Australasian Groundwater and
Environmental Consultants Pty Ltd

Report on

Integra Underground
Groundwater Impact Assessment

Prepared for
HV Coking Coal Pty Limited

Project No. G1285A December 2017

www.ageconsultants.com.au ABN 64 080 238 642

Document details and history

Document details

Project number G1285A
Document title Integra Underground Groundwater Impact Assessment
Site address Hunter Valley NSW
File name G1285A_Integra_4.03_FINAL.docx

Document status and review

Edition	Comments	Author	Authorised by	Date
Draft 1.01	Issued for client comment and review	JT/NM/JB	JT	6/10/17
Draft 2.01	Issued for client comment and review	JT/TD	JT	1/11/17
Draft 2.02	Client comments addressed	JT/TD	JT	03/11/17
Draft 3.01	Client comments addressed	JT/TD	JT	16/11/17
v4.01_Final	Comments addressed	JT/TD	JT	22/11/17
v4.02_Final	Peer review comments addressed	JT/TD/NM	JST	23/11/17
v4.03_Final	Peer review comments addressed	JT/TD/NM	JST	4/12/2017

Australasian Groundwater and Environmental Consultants Pty Ltd

AGE Head Office
Level 2 / 15 Mallon Street,
Bowen Hills, QLD 4006, Australia
T. +61 7 3257 2055
F. +61 7 3257 2088
brisbane@ageconsultants.com.au

AGE Newcastle Office
4 Hudson Street
Hamilton, NSW 2303, Australia
T. +61 2 4962 2091
F. +61 2 4962 2096
newcastle@ageconsultants.com.au

AGE Townsville Office
Level 3 / 201 Sturt Street
Townsville, QLD 4810, Australia
T. +61 429 492 716
F. +61 7 3257 2088
townsville@ageconsultants.com.au

Table of contents

Page No.

1 Introduction 1
1.1 Objectives and scope of work 3
1.2 Modification description 3
1.2.1 Approved operations 3
1.2.2 Modification 4
1.3 Report structure 6

2 Regulatory framework 7
2.1 Water Management Act 2000 7
2.2 Water sharing plans 8
2.3 State groundwater policy 11
2.3.1 Aquifer Interference Policy 11
2.3.2 NSW Strategic Regional Land Use Policy 17
2.4 Water licensing 17
2.5 Conditions of Approval 19
2.6 Commonwealth Environment Protection and Biodiversity Conservation Act 1999 20

3 Environmental setting 21
3.1 Location 21
3.2 Climate 21
3.3 Terrain and drainage 22
3.4 Land use 26

4 Geological setting 28
4.1 Regional geology 28
4.2 Local geology 33
4.2.1 Quaternary alluvium 33
4.2.2 Jerrys Plains Subgroup 36
4.2.3 Vane Subgroup 36
4.2.4 Saltwater Creek Formation 41
4.2.5 Maitland Group 41
4.3 Geological structure 41

5 Hydrogeology 42
5.1 Alluvial groundwater systems 42
5.1.1 Monitoring network 42
5.1.2 Thickness and saturation 46
5.1.3 Flow and water level fluctuations 49
5.1.4 Hydraulic properties 54
5.2 Permian groundwater systems 54
5.2.1 Monitoring network 54
5.2.2 Flow and water level fluctuations 59
5.2.3 Hydraulic parameters 67

Table of contents (continued)

Page No.

5.3 Groundwater quality and beneficial use ... 68

5.3.1 Salinity ... 68

5.3.2 Chemistry and beneficial use ... 71

5.4 Groundwater use ... 73

5.4.1 Private water users ... 73

5.4.2 Groundwater dependent ecosystems ... 75

5.5 Conceptual model ... 77

6 Numerical groundwater model ... 79

6.1 Overview of mining ... 79

6.1.1 Approved mining ... 79

6.1.2 Proposed mine plan ... 83

6.2 Overview of groundwater modelling ... 86

6.3 Peer review ... 87

7 Model predictions and impact assessment ... 89

7.1 Modification groundwater predictions ... 89

7.1.1 Groundwater directly intercepted by mining ... 89

7.1.2 Drawdown and depressurisation during mining operations ... 91

7.1.3 Change in alluvial and surface water fluxes ... 96

7.1.4 Water licensing and water sharing plan rules ... 97

7.1.5 Drawdown in private bores ... 99

7.1.6 Impact on groundwater dependent ecosystems ... 99

7.2 Cumulative drawdown ... 101

7.3 Post mining recovery conditions ... 104

7.3.1 Post closure groundwater recovery ... 104

7.3.2 Groundwater quality changes ... 107

7.4 Sensitivity ... 107

8 Groundwater monitoring and management plan ... 108

8.1 Groundwater monitoring program ... 108

8.2 Water level monitoring plan ... 111

8.3 Water quality monitoring plan ... 111

8.4 Trigger levels ... 112

8.5 Mine water seepage monitoring ... 112

8.6 Future model iterations ... 112

8.7 Data management and reporting ... 112

8.8 Management and mitigation strategies ... 113

9 Summary and conclusions ... 115

10 References ... 116

Glossary and acronyms ... 117

Table of contents (continued)

Page No.

List of figures

Figure 1-1 General location plan ... 2
Figure 1-2 Proposed Modification Layout – 320 panel option ... 5
Figure 2-1 Hunter Unregulated WSP water sources ... 10
Figure 2-2 Highly Productive groundwater (DPI Water) ... 16
Figure 2-3 Volume of water pumped from Integra underground Middle Liddell seam workings ... 18
Figure 3-1 Cumulative Rainfall Departure (SILO) and monthly rainfall (Bulga South Wambo and site SILO) ... 22
Figure 3-2 Terrain and drainage ... 24
Figure 3-3 Baseflow in Glennies Creek at Middle Falbrook (210044) ... 25
Figure 3-4 Baseflow in Hunter River at U/S Foybrook (210126) ... 25
Figure 3-5 Baseflow in Bowmans Creek at Bowmans Creek Bridge (210130) ... 26
Figure 3-6 Historic and existing mining ... 27
Figure 4-1 Regional surface geology ... 30
Figure 4-2 Conceptualised north-east – south-west geological cross section ... 31
Figure 4-3 Conceptualised north-west – south-east geological cross section ... 32
Figure 4-4 Modification surface geology ... 34
Figure 4-5 Structure and thickness contours of the Quaternary alluvium ... 35
Figure 4-6 Photo of Permian strata exposed in 'highwall' of Mount Owen Mine North looking towards the south ... 37
Figure 4-7 Structure and depth contours of the Middle Liddle Coal Seam ... 38
Figure 4-8 Structure and depth contours of the Barrett Seam ... 39
Figure 4-9 Structure and depth contours of the Hebden Seam ... 40
Figure 5-1 Quaternary Alluvium groundwater monitoring locations ... 43
Figure 5-2 Interpolated thickness of Quaternary alluvium ... 47
Figure 5-3 Bettys Creek alluvium exposed in Mount Owen Mine ... 48
Figure 5-4 Main Creek alluvium from channel of Main Creek ... 48
Figure 5-5 Interpolated groundwater levels within Quaternary alluvium 2017 ... 50
Figure 5-6 Bettys Creek alluvium hydrographs – northern bores ... 51
Figure 5-7 Bettys Creek alluvium hydrographs – southern bores ... 51
Figure 5-8 Main Creek alluvium hydrographs – northern bores ... 52
Figure 5-9 Main Creek alluvium hydrographs – midstream bores ... 52
Figure 5-10 Main Creek alluvium hydrographs – southern bores ... 53
Figure 5-11 Glennies Creek alluvium hydrographs – eastern bores ... 53
Figure 5-12 Glennies Creek alluvium hydrographs – western bores ... 54

Table of contents (continued)

Page No.

Figure 5-13 Permian groundwater monitoring locations ... 55
Figure 5-14 Hydrograph - VWP DDH223 ... 60
Figure 5-15 Hydrograph – VWP DDH224 ... 60
Figure 5-16 Hydrograph – PZ-1 ... 61
Figure 5-17 Hydrograph – PZ-4 ... 61
Figure 5-18 Hydrograph – SMO028 ... 62
Figure 5-19 Hydrograph – NPZ1 ... 62
Figure 5-20 Hydrograph – NPZ6 ... 63
Figure 5-21 Hydrograph – NPZ7 ... 63
Figure 5-22 Hydrograph – NPZ8 ... 64
Figure 5-23 Hydrograph – NPZ9 ... 64
Figure 5-24 Hydrograph – NPZ10 ... 65
Figure 5-25 Interpolated groundwater levels in Middle Liddell seam 2017 ... 66
Figure 5-26 Hydraulic conductivity vs depth – Permian coal ... 67
Figure 5-27 Hydraulic conductivity vs. depth – Permian interburden ... 68
Figure 5-28 Electrical conductivity violin plot of monitoring data ... 69
Figure 5-29 Electrical conductivity in Main Creek alluvium ... 70
Figure 5-30 Electrical conductivity in Bettys Creek alluvium ... 70
Figure 5-31 Electrical conductivity in selected Permian monitoring bores ... 71
Figure 5-32 Groundwater use within the vicinity of the Modification ... 74
Figure 5-33 Potential groundwater dependent ecosystems ... 76
Figure 6-1 Approved mining – Middle Liddell seam ... 80
Figure 6-2 Approved mining – Hebden seam ... 81
Figure 6-3 Approved mining – Barrett seam ... 82
Figure 6-4 Proposed Modification – Middle Liddell seam – 320 m panels ... 84
Figure 6-5 Proposed Modification – Middle Liddell seam – 246 m panels ... 85
Figure 6-6 Model extent ... 88
Figure 7-1 Groundwater intercepted from Permian coal measures– 320 m panels ... 90
Figure 7-2 Groundwater intercepted from Permian coal measures – 246 m panels ... 90
Figure 7-3 Maximum zone of drawdown due to Modification– Quaternary alluvium ... 92
Figure 7-4 Maximum zone of drawdown due to Modification– Middle Liddell Seam ... 93
Figure 7-5 Pore pressure – 2017 ... 94
Figure 7-6 Pore pressure – 2035 ... 95
Figure 7-7 Change in flux to Quaternary alluvium and surface water systems from approved mining and Modification combined ... 96

Table of contents (continued)

Page No.

Figure 7-8 Partitioning of water take from streams and Quaternary alluvium for the Modification.... 98

Figure 7-9 GDEs and predicted maximum cumulative drawdown in Quaternary alluvium............100

Figure 7-10 Cumulative drawdown – Quaternary alluvium 102

Figure 7-11 Cumulative drawdown – Middle Liddell Seam 103

Figure 7-12 Recovery of groundwater levels with Modification area........105

Figure 7-13 Post mining maximum drawdown – Quaternary alluvium 106

Figure 8-1 Groundwater monitoring network........110

List of tables

Table 2-1 Water licensing for each water source........9

Table 2-2 Minimal Impact Considerations for Aquifer Interference Activities (DPI Water 2012). 13

Table 2-3 Water licensing - North Coast Fractured and Porous Rock WSP 17

Table 2-4 Water licensing - Hunter Regulated River WSP 18

Table 3-1 Climate averages 21

Table 4-1 Summary of regional geology........ 29

Table 5-1 Quaternary alluvium groundwater monitoring bores........ 44

Table 5-2 Permian groundwater monitoring bores........ 56

Table 5-3 Water quality in selected monitoring bores 72

Table 5-4 Registered bores on private lands 73

Table 7-1 Groundwater licensing summary – during mining........ 97

Table 8-1 Summary of WMP monitoring bores 108

List of appendices

Appendix A Numerical modelling report

Appendix B Compliance with government policy

Report on

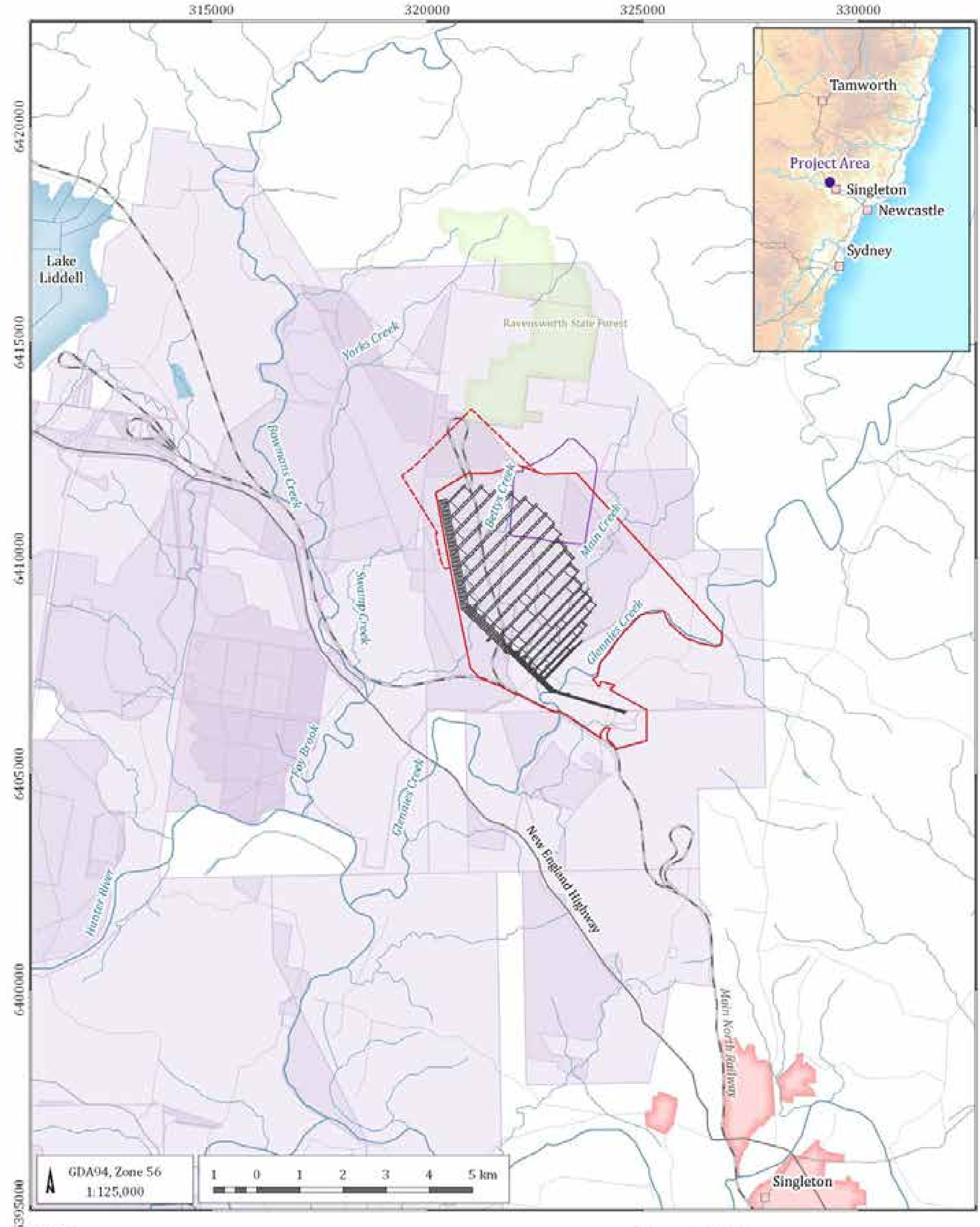
Integra Underground
Groundwater Impact Assessment

1 Introduction

Integra Underground Mine (referred herein as Integra Underground) is situated approximately 12 kilometres (km) north north-west of Singleton in the Singleton Local Government area of New South Wales (NSW) (Figure 1-1). Integra Underground is owned by HV Coking Coal Pty Limited (HVCC) a wholly owned subsidiary of Glencore Coal Pty Limited (Glencore). HVCC currently holds Project Approval PA 08_0101 to conduct longwall mining operations at a rate of up to 4.5 Million tonnes per annum (Mtpa) of Run of Mine (ROM) coal mine until the end of 2035.

HVCC proposes to modify PA 08_0101 to allow an extension of underground mining in the Middle Liddell seam further to the north of the currently approved longwall panels (the Modification). To facilitate this HVCC commissioned Hansen Bailey to prepare an Environmental Assessment (EA) to support a modification application under Section 75W of the Environmental Planning and Assessment Act 1979 (EP&A Act).

This groundwater impact assessment has been prepared by Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) as part of the EA for the Modification. The groundwater assessment has been undertaken in accordance with the scope requested by Department of Planning and Environment (DP&E) in correspondence dated 6 October 2017, and the information guidelines developed by Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC).



LEGEND

- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Coal titles
- Reserve
- Built up area
- Water area
- Major drainage
- Minor drainage
- Major road
- Minor road
- Rail

Integra (G1285A)

General location plan

AGE

DATE 16/11/2017

FIGURE No: **1-1**

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/G1285A.Integra/3_GIS/Workspaces/002_IBA/01.01_G1285A_General location.qgs

1.1 Objectives and scope of work

The objective of the groundwater assessment was to assess the impact of the Modification on the groundwater regime, and address the requirements of the NSW and Federal government legislation and policies. The groundwater assessment comprised two parts, a description of the existing hydrogeological environment, and an assessment of the impacts of mining on that environment.

The groundwater impact assessment included:

- review of existing background data and previous hydrogeological investigations;
- updating the existing groundwater model developed for mining projects within the region in accordance with the National Groundwater Modelling Guidelines (National Water Commission, 2012) and relevant State and Commonwealth guidelines (Appendix B);
- assessment of the impacts as a result of the proposal, including long term impacts on regional groundwater levels and baseflow;
- assessment of potential groundwater dependant ecosystem (GDE) impacts resulting from short and/or long term changes in groundwater;
- assessment of the potential third party impacts (i.e. private bores) as a result of changes to the regional groundwater system;
- assessment against the Aquifer Interference Policy (2012);
- assessment of cumulative impacts;
- assessment of post mining recovery; and
- provision of recommendations for the management of groundwater impacts including recommendations for monitoring.

1.2 Modification description

1.2.1 Approved operations

Integra Underground was formerly part of a mining complex (Integra Coal Complex) that included both underground and open cut mining areas. The Integra Coal Complex comprised the underground mining of the Middle Liddell seam north of Glennies Creek and the open cut operations south of Glennies Creek (Figure 1-2). Prior to the formation of the Integra mining complex the open cut and underground mines had been operated separately, known as the Camberwell open cut mine and Glennies Creek Colliery respectively.

On 18 December 2015 the complex was acquired from Integra Coal Operations Pty Limited after it had been put into care and maintenance in May 2014. The underground operations were acquired by HVCC, whilst the open cut mine and surface facilities were acquired by Bloomfield Collieries Pty Limited (Bloomfield). The mines are now referred to as to as the Integra Underground Mine and Rix's Creek North open cut mine.

Integra Underground, formerly Glennies Creek Colliery, was established in 1999, with the first longwall mining commencing in the Middle Liddell seam in 2002. In 2010 the mine was approved to longwall mine the Hebden, Barrett and Middle Liddell seams at a maximum extraction rate of 4.5 Mtpa of run-of-mine (ROM) coal until 31 December 2035 under PA 08_0101. In mid-2014, the underground operations were placed in care and maintenance at the completion of longwall 12 within the Middle Liddell seam. HVCC recommenced underground mining following purchase of the underground mine in early 2017.

To date mining has occurred only within the Middle Liddell seam and has involved development of main headings and gate roads to gate 14. Longwall secondary extraction has progressed through longwall panels 1 to 12, and is currently active in LW13.

Approved coal mines are also present to the north, south and west of the Modification, which are discussed further in Section 2.5.

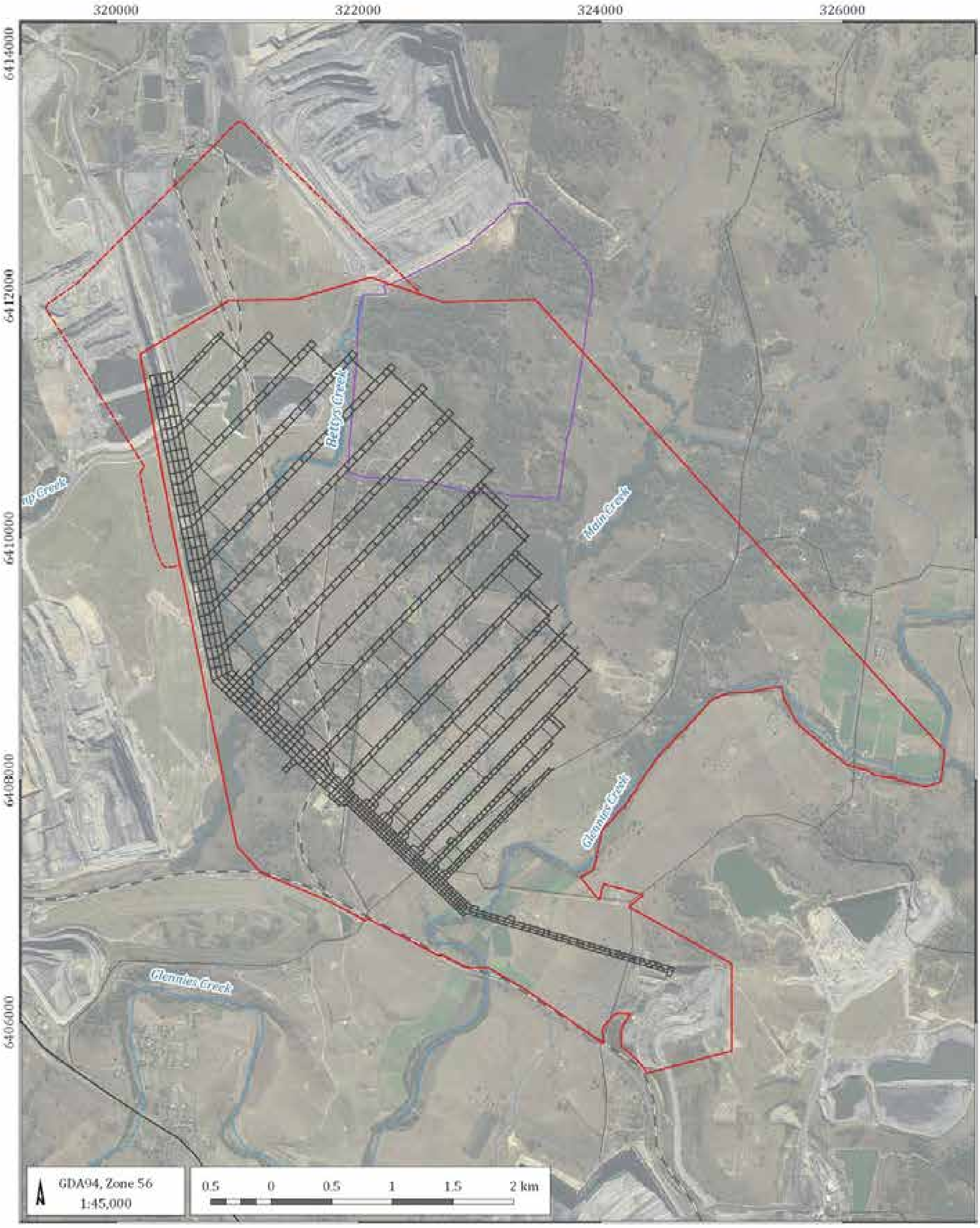
1.2.2 Modification

HVCC is seeking approval to continue longwall mining of the Middle Liddell Seam further to the north of the currently approved longwall panels (the Modification). The Modification also involves the construction and operation of ancillary surface infrastructure.

The Modification includes the following components:

- Adjustments to the approved mine plan for the Middle Liddell Seam including:
  - realignment and extension of the main headings further to the north-west;
  - increases to the lengths and widths of the approved LWs 15-17; and
  - mining of additional longwall panels (LWs 18-19 or LWs 18-20).
- Construction and use of additional surface infrastructure:
  - surface auxiliary fans in the maingate of each longwall panel to assist in the efficient ventilation of the longwall mining area;
  - additional electricity transmission lines and distribution lines;
  - additional dewatering boreholes and associated infrastructure;
  - additional gas drainage boreholes to ensure the safety of underground operations;
  - increased usage of the currently approved gas flares; and
  - relocation of the existing store facility and the construction and use of an additional access road off Middle Falbrook Road.
- Use of the C4 Dam to store raw water from Glennies Creek.

Mount Owen Pty Ltd (Mount Owen), like HVCC is also a subsidiary of Glencore and operates three existing open cut operations in the Mount Owen Complex: Mount Owen (North Pit) and associated infrastructure, Ravensworth East (Bayswater North Pit) and Glendell (Barrett Pit). Prior to HVCC acquiring Integra Underground, the potential to mine all reserves within the North Pit area was limited due to the tenements to mine at certain depths not being held. As Glencore now own and manage both operations and associated mining tenements, a modification to the Mount Owen (North Pit) mine plan is also being proposed as a separate application to optimise coal resource recovery from the North Pit. Given the proximity of the North Pit to Integra Underground and the potential for cumulative impacts the groundwater assessment has considered the Mount Owen modification as part of the proposed mining.



LEGEND

- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining (disturbance to Feb 2017)
- Major drainage
- Minor drainage
- Major road
- Minor road
- Rail

Integra (G1285A)

Proposed modification layout

DATE 16/11/2017

FIGURE No: **1-2**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.
Aerial image (July 2017) provided by Glencore.
G:/Projects/G1285A.Integra/3_GIS/Workspaces/002_EIA/01.02b_G1285A_Proposed project.qgs

1.3 Report structure

This report is structured as follows:

- Section 1 – Introduction: provides an overview of the Modification and the assessment scope.
- Section 2 – Regulatory framework: describes the regulatory framework relating to groundwater.
- Section 3 – Environmental setting: describes the environmental setting of the Modification including the climate, terrain, land uses and other environmental features relevant to the Modification.
- Section 4 – Geological setting: describes the regional geology and local stratigraphy.
- Section 5 – Hydrogeology: describes the existing local groundwater regime for the Modification and surrounding area.
- Sections 6 and 7 – Impact Assessment: provides a detailed description of the proposed mining activities and the potential effects on the local groundwater regime. This section also presents the predicted change on groundwater and the assessment of resulting impacts on groundwater users and the receiving environment. This section includes discussion on findings from the uncertainty analysis.
- Section 8 – Groundwater Monitoring and Management Plan: describes the proposed measures for monitoring and management of groundwater impact.

Appendix A provides a detailed description of the numerical modelling undertaken for the Modification, including details on model construction, calibration and validation. Appendix A also describes the sensitivity analysis undertaken on the numerical groundwater model, including details about the purpose and methodology of the assessment.

Appendix B compares the impacts predicted for the Modification with state and federal government policy and comments on compliance.

2 Regulatory framework

The groundwater assessment was undertaken in accordance with the scope requested by DP&E correspondence dated 6 October 2017. In addition the Modification needs to consider the requirements of the following legislation, policy and guidelines for groundwater:

- NSW Government:
    - *Water Management Act 2000* and the associated Water Sharing Plans;
    - Groundwater Quality Protection Policy (1998);
    - Groundwater Dependent Ecosystems Policy (2002);
    - Groundwater Quantity Management Policy (Policy Advisory Note No. 8);
    - Aquifer Interference Policy (AIP)(2012);
    - Strategic Regional Landuse Policy (SRLU Policy)(2012); and
    - Strategic Regional Landuse Plan – Upper Hunter (2012).
- Commonwealth Government:
    - *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and related Independent Expert Scientific Committee (IESC) information guidelines for coal seam gas (CSG) and large coal mining development proposals.

Sections below summarise the intent of the above legislation, policy and guidelines and how they apply to the Modification.

2.1 Water Management Act 2000

The NSW *Water Management Act 2000* provides for the “protection, conservation and ecologically sustainable development of the water sources of the State”. The *Water Management Act 2000* provides arrangements for controlling land based activities that affect the quality and quantity of the State’s water resources. It provides for three primary types of approval in Part 3:

- water use approval – which authorise the use of water at a specified location for a particular purpose, for up to 10 years;
- water management work approval; and
- controlled activity approval which includes an aquifer interference activity approval – authorises the holder to conduct activities that affect an aquifer such as activities that intersect groundwater, other than water supply bores and may be issued for up to 10 years.

The *Water Management Act 2000* includes the concept of ensuring “no more than minimal harm” for both the granting of water access licences and the granting of approvals. Aquifer interference approvals are not to be granted unless the Minister is satisfied that adequate arrangements are in force to ensure that no more than minimal harm will be done to any water source, or its dependent ecosystems, as a consequence of it being interfered with in the course of the activities to which the approval relates.

While aquifer interference approvals are not currently required to be granted, the minimal harm test under the *Water Management Act 2000* is not activated for the assessment of impacts. Therefore, the AIP establishes and objectively defines minimal impact considerations as they relate to water-dependent assets and as the basis for providing advice to the assessment and/or determining authority.

2.2 Water sharing plans

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

The NSW Department of Primary Industries (DPI) Water is progressively developing WSPs for rivers and groundwater systems across NSW following the introduction of the *Water Management Act 2000*. The purposes of these plans are to protect the health of rivers and groundwater, while also providing water users with perpetual access licences, equitable conditions, and increased opportunities to trade water through separation of land and water.

Three WSP's apply to the aquifers and surface waters affected by the Modification. These are the WSP for the:

- Hunter Regulated River Water Source 2016 (Hunter Regulated WSP);
- Hunter Unregulated and Alluvial Water Sources 2009 (Hunter Unregulated WSP); and
- Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016 (North Coast Fractured and Porous Rock WSP).

The North Coast Fractured and Porous Rock WSP commenced on 1st July 2016 and establishes the management regime relevant for groundwater taken from the Permian bedrock. The proposed Modification falls within the Sydney Basin – North Coast Groundwater Source of the North Coast Fractured and Porous Rock WSP.

The Hunter Regulated WSP covers the Hunter River surface water flows and highly connected alluvials described in the plan. The Hunter Regulated Water Source is divided into three management zones (Zone 1, Zone 2, Zone 3). The zones are defined from a single common point, which is the junction of Glennies Creek with the Hunter River. The Modification is located to the north of Zone 3A which includes Glennies Creek from the upper reaches of Glennies Creek Dam to the Hunter River junction.

The Hunter Unregulated WSP includes the unregulated rivers and creeks within the Hunter River catchment, the highly connected alluvial groundwater (above the tidal limit), and the tidal pool areas. In total, there are 39 water sources covered by the Hunter Unregulated WSP and nine of these are further sub-divided into management zones. The Modification is located within the Jerrys Water Source and Glennies Creek Water Source. The Hunter Regulated River Alluvial water source which covers the Quaternary alluvium associated with Glennies Creek and Station Creek is also a separate water source managed under the Hunter Unregulated WSP.

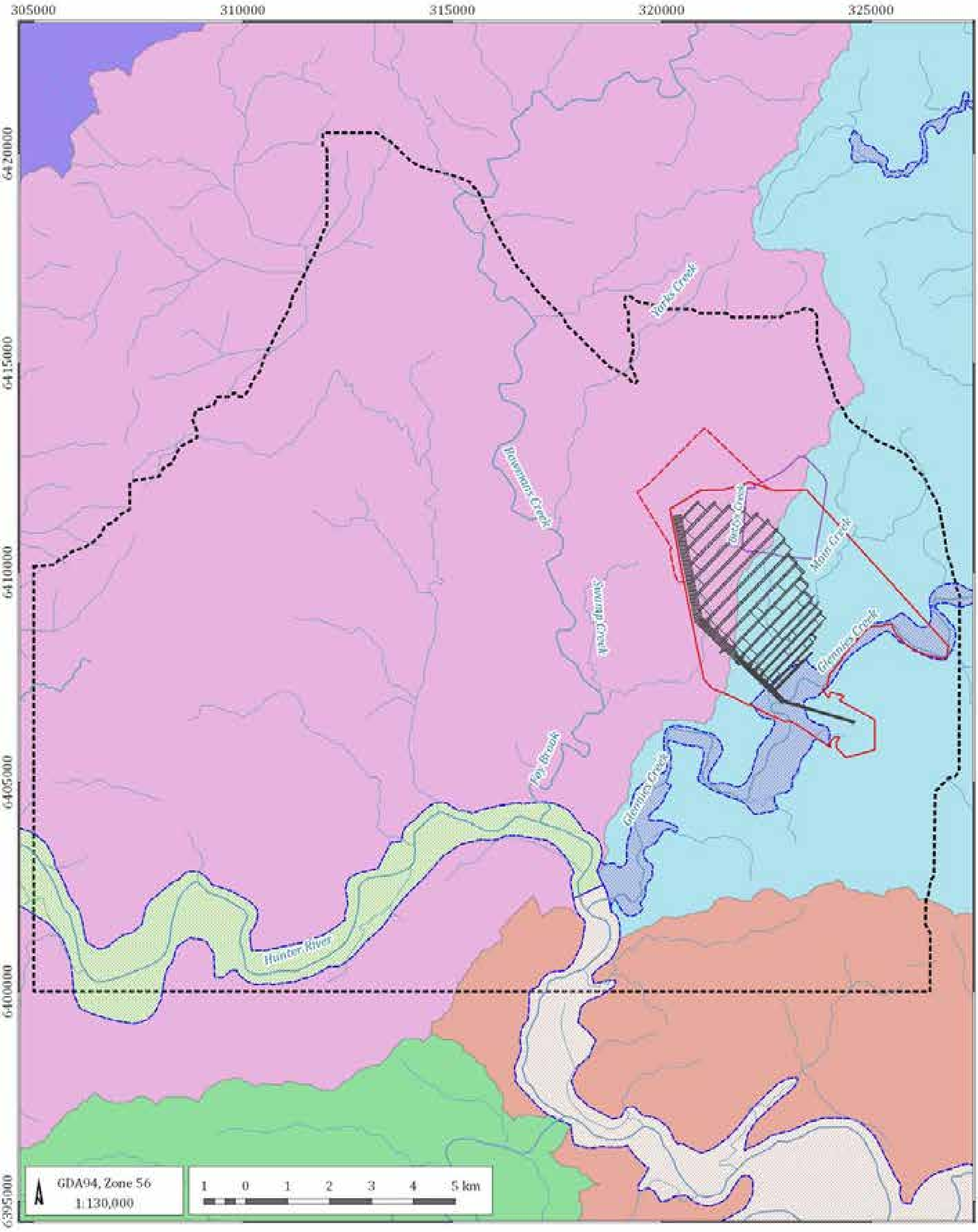
Figure 2-1 shows the water sources and management zones occurring within the area of the Modification. Table 2-1 summarises the number of water access licenses and the aquifer license shares available for each water source.

Table 2-1 Water licensing for each water source

Water source	No. of WALs	Aquifer licence shares
Jerrys	10	1,246
Glennies	2	10
Hunter Regulated River Alluvial	221	24,108
Sydney Basin North Coast	182	69,932.5

The Modification will need to comply with the rules developed for each WSP and water source. The rules relate to

- environmental water;
- access licence dealing;
- access licences;
- water supply work approvals;
- making available water determinations; and
- water allocation accounts.



LEGEND

- Model extent
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining

Alluvial groundwater management area

- Downstream Glennies Creek Management Zone
- Glennies Creek Management Zone
- Upstream Glennies Creek Management Zone

- Major drainage
- Minor drainage

Water Sources

- Glennies Water Source
- Jerrys Water Source
- Lower Wollombi Brook Water Source
- Muswellbrook Water Source
- Singleton Water Source

Integra (G1285A)

Hunter Unregulated WSP water sources

AGE

DATE 16/11/2017

FIGURE No: **2-1**

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/G1285A.Integra/3_GIS/Workspaces/002_EIA/02.01_G1285A_Hunter unregulated WSP water sources.qgs

2.3 State groundwater policy

2.3.1 Aquifer Interference Policy

The *Water Management Act 2000* defines an aquifer interference activity as that which involves any of the following:

- penetration of an aquifer;
- interference with water in an aquifer;
- obstruction of the flow of water in an aquifer;
- taking of water from an aquifer in the course of carrying out mining or any other activity prescribed by the regulations; and
- disposal of water taken from an aquifer in the course of carrying out mining or any other activity prescribed by the regulations.

Examples of aquifer interference activities include mining, coal seam gas extraction, injection of water, and commercial, industrial, agricultural and residential activities that intercept the water table or interfere with aquifers.

The AIP (Department of Primary Industries, 2012) states that:

"*all water taken by aquifer interference activities, regardless of quality, needs to be accounted for within the extraction limits defined by the water sharing plans. A water licence is required under the WM Act (unless an exemption applies or water is being taken under a basic landholder right) where any act by a person carrying out an aquifer interference activity causes:*

- *the removal of water from a water source; or*
- *the movement of water from one part of an aquifer to another part of an aquifer; or*
- *the movement of water from one water source to another water source, such as:*
    - *from an aquifer to an adjacent aquifer; or*
    - *from an aquifer to a river/lake; or*
    - *from a river/lake to an aquifer.* "

Proponents of aquifer interference activities are required to provide predictions of the volume of water to be taken from a water source(s) as a result of the activity. These predictions need to occur prior to Project approval. After approval and during operations, these volumes need to be measured and reported in an annual returns or environmental management reports. The water access licence must hold sufficient share component and water allocation to account for the take of water from the relevant water source when the take occurs.

The AIP states that a water licence is required for the aquifer interference activity regardless of whether water is taken directly for consumptive use or incidentally. Activities may induce flow from adjacent groundwater sources or connected surface water. Flows induced from other water sources also constitute take of water. In all cases, separate access licences are required to account for the take from all individual water sources.

In addition to the volumetric water licensing considerations, the AIP requires details of potential:

- *"water level, quality or pressure drawdown impacts on nearby water users who are exercising their right to take water under a basic landholder right;*
- *water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources;*
- *water level, quality or pressure drawdown impacts on groundwater dependent ecosystems;*
- *increased saline or contaminated water inflows to aquifers and highly connected river systems;*
- *to cause or enhance hydraulic connection between aquifers; and*
- *for river bank instability, or high wall instability or failure to occur."*

In particular, the AIP describes minimal impact considerations for aquifer interference activities based upon whether the water source is highly productive or less productive and whether the water source is alluvial or porous/fractured rock in nature.

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

a) has a Total Dissolved Solids (TDS) concentration less than 1500 mg/L; and
b) contains water supply works that can yield water at a rate greater than 5 L/s.

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

The alluvial groundwater systems occurring in the Modification area associated with Glennies Creek, Main Creek, Bettys Creek and Swamp Creek have been identified by DPI Water as highly productive. The Permian coal measures (porous and fractured rock) are categorised as "less productive" (DPI-Water 2012).

The AIP defines the following Minimal Impact Considerations for "highly productive" and "less productive" groundwater. Table 2-2 summarises the Minimal Impact Considerations for the "highly productive" Quaternary alluvium, and the "less productive" Permian coal measures. If these considerations are not met the Modification needs to demonstrate to the Minister's satisfaction that the impact will be sustainable, or that "make good agreements" are in place.

As indicated under the Minimal Impact Considerations (Table 2-2), the AIP requires that impacts on highly and less productive water sources need to be assessed and accounted for. DPI Water has produced a map of groundwater productivity across NSW, which shows areas classified as either highly or less productive. The DPI Water groundwater productivity map has been produced based on regional scale geological maps. Figure 2-2 shows the DPI Water groundwater productivity map, which indicates the alluvium along Bettys Creek, Main Creek and Glennies Creek has been classified as highly productive. Investigations at Integra Underground and the Mount Owen Complex have determined that the groundwater associated with Bettys Creek, Main Creek and Glennies Creek does not fulfil the definition of 'highly productive' which requires salinity to be less than 1500 mg/L and yields in excess of 5 L/sec. The extent and characteristics of the Quaternary alluvium occurring in the Modification area is further discussed in Section 4.2.1. Section 5.1 and Section 5.3 provide further information on the properties of the alluvial aquifers and why they are not classified as 'highly productive'.

Table 2-2 Minimal Impact Considerations for Aquifer Interference Activities (DPI Water 2012)

Category	1. Water table	Water pressure	Water quality
Highly productive alluvium	1. Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan; or A maximum of a 2 m decline cumulatively at any water supply work. 2. If more than 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any (a) or (b) water sharing plan then appropriate studies (5) will need to demonstrate to the Minister's satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site. If more than 2 m decline cumulatively at any water supply work then make good provisions should apply.	1. A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work. 2. If the predicted pressure head decline is greater than requirement 1. above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long-term viability of the affected water supply works unless make good provisions apply.	1. (a) Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity; and (b) No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. Redesign of a highly connected (3) surface water source that is defined as a "reliable water supply"(4) is not an appropriate mitigation measure to meet considerations 1.(a) and 1.(b) above. (c) No mining activity to be below the natural ground surface within 200 m laterally from the top of high bank or 100 m vertically beneath (or the three dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply". (d) Not more than 10% cumulatively of the three dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200 m laterally from the top of high bank and 100 m vertically beneath a highly connected surface water source that is defined as a "reliable water supply". 2. If condition 1.(a) is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works. If condition 1.(b) or 1.(d) are not met then appropriate studies are required to demonstrate to the Minister's satisfaction that the River Condition Index category of the highly connected surface water source will not be reduced at the nearest point to the activity. If condition 1.(c) or (d) are not met, then appropriate studies are required to demonstrate to the Minister's satisfaction that: - there will be negligible river bank or high wall instability risks; - during the activity's operation and post-closure, levee banks and landform design should prevent the Probable Maximum Flood from entering the activity's site; and - low-permeability barriers between the site and the highly connected surface water source will be appropriately designed, installed and maintained to ensure their long-term effectiveness at minimising interaction between saline groundwater and the highly connected surface water supply;

Category	1. Water table	Water pressure	Water quality
Less productive alluvium		1. A cumulative pressure head decline of not more than 40% of the "post-water sharing plan"(2) pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work. 2. If the predicted pressure head decline is greater than requirement 1. above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long term viability of the affected water supply works unless make good provisions apply.	1. (a) Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity; and (b) No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. Redesign of a highly connected (3) surface water source that is defined as a "reliable water supply"(4) is not an appropriate mitigation measure to meet considerations 1.(a) and 1.(b) above. (c) No mining activity to be below the natural ground surface within 200 m laterally from the top of high bank or 100 m vertically beneath (or the three dimensional extent of the alluvial material - whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply". 2. If condition 1.(a) is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long term viability of the dependent ecosystem, significant site or affected water supply works. If condition 1.(b) is not met then appropriate studies are required to demonstrate to the Minister's satisfaction that the River Condition Index category of the highly connected surface water source will not be reduced at the nearest point to the activity. If condition 1.(c) is not met, then appropriate studies are required to demonstrate to the Minister's satisfaction that: - there will be negligible river bank or high wall instability risks; - during the activity's operation and post closure, levee banks and landform design should prevent the Probable Maximum Flood from entering the activity's site; and - low-permeability barriers between the site and the highly connected surface water source will be appropriately designed, installed and maintained to ensure their long-term effectiveness at minimising interaction between saline groundwater and the highly connected surface water supply;
Less productive porous rock – Permian Coal Measures		1. A cumulative pressure head decline of not more than a 2 m decline, at any [private] water supply work.	1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.

Category	1. Water table	Water pressure	Water quality
		2. If the predicted pressure head decline is greater than requirement 1. above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long term viability of the affected water supply works unless make good provisions apply.	2. If condition 1 is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long term viability of the dependent ecosystem, significant site or affected water supply works.

Notes:

(1) All predicted volumes and aquifer impacts are to be determined using data and modelling as described in section 3.2.3 of the AIP;

(2) "post-water sharing plan" – refers to the period after the commencement of the first water sharing plan in the water source, including the highest pressure head (allowing for typical climatic variations) within the first year after commencement of the first water sharing plan;

(3) "Highly connected" surface water sources are identified in the Regulations and will be based those determined during the water sharing planning process;

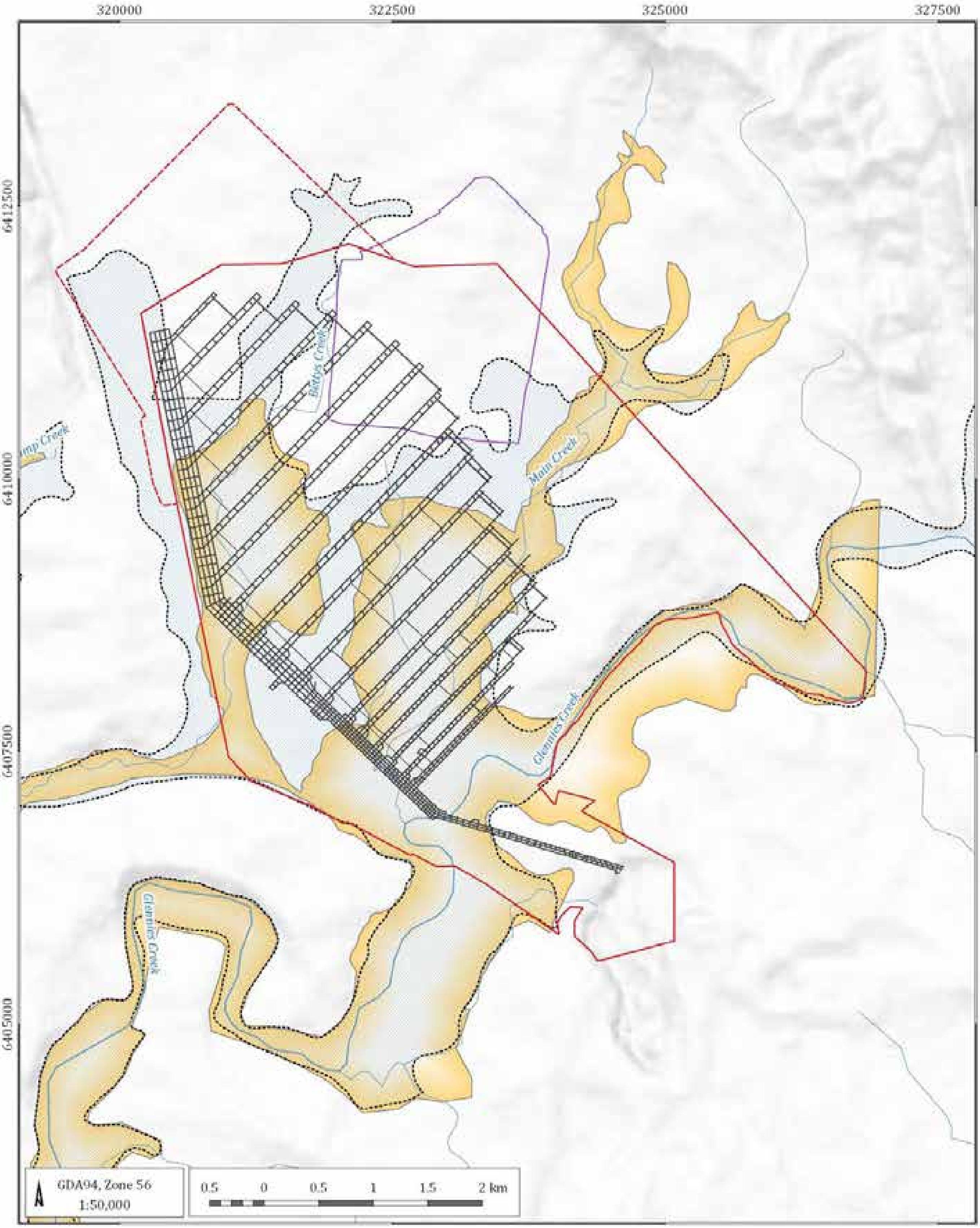
(4) "Reliable water supply" is as defined in the SRLU Policy;

(5) "Appropriate studies" on the potential impacts of water table changes greater than 10% are to include an identification of the extent and location of the asset, the predicted range of water table changes at the asset due to the activity, the groundwater interaction processes that affect the asset, the reliance of the asset on groundwater, the condition and resilience of the asset in relation to water table changes and the long-term state of the asset due to these changes;

(6) Consideration of modelling accuracy is described in Section 3.2.1 of the AIP;

(7) "relevant aquifer" in relation to alluvial water sources is defined in the relevant WSP and relates to that part of the aquifer that can be utilised for productive purposes;

(8) All cumulative impacts are to be based on the combined impacts of all "post-water sharing plan" activities within the water source.



LEGEND

- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Refined alluvium extent adopted in numerical model
- Highly productive groundwater (DPI Water Mapping)
- Major drainage
- Minor drainage

Integra (G1285A)

Highly productive groundwater (DPI Water)

AGE

DATE 16/11/2017

FIGURE No: **2-2**

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/G1285A.Integra/3_GIS/Workspaces/002_IBA/02.02_G1285A_Productive groundwater.qgs

2.3.2 NSW Strategic Regional Land Use Policy

The NSW Strategic Regional Land Use Policy applies to the Hunter Valley in which the Modification resides. Biophysical Strategic Agricultural Land (BSAL) is land with high quality soil and water resources capable of sustaining high levels of productivity. BSAL is mapped along parts of the Hunter River and the Glennies Creek flood plain on the regional mapping (Figure 3-2).

HVCC were granted a Site Verification Certificate on 11th September 2017 confirming that there was no BSAL within the area of a new mining lease required for the Modification.

2.4 Water licensing

HVCC currently holds groundwater licences to dewater up to 950 megalitres per year (ML/year) of groundwater ingress to the underground mining areas under the Sydney Basin North Coast water source of the North Coast Fractured and Porous Rock WSP as summarised in Table 2-3 below.

Table 2-3 Water licensing - North Coast Fractured and Porous Rock WSP

Licence No.	Units	Abstraction purpose
20BL169862	450 units total	dewatering of groundwater
20BL169864		dewatering of groundwater
20BL172505	500 units total	dewatering of groundwater
20BL172506		dewatering of groundwater

HVCC monitor the volume of groundwater pumped from the underground mine with flow meters. Figure 2-3 below shows the volume of water pumped from the underground mine during the care and maintenance period from records held by HVCC. Because no water was being pumped underground for mining purposes during this time the measurements provide a good estimate of the volume of groundwater seeping into the underground mine. The volume of water pumped generally averages 0.8ML/day, which is equivalent to 292 ML/year.

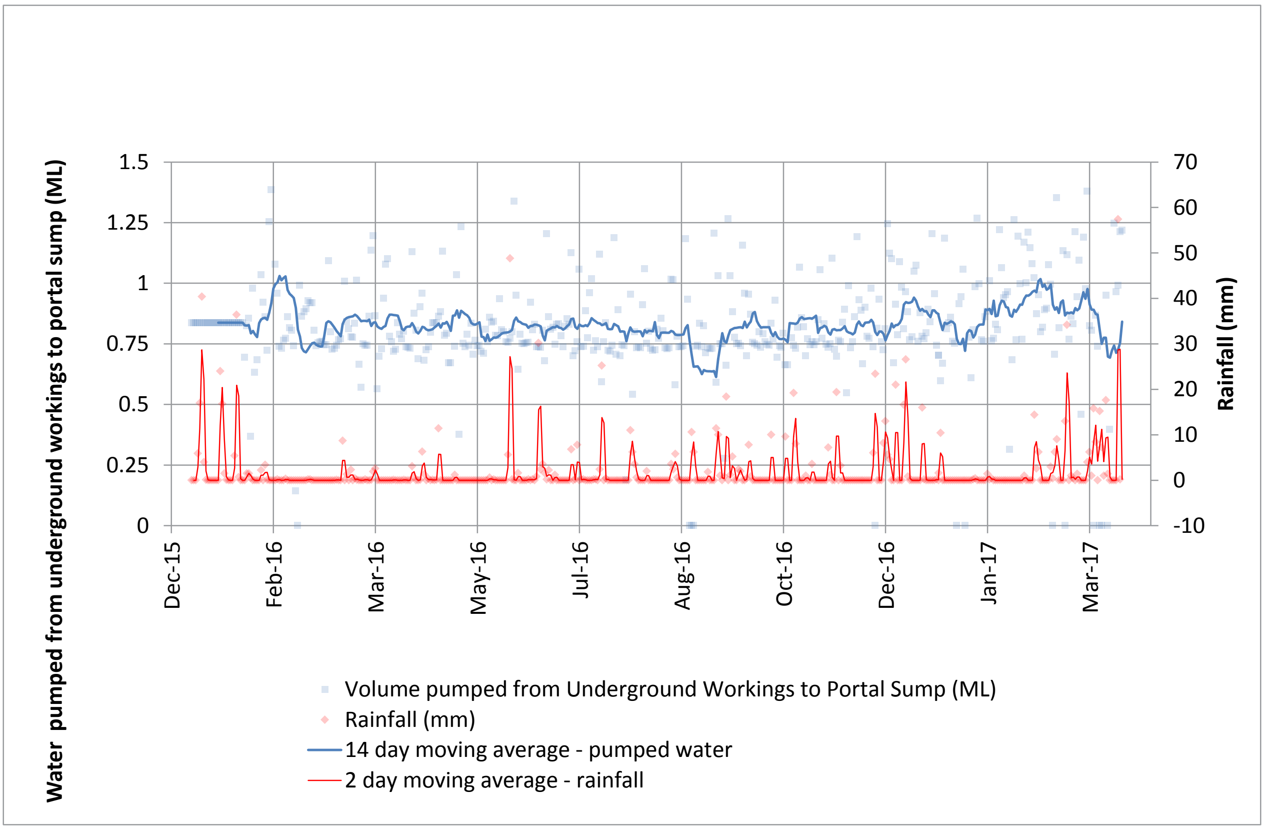


Figure 2-3 Volume of water pumped from Integra underground Middle Liddell seam workings

HVCC also hold licences to abstract up to 618 ML/year of general security water and 3 ML of high security water from Glennies Creek under the Hunter Regulated WSP (Table 2-4).

Table 2-4 Water licensing - Hunter Regulated River WSP

Licence No.	Units	Location
WAL 484	3	High security (Glennies Creek)
WAL 485	99	General security (Glennies Creek)
WAL 960	50	General security (Zone 3A Glennies Creek)
WAL 961	150	General security (Zone 3A Glennies Creek)
WAL 1172	3	General security (Zone 3A Glennies Creek)
WAL 1173	303	General security (Zone 3A Glennies Creek)
WAL 1242	13	General security (Zone 3A Glennies Creek)

2.5 Conditions of Approval

Project approval PA 08_0101 outlines the requirements for a Water Management Plan (WMP) and Water Management Performance Measures at Integra Underground. It also includes a statement of commitments for the project.

Schedule 3, Section 30 of PA 08_0101 provides the following performance measures for Glennies Creek and Station Creek alluvial aquifers as follows:

- *negligible environmental consequences to the alluvial aquifer (as shown in Appendix 6) beyond those predicted in the documents referred to in conditions 2 and 3 of Schedule 2, including:*
    - *negligible change in groundwater levels;*
    - *negligible change in groundwater quality; and*
- *negligible impact to other uses.*

Conditions 2 and 3 within Schedule 2 of PA 08_0101 refers to previous EAs, modifications, the statement of commitments and the conditions of the approval.

Schedule 3, Condition 31 (g) of PA 08_0101 requires the preparation of a Groundwater Management Plan, which must include:

- *detailed baseline data of groundwater levels, yield and quality in the region, particularly for privately-owned groundwater bores that could be affected by the project;*
- *groundwater impact assessment criteria including trigger levels for investigating any potentially adverse groundwater impacts; and*
- *a program to monitor and assess:*
    - *groundwater inflows to the mining operations;*
    - *impacts on regional aquifers;*
    - *impacts on the groundwater supply of potentially affected landowners;*
    - *impacts on the Glennies Creek and Station Creek; and*
    - *impacts on groundwater dependent ecosystems and riparian vegetation.*

HVCC (2017) last updated the WMP for Integra Underground in September 2017 as part of MOD7 that allowed for the construction of a pipeline from Integra Underground to Mount Owen. The WMP outlines how Integra Underground manages environmental and community aspects, impacts and performance relevant to the water management system. The WMP provides a framework for the standards, plans and procedures implemented so that operations are managed in accordance with Glencore business principles, policy, standards and all relevant licences and environmental approvals held by the mine. Section 8 outlines the content of the WMP and how it will continue to be used for this Modification in more detail.

2.6 Commonwealth Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is administered by the Department of the Environment and Energy (DoEE). 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 (the water trigger), significant impacts on water resources associated within coal mining and/or CSG developments were included.

The Modification was referred to DoEE to confirm whether the changes to the approved operations at Integra Underground would result in a significant impact on MNES, namely; threatened species and/or ecological communities; and water resources. The Referral included information prepared to address the requirements under the Significant Impact Guidelines 1.3 (DoE, 2013) and to confirm that the Modification would not result in a significant impact on water resources. This application is currently being considered.

The IESC is a statutory body under the EPBC Act that provides scientific advice to the Commonwealth Environment Minister and relevant state ministers. Guidelines have been developed in order to assist the IESC in reviewing CSG or large coal mining development proposals that are likely to have significant impacts on water resources. A summary of the IESC guidelines and where they are addressed within the report is included in Appendix C.

3 Environmental setting

3.1 Location

Integra Underground is located in the Hunter Coalfields of the Sydney Basin and is entirely within the Singleton Local Government Area. It is approximately 12 km north-west of the Singleton town centre, in the locality of Camberwell. The Integra underground operation lies immediately to the south-east of Glencore's Mount Owen Complex whilst other surrounding mines include the Ashton Mine to the west, and Bloomfield's Rix's Creek North Mine to the south. Surrounding land uses in the locality include mining and mining related development (Figure 1-2) as well as agricultural activities such as cropping and grazing.

3.2 Climate

The climate in the region is temperate and is characterised by hot summers with regular thunderstorms and mild dry winters. Climate data was obtained from the Scientific Information for Land Owners (SILO) database of historical climate records for Australia (DSITI 2015). This service interpolates rainfall and evaporation records from available stations to a selected point. The location selected for the SILO data drill resides at longitude 151.10^0, latitude -32.45^0 decimal and elevation 128 mAHD. Climatic data was obtained for the period between 01/01/1900 to 1/04/2017. A summary of rainfall and evaporation data for is shown in Table 3-1.

Table 3-1 Climate averages

Source	Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Site SILO data	Mean rainfall (mm)	78.9	75.0	65.6	53.5	44.8	52.4	43.8	37.7	41.7	50.6	61.3	69.4	674.7
	Mean evaporation (mm)	203.9	161.1	142.8	103.4	72.5	55.3	63.7	89.2	119.2	156.2	176.8	209.8	1553.7
	Evap minus rainfall	125.0	86.2	77.2	49.9	27.7	2.9	19.9	51.5	77.4	105.6	115.5	140.3	879.1

SILO data is based on observational records provided by BoM, with data gaps addressed through data processing in order to provide a spatially and temporally complete climate dataset. Based on the SILO dataset, average annual rainfall is 675 mm, with January being the wettest month (79 mm). Annual evaporation (1,554 mm/year) exceeds mean rainfall throughout the year, with the highest moisture deficit occurring during the summer months.

Monthly records from the SILO dataset were used to calculate the Cumulative Rainfall Departure (CRD). The CRD shows graphically trends in recorded rainfall compared to long-term averages and provides a historical record of relatively wet and dry periods. A rising trend in slope in the CRD graph indicates periods of above average rainfall, whilst a declining slope indicates periods when rainfall is below average. A level slope indicates average rainfall conditions.

Figure 3-1 shows the CRD and highlights three climatically distinct periods:

- 2000 - 2007 during the Millennium drought where rainfall was commonly below average;
- 2007 – 2012 when rainfall was commonly above average; and
- 2012 to present when rainfall generally remained closer to historical averages, with a relatively neutral trend.

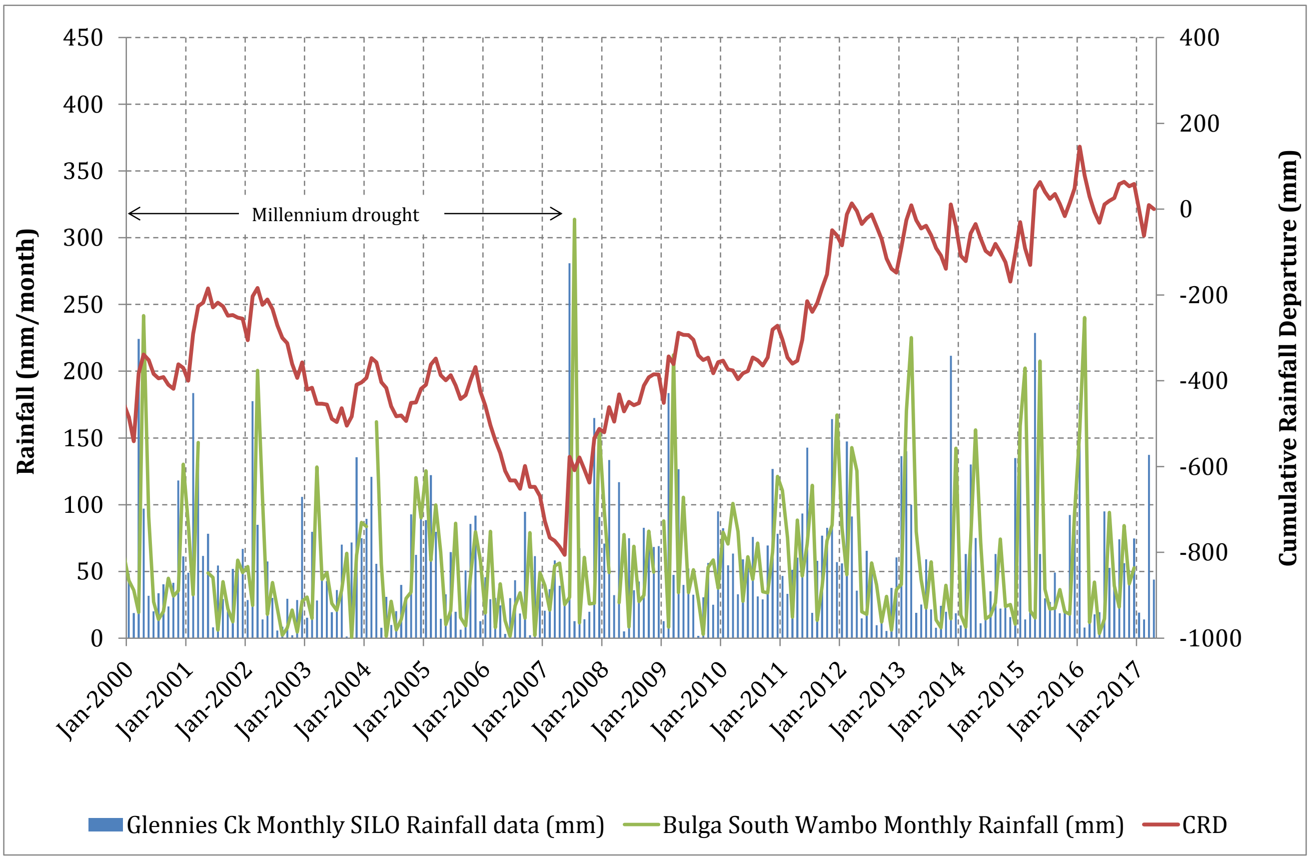


Figure 3-1 Cumulative Rainfall Departure (SILO) and monthly rainfall (Bulga South Wambo and site SILO)

The CRD trends are relevant because groundwater levels particularly in shallow aquifers tend to reflect the same trends, with declining groundwater levels when rainfall is below average and rising trends during periods of above average rainfall. Groundwater levels and climate are discussed further in Section 4.2.4.

3.3 Terrain and drainage

The Modification area is comprised of gently undulating hills dissected by the flood plains along the water courses. The elevation ranges from around 120 to 140 m Australian Height Datum (AHD) in the upper areas of the catchments falling to 60 m to 80 m in the lower alluvial flats to the south west. Due to historical farming and mining, the majority of the Modification area is cleared of vegetation, except for remnants of vegetation occurring in riparian zones along the water courses. Figure 3-2 shows the terrain and the drainage lines.

The southern part of the Modification area is drained by Glennies Creek. Glennies Creek flows in a south-westerly direction immediately south of the Modification area, and joins with the Hunter River approximately 7 km to the south-west. Glennies Creek is perennial with flow being maintained by releases from Lake St Clair. Main Creek, an ephemeral tributary to Glennies Creek, flows southeast across the southern part of the Modification area and joins Glennies Creek approximately 500 m south of the Proposed underground workings.

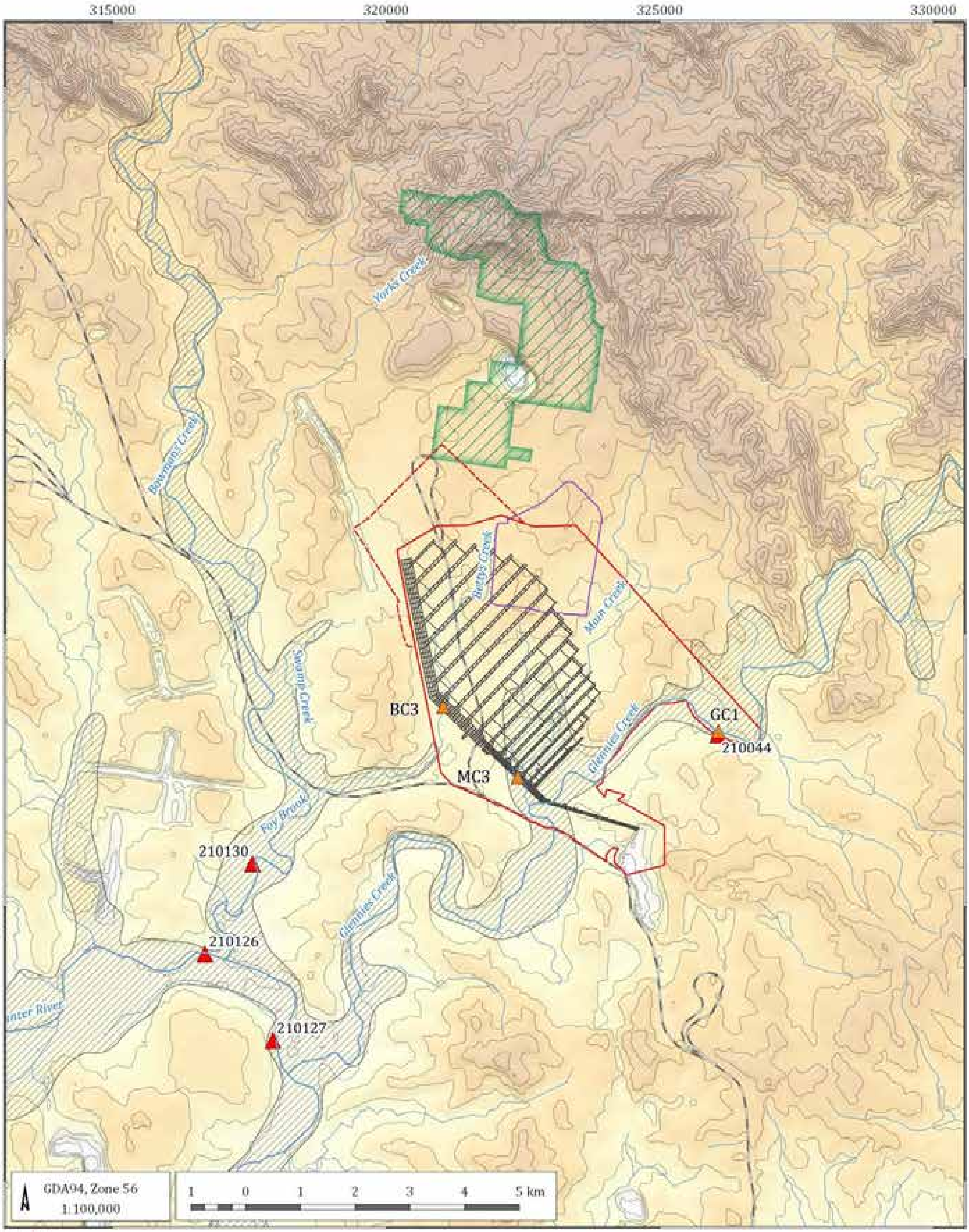
Bowmans Creek is an ephemeral creek located approximately 3 km west of the Modification area. Bowmans Creek joins the Hunter River approximately 6 km south-west of the Modification area. Bettys Creek is ephemeral and flows from north to south across the northern part of the Modification entering Bowmans Creek approximately 3 km to the south-east.

DPI Water monitor stream flow within Glennies Creek, Bowmans Creek, and the Hunter River in real-time with the Hunter Integrated Telemetry System (HITS). Figure 3-2 shows the location of nearby gauging stations. The nearest gauging station along Glennies Creek is at Middle Falbrook (station 210044), which is 2 km southeast of the Modification. The nearest station on Bowmans Creek is at Bowmans Creek Bridge (210130), approximately 4.7 km from the Modification. There are two nearby stations on the Hunter River, Upstream Foybrook (210126), approximately 6.4 km southeast of the Modification and Upstream Glennies (210127), 6.8 km southwest of the Modification.

Stream flow records from the gauging stations were obtained and compared with daily rainfall data to assess the contribution of baseflow to flows in Glennies Creek, Bowmans Creek, and the Hunter River. Figure 3-3, Figure 3-4 and Figure 3-5 show the estimated proportion of baseflow separated from the total recorded stream flow for Glennies Creek, Hunter River, and Bowmans Creek respectively based on the method provided by Arnold and Allen (1999).

The results show that surface water flow is largely a function of rainfall with a lesser contribution from baseflow. Estimates of baseflow into Glennies Creek are between 10 and 50 ML/day, and up to 100 ML/day into Hunter River. These are likely overestimates because upstream releases from Lake St Clair and Glenbawn Dam maintain a constant flow during dry periods. Estimated baseflow into Bowmans Creek is between 1 and 10 ML/day, however Bowmans Creek is ephemeral and periodically receives no baseflow.

HVCC also monitor water level and flow within Glennies Creek (GC1), Bettys Creek (BC3) and Main Creek (MC3). The monitoring site on Glennies Creek (GC1) is situated where the government gauge 210044 is located and therefore serves to supplement the flow data with additional chemical data. Figure 3-2 shows the location of HVCC gauging stations. Monitoring at MC3 and BC3 has confirmed creeks are ephemeral and only flow when rainfall is sufficient to generate runoff.



LEGEND

- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Biophysical strategic agricultural land
- Ravensworth State Forest reserve
- Water area
- Major drainage
- Minor drainage
- Contour (mAHD, 20m interval)
- NSW gauging sites
- Glencore gauging sites

Elevation (mAHD)

- 0
- 40
- 80
- 120
- 200
- 400
- 600

Integra (G1285A)

Terrain and drainage

AGE

DATE 16/11/2017

FIGURE No: **3-2**

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/G1285A.Integra/3_GIS/Workspaces/002_IBA/03.02_G1285A_Terrain and drainage.qgs

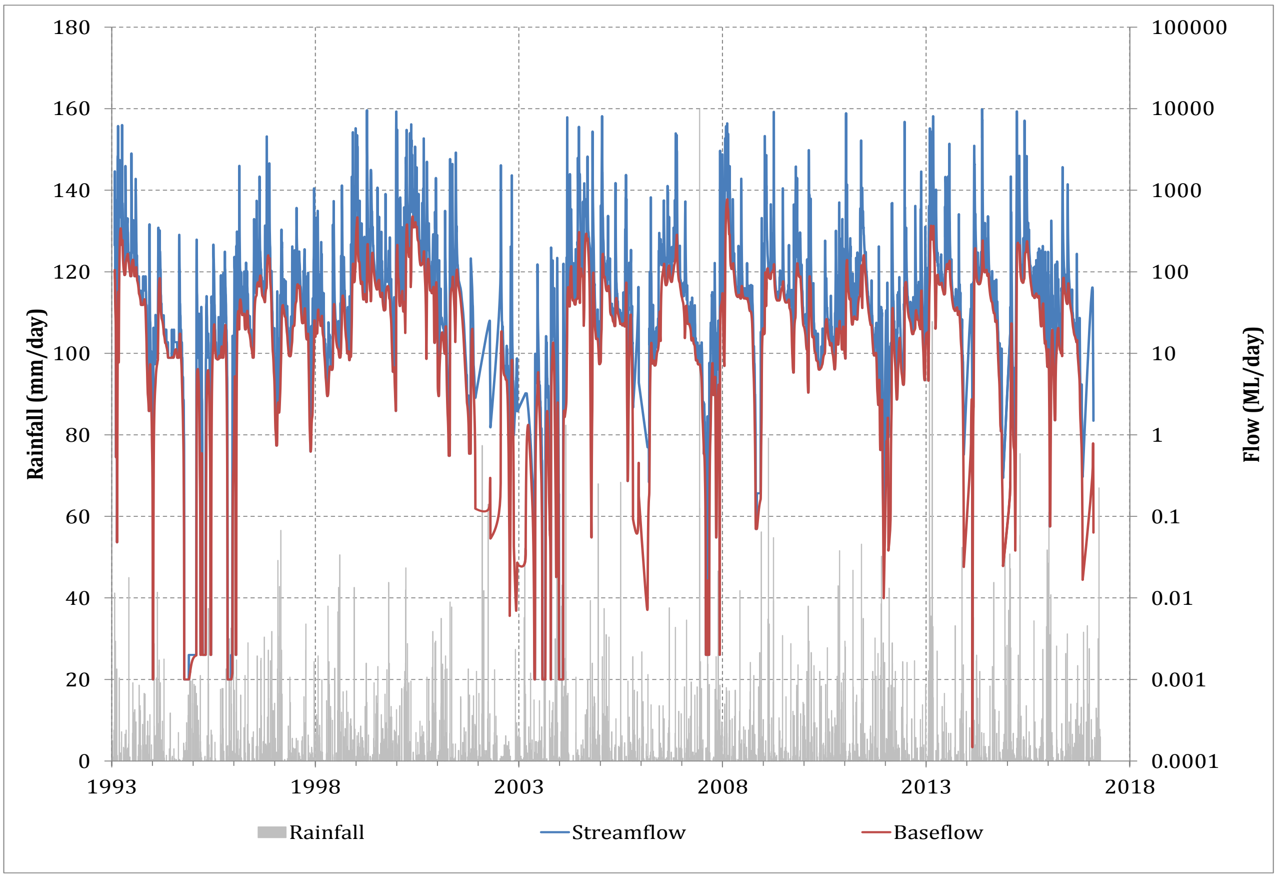


Figure 3-3 Baseflow in Glennies Creek at Middle Falbrook (210044)

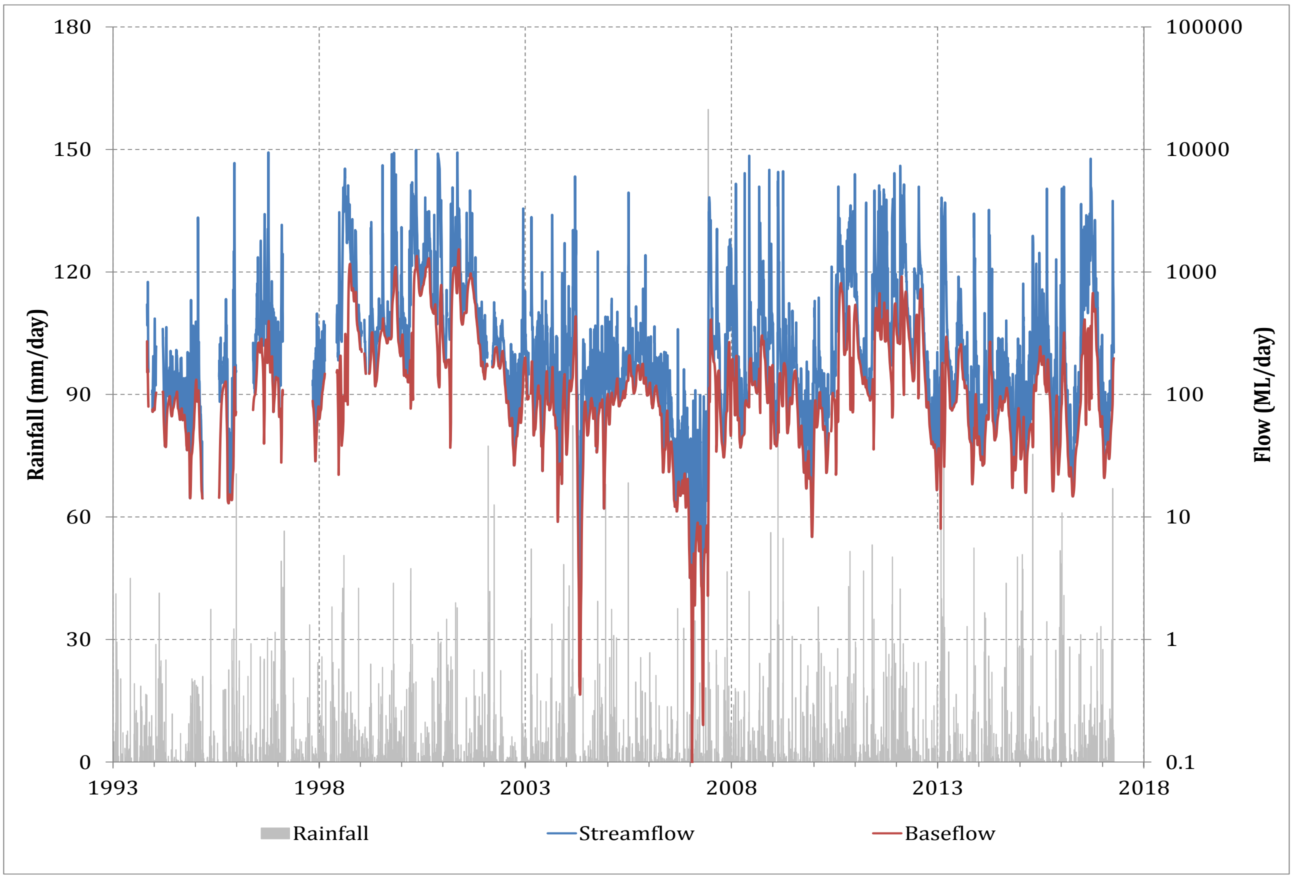


Figure 3-4 Baseflow in Hunter River at U/S Foybrook (210126)

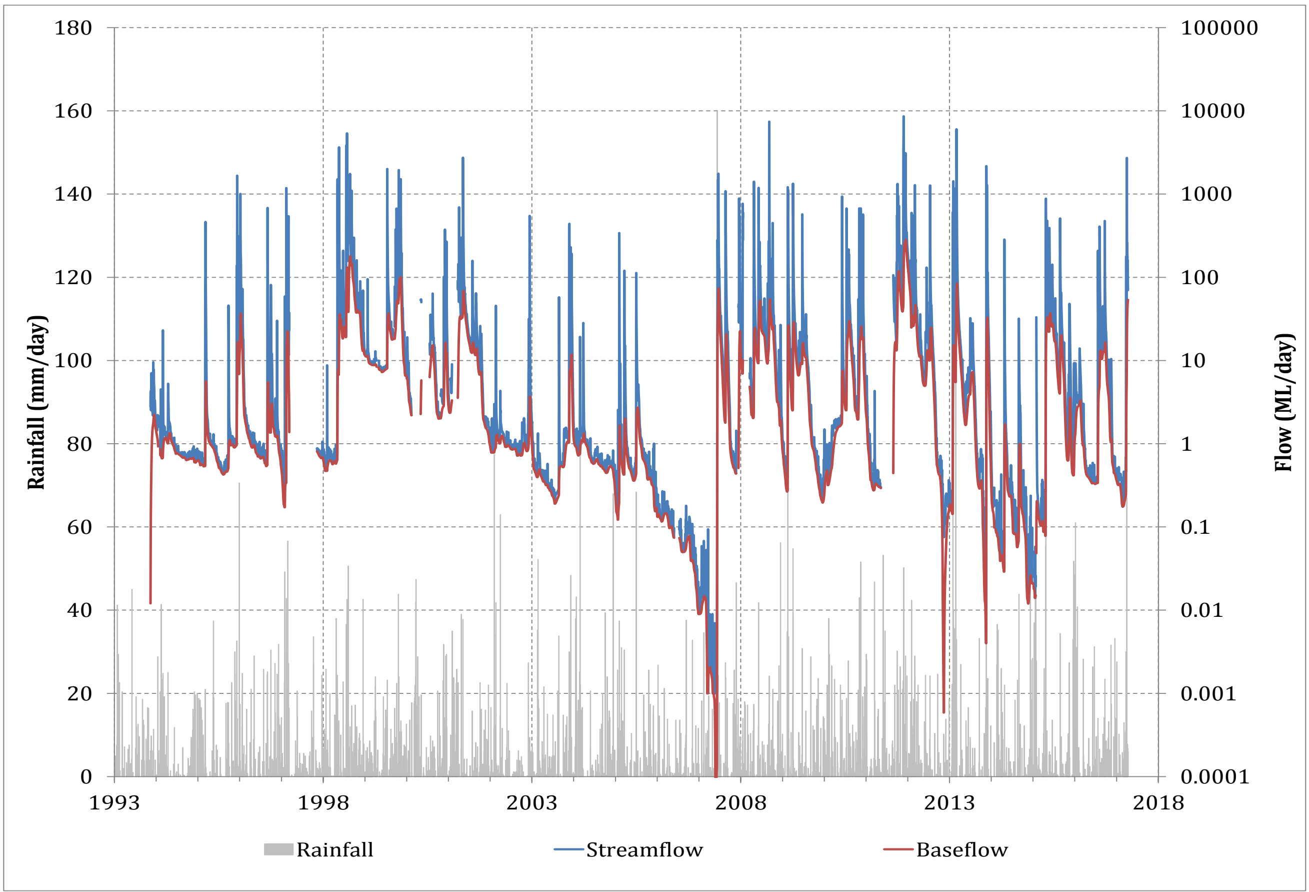


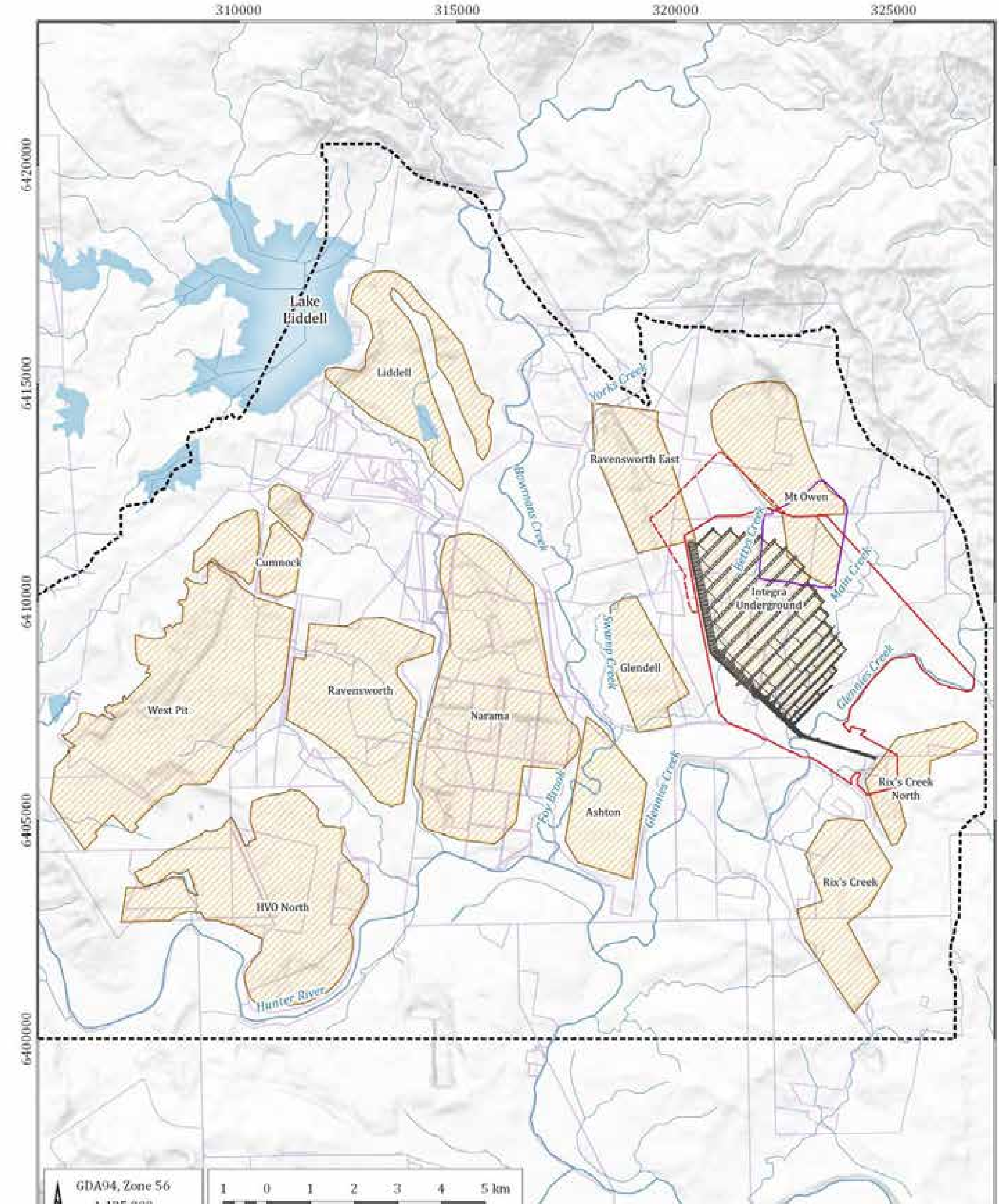
Figure 3-5 Baseflow in Bowmans Creek at Bowmans Creek Bridge (210130)

3.4 Land use

Land use within the Modification area is primarily coal mining. Surrounding the Modification, land use includes coal mining operations and agriculture. Agricultural and environmental land use includes:

- cattle grazing in open pastures;
- improved pasture and cropping along the flood plains; and
- vegetation, including riverine vegetation along drainage lines.

The Modification occurs within the Hunter Valley coalfields, which has a long history of mining the Permian Coal Measures, dating back to the 1950's. Figure 3-6 shows the locations of the approved mines.



LEGEND

- Model extent
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Historic and existing mining operations
- Coal titles
- Water area
- Major drainage
- Minor drainage

Integra (G1285A)

Historic and existing mining

AGE

DATE 16/11/2017

FIGURE No: 3-6

4 Geological setting

The geological setting has been informed by the following data sources:

- publicly available geological maps (Hunter Coalfields map sheets) and reports;
- geological, geotechnical and hydrogeological reports and data prepared for Mount Owen mine and Integra Underground;
- publicly available geological and hydrogeological reports for surrounding mine operations; and
- hydrogeological data held on the DPI Water groundwater database (Pinneena).

This information provided was used to update a 3D numerical groundwater model first developed by Col Mackie and upgraded by Jacobs (2014) for mining projects in the region. Appendix A describes the approach to the groundwater modelling in detail.

4.1 Regional geology

The Modification is located within the Hunter Coalfield towards the north-eastern margins of the Permian and Triassic Sydney Basin. The basin formed during a period of crustal thinning and igneous rifting in the Late Carboniferous to Early Permian and subsequently infilled with Permian and Triassic aged sediments. The basin is structurally bound by the Carboniferous New England Block approximately 3 km to the east and north-east of the Modification.

The Branxton Formation and Mulbring Siltstone, part of the Maitland Group outcrop to the north and southeast of the Modification area. The Branxton Formation comprises conglomerate, sandstone, and siltstone and the Mulbring Siltstone comprises fine-grained siltstone, claystone, and minor fine-grained sandstone. The Maitland Group sediments are present at depth below the Modification.

Within the Modification area, the Late Permian Saltwater Creek Formation, the lowermost formation of the Wittingham Coal Measures, comprises sandstone and siltstone with minor coal seams. Overlying the Saltwater Creek Formation, the Wittingham Coal Measures are divided into the Vane Subgroup and the Jerrys Plains subgroup. The Vane Subgroup overlies the Saltwater Creek Formation and is further separated into the Foybrook Coal Measures which contains the economic coal seams for the Modification, and the Archerfield Sandstone, a well-sorted, quartz lithic sandstone. The Jerrys Plains Subgroup comprises numerous coal seams; claystone, tuff, siltstone, sandstone, and conglomerate. The Permian sediments plunge in a general west to south-westerly direction.

The Permian sediments are unconformably overlain by thin Quaternary alluvial deposits. These deposits comprise silt, sand, and gravel along the present day drainage lines of Glennies Creek, Main Creek and Bettys Creek.

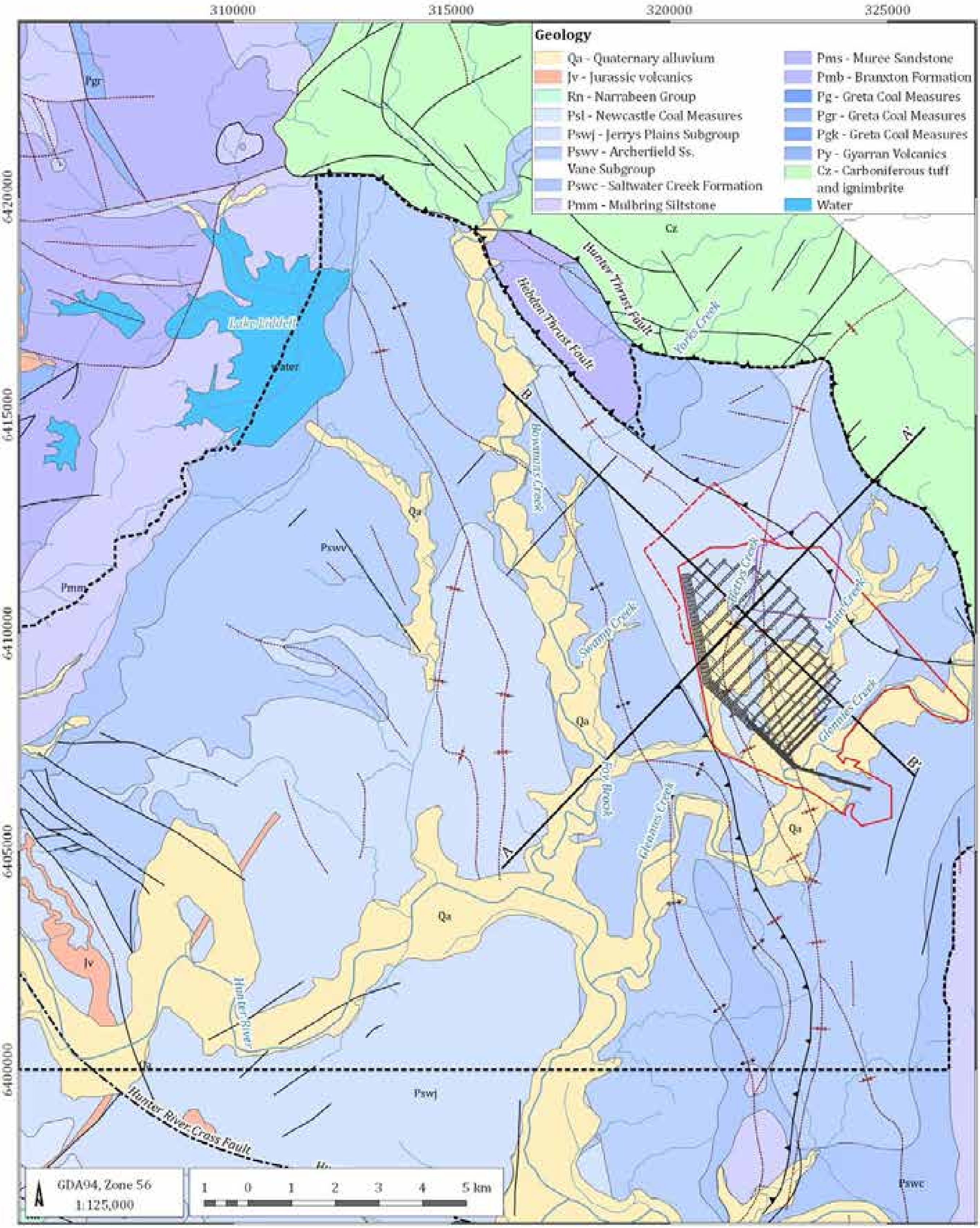
Surficial weathering occurs across the Modification area. The weathering profile is typically present as a thin heterogeneous layer of unconsolidated and highly weathered material (regolith) overlying fresh bedrock.

Figure 4-1 shows the regional surface geology across the site and surrounds, based on the Hunter Coalfield Regional 1:100,000 scale geological map, published by Department of Mineral Resources (Glen & Beckett, 1993). It should be noted that mining has removed Quaternary alluvium within and adjacent to the Modification area along Bettys Creek since the geology map was prepared in 1993.

Table 4-1 provides a detailed summary of the regional geology and relevant stratigraphic units within the Modification and surrounds. Figure 4-2 and Figure 4-3 provide conceptual geological cross-sections showing the relative distribution of key stratigraphic units across the Modification.

Table 4-1 Summary of regional geology

Age	Stratigraphic unit			Description
Quaternary	Quaternary sediments – alluvium (Qa)			Clay, silt, and sand overlying basal clayey sands and gravels in places.
Late Permian	Wittingham Coal Measures	Jerrys Plains Subgroup (Pswj)		Coal seams interbedded with claystone, tuff, siltstone, sandstone, and conglomerate.
		Vane Subgroup (Pswv)	Archerfield Sandstone	Bronze-coloured, well-sorted quartz lithic sandstone
			Foybrook Formation	Coal bearing sequences with wedges of sandstone and siltstone. Includes the economic coal seams for the Modification.
		Saltwater Creek Formation (Pswc)		Sandstone and siltstone, minor coaly bands, siltstone towards base.
Middle Permian	Maitland Group	Mulbring Siltstone (Pmm)		Fine-grained offshore sediments: siltstone, claystone, minor fine sandstone.
		Muree Sandstone (Pms)		Fine to coarse sandstone, conglomerate, and minor clay
		Branxton Formation (Pmb)		Conglomerate, sandstone, and siltstone



LEGEND

- Model extent
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Cross section
- Thrust fault
- Fault
- Anticline
- Syncline
- Fold
- Major drainage
- Minor drainage

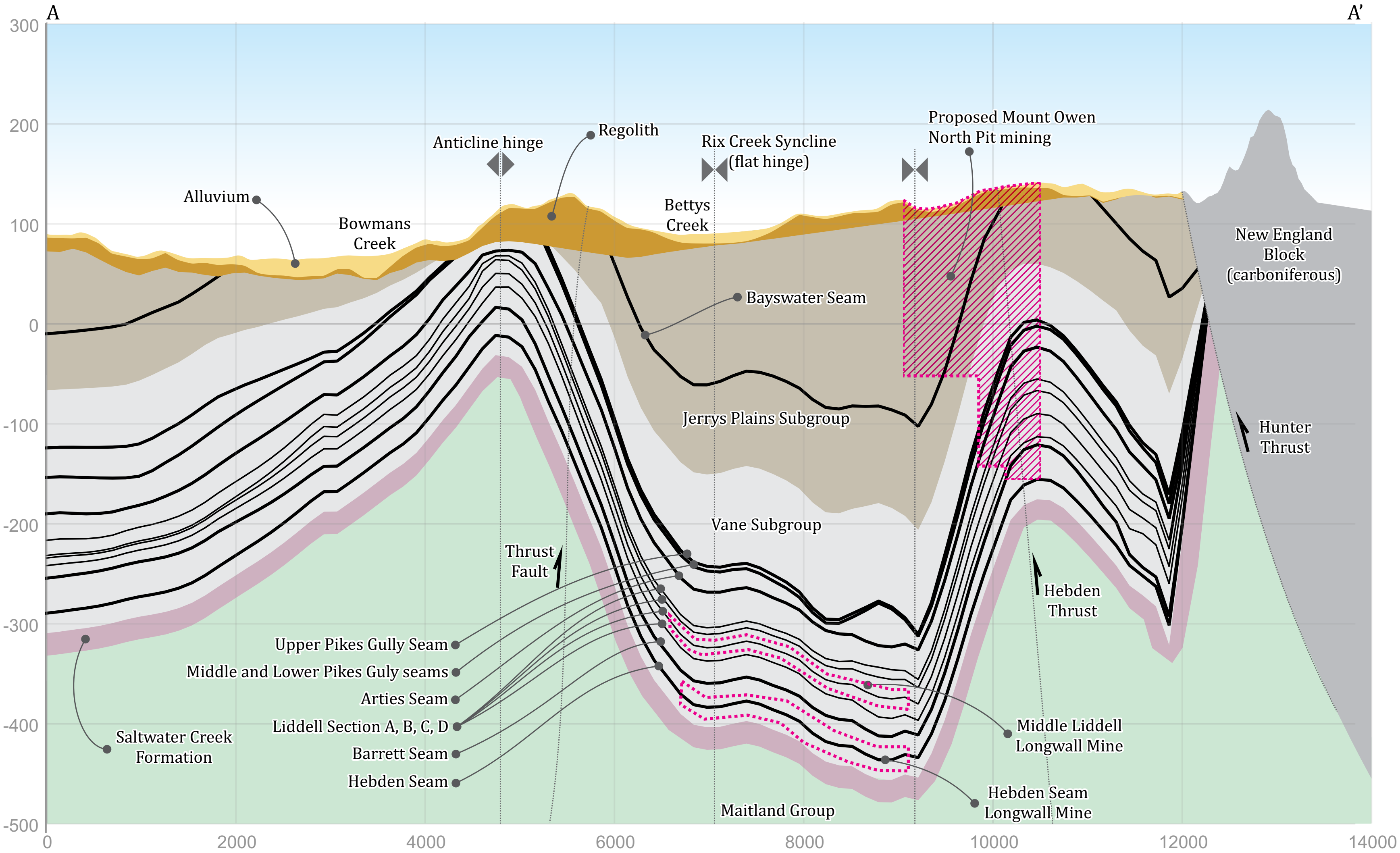
Integra (G1285A)

Regional surface geology

DATE 16/11/2017

FIGURE No: **4-1**

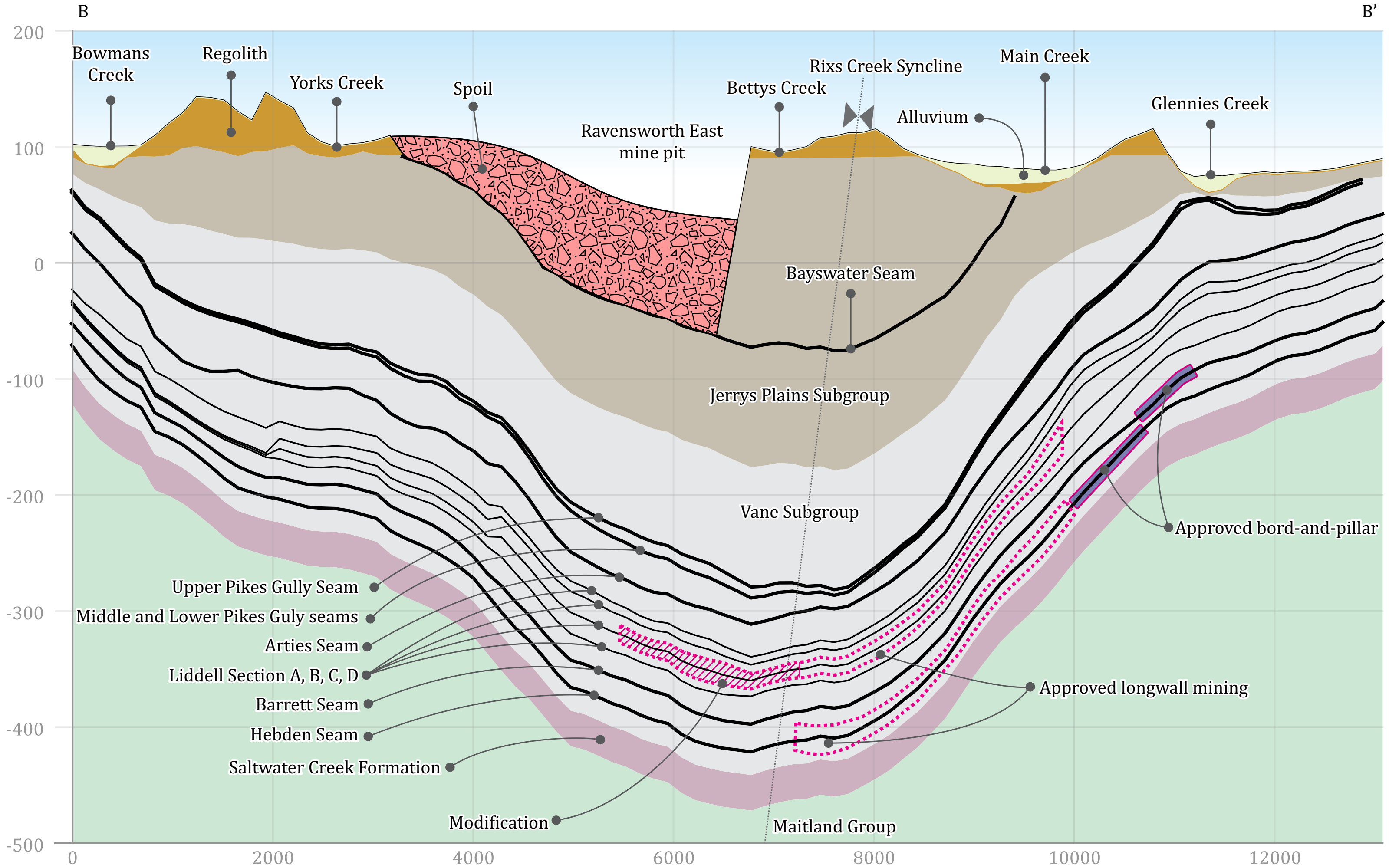
Source: Glen R.A. and Beckett J., 1993, Hunter Coalfield Regional Geology 1:100 000, 2nd edition, Geological Survey of New South Wales, Sydney; G:/Projects/G1285A.Integra/3_GIS/Workspaces/002_EIA/04.01_G1285A_Regional surface geology.qgs



Conceptualised south-west - north-east geological cross-section

Figure 4-2

Integra (G1285A)



Conceptualised north-west - south-east geological cross-section

Figure 4-3

Integra (G1285A)

4.2 Local geology

At a local scale, the following stratigraphic units occur within the Modification and surrounds (from youngest to oldest):

- Quaternary alluvium;
- Jerrys Plains Subgroup;
- Vane Subgroup;
- Saltwater Creek Formation; and
- Maitland Group.

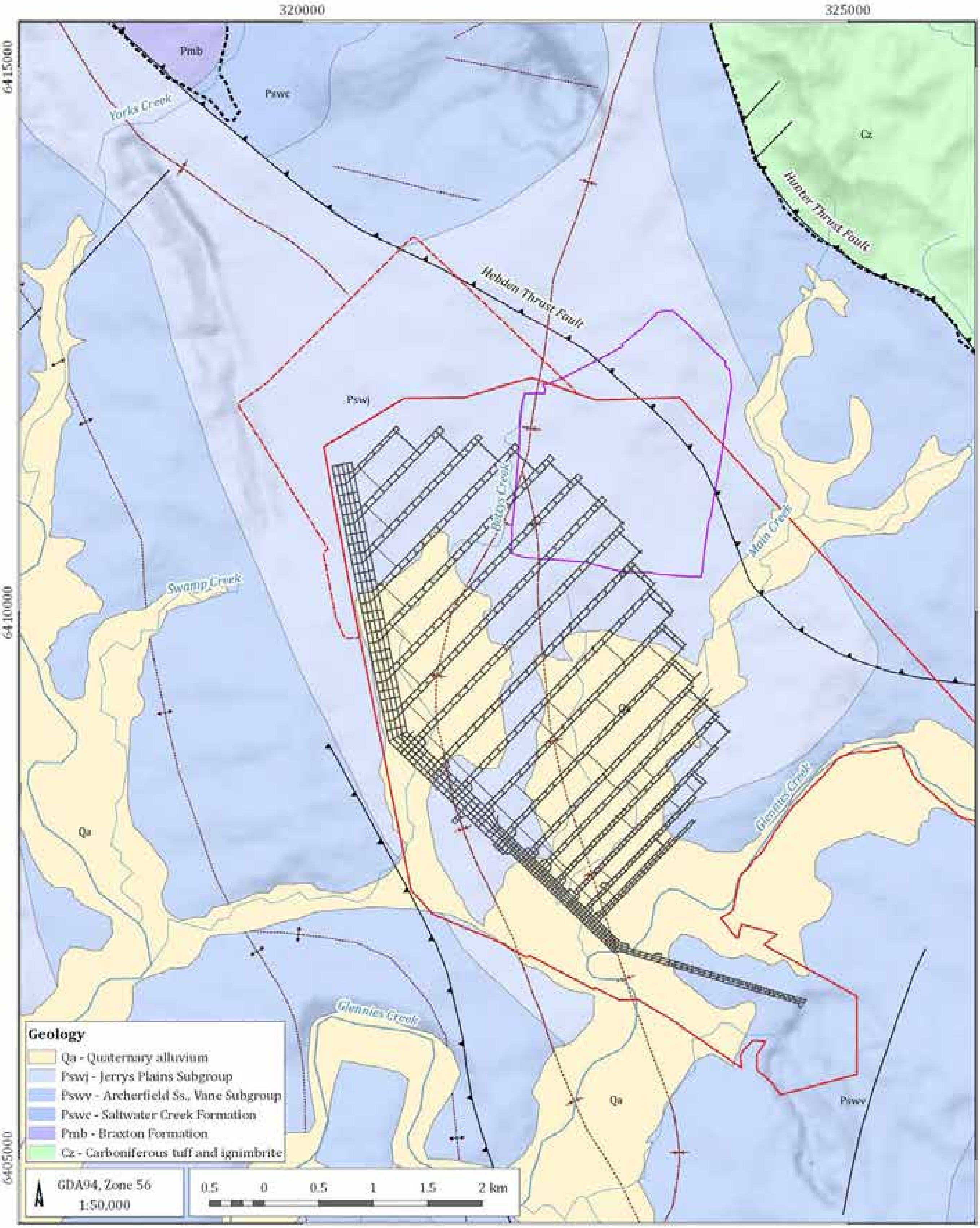
Each of the main stratigraphic units is discussed in further detail below.

Figure 4-4 shows the surface geology of the Modification and immediate surrounds, which is informed by previous field studies.

4.2.1 Quaternary alluvium

Quaternary alluvium (Qa) occurs along the alignments of Glennies Creek, Main Creek, and Bettys Creek The alluvium typically comprises clay, silt and sand overlying basal clayey sands and gravels which unconformably overlie the Permian sediments. The Quaternary sediments are around 5 m thick within the Bettys Creek flood plain and up to 10 m below Main Creek and Glennies Creek in the vicinity of the Integra Mine. Further downstream the thickness of the alluvium in Glennies Creek approaches 20 m closer to the confluence with the Hunter River.

The extent of Quaternary alluvium shown on geological maps was first refined by Jacobs (2014) using LiDAR data and borehole drilling data to account for already mined out alluvium and the realignment of Bettys Creek. AGE (2017) completed a verification study in the northern part of Main Creek to better delineate the extent of the alluvial sediments associated with Main Creek. The investigation included a geophysical (AgTEM) survey and 16 test pits to ground truth the geophysics. The structure, distribution and thickness of the Quaternary alluvium and the regolith are shown on Figure 4-5. The refined extent of the Quaternary alluvium is shown in Figure 4-4.



LEGEND

- Model extent
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved mining Middle Liddell Seam
- Proposed Mount Owen North Pit mining
- Thrust fault
- Fault
- Anticline
- Syncline
- Fold
- Major drainage
- Minor drainage

Integra (G1285A)

Modification surface geology

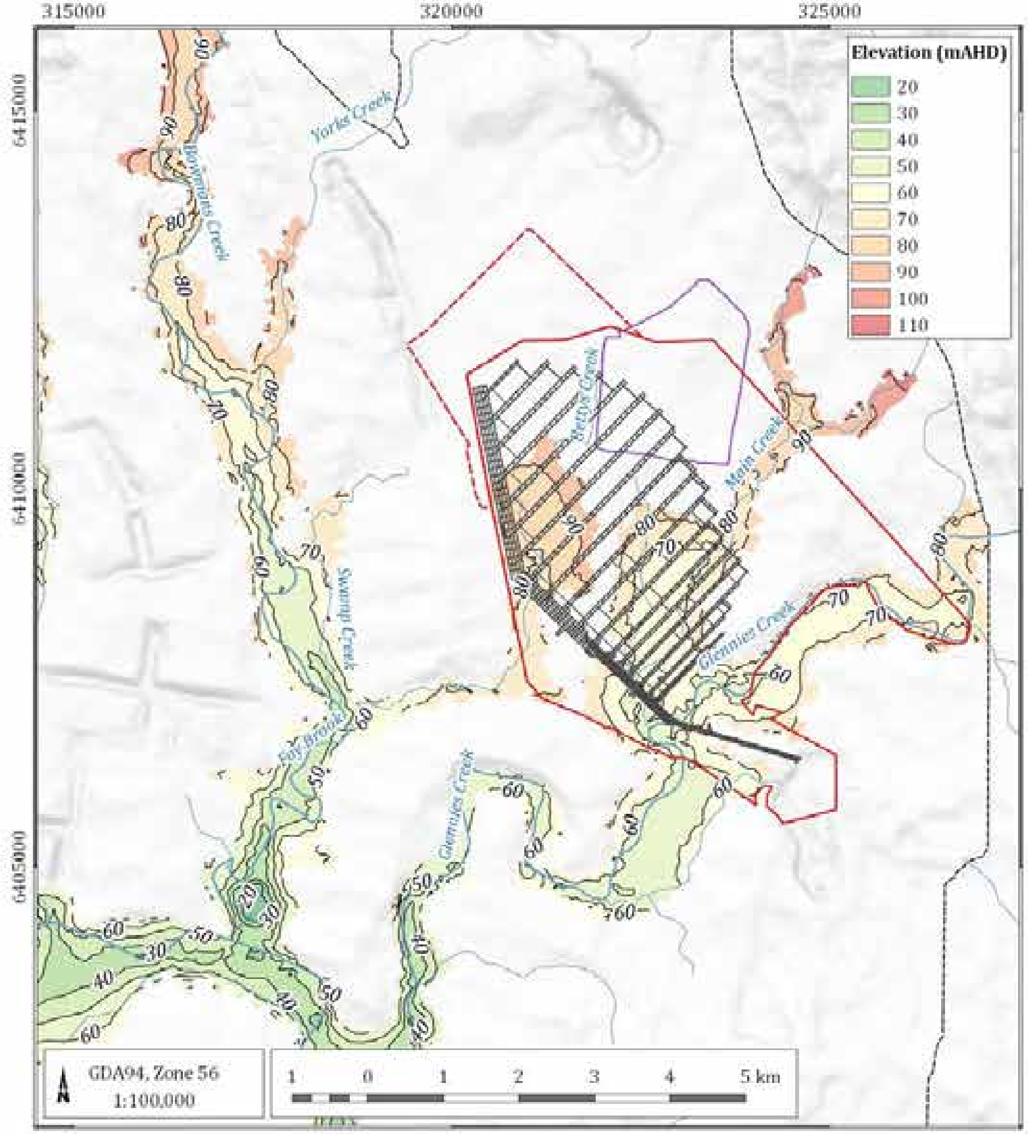
AGE

DATE 16/11/2017

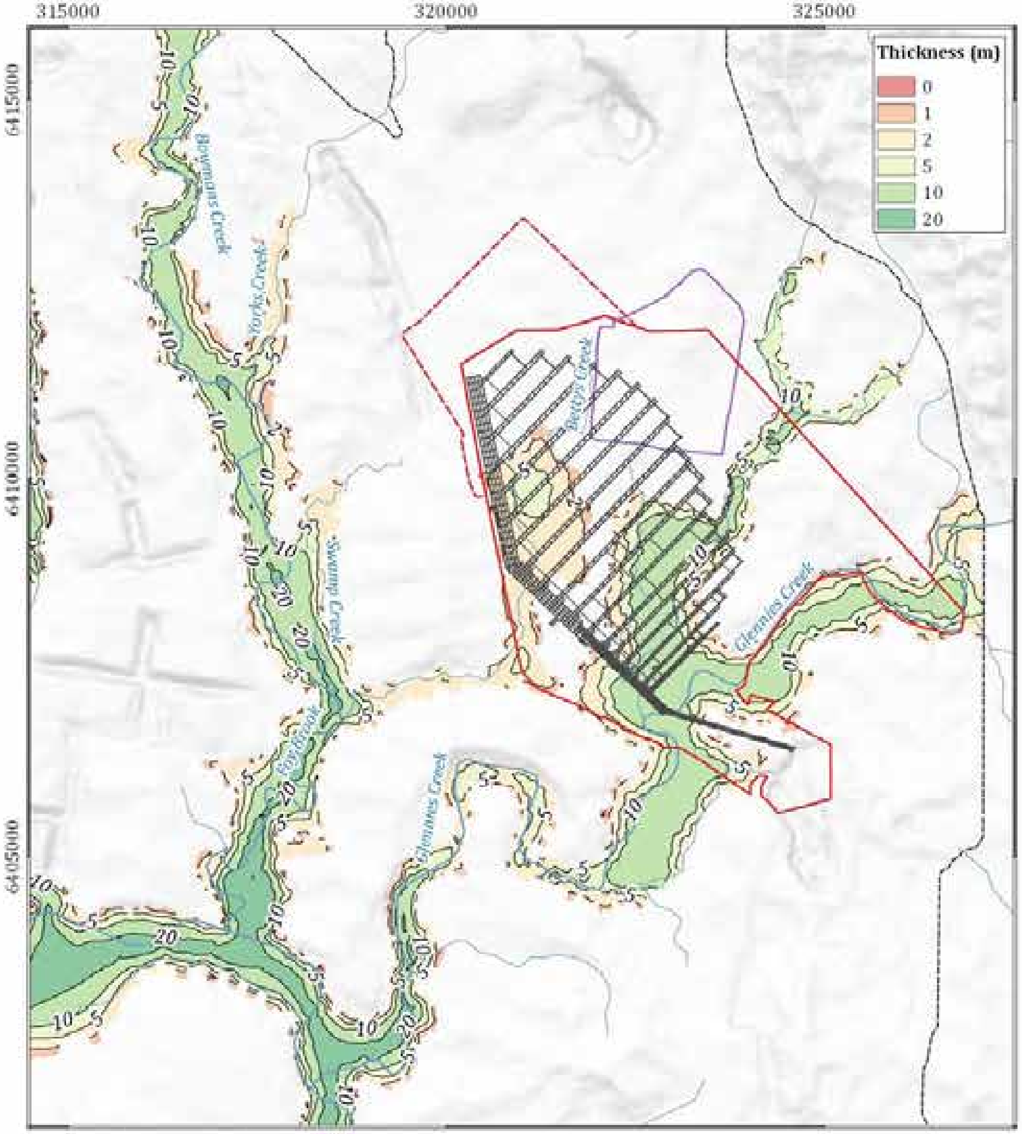
FIGURE No: **4-4**

Source: Glen R.A. and Beckett J., 1993, Hunter Coalfield Regional Geology 1:100 000, 2nd edition, Geological Survey of New South Wales, Sydney;
G:/Projects/G1285A.Integra/3_GIS/Workspaces/002_EIA/04.04_G1285A_Project site surface geology.qgs

Structure contours of the Quaternary alluvium



Thickness contours of the Quaternary alluvium



LEGEND

- Model outline
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Major drainage
- Minor drainage
- Contour line (mAHD)

Integra (G1285A)

DATE
16/11/2017

Structure and thickness contours of the Quaternary alluvium

FIGURE No:
4-5

AGE

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/G1285A.Integra/3_GIS/Workspaces/002_EIA/04.05b_G1285A_Structure thickness contours Quaternary alluvium.qgs

4.2.2 Jerrys Plains Subgroup

The youngest of the Permian aged sediments within the Modification are the Jerrys Plains Subgroup (Pswj), part of the Wittingham Coal Measures. The Jerrys Plains Subgroup outcrops within the Modification area (Figure 4-4) and subcrops below the Quaternary alluvium associated with Bettys Creek and Main Creek. The Jerrys Plains Subgroup is between 20 m and 220 m thick within the Modification area.

The Jerrys Plains Subgroup comprises a sequence of coal seams interbedded with claystone, tuff, siltstone, sandstone, and conglomerate. Within the Jerrys Plains Subgroup there are 15 main coal seams that are mined across the Hunter Valley. In stratigraphic order (youngest to oldest) coal seams include Whybrow Seam, Redbank Creek Seam, Wambo Seam, Whynot Seam, Blakefield Seam, Glen Munro Seam, Woodlands Hill Seam, Arrowfield Seam, Bowfield Seam, Warkworth Seam, Mount Arthur Seam, Piercefield Seam, Vaux Seam, Broonie Seam and Bayswater Seam.

A weathered profile occurs across the palaeo-surface of the Jerrys Plains Subgroup. Although the depth of weathering varies across the Modification area, it is generally less than 25 metres below ground level (mbGL).

4.2.3 Vane Subgroup

The Late Permian Vane Subgroup (Pswv) conformably underlies the Jerrys Plains Subgroup and within the Modification area consists of the Foybrook Formation and the Archerfield Sandstone. The Vane Subgroup outcrops within the Modification area and subcrops below the Quaternary alluvium associated with Bowmans Creek and Glennies Creek.

The uppermost unit is the Archerfield Sandstone which comprises well-sorted quartz lithic sandstone deposited in a wave or current dominated lower delta plain depositional setting. The Foybrook Formation comprises coal bearing sequences with wedges of siltstone and sandstone. There are six main coal seams within the Foybrook Formation; in stratigraphic order (youngest to oldest) coal seams include Lemington Seam, Pikes Gully Seam, Arties Seam, and the economic Middle Liddell, Barrett and Hebden Seams that are approved for mining at Integra. The Modification proposes additional mining of the Middle Liddell seam, which occurs between 350 m and 500 m below the natural land surface. Proposed mining will underlie existing open cut workings at Ravensworth East, which is part of the Mount Owen Complex. There is a vertical separation of 270 m from the Ravensworth East open cut mine to the proposed underground mine in the Middle Liddell Seam.

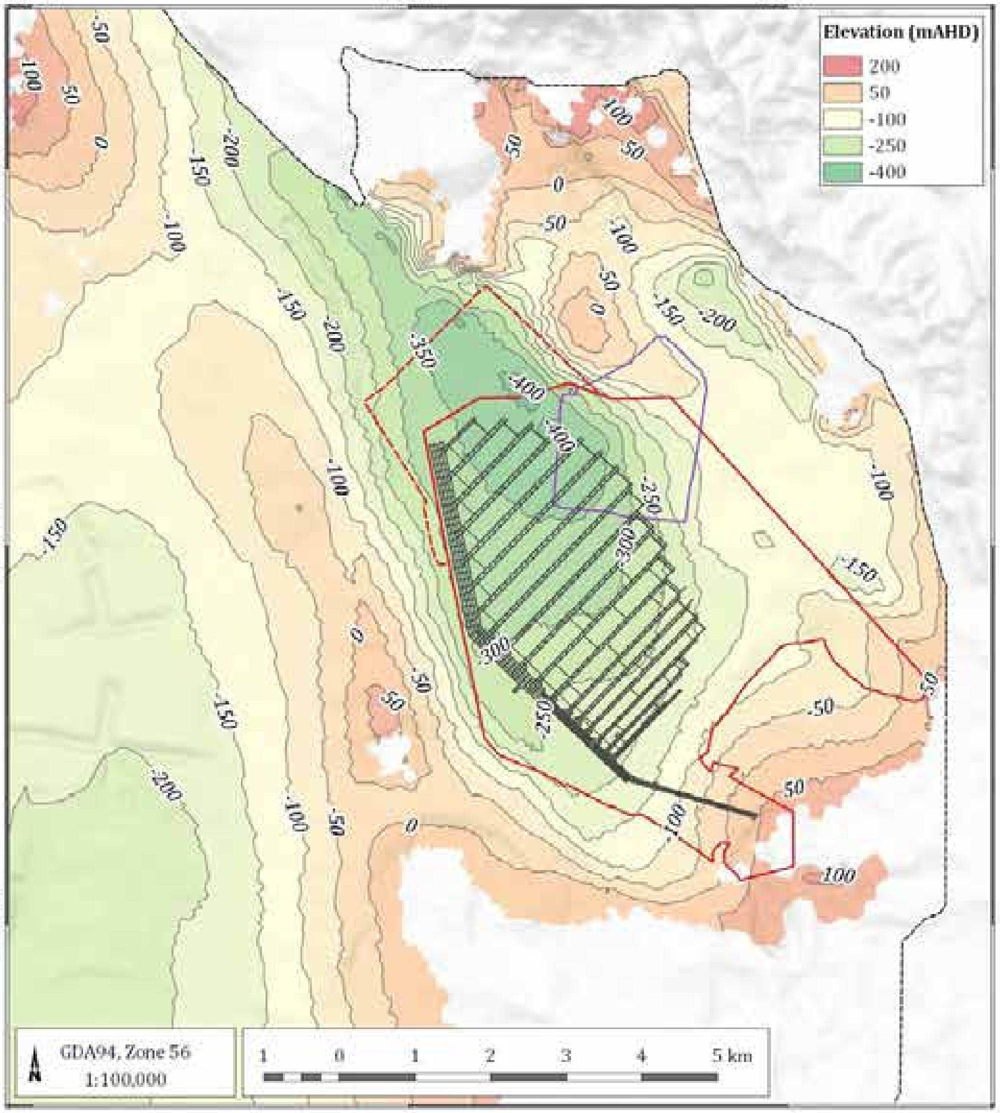
Each coal seam occurs with various splits and plies and varies in thickness across the Integra Underground. The Hebden and Barrett seams are between 1.8 m and 3.7 m thick and are separated by 15 m to 25 m of interburden while the Middle Liddell Seam is approximately 3 m thick overlies and the Barrett Seam with 30 m to 45 m of intervening interburden.

The structure, distribution and depth to the Middle Liddell Seam, Hebden Seam and Barrett seam are presented in Figure 4-7 to Figure 4-9 respectively.

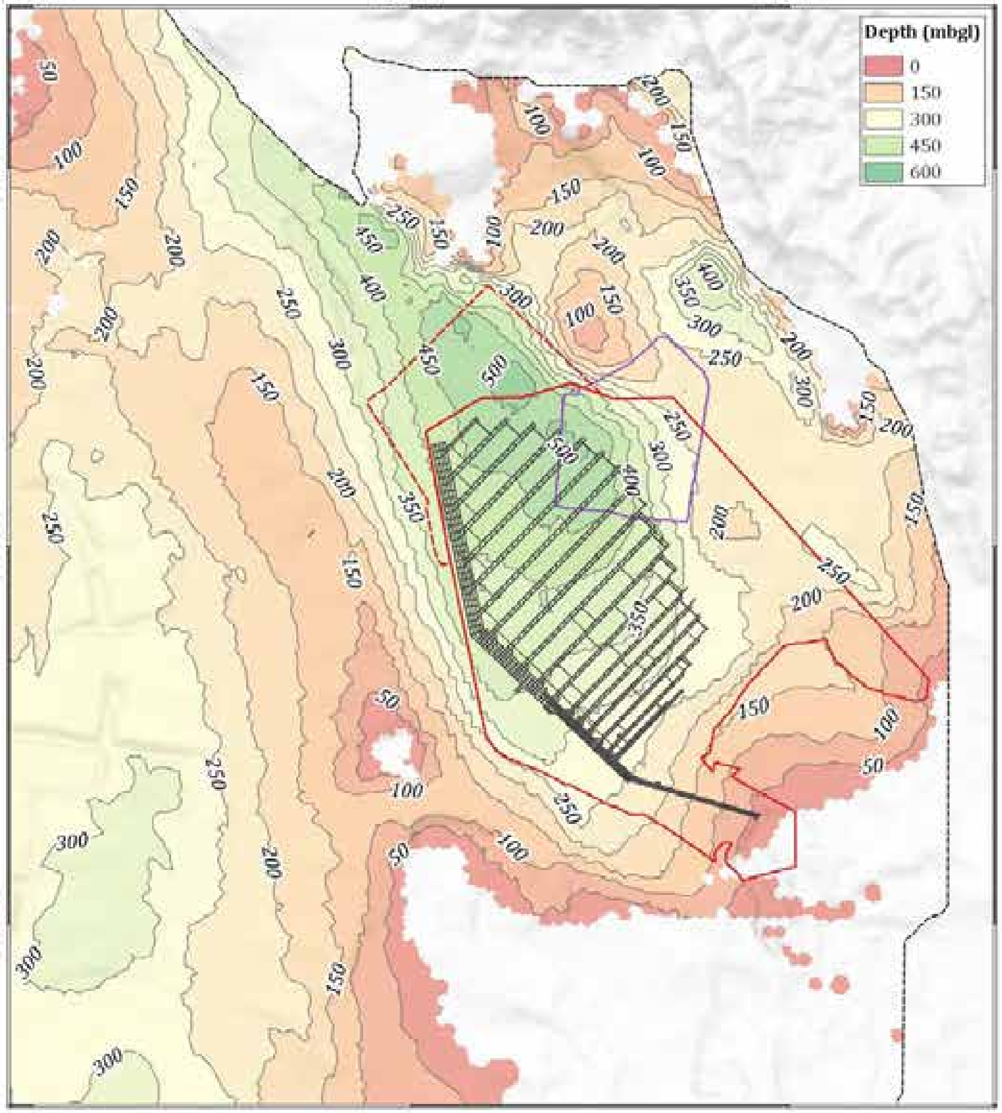
A weathered profile up to 25 m occurs across the Permian strata that are exposed at the land surface. Figure 4-6 shows a photograph of the Permian sequence exposed in the highwall of the Mount Owen Mine. Evident within the photograph is the thin brown weathered profile, overlying the grey and black un-oxidised Permian coal measures. A general lack of fault structures is also apparent within the area of Mount Owen North Pit.

Figure 4-6 Photo of Permian strata exposed in 'highwall' of Mount Owen Mine North looking towards the south

Structure contours of the Middle Liddell Seam



Depth-below-surface contours of the Middle Liddell Seam



LEGEND

- Model outline
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Contour line

Integra (G1205A)

DATE
16/11/2017

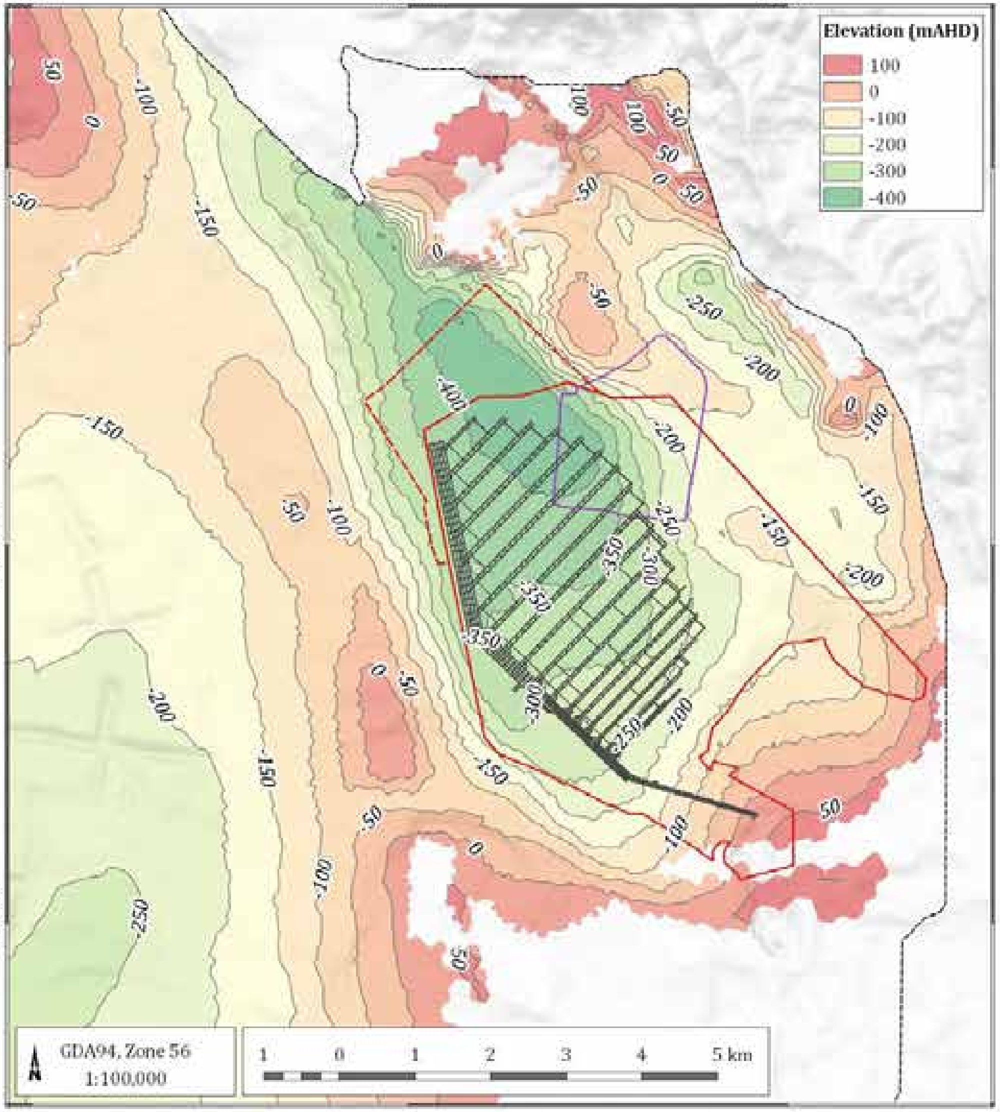
Structure and thickness contours of the Middle Liddell Seam

FIGURE No:
4-7

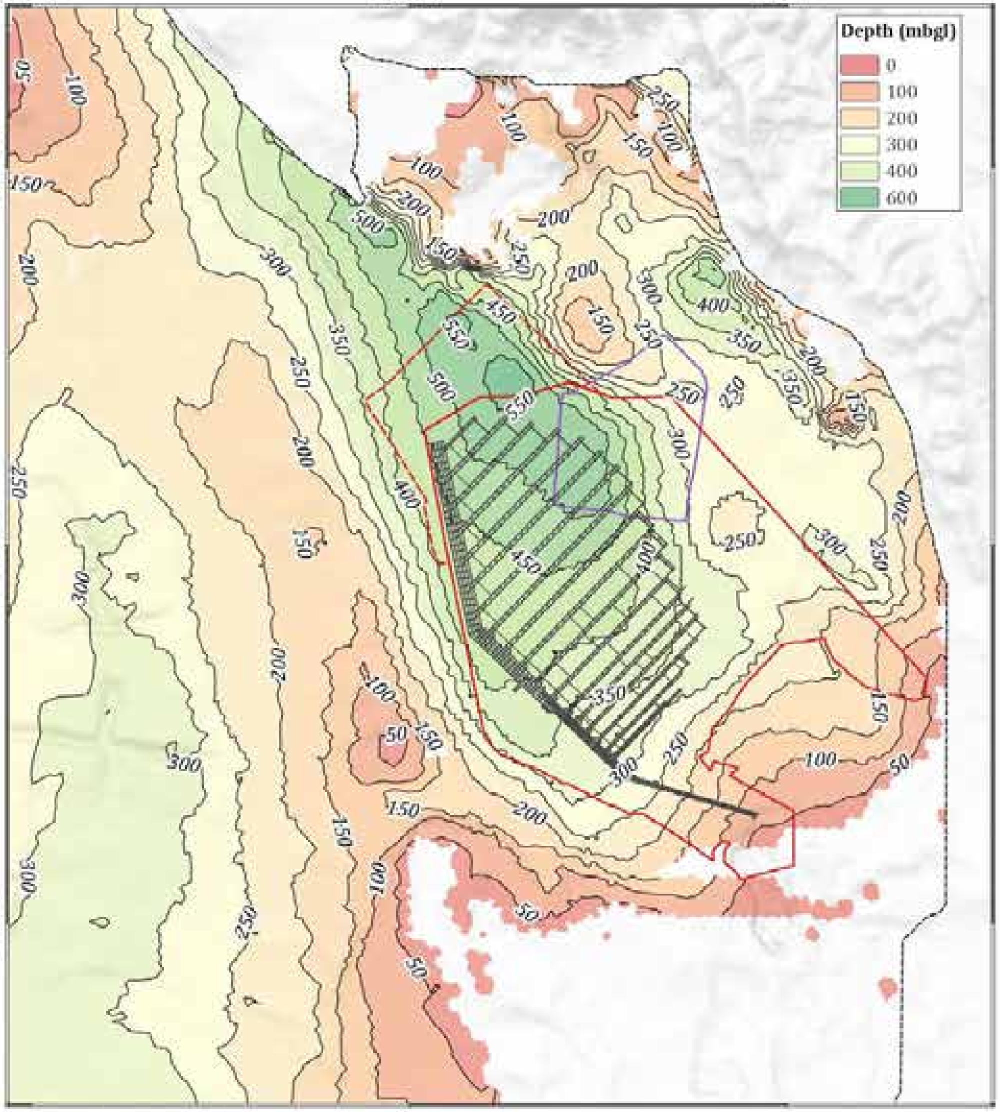
AGE

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/G1205A.Integra/3_GIS/Workspaces/002_EIA/04.06b_G1205A_Structure thickness contours Middle Liddell.qgs

Structure contours of the Barrett Seam



Depth-below-surface contours of the Barrett Seam



LEGEND

- Model outline
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Contour line

Integra (G1205A)

Structure and thickness contours of the Barrett Seam

DATE
16/11/2017

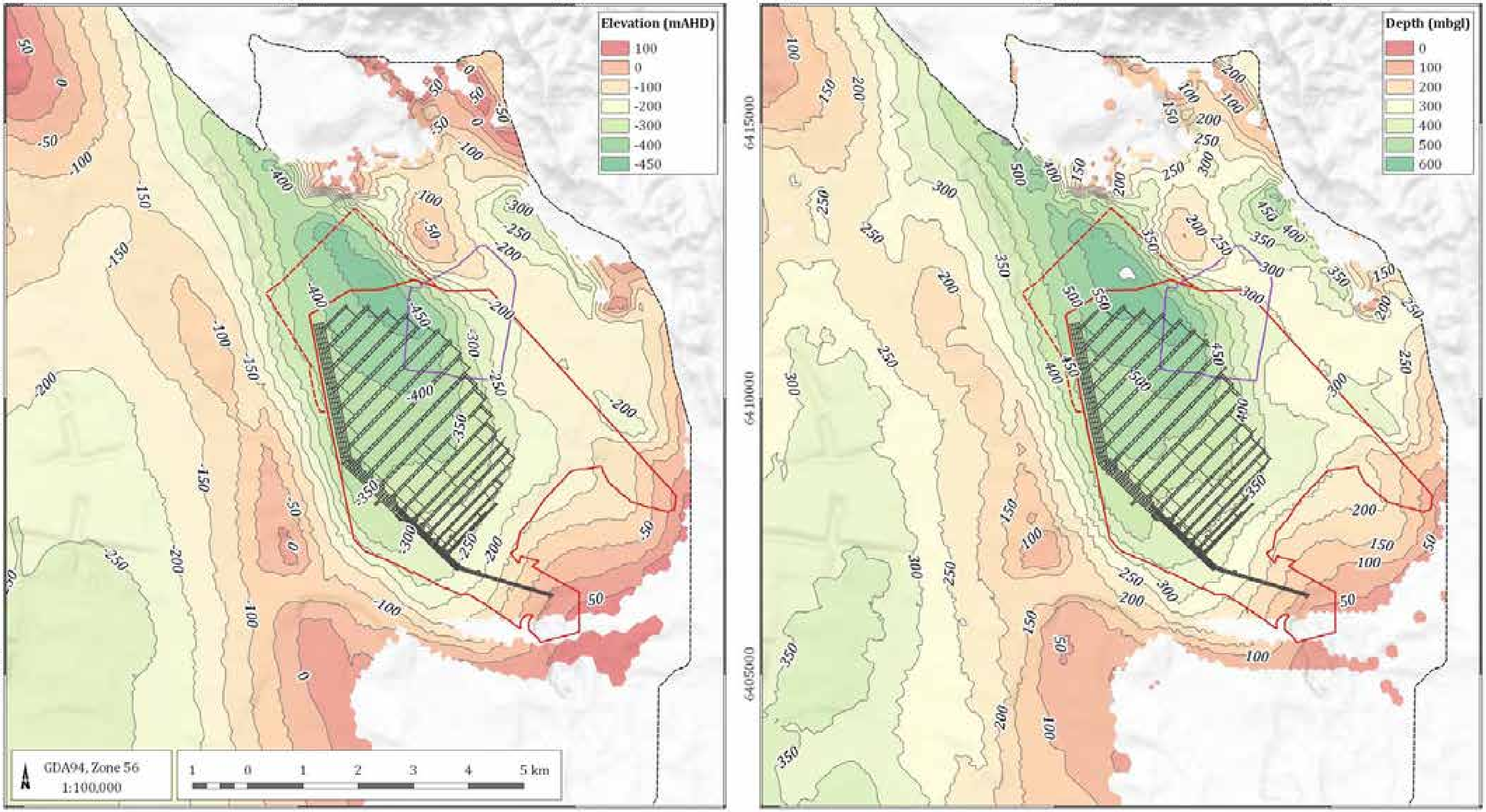
FIGURE No:
4-8

AGE

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
//lne01dc/Shared/Projects/G1205A Integra/3_GIS/Workspaces/002_EIA/04.07_G1205A_Structure thickness contours Barrett.qgs

Structure contours of the Hebden Seam

Depth-below-surface contours of the Hebden Seam



LEGEND

- Model outline
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Contour line

Integra (G1285A)

Structure and thickness contours of the Hebden Seam

DATE 16/11/2017

FIGURE No: **4-9**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:/Projects/G1285A.Integra/3_GIS/Workspaces/002_EIA/04.09_G1285A_Structure thickness contours Hebden.qgs

4.2.4 Saltwater Creek Formation

The Late Permian Saltwater Creek Formation (Pswc) is the lowermost formation of the Wittingham Coal Measures and conformably underlies the Vane Subgroup. The Saltwater Creek Formation comprises sandstone and siltstone with minor coal bands.

The Saltwater Creek Formation outcrops approximately 1.5 km north of the Modification on the eastern side of the Hebden Thrust, and approximately 3.5 km southeast of the Modification.

4.2.5 Maitland Group

The Middle Permian Maitland Group consists of three stratigraphic units, in stratigraphic order (youngest to oldest), the Mulbring Siltstone (Pmm), Muree Sandstone (Pms), and Branxton Formation (Pmb). The Maitland Group sediments were deposited in alluvial fan to prodelta and marine shelf depositional environments. The units comprise conglomerate, fine to coarse sand, siltstone and claystone.

Maitland Group sediments outcrop approximately 4.5 km southeast of the Modification where the Branxton Formation outcrops along the axis of several prominent anticlines.

4.3 Geological structure

The Permian coal measures are stratified (layered) sequences that have undergone deformation resulting in strata dipping approximately seven degrees to the northwest. Regionally, the coal measures are influenced by large fold structures, including the Camberwell Anticline and the Bayswater Syncline, which occur west of the Modification Area and trend in a north to north-west direction. Within the Modification area, the Rixs Creek Syncline axis splits forming a flat hinge structure.

The 1:100,000 Hunter Coalfield Geological Map shows several major northeast trending thrust faults including the Hebden and Hunter thrust faults. The Hunter Thrust represents the boundary between the Carboniferous New England Block which has been thrust over Permian Sydney Basin sediments. Within the Modification area, exploration drilling indicates a series of northeast trending fault zones with up to five meters of throw cut under Glennies Creek (GeoTerra, 2009).

5 Hydrogeology

The geological units described previously can be grouped into the following 'hydrostratigraphic units' based on their ability to transmit groundwater:

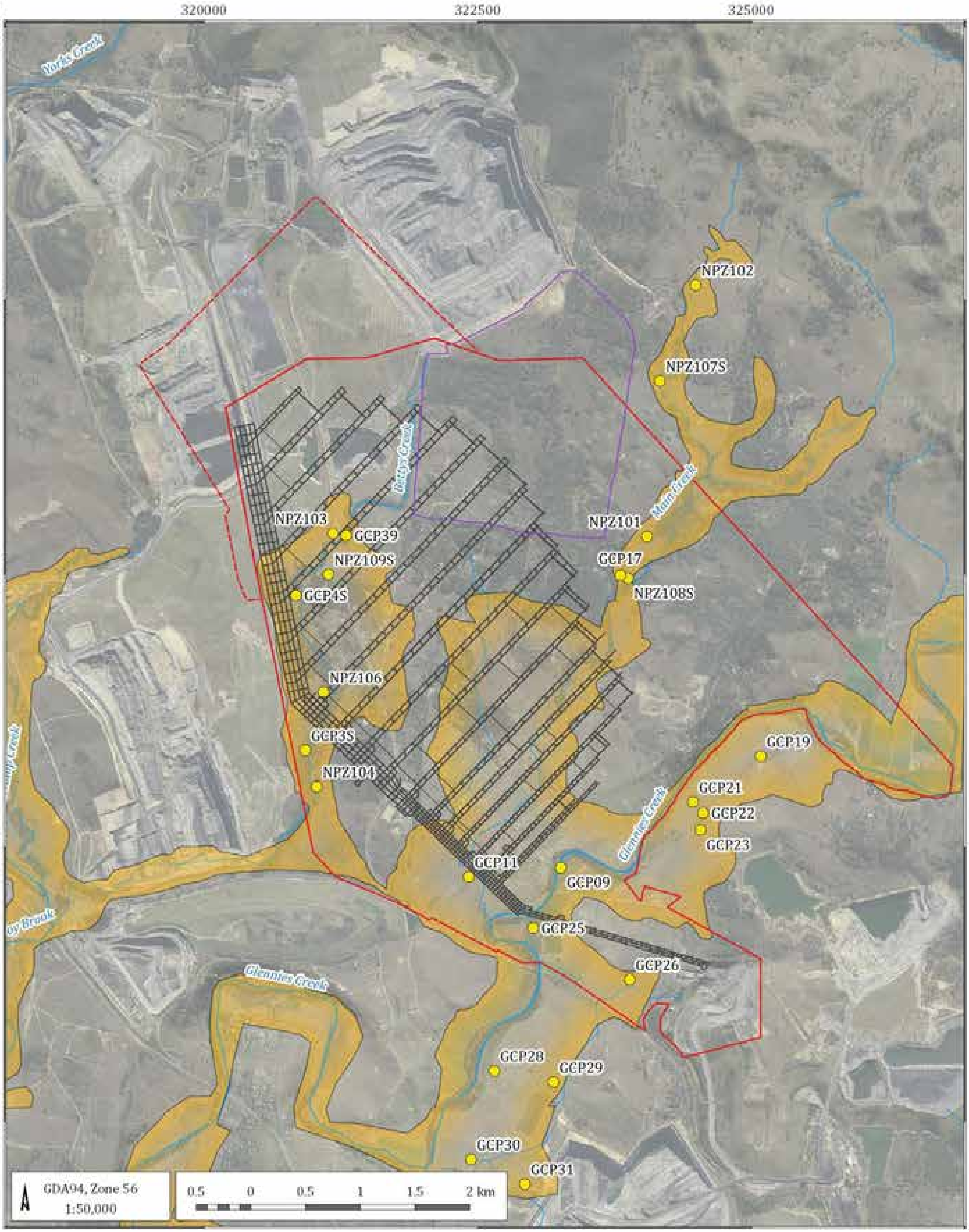
- Quaternary alluvium, which forms a relatively thin aquifer system where it occurs along drainage lines; and
- Permian sediments that can be divided into:
  - thin, generally dry and variably permeable weathered rock (regolith);
  - non coal interburden that forms aquitards; and
  - low to moderately permeable coal seams that act as the most transmissive strata within the coal measures sequence.

The sections below describe the hydrogeological properties of both the Quaternary and Permian hydrostratigraphic units.

5.1 Alluvial groundwater systems

5.1.1 Monitoring network

Glencore monitor groundwater levels within the Quaternary alluvial aquifers within in a network of monitoring bores across the Integra Underground and Mount Owen mines. Figure 5-1 shows the locations of the monitoring bores installed within the Quaternary alluvium deposited within the Bettys Creek, Main Creek and Glennies Creek flood plains. Table 5-1 summarises the construction details for each of the monitoring bores along with information on the thickness of the Quaternary alluvium, recent static water levels and measurements of hydraulic conductivity.



LEGEND

- Model extent
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Alluvium extent
- Major drainage
- Minor drainage
- Alluvium monitoring bore

Integra (G1285A)

Alluvium groundwater monitoring locations

DATE 16/11/2017

FIGURE No: **5-1**

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/G1285A.Integra/3_GIS/Workspaces/002_IBA/05.01 to 05.05b_G1285A_Groundwater monitoring location.qgs

Table 5-1 Quaternary alluvium groundwater monitoring bores

Bore ID	Easting (m) GDA94 Zone 56	Northing (m) GDA94 Zone 56	Alluvial aquifer	Ground elevation (mAHD)	Bore depth (mbgl)	Thickness alluvium (mbgl)	Screened interval (mbgl)	SWL (mAHD)	Date SWL measured	Saturated alluvium thickness (m)	Kh[1] (m/day)
GCP3S	320924	6408389	Bettys Ck	81	5.4	-	3.4-5.4	76.12	8/02/2017	N/A	-
GCP4S	320838	6409804	Bettys Ck	90	6.1	-	4.0-6.1	86.06	8/02/2017	N/A	-
GCP39	321297	6410352	Bettys Ck	96	3.2	3	2.5-3.0	90.86	30/11/2016	0	-
NPZ101	324046	6410343	Main Ck	83	13	12	5.2 - 8.2	79.94	15/04/2017	8.94	-
NPZ102	324489	6412637	Main Ck	121	9	7.5	2.0 - 8.0	119.21	15/03/2017	5.71	-
NPZ103	321177	6410370	Bettys Ck	92.03	6	4	1.5-5.9	88.98	15/03/2017	0.95	-
NPZ104	321028	6408055	Bettys Ck	80	6	5	2.0-5.0	74.55	15/03/2017	0	-
NPZ106	321091	6408918	Bettys Ck	93	7	5.3	2.0-5.0	87.61	15/03/2017	0	-
NPZ107S	324162	6411763	Main Ck	103.3	9	7	7.7 - 10.7	97.03	8/08/2017	0.73	-
NPZ108S	323871	6409960	Main Ck	87.2	10.7	10	2.5-5.5	80.16	8/08/2017	2.96	-
NPZ109S	321134	6409995	Bettys Ck	90.6	5.5	3.9	2.5-5.5	-	8/08/2017	0	-
GCP11	322417	6407232	Main Ck	70.5	-	-	N/A - 12	61.73	15/04/2017	N/A	-
GCP17	323803	6409986	Main Ck	87.5	7.5	7	4.0 - 7.5	79.94	15/04/2017	0	0.06
GCP09	323259	6407315	Glennies Ck	69.9	9	8	5.8 - 8.8	63.65	1/11/2016	1.75	>0.2
GCP19	325086	6408333	Glennies Ck	77.5	12	11.5	8.5 - 12.0	69.02	5/02/2017	3.02	-
GCP21	324466	6407916	Glennies Ck	76	11	10.5	6.0 - 11.0	68.52	5/02/2017	3.02	0.16

Bore ID	Easting (m) GDA94 Zone 56	Northing (m) GDA94 Zone 56	Alluvial aquifer	Ground elevation (mAHD)	Bore depth (mbgl)	Thickness alluvium (mbgl)	Screened interval (mbgl)	SWL (mAHD)	Date SWL measured	Saturated alluvium thickness (m)	Kh[1] (m/day)
GCP22	324558	6407814	Glennies Ck	75	12	11.5	8.5 - 12.0	68.87	5/02/2017	5.37	0.03
GCP23	324535	6407659	Glennies Ck	75	8	7.5	4.6 - 8.0	69.66	5/02/2017	2.16	0.03-0.09
GCP25	323006	6406766	Glennies Ck	72	13	>13	6.0 - 13.0	63.95	13/12/2016	>4.95	0.04
GCP26	323884	6406293	Glennies Ck	71.5	11	10.5	7.0 - 11.0	66.15	13/12/2016	5.15	0.015-0.017
GCP28	322652	6405459	Glennies Ck	69.5	12	>12	6.7 - 12.0	62.76	13/12/2016	>5.26	0.17
GCP29	323194	6405354	Glennies Ck	71	10	9.5	4.5 - 10.0	64.76	13/12/2016	3.26	0.61
GCP30	322440	6404652	Glennies Ck	67.5	12	11	5.5 - 12.0	62.42	25/11/2015	5.92	0.06
GCP31	322930	6404424	Glennies Ck	70	11.5	13.5	9.5 – 11.5	62.35	08/03/2011	5.85	-

1. *Source Geoterra (2009)*

5.1.2 Thickness and saturation

The thickness of the Quaternary alluvium from the borehole logs was interpolated across the flood plain areas and is presented in Figure 5-2. The figure shows the alluvium is typically in the order of 10 m thick within the Glennies Creek and Main Creek flood plains and substantially thinner along Bettys Creek where it is around 5 m thick.

