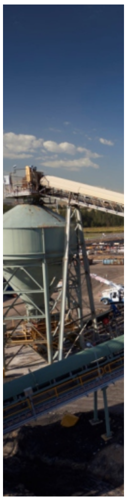

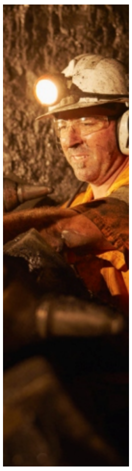

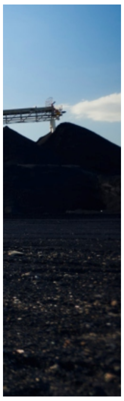


Ashton-Ravensworth Underground Mine Integration

EPBC Act Preliminary Documentation

APPENDIX C

Groundwater Impact Assessment

Australasian Groundwater & Environmental Consultants

Report on

Ashton-Ravensworth Integration Project Groundwater Impact Assessment

Prepared for

Ashton Coal Operations Pty Limited

Project No. ASH5001.003
March 2024

ageconsultants.com.au

ABN 64 080 238 642

Document details and history

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Ashton-Ravensworth Integration Project Groundwater Impact Assessment

1 Introduction

The Ravensworth Mine Complex and Ashton Coal Project are neighbouring open cut and underground coal mining operations, located in the Singleton Local Government Area, in the Hunter Valley region of New South Wales (NSW).

The Ravensworth Mine Complex includes the Ravensworth Open-cut Operations and the Ravensworth Underground Mine (RUM). The RUM is owned and operated by Resource Pacific Pty Ltd. As the majority shareholder of Resource Pacific Pty Ltd, Glencore Australia Holdings Pty Ltd (Glencore) oversees the management of RUM.

The Ashton Coal Project comprises the completed North-East Open Cut (NEOC) and the Ashton Underground Mine (AUM). The Ashton Coal Project is operated by Ashton Coal Operations Pty Limited (ACOL), a wholly owned subsidiary of Yancoal Australia Limited (Yancoal).

The AUM and RUM share a common mining lease boundary and are approved to extract coal from similar coal seams.

The AUM includes longwall mining in the Pikes Gully, Upper Liddell, Upper Lower Liddell and Lower Barrett Seams. Mining has been completed in the Pikes Gully Seam, Upper Liddell Seam and Upper Lower Liddell Seam (Longwalls [LW] 201-204). Mining is in progress in LW 205-208 in the Upper Lower Liddell Seam, and yet to commence in the Lower Barrett Seam.

Operations at the RUM commenced in July 2000 under Development Consent DA 104/96. Mining is approved under Development Consent DA 104/96 in the Lemington, Pikes Gully, Liddell (Upper and Middle) and Barrett Seams. In October 2014, after the completion of LW 1-9 in the Pikes Gully Seam, operations at RUM were placed into care and maintenance and no further underground mining has occurred since. The RUM underlies the Ravensworth South Open Cut and the Ravensworth Narama Open Cut. Mining is approved in the remaining Pikes Gully LW 10-15, Liddell (Upper and Middle) and Barrett Seams.

An opportunity therefore exists for ACOL to access and extract the approved but unmined RUM coal resources. ACOL sought to modify the Ashton Coal Project Development Consent DA No. 309-11-2001-i and the RUM Development Consent DA 104/96 to access and mine approved coal resources at the RUM (herein referred to as the Modifications). The Modifications were approved by the NSW Department of Planning and Environment (DPE) in July 2022.

1.1 Proposed Action

The Proposed Action under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) would involve the following:

- underground mining of the Pikes Gully and Middle Liddell coal seams using longwall mining methods in the Action area as shown on Figure 1.1;
- mining operations until approximately 31 December 2032 (i.e. for a period of approximately 8 years);
- establishment and use of gas, ventilation and water management infrastructure including shafts, bores and pipelines;
- management of water and gas that accumulates in the underground workings within the Action area;
- transfer of run-of-mine coal from the RUM Pikes Gully and Middle Liddell coal seams in the Action area to the neighbouring Ashton Coal Project via connected underground workings; and
- transfer of water and gas from the Action area associated with the secondary extraction of the RUM Pikes Gully and Middle Liddell coal seams to the neighbouring Ashton Coal Project.

The Proposed Action does not include non-subsiding first workings development, which would be used to access and undertake secondary extraction of the longwall panels as part of the Proposed Action.

The Proposed Action is located within an existing mining precinct, which includes historical and ongoing open cut operations including the Ravensworth Operations Project, located above and immediately to the west, and Ravensworth South Open Cut, located above and immediately to the north, Hunter Valley Operations (HVO) North, located approximately 4 kilometres (km) further west, Glendell Open Cut, located to the north-east, and the Ashton Coal Project located adjacent to and east of the RUM.

Yancoal submitted a referral for the Proposed Action in May 2022 (EPBC 2022/09208). A delegate of the Commonwealth Environment Minister determined on 27 September 2022 that the Proposed Action is a “Controlled Action” and therefore the Action requires approval under the EPBC Act, including an assessment of potential impacts on water resources.

1.2 Scope of work

Australasian Groundwater and Environmental Consultants (AGE) were engaged by ACOL to undertake groundwater modelling to support section 4.55 modifications to the AUM and RUM approvals under the NSW *Environmental Planning and Assessment Act 1979*. AGE (2022a) also prepared the *Ravensworth Underground Mine EPBC Referral – Groundwater Review* to support the EPBC Referral for the Proposed Action (EPBC 2022/09208).

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) reviewed the EPBC Referral for the Proposed Action and provided advice (dated 14 December 2022), which included a number of recommendations for additional groundwater modelling and reporting. This report addresses those additional recommendations, with reference to the IESC guidelines where relevant.

1.3 Risk Assessment

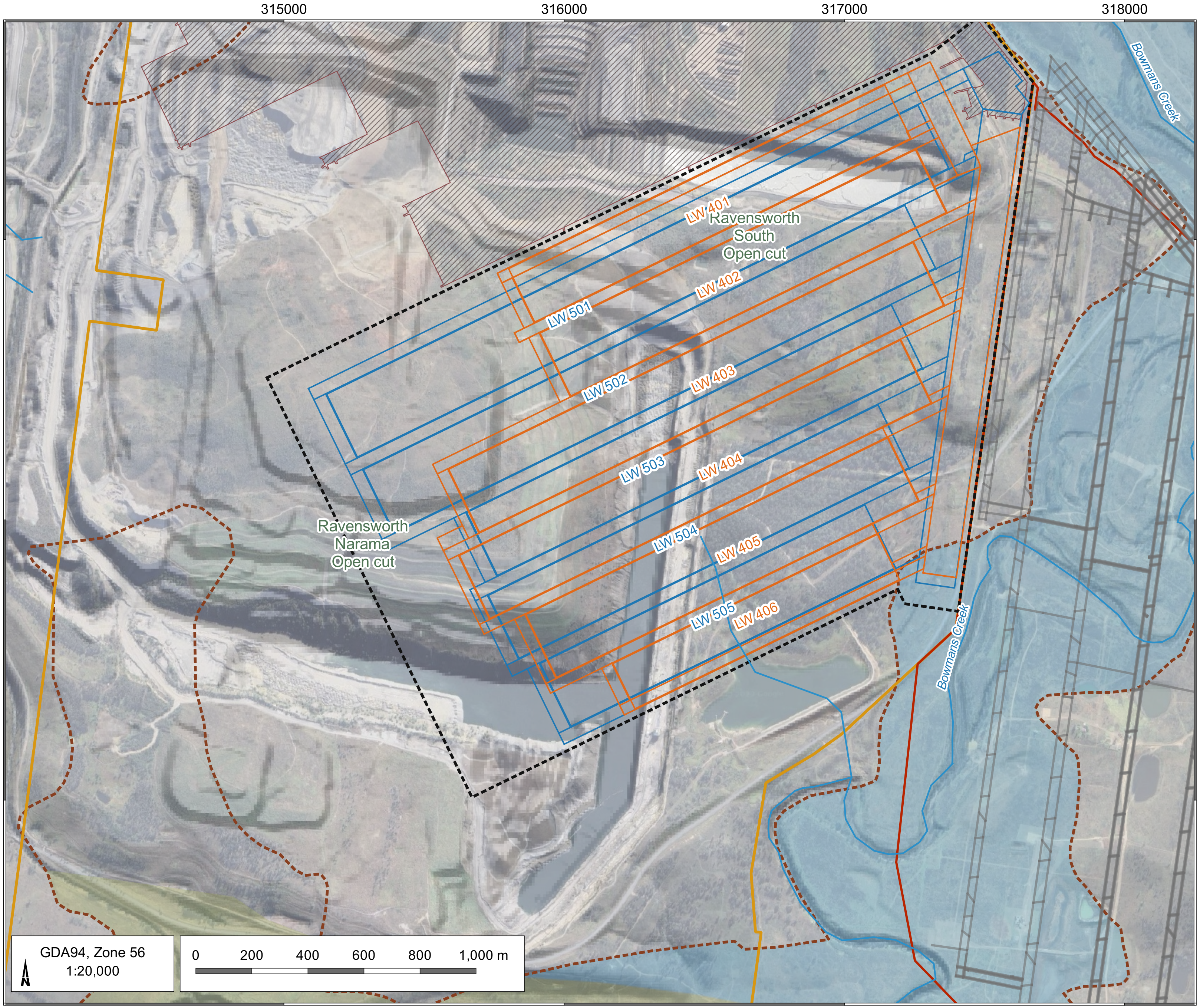
A risk assessment was conducted on 5 May 2020 to review and identify the subsidence-related hazards that may affect the environment and community as a result of the resource extraction from AUM Longwalls 205-208 (i.e. the most western longwall panels at the AUM, immediately adjacent to the Proposed Action; Figure 1.1) (ACOL, 2020). Relevant to the Proposed Action, the risk assessment considered potential impacts of longwall mining on Bowmans Creek and its alluvium. The risk assessment was facilitated by Kylie Hannigan (STAC Consulting) with contribution by the following ACOL workforce representatives and external content/technical experts:

- Tony Sutherland (ACOL – Technical Services Manager);
- Phil Brown (ACOL – Environmental and Community Relations Superintendent);
- Jeff Peck (ACOL – Mining Surveyor);
- David Cooke (ACOL – Operator/Site Safety and Health Representative);
- Lachlan Crawford (ACOL – Environment and Community Coordinator);
- Andrew Durick (Director/Principal Modeller – AGE);
- Dr Ken Mills (Principal Geotechnical Engineer/Director – SCT Operations Pty Ltd);
- Josh Peters (Resource Strategies – Senior Environmental Project Manager); and
- Matthew Copeland (Resource Strategies – Environmental Project Manager).

The high environmental risks identified by the AUM Longwalls 205-208 Extraction Plan risk assessment related to:

- water losses from the surface due to surface cracking from subsidence (including Bowmans Creek and diversion); and
- impacts to alluvial groundwater levels and quality due to mine subsidence being greater than predicted.

The risk assessment for the AUM Longwalls 205-208 Extraction Plan (including identified risks, rankings and associated management and mitigation measures) was reviewed by AGE, ACOL and Resource Strategies in March 2023 with respect to the activities to be undertaken by the Proposed Action. It was found that the Proposed Action would not introduce any new environmental risks. Accordingly, this report has been prepared in consideration of the two abovementioned risks identified as part of the AUM Longwalls 205-208 Extraction Plan risk assessment.



LEGEND

- Drainage
- Ashton longwall panels
- Indicative Pikes Gully Seam Longwall layout
- Indicative Middle Liddell Seam Longwall layout
- Indicative Underground Mining Area
- Ravensworth complex
- Completed Pike Gully Seam Workings
- Ashton mining lease
- Quaternary alluvium/colluvium

Alluvium boundaries

- Bowmans Creek Alluvium
- Hunter River Alluvium

Ashton-Ravensworth Integration Project (ASH5001.003)

Approved RUM vs. Proposed Action panel layout

AGE

DATE
12/10/2023

FIGURE No:
1.1

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2 Regulatory framework

The sections below summarise government legislation, policy, and guidelines relevant to the Proposed Action.

2.1 NSW regulatory framework

The NSW regulatory framework is discussed in detail in the *Ashton-Ravensworth Integration Modification Groundwater Review* (AGE, 2021). As described in Section 1, the Modification was approved by the DPE under the NSW *Environmental Planning and Assessment Act 1979* in July 2022. Accordingly, the NSW regulatory framework is not discussed further in this report.

2.2 Commonwealth Environment Protection and Biodiversity Conservation Act 1999

The EPBC Act is administered by the Department of Climate Change, Energy, the Environment and Water (DCCEEW). The EPBC Act is designed to protect national environmental assets, known as Matters of National Environmental Significance (MNES). Under the 2013 amendment to the EPBC Act, significant impacts on water resources associated with coal mining and/or coal seam gas developments were included as an MNES and are known as the 'Water Trigger'. The Proposed Action has been referred to the Commonwealth for the assessment against the EPBC Act, and has been determined a "Controlled Action".

This Groundwater Impact Assessment (GIA) has been prepared to address recommendations made by the IESC (advice dated 14 December 2022). It has considered the *Information Guidelines for the Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals* (Commonwealth of Australia, 2018) and associated explanatory notes, including:

- Uncertainty Analysis – Guidance for groundwater modelling within a risk management framework (Middlemis and Peeters, 2018);
- Assessing Groundwater-Dependent Ecosystems (Doody, Hancock and Pritchard, 2019); and
- How to Derive Site-specific Guideline Values for Physical and Chemical Parameters (Huynh and Hobbs, 2019).

3 Environmental setting

3.1 Location

The Proposed Action longwall panels (herein referred to as the Action area) are located 14 km north-west of Singleton in the Hunter Valley region of NSW (see Figure 3.1). The Ashton Coal Project is located directly east of the RUM mining leases.

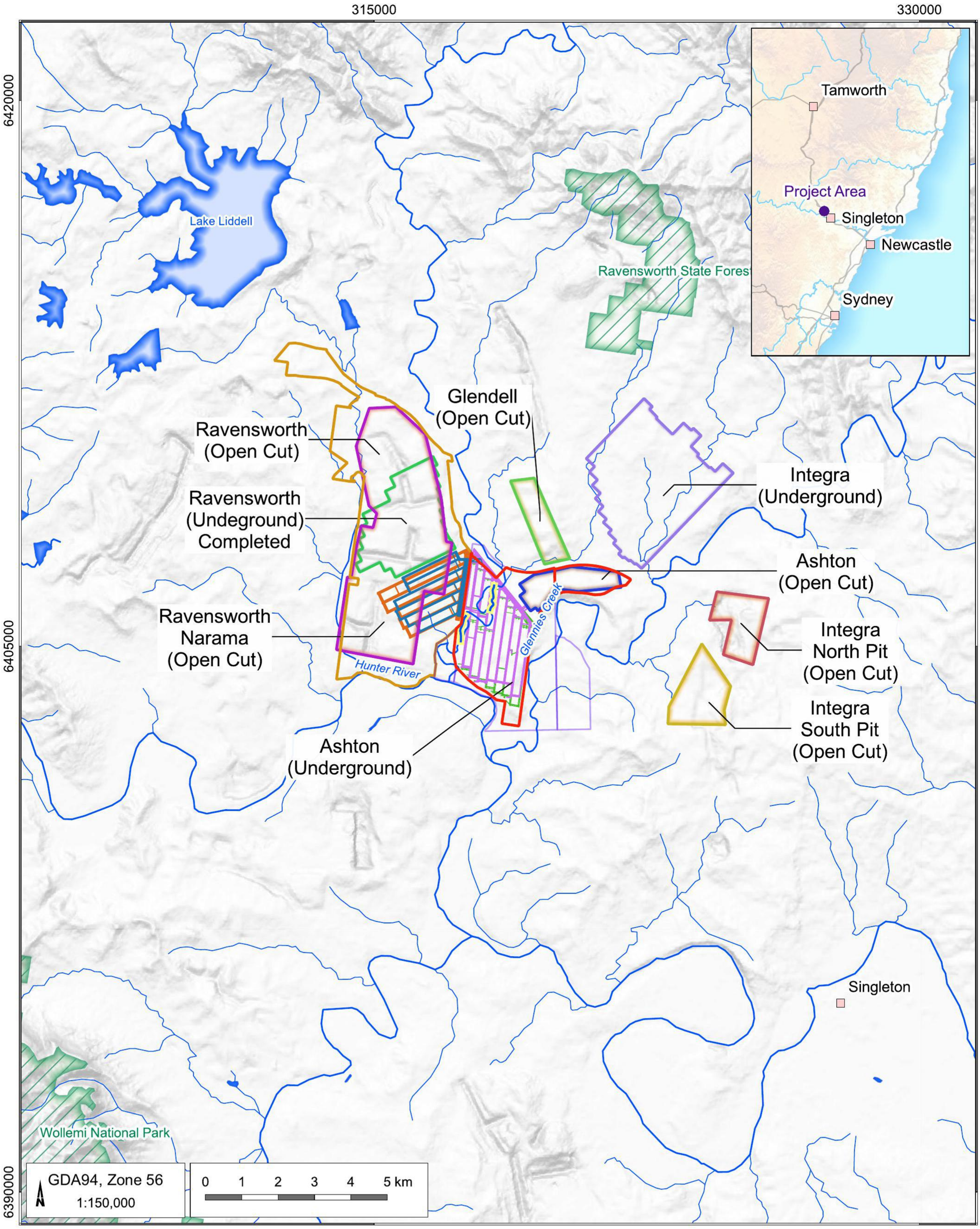
3.2 Climate

The climate of the Proposed Action area is characterised as mild winters and hot summers. The long-term average monthly rainfall and evaporation is summarised in Table 3.1. The data in Table 3.1 was obtained from the SILO[1] database for the period 1990 to 2022 at latitude -32.45 degrees (°), longitude: 151.05°. Precipitation occurs predominantly in the warmer months from November to March averaging 688 millimetres per year (mm/year). Evaporation is more than double the average rainfall at 1497 mm/year.

Table 3.1 Long-term monthly average rainfall and evaporation (1990 – 2022)

Month	Rainfall (mm)	Evaporation (mm)
Jan	67	199
Feb	86	156
Mar	83	135
Apr	43	97
May	37	69
Jun	49	53
Jul	37	60
Aug	37	88
Sep	43	120
Oct	51	154
Nov	76	173
Dec	79	193
Totals	**688**	**1497**

[1] https://www.longpaddock.qld.gov.au/silo/



LEGEND

- Ashton mining lease
- Ashton exploration lease
- Ravensworth complex
- Reserve
- Water area
- Populated place
- Major drainage
- Minor drainage
- Diversion
- AUM Pikes Gully panels
- AUM Upper Lower Liddell panels
- RUM Pikes Gully panels
- RUM Middle Liddell panels
- Integra (Underground)
- Ravensworth (Undeground) Completed
- Ashton (Open Cut)
- Glendell (Open Cut)
- Integra North Pit (Open Cut)
- Integra South Pit (Open Cut)
- Ravensworth (Open Cut)

Ashton-Ravensworth Integration Project (ASH5001.003)

Location

AGE

DATE 12/10/2023

FIGURE **3.1**

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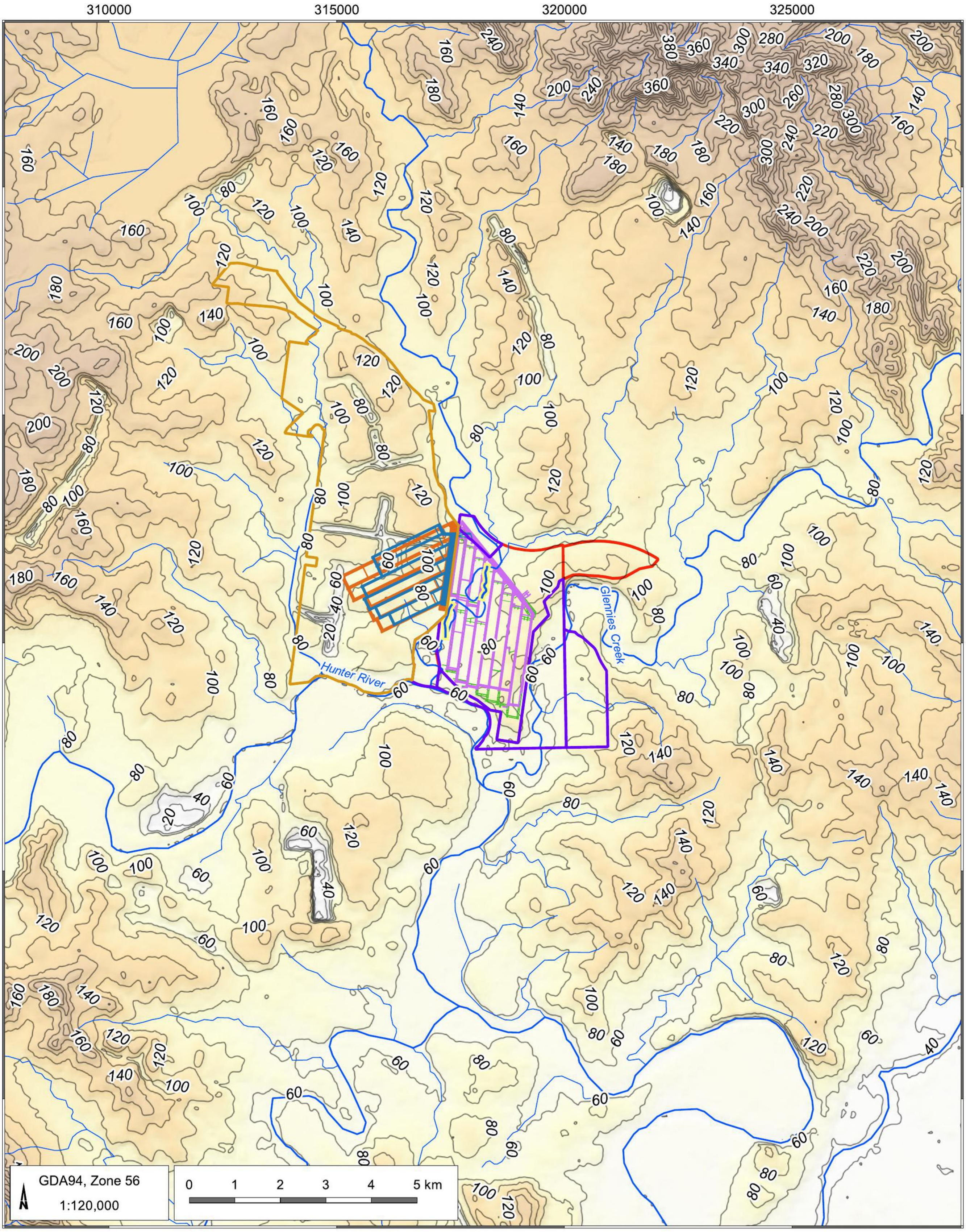
3.3 Topography and drainage

The landscape in the area of the RUM and AUM comprises rolling hills, alluvial river flats and areas disturbed by open cut mining (Figure 3.2). Topographic elevations range between 60 meters Australian Height Datum (mAHD) and 100 mAHD at the site up to some 400 mAHD at the head of the catchment areas (Figure 3.3).

The existing AUM is located between Bowmans Creek and Glennies Creek, close to the confluence with the Hunter River (Figure 3.1). The RUM is located between Bowmans Creek and Bayswater Creek also near the confluence with the Hunter River.

- Bowmans Creek extends approximately 30 km upstream to the north and has a catchment area of some 300 square kilometres (km^2). Bowmans Creek has been diverted in two locations so that it does not flow over the AUM longwall panels.
- Glennies Creek extends about 45 km upstream of AUM with a catchment area of about 600 km^2. Flow in Glennies Creek is controlled by releases from Lake Saint Clair.
- Bayswater Creek extends about 8 km upstream to Lake Liddell. Bayswater Creek has been diverted around the Ravensworth mine in the area of the RUM.

Figure 3.4 and Figure 3.5 show stream flow data at NSW Government gauges in Bowmans Creek (station No. 210130) and Bayswater Creek (station No. 210110). The charts show low flows range between about 0.1 megalitres per day (ML/day) and 10 ML/day in Bowmans Creek and 0.1 ML/day and 1 ML/day in Bayswater Creek depending on climatic conditions.



LEGEND

- Ashton mining lease
- Ashton exploration lease
- Ravensworth complex
- Elevation contour (mAHD)
- Major drainage
- Minor drainage
- Diversion
- AUM Pikes Gully panels
- AUM Upper Lower Liddell panels
- RUM Pikes Gully panels
- RUM Middle Liddell panels

Elevation (mAHD)

- 40
- 80
- 120
- 200
- 400

Ashton-Ravensworth Integration Project
(ASH5001.003)

Terrain and drainage

AGE

DATE
13/03/2023

FIGURE No:
3.2

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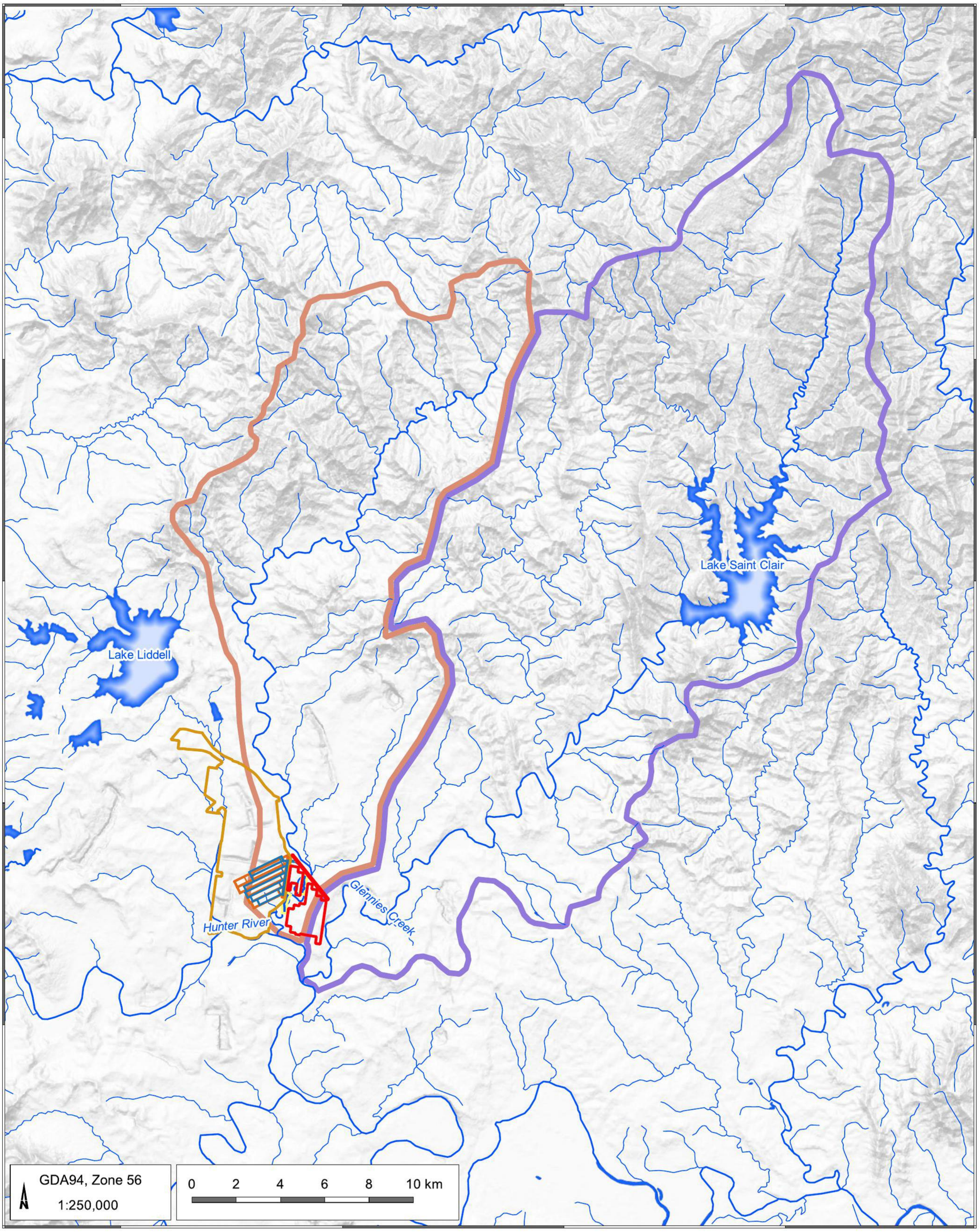

LEGEND

- Ashton underground mine (Pikes Gully level)
- Ravensworth complex
- Water area
- Major drainage
- Minor drainage
- Diversion
- RUM Pikes Gully panels
- RUM Middle Liddell panels

Catchments

- Bowmans Creek
- Glennies Creek

Ashton-Ravensworth Integration Project (ASH5001.003)

Bowmans Creek and Glennies Creek catchment areas

AGE

DATE 13/03/2023

FIGURE No: **3.3**

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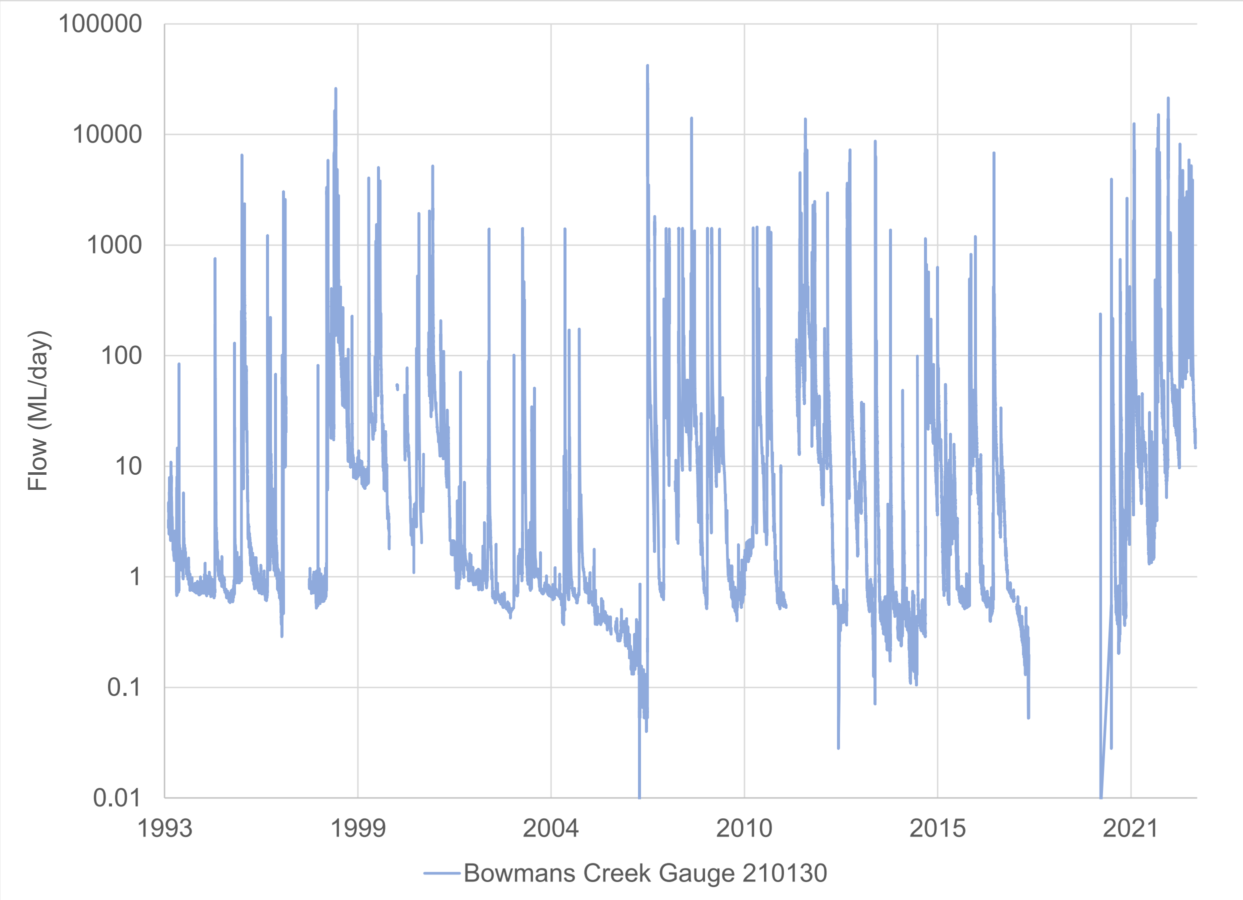


Figure 3.4 Recorded flow in Bowmans Creek at station No. 210130

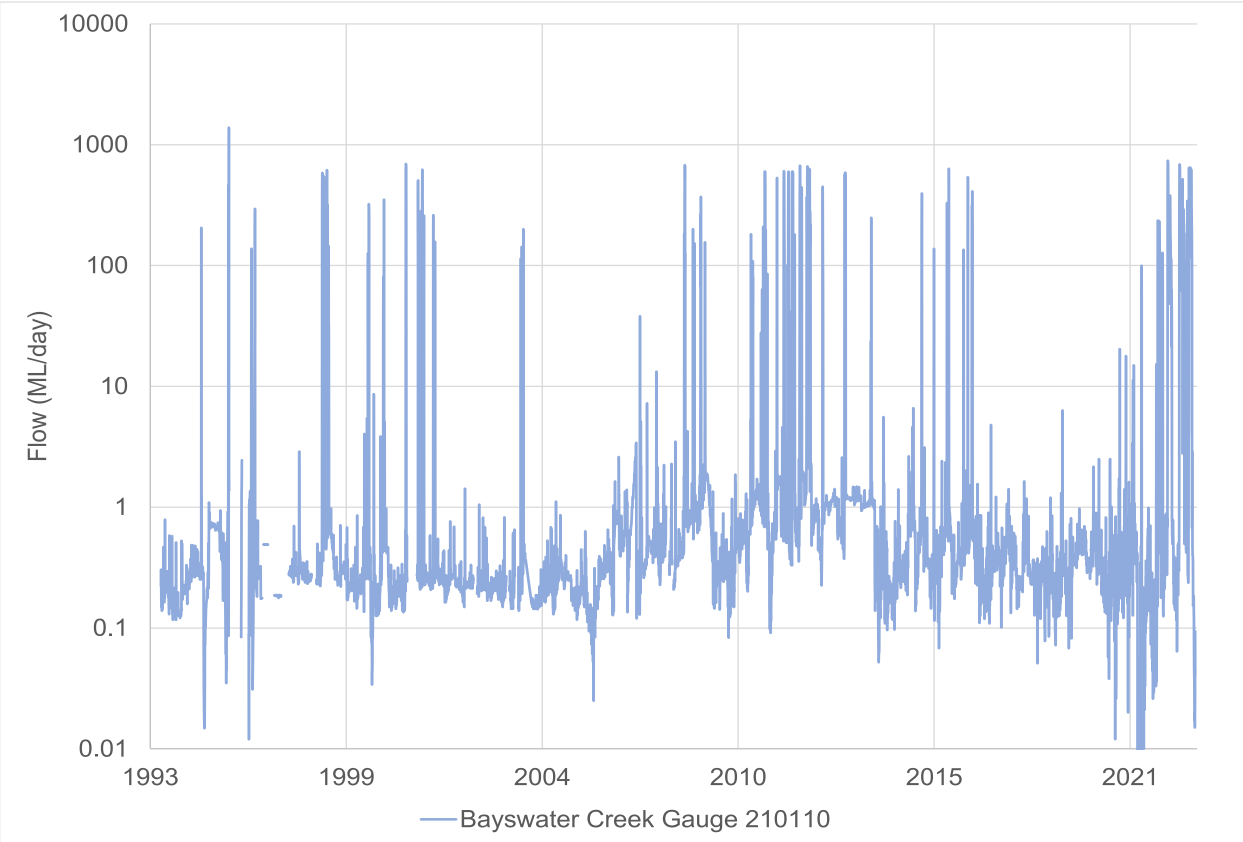


Figure 3.5 Recorded flow in Bayswater Creek at station No. 210110

3.4 Land use

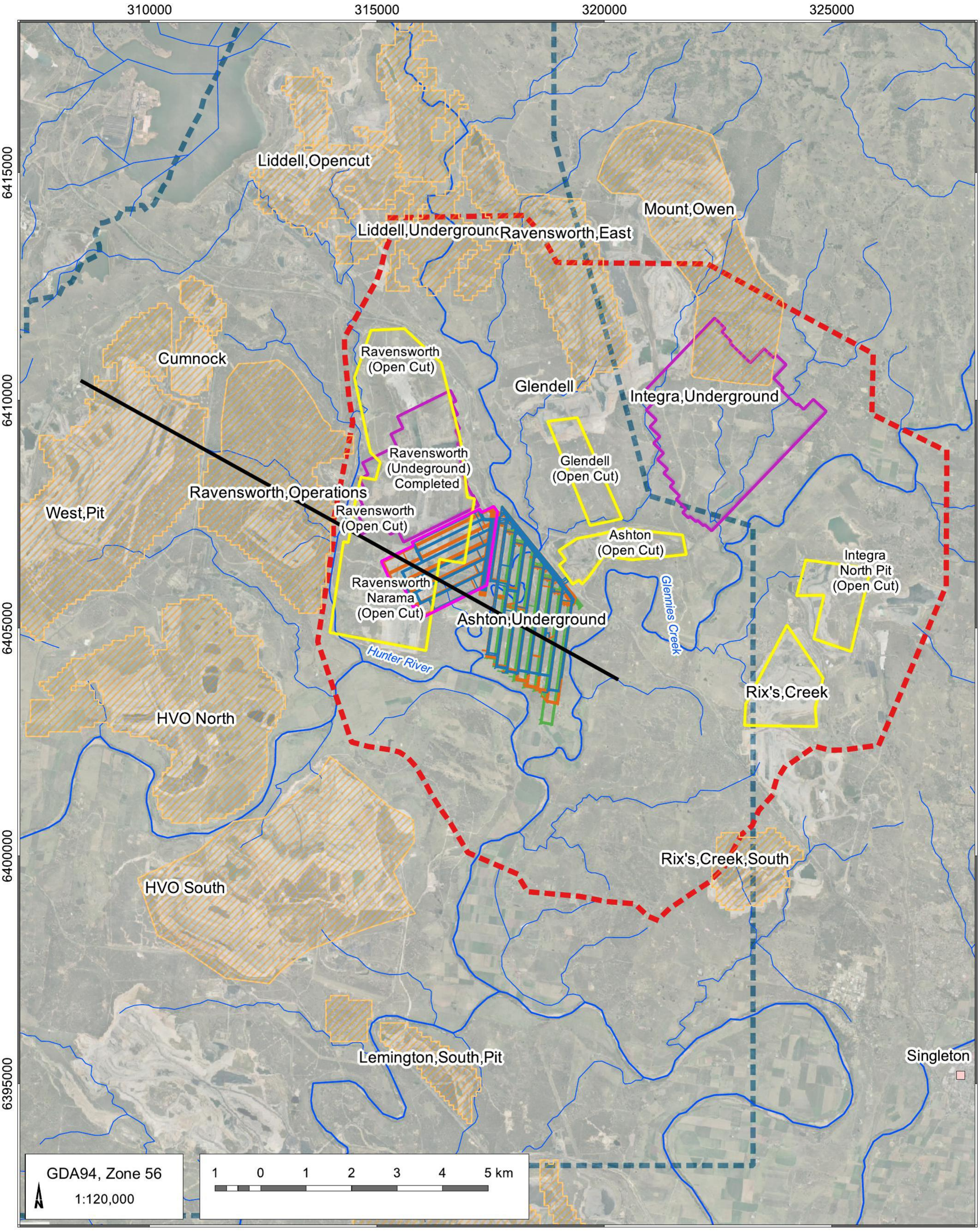
In the area surrounding the RUM, land use includes coal mining operations and agriculture. Agricultural land use includes beef cattle grazing in open pastures and dairy farming. There is also natural vegetation surrounding the Action area, including riverine vegetation along drainage lines (i.e., Hunter River, Bowmans Creek and Glennies Creek).

RUM lies within the Hunter Valley coalfields, which has a long history of mining dating back to the 1940s. Table 3.2 summarises the adjacent mining operations (which all intersect the Whittingham Coal Measures) including their approved timeframes and target coal seams. The locations of the adjacent mining operations are shown on Figure 3.6. The northeast-southwest cross-section across the mining area including adjacent mining operations is illustrated in Figure 3.7.

Table 3.2 Summary of adjacent mining operations

Mine	Mining Type	Seams targeted	From	To	Status
Ashton	Underground	Pikes Gully	2006	2013	Mined
Ashton	Underground	Upper Liddell	2012	2017	Mined
Ashton	Underground	Upper Lower Liddell	2017	2022	In Progress
Ashton	Underground	Lower Barrett	2030	2035	Planned
Ashton NEOC	Open cut	To Lower Barrett	2004	2010	Decommissioned. Void being filled with rejects and tailings
Ravensworth	Underground	Pikes Gully	2007	2014	Care and maintenance
Ravensworth - Narama	Open cut	To Bayswater	1993	2012	Decommissioned. Void used for water storage
Ravensworth - South	Open cut	To Bayswater	1989	2000	Decommissioned. Void being backfilled with tailings/ash
Ravensworth - No.2	Open cut	To Bayswater	1970	1984	Decommissioned. Void being backfilled
Integra	Open cut	To Hebden	1992	1999	Decommissioned. Void open
Integra	Underground	Middle Liddell Seam	2000	2024	Operating
HVO North	Open cut	Bayswater to Hebden (West pit)	1949	2025	Operating
HVO North Proposed	Open cut	Bayswater to Barrett	2025	2050	Proposed
HVO South	Open cut	Bayswater	1997	2030	Operating
HVO South Proposed	Open cut	Bayswater	2030	2045	Proposed
Glendell	Open cut	To Lower Barrett	2009	2042	Operating

The potential for cumulative groundwater impacts associated with the surrounding mine operations is discussed in Section 8.



LEGEND

Cross-Section
Ashton-Ravensworth integration model domain
Adjacent mining areas around model domain
Open-cut mining areas in model domain
Action area
Underground mine areas in model domain
Pikes Gully Seam
Liddell Seam
Barret Seam
Drainage
HVO model domain

Ashton-Ravensworth Integration Project
(ASH5001.003)

Adjacent mining areas

AGE

DATE
21/04/2023

FIGURE No:
3.6

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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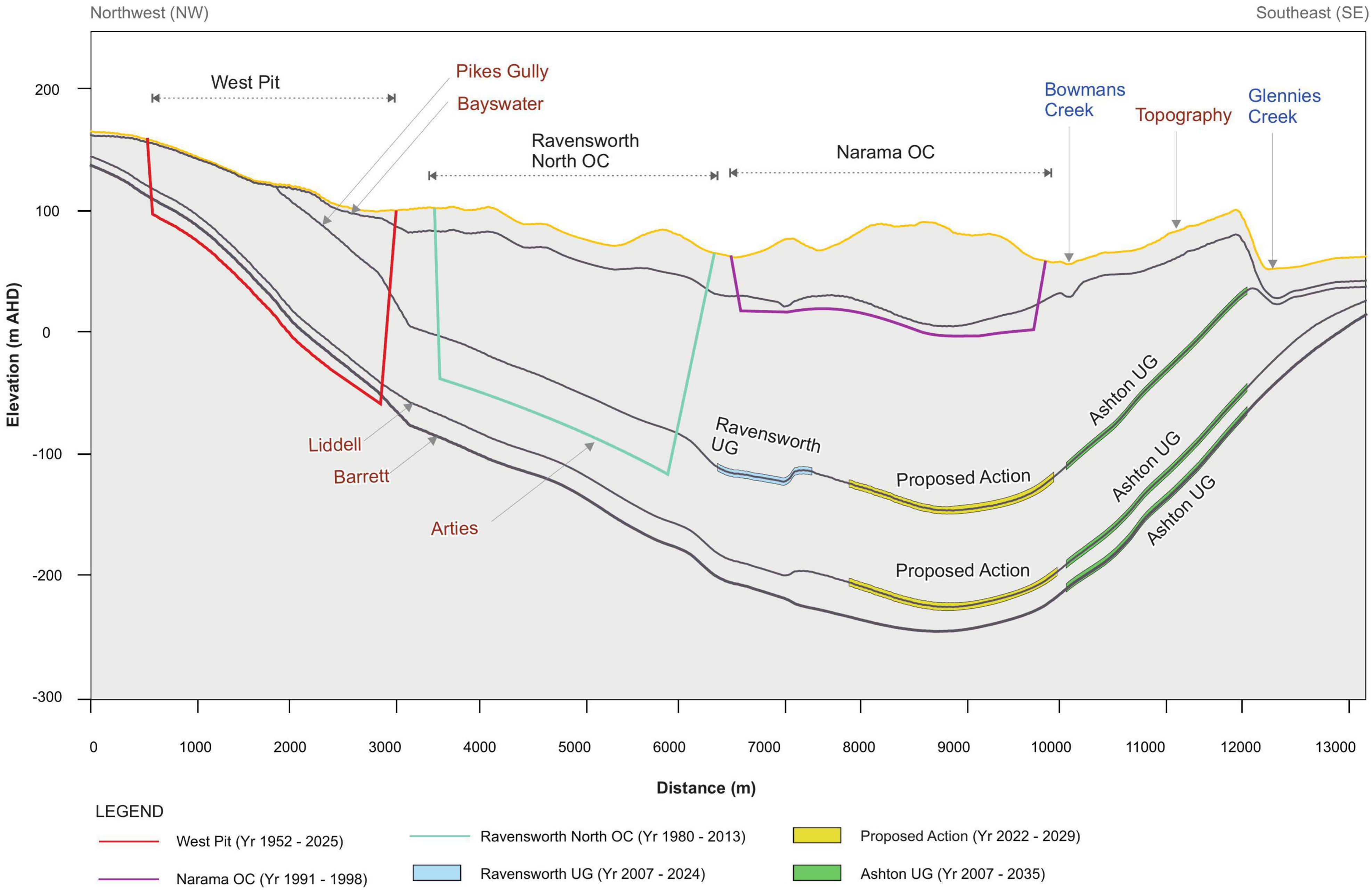

Ashton-Ravensworth mining areas cross section

Figure - 3.7

Ashton Ravensworth Integration Modification (ASH5001.003)

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3.5 Geological Settings

The geological setting described in the following sections was determined using the following data sources:

- publicly available geological maps (Hunter Coalfields map sheets) and reports;
- publicly available geological and hydrogeological reports for adjacent projects and mine operations;
- hydrogeological data held on the Department of Primary Industries - Water groundwater database (Pinneena) and the National Groundwater Information System for existing private groundwater bores;
- a 3D geological model developed by the ACOL for AUM (including the RUM area);
- a 3D groundwater flow model for AUM (RPS 2009/2012/2014); and
- lithological logs for coal mining exploration holes.

This information also provided the structural framework for the development of a 3D numerical groundwater model. Appendix A provides more detail on the approach to the groundwater modelling.

3.6 Stratigraphy

The stratigraphic sequence in the region comprises two distinct units; Quaternary alluvium and Permian strata. The Quaternary alluvium consists of unconsolidated silt, sand and gravel in the alluvial floodplains of the Hunter River, Bowmans Creek, Glennies Creek, and the lower reaches of Bayswater Creek where not diverted. The alluvium unconformably overlies the Permian strata, which comprise coal seam sequences with overburden and interburden consisting of sandstone, siltstone, tuffaceous mudstone, and conglomerate.

The stratigraphic sequence of the Permian coal measures in the Hunter Valley is shown in Figure 3.8. The Middle Permian strata form a regular layered sedimentary sequence, with the Whittingham Coal Measures containing the main economic coal seams. The Hunter Coalfields regional geology map (1:100,000 scale) (Glen & Beckett, 1993) is included in Figure 3.9.

The RUM and AUM are located in the central Hunter Valley of NSW where the lower sequences of the Whittingham Coal Measures (Singleton Supergroup) subcrop. The underground operation targets the Pikes Gully (PG) Seam, Upper Liddell (ULD) Seam, Upper Lower Liddell (ULLD) Seam and the Barrett Seam. Those seams extend into the Proposed Action (RUM) area as they dip downward, however the ULLD Seam is referred to as the Middle Liddell (MLD) Seam at RUM.

The Proposed Action area is located west of the alluvium associated with Bowmans Creek. The alluvium associated with Glennies Creek is located more than 2 km to the east of the Proposed Action. The Bowmans and Glennies Creek alluvium are in direct connection to the Hunter River alluvium. Figure 3.10 shows the extents of the Quaternary alluvium, as well as the subcrop lines for the major coal seams.

3.7 Regional geology

Figure 3.9 shows regional structural features within the Proposed Action area. The Permian coal measures are stratified (layered) sequences that have undergone deformation resulting in strata that are influenced by large fold structures on a regional scale.

The Action area is located on the western limb of the Camberwell anticline. This structure has caused the local geology to dip uniformly to the west-southwest. The Camberwell anticline is located between the Rix's Creek Syncline and the Bayswater Syncline, which bound the mine site to the east and west, respectively. The region is also bound to the north by the Hebden thrust fault (see Figure 3.9).

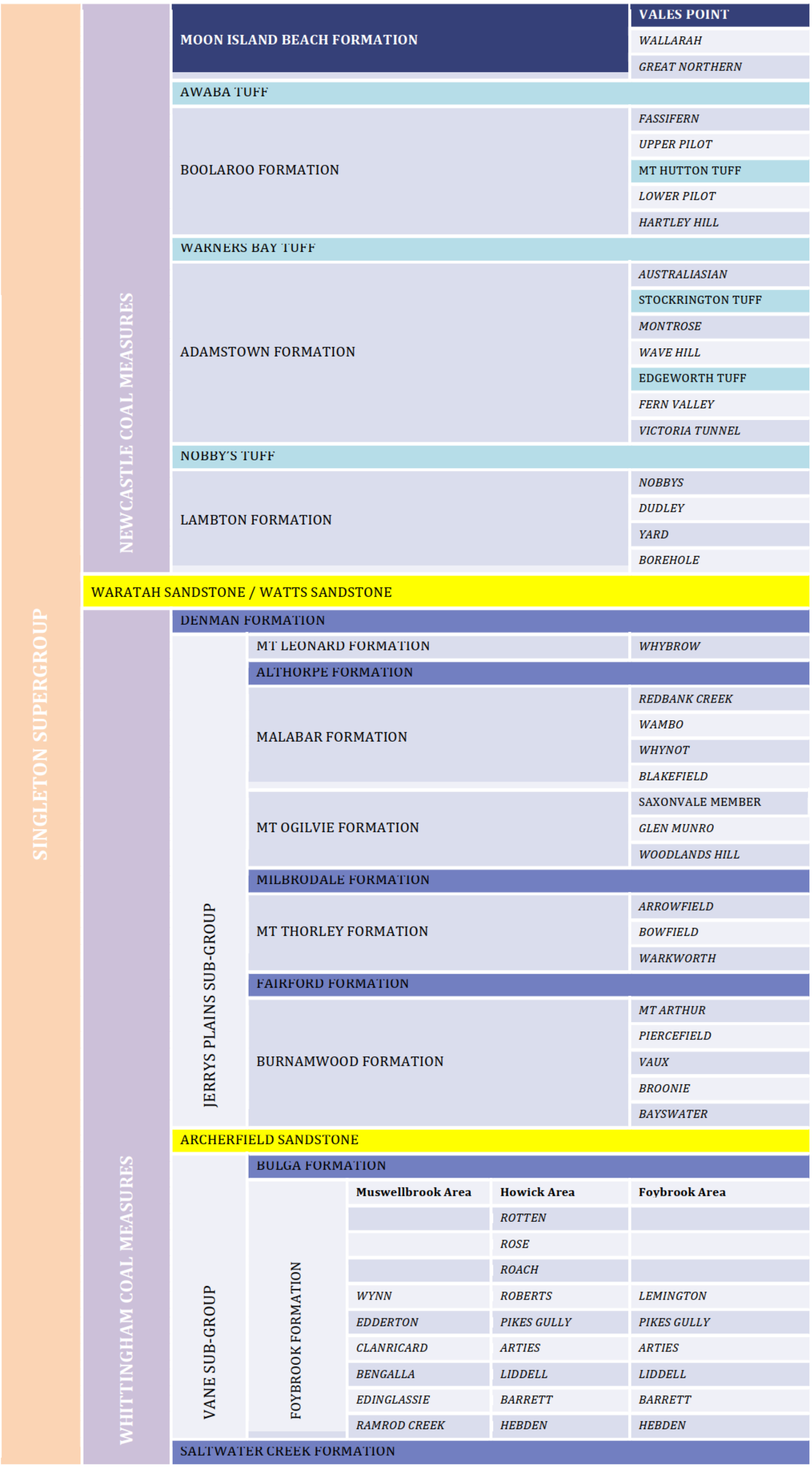
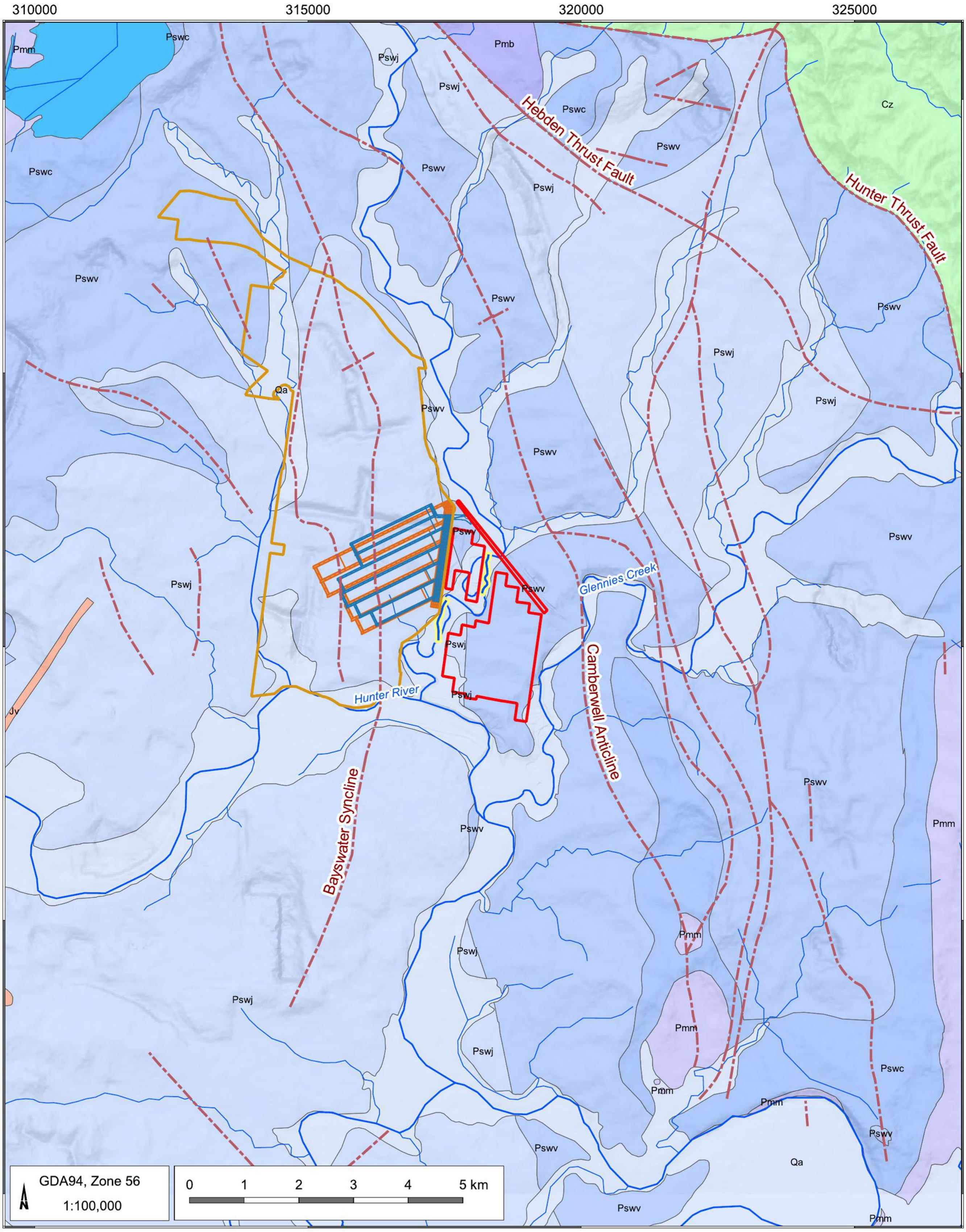


Figure 3.8 Singleton Super Group sequence stratigraphy



LEGEND

- Ashton underground mine (Pikes Gully level)
- Ravensworth complex
- Regional fold
- Regional fault
- Major drainage
- Minor drainage
- Diversion

Geology - Hunter Coalfield Regional 100k

- Qa - Quaternary alluvium
- Jv - Jurassic volcanics
- Pswj - Jerrys Plains Subgroup
- Pswv - Vane Subgroup
- Pswc - Saltwater Creek Formation
- Pmm - Mulbring Siltstone
- Pmb - Braxton Formation
- Cz - Carboniferous tuff and ignimbrite

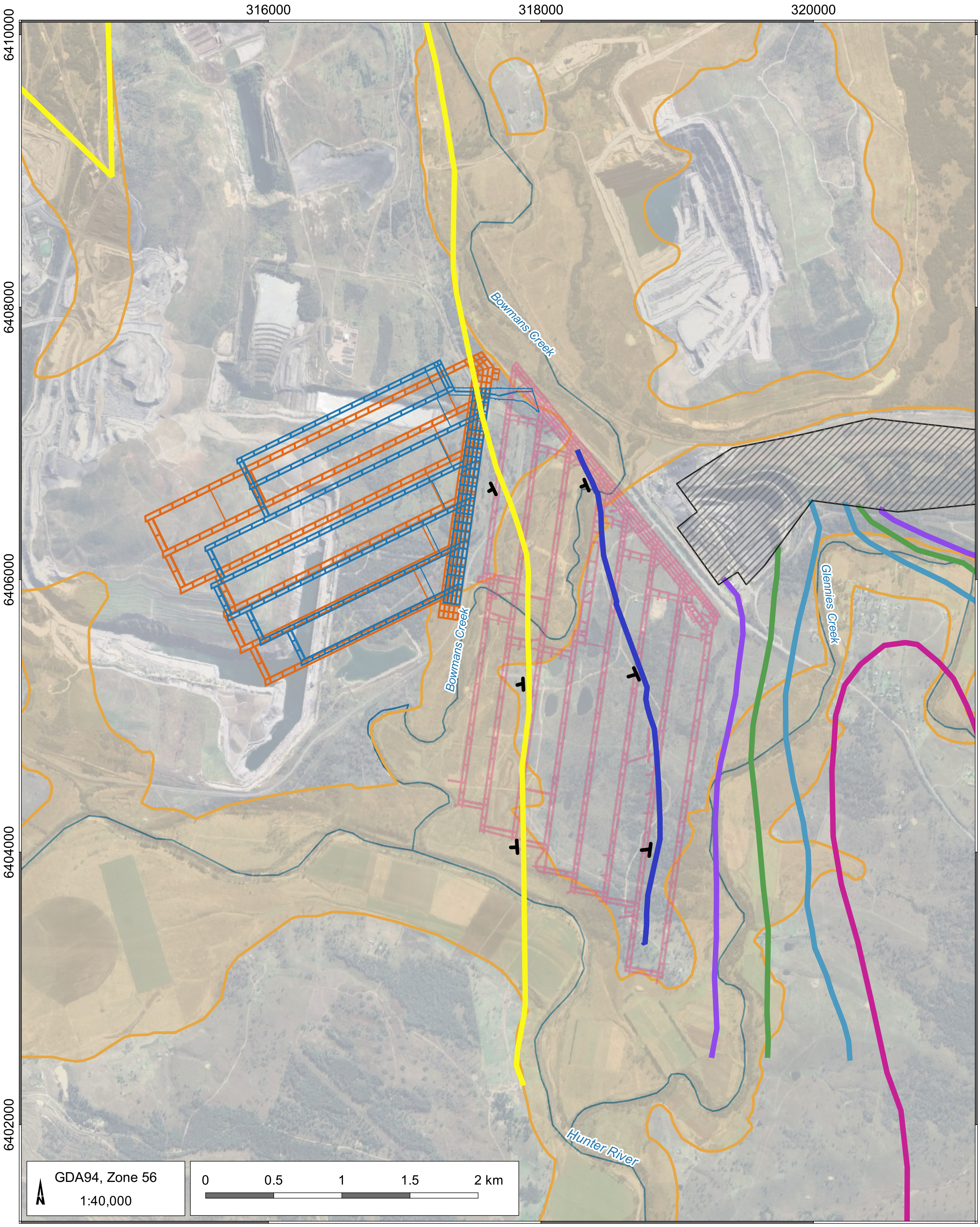
Ashton-Ravensworth Integration Project (ASH5001.003)

Regional geology

AGE

DATE 15/03/2023

FIGURE No: **3.9**



LEGEND

- Open cut boundary
- Quaternary alluvium / colluvium
- Drainages
- Dip direction
- RUM Pikes Gully panels
- RUM Middle Liddell panels

Assumed subcrop lines

- Bayswater Seam
- Lemington Conglomerate
- Pikes Gully Seam
- Upper Liddell Seam
- Upper Lower Liddell Seam
- Lower Barrett Seam

Ashton-Ravensworth Integration Project (ASH5001.003)

Alluvial boundaries and sub crop lines

AGE

DATE 12/10/2023

FIGURE **3.10**

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3.8 Local geology

The following main stratigraphic units occur within the Proposed Action area (from youngest to oldest):

- Recent alluvium; and
- Permian Whittingham Coal Measures, key units of interest include:
  - Regolith/weathered profile;
  - Conglomerate within the Lemington Seams ply profile (from here on referred to as the Lemington Conglomerate); and
  - Four main mining seams – PG Seam, ULD Seam, ULLD Seam/MLD Seam and the Lower Barrett (LB) Seam.

Each of the main stratigraphic units is discussed in further detail below.

3.8.1 Recent alluvium

The Quaternary/recent aged alluvium along the Hunter River, Glennies Creek and Bowmans Creek flood plains comprises two distinct depositional units, a surficial fine-grained sediment and coarser basal material. The surficial alluvium comprises shallow sequences of clay, silty, and sands which overly coarser basal sands and gravels. The alluvial sediments unconformably overlie the Permian strata. Along the minor drainage lines the surficial alluvium is typically constrained within 500 metres (m) of the creeks and is between 7 m to 15 m thick. The extent of alluvium is shown on Figure 3.10. The thickness of alluvium is shown in Figure 3.11.

The alluviums are generally thickest in the middle and then thin out at their edges. Bowmans Creek Alluvium is directly east of the Proposed Action and conforms to the typical range of 7 to 15 m thick. The Hunter River Alluvium is broader and a little more channelised in its structure, with thickness ranging from 12 to 20 m through the area adjacent to the Proposed Action. The alluvium associated with Bayswater Creek is thinner and has been removed in part through historical mining at the Ravensworth Mine Complex.

3.8.2 Permian coal measures

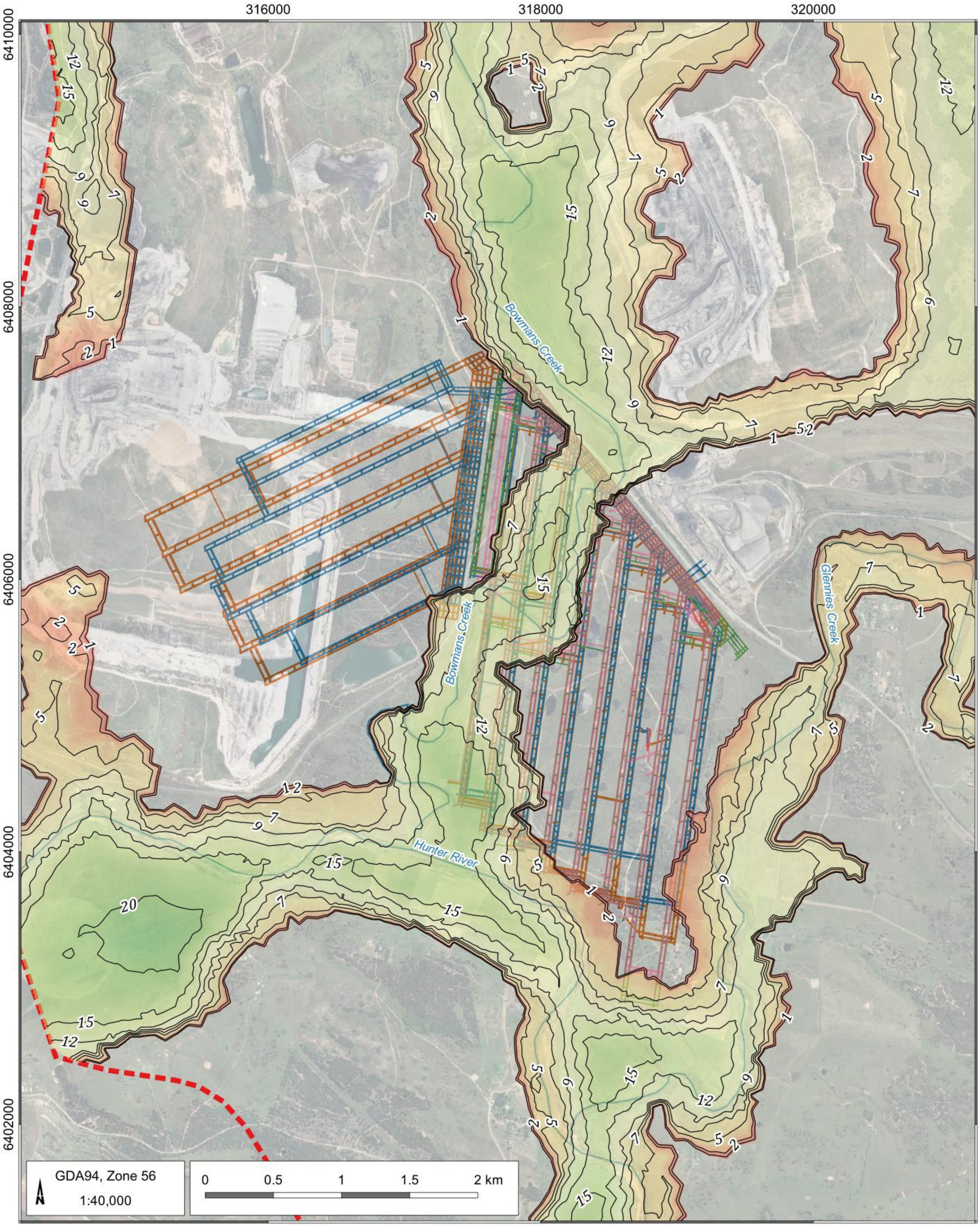
The Whittingham Coal Measures comprise coal seams interbedded with siltstone, sandstone, shales and conglomerates. The non-coal portions of the sequence are referred to as interburden in the mining context. The Whittingham Coal Measures are up to 400 m thick at the RUM, but regionally they range from approximately 250 m to 600 m thickness.

At the RUM and AUM, the lower portion of the Permian aged Whittingham Coal Measures from the Bayswater Seam to the Hebden Seam is present (Figure 3.8). The coal measures from the Bayswater Seam to the Lemington Seam plies subcrop over the underground mine area and the seams from the PG Seam to the LB Seam subcrop east of the underground mine area (see Figure 3.10).

Each target coal seam occurs with various splits and plies, with a coal thickness of between 2 m and 2.5 m. The coal seams are interbedded with units of siltstone, sandstone and shale. The two target coal seams are separated by approximately 100 m of interburden. The overburden above the PG Seam ranges in thickness between 200 m and 260 m.

Over 20 plies of the Lemington Seam profile and the overlying Bayswater Seam are present within the PG Seam overburden. A sandstone/conglomerate unit ranging in thickness from 10 m to 15 m (the Lemington Conglomerate) occurs approximately 90 m above the roof of the PG Seam. This unit varies across the site from coarse sandstone to a predominantly gravel/pebble conglomerate with an abundant sand matrix. This unit is likely to deform differentially to other units at the site. The majority of overburden and interburden at the site is fine grained and is more likely to sag and deform in a ductile manner, whereas the massive conglomerate/sandstone unit is more likely to undergo sudden and brittle fracturing. This is likely to impact the rate of change to vertical connectivity during subsidence deformation. This mechanism is discussed further in Appendix A and in the conceptual model section (Section 5).

The Permian coal measures occur at outcrop or are unconformably overlain by Quaternary alluvium. As a result, the upper Permian stratigraphy has undergone a period of weathering. At RUM, the weathered profile of the Permian strata has been significantly disturbed by historical open cut mining.



LEGEND

- Model boundary
- Quaternary alluvium / colluvium
- Drainages
- Contour
- Indicative Pikes Gully Seam Longwall layout
- Indicative Middle Liddell Seam Longwall layout

Alluvium thickness (m)

0

30

Ashton-Ravensworth Integration Project (ASH5001.003)

Thickness of Alluvium

AGE

DATE 15/03/2023

FIGURE No: **3.11**

G:\Projects\ASH5001.001.Ashton_Ravensworth_Integration_Modification\5_Deliverables\005_Ashton_Ravensworth_Integratsion_Project\03.11_ASH5001.03_Alluvial_Thickness.qgs.qgz

3.8.3 Structures

Figure 3.9 shows regional structural features within the Proposed Action area. The Permian coal measures are stratified (layered) sequences that have undergone deformation resulting in strata that are influenced by large fold structures on a regional scale.

As noted previously, the Proposed Action is located in the flatter part of the Bayswater Syncline whose axis trends north-south and plunges southward; strata dip to the south at a shallow angle of between 2 and 5°.

No other major faults, significant structures or igneous intrusions (dykes or sills) are known to occur in the mining area, although minor dykes and small-scale structures such as rolls or folds in the seams have been observed. One water-bearing, low angle shear zone has been encountered in the PG Seam in the north-west main headings at the AUM, which can also be seen at its outcrop within the NEOC pit (RPS Aquaterra, 2011).

Zones of small scale normal and reverse faulting have been observed in the south of the AUM mine area during mining of the PG and ULD Seams. Underground mining has exposed generally north-south trending faults with throws of <1 m. These faults have persisted at depth and have been located in longwall development roadways in ULLD Seam (Yancoal, 2020).

During mining of AUM LW201-LW204, several geological structures were observed including an igneous Teschenite dyke and two normal separate fault zones. The first normal fault zone was observed within the block of LW201. This fault zone is a graben or trough structure composed of several smaller fault planes dipping 70-80° to the west and of about 1.70 m total down-throw to the west. The second fault zone located within LW204 panel is about 60 m wide. The fault zone is composed of several smaller fault planes of 0.05 m-0.35 m vertical displacement that dip 50-80° to the west and; a larger fault of 2.45 m to 2.85 m vertical displacement dipping 70-80° to the west (Yancoal, 2016). The regional and local faults are shown in Figure 3.12.

To date, monitoring of groundwater levels has not indicated any direct connection between shallow groundwater near receptors and any structure across the AUM, despite the amount of mining and associated dewatering that has already taken place.

Mackie Environmental Research (2009) makes mention of faults and dykes across the RUM area, however there are no specific details or mapping provided in the reporting. More recently, reporting on the nearby Glendell (AGE, 2019) and HVO (AGE, 2022) mine models has provided information on faults and dykes that exist in the area and this is presented on Figure 3.12, which also includes the previous fault mapping for the Proposed Action area. An earlier study for Ravensworth South Environmental Impact Statement (Costin, 1984) noted that there was no indication of the existence of any major igneous intrusions or faulting in the area of the Proposed Action, which is consistent with Figure 3.12.

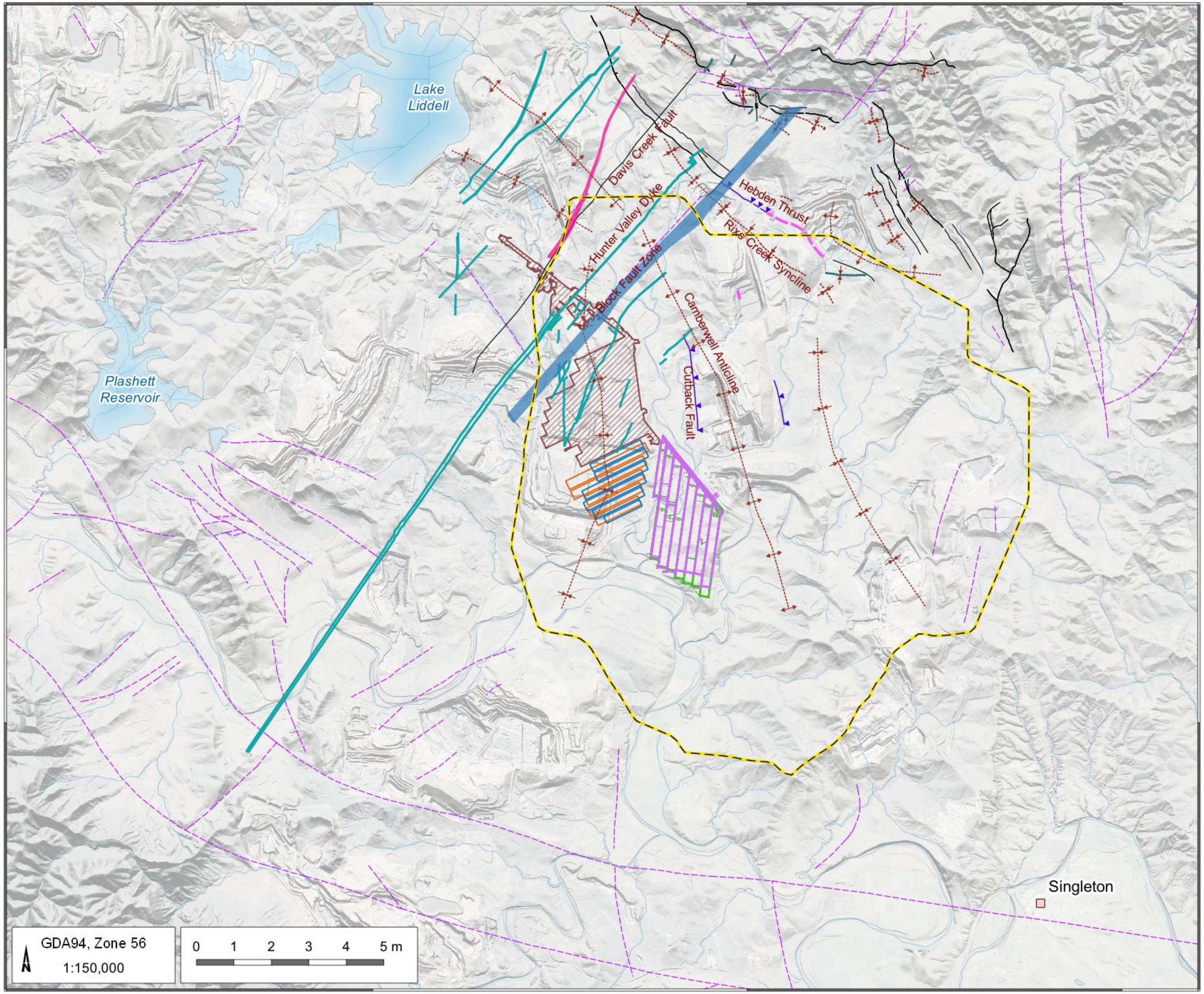
Many of the Glendell model mapped faults are outside of the Ashton–RUM model domain (Figure 3.12), but some of the broader features do traverse into the Ashton–RUM model domain.

Most notable of these is the Block Fault zone (see Figure 3.12). Pells Sullivan Meynink Pty Ltd (2019) investigated the block fault zone for the Glendell Continuation Project and described it as a regional “horst and graben” type structure comprising a series of alternating raised and lowered blocks across the fault zone. PSM confirm “the throw on the faults within the block fault zone are not large and result in only slightly offset coal seams”. Further, “the fault zone visually does not appear to host large amounts of groundwater and is considered a less significant source of groundwater inflow when compared with the coal seams”. Therefore, the exclusion of this feature from the model is not likely to increase uncertainty in the predicted impacts as its influence would be limited.

Just north of the block fault zone is the Hunter Valley dyke which has a similar strike direction to the block fault zone. The hydrogeological nature of this dyke is not known, but it has a typical intrusive thickness of 15 m and associated cindered coal thickness of up to 15 m either side of the dyke.

Of the additional mapped features, there are none that traverse the Proposed Action longwall panels, and only a minor dyke/cinder zone mapped just north of the panels which are expected to be small scale (<4 m) and have no appreciable influence on regional groundwater behaviour.

Many of the known faults and structures surrounding the Proposed Action have already been intercepted by existing mining operations. Further, the Pikes Gully seam has been mined immediately north and east of the Proposed Action area by the existing RUM and Ashton Underground Mine, respectively. The Middle Liddell seam has also been mined by the Ashton Underground Mine immediately to the east of the Proposed Action. Available monitoring data in the local area indicates that groundwater flow and the propagation of depressions from mining does not appear to be fault-controlled. Accordingly, the potential for known or unknown faults to materially influence groundwater movement in the Action area is likely to be very limited.



LEGEND

- Populated place
- Drainage
- Approved Ashton Pikes Gully Liddell Longwall Layout
- Approved Ashton Upper Lower Liddell Longwall Layout
- Proposed Action Pikes Gully Seam Longwall Layout
- Proposed Action Middle Liddell Seam Longwall Layout
- Water area
- Ashton model boundary
- Block fault
- Dyke significant thickness – source Glendell
- Completed Pike Gully Seam Workings
- Regional faults
- Dykes – source Glendell
- Anticlines from site
- Synclines from site
- Monocline
- Reverse fault
- Faults – source Glendell

Ashton-Ravensworth Integration Project (ASH5001.003)

Regional and local structures

DATE
22/03/2024

AGE

FIGURE No:
3.12

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4 Hydrogeology

4.1 Hydrostratigraphic units

Regionally, groundwater is recognised as occurring within both the Quaternary alluvium and the Permian Whittingham Coal Measures. The two main water bearing systems within the RUM area are the Permian coal measures and the unconsolidated alluvial sediments associated with the Hunter River, Glennies Creek and Bowmans Creek.

Groundwater recharge at the site primarily occurs as result of rainfall infiltration at outcrop of the coal measures and the alluvium, and lateral flow through from the alluvium to the Permian coal measures (Aquaterra, 2009). The Whittingham Coal Measures are known to subcrop below the Hunter River alluvium (HRA), Glennies Creek alluvium (GCA) and Bowmans Creek alluvium (BCA). The hydraulic connectivity between the Whittingham Coal Measures and the alluvium is not precisely understood.

Alluvium along the Hunter River within the AUM area adjacent to the Proposed Action is generally 7 m to 15 m thick, with the alluvium thinning to 0 m to 5 m towards the edges of the alluvial plain (Aquaterra, 2009; Wilford, 2015).

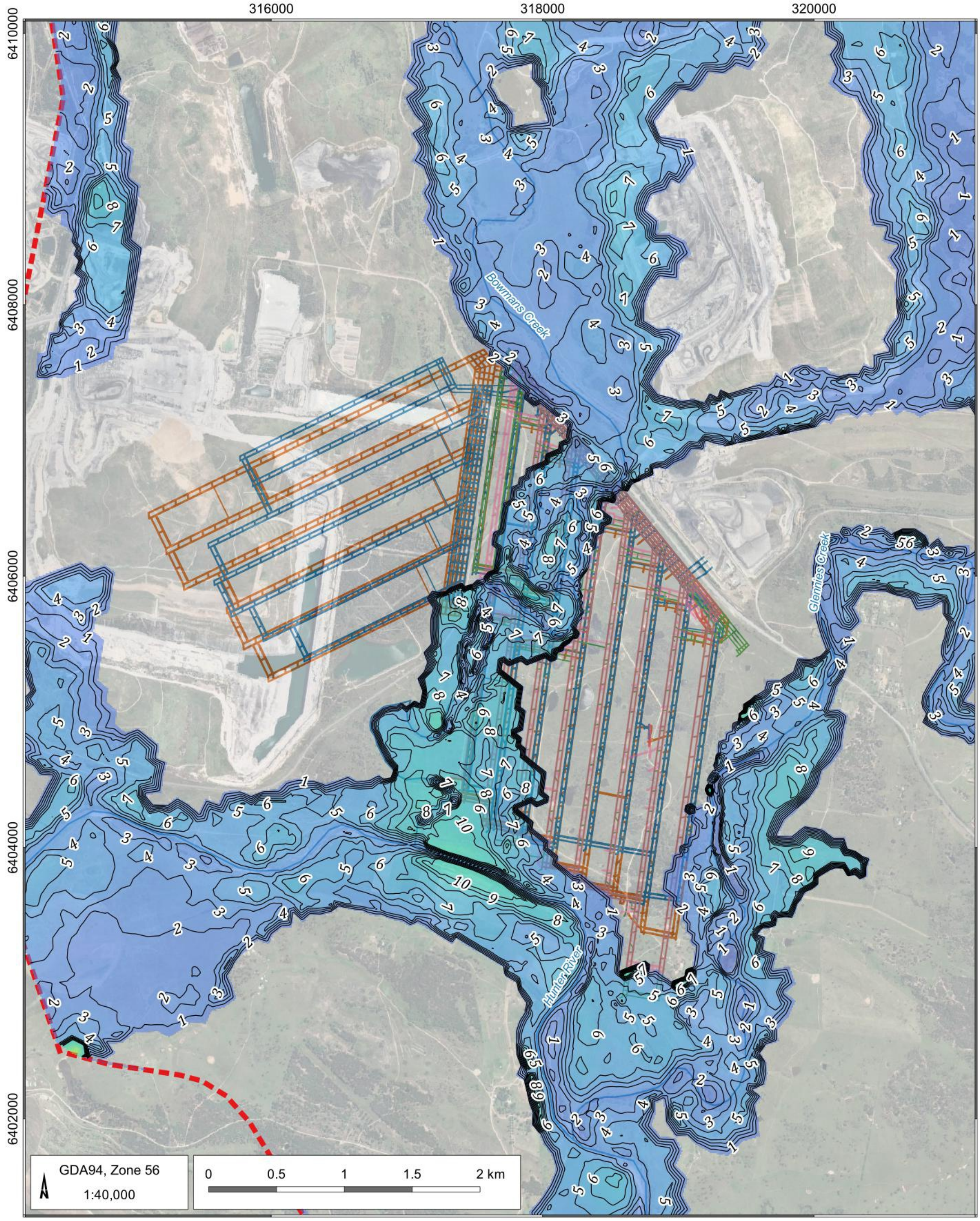
4.2 Groundwater occurrence

Prior to mining in the region, the alluvial sediments along the creeks were generally well saturated with higher pressured higher salinity groundwater in the Permian coal seams and interburdens discharging to surface drainages of the Hunter River and its tributaries (including Bowmans and Glennies Creeks). This would have saturated the alluvium up to at least the creek bed level. The onset of mining and in particular mine dewatering has resulted in the Permian sediments being depressurised and in places the gradients reversing with the alluvial sediments becoming a source to the underlying Permian formation.

