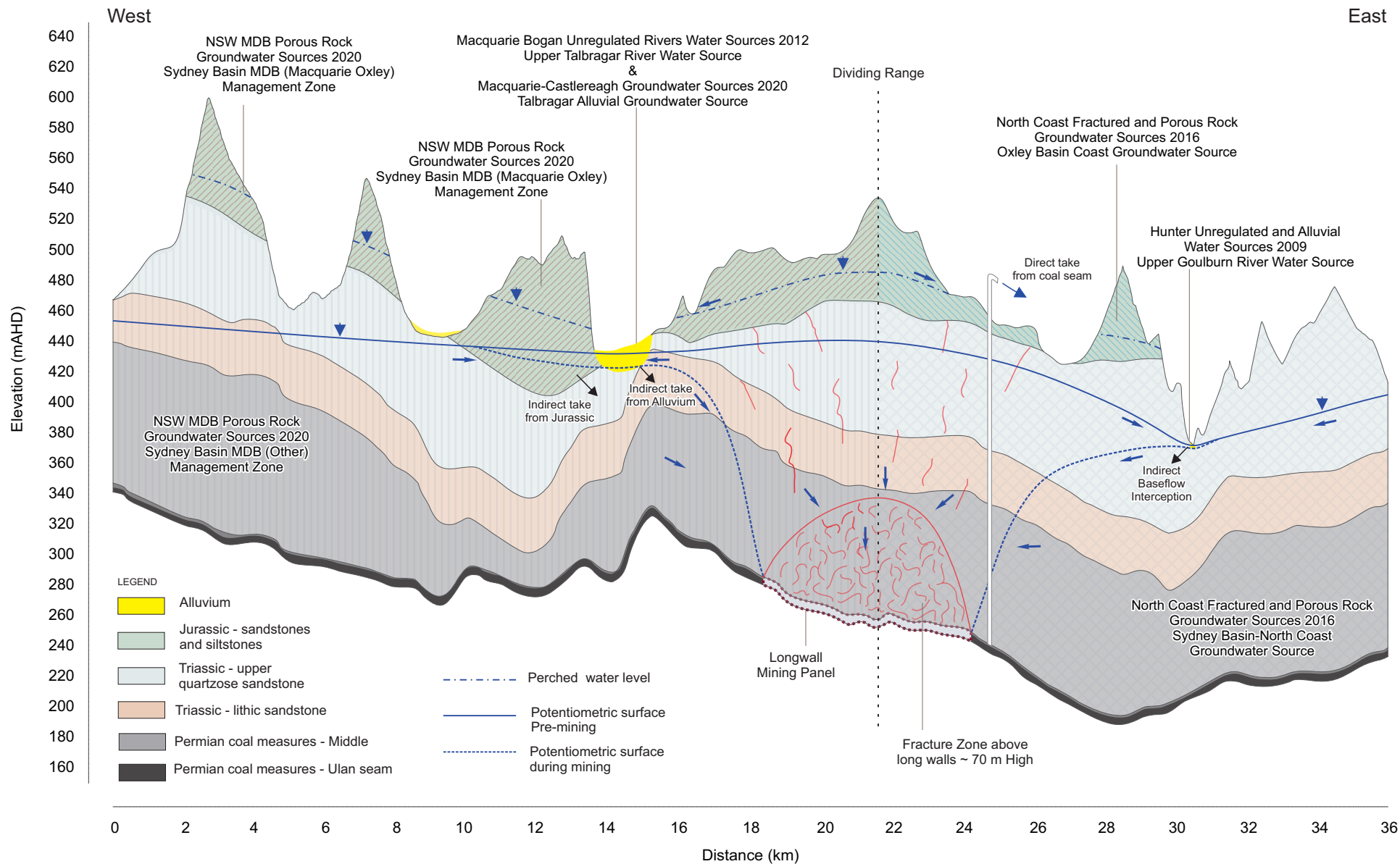
As documented in Section 7, the MODFLOW-USG model was run a number of times with various assumptions to provide a way of comparing and isolating various impacts. To isolate the impacts due to the proposed modification, comparisons were made between the model representing the approved mining including Moolarben (Model 3) and the model simulating the approved mining plus the proposed modification (Model 4). Extracting the drawdown from both of these simulations and then calculating the difference between these drawdowns isolates the incremental change resulting from the footprint of the proposed modification. The same approach was used to isolate the change in flows resulting from the proposed modification. This approach has been used in the GIA discussed below.

8.1 Water licensing requirements

The WM Act and AIP require that all groundwater taken, either directly or indirectly, is accounted for via WALs unless an exemption has been granted. Groundwater intercepted from the mining area is considered a direct take (or incidental take) from the Permian groundwater system, whilst the changes in flow occurring within the Quaternary alluvium and rivers resulting from depressurisation of the underlying Permian is considered an indirect or passive take of water.

The model was used to predict the impact or take from the various water sources associated with the various water sharing plans covering the UCC area and these are discussed in the section below. The various water sources that the UCC impacts are identified in the schematic cross section shown in Figure 8.1, which highlights the complexity of the various water sources as the mine traverses a significant catchment divide.

The reporting includes the take predicted at the end of mining and is consistent with previous reporting, but also provides predicted peak takes post mining, and the long-term residual take from the water sources.



Schematic cross section showing water sources

Figure - 8.1

Ulan MOD6 GIA (G1985G)

8.1.1 Direct take from the Permian (inflow to the mine)

To calculate the direct water take for water sources associated with the Permian sediments, the inflow to the underground mine was partitioned into the two key WSP areas (i.e. North Coast Fractured and Porous Rock and NSW Murray Darling Basin Porous Rock plan areas). In this aspect, the key metric is the maximum annual take of groundwater for licensing constraints.

The modelled take for the approved mine plan is presented in Table 8.1. The results indicate that the peak is 5,222 ML/year and has already occurred in 2015 for the North Coast Fractured and Porous Rock – Sydney Basin – North Coast Groundwater Source, while the peak for NSW Murray Darling Basin Porous Rock Groundwater Sources 2020 - Sydney Basin MDB (Other) Management Zone is predicted to be 5,604 ML/year in 2026/2027 for the approved mining.

When the proposed modification mine plan is simulated, the peak inflow within the North Coast Fractured and Porous Rock – Sydney Basin – North Coast Groundwater Source is unchanged from the approved project. It is understood that GCAA has sufficient licencing across its operations to cover the inflow peak within the North Coast Fractured and Porous Rock – Sydney Basin – North Coast Groundwater Source. The NSW Murray Darling Basin Porous Rock Groundwater Sources 2020 - Sydney Basin MDB (Other) Management Zone peak inflow is predicted to increase to 8,339 ML/year. If the ML/unit share in that water source decreases below 1.2 ahead of 2026/27 (currently 1.25 ML/unit), UCMPL will need to acquire licence allocation in the NSW Murray Darling Porous Rock - Sydney Basin MDB Groundwater Source to support the extraction associated with the modification. The long-term average annual extraction limit for the Sydney Basin MDB Groundwater Source is 19,100 ML/year, current allocations are less than 6000 ML.⁶ The NSW Department of Industry⁷ found that:

- *Shares allocated in these water sources is generally well below their extraction limit – this is due to low yields and varying water quality.*
- *There is limited use of groundwater for irrigation, commercial and town water supply purposes*
- *Groundwater trading is very limited.*
- *There is no concern for water level declines outside natural variations.*

Table 8.1 Comparison of WSP Underground direct take

Water Sharing Plan and Water Sources	Licence (units)	Approved Peak (ML/year)	MOD6 Peak (ML/year)
North Coast Fractured and Porous Rock – Sydney Basin – North Coast Groundwater Source	7060*	5,222 (2014/15)	5,222 (2014/15)
NSW Murray Darling Basin Porous Rock Groundwater Sources 2020 - Sydney Basin MDB (Other) Management Zone	6950**	5,604 (2026/27)	8,339 (2026/27)

Notes * licence at time of peak take, currently being transferred to this water source after being incorrectly assigned. Current Licence allocation of 4000 units sufficient for predicted future peak inflows of up to 3191 ML in 2028.

** UCMPL holds licences for 6950 units of water allocation in this source. Units are currently assigned a value of 1.25ML/ unit meaning the licenced volume is currently 8687.5 ML and exceeds the predicted peak take.

The annual take increases over time, reaching the peak mentioned in Table 8.1 and then reduces as the Ulan Seam becomes increasingly unsaturated towards the end of mining and the groundwater system reaches a new equilibrium.

6 S26 (3) Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2020.

7 NSW Department of Industry (2019) NSW MDB Porous and Fractured Rock Groundwater Status Update. Downloaded from: https://www.industry.nsw.gov.au/__data/assets/pdf_file/0004/270949/groundwater-status-update.pdf on 6 October 2021.

8.1.2 Indirect take from the Jurassic sediments (Oxley Basin)

Peak water take from the Jurassic sediments water sources for the approved and proposed modification mine plans are presented in Table 8.2. The proposed modification results in only minor increases in the passive take from both water sources associated with the Jurassic Sediments. These takes are predicted to peak 50 to 80 years post mining. The 2021 upgrade of the groundwater model included additional layers that made prediction of inflows from the Jurassic sediments possible. UCMPL is undertaking acquisition of allocations within the relevant sources.

Table 8.2 Peak water take from the Jurassic sediments

Water Sharing Plan and Water Sources	Licence (Units)	Approved Peak (ML/year)	MOD6 Peak (ML/year)	Post mining peak (ML/year)	Post mining residual (ML/year)
North Coast Fractured and Porous Rock Groundwater Sources 2016 - Oxley Basin Coast Groundwater Source	0*	11.13	11.98	35.2	0 (2.87 ML/year increase)
NSW Murray Darling Basin Porous Rock Groundwater Sources Order 2020 - Sydney Basin MDB (Macquarie Oxley) Management Zone	0	7.71	8.51	32.0	0 (2.98 ML/year increase)

Note: * 7060 units currently assigned to this water source in error, but is understood 7000 units are in the process of being transferred to the North Coast Fractured and Porous Rock – Sydney Basin – North Coast Groundwater Source, leaving 60 units behind in this water source.

8.1.3 Indirect take from the Talbragar Alluvium and Talbragar River

The peak water take from the Talbragar Alluvium and Talbragar River are shown in Table 8.3.

Post mining the peak take on the Talbragar river baseflow will be 49.11 ML/year (approximately 100 years post mining), before decreasing back and reversing to a residual long term gain of 14.6 ML/year. The take for the Talbragar alluvial groundwater source is 2.45 ML at the completion of mining which is predicted to increase to a peak take of 13.86 ML post mining before reducing to a long term gain of 4.4 ML/year.

UCMPL owns 50 units of allocation in the Macquarie Bogan Unregulated Rivers Water Sources 2012 - Upper Talbragar River Water Source, which is more than adequate to account for the predicted baseflow reduction. Likewise, the predicted peak take from the Macquarie – Castlereagh Groundwater Sources Order 2020 - Talbragar Alluvial Groundwater Source will be covered by the 30 units UCMPL are entitled.

The passive take occurs over a large area and thus impacts on baseflows or changes to the persistence of pools are unlikely to be observable.

Table 8.3 Peak water take from the Talbragar Alluvium

Water Sharing Plan / Water Sources	Licence (Units)	Approved Peak (ML/year)	Proposed Modification Peak (ML/year)	Post mining peak (ML/year)	Post mining residual (ML/year)
Macquarie Bogan Unregulated Rivers Water Sources 2012 - Upper Talbragar River Water Source	50	27.28	31.96	49.11	0 (14.6 ML/year increase)
Macquarie - Castlereagh Groundwater Sources Order 2020 - Talbragar Alluvial Groundwater Source	30	2.33	2.45	13.86	0 (4.4 ML/year increase)

8.1.4 Indirect take from the Upper Goulburn River water source

Drawdown from mining will lower groundwater levels and will in places reduce flow to alluvial sediments and baseflow to surface drainages. This indirect take from the approved operations is predicted to peak for the Upper Goulburn River water source (part of the Hunter River unregulated and alluvial water sources 2009 water sharing plan) at 122.6 ML/year as presented in Table 8.4. The predictions are consistent with the range of baseflow losses/gains that could be ascertained using upstream and downstream gauging station results.⁸ Simulation of the proposed modification mine plan does not increase the take from the Goulburn system. At present UCMPL have 600 units (ML) of licences available in this water source and the predicted take is well within the licenced amount.

Post mining the take from the Upper Goulburn water source is predicted to decrease to 86.97 ML/year due to continued propagation of drawdown as mine workings and the fracture zone rewet. Further into the future, the predicted mounding of groundwater at Ulan and Moolarben, results in an increase in baseflow over the pre mining conditions for the Upper Goulburn water source of 133 ML/year.

Table 8.4 Peak water take from the Upper Goulburn River

Water Sharing Plan / Water Sources	Licence (Units)	Approved Peak (ML/year)	Proposed Modification Peak (ML/year)	Post mining peak (ML/year)	Post mining residual (ML/year)
Hunter River unregulated and alluvial water sources 2009 – Upper Goulburn River water source	600	122.6	122.6	86.97	0 (133 ML/year increase)

⁸ HEC (2021) Ulan Complex: Baseflow Loss Assessment – Goulburn River, part of Ulan Coal 2020 Annual Review, available at www.ulancoal.com.au.

8.2 Water supply bores

Numerical modelling of the approved mining with the updated model indicates that seven of the 44 private bores will potentially experience greater than 2 m drawdown and may experience some loss of yield. Simulation of the proposed modification does not introduce any new bores to the list, with the only change being incremental changes to predicted drawdown in some of the bores already predicted to be impacted. Table 8.5 lists the seven impacted private bores, and outlines their predicted impact for approved and proposed modification mining.

In summary there is only small incremental changes on private users due to the proposed modification.

Table 8.5 Summary of predicted drawdown at private bores during mining

Site ID	Ground elevation (mAHD)	Total depth (mbgl)	Screened strata	Predicted drawdown (m)		
				Approved mining drawdown	Proposed Modification	
					Drawdown	Increase in Drawdown (m)
PB08	436	~ 67	Triassic	133.94	133.94	0.00
PB21	470.1	-	Coal Measures	21.70	21.71	0.01
PB17	445.1	>30	Coal Measures	36.81	36.99	0.18
PB32	494.8	-	Triassic	8.18	8.18	0.00
PB33	491.8	-	Triassic	6.25	6.25	0.00
PB20	453	55	Coal Measures ?	9.81	9.81	0.00
PB16	450.2	65	Coal Measures ?	21.74	21.74	0.00

Post mining the list of bores to be potentially impacted by more than 2 m increases and is presented below in Table 8.6. There are an additional 11 private bores that are predicted to be impacted by 2 or more metres post mining, however all of these 18 bores are predicted to recover higher than the pre-mining water levels into the distant future. Table 8.6 also provides the predicted timing of the maximum drawdown in 'years post mining', with the more distant bores reaching a predicted peak drawdown at equilibrium (denoted by >3000 years).

Table 8.6 Maximum and long term residual drawdown at private bores (>2 m).

Site ID	Maximum predicted drawdown (including post mining) (m)	Predicted years post mining for the maximum drawdown	Long-term predicted residual drawdown (m)
PB08	133.89	-11 (during mining)	-17.3
PB17	44.10	100	-21.3
PB16	29.63	200	-19.2
PB21	27.87	200	-12.3
PB20	20.61	300	-19.5
PB32	16.92	150	-21.8
PB38	14.34	>3000	-14.7
PB33	14.24	150	-16.6
PB14	12.26	300	-14.2
PB36	11.51	>3000	-11.8
PB30	11.02	300	-16.7
PB03	9.85	400	-12.4
PB10	6.74	500	-10.3
PB35	4.61	1000	-7.7
PB25	3.53	>3000	-7.6
PB24	2.68	>3000	-5.8
PB44	2.35	3000	-4.5
PB26	2.29	>3000	-4.5

8.3 Baseflow impacts

Modelling of the proposed modification predicts the peak impact on the baseflow for the Talbragar River system (and its tributaries) is a 7.6% increase (~2.2 ML/year) in intercepted baseflow over the approved level. The total baseflow for the Talbragar River and its tributaries is predicted to be over 3726 ML/year (10.2 ML/day), making the predicted impact from proposed modification comparatively small to imperceptible (0.06% of total baseflow).

The Goulburn River system is not expected to be impacted by the proposed modification given its location and no additional impacts on baseflows in this system are predicted.

8.4 Groundwater quality

The alluvium, regolith and Triassic overburden are the primary source of recharge waters to the deeper Permian coal measure sequences at the UCC. In the longer term, and on cessation of mining, groundwater will continue to migrate downwards through the subsidence zone to the goaf zone and mined area. This influx of relatively low salinity water will gradually flood and fill the mined workings. As there are no open cut voids associated with the proposed modification, there will be no evaporative concentration of salts in groundwaters stored within the underground workings and therefore there is no mechanism for significant changes to groundwater salinity due to mining.

There is no permanent flow of groundwater into Mona Creek that occurs within the proposed modification area and therefore no means by which to impact upon surface water quality or shallow groundwater quality. As discussed, the proposed modification of the existing approved underground mine has no mechanism for evaporative concentration of salts in groundwater. The proposed modification relates to an underground mine with no significant excavation and therefore no exposure of acid generating materials and no mechanism for the release of heavy metals. Organic chemicals are used in the underground mine and will be used in the proposed modification, but these are common fuels, oils and greases which are typically biodegradable and not persistent. Therefore, the available information indicates the nature of the proposed modification means the potential for a significant impact on water quality is very low.

8.5 Groundwater dependent ecosystems

No high priority GDEs have been identified in NSW Government Water Sharing Plans covering the UCC. Riparian vegetation is present in areas of UCC; however, these areas will not be impacted by the proposed modification with no significant additional impacts on baseflow noted, and the only change in shallow groundwater is in the Mona Creek valley sediments where no riparian vegetation is present. The only creek system potentially impacted by the proposed modification is Mona Creek, however riparian vegetation associated with this creek has largely been cleared for agricultural purposes in the areas where longwall panels are proposed for the proposed modification.

Cockabutta Creek will not be impacted by the proposed modification. Baseflow impacts to the Talbragar River are also unlikely to be observable. No predicted drawdown or reductions in baseflow will mean negligible impacts on stream flows or persistence of pools relative to both approved and no-mining conditions.

The Drip will not be impacted by the proposed modification as it is disconnected from the regional groundwater system and exists as a perched recharge fed spring system.

The two springs identified approximately 6 km north of UCC ('unnamed' spring and 'Kelly's Spring') will not be impacted by the proposed modification, due to the radial distance from the mine, and limited propagation of drawdown within the hydrogeological units sourcing the springs (Jurassic sediments and basalts). These springs are not sourced from groundwater within the Ulan Seam.

There is predicted to be some drawdown in parts of the Talbragar alluvium, however the drawdown is not expected to fully desaturate the alluvium, therefore no significant impacts are expected on stygofauna.

8.6 Cumulative impacts

The cumulative impact of mining occurring at Moolarben southeast of Ulan, was considered as part of the assessment (refer to Figure 1.2). Based on the results of the modelling, there is minimal interaction between this mine and the proposed modification. The proposed modification areas are located on the north-western part of the Ulan Underground and Ulan West footprints and are more than 10 km from Moolarben No. 4 underground mine. Given these conditions there is no potential for significant cumulative impacts associated with the proposed modification.

9 Uncertainty analysis

9.1 Overview

The calibrated model (i.e. basecase model) provides the best prediction of the impacts resulting from the proposed modification. There is however an element of non-uniqueness that exists with the calibrated dataset, in that other combination of parameter values (parameter sets) can result in the same model meeting the criteria of being calibrated. What is important about these other calibrated parameter sets is that they could result in different future predictions.

The model non-uniqueness, or uncertainty in model parameters, can be explored through uncertainty analysis. A calibration constrained Monte Carlo uncertainty analysis was undertaken to explore the potentially different predictions that could result from a parameter set that calibrates the model.

This type of analysis produces probability distributions for predictive impacts by assessing a composite likelihood of an impact occurring through assessing and ranking the predictions from hundreds of model 'realisations'. Each model realisation is informed by an observation dataset, by using the relationship between the observation statistics to perturbations of each parameter in the groundwater model.

Of the 500 simulations undertaken, 258 model runs converged and met the criteria of a Scaled RMS error below 10% which can be considered calibrated. Model 3 and Model 4 were used in the uncertainty analysis with a focus on the impacts from the proposed modification being assessed for uncertainty.

Outputs from the uncertainty modelling were processed in accordance with the risk-based calibrated language proposed in Middlemis & Peeters (2018). The ranges adopted are shown in Table 9.1.

Table 9.1 Calibrated uncertainty modelling language

Narrative descriptor	Probability class	Description	Colour code
Very likely	0-10%	Likely to occur even in extreme conditions	
Likely	10-33%	Expected to occur in normal conditions	
About as likely as not	33-67%	About an equal chance of occurring as not	
Unlikely	67-90%	Not expected to occur in normal conditions	
Very unlikely	90-100%	Not likely to occur even in extreme conditions	

9.2 Mine inflow rate

The range of possible inflow rates (using Model 4) from the basecase parameter set (Figure 9.1) indicate that despite calibration, uncertainty in model parameters results in variation in the simulated inflows. The predicted peak inflows range from 26.7 ML/day (1%) to 31.85 ML/day (98%), compared to the predicted inflow for the basecase of 29.6 ML/day.

The modelled 98%ile peak inflow rate of 31.85 ML/day is within the current licencing available to the UCMPL operations through either exiting entitlements or internal Glencore transfer arrangements.

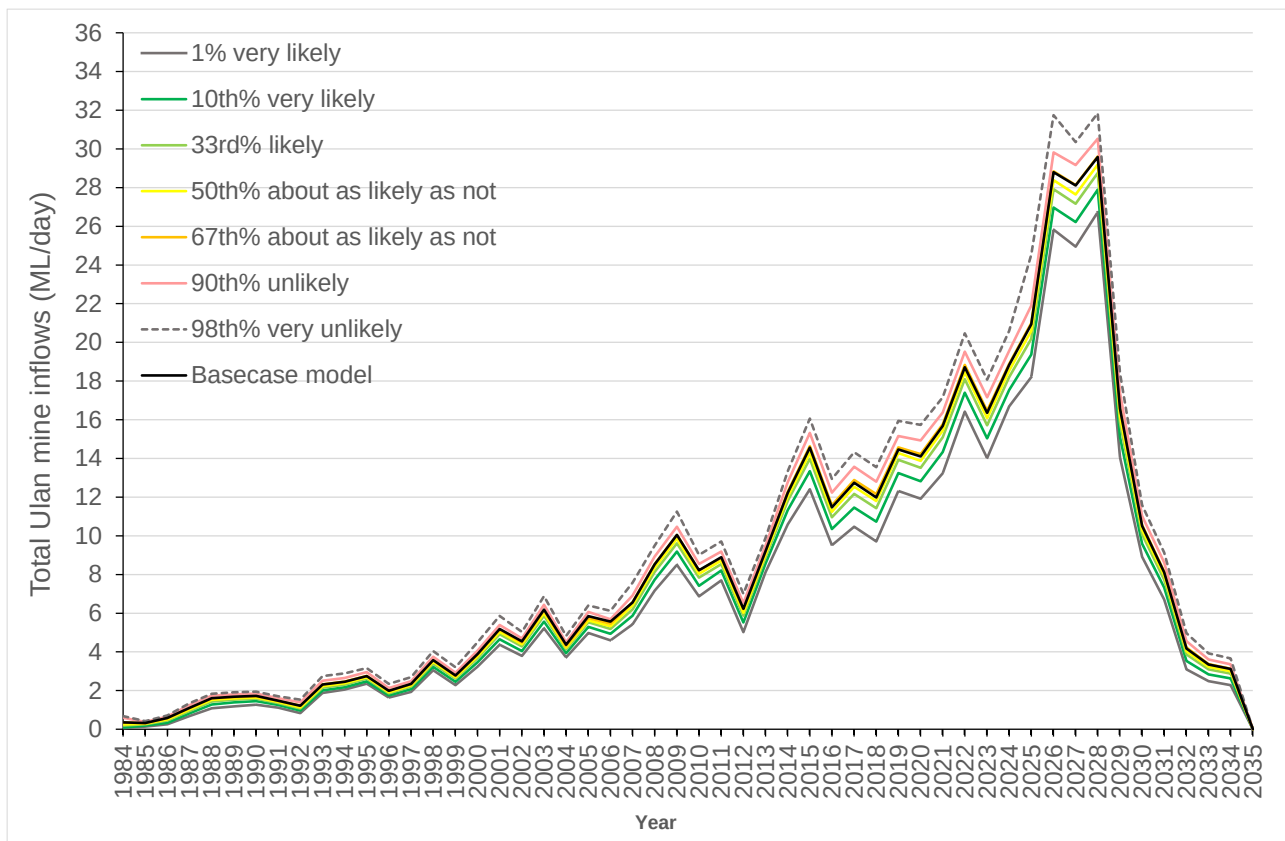


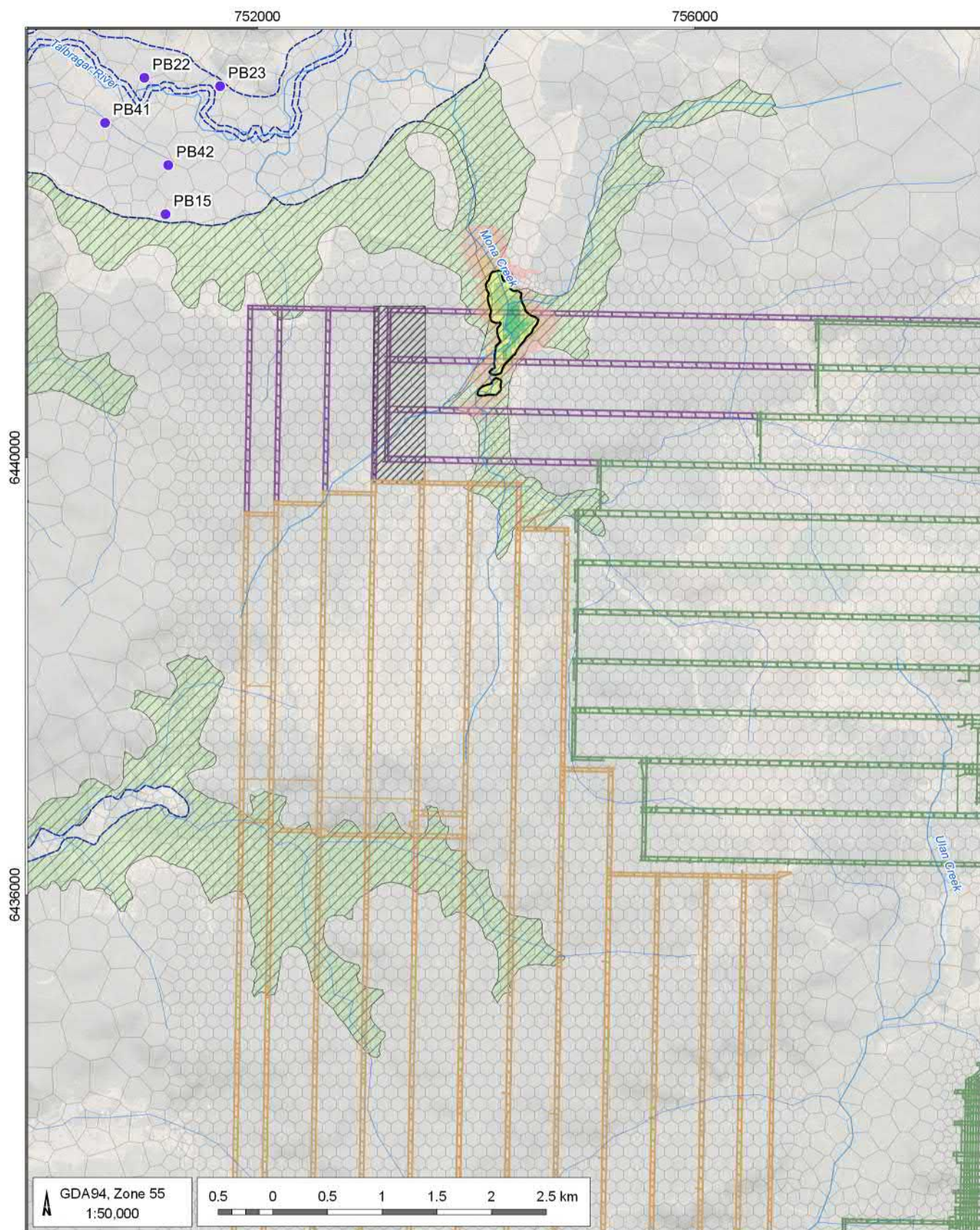
Figure 9.1 Probability distribution for Ulan mine inflow rate

9.3 Zone of 1 m additional drawdown

The extent of the zone of 1 m of additional drawdown at the end of mining (December 2034) was assessed for each of the 94 model runs (comparison between Model 3 and Model 4). The total number of times a model cell had drawdown >1 m was tallied and converted to a percentile. This is shown graphically on Figure 9.2 to Figure 9.5.

The uncertainty plots (Figure 9.2 to Figure 9.5) should be interpreted as the probability that the 1 m difference limit is further out than that location. The green coloured zone indicates that it is very likely that area is within the 1 m contour. Likewise, the pink areas indicate where it is unlikely that the 1 m contour of difference from the proposed modification is outside of this area.

In the Triassic formations the current calibrated base case is on the cusp of the 'unlikely' zone, indicating the predicted 1 m contour is more likely to be within the adopted predicted base case extent. This could in part be a function of the saturation levels in these areas, but also a result of a conservative approach where parameters are more uncertain.



LEGEND

- Drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model mesh
- Alluvial
- Colluvial
- Private bore
- ▨ Flexibility area
- Basecase 1 m drawdown zone

Likelihood of 1 m drawdown

- Very unlikely
- Unlikely
- About as likely as not
- Likely
- Very likely

Ulan MOD6 GIA (G1985G)

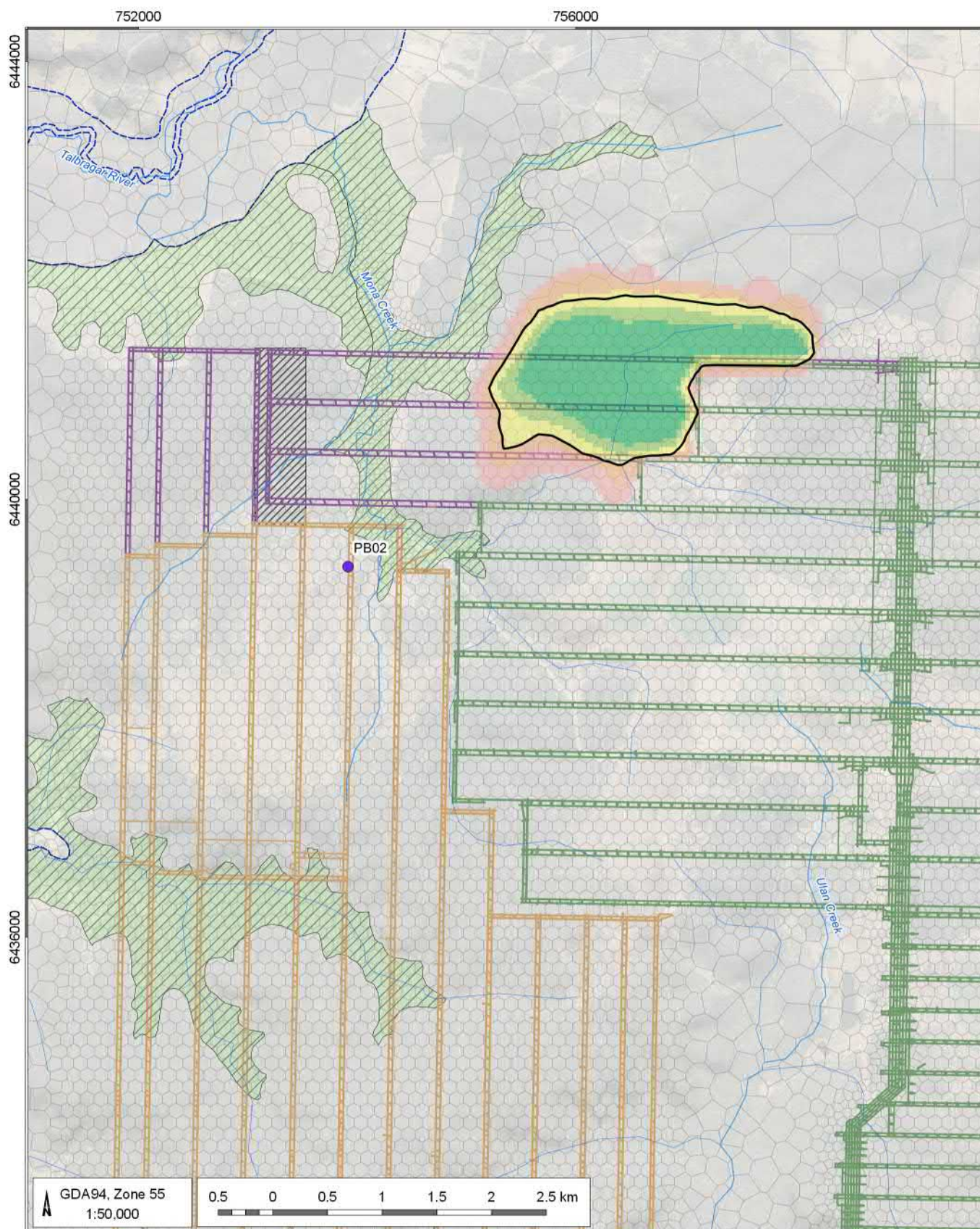
Uncertainty in predicted incremental drawdown from proposed modification for alluvium / colluvium at end of mining



AGE

DATE
12/08/2022

FIGURE No:
9.2



LEGEND

- Drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model mesh
- Alluvial
- Colluvial
- Flexibility area
- Basecase 1 m drawdown zone
- Private bore

Likelihood of 1 m drawdown

- Very unlikely
- Unlikely
- About as likely as not
- Likely
- Very likely

Ulan MOD6 GIA (G1985G)

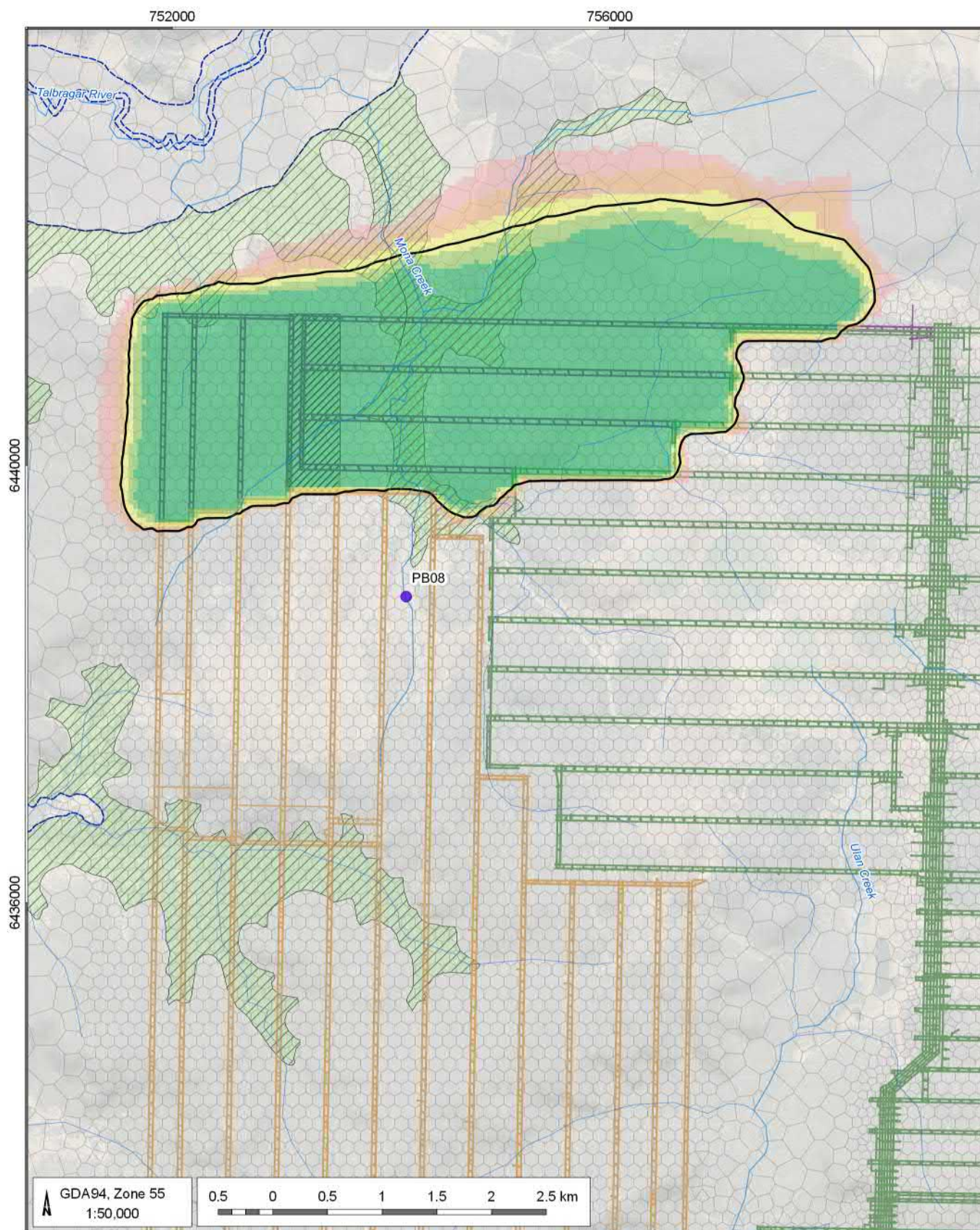
Uncertainty in predicted incremental drawdown from proposed modification for Quartzose Triassic at end of mining



AGE

DATE
12/08/2022

FIGURE No:
9.3



LEGEND

- Drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model mesh
- Alluvial
- Colluvial
- Flexibility area
- Basecase 1 m drawdown zone
- Private bore

Likelihood of 1 m drawdown

- Very unlikely
- Unlikely
- About as likely as not
- Likely
- Very likely

Ulan MOD6 GIA (G1985G)

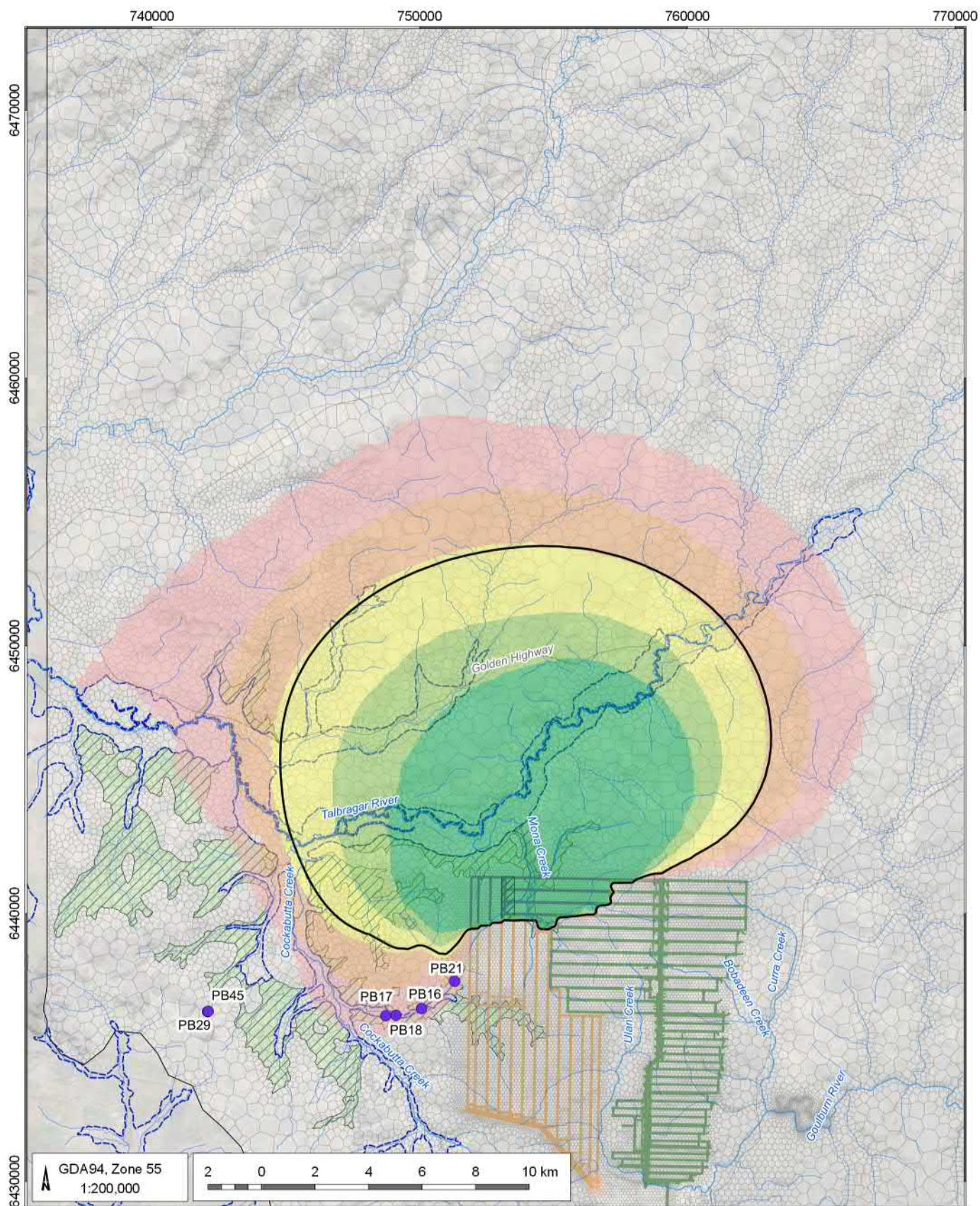
Uncertainty in predicted incremental drawdown from proposed modification for Lithic Triassic at end of mining



AGE

DATE
12/08/2022

FIGURE No:
9.4



LEGEND

- Drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model mesh
- Alluvial
- Colluvial
- Flexibility area
- Basecase 1 m drawdown zone
- Private bore

Likelihood of 1 m drawdown

- Very unlikely
- Unlikely
- About as likely as not
- Likely
- Very likely

Ulan MOD6 GIA (G1985G)

Uncertainty in predicted incremental drawdown from proposed modification for Ulan Seam at end of mining



AGE

DATE
12/08/2022

FIGURE No:
9.5

10 Groundwater monitoring and management

UCMPL currently operates the UCC in accordance with a Water Management Plan (WMP) which was updated in 2021 (UCMPL, 2021c). The WMP describes the management of environmental and community aspects, and impacts and performance relevant to the site's water management system. The existing groundwater monitoring program will be continued so that the impact of the proposed modification is monitored and managed. The sections below outline aspects of the current WMP, and recommended updates (should the proposed modification be approved) to monitor the cumulative impacts of the UCC (incorporating the proposed modification).

10.1 Groundwater Monitoring Program

The currently approved Groundwater Management Program (GWMP) (UCMPL, 2019a) outlines a monitoring program to collect groundwater levels and quality measurements and allow actual impacts to the local groundwater system to be compared against those identified in the environmental assessments.

The GWMP outlines the baseline, ongoing and future monitoring requirements, impact assessment criteria (trigger levels) and investigation and reporting protocols for potential groundwater impacts. To fulfil the principals of this WMP, the GWMP:

- provides historical baseline monitoring data for the surrounding aquifers and regional groundwater;
- provides information on regional groundwater levels;
- provides information on the water quality in the surrounding aquifers;
- provides a prediction of the groundwater contribution to the water balance through groundwater inflow to the open cut and underground workings;
- provides details on the groundwater levels and quality in surrounding privately owned boreholes;
- provides information on the monitoring program for 'The Drip';
- provides information on the monitoring program for impacts on hardrock baseflows;
- outlines relevant groundwater impact assessment criteria (trigger levels);
- establishes a protocol for the assessment and response to monitoring data; and
- provides methods to assess and maintain compliance with the conditions of the PA08_0184, EPL 394 and legislation relating to groundwater.

If an exceedance of any groundwater impact assessment criteria is identified, then the Surface Water and Groundwater Response Plan (SWGWRP) is activated. The objective of the SWGWRP is to provide appropriate trigger, action, response plans (TARPs) and response protocols in the event that mining operations result in adverse impacts to the surrounding surface water and/or groundwater environment(s). It also provides information on the trigger mechanisms, summarises the potential water management issues that may arise and provides information on the appropriate TARP or response procedures to be used.

The SWGWRP provides TARPs or response protocols for the following events:

- impact assessment criteria (trigger level) exceedance;
- EPL 394 criteria exceedance (non-compliance);
- surface water and groundwater impacts on adjacent private landowners;
- variations from the predictions made in the groundwater model;
- potential impacts on groundwater dependant ecosystems;
- unauthorised off-site discharges;
- environmental Incident: Unforeseen Hazard, Unplanned Event or Unauthorised Discharge; and
- community complaints (relating to surface water and groundwater).

A number of events listed above may be the result of subsidence. Subsidence related impacts may include deterioration of stream health and stability, loss of hard rock baseflows, impact to privately owned bores and impacts to Groundwater Dependent Ecosystems. Management of potential subsidence related impacts are detailed in Appendix 4 of the Subsidence Monitoring Program (ULNCX-111515275-1804), Section 4.2 the Ulan West Extraction Plan LW1 to 8 (ULNCX111515275-2777) and Appendix A: Water Management Plan for LW30, LWW6-LWW8.

10.2 Proposed Groundwater Monitoring Program

Groundwater monitoring program (refer to Section 5.3) piezometers are located both within and outside the approved mining boundary and previously mined areas. This program addresses monitoring of the following elements of the alluvial and hardrock/coal aquifers underlying the mining area:

- groundwater inflows to open cut pit and underground mine workings;
- groundwater levels and water quality;
- seepage/leachate from the mine water management system;
- baseflows in watercourses; and
- impacts on 'The Drip'.

In addition to the groundwater monitoring network, annual voluntary monitoring of groundwater levels and water quality for privately owned bores within the area is undertaken. This monitoring program extends to approximately 12 kilometres away from the approved mine footprint (Figure 5.5).

10.2.1 Ground water level and groundwater quality monitoring

Groundwater levels in the BMN and NMN will be assessed quarterly. This will include levels collected from the recently installed groundwater bores monitoring the alluvial sediments associated with Mona Creek (MCMB03A and MCMB04A). The assessment will include departures from predicted data trends in the EA. If consecutive pressure monitoring data over a period of 6 months exhibit divergence in an adverse way from the predicted trends (i.e. from numerical groundwater modelling predictions), then such departures will initiate further actions, as outlined in the SWGWRP.

Groundwater quality is assessed quarterly in the BMN and biannually in the NMN (Section 5.3). The salinity (EC [$\mu\text{S}/\text{cm}$]) ranges relevant for potential groundwater uses⁹ in the Ulan region are:

- Drinking water – humans: < 1600;
- Drinking water – beef cattle: 5970 to 7460;
- Drinking water – dairy cattle: 3730 to 5970; and
- Irrigation – salt sensitive crops: < 650.

Groundwater levels and water quality are monitored through the following groundwater monitoring networks:

- North Monitoring Network (NMN) – quarterly monitoring groundwater levels and biannually monitoring of water quality within regional groundwater systems (Section 5.3).
- The NMN was established over several years to monitor groundwater levels and quality in the Permian Coal Measures and Mesozoic Sandstones within and outside the mine lease. The current NMN monitors the following lithologies and parameters:
 - Basalt;
 - Jurassic Sequence (Purlewaugh Siltstone and Pilliga Sandstone);
 - Triassic Sequence;
 - Permian sequence above the Ulan Seam;
 - Ulan Seam;
 - Permian sequence below the Ulan Seam;

⁹ Source: QLD NRW (2007) Facts Land Series: Measuring Salinity.

- Physical parameters: pH, EC, temperature, silica and total dissolved solids (TDS);
- Major ions: Ca, Cl, K, Na, Mg, SO₄;
- Nutrients: nitrates, nitrites and nitrogen ammonia;
- Fluoride;
- Total alkalinity as CaCO₃. HCO₃, CO₃; and
- Dissolved metals: As, Al, B, Ba, Cd, Cr, Cu, Fe, Hg, Li, Mn, Ni, Pb, Sb, Se, Sr and Zn.
- Bobadeen Monitoring Network (BMN) – quarterly monitoring of groundwater levels and water quality of unconsolidated sediments within the upper catchments of Mona Creek, Ulan Creek, and Spring Gully Creek (in the vicinity of the UCMPL owned Bobadeen Irrigation Scheme) (Section 5.3).
 - Physical parameters: pH, EC, temperature, silica and total dissolved solids (TDS);
 - Major ions: Ca, Cl, K, Na, Mg, SO₄;
 - Nutrients: nitrates, nitrites and nitrogen ammonia;
 - Fluoride;
 - Total alkalinity as CaCO₃. HCO₃, CO₃; and
 - Dissolved metals: As, Al, B, Ba, Cd, Cr, Cu, Fe, Hg, Li, Mn, Ni, Pb, Sb, Se, Sr and Zn.
- Pleuger Monitoring Network (PMN) – daily real time monitoring and weekly field monitoring of underground groundwater levels and water quality (Section 5.3) as required based on areas of operation within the underground mines.

In addition to the monitoring outlined above, UCMPL maintain additional groundwater bores on site that have been used in earlier monitoring programs and are available for future monitoring if required:

- Alluvium Monitoring Network (AMN) - used to monitor groundwater levels and water quality within the alluvium associated with the Goulburn River or Ulan Creek when required.
- Goulburn River Diversion Monitoring Network (GRDMN) – used to monitor groundwater levels within the East Pit; used in conjunction with the AMN to provide groundwater level data for aquifers associated with the Goulburn River when required.
- Intermittent Monitoring Network (IMN) – used to monitor groundwater levels and water quality in hardrock strata or mine spoil; provides additional data to complement the NMN monitoring data if required.

The groundwater monitoring networks will continue to be developed in response to the groundwater management requirements of the Ulan Mine Complex.

10.2.2 The Drip

In accordance with PA 08_0184, UCMPL is required to monitor 'The Drip' to identify any potential impacts from nearby mining operations. A previous Groundwater Assessment (MER, 2009) identified that no impacts are predicted to occur to 'The Drip' as a result of mining operations which are moving northward and westward away from the feature.

Trial samples were collected from two separate locations at 'The Drip'. Initial sampling was conducted after a period of several months of dry weather. Temperature, pH and electrical conductivity (EC) are recorded in the field. One litre samples were collected for laboratory analysis which included:

- Major ions: Calcium (Ca); Magnesium (Mg); Sodium (Na); Potassium (K); Carbonates (CO₃); Bicarbonate (HCO₃), Chloride (Cl) and Sulfate (SO₄); and
- Elements/ metals: Aluminium (Al) Arsenic (As), Boron (B), Barium (Ba), Iron (Fe) (soluble), Lithium (Li), Manganese (Mn), Selenium (Se), Silicon (Si), Strontium (Sr), and Zinc (Zn).

Further monitoring will allow a temporal assessment of the relationship and an indication of changes in 'The Drip' water quality over time. The above monitoring regime will be continued at 'The Drip' on a 2-monthly basis. Additional sampling will be conducted after significant rainfall events (30 mm in 24hrs).

In late 2015, a Vibrating Wireline Piezometer (VWP) consisting of 8 transducers was installed approximately 400 m north of the Drip. The purpose of this VWP is to gain a further understanding of the recharge source of the Drip. Porewater pressure readings will be recorded daily using a data logger and will be analysed on a 3-monthly basis, as part of the Northern Monitoring Network.

10.3 Groundwater model validation

Calibration/validation of the groundwater model of the UCC involves the adjustment of parameters within the model, including strata hydraulic properties and subsidence zone parameters, until the modelled groundwater flows and piezometric levels for both the Triassic strata (Wollar Sandstone lithic facies) and the Ulan Seam reasonably match the measured flows and levels. In adjusting the model parameters, it is important to maintain a reasonable correlation between 'calibrated' and measured aquifer properties.

The groundwater model is calibrated/validated on a two-yearly basis by a qualified groundwater consultant. Monitoring data from the network of standpipe piezometers and porewater pressure transducers will provide the groundwater level information necessary for calibration/validation of the model. The estimated groundwater seepage to the underground operations, calculated through preparation of the site water balance, is used in the model calibration/validation process. Rainfall data, synthetic data derived from interpolation between surrounding point records held by the Bureau of Meteorology, will also be used in the model calibration/validation process.

If there are significant changes to the mining operations, then the groundwater model will be recalibrated. In the event monitoring data identifies a divergence in an adverse way from the predicted trends (i.e. from numerical groundwater modelling predictions), then such departures will initiate further actions, as outlined in the TARP (UCMPL, 2019a) of SWGWRP.

10.3.1 Data management and reporting

The WMP outlines the data management and reporting requirements for groundwater data.

The following will be reported in the Annual Review (UCMPL, 2021b):

- Non-compliances with EPL 394 and PA 08_0184;
- exceedances of surface water and groundwater trigger levels;
- identified impacts on stream health and/or channel stability, including losses to base flow;
- impact on water supply to privately owned land;
- community complaints; and
- any actions taken in response to these impacts (where applicable) and the effectiveness of the actions in preventing a re-occurrence of the impact.

10.3.2 Management and mitigation strategies

The WMP includes a Surface Water and Groundwater Response Plan (SWGWRP) containing actions to implement in the case of groundwater monitoring results being detected outside of the groundwater trigger value range. As detailed in the GWMP (ULNCX-111515275-1643), groundwater monitoring results will be compared to groundwater model predictions and the site derived trigger values on an annual basis. In the event that monitoring suggests divergence from the predicted trends (i.e. from numerical groundwater modelling predictions and the site derived triggers), the Trigger Action Response Plan (TARP) as outlined in the GWMP will be implemented (UCMPL, 2021b). The existing UCC development consent conditions regarding compensatory water supply also remain unchanged and GCAA will continue to meet.

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Glossary and acronyms

AGE	Australasian Groundwater and Environmental Consultants Pty Ltd
AHD	Australian Height Datum
AIP	Aquifer Interference Policy
ALUM	Australian Land Use Mapping
BSAL	Biophysical Strategic Agricultural Land
CSG	Coal seam gas
CRD	Cumulative Rainfall Departure
EMD	Environmental Monitoring Database
DoEE	Department of the Environment and Energy
DPI	Department of Primary Industries
GDE	Groundwater Dependent Ecosystem
IESC	Independent Expert Scientific Committee
ML	Megalitres
MNES	Matters of National Environmental Significance
Mtpa	Million tonnes per annum
SILO	SILO is a database of historical climate records for Australia
SRLU Policy	Strategic Regional Landuse Policy
TARP	Trigger Action Response Plan
TDS	Total Dissolved Solids
VWP	Vibrating wire piezometer

Appendix A

Numerical modelling report

Document details and history



Document details

Project number	G1985G
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Site address	Ulan (Mudgee), NSW
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Australasian Groundwater and Environmental Consultants Pty Ltd

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Ulan MOD6 Groundwater Model

A 1 Introduction

Ulan Coal Mine Complex (UCC) is operated by Ulan Coal Mines Pty Limited (UCMPL), which is 100% owned and managed by Glencore Coal Assets Australia Pty Ltd (GCAA). The UCC is in the central west of New South Wales near the town of Ulan, which is approximately 38 km north-northeast of Mudgee. The mine which is within Environmental Protection Licence (EPL) 394, was approved under Part 3A of the *Environmental Planning & Assessment Act (1979)* (EP&A Act) on 15 November 2010 (PA 08_0184).

UCMPL are proposing to modify project approval PA 08_0184 to facilitate extensions to several longwalls at Ulan West and Ulan Underground Operations (MOD6) (the Project) through:

- extension of Ulan Underground longwall (LW) panels LWW9 to LWW11 to the west
- widening of Ulan Underground LWW11 by approximately 30 metres
- extension of Ulan West LW9 to LW12 to the north.

UCMPL is also proposing some minor changes to surface infrastructure to support underground mining activities including provision of:

- three ventilation shafts and associated infrastructure corridors
- five dewatering bores and associated infrastructure corridors
- an alternate access track
- an infrastructure corridor and service borehole (to deliver gravel and other construction materials and to provide access and power to the underground mine) to the south-west of Ulan West.

There is an area within EL 7542 which may be accessed by either Ulan West Underground or Ulan Underground depending on timing of operations and mining conditions. The area referred to as the 'Flexibility Area'. The coal in the Flexibility Area may be accessed by either a northern extension of Ulan West Underground LW9 or a western extension of Ulan Underground LWW9, 10 and 11. In relation to potential groundwater impacts, the mining of the flexibility area via Ulan West Underground LW9 is the more conservative approach. Accordingly, this assessment has modelled mining of the flexibility area via Ulan West Underground LW9 in order to assess the worst case scenario for MOD6.

This document provides the background information on the model used to predict potential impacts from MOD6. The model provides acceptable history matching.

A 2 Model objectives

The objectives of the model were to assess the potential impacts from MOD6 (proposed modification) on the surrounding groundwater regime. The model needs to:

- predict groundwater inflow into the underground mine based on the approved mine plan;
- simulate and predict the extent and area of influence of mining on the water table and deeper groundwater pressures; and
- predict the loss and/or water take from the water bearing units on site for licensing estimates, including losses to baseflow.

This assessment was achieved through the use of a numerical groundwater model to predict the change due to MOD6. The numerical model was developed out of a conceptual model that is supported by the field observations. The model features important to these objectives include:

- Matching historical groundwater behaviour.
- Using a model that represents the key geological units.
- Simulating the changes to hydraulic properties from mining.
- Including the neighbouring Moolarben mine for cumulative impacts.
- Using a null model to determine the incremental change due to MOD6.
- Uncertainty analysis to quantify the range of potential predicted impacts.

A 2.1 Model software

Numerical modelling has been undertaken using the MODFLOW-USG code (Panday et. al. 2015). MODFLOW-USG is widely used code for groundwater modelling and is considered industry leading. The model design takes advantage of some of the key features of MODFLOW-USG, including truncating model layers to match hydrostratigraphic units and assigning hydraulic property changes in a transient manner.

The model mesh is comprised of Voronoi polygons which have small dimensions in areas where detail is required and get larger where detail is not required.

A 3 Conceptual model Summary

Groundwater occurrence, distribution, movement, and properties are influenced by the site's geology and key system stresses. System stresses include inputs (i.e. rainfall recharge and river leakage) and outputs (i.e. upward and downward leakage, interception through mine dewatering, and baseflow to surface drainages). The conceptual model is discussed in detail in Section 5.8.

The lower aquifer system comprises the coal measures including the Ulan coal seam. The shallow aquifer comprises the Triassic units and alluvium and is where the general regional water table resides. The locally perched aquifer system related to the Drip is associated with the Jurassic sediments.

Transient groundwater levels (refer to Section 5.4) demonstrate limited impact to shallow aquifer systems including the Jurassic formations due to their perched nature. Depressurisation in the Triassic strata appears to be localised above the underground mining operations, suggesting impacts there are caused by vertical goaf fracturing and impacts do not propagate laterally to the same magnitude as in the Ulan Seam. These observations are anticipated to remain the case for MOD6.

Based on the current geological data, the hydrogeological conceptual understanding for the site has remained largely unchanged from that presented in AGE (2018) for the MOD4 assessment, apart from the nature of the Mona Creek sediments. In the past the presence of an alluvium under Mona Creek was assumed, however further investigation and testing has indicated the sediments are colluvium in nature.

A 4 Numerical groundwater model details

A 4.1 Model history

A number of groundwater assessments including numerical groundwater modelling have been prepared for the UCC. These assessments

The most recent groundwater modelling assessments include:

- MOD1 (MER, 2009) – prepared for the continued operations at the UCC. Numerical modelling was undertaken to predict impacts to the water table, fractured rock pressure heads, inflows to the underground mine and stream baseflow. Water take and partitioning of take from water sources was also estimated using the model.
- MOD3 (MER, 2015) – the groundwater model was recalibrated to new monitoring data and groundwater impacts from MOD3, southerly extensions of the Ulan West mine plan, were predicted.
- MOD4 (AGE, 2018) – AGE adopted the model developed by MER (2015) and updated it for the MOD4 mine plan which included refining the model time stepping and implementing a new longwall mining progression. The model provides an assessment of impacts to private water bores, baseflow, and the volume and partitioning of water take from Water Sharing Plans as defined under the *Water Act 2000*.

The modelling undertaken for MOD1, MOD3 and MOD4 utilised the MODFLOW SURFACT software. For the proposed modification, the modelling software was changed to MODFLOW-USG. The modelling above has undergone progressive development and been assessed at each stage through regulatory review. The model used in the MOD4 assessment (AGE, 2018) was the basis for the most recent model development

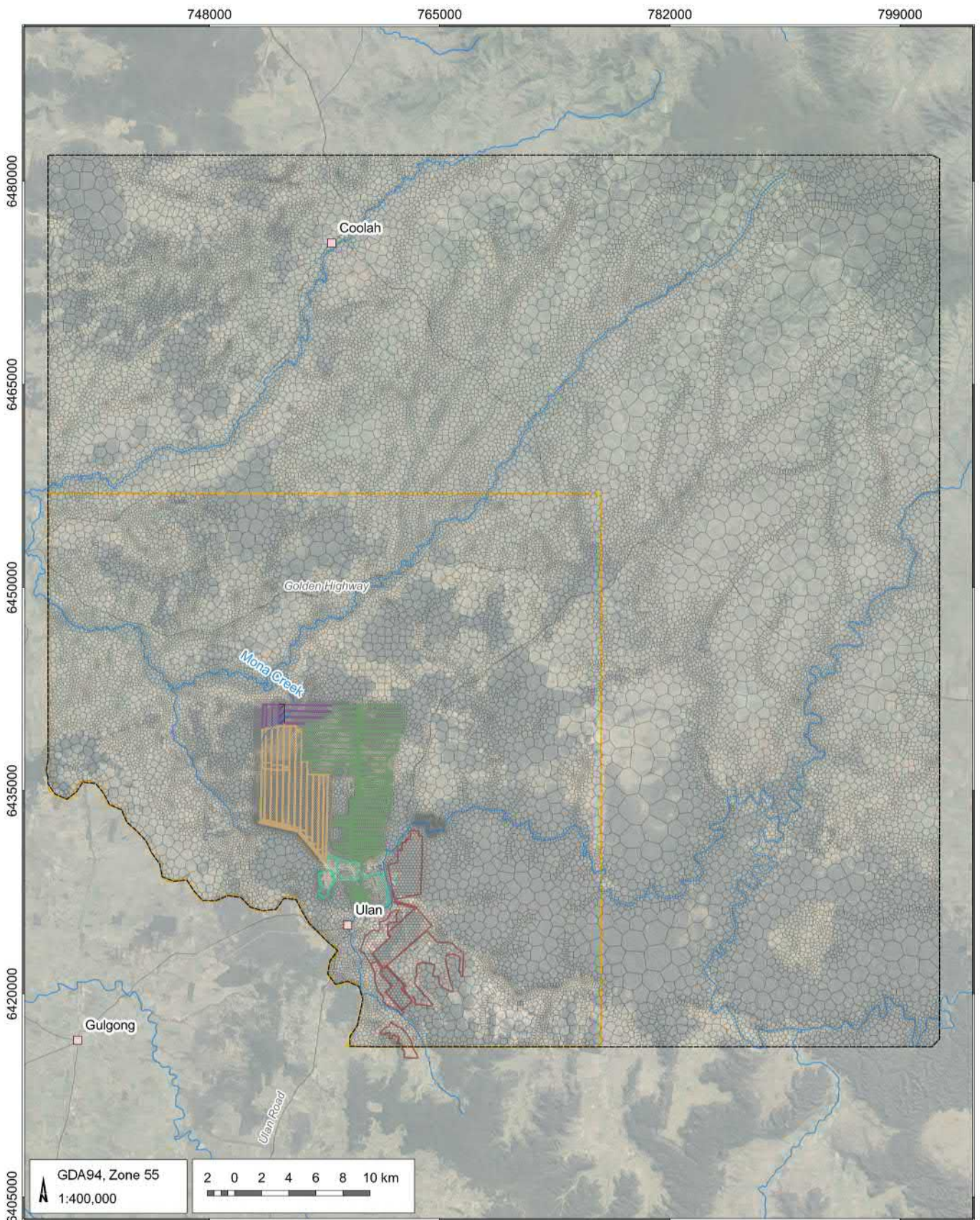
The purpose of this update was to take advantage of the enhanced software features, and the ability to utilise more contemporary methods to represent the fracturing above longwall panels. The updated model was also extended spatially by 25 km in the north and east directions. This increases the study extent into areas covered by the Liverpool Range Volcanics in the north and extends the model to cover a larger area of the Goulburn River National Park. This change was driven by the coal seam impacts extending to the previous model boundaries due to the high hydraulic conductivity, which was then beginning to impact on the predictions in the overlying model layers at the boundaries. The Permian, Triassic and Jurassic sediments all continue to dip towards the north-east and underlie the Liverpool Range basalt.

A 4.2 Model mesh and extent

The shape of the MODFLOW-USG model domain adopts a nominally square domain except in the southwest where the model domain follows the Permian geology subcrops. In agreement with the conceptual groundwater model of the area, the numerical model consists of the three main aquifer systems. The model was discretised into 19 layers comprising up to a maximum of 44,652 cells in each model layer with the dimension of the cells varying. The following Voronoi cell dimensions were adopted for key detail areas of the model domain:

- cells covering the mine areas ~ 125 m x 125 m cells;
- cells around the Drip ~ 25 m x 25 m; and
- cells representing stream and river locations ~ 200 m x 200 m although more refined around the Drip.

The model mesh is shown in Figure A 4.1 which shows how the cell size varies across the model domain. This also shows the truncation of the model domain in the southeast. The boundaries are set at a distance of around 40 km to the north and east from the proposed mining operation, and 20 km to the south and west, which is considered sufficient distance to avoid the boundary having significant influence on the development of the cone of depression around the mine.



LEGEND

- | | |
|---|--|
| ■ Populated place | ■ Ulan open cut |
| — Surface drainage | ■ Moolarben mine area |
| — Road | ■ Model domain |
| — Ulan West Mine Plan | ■ Model mesh |
| — Ulan Underground Mine Plan | ■ Previous SURFACT model extent |
| — Proposed longwall panel | ■ Flexibility area |

Ulan MOD6 GIA (1985G)

Model domain



AGE

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FIGURE No:
A 4.1

A 4.3 Model layers

The vertical extent of the model domain has been discretised into 19 layers (see Table A 4.1) to represent the key hydro-stratigraphic units from alluvium and Jurassic formations to deeper Permian aged coal measures. The site maintain a detailed geological model developed from data collection from extensive exploration and mining activities. AGE were supplied with structure contours from this model which have been used as the source for the vertical dimensions of each major geological unit. Additional sub-layers were then included to add more vertical resolution within some key geological formations.

Layer 1 represents the alluvium and colluvium associated with the Talbragar River, Goulburn River, and their respective tributaries. Topography data with a resolution of 5 m x 5 m (sourced from the ELVIS database) was used to interpolate the model top surface and derive the top of the system, as well as improved drainage line elevations. This updated topography data is a significant improvement over the ground surface adopted in the previous assessment models (Section A 4.1) which utilised 30 m x 30 m data with the vertical value at these points is also not as accurate as the updated elevation data. Data from the regolith thickness dataset from CSIRO¹ has been used to support the structure of the shallow regolith. Layer 2 represents the Tertiary basalt. Layers 3, and 4 represent the Pilliga and Purllewaugh Jurassic strata. Layers 5 to 8 represent the Triassic quartzose sandstone and Layers 9 and 10 represent the Triassic lithic sandstone unit. Layer 7 was found to be main unit discharging water to the Drip. Layers 11 to 18 are Permian layers. The Ulan seam is represented as separate layer (i.e. layer 16) within the Permian strata.

