APPENDIX 16

Groundwater
Impact Assessment

Australasian Groundwater and
Environmental Consultants Pty Ltd

Report on

Groundwater Impact Assessment
Glendell Continued Operations Project

Prepared for
Umwelt (Australia) Pty Limited

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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
Unit 3, Building A, 10 Cummins Street
Hyde Park, QLD 4812, Australia
T. +61 7 4413 2020
F. +61 7 3257 2088
townsville@ageconsultants.com.au

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Report on

Groundwater Impact Assessment
Glendell Continued Operations Project

1 Introduction

The Glendell Mine forms part of the Mount Owen Complex located in the Upper Hunter Valley of New South Wales (NSW), approximately 20 kilometres (km) north-west of Singleton, 24 km south-east of Muswellbrook and to the north of Camberwell (Figure 1-1).

In addition to the Glendell Mine, the Mount Owen Complex comprises mining operations at the Mount Owen Mine (North Pit) and Ravensworth East Mine (Bayswater North Pit). The Mount Owen Complex also includes a coal handling and preparation plant (CHPP) and coal handling and transport infrastructure. The Mount Owen Complex operations are owned by Mt Owen Pty Limited (Mount Owen), a wholly owned subsidiary of Glencore Coal Pty Limited (Glencore).

The Mount Owen Complex is adjacent to the Integra Underground, Liddell Coal Operations and Ravensworth Operations, which are also operations owned and operated by subsidiaries of Glencore and its joint venture partner (JV).

The Glendell Mine currently operates under development consent DA 80/952 (Glendell Consent). The Glendell Consent regulates the mining of coal from the Glendell Pit (also known as the Barrett Pit) and the rehabilitation of the mining area.

The Glendell Continued Operations Project (the Project) proposes to seek approval to extend open cut mining operations north from the existing Glendell Mine. The proposed extension of the current open cut mining operations at Glendell Mine would extract an additional approximately 135 million tonnes (Mt) of run-of-mine (ROM) coal. This extension of the Glendell Pit is referred to as the Glendell Pit Extension and proposes to extract reserves down to and including the Hebden seam with mining continuing to 2044. The Project does not propose any changes to approved mining operations in either of the mining areas approved under the Mount Owen Continued Operations Project development consent SSD-5850 (Mount Owen Consent).

The Project is a State Significant Development (SSD) and will require development consent under the *Environmental Planning and Assessment Act 1979* (EP&A Act). As SSD, an Environmental Impact Statement (EIS) is required to accompany the development application for the Project. To facilitate this Glencore commissioned Umwelt Australia Pty Ltd (Umwelt) to prepare an EIS to support the Project under Section 4.12(8) of the *Environmental Planning and Assessment Act 1979* (EP&A Act) and Schedule 2 of the *Environmental Planning and Assessment Regulation 2000*.

The Project was referred to the Commonwealth Department of Environment and Energy (DoEE) and was determined to be a controlled action under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) on 10 July 2019.

This groundwater assessment has been prepared by Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) to support the EIS for the Project. The scope of the groundwater assessment has been designed to address the Secretary's Environmental Assessment Requirements (SEARs) that relate to groundwater, including the New South Wales Aquifer Interference Policy (2012) (AIP), conditions of the Conditional Gateway Certificate issued by Mining and Petroleum Gateway panel and information guidelines developed by the Independent Expert Scientific Committee (IESC) on Coal Seam Gas and Large Coal Mining Development. Table 1-1 reproduces the relevant SEARs and indicates where these requirements are addressed within this report. Requirement Table 1-2 summarises the requirements of the Conditional Gateway Certificate and again indicates where these have been addressed.

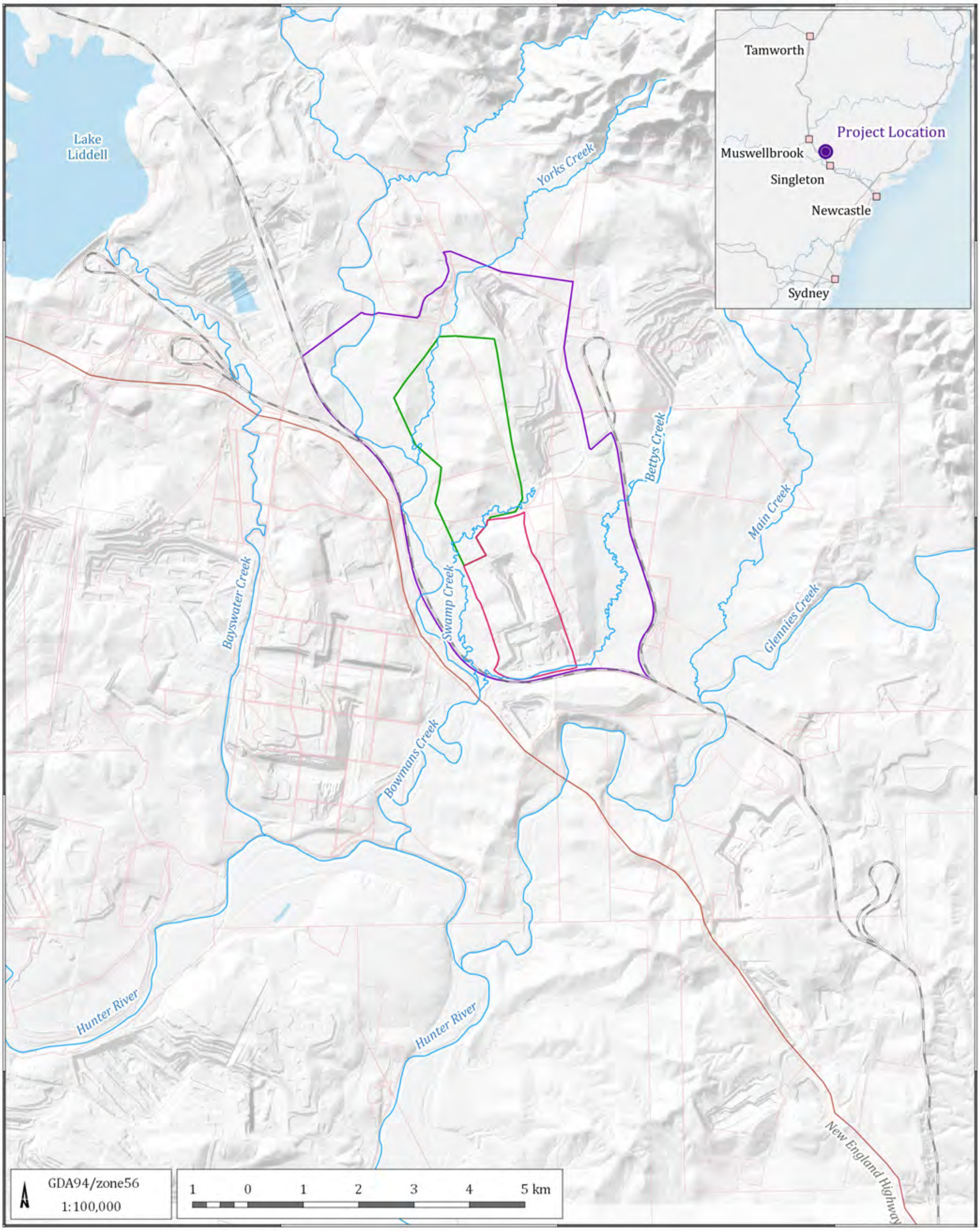
Table 1-1 Secretary's Environmental Assessment requirements relating to groundwater

Requirement	Addressed in report sections
Key issues - Water – including:	
• identification of any licensing requirements or other approvals under the Water Act 1912 and/or Water Management Act 2000;	Section 2
• demonstration that water for the construction and operation of the proposed development can be obtained from an appropriately authorised and reliable supply in accordance with the operating rules of any relevant Water Sharing Plan (WSP) or water source embargo;	Section 2.2, 7.2.8 and 7.3.4
• an assessment of the likely impacts of the development on the quantity and quality of existing surface and groundwater resources including a detailed assessment of proposed water discharge quantities and quality against receiving water quality and flow objectives;	Refer Surface Water Impact Assessment and Section 7
• an assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure, and other water users, including downstream impacts from the Yorks Creek diversion;	Refer Surface Water Impact Assessment and Section 5, 6 and 7

Table 1-2 Mining and Petroleum Gateway Panel requirements relating to groundwater

Requirement	Addressed in report sections
Condition	
• A numerical groundwater flow models is required to be developed to estimate the magnitude of environmental impacts that the proposed mine extension will have on local water assets/environment and to predict mine water inflows.	Section 6 and 7, and Appendix B
• All water losses from affected water sources, caused by mining, will require an appropriate water license.	Sections 2.4, 7.2.8 and 7.3.4
• More work is also required to establish baseline groundwater conditions. In particular the following is inadequately defined:	
o The interaction between surface and groundwater between Bowmans Creek, and the proposed pit extension;	Section 5.6 and 5.10
o Hydraulic parameters of the model layers;	Section 5.7 and Appendix B

Requirement	Addressed in report sections
o Groundwater dependent ecosystems (GDE).	Refer to EIS (Umwelt 2019) and Section 5.9.2
Recommendations	
• Using a calibrated transient 3D model to quantify the impacts on nearby water assets (bores/wells and GDEs).	Section 7.2 and 7.3
This modelling and reporting should: o Capture the hydrogeological complexity of the site;	Appendix B
o Use temporal input data;	Section 5.5
o Have distributed input parameters;	Appendix B
o Quantify any uncertainties in the groundwater/surface water connection;	Section 5.6 and 5.10
o Undertaken both sensitivity and uncertainty analysis and have the model independently peer reviewed.	Section 6.3
• Undertake appropriate studies to establish baseline groundwater conditions, including groundwater dependent ecosystems.	Section 5
• Monitor and report actual mine water inflows and develop a strategy for complying with Water Sharing Plan rules.	Section 8



LEGEND

- Road
- Rail
- Drainage
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area
- Coal titles

Glendell Continued Operations GIA (G1874C)

General location plan

AGE

DATE 21/11/2019

FIGURE No: **1-1**

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\01.01_G1874C_General Location plan.qgs

1.1 Objectives and scope of work

As noted above the objective of the groundwater assessment was to assess the impact of the Project on the groundwater regime and address the requirements of the NSW and Commonwealth government legislation and policies. The groundwater assessment comprise two parts: a description of the existing hydrogeological environment, and an assessment of the impacts of the Project on that environment. The impacts of the Project are detailed separately and also related to the observed and modelled impacts of existing approved operations at Glendell (Approved Operations) and the region more broadly to identify the extent of change in impacts on groundwater resources. The Approved Operations is the operations at Glendell assuming the approval of the Modification 4 application currently under assessment and are discussed further in Section 1.2.

The groundwater impact assessment includes:

- review of existing background data and previous hydrogeological investigations;
- field investigations to assess the extent and thickness of the Bowmans Creek alluvium and associated tributaries (Appendix A);
- updating the existing groundwater regional numerical model for the mid Hunter Region that was last utilised for Mount Owen Consent Modification 2 (AGE 2018) in accordance with the National Groundwater Modelling Guidelines (National Water Commission, 2012) and relevant State and Commonwealth guidelines (Appendix B);
- assessment of impacts resulting from the Project, including impacts on regional groundwater levels and baseflow;
- assessment of potential impact pathways for 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) resulting from 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 monitoring.

1.2 Project description

1.2.1 Approved Operations

The Glendell Consent was granted on 2 May 1983, with the first hydrogeology investigation of the mining area conducted in 1995 (Rust PPK, 1996). A modification of the Glendell Consent was granted in 1997, which provided for amendments to the mining operations and the overburden emplacement areas and then in February 2008 that allowed for the integration of Glendell Mine with the Mount Owen Complex. The most recent modification (Modification 4) application was submitted in late 2018 and proposes:

- an adjustment of the western limit of the disturbance boundary to allow improved internal road layout;
- the addition of a single mining strip (approximately 250 m) to extend the current mining time by approximately 8 months, with no change to the mine life; and
- a reduction in the mine disturbance area by approximately 10 ha. Achieved by increasing the area of riparian vegetation near Bettys Creek that will no longer be disturbed by the mine.

The Glendell Consent allows for mining of up to 4.5 Mt per annum (Mtpa) of ROM coal, by open cut methods until 2024. Mining commenced in the Glendell Pit at Glendell Mine in 2009. The mining occurs along the crest of an anticline that runs through the site in a north-south alignment. Mining occurs in the Vane subgroup coal seams from the Lemington to the Barrett seam.

1.2.2 The Project

The Project proposes the extension of mining at Glendell to the north of the current Glendell Pit ('Glendell Pit Extension'). Mining operation would extend the existing open cut operations to the north with mining down to and including the Hebden seam. Mining operations would initially proceed at the current approved production rate (up to 4.5 Mtpa) with production at Glendell increasing during the life of the operations as production at other Mount Owen Complex mining areas (Bayswater North Pit and North Pit) decline and eventually cease. Maximum annual production from the Glendell Pit Extension would be capped at 10 Mtpa ROM coal. Overburden removed as part of the mining operations will be emplaced in-pit to the south of the mined area as mining progresses to the north. Overburden emplacement would also occur on existing Glendell emplacement areas and areas disturbed as part of the Ravensworth East operations. The final emplaced landform will be developed using natural landform techniques and will be progressively rehabilitated over the life of the Project.

In addition to the existing operations, the new development consent would cover the Glendell Pit Extension and works directly associated with the pit extension including:

- increasing the production rate to 10 Mtpa;
- rehabilitation of areas disturbed by mining activities, including overburden emplacement areas;
- realignment of part of Hebden Road;
- relocation of Ravensworth Homestead;
- realignment of the lower section of Yorks Creek;
- construction/use of MIA facilities and associated related infrastructure and
- construction/use of a Heavy Vehicle Assess Road.

The Project will enable access to approximately 135 Mt of additional ROM coal. Recovery of the additional coal reserves will result in approximately 750 hectares (ha) of additional disturbance (Additional Disturbance Area) beyond areas current approved for mining related disturbance or previously disturbed by mining (refer to Figure 1-2). The Project will require the extension of the mine life through to 2044 (an additional 20 years beyond the current Approved Operations).

Table 1-3 Project summary

Component	Approved Operations
Mining Method	No change - Open cut - Truck and excavator
Target Seams	All seams down to and including the Hebden seam (Glendell Mine currently approved to mine down to and including the Barrett seam).
Additional Coal Reserves Recovered	Approximately 135 Mt ROM coal
Annual Production	Up to 4.5 Mtpa increasing to 10 Mtpa
Mine Life	Glendell Pit Extension to 2044 (Glendell Pit currently approved to 2024). Processing and coal handing operations at Mount Owen to 2045 (currently approved to 2037).
CHPP Capacity	No change - Up to 17 Mtpa
Management of Overburden (Glendell Pit Extension)	Emplacement of overburden in-pit and on existing emplacement areas at Glendell Mine and areas disturbed as part of the Ravensworth East Mine.
Mount Owen CHPP Rejects (coarse and fine)	No change - Fine tailings emplacement within West Pit and other tailings facilities approved at Mount Owen Complex and/or at neighbouring mining operations as part of the Greater Ravensworth Area Water and Tailings Scheme (GRAWTS). Coarse rejects co-disposed with overburden at Mount Owen Complex including overburden associated with the proposed Glendell Pit Extension.
Operational Workforce	Overall workforce at the Mount Owen Complex will remain similar to current workforce numbers of approximately 1,220 full time equivalent (FTE) positions during concurrent operations.
Hours of Operation	No change - 24 hours, 7 days per week
Final Landform	Final landform at Glendell to approximately 200 mAHD (approximately 40 m higher than existing approved operations at Glendell) and to approximately 185 mAHD at Ravensworth East (approximately 15 m higher than existing approved operations). No increase in the number of voids relative to approved operations.
Ravensworth Homestead	Relocation of the Ravensworth Homestead.

The Project does not affect approved mining operations in Bayswater North Pit or North Pit approved under the Mount Owen Consent or landform associated with the catchments of the final voids for these pits.

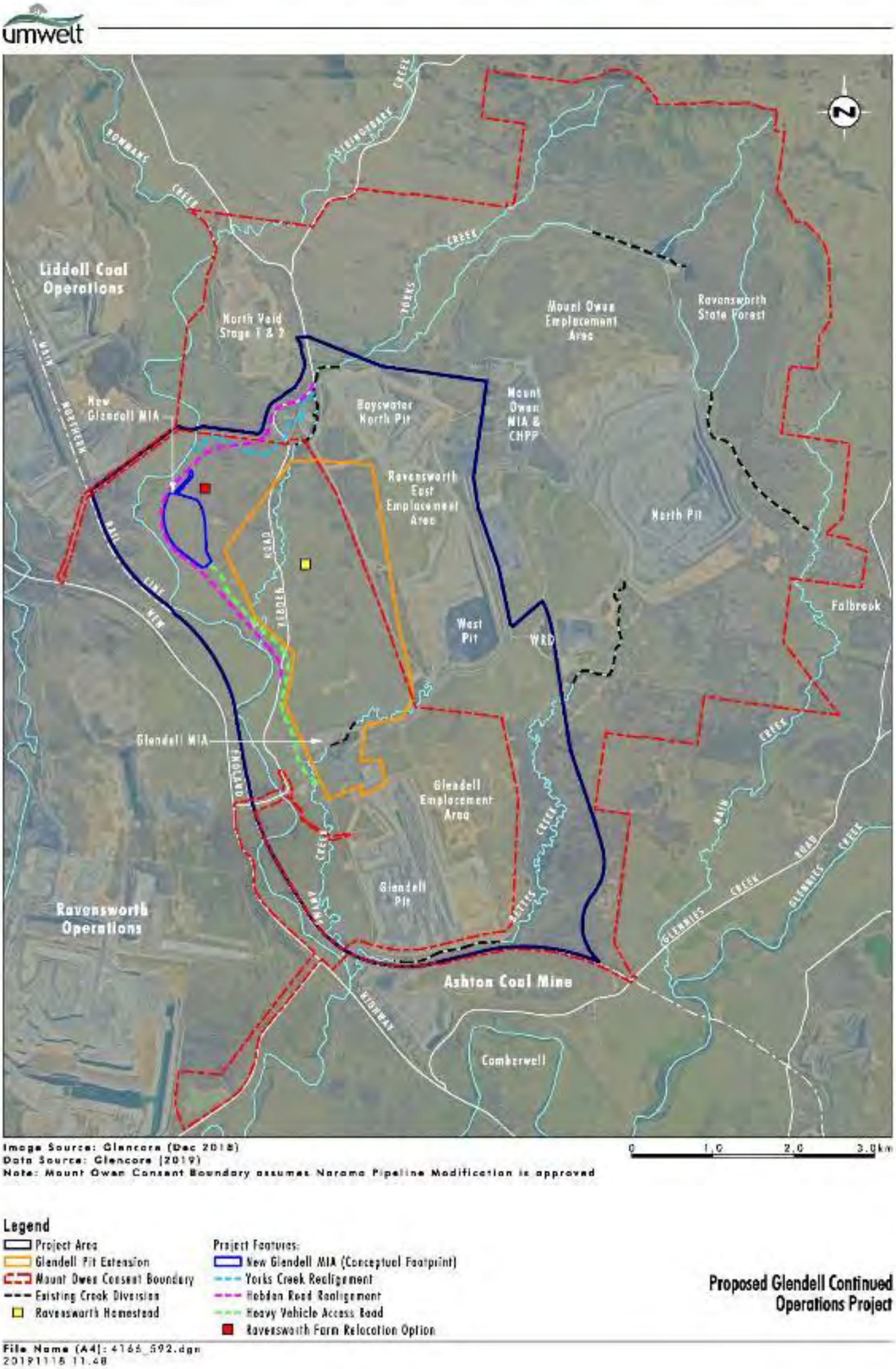


Figure 1-2 Proposed Glendell Continued Operations Project

1.3 Report structure

This report is structured as follows:

- Section 1 – Introduction: provides an overview of the Project 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 Project including the climate, terrain, land uses and other environmental features relevant to groundwater;
- Section 4 – Geological setting: describes the regional geology and local stratigraphy;
- Section 5 – Hydrogeology: describes the groundwater regime within and surrounding the Project;
- Sections 6 and 7 – Impact Assessment: describes the numerical model and the predicted impacts on groundwater users and the receiving environment;
- Section 8 – Groundwater Monitoring and Management Plan: describes the measures for monitoring and management of groundwater impacts;
- Section 9 – Summary and Conclusions;
- Appendix A attaches a report that summarises investigations to define the limit of the alluvium along Bowmans Creek, Yorks Creek and Swamp Creek adjacent to the Project;
- Appendix B provides a detailed description of the numerical modelling undertaken for the Project, including details on model construction, calibration and validation and uncertainty;
- Appendix C contains a table that provides key construction details for each monitoring bore;
- Appendix D contains monitoring bore hydrographs; and
- Appendix E compares the impacts predicted for the Project with State and Commonwealth government policy and comments on compliance.
- Appendix F contains the peer review report.

2 Regulatory framework

The assessment of the Project is required to consider the following legislation, policy and guidelines relating to groundwater:

- NSW Government:
    - Legislation:
        - *Water Management Act 2000* and the associated Water Sharing Plans.
    - Policy and Plans:
        - Groundwater Quality Protection Policy (1998);
        - Groundwater Dependent Ecosystems Policy (2002);
        - Groundwater Quantity Management Policy (Policy Advisory Note No. 8);
        - Aquifer Interference Policy (2012);
        - Strategic Regional Land Use Policy (2012);
        - Strategic Regional Land Use Plan – Upper Hunter (2012); and
        - Water Sharing Plans.
- Commonwealth Government:
    - Legislation:
        - *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).
    - Guidelines and explanatory notes:
        - Information guidelines for proponents preparing coal seam gas and large coal mining development proposals (Commonwealth of Australia, 2018);
        - Uncertainty analysis – Guidance for groundwater modelling within a risk management framework (Middlemis and Peeters, 2018); and
        - Assessing Groundwater Dependent Ecosystems (Doody et al, 2019)

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

2.1 Water Management Act 2000

The NSW *Water Management Act 2000* (WM Act) provides for the "protection, conservation and ecologically sustainable development of the water sources of the State". The WM Act 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. While contained in the legislation, the requirements for an aquifer interference approval have yet to commence.

The WM Act includes the concept of ensuring “no more than minimal harm” for both the granting of water access licences (WALs) 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.

State significant development authorised by a development consent does not require a water use approval due to exemptions in the EP&A Act. These exemptions do not extend to aquifer interface approvals, a water management work approval or an activity approval under the WM Act. While the provisions of the WM Act relevant to the requirement for an aquifer interference approval have not yet commenced, the AIP is used by the NSW Department of Planning, Industry and Environment - Water (DPIE-Water) as guidance document for its assessment of potential impacts associated with activities which interact with aquifers, including coal mining projects. 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 (refer Section 3.2.1 and Table 1 within the AIP).

2.2 Water sharing plans

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

The DPIE-Water is progressively developing WSPs for rivers and groundwater systems across NSW following the introduction of the WM Act. The purposes of the WSPs 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 WSPs apply to the aquifers and surface waters within the vicinity of the Project – 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
- 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 Project 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 Project is located adjacent to and to the north of Zone 3A along Glennies Creek. This zone extends 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 Project is within the Jerrys Water Source. The Glennies Water Source, and the Hunter Regulated River Alluvial Water Source is located to the south and east of the Project Area.

Figure 2-1 shows the water sources and management zones relevant to the Project. The boundary between the Jerrys Water Source and the Glennies Water Source follows the current catchment divide between Bettys Creek and Main Creek except east of the Mount Owen North Pit where Bettys Creek has been diverted into Main Creek; in this area, the water source boundary follows the historical catchment divide whereas the North Pit in-pit emplacement area now forms the actual catchment divide. The effect of this is that the actual Main Creek (and therefore the Glennies Water Source) catchment is larger than mapped in the WSP.

Table 2-1 summarises the number of WALs and the surface water and aquifer licence shares available for each water source.