Despite this reduction in water flowing to the alluvial systems, they have maintained their levels through diffuse rainfall recharge and have largely not demonstrated any impacts from the surrounding mining, though it is noted that the Hunter River and Glennies Creek are both regulated systems. However, Bowmans Creek is not a regulated stream, but it too has maintained groundwater levels that have fluctuated with climate to the point of areas becoming desaturated, but not demonstrated significant drawdowns due to mining. This is evident in the monitoring of Bowmans Creek that has experienced a gradual lowering of water levels from 2016 through to 2020, but has since responded and recovered to higher levels than previously reported due to wetter than average conditions. Bowmans Creek north-east of the Proposed Action has had numerous years of adjacent mining from Ravensworth and from Glendell, which have significantly depressurised the Permian units, however, groundwater levels have remained steady in the alluvium and again responding to climate fluctuation (AGE, 2019).

Interpolation of current/recent water level data and comparison to the topographical information indicates that the depth to water (see Figure 4.1) through the Bowmans Creek area is variable, but in the range of 4 to 10 m directly east of the Proposed Action. The corresponding level of saturation in the alluvial areas is shown in Figure 4.2.

The annual rainfall recharge to the various geological units at the site is discussed in Appendix A.



LEGEND

- Model boundary
- Quaternary alluvium / colluvium
- Drainages
- Contour
- Indicative Pikes Gully Seam Longwall layout
- Indicative Middle Liddell Seam Longwall layout

Depth (m)

0

10

Ashton-Ravensworth Integration Project
(ASH5001.003)

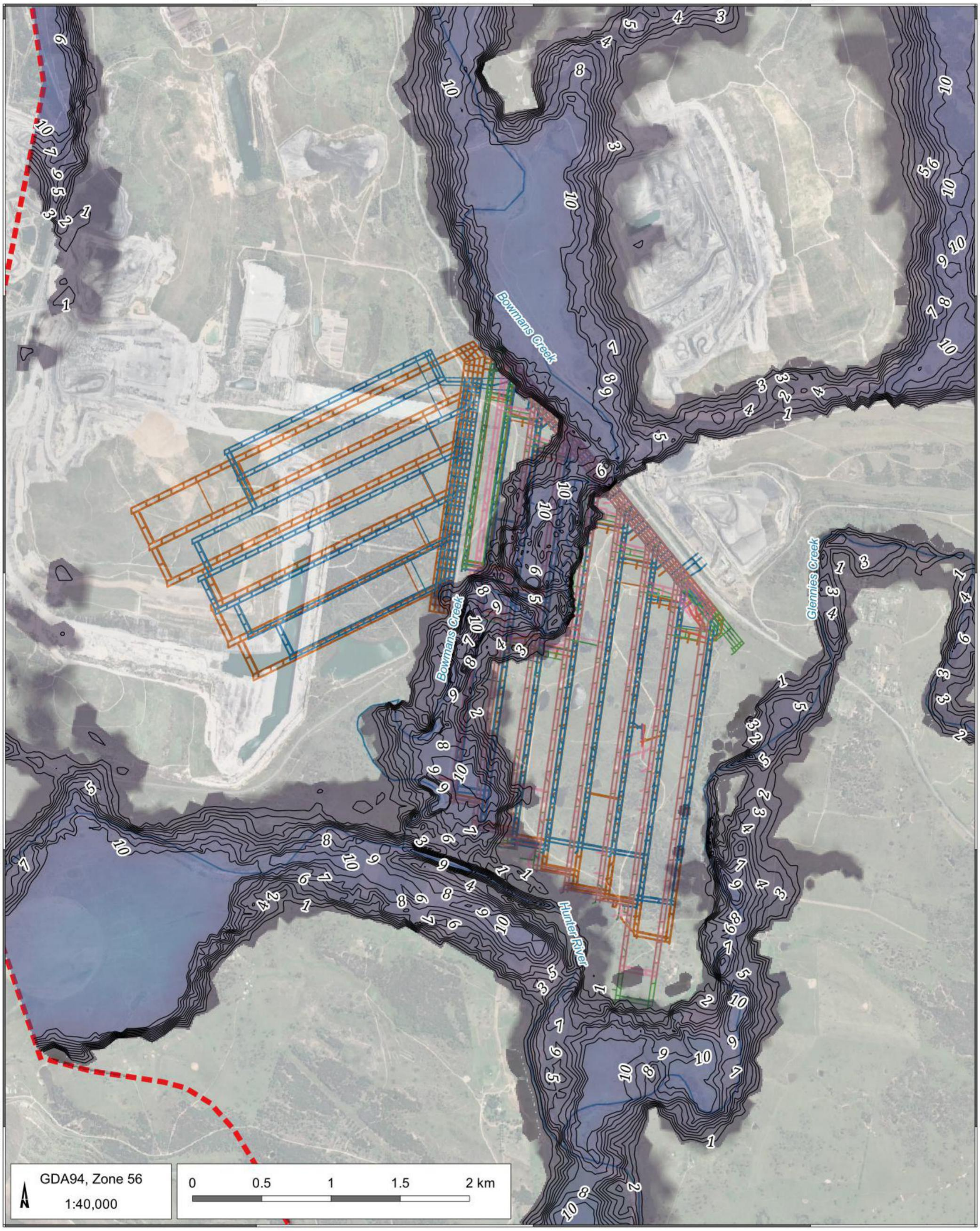
Depth to water table for the alluvial areas

AGE

DATE 17/03/2023

FIGURE No: **4.1**

G:\Projects\ASH5001.001.Ashton_Ravensworth_Integration_Modification\5_Deliverables\005_Ashton_Ravensworth_Integratsion_Project\04.01_ASH5001.003_Depth_to_water_table_for_alluvium_areas.qgz



LEGEND

- Model boundary
- Quaternary alluvium / colluvium
- Drainages
- Contour
- Indicative Pikes Gully Seam Longwall layout
- Indicative Middle Liddell Seam Longwall layout

Saturated depth (m)

0

30

Ashton-Ravensworth Integration Project (ASH5001.003)

Saturated depth for the alluvial areas

AGE

DATE 17/03/2023

FIGURE No: **4.2**

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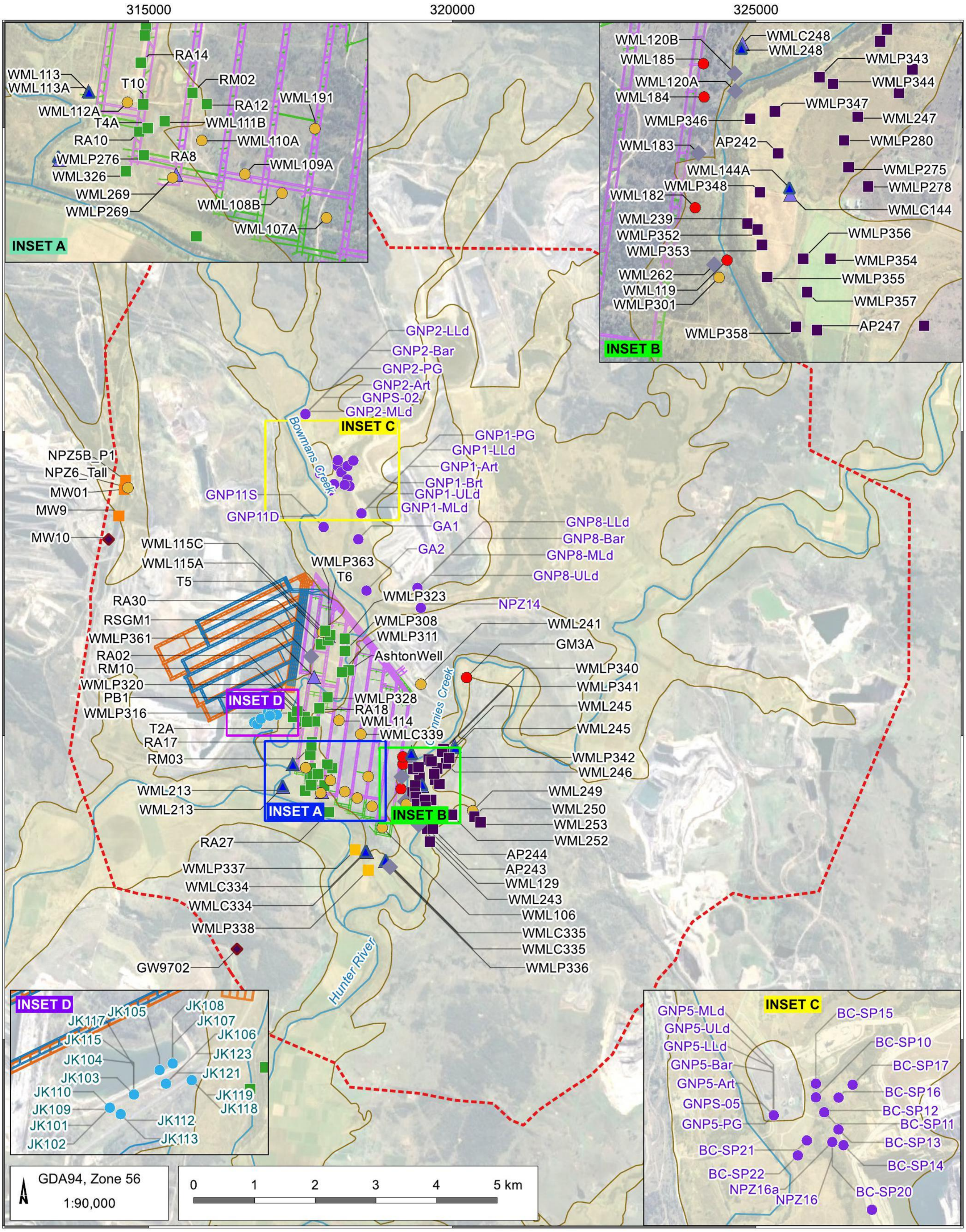
4.3 Groundwater monitoring network

The Ashton Coal Project groundwater monitoring network consists of more than 100 monitoring sites. Of these, 91 monitoring bores and 7 vibrating wire piezometer (VWP) installations are monitored on either a monthly, quarterly, and/or annual basis. In addition to existing Ashton Coal Project monitoring bores, the groundwater assessment has also relied on other public data from Glendell mine (AGE, 2019) and Ravensworth open cut mine (AGE, 2022b), in total of 34 bores. The details of applied monitoring and VWP bores are given in Appendix D.

The sites where routine groundwater monitoring is undertaken are shown on Figure 4.3.

The groundwater monitoring program includes the measurement of:

- groundwater levels in monitoring bores;
- groundwater (piezometric) pressures in VWPs;
- field water quality parameters – pH, electrical conductivity (EC), temperature and total dissolved solids (TDS); and
- water quality analysis for pH, EC, TDS, major ions, metals and nutrients.



LEGEND

- VWP
- EPL Bores
- Hunter River Alluvium
- Glennies Creek Alluvium
- Bowmans Creek Alluvium
- Alluvium
- Regolith
- Coal Measure
- Coal Measure Overburden & Interburden
- Glendell Groundwater Assessment
- HVO Groundwater Assessment
- Drainage
- RUM Model Domain
- Quaternary alluvium

Ashton-Ravensworth Integration Project (ASH5001.003)

Groundwater monitoring locations

AGE

DATE 10/08/2023

FIGURE No: **4.3**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\ASH5001.001.Ashton_Ravensworth_Integration_Modification\5_Deliverables\005_Ashton_Ravensworth_Integratsion_Project\04.03_ASH5001.003_Groundwater monitoring locations_v2.qgz

4.4 Hydraulic parameters

The Permian coal measures can be categorised into the following hydrogeological units:

- hydrogeologically “tight” and hence very low yielding sandstone, siltstone and conglomerate that comprise the majority of the Permian interburden/overburden; and
- low to moderately permeable coal seams, typically ranging in thickness from 0.5 m to 10 m, which are the prime water bearing strata within the Permian coal measures.

The physical properties of the coal and rock units, such as coal cleat spacing/aperture and rock joint/fracture length and aperture, control the hydraulic conductivity of the units. Mackie (2009) noted the hydraulic conductivity within the coal seams within the Hunter Valley typically reduces with depth. A reduction in the hydraulic conductivity of the coal seam aquifers with depth has also been documented by Australian Groundwater Consultants (AGC) (1984) for Hunter Valley coal mines. Hydraulic conductivity data for the Jerrys Plains Sub-group coal seams measured by AGC (1984), which are generally less than 300 m in depth, were combined with the deeper coal seam methane measurements to derive a relationship for hydraulic conductivity versus depth.

Vertical hydraulic conductivities have not been measured at the site, but it is generally accepted that for horizontally bedded sedimentary strata, the vertical hydraulic conductivity is at least ten times lower than the horizontal hydraulic conductivity.

Extensive hydraulic testing has historically been undertaken across the Hunter Valley using field packer testing, lab core permeability testing and slug tests, with the majority of readings compiled as part of a study across the Hunter Valley conducted by Mackie (2009). Individual coal seams and interburden (siltstone and sandstone) within the Jerry’s Plains Sub-group and Vane Sub-group were also tested. The hydraulic conductivity of the coal seams decreases with depth due to the closure of the cleats with increasing stratigraphic pressure. Figure 4.4 shows the distribution in all available horizontal hydraulic conductivity results for interburden/overburden and coal.

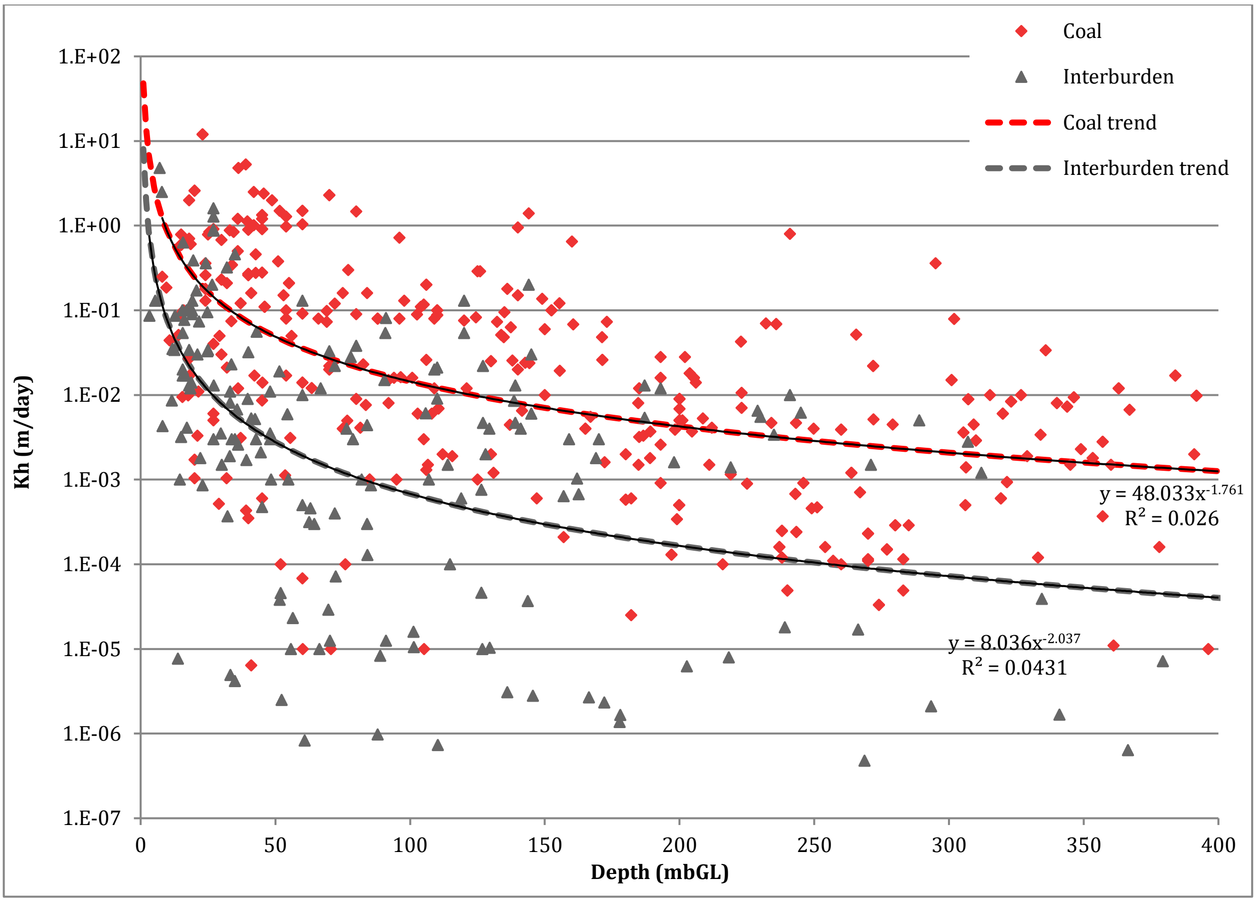


Figure 4.4 Hydraulic conductivity vs depth (Sydney Basin – Hunter Valley) – coal in interburden

The Lemington Conglomerate was identified as a feature that may have an influence on groundwater behaviour, and is therefore included in the conceptual model. Two monitoring bores were installed to intersect and characterise the Permian age Lemington Conglomerate (approximately 70 m above the PG Seam), in areas impacted (YAP017) and un-impacted (YAP018) by mine related subsidence.

Observations during the drilling and review of the hydraulic testing of the bores indicate that hydraulic conductivity of the Lemington Conglomerate likely increases through a secondary hydraulic conductivity change caused by subsidence fracturing. This fracturing is also likely to occur as a brittle fracture, due to the competent nature of the unit, rather than a sagging deformation typical of finer grained units. This fracturing would also likely cause the change in hydraulic conductivity to be sudden rather than a gradual change.

The properties adopted in the model through the calibration process are documented in Appendix A.

4.5 Water levels

Figure 4.5 shows groundwater levels measured in the BCA and the Cumulative Rainfall Departure (CRD). Monthly records from the SILO dataset were used to calculate the CRD. The CRD shows the departure of rainfall from the monthly average rainfall and provides an indication of relatively wet and dry periods. A rising trend in slope in the CRD plot indicates periods of above average rainfall, whilst a declining slope indicates periods when rainfall is below average. A standard technique for assessing groundwater level trends is to compare the water level hydrographs with the CRD. The CRD can be used to assess if changes in groundwater levels are correlated with climatic conditions, or where trends are not correlated with climate conditions if other factors such as resource extraction, irrigation etc. could be impacting upon groundwater levels. The trends in groundwater levels recorded within the BCA generally show a correlation with the CRD, with no significant impact from other activities including mining evident in the records.

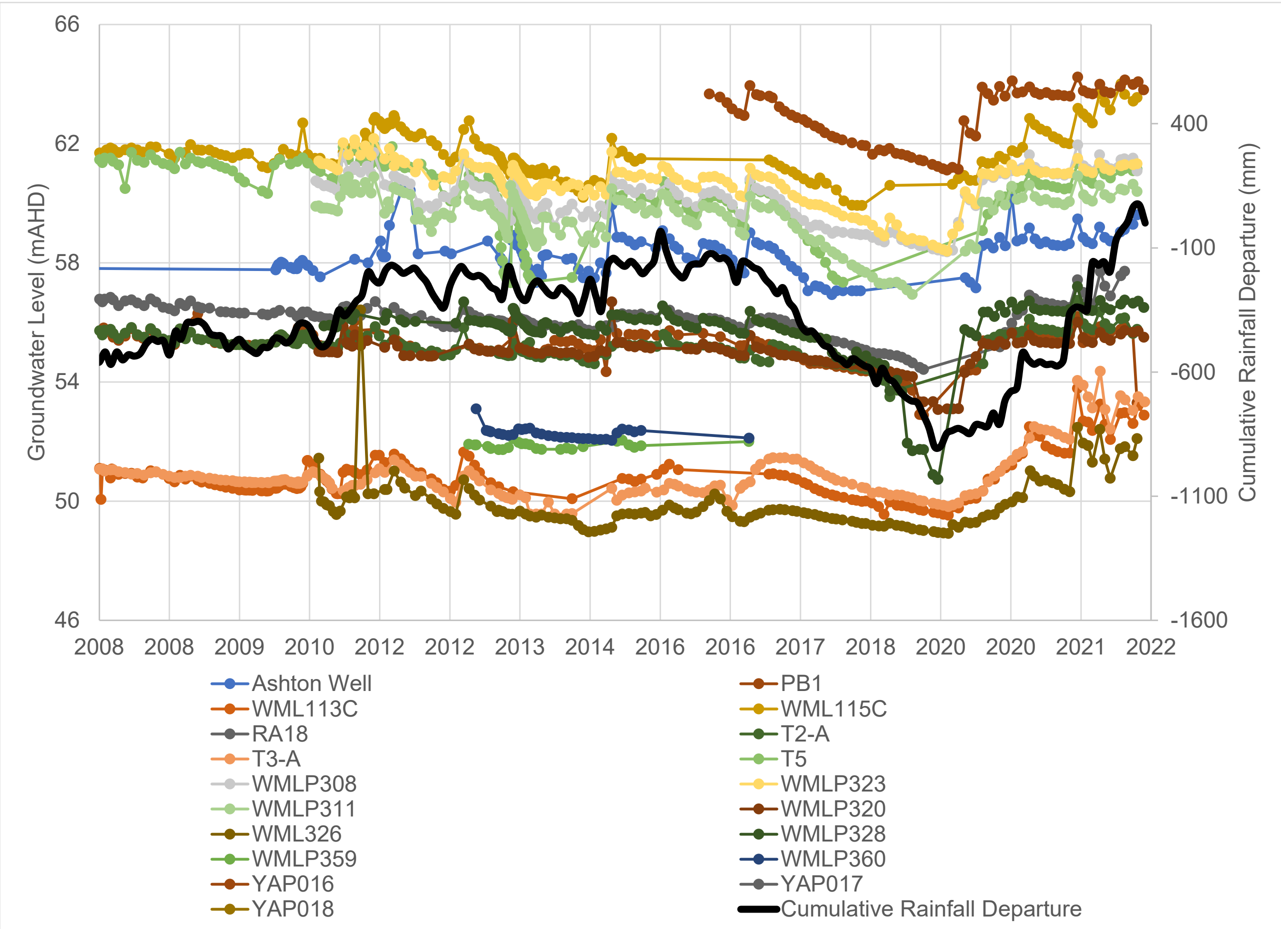


Figure 4.5 Groundwater levels in Bowmans Creek Alluvium

Figure 4.6 shows groundwater levels measured in the GCA and the CRD. The groundwater levels recorded within the GCA are relatively stable, even during the 2017 to 2019 drought period that that maybe due to recharge from upstream dam releases. Groundwater levels have generally risen about 1 m in 2021/2022 in response to above average rainfall and La Niña conditions.

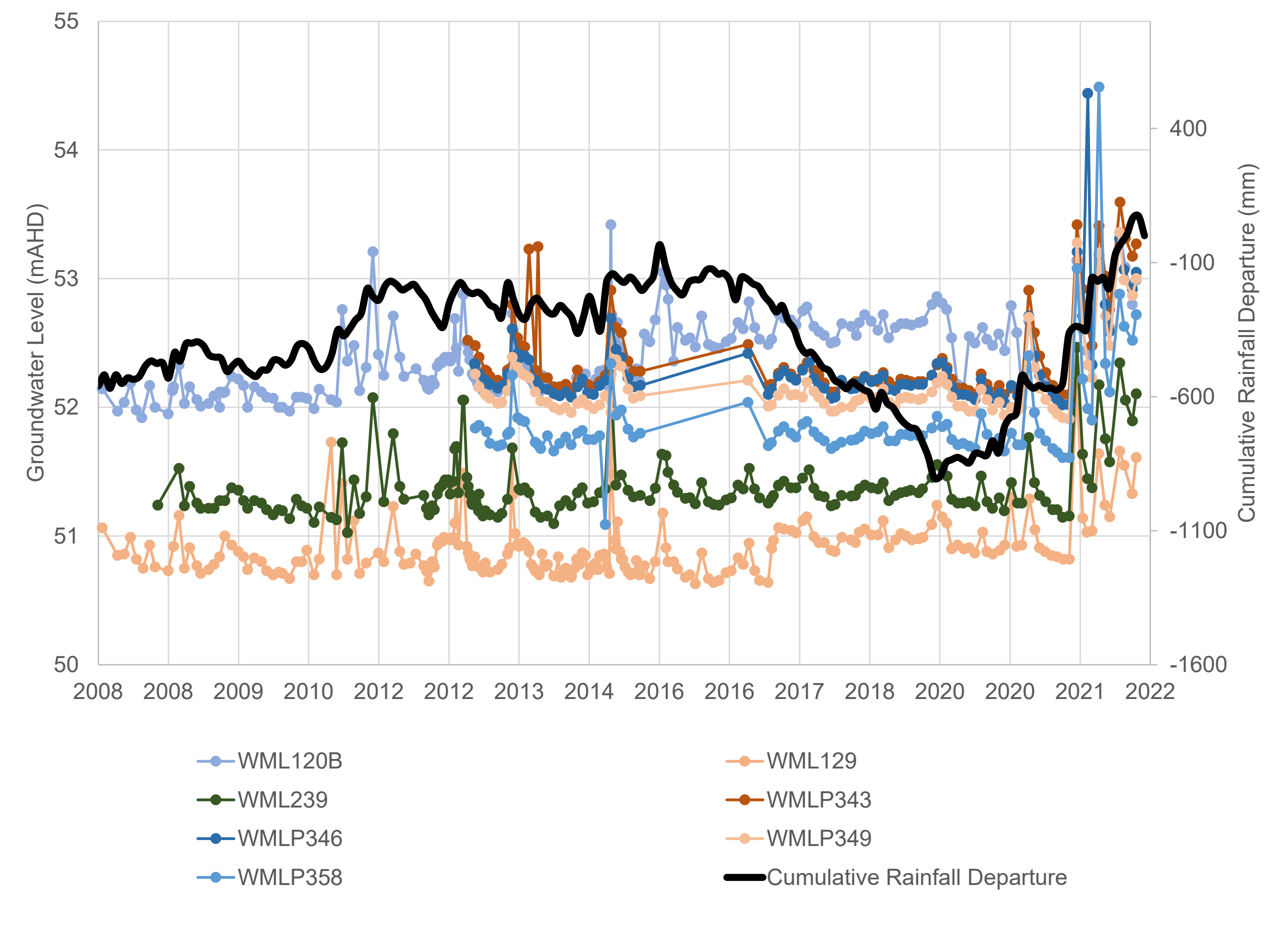


Figure 4.6 Groundwater levels in Glennies Creek Alluvium

4.5.1 Groundwater flow

The water table in the alluvium/regolith is a subdued reflection of topography. Groundwater within the HRA flows generally in an easterly direction, while groundwater within GCA and the BCA flows generally in a southerly direction towards the HR, with local flow towards the respective river/creeks.

The direction of groundwater flow for the coal seams is influenced by the local geomorphology and structural geology as well as the long history of mining within the region. Groundwater flow within the Permian Coal Measures is understood to be to the south-west.

The mining of the Pikes Gully seam at RUM and AUM, and additionally the Bayswater, Upper Liddell, and Upper Lower Liddell/Middle Liddell seams in surrounding mines has impacted the groundwater regime at RUM. Mining has induced subsidence cracking that extends to the ground surface above parts of Ashton, and to a lesser height above the goaf in other areas where the cover depth above the PG seam is greater (i.e. near the proposed RUM mine area). It is likely that in areas of shallower cover depth, this cracking has penetrated both the overburden of the PG, along with the BCA from mining at Ashton. Surface cracking is also visible along and across the longwall panel areas immediately following subsidence. This surface cracking is expected to extend for only a limited depth below surface and may or may not intersect with the subsidence cracking emanating up from the goaf, depending on cover depth and subsidence magnitude.

The presence of subsidence cracking over parts of the underground mine increases the potential connectivity of the mine with the water within the creeks and associated alluvium and may allow for reactivation of subsidence and subsidence related fracturing within these areas (AGE, 2016).

4.6 Groundwater quality and beneficial use

The RUM and AUM groundwater monitoring network consists of more than 100 monitoring bores. Groundwater levels and quality monitoring has been undertaken at the site since 2000.

The groundwater quality of the two main hydrogeological units is typical of a coal measure sequence overlain by alluvium. Alluvial groundwater in the floodplains of Bowmans Creek and the Hunter River is generally of a quality suitable for stock, and in some isolated pockets, domestic use. The baseline and continued groundwater quality for the alluviums at the AUM and surrounds (2007 to 2022) is summarised in Table 4.1. This data highlights that the alluvium is generally of neutral pH and low to medium salinity.

The large range of EC in the alluvium is likely the result of the heterogeneous nature of the sediments and that some areas are readily flushed with fresher recharge while other areas are not as permeable but have mixed with saline Permian waters that were discharging to the alluvium and the surface drainage system prior to those Permian units being depressurised/dewatered due to mining.

Table 4.1 Summary of baseline alluvial groundwater quality

Aquifer	pH		EC (microsiemens per centimetre [µS/cm])	
	Mean	Range	Mean	Range
Bowmans Creek Alluvium	7.2	6.4 - 10.1	1,622	722 – 9,920
Hunter River Alluvium	7.0	6.8 - 7.1	2,091	1,375 – 2,540
Glennies Creek Alluvium	7.0	6.5 - 7.8	3,202	300 – 16,300

The groundwater quality of the coal seams and interburden is of poorer quality. Permian groundwater is brackish to saline with historical EC measurements of up to 18,700 µS/cm (WML108B – 30 Aug 2012). pH values for Permian groundwater are highly variable. Historical pH measurement for Permian bores range from 5.3 (WML119 – 06 Nov 2007) to 9.6 (WML261 – 04 Feb 2015).

Groundwater quality data provides useful information on the beneficial use of the groundwater associated with the major stratigraphic units. Salinity is a key constraint to water management and groundwater use which can be described by TDS concentrations. TDS concentrations are commonly classified on a scale ranging from fresh to extremely saline. Food and Agriculture Organisation of the United Nations (FAO) (2013) provide a useful set of categories for assessing salinity based on TDS concentrations as follows:

- Fresh water <500 milligrams per litre (mg/L) (<950 µS/cm)
- Brackish (slightly saline) 500 to 1,500 mg/L (950 to 2,700 µS/cm)
- Moderately saline 1,500 to 7,000 mg/L (2,700 to 12,000 µS/cm)
- Saline 7,000 to 15,000 mg/L (12,000 to 25,000 µS/cm)
- Highly saline 15,000 to 35,000 mg/L (25,000 to 55,000 µS/cm)
- Brine >35,000 mg/L (>55,000 µS/cm)

The Australian and New Zealand Environment and Conservation Council (ANZECC) (2000) guidelines outline TDS limits for stock watering, including pigs and poultry (3,000 mg/L), dairy cattle (4,000 mg/L), beef cattle (5,000 mg/L) and horses (6,000 mg/L). The World Health Organisation suggests 1,000 mg/L TDS as the aesthetic limit of drinking water. The baseline groundwater quality indicates that the groundwater within the alluvium aquifers on site is likely suitable for stock water supply; however, the groundwater is of limited potable use. There are no privately-owned groundwater bores in close proximity to the Action as the land north of the Hunter River is owned by ACOL, Glencore and AGL Energy Ltd (AGL).

4.7 Groundwater dependent assets

There are no privately-owned groundwater bores in close proximity to the Action as the land north of the Hunter River is owned by ACOL, Glencore and AGL.

Groundwater Dependent Ecosystems (GDEs) are ecosystems that rely upon groundwater for their continued existence. GDEs may be completely dependent on groundwater (i.e. obligate GDEs), such as aquifer GDEs, or may access groundwater intermittently to supplement their water requirements (i.e. facultative GDEs), such as riparian tree species in arid and semi-arid areas (Doody, Hancock and Pritchard, 2019).

There are no high priority GDEs identified in the area on either the Hunter Regulated or Hunter Unregulated and Alluvial Water Sources Water Sharing Plans (WSPs).

The Groundwater Dependent Ecosystem Atlas (GDE Atlas) was developed by the Bureau of Meteorology (BoM) as a national dataset of Australian GDEs to inform groundwater planning and management (BoM, 2020). The GDE Atlas contains information about three types of ecosystems defined in the Australian Groundwater Dependent Ecosystems Toolbox (Richardson et al., 2011).

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

- High potential for groundwater interaction.
- Moderate potential for groundwater interaction.
- Low potential for groundwater interaction.

The GDE Atlas identifies the following potential aquatic GDEs in the vicinity of the Proposed Action (Figure 4.7):

- Bowmans Creek is mapped as having moderate potential for groundwater interaction; and
- the Hunter River is mapped as having high potential for groundwater interaction.

The GDE Atlas identifies the following potential terrestrial GDEs in the vicinity of the Action (Figure 4.7):

- vegetation within the Action area is mapped as having low potential for groundwater interaction;
- vegetation along Bowmans Creek is mapped as having either high or low potential for groundwater interaction; and
- vegetation along the Hunter River is mapped as having either high or low potential for groundwater interaction.

A site-specific review of potential GDEs in the vicinity of the Action was completed by Hunter Eco (2023). A survey of the vegetation along the section of Bowmans Creek south of the existing diversion was conducted on 24 January 2023. The creek upstream from this point has been highly modified with eastern and western diversion channels constructed to relocate those parts of the original creek away from AUM subsidence impacts. Bowmans Creek is incised to a depth of approximately 5 m in relation to the surrounding land and over 50 m wide between tops of bank (Hunter Eco, 2023).

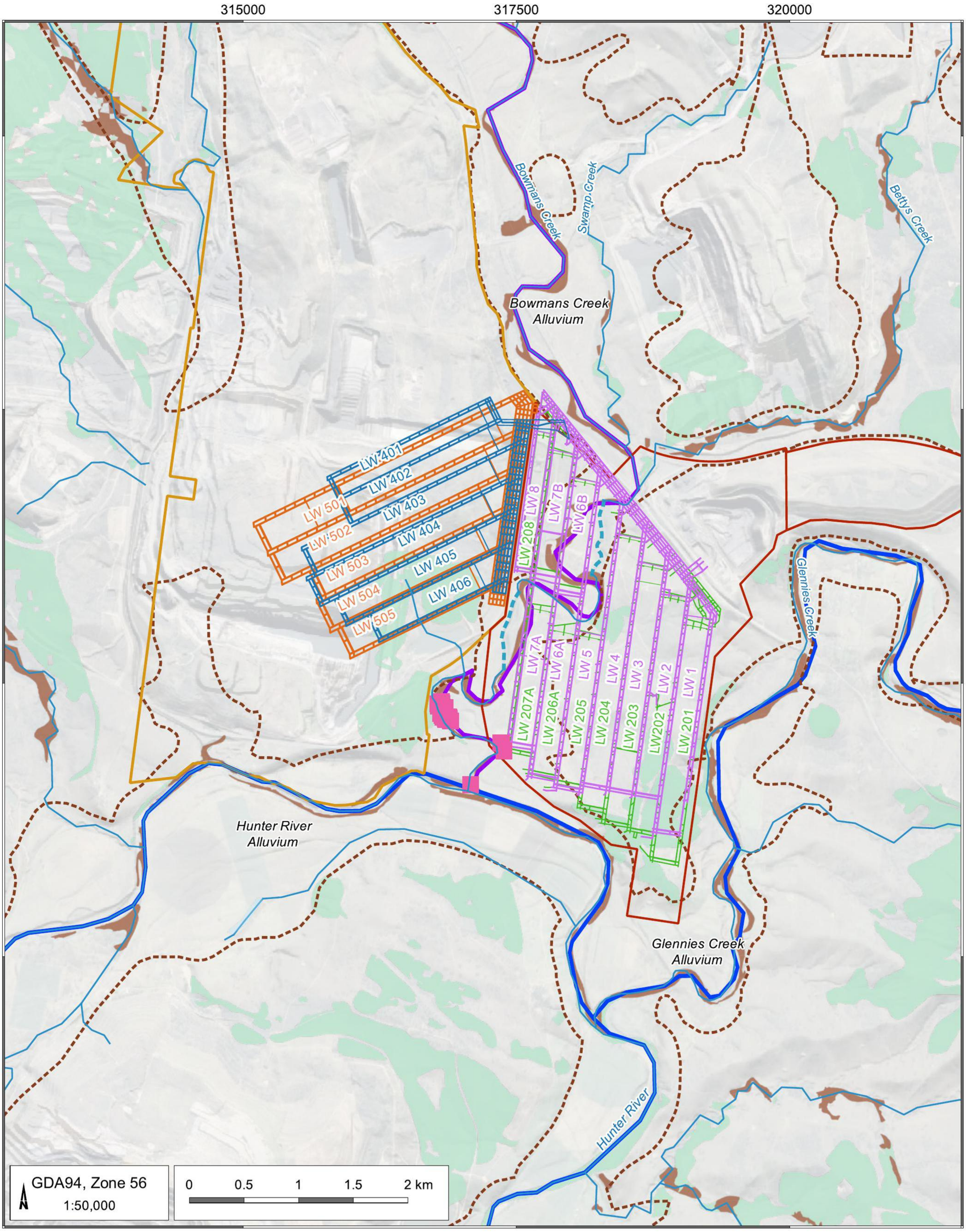
The trees along the creek follow a typical riparian gallery pattern generally confined to creek bed level and steep sides. The canopy was dominated by River Oak (*Casuarina cunninghamiana*) on both sides of the creek, along with an approximately 200 m patch of 19 River Red Gums (*Eucalyptus camaldulensis*) again on both sides; there were also four scattered River Red Gums downstream to the Hunter River. The patch of River Red Gums contained a mix of ages from small saplings, through to large and very old trees up to over 1 m diameter at breast height. Overall, these trees were in healthy condition with no evidence of dieback; similarly for the River Oak. At the water edge there were patches of native Common Reed (*Phragmites australis*). Typical of Hunter waterways there were a number of exotic species scattered throughout: Balloon Vine (*Cardiospermum grandiflorum*), Giant Reed (*Arundo donax*), Pepper Tree (*Schinus molle var. areira*) and Weeping Willow (*Salix spp.*). Ground cover consisted of exotic grasses (Hunter Eco, 2023).

The gallery forest structure along Bowmans Creek is indicative of an aquatic GDE with vegetation primarily dependent on creek baseflow (Hunter Eco, 2023).

Interpolated depth to water in the alluvial areas presented earlier in Figure 4.1 indicate that the potential for GDEs in the section of BCA north of the Proposed Action and in the Hunter River to the south of the Proposed Action is high with relatively shallow depths to water. Bowmans Creek directly east of the Proposed Action is more variable and generally deeper. There will be areas here where the riparian vegetation is utilising some groundwater, but this opportunity will be limited in areas where the depth to water is around 10 m.

The River Red Gums are the only confirmed GDEs identified in the vicinity of the RUM and AUM. Small stands of River Red Gums are located on the lower reaches of Bowmans Creek, within 1 km of the Hunter River confluence, and the lower reaches of Glennies Creek. The locations of these are shown on Figure 4.7.

An *Aquatic Ecology and Groundwater Dependent Ecosystem Assessment* was prepared by EcoLogical Australia (2022) for the HVO Continuation Project, located to the west of the Action. Numerous stygofauna surveys have been undertaken in the HRA and surrounds since 2000. Stygofauna are known to occur in the alluvium of the Hunter River and Bowmans Creek. The taxa collected to date are known from other parts of the Hunter Valley, although there are potentially other stygofauna taxa in the aquifers that have not been sampled (EcoLogical Australia, 2022).



LEGEND

- Drainage
- Diversion
- AUM Pikes Gully panels
- AUM Upper Lower Liddell panels
- River Red Gum
- Ravensworth complex
- Ashton mining lease
- Quaternary alluvium/colluvium

Aquatic GDEs

- High potential GDE - from national assessment
- Moderate potential GDE - from national assessment

Terrestrial GDEs

- High potential GDE - from regional studies
- Low potential GDE - from regional studies

Note:
The approved Upper Liddell and Lower Barrett seams at the Ashton Coal Project and approved Lemington and Barrett Seams at the RUM are not shown on this figure

Ashton-Ravensworth Integration Project (ASH5001.003)

Location of River Red Gums

AGE

DATE 12/10/2023

FIGURE No: **4.7**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\ASH5001.001.Ashton_Ravensworth_Integration_Modification\3_GIS\Workspaces\005_Ashton_Ravensworth_Integratsion_Project\04.07_ASH5001.03_Location of River Red

5 Conceptual model and causal pathways

This section describes the processes that control and influence the storage and movement of groundwater in the hydrogeological system. Figure 5.1 represents a west to east cross-section through RUM and AUM mining areas and represents an end of mining conceptual model. The conceptual cross-section is of a similar alignment to that shown in Figure 3.6. The cross section graphically shows the main processes influencing the groundwater regime including recharge, flow directions and discharge. The main groundwater bearing units are the alluvia of the HRA, GCA and the BCA units, with less productive groundwater occurring within the Permian coal seams.

Groundwater flows from areas of high head (pressure plus elevation) to low head. The coal seams above the PG Seam sub-crop over the underground areas of RUM and AUM. The PG Seam and underlying seams outcrop east of the underground area. Recharge occurs from direct rainfall to the ground surface, infiltrating into the formations through the thin soil cover and weathered profile (regolith). The coal measures also occur at sub-crop in localised zones beneath the HRA, GCA and the BCA. In these areas the Permian coal measures are recharged by downward seepage from the alluvium where head differences promote this flow.

Prior to mining the potentiometric surface (and flow direction) was a subdued reflection of topography. Groundwater within the HRA flows in an easterly direction, while groundwater within GCA and the BCA flows in a southerly direction towards the Hunter River. The direction of groundwater flow for the coal seams is influenced by the local geomorphology and structural geology as well as the long history of mining within the region.

Mining and the associated dewatering have resulted in depressurisation of the Permian coal seams and resulted in a reversal of gradient between the Permian coal seams and the connected alluvial systems. Figure 3.6 highlights the extent of mining both current and historical in the area surrounding RUM. This surrounding mining, including the initial phase of mining in PG Seam at RUM that has been in care and maintenance since 2014 in the west and AUM in the east (see Figure 3.7) has already created a significantly impacted Permian groundwater regime for the Proposed Action.

The Quaternary alluvium is an unconfined groundwater system that is recharged by rainfall infiltration, streamflow and upward leakage from the underlying stratigraphy, particularly along Glennies and Bowmans Creeks. The combined catchment area providing recharge to the combined AUM and Proposed Action area is significantly greater in size than the mine area itself. Recharge within the catchment area (and more specifically the mine area) is to the alluvium of Bowmans Creek and the Hunter River and to the underlying Permian coal measures. It is noted that the Permian coal measures contain a large conglomerate unit, comprised of gravel to cobble sized material in a fine to coarse sandstone matrix which is likely to impact the changes in hydraulic conductivity during subsidence.

The mining of the PG Seam and ULD Seam has significantly impacted the groundwater regime at the AUM. Mining has induced subsidence cracking at the ground surface above parts of the AUM. It is likely that this cracking has penetrated both the overburden of the Permian coal measures and the conglomerate unit, along with the BCA.

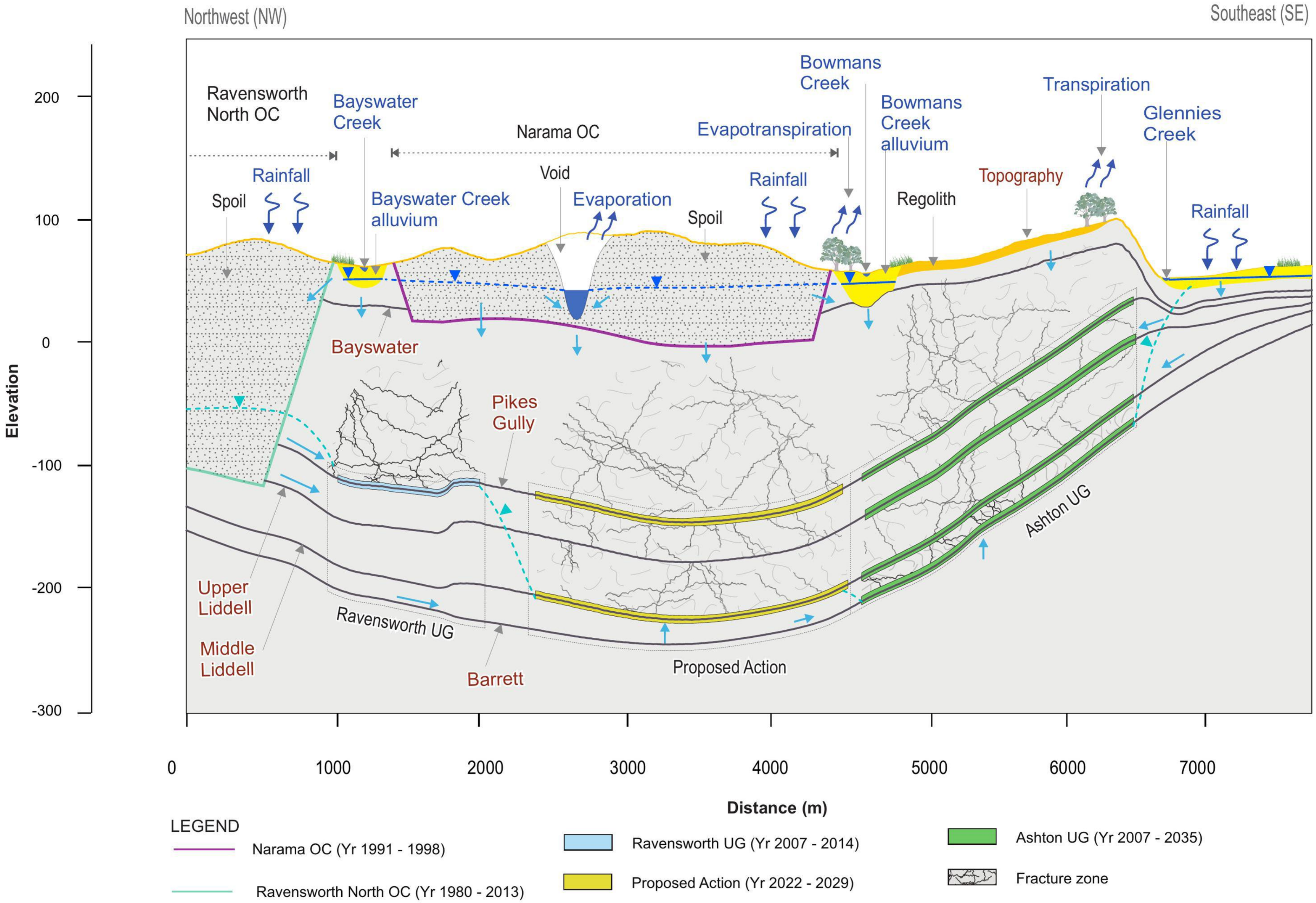
The presence of subsidence cracking over parts of the underground mine, increases the potential connectivity of groundwater hosted within the coal seams and the water within the creeks and associated alluvium.

Future longwall panels within the underlying ULD, ULLD and LB Seams at AUM and PG and MLD Seams at the Proposed Action may allow for reactivation of subsidence and subsidence related fracturing within the overlying areas. This reactivation has the potential to cause a further increase in groundwater inflow into the current and planned underground workings. Groundwater pressures will stabilise over time following subsidence and may even repressurise within the overburden. If this is the case, groundwater inflow to the mine may decrease over time, only to increase when mining occurs at the same location in a deeper seam.

The shallower seams above the Proposed Action have been mined through open cut techniques and these areas have been largely backfilled with waste rock (spoil) and in some select locations with tailings or fly ash. The disturbed nature of the spoil means it has increased recharge over the prior in-situ regolith. Once the spoil is saturated, seepage from the base of the pit is likely to occur into the underlying Permian formations and continue into fracture zones and into mine workings.

Existing users of groundwater and GDEs have the potential to be impacted through drawdown from mining propagating outwards and upwards through vertical connections enhanced through mine related subsidence and fracturing, although that is yet to be seen at AUM.

There is limited potential for impacts to occur to Glennies Creek (and its alluvium) due to the Proposed Action as it is located more than 2 km east of the proposed longwalls. Conservatively, assessment of impacts to Glennies Creek are considered in this report including potential cumulative impacts with the AUM and other nearby mines.



Post mining conceptual cross section

Figure - 5.1

Ashton Ravensworth Integration Project (ASH5001.003)

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6 Numerical groundwater model

6.1 Model objectives

The model objectives are to use the existing AUM groundwater model to predict the potential future changes to the groundwater regime resulting from the Proposed Action. To achieve this, the model added in the Proposed RUM panels and adjusted the subsequent timing of the future AUM approved mining to splice in the Proposed mining at RUM.

Adjustment to some components of the model setup were made to account for the new mining at RUM, including the fracture height calculation and calibration to historical mine inflow at RUM. These are discussed in more detail below and in Appendix A.

Model development has been undertaken with alignment to the Australian modelling guidelines (Barnett et al., 2012) where applicable.

6.2 Approach to assessing impacts

Potential future changes in groundwater levels and water take as a result of the Proposed Action were interrogated using the groundwater model. This included consideration of:

- drawdown in groundwater levels in saturated proximal Quaternary alluvium and in the Permian coal measures as a result of mining;
- the volume of groundwater directly intercepted by mining from the coal measures, and the indirect take from Quaternary alluvium and surface water features;
- change to alluvial fluxes and baseflow;
- impact on private bores;
- drawdown impact to potential GDEs; and
- individual water sources water licensing requirements.

To achieve this, the model has been updated to:

- better match the historical observations at RUM;
- simulate the dewatering at RUM and AUM; and
- process model water budgets to provide Water Sharing Plan impacts from the Proposed Action (and approved Ashton Coal Project including the AUM).

Three models were run to compare the impacts of the Proposed Action on the groundwater system and surrounding surface water sources from that previously assessed and approved. The initial model is the 'base case' model scenario which included all approved mining plus the Proposed Action. The second model is a ‘no RUM mining’ model scenario which included surrounding historical and approved future mining but excluded mining of the Proposed Action RUM longwall panels. The third model is the ‘no mining’ model scenario without any mining activities in the area to calculate cumulative impacts.

6.3 Summary of model development

AGE updated the AUM groundwater model to assess the Proposed Action. The model was originally constructed in 2015 with a further revision in 2019 (AGE, 2016, 2020). The model is built on MODFLOW-USG (Panday et al. 2017) and comprises 17 layers and 370,468 nodes.

The model structure, general head and no-flow boundary conditions were identical to those of the previous 2019 model build. For the longwall mining associated with the Proposed Action, the fracture model was adjusted to improve representation of fracturing in the increased overburden thickness at RUM (Ditton & Merrick, 2014; Guo et al., 2007). The model was then recalibrated using PEST HP (Watermark Numerical Computing, 2021). Groundwater levels from ongoing AUM monitoring and public domain monitoring data from surrounding operations formed one of the datasets for the calibration. These were supplemented by a monthly water balance model based on AUM metered pumping data to June 2021. The inclusion of the water balance model in the calibration reduced parameter non-uniqueness and ensured that recent inflows to AUM were reflected in the model parameters. The model calibration achieved 7.85 percent (%) scale root mean squared (SRMS) for water levels which confirms with performance targets advocated in modelling guidelines. Details of the model are provided in Appendix A.

6.4 Model verification using additional monitoring data

Additional groundwater monitoring data to the south and west of the Proposed Action have been assessed by AGE. Table 6.1 lists the additional Ravensworth Operations groundwater bores assessed by AGE. Bores RNVW5, RNVW7, RNVW8 and NPZ7 are within the groundwater model domain (Figure 6.1). Groundwater bores NPZ1, RNVW1, RNVW2 and RNVW4 are located just outside of the model domain, but to make use of the data, a location just within the model domain has been adapted, allowing a comparison of observed to modelled water levels to be made (Figure 6.1). The true locations of these bores are shown as blue dots in Figure 6.1, with arrows linking the adopted surrogate locations within the model domain.

Table 6.1 Ravensworth Operations Monitoring Bores

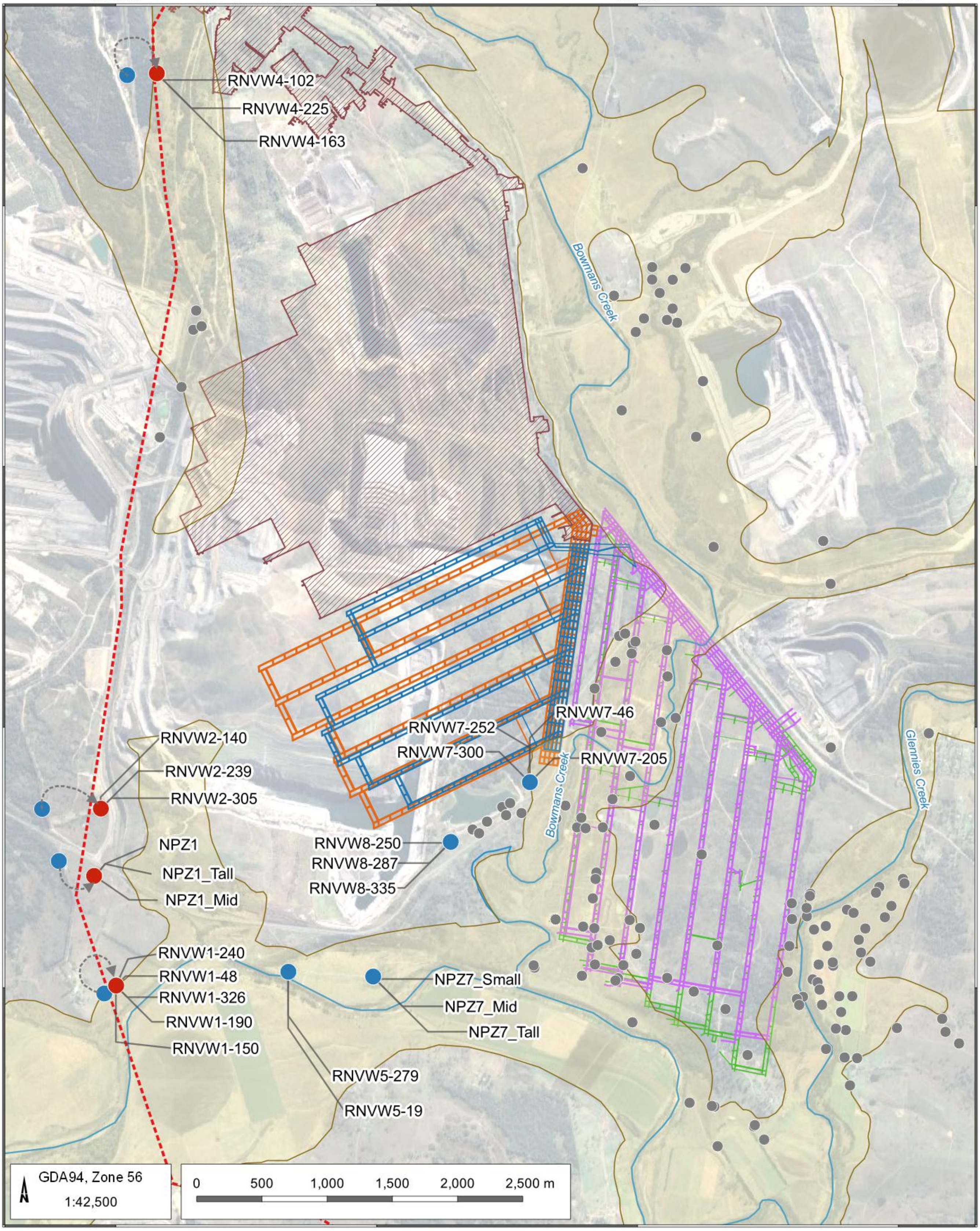
Bore ID	Easting (m) GDA94 Z56	Northing (m) GDA94 Z56	Type	Formation	Data Period
NPZ1	313833*	6404858*	Multi standpipe	Alluvium	October 2005 – November 2017
NPZ1_Mid	313833*	6404858*	Multi standpipe	Overburden	January 2008 – October 2014
NPZ1_Tall	313833*	6404858*	Multi standpipe	Lemington	October 2005 – August 2023
NPZ7_Mid	315973	6404086	Multi standpipe	Overburden	January 2012 – April 2020
NPZ7_Small	315973	6404086	Multi standpipe	Alluvium	January 2012 – September 2023
NPZ7_Tall	315973	6404086	Multi standpipe	Bayswater	January 2012 – September 2023
RNVW1-48	314002*	6404017*	VWP	Alluvium/Bayswater	May 2008 – December 2021
RNVW1-150	314002*	6404017*	VWP	Pikes Gully	May 2008 – December 2021
RNVW1-190	314002*	6404017*	VWP	Arties	May 2008 – December 2021
RNVW1-240	314002*	6404017*	VWP	Upper Liddell	May 2008 – December 2021
RNVW1-326	314002*	6404017*	VWP	Barrett	May 2008 – December 2021
RNVW2-140	313884.6*	6405374*	VWP	Pikes Gully	May 2008 – July 2022
RNVW2-239	313884.6*	6405374*	VWP	Upper Liddell	May 2008 – July 2022
RNVW2-305	313884.6*	6405374*	VWP	Barrett	May 2008 – July 2022
RNVW4-102	314314*	6411016*	VWP	Pikes Gully	December 1979 – January 2023
RNVW4-163	314314*	6411016*	VWP	Upper Liddell	December 1979 – January 2023
RNVW4-225	314314*	6411016*	VWP	Barrett	December 1979 – January 2023
RNVW5-19	315322.5	6404123	VWP	Alluvium	December 1979 – March 2016
RNVW5-279	315322.5	6404123	VWP	Upper Liddell	December 1979 – March 2015
RNVW7-46	317174.7	6405577	VWP	Bayswater	March 2011 – September 2012

Bore ID	Easting (m) GDA94 Z56	Northing (m) GDA94 Z56	Type	Formation	Data Period
RNVW7-205	317174.7	6405577	VWP	Pikes Gully	March 2011 – September 2012
RNVW7-252	317174.7	6405577	VWP	Upper Liddell	March 2011 – September 2012
RNVW7-300	317174.7	6405577	VWP	Barrett	March 2011 – September 2012
RNVW8-250	316567.5	6405119	VWP	Pikes Gully	March 2011 – September 2012
RNVW8-287	316567.5	6405119	VWP	Upper Liddell	March 2011 – September 2012
RNVW8-335	316567.5	6405119	VWP	Barrett	March 2011 – September 2012

Notes: VWP = vibrating wire piezometers

* Coordinates of adopted surrogate location (i.e. not true coordinates). The true location of the bore is shown on Figure 6.1.

Hydrographs have been generated using the predicted water levels at these bores to understand how well the model matches measured water levels. The hydrographs are presented in Appendix F. Despite not having them in the calibration dataset, the model replicates the measured water levels to a sufficient level.



LEGEND

- VWP
- Surrogate bore location within model domain
- True location of monitoring sites
- Location shift
- Drainage
- Approved Ashton Pikes Gully Liddell Longwall Layout
- Approved Ashton Upper Lower Liddell Longwall Layout
- Proposed Action Pikes Gully Seam Longwall Layout
- Proposed Action Middle Liddell Seam Longwall Layout
- RUM Model Domain
- Quaternary alluvium
- Completed Pike Gully Seam Workings

Ashton-Ravensworth Integration Project (ASH5001.003)

Additional Ravensworth Operations groundwater monitoring bores

AGE

DATE 22/03/2024

FIGURE No: 6.1

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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7 Model predictions

The impacts of the Proposed Action were generated by comparing the outputs of model runs with and without the Proposed Action simulated.

To generate the predictions, six longwall panels were added to the PG Seam (model Layer 8) and five longwall panels were added to the MLD Seam (model Layer 14) at RUM. The RUM mining schedule used in the simulation is documented in Table 7.1.

For consistency with Mackie Environmental Research (MER) (2012), the starting condition of the overlying Ravensworth Narama open cut mine (shown on Figure 1.1) was largely dewatered spoils and any final landforms, voids, additional recharge to voids and spoil or any other features of water level recovery were not simulated. As mining-induced hydraulic parameter changes were applied to model cells beneath the Narama spoil, a simple analytical model based on Darcy's Law was applied to predict the volume of potential additional inflows between the spoil and the proposed underground workings (Section 7.1).

Table 7.1 RUM mining schedule applied in groundwater model

Seam	Panel	Start Date	Completion Date
Pikes Gully (RUM)	Mains Level 4	14/08/2022	2/04/2025
	LW401	2/01/2024	18/03/2024
	LW402	30/04/2024	16/09/2024
	LW403	3/11/2024	30/04/2025
	LW404	6/06/2025	22/10/2025
	LW405	8/12/2025	17/04/2026
	LW406	25/05/2026	17/08/2026
Middle Liddell (RUM)	Mains Level 5	9/04/2025	14/01/2028
	LW501A	4/10/2026	6/12/2026
	LW501B	18/01/2027	8/07/2027
	LW502	14/08/2027	27/03/2028
	LW503	9/05/2028	3/11/2028
	LW504	10/12/2028	31/05/2029
	LW505	8/07/2029	24/11/2029

7.1 Groundwater inflows to mining area

The predicted inflow rate per seam over time (Figure 7.1) was converted to a volume, with the volumes accumulated per water year to calculate the total predicted inflows for the Proposed Action mining (Figure 7.2).

The predicted inflows to the PG workings (RUM) are consistent with the 0.6 ML/day inflows reported by MER (2012) and ACOL holds water access licences (WALs) with sufficient entitlements to account for the predicted take. As discussed in MER (2012), if connected fracturing above the longwalls causes hydraulic conductivity increases greater than those predicted by the groundwater model, additional inflows may occur. The potential for additional inflows from the overlying Ravensworth Narama open cut spoils was quantified per model cell using Darcy’s Law, with a maximum rate of 16 megalitres per year (ML/year) predicted over the life of the Proposed Action. Similarly, should fracturing connect any water held in the goaf of LW 1-9 with the new workings, additional inflows may occur. The peak predicted inflows to the PG Seam are 0.49 ML/day in March 2026, which is less than the 1.1 ML/day predicted in MER (2012), thought to be the result of continued depressurisation of the PG Seam as underlying seams at AUM were mined.

The predicted inflows to the MLD workings (RUM) are slightly greater than those observed at AUM. This is consistent with the site conceptual model, as the saturated thickness of interburden and unmined coal above the MLD Seam exceeds that of AUM (e.g., the ULD Seam is mined at AUM but would not be mined at RUM). The peak predicted inflow to the MLD Seam is 2.02 ML/day in December 2028, which is consistent with the 1.8 ML/day peak inflow reported in MER (2012).

The total predicted inflows are contributed to by dewatering of the surrounding rock mass, known as direct take (Figure 7.2), as well as by unconsolidated sediments such as alluvium and surface water features. The latter, referred to collectively as indirect take or passive take (Section 0), are not directly connected to the underground workings but are intercepted by mining-induced drawdown, which results in reduced baseflow compared to the ‘no RUM mining’ scenario.

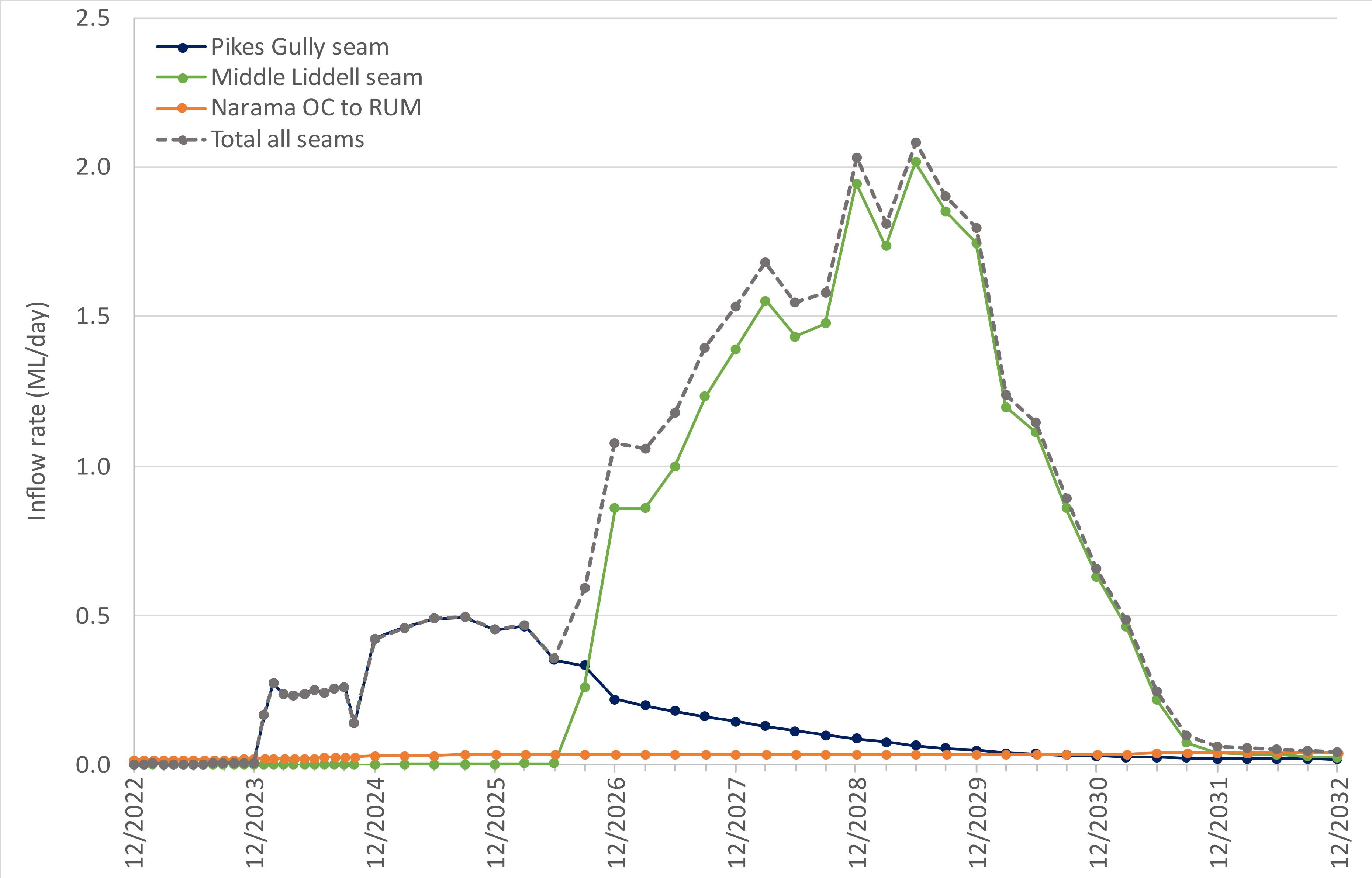


Figure 7.1 Predicted inflow timeseries for the proposed RUM mine areas

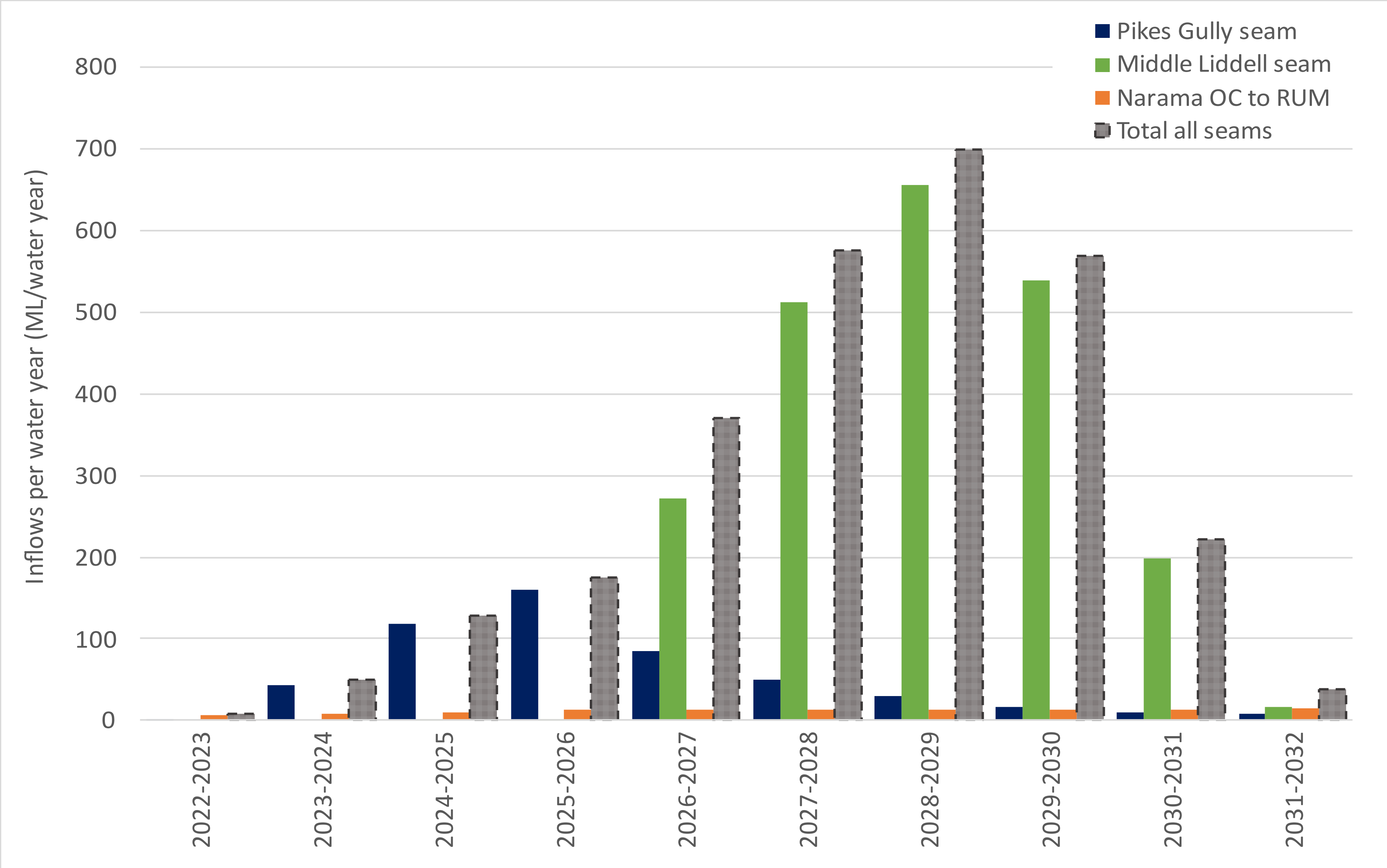


Figure 7.2 Predicted inflows per water year to the proposed RUM mine areas

7.2 Change in alluvial and surface water flows

The model was used to determine the potential for mining to interfere with the alluvial groundwater systems and to provide estimates of indirect 'water take' in accordance with the NSW Aquifer Interference Policy (AIP) (NSW Office of Water, 2012). Mining will not directly intercept alluvial aquifers, however, an indirect impact or 'water take' occurs as the Permian strata become depressurised and the volume of groundwater flowing from the Permian to the Quaternary alluvium reduces progressively. Whilst this alluvial groundwater does not necessarily enter the mine workings, the volume of groundwater entering the alluvial groundwater systems is reduced by lower pressures within the Permian or the reversal of flow direction due to mining, and this has been considered 'water take' that needs to be licensed.

The change in alluvial water resources was determined by comparing water budgets for alluvial zones using versions of the model that either contained or excluded the Proposed Action.

The indirect take component of the total mine inflows for the Proposed Action was negligible (less than 1 ML/year) for each of the HRA, GCA and BCA. Similarly, the reduction in baseflow in the Hunter River, Glennies Creek and Bowmans Creeks was negligible during mining.

7.3 Water licensing and water sharing plan rules

As described in Section 2.1, the NSW AIP requires that all groundwater taken as a result of an aquifer interference activity, either directly or indirectly, is accounted for via water licences. Groundwater intercepted from the mining area is considered a direct take from the Permian groundwater system, while the changes in flow occurring within the Quaternary alluvium and rivers resulting from depressurisation of the underlying Permian is considered an indirect take.

During the mining period, the total inflows are contributed near-entirely by direct take from the Permian strata. The predicted indirect take is negligible (< 1 ML/year). The proportion of inflows from the various water sources is summarised in Table 7.2.

Post-mining, dewatering activities in the Permian strata cease. Water will continue to flow into the mined panels though the rate would be less than the predicted peak take of 698.3 ML/year during mining.

The predicted post-mining take from the surface water and alluvium is negligible, as it was during the mining period (Table 7.3).

ACOL holds sufficient WAL entitlements within each water source under the relevant WSPs to account for the predicted peak take for the Proposed Action (in addition to the Ashton Coal Project). A summary of WALs held by ACOL is provided in Table 7.4.

Table 7.2 Predicted take for the Proposed Action during mining period (ML/year)

Water Year	Total underground inflows	Hunter River Alluvium	Glennies Creek Alluvium	Bowmans Creek Alluvium	From Rock Mass
2022-2023	7.4	0.00	0.00	0.00	7.4
2023-2024	50.6	0.00	0.00	0.00	50.6
2024-2025	128.2	0.00	0.00	0.00	128.2
2025-2026	174.6	-0.01	0.00	-0.06	174.67
2026-2027	369.6	0.00	0.00	0.06	369.55
2027-2028	575.3	0.01	0.00	0.11	575.17
2028-2029	698.6	0.03	0.00	0.12	698.45
2029-2030	568.9	0.04	0.00	0.12	568.74
2030-2031	221.7	0.05	0.00	0.11	221.54
2031-2032	38.7	0.06	0.00	0.13	38.51

Table 7.3 Predicted post-mining take for the Proposed Action (ML/year)

Water Year	Hunter River Alluvium	Glennies Creek Alluvium	Bowmans Creek Alluvium
2030-2031	0.05	0.00	0.11
2031-2032	0.06	0.00	0.13
2032-2033	0.07	0.00	0.15
2033-2034	0.07	0.00	0.15
2034-2035	0.08	0.00	0.16
2035-2036	0.09	0.01	0.14
2036-2037	0.09	0.00	0.12
2037-2038	0.09	0.01	0.12
2038-2039	0.09	0.01	0.10
2039-2040	0.09	0.01	0.09
2040-2041	0.10	0.01	0.09
2041-2042	0.10	0.01	0.08
2042-2043	0.09	0.01	0.07
2043-2044	0.09	0.01	0.07
2044-2045	0.09	0.01	0.06
2045-2046	0.09	0.02	0.05
2046-2047	0.08	0.02	0.05
2047-2048	0.08	0.01	0.04
2048-2049	0.08	0.01	0.04
2049-2050	0.08	0.02	0.04
2050-2051	0.07	0.02	0.05
2051-2052	0.07	0.02	0.04
2052-2053	0.07	0.02	0.04
2053-2054	0.07	0.02	0.04
2054-2055	0.07	0.02	0.04
2085-2086	0.03	0.04	0.02
2135-2136	0.05	0.45	0.07

Table 7.4 ACOL water licences

Licence No.	Water Source / Category	Entitlement (ML/year)
WAL 984	Hunter Regulated River - Glennies Creek (General Security)	9
WAL 15583	Hunter Regulated River - Glennies Creek (General Security)	354
WAL 997	Hunter Regulated River - Glennies Creek (High Security)	11
WAL 8404	Hunter Regulated River - Glennies Creek (High Security)	80
WAL 1358	Hunter Regulated River - Glennies Creek (Supplementary)	4
WAL 1121	Hunter Regulated River - Zone 1B (General Security)	335
WAL 6346	Hunter Regulated River - Zone 1B (Supplementary)	15.5
WAL 1120	Hunter Regulated River - Zone 1B (High Security)	3
WAL 19510	Hunter Regulated River - Zone 1B (High Security)	130
WAL 23912	Jerrys Water Source (Unregulated River)	14
WAL 36702	Jerrys Water Source (Unregulated River)	116
WAL 36703	Jerrys Water Source (Unregulated River)	150
WAL 29566	Jerrys Water Source (Aquifer)	358
WAL 41501	Sydney Basin-North Coast Groundwater Source (Aquifer)	100
WAL 41552	Sydney Basin-North Coast Groundwater Source (Aquifer)	511
WAL 41553	Sydney Basin-North Coast Groundwater Source (Aquifer)	81
WAL 41529	Sydney Basin-North Coast Groundwater Source (Aquifer)	400

7.4 Predicted groundwater drawdown

The Proposed Action is surrounded by a number of open cut and underground operations targeting the same coal seams (i.e. PG and MLD Seams). As part of a NSW modification application for the RUM, MER (2012) concluded that historical mining operations in proximity to RUM had extensively depressurised the coal measures.

In addition to the adjacent AUM, the West Pit at HVO North, located approximately 4 km to the west of the Proposed Action, and the Glendell Open Cut, north-east of RUM, target coal seams down to the Barrett Seam. Predictions in MER (2012) show significant depressurisation of coal measures including PG, Liddell and Barrett Seams associated with these operations surrounding the RUM. In addition, mining at Ravensworth North, located between Ravensworth Narama open cut mine and the West Pit at HVO North, targets seams to the Barrett ahead of the Proposed Action. Figures 3.6 and 3.7 show the surrounding mines and a cross-section through the Proposed Action.

The maximum predicted drawdown due to mining the Proposed Action (Table 7.5) is less extensive than that previously approved for RUM (MER 2012), attributed to the reduced footprint. In addition, there is no extraction of the ULD Seam, although the ULD is intersected by drawdown generated by mining of the underlying MLD Seam.

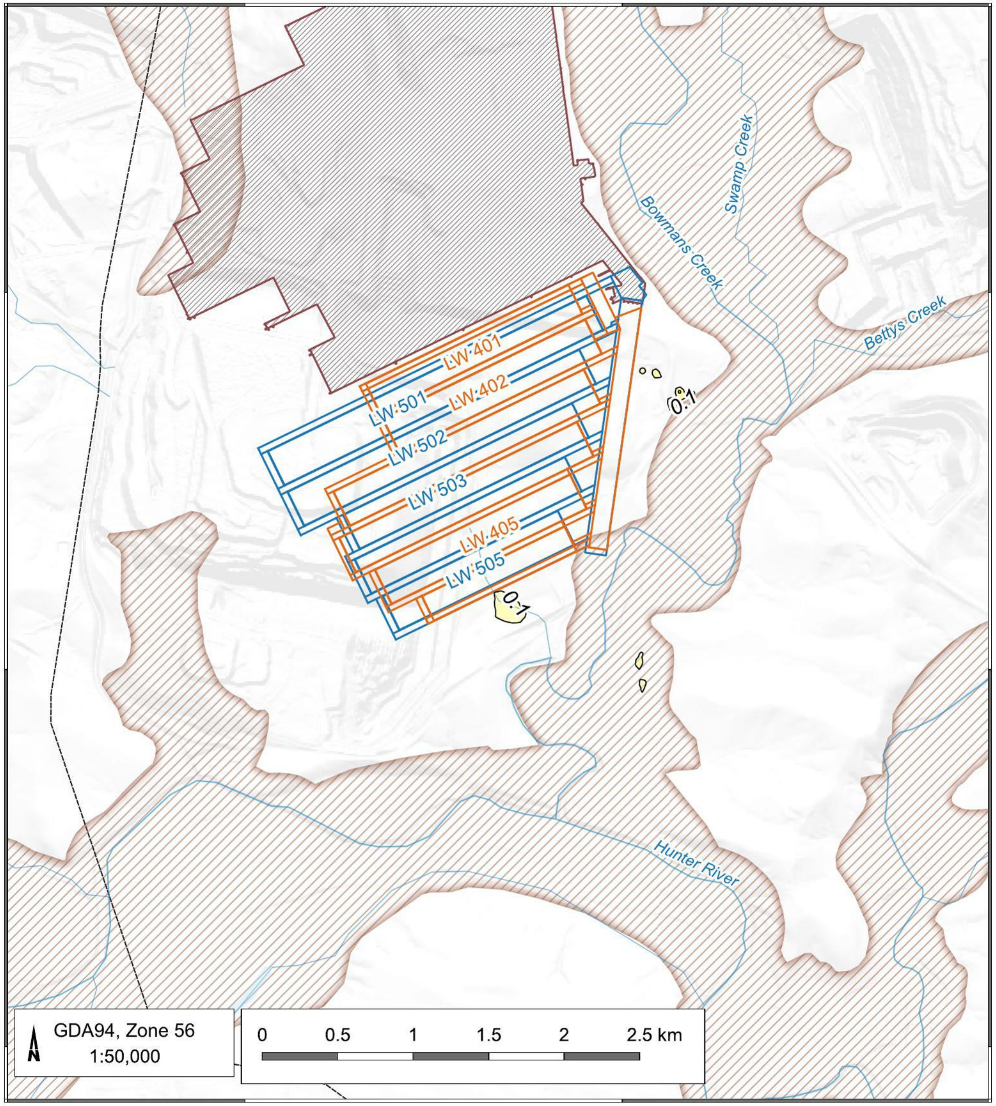
Table 7.5 Maximum predicted drawdown

Model Layer	Maximum drawdown attributed to Proposed Action	Maximum cumulative drawdown surrounding RUM
1 (Alluvium and regolith)	0.2 m	10 m
8 (Pikes Gully seam)	100 m	200 m
11 (Upper Liddell seam)	100 m	200 m
14 (Middle Liddell seam)	200 m	> 200 m

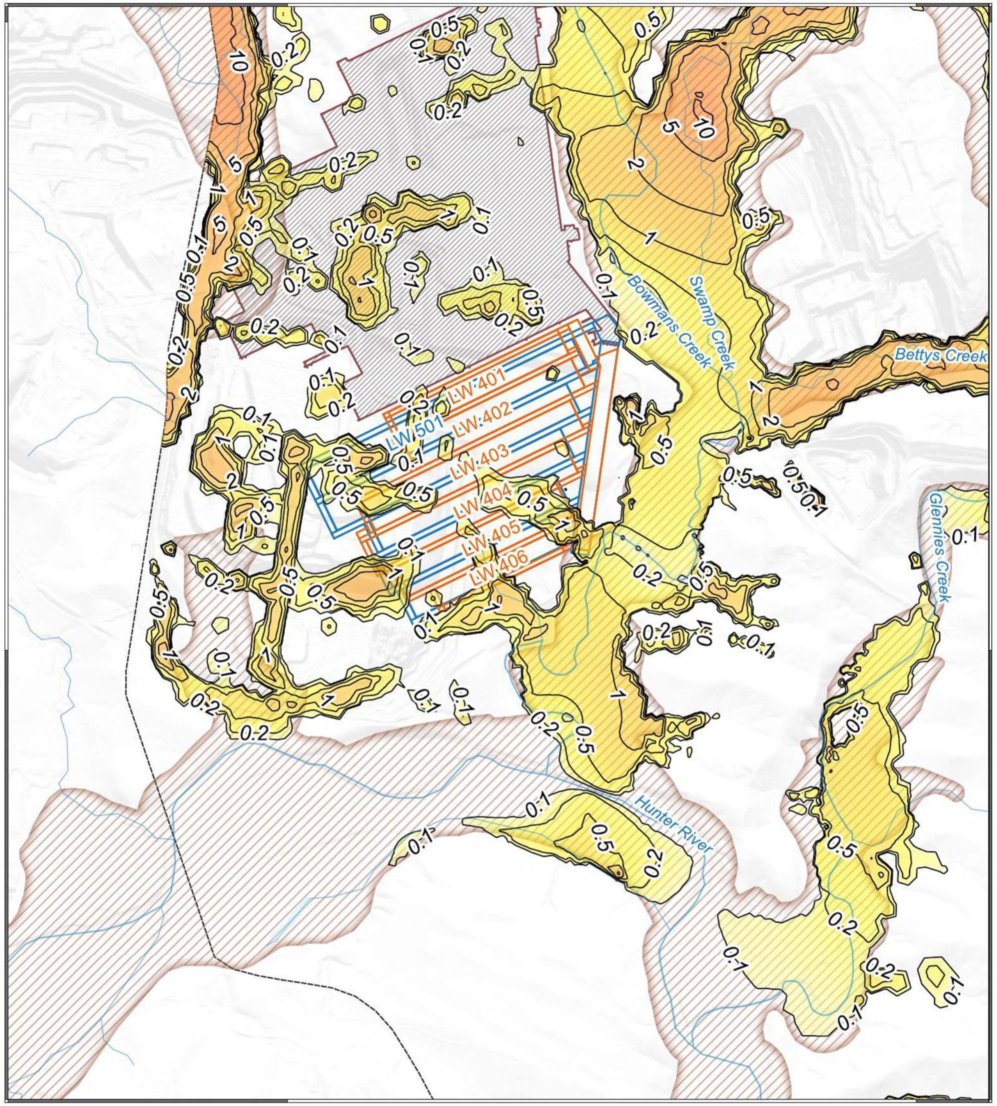
Drawdown maps around the mining operation area are presented for the alluvium and regolith (Layer 1; Figure 7.3), PG Seam (Layer 8; Figure 7.4), and ULLD Seam/MLD Seam (Layer 14; Figure 7.5). The drawdown presented is that attributed directly to the proposed panels at RUM (as shown on Figure 1.1) as well as the cumulative maximum drawdown for all mining simulated in the model, including continued ongoing mine dewatering in neighbouring mines post RUM and AUM mining. The Proposed Action results in less than 0.1 m of additional drawdown to remnant vegetation overlying LW 405 and LW 406 at RUM (Figure 7.3). This information is included to facilitate a comprehensive assessment, as the vegetation is mapped as a low potential groundwater dependent asset (see Figure 4.7).