The structure contours for these layers are shown in Appendix A 4.

Table A 4.1 Model layers

Layer	Represents	Average thickness (m)
1	Alluvium and colluvium	12.2
2	Tertiary volcanic	150.7
3	Jurassic- Pilliga	216.2
4	Jurassic- Purllewaugh	126.9
5	Triassic – Quartzose-Upper	30.4
6	Triassic – Quartzose-Middle-1	19.3
7	Triassic – Quartzose-Middle-2	37.5
8	Triassic – Quartzose-Lower	19.6
9	Triassic-Lithic-Upper	19.7
10	Triassic-Lithic-Lower	19.8
11	Permian Upper-1	22.6
12	Permian Upper-2	11.8
13	Permian Middle-1	34.0
14	Permian Middle-2	6.0
15	Permian Ulan	3.0
16	Ulan – coal seam	6.0
17	Permian lower-1	8.0
18	Permian lower-2	1.0
19	Bedrock	100.0

¹ CSIRO Soil and Landscape Grid of Australia (<http://www.clw.csiro.au/aclep/soilandlandscapegrid/index.html>), viewed Dec 2015.

The advantage of MODFLOW-USG means that the relationship between geologies can be better represented. For instance, where the Ulan seam subcrops in the southwest it is usually just below the surface geology and the opportunity for connection to surface layers is high. In a small number of discrete locations, the coal seam subcrops directly beneath the Talbragar alluvium and its tributaries. MODFLOW-USG allows for the removal of the intervening layers (while still applying an appropriate transition zone through hydraulic properties) that would have persisted in the SURFACT model and provided an element of attenuation to the simulated connection, and in doing so provides a more realistic connection.

A 4.4 Stress periods

The model begins with a steady state stress period representing pre mining conditions before becoming transient. The transient period runs from 1 January 1984 to 31 December 2035 using quarterly stress periods.

A 4.5 Solver settings

The sparse matrix solver (SMS) package is used to solve the simultaneous equations of a MODFLOW-USG groundwater model. The groundwater model uses the unstructured preconditioned conjugate gradient (PCGU) solver with the preconditioned bi-conjugate gradient stabilized (BCGS) linear acceleration method. The head change criterion (HCLOSE) and head change criterion for convergence (HICLOSE) were set to 0.08 and 0.05 respectively.

A 4.6 Model boundary conditions

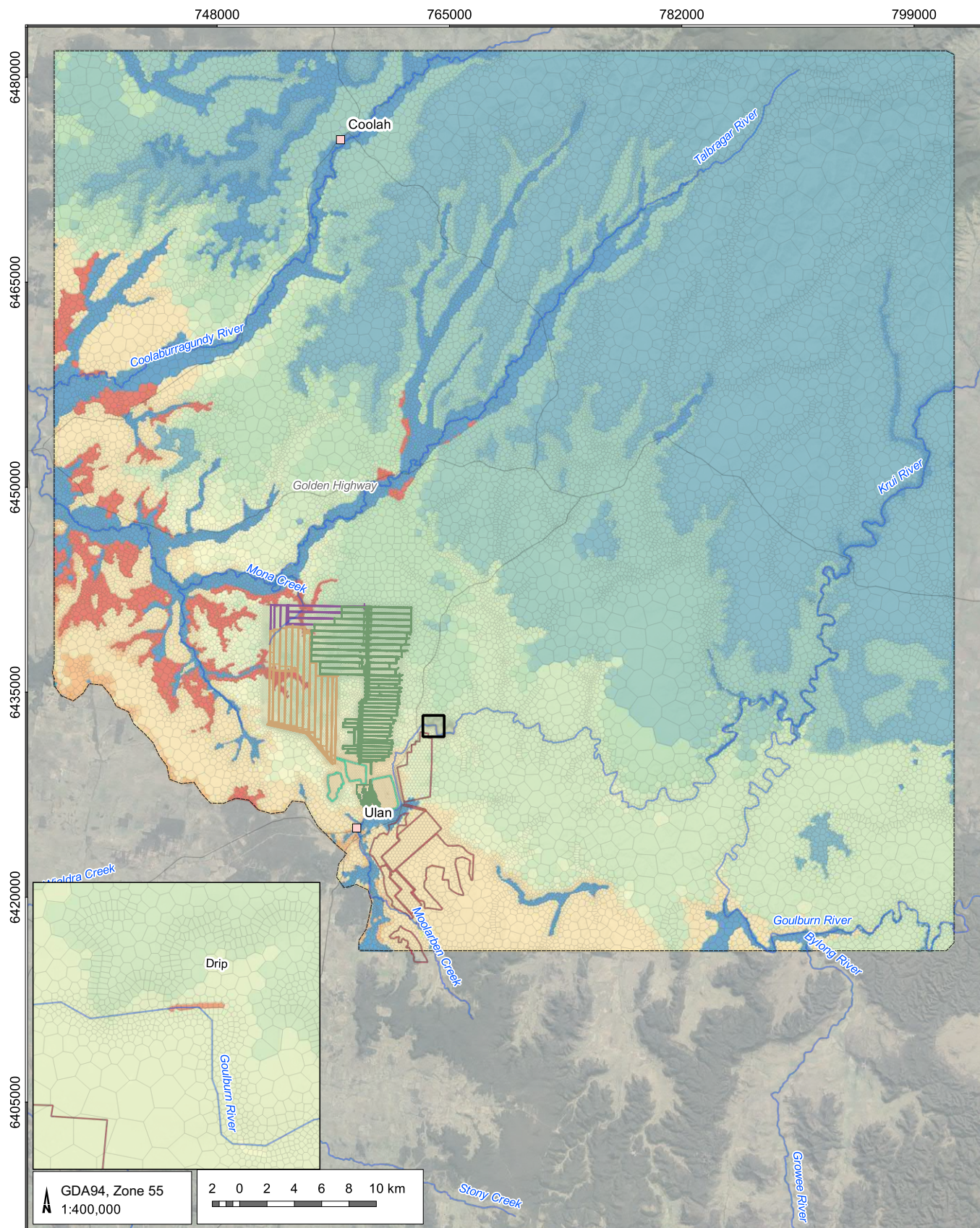
Model boundary conditions refer to any stresses applied to the model domain that influence the flow of groundwater within the model domain. The conceptual model indicates that the stresses on the groundwater system include diffuse recharge from rainfall, and stream leakage, and discharge from mine dewatering and baseflow to streams. Model boundary conditions are presented and discussed in the following sections.

A 4.6.1 Recharge

The dominant mechanism for recharge to the groundwater system is through diffuse infiltration of rainfall through the soil profile and subsequent deep drainage to underlying groundwater systems. The MODFLOW-USG recharge package (RCH) was used to represent diffuse rainfall recharge where the model input is a 'net' rate of recharge, incorporating evapotranspiration and infiltration and adopting a rate that represents drainage of water below the root zone. Recharge was applied to the highest active (i.e. wet) cell. Table A 4.2 presents the calibrated rate of recharge for each geological unit. Figure A 4.2 shows the recharge distribution zones, which equate to the locations where various geologies outcrop and where recharge could be received. Recharge for the predictive phase adopted constant steady state recharge rate, which was a single long-term local rainfall average.

Table A 4.2 Recharge rates

Zone	Net Annual Recharge (mm/year)
787Alluvium	30.5
Volcanic and Basalt	1.25
Jurassic outcrop - Pilliga	0.4
Jurassic outcrop- Purlewaugh	0.06
Triassic – Quartzose - Upper	0.005
Triassic – Quartzose - Lower	0.006
Triassic - Lithic	0.0007
Permian above Ulan seam	0.0005
Ulan seam	0.00006
Lower Permian and bedrock	0.00002
Colluvium	0.3



LEGEND

- Populated place
- Surface drainage
- Road
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- Model domain
- Flexibility area

Recharge zones

- Alluvium
- Volcanics/basalt
- Jurassic subcrop (Pilliga)
- Jurassic subcrop (Purlewaugh)
- Triassic subcrop (quartzose SSN upper)
- Triassic subcrop (quartzose SSN lower)
- Triassic subcrop (lithic SSN)
- Permian above Ulan seam - subcrop
- Permian Ulan - subcrop
- Lower Permian basement - subcrop
- The Drip
- Colluvium

Ulan MOD6 GIA (1985G)

Recharge zones



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FIGURE No:
A 4.2

A 4.6.2 Surface drainage

Groundwater interaction with surface drainage was modelled using the river package (RIV) of MODFLOW. The cells assigned to the RIV boundary condition are shown in Figure A 4.3. As gaining streams, all surface drainages in the model domain were given the ability to remove water from the water table where the water table is above the bed of the river but not to lose water to the groundwater systems.

To replicate the seepage at the face of the Drip, river cells were also assigned along the edge of the Drip. These river cells act as discharge points and remove water from the face of Drip. Table A 4.3 shows the parameters used in the river package.

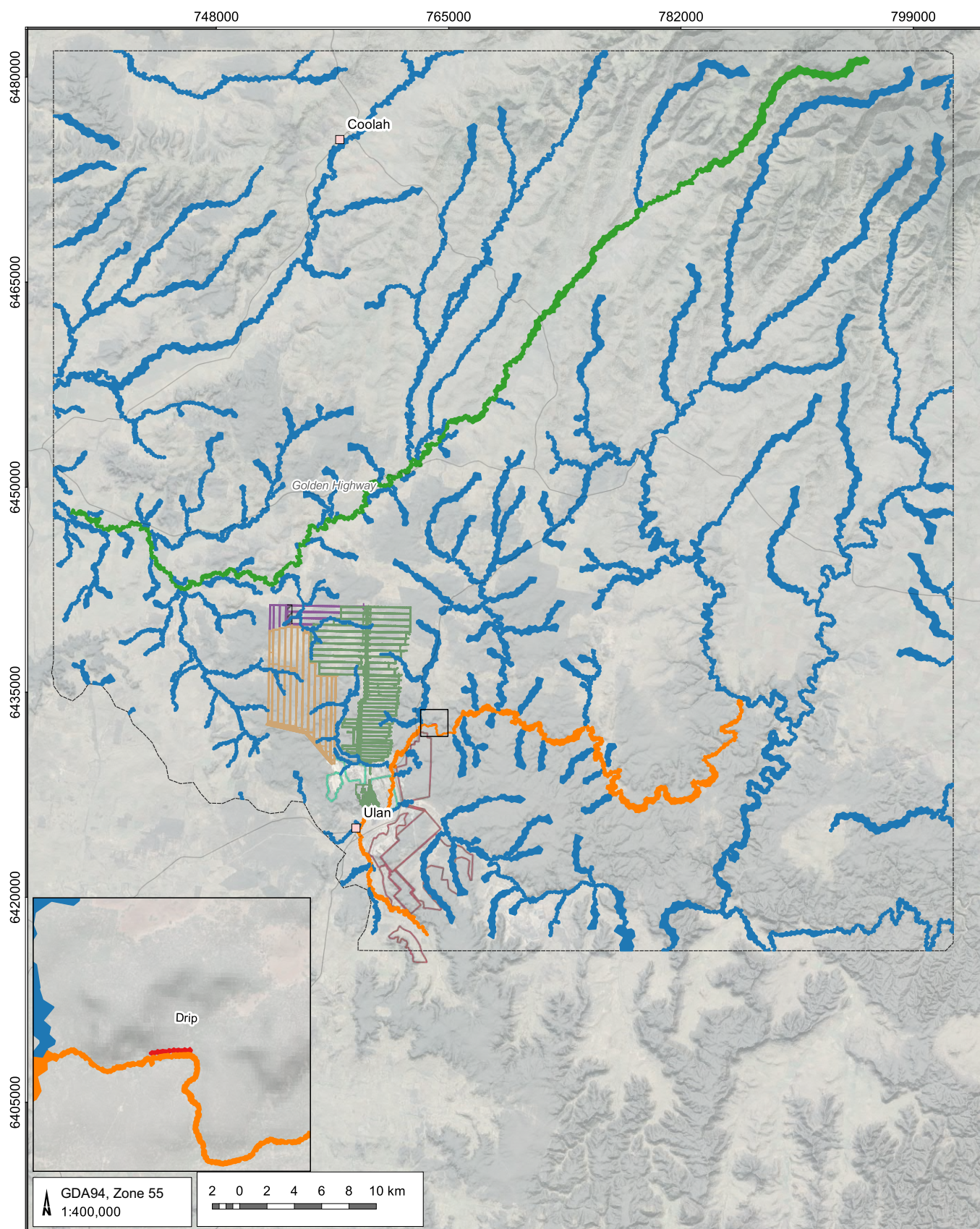
Table A 4.3 River (RIV) bed parameters

Segment Number	Segment name	Vertical hydraulic conductivity (m/day)	Width (m)	Incision below topography (m)	Bed thickness (m)
1	Talbragar River	0.1	10.0	1.0	5.0
2	Goulburn River	0.1	10.0	1.0	5.0
3	Other surface drainage	1.1	5.0	1.0	2.0
4	The Drip seepage area	5.1	1.0	0.0	1.0

Conductance applied to each model cell is determined cell-by-cell using the equation:

$$C_b = K_v \frac{A}{b}$$

where C_b is the conductance of the stream bed, K_v is the vertical hydraulic conductivity, A is the area (calculated as the length of the drainage line passing through a cell multiplied by the width), and b is the thickness.



LEGEND

- Populated place
- Road
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- Model domain
- Flexibility area

River zones

- Talbragar River
- Goulburn River
- Other surface drainage
- The Drip

Ulan MOD6 GIA (1985G)

River (RIV) cells



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FIGURE No:
A 4.3

A 4.6.3 Faulting

Faulting is noted in the area with a number of mapped faults. The nature of these faults is largely unknown, with only some knowledge of the Spring Gully Fault gained through mining adjacent to it. The approach with faults has been to not model them as discrete features.

A 4.6.4 Mine dewatering

Historic and the proposed mine dewatering is simulated using the MODFLOW-USG Drain (DRN) package. Overall, the drain package removes water out of the model when the water level in the model cell is above the defined drain elevation. When the head is below the defined drain elevation, the drain will become inactive.

A 4.6.4.1 Open cut simulation

Publicly available data was used to determine the extent of historical and future open-cut mining at Moolarben (HydroSimulations 2017). With regards to Ulan open-cut mine, AGE adopts the open-cut progression provided by UCMPL. For both Moolarben and Ulan open-cut mines, the drains representing dewatering were assigned to the base of Ulan seam as well as any layers overlying the Ulan seam with a conductance of 1000 m²/day to ensure the internal space of the open cut remained dewatered. Once the drain boundary condition is applied, the drain remains active until the end of mining.

A 4.6.4.2 Underground mine

The model represented the Ulan and Moolarben underground mining using the DRN (drain) package. Within the underground mine, drain cells were applied to model cells, at reference elevations set to the floor of each cell of the mined Ulan coal seam (i.e. layer 16). A conductance value of 1000 m²/day was applied to ensure that dewatering of the 'mined' cell was rapid and the cell remained dewatered. The mine plan and schedule was used to define when model cells became 'active' in the dewatering process for each stress period. Once applied, the drains remain active until the end of underground mine.

A 4.6.4.3 Fracturing above longwalls

Changes in aquifer parameters resulting from the effects of the subsidence of material into the mined void/goaf and the formation of a fracture zone above the panel were applied. If the distance between the coal seam roof and the vertical centre of the model layer is within the expected extent of continuous cracking, then it is assumed fracturing will extend through to the model layer and possibly form a pathway for enhanced vertical and / or horizontal groundwater flow. Water will drain through the cracks from the fracture zone to the workings of the Ulan seam based on a change in vertical and horizontal hydraulic conductivity. These fractures reduce in size and frequency the higher up the profile they propagate.

To determine the height of continuous fracturing a number of approaches have emerged. The two main ones are the "Ditton- Merrick" approach and the "Tametta" approach both named after the authors involved. These approaches add more sophistication to the way in which the fracture zone is being simulated. A report on fracture height calculations for a ACARP (Project C27045) (Adhikary et. al., 2020) mentions both methods are applicable depending on the local geological conditions. For the Ulan site AGE have adopted the "Ditton-Merrick" approach based on matching to observed water level response to the fracturing.

Ditton and Merrick's 2014 work derived two models from non-linear regression techniques. These are described below.

- **Geometry Model** $A = 2.215 W'^{0.357} H^{0.271} T^{0.372}$
- **Geology Model** $A = 1.52 W'^{0.4} H^{0.535} T^{0.464} t'^{-0.4}$

Where:

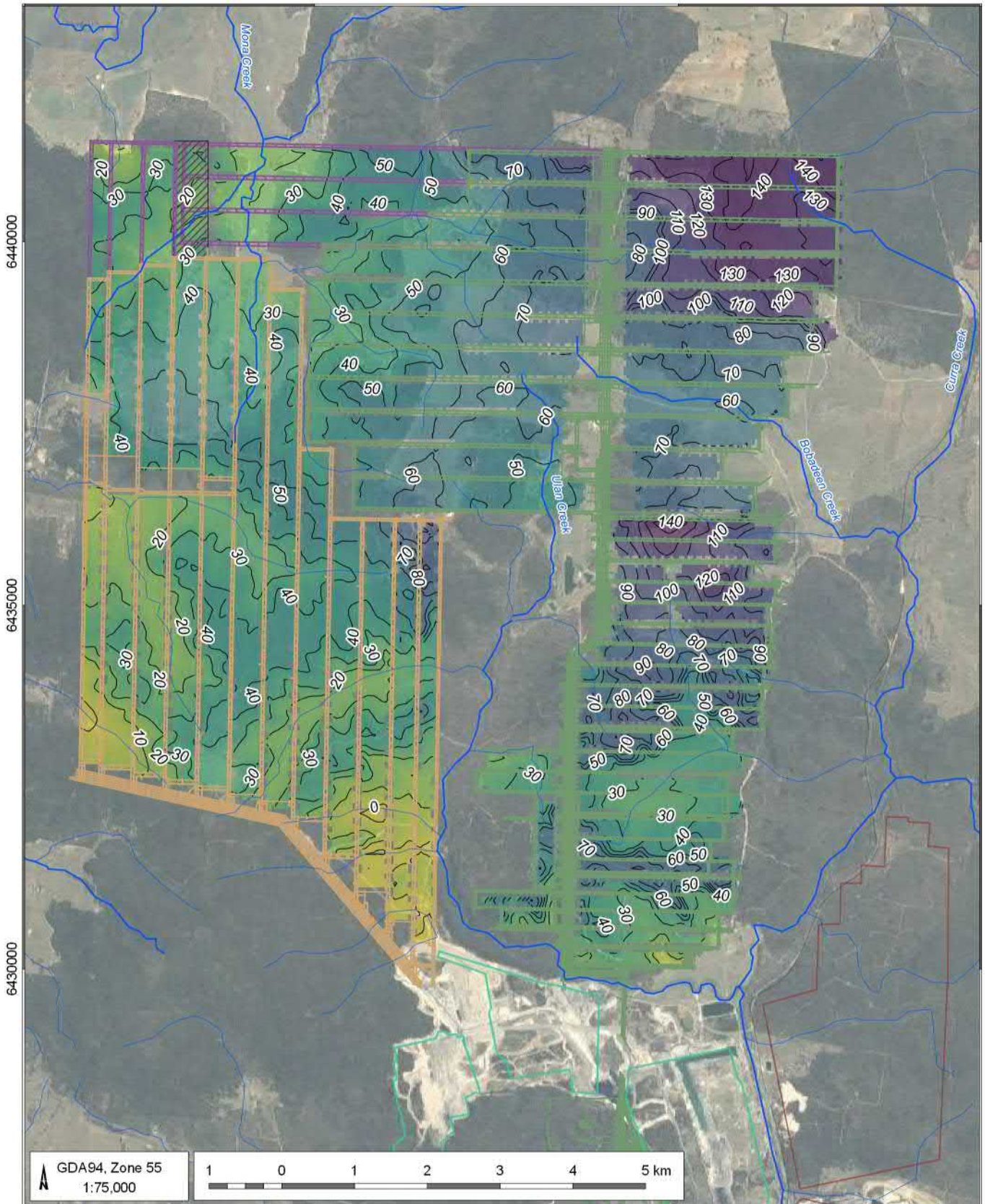
- A = The height of continuous fracturing;
- W' = Critical Width (also reported as Effective Panel Width);
- H = Cover Depth (m);
- T = Mining Height (m);
- t' = Effective Strata Unit Thickness also known as the Beam Thickness.

For Ulan the work has adopted the **Geology Model** and have adopted a beam thickness (t') of 30 m and an extraction thickness (T) of 3.5 m. The critical width (W') is calculated in the model set up on a cell by cell basis where the cover material and panel width are used to define the appropriate critical width.

Figure A 4.4 shows the depth to the top of the fracture zone from ground surface and Table A 4.4 shows the changes in hydraulic conductivity applied in the fracture zone. There have been some other studies done on the aquifer property changes within the fracture zone and these have been also used to inform the adopted ranges shown in Table A 4.4. Figure A 4.5 shows the fracture height above the coal seam derived from "Ditton-Merrick" approach.

755000

760000



LEGEND

- Major drainage
- Minor drainage
- Depth to top of connected fracturing contour (m)
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- ▨ Flexibility area

Depth to top of connected fracturing (m)

- 0
- 10
- 20
- 30
- 40
- 50
- 60
- 80
- 100
- 120
- 140

Ulan MOD6 GIA (G1985G)

Depth to top of fracture zone

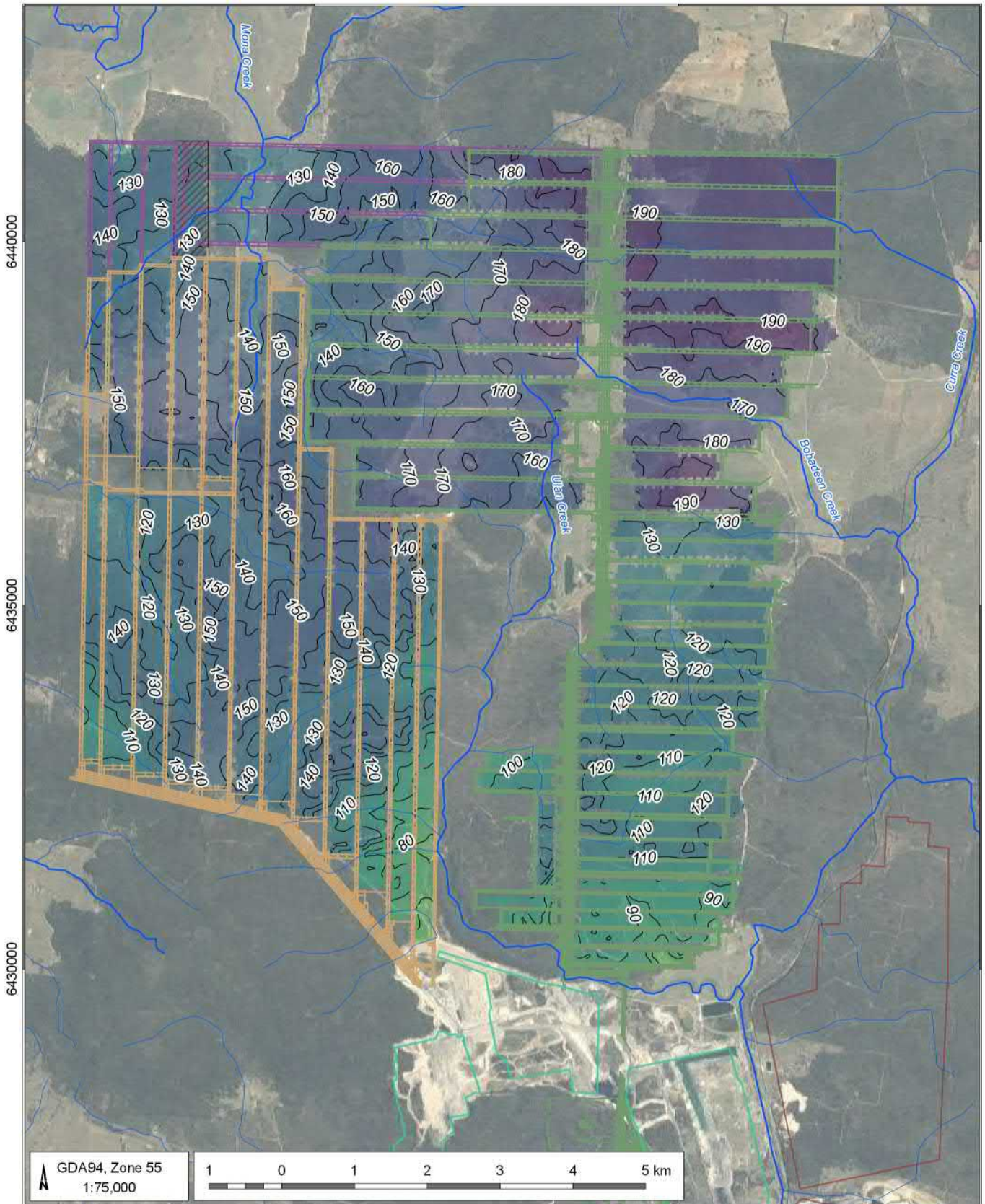


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FIGURE No:
A 4.4

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LEGEND

- Major drainage
- Minor drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- ▨ Flexibility area

Fracture height (m)

- 50
- 60
- 80
- 100
- 120
- 150
- 180
- 200

Ulan MOD6 GIA (G1985G)

Fracture height above the Ulan seam



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FIGURE No:
A 4.5

Table A 4.4 The ratio of average hydraulic conductivity after fracture (K_{AF}) to average hydraulic conductivity before fracture (K_{BF})

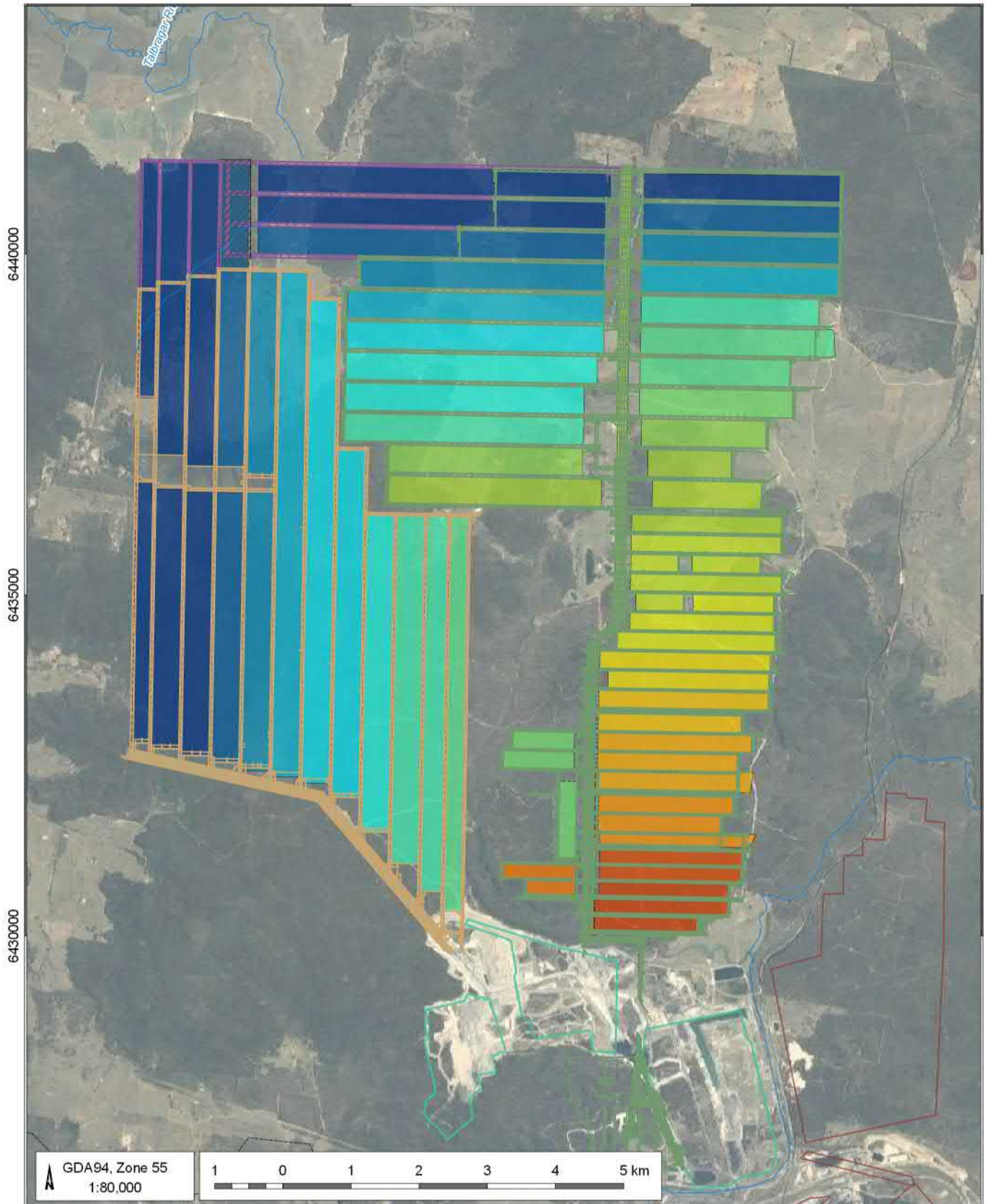
Model layer	HK_{AF}/HK_{BF}	VK_{AF}/VK_{BF} (-)
1	1.0	3.4
5	1.0	1.7
6	1.2	7.6
7	2.0	25
8	3.2	39
9	481	34,704
10	879	54,215
11	564,392	45,284,572
12	1,048,059	96,575,871
13	296,569	25,672,127
14	297,016	27,047,110
15	302,105	22,054,313

A 4.6.5 Mining progression

The mine progression of the underground longwall panels is shown in Figure A 4.6 which also includes the MOD6 panel extensions and presents the option where LWUW9 was extended to the northern boundary of EL 7542 as this was the option simulated. Quarterly stress periods were adopted to simulate the historical and future mine progression (i.e. 1984 to 2034). In doing so, the model first divides the longwall up into quarterly blocks based on start and finish times. This can result in a more gradual build up to the dewatering in each panel.

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LEGEND

- Populated place
- Surface drainage
- Road
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- Flexibility area

Mine Progression (Year)

1984 - 1986	2000 - 2002	2017 - 2019
1986 - 1988	2002 - 2004	2019 - 2021
1988 - 1990	2004 - 2006	2021 - 2023
1990 - 1992	2006 - 2009	2023 - 2025
1992 - 1994	2009 - 2011	2025 - 2027
1994 - 1996	2011 - 2013	2027 - 2029
1996 - 1998	2013 - 2015	2029 - 2035
1998 - 2000	2015 - 2017	

Ulan MOD6 GIA (1985G)

Mine Progression - including proposed MOD6 panels



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FIGURE No:

A 4.6

A 5 Model Calibration

The model was constructed to allow for the simulation of both historical and future approved mining at the Ulan mine, with the historical period allowing for comparison between observed and model predicted groundwater level and flow behaviour. The model starts with the generation of a pre-mining steady state condition, before progressing to transient model conditions. The transient model is divided into quarterly stress periods, which simulate the groundwater changes from January 1984 to 2034, with the calibration period covering 1984 to 2019.

The combined steady state and historical transient model was calibrated by adjusting aquifer parameters and recharge rates to produce the best match between the observed and simulated water levels, while also aligning to observed mine inflow and plausible baseflows. Automated parameterisation software (PEST, Doherty 2010) was used to determine optimal hydraulic parameters and recharge rates to achieve the best statistical calibration of the groundwater model to the observed heads.

A 5.1 Calibration targets

A 5.1.1 Groundwater levels

The model simulated water levels at all available monitoring bores with reliable datasets. A total of 151 monitoring sites were available to calibrate the model. Details of these sites are listed in Appendix A 2. For model calibration purposes, the observation bore water level records were weighted as follows:

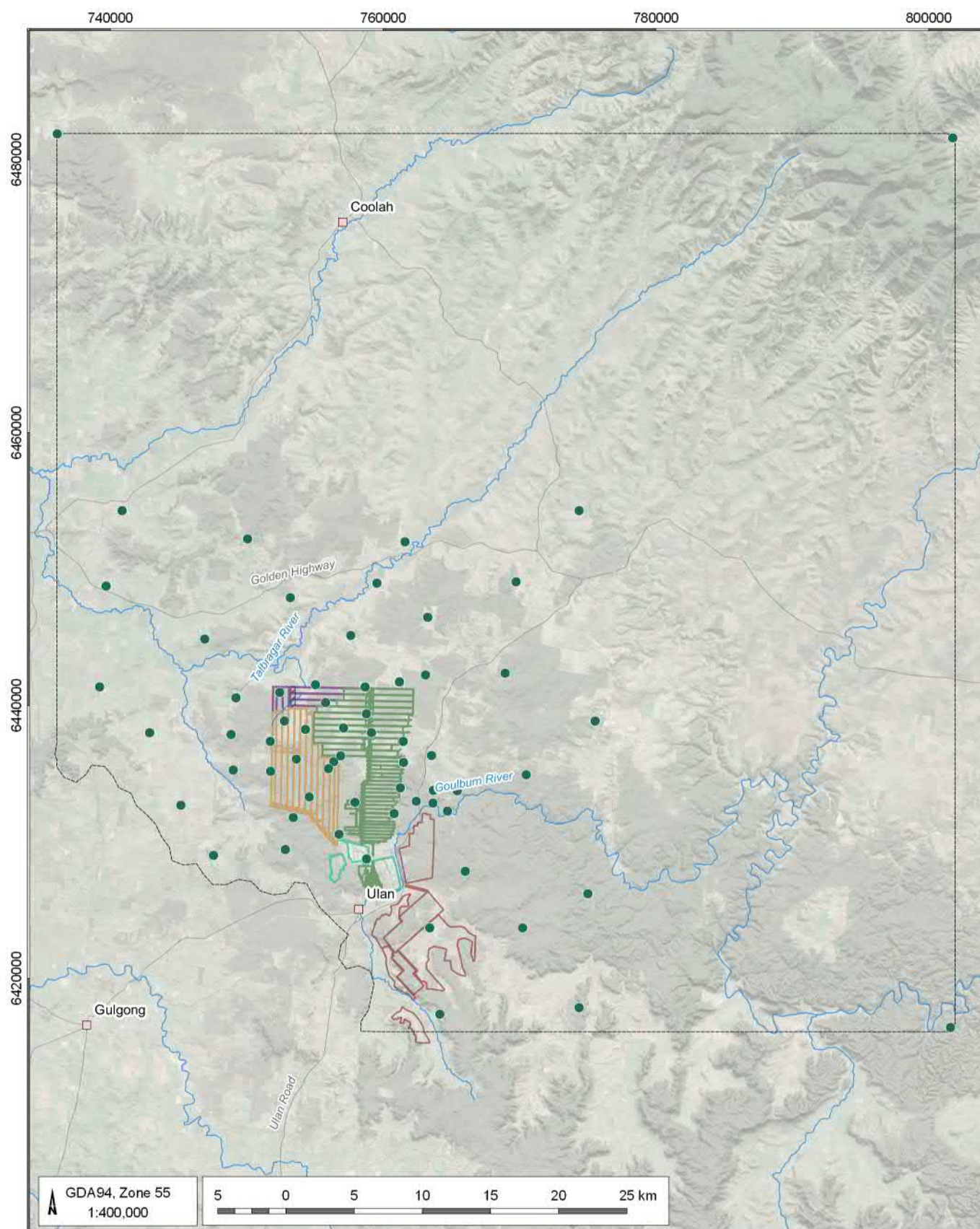
- obviously anomalous results were removed;
- datalogger data was reduced to a monthly frequency; and
- datapoints for each location were weighted according to the formula:
 - Weight of datapoint = $1/\sqrt{\text{number of points for that site}}$.

Using this method bores with longer records have a lower weighting per datapoint, but a higher overall weighting in the combined dataset. The model was calibrated to the observed water level datasets, with the 'best calibrated' model returning the lowest objective function (phi) value. Phi is the sum of the squared residuals, where the residuals are the differences between the observed and modelled values.

A 5.1.2 Addition of spatial variability in parameters

To explore the heterogeneity within the model domain and provide a degree of flexibility during the calibration, a series of pilot points were added to all model layers except layer 16 (Ulan Seam). The values applied to each pilot point were factors used to perturbate the base calibrated value up and down within an order of magnitude for that value. The locations of the pilot points (consistent for each layer) are shown in Figure A 5.1. It should be noted that the pilot points were only applied to hydraulic parameters. In doing so, the pilot points were first interpolated across the model domain in each layer of the model using ordinary automatic Kriging through PLPROC (Watermark Numerical Computing, 2015). Horizontal and vertical conductivity base values at each cell were then adjusted by multiplying the corresponding interpolated factors defined by the pilot point values. The initial values in the model calibration for all pilot points was set to 1 (i.e. no perturbation of base values).

The Ulan coal seam does not get adjusted by the pilot point multiplier process in the calibration. The hydraulic conductivity is defined by a depth dependence relationship. Detail of this is provided in Section A 5.2.1



LEGEND

- Populated place
- Surface drainage
- Road
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- Model domain
- Flexibility area

● Pilot points

Ulan MOD6 GIA (1985G)

Location of pilot points



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FIGURE No:
A 5.1

A 5.2 Calibration results

Figure A 5.2 presents the observed and simulated groundwater levels graphically as a scattergram for the historical transient calibration.

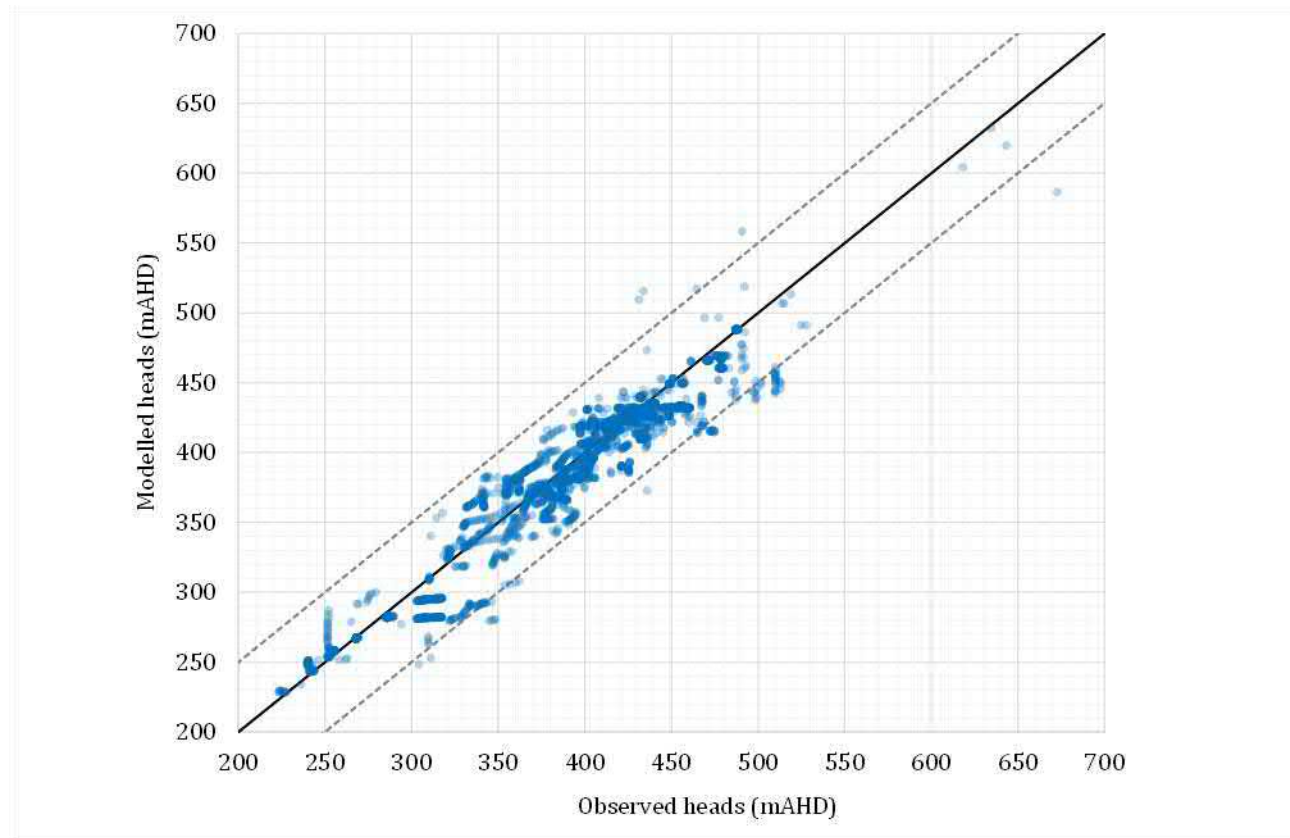


Figure A 5.2 Transient calibration – modelled vs observed groundwater levels

The root mean square (RMS) error calculated for the calibrated model was 17.85 m. The total measured head change across the model domain was 449.41 m, with a scaled unweighted RMS (SRMS) of 3.95%. This is less than half of the SRMS target of < 10% suggested in the Australian Modelling Guidelines (Barnett, 2012). Table A 5.1 presents the unweighted statistics for the transient calibration model.

Table A 5.1 Statistical analysis

Calibration performance measure	Unweighted value
Sum of Residuals (SR) (m)	-18,273
Mean Sum of Residuals (MSR) (m)	-5.51
Scaled Mean Sum of Residuals (SMSR) (%)	-1.23
Sum of Squares (SSQ) (m ²)	1,043,964
Mean Sum of Squares (MSSQ) (m ²)	314.6
Root Mean Square (RMS) (m)	17.74
Root Mean Fraction Square (RMFS) (%)	0.21
Scaled RMFS (SRMFS) (%)	0.18
Scaled RMS (SRMS) (%)	3.95

Figure A 5.3. presents hydrographs showing the match between observed and simulated water levels at selected bores, noting the y-axis represents metres above Australian Height Datum. The model has replicated properly the complex response to the ongoing mining activities at Ulan underground mine in the Permian formations (e.g. DDH266-189, DDH293-167 and PZ06B). The model also can replicate closely the perched water levels (>450 mAHD) particularly in Jurassic bores (PZ10B) and the pressure difference between the Jurassic (PZ09C) and Triassic (PZ09D) units. All hydrographs are presented in Appendix A 3.

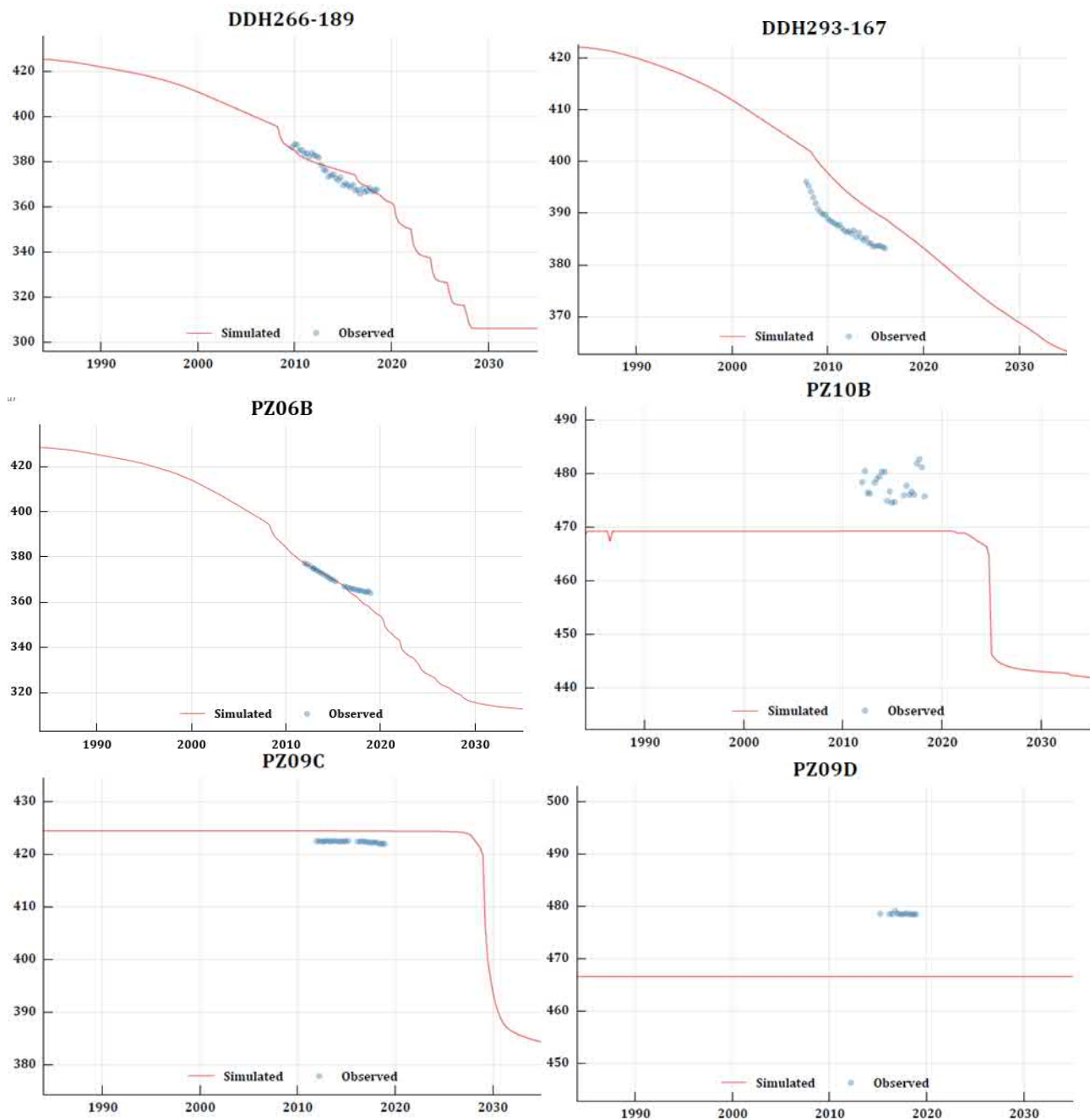


Figure A 5.3 Hydrographs for selected bores

In terms of mine inflow, it is understood that the observed current inflow rate is around 15 ML/day. The model is simulating this same quantum of inflows (see Figure A 6.6 in Section A 6.5) increasing confidence in the model predictions as model parameter non-uniqueness has been reduced by matching flows as well as heads.

A 5.2.1 Calibrated hydraulic properties

Table A 5.2 summarises the calibrated hydraulic conductivity for each of the hydrostratigraphic units within the model domain. The values presented are the base value for each layer.

These values are then adjusted at each of the pilot points mentioned in section 7.1.2. An example of how the pilot points adjust the parameter ranges within a model layer are shown in Figure A 5.4. Appendix A 1 lists the hydraulic conductivity ranges for each layer.

Table A 5.2 Base hydraulic conductivity values

Model layer	Lithology	Horizontal hydraulic conductivity – Kh (m/day)	Horizontal to vertical hydraulic conductivity ratio (Kh:Kv)
1	Colluvium	5.0E-01	10
1	Alluvium	3.5E+01	10
2	Tertiary basalt	1.0E-03	50
3	Jurassic Pilliga	1.0E-03	1.0
4	Jurassic Purlewaugh	1.0E-03	1.0
5 – 8	Triassic – Quartzose	1.0E-02	1.0
9 – 10	Triassic – Lithic	5.0E-04	1.0
11	Permian Upper-1	1.0E-05	1.0
12	Permian Upper-2	1.0E-05	1.0
13	Permian Middle-1	1.0E-04	1.0
14	Permian Middle-2	1.0E-04	1.0
15	Permian Ulan	1.0E-04	1.0
16	Ulan – coal seam	15E+00 *	1.0
17	Permian lower-1	1.0E-04	1.0
18	Permian lower-2	1.0E-04	1.0
19	Bedrock	1.0E-04	1.0

Note: * - this value is a coefficient used in a depth dependence equation for the coal seam as described below.

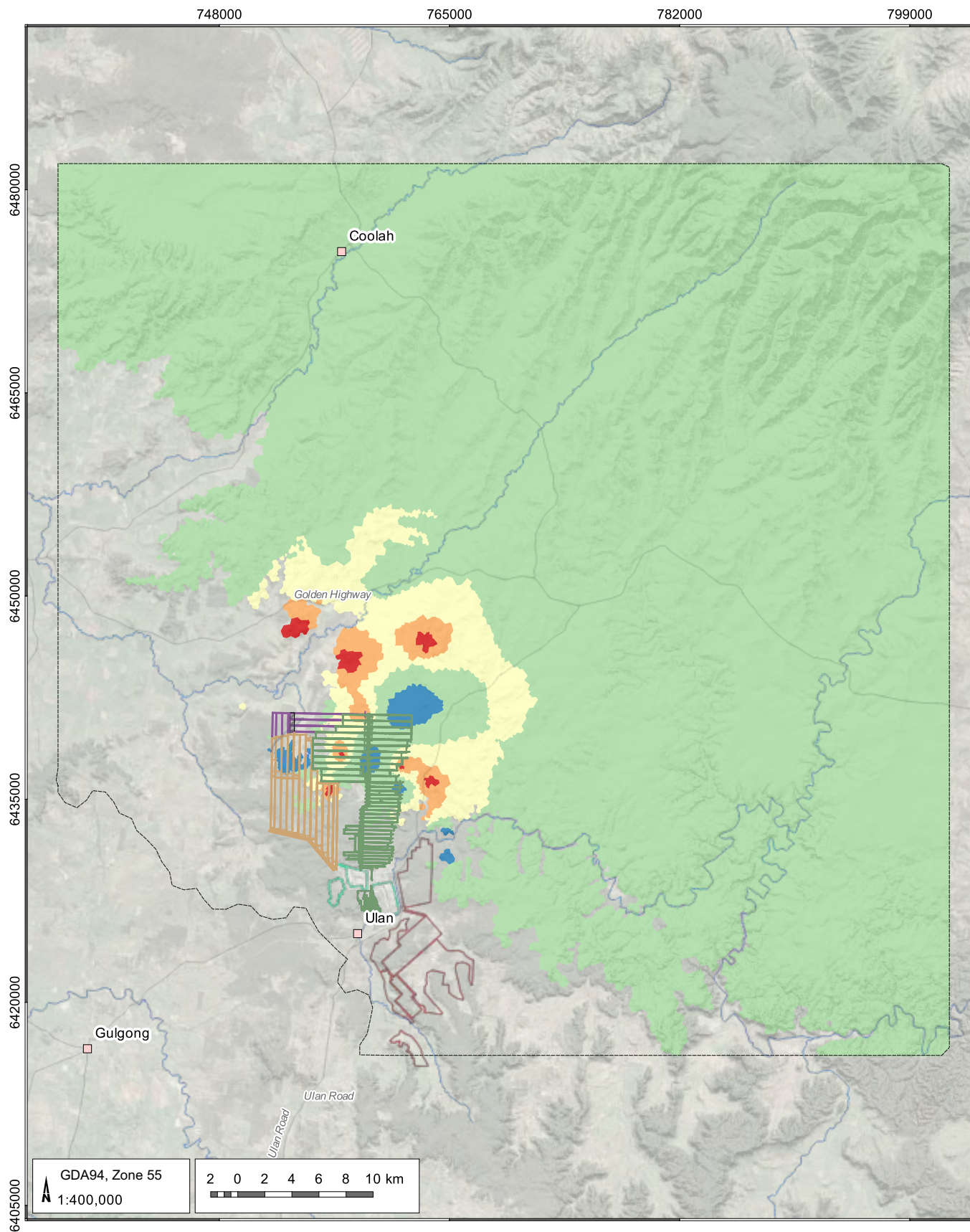
In order to simulate cleats in the coal closing under overburden pressure, horizontal hydraulic conductivity of the Ulan coal seam decreases as depth from ground surface increases. The equation used to calculate Kh of the Ulan coal seam is:

$$K_h = K_0 \cdot e^{sd}$$

where K_0 is the base hydraulic conductivity value in Table A 5.2, s is the slope (-0.005), and d is the depth (m). The Ulan coal seam Kh values were capped at a maximum of 0.6 m/day.

Section 5.2 of the main report presents a summary of the local field testing that has been undertaken at the site. The calibrated parameters presented above in Table A 5.2 are generally in line with the log normal mean values listed in Table 5.1. The calibrated Permian values are generally an order of magnitude or more higher than the mean core test values, but are the middle of the range of Permian packer tests results also presented in Mackie (2009).

The horizontal hydraulic conductivity has calibrated to 35 m/day. This is higher than the measured range noted by Mackie (2009) for the Goulburn River alluvium, although it is also significantly less than the theoretical upper limit for gravels and sands that have maximum values above of more than 100 m/day. The value of 35 m/day is also less than the calibrated value of 50 m/day used for the model underpinning the Ulan MOD4 approval which has been through regulator review.



LEGEND

- Populated place
- Surface drainage
- Road
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- Model domain
- Flexibility area

Hydraulic conductivity (m/day)

- 0.005 to 0.008
- 0.008 to 0.011
- 0.011 to 0.014
- 0.014 to 0.017
- 0.017 to 0.020

Ulan MOD6 GIA (1985G)

Example of hydraulic conductivity variations generated by Pilot Points – Model layer 5 (i.e. Triassic – Quartzose)



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FIGURE No:
A 5.4

Percentile plots showing the calibrated ranges in hydraulic conductivity are shown in Figure A 5.5 (horizontal) and Figure A 5.6 (vertical). The plots use data from a regularised 400 m grid covering the model domain rather than model cell centres. This approach has been used to remove the effect of different cell sizes, which could bias the outputs.

If there were no pilot points the value for each of the layers with a single strata type would plot as horizontal lines. The slight gradients observed for each layer show that although the pilot points do adjust the hydraulic properties within each layer the variations are generally very small. The notable steps in values in layer 1 represent the different stratigraphic zones present within that layer e.g. alluvium and colluvium, and in simulating a transition zone at the base of the alluvium through vertical hydraulic conductivity values to provide a more realistic interaction between the alluvium and sub cropping coal seams.

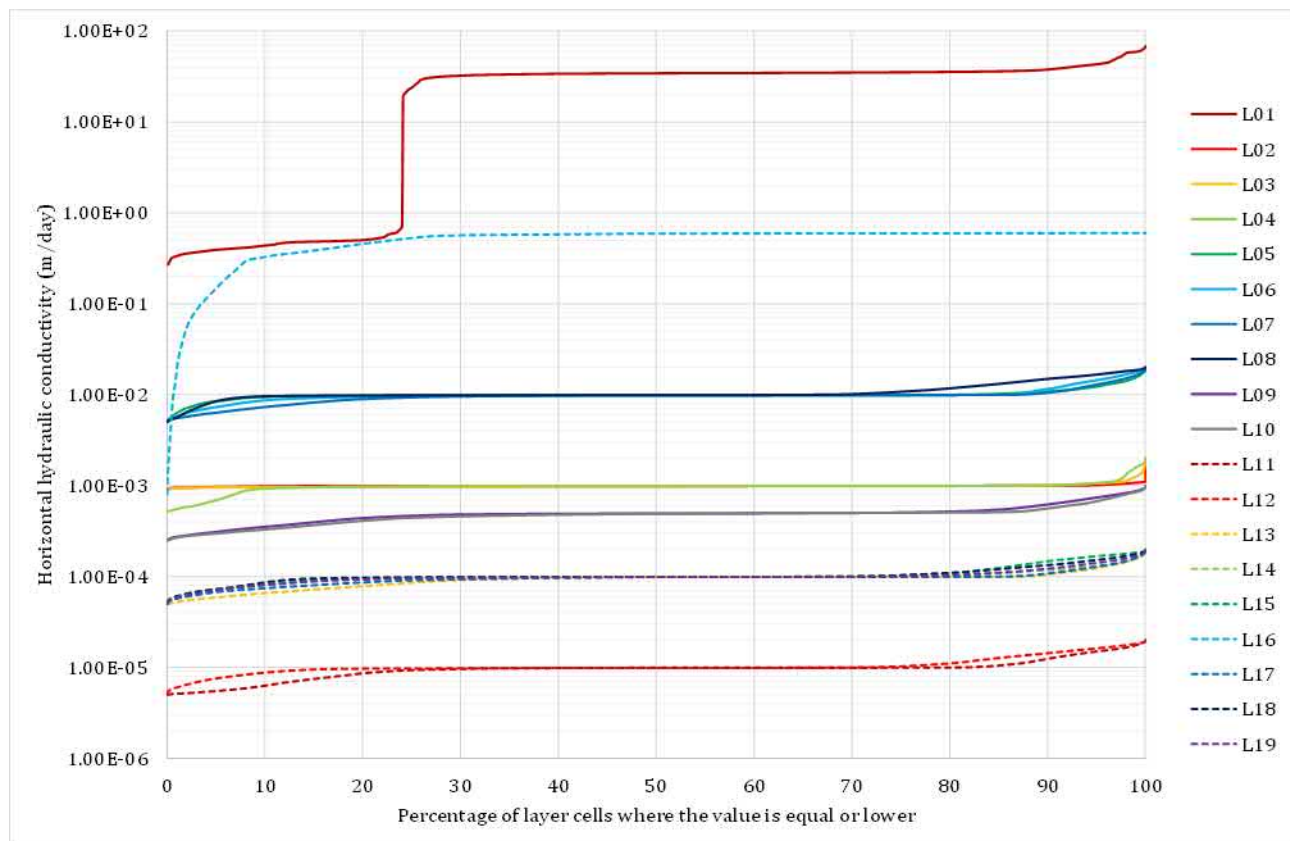


Figure A 5.5 Calibrated horizontal hydraulic conductivity ranges in each model layer

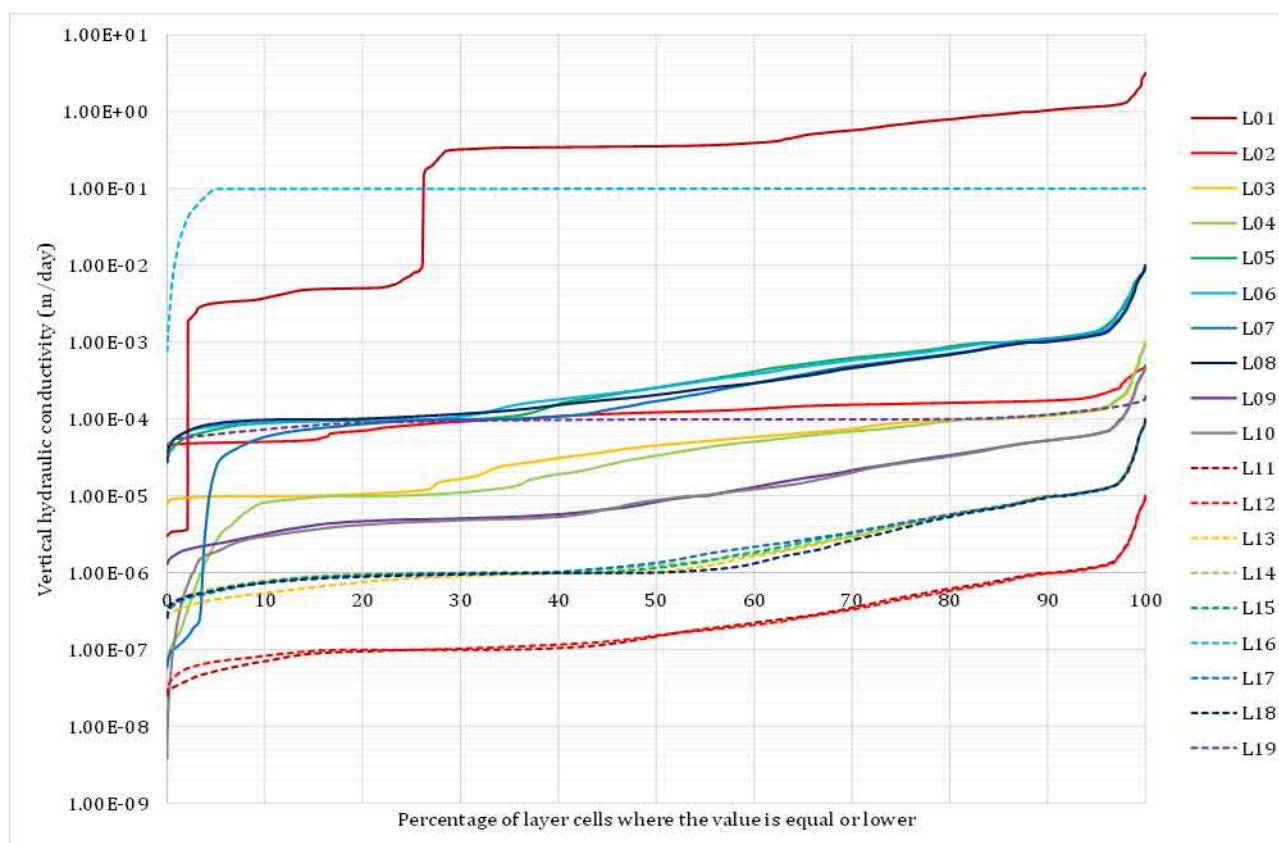


Figure A 5.6 Calibrated vertical hydraulic conductivity ranges in each model layer

A 5.2.2 Storage properties

Table A 5.3 summarises the calibrated values for specific storage and specific yield. It should be noted that it assumed that the storage properties are uniform within lithologies and hence no pilot points were applied to the storage parameters. Generally, specific yield is only relevant in the model where the layers become unconfined, so the parameter is not active in all parts of the model and not likely to be active in model layers below the coal seam. Specific storage is only applied where the model layers are confined and is therefore not relevant to layers that intercept the water table.

The value of specific yield adopted for the colluvium is at the low end of the potential range for unconsolidated materials and reflects the clay dominant material.

Table A 5.3 Storage values

Model layer	Lithology	Specific yield – Sy	Specific storage – Ss (m ⁻¹)
1	Colluvium	8.0E-03	5.0E-06
1	Alluvium	1.0E-01	1.3E-05
1	Weathered coal	1.0E-01	1.3E-05
2	Tertiary basalt	2.0E-02	5.0E-06
3	Jurassic Pilliga	1.0E-02	5.0E-06
4	Jurassic Purlewaugh	5.0E-03	5.0E-06
5 – 8	Triassic – Quartzose	3.0E-02	1.0E-05
9 – 10	Triassic – Lithic	1.0E-02	8.0E-06
11	Permian Upper-1	5.0E-03	1.0E-06

Model layer	Lithology	Specific yield – Sy	Specific storage – Ss (m ⁻¹)
12	Permian Upper-2	2.0E-03	2.0E-06
13	Permian Middle-1	4.0E-03	1.0E-06
14	Permian Middle-2	2.0E-02	2.0E-06
15	Permian Ulan	4.0E-03	1.0E-06
16	Ulan – coal seam	2.0E-02	2.0E-06
17	Permian lower-1	5.0E-03	1.0E-06
18	Permian lower-2	8.0E-03	2.0E-06
19	Bedrock	1.0E-03	1.0E-06

These values are consistent with the values adopted in the model that supports the regulator reviewed MOD4 approval process. The specific storage values also conform to the plausible range suggested by Rau (2018).

A 5.2.3 Water budget

The mass balance error, that is, the difference between calculated model inflows and outflows at the completion of the steady state calibration was 0.00%. The maximum percent discrepancy at any time step in the simulation was also 0.01%. This value indicates that the model is stable and has achieved an accurate numerical solution. Table A 5.4 shows the water budget for the steady state (pre-mining) model.

Table A 5.4 Model budgets – steady state

Parameter	In (ML/day)	Out (ML/day)	In - Out (ML/day)
Rainfall recharge	35.98	-	35.98
River	0.0	35.98	-35.98
Total	35.98	35.98	0.00

The water budget indicates that the recharge to the groundwater system averages 35.98 ML/day, with all recharge being discharged via surface drainage. This discharge to surface drainage is considered baseflow. Table A 5.5 shows steady state baseflow calculated at the baseflow budget zones illustrated in Figure A 5.7.

Table A 5.5 Summary of predicted steady state baseflow

Zone number	Zones	Steady state baseflow (ML/day)
1	Talbragar R below Cockabutta Ck	3.51
2	Main Talbragar from Mona to Cockabutta Ck	1.09
3	Main Talbragar above Mona Ck (inside previous model domain)	4.70
4	Cockabutta Ck	0.40
5	Mona Ck	0.00
6	Goulburn R below Murrumbline Ck (inside previous model domain)	0.07
7	Goulburn R from Bobadeen to Murrumbline Ck	0.02
8	The Drip	0.002
9	Bobadeen Ck/Spring Gully	0.00
10	Goulburn R from Sportsman Hollow Ck	0.49
11	Upper Goulburn R. above Sportsman	0.72
12	Ulan Ck	0.001
13	Curryall - Murrumbline Ck	0.08
14	Main Talbragar above Mona Ck (outside previous model domain)	0.50
15	Goulburn R below Murrumbline Ck (outside previous model domain)	2.19

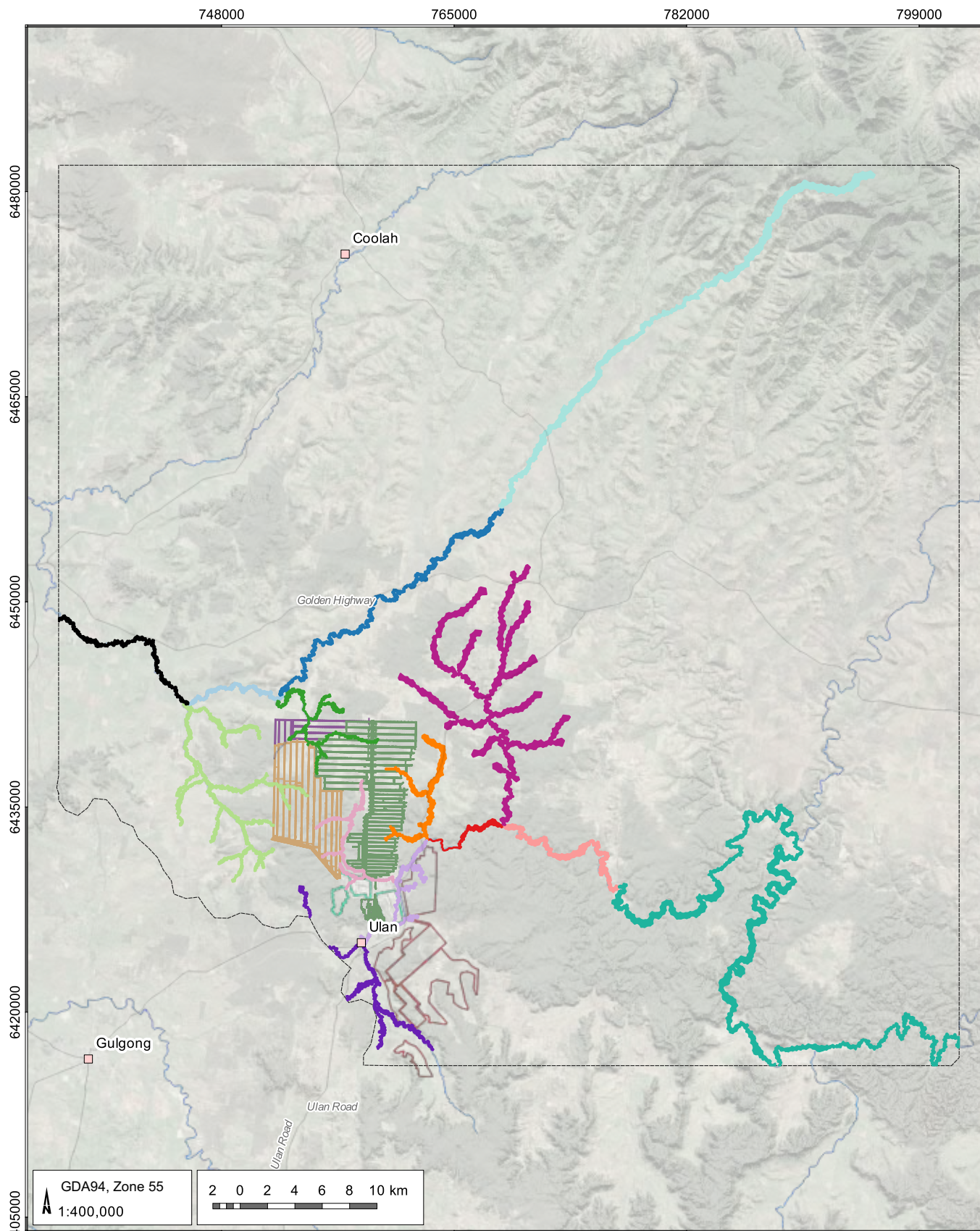
Table A 5.6 shows the average water budget for the transient calibration (1984 to 2019).