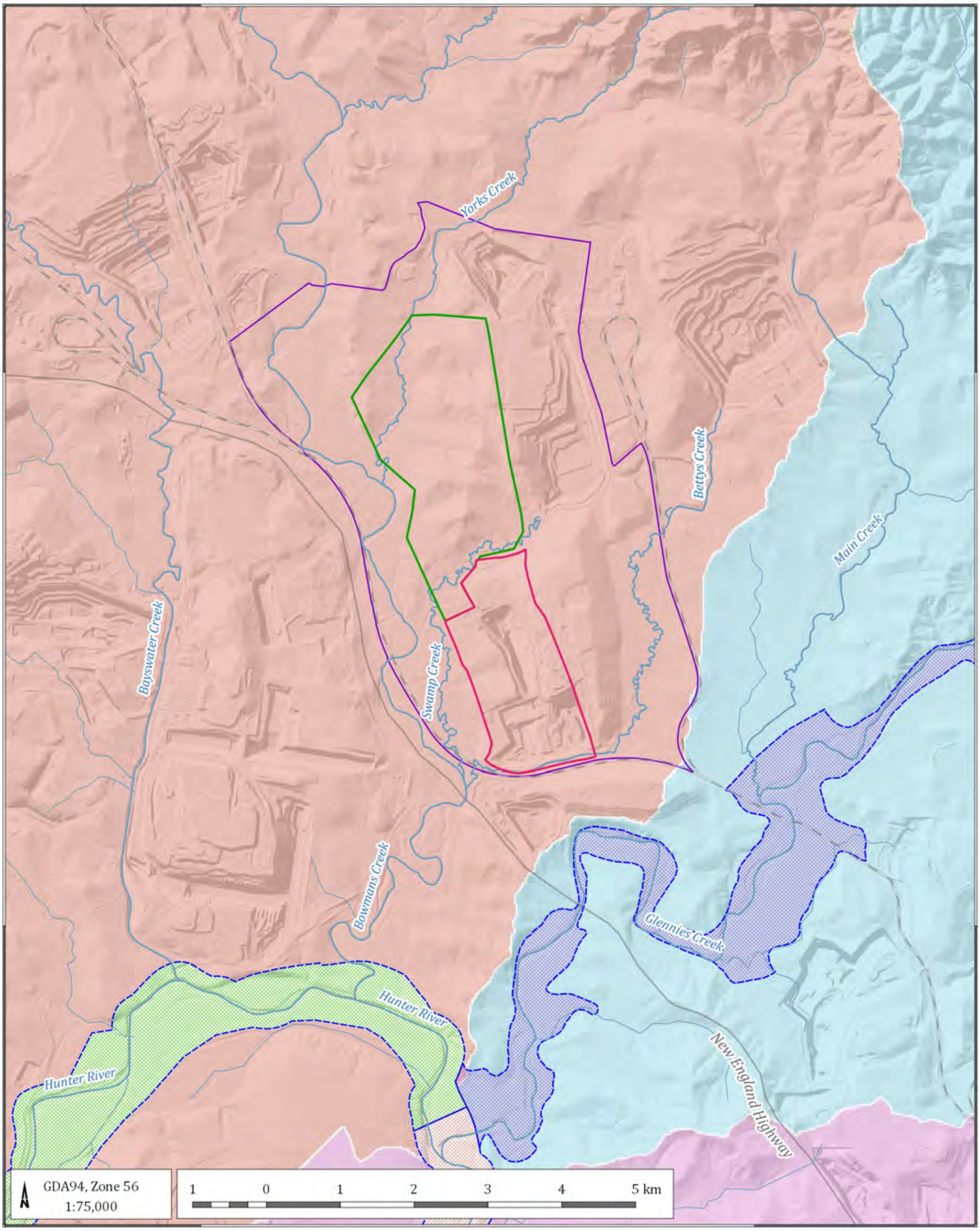
Table 2-1 Water licensing for each water source

Water source	Aquifer access licence units		Unregulated river surface water units	
	No. of WALs[1]	Total units	No. of WALs	Total units
Jerrys	10	1,246	19	2,097
Glennies	2	10	12	446
Hunter Regulated River Alluvial	221	24,118	n/a	n/a
Hunter Regulated River Zone 3	n/a	n/a	-	1,765 (high security)[2] 6,050 (general security)
Sydney Basin North Coast	164	63,575.5	n/a	n/a

Notes: *1. based on information within NSW Water register accessed on 18 February 2019,*
2. https://www.water.nsw.gov.au/__data/assets/pdf_file/0006/572091/Draft-report-card-Hunter.pdf

The water sharing rules are implemented through WAL's and relate to:

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



LEGEND

- Road
- Drainage
- Rail
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Water Sources

- Glennies Water Source
- Jerrys Water Source
- Singleton Water Source

Hunter Regulated River Alluvial Water Source

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

Glendell Continued Operations GIA (G1874C)

Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009 - Water sources and Management zones

AGE

DATE 21/11/2019

FIGURE No: **2-1**

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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2.3 State groundwater policy

2.3.1 Aquifer Interference Policy

The WM Act 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 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 as a result of the proposed activity. These predictions need to occur prior to approval. After approval and during operations, these volumes need to be measured and reported in an annual review or environmental management reports. The person responsible for the take must hold sufficient WAL share components 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:

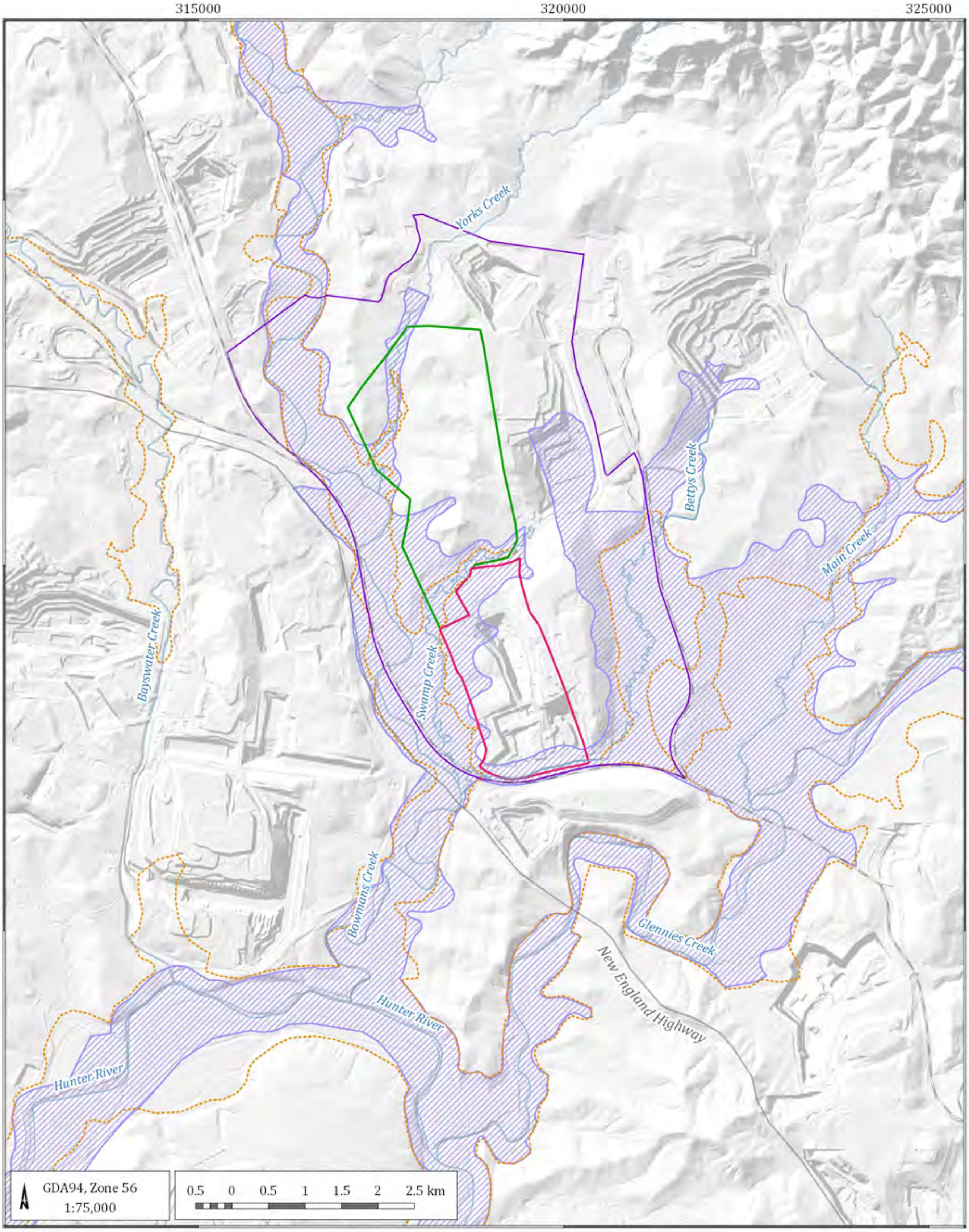
a) has a Total Dissolved Solids (TDS) concentration less than 1,500 mg/L; and
b) contains water supply works that can yield water at a rate greater than 5 L/s.

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.

DPIE-Water has produced a map of groundwater productivity across NSW, which shows areas classified as either highly or less productive. The groundwater productivity map has been produced based on regional scale geological maps. Figure 2-2 shows the DPIE-Water groundwater productivity map, which indicates the alluvium along Bowmans Creek and Bettys Creek has been classified as highly productive.

The extent and characteristics of the Quaternary alluvium is further discussed in Section 4.2.1. Work conducted to define the limit of the alluvial aquifer is described in Appendix A. Section 5.3 and Section 5.8 provide further information on the properties of the alluvial aquifers and if they are considered 'highly productive'.

The minimal impact considerations are a series of threshold levels defining minimal impact on groundwater sources, connected water sources, groundwater dependent ecosystems, culturally significant sites and water users. The thresholds specify impact thresholds for water table and groundwater pressure drawdown changes as well as groundwater and surface water quality changes. Section 7 presents the Project impacts and compares these with the AIP thresholds. Appendix D notes where information required to address the AIP is presented within the report.



LEGEND

- Drainage
- Road
- Rail
- Mapped alluvium boundary
- Highly productive groundwater (DPI Water, 2012)
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Glendell Continued Operations GIA (G1874C)

Highly productive groundwater

DATE 21/11/2019

FIGURE No: **2-2**

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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2.3.2 NSW Strategic Regional Land Use Policy

The NSW Strategic Regional Land Use Policy applies to the Hunter Valley in which the Project 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 Bowmans Creek, Glennies Creek, Bettys Creek and Hunter River flood plain on the regional mapping (Figure 3-4). Site verification has confirmed that no BSAL exists within the Glendell Pit Extension, but a small area of BSAL is present within the Additional Disturbance Area.

2.4 Water licensing

Glencore currently holds water entitlements within the Sydney Basin North Coast Groundwater Source of the North Coast Fractured and Porous Rock WSP to account for up to 1,160 megalitres per year (ML/year) of groundwater ingress into the open cut mining areas for the approved operations at Mount Owen Complex. There are a total of three entitlements as summarised in Table 2-2.

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

WAL number	Reference number	Water source	Units
41540	20AL219002	Sydney Basin North Coast	140
41541	20AL219003	Sydney Basin North Coast	800
41542	20AL219004	Sydney Basin North Coast	220
		TOTAL	**1,160**

The approved Glendell Mine operates in a relatively low permeability geological regime where groundwater is not problematic for mining and is commonly evident only as damp evaporating seeps in mine faces (Figure 2-3). There are no permanent flows of groundwater into the approved Glendell Pit which require continuous pumping and therefore the volume of groundwater intercepted by the mining operations cannot be directly measured. In contrast rainfall runoff that enters the pits is pumped out and the volumes recorded as part of the site water balance. The fact that groundwater does not need pumping does not indicate it is not entering the mine, but rather that the rate of inflow is low enough that it is largely evaporated or adheres to mined materials preventing it from accumulating on the pit floor.

Figure 2-3 Glendell Pit looking north & west (20 June 2018)

Glencore estimate the volume of groundwater entering the approved Glendell Pit annually using a water balance model (SLR 2019). The volume of groundwater entering the Glendell Pit was estimated at 0.6 ML for the 2018 calendar year. The fact that essentially no groundwater inflow was estimated using the water balance method for the 2018 calendar year indicates inflows are very low and any groundwater inflow was either evaporated or adhered to mined materials. This conclusion is supported by observations of the mining area that indicate it is relatively dry (Figure 2-3).

Glencore also holds licences to take up to 200 ML/year from the Jerrys Water Source and up to 17 ML/year from the Glennies Water Source (based on 100% available water determinations) under the Hunter Unregulated WSP. In addition, Glencore also holds licences to extract up to 1,056 ML/year of High Security, 858 ML/year of General Security, 31.2 ML/year of Supplementary and 39 ML/year of Domestic and Stock water from Glennies Creek Management Zone 3a under the Hunter Regulated WSP (based on 100% available water determinations). Glencore's current entitlements are summarised in Table 2.3.

Table 2-3 Water licensing - Hunter Unregulated WSP and Hunter Regulated WSP

Hunter Unregulated WSP			
Licence No.	**Water Source / Management Zone**	**Type**	**Units**
WAL18310	Jerrys Water Source	Surface water	200
WAL18000	Glennies Water Source	Surface water	17
Hunter Regulated WSP			
Licence No.	**Water Source / Management Zone**	**Type**	**Units**
WAL704	Glennies Creek Management Zone 3a	High Security	3
WAL1118	Glennies Creek Management Zone 3a	High Security	3
WAL7814	Glennies Creek Management Zone 3a	High Security	1,000
WAL9521	Glennies Creek Management Zone 3a	High Security	50
		Total High Security	**1,056**
WAL612	Glennies Creek Management Zone 3a	General Security	147
WAL613	Glennies Creek Management Zone 3a	General Security	192
WAL637	Glennies Creek Management Zone 3a	General Security	384
WAL705	Glennies Creek Management Zone 3a	General Security	27
WAL1119	Glennies Creek Management Zone 3a	General Security	60
WAL1215	Glennies Creek Management Zone 3a	General Security	48
		Total General Security	**858**
WAL1364	Glennies Creek Management Zone 3a		2.2
WAL1420	Glennies Creek Management Zone 3a	Supplementary	29
		Total Supplementary	**31.2**
WAL706	Glennies Creek Management Zone 3a	Domestic and Stock	8
WAL754	Glennies Creek Management Zone 3a	Domestic and Stock	16
WAL1218	Glennies Creek Management Zone 3a		3
WAL7817	Glennies Creek Management Zone 3a	Domestic and Stock	3
WAL7823	Glennies Creek Management Zone 3a	Domestic and Stock	9
		Total Domestic and Stock	**39**

2.5 Conditions of approval

The Mount Owen Consent (SSD-5850) and Glendell Consent (DA 80/952) requires development of a Water Management Plan (WMP) and a Groundwater Management and Monitoring Plan (GWMMP), which is a component of the overarching WMP. Glencore is required to hold all necessary water licences for the approved operations at the Mount Owen Complex.

The WMP and GWMMP outlines how Glencore 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 Glencore. Section 8 outlines the content of the WMP and how it will continue to be used for this Project in more detail.

2.6 Commonwealth Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is Commonwealth legislation 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 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.

The Project was referred to DoEE to determine whether it should be categorised as a 'controlled action'. At the time of referral, detailed surface and groundwater studies had not been finalised. In the absence of study results, the Project was identified as having potential to significantly impact on water resources. The EPBC Act referral was placed on exhibition for public comment on 12 April 2019. On 10 July 2019, the referred action was determined to be a controlled action and therefore requires approval under the EPBC Act for the following controlling provisions:

- Listed threatened species and communities (sections 18 & 18A)
- A water resource, in relation to coal seam gas development and large coal mining development (section 240 & 24E)

A summary of the IESC guidelines and where they are addressed within the report is included in Appendix A.

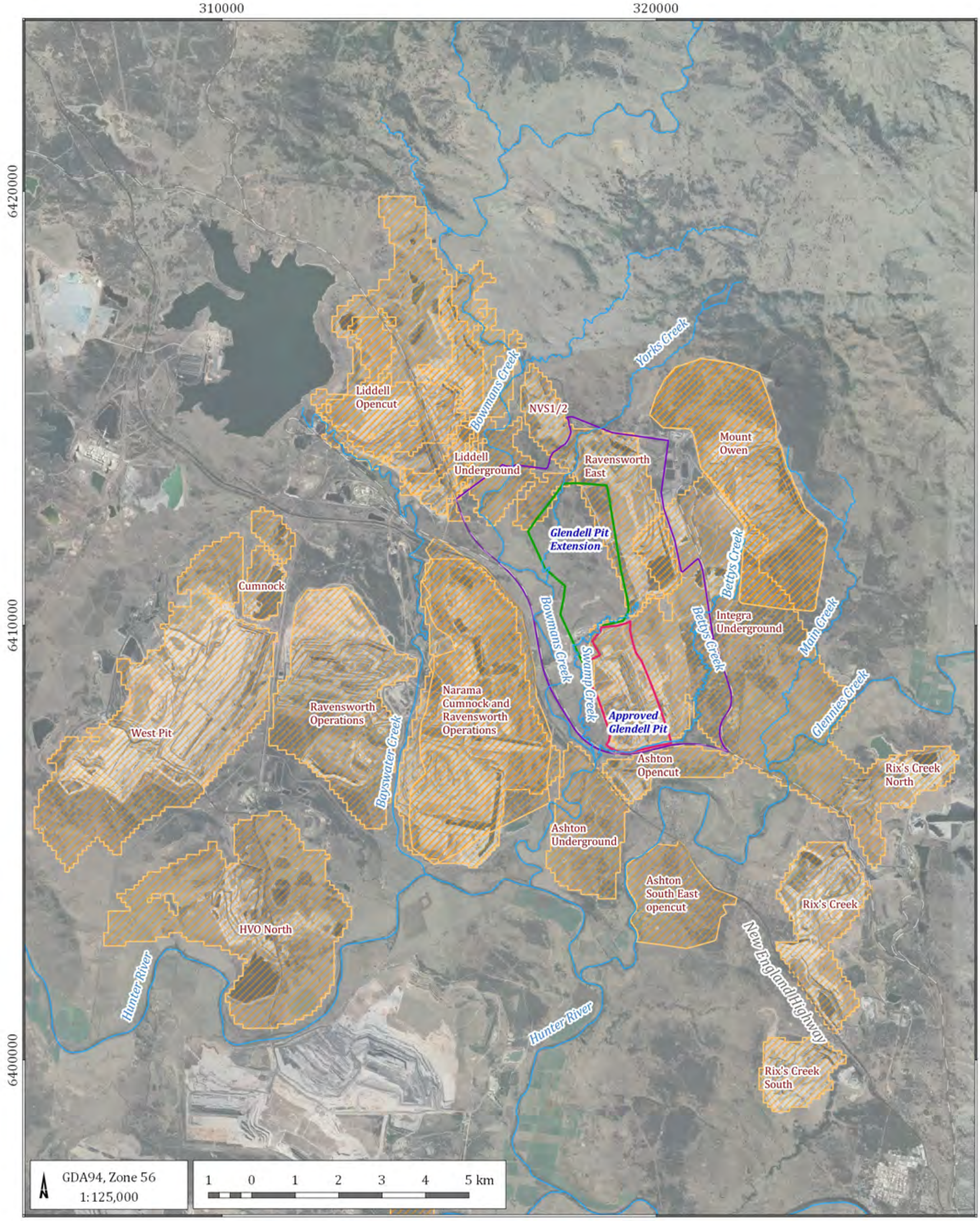
3 Environmental setting

3.1 Location and land-use

Glendell Mine is located within the Hunter Coalfields of the Sydney Basin approximately 20 km north-west of the Singleton town centre. Surrounding mines include the Ashton Coal Mine directly to the south, Integra Underground to the east and Ravensworth Operations and Liddell Coal Operations to the west and north west. Surrounding land uses in the locality include mining and mining related development, Ravensworth State Forest and agricultural activities such as cropping and grazing.

Land within and surrounding the Mount Owen Complex has been subject to historical disturbance associated with agricultural land uses and, in the last 50 years, coal mining developments. Prior to the commencement of mining operations, the Glendell Mine was predominantly used for grazing purposes with only small areas of remnant and regrowth vegetation. The floodplains associated with Bowmans Creek and Swamp Creek (and to a lesser extent, Yorks Creek) have also been cropped in the past however there is no evidence of extensive use of irrigation associated with these cropping activities. The Glendell Pit Extension predominantly comprises grasslands and limited areas of regenerated trees. The majority of the current mid and upper storey vegetation within and surrounding the Mount Owen Complex exists as a result of extensive regrowth of the past 30 years (refer Umwelt, 2019a, Umwelt 2019b).

The Project occurs within the Hunter Valley coalfields, which has a long history of mining the Permian Coal Measures, dating back to the 1950's. Figure 3-1 shows the locations of the historic and approved mines in the immediate area surrounding the Project.



LEGEND

- Road
- Drainage
- Rail
- Approximate historic and existing mining operations
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Glendell Continued Operations GIA (G1874C)

Historic and approved mining

AGE

DATE 28/11/2019

FIGURE No: **3-1**

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\03.01_G1874C_Historic and approved mining.qgs

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 point within the Mount Owen Complex. Climatic data was obtained for the period between 01/01/1900 to 31/12/2018. A summary of rainfall and evaporation data 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)	78.1	74.8	65.9	53.2	44.3	52.1	43.1	37.3	41.3	50.9	60.9	69.1	671.0
	Mean evaporation (mm)	204.5	161.4	142.9	103.6	72.5	55.2	63.9	89.4	119.6	156.1	177.0	210.0	1,556.2
	Evap minus rainfall	126.4	86.6	77.1	50.4	28.2	3.1	20.8	52.1	78.3	105.2	116.2	140.9	885.1

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 671 mm, with January being the wettest month (78 mm). Annual evaporation (1,556 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 3-2 shows the CRD and highlights three climatically distinct periods:

- 2000 - 2007 during the Millennium drought where rainfall was commonly below average and El Niño events occurred;
- 2007 – 2012 when rainfall was commonly above average and La Niña events occurred;
- 2012 to 2016 - when rainfall generally remained closer to historical averages, with a relatively neutral trend; and
- 2017 to present – a period where rainfall was consistently below average, and the region was declared as drought affected by NSW DPI.

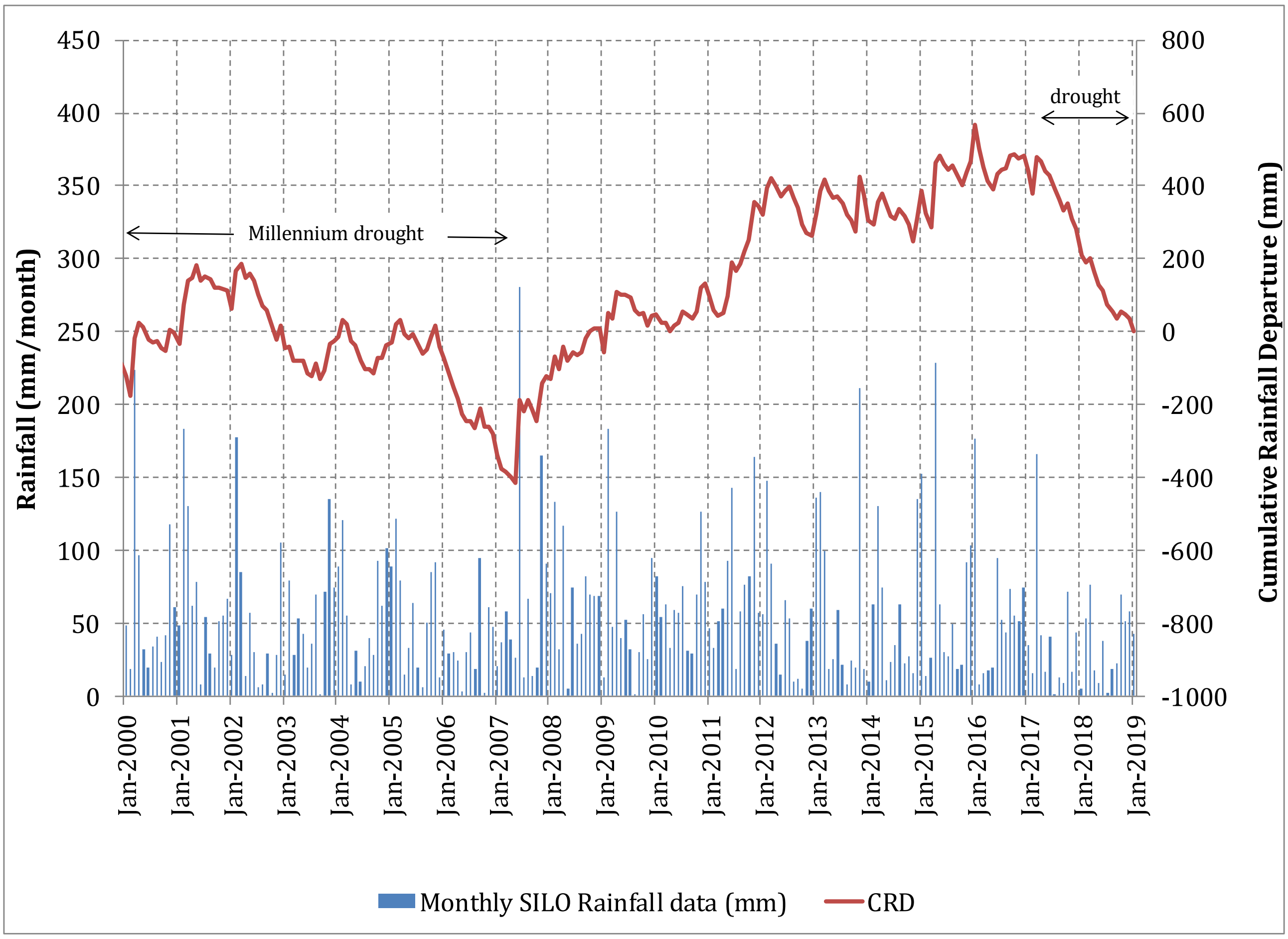


Figure 3-2 Cumulative Rainfall Departure (SILO) and monthly rainfall

The falling trend shown on the graph in recent years is due to below average rainfall since 2016, with very low rainfall during 2017, 2018 and 2019. Groundwater levels within shallow groundwater systems would be expected to decline naturally during these drier periods due to ongoing drainage from the aquifers exceeding the replenishment rate from rainfall recharge. Groundwater levels and climate are discussed further in Section 5.

3.3 Terrain and drainage

The terrain at Glendell Mine is gently sloping towards the surrounding drainage lines, with steeper slopes occurring where mining spoils have been placed. The mine is located adjacent to a number of water courses, the most significant being Bowmans Creek.

Bowmans Creek is located around 200 to 800 m west of the Glendell Pit Extension and flows in a southerly direction before entering the Hunter River around 3.5 km south of Glendell Mine. Tributaries of Bowmans Creek adjacent to the Approved Operations are Yorks Creek and Swamp Creek to the north and west, and Bettys Creek to the south and east.

The catchment of Swamp Creek is within the approved Mount Owen and Glendell Mine disturbance areas with the upper catchment approved to be returned back to Swamp Creek once mining and rehabilitation are completed. A section of Swamp Creek to the immediate north of Glendell Pit has been diverted around the Glendell mine infrastructure area (MIA) (Glendell MIA Diversion). The headwaters of Swamp Creek are diverted around the Mount Owen emplacement area and into Yorks Creek (Swamp Creek Diversion).

The upper catchment of Bettys Creek has been diverted into Main Creek (Upper Bettys Creek Diversion), a tributary of Glennies Creek. To the south Bettys Creek has also been diverted around the southern extent of the Eastern Rail Pit (Middle Bettys Creek Diversion) and also at the southern end of the Glendell Pit (Lower Bettys Creek Diversion). In the Lower Bettys Creek Diversion area thin Quaternary alluvial sediments associated with Bettys Creek have been removed. Bettys Creek, Yorks Creek and Swamp Creek are ephemeral water courses, with no permanent groundwater fed baseflow (Figure 3-3). The realigned Bettys Creek runs along the southern edge of approved mining boundary. Bettys Creek enters Bowmans Creek approximately 400 m to the south-west of the Project.

Yorks Creek is a tributary of Bowmans Creek and flows through the northern part of the Glendell Pit Extension. An approximately 1.5 km section of Yorks Creek has previously been diverted around the Ravensworth East MIA as part of the former Swamp Creek Mine operations (Yorks Creek Diversion). The upper catchment of Yorks Creek has been significantly modified by approved mining at Ravensworth East and Mount Owen. As these areas are rehabilitated, runoff will be progressively returned into the Yorks Creek catchment. This progressive increase in the size of the upper catchment will occur during the life of the Project.

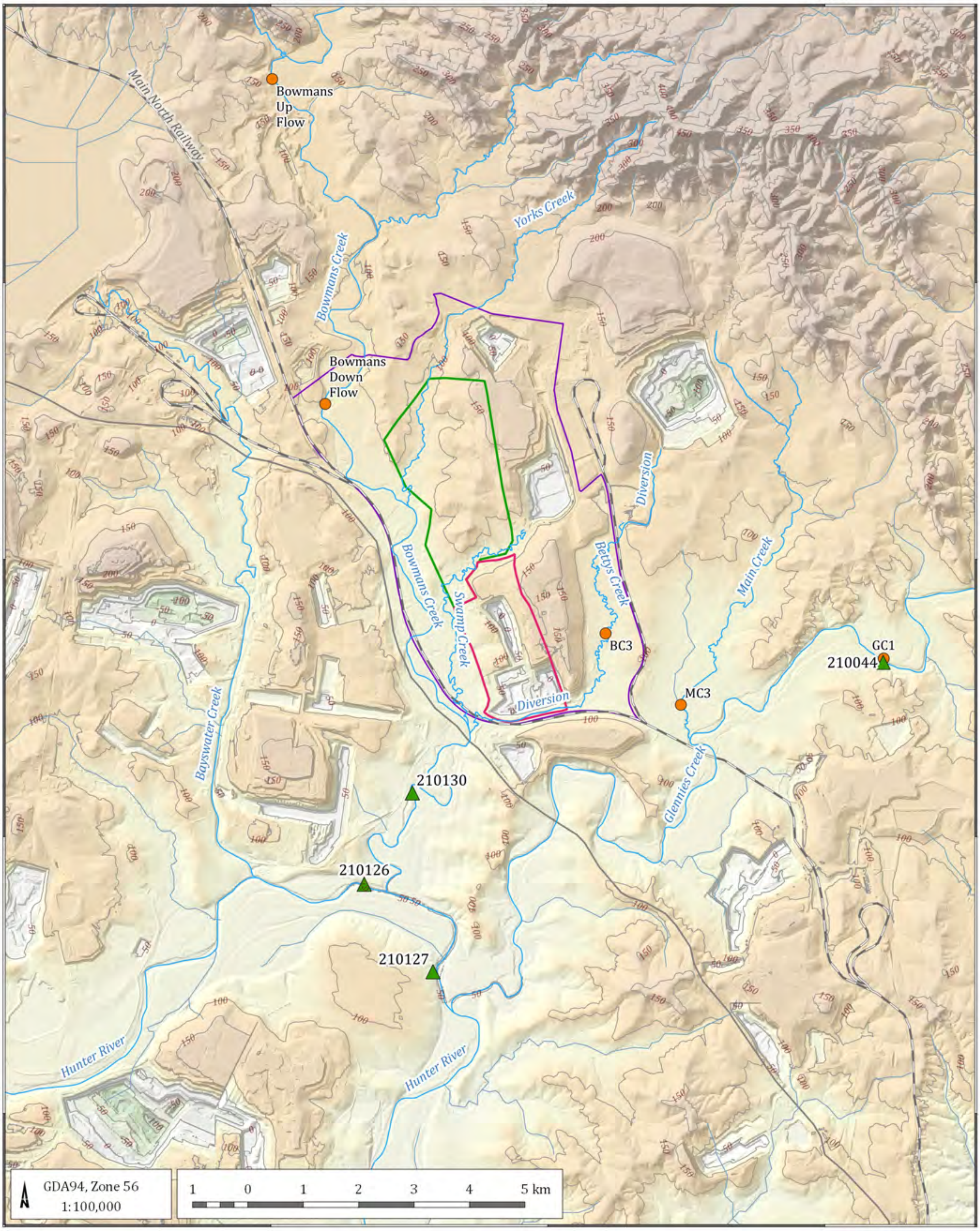
Figure 3-3 Lower Bettys Creek diversion adjacent to Glendell (left) and Swamp Creek (right)

Water NSW record streamflow at Glennies Creek, Bowmans Creek, and the Hunter River. Figure 3-4 shows the location of nearby gauging stations. The nearest gauging station along Glennies Creek is at Middle Falbrook (station 210044), 7 km southeast of the Additional Disturbance Area. The nearest station on Bowmans Creek is at Bowmans Creek Bridge (210130), approximately 2 km from the Additional Disturbance Area. On the Hunter River, the Upstream Foybrook (210126) station is approximately 4 km southwest.