The cumulative drawdown results across the whole model domain are provided in Appendix A.

Maximum drawdown due to proposed Action



Maximum cumulative drawdown



LEGEND

- Drainage
- Drawdown contour (m)
- Indicative Pikes Gully Seam Longwall layout
- Indicative Middle Liddell Seam Longwall layout
- Quaternary alluvium/colluvium
- Model boundary
- Completed Pike Gully Seam Workings

Drawdown (m)

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

AGE

Ashton-Ravensworth Integration Project (ASH5001.003)

Predicted drawdown in alluvium and regolith (Layer 1)

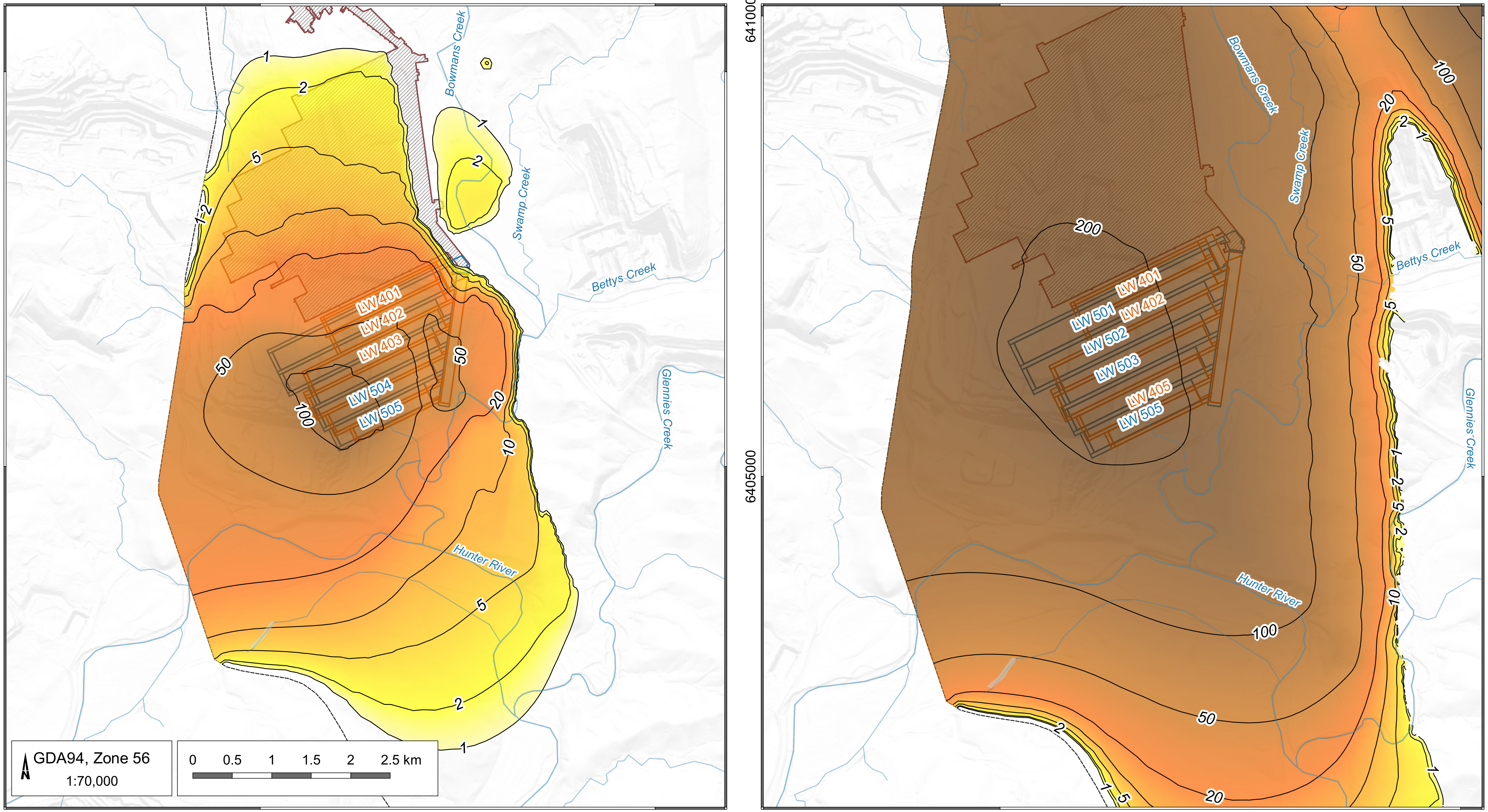
DATE 12/10/2023

FIGURE **7.3**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\ASH5001.001.Ashton_Ravensworth_Integration_Modification\3_GIS\Workspaces\005_Ashton_Ravensworth_Integratsion_Project\07.03_ASH5000.000_Predicted drawdown in alluvium and regolith (Layer 1).qgs

Maximum drawdown due to proposed Action

Maximum cumulative drawdown



LEGEND
- Drainage
- Drawdown contour (m)
- Indicative Pikes Gully Seam Longwall layout
- Indicative Middle Liddell Seam Longwall layout
- Model boundary
- Completed Pike Gully Seam Workings

Drawdown (m)

0	20
1	50
2	100
5	200
10	500

AGE

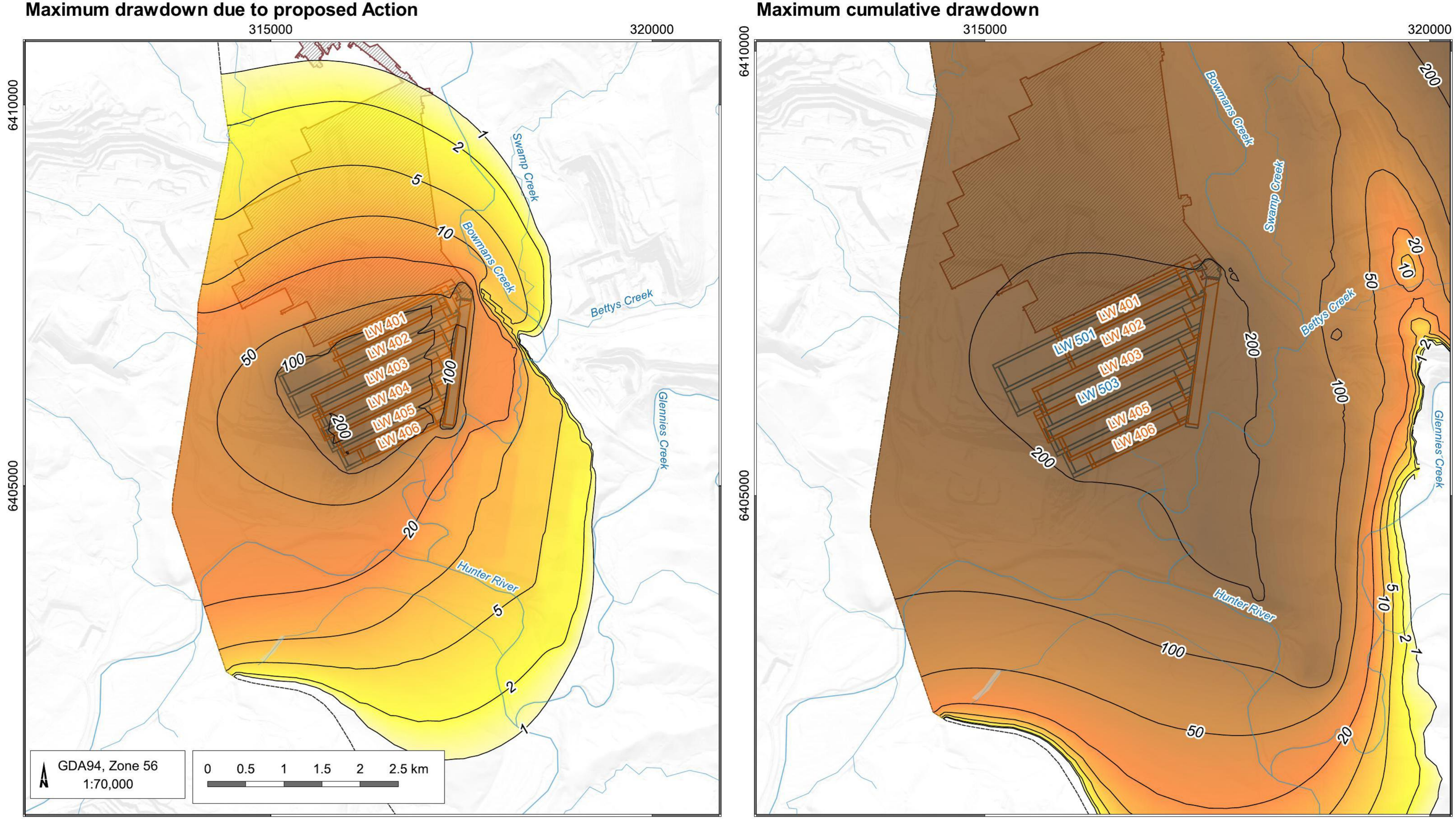
Ashton-Ravensworth Integration Project (ASH5001.003)

Predicted drawdown in Pikes Gully Seam (Layer 8)

DATE
12/10/2023

FIGURE No:
7.4

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\ASH5001.001.Ashton_Ravensworth_Integration_Modification\3_GIS\Workspaces\005_Ashton_Ravensworth_Integratsion_Project\07.04_ASH5000.000_Predicted drawdown in Pikes Gully seam (Layer 8).qgs



LEGEND
- Drainage
- Drawdown contour (m)
- Indicative Pikes Gully Seam Longwall layout
- Indicative Middle Liddell Seam Longwall layout
- Model boundary
- Completed Pike Gully Seam Workings

Drawdown (m)

0	20
1	50
2	100
5	200
10	500

AGE

Ashton-Ravensworth Integration Project (ASH5001.003)

Predicted drawdown in Middle Liddell Seam (Layer 14)

DATE
12/10/2023

FIGURE No:
7.5

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\ASH5001.001.Ashton_Ravensworth_Integration_Modification\3_GIS\Workspaces\005_Ashton_Ravensworth_Integratsion_Project\07.05_ASH5000.000_Predicted drawdown in Middle Liddell seam (Layer 14).qgs

7.5 Climate change scenario

It is important to explore the likely impacts due to potential climate changes on the post-mining period. The impacts from climate changes can be assessed by adopting the potential variations in annual rainfall recharge and evapotranspiration rate. Here, as guided in the Climate Change in Australia (Whetton et al., 2012), the climate change scenarios are classified into three categories: best case, worst case and maximum consensus determined with parameter variations, as presented in Table 7.6. These changes are applied in the model at the recovery period (e.g., from year 2036 to 2135). The predicted potential impacts due to climate changes focus on the baseflow to the rivers and indirect take form alluvium for 100-years recovery period.

Table 7.6 Climate change scenario classifications

Climate change classifications	Annual rainfall change (%)	Annual evapotranspiration change (%)
Best Case	19.1	8.3
Worst Case	- 34.0	14.5
Maximum Consensus	- 15.4	15.2

For the likely impacts on the baseflow due to potential climate changes in Hunter River (Figure 7.6), Bowmans Creek (Figure 7.7) and Glennies Creek (Figure 7.8) during the post-mining recovery periods, the Worst Case and Maximum Consensus predicted minimal results changes, suggesting no significant baseflow alterations are expected in these rivers. However, under the Best Case condition, the baseflow increase in these rivers are predicted as: maximum increase at 30.88 ML/year in Hunter River, maximum increase at 47.36 ML/year in Bowmans Creek, and maximum increase at 43.42 ML/year.

In the Hunter River alluvium (Figure 7.9) and Glennies Creek (Figure 7.11), the climate change induces minimal changes in the groundwater indirect take during the post-mining recovery period in both areas. For the Hunter River alluvium, the maximum indirect take difference occurs in the Best Case with a decrease of 0.02 ML in the year 2045 compared with the base case predictions. For the Glennies Creek, the groundwater indirect take continues to increase in the post-mining recovery period, but the Best Case climate scenarios predicts the higher increase rate compared to other conditions and subsequently results in the 0.046 ML/year maximum difference at the end of recovery period. In the Bowmans Creek alluvium (Figure 7.10), minimal changes can be observed between Base Case, Worst Case and Maximum Consensus in terms of groundwater indirect take. However, the Best Case predicted different pattern: the groundwater recharge is predicted at 0.13 ML/year to Bowmans Creek alluvium at the beginning of post-mining, and then aligns with the Base Case predicted scenarios as the recovery period progresses.

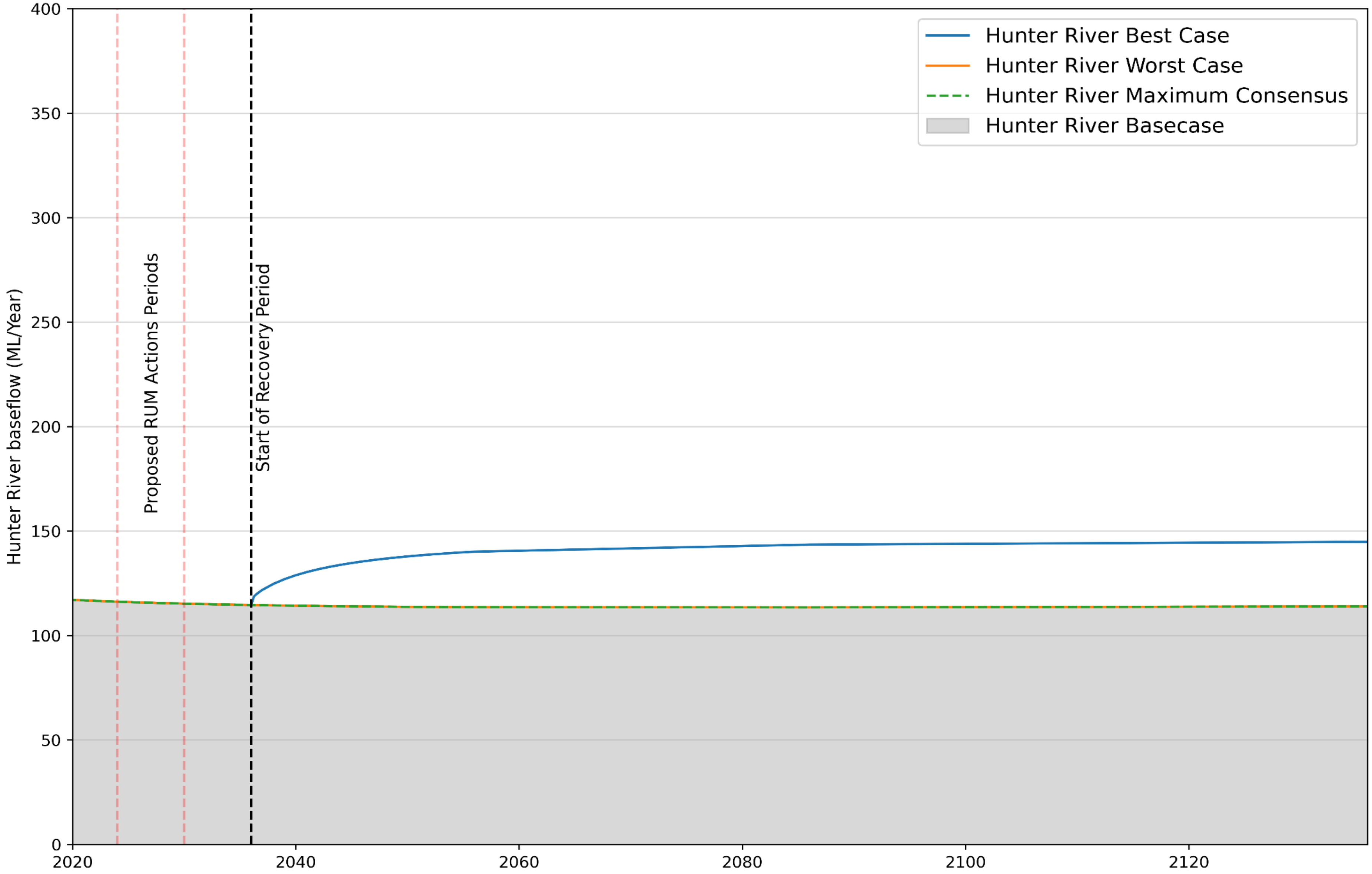


Figure 7.6 Predicted Hunter River baseflow in different climate changes scenarios

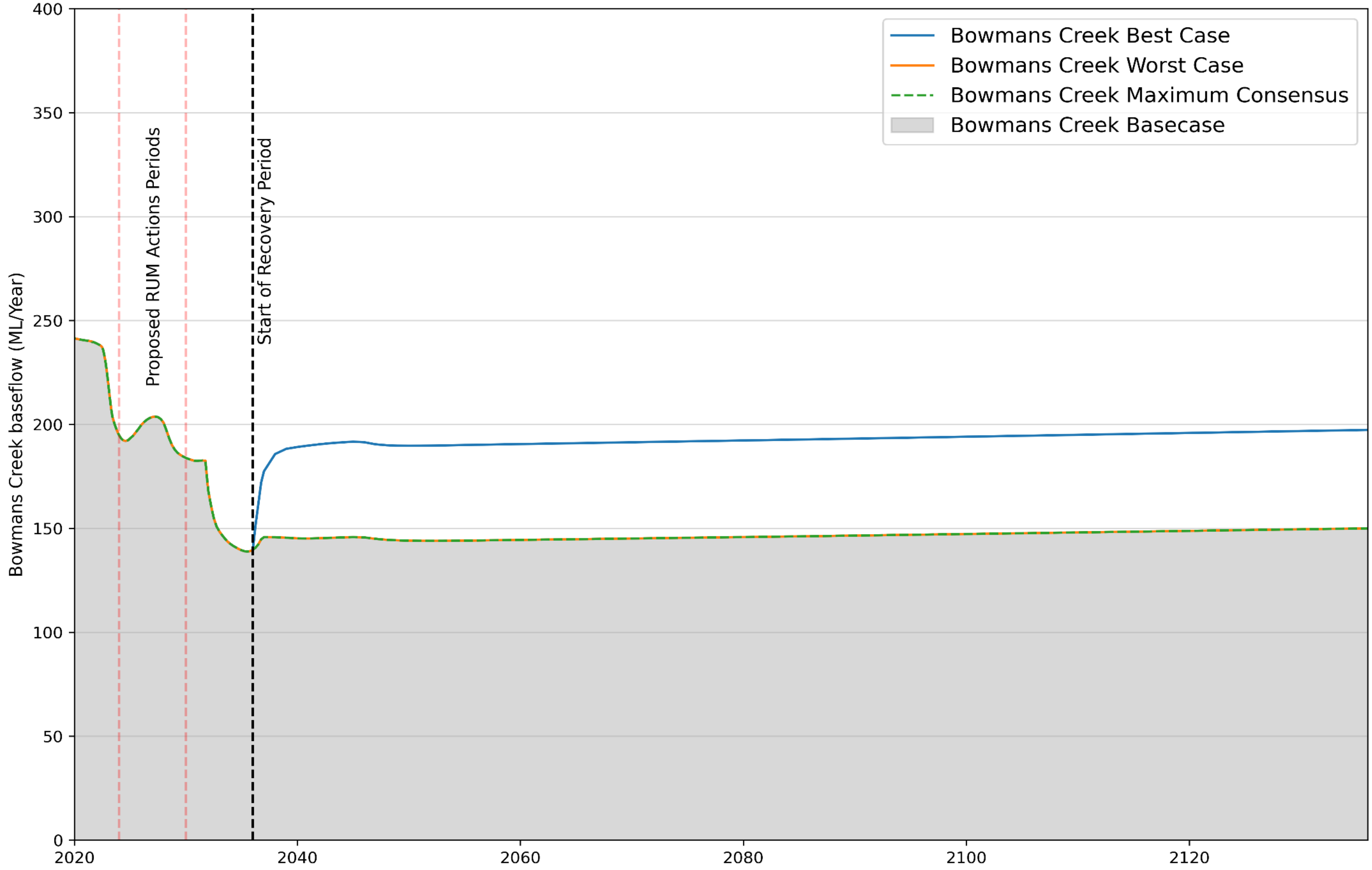


Figure 7.7 Predicted Bowmans Creek baseflow in different climate changes scenarios

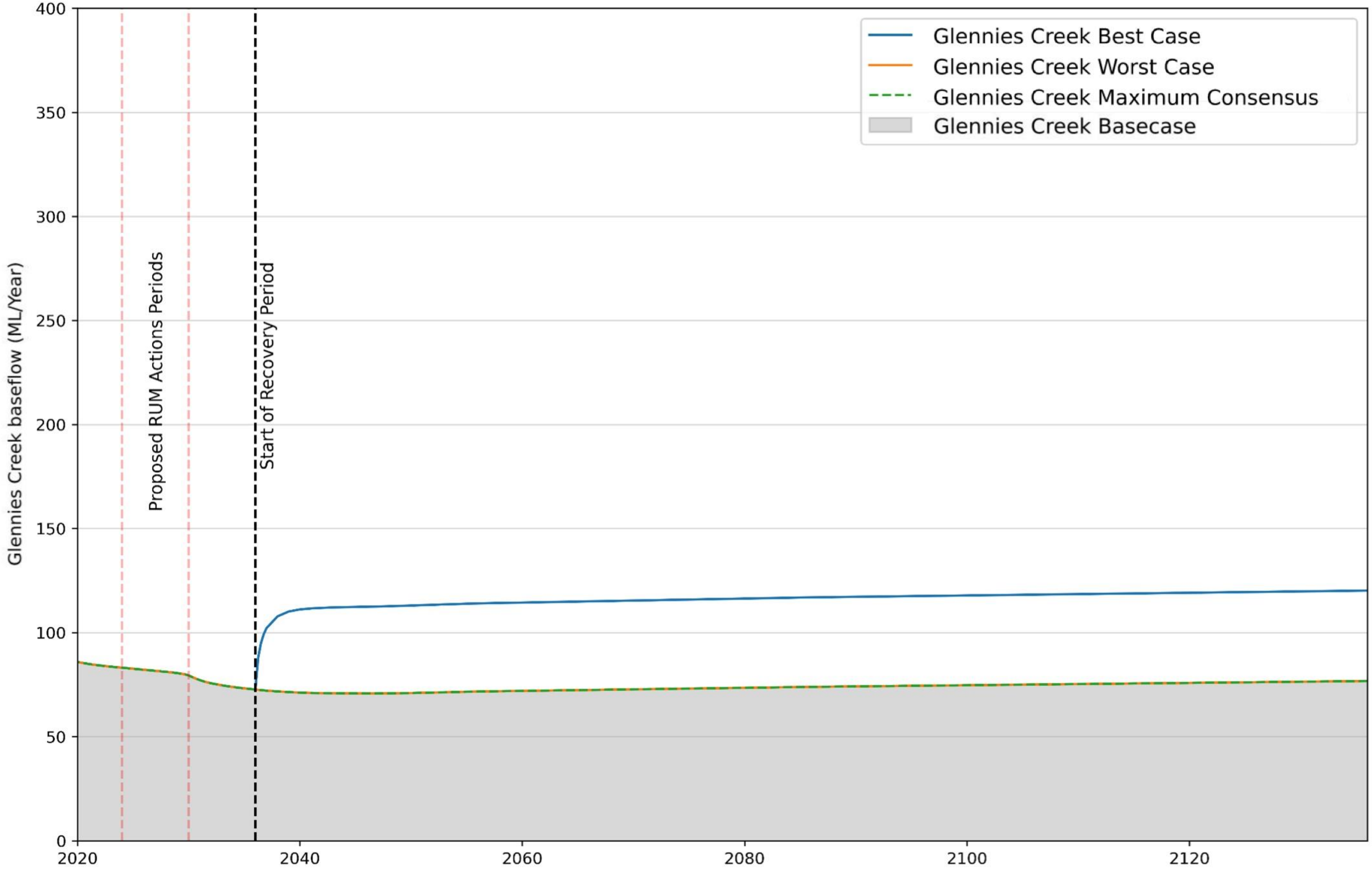


Figure 7.8 Predicted Glennies Creek Baseflow in different climate changes scenarios

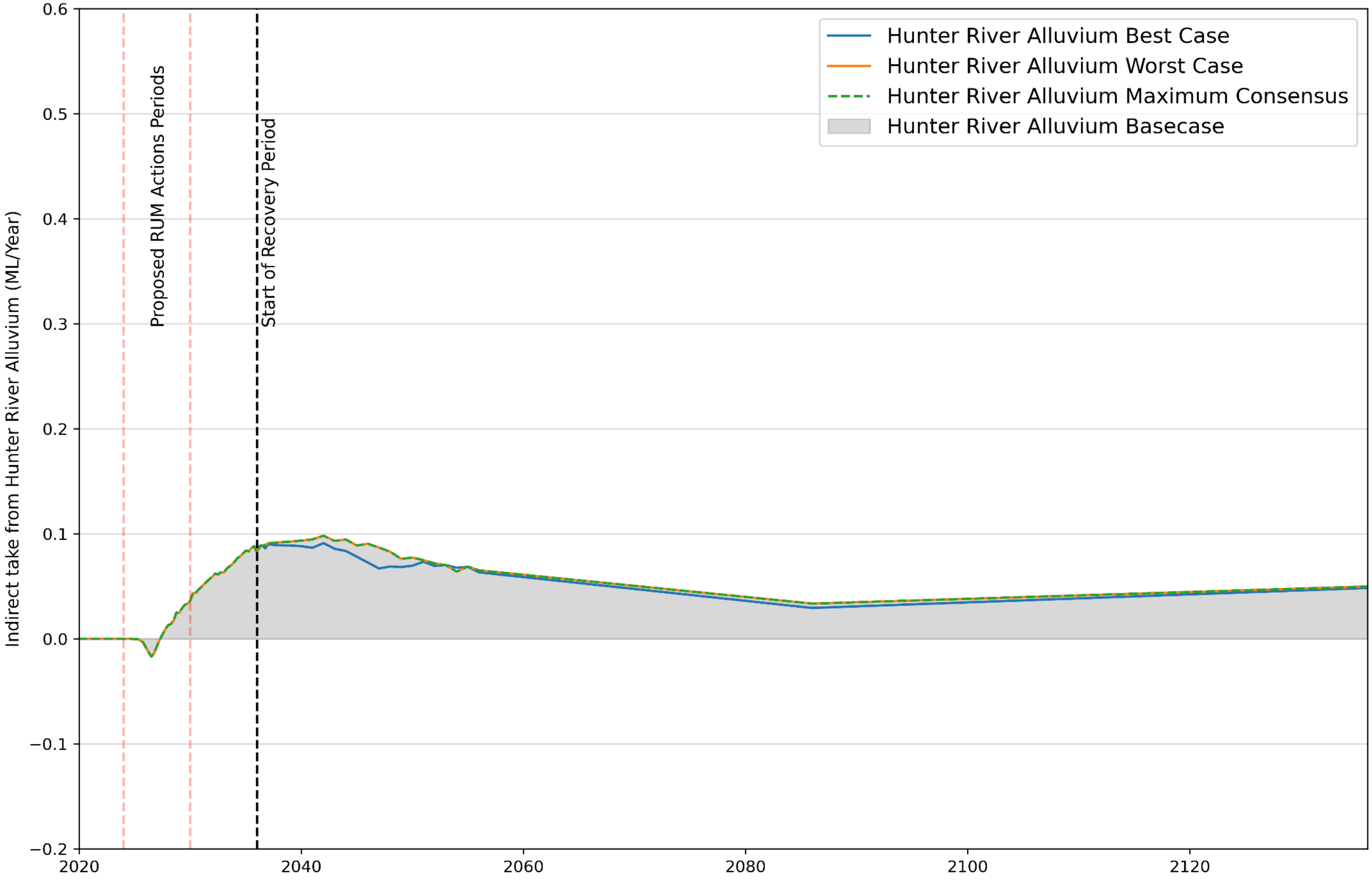


Figure 7.9 Predicted indirect take from Hunter River alluvium in different climate changes scenarios

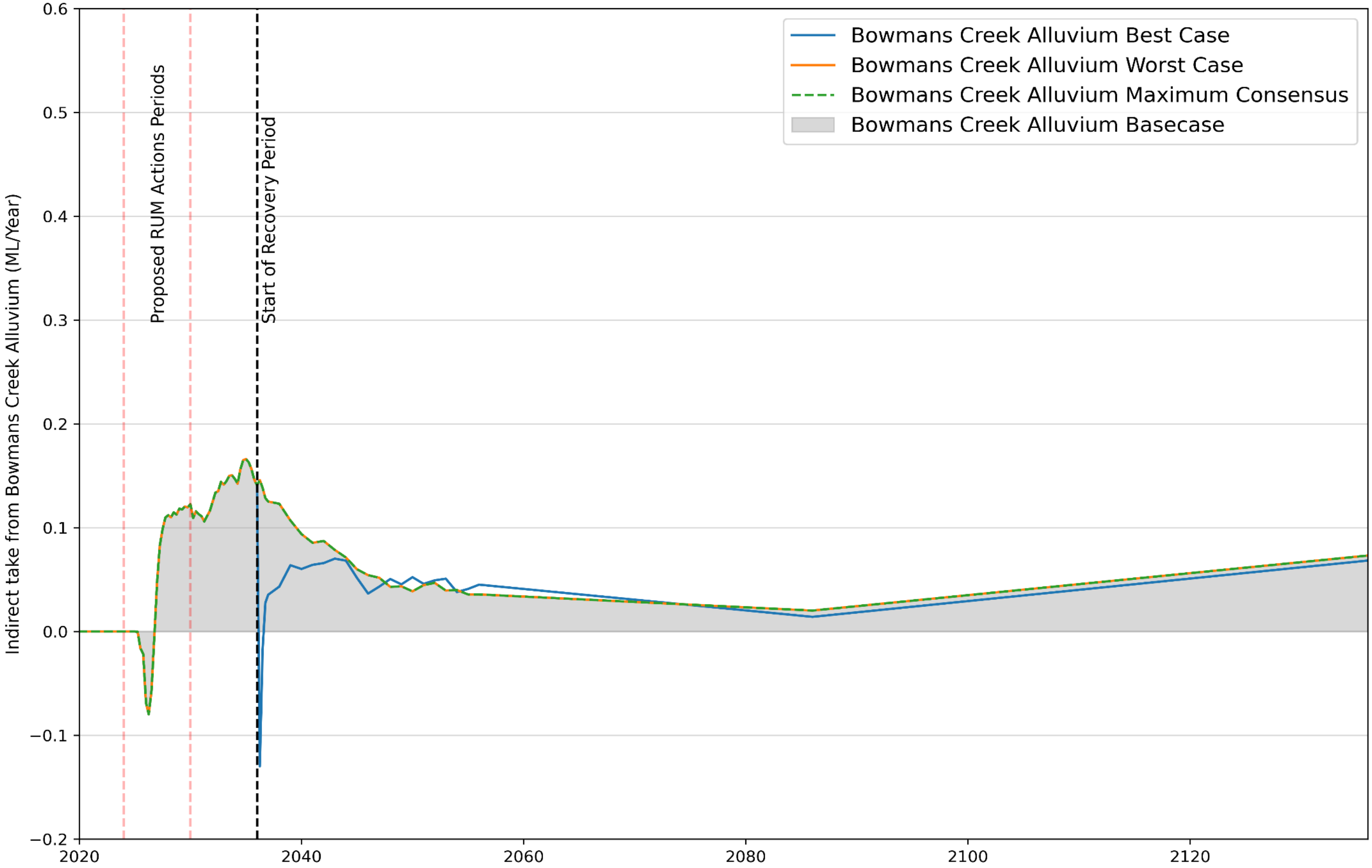


Figure 7.10 Predicted indirect take from Bowmans Creek alluvium in different climate changes scenarios

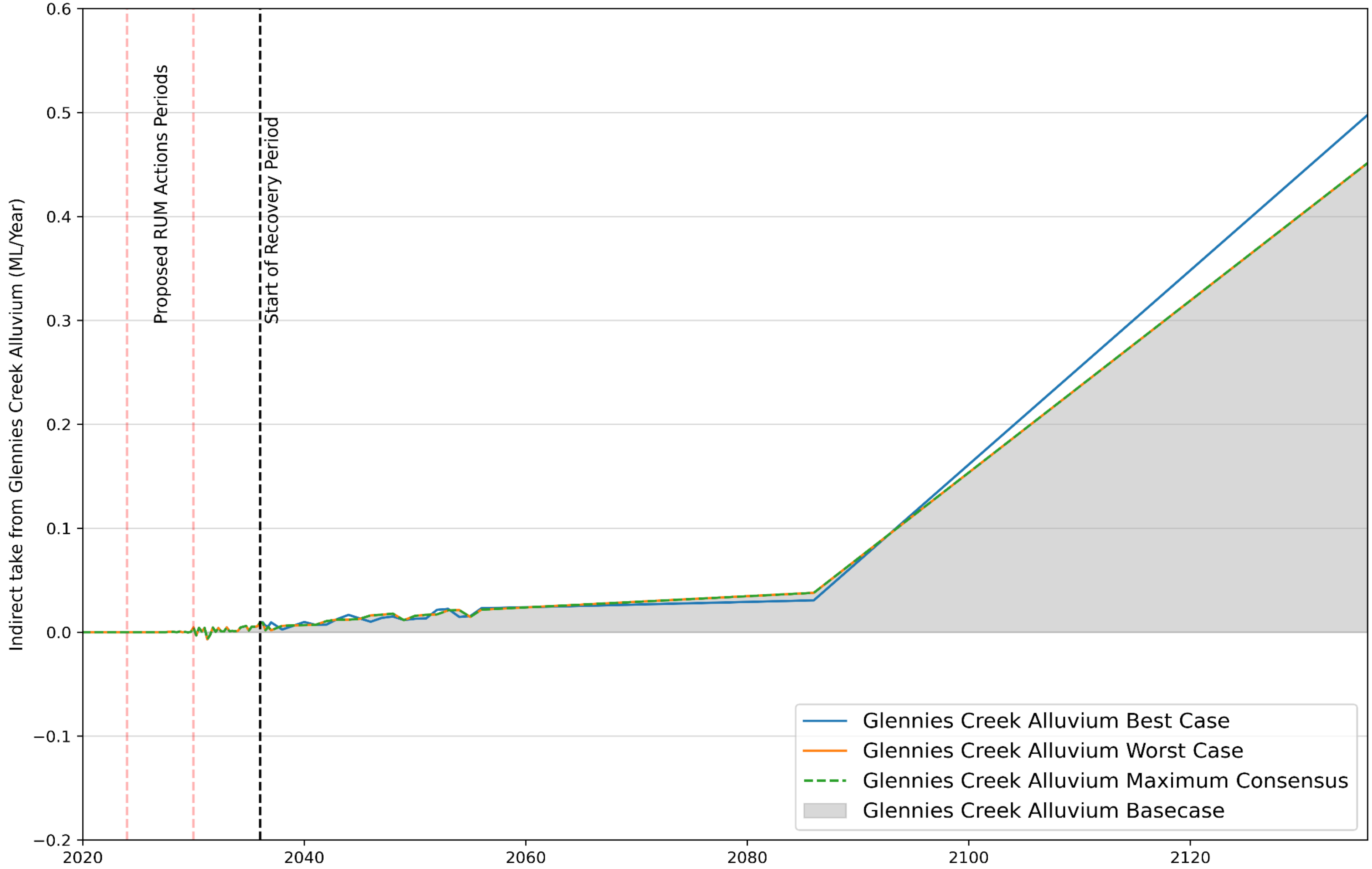


Figure 7.11 Predicted indirect take from Glennies Creek alluvium in different climate change scenarios

8 Groundwater impact assessment

8.1 Water supply bores

There are no privately-owned groundwater bores in close proximity to the Proposed Action as the land north of the Hunter River is owned by ACOL, Glencore and AGL.

Therefore, no privately-owned bores are predicted to experience more than 0.1 m of drawdown from the Proposed Action.

8.2 Groundwater dependent ecosystems

There are no high priority GDEs identified in the area on either the Hunter Regulated or Hunter Unregulated and Alluvial Water Sources WSPs.

River Red Gums are the only confirmed terrestrial GDEs in the vicinity of the Proposed Action. Small stands of River Red Gums are located on the lower reaches of Bowmans Creek, within 1 km of the Hunter River confluence. These GDEs are likely to access shallow alluvial groundwater, supported by baseflow from creeks.

There are three stands of River Red Gums in the riparian zone of Bowmans Creek. The predicted drawdown is less than 0.1 m on completion of the Proposed Action and is also considered insignificant (Figure 8.1).

Bowmans Creek is also a potential aquatic GDE. The reduction in baseflow to Bowmans Creek due to the Action is predicted to be negligible.

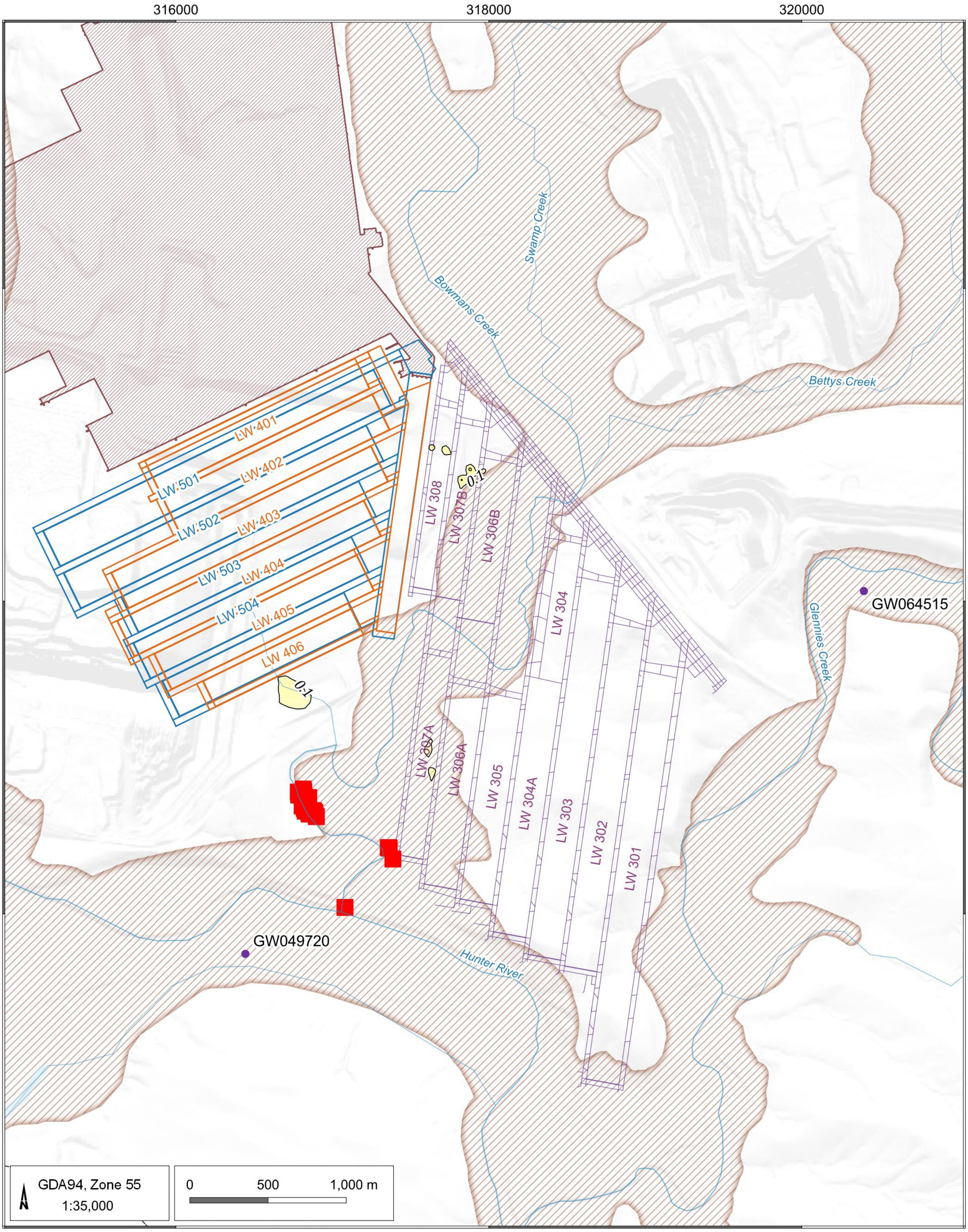
Potential impacts to GDEs would be managed through the Extraction Plan (including the Water Management Plan [WMP]) required under Condition 6, Schedule 3 of Development Consent DA 104/96 as well as the existing ACOL WMP and Biodiversity Management Plan, required under Conditions 26 and 28 of Development Consent DA No. 309-11-2001-i (these existing plans would be updated to incorporate the Action).

The existing Ashton WMP and Biodiversity Management Plan include the following monitoring and management measures relevant to the identified potential GDEs:

- extensive surface water and groundwater monitoring programs;
- groundwater and surface water trigger levels (including groundwater level triggers that relate to baseflow);
- annual riparian vegetation monitoring (including of potential GDEs on Bowmans Creek);
- bi-annual (spring and autumn) aquatic ecology monitoring; and
- trigger action response plans in the event that triggers or performance indicators are exceeded.

8.3 Groundwater quality

Mining activities at the RUM and AUM promote a downward vertical hydraulic gradient due to underground dewatering and subsidence, which minimises the potential risk of saline groundwater from the Permian strata flowing into alluvium and creeks. Discharge from the Permian strata to the alluvial groundwater is reduced by increasing depressurisation of the underlying seams, and therefore the salinity of alluvial groundwater is likely to decrease over time. This finding is consistent with previous approvals (Aquaterra, 2009).



LEGEND

- Private bores
- Drainage
- Drawdown contour (m)
- AUM Lower Barrett
- Indicative Pikes Gully Seam Longwall layout
- Indicative Middle Liddell Seam Longwall layout
- Model boundary
- River Red Gum
- Completed Pike Gully Seam Workings

Drawdown (m)

- 0
- 0.1
- 0.2
- 0.5

Ashton-Ravensworth Integration Project (ASH5001.003)

Predicted maximum alluvial drawdown near private bores and GDEs

AGE

DATE 22/03/2024

FIGURE No: **8.1**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\ASH5001.003 Ashton-Ravensworth Integration\3_GIS\Workspaces\001_Deliverable1\08.01_AHS5001_Predicted maximum alluvial drawdown near private bores and

9 Uncertainty analysis

9.1 Overview

The calibrated model (i.e., basecase model) provides the best prediction of the impacts resulting from the Proposed Action. There is however an element of non-uniqueness that exists with the calibrated dataset, in that other combinations 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 400 simulations undertaken, 224 model runs converged and with SRMS being less than 12%. Models with and without the Proposed Action were used in the uncertainty analysis with a focus on the impacts from the proposed RUM mining being assessed for uncertainty.

Outputs from the uncertainty modelling were processed in accordance with the likelihood of exceedance proposed in Middlemis and 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%	Very likely that the outcome is larger than this value	
Likely	10-33%	Likely that the outcome is larger than this value	
About as likely as not	33-67%	As likely as not that the outcome is larger than this value	
Unlikely	67-90%	Unlikely that the outcome is larger than this value	
Very unlikely	90-100%	Very unlikely that the outcome is larger than this value	

9.2 Mine inflow rate

The range of possible total inflow rates for the Proposed Action mining operations including PG and ULLD from the calibrated parameter set has been provided in Figure 9.1. Overall, the uncertainty analysis suggests that it is 50% as about as likely that the total inflow rate exceeds that base case predictions from 2024 to 2027, but it is 90% unlikely that the value will be higher than base case run after 2027 with an average of approximate 1 ML/day. The results indicate that the calibrated or base case predicts an inflow for the period that the MLD is mined (2027 onwards) that is in the range indicating that it is unlikely to be exceeded. The peak inflow rate determined using the basecase model is at 2.08 ML/day, while the uncertainty results demonstrate that the predicted peak total mine inflow rates could range from around 0.50 ML/day (e.g., 10% very likely to be exceeded) to 3.0 ML/day (e.g., 90% very unlikely to be exceeded).

9.3 Impacts on indirect take from alluvium

The range of possible direct take from Hunter River alluvium, Glennies Creek alluvium and Bowmans Creek alluvium for the Proposed Action are presented in Figure 9.2, Figure 9.3 and Figure 9.4 respectively.

For the Hunter River alluvium (Figure 9.2), the indirect take from the calibrated model predictions is between the 50% to 67% of uncertainty model runs. It is 10% very likely to 50% as about as likely as not that indirect take from Hunter River alluvium is lower than the base model run. The maximum indirect take could reach approximately at 1.02 ML/year (e.g., 90% unlikely to be exceeded) at the end of post-mining recovery period.

For the Glennies Creek alluvium (Figure 9.3), the indirect take predicted in the base case model run aligns closely with the 50% uncertainty percentile. The maximum indirect take approximates at 2.8 ML/year, but it is 90% very unlikely to occur at the end of post-mining recovery period.

For the Bowmans Creek alluvium (Figure 9.4), it is 50% as about likely to 67% unlikely that the indirect take occurs close to the predicted value in base case condition, with a difference at around 0.5 ML/year. It is 90% very unlikely that the peak indirect take from Bowmans Creek rise up to around 8.5 ML/year.

9.4 Impacts on indirect take from surface water

The range of possible baseflow decline from Hunter River, Glennies Creek and Bowmans Creek due to the Proposed Action are presented in Figure 9.5, Figure 9.6 and Figure 9.7 respectively.

For the Hunter River, the baseflow decline predicted from base model conditions aligns closely with the 50% uncertainty percentile. It is 67% unlikely to 90% very unlikely that the baseflow decline exceeds the base case by a maximum of approximate 0.9 ML/Year.

For the Glennies Creek, it is 67% unlikely to 90% very unlikely that the baseflow decline exceeds the base case predictions. It is very 90% unlikely that the baseflow decline from Glennies Creek can reach to 2.0 ML/year in the recovery period.

For the Bowmans Creek, the baseflow decline predicted from base model conditions present similar trend to the 67% unlikely uncertainty percentile. It is 10% likely to 67% unlikely that the baseflow decline will be lower than the base case scenario.

9.5 Zone of drawdown

The potential variability of the extent of the zone of saturated drawdown for the proposed action was assessed for each of the 224 model runs (e.g., comparison with basecase model). It is worth noting that the uncertainty analysis concentrates on the maximum saturated drawdown across the complete model run including both the proposed action and recovery period (e.g., until year 2135) in targeting layers. The total number of times which a model cell had drawdown greater than the chosen drawdown (e.g., 0.1 m or 2 m) for these layers was tallied and converted to a percentile. Overall, the uncertainty results suggest that the drawdown area is likely to occur in a more restricted extent compared to the base case model run.

In the alluvium and regolith (Layer 1), the 0.1 m drawdown was chosen as it is considered a notable drawdown for GDEs. As presented in Figure 9.8, it is unlikely that the 0.1 drawdown exceeds the area predicted in the base case condition.

The PG Seam (Layer 8), and ULLD Seam (Layer 14) were assigned a 2 m target for comparison. As presented in Figure 9.9 and Figure 9.10, the greater than 2 m drawdown area in these layers due to proposed actions is generally unlikely to extend further than the results in base case model condition.

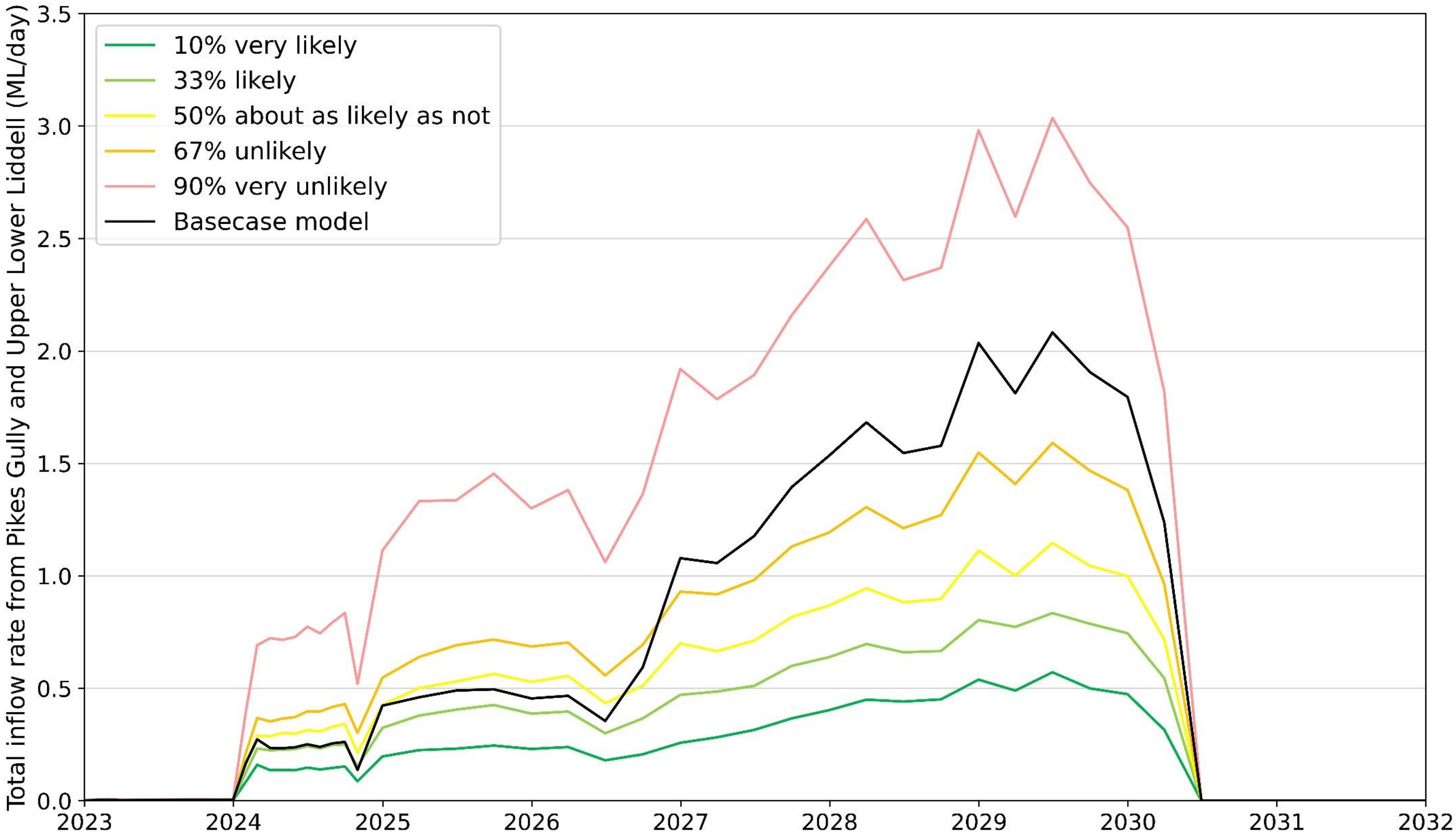


Figure 9.1 Exceedance probability distribution of predicted mine inflow

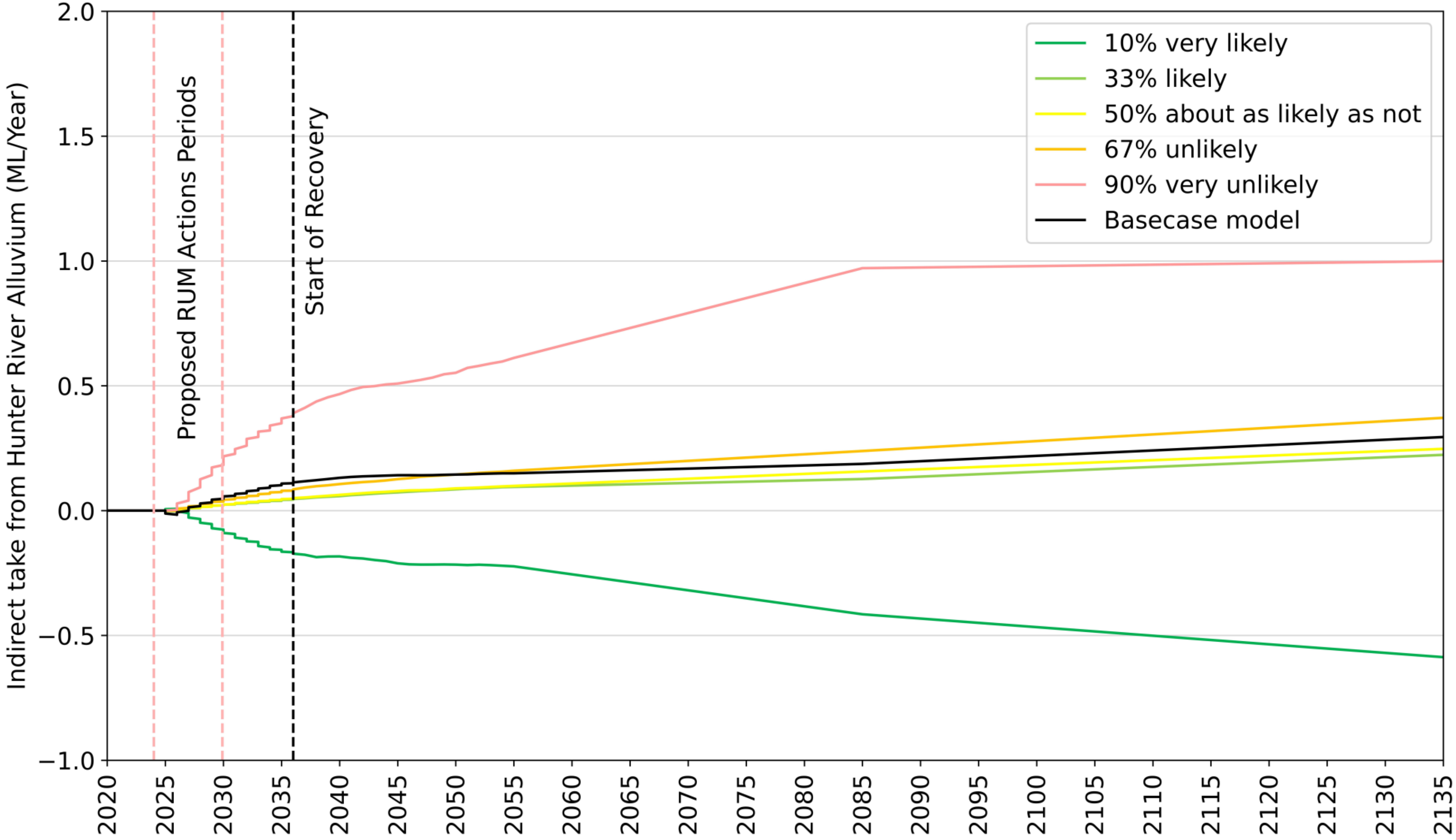


Figure 9.2 Exceedance probability distribution of predicted impacts to Hunter River Alluvium

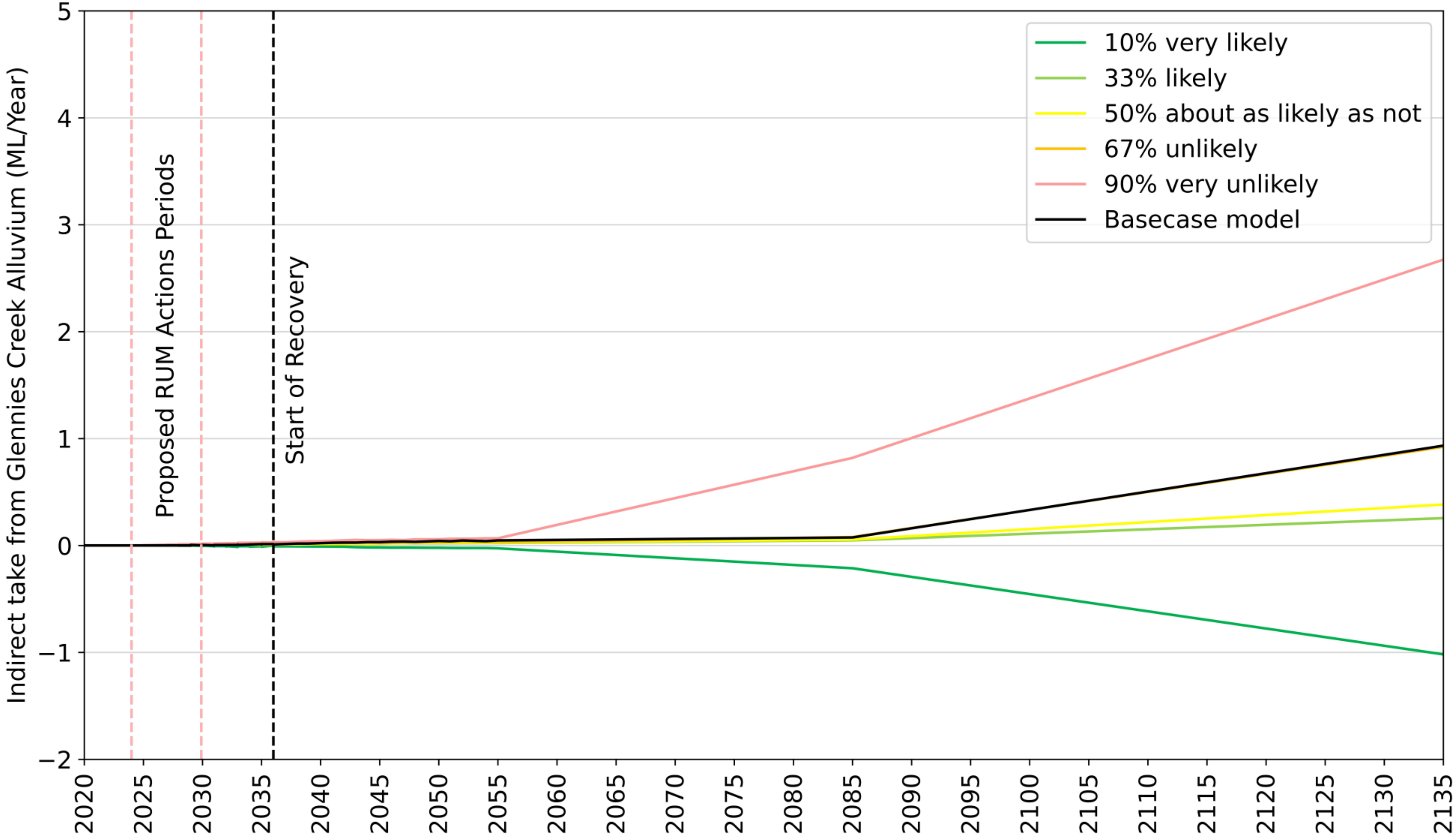


Figure 9.3 Exceedance probability distribution of predicted impacts to Glennies Creek Alluvium

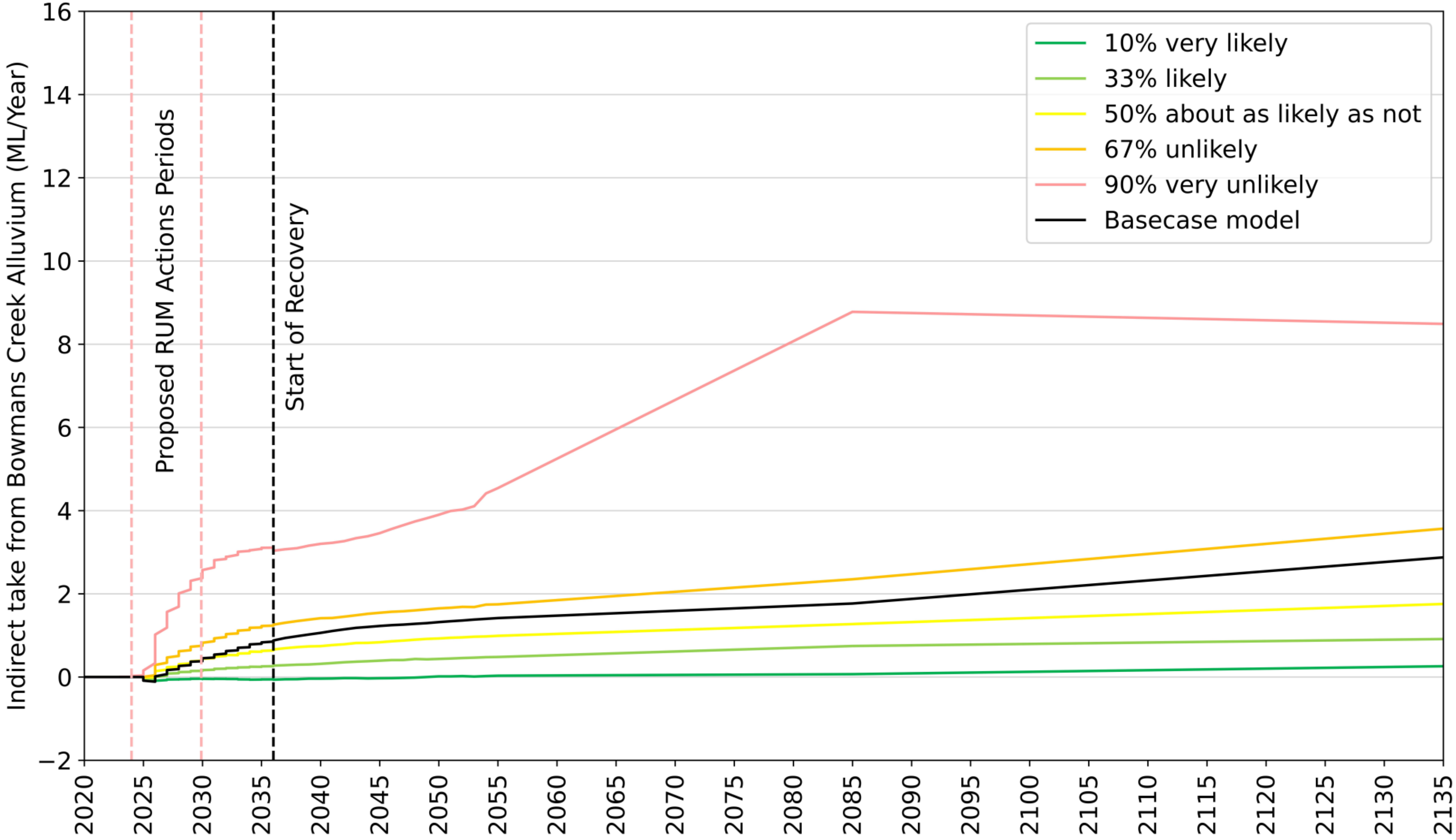


Figure 9.4 Exceedance probability distribution of predicted impacts to Bowmans Creek Alluvium

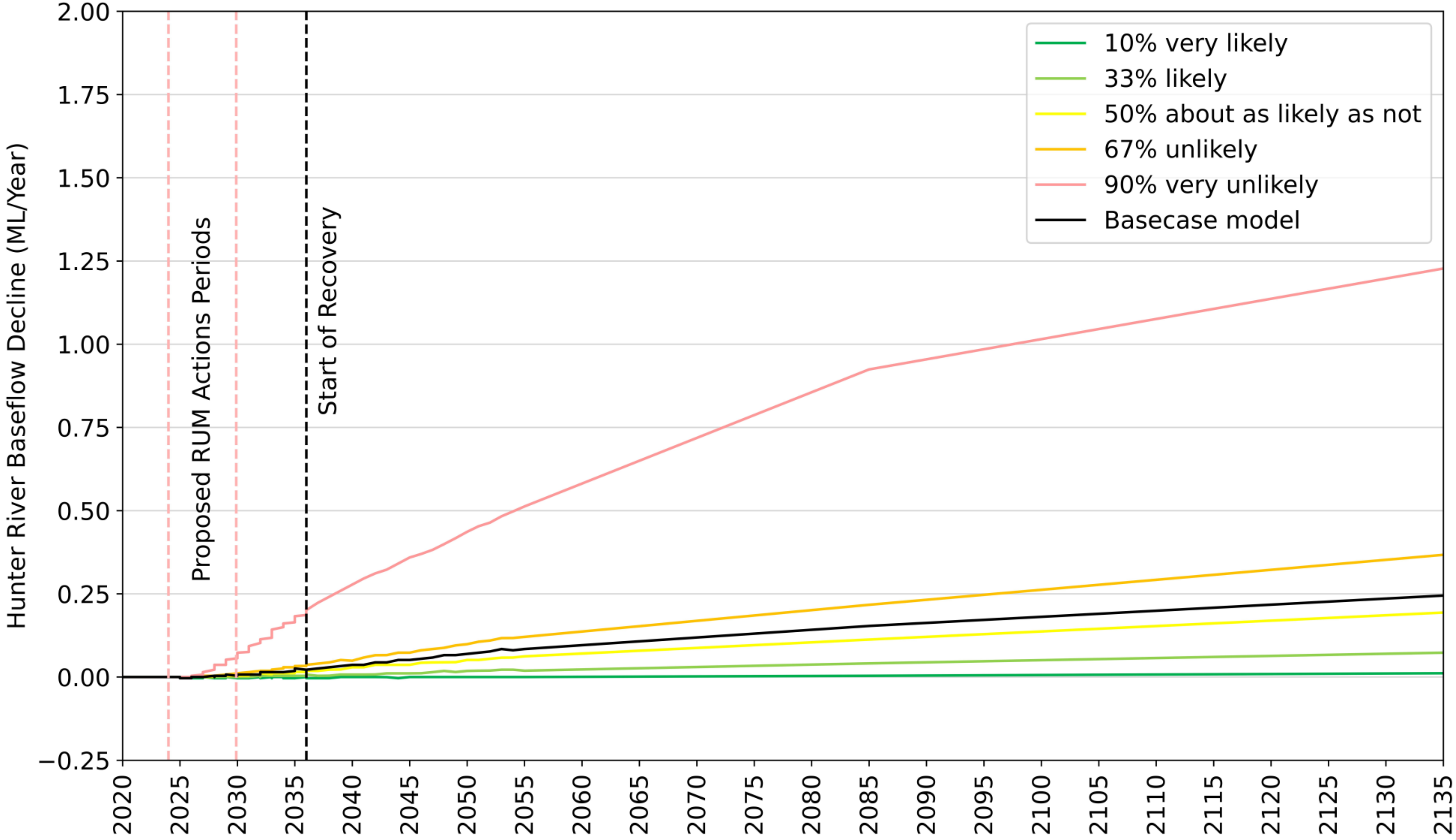


Figure 9.5 Exceedance probability distribution of predicted baseflow impacts to Hunter River

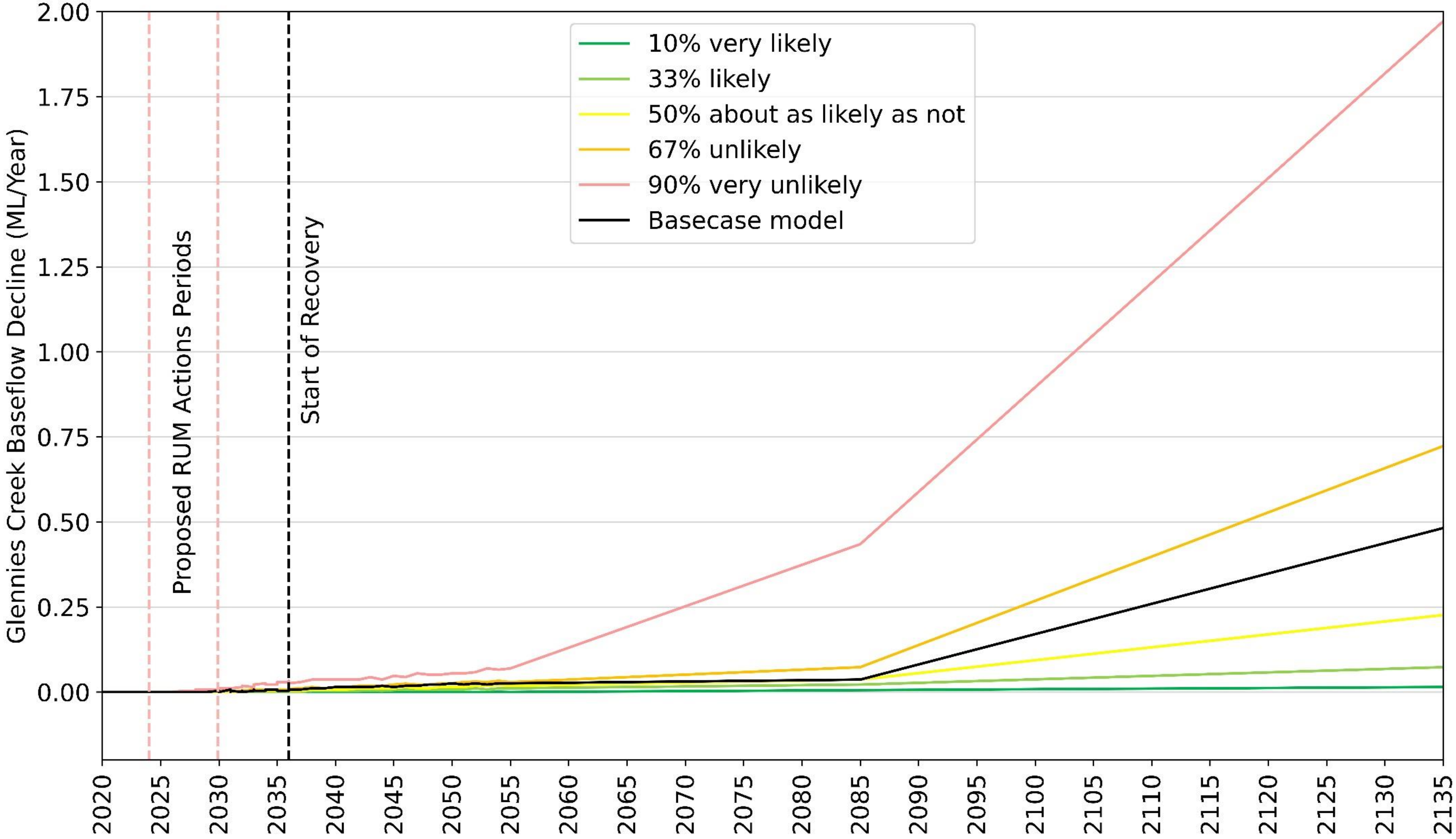


Figure 9.6 Exceedance probability distribution of predicted baseflow impacts to Glennies Creek

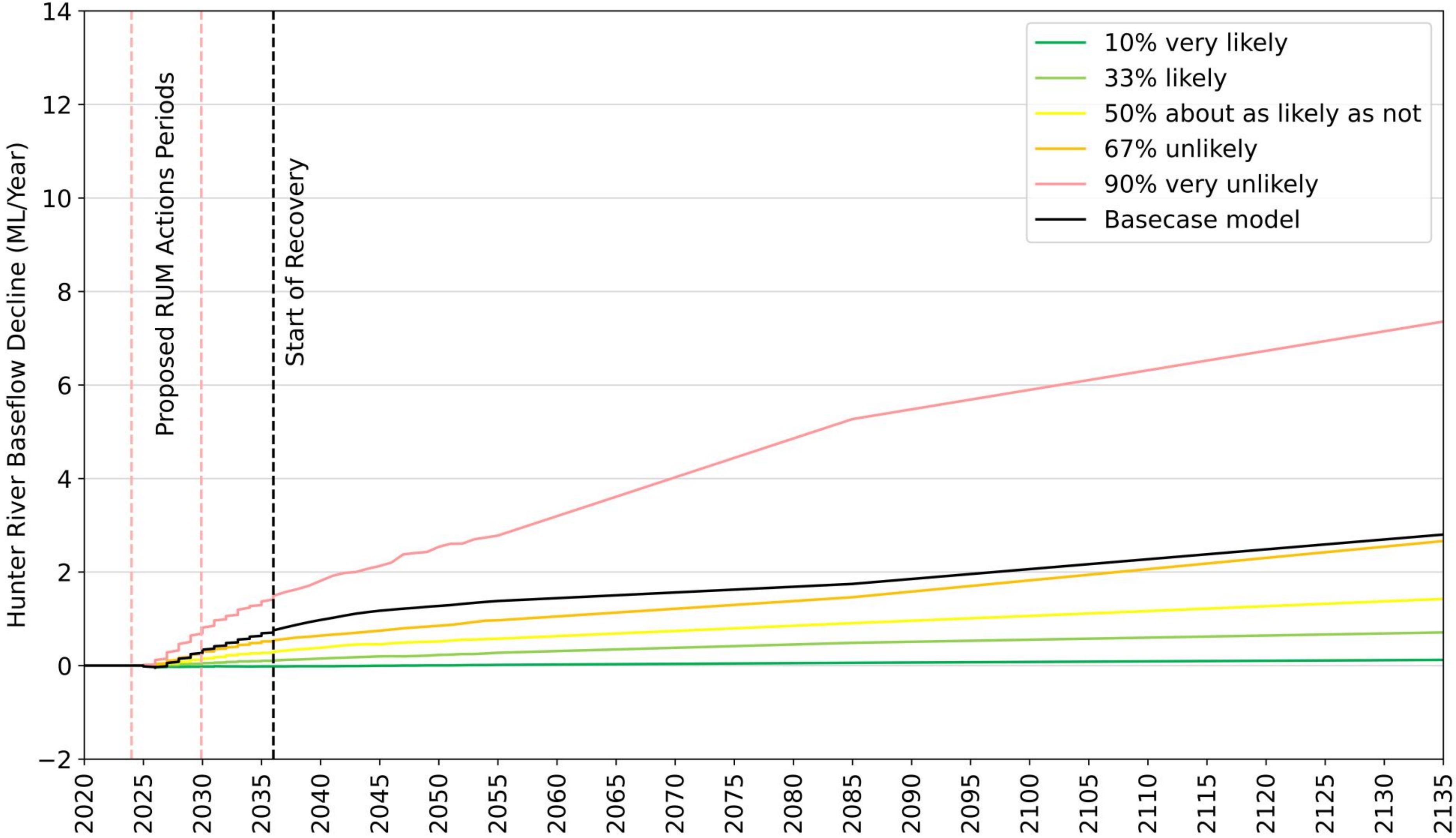
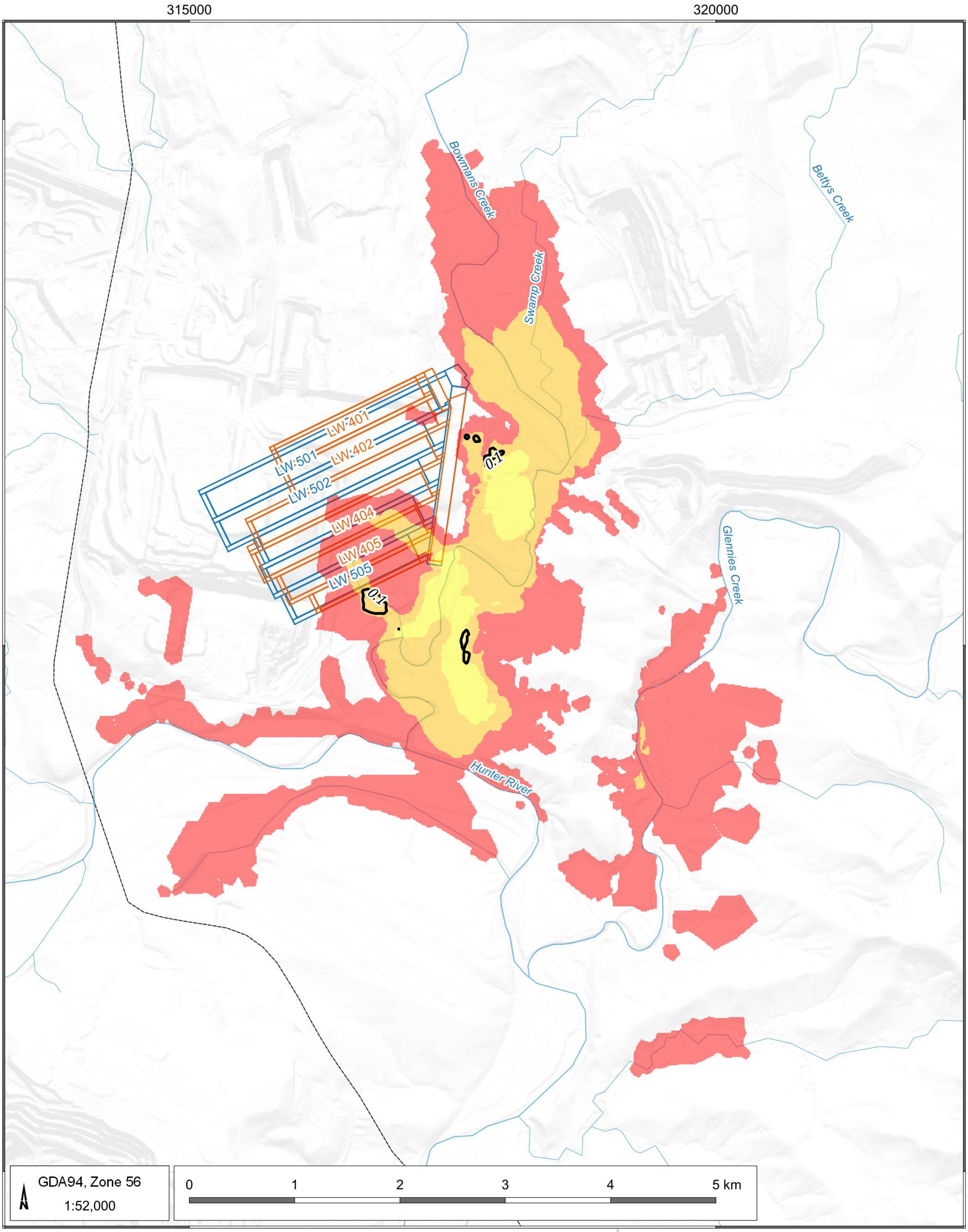


Figure 9.7 Exceedance probability distribution of predicted baseflow impacts to Bowmans Creek



LEGEND

- Basecase 0.1m drawdown
- Drainage
- Indicative Pikes Gully Seam Longwall layout
- Indicative Middle Liddell Seam Longwall layout
- Model boundary

Probability

- 0-10% (Very likely to exceed)
- 10-33% (Likely to exceed)
- 33-67% (As likely as not to exceed)
- 67-90% (Unkikely to exceed)
- 90-100% (Very unlikely to exceed)

Ashton-Ravensworth Integration Project (ASH5001.003)

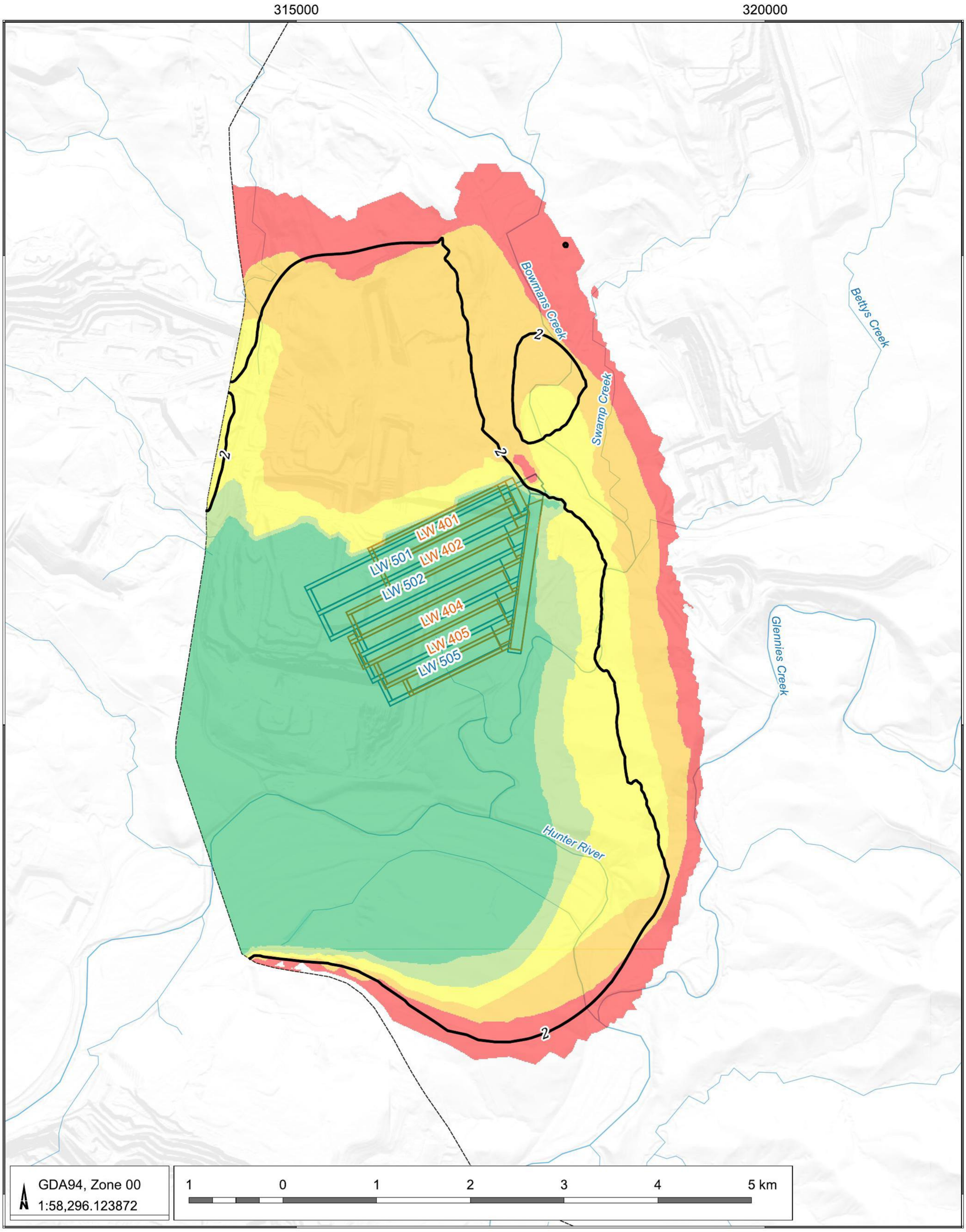
Probability of greater than 0.1 m drawdown in Alluvium and Regolith (Layer 1)

AGE

DATE 22/03/2024

FIGURE No: **9.8**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\ASH5001.003 Ashton-Ravensworth Integration\3_GIS\Workspaces\001_Deliverable1\09.08_ASH5001_UNC_Probability_of_greater_than_2m_drawdown_in_Alluvium(Layer1).qgz



LEGEND

- Basecase 2m drawdown
- Drainage
- Indicative Pikes Gully Seam Longwall layout
- Indicative Middle Liddell Seam Longwall layout
- Model boundary

Probability

- 0-10% (Very likely to exceed)
- 10-33% (Likely to exceed)
- 33-67% (As likely as not to exceed)
- 67-90% (Unkikely to exceed)
- 90-100% (Very unlikely to exceed)

Ashton-Ravenwsworth Integration Project (ASH5001.003)

Probability of greater than 2 m drawdown in Pikes Gully Seam (Layer 8)

AGE

DATE 11/09/2023

FIGURE No: **9.9**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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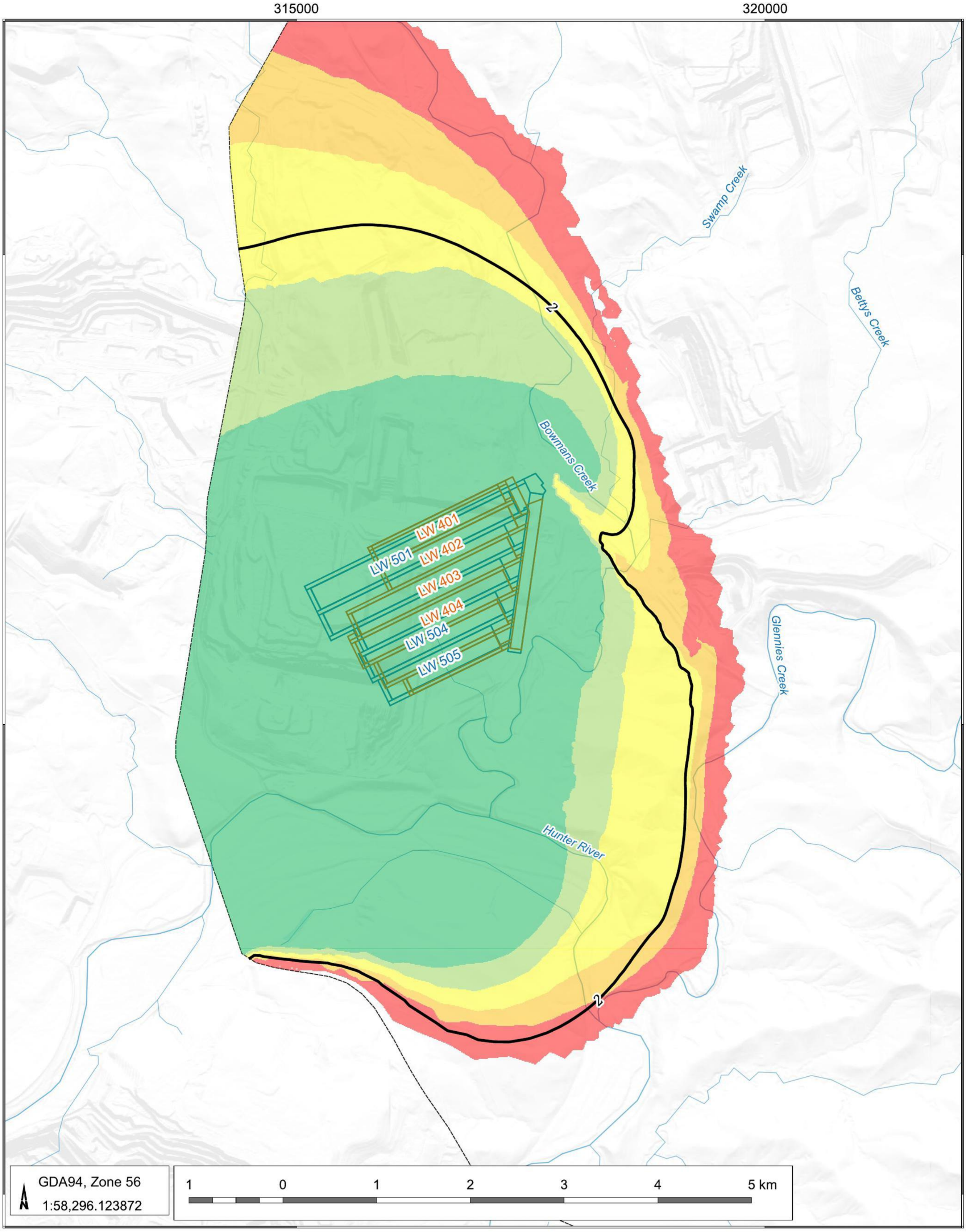

Basecase 2m drawdown
Drainage
Indicative Pikes Gully Seam Longwall layout
Indicative Middle Liddell Seam Longwall layout
Model boundary

Probability

0-10% (Very likely to exceed)
10-33% (Likely to exceed)
33-67% (As likely as not to exceed)
67-90% (Unkikely to exceed)
90-100% (Very unlikely to exceed)

Ashton-Ravenwsworth Integration Project
(ASH5001.003)

Probability of greater than 2 m drawdown in Middle Liddell (Layer 14)

AGE

DATE
12/10/2023

FIGURE No:
9.10

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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10 Groundwater monitoring and management

Condition 6, Schedule 3 of Development Consent DA 104/96 requires preparation of an Extraction Plan, which must be approved by the Secretary of the NSW DPE prior to secondary extraction. The Extraction Plan is required to include a WMP.