Table A 5.6 Model budgets – transient calibration

Parameter	In (ML/day)	Out (ML/day)	In - Out (ML/day)
Rainfall recharge	39.47	-	39.47
River	0.00	38.52	-38.52
Drains	-	6.76	-6.76
Component Total	39.47	45.28	-5.81
Storage	12.85	7.05	5.80
Numerical check	52.32	52.33	-0.01

The transient water budget indicates that the groundwater system departs from steady state conditions because of expanding mining in the model domain. Recharge within the model averages 39.47 ML/day. The differences between the steady state and transient recharge rates are due to different climatic conditions during the transient calibration period (1984 to 2019) when compared to the long-term annual average (steady state). The transient budget also shows that, on average, drains (mining) take out 6.76 ML/day during this historical period. The transient water budget is presented in Figure A 5.8.

The 'percent discrepancy' or mass balance error for the steady state timestep was 0.00%. The maximum percent discrepancy at any time step in the transient calibration simulation was only 0.05%. This value indicates that the model is stable and has achieved an accurate numerical solution.



LEGEND

- Populated place
- Surface drainage
- Road
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Ulan open cut
- Moolarben mine area
- Model domain

Baseflow budget zones

- 1 - Talbragar R below Cockabutta Ck
- 2 - Main Talbragar from Mona to Cockabutta Ck
- 3 - Main Talbragar above Mona Ck (inside previous)
- 4 - Cockabutta Ck
- 5 - Mona Ck
- 6 - Goulburn R below Murrumbline Ck (inside previous)
- 7 - Goulburn R from Bobadeen to Murrumbline Ck
- 8 - The Drip
- 9 - Bobadeen Ck/Spring Gully
- 10 - Goulburn R from Sportsman Hollow Ck
- 11 - Upper Goulburn R. above Sportsman
- 12 - Ulan Ck
- 13 - Curryall - Murrumbline Ck
- 14 - Main Talbragar above Mona Ck (outside previous)
- 15 - Goulburn R below Murrumbline Ck (outside previous)

Ulan MOD6 GIA (1985G)

Baseflow budget zones



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FIGURE No:
A 5.7

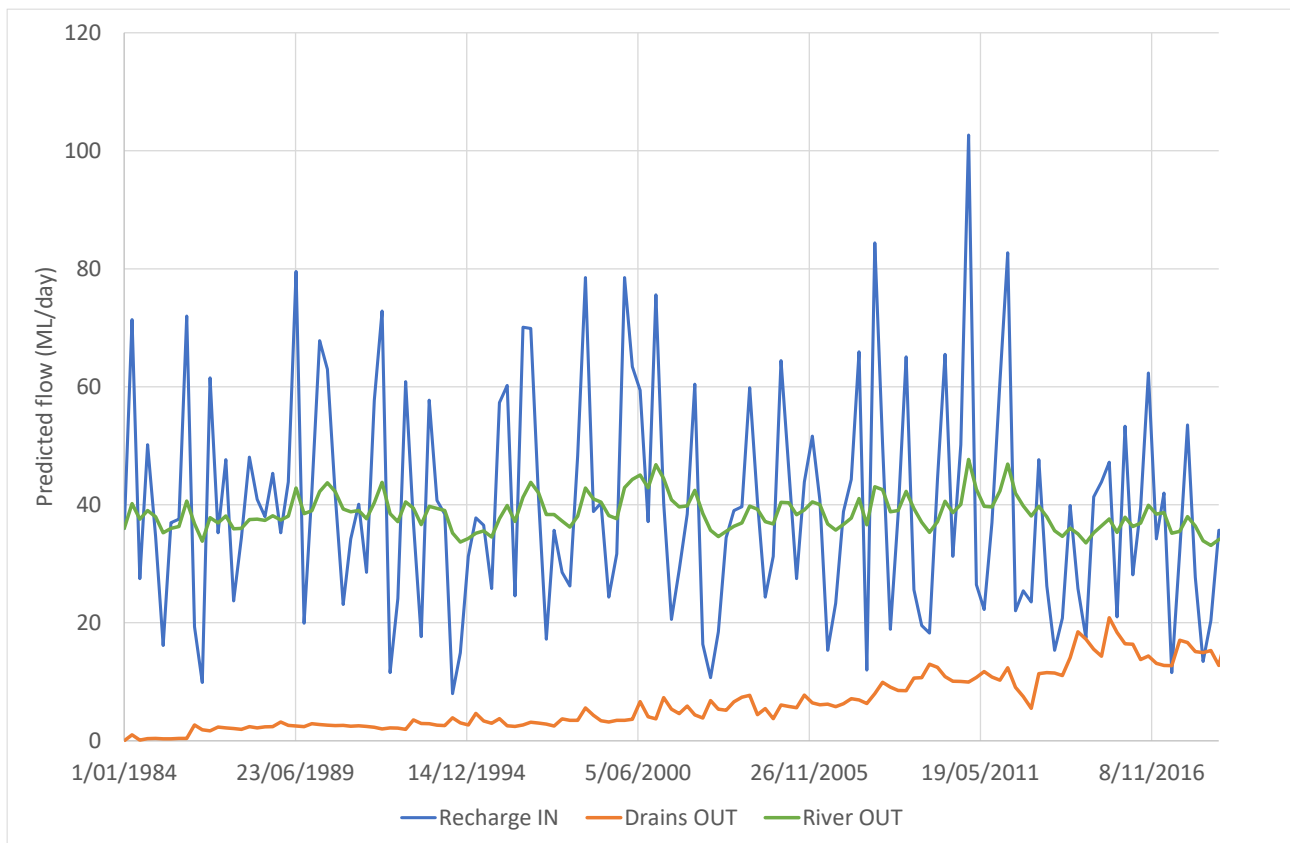


Figure A 5.8 Transient water budget during calibration

A 6 MOD6 Predictions

Predictive numerical modelling was undertaken to assess the impact of MOD6 at Ulan on the groundwater regime. The objectives of the predictive modelling were to:

- predict groundwater inflow into the underground mine for MOD6;
- simulate and predict the extent and area of influence of mining on the water table and deeper groundwater pressures; and
- predict the additional loss and/or water take from the water bearing units on site for licensing estimates, including losses to baseflow.

To make an assessment of the changes resulting from the proposed modification, a comparison is made between two models, one representing the situation without the change (the 'null' model) and one representing the changed situation. The difference between corresponding predictions from these two models defines the impact of the change. To assess the changes due to the proposed modification at Ulan the following model situations or scenarios (Table A 6.1) were created and used in various combinations to produce a range of required assessment items.

Table A 6.1 Model setups used in the groundwater assessment

Model Setup	Model Description
1	No Mine model – simulates no mining in the model domain.
2	Only Moolarben - simulates the presence of Moolarben mine but excludes all Ulan mining. This can be used to isolate the Ulan only impacts out of a cumulative model run
3	Approved Mine – simulates the mine plan approved under MOD4. This model also simulates the Moolarben mine
4	Modification Model – simulates the approved mining and additional proposed mining at Ulan and the mining at Moolarben.

All the predictions in the following sections are derived from combinations of these model setups.

The following sections describe the predicted impacts to the groundwater regime from MOD6 mining simulation, comparing against the approved mining (MOD4) impacts and presenting the cumulative impacts with Moolarben Mine.

A 6.1 Cumulative drawdown and depressurisation during mining

The process of open cut and underground mining reduces groundwater pressures within the target coal seam and in other hydraulically connected aquifers. The extent of groundwater level drawdown/depressurisation is dependent on the properties of the coal seams, interburden units, and other surrounding hydrostratigraphic units. Groundwater level drawdown within the coal seam is greatest at the working coalface, and gradually reduces with distance from the mine.

The numerical model calculated the extent of groundwater level drawdown within each of the model layers due to MOD6 through comparison of two models: one simulating the proposed modification mine plan (Model 4), and one not simulating any mining (Model 1). The difference in predicted groundwater levels between the two models represents the cumulative drawdown due to the proposed modification.

For comparison purposes, another combination of models was run to produce the 2m drawdown extent for the approved mining. This required the predictions from Model 3 to be compared to the no-mine simulation of Model 1 allowing the drawdown to be calculated.

Layers 1, 4, 7, 10 and 16 represent the quaternary alluvium, Jurassic Purlewaugh, quartzose Triassic, lithic Triassic, and the Ulan coal seam respectively. Figure A 6.1 to Figure A 6.5 show the predicted cumulative drawdown for each of these model layers for the proposed modification. The Triassic formation is important as it hosts the better-quality water within the local groundwater regime, and from where most of the local hard rock groundwater for domestic and agricultural use is sourced. These figures also show the predicted 2 m drawdown for the approved mining as a dashed line so the changes due to the proposed modification can be assessed.

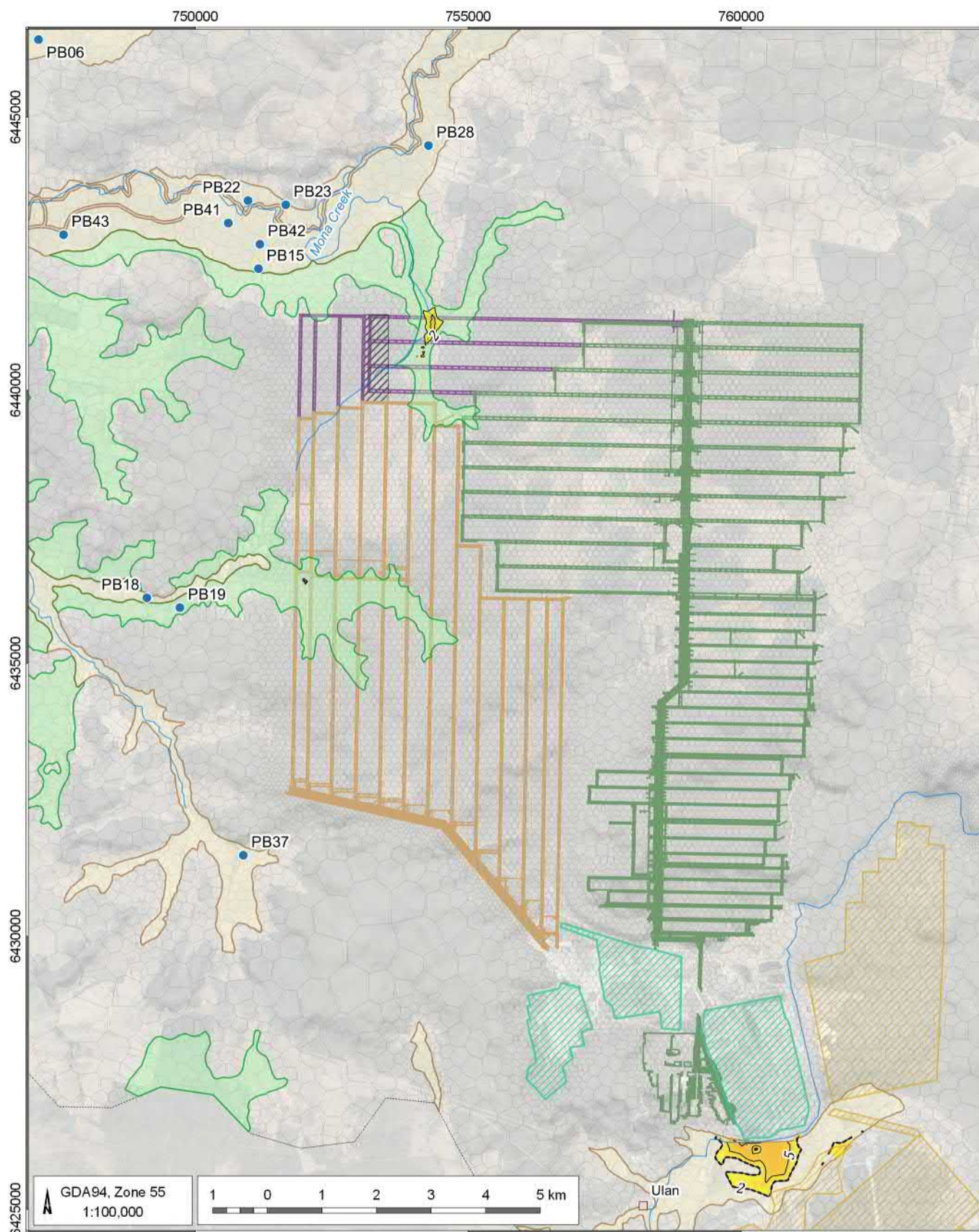
Figure A 6.1 shows 2 m or more drawdown in the colluvium associated with Mona Creek. Drawdown occurring immediately to the south of the Ulan open cut is due to the approved mining as indicated by the dashed 2 m contour.

Figure A 6.2 indicates that no drawdown greater than 2 m is predicted in the Jurassic lithology due to either the approved or MOD6 mining. The reason for this is the limited extent of Jurassic sediments across the Ulan mine footprint, and where it is present it is mostly unsaturated.

Figure A 6.3 and Figure A 6.4 shows that the drawdown is more extensive in the Triassic formations compared to Jurassic and occurs predominantly in the north-eastern extent of the longwall panels where the Triassic sediments are saturated.

Figure A 6.5 illustrates that the impacts from mining are extensive in the Ulan seam, however, there are no known beneficial users of this resource.

In most areas away from the MOD6 mine footprint there is no discernible change in the 2 m drawdown between the approved mining (dashed line) and the MOD6 predicted drawdown. There will be obvious changes across the MOD6 footprint, and the approved 2 m contour can be observed cutting through this area for the Triassic formations.



LEGEND

- Private bore
- Populated place
- Drainage
- Drawdown contour (m)
- Approved mine plan 2m drawdown contour
- Ulan Underground Mine Plan
- Ulan West Mine Plan
- Proposed longwall panel
- Moolarben mine area
- Ulan open cut
- Alluvium
- Colluvium
- Flexibility area
- Model domain
- Model mesh

Drawdown (m)

- 0
- 1
- 2
- 5
- 10
- 20
- 50
- 100
- 200

Ulan MOD6 GIA (G1985G)

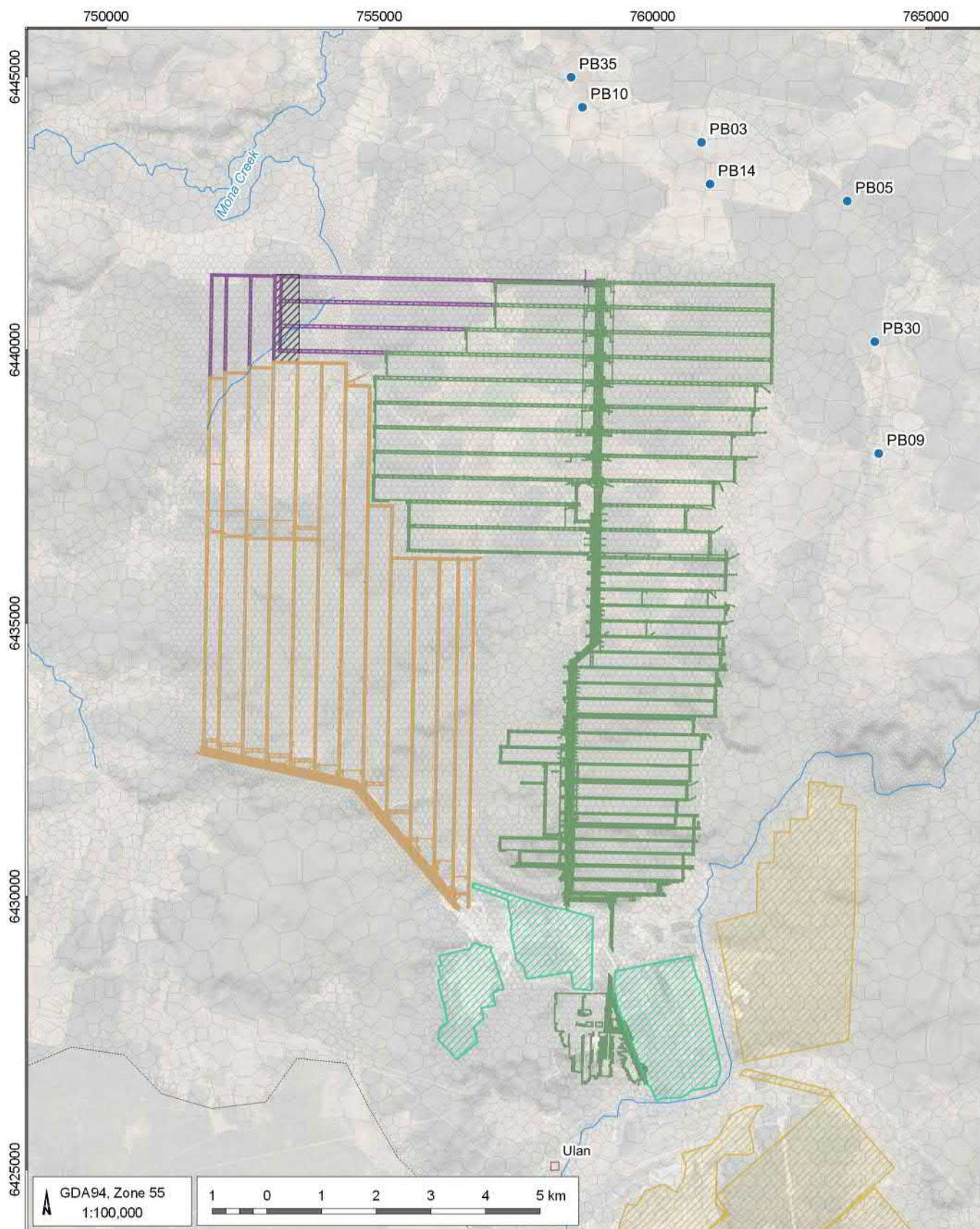
Predicted cumulative drawdown in the Quaternary alluvium and colluvium (Layer 1) at the end of approved mining



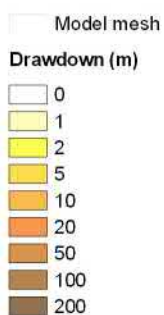
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FIGURE No:
A 6.1



- LEGEND**
- Private bore
 - Populated place
 - Drainage
 - Drawdown contour (m)
 - - - - - Approved mine plan 2m drawdown contour
 - Ulan Underground Mine Plan
 - Ulan West Mine Plan
 - Proposed longwall panel
 - ▨ Moolarben mine area
 - ▨ Ulan open cut
 - ▨ Flexibility area
 - Model domain



Ulan MOD6 GIA (G1985G)

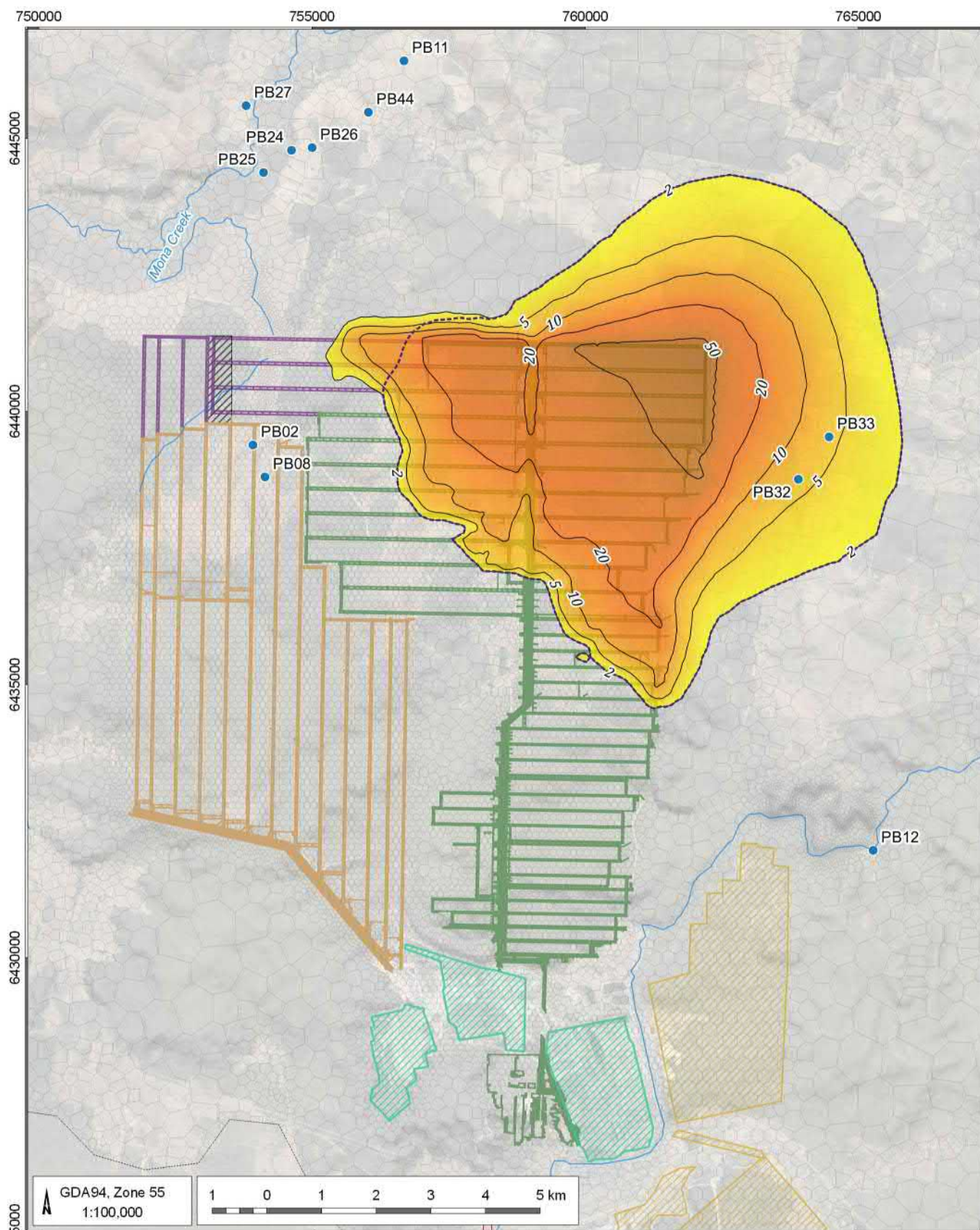
Predicted cumulative drawdown in the Jurassic Purlewaugh (Layer 4) at the end of approved mining



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FIGURE No:
A 6.2



- LEGEND**
- Private bore
 - Populated place
 - Drainage
 - Drawdown contour (m)
 - Approved mine plan 2m drawdown contour
 - Ulan Underground Mine Plan
 - Ulan West Mine Plan
 - Proposed longwall panel
 - Moolarben mine area
 - Ulan open cut
 - Model domain
 - Model mesh

- Drawdown (m)**
- 0
 - 1
 - 2
 - 5
 - 10
 - 20
 - 50
 - 100
 - 200
 - Flexibility area

Ulan MOD6 GIA (G1985G)

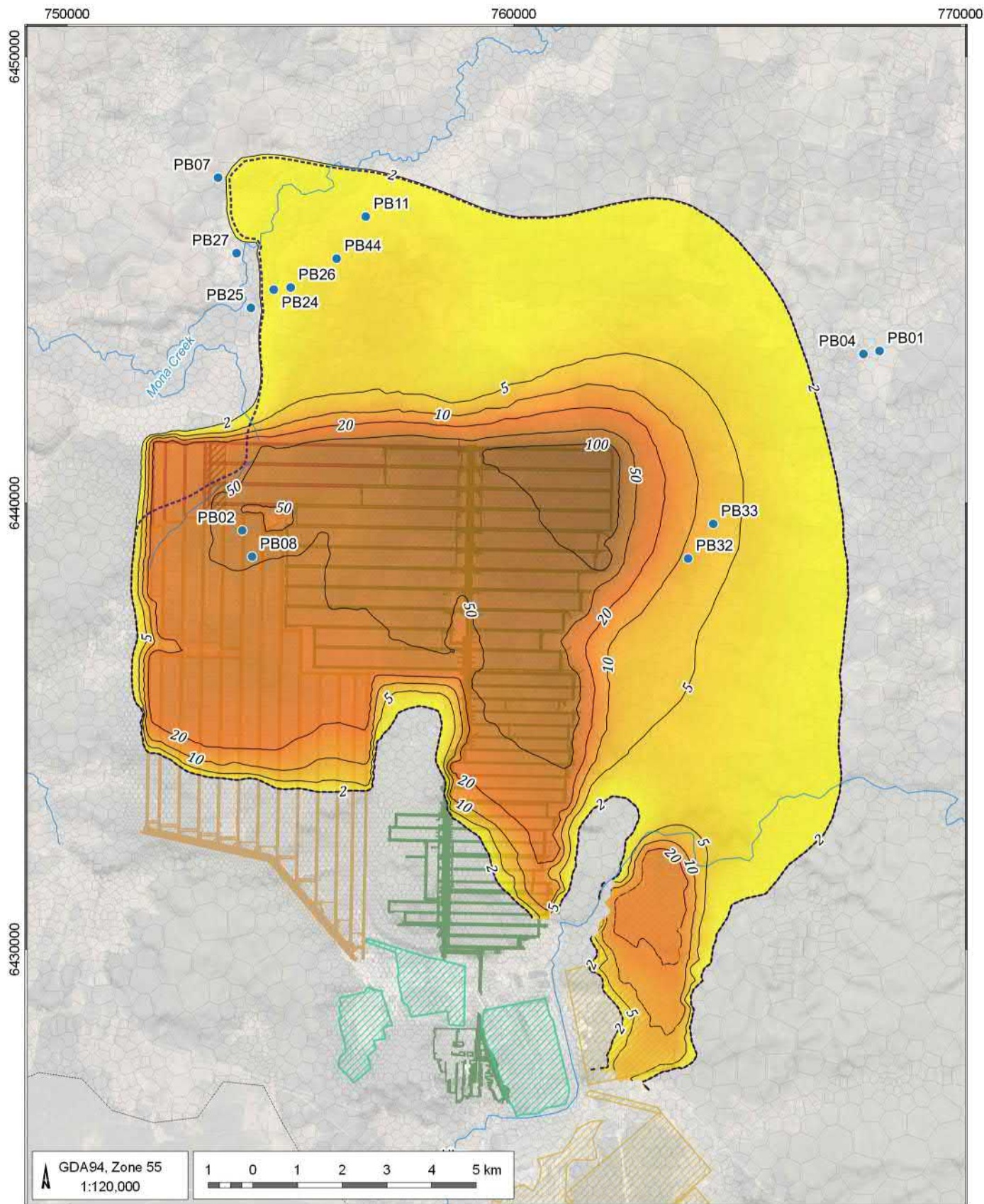
Predicted cumulative drawdown in the quartzose Triassic (Layer 7) at the end of approved mining



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FIGURE No:
A 6.3



LEGEND

- Private bore
- Populated place
- Drainage
- Drawdown contour (m)
- Approved mine plan 2m drawdown contour
- Ulan Underground Mine Plan
- Ulan West Mine Plan
- Proposed longwall panel
- ▨ Moolarben mine area
- ▨ Ulan open cut
- ▨ Flexibility area
- Model domain

Model mesh

Drawdown (m)

- 0
- 1
- 2
- 5
- 10
- 20
- 50
- 100
- 200

Ulan MOD6 GIA (G1985G)

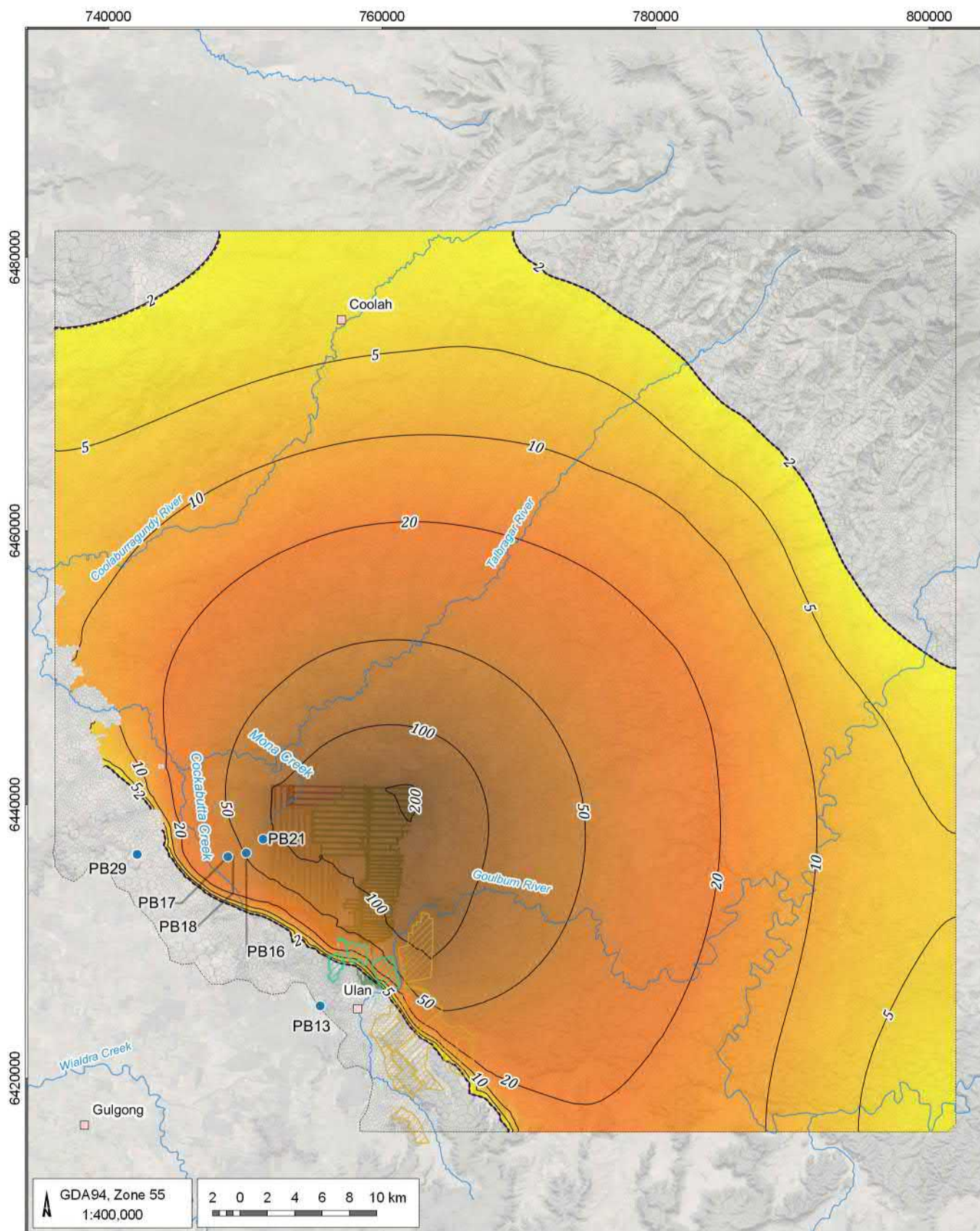
Predicted cumulative drawdown in the lithic Triassic (Layer 10) at the end of approved mining



AGE

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FIGURE No:
A 6.4



LEGEND

- Private bore
- Populated place
- Drainage
- Drawdown contour (m)
- Approved mine plan 2m drawdown contour
- Ulan Underground Mine Plan
- Ulan West Mine Plan
- Proposed longwall panel
- ▨ Moolarben mine area
- ▨ Ulan open cut
- ▨ Flexibility area
- Model domain

Model mesh

Drawdown (m)

- 0
- 1
- 2
- 5
- 10
- 20
- 50
- 100
- 200

Ulan MOD6 GIA (G1985G)

Predicted cumulative drawdown in the Ulan seam (Layer 16) at the end of approved mining



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FIGURE No:
A 6.5

A 6.2 Predicted drawdown at private bores

Table A 6.2 shows the private bores that are likely to be impacted by two or more metres by the cumulative approved mining (Model 3) and by the addition of the proposed modification (Model 4). The updated model has resulted in changes to the list produced by the MODFLOW SURFACT model, where the revised structure and ability to simulate perched groundwater has resulted in two additional bores being added to the list and seven of the previous bores now showing less than 2 m drawdown and will be removed from that list of impacted bores.

The predicted drawdowns presented have not been limited to the saturated levels, instead these drawdowns reflect the total drawdown at the bore locations.

Table A 6.2 Summary of impacted private bores (>2 m drawdown)

Site ID	Ground elevation (mAHD)	Total depth (mbgl)	Screened strata	Predicted drawdown (m)		
				Approved mining drawdown	Proposed Modification	
					Drawdown	Increase in Drawdown (m)
PB08	436	~ 67	Triassic	133.94	133.94	0.00
PB21	470.1	-	CM	21.70	21.71	0.01
PB17	445.1	>30	CM	36.81	36.99	0.18
PB32	494.8	-	Triassic	8.18	8.18	0.00
PB33	491.8	-	Triassic	6.25	6.25	0.00
PB20	453	55	CM?	9.81	9.81	0.00
PB16	450.2	65	CM?	21.74	21.74	0.00

Post mining predicted drawdowns are presented in Section 8.2 of the main report.

A 6.3 Potential impact to baseflows

Dewatering activities from mining will result in a lowering of the water table in and around the mine. The lowering of the water table will reduce and sometimes reverse gradients in the groundwater regime which will temporarily divert water that might migrate to surface drainages and become baseflow.

Predicted baseflows were extracted from the approved mining (Model 3) and the proposed modification (Model 4) simulations to estimate the predicted change in baseflow due to the proposed modification. The results from this are summarised below in Table A 6.3.

Table A 6.3 Predicted baseflow impacts

	Reduction in baseflow (ML/day)			
	Approved Mining		Proposed Modification	
	<u>Goulburn River</u>	<u>Talbragar River</u>	<u>Goulburn River</u>	<u>Talbragar River</u>
Predicted reduction at end of mining	0.272	0.078	0.272	0.081

The additional baseflow that is intercepted in the Talbragar catchment is 0.003 ML/day which would not be measurable or noticeable in any practical sense.

A 6.4 Potential impact to The Drip

In the model The Drip seepage face is represented by a series of RIV cells assigned to the identified seepage elevations of The Drip (see Section A 4.6.2). The RIV cells remove water from the model when groundwater levels are above the seepage elevation. The volume of water removed through the RIV boundary condition is captured throughout the model run. The model run shows no discernible change in the flow rate for The Drip (see Table A 6.4) and the model simulates a discharge rate of 0.021 L/s (or 0.0018 ML/day). From observations of the drip this volume is plausible.

Table A 6.4 Predicted groundwater discharge at The Drip

	Discharge rate (ML/day)
Pre-mining	0.0018
End of mining	0.0018

A 6.5 Predicted groundwater inflows

The predicted mine inflow has been determined through examination of the water budget for the drains representing the various mining areas. The predicted inflow to Ulan Underground and Ulan West Underground for both the approved mining and the MOD6 mine plan are presented below in Figure A 6.6. It shows that:

- the inflows from approved mine plan are predicted to peak at 22 ML/day in year 2028;
- MOD6 will increase that peak take to 29.6 ML/day;
- a significant amount of that predicted additional inflow is associated with the Ulan Underground panels. These are situated under areas where there is more saturated Triassic sediments, which become a source of inflow with the associated fracture zone above the mined longwall panels; and
- over the life of the mine MOD6 generates an 7.8% increase on the total inflow which aligns to the increase in mine footprint.

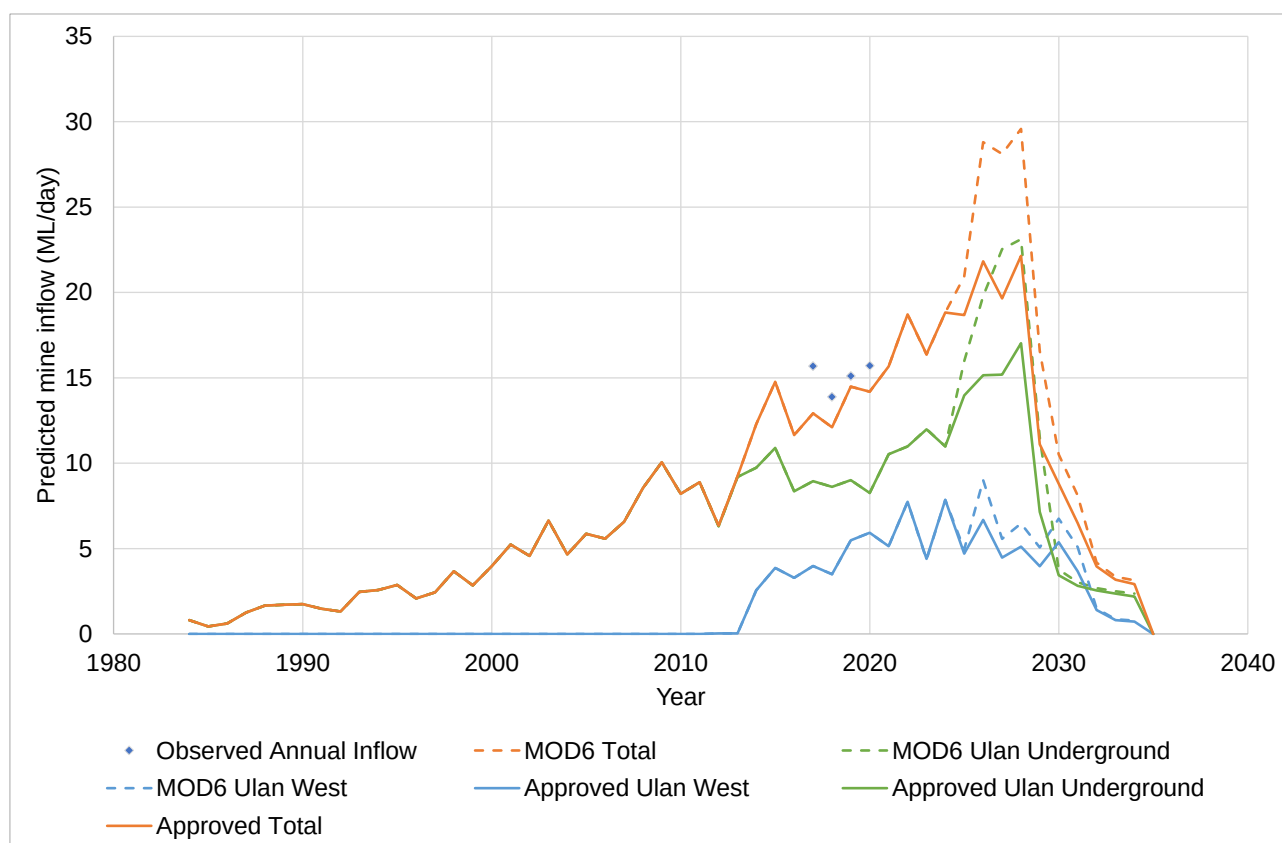


Figure A 6.6 Predicted inflow to mine areas

A 6.6 Post mining model predictions

At the completion of mining dewatering of the underground will cease and the underground workings will be left to flood, and groundwater will rise in the mine to a new static level. Away from the mine the propagation of drawdown outwards away from the mine will continue, but the rate of that propagation will diminish as groundwater levels at the mine workings rise and the gradient back to the mine reduces. After some time, there will be places where the drawdown extent will retreat back towards the mine due to the reduced gradient.

The backfilling of pits will also offer the opportunity for groundwater to mound up to levels potentially above the pre mining water levels in the area. A post mining void is also planned to be maintained at the Ulan site, utilising the northeast portion of the existing East Pit void (as the remainder of that void will be backfilled).

To predict the post mining conditions the model representing the proposed modification mining period was extended with the addition of 48 transient stress periods representing 1 x six-month, 25 x yearly, 5 x 5-year, 5 x 10-year, 2 x 25-year, 1 x 50-year, 3 x 100-year, 1 x 500 year, 1x 1000-year and a final steady state model to represent the long-term groundwater conditions. This setup was designed to capture both the peak water take from water sources and the long-term residual take and groundwater conditions. The transient simulation post mining accumulates to cover a time period of 2000 years into the future.

The hydraulic property and boundary condition assumptions adopted in the post mining simulation are described below in Table A 6.4. The spoil properties were assigned across all the open cut voids and the GHB boundary conditions were assigned where the voids were planned / expected to be. An assumption was made that the Moolarben mining will finish at the same time Post mining predictions are presented in Section 7.4 of the main report.

Table A 6.5 Post mining model setup

Model Feature	Adopted Value
Spoil K_h	2 m/day
Spoil K_v	0.8 m/day
Spoil Recharge	2% of rainfall
Spoil S_s	1E-04 m^{-1}
Spoil S_y	0.1
Remaining East Pit void	Represented by the general head boundary assigned to all model layers intercepting the void with a reference level of 359 mAHD and a nominally high conductance of 9999 m^2/day
Assumed void at Moolarben	GHB package with a reference level of 421 mAHD (essentially pre mining level) and conductance of 9999 m^2/day

A 6.7 Groundwater sources and partitioning

The model was also used to estimate the impact or take from the various water sources associated with the various water sharing plans covering the Ulan mine area. This was determined by zoning up the model domain (in three dimensions) to assign every model cell to a water source. The budgeting then assesses water movement between zones. To determine the impact of mining this budgeting is undertaken for both the simulation with mining and the simulation without mining (null model) and the difference in the budgets then determines the take of water from that zone.

The direct take of water (also referred to as incidental water) at the mine site from dewatering activities is calculated by processing the Drain budget for the water sources containing the Drain boundary conditions (see Figure A 6.6). This equates to the total take from the groundwater system as a result of the mining, and this take has created gradients in the model and caused water to flow resulting in changes in flows across the water source boundaries. These changes in flow provide the indirect take (or passive water take) resulting from the operation.

The change in flow to a shallow alluvial zone will encapsulate the reduction in baseflow to the associated surface drainage. While there is only a small area of specific alluvium water source in the model domain, the impacts on the baseflows must also be captured because the creeks are highly connected to groundwater in the area.

The results of this analysis are presented in Section 8.2 of the main report.

A 7 Uncertainty analysis

A 7.1 Overview

Middlemis and Peeters (2018) outline three general approaches to analysing parameter uncertainty in increasing order of complexity and of the level of resources required, they are:

1. deterministic scenario analysis with subjective probability assessment;
2. deterministic modelling with linear probability quantification; and
3. stochastic modelling with Bayesian probability quantification.

In this case a Monte Carlo uncertainty analysis was undertaken (option 3) to quantify the magnitude of uncertainty in the future impacts predicted by the model. This type of analysis produces probability distributions for predictive impacts by assessing a composite likelihood of an impact occurring through assessing and ranking the predictions from hundreds of model 'realisations'. Each model realisation is informed by the observation dataset by using the relationship between the observation statistics to perturbations of each parameter in the groundwater model.

This uncertainty analysis was essentially undertaken as a three-part process. Firstly, a valid range for each parameter (i.e. pre-calibration range) was determined, and then 200 model realisations were created, each with varied values of model parameters. The pre-calibration range used was identical to that used previously in the basecase model calibration (Appendix A 1).

The constrained realisations were tested and the models that failed to converge or could not achieve adequate calibration were rejected, leaving the output from 94 successful models. Models were considered to have an acceptable calibration if SRMS error (heads) $\leq 10\%$. The outputs were analysed to provide a statistical distribution of the predictive impacts.

Outputs from the uncertainty modelling were processed in accordance with the risk-based calibrated language proposed in Middlemis & Peeters (2018). The ranges adopted are shown in Table A 7.1.

Table A 7.1 Calibrated uncertainty modelling language

Narrative descriptor	Probability class	Description	Colour code
Very likely	0-10%	Likely to occur even in extreme conditions	
Likely	10-33%	Expected to occur in normal conditions	
About as likely as not	33-67%	About an equal chance of occurring as not	
Unlikely	67-90%	Not expected to occur in normal conditions	
Very unlikely	90-100%	Not likely to occur even in extreme conditions	

The range of model predictions resulting from the parameter uncertainty is presented in Section 9 of the main report for both total mine inflow and predicted drawdown due to the proposed modification.

A 8 Model Classification

Groundwater modelling has taken into account the Murray-Darling Basin Commission (MDBC) Groundwater Flow Modelling Guideline (MDBC, 2000) as well as the Australian Groundwater Modelling Guidelines (Barnett et al., 2012). Under the earlier MDBC modelling guideline, the model is best categorised as an Impact Assessment Model of medium complexity. That earlier guide (MDBC, 2000) describes this model type as follows:

“Impact Assessment model - a moderate complexity model, requiring more data and a better understanding of the groundwater system dynamics, and suitable for predicting the impacts of proposed developments or management policies.”

Under the more recent (Barnett et al., 2012) guidelines, this model would be classified as a Confidence Level 2 groundwater model, with the following key indicators (based on Table 2-1 of Barnett et al., 2012):

- rainfall and evaporation data are available for the site (Level 3);
- groundwater head observations and bore logs are available and with a good coverage around UCC and relevant nearby mines, but without spatial coverage throughout the model domain (Level 2);
- streamflow data and baseflow estimates available at a few points (Level 2);
- seasonal fluctuations reasonably replicated in many parts of the model domain (Level 2);
- scaled RMS error and other calibration statistics, e.g. mean residual, are acceptable (Level 3); and
- suggested use is for prediction of impacts of proposed developments in aquifers with a medium to high value (Level 2).

Table A 8.1 Model classification – model performance indicators

Class	Data	Calibration	Prediction	Quantitative Indicators
1 (Simple)	× Not much × Sparse coverage × No metered usage × Low resolution × Poor aquifer geometry	× Not possible × Large error statistic × Inadequate data spread × Targets incompatible with model purpose.	× Timeframe >> Calibration × Long stress periods × Poor/no validation × Transient prediction but steady-state calibration	× Timeframe > 10x × Stresses < 5x × Mass balance > 1% (or one-off 5%) × Properties < > field values × No review by Hydro/Modeller
2 (Impact Assessment)	× Some ✓ Ok coverage ~ Some usage data/ low volumes × Baseflow estimates. Some K & S measurements ✓ Some high resolution topographic DEM &/or some aquifer geometry	✓ Partial performance ✓ Some long term trends wrong. × Short term record. ✓ Weak seasonal match. ✓ No use of targets compatible with model purpose (heads & fluxes)	× Timeframe > Calibration × Long stress periods ✓ Ok validation ✓ Transient calibration and prediction ✓ New stresses not in calibration	× Time frame = 3-10x ✓ Stresses = 2-5x ✓ Mass balance <1% ✓ Some properties < > field values. Review by Hydrogeologist × Some coarse discretisation in key areas of grid or at key times
3 (Complex Simulator)	~ Lots, with good coverage. ~ Good metered usage info. ✓ Local climate data ~ Kh, Kv & Sy measurements from range of tests ✓ High resolution DEM all areas. ✓ Good aquifer geometry.	✓ Good performance stats ✓ Most long term trends matched ✓ Most seasonal matches ok. ✓ Present day data targets ✓ Head & Flux targets used to constrain calibration	✓ Timeframe ~ calibration ✓ Similar stress periods × Good validation ✓ Calibration & prediction consistent (transient or steady state). ✓ Similar stresses to those in calibration.	✓ Timeframe < 3x ✓ Stresses < 2x ✓ Mass balance < 0.5% ~ Properties ~field measurements ✓ No coarse discretisation in key areas (grid or time) ✓ Review by experienced Modeller

A 9 References

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Appendix A 1

Calibrated Hydraulic Conductivity Ranges

Table 2 Horizontal hydraulic conductivity Kh (m/day)

Model layer	Lithology	Horizontal hydraulic conductivity Kh (m/day)		
		Min	Mean	Max
1	Quaternary alluvium/colluvium	2.70E-01	2.77E+01	6.80E+01
2	Tertiary basalt	9.10E-04	1.00E-03	1.90E-03
3	Jurassic Pilliga	9.10E-04	1.00E-03	2.00E-03
4	Jurassic Purlewaugh	5.10E-04	9.90E-04	2.00E-03
5	Triassic quartzose sandstone	5.10E-03	1.02E-02	2.00E-02
6	Triassic quartzose sandstone	5.10E-03	1.02E-02	2.00E-02
7	Triassic quartzose sandstone	5.10E-03	9.78E-03	2.00E-02
8	Triassic quartzose sandstone	5.00E-03	1.10E-02	2.00E-02
9	Triassic lithic sandstone	2.50E-04	5.00E-04	9.90E-04
10	Triassic lithic sandstone	2.50E-04	4.83E-04	9.90E-04
11	Permian coal measures	5.00E-06	9.91E-06	2.00E-05
12	Permian coal measures	5.10E-06	1.08E-05	2.00E-05
13	Permian coal measures	5.00E-05	9.48E-05	2.00E-04
14	Permian coal measures	5.00E-05	1.02E-04	2.00E-04
15	Permian coal measures	5.00E-05	1.07E-04	2.00E-04
16	Ulan coal seam	8.10E-04	5.26E-01	6.00E-01
17	Permian coal measures	5.00E-05	9.74E-05	2.00E-04
18	Permian coal measures	5.10E-05	1.06E-04	2.00E-04
19	Basement metasediments	5.10E-05	1.02E-04	2.00E-04

Table 3 Vertical hydraulic conductivity Kv (m/day)

Model layer	Lithology	Vertical hydraulic conductivity Kv (m/day)		
		Min	Mean	Max
1	Quaternary alluvium/colluvium	3.00E-06	4.66E-01	3.20E+00
2	Tertiary basalt	4.50E-05	1.28E-04	5.00E-04
3	Jurassic Pilliga	7.90E-06	6.19E-05	1.00E-03
4	Jurassic Purlewaugh	5.70E-08	5.67E-05	1.00E-03
5	Triassic quartzose sandstone	2.70E-05	5.74E-04	1.00E-02
6	Triassic quartzose sandstone	2.80E-05	5.57E-04	1.00E-02
7	Triassic quartzose sandstone	6.00E-08	4.80E-04	1.00E-02
8	Triassic quartzose sandstone	2.80E-05	4.87E-04	1.00E-02
9	Triassic lithic sandstone	1.30E-06	2.31E-05	5.00E-04
10	Triassic lithic sandstone	3.80E-09	2.25E-05	5.00E-04
11	Permian coal measures	2.50E-08	4.25E-07	1.00E-05
12	Permian coal measures	2.60E-08	4.16E-07	1.00E-05
13	Permian coal measures	2.60E-07	3.88E-06	1.00E-04
14	Permian coal measures	2.60E-07	3.95E-06	1.00E-04
15	Permian coal measures	2.60E-07	3.98E-06	1.00E-04
16	Ulan coal seam	7.50E-04	9.75E-02	1.00E-01
17	Permian coal measures	2.60E-07	4.03E-06	1.00E-04
18	Permian coal measures	2.60E-07	3.75E-06	1.00E-04
19	Basement metasediments	3.40E-05	9.88E-05	2.00E-04

Appendix A 2

Bore details

Name	Easting (mMGA)	Northing (mMGA)	Ground elevation (mAHD)	Total depth (mbgl)	Screen from (mbgl)	Screen to (mbgl)	Comment
EAST 7	760843.3	6431461	468.5	-	-	-	
EAST 9	760819.9	6432099	454.9	-	-	-	
EAST 10	760834.4	6432411	443.6	-	-	-	
EAST 15	761221.8	6433960	441.3	-	-	-	
EAST 18	761362.2	6434750	483	-	-	-	
Mg 21	761517.6	6435884	456.7*	-	-	-	
Mg22	761547.4	6436239	460.1	-	-	-	
Mg23	761252.5	6436758	467.35	-	-	-	
Mg27	762073	6438490	516.8	-	-	-	
PB1	768187	6443408	429.2	36.5	-	-	Private bore
PB2	753917	6439385	466.1	37.51	-	-	Private bore
PB3	760895	6443799	515.9	AR	-	-	Private bore
PB4	767827	6443340	420.8	20	-	-	Private bore
PB5	763563	6442725	465.1	46.73	-	-	Private bore
PB6	753377	6447290	487.5	38.35	-	-	Private bore
PB7	747127	6446421	428.1	AR	-	-	Private bore
PB8	745138	6438804	436	~ 67	-	-	Private bore
PB10	758716	6444442	510.3	AR	-	-	Private bore
PB11	756683	6446419	465.4	24.5	-	-	Private bore
PB12	765270	6431962	381.9	28.38	9.1	21.03	Private bore
PB13	755475	6425279	456	24	-	-	Private bore
PB14	761051	6443035	508.2	17.19	-	-	Private bore
PB15	751158	6442224	429.3	26.5	-	-	Private bore
PB16	750066	6436450	450.2	65	10	18?	Private bore
PB17	748728	6436179	445.1	66	20	58	Private bore
PB18	749112	6436196	445	AR	-	-	Private bore
PB19	749718	6436017	453.9	AR	-	-	Private bore
PB21	751303	6437467	470.1	-	-	70	Private bore
PB22	750965	6443472	423.8	12.62	-	-	Private bore
PB23	751657	6443395	426.3	14.16	-	-	Private bore
PB24	754623	6444780	437.2	>30	-	-	Private bore
PB25	754112	6444373	430.6	25.73	-	-	Private bore
PB26	755002	6444829	445.1	42	-	-	Private bore
PB27	753792	6445598	435.7	AR	-	-	Private bore
PB28	754272	6444480	432.1	AR	-	-	Private bore
PB29	742070	6436332	484.4	-	-	-	Private bore
PB30	764066	6440151	490.2	-	-	-	Private bore

Name	Easting (mMGA)	Northing (mMGA)	Ground elevation (mAHD)	Total depth (mbgl)	Screen from (mbgl)	Screen to (mbgl)	Comment
PB31	760886	6443801	515.9	-	-	-	Private bore
PB32	763901	6438757	490.00				Private bore
PB33	764473	6439541	494.52				Private bore
PB34	776588	6431354	349.53				Private bore
PB35	758508	6444991	499.07				Private bore
PB36	748523	6439576	454.81				Private bore
PB37	750880	6431482	470.58				Private bore
PB38	747811.6	6439235	464.97				Private bore
PB39	751224.8	6448046	448.66				Private bore
PB40	742530	6437351	454.51				Private bore
PB41	750605	6443060	426.37				Private bore
PB42	751183	6442673	427.81				Private bore
PB43	747585	6442847	421.24				Private bore
PB44	756031	6445477	446.00				Private bore
PB45	742097	6436348	486.92				Private bore
R752	756607	6436339	549.1*	46	31	43	
R755A	761457	6437292	462.42*	91	78	90	
R855	761195	6436392	492	264	0	44	
UB1	753710	6443142	436.8	10.4	-	Open	
UB3	751580	6436677	462.9	AR	-	-	
DDH336	754303	6438225	488	197	0	42	Piezometer with multiple sensors
R933	756381	6435863	545	236	0	40	Piezometer with multiple sensors
TAL1	752396.9	6440925	465	150	0	28	Piezometer with multiple sensors
DDH293	751740	6435175	517	169	0	40	Piezometer with multiple sensors
EX03	760017	6440386	537.5	-	-	-	Exploration bore
EX06	757207.9	6439000	498.3	34	0	8.5	Exploration bore
EX09	763522.4	6438119	478.1	-	-	-	Exploration bore
R894	763091	6442209	487	261	0	90†	Piezometer with multiple sensors
R936	756011	6435376	533	218	0	130	Piezometer with multiple sensors
R988	756877	6436276	527	193	0	130	Piezometer with multiple sensors
TAL2	748873	6437875	498	138	0	50	Piezometer with multiple sensors
UW1	756754.1	6430579	436	80	0	22	Piezometer with multiple sensors
UW3	749037	6435250	474	108	0	40	Piezometer with multiple sensors
DDH266	752760	6438854	494	192	0	84	Piezometer with multiple sensors
DDH270	753643	6436046	491	173	0	76	Piezometer with multiple sensors
DDH271	754574	6433293	508	156	0	47	Piezometer with multiple sensors
UW2	755064	6430700	520	132	0	50	Piezometer with multiple sensors

Name	Easting (mMGA)	Northing (mMGA)	Ground elevation (mAHD)	Total depth (mbgl)	Screen from (mbgl)	Screen to (mbgl)	Comment
PZ01A	761186	6441552	534.3*	165	144	159	Piezometer
PZ04A	762140	6435921	440.7*	55	42	54	Piezometer
PZ06A	755106	6441412	449.7	169	161	169	Piezometer
PZ06B	755109	6441425	449.8	159	147	159	Piezometer
PZ06C	755105	6441437	449.7	71	58	71	Piezometer
PZ07A	759136	6438002	502.4	274	262	274	Piezometer
PZ07B	759122	6438005	502.1	255	240	255	Piezometer
PZ07C	759105	6438009	501.9	121	102	121	Piezometer
PZ08B	761995	6437847	481.1	265	170	265	Piezometer
PZ08C	762011	6437848	482	130	90	130	Piezometer
PZ09A	758720	6441337	541.8	330	314	330	Piezometer
PZ09B	758702	6441339	541.6	310	290	310	Piezometer
PZ09C	758683	6441343	541	165	150	165	Piezometer
PZ09D	758668	6441348	540.6	80	50	80	Piezometer
PZ10A	758812	6439393	513.8	165	150	165	Piezometer
PZ10B	758808	6439383	514.1	46	26	46	Piezometer
PZ11A	757426	6435557	476.7	175	160	175	Piezometer
PZ11B	757434	6435550	476.5	82	68	82	Piezometer
PZ12	753526	6431739	571.2*	-	-	-	Piezometer
PZ13A	749207	6440479	445.3*	-	-	-	Piezometer
PZ14	766633	6437221	453.7*	-	-	-	Piezometer
PZ14C	766637	6437208	454.2	56	32	56	Piezometer
PZ24A	763109	6434793	420.8	236	208	236	Piezometer
PZ24B	763107	6434783	420.6	74	44	74	Piezometer
PZ25A	763535	6423746	430.8	86	78	86	Piezometer
PZ25B	763533	6423732	430.7	78	60	78	Piezometer
PZ26A	759629	6448988	448.3	265	248^	265*	Piezometer
PZ26B	759621	6448966	448.2	243	225*	240*	Piezometer
PZ26C	759613	6448943	447.9	130	60*	90*	Piezometer
PZ26D	759605	6448921	447.6	22	16*	22*	Piezometer
PZ28A	757722	6445002	475.4	130	108	130	Piezometer
PZ28B	757712	6445005	475.2	44	38	44	Piezometer
PZ29	763673.2	6433747	443.6	243	0	18†	Piezometer
GW000919	771334.6	6447439	497.1	67.9	-	-	Public bore
GW013142	771991.6	6455345	592.0	108.2	-	-	Public bore
GW047195	762681	6434565	434.2	107.3	-	-	Public bore
GW047495	762805.8	6435332	436.9	149.4	-	-	Public bore

Name	Easting (mMGA)	Northing (mMGA)	Ground elevation (mAHD)	Total depth (mbgl)	Screen from (mbgl)	Screen to (mbgl)	Comment
GW049542	758104.9	6425091	421.1	31.1	-	-	Public bore
GW058876	775156.9	6456439	467.2	47.2	-	-	Public bore
GW059035	761036.9	6429767	402.3	79.8	-	-	Public bore
GW079745	763187.9	6435867	428.0	34.3	-	-	Public bore
GW080107	776183.5	6436994	375.9	7.5	-	-	Public bore
GW080135	767004	6440831	416.1	20	-	-	Public bore
GW080404	772446.9	6417465	379.5	3.5	-	-	Public bore
GW080408	769663.9	6421162	378.8	4.5	-	-	Public bore
GW080411	770634.9	6419801	373.1	5	-	-	Public bore
GW273094	759655.1	6419510	448.1	23.5	-	-	Public bore
GW273095	759191.1	6421311	439.7	17.5	-	-	Public bore
GW273096	759303	6417393	474.1	17.5	-	-	Public bore
GW273098	760402.1	6416289	490.0	23.5	-	-	Public bore
DDH598	754142	6440354	446.3	152.0	-	-	Piezometer with multiple sensors
MCMB01A	754398	6439488	455.1	6.37	3.37	6.37	Piezometer
MCMB01B	754408	6439483	455.1	30.45	24.45	30.45	Piezometer
MCMB03A	754217	6441102	444.2	14	8	14	Piezometer
MCMB03B	754226	6441098	444.2	30	24	30	Piezometer
MCMB04A	753969	6443255	433.0	9.7	6.7	9.65	Piezometer
MCMB04B	753970	6443243	433.0	24	14.3	17.3	Piezometer
GW006299	801168	6432629	357.1	-	-	-	Piezometer
GW007162	792053	6458645	531.4	-	-	-	Piezometer
GW007163	792051	6458583	534.2	-	-	-	Piezometer
GW007739	792991	6449213	405.5	-	-	-	Piezometer
GW007740	793805	6447922	348.8	-	-	-	Piezometer
GW012325	775163	6463861	623.7	-	-	-	Piezometer
GW012344	771301	6458014	505.4	-	-	-	Piezometer
GW013392	772093	6460151	500.6	-	-	-	Piezometer
GW018107	769458	6459882	498.1	-	-	-	Piezometer
GW030977	775217	6473725	728.5	-	-	-	Piezometer
GW031287	783746	6469978	683.4	-	-	-	Piezometer
GW034346	788819	6453957	474.3	-	-	-	Piezometer
GW047378	781381	6454612	382.7	-	-	-	Piezometer
GW049400	794597	6444665	316.3	-	-	-	Piezometer
GW052134	754367	6476512	657.8	-	-	-	Piezometer
GW052313	792212	6466071	530.6	-	-	-	Piezometer
GW057298	788557	6445639	400.9	-	-	-	Piezometer

Name	Easting (mMGA)	Northing (mMGA)	Ground elevation (mAHD)	Total depth (mbgl)	Screen from (mbgl)	Screen to (mbgl)	Comment
GW059385	756541	6476119	528.2	-	-	-	Piezometer
GW061317	783732	6428297	291.4	-	-	-	Piezometer
GW062593	747535	6480224	529.1	-	-	-	Piezometer
GW063800	787970	6461910	445	-	-	-	Piezometer
GW067273	794373	6429779	304.9	-	-	-	Piezometer
GW080923	783976	6453414	516.6	-	-	-	Piezometer
GW080932	795762	6444701	370.7	-	-	-	Piezometer
GW080933	794821	6445006	333.5	-	-	-	Piezometer
GW080934	786355	6438520	385.1	-	-	-	Piezometer
GW080936	784193	6453618	500.2	-	-	-	Piezometer
GW080937	785113	6459242	423.2	-	-	-	Piezometer
GW080941	785926	6418080	245.5	-	-	-	Piezometer

Notes: Coordinates in MGA94 Zone 55.

* Ground elevations are approximate only and need to be surveyed.

† Monitoring point not monitored or erroneous (i.e. dry or faulty VWP sensor).

AR – access restrictions.

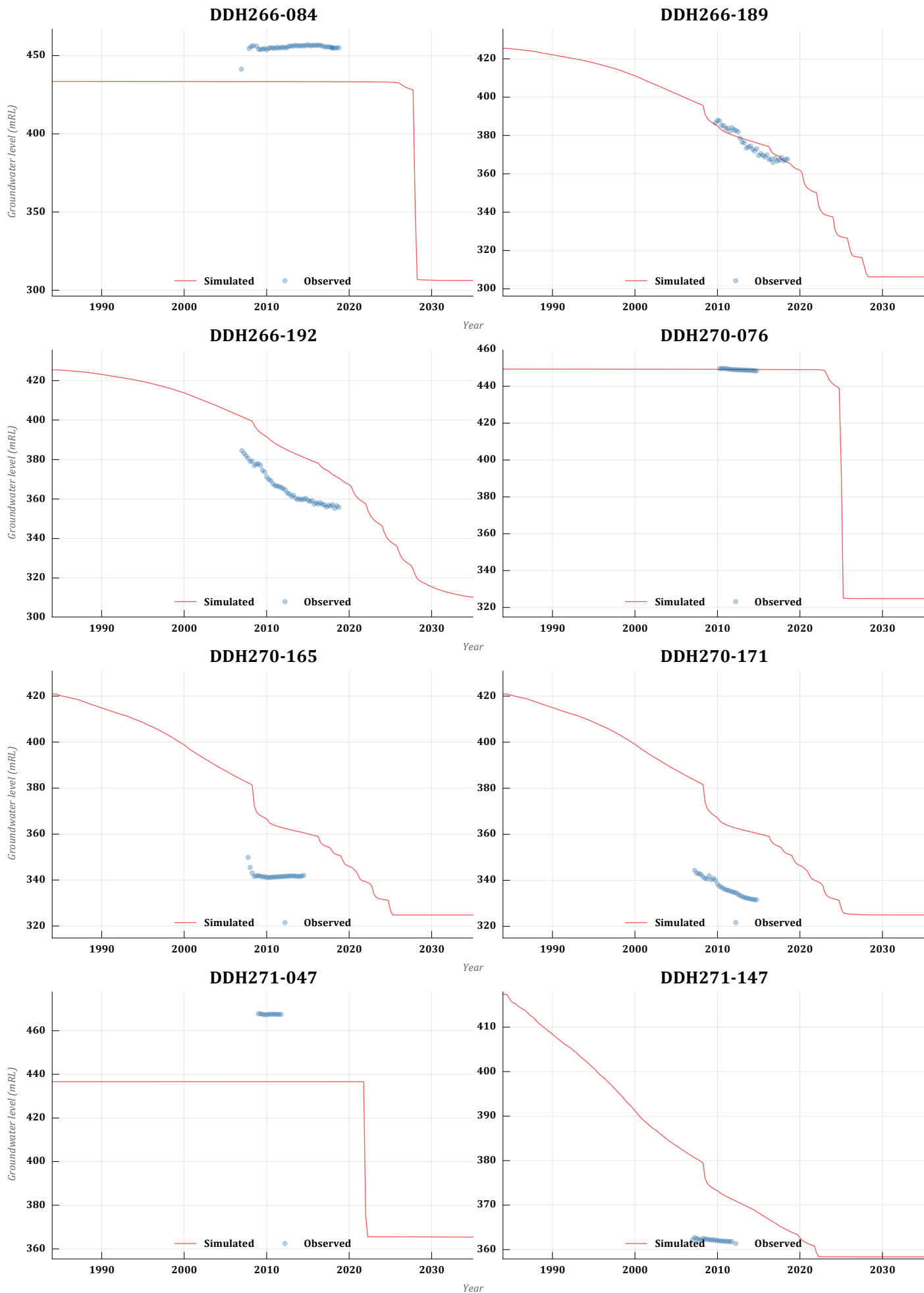
SS – sandstone.

CM – coal measures.

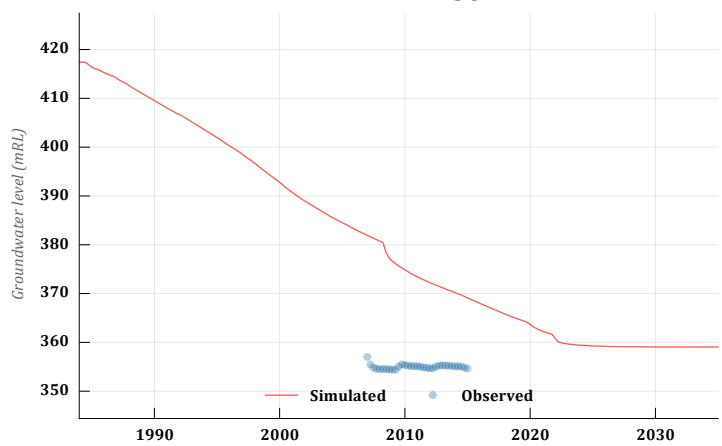
? – screened strata estimated based on bore depth, mapped geology and groundwater model layers.