There are seven bores monitoring the Bettys Creek alluvium, ranging in depth from 3.2 m to 7 m. The alluvium is defined by thin horizons usually no more than 2 m thick of clay, silt, sand, and gravel. Most layers are predominantly clay, with associated silt, sand, or gravel. Clays vary in colour across red, brown, and yellow to white and grey. Gravels are consistently rounded to sub-rounded, and sands vary from fine to coarse grained. The photograph in Figure 5-3 was taken within the Mount Owen Mine where the Bettys Creek alluvium has been intersected by mining operations and illustrates the horizons of silt and clay to gravel and coarse sand.

The water table and the ground surface elevation across the Bettys Creek alluvium varies within a range of 15 m from the upper to lower areas of the catchment. The saturated proportion of the Quaternary alluvium is minimal. Bores NPZ104, NPZ106, and NPZ109S are dry, despite being screened to the base of the Quaternary alluvium. Bore NPZ103 has a saturated thickness of about 1 m, and the Quaternary alluvium at that location is 4 m thick. Bores GCP3S and GCP4S do not have drilling logs, and so the depth of the Quaternary alluvium and saturated thickness is not known.

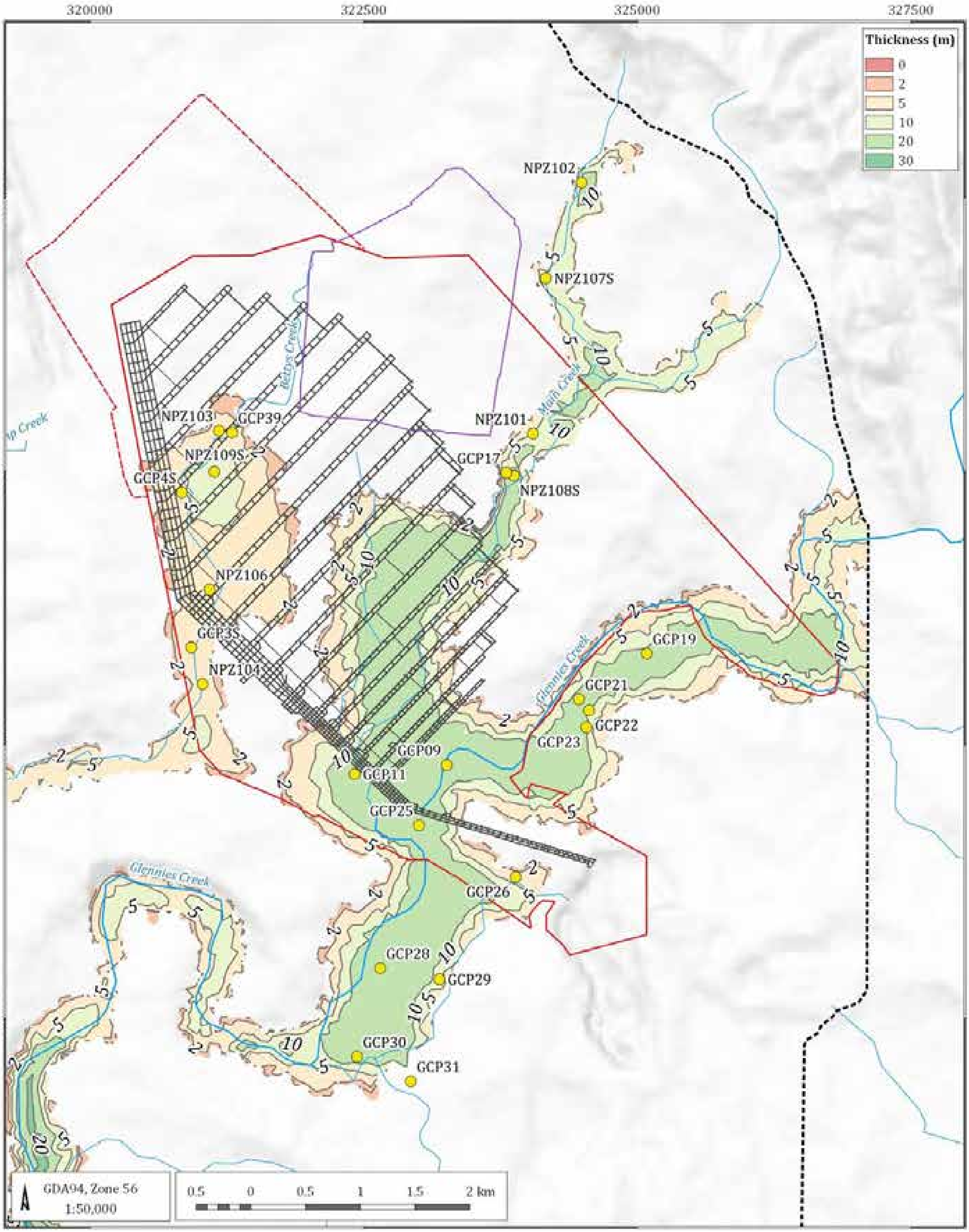
Main Creek alluvium is monitored by six bores between 7 and 12 m in depth. The Quaternary alluvium consists of clay horizons with associated sand and gravel, and occasional sand and gravel horizons with minor clays. Sands and gravels are consistently sub-angular to sub-rounded and poorly sorted. Clay consistency ranges up to high plasticity and very sticky, with colours of grey and white to orange, yellow, and brown. The distinct horizons are mostly between 1 and 3 m thick. The photograph taken in the bed of Main Creek included as Figure 5-4 illustrates the fine sediments where cracking is visible, and the presence of sand and gravel towards the base of the sequence.

Main Creek falls approximately 30 m over a 4.8 km distance. The depth from surface to groundwater is around 6 m to 7 m in all bores except NPZ101, which is only around 3 m. The standing water level follows the topographic elevation closely at each bore location.

The saturated thickness within Main Creek alluvium appears to be patchy and variable depending on location, ranging from unsaturated to almost 9 m. The available data indicates that the Quaternary alluvium becomes saturated where the Quaternary alluvium thickens towards the centre of the flood plain but can be unsaturated towards the edges, or where the base of the Quaternary alluvium is potentially affected by bedrock features such as buried rock bars.

Glennies Creek alluvium is monitored by ten bores between 8 and 14 m in depth. The Quaternary alluvium is dominated by horizons of clays and gravels, with associated sand, silt, and loam, which are mostly between 1 and 5 m thick. Gravels and fine to coarse grained sands are potentially more common in the larger fluvial environment of Glennies Creek, compared to Bettys Creek and Main Creek.

Glennies Creek has a gentler topographic gradient than the more steeply sloping Bettys Creek and Main Creek, with less than 10 m change in elevation through the Modification area. The monitoring bores within the Glennies Creek alluvium have recorded a saturated thickness varying from 1.75 m to almost 6 m.



LEGEND

- Model extent
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Major drainage
- Minor drainage
- Contour line (m)
- Alluvium monitoring bore

Integra (G1285A)

Interpolated thickness of alluvium

AGE

DATE 16/11/2017

FIGURE No: **5-2**

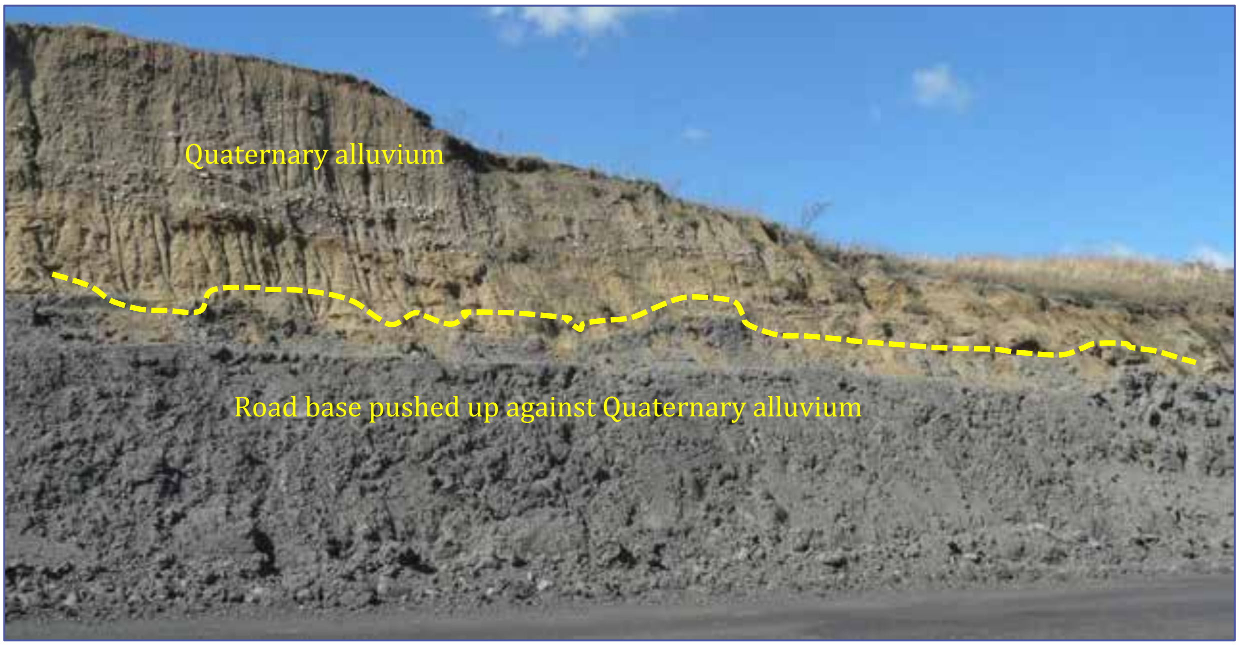


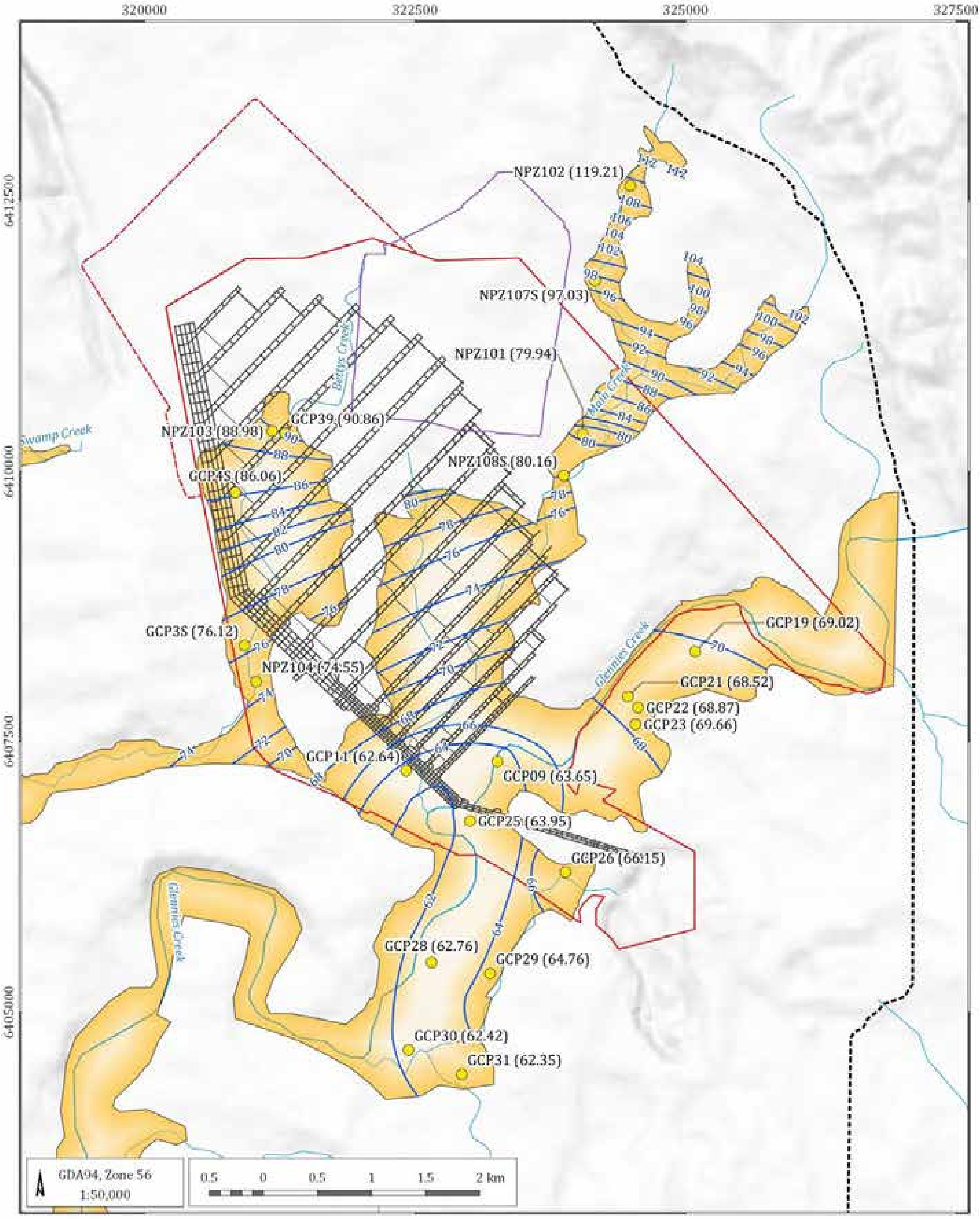
Figure 5-3 Bettys Creek alluvium exposed in Mount Owen Mine

Figure 5-4 Main Creek alluvium from channel of Main Creek

5.1.3 Flow and water level fluctuations

Standing water level measurements from monitoring bores across the Modification area indicate groundwater flow within the alluvial aquifers is a reflection of the surface topography. Figure 5-5 shows interpolated groundwater levels from the monitoring bores, and highlights the generally south to south-westerly trend in flow. The hydraulic gradients are relatively steep in Bettys Creek and Main Creek at about 1:100 to 1:200, whereas a gentler gradient occurs in Glennies Creek up to about 1:1000. This slighter hydraulic gradient within Glennies Creek appears due to the presence of more permeable sediments and a flatter terrain along the creek.

Long term manual groundwater level measurements have been recorded at each bore within the Quaternary alluvium across the Modification area. These are presented in Figure 5-6 to Figure 5-12. The CRD is also included on the graphs to show climatic cycles and rainfall trends relative to long term averages. In general, groundwater levels within the Quaternary alluvium show a relationship to the CRD indicating the influence of climatic cycles on rainfall recharge. No significant drainage from the alluvial aquifers due to mining activities is obvious within the available datasets.



LEGEND

- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Major drainage
- Minor drainage
- Groundwater level (mAHD)
- Alluvium monitoring bore

Integra (G1285A)

Interpolated groundwater levels within alluvium, 2017

DATE 16/11/2017

FIGURE No: 5-5

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/G1285A.Integra/3_GIS/Workspaces/002_EIA/05.01 to 05.05b_G1285A_Groundwater monitoring location.qgs

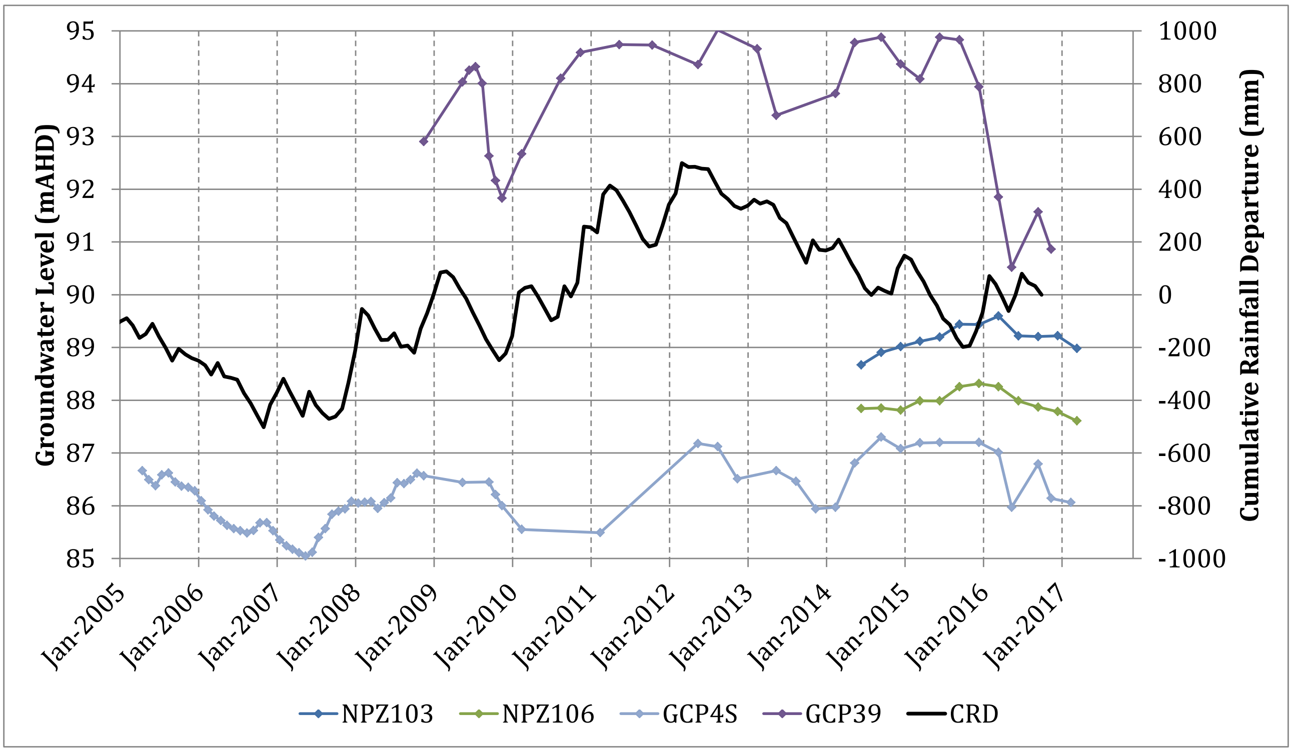


Figure 5-6 Bettys Creek alluvium hydrographs – northern bores

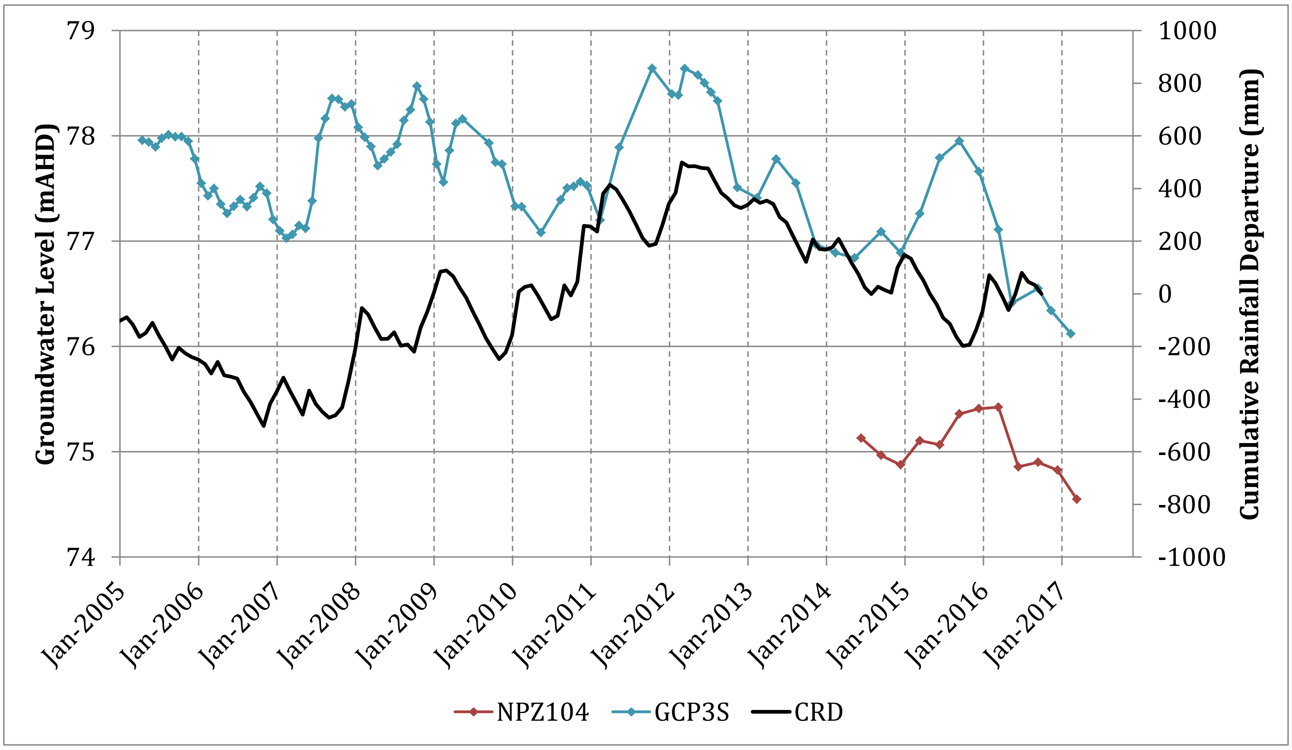


Figure 5-7 Bettys Creek alluvium hydrographs – southern bores

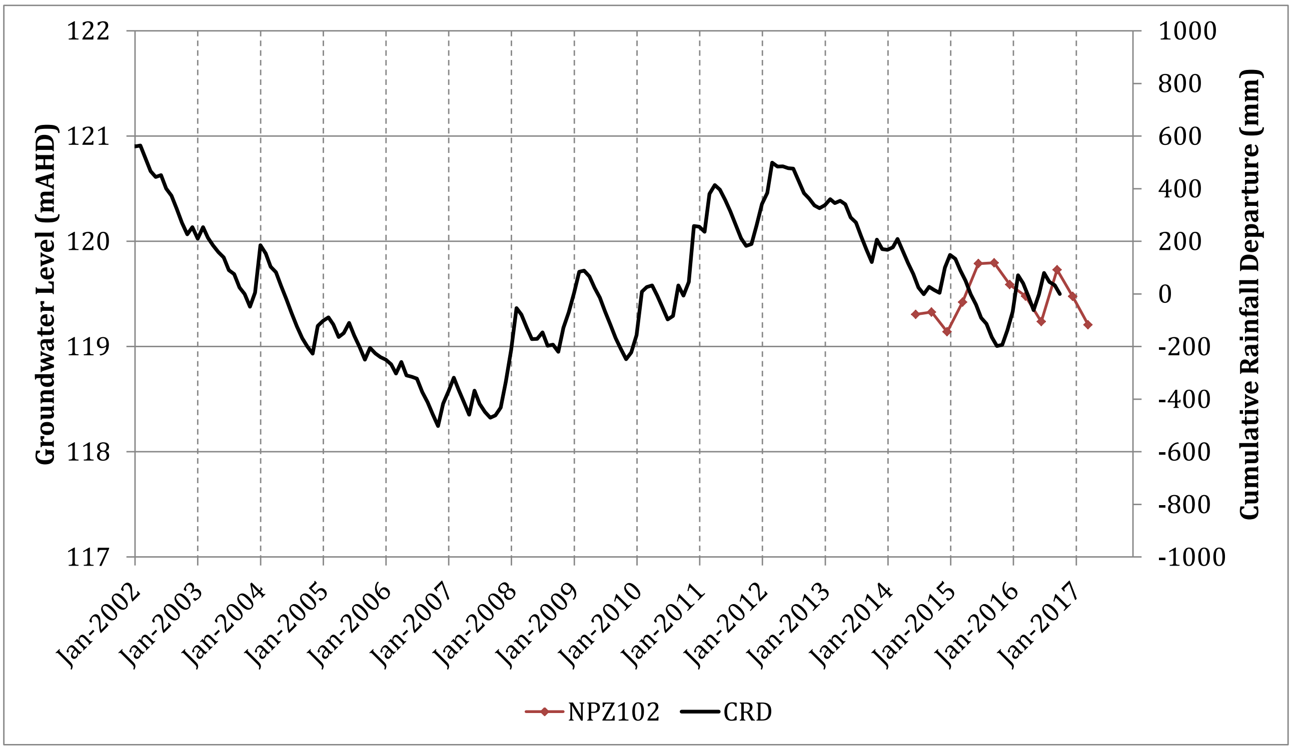


Figure 5-8 Main Creek alluvium hydrographs – northern bores

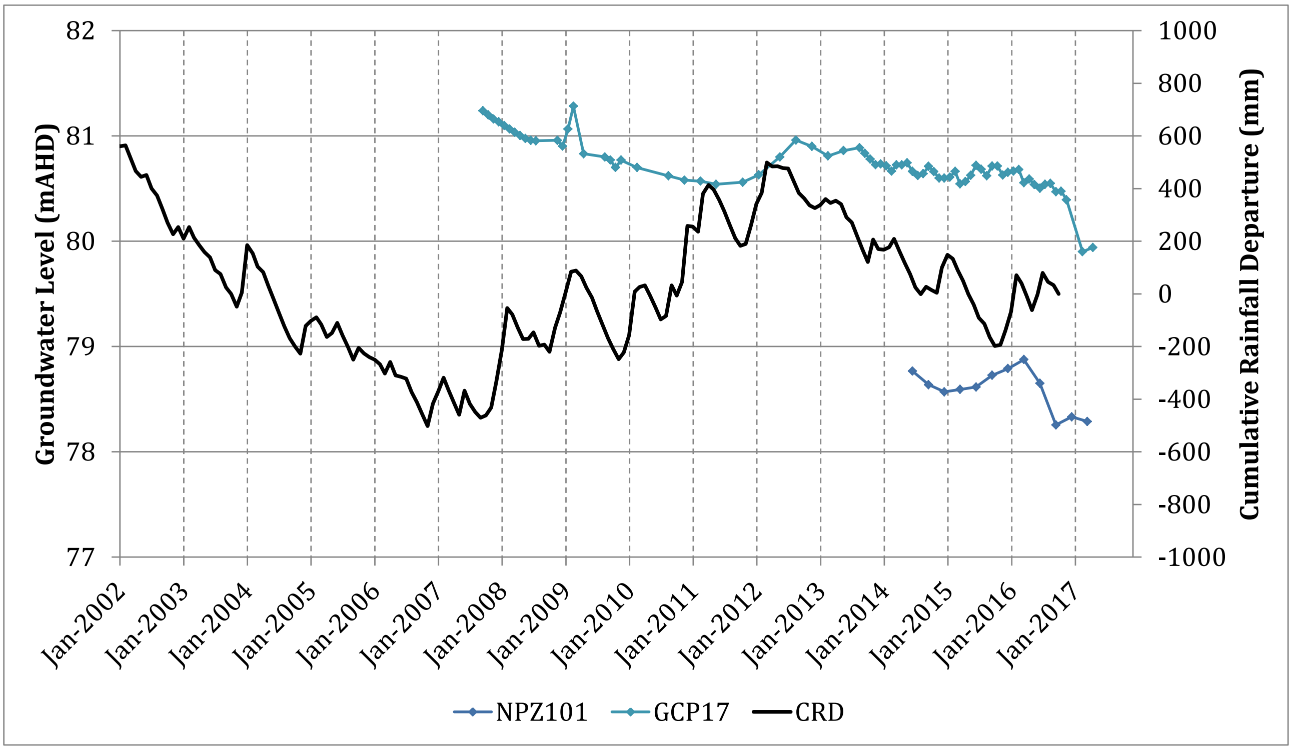


Figure 5-9 Main Creek alluvium hydrographs – midstream bores

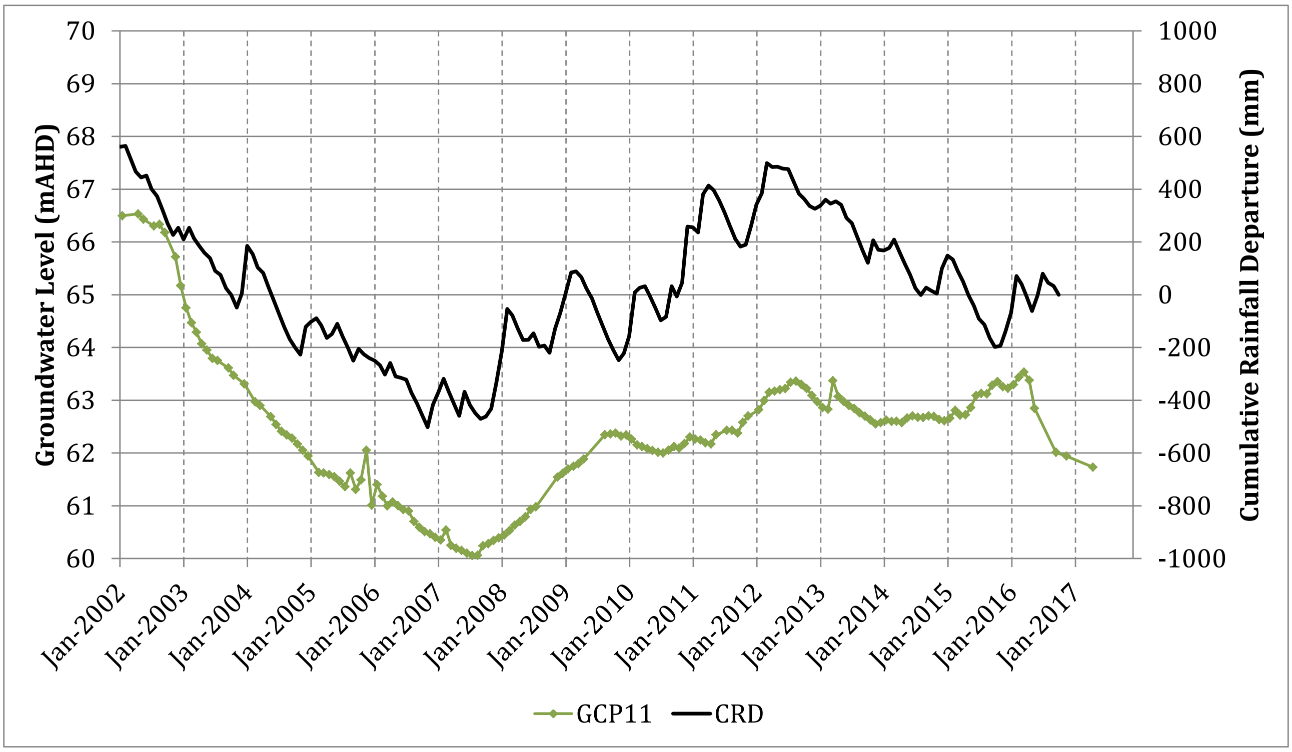


Figure 5-10 Main Creek alluvium hydrographs – southern bores

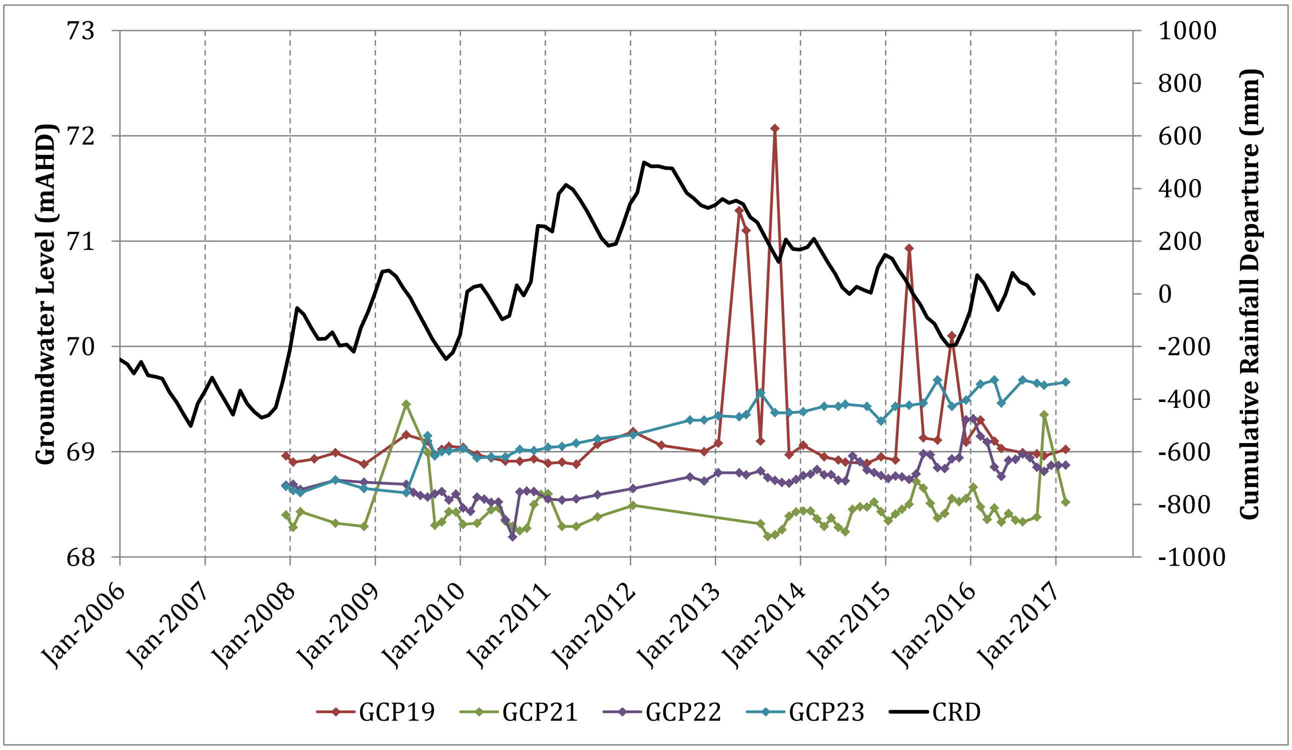


Figure 5-11 Glennies Creek alluvium hydrographs – eastern bores

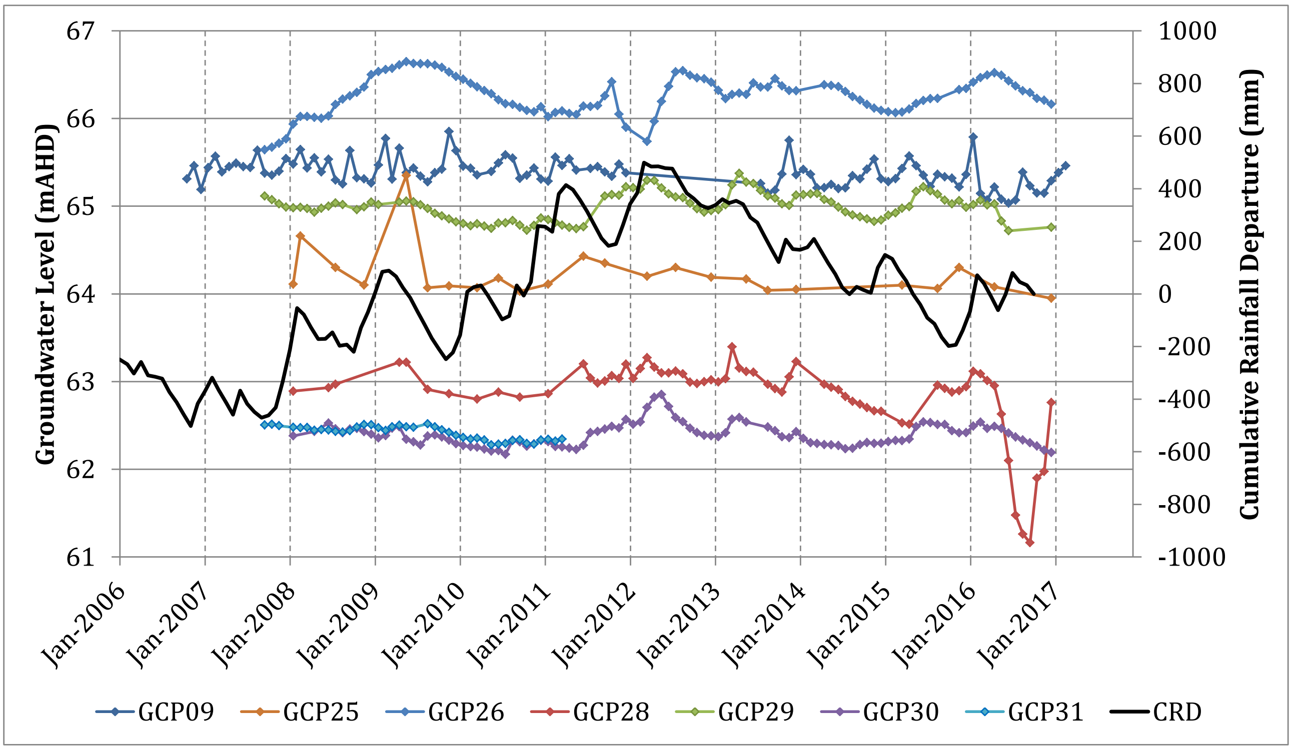


Figure 5-12 Glennies Creek alluvium hydrographs – western bores

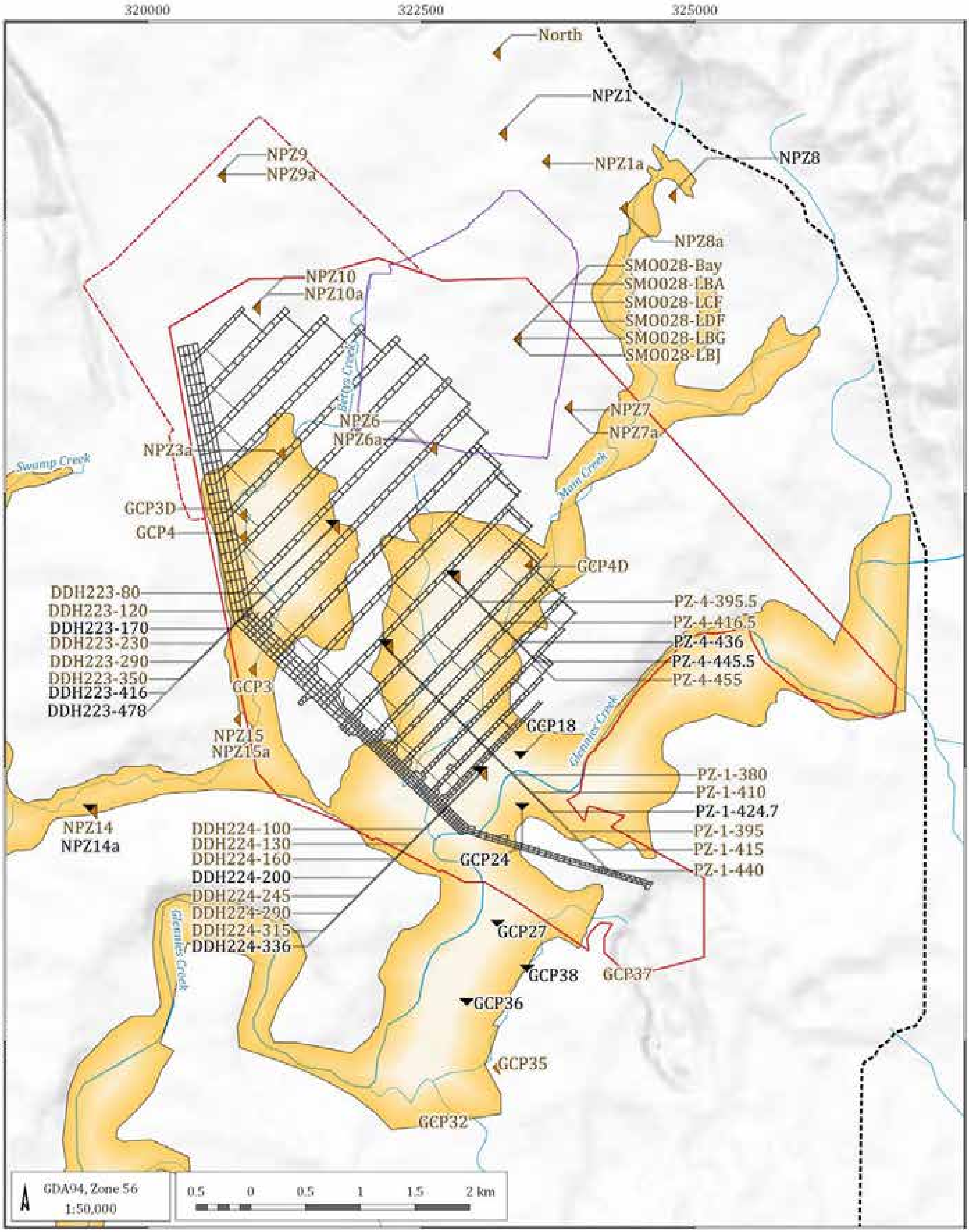
5.1.4 Hydraulic properties

The general dominance of clays within borehole logs for Bettys Creek and Main Creek alluvium suggests a moderate to low hydraulic conductivity for the alluvial sediments. This is confirmed by available hydraulic conductivity measurements for the alluvial sediments summarised in Table 5-1, which indicate a hydraulic conductivity in the Main Creek alluvium of 0.06 m/day at bore GCP17. No measurements of hydraulic conductivity are available for Bettys Creek alluvium, but the lithology within the borehole logs suggests it would be similar to Main Creek, and therefore moderate to low for unconsolidated alluvial sediment. Table 5-1 shows the hydraulic conductivity measurements in Glennies Creek range from approximately 0.01 to 0.6 m/day indicating significant variability. The prevalence of coarser sands and gravels in the borehole logs, and the slighter hydraulic gradients suggest on average the hydraulic conductivity within the Glennies Creek alluvium is higher than within the Main Creek and Bettys Creek alluvium.

5.2 Permian groundwater systems

5.2.1 Monitoring network

Glencore monitor groundwater levels within the Permian strata using a combination of open PVC cased monitoring bores and arrays of vibrating wire pressure sensors (VWPs) installed through the Permian geological sequence. Figure 5-13 shows the locations of the monitoring and VWPs installed within the Permian strata. Table 5-2 summarises the construction details for each monitoring site.



LEGEND

- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Alluvium extent
- Major drainage
- Minor drainage

Monitoring bore stratigraphy

Integra (G1285A)

Permian groundwater monitoring locations

AGE

DATE 16/11/2017

FIGURE No: **5-13**

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/G1285A.Integra/3_GIS/Workspaces/002_EIA/05.01 to 05.05b_G1285A_Groundwater monitoring location.qgs

Table 5-2 Permian groundwater monitoring bores

Bore ID	Easting (m) GDA94 Zone 56	Northing (m) GDA94 Zone 56	Aquifer	Ground elevation (mAHD)	Bore depth (mbgl)	Screened interval (mbgl)	SWL (mAHD)	Date SWL measured
DDH223-120	321684	6409694	Interburden	98.49	-	-	21.68	15/08/2012
DDH223-170	321684	6409694	Interburden	98.49	-	-	-2.70	15/04/2011
DDH223-230	321684	6409694	Interburden	98.49	-	-	29.07	15/09/2012
DDH223-290	321684	6409694	Interburden	98.49	-	-	-102.95	15/09/2012
DDH223-350	321684	6409694	Interburden	98.49	-	-	-109.97	15/09/2017
DDH223-416	321684	6409694	Interburden	98.49	-	-	-122.37	15/09/2012
DDH223-478	321684	6409694	Interburden	98.49	-	-	-17.16	15/09/2012
DDH224-100	323034	6407439	Interburden	75.3	-	-	10.17	15/03/2017
DDH224-130	323034	6407439	Interburden	75.3	-	-	-19.79	15/03/2017
DDH224-160	323034	6407439	Interburden	75.3	-	-	-14.28	15/03/2017
DDH224-200	323034	6407439	Interburden	75.3	-	-	-89.05	15/03/2017
DDH224-245	323034	6407439	Interburden	75.3	-	-	-120.84	15/03/2017
DDH224-290	323034	6407439	Interburden	75.3	-	-	-162.38	15/03/2017
DDH224-315	323034	6407439	Interburden	75.3	-	-	-142.09	15/03/2017
DDH224-336	323034	6407439	Interburden	75.3	-	-	-72.78	15/03/2017
GCP18	323406	6407580	Coal Seam	73	108.5	-	65.22	15/04/2017
GCP24	323421	6407105	Coal Seam	71.3	48	46 – 48	53.22	15/12/2017
GCP27	323197	6406037	Coal Seam	70	37.5	35.5 – 37.5	62.34	15/03/2010
GCP3	320924	6408389	Interburden	81	49.2	-	-	-

Bore ID	Easting (m) GDA94 Zone 56	Northing (m) GDA94 Zone 56	Aquifer	Ground elevation (mAHD)	Bore depth (mbgl)	Screened interval (mbgl)	SWL (mAHD)	Date SWL measured
GCP32	322491	6404250	Interburden	70.5	55.55	-	62.69	15/06/2017
GCP35	323149	6404757	Interburden	71	197	-	-	-
GCP36	322915	6405320	Coal Seam	70.5	16	-	63.09	15/12/2017
GCP37	324156	6405612	Interburden	80	127.5	-	-	-
GCP38	323468	6405626	Coal Seam	71	24.3	-	63.83	15/12/2016
GCP3D	320838	6409800	Interburden	81	48.5	-	41.35	15/02/2017
GCP4	320838	6409600	Interburden	90	36	-	-	-
GCP4D	323447	6409344	Interburden	90	36	-	73.94	15/02/2017
North Bore	323156.2	6414021	Interburden	140.65	-	-	131.75	15/03/2017
NPZ1	323213	6413286	Interburden	126.2	60	-	111.29	15/12/2016
NPZ1a	323213	6413286	Interburden	126.2	130	-	87.44	15/03/2017
NPZ3a	321182	6410365	Interburden	93.53	30	-	54.01	15/03/2017
NPZ6	322577	6410410	Interburden	125.74	65	-	68.32	15/03/2017
NPZ6a	322577	6410410	Interburden	125.74	102	-	32.06	15/03/2017
NPZ7	323812.2	6410786	Interburden	95.38	62	-	81.18	15/03/2017
NPZ7a	323812.2	6410786	Interburden	95.38	110	-	35.71	15/03/2017
NPZ8	324761	6412715	Interburden	120.02	60	-	110.59	15/03/2017
NPZ8a	324761	6412715	Interburden	120.02	130	-	86.08	15/03/2017
NPZ9	320643	6412905	Interburden	113.86	22	-	109.99	15/03/2017
NPZ9a	320643	6412905	Interburden	113.86	50	-	88.68	15/03/2017

Bore ID	Easting (m) GDA94 Zone 56	Northing (m) GDA94 Zone 56	Aquifer	Ground elevation (mAHD)	Bore depth (mbgl)	Screened interval (mbgl)	SWL (mAHD)	Date SWL measured
NPZ10	320961	6411696	Interburden	116.62	27	-	90.13	15/03/2017
NPZ10a	320961	6411696	Interburden	116.62	61	-	79.44	15/03/2017
NPZ14	319470.6	6407093	Interburden	74.59	51	-	32.23	15/06/2011
NPZ14a	319470.6	6407093	Coal Seam	74.59	91	-	25.40	15/01/2012
NPZ15	320784.3	6407934	Interburden	81.6	59	-	22.4	15/03/2011
NPZ15a	320784.3	6407934	Interburden	81.6	130	-	-17.33	15/10/2011
PZ-1-395	322172.84	6408597.57	Interburden	81.8	380	-	-189.91	15/03/2017
PZ-1-415	322172.84	6408597.57	Interburden	81.8	380	-	-150.13	15/09/2013
PZ-1-440	322172.84	6408597.57	Interburden	81.8	380	-	-110.50	15/03/2017
PZ-4-395.5	322786.68	6409232.79	Interburden	82.4	395.5	-	-262.32	15/03/2017
PZ-4-416.5	322786.68	6409232.79	Interburden	82.4	395.5	-	-230.76	15/03/2017
PZ-4-436	322786.68	6409232.79	Interburden	82.4	395.5	-	-272.87	15/03/2017
PZ-4-445.5	322786.68	6409232.79	Interburden	82.4	395.5	-	-232.78	15/03/2017
SMO028-Bay	323346	6411410	Interburden	109.65	183	20	89.079	15/12/2016
SMO028-LDF	323346	6411410	Interburden	109.6485	183	42.5	126.605	15/12/2016
SMO028-LCF	323346	6411410	Interburden	109.6485	183	77.2	93.493	15/12/2016
SMO028-LBJ	323346	6411410	Interburden	109.6485	183	100	101.733	15/12/2016
SMO028-LBG	323346	6411410	Interburden	109.6485	183	109.5	83.840	15/12/2016
SMO028-LBA	323346	6411410	Interburden	109.6485	183	128.5	99.263	15/12/2016

Note*: - Kh – horizontal hydraulic conductivity (m/day)*

5.2.2 Flow and water level fluctuations

As mining at Integra Underground and the adjacent Mount Owen Mine is relatively deep, arrays of VWPs have been used to monitor changes in pore pressure and depressurisation. Three arrays of VWPs are located within the footprint of the Integra Underground (DDH223, PZ-1, PZ-4), whilst a single site is immediately adjacent to the mining area (DDH224). Arrays are also located around Mount Owen Mine (SMO028). The arrays of VWPs are fitted with data loggers and therefore provide a continuous record of how pressure within Permian strata has responded to underground mining. Figure 5-14 to Figure 5-17 below show pressures recorded by each VWP sensor in equivalent Australian Height Datum (AHD) in the vicinity of the Integra mine. The sites of the VWPs are overlain by alluvial sediment and therefore the interpolated groundwater levels within the Quaternary alluvium are shown for the site of each sensor for comparison. The hydrographs illustrate the gradual depressurisation of the Permian strata overlying and underlying the Integra Underground within the Middle Liddell seam. Note DDH223 was reported damaged by mine subsidence in 2012. Of particular note within the VWPs records is that whilst all of the sensors have recorded reduced pressures within the Permian strata in response to fracturing induced by mining, none of the sensors have recorded 'zero pressure' which would indicate complete drainage of the Permian strata. Many of the VWPs have recorded a continuous but slow decline in pressure indicating the Permian strata has a relatively low hydraulic conductivity resulting in very slow drainage of groundwater from the strata due to mining.

Figure 5-18 to Figure 5-24 further below show hydrographs for selected bores and VWPs that are located within the Permian strata in the region of Mount Owen North Pit. The influence of mining is evident in many of the hydrographs with depressurisation resulting in a characteristic slow decline in groundwater levels within Permian strata over time, which is typical for the relatively low permeability material that is slow to drain.

Whilst the hydrographs indicate the variability in the drawdown occurring through the Permian sequence, Figure 5-25 shows groundwater levels measured in mid-2017 in piezometers installed within the Middle Liddell coal seam. The flow contours, whilst influenced by the availability of measurement points, do illustrate the depressurisation resulting from mining activity across the region within the Middle Liddell seam.

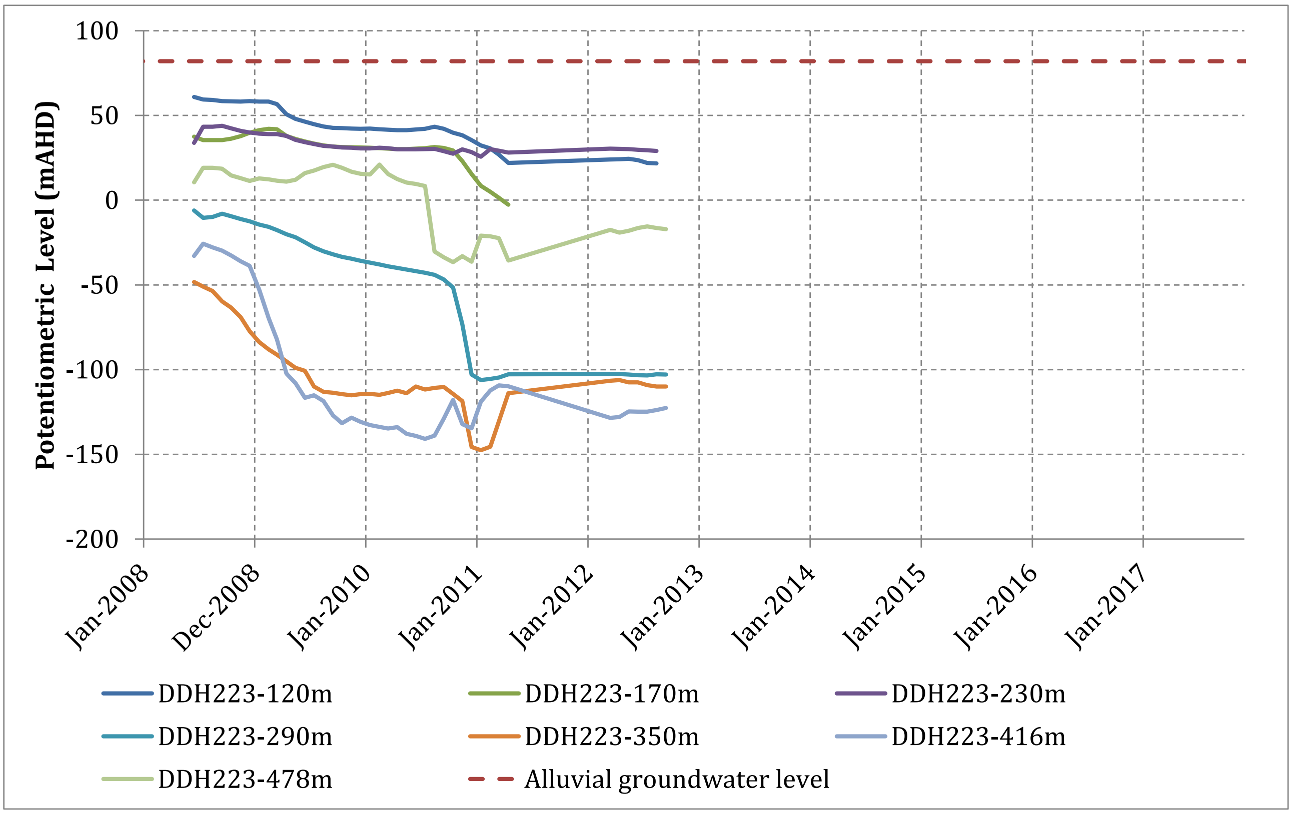


Figure 5-14 Hydrograph - VWP DDH223

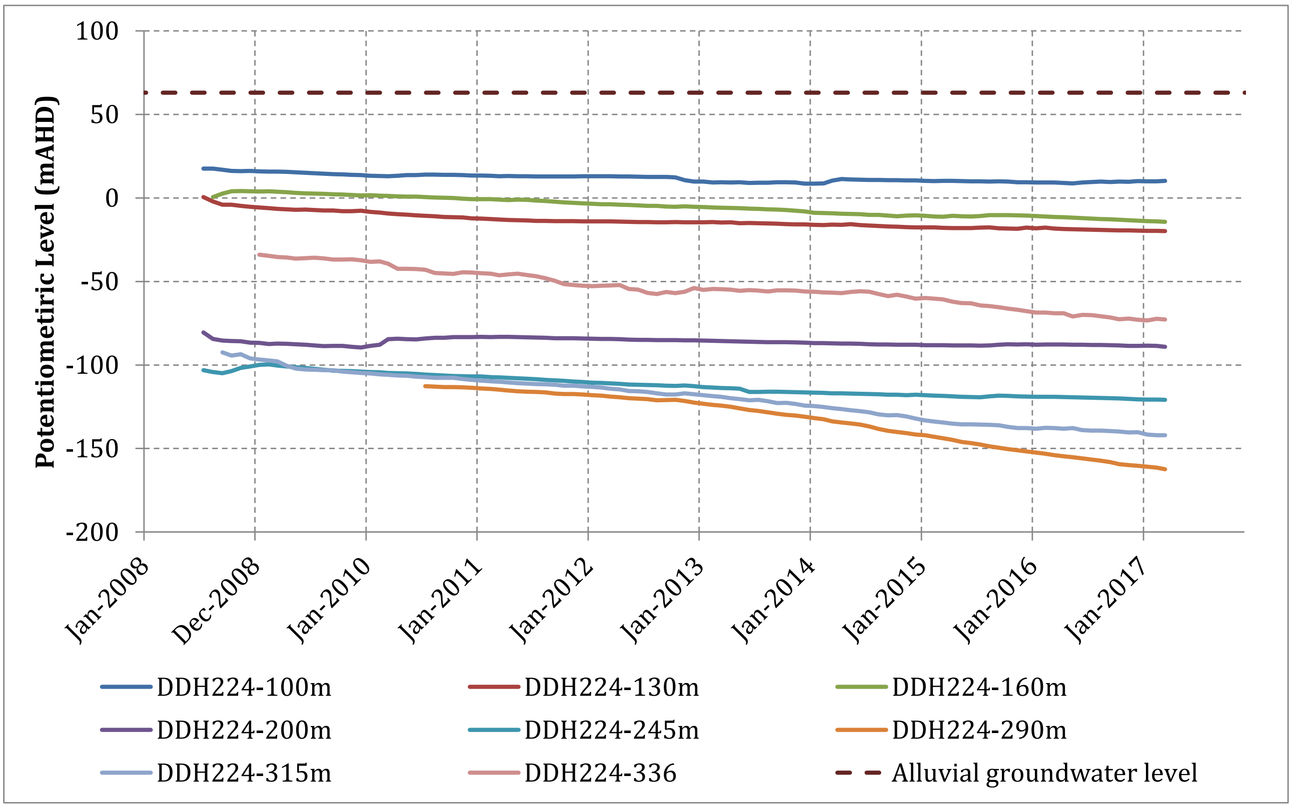


Figure 5-15 Hydrograph – VWP DDH224

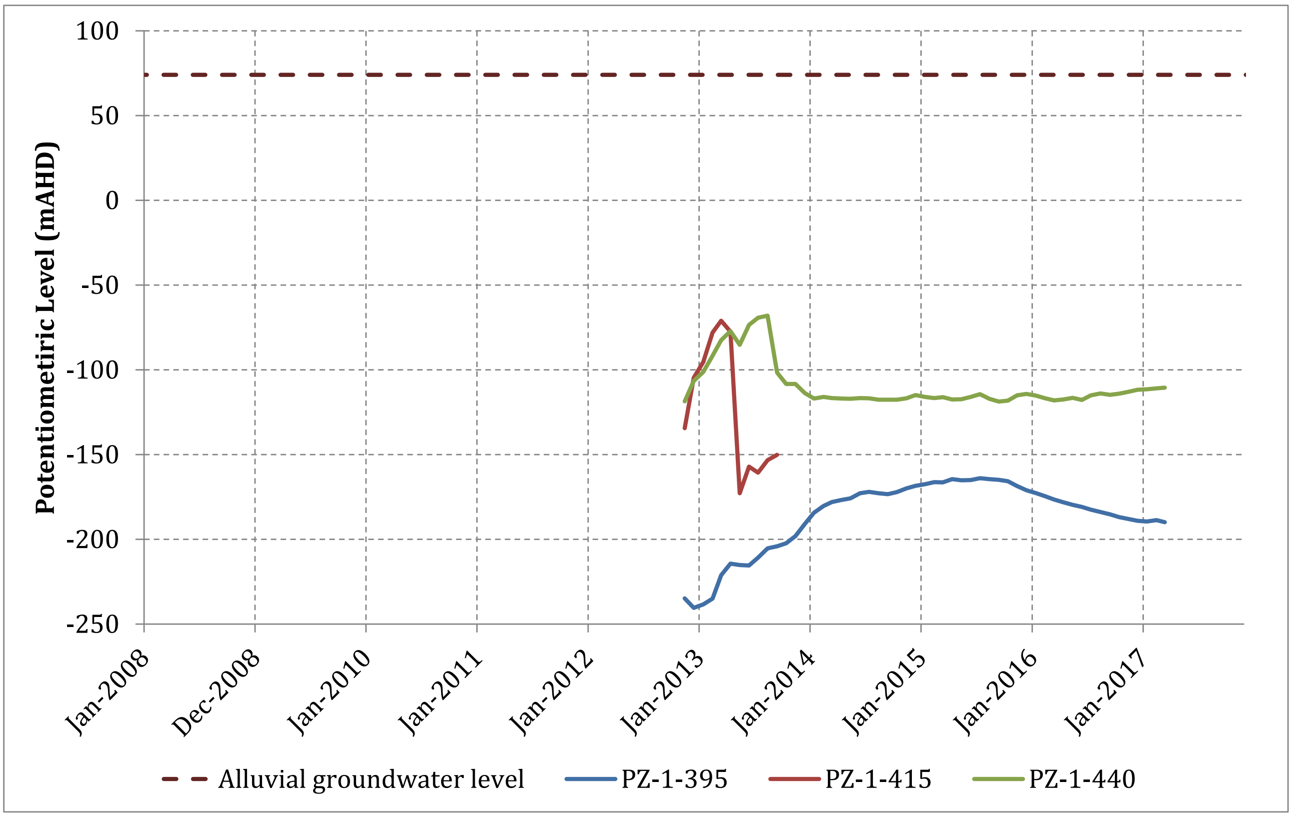


Figure 5-16 Hydrograph – PZ-1

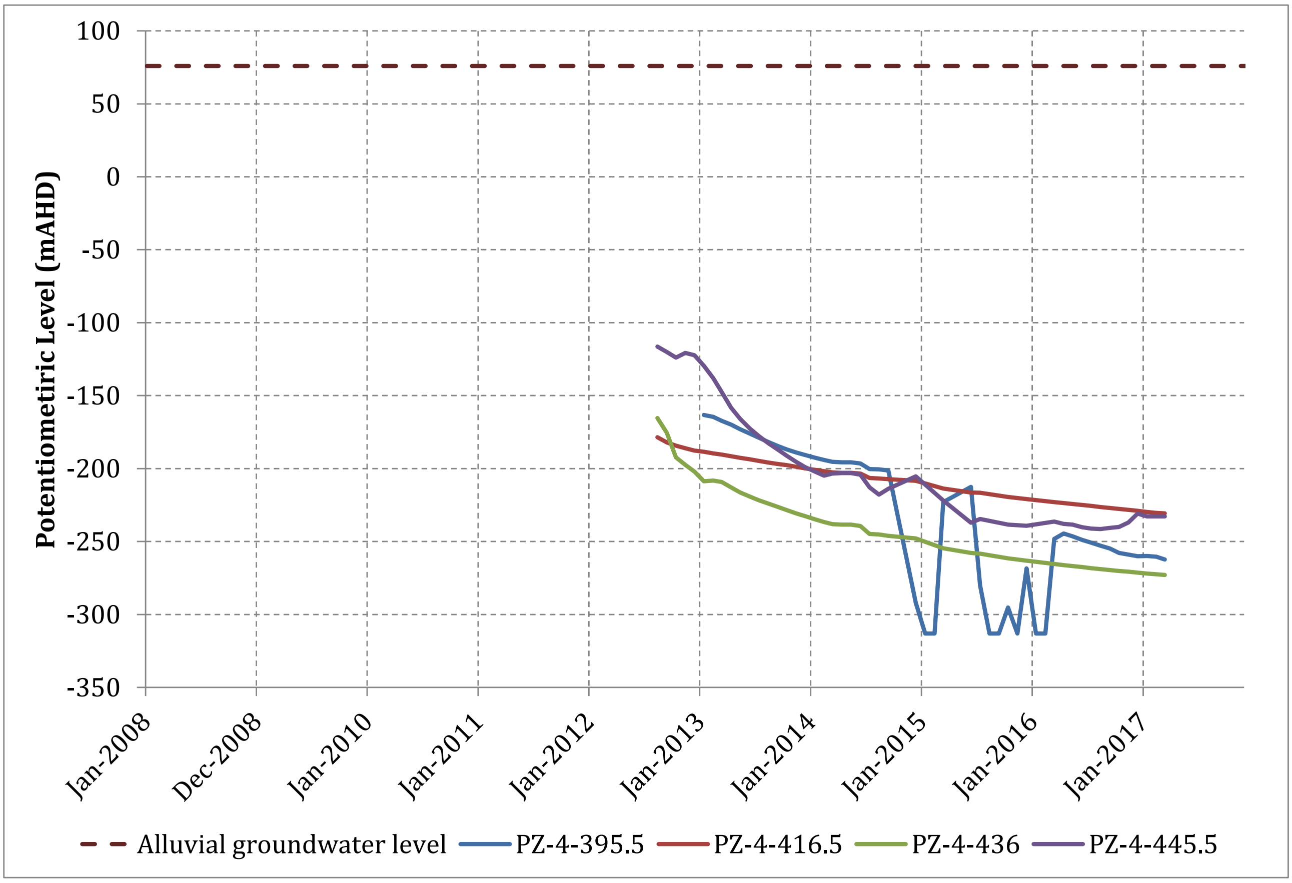


Figure 5-17 Hydrograph – PZ-4

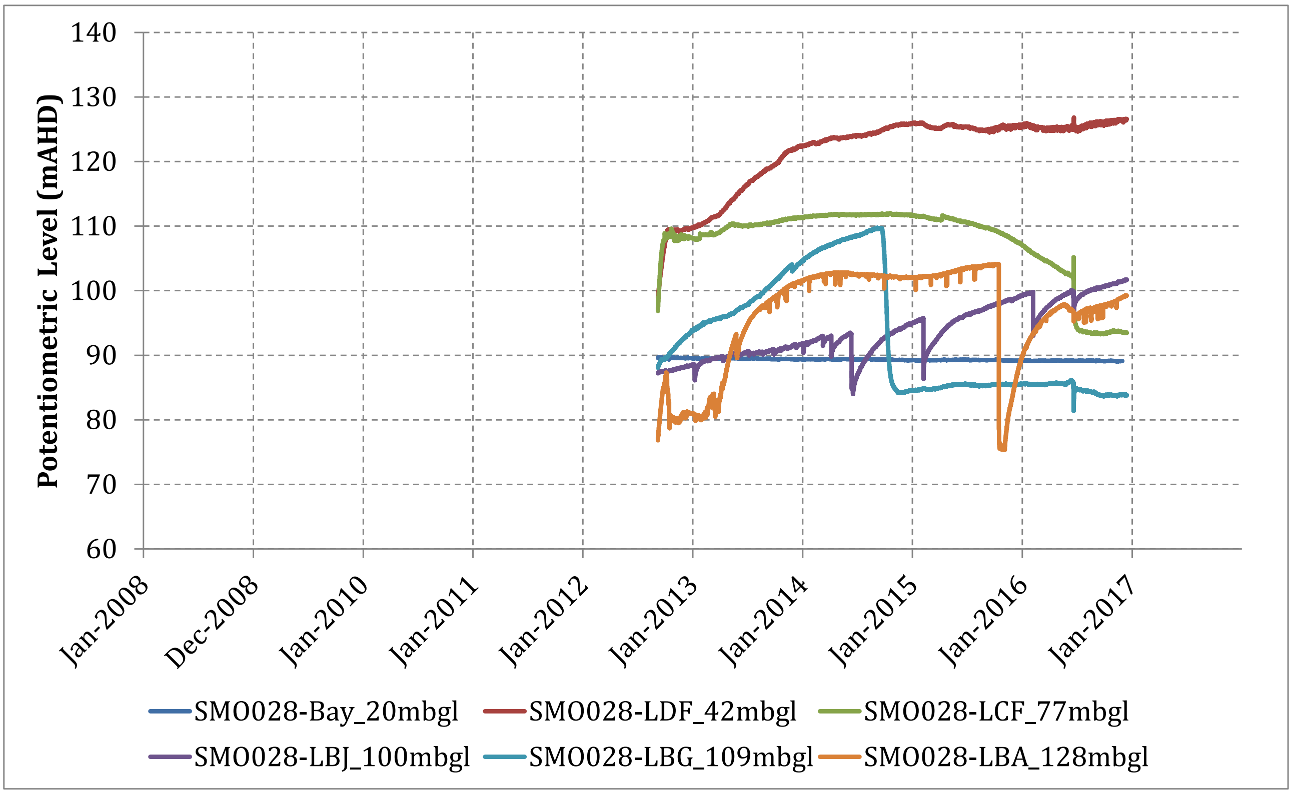


Figure 5-18 Hydrograph – SMO028

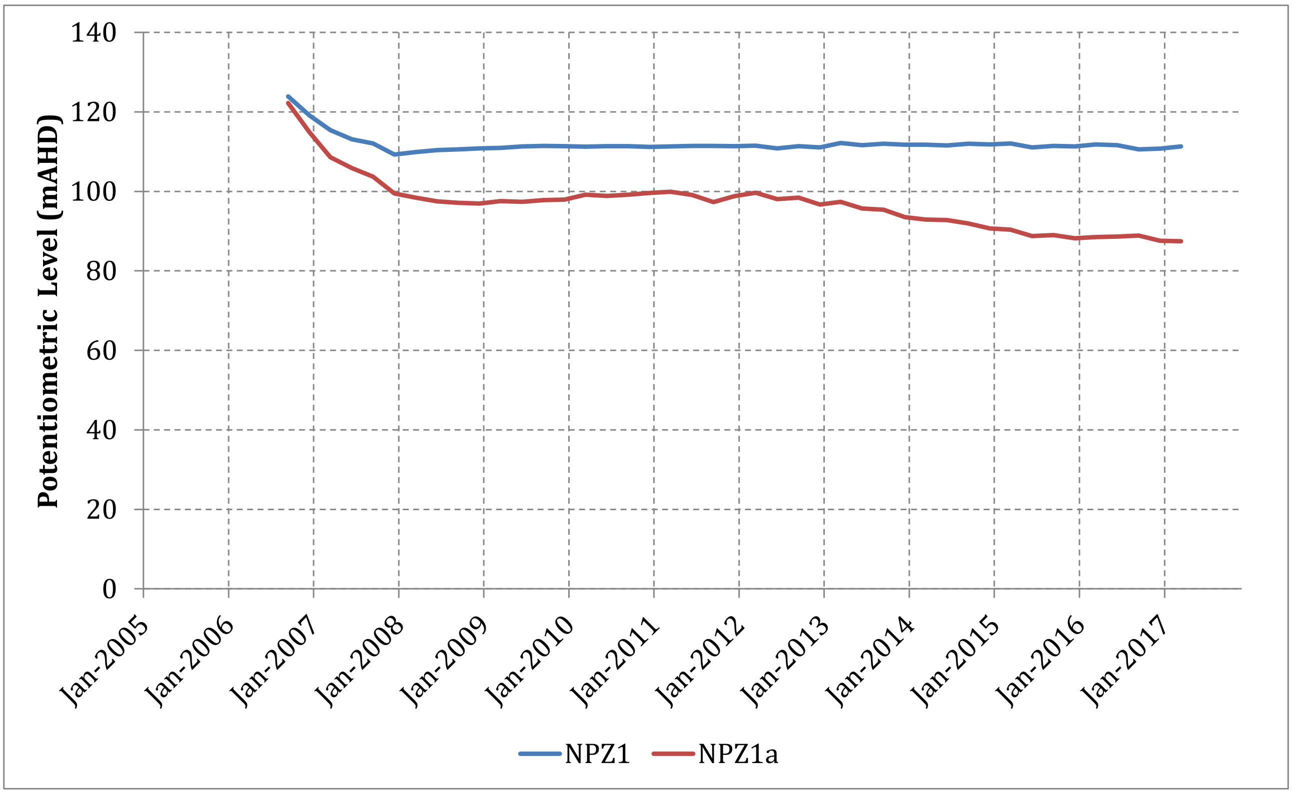


Figure 5-19 Hydrograph – NPZ1

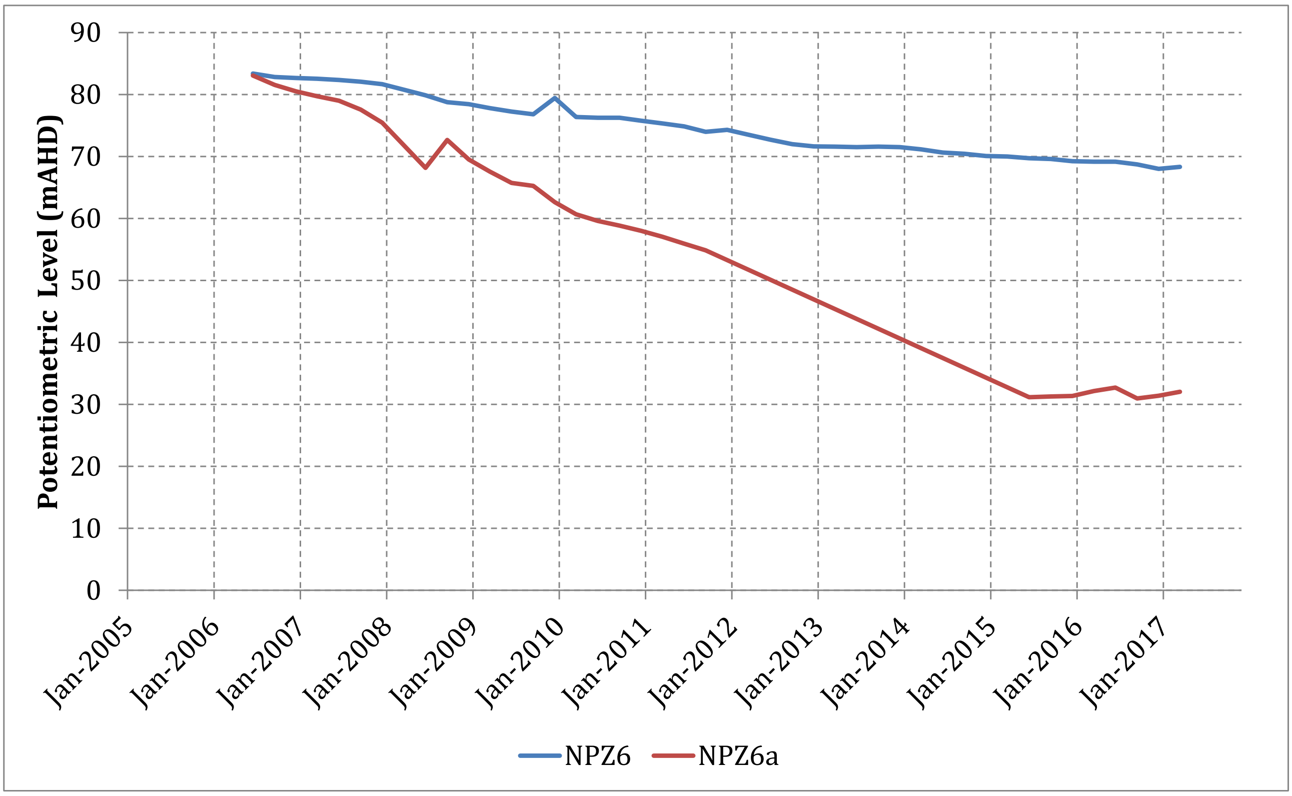


Figure 5-20 Hydrograph – NPZ6

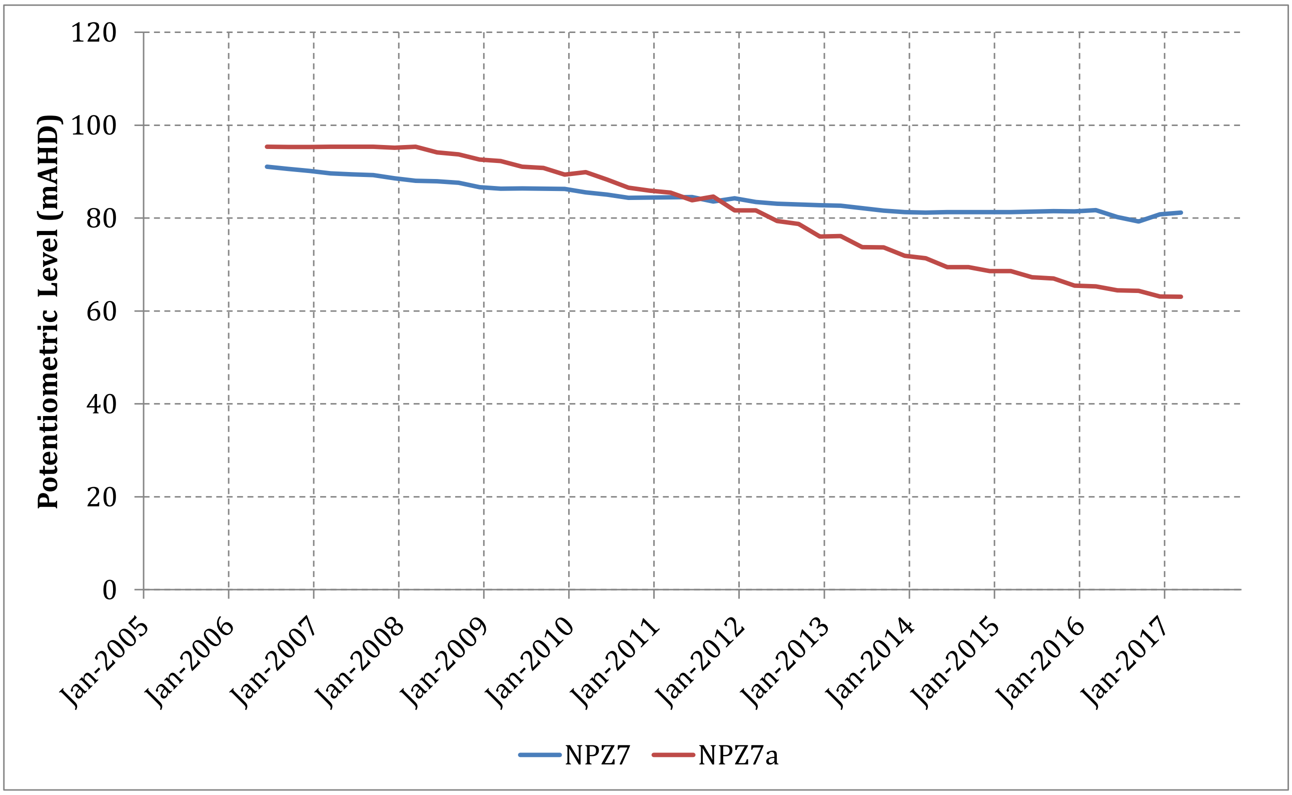


Figure 5-21 Hydrograph – NPZ7

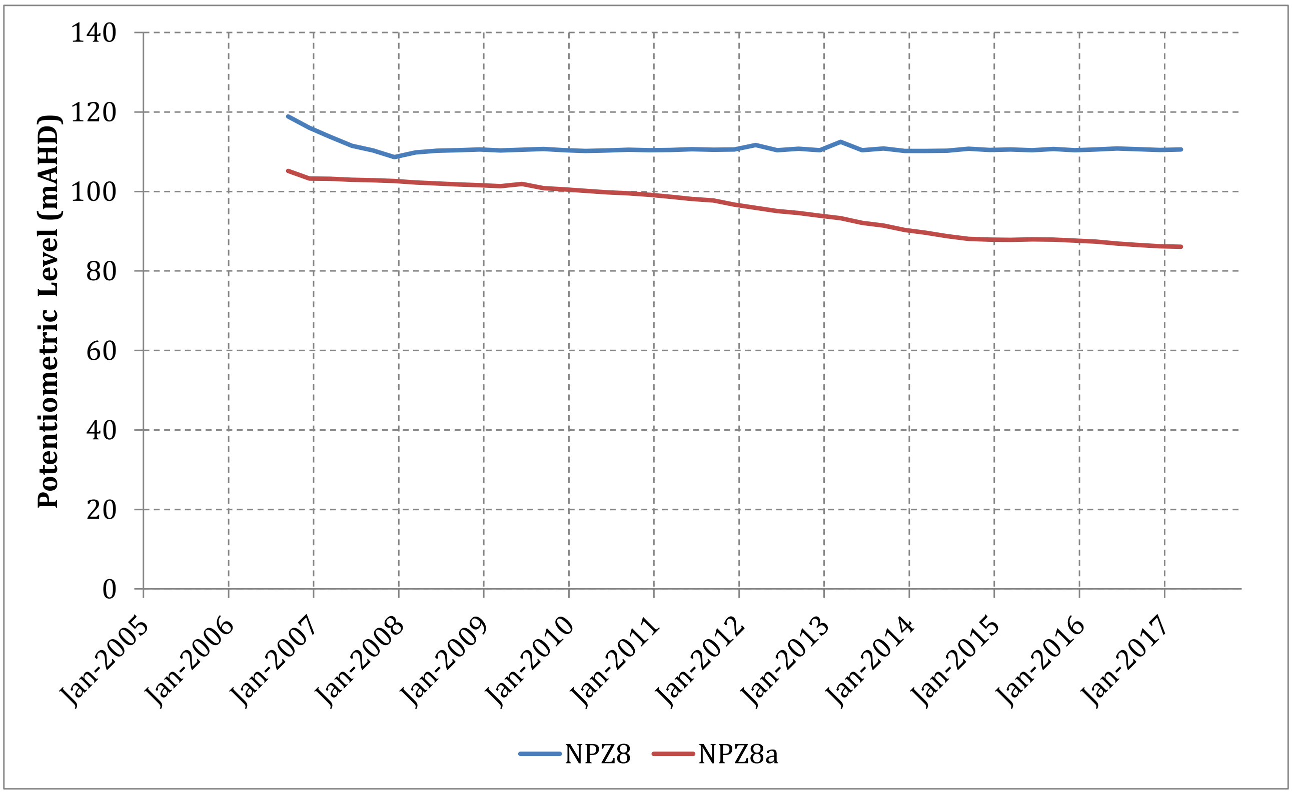


Figure 5-22 Hydrograph – NPZ8

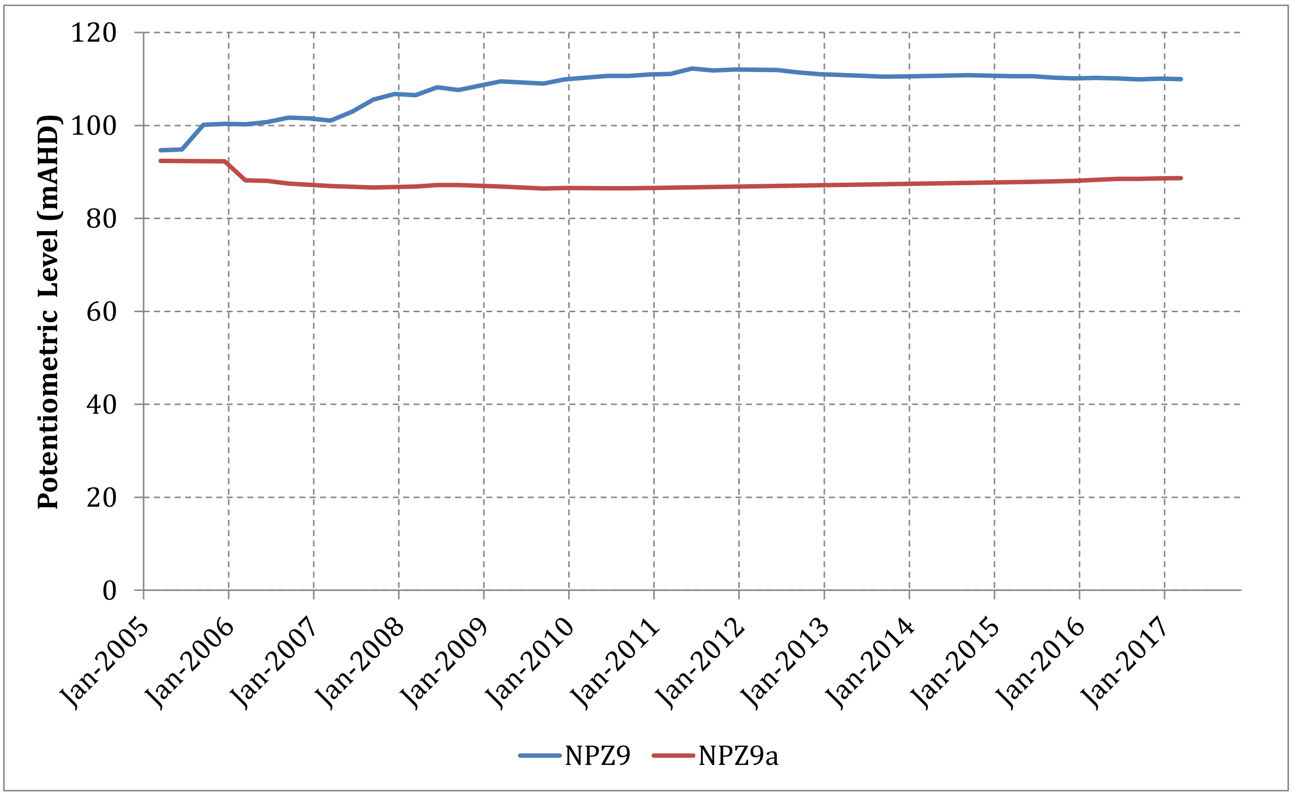


Figure 5-23 Hydrograph – NPZ9

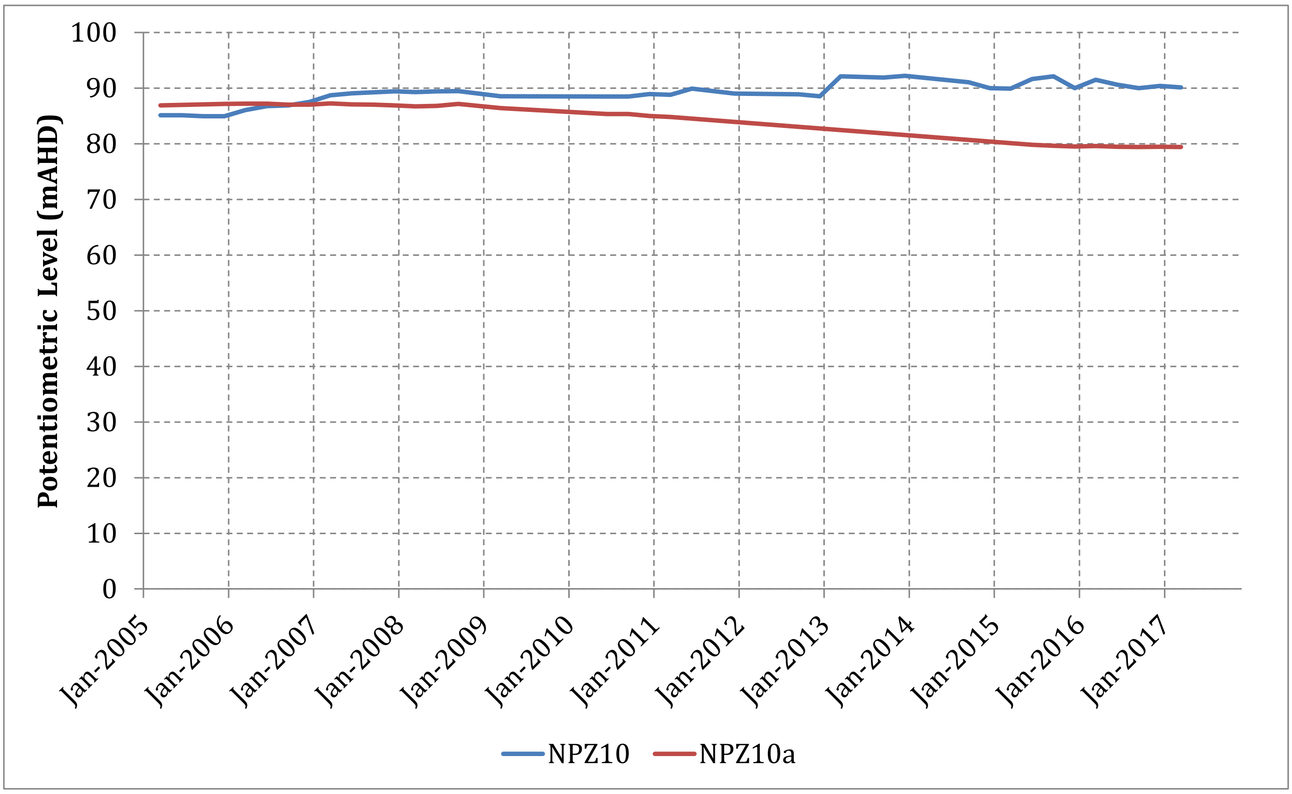
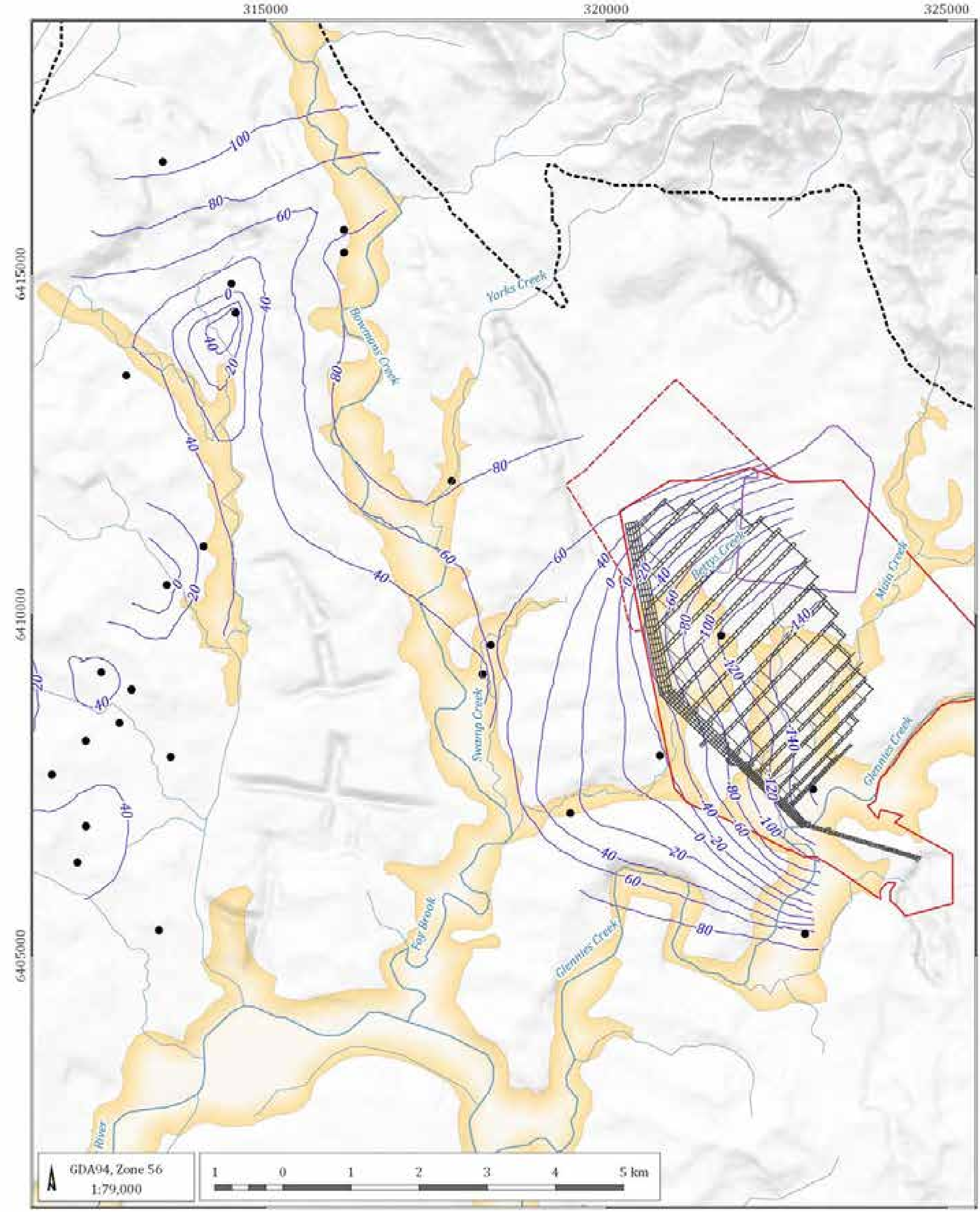


Figure 5-24 Hydrograph – NPZ10



LEGEND

- Model extent
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Alluvium extent
- Middle Liddell Groundwater level (mAHD)
- Major drainage
- Minor drainage
- Observation bore

Integra EPBC (G1285A)

Interpolated groundwater levels in Middle Liddell Seam (2017)

AGE

DATE 22/11/2017

FIGURE No: 5-25

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/G1285A.Integra/3_GIS/Workspaces/002_IBA/05.25_G1285A_Interpolated groundwater levels in Middle Liddell Seam.qgs

5.2.3 Hydraulic parameters

The hydraulic properties that govern groundwater storage and flow across the region vary considerably between the unconsolidated Quaternary alluvial systems and the confined hard rock Permian aquifer system associated with the coal measures.

Measurements of hydraulic conductivity within the Permian strata are available for many of the coal mines within the Hunter Valley region and in the wider Sydney Basin. Hydraulic conductivity has been measured using a variety of methods, including packer testing, lab core permeability testing, air lift pumping tests and slug tests. Mackie (2009) compiled much of this data in a single report, and this data has been supplemented with more recent data collected within the Modification area and from public domain reports for surrounding mining. The most relevant testing available for the Integra mine is an extensive packer testing program within borehole DDH223, that comprised a total of 79 separate tests from near surface to around 480 m deep (SCT, 2008).

Figure 5-26 and Figure 5-27 show the available hydraulic conductivity measurements for Permian coals and Permian interburden. The graphs illustrate the general decline in hydraulic conductivity with depth below the surface due to the closure of the fractures with increasing stratigraphic pressure, and possible infilling due to mineral precipitates. The site specific data from DDH223 is shown separately on the graphs.

Figure 5-26 shows the decline in the coal seam hydraulic conductivity with depth and the relationship determined by Mackie (2009) highlighted in light blue. The variability in hydraulic conductivity is also illustrated with up to four orders of magnitude variability. This is illustrated by the testing from DDH223 that recorded coal seam hydraulic conductivity ranging from 9 x 10^{-6} to 1 x 10^{-2} m/day.

Three to four orders of magnitude variability in hydraulic conductivity is also evident in the Permian non-coal interburden strata, as illustrated in the packer testing measurements recorded from DDH223 shown in Figure 5-27. The figure indicates the typically low hydraulic conductivity in the interburden ranging from 9 x 10^{-3} to 1 x 10^{-6} m/day in the measurements from DDH223 at Integra Underground.

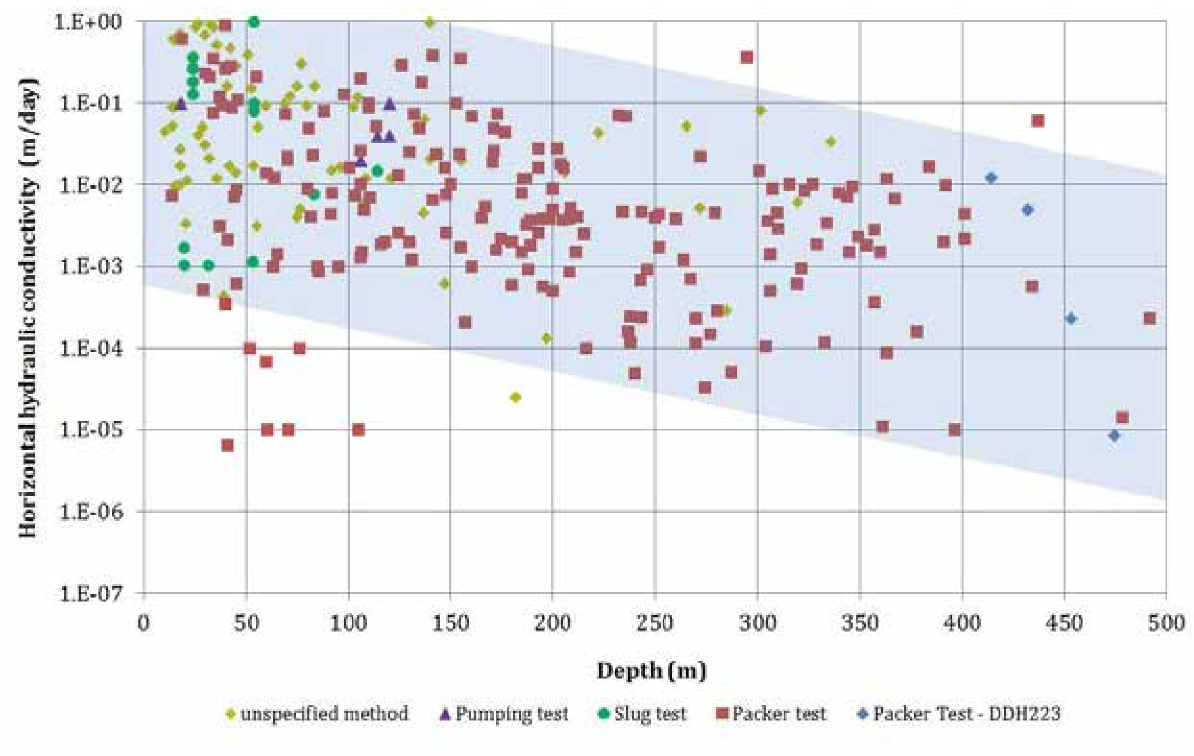


Figure 5-26 Hydraulic conductivity vs depth – Permian coal

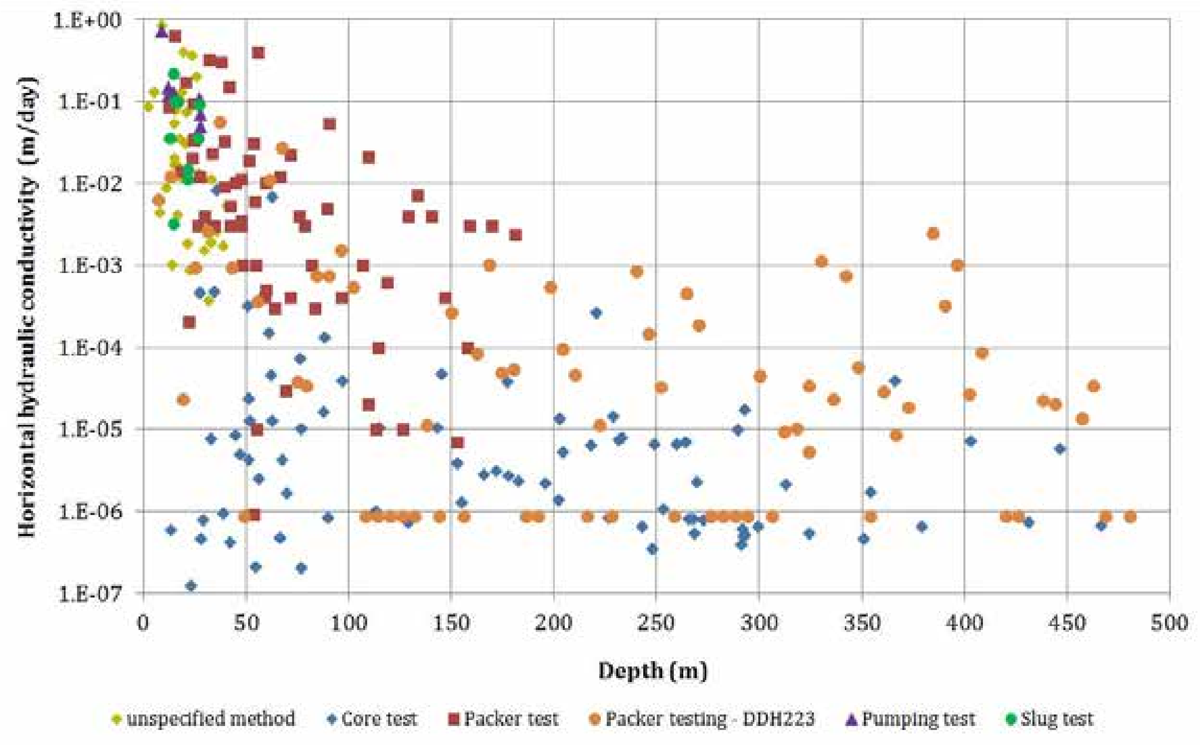


Figure 5-27 Hydraulic conductivity vs. depth – Permian interburden

5.3 Groundwater quality and beneficial use

5.3.1 Salinity

This section describes the water quality and beneficial use of groundwater within the Quaternary alluvium and Permian groundwater systems. Salinity is the key constraint to groundwater use, and can be described by total dissolved solid (TDS) concentrations. TDS concentrations are commonly classified on a scale ranging from fresh to extremely saline. FAO (2013) provide a useful set of categories for assessing salinity based on TDS concentrations as follows:

- Fresh water <500 mg/L
- Brackish (slightly saline) 500 to 1,500 mg/L
- Moderately saline 1,500 to 7,000 mg/L
- Saline 7,000 to 15,000 mg/L
- Highly saline 15,000 to 35,000 mg/L
- Brine >35,000 mg/L

Electrical conductivity data is collected routinely from the monitoring bore network at the site and surrounds. By multiplying it by 0.67, electrical conductivity can be used to estimate TDS concentrations and classify salinity according to the system described above. Figure 5-28 presents electrical conductivity measurements in monitoring bores from key geological units within the Modification area as a violin plot. A violin plot shows the density of data at different values and has been used to illustrate the density of data within each of the salinity categories above. The salinity categories described previously are shown with equivalent electrical conductivity measurements.

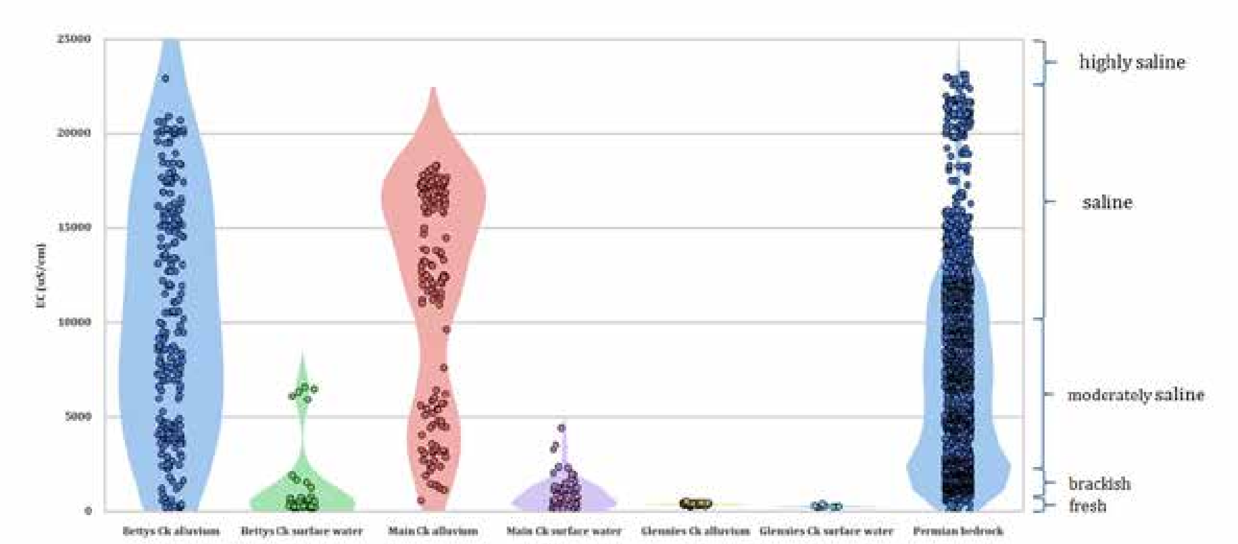


Figure 5-28 Electrical conductivity violin plot of monitoring data

The violin plot shows graphically a number of factors including the generally variable nature of salinity with the groundwater systems and the contrast between the surface water and the groundwater salinity. The plot shows samples collected from the monitoring bores installed within Bettys Creek alluvium and Main Creek alluvium yield samples with a wide range in salinity from fresh to saline. High level mapping by the NSW government has classified the Quaternary alluvium occurring along Main Creek and Bettys Creek as a "highly productive" groundwater source. To meet this criteria the groundwater system must yield groundwater with a TDS concentration less than 1500 mg/L and contain water supply works that can yield water at a rate greater than 5 L/s. The available data, indicate high salinity, low transmissivity, and low saturated thickness, meaning that Main Creek and Bettys Creek alluvium do not meet the NSW government criteria of a highly productive groundwater source.

Figure 5-28 shows the salinity of surface water within Main Creek and Bettys Creek also varies from fresh to brackish, dependent on location and climatic conditions during sample collection.

The available samples from monitoring bores installed within the Glennies Creek alluvium suggest a relatively fresh groundwater system. However, it should be noted other monitoring bores that are now part of the adjacent open cut mine operated by Bloomfield Collieries have recorded fresh to saline water quality and are not recorded in the dataset shown on the violin plot. The bores closer to Glennies Creek are noted as yielding fresh to brackish water, with bores more distant from the creek becoming saline.

The violin plots show data from the Permian strata that are drawn from the Glencore mines within the mid Hunter Valley (Mt Owen, Liddell, Ravensworth, Integra). The figure illustrates the variability in the salinity of groundwater occurring within the Permian strata ranging from fresh to highly saline. The shape of the violin shows the median for the dataset occurs within the brackish to moderately saline range. Of note is the similarity in the salinity range measured within the Permian compared with the alluvial groundwater from Bettys Creek alluvium and Main Creek alluvium. This similarity suggests that inflow of Permian groundwater into the Quaternary alluvium, where groundwater levels promote connectivity, influences the salinity of the Quaternary alluvium, and that recharge from fresher diffuse rainfall is relatively low. Mackie (2009) noted that flow of Permian groundwater into the base of alluvial aquifers is a common process in the Hunter Valley that reduces groundwater pressure in the bedrock in low lying areas, and can increase salinity within alluvial sediments.

The violin plot combines salinity data over different time periods into a single graphic. To examine trends over time Figure 5-29 to Figure 5-31 were prepared, and show the variability in the salinity of samples collected over time from bores within the Main Creek alluvium, Bettys Creek alluvium and the Permian respectively.

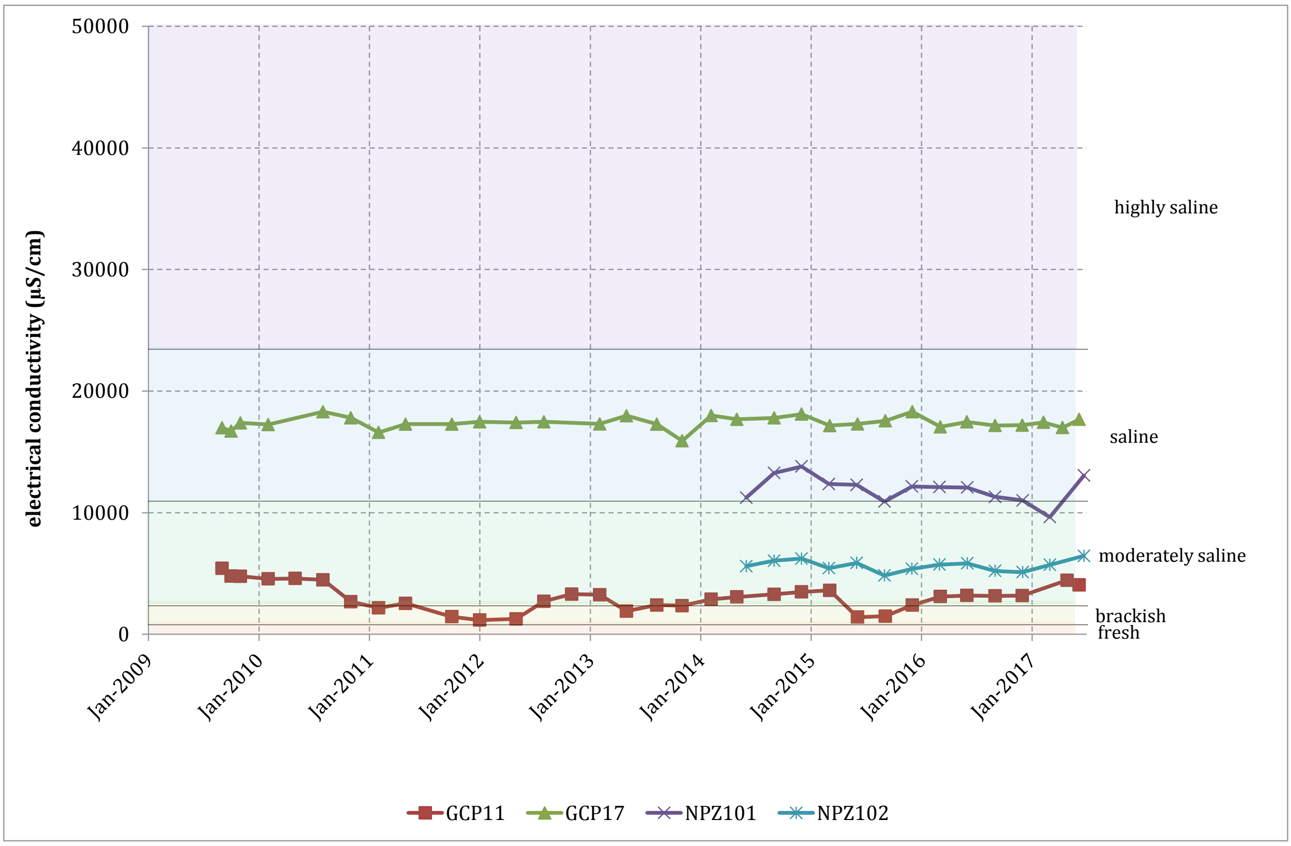


Figure 5-29 Electrical conductivity in Main Creek alluvium

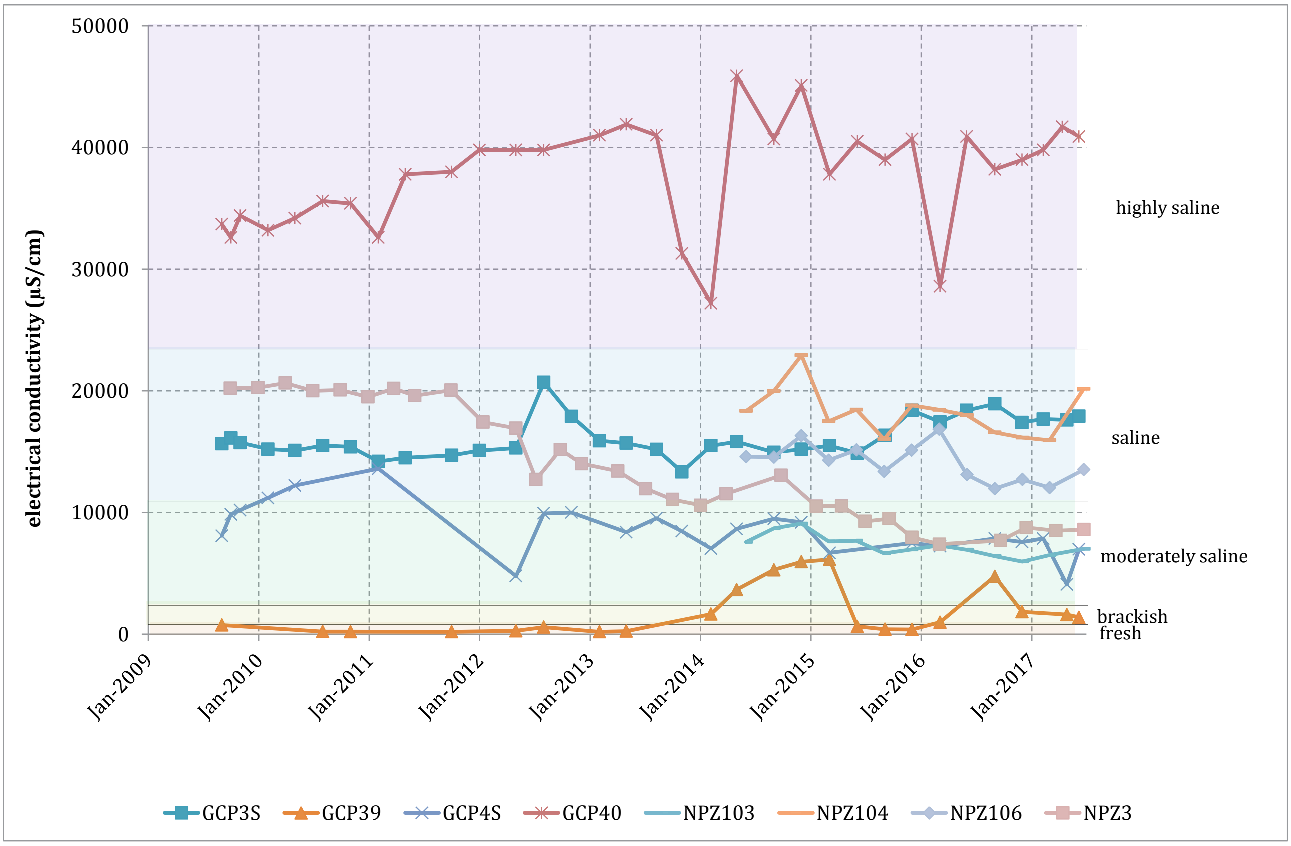


Figure 5-30 Electrical conductivity in Bettys Creek alluvium

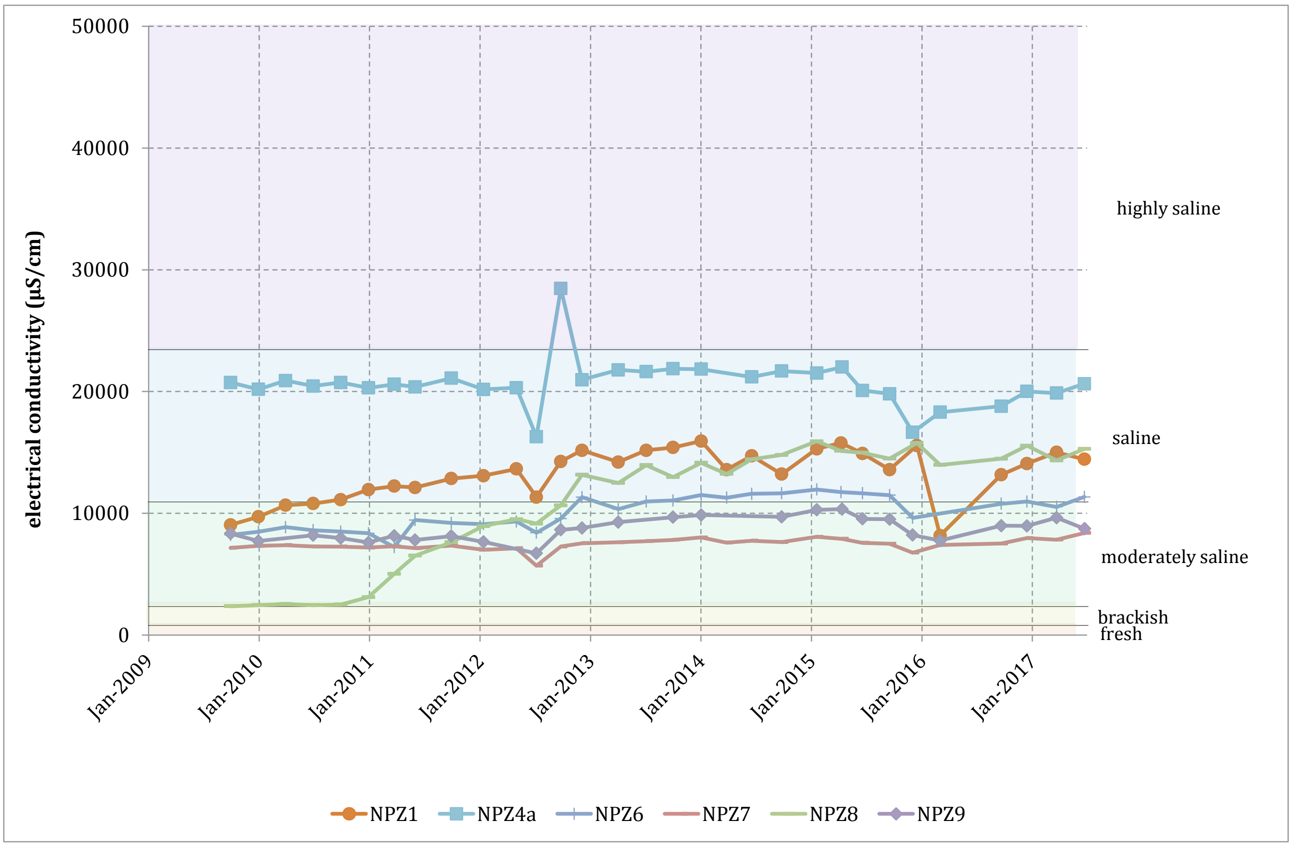


Figure 5-31 Electrical conductivity in selected Permian monitoring bores

The charts indicate a level of variability in the salinity of samples collected from each monitoring bore over time. No uniform cycles are evident between monitoring bores within the Quaternary alluvium, whereas salinity trends appear more correlated between samples collected from the Permian bores. The generally variable nature of salinity within the alluvial groundwater systems suggests relatively slow movement of groundwater, with low permeability areas retarding the flushing of salts from the sediments. The limited transmissivity within Bettys Creek in particular appears to promote this high salinity. For these reasons Bettys Creek and Main Creek alluvium do not form productive aquifers, and have they have not been exploited for any beneficial use. The occurrence of the salinity is considered due to evapo-concentration of rainfall recharge and flow from the underlying Permian into the base of the Quaternary alluvium.

5.3.2 Chemistry and beneficial use

In September 2017 groundwater samples were collected from selected monitoring bores installed within the Quaternary alluvium and Permian groundwater systems for a comprehensive laboratory analysis of water quality indicators. Table 5-3 below presents the results of the analyses of the selected bores and highlights where the results exceed guideline levels for aquatic ecosystems, irrigation, stock and potable consumption.

The table indicates that the groundwater from both the Quaternary alluvium and Permian groundwater systems is not suitable for potable or irrigation uses. The concentration of total metals indicates the groundwater in an undiluted state is not suitable for freshwater aquatic ecosystems. The data does suggest the groundwater from some areas within the Quaternary alluvium and Permian could be used for stock, but this use is variable and generally controlled by the salinity.

The salinity of water is the key restriction on beneficial use, and means the groundwater from much of the region is unsuitable for more sensitive uses such as human consumption and irrigation. The monitoring bore data indicates some regions of Quaternary alluvium and Permian could yield groundwater with salinity levels that would be tolerated by some stock, but these areas are not consistent through the groundwater systems.

Table 5-3 Water quality in selected monitoring bores

Parameter	Units	LOR[#]	ANZECC GUIDELINES				NHMRC																		
Sample Location																									
Bore ID			Fresh Water Aquatic (95th)	Short term irrigation	Long Term irrigation	Stock Water	Drinking Water	NPZ4A	NPZ11A	NPZ101	NPZ102	NPZ103	NPZ104	GCP09	GCP11	GCP17	GCP18	GCP19	GCP21	GCP24	GCP25	GCP27	GCP28	GCP36	GCP40
Date Sampled								1/09/2017	1/09/2017	1/09/2017	1/09/2017	1/09/2017	1/09/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017
Lithology																									
Physical Parameters																									
pH	pH Units	0.1	6.5 - 8.5	6.0 - 8.5	6.0 - 8.5	-	6.5 - 8.5[b]	7.7	8.3	7.8	7.7	7.7	7.9	7.5	7.9	7.6	7.5	7.6	7.8	8.0	7.2	11.5	7.5	8.1	7.6
Electrical conductivity	µS/cm	1	120 - 300	-		-	-	19800	9960	12800	6300	6860	19100	411	3320	16700	590	3340	1360	2990	530	3530	496	990	38000
Sodium Absorption Ration (SAR)	-	0.01		-		-	-	42.3	76.3	27.7	11.1	13.1	34.7	1.33	18.6	23	8.27	7.06	4.12	17.1	1.4	44.7	1.57	4.98	24.2
Total Dissolved Solids (calc)	mg/L	1.00		-		3000 - 13000*	600[b]	12900	6470	8320	4100	4460	12400	267	2160	10800	384	2170	884	1940	344	2290	322	644	24700
Total Hardness as $CaCO_3$	mg/L	1.00		-		-	200[b]	1920	148	1460	1360	1190	2140	96	217	2420	35	604	272	164	105	25	117	135	8650
Hydroxide Alkalinity as $CaCO_3$	mg/L	1.00		-		-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	229.00	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1.00		-		-	-	<1	17.00	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	373.00	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1.00		-		-	-	450	742	831	766	588	783	90	839	932	164	281	252	350	106	<1	105	244	785
Total Alkalinity as $CaCO_3$	mg/L	1.00		-		-	-	450	759	831	766	588	783	90	839	932	164	281	252	350	106	602	105	244	785
Major Ions																									
Sulfate as SO_4 - Turbidimetric	mg/L	1		-		1000 - 2000	500[a] / 250[b]	2520	21	1170	469	88	507	10	89	1250	24	55	40	54	21	59	11	22	1130
Chloride	mg/L	1			40	-	250[b]	5670	3030	3520	1400	1880	6220	57	611	5110	63	889	294	737	82	516	80	181	13100
Fluoride	mg/L	0.1		2.0	1.0	2	1.5[a]	0.4	1.6	0.6	0.8	0.4	0.6	0.2	0.5	0.5	0.4	0.4	0.5	0.6	0.2	0.2	0.1	0.1	0.5
Calcium	mg/L	1		-		1000	-	311	36	103	95	137	166	22	39	238	4	110	61	36	25	10	27	32	991
Magnesium	mg/L	1		-		-	-	278	14	293	272	205	419	10	29	443	6	80	29	18	12	<1	12	17	1640
Sodium	mg/L	1		-		-	180[b]	4260	2130	2440	938	1040	3690	30	628	2600	112	399	156	503	37	514	39	152	5180
Potassium	mg/L	1		-		-	-	18	6	7	2	3	30	<1	2	6	<1	2	1	8	2	87	2	2	11
Total Anions	meq/L	0.01		-		-	-	221	101	140	64.6	66.6	202	3.61	35.8	189	5.55	31.8	14.2	28.9	4.87	27.8	4.58	10.4	409
Total Cations	meq/L	0.01		-		-	-	224	95.8	136	68	69	204	3.22	31.7	162	5.56	29.5	12.2	25.4	3.9	25.1	4.08	9.66	410
Ionic Balance	%	0.01		-		-	-	0.62	2.7	1.7	2.58	1.78	0.59	5.68	6.14	7.76	0.1	3.84	7.27	6.53	11.1	5.16	5.78	3.88	0.16
Nutrients																									
Ammonia as N	mg/L	0.01	0.9	-		-	0.5[b]	4.62	2.18	<0.01	0.02	<0.01	0.03	<0.01	10.1	0.24	<0.01	1.51	<0.01	11.4	0.06	14.4	0.11	0.05	0.22
Nitrite as N	mg/L	0.01		-		30	3[a]	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	0.05	<0.01	9.11	0.04	0.05	<0.01
Nitrate as N	mg/L	0.01	0.7	-		-	50[a]	0.03	<0.01	0.1	0.04	0.11	0.1	0.89	0.04	0.04	3.62	1.6	0.17	<0.01	0.31	25.3	1.65	1.42	<0.01
Nitrite + Nitrate as N	mg/L	0.01		-		400	-	0.03	0.03	0.1	0.04	0.11	0.1	0.89	0.04	0.04	3.62	1.67	0.17	0.04	0.31	34.4	1.69	1.47	<0.01
Total Kjeldahl Nitrogen as N	mg/L	0.1		-		-	-	5.4	2.5	0.3	0.2	0.9	0.6	0.3	10.6	0.3	0.4	1.8	0.4	11.9	2.3	79	4.1	1.4	<0.5
Total Nitrogen as N	mg/L	0.1		25 - 125	5	-	-	5.4	2.5	0.4	0.2	1	0.7	1.2	10.6	0.3	4	3.5	0.6	11.9	2.6	113	5.8	2.9	<0.5
Total Phosphorus as P	mg/L	0.01		0.8 - 12	0.05	-	-	0.08	0.06	0.03	0.16	0.39	0.05	0.5	0.75	0.03	0.36	0.36	0.05	0.77	1.45	11	0.41	0.14	<0.05
Reactive Phosphorus as P	mg/L	0.01				-	-	0.07	0.03	0.03	0.06	0.01	<0.01	<0.01	0.64	<0.01	0.34	0.24	0.04	0.66	0.01	1.73	0.05	0.04	<0.01
Total Metals																									
Aluminium	mg/L	0.01	0.055	5		5	0.2[b+]	0.48	1.09	0.38	5.45	4.23	1.66	1.31	1.62	3.29	1.22	0.42	0.33	<0.01	135	3.01	2.03	0.25	2.1
Arsenic	mg/L	0.001	As (III) 0.024 As (V) 0.013	2.0	0.1	0.5	0.01[a]	<0.001	0.002	0.001	0.005	0.002	0.002	0.003	0.002	0.013	0.002	<0.001	<0.001	<0.001	0.032	0.004	0.001	0.002	0.01
Beryllium	mg/L	0.001		0.5	0.1	-	0.06[a]	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.007	<0.001	<0.001	<0.001	<0.001
Barium	mg/L	0.001		-		-	2[a]	0.066	2.9	0.04	0.087	0.518	0.102	0.035	0.098	0.091	0.009	0.082	0.044	0.169	0.444	0.562	0.068	0.133	0.241
Cadmium	mg/L	0.0001	0.0002	0.05	0.01	0.01	0.002[a]	0.0002	<0.0001	0.0002	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	0.0005	0.0019	0.0002	0.0002	<0.0001
Chromium	mg/L	0.001	CrIII – ID Cr(VI) 0.001	1.0	0.1	1.0	0.05[a]	0.002	0.002	0.004	0.009	0.008	0.007	0.001	0.001	0.006	<0.001	<0.001	<0.001	<0.001	0.131	0.01	0.004	0.001	0.038
Cobalt	mg/L	0.001		0.10	0.05	1.0	-	<0.001	0.002	<0.001	0.008	0.008	0.004	<0.001	0.001	0.016	<0.001	0.002	<0.001	<0.001	0.033	0.004	0.003	<0.001	0.024
Copper	mg/L	0.001	0.0014	5.0	0.2	0.5 - 5^	2[a] / 1[b]	0.005	0.014	0.002	0.006	0.01	0.01	0.047	0.005	0.092	0.013	0.007	0.052	<0.001	0.383	0.387	0.035	0.029	9.96
Lead	mg/L	0.001	0.0034	5.0	2.0	0.1	0.01[a]	0.007	0.011	<0.001	0.004	0.006	0.004	0.002	0.003	0.026	<0.001	0.002	<0.001	<0.001	0.197	0.07	0.021	0.012	0.011
Manganese	mg/L	0.001	1.9	10.0	0.2	-	0.5[a] / 0.1[b]	0.197	0.063	0.044	0.448	0.637	0.098	0.174	0.478	2.91	0.018	0.21	0.082	0.171	0.812	0.278	2.74	0.199	2.81
Mercury	mg/L	0.0001	0.0006	0.002	0.002	0.002		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0005	<0.0001	<0.0001	<0.0001	<0.0001
Molybdenum	mg/L	0.001	-	0.05	0.01	0.15	0.05[a]	0.01	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	<0.001	<0.001	<0.001	0.008	<0.001	0.054	0.001	<0.001	0.002
Nickel	mg/L	0.001	0.011	2.0	0.2	1	0.02[a]	0.007	0.007	0.005	0.009	0.008	0.008	0.002	0.002	0.011	0.001	0.004	0.001	0.002	0.068	0.03	0.014	0.109	0.235
Selenium	mg/L	0.01	Total – 0.011 SelIV - ID	0.05	0.02	0.02	0.01[a]	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
Strontium	mg/L	0.001			-	-	-	22.9	8.85	8.3	4.76	6	11.7	0.25	2.34	20	0.169	2.89	0.953	3.96	1.27	2.8	0.395	0.496	37
Vanadium	mg/L	0.01	-	0.5	0.1	-	-	<0.01	<0.01	<0.01	0.02	0.02	<0.01	0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.3	<0.01	<0.01	<0.01	<0.01
Zinc	mg/L	0.005	0.008	2.0	2.0	20	3[b]	0.24	0.08	0.014	0.021	0.035	0.035	0.017	0.013	0.087	0.006	0.819	0.021	<0.005	0.56	11.1	0.537	0.636	0.123
Boron	mg/L	0.05	0.37	Refer to guideline	0.5	5.0	4[a]	0.7	0.25	0.06	0.17	0.09	0.08	<0.05	0.06	0.08	<0.05	<0.05	0.05	0.13	0.06	<0.05	<0.05	<0.05	0.07
Iron	mg/L	0.05	-	10.0	0.2	-	0.3[b]	1.08	2.24	0.65	6.58	5.59	2.36	7.9	2.83	16.3	1.22	0.73	0.6	0.87	167	6.68	5.35	1.49	12.9

#	Limit of Reporting
a	NHMRC Health Guidelines for Drinking Water (2015)
b	NHMRC Aesthetic Guidelines for Drinking Water (2015)
m TOC	metres below top of casing
1	Exceeds the ANZECC (2000) Long Term Irrigation Water Guidelines
2	Exceeds the ANZECC (2000) Stock Water Guidelines
3	Exceeds the NHMRC (2011) Drinking Water Guidelines
*	Maximum concentration at which good condition might be expected, with 13,000 mg/L for sheep, 5,000 mg/L for beef cattle, 4,000 mg/L for dairy cattle, 6,000 mg/L for horses and 3,000 mg/L for pigs and poultry.
^	Maximum concentrations of copper for sheep is 0.5 mg/L, 1 mg/L for cattle and 5 mg/L for pigs & poultry.
+	NHMRC acid-soluable aluminium concentrations (2015)
-	No value.

5.4 Groundwater use

5.4.1 Private water users

A search of the NSW state government groundwater bore database was conducted to identify the locations of any private water supply bores in proximity to the Modification. Figure 5-32 shows the locations of bores within the database and land parcels that are privately owned. The figure shows there are three bores from the database that are located on private properties. The remainder of the bores are located on land owned by mining companies and are used for monitoring the impact of mining, or are former water bores or wells no longer in use. Table 5-4 summarises the details within the NSW government database for the three registered bores located on private land.

Table 5-4 Registered bores on private lands

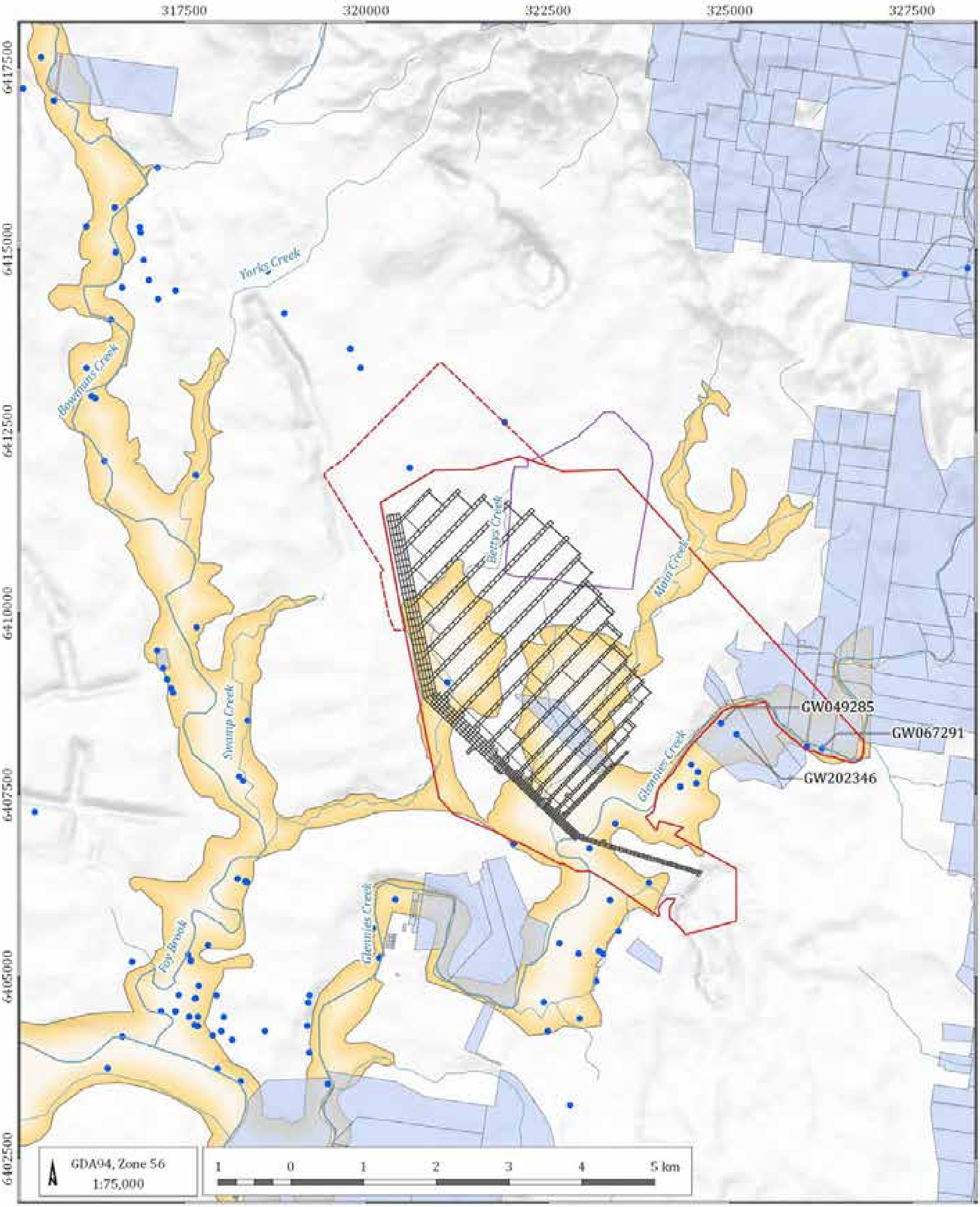
Registered number	Authorised purpose	Date	Depth (m)	Casing type	Casing dia (mm)	Standing water level (m)	Yield (L/sec)
GW067291	stock, domestic, farming	1981	10.1	concrete	1200	2	1
GW049285	farming	1979	-	-	-	-	-
GW202346	monitoring bore	2007		uPVC	50	8.45	1

The table indicates two of the bores are authorised for farming purposes (GW067291 and GW049285), with the third bore, GW202346 recorded as a monitoring bore. The depth of bore GW067291 is recorded in the database as 90 m deep, however this is presumably an error as the bore is reportedly cased with a 1.2 m dia concrete pipe, and has been measured at 10.1m deep (Geoterra 2009).

Geoterra (2009) noted whilst preparing the groundwater assessment for underground mining within the Middle Liddell seam that whilst there are private bores and wells registered within proximity to the underground mine, none are active or present apart from GW067291, which is located on the north bank of Glennies Creek near the Middle Falbrook Road Bridge.

No detail on the construction of bore GW049285 is recorded within the database other than it was constructed as a well. There is a note in the database about a dairy operation, which was presumably the intended purpose at the time, and would explain why the bore is no longer in use as dairying is no longer active in the area.

Given the private bores described were designed as wells they are expected to only extract shallow groundwater from the Quaternary alluvium along Glennies Creek. There are no records of any private water bores extracting groundwater from the Permian strata, or from Bettys Creek and Main Creek alluvium, presumably because of high salinity and low yield making the water unsuitable.



LEGEND

- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Privately owned land
- Quaternary alluvium
- Major drainage
- Minor drainage
- Registered bore

Integra (G1285A)

Groundwater use within the vicinity of the Modification

AGE

DATE 16/11/2017

FIGURE No: **5-32**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.; Glen R.A. and Beckett J., 1993, Hunter Coalfield Regional Geology 1:100 000, 2nd edition, Geological Survey of New South Wales, Sydney.;
G:/Projects/G1285A.Integra/3_GIS/Workspaces/002_EIA/05.32_G1285A_Groundwater use.qgs

5.4.2 Groundwater dependent ecosystems

Macfarlane et al (2016) provides a register of water-dependent assets in the Hunter subregion prepared as a component of the Federal Governments Bioregional Assessments Process. Water dependent assets are classified into three subgroups and seven classes. All landscape features such as aquifers, rivers, lagoons, lakes, springs and wetlands, and the habitats dependent on them, are inherently water dependent; hence, all assets in the subgroups 'Surface water feature' and 'Groundwater feature (subsurface)' are included in the water-dependent asset register. Figures within the register indicate the Hunter River alluvium in proximity to the Modification is an alluvial aquifer asset, but the alluvial groundwater systems along Glennies Creek, Main Creek and Bettys Creek are not noted as alluvial aquifer assets.

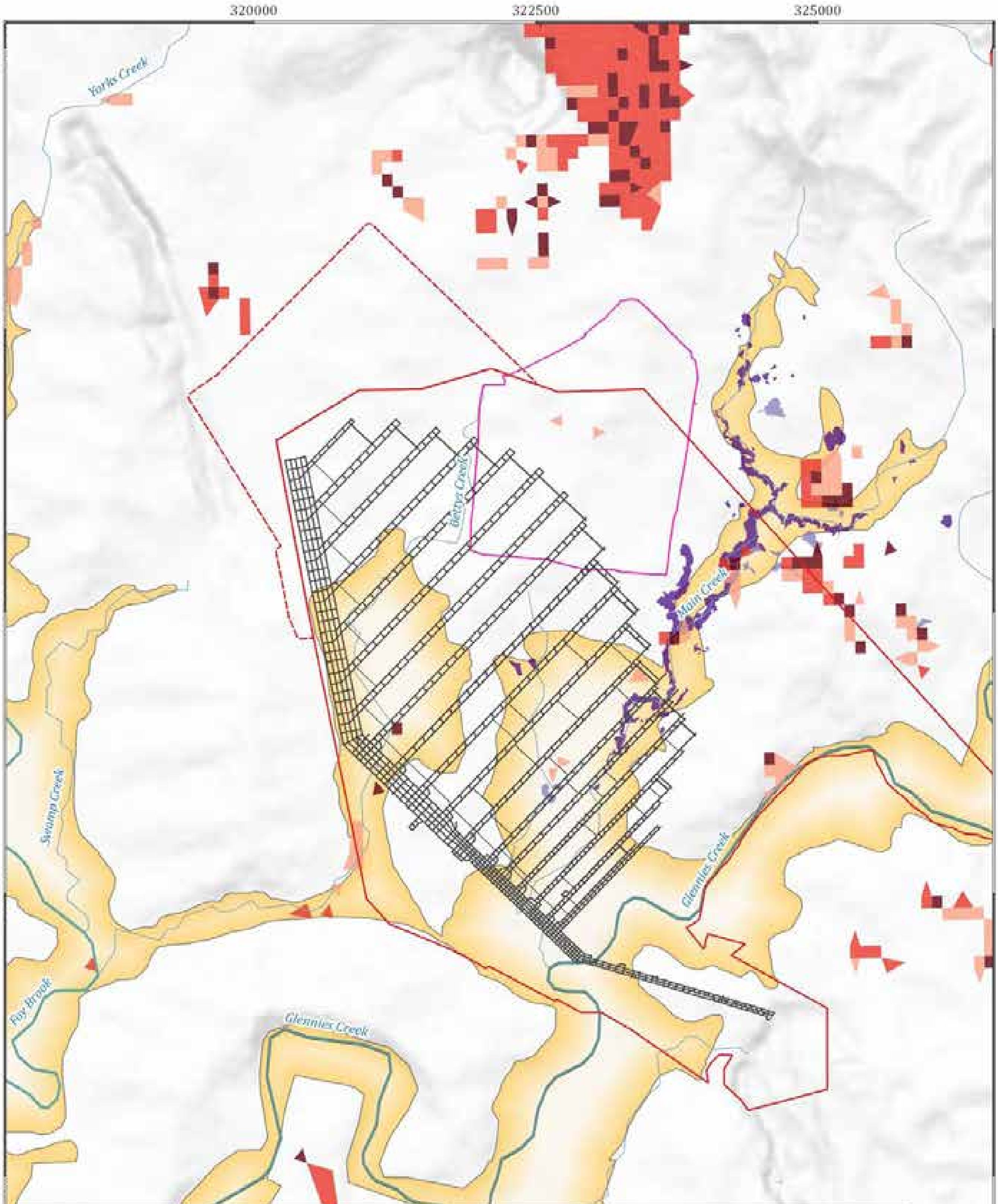
The 'Vegetation' subgroup includes groundwater dependent ecosystems (GDEs) derived from the National Atlas of Groundwater Dependent Ecosystems. The register indicates riverine forests on flood plains associated with Glennies Creek and Bowmans Creek form GDEs.

Cumberland Ecology (2017) assessed the ecological communities and potential impacts associated with the Modification. The ecology study for the Modification identified the Central Hunter Swamp Oak Forest and the Hunter Valley River Oak Forest as vegetation communities that would likely access shallow aquifers '*where there is interaction with the alluvial aquifer and when flows are provided by baseflows, and when the creek is dry'*. The vegetation communities were therefore classed as a 'Terrestrial Vegetation' 'GDEs. Figure 5-33 shows the locations of these vegetation communities that occurs in a thin riparian zone along Main Creek.

Umwelt (2015) as part of a report responding to submissions on the Mount Owen Continuation Project noted the Hunter Swamp Oak Forest and a small area of Hunter Lowland Red Gum Forest community that were mapped as occurring on Main Creek within an area where drawdown was predicted and may possibly be groundwater dependent due to reliance in some circumstances on groundwater in periods of drought. However it was also noted these vegetation communities can also exist further upstream and in other creek systems where there is unlikely to be any significant alluvial groundwater present. This was particularly the case with the Hunter Lowland Red Gum Forest which is mapped as extending well into areas where there is little or no alluvium, and vegetation in these areas would be reliant on soil moisture and rainfall.

Umwelt (2015) describe a literature review of the dependence of the Central Hunter Swamp Oak Forest on groundwater. The review focussed on Casuarina glauca which is the only species in the Central Hunter Swamp Oak Forest, and indicated the species has a root system that consists of a dense network of fibres making up the main root ball with numerous lateral and sinker roots extending from it. The literature review indicated cases where C. glauca can have a strong reliance on groundwater, or little reliance. Most studies of the species focussed on C. glauca growing in swamp like conditions or areas with elevated water tables (0 to 3 metres below ground level) where there is a clear connectivity between the root system and alluvial groundwater. These studies have logically identified C. glauca as having a typically shallow root system to less than 3 metres in depth. However, in the Hunter Valley it was noted the species is considered an opportunistic coloniser that readily colonises areas with little or no groundwater present; for example, the species has been widely observed growing on roadsides where it would be reliant on runoff water and on hill slopes where it would be reliant on runoff and soil moisture.

Based on the literature review it was concluded due to the current depth of the water table along Main Creek and Bettys Creek that the species, which is typically shallow rooted, will have little direct connectivity with the groundwater Quaternary alluvium and is more likely to be reliant on soil moisture. It was also noted that there is the possibility of some sinker roots in larger trees extending to the alluvial groundwater particularly during wetter periods when the water table in the Quaternary alluvium is higher.



LEGEND

- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Alluvium extent
- Major drainage
- Minor drainage

Vegetation (Cumberland Ecology, 2017)

- Central Hunter Swamp Oak Forest
- Hunter Lowland Red Gum Forest

Potential GDE - Subsurface (GDE Atlas)

- High potential for GW interaction
- Moderate potential for GW interaction
- Low potential for GW interaction

Potential GDE - Surface (GDE Atlas)

- High potential for GW interaction
- Moderate potential for GW interaction
- Low potential for GW interaction

Integra (G1285A)

Potential groundwater dependent ecosystems

AGE

DATE 16/11/2017

FIGURE No: **5-33**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
Glen R.A. and Beckett J., 1993, Hunter Coalfield Regional Geology 1:100 000, 2nd edition. Geological Survey of New South Wales, Sydney;
GDE Atlas © State of NSW (DPI Water);
G:/Projects/G1285A.Integra/3_GIS/Workspaces/002_EIA/05.33_G1285A_Groundwater dependent ecosystems.qgs

Eco Logical (2017) investigated the potential for Stygofauna to occur in the area as part of the Mount Owen project's plans to extend North Pit. Samples were collected from two bores in Permian coal seams, two in shallow rock and twelve 12 in Quaternary alluvial aquifers of Swamp Creek, Main Creek, Betty's Creek and Yorks Creek.

Five of the taxa collected were classified as stygofauna. These were Notobathynella sp, Cyclopoida, Ostracoda (all crustaceans), Hydrobiidae sp. (a snail), Carabhydrus stephanieae (a subterranean diving beetle). These taxa were collected from the alluvial aquifers of Yorks Creek, Swamp Creek, and Station Creek/Glennies Creek. No stygofauna were collected from the shallow hard rock aquifers, coal seam aquifers, nor the Betty's Creek and Main Creek alluvial aquifers.

5.5 Conceptual model

This section describes the processes that control and influence the storage and movement of groundwater in the hydrogeological systems occurring in vicinity to the Modification and the broader region.

Groundwater recharge to the Permian strata occurs via rainfall to the ground surface infiltrating into the formations through the soil cover and weathered profile. The coal seams also occur as subcrops in localised zones underlying alluvial sediments, and localised recharge may occur where gradients promote this flow. The alluvial sediments are also recharged by seepage through the bed of creeks when they are flowing, where the stream bed sediments and the underlying groundwater levels allow this to occur.

The alluvial sediments occurring in the flood plain along Main Creek and Bettys Creek are relatively thin, and are commonly clay bound, limiting the transmissivity of these formations. The concentration of salts within the Main Creek and Bettys Creek alluvium indicates limited recharge and flushing of the system. The salt concentration is due to either upward flow of Permian groundwater into the Quaternary alluvium and/or evaporative concentration of rainfall recharge. The Main Creek and Bettys Creek alluvium appear to have not been historically exploited for groundwater extraction due to the yield and salinity limiting productivity. The available data indicates these systems do not meet NSW government criteria to be classified as a "highly productive" groundwater source, which requires TDS concentrations less than 1500 mg/L and contain water supply works that can yield water at a rate greater than 5 L/s.