The WMP would include surface and groundwater impact assessment criteria and trigger levels for investigating any potentially adverse impacts on water resources or water quality.

ACOL has developed and implemented a site WMP in accordance with Condition 26, Schedule 3 of Development Consent DA No. 309-11-2001-i to monitor and manage potential mining related impacts to the groundwater regime. The existing Ashton WMP would be reviewed and updated to incorporate the Proposed Action.

The current groundwater monitoring program is comprehensive and aims to identify potential mining related impacts to the groundwater regime. The WMP outlines the following:

- groundwater monitoring network, with bores targeting alluvium and Permian units;
- monitoring frequency for groundwater levels and quality;
- groundwater levels and quality triggers for early identification of potential adverse impacts to the groundwater regime;
- monitoring of groundwater abstraction from the underground workings; and
- a surface water and groundwater response plan that is implemented if a trigger level is exceeded.

The current groundwater monitoring network consists of 132 monitoring bores and VWP installations that monitor the alluvial and fractured rock aquifers. The groundwater monitoring network and level/quality impact assessment criteria for the alluvium aquifer are considered sufficient and appropriate to monitor impacts predicted by the groundwater model.

There is limited ACOL groundwater monitoring southwest of the Proposed Action, and it is recommended that the use of data from existing Ravensworth Operations monitoring bores in this area be investigated. If available and working, these bores should be monitored by ACOL for groundwater levels during mining of the Proposed Action. Where available, ACOL should include these bores within its monitoring program for the Proposed Action.

ACOL prepares a number of reports to assess if the impacts to Glennies Creek, Bowmans Creek and the Hunter River (and connected alluvium) are within the approved predictions, including monthly compliance, end-of-panel (EOP) and annual environmental monitoring (AEMR) reporting. These reports are considered appropriate, although the groundwater impacts review undertaken for the EOP and AEMR could be combined into a single document.

Groundwater flow into the underground has been estimated with the numerical model. In order to better understand and manage groundwater at RUM, we suggest a number of actions be implemented, including:

- maintaining a register of mine inflows;
- accurately recording all water pumped into and out of the mine with flow meters on pumps; and
- monitoring the quality of water abstracted from the mine water quarterly.

11 Conclusions

This report provides an assessment of the potential impacts to groundwater resources from the Proposed Action. The report also addresses the comments and recommendations raised by the IESC on the Groundwater Review (AGE, 2022a) that supported the EPBC Referral for the Action. The outcomes presented here support the findings of AGE (2022a), specifically that the Proposed Action would not have a significant impact on sensitive receptors in the area.

The specifically noted River Red Gums along Bowmans Creek and the Hunter River are not impacted by the Proposed Action and the incremental changes to baseflows and limited drawdown in the Bowmans Creek and Hunter River alluvium indicates that the potential GDEs along water courses will also not be impacted.

The nearest private bores licensed to take water from the HRA and GCA will not be impacted by the Proposed Action.

In consideration of the impacts that are already occurring and are approved to occur at open cut and underground mining operations surrounding the Proposed Action and the approved future mining associated with these developments, the impacts of the Proposed Action on a water resource have been assessed as not being significant.

The Proposed Action is not predicted to result in an impact that is of sufficient scale or intensity as to significantly reduce the current or future utility of the water resource for third party users, including environmental and other public benefit outcomes.

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Appendix A

Groundwater modelling details

A 1 Model objectives

The model objectives are to predict potential change to groundwater resulting from the Proposed Action. Specifically, the model needs to predict:

- drawdown in groundwater levels in saturated proximal Quaternary alluvium and in the Permian coal measures as a result of mining;
- the volume of groundwater directly intercepted by mining from the coal measures, and the indirect take from Quaternary alluvium and surface water features;
- change to alluvial fluxes and baseflow;
- impact on private bores;
- drawdown impact to potential Groundwater Dependent Ecosystems (GDEs); and
- individual water sources water licensing requirements.

To achieve this, the model has been updated to:

- better match the historical observations at Ravensworth Underground Mine (RUM);
- simulate the dewatering at RUM and Ashton Underground Mine (AUM); and
- process model water budgets to provide Water Sharing Plan impacts from the Proposed Action (and approved Ashton Coal Project including the AUM).

A 2 Model software

Numerical modelling has been undertaken using the MODFLOW-USG code (Panday et al., 2017). 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 Model history

Several groundwater studies, including numerical models, have been prepared for the AUM, including five numerical model updates prior to the Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) (2022b) model rebuild (Table A 1). Each update has improved upon the previous representation of the site geology and groundwater interaction and utilised the leading groundwater modelling software at the time of development.

Table A 1 Ashton Coal Project numerical models to 2020

Year	Developed by	Description
2001	HLA Envirosciences (2001)	An initial groundwater model was developed for the mine approval environmental impact statement. This model was created using MODFLOW, and included 120 columns, 120 rows and 7 layers.
2009	Aquaterra	The 2001 model was updated in 2009 for the Bowmans Creek Diversion environmental assessment. MODFLOW-SURFACT v4 (a version of MODFLOW) was the code selected for the model. The updated model included 188 columns, 252 rows and 15 layers.
2014	RPS (formerly Aquaterra)	Another update was performed upon completion of mining the Pikes Gully seam. For this update, MODFLOW-SURFACT v4 was also used, and the model geometry and domain remained unchanged.
2016	AGE Consultants	A new numerical groundwater flow model was developed using MODFLOW-USG (Panday et al. 2015). MODFLOW-USG is a recent version of the MODFLOW code which uses unstructured grids instead of traditional rows and columns. This version of the model included 18 layers and 370468 total nodes.
2020	AGE Consultants	The 2016 model was recalibrated to include updated monitoring data at the AUM and surrounds.

The current model has the 2020 model as its basis, and then is further developed for this assessment by adding the RUM longwall panels and minor adjustments to the calibration to better simulate the conditions observed at both the AUM and RUM.

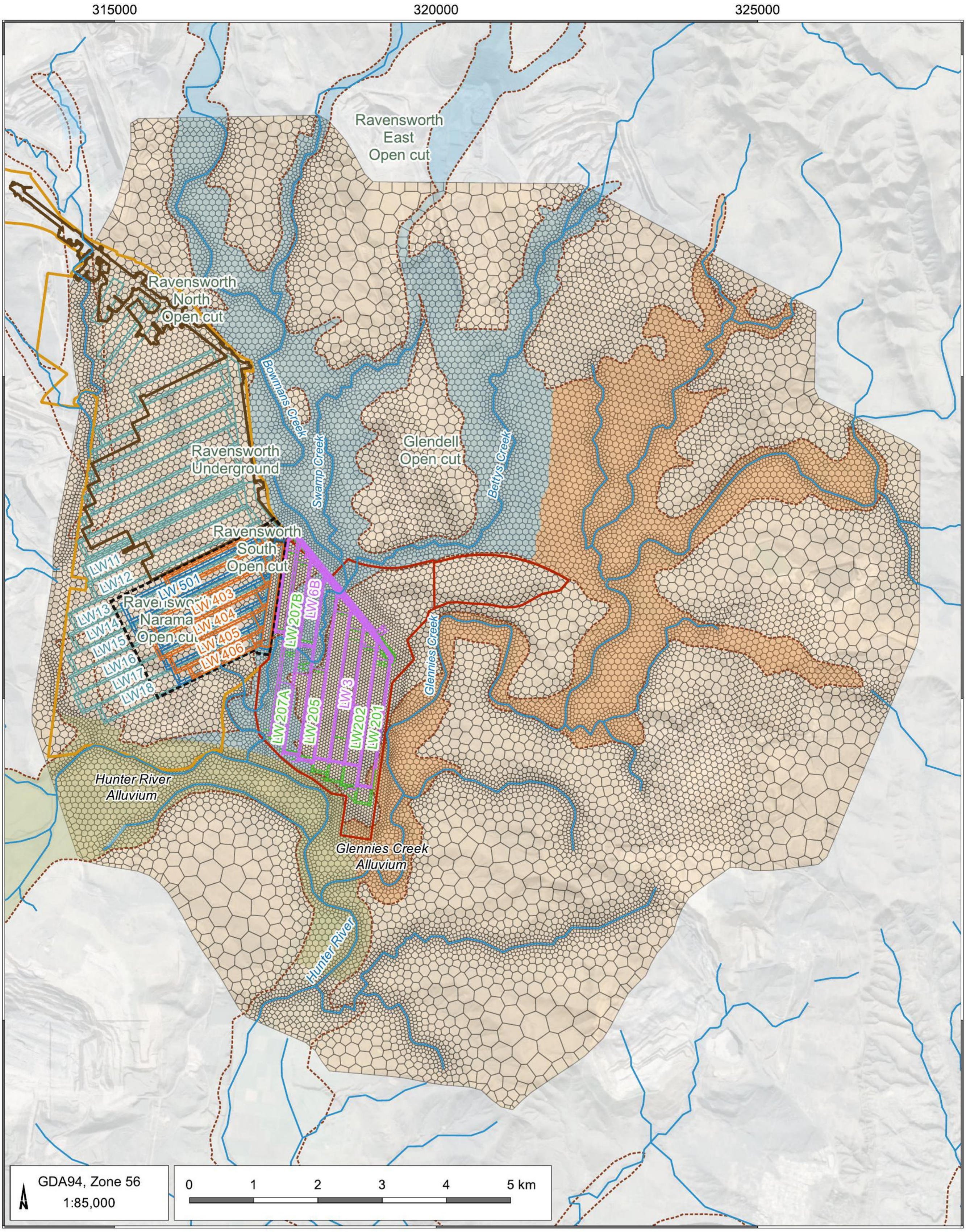
The most recent modification to approvals for RUM was assessed with modelling from Mackie Environmental Research (MER) in 2012. This model is a MODFLOW SURFACT model. We have relied on some of the assumptions in the model development to guide any changes made to the Ashton model, such as the approach to overlying spoil areas, and a lot of other components were consistent between the models.

A 4 Model structure

A 4.1 Model mesh and extent

The model domain (Figure A 1) was divided into variable sized cells comprising up to 25,193 cell nodes in each layer. The number of active cells varies between layers, with the model comprising 370,468 active cells. Within the mining areas at the AUM, the cells were aligned with the existing/proposed underground mine layout and refined into 50 metres (m) by 50 m regular hexagonal cells. Refinement was also applied along the major waterways (i.e., Hunter River, Bowmans Creek and Glennies Creek) and alluvium. Where possible, the cells were also aligned to the progression of surrounding mines (Figure A 1).

The model domain encompasses both the AUM and the surrounding mines. The surrounding mines were included within the model domain as they propose to mine, or have previously mined, several of the equivalent coal seams intersected at the AUM, including RUM.



LEGEND

- Drainage
- Approved RUM Middle Liddell panels
- AUM Pikes Gully panels
- AUM Upper Lower Liddell panels
- Ravensworth complex
- Ashton mining lease
- Quaternary alluvium/colluvium

Alluvium boundaries

- Bowmans Creek Alluvium
- Glennies Creek Alluvium
- Hunter River Alluvium

Ashton Ravensworth Integration Project (ASH5001.003)

Model extent and mesh

AGE

DATE 13/10/2023

FIGURE No: **A 1**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;

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A 4.2 Model layers

The key geological/hydrogeological units are represented by 18 layers. The layers are listed in Table A 2 below:

Table A 2 Model layers

Geological age	Stratigraphic unit			Model layer
Quaternary	Alluvium/regolith (CSIRO, 2015) (Qa)			1
Permian	Whittingham Coal Measures	Jerrys Plains Subgroup	Overburden	2
			Bayswater seam	3
		Vane Subgroup	Interburden (incl. Lemington 1 to 9)	4
			Conglomerate	5
			Interburden (incl. Lemington 10 to 25)	6
			Interburden (incl. Lemington 10 to 25)	7
			Coal seam - Pikes Gully*	8
			Interburden (incl. Arties coal seam)	9
			Interburden	10
			Coal seam - Upper Liddell*	11
			Interburden	12
			Interburden	13
			Coal seam - Upper Lower Liddell*	14
			Interburden (incl. Lower Lower Liddell)	15
			Interburden (incl. Upper Barrett)	16
			Coal seam - Lower Barrett*	17
			Underburden (incl. Hebden)	18

Note: *Current/Proposed mining target for the AUM. The Proposed Action targets the Pikes Gully and Middle Liddell (Upper Lower Liddell equivalent) seams.

A 4.3 Model stress periods and timing

The model run starts with a steady state model. Next it broadly simulates the historical mining at both AUM, RUM and all other surrounding mines. The initial stress period lengths are 5 years from 1970 to 1995, then they change to yearly from 1995 to 1999. From 2000 onwards the stress periods are quarterly until 2004, and from 2005 they are monthly and remain monthly until October 2024. Predictions beyond this time are made on a quarterly basis until the end of mining (2036). Post mining, the stress periods increase to yearly and ramp to have the last stress period simulate a 50-year period.

A 4.4 Model solver

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 0.01 and 0.008 respectively.

A 4.5 Model boundary conditions

General head boundary conditions were adopted for the northern and southern extents of the model domain (refer Figure A 2). General head boundaries are intended to simulate the regional groundwater flow in a simplified manner. The general head boundaries are established far enough from the model target so that they do not impact on the model result. These extents have pressure heads fixed at groundwater elevation in the area. These are considered general head boundaries as they are roughly consistent with regional groundwater trends. Recharge to the domain from these boundaries is calculated by the model but the rates would essentially be fixed. The hydraulic conductivities of these boundaries are established during the calibration phase of the modelling.

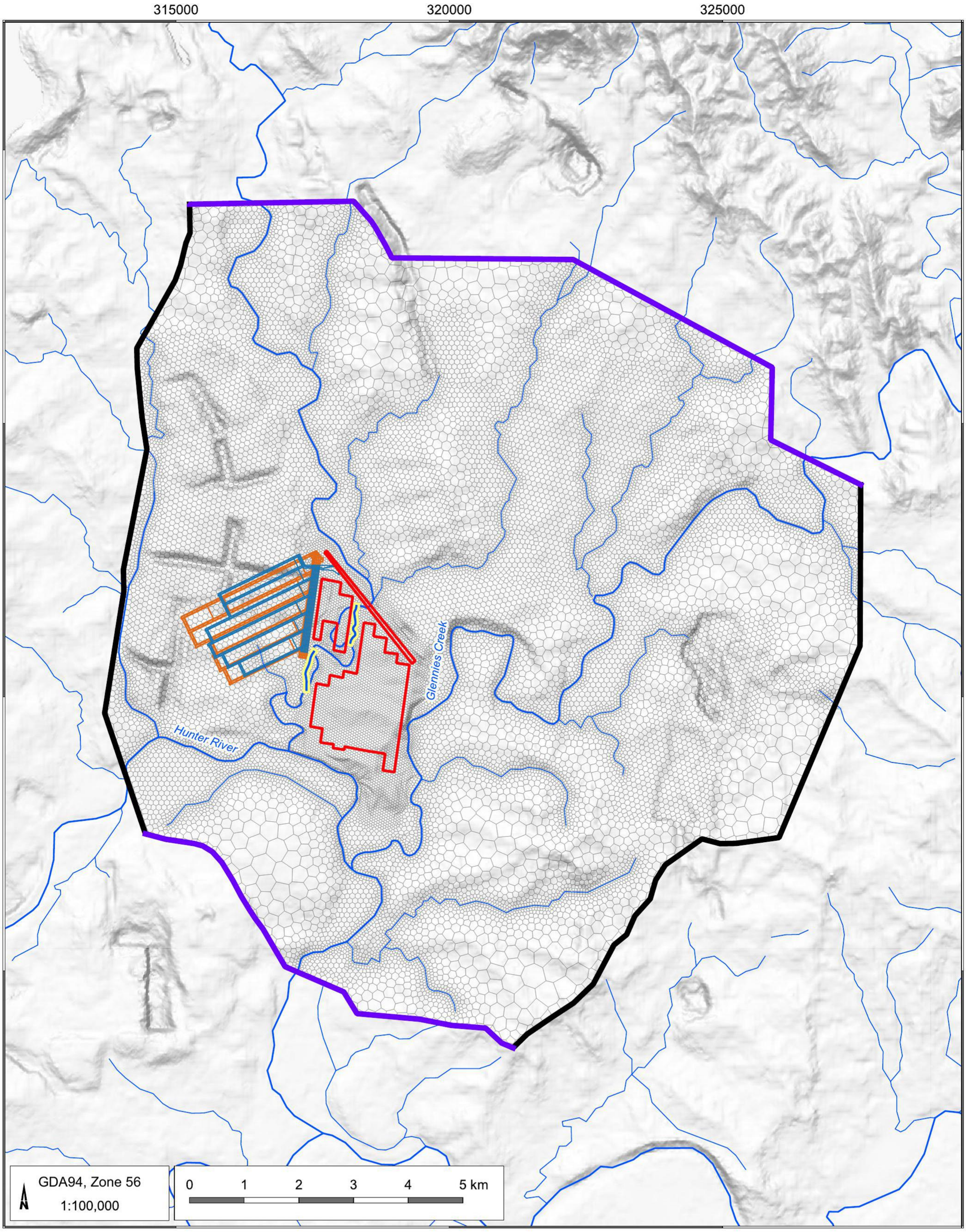
Flows into and out of the model included gross recharge from rainfall, baseflow in creeks, evapotranspiration, and 'drains' to represent mine inflow discharge along these boundaries (see Figure 5.1 in main report).

No flow boundaries lie beyond the outcrop/sub-crop limit of the Barrett Seam in the east of the model domain, which is the lowermost coal seam to be mined at the AUM. A no-flow boundary exists on the western side of the model. It is recognised that this boundary is not a physical boundary as the coal seams and formations within the model boundary continue beyond the boundary, but it has been assigned in the model on the basis that it is perpendicular to the regional groundwater flow and drainage into the Hunter River when mining is well advanced.

The Hunter Valley Operations (HVO) and Ravensworth Operations mining areas are located to the south and west of the western model boundary. The area of Project-related drawdown that extends to the western boundary of the model aligns with the Ravensworth North Open Cut and HVO North pit. The *HVO Continuation Project - Groundwater Impact Assessment* (AGE, 2022b) indicates that HVO North would extract to the base of the Barrett Seam (which is below the Pikes Gully and Upper Lower Liddell Seams, which are the target seams for the Proposed Action).

Accordingly, depressurisation of the Pikes Gully and Upper Lower Liddell Seams or overlying coal measures, resulting from the operation of the Proposed Action, would not extend through the HVO North area because of the depressurisation (and extraction) of the coal seam that will occur due to HVO's operations. Therefore, extending the groundwater model boundary further west would not identify any additional impacts of the Action on sensitive groundwater receptors.

Use of a no-flow boundary instead of a head dependent boundary is considered conservative on the basis that it does not allow for lateral flow of water across the model boundary to 'offset' the predicted drawdowns from the Action. Due to the extensive mining and related depressurisation that has or will occur west of the model boundary, a no-flow boundary is considered a reasonable representation of post-mining conditions (i.e. there is unlikely to be a significant hydraulic gradient towards the model boundary from the western areas once these areas are depressurised by previous and future mining operations).



LEGEND

- Model mesh
- Ashton underground mine (Pikes Gully level)
- General head boundary
- No-flow boundary
- Major drainage
- Minor drainage
- Diversion
- RUM Pikes Gully panels
- RUM Middle Liddell panels

Ashton-Ravensworth Integration Modification GIA (ASH5001.003)

Model boundary conditions

AGE

DATE 12/10/2023

FIGURE No: **A 2**

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A 4.6 Recharge

MODFLOW-USG simulates diffuse rainfall recharge using the recharge package. The dominant mechanism for recharge to the groundwater system is through infiltration and deep drainage of rainfall. River leakage to the groundwater system can also be significant in alluvial areas. Given the fine nature of the upper alluvial sediments and the relatively low permeability of the regolith, the recharge rate to the groundwater regime is relatively low. The site-measured rainfall rate is around 1.86 millimetres per day [mm/day]. Table A 3 presents the rate of calibrated recharge for each geological unit. For modelling the impacts for different post-mining operations, the recharge rates are changed for spoil and void recharge as presented in Table A 4, with spoil recharge representative of upper bound and early spoil development to capture peak inflows.

Table A 3 Recharge rates

Zone	Diffuse recharge rate (percent [%] of average annual rainfall)	Applied recharge rate (mm/day)
Highly productive (basal) alluvium	4.4	0.08
Less productive alluvium	0.90	0.017
Regolith	0.17	0.003

Table A 4 Changes to recharge due to mining

Zone	Diffuse recharge rate (% of average annual rainfall)	Applied recharge rate (mm/day)
Spoil emplacement	10	0.19
Voids	100	1.86

Diffuse rainfall recharge in the Upper Hunter Region ranges from zero to 2 percent (%) of annual rainfall based on previous studies (Mackie, 2009). Assuming an annual rainfall of 688 millimetres[1] (mm), the average annual recharge for the Proposed Action area is up to 13.8 millimetres per year (mm/year). Estimates of mean annual recharge by Herron *et al*. (2018) for the Hunter subregion have returned a similar value of 1.5% of rainfall, or 10.3 mm/year. Herron *et al.* (2018) recharge estimate is primarily based on the chloride mass balance method as described in Wood (1999), but also further considers variability of recharge from surface geology, vegetation, and distribution of rainfall.

Those values are broader regional averages, but give guidance to the quantum of recharge expected in the Proposed Action area. The groundwater model simulates recharge zones representing high productive alluvium, low productive alluvium, and regolith. The calculated area weighted recharge rate of 1,421 megalitres per year (ML/year) recharge volume across the model domain, which equates to 9.2 mm/year, (or 1.3% of rainfall), is in line with Herron *et al*. (2018).

Comparisons have also been made to other studies around the area to determine if the calibrated recharge rates adopted in the Ashton-RUM model are outliers or are regionally consistent. In particular, the alluvium recharge rates from recent and historical models for nearby studies (MER 2009, MER 2012, AGE 2019, AGE 2020, AGE 2022) provide a range of 3.2% to 11.7% of rainfall, to which the Ashton-RUM calibrated value of approximately 4.4% is within this range. Different recharge rates were explored through the uncertainty analysis, and underlies those impact predictions.

[1] Based on Scientific Information for Land Owners data drill between 1990 to 2022.

Enhanced recharge to deeper strata may temporarily become available where subsidence results in connective surface cracking. However, this opportunity is expected to be limited and only temporary due to surface remediation works and as deeper fractured rock areas 'heal' through infill of fines and changes in rock stress as settlement continues over time. Healing of cracking is supported through observation at the Ashton Underground Mine, where surface cracking associated with mining in shallow overburden areas (35 m below surface in areas of LW1) did not result in additional inflow to mine workings during a significant 2007 flood event. The depth of mining at the Proposed Action will be deeper than these initial Ashton Underground Mine mining areas and therefore long-term enhanced recharge through connected cracking is unlikely.

Subsidence may also result in ponding and increased residence time of runoff providing further recharge opportunities. However, based on the pre-mining and predicted post-mining drainage paths (Hunter Eco, 2023), this is not expected to be a significant contributor to recharge across the Proposed Action area and surrounds.

A 4.7 Evapotranspiration

The impacts from the direct evaporation on the ground surface was modelled using the evapotranspiration package in MODFLOW-USG. The cells on the upper most surface across the model domain were assigned to evapotranspiration conditions. The water is removed from these cells based on a depth-varying evaporation rate when the water table is within the extinction depth for evapotranspiration to occur (e.g., root depth from surface elevation). Table A 5 presents the parameters applied in the evapotranspiration package.

Table A 5 Evapotranspiration rates

Evapotranspiration zone	Maximum evapotranspiration rate (mm/day)	Extinction depth (m)
Model Domain	2.18	1.5

A shallow extinction depth was used because most of the evapotranspiration occurring in the model was captured in determining the net recharge rate. Therefore this boundary condition looks to add the additional controls to areas where the water table is approaching the surface, and for applying evaporation losses in final voids post mining.

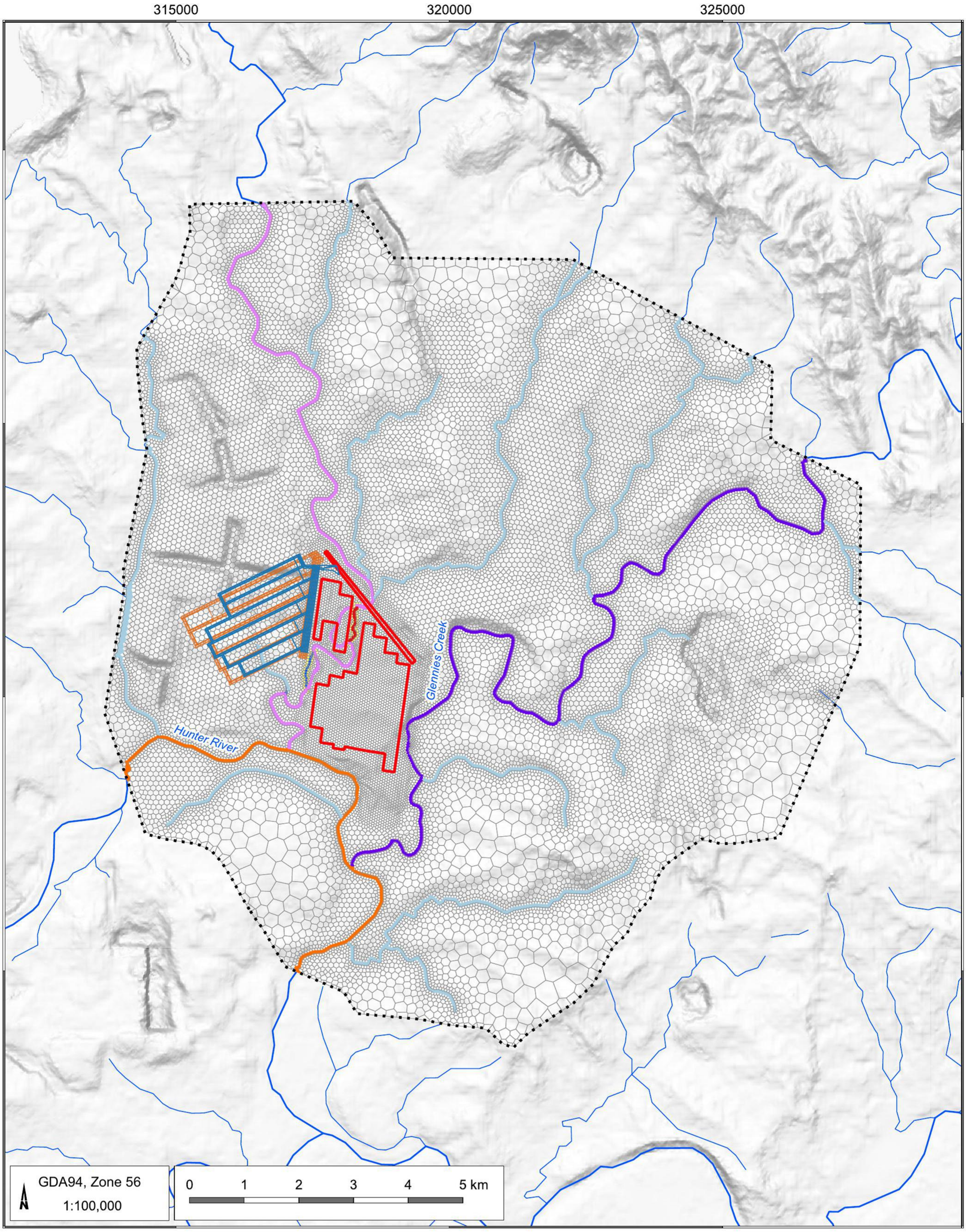
A 4.8 Surface drainage

Groundwater interaction with surface drainage was modelled using the river package. The model river and surface drainage cells are shown on Figure A 3. This package requires the level of the river bed and the depth of perennial water to be above this level. The river bed conductance was calculated from river width, length, riverbed thickness, and the vertical hydraulic conductivity of the riverbed material. The depth of water for all minor ephemeral streams and creeks within the model domain was set to 0 m, resulting in the river acting only as a drainage line for baseflow from the groundwater. Table A 6 summarises the parameters representing the drainage lines and creeks.

The stage height for rivers and creeks where persistent streamflow occurs (i.e. Hunter River, Bowmans Creek and Glennies Creek) was based on interpolated levels from NSW stream gauges (NSW DPI, 2014) and site data. The river stage heights recorded from these gauges were linearly interpolated and applied at a cell-by-cell level to the model river cells, per stress period. The location of the river cells in the groundwater model were assigned to layer 1 along the Hunter River, Bowmans Creek and Glennies Creek to replicate the conceptualised hydraulic connection to the productive alluvial aquifer. Figure A 3 displays the different river zones.

Table A 6 River parameters

Zone	Vertical hydraulic conductivity Kz (metres per day [m/day])	Width (m)	Incised depth (m)	Average stage height (m)	Bed thickness (m)	ID
1	0.005	10	5	1.5	2	Hunter River
2	0.005	5	2	0.5	2	Bowmans Creek
3	0.005	5	2	0.75	2	Glennies Creek
4	0.005	1	1	0	2	Minor Drainages
5	1E-10	1	1	0.5	1	Bowmans Diversion



LEGEND

- Ashton underground mine (Pikes Gully level)
- Model extent
- Model mesh
- Major drainage
- Minor drainage
- RUM Pikes Gully panels
- RUM Middle Liddell panels

River zones

- Hunter River
- Bowmans Creek
- Glennies Creek
- Diversion
- Other drainage

Ashton-Ravensworth Integration Project (ASH5001.003)

River and surface drainage cells

AGE

DATE 21/04/2023

FIGURE No: **A 3**

A 4.9 Faulting

The model does not simulate faulting. Mapping indicates that no significant faulting is noted across the site, nor in the surrounding area for both the AUM and the RUM panels. Faulting that has been observed through mining at the AUM has not been significant (see Section 3.8.3 of the main report) with only minor throws of around 2 to 3 m at most, and not likely to hydraulically disconnect or impede lateral groundwater movement. Most major faulting appears in the south and in the north of the Hunter Valley and outside of the model domain. The major structural features of the area are the rolling and folding causing anticlines and synclines to be present. These features are captured in the model through the layer geometry. Locations of regional and local faults are presented in Figure 3.12 in the main report.

A 4.10 Mine dewatering

The model represented mining using the drain (DRN) package. During the predictive run, drain cells were used to simulate the effect of the Proposed Action and other mines in the area such as AUM, Glendell, Integra, Ravensworth, and Rixs Creek. The following mining operations were included in the cumulative groundwater modelling:

- proposed mining of the Pikes Gully and Middle Liddell Seams at RUM;
- previous mining of the Pikes Gully, Upper Liddell and Upper Lower Liddell Seams at AUM;
- approved future mining of the Lower Barrett Seam at the AUM;
- previous mining of all seams to the Lower Barrett Seam by the Ashton North-East Open Cut;
- previous mining of the Pikes Gully Seam at the RUM;
- previous mining of all seams to the Bayswater Seam at the Ravensworth Open Cut mines;
- previous mining of all seams to the Hebden Seam at the Integra Open Cut Mine;
- previous and current mining of the Middle Liddell Seam at the Integra Underground Mine; and
- previous and current mining of all seams to the Lower Barrett Seam at the Glendell Open Cut Mine.

A nominally high drain conductance of 100 square metres per day was applied to the drain cells and the elevation of the base of the modelled layer was used as the drain level. For the open-cut mines, the drain cells were set in all layers from the lowermost mined seam to the surface. Groundwater levels in the model are compared to the reference elevation in each cell, and when the groundwater level was above the reference level, water was removed from the model domain at a rate determined by the head difference and the conductance term.

A 4.11 Modelling hydraulic changes due to longwall mining

The model represented the open cut and underground dewatering of mine areas using the DRN package with the progression of mining over time based on the schedules provided by Ashton Coal Operations Pty Limited and infilled with data available in the public domain. The model simulated the changes to hydrostratigraphic units in response to mining (e.g., longwall goafing and spoil emplacement) using MODFLOWs time varying materials (TVM) package.

Within the open-cut mine areas, drain cells were applied to all intersected model cells, at reference elevations set to the floor of each cell down to the target coal seam. The drains were set up to remain active within the open cut mining areas for 1 year after mining before being turned off and converted to represent the in-pit spoil piles. This way, the model represented the growth of spoil piles for the open-cut by progressively changing the hydraulic properties of mined cells (Kh, Kv, Sy and Ss) behind the active open cut mining area once the drains became inactive.

The hydraulic properties used to represent the material property changes post-mining are provided in Table A 7.

Table A 7 Mining parameters applied to TVM package

Type	Horizontal K (m/day)	Vertical K (m/day)	Specific yield (%)	Specific storage (m-1)
Goaf	5	5	10	1.0E-6
Spoil	0.3	0.1	0.1	1.0E-5
Void	1000	1000	100	5.0E-6

Recharge rates to the spoil were not enhanced as deep drainage of rainfall through the spoil is captured within the mining areas and does not represent water from the groundwater systems. This was a conservative approach implemented to represent the gradual rewetting of the unsaturated spoil over time.

Fracturing above the longwall panels was simulated using an equivalent fracture network methodology. Once the longwall miner has removed the coal seam and advanced, the roof strata subside into the mined cavity (goaf) creating a zone of rubble within the goaf that is overlain by a zone where fracturing is enhanced above the spent coal seam. The occurrence of fracturing gradually decreases with height above the seam to a 'fracture height', or the maximum height of continuous connective hydraulic fracturing. The fracture height (A) was calculated using the Ditton-Merrick formula using the 'Geology model' (Ditton, 2014), viz:

$$A = 1.52W^{0.4}H^{0.535}T^{0.464}t'^{-0.4} \pm [0.1 - 0.15]W' \qquad \text{(eq. 1)}$$

Where:

- H = overburden thickness (m)
- W = panel width (m)
- W' = minimum (W,1.4×H) (m)
- T = extraction thickness (m)
- t' = effective thickness of the stratum where the A-Zone height occurs

T was taken as the 2.7 m extraction thickness from the Pikes Gully seam and t' was calibrated within the range of 15-25 m. The 2020 model calibrated a value of 27.33 m for t', which is further adjusted to 20 m in the recent 2022 adjustments during calibration, to better reflect the historical conditions measured from the deeper RUM. The W' is computed as the lower value between panel width W and $1.4 \times H$. The panel width, fracture height and potential impacted layers in the fractured zones are presented in Table A 8.

Table A 8 Fracture height and impacted layers in goaf area

Target Seams	Layer	Panel width (m)	Fracture height (m)	Maximum impacted layers in fractured zone
Pikes Gully (RUM)	8	175 – 230	93 - 126	3,4,5,6,7
Middle Liddell (RUM)	14	250	125 – 146	5,6,7,8,9,10,11,12,13

The hydraulic properties of the strata within the fracture height will be modified. The model applies a 'non-uniform ramp function' for the vertical hydraulic conductivity which relates to the in-situ properties. The horizontal hydraulic conductivity changes due to fracturing are related to the changed vertical hydraulic conductivity. The equations below show the calculations involved, and these were derived in-house conforming to Guo's (Guo et. al., 2007) conceptualisation and parameterisation and SCT's free draining fracture network for another site in the Hunter Valley (SCT, 2008), and documented in AGE (2017).

$$Kz_{frac} = \text{ct}\,\frac{(0.991^{h})\sqrt{\left(\frac{Kz}{h}\right)}}{\left(log(h+10)\right)}$$

$$Kx_{frac} \;=\frac{Kz_{frac} * 20}{\left(log(h+10)\right)}$$

Where:

- Ct = adjustable constant (4.2)
- h = height above longwall panel (m)
- Kz = in-situ vertical hydraulic conductivity
- Kz_{frac} = estimated fractured vertical hydraulic conductivity
- Kx = in-situ horizontal hydraulic conductivity
- Kx_{frac} = estimated fractured horizontal hydraulic conductivity

The fractured hydraulic conductivity values are calculated individually for each model cell based on their in-situ values and on their height above the mined longwall panel. The changes to fracturing are only applied when the changes are greater than the in-situ values. When the fracturing height extends up into a previous mining area, the previous fracture adjustments are only changed if the new changes are larger than the already applied changes.

Storage properties in the fracture zone are not changed, just the storage in the mined goaf, with the values indicated in Table A 7.

A 5 Model calibration

The model was calibrated in the 2020 model update and while that calibration is still relevant for the AUM, it was not informed by the historical inflows at RUM. Therefore, tweaks were made to model parameters to allow an improved match to the inflows at RUM while still maintaining the calibration at the AUM. The optimal parameters are achieved through the automated parametrisation software (PEST, Watermark 2021). The steady state to transient stress periods considered in model calibration is from December 1969 to December 2022.

For the Proposed Action, the fracture model was adjusted from the 2020 model to improve representation of fracturing in the increased overburden thickness at RUM. The *t'* (beam thickness) of the Ditton-Merrick formula was manually tweaked and compared for inflows utilising the prior calibration from the 2020 model for other model inputs with a focus on the deeper RUM historical inflows as well as inflows at the AUM. Once the beam thickness was adjusted to provide realistic fracture heights and inflows, the aquifer parameters of hydraulic conductivity and storage properties were allowed to vary with the fracture height and fracture zone property changes (derived from a log-linear ramp function) remaining constant.

Two datasets were input as calibration targets; the groundwater levels from ongoing AUM monitoring were supplemented by a monthly water balance model based on AUM metered pumping data to June 2021 and by initial historical inflows to RUM. The inclusion of the water balance model in the calibration reduced parameter non-uniqueness and ensured that recent inflows to AUM were reflected in the model parameters. The previous model calibration achieved a root mean square (RMS) of 14.1 m and a Scaled Root Mean Square (SRMS) of 7.7 % which conforms with performance targets advocated in modelling guidelines.

The initial Independent Expert Scientific Committee advice requested additional monitoring data be included. All available water level data from the Ravensworth site and from data in the public domain for other neighbouring projects has been compiled and added to the calibration dataset. Of relevance are the monitoring data from the Glendell project that monitor the Bowmans Creek directly north of RUM (AGE, 2019) and monitoring data reported for Ravensworth open cut mine in an assessment for Hunter Valley Operations mine (AGE, 2022b). Monitoring locations are shown in Figure 4.3 in the main report.

A 5.1 Calibration results

The level of calibration was reassessed with the additional monitoring data as mentioned in Section 4.3. The RMS slightly increased to 14.23 m and the SRMS increased to 7.85 %.

It was noted that this calibration relies on data pre-2021, so available additional monitoring data from 2021 to mid-2023 was used to verify the calibration. Alone the verification data has an RMS of 21.7 m and a SRMS of 10.79 % which is due to the decreased range over recent measurements. Combining the calibration and verification datasets results in a slight increase in RMS of 15.37 m, but a decrease in SRMS to 6.77 %. The decrease is due to the larger range of observations from the additional recent measurements.

Figure A 4 presents the scatter diagram showing the match of observed and predicted water levels across the model domain for the calibration and verification periods. Of note is the verification dataset includes the 'tails' of the data from bores that have moved away from the line of perfect fit due to mining impacts. This is expected as this data hasn't been used to train the calibration at present, but will next time the model is calibrated.

The recent updated monitoring data (verification) includes water level observations at L213_275 that exhibits a significant drop in the verification period water levels after calibrating reasonably well. This water level drop and monitoring point will need further investigation for future calibration efforts.

The calibration (and verification for data post 2020) can also be assessed by examining the hydrographs in Appendix C that present model predicted and observed water levels at monitoring points within the model. While not all water levels are matched perfectly, the trends in monitored groundwater levels are generally followed, particularly where the observation data is displaying obvious stresses from mine dewatering.

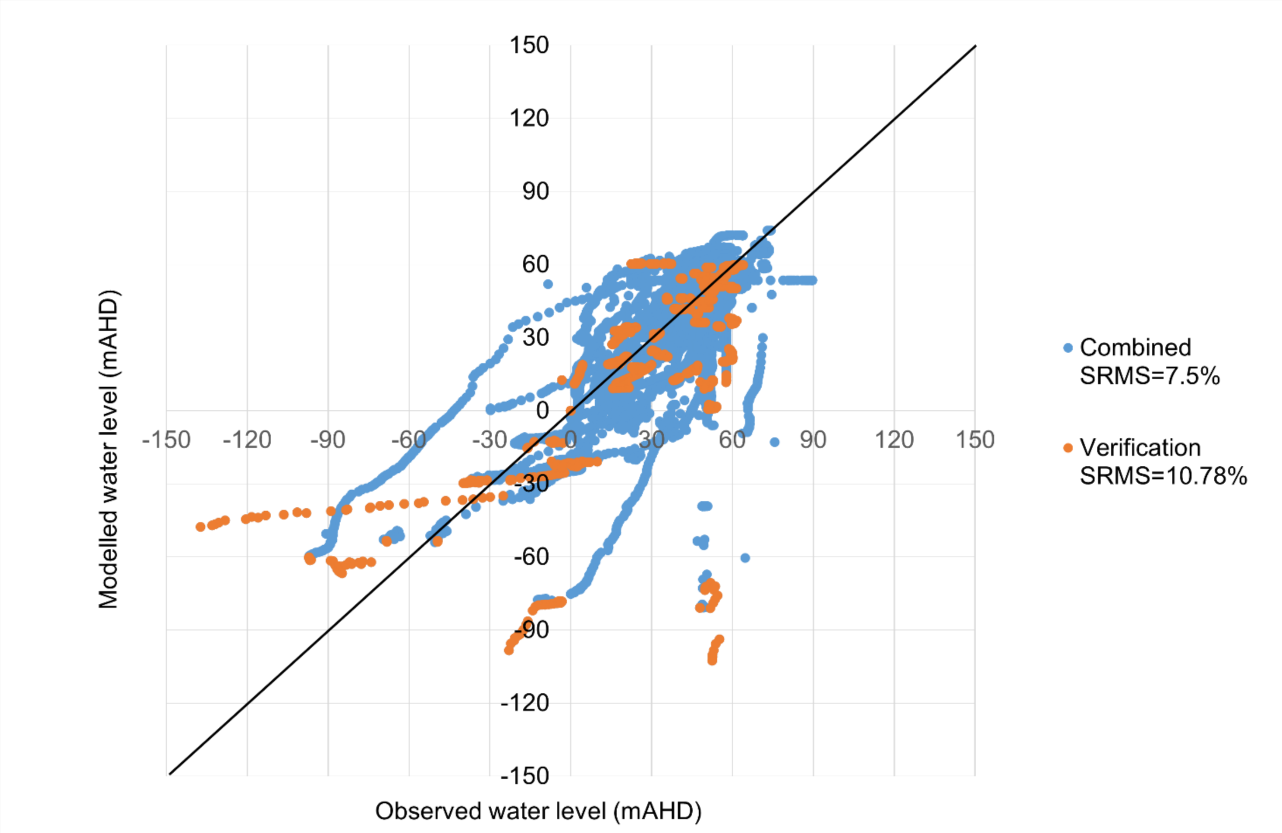


Figure A 4 Scatter diagram

Moreover, the comparison of predicted inflows also provides confidence to model predictions. The predicted inflows to the Pikes Gully historical workings (RUM) were predicted to be 0.614 megalitres per day (ML/day), which are consistent with the 0.6 ML/day inflow reported by MER (2012).

The simulated AUM inflows were generally well matched to the inflows calculated in the model water balance (Figure A 5). The SRMS for the simulated inflows was 13%, which is considered acceptable given the reliability of the data and the utility of it reducing parameter non-uniqueness.

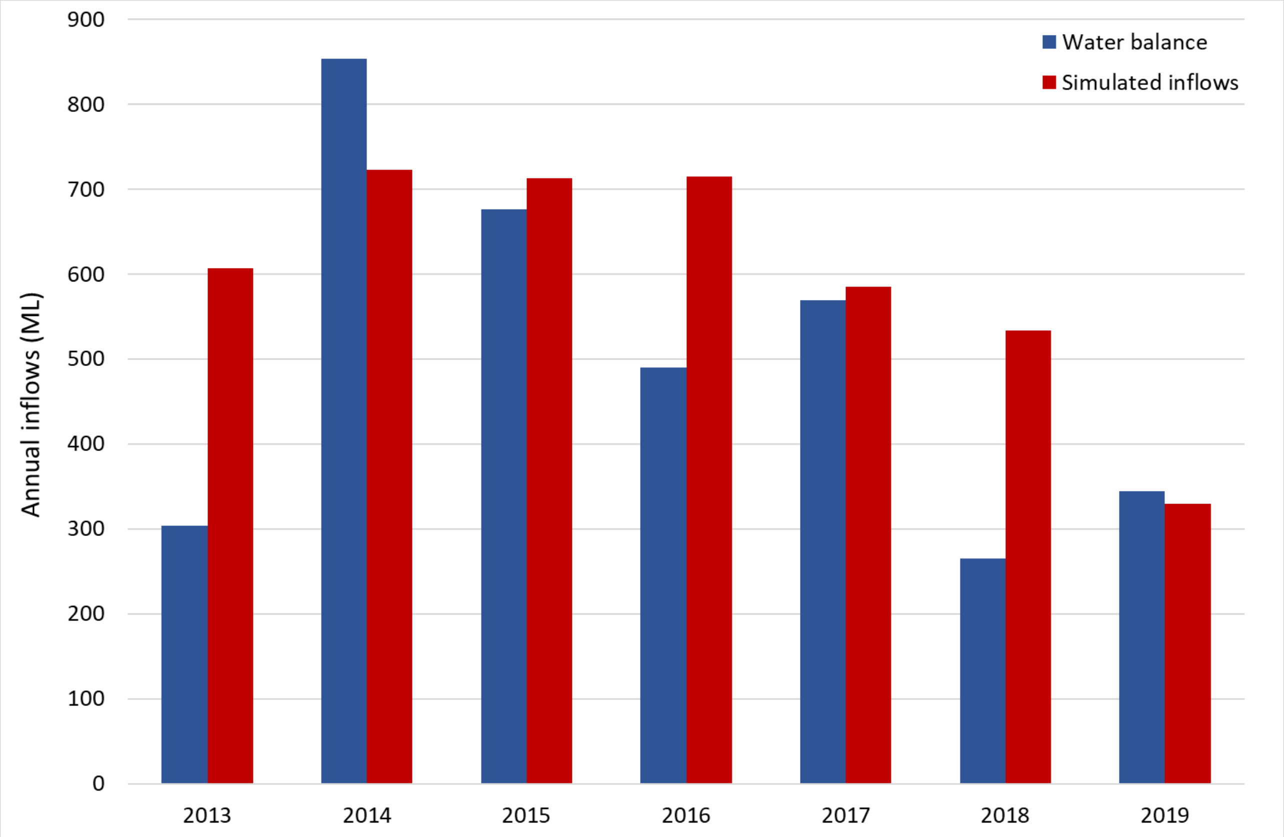


Figure A 5   Model calibration - water balance model vs. simulated inflows

A 5.2 Sensitivity of calibrated parameters

The relative sensitivities of the calibrated parameters to the observation dataset are available and shown in Appendix G; these were derived from a Jacobian matrix, and form a local sensitivity analysis.

The most sensitive parameters are the recharge parameters, with the alluvium (high K) zone being the largest, which correlates to its relative value and to the number of monitoring bores in the high productive areas of the alluvium. The specific storage values of the alluvium zones are insensitive to the observations, which is expected as this upper layer does not experience confined conditions.

The relative sensitivity shown in Appendix G is shown on a logarithmic axis and therefore the sensitivity of the recharge (i.e. top three parameters) to observations is significantly higher than other parameters.

Below the recharge parameters, there is generally an exponential (log-linear) decline in sensitivity across the hydraulic conductivity and storage properties, and a trend of sensitivity declining with depth. This is in part due to a reduction in monitoring data with depth, and with mining not progressing to the deepest seams to date.

The main conclusion drawn from the sensitivity analysis is that the calibrated recharge rates have been informed by monitoring data. Further to this, the general trend is that the calibrated hydraulic conductivities and storage values of the shallower units are also informed by observations, but in general parameter values are less identifiable with depth. Therefore, parameters listed in the lower sections of Appendix G are more likely to be sources of uncertainty for model predictions.

The automated components of the calibration process involved a form of regularising through the application of singular value decomposition (SVD) and 'super parameters'', formed by projection of the real-world parameters back to orthogonal axes that span the calibration solution space. During the calibration process parameter updates are made to the super parameters which are then un-projected back to the real-world parameters. Through this process, it is unlikely any of the insensitive parameters had significant influence on the calibration process. The relative sensitivities in Appendix G were derived from the individual parameters, and not from the super parameters used in SVD.

A 5.3 Calibrated hydraulic properties

The calibrated hydraulic properties remained similar to the 2020 model with only minor corrections required after the initial manual calibration to the beam thickness of the Ditton-Merrick fracture height calculation to 20 m.

A 5.3.1 Hydraulic conductivity functions

The hydraulic conductivity of the interburden and coal seams decreases with depth. A power function was used to describe the change in hydraulic conductivity with increasing depth below the surface:

$$HC = HC_0 \times depth^{slope} \qquad \text{(eq. 2)}$$

where:

- HC is horizontal hydraulic conductivity at a specific depth
- HC_0 is horizontal hydraulic conductivity at depth of 0 m (intercept of the curve)
- *depth* is depth of the floor of the layer (thickness of the cover material)
- *slope* is a term representing slope of the formula (steepness of the curve)

Following AGE (2020), the power functions were used to define the upper and lower bounds of possible horizontal hydraulic conductivity for the calibration. The calibrated hydraulic conductivity of the interburden blocks, along with the model bounds can be seen in Figure A 6.

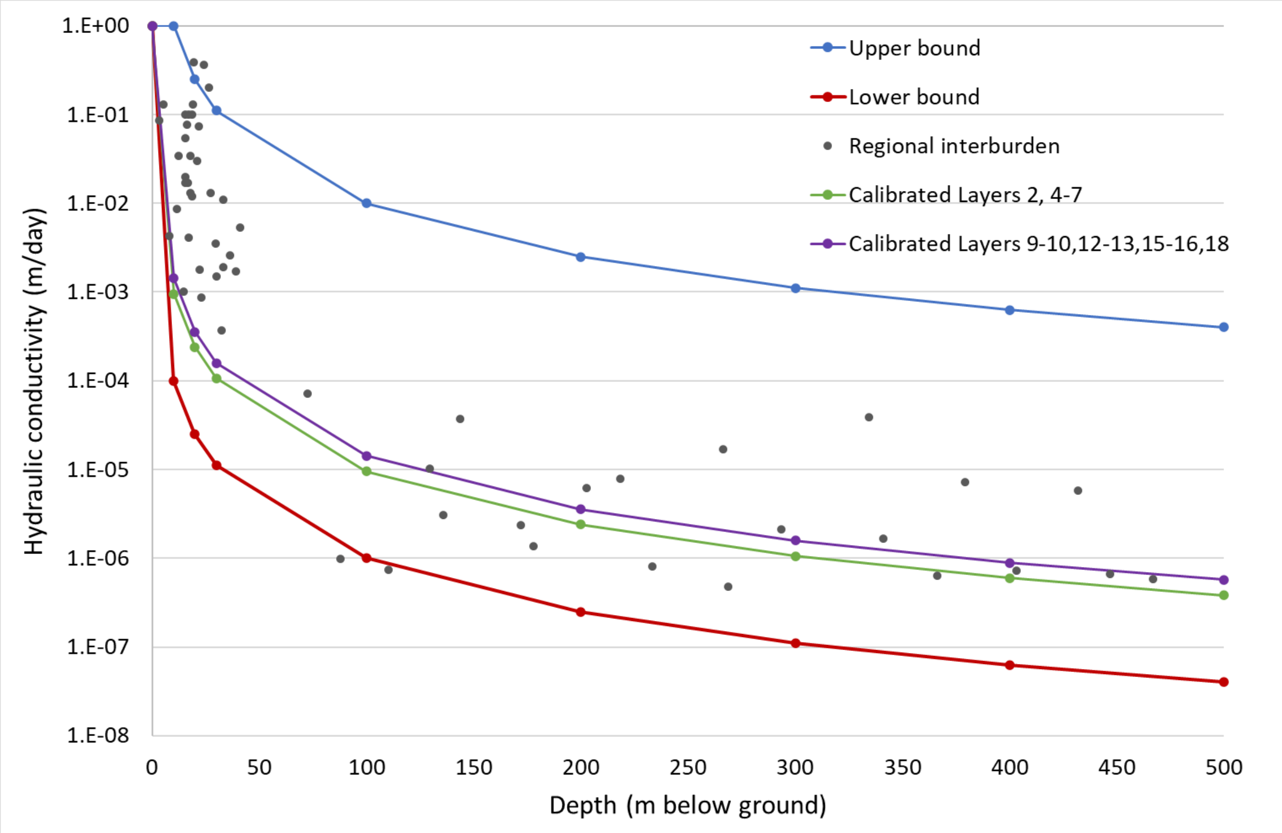


Figure A 6 Calibrated K and parameter bounds for interburden layers

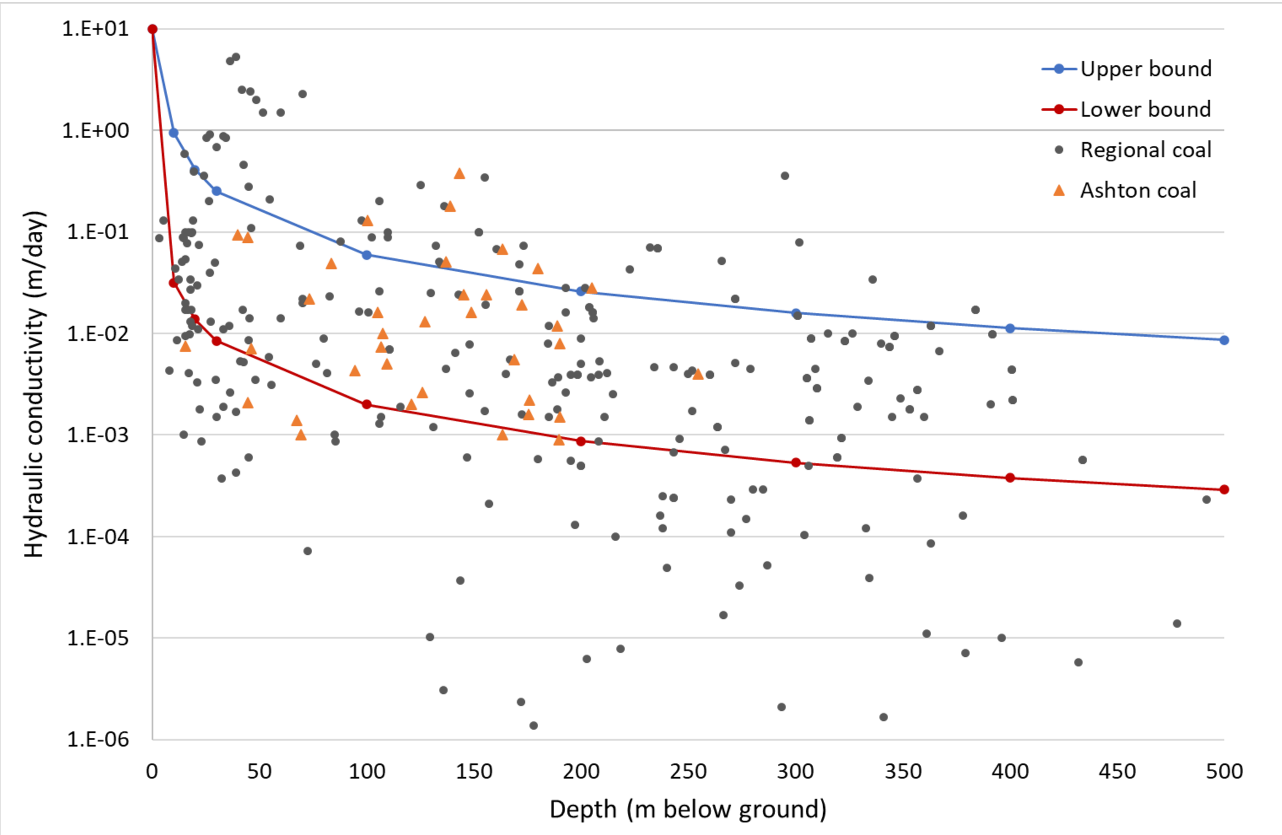


Figure A 7 Regional and AUM/RUM coal conductivity with model parameter bounds

The coal seam parameter bounds were derived to encompass most of the data collected at the AUM (Figure A 7). The hydraulic conductivity of the coal at the AUM displayed reduced data spread compared to the regional Hunter Valley conductivity values.

At the AUM, the coal seams indicated higher hydraulic conductivity than the interburden layers, which is consistent with the geological setting and expected material properties. The calibrated conductivity functions for each coal seam can be seen in Figure A 8. The function for the Lower Barrett Seam calibrated to the upper bound, thought to be due to the absence of observation data to inform the parameter distribution. A future recalibration of the model closer to mining of the Lower Barrett Seam will likely yield greater insight. The horizontal and vertical hydraulic conductivity ranges per model layer are documented in Table A 9.

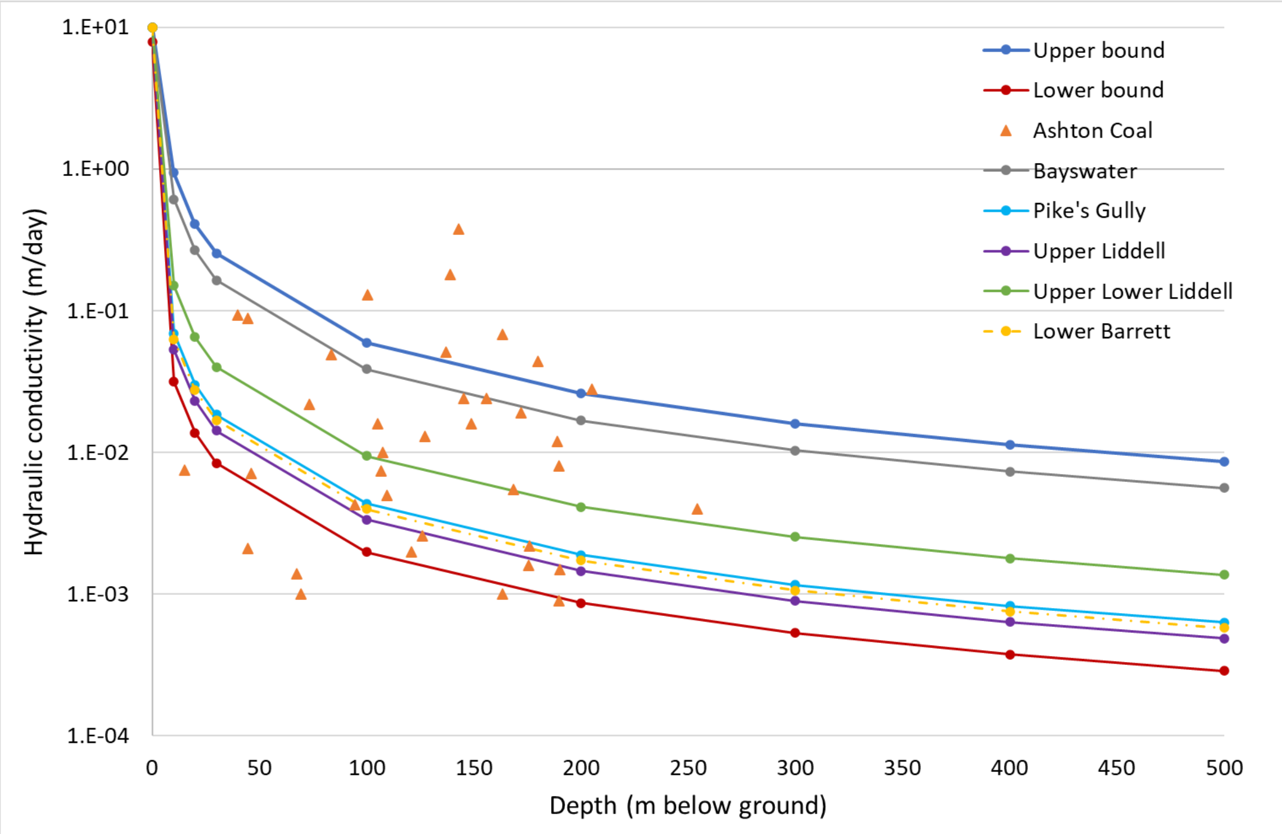


Figure A 8 Calibrated coal hydraulic conductivity functions

Table A 9 Calibrated hydraulic conductivity of model zones

Layer	Description	Horizontal K (m/day)	Vertical K (m/day)
1	Alluvium (regional)	0.3	0.01
1	Alluvium Hunter (high K)	20	0.39
1	Alluvium Hunter (low K)	5	0.5
1	Alluvium Glennies Ck (high K)	20	2.17
1	Alluvium Glennies Ck (low K)	0.1	$1*10^{-2}$
1	Alluvium Bowmans Ck (high K)	5.14	1.8
1	Alluvium Bowmans Ck (low K)	1.18	$1.95*10^{-1}$
1	Alluvium Bowmans Ck Diversion	2.82	$2.05*10^{-1}$
1	Regolith	1	$5*10^{-3}$

Layer	Description	Horizontal K (m/day)	Vertical K (m/day)
2,4,5,6,7	Interburden	$3.66*10^{-7}$ - $4*10^{-2}$	5.53^{*10} - $6.04*10^{-5}$
3	Bayswater seam	$7.73*10^{-3}$ - 5.12	$3.68*10^{-6}$ - $2.44*10^{-1}$
9,10,12,13,15,16,18	Interburden	$3.35*10^{-7}$ - $3.89*10^{-2}$	$3.35*10^{-8}$ - $3.89*10^{-3}$
8	Pikes Gully seam	$5.85*10^{-4}$ - $3.74*10^{-1}$	$5.31*10^{-7}$ - $2.89*10^{-4}$
11	Upper Liddell seam	$4.17*10^{-4}$ * $3.58*10^{-1}$	$2.82*10^{-5}$ - $2.42*10^{-2}$
14	Upper Lower Liddell seam	$1.12*10^{-3}$ - $9.68*10^{-1}$	$7.71*10^{-5}$ - $6.67*10^{-2}$
17	Lower Barrett seam	$4.36*10^{-4}$ -$4.11*10^{-1}$	$3.49*10^{-6}$ – $3.29*10^{-3}$

A 5.3.2 Specific storage and specific yield

The specific storage values were calibrated to the bounds specified in Rau et al. (2016), who contend that over a range of geologic materials from sands to clays, the physical upper limit of Ss was approximately equal to 1.3 x 10^{-5} m^{-1}. The calibrated specific storage and specific yield values are documented in Table A 10.

Table A 10 Calibrated specific storage and specific yield of model zones

Layer	Description	Specific storage (m-1)	Specific yield (%)
1	Alluvium (regional)	$5*10^{-6}$	19.8
1	Alluvium Hunter (high K)	$5*10^{-6}$	35
1	Alluvium Hunter (low K)	$5*10^{-6}$	9.4
1	Alluvium Glennies Ck (high K)	$5*10^{-6}$	10.9
1	Alluvium Glennies Ck (low K)	$5*10^{-6}$	15.7
1	Alluvium Bowmans Ck (high K)	$5*10^{-6}$	35
1	Alluvium Bowmans Ck (low K)	$5*10^{-6}$	9.8
1	Alluvium Bowmans Ck Diversion	$5*10^{-6}$	7.3
1	Regolith	$5*10^{-6}$	0.5
2,4,5,6,7	Interburden	$2.3*10^{-7}$	0.7
3	Bayswater seam	$1*10^{-6}$	1
9,10,12,13,15,16,18	Interburden	$2.3*10^{-7}$	2
8	Pikes Gully seam	$1*10^{-6}$	1
11	Upper Liddell seam	$1*10^{-6}$	1
14	Upper Lower Liddell seam	$1*10^{-6}$	1
17	Lower Barrett seam	$1*10^{-6}$	1

A 5.4 Water budgets

The model-wide averaged water budget is provided in Table A 11 and Table A 12 for the calibration period.

Table A 10shows the water budget for the steady state (pre-mining) model. The mass balance error, which is the difference between calculated model inflows and outflows at the completion of the steady state calibration, was 0.00 %. This value indicates that the model is stable and has achieved an accurate numerical solution. For the overall river baseflow, the represented surface drainages (Hunter River, Bowmans Creek and Glennies Creek) accumulate 1.68 ML/day at the pre-mining preiod.

Table A 12 shows the averaged water budget for the transient calibration period.The averaged percent discrepancy in the transient simulation was 0.01% which results in an accurate numerical solution.

Table A 11 Model budgets – steady state calibration period

Budget Component	In (ML/day)	Out (ML/day)	In – Out (ML/day)
River leakage/baseflow	0.86	2.54	-1.68
Evaporation	-	1.86	-1.86
General head boundary	0.003	0.345	-0.342
Recharge	3.89	-	3.89
Total	**4.753**	**4.745**	**0.008**

Table A 12 Model budgets – transient calibration period

Budget Component	In (ML/day)	Out (ML/day)	In – Out (ML/day)
River leakage/baseflow	0.86	2.4	-1.54
Evaporation	-	1.69	-1.69
General head boundary	14	0.33	13.67
Recharge	3.89	-	3.89
Drains	-	13.24	-13.24
Component total	**18.75**	**17.66**	**1.09**
Storage	**1.76**	**2.84**	**-1.08**
Total	**20.51**	**20.5**	**0.01**

The steady state water balance represents the system stresses prior to any mining activity. The transient water balance represents the gradually increasing stresses on the system from mining which results in a reduction of baseflow to the surface drainages, the addition of the drains boundary condition representing opencut and underground mine dewatering for all mines in the model domain, and an increase in inflow from the general head boundary which represents mining on the northern (Liddell and Mt Owen) and eastern (Rixs Creek South) model extents. Evaporation losses also decrease during the calibration period as dewatering lowers water table and reducing opportunity for evaporation.

A 6 Model predictions

Key model predictions are summarised in Sections 7, 8 and 9 of the main report. These predictions focus on the Proposed Action specifically, in which the mining operations between August 2022 to November 2029. The proposed Ravensworth longwall panels and the AUM are surrounded by active coal mines at various stages of development. Section 3.4 in the main report outlines the land use in the area, and the neighbouring mines are listed in Table 3.2.

A 6.1 Transient water balance through to the end of mining

Table A 13 shows the averaged water budget for the transient state model at the completion of mining operations. The results indicate that the groundwater system departs from steady state conditions due to the mining operations represented in the model domain. From the results, the dewatering activities account for an average of 16.82 ML/day, and the baseflow accounts for an average of 2.3 ML/day. The averaged percent discrepancy in the transient simulation was 0.00 % which results in an accurate numerical solution.

Table A 13 Model budgets (averaged) – transient

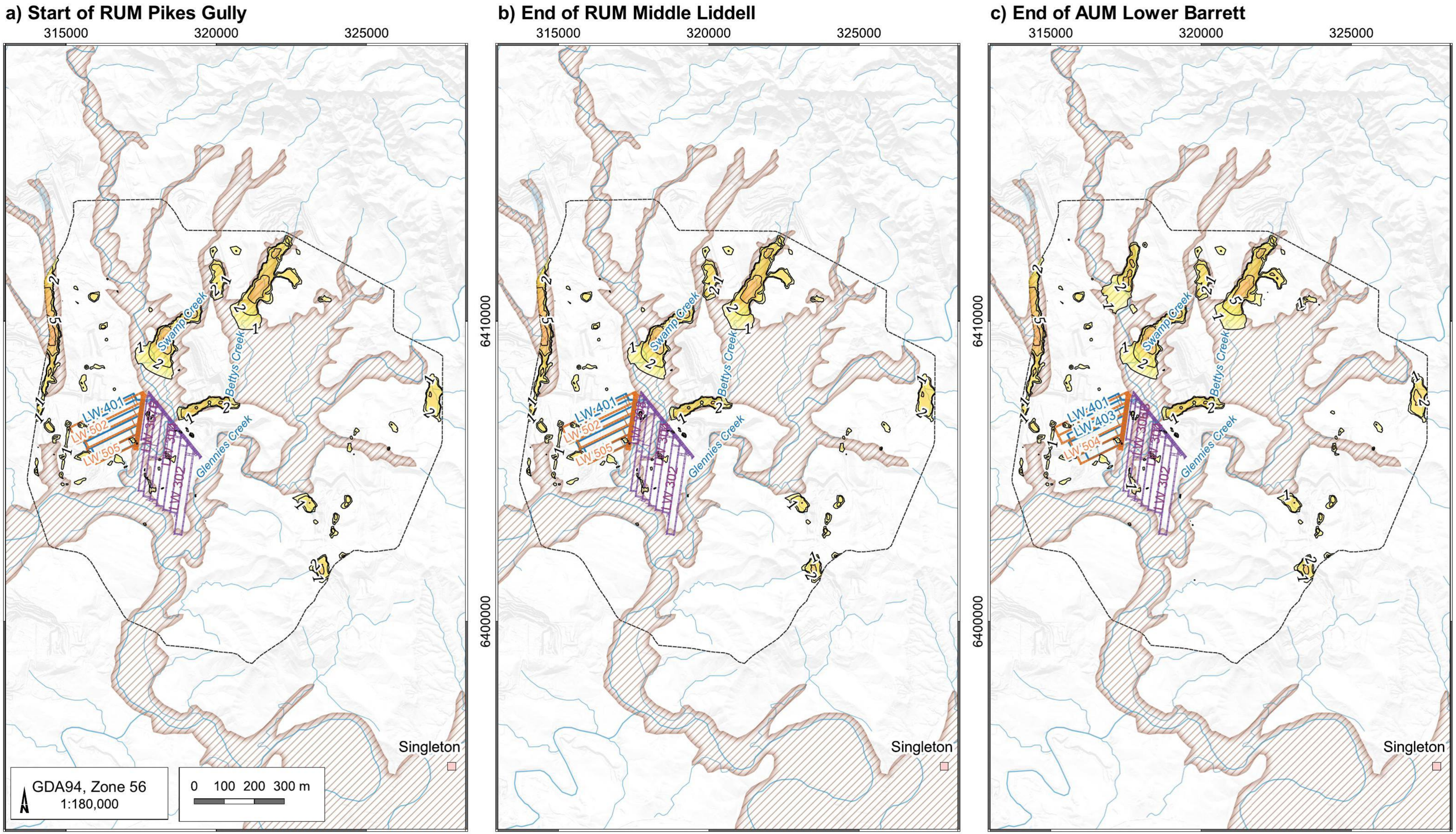
Budget Component	In (ML/day)	Out (ML/day)	In – Out (ML/day)
River leakage/baseflow	0.87	2.31	-1.44
Evaporation	-	1.61	-1.61
General head boundary	18.71	0.35	18.36
Recharge	3.89	-	3.89
Drains	-	16.82	-16.82
Component total	**23.47**	**21.09**	**2.39**
Storage	**2.99**	**5.38**	**-2.39**
Total	**26.46**	**26.46**	**0.00**

Future predictions indicate that the baseflow is further reduced into the future, and this is a function of the continued dewatering from mining and the propagation of impacts from all mines in the model domain. There are also further reductions in evaporation due to continuing mine dewatering across the model domain. Total mine inflow across the model domain increases from around 13.2 ML/day during the calibration period to 16.8 ML/day representing the larger footprints of mines with time.

A 6.2 Cumulative drawdown and depressurisation during mining

Drawdown directly attributable to the Proposed Action, as well and cumulative drawdown from all mines has been assessed. The drawdown attributable to only the Proposed Action is summarised in Section 7.1.4 in the main report, and was derived from undertaking two model simulations (one with and one without the Proposed Action) The cumulative groundwater drawdown from all the historical and future mining operations is presented in this section. The cumulative drawdown is generated by simulating two model runs: a ‘base case’ model and a ‘no mining’ or null model. The ‘base case’ model simulates all the relevant mining operations in the model domain, while the ‘no mining’ assumes no mining development has taken place.

The simplified representation of neighbouring mines and assumptions around leaving dewatering active in the Ashton-Ravensworth area means that these are representative of the maximum potential drawdown at those times. For the alluvium (Figure A 9), the maximum cumulative drawdown of around 3 m occurs at Swamp Creek and the north side of Bettys Creek. For the targeted seams (Figure A 10 to Figure A 13), the cumulative groundwater drawdown is predicted to occur across the whole model domain which reach more than 200 m in each seam. The extensive drawdown predicted by the model, and in particular drawdown right up to the model boundaries, is expected as the model domain is centrally located within the broader coal mining areas of the Hunter Valley. Dewatering from historical mining has depressurised the key coal seams in the area over a number of decades.