Figure 3-5, Figure 3-6 and Figure 3-7 show the total recorded stream flow for Glennies Creek, Hunter River, and Bowmans Creek respectively. Of note is the significant reduction in flow recorded in Bowmans Creek since early 2018. This period of very low or no flow is aligned with a period of drought described in Section 3.2.

The figures also show the estimated baseflow using the method developed by Lyne and Hollick (1979). Figure 3-7 shows the baseflow in Bowmans Creek adjacent to the Glendell Pit Extension is between 0.1 ML/day and 10 ML/day, depending on climatic conditions.

Figure 3-4 shows the location of monitoring sites operated by Glencore. The adjacent Integra Underground monitors water level and flow within Glennies Creek (GC1), Bettys Creek (BC3) and Main Creek (MC3). Liddell Coal Operations operates the 'Bowmans upflow' and 'Bowmans downflow' gauges in Bowmans Creek which were installed in 2017. The limited duration of this data means that it has not been used in this assessment.



LEGEND

- River gauging stations
- Glencore gauging site
- Road
- Rail
- Drainage
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Elevation (mAHD)*

-150
-50
0
50
100
200
300
600

Elevation contours (50m)

*Elevation : ELVIS LiDAR (2016)

Glendell Continued Operations GIA (G1874C)

Terrain and drainage

AGE

DATE 21/11/2019

FIGURE No: **3-4**

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\03.04_G1874C_Terrain and drainage.qgs

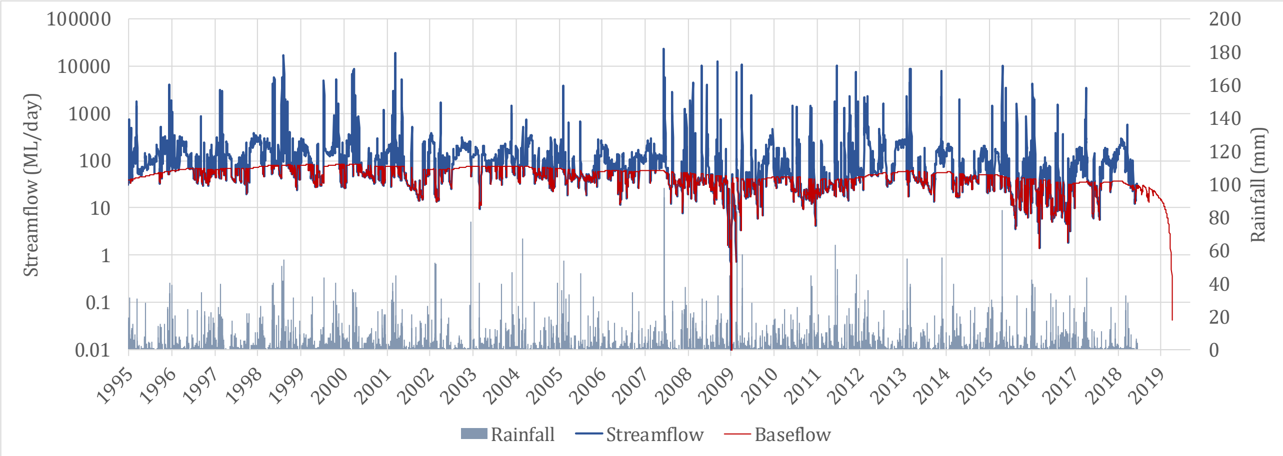


Figure 3-5 Streamflow in Glennies Creek at Middle Falbrook (210044)

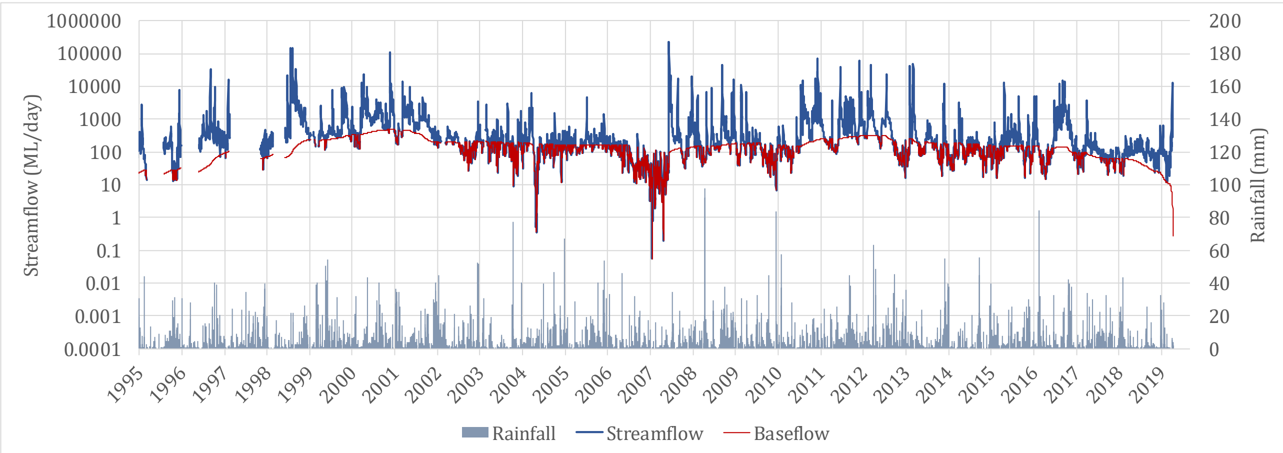


Figure 3-6 Streamflow in Hunter River at U/S Foybrook (210126)

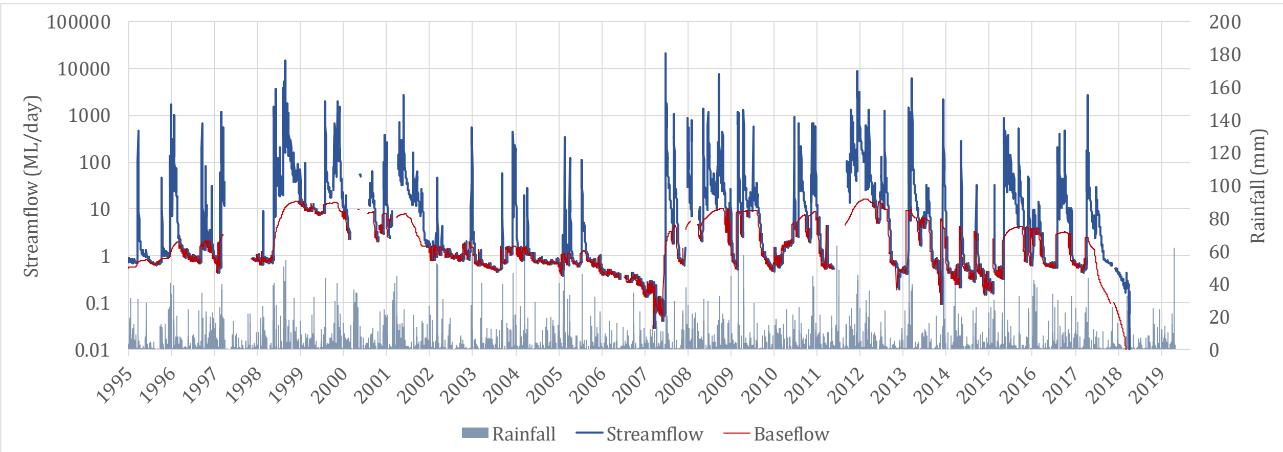


Figure 3-7 Streamflow in Bowmans Creek at Bowmans Creek Bridge (210130)

4 Geological setting

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

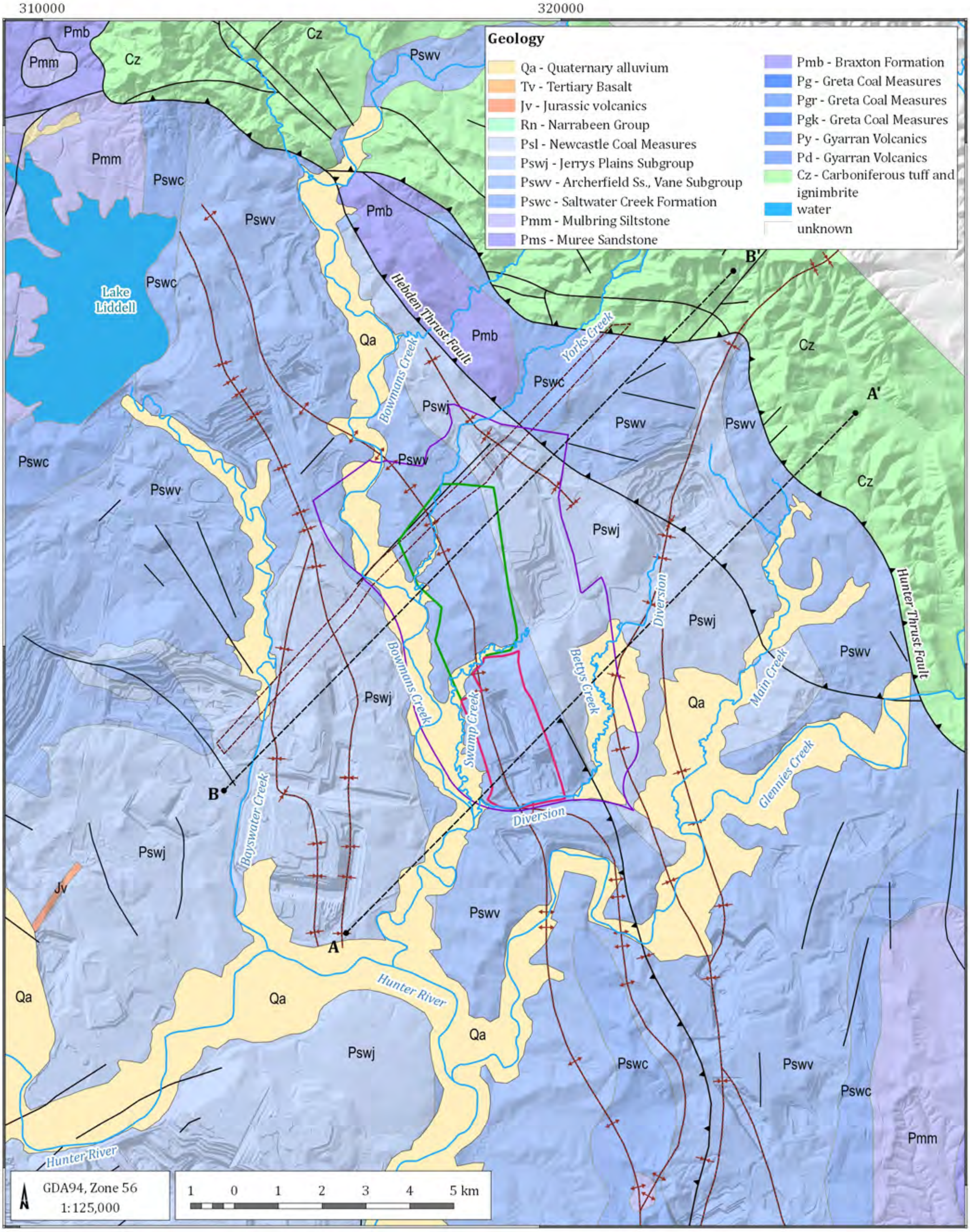
- publicly available geological maps (Hunter Coalfields map sheets) and reports;
- geological models and hydrogeological reports and data prepared for the Mount Owen Complex, Liddell Coal Operations, Ravensworth Operations and Integra Underground; and
- hydrogeological data held on the Water NSW groundwater database (Pinneena).

4.1 Regional geology

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). The extent of the Quaternary alluvium in the map has been updated where localised studies (refer to Section 4.2.1 and Appendix A) have confirmed the extent of alluvial sediments. Table 4-1 provides a detailed summary of regional geology and relevant stratigraphic units. Figure 4-2 and Figure 4-3 provides a conceptual geological cross-section showing the relative distribution of key stratigraphic units through the existing Glendell Mine and through the Glendell Pit Extension respectively.

Table 4-1 Summary of regional geology

<table>
<tr><th>Age</th><th colspan="4">Stratigraphic unit</th><th>Description</th></tr>
<tr><td>Quaternary</td><td colspan="4">Quaternary sediments – alluvium (Qa)</td><td>Clay, silt, and sand overlying basal clayey sands and gravels in places.</td></tr>
<tr><td rowspan="4">Late Permian</td><td rowspan="4">Wittingham Coal Measures</td><td colspan="3">Jerrys Plains Subgroup (Pswj)</td><td>Coal seams interbedded with claystone, tuff, siltstone, sandstone, and conglomerate.</td></tr>
<tr><td rowspan="2" colspan="2">Vane Subgroup (Pswv)</td><td>Archerfield Sandstone</td><td>Bronze-coloured, well-sorted quartz lithic sandstone</td></tr>
<tr><td>Foybrook Formation</td><td>Coal bearing sequences with wedges of sandstone and siltstone.
Includes the economic coal seams for the Modification.</td></tr>
<tr><td colspan="3">Saltwater Creek Formation (Pswc)</td><td>Sandstone and siltstone, minor coaly bands, siltstone towards base.</td></tr>
<tr><td rowspan="3">Middle Permian</td><td rowspan="3">Maitland Group</td><td colspan="3">Mulbring Siltstone (Pmm)</td><td>Fine-grained offshore sediments: siltstone, claystone, minor fine sandstone.</td></tr>
<tr><td colspan="3">Muree Sandstone (Pms)</td><td>Fine to coarse sandstone, conglomerate, and minor clay</td></tr>
<tr><td colspan="3">Branxton Formation (Pmb)</td><td>Conglomerate, sandstone, and siltstone</td></tr>
</table>



LEGEND
- Anticline
- Syncline
- Thrust fault
- Fold
- Fault
- Section lines
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Glendell Continued Operations GIA (G1874C)

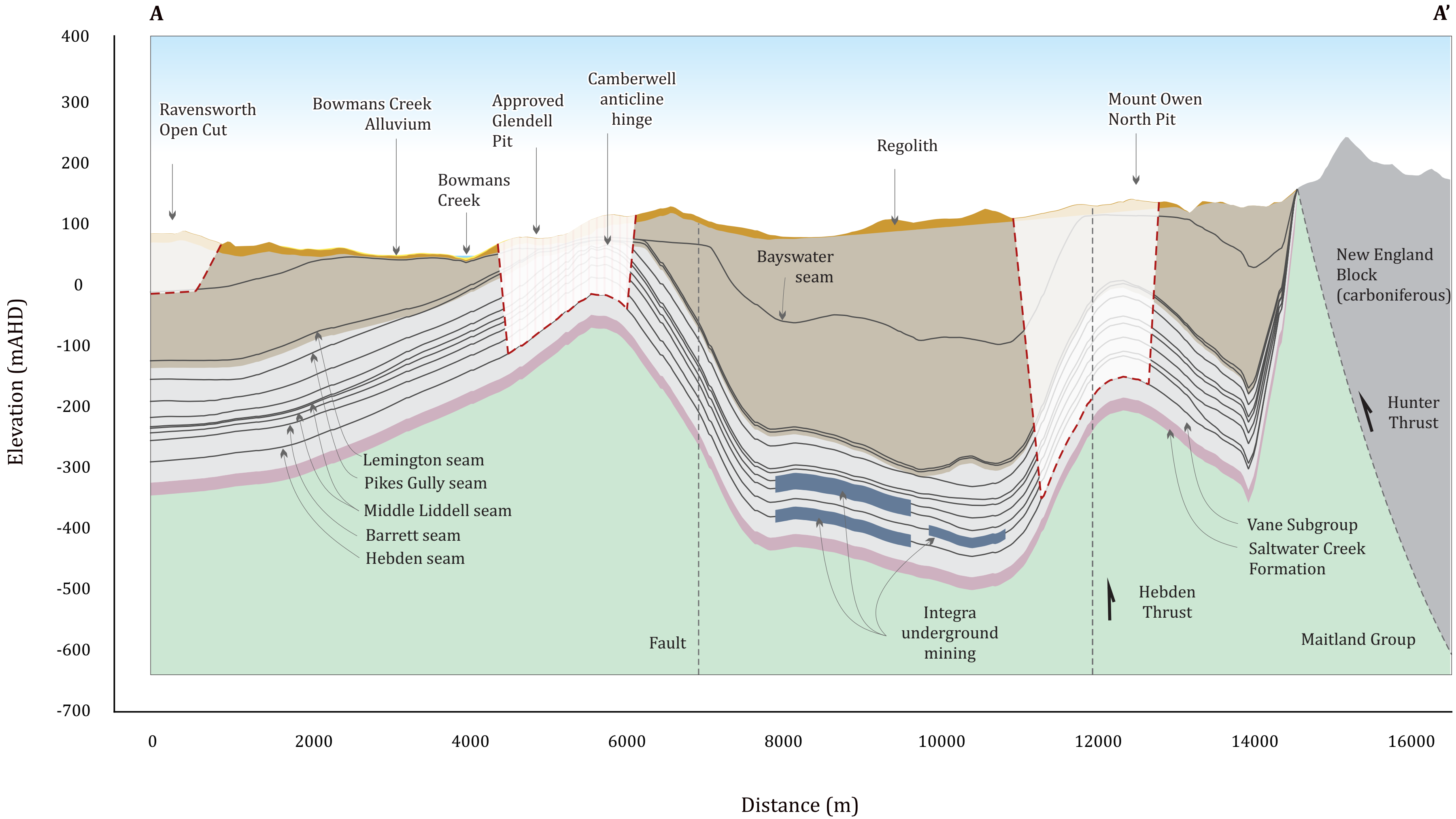
Regional surface geology

AGE

DATE: 21/11/2019

FIGURE No: **4-1**

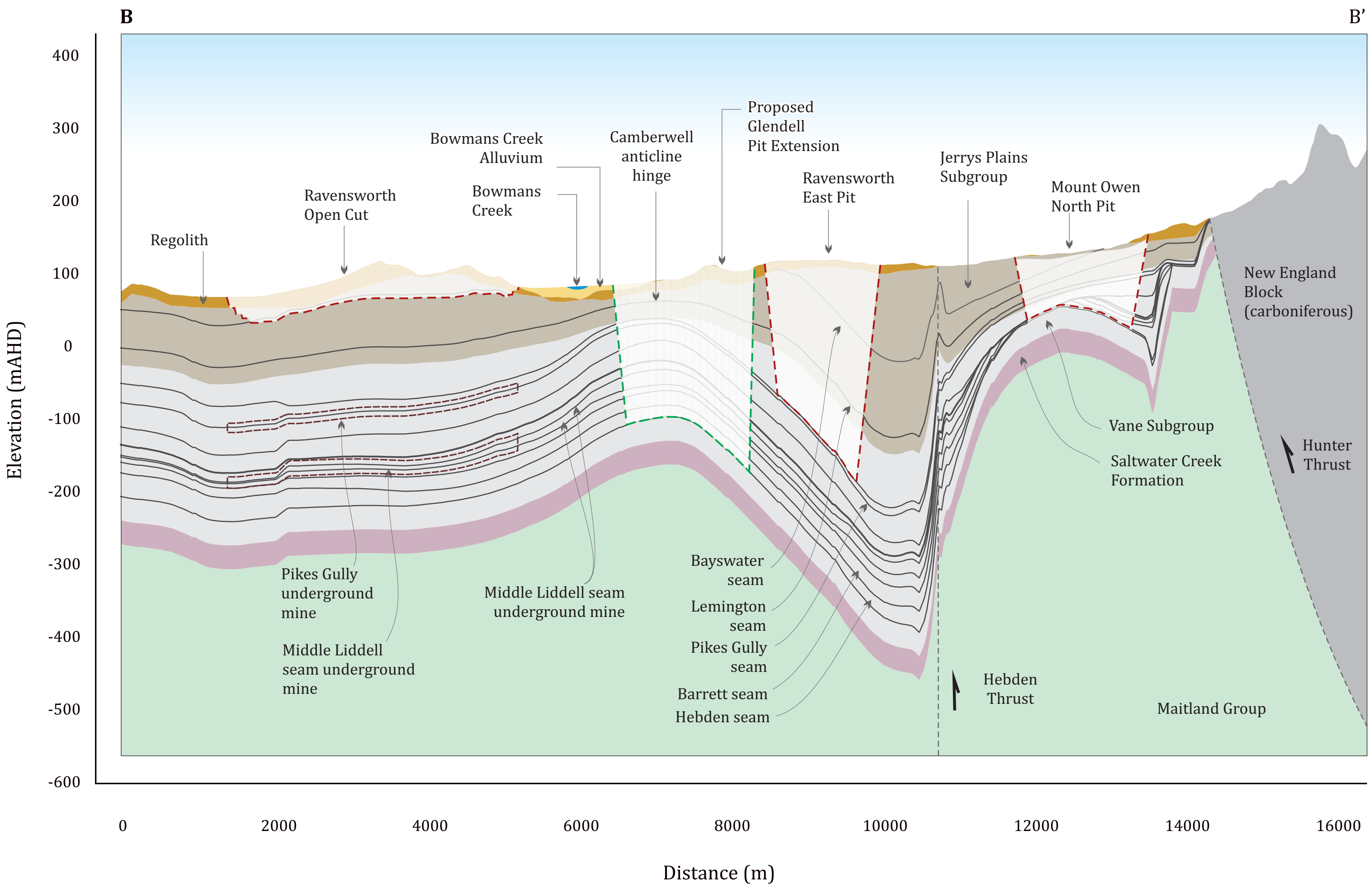
Source: Glen R.A. and Beckett J., 1993, Hunter Coalfield Regional Geology 1:100 000, 2nd edition. Geological Survey of New South Wales, Sydney;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\04.01_G1874C_Regional surface geology.qgs



Location of section can be seen on Fig 4-1

Conceptualised geological cross-section A-A'

Figure - 4-2



Conceptualised geological cross-section B-B’

Figure - 4-3

Glendell Continued Operations GIA (G1874C)

The Project 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 4 km to the east.

The Glendell Mine is located along the Camberwell Anticline, which is a major structural feature aligned in a north-south direction. The Camberwell Anticline exhibits steep dips (>20 degrees) on the eastern flank, and up to 12 degrees on the western flank. The Glendell Mine currently extracts coal on the eastern and western side of the anticline hinge from the Lemington through to the Barrett seams, which are discussed in Section 4.2.2.

The Permian sediments are unconformably overlain by thin Quaternary alluvial sediments deposited along drainage line flood plains. These deposits comprise silt, sand, and gravel along the present-day alignments of Bowmans Creek, Glennies Creek, and Bettys Creek. A weathering profile is typically present as a thin heterogeneous layer of unconsolidated weathered material (regolith) grading to fresh bedrock.

Regionally, the coal measures are influenced by a series of fold structures and thrust faults that trend in a northwest-southeast direction. The Hunter Thrust forms the boundary between the Carboniferous New England Block which has been thrust over Permian Sydney Basin sediments. A series of structures including faults and dykes occur perpendicular to the strike of the anticline hinge. The most notable is a block fault occurring in the northern part of the Glendell Pit Extension as shown on Figure 4-1.

Figure 2-3 included within Section 2.4 shows a photograph of the exposed Permian sequence in the operating Glendell Pit. It highlights the general lack of significant fault structures at the scale of the operating mining area.

4.2 Local geology

At a local scale, the following stratigraphic units occur within or adjacent to the Glendell Pit Extension and surrounds (from youngest to oldest):

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

Each of the main stratigraphic units is discussed in further detail below. Figure 4-1 shows the surface geology of the Project and immediate surrounds. The stratigraphic sequence and main coal seams occurring in the Glendell Pit Extension are shown in Figure 4-4.

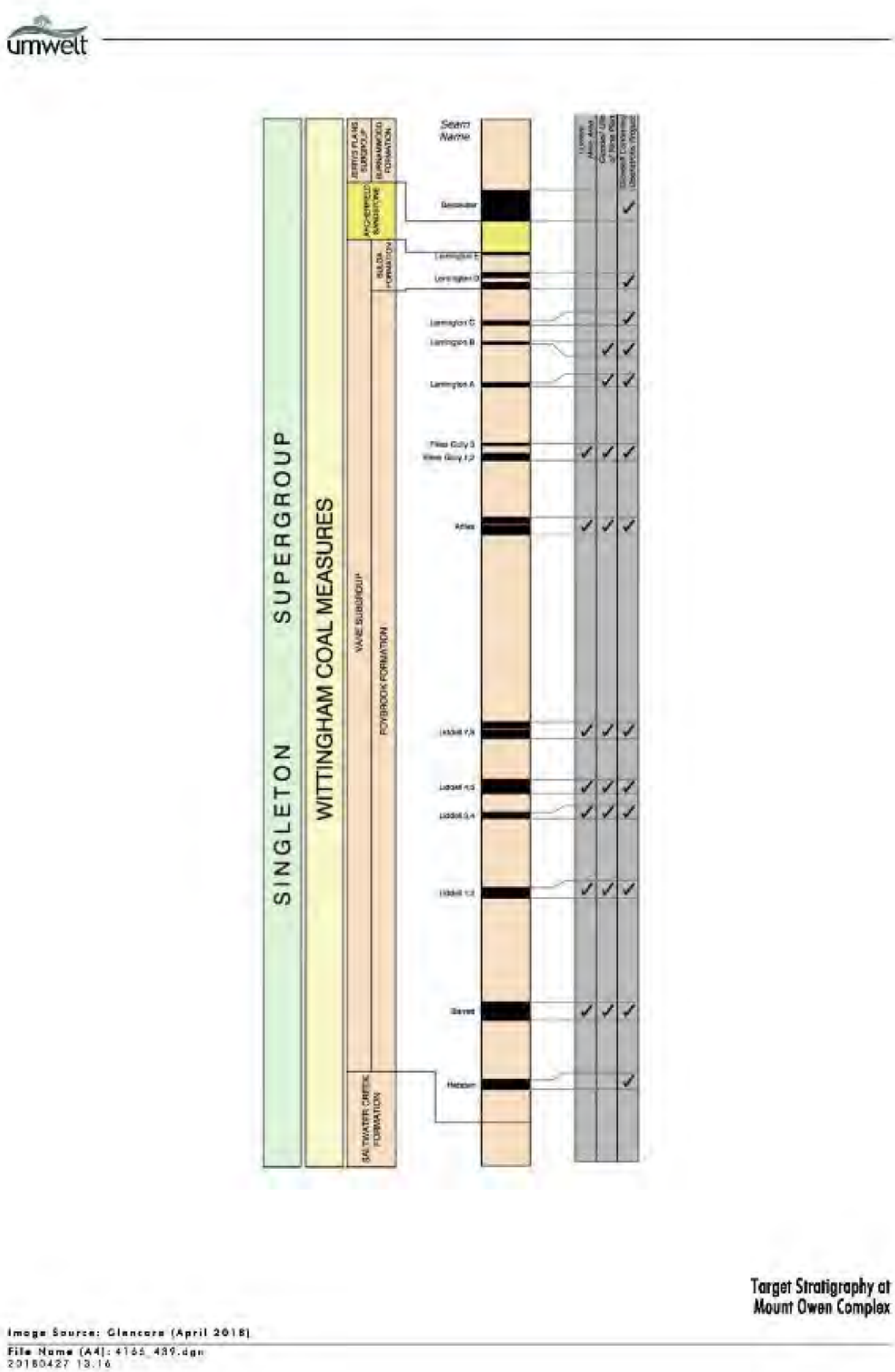


Figure 4-4 Glendell typical stratigraphic section

4.2.1 Quaternary alluvium

Quaternary alluvium (Qa) occurs along Bowmans Creek west of the Glendell Pit Extension and along the tributaries of Bowmans Creek being Bettys Creek, Swamp Creek and Yorks Creek. The alluvium typically comprises clay, silt and sand overlying basal sands and gravels which unconformably overlie the Permian strata.