Appendix A 3

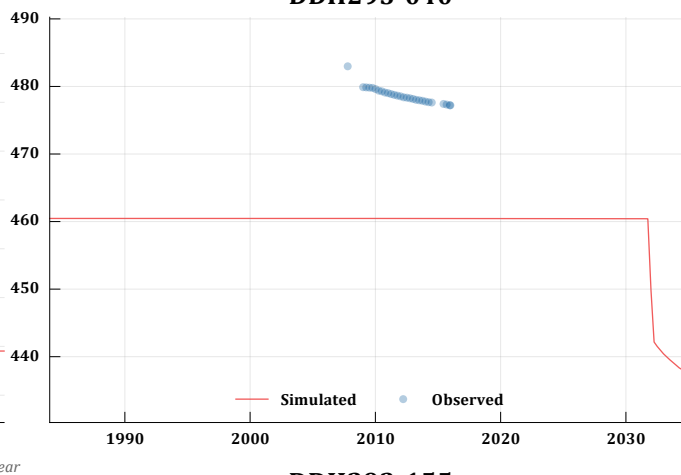
Calibration hydrographs



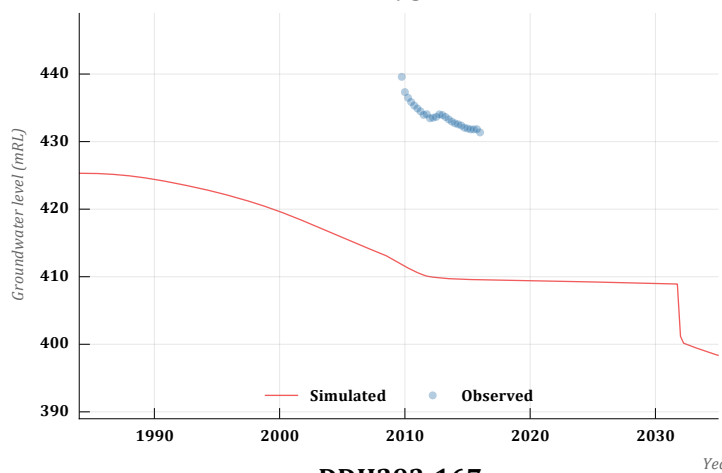
DDH271-156



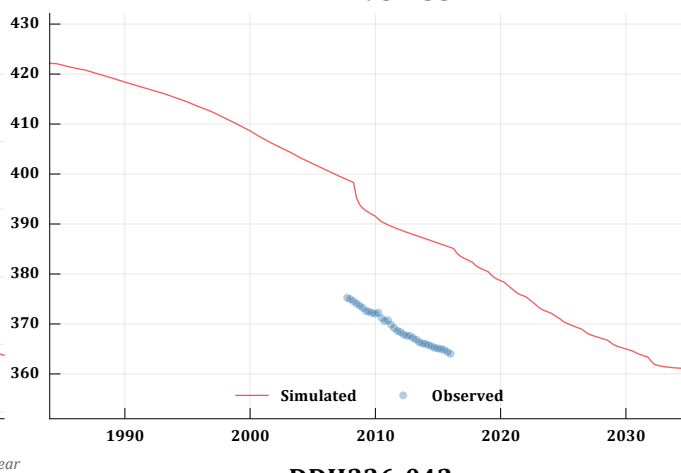
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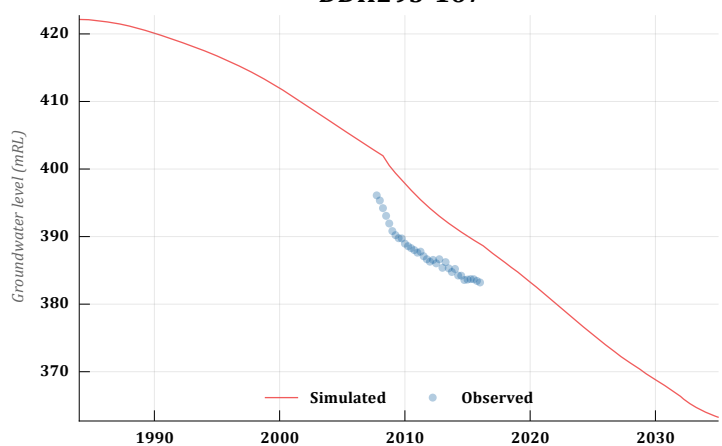
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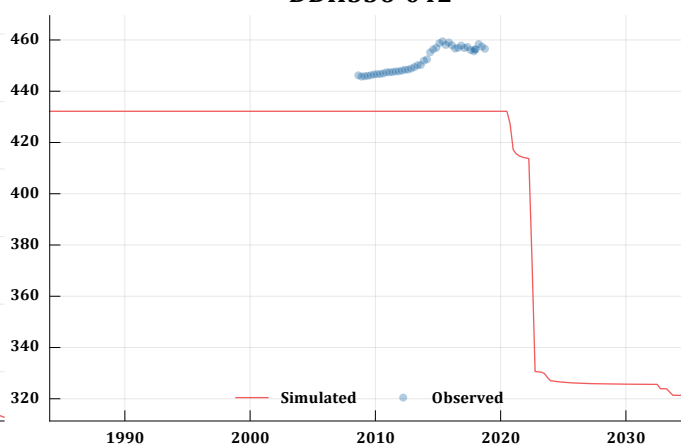
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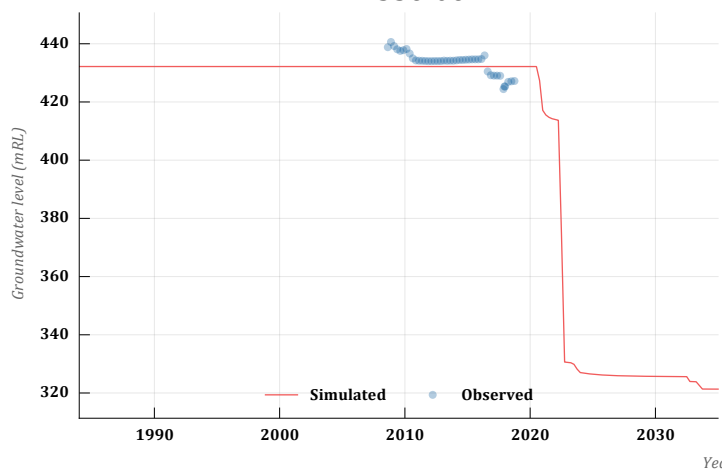
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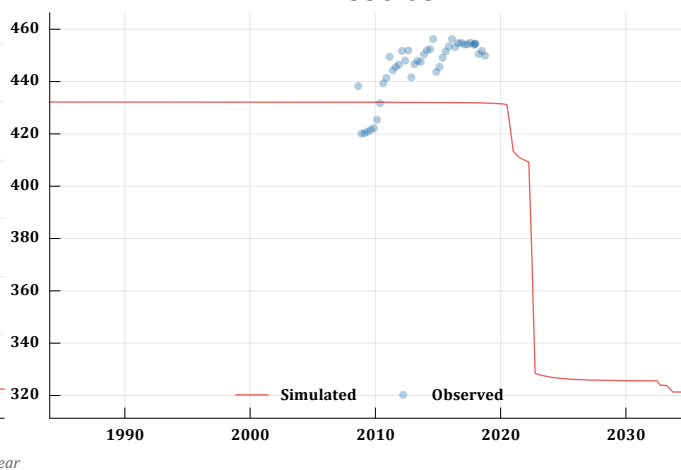
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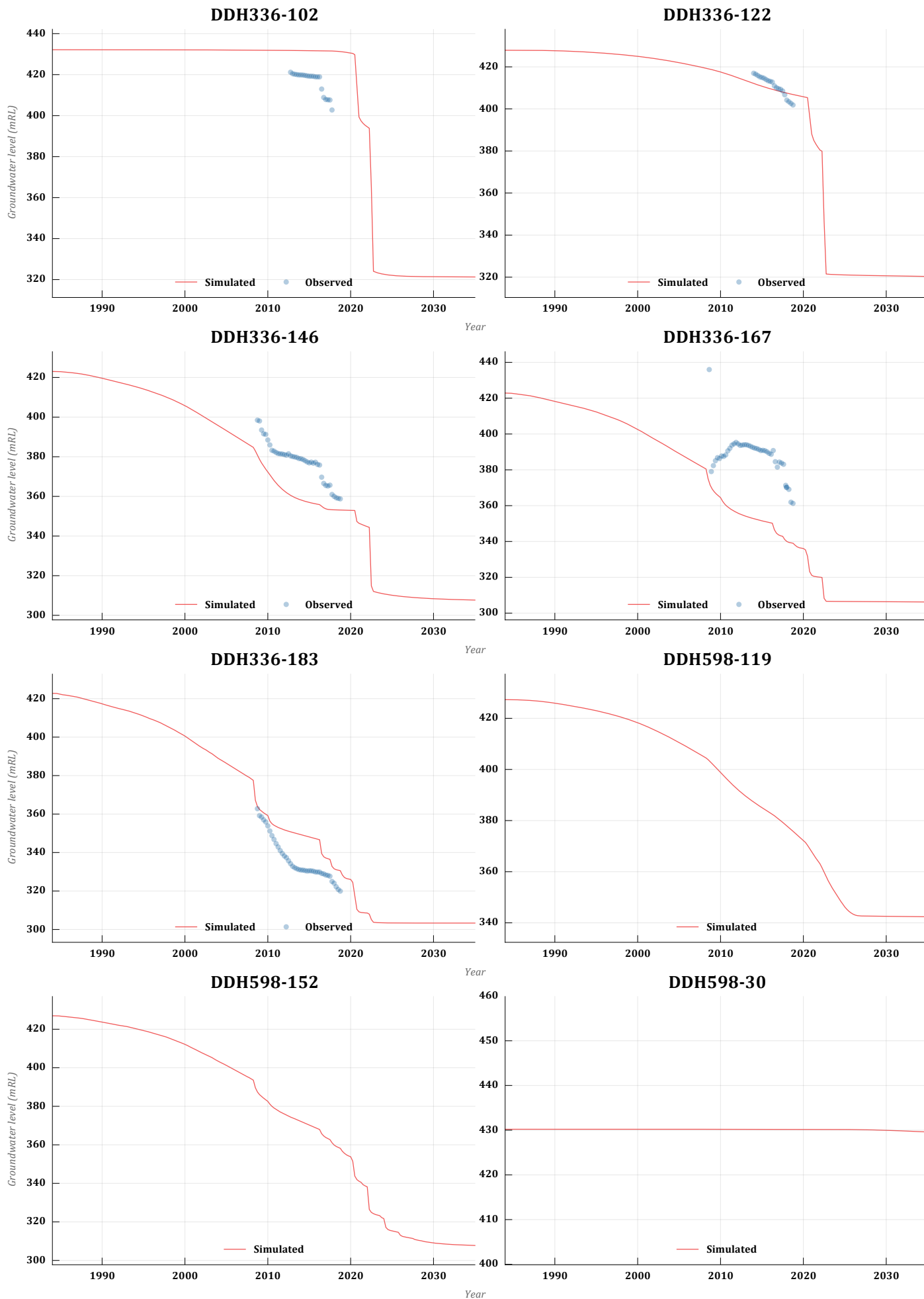


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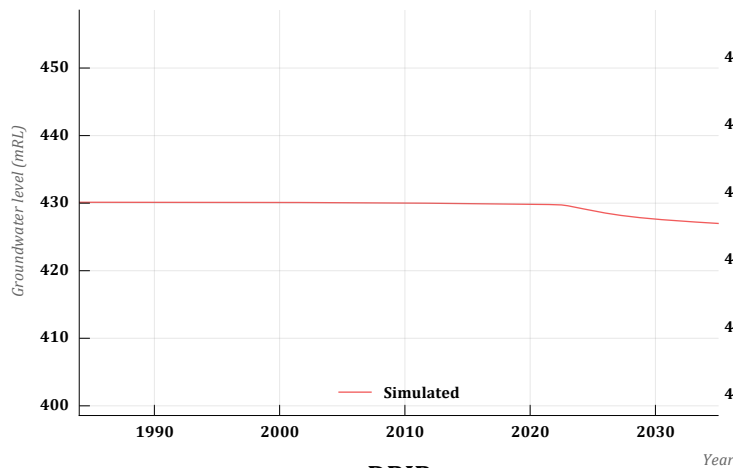


DDH336-082

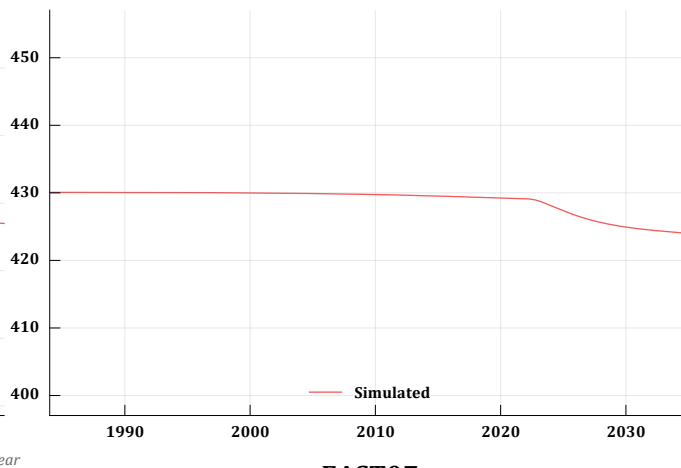




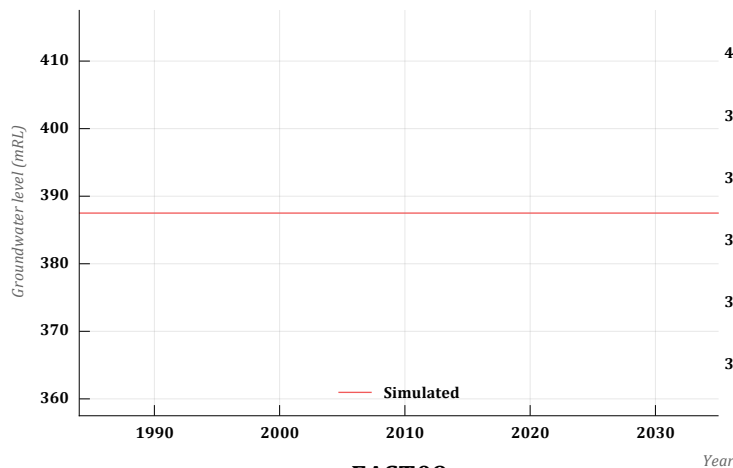
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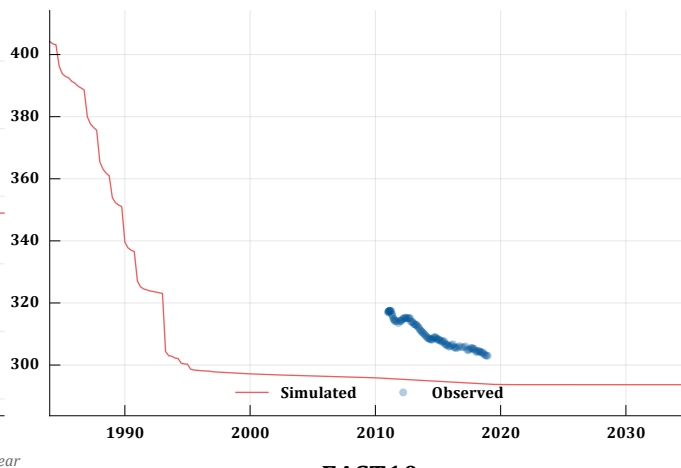
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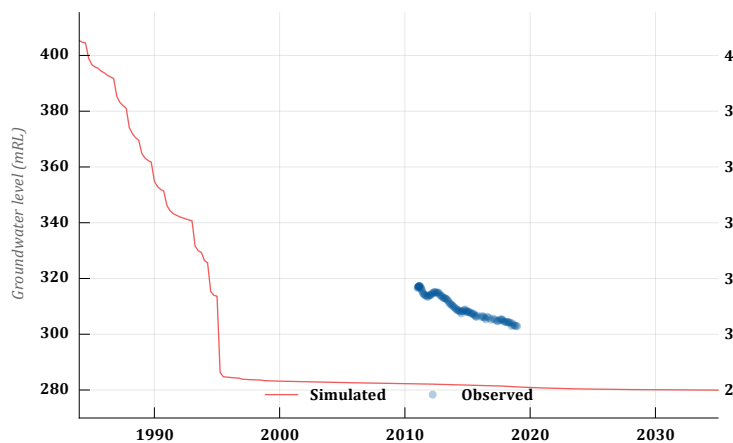
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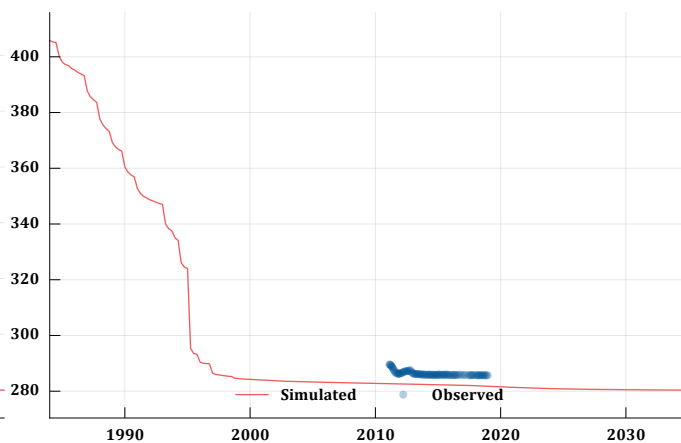
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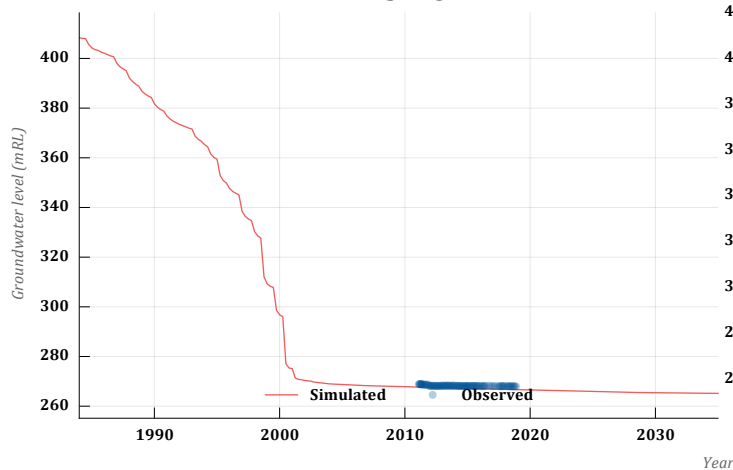
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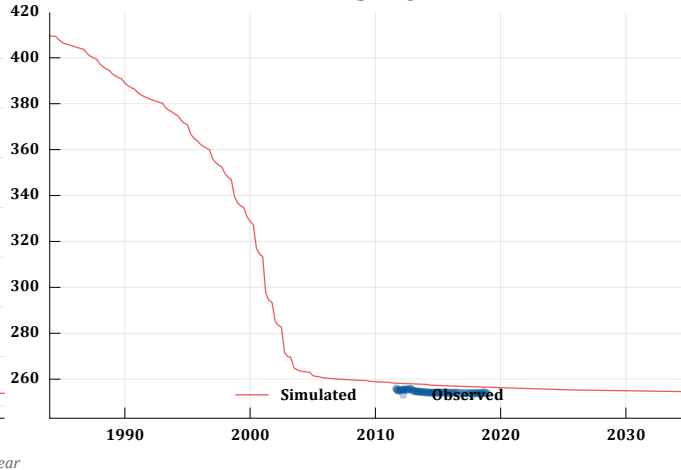
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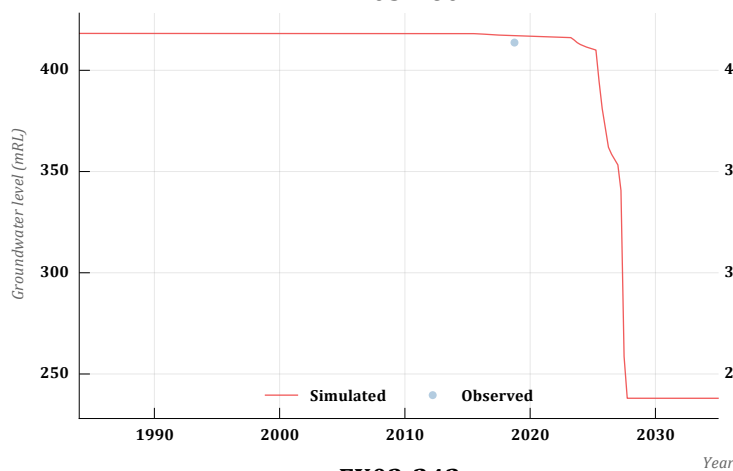
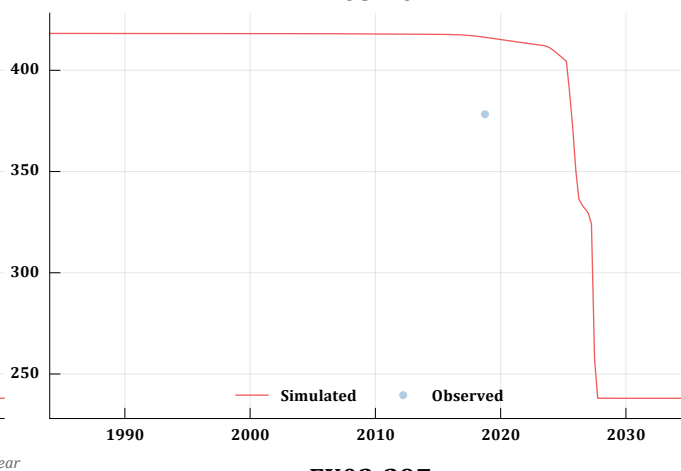
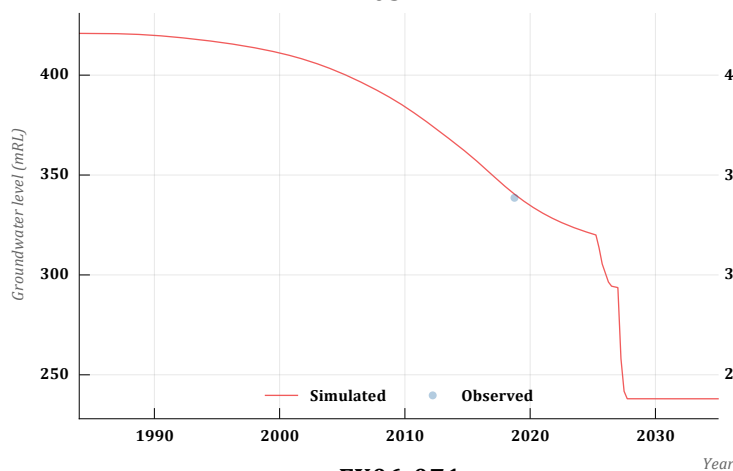
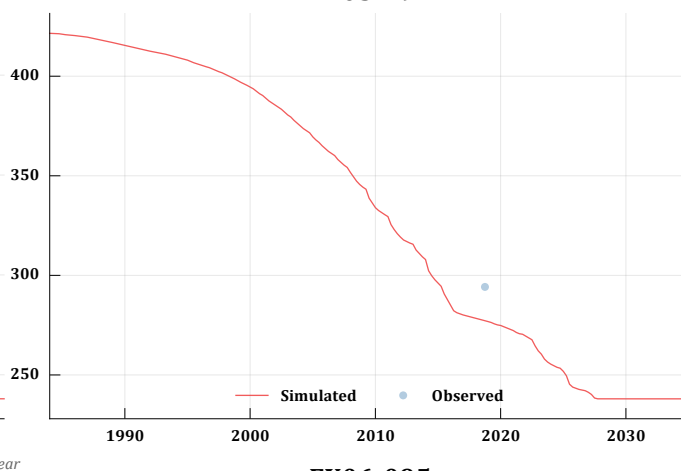
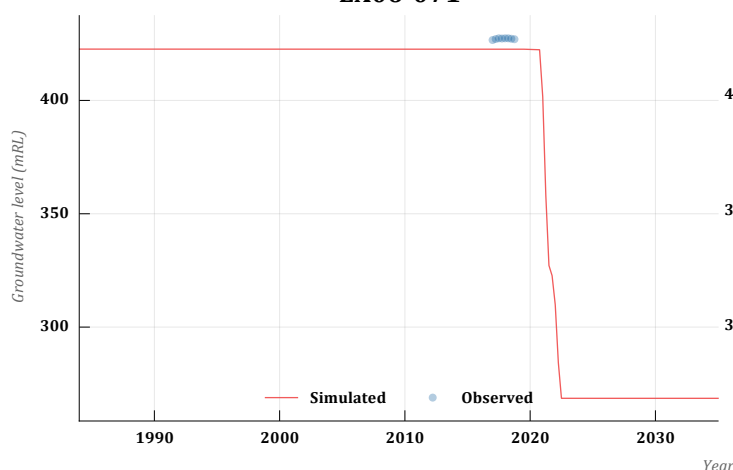
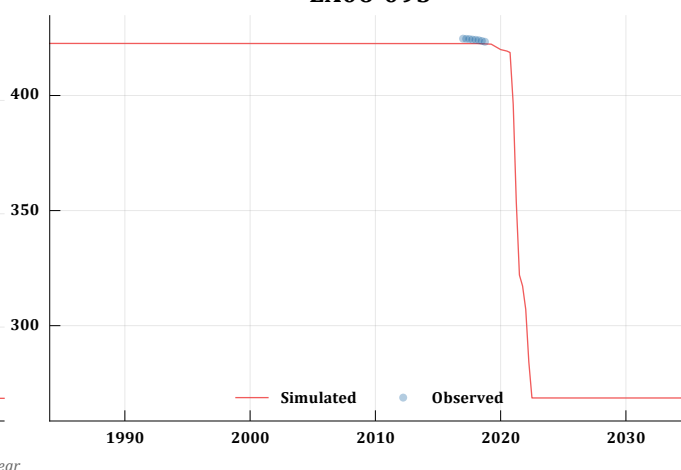
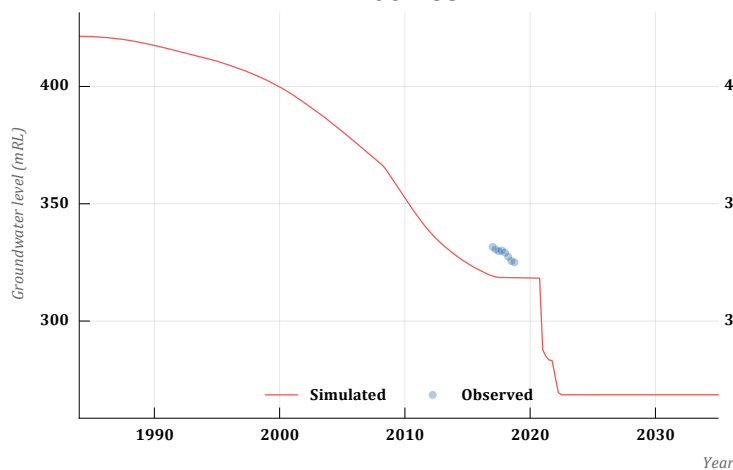
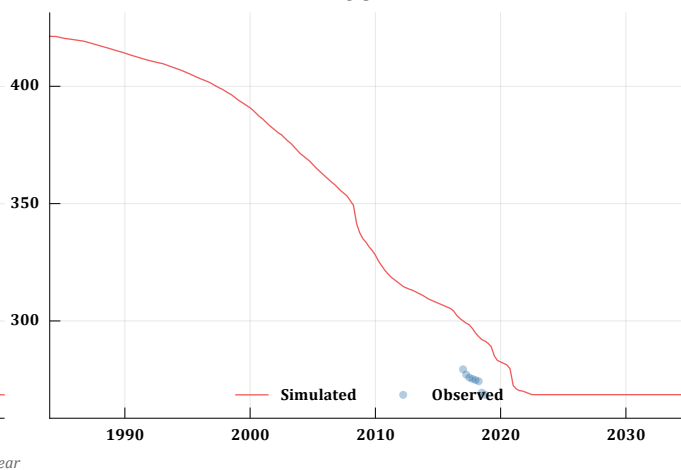


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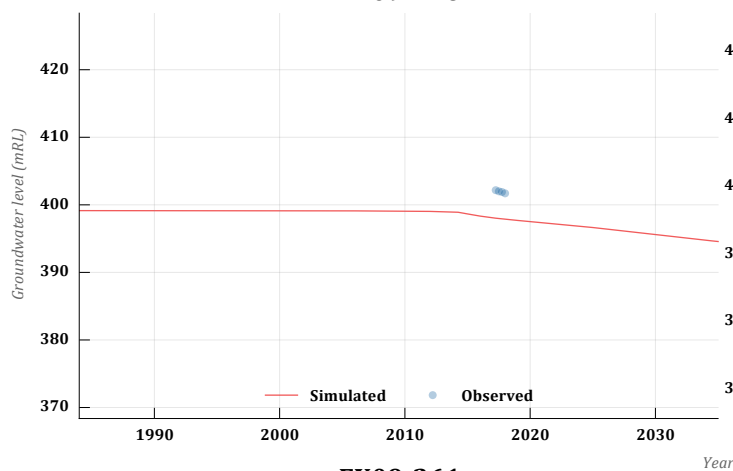


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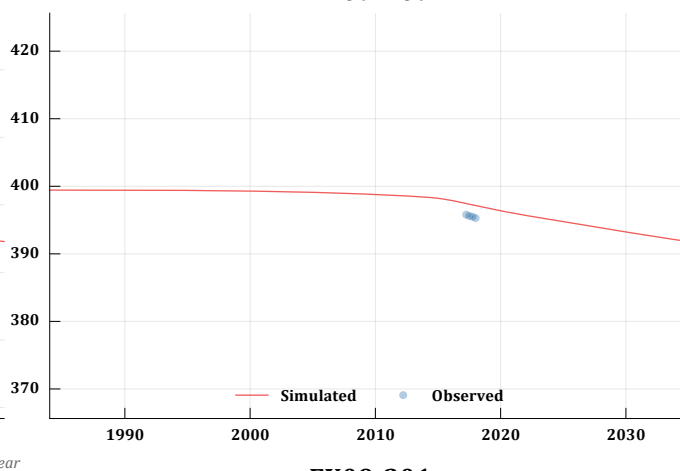


EX03-160**EX03-201****EX03-242****EX03-297****EX06-071****EX06-095****EX06-185****EX06-227**

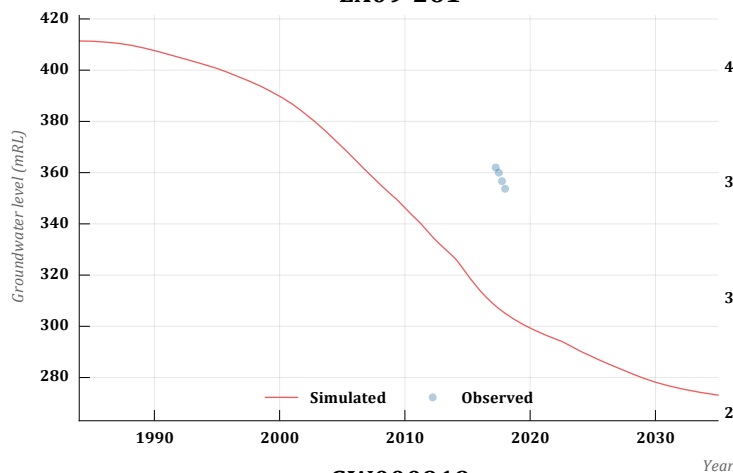
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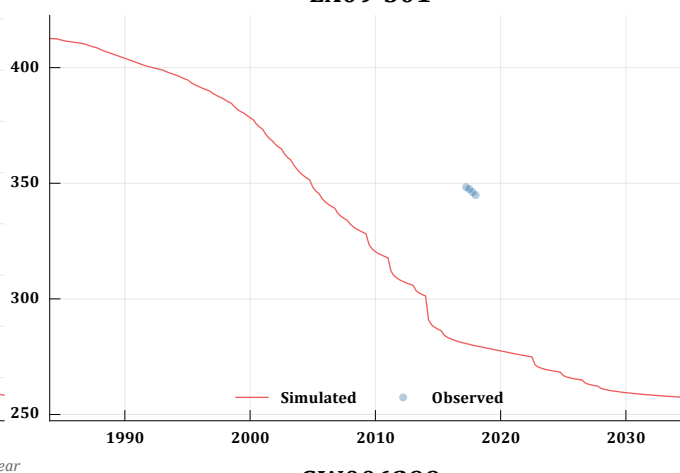
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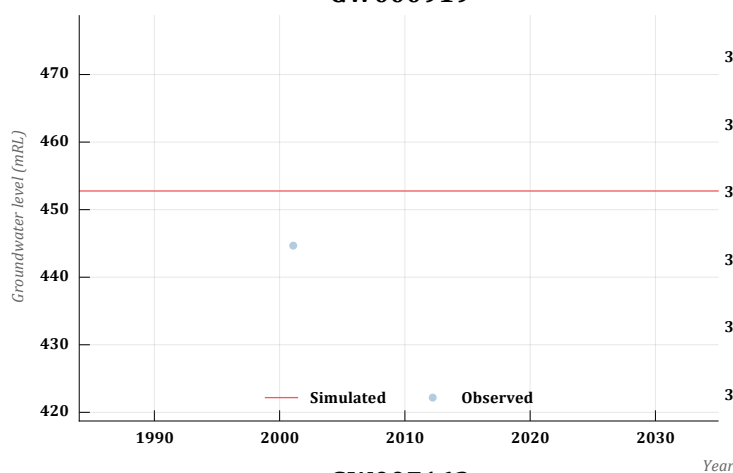
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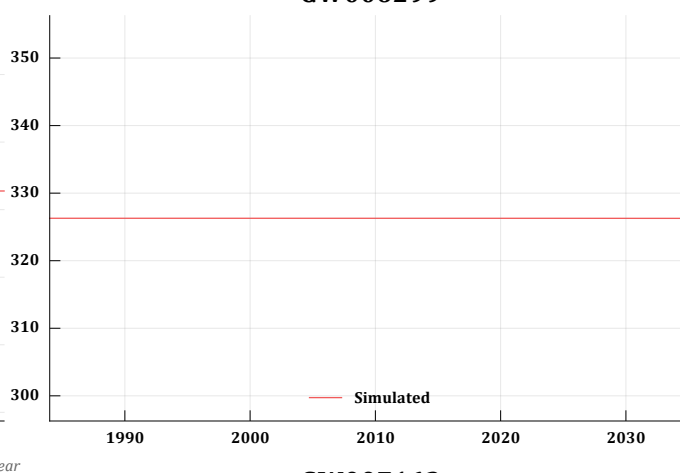
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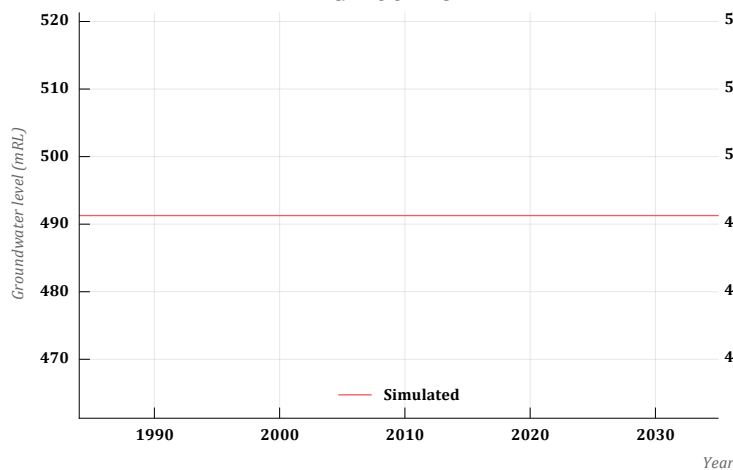
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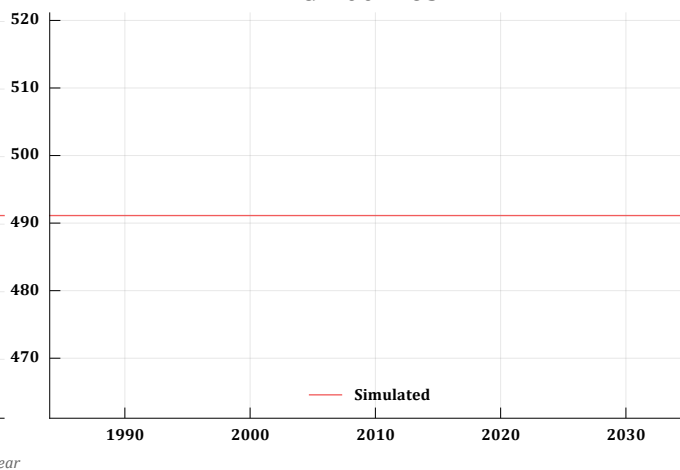
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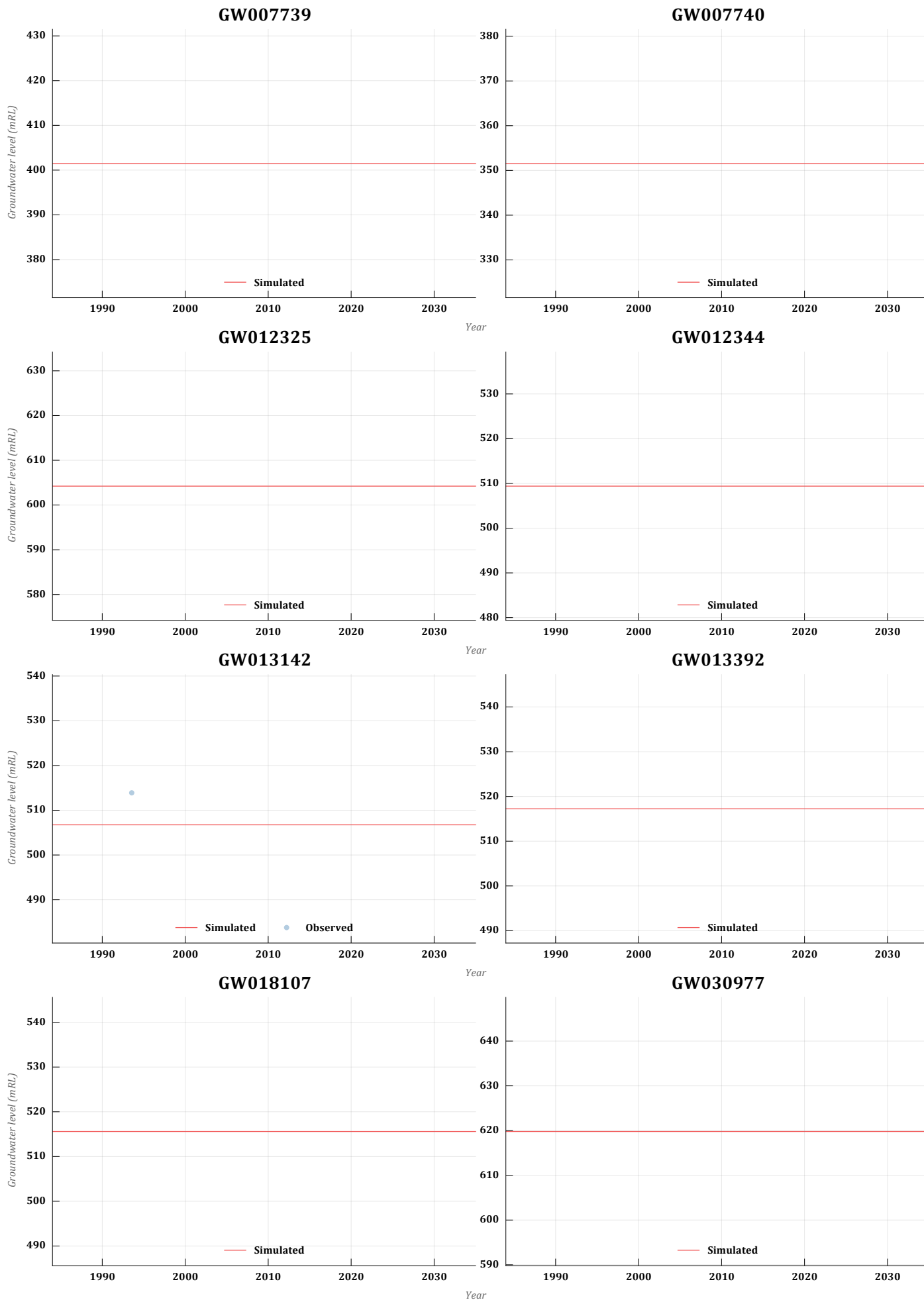


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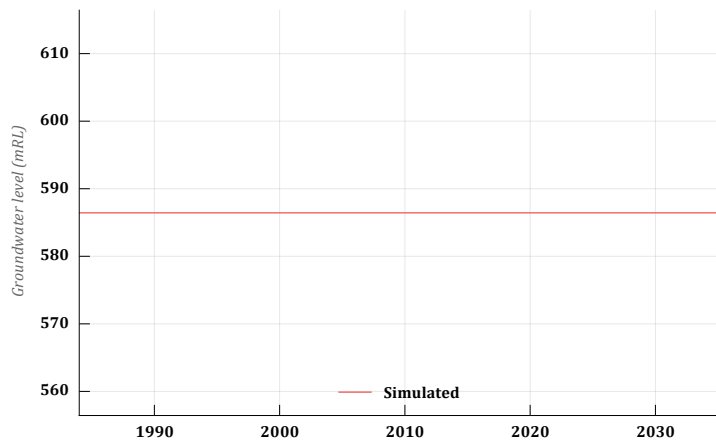


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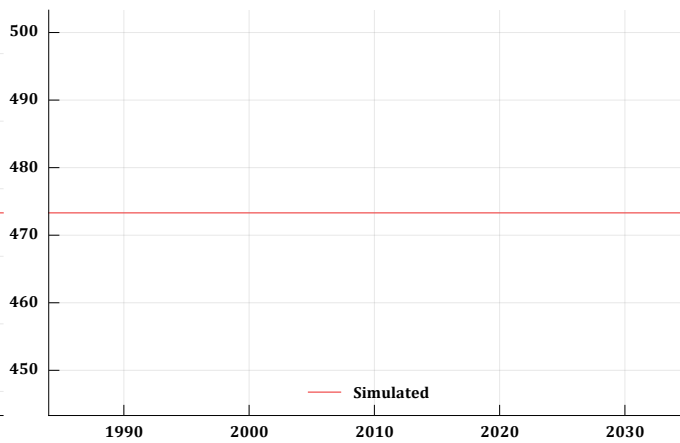




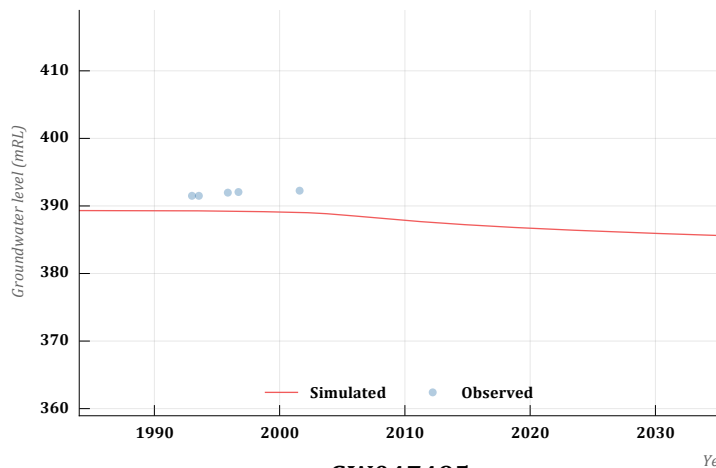
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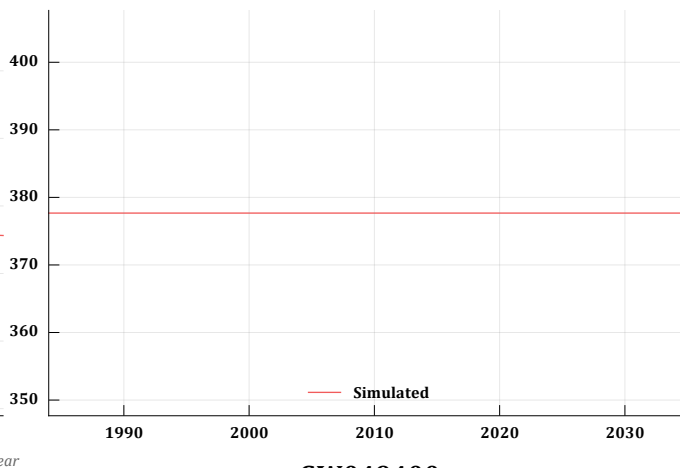
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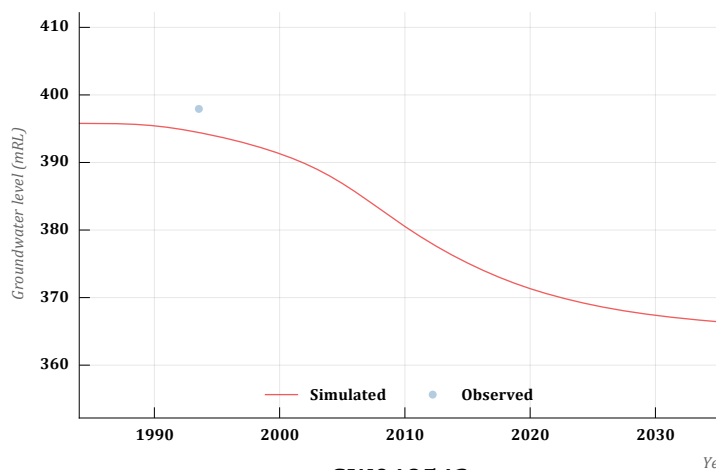
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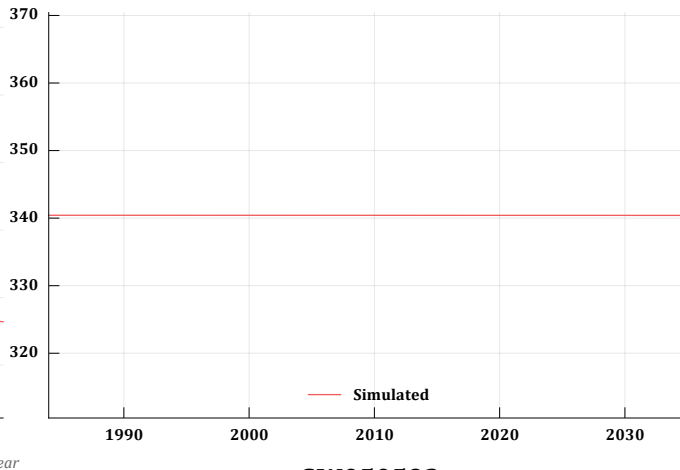
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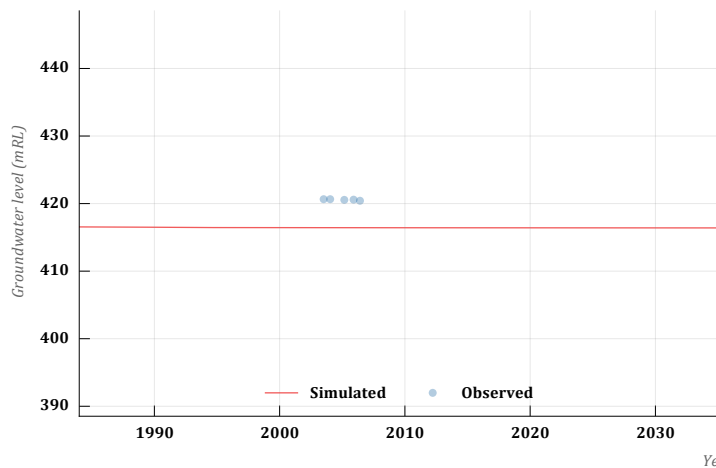
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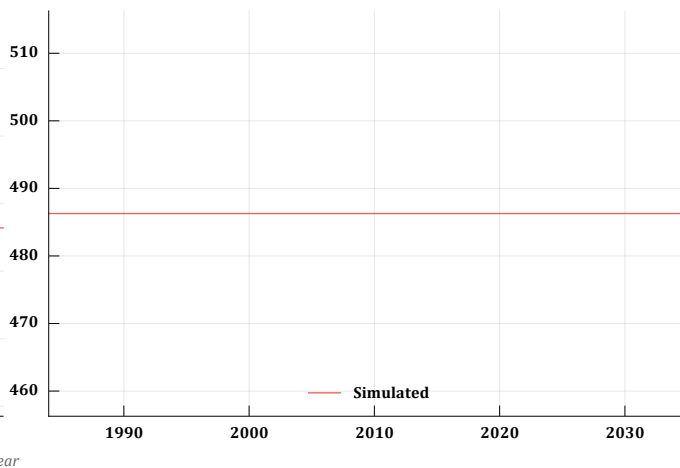
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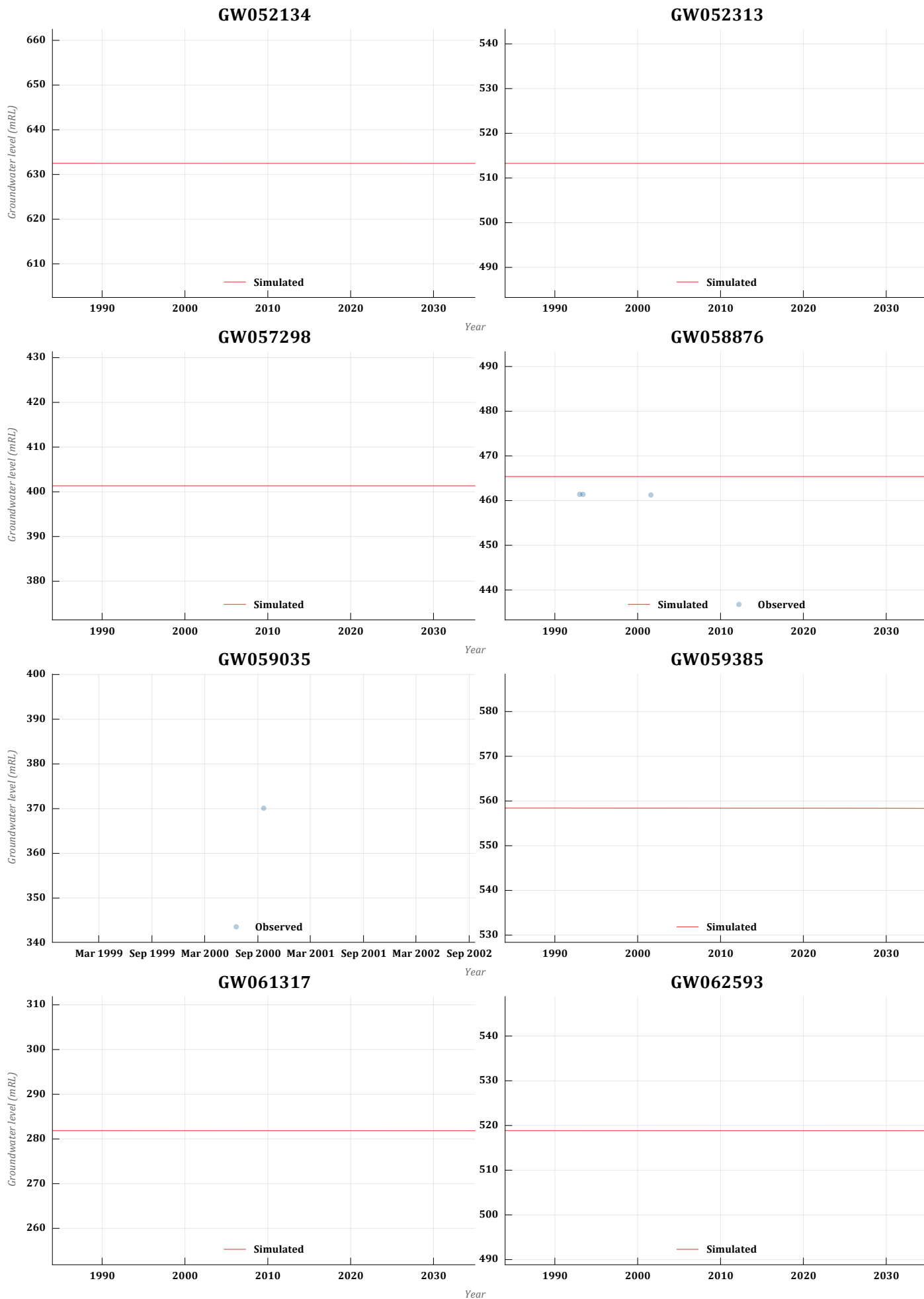


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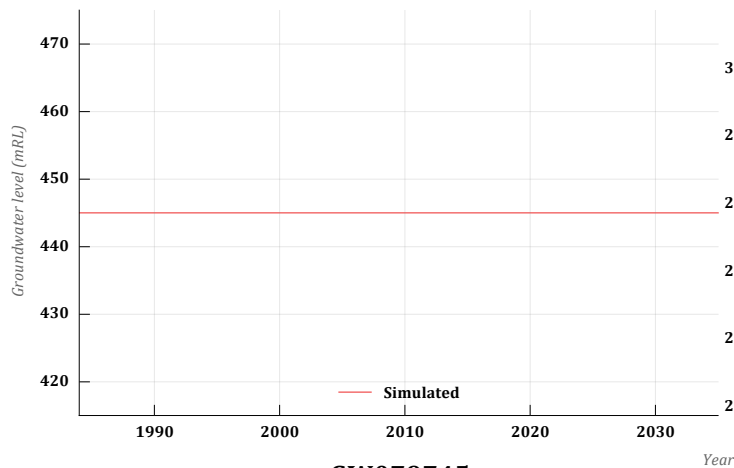


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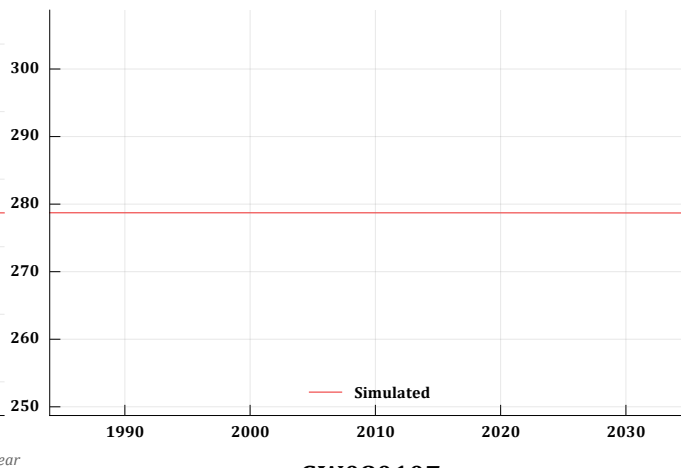




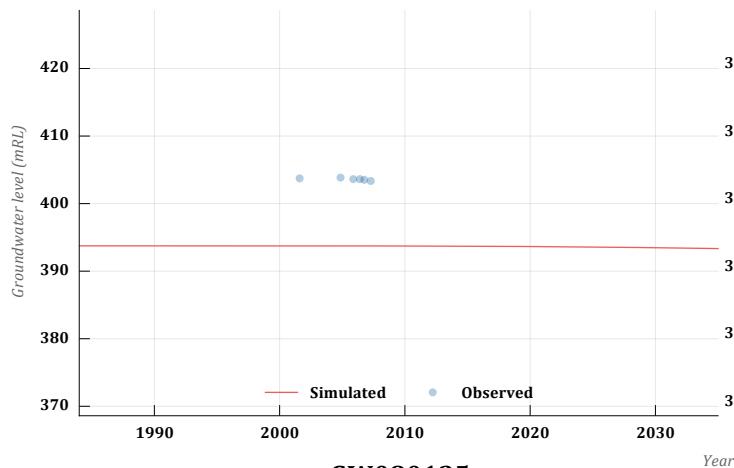
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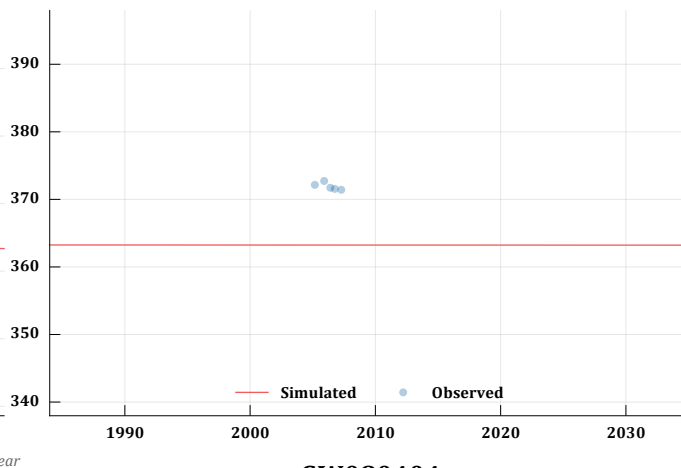
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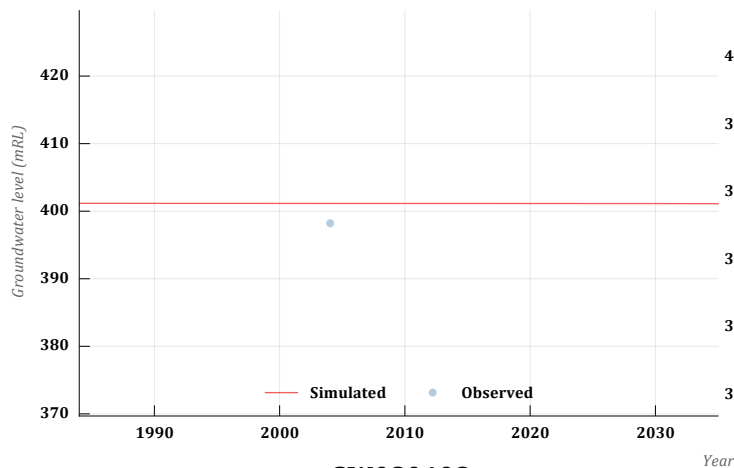
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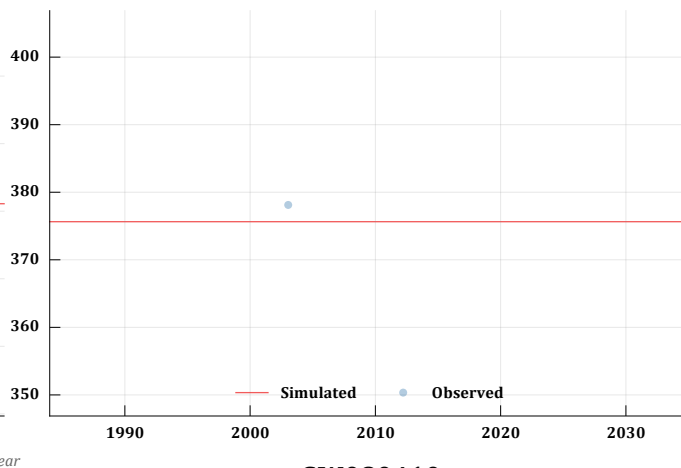
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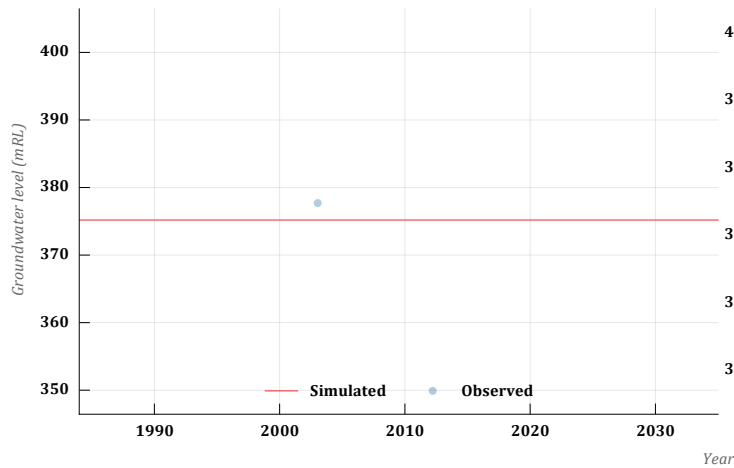
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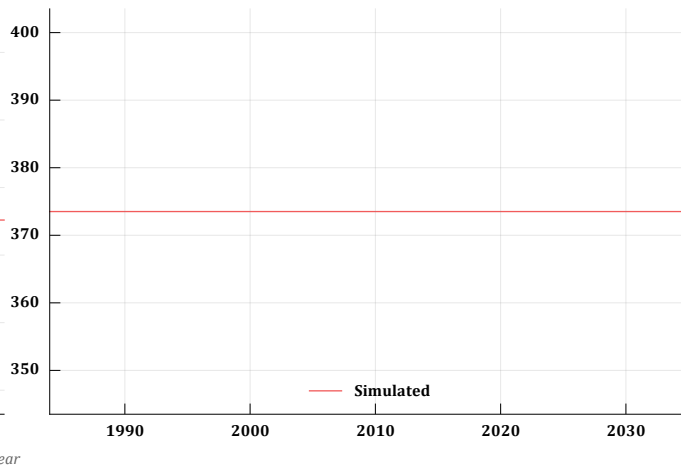
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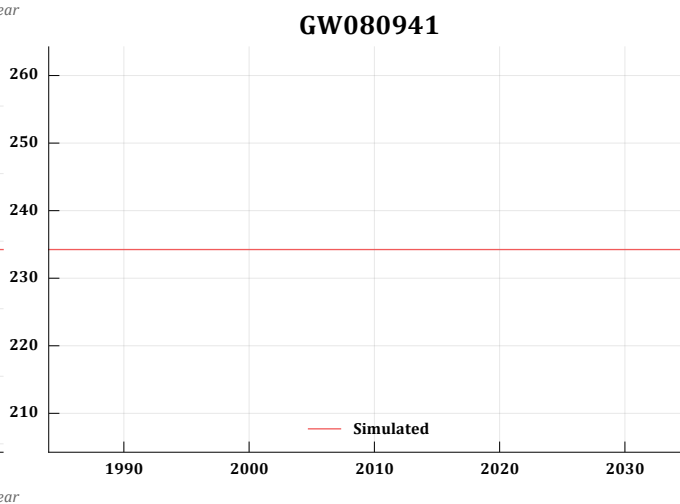
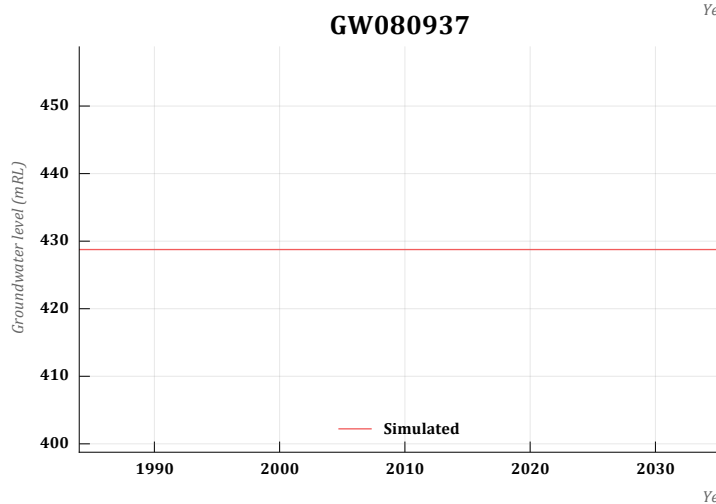
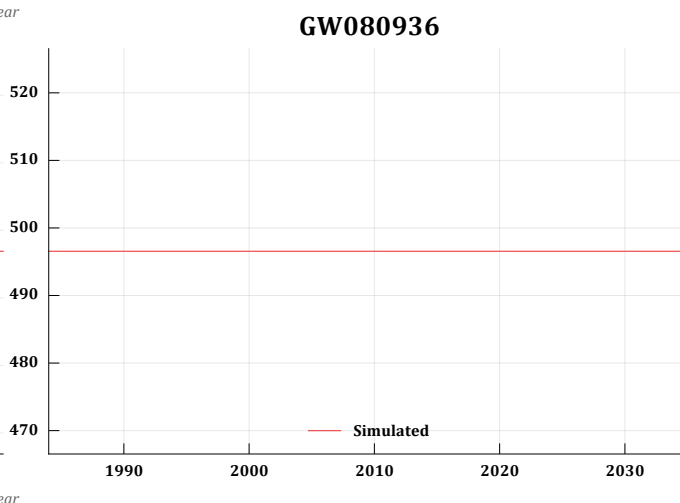
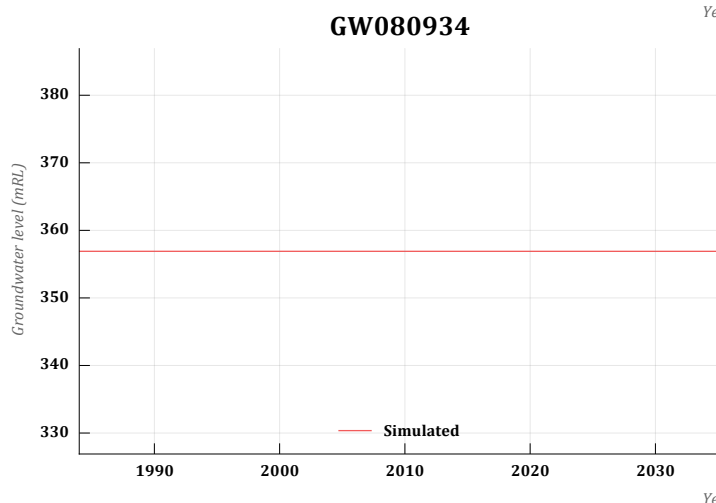
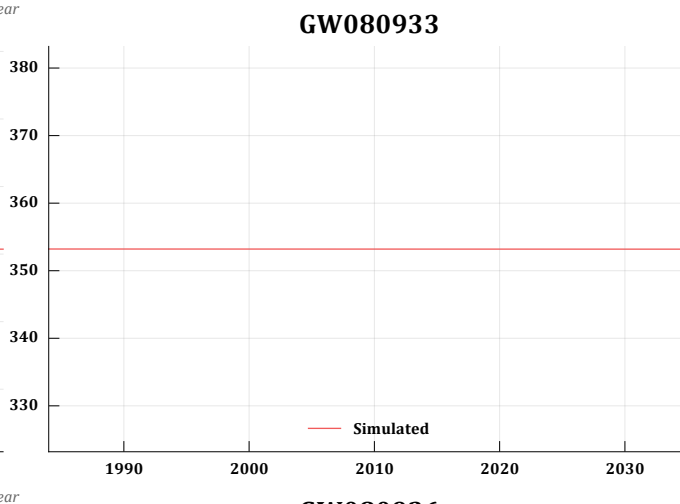
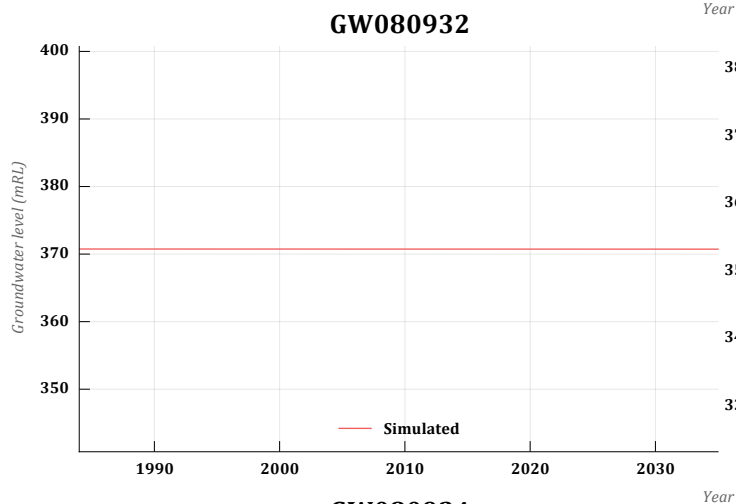
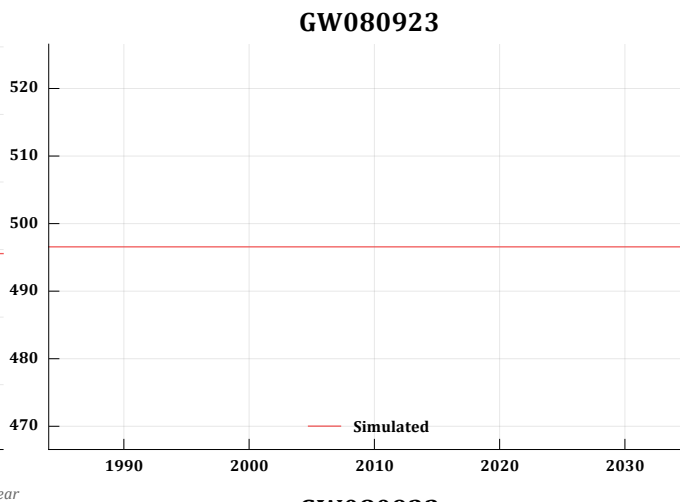
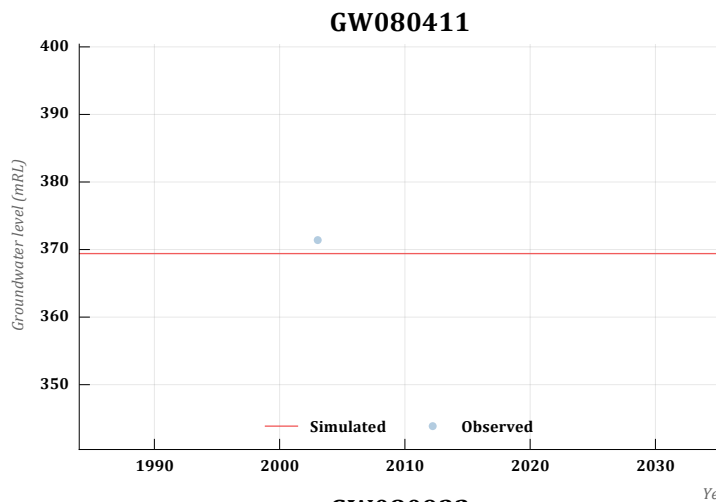