LEGEND

- Drainage
- AUM Lower Barrett panels
- RUM Pikes Gully panels
- RUM Middle Liddell panels
- Quaternary alluvium/colluvium
- Model boundary

Drawdown (m)

- 1
- 2
- 5
- 10
- 50
- 100

AGE

Ashton Ravensworth Integration Project (ASH5001.003)

Simulated cumulative drawdown in alluvium and regolith (Layer 1)

DATE
12/10/2023

FIGURE No:
A 9

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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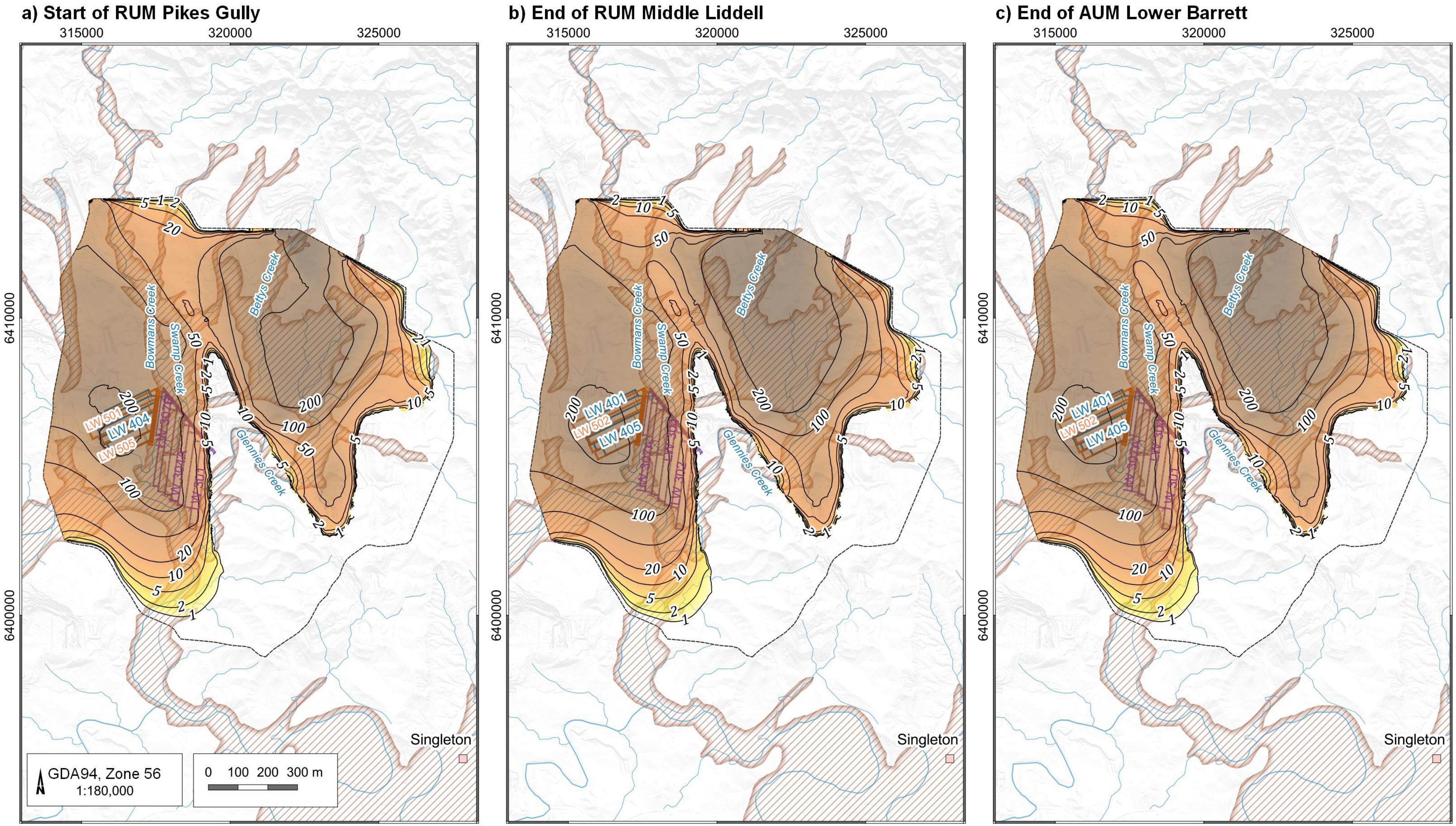

LEGEND

- Drainage
- AUM Lower Barrett panels
- RUM Pikes Gully panels
- RUM Middle Liddell panels
- Quaternary alluvium/colluvium
- Model boundary

Drawdown (m)

- 1
- 2
- 10
- 50
- 100
- 200

AGE

Ashton Ravensworth Integration Project (ASH5001.003)

Simulated cumulative drawdown in Pikes Gully Seam (Layer 8)

DATE
12/10/2023

FIGURE No:
A 10

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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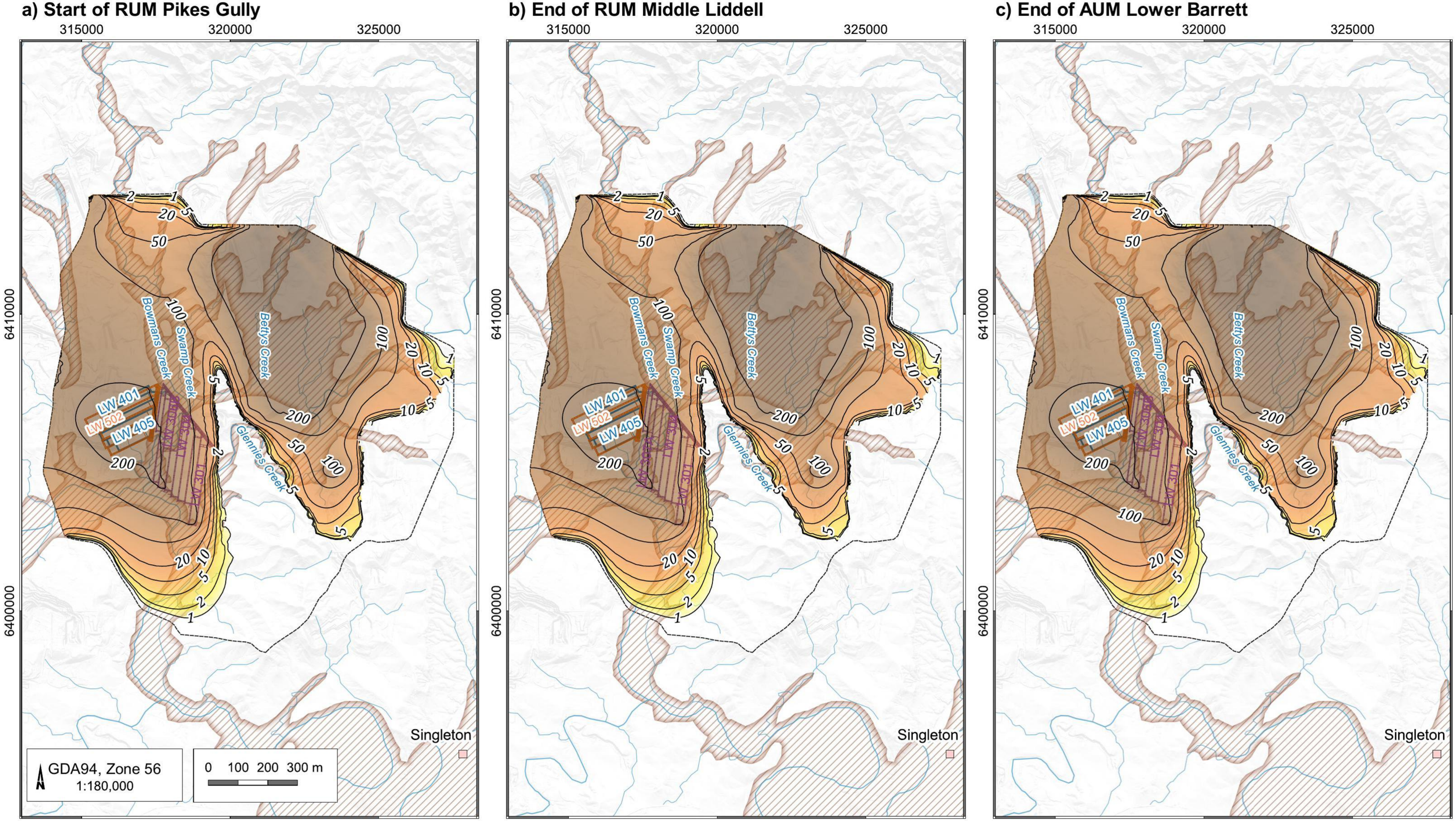

LEGEND

- Drainage
- AUM Lower Barrett panels
- RUM Pikes Gully panels
- RUM Middle Liddell panels
- Quaternary alluvium/colluvium
- Model boundary

Drawdown (m)

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

AGE

Ashton Ravensworth Integration Project (ASH5001.003)

Simulated cumulative drawdown in Upper Liddell Seam (Layer 11)

DATE
12/10/2023

FIGURE No:
A 11

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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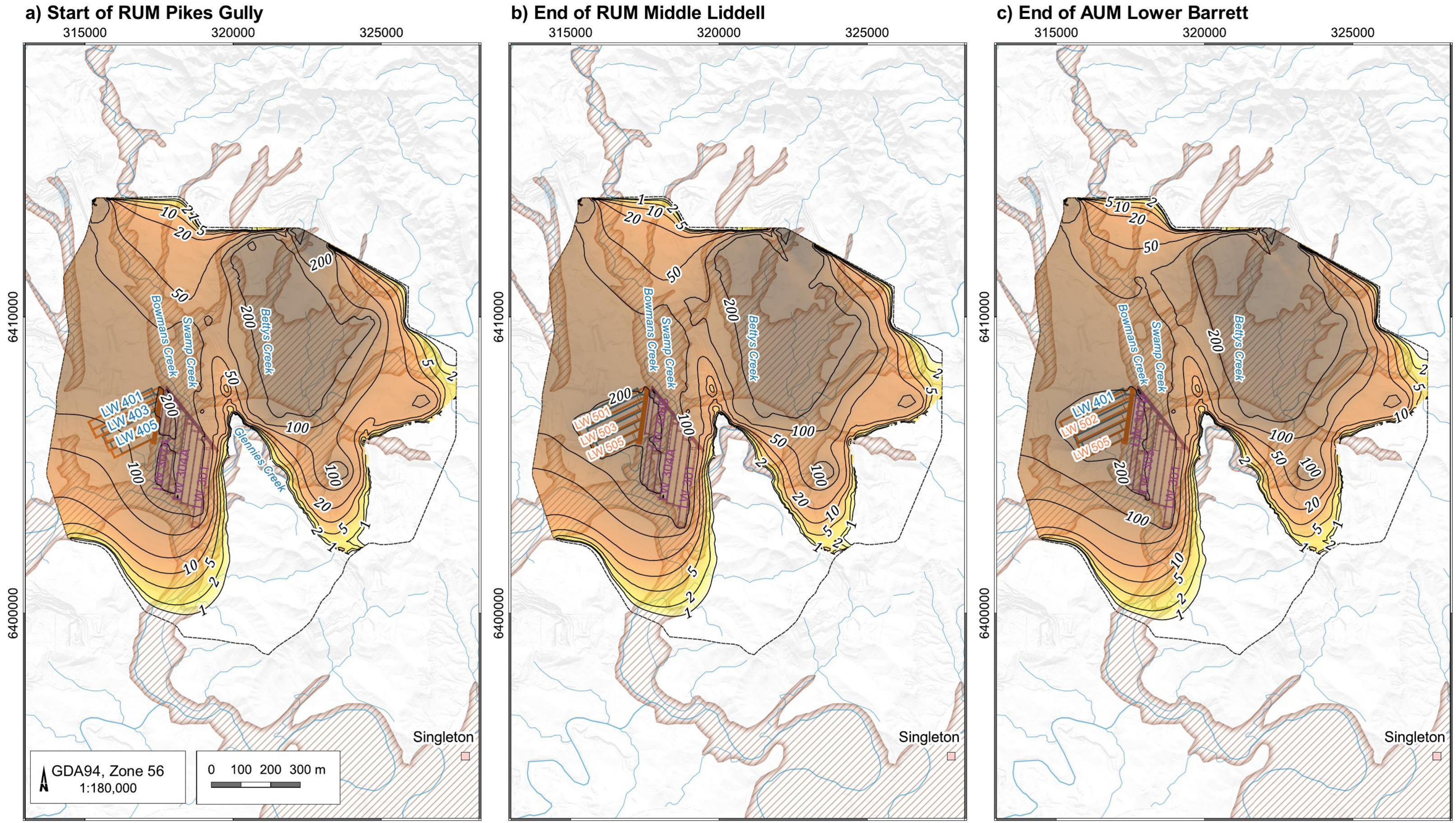


LEGEND

- Drainage
- AUM Lower Barrett panels
- RUM Pikes Gully panels
- RUM Middle Liddell panels
- Quaternary alluvium/colluvium
- Model boundary

Drawdown (m)

- 1
- 2
- 10
- 50
- 100
- 200

AGE

Ashton Ravensworth Integration Project (ASH5001.003)

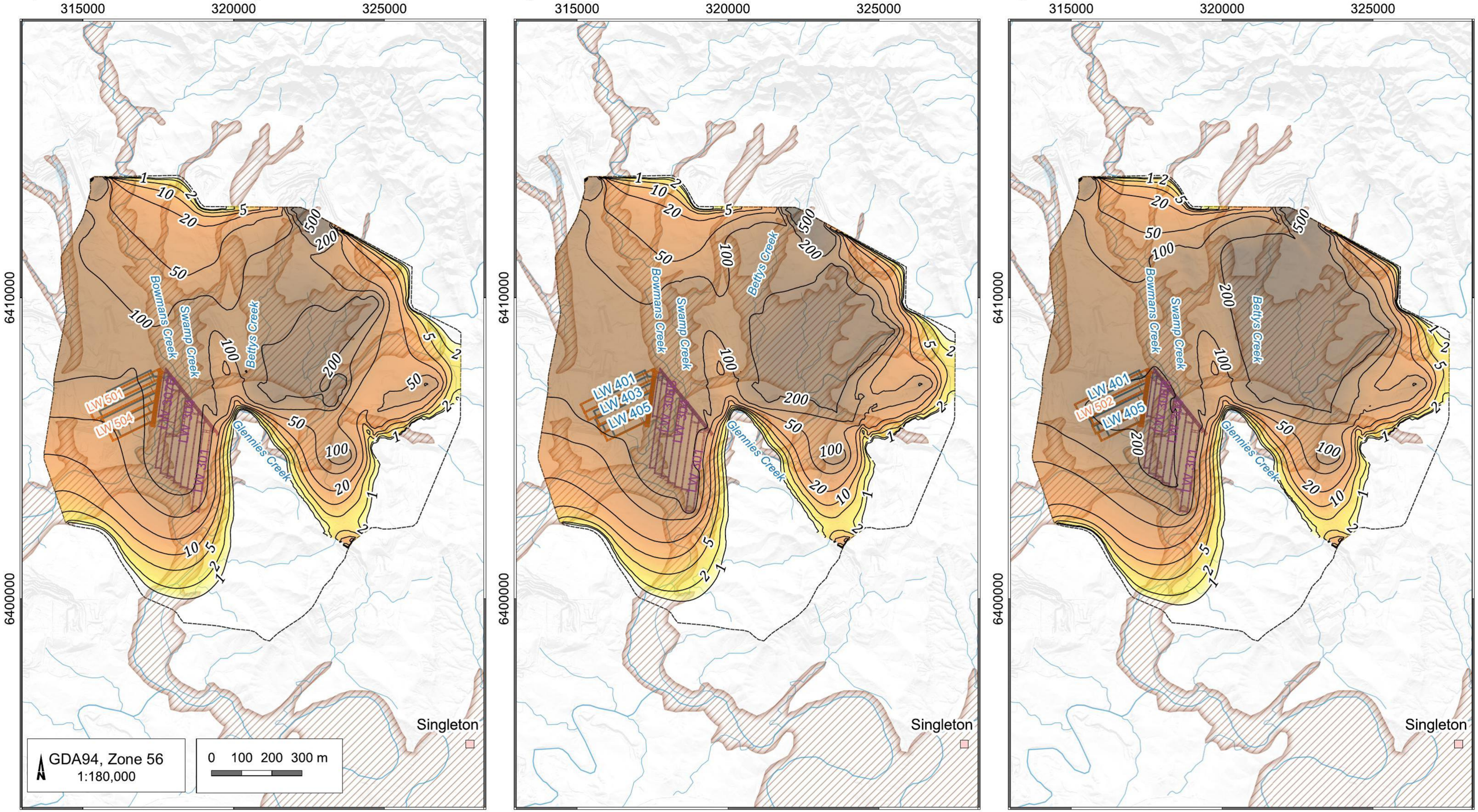
Simulated cumulative drawdown in Middle Liddell Seam (Layer 14)

DATE
12/10/2023

FIGURE
A 12

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.; G:\Projects\ASH5001.001.Ashton_Ravensworth_Integration_Modification\3_GIS\Workspaces\005_Ashton_Ravensworth_Integratsion_Project\A - 12_AHS5000.01_Simulated cumulative drawdown in Middle Liddel seam (Layer 14).qgs

a) Start of RUM Pikes Gully **b) End of RUM Middle Liddell** **c) End of AUM Lower Barrett**



LEGEND

- Drainage
- AUM Lower Barrett panels
- RUM Pikes Gully panels
- RUM Middle Liddell panels
- Quaternary alluvium/colluvium
- Model boundary

Drawdown (m)

- 1
- 2
- 10
- 20
- 100
- 200

AGE

Ashton Ravensworth Integration Project (ASH5001.003)

Simulated cumulative drawdown in Lower Barrett Seam (Layer 17)

DATE
12/10/2023

FIGURE
A 13

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\ASH5001.001.Ashton_Ravensworth_Integration_Modification\3_GIS\Workspaces\005_Ashton_Ravensworth_Integratsion_Project\A - 13_AHS5000.01_Simulated cumulative drawdown in Lower Barrett Seam (Layer 17).qgs

A 7 Uncertainty analysis

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, the 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'.

This uncertainty analysis was essentially undertaken as a three-part process. Firstly, a valid range for hydraulic conductivity (see Table A 14), specific storage and specific yield (see Table A 15), recharge rate (see Table A 16), river vertical hydraulic conductivity (see Table A 17) and effective thickness of stratum to estimate the fracture height (see Table A 18) were determined based on Gaussian distribution, and then 400 model realisations were created, each with varied values of model parameters. For the model layers (e.g., Pikes Gully Seam, Upper Liddell Seam, Upper Lower Liddell Seam and Lower Barrett Seam) of which the hydraulic conductivity distribution is defined with the depth function, the base value HC_0 at the top boundary of these layers were determined according to the same rule and the slope value in the depth function is kept unchanged to create a valid range of parameters. The uncertainty analysis mainly focused on the uncertainty in the calibrated aquifer parameters, but the beam thickness which determined the fracture height is also explored for values with a range between 15 m to 25 m based on Gaussian distribution, so that each realisation will have a slightly different fracture height and slightly different changes to hydraulic properties resulting to the variance in fracture height.

Table A 14 Range of hydraulic conductivity in uncertainty analysis

Layer	Description	Horizontal K (m/day)	Vertical K (m/day)
1	Alluvium (regional)	0.01 - 5	$1.00*10^{-5}$ - 0.5
1	Alluvium Hunter River (high K)	0.01 - 5	$1.00*10^{-5}$ - 0.5
1	Alluvium Bowmans Creek (high K)	0.01 - 20	$1.00*10^{-5}$ - 4
1	Alluvium Glennies Creek (high K)	0.01 - 30	$1.00*10^{-5}$ - 3
1	Alluvium Hunter River (low K)	0.001 - 5	$1.00*10^{-5}$ - 1
1	Alluvium Bowmans Creek (low K)	0.01 - 20	$1.00*10^{-5}$ - 2
1	Alluvium Glennies Creek (low K)	0.01	$1.00*10^{-5}$ - 0.5
1	Alluvium Bowmans Creek Diversion	0.01 - 30	$1.00*10^{-5}$ - 3
1	Regolith	0.01 - 1	$1.00*10^{-5}$ - 0.1
2 to 7	Interburden	0.01 - 15	$1.00*10^{-5}$ - 1.5
3	Bayswater seam	0.5 - 30	$5.00*10^{-4}$ - 3
9 to 18	Interburden	0.01 - 15	$1.00*10^{-5}$ - 3
8	Pikes Gully seam (Top)	0.5 - 15	0.5 - 15
11	Upper Liddell seam (Top)	0.5 - 45	0.5 - 45
14	Upper Lower Liddell seam (Top)	0.01 - 15	0.01 - 15
17	Lower Barrett seam (Top)	0.1 - 15	0.1 - 15

Table A 15 Range of specific storage and specific yield in uncertainty analysis

Layer	Description	Specific yield (m/m)	Specific storage (m^{-1})
1	Alluvium (regional)	0.005 - 0.1	$1.00*10^{-6}$ - $1.30*10^{-5}$
1	Alluvium Hunter River (high K)	0.03 - 3.4	$1.00*10^{-6}$ - $1.30*10^{-5}$
1	Alluvium Bowmans Creek (high K)	0.02 - 0.35	$1.00*10^{-6}$ - $1.30*10^{-5}$
1	Alluvium Glennies Creek (high K)	0.001 - 0.35	$1.00*10^{-6}$ - $1.30*10^{-5}$
1	Alluvium Hunter River (low K)	0.005 - 0.1	$1.00*10^{-6}$ - $1.30*10^{-5}$
1	Alluvium Bowmans Creek (low K)	0.005 - 0.1	$1.00*10^{-6}$ - $1.30*10^{-5}$
1	Alluvium Glennies Creek (low K)	0.005 - 0.1	$1.00*10^{-6}$ - $1.30*10^{-5}$
1	Alluvium Bowmans Creek Diversion	0.0001 - 0.15	$1.00*10^{-6}$ - $1.30*10^{-5}$
1	Regolith	0.001 - 0.02	$2.30*10^{-8}$ - $5.00*10^{-5}$
2 to 7	Interburden	0.0001 - 0.017	$2.30*10^{-7}$ - $5.00*10^{-6}$
3	Bayswater seam	0.01 - 0.05	$1.00*10^{-6}$ - $1.30*10^{-5}$
9 to 18	Interburden	0.001 - 0.1	$2.30*10^{-7}$ - $5.00*10^{-6}$
8	Pikes Gully seam	0.01 - 0.05	$1.00*10^{-6}$ - $1.30*10^{-5}$
11	Upper Liddell seam	0.001 - 0.05	$1.00*10^{-6}$ - $1.30*10^{-5}$
14	Upper Lower Liddell seam	0.001 - 0.05	$1.00*10^{-6}$ - $1.30*10^{-5}$
17	Lower Barrett seam	0.001 - 0.05	$1.00*10^{-6}$ - $1.30*10^{-5}$

Table A 16 Range of recharge rate in uncertainty analysis

Zone	Diffuse recharge rate (percent [%] of mm/day)
Highly productive (basal) alluvium	1.0 - 7.0
Less productive alluvium	0.2 – 2.0
Regolith	0.1 – 2.0

Table A 17 Range of river vertical hydraulic conductivity in uncertainty analysis

Zone	Vertical hydraulic conductivity Kz (m/day)
1	0.001 - 0.1
2	0.001 – 1.0
3	0.001 – 0.1
4	0.001 – 1.0
5	0.001 – 0.1

Table A 18 Range of effective thickness of stratum (fracture height calculation)

Description	Range (m)
Effective thickness of stratum (*t'*)	15 - 35

The range of t' explored in the uncertainty analysis (15 m to 35 m) meant that fracture heights varied between 121 m and 160 m for the Pikes Gully longwalls and 150 m to 190 m for the Middle Liddell longwall panels. These ranges would result in the top of fracturing appearing in different model layers within the various uncertainty runs. Further to this, the property changes due to fracturing are derived from the *in-situ* hydraulic properties assigned in the model, so consequently the fracture properties applied in each realisation involved in the uncertainty analysis will vary from the basecase data set as well.

The constrained realisations were evaluated and the models which failed to converge or could not achieve adequate calibration (e.g., SRMS>=12%) were rejected, leaving the output from 224 successful models from 400 model runs. The prior and posterior mean are computed for each parameter considered in uncertainty analysis, as summarized in

Table A 19 to Table A 25. The full range of prior and posterior parameter distributions are given in Appendix D. These results shows that the 224 successful uncertainty model runs used for analysis are within reasonable calibrated ranges.

Table A 19 Prior and posterior mean of horizontal hydraulic conductivity

Layer	Description	Prior (m/day)	Posterior (m/day)	Difference (%)
1	Alluvium (regional)	1.10	1.14	3.23
1	Alluvium Hunter River (high K)	0.83	0.84	1.33
1	Alluvium Bowmans Creek (high K)	3.80	4.17	9.05
1	Alluvium Glennies Creek (high K)	5.60	5.66	0.54
1	Alluvium Hunter River (low K)	0.23	0.24	6.13
1	Alluvium Bowmans Creek (low K)	3.16	3.32	4.99
1	Alluvium Glennies Creek (low K)	1.05	1.06	0.99
1	Alluvium Bowmans Creek Diversion	5.00	5.12	2.37
1	Regolith	0.26	0.27	4.21
2 to 7	Interburden	2.68	2.39	11.04
3	Bayswater seam	8.87	9.10	2.59
9 to 18	Interburden	2.50	2.85	14.04
8	Pikes Gully seam	4.25	4.66	9.62
11	Upper Liddell seam	13.00	11.31	13.02
14	Upper Lower Liddell seam	1.40	1.50	3.78
17	Lower Barrett seam	1.80	1.81	0.57

Table A 20 Prior and posterior mean of ratio between vertical hydraulic conductivity and horizonal hydraulic conductivity

Layer	Description	Prior (m/day)	Posterior (m/day)	Difference (%)
1	Alluvium (regional)	0.012	0.013	6.325
1	Alluvium Hunter River (high K)	0.011	0.010	10.184
1	Alluvium Bowmans Creek (high K)	0.054	0.062	15.103
1	Alluvium Glennies Creek (high K)	0.027	0.028	4.359
1	Alluvium Hunter River (low K)	0.056	0.058	4.427
1	Alluvium Bowmans Creek (low K)	0.017	0.017	0.051
1	Alluvium Glennies Creek (low K)	0.023	0.024	1.884
1	Alluvium Bowmans Creek Diversion	0.030	0.030	0.778
1	Regolith	0.023	0.023	1.123
2 to 7	Interburden	0.012	0.011	10.880
3	Bayswater seam	0.021	0.023	7.567
9 to 18	Interburden	0.053	0.051	4.447

Table A 21 Prior and posterior mean of specific yield

Layer	Description	Prior (m/m)	Posterior (m/m)	Difference (%)
1	Alluvium (regional)	0.019	0.020	3.45
1	Alluvium Hunter River (high K)	0.539	0.598	11.12
1	Alluvium Bowmans Creek (high K)	0.076	0.082	7.34
1	Alluvium Glennies Creek (high K)	0.050	0.048	5.64
1	Alluvium Hunter River (low K)	0.038	0.036	3.81
1	Alluvium Bowmans Creek (low K)	0.041	0.039	4.81
1	Alluvium Glennies Creek (low K)	0.021	0.020	6.33
1	Alluvium Bowmans Creek Diversion	0.018	0.019	5.51
1	Regolith	0.005	0.005	5.03
2 to 7	Interburden	0.002	0.003	33.68
3	Bayswater seam	0.020	0.021	1.86

Layer	Description	Prior (m/m)	Posterior (m/m)	Difference (%)
9 to 18	Interburden	0.024	0.023	3.65
8	Pikes Gully seam	0.029	0.031	3.81
11	Upper Liddell seam	0.013	0.012	5.27
14	Upper Lower Liddell seam	0.012	0.012	1.44
17	Lower Barrett seam	0.013	0.013	1.64

Table A 22 Prior and posterior mean of specific storage

Layer	Description	Prior (m^{-1})	Posterior (m^{-1})	Difference (%)
1	Alluvium (regional)	4.04E-06	4.04E-06	0.056
1	Alluvium Hunter River (high K)	1.95E-05	1.99E-05	2.02
1	Alluvium Bowmans Creek (high K)	3.55E-06	3.52E-06	0.67
1	Alluvium Glennies Creek (high K)	2.45E-05	2.53E-05	2.94
1	Alluvium Hunter River (low K)	5.55E-06	5.45E-06	1.78
1	Alluvium Bowmans Creek (low K)	4.95E-06	5.02E-06	1.27
1	Alluvium Glennies Creek (low K)	5.67E-06	5.73E-06	1.16
1	Alluvium Bowmans Creek Diversion	4.30E-06	4.40E-06	2.41
1	Regolith	2.42E-06	2.36E-06	2.40
2 to 7	Interburden	1.95E-06	1.71E-06	12.38
3	Bayswater seam	3.17E-06	3.11E-06	1.69
9 to 18	Interburden	1.62E-06	1.64E-06	1.16
8	Pikes Gully seam	3.55E-06	3.60E-06	1.57
11	Upper Liddell seam	3.07E-06	2.92E-06	4.73
14	Upper Lower Liddell seam	3.20E-06	3.31E-06	3.42
17	Lower Barrett seam	3.33E-06	3.29E-06	1.12

Table A 23 Prior and posterior mean of recharge rate

Zone	Prior (percent [%] of mm/day)	Posterior (percent [%] of mm/day)	Difference (%)
Highly productive (basal) alluvium	3.57	3.75	5.077
Less productive alluvium	0.879	0.88	0.39
Regolith	0.399	0.394	1.08

Table A 24 Prior and posterior mean of river vertical hydraulic conductivity

Zone	Prior (m/day)	Posterior (m/day)	Difference (%)
Hunter River	0.028	0.027	4.38
Bowmans Creek	0.18	0.10	43.52
Glennies Creek	0.011	0.012	9.41
Minor Drainages	0.15	0.17	8.81
Bowmans Diversion	0.0117	0.0115	2.18

Table A 25 Prior and posterior mean of effective thickness of stratum

Description	Prior (m)	Posterior (m)	Difference (%)
Stratum effective thickness	21.65	21.86	0.10

Finally, the outputs were analysed to provide a statistical distribution of the predicted impacts on baseflows, alluvial take, drawdowns, and mine inflows. The range of key 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 Action. Outputs from the 224 successful model runs were processed in accordance with the likelihood of exceedance proposed in Middlemis and Peeters (2018). The range adopted are shown in Figure A 14 and Figure A 15, the percentile analysis of the maximum inflows in Pikes Gully seam and maximum baseflow decline in Bowmans Creek present a stable trend after the uncertainty reaches 90 runs, which confirms an adequate number of realisations has been achieved.

Table A 26 Calibrated uncertainty modelling language

Narrative descriptor	Probability class	Description (likelihood of exceedance)	Colour code
Very likely	0-10%	Very likely that the outcome is larger than	
Likely	10-33%	Likely that the outcome is larger than	
About as likely as not	33-67%	As likely as not that the outcome is larger than	
Unlikely	67-90%	Unlikely that the outcome is larger than	
Very unlikely	90-100%	Very unlikely that the outcome is larger than	

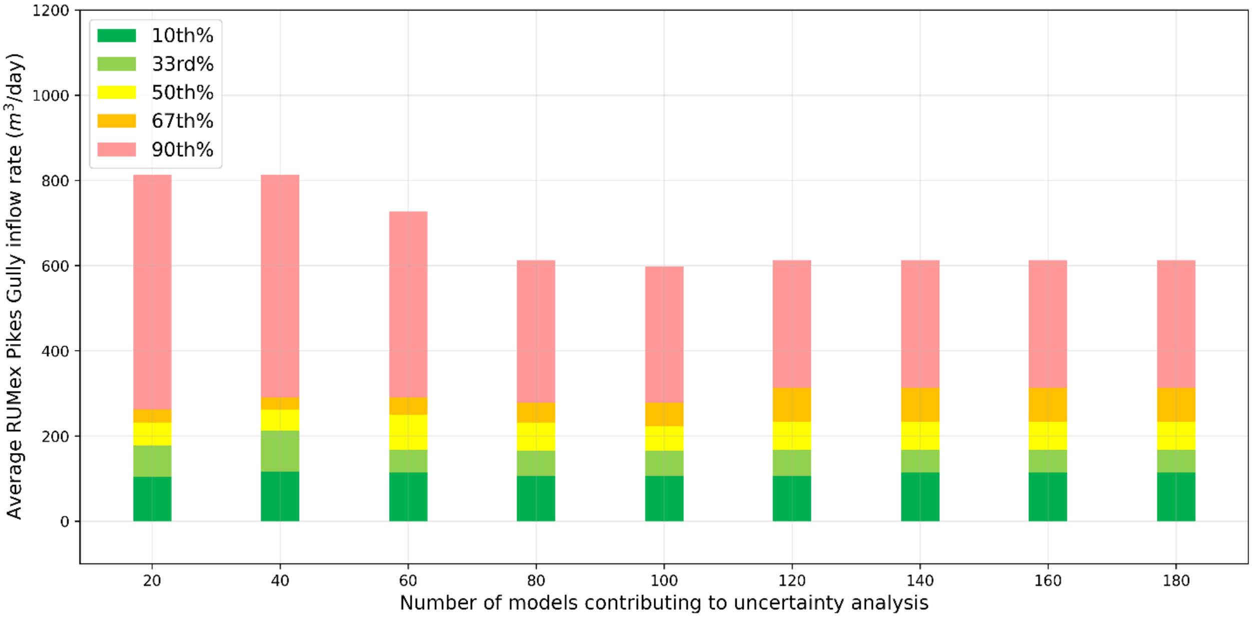


Figure A 14 Convergence of average inflow rate in Pikes Gully seam

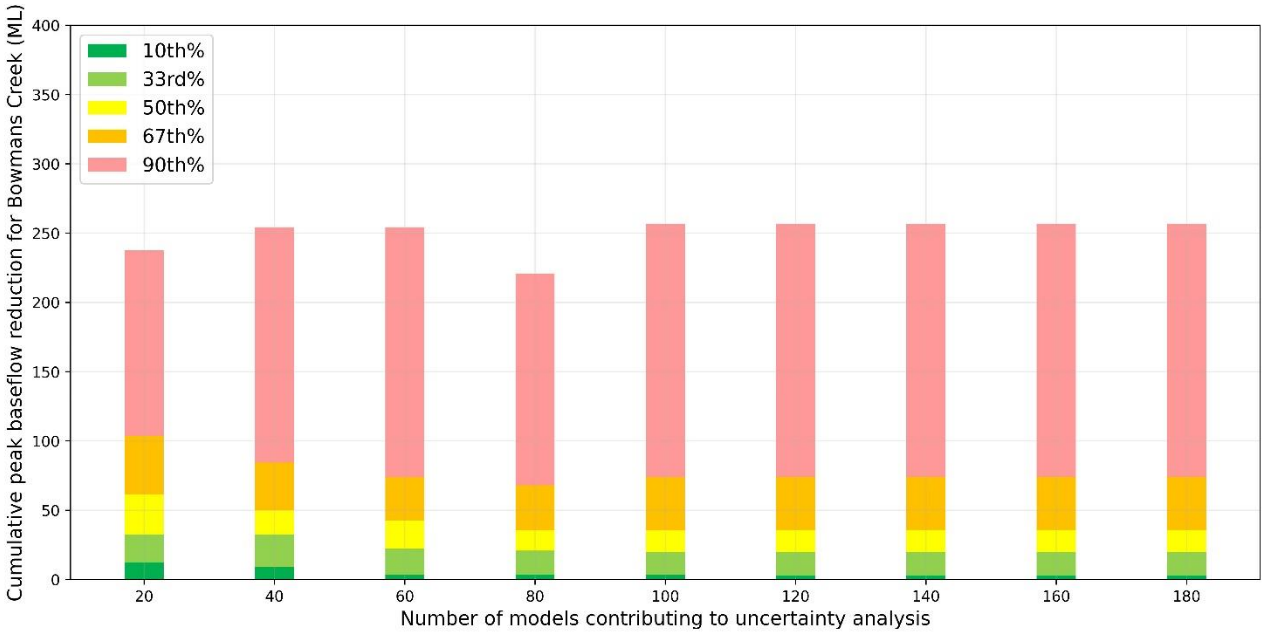


Figure A 15 Convergence of cumulative peak baseflow decline in Bowmans Creek

The uncertainty analysis has explored the uncertainty in the model parameters but has not addressed measurement or structural uncertainty explicitly. There will be uncertainty in the model structure as the model layers have been derived from geological models that are informed by point data and the interpolated. The geological information will be reliable around the mine, but away from the mine areas the model layers rely on interpolation. The model does not represent fault structures explicitly as there are no known faults reported at site. The geological structures are folds with anti-cline and syncline features which are captured in the geological structure information. Boundary conditions at the model extents may be less informed by measurements and more around assumptions, such as the assigned boundary to the west of RUM, which is assumed to be no-flow with water levels west of the model domain similarly reduced along the model boundary due to mining at Ravensworth and HVO. Simplifications in the mine plan and in simplifications derived from discretisation of the model domain into cells introduce uncertainty as well.

Measurement uncertainty will exist also in the data that the model build has relied upon, such as natural surface data, bore stratigraphy levels and interpretation of formations based on drilling outputs (rock chips or core), from measured water levels in bores and open water sources, and from measured flows. Some of these measurements become calibration targets, however these are minor in comparison to other uncertainties in the model development and significantly smaller that the calibration target achievable. Any inaccuracy in the measurements is somewhat compensated for in the calibrated model parameters.

The modelling focuses on incremental changes due to the Proposed Action and calculating this incremental change using two models (identical except for the representation of the Proposed Action) means that some of the uncertainty exists in both models, and the influence of model uncertainty in the predictions is reduced.

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. The 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 Class 2 groundwater model, with many Class 3 elements as indicated on Table A 24, 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 the AUM and RUM and relevant nearby mines (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);
- SRMS 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 27 Model classification – model performance indicators

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

Appendix B

Compliance with government policy

B 1 Compliance with Commonwealth government policy

B1.1 Commonwealth assessment requirements for the proposed action

Table B 1 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
Aquifer pressure or pressure relationships between aquifers?	No – depressurisation already occurring in the area, extent expanded slightly but within previous approved extents and 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
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 licensing for current mining
Cumulative impact?	No – There will be cumulative impact with adjacent mining operations, however the site is surrounded by mining and the only cumulative change above current operations will be directly over the Ravensworth Underground Mine (RUM) panels.

Table B 2 Summary of impacts to the water quality of the water resource compared to the Department of the Environment and Energy 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 accumulate in the environment?	Refer to Section 9.5. As there are no open cut voids associated with the proposed Action 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. Australian and New Zealand Environment and Conservation Council [ANZECC] guidelines for Fresh and Marine Water Quality)?	No
Salt concentration/generation?	As there are no open cut voids associated with the proposed Action 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

B1.2 IESC Information Guidelines for Coal Seam Gas and Large Coal Mining Development

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) 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 relevant to the Proposed Action have been addressed within this report.

Table B 3 Description of the proposal

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 coal seam gas (CSG) developments.	Section 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
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 4 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.	Section 1.3 & 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 1.3 & 8
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, 7 & 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.	Section 1.3 & 8

Table B 5 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.	Section 4
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 5.4 & Appendix A
Provide time series level and water quality data representative of seasonal and climatic cycles.	Section 4.5 & 4.6
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 4.5 & 4.6
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 4 & Section 5
Describe the likely recharge, discharge and flow pathways for all hydrogeological units likely to be impacted by the proposed development.	Section 6
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 6

Table B 6 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 7 & Appendix A
Undertaken groundwater modelling in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al. 2012), including independent peer review.	Section 7 & 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 and 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 6 & 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 1, 8 & Appendix A
Identify the volumes of water predicted to be taken annually with an indication of the proportion supplied from each hydrogeological unit.	Section 8 & 9
Undertake model verification with past and/or existing site monitoring data.	Appendix A and Appendix C
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 6
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 uncertainty analysis of boundary conditions and hydraulic and storage parameters, and justify the conditions applied in the final groundwater model (see Middlemis and Peeters, 2018).	Section 9 & Appendix A
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 & Appendix A
Undertake an uncertainty analysis of model construction, data, conceptualisation and predictions (see Middlemis and Peeters, 2018).	Section 9 & Appendix A
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 8

Table B 7 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; and • 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 5, 6 & Appendix A
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.	Section 9
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 & 9
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 & 9
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.	Appendix A
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 8 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 4.3 & 4.5
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 Groundwater Dependent Ecosystems (GDEs), the hydraulic properties of significant faults, fracture networks and aquitards in the impacted system, etc., where appropriate.	Section 10
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 guidelines (ANZECC/ARMCANZ 2000) and relevant legislated state protocols (e.g. Queensland [QLD] Government 2013).	Section 10

Table B 9 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 et al. [in press]). • public health, recreation, amenity, Indigenous, tourism or agricultural values for each water resource.	Section 4.7
Identify GDEs in accordance with the method outlined by Eamus *et al*. (2006). Information from the GDE Toolbox (Richardson *et al*. 2011) and GDE Atlas (CoA 2017a) may assist in identification of GDEs (see Doody *et al*. [in press]).	Section 4.7 & Ecology Report
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).	Ecology Report
Estimate the ecological water requirements of identified GDEs and other water-dependent assets (see Doody *et al*. [in press]).	Ecology Report
Identify the hydrogeological units on which any identified GDEs are dependent (see Doody *et al*. [in press]).	Section 4.1 & 4.7
Provide an outline of the water-dependent assets and associated environmental objectives and the modelling approach to assess impacts to the assets.	Section 7, 9.4, Appendix A & Ecology Report
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 10 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 *et al*. [in press]).	Section 9.1, 9.3 & 9.4
Describe the potential range of drawdown at each affected bore, and clearly articulate of the scale of impacts to other water users.	Section 9.5
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 8.3 & 9.5
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
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 & Ecology Report
Assess the overall level of risk to water-dependent assets through combining probability of occurrence with severity of impact.	Refer to Ecology Report
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
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

Table B 11 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 *et al*. [in press]).	Refer to Ecology Report
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 *et al*. [in press]).	Refer to Ecology Report
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 *et al*. [in press]).	Refer to Ecology Report
Describe the proposed process for regular reporting, review and revisions to the monitoring program.	Section 11 & Ecology Report
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

Table B 12 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
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
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
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

Table B 13 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 A 6.1
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 3.4 & A 6.1

Table B 14 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 & Ecology Report
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 8, 9 & A 6.1

Table B 15 Cumulative Impacts – Mitigation, monitoring and management

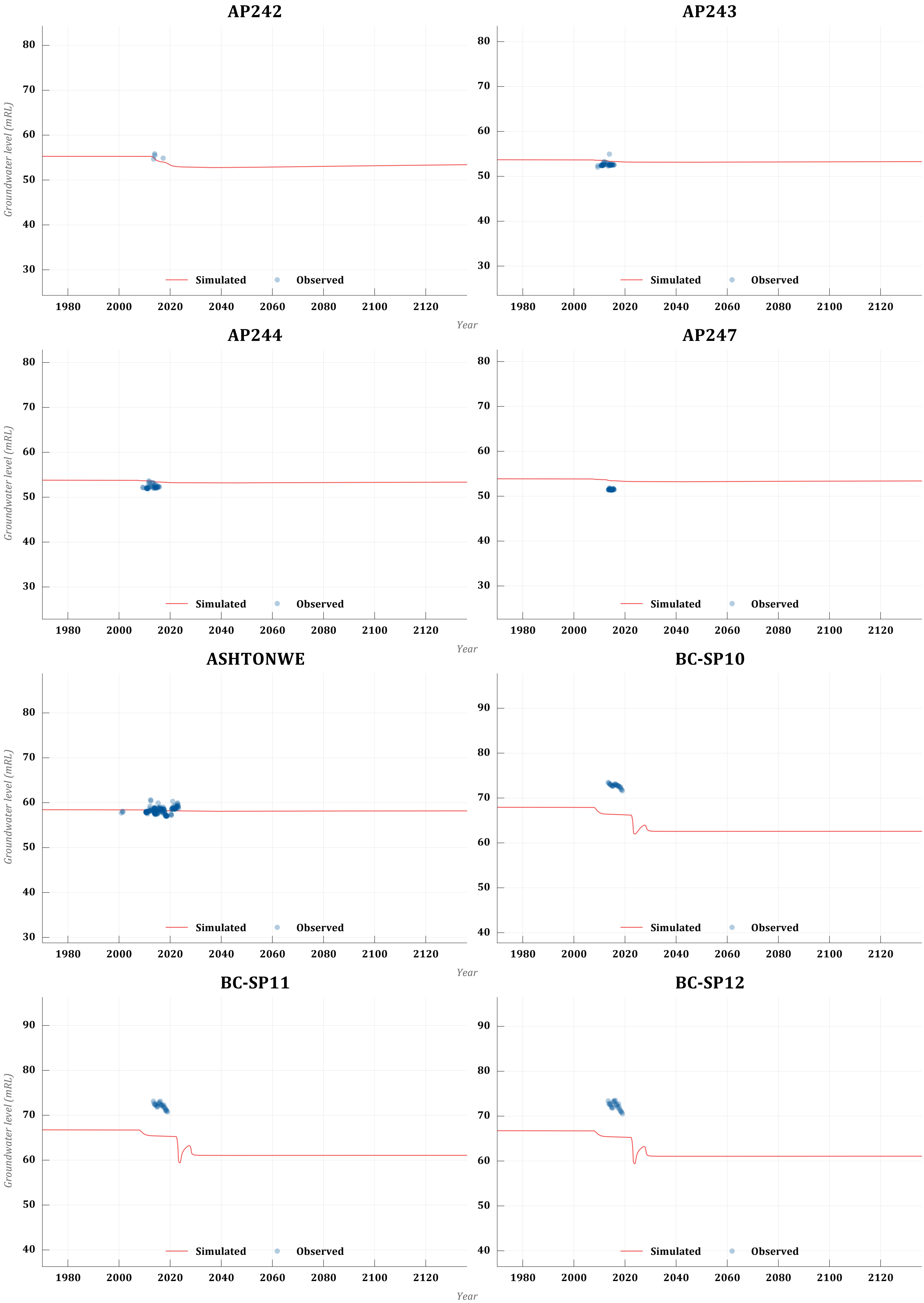
Project Information	Addressed in section
Identify modifications or alternatives to avoid, minimise or mitigate potential cumulative impacts. Evidence of the likely success of these measures (e.g. case studies) should be provided.	N/A
Identify measures to detect and monitor cumulative impacts, pre and post development, and assess the success of mitigation strategies.	Section 10
Identify cumulative impact environmental objectives.	Section 2 & 10
Describe appropriate reporting mechanisms.	Section 10
Propose adaptive management measures and management responses.	Section 10

Table B 16 Final landform and voids – coal mines

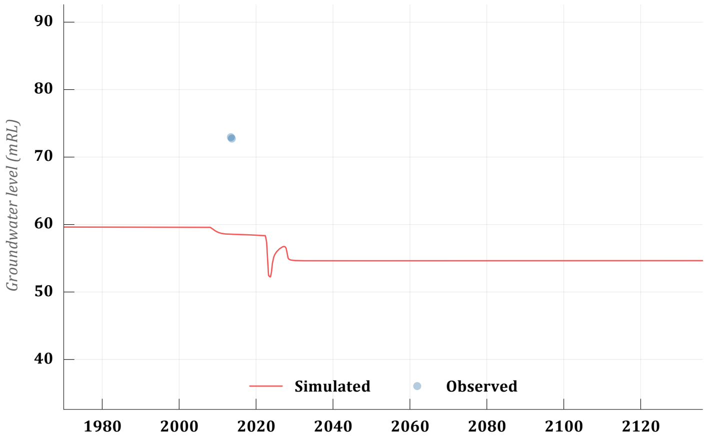
Project Information	Addressed in section
Identify and consider landscape modifications (e.g. voids, on-site earthworks, and roadway and pipeline networks) and their potential effects on surface water flow, erosion, sedimentation and habitat fragmentation of water-dependent species and communities.	N/A – proposed Action is an underground mine
Assess the adequacy of modelling, including surface water and groundwater quantity and quality, lake behaviour, timeframes and calibration.	N/A
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.	N/A
Evaluate mitigating inflows of saline groundwater by planning for partial backfilling of final voids.	N/A
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, potential of Hydrogen (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.	N/A
Assess the probability of overtopping of final voids with variable climate extremes, and management mitigations.	N/A

Appendix C

Calibration hydrographs


AP242
AP243
AP244
AP247
ASHTONWE
BC-SP10
BC-SP11
BC-SP12
Groundwater level (mRL)
Year
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120
30
40
50
60
70
80
90

BC-SP13



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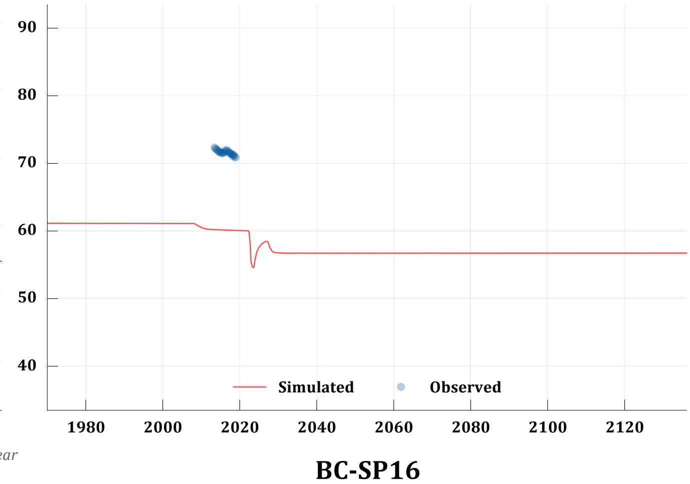

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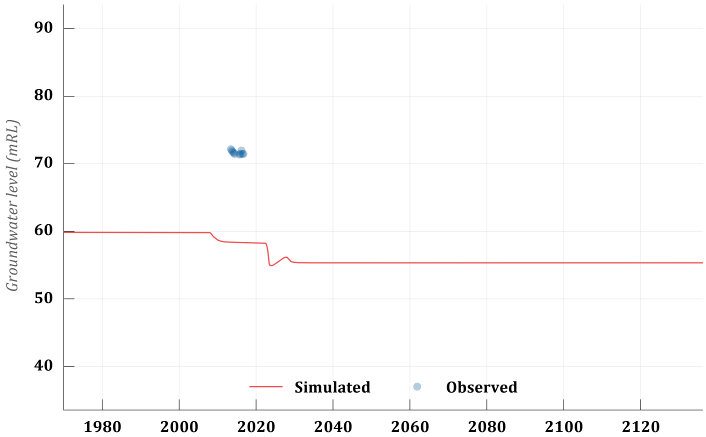

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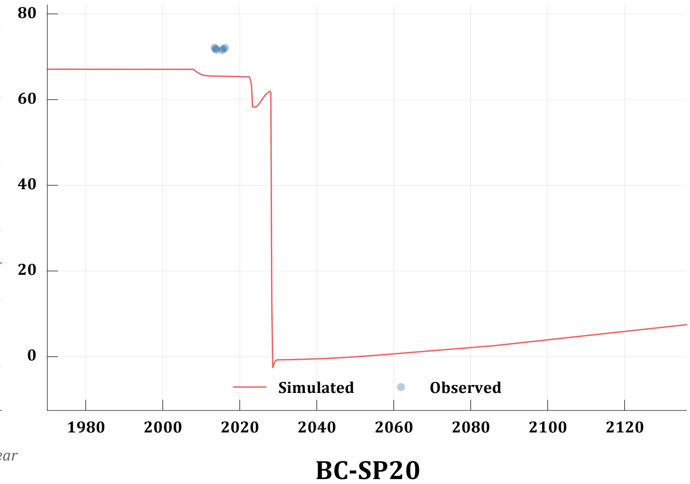

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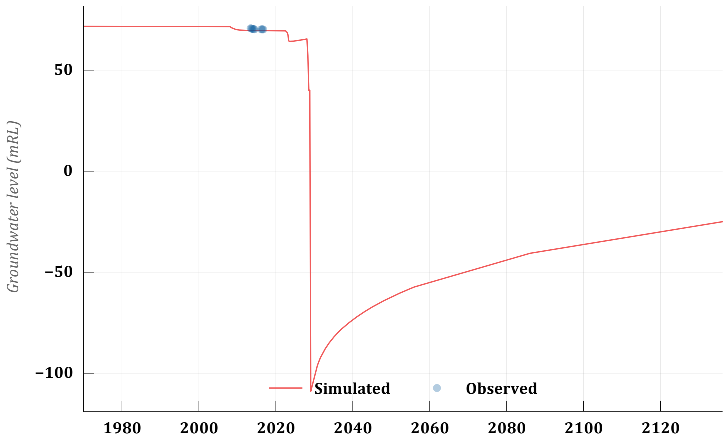

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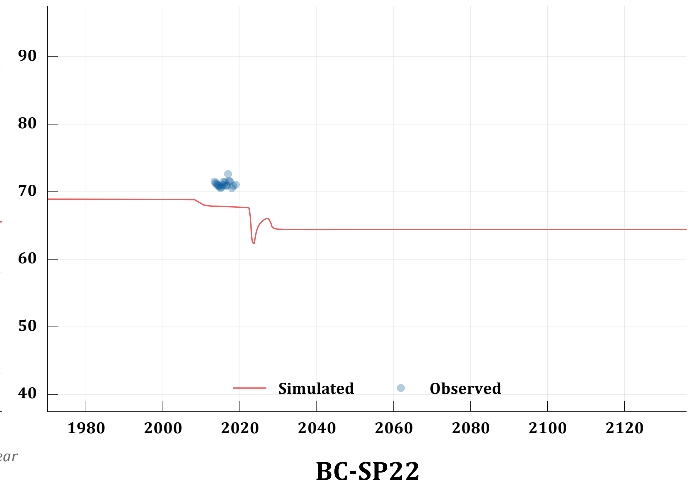

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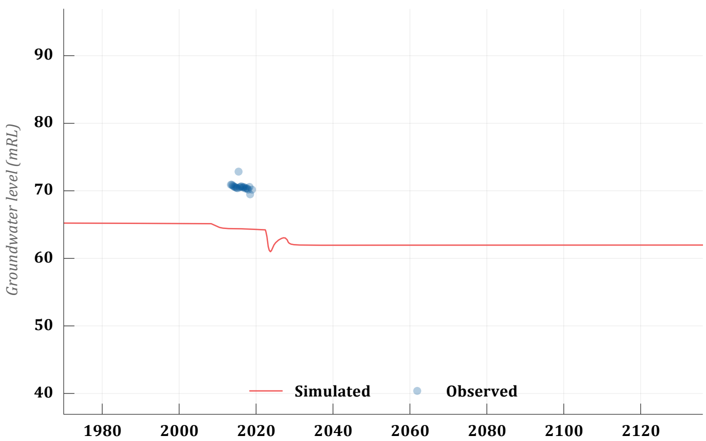

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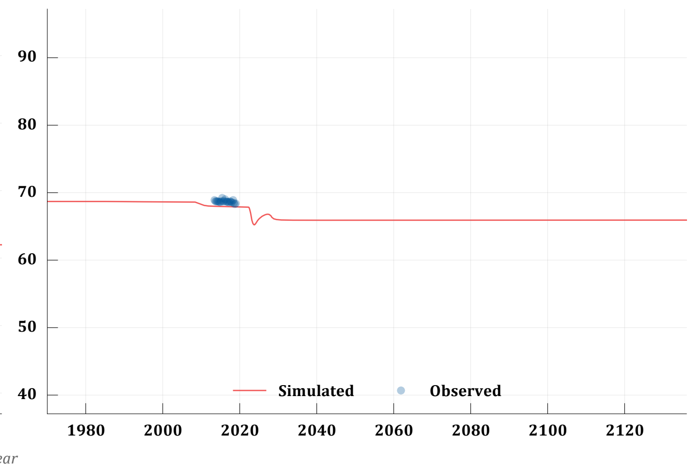
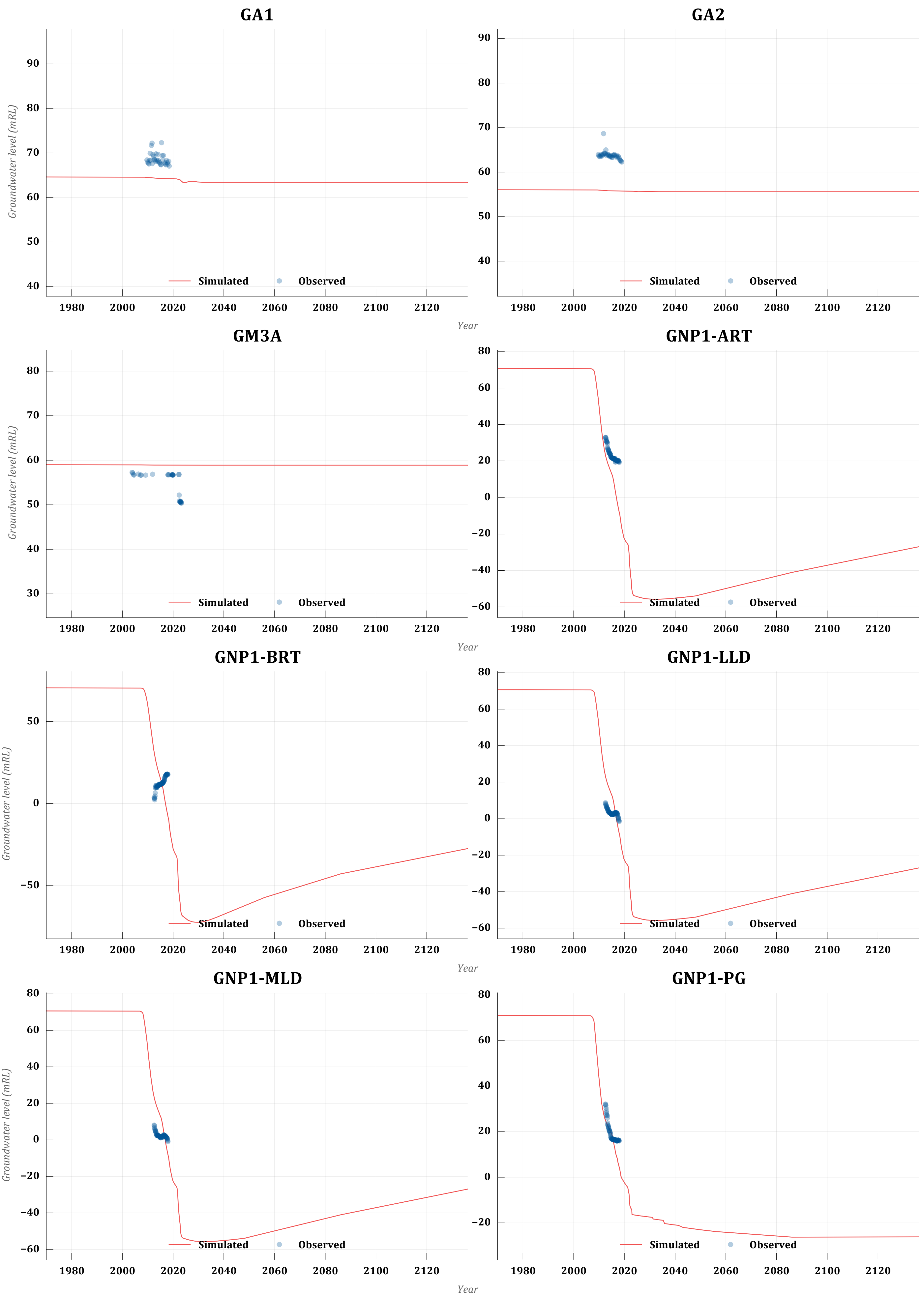
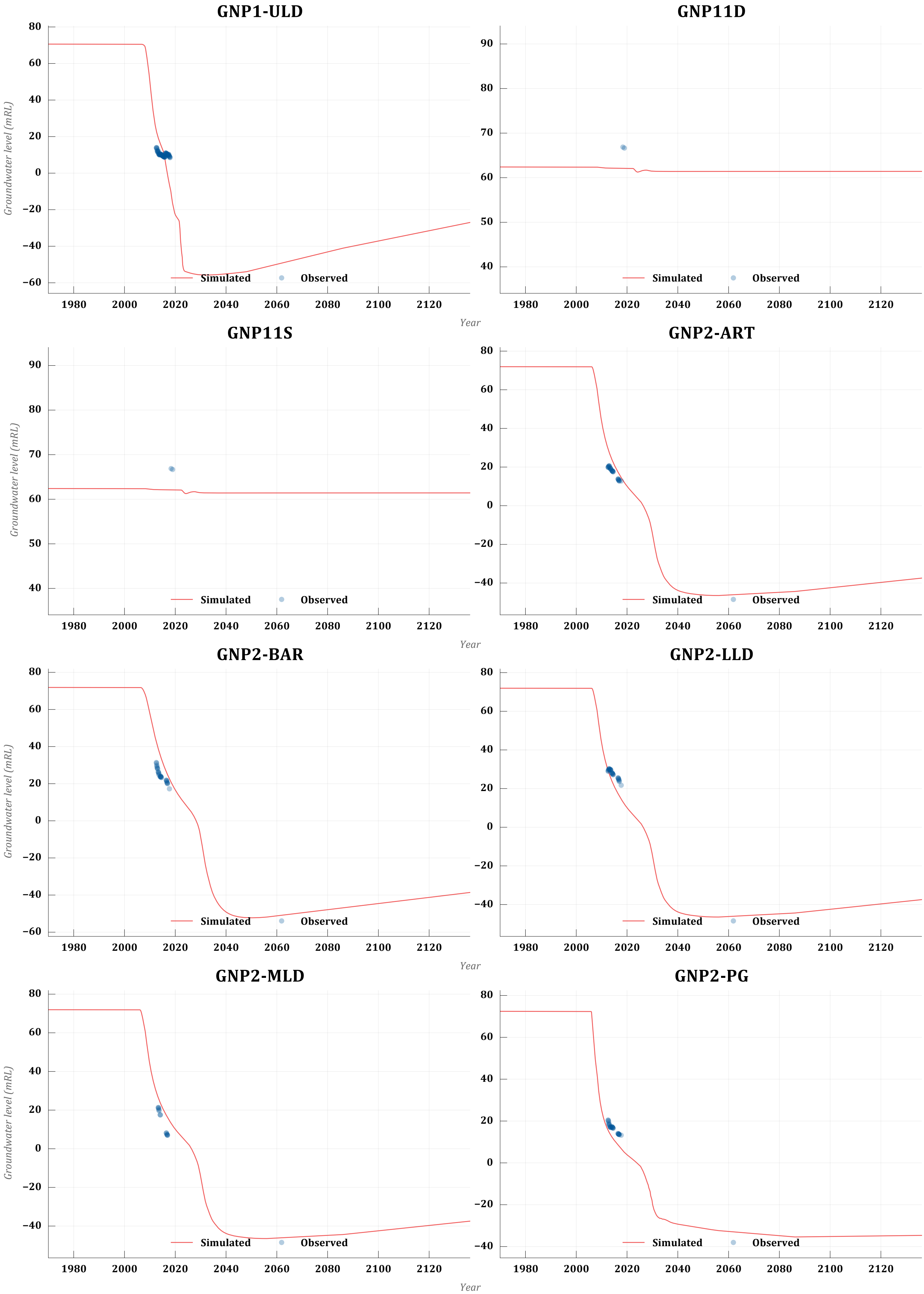



GA1
GA2
GM3A
GNP1-ART
GNP1-BRT
GNP1-LLD
GNP1-MLD
GNP1-PG
Groundwater level (mRL)
Year
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120



GNP1-ULD
GNP11D
GNP11S
GNP2-ART
GNP2-BAR
GNP2-LLD
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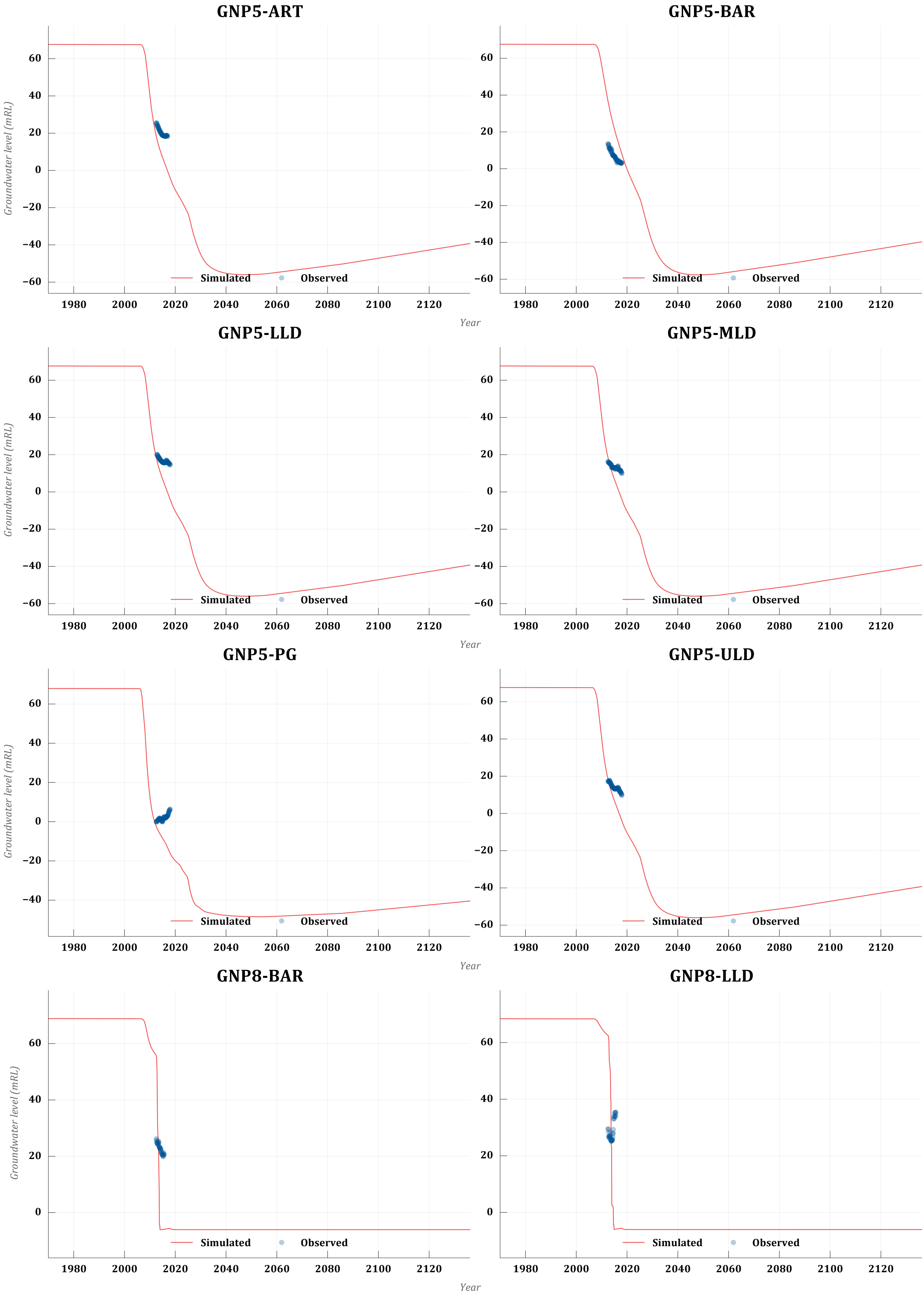
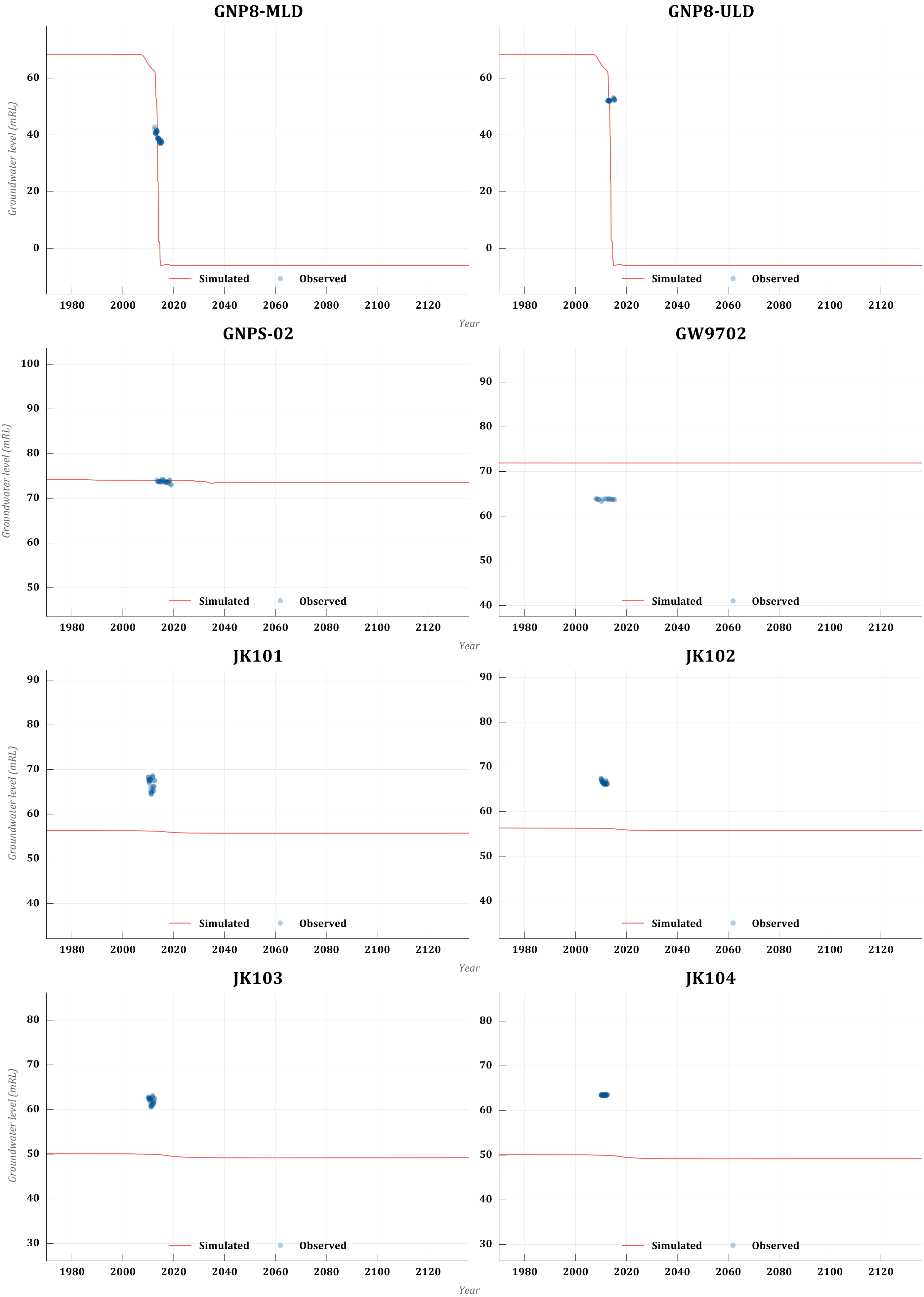
GNP2-PG
Groundwater level (mRL)
Year
Simulated
Observed


GNP5-ART
GNP5-BAR
GNP5-LLD
GNP5-MLD
GNP5-PG
GNP5-ULD
GNP8-BAR
GNP8-LLD
Groundwater level (mRL)
Year
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120
60
40
20
0
−20
−40
−60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GNP8-ULD
GNPS-02
GW9702
JK101
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JK103
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Year
Simulated
Observed
1980
2000
2020
2040
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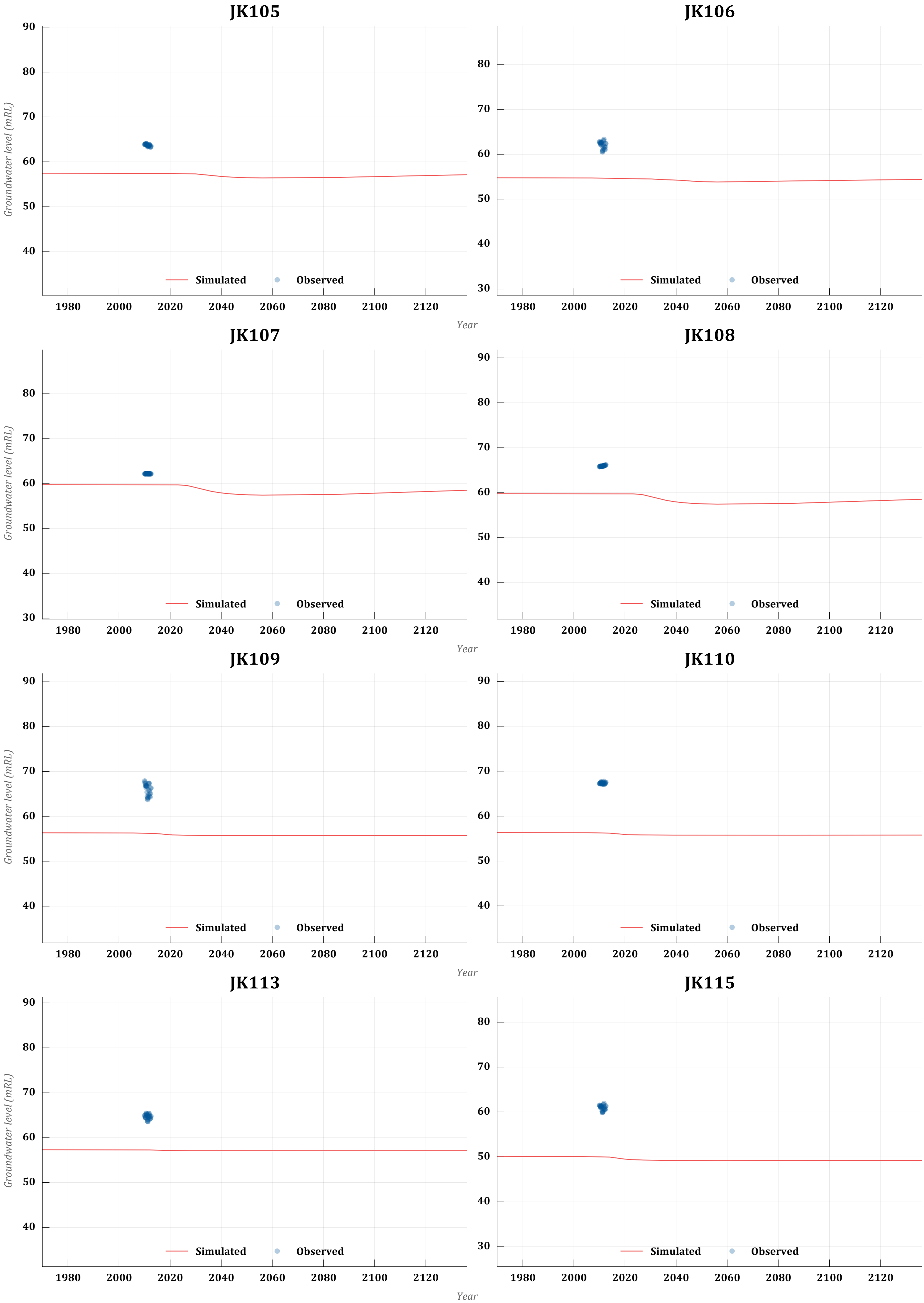
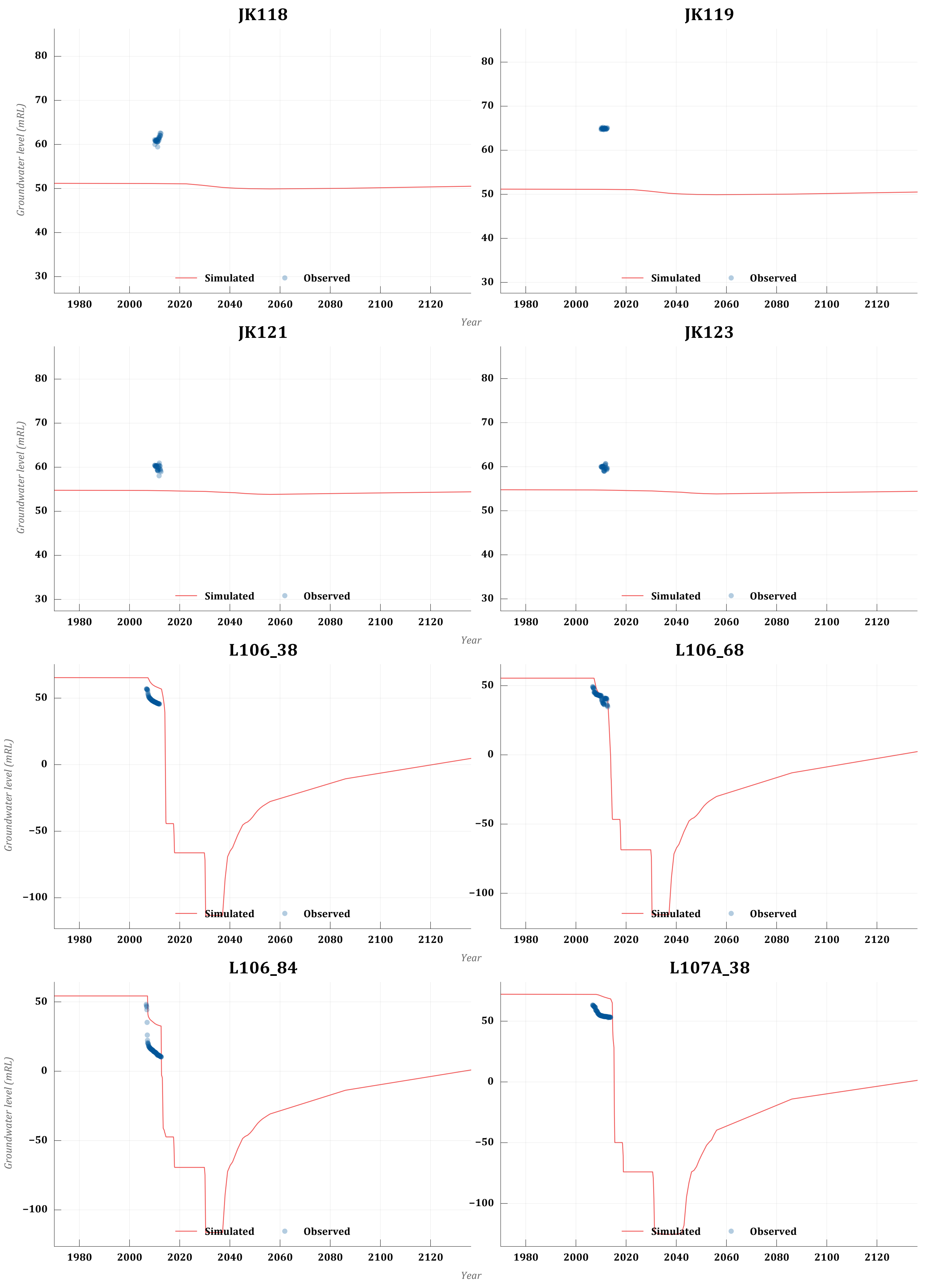

JK105
JK106
JK107
JK108
JK109
JK110
JK113
JK115
Groundwater level (mRL)
Year
Simulated
Observed
1980 2000 2020 2040 2060 2080 2100 2120
30 40 50 60 70 80 90


JK118
JK119
JK121
JK123
L106_38
L106_68
L106_84
L107A_38
Groundwater level (mRL)
Year
Simulated
Observed
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2000
2020
2040
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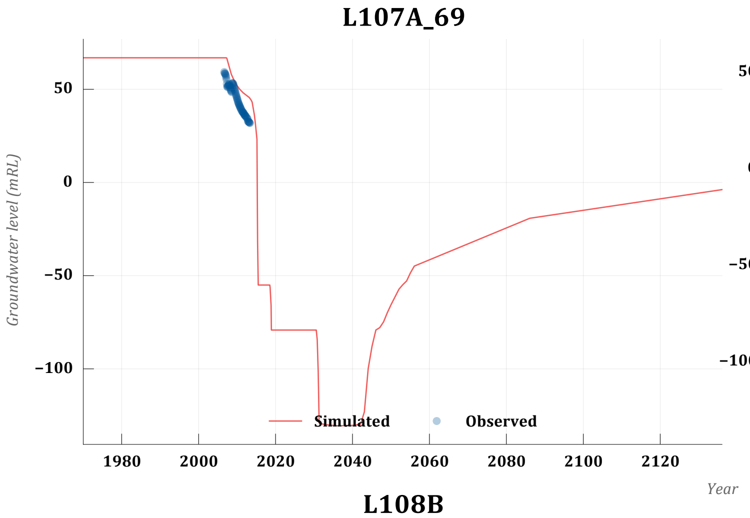
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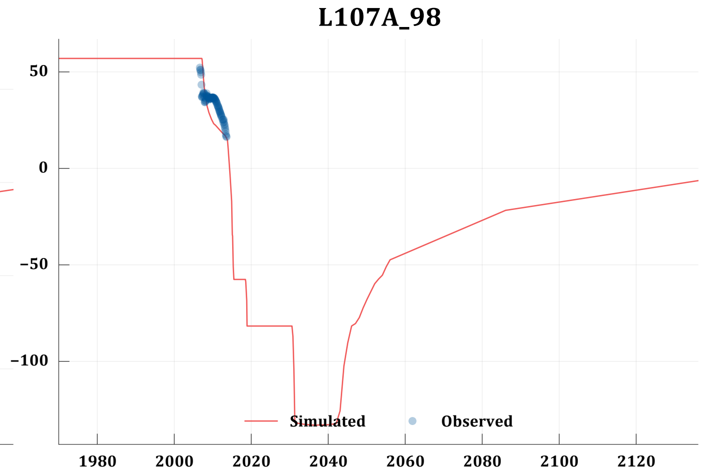
Simulated
Observed
Year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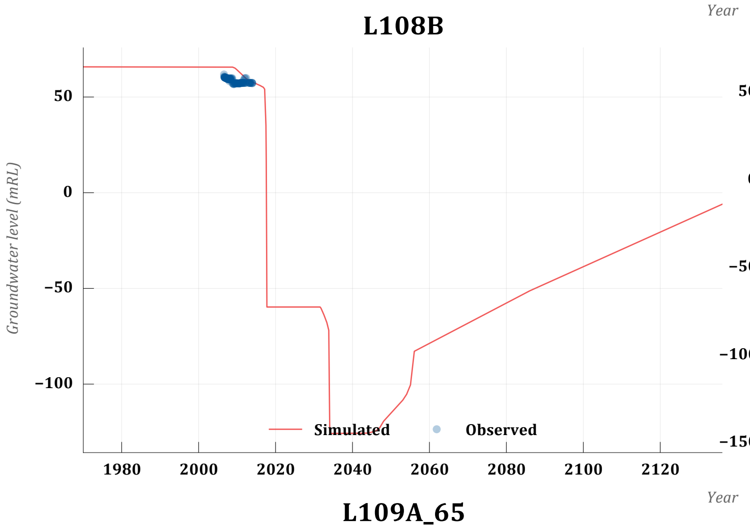
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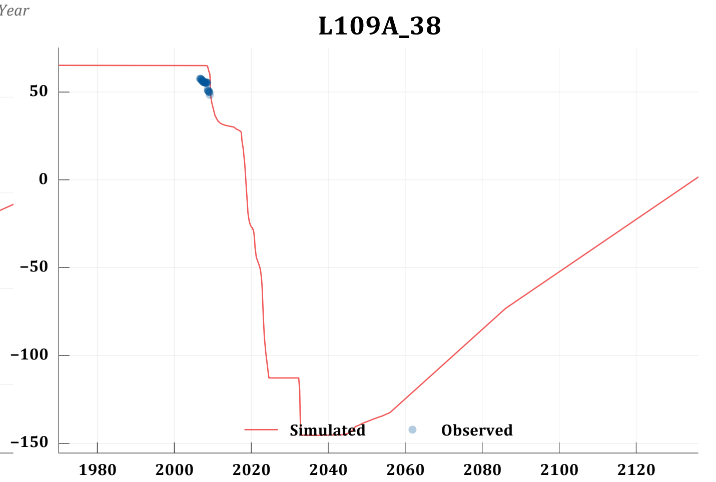
Observed
Year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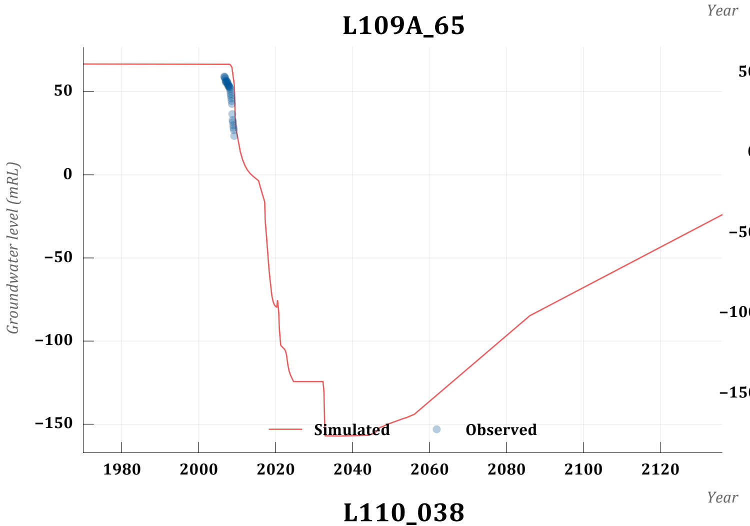
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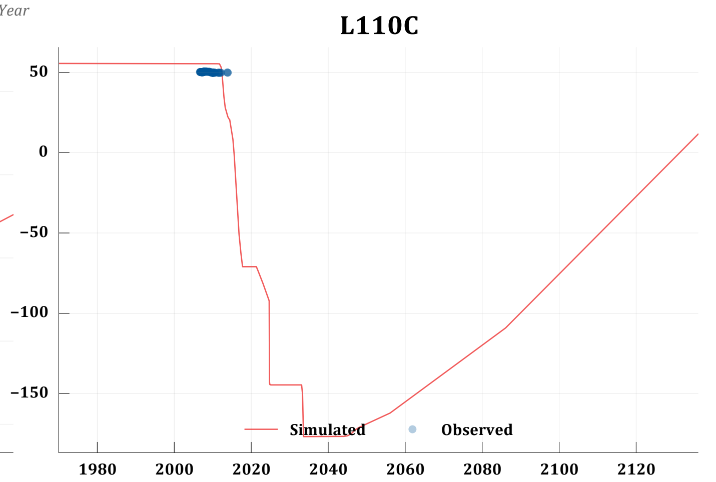
Simulated
Observed
Year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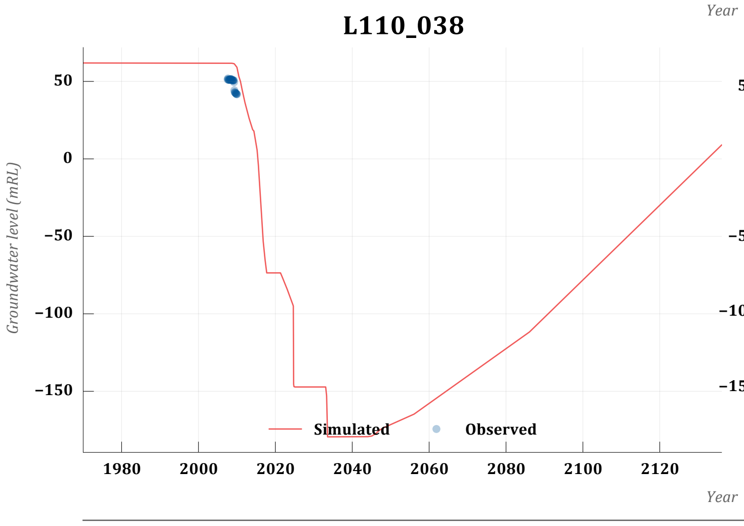
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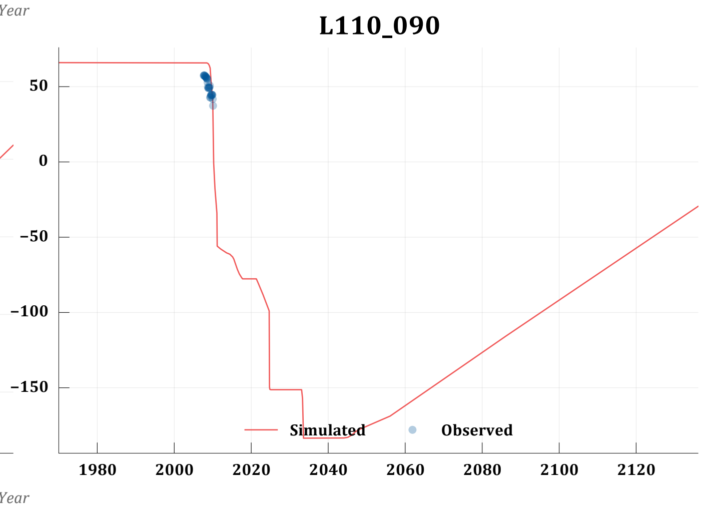
Year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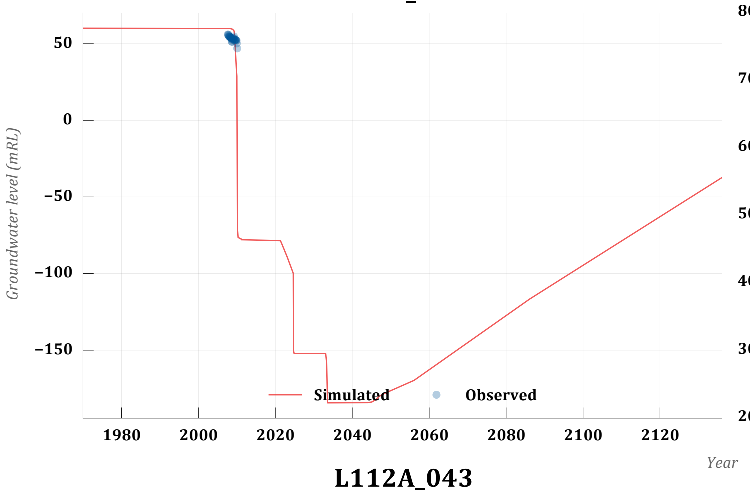
Observed