The extent of Quaternary alluvium shown on geological maps was reviewed and a verification study undertaken along Bowmans Creek, Swamp Creek and Yorks Creek to improve the delineation of the extent of the alluvial sediments in the vicinity of the Glendell Pit Extension (refer Appendix A). The investigation included review of desktop datasets including LIDAR data, soils maps and drilling data. A total of 38 test pits were excavated to confirm the findings of the desktop assessment and define the limit of the alluvial sediments and aquifer.

The refined extent of the Quaternary alluvium is shown in Figure 4-1. The structure of the Quaternary alluvium is shown on Figure 4-5, and the distribution of alluvial thickness and the regolith are shown on Figure 4-6. The investigations resulted in a reduction in the mapped extent of alluvium along Swamp Creek and Yorks Creek, and a reduction in the thickness of the Bowmans Creek alluvium from that assumed in previous investigations.

LEGEND

- Drainage
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Elevation (mAHD)

20, 30, 40, 50, 60, 70, 80, 90, 100, 110

Contour line

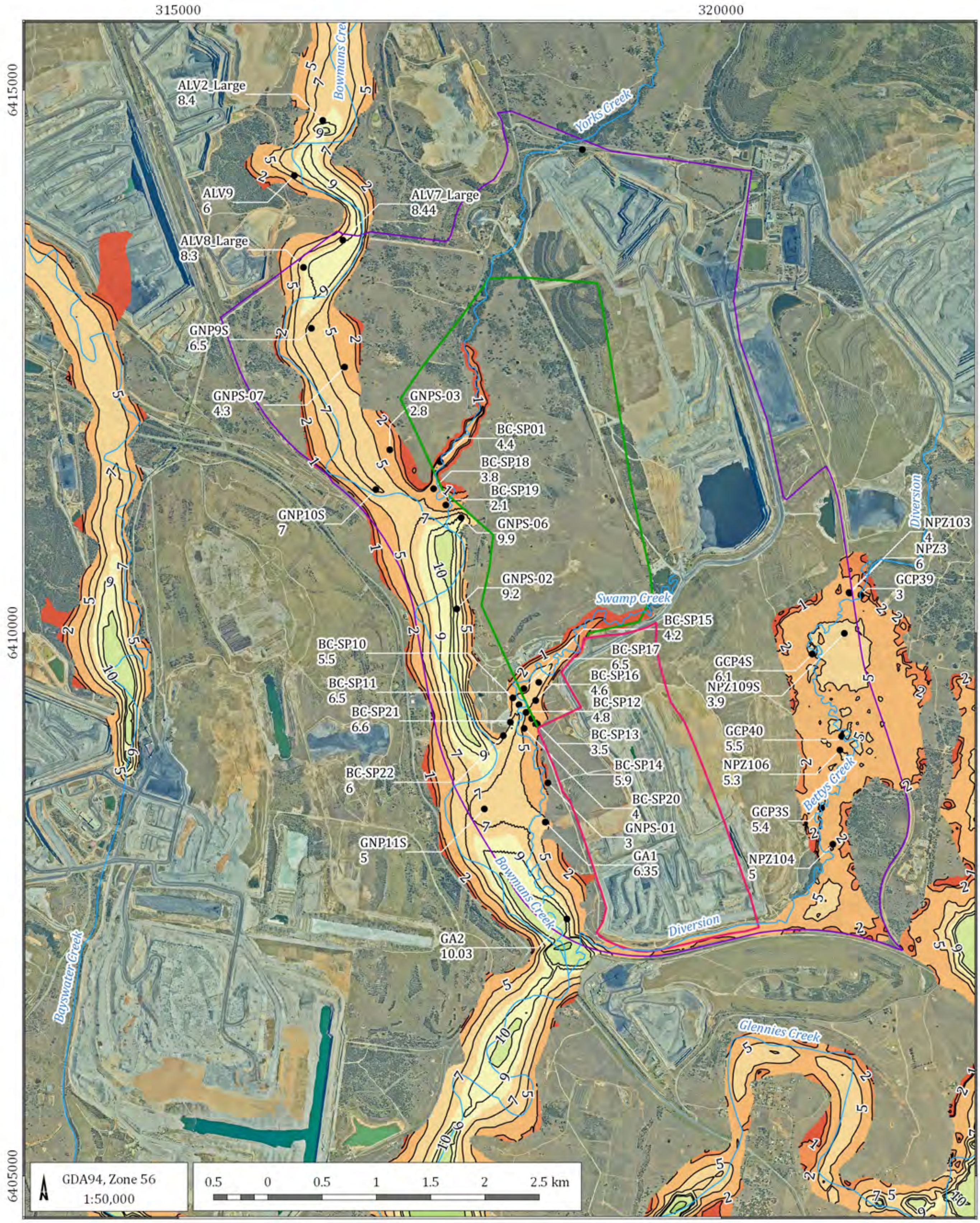
Glendell Continued Operations GIA (G1874C)

Basal elevations of the Quaternary alluvium

DATE 21/11/2019

FIGURE No: **4-5**

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\04.05_G1874C_Structure thickness contours Quaternary alluvium.qgs



LEGEND

- Monitoring bores
  GA2 : BoreID
  10.03 : alluvium depth (m)
- Drainage
- Alluvium boundary
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Thickness (m)

0 - 1	10 - 15
1 - 2	15 - 20
2 - 5	20 - 30
5 - 8	30 - 40
8 - 10	40 - 50

Contour line

Glendell Continued Operations GIA (G1874C)

Thickness contours of the Quaternary alluvium

AGE

DATE 21/11/2019

FIGURE No: 4-6

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\04.05_G1874C_Structure thickness contours Quaternary alluvium.qgs

4.2.2 Permian geology

The youngest of the Permian aged sediments within the Glendell Pit Extension and surrounds are the Jerrys Plains Subgroup (Pswj), part of the Wittingham Coal Measures. 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. In the Glendell Pit Extension much of the Jerrys Plains subgroup has been removed by the weathering and erosion with only the Bayswater seam remaining. Figure 4-7 shows the sub-crop of the Bayswater seam which is largely outside the Glendell Pit Extension.

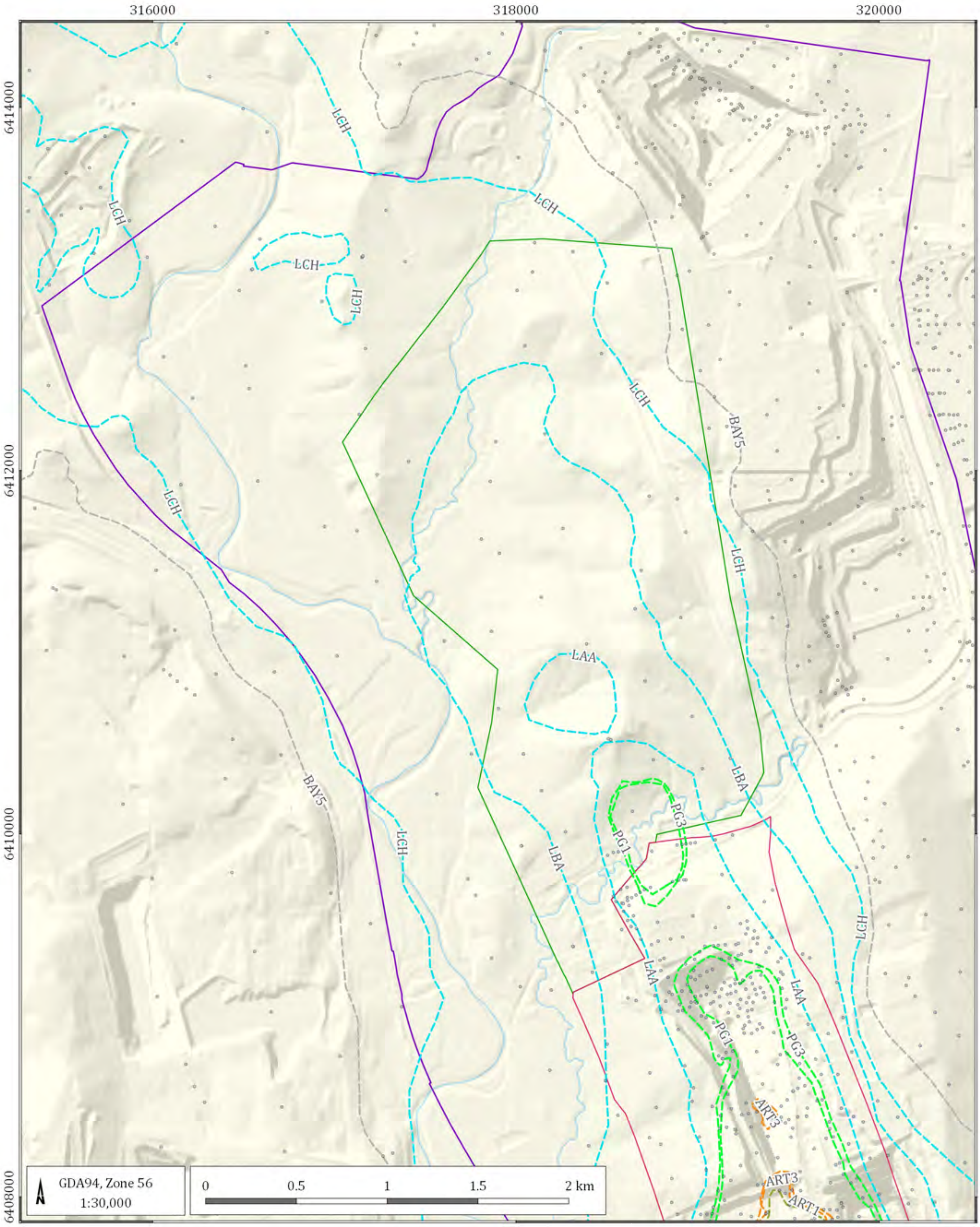
The Late Permian Vane Subgroup (Pswv) conformably underlies the Jerrys Plains Subgroup and is subdivided into the Foybrook Formation and the Archerfield Sandstone. The uppermost unit is the Archerfield Sandstone which comprises well-sorted quartz lithic sandstone deposited in a wave or current dominated lower delta plain depositional setting. The Archerfield Sandstone occurs at the base of the Bayswater seam, and is distinguishable as a massive, light brown or honey coloured sandstone.

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 (three plies), Pikes Gully, Arties, Liddell, Barrett and Hebden seams. Figure 4-7 shows the Lemington seam plies and Pikes Gully seam subcropping within and adjacent to the Glendell Pit Extension. The seam subcrops encircle the Camberwell Anticline and create a dome like feature in the shallow geology. The coal seams occurring in the Glendell Pit Extension vary in thickness as described below:

- Lemington seam – comprises three major plies (LC, LB and LA) with a cumulative thickness varying between 8 m and 12 m;
- Pikes Gully seam – comprises three plies (PG1, PG2 and PG3) with an average cumulative thickness of 2.7 m;
- Arties seam – comprises three major plies (ART1, ART2 and ART3) with an average cumulative thickness of approximately 2 m;
- Liddell seams – comprises Upper, Middle and Lower Liddell seams each with several plies and rider seams - each of the seams ranges in thickness from 1 m to 4 m;
- Barrett seam – comprises three plies (BAR1, BAR2 and BAR3) with an average cumulative thickness of 2 m to 3 m; and
- Hebden seam – comprises the Upper and Lower Hebden seams, with an average thickness of 1.8 m and <1.2 m respectively.

Figure 4-8 and Figure 4-9 show the surface and depth of the Barrett and Middle Liddell seams respectively. The figures highlight the anticline aligned through the Glendell Pit Extension and the strata dipping away from the fold axis and plunging gently to the north.

A thin weathered profile occurs across the Permian strata that are exposed at the land surface. Figure 4-10 shows the exposed Permian sequence exposed in the southern wall of the Glendell Pit. Weathered sub-cropping coal seams are also visible in the photograph.



LEGEND

- Drill holes
- Drainage

Subcrops

- Arties Seam
- Bayswater Seam
- Lemington Seam
- Liddell Seam
- Pikes Gully Seam

- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Glendell Continued Operations GIA (G1874C)

Coal seam subcrops (source GCCA 2018 PFS report)

AGE

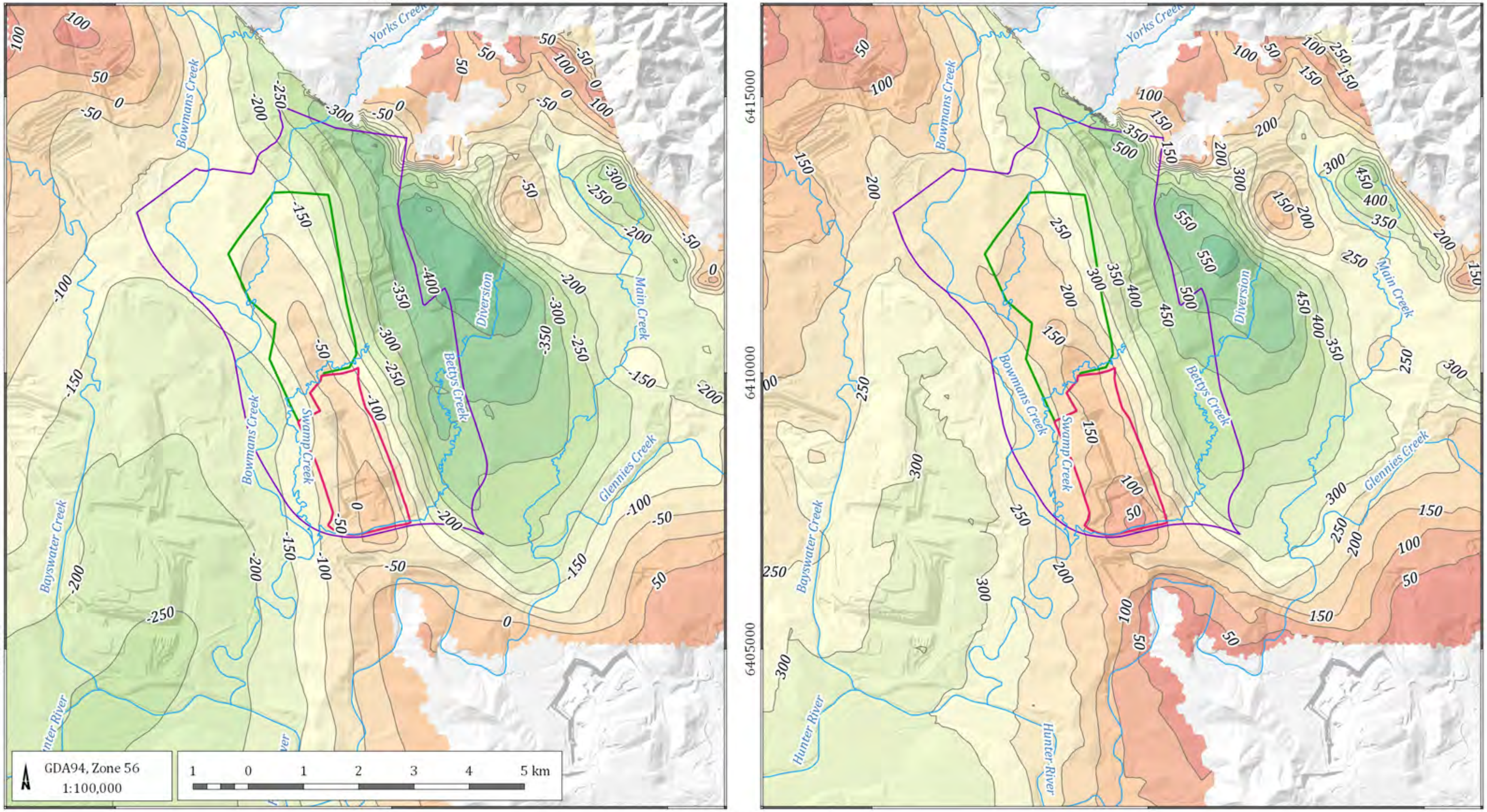
DATE 28/11/2019

FIGURE No: **4-7**

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\04.07_G1874C_Coal seam subcrops_source GCCA 2018 PFS report.qgs

Elevation contours of the Barrett Seam

Depth-below-surface contours of the Barrett Seam



LEGEND

- Drainage
- Contour line
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Elevation (mAHD)

- -400
- -300
- -200
- -100
- 0
- 100
- 200

Depth (mbgl)

- 0
- 100
- 200
- 300
- 400
- 500
- 600

Glendell Continued Operations GIA (G1874C)

Elevation and depth below surface of the Barrett seam

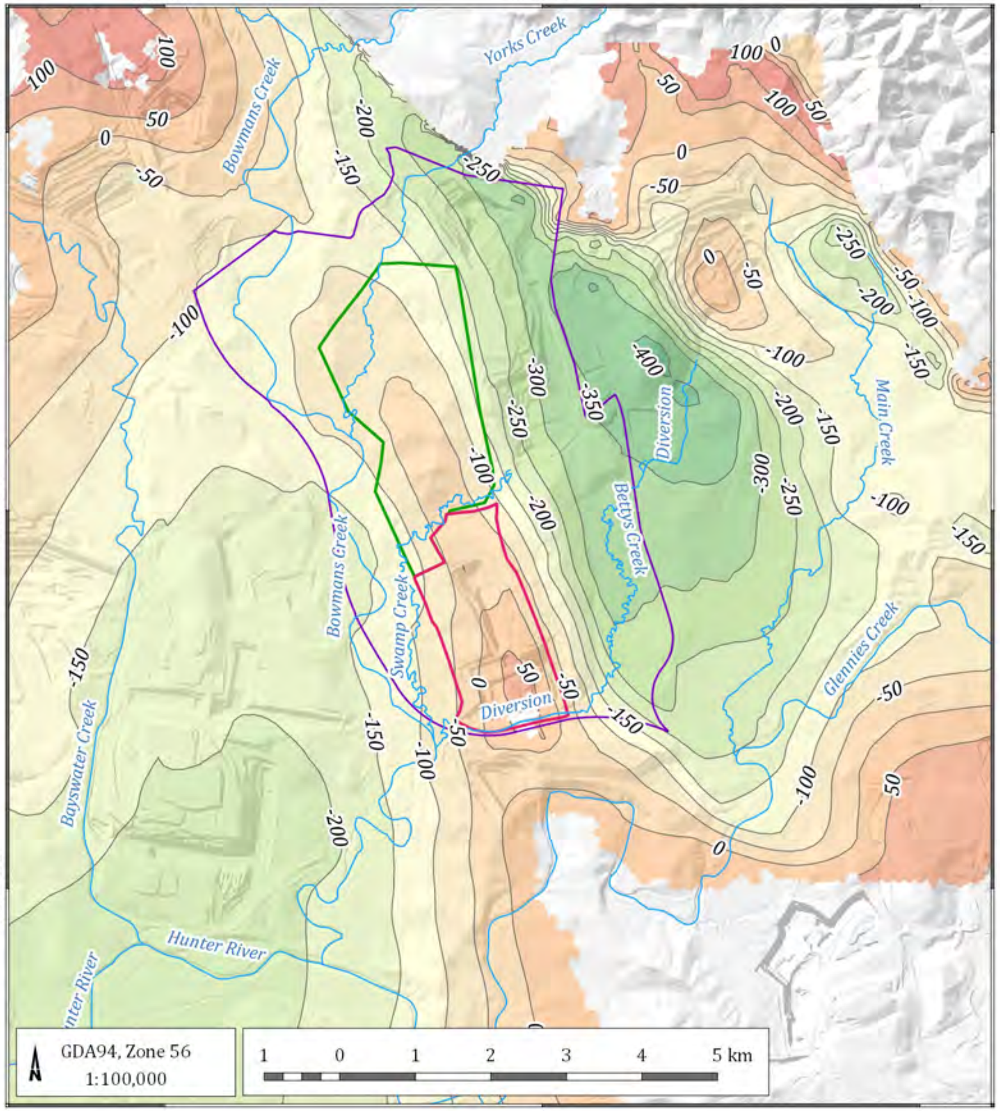
DATE
21/11/2019

FIGURE No:
4-8

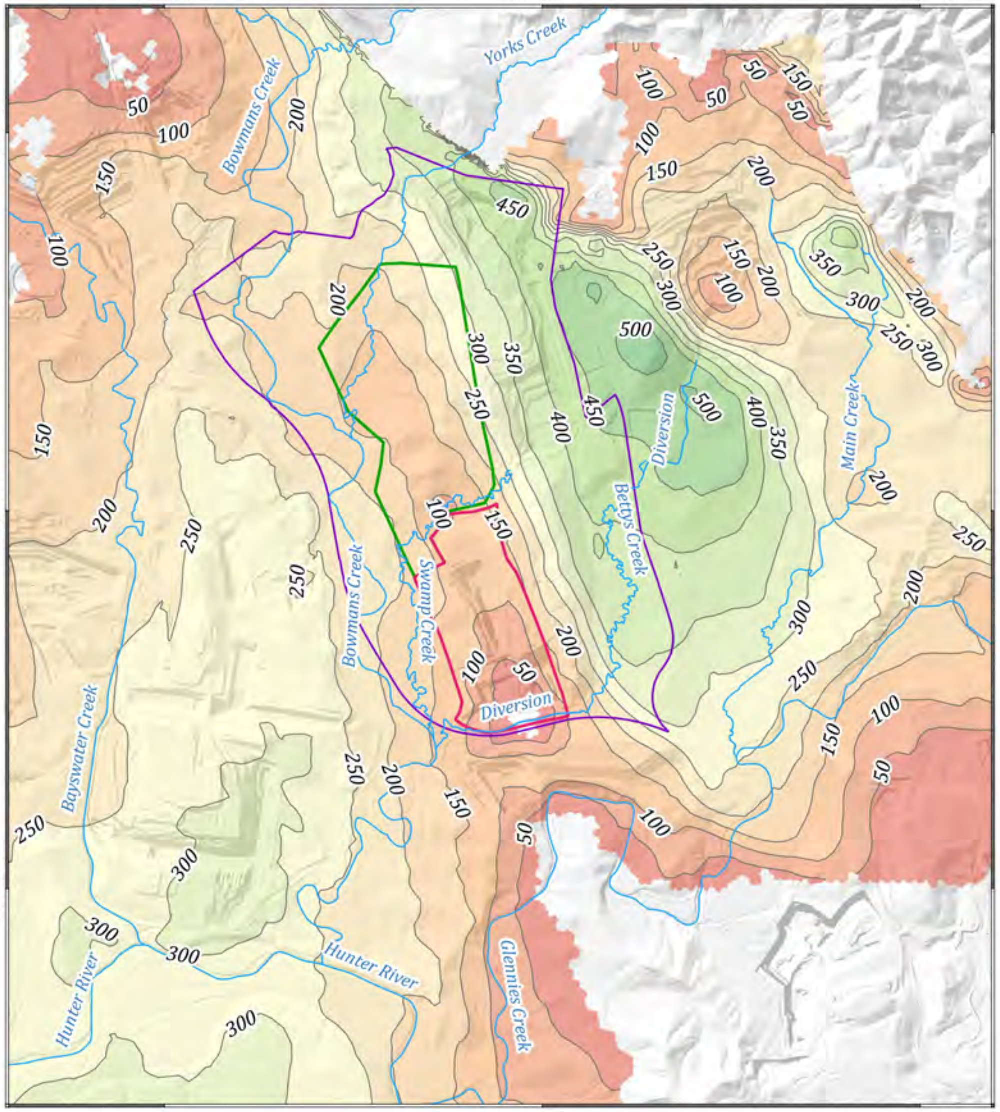
AGE

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\04.08_G1874C_Structure and depth to base of Barrett Seam.qgs

Elevation contours of the Middel Liddell Seam



Depth-below-surface contours of the Middle Liddell Seam



LEGEND

- Drainage
- Contour line
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Elevation (mAHD): -400, -300, -200, -100, 0, 100, 200

Depth (mbgl): 0, 100, 200, 300, 400, 500, 600

Glendell Continued Operations GIA (G1874C)

Elevation and depth below surface of the Middle Liddell seam

DATE
21/11/2019

FIGURE No:
4-9

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\04.09_G1874C_Structure and depth to base of Middle Liddell Seam.qgs

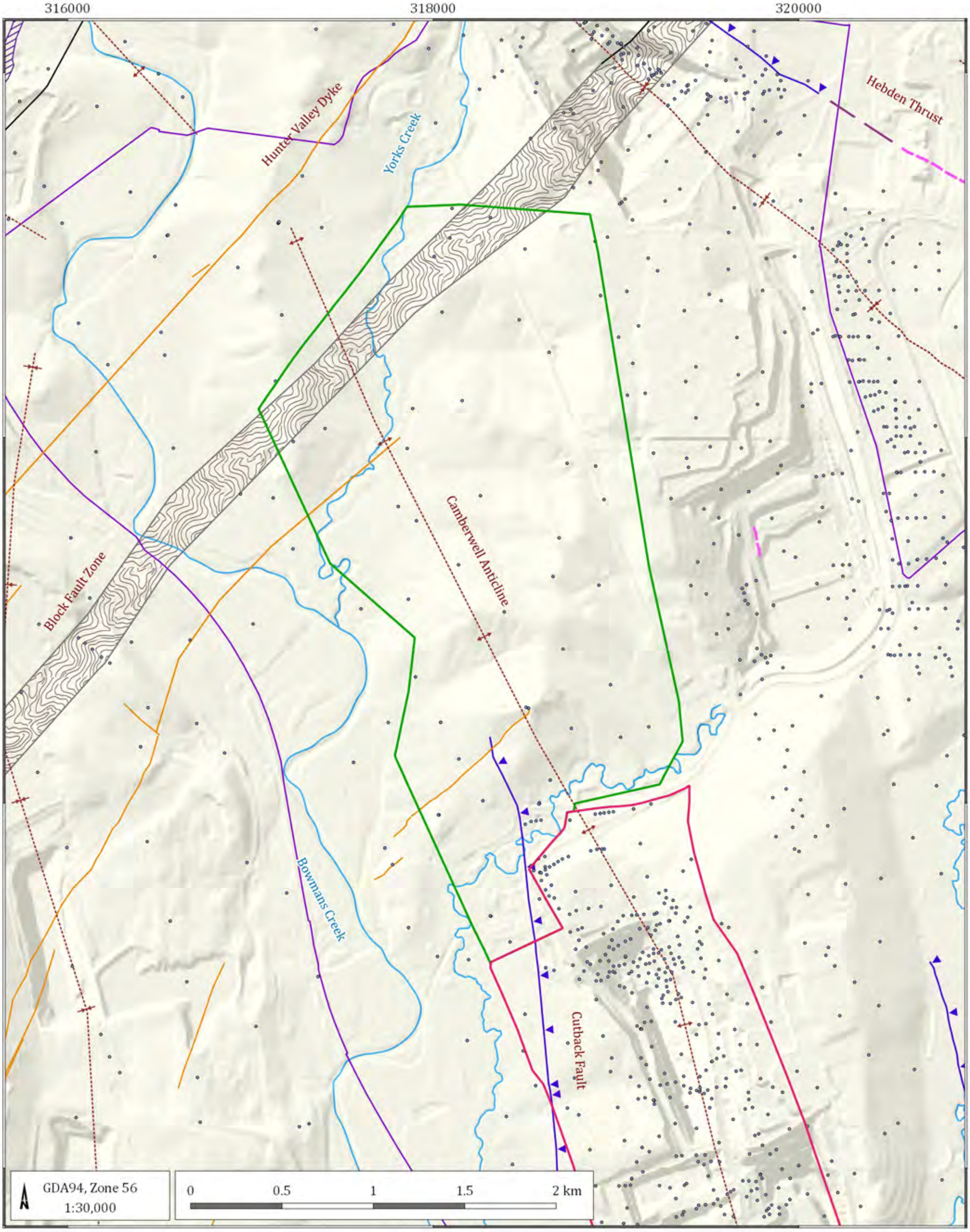
Figure 4-10 Weathering of Permian strata and sub-cropping coal seams in south wall of Glendell Pit (20 June 2018)

4.2.3 Geological structures

The main regional geological structures in the Glendell Pit Extension and surrounding region are shown in Figure 4-11. There are four main regional geological structures as follows:

- Camberwell Anticline – centrally located within the Glendell Pit Extension, trending north-south with strata gently dipping (<20 degrees) away from the fold axis and plunging gently to the north.
- Cutback Fault – a reverse fault with an approximate 3 m to 5 m displacement located west of the Camberwell Anticline, and dipping at approximately 12 degrees to the east.
- Block Fault Zone – located in the northern parts of the Glendell Pit Extension and comprising a 250 m to 300 m wide zone of north east striking horst and graben type normal fault structures, with typical displacements of less than 12 m and some minor <4 m thick igneous intrusions.
- Hunter Valley Dyke, which occurs in the north beyond the Glendell Pit Extension striking northeast, with typical intrusive thickness of up to 15 m and associated cindered coal thicknesses (either side of the intrusion) of up to 15 m.