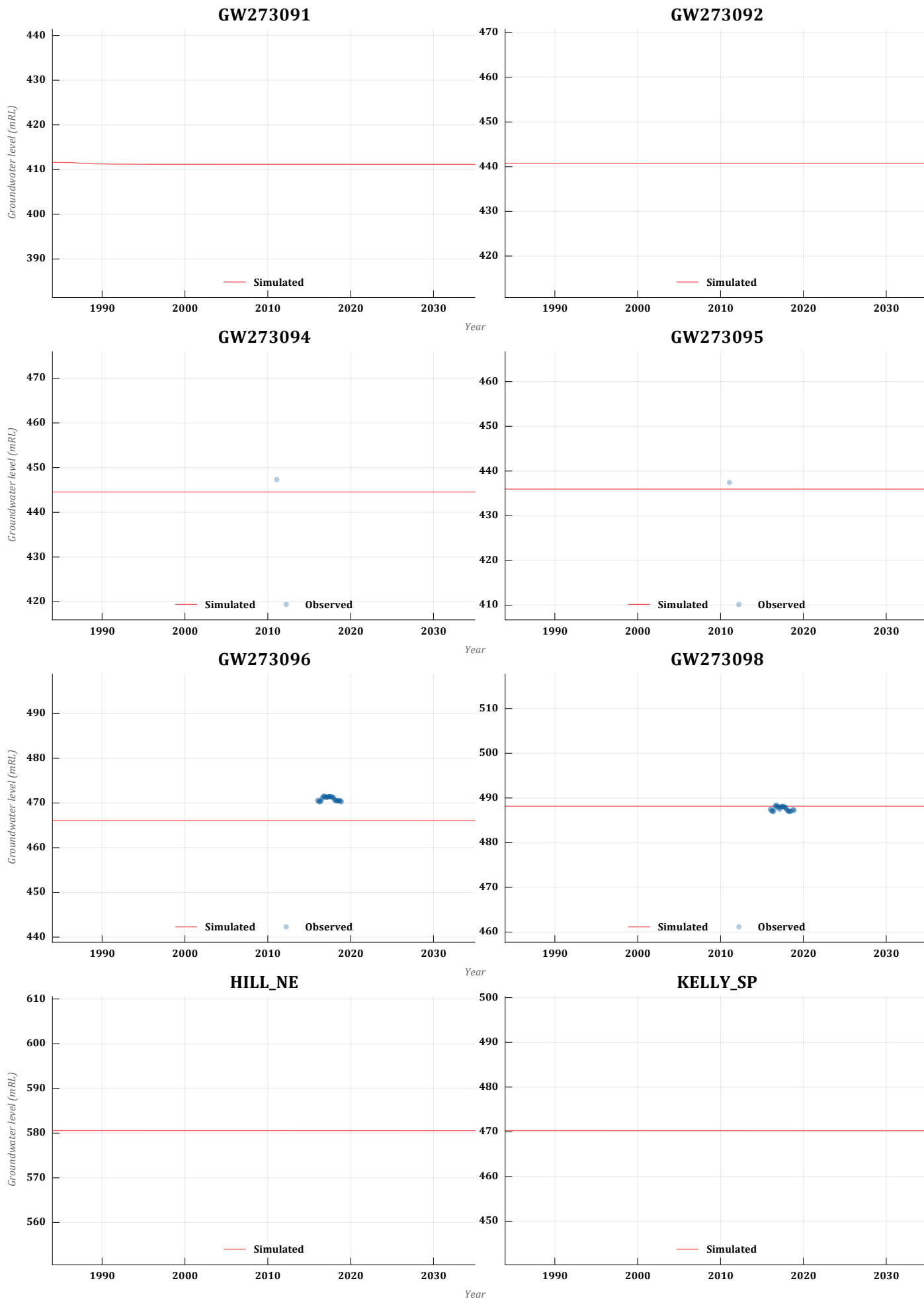
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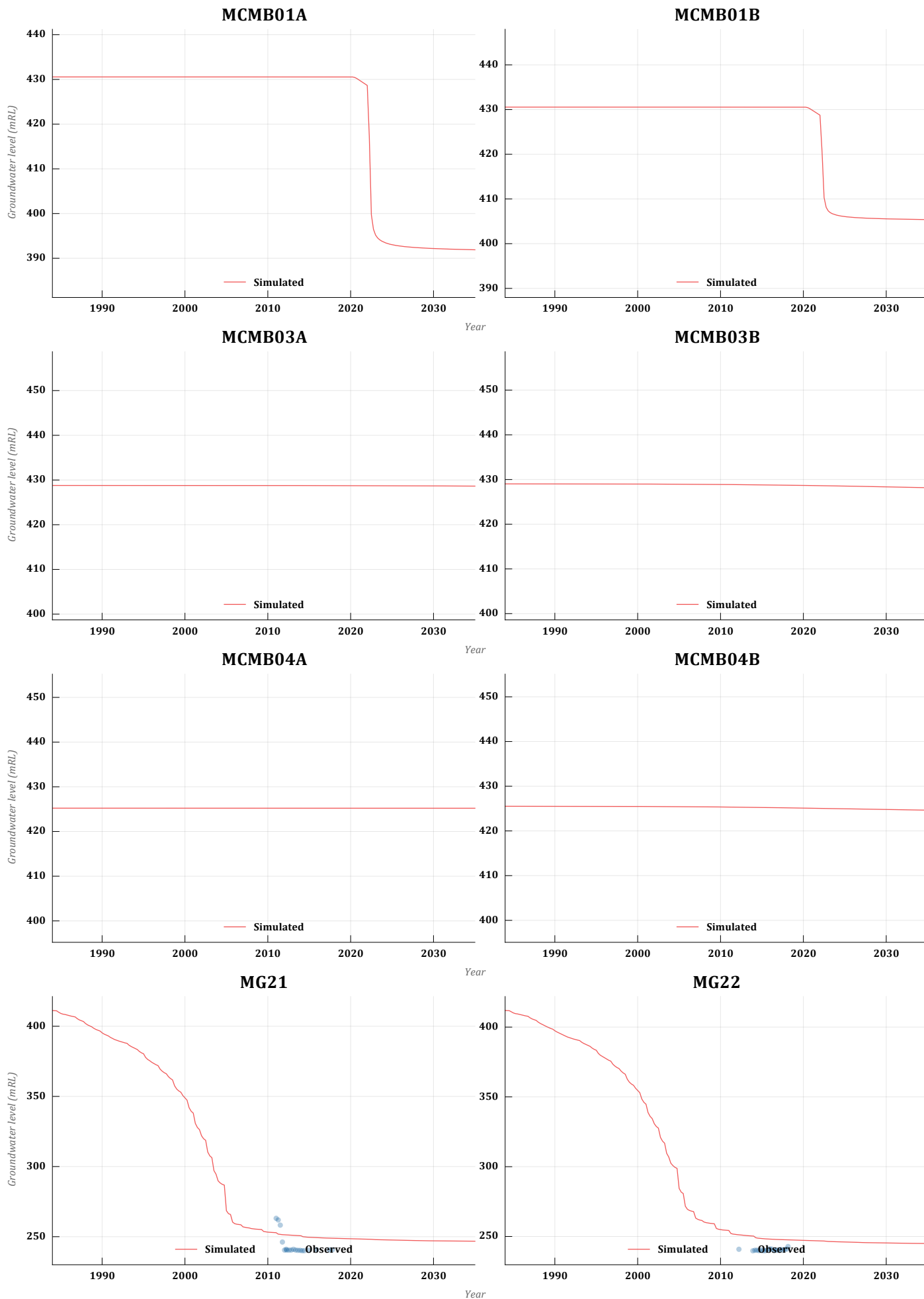


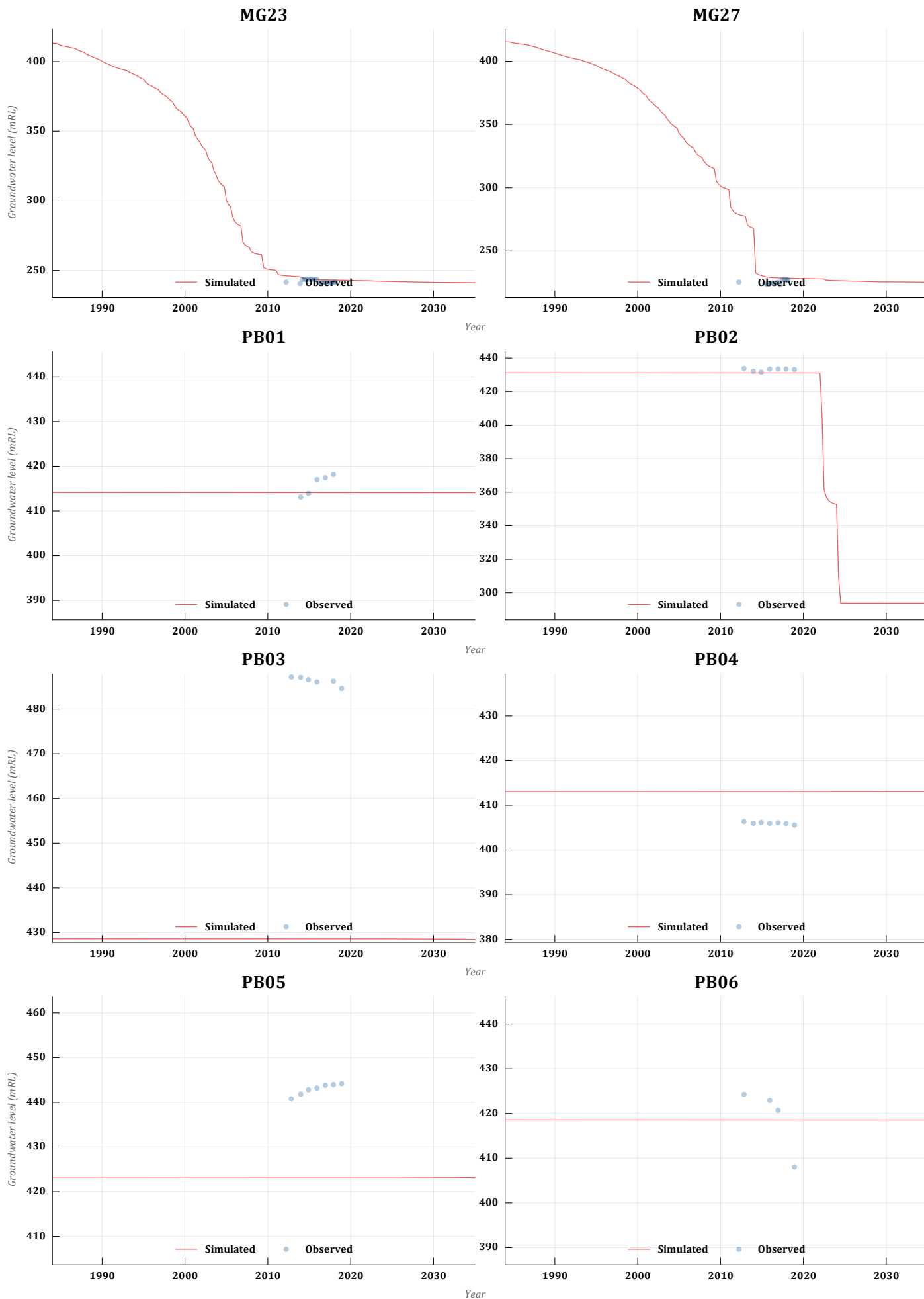
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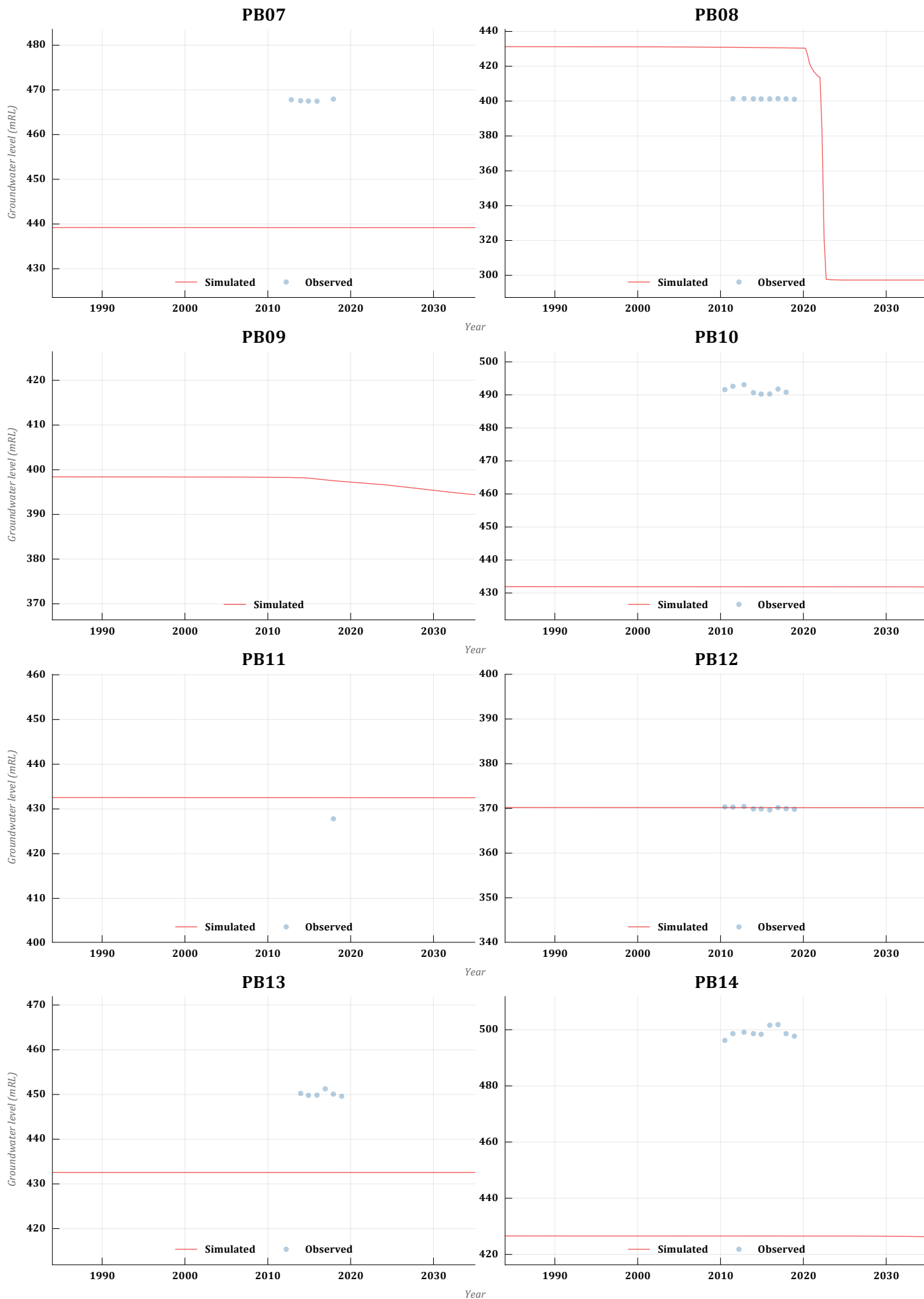


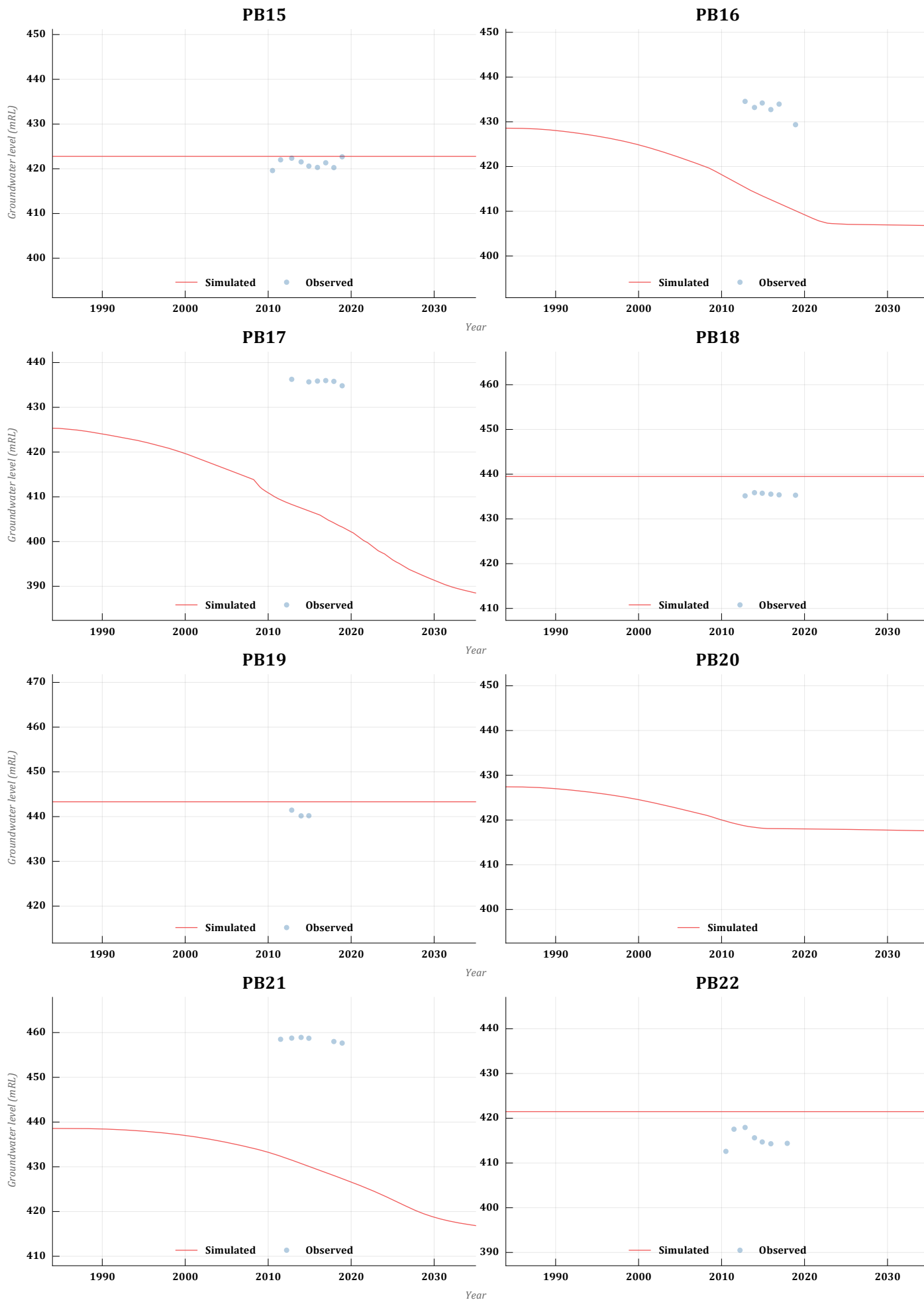


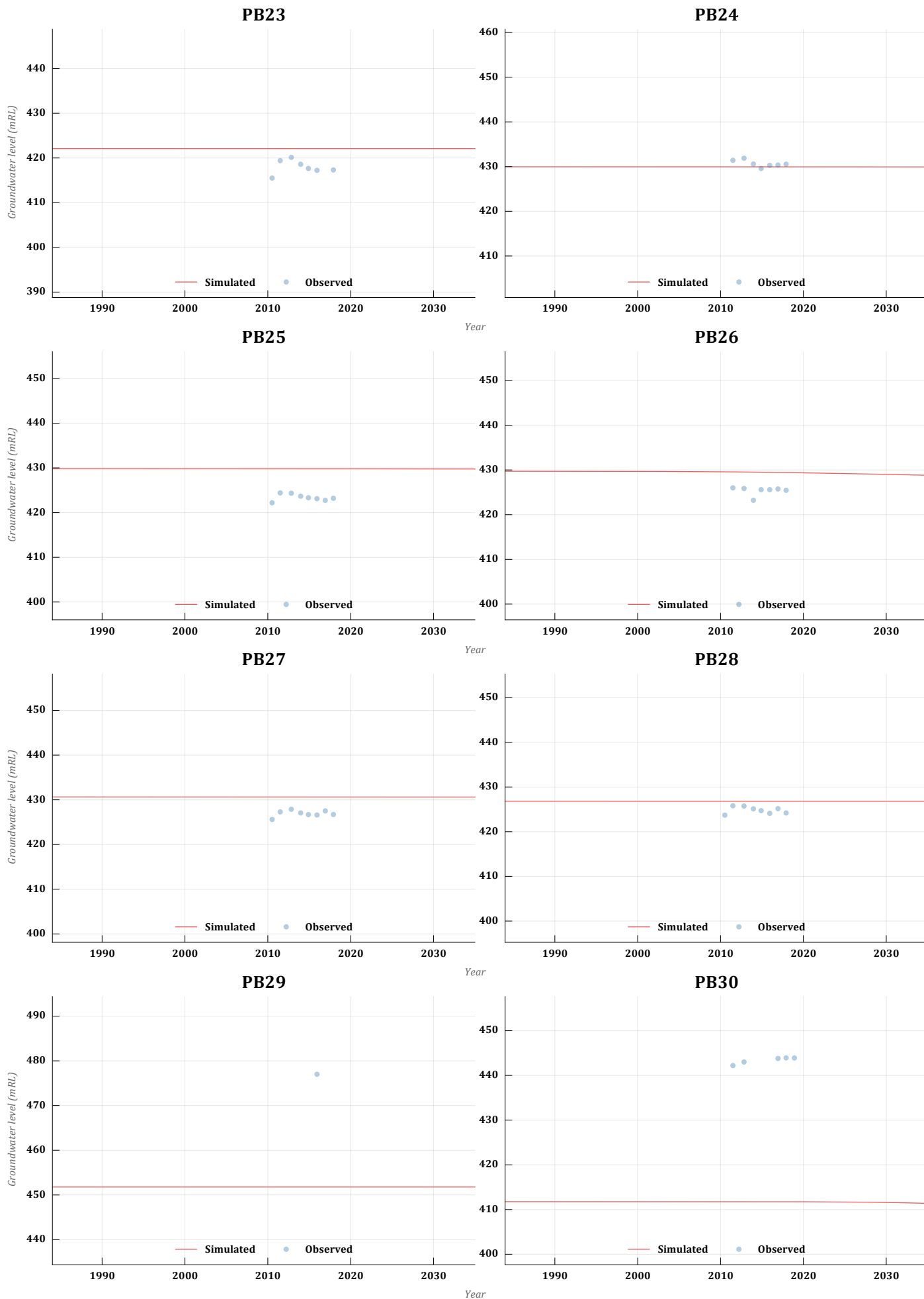




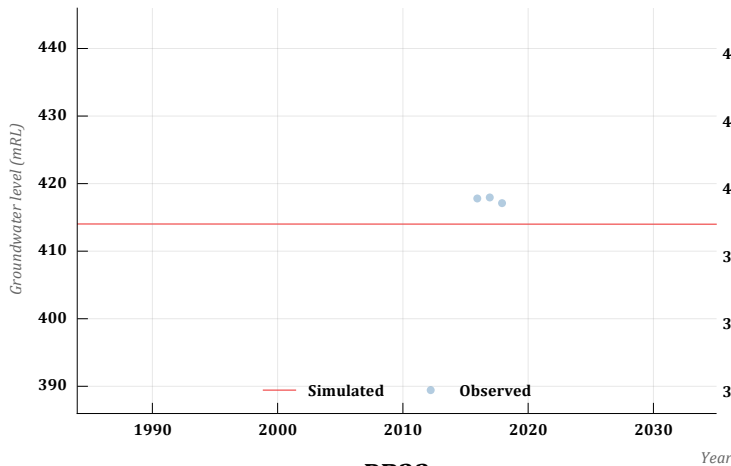




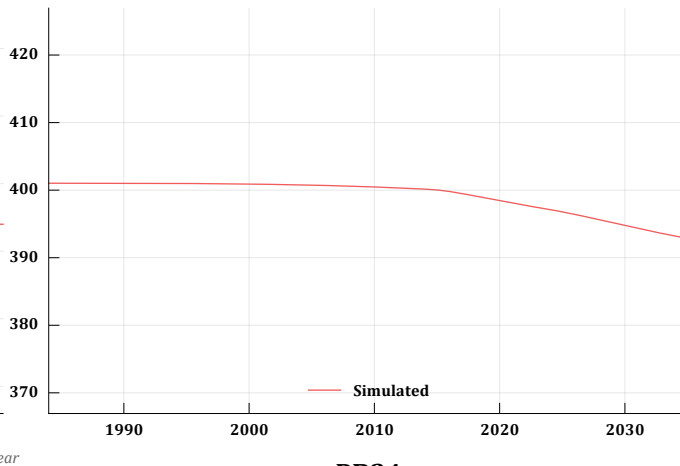




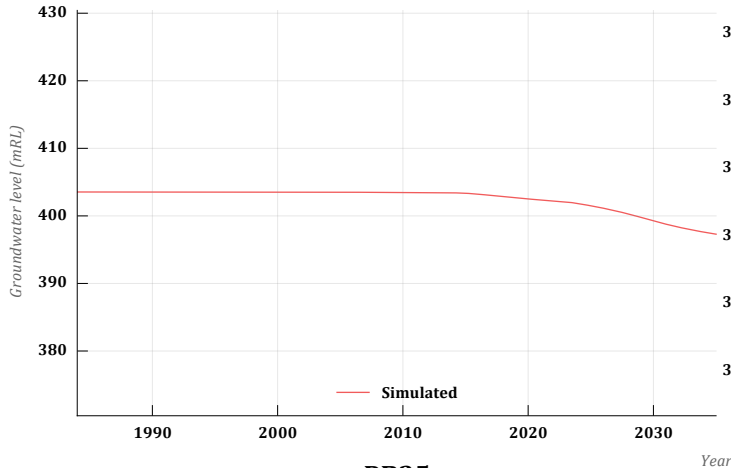
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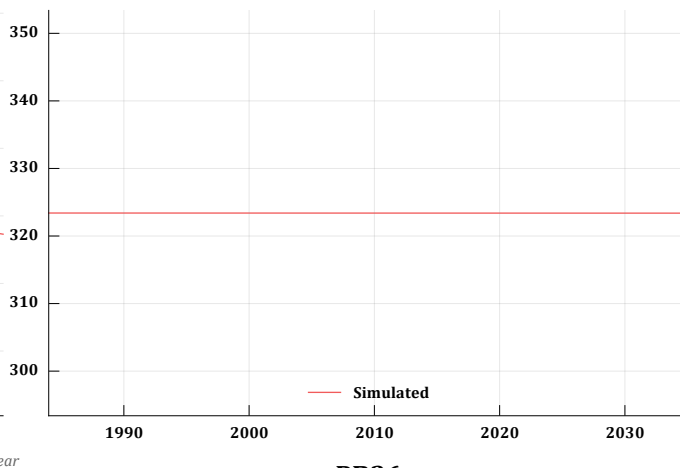
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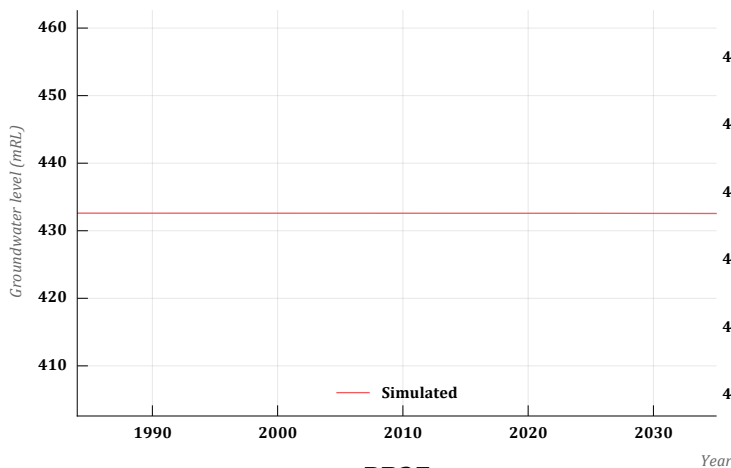
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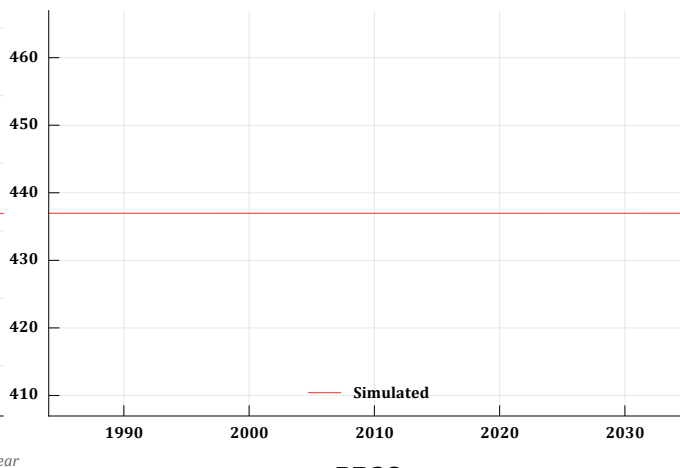
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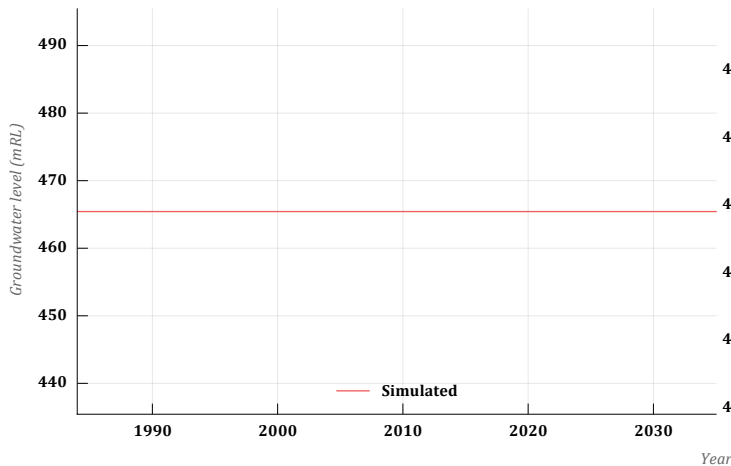
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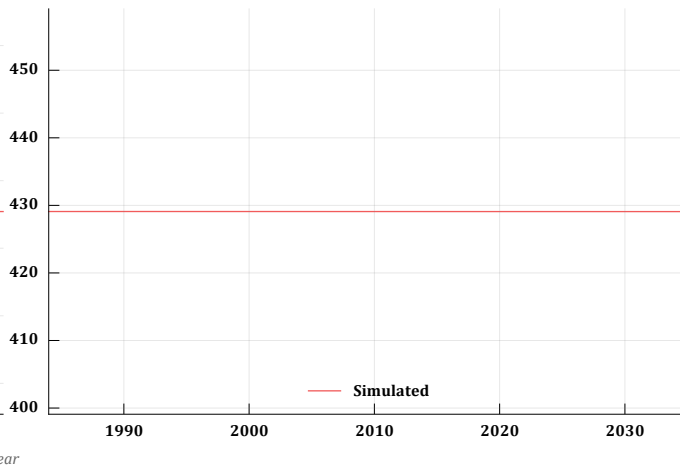
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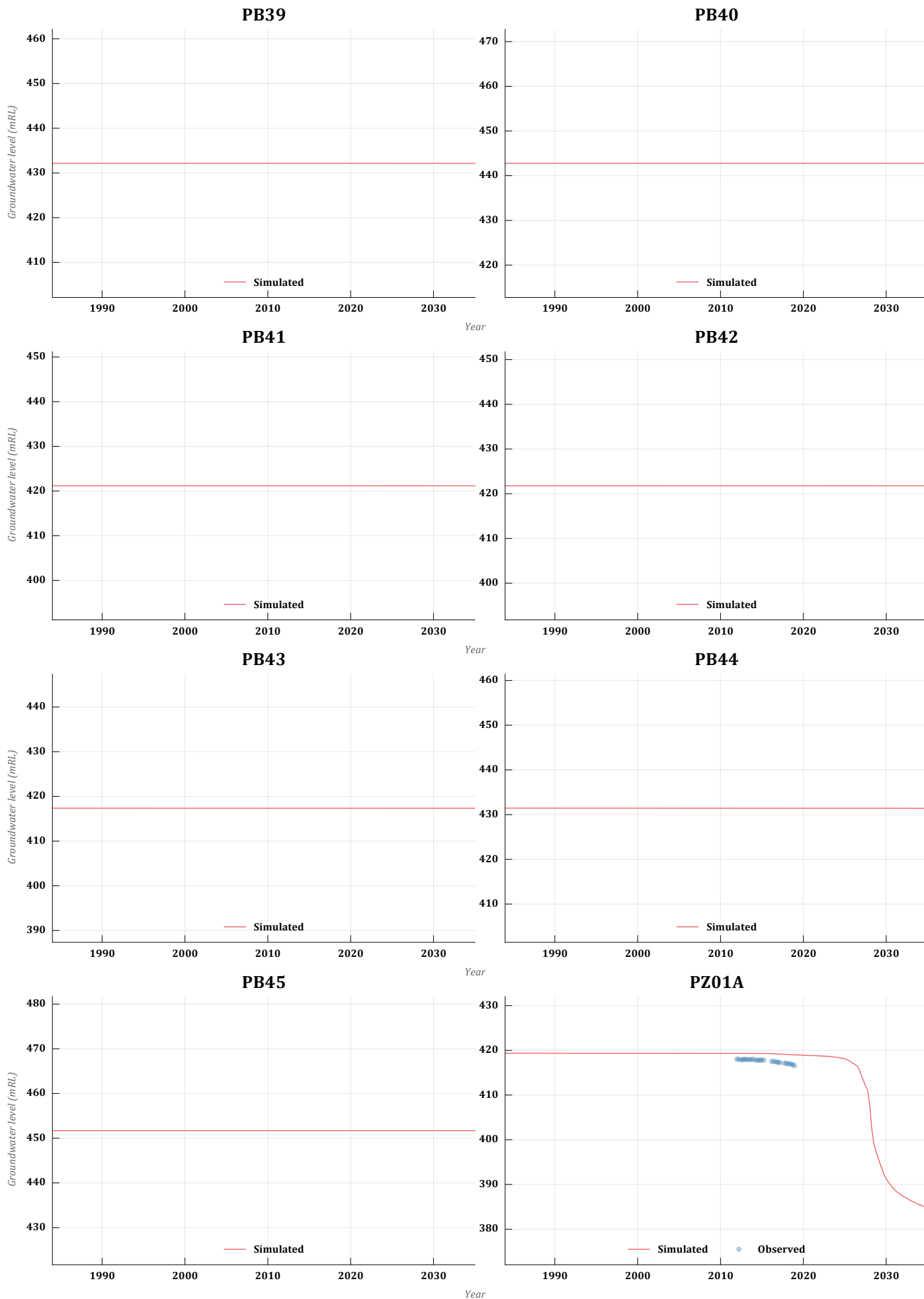


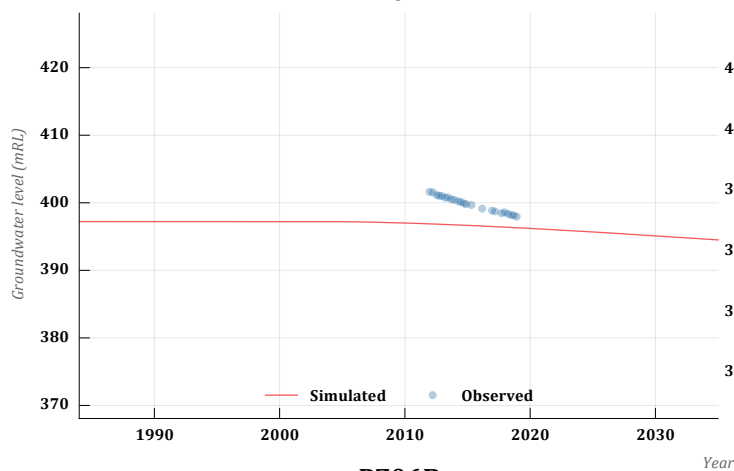
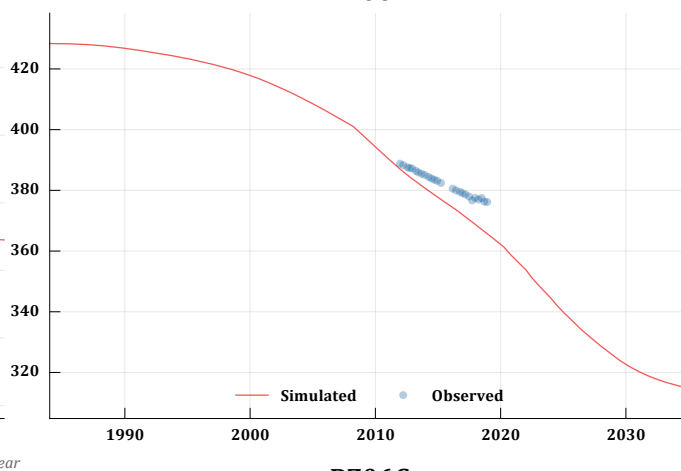
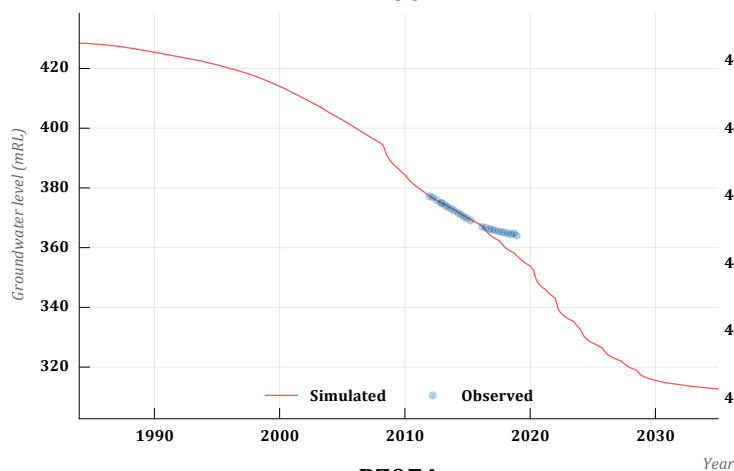
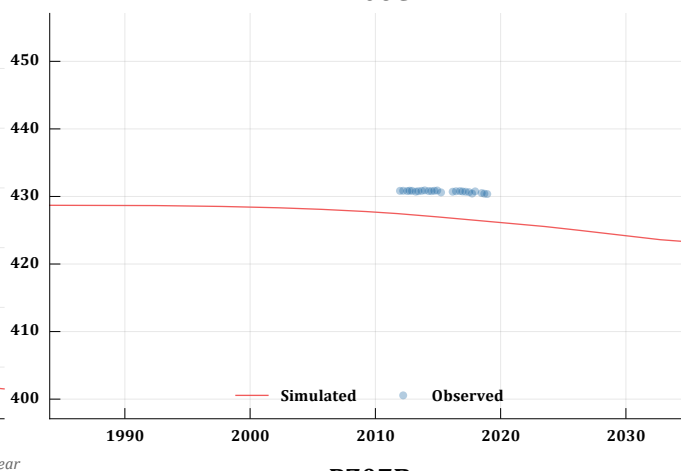
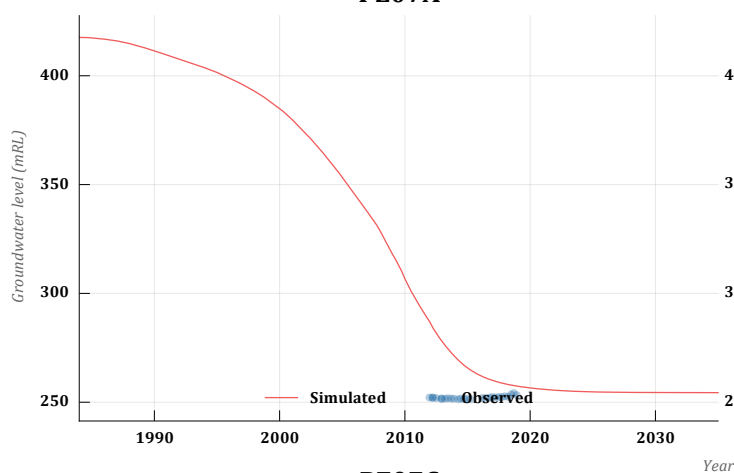
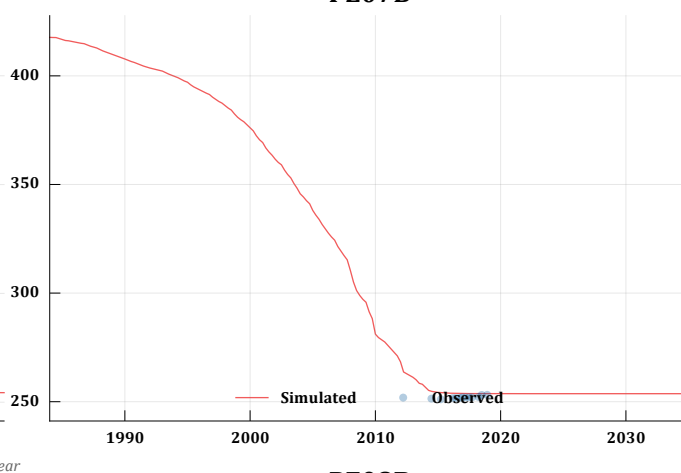
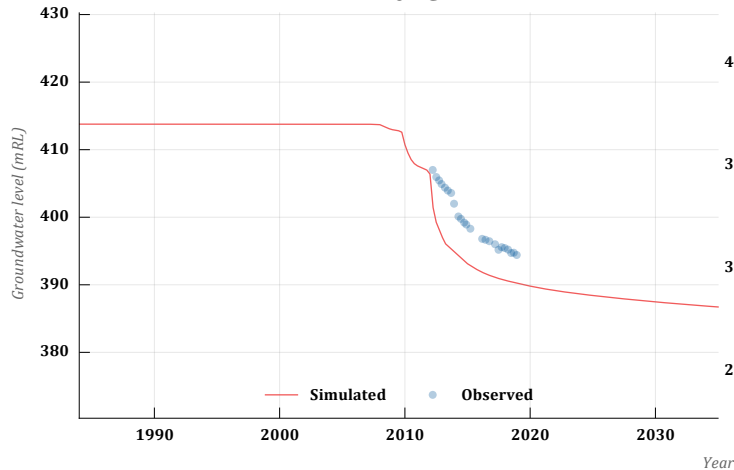
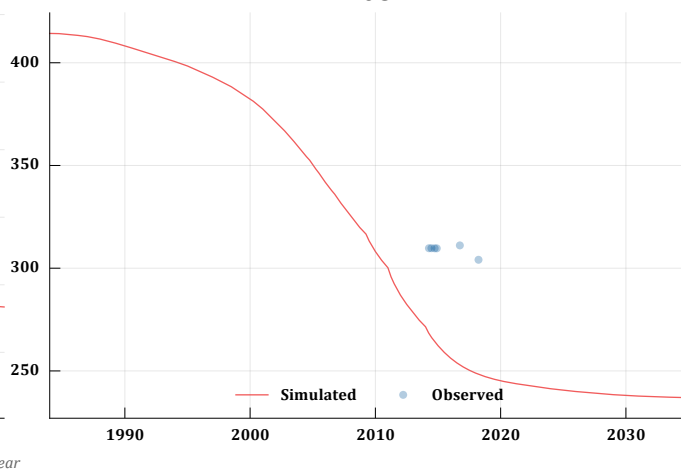
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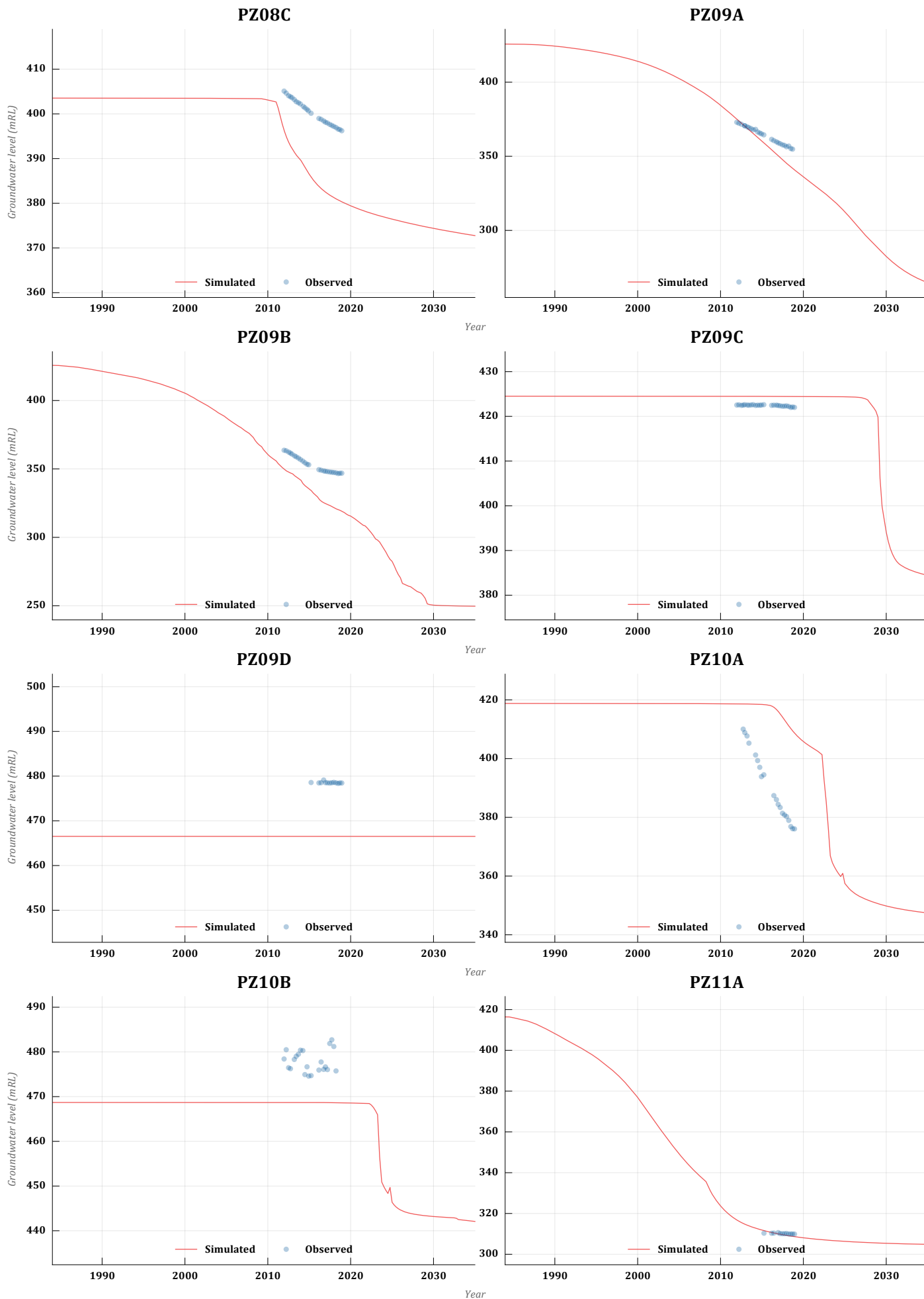


PB38

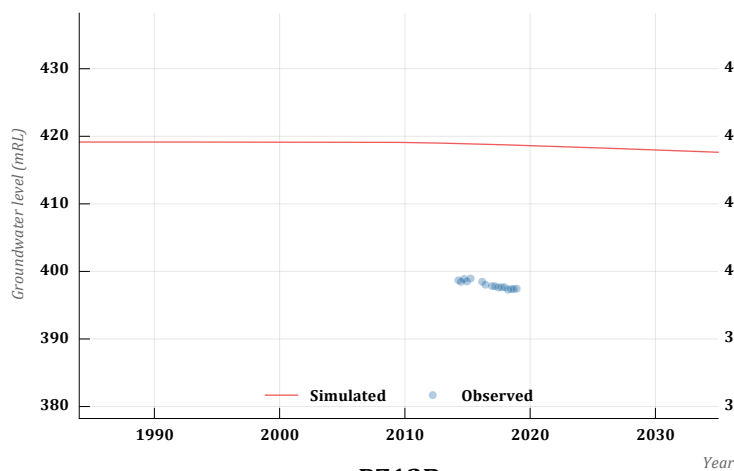




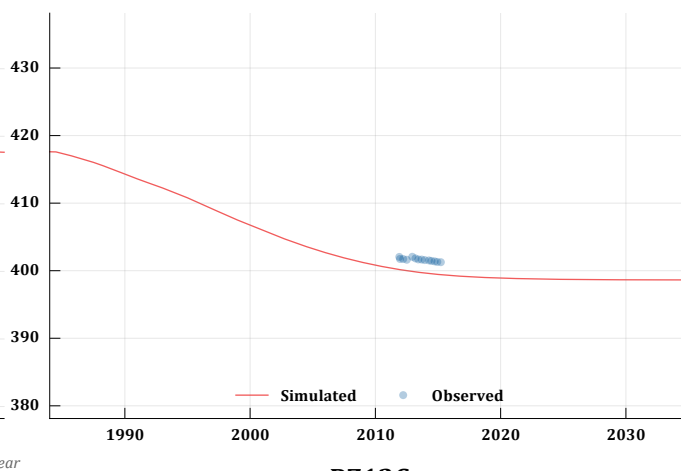
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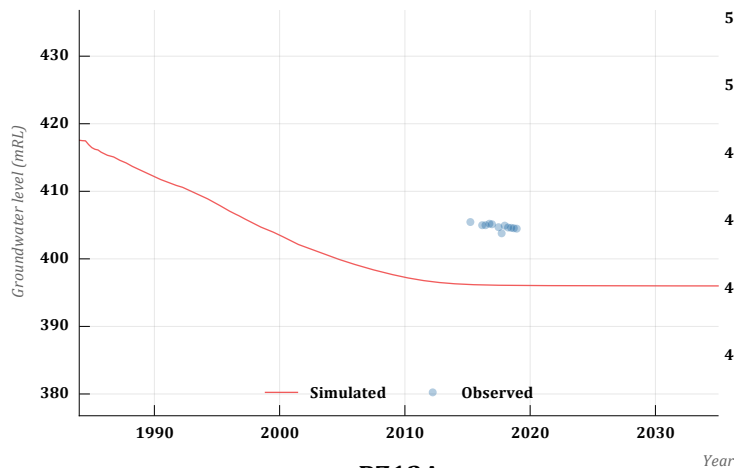
PZ11B



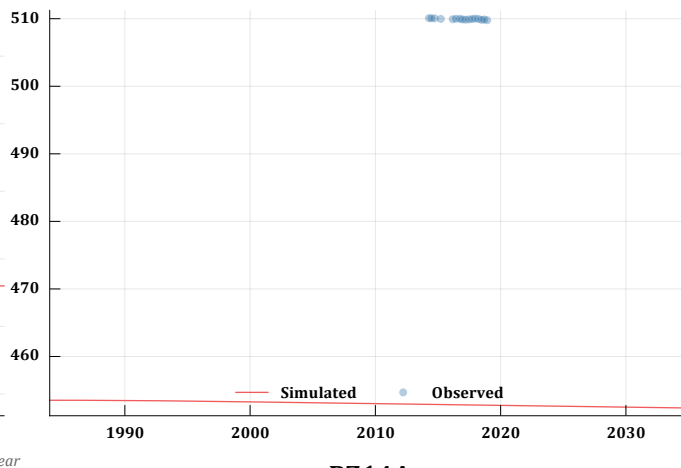
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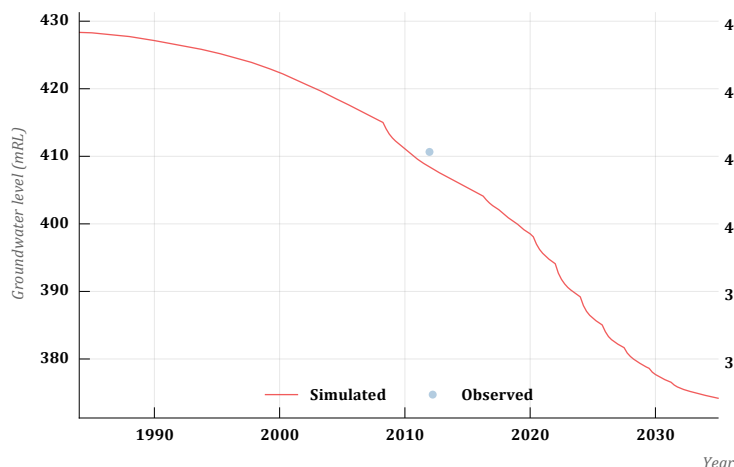
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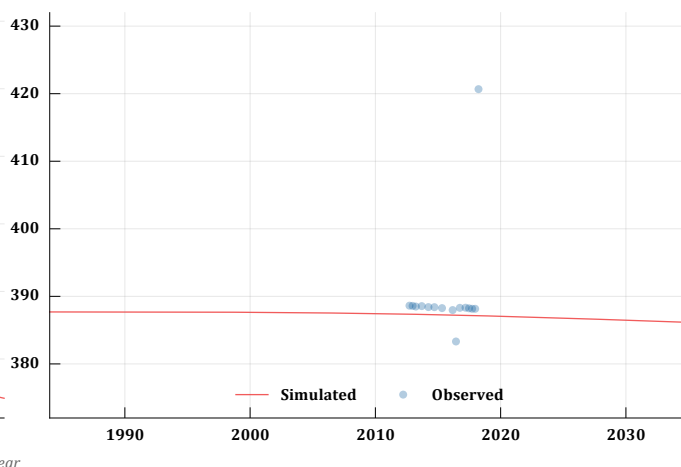
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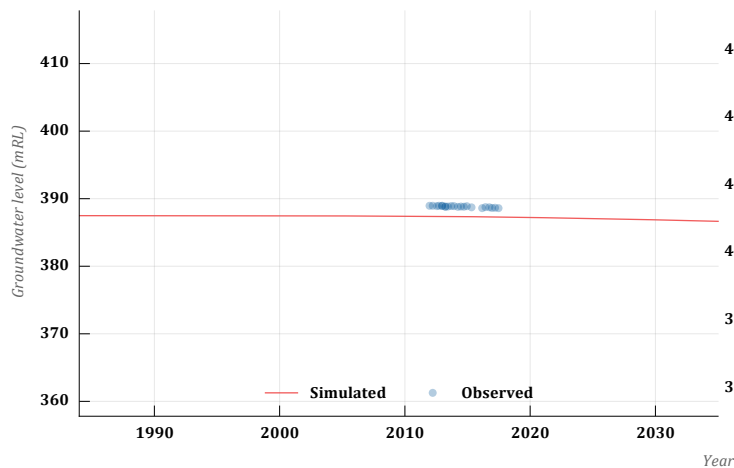
PZ13A



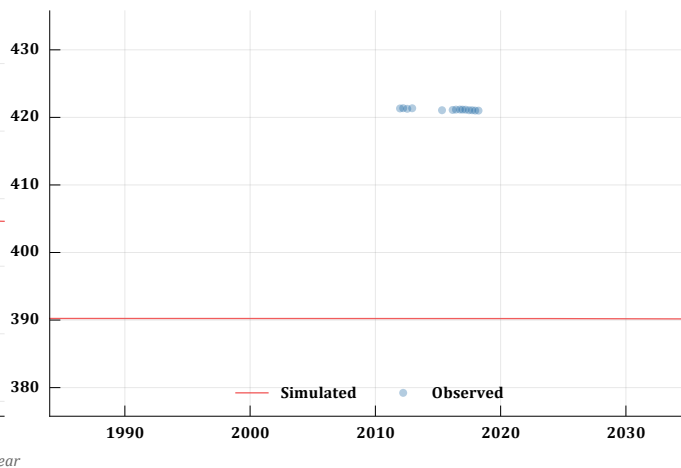
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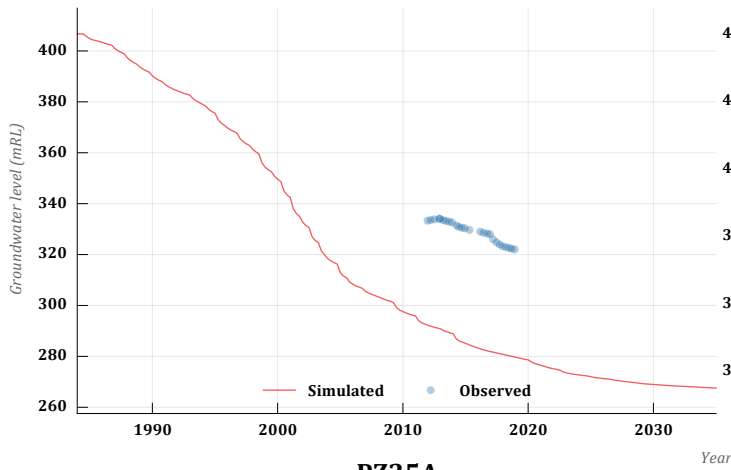
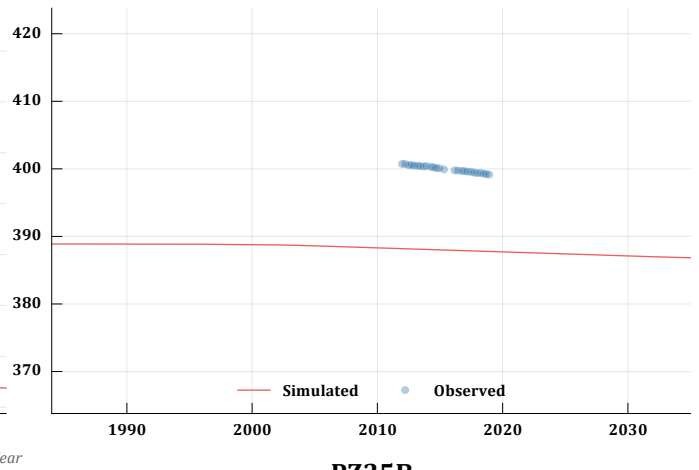
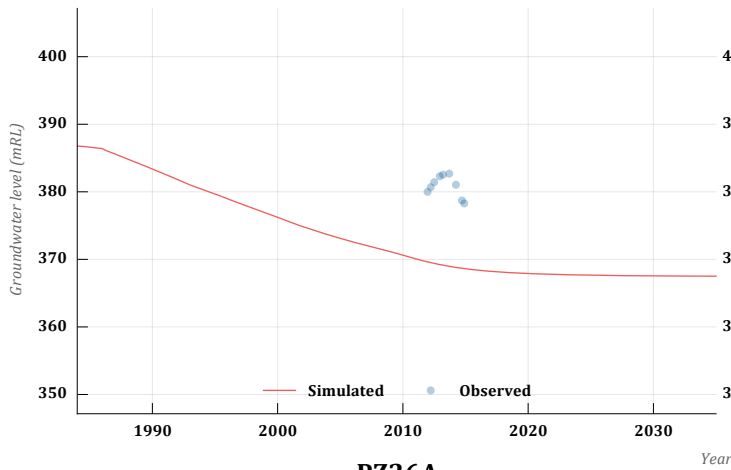
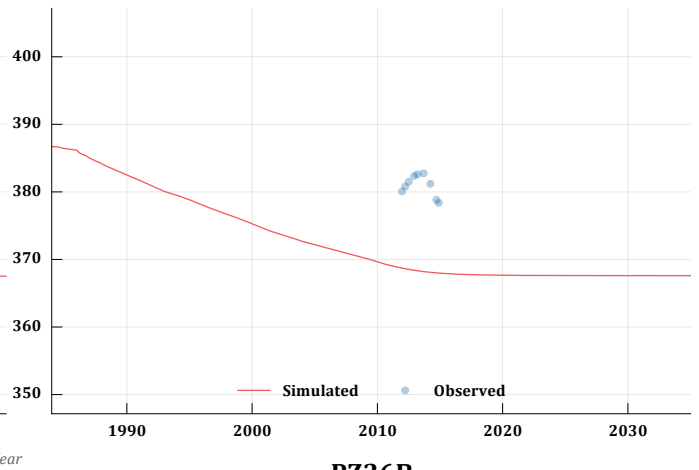
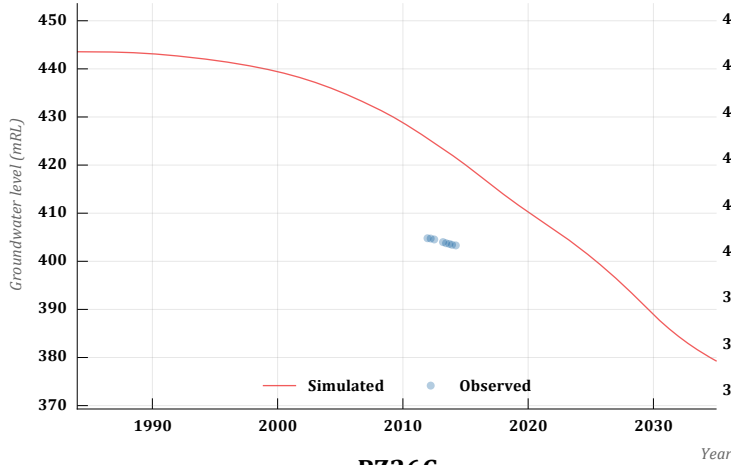
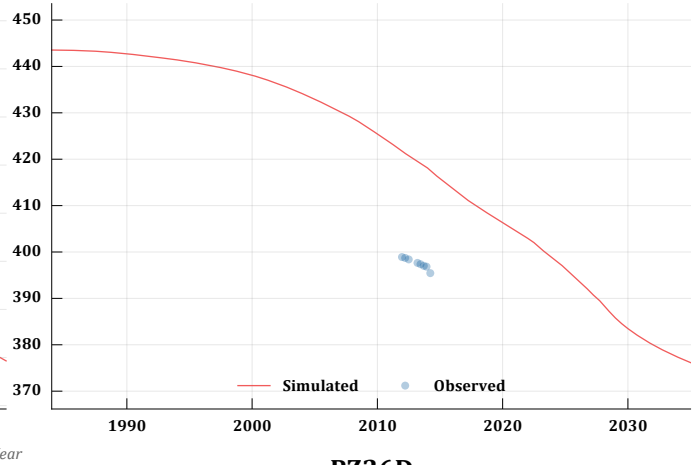
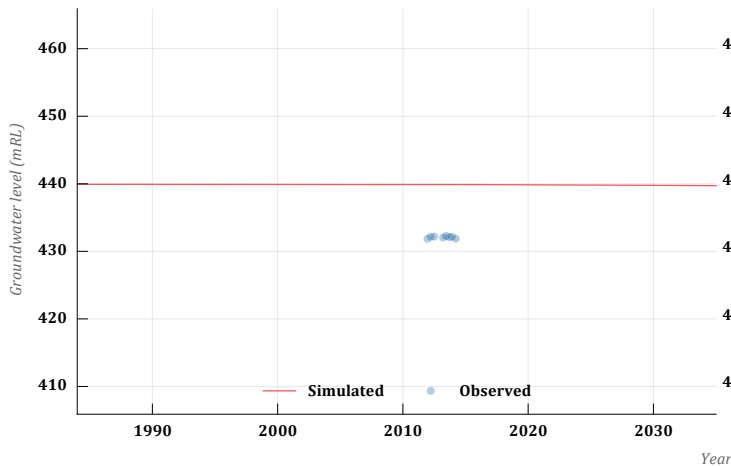
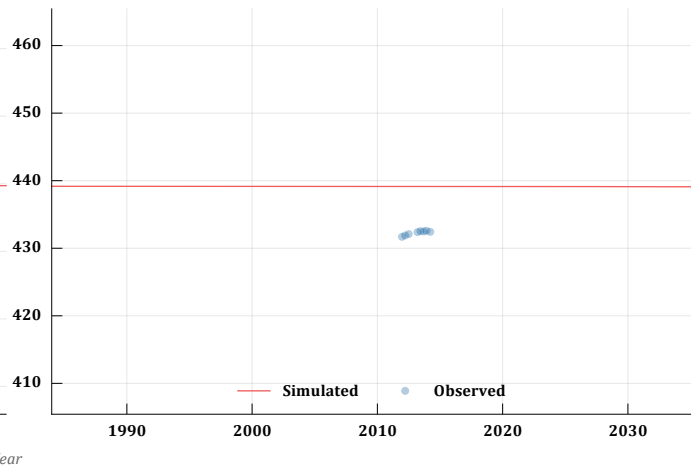