Vegetation communities that potentially depend on shallow groundwater within the Quaternary alluvium occur in a riparian zone along Main Creek and Bettys Creek. Previous work has indicated that the depth of the water table along Main Creek and Bettys Creek is typically like to preclude direct connectivity, with the vegetation communities reliant on soil moisture. It was noted that there is the possibility of some sinker roots in larger trees extending to the alluvial groundwater particularly during wetter periods when the water table in the Quaternary alluvium is higher.

In contrast, the Quaternary alluvium occurring within the Glennies Creek flood plain is generally more permeable, and can have a lower concentration of dissolved salts closer to the creek. This is potentially due to the larger upstream catchment promoting the deposition of more permeable sediments and the regulated releases of surface water from the Glennies Creek Dam seeping into the alluvial aquifer. The alluvial sediments along Glennies Creek have historically been tapped for agricultural purposes using shallow wells. Whilst this practice has decreased with the growth of mining in the region, a single well remains active within the Glennies Creek alluvium to the east of the Integra Underground on Glennies Creek.

The Permian coal measures form less productive groundwater systems, when compared to the shallow alluvial systems, with the coal seams being the most permeable lithology within the Permian sequences. The coal occurs in a basin structure with the seams being confined as they dip towards the north-east by the lower permeability interburden. There is no recorded abstraction of groundwater from the Permian strata for agricultural or other uses, again due to the yield and salinity limiting productivity.

Groundwater flows from areas of high head (pressure plus elevation) to low head via the most permeable and transmissive pathways. The water table surface and flow direction within the alluvial sediments of Main, Bettys and Glennies Creeks is a reflection of the topography, with groundwater flowing 'downstream' in a south-westerly direction towards the Hunter River. The groundwater levels within the Permian are influenced by topography and the proximity of mining activities. No connectivity between the Permian and Quaternary alluvium groundwater is evident in more elevated upstream areas of Main Creek, however further downstream, water level measurements indicate Permian groundwater discharges to the Quaternary alluvium. Depressurisation of the Permian strata below the level of the alluvial aquifers is evident in the monitoring bore network, indicating a reduced flow of Permian groundwater towards the Quaternary alluvium.

A series of thrust faults occur to the east of the Integra Underground, with a large fault defining the eastern limit of the Modification. Whilst the potential to transmit groundwater through the faults has not been established it is expected to be relatively limited, given the limited cross sectional area of the fault zone and the potential for the fault gouge sediment to retard groundwater flow. When groundwater levels are compared at monitoring points either side of the fault there is a notable difference (e.g DDH223 vs SMO028) suggesting limited connectivity and supporting the concept the faults retard, rather than enhance flow across the fault plane.

6 Numerical groundwater model

This section presents the results from numerical groundwater modelling and is structured as follows:

- Section 6.1 describes the proposed underground mining activities of the Modification;
- Section 6.2 provides an overview of the groundwater model developed to assess the impact of the proposed mining activities. Appendix A provides a detailed technical description of the model development, construction and calibration; and
- Section 6.3 outlines the peer review process followed as part of the groundwater assessment.

6.1 Overview of mining

6.1.1 Approved mining

Integra Underground is approved currently approved (PA 08_0101) to conduct longwall mining at up to 4.5 Mtpa of ROM coal until the end of 2035 from the Middle Liddell, Hebden and Barrett coal seams.

The approval allows mining of 17 longwall panels (LW1 to LW17) within the Middle Liddell Seam. LW1 to LW12 were mined by the former operators Vale, before Integra Underground was placed in care and maintenance in May 2014. HVCC acquired Integra Underground in late 2015 and commenced mining LW13 in early 2017.

The Modification approval also allows for longwall mining of 15 panels (H1 – H15) within the underlying Hebden seam and smaller areas of bord and pillar mining in areas not suitable for longwall. Bord and pillar mining along with the extraction of a single longwall panel is also approved in the Barrett coal seam. Mining of the Hebden and Barret seams have not commenced to date.

Figure 6-1 to Figure 6-3 show the approved mining areas within the Middle Liddell, Hebden and Barrett seams respectively.

LEGEND

- Integra Underground Project approval boundary
- Modification Project boundary
- Approved bord and pillar mining - Middle Liddell Seam
- Approved longwall panels - Middle Liddell Seam

Integra (G1285A)

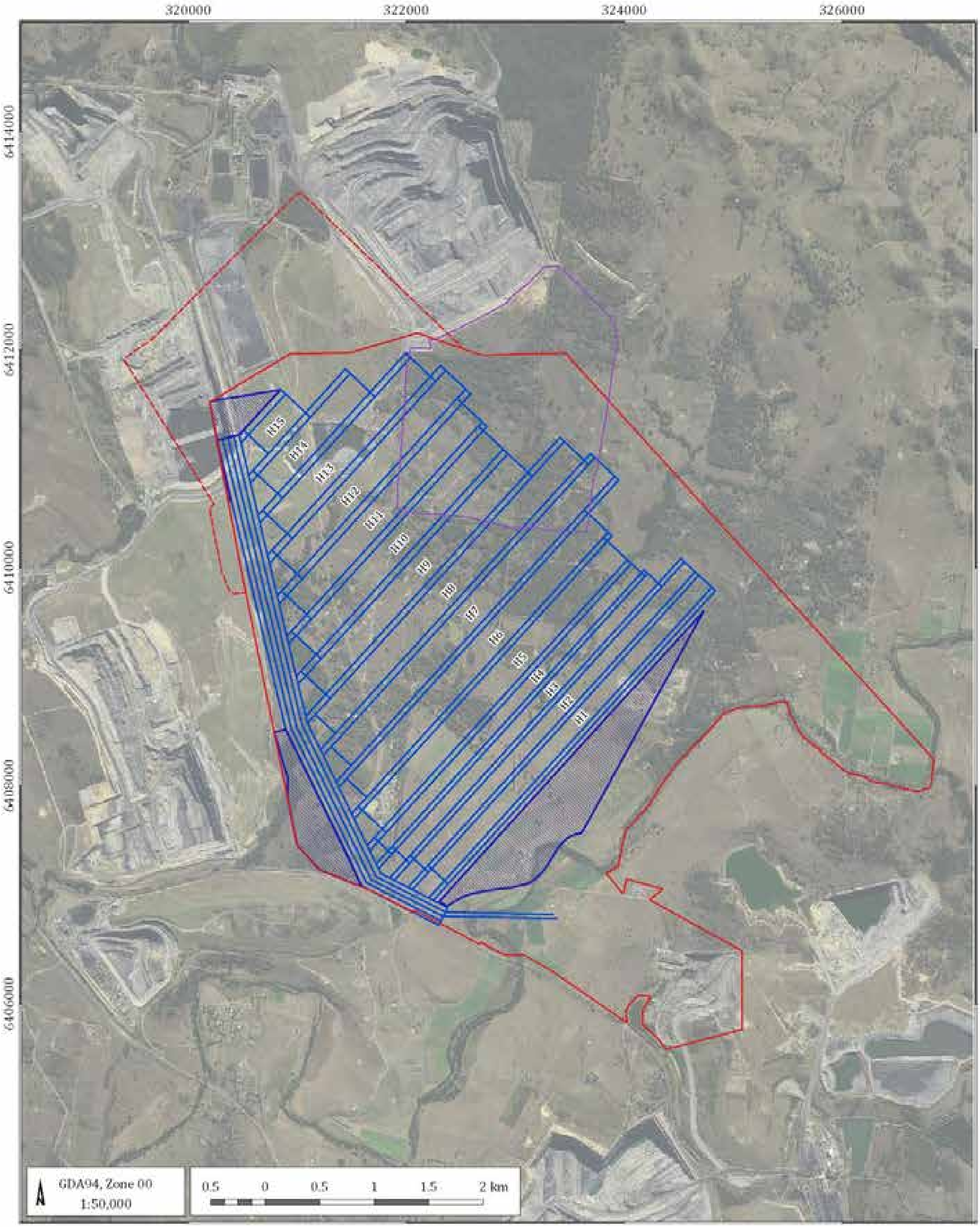
Approved mining - Middle Liddell seam

AGE

DATE 16/11/2017

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.;
G:/Projects/G1285A.Integra/3_GIS/Workspaces/002_EIA/06.01_G1285A_Approved mining.qgs



LEGEND

- Integra Underground Project approval boundary
- Modification Project boundary
- Approved bord and pillar mining - Hebden Seam
- Approved longwall panels - Hebden Seam

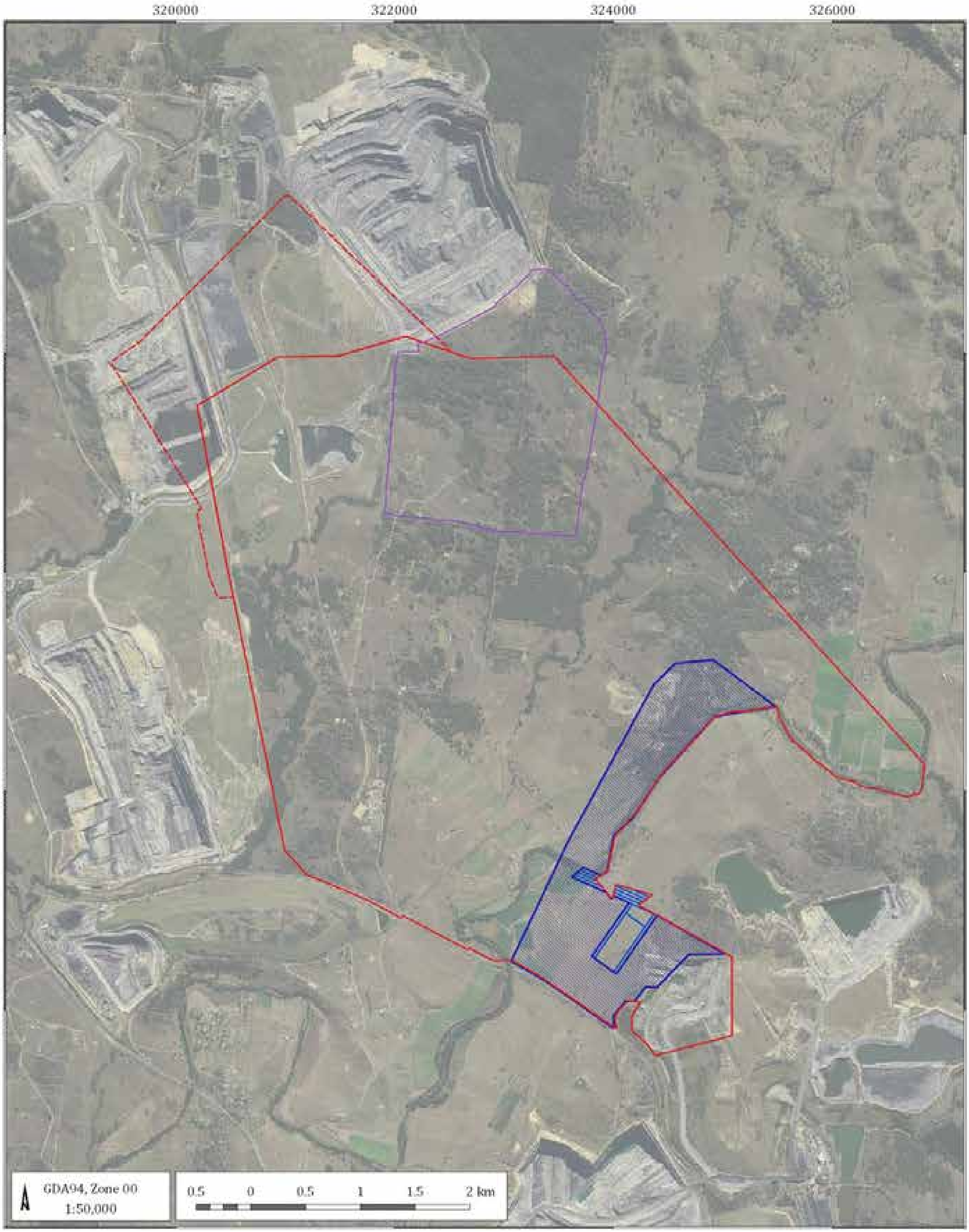
Integra (G1285A)

Approved mining - Hebden Seam

DATE 16/11/2017

FIGURE No: **6-2**

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/G1285A.Integra/3_GIS/Workspaces/002_IBA/06.01_G1285A_Approved mining.qgs



LEGEND

- Integra Underground Project approval boundary
- Modification Project boundary
- Approved bord and pillar mining - Barrett Seam
- Approved longwall panel - Barrett Seam

Integra (G1285A)

Approved mining - Barrett Seam

DATE 16/11/2017

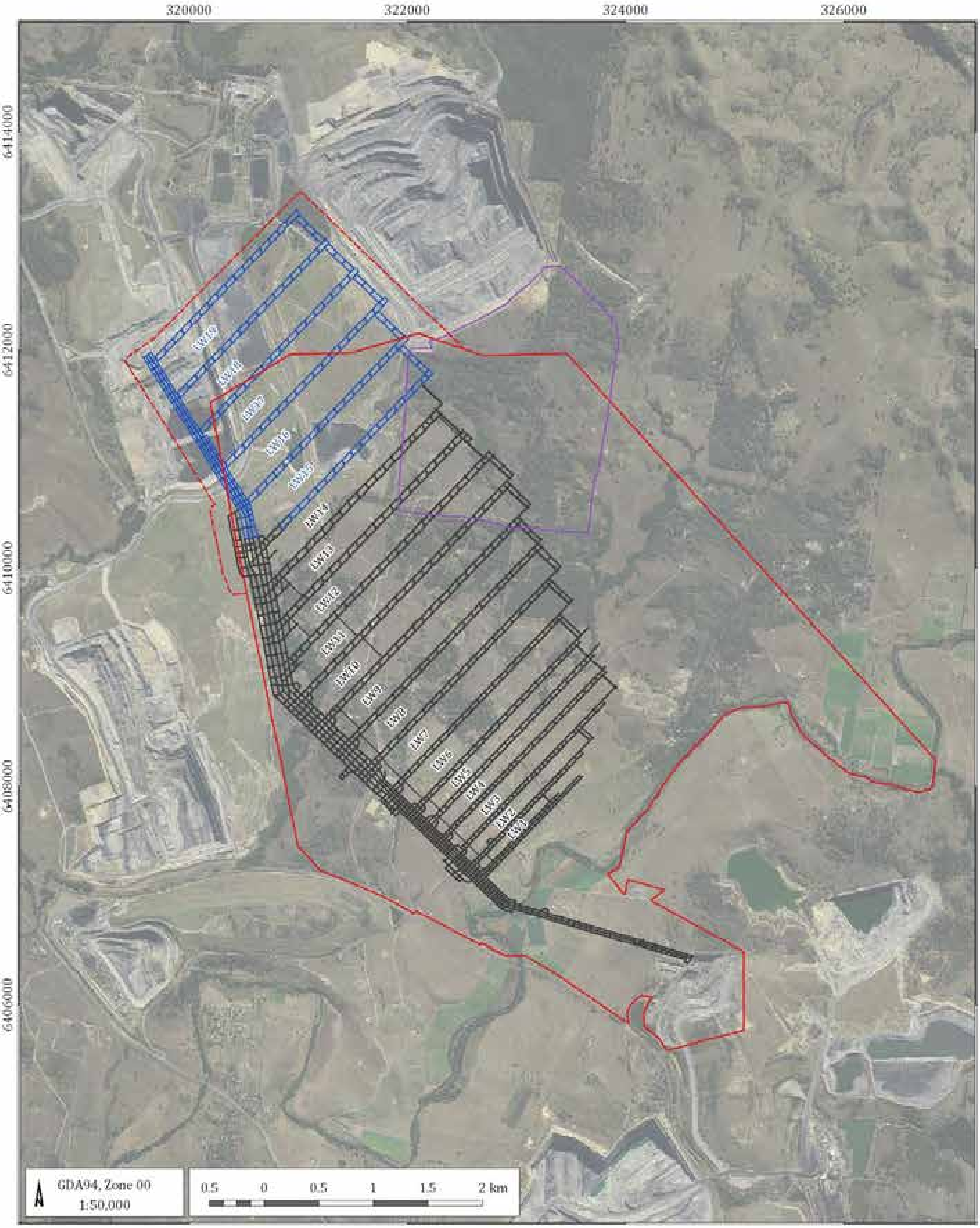
FIGURE No: **6-3**

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/G1285A.Integra/3_GIS/Workspaces/002_IBA/06.01_G1285A_Approved mining.qgs

6.1.2 Proposed mine plan

HVCC proposes to modify the Project approval to facilitate a greater recovery of coal from the Middle Liddell Seam. The Modification would entail realignment and extension of the main headings further to the north-west, increases to the lengths and widths of the approved longwall panels 15-17, and mining of additional longwall panels 18-19 or 18-20. HVCC are evaluating a panel width of either 320 m or 246 m, which will be determined on an internal financial analysis at a later date. Both options cover the same area but the 320 m option includes five additional panels (LW 15 to LW19), whilst the 246 m option includes six (LW15 to LW20). Groundwater modelling undertaken for this Project presents the worst-case impacts, which are highest for the 320 m scenario, because the connective fracturing is more extensive with wider panel widths.

Figure 6-4 and Figure 6-5 show the proposed longwall layouts for the 320 m and 246 m wide Modification options respectively. Ongoing mining is proposed to continue for a period of 18 years as currently approved under PA 08-010. For modelling purposes, this has been assumed to be from 2018 to 2035. All groundwater modelling results are based around the 320 m panel width option. A simulation with the 246 m panel option was also undertaken as a sensitivity analysis to determine how groundwater inflows to the mining area would change.



LEGEND

- Integra Underground Project approval boundary
- Modification Project boundary
- Approved longwall panels
- Proposed 320 m longwall panels

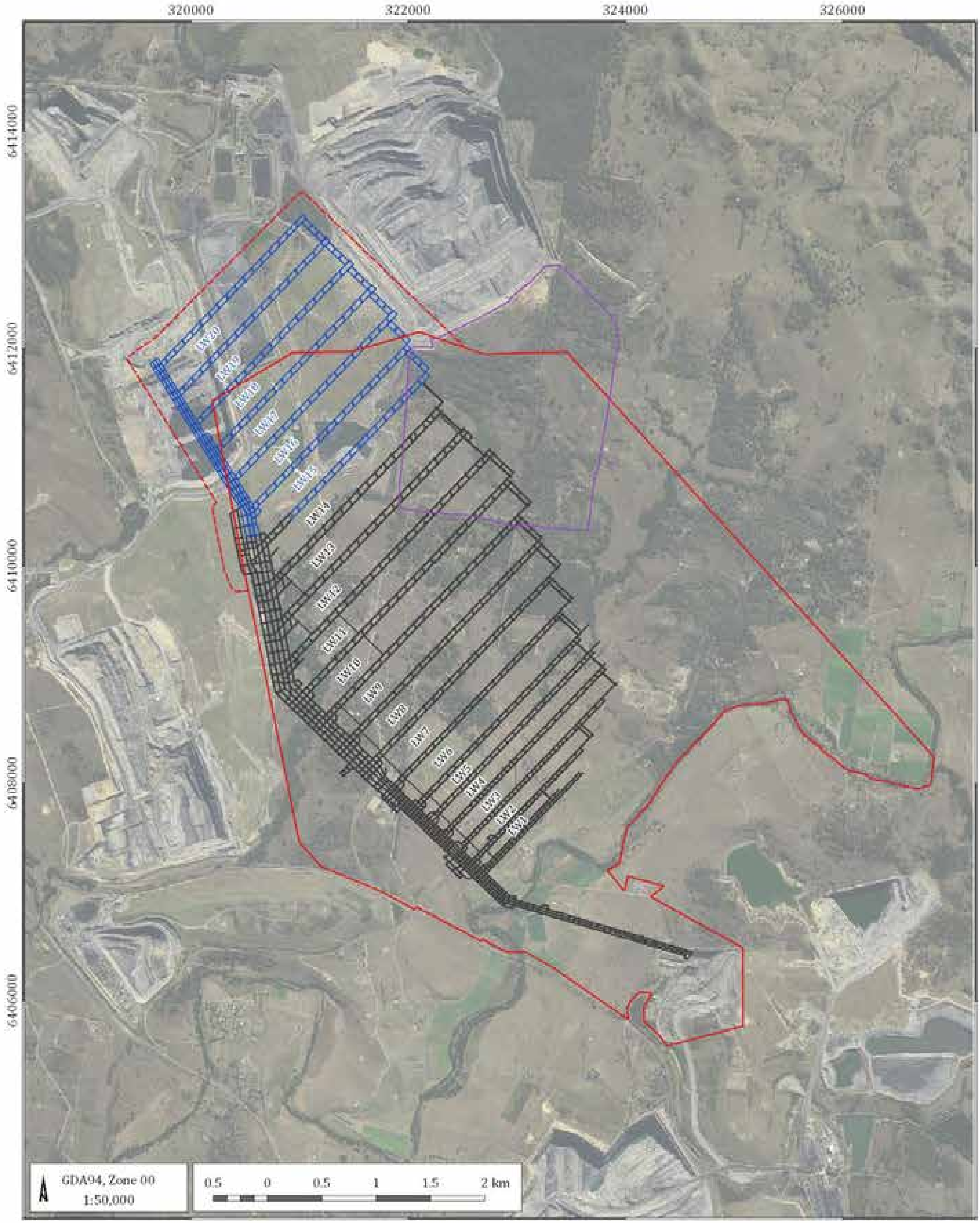
Integra (G1285A)

Proposed Modification - Middle Liddell Seam - 320 m panels

DATE 16/11/2017

FIGURE No: **6-4**

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/G1285A.Integra/3_GIS/Workspaces/002_IBA/06.01_G1285A_Approved mining.qgs



LEGEND

- Integra Underground Project approval boundary
- Modification Project boundary
- Approved longwall panels
- Proposed 246 m longwall panels

Integra (G1285A)

Proposed Modification - Middle Liddell Seam - 246 m panels

AGE

DATE 16/11/2017

FIGURE No: 6-5

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/G1285A.Integra/3_GIS/Workspaces/002_IBA/06.01_G1285A_Approved mining.qgs

6.2 Overview of groundwater modelling

A 3D numerical groundwater flow model was developed for the Modification using MODFLOW-USG. A detailed description of the modelling logic is provided in Appendix A.

The model represents the key geological units as 21 layers extending approximately 25 km from west to east and 26 km long in the north to south direction. It comprises up to 32,212 cells per layer, making it spatially a large model (Figure 6-6).

The prevalence of mining in the region means there have been many previous groundwater modelling efforts. The numerical model developed for the Modification was built upon an existing large regional model that represented Integra Underground first developed by Mackie Environmental Research (MER), then updated by Jacobs as described in Jacobs (2014). This approach was undertaken to as far as possible to create consistency with previous work, and also to continue to build upon the regional flow model to represent the cumulative impacts of mining in the Modification and the surrounding region. The model was updated as follows:

- converting model to MODFLOW USG including development of new model mesh and layers;
- updating water level monitoring dataset;
- representing hydraulic conductivity as decreasing with depth in Permian model layers;
- adjusting coal seam levels based on an updated geological model from Mt Owen mine and new geological data that became available when Glencore acquired Integra Underground;
- updating the thickness and extent of the Quaternary alluvium based on borehole logs and geophysical investigations at Mt Owen;
- recalibrating model to water level records and mine inflows at Integra;
- updating progression of approved and proposed mining at Integra Underground mine;
- adding approved open cut mining at Rix Creek North Mine (former Integra open cut); and
- updating progression of foreseeable mining at Mt Owen Mine predicting impacts on groundwater regime for proposed mining at Integra Underground.

Appendix A describes the evolution of the regional model over time and the changes made to quantify the impact of the Modification.

The model was used to identify the influence of the Modification on the groundwater regime by comparing the impacts generated by the approved and proposed mine plans. All currently approved and foreseeable mine plans within the region including the Mount Owen North Pit extension were included in order to account for cumulative impacts. Further details about how mining within the region was represented in the model are included in Appendix A.

The model was calibrated using existing groundwater levels at bores, data available within the model domain was considered reliable. The volume of groundwater estimated pumped from Integra Underground was also used to guide the calibration of the model. A detailed description of the calibration procedure is provided in Appendix A. The objective of the calibration was to replicate the groundwater levels measured in the monitoring network, and the mine inflows in accordance with *Australian groundwater modelling guidelines* (Barnett *et al.* 2012). The transient calibration achieved a 6.1% scaled root mean square (SRMS) error, which is well within acceptable limits (i.e. 10%), recommended by the *Australian groundwater modelling guidelines* (Barnett *et al.* 2012).

Following calibration, the model was used to estimate changes in the alluvial water table and the Permian groundwater pressure (drawdown), as well as the amount of groundwater intercepted by the Modification, in accordance with the proposed mine plans. The influence of the Modification on the groundwater regime was estimated by comparing the impacts predicted by the numerical model for the approved and proposed mine plans. Two model scenarios were run and their results compared as follows:

- Approved - with all currently approved and foreseeable operations within the region; and
- Approved + Modification – which includes all approved and foreseeable operations as well as the Modification.

Model scenarios were also developed, which excluded all future mining at Integra Underground from the commencement of each WSP. The purpose of this was to quantify the volume of water taken from each water source and the drawdown since each WSP commenced. To achieve these two additional models were run, one from 2009 for the Hunter Unregulated WSP, and a second from 2016 for the North Coast Fractured and Porous Rock WSP. The drawdown presented therefore represents the change in groundwater levels from the commencement of each WSP. The change in flux to the alluvial aquifers is also relative to baseline fluxes at the commencement of the Hunter Unregulated WSP. The groundwater inflow from the North Coast Fractured and Porous Rock WSP to the Modification was not calculated relative to the start of the WSP, and therefore represents a total water take including previously approved mining impacts.

It is important to note that the currently approved operations at Integra Underground have been approved based on previously completed groundwater assessments (Geoterra 2009). Because the groundwater model has been refined and approved for other projects since this time there are some differences in the impacts predicted for the approved mining activities. Whilst there are some difference these are not considered material, and at a high level the impacts are consistent with those previously predicted. These impacts described later in Section 7.

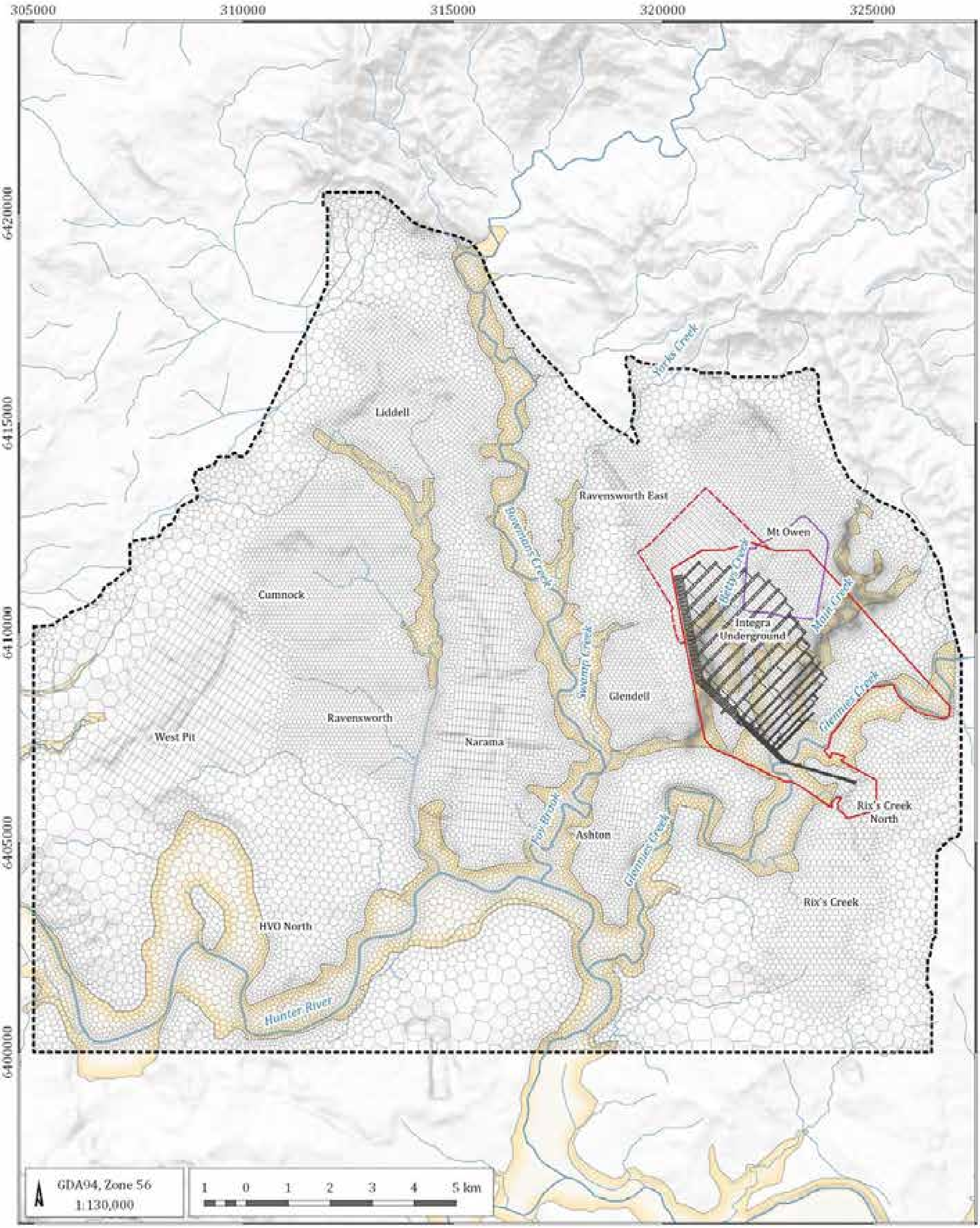
The uncertainty of the final model predictions resulting from initial uncertainty in the assumptions and input parameters was analysed. The analysis focussed on varying model parameters and design features that has the most influence on model predictions. The model parameters were adjusted to encompass the expected range of uncertainty. Appendix A provides a detailed discussion of the uncertainty analyses and Section 7 describes the groundwater model predictions.

6.3 Peer review

An external peer review was conducted by Dr Noel Merrick of HydroAlgorithmics, who has over 40 years of experience in hydrogeological investigations and groundwater modelling. The review was in accordance with the Australian groundwater modelling guidelines (Barnett *et al.* 2012) and included input and involvement from Dr Merrick over the three main stages of numerical groundwater modelling as follows:

- Conceptualisation and model updates;
- Model calibration; and
- Model predictions.

At the time of finalisation of this report, Dr Merrick had reviewed the groundwater assessment report and provided feedback that was incorporated into this document. Dr Merrick was still reviewing the groundwater modelling report in Appendix A, but had provided the results of the model appraisal checklist.



LEGEND

- Model extent
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Model mesh
- Alluvium extent
- Major drainage
- Minor drainage

Integra (G1285A)

Model extent

DATE 16/11/2017

FIGURE No: 6-6

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:/Projects/G1285A.Integra/3_GIS/Workspaces/002_IBA/06.06_G1285A_Model extent.qgs

7 Model predictions and impact assessment

This section describes the numerical model predictions and impacts of the Modification including the:

- groundwater directly intercepted by mining from the Permian coal measures within the Modification area (Section 7.1);
- drawdown in groundwater levels in the Quaternary alluvium and Permian coal measures as a result of the Modification (Section 7.1.2);
- change in alluvial and baseflow availability (Section 7.1.3);
- water licensing requirements (Section 7.1.4);
- impact on private bores (Section 7.1.5); and
- drawdown impact to potential GDEs (Section 7.1.6).

Cumulative impacts are outlined in Section 7.2, with post closure impacts discussed in Section 7.3.

7.1 Modification groundwater predictions

7.1.1 Groundwater directly intercepted by mining

Figure 7-1 and Figure 7-2 show the total flux of groundwater to the drain cells within the model which represents the water intercepted from the Permian coal measures as seepage to the mine face. The figures show the volume of Permian water intercepted for the 320 m and the 246 m wide panel options respectively.

As shown in Figure 7-1, groundwater intercepted from the Permian coal measures due to the Modification peaks in Year 5 at 257 ML/year for the 320 m panels and at 138 ML/year for the 246 m panels. The Modification represents about one third of the total inflow to the mining areas for the 320 m panels and about one quarter of the total inflow for the 246 m wide panels, with the remaining occurring in approved mining areas. The higher inflow to the 320 m panels occurs due to the increased height of fracturing from the wider panels compared with the narrower 246 m panels. Sections below present only the impacts for the 320 m wide panels.

Because longwall mining is approved to occur within the Hebden seam underlying the Middle Liddell seam it will be necessary to continue to pump groundwater from the Modification area after mining is completed for safety reasons. The figures show the ongoing inflow to the Modification area reduces slowly after mining is complete and represents about 10% to 15% of the total inflow at the end of all approved mining.

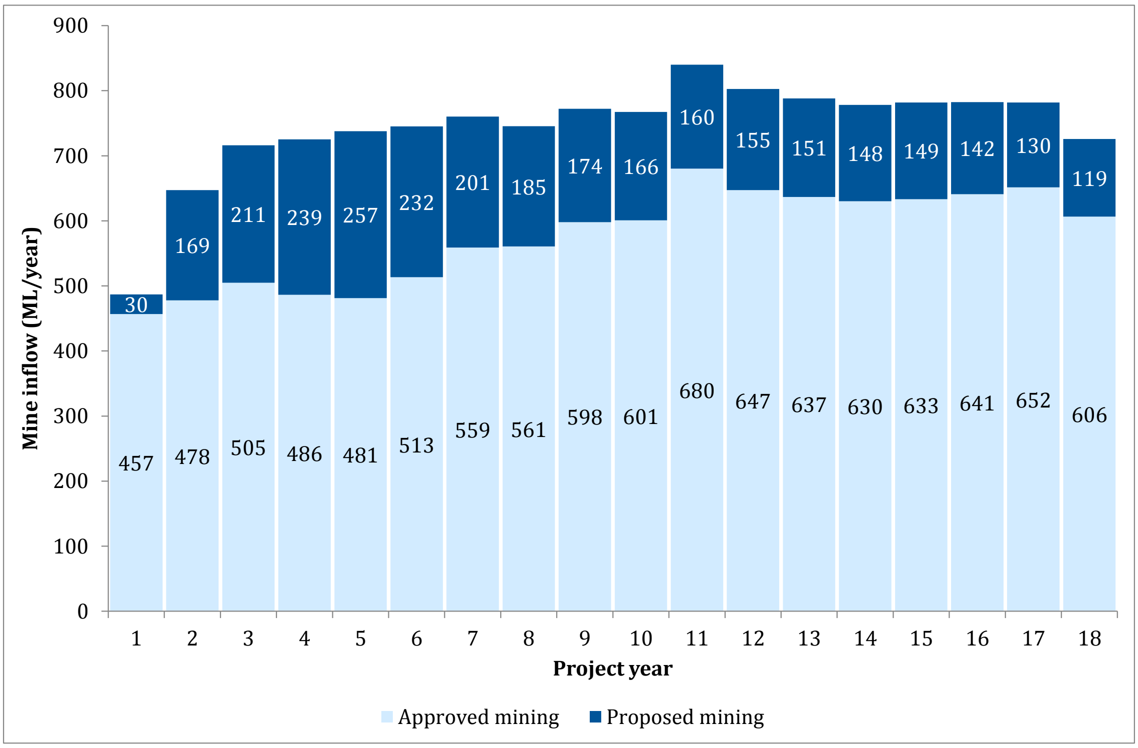


Figure 7-1 Groundwater intercepted from Permian coal measures– 320 m panels

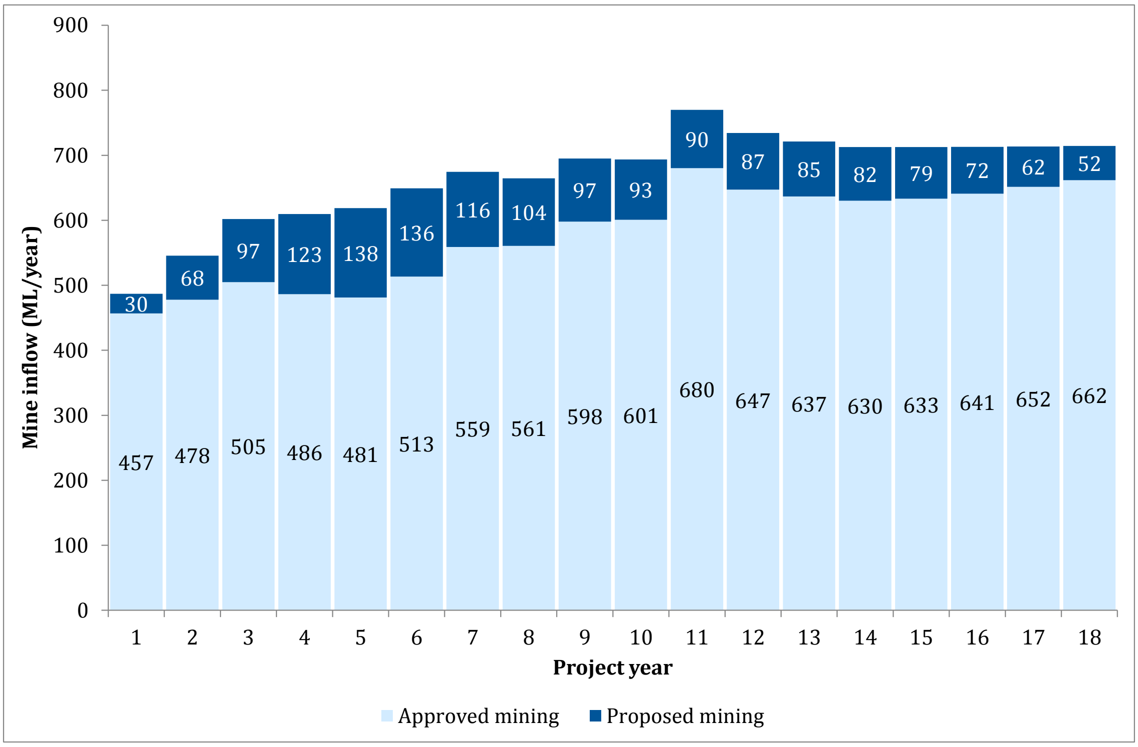


Figure 7-2 Groundwater intercepted from Permian coal measures – 246 m panels

7.1.2 Drawdown and depressurisation during mining operations

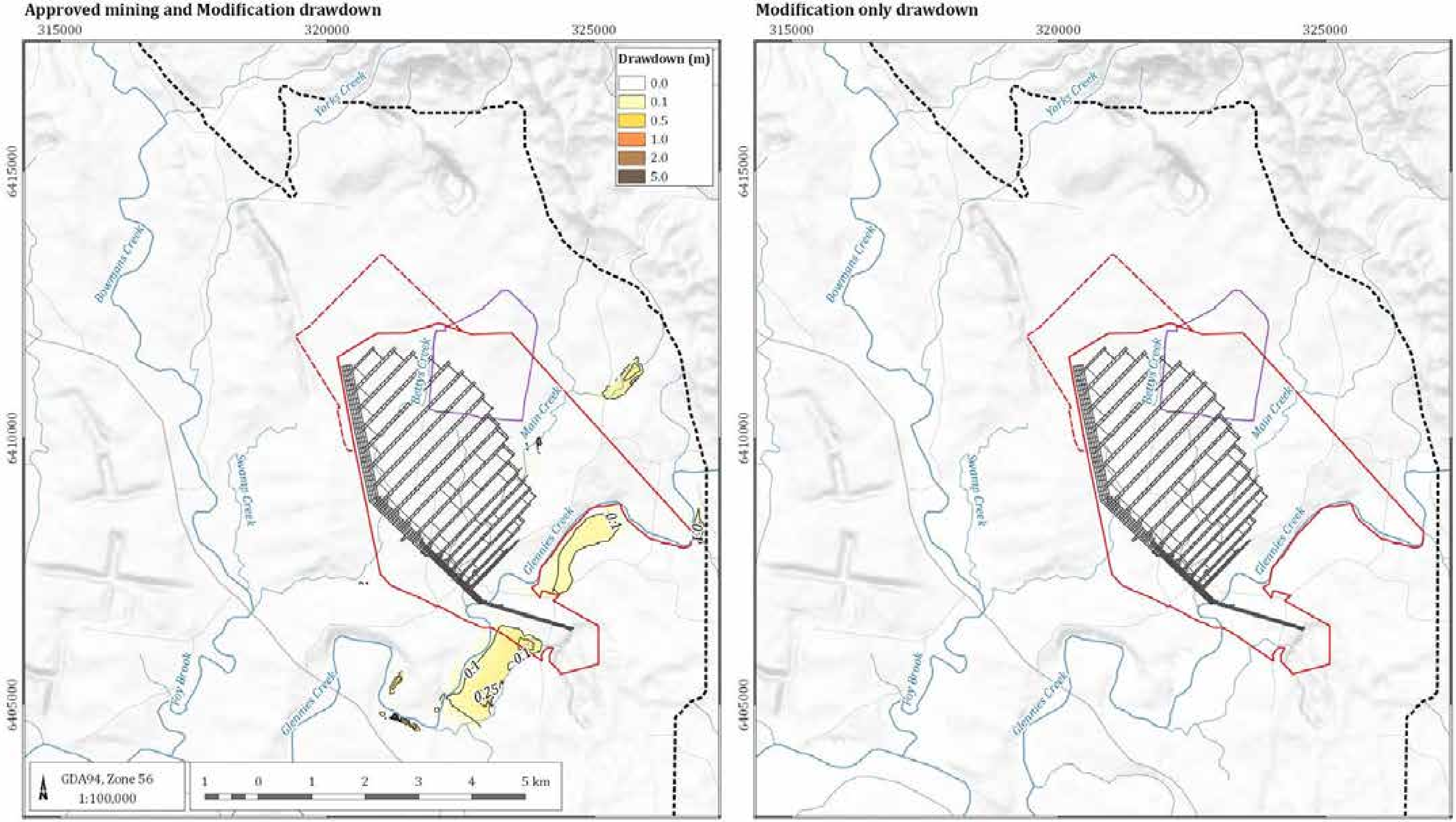
Figure 7-3 and Figure 7-4 show the predicted maximum drawdown occurring during the 18 year simulation period. The figures show the drawdown predicted to occur within the Quaternary alluvium and the Middle Liddell seam layers within the numerical model. Two windows are included within each of the figures. The first window shows the predicted drawdown from the currently approved underground mining plus the additional drawdown generated by the Modification for the 320 m panels option, with the second window showing the amount of drawdown contributed by the Modification only. It should be noted the drawdown within the Quaternary alluvium is calculated from the commencement of the Hunter Unregulated WSP in 2009, whilst the Permian drawdown is from the start of the North Coast Fractured and Porous Rock WSP which commenced in 2016 (i.e. incremental drawdown assuming mining ceases at 2009 and 2016, respectively). Whilst the drawdown predicted within the Middle Liddell seam is extensive, it is important to note this coal seam is deep, contains poor quality groundwater and therefore does not form a resource with any environmental value.

Figure 7-3 shows that the numerical model predicts limited drawdown within the Quaternary alluvium for the approved mining and Modification scenario. The limited amount of drawdown is predicted to occur within the Glennies Creek alluvium and within the Main Creek alluvium. The drawdown is generally less than 1 m in all areas. The second window in Figure 7-3 shows that no drawdown in the alluvial aquifers is predicted to be caused by the Modification only.

Figure 7-4 shows the zone of depressurisation within the Middle Liddell seam extends to the Hunter Thrust fault some 5 km to the east, and the outcrop of the seams about 2 km to south. It should be noted that within the impact area, the Permian groundwater system is not utilised and is of poor quality. To the north-west where the Middle Liddell seam is continuous in the numerical model, the drawdown extends about 5 km to the 1 m drawdown contour. Figure 7-4 shows there are areas within the longwall panels that do not report any drawdown. This is because mining was conducted prior to the commencement of the North Coast Fractured and Porous Rock WSP in 2016, the point from which drawdown has been calculated. The total cumulative drawdown from the commencement of the model is shown within the figures included in Section 7.2.

The second window in Figure 7-4 shows the drawdown attributable to the Modification only and indicates drawdown from the Modification occurs largely within the footprint and to the north-west of the Modification area. The lack of significant drawdown occurring to the south where approved mining is largely complete in the Middle Liddell seam, explains the lack of drawdown predicted by the numerical model within the overlying alluvial groundwater systems of Main Creek, Bettys Creek and Glennies Creek due to the Modification. It should be noted this figure represents additional drawdown from the start of the North Coast Fractured and Porous Rock WSP in 2016.

Figure 7-5 and Figure 7-6 are vertical sections through the model showing the pore pressure simulated by the model before the Modification commences in 2018 and after the Modification and approved mining is completed in 2035. The areas where the pore pressure is reduced to zero occur where mining is represented in the numerical model as actively dewatering the coal seam. The zone of atmospheric pressure where there is complete drainage of the strata extends to about 50 m above the Middle Liddell Seam mining area. Above this height sections indicate the strata will be depressurised but not completely drained. This prediction is supported by the pore pressure measurements from the VWP sensors that show remaining pore pressure above the mining areas.



LEGEND

- Mount Owen Mine area
- Proposed disturbance area
- Model extent
- Major drainage
- Minor drainage
- Major road
- Minor road
- Rail
- Drawdown contour (m)

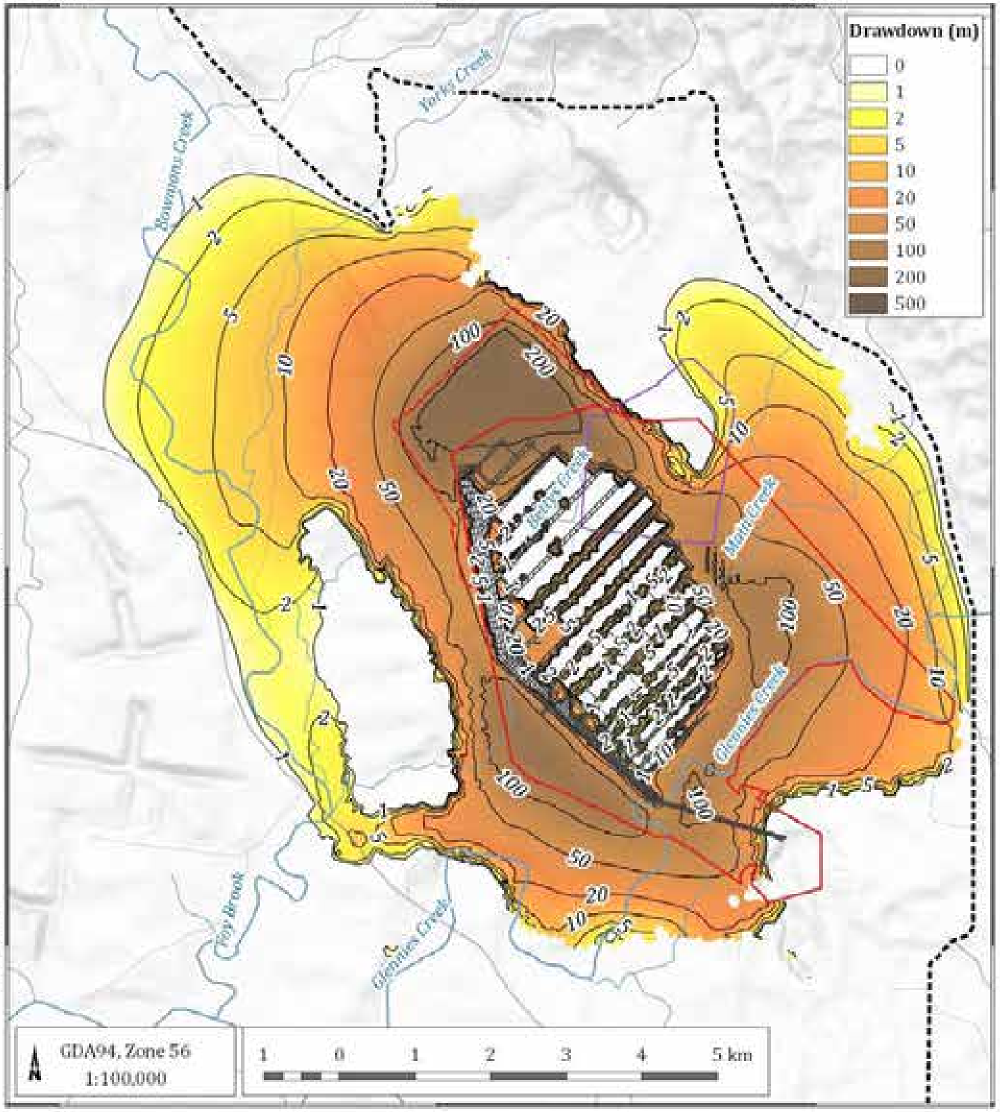
Mount Owen (G1862A)

Maximum zone of drawdown due to Project - Quaternary alluvium

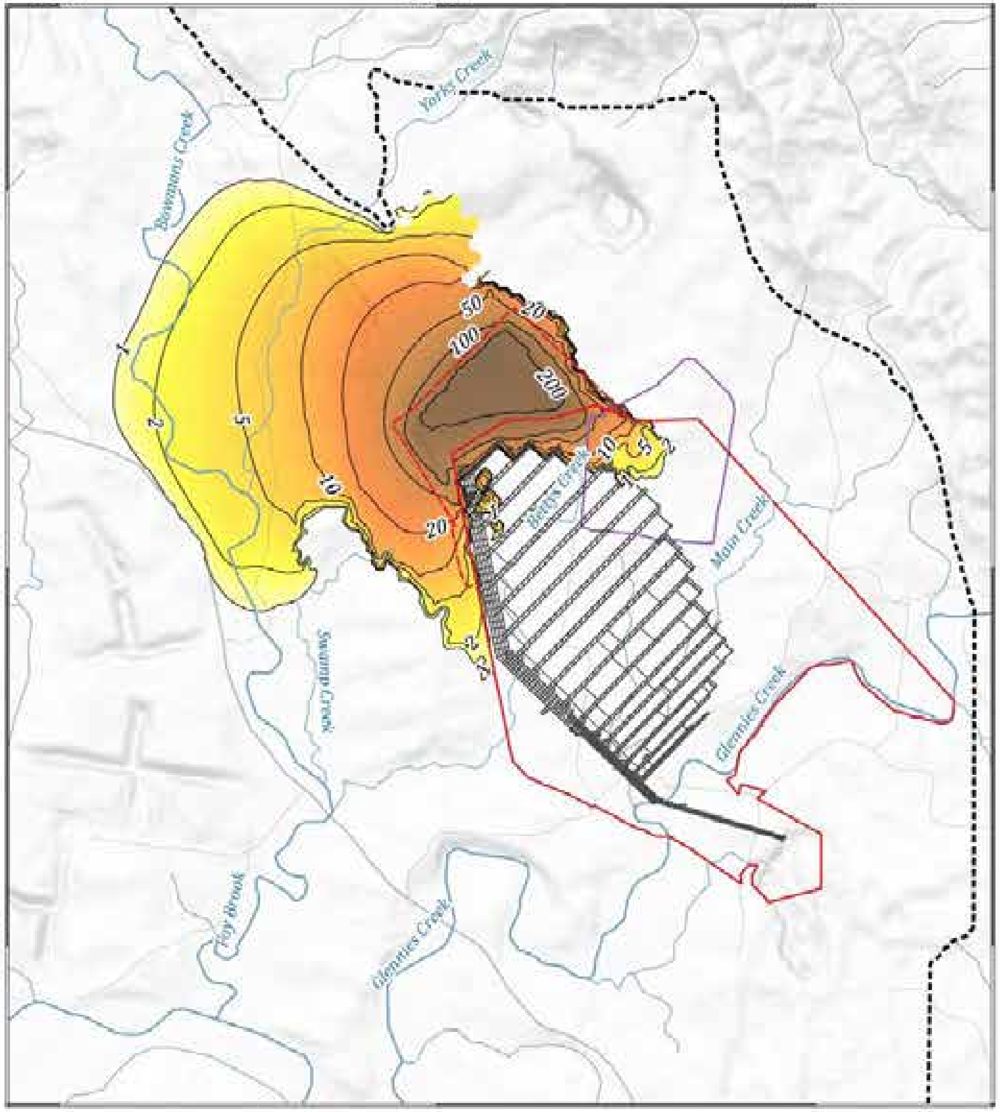
DATE 16/11/2017

FIGURE No. **7-3**

Approved mining and Modification drawdown



Modification only drawdown



LEGEND

- Model extent
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Major drainage
- Minor drainage
- Major road
- Minor road
- Rail
- Drawdown contour (m)
- Cross section

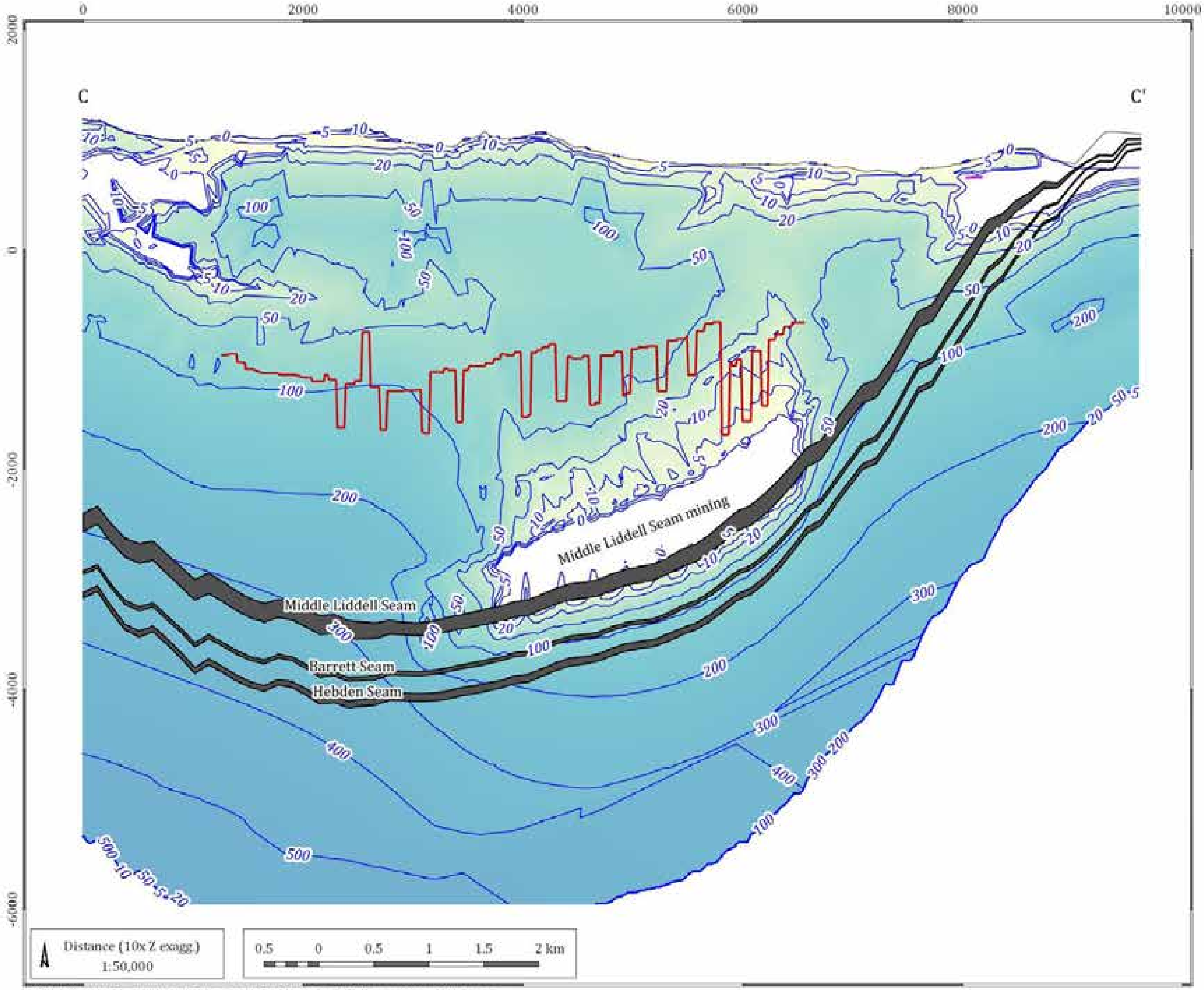
Integra (G1205A)

AGE

Maximum zone of drawdown due to Modification - Middle Liddell Seam

DATE
16/11/2017

FIGURE No:
7-4



LEGEND

- Target coal seam
- Pore pressure (m)
- Middle Liddell and Hebden Seam mining fracture surface
- Barrett Seam mining fracture surface

Pore pressure (m)

- 0
- 10
- 20
- 50
- 100
- 200
- 1000

Integra (G1285A)

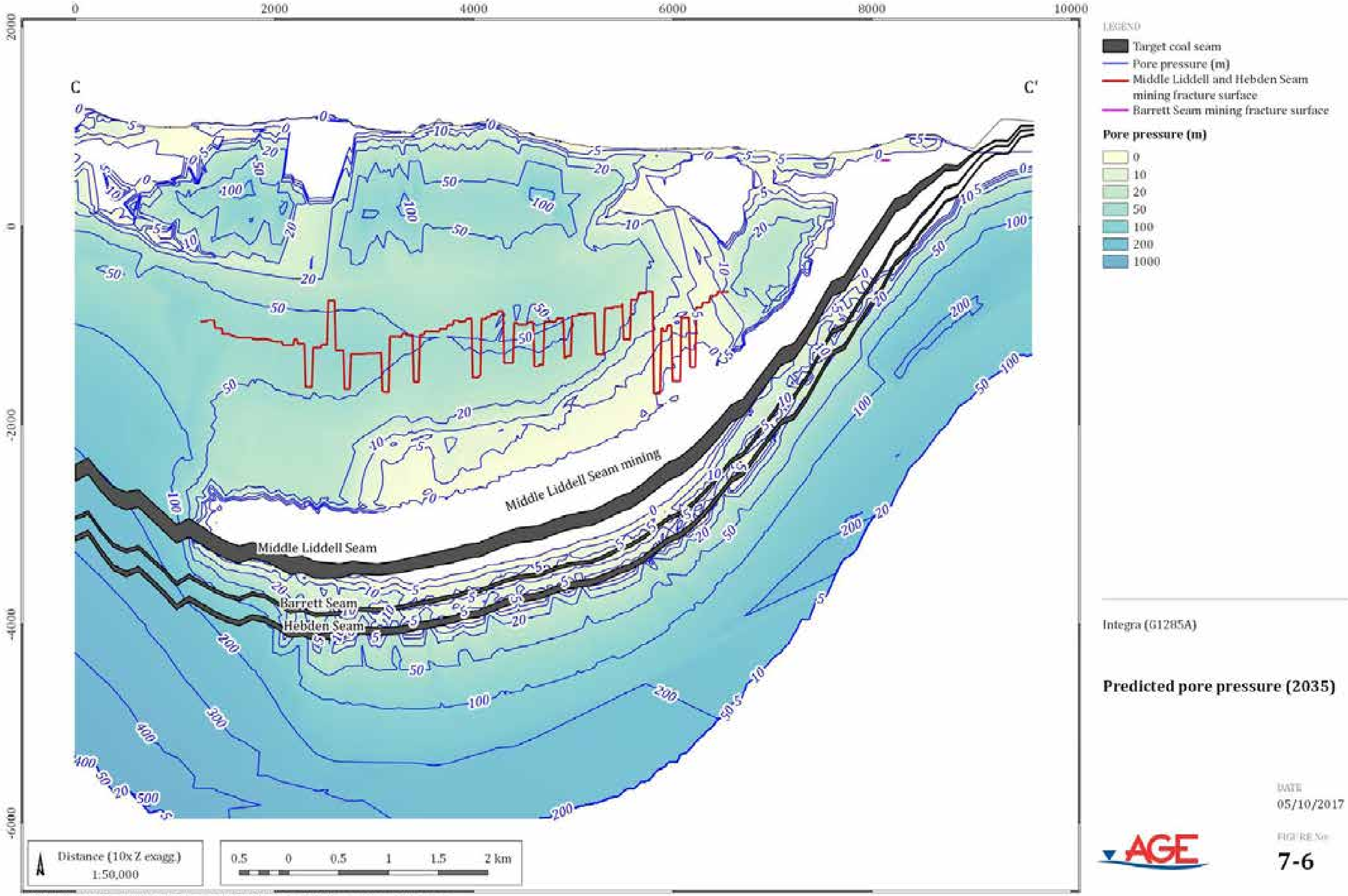
Predicted pore pressure - 2017

DATE
06/10/2017

AGE

FIGURE No:
7-5

G:/Projects/G1285A.Integra/3_GIS/Workspaces/002_EIA/07.05_G1285A_pressure_year_2017.qgs



Integra (G1285A)

Predicted pore pressure (2035)

DATE
05/10/2017

FIGURE No:
7-6

7.1.3 Change in alluvial and surface water fluxes

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 AIP. 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 progressively reduces. 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 due to mining, and this has been considered 'water take' that needs to be accounted for with water licences except where negligible take occurs (AIP, 2012). The change in alluvial water resources was determined by comparing water budgets for alluvial zones using versions of the numerical model that contained and excluded the Modification. Figure 7-7 shows the change in flux predicted by the numerical model within Main Creek and Glennies Creek alluvial and surface water systems due to the approved mining and the Modification.

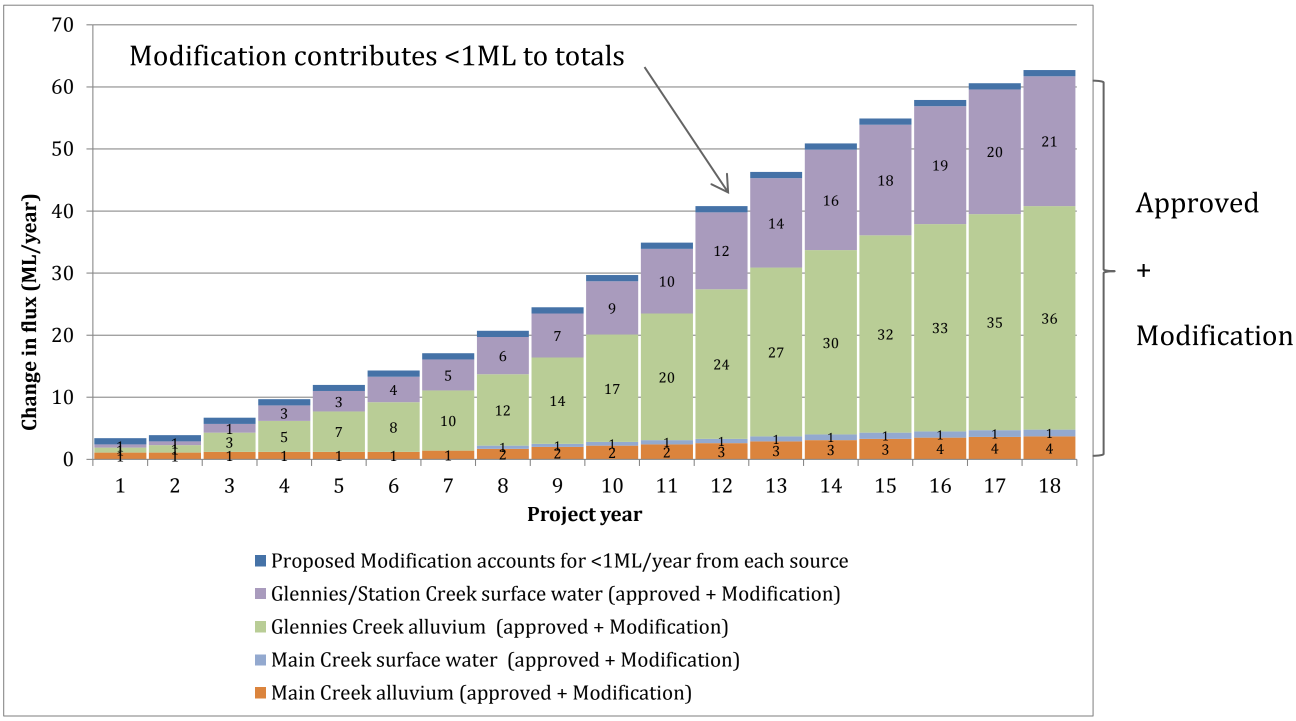


Figure 7-7 Change in flux to Quaternary alluvium and surface water systems from approved mining and Modification combined

When interpreting Figure 7-7 it is important to note the figure shows the change in flux due to approved and proposed mining combined. When the change in flux attributable to the Modification only is calculated, which is the focus of this report it represents less than 1 ML/year from each alluvial and surface water system, and is therefore negligible.

Figure 7-7 shows the flux to the alluvial groundwater systems gradually reduces over the 18 year period due to the increasing footprint of the approved mining. The reduction in flux of groundwater to the alluvial systems peaks at 36 ML/year in Glennies Creek alluvium and 4 ML/year in the Main Creek alluvium. The reduced groundwater flux from the Permian strata into the overlying Quaternary alluvium also reduces the rate of groundwater discharge into creeks as baseflow. Figure 7-7 shows the change in flux to Quaternary alluvium also induces a change in the baseflow within Glennies Creek of 21 ML/year and by 1 ML/year within Main Creek. The gauging station on Glennies Creek (210044) has recorded an average flow of 66,335 ML/year, indicating the predicted change in groundwater baseflow of 21 ML/year is negligible. Main Creek is an ephemeral system with no recorded permanent baseflow.

7.1.4 Water licensing and water sharing plan rules

The AIP requires the accounting for all groundwater take, either directly or indirectly from groundwater systems. Groundwater intercepted from the mining area is considered a direct take from the Permian groundwater system, whilst the changes in fluxes occurring within the Quaternary alluvium and rivers resulting from depressurisation of the underlying Permian is considered an indirect take. This section discusses the water licences required to account for the peak direct and indirect takes of groundwater and surface water due to the proposed Modification and the approved mining.

As discussed in Section 2, three WSP's apply to the aquifers and surface waters affected by the Modification as follows:

- Hunter Regulated River Water Source 2016 (Hunter Regulated WSP);
- Hunter Unregulated and Alluvial Water Sources 2009 (Hunter Unregulated WSP); and
- Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016 (North Coast Fractured and Porous Rock WSP).

The Hunter Unregulated WSP is divided into water sources that are largely based on catchment boundaries. Integra Underground falls within the Jerrys Water Source and Glennies Creek Water Source. The Glennies Creek alluvium is within the Hunter Regulated River alluvial water source also regulated under the Hunter Unregulated WSP.

The predicted annual groundwater volumes required to be licensed to account for the peak water take over the life of mining for the currently approved and proposed mining activities at Integra Underground are summarised in Table 7-1. The volumes are calculated from the commencement of each of the WSPs.

Table 7-1 Groundwater licensing summary – during mining

Water sharing plan	Water source/ management zone	Type	Peak volume requiring licensing during mining (ML/year)		
			Approved mining	Approved and modification	Modification only
North Coast Fractured and Porous Rock WSP	Sydney Basin – North Coast	groundwater	647 (Year 12)	840 (Year 11)	257 (Year 5)
Hunter Unregulated WSP	Jerrys	groundwater	1	1	1
		surface water	1	1	1
	Glennies	groundwater	4	4	0
		surface water	1	1	0
	Hunter Regulated River alluvium	groundwater	36	36	0
Hunter Regulated WSP	Management Zone 3A - Glennies Creek + Station Creek surface water	surface water	21	21	0

As reported in Section 2.4, HVCC has a total entitlement of 950 ML/year from the North Coast Fractured and Porous Rock WSP. HVCC hold sufficient licences to account for the combined 'water take' from this water source of 840 ML/year for the approved and proposed mining.

HVCC hold a large volume of entitlements from the Hunter Regulated WSP (2097 units), which will readily account for 'water take' predicted from Glennies Creek baseflow which is within Management Zone 3A.

At the time of writing HVCC was in the process of acquiring entitlements from the Jerrys Water Source, Glennies Water Source and the Hunter Regulated River Alluvial Water Source to account for the peak 'water take' from these water sources for the approved and proposed mining. When interpreting the predicted changes in flux due to the Modification it is important to consider the volumes in context. The change in flux due to the Modification is essentially undetectable and unmeasurable within the environment.

When considering the above it is important to note that no adjustments have been made to correct for double accounting of water. Figure 7-8 shows graphically the change in flux induced in the Main Creek and Glennies Creek systems Quaternary alluvium and surface water systems due to depressurisation of the Permian bedrock. Where groundwater and surface water are regulated under the same WSP and within the same water source then to prevent double accounting, the change in the baseflow should be subtracted from the alluvial flux change. However because the Modification has negligible impact on the Jerrys and Glennies water sources regulated under the Hunter Unregulated WSP this has not been necessary.

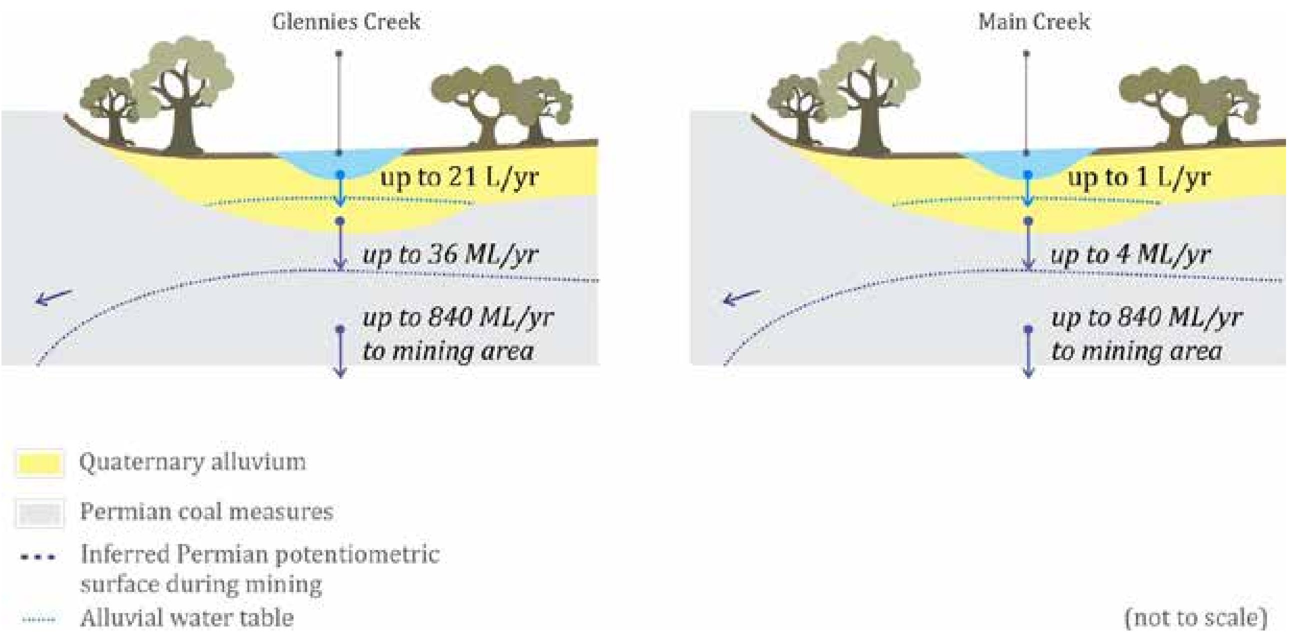


Figure 7-8 Partitioning of water take from streams and Quaternary alluvium for the Modification

The Glennies and Jerrys Water Sources have 'cease to pump' rules that require *"from year six of the plan, all licence holders must cease to pump when there is either no visible inflow to, or outflow from, the pumping pool. N.B. From year six of the plan the cease to pump condition will apply to aquifer access licences extracting from all alluvial aquifers within 40m of an unregulated river, except for Domestic and Stock access licences and Local Water Utilities Access licences".*

The AIP requires an assessment of the ability to comply with the rules for each water source. The above rule pertains to direct extraction and not incidental take. Predicted take from Glennies and Jerrys Water Sources due to the activity occurs only incidentally due to depressurisation of the underlying bedrock, and not from direct extraction. This rule is therefore not applicable to the Modification.

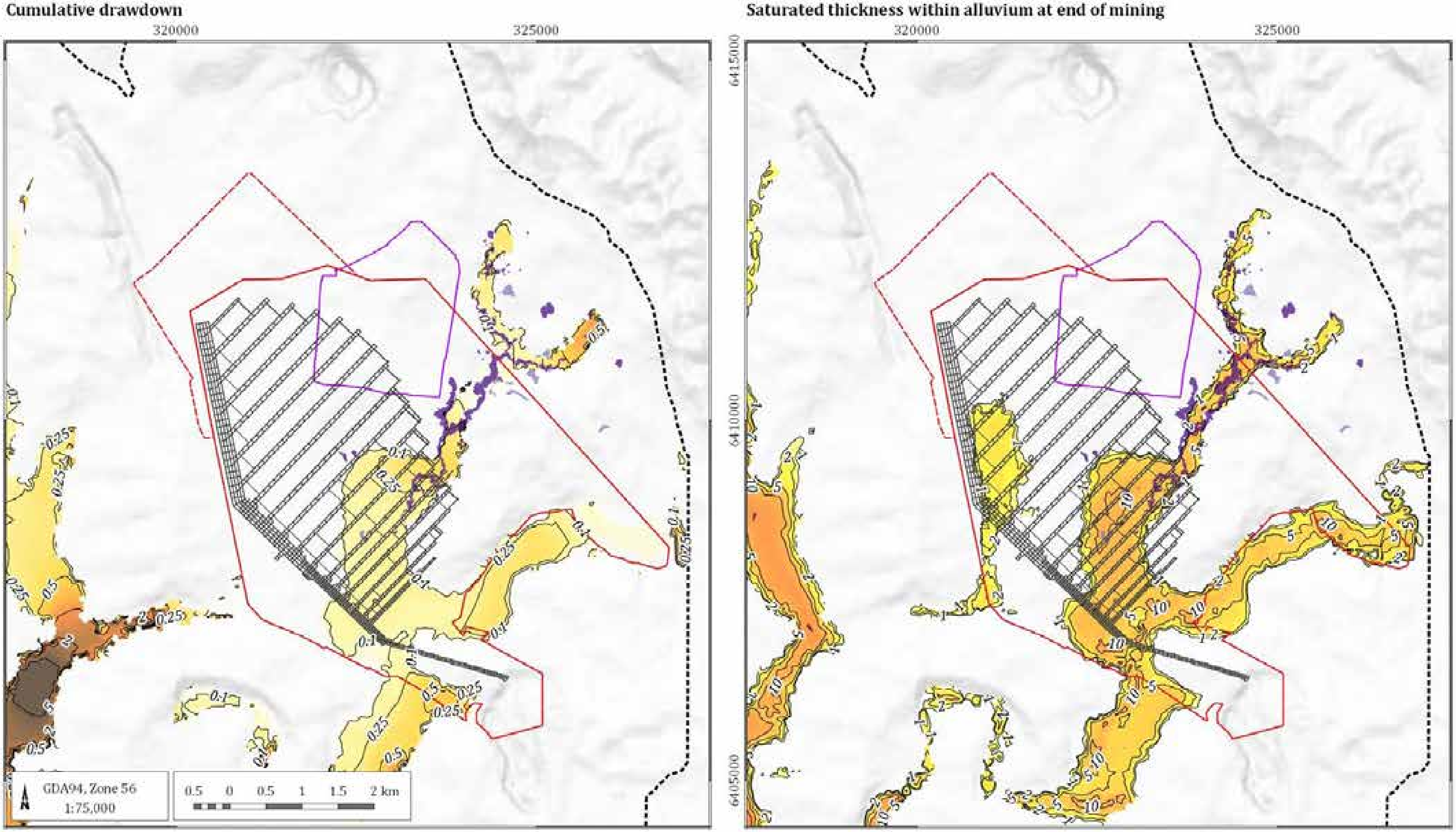
7.1.5 Drawdown in private bores

Section 5.4.1 described groundwater usage in private bores in proximity to the Modification. The majority of bores within the region are located on land owned by mining companies and are either used for monitoring the impact of mining, or are former water bores/wells no longer in use. Only one bore potentially in active use was identified as being located on private property and in proximity to the project. Bore GW067291 is a well located on the northern bank of Glennies Creek near the Middle Falbrook Road Bridge and is drawing water from the Glennies Creek alluvium. The assessment predicts a non-measurable decline in groundwater levels from approved mining or the proposed Modification at this bore. The water level and water quality in GW067291 is currently monitored on a bi-monthly basis by the adjacent open cut operations due to the proximity of these projects.

7.1.6 Impact on groundwater dependent ecosystems

As detailed under Section 5.4.2, potential GDEs have been identified primarily in riparian vegetation along Bettys Creek and Main Creek. Figure 7-9 shows the location of the identified GDEs along with the maximum cumulative drawdown predicted within the Quaternary alluvium. Figure 7-9 also shows saturated thickness remaining within the alluvial sediments at the end of the simulated mining period.

When interpreting these figures it is important to note that the Modification is predicted to generate no detectable drawdown. The already approved cumulative impact is therefore provided as it represents the maximum impact on potential GDEs. The figures show that whilst the numerical model predicts the potential for a small amount of drawdown in the order of 0.25 m this is essentially undetectable and outside the expected accuracy of the model. The figures show the limited drawdown from the already approved cumulative impacts of mining does not dewater the alluvial sediments. A survey of bores installed within the Betty's Creek and Main Creek alluvial aquifers did not detect the presence of stygofauna. Stygofauna were detected Glennies Creek alluvium however it is considered there is a low risk of mining related impacts based on the limited drawdown predicted to occur within the Quaternary alluvium.



LEGEND

- Model extent
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Quaternary alluvium extent
- Major road
- Minor road
- Major drainage
- Minor drainage
- Contour line (m)

Vegetation (Umwelt, 2017)

- Central Hunter Swamp Oak Forest
- Hunter Lowland Red Gum Forest

Integra (G1205A)

AGE

GDEs and predicted maximum cumulative drawdown in Quaternary alluvium

DATE
16/11/2017

FIGURE No:
7-9

7.2 Cumulative drawdown

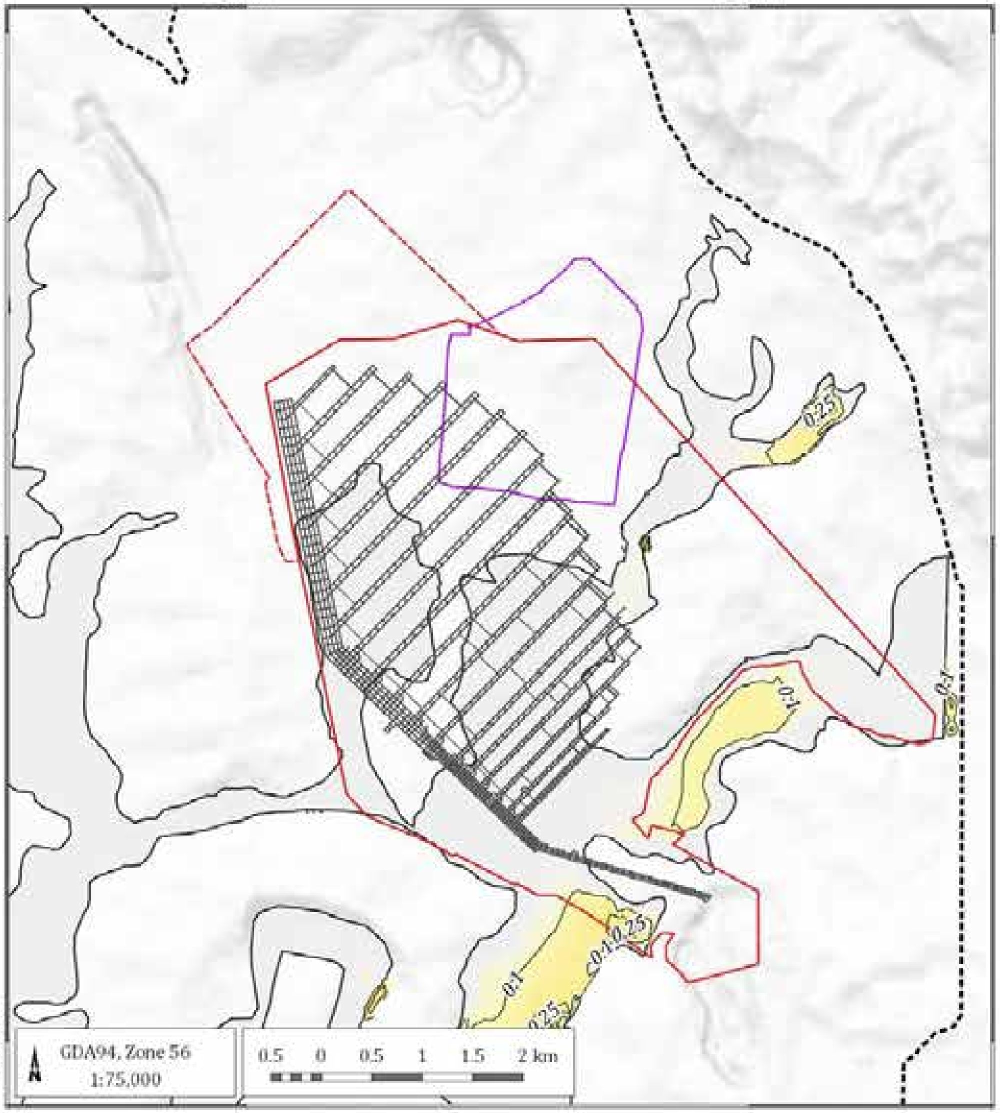
Approved coal mines within the region operate below the water table in relatively close proximity to the Modification and therefore create a cumulative impact where the zones of drawdown overlap. No coal seam gas extraction projects are currently in operation or proposed in the vicinity of the Modification based on publicly available information.

The numerical groundwater model was used to assess the cumulative drawdown generated where zones of drawdown from over mines overlap. The surrounding mines included approved and foreseeable operations at Integra Underground, Rixs Creek North, Mount Owen Mine, Ravensworth East, Glendell Mine, Ravensworth Operations, Liddell Mine, Ashton Underground, and Hunter Valley Operations (HVO) North mine. The simulation of mining at these sites using the numerical model was based on the 2014 version of the numerical model which was updated for Integra Underground and mines within the Mount Owen Complex that are proposing to modify approved mining operations.

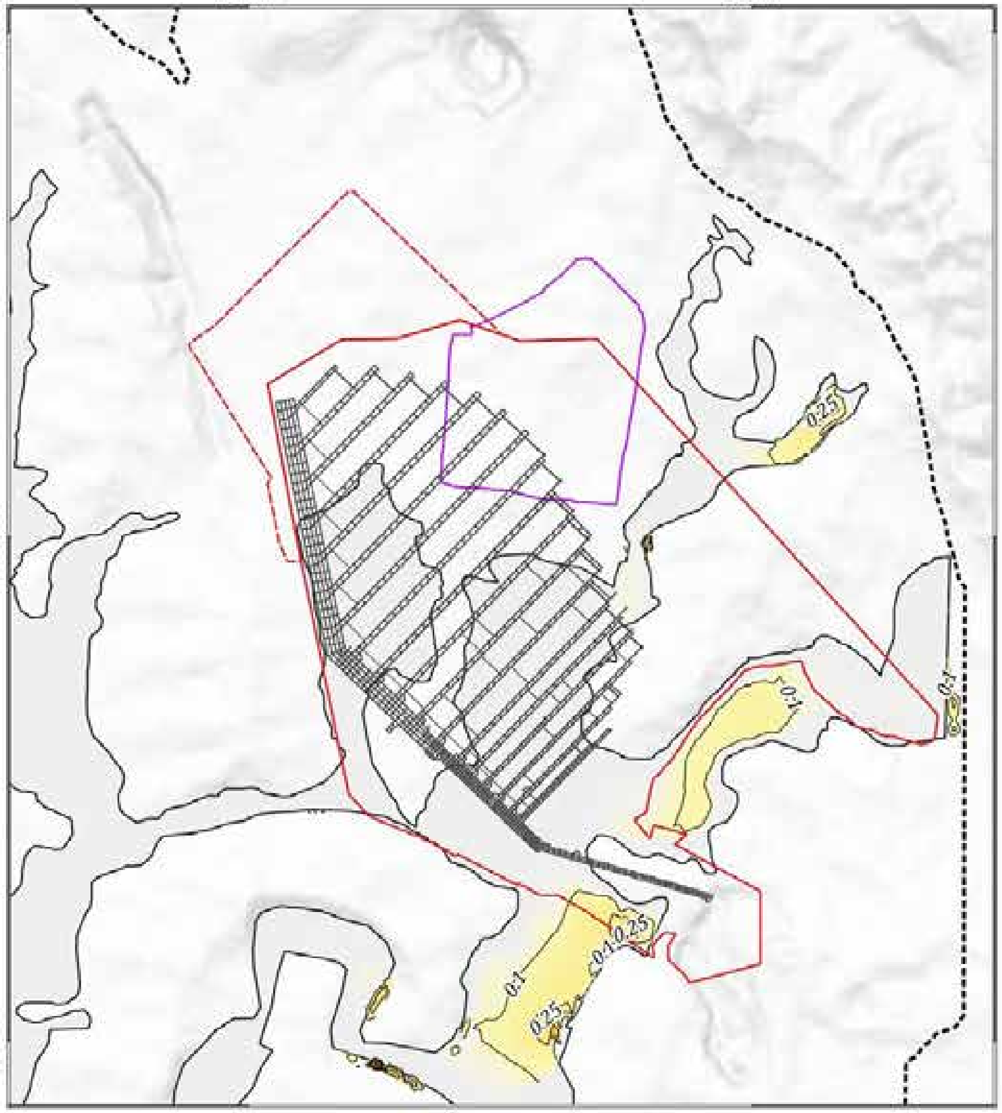
Figure 7-10 and Figure 7-11 show the maximum cumulative drawdown for the Quaternary alluvium and Middle Liddell Seam respectively. The cumulative drawdown is calculated assuming no mining development occurred within the region as baseline levels. Figure 7-10 compares the predicted drawdown within the Quaternary alluvium for the approved mining and proposed Modification at Integra Underground with the cumulative impact from all surrounding mining (including Integra Underground). It indicates the cumulative drawdown induced by all mining ranges from 0.1 m to 0.5 m within the alluvial systems.

Figure 7-11 shows the Middle Liddell seam is predicted to be significantly depressurised in the region due to the cumulative impacts of mining operations.

Approved mining and Modification drawdown



Cumulative drawdown



LEGEND

- Model extent
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Quaternary alluvium extent
- Major road
- Minor road
- Major drainage
- Minor drainage
- Drawdown contour line (m)

Integra (G1285A)

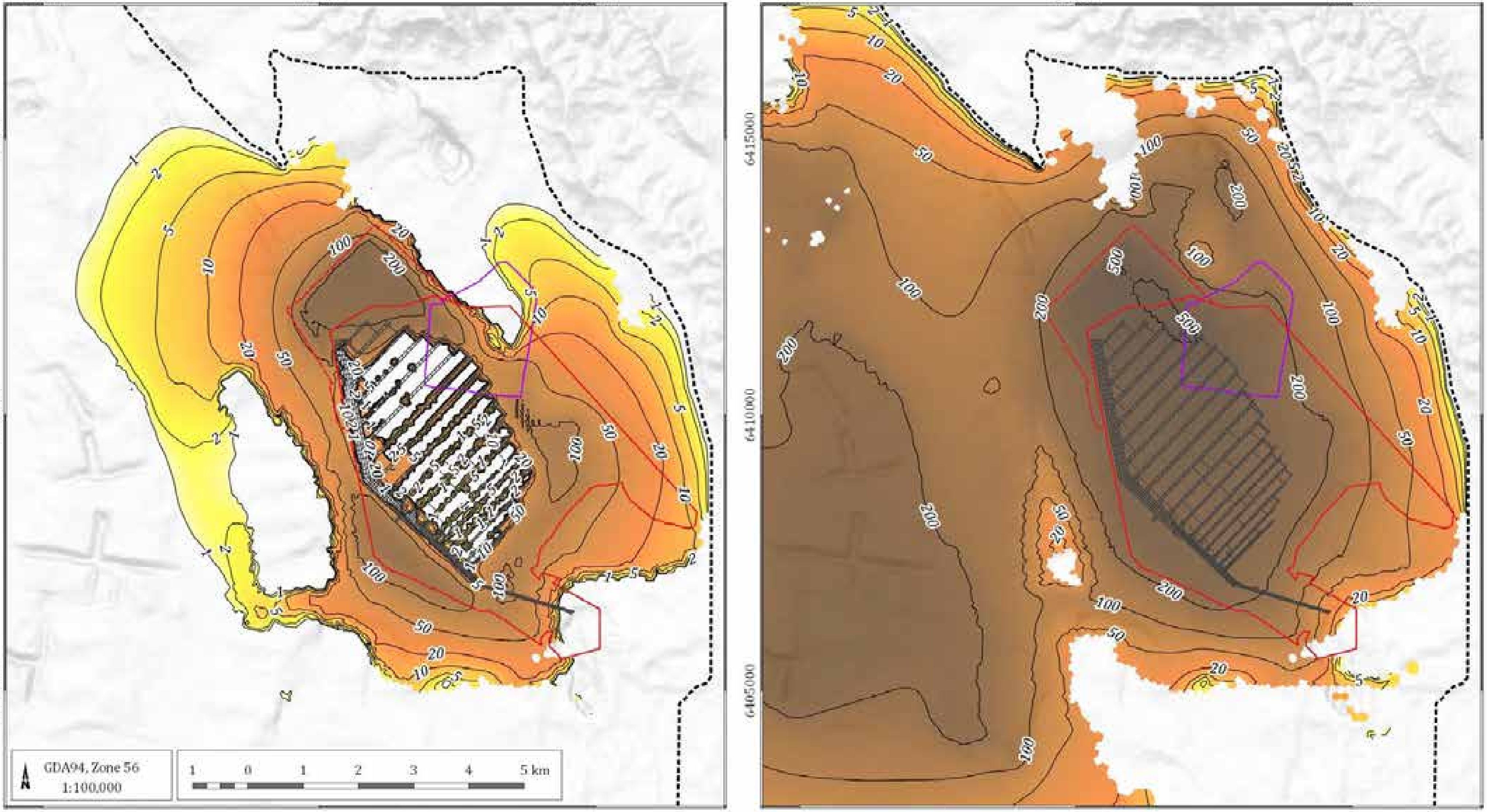
Cumulative drawdown - Quaternary alluvium

DATE
16/11/2017

FIGURE No:
7-10

G:/Projects/G1285A.Integra/3_GIS/Workspaces/002_EIA/07.14_G1285A_Cumulative drawdown.qgs

Approved mining and Modification drawdown | **Cumulative drawdown**



LEGEND

- Model extent
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Drawdown contour line (m)

Integra (G1285A)

AGE

Cumulative drawdown - Middle Liddell Seam

DATE
16/11/2017

FIGURE No:
7-11

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:/Projects/G1285A.Integra/3_GIS/Workspaces/002_EIA/07.14_G1285A_Cumulative drawdown.qgs

7.3 Post mining recovery conditions

Post mining conditions were also simulated using the numerical model to determine if the changes to hydraulic conductivity created by the approved mining and the Modification result in a long term impacts to the groundwater systems. Appendix A (Section A4) provides details of the model set up and the representation of post mining conditions. The sections below describe the post mining predictions of water levels, drawdown, changes in water quality.

7.3.1 Post closure groundwater recovery

Post mining conditions were simulated using a transient model run over a period of 1,000 years. Groundwater levels from the end of mining were used as the starting heads after removal of all mine 'drain cells' in the model. The fracture network induced by subsidence above the longwall panels was introduced to the model by increasing the hydraulic conductivity according to the relationship described in Appendix A.

When interpreting the post mining results it is important to note that the length of the recovery simulation period reduces the confidence in the forecast of post mining predictions. The post mining predictions should therefore be considered an indicator of potential impacts post mining, that can be used to assist in post closure planning for the approved mining and the Modification.

The model results indicate that groundwater will gradually seep into the underground mining areas and re-pressurise the Permian strata slowly over time. During the period where the strata is re-pressurising the Integra Underground Mine workings, including the Modification will be a 'sink' for groundwater flow, meaning groundwater will flow into the mine, not out. As the mined strata re-pressurise groundwater flow will be governed by the established hydraulic gradients, that will facilitate the slow movement of groundwater from the underground mine into surrounding rock units.

The groundwater levels within the model layers were extracted to examine the rate of recovery. Figure 7-12 shows the recovery in groundwater levels within selected layers for the deepest point within the Modification area.

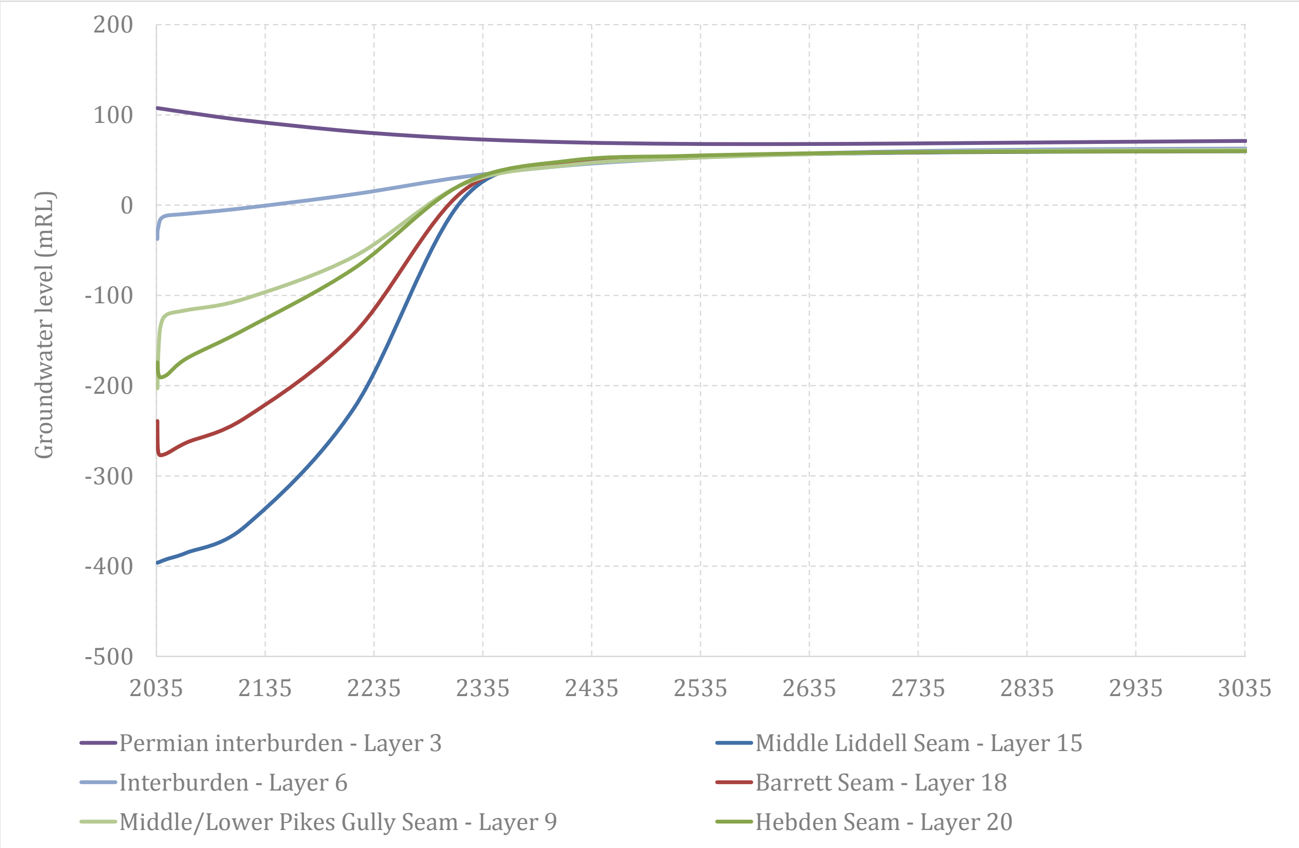


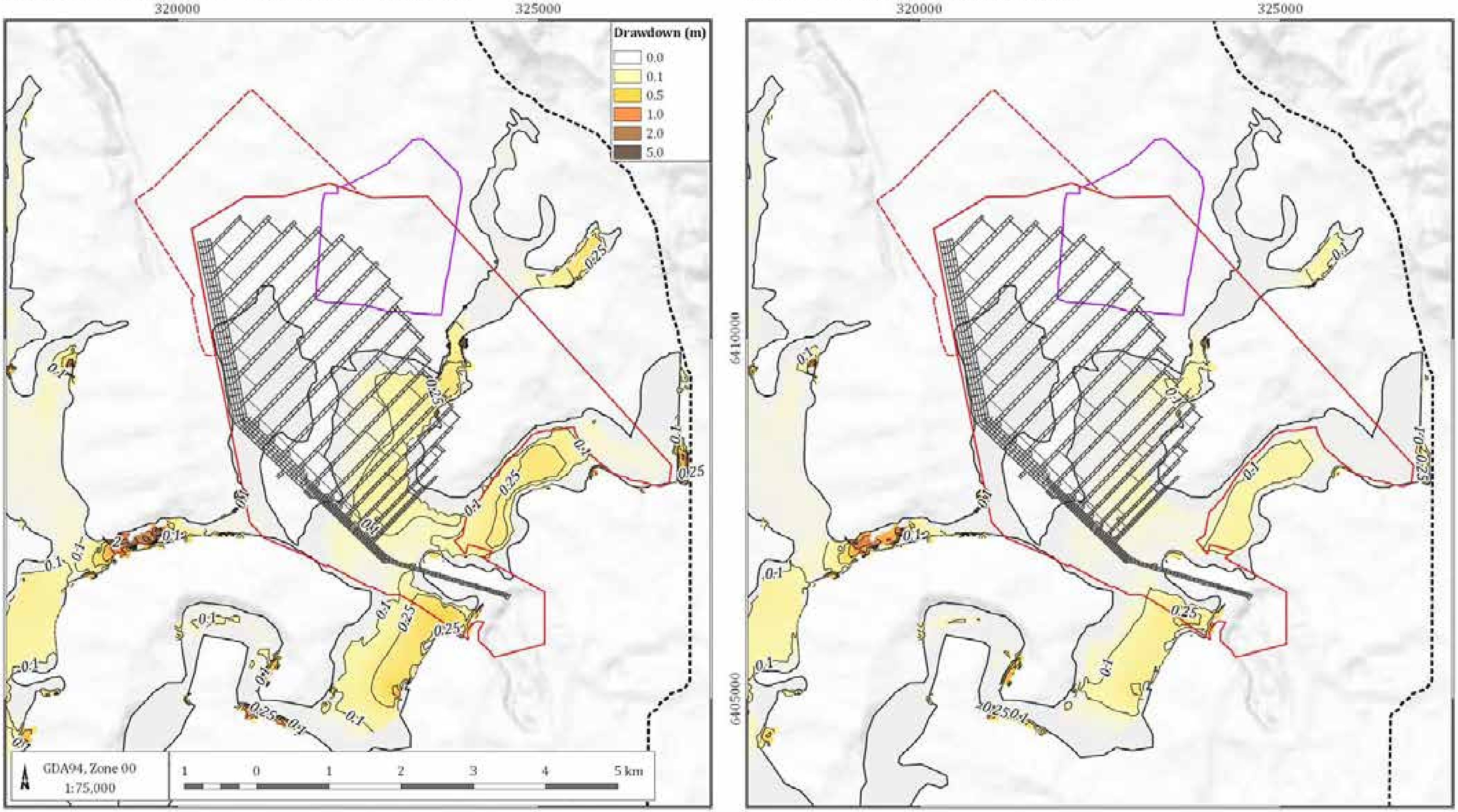
Figure 7-12 Recovery of groundwater levels with Modification area

Figure 7-12 shows a short term change in water levels within a number of the model layers immediately following the cessation of mining. This change occurs when the drain cells are removed and the hydraulic conductivity is adjusted to represent the post-mining fracture network. The groundwater levels and pressures then slowly recover within the Middle Liddell seam over a period of about 500 years reaching an equilibrium level of around 57 m AHD at that point. Groundwater levels within the Barrett and Hebden seams which have not been mined within the area of the Modification also recover to a similar level.

Figure 7-13 shows the maximum drawdown within the Quaternary alluvium that occurred during recovery. The figures shows that post mining the drawdown within the Quaternary alluvium becomes slightly more extensive in response to the continuing drainage of groundwater into the underground mine. The magnitude of the drawdown within the Quaternary alluvium is relatively limited at generally less than 0.25 m which is considered undetectable from seasonal fluctuations.

Approved mining plus Modification post-mining drawdown

Modification only post-mining drawdown



LEGEND

- Model extent
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Quaternary alluvium extent
- Major drainage
- Minor drainage
- Major road
- Minor road
- Drawdown contour (m)

Integra (G1205A)

AGE

Post-mining maximum drawdown - Quaternary alluvium

DATE
16/11/2017

FIGURE No:
7-13

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/G1205A.Integra/3_GIS/Workspaces/002_EIA/07.13_G1205A_Post mining equilibrium.qgs

7.3.2 Groundwater quality changes

As stated previously, post mining the portals to the underground mining areas will be sealed and groundwater seepage from the surrounding Permian strata will slowly flood the workings. Unlike open cut mining there is no potential for evaporation to concentrate salts within the underground mining areas, and therefore an increase in salinity of the Permian water seeping into the mine is not expected to occur. Any oxidised zones of sulfidic material occurring on the roof and floor of the underground mines has the potential to influence the groundwater quality within the underground mining area. HVCC monitor the quality of groundwater pumped from the currently operating longwall mine at a sump located at the mine portal. Recent monitoring data indicates the groundwater pumped from the underground mine is neutral to slightly alkaline in pH ranging from 7.5 to 8.5 pH units and therefore does not indicate acidification impacts. The annual review for Integra Underground indicated TDS ranges from 1,310 mg/L to 5,900 mg/L and is typically in the moderately saline range (EMM 2016). As noted previously, when the underground mining area has refilled post mining a hydraulic gradient forms from the underground mining area towards the North Pit open void lake at Mount Owen mine.

7.4 Sensitivity

The uncertainty in the model conceptualisation was assessed using a traditional sensitivity analysis where model assumptions were adjusted individually to assess the impact upon the predictions. A more complex non-linear uncertainty analysis was also undertaken where numerous model parameters were changed at the same time using 179 model realisations. Appendix A presents the results of the sensitivity and uncertainty analyses.

The majority of the 179 model realisations developed for the uncertainty analysis produced groundwater inflows representative of rates observed during 2016 at around 300 ML/year. The uncertainty analysis indicated future inflows up to 888 ML/year at 1 standard deviation above the median in year 2032.

The uncertainty analysis did not predict any significant impacts to the alluvium due to the Modification. The median drawdown + 2 standard deviations predicted for the Modification was 0.03m with 0.01 m predicted for +1 standard deviation. These levels of drawdown would not be detectable from natural fluctuations in groundwater levels.

8 Groundwater monitoring and management plan

HVCC currently operates Integra Underground in accordance with a WMP which was prepared in consultation with NSW government agencies and approved in 2017. As stated previously, the WMP has been recently updated to incorporate a recent modification to the Project Approval. The WMP describes the management of environmental and community aspects, impacts and performance relevant to the sites water management system (Glencore 2017). The existing groundwater monitoring programs will be continued and augmented to ensure the impact of the Modification is monitored and managed. The sections below outline aspects of the current WMP, and recommended updates to monitor the impact of the Modification. If the Modification is approved the WMP will be updated in accordance with the requirements of PA 08-0101 (as modified).

8.1 Groundwater monitoring program

The current WMP includes as a subsection a Groundwater Management Plan. The Groundwater Management Plan outlines a monitoring program to collect groundwater levels and quality measurements and allow actual impacts to the local groundwater system to be compared against those identified in the environmental assessments. The groundwater monitoring program focusses on collecting information on potential impacts to:

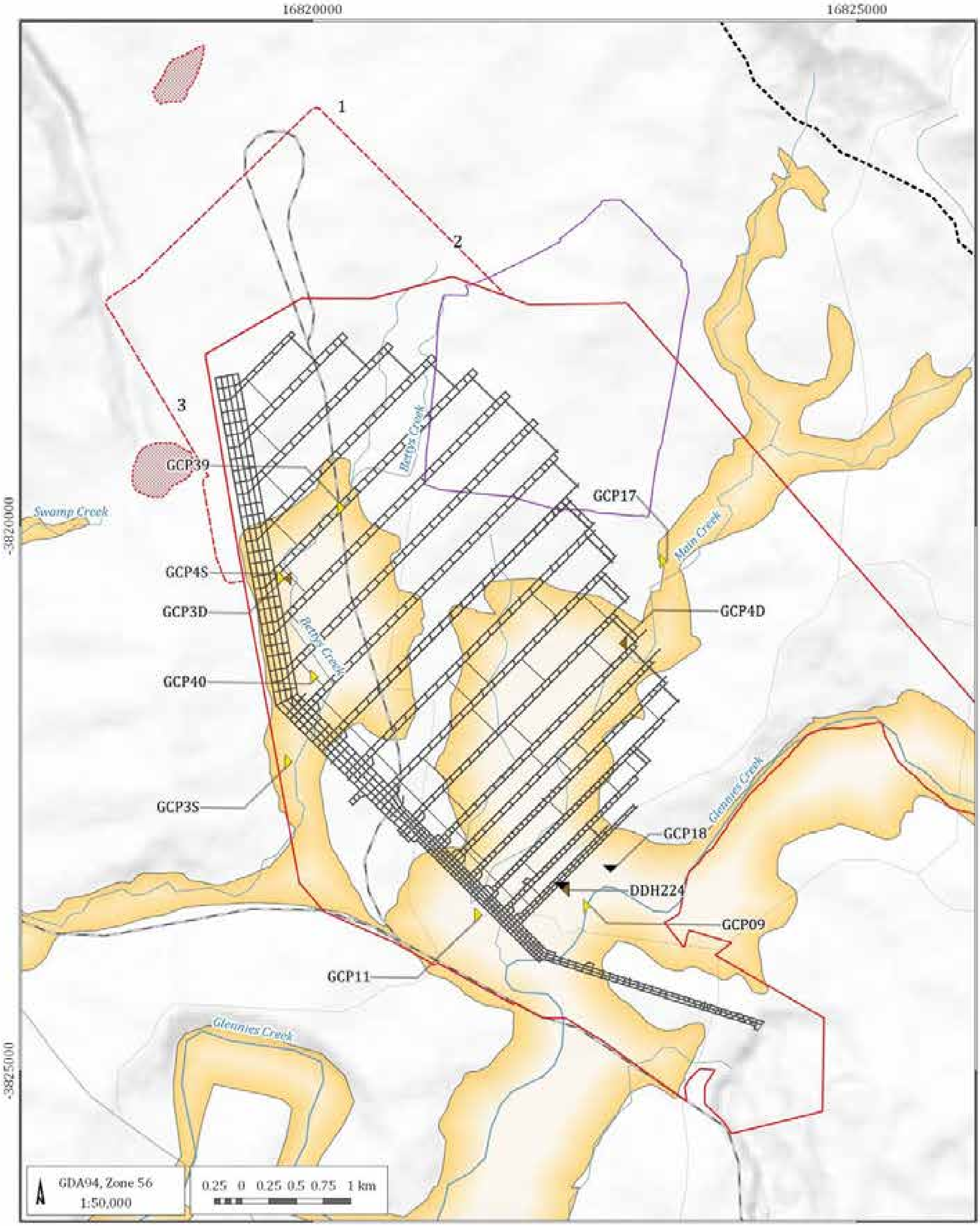
- groundwater levels on neighbouring properties and any beneficial groundwater users;
- groundwater quality; and
- water licence compliance.

Table 8-1 below indicates the monitoring bores that form the current groundwater monitoring network for Integra Underground. The monitoring network is comprised of standard 50 mm PVC monitoring bores installed with the alluvial aquifers and the coal measures. An array of VWPs cemented into drillhole DDH224 are also included within the monitoring network. The locations of the monitoring bores are shown in Figure 8-1.

Table 8-1 Summary of WMP monitoring bores

Bore ID	Aquifer	Bore licence	Screen zone (mbgl)
GCP3S	Bettys Creek alluvium	20 BL 169571	3.4 – 5.4
GCP4S	Bettys Creek alluvium	20 BL 169571	4.0 - 6.1
GCP17	Main Creek alluvium	20 BL 171813	4.0 – 7.5
GCP40	Bettys Creek alluvium	20 BL 171870	5.0 – 6.0
GCP39	Bettys Creek alluvium	20 BL169571	0.0 – 3.0
GCP11	Main Creek alluvium	20 BL167917	N.A – 12
GCP9	Glennies Creek alluvium	20 BL 171708	N.A
GCP3D	coal measures	20 BL 169571	40.0 – 48.5
GCP4D	coal measures	20 BL 169571	13.5-35.8
GCP 18	coal measures	20 BL 171707	Open hole
DDH 224	coal measures	none – fully cemented VWP array	Various

The existing monitoring network will be augmented with additional sites to monitor the impact of the Modification. The monitoring sites need to be located outside the subsidence footprint of the Modification in areas where the sequence of coal seams remains. Areas where opencut mining has occurred or is proposed are also not suitable. Given these constraints two areas have been selected for installation of monitoring bores. Figure 8-1 shows the areas suitable for installation of new bores to monitor the impact of the Modification. The final sites will be selected in consultation with DPI Water and documented in the WMP. These sites will be constructed with an array of multilevel vibrating piezometers installed throughout the geological sequence to monitor depressurisation vertically through the geological sequence. To ensure cumulative impacts are addressed annual reviews also review the groundwater monitoring data collected at the Mount Owen mine where the bores are in proximity to Integra Underground.



LEGEND

- Integra Underground Project approval boundary
- Modification Project boundary
- Approved Middle Liddell seam mining
- Proposed Mount Owen North Pit mining
- Alluvium extent
- Proposed area for new monitoring bores
- Major drainage
- Minor drainage
- Major road
- Minor road
- Rail

Groundwater monitoring bores

- Alluvium
- Coal Seam
- Interburden

Integra (G1285A)

Groundwater monitoring network

DATE 22/11/2017

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/G1285A.Integra/3_GIS/Workspaces/002_IBA/08.01_G1285A_Groundwater monitoring network.qgs

8.2 Water level monitoring plan

Currently groundwater levels are measured in the monitoring bores on a bi-monthly basis, in addition to twice daily readings recorded by the dataloggers in the monitoring bores and VWPs. The current monitoring along with the additional proposed bores are considered adequate to monitor the predicted impacts of the Modification. Groundwater levels will continue to be monitored at the groundwater monitoring network locations discussed in Section8.1. Ongoing monitoring will enable natural groundwater level fluctuations (such as responses to rainfall) to be distinguished from potential groundwater level impacts due to depressurisation resulting from proposed mining activities. Ongoing monitoring of groundwater levels will also be used to assess the extent and rate of depressurisation against model predictions.

Yearly reporting of the water level results from the monitoring network will be included in the annual review. The annual review will also identify if any additional monitoring sites are required, or if optimisation of the existing monitoring sites should be undertaken.

8.3 Water quality monitoring plan

Currently groundwater monitoring is conducted at Integra Underground on a bi-monthly basis for field water quality (EC and pH), and on an annual basis for more comprehensive water quality analysis at selected bores. The more comprehensive water quality analysis includes:

- pH, electrical conductivity, total dissolved solids;
- Major ions - Ca, Cl, K, Na, Mg, SO_4, HCO_3;
- Hardness;
- Nutrients - NO_3, Total N, Total P; and
- Total metals- Cu, Pb, Zn, Ni, Fe, Mn, As, Se, Cd, Cr.

Groundwater quality analysis will continue in order to detect any changes in groundwater quality during mining. The current monitoring is considered adequate to monitor the predicted impacts of the Modification on groundwater quality. The full groundwater quality suite will be expanded in order to include key analytes to determine any changes in beneficial groundwater use (i.e. livestock drinking water). The revised full suite will include:

- physio-chemical indicators – pH, electrical conductivity, total dissolved solids;
- major ions – Ca, F, Mg, K, Na, Cl, SO_4;
- total alkalinity as $CaCO_3$, HCO_3, CO_3; and
- dissolved and total metals – aluminium, arsenic, barium, boron, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, strontium, silver, vanadium and zinc.

Similar to the water level monitoring, yearly reporting of the water quality results from the monitoring network should be included in the annual review. The annual review should consider if any additional monitoring sites are required, or if optimisation of the existing monitoring sites, frequency of sampling and analytical suite should be undertaken. The WMP updates will consider the optimal sites for monitoring of groundwater quality during the life of the Modification.

8.4 Trigger levels

The WMP currently provides triggers for pH, EC and depth to groundwater for the standpipe bores within the network. The trigger levels have been calculated as the 20th and 80th percentile of water quality and level data collected between 2009 and 2016. These are considered appropriate to monitor the impacts of the Modification.

8.5 Mine water seepage monitoring

The WMP includes the requirement to monitor groundwater inflow to the underground mine on a quarterly basis, and provides a preliminary and secondary trigger based on the inflow volume. The preliminary trigger is 73 ML/quarter and the primary trigger 90 ML/quarter. The WMP requires that if either trigger volume is met an investigation is initiated to understand the deviation from predicted groundwater inflow volumes and to ensure no exceedance of groundwater dewatering licences occurs. The trigger in the WMP for inflow volume will be updated based on the updated groundwater modelling conducted for the Modification.

8.6 Future model iterations

Every five years the validity of the model predictions will be assessed and if the data indicates significant divergence from the model predictions, an updated groundwater model will be constructed for the simulation of mining. It is considered this remains appropriate to track the impacts of the Modification on the groundwater regime.

8.7 Data management and reporting

The WMP outlines the data management and reporting requirements for groundwater data. This includes an annual review of the monitoring data, and a standalone report following the completion of extraction of each longwall panel. Conditions outlined in licences 20 BL 172505 and 20 BL 172506 also require annual reporting of:

- all raw water monitoring data, an interpretation of that data and a discussion of trends identified in the data and their implications;
- all groundwater extraction data (volumes and rates) taken by the works, the extent of aquifer depressurisation and the salinity impacts, compared with predictions of aquifer performance made in the Environmental Impact Statement or similar project documents;
- an overall comparison of groundwater performance with predictions for the life of the mine provided in the development application and supporting documentation;
- water related activities performed and the level of compliance with the Groundwater Management Plan, and an outline of the proposed adaptive or remediation actions; and
- assessment of extraction or other depressurisation impacts caused by the works to external water sources, water users or GDEs.

These procedures remains appropriate to report the impacts of the Modification on the groundwater regime.

8.8 Management and mitigation strategies

The WMP provides a Trigger Action Response Plan (TARP) to implement in the case of groundwater monitoring results being detected outside the groundwater trigger value range. The actions to be implemented in the event of a trigger exceedance are:

- confirm the timing and general location of the exceedance(s);
- confirm the meteorological conditions at the time of the exceedance(s) (where relevant);
- identify any potential contributing factors;
- assess the monitoring results against background trends to identify any anomalies or causes;
- if the exceedance is not attributable to Integra Underground, the routine monitoring program will be assessed for its effectiveness;
- where the exceedance is potentially attributable to Integra Underground appropriate mitigation and management strategies will be developed and implemented;
- where mitigation and management strategies have been implemented additional monitoring and reviews will be undertaken to measure the effectiveness of the strategies undertaken;
- the exceedance will be reported in accordance with the reporting mechanisms outlined in the water monitoring program; and
- investigation must consider the requirement for an independent investigation by a suitably qualified hydrogeologist whose appointment has been approved by the Secretary.

If dewatering volumes exceed the trigger levels specified the following actions will be implemented:

- initiate an investigation to understand the deviation from predicted groundwater inflow volumes and to ensure no exceedance of groundwater dewatering licences occur; and
- the investigation must consider the requirement for an independent investigation by a suitably qualified hydrogeologist whose appointment has been approved by the Secretary.

The WMP also provides a TARP for baseflow changes in Bettys Creek, Main Creek and Glennies Creek. The trigger is if observable loss of baseflow occurs then specific baseflow trigger levels will be derived once sufficient streamflow data is available. Actions specified in the WMP include:

- a qualified hydrologist will be commissioned to assess whether the loss of flow is due to the underground mine; and
- management strategies will be developed and implemented where loss of flow is due to the underground mine.

The WMP also notes that are no predicted impacts on private water bores, but allows for monitoring if requested by private landowners. The WMP provides for the following actions if a reduction in water level is established as a consequence of mining:

- re-establishment of saturated thickness (alluvial aquifer) or standing water level (basement aquifer) in the affected bore(s) through bore deepening;
- establishment of additional bores to provide a yield at least equivalent to the affected bore prior to mining;
- provision of access to alternative sources of water; and/or
- compensation to reflect increased water extraction costs, e.g. due to lowering pumps or installation of additional or alternative pumping equipment.

The WMP also includes the following protocol for management of any unforeseen impacts on groundwater:

- conduct a preliminary review of the nature of the impact, including:
    - initial assessment of environmental harm;
    - any relevant monitoring data; and
    - current mine activities and land use practices.
- commission an investigation into the unforeseen impact to confirm cause and effect and consider relevant options for amelioration of impact(s) as appropriate;
- prepare an action plan in consultation with the relevant stakeholders;
- mitigate causal factors where possible; and
- implement additional monitoring as necessary to measure the effectiveness of the controls implemented.

The management and mitigation strategies outlined above will be continued for the Modification.

9 Summary and conclusions

The groundwater assessment for the Modification considered the impacts of underground mining the Middle Liddell Seam including:

- realignment and extension of the main headings further to the north-west;
- increases to the lengths and widths of the approved LWs 15-17; and
- mining of additional longwall panels (LWs 18-19 or LWs 18-20).

The Modification is proposed to occur within the Middle Liddell Coal seam that is relatively deep occurring some 300 m to 500 m below the land surface. The Modification underlies a disturbed landscape with areas of open cut mining and out of pit overburden dumps occurring over much of the Modification footprint. Alluvial aquifers are not present within the footprint of longwall mining proposed for the Modification and do not meet the criteria of highly productive aquifers. Subsidence will create a fracture network above the Modification, which will potentially enhance the connectivity through the Permian strata but will not directly connect with the Quaternary alluvium. Therefore from a groundwater perspective the Modification is not considered to occur within an environmentally sensitive area.

The prevalence of mining in the region means there have been many previous groundwater modelling efforts. The numerical model developed for the Modification was built upon an existing large regional model to create consistency with previous work and to represent the cumulative impacts of the Modification and the surrounding region.

The model was used to assess the incremental effects of the Modification and changes to approved impacts brought about through recalibration. Cumulative effects from neighbouring mines were also assessed. The key findings were:

- the enhanced permeability induced by subsidence of strata overlying the Modification will induce inflow that will directly intercept up to 257 ML/year of groundwater from the Permian coal measures – HVCC hold sufficient water license entitlements to account for this;
- the inflow to the Modification will generate a zone of drawdown within the Permian coal measures focussed around the Modification footprint – there are no private water bores or GDEs within this drawdown zone;
- the maximum net loss of groundwater from the Quaternary alluvium and from connected stream baseflow due to the Modification is predicted to be negligible at less than 1 ML/year and therefore undetectable;
- the Modification will not result any in detectable incremental drawdown within Quaternary alluvial aquifers, due primarily to the significant depth of mining – therefore private water bores and GDEs reliant on the alluvial systems will not be affected.
- at closure groundwater will gradually seep into the Modification area and re-pressurise the Permian strata slowly over time - during the period where the strata is re-pressurising the Modification will be a ‘sink’ for groundwater flow.

No additional groundwater impact mitigation measures are proposed for the Modification. Groundwater levels and quality should continue to be monitored in accordance with the approved WMP. It is recommended that the monitoring bore network be augmented to include the installation of additional monitoring sites around the footprint of the Modification.

Consistent with the currently approved WMP, in the event that a groundwater quality or level trigger level specified is exceeded, an investigation should be conducted in accordance with the Surface and Groundwater Response Plan.

10 References

Australasian Groundwater and Environmental Consultants Pty Ltd (2017), *"Report on Main Creek Alluvium Verification and Mapping – Mount Owen Continued Operations – Mod 2"*, Project No. G1862, 26 September 2017

Arnold and Allen (1999), *"Automated methods for estimating baseflow and groundwater recharge from streamflow records"*, Journal of the American Water Resources Association vol 35(2) (April 1999): 411-424

Barnett B., Townley L.R., Post V., Evans R.E., Hunt R.J., Peeters L., Richardson S., Werner A.D., Knapton A. and Boronkay A. 2012, *"Australian groundwater modelling guidelines"*, Waterlines report, National Water Commission, Canberra, June 2012.

Commonwealth of Australia (2013), "*Significant impact guidelines 1.3: Coal seam gas and large coal mining developments – impacts on water resources",* Department of the Environment, 2013.

Cumberland Ecology (2017), *"Integra Underground Longwall Extension Modification, Ecological Impact Assessment*", prepared for Hansen Bailey, October 2017, Report No.17059RP1

DPI-Water (2012) http://www.water.nsw.gov.au/__data/assets/pdf_file/0008/547343/law_use_groundwater_productivity_nov_2012.pdf

Eco Logical (2017), *"Mount Owen Continued Operations, Modification 2, Stygofauna Assessment."* Prepared for Umwelt Australia, Project No. 17ARM-7149 (Draft)

EMM (2016). *"Glencore Integra Underground Mine, Annual Review 2016"*, 14 August 2017. http://www.glencore.com.au/en/who-we-are/energy-products/integra/ems/Reporting/2016-Annual-Review_Additional%20Information.pdf

FAO (2013), Food and Agricultural Organisation of the United Nations: http://www.fao.org/docrep/t0667e/t0667e05.htm

Geoterra (2009), *"Middle Liddell, Barrett and Hebden Seam Underground Mining Project Area Groundwater Assessment, Integra Underground, NSW*", C12-R1D, 16 June 2009

HVCC (2017), *"Integra Underground Water Management Plan"*, 13/2/2017, document number NTUG-793190785-68

Jacobs (2014), *"Mount Owen Continued Operations Project, Groundwater Impact Assessment"*, Revision D, Final post peer review, Project No. 3109H, 29 October 2014

Mackie, CD (2009), "*Hydrogeological Characterisation of coal measures and overview of impacts of coal mining on groundwater systems in the Upper Hunter Valley of NSW*", phD thesis, Faculty of Science, University of Technology, Sydney.

Macfarlane C, Rachakonda PK, Herron NF, Marvanek SP, Wang J, Moore B, Bell J, Slegers S, Mount RE and McVicar TR (2016), *"Description of the water-dependent asset register for the Hunter subregion"*. Product 1.3 for the Hunter subregion from the Northern Sydney Basin Bioregional Assessment. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. http://data.bioregionalassessments.gov.au/product/NSB/HUN/1.3.

McIlveen G.R. (1984), "*Singleton 1:25 000 Geological Map"*, 9132-IV-N, Geological Survey of New South Wales, Sydney.

New South Wales Officer of Water (2012), "*Aquifer Interference Policy"*, NSW Government policy for the licensing and assessment of aquifer interference activities, Department of Primary Industries.

SCT (2008B), *"Packer test summary hole DDH223"*

Umwelt (2015), *"Mount Owen Continued Operations Project. Report B Response to the Department of Environment Submission"*, August 2015.

Glossary and acronyms

AGE	Australasian Groundwater and Environmental Consultants Pty Ltd
AHD	Australian Height Datum
AIP	Aquifer Interference Policy
BSAL	Biophysical Strategic Agricultural Land
CSG	Coal seam gas
CRD	Cumulative Rainfall Departure
DoEE	Department of the Environment and Energy
DPI	Department of Primary Industries
GDE	Groundwater Dependent Ecosystem
Glencore	Glencore Coal Pty Limited
HVCC	HV Coking Coal Pty Ltd, a wholly owned subsidiary of Glencore Coal Pty Ltd
IESC	Independent Expert Scientific Committee
LW	Longwall mining panel
ML	Megalitres
MNES	Matters of National Environmental Significance
Mount Owen	Mount Owen Pty Ltd
Mtpa	Million tonnes per annum
Pinneena	NSW Office of Water supplied database of registered groundwater bores
SILO	SILO is a database of historical climate records for Australia
SRLU Policy	Strategic Regional Landuse Policy
TARP	Trigger Action Response Plan
TDS	Total Dissolved Solids
VWP	Vibrating wire piezometer
WMP	Water management plan
WSP	NSW Water Sharing Plan

Appendix A

Numerical Modelling Report

A1 Introduction

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

- assess the groundwater inflow to the mine workings as a function of mine position and timing;
- simulate and predict the extent and area of influence of dewatering and the level and rate of drawdown at specific locations;
- identify areas of potential risk where groundwater impact mitigation/control measures may be necessary; and
- simulate and predict the extent of influence of drawdown and potential impacts during the groundwater recovery phase, after mining activities and dewatering are ceased.

The key to the modelling exercise is the adequate conceptualisation of the groundwater regime, and calibration of the model against observed data. The conceptual model is a demonstration of how the groundwater system operates given the available data, and is an idealised and simplified representation of the natural system. The conceptual groundwater model of the project site and surrounding area was developed based on various data sources, including:

- geological and topographical maps;
- geological models developed by the proponent; and
- results from previous hydrogeological investigations and relevant data from the publicly available datasets.

The main report details the conceptual understanding of the hydrogeological regime at the project site. The purpose of appendix is to describe the model setup, calibration and predictive scenarios undertaken with the numerical model.

A2 Model construction and development

A2.1 Model version and update log

Numerical groundwater models used for mining operations inherently require continuous updates and revisions in light of the results that each model version generates and any new information and data collected through observations and monitoring.

The significant development of mining in the region means there have been many previous groundwater modelling efforts. The numerical model developed for the Project was built upon an existing large regional model that was developed by Jacobs (2014) and included the Integra Underground Mine. Glencore commissioned Jacobs to develop the regional scale model which is intended to be updated and refined to represent the impacts of Glencore operations and future mining plans within the model domain. This approach was undertaken to ensure consistency with previous work, and continue the development a large regional flow model that can represent the cumulative impacts of mining in the Project area and surrounding region.

This approach is a good example of a fundamental guiding principle described by Middlemis (2004) that "*.....model development is an on-going process of refinement from an initially simple representation of the aquifer system to one with an appropriate degree of complexity. Thus, the model realisation at any stage is neither the best nor the last, but simply the latest representation of our developing understanding of the aquifer system.*"

Jacobs (2014) provide a model version naming protocol and update log to identify the version of the 'base' model used for various projects. A new version number is assigned when there are changes to the base condition of the regional model, such as model structure, calibration, approved current or future mining operations. Table A 1 below summarises the model version and modifications undertaken since development of the model in 2012.

Table A 1 Model versions

Model version	Model build	Project	Description of modification(s)	Model version number
1	0		• initial model setup; • model calibration	1
1	1	Liddell	• stochastic predictive simulations of proposed operations	1.1 Liddell
2	0		• refined historic mining and backfill sequencing at Ravensworth East, Glendell and Mount Owen operations; • updated geology models for Mount Owen and Ravensworth areas	2
2	1	Ravensworth East	• stochastic predictive simulations of proposed RERR operations	2.1 Rav
2	2	Liddell	• updated stochastic predictive simulations of proposed operations	2.2 Liddell
3	0		• refinement of historic Liddell open cut operations; Inclusion of additional coal barriers around Hazeldene workings	3
3	1	Liddell	• updated stochastic predictive simulations of proposed operations	3.1 Liddell
4	0		• inclusion of historic dewatering operations at Liddell underground workings; • conversion of Bowmans Creek "River" boundary conditions to "Stream" cells; • refinement of top and bottom elevations for Bowmans Creek alluvium based upon new LIDAR; • recalibration (steady state and transient); Creation\selection of new input datasets for stochastic simulations	4
4	1	Liddell	• updated stochastic predictive simulations of proposed operations	4.1 Liddell
5	0		• modification to underground working at Liddell; Addition of new dewatering bore at Middle Liddell underground workings	5
5	1	Liddell	• updated stochastic predictive simulations of proposed operations	5.1 Liddell

Model version	Model build	Project	Description of modification(s)	Model version number
6	0		• refined model progression for mining and backfill sequencing based upon peer review comments; • updated HFB for faults regionally	6
6	1	Liddell	• updated stochastic predictive simulations of proposed operations	6.1 Liddell
7	0	Liddell	• representation of Glennies Creek and Main Creek alluvium based upon LIDAR data; • refinement of Glendell and Mount Owen approved mine sequences and plans; • incorporation of Integra Underground mine; • modification of hydrogeological parameters to account for enhanced conductivity above former underground workings and according to depth of overburden; • modification of model size and stress periods to accommodate updated mine sequencing; • recalibration (steady state and transient) to extended calibration dataset; • updated stochastic predictive simulations of proposed operations	7
7	1	Mount Owen	• recalibration to refine specific yields	7.1 Mount Owen
	2	Liddell	• incorporation of Liddell base case into Version 7	7.2 Liddell
8	0	Mount Owen	recalibration of the model to account for • changes in ET values: Non-mining areas use Actual Areal Evapotranspiration values for maximum ET rates; • inclusion of Liddell total dewatering rates for 2012 and 2013;I • inclusion of additional alluvial monitoring data	8
8	1	Mount Owen	• predictive simulations for Mount Owen Continued Operations EIS	8.1 Mount Owen

Model version	Model build	Project	Description of modification(s)	Model version number
9	0	Integra Underground Mine	• modelling taken over by AGE • converting model to MODFLOW USG including development of new model mesh and layers • updating water level monitoring dataset • representing hydraulic conductivity as decreasing with depth in Permian model layers • adjusted coal seam levels based on updated geological model from Mt Owen mine • updating the thickness of the alluvium based on borehole logs • recalibrating model to water level records and mine inflows at Integra • updating progression of approved and proposed mining at Integra Underground mine • adding approved open cut mining at Rix Creek North Mine (former Integra open cut) • updating progression of foreseeable mining at Mt Owen Mine • predicting impacts on groundwater regime for proposed mining at Integra Underground	9

A2.2 Model code

MODFLOW-USG was determined to be the most suitable modelling code to meet the model objectives because it:

- allows use of an unstructured mesh where cells are refined in the areas of interest to represent hydrogeological and mining features, and larger cells are used where refinement was not required;
- does not need layers to be continuous over the model domain, allowing layers to stop where geological units pinch out or outcrop such as coal seams and alluvium;
- effectively reduces the number of cells with the refinement and pinching options that allow faster model run times; and
- better represents flow transfer processes between systems such as bedrock and alluvial groundwater systems through the pinching out of layers.

The model was supplied by Jacobs and converted from MODFLOW SURFACT to MODFLOW-USG Beta (Panday *et al.* 2015). MODFLOW-USG simulates unsaturated conditions, allowing the process of progressive dewatering during active mine operations, and then re-wetting following closure to be represented. The upstream-weighting method and the CONSTANTCV setting for vertical conductivity correction were adopted in the model to simulate the recharge process, and therefore vadose zone properties were not required in the simulation.

The input files for the MODFLOW-USG model were created using custom Fortran code and a MODFLOW-USG edition of the Groundwater Data Utilities by Watermark Numerical Computing (2016). The mesh was generated using Algomesh (HydroAlgorithmics, 2014).

A2.3 Model design

A2.3.1 Model grid

The model grid was designed to be sufficiently extensive to capture the Project and surrounding mines which may have influence on the groundwater system, with a surrounding buffer wide enough to minimize effects from the boundaries on the system. The model domain is approximately 25 km wide (west to east direction) and 26 km long (north to south direction) as shown in Figure A 1.

The model has a triangular shape designed to align with key regional geological features as follows:

- North east – set approximately 3 to 5 km north-east of the Project site where the coal seams are terminated by the presence of the Hunter Thrust fault that abuts non coal bearing Carboniferous sediments against the Permian coal measures of the Hunter Valley (refer to Geological Map in Section 4 of main report).
- North west – set approximately 11 km north-west of the Project site, where the Whittingham Coal Measures outcrop and terminate.
- South – set at approximately 8 km south of the project site beyond the limit of depressurisation from the Project.

The model domain was discretised and arranged into 21 layers comprising up to 32,212 cell nodes in each layer with the dimensions of the cells varying according to the features that required representation. The following cells dimensions where adopted:

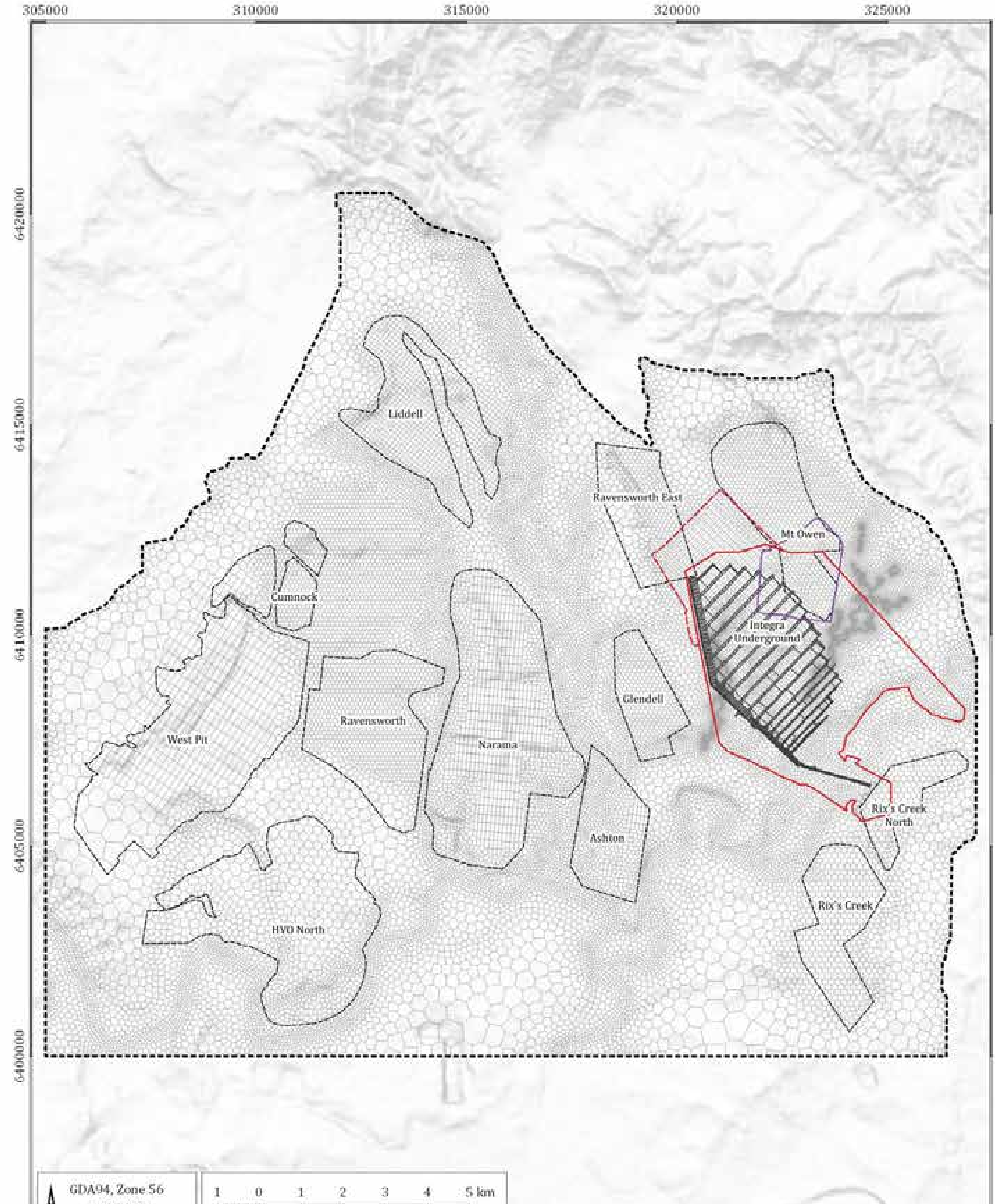
- longwall mining areas - 75 m x 150 m rectangular cells aligned to longwall panels;
- open cut areas - 100 x 100 m voronoi cells;
- streams and alluvial flood plains - from 50 x 50 m to 150 x 150 m; and
- groundwater dependent ecosystems (GDEs) within alluvial flood plains - 20 x 20 m.

Overall, the model comprised 542,322 cells across the 21 layers. Compared to Model version 8, this represents a significant decrease in the number of cells in the model. Coupled with the improved cell communication between Voronoi cells close to dewatered zones, Model version 9 runs significantly faster than its predecessors.

As shown in Figure A-1, the model includes the full extents of the existing Integra Underground mine, as well as the:

- Mt Owen Mining Complex, including North Pit where Glencore are proposed a modification to the approval;
- Rix Creek North Mine (formerly Integra Open cut);
- Liddell Mine;
- Ashton Underground Mine;
- Ravensworth Operations; and
- Hunter Valley Operations (HVO) North.

These mining areas were encompassed within the model domain as in some cases they target equivalent coal seams intersected at the project site and are necessary to represent and assess the magnitude of cumulative impacts.



LEGEND

- Model extent
- Integra Underground Project approval boundary
- Modification Project boundary
- Approved mining Middle Liddell Seam
- Proposed Mount Owen North Pit mining
- Historic and existing mining operations
- Model mesh
- Major drainage
- Minor drainage

Integra (G1285A)

Grid layout

DATE 16/11/2017

FIGURE No: **A-1**

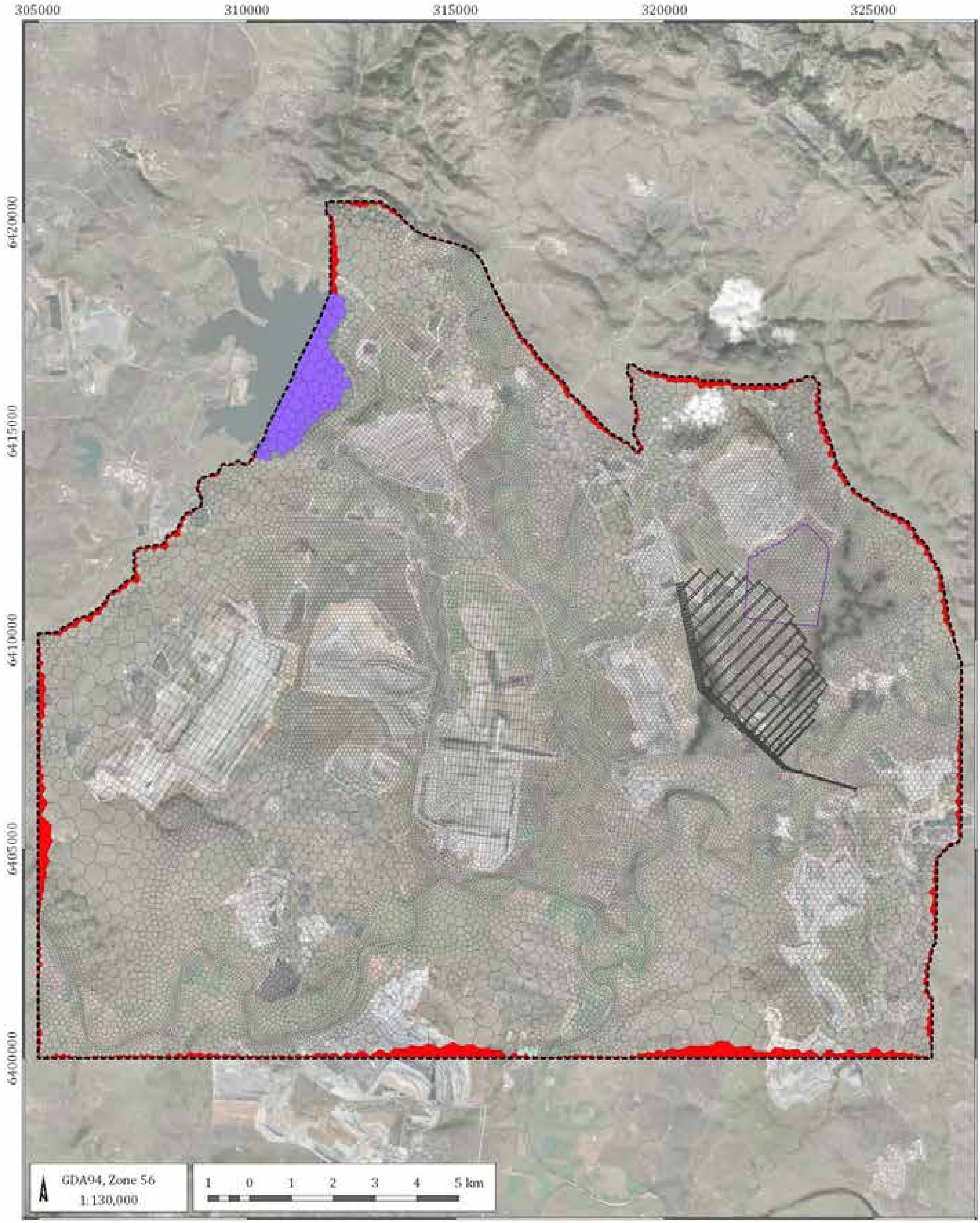
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:/Projects/G1285A.Integra/3_GIS/Workspaces/002_EIA/A-01_G1285A_Grid layout.qgs

A2.3.2 Model boundary conditions

Previous versions of the model represented the model boundaries including the Hunter Thrust fault where the coal seams terminate to the north-east of the Project site with a 'no flow' boundary condition. Whilst coal seams are terminated at this fault, it was considered there is potential for groundwater flow into the model domain to occur through surficial layers from up topographic gradient catchments that occur to the north-east of the Project site. The 'no flow' boundaries were therefore converted to a general head boundary to allow groundwater to enter the model from the up-gradient catchments.

The general head boundary cells in the model are displayed in Figure A 2.

Further flows into the model domain were in the form of recharge from rainfall. Flows into and out of the model domain occur through baseflow in creeks and out through evapotranspiration across the ground surface. Groundwater is also removed from the system using drain packages representing mine dewatering.



LEGEND

- Model extent
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Model mesh
- Constant head cell
- General head boundary cell

Integra (G1285A)

Constant head (CHD) and general head boundary (GHB) cells

DATE 16/11/2017

FIGURE No: **A-2**

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/G1285A.Integra/3_GIS/Workspaces/002_IBA/A-01_G1285A_GridLayout.qgs

A2.3.3 Model layers

The previous version of the model included 20 model layers representing the key hydro-stratigraphic horizons within the Quaternary alluvium and Permian formations. The layers were based on horizons in available geological models, and extrapolated beyond the limit of geological models using available data and experience. A further layer was added to this revision of the model by subdividing the Liddell seam, which allows a more accurate representation of mining at the Project site. In total the updated model included 21 layers, as summarised in Table A 2.

Table A 2 Model layers

Geological age	Stratigraphic unit		Description	Model layer
Quaternary	Alluvium (Qa)		alluvial deposits surrounding the major rivers	1
	Alluvium (Qa)/Regolith		basal alluvial sediments surrounding the rivers and regolith (weathered rock) elsewhere	2
Permian (Wittingham Coal Measures)	Overburden		strata between the base of weathering and the top of the Bayswater seam - can include seams, but mostly sandstone, claystone and/or siltstone	3
	Jerrys Plains sub-group	Bayswater seam	all the Bayswater Seams plys including the upper Bayswater 1, upper Bayswater 2 and Lower Bayswater at Liddell - also includes interburden between these seams	4
	Vane Sub-group	interburden	strata between the base of the Bayswater seam and the top of the Upper Pikes Gully seam (includes Lemington Seam)	5
		interburden	strata between the base of the Bayswater seam and the top of the Upper Pikes Gully seam including Lemington seam	6
		Upper Pikes Gully seam	Upper Pikes Gully seam plys	7
		interburden	strata between the base of the upper Pikes Gully seam and the top of the middle Pikes Gully Seam	8
		Middle and lower Pikes Gully seam	strata between the top of the middle Pikes Gully seam and the base of the lower Pikes Gully seam including interburden between the two seams	9
		interburden	strata between the base of the lower Pikes Gully seam and the top of the Arties seam	10
		Arties seam	all Arties seams plys including the Arties A, Arties B, Arties L1 and Arties L2 at Liddell	11
		interburden	strata between the base of the Arties seam and the top of the Liddell seam	12
		Liddell seam Sections A & B	all Liddell seam plys in Sections A and B including Liddell A1, Liddell Parting, Liddell B1, upper Liddell B2 and lower Liddell B2 at Liddell - also includes interburden between seam plys	13 & 14
		Liddell seam Section C	all Liddell seam plys in Section C including upper Liddell C1, lower Liddell C1 at Liddell, and interburden between seams	15
		Liddell seam Section D	all the Liddell seams plys in Section D including upper Liddell D1, lower Liddell D1 at Liddell, and interburden between the two seams	16
		interburden	all strata between the base of the Liddell seam Section D and the top of the Barrett Seam	17

Geological age	Stratigraphic unit		Description	Model layer
		Barrett seam	all the Barrett seams plys including the Barrett A, upper Barrett B, middle Barrett B, lower Barrett B, Barrett C1, Barrett C2 and Barrett D at Liddell, and interburden between seams	18
		interburden	all strata between the base of the Barrett Seam and the top of the Hebden Seam.	19
		Hebden seam	all the Hebden seam plys, including upper Hebden and lower Hebden at Liddell and interburden between seams	20
	Saltwater Creek Formation		upper section of the Saltwater Creek Formation	21

The Quaternary alluvial sediments were represented using the top model layer which was limited in horizontal extent to the flood plains. The extent of these sediments was previously defined by regional geology maps and site specific data, including previous reports and lithological logs. Further refinement of the horizontal extent and thickness was carried out based on a geophysical survey and field investigation undertaken by AGE (2017), and further review of available borehole logs. The weathered zone regolith layer was represented in the model as layer 2.

A2.3.4 Timing

The previous version of the model simulated groundwater flow from 1980 to 2030 as follows:

- Last day of 1979 - steady state stress period;
- 1980 to 2000 - 4 x five yearly stress periods (transient here and after);
- 2000 to 2002 - 1 x two yearly stress period; and
- 2002 to 2030 - annual stress periods.

The model was updated to more finely divide time allowing improved representation of the progress of mining over time and the seasonal variability in groundwater levels from climate. Similarly to previously the calibration involved an initial steady state calibration to obtain pre-mining conditions, followed by a transient calibration. The transient model was set up as follows:

- Last day of 1979 - steady state stress period;
- 1980 to 1999 - 4 x five yearly stress periods (transient here and after);
- 2000 to 2002 – 1 x three yearly stress period;
- 2003 to 2008 – 12 x six monthly stress periods; and
- 2009 to 2035 – 108 x quarterly stress periods.

Quarterly stress periods were introduced to the model so that seasonal variability in recharge and stream flows could be represented where data was available for the calibration period. The drains representing mining were advanced in quarterly intervals and turned off after a 3.5 year period.