Apart from the major faults and fold structures, it is expected that there will be zones of structural disturbance characterised by small-scale faulting (<2 m), shearing and coal seam mylonite in the Glendell Pit Extension, as these are found elsewhere at the Mount Owen Complex. It is also anticipated there will be zones of igneous intrusions (dykes) occurring as continuations of the northeast trending small-scale dyke/cinder zones (<4 m), found in open cut workings adjacent to the Project (including Ravensworth East and Glendell). It is expected that these small-scale fault and dyke zones will have no appreciable impact on mining and/or resources, as they currently present no significant issues in other parts of the Mount Owen Complex. Figure 4-12 shows the generally continuous nature of the coal seams exposed with the Glendell Mine. Figure 4-13 shows a small reverse/thrust fault exposed at Glendell Pit.



LEGEND

- Drainage
- Dykes
- Synclines
- Anticlines
- Monocline
- Reverse fault
- Fault
- Drill holes
- Dyke significant thickness
- Block fault
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Glendell Continued Operations GIA (G1874C)

Geological structures

AGE

DATE 28/11/2019

FIGURE No: **4-11**

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\04.11_G1874C_Geological structures.qgs

Figure 4-12 Glendell Pit western highwall showing the generally continuous nature of the coal seams

Figure 4-13 Fault exposed in Glendell Pit (20 June 2018)

PSM (2019) investigated the block fault zone as part of geotechnical studies for the proposed Glendell Pit Extension. PSM described the block fault zone as a regional "horst and graben" type structure comprising a series of alternating raised and lowered blocks across the fault zone. Because the fault zone is a regional feature identifiable across the Hunter Valley PSM investigated where the fault has been intersected in other mining operations. Figure 4-13 to Figure 4-14 below are reproduced from the PSM (2019) report and have been marked up to highlight individual faults and structures encountered in the Bayswater North Pit. The photos show the throw on the faults within the block fault zone are not large and result in only slightly offset coal seams. Occurrence of groundwater varies in the photos, but the fault zone visually does not appear to host large amounts of groundwater and is considered a less significant source of groundwater inflow when compared with the coal seams.

Figure 4-14 Block fault zone exposed at Bayswater North Pit (from PSM 2019)

Figure 4-15 Block fault zone exposed at Bayswater North Pit in 2017 (from PSM 2019)

5 Conceptual model of groundwater regime

5.1 Hydrostratigraphic units

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

- Quaternary alluvium, which forms a relatively thin aquifer system where it occurs along the major creeks and rivers;
- Permian sediments that can be divided into:
  - thin 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.

SKM (2012) conducted drilling within the Glendell Pit Extension in 2012 which included the installation of the GNP series of bores along Bowmans Creek. They describe the morphology of the alluvial areas as characterised by a vertical succession of essentially three units from a basal coarse-grained bed load comprising sand size to cobble size deposits, to finer grained levee (low level terrace) deposits and then to floodplain deposits. These unconsolidated deposits act as a groundwater store supporting baseflow contributions to Bowmans Creek. The coal seams are described as typically representing the most permeable hardrock strata in the region through the presence of cleating and jointing with permeabilities that are at least two and often three orders of magnitude higher than interburden.

The following sections summarise the data available for each hydrostratigraphic units and present a conceptual model for the groundwater regime.

5.2 Groundwater monitoring network

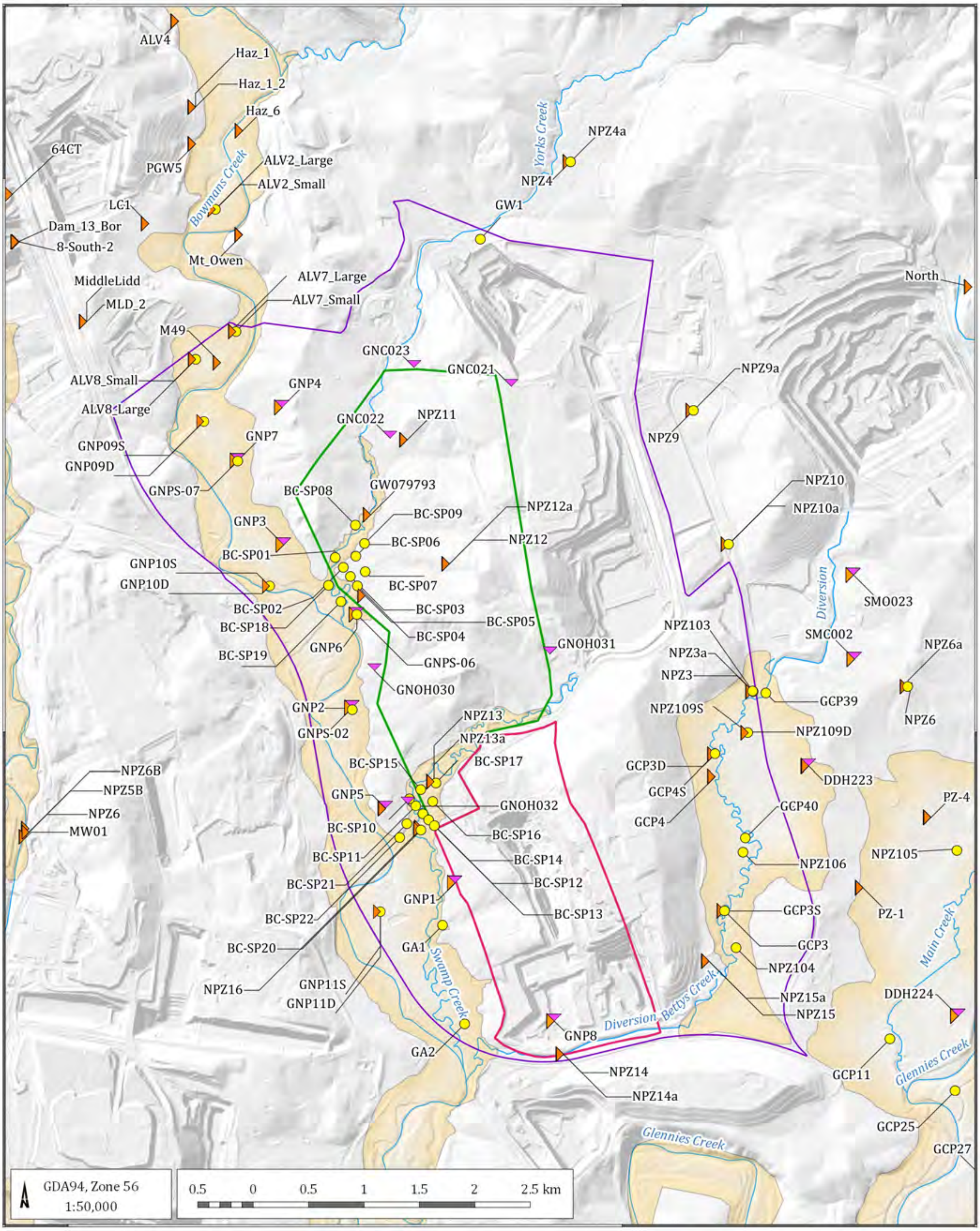
Glencore monitor groundwater levels at each of its operations across the mid Hunter region using a network of monitoring bores and vibrating wire piezometers (VWP). The monitoring network targets the Quaternary alluvium along drainage lines and the Permian interburden/coal seams. Monitoring bores within the Quaternary alluvium are typically shallow, owing to the nature of the local alluvial deposits. The Permian strata is monitored using a combination of monitoring bores and VWP arrays for the deeper strata within the geological sequence. The locations of the monitoring bores and VWPs are presented in Figure 5-1.

Of particular relevance to the conceptual model are the monitoring bores installed within and underlying the Bowmans Creek alluvium, which is the main water source adjacent to the Project. The monitoring network in this area and along Bowmans Creek has been gradually installed over time to address a range of objectives. The bores shown on Figure 5-1 installed have a unique prefix that relates to each drilling campaign as follows:

- 2001 – ALV series comprises pairs of bores installed within the Bowmans Creek alluvium and the underlying Permian regolith for monitoring the impact of the Liddell Coal Operations. Additional bores have been added to the ALV series over time.
- 2006 – NPZ series comprises pairs of 25 mm and 50 mm PVC monitoring bores installed in single exploration holes around the Mount Owen Complex (NPZ4, NPZ6, NPZ7 and NPZ11 to NPZ16).
- 2007 – 2008 – GCP - "Glennies Creek Project" series comprises alluvial monitoring bores installed along Bettys Creek, Main Creek and Glennies Creek alluvium for the Integra Underground and open cut mining operation (now known as Rix's Creek North).
- ~2009 – GA – "Glendell Alluvium" series – comprises two alluvial bores, GA1 and GA2 installed when mining commenced in the Glendell Pit - the exact date of installation is not certain but data from the bores is available since 2009.
- 2012 – BC series – "Bowmans Creek" series comprises two clusters of alluvial bores installed in 2012 to evaluate the hydrogeological properties of the Swamp Creek and Yorks Creek alluvium where the continuation of mining is proposed (BC01 to BC22).
- 2012 – 2018 – GNP series – the "Glendell North Project" series comprises a network of twin sites that have been gradually added to over time as follows:
  - 2012 – installation of shallow monitoring bores (GNPS-01 to GNPS-07prefix) within the Bowmans Creek alluvium and arrays of VWPs within the underlying Permian coal measures (GNP1 to GNP8).
  - 2018 – installation of GNP9S to GNP11S within the Bowmans Creek alluvium paired with GNP9D to GNP11D within the immediately underlying Permian strata.
- 2017 – NPZ series – three pairs of standpipe bores were added to the NPZ series installed in separate boreholes within Quaternary alluvium and Permian strata for the Mount Owen Continued Operations Project (NPZ107 to NPZ109).
- 2018 – 2019 – Additional bores added to SMO, GNOH, and GNC series:
  - SMO series – three new VWPs were installed across Liddell, Hebden, and Lemington seams in May 2018.
  - GNOH series – the "Glendell North Open Hole" series comprises three new VWPs installed in various coal seams and interburden in August 2018.
  - GNC series – the "Glendell North Core Hole" series comprises three new VWPs installed across the Arties, Pikes Gully, Upper Liddell, Middle Liddell, and Hebden seams. Holes were drilled at an angle to define the block fault zone.

Figure 5-1 shows the locations of the monitoring bores and VWPs. As shown on the map the monitoring bores target the Quaternary alluvium deposited within Bowmans Creek and its tributaries that surround the Project and also along Main Creek, and Glennies Creek, as well within key coal seams and interburden units being mined. Tables within Appendix B summarise the construction details for each of the monitoring sites.

The locations of the SMO, GNOH and GNC series VWPs that were installed in 2018-2019 are shown on Figure 5-1, but as the sites are only recently installed there is no significant data accumulated.



LEGEND

- Drainage
- Alluvium boundary
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Monitoring bores & VWPs

- Alluvium - Monitoring bore
- Permian - Monitoring bore
- Permian - Vibrating Wire Piezometer

Glendell Continued Operations GIA (G1874C)

Groundwater monitoring locations

AGE

DATE 21/11/2019

FIGURE No: **5-1**

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\05.01_G1874C_Alluvium bores.qgs

5.3 Saturation and productivity

Where saturated the Quaternary alluvium forms a groundwater system with varying productivity. The potential to form a useful groundwater resource is controlled by the aquifer thickness and the water quality. The alluvial material typically offers significantly increased groundwater storage when compared to the underlying Permian coal seams, through higher interstitial porosity.

Figure 5-2 below shows the saturated thickness of the Quaternary alluvium measured in key monitoring bores during 2018. The figure also shows the saturated thickness interpolated through the Quaternary alluvium based on observed saturation within the monitoring bore network.

The monitoring data shows that Bowmans Creek forms the most significant aquifer system within the vicinity of the Project with saturated thickness reaching 5 m to 10 m in the thicker parts of the alluvium. The saturated thickness thins towards the edges of the Bowmans Creek Quaternary alluvium, and at the fringes is dry as the water table is within the weathered rock below the base of the alluvium.

Borehole logs from monitoring bores installed in areas where the saturation of the Bowmans Creek alluvium is most significant indicate groundwater occurs within coarse sands and gravels occurring at the base of the alluvial sequence. In some areas the sands and gravels can be relatively clean with only minor fine sediments present, whilst in other areas the sand and gravel sediments can be clay bound. Where the Bowmans Creek alluvium has a saturated thickness of 5 m to 10 m and is comprised of relatively clean sand and gravels then it is likely it meets the criteria for a “highly productive” aquifer. This is because yields of more than 5 L/sec would be possible from properly constructed water supply bores in the areas where there is significant saturation and permeability. In areas of thinner and more clay bound alluvium, yields exceeding 5 L/sec are less likely and, even if present initially, are unlikely to be maintained for any significant period.

As noted in Section 5.2 there are clusters of monitoring bores installed to evaluate the hydrogeological properties of the Swamp Creek and Yorks Creek alluvium. In contrast to Bowmans Creek the monitoring bores installed within Quaternary alluvium along the tributaries of Bowmans Creek, being Bettys Creek, Yorks Creek and Swamp Creek record very limited saturated thickness or are dry. Figure 5-2 shows both Yorks Creek and Swamp Creek, which will be intersected by the proposed mining, have a relatively narrow flood plain with the alluvium being relatively thin and largely above the water table. The monitoring bore logs indicate a lower energy depositional environment with coarse gravels uncommon and finer sandy clay sediments predominant within the alluvial sequence. The available data therefore indicates that the alluvium occurring along Yorks Creek and Swamp Creek could not be classified as a “highly productive” aquifer due to the limited aquifer saturation and limited permeability due to the presence of clays. It should also not be considered as “less productive” as it is predominantly dry and therefore does not form an aquifer system, with groundwater only present within the underlying weathered rock of following extended wet periods when the regional shallow water table is also elevated.

Bettys Creek is also a tributary of Bowmans Creek joining Bowmans Creek downstream of Glendell Mine. Bettys Creek has been previously diverted between Glendell Pit and the Main Northern Railway north of the Ashton Coal Mine. The diversion has resulted in the removal of alluvial sediments in the area of the diversion. Further upstream of this area monitoring bores logs indicate the Bettys Creek alluvium is relatively thin with horizons of clay, silt, sand, and gravel. Borehole logs indicate the alluvium is commonly 2 m to 6 m in thickness, with only one borehole intersecting some 8 m of sediments. The limited thickness of alluvium with Bettys Creek means it is commonly dry or has limited saturated thickness. Similar to the other tributaries of Yorks and Swamp Creek the limited saturation and permeability mean it does not meet the criteria to form a “highly productive” aquifer.

As outlined in Section 2.3.1 the division of an alluvial aquifer into “highly productive” or “less productive” categories is based upon potential water bore yields and also the salinity of groundwater. The salinity of groundwater within the tributaries of Bowmans Creek also limits the beneficial use of groundwater and is discussed further in Section 5.8.1.

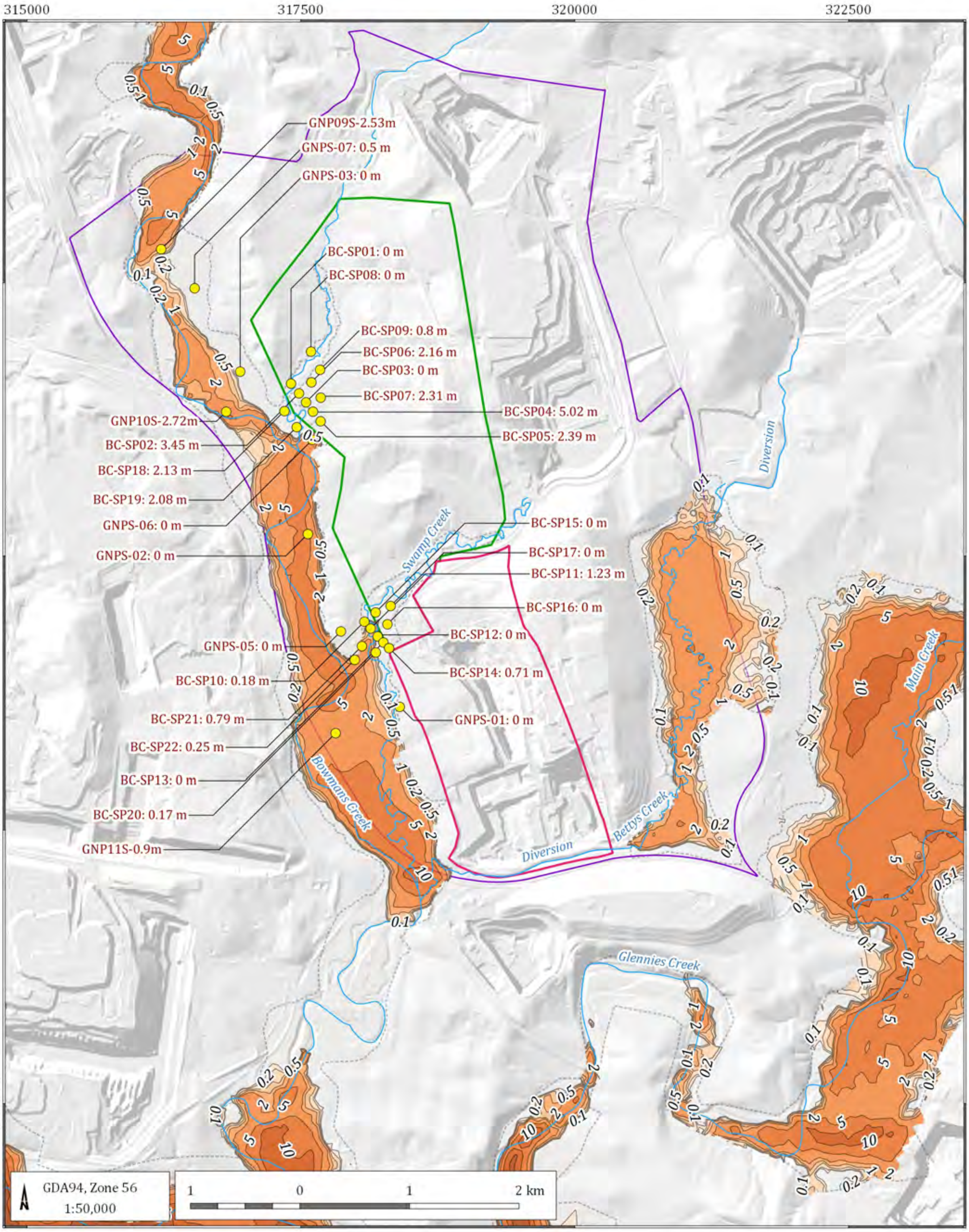
Saturation of the Permian strata occurs in both the coal seams and interburden. The ability to yield water is limited to the coal seams, as the interburden does not transmit significant volumes of groundwater and acts as an aquitard confining the coal seams. The coal seams are comprised of multiple plies with intervening non-coal interburden. When the plies and non-coal layers are combined each seam can range from 2.5 m to 10 m in thickness and is generally fully saturated with groundwater. The yield from the coal seams is also relatively low due to limited permeability and thickness, meaning they also cannot be classified as ‘highly productive”, and are considered “less productive”. Figure 2-3 shows the coal seams intersected in Glendell Pit and illustrates the lack of significant seepage from the interburden rock units and the zones of limited seepage from the deeper coal seams. This limited seepage from the coal seams is typical of Hunter Valley mines, which do not commonly need to remove significant volumes of groundwater from the mining face/pit as the volumes of seepage are low enough to readily evaporate. Due to these complications, groundwater seepage into historic mining areas is difficult to quantify, which increases the uncertainty of forward predictions.

5.4 Groundwater flow directions

Standing water level measurements from monitoring bores in the Project region indicate groundwater flow within the Quaternary alluvium is a reflection of the surface topography. Figure 5-3 shows interpolated groundwater levels from monitoring bores within saturated alluvium. The figure highlights the generally southerly trend in groundwater flow towards the Hunter River in the south. The hydraulic gradients in Bettys Creek are about 1:100, whereas a gentler gradient occurs in Bowmans Creek at 1:300. This gentler hydraulic gradient within Bowmans Creek is expected to be due to the presence of more permeable sediments and a higher transmissivity through the alluvial aquifer resulting in flatter hydraulic gradients. No zones of anomalously low-lying groundwater levels, or hydraulic gradients towards mining areas are evident in the interpolated water table surface along Bowmans Creek or Bettys Creek, and therefore no impact from existing mining activities is immediately evident in the flow directions.

Groundwater levels measured within the Permian strata were also reviewed to determine groundwater flow directions. A potentiometric surface was created by interpolating measured water levels from the Middle Liddell seam, which has a large number of monitoring locations and is intersected by a large number of the surrounding mining operations. Figure 5-4 shows the potentiometric surface developed from water levels measured in 2017.

The figure indicates the potentiometric surface has only a weak relationship with surface topography, with higher water levels measured in the north in the more elevated terrain, and lower levels towards the Hunter River which is a regional low point in the topography. Across the potentiometric surface are localised area with hydraulic gradients aligned towards depressurised mining areas at Liddell underground mine, Integra Underground and Ravensworth Operations which includes both open cut and underground longwall mining areas. Figure 5-4 shows that approved mining operations have depressurised the Permian and lowered the potentiometric surface within the Middle Liddell seam to well below levels measured within the overlying alluvial aquifers, particularly at Bowmans Creek. This transient effect of depressurisation is to reduce and eventually remove Permian discharge to overlying alluvial aquifers. This is discussed further in Section 5.5.



LEGEND

- Groundwater monitoring bore
- Drainage
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area
- Alluvium boundary

Saturated thickness of alluvium (m)

- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 25

Glendell Continued Operations GIA (G1874C)

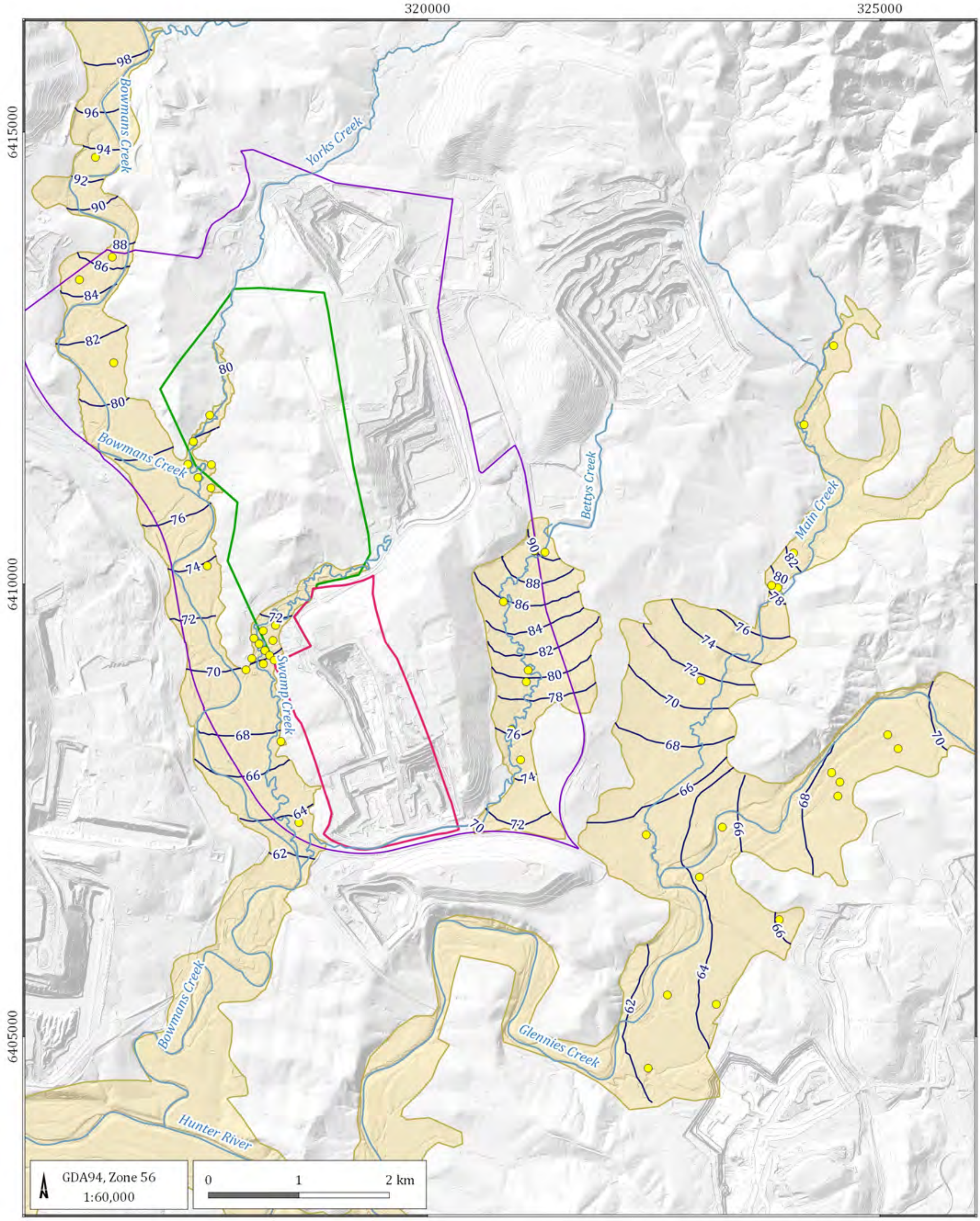
Quaternary alluvium saturation - 2018

AGE

DATE 21/11/2019

FIGURE No: **5-2**

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\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\05.02_G1874C_Quaternary alluvium saturation.qgs



LEGEND

- Alluvium monitoring bore
- Drainage
- Groundwater level contour (mAHD)
- Alluvium boundary
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