PZ14B

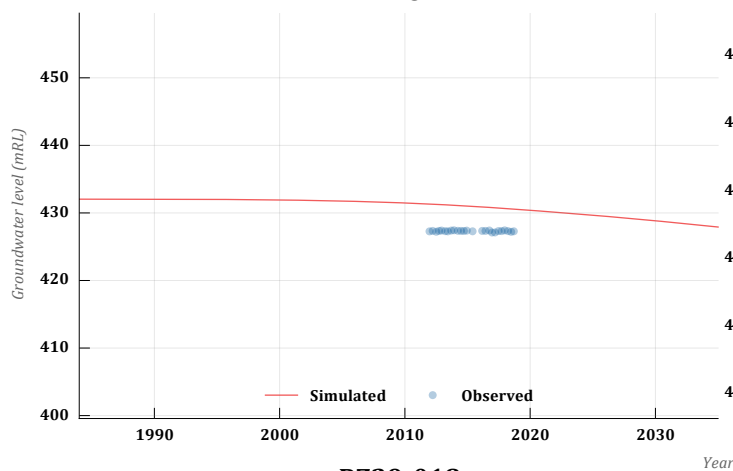


PZ14C

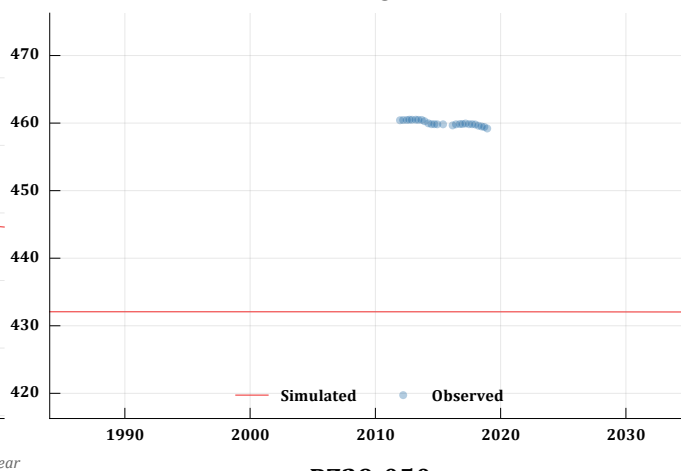


PZ24A**PZ24B****PZ25A****PZ25B****PZ26A****PZ26B****PZ26C****PZ26D**

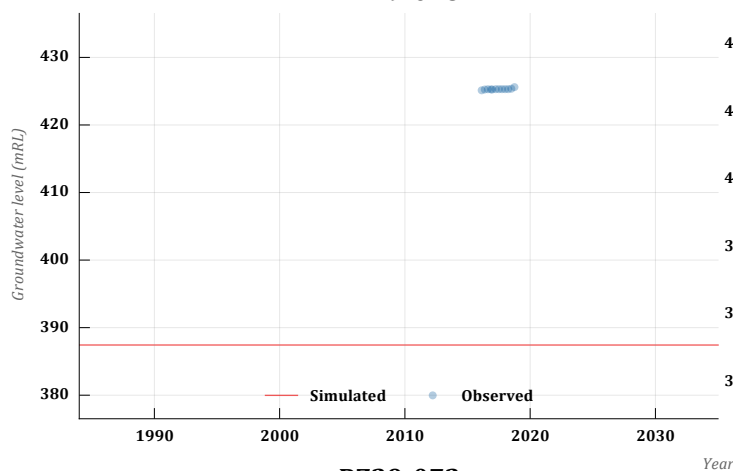
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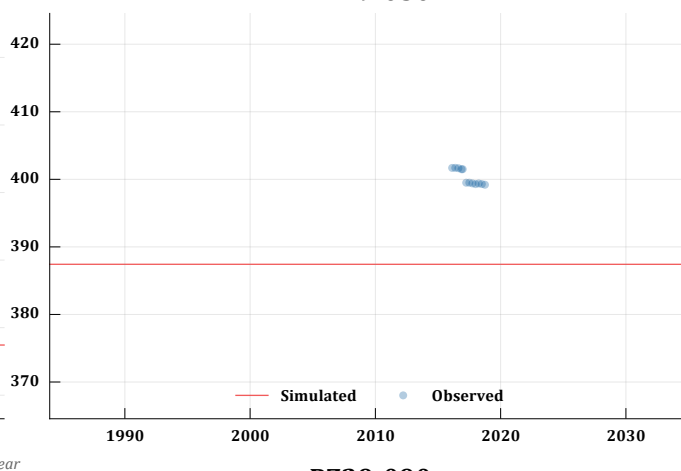
PZ28B



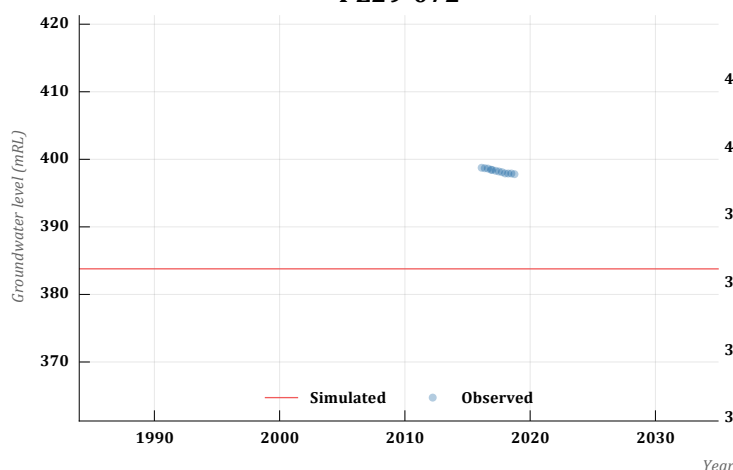
PZ29-018



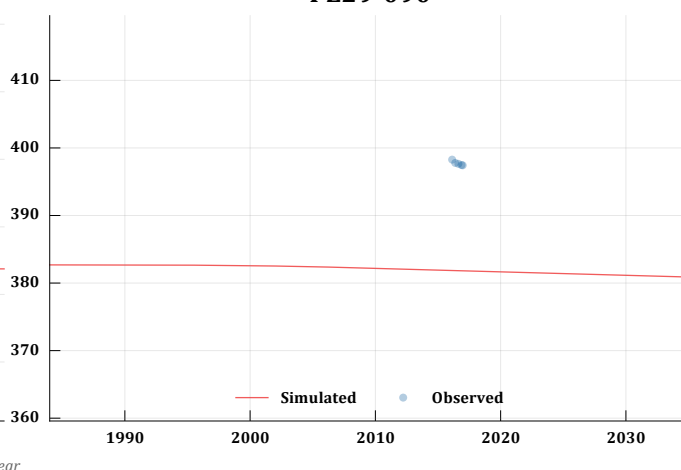
PZ29-050



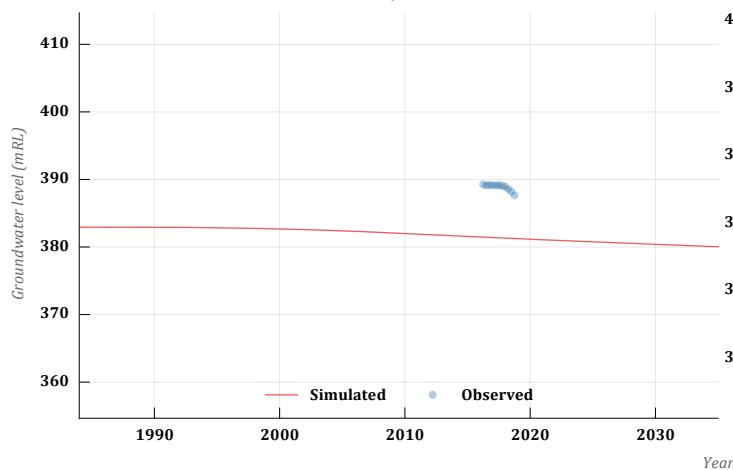
PZ29-072



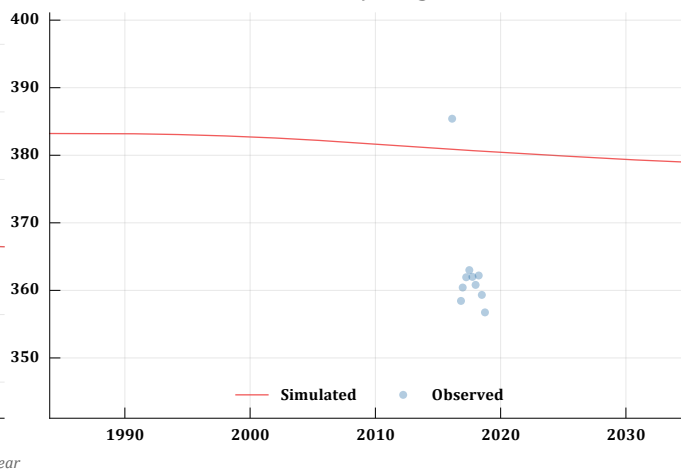
PZ29-090

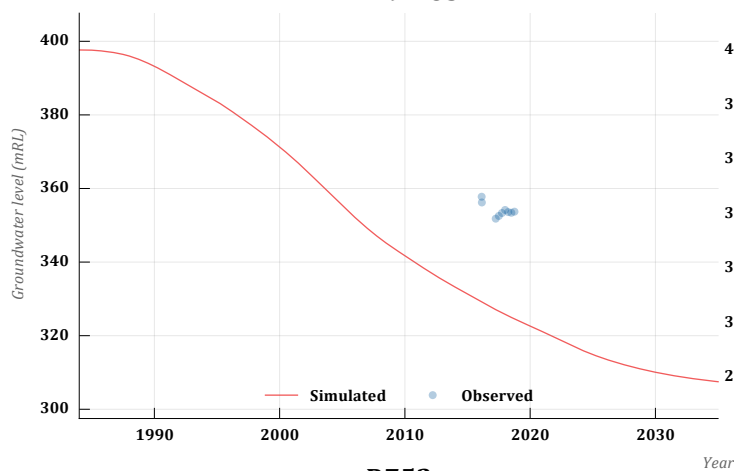
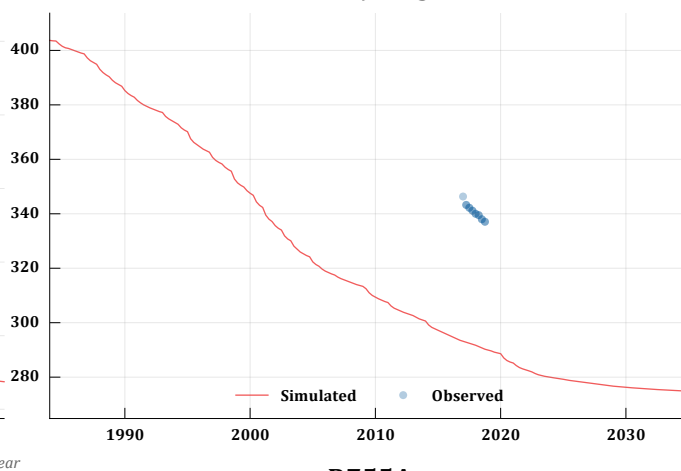
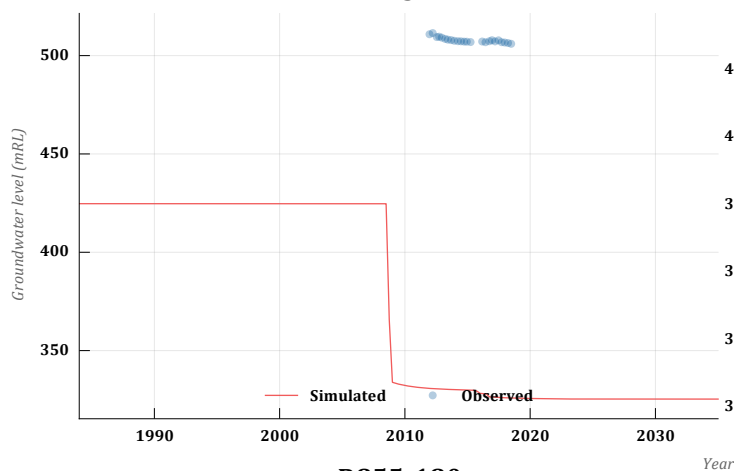
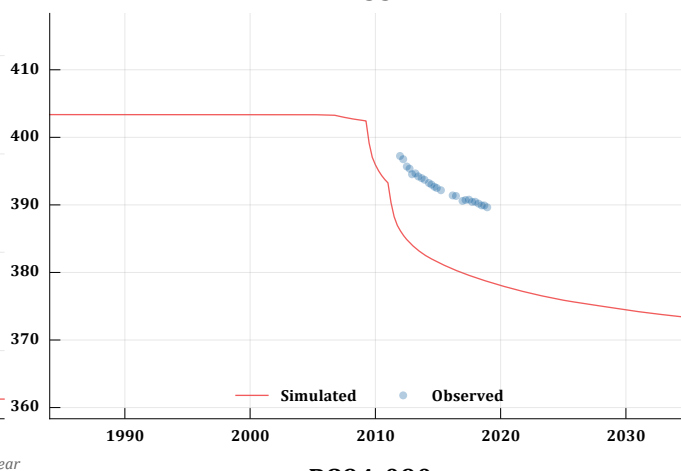
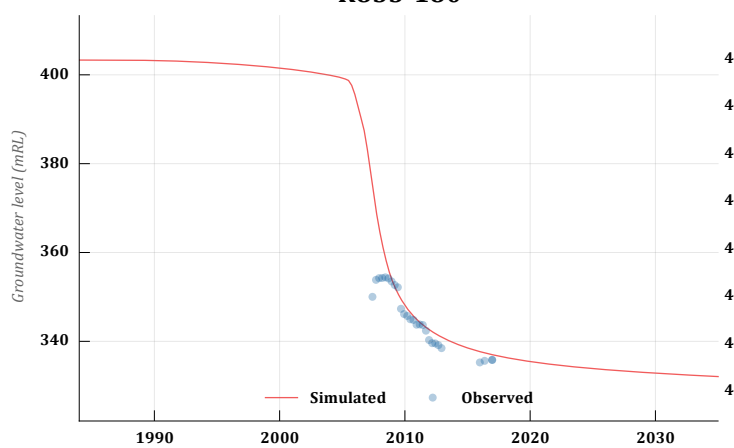
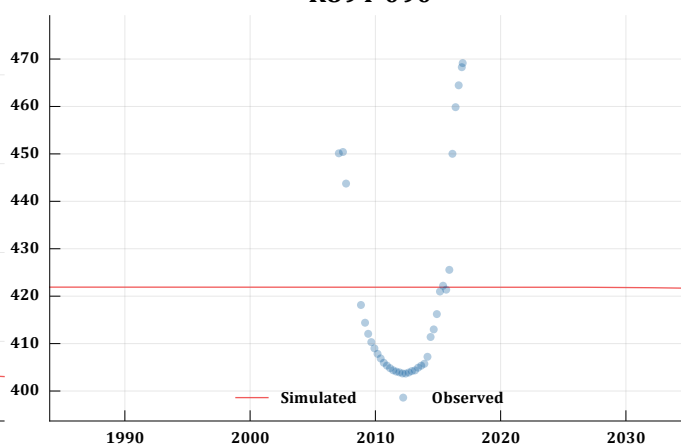
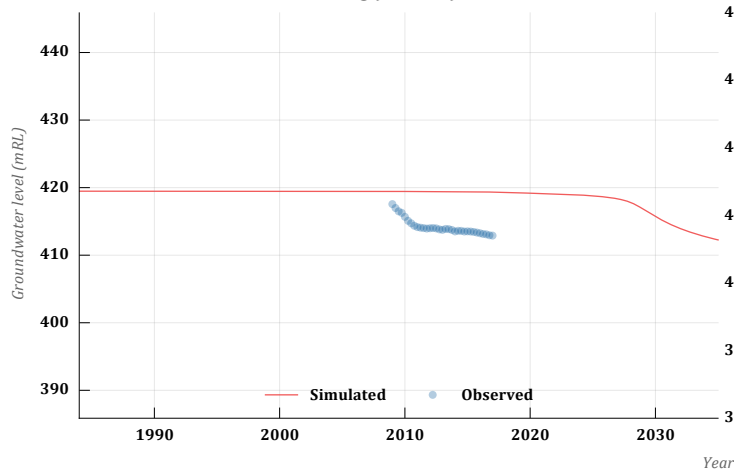
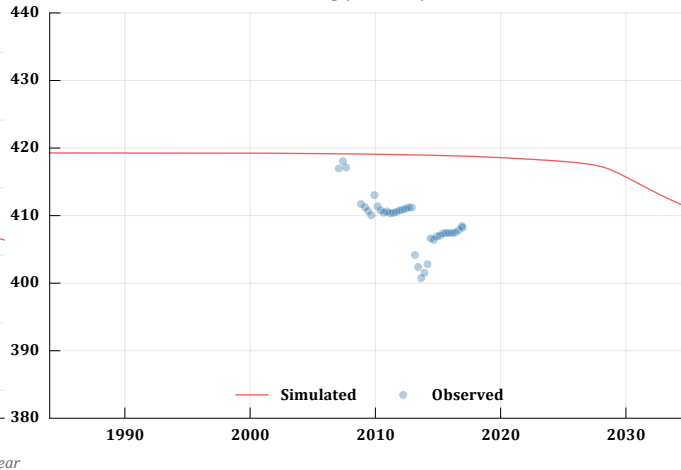


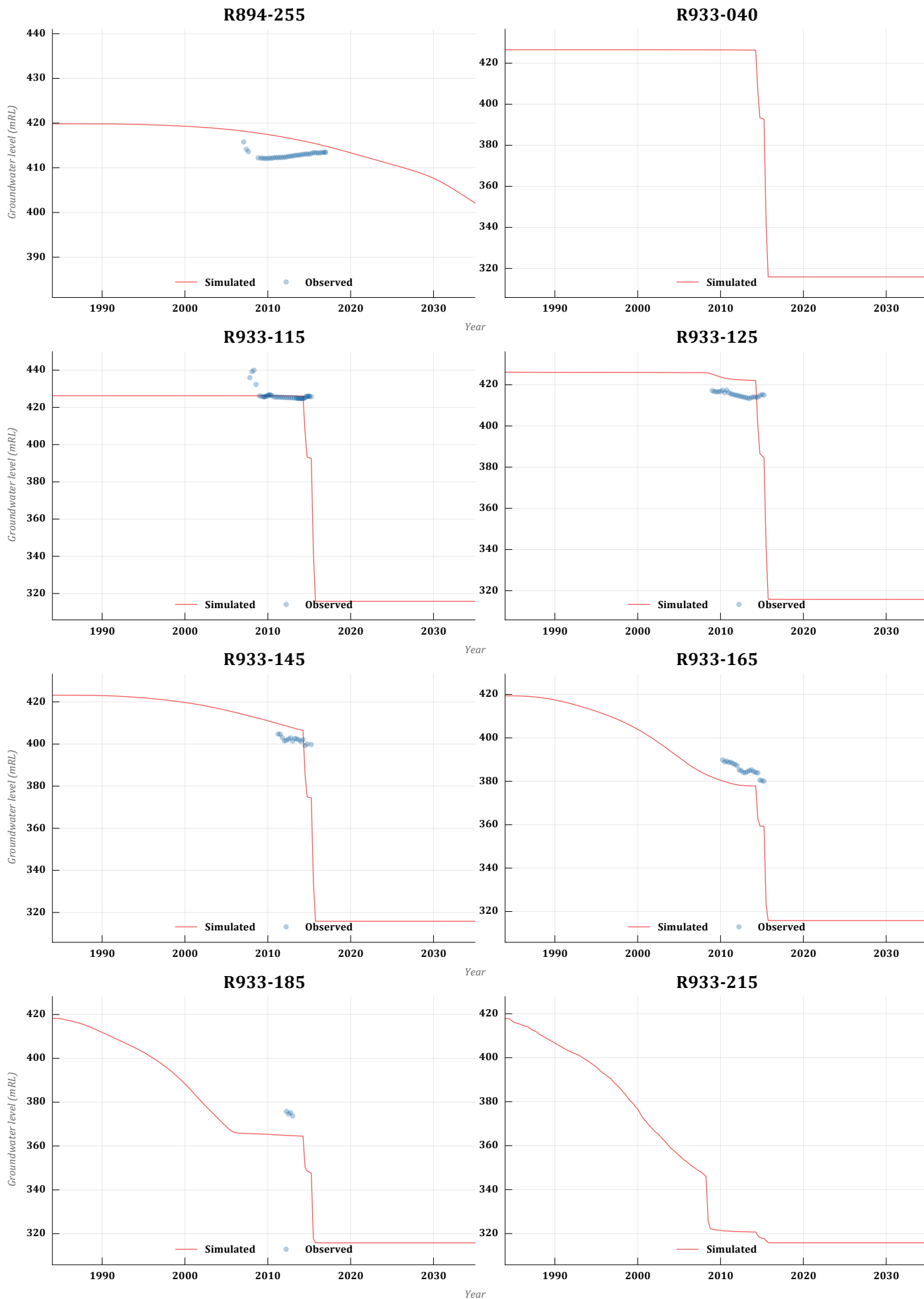
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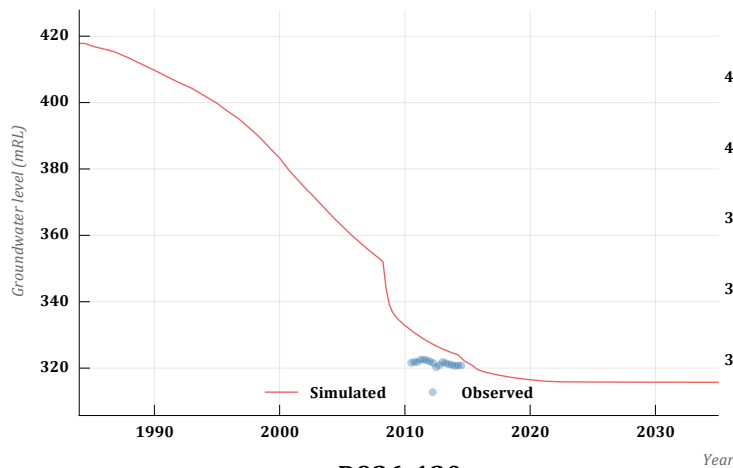
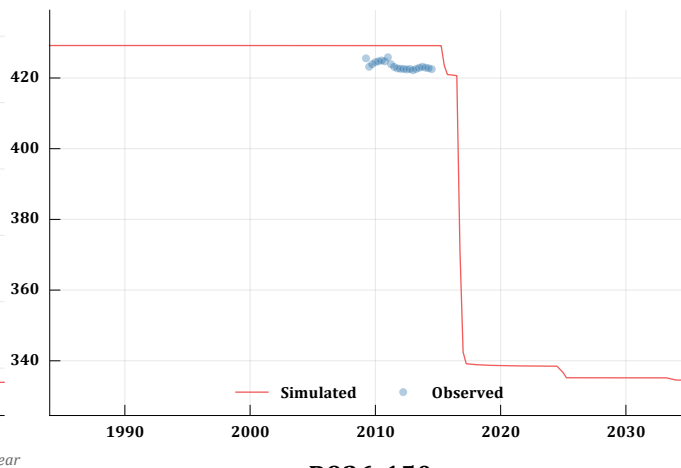
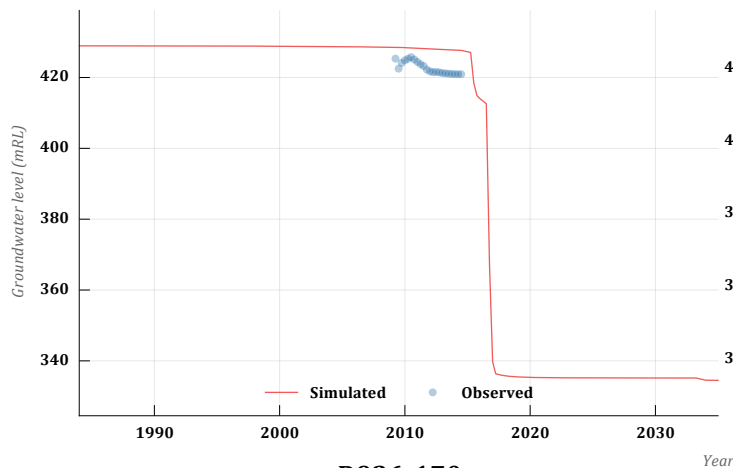
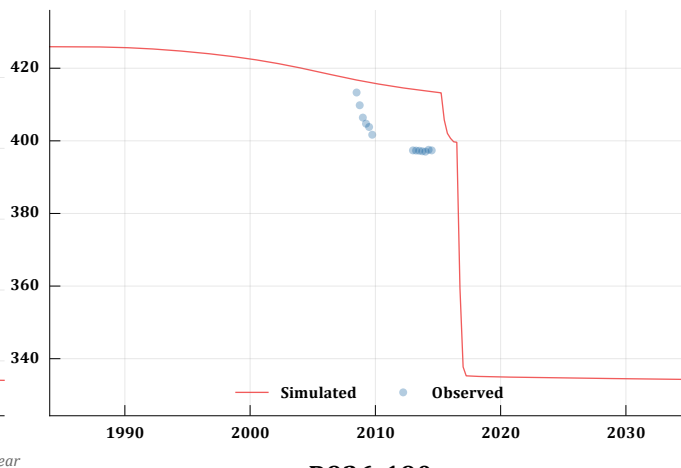
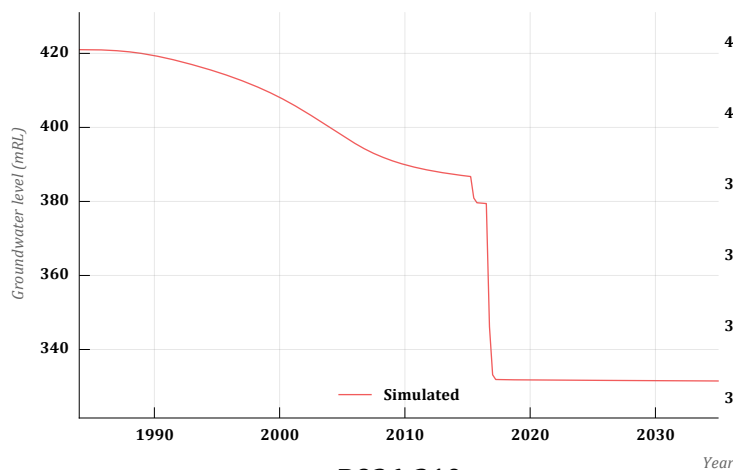
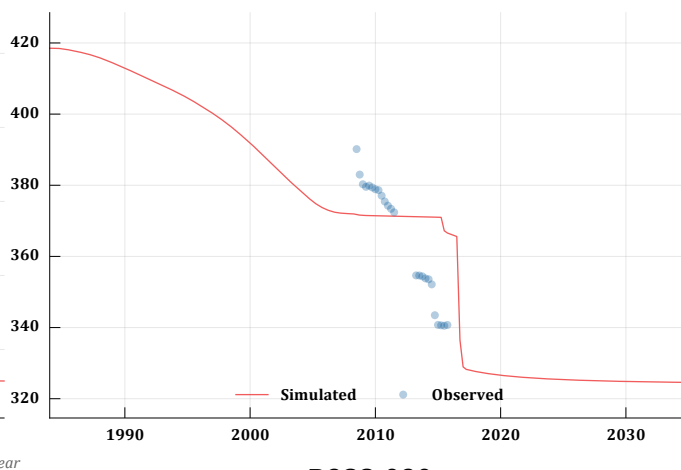
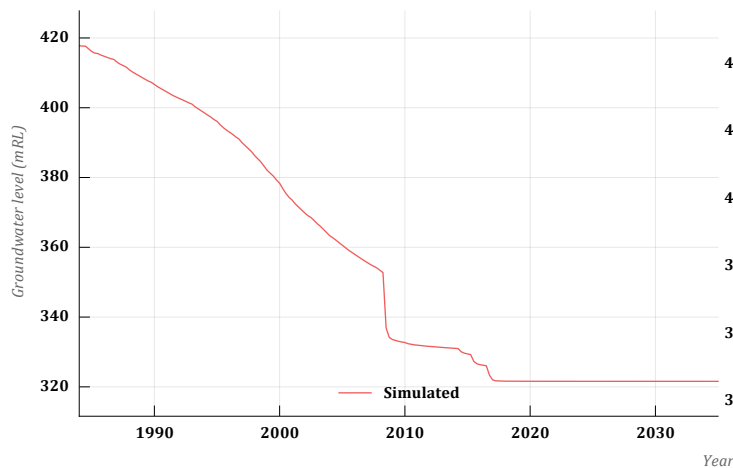
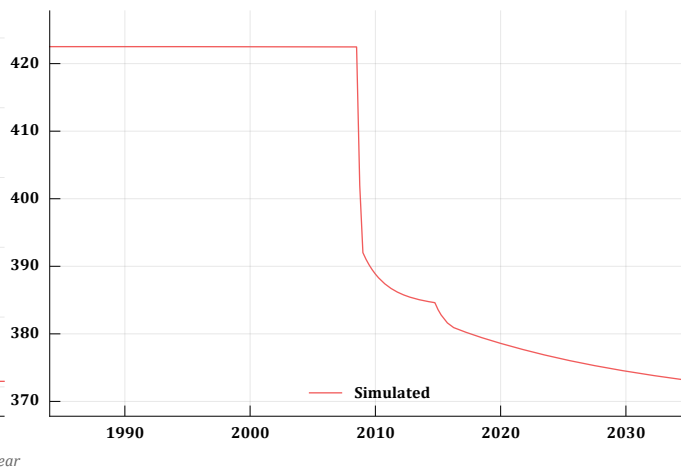


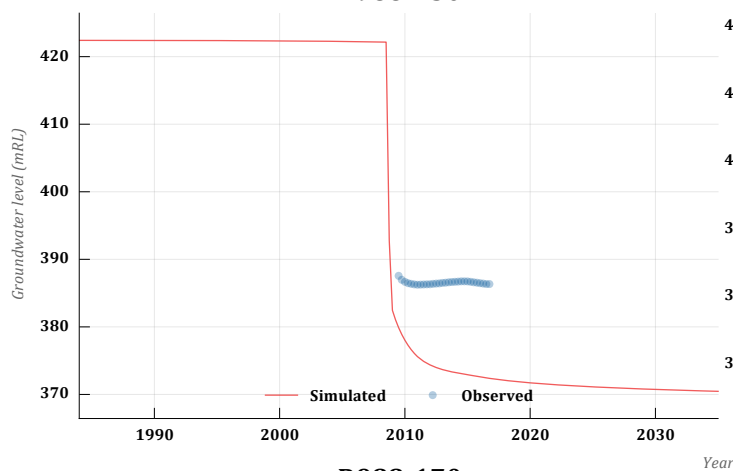
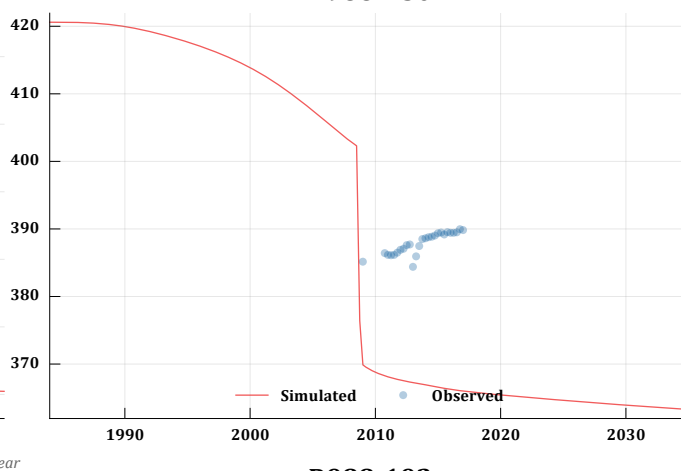
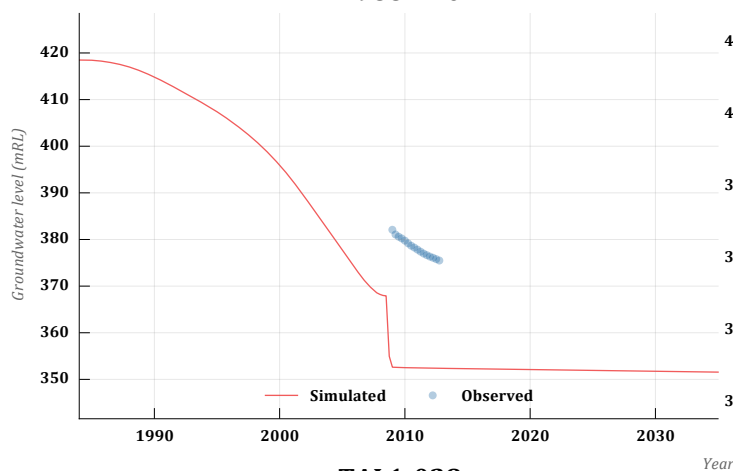
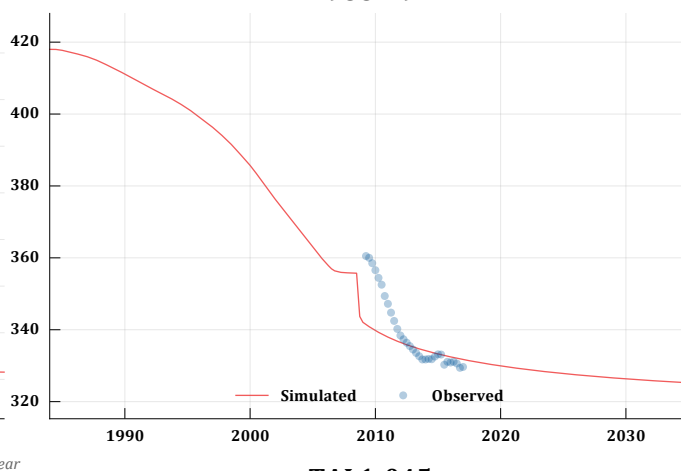
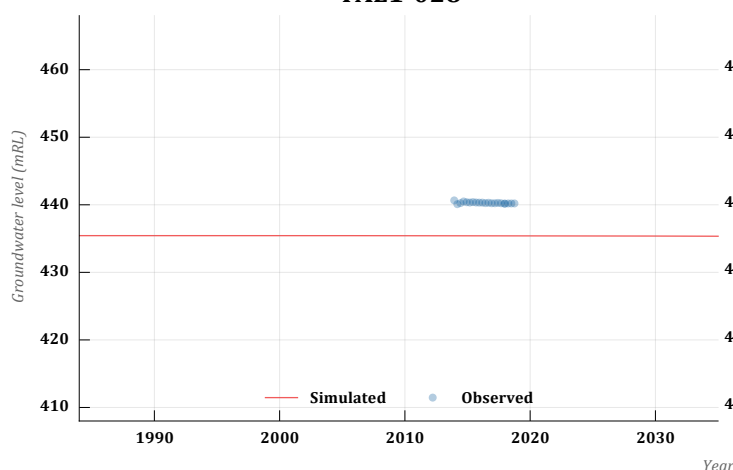
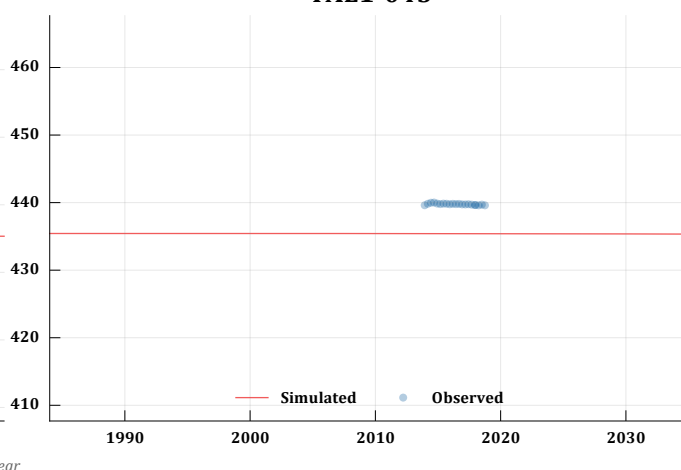
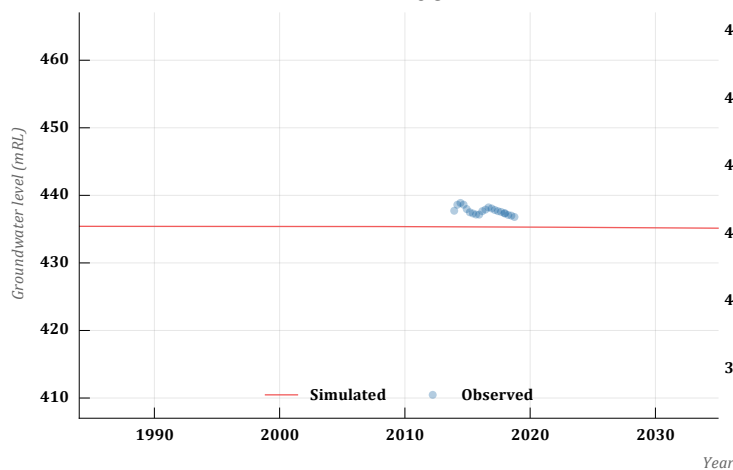
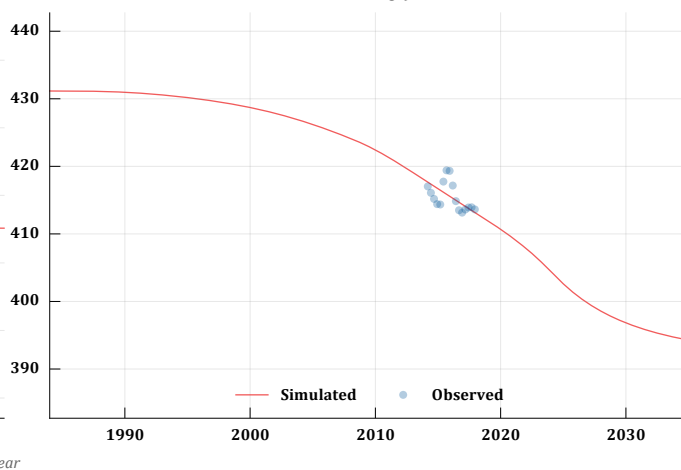
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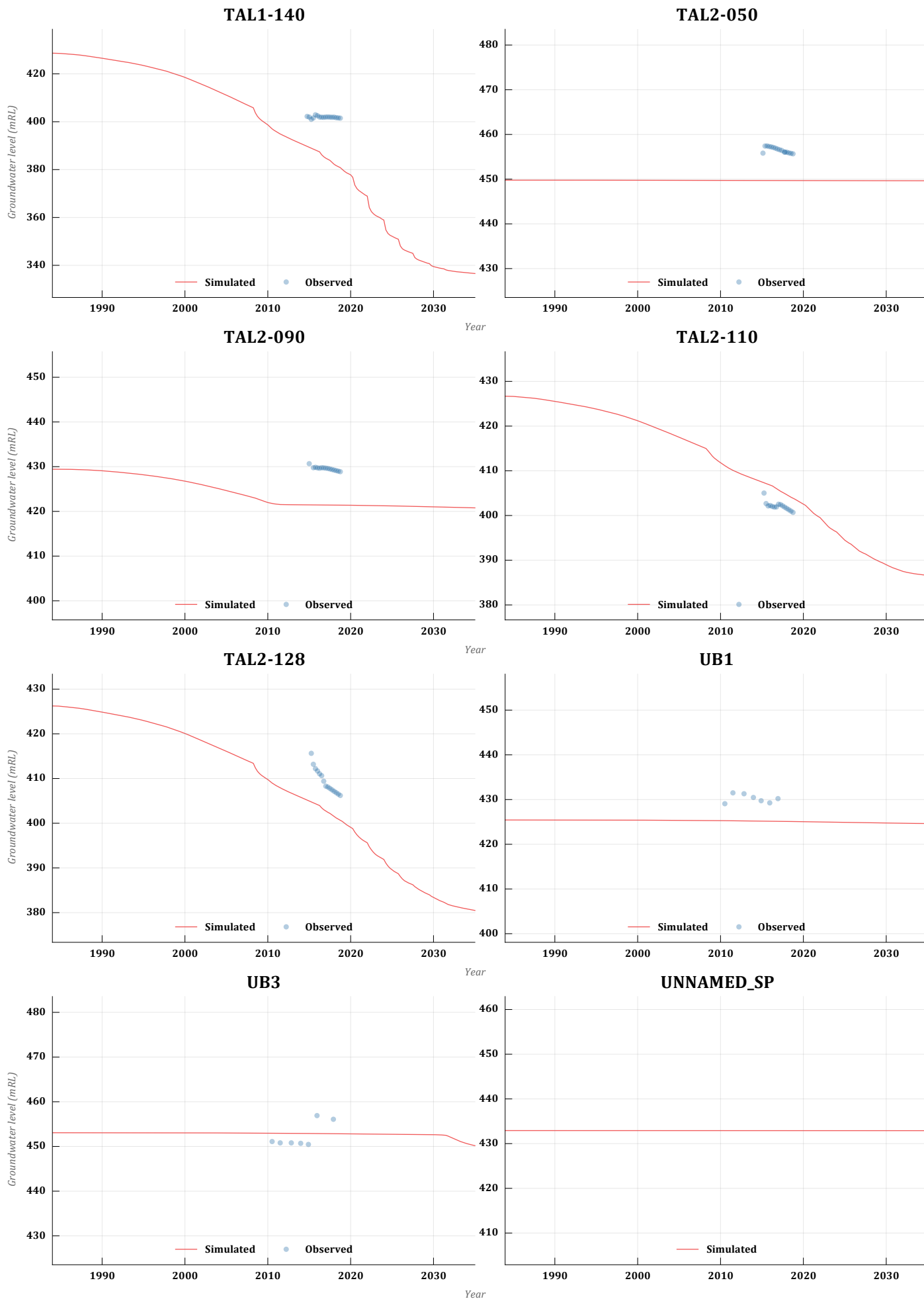


PZ29-183**PZ29-243****R752****R755A****R855-180****R894-090****R894-119****R894-219**

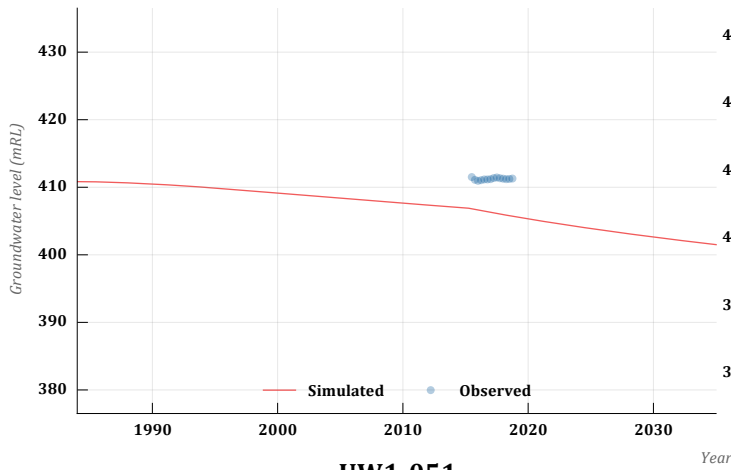


R933-225**R936-110****R936-130****R936-150****R936-170****R936-190****R936-210****R988-090**

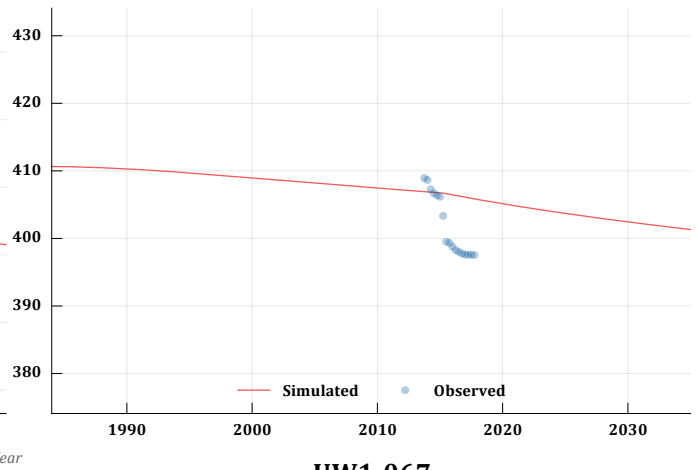
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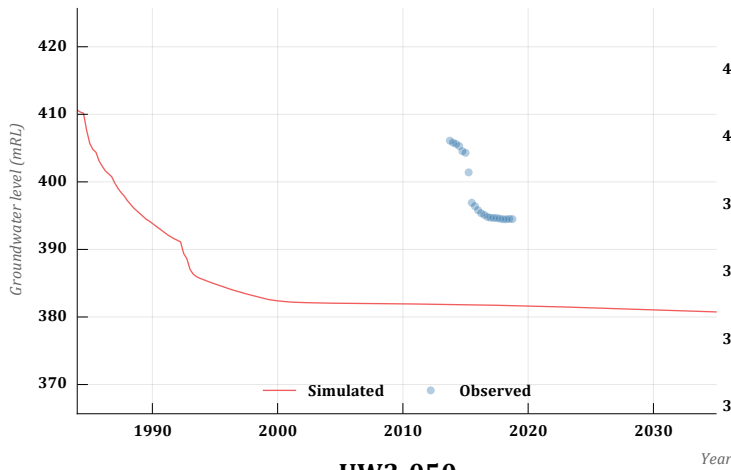
UW1-022



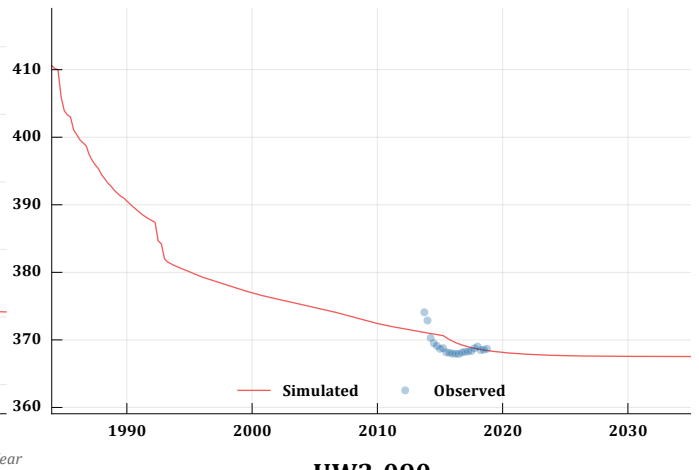
UW1-035



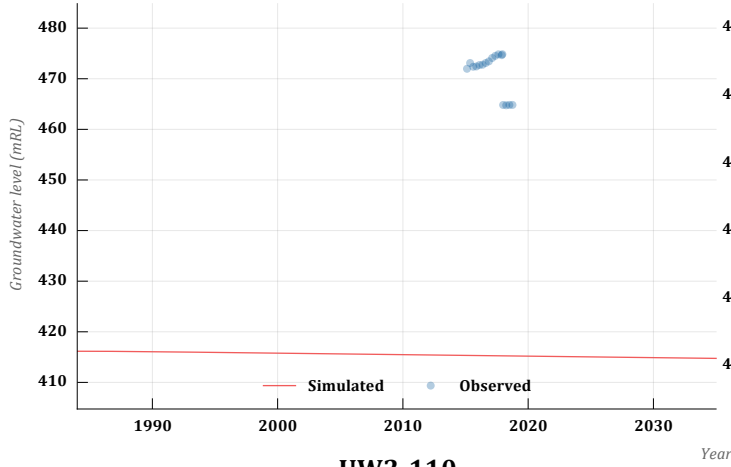
UW1-051



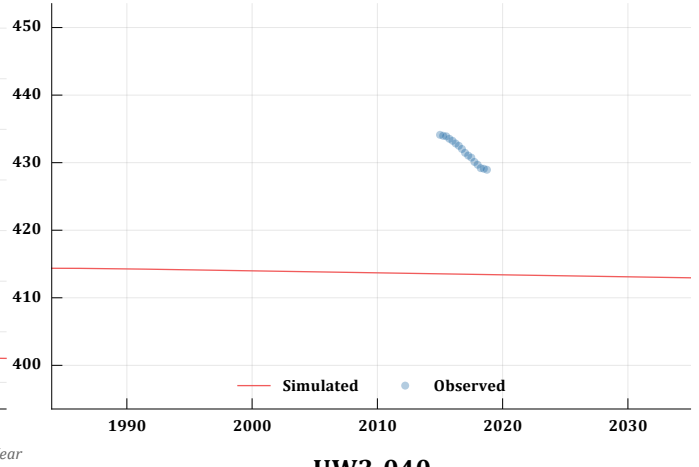
UW1-067



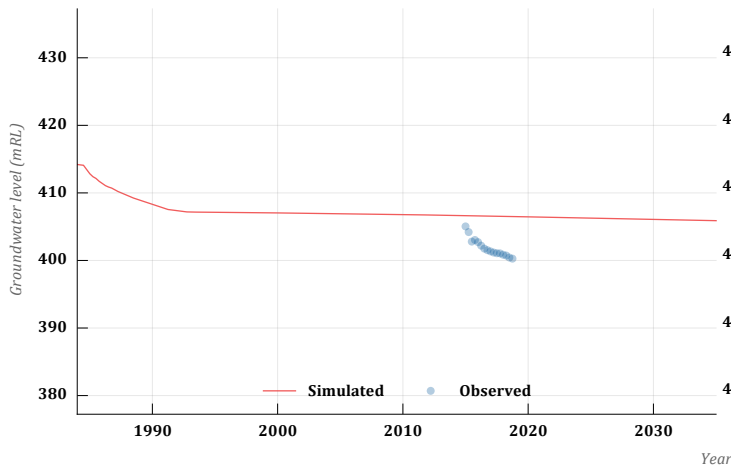
UW2-050



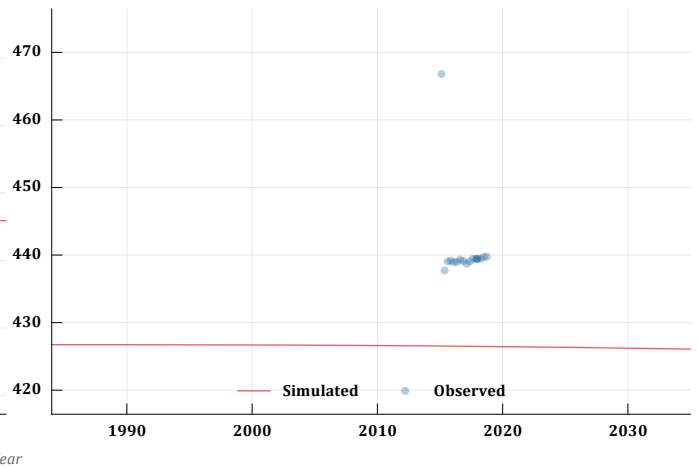
UW2-090



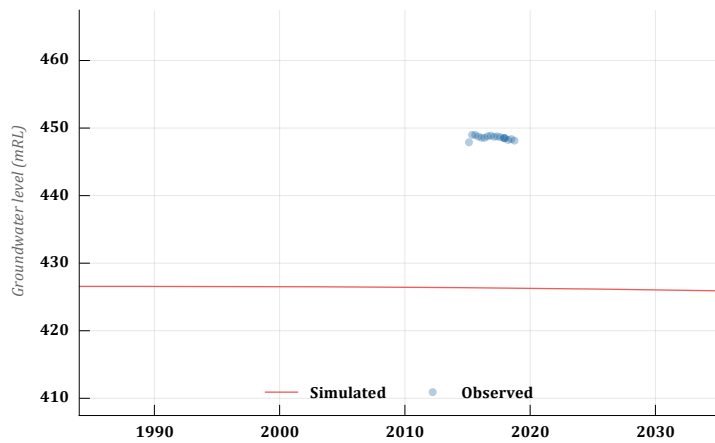
UW2-110



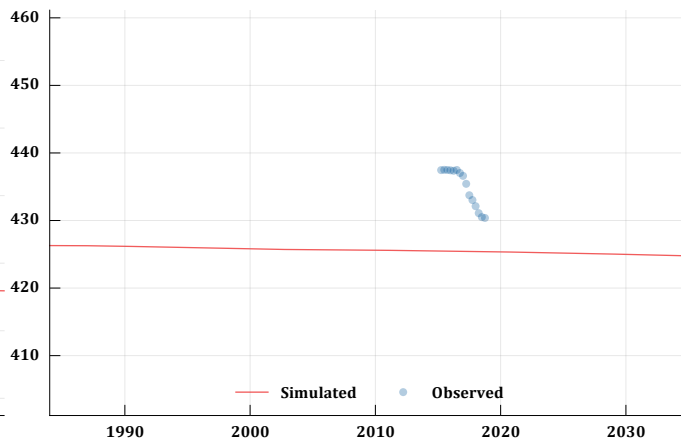
UW3-040



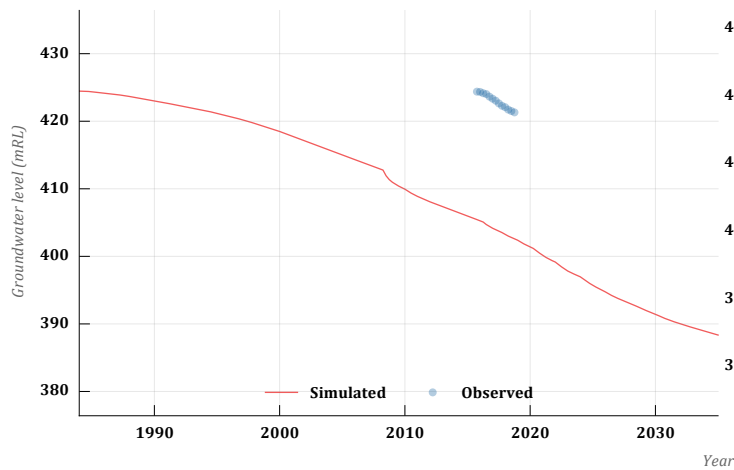
UW3-060



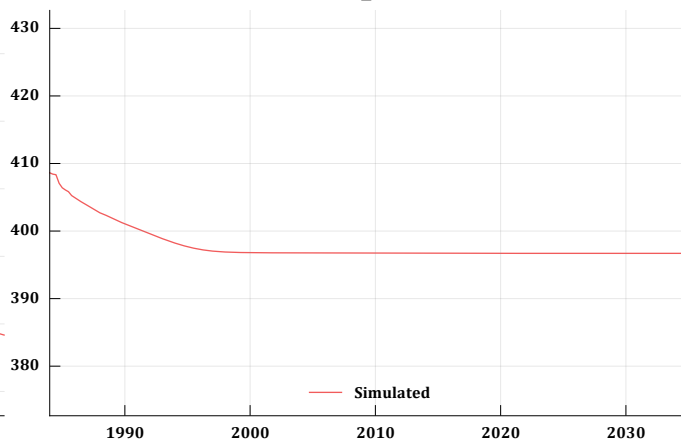
UW3-075



UW3-098



VOID_WEST



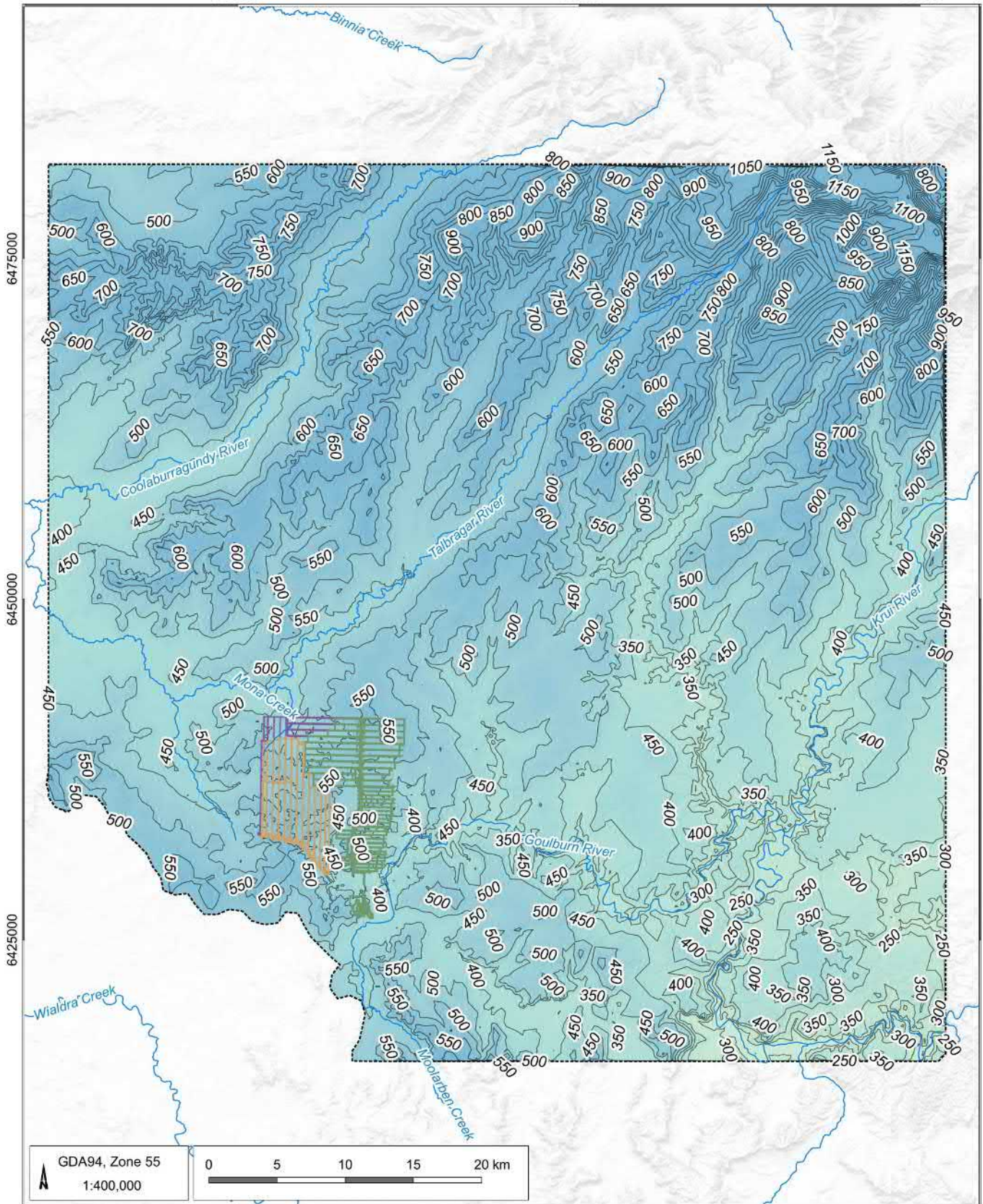
Appendix A 4

Model layer contours

750000

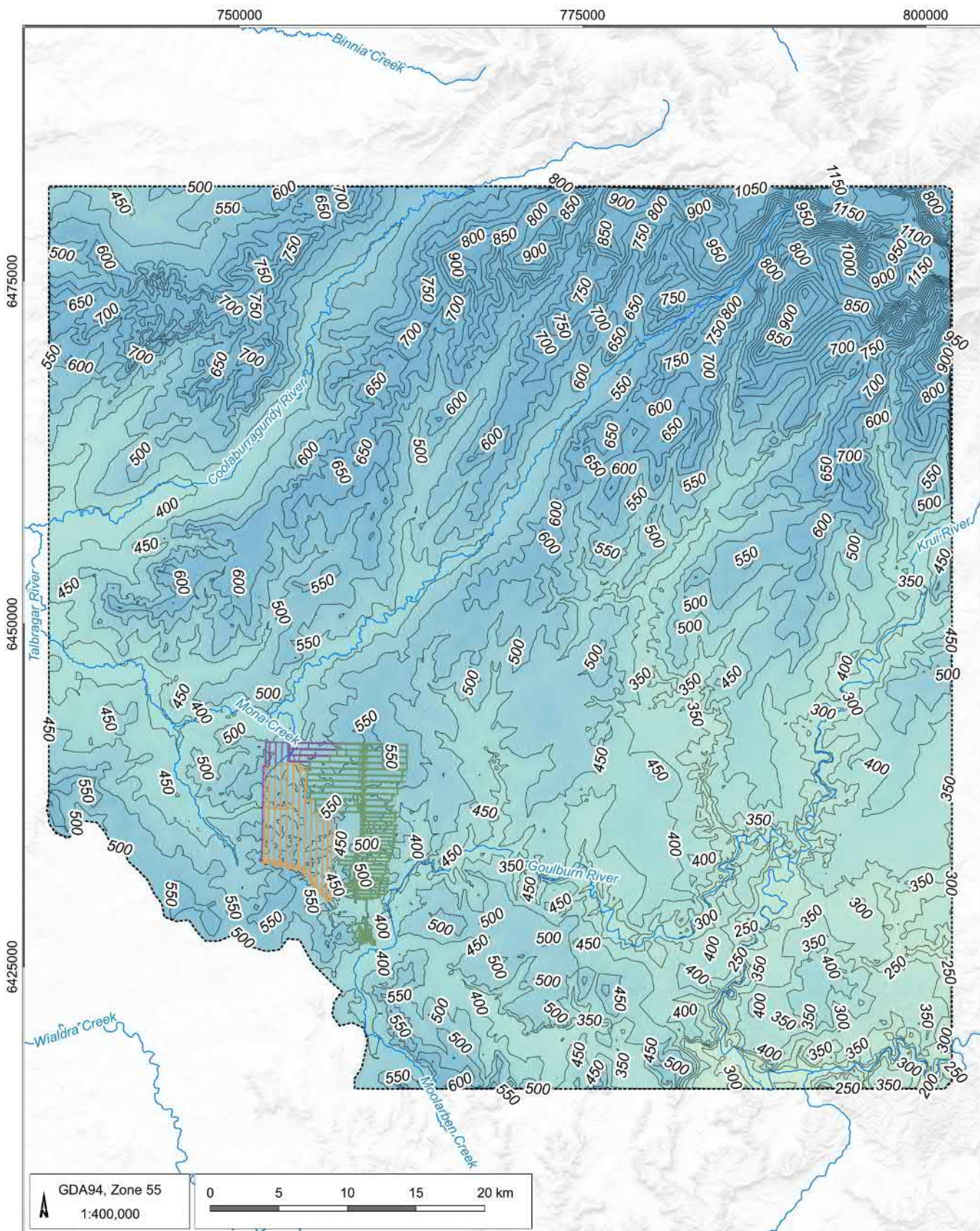
775000

800000



DATE
27/01/2022

FIGURE No:
A 4.1



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model domain

Elevation (mAHd)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

Ulan MOD6 GIA (G1985G)

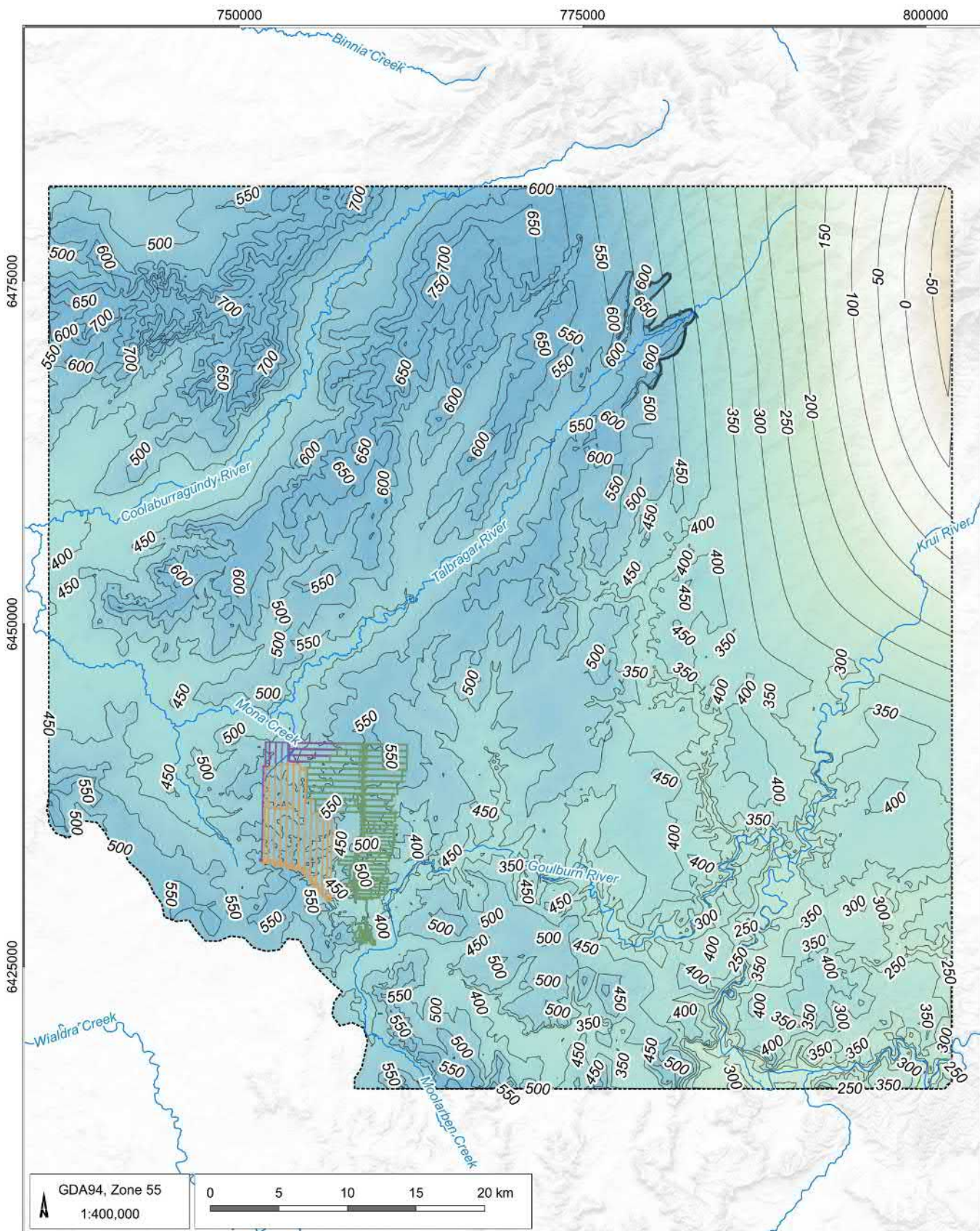
Base of model layer contours - Layer 1



AGE

DATE
27/01/2022

FIGURE No:
A 4.2



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model domain

Elevation (mAHd)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

Ulan MOD6 GIA (G1985G)

Base of model layer contours - Layer 2



AGE

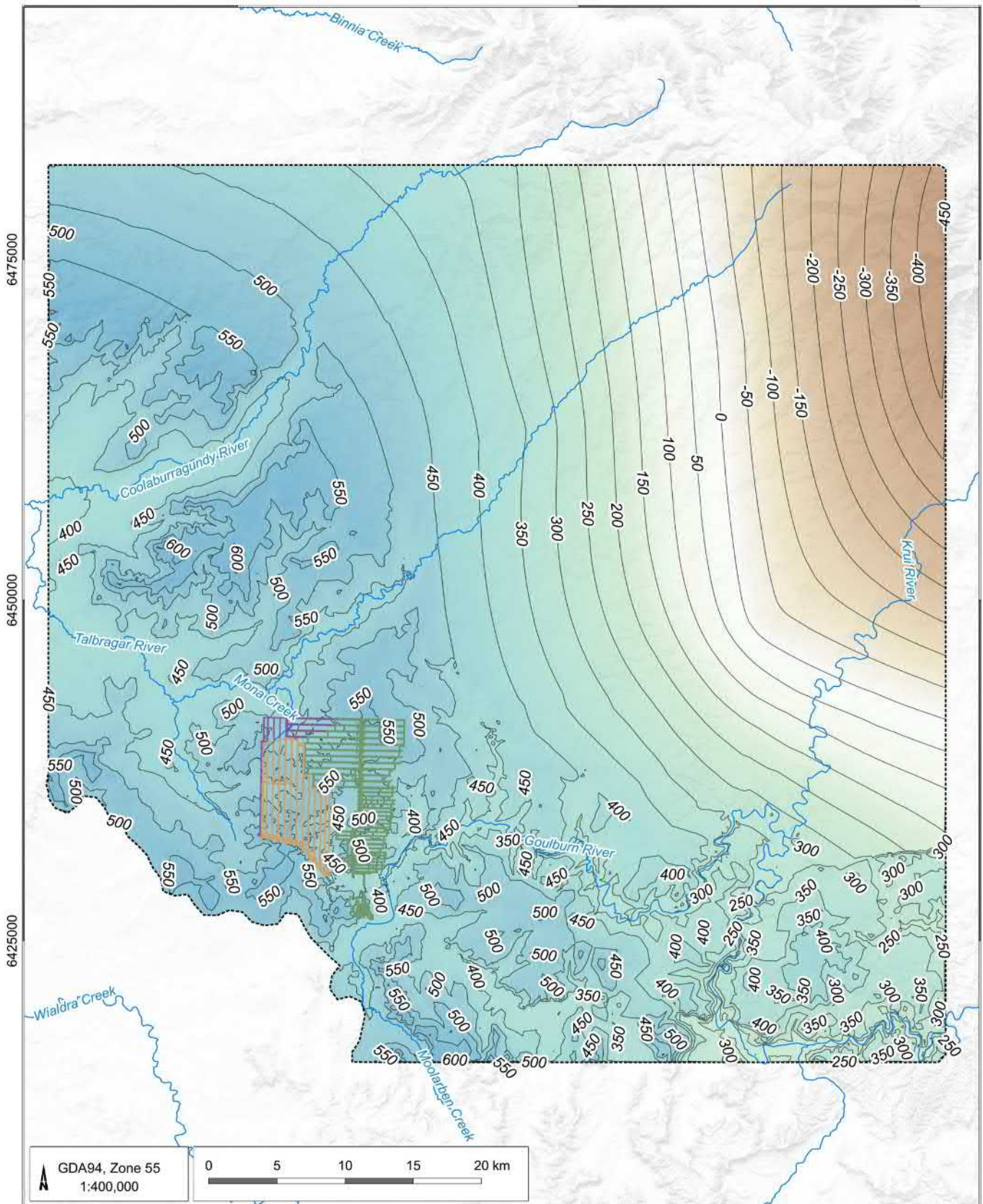
DATE
27/01/2022

FIGURE No:
A 4.3

750000

775000

800000



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model domain

Elevation (mAHD)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

Ulan MOD6 GIA (G1985G)