An additional version of the model was developed for simulating recovery after mining ceased at the Project in 2036. Both models were combined into a single, continuous simulation with one finishing and the other starting at the beginning 2036. The timing for the recovery model was set up as a single transient stress period with 1000 years duration.

A2.3.5 Mining progression

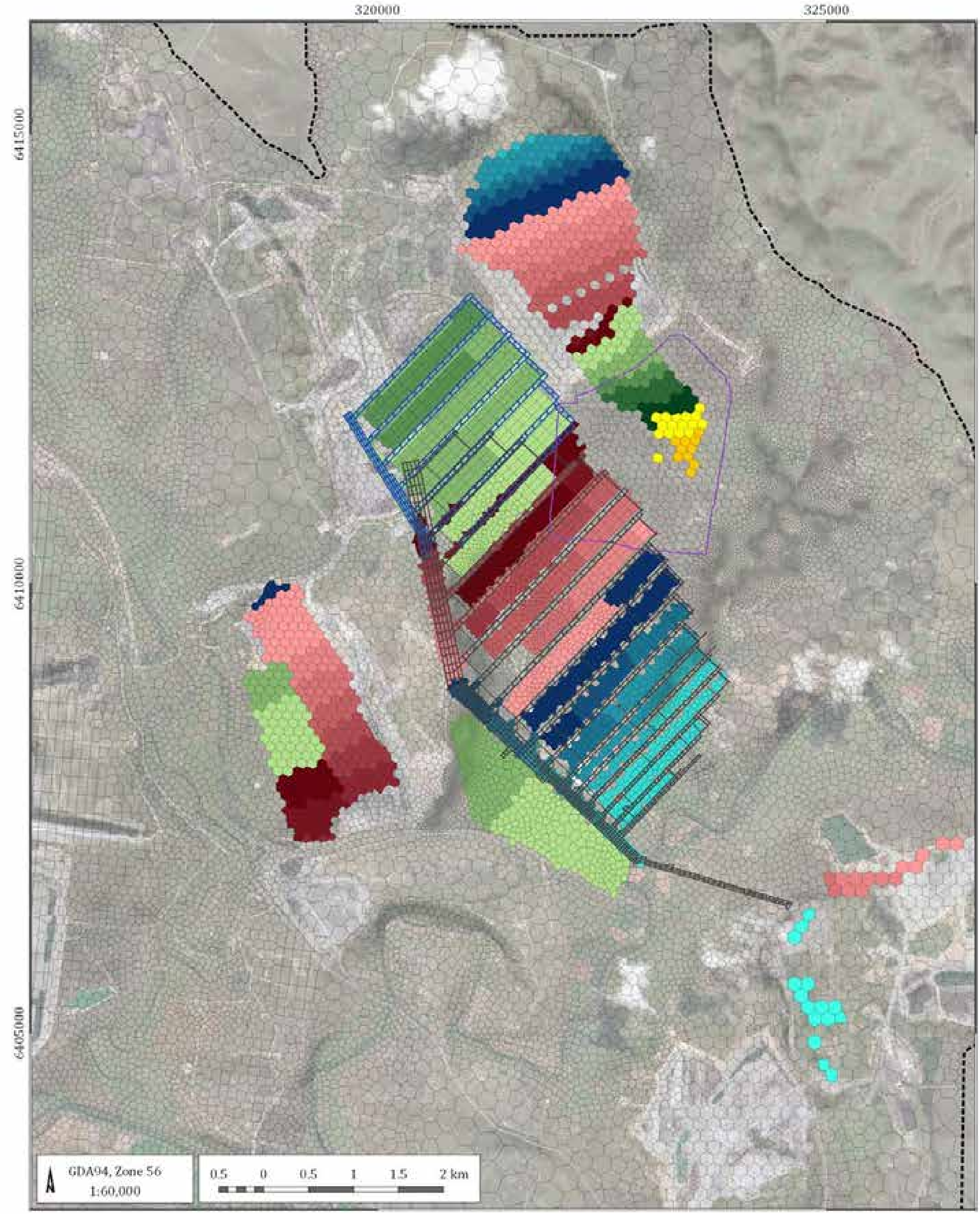
Two mining designs were considered for the proposed development of the mine in the Middle Liddell Seam, using 246 m or 320 m wide longwall panels. Both options cover the same footprint, however only five panels are required for the 320 m width option, whereas six are needed for the 246 m scenario. Figure A 2 and Figure A 3 show the footprint and timing of the proposed options. Figure A 4 to Figure A 6 shows the mine progression for the Barrett Seam.

Future mining at surrounding mines and their corresponding model layers detailed in Table A 3.

Mining activities associated with the project commenced in 2003, with the proposed mining modification beginning in 2018. The simulation of approved mining in the model was based on the detailed mine schedules described by Jacobs (2014) and updated with foreseeable mining proposed at the Mt Owen mine, and proposed mining for the Project according to plans and data provided by Glencore. For consistency with the Jacobs (2014) modelling, development headings were not in the approved scenario simulated. Development headings were only simulated post 2012 for the modification scenarios.

Table A 3 Model domain historic and approved mine progression

Layer	Geology	HVO		Ashton			Ravensworth Ops								Liddell		Mt Owen Complex							Integra		
		West Pit	HVO_North	Ashton_PikesG	Ashton_Liddell	Ashton_Barrett	Cumnock_OC	Cumnock_Lower_Pikes_Gully	Cumnock_Liddell	Cumnock_Barrett	RUM_Lower_Pikes_Gully	RUM_Liddell	Rav_North	Rav_Narama	Liddell_South_Cut_Pit	Liddell_Entrance_Pit	North_Pit	Glendell	West_Pit	RW_Pit	Tailings_Pit_1_(TP1)	Tailings_Pit_2_(TP2)	Eastern_Rail_Pit	Integra_Liddell	Integra_Barrett	Integra_Hebden
L01	Alluvium																									
L02	Regolith																									
L03	Overburden																									
L04	Bayswater Seam																									
L05	Interburden (incl Lemington)																									
L06	Interburden (incl Lemington)																									
L07	Upper Pikes Gully Seam																									
L08	Interburden																									
L09	Mid and Lower Pikes Gully Seam																									
L10	Interburden																									
L11	Arties Seam																									
L12	Interburden																									
L13	Liddell AB Seam Section																									
L14	Liddell AB Seam Section																									
L15	Liddell C Seam Section																									
L16	Liddell D Seam Section																									
L17	Interburden																									
L18	Barrett Seam																									
L19	Interburden																									
L20	Hebden Seam																									
L21	Saltwater Creek Formation																									



LEGEND

- Model extent
- Approved Middle Liddell Seam mining
- Proposed 246 m longwall panels
- Proposed Mount Owen North Pit mining
- Model mesh

Mine start year

1979	2009	2020
1984	2010	2022
1989	2011	2024
1994	2012	2026
2000	2013	2028
2002	2014	2030
2003	2015	2032
2005	2016	2034
2006	2017	2036
2007	2018	

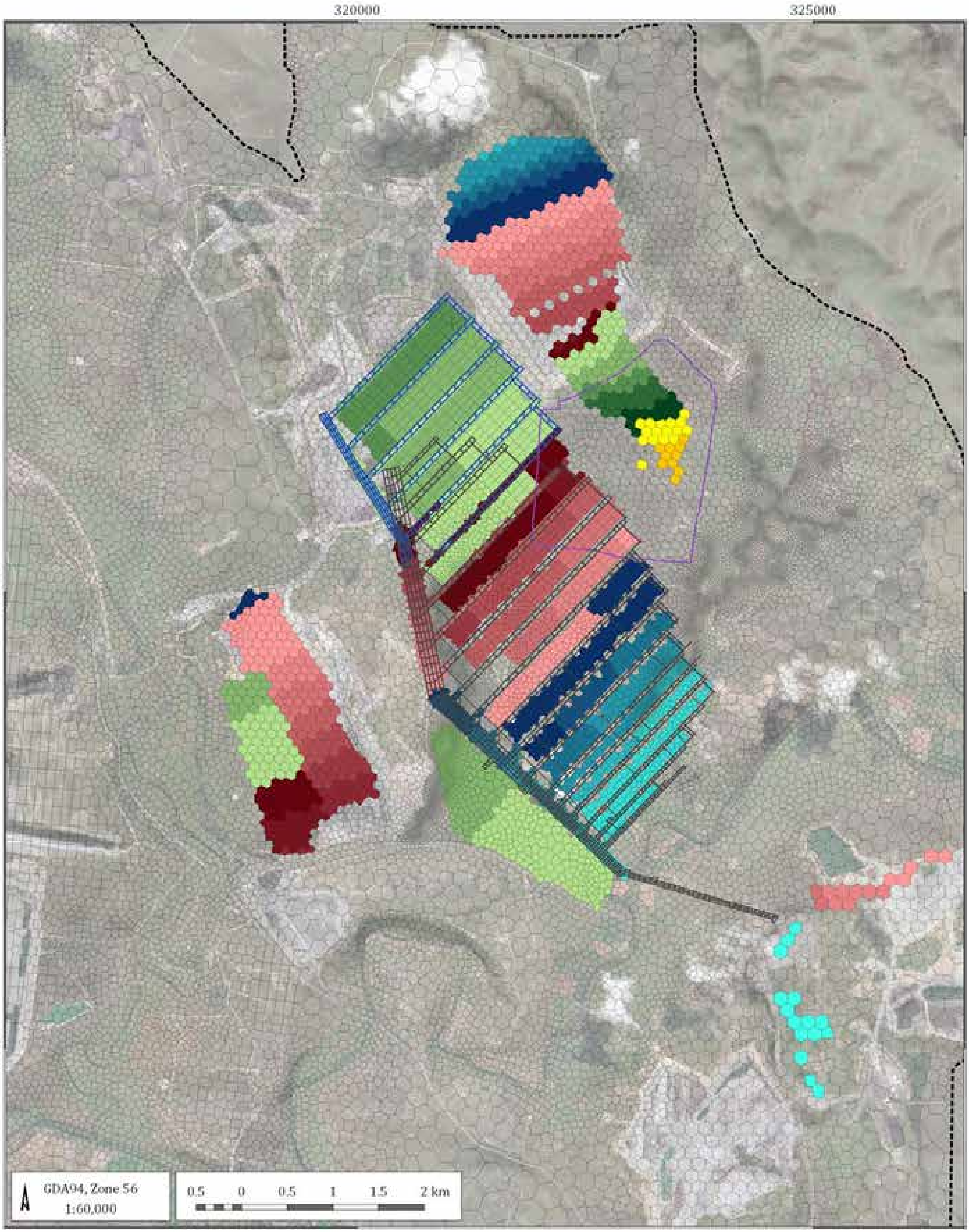
Integra (G1285A)

Predictive mine progression for the Project - Middle Liddell Seam 246 m panels

AGE

DATE 16/11/2017

FIGURE No: **A-3**



LEGEND

- Model extent
- Approved Middle Liddell Seam mining
- Proposed 320 m longwall panels
- Proposed Mount Owen North Pit mining
- Model mesh

Mine start year

1979	2009	2020
1984	2010	2022
1989	2011	2024
1994	2012	2026
2000	2013	2028
2002	2014	2030
2003	2015	2032
2005	2016	2034
2006	2017	2036
2007	2018	

Integra (G1285A)

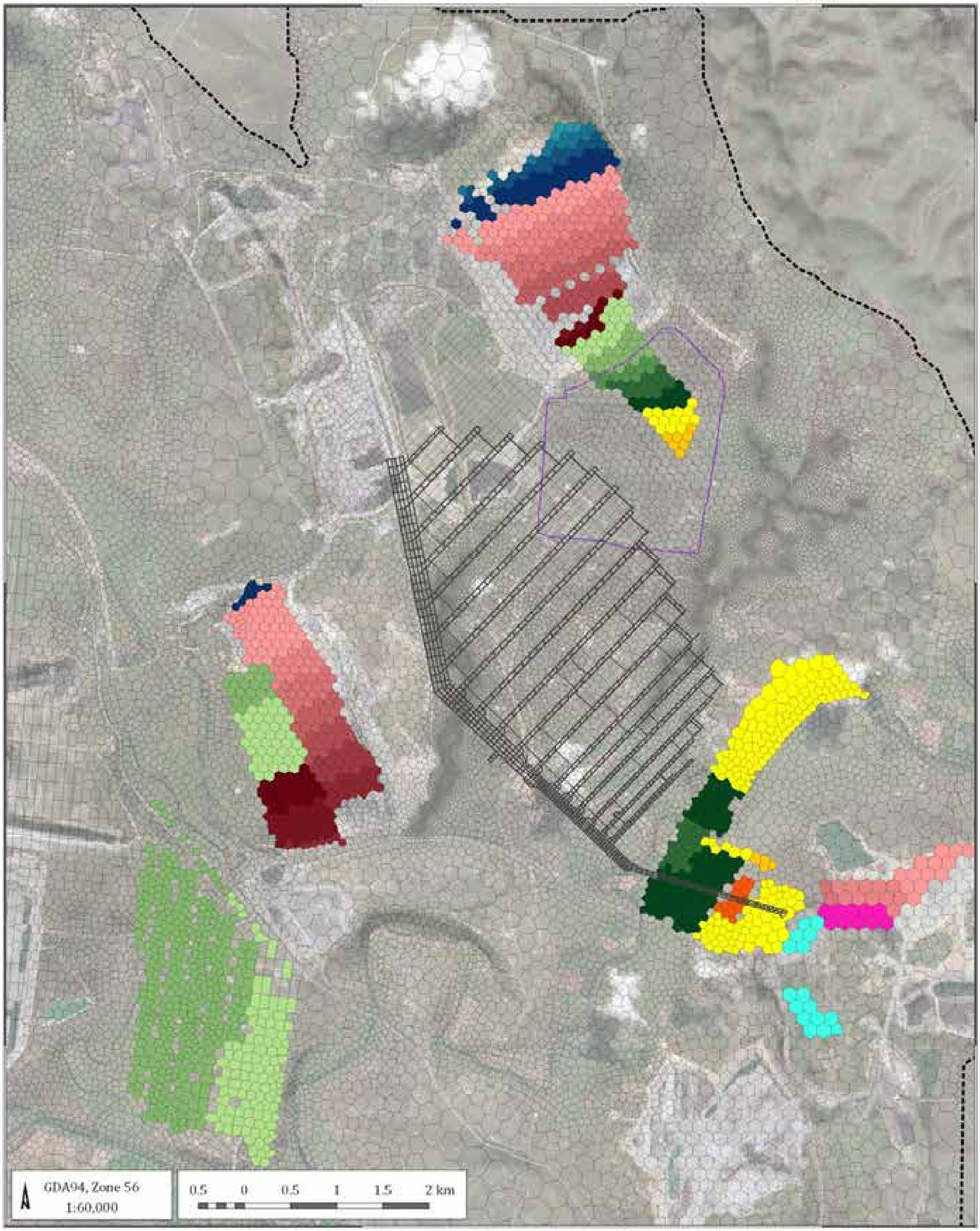
Predictive mine progression for the Project - Middle Liddell Seam 320 m panels

AGE

DATE 16/11/2017

FIGURE No: **A-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/G1285A.Integra/3_GIS/Workspaces/002_EIA/A-01_G1285A_Gridlayout.qgs



LEGEND

- Model extent
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Model mesh

Mine start year

1979, 1984, 1989, 1994, 2000, 2002, 2003, 2005, 2006, 2007, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2020, 2022, 2024, 2026, 2028, 2030, 2032, 2034, 2036

Integra (G1285A)

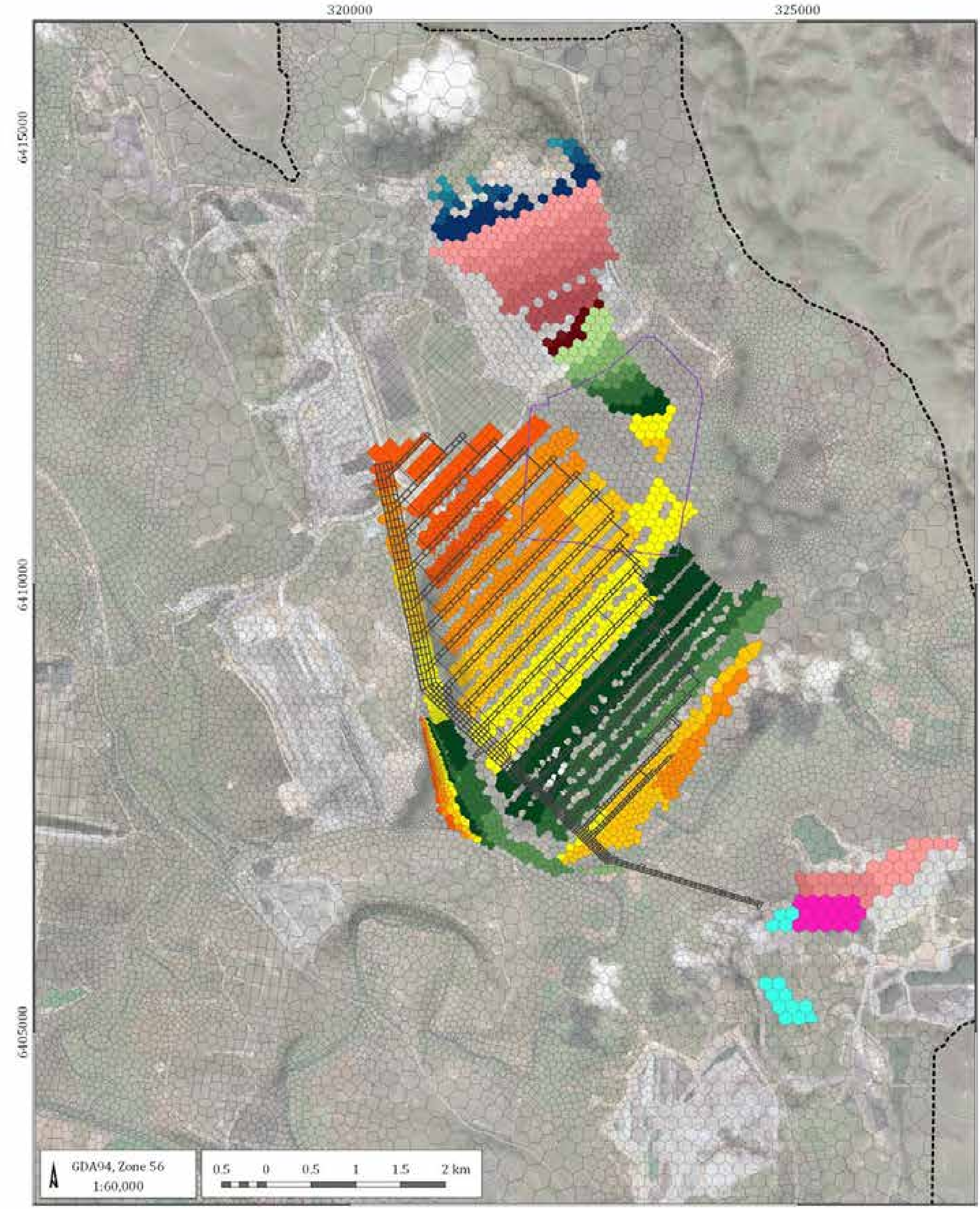
Predictive mine progression for the Project - Barrett Seam

AGE

DATE 16/11/2017

FIGURE No: **A-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/G1285A.Integra/3_GIS/Workspaces/002_IBA/A-01_G1285A_GridLayout.qgs



LEGEND

Model extent
Model mesh

Mine start year

1979	2009	2020
1984	2010	2022
1989	2011	2024
1994	2012	2026
2000	2013	2028
2002	2014	2030
2003	2015	2032
2005	2016	2034
2006	2017	2036
2007	2018	

Integra (G1285A)

Predictive mine progression for the Project - Hebden Seam

AGE

DATE 16/11/2017

FIGURE No: **A-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.;
G:/Projects/G1285A.Integra/3_GIS/Workspaces/002_IBA/A-01_G1285A_GridLayout.qgs

A2.4 System stresses

A2.4.1 Recharge

The MODFLOW USG recharge package (RCH) was used to represent diffuse rainfall recharge. The upstream weighting function with the CONSTANTCV option was selected to ensure flow through the vadose zone was not represented due to a lack of available parameters to represent unsaturated flow.

The dominant mechanism for recharge to the groundwater system is through diffuse infiltration of rainfall through the soil profile and subsequent deep drainage to underlying groundwater systems. River leakage can also provide recharge to underlying groundwater systems in alluvial areas. In general, the clayey nature of the upper alluvial sediments and the low permeability of the regolith, means recharge rates to the groundwater regime were relatively low in the model. A spreadsheet based soil moisture deficit calculation was used to estimate the timing and magnitude of recharge events used in the model. The simple soil moisture balance estimates when the soil profile reaches field capacity and deep drainage to the underlying water table occurs.

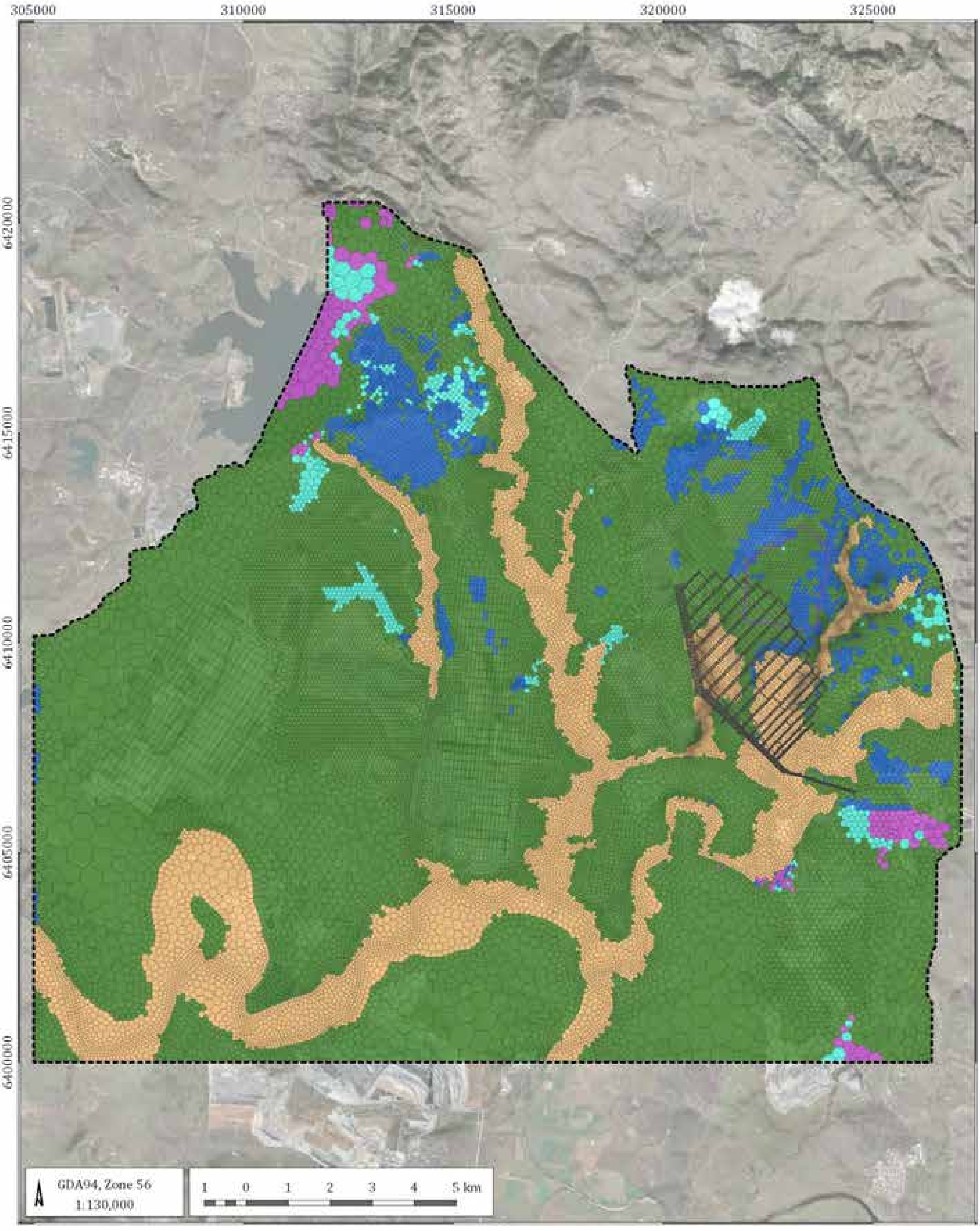
Table A 4 represents the calibrated rate of recharge for each geological unit. Figure A 7 shows the recharge distribution zones.

Table A 4 Modelled recharge rates

Zone	Diffuse recharge rate - transient	
	mm/year	% of annual rainfall
Alluvium	55.5 (2 - 184)	8.4%
Permian regolith	2.4	0.4%
Permian overburden	0.4	0.1%
Permian unweathered	0.6 (0.1-2.0)	0.1%
Saltwater Creek Formation	0.1	0.01%

Recharge for the predictive and recovery phases (2018+) adopted constant steady state recharge rates.

A simple SWAT model (Arnold, 2012) covering the model domain catchment area was developed to validate the groundwater recharge rates assumed during the calibration process. Global FAO soil and static land use data were assumed, and weather was applied using interpolated SILO climate data. SWAT calculated that percolation rates to the alluvium of about 112 mm/year and Permian groundwater recharge at a rate of 6 mm/year.



LEGEND

Model extent
Approved Middle Liddell Seam mining
Proposed Mount Owen North Pit mining
Model mesh

Recharge zones

Quaternary alluvium
Permian regolith
Permian interburden
Permian overburden
Salt Water Creek Formation

Integra (G1285A)

Recharge zones

DATE 16/11/2017

FIGURE No: **A-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/G1285A.Integra/3_GIS/Workspaces/002_IBA/A-01_G1285A_Gridlayout.qgs

A2.4.2 Evapotranspiration

Evapotranspiration from shallow water tables was represented with the evapotranspiration package (EVT). Evapotranspiration occurred from the upper most model cells across the model domain at an areal potential evaporation rates (440mm/year) decreasing linearly to a maximum depth of 2 m below the surface.

The results from the SWAT modelling correlated with the areal potential evaporation datasets, producing an average of 448 mm/year.

A2.4.3 Abstraction

Abstraction from landholder pumping wells is not significant in the region and was therefore not included in the model simulation. This is consistent with the previous modelling exercises.

A2.4.4 Surface drainage

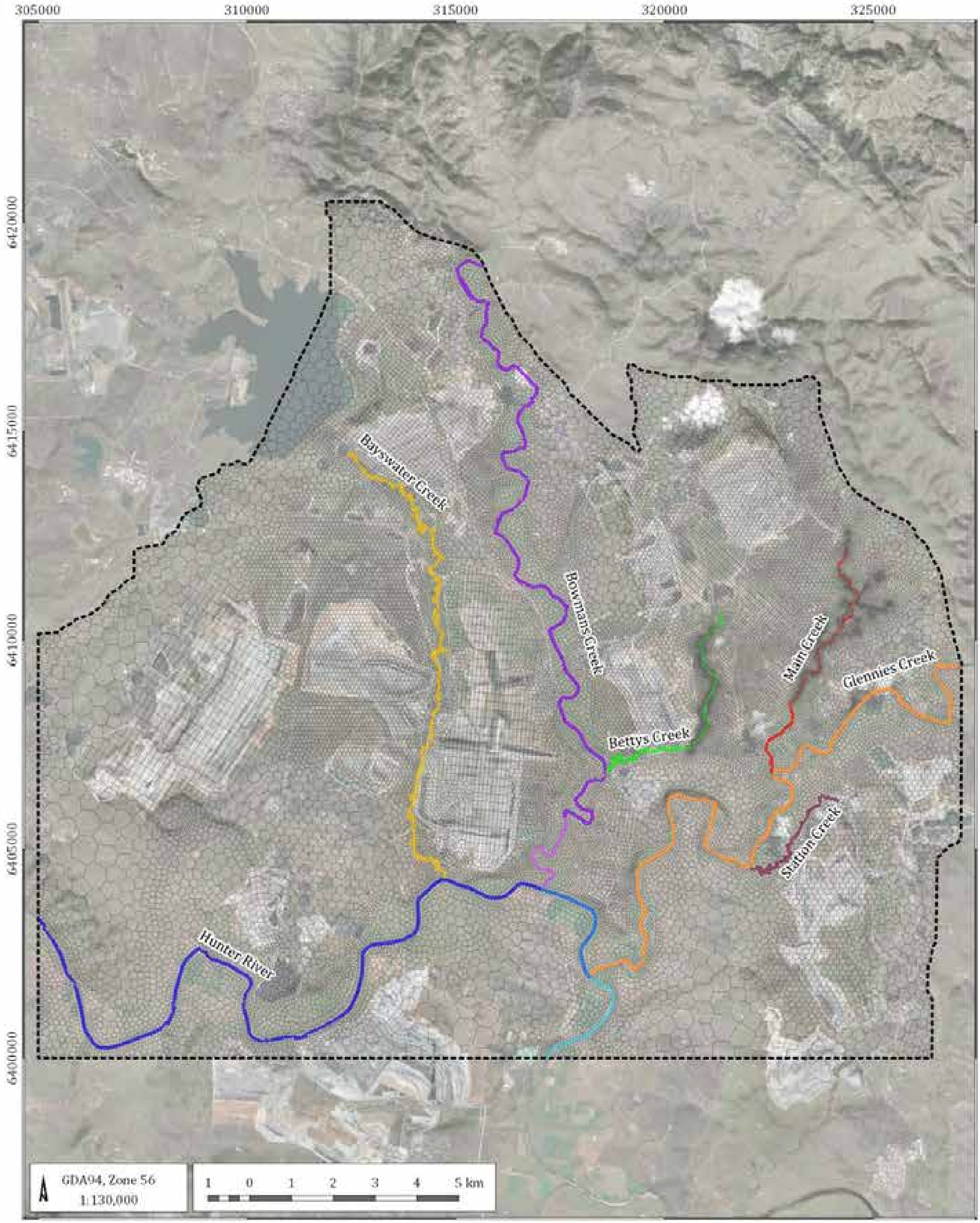
Groundwater interaction with surface drainage was modelled using the stream package (STR) and the river package (RIV) of MODFLOW. The cells assigned to these packages in the model, divided by zones, are displayed on Figure A 8.

Major streams systems, including the Hunter River, Bowmans Creek, and Glennies Creek were assigned to the stream package, whereas minor drainage systems were simulated using the river package. The STR package requires the level of the river bed and the flux of surface water across the river surface. The river bed conductance was calculated from river width, length, riverbed thickness, and an estimated vertical hydraulic conductivity of the riverbed material. The stage height for rivers and creeks where perennial stream flow occurs (i.e. Hunter River and Glennies Creek) was internally calculated by MODFLOW-USG using an interpolated flow gauging data from DPI Water stream gauges (NSW DPI, 2017) available online. Manning's coefficient values were based on the metric application of firm soil to gravel streambeds, which ranges from 0.025 to 0.035 (USGS, 1989)

Table A 5 summarises the stream and river cell parameters in the model.

Table A 5 Modelled stream (STR) and river (RIV) bed parameters

Seg-ment No	Segment name	Vertical hydraulic conductivity Kz (m/day)	Width (m)	Incised depth (m)	Slope	Bed thickness (m)	Manning's Coefficient
1	Bowmans Creek Seg1	0.08	3.0	1	0.004	1.5	0.03
2	Bowmans Creek Seg2	0.09	3.0	1	0.004	1.5	0.03
3	Hunter River Seg1	0.04	5.0	2	0.0005	2.0	0.03
4	Hunter River Seg2	0.08	5.0	2	0.0007	2.0	0.03
5	Glennies Creek	0.12	5.0	2	0.0015	2.0	0.03
6	Hunter River Seg3	0.09	5.0	2	0.001	2.0	0.03
7	Bettys Creek (RIV)	0.1	5.0	1	-	1.0	-
8	Station Creek (RIV)	0.1	5.0	1	-	1.0	-
9	Main Creek (RIV)	0.1	5.0	1	-	1.0	-
10	Bayswater Creek (RIV)	0.1	5.0	1	-	1.0	-



LEGEND

Model extent

Model mesh

River Zones

- Bayswater Creek
- Bettys Creek
- Main Creek
- Station Creek

Stream Zones

- Bowmans Creek (1)
- Bowmans Creek (2)
- Hunter River (1)
- Hunter River (2)
- Hunter River (3)
- Glennies Creek

Integra (G1285A)

River and surface drainage cells

DATE 15/11/2017

FIGURE No: **A-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/G1285A.Integra/3_GIS/Workspaces/002_IBA/A-01_G1285A_GridLayout.qgs

The water level above the river bed was set at 0 m for all minor ephemeral streams and creeks within the model domain. The location of the river cells in the groundwater model were assigned to the highest active layer in the model, which was generally layer 1 or layer 2.

A2.4.5 Lakes and dams

Lake Liddell was represented in the model using the constant head package (CHD). A fixed head of 128 m AHD was applied to all nodes in all present layers in the model to represent Lake Liddell. Figure A-2 includes the extent of the CHD cells assigned to Lake Liddell.

A2.4.6 Mining

The model represented the open cut and underground mining using the DRN (drain) package with the progression of mining over time based on the schedules described by Jacobs (2014). The model simulated the changes to hydrostratigraphic units in response to mining (e.g. longwall goafing and spoil emplacement) using a combination of MODFLOW's drain and TVM (time varying materials) packages.

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 setup to remain active within the open cut mining areas for 3.5 years after mined before being turned off and converted to represent the in-pit spoil piles. This timing was selected, based on an assessment of the mining plan. 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.

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. Storage was changed in a step-wise manner above the mined seam to avoid creating water in partly saturated layers. Further details about the calibrated hydraulic parameters are included in A3.2.2

Goafing and 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 subsides into the mined area creating the goaf zone within the mining footprint. This creates 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 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)

T = extraction thickness (m)

t' = effective thickness of the stratum where the A-Zone height occurs

Extraction thickness, T adopted the upper bound of 3.4 m, and t' assumed 20 m thickness. To further assist with model calibration at vibrating wire piezometers DDH223 and DDH224, the model adopted +aW' (95th percentile) as the maximum fracture height from the 'Geology model' (Ditton & Merrick, 2014), which essentially increases the height a further 10-15% of the panel width on the calculated fracture height.

Fortran code was used to automatically calculate the fracture height at a cell-by-cell level. Figure A 9 shows the final fracture height from mining in the Middle Liddell, Barrett, and Hebden seams. In this figure, the fracture heights above each of the three seams are combined in a single map, displaying the maximum height value from the three input maps.

To represent the removal of groundwater directly from the coal seam through mining and the depressurisation of the stratum within the fracture network, a derivation of the equivalent fracture network was necessary. SCT calculated the hydraulic conductivity of the unsaturated fracture network above the longwall panel using the cubic flow equation (SCT, 2008). Using site specific height versus hydraulic conductivity relationships in similar geological settings, rearranging this equation provides a log-linear relationship between the total aperture of the fracture network (A_p) and the height above the longwall panel, given by:

$$A_p = -0.011 \ln(h) + 0.0595 \qquad \text{(eq. 2)}$$

where,

h = height above the longwall panel

A lower bound of A_p of 0.00001 m was assumed in cases where maximum fracture height exceeded the 0.0 m interception using equation 2. The range of A_p explored ranged from 0.1 m to 0.00001 m. Higher A_p values were tested, ranging from 3.1 m to 0.2 m using a higher skin factor (1.0), which yielded similar conductance values to using a A_p lower value with a lower skin factor.

MODFLOW-USG recently introduced the connected linear network package (CLN), which simulates the connection between the groundwater flow equation and a model independent 'pipe' network. The CLN package as a method to represent the fracture network using the fracture aperture at specified heights above the longwall described above. However it was determined the CLN package slowed the model runtime and stability significantly and could not be used directly to represent the fracture network. Instead the formula behind the CLN package was used to calculate the drain conductance (Panday *et al*., 2013) and this used in the drain (DRN) package The CLN equation was effectively converted from a horizontal to a vertical conductance calculation, with drain elevations set to the base of each cell between the longwall panel and fracture height. Drain conductance, or 'fracture conductance' (α_{fn}) was calculated as follows,

$$\alpha_{fn} = \left[\frac{\ln\left(\frac{r_{oz}}{r_n}\right)+S_f}{2\pi l K_{xz}\sqrt{1/\Re_{rz}}}\right] \qquad \text{(eq. 3)}$$

where,

r_{oz} = effective external radius of MODFLOW cell to fractured network

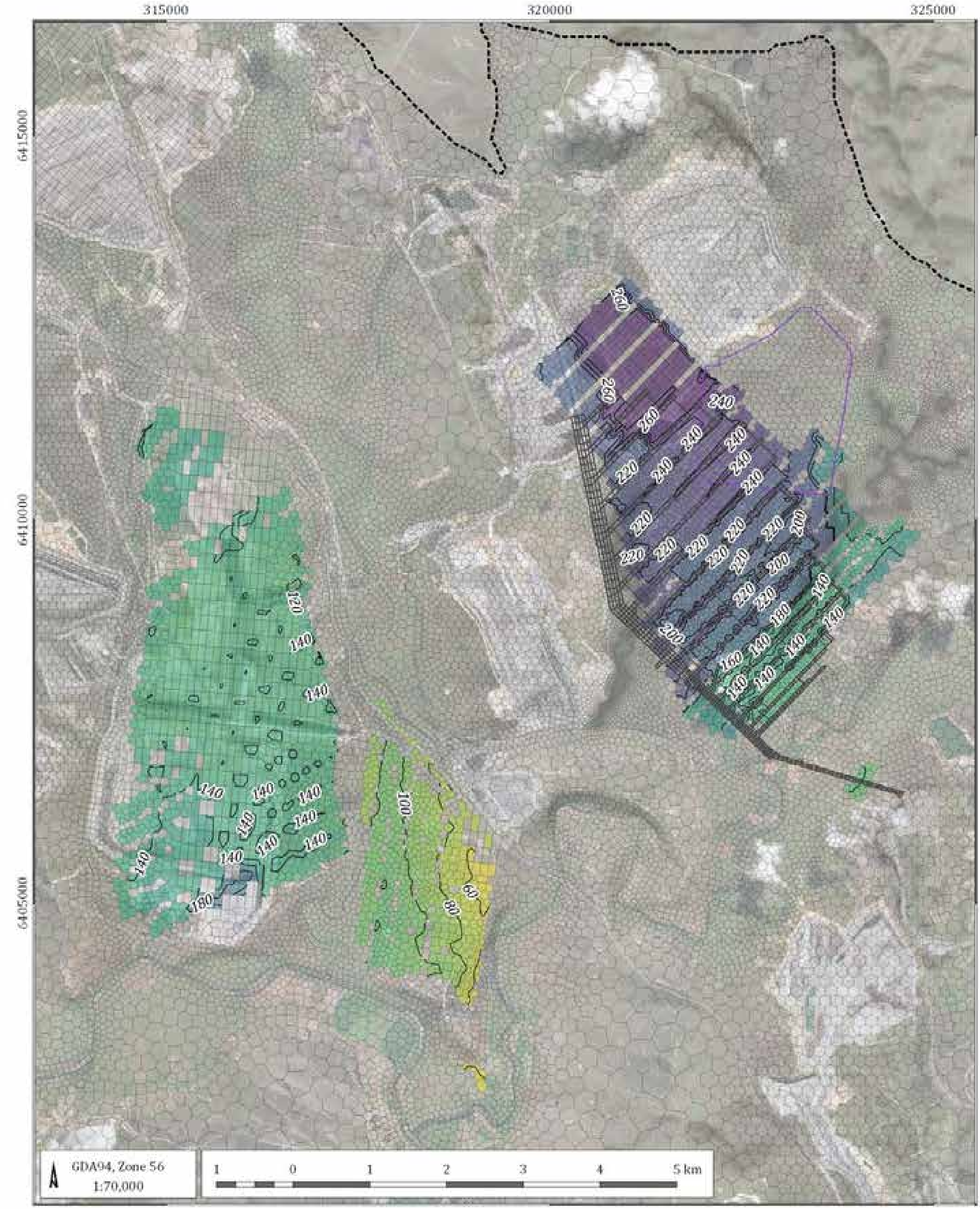
r_n = effective radius of the fracture network (A_p)

S_f = skin factor

l = effective thickness of fracturing within the model cell

K_{xz} = host vertical hydraulic conductivity

$\Re_{rz}$ = x:y anisotropy ratio (K_{xx} / K_{yy})



LEGEND

- Model extent
- Approved Middle Liddell Seam mining
- Proposed 320 m longwall panels
- Model mesh
- Proposed Mount Owen North Pit mining
- Contour line (m)

Fracture height above seam (m)

- 50
- 75
- 100
- 125
- 150
- 175
- 200
- 225
- 250
- 300

Integra (G1285A)

Modelled fracture height

DATE 16/11/2017

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.;
G:/Projects/G1285A.Integra/3_GIS/Workspaces/002_IBA/A-01_G1285A_GridLayout.qgs

Upon fracturing, delamination causes the horizontal hydraulic conductivity to enhance to a much higher rate than the effective vertical hydraulic conductivity (SCT, 2008). To simulate these phenomena, the drain cells applied to represent longwall fracturing remained active for the entirety of the predictive model simulation; effectively replicating the transmissive flow network established once longwall mining progresses. To ensure complete drainage of the goaf, a value of 100 m^2/day was applied to first 10 m above the mined coal seam. Drain conductance ranged from approximately 0.5 m^2/day to 0.001 m^2/day above this highly fractured zone, which was highly dependent on the host permeability of the fractured strata and thickness of the model cell. Drain conductance was dynamically calculated with the model calibration and uncertainty parameter sets.

A separate model run was built to simulate recovery of the groundwater system once all longwall mining is complete. In this model, the drain cells were removed and the hydraulic conductivity enhanced to represent the residual fracture network. An equation was developed, which respects the fracture network (A_p), the host material hydraulic conductivity, and previous conceptualisations of transmissivity changes to the fracture network. This equation is a general use equation that is primarily based on the Guo enhanced permeability equation (Guo, 2007); however, it more appropriately enhances permeability of compromised impermeable strata within the intensely fractured zone. The equation provided the vertical hydraulic conductivity of the collapsed strata (Kz_{frac}) for the regional groundwater model as follows:

$$Kz_{frac} = ct \frac{(0.991^{\,h})\sqrt{\left(\frac{Kz}{h}\right)}}{(\log(h+10))} \qquad \text{(eq. 4)}$$

where,

ct = adjustable constant (0.2)

h = height above longwall panel (m)

Kz = in-situ vertical hydraulic conductivity

Similar to equation 4, an equation was developed based primarily on the Guo equation to derive the horizontal hydraulic conductivity of fractured strata. Kx_{frac}, the horizontal hydraulic conductivity of the collapsed strata can be expressed as:

$$Kx_{frac} = \frac{Kz_{frac}*20}{(\log(h+10))} \qquad \text{(eq. 5)}$$

Changes to the horizontal and vertical hydraulic conductivity were applied to the single stress period recovery model.

Specific yield and specific storage parameters representing highly fractured goaf zones were applied to mined coal seam layers only (layers 4, 14, 15, 18, and 20). Table A 6 presents the aquifer parameters applied to the post mining underground workings.

Table A 6 Recovery model underground parameters

Recovery model zone	Horizontal hydraulic conductivity Kx (m/day)	Vertical hydraulic conductivity Kz (m/day)	Specific storage (m-1)	Specific yield (%)
Mined coal seam fracture zone and goaf	Kx_{frac}	Kz_{frac}	5.0E-06	0.1
Bord and Pillar	100	100	5.0E-06	1.0

Bord and pillar and main/access roads were simulated using drain cells with a drain conductance of 100 m^2/day. Upon completion, bord and pillar and main road cells were converted to replicate void properties with high hydraulic conductivity and storage.

A3 Model calibration

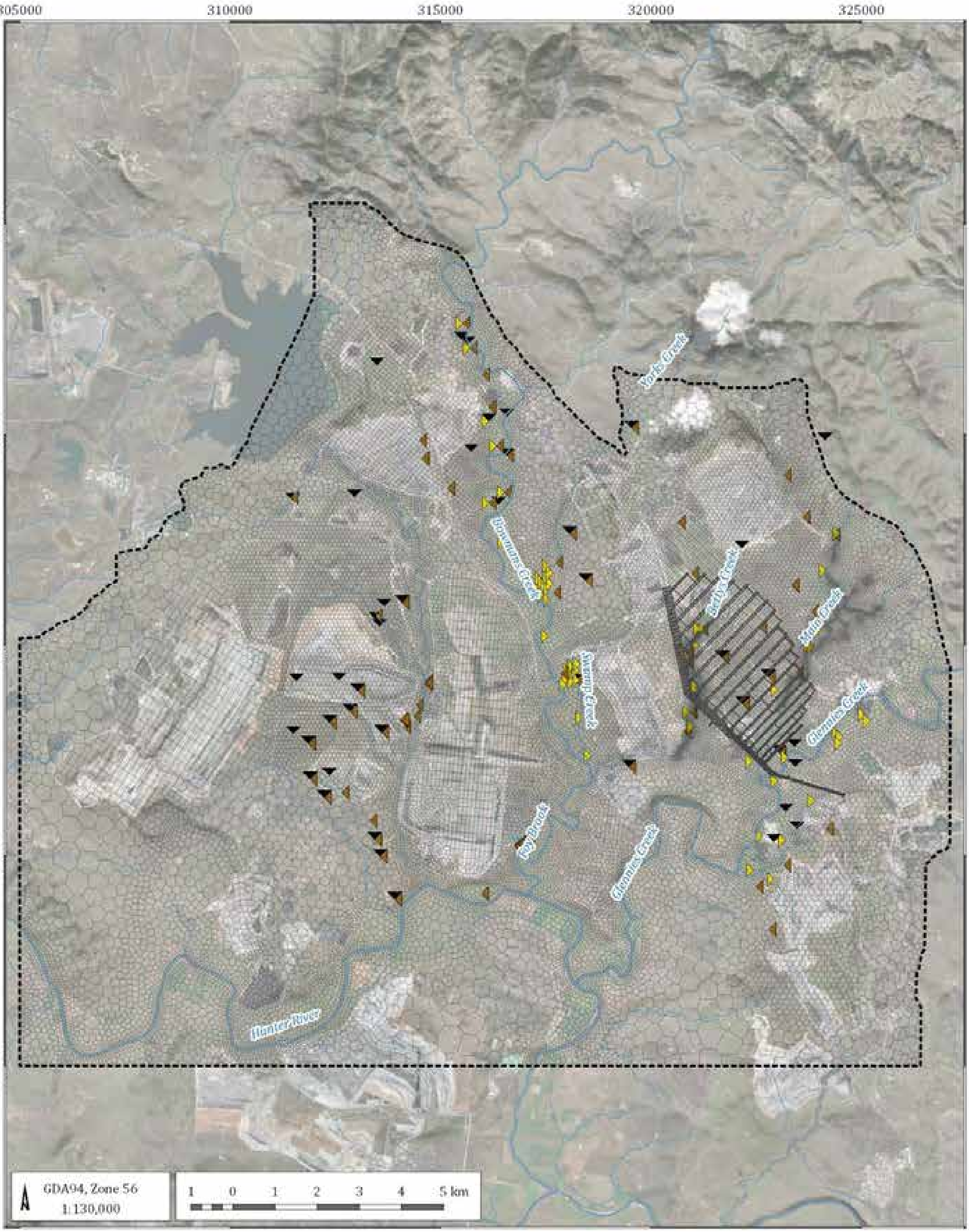
The groundwater model was calibrated with a pre-mining steady state run and a transient run (1980 to 2017) using available groundwater level data and documented mine inflows. The model was calibrated by adjusting aquifer parameters and stresses to produce the best match between the observed and simulated water levels. Manual testing and automated parameterisation software (PEST, Doherty 2010) were used to determine optimal hydraulic parameters and recharge rates to achieve the most representative calibration of the groundwater model.

A3.1 Calibration targets

The steady state and transient model simulated water levels in all available monitoring bores within the bedrock and alluvial aquifers. A total of 254 monitoring points were used to calibrate the model, comprising:

- 253 monitoring points from the Integra, Mt Owen, Ravensworth and Liddell monitoring network, which included bores and VWPs that screen the alluvium and Permian coal measures;
- 1 private registered bore with available water level data, which intersects Quaternary alluvium;
- 52 monitoring points across the model domain that screen the alluvium from monitoring wells;
- 178 monitoring points that screen the Permian coal measures and interburden from monitoring wells; and
- 24 monitoring points from vibrating wire piezometers.

Figure A 10 presents the observation bores that were used in the calibration. The installation details for a number of bores could not be determined and were therefore not included within the model.



LEGEND

- Model extent
- Model mesh
- Alluvium extent
- Major drainage
- Minor drainage

Observation bores

- Alluvium
- Coal Seam
- Interburden

Integra (G1285A)

Observation target locations

DATE 15/11/2017

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.;
G:/Projects/G1285A.Integra/3_GIS/Workspaces/002_IIA/A-01_G1285A_Gridlayout.qgs

A3.2 Calibration results

Figure A 11 presents the observed and simulated groundwater levels graphically as a scattergram for the historic transient calibration.

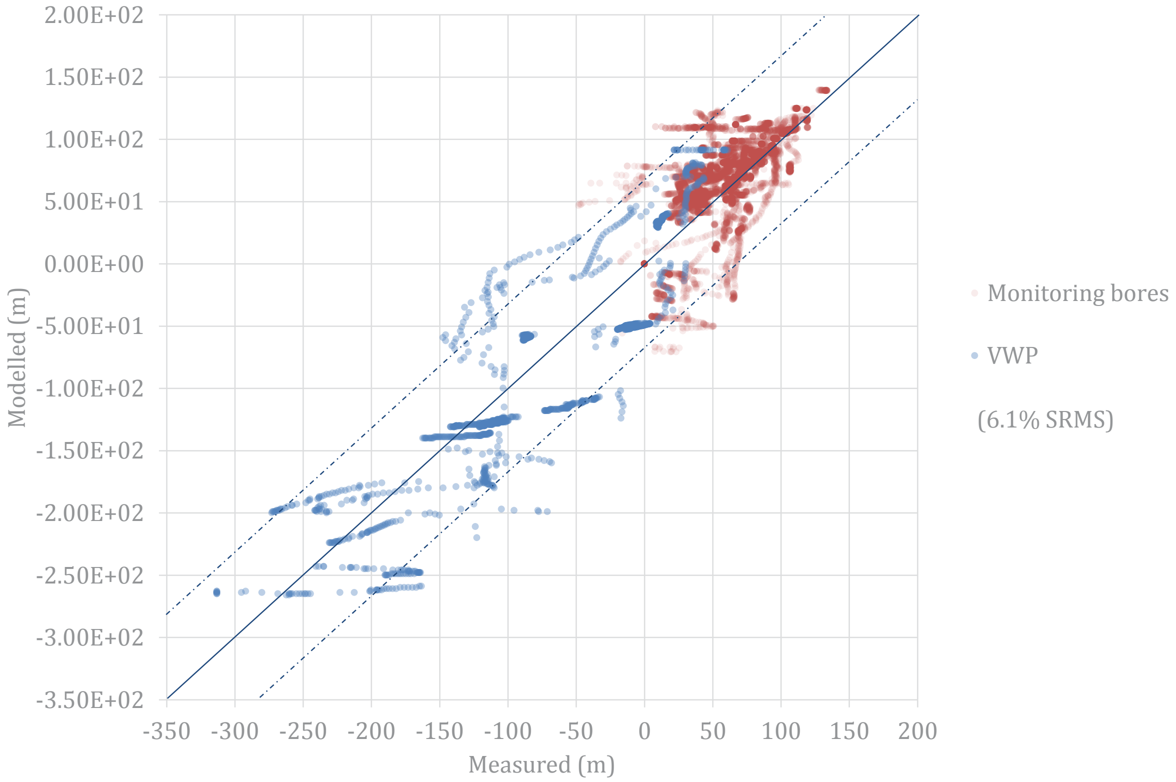


Figure A 11 Transient calibration – modelled vs observed groundwater levels

The root mean square (RMS) error calculated for the calibrated model was 27.1 m. The total measured head change across the model domain was 446.9 m, with a standardised unweighted RMS (SRMS) of 6.1%, indicating a relatively good match for the type of system being modelled. Table A 7 presents the unweighted statistics for the transient calibration model.

Table A 7 Statistical analysis

Calibration performance measure	Unweighted value
Sum of Residuals (SR) (m)	-52758
Mean Sum of Residuals (MSR) (m)	-4.1
Scaled Mean Sum of Residuals (SMSR) (%)	-0.9
Sum of Squares (SSQ) (m2)	9425372
Mean Sum of Squares (MSSQ) (m2)	734
Root Mean Square (RMS) (m)	27.1
Root Mean Fraction Square (RMFS) (%)	13164
Scaled RMFS (SRMFS) (%)	15218
Scaled RMS (SRMS) (%)	6.06

Figure A 12 shows the relationship between the observed water levels and the residuals. The results show more clearly that the observations above 20 mAHD are more closely matched by the model, whilst the observations from deeper VWPs that have recorded mining induced depressurisation and not replicated as closely.

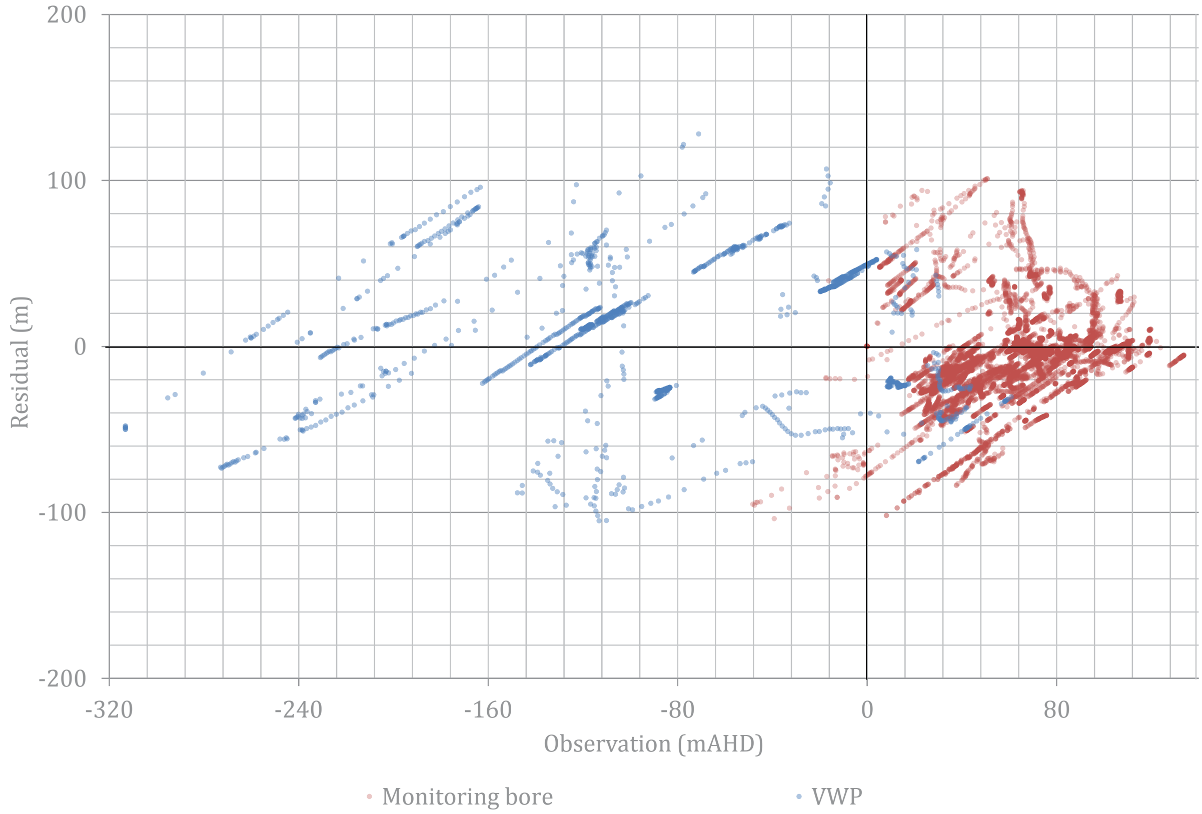


Figure A 12 Observations versus residuals

Appendix A-1 presents the historic calibration hydrographs, showing the fit between modelled and observed groundwater levels from 1980 to April 2017.

An analysis of simulated vs. measured vertical pressures in available VWP columns was also carried out to verify the accuracy of the model. The result is displayed on Figure A 13. As it can be seen in the figure, although absolute values are not replicated exactly, simulated vertical pressure gradients (shape of simulated curves) closely resemble the observed gradients (shape of observed curves) indicating that at these locations the model succeeds to replicate the vertical behaviour of the natural groundwater system at the modelled scale.

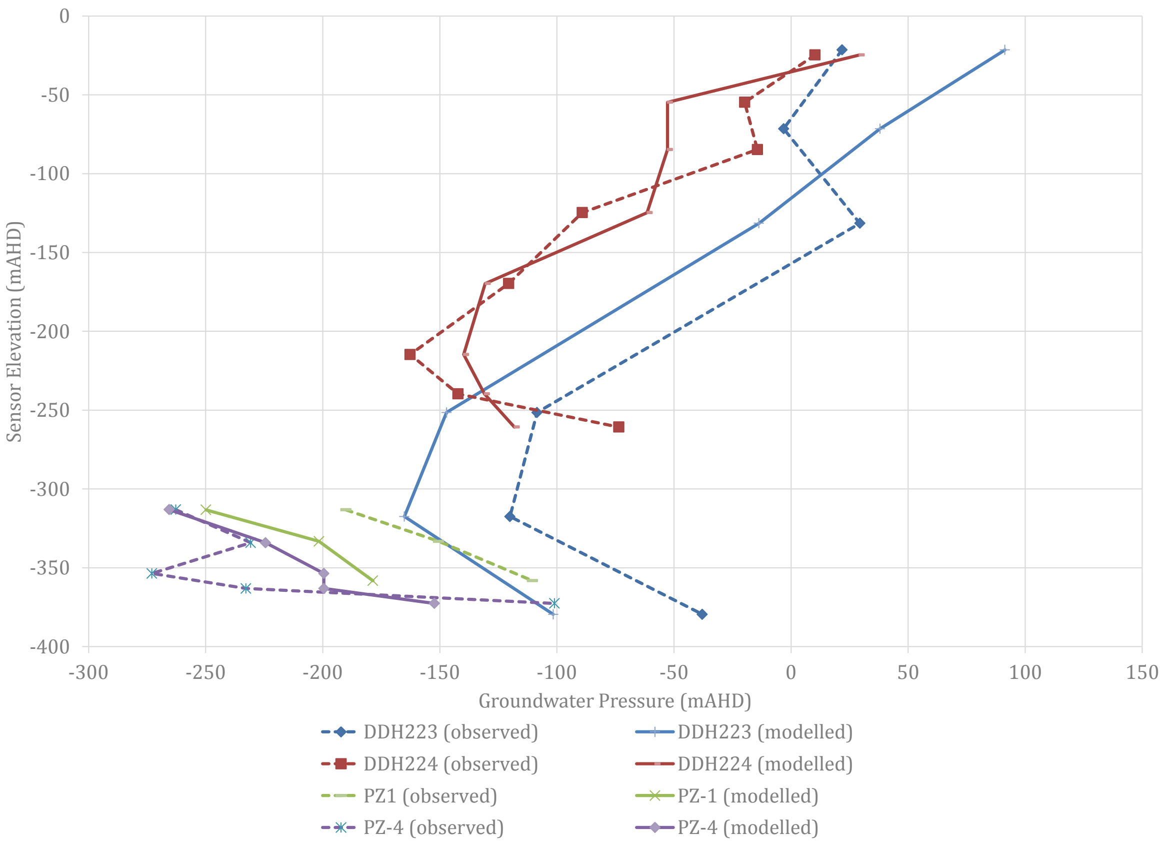


Figure A 13 Modelled versus observed vertical pressures at VWP locations

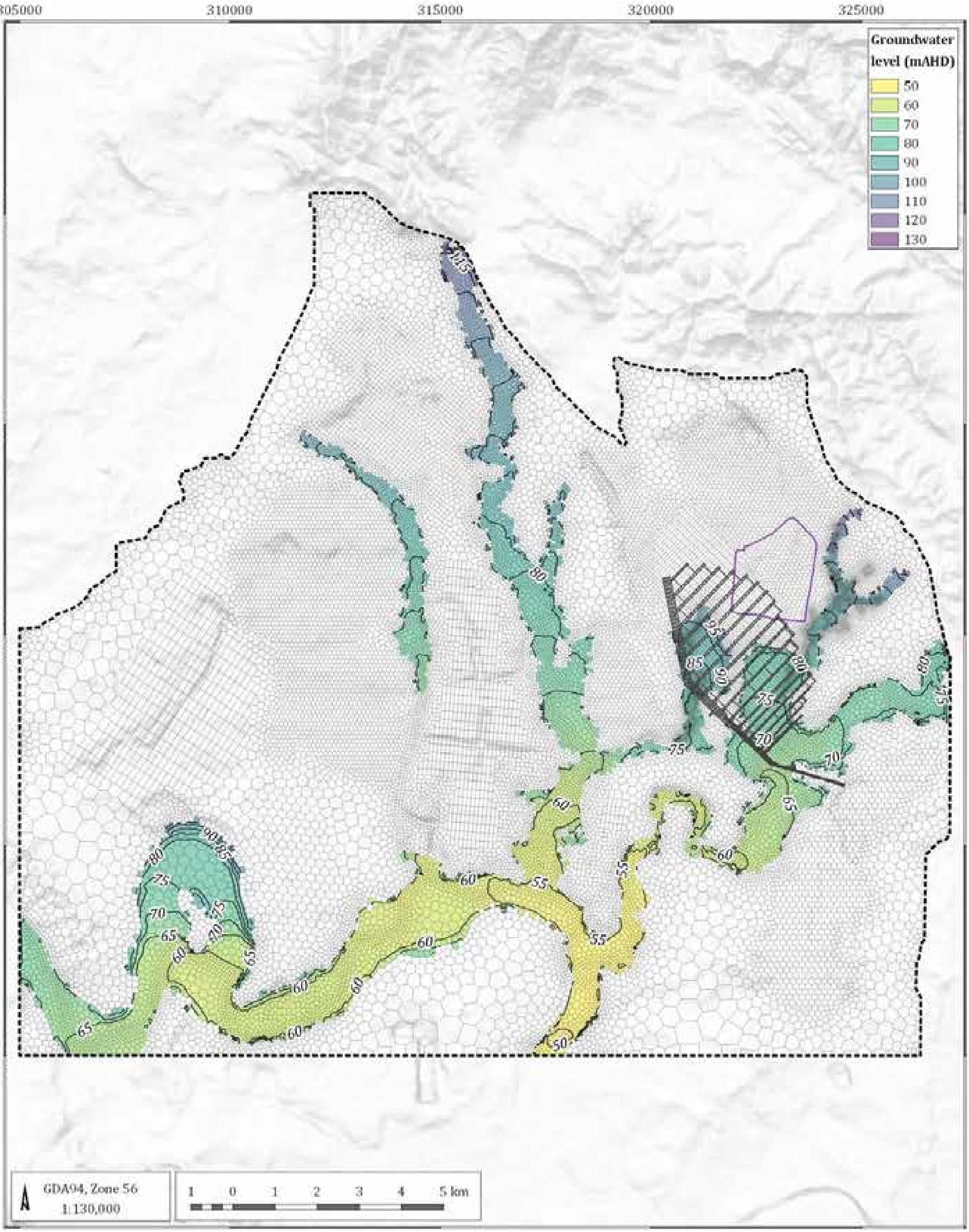
The model has commonly replicated in a simple way the complex response to the numerous mining activities seen in the monitoring data over the calibration period. In some instances, the model does not replicate water level changes in the groundwater system. This is most likely due to simplified assumptions to help speed up the calibration process, such as homogeneous hydraulic conductivity per layer using a set value or a set depth-dependent equation. The resolution of the model layering may also hinder model calibration, particularly within thick models layers, such as layer 5 and 6, where the level of fracturing, or host permeability may vary significantly..

However, it is considered the major responses to depressurisation from longwall mining and open cut mining have been replicated adequately to meet the modelling objectives. Some groundwater level responses to seasonal fluctuations have also been replicated, which is most evident in the hydrographs (Appendix A1) for bores within alluvium (i.e. ALV and BC-SP bores).

A3.2.1 Calibration heads

The calibrated heads from the steady state calibration model are presented in Figure A 14, Figure A 15 and Figure A 16 for the unconsolidated sediments (alluvium and regolith) and coal seams (Middle Liddell and Barrett respectively). The figures show groundwater generally flows southeast to the local drainage systems without the presence of active open-cut and longwall mining.

The calibrated heads at the end of the transient calibration model (2017) are presented in Figure A 17, Figure A 18 and Figure A 19 for the unconsolidated sediments (alluvium and regolith) and coal seams (Middle Liddell and Barrett) respectively. Groundwater levels representing 2017 conditions show the depressurised zones within the potentiometric surface caused by the advancement of mining. Depressurisation within the Middle Liddell Seam reflects the advance of works at the West Pit, Ravensworth, Liddell, Ashton, Glendell, Mount Owen and Integra Underground mines.



LEGEND

Model extent
Approved Middle Liddell Seam mining
Proposed Mount Owen North Pit mining
Model mesh
Groundwater level contour (mAHD)

Integra (G1285A)

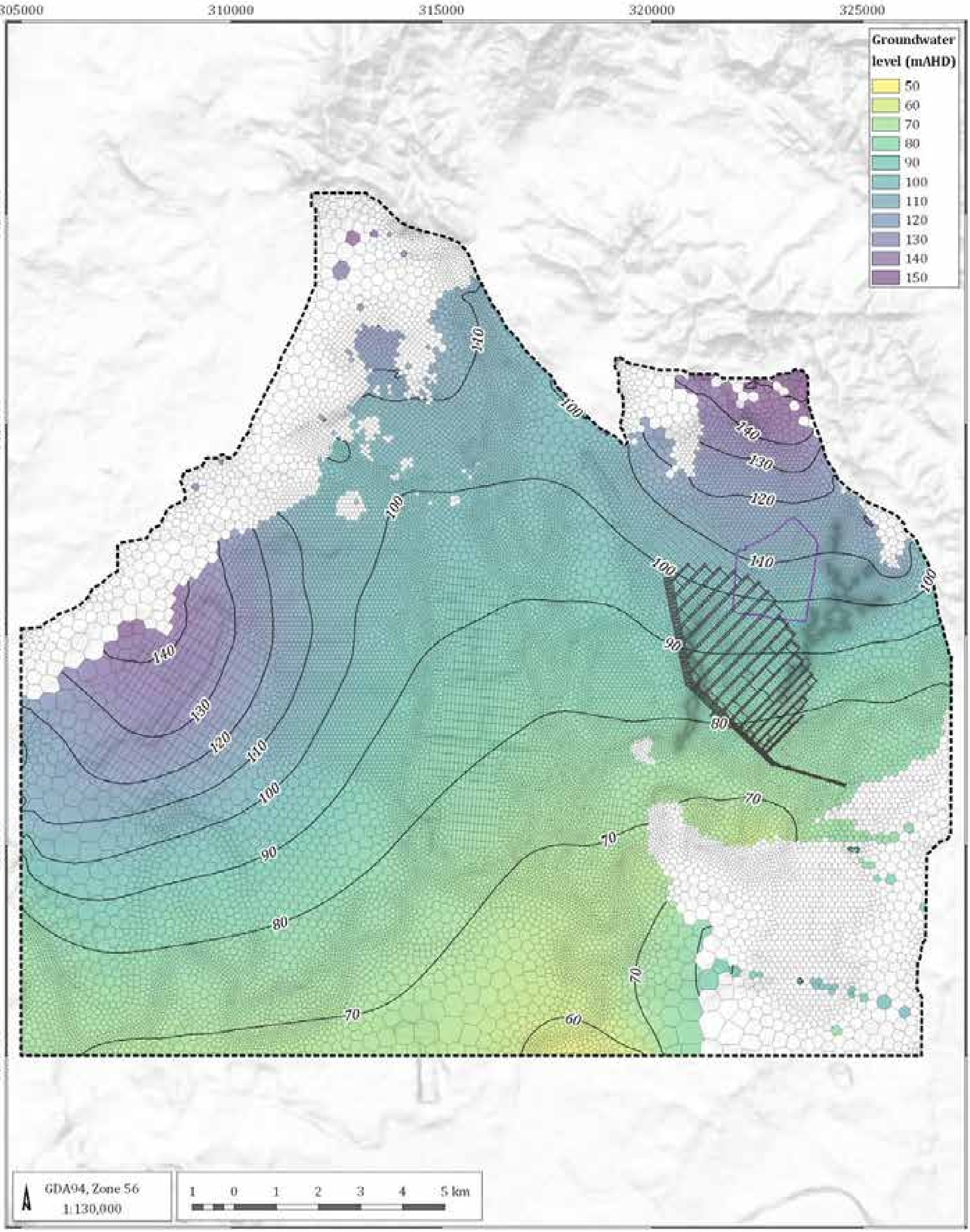
Predicted pre-mining groundwater levels - Alluvium and regolith

AGE

DATE 16/11/2017

FIGURE No: **A-14**

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/G1285A.Integra/3_GIS/Workspaces/002_EIA/A-09_G1285A_Predicted pre-mining groundwater levels.qgs



LEGEND

Model extent
Approved Middle Liddell Seam mining
Proposed Mount Owen North Pit mining
Model mesh
Groundwater level contour (mAHD)

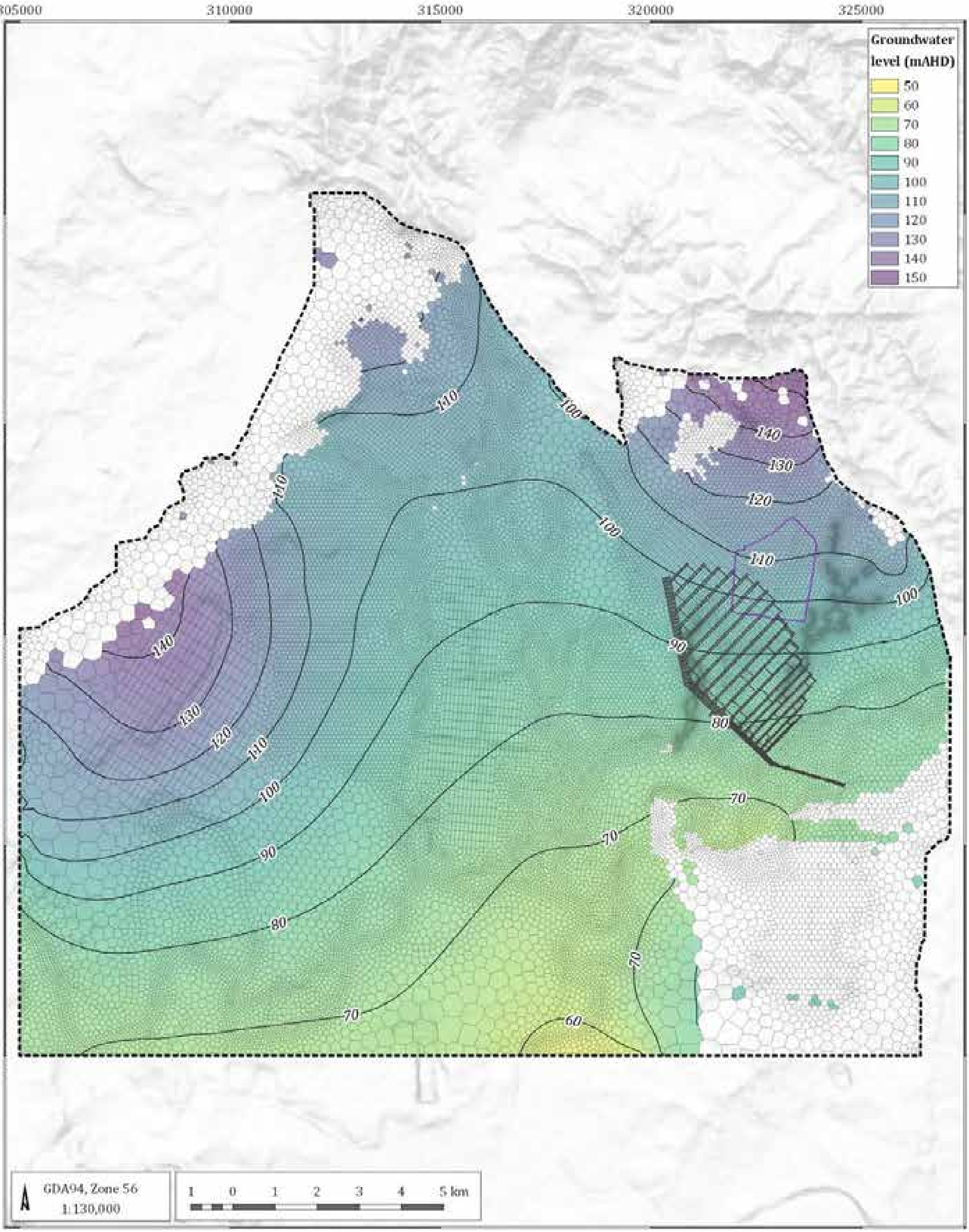
Integra (G1285A)

Predicted pre-mining groundwater levels - Middle Liddell Seam

DATE 16/11/2017

FIGURE No: **A-15**

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/G1285A.Integra/3_GIS/Workspaces/002_IBA/A-09_G1285A_Predicted pre-mining groundwater levels.qgs



LEGEND

- Model extent
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Model mesh
- Groundwater level contour (mAHD)

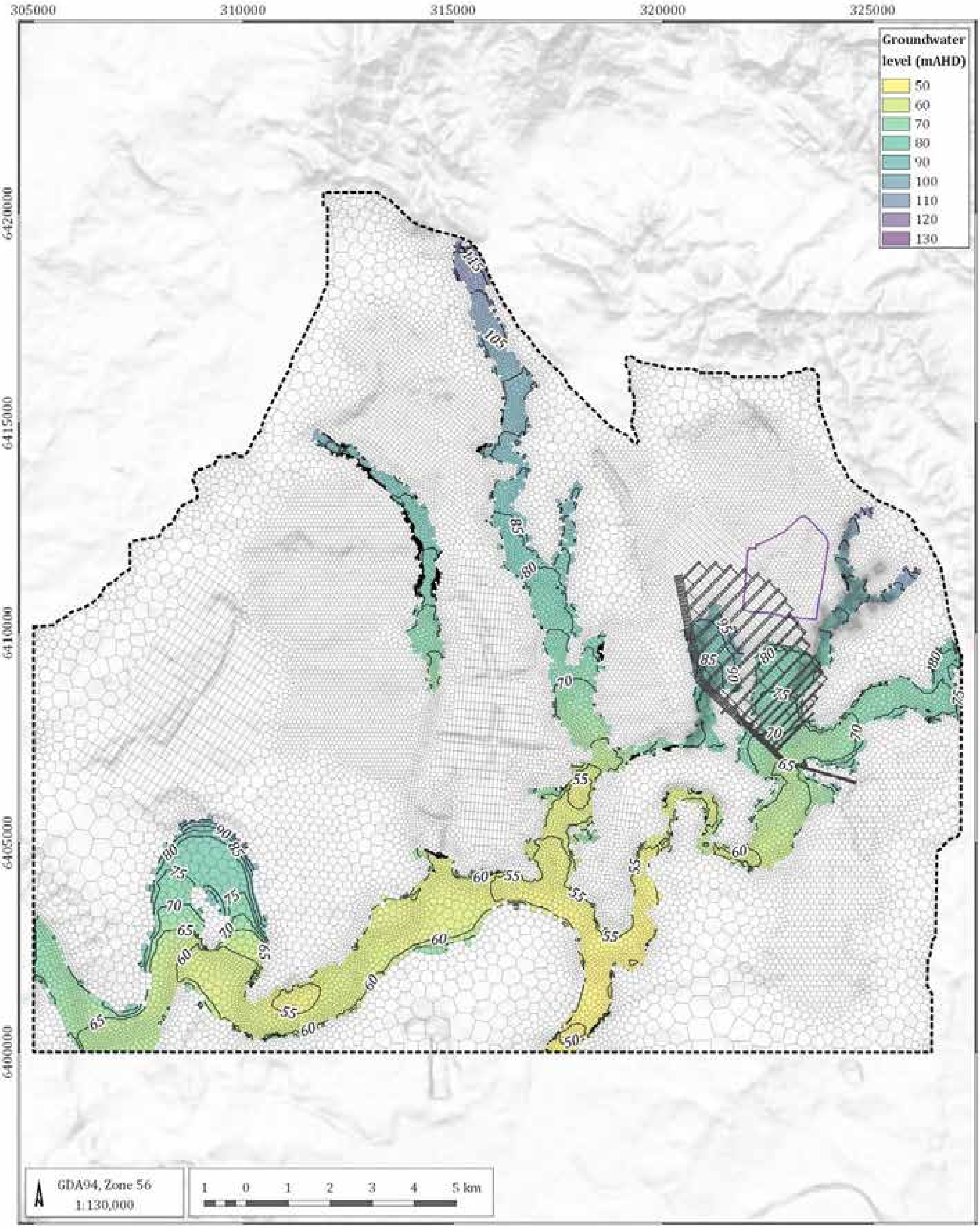
Integra (G1285A)

Predicted pre-mining groundwater levels - Barrett Seam

DATE 16/11/2017

FIGURE No: **A-16**

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/G1285A.Integra/3_GIS/Workspaces/002_EIA/A-09_G1285A_Predicted pre-mining groundwater levels.qgs



LEGEND

- Model extent
- Approved mining Middle Liddell Seam
- Proposed Mount Owen North Pit mining
- Model mesh
- Groundwater level contour (mAHD)

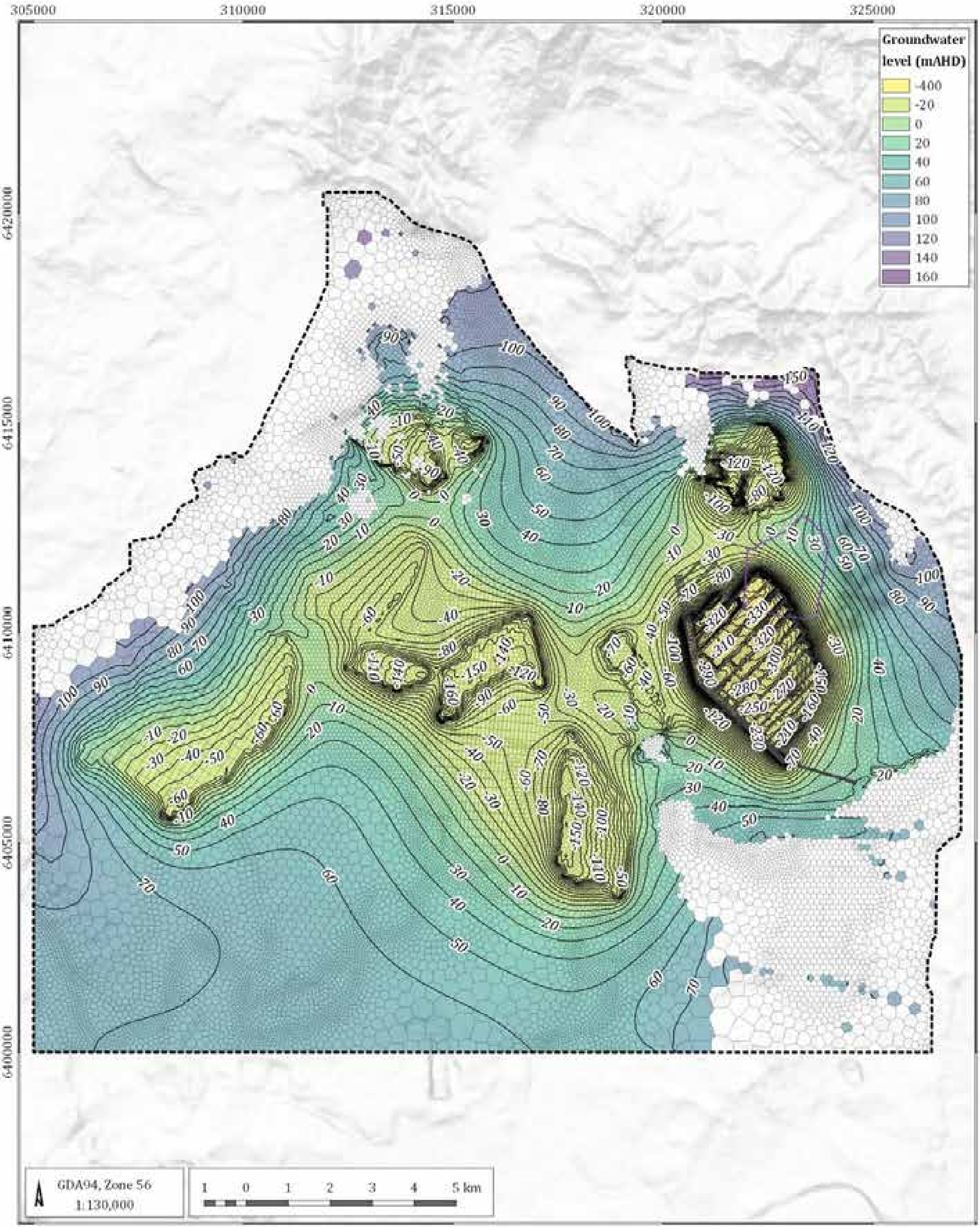
Integra (G1285A)

Predicted groundwater levels (2017) - Alluvium and regolith

DATE 16/11/2017

FIGURE No: **A-17**

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/G1285A.Integra/3_GIS/Workspaces/002_EIA/A-09_G1285A_Predicted pre-mining groundwater levels.qgs



LEGEND

- Model extent
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Model mesh
- Groundwater level contour (mAHD)

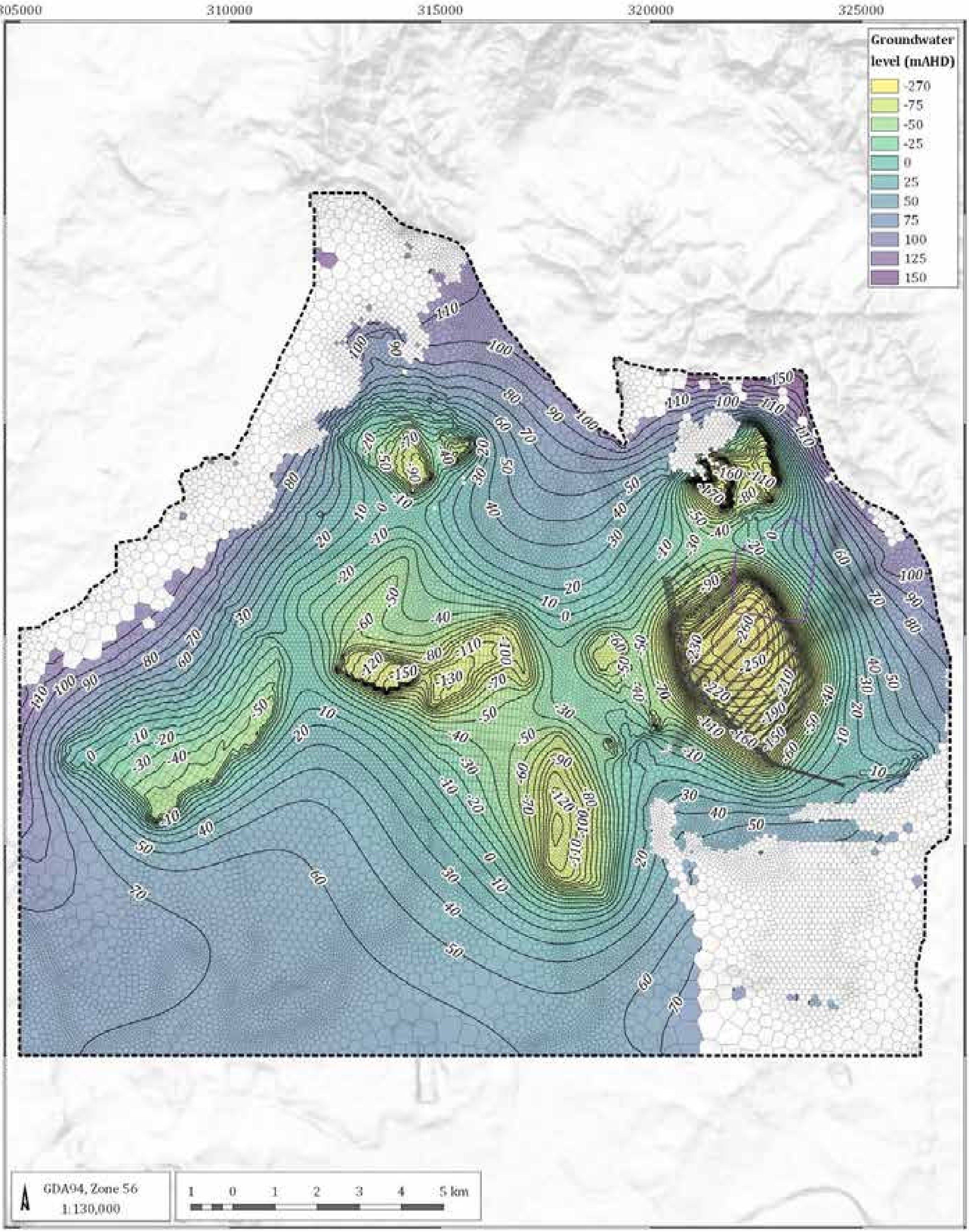
Integra (G1285A)

Predicted groundwater levels (2017) - Middle Liddell Seam

DATE 16/11/2017

FIGURE No: **A-18**

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/G1285A.Integra/3_GIS/Workspaces/002_IBA/A-09_G1285A_Predicted pre-mining groundwater levels.qgs



LEGEND

Model extent
Approved Middle Liddell Seam mining
Proposed Mount Owen North Pit mining
Model mesh
Groundwater level contour (mAHD)

Integra (G1285A)

Predicted groundwater levels (2017) - Barrett Seam

AGE

DATE 16/11/2017

FIGURE No: **A-19**

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/G1285A.Integra/3_GIS/Workspaces/002_EIA/A-09_G1285A_Predicted pre-mining groundwater levels.qgs

A3.2.2 Hydraulic parameters

Table A 8 summarises the calibrated maximum hydraulic conductivity for each of the hydrostratigraphic units within the model domain. The table presents the set hydraulic conductivity values for Layers 1, 2, 3 and 21. The hydraulic properties of the Permian coal measures and interburden (Layers 4 to 20) change with depth; therefore, the values presented for the coal and interburden in Table A 8 are the uppermost hydraulic conductivity value for each layer. The relationship with depth is further discussed below.

Table A 8 Calibrated hydraulic conductivity values (at surface)

Model layer	Lithology	Horizontal hydraulic conductivity Kx (m/day)*	Vertical hydraulic conductivity factor (Kv/Kh)
1	Alluvium (Qa)	Set value: 5	$2.0x10^{-2}$
2	Regolith	Set value: $2.4 x10^{-3}$	$1.0x10^{-2}$
3	Overburden	Set value: $1.4x10^{-4}$	$1.1x10^{-2}$
4	Bayswater Seam	0-100m: $1.0x10^{-1}$ - $1.0x10^{-1}$ 100-300m: $5.5x10^{-3}$ - $1.0x10^{-1}$ 300-700m: $8.6x10^{-6}$ - $5.5x10^{-3}$	1
5	Interburden	0-100m: $1.0x10^{-3}$ - $1.0x10^{-3}$ 101-300m: $1.0x10^{-3}$ - $1.0x10^{-3}$ 301-700m: $2.3x10^{-4}$ - $1.0x10^{-3}$	$1.3x10^{-2}$
6	Interburden	0-100m: $1.0x10^{-3}$ - $1.0x10^{-3}$ 101-300m: $5.3x10^{-4}$ - $1.0x10^{-3}$ 301-700m: $1.0x10^{-4}$ - $5.3x10^{-4}$	$1.0x10^{-1}$
7	Upper Pikes Gully Seam	0-100m: $8.5x10^{-3}$ - $6.9x10^{-2}$ 101-300m: $1.3x10^{-4}$ - $8.5x10^{-3}$ 301-700m: $8.6 x10^{-6}$ - $1.3x10^{-4}$	1
8	Interburden	0-100m: $1.0x10^{-3}$ - $1.0x10^{-3}$ 101-300m: $4.0x10^{-4}$ - $1.0x10^{-3}$ 301-700m: $8.5x10^{-5}$ - $4.0x10^{-4}$	$1.0x10^{-1}$
9	Middle and Lower Pikes Gully Seam	0-100m: $4.0x10^{-3}$ - $3.3x10^{-2}$ 101-300m: $6.0x10^{-5}$ - $4.0x10^{-3}$ 301-700m: $8.6 x10^{-6}$ - $6.0x10^{-5}$	$8.9x10^{-2}$
10	Interburden	0-100m: $1.0x10^{-3}$ - $1.0x10^{-3}$ 101-300m: $2.3x10^{-4}$ - $1.0x10^{-3}$ 301-700m: $4.8x10^{-5}$ - $2.3x10^{-4}$	$1.0x10^{-2}$
11	Arties Seam	0-100m: $4.9x10^{-2}$ - $1.0x10^{-1}$ 101-300m: $7.4x10^{-4}$ - $4.9x10^{-2}$ 301-700m: $8.6 x10^{-6}$ - $4.4x10^{-4}$	1
12	Interburden	0-100m: $1.0x10^{-3}$ - $1.0x10^{-3}$ 101-300m: $1.0x10^{-3}$ - $1.0x10^{-3}$ 301-700m: $2.3x10^{-4}$ - $1.0x10^{-3}$	$1.0x10^{-1}$
13	Liddell Seam Section A	0-100m: $8.3x10^{-4}$ - $6.8x10^{-3}$ 101-300m: $1.2x10^{-5}$ - $8.3x10^{-4}$ 301-700m: $8.64x10^{-6}$ - $1.2x10^{-5}$	1

Model layer	Lithology	Horizontal hydraulic conductivity Kx (m/day)*	Vertical hydraulic conductivity factor (Kv/Kh)
14	Liddell Seam Section B	0-100m: 6.1×10^{-4} - 5.0×10^{-3} 101-300m: 9.2×10^{-6} - 6.1×10^{-4} 301-700m: 8.6×10^{-6} - 9.2×10^{-6}	1
15	Liddell Seam Section C	0-100m: 3.0×10^{-2} - 1.0×10^{-1} 101-300m: 4.6×10^{-4} - 3.0×10^{-2} 301-700m: 8.64×10^{-6} - 4.6×10^{-4}	1
16	Liddell Seam Section D	0-100m: 1.0×10^{-3} - 1.0×10^{-3} 101-300m: 1.0×10^{-3} - 1.0×10^{-3} 301-700m: 2.3×10^{-4} - 1.0×10^{-3}	4.5×10^{-1}
17	Interburden	0-100m: 1.0×10^{-3} - 1.0×10^{-3} 101-300m: 1.0×10^{-3} - 1.0×10^{-3} 301-700m: 2.3×10^{-4} - 1.0×10^{-3}	1.9×10^{-2}
18	Barrett Seam	0-100m: 4.6×10^{-2} - 1.0×10^{-1} 101-300m: 6.9×10^{-4} - 4.6×10^{-2} 301-700m: 8.6×10^{-6} - 6.9×10^{-4}	1
19	Interburden	0-100m: 1.0×10^{-3} - 1.0×10^{-3} 101-300m: 1.7×10^{-4} - 1.0×10^{-3} 301-700m: 3.8×10^{-5} - 1.7×10^{-4}	1.6×10^{-1}
20	Hebden Seam	0-100m: 1.2×10^{-2} - 1.0×10^{-1} 101-300m: 1.9×10^{-4} - 1.2×10^{-2} 301-700m: 8.6×10^{-6} - 1.9×10^{-4}	1
21	Saltwater Creek Formation	Set value: 1.0×10^{-3}	2.4×10^{-1}
-	Spoil	Set value: 3.0×10^{-1}	3.3×10^{-1}

Note: ** the ranges were derived using depth dependence formulas*

The hydraulic conductivity of the Permian interburden material in the model reduces with depth in order to reflect field observations gathered from the site and surrounding regional mines. Because the decrease of Kh within the interburden rock units is driven by an increase in overburden pressure, the relationship between Kh and depth is different from that of coal seams.

The hydraulic conductivity of the coal seam and interburden layers decreases with depth according to Equations 1 (exponential) and 2 (power):

Coal: $HC = HC_0 \times e^{(slope \times depth)}$ (Eq. 1)

Interburden: $HC = HC_0 \times depth^{slope}$ (Eq. 2)

Where: HC is horizontal hydraulic conductivity at specific depth.

HC_0 is horizontal hydraulic conductivity at depth of 0m (intercept of the curve).

depth is depth of the centre of the layer (average thickness of the cover material).

slope is a coefficient related to the slope (steepness) of the curve.

After using the depth-dependence equations, the horizontal hydraulic conductivity of the coal was capped at a maximum of $1x10^{-1}$ m/day and the interburden at a maximum of $1x10^{-3}$ m/day. Both coal and interburden were also caped at a lower bound of 8.64×10^{-6} m/day.

The *slope* and HC_0 parameters for depth dependence equations of individual layers were calibrated.

The Kh vs. depth relationship for the individual coal seams and interburden units are presented in Figure A 20 and Figure A 21. As shown in Figure A 20 and Figure A 21, the calibrated depth dependence trends for the various coal and interburden layers largely follow the averaged trend identified for the available field data within the main report. The relationship used for the interburden in the model was skewed towards the more permeable measurements in the field data below 150 m, indicating the base model is conservative.

In order to demonstrate the application of the depth dependence function, the spatial distribution of hydraulic conductivity values is presented in Figure A 22 for the Barrett Seam. Figure A 22 shows a decline in hydraulic conductivity with depth in the Integra Underground area (with depths up to 500 m to 600 m in the Barrett Seam), as well as the southwestern area of the model (with depths close to 400 m in the Barrett Seam).

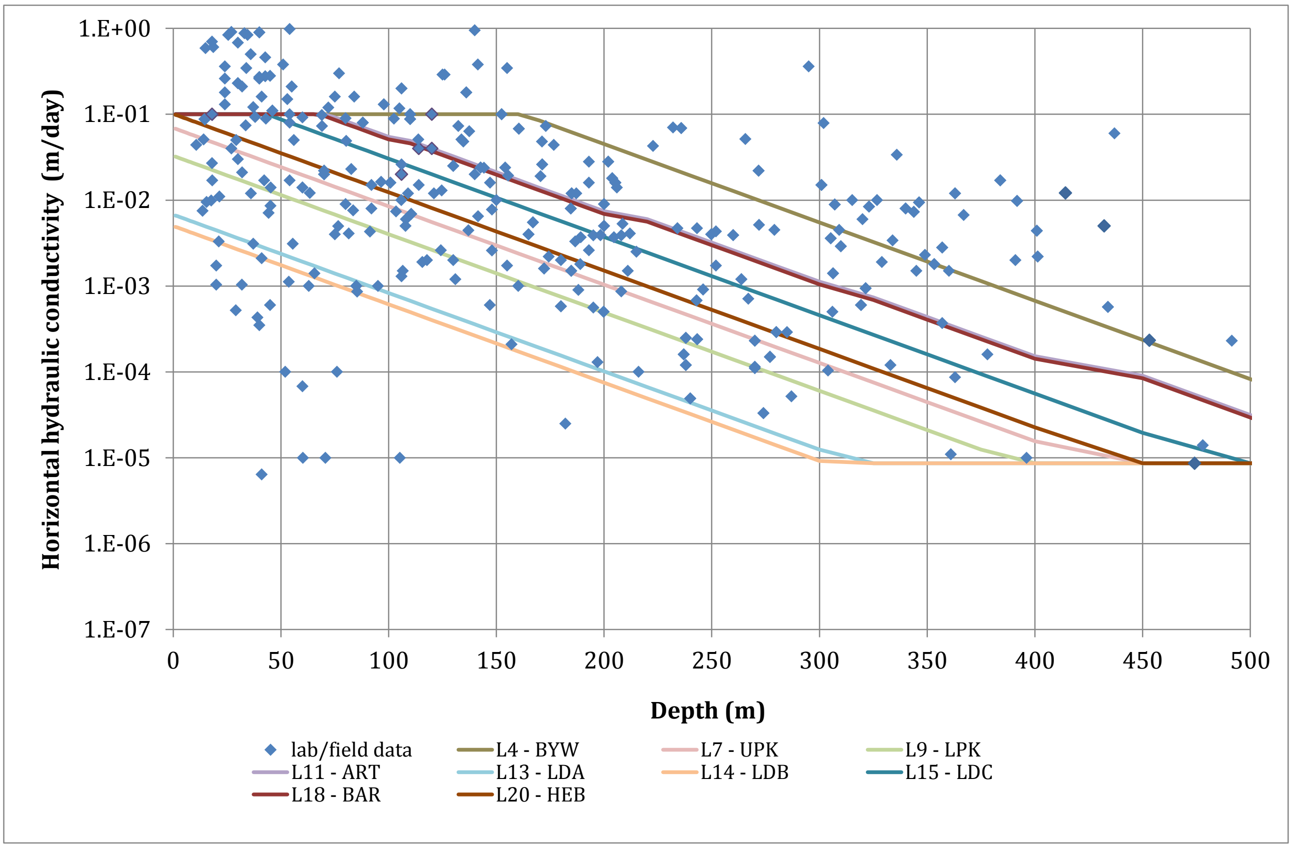


Figure A 20 Coal hydraulic conductivity distribution graph

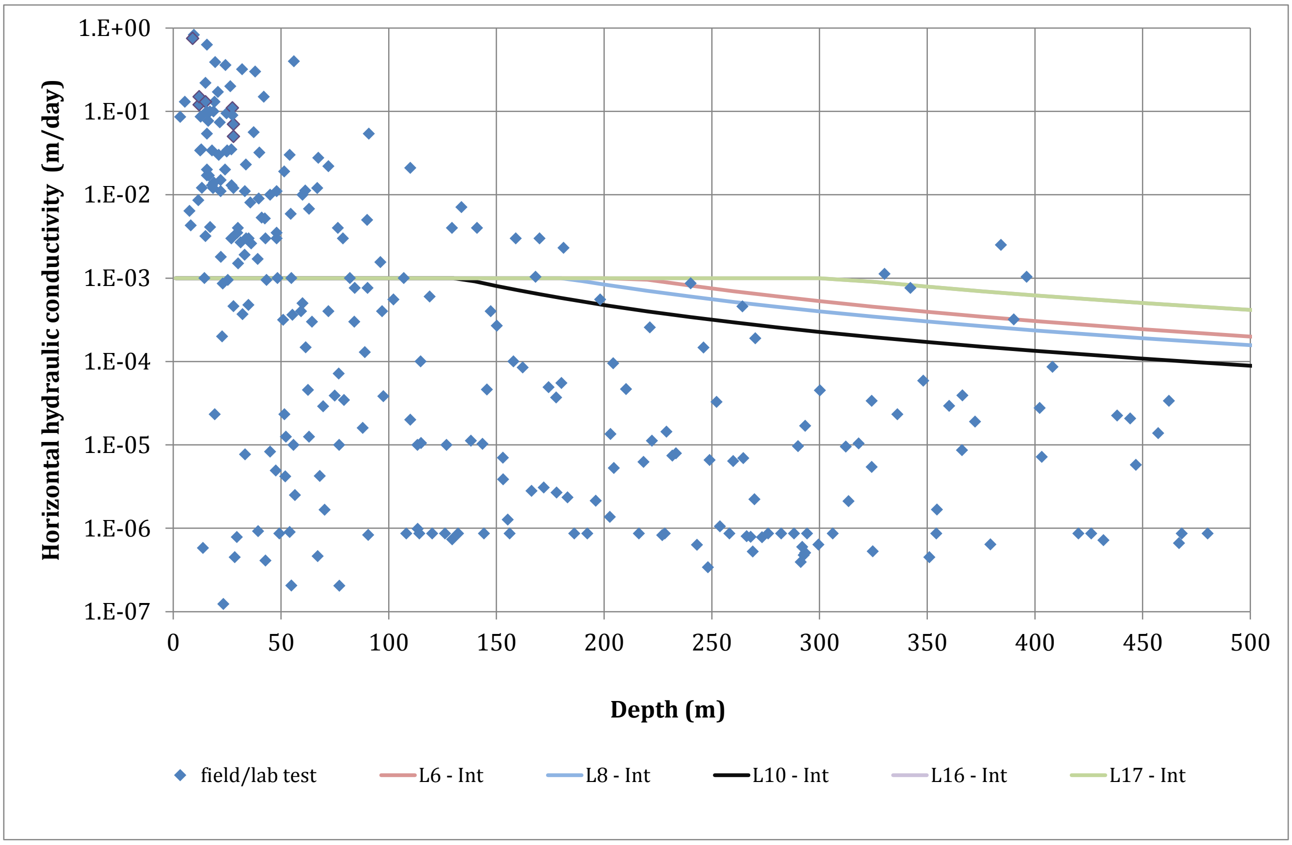


Figure A 21 Interburden hydraulic distribution graph

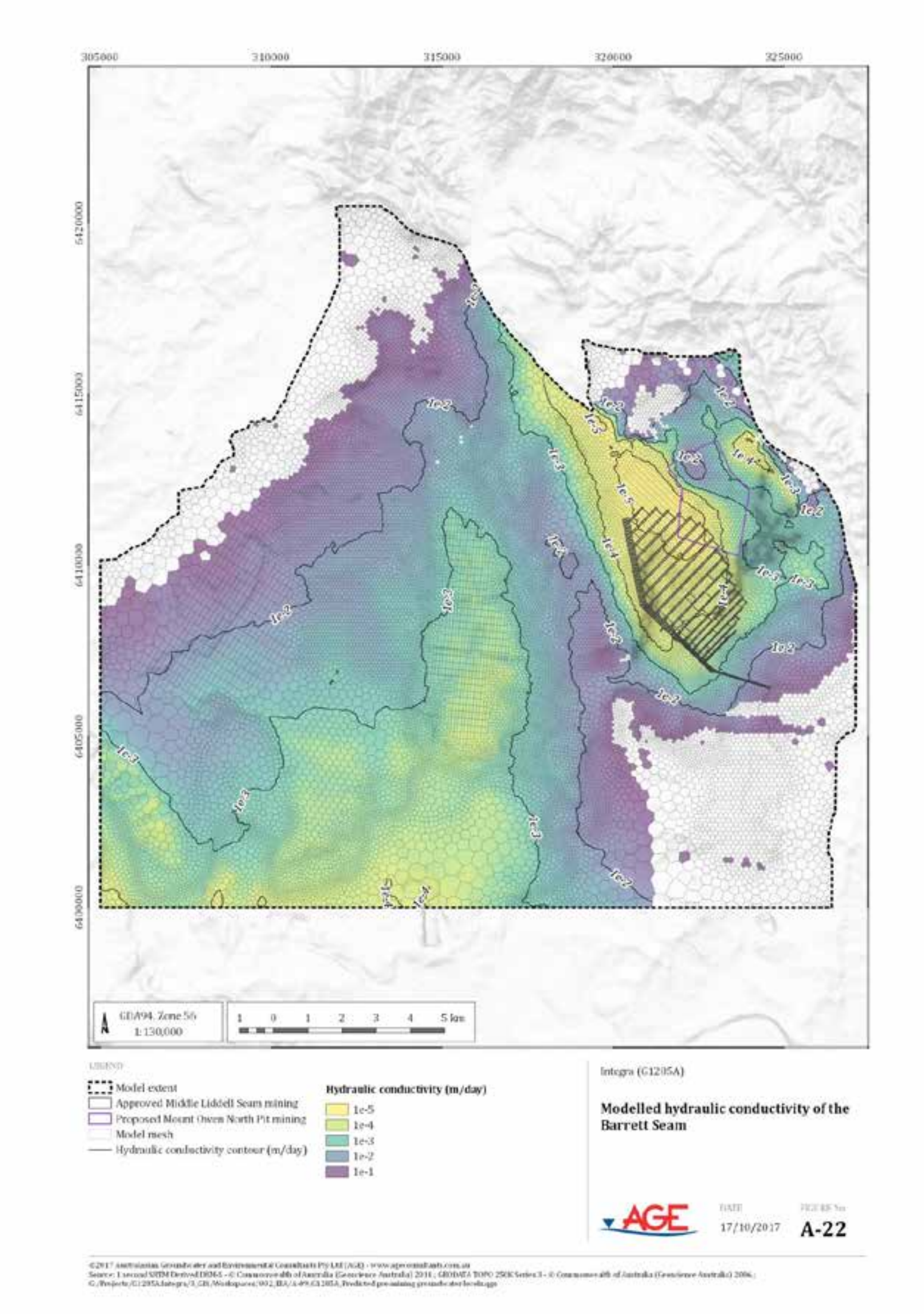


Figure A 22 Modelled hydraulic conductivity of the Barrett Seam

A3.2.3 Storage properties

Table A 9 summarises the calibrated values for specific storage and specific yield.

Table A 9 Model layer storage properties

Model layer	Lithology	Specific yield - Sy	Specific storage - Ss (m^{-1})
1	Alluvium (Qa)	$5.0x10^{-2}$	$9.7x10^{-4}$
2	Regolith	$1.2x10^{-2}$	$9.6x10^{-4}$
3	Overburden	$1.0x10^{-2}$	$1.9x10^{-4}$
4	Bayswater Seam	$3.0x10^{-2}$	$5.0x10^{-6}$
5	Interburden	$4.1x10^{-3}$	$3.4x10^{-6}$
6	Interburden	$1.0x10^{-4}$	$1.1x10^{-6}$
7	Upper Pikes Gully Seam	$4.8x10^{-4}$	$3.4x10^{-6}$
8	Interburden	$2.5x10^{-4}$	$3.1x10^{-6}$
9	Middle and Lower Pikes Gully Seam	$1.1x10^{-3}$	$1.0x10^{-5}$
10	Interburden	$2.2x10^{-4}$	$5.0x10^{-7}$
11	Arties Seam	$3.3x10^{-4}$	$1.5x10^{-6}$
12	Interburden	$1.0x10^{-4}$	$5.0x10^{-7}$
13	Liddell Seam Section A	$1.8x10^{-4}$	$1.2x10^{-6}$
14	Liddell Seam Section B	$1.5x10^{-4}$	$1.3x10^{-6}$
15	Liddell Seam Section C	$1.9x10^{-4}$	$6.3x10^{-7}$
16	Liddell Seam Section D	$1.9x10^{-4}$	$7.0x10^{-7}$
17	Interburden	$1.0x10^{-4}$	$5.0x10^{-7}$
18	Barrett Seam	$9.2x10^{-3}$	$2.9x10^{-6}$
19	Interburden	$2.8x10_{-4}$	$7.4x10^{-7}$
20	Hebden Seam	$2.0x10^{-4}$	$3.5x10^{-6}$
21	Saltwater Creek Formation	$2.4x10^{-4}$	$5.0x10^{-7}$
-	Spoil	$1.0x10^{-1}$	$1.0x10^{-4}$

Note: *Parameters used in the model are conservative estimates using a combination of field data, experience, knowledge of the region and automatic and manual model calibration.*

Direct testing data are not generally available for specific storage (Ss) of coal seams or interburden. However, good estimates can be made based on Young's Modulus and porosity. For coal, Ss generally lies in the range 5×10^{-6} m^{-1} to 5×10^{-5} m^{-1}, and interburden is generally slightly higher than this due to the greater porosity (Mackie, 2009). The calibrated parameters for coal were guided by these bounds, although some flexibility was allowed for improvement of the calibration results.

A3.2.4 Water budget

The mass balance error, that is, the difference between calculated model inflows and outflows at the completion of the steady state calibration was 0.00%. The maximum percent discrepancy at any time step in the simulation was also 0.00%. This value indicates that the model is stable and achieves an accurate numerical solution. Table A 10 shows the water budget for the steady state (pre-mining) model.

Table A 10 Model budgets – steady state

Parameter	In (ML/day)	Out (ML/day)	In - Out (ML/day)
Rainfall recharge	10.6	-	10.6
River	-	0.3	-0.3
Stream	2.4	4.0	-1.6
Evapotranspiration	-	10.1	-10.1
General head boundary	3.5	2.2	1.3
Constant head	0.0	0.0	0.0
Total	**16.6**	**16.6**	**0.0**

The water budget indicates that recharge to the groundwater system within the model averages 10.6 ML/day, with approximately 4.3 ML/day being discharged via surface drainage, and 10.1 ML/day lost to evapotranspiration in areas where the water table is within 2.0 m of the land surface. Regional through flow from the general head boundary contributes 21% of the total input to the groundwater model, whereas the constant head boundary, which represents Lake Liddell, has a very low contribution to the overall model budget.

Table A 11 shows the average water budget for the transient calibration (1979 to 2017).

Table A 11 Model budgets – transient calibration

Parameter	In (ML/day)	Out (ML/day)	In - Out (ML/day)
Storage	12.5	9.8	2.7
Rainfall recharge	10.7	-	10.7
River	-	0.3	-0.3
Stream	3.0	4.3	-1.3
Evapotranspiration	-	8.4	-8.4
General head boundary	4.0	2.1	2.0
Constant head	0.1	0.0	0.0
Drains	-	9.8	-9.8
Total	**30.3**	**30.3**	**0.0**

The water budget indicates that the groundwater system slightly departs from steady state conditions because of extensive mining in the model domain. Recharge (rainfall and river leakage) within the model averages 10.7 ML/day, with approximately 4.6 ML/day being discharged via surface drainage surface. The differences between the steady state recharge rates are due to different climatic conditions during the transient calibration period (1979 to 2017) when compared to the annual average (steady state). Table A 11 shows regional dewatering extracts at 9.8 ML/day on average, which indirectly reduces surface drainage, evaporation rates, and increases inflows from the general and constant head boundaries.

A3.2.5 Baseflow verification

Figure A 23 shows estimated observed baseflow at Bowmans Creek downstream of the mine (station 210004), compared to simulated baseflow. Flow out of the model domain is displayed as a negative value and observed baseflow was calculated using a search algorithm adopted from Arnold and Allen (1999) via the 'SWAT Bflow' executable (Texas A&M University, 2014).

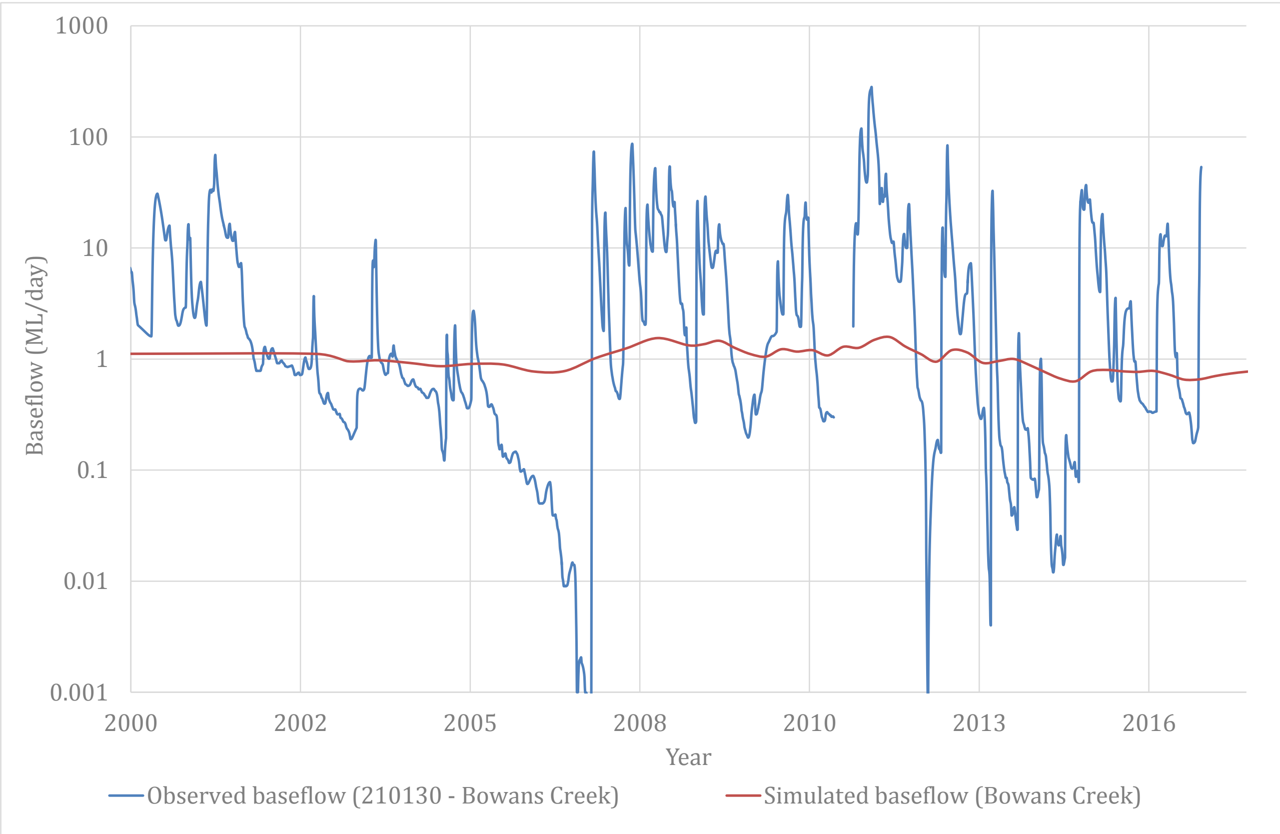


Figure A 23 Modelled vs observed baseflow analysis at Bowmans Creek

The results show the model generally replicates the calculated baseflow levels and climatically controlled trends in a subdued manner. Figure A 24 the baseflow calculated for the Glennies Creek station that is just outside the model domain (station 210044), compared to baseflow within the model domain.

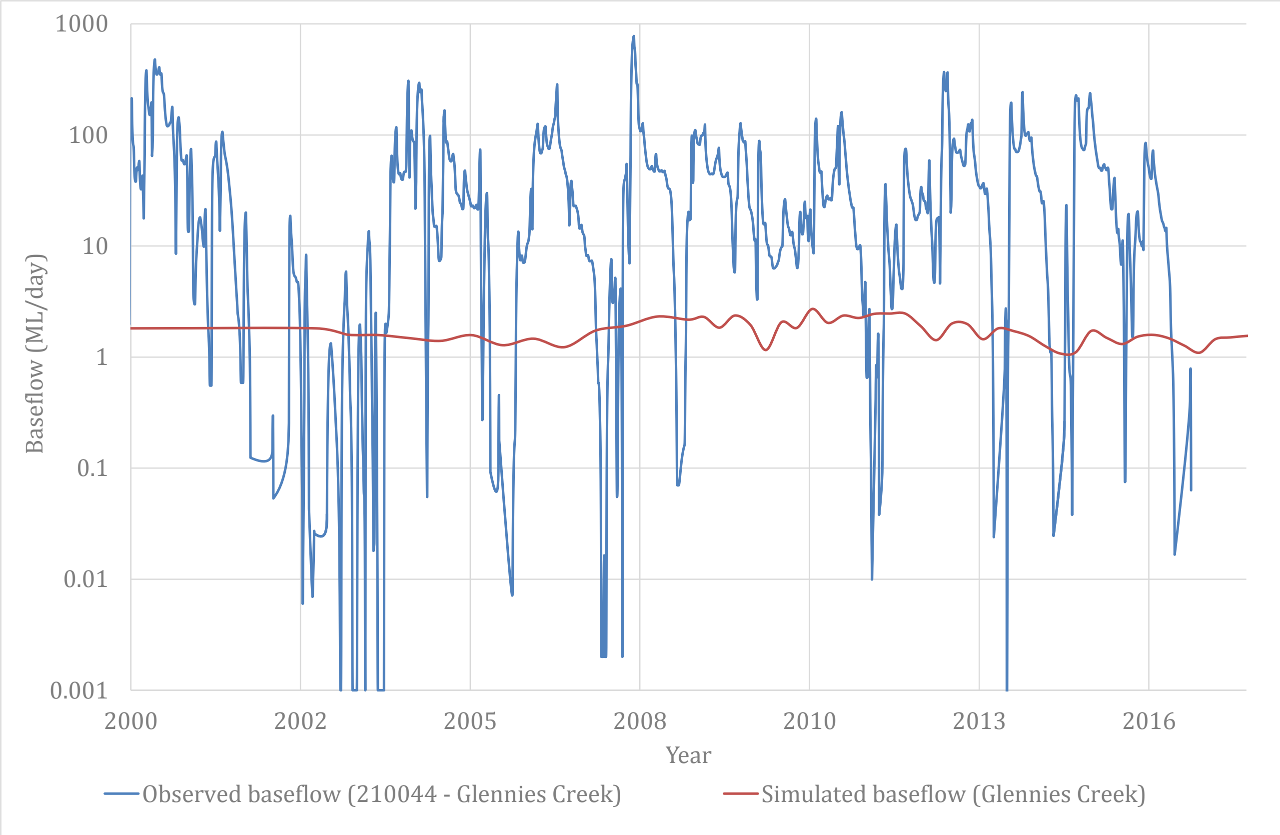


Figure A 24 Modelled vs observed baseflow analysis at Glennies Creek

Again the result is similar to Bowmans Creek showing the model is replicating some climatic trends in a subdued manner. An exact match the Glennies Creek baseflow is not possible because the flow is controlled by upstream releases of surface water that are not represented within the model.

A3.2.6 Mine inflow verification

The underground workings at Integra are estimated to have received average inflows of less than 1 ML/day at the sumps between 2015 and 2017. These measurements relate to the period the workings were in care and maintenance and therefore not influenced by water being pumped underground.

Figure A 25 presents the inflow to the entire Integra underground workings in the groundwater model. These represent the raw outflow from the entire fracture network, without correction for losses typically factored into water balance calculations, such as ventilation, floor seepage, moisture loss, and fracture discontinuity. Applying an approximate correction 0.6 produces results in very good agreement with measured underground inflow measurements, which suggests the host and fractured hydraulic and storage parameters adopted in the model are appropriate.

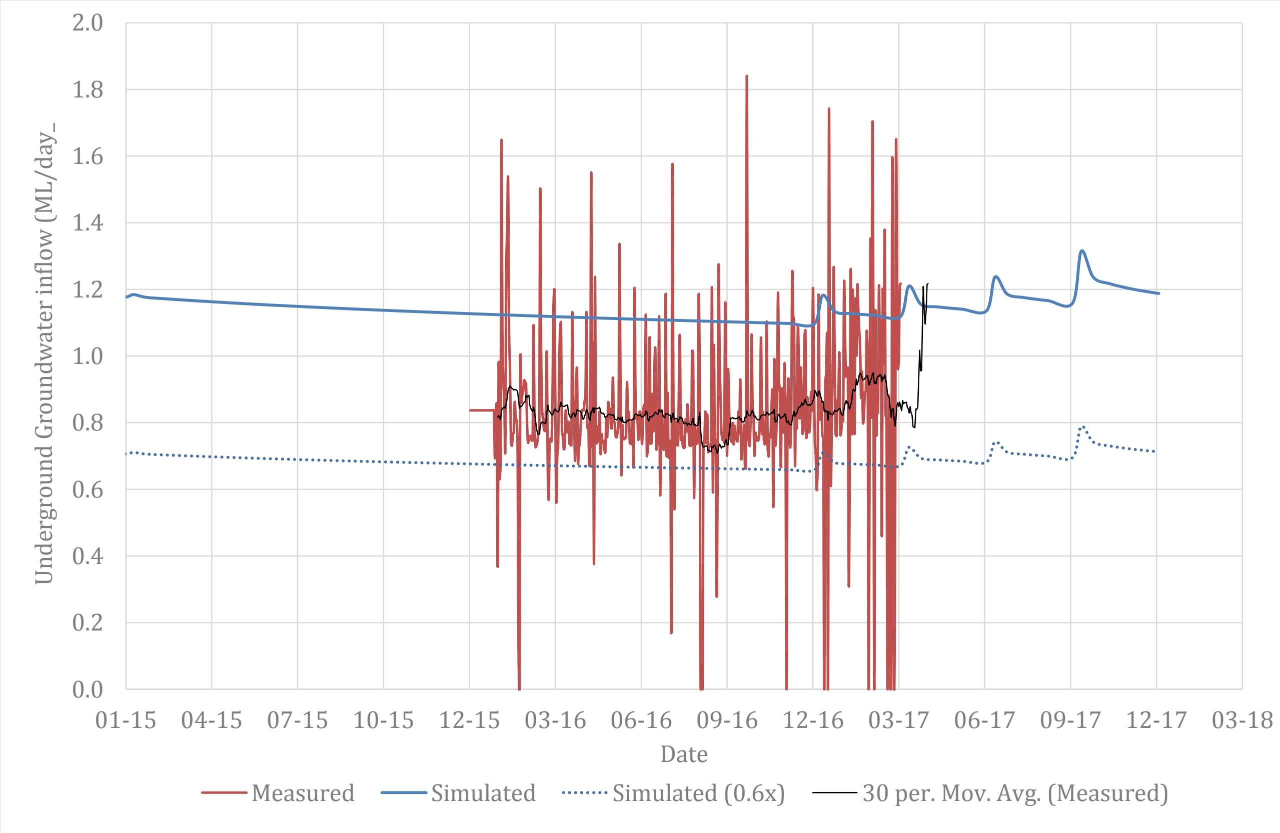


Figure A 25 Measured versus simulated underground groundwater inflows

A3.2.7 Model confidence level classification

The Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012) developed a system to classify the confidence-level for groundwater models. Models are classified as either Class 1, Class 2 or Class 3 in order of increasing confidence (i.e. Class 3 has the highest level of confidence). Several factors are considered in determining the model confidence level:

- available data;
- calibration procedures;
- consistency between calibration and predictive analysis; and
- level of stresses.

Table A 12 below is a check list provided by the peer reviewer Dr Noel Merrick to classify the confidence level for the model. The table shows the model generally achieves aspects of Class 2 and Class 3 confidence level criteria. It does this by simulating a similar calibration period to the predictive model, replicating seasonal responses to surface water/rainfall interaction, and meeting calibration and model error statistics.

Table A 12 Model confidence level classification

Class	Data	Calibration	Prediction	Indicators
1	• Not much • Sparse • No metered usage • Remote climate data	• Not possible • Large error statistic • Inadequate data spread • Targets incompatible with model purpose	• Timeframe>>calibration • Long stress periods • Transient prediction but steady-state calibration • Bad verification	• Timeframe>10x • Stress >5x • Mass balance>1% (or single 5%) • Properties<>field • Bad discretisation • No review
2	• Some • Poor coverage • Some usage info. • Baseflow estimates ✓	• Partial performance • Long-term trends wrong • Short time record • Weak seasonal replication • No use of targets compatible with model purpose ✓	• Timeframe>calibration • Long stress periods ✓ • New stresses not in calibration • Poor verification	• Timeframe =3-10x • Stresses=2-5x • Mass balance <1% • Some properties <>field measurements ✓ • Some key coarse discretisation ✓ • Review by hydrogeo
3	• Lots. ✓ • Good aquifer geometry. ✓ • Good usage info. • Local climate info. ✓ • K measurements. ✓ • Hi-res DEM.	• Good performance stats. ✓ • Long-term trends replicated ✓ • Seasonal fluctuations OK. ✓ • Present day data targets. ✓ • Head and flux targets. ✓	• Timeframe ~calibration ✓ • Similar stress periods. ✓ • Similar stresses to those in calibration. ✓ • Steady-state prediction consistent with steady-state calibration. ✓ • Good verification	• Timeframe <3 x • Stresses < 2x ✓ • Mass balance <0.5% ✓ • Properties ~ field measurements. • Some key coarse discretisation. ✓ • Review by modeller ✓

A4 Recovery simulations

At the completion of mining, drain cells were removed and the model simulated post-mining conditions, which includes final voids within the Mt Owen complex. A transient model was created to ascertain post-mining impacts. A 1000 year recovery simulation was run, with all drain cells removed, thus allowing the groundwater levels in the coal seams and the overlying water-bearing strata to recover. Model cells located within the final voids were assigned a high horizontal and vertical hydraulic conductivity (1000 m/day) and storage parameters (specific yield of 1.0, storage coefficient of 5.0×10^{-6}), to simulate free water movement within the void. This approach is often referred to as a 'high-k' lake.

The percentage of the rainfall becoming recharge across the void pit was set to 100% annual rainfall recharge and the pan evaporation rate was set at 1.0.

A5 Uncertainty analysis

Groundwater models represent complex environmental systems and processes in a simplified manner. This means that predictions from groundwater models, likely so many other environmental models are inherently uncertain. The preceding sections highlight uncertainties in model inputs and the necessary simplifications within models to represent natural systems. National modelling guidelines encourage the acknowledgement of uncertainty and suggest methods to formulate predictions in which uncertainties are minimised. Barnett *et al* (2012) recommend uncertainty in model predictions can be quantified using linear or non-linear methods. The sections below describe the methodology and results of the uncertainty analysis.

A5.1 Methodology

A pseudo Null-space Monte Carlo uncertainty analysis was undertaken 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 by assessing and ranking the predictions from hundreds of model 'realizations'. Each model realisation is informed by the observation dataset by using the relationship between the observations statistics to perturbations of each parameter in the groundwater model. The approach is described as a 'pseudo' Null-space Monte Carlo simply because this model did not utilise a 'highly parameterised inversion' approach, whereby pilot points are used extensively across the model as to not introduce artificial sensitivity (and consequently 'certainty') to small changes to homogenous aquifer units. To compensate, 'posterior' or post-calibration parameter ranges were informed by the Jacobian matrix, but were manually inspected and adjusted where posterior ranges appeared artificially constrained.

A5.2 Parameter generation

To undertake this type of analysis it is necessary to firstly assess the response of the calibration statistics to changes in the parameters in the groundwater model using a 'prior' or pre-calibration range.

Figure A 26 and Table A 13 to Table A 18 shows the 'prior' range explored during the uncertainty analysis simulation. This represents the 95^{th} confidence interval best on prior information of the likely range of the model parameters prescribed to an entire homogenous unit. All parameters were assumed to possess a log-normal distribution using a mean value, or the most probable value, derived from the calibration exercise. The rainfall recharge rates for each unit were adjusted to cover the natural cycles of wet and dry years indicated in the 117 year historical dataset.

A total of 275 models were generated using a random parameter generator to produce 'realisations' to assess predictive impacts.

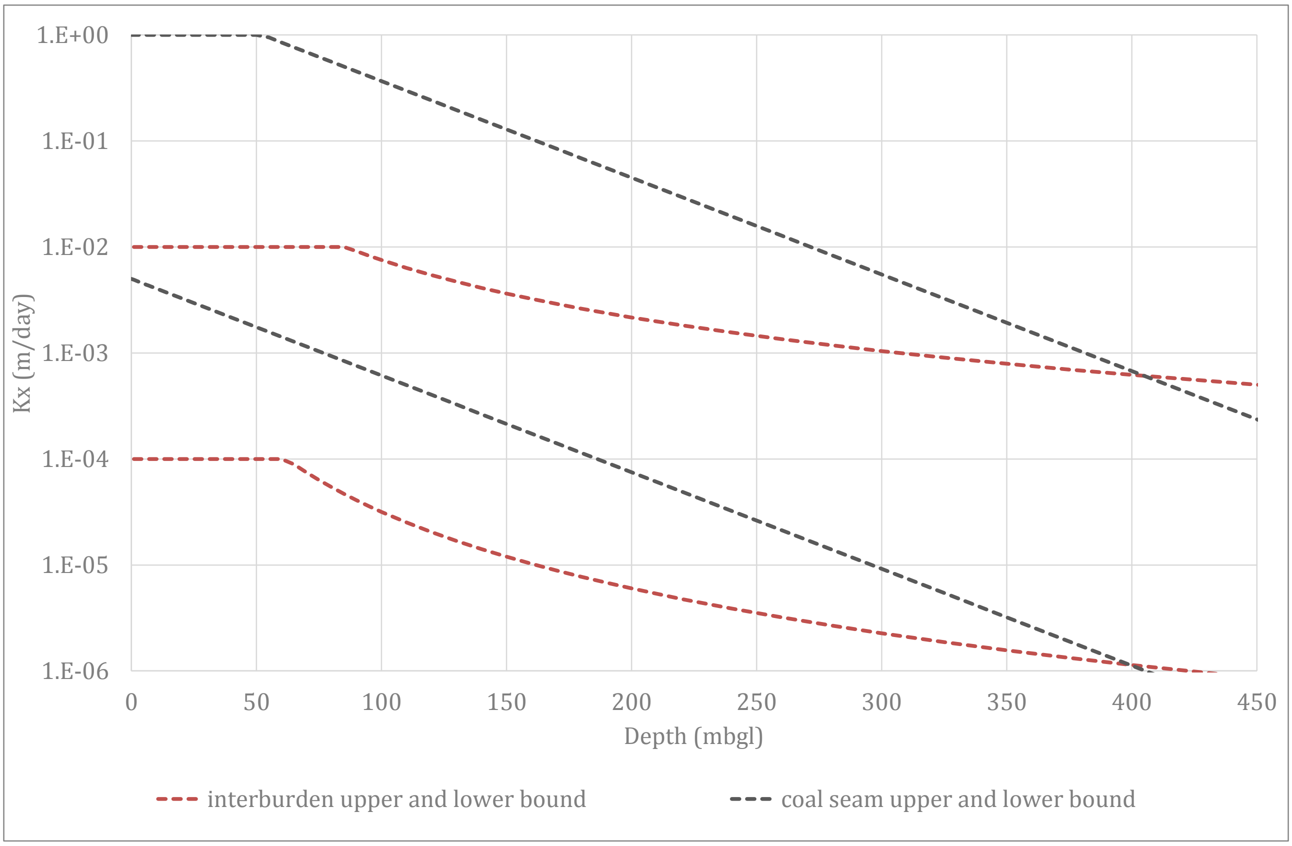


Figure A 26 Prior uncertainty range – Kx coal and interburden

Table A 13 Prior homogenous uncertainty range - Kx

Model layer	Lithology	Horizontal hydraulic K m/day (lower)	Horizontal hydraulic K m/day (mean)	Horizontal hydraulic K m/day (upper)
1	Alluvium (Qa)	5.00E-02	5.00E+00	1.00E+01
2	Regolith	1.00E-04	2.44E-03	1.20E-01
3	Overburden	1.00E-06	1.37E-04	1.00E-03
4-20	Coal seam limit (Kcap)	8.00E-3	1.00E-01	1.00E-00
5-19	Interburden limit (Kcap)	1.00E-4	1.00E-03	1.00E-02
21	Saltwater Creek Formation	1.00E-05	1.00E-03	5.00E-03

Table A 14 Prior range – Kz factor

Model layer	Lithology	Vertical hydraulic K factor (lower)	Vertical hydraulic K factor (mean)	Vertical hydraulic K factor (upper)
1	Alluvium (Qa)	0.010	0.020	0.8
2	Regolith	0.010	0.010	0.8
3	Overburden	0.010	0.011	0.5
4	Bayswater Seam	0.250	1.000	1
5	Interburden	0.010	0.013	0.5
6	Interburden	0.010	0.100	0.5
7	Upper Pikes Gully Seam	0.250	1.000	1
8	Interburden	0.010	0.100	0.5
9	Middle and Lower Pikes Gully Seam	0.010	0.089	0.5
10	Interburden	0.010	0.010	0.5
11	Arties Seam	0.250	1.000	1
12	Interburden	0.010	0.100	0.5
13	Liddell Seam Section A	0.250	1.000	1
14	Liddell Seam Section B	0.250	1.000	1
15	Liddell Seam Section C	0.250	1.000	1
16	Liddell Seam Section D	0.010	0.452	0.5
17	Interburden	0.010	0.019	0.5
18	Barrett Seam	0.250	1.000	1
19	Interburden	0.010	0.158	0.5
20	Hebden Seam	0.250	1.000	1
21	Saltwater Creek Formation	0.010	0.239	0.5

Table A 15 Prior range – Specific yield

Model layer	Lithology	Specific yield - Sy (lower)	Specific yield - Sy (mean)	Specific yield - Sy (upper)
1	Alluvium (Qa)	5.00%	5.00%	25.00%
2	Regolith	0.09%	1.18%	8.80%
3	Overburden	0.07%	1.02%	2.00%
4	Bayswater Seam	0.13%	3.00%	4.00%
5	Interburden	0.04%	0.41%	1.00%
6	Interburden	0.01%	0.01%	1.00%
7	Upper Pikes Gully Seam	0.02%	0.05%	1.00%
8	Interburden	0.01%	0.03%	1.00%
9	Middle and Lower Pikes Gully Seam	0.02%	0.11%	1.00%
10	Interburden	0.01%	0.02%	1.00%

Model layer	Lithology	Specific yield - Sy (lower)	Specific yield - Sy (mean)	Specific yield - Sy (upper)
11	Arties Seam	0.02%	0.03%	1.00%
12	Interburden	0.01%	0.01%	1.00%
13	Liddell Seam Section A	0.01%	0.02%	1.00%
14	Liddell Seam Section B	0.01%	0.02%	1.00%
15	Liddell Seam Section C	0.01%	0.02%	1.00%
16	Liddell Seam Section D	0.01%	0.02%	1.00%
17	Interburden	0.01%	0.01%	1.00%
18	Barrett Seam	0.60%	0.92%	1.00%
19	Interburden	0.01%	0.03%	1.00%
20	Hebden Seam	0.01%	0.02%	1.00%
21	Saltwater Creek Formation	0.01%	0.02%	1.00%

Table A 16 Prior range – Specific storage

Model layer	Lithology	Specific Storage m-1 (lower)	Specific Storage m-1 (mean)	Specific Storage m-1 (upper)
1	Alluvium (Qa)	1.00E-04	9.67E-04	5.00E-03
2	Regolith	1.00E-05	9.57E-04	1.00E-03
3	Overburden	5.00E-07	1.92E-04	5.00E-04
4	Bayswater Seam	5.00E-07	5.04E-06	5.00E-05
5	Interburden	5.00E-07	3.44E-06	5.00E-05
6	Interburden	5.00E-07	1.07E-06	5.00E-05
7	Upper Pikes Gully Seam	5.00E-07	3.36E-06	5.00E-05
8	Interburden	5.00E-07	3.08E-06	5.00E-05
9	Middle and Lower Pikes Gully Seam	5.00E-07	1.02E-05	5.00E-05
10	Interburden	5.00E-07	5.00E-07	5.00E-05
11	Arties Seam	5.00E-07	1.55E-06	5.00E-05
12	Interburden	5.00E-07	5.00E-07	5.00E-05
13	Liddell Seam Section A	5.00E-07	1.16E-06	5.00E-05
14	Liddell Seam Section B	5.00E-07	1.30E-06	5.00E-05
15	Liddell Seam Section C	5.00E-07	6.33E-07	5.00E-05
16	Liddell Seam Section D	5.00E-07	6.97E-07	5.00E-05
17	Interburden	5.00E-07	5.00E-07	5.00E-05
18	Barrett Seam	5.00E-07	2.85E-06	5.00E-05
19	Interburden	5.00E-07	7.44E-07	5.00E-05
20	Hebden Seam	5.00E-07	3.55E-06	5.00E-05
21	Saltwater Creek Formation	5.00E-07	5.00E-07	5.00E-05

Table A 17 Prior range – recharge

Model layer	Lithology	Recharge factor (lower)	Recharge factor (mean)	Recharge factor (upper)
1	Alluvium (Qa)	0.025	0.6	1
2	Regolith	0.0007	0.026	0.1
3	Overburden	0.0007	0.004	0.1
4-20	Permian interburden and coal seams	0.0007	0.007	0.1
21	Saltwater Creek Formation	0.0001	0.0008	0.01

Table A 18 Prior range – streambed Kz

Unit	Lithology	Vertical hydraulic conductivity (lower)	Vertical hydraulic conductivity (mean)	Vertical hydraulic conductivity (upper)
1	Bowmans Creek Seg1	0.005	0.08	0.5
2	Bowmans Creek Seg2	0.005	0.09	0.5
3	Hunter River Seg1	0.005	0.04	0.5
4	Hunter River Seg2	0.005	0.08	0.5
5	Glennies Creek	0.005	0.12	0.5
6	Hunter River Seg3	0.005	0.09	0.5

The posterior range was derived using information from the Jacobian matrix. If parameter ranges were constrained by more than a 50% improvement, the posterior range was restricted to this as a limit. Appendix A-2 presents the posterior parameter ranges applied to each adjustable parameter.

The uncertainty of the application of the fracture network was explored by allowing the skin factor (SF) to vary between 0.1 and 100. This roughly equates to a 1± magnitude change to the drain conductance value applied to the pseudo-clns (DRN) in the model. Changes to the host vertical hydraulic conductivity in the realisations automatically changed the drain conductance value, which expands the posterior drain conductance value applied to the drain package to ± several orders of magnitude.

A5.3 Results

A total of 179 models achieved model convergence and produced acceptable calibration statistics. A summary of the calibration performance and predictive response to mining is provided as Appendix A-3. The hydrographs show the composite distribution of the heads across all 179 realisations and indicate that the majority of the models are acceptably calibrated.

A5.3.1 Permian Groundwater inflow

Figure A 27 presents the uncertainty of Permian groundwater inflow into the approved mining and the Modification combined from 2009 to 2035.

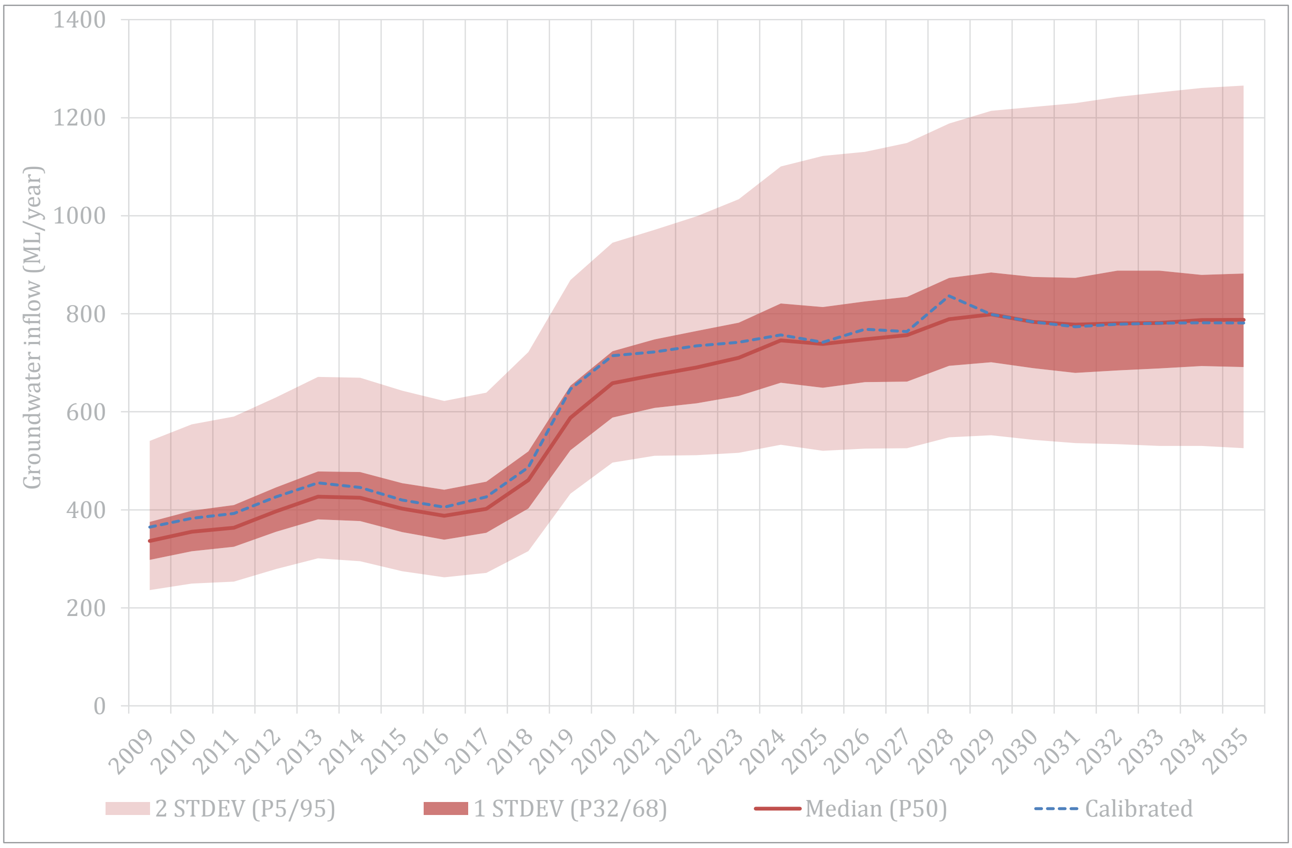


Figure A 27 Approved + Modification groundwater inflow uncertainty

The results indicate the majority of the realisations produced groundwater inflows representative of rates observed during 2016 period (~300 ML/year). The uncertainty analysis indicated future inflows up to 888 ML/year at 1 standard deviation in year 2032. Table A 19 presents the uncertainty in the incremental inflow to the Modification area only for each year.

Table A 19 MOD8 Incremental Permian inflow (‘take’)

Year	Groundwater inflow (-2 STDEV)	Groundwater inflow (-1 STDEV)	Groundwater inflow (Median)	Groundwater inflow (+1 STDEV)	Groundwater inflow (+2 STDEV)
2016	-80	-94	-96	-107	-141
2017	-45	-50	-57	-64	-92
2018	18	22	19	16	19
2019	125	130	133	140	161
2020	163	169	179	188	213
2021	186	200	205	224	250
2022	195	213	222	238	276
2023	179	197	208	213	246
2024	166	170	186	190	197
2025	152	152	167	168	197
2026	132	147	159	150	182
2027	129	137	152	141	175

Year	Groundwater inflow (-2 STDEV)	Groundwater inflow (-1 STDEV)	Groundwater inflow (Median)	Groundwater inflow (+1 STDEV)	Groundwater inflow (+2 STDEV)
2028	114	134	139	144	165
2029	107	128	134	134	157
2030	108	124	132	129	151
2031	108	115	130	130	152
2032	106	115	132	138	151
2033	98	112	119	125	141
2034	94	106	119	107	133
2035	85	93	111	103	121
Max	**195**	**213**	**222**	**238**	**276**

A5.3.2 Alluvial groundwater and surface water 'take'

The results from the uncertainty analysis indicated that the change in flux to the Quaternary alluvial aquifers remained at less than 1 ML/year for all scenarios. The change in flux to the Quaternary alluvial aquifers for the approved mining and the Modification combined was also assessed. Figure A 28 to Figure A 31 present the change in flux to the alluvial systems for the approved mining and the Modification. Due to the negligible influence from the Modification these graphs represent the uncertainty in the impact from approved mining.