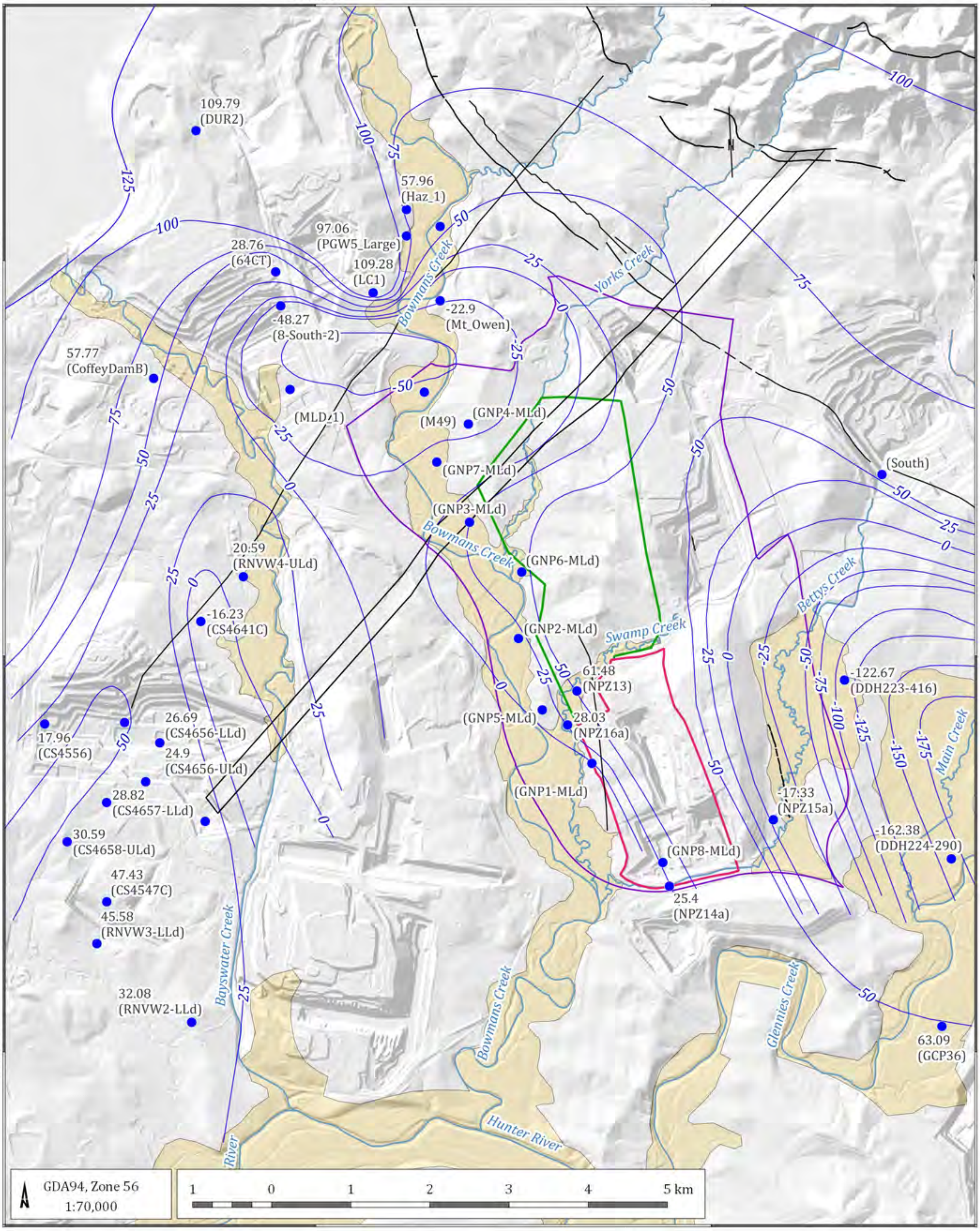
Glendell Continued Operations GIA (G1874C)

Interpolated groundwater levels within Quaternary alluvium

DATE
21/11/2019

FIGURE No:
5-3

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\05.03_G1874C_Interpolated groundwater levels within Quaternary alluvium.qgs



LEGEND

- Groundwater observation bore
- Fault
- Potentiometric head contour (mAHD)
- Drainage
- Alluvium boundary
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Glendell Continued Operations GIA (G1874C)

Interpolated potentiometric surface for the Middle Liddell Seam

DATE 21/11/2019

FIGURE No: **5-4**

Source: ELVIS LiDAR DEM - 2016.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\05.04_G1874C_Interpolated potentiometric surface for the Middle Liddell seam.qgs

As discussed, the monitoring data indicates depressurisation at the Liddell underground mine. The Liddell underground mine is a former bord and pillar operation in the Middle Liddell seam, with limited longwall mining areas. The now abandoned workings are used to store excess mine water from Liddell Coal Operations and is accessed through a series of bores drilled into various sections of the workings. The hydraulic gradient towards the Liddell underground mine appears to extend several kilometres from the abandoned workings. Additional water level records from the Liddell underground mine are presented in Section 5.5.

Data from VWPs also indicates depressurisation within the Middle Liddell seam and localised hydraulic gradients aligned towards the Ravensworth Operations, which includes both open cut and underground longwall mining areas, Integra Underground longwall mining areas and Glendell Mine. In some areas a cumulative impact from the surrounding mining operations is likely, but difficult to identify. Despite this the potentiometric surface provided in Figure 5-4 highlights the pre-existing impact of approved mining operations on the Project Area, which has reversed horizontal and vertical hydraulic gradients in the Permian coal seams away from alluvial discharge zones towards lower lying mining areas.

5.5 Water level fluctuations and inter-strata connectivity

As described in Section 5.2 a monitoring network has been gradually installed at the Mount Owen Complex and in the surrounding region over time. The majority of the locations in the monitoring bore network were installed prior to 2012 and provide baseline records for the Quaternary alluvium and Permian coal measures. The existing network has been supplemented with three additional monitoring sites, filling gaps in the monitoring network within the Bowmans Creek alluvium and underlying strata. The water level monitoring has identified influences from climatic variability and also the cumulative impact of surrounding mining operations on groundwater levels in the Project Area.

Appendix C contains hydrographs for key monitoring sites within and surrounding the Glendell Pit Extension. As noted previously the monitoring bore network consists of PVC cased 'stand pipe' monitoring bores within the shallow strata and VWPs installed within the deeper coal seams. The VWPs are fitted with data loggers that provide a continuous record of groundwater pressure within Permian strata, with the groundwater levels within the standpipe monitoring bores measured on a routine basis manually.

Many of the monitoring sites are paired. The monitoring pairs are constructed with either two PVC standpipes at different depths, or a shallow standpipe bore paired with VWPs in deeper coal seams. Where there are pairs of bores and VWPs constructed in close proximity water levels from both sites are shown on the same hydrograph in Appendix C so the relationship between shallow and deeper groundwater levels can be examined. This information is particularly useful in understanding if depressurised coal seams in the Permian strata is influencing shallow groundwater systems in the Quaternary alluvium and regolith. Because changes to groundwater level may be due to either prevailing climatic conditions or by mining the CRD is also included on the hydrographs in Appendix D. This illustrates any correlation between fluctuations in groundwater elevation and rainfall trends.

Examination of the hydrographs recorded from monitoring bores completed within the Bowmans Creek Quaternary alluvium indicates the recorded water levels generally correlate with the climatic trends as indicated by the CRD. This is particularly evident in the clusters of monitoring bores installed within the Yorks Creek and Swamp Creek areas that show the aquifer water levels generally responding in a similar manner aligned with prevailing climate conditions. Monitoring within alluvium has recorded a general decline in water levels since late 2013 due to generally below average rainfall, with a period of drought since late 2016 resulting in a notably rapid decline in groundwater levels. The decline in groundwater levels is typically in the range of 0.5 m to 2 m since 2013 in the Swamp Creek and Yorks Creek areas.

Of particular interest are monitoring bores GA1 and GA2 which are located within the Swamp Creek alluvium adjacent to the Glendell Pit.

The water levels in GA2 shows a close correlation to climatic conditions but no obvious indications that mining which commenced in 2009 has significantly influenced groundwater levels within the alluvium.

Charts of groundwater levels for monitoring bores installed within the Bowmans Creek alluvium are presented in Figure 5-5 to Figure 5-9. The charts show the relationship between groundwater levels and climate as indicated by CRD trends. The hydrographs serve to graphically illustrate the influence of the current drought on the saturated thickness of the Bowmans Creek alluvium. The charts show the water table has fallen below the base of the Bowmans Creek alluvium at the sites of GNP09 and GNP11. Some 2 m of saturation remains at the site of GNP10. Soil samples could not be retrieved from GNP02 and GNP06 whilst drilling to determine the base of the Bowmans Creek alluvium at these sites, but the water level trends indicate between 1 m and 4 m decline since the drought conditions were declared in 2017. The monitoring records from these bores illustrate that the Bowmans Creek alluvium becomes variably unsaturated in response to periods of very low recharge and drought.

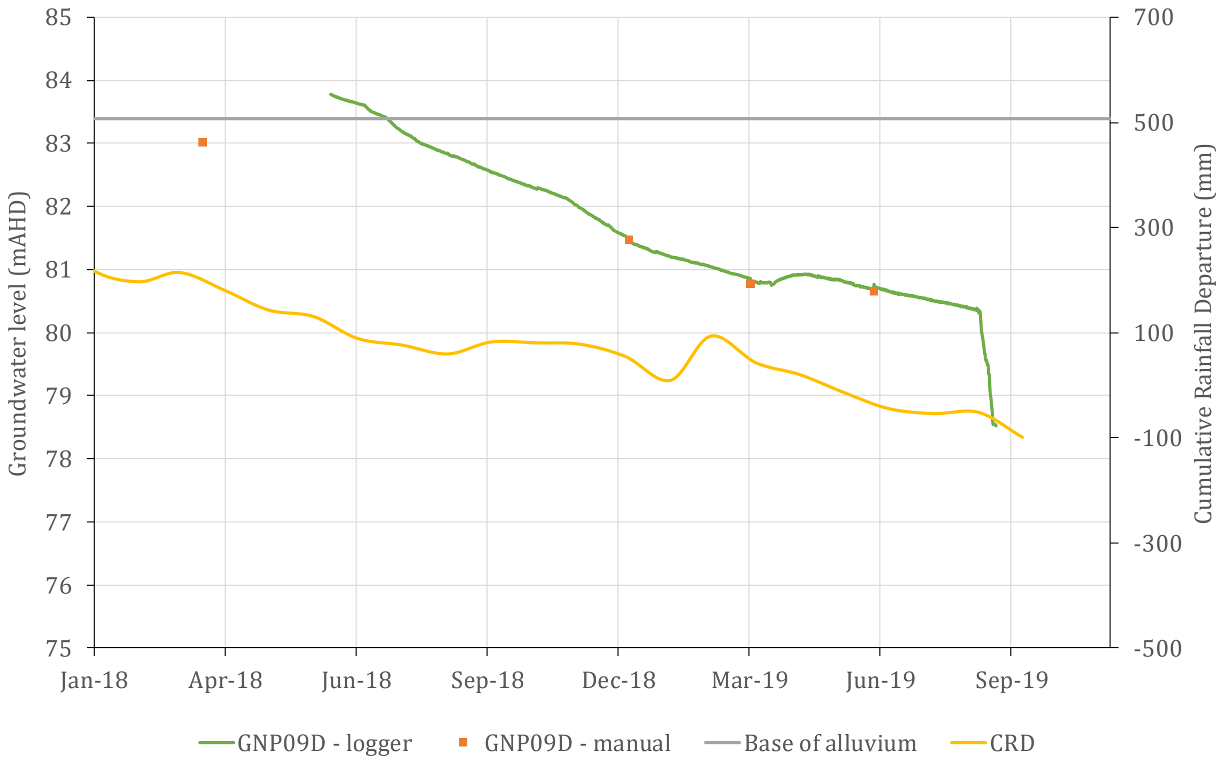


Figure 5-5 Groundwater levels and CRD – GNP09

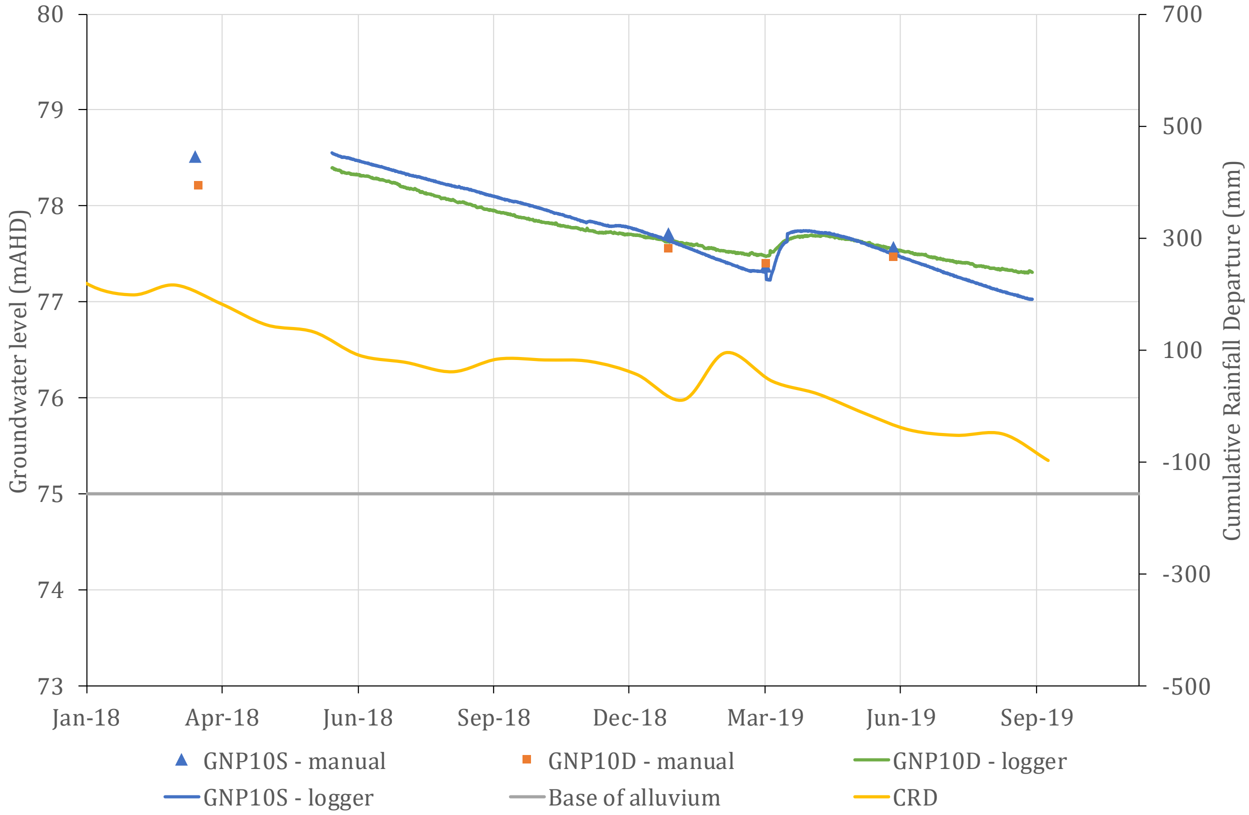


Figure 5-6 Groundwater levels and CRD – GNP10

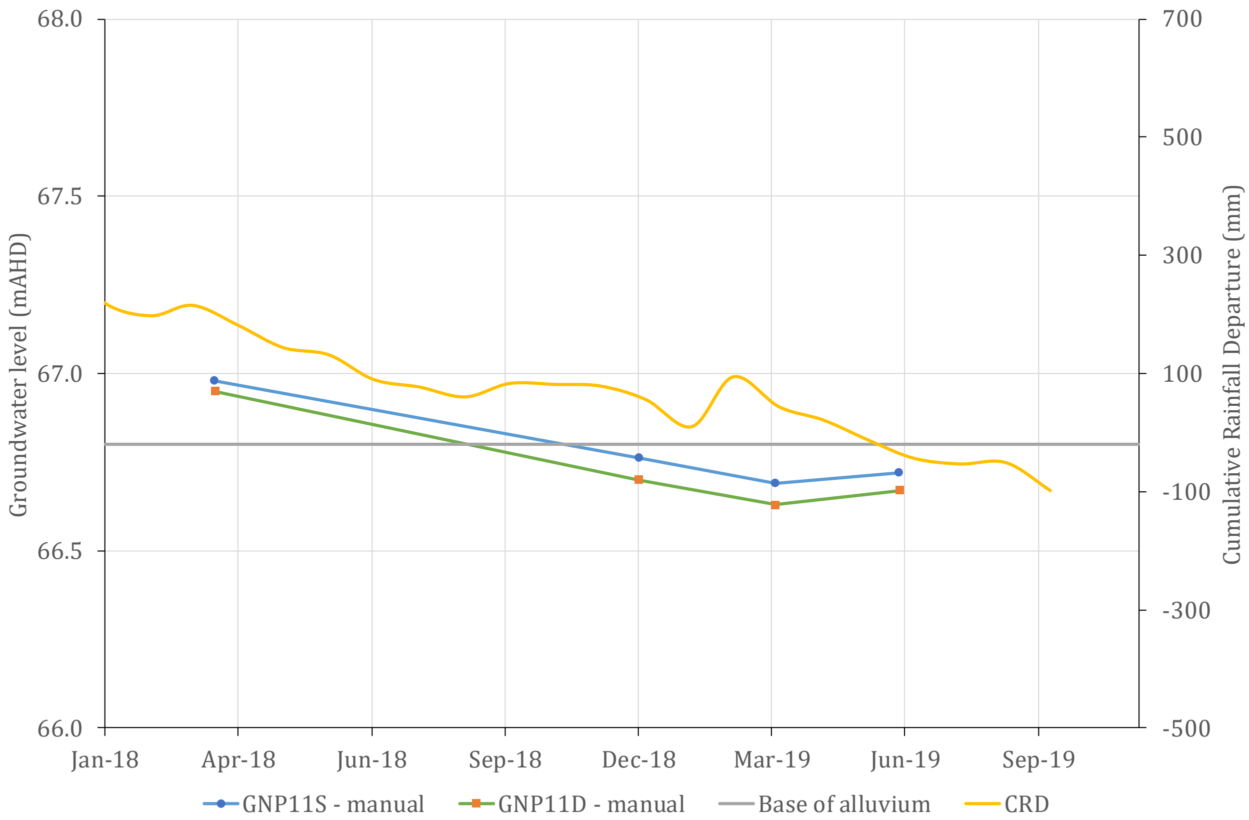


Figure 5-7 Groundwater levels and CRD – GNP11

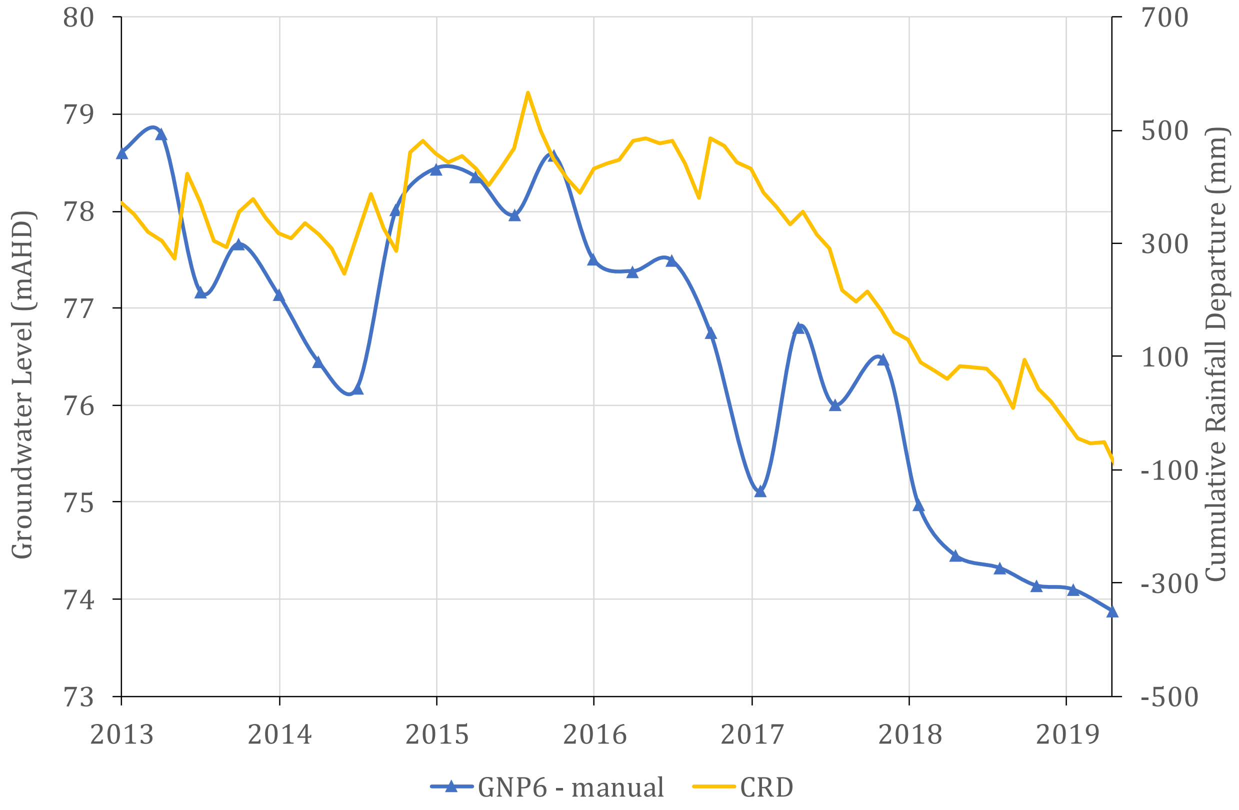


Figure 5-8 Groundwater levels and CRD – GNP02

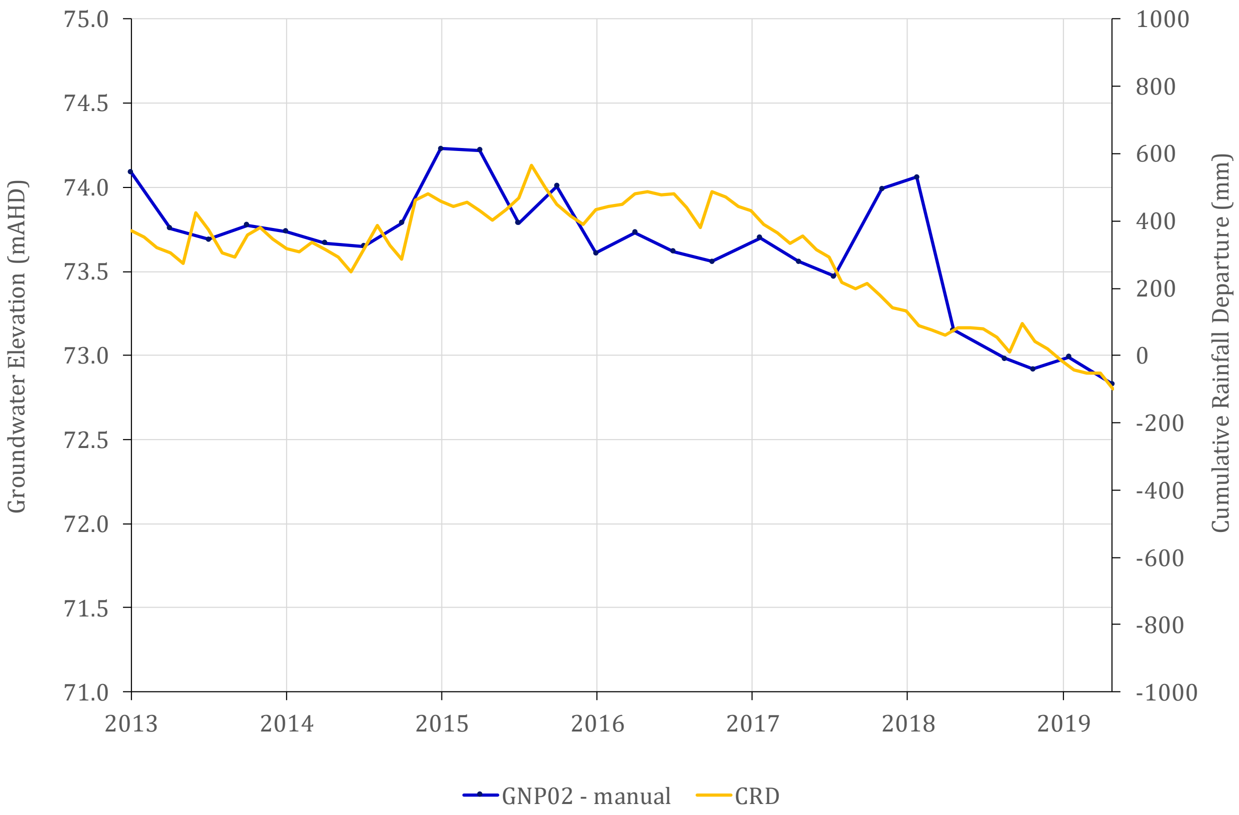


Figure 5-9 Groundwater levels and CRD – GNP06

The overall conclusion drawn from the baseline monitoring conducted within the Quaternary alluvium is that the water levels fluctuate some 1 to 4 m and are strongly correlated with climatic conditions. The influence of approved surrounding mining is less significant, and not readily evident in the water level datasets due to the masking influence of climate.

Nested monitoring bores with separate piezometers within the regolith and Bowmans Creek alluvium were installed at three sites adjacent to the Glendell Pit Extension in 2018 (GNP9S/D to GNP11S/D). The water levels recorded within the alluvium and underlying regolith are similar indicating a degree if connectivity between these units. Moderate groundwater flow is expected through the relatively permeable regolith and is expected to follow topography. The regolith has the potential to hydraulically connect the alluvium to the mine workings; however, the unit is typically dry and thin distal to the saturated alluvium.

In contrast to the alluvium, the monitoring locations installed within the deeper underlying Permian coal seams have recorded significant depressurisation during the baseline monitoring period. The groundwater levels measured within the Permian coal seams are related to the groundwater level at the discharge zone for each seam. In the absence of mining activities, the main discharge mechanism for groundwater within coal seams is through slow upward flow to low lying Quaternary alluvium along creeks. In the absence of mining activities, groundwater levels within coal seams would be at least equal to or higher than the level of the discharge zone, and therefore similar to groundwater levels within alluvium.

A review of the groundwater levels recorded within coal seams in the Project Area since 2012 shows that the measured levels are commonly well below the water levels recorded within the Quaternary alluvium. This indicates there is a lower lying discharge zone available for the coal seams through which to ‘depressurise’ over time. Approved mining operations that surround the Glendell Pit Extension extend to the Barrett seam at Glendell, Ravensworth Operations and Ashton Coal Mine, the Hebden seam at Liddell Coal Operations and Mount Owen Complex, and the Middle Liddell seam at Integra Underground. The cumulative effect of these operations is to depressurise the coal seams existing in the Glendell Pit Extension. The proposed Glendell Pit Extension is particularly susceptible to drainage and depressurisation from the surrounding mines as it is located at the ridge of an anticline structure. This means the coal seams targeted for mining are relatively elevated compared to surrounding mines, particularly Ravensworth Operations and Integra Underground which are depressurising the seams at a greater depth.