Base of model layer contours - Layer 3



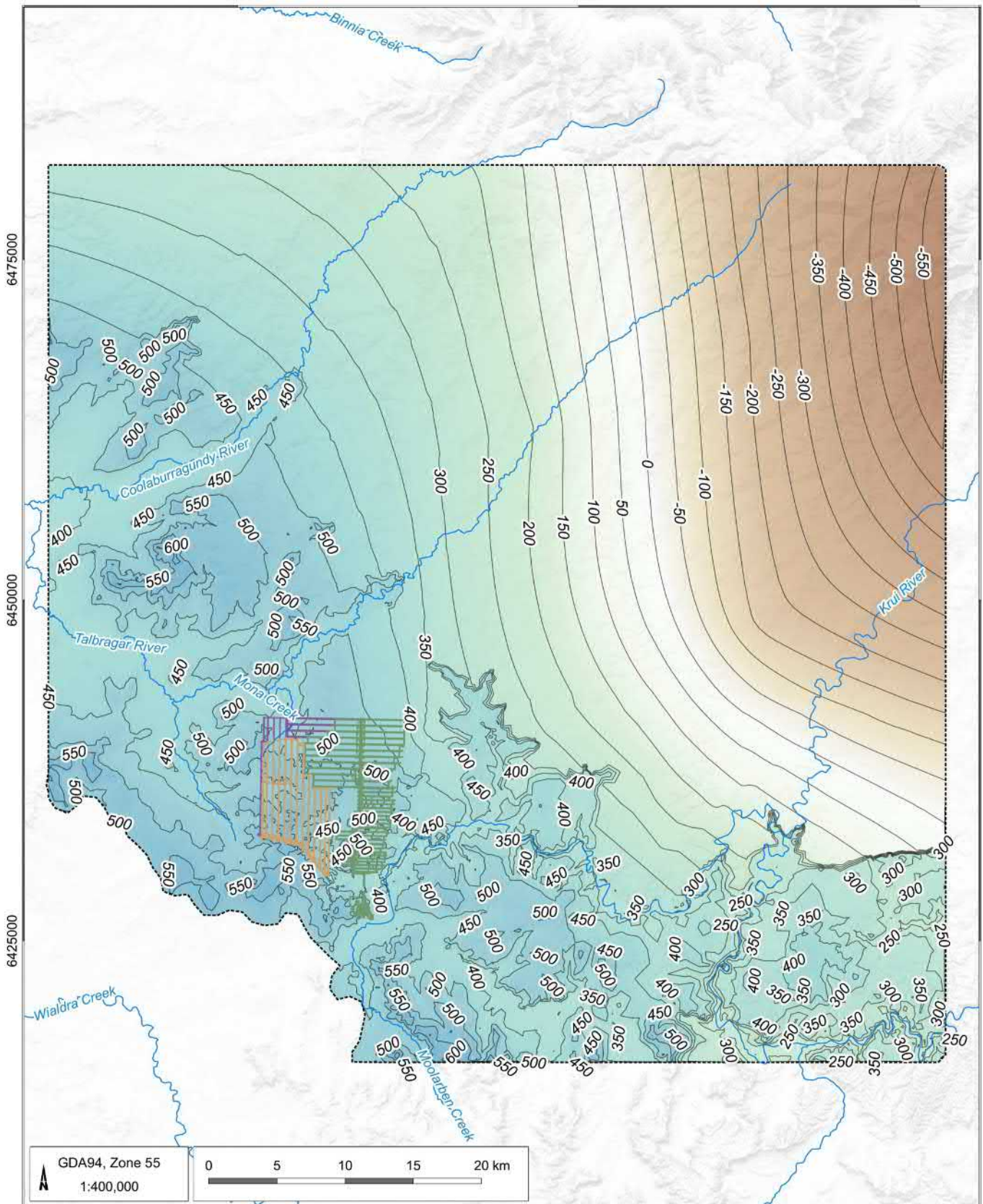
DATE
27/01/2022

FIGURE No:
A 4.4

750000

775000

800000



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model domain

Elevation (mAH)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

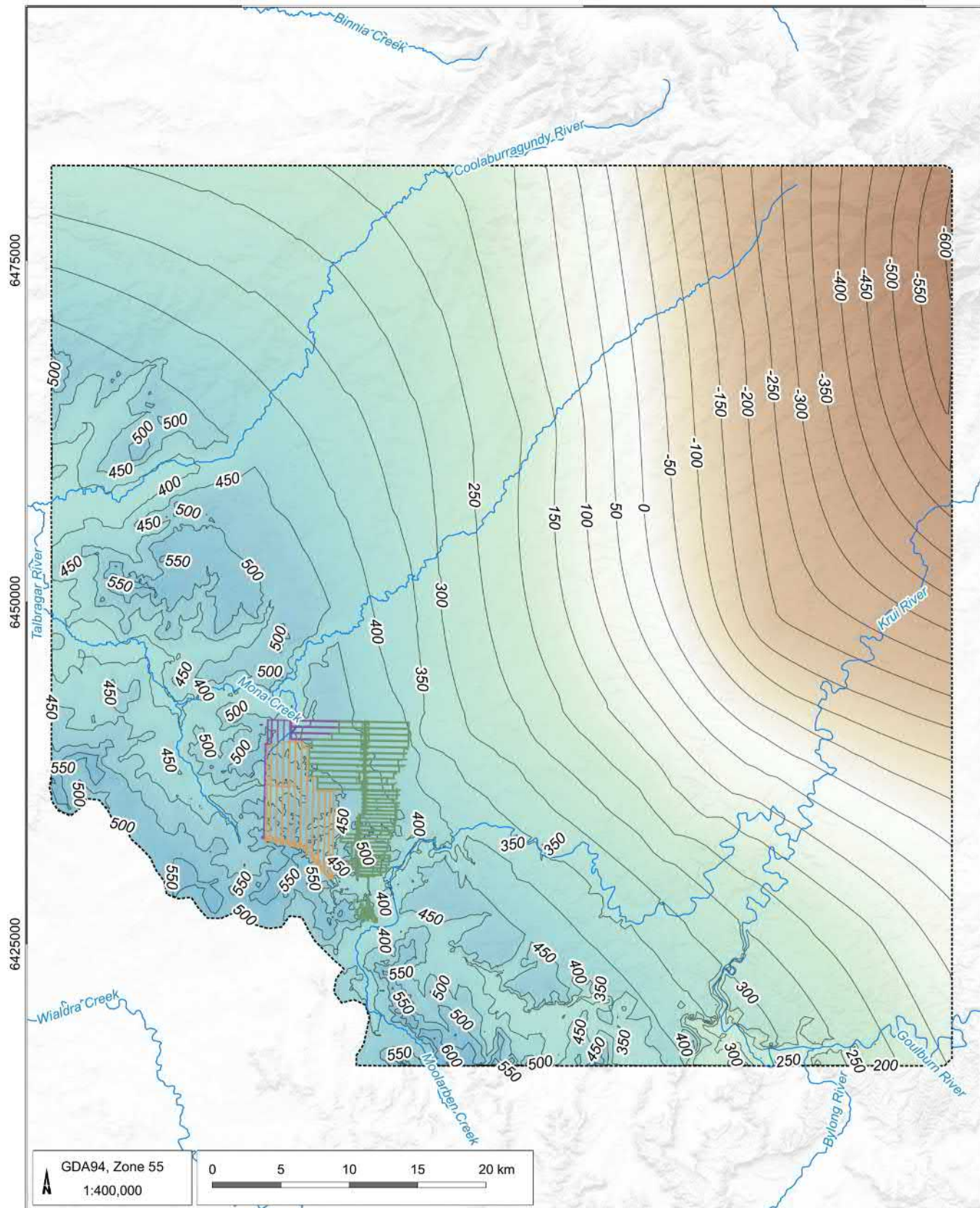
Ulan MOD6 GIA (G1985G)

Base of model layer contours - Layer 4



DATE
27/01/2022

FIGURE No:
A 4.5



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model domain

Elevation (mAHd)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

Ulan MOD6 GIA (G1985G)

Base of model layer contours - Layer 5



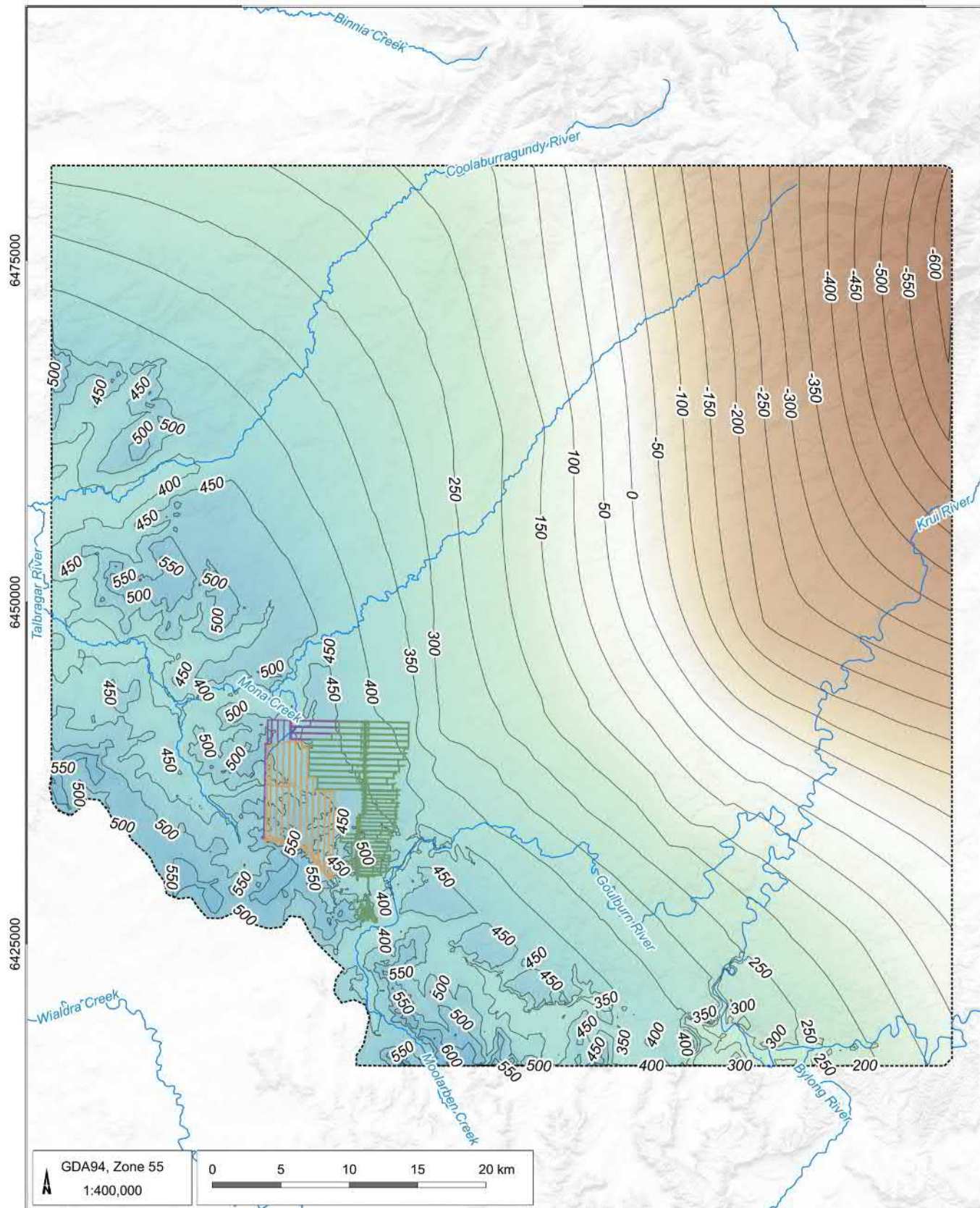
AGE

DATE
27/01/2022FIGURE No:
A 4.6

750000

775000

800000



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model domain

Elevation (mAHD)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

Ulan MOD6 GIA (G1985G)

Base of model layer contours - Layer 6



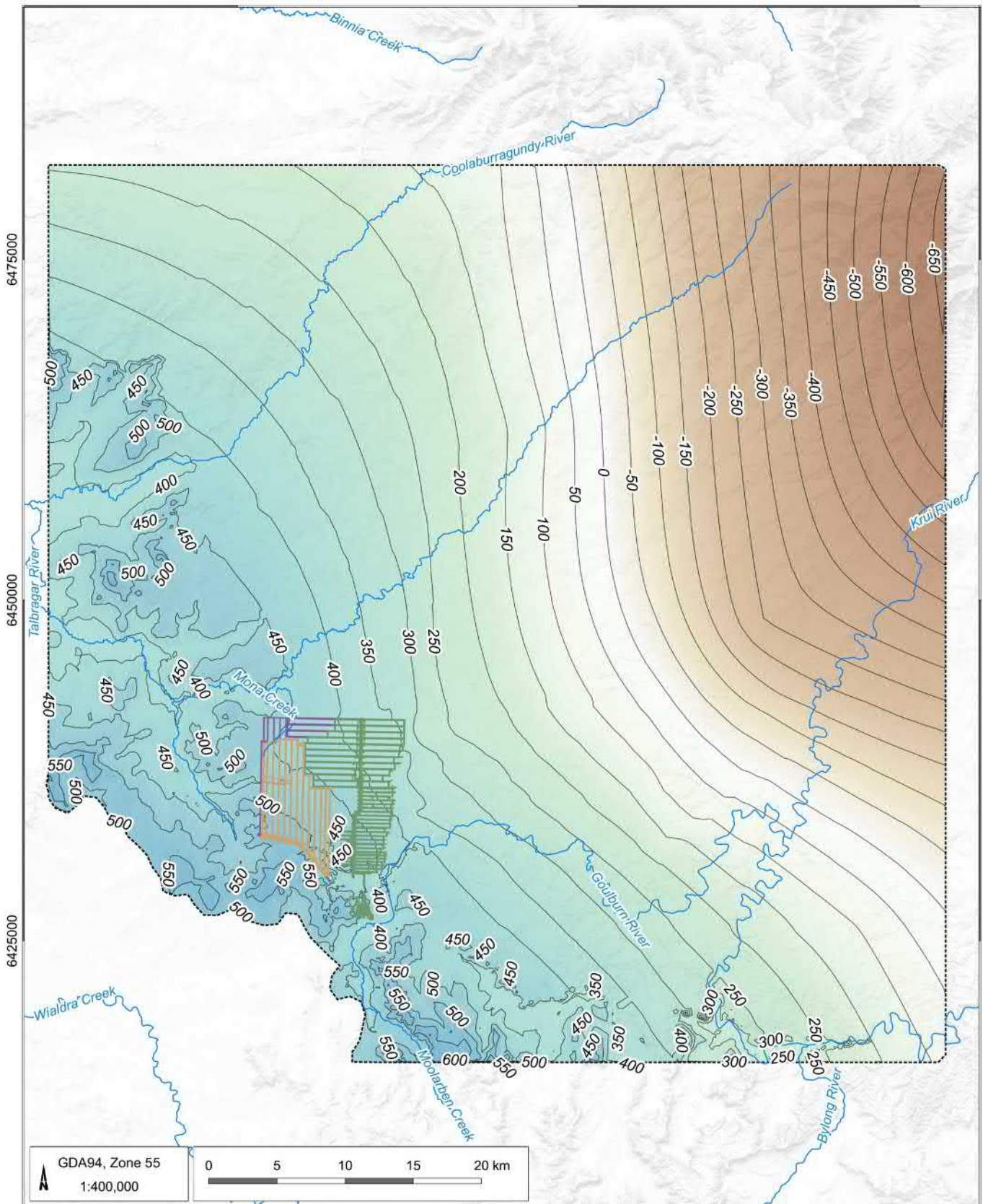
AGE

DATE
27/01/2022FIGURE No:
A 4.7

750000

775000

800000



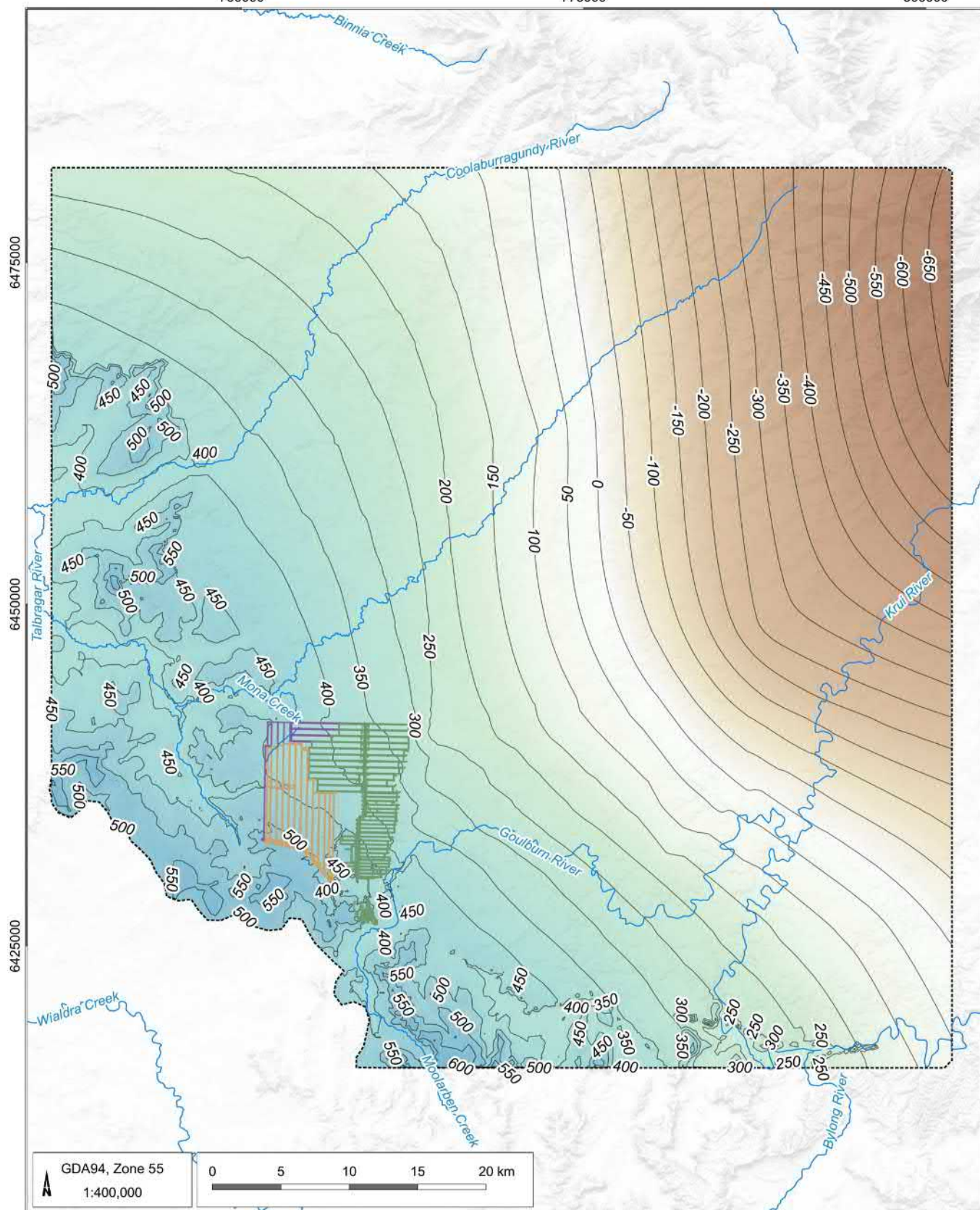
AGE

DATE
27/01/2022FIGURE No:
A 4.8

750000

775000

800000



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model domain

Elevation (mAHd)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

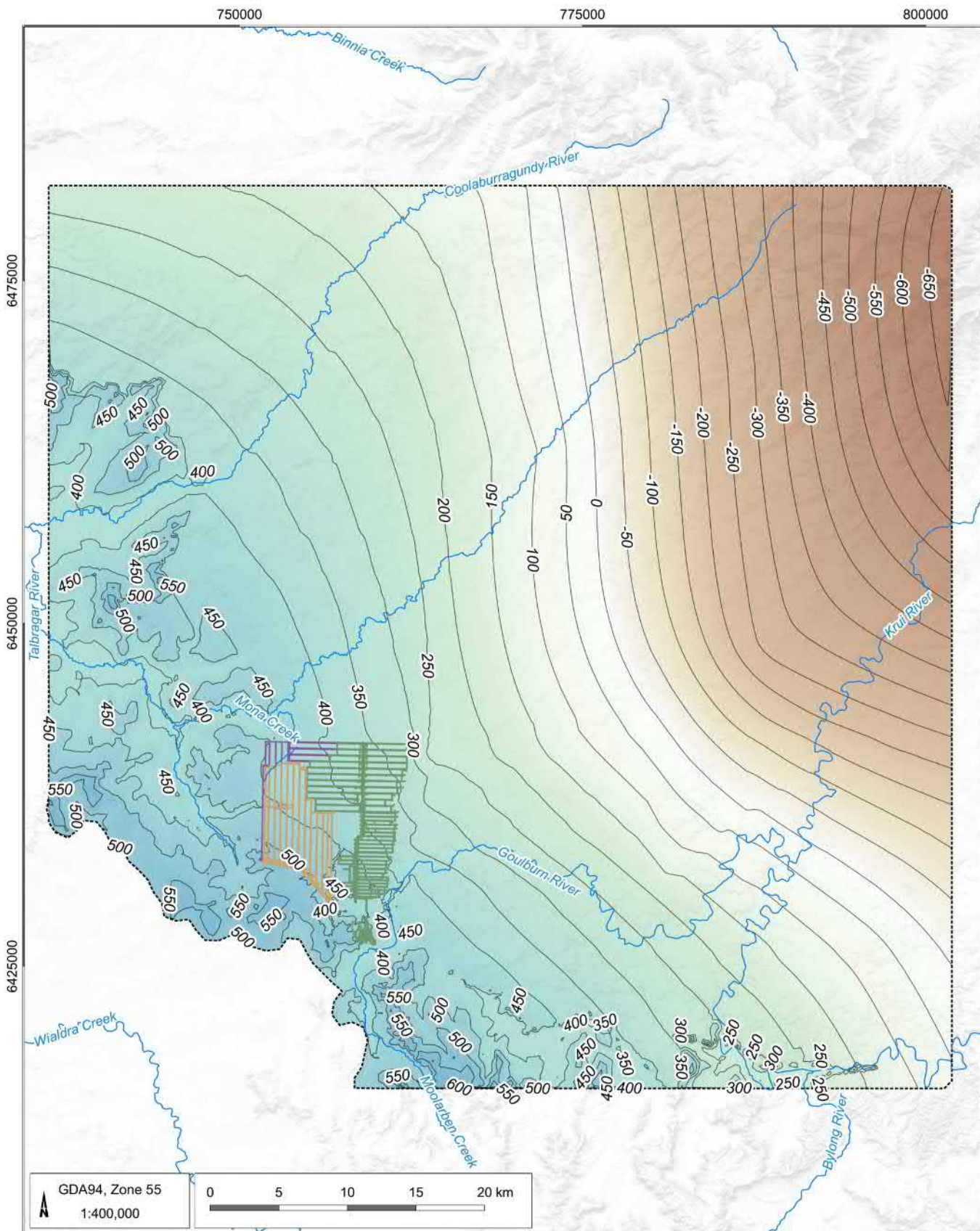
Ulan MOD6 GIA (G1985G)

Base of model layer contours - Layer 8



AGE

DATE
27/01/2022FIGURE No:
A 4.9



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- ▭ Model domain

Elevation (mAHD)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

Ulan MOD6 GIA (G1985G)

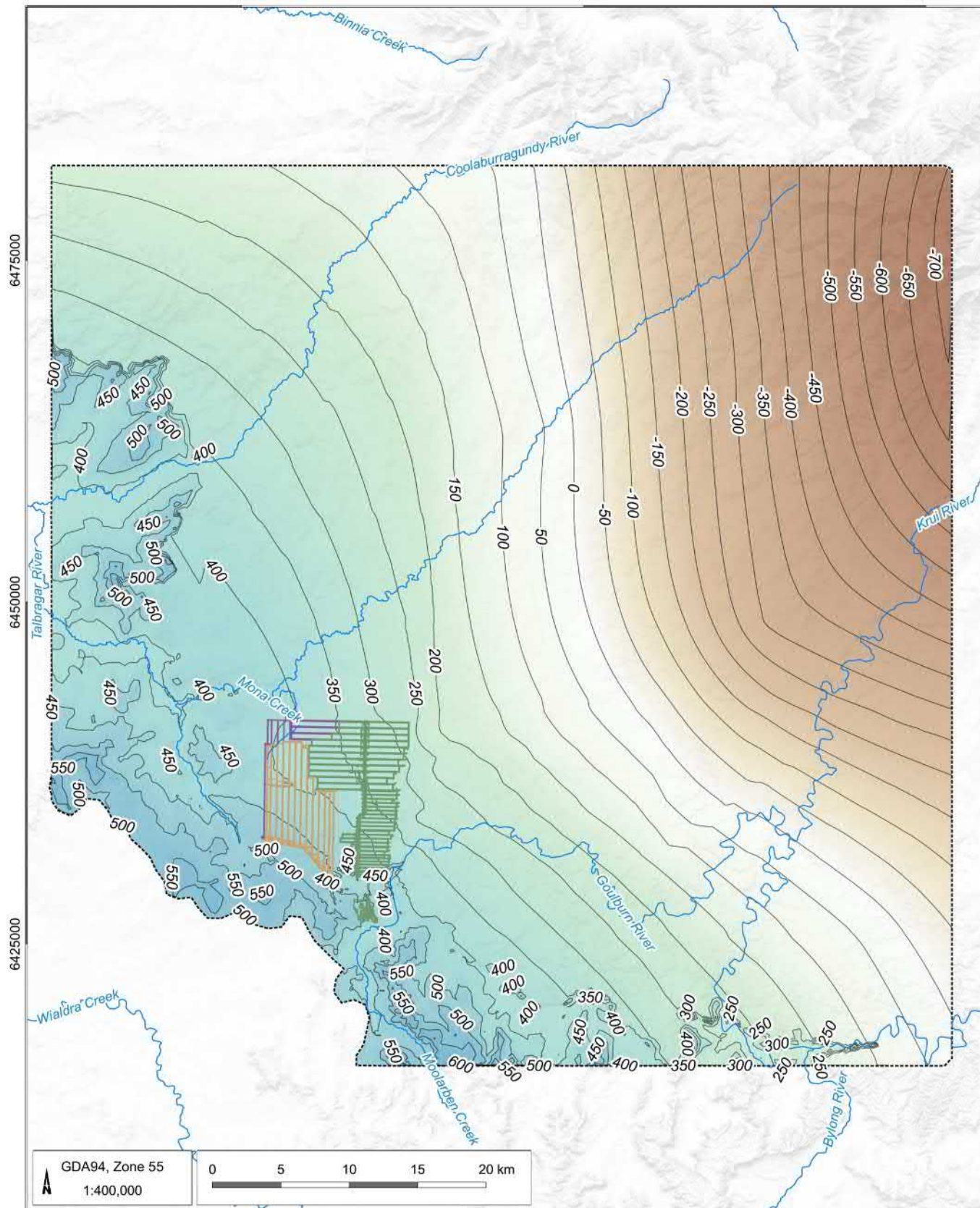
Base of model layer contours - Layer 9



AGE

DATE
27/01/2022

FIGURE No:
A 4.10



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model domain

Elevation (mAH)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

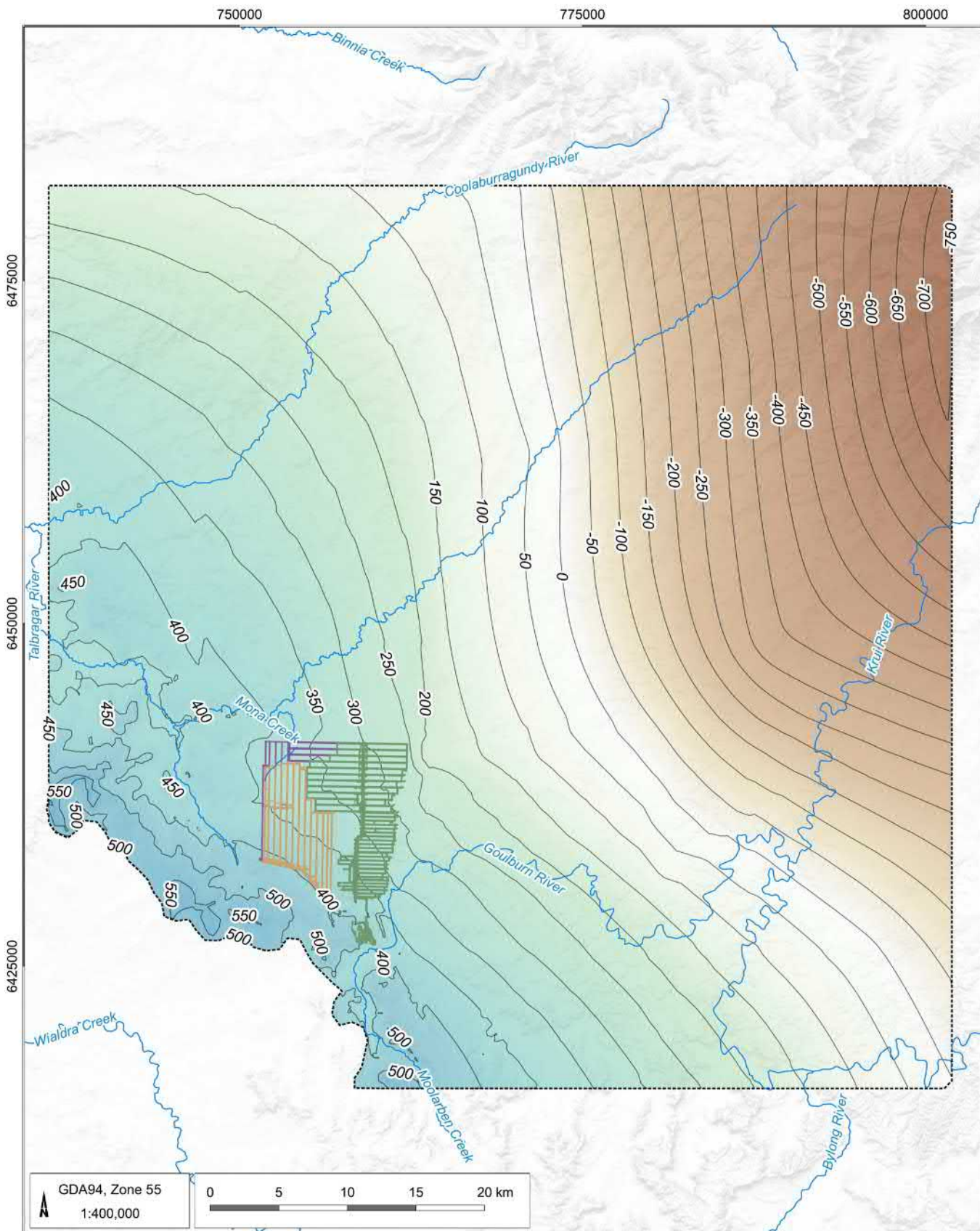
Ulan MOD6 GIA (G1985G)

Base of model layer contours - Layer 10



AGE

DATE
27/01/2022FIGURE No:
A 4.11



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model domain

Elevation (mAHd)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

Ulan MOD6 GIA (G1985G)

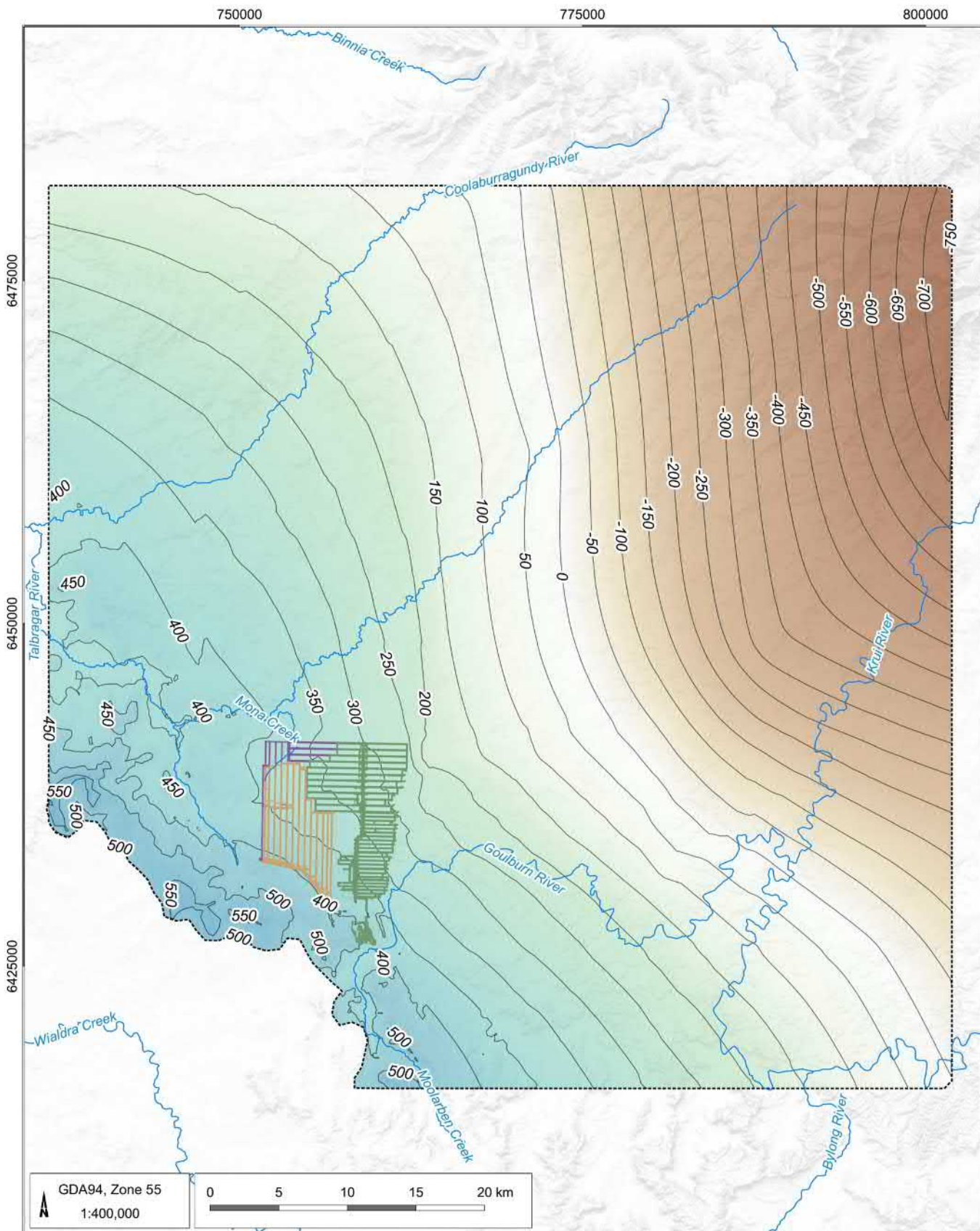
Base of model layer contours - Layer 11



AGE

DATE
01/02/2022

FIGURE No:
A 4.12



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model domain

Elevation (mAHd)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

Ulan MOD6 GIA (G1985G)

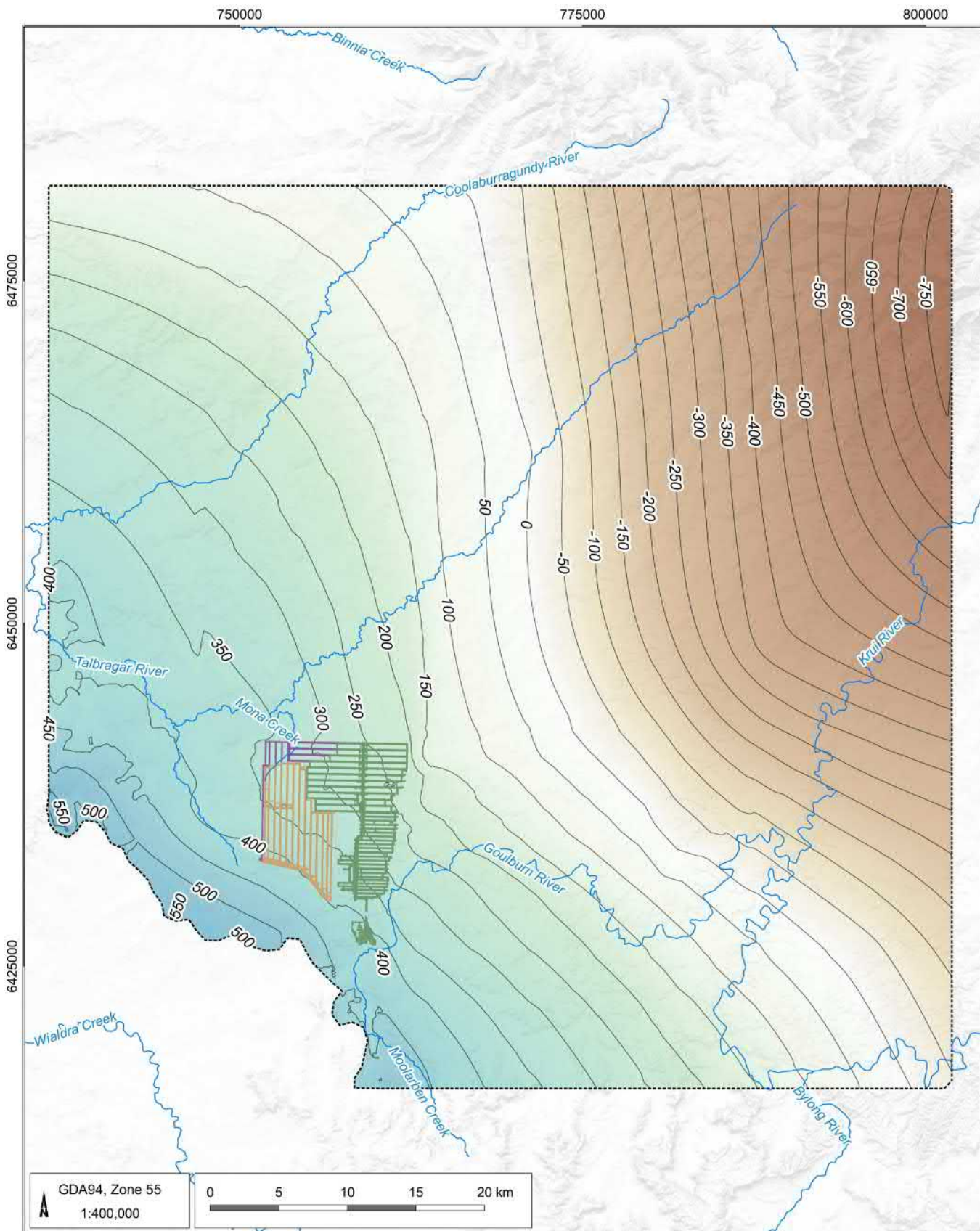
Base of model layer contours - Layer 12



AGE

DATE
27/01/2022

FIGURE No:
A 4.13



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model domain

Elevation (mASL)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

Ulan MOD6 GIA (G1985G)

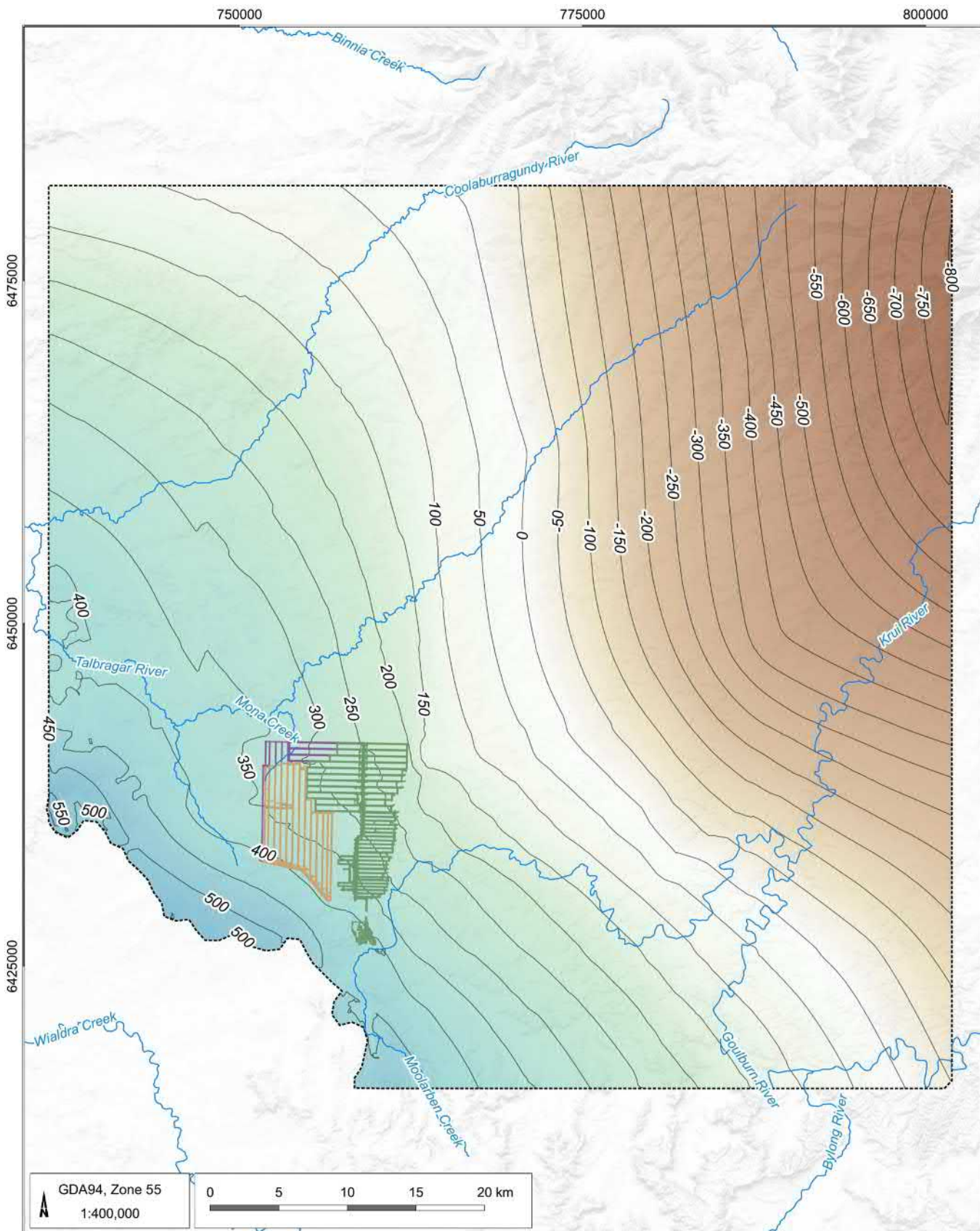
Base of model layer contours - Layer 13



AGE

DATE
27/01/2022

FIGURE No:
A 4.14



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model domain

Elevation (mAH)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

Ulan MOD6 GIA (G1985G)

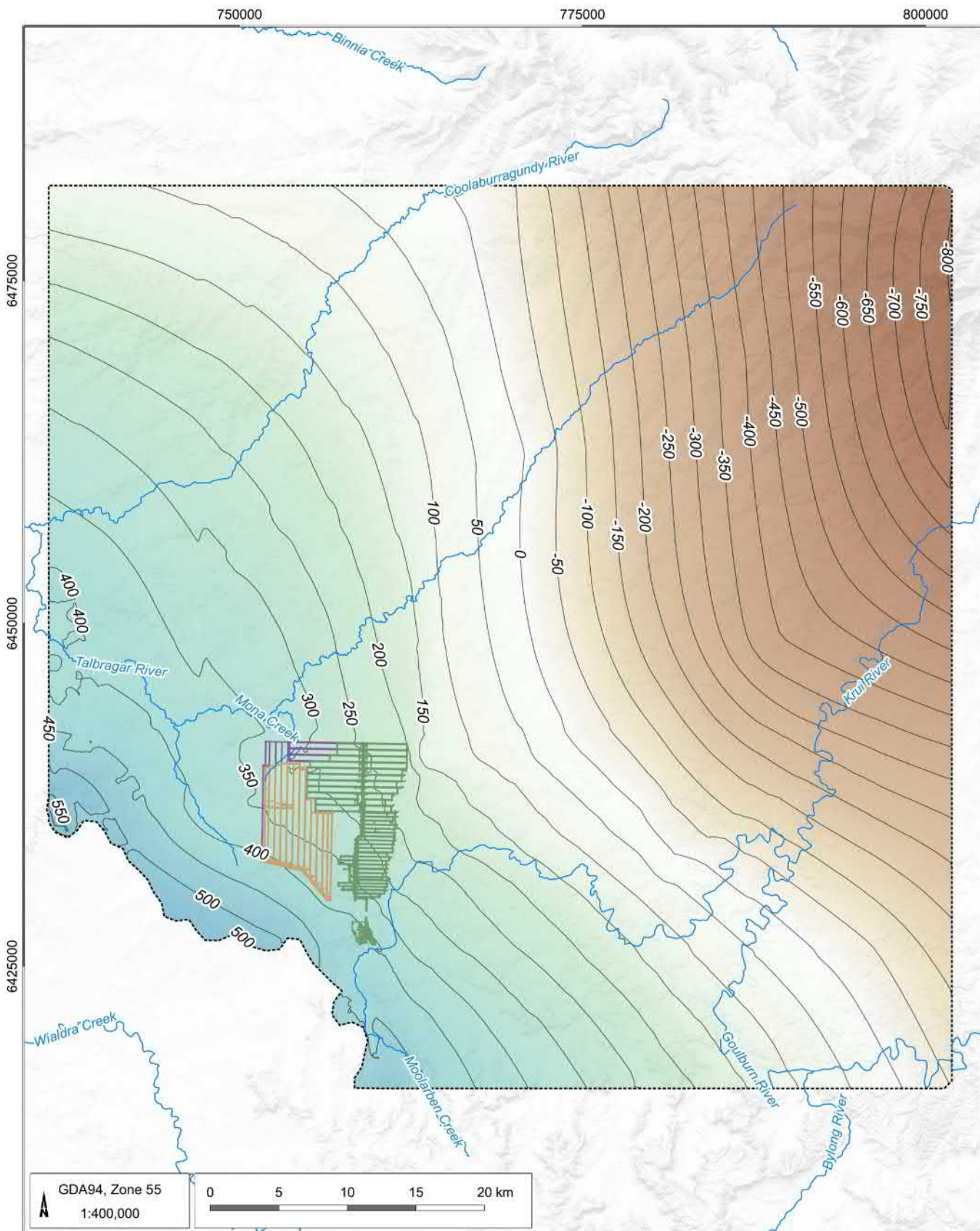
Base of model layer contours - Layer 14



AGE

DATE
27/01/2022

FIGURE No:
A 4.15



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model domain

Elevation (mAH)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

Ulan MOD6 GIA (G1985G)

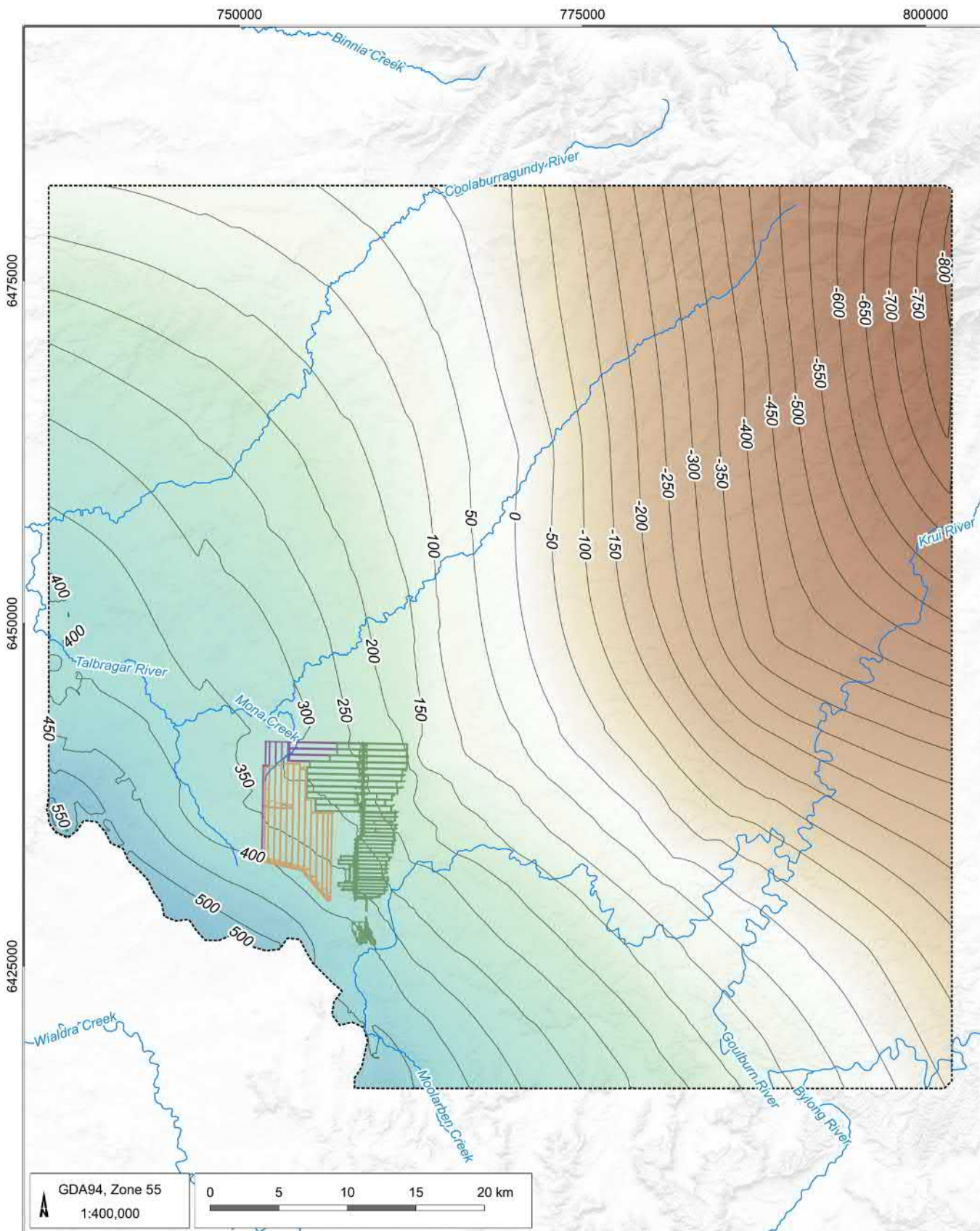
Base of model layer contours - Layer 15



AGE

DATE
27/01/2022

FIGURE No:
A 4.16



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model domain

Elevation (mAHd)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

Ulan MOD6 GIA (G1985G)

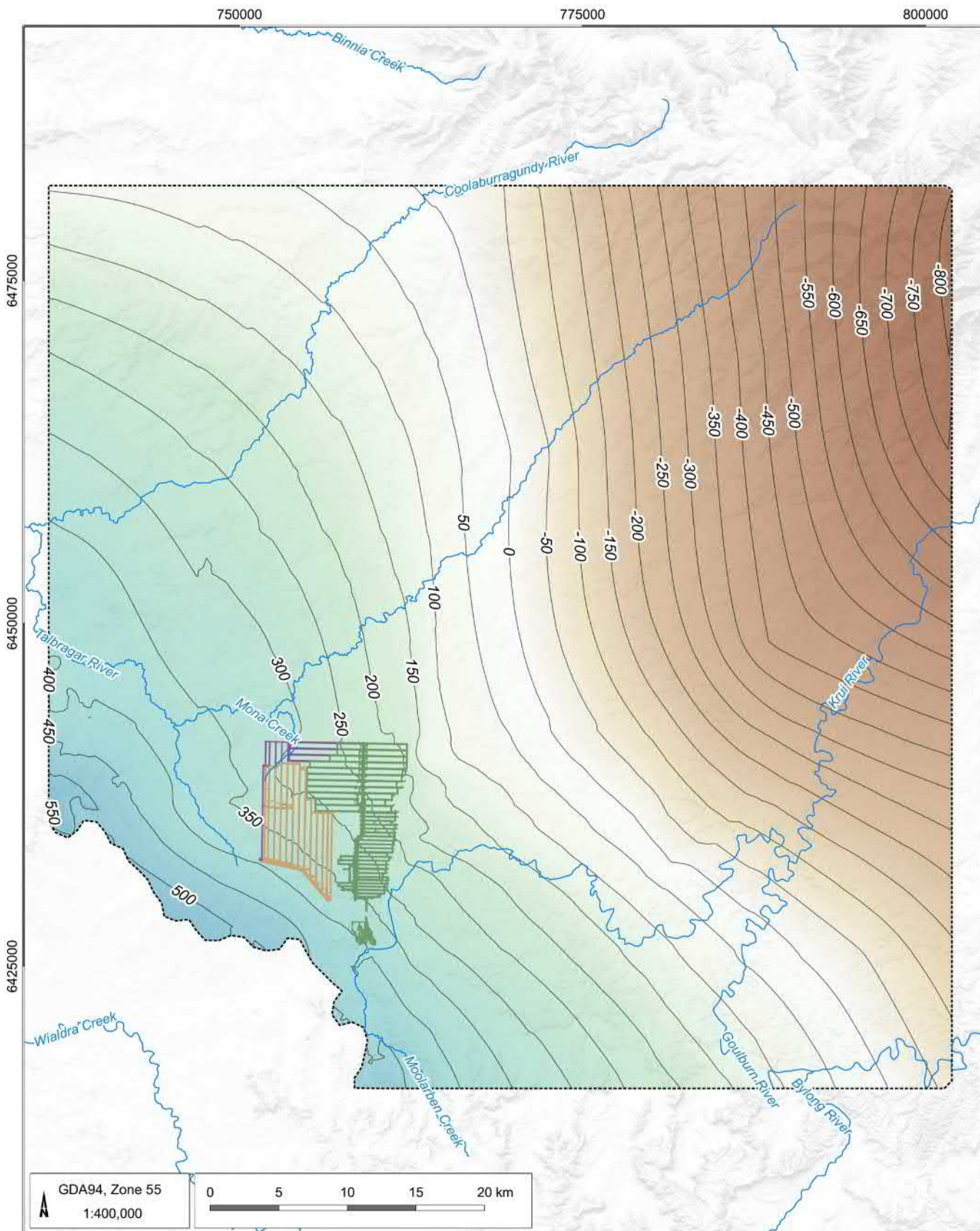
Base of model layer contours - Layer 16



AGE

DATE
27/01/2022

FIGURE No:
A 4.17



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model domain

Elevation (mAHd)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

Ulan MOD6 GIA (G1985G)

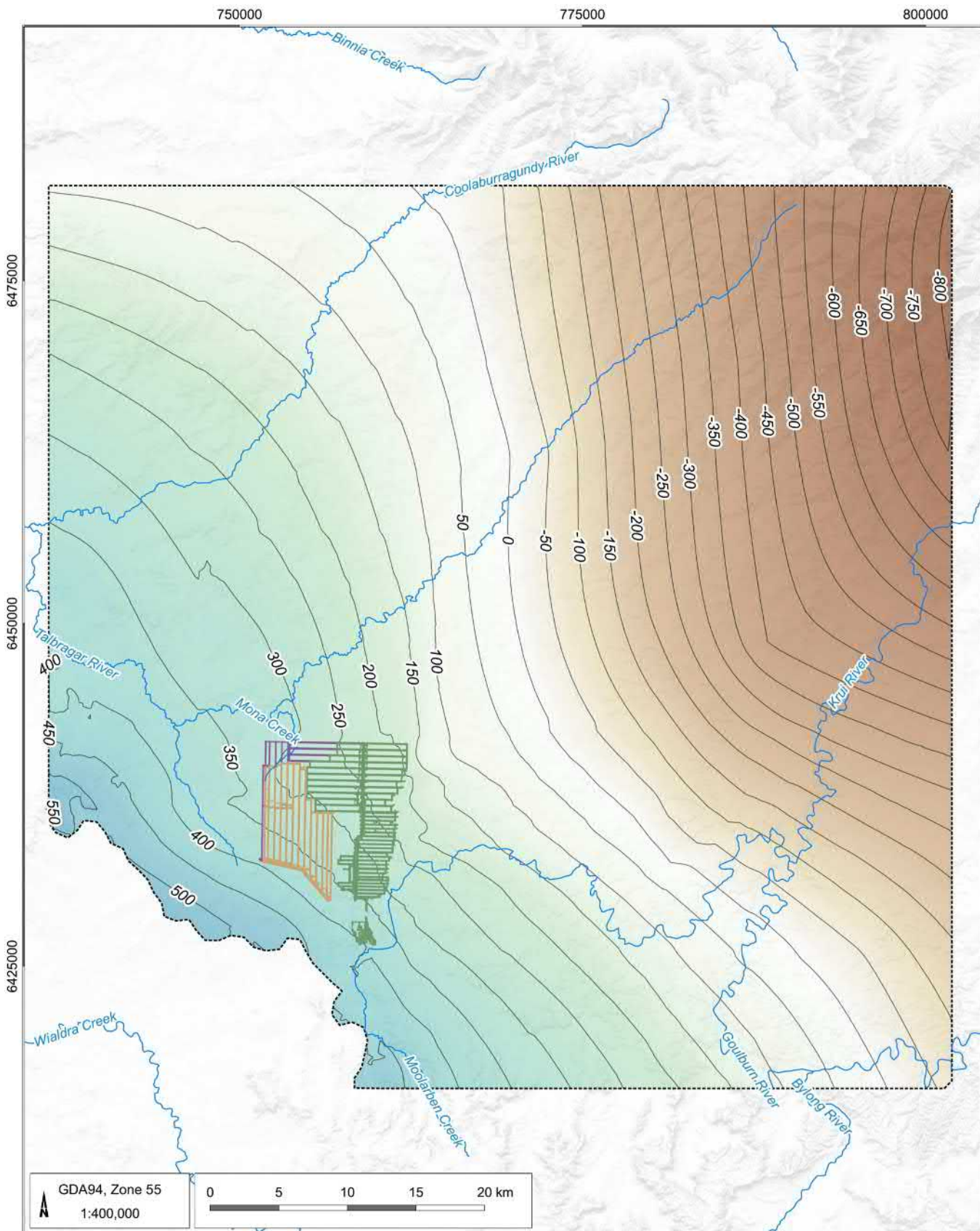
Base of model layer contours - Layer 17



AGE

DATE
27/01/2022

FIGURE No:
A 4.18



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model domain

Elevation (mAH)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

Ulan MOD6 GIA (G1985G)

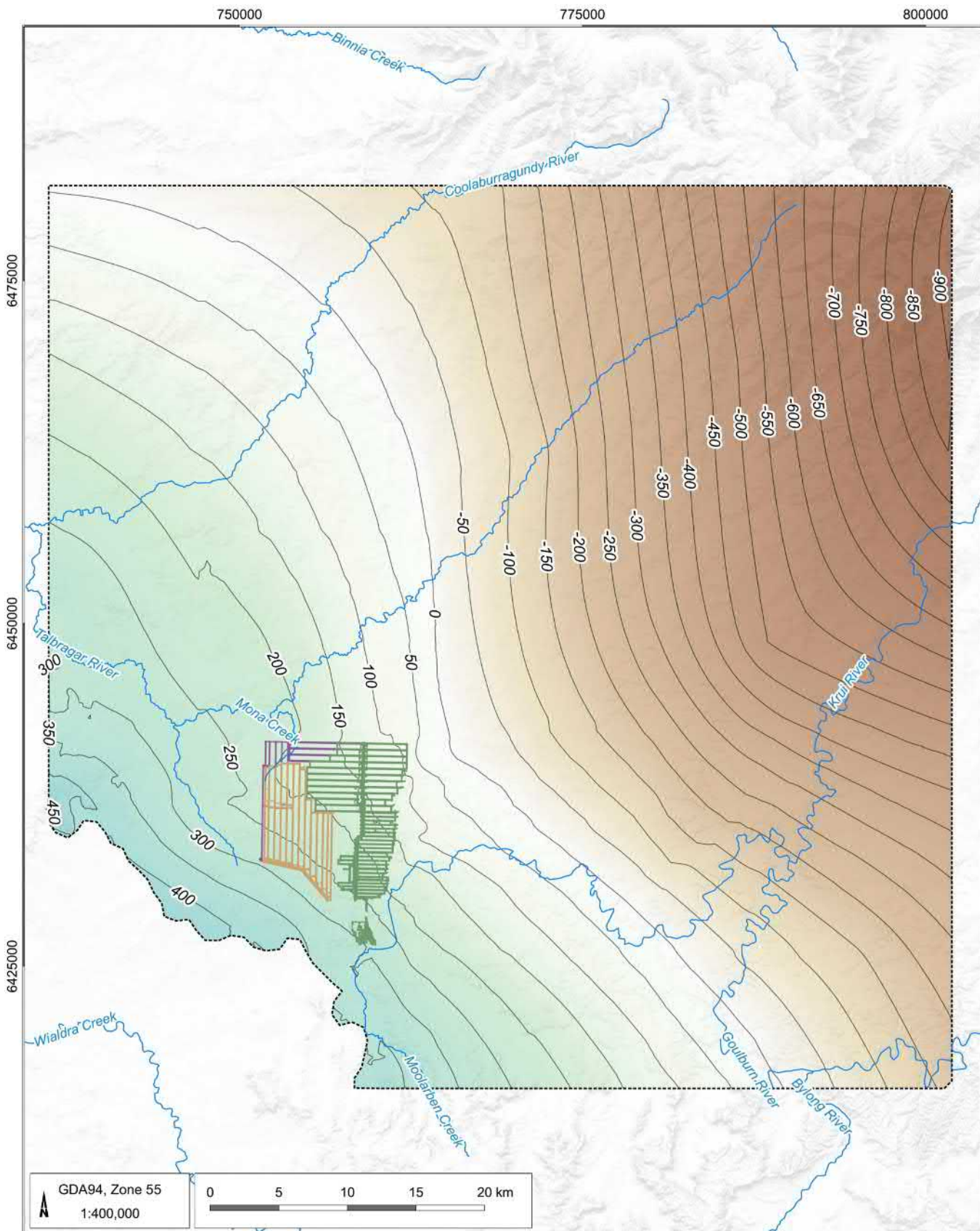
Base of model layer contours - Layer 18



AGE

DATE
27/01/2022

FIGURE No:
A 4.19



LEGEND

- Major drainage
- Contour line
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Model domain

Elevation (mAHd)

- 850
- 600
- 400
- 200
- 100
- 0
- 100
- 200
- 400
- 600

Ulan MOD6 GIA (G1985G)

Base of model layer contours - Layer 19



AGE

DATE
27/01/2022

FIGURE No:
A 4.20

Appendix B

Compliance with government policy

B 1 Compliance with New South Wales Policy

B1.1 Aquifer interference policy (AIP)

This section discusses the ability of proposed modification to comply with the AIP. Table B 1 to Table B 2 below compare the groundwater impact predictions for MOD6 against the requirements under the AIP. Table B 3 to Table B 4 address the minimal impact considerations, as defined in the Aquifer Interference Assessment Framework.

Table B 1 Accounting for or preventing the take of water

AIP requirement		Proponent response
1	Described the water source (s) the activity will take water from?	Section 2.1 describes the water sharing plans that the UCMPL will take water from, namely (for approved and the proposed modification): Incidental water take from water sources associated with the Permian sediments: • North Coast Fractured and Porous Rock Groundwater Sources 2016 - Sydney Basin - North Coast Groundwater Source; and • NSW Murray Darling Basin Porous Rock Groundwater Sources 2020 - Sydney Basin MDB (Other) Management Zone. Indirect water take through: • North Coast Fractured and Porous Rock Groundwater Sources 2016 - Oxley Basin Coast Groundwater Source; • Hunter Unregulated and Alluvial Water Sources 2009 - Upper Goulburn River Water Source; • NSW Murray Darling Basin Porous Rock Groundwater Sources Order 2020 - Sydney Basin MDB (Macquarie Oxley) Management Zone; • Macquarie Bogan Unregulated Rivers Water Sources 2012 - Upper Talbragar River Water Source; and • Macquarie - Castlereagh Groundwater Sources Order 2020 - Talbragar Alluvial Groundwater Source.
2	Predict the total amount of water that will be taken from each connected groundwater or surface water source on an annual basis as a result of the activity?	Section 7.1 and Section 8.1 summarise the peak take of groundwater and surface water from each water source due to the approved mining and the additional incremental effect of the proposed modification.
3	Predicted the total amount of water that will be taken from each connected groundwater or surface water source after the closure of the activity?	Estimates of take post-mining are presented in Section 8.1.
4	Made these predictions in accordance with Section 3.2.3 of the AIP? (page 27)	Based on 3D numerical modelling.
5	Described how and in what proportions this take will be assigned to the affected aquifers and connected surface water sources?	Section 8.1 summarises the peak take of surface water and groundwater from each water source due to mining at UCMPL (incorporating the proposed modification).
6	Described how any licence exemptions might apply?	Refer to Section 8.1

AIP requirement		Proponent response
7	Described the characteristics of the water requirements?	Section 5 describes the hydrogeology; Section 7.1 presents the predicted mine inflows; and Section 8.1 presents the predicted take.
8	Determined if there are sufficient water entitlements and water allocations that are able to be obtained for the activity?	Section 2.1.2 describes the entitlements held by the proponent and where any additional water allocations may be required. The proponent will ensure all necessary water licences are obtained for UCMPL.
9	Considered the rules of the relevant water sharing plan and if it can meet these rules?	Refer to Section 8.1.
10	Determined how it will obtain the required water?	Via direct and indirect take (refer to Section 8.1). Refer to Section 8.1 for discussion regarding available water access licences.
11	Considered the effect that activation of existing entitlement may have on future available water determinations?	Not applicable.
12	Considered actions required both during and post-closure to minimise the risk of inflows to a mine void as a result of flooding?	Refer to the Surface Water Assessment
13	Developed a strategy to account for any water taken beyond the life of the operation of the Project?	Refer to Section 8.1
	Will uncertainty in the predicted inflows have a significant impact on the environment or other authorised water users? Items 14-16 must be addressed if so.	Refer to Section 9.
14	Considered any potential for causing or enhancing hydraulic connections, and quantified the risk?	Observations (refer to Section 5.8 and Appendix A) have guided the application of the empirical formulas to determine the height of continuous fracturing. Available information shows that the zone of continuous / connected fracturing has / will come to the surface in the southern extents of the approved mine plan. No areas in the proposed modification mine plan are expected to fracture to the surface. The impact assessment is covered in Section 8 and groundwater modelling has included hydraulic property changes due to fracturing, the impacts of which are encapsulated in the predictions.
15	Quantified any other uncertainties in the groundwater or surface water impact modelling conducted for the activity?	Refer to Section 9.
16	Considered strategies for monitoring actual and reassessing any predicted take of water throughout the life of the Project, and how these requirements will be accounted for?	Refer to Sections 8.1 & 10.