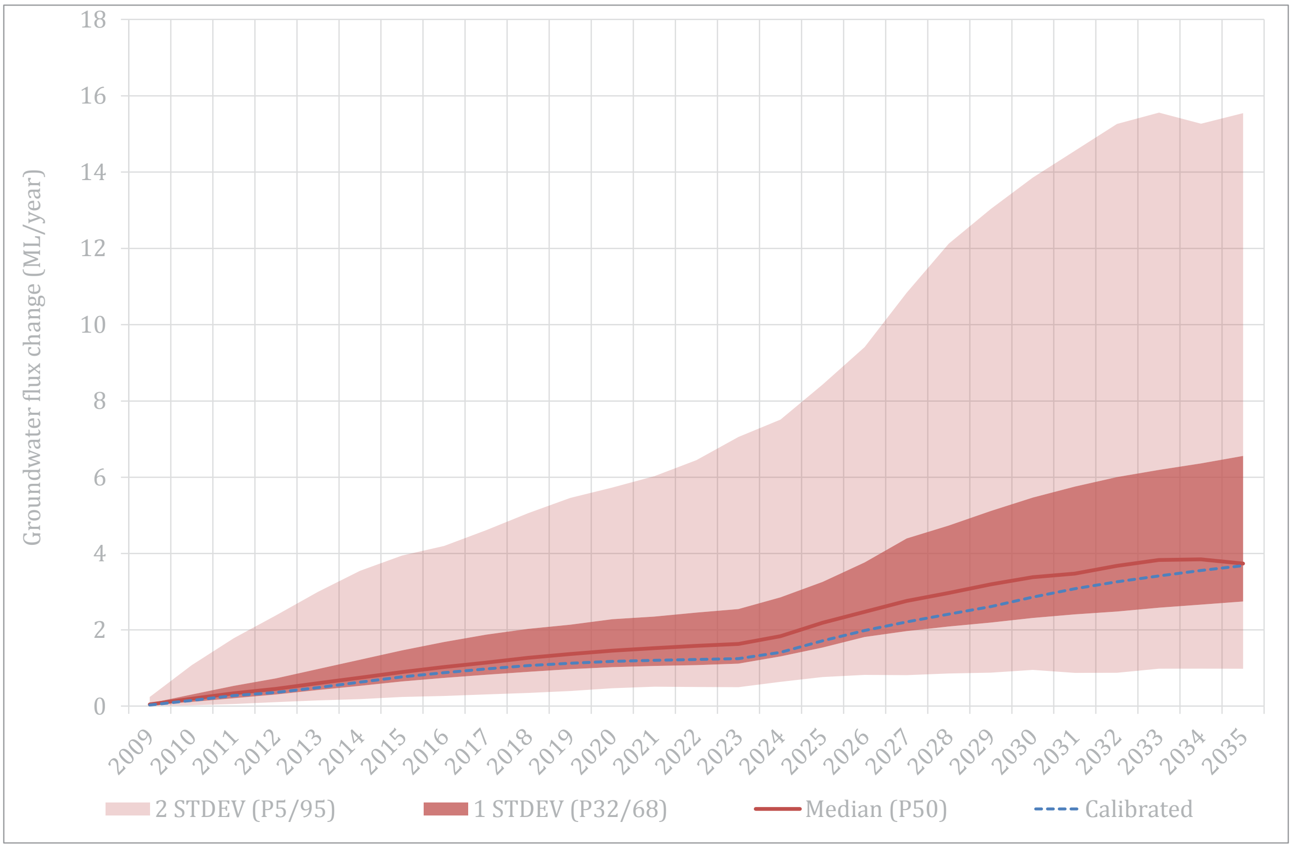


Figure A 28 Uncertainty in alluvial flux change - approved + Modification - Main Creek alluvium

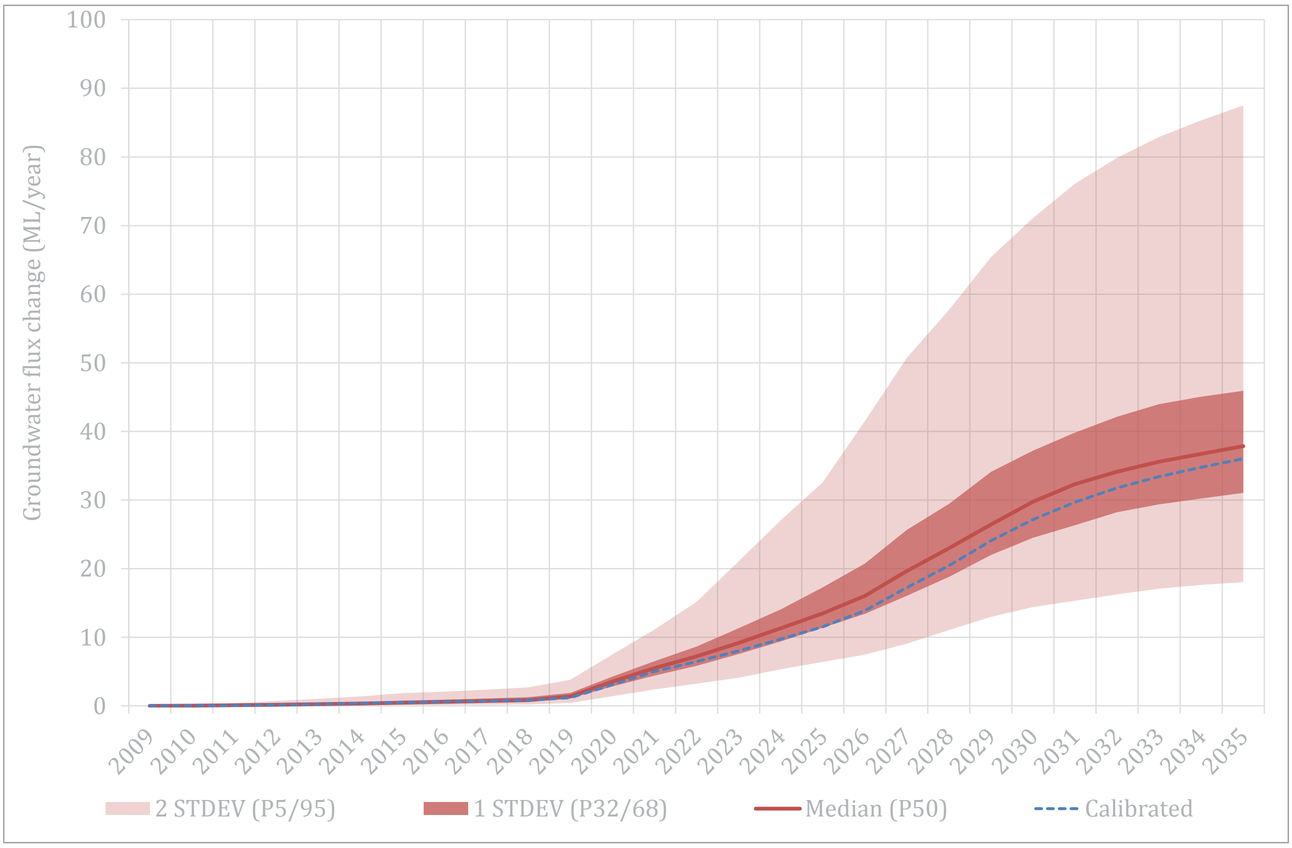


Figure A 29 Uncertainty in alluvial flux change - approved + Modification - Glennies Creek alluvial take

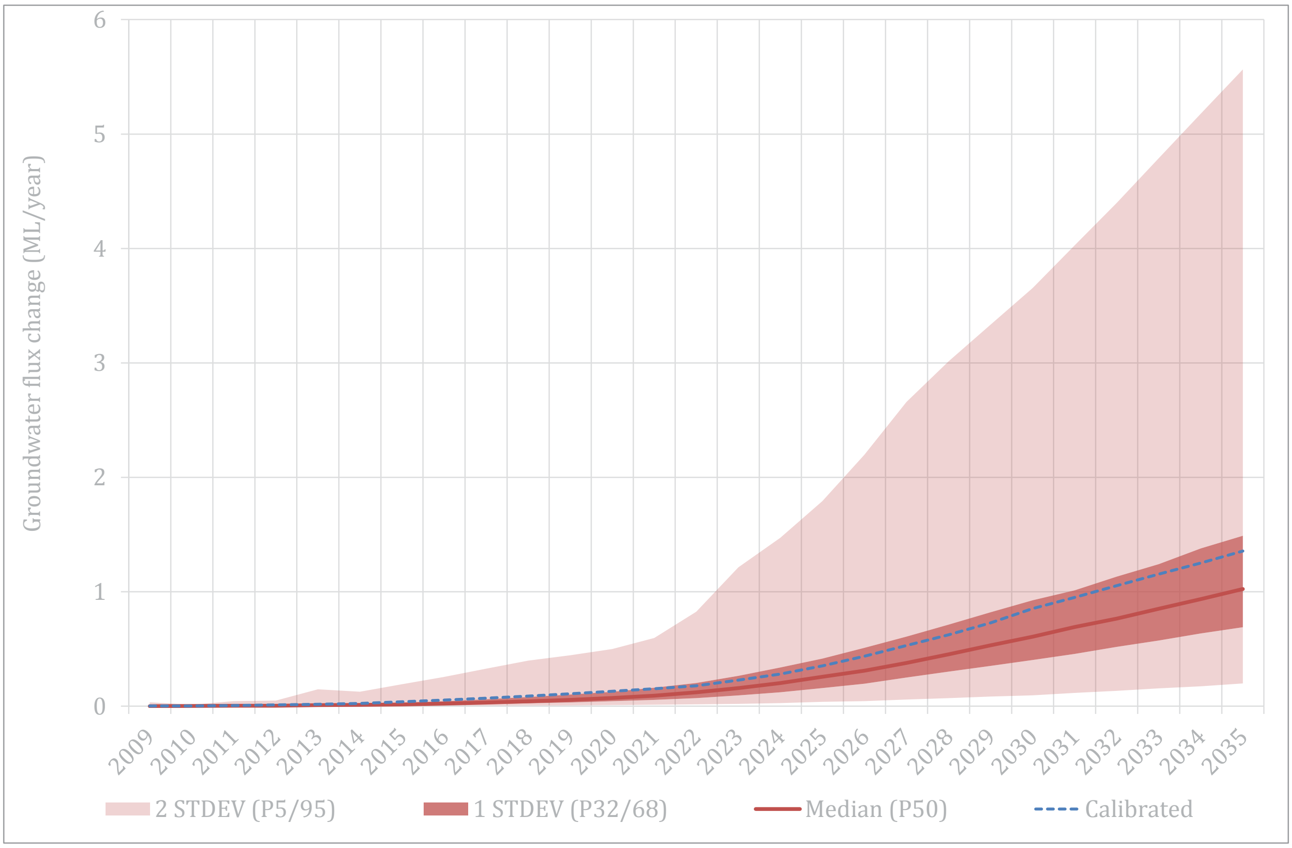


Figure A 30 Uncertainty in alluvial flux change - approved + Modification - Bowmans Creek alluvial take

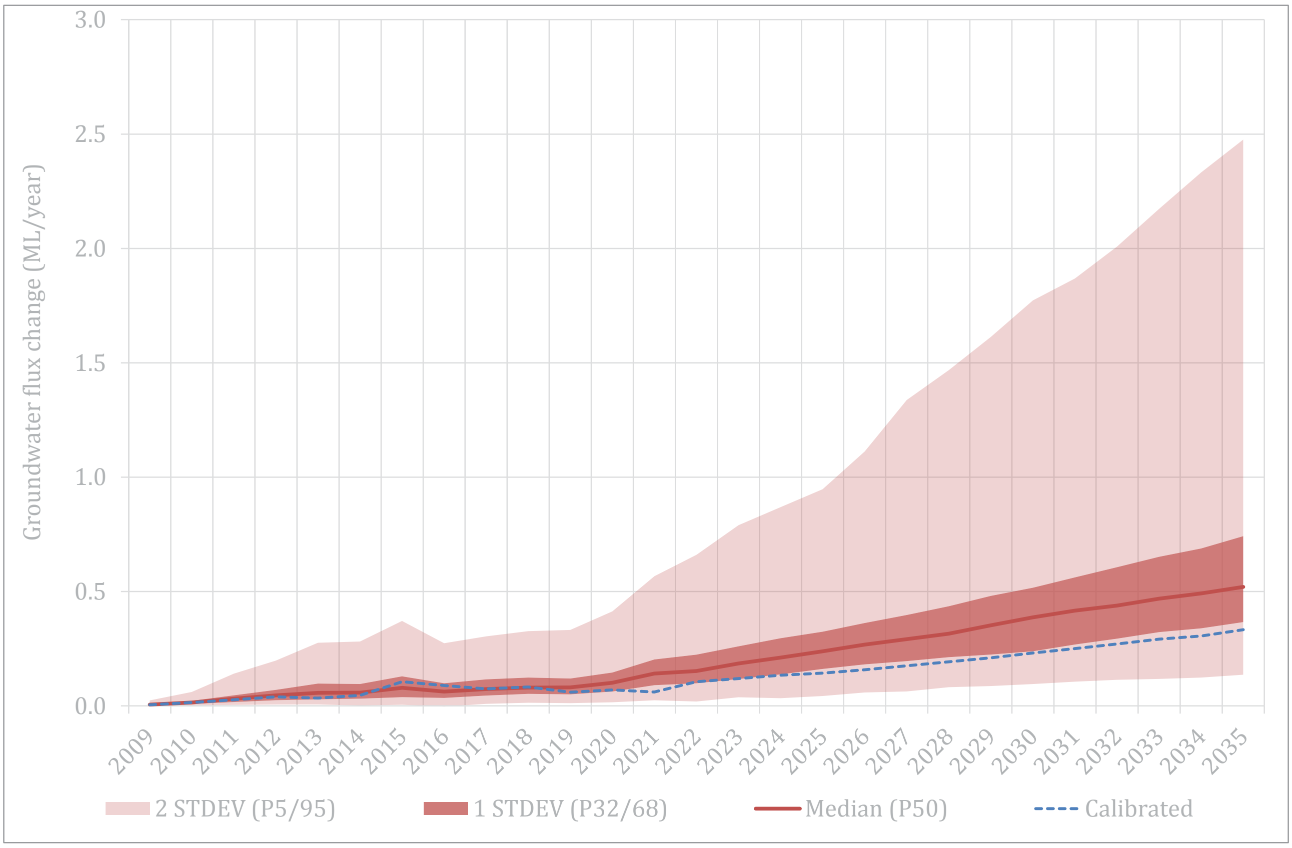


Figure A 31 Uncertainty in alluvial flux change - approved + Modification - Bettys Creek alluvial take

Table A 20 shows the change in flux to the alluvial groundwater systems and the resultant change in stream baseflow due to the approved mining and Modification for the +1 standard deviation outcome from the uncertainty analysis. The alluvial takes have been corrected for double-accounting by subtracting the incremental baseflow change from the corresponding raw alluvial flux change where the groundwater and surface water are within the same water source and WSP. The Glennies Creek flux changes were not corrected as the groundwater and surface water are regulated under different WSPs.

Table A 20 Maximum likely (+1 STDEV) alluvial and surface water takes

Year	Main Creek alluvium (ML)	Main Creek (ML)	Glennies Creek alluvium (ML)	Glennies Creek (ML)	Bowmans Creek alluvium (ML)	Bowmans Creek (ML)	Bettys Creek alluvium (ML)	Bettys Creek (ML)
2009	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0
2011	0.4	0.1	0.1	0.1	0.0	0.0	0.0	0.0
2012	0.6	0.1	0.1	0.1	0.0	0.0	0.1	0.0
2013	0.8	0.2	0.2	0.2	0.0	0.0	0.1	0.0
2014	1.0	0.2	0.3	0.2	0.0	0.0	0.1	0.0
2015	1.2	0.3	0.4	0.4	0.0	0.0	0.1	0.0
2016	1.4	0.3	0.5	0.4	0.0	0.0	0.1	0.0
2017	1.5	0.4	0.5	0.5	0.0	0.0	0.1	0.0

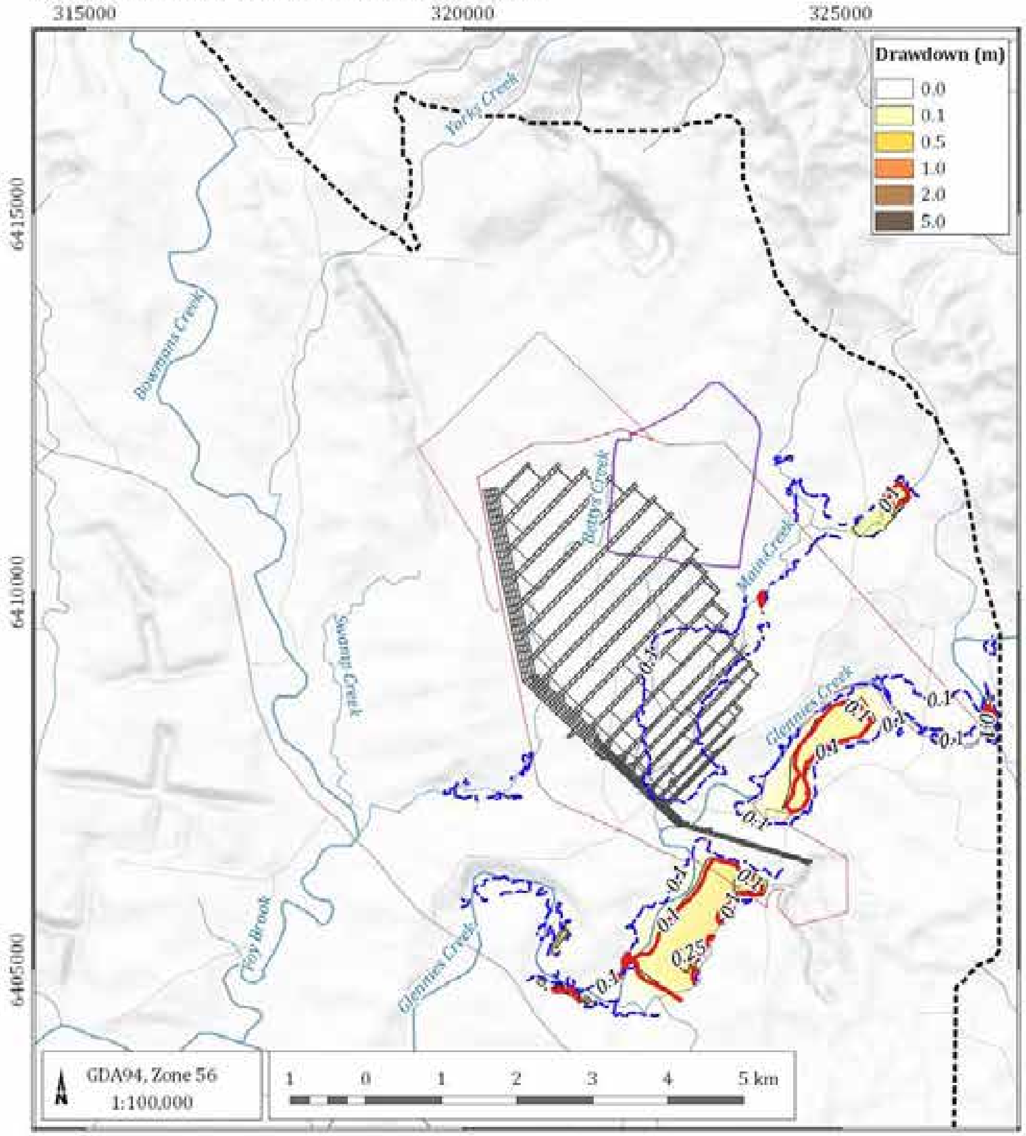
Year	Main Creek alluvium (ML)	Main Creek (ML)	Glennies Creek alluvium (ML)	Glennies Creek (ML)	Bowmans Creek alluvium (ML)	Bowmans Creek (ML)	Bettys Creek alluvium (ML)	Bettys Creek (ML)
2018	1.6	0.5	0.6	0.7	0.1	0.0	0.1	0.0
2019	1.6	0.5	1.0	0.9	0.1	0.0	0.1	0.0
2020	1.7	0.6	2.5	1.8	0.1	0.0	0.1	0.0
2021	1.8	0.6	3.6	2.9	0.1	0.0	0.2	0.0
2022	1.9	0.6	4.7	4.0	0.1	0.1	0.2	0.0
2023	2.0	0.6	6.3	5.0	0.2	0.1	0.2	0.0
2024	2.3	0.6	7.7	6.4	0.2	0.1	0.3	0.0
2025	2.6	0.6	9.4	7.9	0.3	0.1	0.3	0.0
2026	3.0	0.7	11.4	9.4	0.4	0.1	0.3	0.0
2027	3.6	0.8	14.5	11.2	0.4	0.2	0.4	0.0
2028	3.8	1.0	16.5	12.9	0.5	0.2	0.4	0.0
2029	4.1	1.1	19.3	14.8	0.6	0.3	0.4	0.0
2030	4.3	1.2	20.5	16.7	0.6	0.3	0.5	0.0
2031	4.5	1.2	21.5	18.4	0.7	0.3	0.5	0.0
2032	4.7	1.3	22.4	19.7	0.8	0.4	0.6	0.0
2033	4.8	1.3	23.0	20.9	0.8	0.4	0.6	0.0
2034	5.0	1.4	23.3	21.8	0.9	0.4	0.6	0.1
2035	5.2	1.4	23.1	22.8	1.0	0.5	0.7	0.1
Max	**5.2**	**1.4**	**23.3**	**22.8**	**1.0**	**0.5**	**0.7**	**0.1**

A5.3.3 Groundwater drawdown

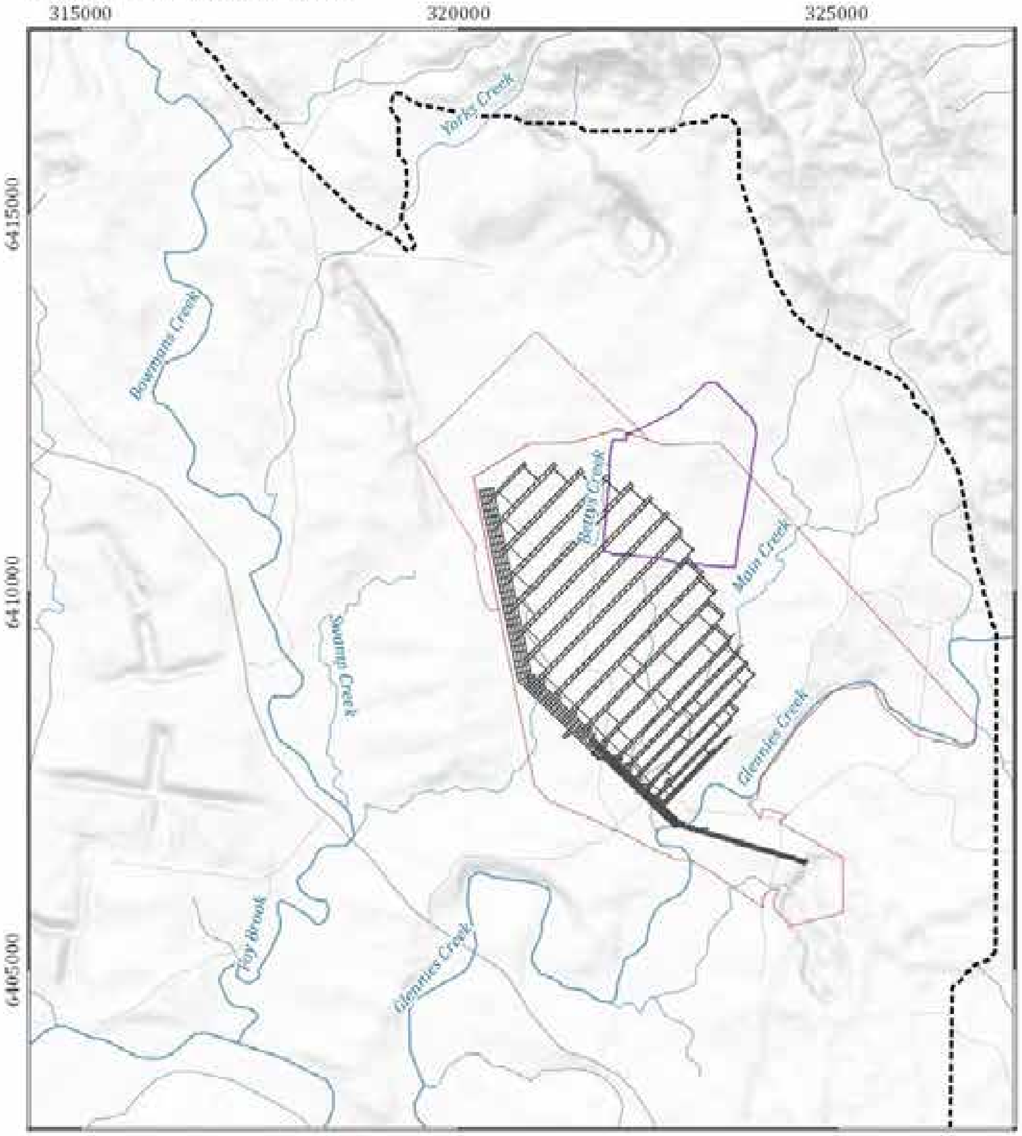
Figure A 32 presents the uncertainty in maximum groundwater drawdown at any time within the Quaternary alluvium due to the approved mining and the Modification. The results show that the majority of the models do not predict significant impacts to the alluvium during the mining. The maximum drawdown value (median + 2 standard deviations) predicted for the approved mining and the Modification was 3.0 m and 0.03m, respectively. These values occur at isolated cells along Main Creek and Glennies Creek, although this result is unlikely. For comparison, the maximum drawdown encountered from the median result +1 standard deviation was 0.7 m and 0.01 m for the approved mining and the Modification respectively.

Figure A 33 shows the uncertainty in maximum groundwater drawdown at any time within the Middle Liddell seam due to the approved mining and the Modification. The maximum groundwater drawdown from the approved mining is predicted to extend as far as 6.5 km from the approved underground area in the Middle Liddell seam. Incremental drawdown due to the Modification extends approximately 4.2 km from the mining area within the Middle Liddell seam.

Approved mining and Modification drawdown



Modification only drawdown



LEGEND

- Model extent
- Integra UG approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mt. Owen North Pit mining
- Major drainage
- Minor drainage
- Major road
- Minor road
- Rail
- Drawdown contour (m)
- +2 STDEV drawdown contour (0.1 m)
- Median drawdown contour (0.1 m)
- -2 STDEV drawdown contour (0.1 m)

Integra (G1285A)

AGE

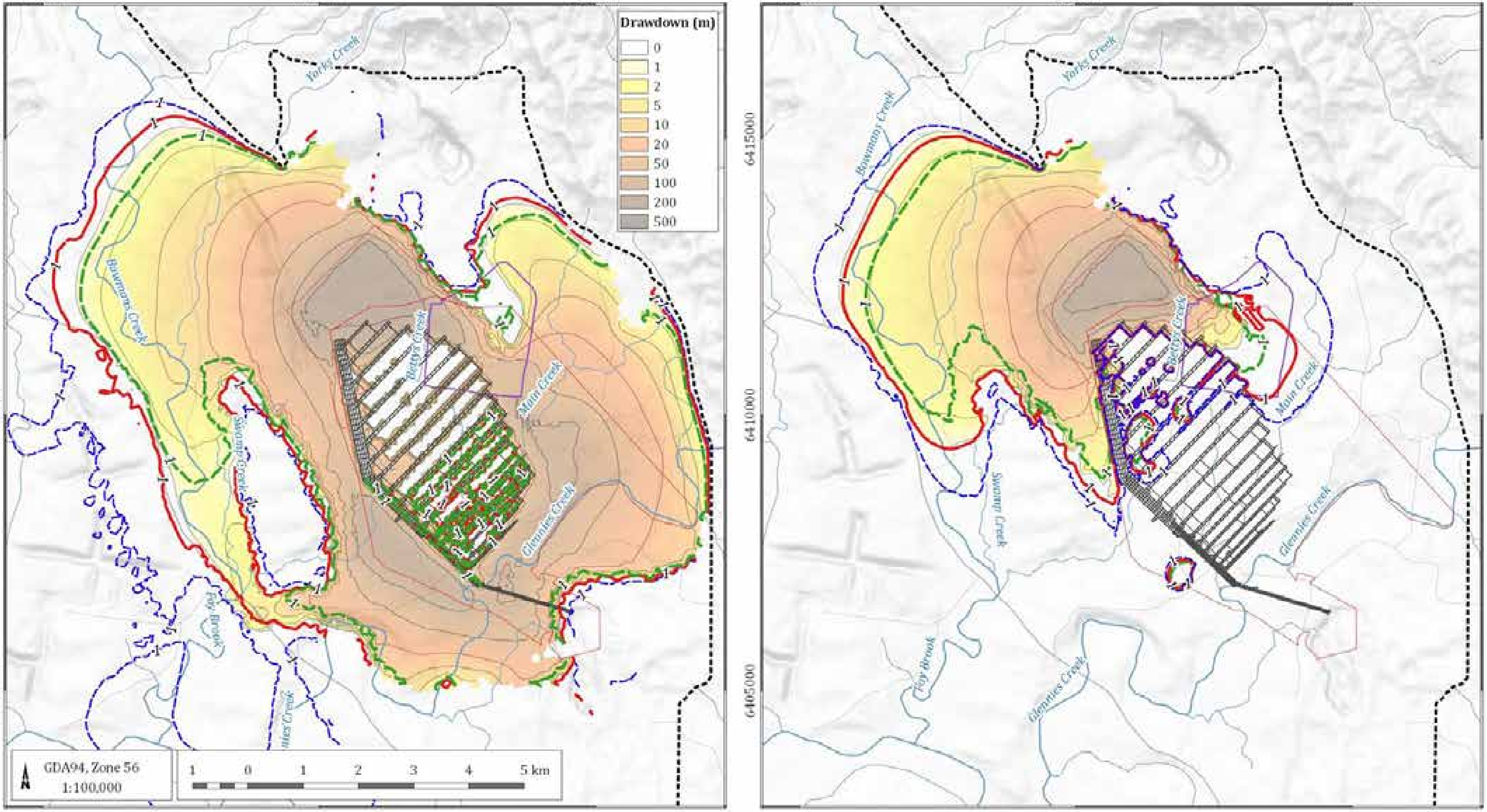
Uncertainty of maximum zone of drawdown due to Modification - Quaternary alluvium

DATE
16/11/2017

FIGURE No:
A-32

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/G1285A.Integra/3_GIS/Workspaces/002_EIA/A-32-33.qgs

Approved mining and Modification drawdown | **Modification only drawdown**



LEGEND

- Model extent
- Integra UG Project approval boundary
- Modification Project boundary
- Approved Middle Liddell Seam mining
- Proposed Mount Owen North Pit mining
- Major drainage
- Minor drainage
- Major road
- Minor road
- Rail
- Drawdown contour (m)
- -2 STDEV drawdown contour (1 m)
- Median drawdown contour (1 m)
- +2 STDEV drawdown contour (1 m)

Integra (G1285A)

AGE

Uncertainty of maximum zone of drawdown due to Modification - Middle Liddell Seam

DATE
16/11/2017

FIGURE No:
A-33

A6 Sensitivity Analysis

In addition to the uncertainty analysis two traditional sensitivity runs were undertaken. The following scenarios were simulated:

- General head boundary conductance ± 1 magnitude; and
- Permeable fault running along Northern longwall extent.

The fault was simulated through all layers in the groundwater model using the same parameters assigned to the Quaternary alluvium to simulate an extreme, brecciated fault zone.

Figure A 34 presents the change in flux to the alluvial systems for the approved mining and the Modification for the three sensitivity scenarios. The results indicate the model is insensitive to changes in the General head boundary package. Note, the model did no achieve convergence past year 2030 for the enhanced fault scenario.

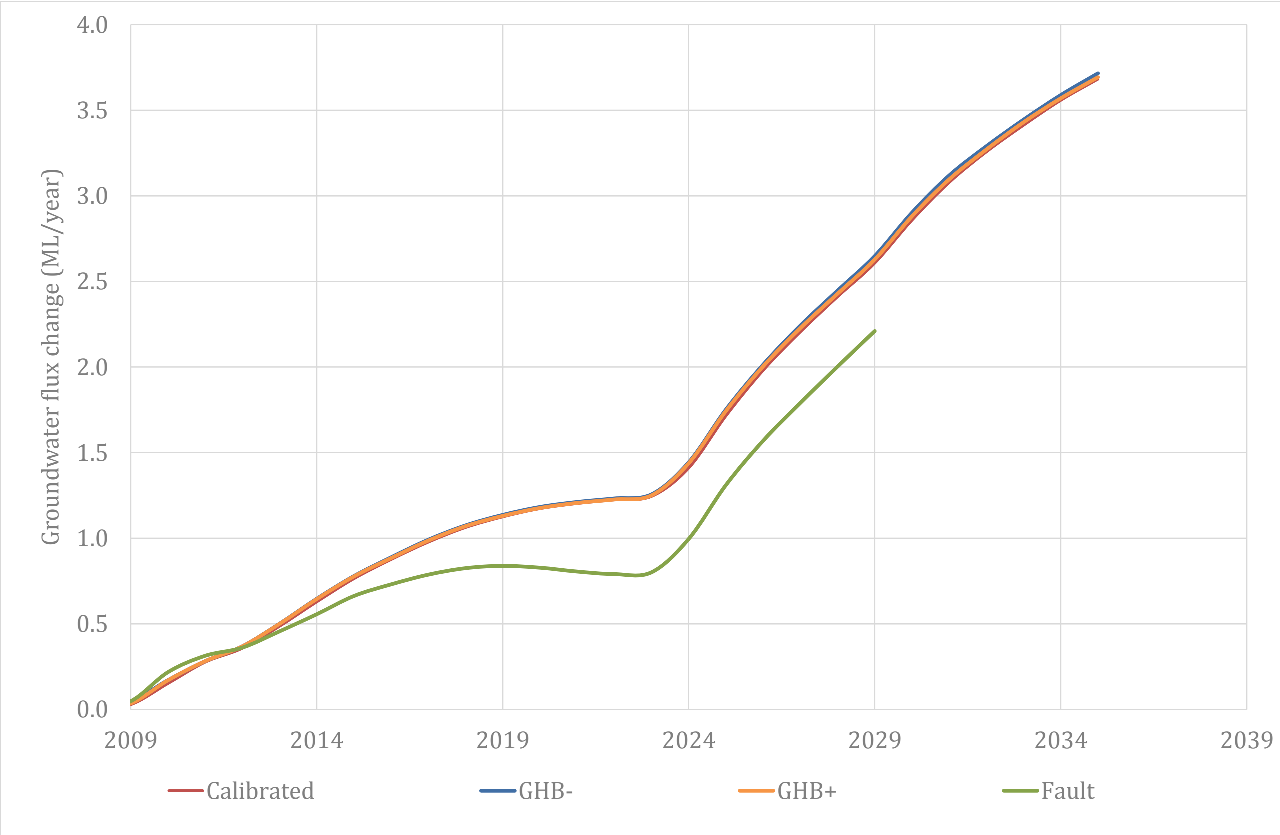


Figure A 34 Sensitivity of flux to Main Creek alluvium due to approved mining and Modification

A7 References

AGE (2017) – Main Creek Alluvium Verification and Mapping – Mt Owen Continued Operations – Mod 2, Project No. G1862, 26 September 2017

Arnold, J. *et al*, 2012, Soil & Water Assessment Tool, Input/Output Documentation, Version 2012

Arnold, J. and Allen, P., 1999, *Automated methods for estimating baseflow and groundwater recharge from streamflow records*, Journal of the American Water Resources Association vol 35(2) (April 1999): 411-424

Barnett, B, Townley, LR, Post, V, Evans, RE, Hunt, RJ, Peeters, L Richardson, S, Werner, AD, Knapton, A, & Boronkay, A 2012, "*Australian groundwater modelling guidelines*", Waterlines report, National Water Commission, Canberra.

Beckett, J 1988, "*The Hunter Coalfield Notes to Accompany the 1:100,000 Hunter Coalfield Geological Map",* Geological Survey of New South Wales, Sydney.

Commonwealth Scientific and Industrial Research Organisation 2015, *Soil and Landscape Grid of Australia*, URL: http://www.clw.csiro.au/aclep/soilandlandscapegrid/; accessed 07/2015

Ditton, S., and Merrick, N.P. (2014). A new sub-surface fracture height prediction model for longwall mines in the NSW coalfields. Paper presented at the Australian Earth Science Convention, Newcastle NSW.

Doherty, J 2010, "*PEST – Model independent parameter estimation user manual: 5th edition"*, Watermark Numerical Computing, Corinda, Australia, 2010.

Doherty, John. (2015) *"Watermark Numerical Computing, Calibration and Uncertainty Analysis for Complex Environmental Models".*

Doherty, J, & Hunt, R, J 1999, Two statistics for evaluating parameter identifiability and error reduction*, "Journal of Hydrology",* vol. 366, issue 3, pp. 481-488.

Glen, RA, & Beckett, J 1993, "*Hunter Coalfield Regional Geology 1:100 000, 2nd edition"*. Geological Survey of New South Wales, Sydney.

Guo, H., Adhikary, D., and Gaveva, D. (2007). Hydrogeological response to longwall mining, ACARP Report C14033, CSIRO Exploration and Mining: Australian Coal Industry's Research Program (ACARP).

HydroSimulations 2014, "*North Wambo Underground Mine Longwall 10A Modification Groundwater Assessment"*, prepared for Wambo Coal Pty Ltd, September 2014.

Hydroalgorithmics 2014, "*Algomesh User Guide, Version 1.4"*, March 2014.

Jacobs 2014, *"Mount Owen Continued Operations Project, Groundwater Impact Assessment Revision D"* prepared for Umwelt (Australia) P/L for Mount Owen P/L, project number 3109H, dated 29 October 2014

Lyne, V. & Hollick, M. 1979, "*Stochastic time variable rainfall-runoff modelling*", Proceedings of the Hydrology and Water Resources Symposium, Perth, 10-12 September, Institution of Engineers National Conference Publication, No. 79/10, pp. 89-92

Mackie, CD 2009, "*Hydrogeological Characterisation of coal measures and overview of impacts of coal mining on groundwater systems in the Upper Hunter Valley of NSW*", PhD thesis, Faculty of Science, University of Technology, Sydney.

Mackie, C 2013, Bulga Coal Management, "*Assessment of groundwater related impacts arising from the proposed Bulga Optimisation Project"*, April 2013.

Middlemis (2004), *"Benchmarking Best Practice for Groundwater Flow Modelling"* The Winston Churchill Memorial Trust of Australia, 21 December 2004.

Murray Darling Basin Commission 2000, "*Murray Darling Basin Commission Groundwater Modelling Guidelines",* November 2000, Project No. 125, Final guideline issue January 2001.

New South Wales Department of Primary Industries 2014, "*PINNEENA Historic data Groundwater Works DVD – version 10.1"*, Department of Primary industries, Office of Water, Parramatta, NSW, Australia, October 2014; URL: http:// http://waterinfo.nsw.gov.au/pinneena/gw.shtml

New South Wales Department of Primary Industries 2017, River gauging data downloaded from http://waterinfo.nsw.gov.au/

Panday, S, Langevin, CD, Niswonger, RG, Ibaraki, M & Hughes, JD 2013, "*MODFLOW-USG version 1: An unstructured grid version of MODFLOW for simulating groundwater flow and tightly coupled processes using a control volume finite-difference formulation";* U.S. Geological Survey Techniques and Methods, book 6, chap. A45, 66 p.

SCT 2008, *Assessment of Multi Seam Mining Layout Guidelines for Hebden Seam at Glennies Creek*, Report INT3249, 15th December 2008.

Texas A&M University, 2014, http://swat.tamu.edu/software/baseflow-filter-program/

USGS, G.J. Arcement, Jr. and V.R. Schneider, Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains United States Geological Survey Water-supply Paper 2339, Metric Version, 1989

Watermark Numerical Computing 2016, "Groundwater Data Utilities Part C: Programs Written for Unstructured Grid Models" http://www.pesthomepage.org/getfiles.php?file=gwutil_c.pdf

Appendix A-1

Calibration Details and Hydrographs

Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
64CT	314495	6414857	16	-61.92	-91.04	-39.80
8-South-2	314559	6414428	16	-73.97	-103.91	-59.58
ALV1_Large	315528	6417638	1	0.04	-2.47	1.38
ALV1_Small	315528	6417638	5	0.09	-3.30	1.72
ALV2_Large	316328	6414721	1	-1.22	-3.60	-0.53
ALV2_Small	316328	6414721	2	-0.83	-5.12	0.15
ALV3_Large	315704	6417044	1	-0.92	-2.88	-0.15
ALV3_Small	315704	6417044	5	-2.38	-4.30	-1.25
ALV4_Large	315995	6416421	2	-1.98	-3.93	-0.91
ALV4_Small	315995	6416421	2	-2.57	-4.91	-1.60
ALV7_Large	316514	6413617	1	-0.92	-1.89	-0.25
ALV7_Small	316514	6413617	5	-3.72	-7.23	1.31
ALV8_Large	316151	6413367	1	-1.94	-5.93	-0.71
ALV8_Small	316151	6413367	5	-0.68	-5.36	4.90
BC-SP02	317483	6411487	1	-3.91	-4.50	-3.43
BC-SP03	317547	6411405	1	5.77	5.28	6.21
BC-SP04	317610	6411320	1	-7.32	-7.55	-7.07
BC-SP05	317680	6411232	2	-3.20	-3.63	-2.64
BC-SP06	317596	6411588	1	-3.59	-4.15	-3.13
BC-SP07	317681	6411448	1	-4.74	-5.06	-4.37
BC-SP08	317592	6411869	2	-1.73	-2.05	-1.37
BC-SP09	317675	6411703	1	-2.43	-3.24	-2.02
BC-SP10	318080	6409400	1	-1.55	-1.86	-1.13
BC-SP11	318137	6409337	1	-0.92	-1.36	-0.18
BC-SP12	318201	6409265	1	-0.10	-0.73	0.84
BC-SP13	318253	6409210	1	-0.11	-0.50	0.24
BC-SP14	318305	6409158	1	-0.65	-0.95	-0.29
BC-SP15	318182	6409484	1	-2.40	-2.67	-1.90
BC-SP16	318290	6409376	1	-2.15	-2.57	-1.51
BC-SP17	318319	6409543	1	-4.64	-4.90	-4.43
BC-SP18	317350	6411325	1	-0.94	-0.94	-0.93

Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
BC-SP19	317462	6411178	1	-0.23	-0.77	0.50
BC-SP20	318184	6409118	1	-0.54	-1.18	1.31
BC-SP21	318057	6409176	1	-1.11	-1.66	1.12
BC-SP22	317992	6409051	1	-1.92	-2.38	-1.34
Borehole_P	313445	6410681	8	85.04	74.79	93.89
CS4536_HF7	312586	6409158	15	44.36	26.58	64.82
CS4539A_S2	311501	6407889	9	-13.98	-22.02	-3.22
CS4545B	312852	6408414	15	-15.76	-22.31	-12.08
CS4545B_Mi	312852	6408414	2	-9.12	-16.85	-4.03
CS4545B_Sm	312852	6408414	2	-6.38	-8.80	-2.71
CS4545C	312852	6408414	18	29.79	27.43	31.72
CS4545D	312852	6408414	20	33.38	29.67	35.70
CS4545_S4	312852	6408418	11	-9.84	-28.38	31.42
CS4547C	312360	6406897	15	-13.90	-18.48	-8.68
CS4556	311576	6409139	15	16.34	-29.68	25.84
CS4641C	313549	6410436	15	65.14	39.54	100.98
CS4655-Bay	313605	6407913	4	16.31	14.41	19.51
CS4655-Brt	313605	6407913	18	-13.40	-17.27	-6.10
CS4655-LLd	313605	6407913	14	-14.98	-18.06	-6.62
CS4655-LmA	313605	6407913	6	-10.57	-13.21	-2.63
CS4655-LmH	313605	6407913	6	-5.60	-7.89	2.97
CS4655-UAr	313605	6407913	10	-12.90	-15.66	-5.86
CS4655-ULd	313605	6407913	14	-11.81	-13.85	-5.94
CS4655-UPG	313605	6407913	8	-13.33	-16.13	-6.35
CS4656-Brt	313031	6408901	18	4.36	-12.51	21.06
CS4656-LLd	313031	6408901	14	-13.51	-18.44	-5.94
CS4656-LmA	313031	6408901	6	-2.55	-11.33	3.72
CS4656-LmF	313031	6408901	6	10.19	2.40	12.79
CS4656-LmH	313031	6408901	6	17.19	16.43	20.68
CS4656-UAr	313031	6408901	10	-17.98	-26.81	-5.40
CS4656-ULd	313031	6408901	14	-15.18	-20.18	-7.73

Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
CS4656-UPG	313031	6408901	8	-25.19	-38.32	-11.95
CS4657-Brt	312359	6408152	19	-24.43	-27.79	-20.25
CS4657-LLd	312359	6408152	15	-26.09	-28.70	-22.27
CS4657-LPG	312359	6408152	8	-24.66	-29.45	-18.65
CS4657-LmA	312359	6408152	6	-24.81	-29.66	-13.44
CS4657-LmF	312359	6408152	6	3.79	-1.53	4.95
CS4657-LmH	312359	6408152	6	8.18	5.89	9.51
CS4657-UAr	312359	6408152	10	-21.67	-25.41	-16.69
CS4657-ULd	312359	6408152	14	-20.42	-28.35	-13.38
CS4658-Bay	311860	6407656	4	-8.38	-9.08	-4.84
CS4658-Brt	311860	6407656	19	-35.62	-39.03	-32.03
CS4658-LLd	311860	6407656	15	-37.69	-41.14	-34.12
CS4658-LmA	311860	6407656	6	-26.05	-30.62	-21.79
CS4658-LmH	311860	6407656	6	-6.83	-11.60	-4.23
CS4658-UAr	311860	6407656	10	-34.36	-39.54	-29.31
CS4658-ULd	311860	6407656	14	-33.91	-37.67	-30.22
CS4658-UPG	311860	6407656	8	-34.77	-41.13	-31.02
CoffeyDamB	312953	6413510	15	19.75	7.85	40.03
DDH223-120	321684	6409694	3	-49.11	-69.64	-30.42
DDH223-170	321684	6409694	4	-43.09	-53.00	-37.11
DDH223-230	321684	6409694	5	-12.08	-35.90	42.81
DDH223-290	321684	6409694	6	-45.15	-89.12	20.44
DDH223-350	321684	6409694	10	-60.12	-105.09	70.11
DDH223-416	321684	6409694	15	-40.76	-96.68	97.67
DDH223-478	321684	6409694	20	44.44	8.51	106.38
DDH224-100	323034	6407439	5	-22.56	-24.83	-18.98
DDH224-130	323034	6407439	6	36.72	32.99	48.41
DDH224-160	323034	6407439	6	45.40	38.51	52.28
DDH224-200	323034	6407439	7	-27.03	-31.90	-23.71
DDH224-245	323034	6407439	13	16.60	9.78	26.73
DDH224-290	323034	6407439	16	4.87	-22.54	23.47

Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
DDH224-315	323034	6407439	17	7.97	-11.14	30.38
DDH224-336	323034	6407439	18	59.69	44.80	74.46
DUR2	313488	6416643	15	7.70	-6.27	29.59
Dam_13_Bor	314549	6414428	6	-75.49	-91.50	-70.07
GA1	318379	6408259	1	-1.56	-3.06	1.93
GA2	318578	6407367	1	-1.21	-2.07	-0.29
GCP09	323259	6407315	1	-2.39	-3.14	-1.73
GCP11	322417	6407232	1	-17.00	-19.41	-12.98
GCP17	323803	6409986	1	-4.07	-4.74	-3.70
GCP18	323406	6407580	7	91.79	88.85	93.96
GCP19	325086	6408333	1	-2.91	-3.88	-0.01
GCP21	324466	6407916	1	-1.14	-1.99	0.21
GCP22	324558	6407814	1	-0.85	-1.85	-0.06
GCP23	324535	6407659	1	-0.23	-1.54	0.88
GCP24	323421	6407105	7	39.15	36.51	42.12
GCP25	323005	6406764	1	-1.10	-1.74	-0.27
GCP26	323888	6406292	1	-3.25	-3.91	-2.84
GCP27	323197	6406037	18	35.77	35.36	36.10
GCP28	322651	6405459	1	0.00	-1.36	0.43
GCP29	323191	6405356	1	0.80	0.17	1.63
GCP30	322438	6404649	1	1.82	1.42	2.13
GCP31	322930	6404424	3	-2.19	-2.33	-2.08
GCP32	322491	6404250	21	-0.91	-1.49	-0.35
GCP34	322800	6403235	2	-35.08	-42.32	-29.57
GCP36	322915	6405320	14	4.24	3.03	5.64
GCP38	323468	6405626	11	13.63	10.66	16.17
GCP39	321297	6410352	1	1.85	-1.19	3.44
GCP3D	320838	6409800	3	-32.93	-51.57	-15.84
GCP3S	320924	6408389	1	-0.80	-2.08	0.02
GCP4D	323447	6409344	2	0.86	-2.75	6.16
GCP4S	320838	6409804	1	-1.13	-2.31	0.28

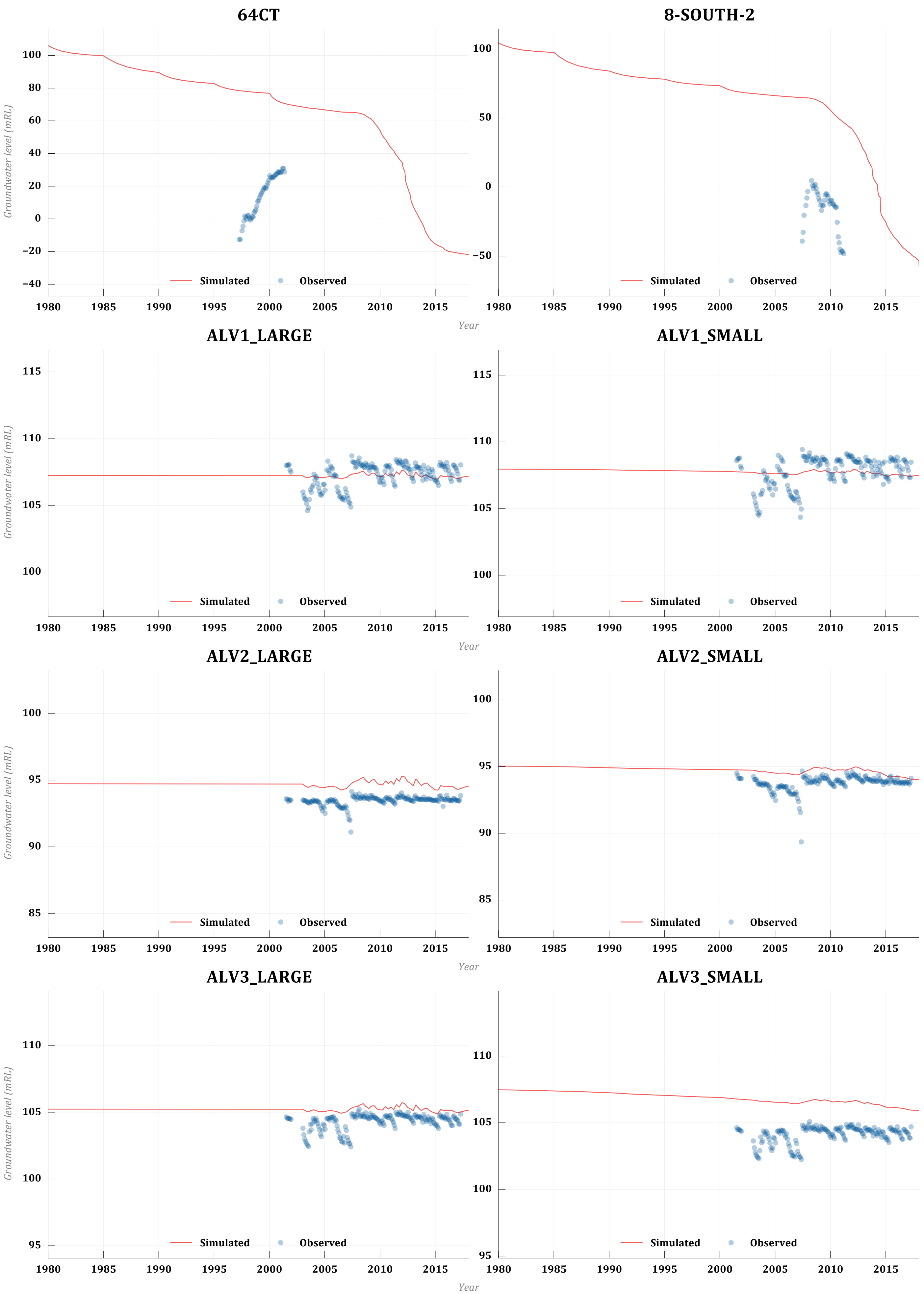
Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
GNPS-02	317564	6410201	1	-4.08	-4.44	-3.65
GNPS-05	317865	6409311	2	-5.22	-5.66	-4.39
GNPS-06	317605	6411062	1	-3.18	-4.40	-1.98
GNPS-07	316530	6412448	1	0.77	0.77	0.77
GW079793	317730	6411962	16	1.19	-0.27	3.41
Haz_1	316148	6415645	16	-9.34	-32.05	5.60
Haz_1_2	316148	6415645	16	-6.85	-11.66	-4.06
Haz_3	315650	6417145	15	-52.67	-101.95	-6.37
Haz_4	315639	6417148	15	-55.62	-101.95	-4.90
Haz_6	316574	6415431	15	-30.29	-33.50	-25.08
JK101	316753	6405243	2	0.61	-1.72	2.43
JK102	316752	6405243	2	0.36	-0.13	1.32
JK103	316853	6405293	2	-1.28	-2.63	-0.12
JK104	316854	6405293	2	0.21	0.09	0.31
JK105	316957	6405345	2	-0.02	-0.57	0.39
JK106	316955	6405345	2	-0.40	-1.91	0.86
JK107	317047	6405388	2	-0.01	-0.11	0.04
JK108	317047	6405389	2	3.75	3.60	3.98
JK109	316757	6405224	2	-0.21	-2.41	1.78
JK110	316759	6405224	2	1.18	0.84	1.58
JK112	316788	6405215	2	19.05	2.63	40.65
JK113	316788	6405216	2	0.01	-1.06	0.82
JK115	316862	6405266	2	-2.30	-3.37	-1.32
JK117	316863	6405267	2	11.80	1.03	42.50
JK118	317058	6405365	2	-1.05	-2.70	0.34
JK119	317058	6405365	2	2.74	2.51	3.08
JK121	316974	6405312	2	-2.55	-4.42	-1.54
JK123	316976	6405314	2	-2.66	-3.48	-1.76
LBH_Coal	315490	6417260	5	-0.67	-2.85	0.34
MW01	314624	6409058	2	-0.78	-1.02	-0.46
MW1	314064	6408206	3	-6.68	-7.28	-5.87

Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
MW10	314356	6408297	2	-4.94	-6.24	-4.11
MW12	314126	6408039	5	30.70	29.24	31.63
MW2	314056	6408197	3	-10.64	-10.99	-10.40
MW3	314047	6408196	3	-11.40	-11.44	-11.37
MW4	314036	6408207	3	-15.76	-15.83	-15.71
MW5	314042	6408221	3	-10.90	-10.96	-10.83
MW6	314095	6408208	2	-0.94	-0.96	-0.92
MW9	314423	6408565	2	-14.26	-14.74	-13.90
NPZ1	323606	6413034	3	-12.92	-15.54	-0.92
NPZ1-122	323606	6413034	6	-66.58	-83.85	-48.87
NPZ1-91	323606	6413034	5	-68.13	-71.00	-61.47
NPZ10	320961	6411696	2	-19.37	-27.21	-13.97
NPZ101	324046	6410343	1	-9.32	-9.64	-9.09
NPZ102	324489	6412637	1	9.95	9.41	10.28
NPZ103	321177	6410370	1	-2.00	-2.58	-1.67
NPZ104	321028	6408055	1	-1.74	-2.19	-1.41
NPZ106	321091	6408918	1	6.14	5.84	6.39
NPZ10a	320961	6411696	3	-17.81	-22.65	-15.02
NPZ11	318059	6412639	2	-10.28	-12.72	-9.31
NPZ11a	318059	6412639	7	-26.99	-27.71	-26.03
NPZ12	318440	6411519	2	-22.39	-24.64	-20.25
NPZ12a	318440	6411519	7	-15.95	-25.36	24.09
NPZ13	318302	6409556	16	70.65	52.19	86.84
NPZ13a	318302	6409556	13	40.26	33.46	51.91
NPZ14	319471	6407093	16	-22.61	-24.16	-20.26
NPZ14a	319471	6407093	20	-21.62	-30.09	-16.45
NPZ15	320784	6407934	2	-56.10	-56.66	-54.06
NPZ15a	320784	6407934	16	-17.88	-19.98	-8.11
NPZ16	318193	6409141	13	66.86	38.36	86.04
NPZ16a	318184	6409127	14	39.50	37.60	41.59
NPZ1_Mid	313562	6404972	4	0.66	-7.05	7.27

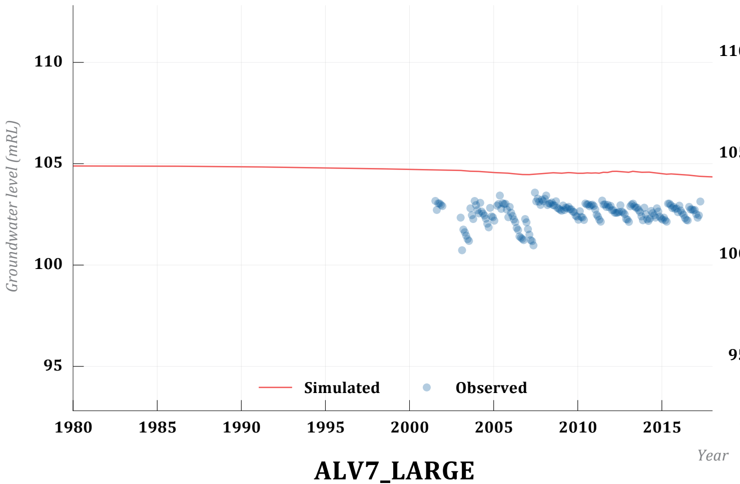
Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
NPZ1_Tall	313562	6404972	6	-5.64	-10.34	1.10
NPZ1a	323606	6413034	6	11.94	-17.11	40.11
NPZ2-120	313315	6405816	6	-18.50	-20.76	-16.74
NPZ3	321182	6410365	1	-13.21	-18.56	-5.07
NPZ3-110	321182	6410365	6	-21.48	-25.43	-11.70
NPZ3-64	321182	6410365	6	-14.23	-18.91	-9.48
NPZ3a	321182	6410365	3	-32.53	-46.58	-13.85
NPZ4	319534	6415151	3	-4.67	-5.38	-4.20
NPZ4-90	319534	6415151	21	-43.75	-49.02	-41.46
NPZ4a	319534	6415151	21	3.74	2.05	4.91
NPZ5B_P1	314645	6409132	2	-4.75	-7.45	-0.98
NPZ5B_P2	314646	6409100	2	-0.75	-3.00	-0.30
NPZ6	322577	6410410	3	-24.34	-30.36	-15.20
NPZ6-70	322577	6410410	3	-33.72	-34.46	-32.39
NPZ6B-12	322577	6410410	2	-44.86	-45.17	-44.46
NPZ6B-24	322577	6410410	3	-32.54	-33.15	-32.10
NPZ6a	322577	6410410	5	26.61	-3.56	78.87
NPZ7	323812	6410786	5	4.84	2.82	9.87
NPZ7_Mid	323812	6410786	5	-27.37	-31.44	-23.26
NPZ7_Small	323812	6410786	5	-42.42	-47.90	-35.60
NPZ7_Tall	323812	6410786	5	-38.83	-43.61	-33.44
NPZ7a	323812	6410786	6	41.26	20.06	47.21
NPZ8	324314	6412607	5	-3.52	-9.40	1.26
NPZ8a	324314	6412607	6	-9.11	-11.46	-5.73
NPZ9	320643	6412905	3	-0.35	-14.66	3.51
NPZ9a	320643	6412905	3	-20.82	-22.60	-16.91
North	323156	6414021	3	-7.46	-11.71	-5.26
PGW5_Large	316149	6415312	15	11.97	-2.45	32.32
PGW5_Small	316149	6415312	2	-4.58	-8.06	-2.86
PZ-1-395	322173	6408598	17	60.91	2.50	84.23
PZ-1-415	322173	6408598	19	76.06	26.87	127.70

Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
PZ-1-440	322173	6408598	21	58.46	34.42	91.65
PZ-4-395.5	322787	6409233	17	29.74	-49.75	96.05
PZ-4-416.5	322787	6409233	19	9.26	-6.34	27.76
PZ-4-436	322787	6409233	20	-50.59	-73.35	9.68
PZ-4-445.5	322787	6409233	20	-10.47	-43.34	58.56
PZ-4-455	322787	6409233	21	23.92	5.45	47.91
RNVW1-Bay	313911	6403956	3	-14.86	-16.14	-13.95
RNVW1-Brt	313911	6403956	18	-2.71	-7.74	0.82
RNVW1-LLd	313911	6403956	11	-28.27	-40.98	-9.11
RNVW1-LmA	313911	6403956	3	-43.91	-49.49	-27.50
RNVW1-LmH	313911	6403956	3	-18.39	-27.88	-14.80
RNVW1-UAr	313911	6403956	6	-2.34	-4.63	1.12
RNVW1-ULd	313911	6403956	10	-16.66	-24.12	-6.10
RNVW1-UPG	313911	6403956	6	-13.52	-15.29	-6.99
RNVW2-Brt	313434	6405372	18	-13.30	-14.66	-10.85
RNVW2-LLd	313434	6405372	14	-18.55	-23.36	-14.18
RNVW2-LmA	313434	6405372	4	-16.09	-20.62	-3.96
RNVW2-LmH	313434	6405372	3	-23.08	-23.41	-19.27
RNVW2-UAr	313434	6405372	6	-15.69	-17.63	-10.77
RNVW2-ULd	313434	6405372	10	-17.77	-23.60	-11.56
RNVW2-UPG	313434	6405372	6	-14.78	-16.33	-10.18
RNVW3-Brt	312235	6406367	19	-23.37	-26.34	-18.11
RNVW3-LLd	312235	6406367	14	-20.55	-23.46	-12.20
RNVW3-LmA	312235	6406367	4	-23.57	-33.51	-10.66
RNVW3-UAr	312235	6406367	6	-27.74	-33.67	-17.67
RNVW3-ULd	312235	6406367	10	-27.63	-33.86	-18.01
RNVW3-UPG	312235	6406367	6	-22.77	-29.62	-12.94
RNVW4-Brt	314087	6411002	21	33.17	23.47	40.82
RNVW4-LLd	314087	6411002	19	36.03	31.86	40.15
RNVW4-UAr	314087	6411002	10	25.41	21.89	27.54
RNVW4-ULd	314087	6411002	14	44.39	36.76	50.50

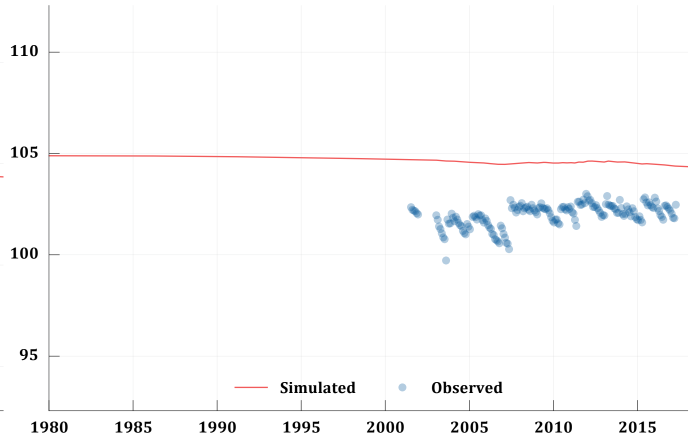
Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
RNVW4-UPG	314087	6411002	10	30.85	21.79	37.22
SDH16	313660	6410914	9	59.37	42.28	82.07
SDH18	313460	6410602	9	46.40	13.76	80.56
South	322157	6412294	15	3.93	-12.61	28.65
WPP1	311490	6413429	11	32.01	29.00	33.22
WPP2	311447	6413503	17	28.57	26.43	29.96


64CT
8-SOUTH-2
ALV1_LARGE
ALV1_SMALL
ALV2_LARGE
ALV2_SMALL
ALV3_LARGE
ALV3_SMALL
Groundwater level (mRL)
Year
Simulated
Observed
1980 1985 1990 1995 2000 2005 2010 2015

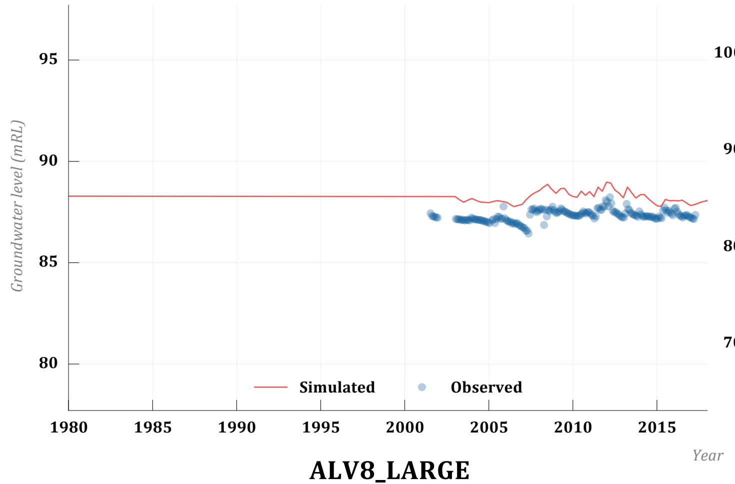
ALV4_LARGE



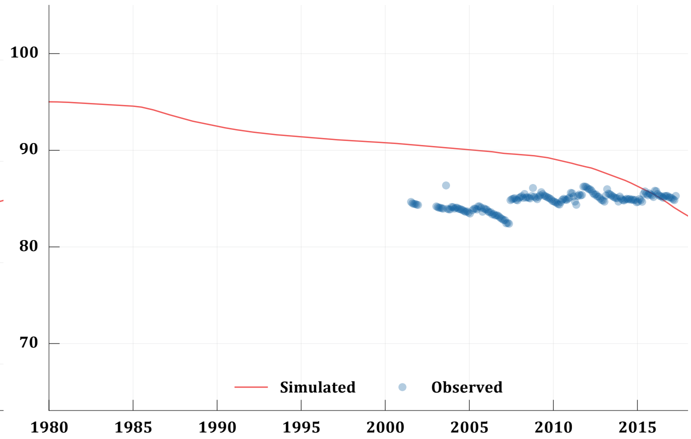
ALV4_SMALL



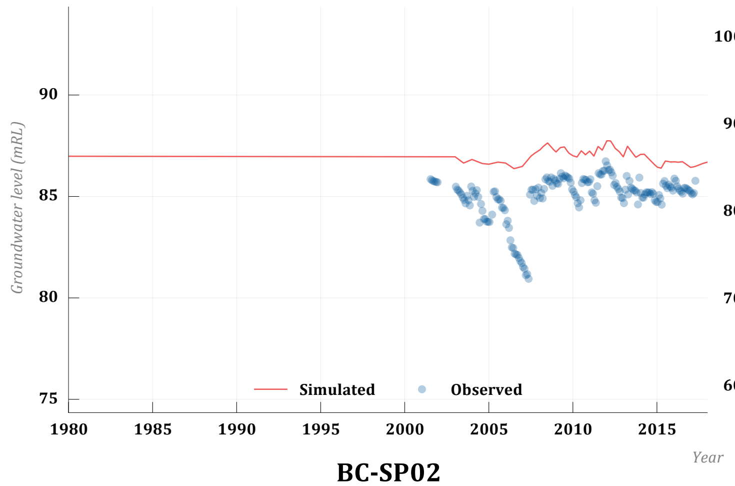
ALV7_LARGE



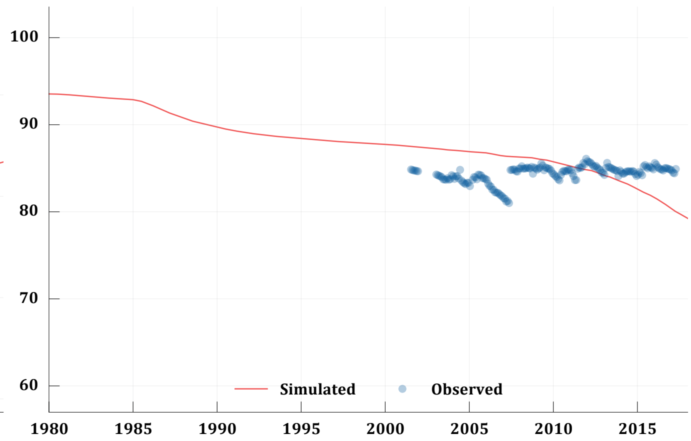
ALV7_SMALL



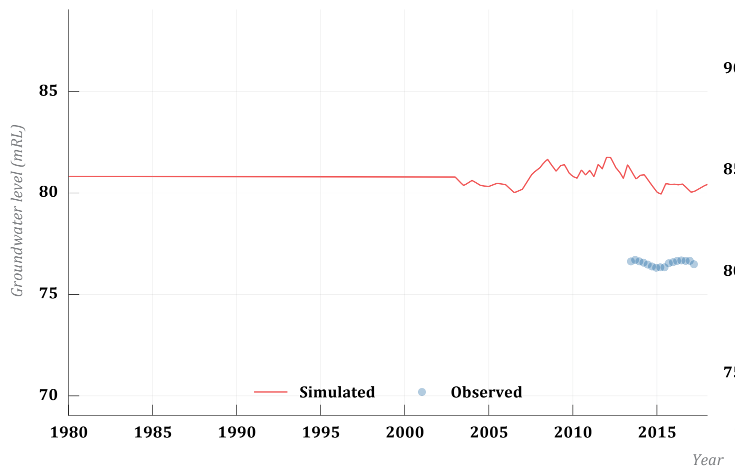
ALV8_LARGE



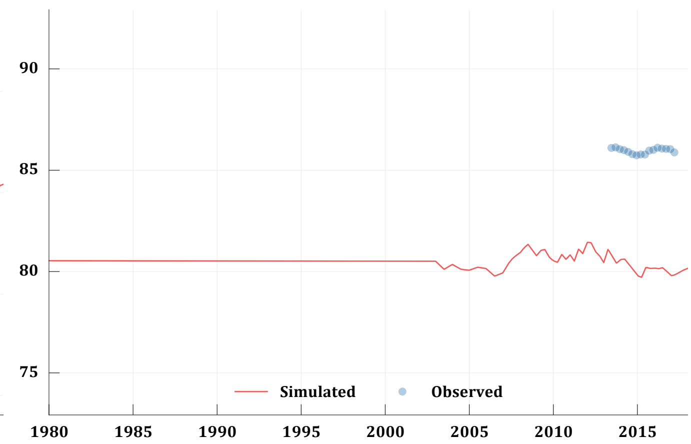
ALV8_SMALL

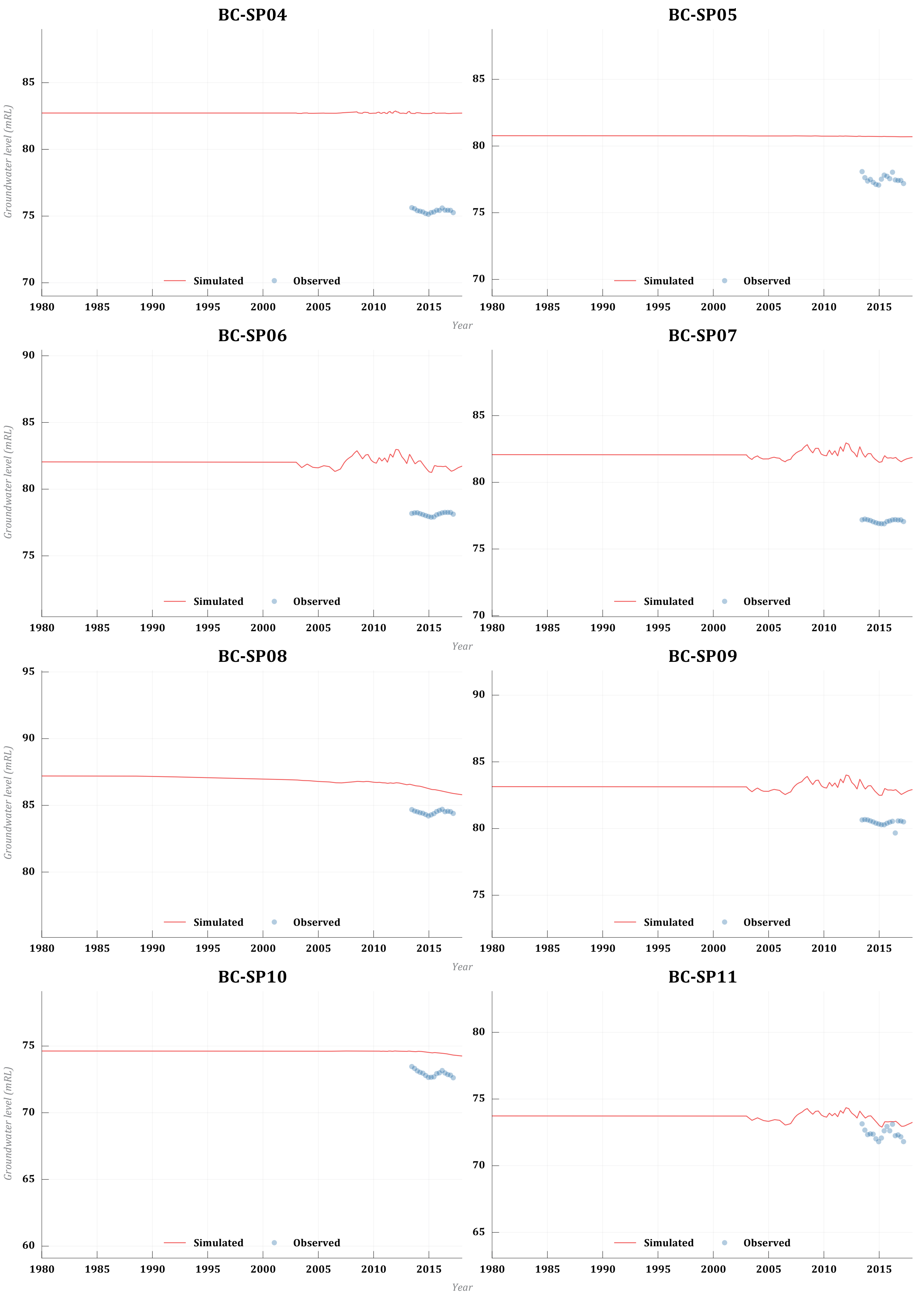


BC-SP02

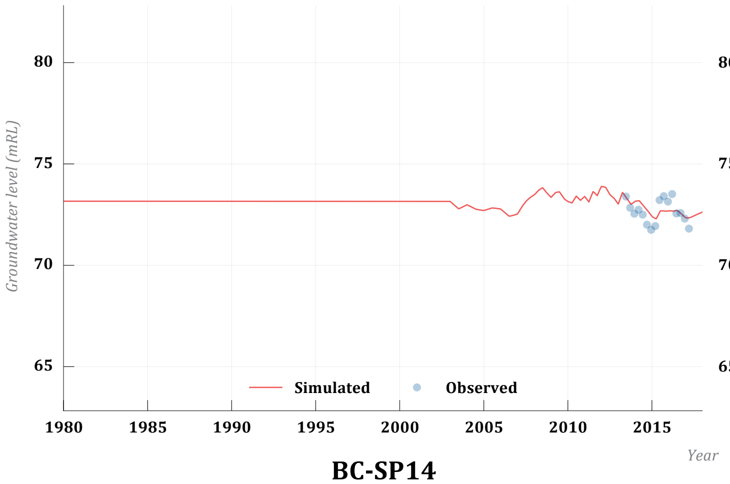


BC-SP03

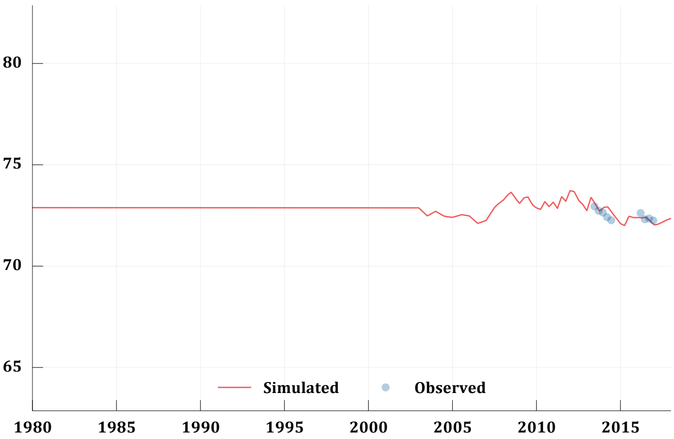



BC-SP04
BC-SP05
BC-SP06
BC-SP07
BC-SP08
BC-SP09
BC-SP10
BC-SP11
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

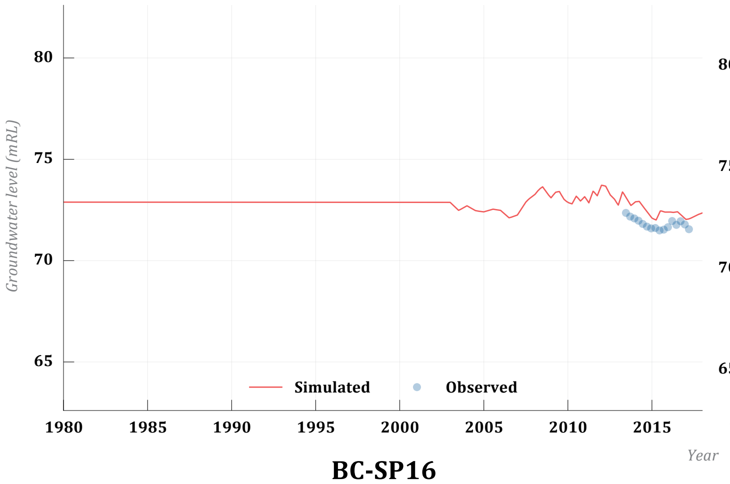
BC-SP12



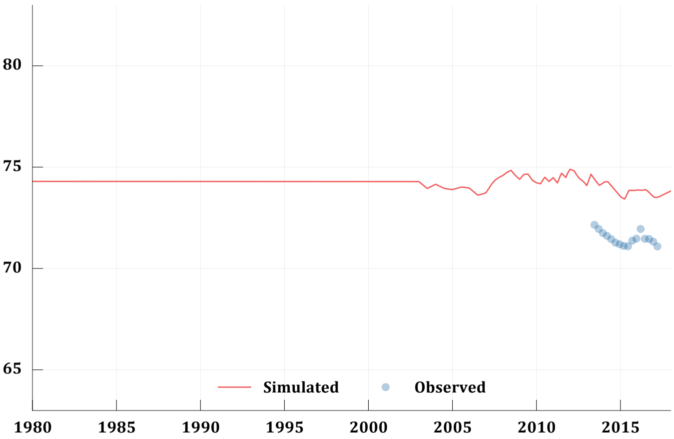
BC-SP13



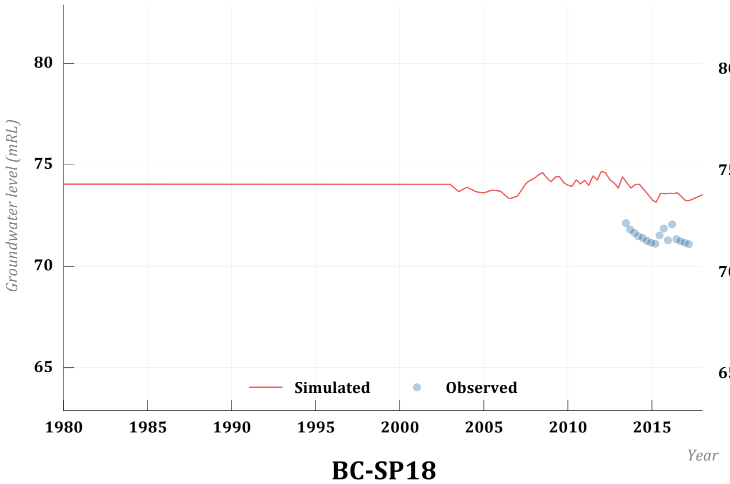
BC-SP14



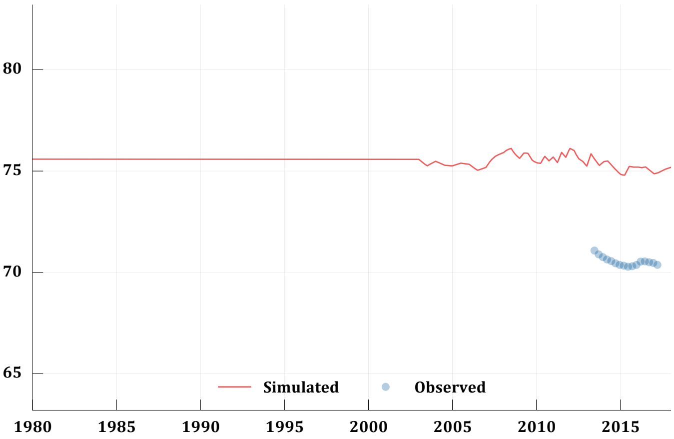
BC-SP15



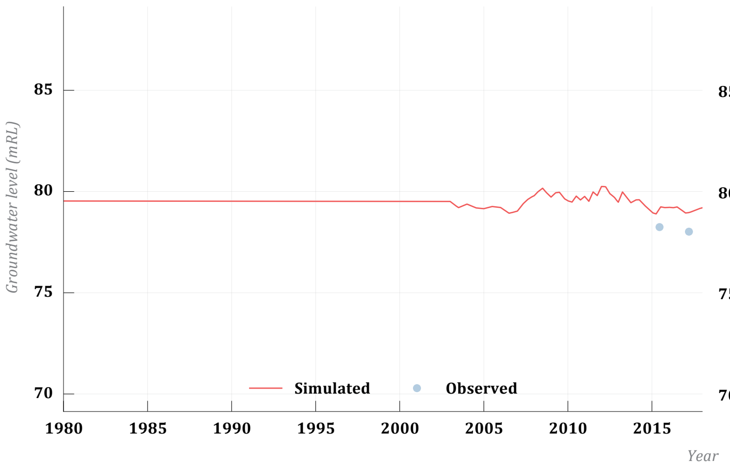
BC-SP16



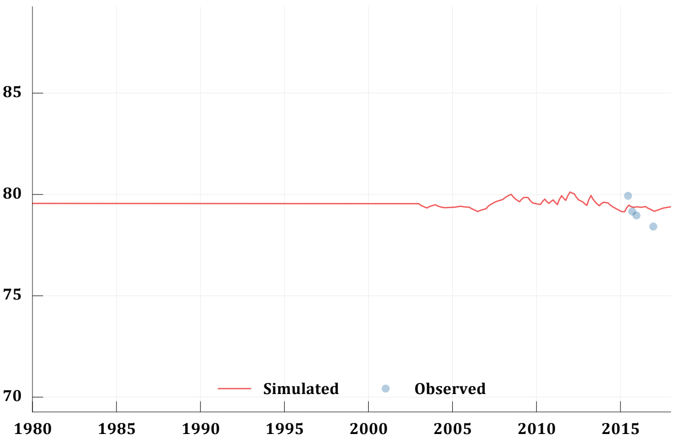
BC-SP17

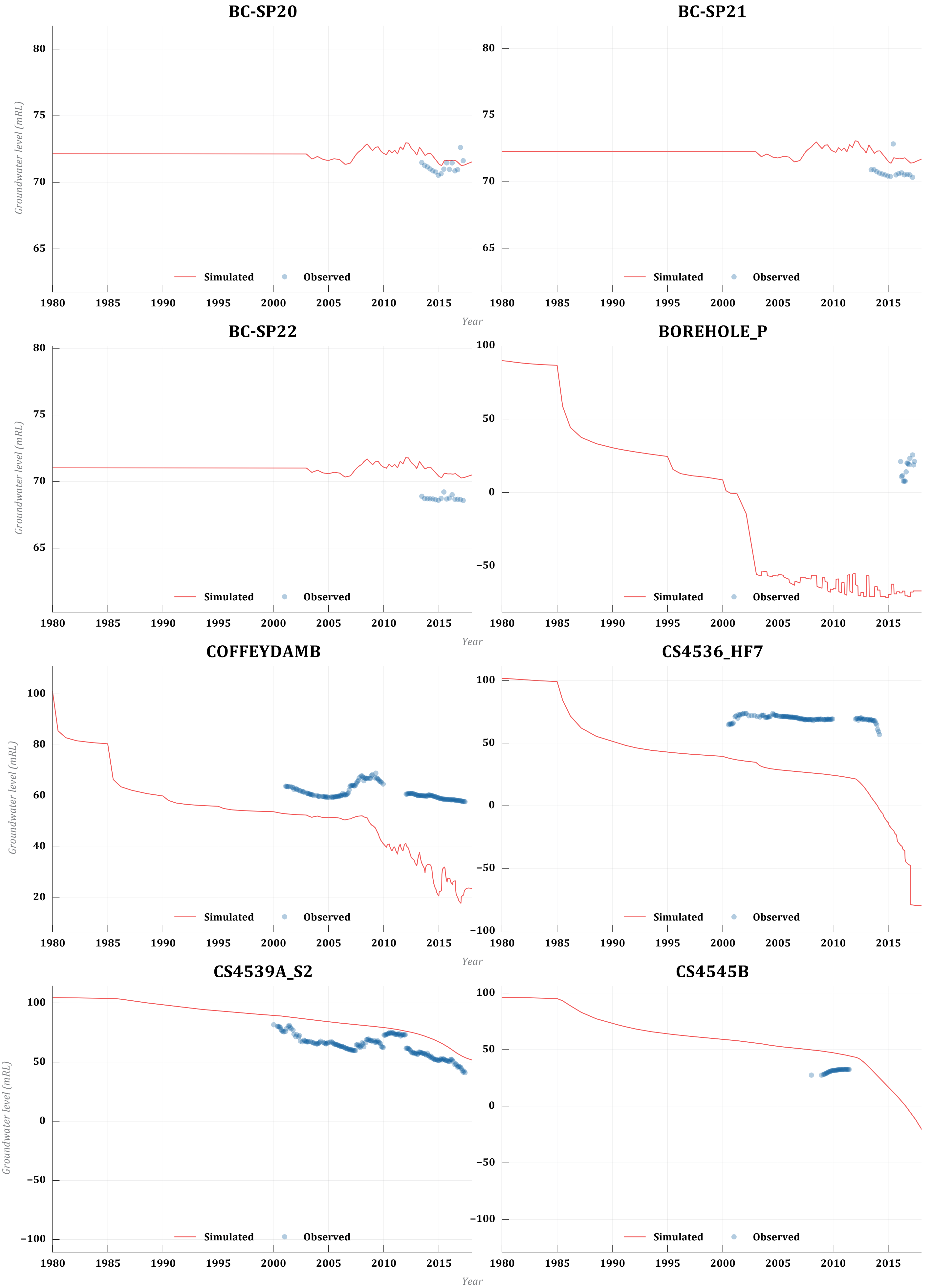


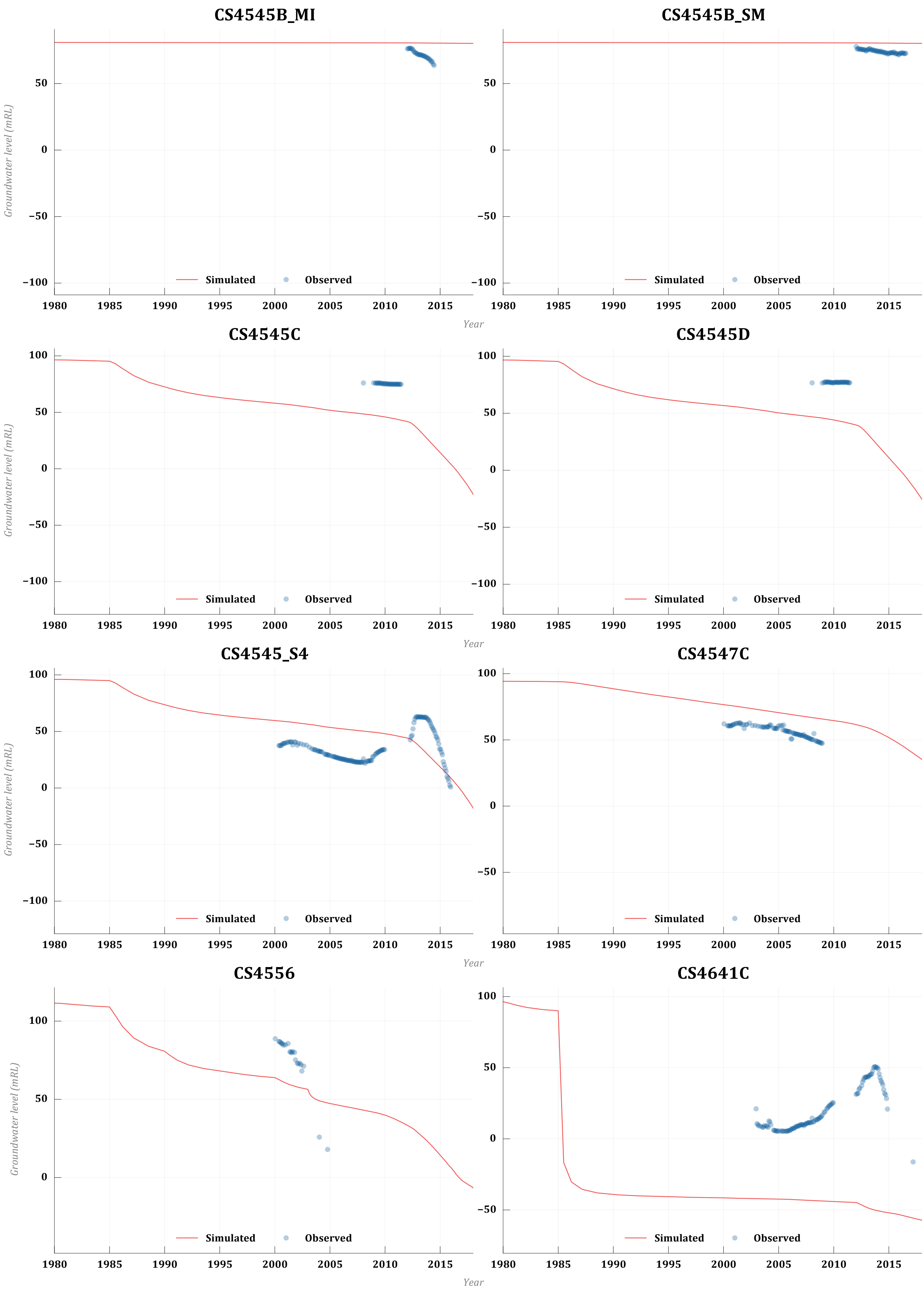
BC-SP18

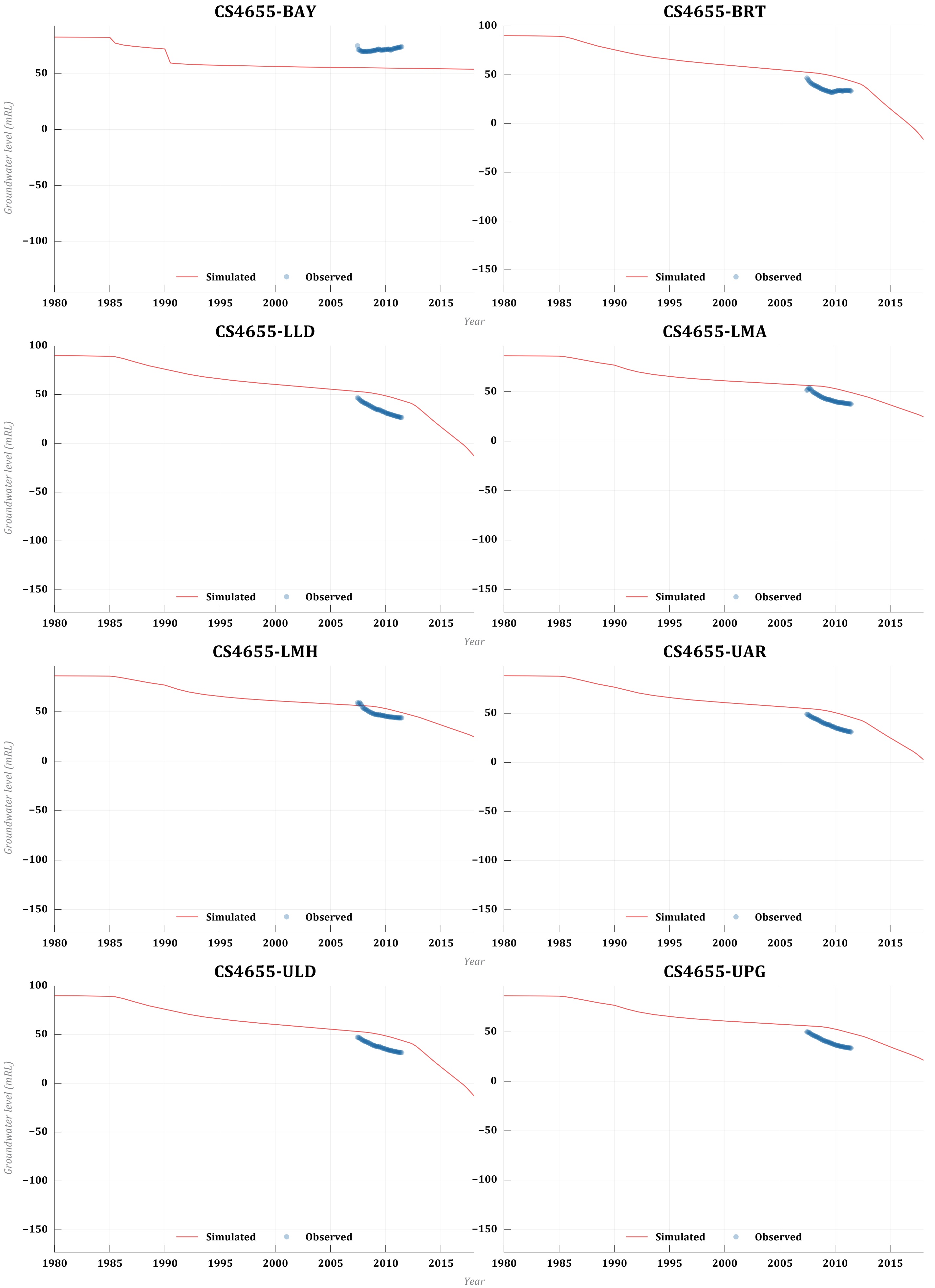


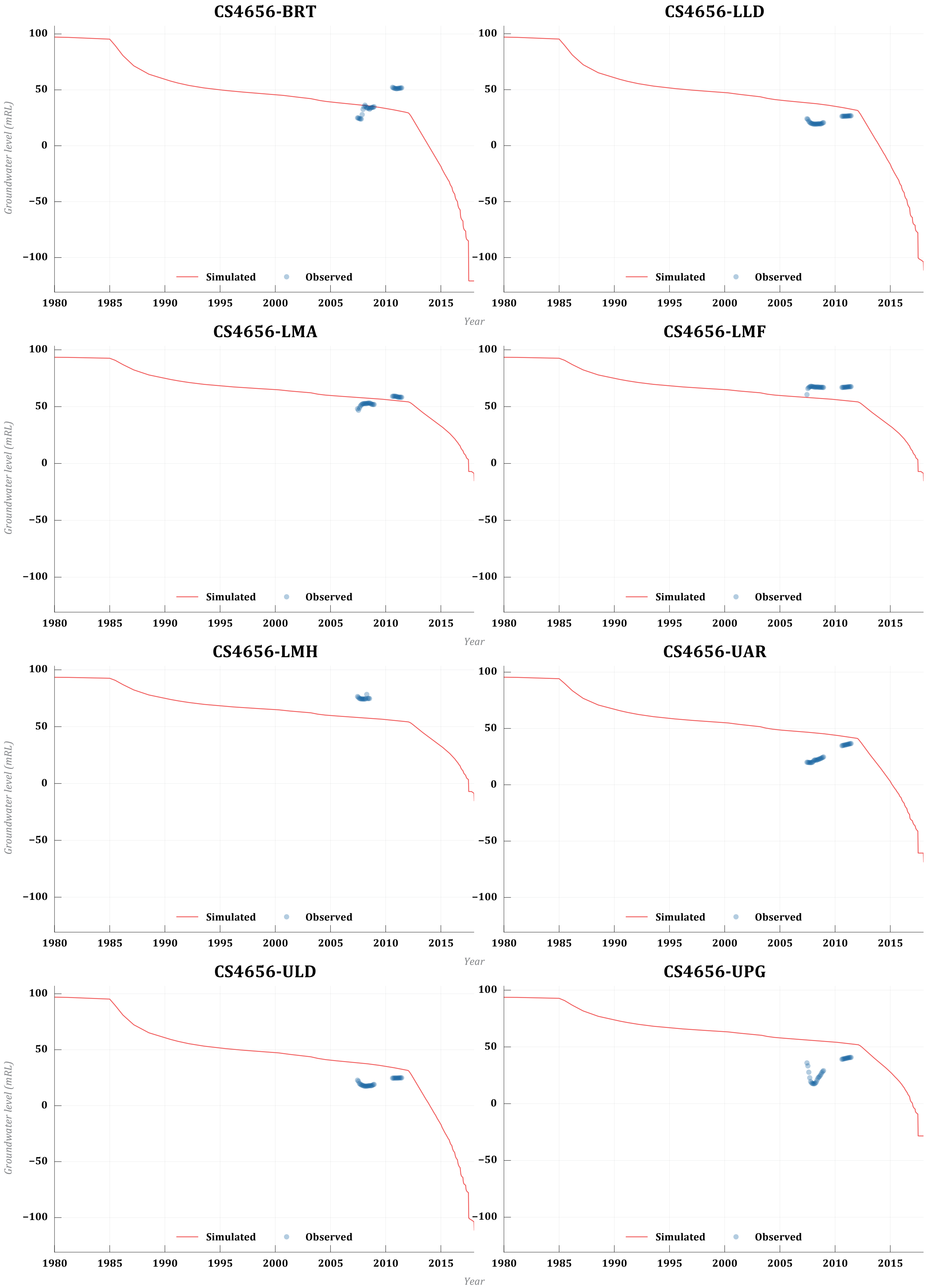
BC-SP19

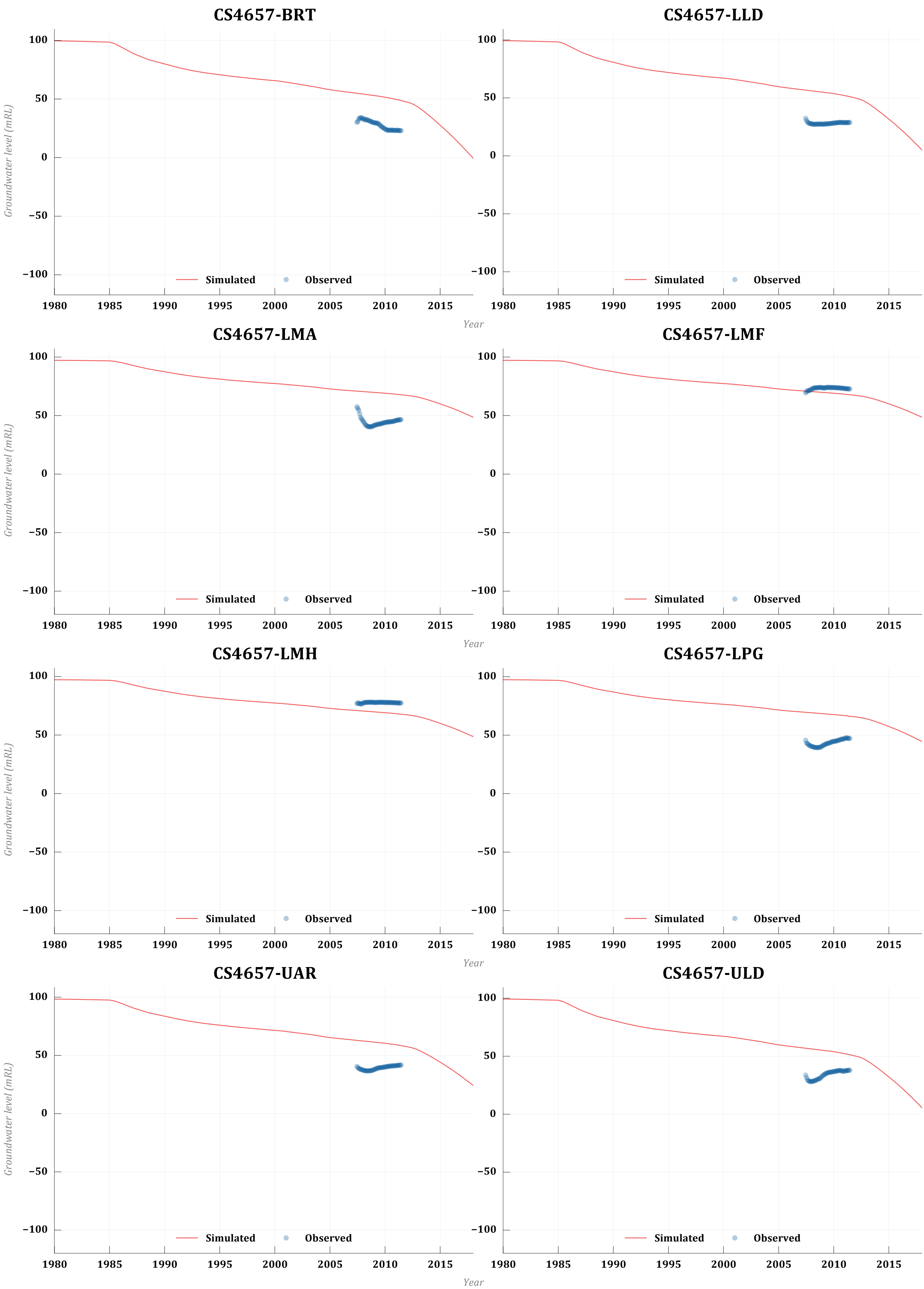



BC-SP20
BC-SP21
BC-SP22
BOREHOLE_P
COFFEYDAMB
CS4536_HF7
CS4539A_S2
CS4545B
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015
80
75
70
65
100
50
0
−50
−100
60
40
20

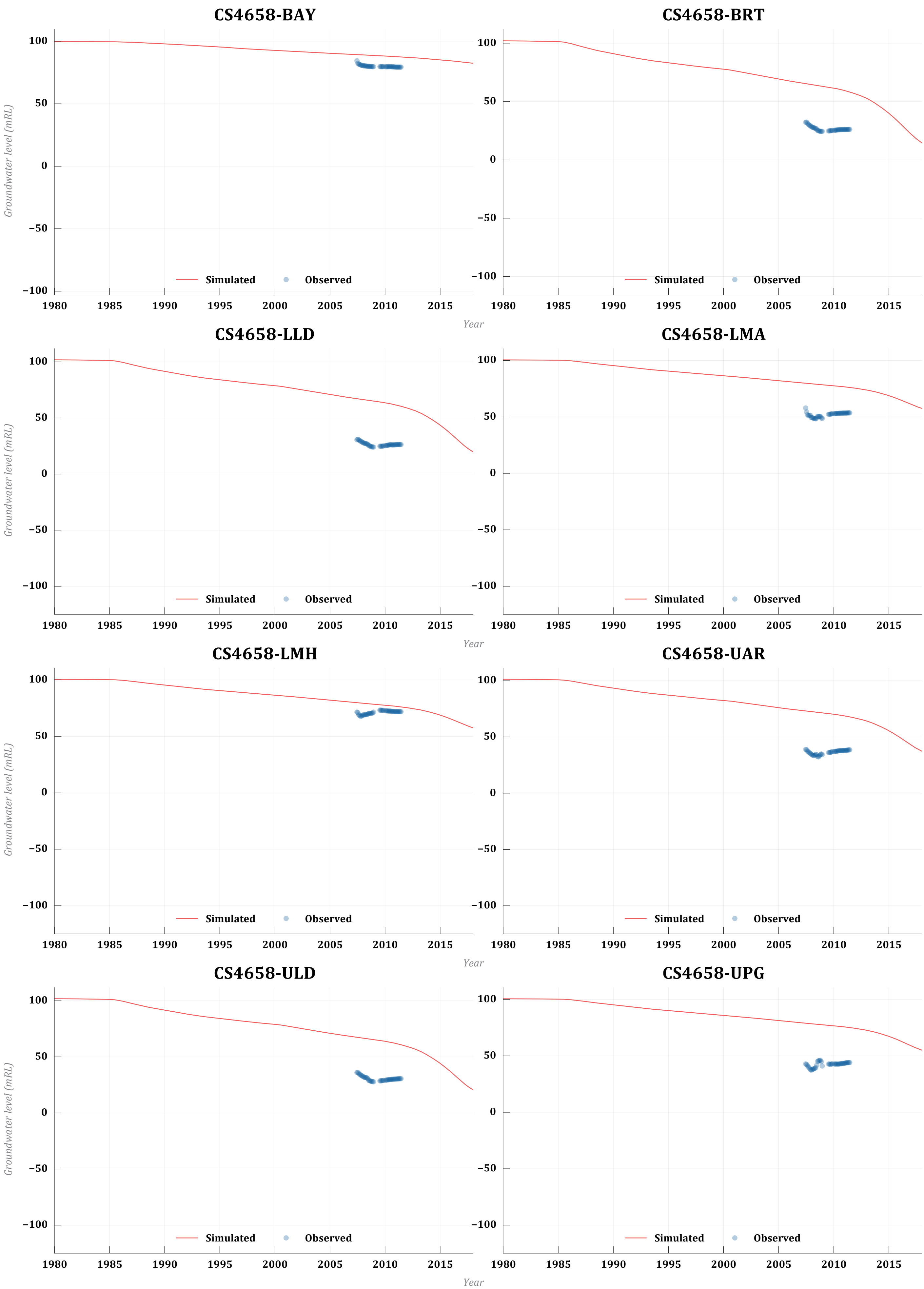

CS4545B_MI
CS4545B_SM
CS4545C
CS4545D
CS4545_S4
CS4547C
CS4556
CS4641C
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015
100
50
0
−50
−100

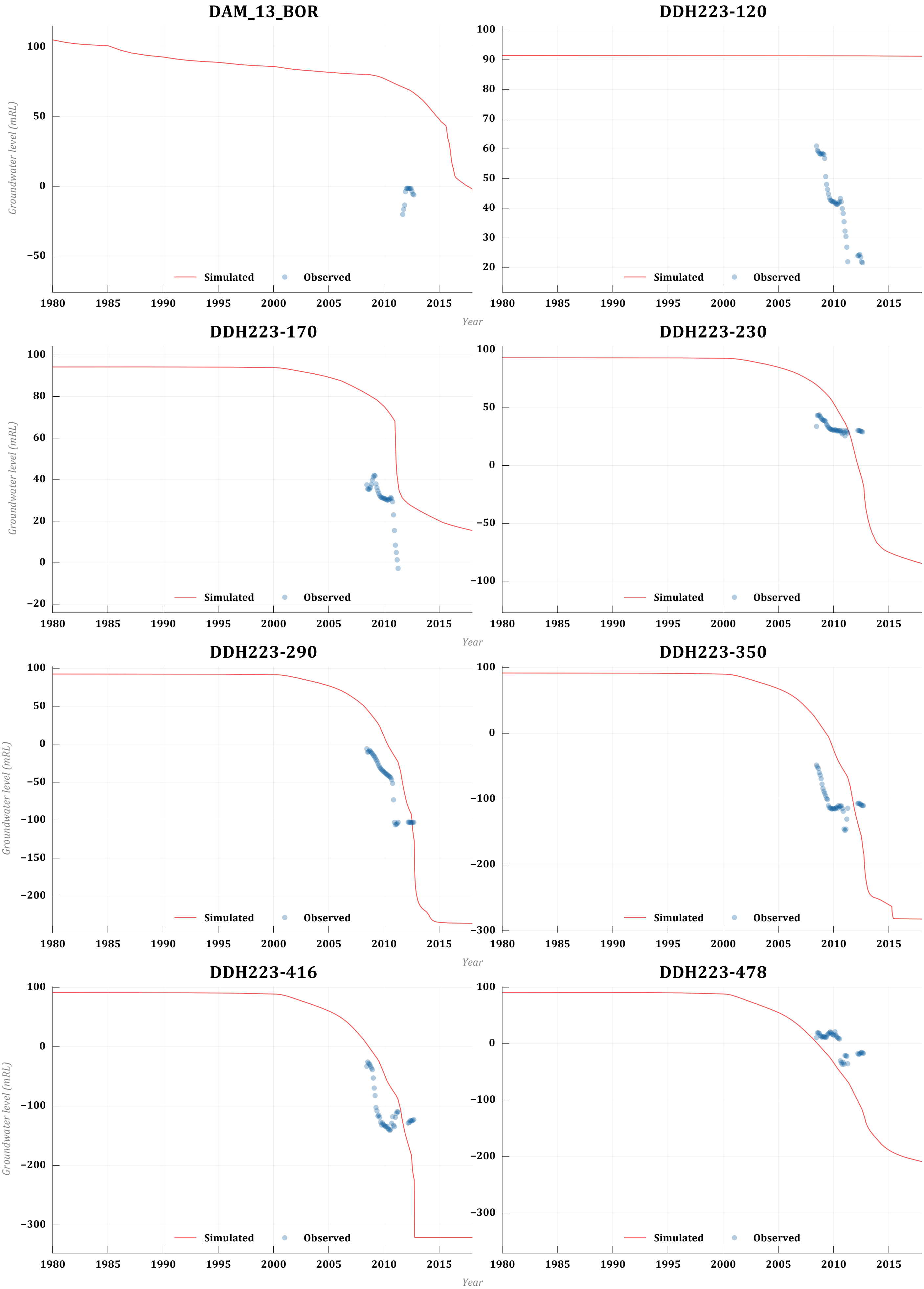

CS4655-BAY
CS4655-BRT
CS4655-LLD
CS4655-LMA
CS4655-LMH
CS4655-UAR
CS4655-ULD
CS4655-UPG
Groundwater level (mRL)
Year
Simulated
Observed
100
50
0
−50
−100
−150
1980
1985
1990
1995
2000
2005
2010
2015

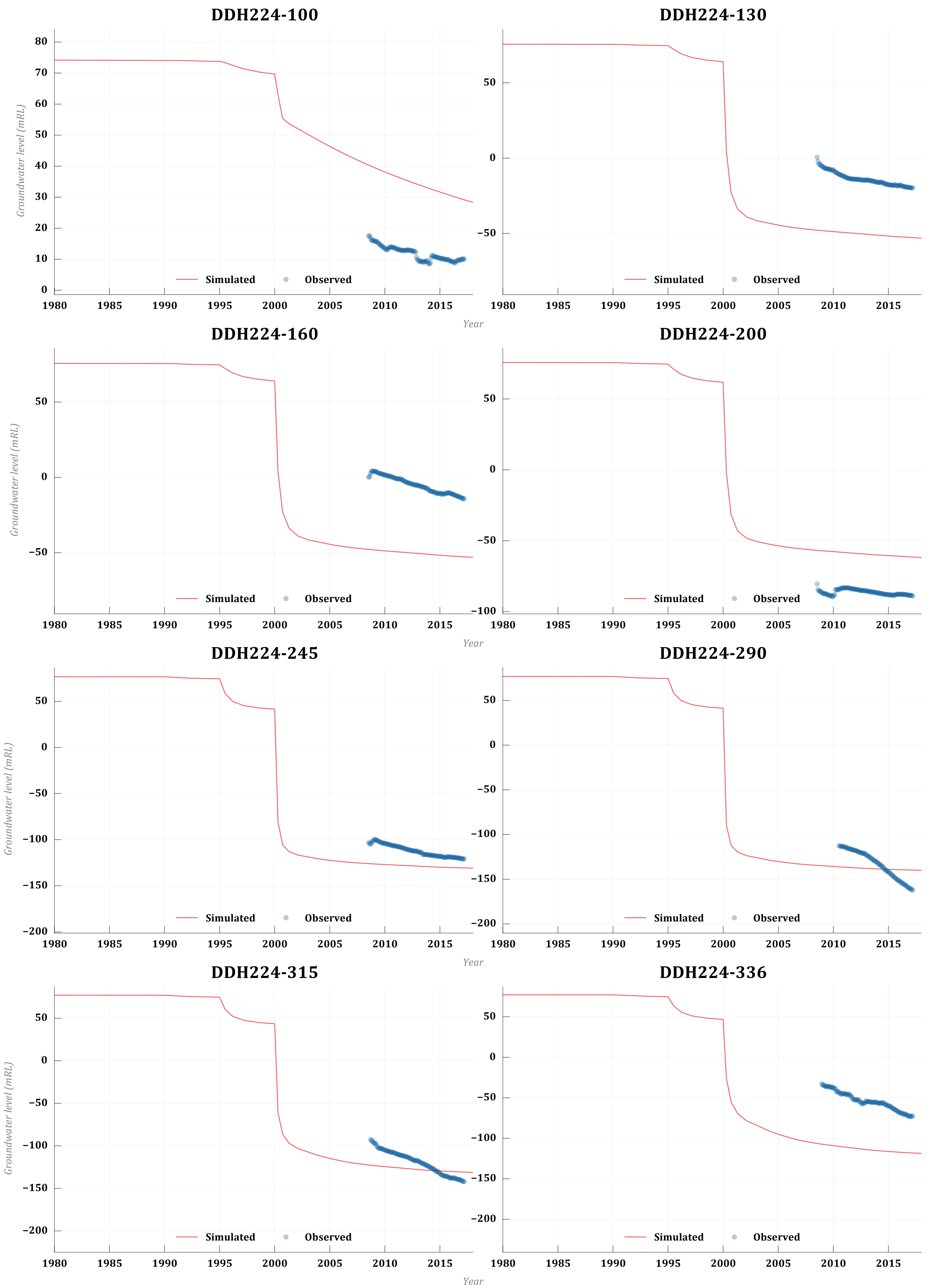

CS4656-BRT
CS4656-LLD
CS4656-LMA
CS4656-LMF
CS4656-LMH
CS4656-UAR
CS4656-ULD
CS4656-UPG
Groundwater level (mRL)
Year
Simulated
Observed
100
50
0
−50
−100
1980
1985
1990
1995
2000
2005
2010
2015

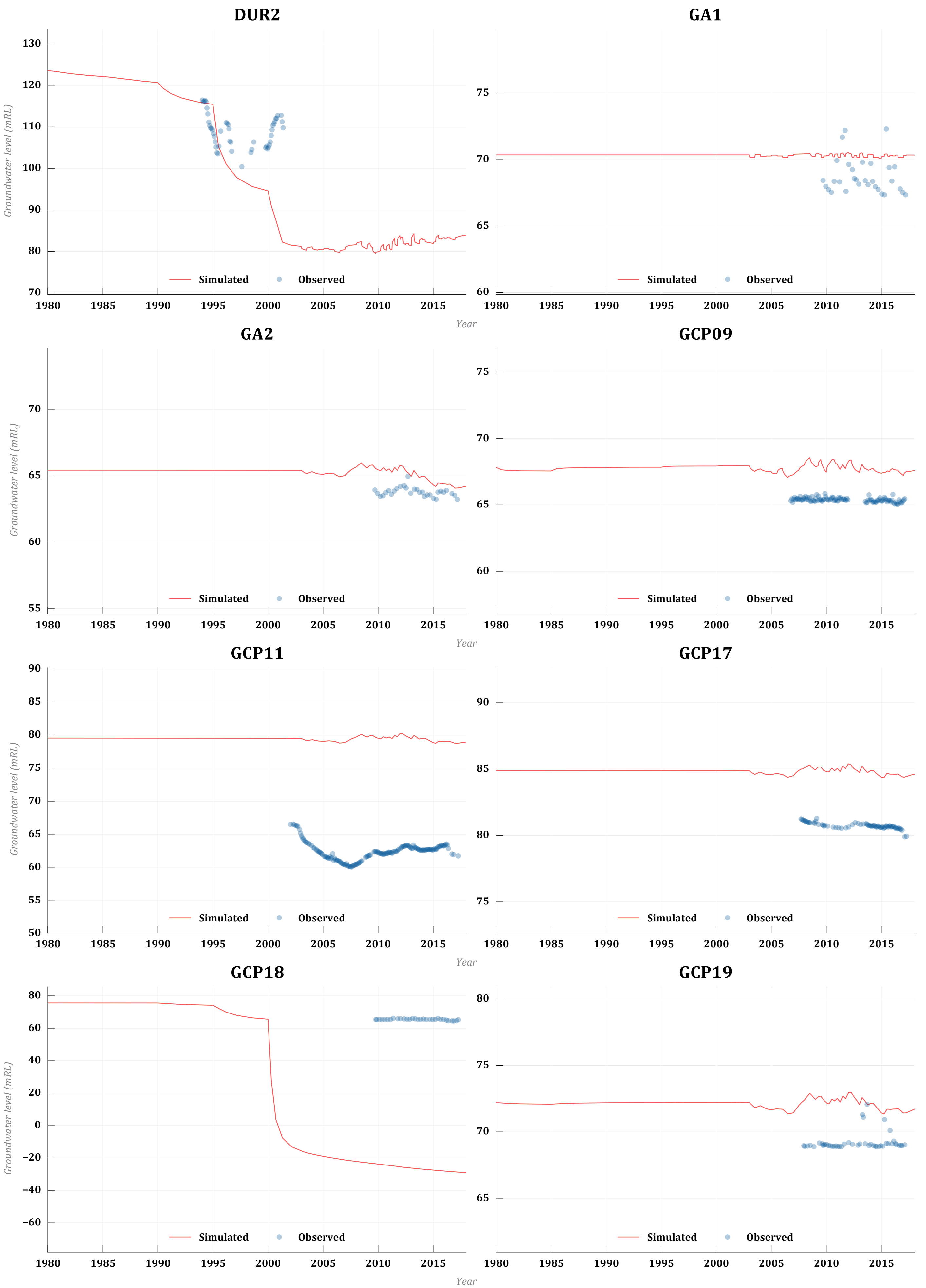


CS4657-BRT
CS4657-LLD
CS4657-LMA
CS4657-LMF
CS4657-LMH
CS4657-LPG
CS4657-UAR
CS4657-ULD
Groundwater level (mRL)
Year
Simulated
Observed
100
50
0
−50
−100
1980
1985
1990
1995
2000
2005
2010
2015

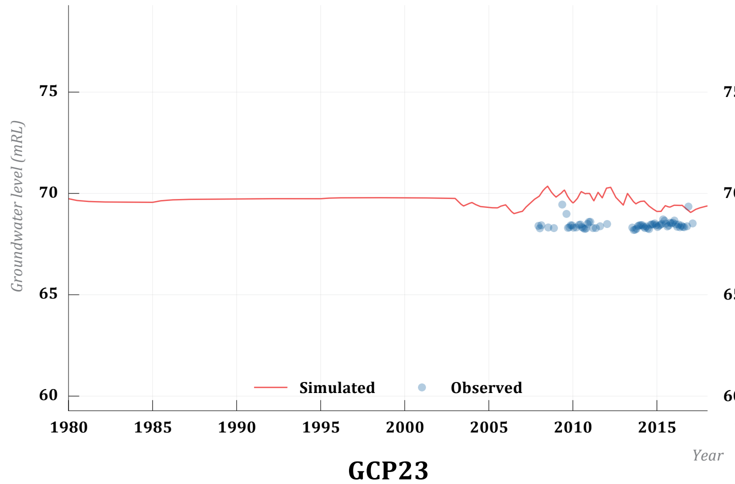

CS4658-BAY
CS4658-BRT
CS4658-LLD
CS4658-LMA
CS4658-LMH
CS4658-UAR
CS4658-ULD
CS4658-UPG
Groundwater level (mRL)
Year
Simulated
Observed
100
50
0
−50
−100
1980
1985
1990
1995
2000
2005
2010
2015


DAM_13_BOR
DDH223-120
DDH223-170
DDH223-230
DDH223-290
DDH223-350
DDH223-416
DDH223-478
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

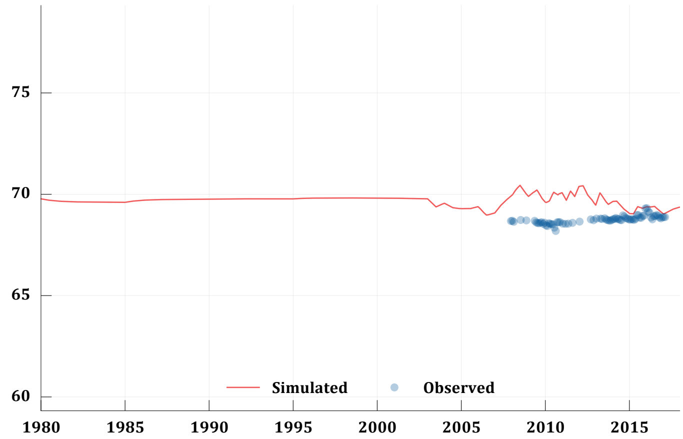

DDH224-100
DDH224-130
DDH224-160
DDH224-200
DDH224-245
DDH224-290
DDH224-315
DDH224-336
Groundwater level (mRL)
Year
Simulated
Observed


DUR2
GA1
GA2
GCP09
GCP11
GCP17
GCP18
GCP19
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

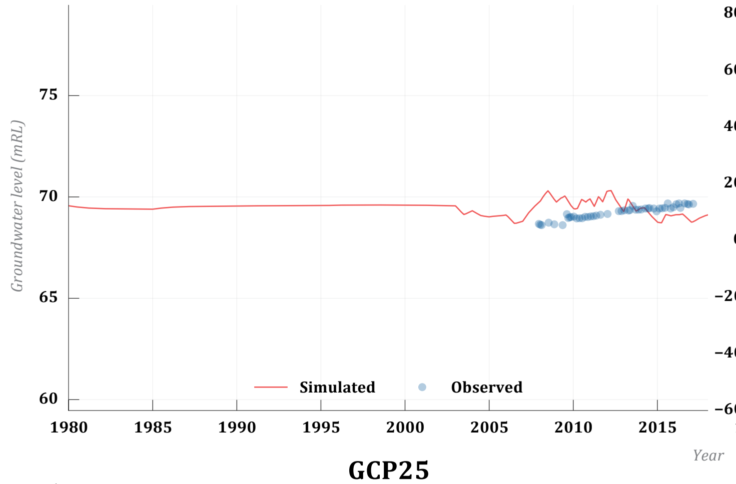
GCP21



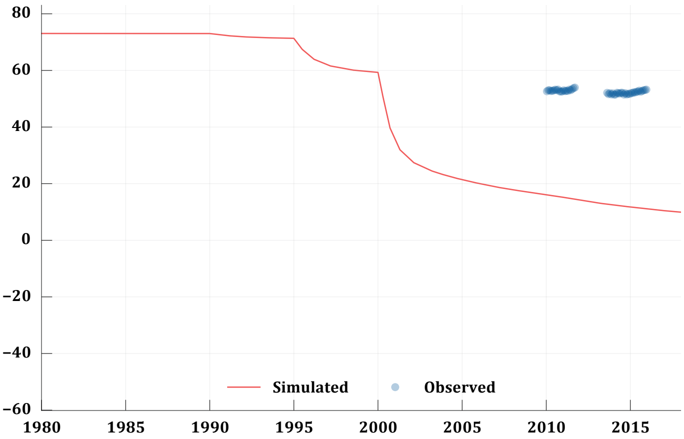
GCP22



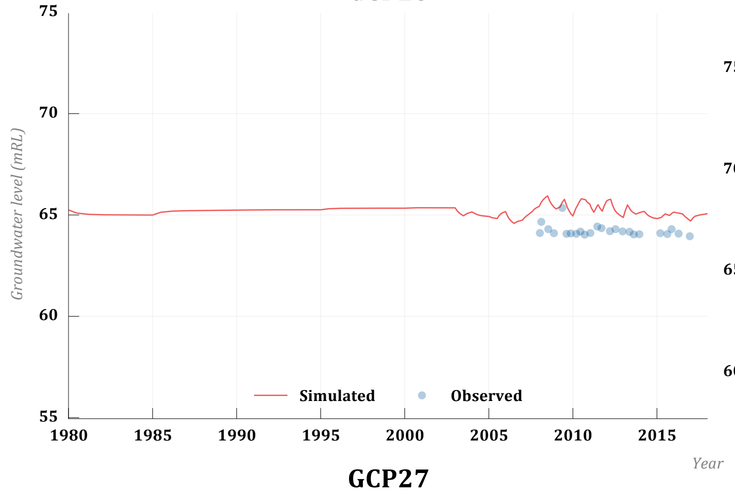
GCP23



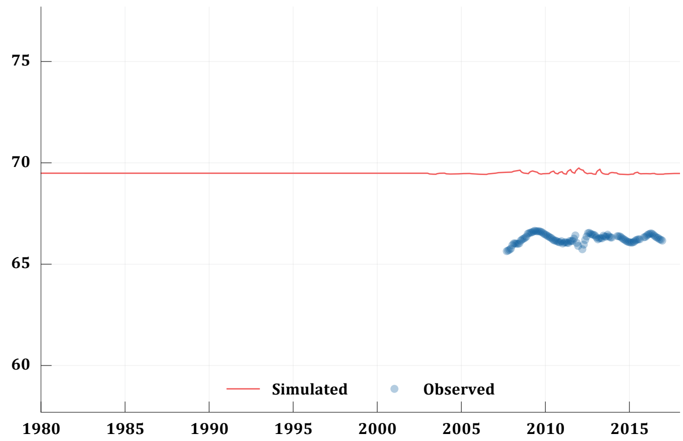
GCP24



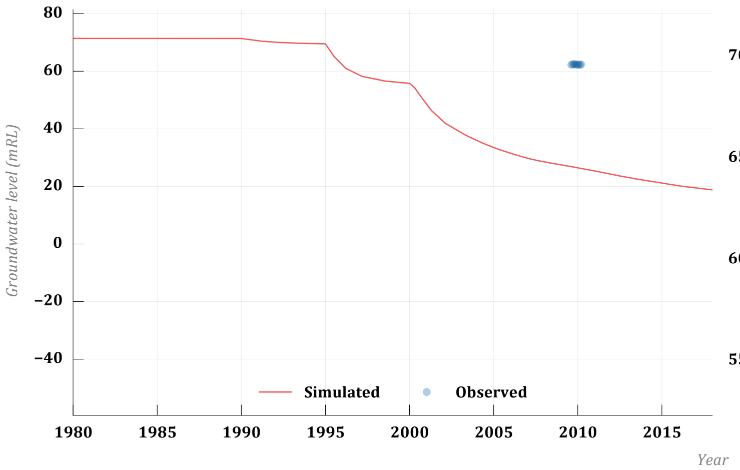
GCP25



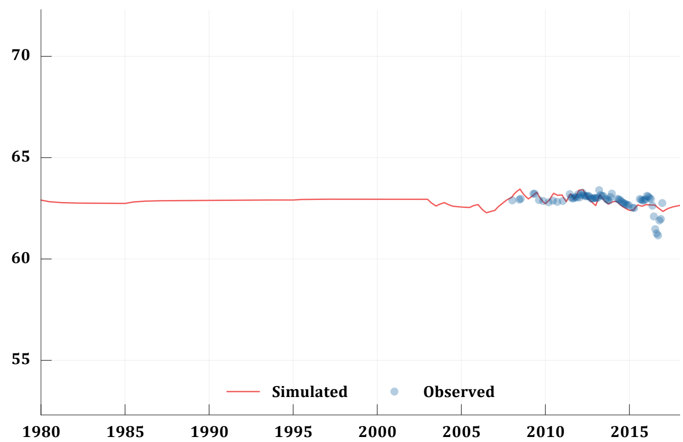
GCP26

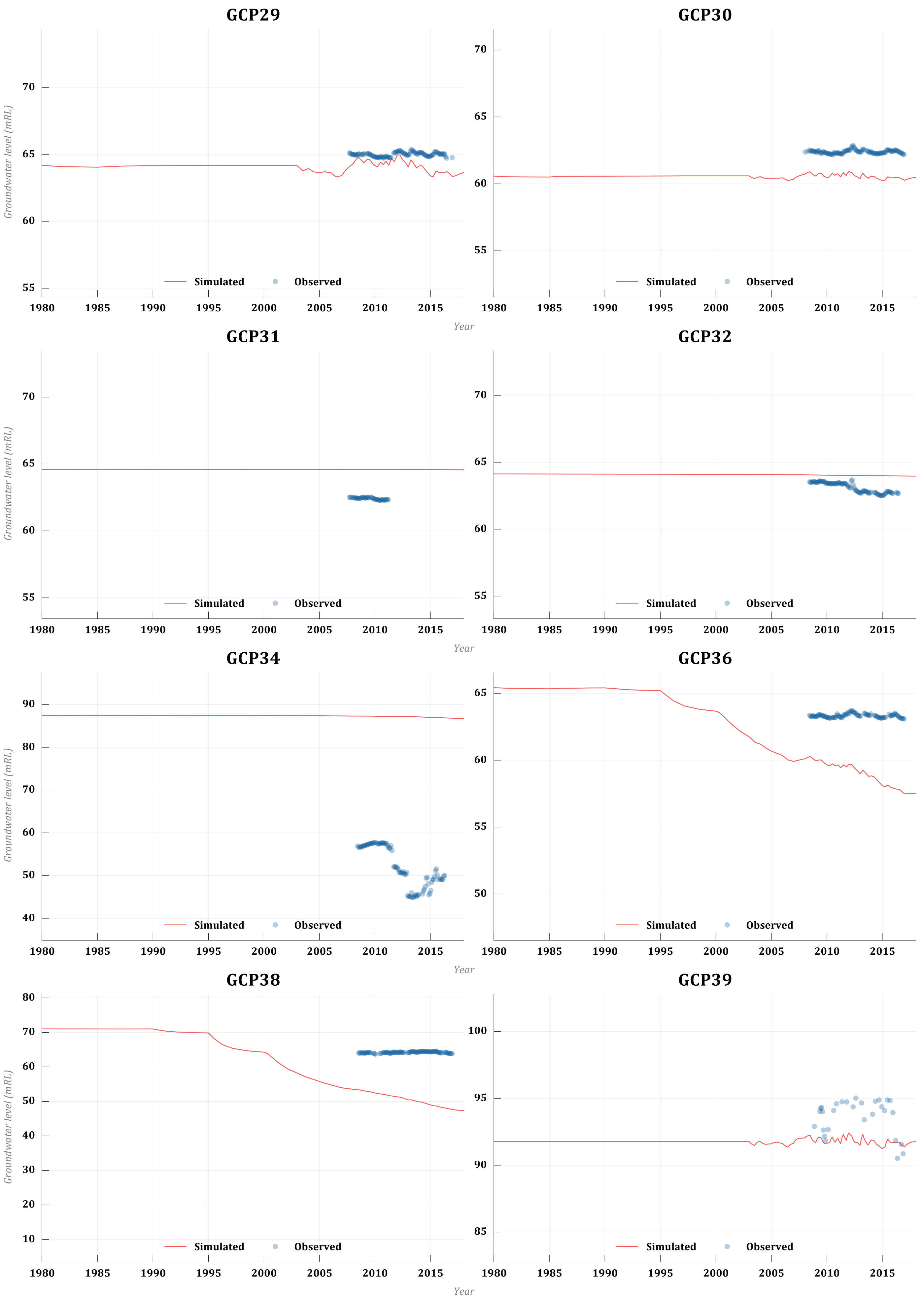


GCP27

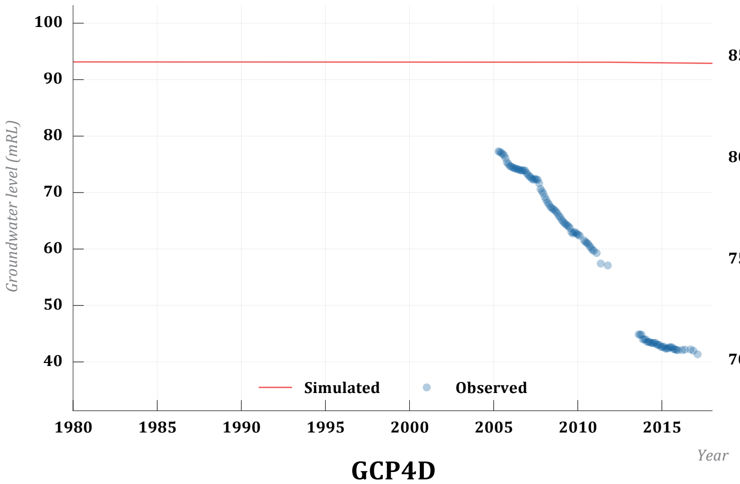


GCP28

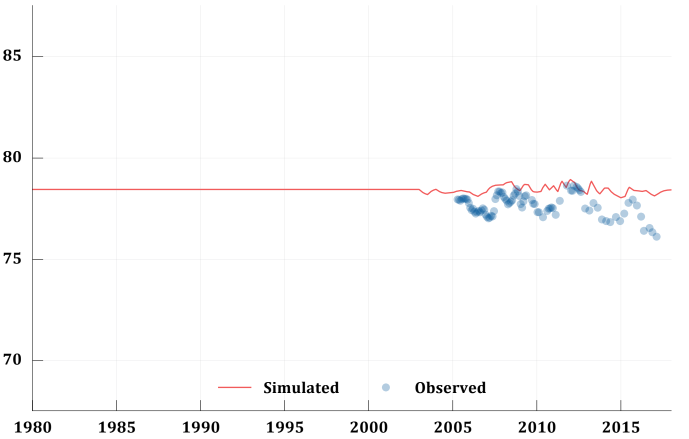



GCP29
GCP30
GCP31
GCP32
GCP34
GCP36
GCP38
GCP39
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