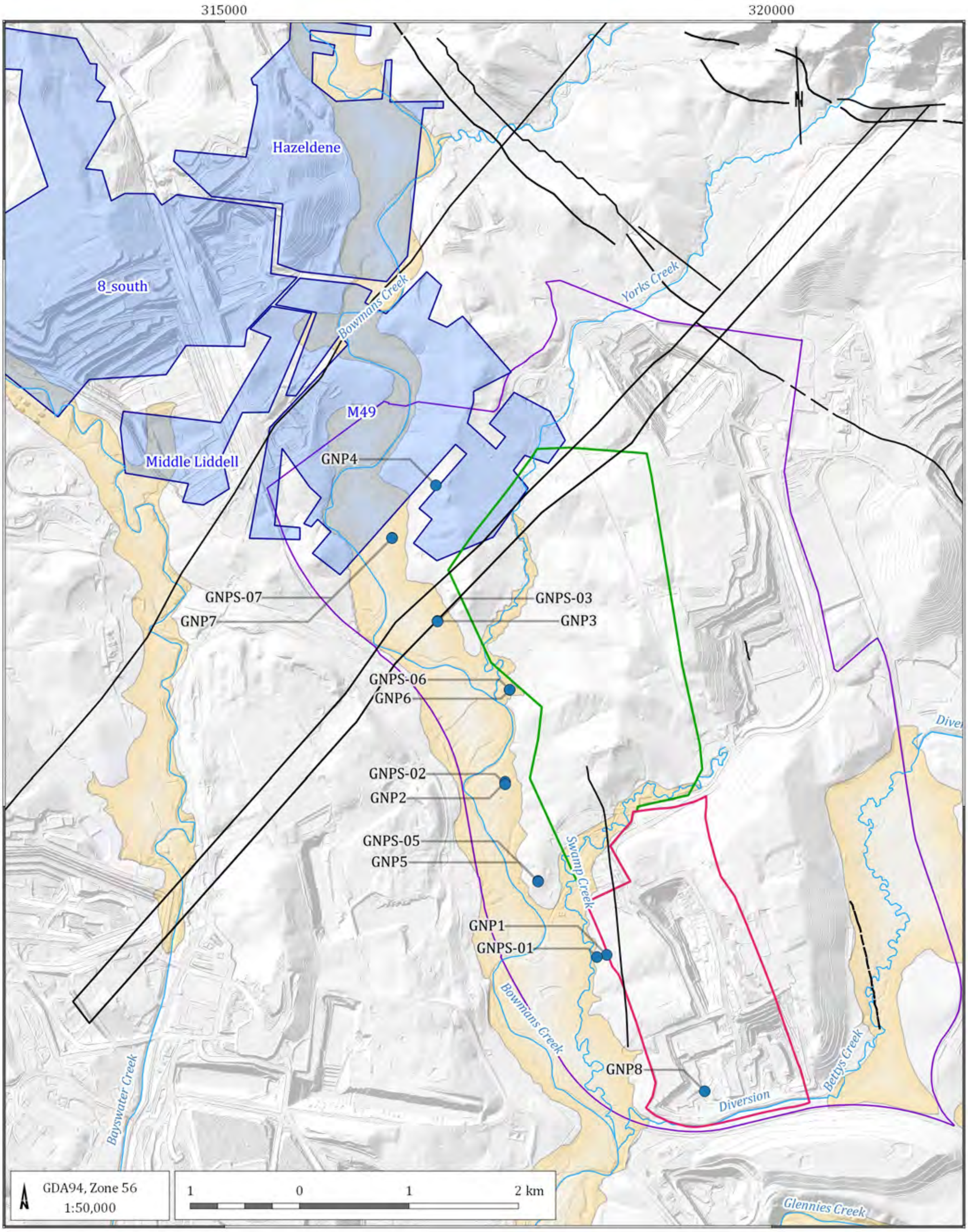
The GNP-series VWPs along Bowmans Creek (Appendix D) all show a generally downward trend in groundwater elevation in the targeted coal seams. There is no strong correlation between CRD and groundwater level trends in the Permian units, and therefore the observed decline is attributed to depressurisation induced by surrounding mining. The GNP series of VWPs indicate that the coal seams have been depressurised to a level which is below the base of the Bowmans Creek alluvium. This means there is no longer any potential for upward flow of groundwater from the Permian coal measures to the Bowmans Creek alluvium as the hydraulic gradient has reversed and is downwards from the alluvium to the Permian. The fact that the Bowmans Creek alluvial aquifer shows no notable drawdown in response to open cut mining indicates the volume of groundwater moving downwards to the Permian is limited and less than recharge rates from rainfall and streamflow that serve to buffer any losses.

Of particular relevance to the Project are two VWP arrays, GNP1 and GNP5 that are located on the north-western and western side of Glendell Pit Extension, respectively. These VWPs have recorded the depressurisation occurring within the coal seams due to mining the Approved Operations and therefore serve as potential indicator for impacts from the Project. GNP1 is located approximately 500 m west of previously mined areas in the Glendell Pit and approximately 500 m north-west of the current active mining area. The hydrographs for this site show a general decline in piezometric elevations within the coal seams over time. The piezometric elevations range from about 20 to -10 mAHD. This is a typical response for coal seams in proximity to mining as expected from previous hydrogeological studies.

The piezometric elevations within the coal seams are approximately 40 m below the level of groundwater occurring within the adjacent alluvium which is around 70 mAHD. This highlights again that despite the depressurisation of the coal seams the groundwater levels within the overlying alluvial systems are not detectably affected.

GNP5 is located approximately 250 m west of Swamp Creek and 1,400 m north-west of the current active mining area in Glendell Pit. This site has also recorded a general decline in the piezometric elevations within the coal seams over time due to mining. Again, similar to other sites whilst the coal seams have been depressurised, the piezometric elevations recorded within the upper interburden at 40 m depth does not show any decline and is a similar elevation as the alluvium groundwater levels (~70 mAHD). This again indicates that the depressurisation of the coal seams from opencut mining does not propagate into the shallow bed rock and alluvium due to higher recharge and storage in these layers.

Some of the VWPs have recorded more complex trends with downwards and upward trends. This is particularly evident at site GNP4 which is adjacent to the former Liddell underground mine. Underground workings at Liddell in the Middle Liddell seam are used for storage of excess mine water. Figure 5-10 shows the location of the underground workings and surrounding monitoring locations. Production bores drilled into the former underground mine are used to pump mine water into and out of the workings. The bores are named M49, Middle Liddell, Hazeldene, and 8-South and serve to manage water in different underground mine areas. Water levels within each of the water storages are measured regularly through the bores and are shown in Figure 5-11.



LEGEND

- Groundwater monitoring bore
- Fault
- Drainage
- Alluvium boundary
- Historical underground workings w/ associated production bore name
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Glendell Continued Operations GIA (G1874C)

Liddell Coal Operations former underground workings

AGE

DATE 21/11/2019

FIGURE No: **5-10**

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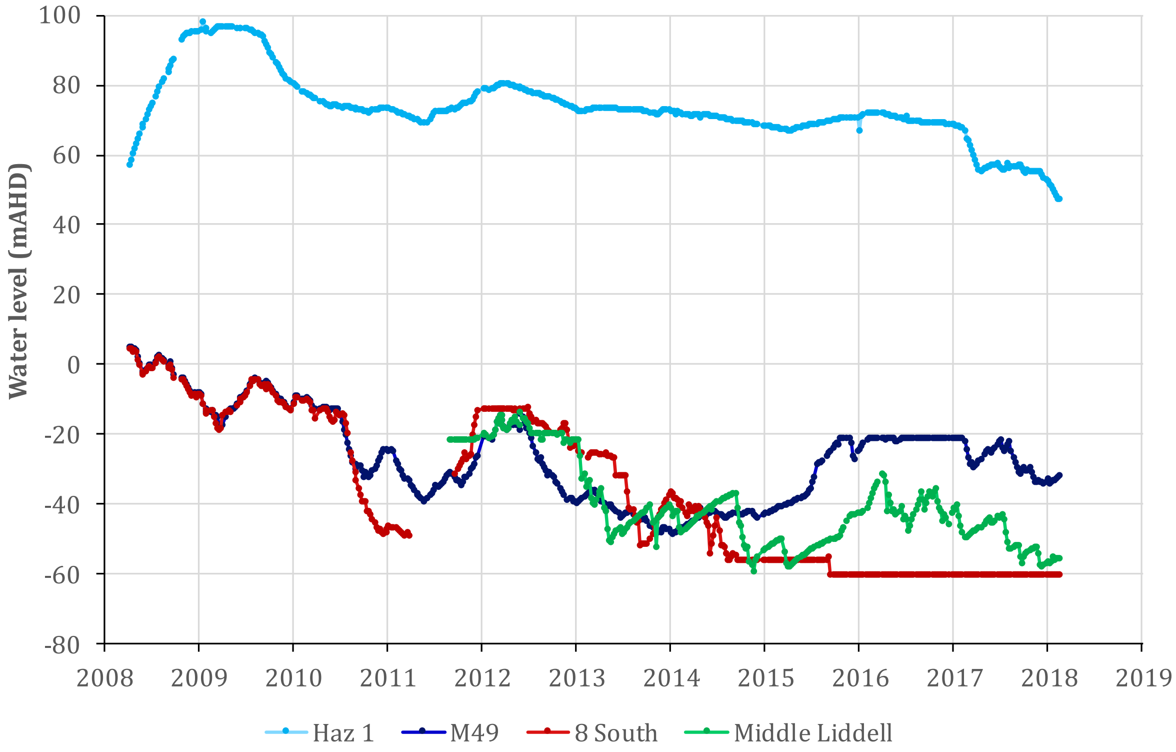


Figure 5-11 Liddell Coal Operations water storage elevations

Figure 5-11 shows the water level within the M49 workings, which are the closest to the Glendell Pit Extension, are maintained between about -20 and -40 mAHD. This is well below expected pre-mining groundwater levels and the base of the adjacent Bowmans Creek alluvium as discussed previously. Figure 5-10 highlights the proximity of the GNP series VWPs to the underground water storage area. Figure 5-12 compares the water levels recorded by the VWP sensors in the Upper and Middle Liddell seams in proximity to the Liddell Coal Operations underground water storage area.

Figure 5-12 shows the groundwater levels measured at GNP4 closely align with the water levels within the Liddell underground mine workings. This is expected given the close proximity of this monitoring site to the underground mine. A much more subtle response to the water level changes within the underground mine has been recorded at GNP7, and with no detectable response beyond GNP7, apart from depressurisation and downward trends.

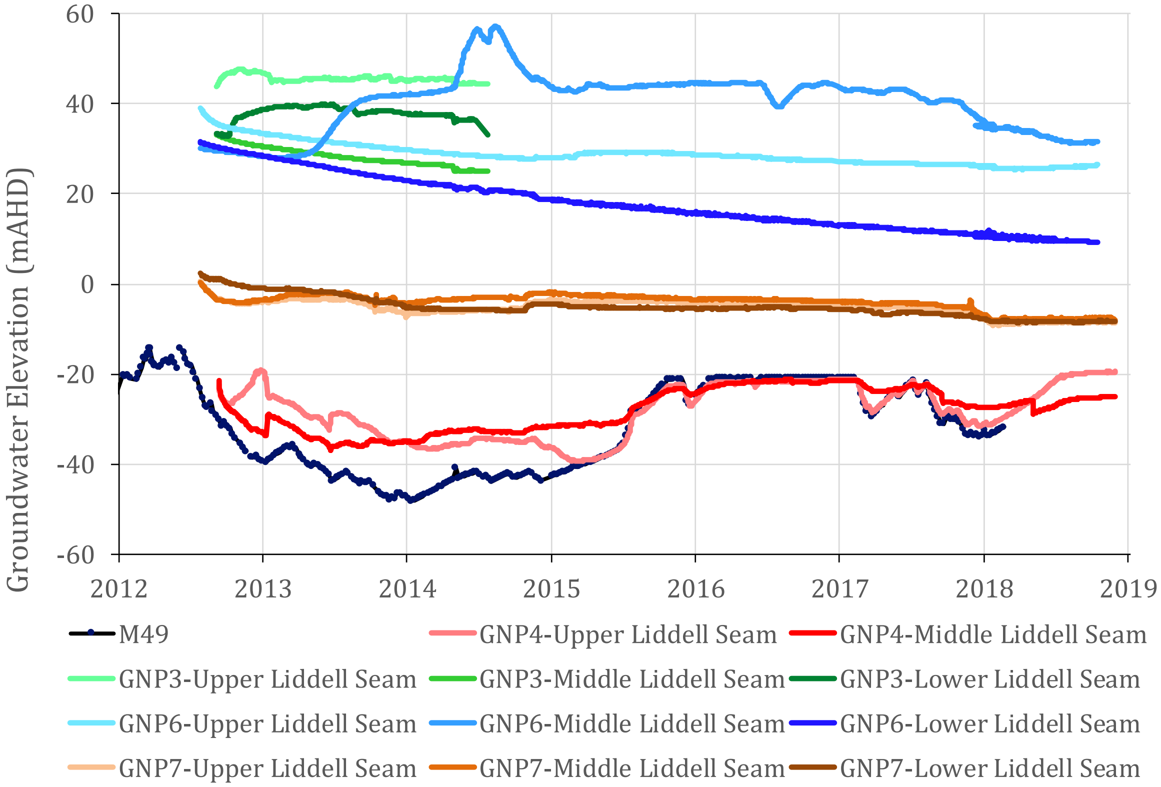
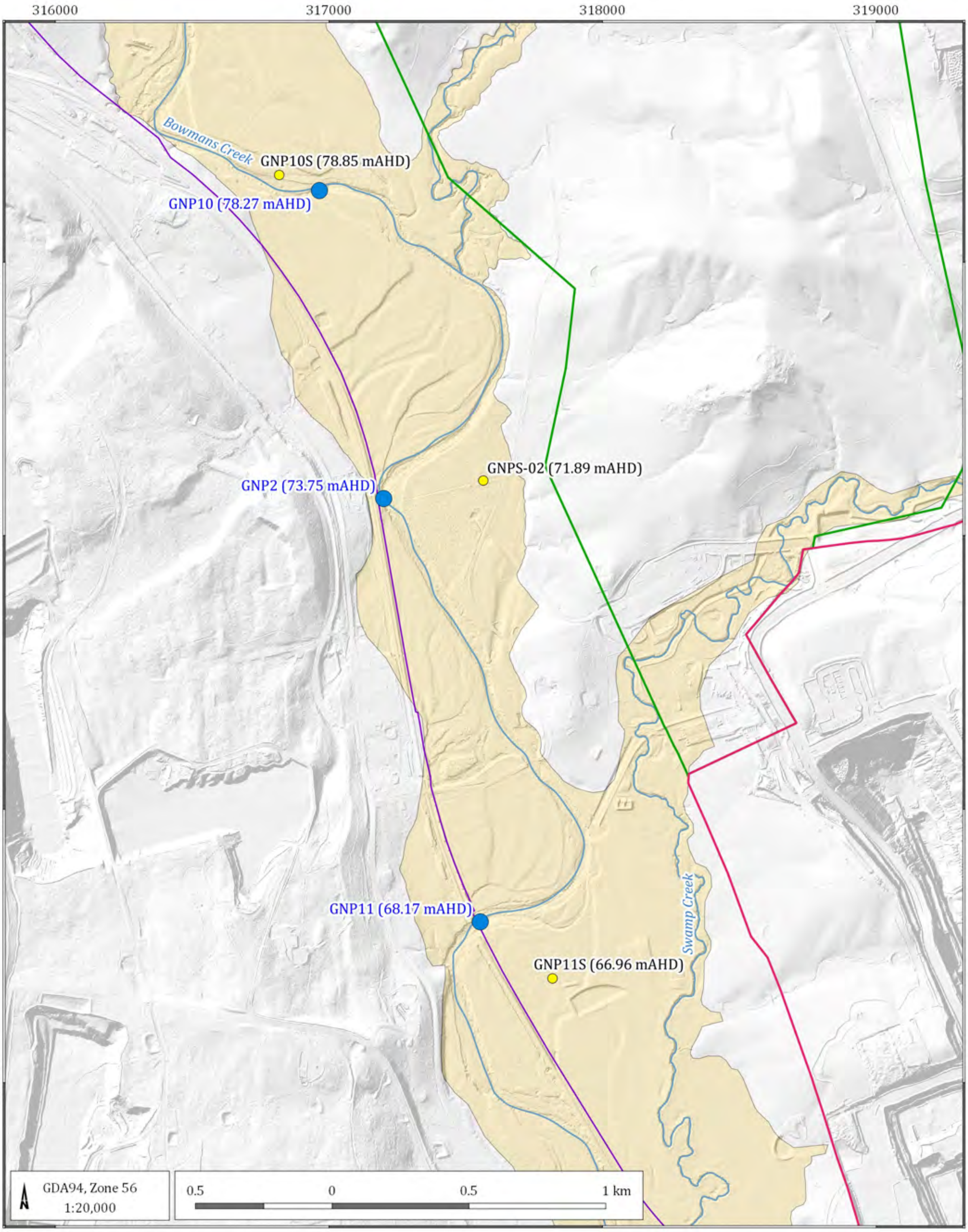


Figure 5-12 Liddell underground water storage levels and surrounding groundwater levels within the Liddell Upper and Middle seams

5.6 Groundwater – surface water connectivity

Bowmans Creek was inspected on 18 June 2018 to understand the potential for connectivity between surface water flow in the creek and groundwater in the underlying alluvial aquifer. The inspection was done during a relatively dry period with little preceding rainfall, and therefore provided an opportunity to inspect the Bowmans Creek in the absence of significant rainfall runoff. Adjacent to the Glendell Pit Extension, Bowmans Creek was observed to comprise a series of pools connected by thin rivulets of flow occurring through a gravel/cobble bed load, interspliced with areas where no surface water flow was evident.

During the site visit three pools adjacent to monitoring bores within the alluvium were identified for further investigation. Figure 5-13 shows the locations of the pools and monitoring bores. The water level and depth of each pool was measured by a surveyor on 11 July 2018, and water samples collected for laboratory analysis. Table 5-1 presents the measured water levels and water quality data collected from the three pools and adjacent bores. Figure 5-14 to Figure 5-16 show photographs of each of the pools during the surveying. A follow-up visit to the pools was undertaken in August 2019 to observe the further decline in water levels and another photo taken for comparison.



LEGEND

- Groundwater monitoring bore / water table elevation
- Pool/water level surface elevation
- Drainage
- Alluvium boundary
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Glendell Continued Operations GIA (G1874C)

Bowmans Creek pools and adjacent monitoring bores

AGE

DATE 26/11/2019

FIGURE No: **5-13**

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\05.13_G1874C_Bowmans Creek pools and adjacent monitoring bores.qgs

Table 5-1 Bowmans Creek water levels and quality

Pool location adjacent to	Water levels (mAHD)		Pool depth (m)	pH		Electrical conductivity (uS/cm)	
	Pool	Bore		Pool	Bore	Pool	Bore
GNP11	68.17	66.96	0.4	7.93	7.23	1,260	1,200
GNPS-02	73.75	71.89	1.2	7.86	6.76	1,720	1,312
GNP10	78.27	78.85	0.6	7.41	7.39	1,300	1,795

Figure 5-14 Bowmans Creek pool – adjacent bore GNP11 (Left - July 2018, Right August 2019)

Figure 5-15 Bowmans Creek pool – adjacent bore GNPS-02 (Left - July 2018, Right August 2019)

Figure 5-16 Bowmans Creek pool – adjacent bore GNP10 (Left - July 2018, Right August 2019)

Table 5-1 indicates the surface water level in the pools and groundwater level in the associated bores are very similar. The hydraulic gradient at the GNP10 pool suggests flow from the alluvial aquifer toward Bowmans Creek, and the reverse at the GNPS-02 and GNP11 pools with flow potentially from Bowmans Creek into the alluvial aquifer in 2018.

Water chemistry is likewise very similar, with the chemical markers pH and EC showing no significant variation between the pools and bore locations. The similarity in both water levels and water chemistry between the pools of standing water and nearby alluvial aquifer monitoring bores indicates the pools are windows within the Bowmans Creek alluvium and are an expression of the water table. This indicates the Bowmans Creek alluvial aquifer is directly connected to surface water pools occurring in Bowmans Creek during periods of low flow.

Since June 2018, water levels in the pools and monitoring bores have continued to decline in response to very low rainfall. At the time of writing there was no observable streamflow in Bowmans Creek (October 2019). This indicates the pools are not perennial features but do dry out in response to extended periods of low rainfall.

5.7 Hydraulic properties

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.

A number of efforts have been made to measure the hydraulic conductivity of the Bowmans Creek alluvium. Falling and rising head tests were conducted in the ALV series bores (ALV1,2,3,7,8) located upstream of the Glendell Pit Extension adjacent to Liddell Coal Operations in 2013. The testing indicated a hydraulic conductivity ranging from 1 m to 32 m/day, indicating a moderate to high permeability. Additional testing was conducted adjacent to the Glendell Pit Extension by Jacobs (2018) in newly installed alluvial monitoring bores GNP10S and GNP11S. GNP10S, which is screened in gravels, recorded a high hydraulic conductivity between 10 m and 30 m/day. A moderate permeability of 0.04 m/day was recorded in GNP11S, which is screened in sandy clay. No measurements of hydraulic conductivity are available for Bettys Creek alluvium, but the lithology within the borehole logs suggests it would be moderate to low due to the general dominance of clays.

SKM (2012) conducted a significant program of packer testing to measure the hydraulic conductivity of coal seams and interburden in the Glendell Pit Extension in the GNP series of boreholes along Bowmans Creek. The packer testing involved isolating sections of each borehole and injecting water under pressure into the rock to determine the hydraulic conductivity. The water flow rate and pressure were recorded over a number of increasing steps and used to estimate the hydraulic conductivity of the test zone. Table 5-2 presents the test results for each coal seam and interburden zone, and indicates the permeability for the coal seams ranges from a very low permeability of 3.1 x -10^{-6} m/day up to a moderately permeability of 1.7 x -10^{-2} m/day.

Table 5-2 Hydraulic conductivity test data

Bore ID	Test zone	Test depth	Hydraulic conductivity (m/day)
GNP5	interburden	39.5-43.1	7.1 x -10^{-4}
	Pike Gully seam	146.5-150.1	1.7 x -10^{-2}
	Arties seam	168.5-171.1	2.8 x -10^{-3}
	Upper Liddell seam	199.5-203.1	3.2 x -10^{-3}
	Middle Liddell seam	212.9-216.5	2.5 x -10^{-3}
	Lower Liddell seam	231.5-235.1	1.1 x -10^{-3}
	Barrett seam	247.5-251.1	5.6 x -10^{-3}
GNP6	interburden	37.59-41.19	7.0 x -10^{-4}
	Pike Gully seam	82.6-86.2	1.5 x -10^{-3}
	Upper Liddell seam	124-127.6	4.8 x -10^{-4}
	Middle Liddell seam	142.6-146.2	1.9 x -10^{-3}
	Lower Liddell seam	157.6-161.2	4.0 x -10^{-3}
	Barrett seam	172.6-176.2	2.2 x -10^{-3}
	interburden	187.6-191.2	9.0 x -10^{-4}
	Hebden seam	199.5-203.1	1.1 x -10^{-2}
GNP7	Pikes Gully seam	124.0 - 127.6	1.1 x -10^{-5}
	Arties seam	146.0 - 149.6	3.1 x -10^{-6}
	Upper Liddell seam	167.0 - 170.6	1.2 x -10^{-5}
	Middle Liddell seam	189.0 - 192.6	8.6 x -10^{-6}
	Lower Liddell seam	202.0 - 205.6	9.3 x -10^{-6}
	interburden	208.5 - 212.1	3.8 x -10^{-4}
	Barrett seam	218.5 - 222.1	4.6 x -10^{-6}
	Hebden seam	239.83 - 243.43	9.5 x -10^{-6}
GNP8	Lower Liddell seam	63.5 - 67.1	4.1 x -10^{-3}
	Barrett seam	84.5 - 88.1	1.1 x -10^{-3}
	Interburden	95.0 - 98.6	4.1 x -10^{-3}

Measurements of hydraulic conductivity within the Permian strata are also available for many of the surrounding 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 area of the Glendell Pit Extension and from public domain reports for surrounding mining.

Figure 5-17 and Figure 5-18 show the available hydraulic conductivity measurements for Permian coals and Permian interburden regionally. 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. Test data from the Glendell Pit Extension is also shown on Figure 5-17 and Figure 5-18.

Figure 5-17 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 undertaken by SKM that recorded coal seam hydraulic conductivity ranging from 3.1 x -10^{-6} m/day up to a moderately permeability of 1.7 x -10^{-2} m/day as described above.