L110_110



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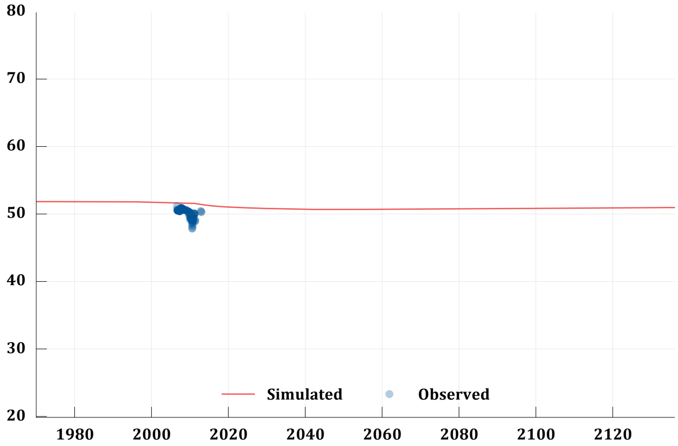

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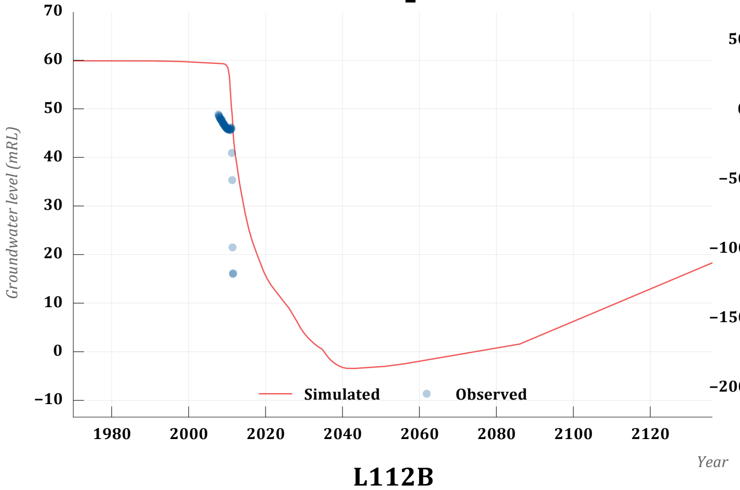

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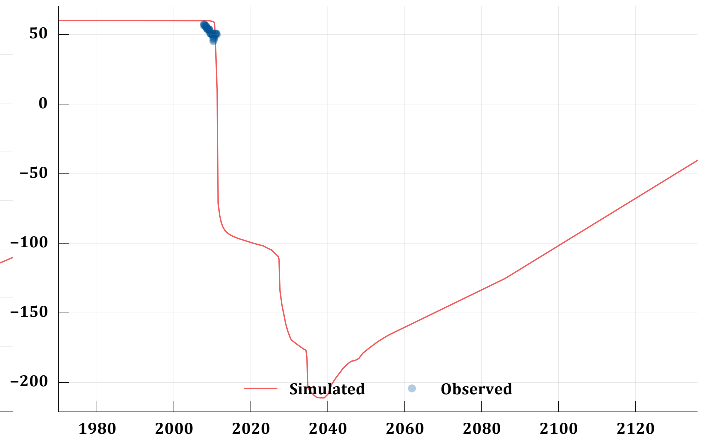

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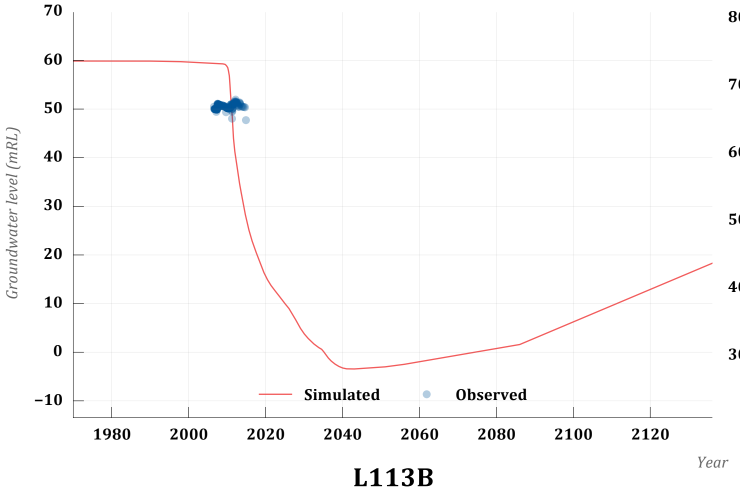

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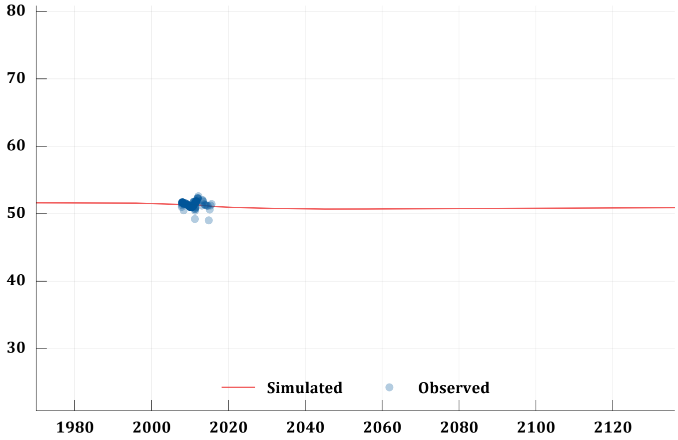

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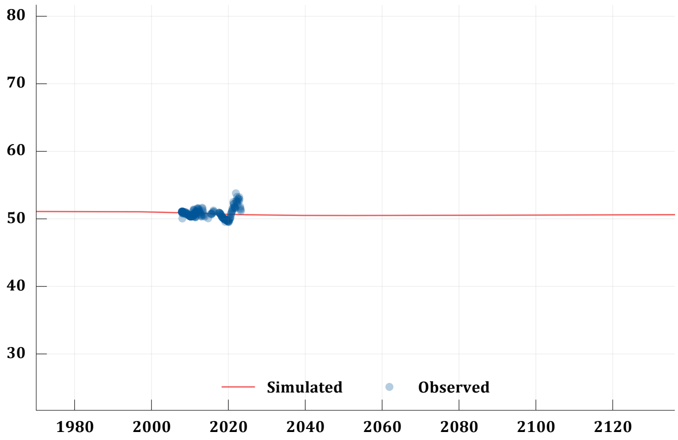

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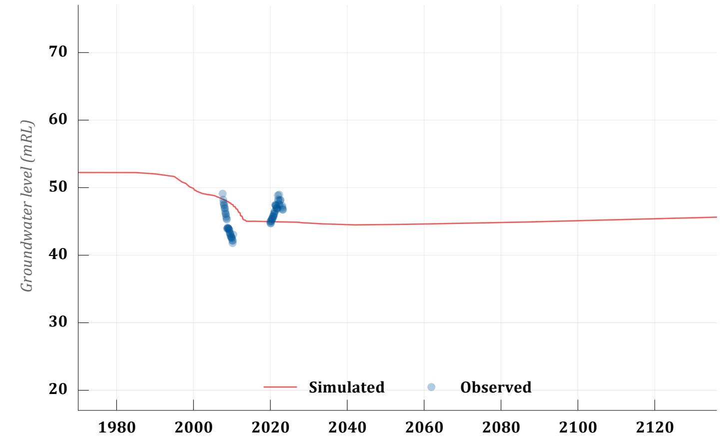

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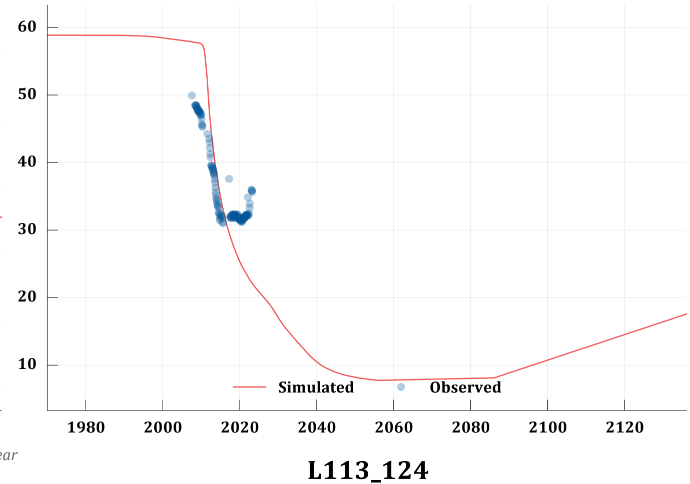

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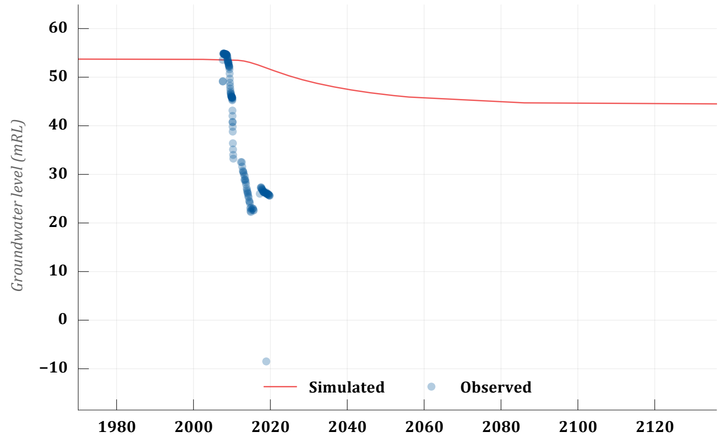

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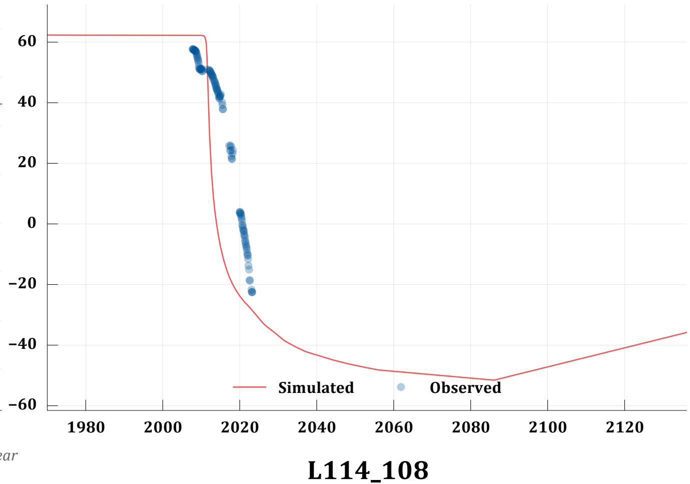

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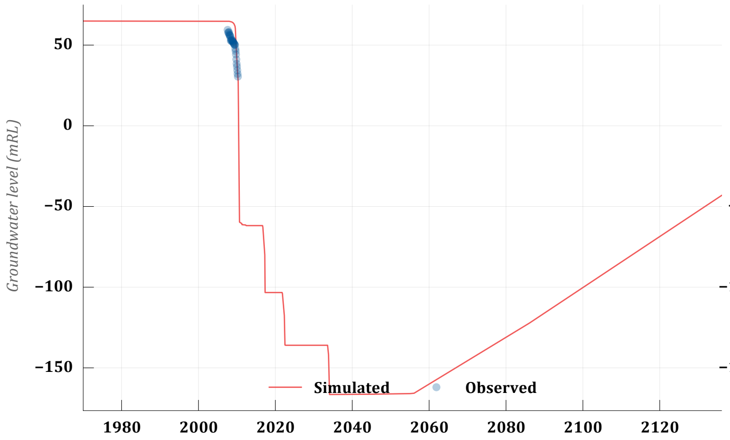
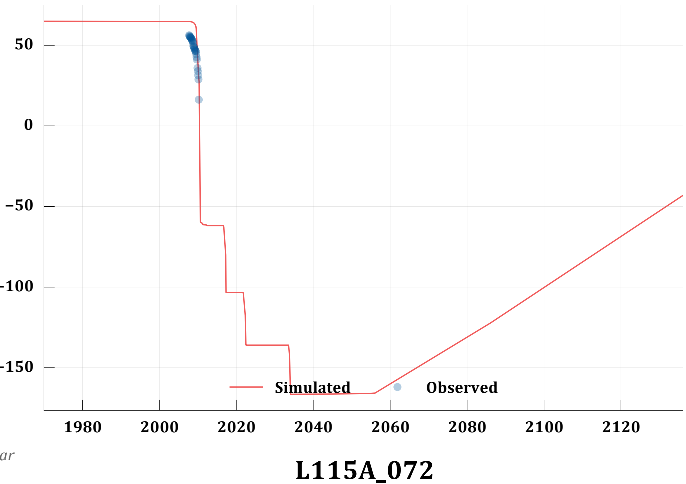
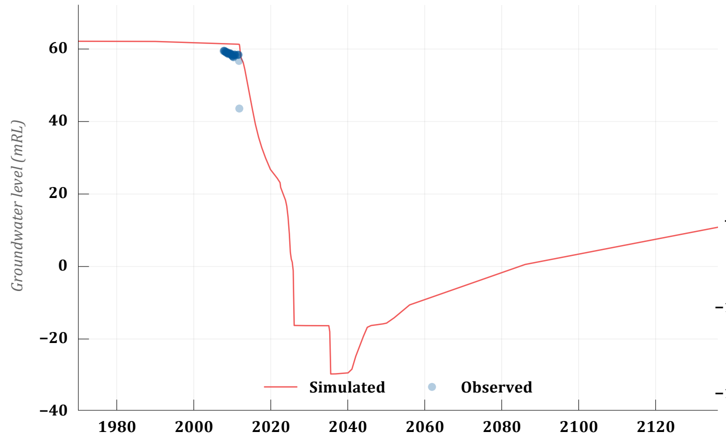


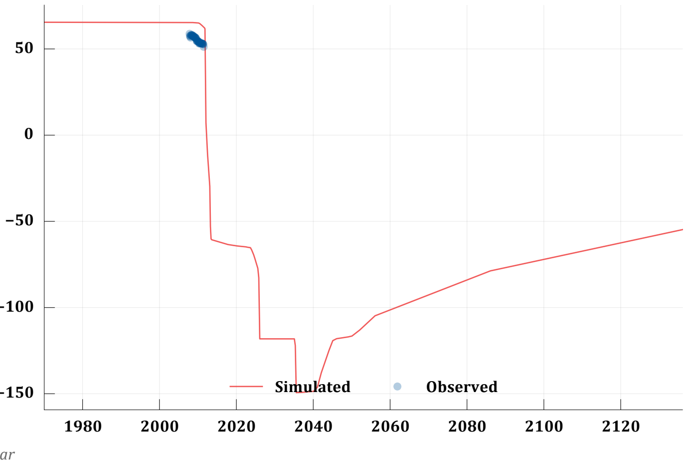
L114_108

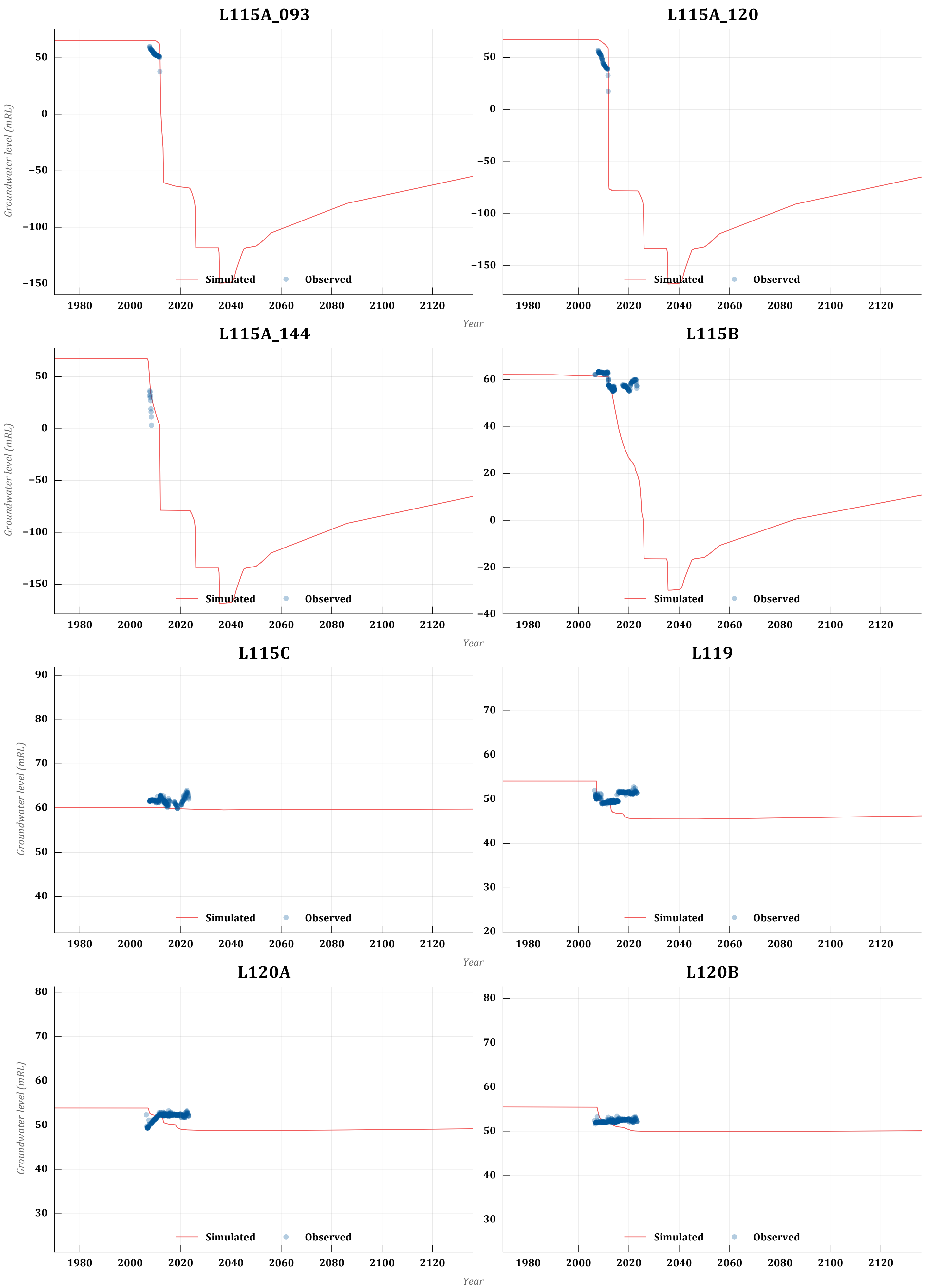


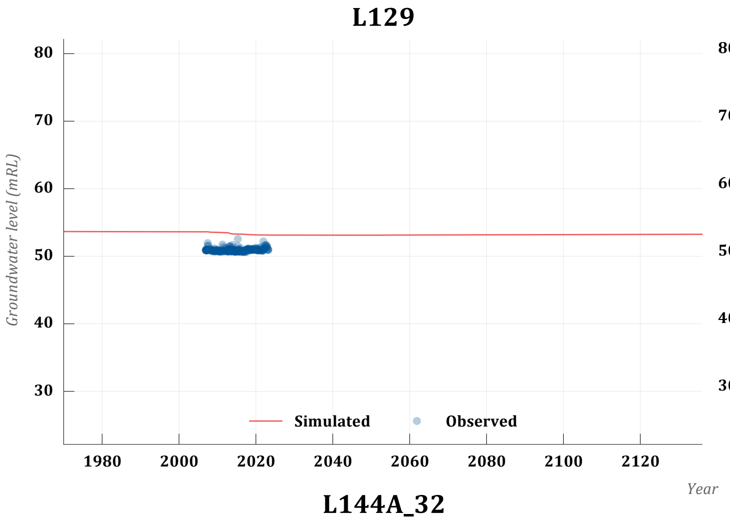
L115A_040

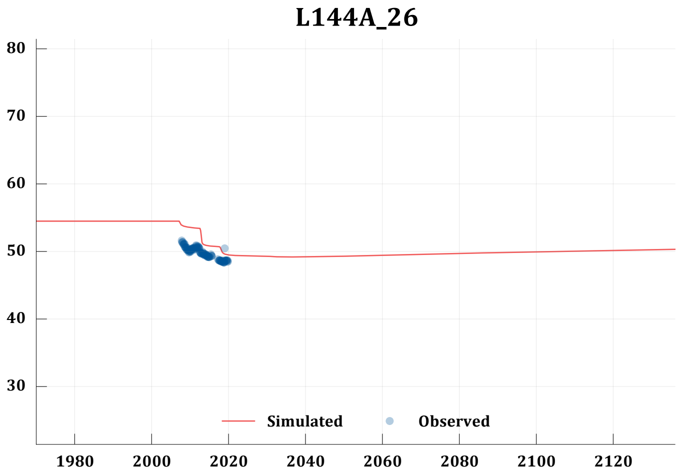


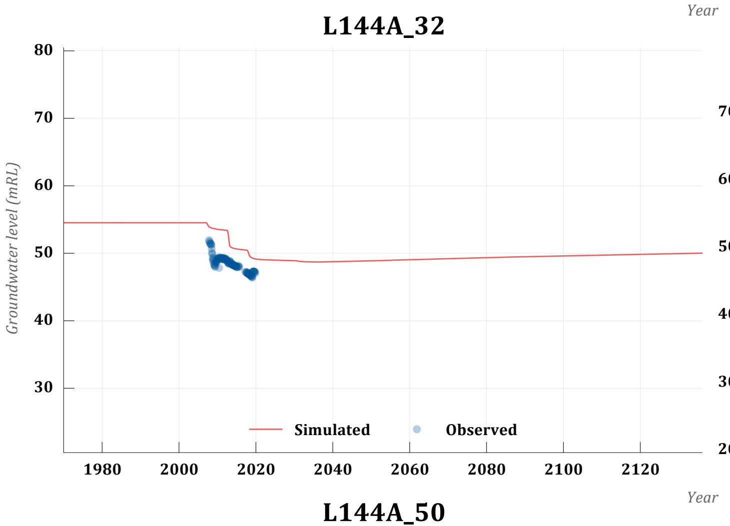
L115A_072

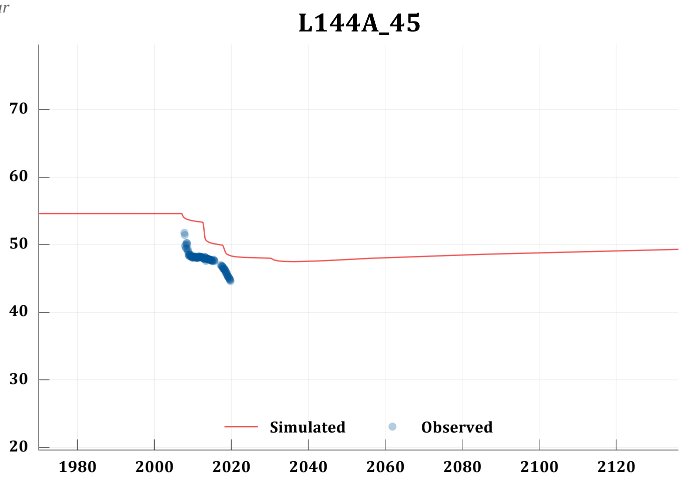


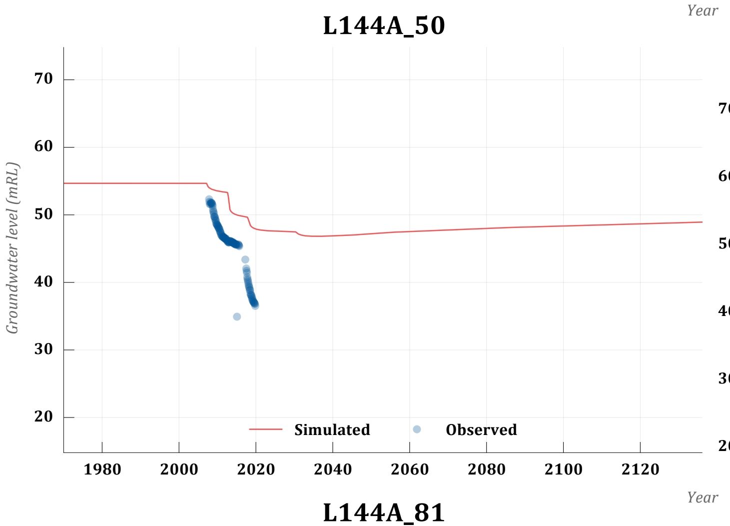

L115A_093
L115A_120
L115A_144
L115B
L115C
L119
L120A
L120B
Groundwater level (mRL)
Year
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120

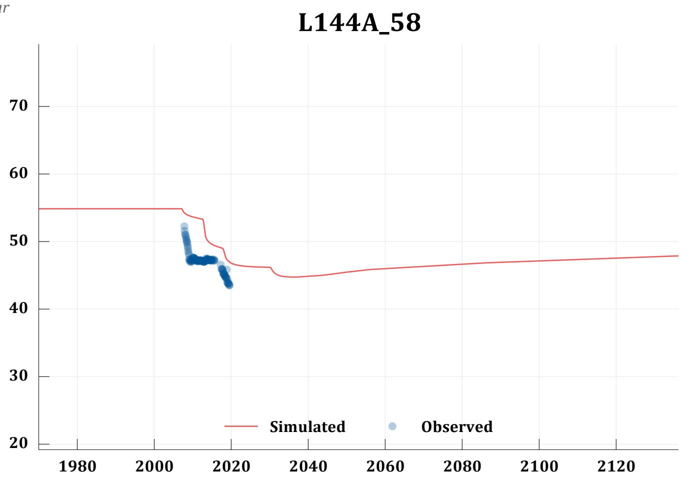

L129
Groundwater level (mRL)
Simulated
Observed
Year

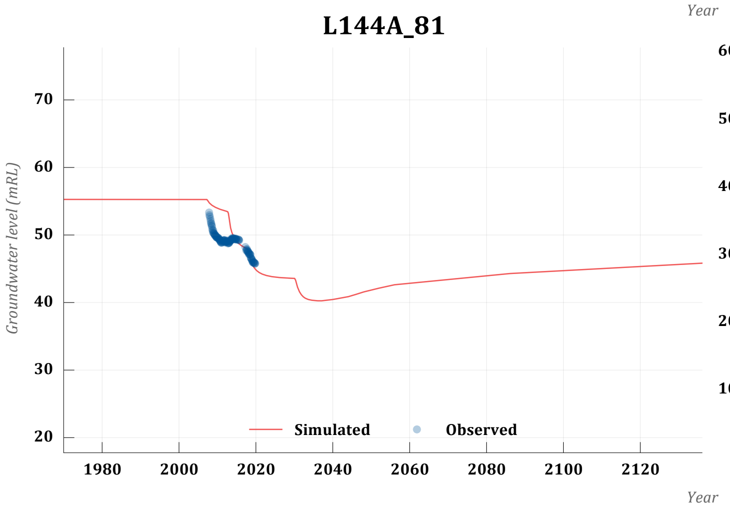

L144A_26
Simulated
Observed

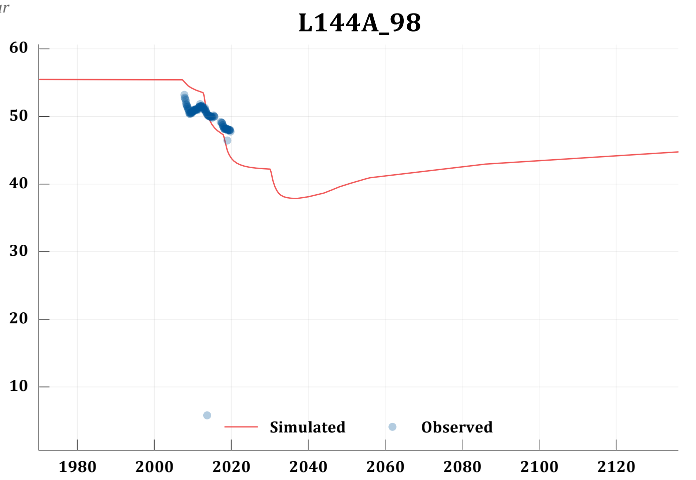

L144A_32
Groundwater level (mRL)
Simulated
Observed
Year

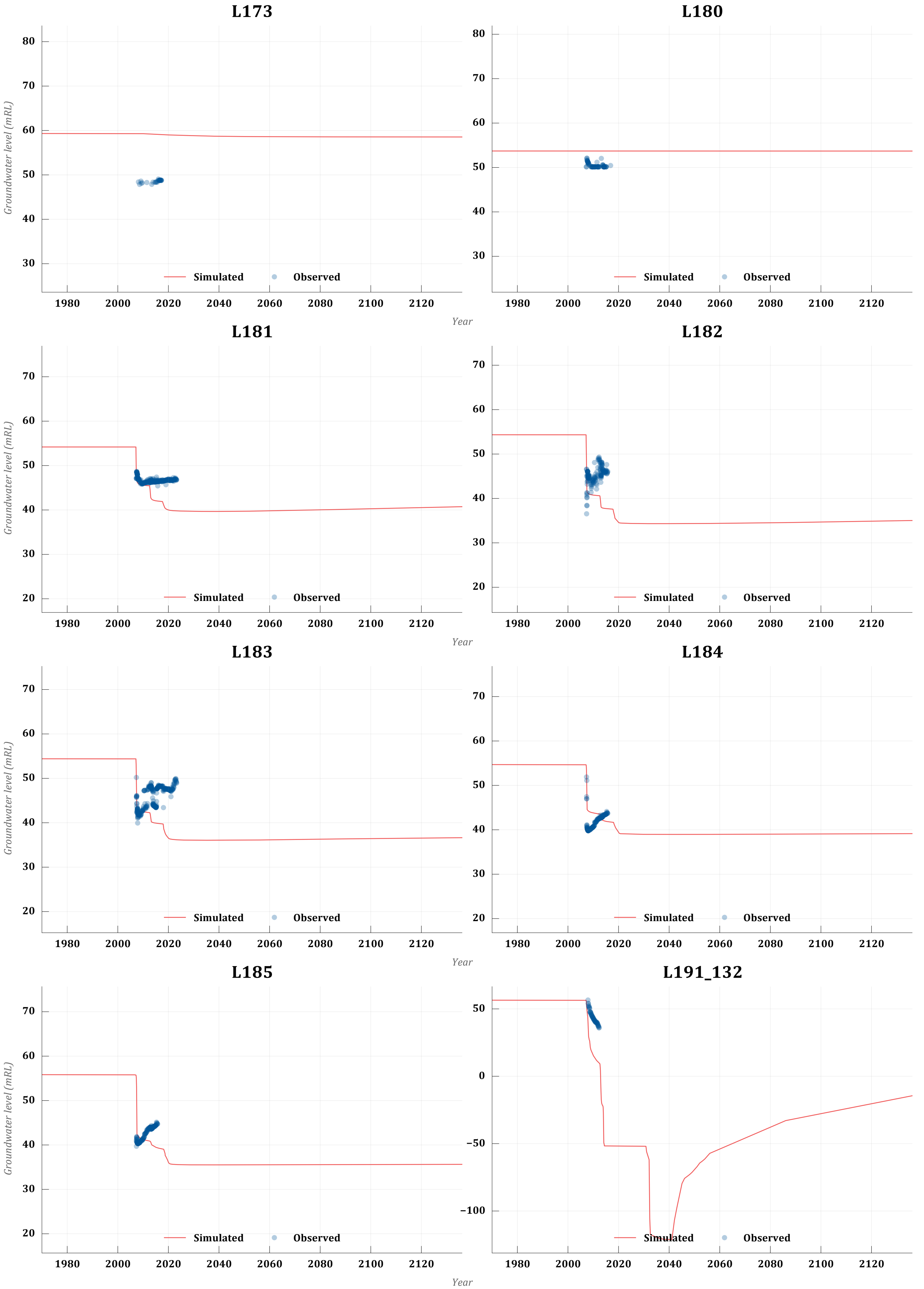

L144A_45
Simulated
Observed


L144A_50
Groundwater level (mRL)
Simulated
Observed
Year

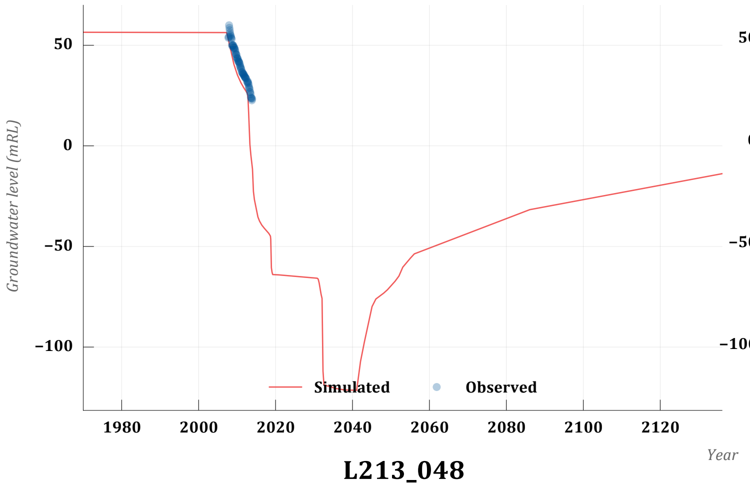

L144A_58
Simulated
Observed


L144A_81
Groundwater level (mRL)
Simulated
Observed
Year

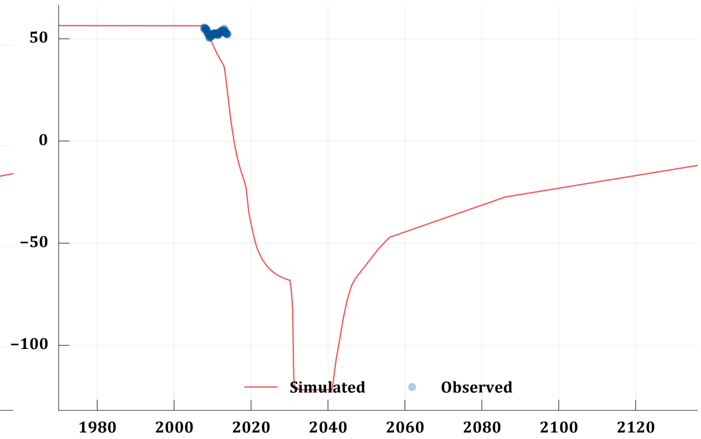

L144A_98
Simulated
Observed


L173
L180
L181
L182
L183
L184
L185
L191_132
Groundwater level (mRL)
Year
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120
80
70
60
50
40
30
20
0
−50
−100

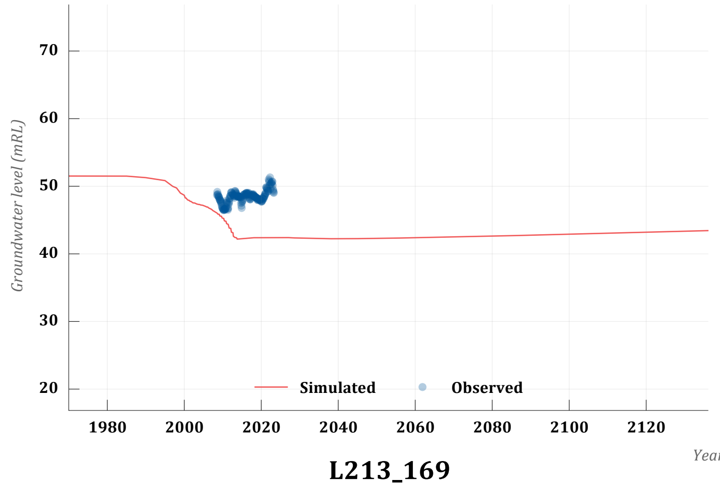
L191_155



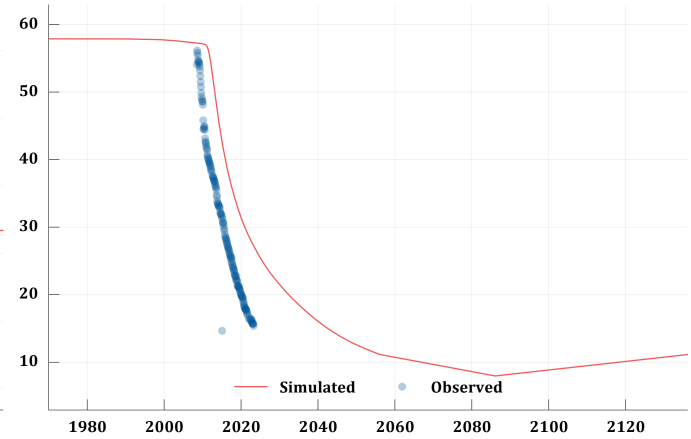
L191_200



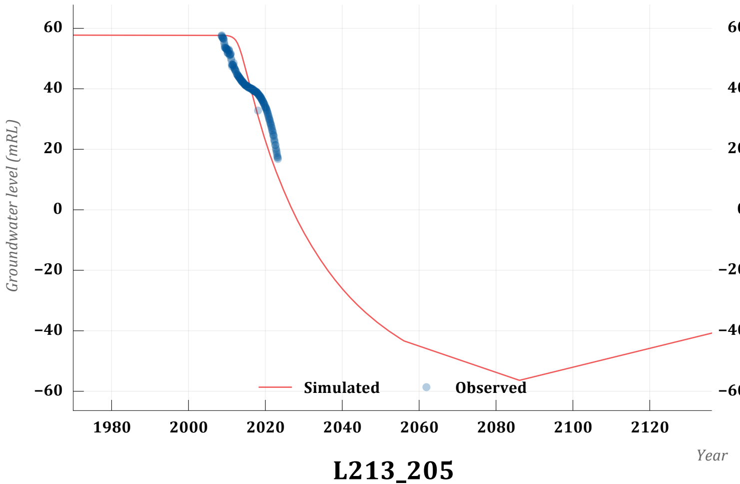
L213_048



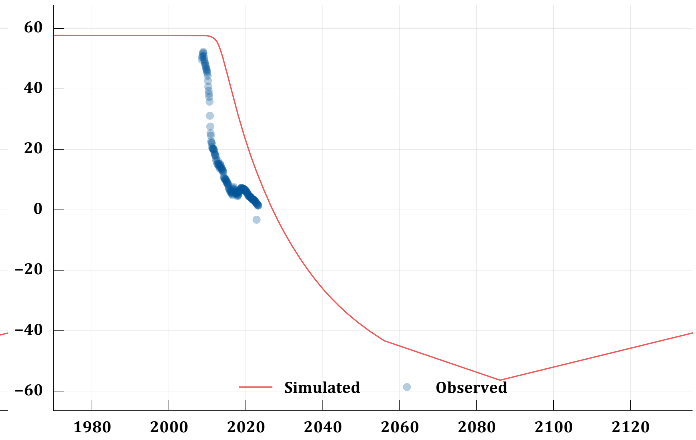
L213_110



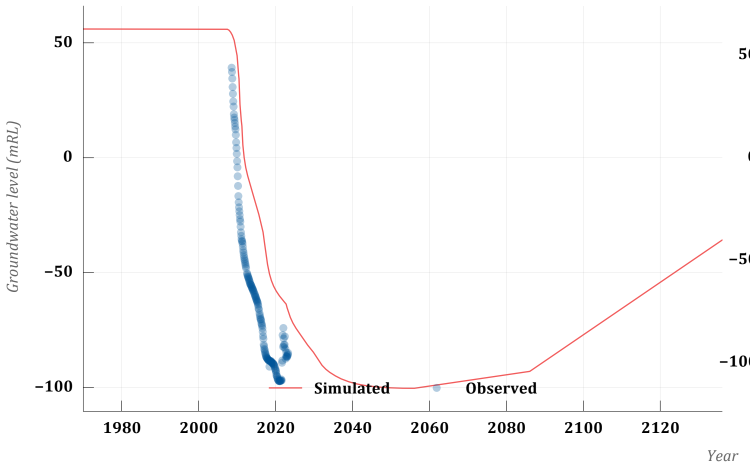
L213_169



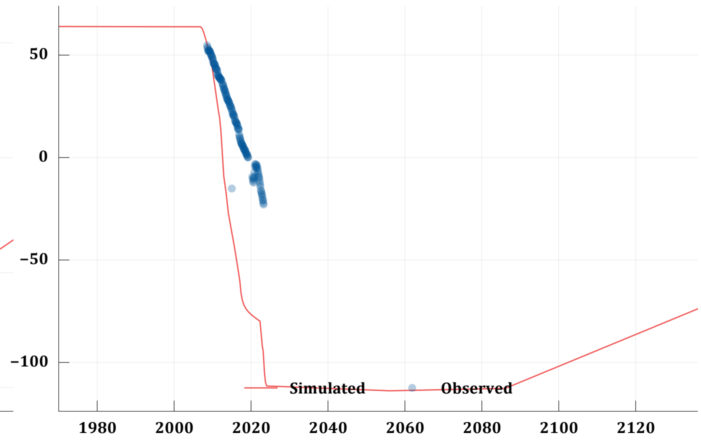
L213_185



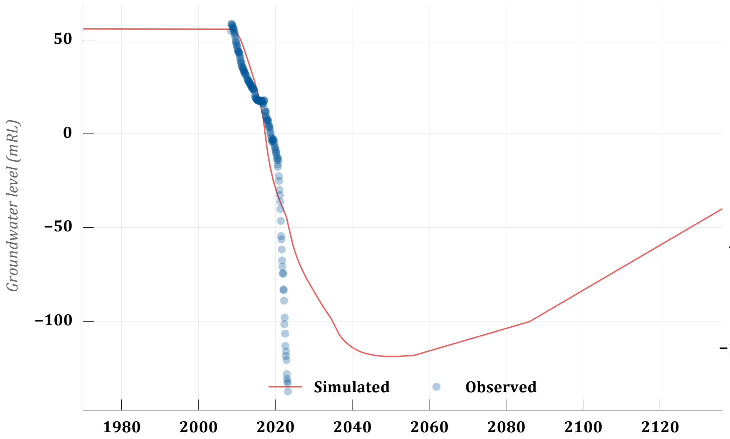
L213_205



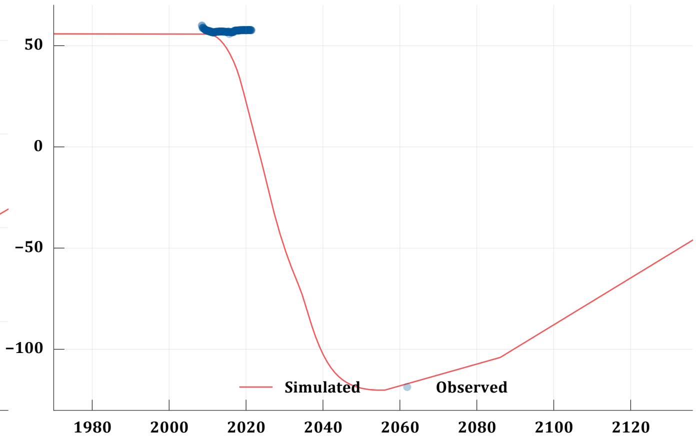
L213_247



L213_275

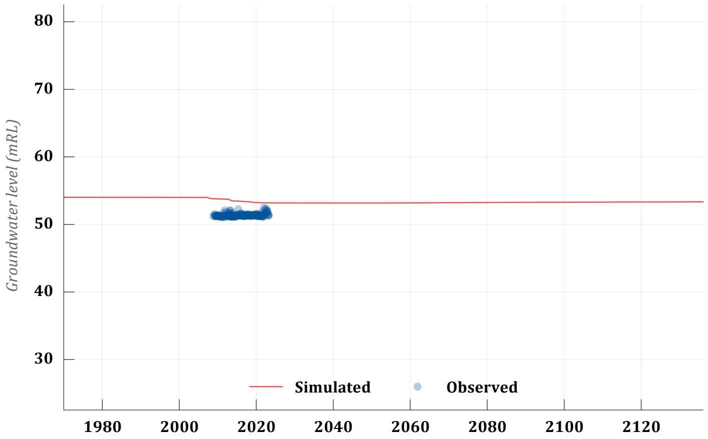


L213_308

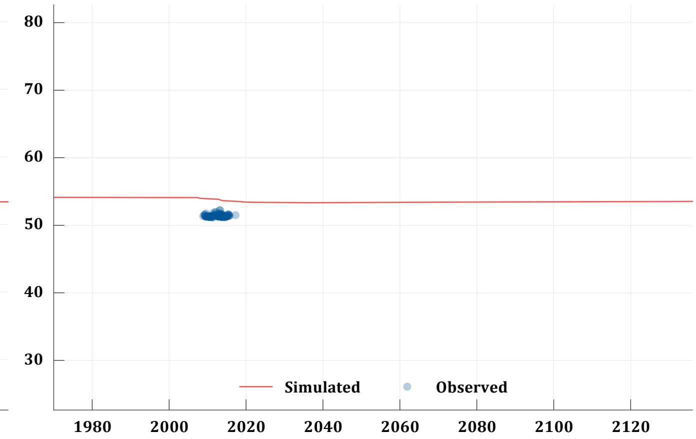


Year

L239

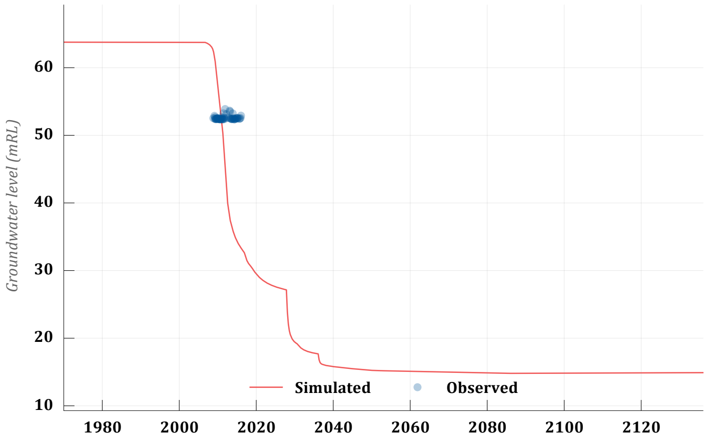


L240

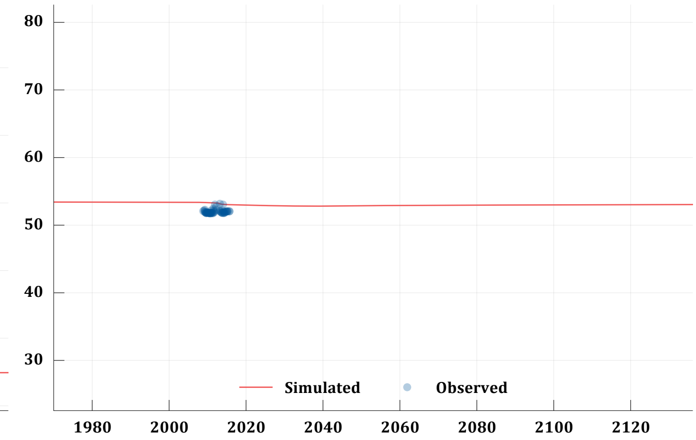


Year

L241

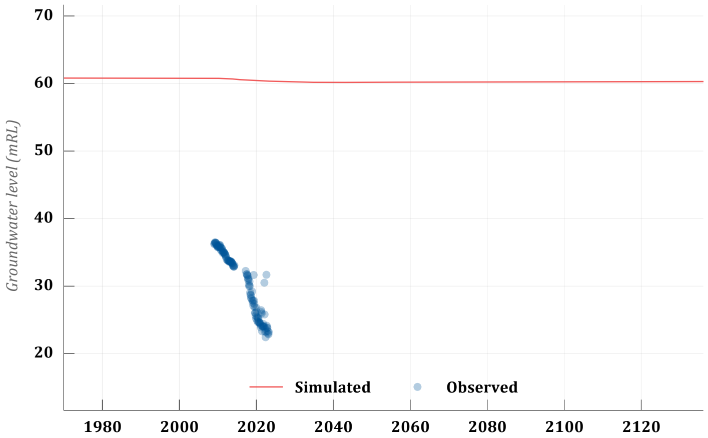


L243

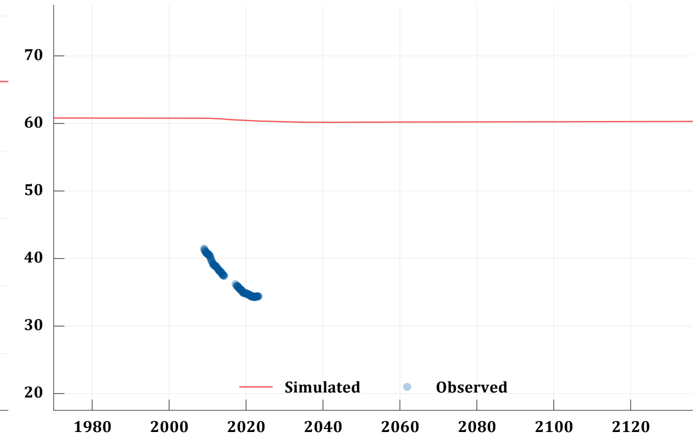


Year

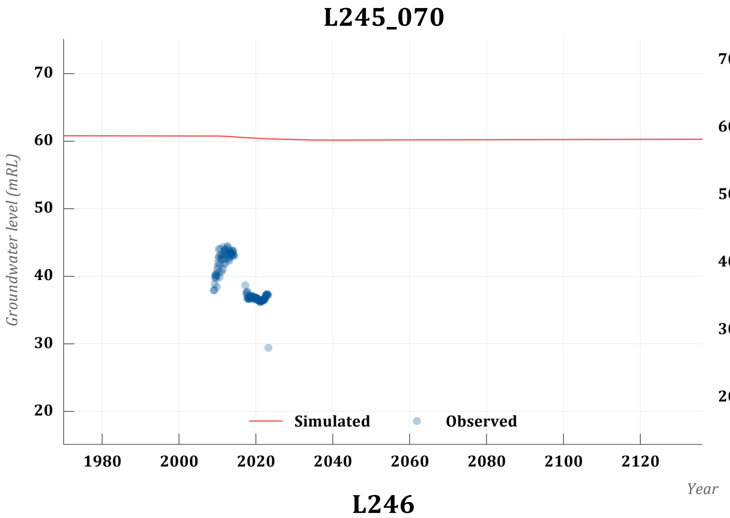
L245_055

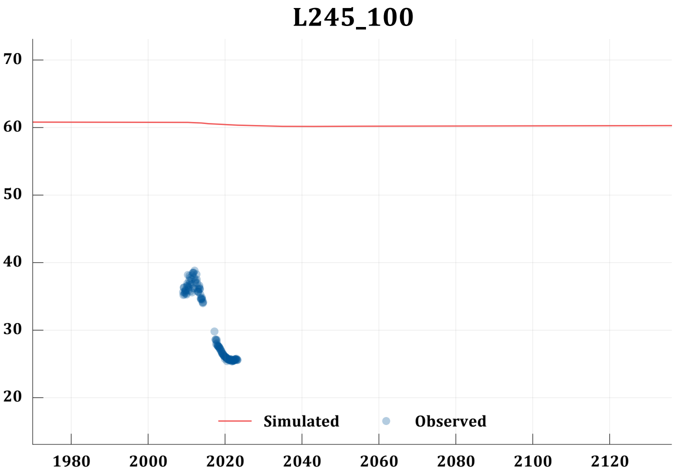


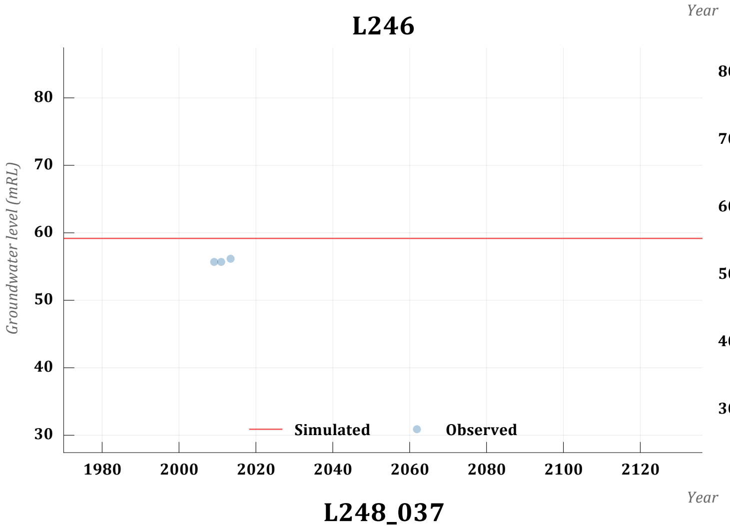
L245_065

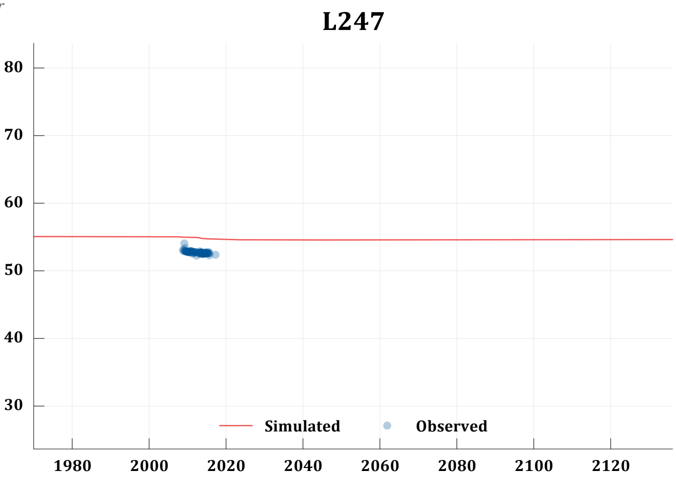


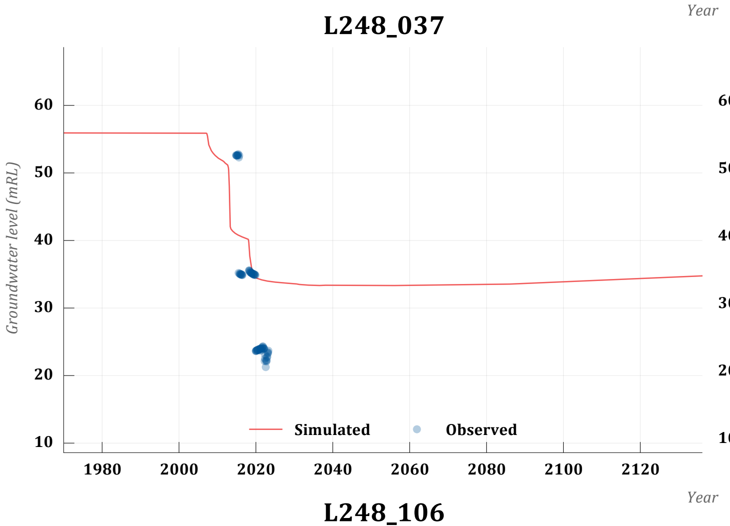
Year

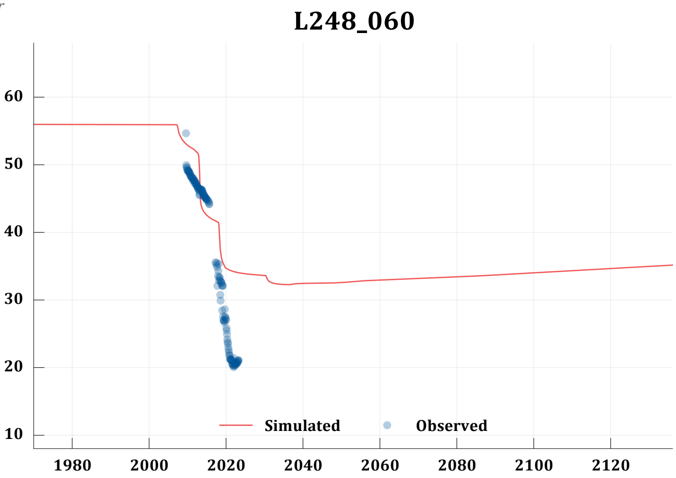

L245_070
Groundwater level (mRL)
70
60
50
40
30
20
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120
Year

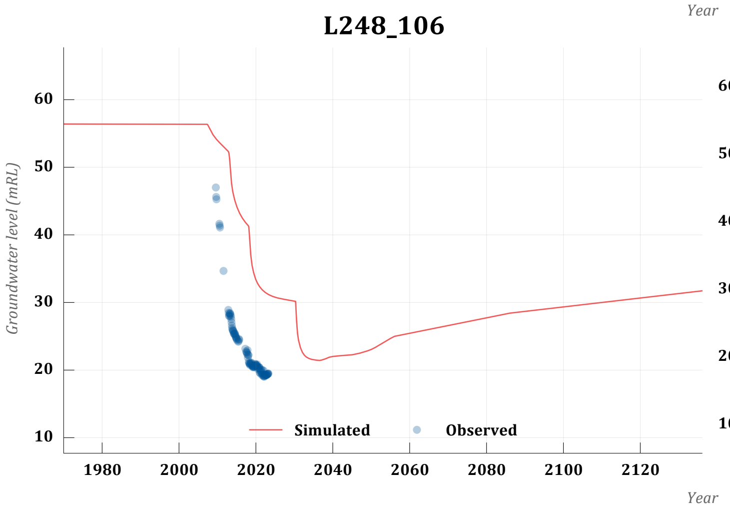

L245_100
70
60
50
40
30
20
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120

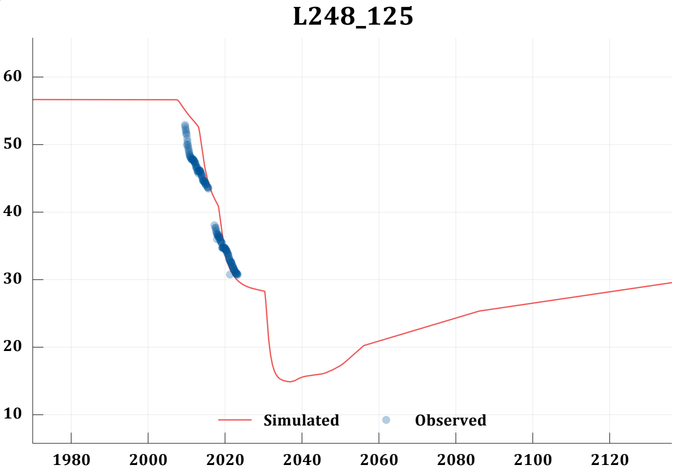

L246
Groundwater level (mRL)
80
70
60
50
40
30
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120
Year


L247
80
70
60
50
40
30
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120

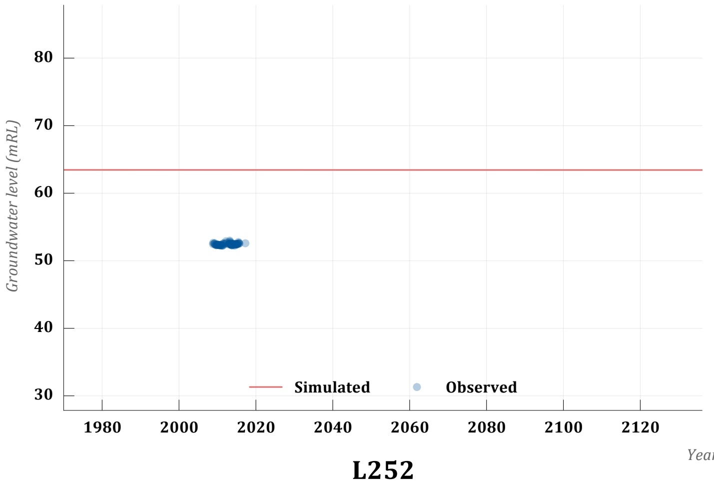

L248_037
Groundwater level (mRL)
60
50
40
30
20
10
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120
Year


L248_060
60
50
40
30
20
10
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120

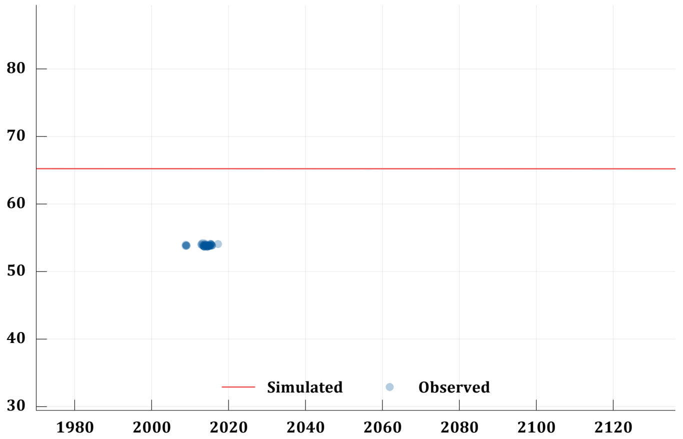

L248_106
Groundwater level (mRL)
60
50
40
30
20
10
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120
Year


L248_125
60
50
40
30
20
10
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120

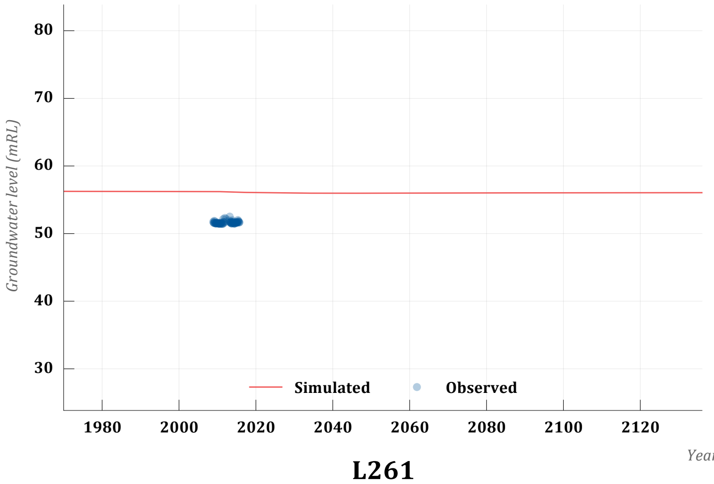
L249



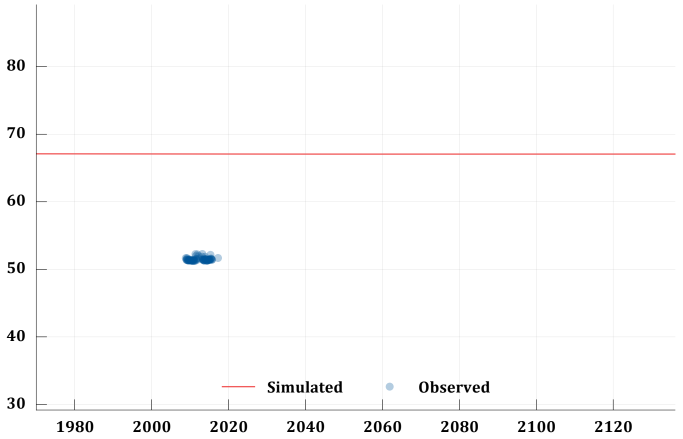
L250



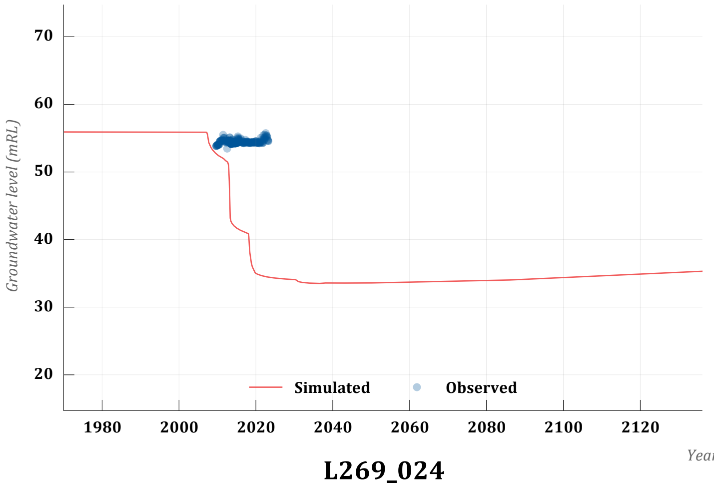
L252



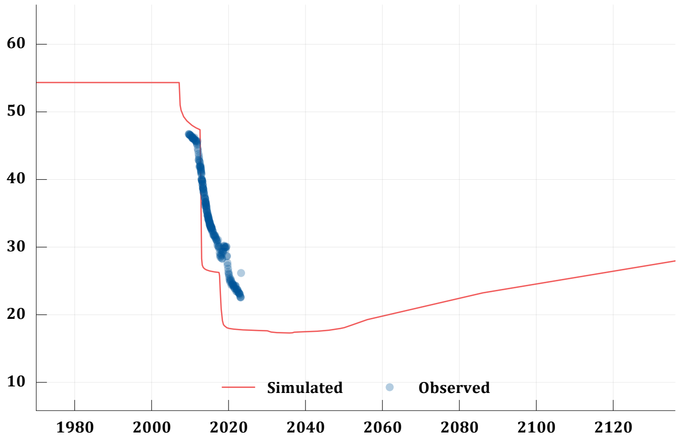
L253



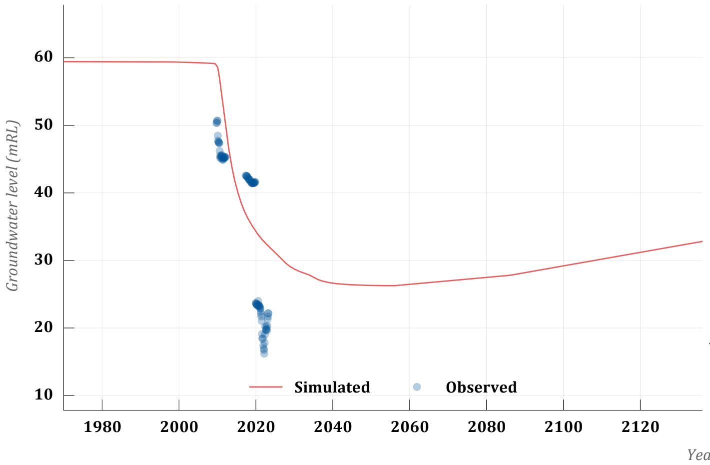
L261



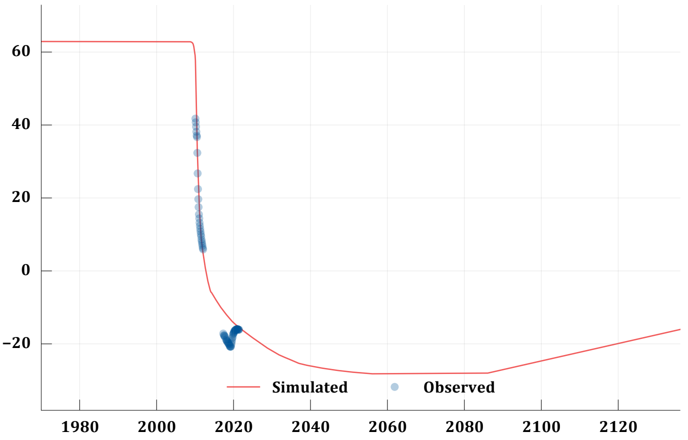
L262

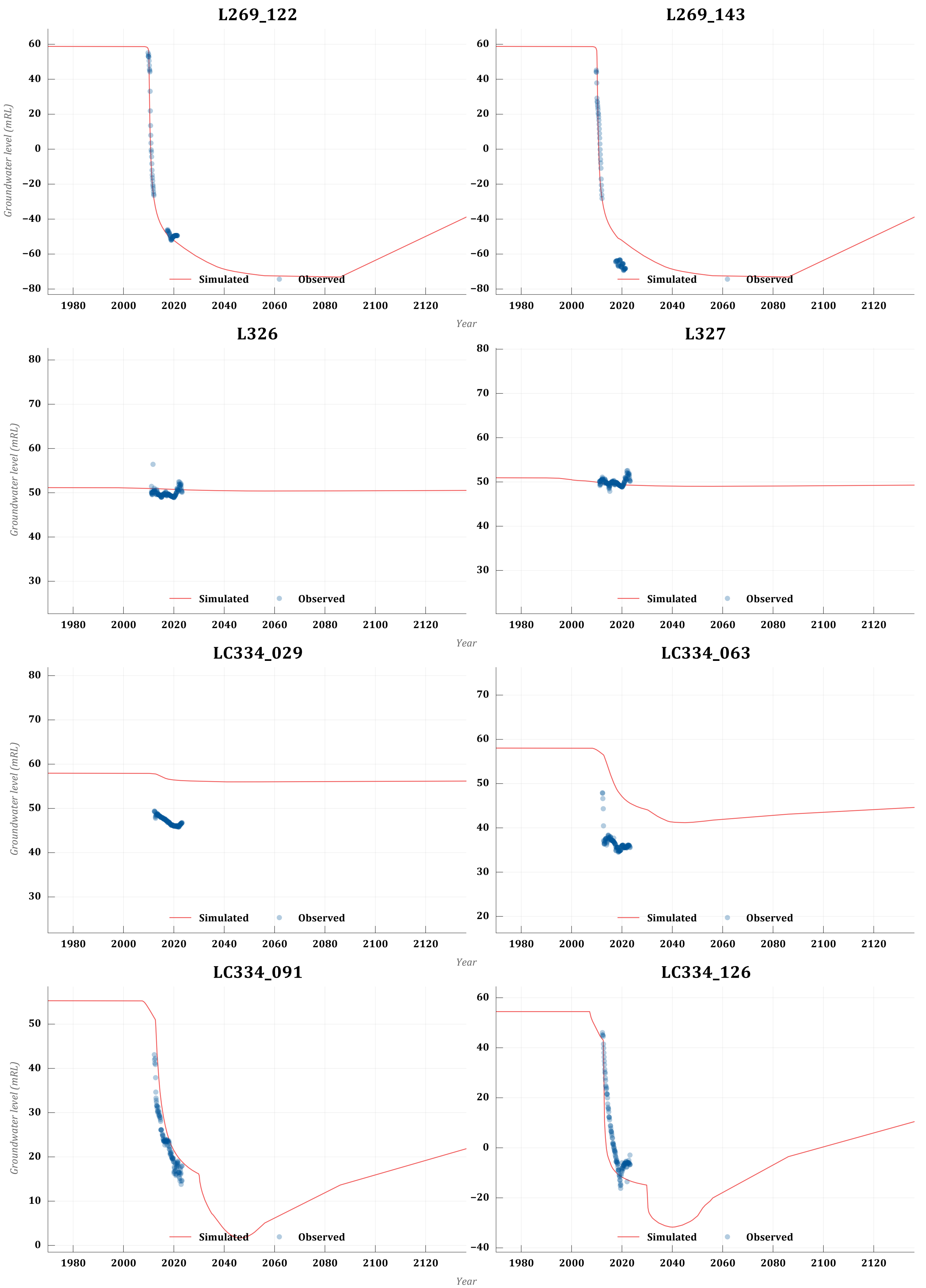


L269_024

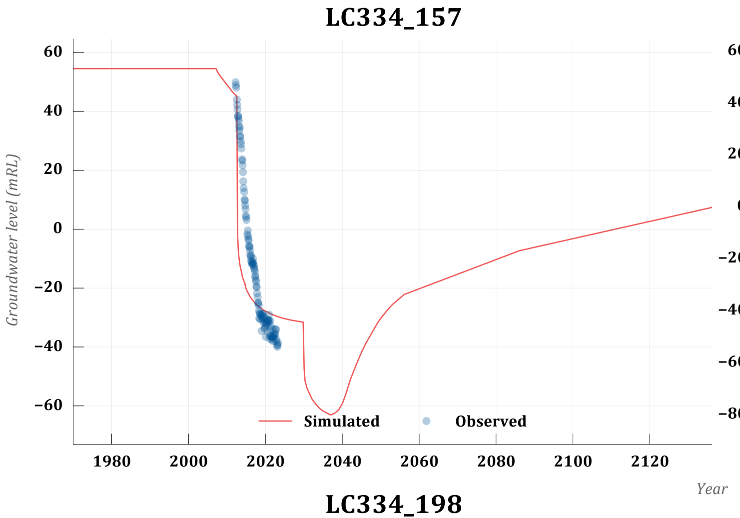


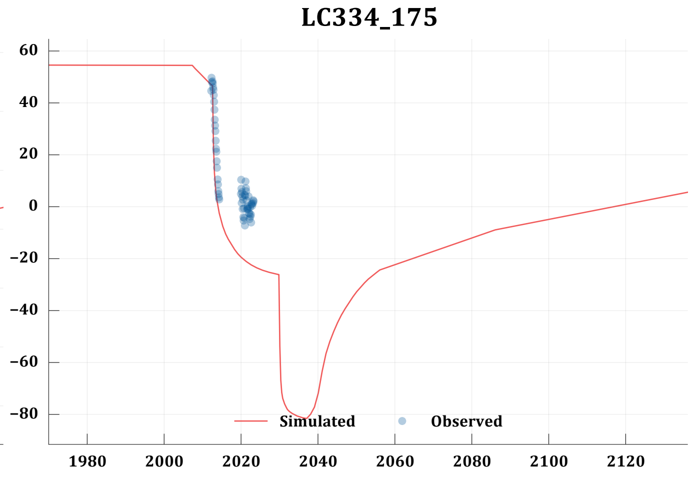
L269_092

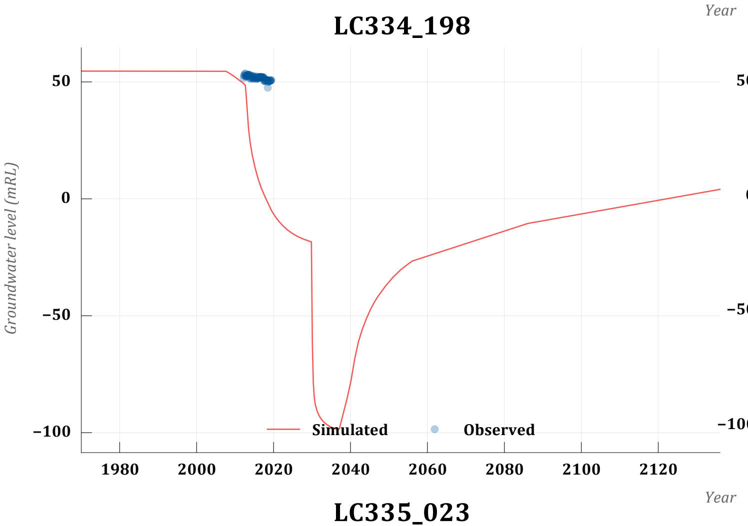


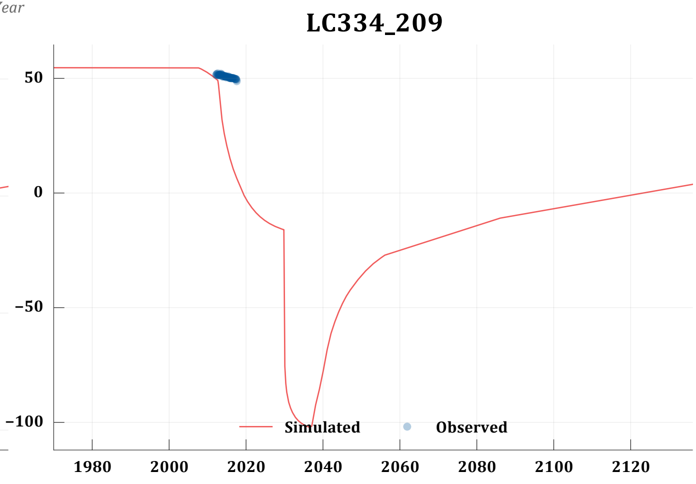


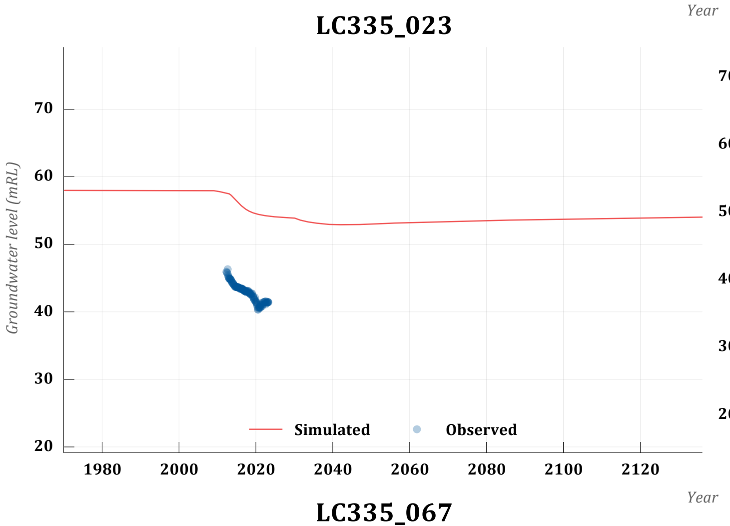
L269_122
L269_143
L326
L327
LC334_029
LC334_063
LC334_091
LC334_126
Groundwater level (mRL)
Year
Simulated
Observed