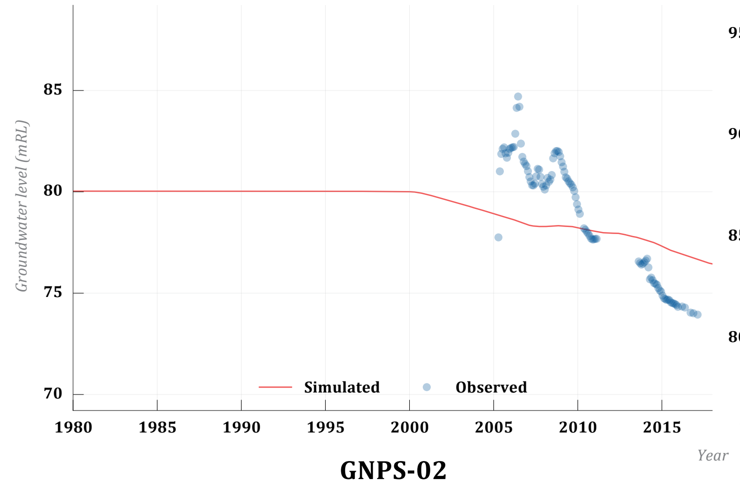
GCP3D



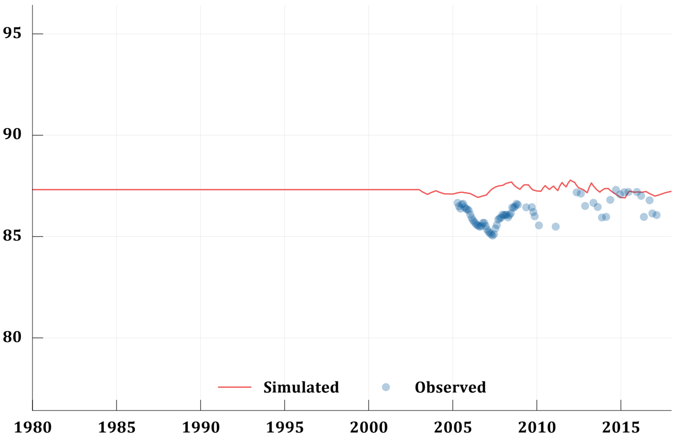
GCP3S



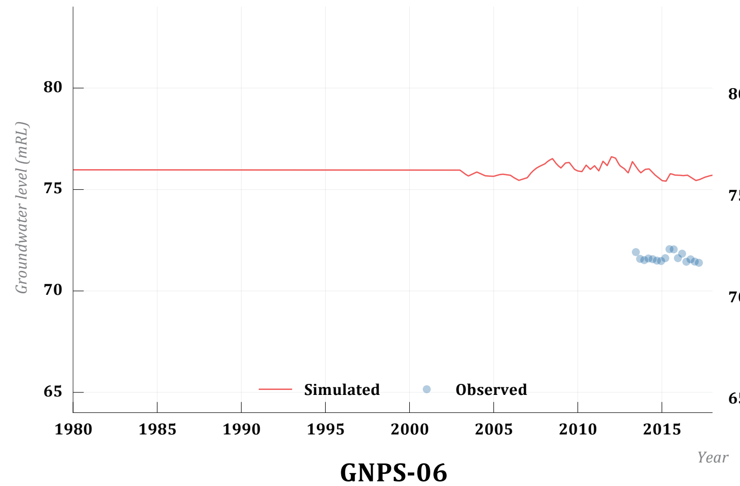
GCP4D



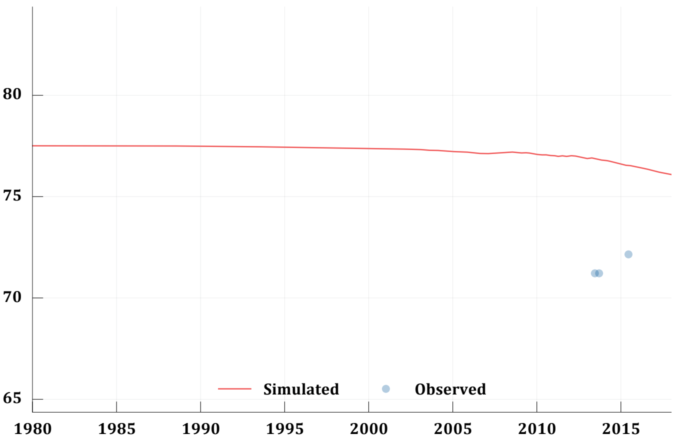
GCP4S



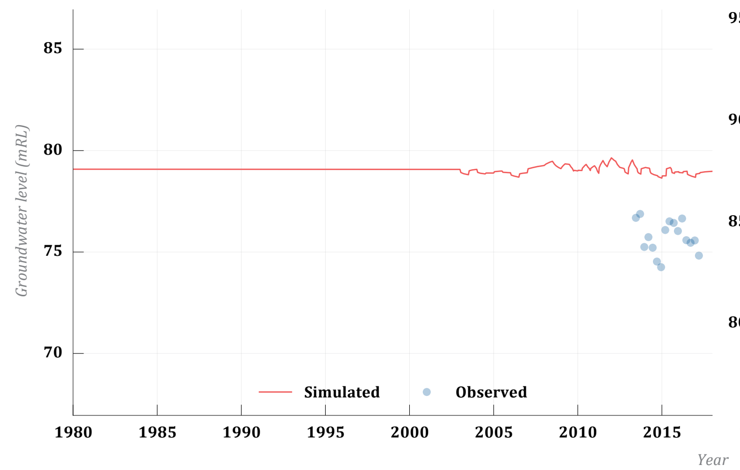
GNPS-02



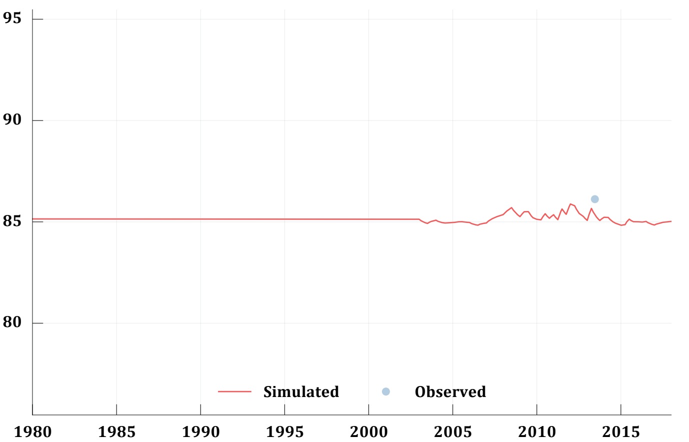
GNPS-05



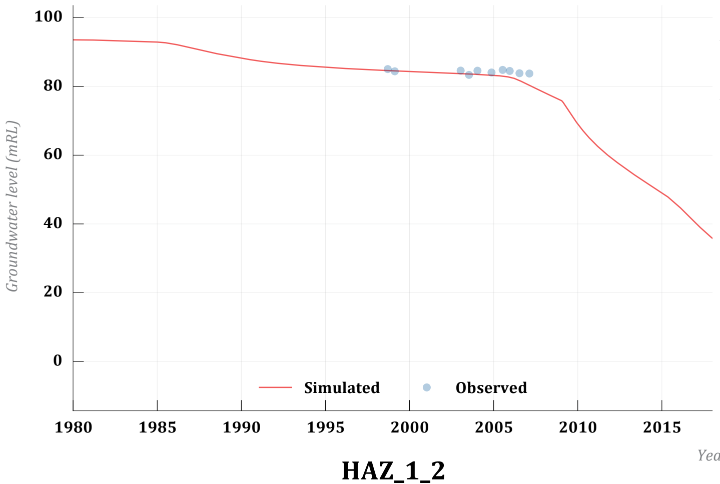
GNPS-06



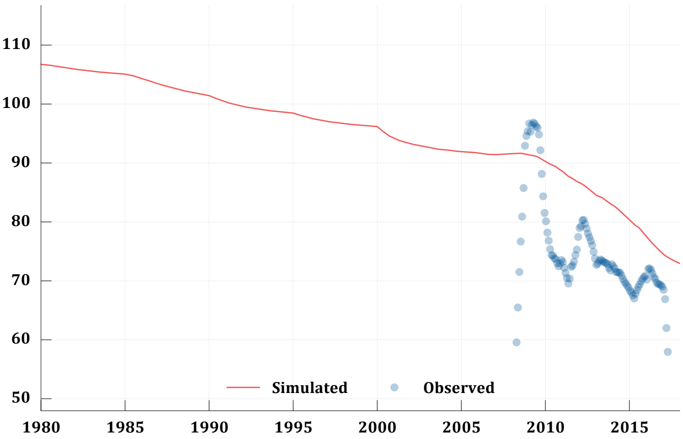
GNPS-07



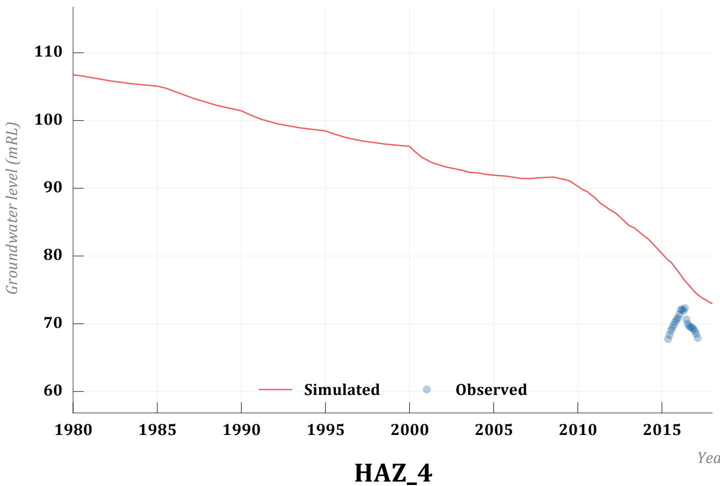
GW079793



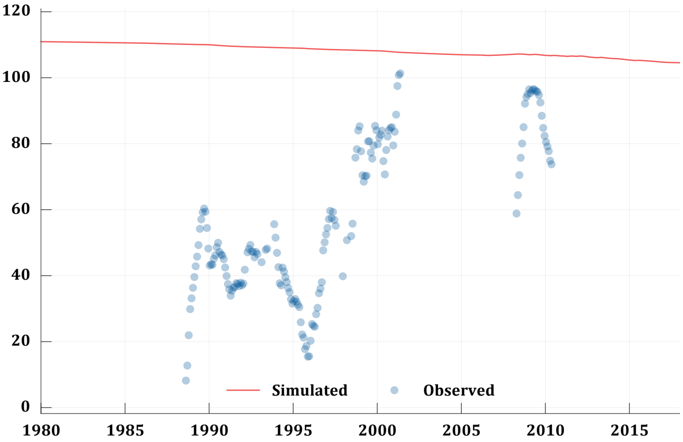
HAZ_1



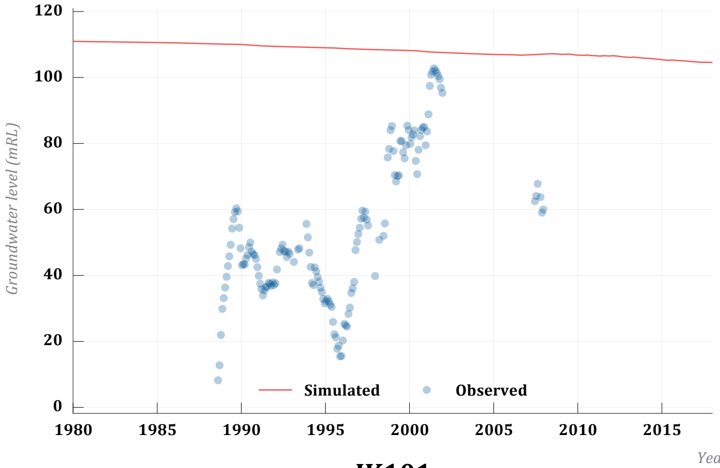
HAZ_1_2



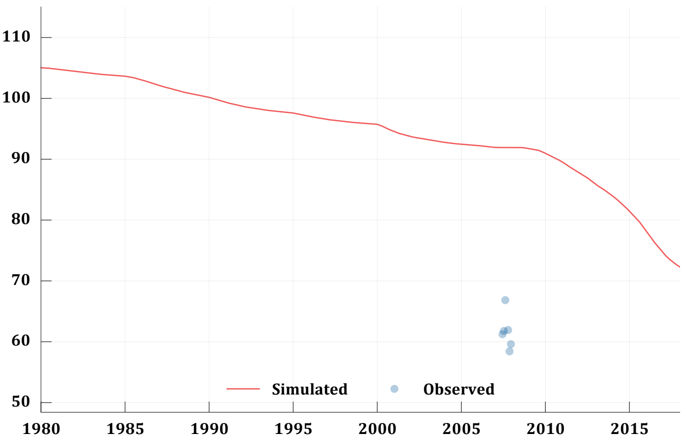
HAZ_3



HAZ_4

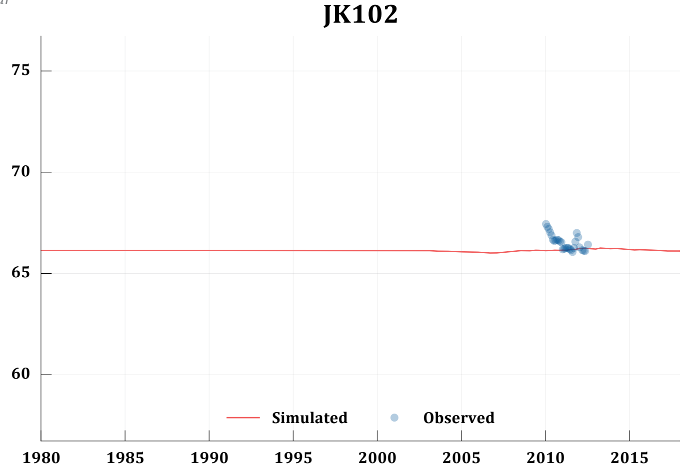


HAZ_6

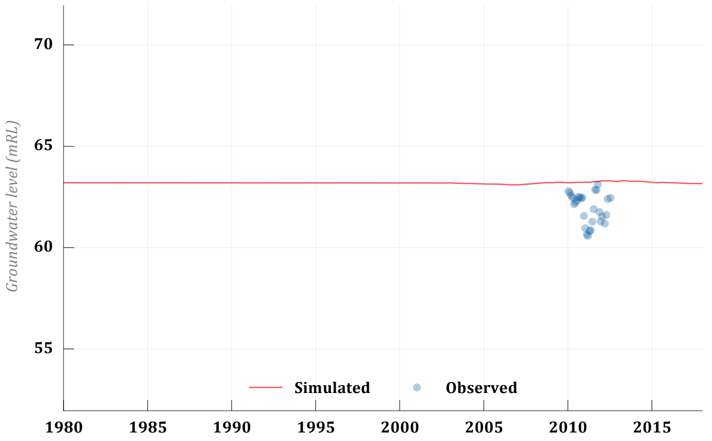


JK101

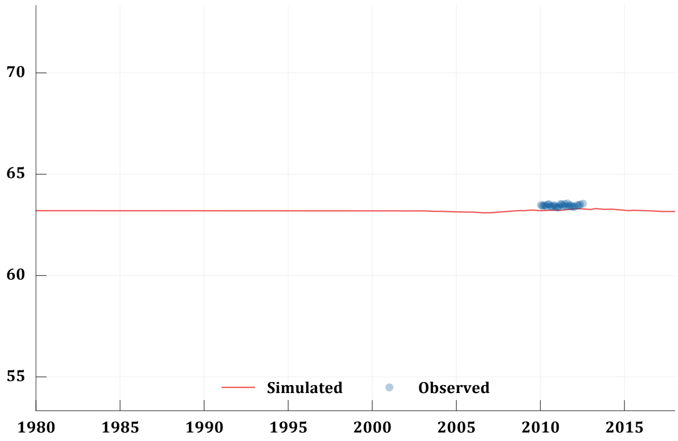
JK102



JK103

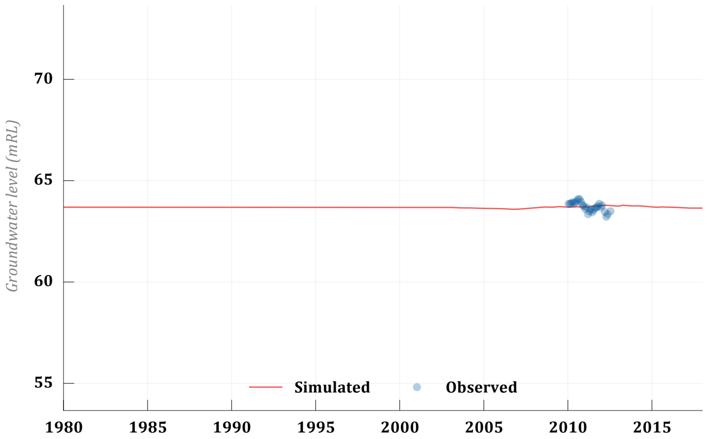


JK104

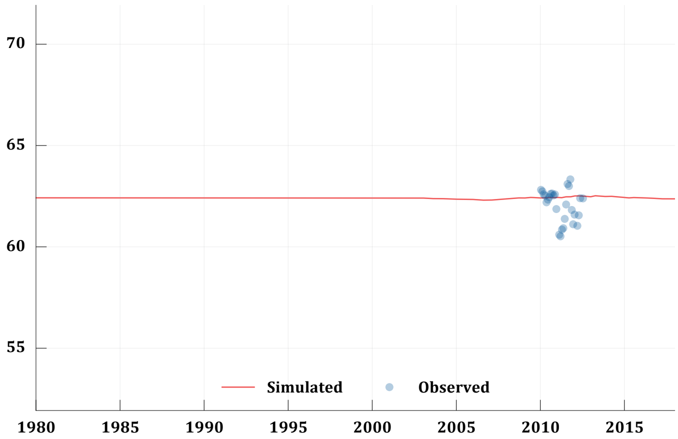


Year

JK105

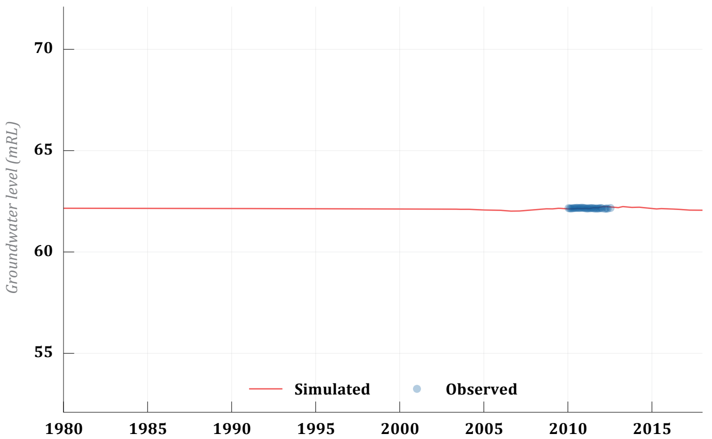


JK106

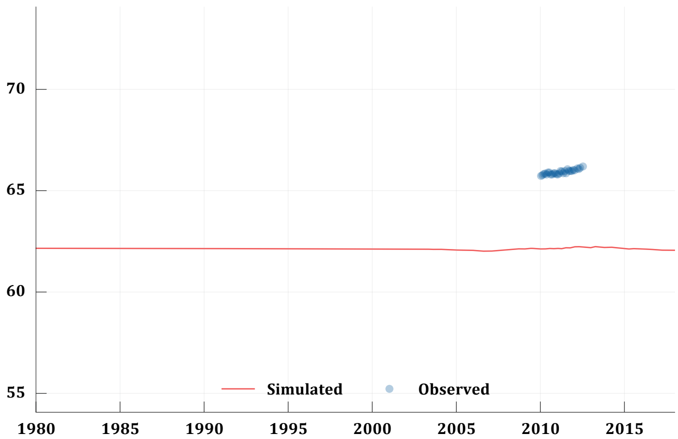


Year

JK107

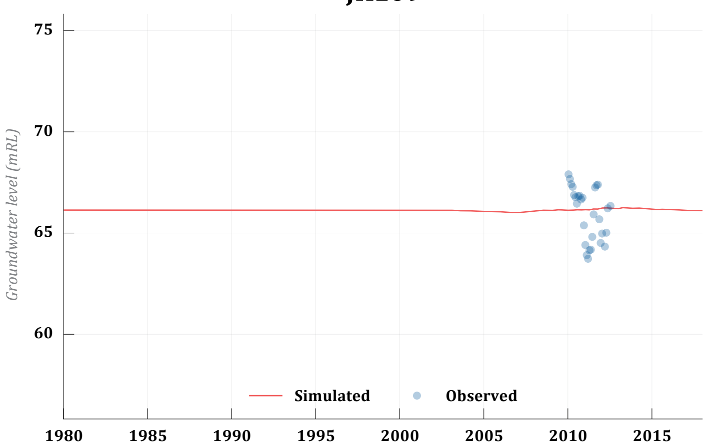


JK108

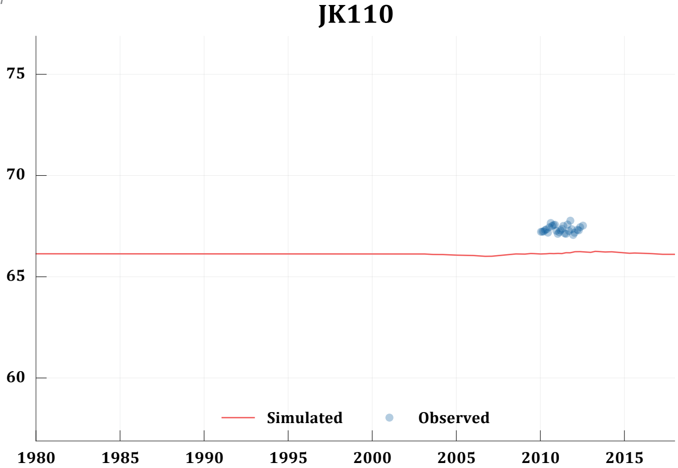


Year

JK109

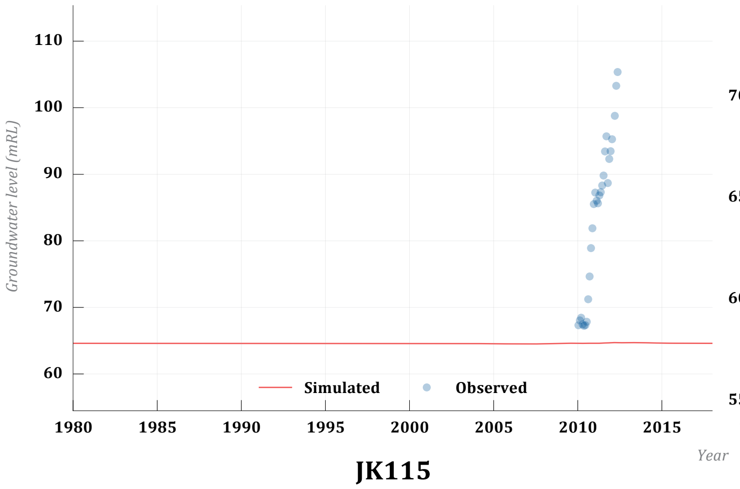


JK110

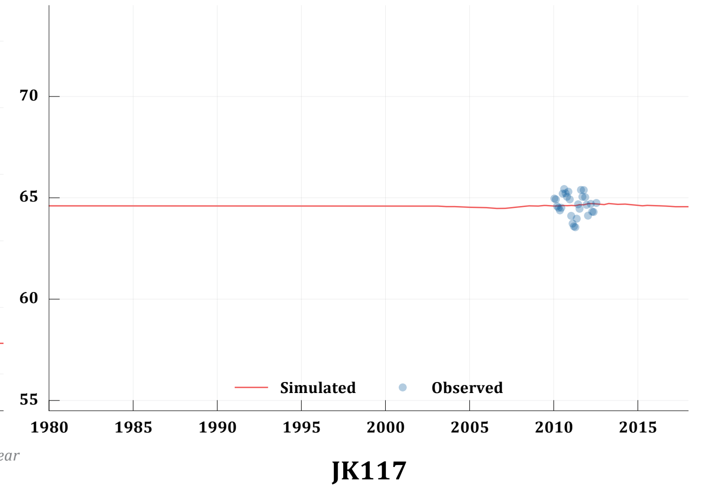


Year

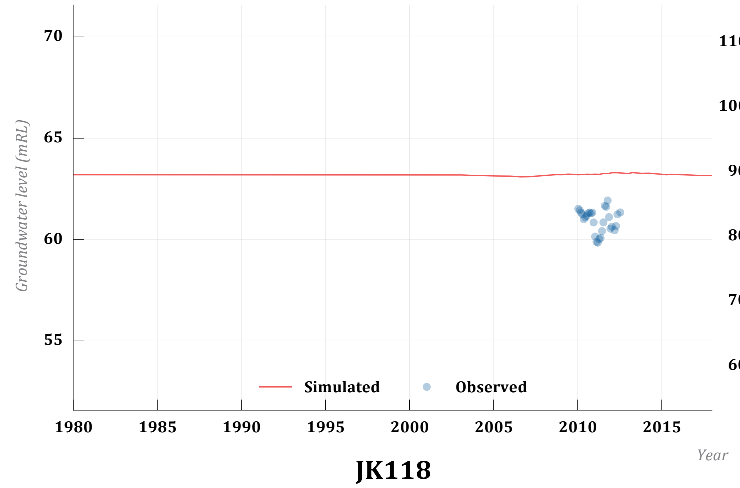
JK112



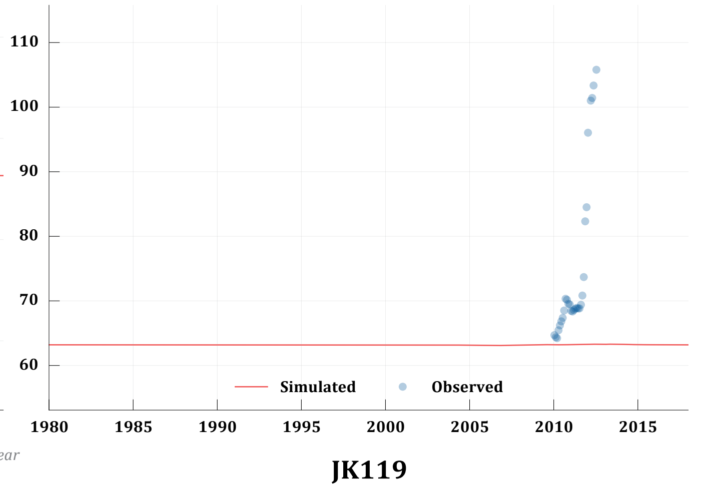
JK113



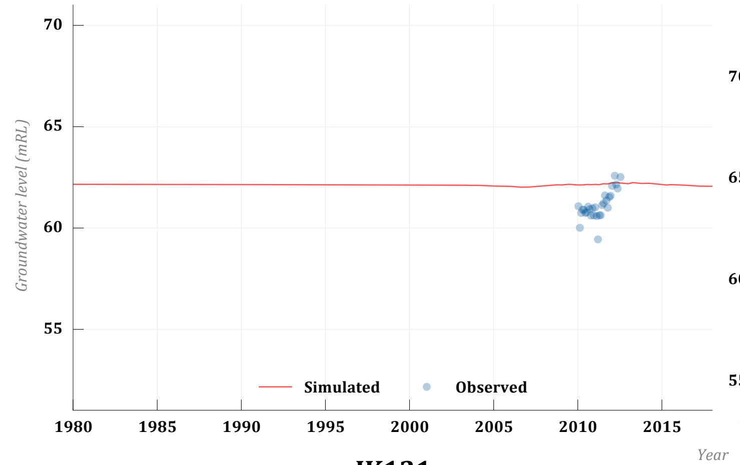
JK115



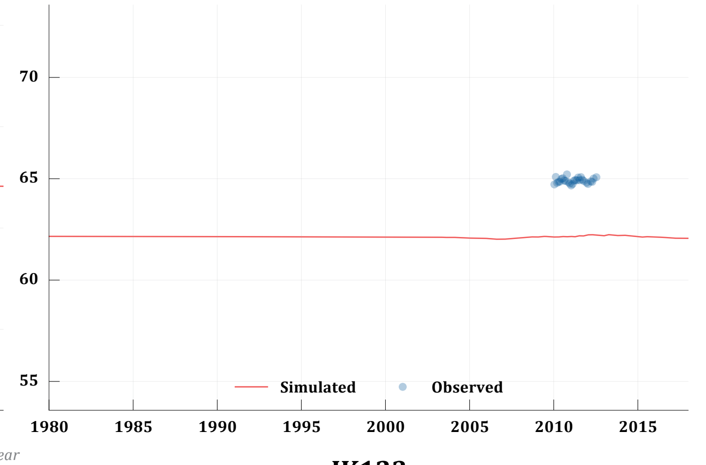
JK117



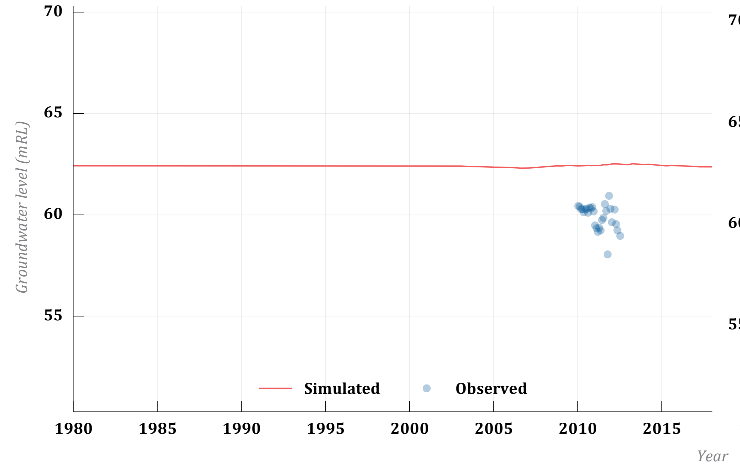
JK118



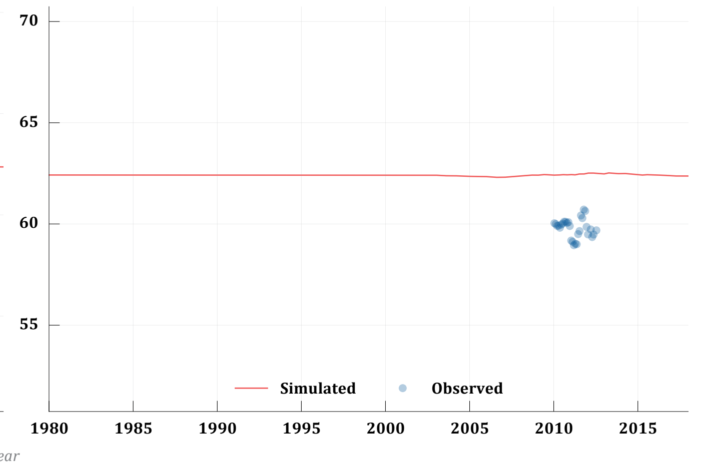
JK119

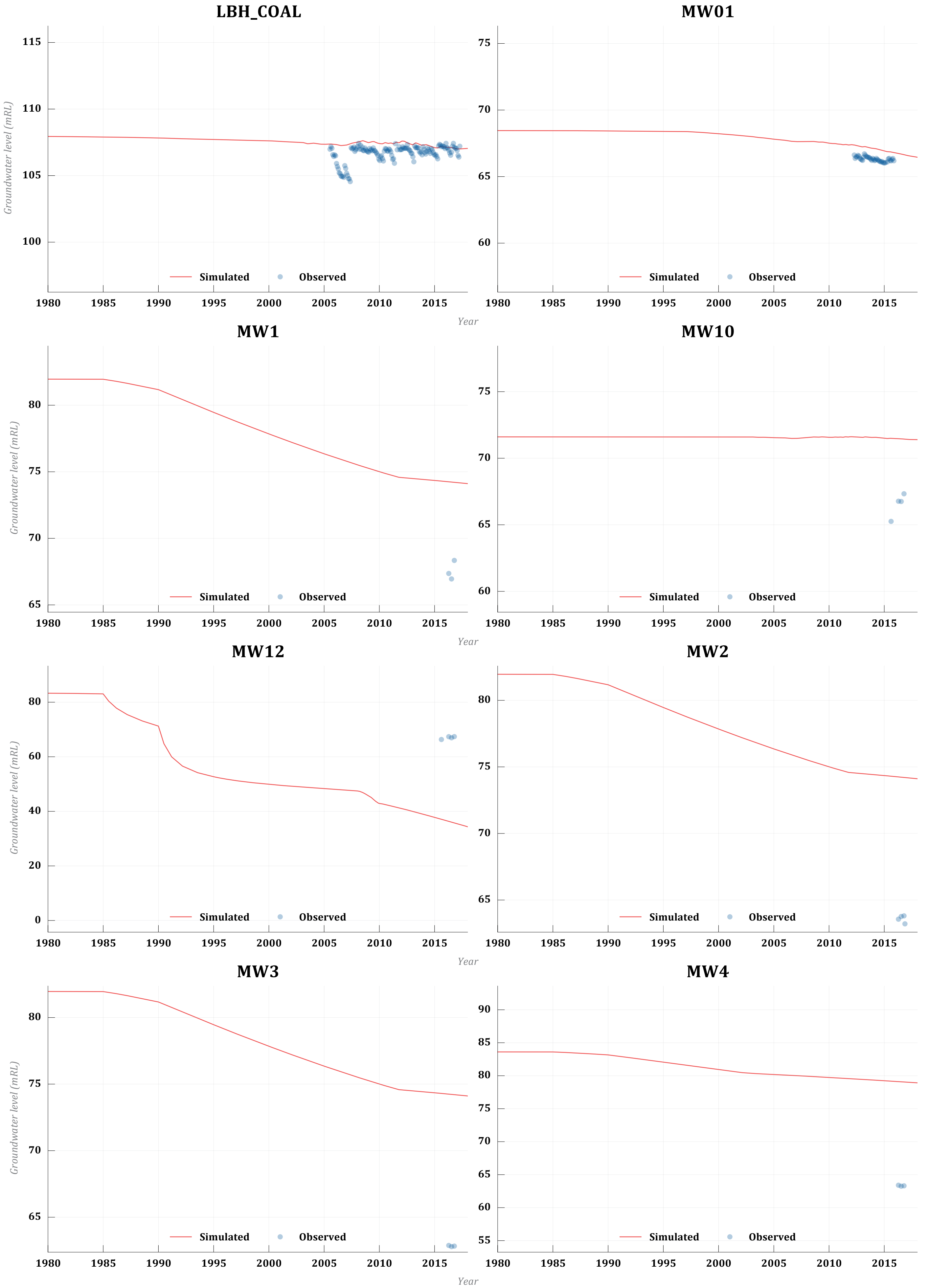


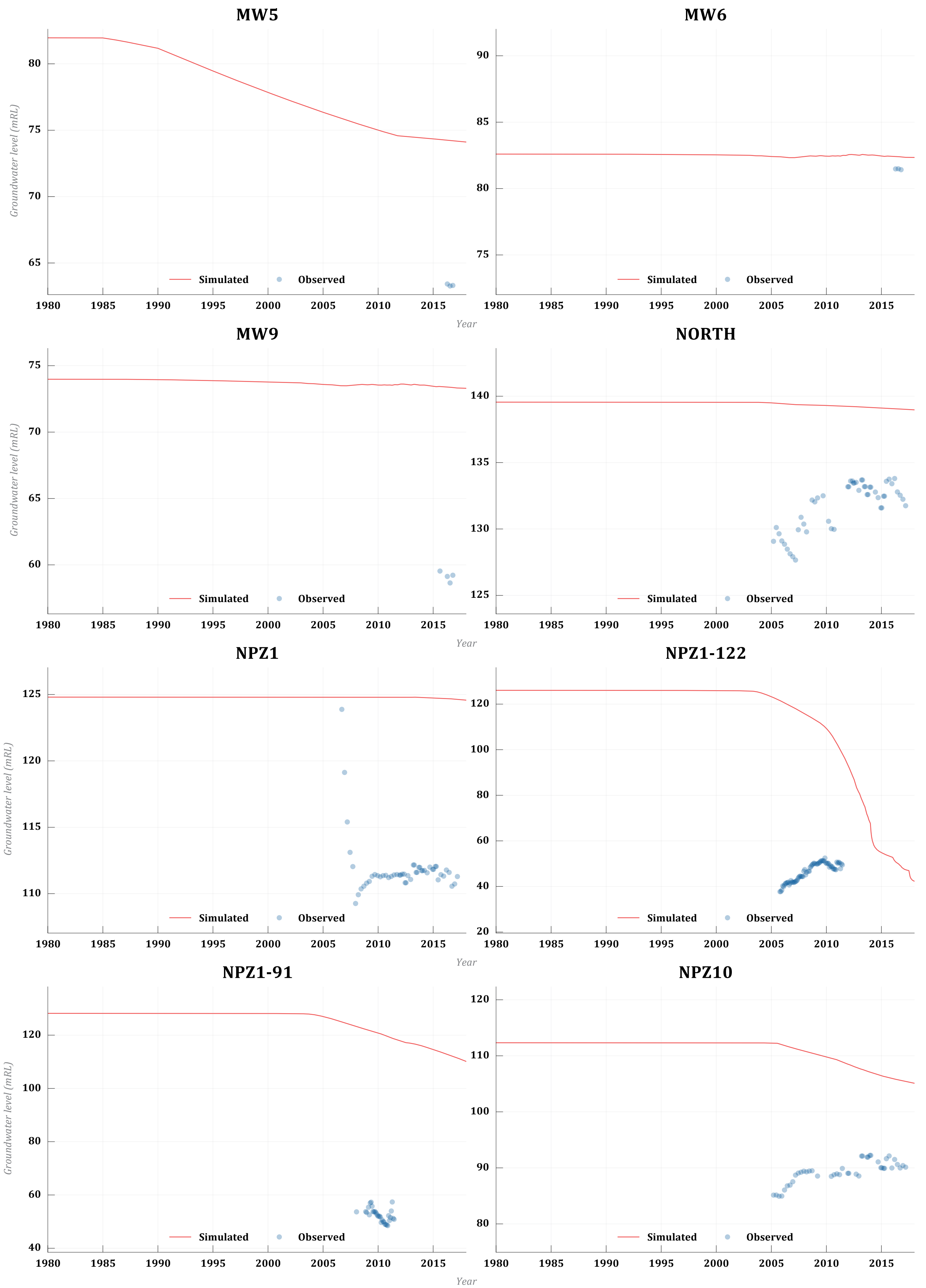
JK121



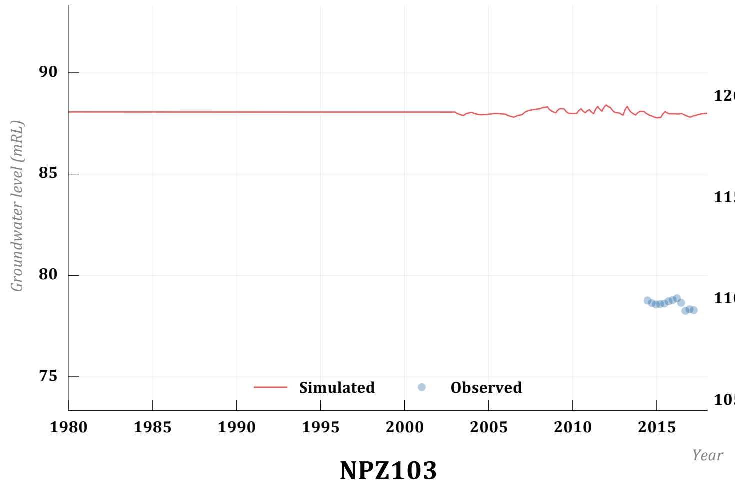
JK123



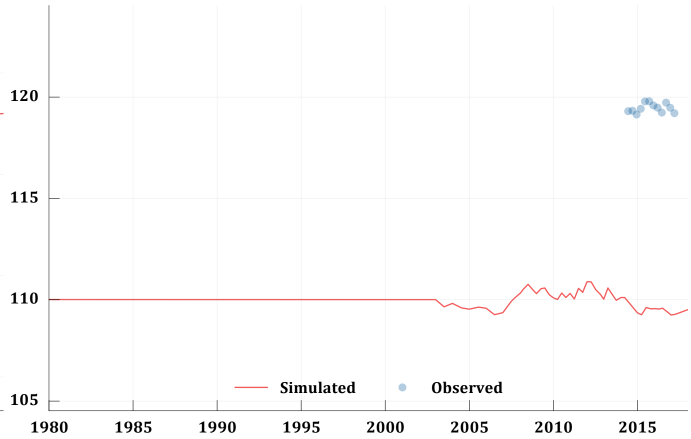

LBH_COAL
MW01
MW1
MW10
MW12
MW2
MW3
MW4
Groundwater level (mRL)
Year
Simulated
Observed
115
110
105
100
75
70
65
60
80
40
20
0
90
85
55
1980
1985
1990
1995
2000
2005
2010
2015


MW5
MW6
MW9
NORTH
NPZ1
NPZ1-122
NPZ1-91
NPZ10
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

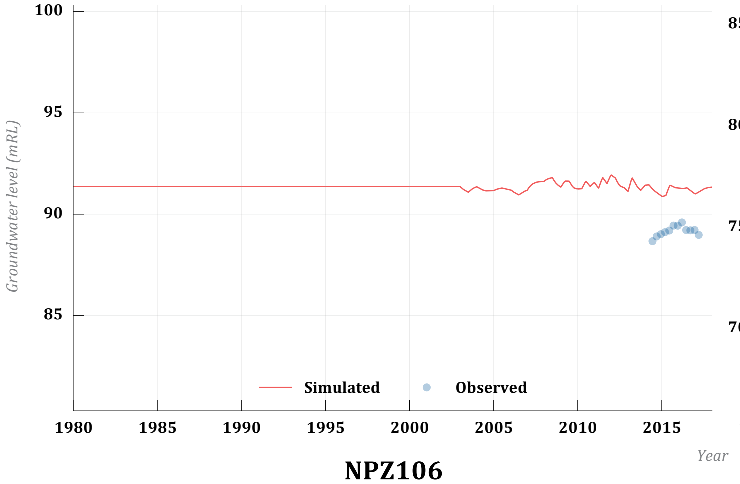
NPZ101



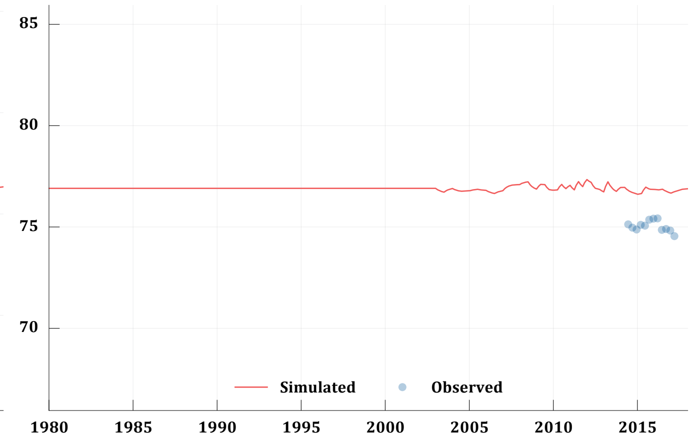
NPZ102



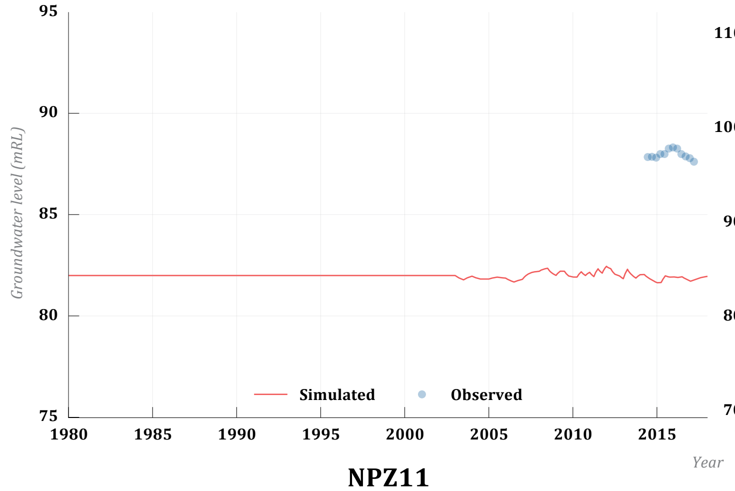
NPZ103



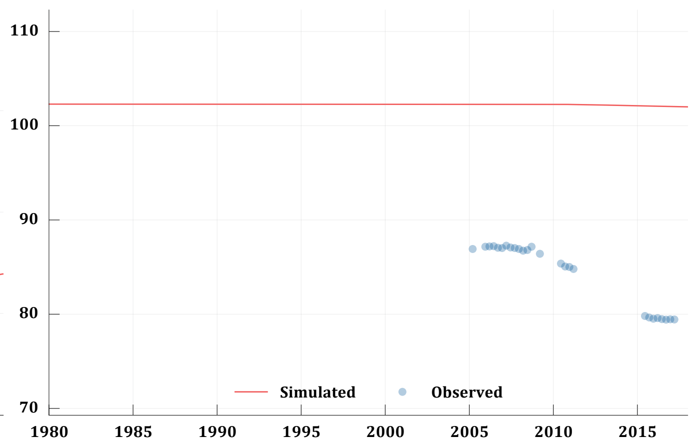
NPZ104



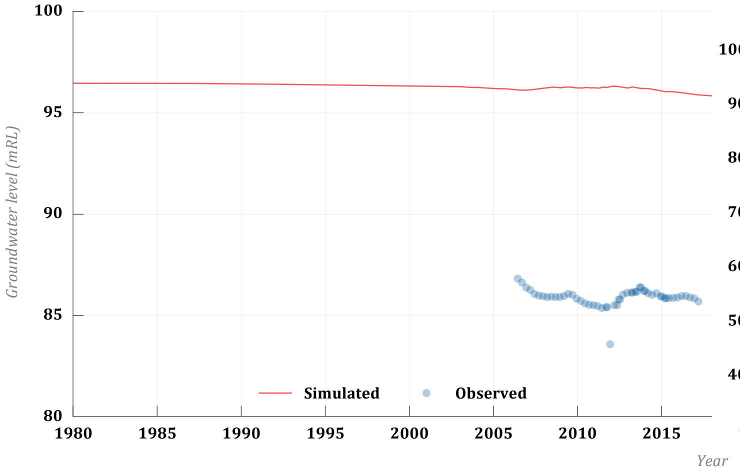
NPZ106



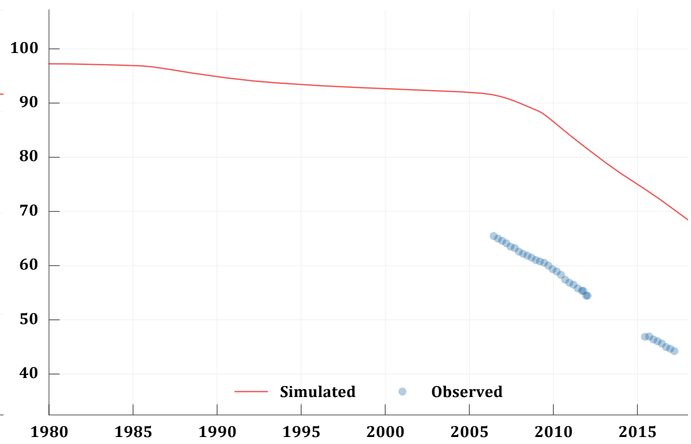
NPZ10A



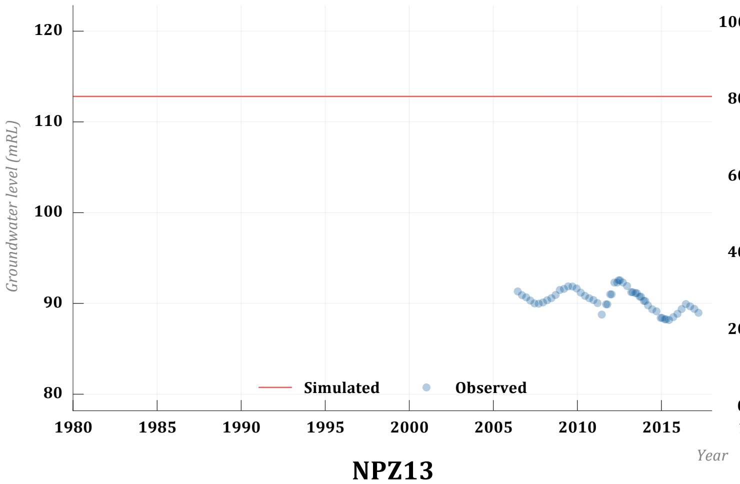
NPZ11



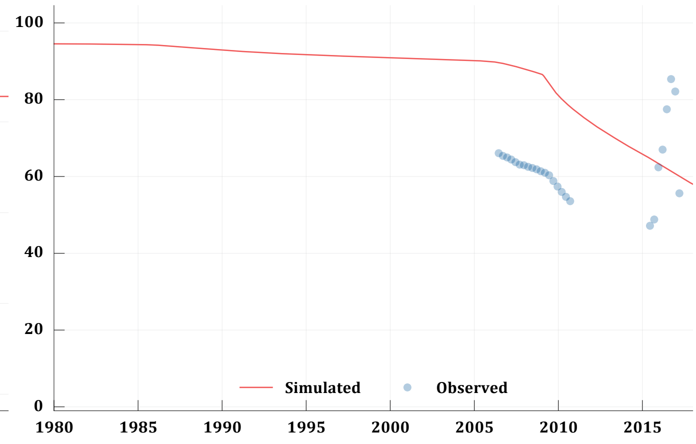
NPZ11A



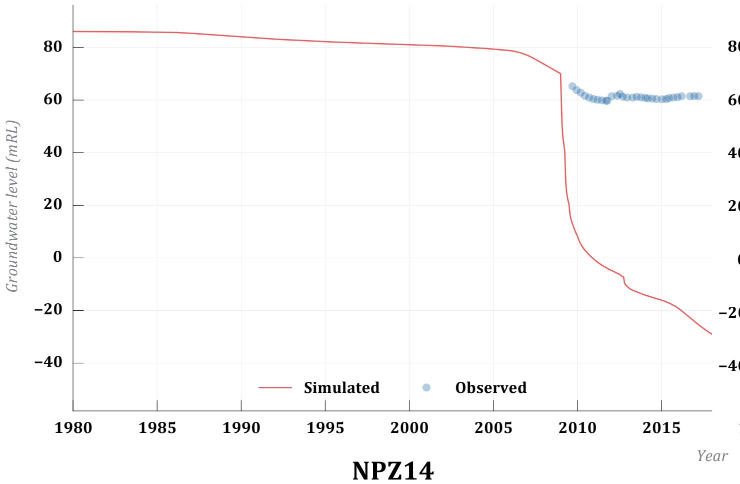
NPZ12



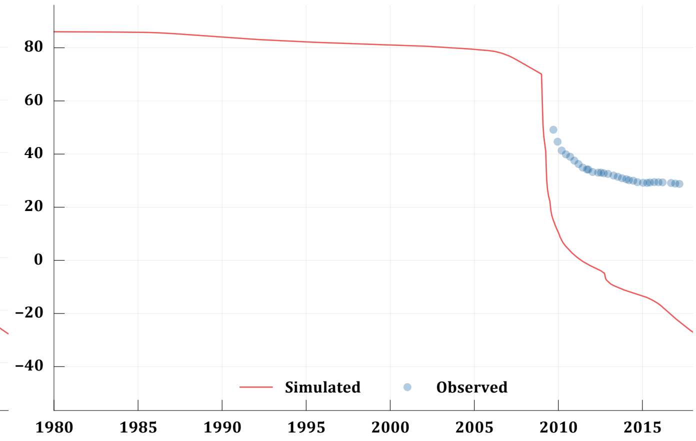
NPZ12A



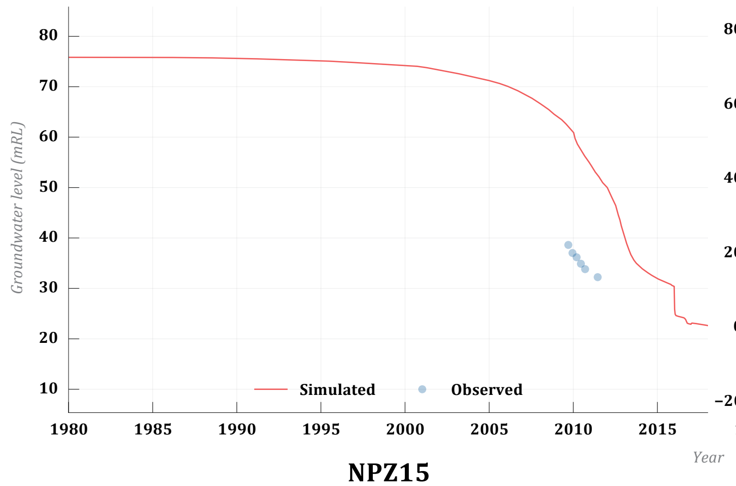
NPZ13



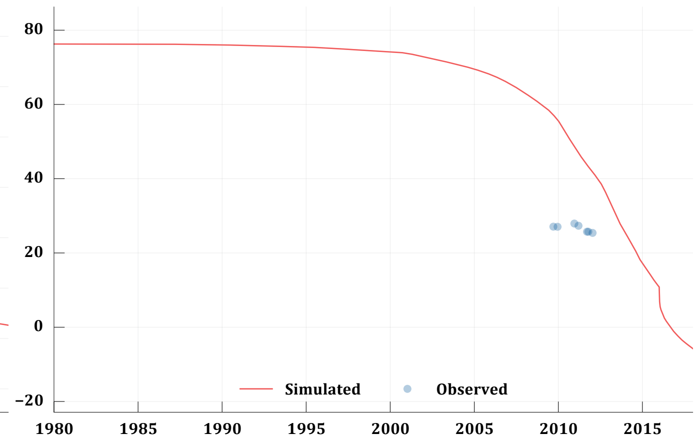
NPZ13A



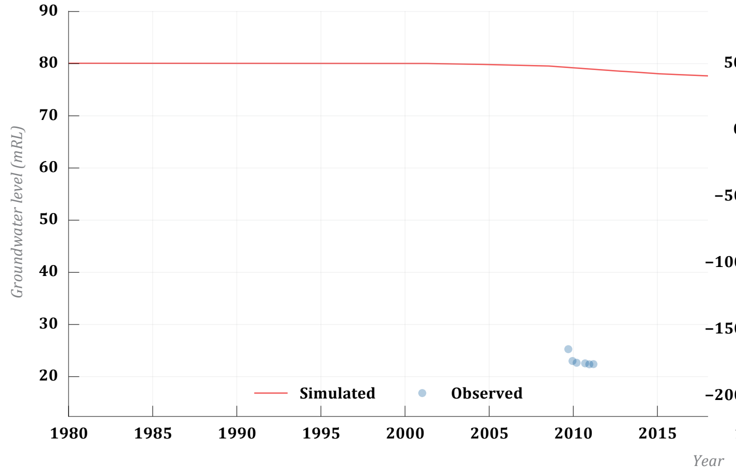
NPZ14



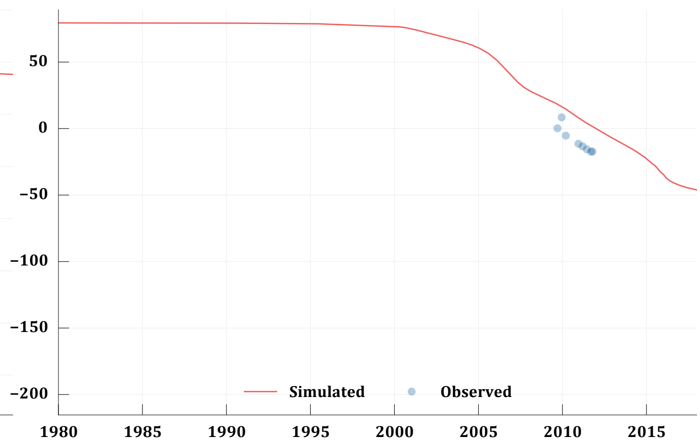
NPZ14A

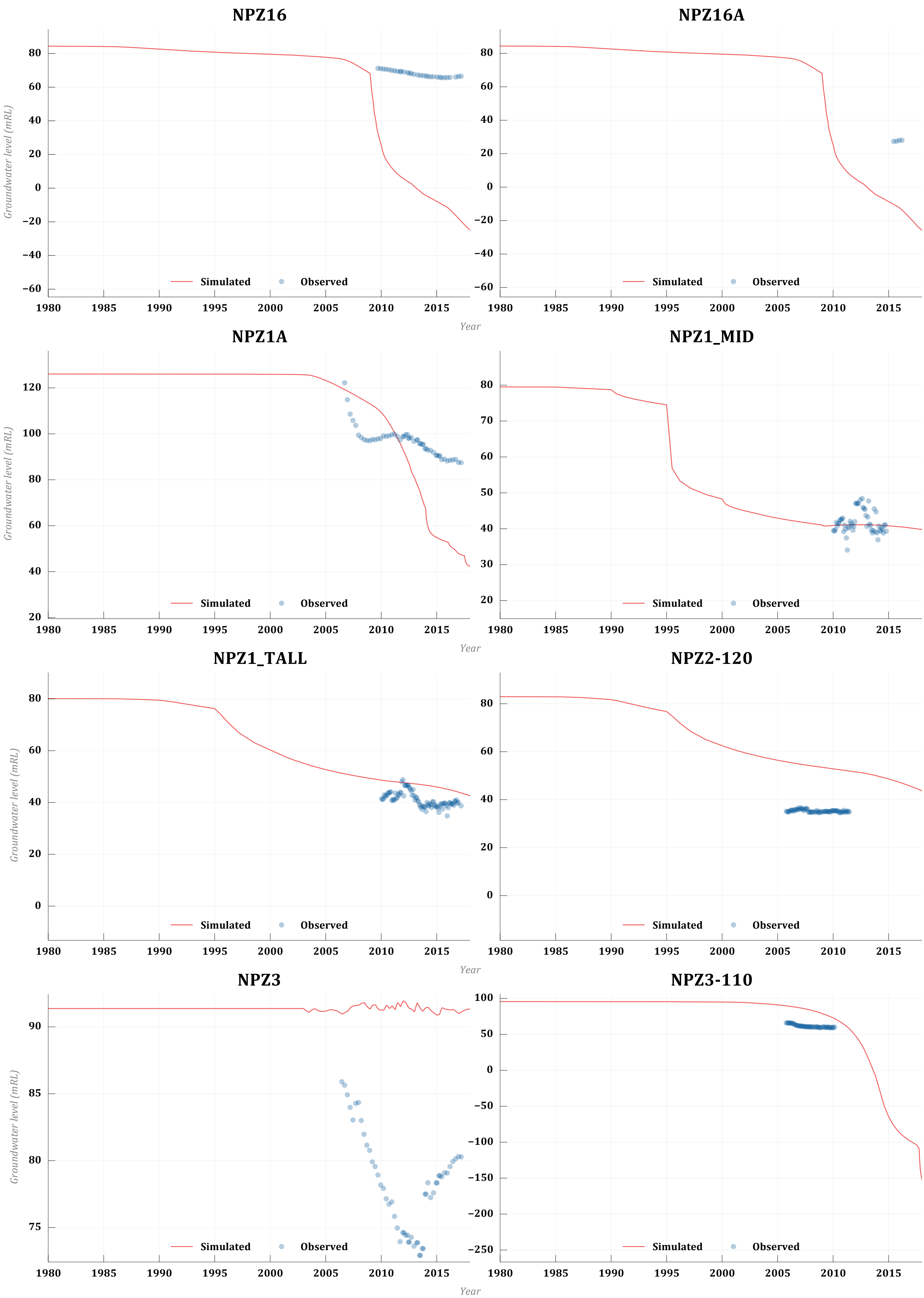


NPZ15

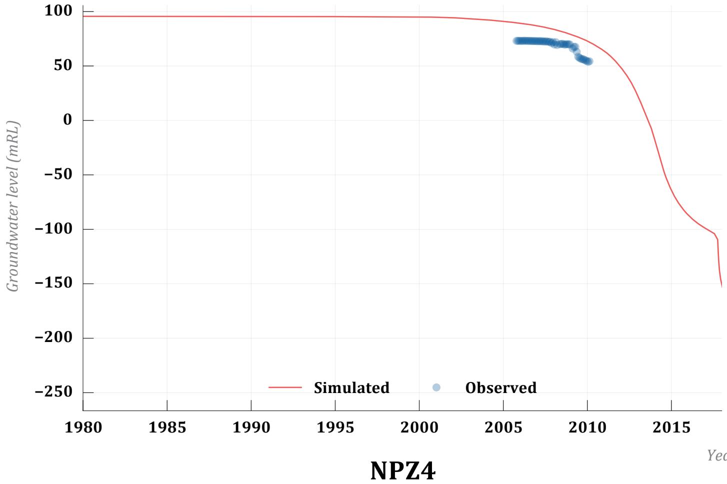


NPZ15A

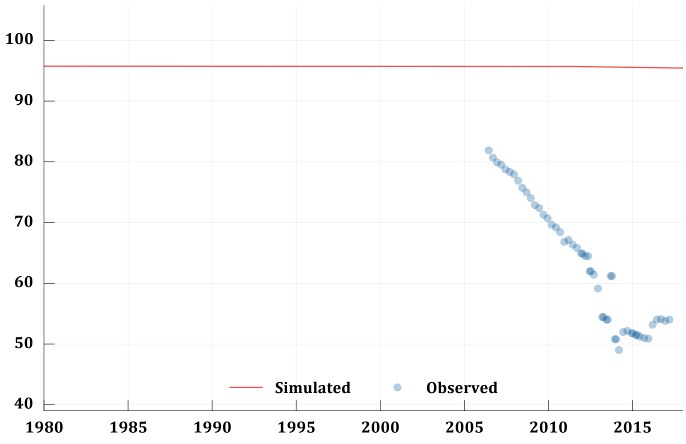



NPZ16
NPZ16A
NPZ1A
NPZ1_MID
NPZ1_TALL
NPZ2-120
NPZ3
NPZ3-110
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

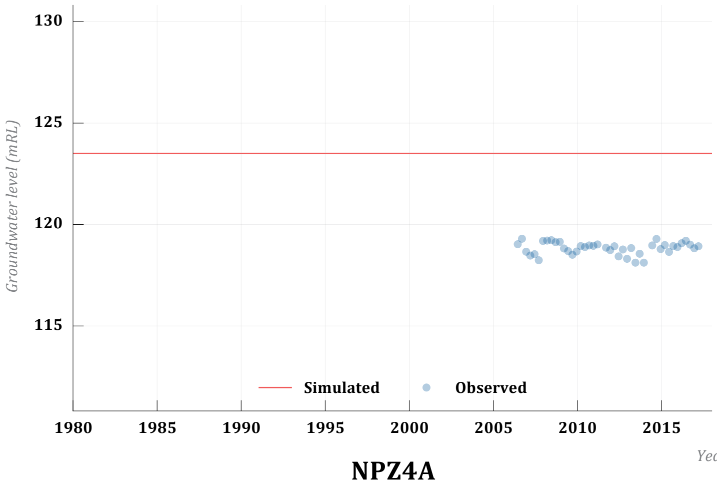
NPZ3-64



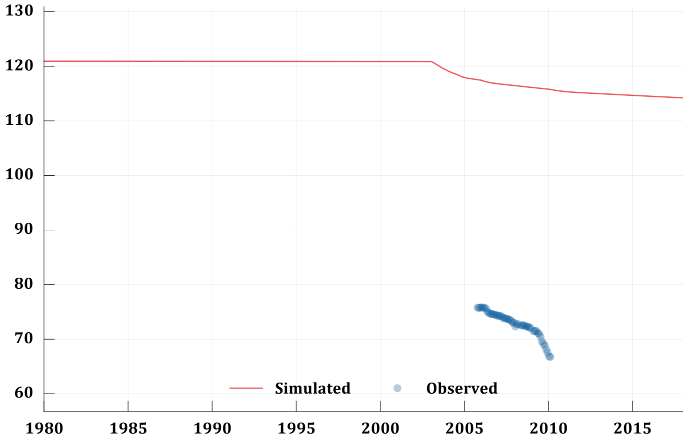
NPZ3A



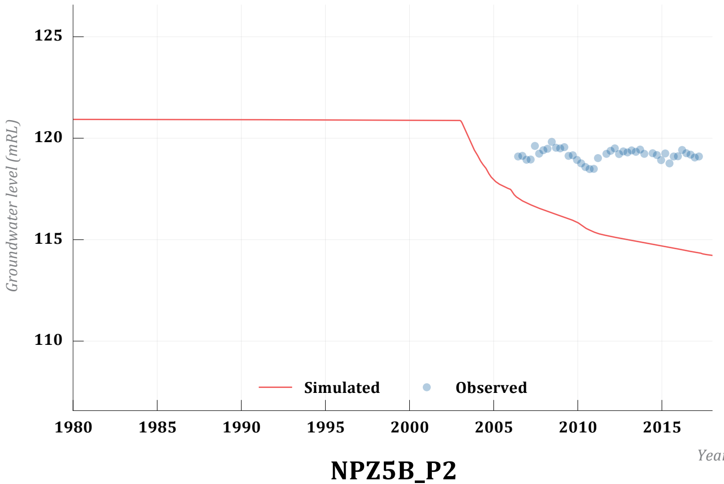
NPZ4



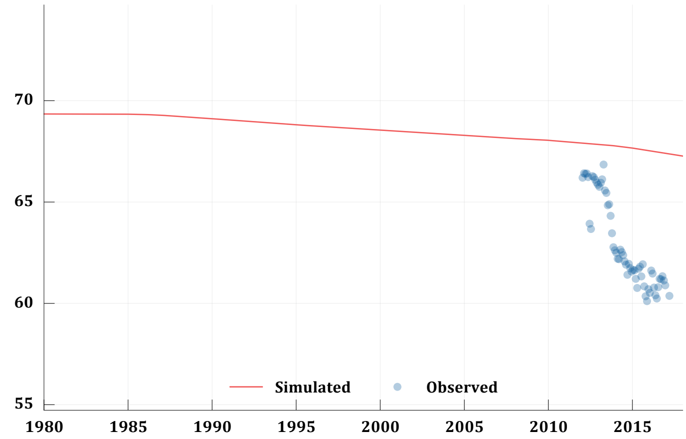
NPZ4-90



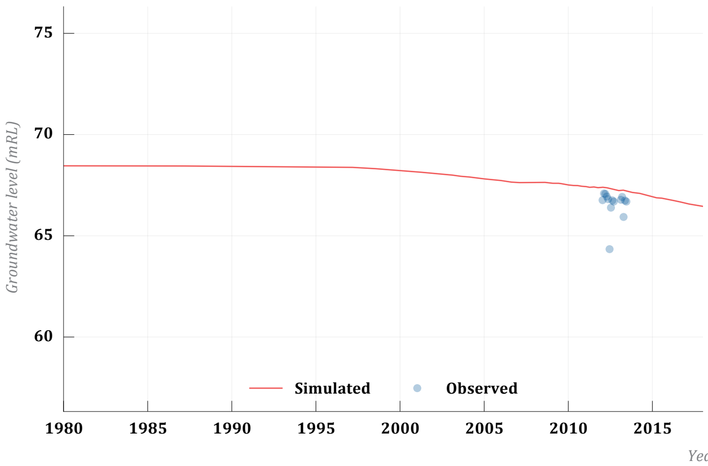
NPZ4A



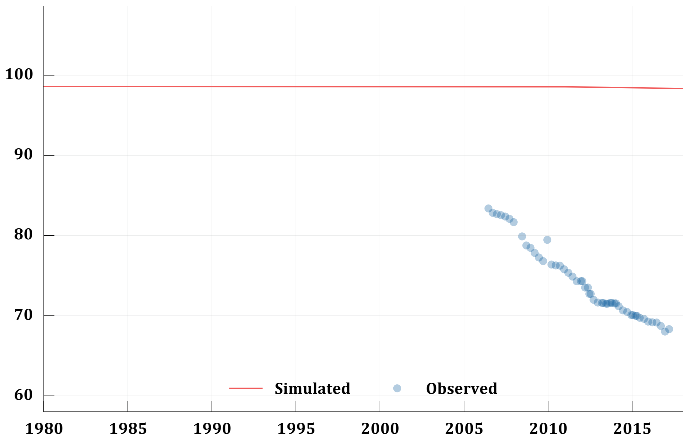
NPZ5B_P1

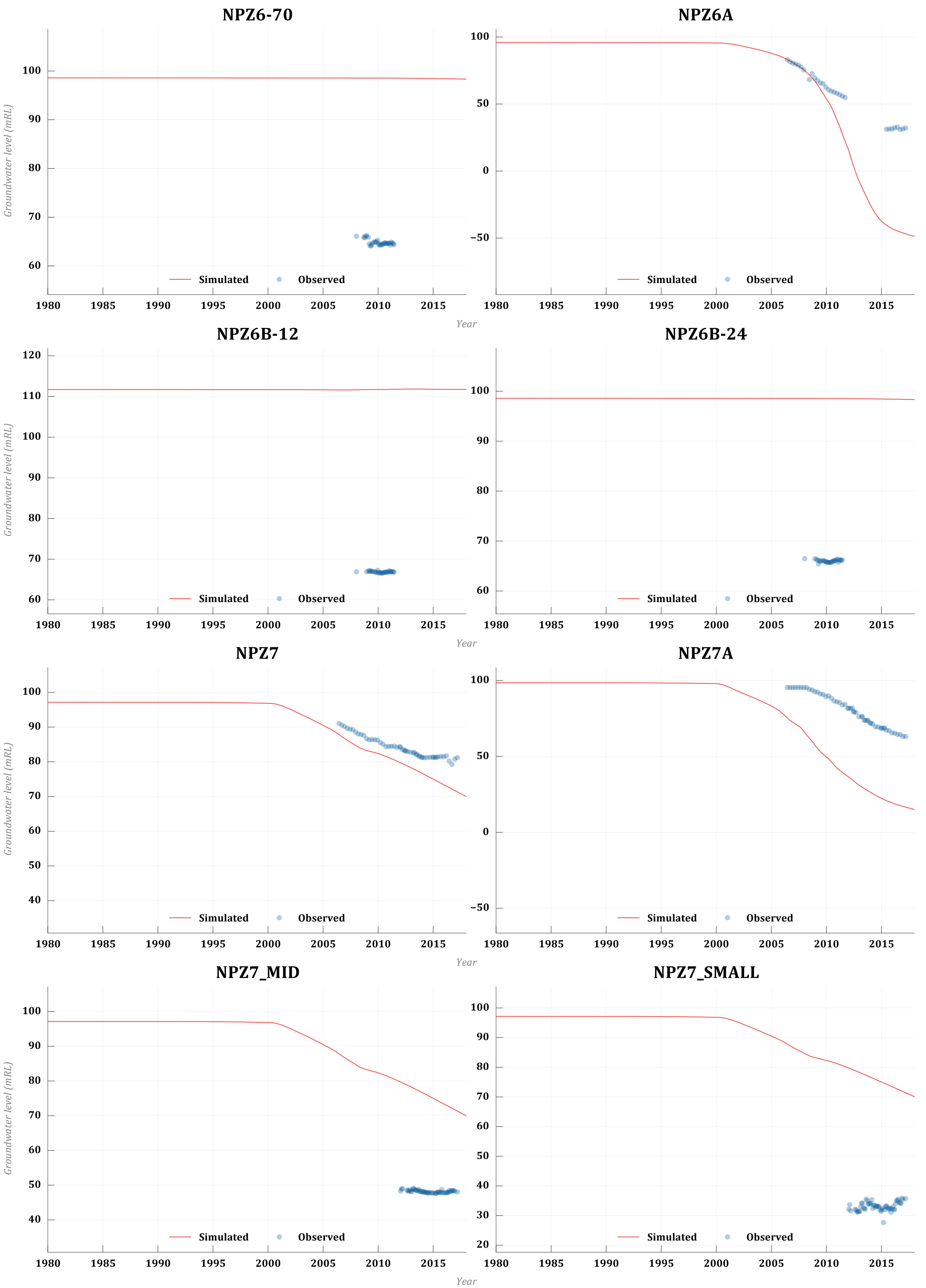


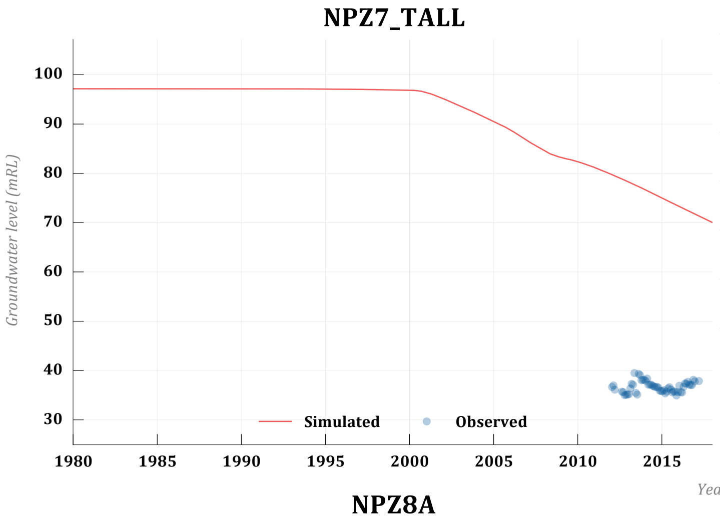
NPZ5B_P2

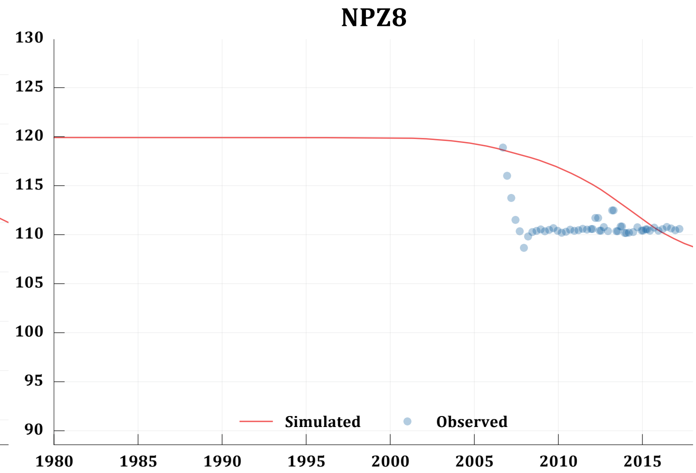


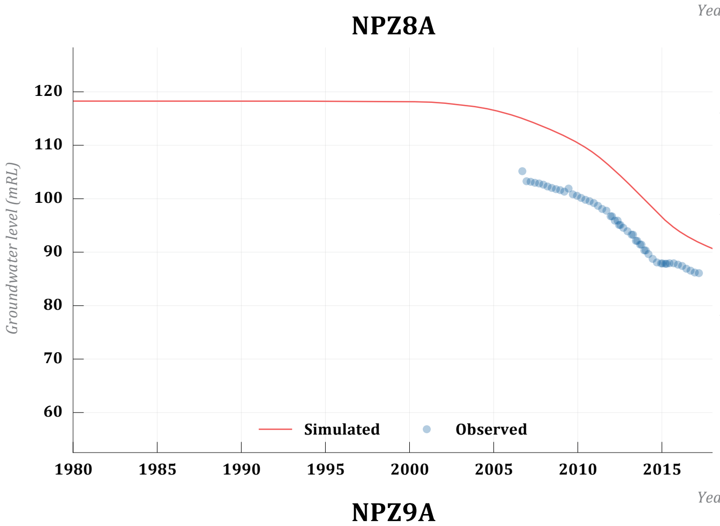
NPZ6

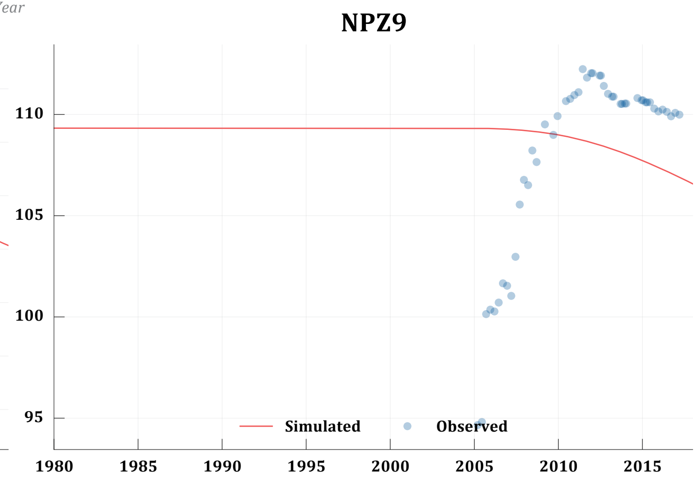


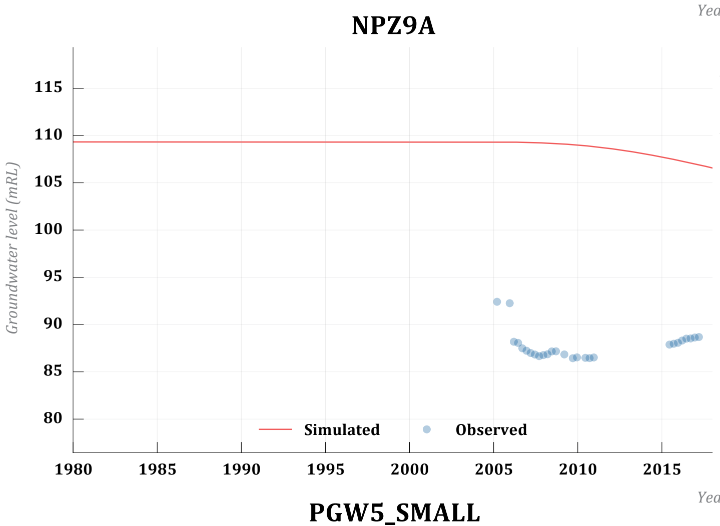

NPZ6-70
NPZ6A
NPZ6B-12
NPZ6B-24
NPZ7
NPZ7A
NPZ7_MID
NPZ7_SMALL
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

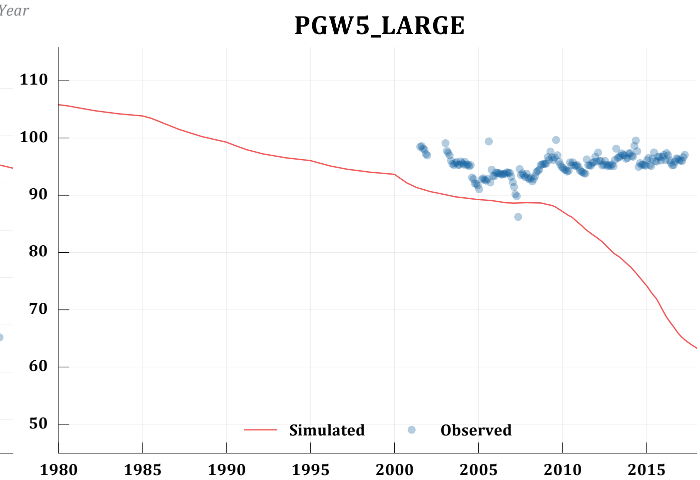

NPZ7_TALL
Groundwater level (mRL)
100
90
80
70
60
50
40
30
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015
Year

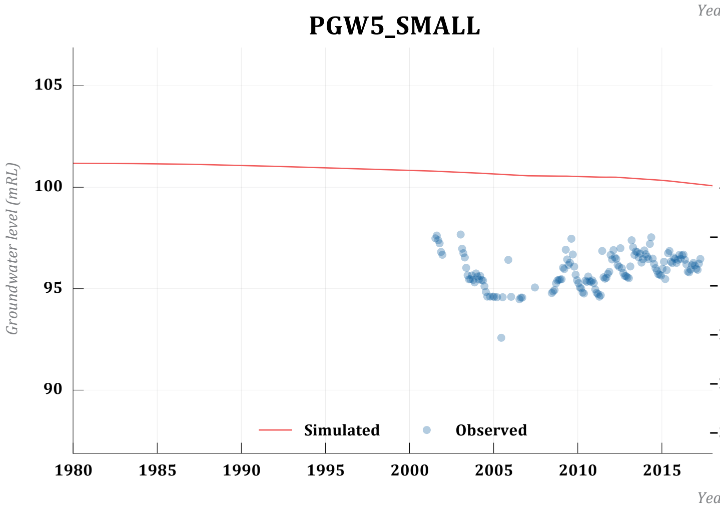

NPZ8
130
125
120
115
110
105
100
95
90
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

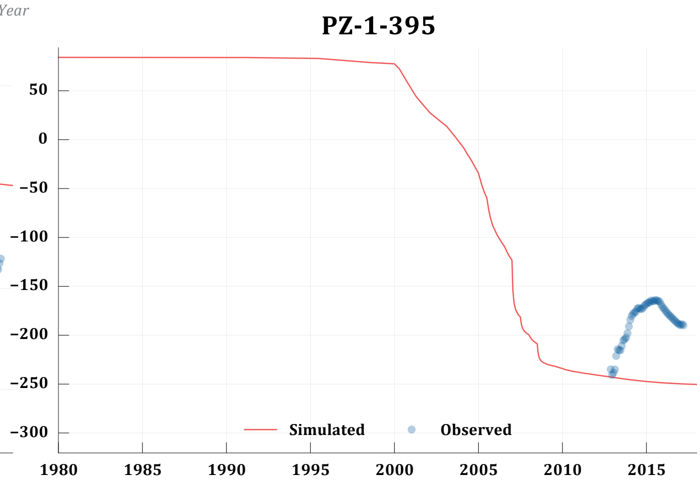

NPZ8A
Groundwater level (mRL)
120
110
100
90
80
70
60
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015
Year

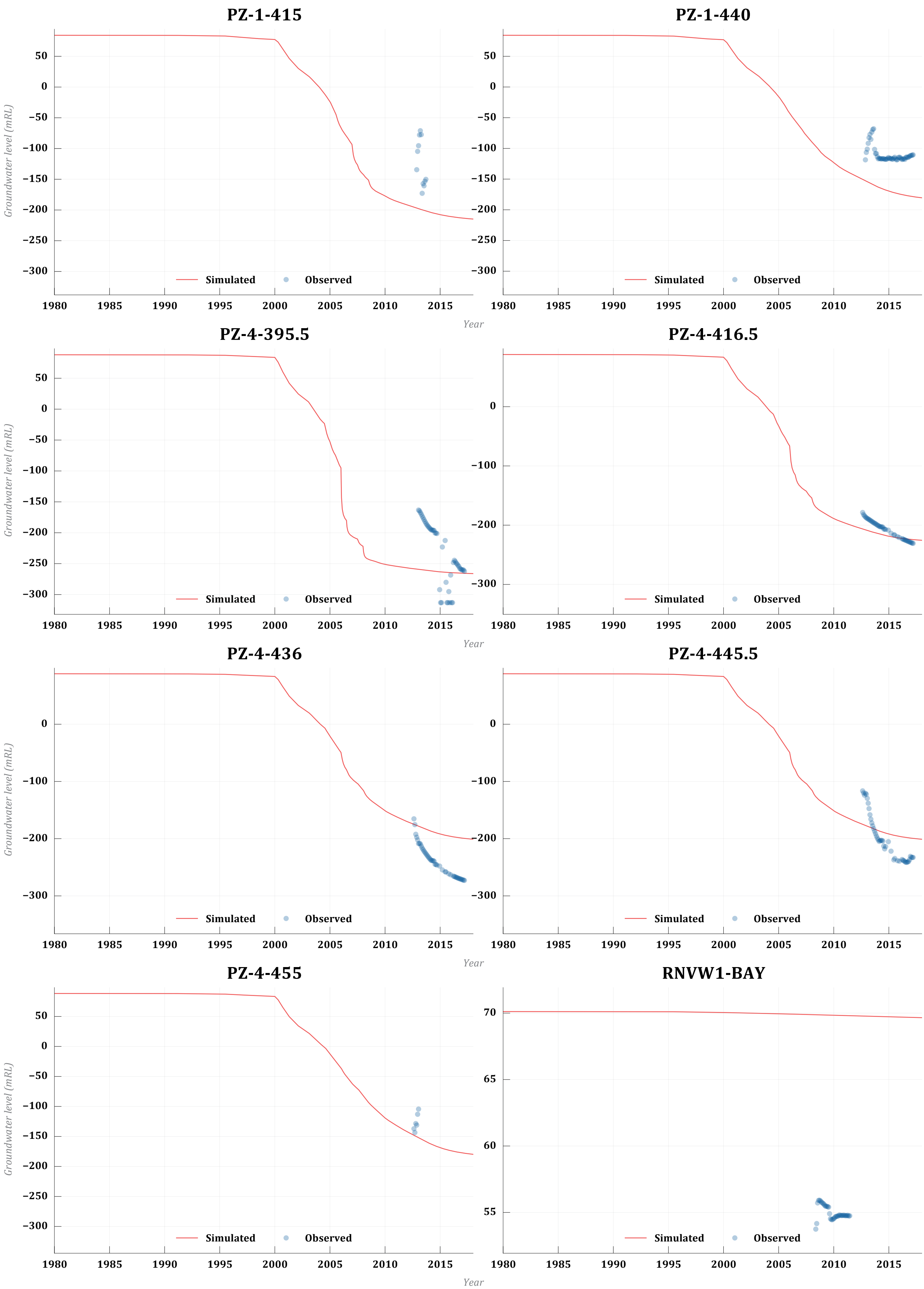

NPZ9
110
105
100
95
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

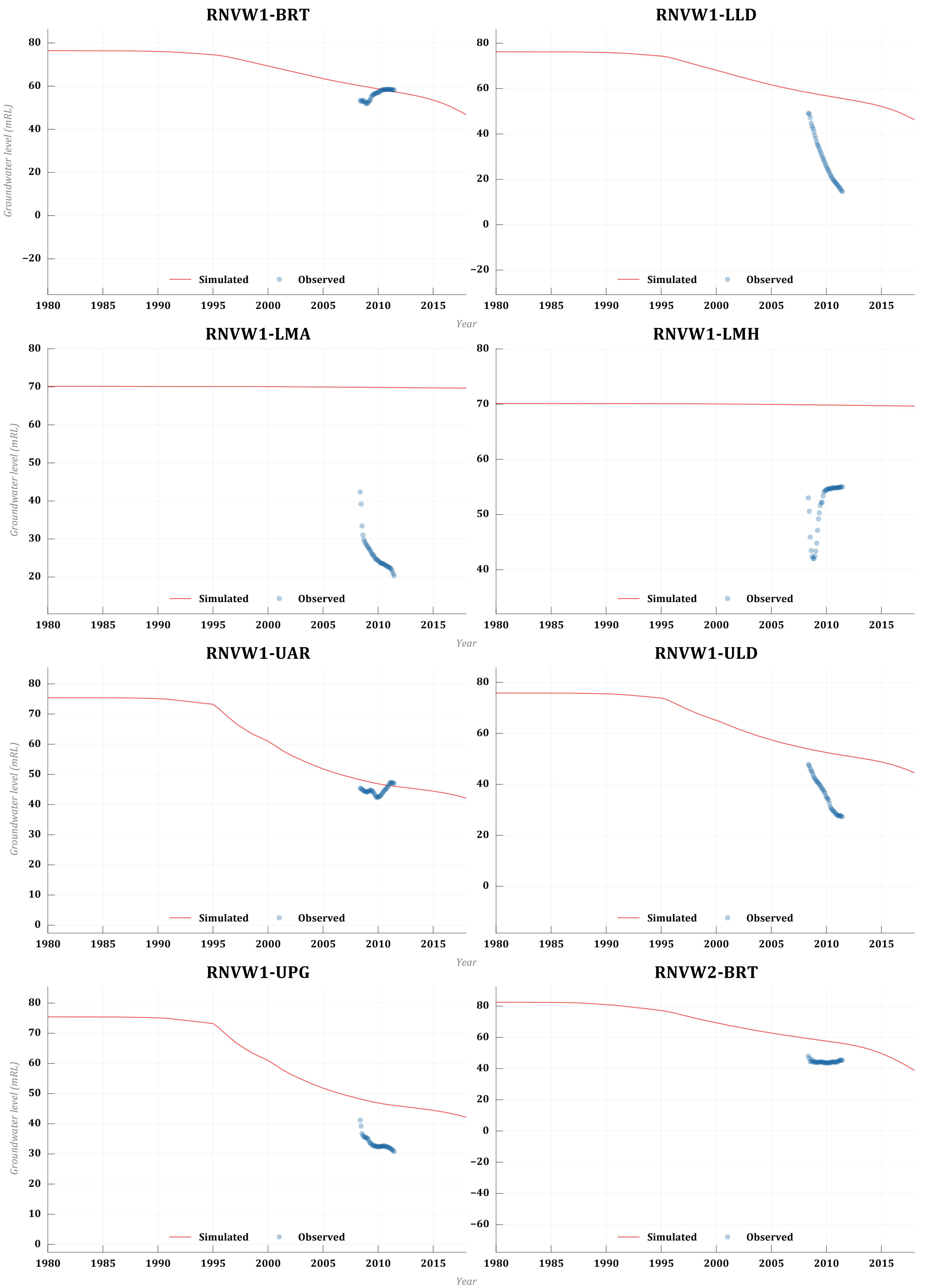

NPZ9A
Groundwater level (mRL)
115
110
105
100
95
90
85
80
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015
Year

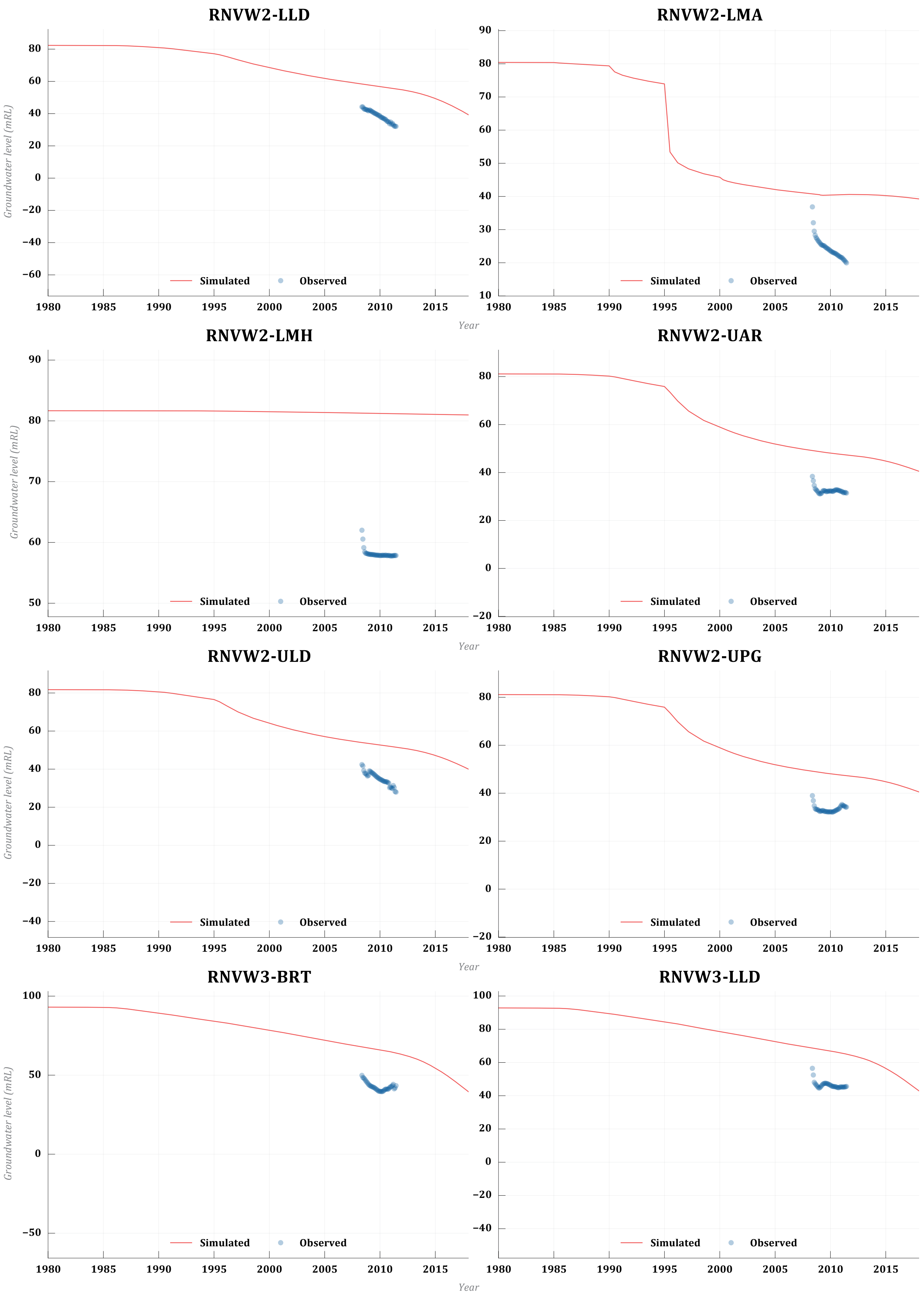

PGW5_LARGE
110
100
90
80
70
60
50
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

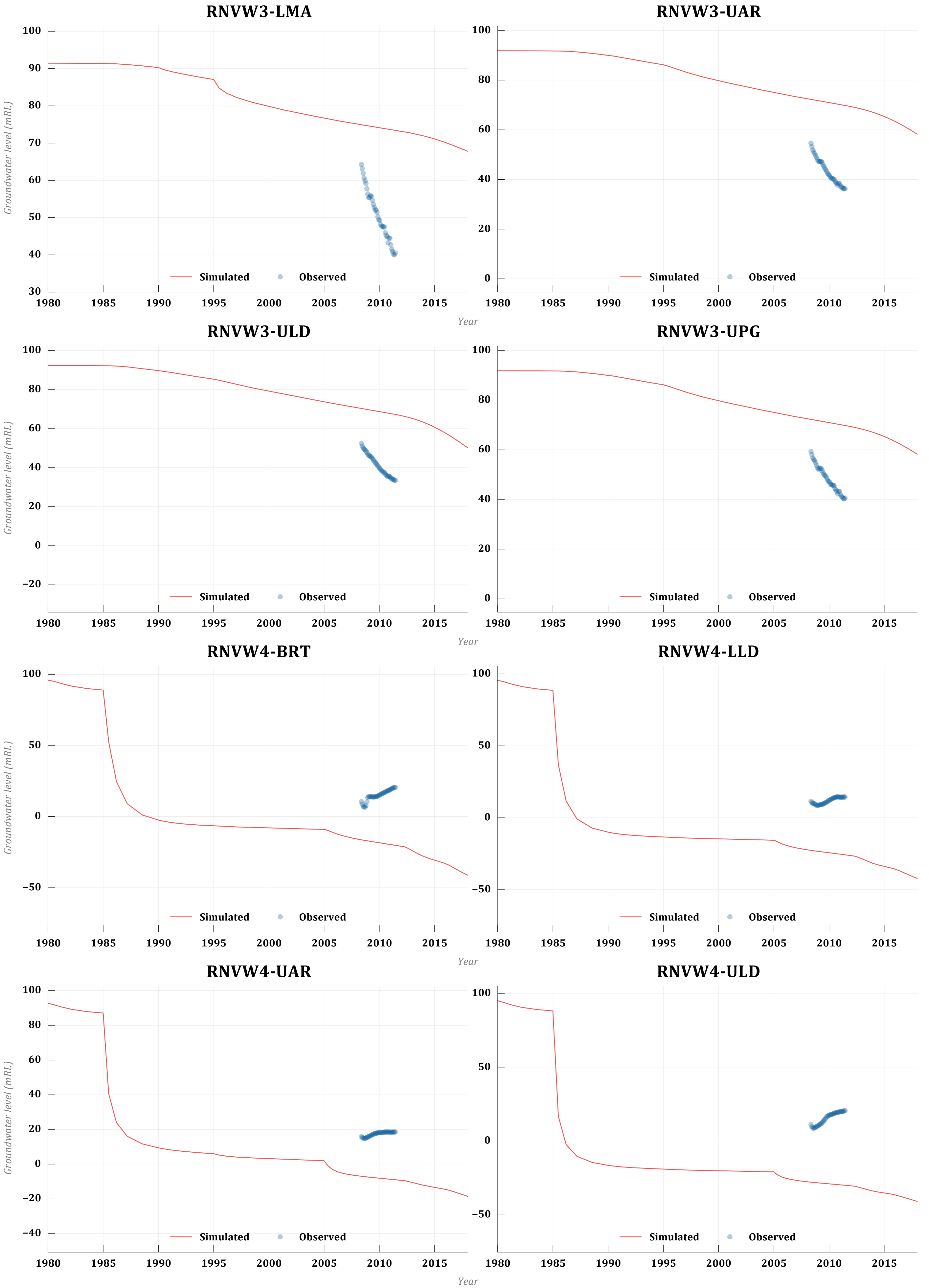

PGW5_SMALL
Groundwater level (mRL)
105
100
95
90
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015
Year

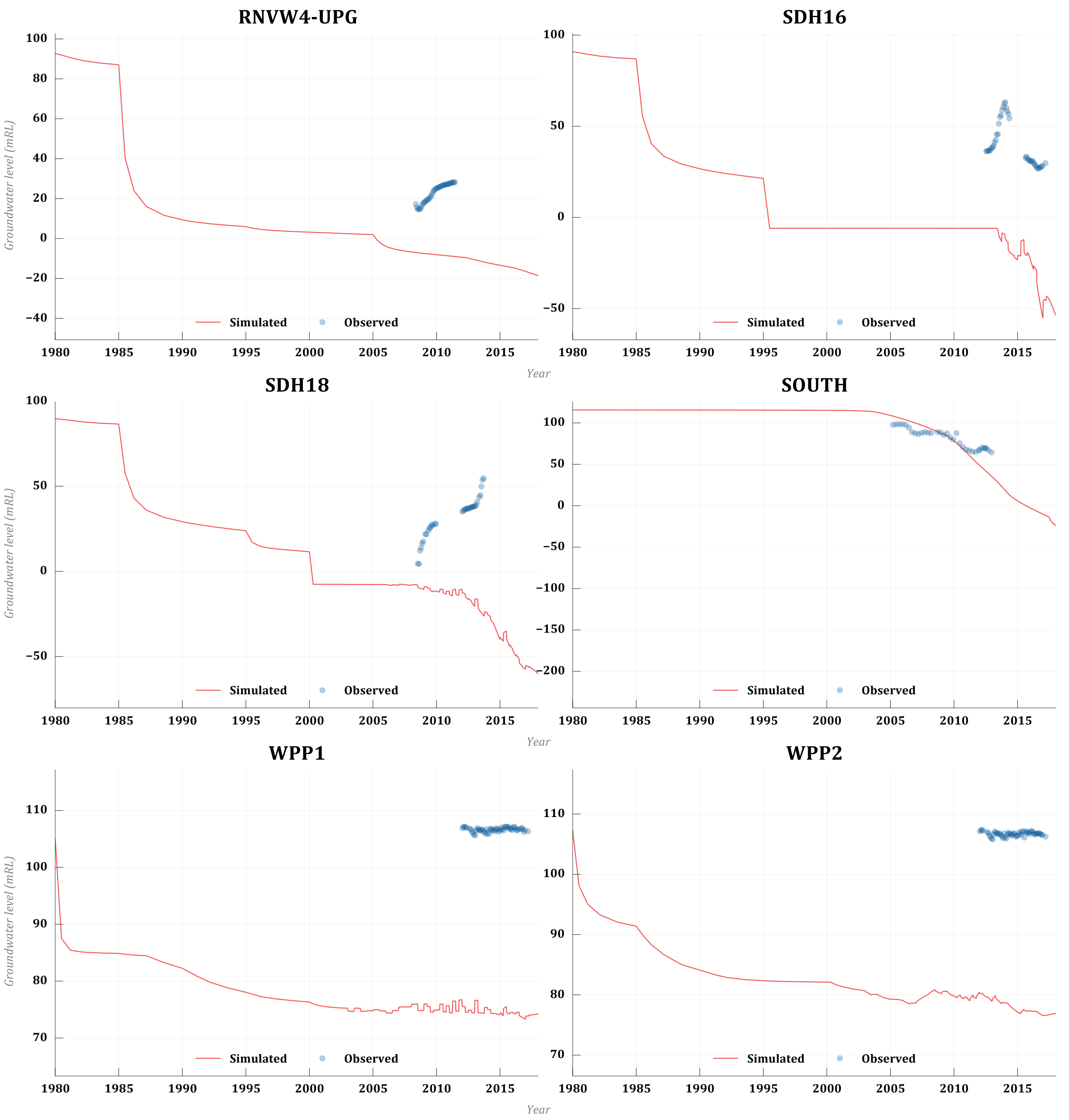

PZ-1-395
50
0
−50
−100
−150
−200
−250
−300
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015


PZ-1-415
PZ-1-440
PZ-4-395.5
PZ-4-416.5
PZ-4-436
PZ-4-445.5
PZ-4-455
RNVW1-BAY
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015
50
0
−50
−100
−150
−200
−250
−300
70
65
60
55


RNVW1-BRT
RNVW1-LLD
RNVW1-LMA
RNVW1-LMH
RNVW1-UAR
RNVW1-ULD
RNVW1-UPG
RNVW2-BRT
Groundwater level (mRL)
Year
Simulated
Observed
1980 1985 1990 1995 2000 2005 2010 2015

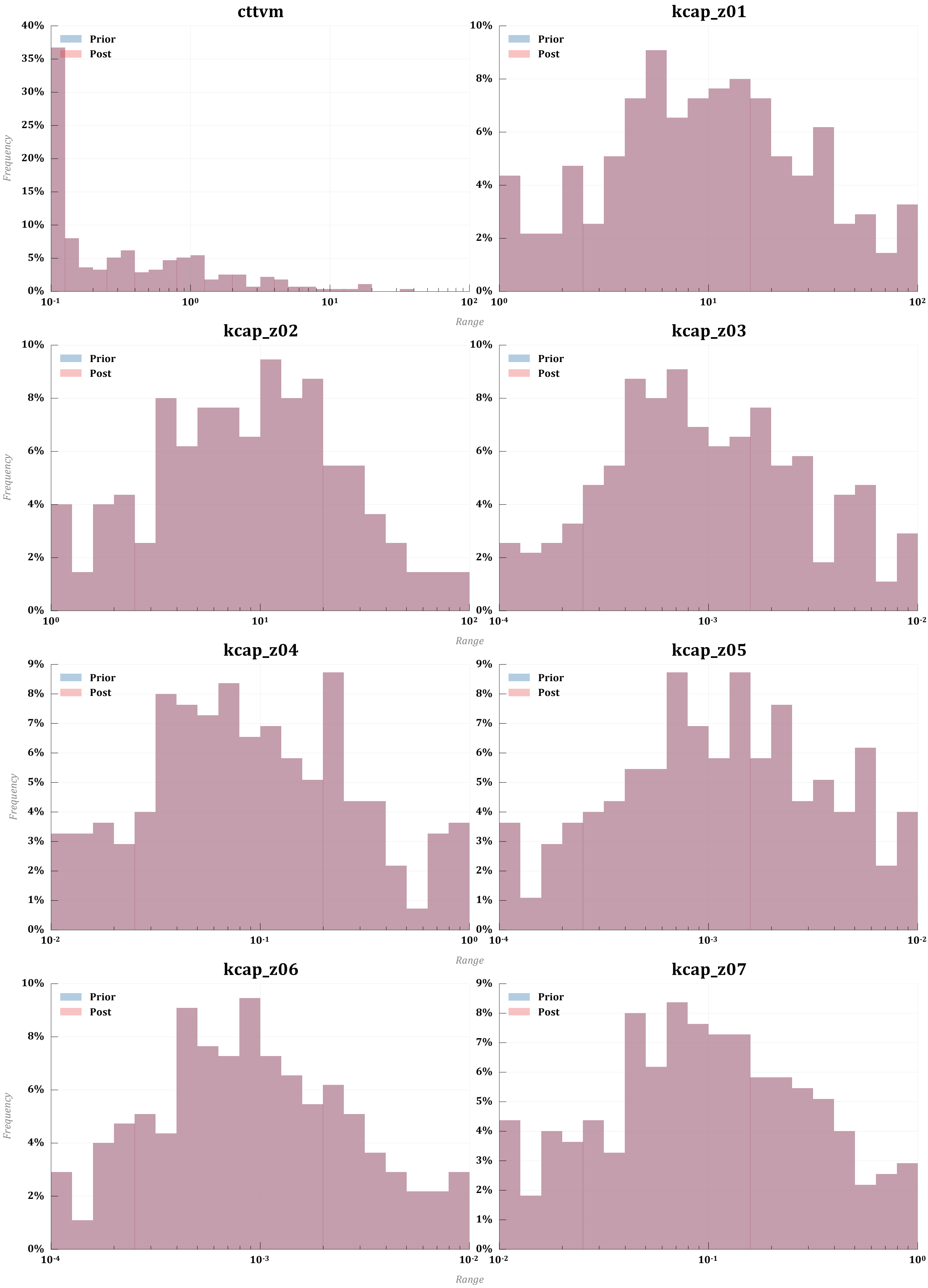

RNVW2-LLD
RNVW2-LMA
RNVW2-LMH
RNVW2-UAR
RNVW2-ULD
RNVW2-UPG
RNVW3-BRT
RNVW3-LLD
Groundwater level (mRL)
Year
Simulated
Observed

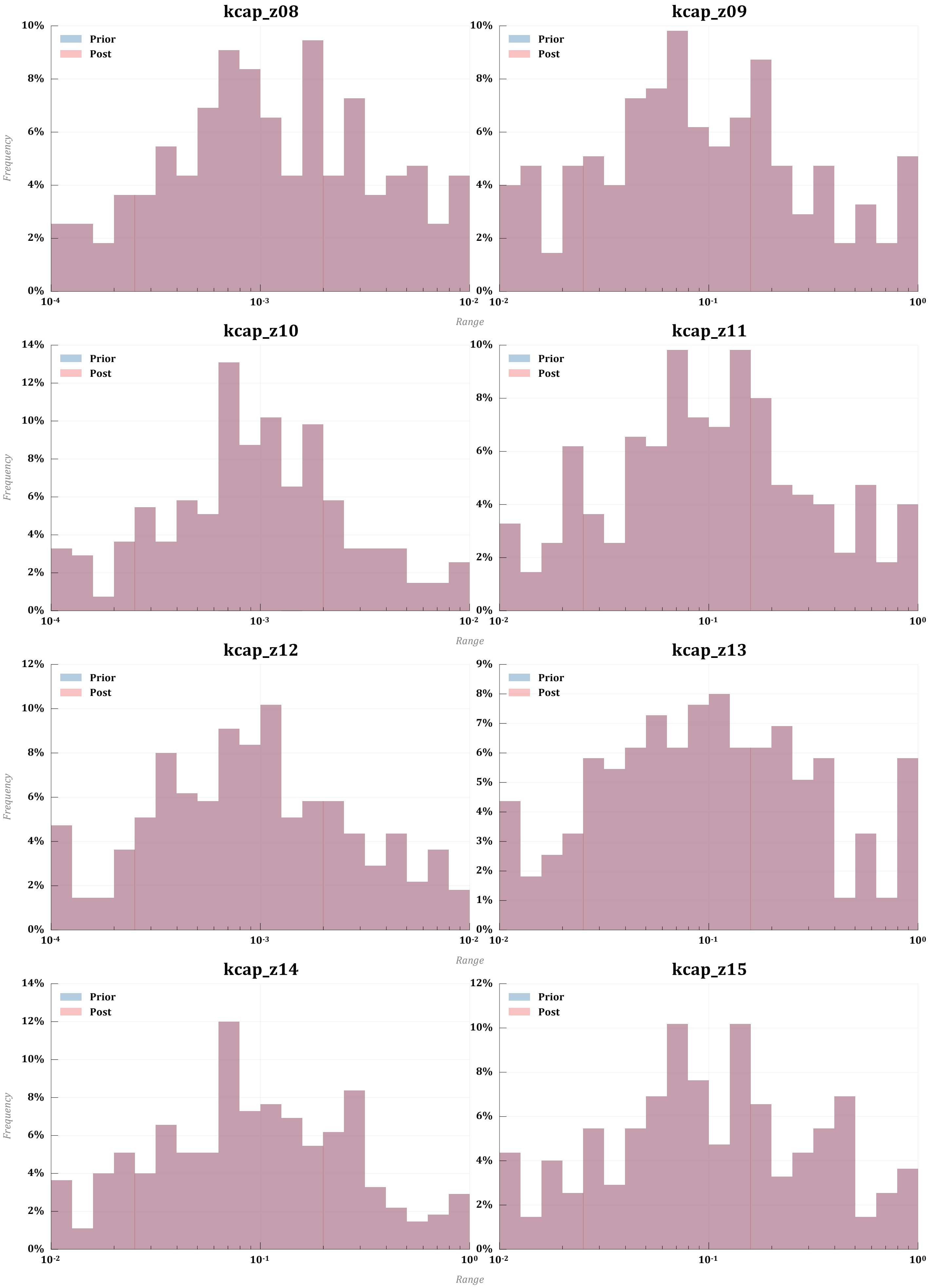

RNVW3-LMA
RNVW3-UAR
RNVW3-ULD
RNVW3-UPG
RNVW4-BRT
RNVW4-LLD
RNVW4-UAR
RNVW4-ULD
Groundwater level (mRL)
Year
Simulated
Observed

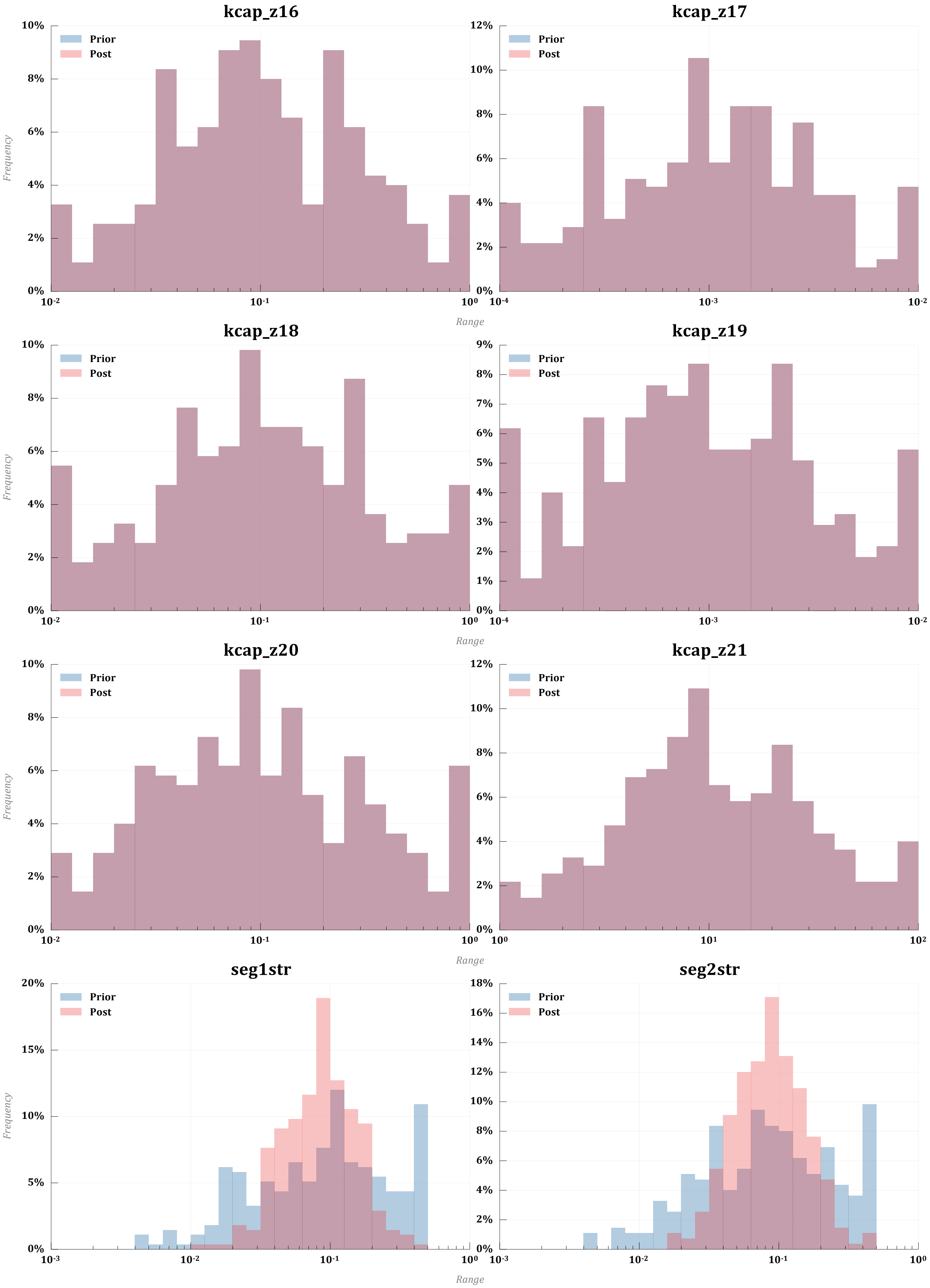

RNVW4-UPG
SDH16
SDH18
SOUTH
WPP1
WPP2
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

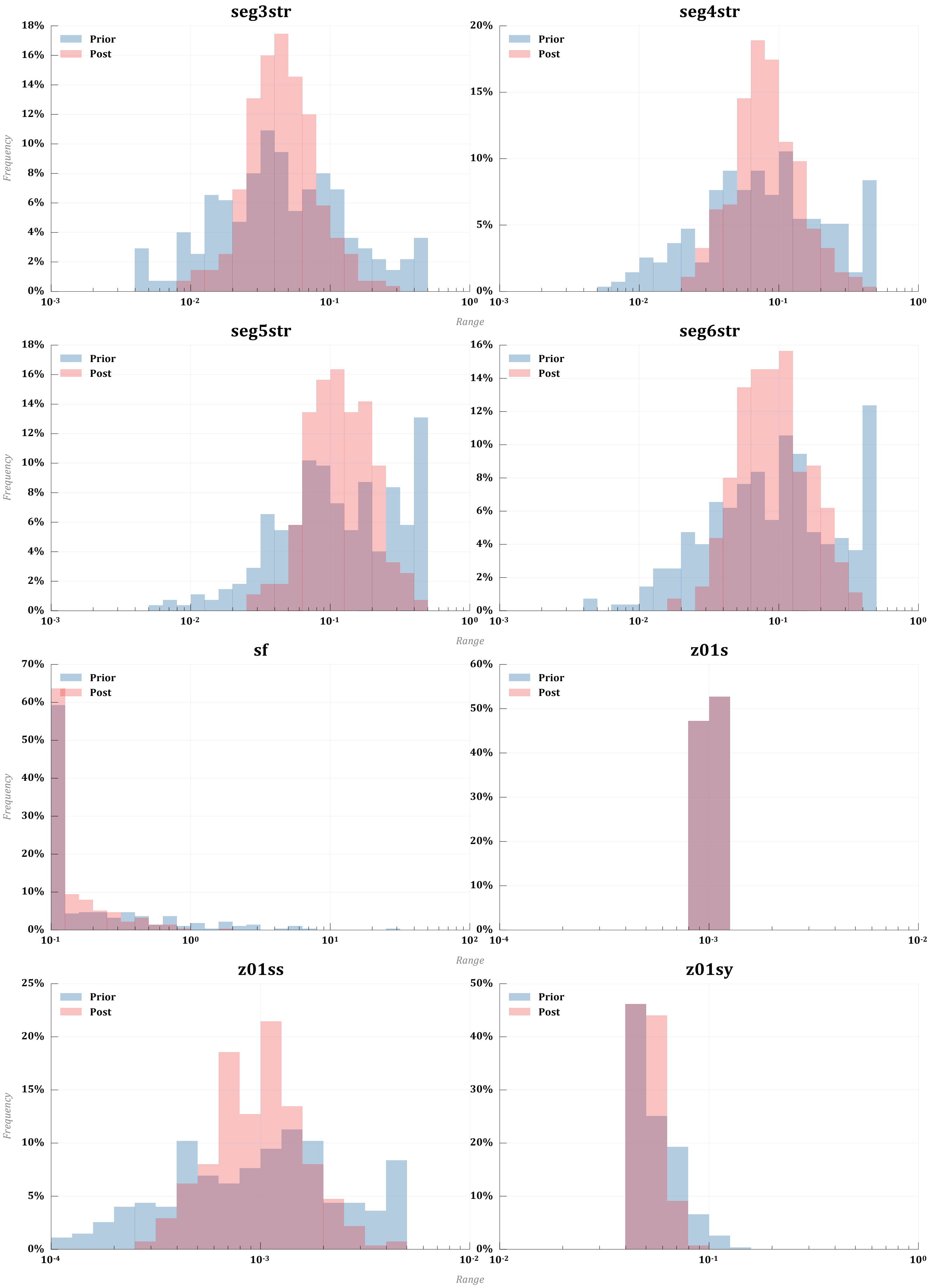
Appendix A-2

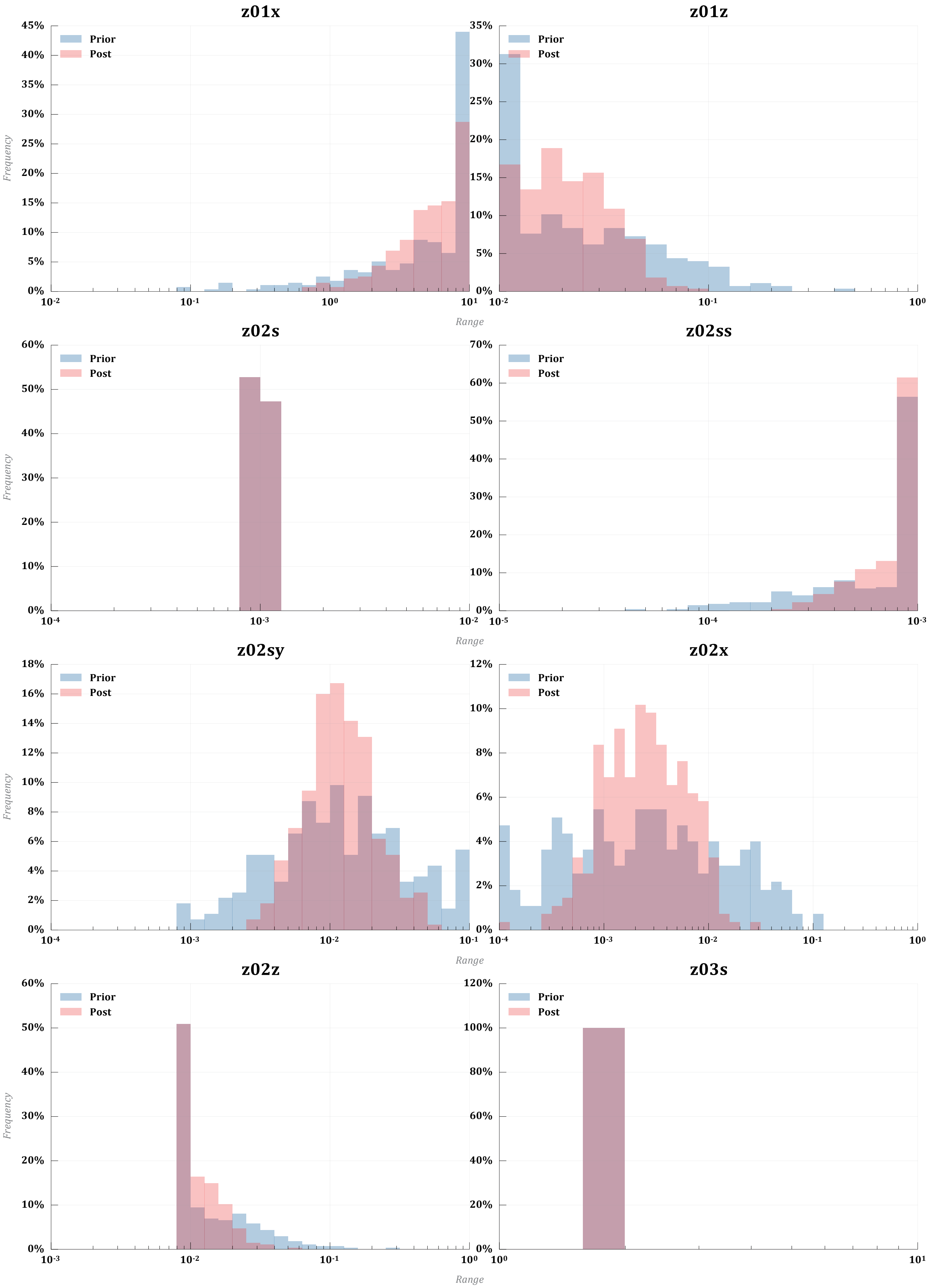
Prior and posterior parameter confidence distributions

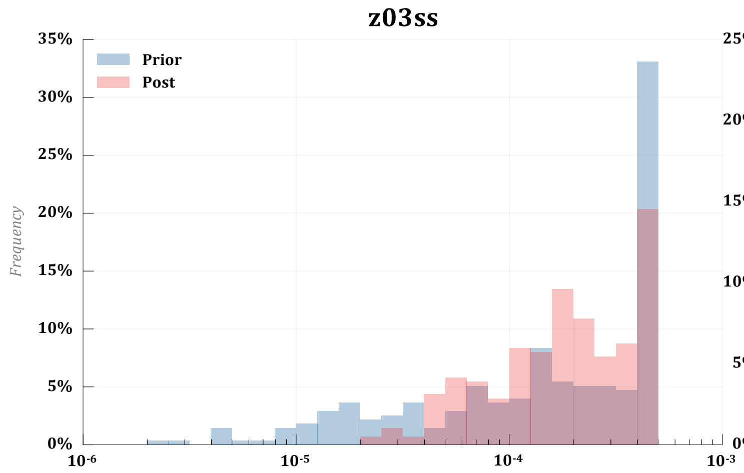

cttvm
kcap_z01
kcap_z02
kcap_z03
kcap_z04
kcap_z05
kcap_z06
kcap_z07
Prior
Post
Frequency
Range

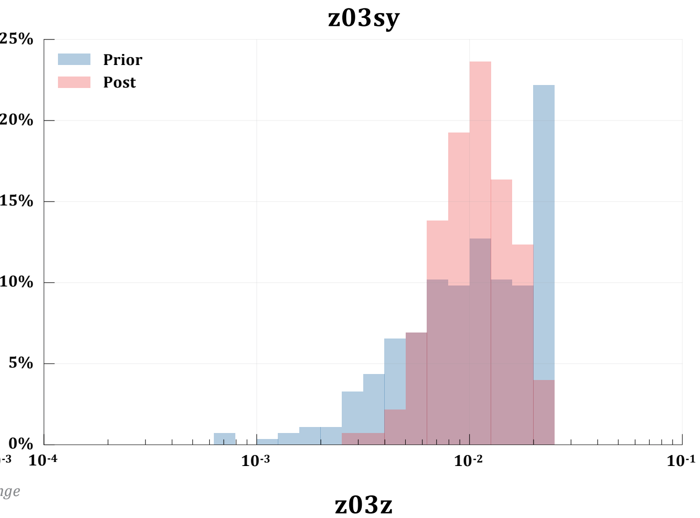

kcap_z08
kcap_z09
kcap_z10
kcap_z11
kcap_z12
kcap_z13
kcap_z14
kcap_z15
Prior
Post
Frequency
Range

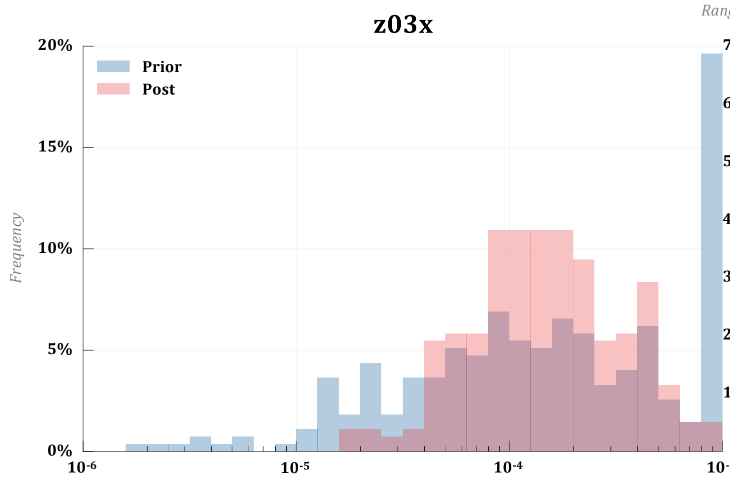

kcap_z16
kcap_z17
kcap_z18
kcap_z19
kcap_z20
kcap_z21
seg1str
seg2str
Prior
Post
Frequency
Range

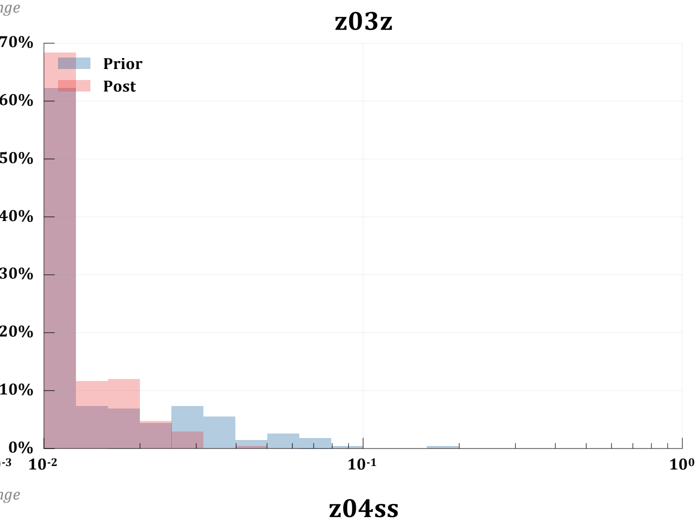

seg3str
seg4str
seg5str
seg6str
sf
z01s
z01ss
z01sy
Prior
Post
Frequency
Range

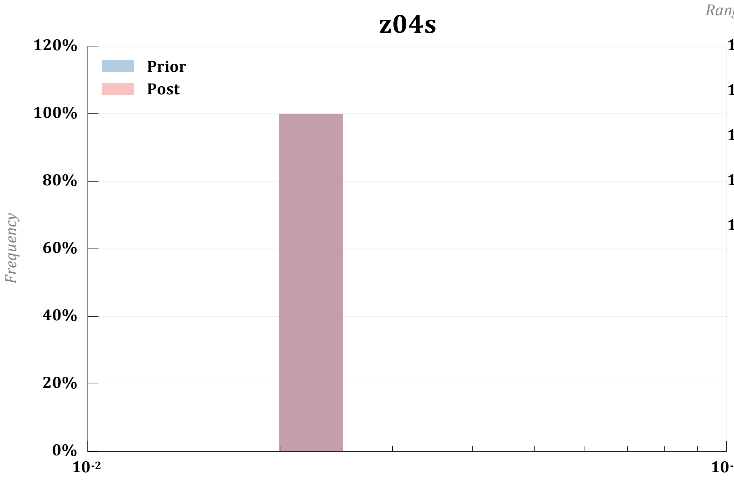

z01x
z01z
z02s
z02ss
z02sy
z02x
z02z
z03s
Prior
Post
Frequency
Range

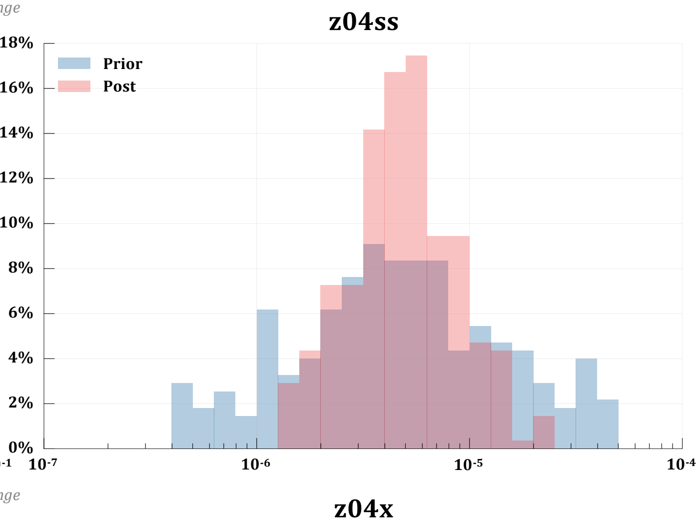

z03ss
Prior
Post
Frequency
35%
30%
25%
20%
15%
10%
5%
0%
10-6
10-5
10-4
10-3

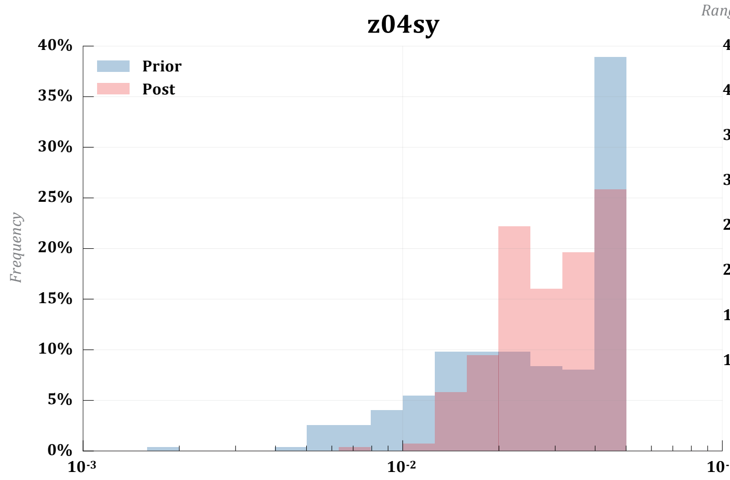

z03sy
Prior
Post
25%
20%
15%
10%
5%
0%
10-4
10-3
10-2
10-1
Range

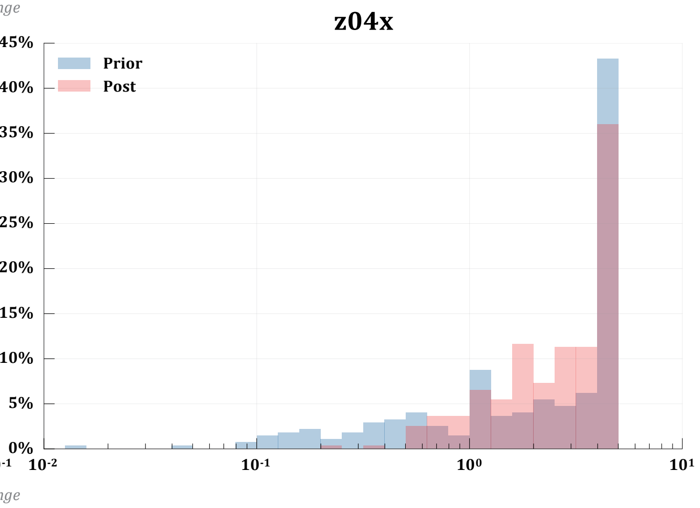

z03x
Prior
Post
Frequency
20%
15%
10%
5%
0%
10-6
10-5
10-4
10-3

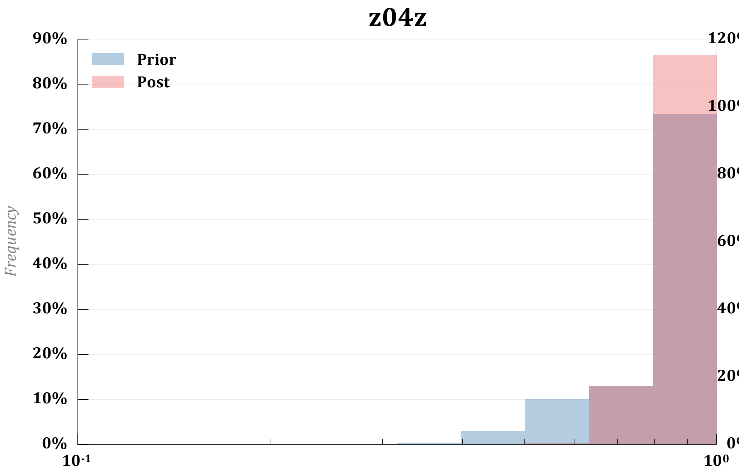

z03z
Prior
Post
70%
60%
50%
40%
30%
20%
10%
0%
10-2
10-1
100
Range

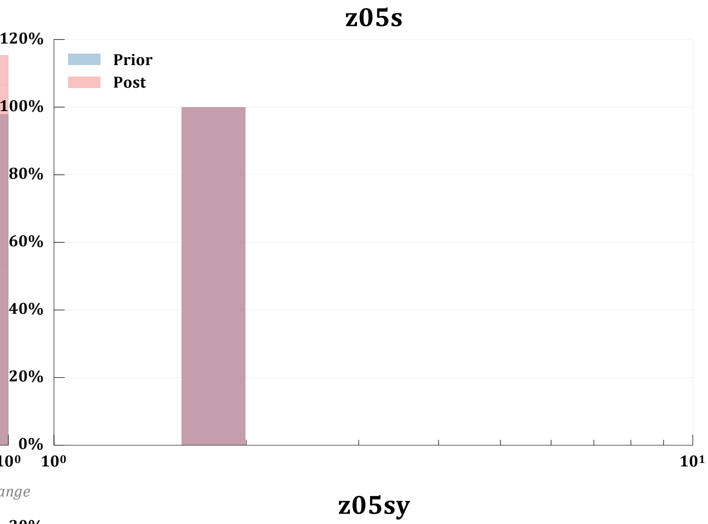

z04s
Prior
Post
Frequency
120%
100%
80%
60%
40%
20%
0%
10-2
10-1

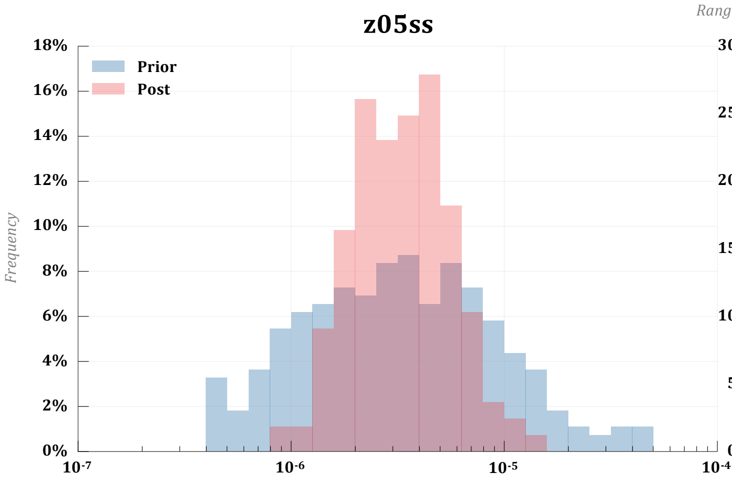

z04ss
Prior
Post
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
10-7
10-6
10-5
10-4
Range

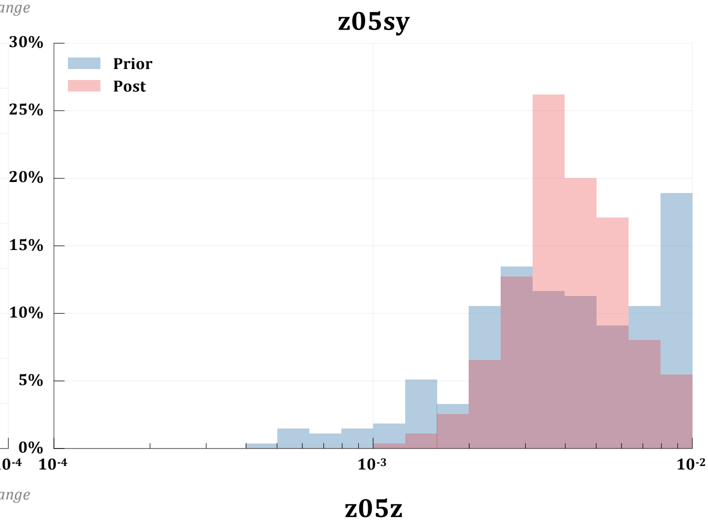

z04sy
Prior
Post
Frequency
40%
35%
30%
25%
20%
15%
10%
5%
0%
10-3
10-2
10-1

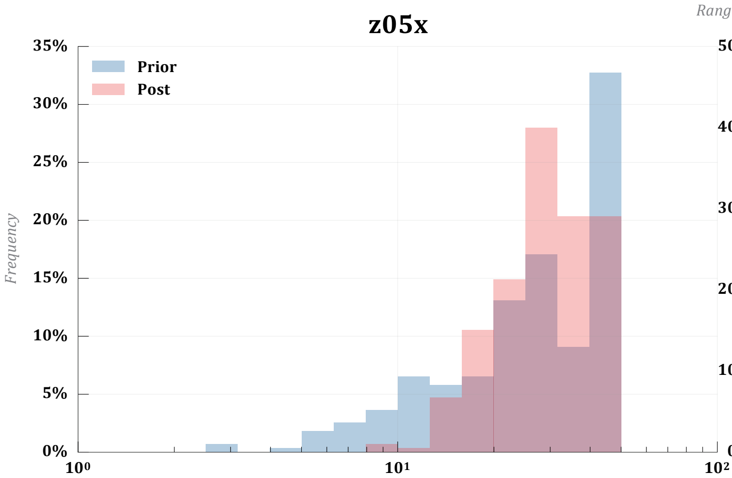

z04x
Prior
Post
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
10-2
10-1
100
101
Range

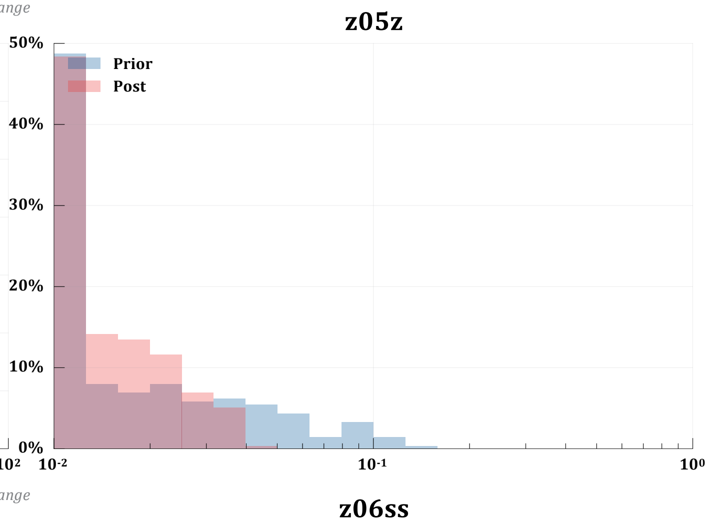

z04z
Prior
Post
Frequency
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
10-1
100

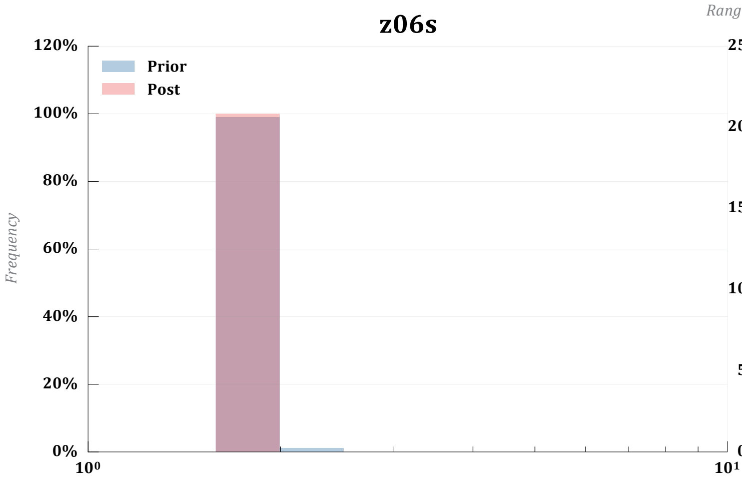

z05s
Prior
Post
120%
100%
80%
60%
40%
20%
0%
100
101
Range

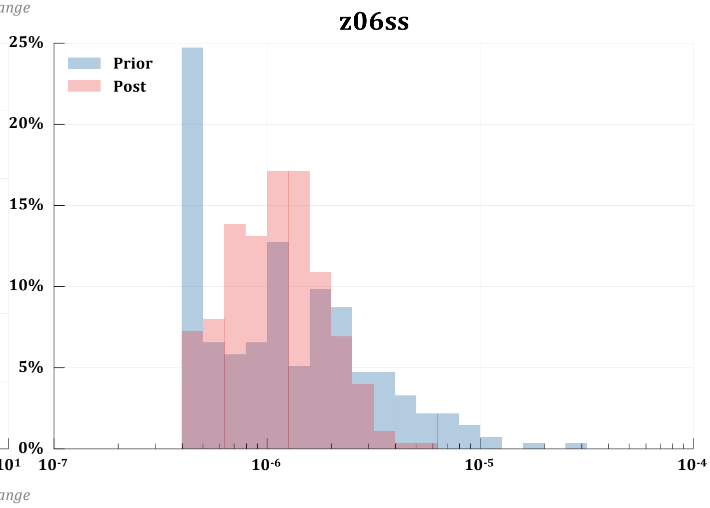

z05ss
Prior
Post
Frequency
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
10-7
10-6
10-5
10-4

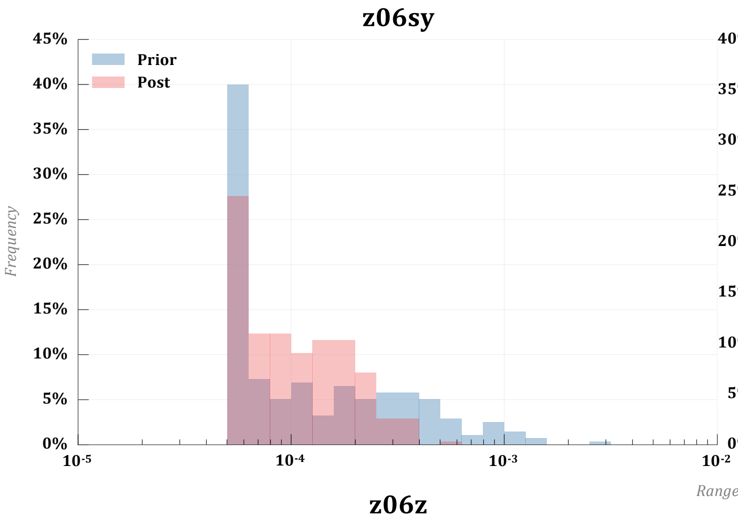

z05sy
Prior
Post
30%
25%
20%
15%
10%
5%
0%
10-4
10-3
10-2
Range


z05x
Prior
Post
Frequency
35%
30%
25%
20%
15%
10%
5%
0%
100
101
102

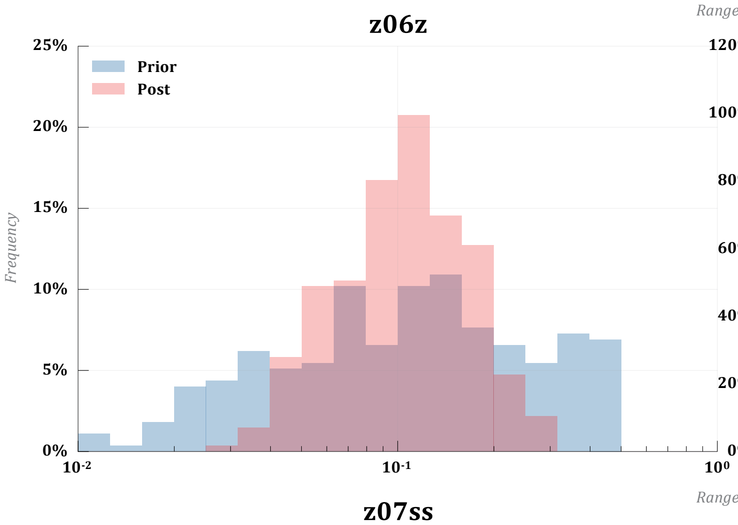

z05z
Prior
Post
50%
40%
30%
20%
10%
0%
10-2
10-1
100
Range

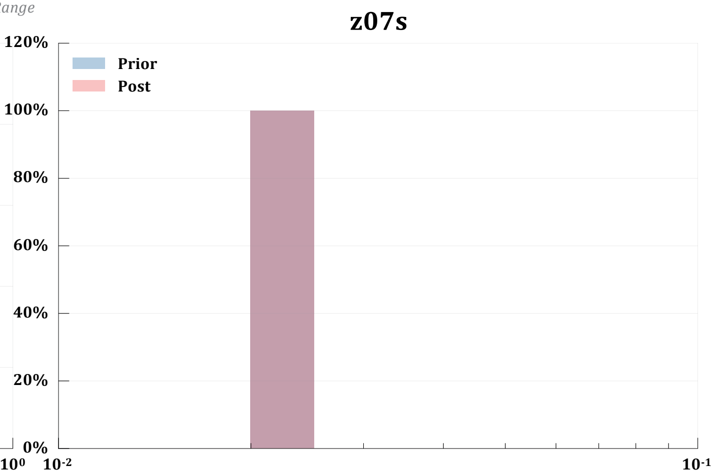

z06s
Prior
Post
Frequency
120%
100%
80%
60%
40%
20%
0%
100
101

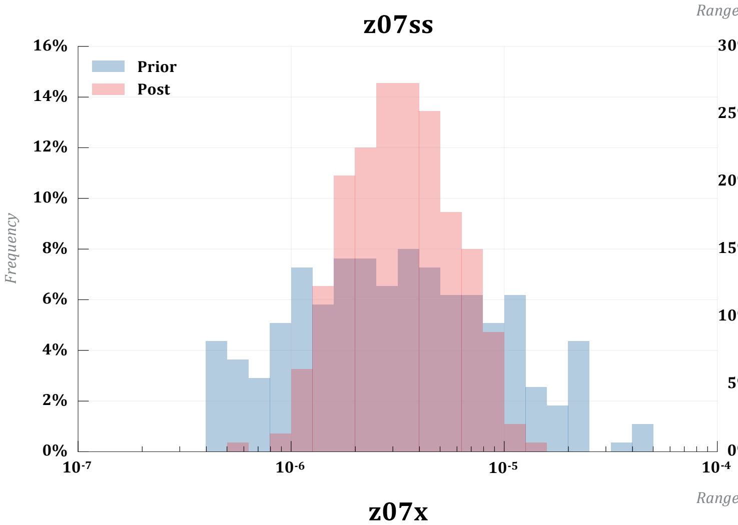

z06ss
Prior
Post
25%
20%
15%
10%
5%
0%
10-7
10-6
10-5
10-4
Range

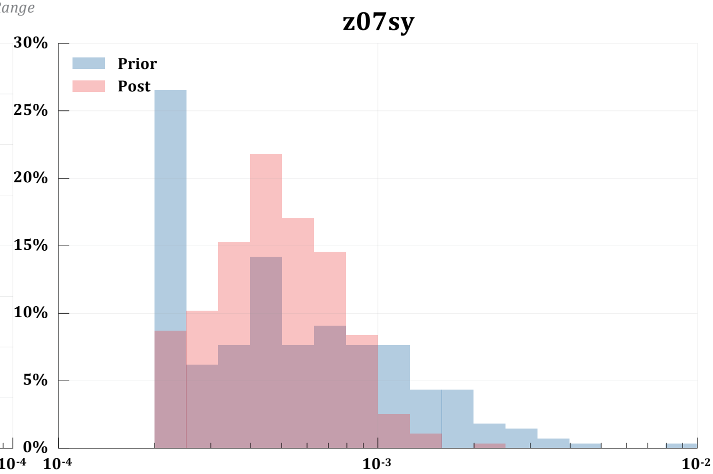

z06sy
Prior
Post
Frequency
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
10^{-5}
10^{-4}
10^{-3}
10^{-2}
Range

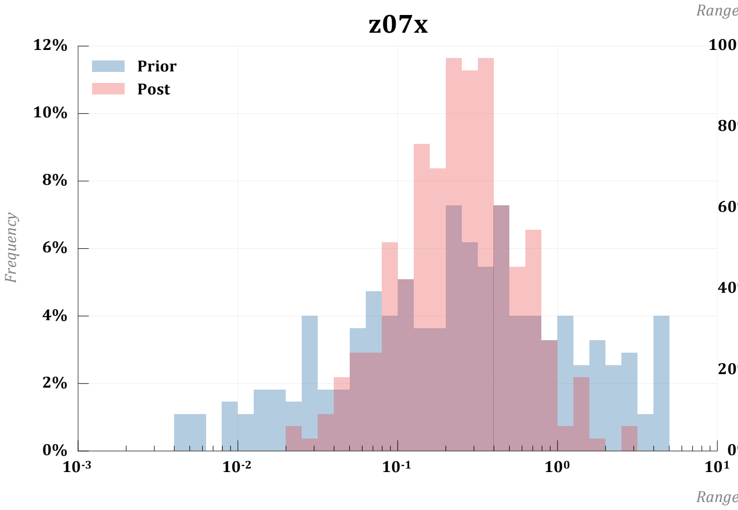

z06x
Prior
Post
40%
35%
30%
25%
20%
15%
10%
5%
0%
10^{0}
10^{1}
10^{2}

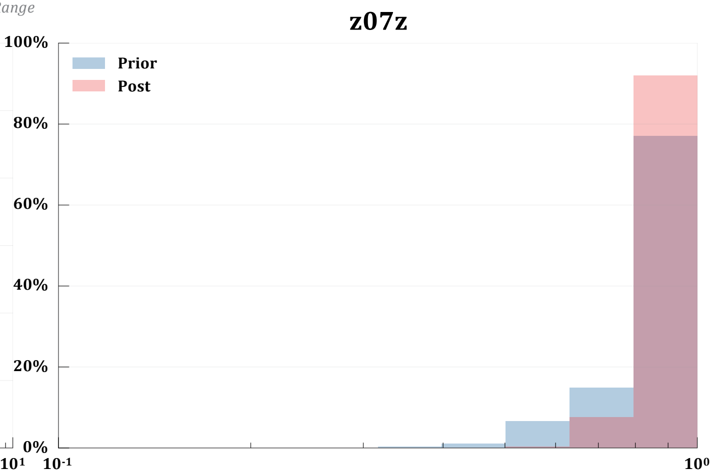

z06z
Prior
Post
Frequency
25%
20%
15%
10%
5%
0%
10^{-2}
10^{-1}
10^{0}
Range

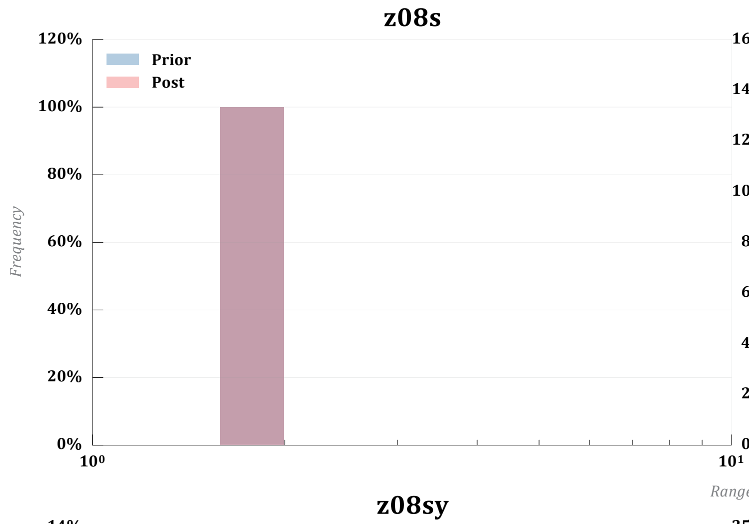

z07s
Prior
Post
120%
100%
80%
60%
40%
20%
0%
10^{-2}
10^{-1}

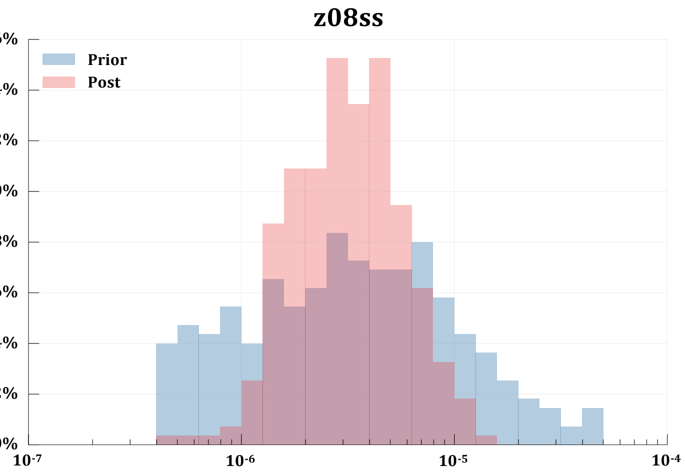

z07ss
Prior
Post
Frequency
16%
14%
12%
10%
8%
6%
4%
2%
0%
10^{-7}
10^{-6}
10^{-5}
10^{-4}
Range

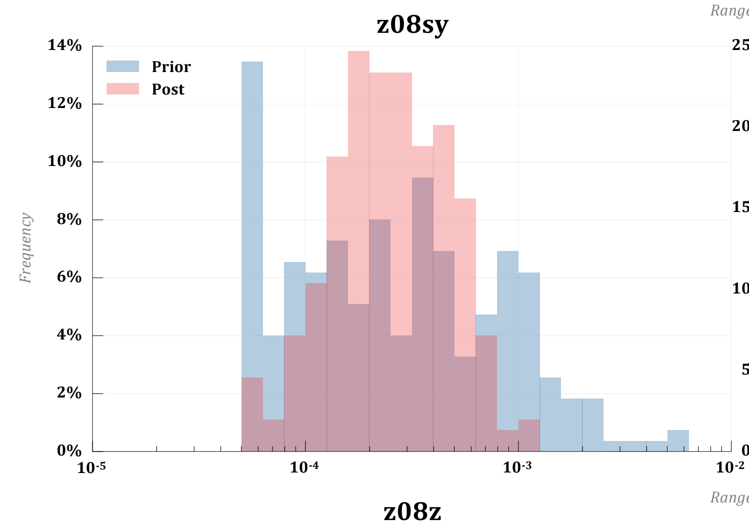

z07sy
Prior
Post
30%
25%
20%
15%
10%
5%
0%
10^{-4}
10^{-3}
10^{-2}

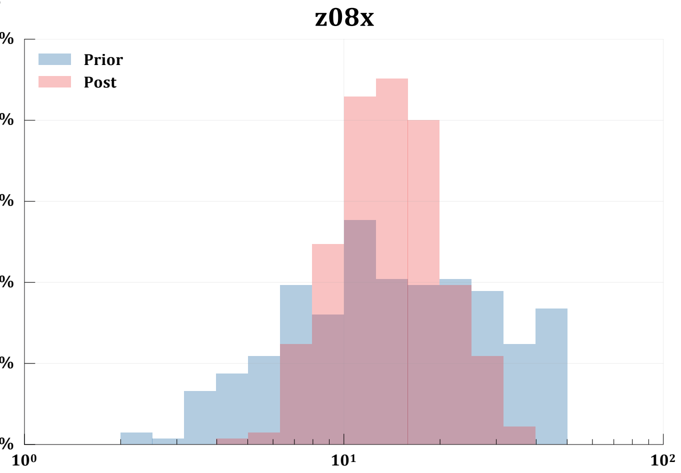

z07x
Prior
Post
Frequency
12%
10%
8%
6%
4%
2%
0%
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
Range

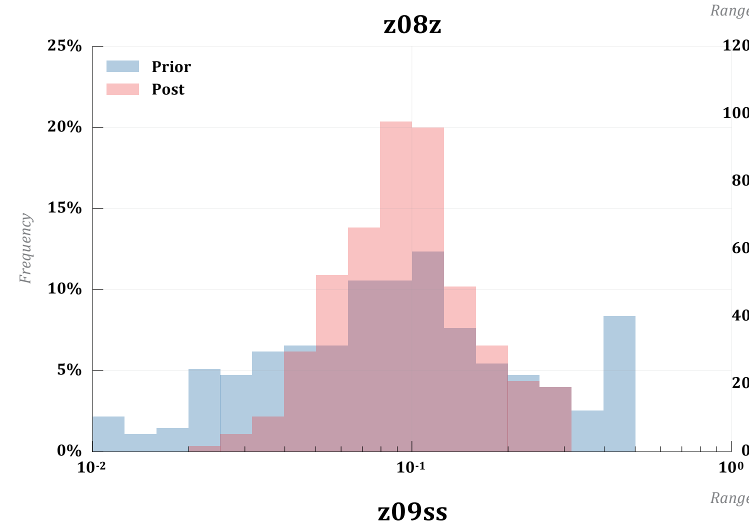

z07z
Prior
Post
100%
80%
60%
40%
20%
0%
10^{-1}
10^{0}

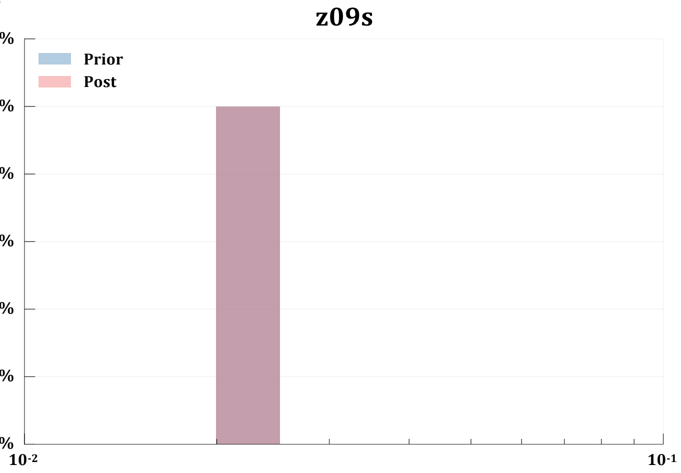

z08s
Prior
Post
Frequency
120%
100%
80%
60%
40%
20%
0%
10^{0}
10^{1}

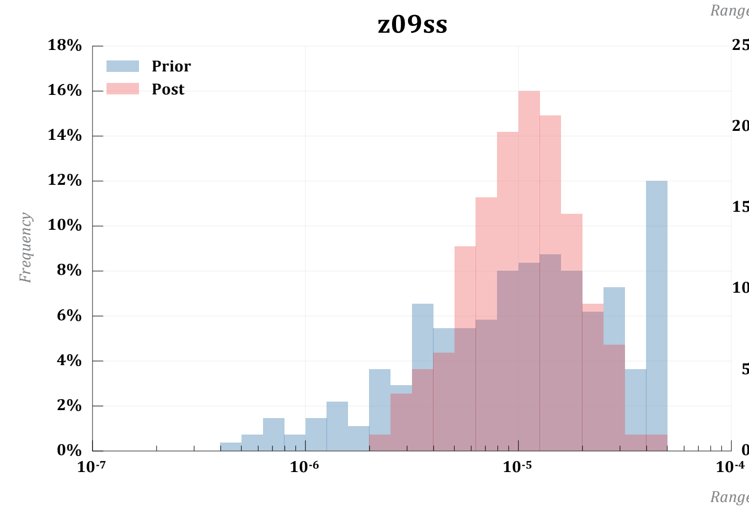

z08ss
Prior
Post
16%
14%
12%
10%
8%
6%
4%
2%
0%
10^{-7}
10^{-6}
10^{-5}
10^{-4}
Range

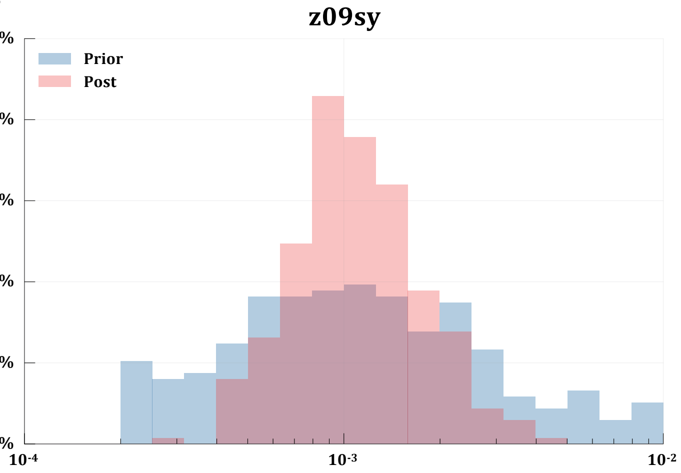

z08sy
Prior
Post
Frequency
14%
12%
10%
8%
6%
4%
2%
0%
10^{-5}
10^{-4}
10^{-3}
10^{-2}


z08x
Prior
Post
25%
20%
15%
10%
5%
0%
10^{0}
10^{1}
10^{2}
Range

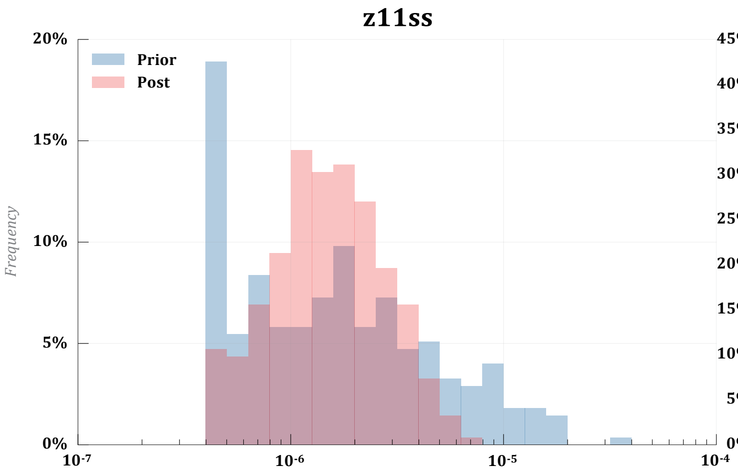

z08z
Prior
Post
Frequency
25%
20%
15%
10%
5%
0%
10^{-2}
10^{-1}
10^{0}

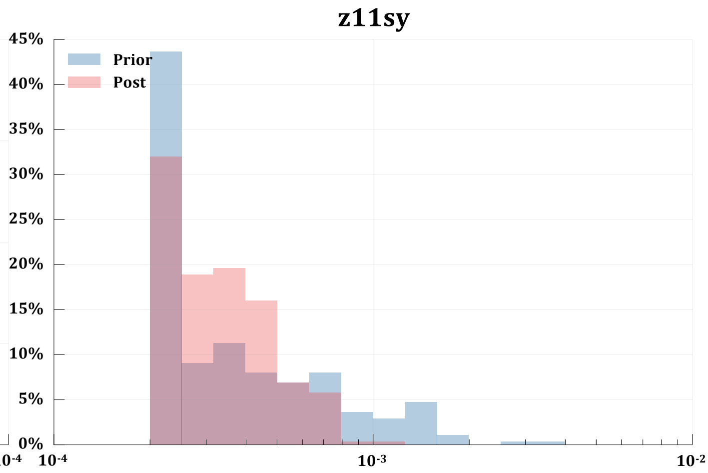

z09s
Prior
Post
120%
100%
80%
60%
40%
20%
0%
10^{-2}
10^{-1}
Range

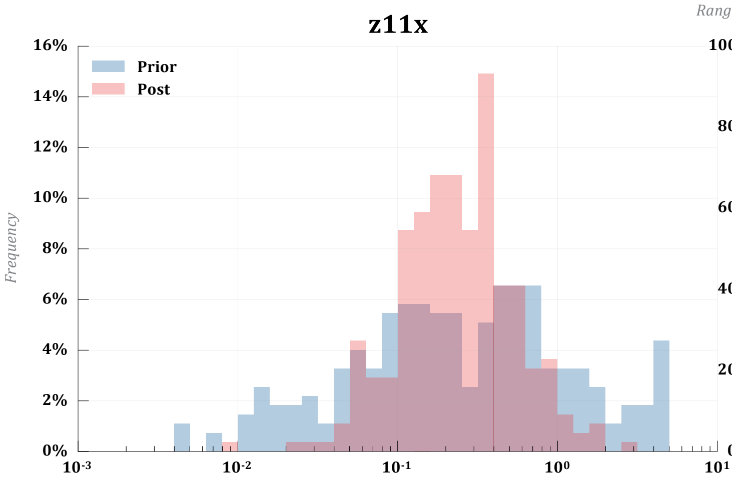

z09ss
Prior
Post
Frequency
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
10^{-7}
10^{-6}
10^{-5}
10^{-4}