Table B 2 Determining water predictions

AIP requirement		Proponent response
1	Establishment of baseline groundwater conditions?	Refer to Section 5. The monitoring bore network at the UCC has been installed over a number of different campaigns since 1997. The monitoring network has been adapted over time to ensure that good spatial coverage is maintained.
2	A strategy for complying with any water access rules?	Refer to Section 8.1.
3	Potential water level, quality or pressure drawdown impacts on nearby basic landholder rights water users?	Refer to Section 0
4	Potential water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources?	Refer to Sections 0, 8.1.4, & 0.
5	Potential water level, quality or pressure drawdown impacts on groundwater dependent ecosystems?	There are no high priority GDEs, as defined within WSPs, within the predicted area of drawdown related to the proposed modification (refer to Section 8.3).
6	Potential for increased saline or contaminated water inflows to aquifers and highly connected river systems?	Refer to Section 8.4
7	Potential to cause or enhance hydraulic connection between aquifers?	Connections have already been made between the major aquifers due to fracturing that has already occurred. The footprint of these connections will be increased, but there will be no new connections between aquifers
8	Potential for river bank instability, or high wall instability or failure to occur?	Refer to Surface Water Assessment (Engeny, 2021)
9	Details of the method for disposing of extracted activities (for CSG activities)?	N/A

Table B 3 Minimal impact considerations – Less Productive Alluvial Aquifer

	AIP requirement	Proponent response
1	Water table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 metres from any: • high priority groundwater dependent ecosystem or • high priority culturally significant site listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 metre water table decline cumulatively at any water supply work.	Level 1 Impact – Acceptable Refer to Section 7 High priority GDEs or high priority culturally significant sites have not been identified in the area of the predicted incremental drawdown.
2	Water pressure A cumulative pressure head decline of not more than 40% of the 'post-water sharing plan' pressure head above the base of the water source to a maximum of a 2 metre decline, at any water supply work.	Not Applicable
3	Water quality Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity. No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. No mining activity to be below the natural ground surface within 200 metres laterally from the top of high bank or 100 metres vertically beneath (or the three dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a 'reliable water supply'.	Level 1 Impact – Acceptable Refer to Section 8.4 Groundwater does not discharge to Mona Creek and the modification is not predicted to change this process.

Table B 4 Minimal impact considerations – Less Productive Porous or Fractured Rock Aquifer

AIP requirement	Proponent response
Water table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 metres from any: • high priority groundwater dependent ecosystem or • high priority culturally significant site listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 metre water table decline cumulatively at any water supply work.	Level 1 Impact – Acceptable Refer to Section 7 High priority GDEs or high priority culturally significant sites have not been identified in the area of the predicted incremental drawdown.
Water pressure A cumulative pressure head decline of not more than a 2 metre decline, at any water supply work.	Level 2 Impact – Make good provisions apply Refer to Section 8.2 The numerical model predicts drawdown >2 m at third-party landholder bores (water supply works) during mining. These bores have been identified for the approved mine plan and proposed modification. The development consent includes conditions regarding compensatory water supply. Post-mining modelling predicts additional bores with >2 m drawdown, however the time period that the impact is predicted varies and is generally in the very long-term.
Water quality Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.	Level 1 Impact – Acceptable Refer to Section 8.4 No change to the beneficial use of groundwater sources due to the activity (modification 6).

B 2 Compliance with Commonwealth government policy

B2.1 Commonwealth Assessment Requirements for the proposed modification

Table B 5 Summary of changes to hydrological characteristics

Is there a substantial change to the hydrology of the water resource for:	Potential for significant impact
Flow volume?	No – minor reduction in baseflow
Flow timing?	No
Flow duration and frequency of water flows?	No
Recharge rates?	No – no change to recharge rates from MOD6
Aquifer pressure or pressure relationships between aquifers?	No – depressurisation already occurring in the area, extent expanded slightly but no additional aquifers impacted on
Groundwater table levels?	No – dewatering already occurring in the area, extent expanded slightly but not impacting on existing users
Groundwater/surface interactions?	No – minimal additional reductions to baseflow (7.6% increase for Talbragar system, equating to 0.06% of total baseflow to the Talbragar system)
River/floodplain connectivity?	No
Inter-aquifer connectivity?	No – fracturing above longwall panels will cause enhanced permeability, but connections already exist due to approved mining
Coastal processes?	Not applicable
Large scale subsidence?	No -Subsidence will occur but no impacts on resource function are expected
Other uses?	No
State water resource plans?	No – Proponents hold licencing for current mining and will acquire the additional licencing from within the GCAA group
Cumulative impact?	No - MOD6 does not influence inflow or drawdown at neighbouring Moolarben mine

Table B 6 Summary of impacts to the water quality of the water resource compared to the Department of the Environment and Energy (DoEE) guidelines

Is there a substantial change in water quality of the water resource?	Comment
Create risks to human or animal health or the condition of the natural environment?	No
Substantially reduce the amount of water available for human consumptive uses or for other uses dependent on water quality?	No
Cause persistent organic chemicals, heavy metals, salt or other potentially harmful substances to <u>accumulate in the</u> environment?	Refer to Section 8.4.8.5 As there are no open cut voids associated with proposed modification there will be no evaporative concentration of salts in groundwaters and therefore there is no mechanism for significant changes to groundwater salinity due to mining.
Results in worsening of local water quality where local water quality is superior to local or regional water quality objectives (i.e. ANZECC guidelines for Fresh and Marine Water Quality)?	No
Salt concentration/generation?	As there are no open cut voids associated with proposed modification there will be no evaporative concentration of salts in groundwaters and therefore there is no mechanism for significant changes to groundwater salinity due to mining.
Cumulative impact?	Cumulative impacts have been predicted using a numerical model. The cumulative impacts are not predicted to result in a substantial change in water quality.
If significant impact on hydrology or water quality above, the likelihood of significant impacts to function and ecosystem integrity are to be assessed. The ecosystem function and integrity of a water resource includes the ecosystem components, processes and benefits/services that characterise the water resource.	No

B2.2 IESC Information Guidelines for Coal Seam Gas and Large Coal Mining Development

The Independent Expert Scientific Committee (IESC) on Coal Seam Gas and Large Coal Mining Development has information guidelines for advice on coal seam gas and large coal mining development proposals (IESC, 2018). The following tables specify where the IESC information requirements for individual proposals have been addressed within this report and relate to the proposed modification.

Table B 7 Description of the proposal (the proposed modification (MOD6))

Project Information	Addressed in section
Provide a regional overview of the proposed project area including a description of the geological basin; coal resource; surface water catchments; groundwater systems; water-dependent assets; and past, present and reasonably foreseeable coal mining and CSG developments.	Sections 1,3,4 & 5
Describe the statutory context, including information on the proposal's status within the regulatory assessment process and any applicable water management policies or regulations.	Section 2
Describe the proposal's location, purpose, scale, duration, disturbance area, and the means by which it is likely to have a significant impact on water resources and water-dependent assets.	Section 1.1
Describe how impacted water resources are currently being regulated under state or Commonwealth law, including whether there are any applicable standard conditions.	Section 2

Table B 8 Risk Assessment

Project Information	Addressed in section
Identify and assess all potential environmental risks to water resources and water-related assets, and their possible impacts. In selecting a risk assessment approach consideration should be given to the complexity of the project, and the probability and potential consequences of risks.	Sections, 7, 8 & Appendix A
Assess risks following the implementation of any proposed mitigation and management options to determine if these will reduce risks to an acceptable level based on the identified environmental objectives.	Section 8 & 10
Incorporate causal mechanisms and pathways identified in the risk assessment in conceptual and numerical modelling. Use the results of these models to update the risk assessment.	Section 6 & Appendix A
The risk assessment should include an assessment of: - all potential cumulative impacts which could affect water resources and water-related assets; and, - mitigation and management options which the proponent could implement to reduce these impacts.	Sections 7 & 8

Table B 9 Groundwater – Context and conceptualisation

Project Information	Addressed in section
Describe and map geology at an appropriate level of horizontal and vertical resolution including: - definition of the geological sequence(s) in the area, with names and descriptions of the formations and accompanying surface geology, cross-sections and any relevant field data. - geological maps appropriately annotated with symbols that denote fault type, throw and the parts of sequences the faults intersect or displace.	Section 4
Define and describe or characterise significant geological structures (e.g. faults, folds, intrusives) and associated fracturing in the area and their influence on groundwater – particularly groundwater flow, discharge or recharge. - Site-specific studies (e.g. geophysical, coring / wireline logging etc.) should give consideration to characterising and detailing the local stress regime and fault structure (e.g. damage zone size, open/closed along fault plane, presence of clay/shale smear, fault jogs or splays). - Discussion on how this fits into the fault's potential influence on regional-scale groundwater conditions should also be included.	Sections 4, & 5 (5.8)
Provide site-specific values for hydraulic parameters (e.g. vertical and horizontal hydraulic conductivity and specific yield or specific storage characteristics including the data from which these parameters were derived) for each relevant hydrogeological unit. In situ observations of these parameters should be sufficient to characterise the heterogeneity of these properties for modelling.	Section 5.2 & Appendix A
Provide time series level and water quality data representative of seasonal and climatic cycles.	Section 5.4, 5.5 & 5.8
Provide data to demonstrate the varying depths to the hydrogeological units and associated standing water levels or potentiometric heads, including direction of groundwater flow, contour maps, and hydrographs. All boreholes used to provide this data should have been surveyed.	Section 5.1, 5.4 & 5.8
Provide hydrochemical (e.g. acidity/alkalinity, electrical conductivity, metals, and major ions) and environmental tracer (e.g. stable isotopes of water, tritium, helium, strontium isotopes, etc.) characterisation to identify sources of water, recharge rates, transit times in aquifers, connectivity between geological units and groundwater discharge locations.	Section 5
Describe the likely recharge, discharge and flow pathways for all hydrogeological units likely to be impacted by the proposed development.	Section 5
Assess the frequency (and time lags if any), location, volume and direction of interactions between water resources, including surface water/groundwater connectivity, inter-aquifer connectivity and connectivity with sea water.	Section 5

Table B 10 Groundwater – Numerical modelling

Project Information	Addressed in section
Provide a detailed description of all analytical and/or numerical models used, and any methods and evidence (e.g. expert opinion, analogue sites) employed in addition to modelling.	Section 6 & Appendix A
Undertaken groundwater modelling in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al. 2012), including independent peer review.	Section 6 & Appendix A
Calibrate models with adequate monitoring data, ideally with calibration targets related to model prediction (e.g. use baseflow calibration targets where predicting changes to baseflow).	Appendix A
Describe each hydrogeological unit as incorporated in the groundwater model, including the thickness, storage and hydraulic characteristics, and linkages between units, if any.	Section 5 & Appendix A
Describe the existing recharge/discharge pathways of the units and the changes that are predicted to occur upon commencement, throughout, and after completion of the proposed project.	Section 5.8 & Appendix A
Describe the various stages of the proposed project (construction, operation and rehabilitation) and their incorporation into the groundwater model. Provide predictions of water level and/or pressure declines and recovery in each hydrogeological unit for the life of the project and beyond, including surface contour maps for all hydrogeological units.	Section 6 & Appendix A
Identify the volumes of water predicted to be taken annually with an indication of the proportion supplied from each hydrogeological unit.	Sections 7 & 8
Undertake model verification with past and/or existing site monitoring data.	Appendix A
Provide an explanation of the model conceptualisation of the hydrogeological system or systems, including multiple conceptual models if appropriate. Key assumptions and model limitations and any consequences should also be described.	Section 5.8
Consider a variety of boundary conditions across the model domain, including constant head or general head boundaries, river cells and drains, to enable a comparison of groundwater model outputs to seasonal field observations.	Appendix A
Undertake sensitivity analysis and uncertainty analysis of boundary conditions and hydraulic and storage parameters, and justify the conditions applied in the final groundwater model (see Middlemis and Peeters).	Section 9
Provide an assessment of the quality of, and risks and uncertainty inherent in, the data used to establish baseline conditions and in modelling, particularly with respect to predicted potential impact scenarios.	Section 9
Undertake an uncertainty analysis of model construction, data, conceptualisation and predictions (see Middlemis and Peeters).	Section 9
Provide a program for review and update of models as more data and information become available, including reporting requirements.	Section 10
Provide information on the magnitude and time for maximum drawdown and post-development drawdown equilibrium to be reached.	Section 7.4

Table B 11 Groundwater – Impacts on water resources and water dependent assets

Project Information	Addressed in section
Provide an assessment of the potential impacts of the proposal, including how impacts are predicted to change over time and any residual long-term impacts. Consider and describe: - any hydrogeological units that will be directly or indirectly dewatered or depressurised, including the extent of impact on hydrological interactions between water resources, surface water/groundwater connectivity, inter-aquifer connectivity and connectivity with sea water. - the effects of dewatering and depressurisation (including lateral effects) on water resources, water-dependent assets, groundwater, flow direction and surface topography, including resultant impacts on the groundwater balance. - the potential impacts on hydraulic and storage properties of hydrogeological units, including changes in storage, potential for physical transmission of water within and between units, and estimates of likelihood of leakage of contaminants through hydrogeological units. - the possible fracturing of and other damage to confining layers. - for each relevant hydrogeological unit, the proportional increase in groundwater use and impacts as a consequence of the proposed project, including an assessment of any consequential increase in demand for groundwater from towns or other industries resulting from associated population or economic growth due to the proposal.	Section 8
Describe the water resources and water-dependent assets that will be directly impacted by mining or CSG operations, including hydrogeological units that will be exposed/partially removed by open cut mining and/or underground mining.	Sections 5 & 8
For each potentially impacted water resource, provide a clear description of the impact to the resource, the resultant impact to any water-dependent assets dependent on the resource, and the consequence or significance of the impact.	Section 8
Describe existing water quality guidelines, environmental flow objectives and other requirements (e.g. water planning rules) for the groundwater basin(s) within which the development proposal is based.	Section 2
Provide an assessment of the cumulative impact of the proposal on groundwater when all developments (past, present and/or reasonably foreseeable) are considered in combination.	Section 7.3 & Section 8
Describe proposed mitigation and management actions for each significant impact identified, including any proposed mitigation or offset measures for long-term impacts post mining.	Section 10
Provide a description and assessment of the adequacy of proposed measures to prevent/minimise impacts on water resources and water-dependent assets.	Section 10

Table B 12 Groundwater – Data and monitoring

Project Information	Addressed in section
Provide sufficient data on physical aquifer parameters and hydrogeochemistry to establish pre-development conditions, including fluctuations in groundwater levels at time intervals relevant to aquifer processes.	Section 5
Develop and describe a robust groundwater monitoring program using dedicated groundwater monitoring wells – including nested arrays where there may be connectivity between hydrogeological units – and targeting specific aquifers, providing an understanding of the groundwater regime, recharge and discharge processes and identifying changes over time.	Section 5 & 10
Develop and describe proposed targeted field programs to address key areas of uncertainty, such as the hydraulic connectivity between geological formations, the sources of groundwater sustaining GDEs, the hydraulic properties of significant faults, fracture networks and aquitards in the impacted system, etc., where appropriate.	Section 5
Provide long-term groundwater monitoring data, including a comprehensive assessment of all relevant chemical parameters to inform changes in groundwater quality and detect potential contamination events.	Section 5 & 10
Ensure water quality monitoring complies with relevant National Water Quality Management Strategy (NWQMS) guidelines (ANZECC/ARMCANZ 2000) and relevant legislated state protocols (e.g. QLD Government 2013).	Section 10

Table B 13 Water dependent assets – Context and conceptualisation

Project Information	Addressed in section
Identify water-dependent assets, including: - water-dependent fauna and flora and provide surveys of habitat, flora and fauna (including stygofauna) (see Doody <i>et al.</i> [in press]). - public health, recreation, amenity, Indigenous, tourism or agricultural values for each water resource.	Section 5.6
Identify GDEs in accordance with the method outlined by Eamus <i>et al.</i> (2006). Information from the GDE Toolbox (Richardson <i>et al.</i> 2011) and GDE Atlas (CoA 2017a) may assist in identification of GDEs (see Doody <i>et al.</i> [in press]).	Section 5.6
Describe the conceptualisation and rationale for likely water-dependence, impact pathways, tolerance and resilience of water-dependent assets. Examples of ecological conceptual models can be found in Commonwealth of Australia (2015).	Section 5.8, 5.9 & Ecology Report (Umwelt, 2022)
Estimate the ecological water requirements of identified GDEs and other water-dependent assets (see Doody <i>et al.</i> [in press]).	Section 5 & Ecology Report (Umwelt, 2022)
Identify the hydrogeological units on which any identified GDEs are dependent (see Doody <i>et al.</i> [in press]).	Section 5.6
Provide an outline of the water-dependent assets and associated environmental objectives and the modelling approach to assess impacts to the assets.	Section 5.6, Appendix A, & Ecology Report (Umwelt, 2022)
Describe the process employed to determine water quality and quantity triggers and impact thresholds for water-dependent assets (e.g. threshold at which a significant impact on an asset may occur) triggers and impact thresholds for water-dependent assets (e.g. threshold at which a significant impact on an asset may occur).	Section 10

Table B 14 Water dependent assets – Impacts, risk assessment and management of risks

Project Information	Addressed in section
Provide an assessment of direct and indirect impacts on water-dependent assets, including ecological assets such as flora and fauna dependent on surface water and groundwater, springs and other GDEs (see Doody <i>et al.</i> [in press]).	Section 8.3 & 8.4
Describe the potential range of drawdown at each affected bore, and clearly articulate of the scale of impacts to other water users.	Section 0
Indicate the vulnerability to contamination (e.g. from salt production and salinity) and the likely impacts of contamination on the identified water-dependent assets and ecological processes.	Section 8.5
Identify and consider landscape modifications (e.g. voids, on-site earthworks, and roadway and pipeline networks) and their potential effects on surface water flow, erosion and habitat fragmentation of water-dependent species and communities.	Refer to Ecology Report (Umwelt, 2022)
Provide estimates of the volume, beneficial uses and impact of operational discharges of water (particularly saline water), including potential emergency discharges due to unusual events, on water-dependent assets and ecological processes.	Refer to Surface Water Assessment (Engeny, 2021) & Ecology Report (Umwelt, 2022)
Assess the overall level of risk to water-dependent assets through combining probability of occurrence with severity of impact.	Refer to Ecology Report (Umwelt, 2022)
Identify the proposed acceptable level of impact for each water-dependent asset based on leading-practice science and site-specific data, and ideally developed in conjunction with stakeholders.	Refer to Ecology Report (Umwelt, 2022)
Propose mitigation actions for each identified impact, including a description of the adequacy of the proposed measures and how these will be assessed.	Refer to Ecology Report (Umwelt, 2022)

Table B 15 Water dependent assets – Data and monitoring

Project Information	Addressed in section
Identify an appropriate sampling frequency and spatial coverage of monitoring sites to establish pre-development (baseline) conditions, and test potential responses to impacts of the proposal (see Doody <i>et al.</i> [in press]).	Refer to Ecology Report (Umwelt, 2022)
Consider concurrent baseline monitoring from unimpacted control and reference sites to distinguish impacts from background variation in the region (e.g. BACI design, see Doody <i>et al.</i> [in press]).	Refer to Ecology Report (Umwelt, 2022)
Develop and describe a monitoring program that identifies impacts, evaluates the effectiveness of impact prevention or mitigation strategies, measures trends in ecological responses and detects whether ecological responses are within identified thresholds of acceptable change (see Doody <i>et al.</i> [in press]).	Refer to Ecology Report (Umwelt, 2022)
Describe the proposed process for regular reporting, review and revisions to the monitoring program.	Section 10, & Ecology Report (Umwelt, 2022)
Ensure ecological monitoring complies with relevant state or national monitoring guidelines (e.g. the DSITI guideline for sampling stygofauna [QLD Government 2015]).	Refer to Ecology Report (Umwelt, 2022)

Table B 16 Water and salt balance and water management strategy

Project Information	Addressed in section
Provide a quantitative site water balance model describing the total water supply and demand under a range of rainfall conditions and allocation of water for mining activities (e.g. dust suppression, coal washing etc.), including all sources and uses.	Refer to Surface Water Assessment (Engeny, 2021)
Describe the water requirements and on-site water management infrastructure, including modelling to demonstrate adequacy under a range of potential climatic conditions.	Refer to Surface Water Assessment (Engeny, 2021)
Provide estimates of the quality and quantity of operational discharges under dry, median and wet conditions, potential emergency discharges due to unusual events and the likely impacts on water-dependent assets.	Refer to Surface Water Assessment (Engeny, 2021)
Provide salt balance modelling that includes stores and the movement of salt between stores, and takes into account seasonal and long-term variation.	Refer to Surface Water Assessment (Engeny, 2021)

Table B 17 Cumulative Impacts – Context and conceptualisation

Project Information	Addressed in section
Provide cumulative impact analysis with sufficient geographic and temporal boundaries to include all potentially significant water-related impacts.	Section 7.3 & Section 8.6
Consider all past, present and reasonably foreseeable actions, including development proposals, programs and policies that are likely to impact on the water resources of concern in the cumulative impact analysis. Where a proposed project is located within the area of a bioregional assessment consider the results of the bioregional assessment.	Section 8

Table B 18 Cumulative Impacts – Impacts

Project Information	Addressed in section
Provide an assessment of the condition of affected water resources which includes: - identification of all water resources likely to be cumulatively impacted by the proposed development; - a description of the current condition and quality of water resources and information on condition trends; - identification of ecological characteristics, processes, conditions, trends and values of water resources; - adequate water and salt balances; and, - identification of potential thresholds for each water resource and its likely response to change and capacity to withstand adverse impacts (e.g. altered water quality, drawdown).	Section 5 & Section 8 Refer to Ecology Report (Umwelt, 2022)
Assess the cumulative impacts to water resources considering: - the full extent of potential impacts from the proposed project, (including whether there are alternative options for infrastructure and mine configurations which could reduce impacts), and encompassing all linkages, including both direct and indirect links, operating upstream, downstream, vertically and laterally; - all stages of the development, including exploration, operations and post closure / decommissioning; - appropriately robust, repeatable and transparent methods; - the likely spatial magnitude and timeframe over which impacts will occur, and significance of cumulative impacts; and, - opportunities to work with other water users to avoid, minimise or mitigate potential cumulative impacts.	Section 7 & 8

Table B 19 Cumulative Impacts – Mitigation, monitoring and management

Project Information	Addressed in section
Identify modifications or alternatives to avoid, minimise or mitigate potential cumulative impacts. Evidence of the likely success of these measures (e.g. case studies) should be provided.	Section 8.6 & 10
Identify measures to detect and monitor cumulative impacts, pre and post development, and assess the success of mitigation strategies.	Section 8.6 & 10
Identify cumulative impact environmental objectives.	Section 8.6 & 10
Describe appropriate reporting mechanisms.	Section 10
Propose adaptive management measures and management responses.	Section 10

Table B 20 Final landform and voids – coal mines

Project Information	Addressed in section
Identify and consider landscape modifications (e.g. voids, on-site earthworks, and roadway and pipeline networks) and their potential effects on surface water flow, erosion, sedimentation and habitat fragmentation of water-dependent species and communities.	Conceptual Mine Closure Plan and Rehabilitation Management Plan
Assess the adequacy of modelling, including surface water and groundwater quantity and quality, lake behaviour, timeframes and calibration.	Conceptual Mine Closure Plan and Rehabilitation Management Plan
Provide an evaluation of stability of void slopes where failure during extreme events or over the long term (for example due to aquifer recovery causing geological heave and landform failure) may have implications for water quality.	Conceptual Mine Closure Plan and Rehabilitation Management Plan
Evaluate mitigating inflows of saline groundwater by planning for partial backfilling of final voids.	Conceptual Mine Closure Plan and Rehabilitation Management Plan
Provide an assessment of the long-term impacts to water resources and water-dependent assets posed by various options for the final landform design, including complete or partial backfilling of mining voids. Assessment of the final landform for which approval is being sought should consider: groundwater behaviour – sink or lateral flow from void. water level recovery – rate, depth, and stabilisation point (e.g. timeframe and level in relation to existing groundwater level, surface elevation). seepage – geochemistry and potential impacts. long-term water quality, including salinity, pH, metals and toxicity. measures to prevent migration of void water off-site. For other final landform options considered sufficient detail of potential impacts should be provided to clearly justify the proposed option.	Conceptual Mine Closure Plan and Rehabilitation Management Plan
Assess the probability of overtopping of final voids with variable climate extremes, and management mitigations.	Surface Water Assessment (Engeny, 2021)

Appendix C

Peer Review Comments

C1 Response to Peer Review Comments

Table C 1 details responses to the peer review comments received, and recommendations adopted in the final (v2.02) Groundwater Impact Assessments report.

Table C 1 Response to Review Comments

Item	Criticality	Page Number (1 st Mention)	AGE Response
Partitioning of groundwater fluxes			
The take needs to be reported for each water source, as per the requirements of the AIP.	Recommendation	2	Addressed in V2.02 report.
It is recommended AGE re-calculates the take and separates it between surface water (from the Upper Talbragar unregulated river) and groundwater (from the Talbragar Alluvial Groundwater Source).	Recommendation	9	Addressed in V2.02 report.
Section 8.1 presents the calculated peak take from each water source (the annual predicted take is not presented).	Comment	10	Reporting of the peak annual take was considered most appropriate for water licensing requirements.
Water Licensing			
It is recommended the GIA (or EIS) includes information regarding the intended pathway to secure the additional water entitlement to account for the predicted additional take.	Recommendation	2	Addressed in V2.02 report.
The GIA identifies a shortfall (of 1,389 ML) in water entitlement held by UCMLP in the Sydney Basin MDB Groundwater Source (Sydney Basin MDB (Other) and Macquarie Oxley Management Zone) managed under the NSW Murray Darling Basin Porous Rock Groundwater Sources 2020 WSP.	Comment	9	Addressed in V2.02 report.
It is unclear, at this stage, if additional entitlement is required for the indirect take from the Upper Talbragar River water source (unregulated river) or the Talbragar Alluvial Groundwater Source.	Comment	9	Addressed in V2.02 report.
Hydrographs			
Data recorded at vibrating wire piezometer PZ29 is presented and discussed in Section 5, however Appendix A2 includes a note saying that the monitoring point at PZ29 is "not monitored or erroneous (i.e. dry or faulty VWP sensor)". It is recommended this be checked, clarified or corrected.	Recommendation	24	The erroneous flag in the modelling appendix has been removed.
Commentary regarding Self Sealing of Mona Creek Colluvial Sediments			
The NSW Government may not accept "self-sealing" as a control to limit vertical connection between the colluvium and the underground mine.	Comment	9	This statement was made with respect to limited anecdotal evidence and has been re-worded accordingly.
Faulting and Fracturing			
It is recommended to reference subsidence modelling work completed for the modification (if available) and the surface water assessment.	Recommendation	14	Addressed in V2.02. See SCT (2021).

Item	Criticality	Page Number (1 st Mention)	AGE Response
Faults and joints within the Triassic Sandstone underlying Mona Creek have been mapped using geophysical surveys; however, the potential influence of these and the implication of enhanced vertical fracturing due to underground mining has not been discussed in the GIA.	Comment	23	These features have been inferred from geophysical surveys. Enhanced vertical fracturing will occur independently and is discussed in Section 5.8.
Uncertainty Analysis			
Changes to baseflow are not discussed. To address this comment, it is recommended the GIA be updated to include predicted changes in baseflow.	Recommendation	14	Uncertainty analysis of baseflows was not considered critical based on the reported uncertainty in modelled mine inflows. This may be completed during future works.
Drawdown Prediction			
This suggests the maximum drawdown is predicted to occur at the end of mining; however, this is not explicitly stated.	Discussion	8	Maximum drawdown will occur at different intervals depending on the proximity from the operation.
Monitoring			
It is recommended the Surface Water and Groundwater Response Plan be reviewed to ensure the trigger action response plan is still appropriate with the addition of these bores (i.e. might need a different trigger, action, response).	Recommendation	20	The Groundwater Response Plan will be reviewed to safeguard its adequacy.
Figure Amendments			
It might be beneficial to provide further supporting information regarding areas where the depth to the water table is small (i.e. shallow).	Suggestion	8	Depth to water is highly variable based on topography. Approximate depth to water table can be inferred from the four hydrogeological cross sections. Additional maps may be considered during further works.
It is recommended consideration of including a figure showing areas (or bores) where the depth to water table is less than 5-10 mbgl, depending on the ecological specialist's understanding of root depths.	Suggestion	16	See above comment.
It would be beneficial to include PZ10A and R894_119 on hydrographs, to support discussions in Section 5.4.	Suggestion	23	Future works may incorporate this suggestion. The monitoring points reported were selected based on an analysis of all hydrogeological responses, and were deemed to give a characteristic spread of hydrogeological response.
There appear to be some bores missing from the maps (eg R894_119 on Figure 5.6 and PZ10A on Figure 5.7).	Comment	24	Future works may incorporate changes. Not deemed critical.

04 November 2022

Glencore
Ulan Coal Mines Pty Limited

Attention: Greg Newton
via email: Greg.Newton@glencore.com.au

Dear Greg,

Ulan MOD6 EPBC assessment requirements

1 Introduction

Ulan Coal Mine Complex (UCC) is operated by Ulan Coal Mines Pty Limited (UCMPL), which is 100% owned and managed by Glencore Coal Pty Ltd (Glencore). The UCC is in the central west of New South Wales near the town of Ulan and is approximately 45 km northeast of Mudgee.

UCMPL was granted NSW Project Approval (PA) 08_0184 under the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) on 15 November 2010 for the Ulan Coal – Continued Operations Project. The existing UCC operations are also approved by Controlled Activity approvals 2009/5252 and 2015/7511, issued under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

UCMPL is proposing to modify project approval PA 08_0184 to extend longwalls at the Ulan West and Ulan Underground operations through Modification 6 (MOD6).

UCMPL referred MOD6 to the Commonwealth for consideration under the *Environment Protection & Biodiversity Conservation Act (1999)* (EPBC) and on 12 September 2022 it was determined to be a controlled action (EPBC 2022/09292) requiring assessment and approval under the EPBC Act due to controlling provisions related to listed threatened species and communities and impacts to a water resource.

Following the controlled action decision, the Commonwealth provided its assessment requirements. The following sections address these requirements as they relate to groundwater key areas of this feedback and provide a summary of the necessary information, referring to the detailed Groundwater Impact Assessment report as relevant.

2 Climate change predictions

This section addresses the following requirement:

19 iv. e. inclusion of accurate climate projections in the modelling

The model is currently calibrated using historical rainfall and future predictions utilise the long-term averages of the historical data to continue this 'unknown' input into the future. This assumption does not account for potential climate change.

To address this a number of model runs were undertaken to explore the potential impacts from climate change. These models were set up to be consistent through the mining phase, but then employ different recharge rates across the recovery or post mining phase. The different recharge rates were sourced from predicted changes in rainfall coming from climate change modelling.

There are a number of climate models available, and the Proposed Modification has decided to adopt the RCP-4.5 case for the Central Slopes¹ as being the most appropriate. In terms of rainfall the climate model provides an estimate of the percent of increase or decrease in annual rainfall total at various times into the future.

To explore the potential impacts of climate change, three model runs were undertaken adopting the predicted annual rainfall change percentage in 2090 across the recovery period, covering the most likely 50th percentile, and the extremes at 90th and 10th percentiles as shown in Table 1 below.

Table 1 Simulated changes to rainfall input due to climate change

Model	Percentile of prediction	Predicted change in rainfall at 2090
RCP-4.5	90 th	Increased by 6.5 %
RCP-4.5	50 th	Reduced by 4.2 %
RCP-4.5	10 th	Reduced by 16.1 %

The change in recharge rates results in changes to the level of mounding occurring in the model. Figure 1 to Figure 5 present the changes in the predicted 2 and 5m drawdowns and mounding contours. From these figures it can be seen that the level of climate change from the RCP-4.5 model does not significantly change the predicted drawdown and mounding extent across most of the area.

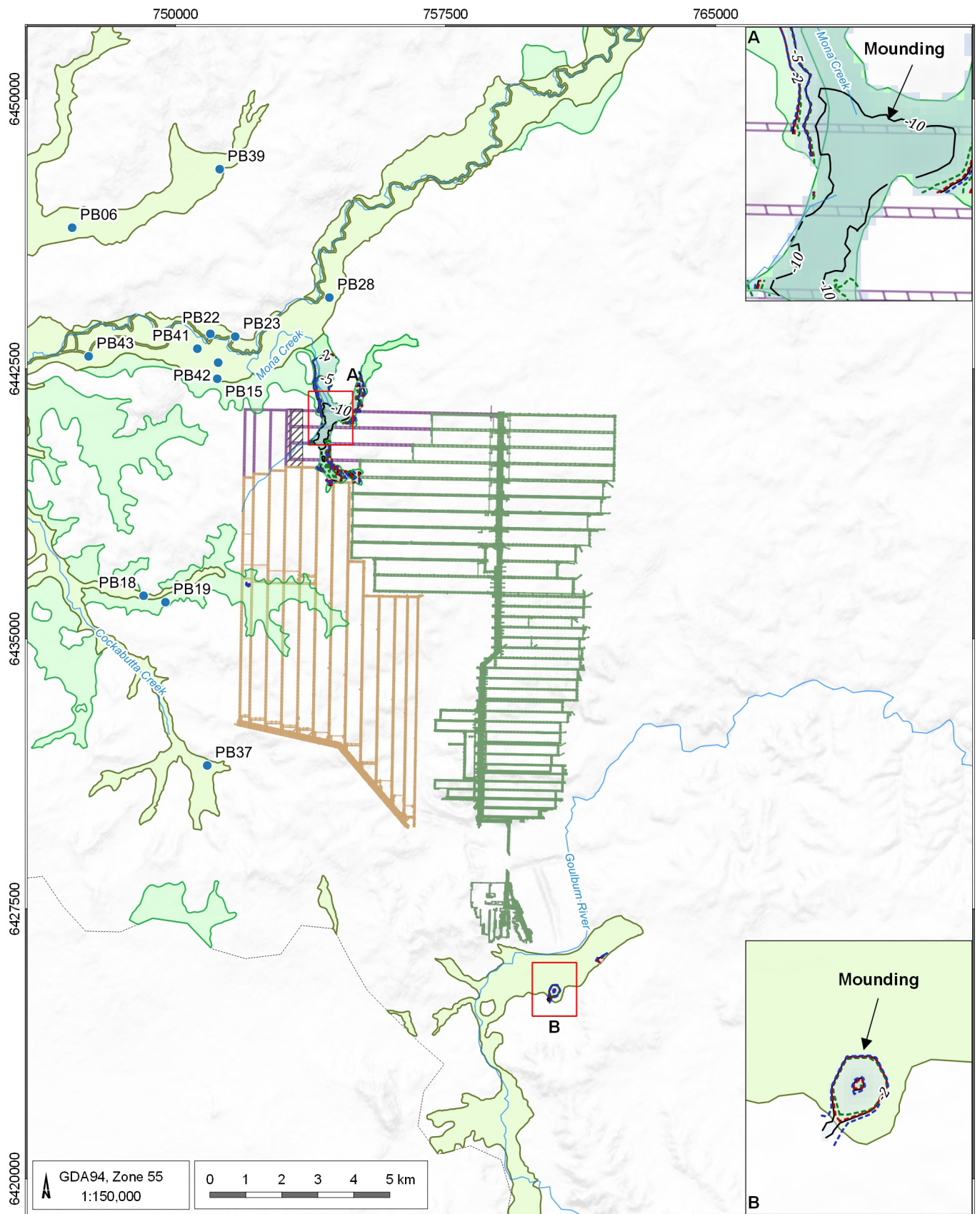
The change in drawdown and mounding also changes the amount of baseflow predicted to occur long term. The changes are presented in Table 2 for the Goulburn and Talbragar rivers and modelled tributaries within the model domain.

Table 2 Predicted long-term baseflow changes in climate change scenarios

Case	% Change in rainfall	Increase in Baseflow for Goulburn River and tribs (ML/year)	Increase in Baseflow for Talbragar River and tribs (ML/year)
Basecase	no change	283	133
10 th Percentile	Reduced by 16.1 %	214	87.9
50 th Percentile	Reduced by 4.2 %	267	122
90 th Percentile	Increased by 6.5 %	317	374

¹ Climate projections for the Proposed Modification were obtained using the Climate Futures tool provided on the Climate Change in Australia website.

The key aspect of these results is that simulation of the RCP-4.5 climate model produces some minor changes to the extent of mounding in the area, but results in more variation in baseflow volumes. This indicates that baseflow, or more specifically the discharge of groundwater to surface drainages, is controlling the extent of mounding and is more directly impacted due to changes in recharge. It should be noted that these baseflow estimates are still a smaller component of the overall flow in the creeks and rivers.



LEGEND

- Private bore
- Major drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Basecase - Drawdown/Mounding contour (m)
- 10th percentile - Climate change predictions
- 50th percentile - Climate change predictions
- 90th percentile - Climate change predictions
- Alluvium
- Colluvium
- Model domain
- Flexibility area

Drawdown (m)

- 0
- 2
- 5
- 10
- 20
- 50
- 100
- 200
- 500

Mounding (m)

- 500
- 200
- 100
- 50
- 20
- 10
- 5
- 2
- 0

Ulan MOD6 GIA (G1985G)

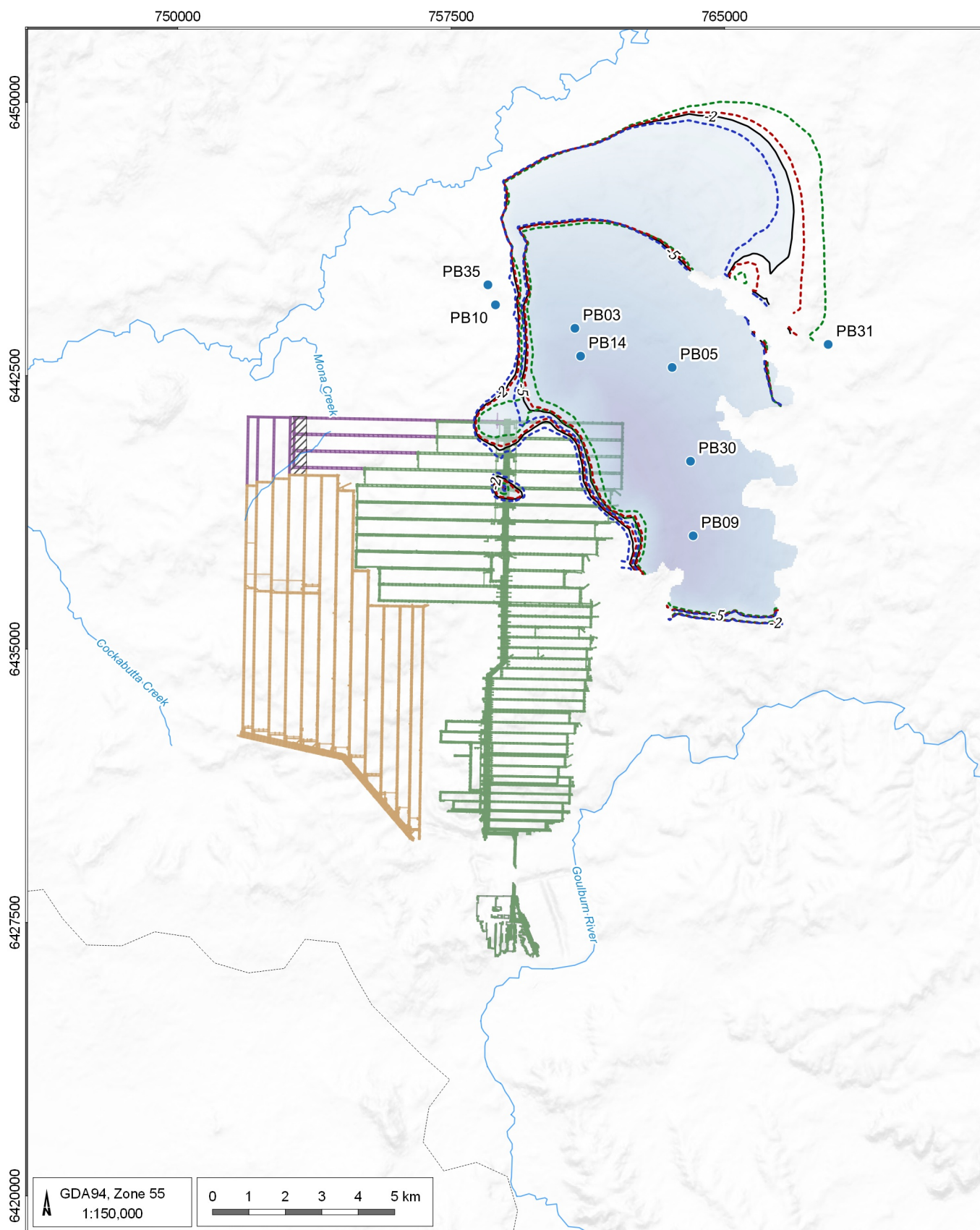
Predicted long term drawdown and mounding - alluvium / colluvium



AGE

DATE
03/11/2022

FIGURE No:
1



LEGEND

- Private bore
- Major drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Basecase - Drawdown/Mounding contour (m)
- 10th percentile - Climate change predictions
- 50th percentile - Climate change predictions
- 90th percentile - Climate change predictions
- Model domain
- ▨ Flexibility area

Drawdown (m)

- 0
- 2
- 5
- 10
- 20
- 50
- 100
- 200
- 500

Mounding (m)

- 500
- 200
- 100
- 50
- 20
- 10
- 5
- 2
- 0

Ulan MOD6 GIA (G1985G)

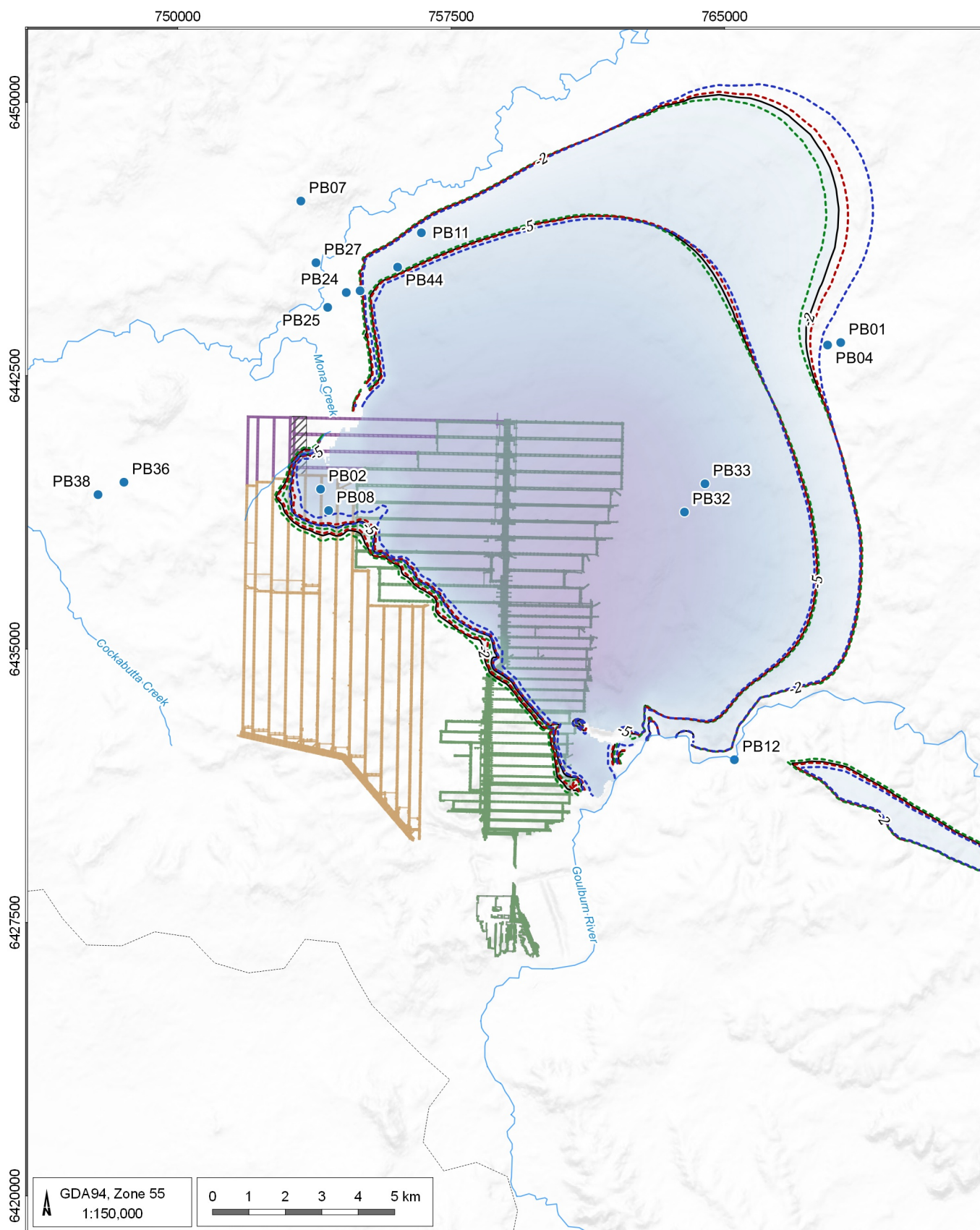
Long-term drawdown (and mounding) in Jurassic (layer 4) - climate change scenarios



AGE

DATE
03/11/2022

FIGURE No:
2



LEGEND

- Private bore
- Major drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Basecase - Drawdown/Mounding contour (m)
- 10th percentile - Climate change predictions
- 50th percentile - Climate change predictions
- 90th percentile - Climate change predictions
- Model domain
- ▨ Flexibility area

Drawdown (m)

- 0
- 2
- 5
- 10
- 20
- 50
- 100
- 200
- 500

Mounding (m)

- 500
- 200
- 100
- 50
- 20
- 10
- 5
- 2
- 0

Ulan MOD6 GIA (G1985G)

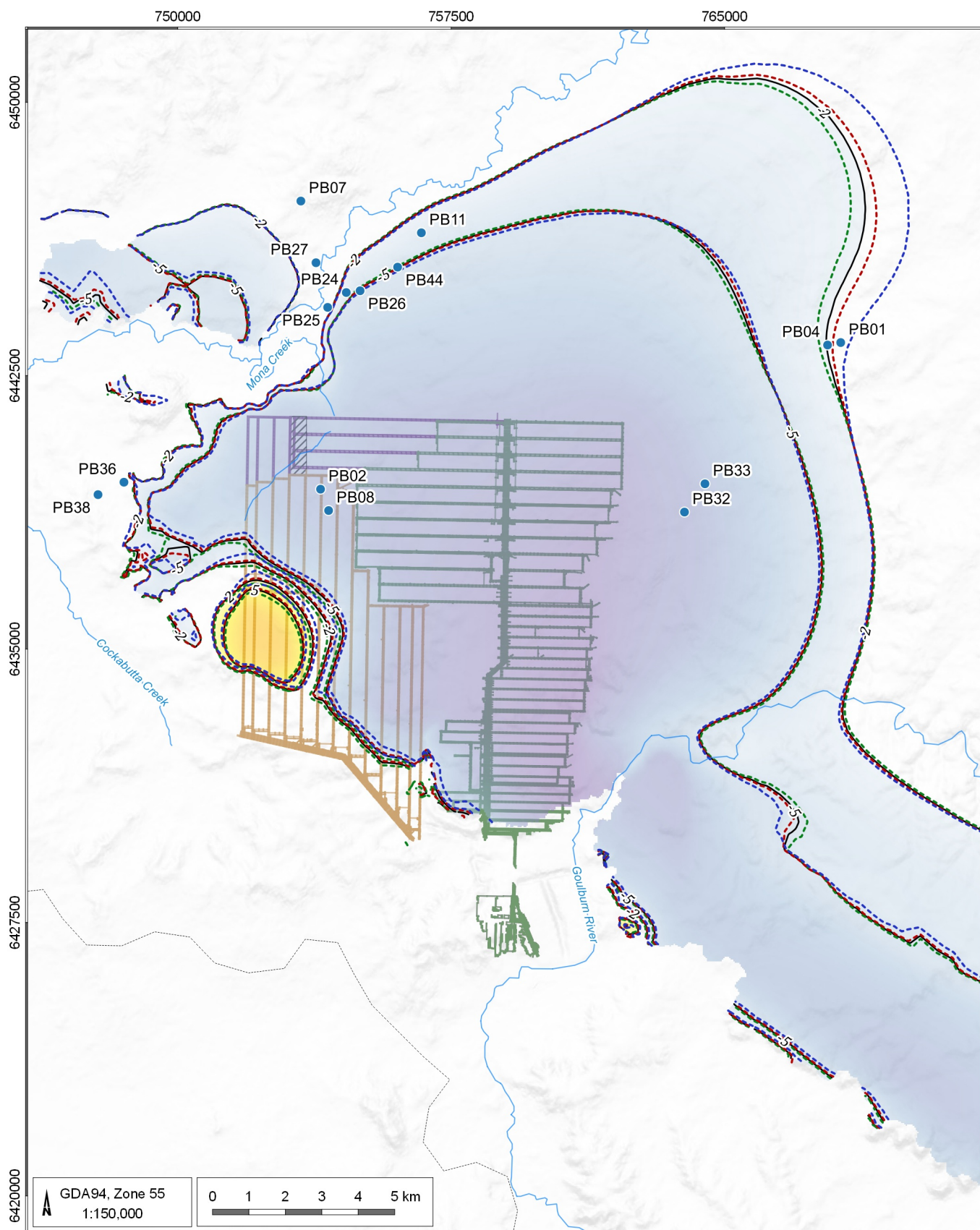
**Long-term drawdown (and mounding)
in Quartzose Triassic (layer 7) -
climate change scenarios**



AGE

DATE
03/11/2022

FIGURE No:
3



LEGEND

- Private bore
- Major drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Basecase - Drawdown/Mounding contour (m)
- 10th percentile - Climate change predictions
- 50th percentile - Climate change predictions
- 90th percentile - Climate change predictions
- Model domain
- ▨ Flexibility area

Drawdown (m)

- 0
- 2
- 5
- 10
- 20
- 50
- 100
- 200
- 500

Mounding (m)

- 500
- 200
- 100
- 50
- 20
- 10
- 5
- 2
- 0

Ulan MOD6 GIA (G1985G)

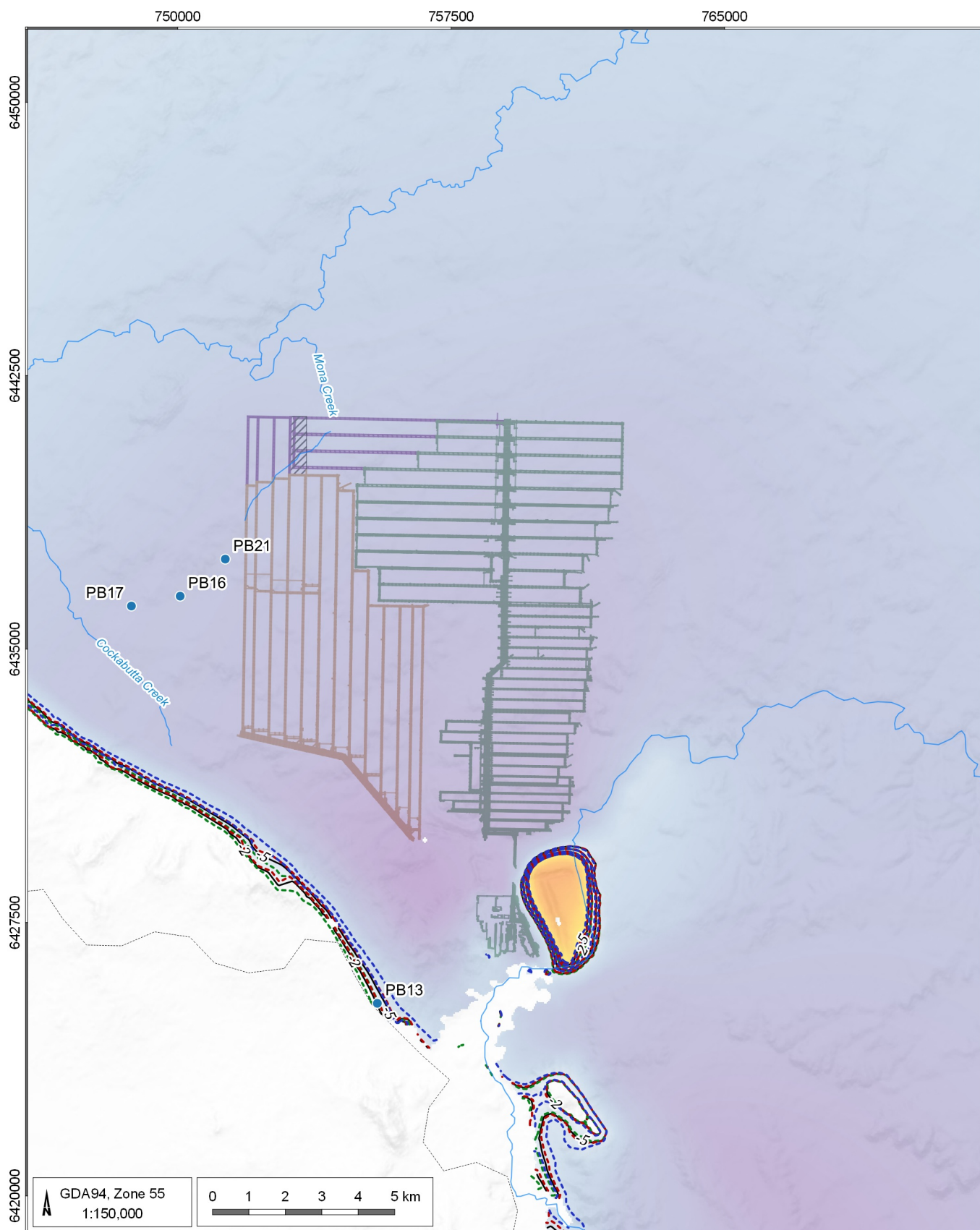
**Long-term drawdown (and mounding)
in Lithic Triassic (layer 10) - climate
change scenarios**



AGE

DATE
03/11/2022

FIGURE No:
4



LEGEND

- Private bore
- Major drainage
- Ulan West Mine Plan
- Ulan Underground Mine Plan
- Proposed longwall panel
- Basecase - Drawdown/Mounding contour (m)
- 10th percentile - Climate change predictions
- 50th percentile - Climate change predictions
- 90th percentile - Climate change predictions
- Model domain
- ▨ Flexibility area

Drawdown (m)

- 0
- 2
- 5
- 10
- 20
- 50
- 100
- 200
- 500

Mounding (m)

- 500
- 200
- 100
- 50
- 20
- 10
- 5
- 2
- 0

Ulan MOD6 GIA (G1985G)

**Long-term drawdown (and mounding)
in Ulan Seam (layer 16) - climate
change scenarios**



AGE

DATE
03/11/2022

FIGURE No:
5

One thing to note from the figures and the comparison of the different scenarios is that the higher recharge scenario results in a larger, albeit slightly, footprint of mounding in the Ulan coal seam. However, this is reversed in the other model layers. This is a function of the drawdown and mounding being derived from the difference between a model which has simulated mining and one that has not. The model that has simulated mining has hydraulic property changes related to the mining representing both backfilled spoil and fracturing above longwall panels. The mining model receives a higher volume of recharge through the presence of the spoil. This recharge will move down through the spoil to where the spoil adjoins the coal seam and then spread laterally out from there into goafs, and then upwards through the fracture zone. The fracture zone readily connects the water levels vertically through the model layers above the mined panels in the mining simulation. This neutralises the impact of the recharge change on the water levels, however there is more variability in the no-mine or null simulation resulting from recharge changes, leading to the non-linear response. These nuances have only limited influence on the mounding, as it appears to be controlled by baseflow discharge anyway.

These predictions and the degree of mounding are directly related to the adopted percentage of rainfall that becomes recharge across the spoil, and to the configuration of any final voids. Design of final landforms and void configurations post mining as part of detailed closure planning will minimise any long-term adverse impacts, whether that be drawdown or mounding and aim to return groundwater levels and quality to pre-mining conditions

3 Fracture height calculations

This section addresses the following requirement:

19 iv.d. a comparison of fracturing height estimates using the Ditton-Merrick method and Tammetta method

The groundwater model used for the GIA adopts the approach of Ditton-Merrick in determining the height of connected fracturing above longwall panels (see Section A 4.6.4.3 in the GIA). This approach has been driven by monitoring data, and specifically replicating the lack of response to underground mining in shallow (upper parts of the Triassic formations and above) monitoring points.

The other significantly documented method is the Tammetta method. Tammetta's approach relates panel width, overburden thickness (depth of cover), and the mined thickness to define the upper limit to the height of connected fractures, or the zone where there is desaturation.

The equation published in 2013 (Groundwater, Vol 51, no. 5: 723-734) takes the form of:

$$H = 1438 \ln(4.325 \times 10^{-5}u + 0.9818) + 26$$

and

$$u = wt^{1.4}d^{0.2}$$

where H is the height of connected fracturing (or desaturation), w is the longwall panel width, t is the mined thickness, and d is the depth of overburden cover.

A recent Australian Coal Association Research Program (ACARP) project (C27045) (Adhikary et. al., 2020) provided further advice around the likely range of the height of connected fracturing, and presented the equation below to be used in estimations:

$$H = \alpha W't + c$$

where α is a coefficient, W' is the minimum between the width of the panel and the overburden depth, and c is another variable. The variables α and c can be assigned values that provide upper ($\alpha = 0.325 \text{ m}^{-1}$, $c = 0 \text{ m}$) and lower ($\alpha = 0.18 \text{ m}^{-1}$, $c = -15 \text{ m}$) limits for the height of connected fracturing.

A comparison of the calculated height of connected fracturing (HoF) for Ditton-Merrick, Tammetta, and the ACARP study methods are presented in Table 3. The table provides estimates across the range of cover depths encountered at the Ulan Coal Complex and for the average depth of cover across the proposed MOD6 panels.

Table 3 Comparison of methods to estimate height of connected fracture

Parameter	Deep example	Average of MOD6 footprint	Shallow example
Panel Width (m)	400	400	400
Mined Thickness (m)	3.5	3.5	3.5
Depth of overburden (m)	331	130	72
HoF (m) - Tammetta	403	342	308
HoF (m) - ACARP Upper	377	148	81.9
HoF (m) - ACARP Lower	194	67	30.4
HoF (m) - Ditton-Merrick	188	121	67

The Tammetta estimates at all three depths of overburden have the height of connected fracturing reaching the land surface (i.e. height of connected fracturing greater than depth of overburden). This level of connection and desaturation has not been observed in shallow groundwater levels across the mined areas to date, indicating that this estimate is not the most applicable to the conditions observed at Ulan. This can be seen with the water levels presented in Figure 5.24 of the GIA. Water levels in bores EX06, PZ10 and PZ07 all show fully depressurised water levels in the Ulan coal seam and Permian overburden, however monitoring in the overlying Quartzose Triassic remain saturated. The ACARP range is large, with the upper estimate resulting in connected fracturing to the land surface, and the lower limit generally below the adopted Ditton-Merrick estimate in the model. It is noted that as the seam gets deeper the Ditton Merrick estimated height does go lower than the lower end of the range that the ACARP equation predicts.

Where the coal seams are nearer the land surface and shallower, there has been indications the height of connected fracturing does get very close to the land surface.

4 Alternate Drip considerations

This section addresses the following requirement:

19 iv. c. *simulations of mining related impacts on The Drip should be reconsidered, as current predictions may not be accurate due to the conceptualised isolation of the feature from other Triassic formations*

All the literature and empirical data indicates that the most likely conceptual model of The Drip and its surrounds is that it is the seepage face of a local aquifer in the Triassic Narrabeen Group isolated on a layer of relatively low-permeability ironstone. It is recharged by infiltrating rainfall and does not appear to be hydraulically connected to the regional aquifer in the basal portion of the Triassic sediments and Permian coal measures.

The Drip is represented within the model by the River (RIV) boundary condition assigned in layer 7, which represents a portion of the Quartzose Triassic formation thickness. The model layer below also represents a portion of the Quartzose Triassic formation and is the host of the RIV boundary condition for the Goulburn River that is located some 7.5 m below the elevation of The Drip. Locally, vertical connection between these layers has been reduced and recharge increased in order for water to remain perched above the influence of the Goulburn River below. Without this approach there would be no flow predicted at the RIV boundary condition representing The Drip in the model.

This local reduction in vertical connection does not mean the model cells at the location of The Drip are isolated from other areas of the model. Layer 7, where The Drip is assigned, is laterally extensive wherever Quartzose Triassic is mapped, the extent of layer 7 is shown as the yellow coloured cells in Figure 6. The cells where The Drip boundary condition is applied are horizontally connected to areas where longwall mining in the Ulan Seam and subsequent fracturing is influencing water levels in Layer 7.

Furthermore, the simplifying that occurs through the discretisation of the model domain into cells that are readily connected to neighbouring cells is likely to enhance the connection across the model above reality. The model has limited opportunity to apply the heterogeneity that exists in the real world which connects and disconnects areas at a local (and possibly sub cell) scale.

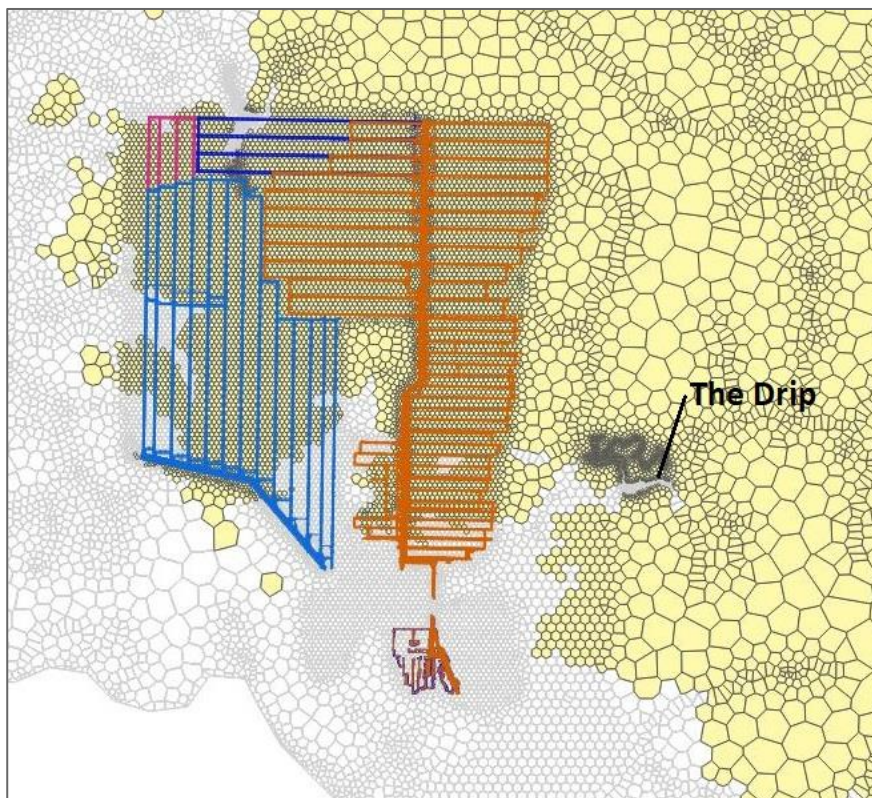


Figure 6 Extent of layer 7 (yellow cells) in the groundwater model

While conceptually The Drip is described as an isolated feature, its representation in the model is not isolated from impacts. The connection that exists in the model means The Drip representation is conservative and is likely to over predict rather than underpredict impacts there.

5 Representing faults in the model

This section addresses the following requirement:

19 iv. b. *geophysical information regarding faults and other features identified in the project area with a view to how these may enhance impacts, including incorporation into the groundwater model*

As discussed in the GIA, faults have not been directly represented in the model. There is no regional scale thrust faulting in the area that would significantly displace aquifers. There are mapped and named faults including Spring Gully, Curra Creek, Green Hills, and Broken Back Creek faults. Of these faults, only Spring Gully fault has been studied in any detail, notably because of its location adjacent to eastern extent of longwall mining at Ulan Underground.

Underground mining at Ulan has not directly intercepted any major faults, rather the major faults have defined the limits of mining. Due to the limited data on some of the regional faults, the nature of the faults were not known, and they have not been directly modelled in the current model. Additionally, water level behaviour around Spring Gully fault (see Section 4.6 of the GIA) suggests that this is not an effective barrier to groundwater flow, supporting this decision.

It is known that faults can act as both a barrier and a conduit to flow. That is, while a fault may provide a barrier to perpendicular horizontal flow, it may provide a localised heightened vertical connection and become a conduit in the vertical direction, or laterally along the fault

In previous versions of the model, the named faults have been simulated using the horizontal flow barrier. When applied, it was assigned to the Ulan Seam and the Permian model layers above, but did not continue into the overlying Triassic layers. The influence of the applied barriers was noted in the predicted water level contours for the Permian layers, but as the faults were not extensive, the influence was only local to the fault and only in the layers it was assigned. For that earlier calibration to be successful, the faults were required to have limited impact.

The current MODFLOW-USG model is a single continuum model, and is replicating fracture flow through an equivalent porous media (EPM) approach. Hydraulic properties assigned to cells in the model are spatially distributed through pilot points to add variability in aquifer parameters across the model domain for all model layers. Through the calibration process of these properties, the influence of faults on the regional groundwater flow has been captured to some extent through matching the historical water level responses to mining. Pilot points have not specifically been assigned along faults, but the fault influence regionally (if any) is captured through this process.

The model is well calibrated achieving a SRMS of less than 4% and has replicated the extent of impacts that is been observed in monitoring data. Not simulating the faults directly as features has not limited the model's ability to replicate historical impacts and is unlikely to impact on the predicted impacts from the Proposed Modification.

6 Reconsideration of boundary conditions

This section addresses the following requirement:

19 iv. f. a reconsideration of boundary conditions and a reassessment of potential impacts from groundwater drawdown following that reconsideration (if required)

During the model update phase where the model extents were extended to the north and east, consideration was given to connecting these boundaries to 'the outside world' beyond the model domain. The model boundary to the southwest was largely defined by the sub-cropping Permian coal measures. To the north and the east, the principal aquifer of the Ulan Seam becomes very deep (-700 m AHD which is 1400 m below surface), and it is likely the hydraulic conductivity of the coal seam is significantly reduced due to overburden pressure. Because of these reasons the model extent remained a non-flow boundary.

The other boundary conditions applied in the model have been chosen because they provide the best functionality to the feature they represent. For instance, the Drain (DRN) package has been used to simulate mine dewatering because it requires a specified elevation that dewatering is needed which is readily available, and then it is left to the model to determine how much water is removed to maintain those conditions.

Consideration of alternate boundary conditions has been undertaken through the model update phase and reconsidered here to respond to the assessment requirements. Alternate approaches are not considered necessary as they are not expected to change any of the predictions related to the Proposed Modification.

Yours faithfully,



Andrew Durick

Director / Principal Modeller

Australasian Groundwater and Environmental Consultants Pty Ltd