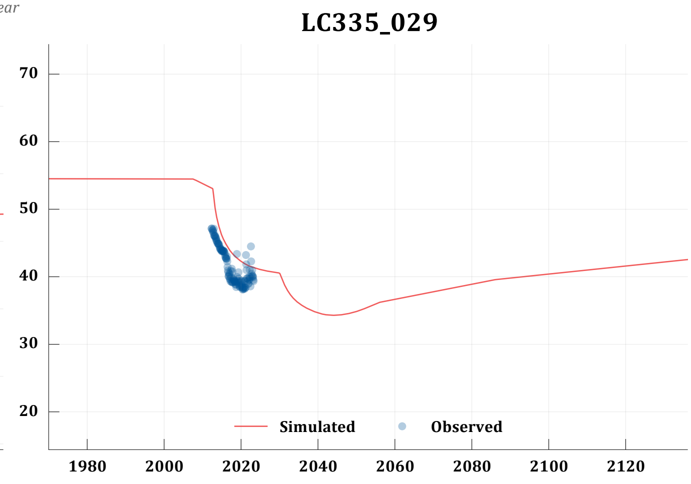

LC334_157
Groundwater level (mRL)
Simulated
Observed
Year

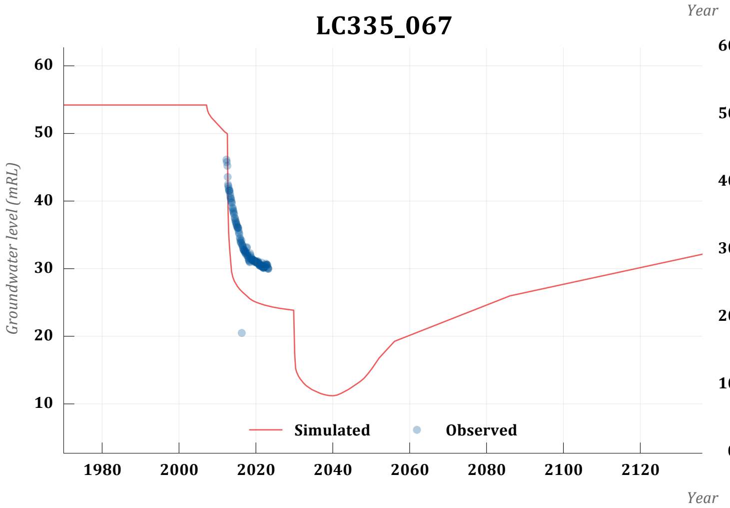

LC334_175
Simulated
Observed

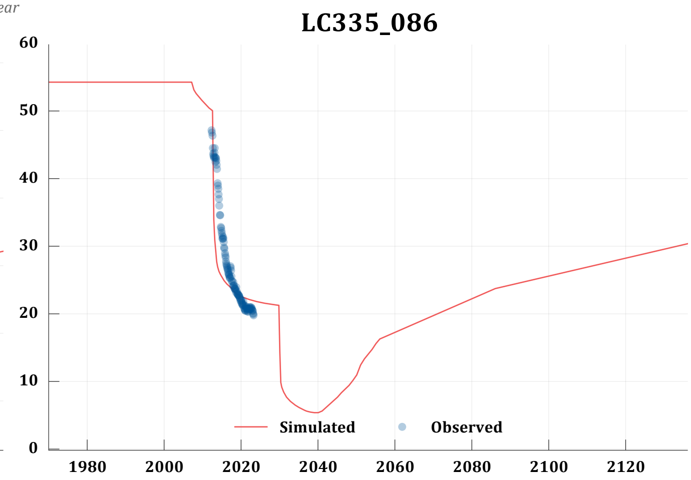

LC334_198
Groundwater level (mRL)
Simulated
Observed
Year

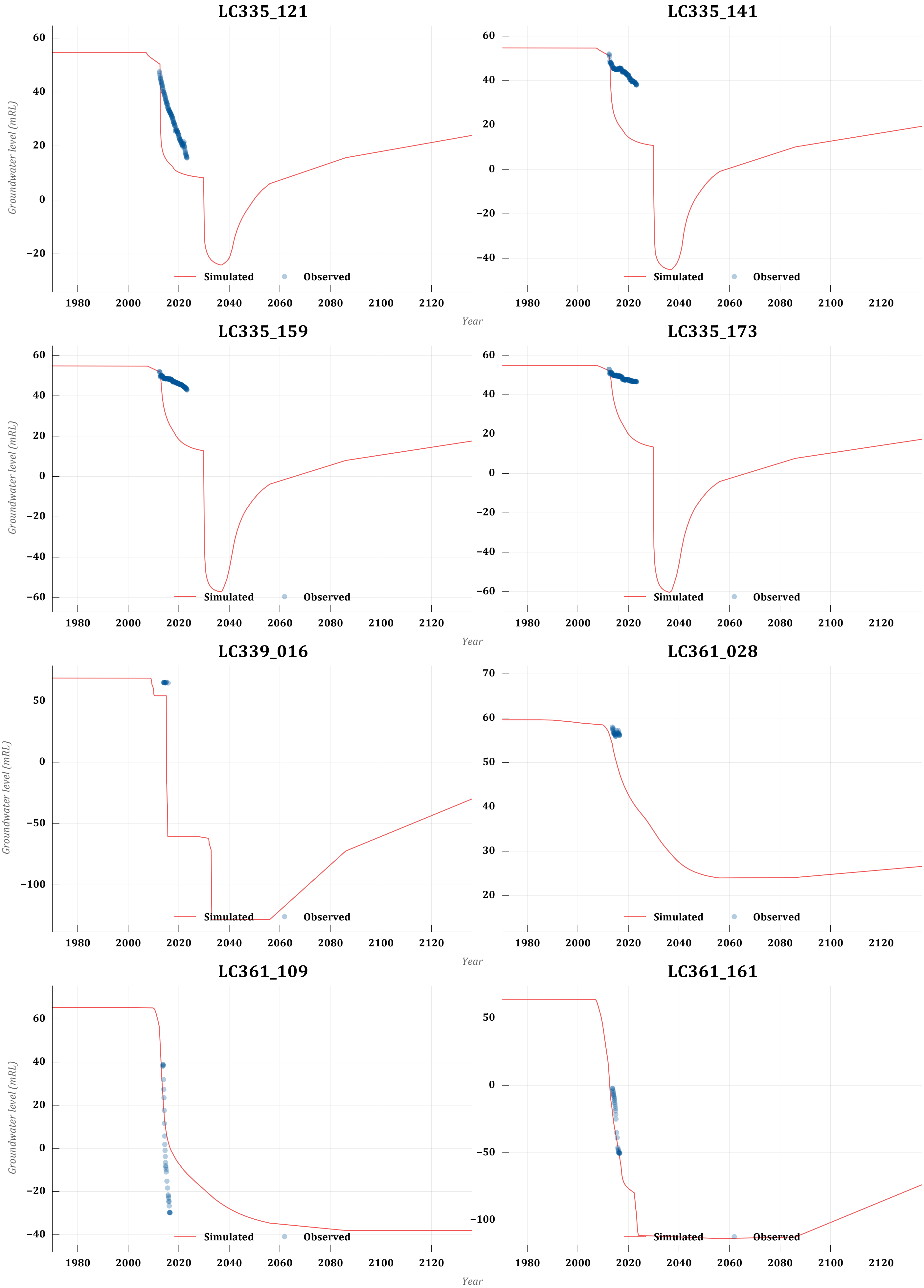

LC334_209
Simulated
Observed

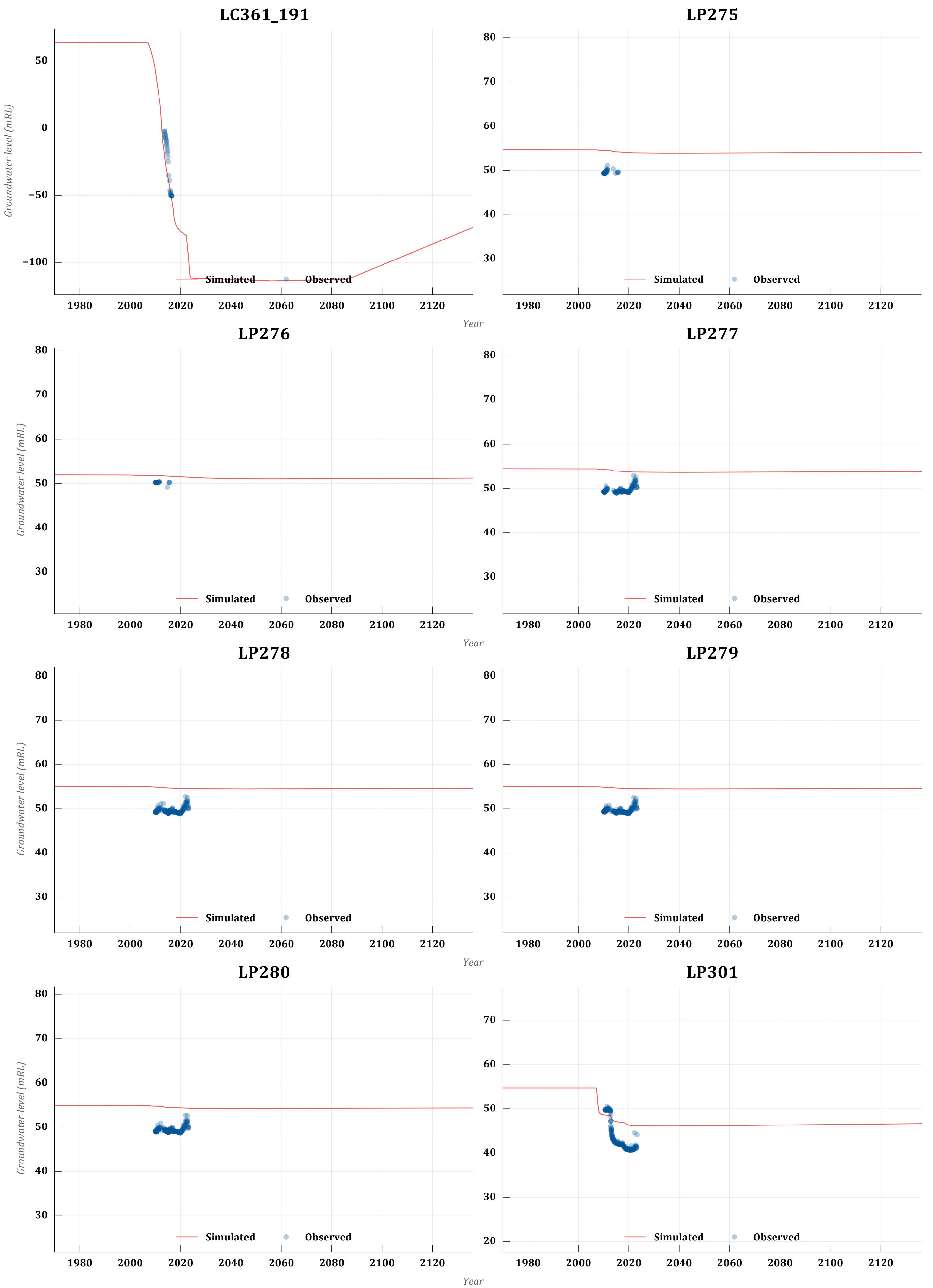

LC335_023
Groundwater level (mRL)
Simulated
Observed
Year

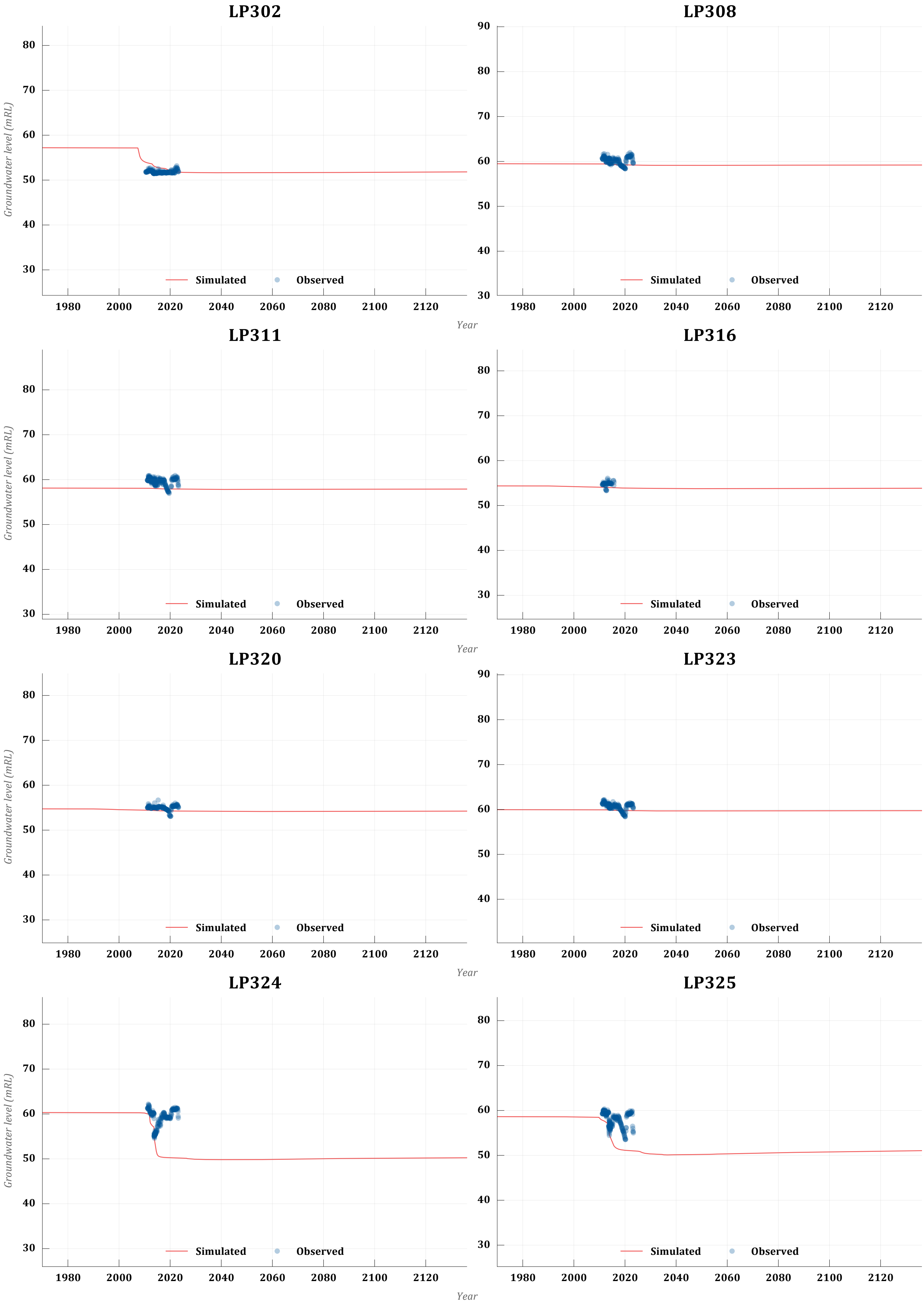

LC335_029
Simulated
Observed

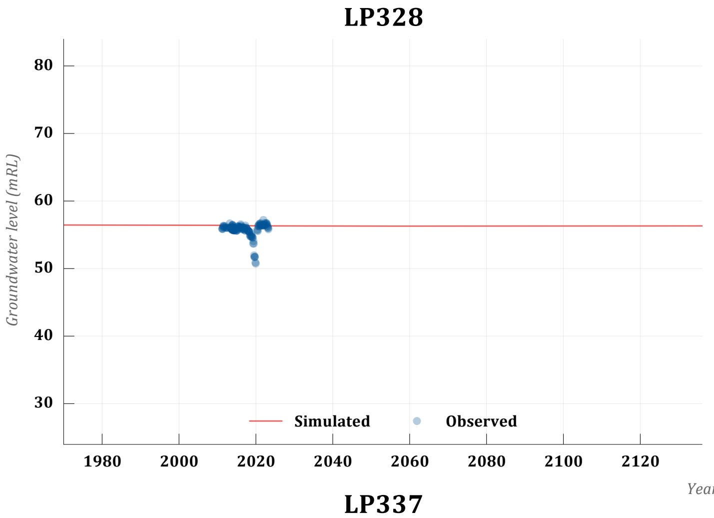

LC335_067
Groundwater level (mRL)
Simulated
Observed
Year

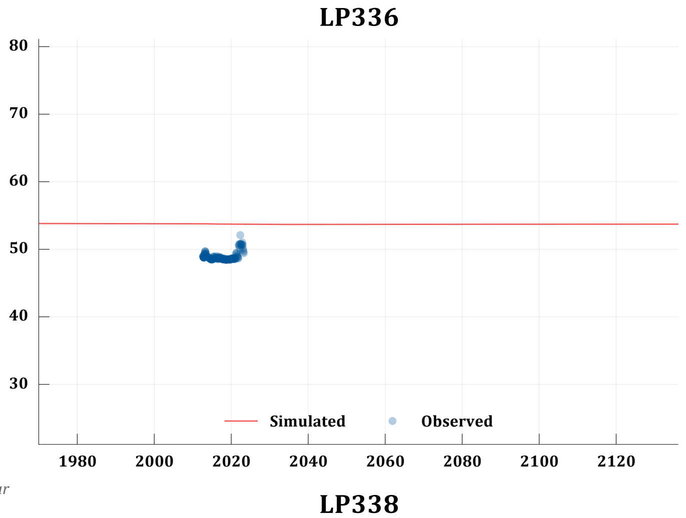

LC335_086
Simulated
Observed

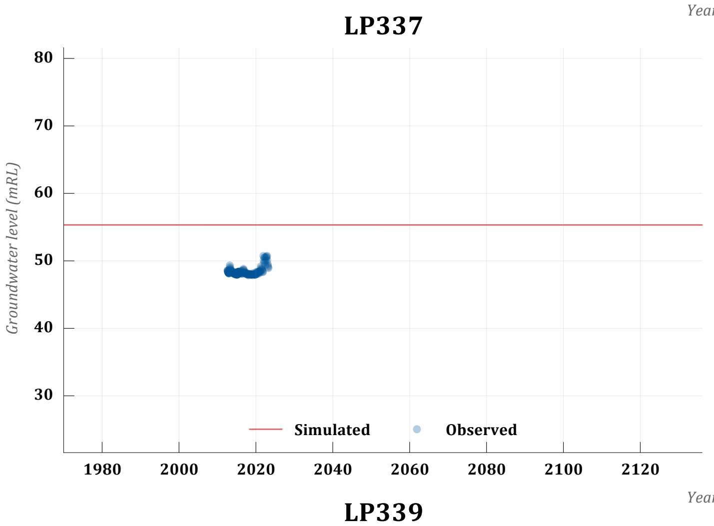

LC335_121
LC335_141
LC335_159
LC335_173
LC339_016
LC361_028
LC361_109
LC361_161
Groundwater level (mRL)
Year
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120

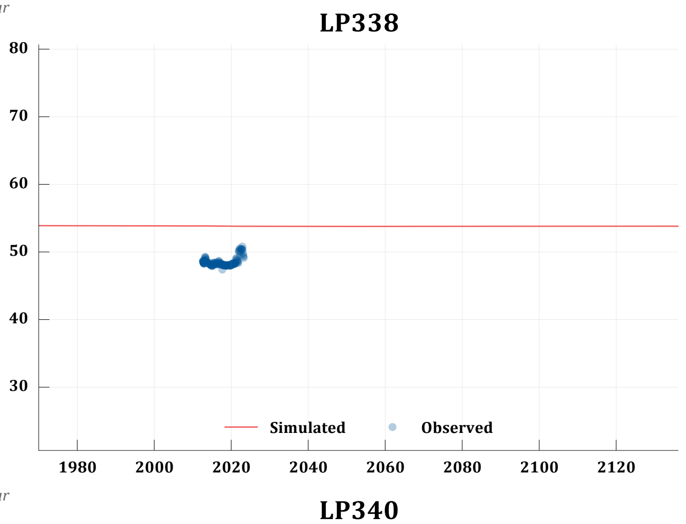

LC361_191
LP275
LP276
LP277
LP278
LP279
LP280
LP301
Groundwater level (mRL)
Year
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120

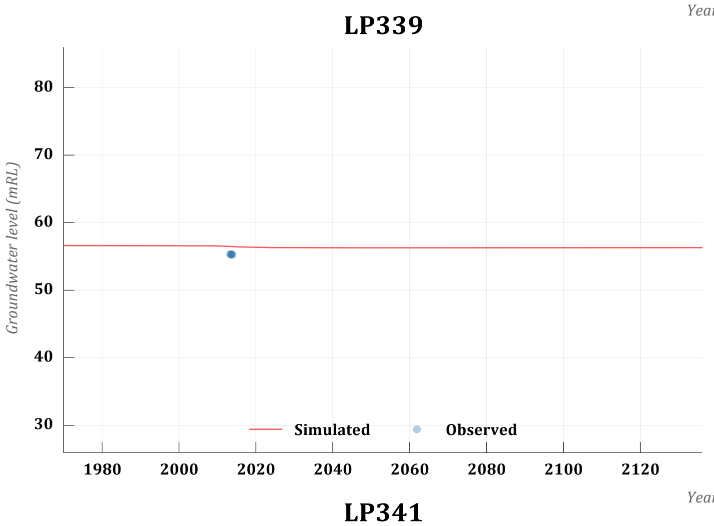

LP302
LP308
LP311
LP316
LP320
LP323
LP324
LP325
Groundwater level (mRL)
Year
1980
2000
2020
2040
2060
2080
2100
2120
30
40
50
60
70
80
90
Simulated
Observed

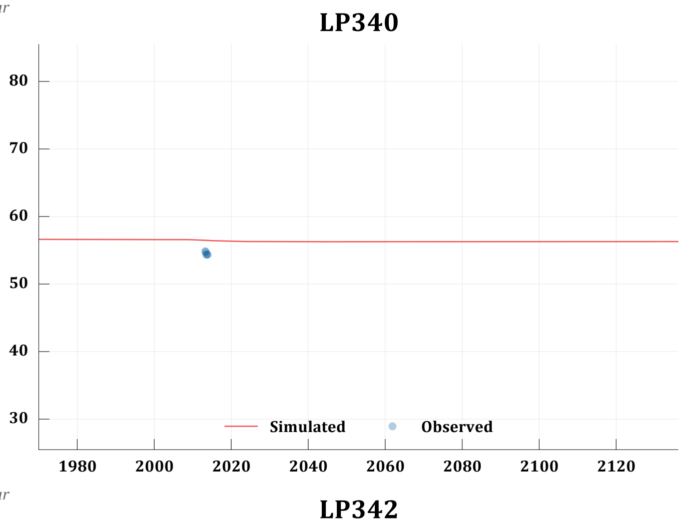

LP328
Groundwater level (mRL)
80
70
60
50
40
30
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120

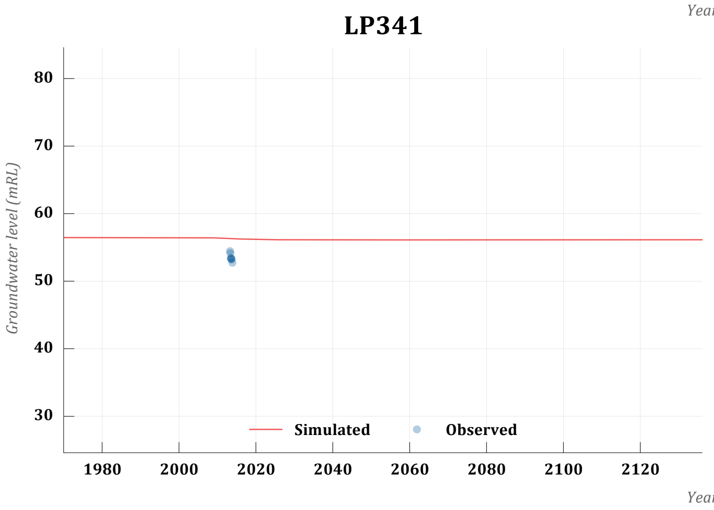

LP336
80
70
60
50
40
30
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120
Year

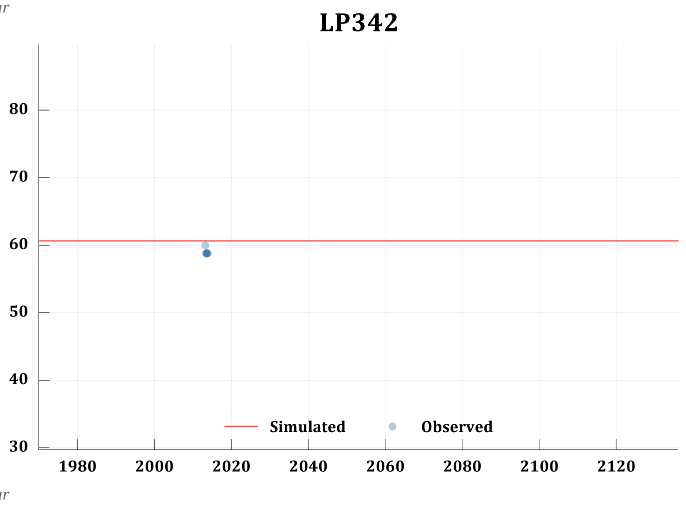

LP337
Groundwater level (mRL)
80
70
60
50
40
30
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120


LP338
80
70
60
50
40
30
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120
Year

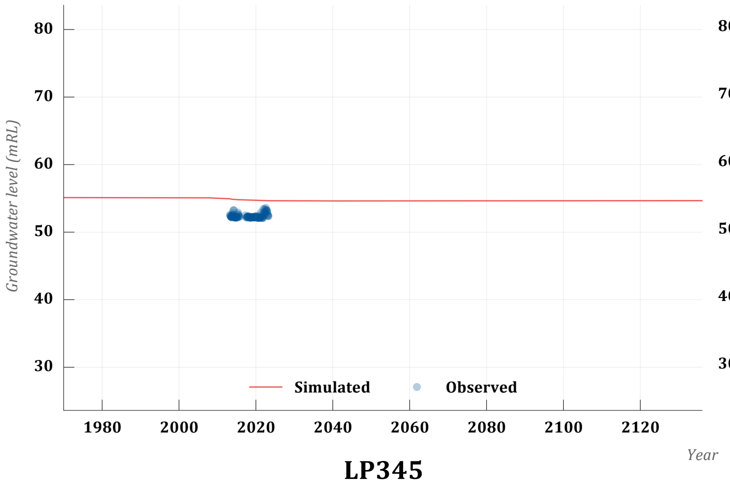

LP339
Groundwater level (mRL)
80
70
60
50
40
30
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120


LP340
80
70
60
50
40
30
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120
Year

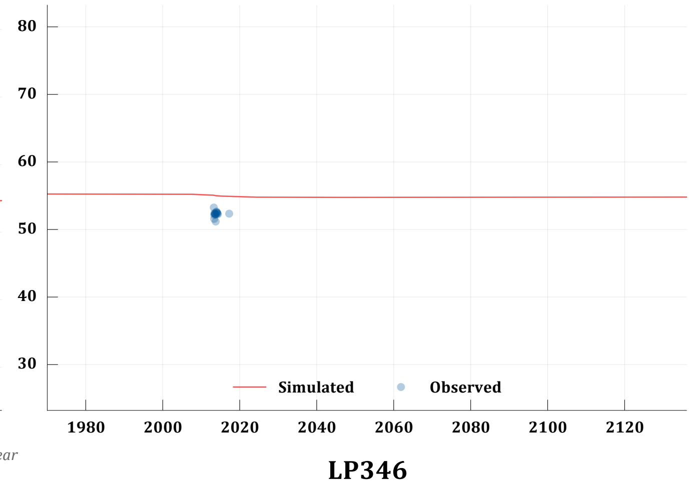

LP341
Groundwater level (mRL)
80
70
60
50
40
30
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120


LP342
80
70
60
50
40
30
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120
Year

LP343



LP344



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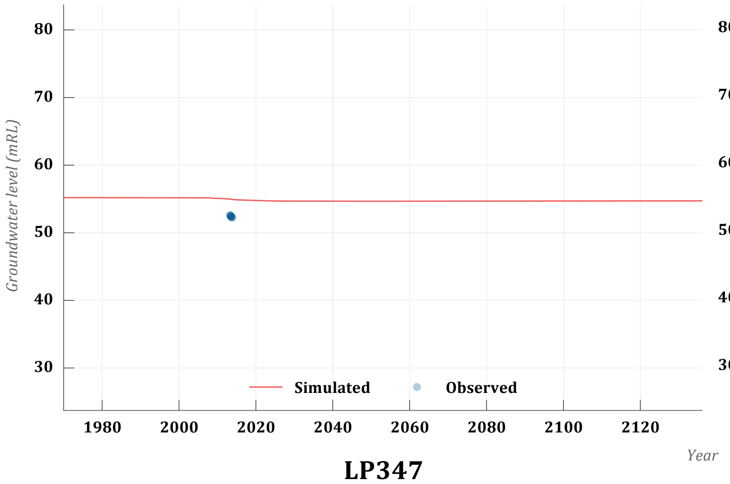

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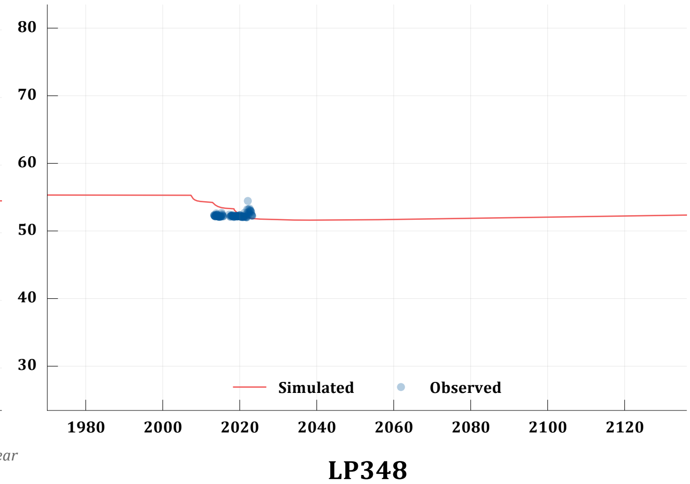

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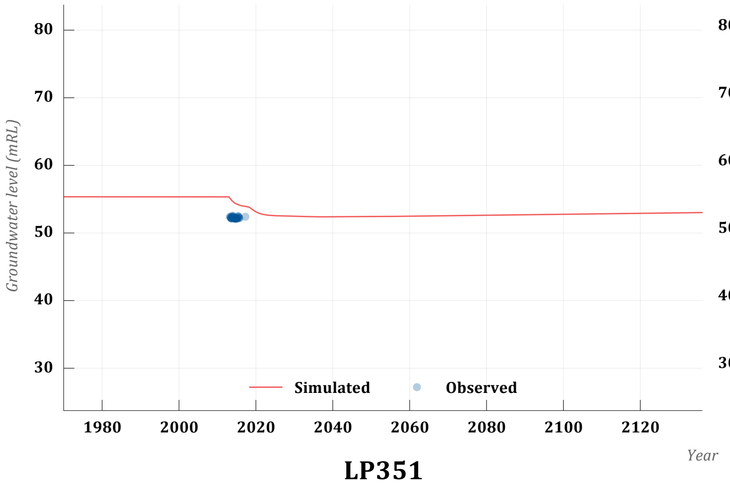

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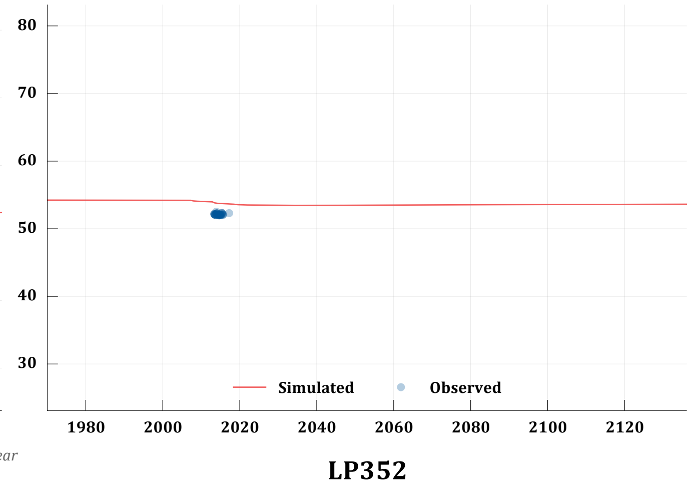
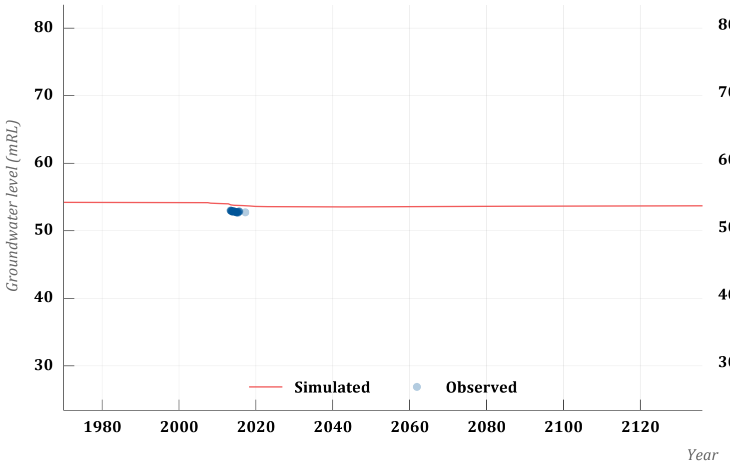
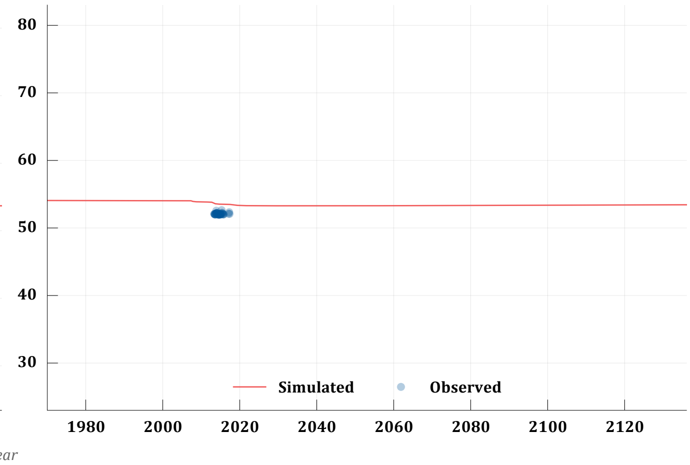
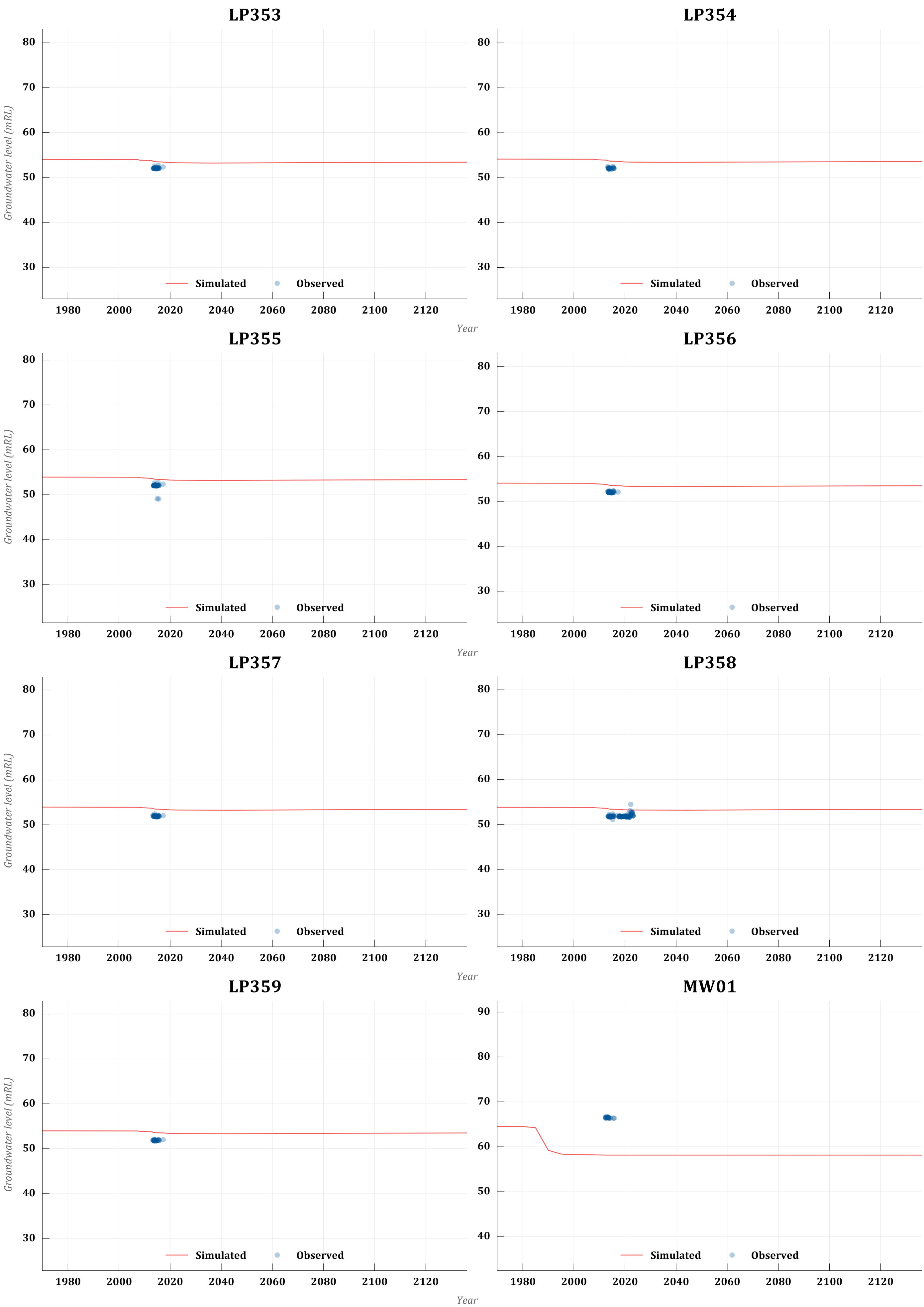


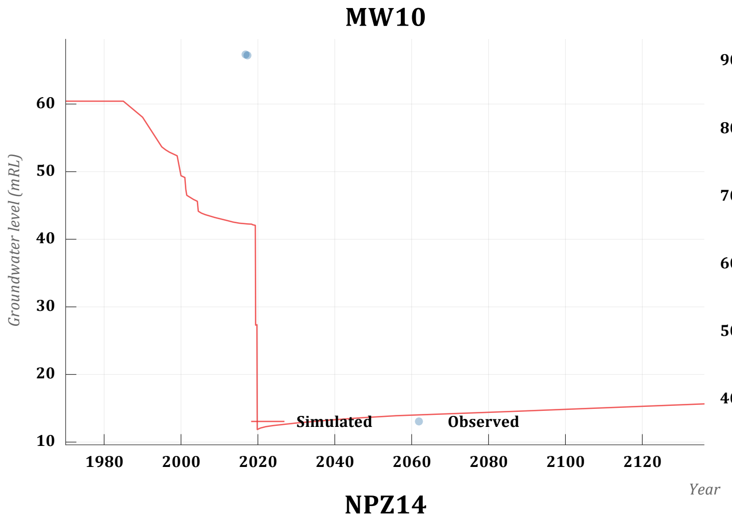
LP351

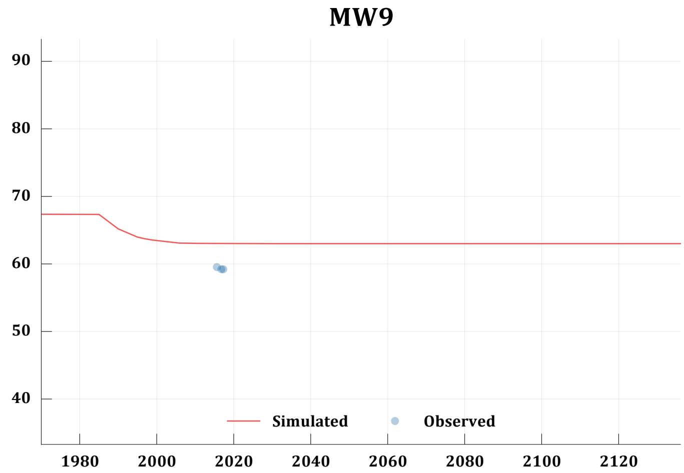


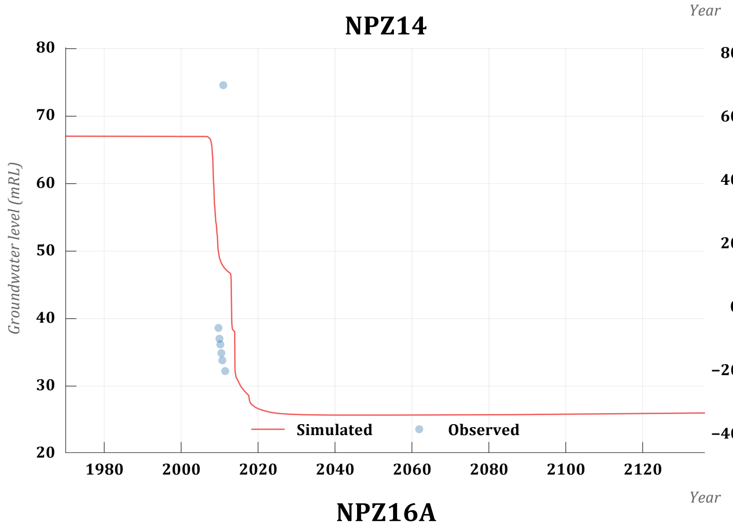
LP352

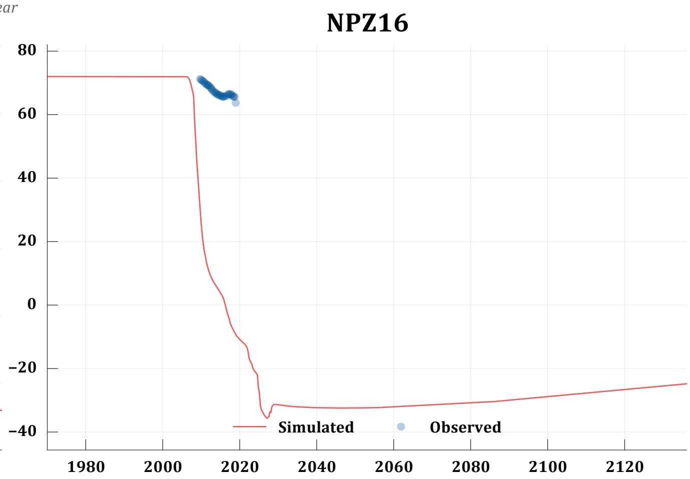


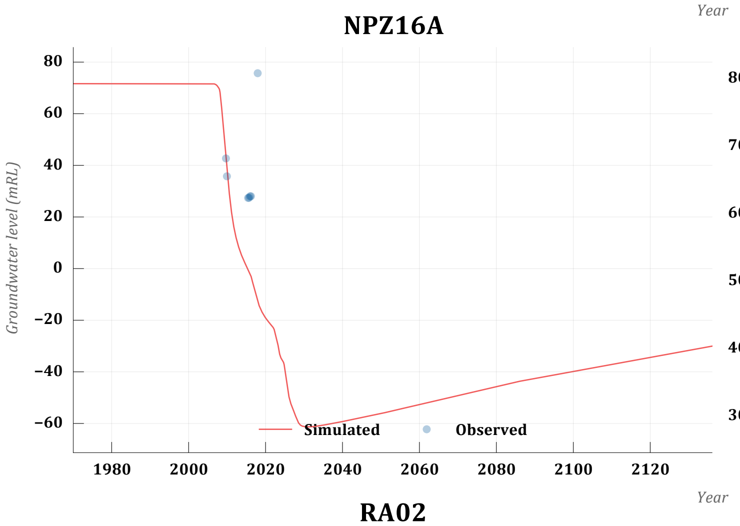

LP353
LP354
LP355
LP356
LP357
LP358
LP359
MW01
Groundwater level (mRL)
Year
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120
30
40
50
60
70
80
90

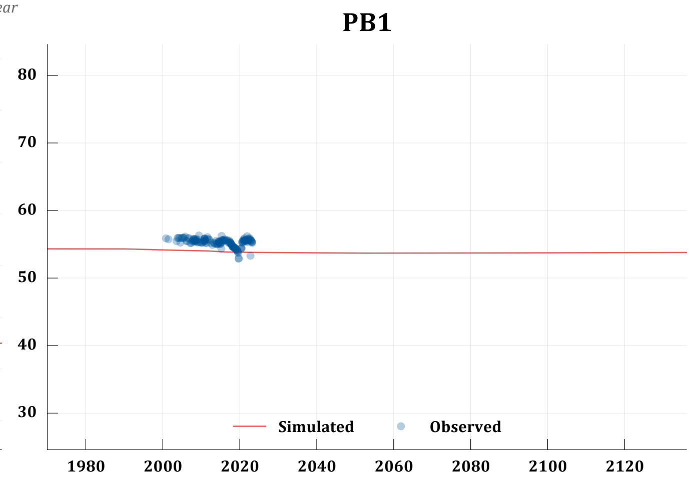

MW10
Groundwater level (mRL)
Simulated
Observed
Year

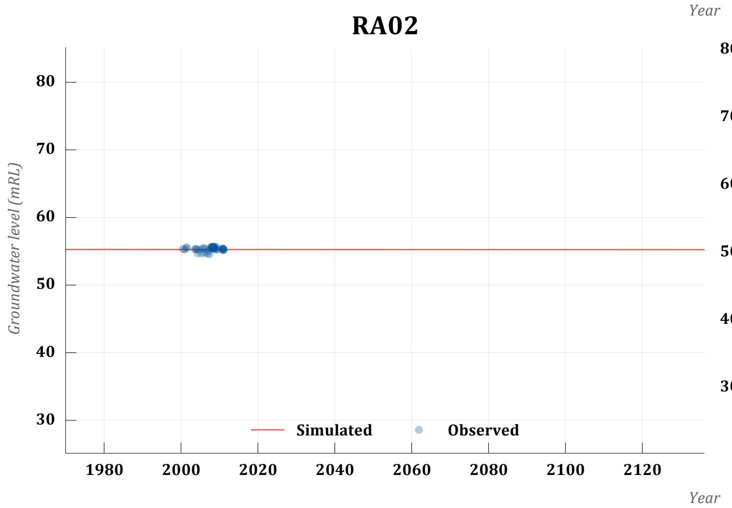

MW9
Simulated
Observed

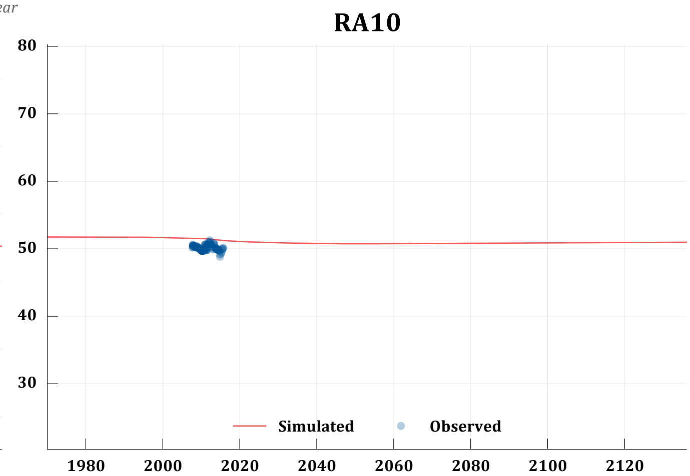

NPZ14
Groundwater level (mRL)
Simulated
Observed
Year

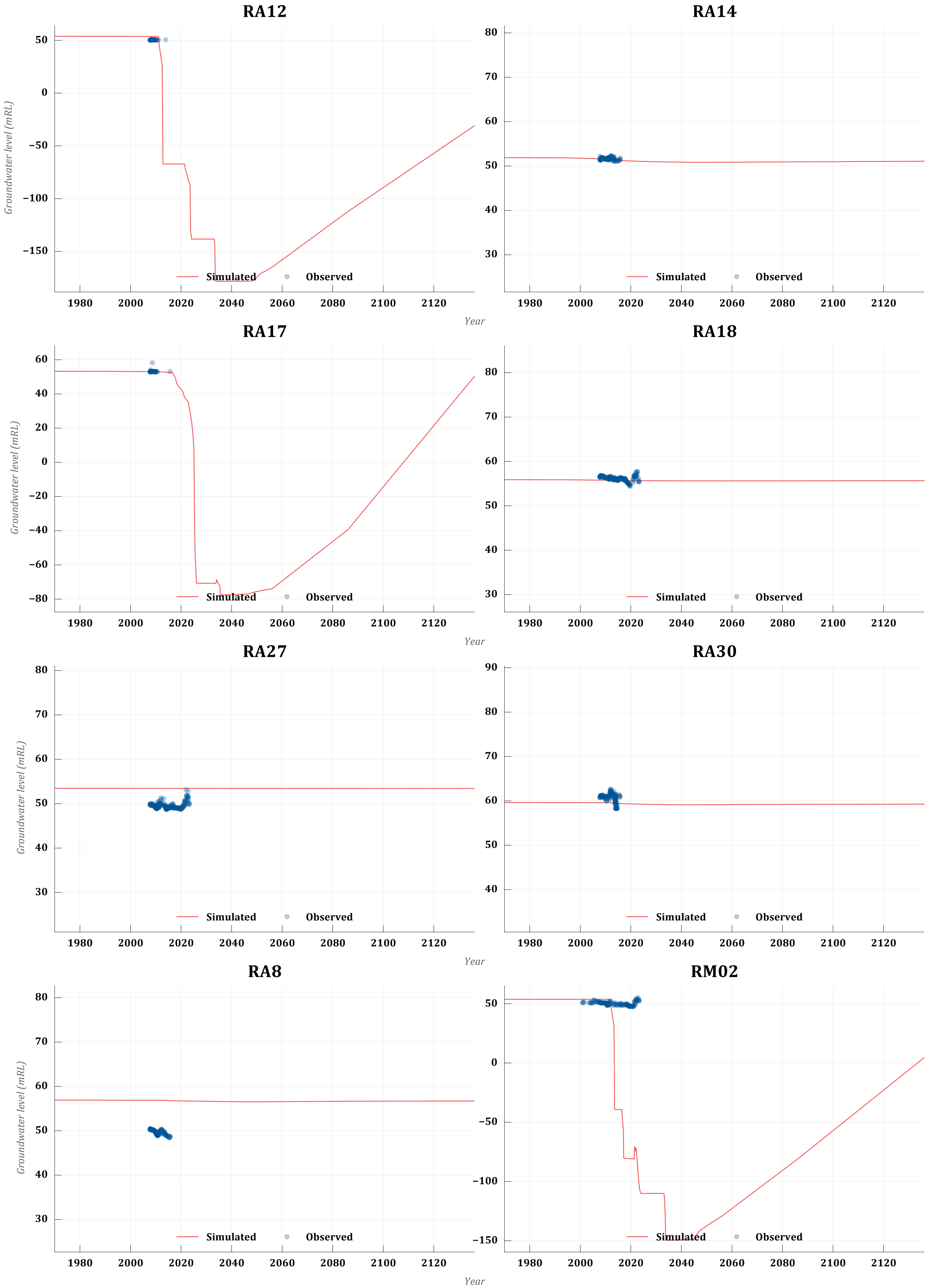

NPZ16
Simulated
Observed


NPZ16A
Groundwater level (mRL)
Simulated
Observed
Year

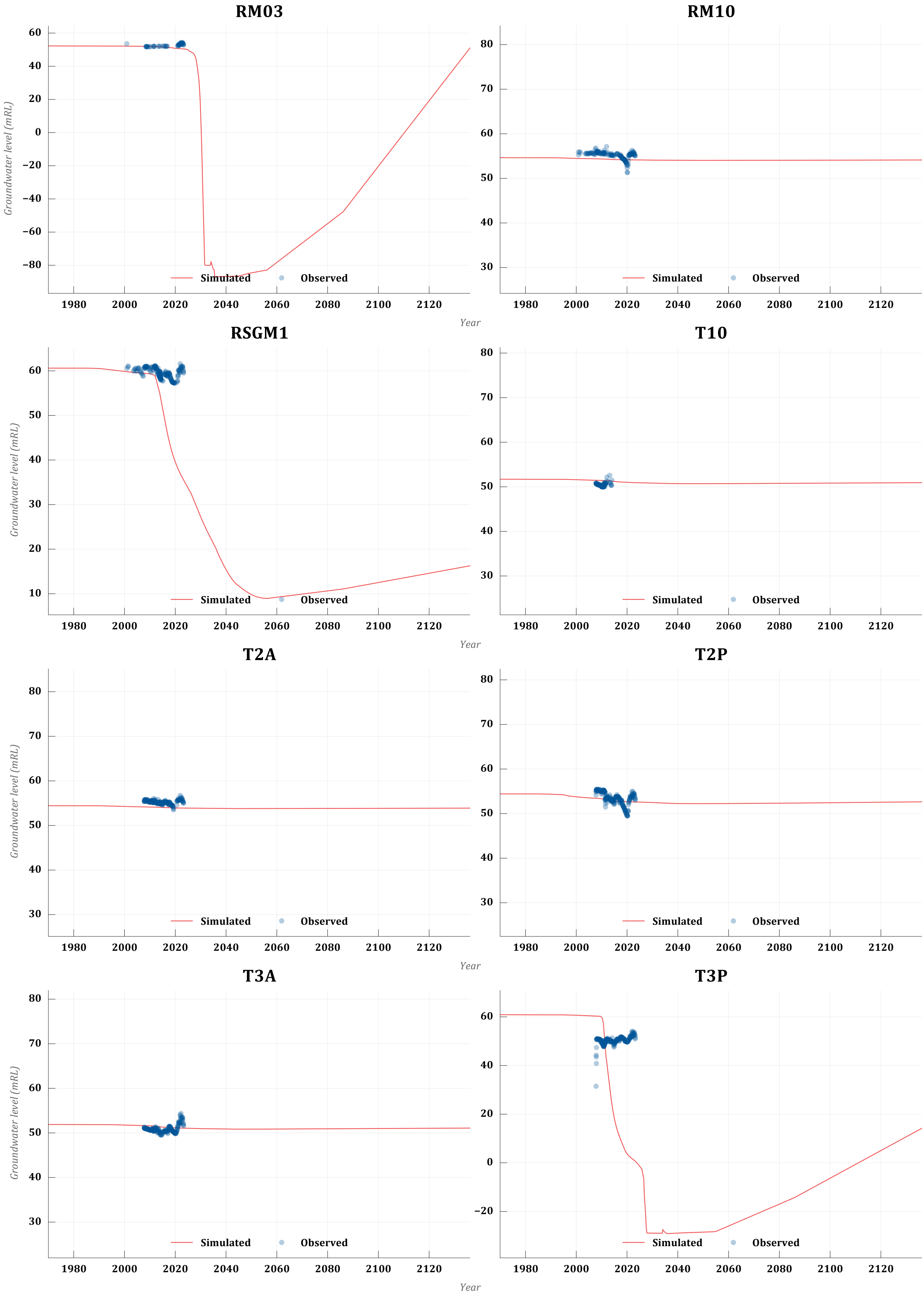

PB1
Simulated
Observed

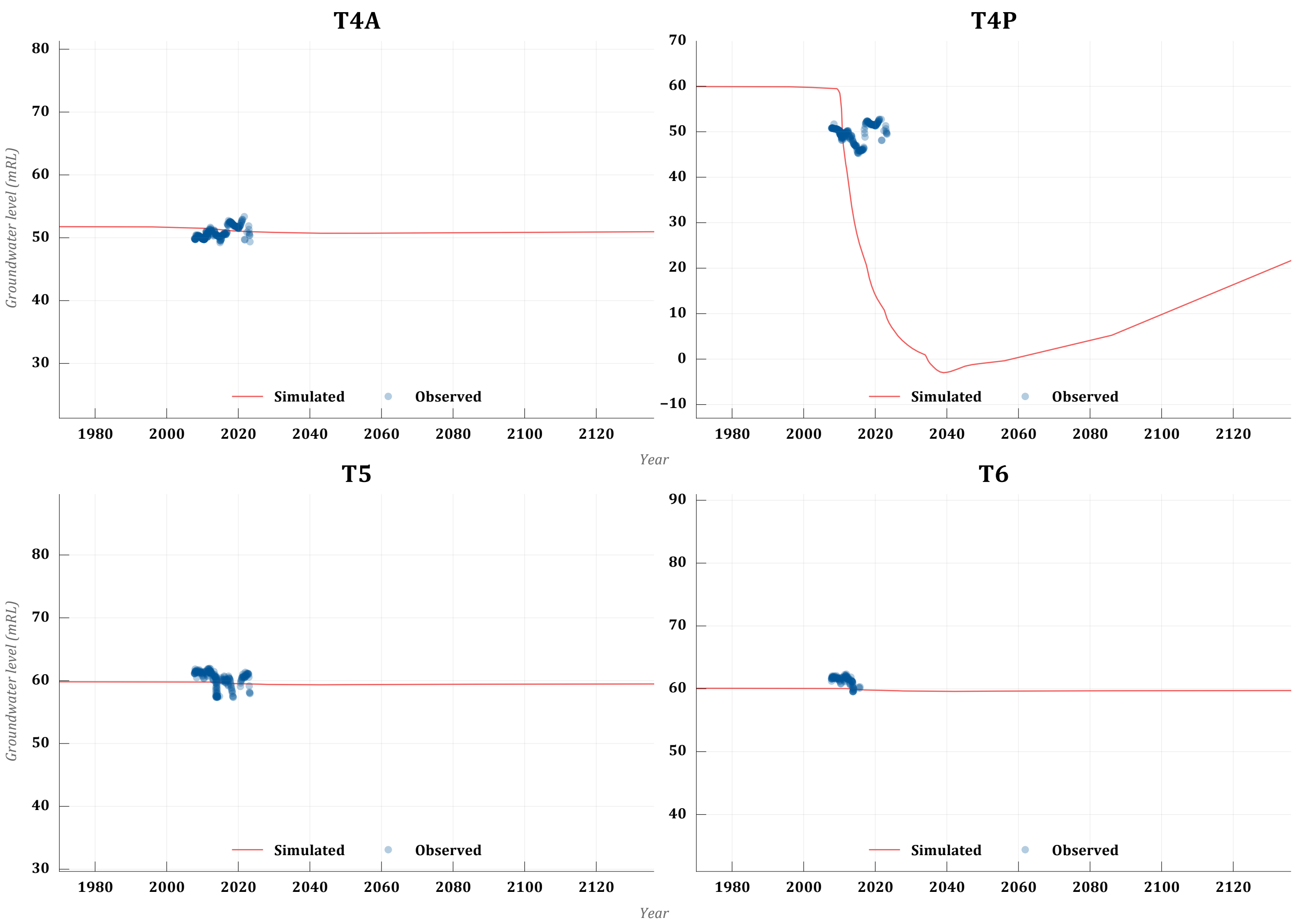

RA02
Groundwater level (mRL)
Simulated
Observed
Year


RA10
Simulated
Observed



RA12
RA14
RA17
RA18
RA27
RA30
RA8
RM02
Groundwater level (mRL)
Year
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120


RM03
RM10
RSGM1
T10
T2A
T2P
T3A
T3P
Groundwater level (mRL)
Year
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120


T4A
T4P
T5
T6
Groundwater level (mRL)
Year
Simulated
Observed
1980
2000
2020
2040
2060
2080
2100
2120

Appendix D

Summary of groundwater monitoring sites

ID	Type	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Top of casing (mAHD)	Depth (mBGL)
AP242	Monitoring Bores	319455.5	6404320	-	17.3
AP243	Monitoring Bores	319587.9	6403465	-	10.3
AP244	Monitoring Bores	319683.3	6403460	-	7.8
AP247	Monitoring Bores	319596.8	6403675	-	11
ASHTONWELL	Monitoring Bores	318292.4	6406071	62	30
BC-SP10	Monitoring Bores	318112	6409434	77.43	6
BC-SP11	Monitoring Bores	318170	6409331	76	9.4
BC-SP13	Monitoring Bores	318269	6409212	76.18	3.5
BC-SP14	Monitoring Bores	318304	6409102	76.06	5.9
BC-SP15	Monitoring Bores	318112	6409529	76.35	5
BC-SP16	Monitoring Bores	318270	6409433	76.1	4.6
BC-SP17	Monitoring Bores	318367	6409522	77	6.5
BC-SP20	Monitoring Bores	318226	6409124	74.87	4.5
BC-SP21	Monitoring Bores	318050	6409135	76.08	6.7
BC-SP22	Monitoring Bores	317987	6409031	74.15	6
GA1	Monitoring Bores	318449	6408228	6.35	68.43
GA2	Monitoring Bores	318583	6407383	10.03	63.93
GM3A	Monitoring Bores	320233.4	6405952	64.28	30
GNP11D	Monitoring Bores	317879	6408430	71.77	11.12
GNP1-Art	Monitoring Bores	318501	6408654	76.75	-
GNP2-Art	Monitoring Bores	317578	6410288	78.26	-
GNP5-Art	Monitoring Bores	317819	6409310	86.26	-
GNP8-Bar	Monitoring Bores	319424	6407428	82.89	-
GW9702	Monitoring Bores	316451	6401484	-	-
JK101	Monitoring Bores	316735.8	6405214	74.1	14.3
JK102	Monitoring Bores	316735.8	6405214	74.11	6.5
JK103	Monitoring Bores	316845.9	6405275	74.15	16.5
JK104	Monitoring Bores	316845.9	6405275	74.09	10.5
JK105	Monitoring Bores	316962.5	6405387	74.14	12.1
JK106	Monitoring Bores	316992.2	6405324	74.11	18
JK107	Monitoring Bores	317022.7	6405417	74.18	12
JK108	Monitoring Bores	317022.7	6405417	74.14	8.3
JK109	Monitoring Bores	316735.8	6405214	68.07	6.2
JK110	Monitoring Bores	316735.8	6405214	68.1	0.7

ID	Type	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Top of casing (mAHD)	Depth (mBGL)
JK113	Monitoring Bores	316785	6405185	66.88	0.7
JK115	Monitoring Bores	316845.9	6405275	64.53	7.3
JK118	Monitoring Bores	317110.1	6405340	65.59	5
JK119	Monitoring Bores	317110.1	6405340	65.67	0.7
JK121	Monitoring Bores	316992.2	6405324	61.11	6.5
JK123	Monitoring Bores	316992.2	6405324	61.1	2.2
MW01	Monitoring Bores	314593.7	6409049	72	5.66
MW10	Monitoring Bores	314337.3	6408224	81.457	14.26
MW9	Monitoring Bores	314503.4	6408609	77.107	17.9
NPZ14	Monitoring Bores	319480	6407099	74.59	51
NPZ5B_P1	Monitoring Bores	314615.8	6409196	76	15.05
NPZ6_Tall	Monitoring Bores	314656.9	6409076	76.3	-
PB1	Monitoring Bores	317536.3	6405231	61.1	7.8
RA02	Monitoring Bores	317733.6	6405230	55.18	11.3
RA10	Monitoring Bores	317647.8	6404308	-	13
RA12	Monitoring Bores	318018.7	6404458	-	12
RA14	Monitoring Bores	317657.1	6404686	-	11
RA17	Monitoring Bores	317684.9	6404884	-	10.7
RA18	Monitoring Bores	317807.8	6405447	-	8.5
RA27	Monitoring Bores	317960.6	6403734	-	15.5
RA30	Monitoring Bores	317830.7	6406501	-	9
RA8	Monitoring Bores	317891.1	6404173	-	15
RM02	Monitoring Bores	317939.9	6404520	61.05	12.4
RM03	Monitoring Bores	317678	6404834	62.1	11
RM10	Monitoring Bores	317569.1	6405304	61.55	10.8
RSGM1	EPL Bores	317670.7	6406296	65.6	-
T10	Monitoring Bores	317668.7	6404457	58.69	-
T2A	Monitoring Bores	317601.5	6405224	60.8	8.9
T4A	Monitoring Bores	317694.1	6404327	58.58	10.7
T5	Monitoring Bores	317955.1	6406564	65.33	8.8
T6	Monitoring Bores	317983.7	6406656	65.96	8
WML106	Monitoring Bores	318843.7	6403484	83.07	88.00
WML107A	Monitoring Bores	318674.5	6403836	95.53	120.43
WML108B	Monitoring Bores	318431.2	6403971	81.38	30.00

ID	Type	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Top of casing (mAHD)	Depth (mBGL)
WML109A	Monitoring Bores	318227.2	6404076	72.58	84
WML110A	Monitoring Bores	317990.8	6404260	63.71	110
WML111B	Monitoring Bores	317786.9	6404365	58.33	12
WML112A	Monitoring Bores	317582.9	6404469	59.44	285.52
WML113	VMP	317372	6404524	60.20	150.00
WML114	Monitoring Bores	318130	6405250	71.53	150.00
WML115A	Monitoring Bores	317858.5	6406699	65.189	178.39
WML115C	Monitoring Bores	317904.9	6406717	64.958	6.2
WML119	Monitoring Bores	319268.7	6403931	61.45	35.00
WML120A	EPL Bores	319298.2	6404548	60.35	20.00
WML120B	EPL Bores	319296.1	6404613	60.12	9.00
WML129	EPL Bores	319445.6	6403531	55.34	7.00
WML144A	VMP	319496.8	6404195	59.26	98.00
WML182	Monitoring Bores	319152.1	6404122	71.80	44.00
WML183	EPL Bores	319163.7	6404320	76.72	46.00
WML184	Monitoring Bores	319184.6	6404527	103.36	72.60
WML185	Monitoring Bores	319182.2	6404648	105.41	72.00
WML191	Monitoring Bores	318612	6404324	82.516	235
WML213	VMP	317203.5	6404171	61.534	316
WML239	Monitoring Bores	319342.9	6404064	58.816	13.5
WML241	Monitoring Bores	319481.4	6405843	103.66	145
WML243	Monitoring Bores	319628.8	6403251	60.392	15
WML245	VMP	320046.8	6404801	65.642	100
WML246	Monitoring Bores	319896.8	6404541	64.885	10
WML247	Monitoring Bores	319746.8	6404454	63.361	13
WML248	VMP	319321.3	6404704	58.493	144.68
WML249	Monitoring Bores	320336.1	6403762	67.827	60
WML250	Monitoring Bores	320361.3	6403662	71.13	60
WML252	Monitoring Bores	319989.5	6403691	62.799	60
WML253	Monitoring Bores	320465.6	6403573	75.932	60
WML262	EPL Bores	319221.5	6403914	63.244	60.3
WML269	Monitoring Bores	317830.9	6404055	65.5336	189
WML326	Monitoring Bores	317573.6	6404092	60.64	15.45
WMLC334	VMP	318570.2	6403093	75.92	218.52

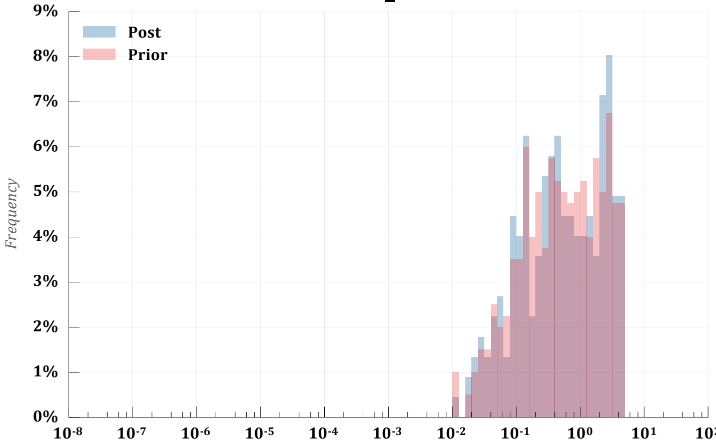
ID	Type	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Top of casing (mAHD)	Depth (mBGL)
WMLC335	VMP	318899.3	6402946	64.53	200.51
WMLC339	Monitoring Bores	318491.6	6405023	76.13	219.6
WMLP275	Monitoring Bores	319713.4	6404270	61	12
WMLP276	Monitoring Bores	317673.3	6404179	58.646	9.4
WMLP278	Monitoring Bores	319785.2	6404200	62.335	12.5
WMLP280	Monitoring Bores	319696.8	6404368	62.457	16
WMLP301	Monitoring Bores	319239.5	6403868	60.172	10
WMLP308	Monitoring Bores	318230.3	6406389	65.69	9.05
WMLP311	Monitoring Bores	318179.9	6406037	63.638	7.6
WMLP316	Monitoring Bores	317376.6	6405300	61.595	8.31
WMLP320	Monitoring Bores	317446.5	6405398	61.5	8
WMLP323	Monitoring Bores	318225.3	6406590	64.474	7.34
WMLP328	Monitoring Bores	317942.8	6405625	62.762	-
WMLP336	EPL Bores	318971.1	6402835	60.637	15.45
WMLP337	Monitoring Bores	318398.6	6403117	59.851	13.5
WMLP338	Monitoring Bores	318614.2	6402784	58.774	12.9
WMLP340	Monitoring Bores	319853.8	6404774	62.718	14.27
WMLP341	Monitoring Bores	319828.4	6404729	63.199	13.75
WMLP342	Monitoring Bores	319946.8	6404628	66.333	9.55
WMLP343	Monitoring Bores	319606	6404599	60.999	11.86
WMLP344	Monitoring Bores	319656.5	6404574	60.117	11.74
WMLP346	Monitoring Bores	319353.2	6404447	60.682	12.5
WMLP347	Monitoring Bores	319443.9	6404473	60.649	12.51
WMLP348	Monitoring Bores	319388.7	6404178	59.226	12.67
WMLP352	Monitoring Bores	319380.2	6404042	59.711	13.66
WMLP353	Monitoring Bores	319395.8	6403986	58.648	11.5
WMLP354	Monitoring Bores	319646.8	6403935	60.455	10.5
WMLP355	Monitoring Bores	319414.7	6403869	57.02	10
WMLP356	Monitoring Bores	319546.8	6403935	60.093	9.5
WMLP357	Monitoring Bores	319561.3	6403814	58.121	10.71
WMLP358	Monitoring Bores	319520.9	6403687	59.664	11.2

Note: * Per EPL 11879 (Licence version date: 21 November 2019).
MBGL – metres below ground level

Appendix E

Probability distributions

kx_z1



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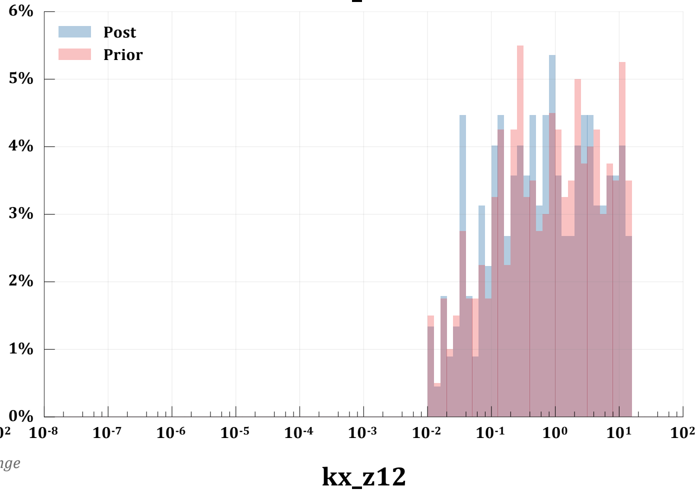

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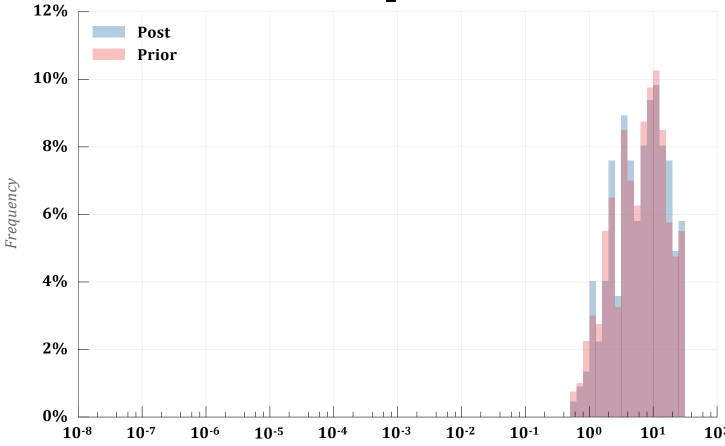

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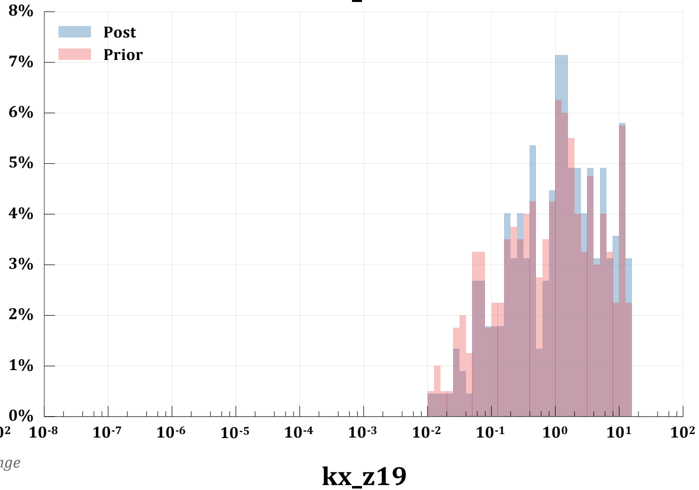

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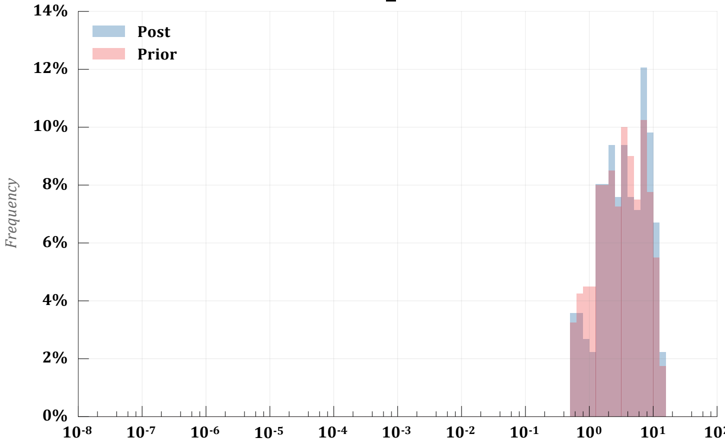

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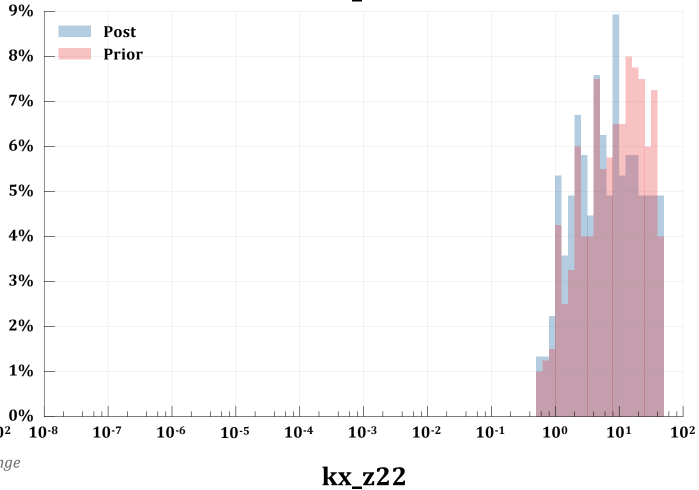
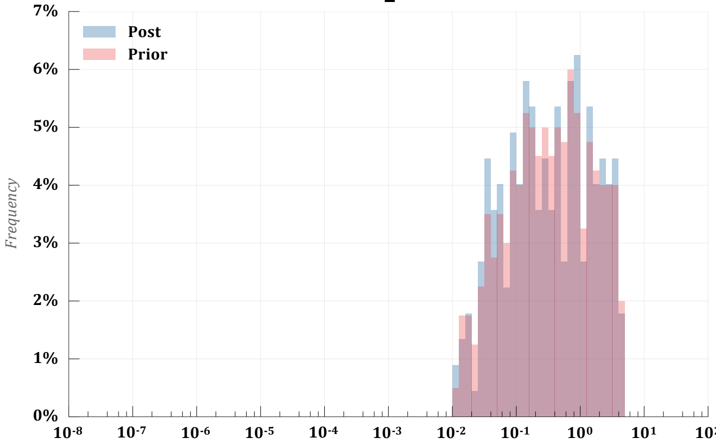
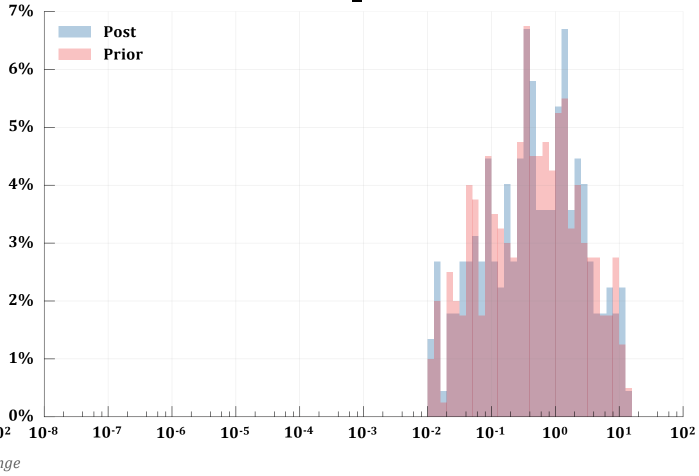
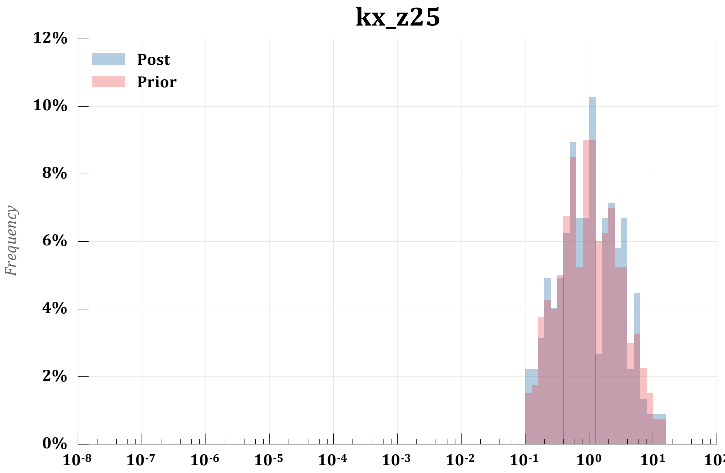


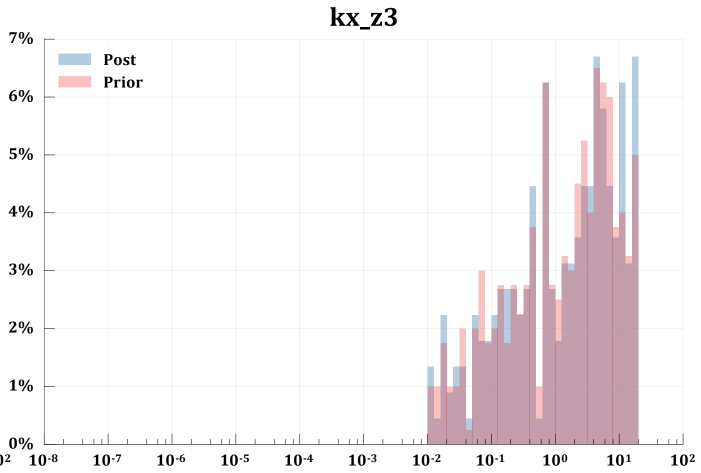
kx_z2



kx_z22







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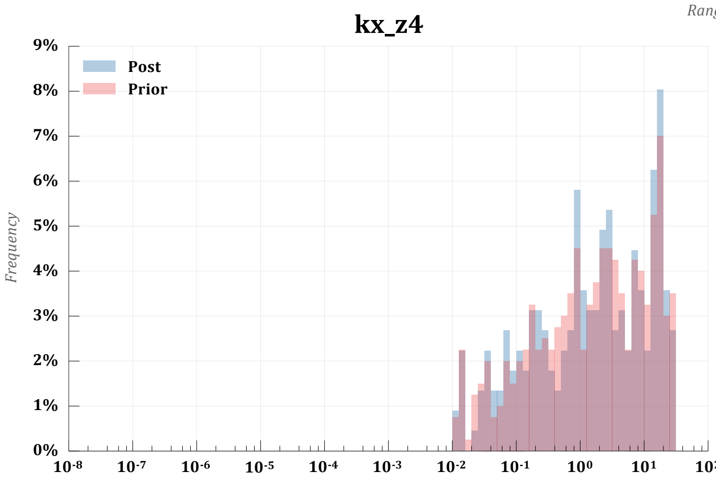

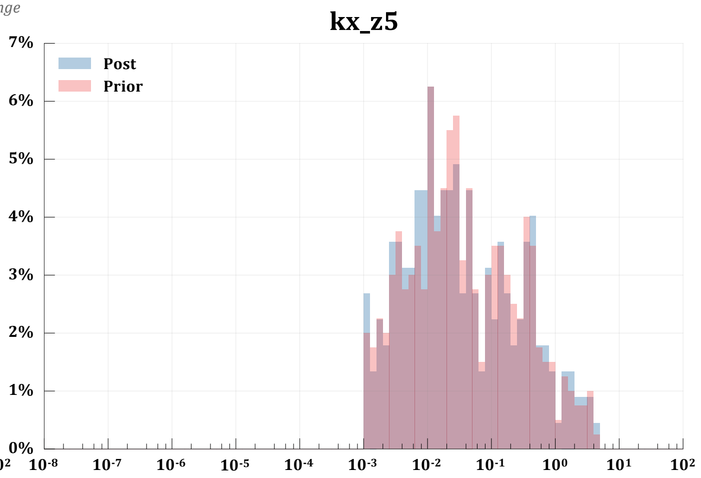

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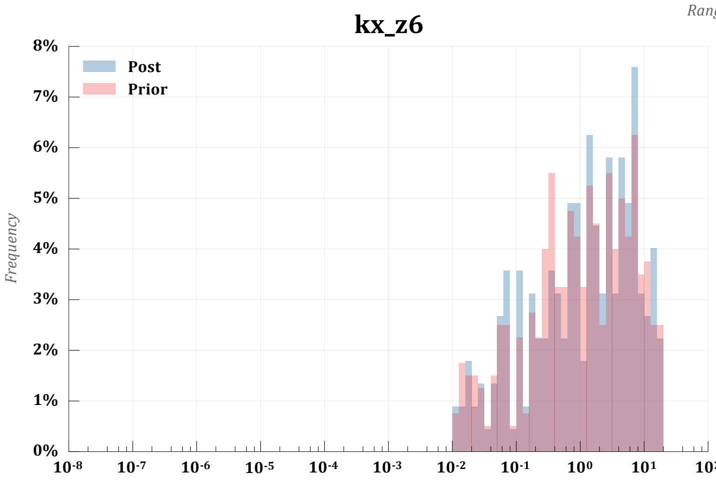

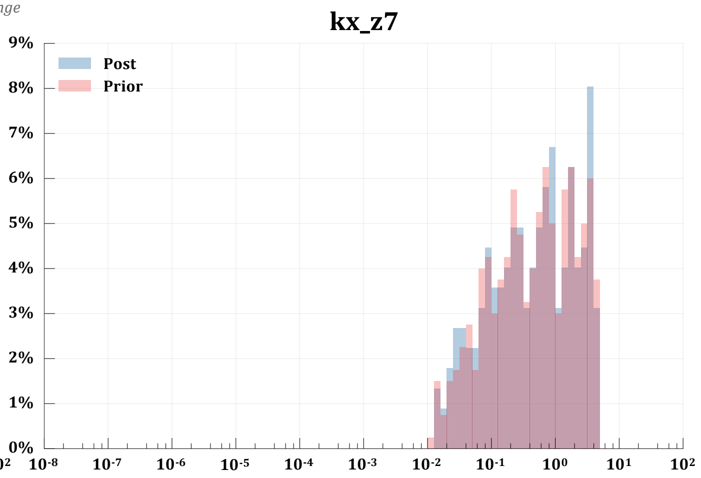

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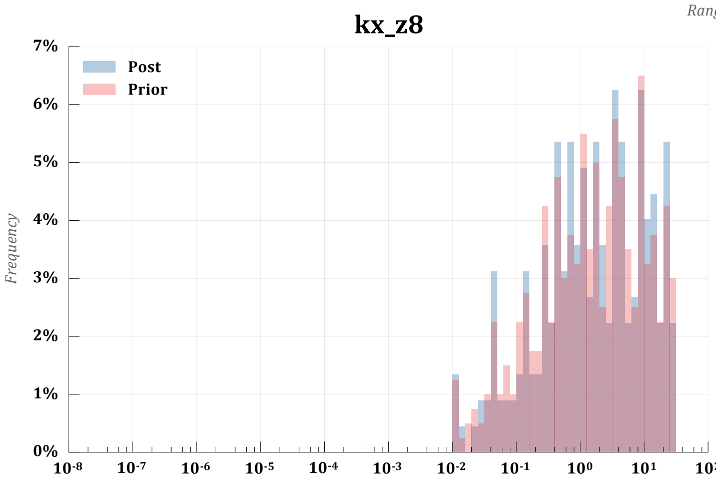