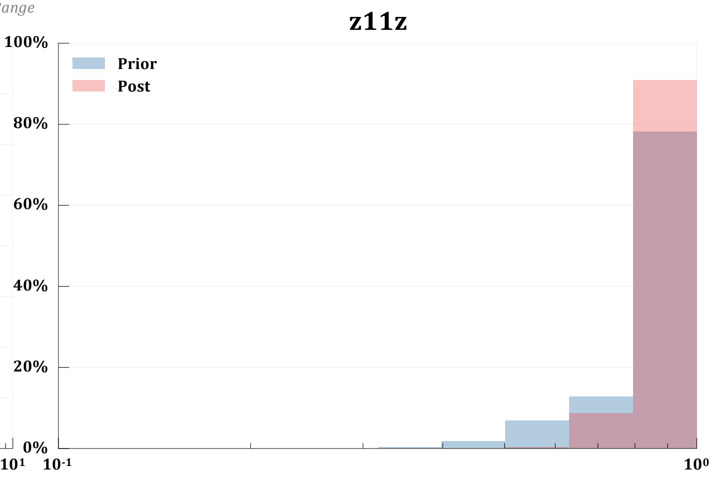

z09sy
Prior
Post
25%
20%
15%
10%
5%
0%
10^{-4}
10^{-3}
10^{-2}
Range

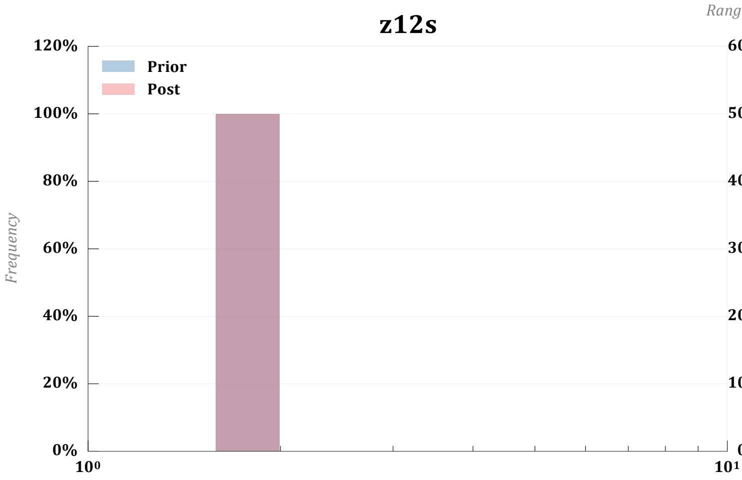

z09x
z09z
z10s
z10ss
z10sy
z10x
z10z
z11s
Prior
Post
Frequency
Range

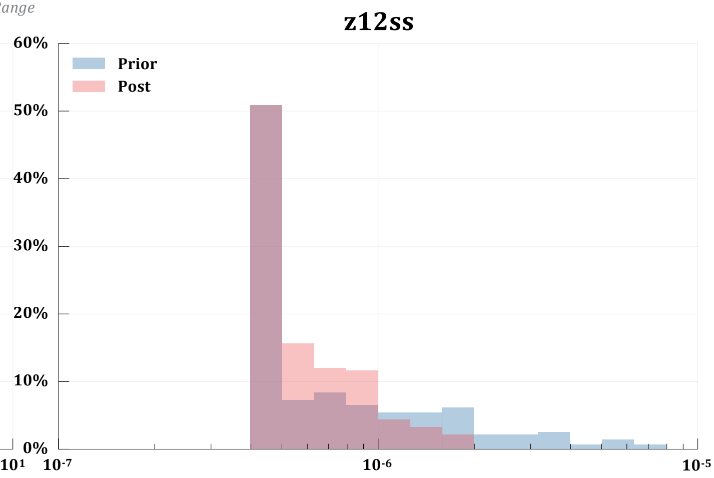

z11ss
Prior
Post
Frequency
20%
15%
10%
5%
0%
10-7
10-6
10-5
10-4

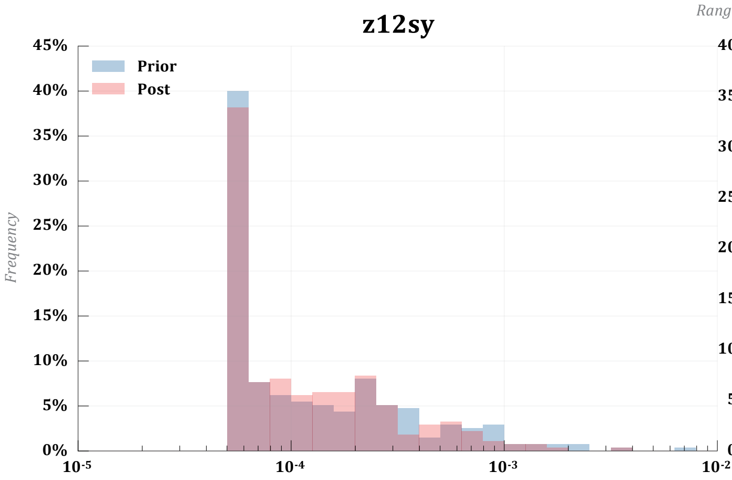

z11sy
Prior
Post
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
10-4
10-3
10-2
Range

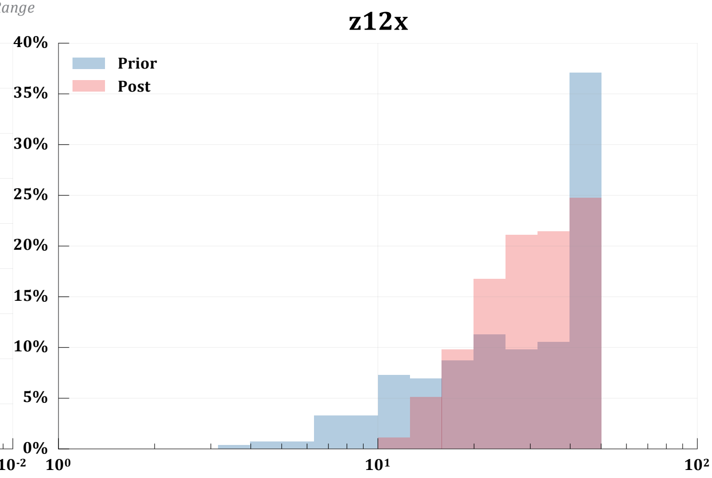

z11x
Prior
Post
Frequency
16%
14%
12%
10%
8%
6%
4%
2%
0%
10-3
10-2
10-1
100
101


z11z
Prior
Post
100%
80%
60%
40%
20%
0%
10-1
100
Range

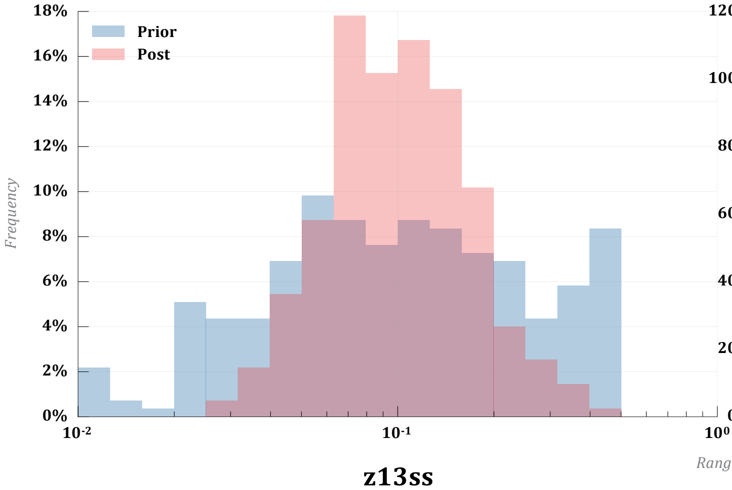

z12s
Prior
Post
Frequency
120%
100%
80%
60%
40%
20%
0%
100
101


z12ss
Prior
Post
60%
50%
40%
30%
20%
10%
0%
10-7
10-6
10-5
Range

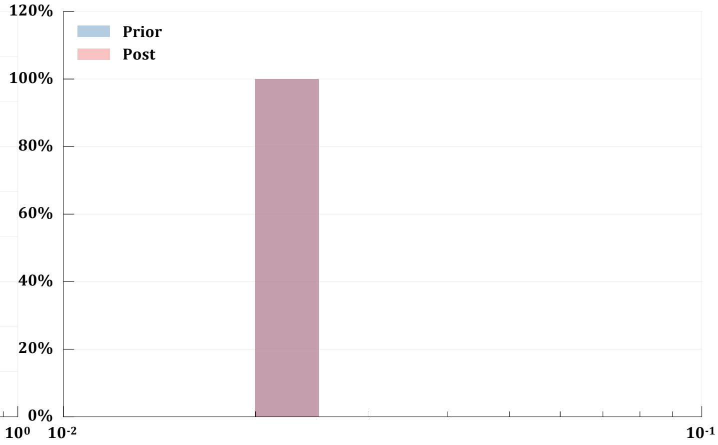

z12sy
Prior
Post
Frequency
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
10-5
10-4
10-3
10-2


z12x
Prior
Post
40%
35%
30%
25%
20%
15%
10%
5%
0%
100
101
102
Range

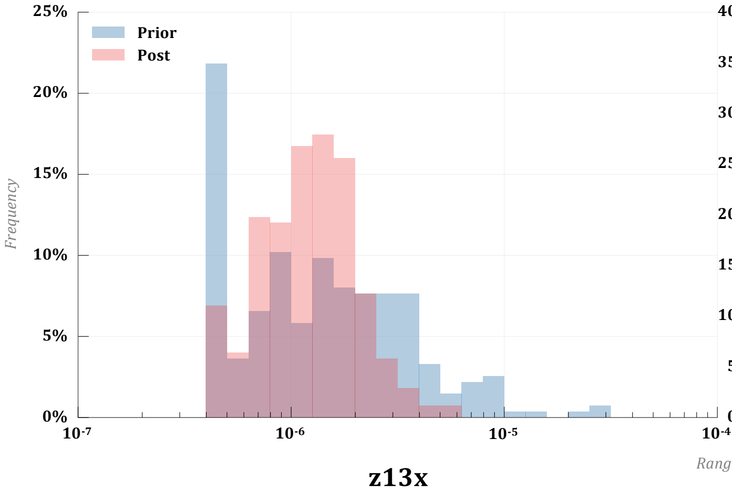
z12z



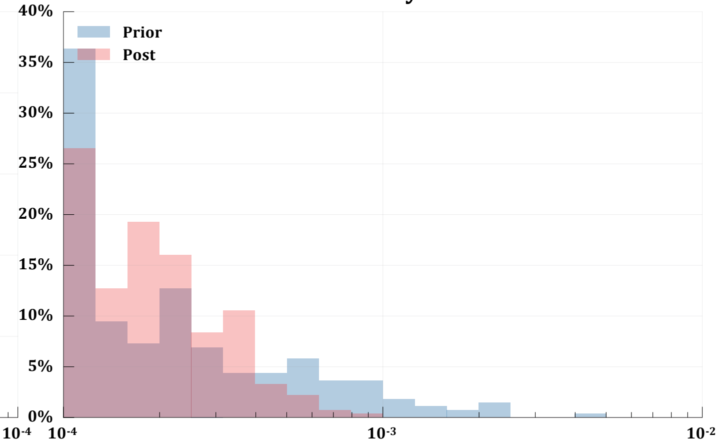
z13s



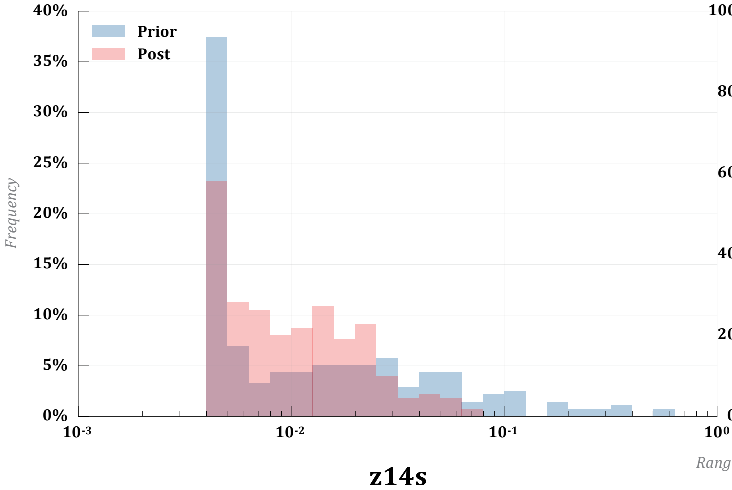
z13ss



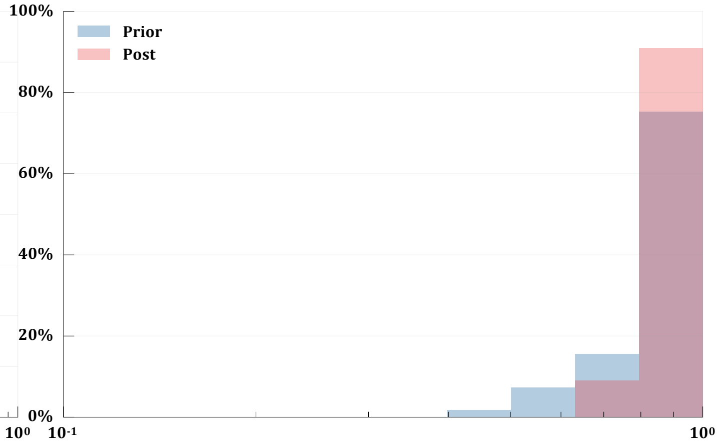
z13sy



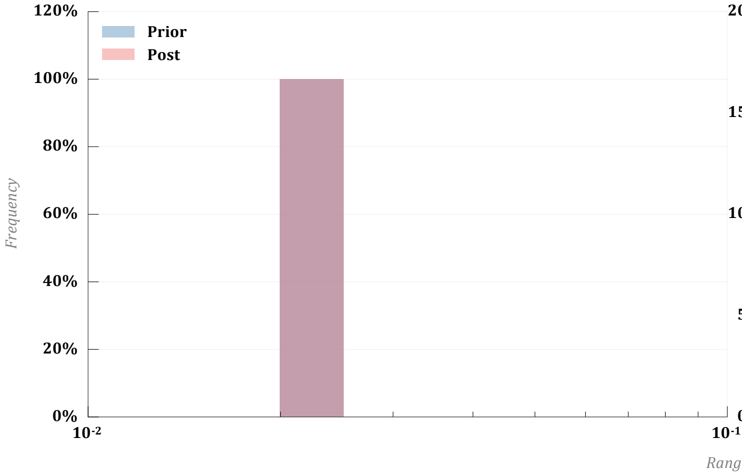
z13x



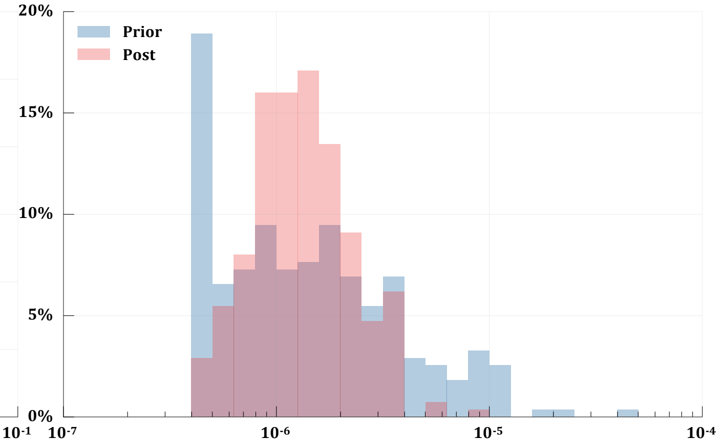
z13z



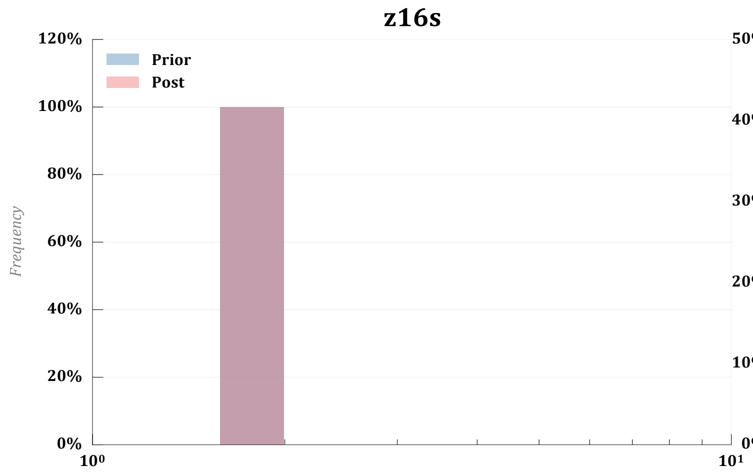
z14s

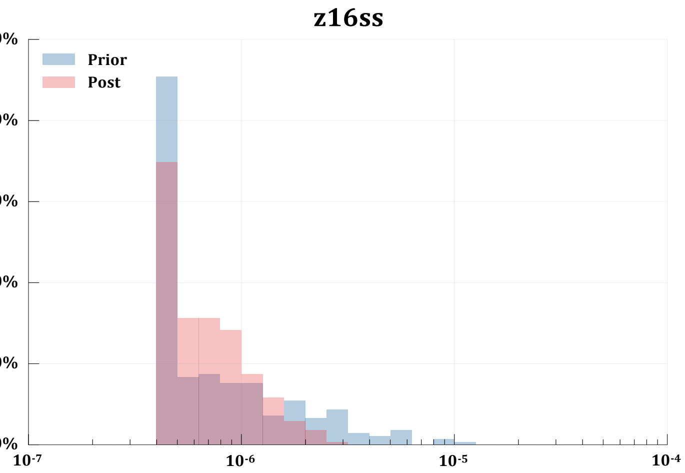


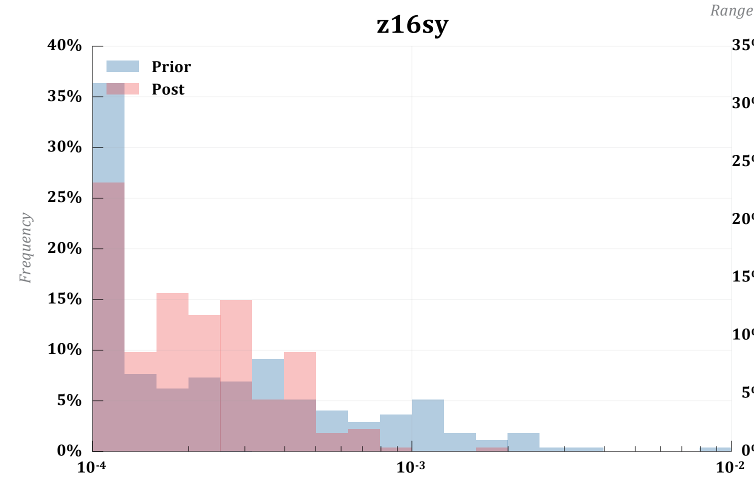
z14ss

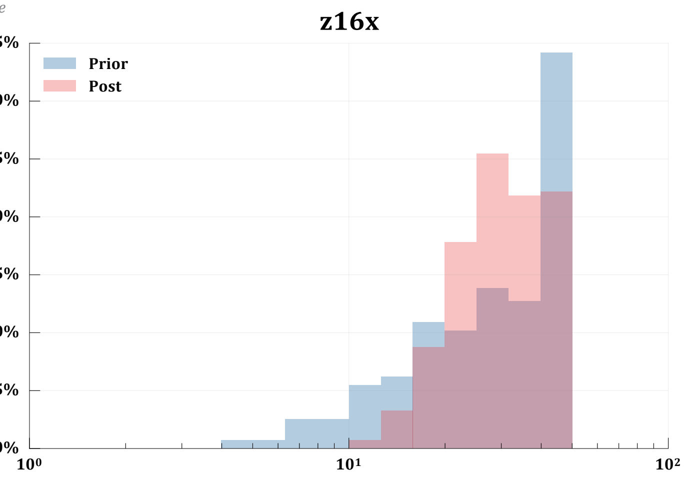


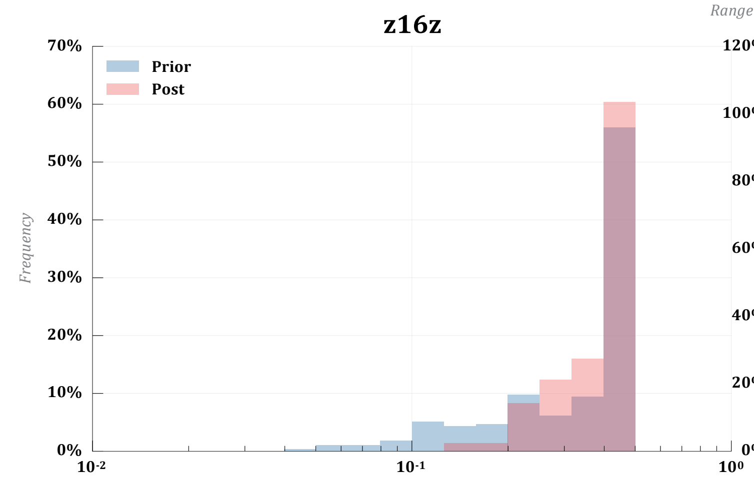

z14sy
z14x
z14z
z15s
z15ss
z15sy
z15x
z15z
Prior
Post
Frequency
Range

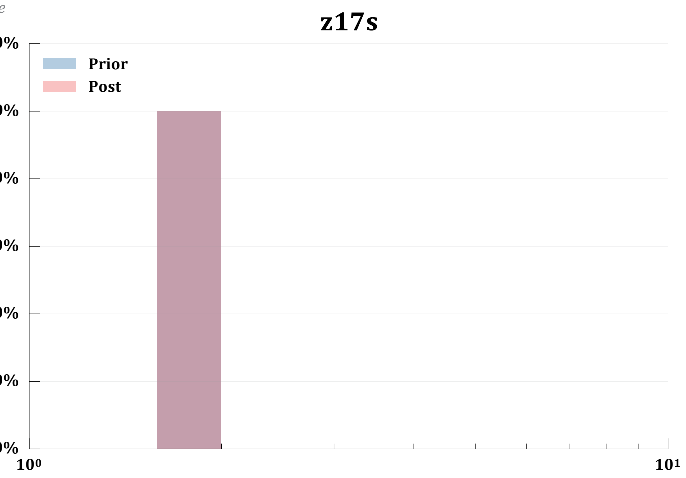

z16s
Prior
Post
Frequency
120%
100%
80%
60%
40%
20%
0%
10⁰
10¹

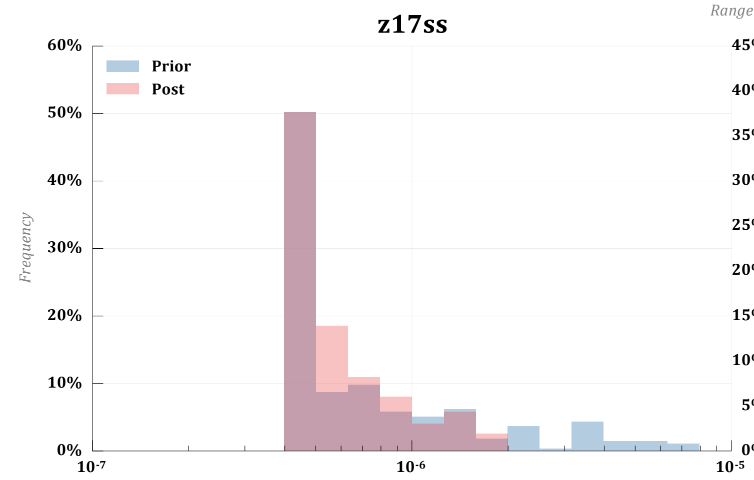

z16ss
Prior
Post
50%
40%
30%
20%
10%
0%
10-7
10-6
10-5
10-4
Range

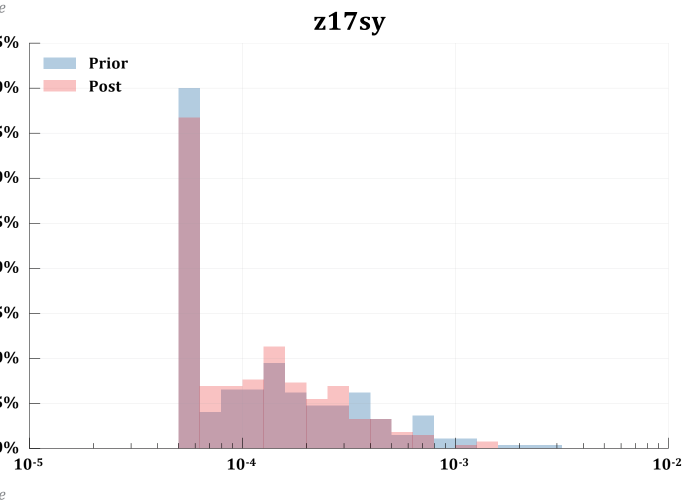

z16sy
Prior
Post
Frequency
40%
35%
30%
25%
20%
15%
10%
5%
0%
10-4
10-3
10-2

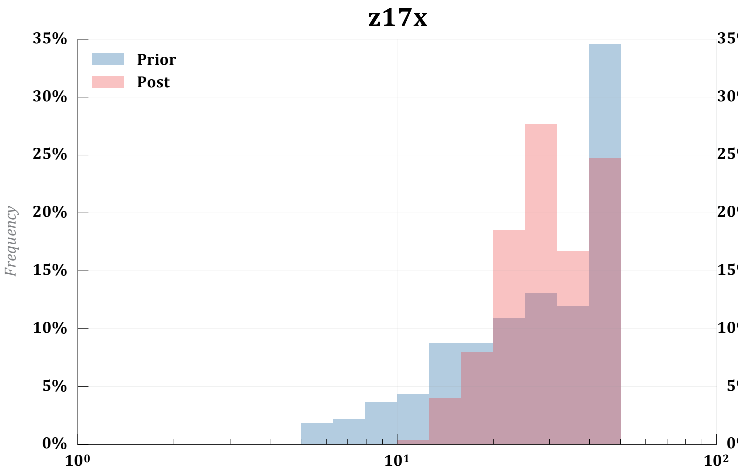

z16x
Prior
Post
35%
30%
25%
20%
15%
10%
5%
0%
10⁰
10¹
10²
Range

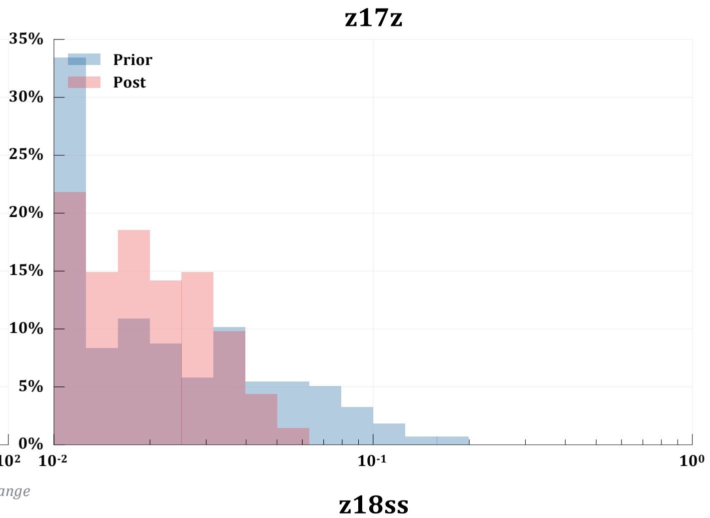

z16z
Prior
Post
Frequency
70%
60%
50%
40%
30%
20%
10%
0%
10-2
10-1
10⁰

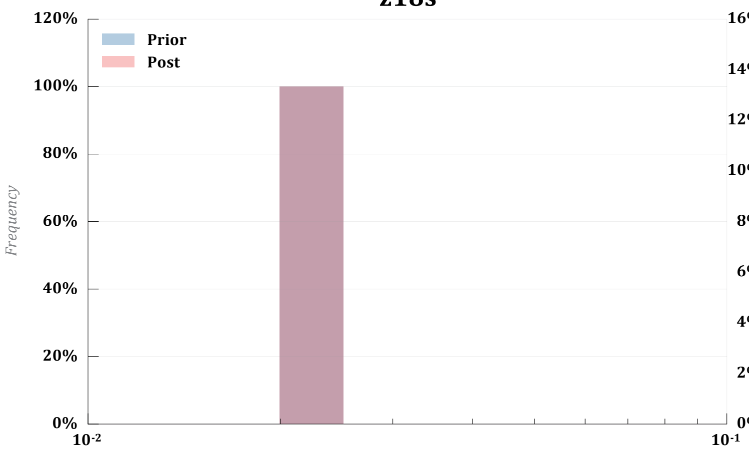

z17s
Prior
Post
120%
100%
80%
60%
40%
20%
0%
10⁰
10¹
Range

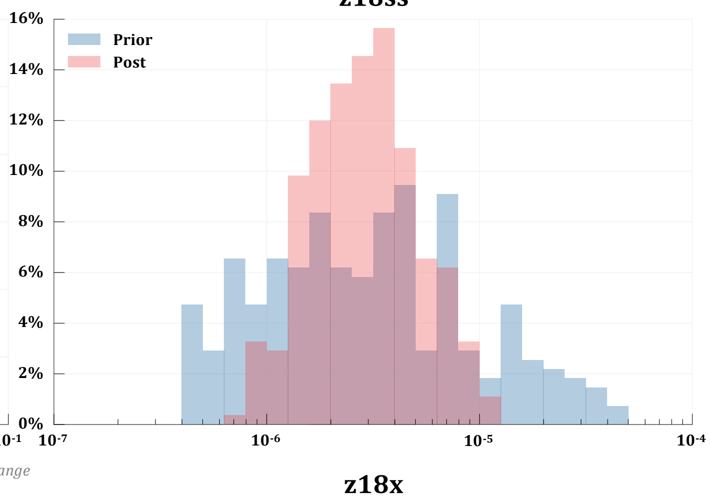

z17ss
Prior
Post
Frequency
60%
50%
40%
30%
20%
10%
0%
10-7
10-6
10-5

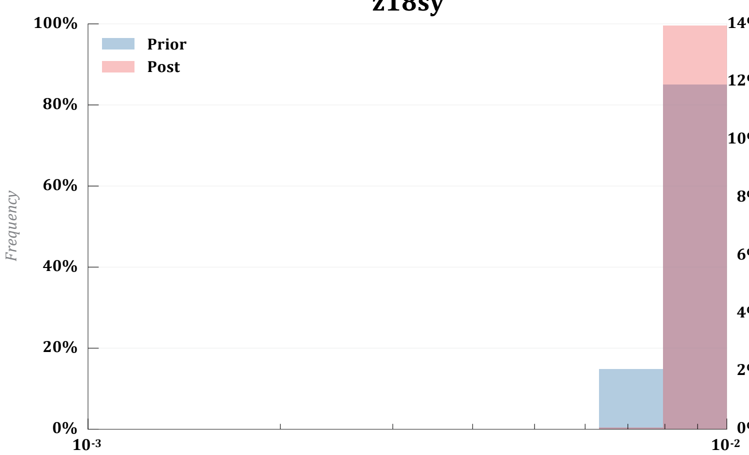

z17sy
Prior
Post
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
10-5
10-4
10-3
10-2
Range

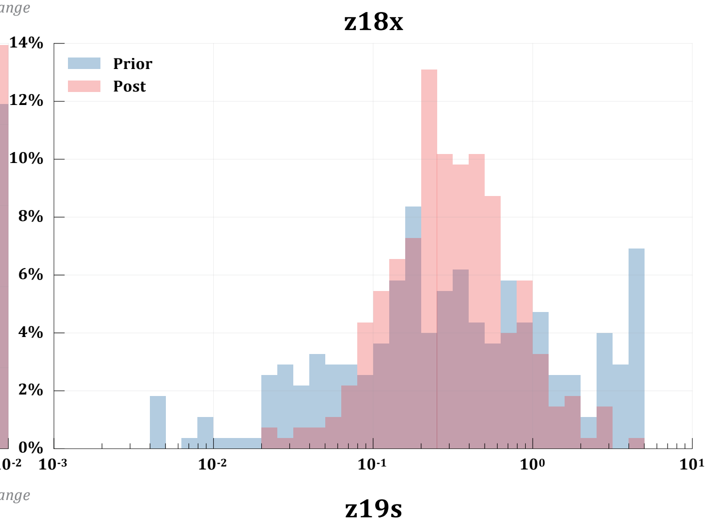

z17x
Prior
Post
Frequency
35%
30%
25%
20%
15%
10%
5%
0%
10^{0}
10^{1}
10^{2}

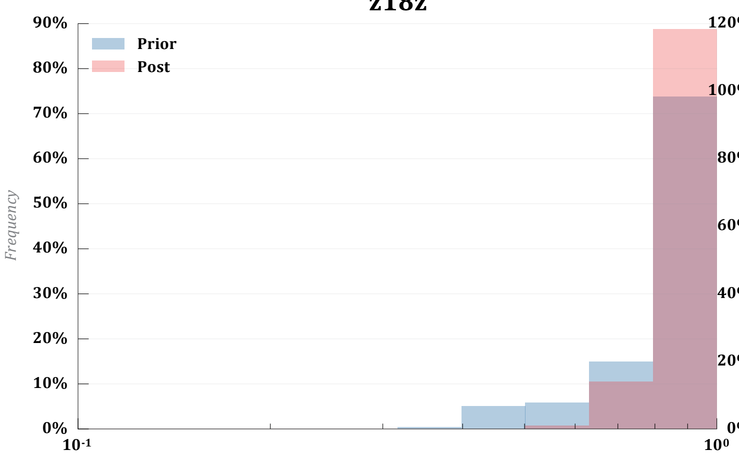

z17z
Prior
Post
35%
30%
25%
20%
15%
10%
5%
0%
10^{-2}
10^{-1}
10^{0}
Range

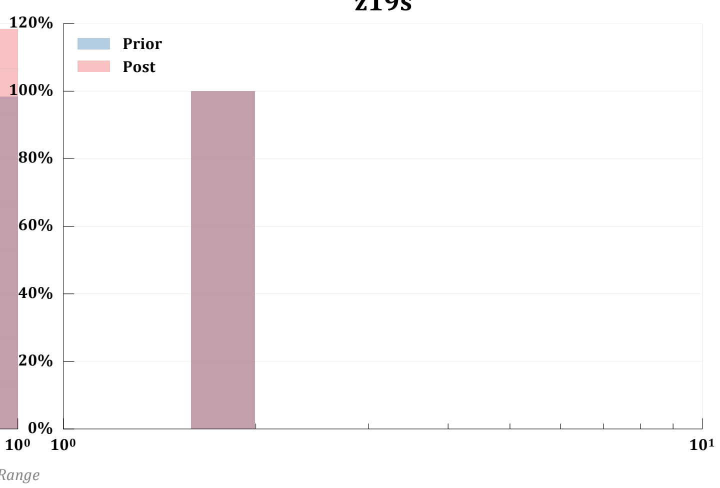

z18s
Prior
Post
Frequency
120%
100%
80%
60%
40%
20%
0%
10^{-2}
10^{-1}

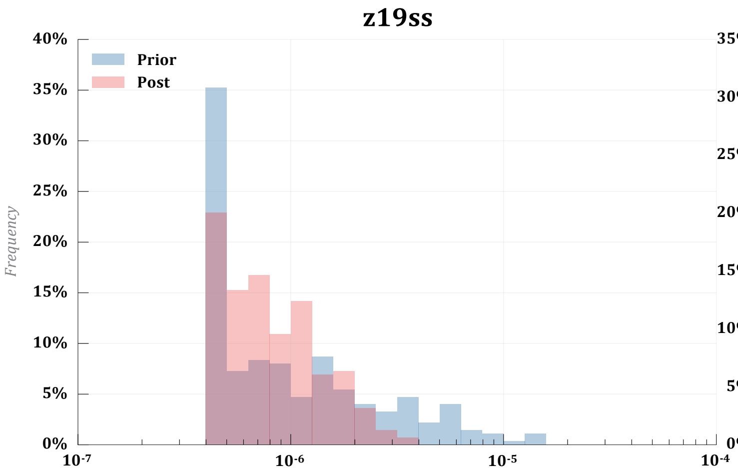

z18ss
Prior
Post
16%
14%
12%
10%
8%
6%
4%
2%
0%
10^{-7}
10^{-6}
10^{-5}
10^{-4}
Range

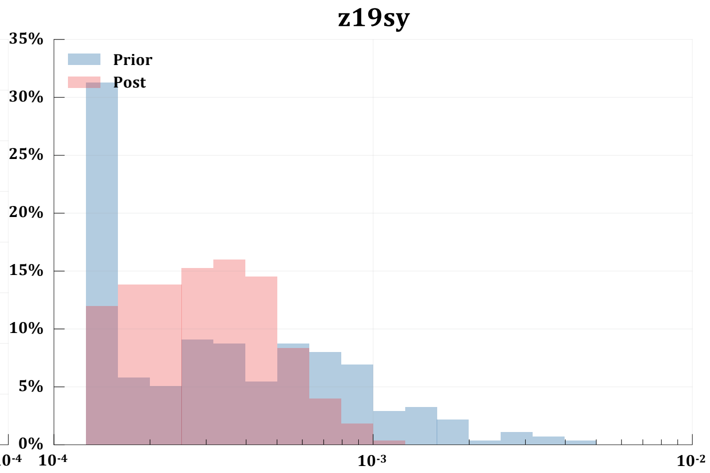

z18sy
Prior
Post
Frequency
100%
80%
60%
40%
20%
0%
10^{-3}
10^{-2}

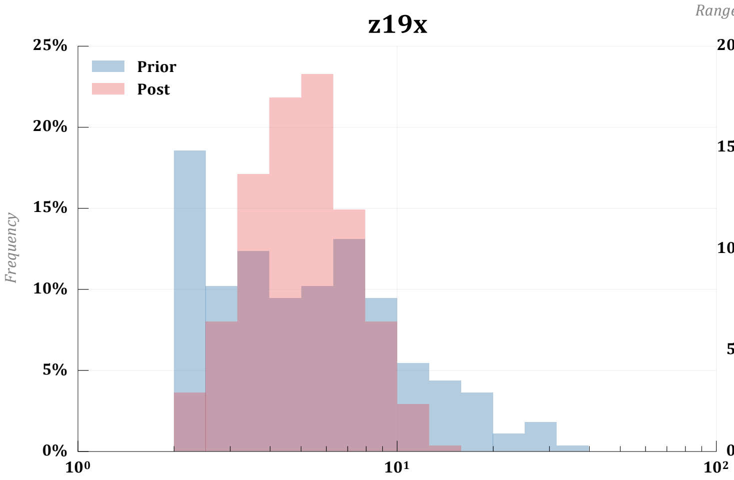

z18x
Prior
Post
14%
12%
10%
8%
6%
4%
2%
0%
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
Range

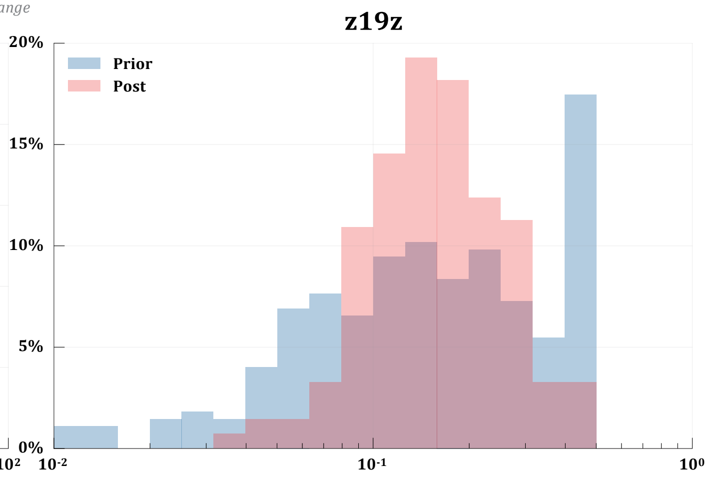

z18z
Prior
Post
Frequency
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
10^{-1}
10^{0}

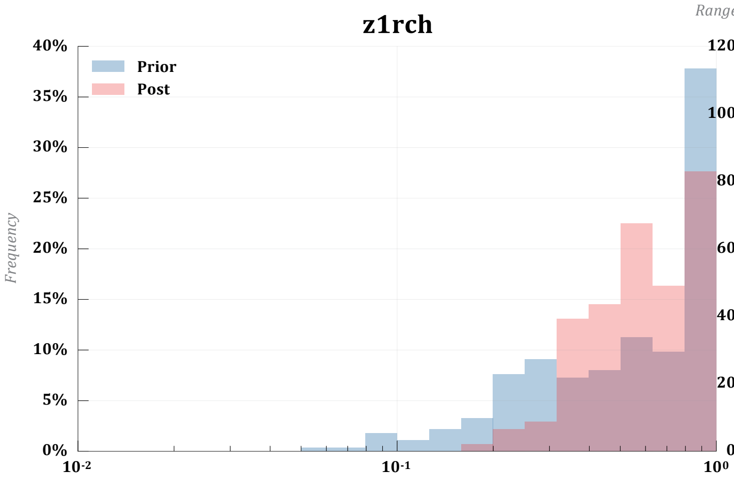

z19s
Prior
Post
120%
100%
80%
60%
40%
20%
0%
10^{0}
10^{1}
Range

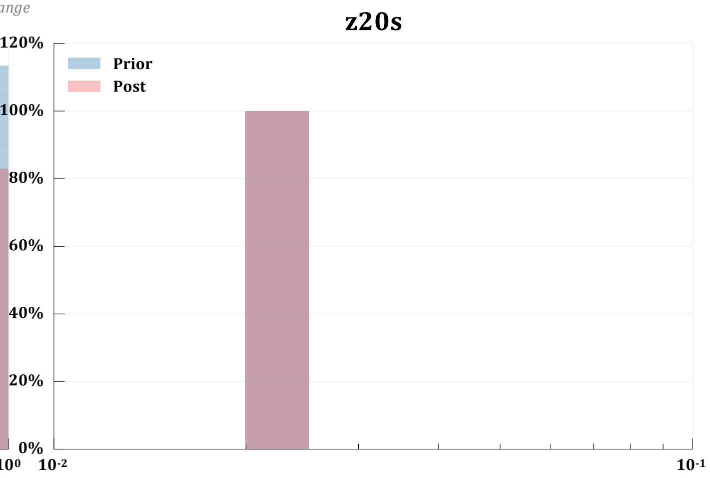

z19ss
Prior
Post
Frequency
40%
35%
30%
25%
20%
15%
10%
5%
0%
10^{-7}
10^{-6}
10^{-5}
10^{-4}

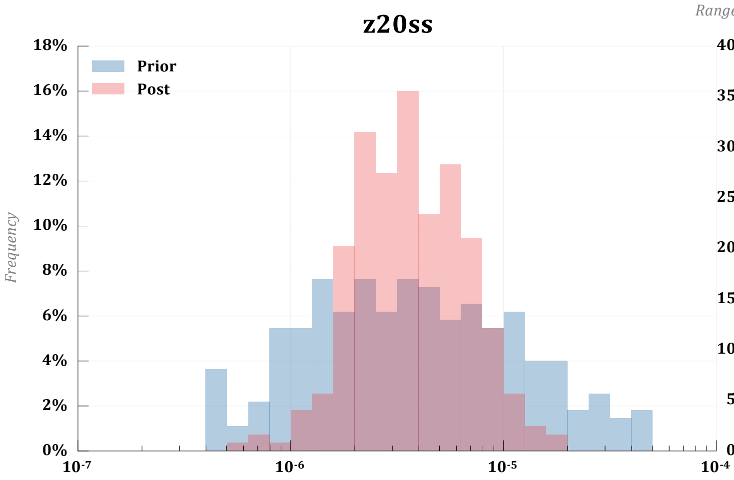

z19sy
Prior
Post
35%
30%
25%
20%
15%
10%
5%
0%
10^{-4}
10^{-3}
10^{-2}
Range

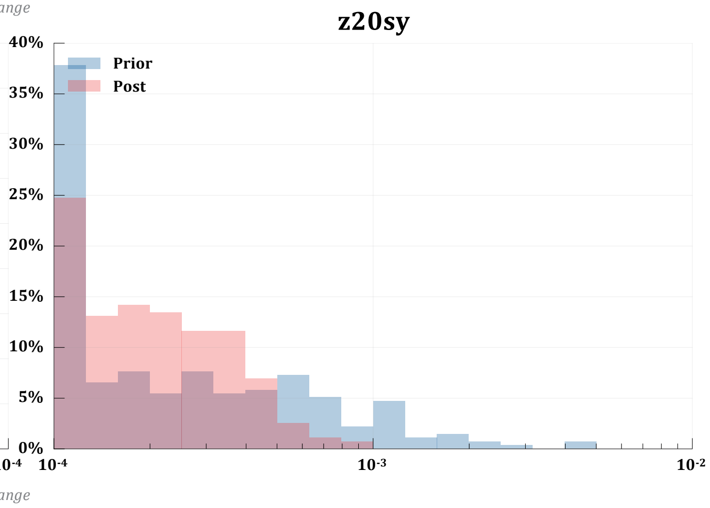

z19x
Prior
Post
Frequency
25%
20%
15%
10%
5%
0%
10^{0}
10^{1}
10^{2}

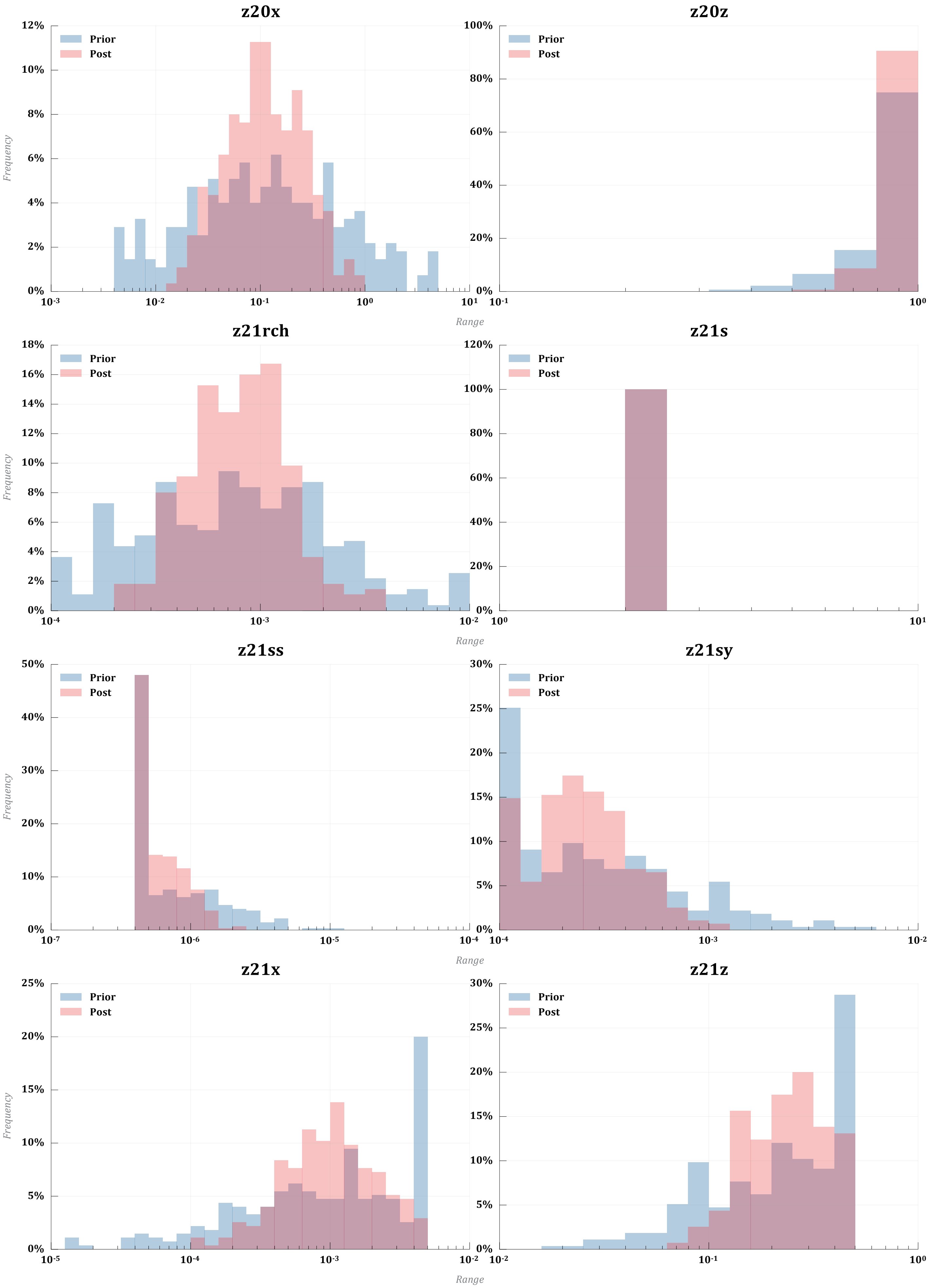

z19z
Prior
Post
20%
15%
10%
5%
0%
10^{-2}
10^{-1}
10^{0}
Range

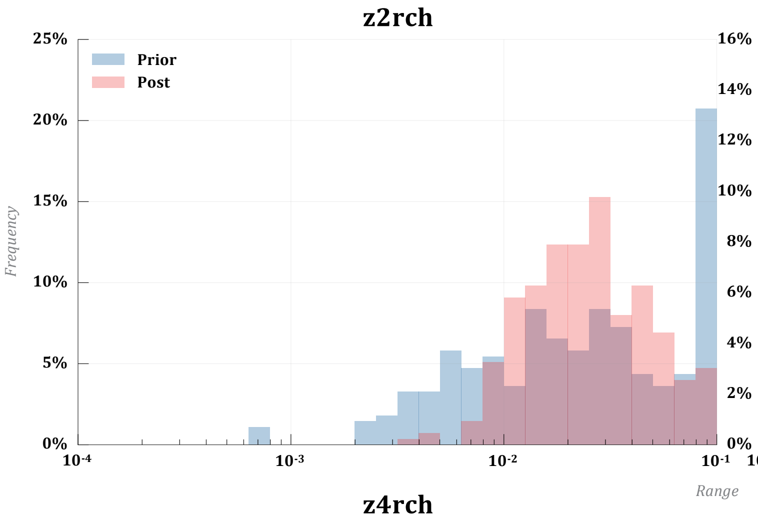

z1rch
Prior
Post
Frequency
40%
35%
30%
25%
20%
15%
10%
5%
0%
10^{-2}
10^{-1}
10^{0}

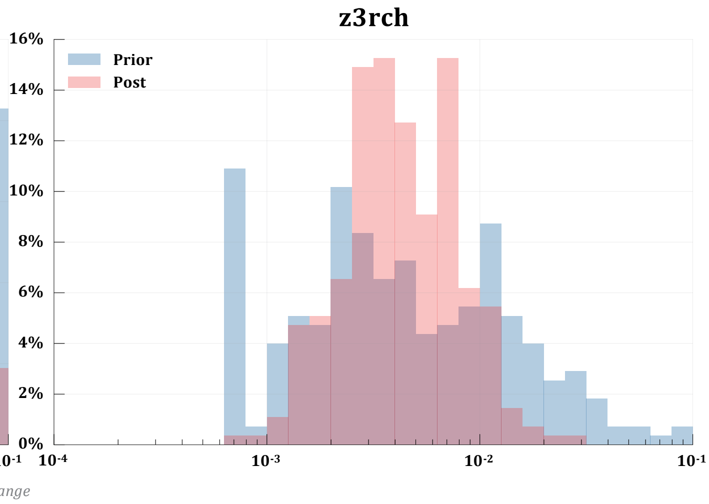

z20s
Prior
Post
120%
100%
80%
60%
40%
20%
0%
10^{-2}
10^{-1}
Range

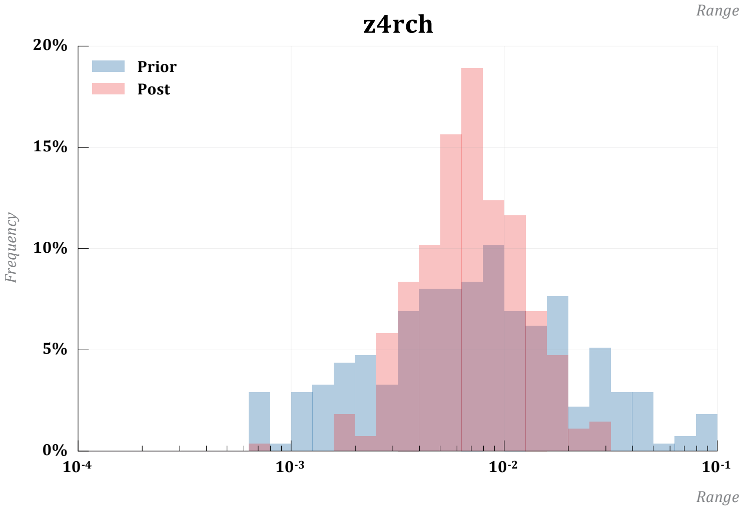

z20ss
Prior
Post
Frequency
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
10^{-7}
10^{-6}
10^{-5}
10^{-4}


z20sy
Prior
Post
40%
35%
30%
25%
20%
15%
10%
5%
0%
10^{-4}
10^{-3}
10^{-2}
Range


z20x
z20z
z21rch
z21s
z21ss
z21sy
z21x
z21z
Prior
Post
Frequency
Range

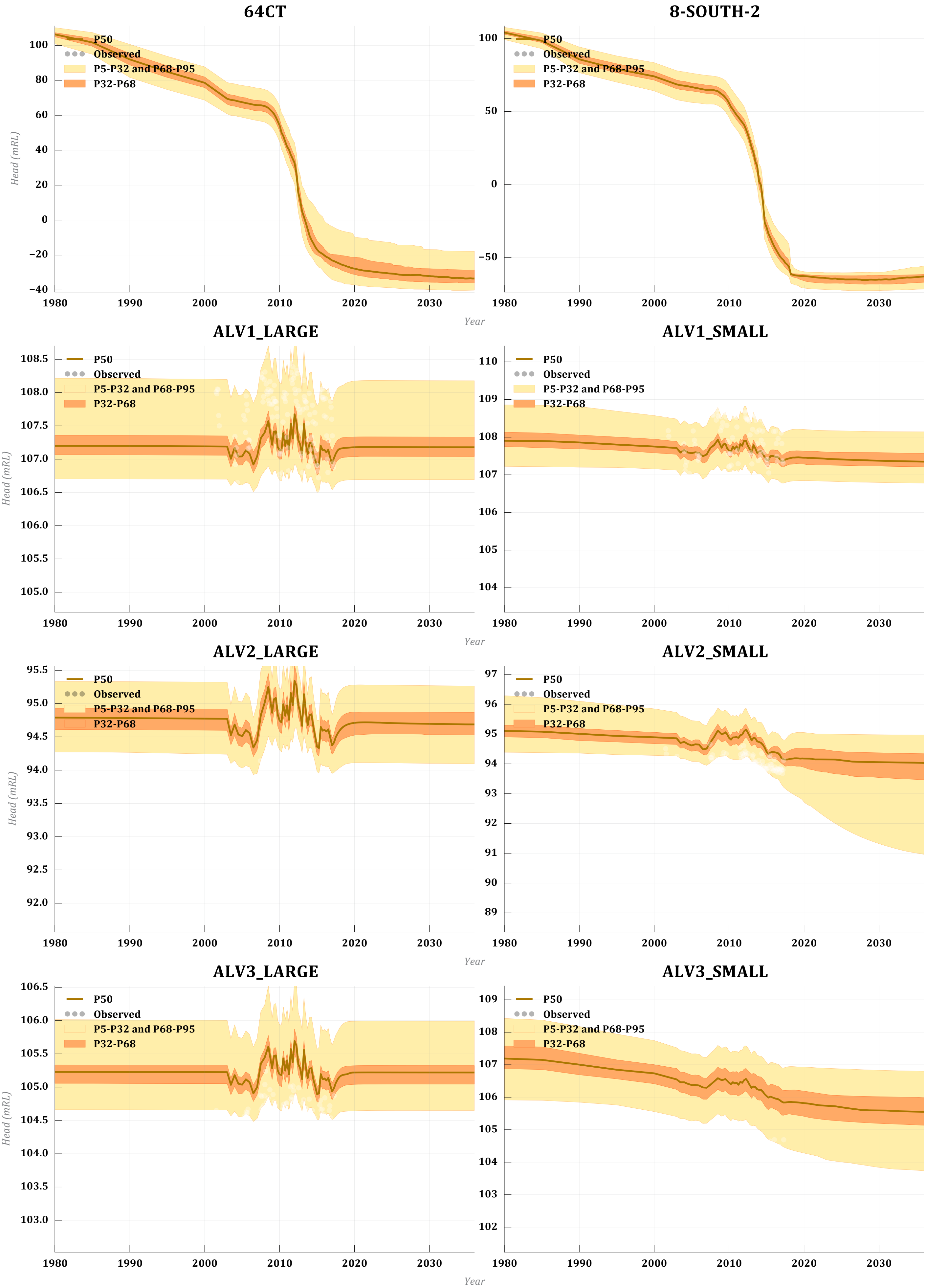

z2rch
Prior
Post
Frequency
25%
20%
15%
10%
5%
0%
10-4
10-3
10-2
10-1


z3rch
Prior
Post
16%
14%
12%
10%
8%
6%
4%
2%
0%
10-4
10-3
10-2
10-1
Range

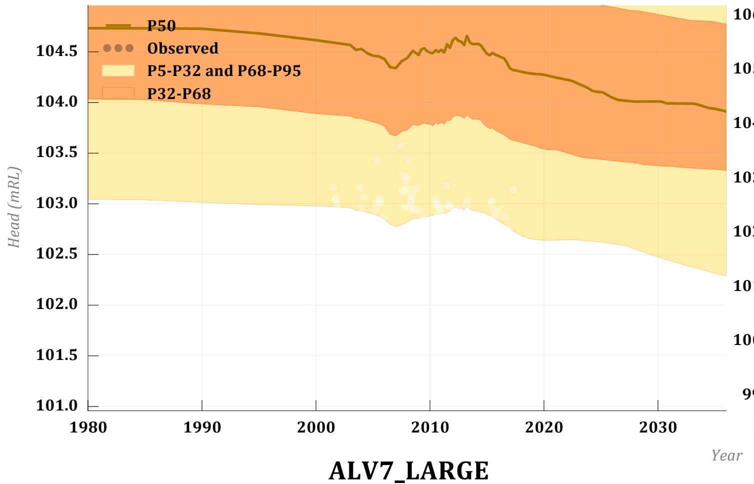

z4rch
Prior
Post
Frequency
20%
15%
10%
5%
0%
10-4
10-3
10-2
10-1
Range

Appendix A-3

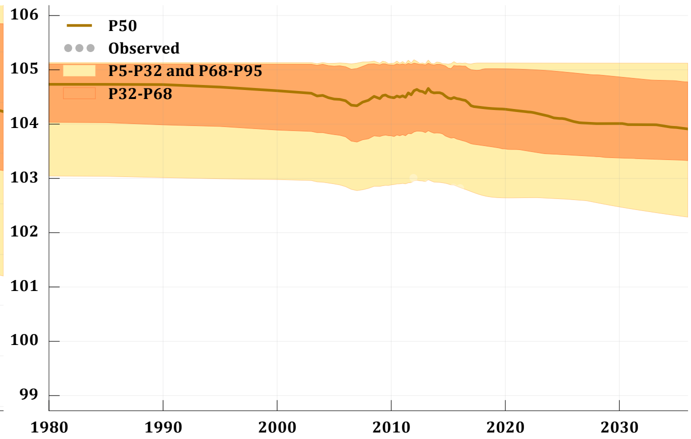
Predictive uncertainty hydrographs


64CT
8-SOUTH-2
ALV1_LARGE
ALV1_SMALL
ALV2_LARGE
ALV2_SMALL
ALV3_LARGE
ALV3_SMALL
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year

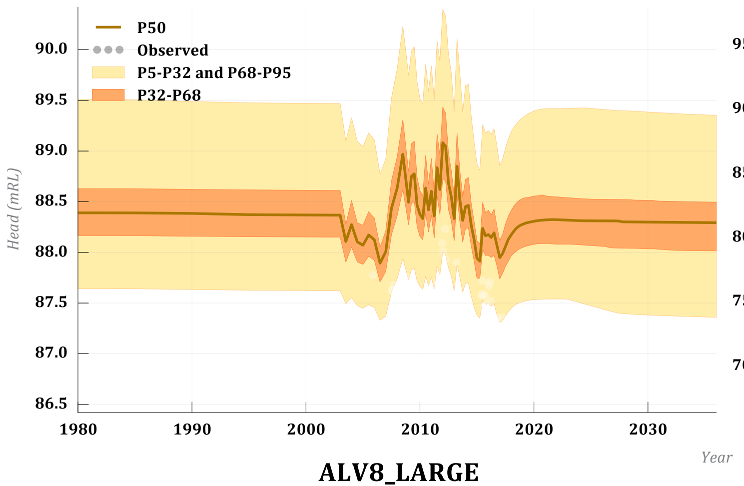
ALV4_LARGE



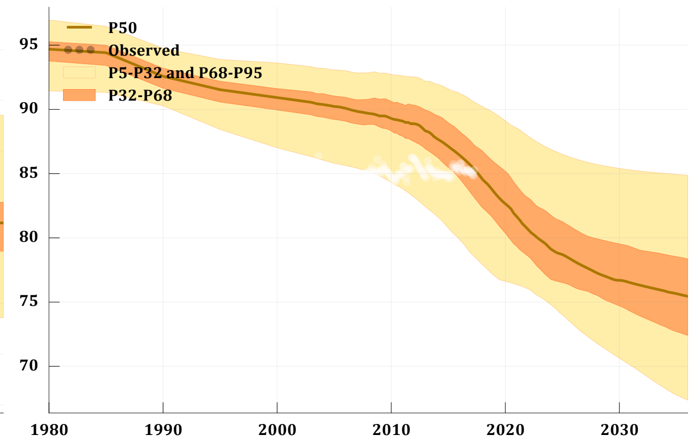
ALV4_SMALL



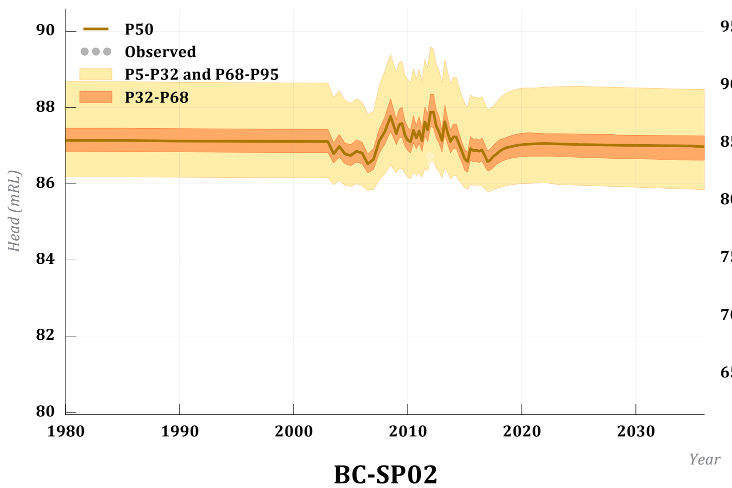
ALV7_LARGE



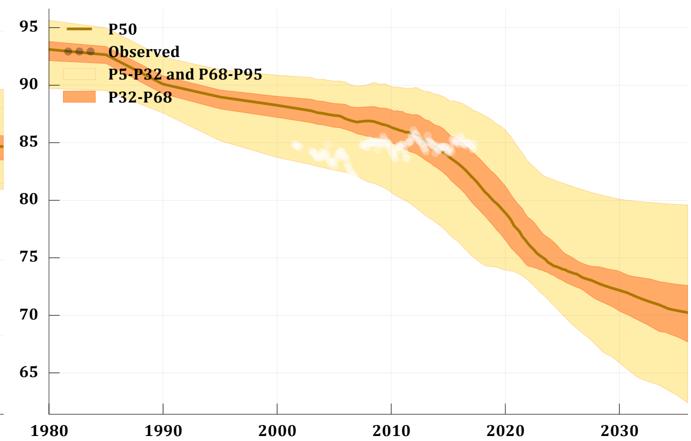
ALV7_SMALL



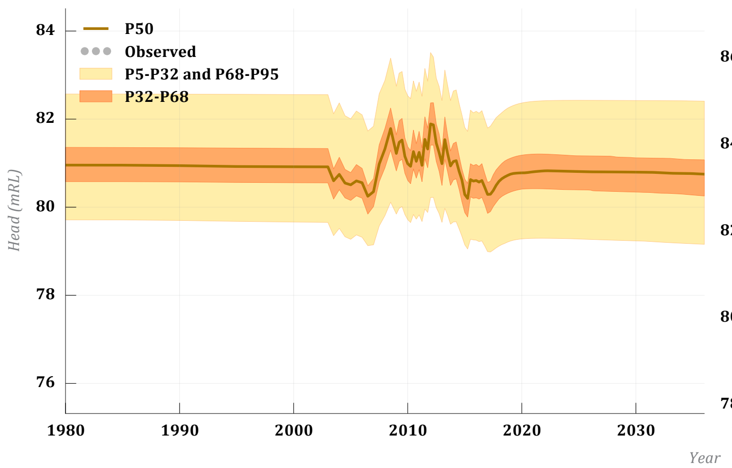
ALV8_LARGE



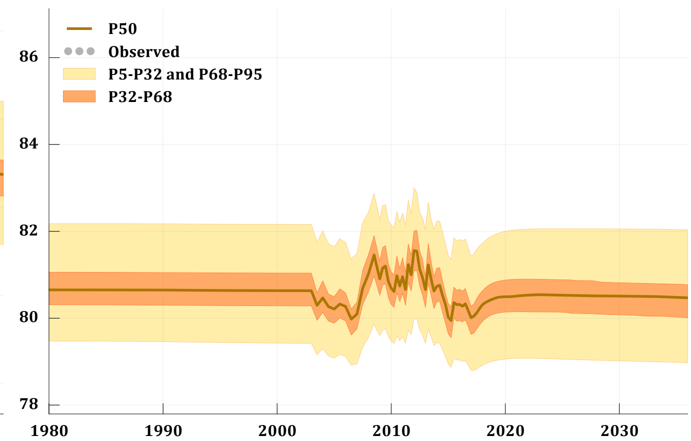
ALV8_SMALL

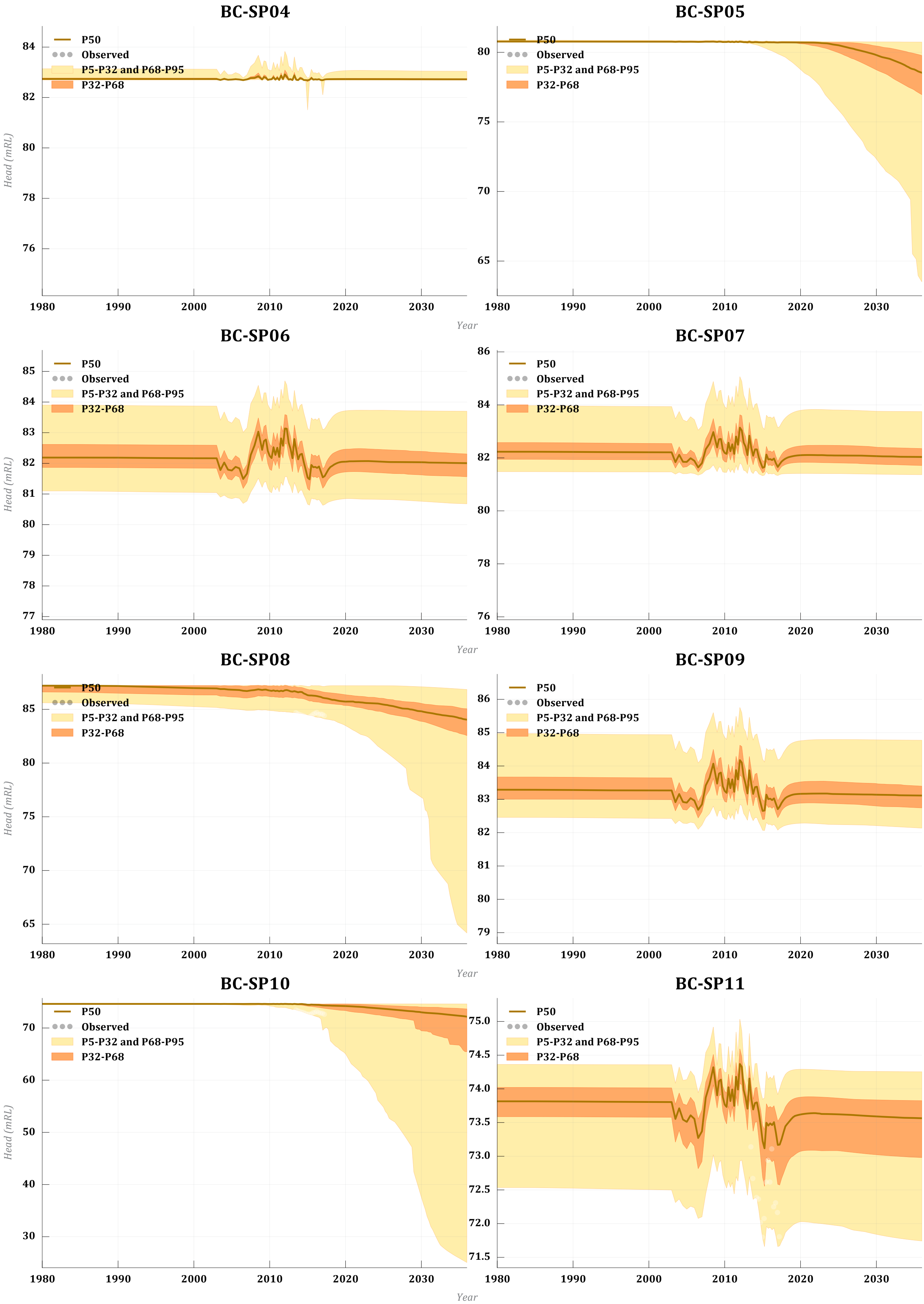


BC-SP02

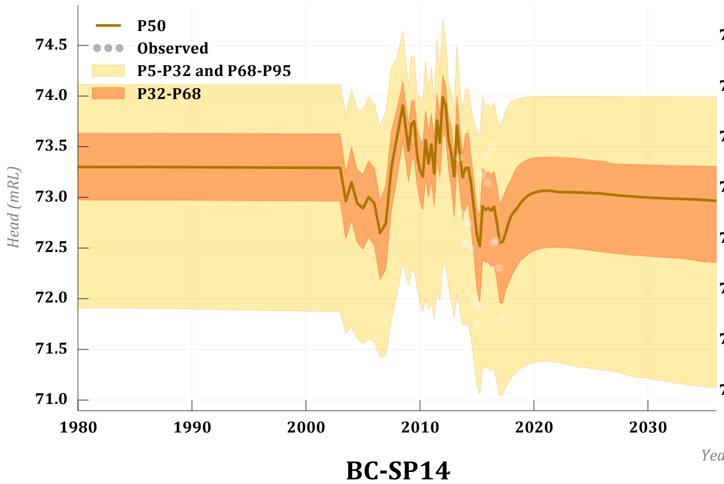


BC-SP03

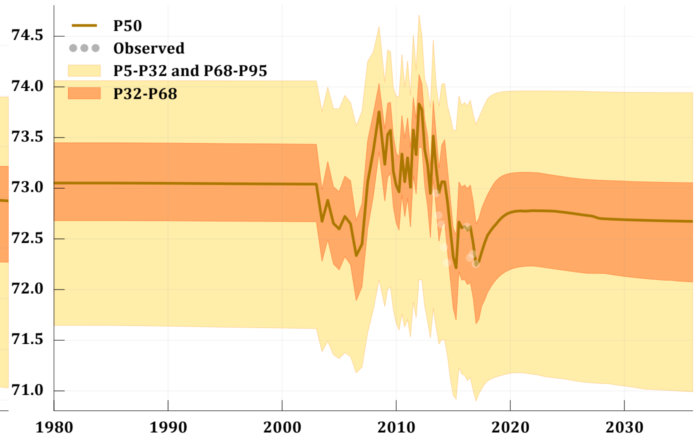



BC-SP04
BC-SP05
BC-SP06
BC-SP07
BC-SP08
BC-SP09
BC-SP10
BC-SP11
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030

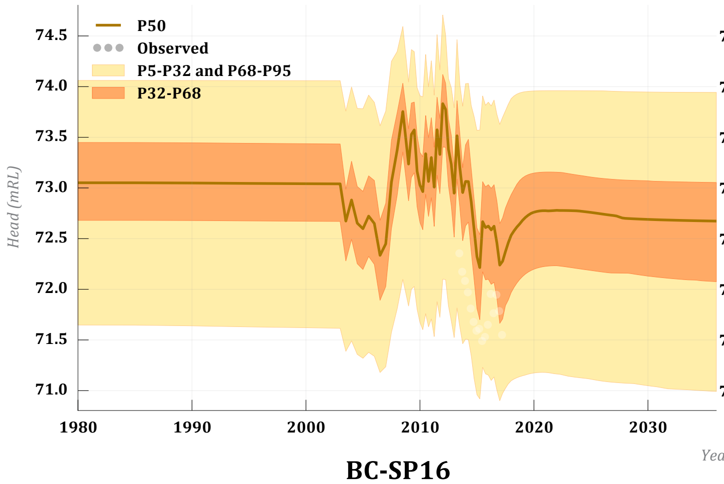
BC-SP12



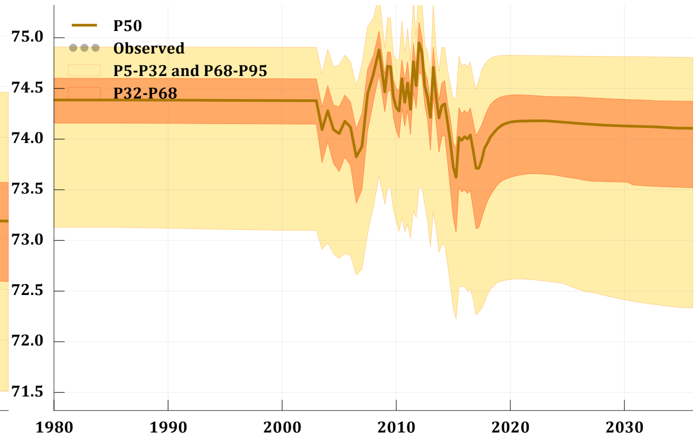
BC-SP13



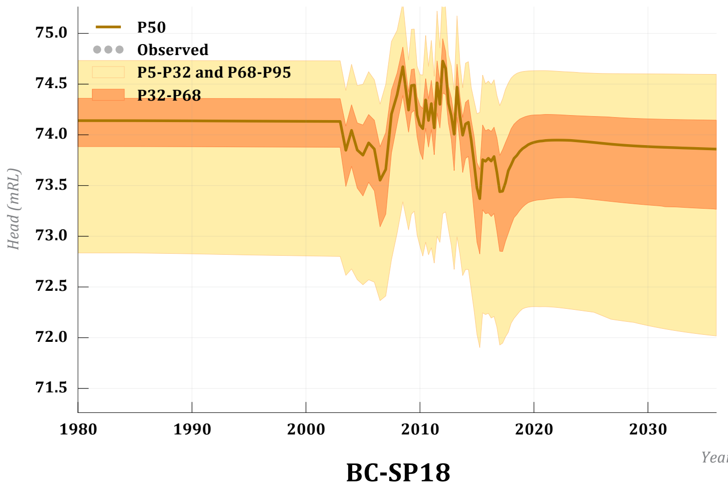
BC-SP14



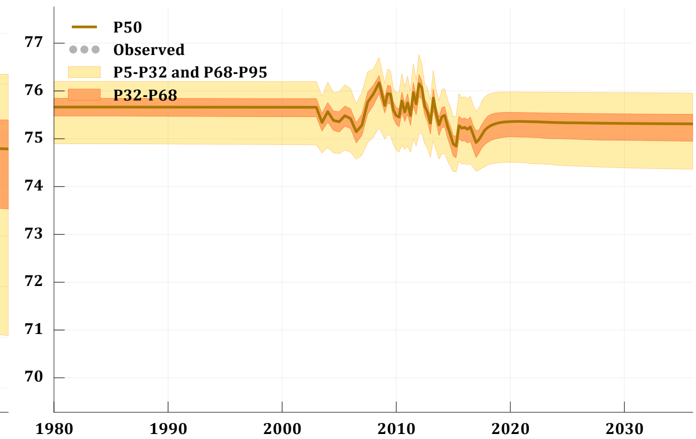
BC-SP15



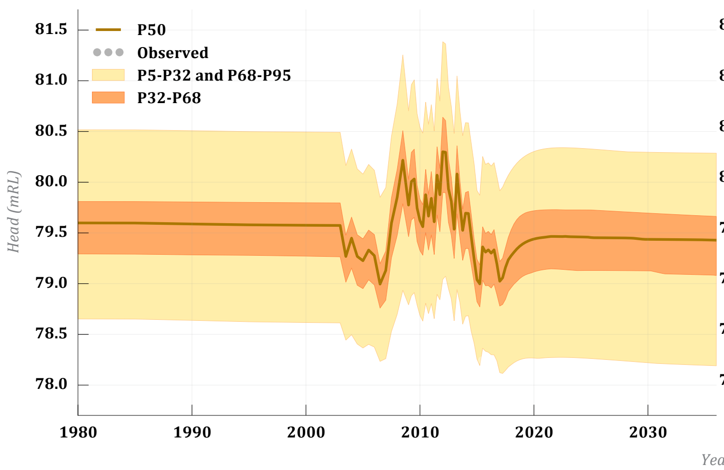
BC-SP16



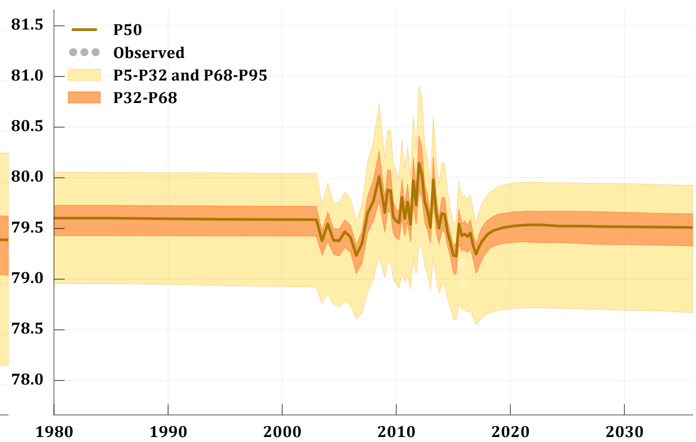
BC-SP17



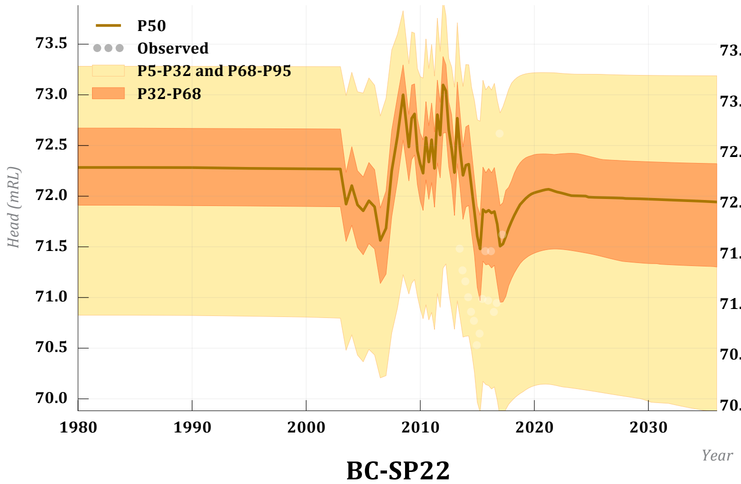
BC-SP18



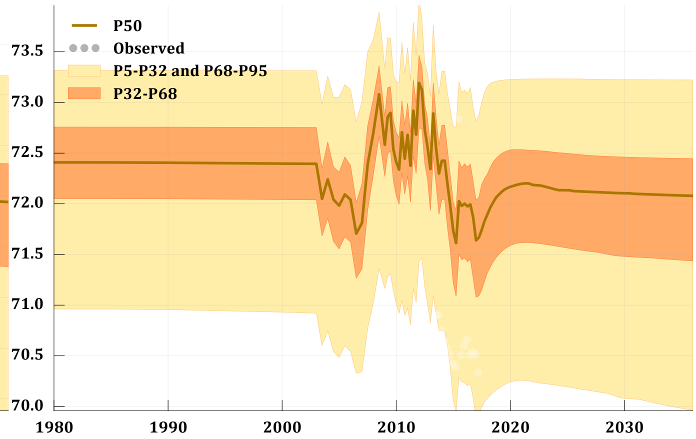
BC-SP19



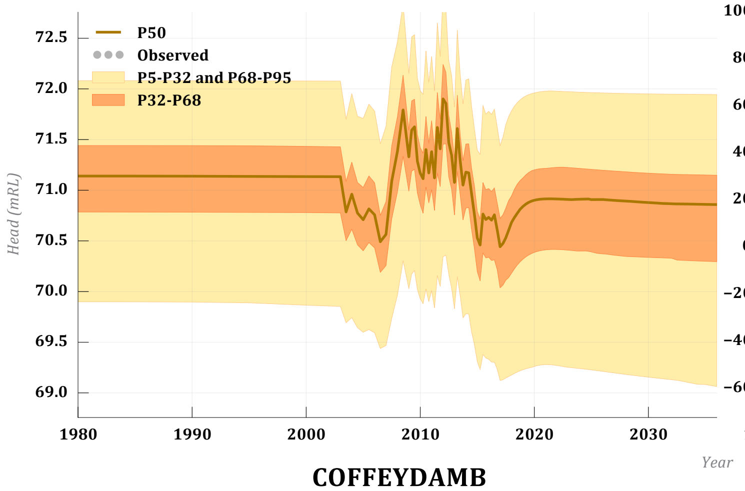
BC-SP20



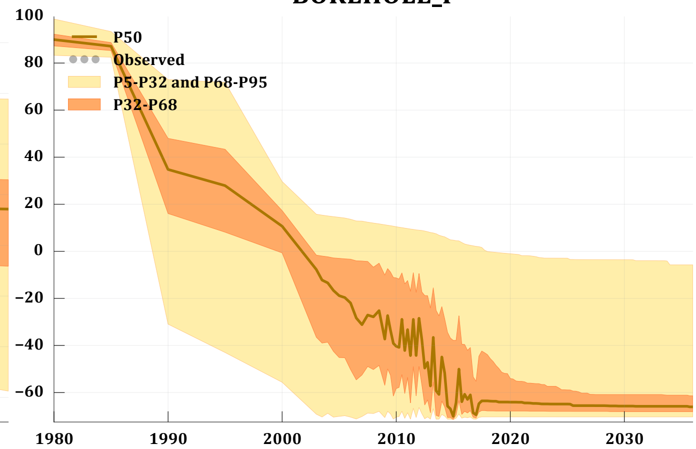
BC-SP21



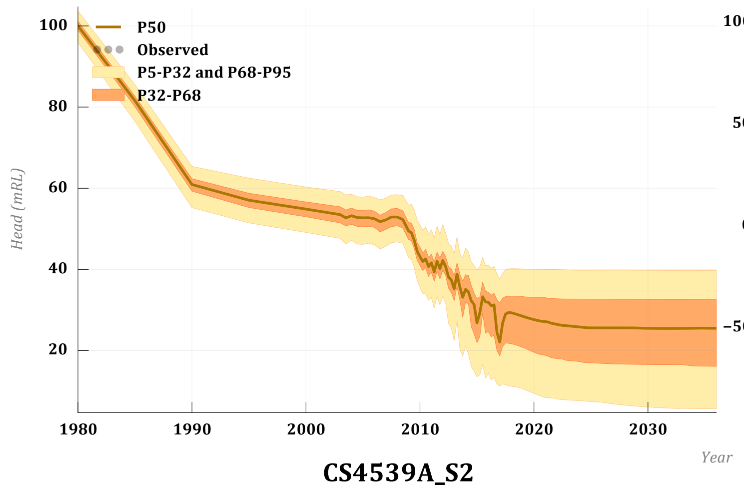
BC-SP22



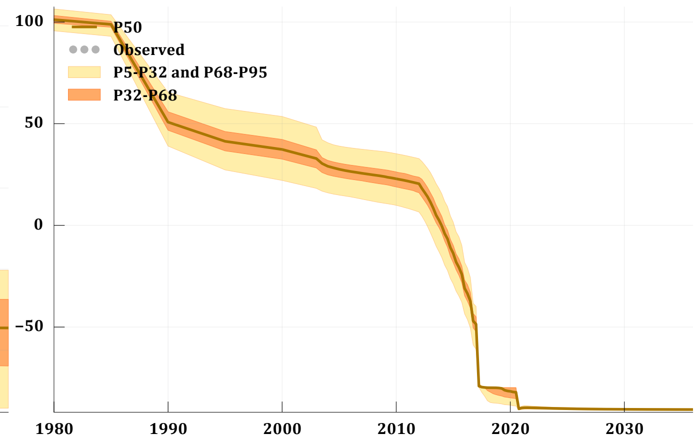
BOREHOLE_P



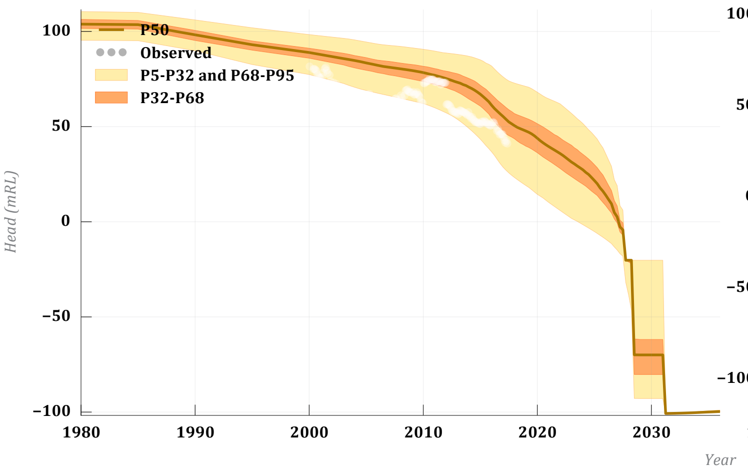
COFFEYDAMB



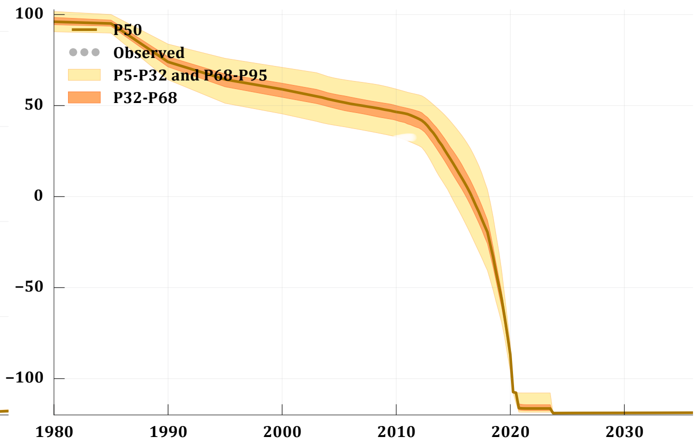
CS4536_HF7

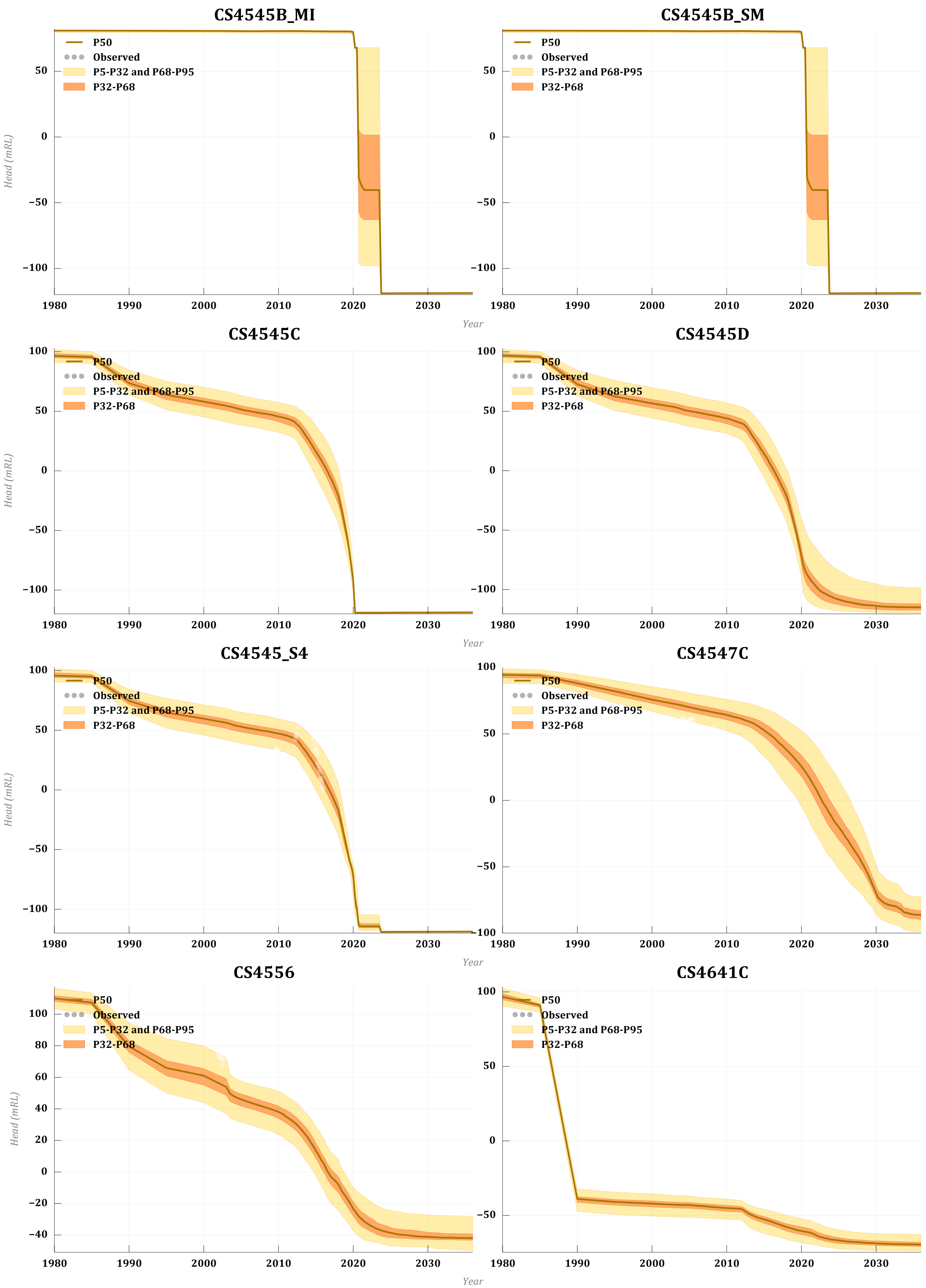


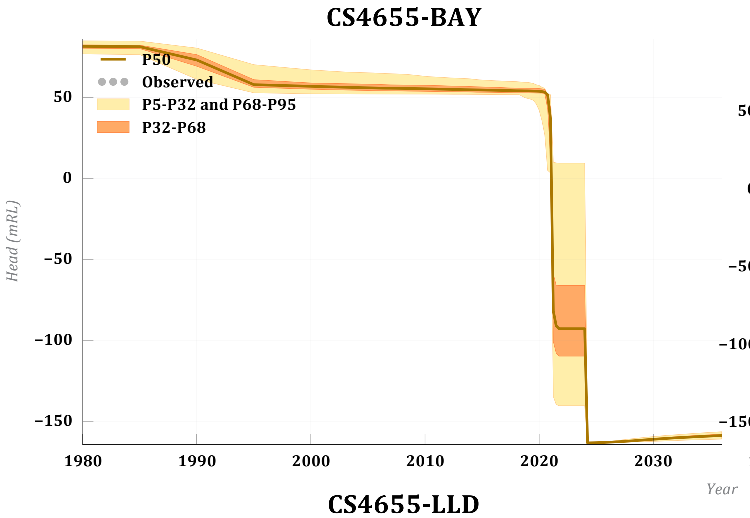
CS4539A_S2

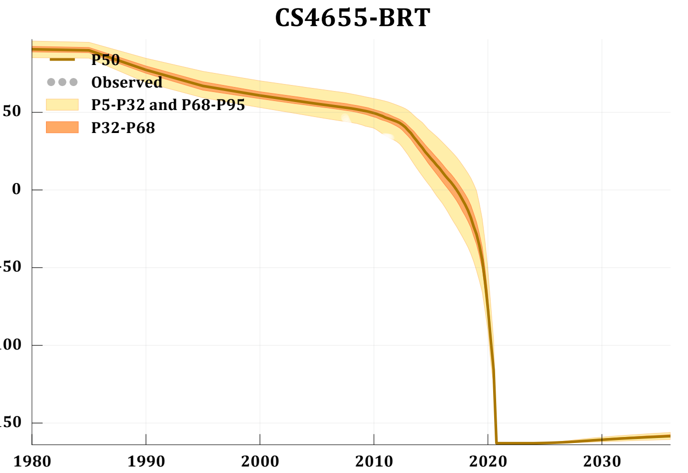


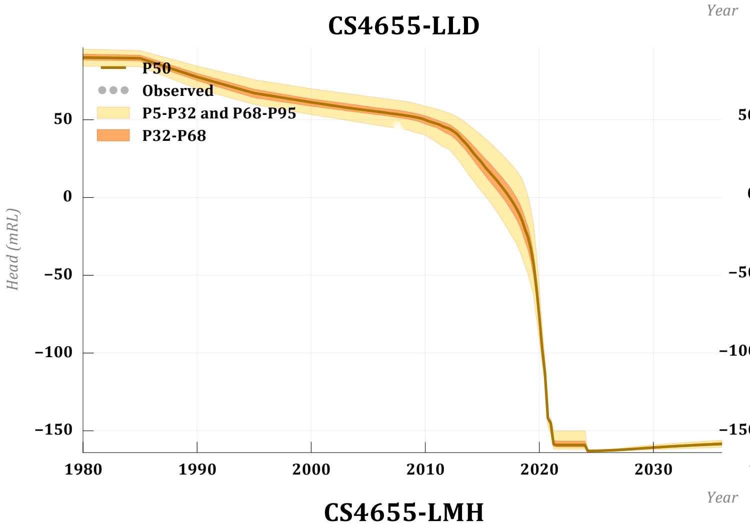
CS4545B

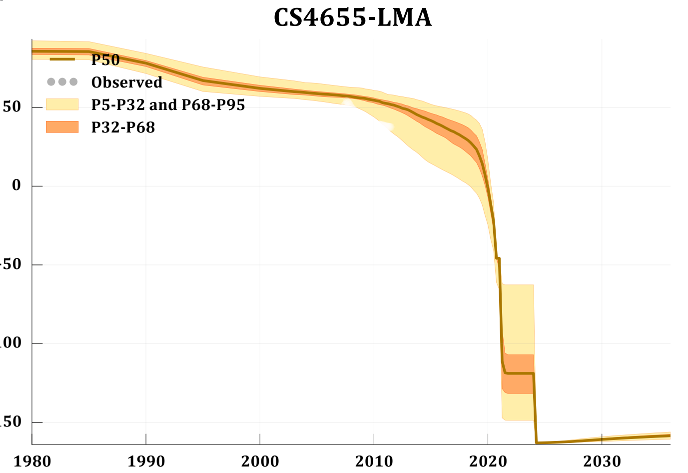


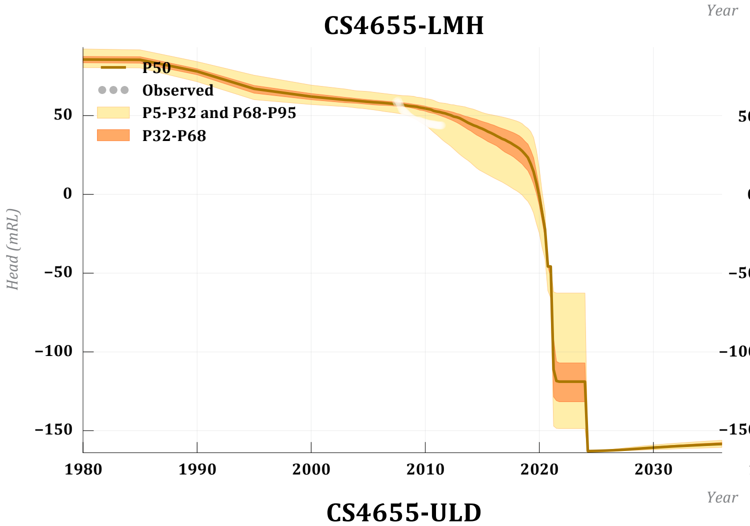

CS4545B_MI
CS4545B_SM
CS4545C
CS4545D
CS4545_S4
CS4547C
CS4556
CS4641C
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030
100
50
0
−50
−100
80
60
40
20
−20
−40

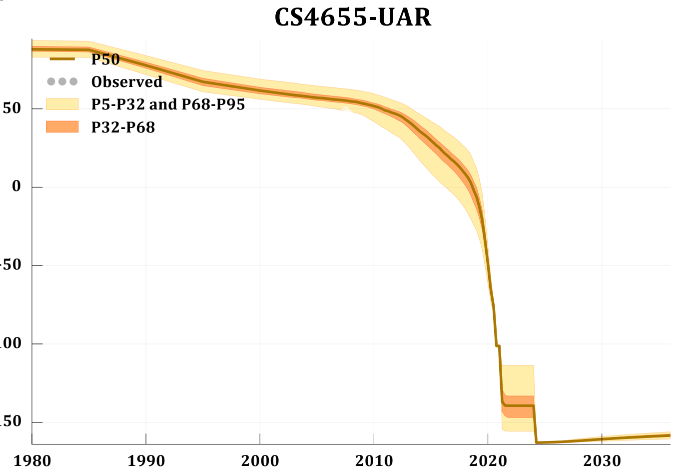

CS4655-BAY
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
50
0
−50
−100
−150
1980
1990
2000
2010
2020
2030
Year

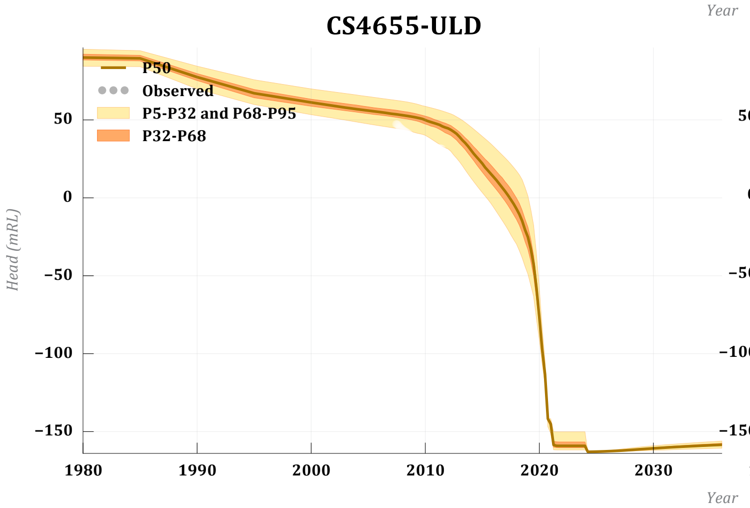

CS4655-BRT
P50
Observed
P5-P32 and P68-P95
P32-P68
50
0
−50
−100
−150
1980
1990
2000
2010
2020
2030

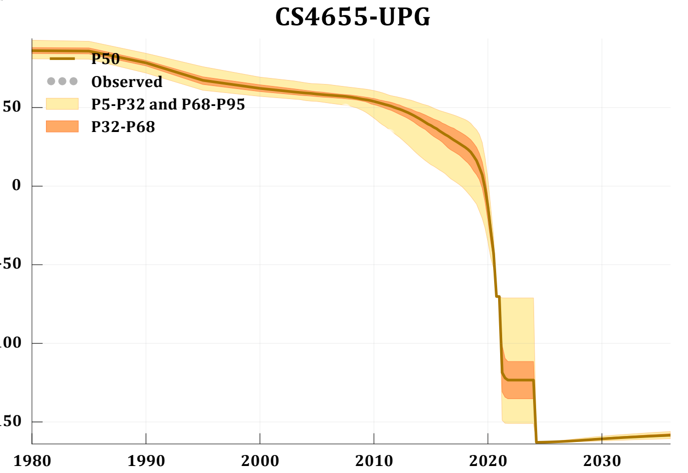

CS4655-LLD
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
50
0
−50
−100
−150
1980
1990
2000
2010
2020
2030
Year

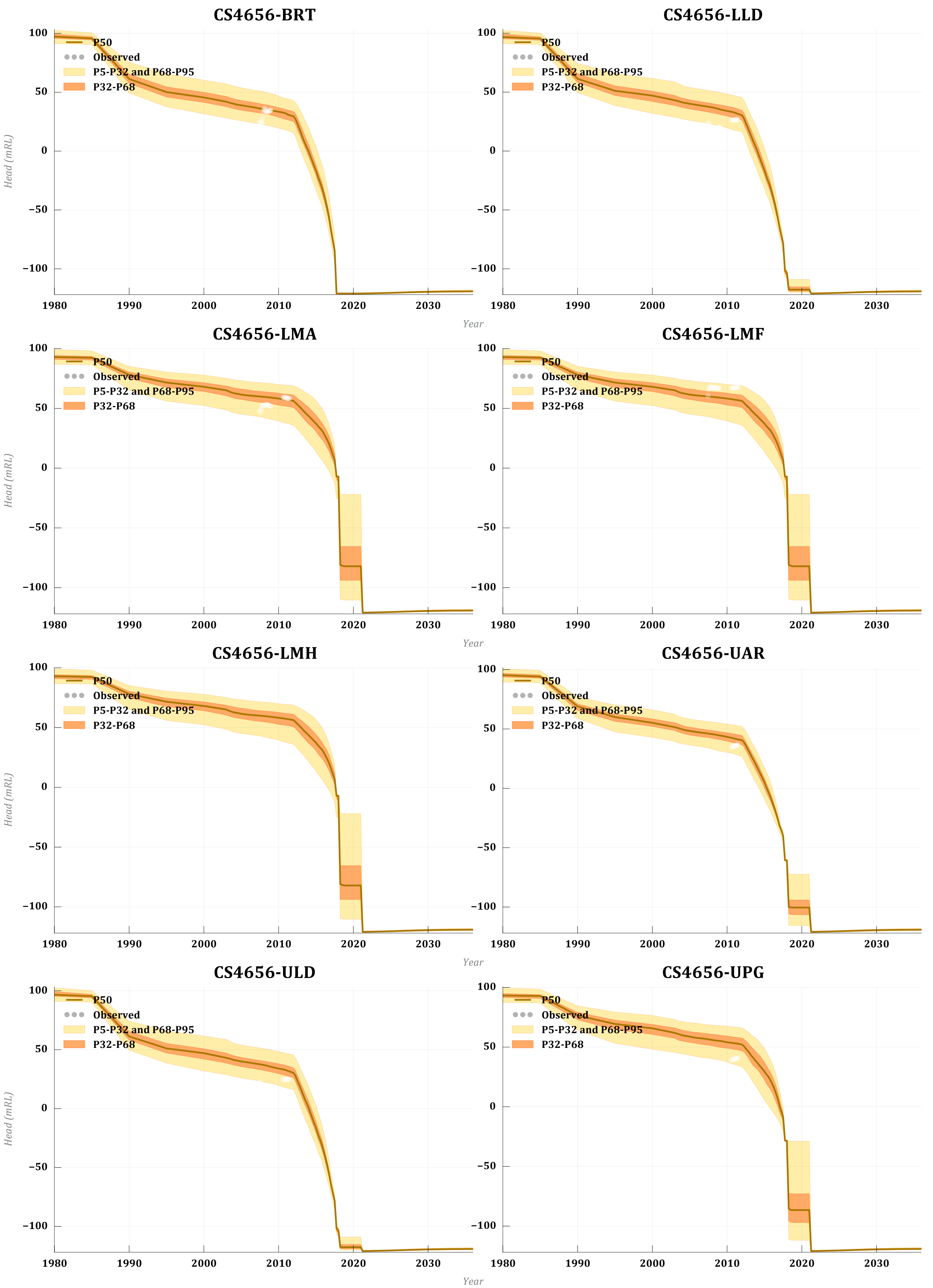

CS4655-LMA
P50
Observed
P5-P32 and P68-P95
P32-P68
50
0
−50
−100
−150
1980
1990
2000
2010
2020
2030

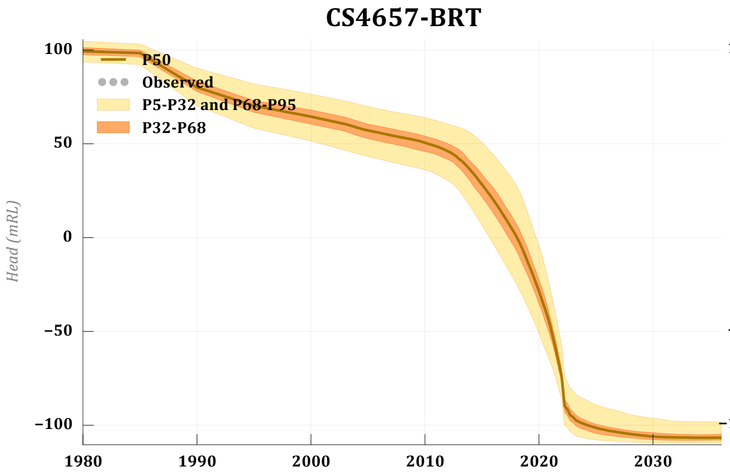

CS4655-LMH
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
50
0
−50
−100
−150
1980
1990
2000
2010
2020
2030
Year

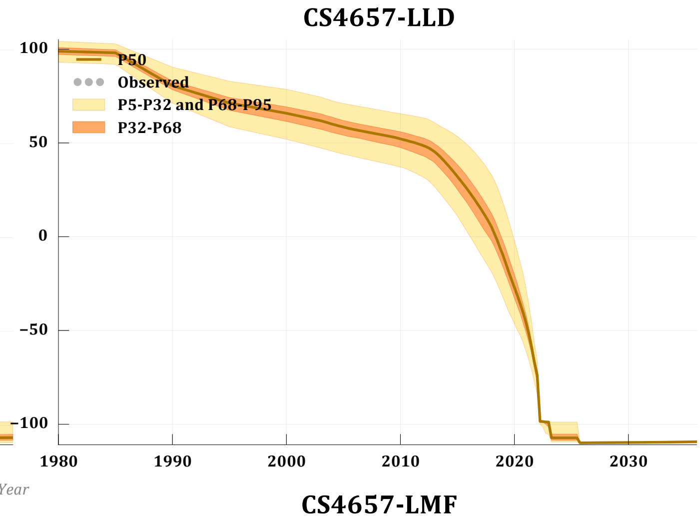

CS4655-UAR
P50
Observed
P5-P32 and P68-P95
P32-P68
50
0
−50
−100
−150
1980
1990
2000
2010
2020
2030

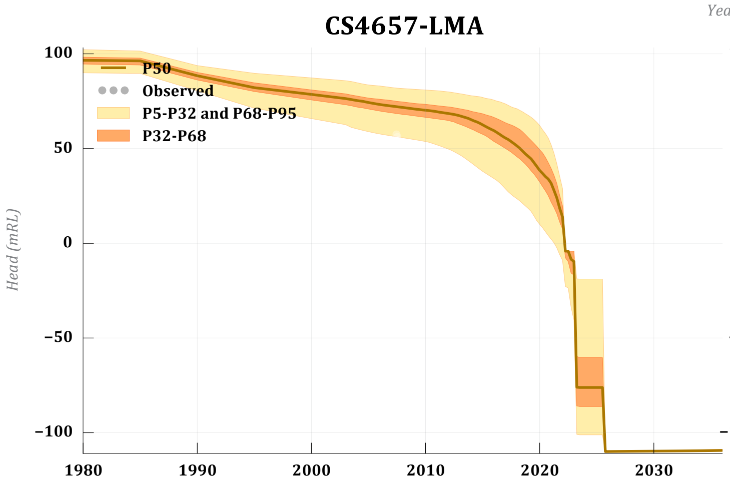

CS4655-ULD
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
50
0
−50
−100
−150
1980
1990
2000
2010
2020
2030
Year

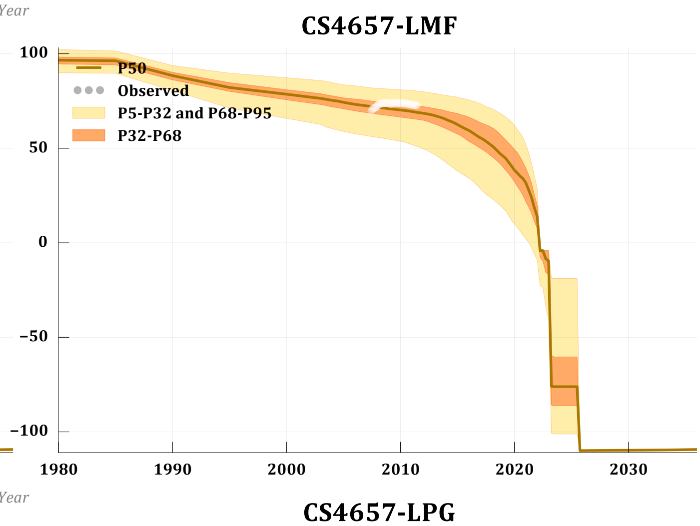

CS4655-UPG
P50
Observed
P5-P32 and P68-P95
P32-P68
50
0
−50
−100
−150
1980
1990
2000
2010
2020
2030

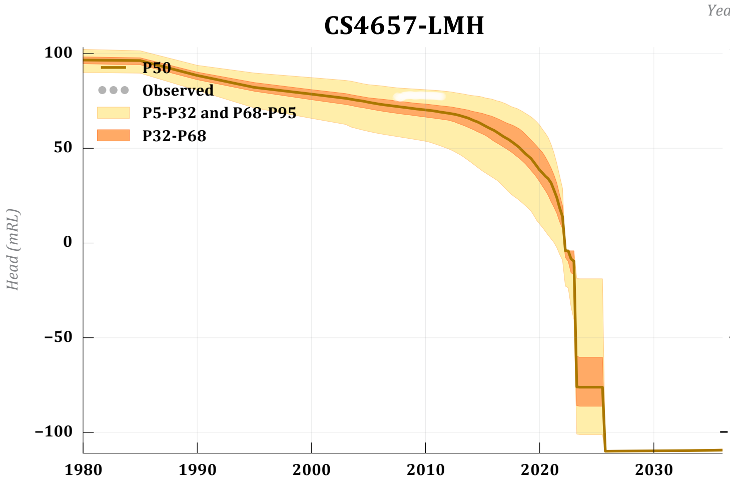

CS4656-BRT
CS4656-LLD
CS4656-LMA
CS4656-LMF
CS4656-LMH
CS4656-UAR
CS4656-ULD
CS4656-UPG
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
100
50
0
−50
−100
1980
1990
2000
2010
2020
2030

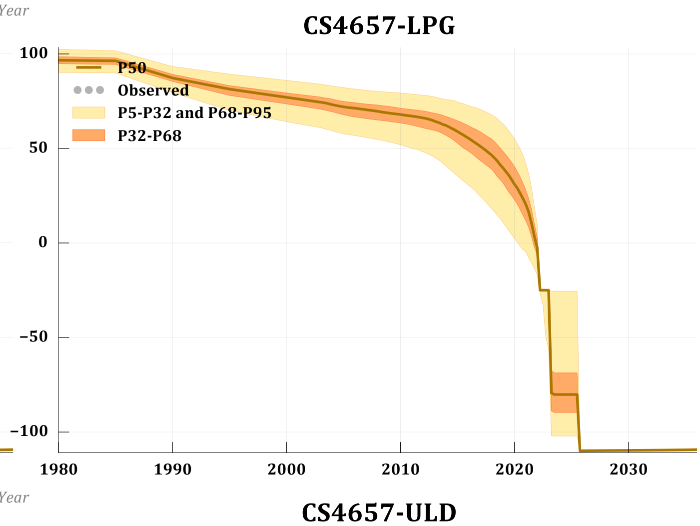

CS4657-BRT
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
100
50
0
−50
−100
1980
1990
2000
2010
2020
2030

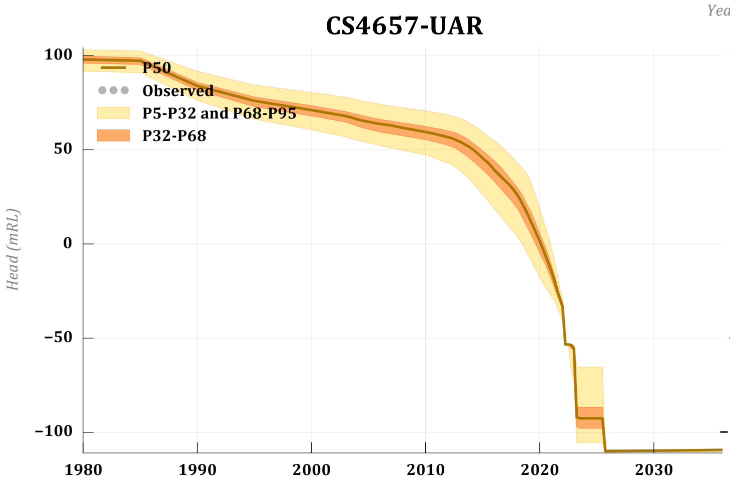

CS4657-LLD
P50
Observed
P5-P32 and P68-P95
P32-P68
100
50
0
−50
−100
1980
1990
2000
2010
2020
2030
Year

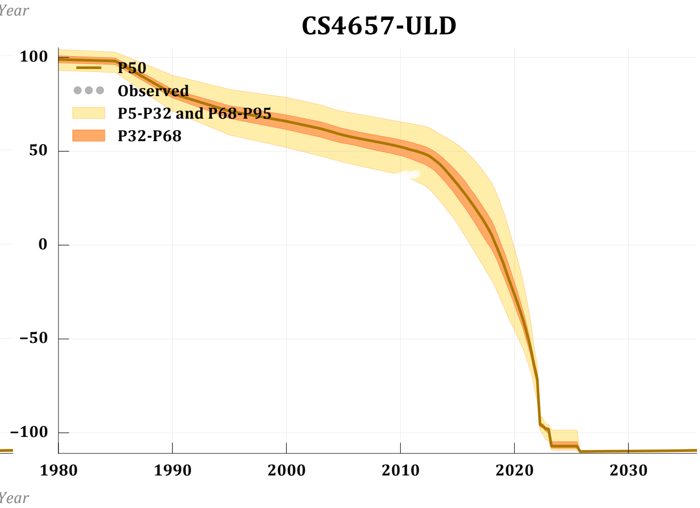

CS4657-LMA
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
100
50
0
−50
−100
1980
1990
2000
2010
2020
2030

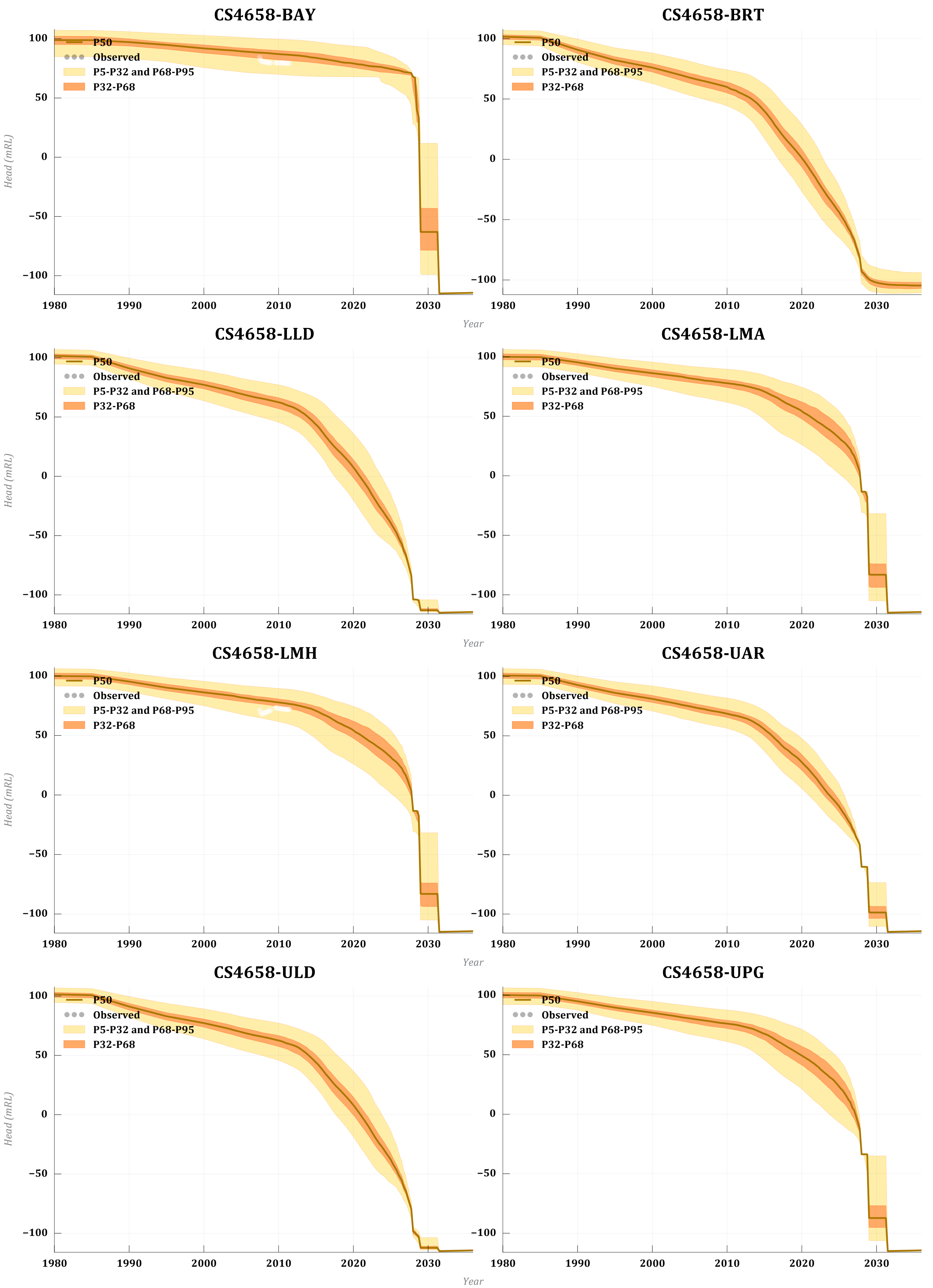

CS4657-LMF
P50
Observed
P5-P32 and P68-P95
P32-P68
100
50
0
−50
−100
1980
1990
2000
2010
2020
2030
Year

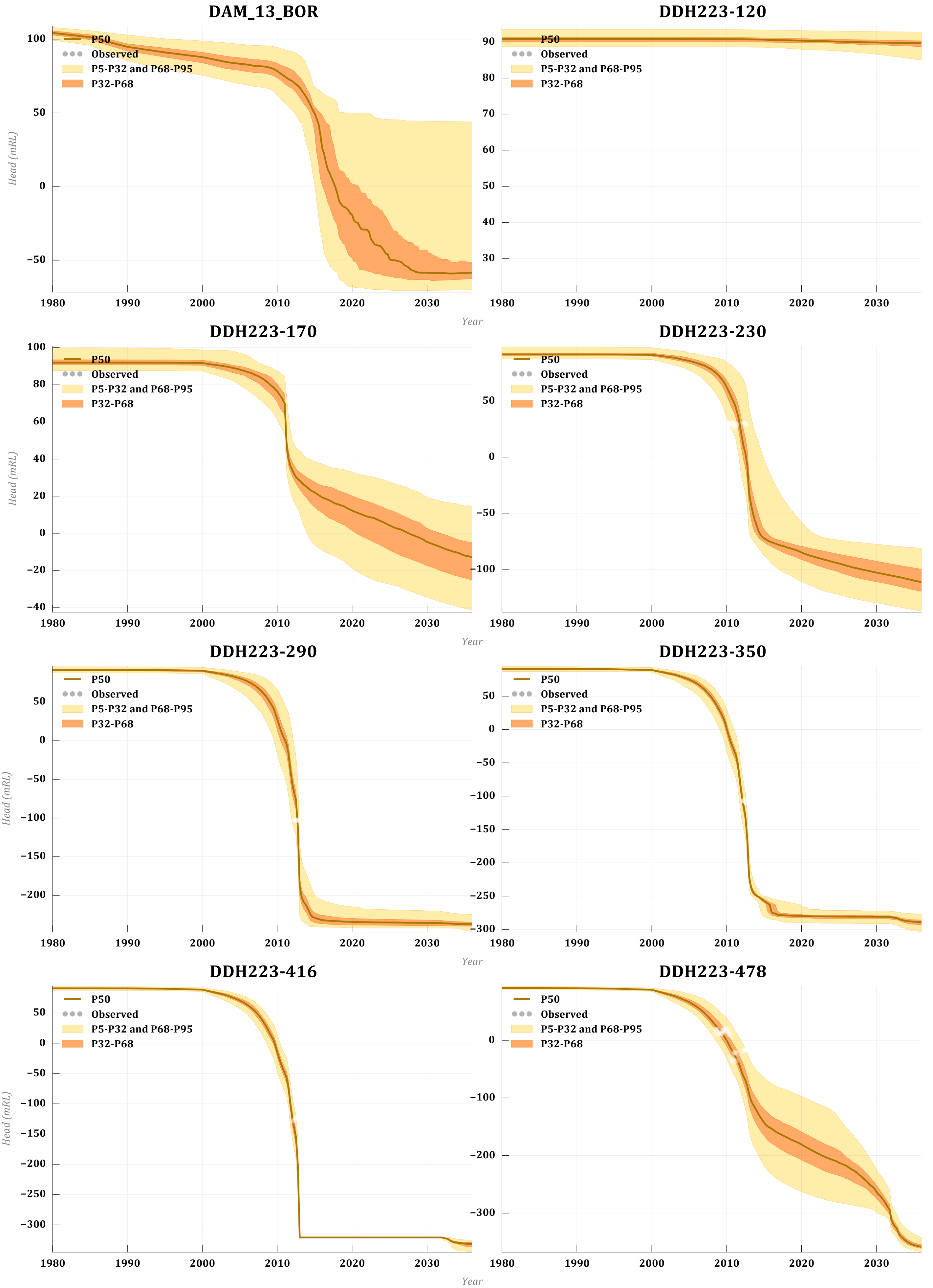

CS4657-LMH
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
100
50
0
−50
−100
1980
1990
2000
2010
2020
2030

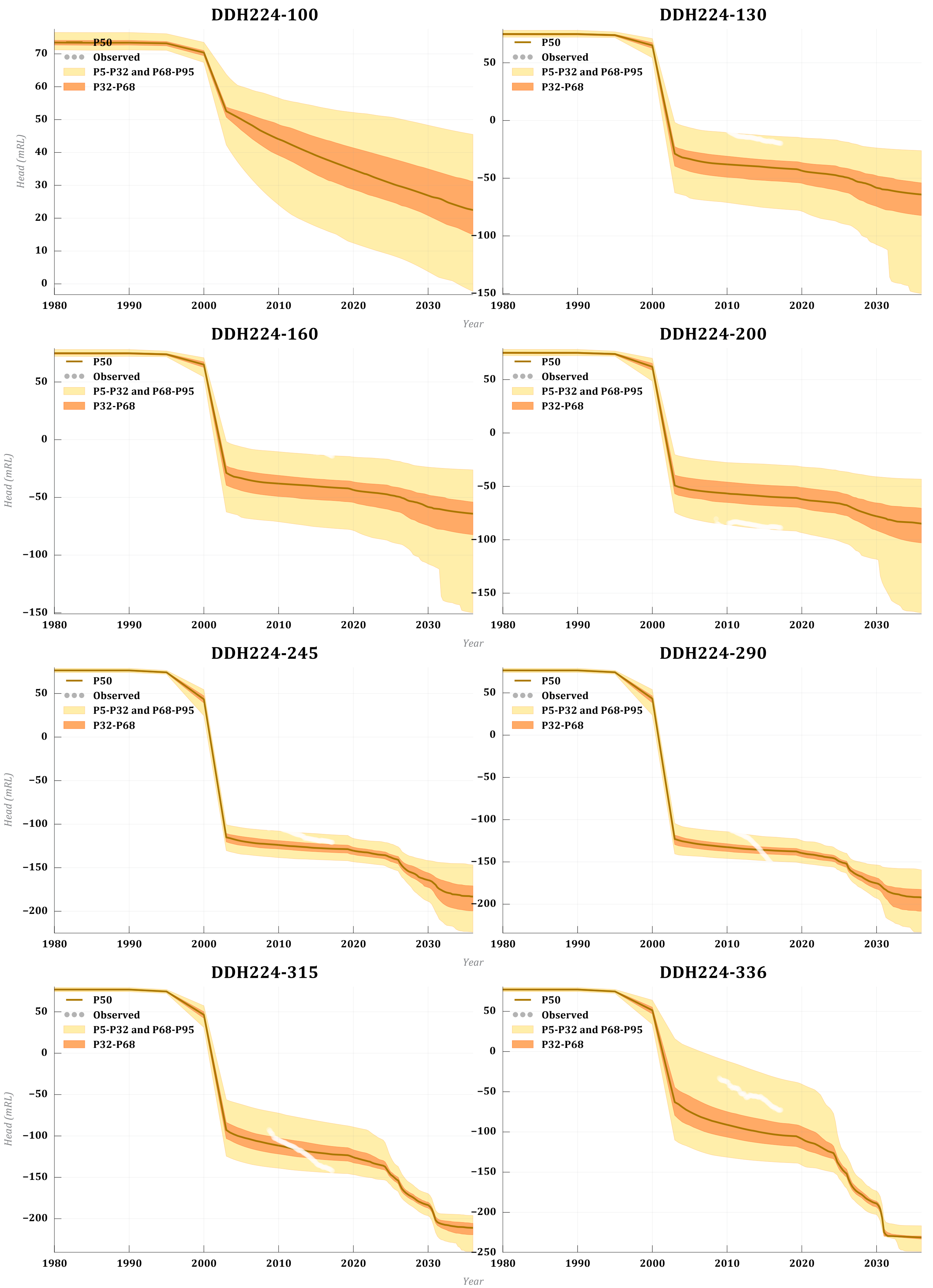

CS4657-LPG
P50
Observed
P5-P32 and P68-P95
P32-P68
100
50
0
−50
−100
1980
1990
2000
2010
2020
2030
Year

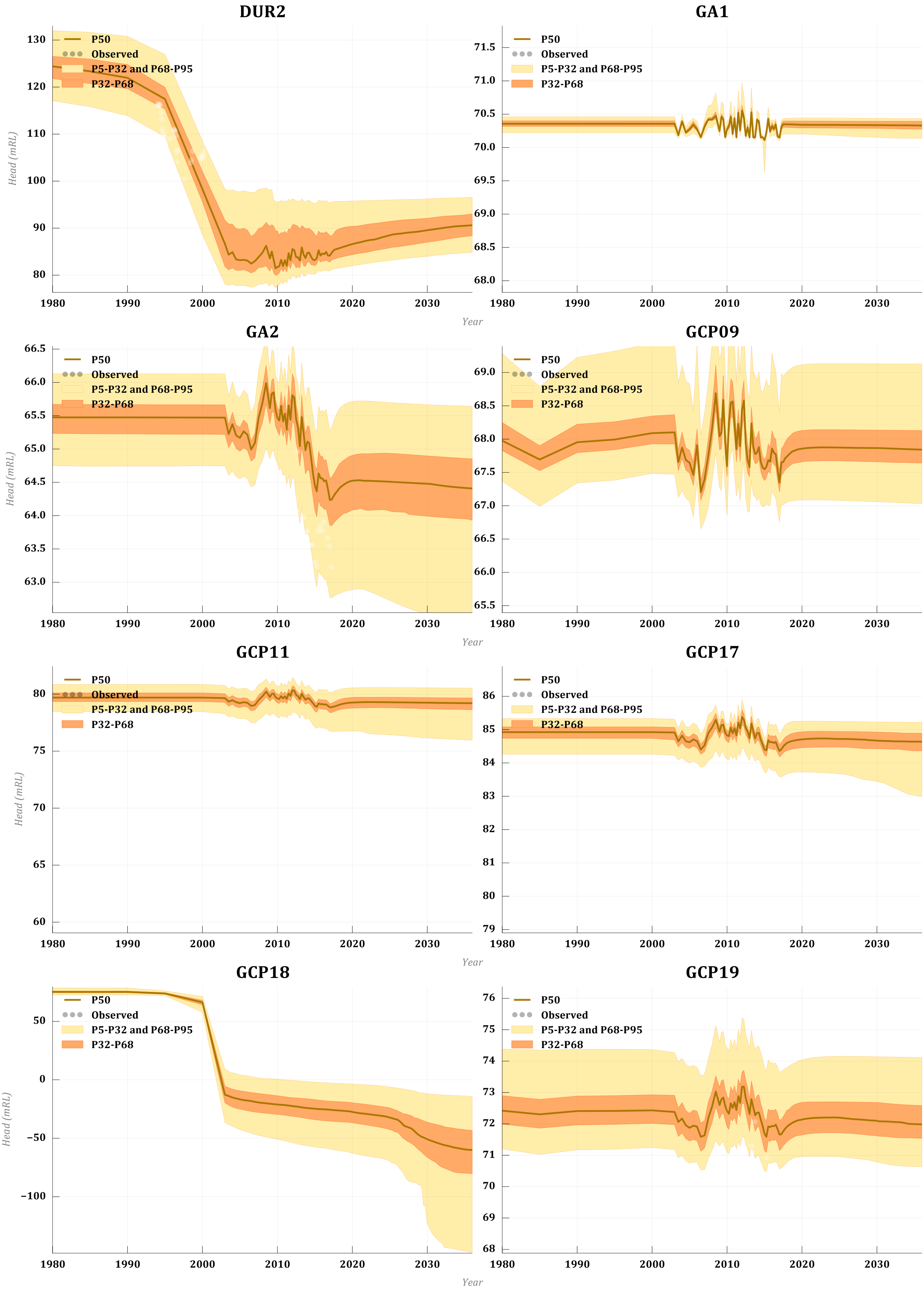

CS4657-UAR
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
100
50
0
−50
−100
1980
1990
2000
2010
2020
2030


CS4657-ULD
P50
Observed
P5-P32 and P68-P95
P32-P68
100
50
0
−50
−100
1980
1990
2000
2010
2020
2030
Year

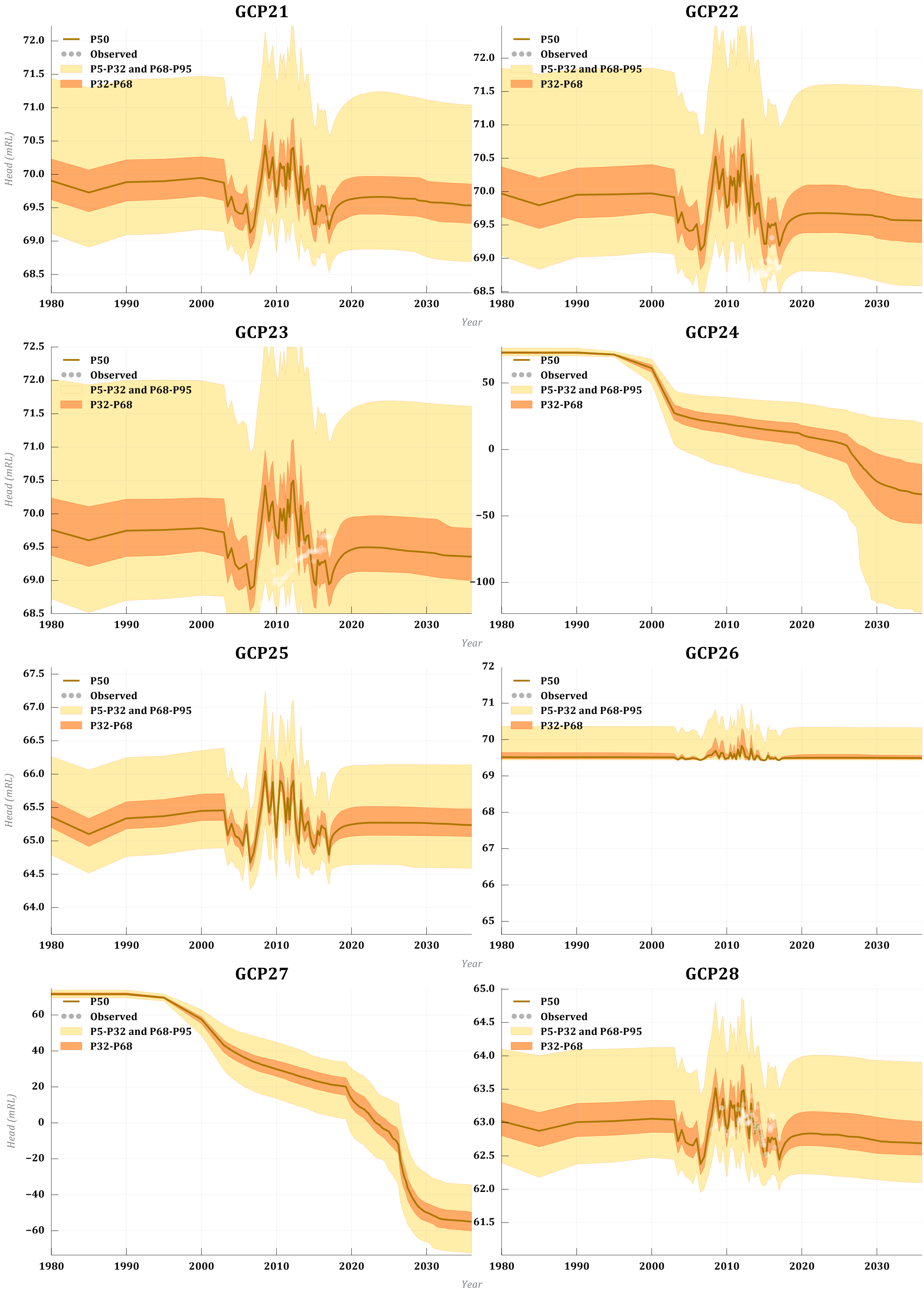

CS4658-BAY
CS4658-BRT
CS4658-LLD
CS4658-LMA
CS4658-LMH
CS4658-UAR
CS4658-ULD
CS4658-UPG
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
100
50
0
−50
−100
1980
1990
2000
2010
2020
2030

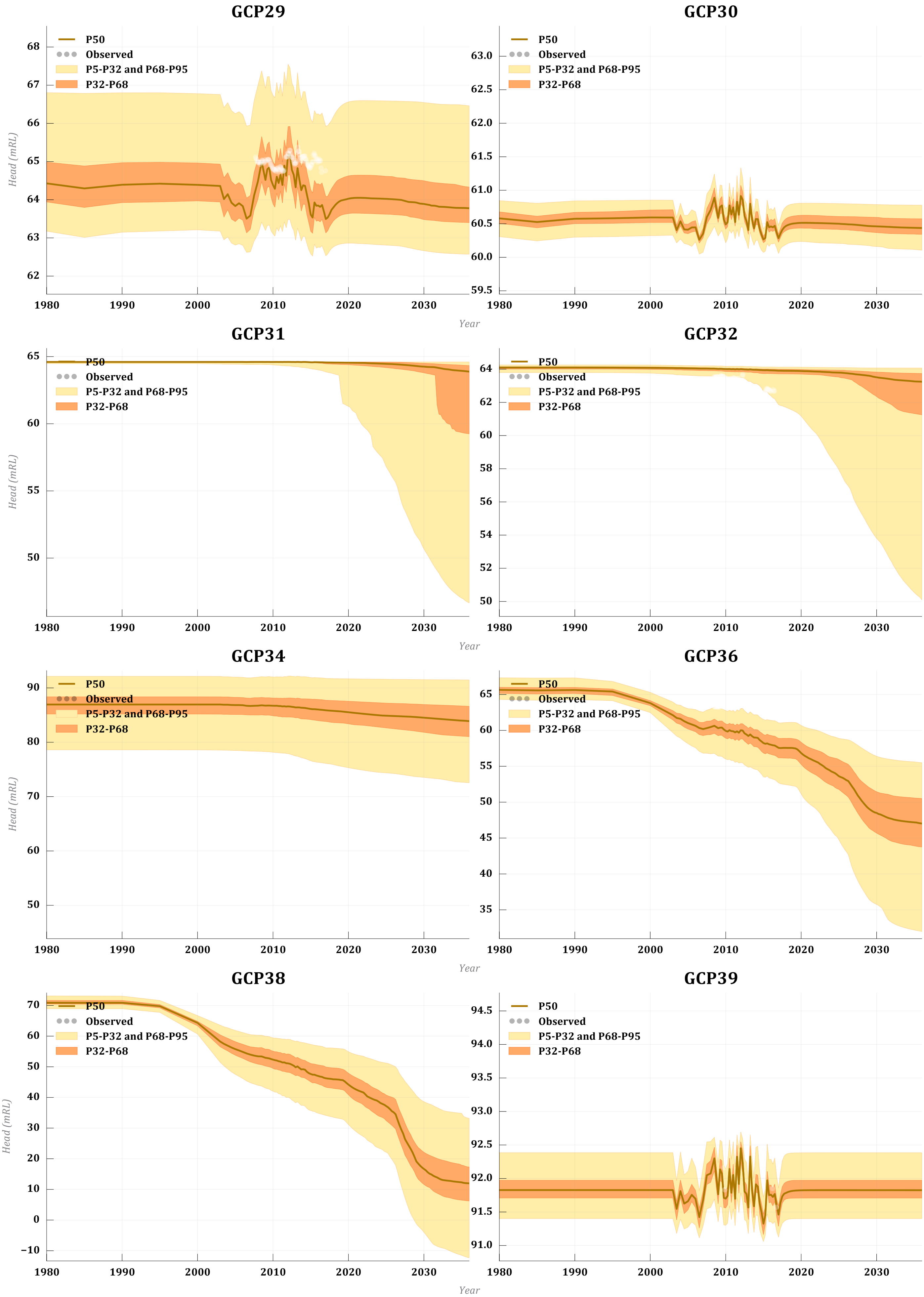

DAM_13_BOR
DDH223-120
DDH223-170
DDH223-230
DDH223-290
DDH223-350
DDH223-416
DDH223-478
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030


DDH224-100
DDH224-130
DDH224-160
DDH224-200
DDH224-245
DDH224-290
DDH224-315
DDH224-336
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year

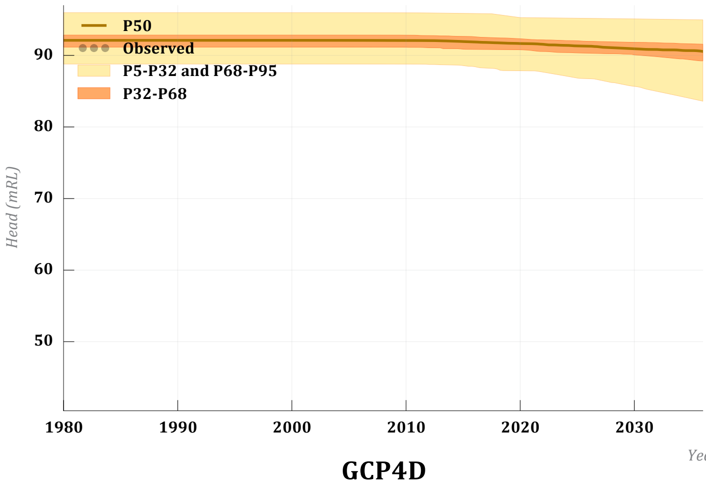


DUR2
GA1
GA2
GCP09
GCP11
GCP17
GCP18
GCP19
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030

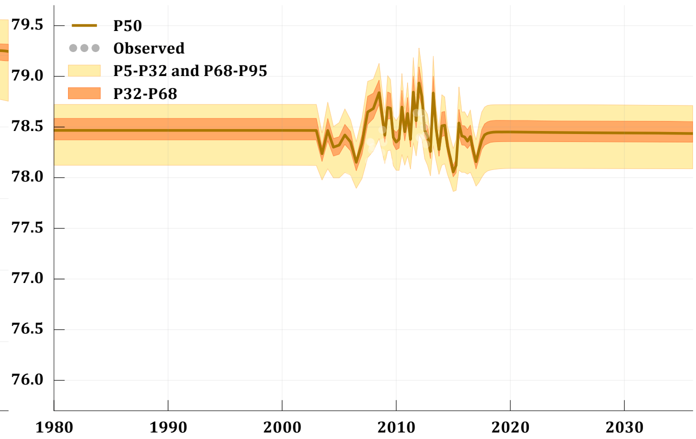

GCP21
GCP22
GCP23
GCP24
GCP25
GCP26
GCP27
GCP28
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year


GCP29
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
GCP30
GCP31
GCP32
GCP34
GCP36
GCP38
GCP39
Year
1980
1990
2000
2010
2020
2030