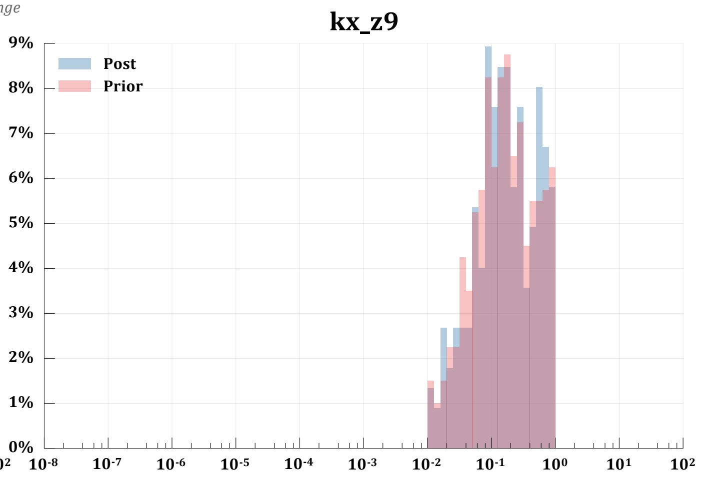

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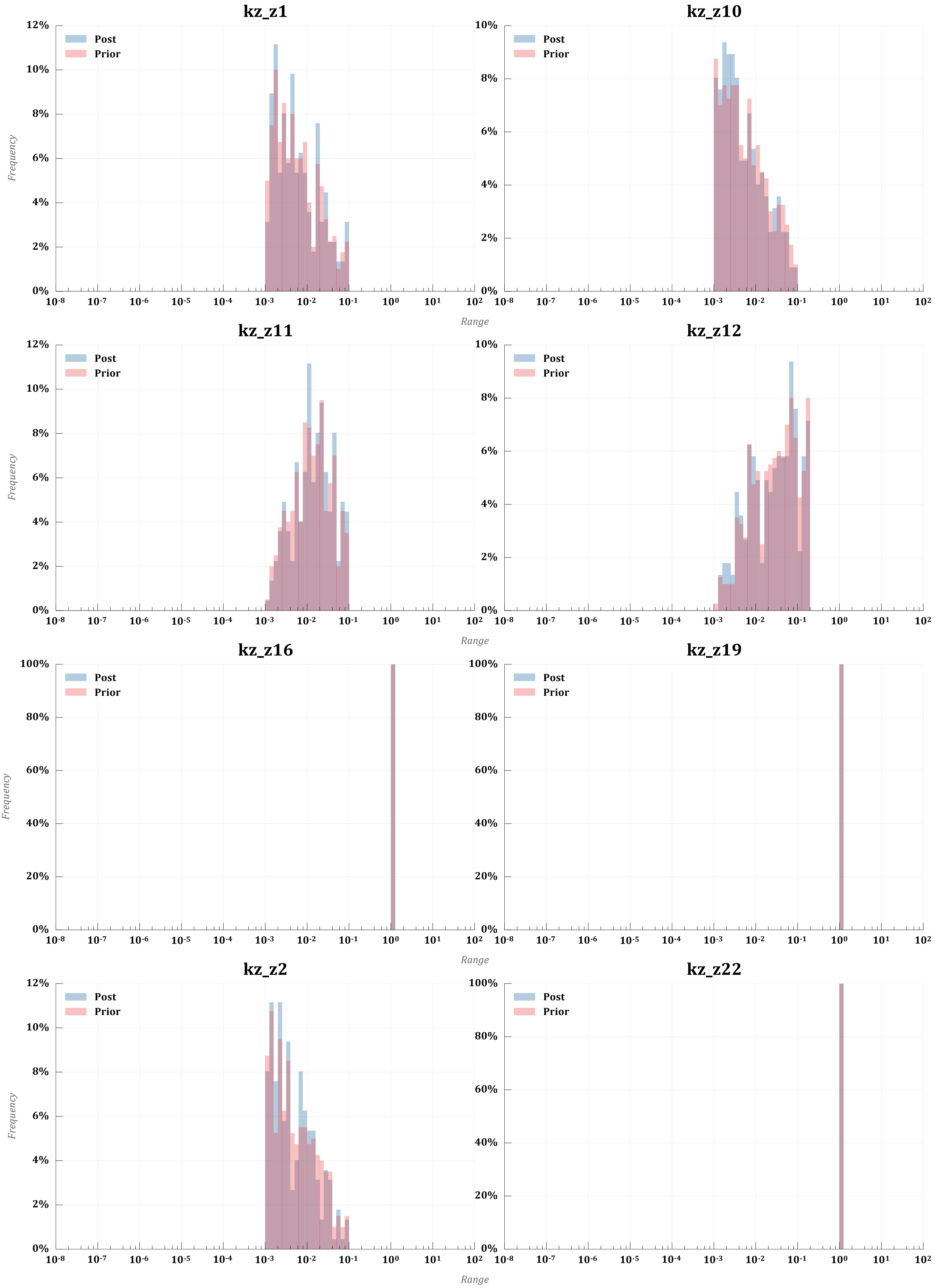
kz_z1
kz_z10
kz_z11
kz_z12
kz_z16
kz_z19
kz_z2
kz_z22
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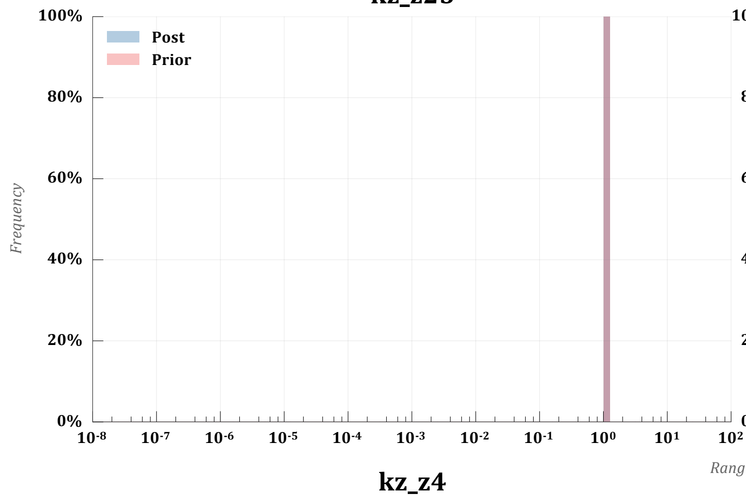
Prior
Frequency
Range

kz_z25



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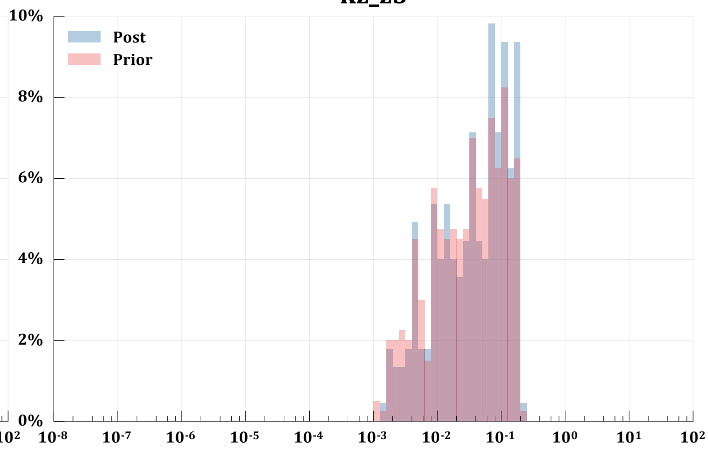
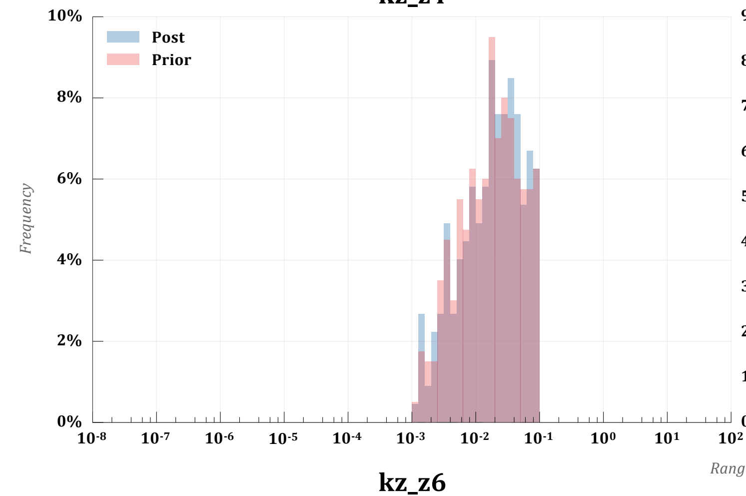


kz_z4



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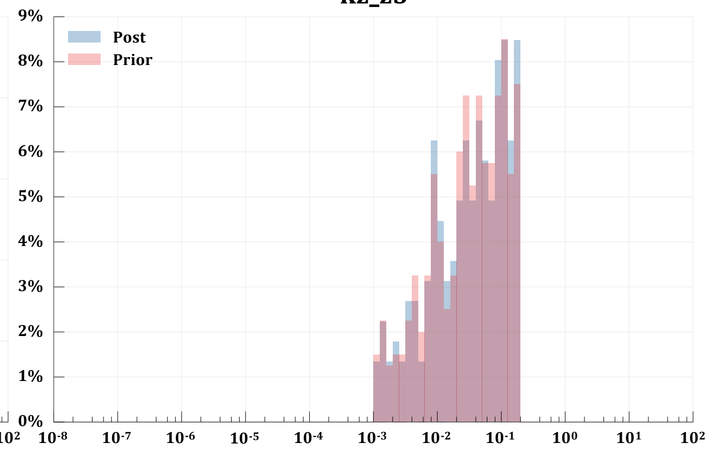
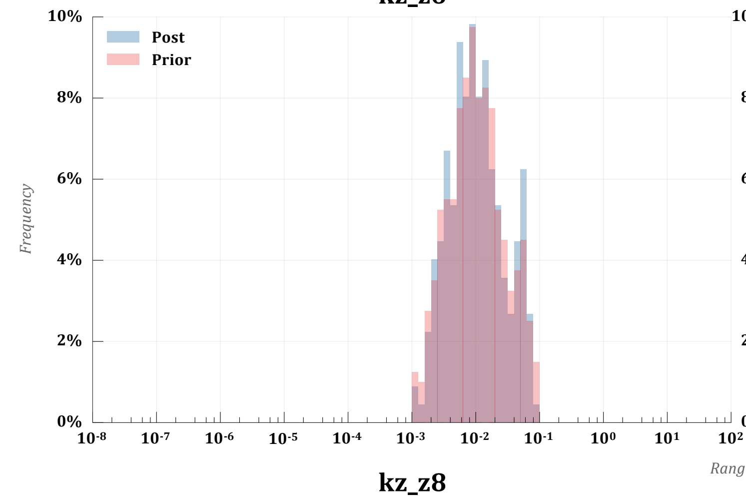
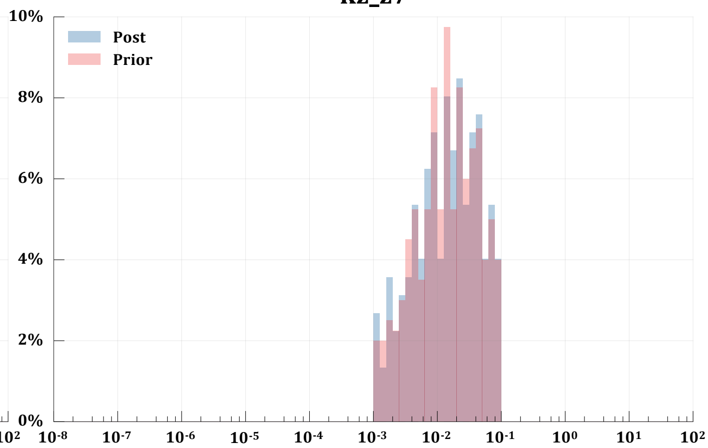


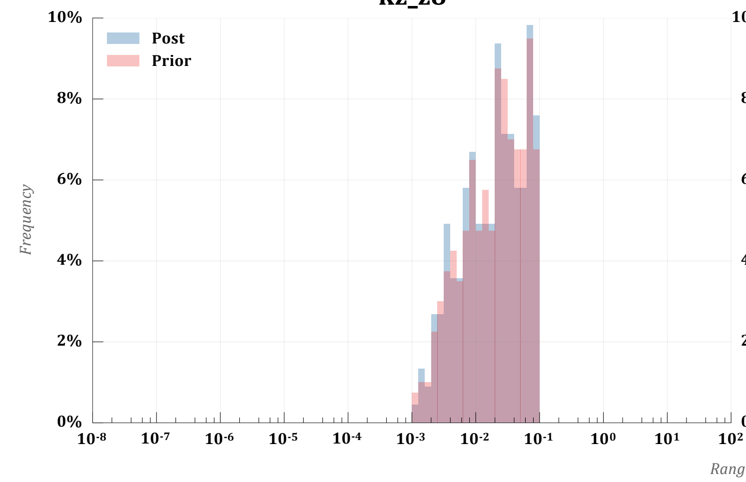
kz_z6



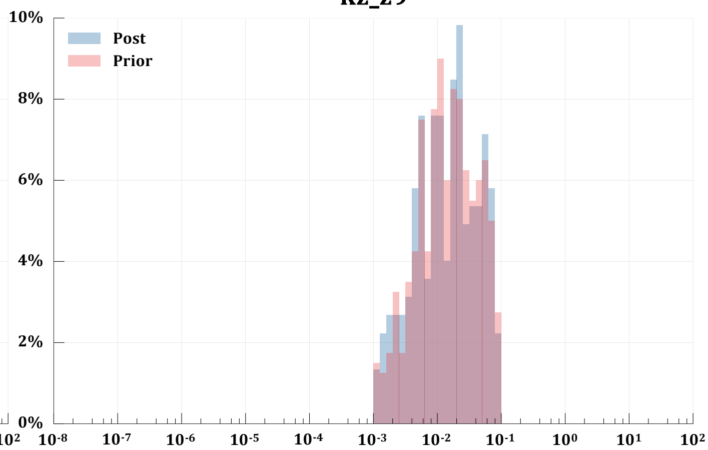
kz_z7

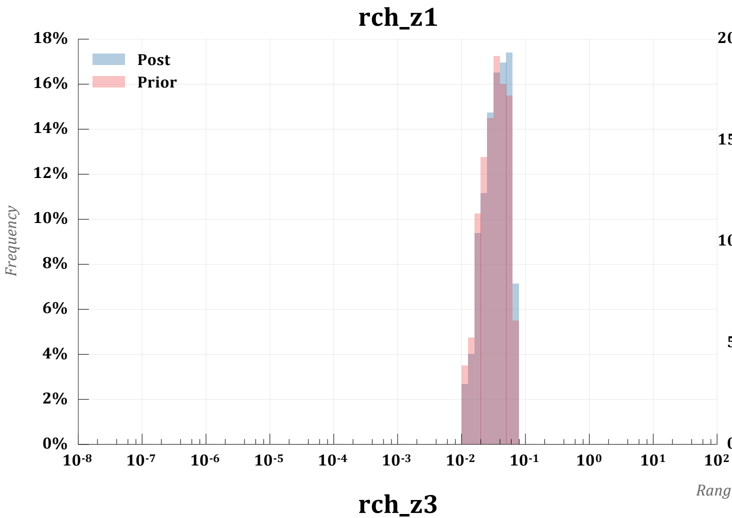


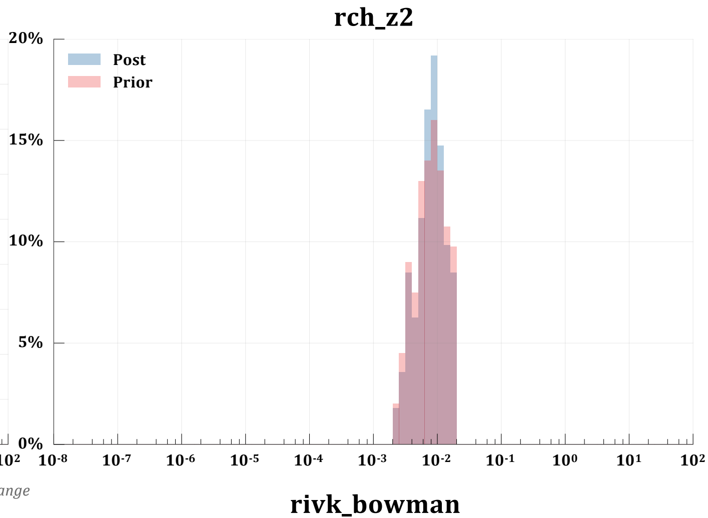
kz_z8



kz_z9




rch_z1
Post
Prior
Frequency


rch_z2
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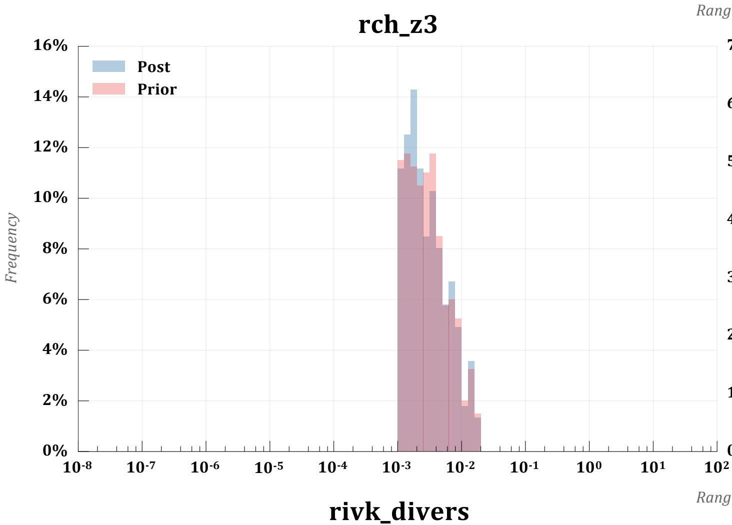
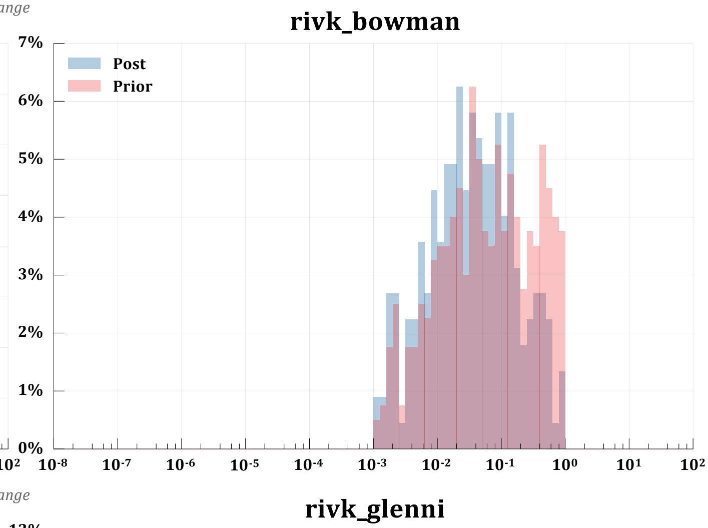
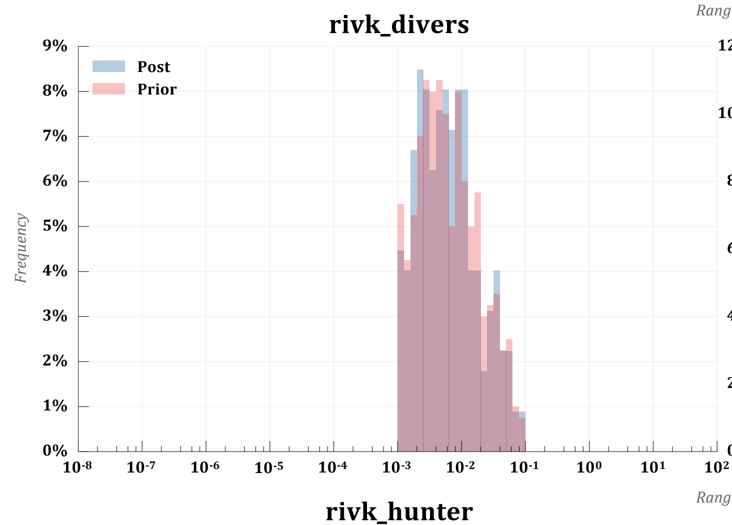
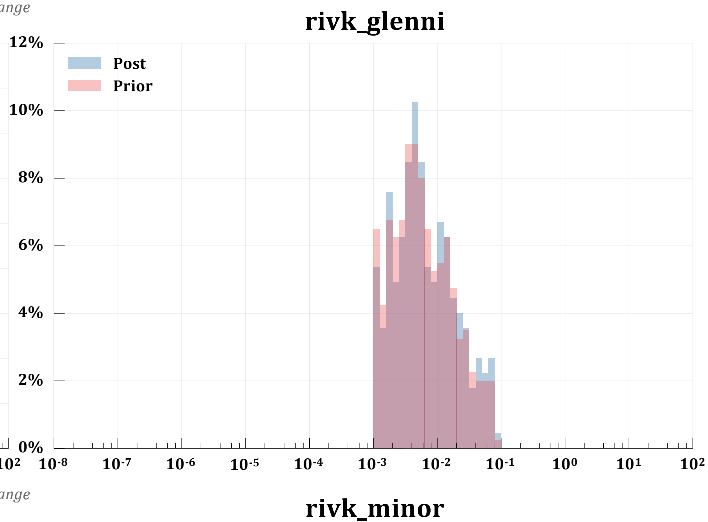
Prior
Range


rch_z3
Post
Prior
Frequency


rivk_bowman
Post
Prior
Range


rivk_divers
Post
Prior
Frequency


rivk_glenni
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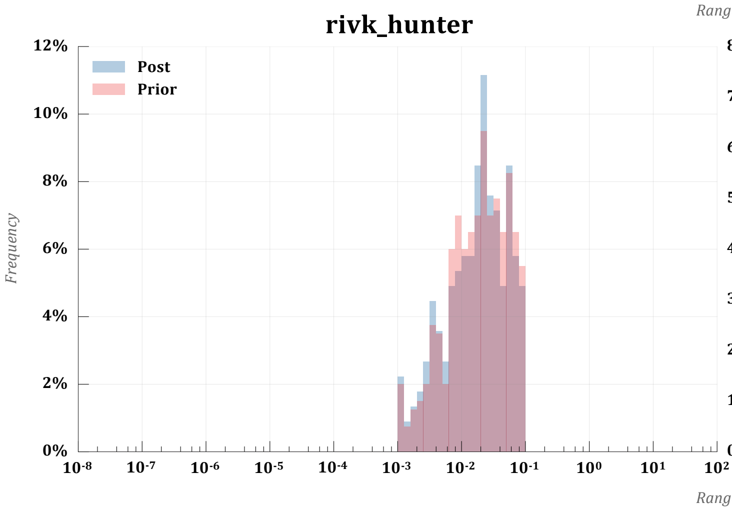
Prior
Range


rivk_hunter
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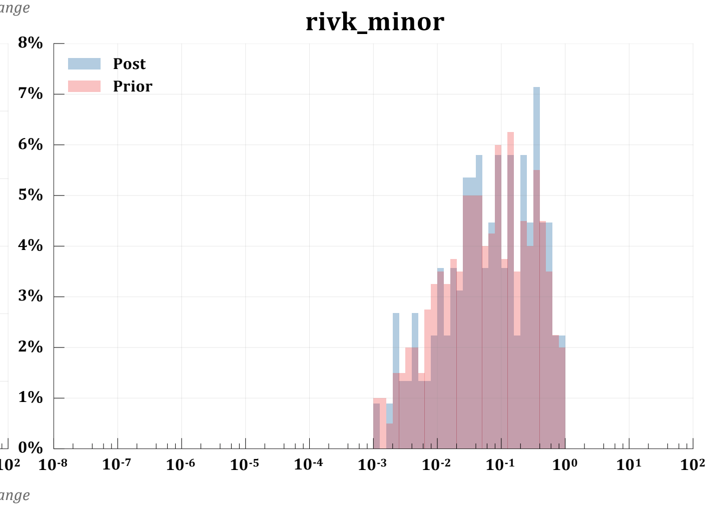
Prior
Frequency


rivk_minor
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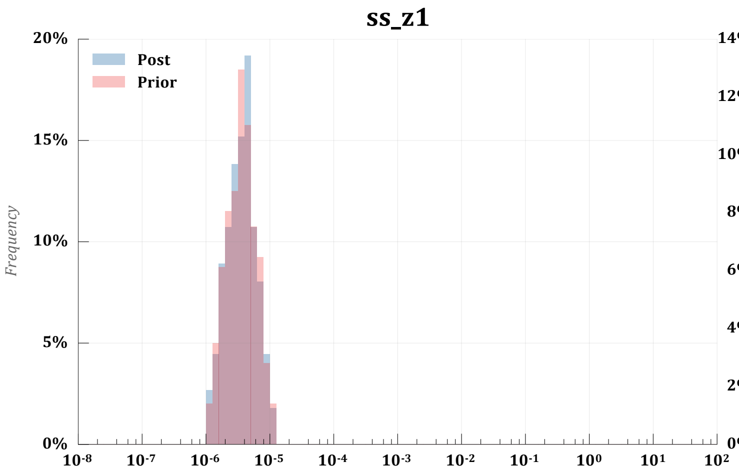
Range


ss_z1
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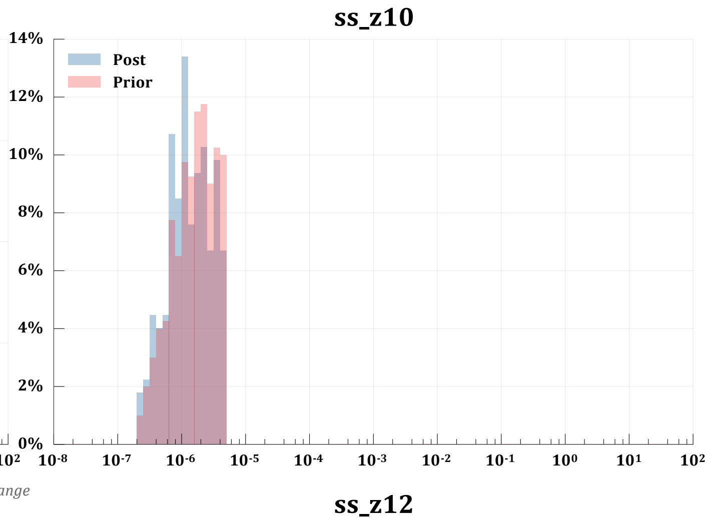
Frequency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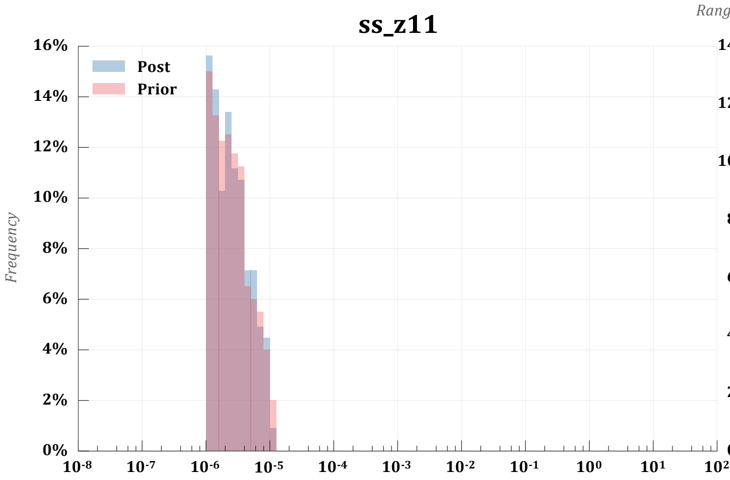
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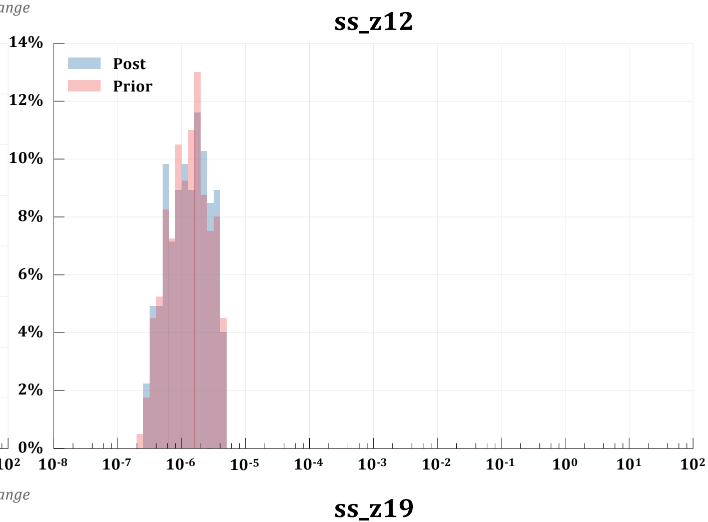
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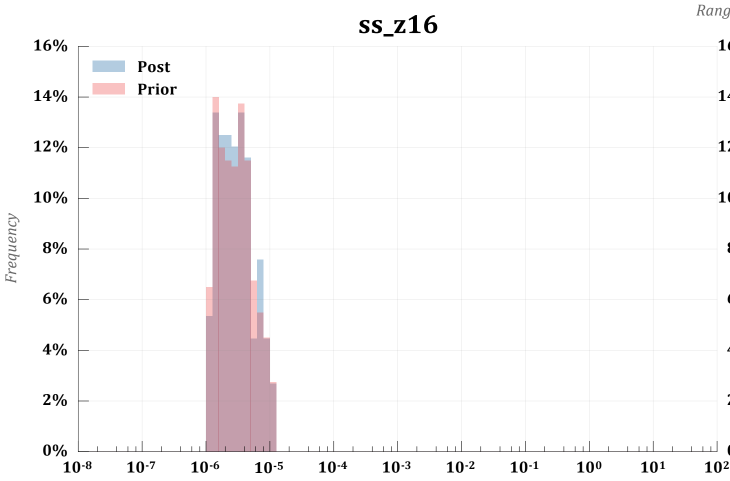
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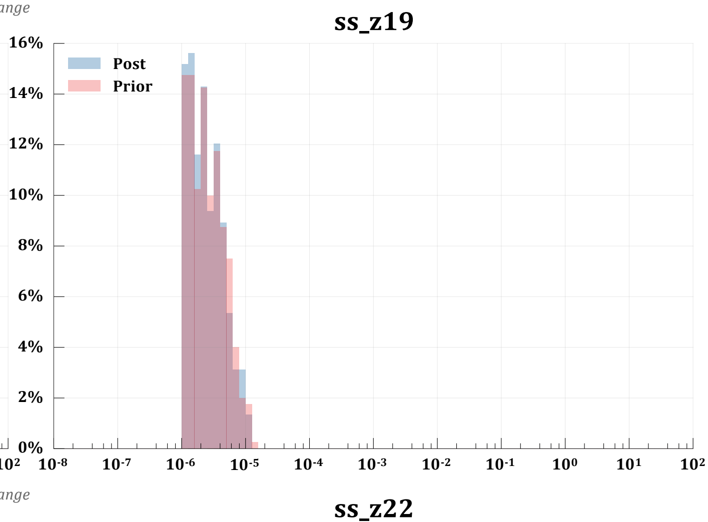
Prior
Frequency


ss_z19
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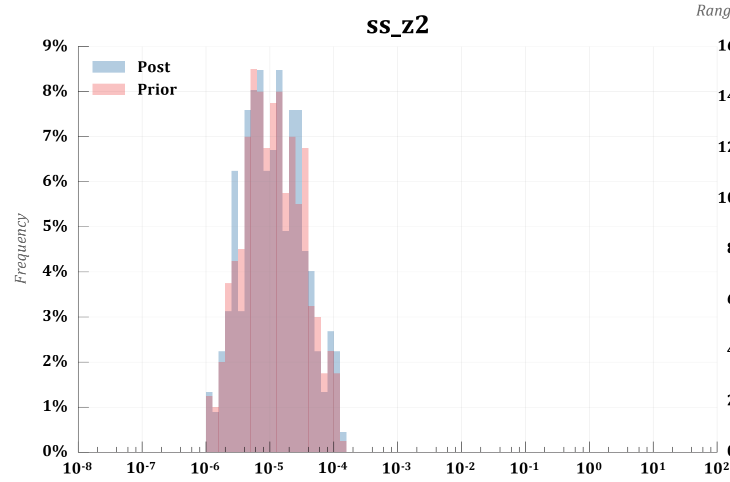
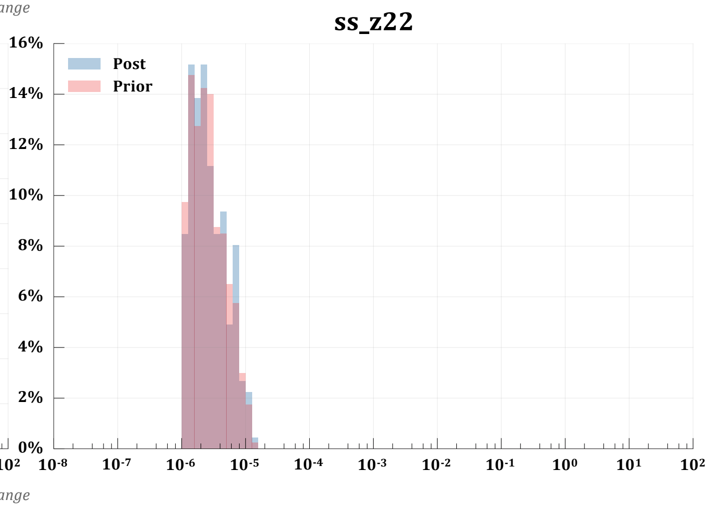
Prior
Range


ss_z2
Post
Prior
Frequency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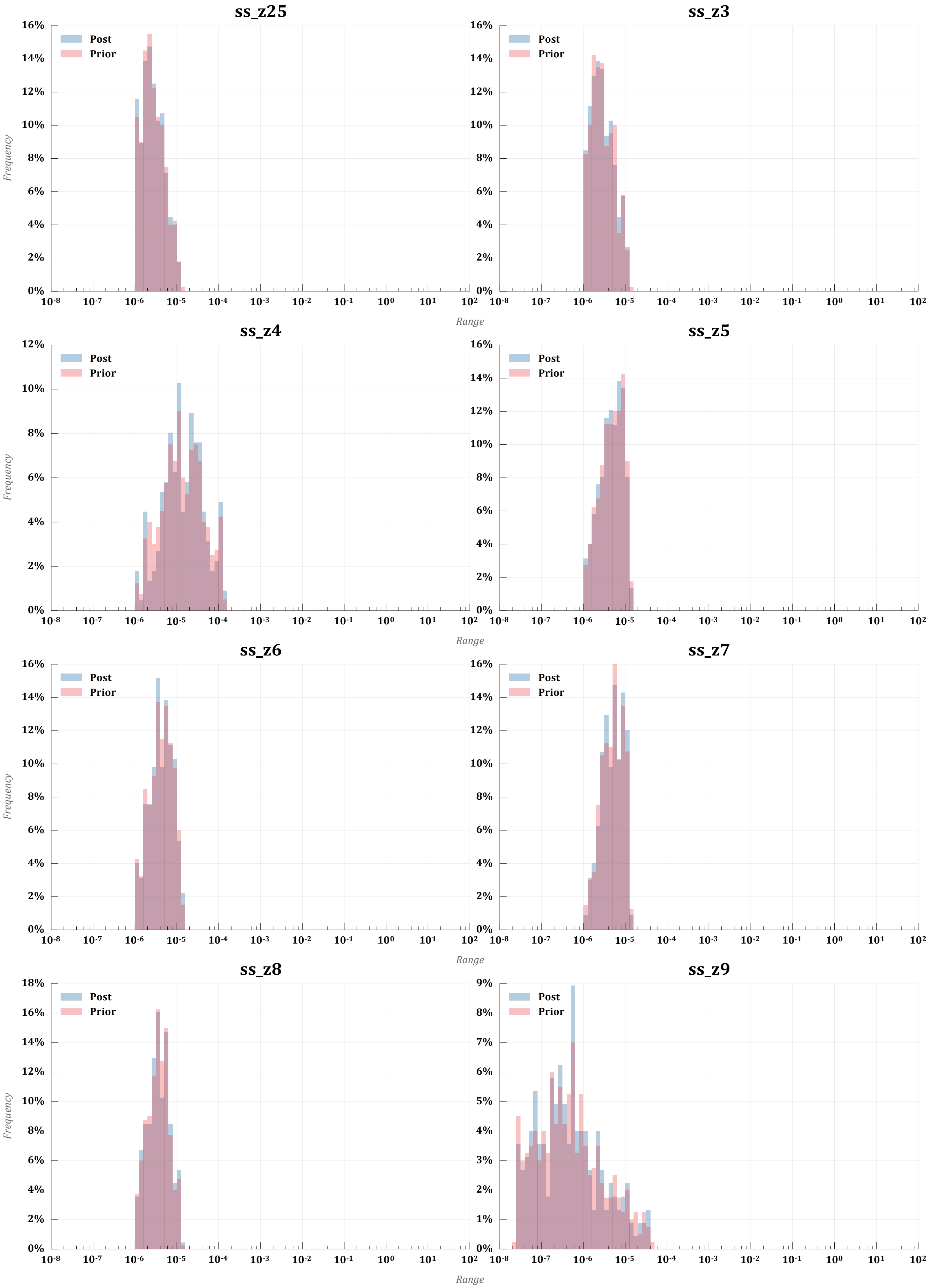
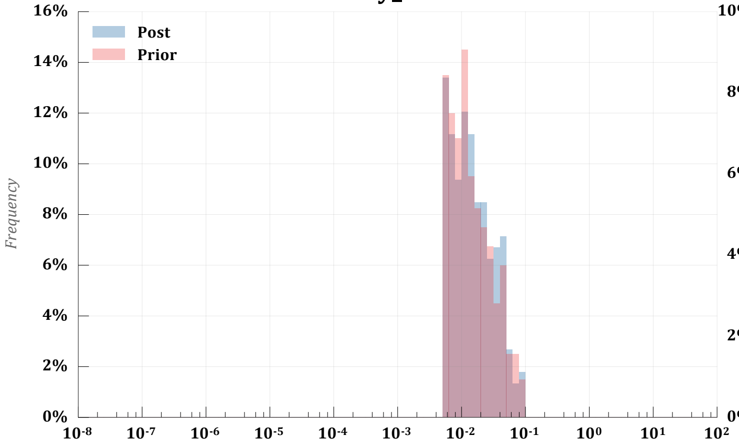
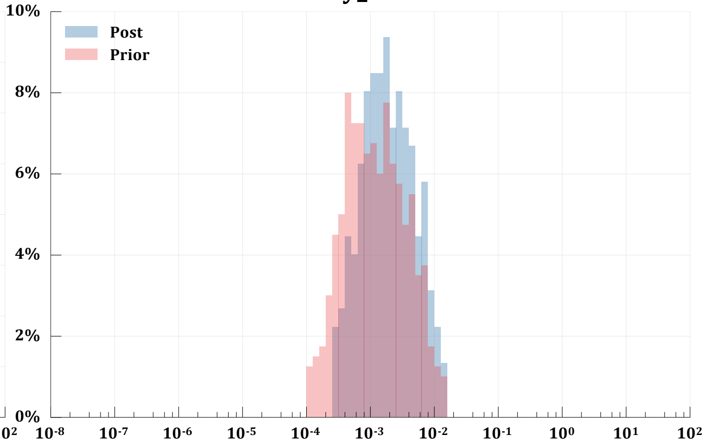

ss_z25
ss_z3
ss_z4
ss_z5
ss_z6
ss_z7
ss_z8
ss_z9
Post
Prior
Frequency
Range

sy_z1

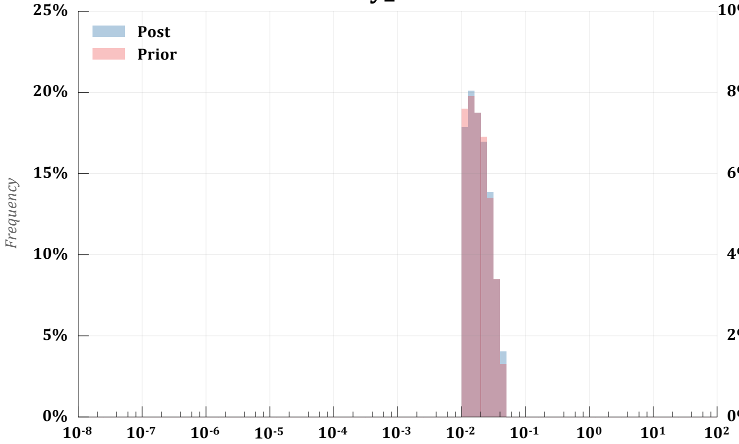


sy_z10

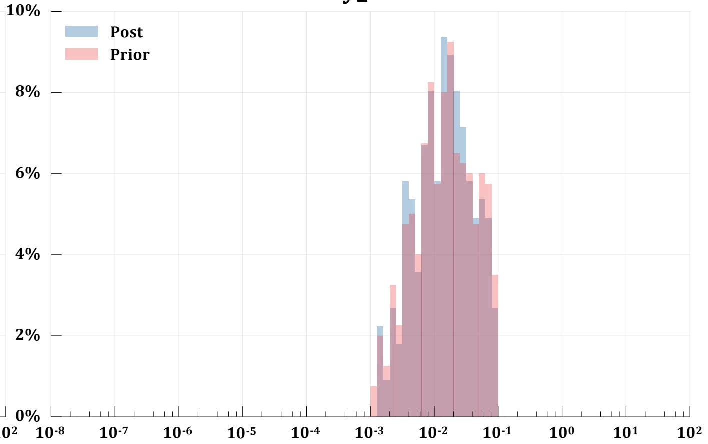


Range

sy_z11

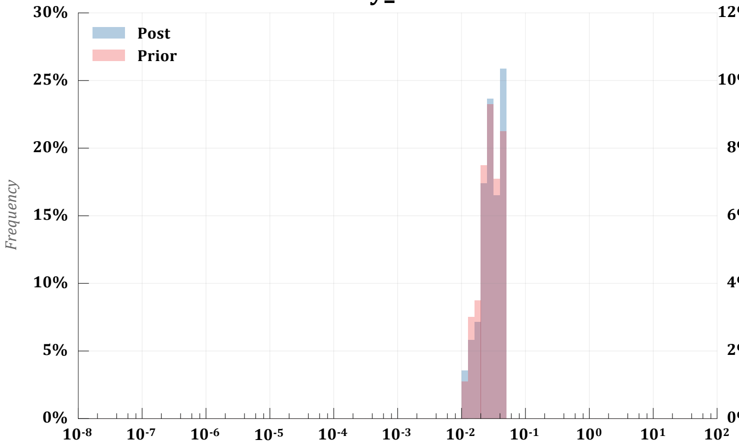


sy_z12



Range

sy_z16



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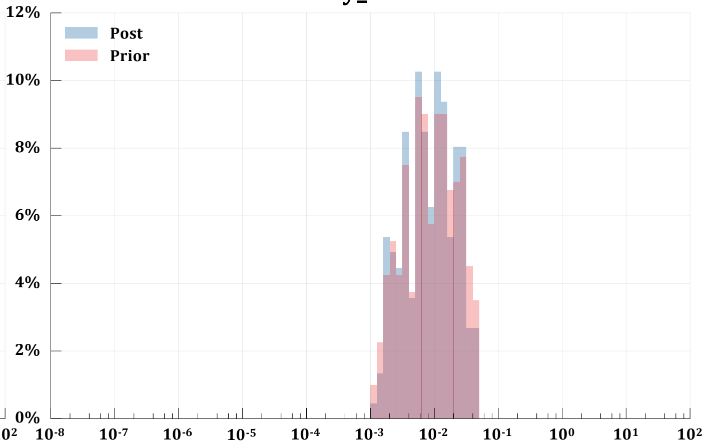
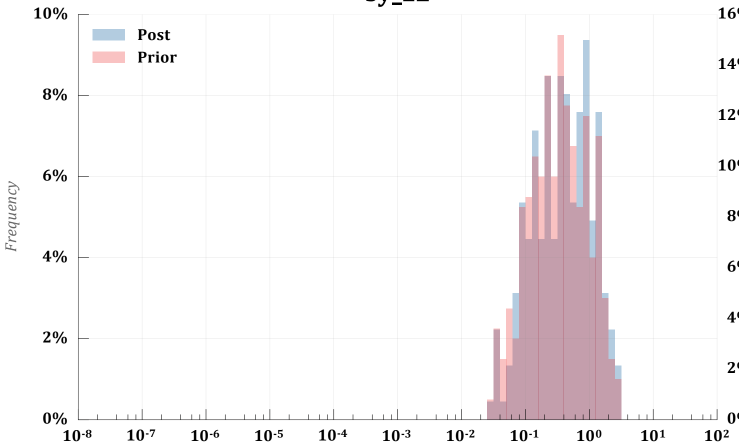
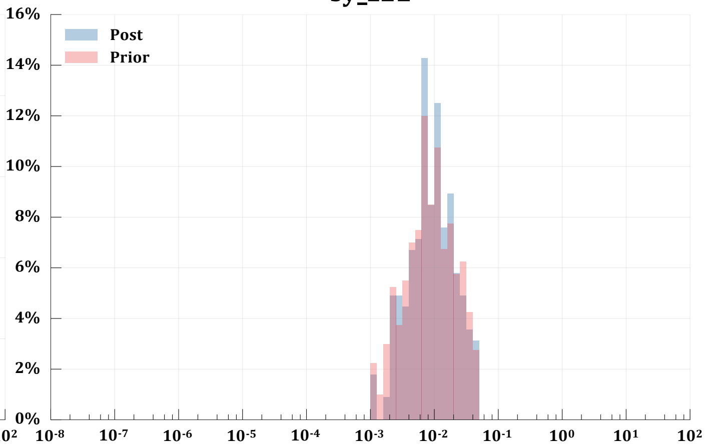


Range

sy_z2



sy_z22



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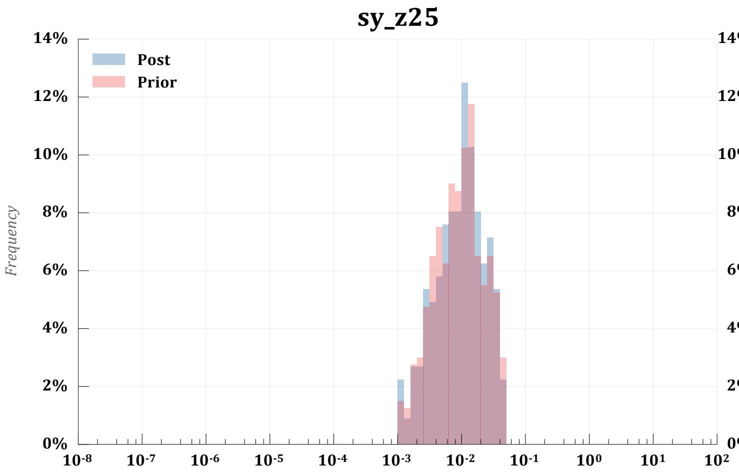

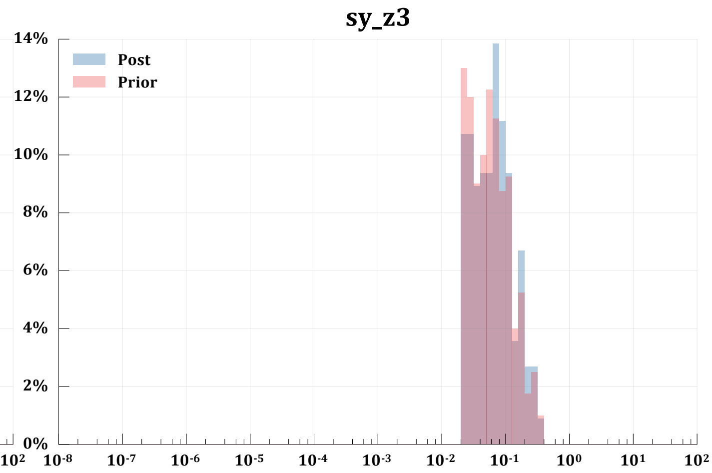

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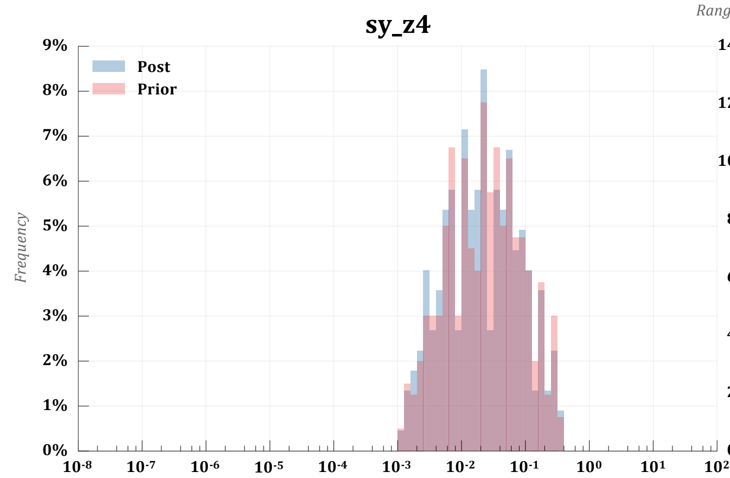

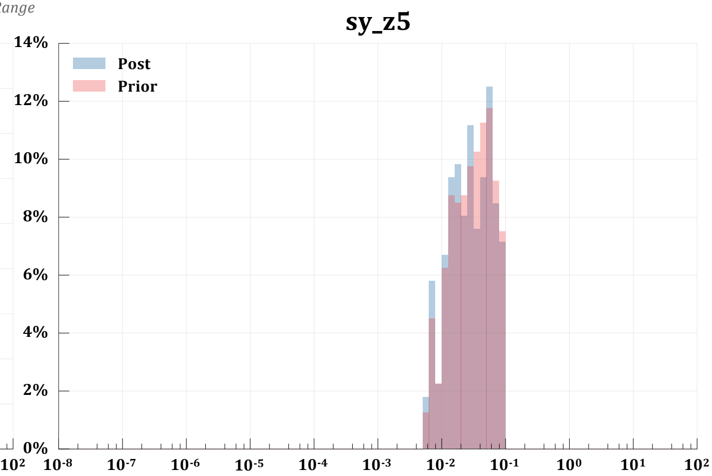

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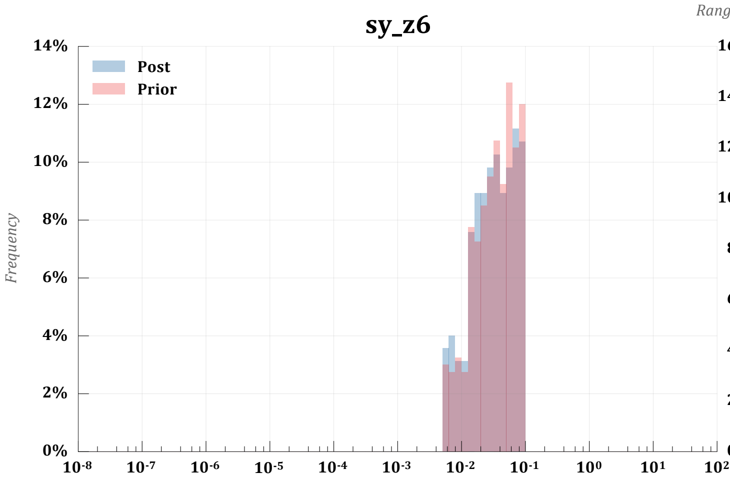

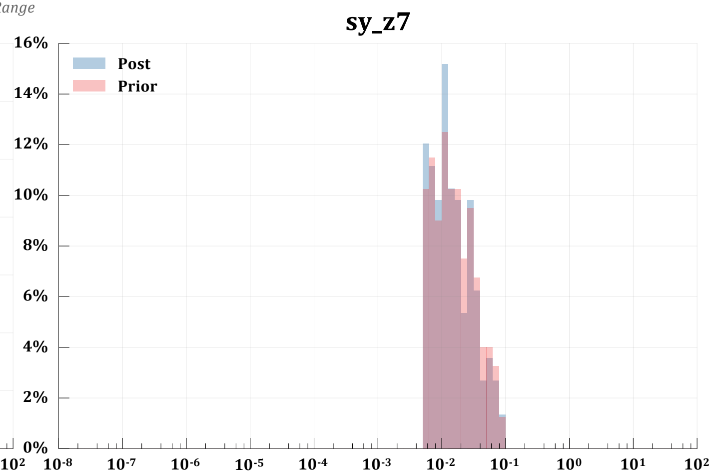

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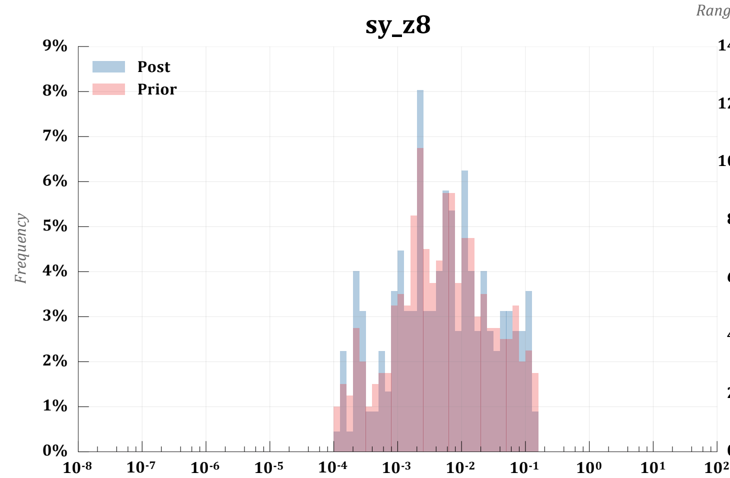

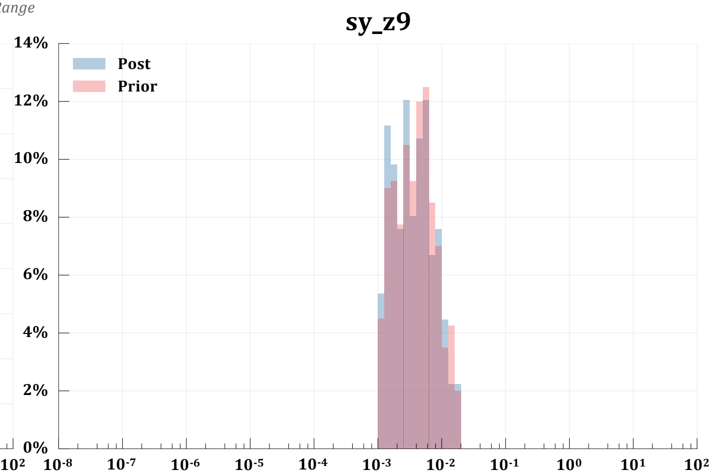

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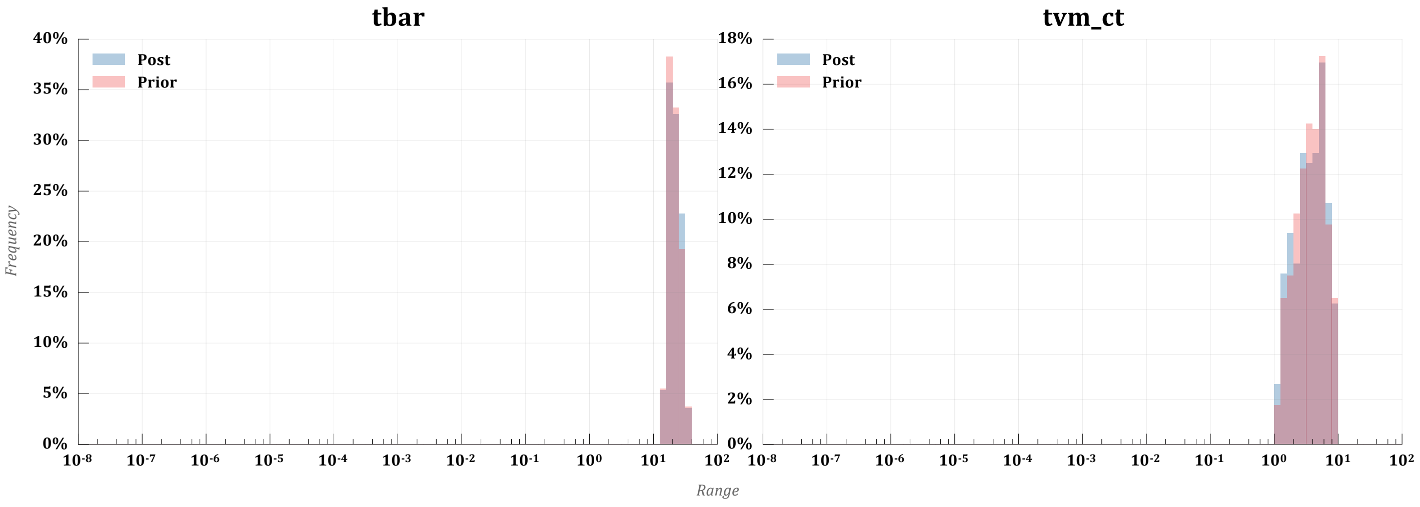
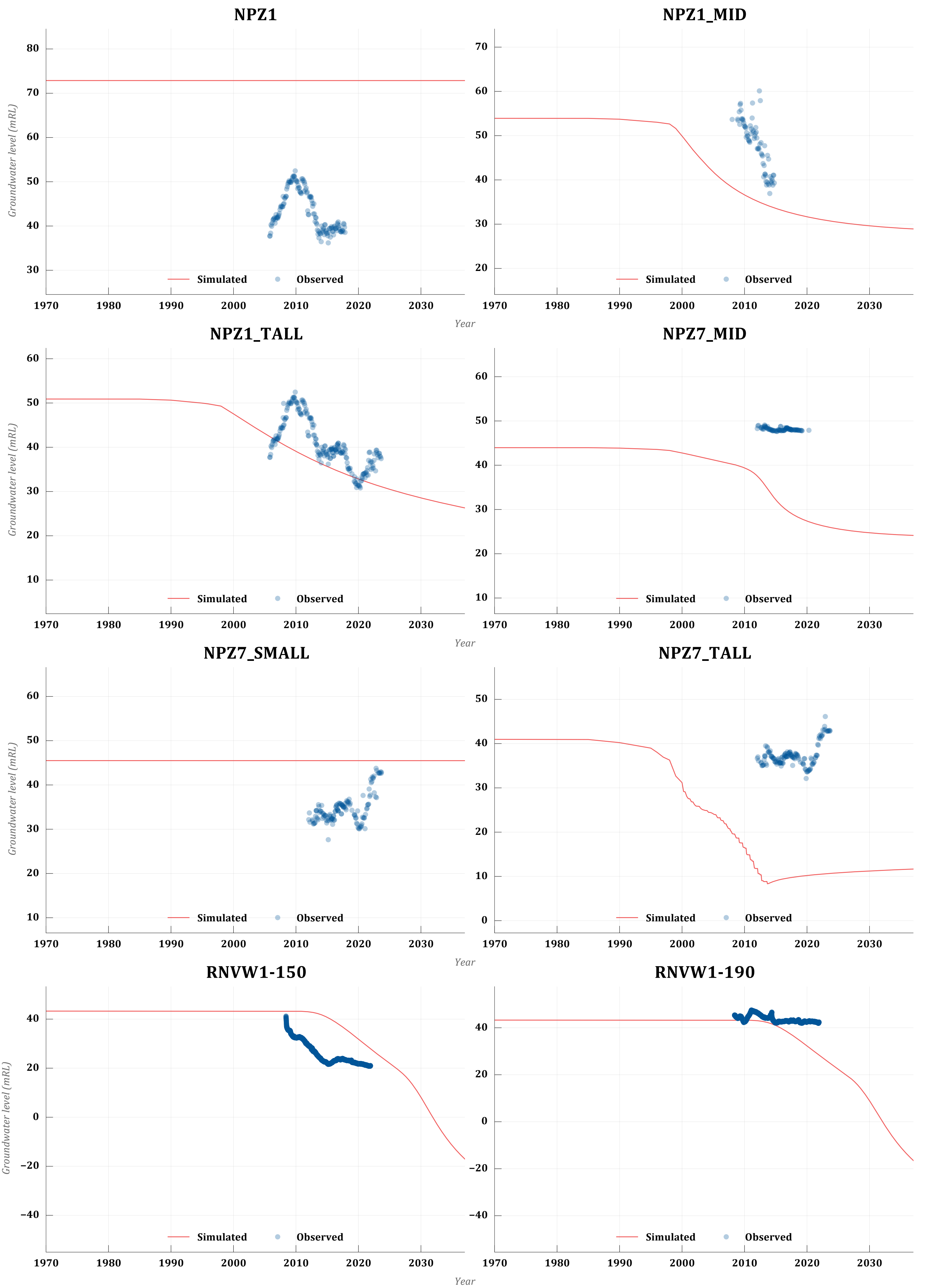
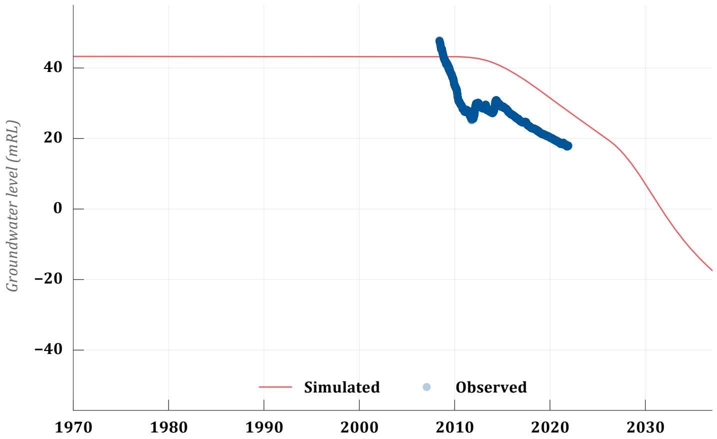

tbar
tvm_ct
Post
Prior
Frequency
Range
40%
35%
30%
25%
20%
15%
10%
5%
0%
18%
16%
14%
12%
10%
8%
6%
4%
2%
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

Appendix F

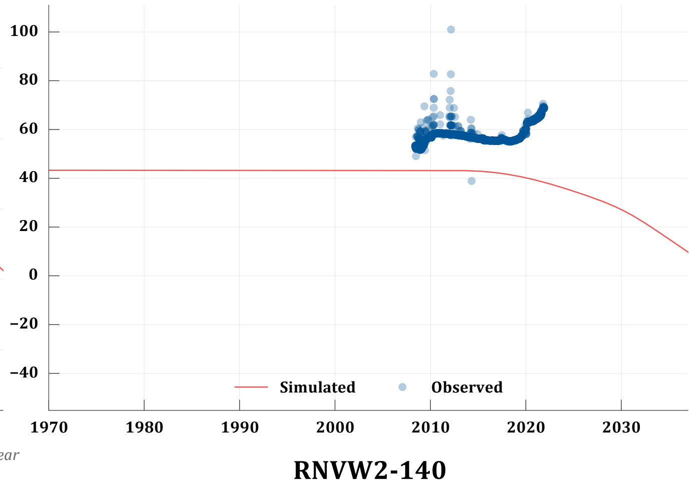
Ravensworth bore hydrographs


NPZ1
NPZ1_MID
NPZ1_TALL
NPZ7_MID
NPZ7_SMALL
NPZ7_TALL
RNVW1-150
RNVW1-190
Groundwater level (mRL)
Year
Simulated
Observed
1970
1980
1990
2000
2010
2020
2030

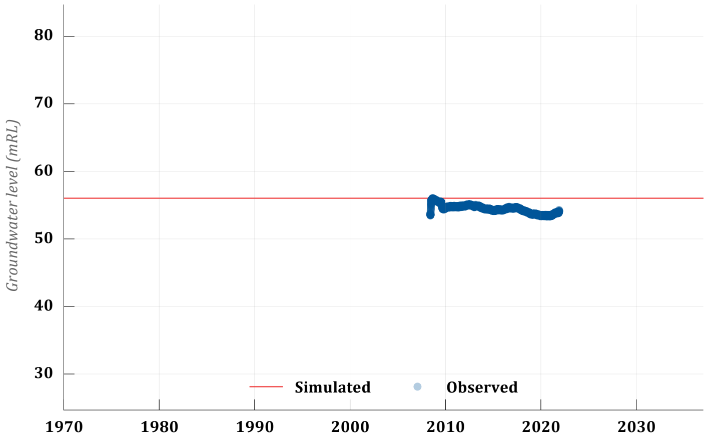
RNVW1-240



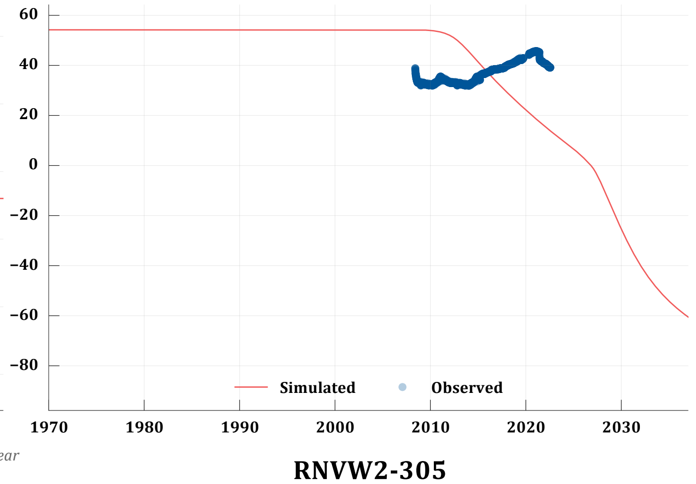
RNVW1-326



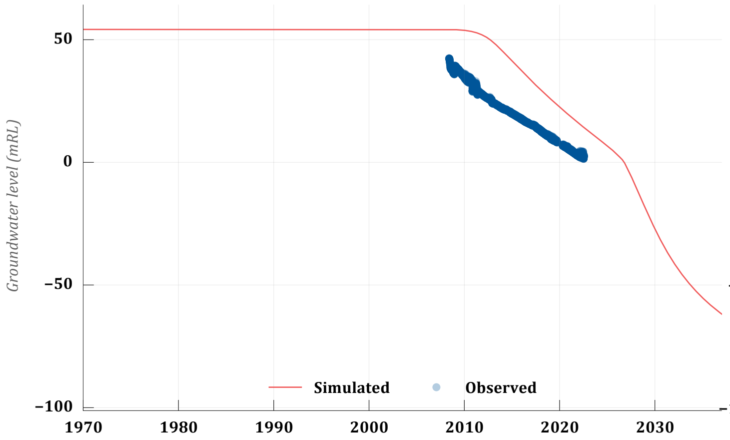
RNVW1-48



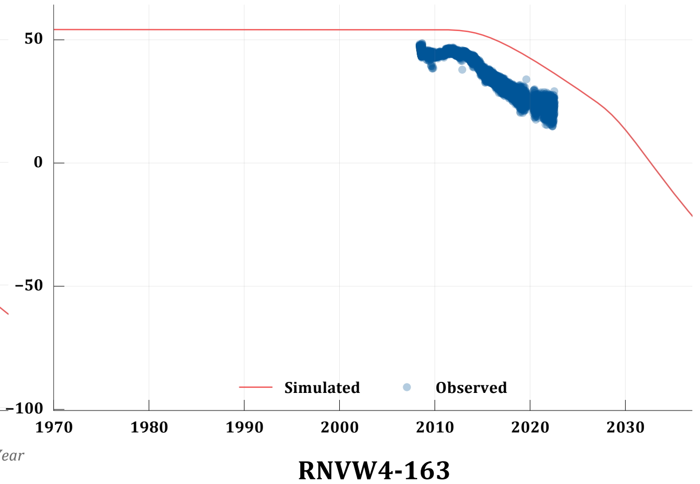
RNVW2-140



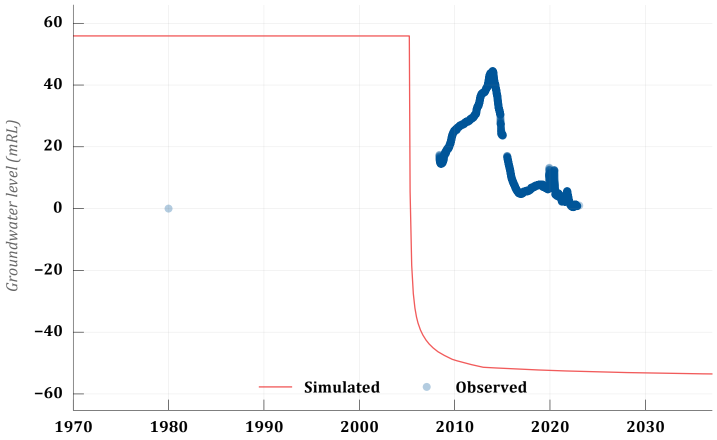
RNVW2-239



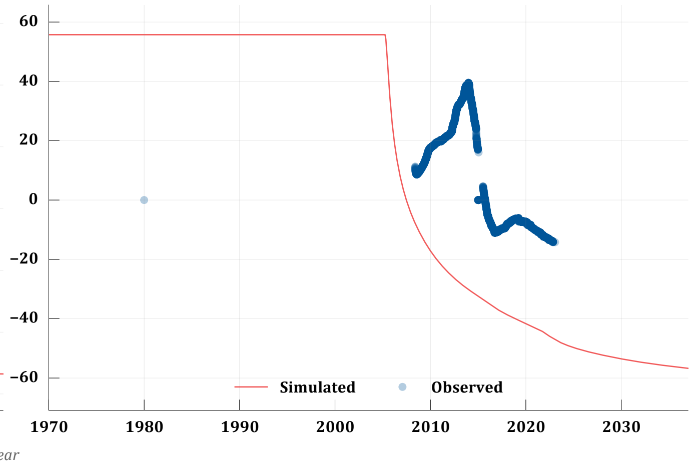
RNVW2-305

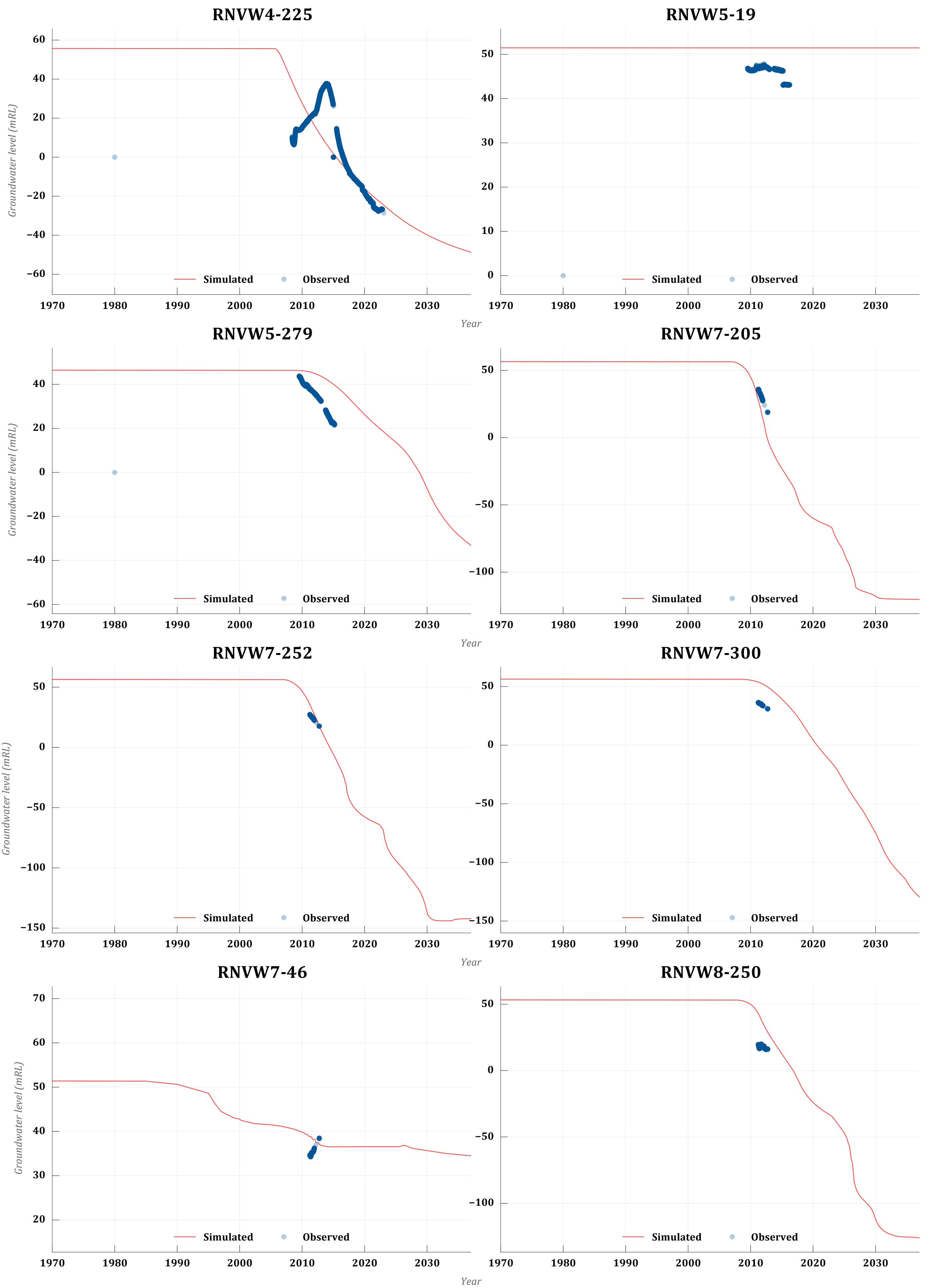


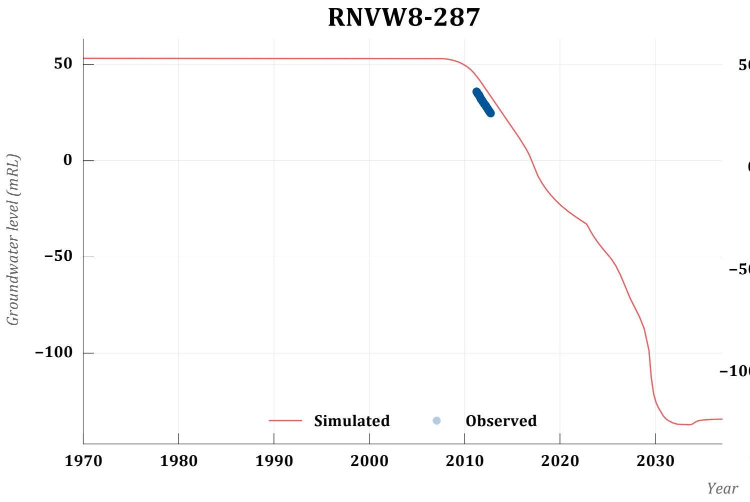
RNVW4-102

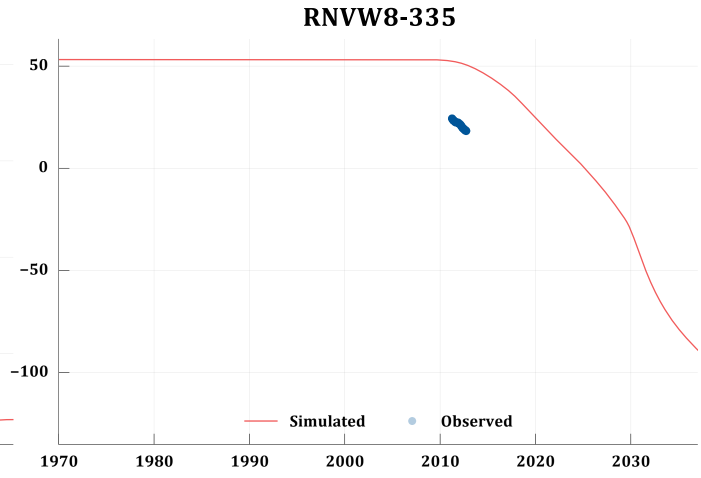


RNVW4-163



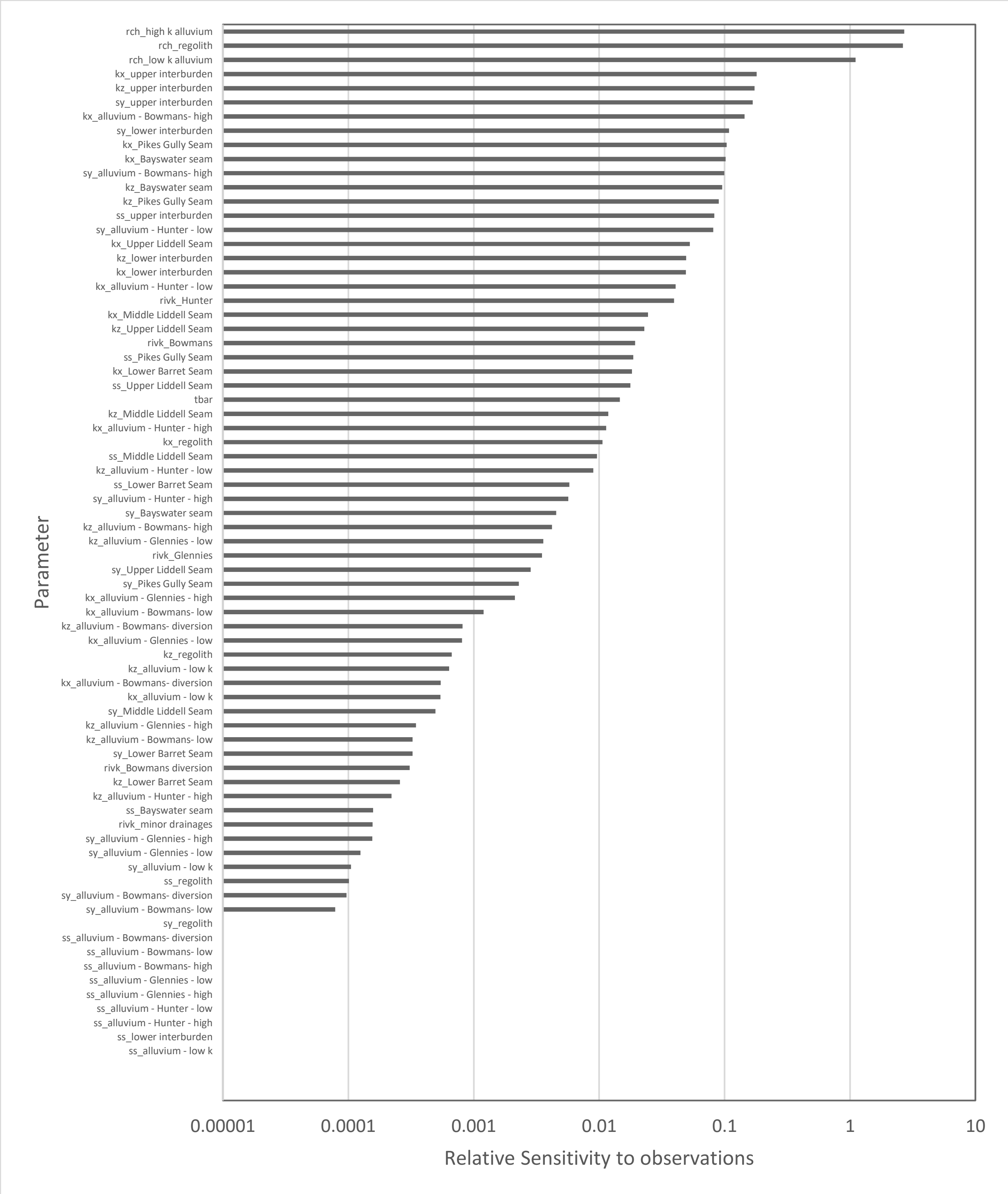

RNVW4-225
RNVW5-19
RNVW5-279
RNVW7-205
RNVW7-252
RNVW7-300
RNVW7-46
RNVW8-250
Groundwater level (mRL)
Year
Simulated
Observed
1970
1980
1990
2000
2010
2020
2030


RNVW8-287
50
0
−50
−100
Groundwater level (mRL)
Simulated
Observed
1970
1980
1990
2000
2010
2020
2030


RNVW8-335
50
0
−50
−100
Simulated
Observed
1970
1980
1990
2000
2010
2020
2030
Year

Appendix G

Relative sensitivity of calibrated parameters


rch_high k alluvium
rch_regolith
rch_low k alluvium
kx_upper interburden
kz_upper interburden
sy_upper interburden
kx_alluvium - Bowmans- high
sy_lower interburden
kx_Pikes Gully Seam
kx_Bayswater seam
sy_alluvium - Bowmans- high
kz_Bayswater seam
kz_Pikes Gully Seam
ss_upper interburden
sy_alluvium - Hunter - low
kx_Upper Liddell Seam
kz_lower interburden
kx_lower interburden
kx_alluvium - Hunter - low
rivk_Hunter
kx_Middle Liddell Seam
kz_Upper Liddell Seam
rivk_Bowmans
ss_Pikes Gully Seam
kx_Lower Barret Seam
ss_Upper Liddell Seam
tbar
kz_Middle Liddell Seam
kx_alluvium - Hunter - high
kx_regolith
ss_Middle Liddell Seam
kz_alluvium - Hunter - low
ss_Lower Barret Seam
sy_alluvium - Hunter - high
sy_Bayswater seam
kz_alluvium - Bowmans- high
kz_alluvium - Glennies - low
rivk_Glennies
sy_Upper Liddell Seam
sy_Pikes Gully Seam
kx_alluvium - Glennies - high
kx_alluvium - Bowmans- low
kz_alluvium - Bowmans- diversion
kx_alluvium - Glennies - low
kz_regolith
kz_alluvium - low k
kx_alluvium - Bowmans- diversion
kx_alluvium - low k
sy_Middle Liddell Seam
kz_alluvium - Glennies - high
kz_alluvium - Bowmans- low
sy_Lower Barret Seam
rivk_Bowmans diversion
kz_Lower Barret Seam
kz_alluvium - Hunter - high
ss_Bayswater seam
rivk_minor drainages
sy_alluvium - Glennies - high
sy_alluvium - Glennies - low
sy_alluvium - low k
ss_regolith
sy_alluvium - Bowmans- diversion
sy_alluvium - Bowmans- low
sy_regolith
ss_alluvium - Bowmans- diversion
ss_alluvium - Bowmans- low
ss_alluvium - Bowmans- high
ss_alluvium - Glennies - low
ss_alluvium - Glennies - high
ss_alluvium - Hunter - low
ss_alluvium - Hunter - high
ss_lower interburden
ss_alluvium - low k
Parameter
0.00001
0.0001
0.001
0.01
0.1
1
10
Relative Sensitivity to observations