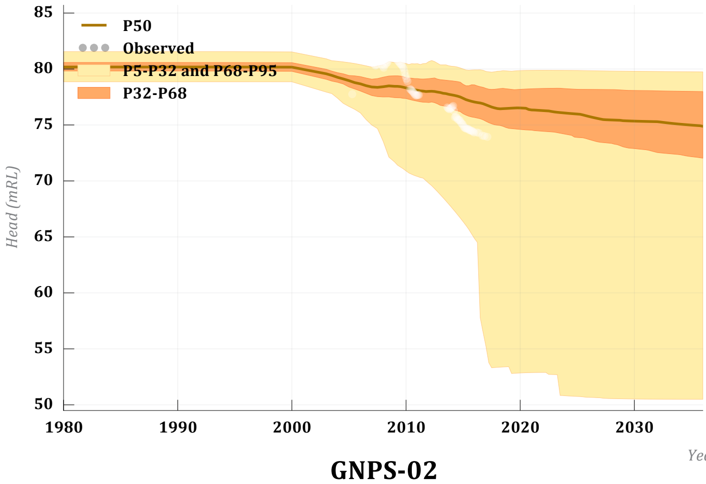
GCP3D



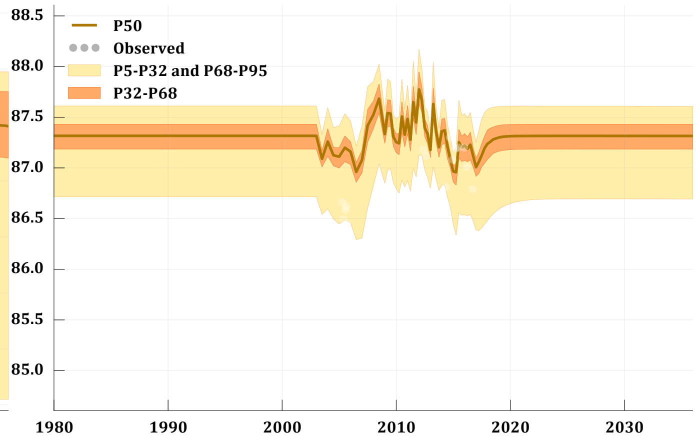
GCP3S



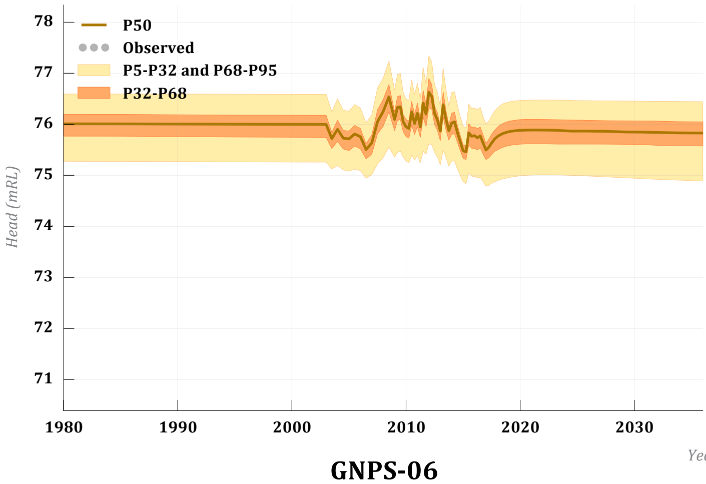
GCP4D



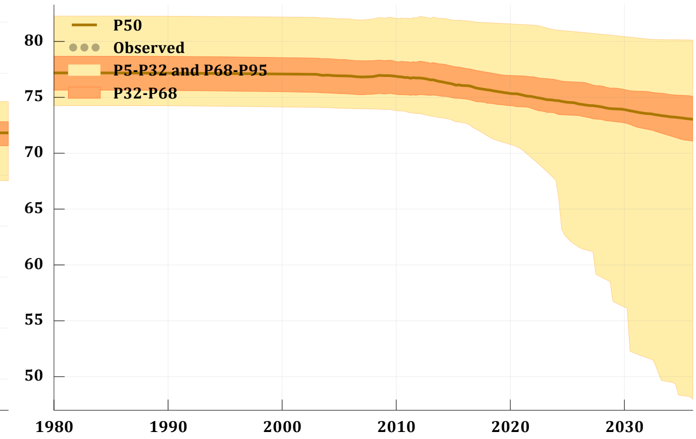
GCP4S



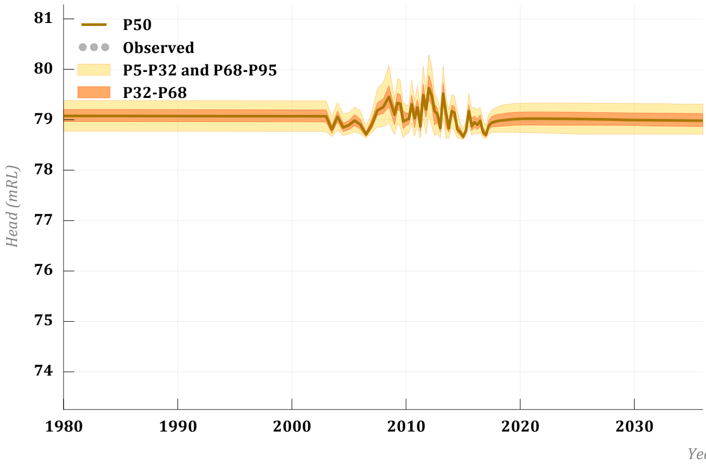
GNPS-02



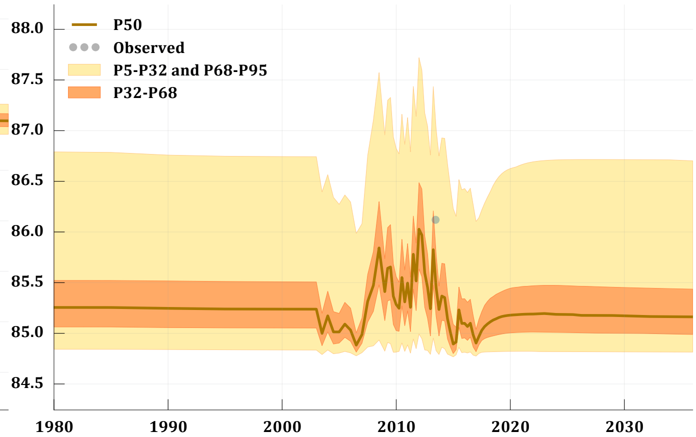
GNPS-05



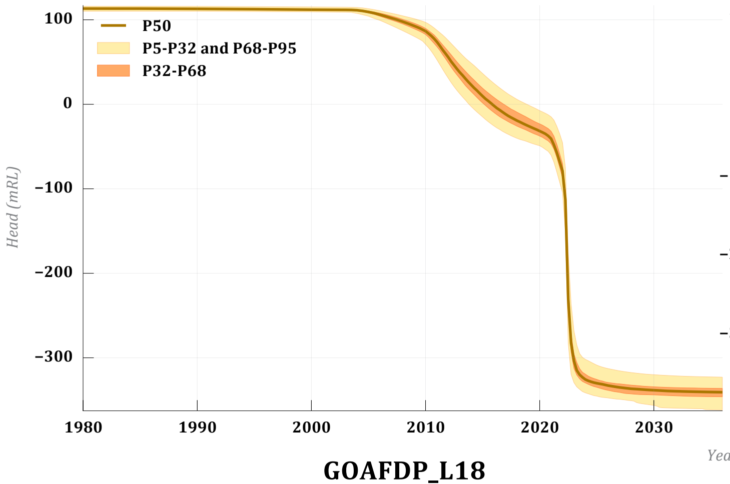
GNPS-06



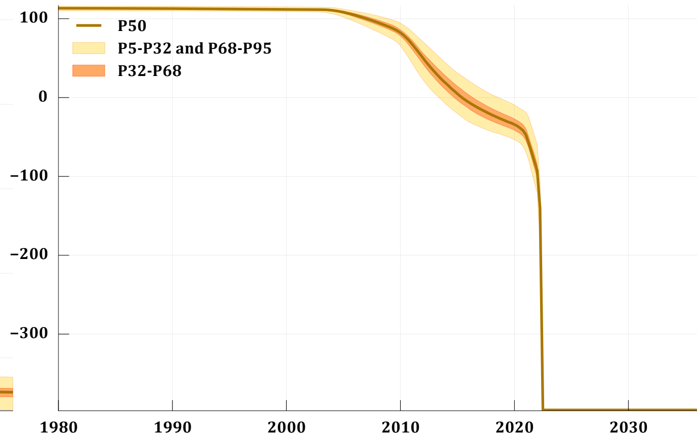
GNPS-07



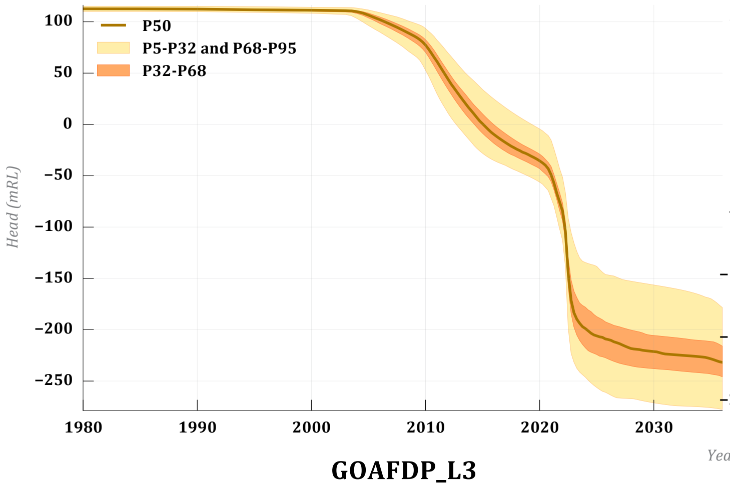
GOAFDP_L12



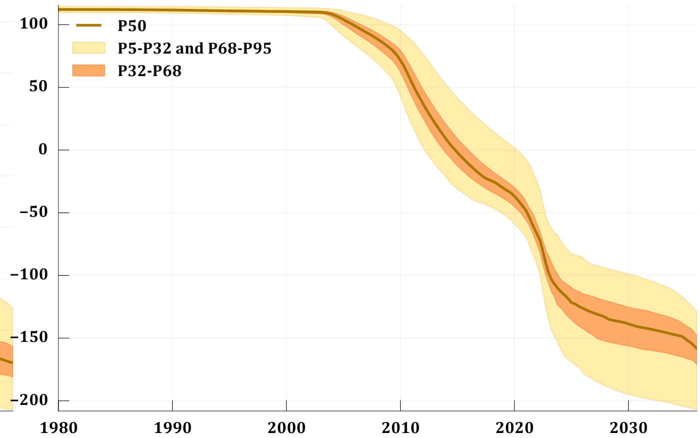
GOAFDP_L15



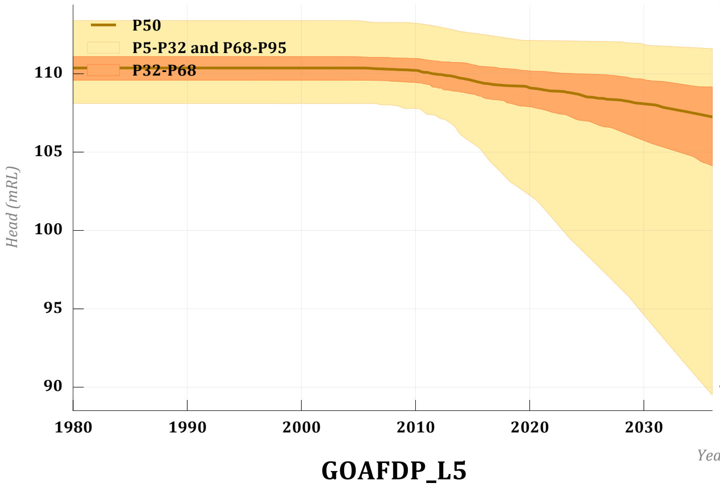
GOAFDP_L18



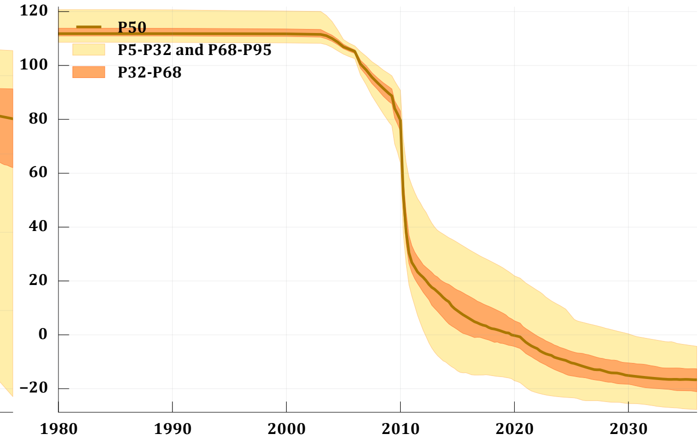
GOAFDP_L20



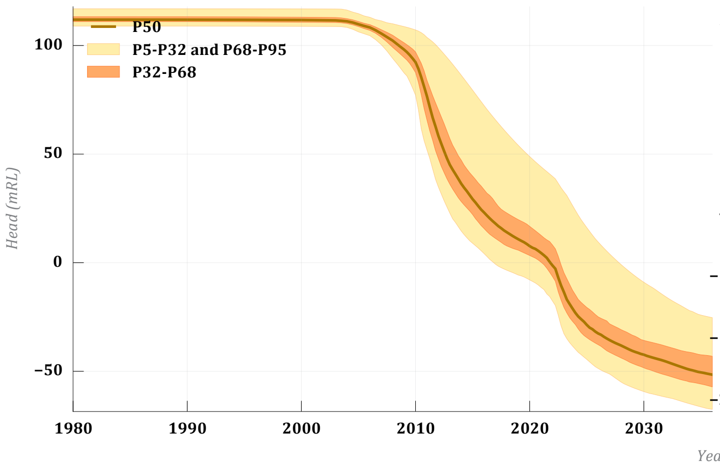
GOAFDP_L3



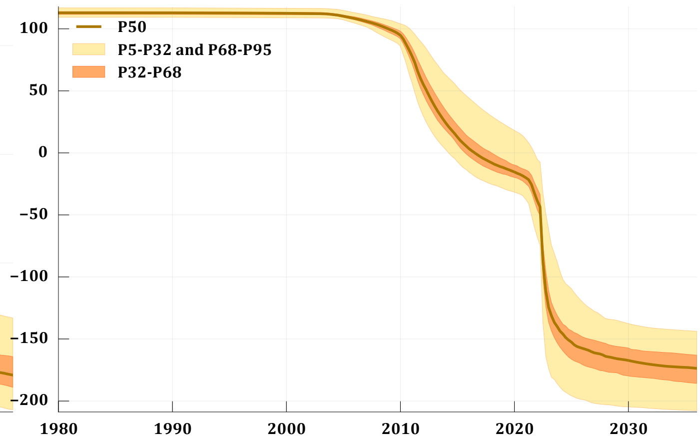
GOAFDP_L4

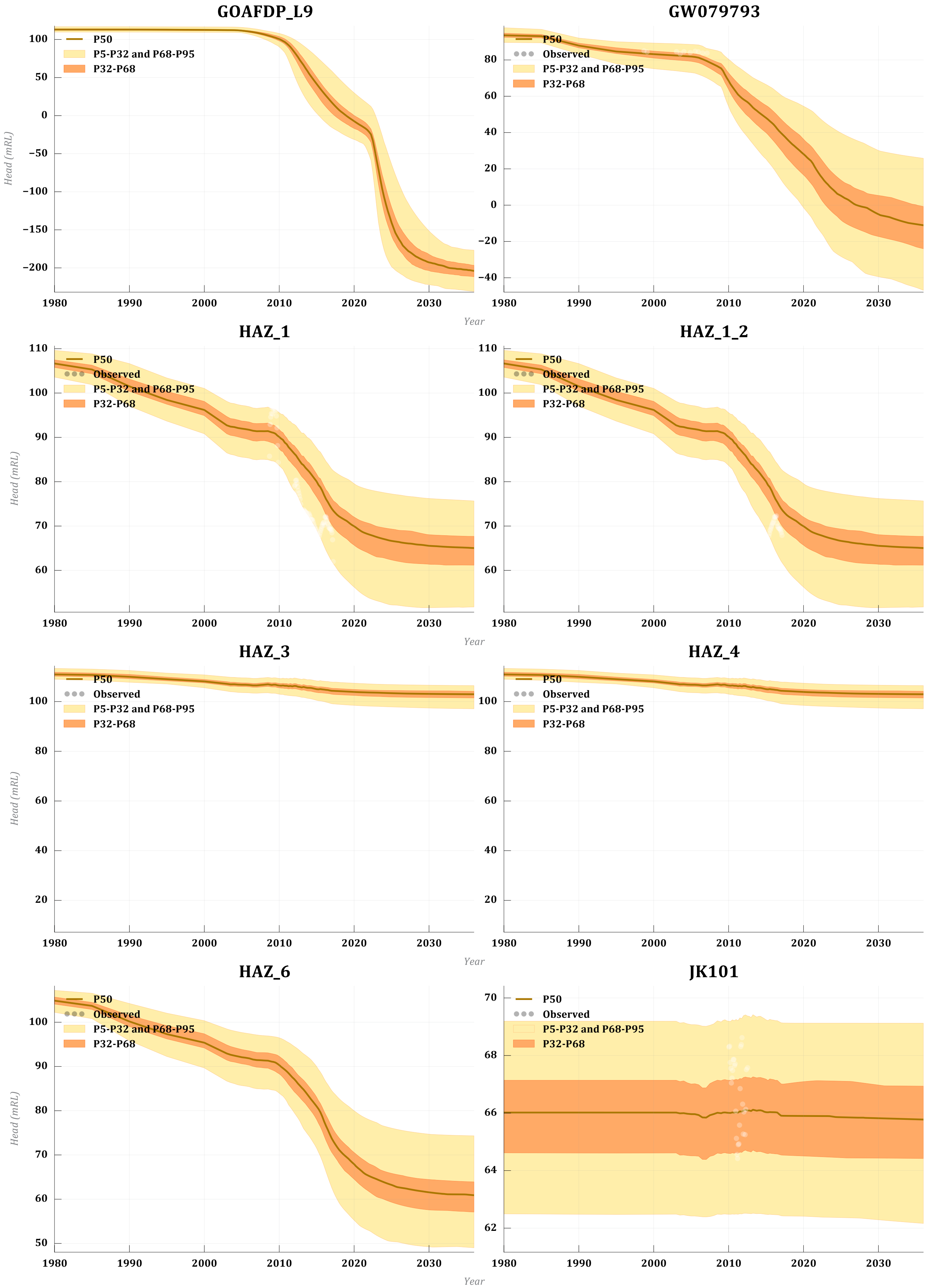


GOAFDP_L5

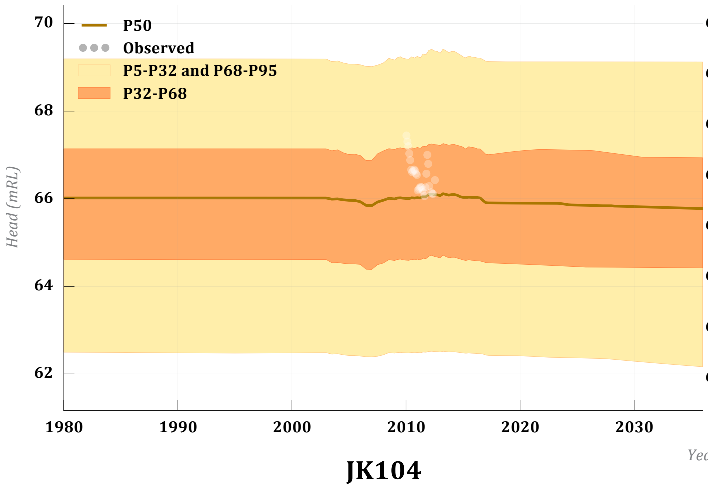


GOAFDP_L6

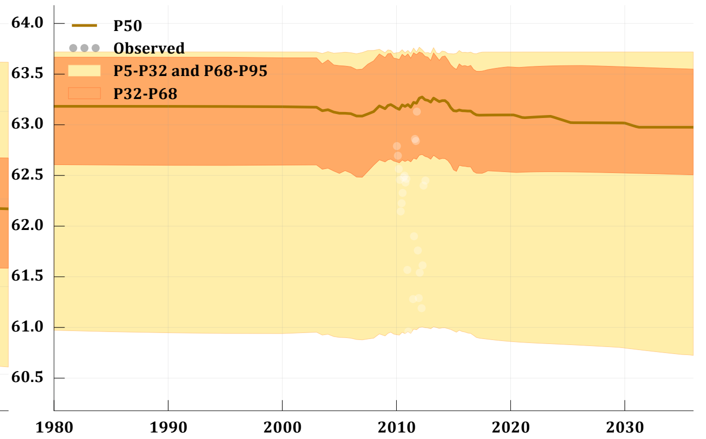



GOAFDP_L9
GW079793
HAZ_1
HAZ_1_2
HAZ_3
HAZ_4
HAZ_6
JK101
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030

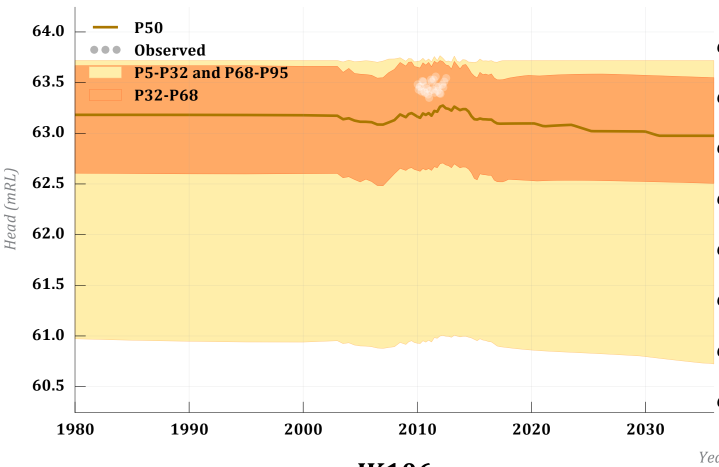
JK102



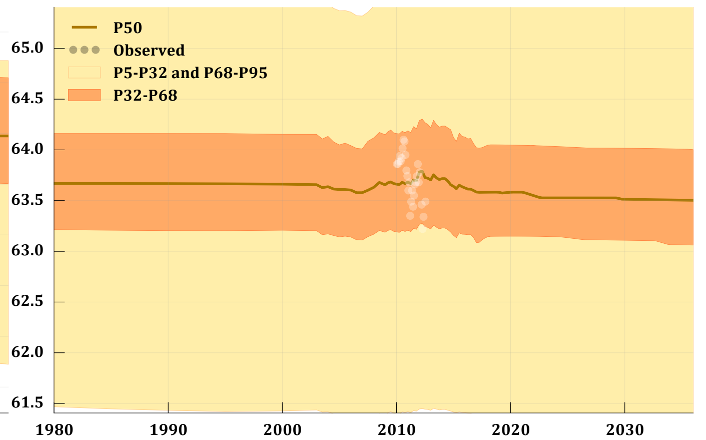
JK103



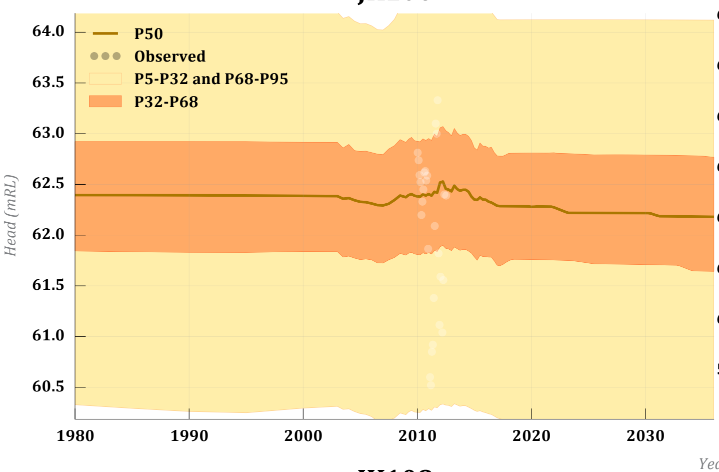
JK104



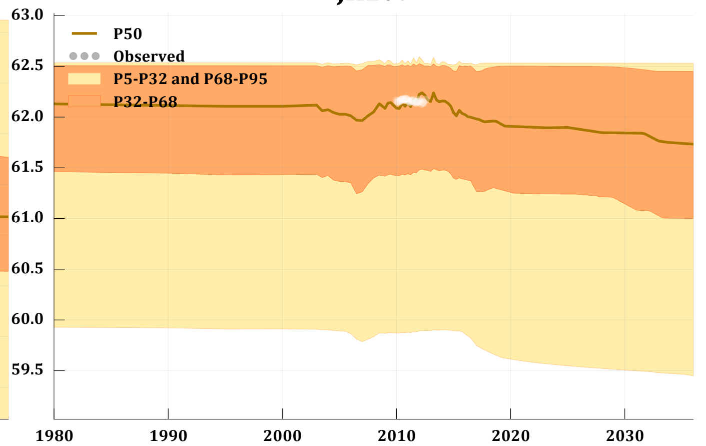
JK105



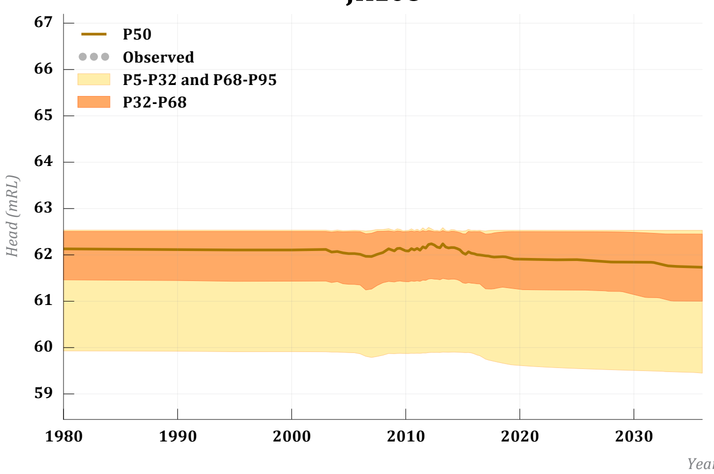
JK106



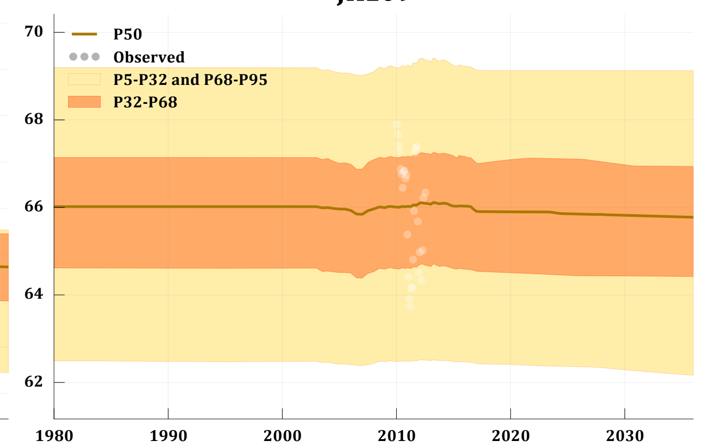
JK107



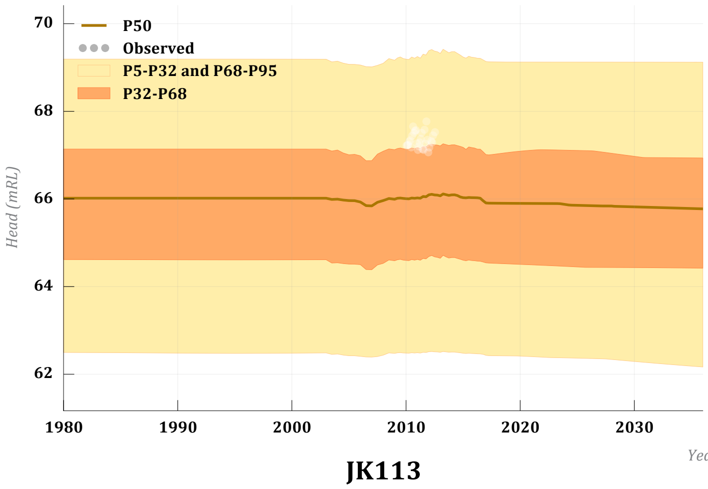
JK108



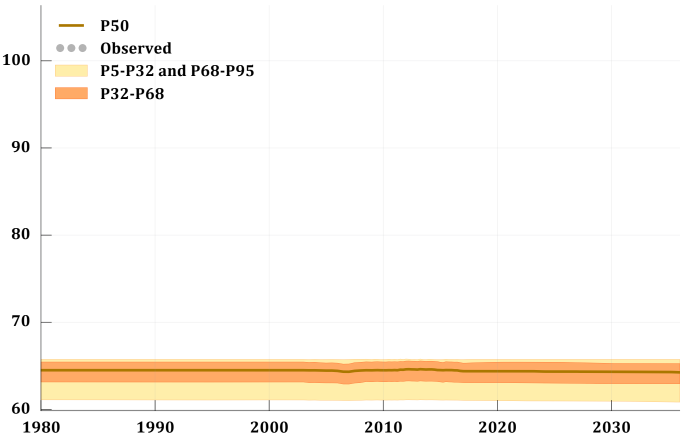
JK109



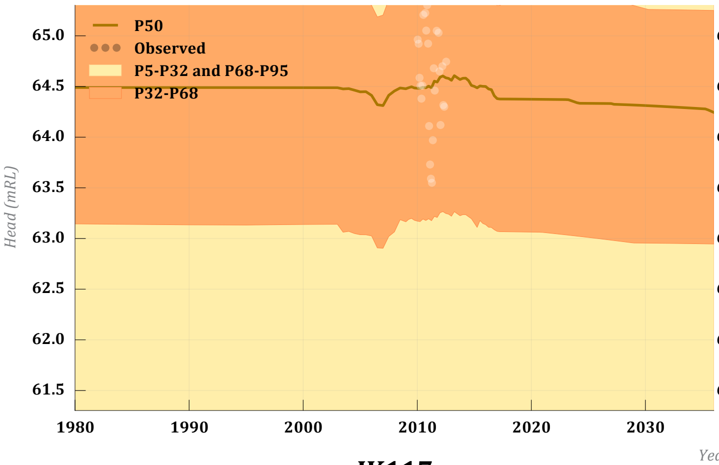
JK110



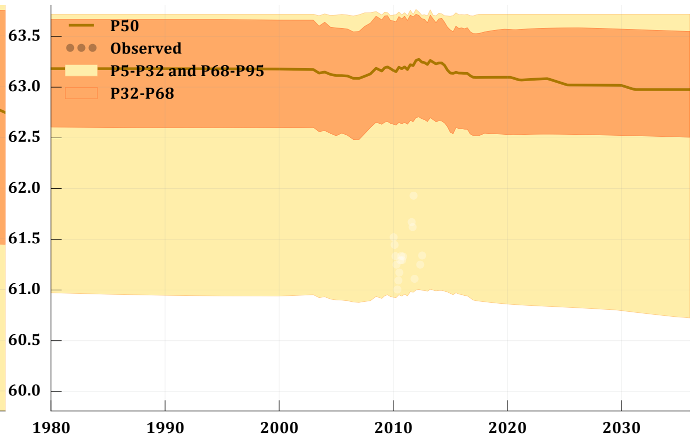
JK112



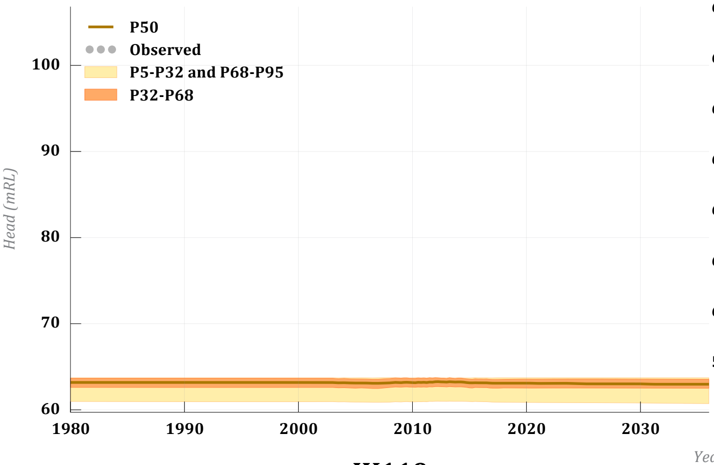
JK113



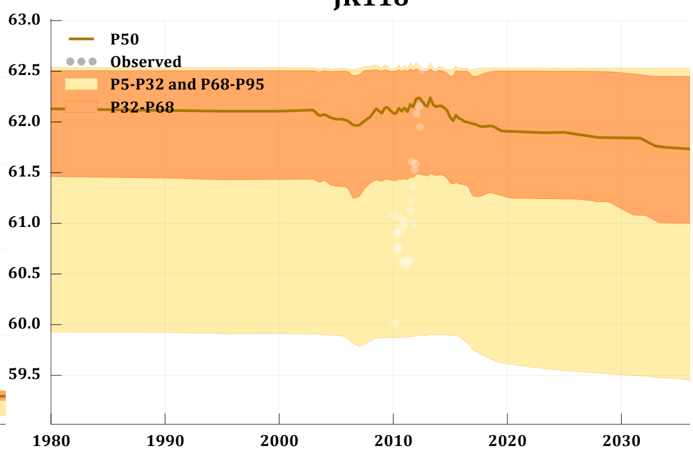
JK115



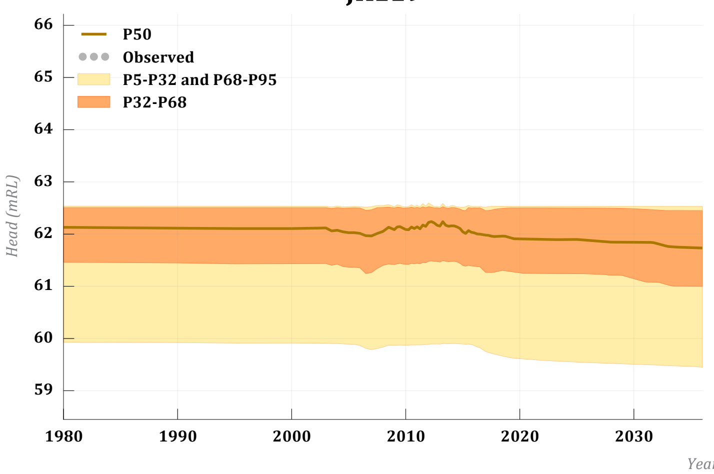
JK117



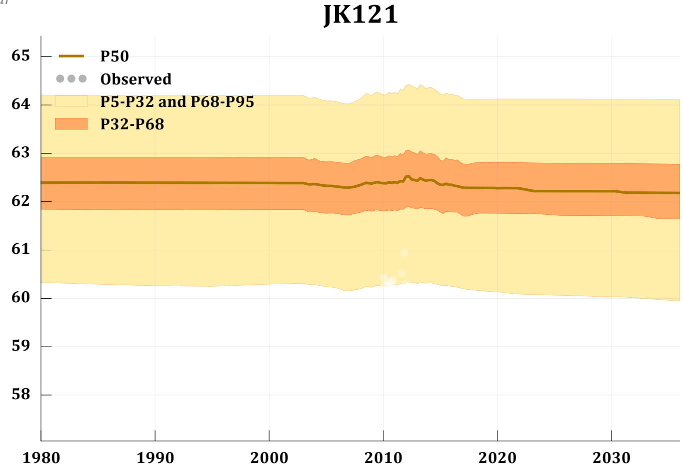
JK118

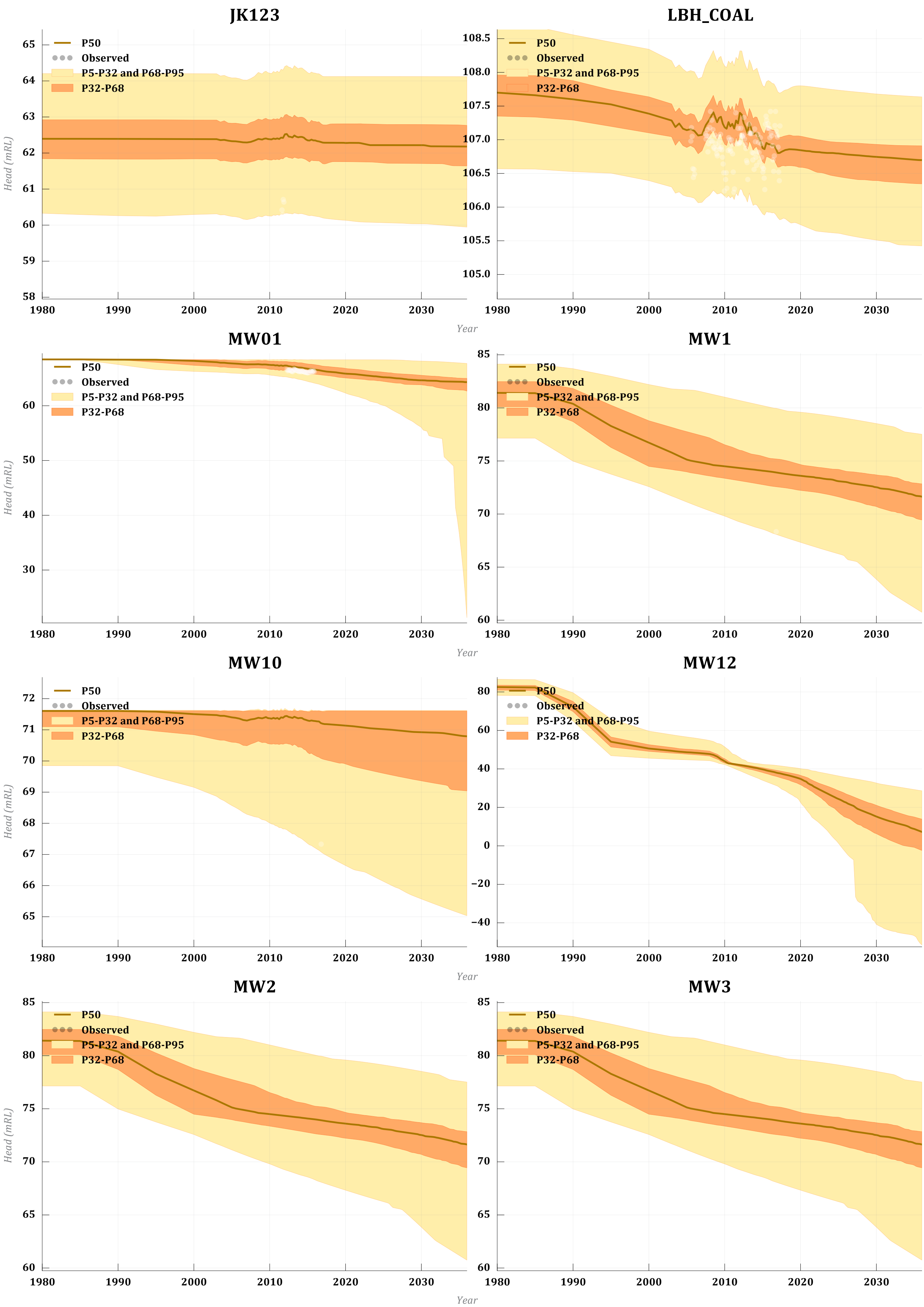


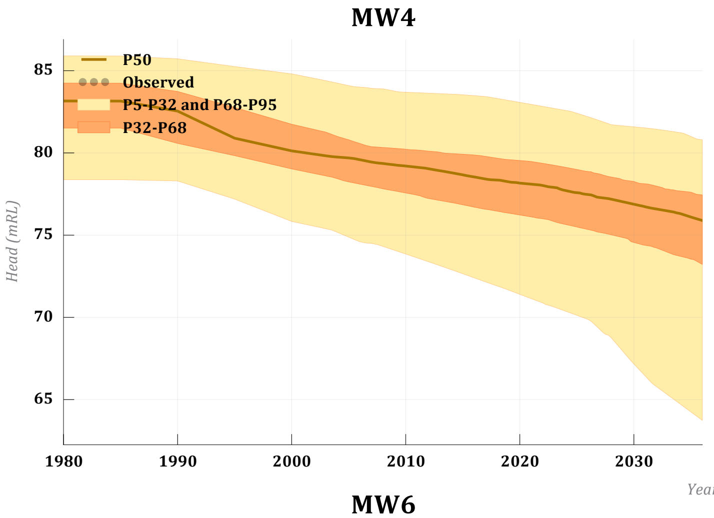
JK119

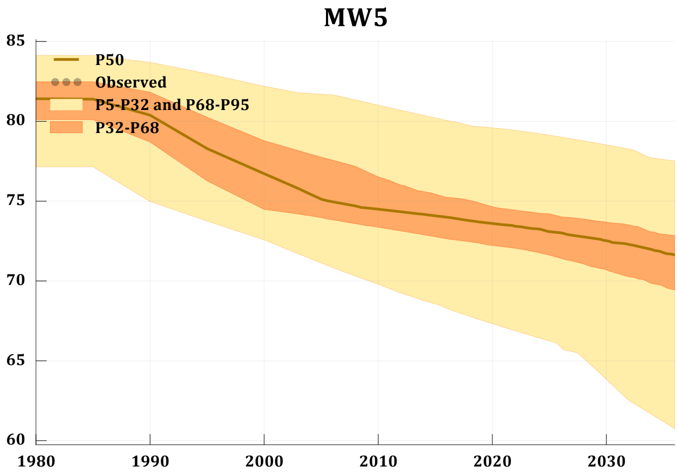


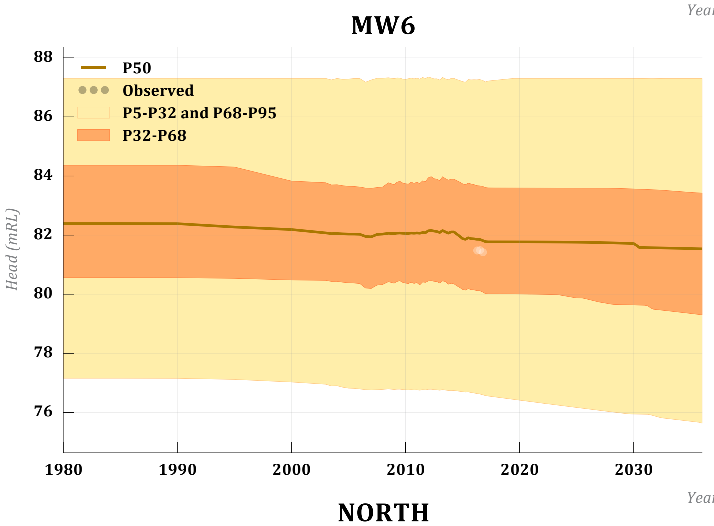
JK121

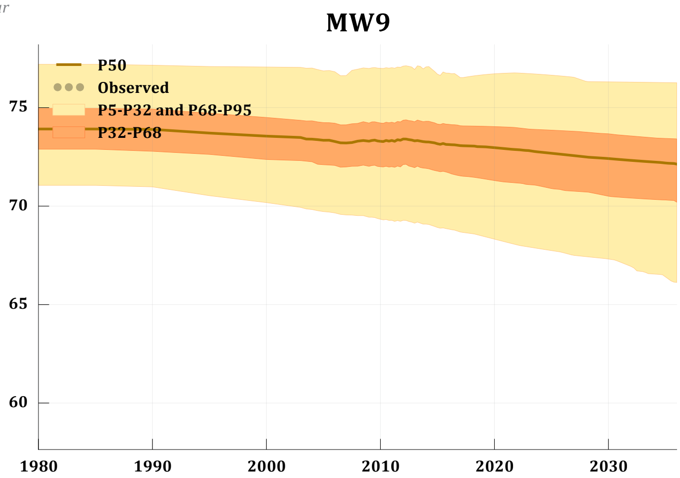


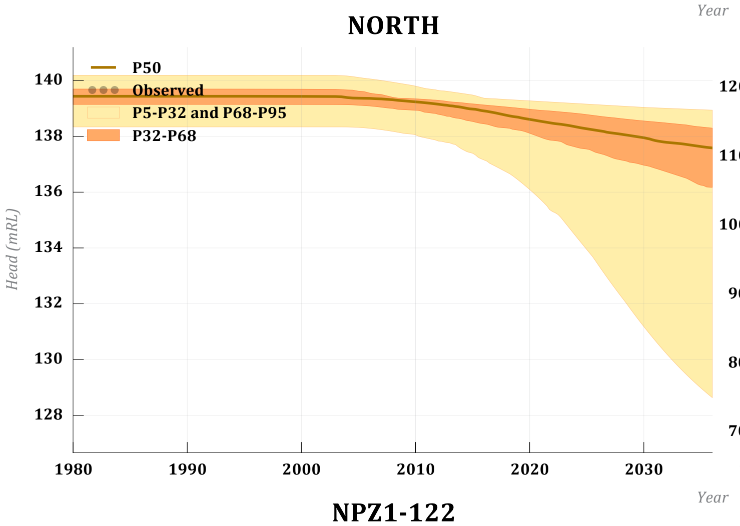

JK123
LBH_COAL
MW01
MW1
MW10
MW12
MW2
MW3
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030

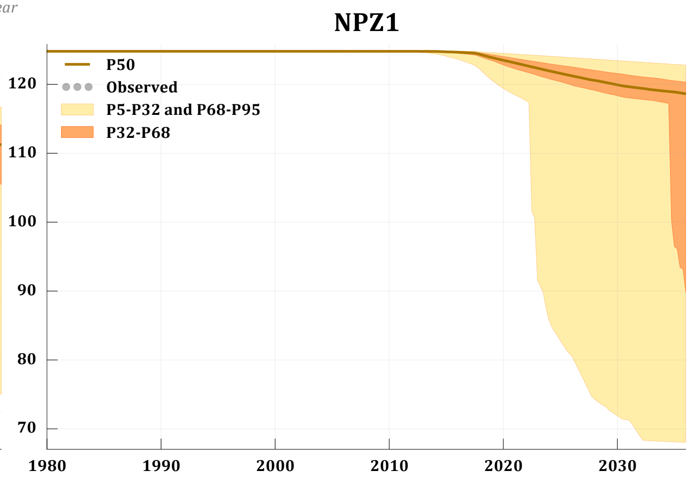

MW4
Head (mRL)
85
80
75
70
65
1980 1990 2000 2010 2020 2030
Year
P50
Observed
P5-P32 and P68-P95
P32-P68

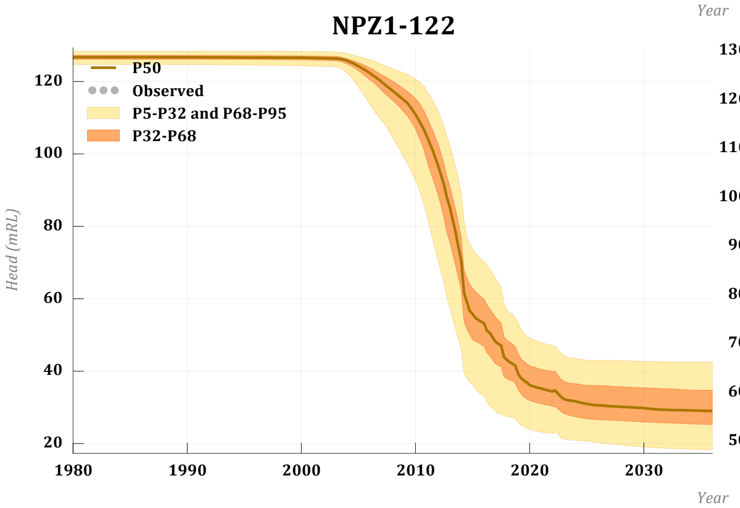

MW5
85
80
75
70
65
60
1980 1990 2000 2010 2020 2030
P50
Observed
P5-P32 and P68-P95
P32-P68

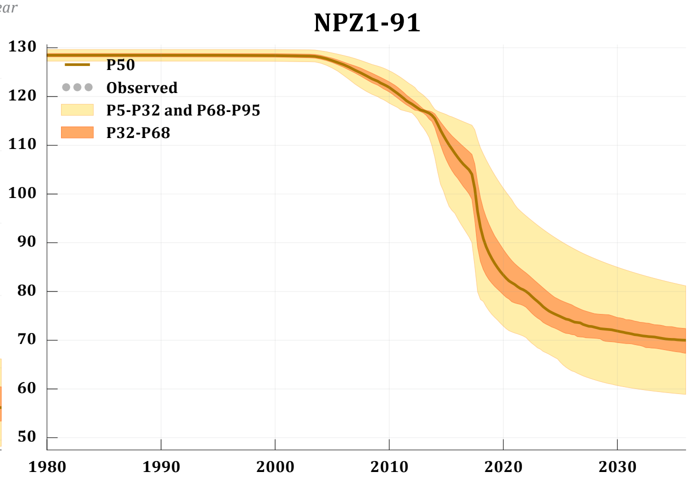

MW6
Head (mRL)
88
86
84
82
80
78
76
1980 1990 2000 2010 2020 2030
Year
P50
Observed
P5-P32 and P68-P95
P32-P68


MW9
75
70
65
60
1980 1990 2000 2010 2020 2030
P50
Observed
P5-P32 and P68-P95
P32-P68

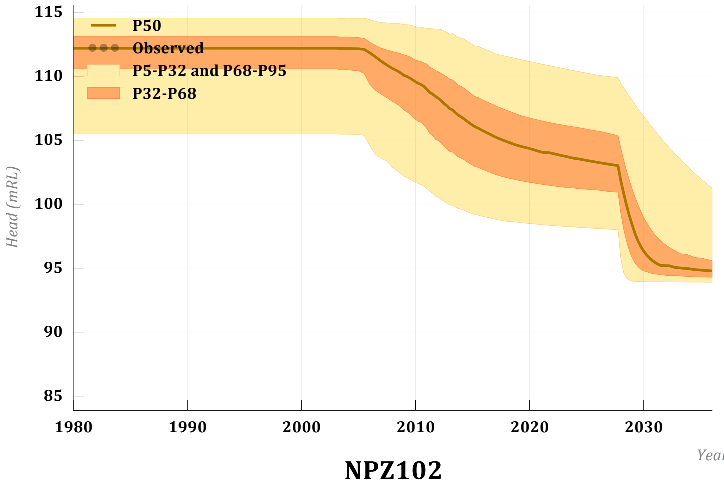

NORTH
Head (mRL)
140
138
136
134
132
130
128
1980 1990 2000 2010 2020 2030
Year
P50
Observed
P5-P32 and P68-P95
P32-P68


NPZ1
120
110
100
90
80
70
1980 1990 2000 2010 2020 2030
P50
Observed
P5-P32 and P68-P95
P32-P68

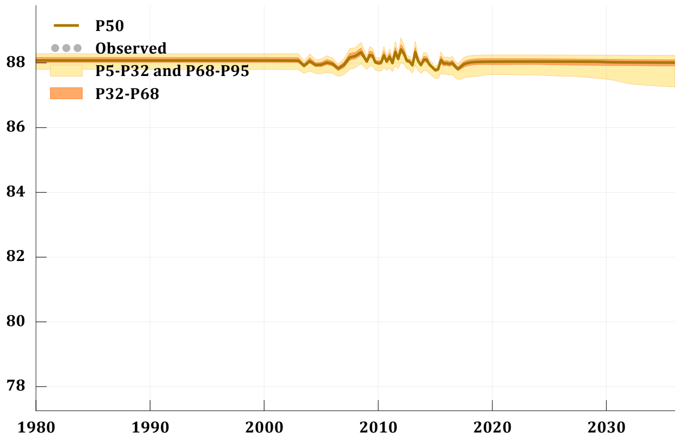

NPZ1-122
Head (mRL)
120
100
80
60
40
20
1980 1990 2000 2010 2020 2030
Year
P50
Observed
P5-P32 and P68-P95
P32-P68


NPZ1-91
130
120
110
100
90
80
70
60
50
1980 1990 2000 2010 2020 2030
P50
Observed
P5-P32 and P68-P95
P32-P68

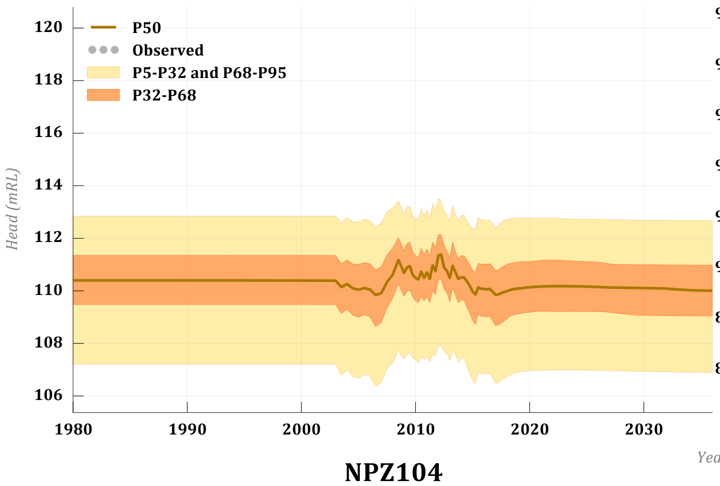
NPZ10



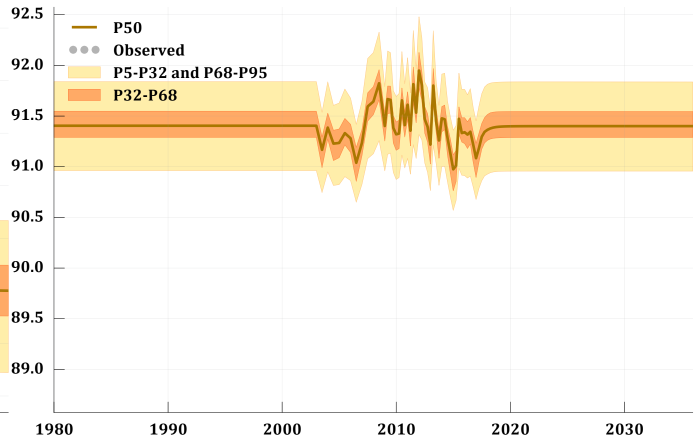
NPZ101



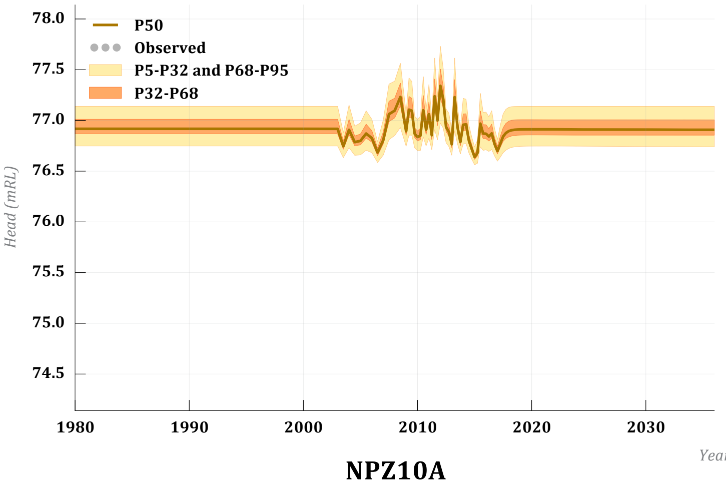
NPZ102



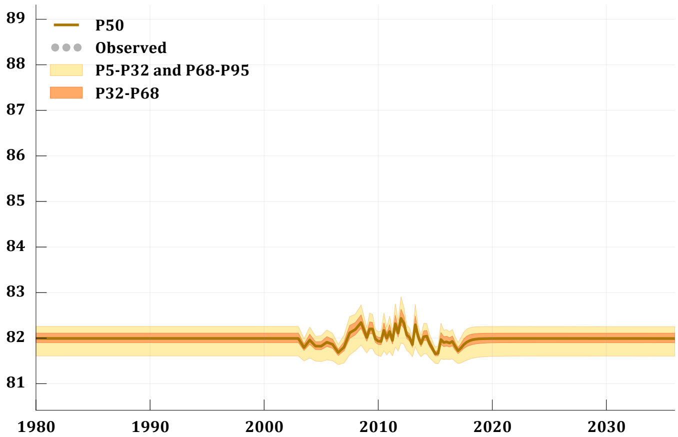
NPZ103



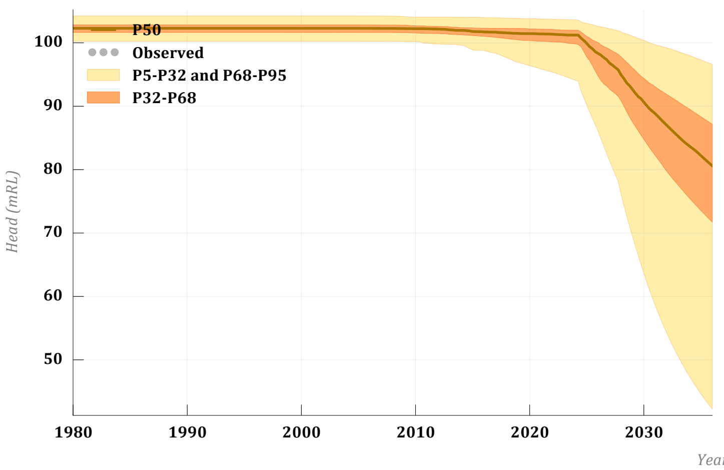
NPZ104



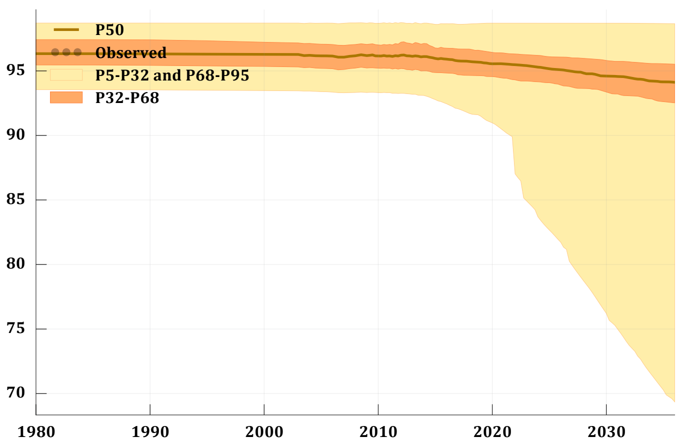
NPZ106

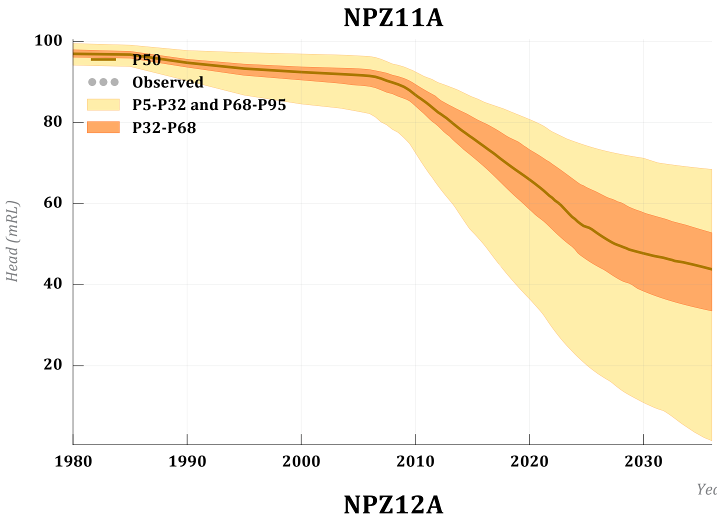


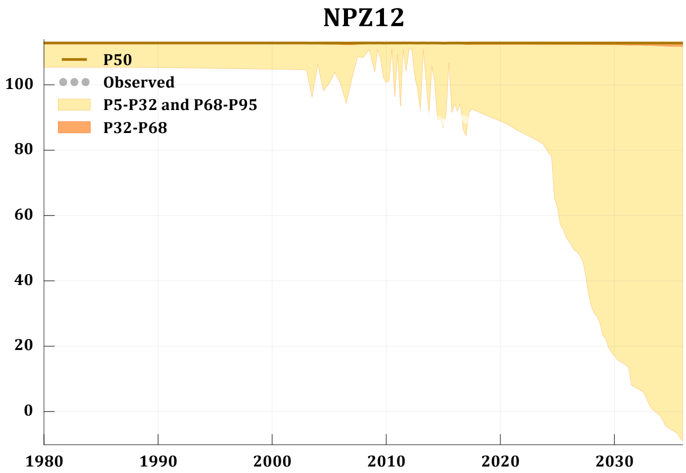
NPZ10A

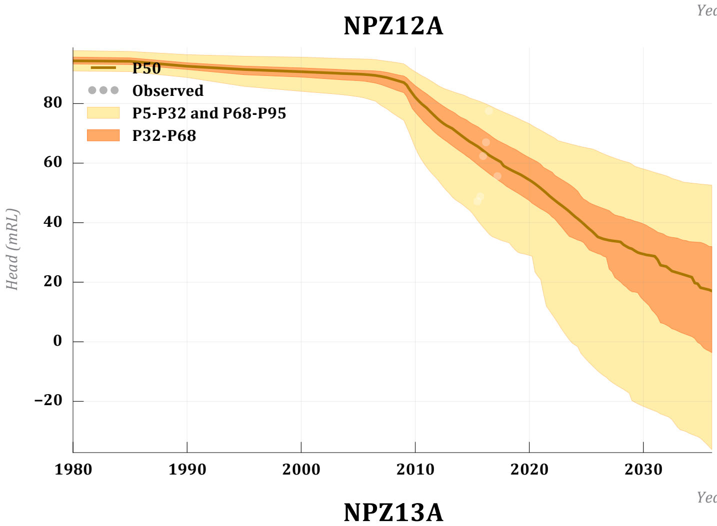


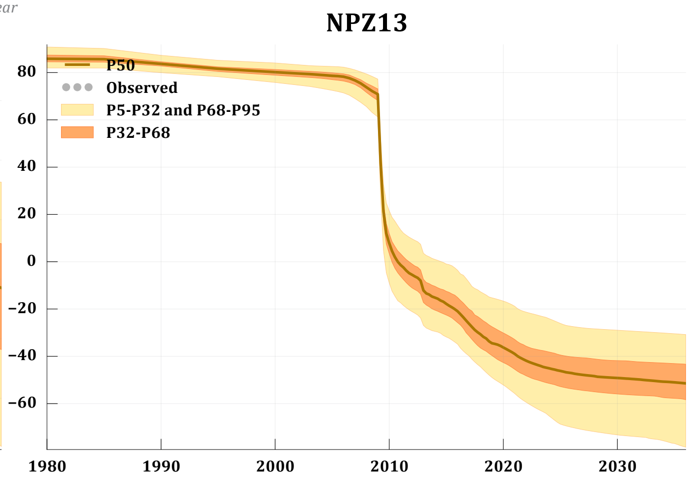
NPZ11

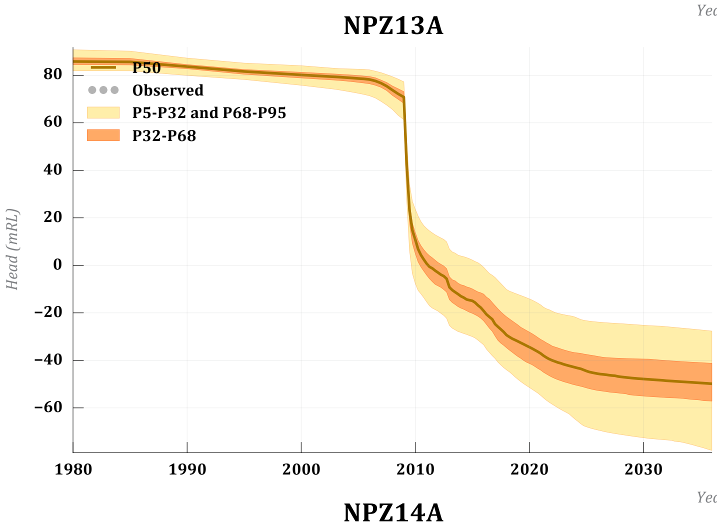


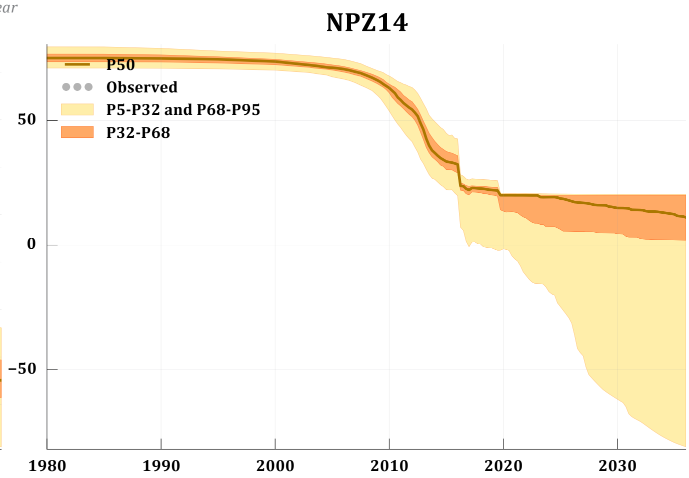

NPZ11A
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
100
80
60
40
20
1980
1990
2000
2010
2020
2030
Year

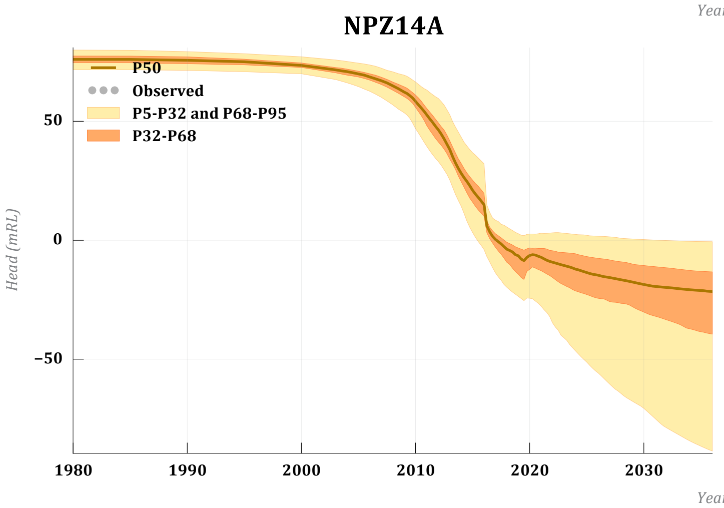

NPZ12
P50
Observed
P5-P32 and P68-P95
P32-P68
100
80
60
40
20
0
1980
1990
2000
2010
2020
2030

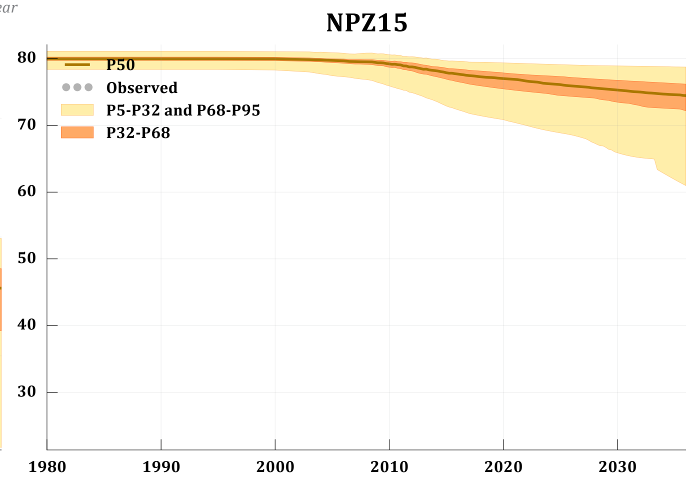

NPZ12A
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
80
60
40
20
0
−20
1980
1990
2000
2010
2020
2030
Year

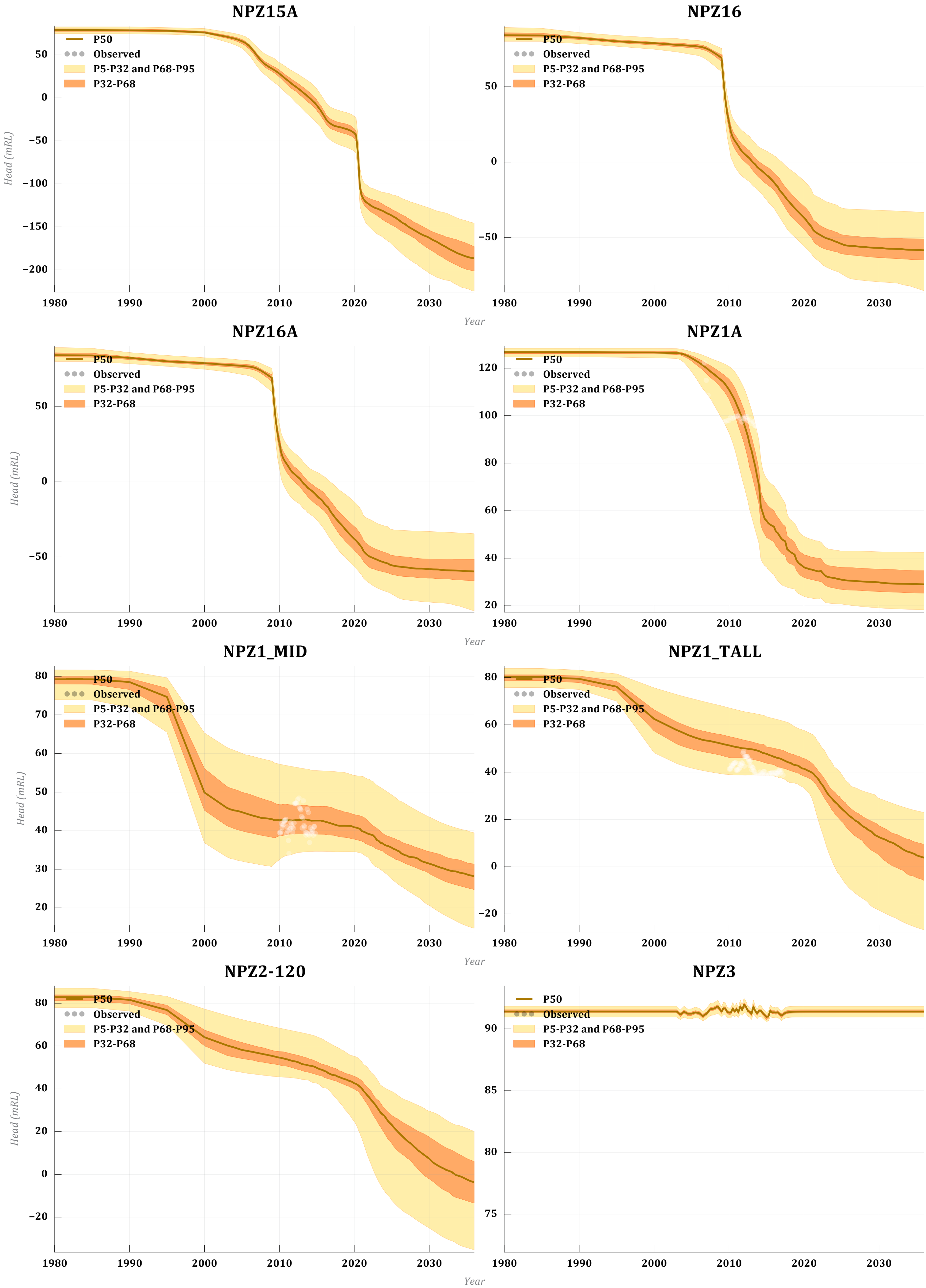

NPZ13
P50
Observed
P5-P32 and P68-P95
P32-P68
80
60
40
20
0
−20
−40
−60
1980
1990
2000
2010
2020
2030


NPZ13A
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
80
60
40
20
0
−20
−40
−60
1980
1990
2000
2010
2020
2030
Year

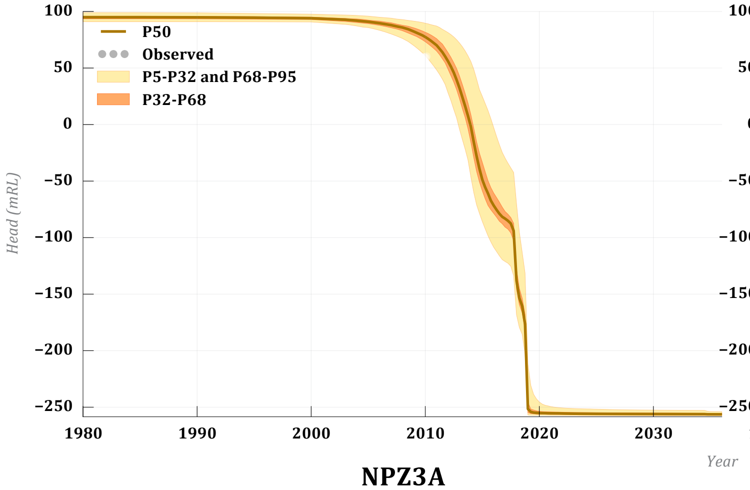

NPZ14
P50
Observed
P5-P32 and P68-P95
P32-P68
50
0
−50
1980
1990
2000
2010
2020
2030


NPZ14A
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
50
0
−50
1980
1990
2000
2010
2020
2030
Year

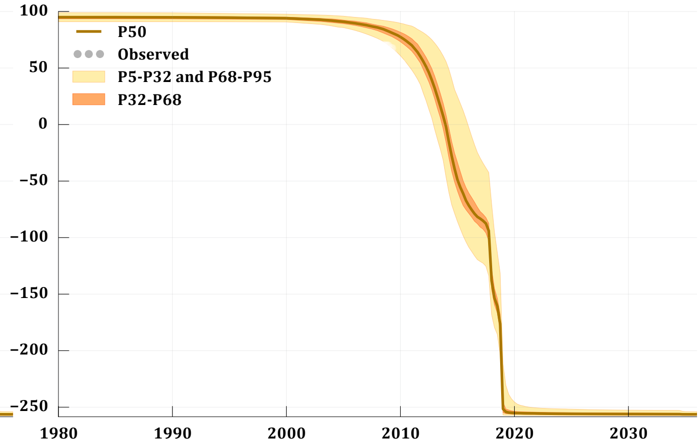

NPZ15
P50
Observed
P5-P32 and P68-P95
P32-P68
80
70
60
50
40
30
1980
1990
2000
2010
2020
2030


NPZ15A
NPZ16
NPZ16A
NPZ1A
NPZ1_MID
NPZ1_TALL
NPZ2-120
NPZ3
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year

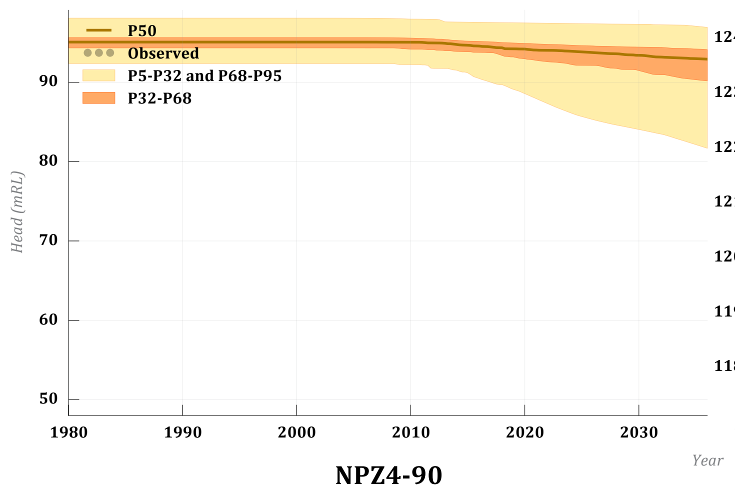
NPZ3-110



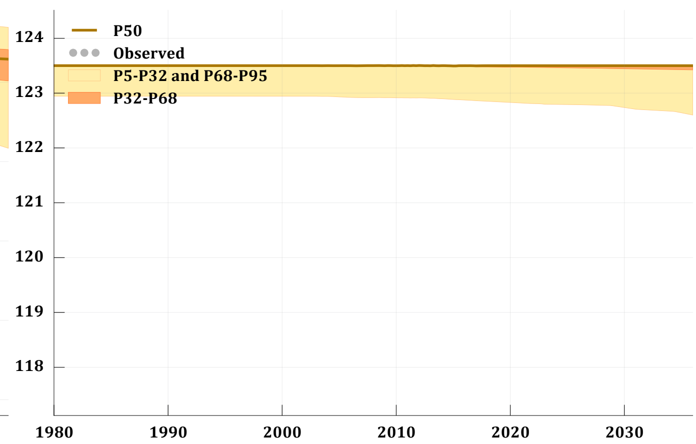
NPZ3-64



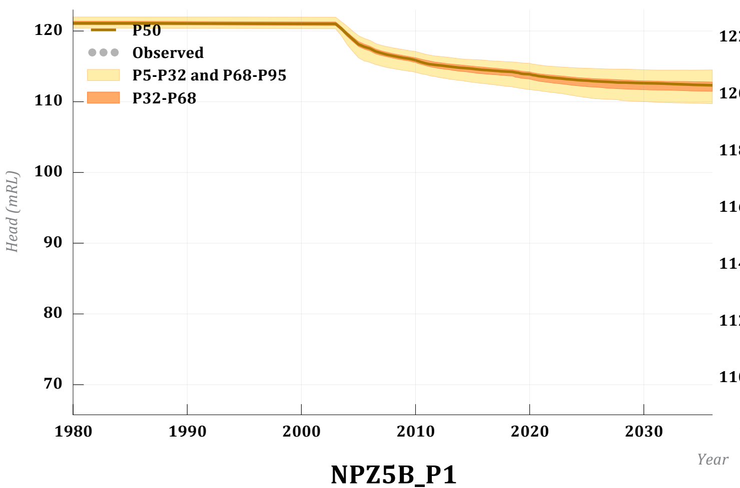
NPZ3A



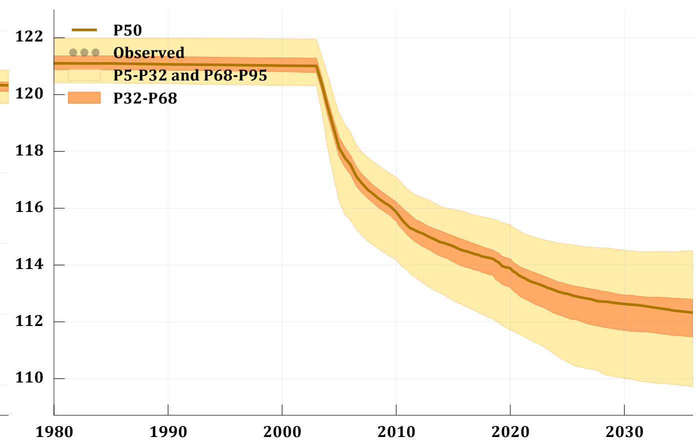
NPZ4



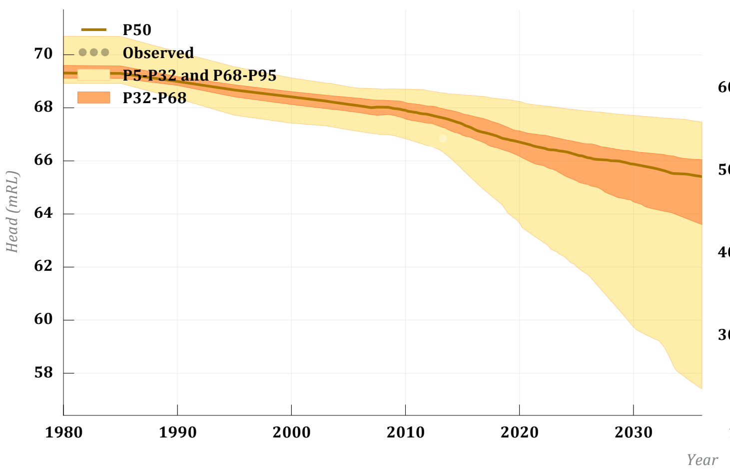
NPZ4-90



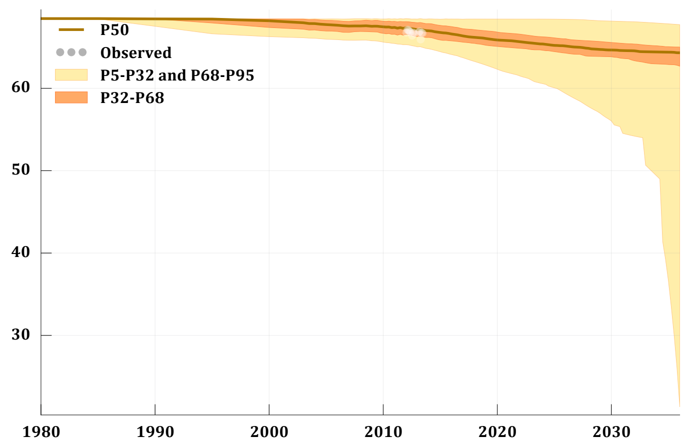
NPZ4A

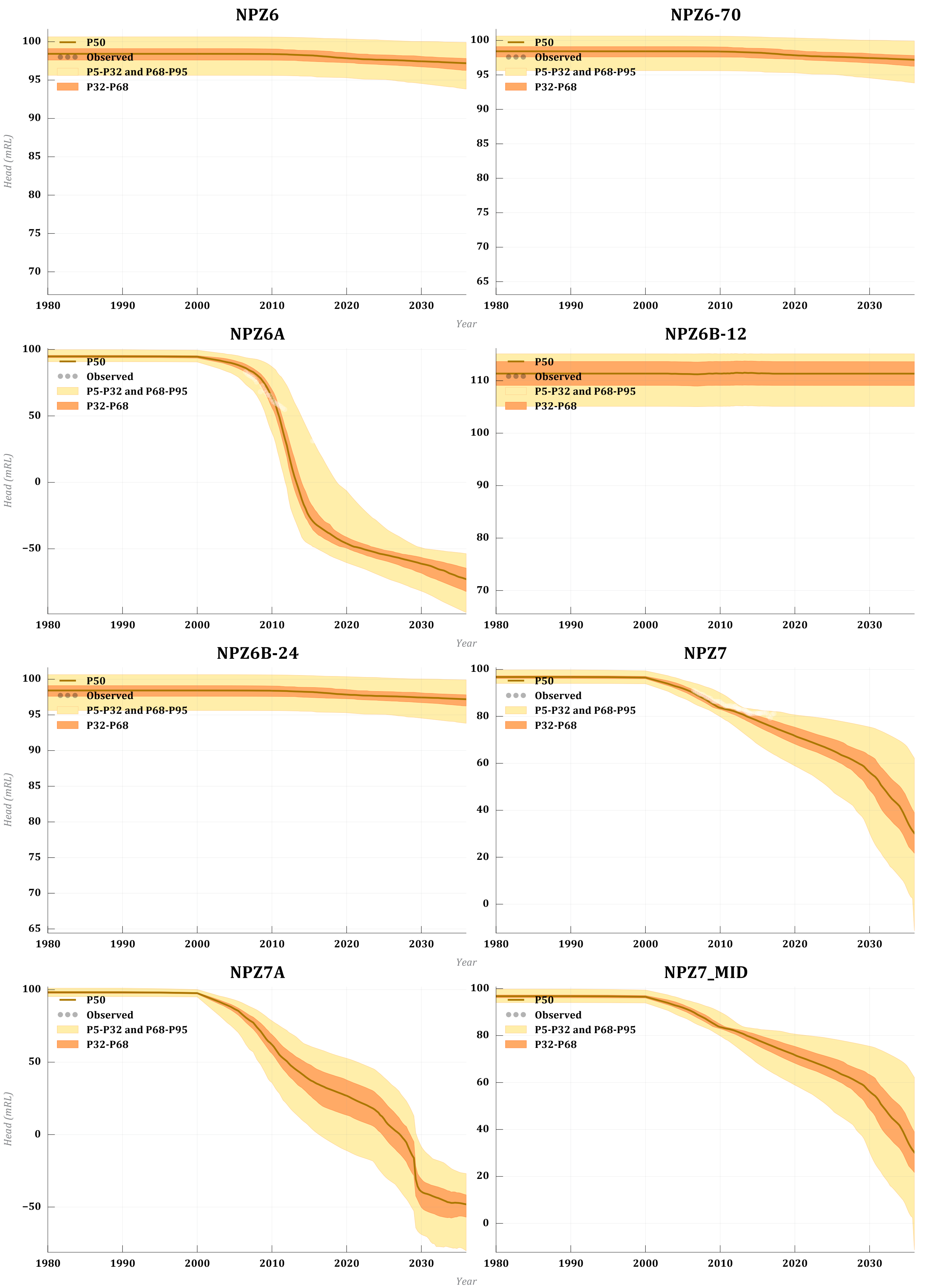


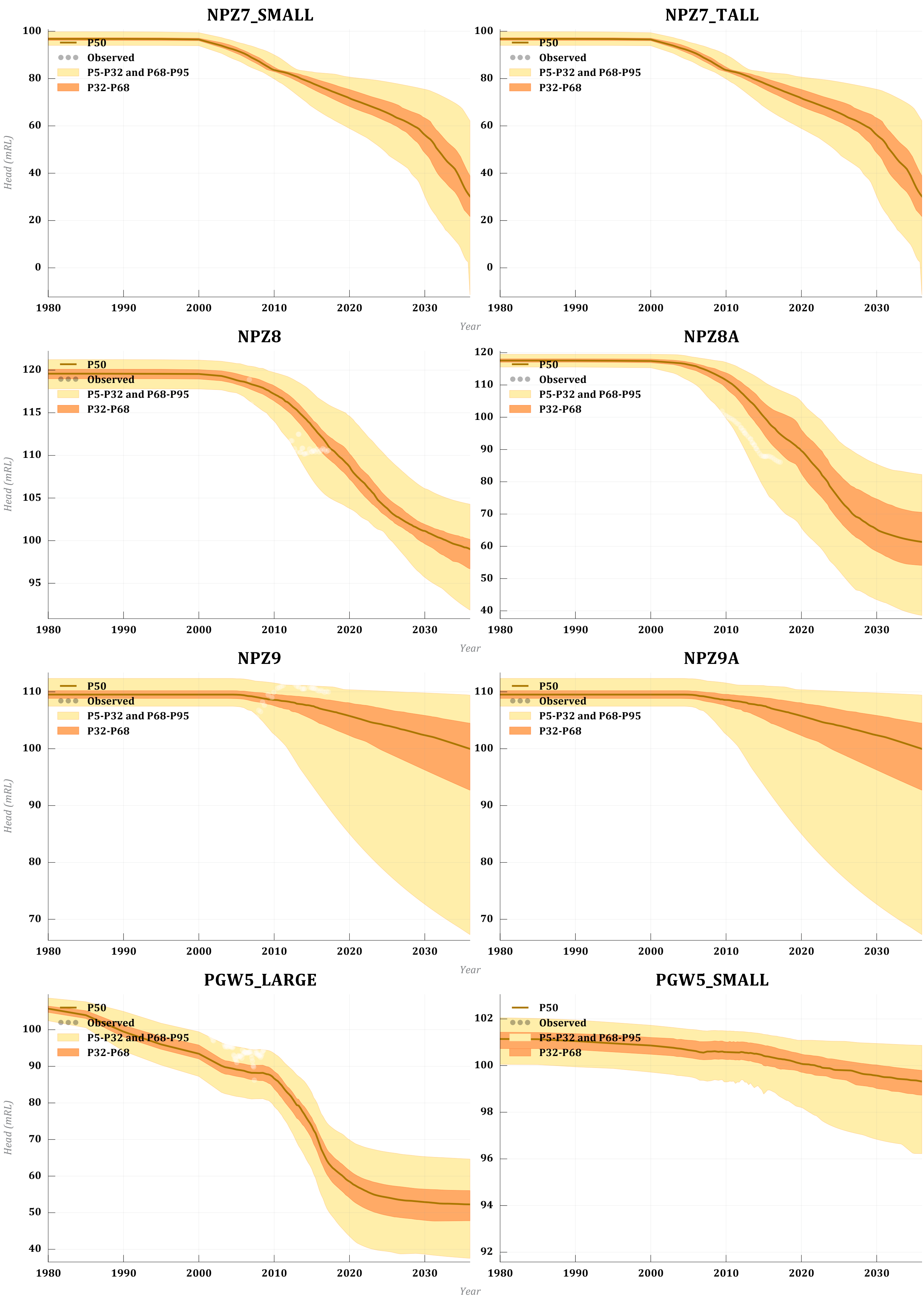
NPZ5B_P1

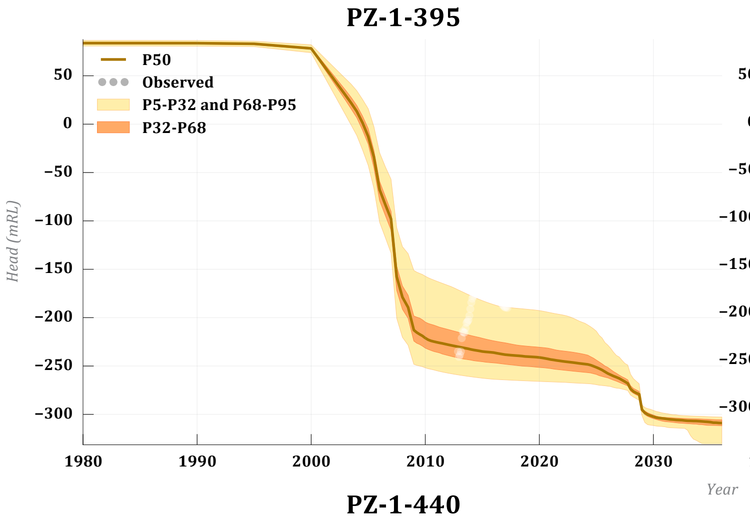


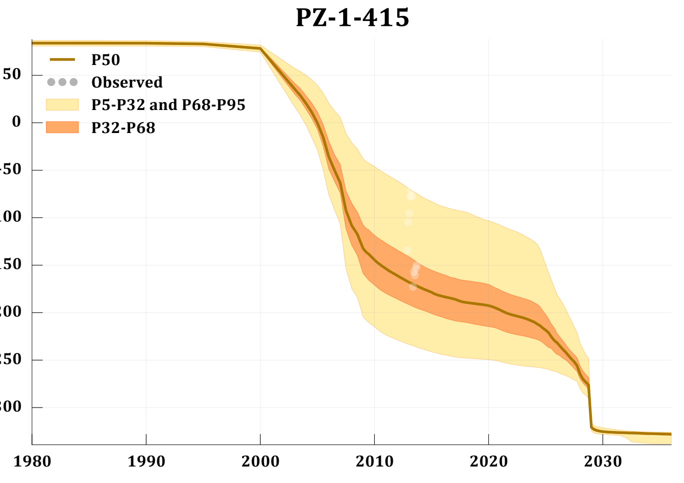
NPZ5B_P2

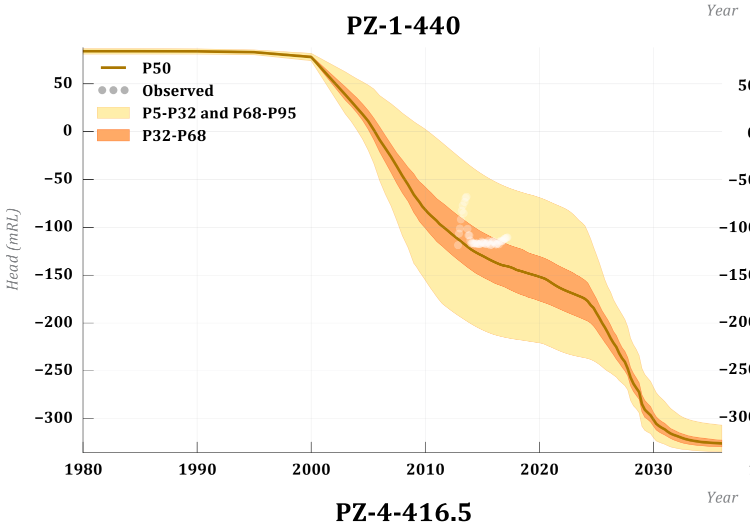


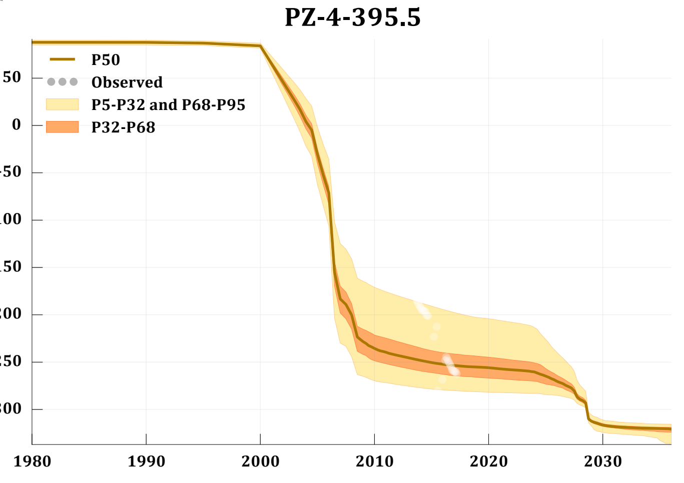

NPZ6
NPZ6-70
NPZ6A
NPZ6B-12
NPZ6B-24
NPZ7
NPZ7A
NPZ7_MID
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030

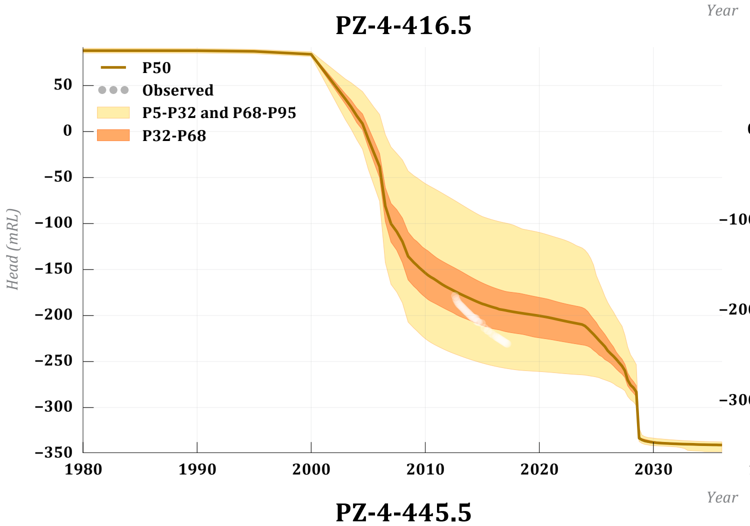

NPZ7_SMALL
NPZ7_TALL
NPZ8
NPZ8A
NPZ9
NPZ9A
PGW5_LARGE
PGW5_SMALL
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030

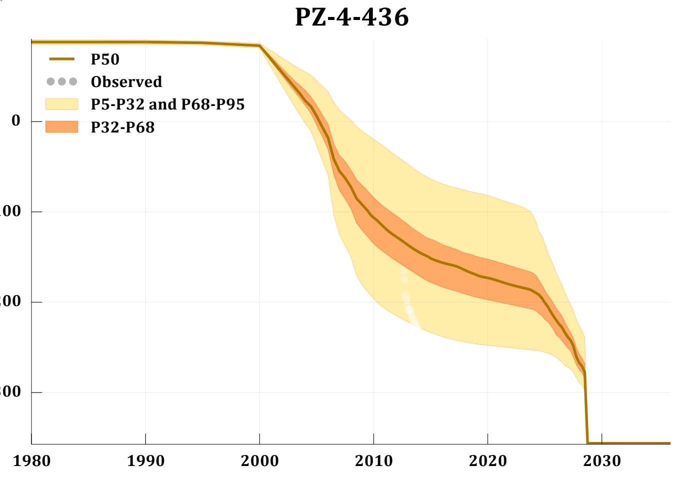

PZ-1-395
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year

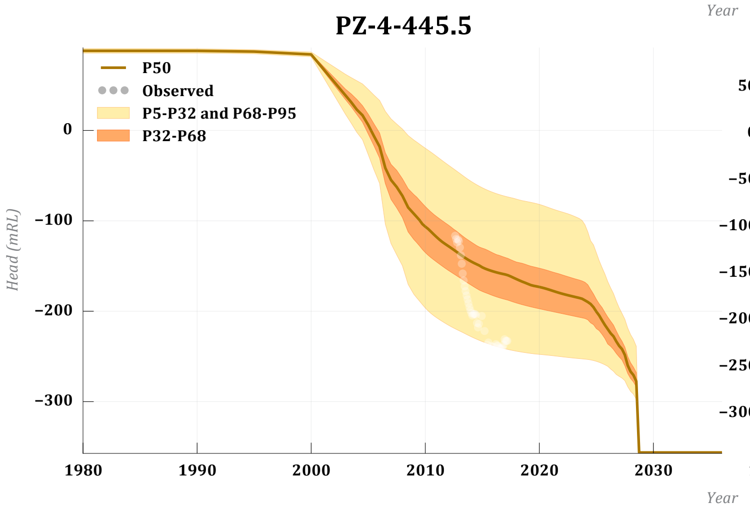

PZ-1-415
P50
Observed
P5-P32 and P68-P95
P32-P68

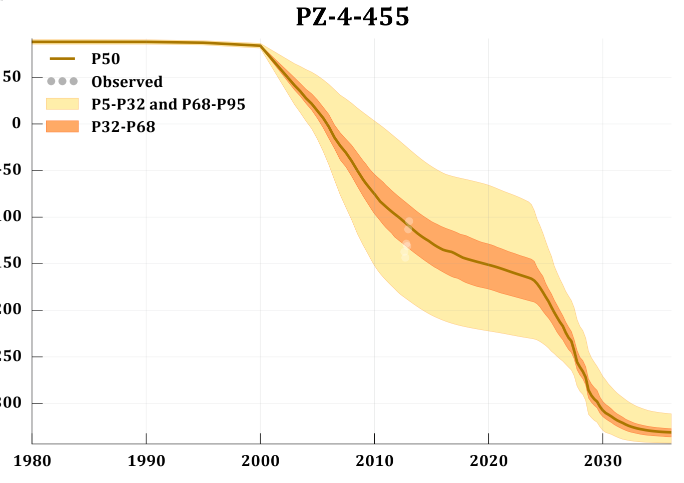

PZ-1-440
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year

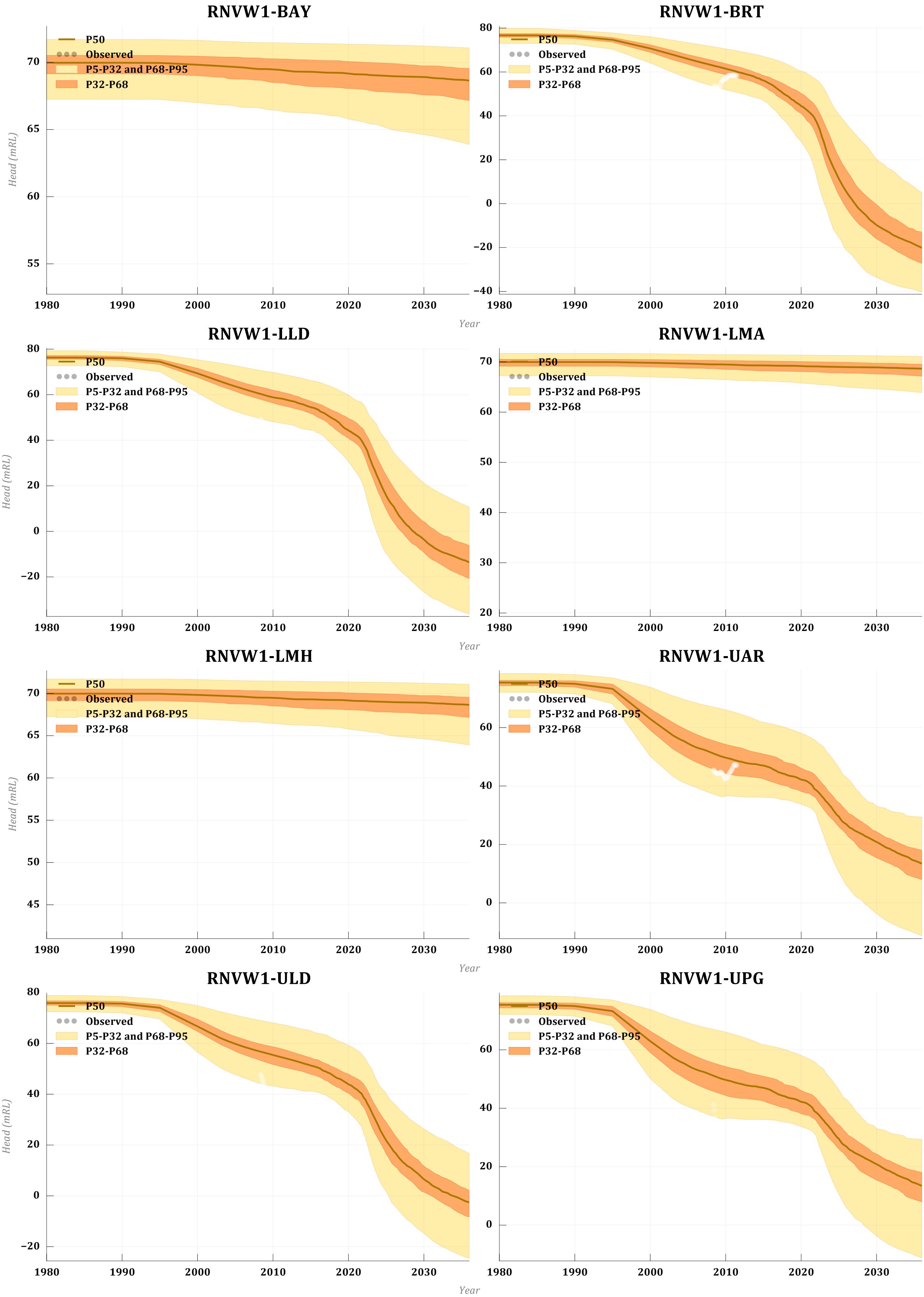

PZ-4-395.5
P50
Observed
P5-P32 and P68-P95
P32-P68


PZ-4-416.5
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year


PZ-4-436
P50
Observed
P5-P32 and P68-P95
P32-P68

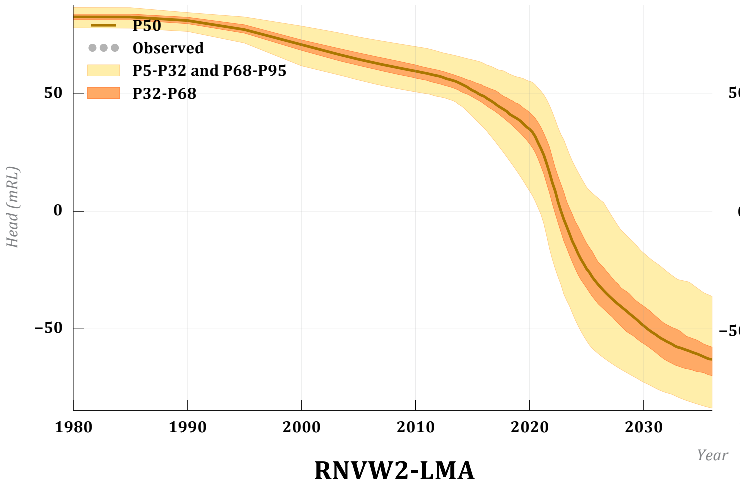

PZ-4-445.5
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year


PZ-4-455
P50
Observed
P5-P32 and P68-P95
P32-P68

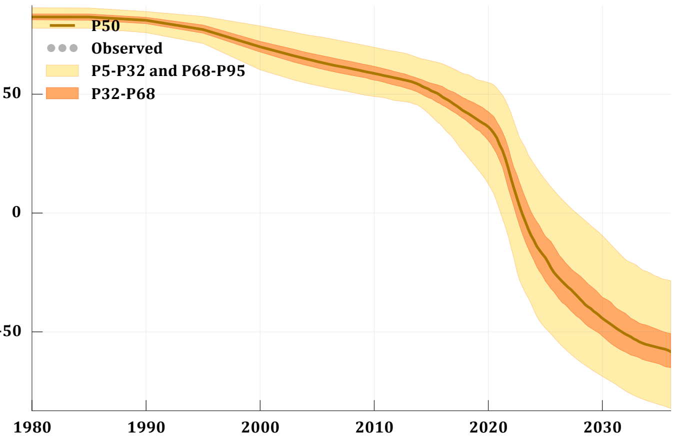


RNVW1-BAY
RNVW1-BRT
RNVW1-LLD
RNVW1-LMA
RNVW1-LMH
RNVW1-UAR
RNVW1-ULD
RNVW1-UPG
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030

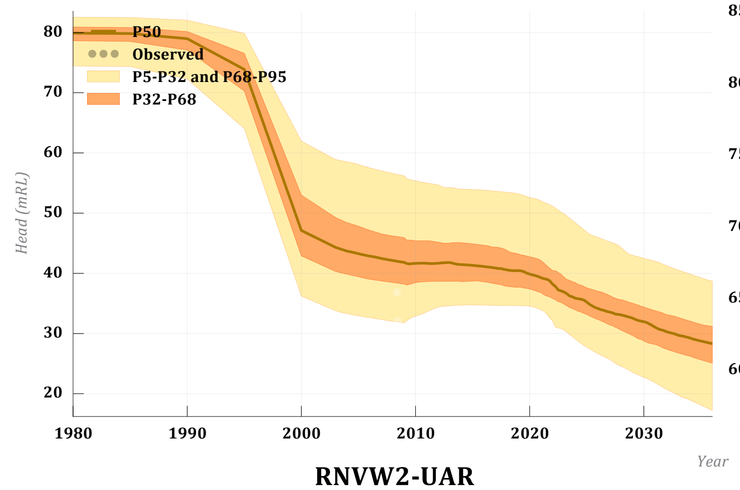
RNVW2-BRT



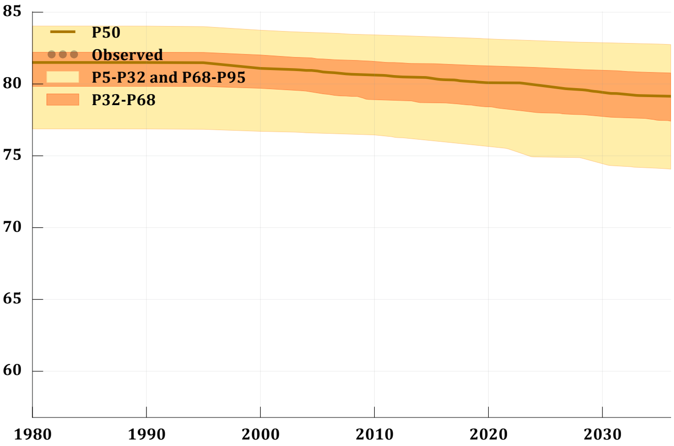
RNVW2-LLD



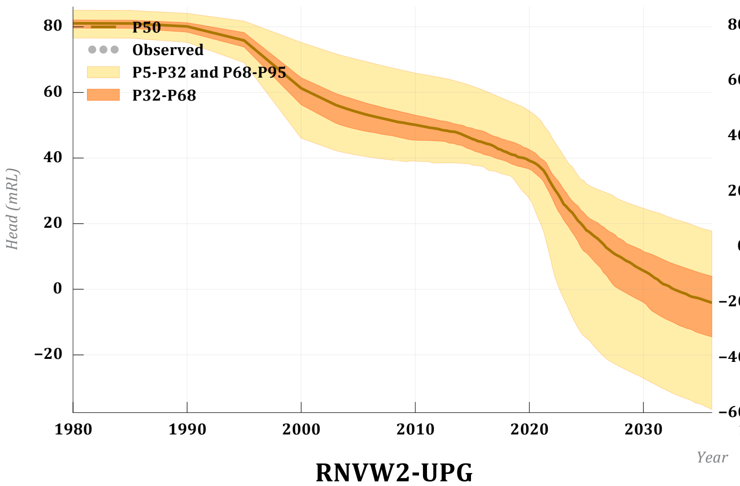
RNVW2-LMA



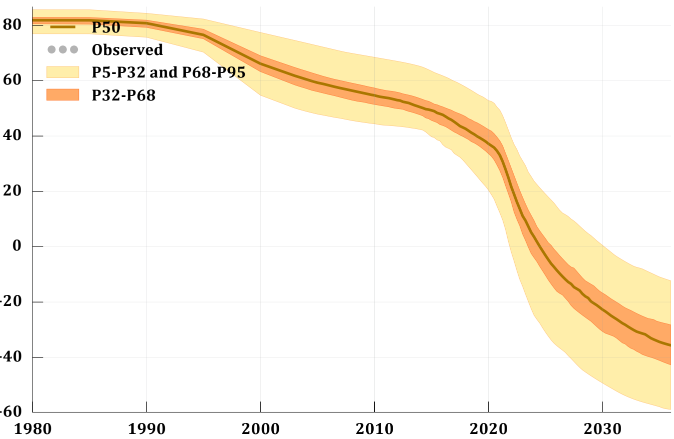
RNVW2-LMH



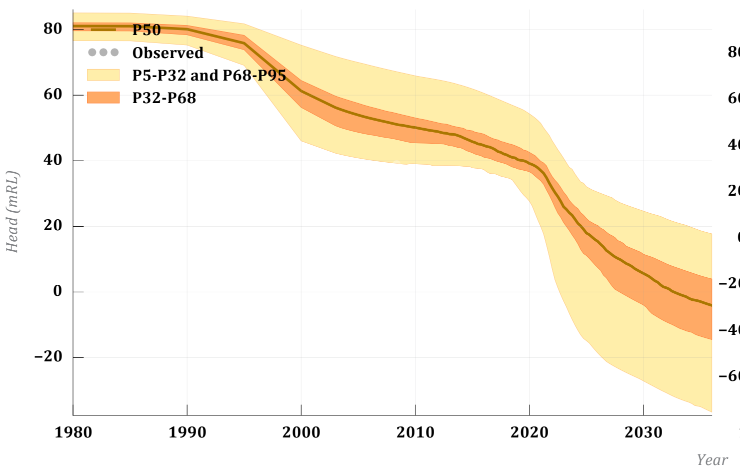
RNVW2-UAR



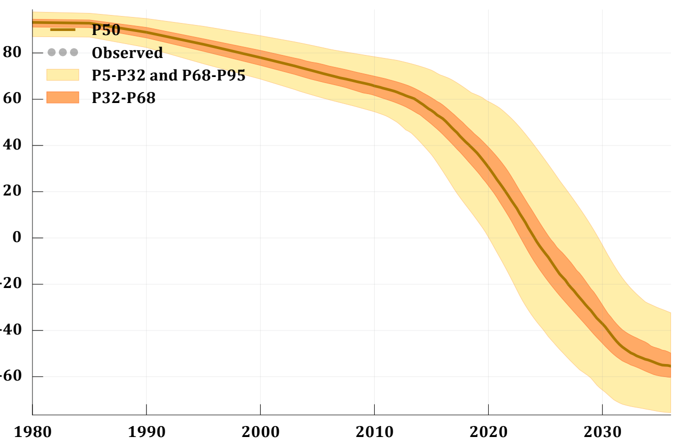
RNVW2-ULD



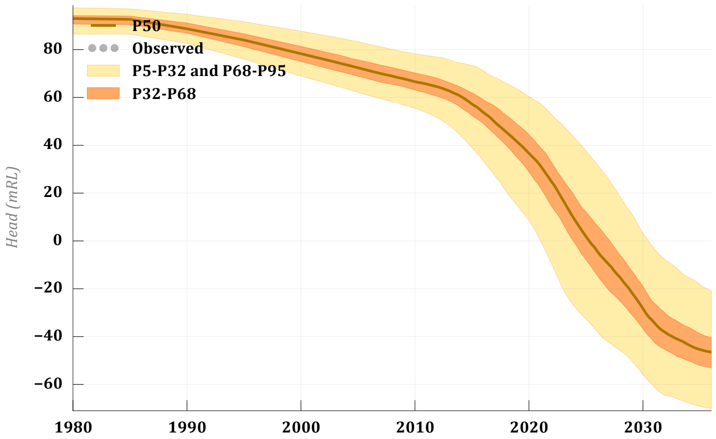
RNVW2-UPG



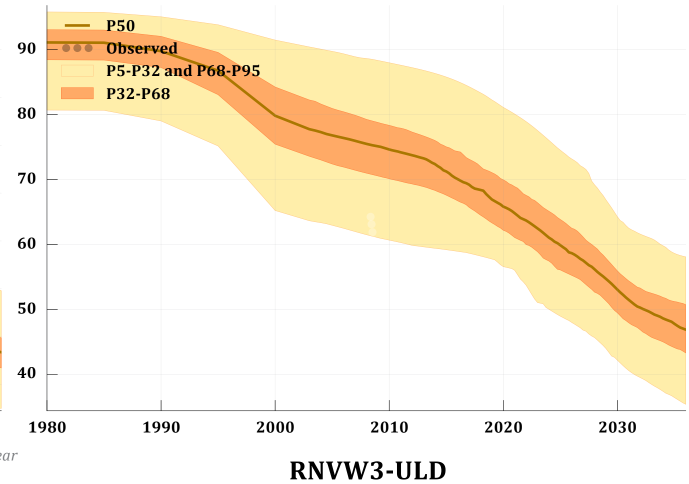
RNVW3-BRT



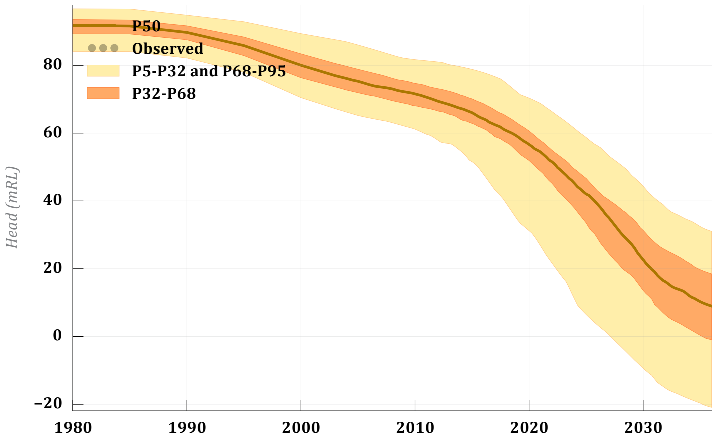
RNVW3-LLD



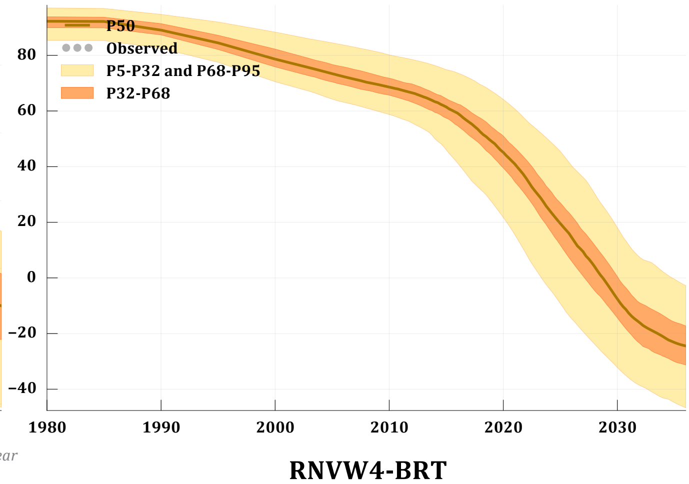
RNVW3-LMA



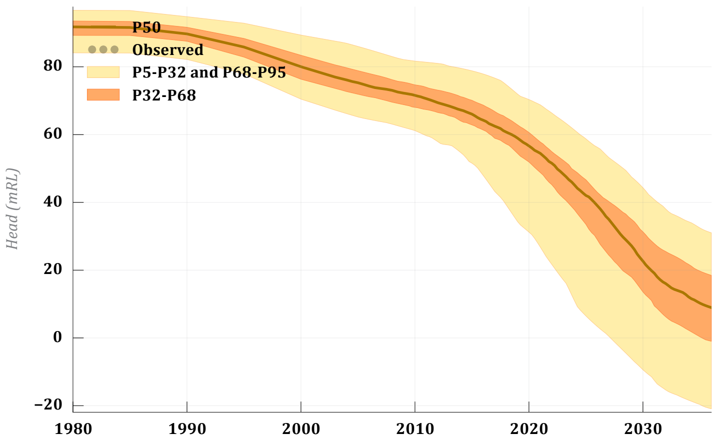
RNVW3-UAR



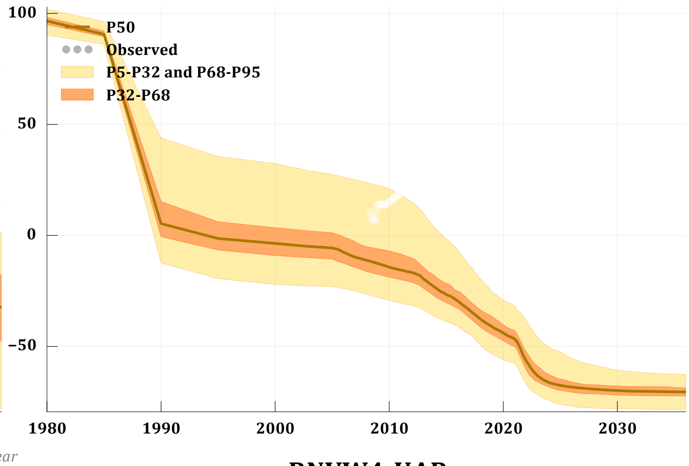
RNVW3-ULD



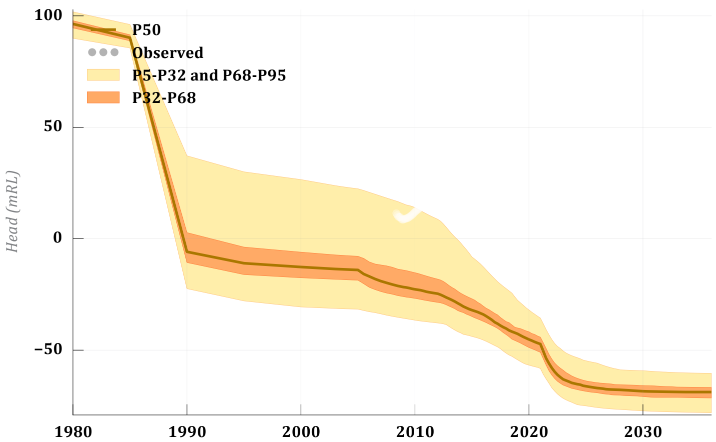
RNVW3-UPG



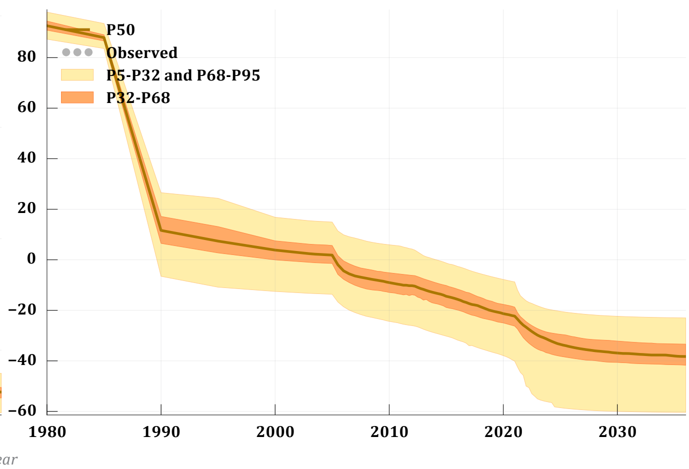
RNVW4-BRT

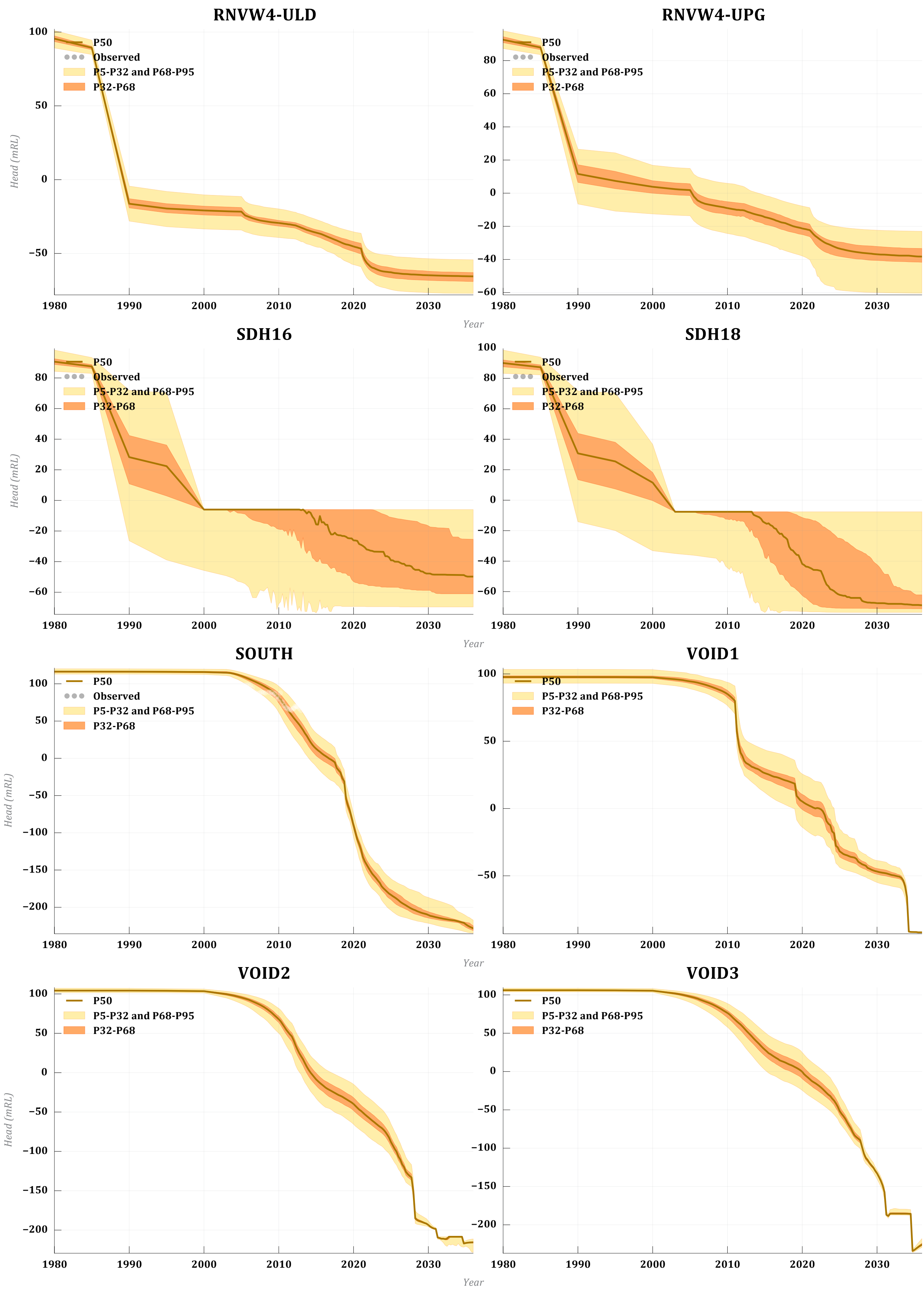


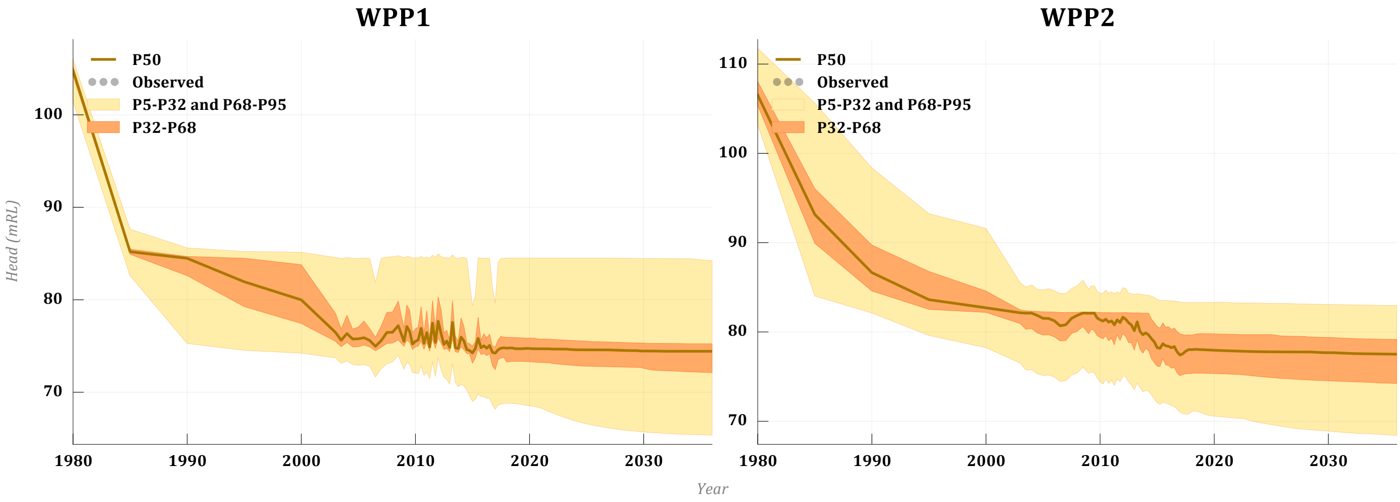
RNVW4-LLD



RNVW4-UAR




RNVW4-ULD
RNVW4-UPG
SDH16
SDH18
SOUTH
VOID1
VOID2
VOID3
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030


WPP1
WPP2
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030
70
80
90
100
110

Appendix B

Compliance with government policy

B11 Compliance with NSW government policy

This section discusses the ability of the Modification to comply with the conditions of approval and the NSW AIP.

B11.1 Conditions of Approval

Condition 24 of the conditions of approval for Integra Underground requires that:

> *"the Proponent must offset the loss of any baseflow to the surrounding watercourses and/or associated creeks caused by the project to the satisfaction of the Secretary.*
>
> *Notes:*
>
> - *This condition does not apply in the case of losses of baseflow which are negligible.*
> - *Offsets should be provided via the retirement of adequate water entitlements to account for the loss attributable to the project.*
> - *The Proponent is not required to provide additional baseflow offsets where such offsets have already been provided under previous consents or approvals for the project. These existing offsets are to be described and evaluated in the Surface and Ground Water Response Plan (see below)."*

For the purposes of the Modification any losses of baseflow or alluvial flux below 1 ML/year have been considered negligible. To ensure the Modification complies with Condition 24 in the conditions of approval, HVCC will use water entitlements to account for the impact of the approved mining and the proposed Modification The entitlements will be held by HVCC until the closure of the activity when the entitlements will be retired to ensure the impact of the approved and proposed mining is permanently accounted for.

Condition 30 of the conditions of approval include water management performance measures that must be complied with to the satisfaction of the Secretary. For Glennies Creek and Station Creek alluvial aquifers the following performance measure are stipulated:

- negligible environmental consequences to the alluvial aquifer (as shown in Appendix 6) beyond those predicted in the documents referred to in conditions 2 and 3 of Schedule 2, including:
  - negligible change in groundwater levels;
  - negligible change in groundwater quality; and
  - negligible impact to other groundwater users.

Schedule 2 refers to Appendix 2 which lists the previous documents with environmental impact predictions. Appendix 2 lists the Glennies Creek Underground Coal Project (06_0213) prepared by Environmental Resources Management Australia Pty Ltd in 2007. It does not list the subsequent modification to include the Middle Liddell Seam mining area which was assessed by Geoterra (2009).

The Geoterra (2009) assessment predicted drawdown at the single verified private groundwater user would be less than 0.5 m. Updated modelling for the Modification documented in this report has also reached the same conclusion, with no significant drawdown predicted at this private water bore.

Regarding groundwater quality Geoterra (2009) previously concluded that *"the existing high salinity in the alluvium of the three creeks and the general presence of surficial, low permeability clays it is not anticipated that the alluvial groundwater quality of Glennies Creek, Bettys Creek or Main Creek will be reduced through extraction of the proposed underground workings."* This statement remains consistent with the current assessment that has also concluded it is improbable there will be any impact on groundwater quality.

When the groundwater levels and drawdown from the Geoterra (2009) modelling are compared with the updated modelling for the Modification it is evident there are differences due to inevitable changes in the model structure and calibrated properties that have occurred as larger datasets have become available. At the time of the previous assessment Geoterra (2009) noted that *"…the model was not calibrated to water levels mainly due to the lack of time variant groundwater extraction data, which affects groundwater levels."* The updated model therefore is considered to provide an improved assessment of groundwater level and drawdown.

B11.2 Aquifer Interference Policy

Table B 11-1 to Table B 1-3 below compare the groundwater impact predictions for the Modification against the requirements under the NSW AIP (NOW, 2012).

Table B 11-1 Accounting for or preventing the take of water

AIP requirement		Proponent response
1	Described the water source (s) the activity will take water from?	Section 7.1.4 describes the results of field investigations used to describe the properties of the water sources in the area of the activity and numerical modelling used to estimate the volume of water taken from the: • Sydney Basin – North Coast Water Source • Jerrys Water Source • Glennies Water Source • Hunter Regulated River Alluvial Water Source • Hunter Regulated River Water Source
2	Predict the total amount of water that will be taken from each connected groundwater or surface water source on an annual basis as a result of the activity?	Table 7-1 summarises the peak take of surface water and groundwater from each water source due to the approved mining and the additional incremental effect of the Modification.
3	Predicted the total amount of water that will be taken from each connected groundwater or surface water source after the closure of the activity?	Section describes post mining impacts.
4	Made these predictions in accordance with Section 3.2.3 of the AIP? (page 27)	Based on 3D numerical modelling
5	Described how and in what proportions this take will be assigned to the affected aquifers and connected surface water sources?	Table 7-1 summarises the peak take of surface water and groundwater from each water source due to the approved mining and the additional incremental effect of the Modification
6	Described how any licence exemptions might apply?	Not necessary.

<table>
<tr><th colspan="2">AIP requirement</th><th>Proponent response</th></tr>
<tr><td>7</td><td>Described the characteristics of the water requirements?</td><td>Refer to surface water assessment</td></tr>
<tr><td>8</td><td>Determined if there are sufficient water entitlements and water allocations that are able to be obtained for the activity?</td><td>Section 7.1.4 describes the entitlements held by the proponent and indicates these are sufficient to account for water taken from the following water sources by the approved and proposed activity:
• Sydney Basin – North Coast Water Source
• Hunter Regulated River Water Source

The proponent is in the process of acquiring entitlements to account for water taken from the following water sources:
• Jerrys Water Source
• Glennies Water Source
• Hunter Regulated River Alluvial Water Source</td></tr>
<tr><td>9</td><td>Considered the rules of the relevant water sharing plan and if it can meet these rules?</td><td>The ‘Cease to Pump’ rules for the Glennies and Jerrys Water Sources requires “From year six of the plan, all licence holders must cease to pump when there is either no visible inflow to, or outflow from, the pumping pool. N.B. From year six of the plan the cease to pump condition will apply to aquifer access licences extracting from all alluvial aquifers within 40m of an unregulated river, except for Domestic and Stock access licences and Local Water Utilities Access licences.”

The predicted take of water from the Glennies and Jerrys Water Sources due to the activity is an indirect and passive water take that occurs not due to pumping from the water source, but due to depressurisation of the underlying bedrock being mined. This rule has been considered and it is concluded it is not possible to meet this rule as it is designed for active pumping sites.</td></tr>
<tr><td>10</td><td>Determined how it will obtain the required water?</td><td>Via seepage to the mine face – a portion will be removed as moisture in coal and will not enter the site water circuit (Refer to section 7.1.1).</td></tr>
<tr><td>11</td><td>Considered the effect that activation of existing entitlement may have on future available water determinations?</td><td>The following WALS and share components are available for each of the water sources affected to be impacted by the approved and proposed activity:
• Jerrys Water Source – 10 WALs and 1246 aquifer licence shares
• Glennies Water Source – 2 WALs and 10 aquifer licence shares
• Hunter Regulated River Alluvial Water Source - 221 WALs and 24108 aquifer licence shares
• Sydney Basin North Coast Water Source - 182 WALs and 69932.5 aquifer licence shares

Future available water determinations are a matter for the NSW government, however based on volume of water taken by the activity is only considered a significant component of the Glennies Water Source.

Source - http://www.water.nsw.gov.au/water-licensing/registers

(refer to Section 2.2)</td></tr>
<tr><td>12</td><td>Considered actions required both during and post-closure to minimise the risk of inflows to a mine void as a result of flooding?</td><td>Refer to the Modification Surface Water Assessment for further information.</td></tr>
</table>

AIP requirement		Proponent response
13	Developed a strategy to account for any water taken beyond the life of the operation of the Project?	Allocate existing and future water entitlements to the Modification water takes to license take of water as necessary.
	Will uncertainty in the predicted inflows have a significant impact on the environment or other authorised water users? Items 14-16 must be addressed if so.	There is inherent uncertainty in the predictions of groundwater models as the 'water take' predictions are difficult to measure and validate. Despite this fact, a significant portion of the underground mine has already been completed and monitoring has not detected any unforeseen impacts on the environment or authorised water users. The proposed Modification is in an area more remote from the existing alluvial aquifers, GDEs and authorised users and therefore is considered to pose a lesser risk than already completed mining. Given this, some uncertainty in the predictions is not expected to have a significant impact on the outcomes of the proposed activity.
14	Considered any potential for causing or enhancing hydraulic connections, and quantified the risk?	Numerical modelling has represented fracturing of strata from subsidence and the reporting has considered the potential for any flow on environmental impacts.
15	Quantified any other uncertainties in the groundwater or surface water impact modelling conducted for the activity?	A sensitivity and uncertainty analysis has been completed to identify model features and parameters that demonstrate most substantial changes in the predictions.
16	Considered strategies for monitoring actual and reassessing any predicted take of water throughout the life of the Project, and how these requirements will be accounted for?	Ongoing monitoring and verification of modelling.

Table B 1-2 Determining water predictions

AIP requirement		Proponent response
1	Addressed the minimum requirements found on page 27 of the AIP for the estimation of water quantities both during and following cessation of the proposed activity?	Predictions based on modelling made to address the requirements of page 27 of the AIP. Provided in Section 7.

Table B 1-3 Determining water predictions

AIP requirement		Proponent response
1	Establishment of baseline groundwater conditions?	Refer Section 5. Water quality and level data has been collected at the Modification area since 2005 for some of the key groundwater units and tested for a selection of analytes. Extensive water quality and level data has been collected at neighbouring mines.
2	A strategy for complying with any water access rules?	Not applicable as water is taken in an indirect passive manner.
3	Potential water level, quality or pressure drawdown impacts on nearby basic landholder rights water users?	No private bores are predicted to be impacted >2 m.
4	Potential water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources?	No private bores are predicted to be impacted >2 m.
5	Potential water level, quality or pressure drawdown impacts on groundwater dependent ecosystems?	No significant drawdown is predicted at the sites of the potential groundwater dependent ecosystems.
6	Potential for increased saline or contaminated water inflows to aquifers and highly connected river systems?	The activity proposed is underground mining only, and there is no identified potential to increase saline or contaminated water inflows to aquifers and highly connected river systems
7	Potential to cause or enhance hydraulic connection between aquifers?	Subsidence will create a fracture network above the mining area, which will potentially enhance the connectivity through the Permian strata, but not create any connectivity with Quaternary alluvial aquifers. The impact of the permeability enhancement within the Permian has been assessed using numerical modelling and concluded the fracturing will not result in impacts on licensed users, baseflow or groundwater dependent ecosystems.
8	Potential for river bank instability, or high wall instability or failure to occur?	Refer to Surface Water Assessment
9	Details of the method for disposing of extracted activities (for CSG activities)?	N/A

There are two levels of minimal impact considerations specified in the AIP. If the predicted impacts are less than the Level 1 minimal impact considerations, then these impacts will be considered as acceptable. Where the predicted impacts are greater than the Level 1 minimal impact considerations then the AIP requires additional studies to fully assess these predicted impacts. If this assessment shows that the predicted impacts do not prevent the long-term viability of the relevant water-dependent asset, then the impacts will be considered to be acceptable. The modelling indicates the Level 1 minimal impact considerations will not be exceeded.

B12 Compliance with Commonwealth government policy

B12.1 EPBC Act Significant Impact on Water Resources Guidelines

In June 2013 the Federal Government enacted changes to the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), to provide that 'water resources' are a matter of national environmental significance in relation to coal seam gas and large coal mining development. This change is referred to as the 'water trigger'. In December 2013, the Federal Department of Environment (DoE) released guidelines for proponents of coal seam gas and large coal mining projects to assess the potential for significant impacts on water resources. The guideline outlines a 'self-assessment' process that assists proponents to identify if their project is likely to have a significant impact on water resources.

This report considers the impact of the Modification on groundwater resources, and if these impacts are significant according to the guidelines. It compares the predicted impacts against the DoE guidelines to determine if the Modification could have a significant impact on water resources. It also considers the potential for cumulative impacts with other developments.

It is important to note that coal mining will always impact the groundwater regime, as dewatering of the mine workings is essential to extract coal safely. However, we have interpreted the DoE guidelines (Commonwealth of Australia, 2013) to mean that this unavoidable impact is only considered significant where there is a consequence from this impact, i.e. that groundwater users or the environment are affected by changes in the quality or quantity of groundwater.

The guidelines indicate that the Modification must have '*a real or not remote chance or possibility that it will directly or indirectly result in a change to*' the '*hydrology*' or '*water quality*' of the water resource. This change must be of '*sufficient scale or intensity as to reduce the current or future utility of the water resource for third party users*'. Third party users can include '*environmental and other public benefit outcomes, or to create a material risk of such reduction in utility occurring*'. Furthermore, '*whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the water resource which is impacted, and upon the intensity, duration, magnitude and geographic extent of the impacts*'.

The discussion below focusses on the incremental impact of the Modification, not the impact of the already approved mining.

B12.1.1 Water availability to users

There is only one known operating private bore within proximity to the Modification, which is constructed as a well extracting from the Glennies Creek alluvial aquifer. This bore is currently monitored by the adjacent Rix Creek North open cut mine which is closer to the well than the Modification. The results do not indicate the potential for any drawdown at this bore due to the Modification. Regardless of this, the WMP currently implemented for Integra Underground (refer Section 8) provides a 'make-good' measure for any private bores impacted by the Project.

B12.1.2 Water availability to the environment

The numerical modelling indicates the depressurisation due to the Modification will not significantly reduce the flow of Permian groundwater to the alluvial aquifers during mining. Therefore, during mining there is not predicted to be any detectable drawdown occurring within the alluvial aquifers in proximity to the mine. Post mining the gradual seepage of Permian groundwater into the underground mining areas is predicted to reduce the flux of groundwater into the overlying alluvial aquifers. This will potentially result in some very limited lowering of groundwater levels within areas of the Quaternary alluvium. Riparian vegetation occurring along Main Creek, Bettys Creek and Glennies Creek has been identified as having the potential to depend on groundwater. Whilst the level of dependence is not known, the water level fluctuations observed within the monitoring network significantly exceed the level of drawdown predicted for the Modification, and therefore a long term impact on the vegetation is considered improbable.

B12.1.3 Water quality

Post mining the portals to the underground mining areas will be sealed and groundwater seepage from the surrounding Permian strata will slowly flood the workings. Unlike open cut mining there is no potential for evaporation to concentrate salts within the underground mining areas, and therefore an increase in salinity of the Permian water seeping into the mine is not expected to occur. As noted previously when the underground mining area has refilled post mining a hydraulic gradient forms from the underground mining area towards the Mount Owen North Pit open void. Whilst no degradation in groundwater quality is expected to occur within the underground mining area all water in the mining area will eventually flow towards and be captured within the Mount Owen final void.

B12.1.4 Cumulative impacts

Cumulative impacts in the region of the proposed Modification are significant. Large mines targeting the same coal seams surround the proposed Modification and all depressurise the Permian strata. Logically the drawdown that is most attributable to the proposed Modification is that adjacent to the mining area, with the zone of influence reducing with distance. Previous sections that outline the cumulative impacts suggest the Modification will only add a small to moderate 'water take' to the already approved mines.

B12.1.5 Avoidance or mitigation measures

The mine plan avoids the flood plain and does not intersect existing alluvial aquifers. The impacts on the alluvial aquifers are therefore indirect, and occur through the depressurisation of the underlying Permian coal measures. Locating the mining outside the alluvial flood plain effectively mitigates the impact upon the alluvial aquifer and connected streams. The groundwater seepage to the mining areas cannot be prevented, and must be removed to ensure safe operating conditions within the mining areas.

If the Modification interferes with any private groundwater user possessing a water supply work, and mitigation measures are not feasible, make good measures with affected land owners will implemented.

B12.1.6 Tabulated impacts

Table B 2-1 and Table B 2-2 summarise the conclusions compared against DoE guidelines:

Table B 2-1 Summary of impacts to the hydrology of the water resource compared to the DoE guidelines

Is there a substantial change to the hydrology of the water resource for:	Comment relating to Modification
flow volume?	Modelling predicts changes in flows of groundwater from Permian bedrock to the alluvial aquifers, but this does not create, flow on effects for private water bores or GDEs.
flow timing?	Impacts are predicted to gradually increase and peak post mining as system re-equilibrates to the changed conditions resulting from mining.
flow duration and frequency of water flows?	Volumes of baseflow removed are relatively small compared to surface water flows within the creek systems.
recharge rates?	Recharge rates may be altered due to fracturing associated with subsidence – this has been assessed using numerical modelling.
aquifer pressure or pressure relationships between aquifers?	Pressures will reduce in coal measures and Quaternary alluvium during the mine life but slowly recover post mining.
groundwater table levels?	The water table within the Quaternary alluvium will be largely unaffected with drawdown less than 1m in all areas.
groundwater/surface interactions?	Water table drawdown within the Quaternary alluvium will reduce base flow to, or increase leakage from, the interconnected streams.
river/floodplain connectivity?	No impact as no mining proposed in flood plain. There is indirect connectivity through the Permian aquifer to the base of the Quaternary alluvium and river system.
inter-aquifer connectivity?	The fracture zone above the mining area is expected to enhance the connectivity through the Permian strata.
coastal processes?	Not applicable
large scale subsidence?	Subsidence will be largely limited to areas already disturbed by mining activities in shallower strata.
other uses?	No
state water resource plans?	Numerical modelling has been used to assess volumes of groundwater that need to be accounted for with water licences. Proponent holds water licences for Permian water and developing a strategy to acquire additional licences for alluvial water.
cumulative impact?	Yes - extensive mining within the Permian strata has been assessed using a regional groundwater model.

Table B 12-2 Summary of impacts to the water quality of the water resource compared to the DoE 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?	No there will be no evaporative concentration of salt in the mining areas.
results in worsening of local water quality where local water quality is superior to local or regional water quality objectives (i.e. ANZECC guidelines for Fresh and Marine Water Quality)?	No
salt concentration/generation?	No
cumulative impact?	Yes - cumulative impacts have been estimated using a numerical model.
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

B12.1.7 IESC Information Guidelines

Information requirement	Addressed in Section
Description of the proposal	
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, current and reasonably foreseeable coal mining and CSG developments.	3, 4, 4.2.4, 6.1
A description of the statutory context, including information on the proposal's status within the regulatory assessment process and on any water management policies or regulations applicable to the proposal	2
A description of 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	1.1, 6.1
A description of how impacted water resources are currently being regulated under state or Commonwealth law, including whether there are any applicable standard conditions	2
Groundwater	
Context and conceptualisation	
Descriptions and mapping of 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 with accompanying surface geology and cross-sections.	4
• definitions of any significant geological structures (e.g. faults) in the area and their influence on groundwater, in particular, groundwater flow, discharge or recharge	4.2.4
Values for hydraulic parameters (e.g. vertical and horizontal hydraulic conductivity and storage characteristics) for each hydrogeological unit.	5.1.4, 5.2.3
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, hydrographs and hydrochemical characteristics (e.g. acidity/alkalinity, electrical conductivity, metals, major ions). Time series data representative of seasonal and climatic cycles.	4.2, 5.1.3, 5.2.2
Description of the likely recharge, discharge and flow pathways for all hydrogeological units likely to be impacted by the proposed development.	Appendix A
Assessment of the frequency, location, volume and direction of interactions between water resources, including surface water/groundwater connectivity, inter-aquifer connectivity and connectivity with sea water.	5.5
Analytical and numerical modelling	
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.	Appendix A
Undertaken in accordance with the Australian Groundwater Modelling Guidelines , including peer review	Appendix A
Calibration 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
Representations of each hydrogeological unit, the thickness, storage and hydraulic characteristics of each unit, and linkages between units, if any.	Appendix A
Representation of the existing recharge/discharge pathways of the units and the changes that are predicted to occur upon commencement, throughout, and after completion of the development activities.	Appendix A

Information requirement	Addressed in Section
Incorporation of the various stages of the proposed development (construction, operation and rehabilitation) with 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.	Appendix A
Identification of the volumes of water predicted to be taken annually with an indication of the proportion supplied from each hydrogeological unit.	7.1.1
An explanation of the model conceptualisation of the hydrogeological system or systems, including key assumptions and model limitations, with any consequences described.	5.5
Consideration of 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
Sensitivity analysis of boundary conditions and hydraulic and storage parameters, and justification for the conditions applied in the final groundwater model.	Appendix A
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.	Appendix A
A programme for review and update of the models as more data and information become available, including reporting requirements.	8.6
Information on the time for maximum drawdown and post-development drawdown equilibrium to be reached.	7.3
Impacts to water resources and water-dependent assets	
An assessment of the potential impacts of the proposal, including how impacts are predicted to change over time and any residual long-term impacts:	
• Description of 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.	4.2.4
• 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.	4.2.4, 7
• Description of 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.	Appendix A
• Consideration of possible fracturing of and other damage to confining layers.	Appendix A
• For each relevant hydrogeological unit, the proportional increase in groundwater use and impacts as a consequence of the development proposal, 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.	N/A
Description of 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.	6.1
For each potentially impacted water resource, 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.	7
Description of existing water quality guidelines and targets, environmental flow objectives and other requirements (e.g. water planning rules) for the groundwater basin(s) within which the development proposal is based.	2

Information requirement	Addressed in Section
An assessment of the cumulative impact of the proposal on groundwater when all developments (past, present and/or reasonably foreseeable) are considered in combination.	7.2
Proposed mitigation and management actions for each significant impact identified, including any proposed mitigation or offset measures for long-term impacts post mining.	8
Description and assessment of the adequacy of proposed measures to prevent/minimise impacts on water resources and water-dependent assets.	8
Data and monitoring	
Sufficient physical aquifer parameters and hydrogeochemical data to establish pre-development conditions, including fluctuations in groundwater levels at time intervals relevant to aquifer processes.	4.2.4
A robust groundwater monitoring programme, utilising dedicated groundwater monitoring wells and targeting specific aquifers, providing an understanding of the groundwater regime, recharge and discharge processes and identifying changes over time.	4.2.4, 8
Long-term groundwater monitoring, including a comprehensive assessment of all relevant chemical parameters to inform changes in groundwater quality and detect potential contamination events.	8
Water quality monitoring complying with relevant National Water Quality Management Strategy (NWQMS) guidelines and relevant legislated state protocols .	8
Water dependent assets	
Context and conceptualisation	
Identification of water-dependent assets, including:	
• Water-dependent fauna and flora supported by habitat, flora and fauna (including stygofauna) surveys.	5.4.2, 7.1.6
• Public health, recreation, amenity, Indigenous, tourism or agricultural values for each water resource.	N/a
Identification of GDEs in accordance with the method outlined by Eamus et al. (2006) . Information from the GDE Toolbox and GDE Atlas may assist in identification of GDEs.	5.4.2
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)2.	7.1.6
An estimation of the ecological water requirements of identified GDEs and other water-dependent assets.	7.1.6
Identification of the hydrogeological units on which any identified GDEs are dependent.	5.4.2
An outline of the water-dependent assets and associated environmental objectives and the modelling approach to assess impacts to the assets.	7.1.6
A description of 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).	N/a
Impacts, risk assessment and management of risks	
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.	7.1.6
A description of the potential range of drawdown at each affected bore, and a clear articulation of the scale of impacts to other water users.	5.4.1, 7.1.5
Indication of the vulnerability to contamination (for example, from salt production and salinity) and the likely impacts of contamination on the identified water-dependent assets and ecological processes.	7.3.2

Information requirement	Addressed in Section
Identification and consideration of landscape modifications (for example, voids, onsite earthworks, roadway and pipeline networks) and their potential effects on surface water flow, erosion and habitat fragmentation of water-dependent species and communities.	See Ecology report
Estimates of the impact of operational discharges of water (particularly saline water), including potential emergency discharges due to unusual events, on water-dependent assets and ecological processes.	See Ecology report
An assessment of the overall level of risk to water-dependent assets that combines probability of occurrence with severity of impact.	See Ecology report
The proposed acceptable level of impact for each water-dependent asset based on the best available science and site-specific data, and ideally developed in conjunction with stakeholders.	See Ecology report
Proposed mitigation actions for each identified impact, including a description of the adequacy of the proposed measures and how these will be assessed.	See Ecology report
Data and monitoring	
Sampling sites at an appropriate frequency and spatial coverage to establish pre-development (baseline) conditions, and test hypothesised responses to impacts of the proposal.	8.1
Concurrent baseline monitoring from unimpacted control and reference sites to distinguish impacts from background variation in the region (e.g. BACI design).	8.1
Monitoring 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 Ecology report
Regular reporting, review and revisions to the monitoring programme.	8
Ecological monitoring complying with relevant state or national monitoring guidelines.	See Ecology report
Cumulative Impacts	
Context and conceptualisation	
Cumulative impact analysis with sufficient geographic and time boundaries to include all potentially significant water-related impacts.	7.2
Cumulative impact analysis identifies all past, present, and reasonably foreseeable actions, including development proposals, programs and policies that are likely to impact on the water resources of concern.	7.2
Impacts	
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.	4.2.4
• A description of the current condition and quality of water resources and information on condition trends.	4.2.4
• Identification of ecological characteristics, processes, conditions, trends and values of water resources.	5.4
• Adequate water and salt balances.	See surface water assessment
• 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).	8.4
An assessment of cumulative impacts to water resources which considers:	
• The full extent of potential impacts from the proposed development, including alternatives, and encompassing all linkages, including both direct and indirect links, operating upstream, downstream, vertically and laterally.	7

Information requirement	Addressed in Section
• An assessment of impacts considered at all stages of the development, including exploration, operations and post closure / decommissioning.	7
• An assessment of impacts, utilising appropriately robust, repeatable and transparent methods.	7, Appendix A
• Identification of the likely spatial magnitude and timeframe over which impacts will occur, and significance of cumulative impacts.	7
• Identification of opportunities to work with others to avoid, minimise or mitigate potential cumulative impacts.	7.2
Mitigation, monitoring and management	
Identification of modifications or alternatives to avoid, minimise or mitigate potential cumulative impacts	8
Identification of measures to detect and monitor cumulative impacts, pre and post development, and assess the success of mitigation strategies	8
Identification of cumulative impact environmental objectives	8
Appropriate reporting mechanisms	8
Proposed adaptive management measures and management responses	8