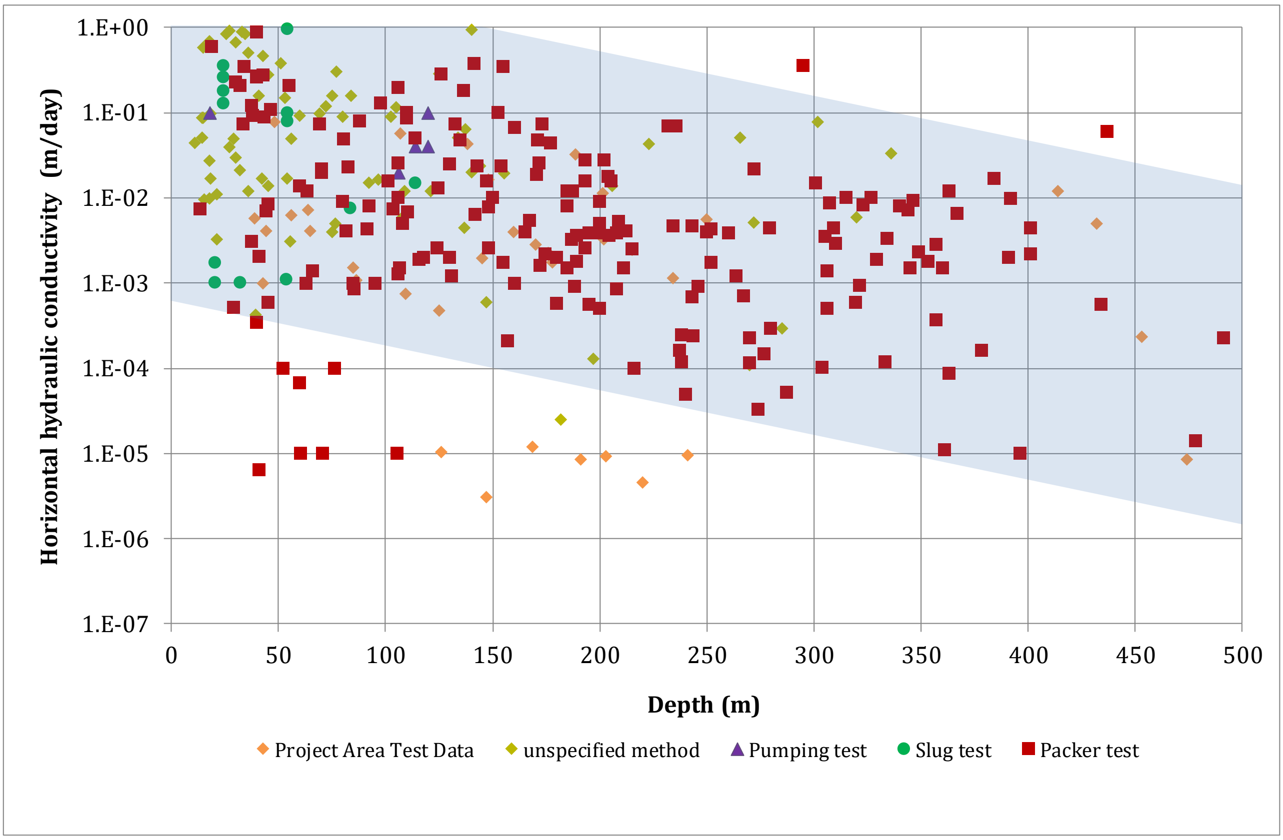


Figure 5-17 Hydraulic conductivity vs depth – Permian coal

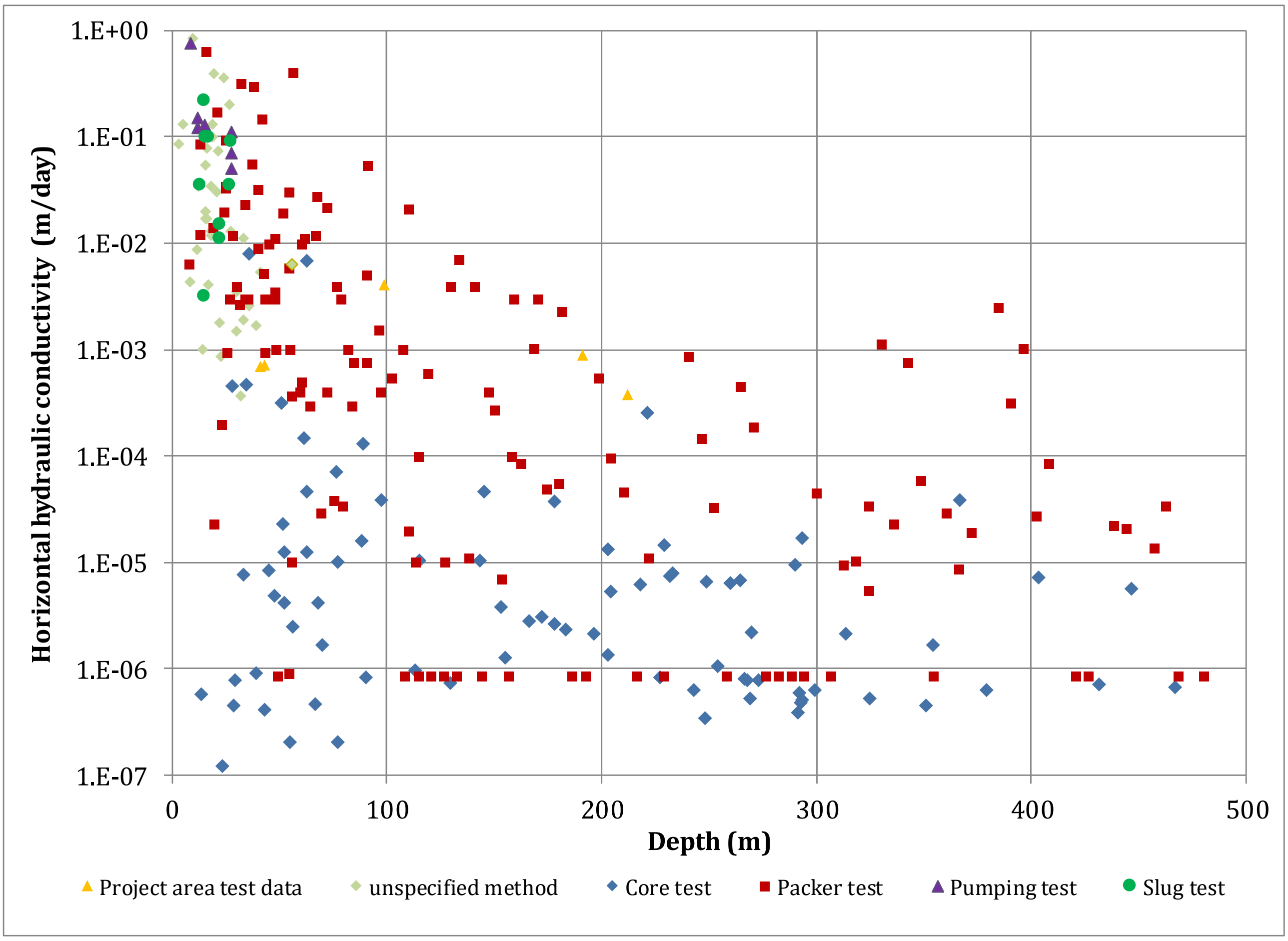


Figure 5-18 Hydraulic conductivity vs. depth – Permian interburden

5.8 Groundwater quality and beneficial use

5.8.1 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. Food and Agriculture Organization of the United Nations ('FAO') (2013) provide a useful set of categories for assessing salinity based on TDS concentrations as follows:

- Fresh water — <500 mg/L
- 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. Electrical conductivity can be used to estimate TDS concentrations by multiplying by 0.67 (ANZECC 2000). Figure 5-19 presents electrical conductivity measurements in monitoring bores from key geological units within the Glendell Pit Extension as a violin plot. A violin plot shows the density of data at different values and has been used to illustrate the distribution of data within each of the salinity categories above. The salinity categories described previously are shown with equivalent electrical conductivity measurements.

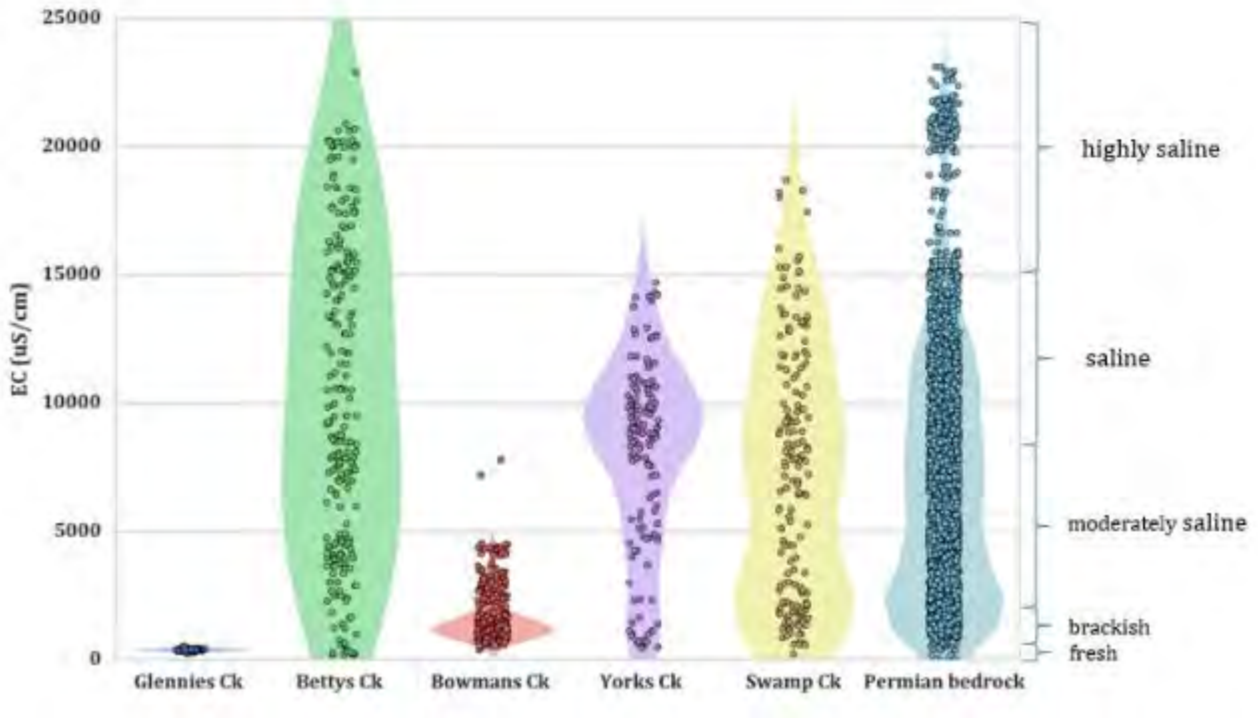


Figure 5-19 Electrical conductivity violin plot of monitoring data

The violin plot shows graphically a number of factors including the generally variable nature of salinity within the groundwater systems. The lowest salinity groundwater occurs within the Glennies Creek alluvium. Flow in Glennies Creek is regulated by releases from the upstream dam and this may contribute to the generally low salinity within the alluvial sediments. Bowmans Creek alluvium records typically fresh to brackish groundwater, whilst samples of groundwater from Bettys Creek, Swamp Creek and Yorks Creek (which are tributaries of Bowmans Creek) record widely varying salinity from fresh to highly saline waters.

High level mapping by the NSW government has classified the Quaternary alluvium occurring along all the water courses in the area including Bettys Creek, Swamp Creek and Yorks Creek as a "highly productive" groundwater source (refer Section 2.3.2). To meet the criteria the groundwater system must yield groundwater with a TDS concentration less than 1,500 mg/L (approximately 2,200 µS/cm in EC). Groundwater with a salinity exceeding 1,500 mg/L is classified as "less productive". The available data indicate high salinity, low transmissivity, and low saturated thickness, meaning that Swamp Creek, Yorks Creek and Bettys Creek alluvium do not meet the NSW government criteria of a highly productive groundwater source and is therefore in the "less productive" category (refer Section 5.3 for detail on saturation of alluvium).

Figure 5-19 shows the salinity of samples collected from the Bowmans Creek alluvium varies from fresh to brackish, depending on the location. This means that in some areas the Bowmans Creek alluvium can be considered 'highly productive' based on salinity, and in other areas it is within the 'less productive' category. The samples from the Glennies Creek alluvium further to the south of the Glendell Pit Extension indicate a relatively fresh groundwater system. However, it should be noted other monitoring bores that are now part of the adjacent Rix's Creek North 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 violin plots in Figure 5.14 also include data from the Permian strata that are drawn from the Glencore mines within the mid Hunter Valley (Mount Owen Complex, Liddell Coal Operations, Ravensworth Operations and Integra Underground). The figure illustrates the variability in the salinity of groundwater occurring within the Permian strata ranging from fresh to highly saline. This variability is expected to be a function of water sample depth, aquifer residence time and evapo-concentration processes in the recharge area. Of note is the similarity in the salinity range measured within the Permian compared with the alluvial groundwater from Bettys Creek, Bowmans Creek and Swamp Creek alluvium. This similarity suggests that historical upwelling of Permian groundwater into the Quaternary alluvium, prior to significant depressurisation of the Permian strata by mining had a significant influence on alluvial groundwater quality where groundwater levels promote connectivity. The fact the saline water entering the alluvium through the base is not significantly diluted upon entering the alluvium indicates that fresher recharge from 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. Whilst the influence of mining has reduced connectivity between the Permian and the alluvium, it is expected any reduction in salt load to the alluvium will take a long time to become evident as the process of flushing salts from aquifers is relatively slow.

The water quality data was examined for spatial trends that could indicate groundwater flow processes. Water quality in Bowman Creek is generally brackish, but fresher than groundwater in the alluvial tributaries of Yorks Creek, Swamp Creek and Bettys Creek. The York Creek and Swamp Creek alluvium are moderately saline to saline, but become more brackish (i.e. less saline) towards the aquifer confluence with Bowmans Creek, likely due to an increase in recharge and through-flow. Overall, there are no obvious spatial trends in water quality from north to south through the Bowmans Creek alluvium. There are however a number of sites where a moderate salinity aligns with thicker alluvial sediments, suggesting there could be salinity stratification in lower lying areas of the alluvial aquifer where denser more saline water would collect.

The violin plot combines salinity data over different time periods into a single graphic. To examine trends over time Figure 5-20 to Figure 5-24 were prepared, and show the variability in the salinity of samples collected over time from bores within the alluvial groundwater systems of Bowmans Creek, Yorks Creek, Swamp Creek and Bettys Creek alluvium as well as samples collected from the Permian strata.

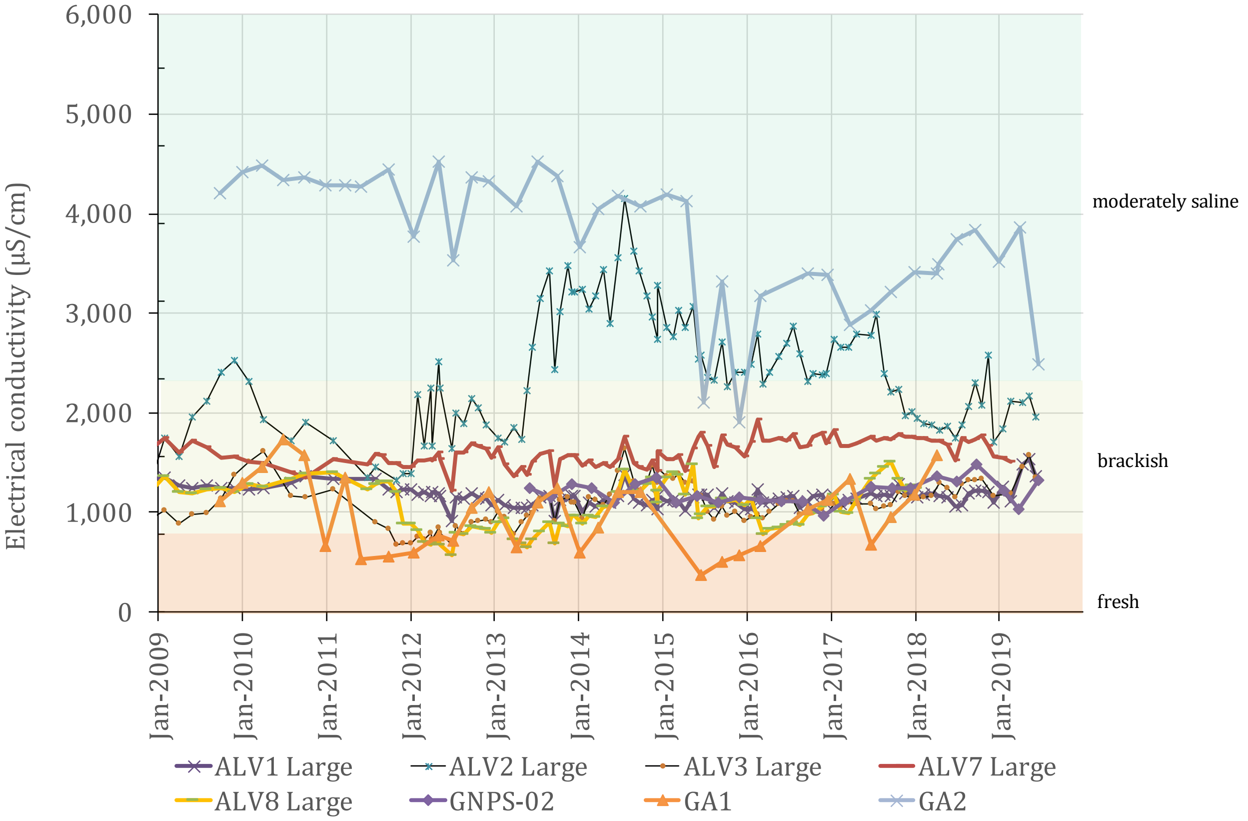


Figure 5-20 Electrical conductivity in Bowmans Creek alluvium

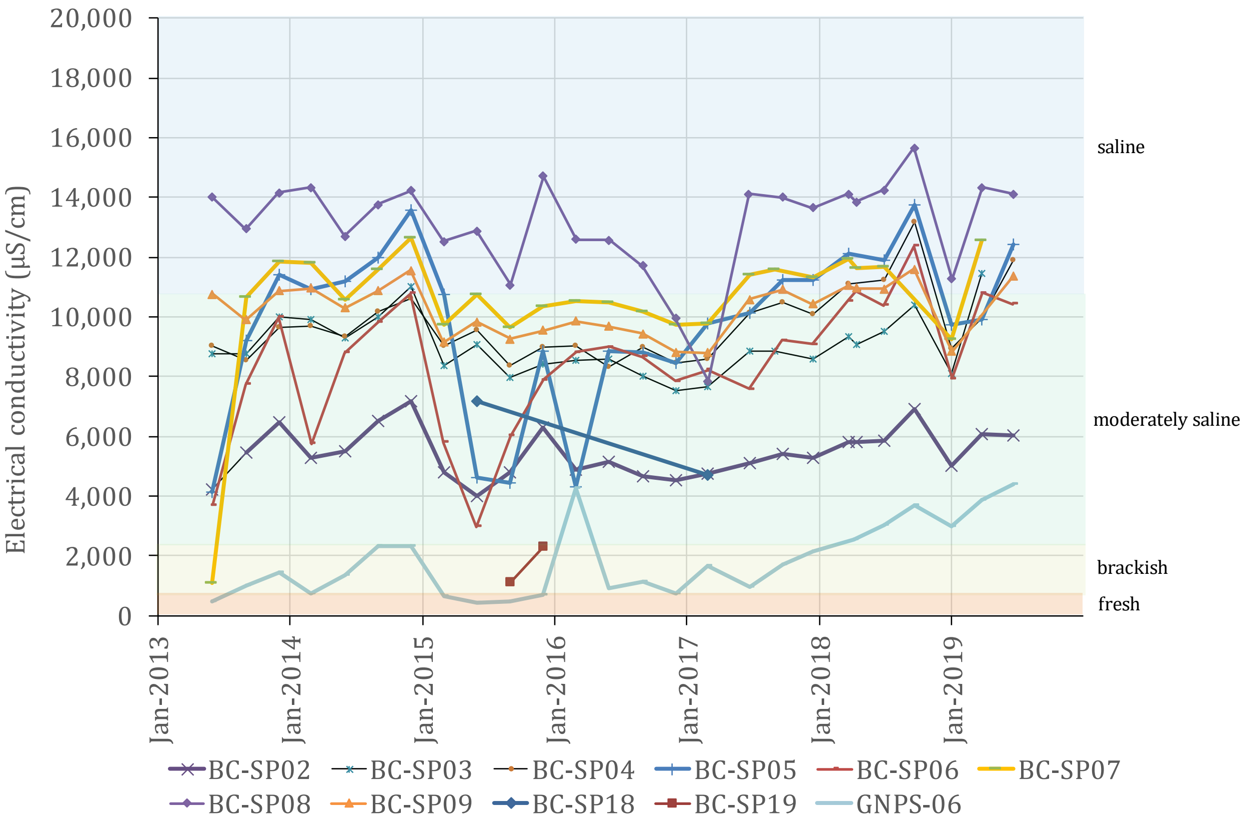


Figure 5-21 Electrical conductivity in Yorks Creek alluvium

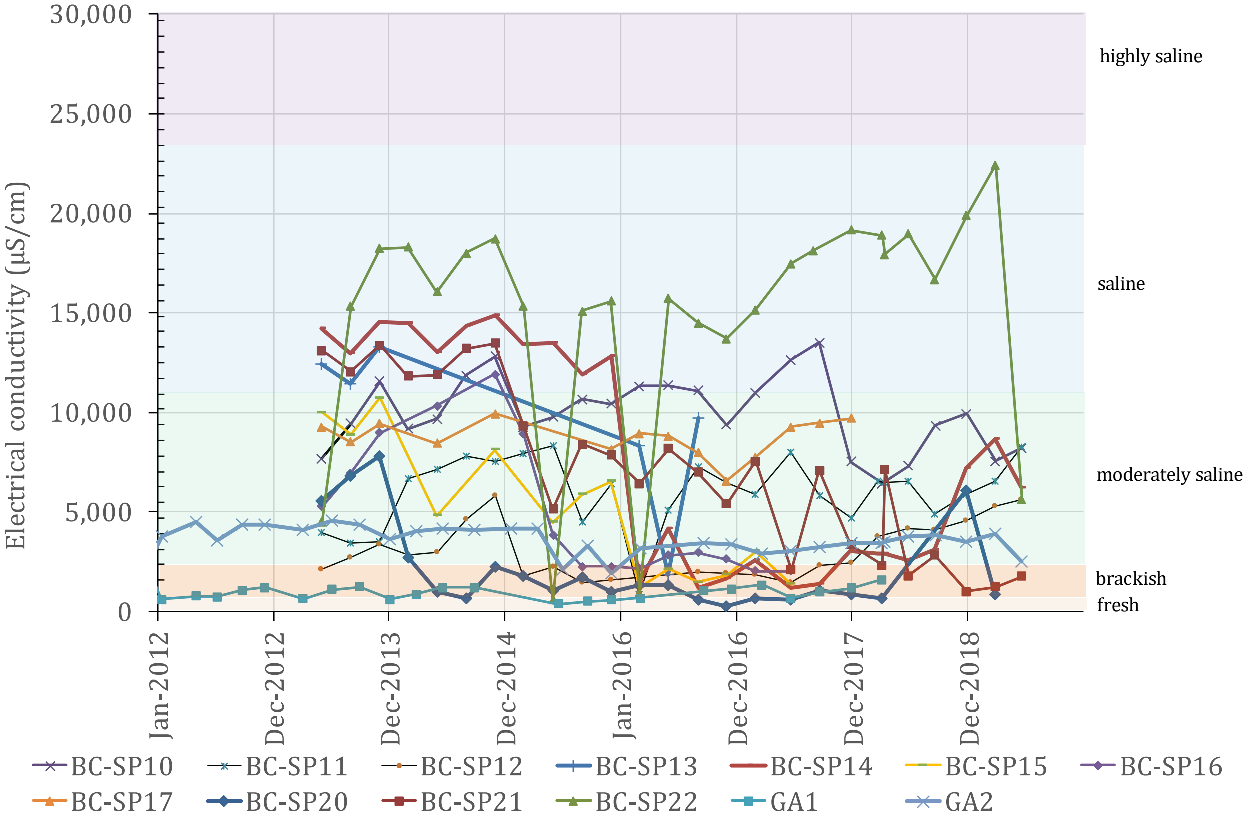


Figure 5-22 Electrical conductivity in Swamp Creek alluvium

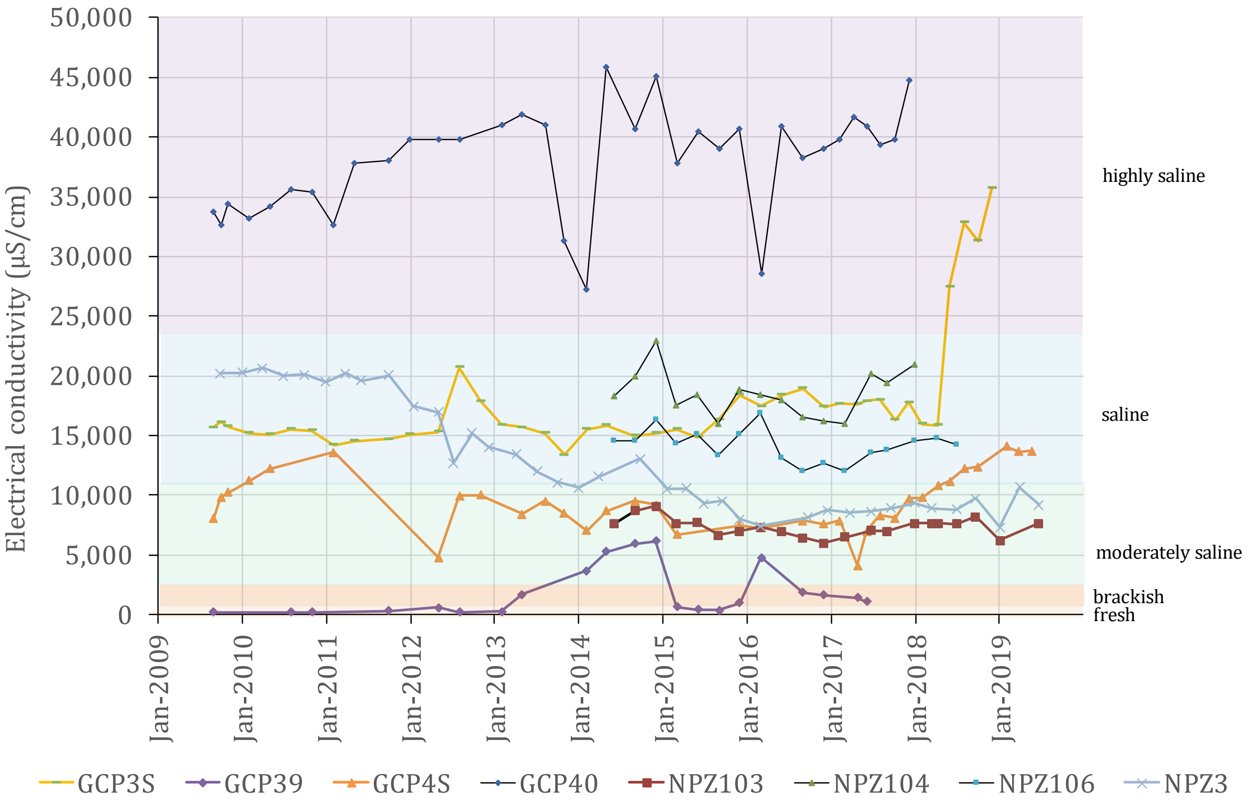


Figure 5-23 Electrical conductivity in Bettys Creek alluvium

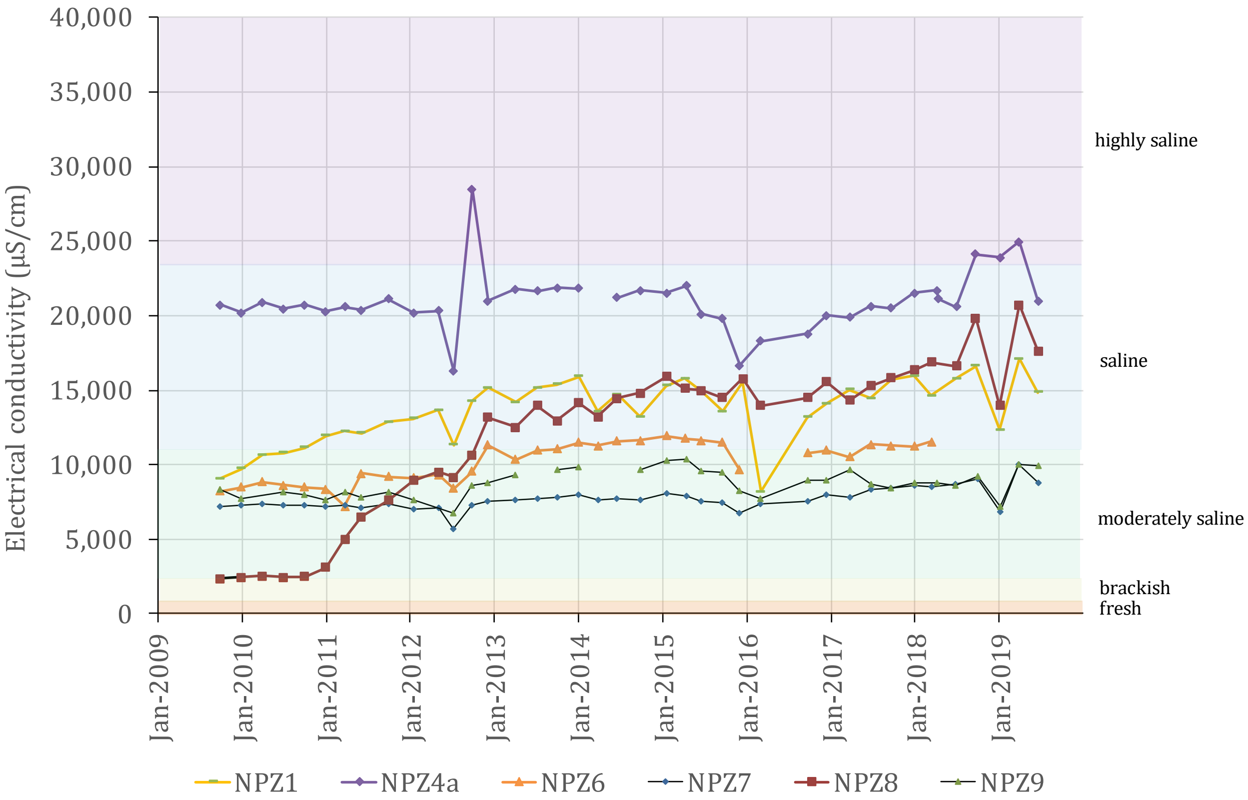


Figure 5-24 Electrical conductivity in selected Permian monitoring bores

The above charts indicate a level of variability in the salinity of samples collected from each monitoring bore over time. Of note is the brackish to saline nature of groundwater samples collected from bores installed in the tributaries of Bowmans Creek, i.e. Yorks Creek, Swamp Creek and Bettys Creek. No uniform cycles are evident between monitoring bores within the Quaternary alluvium. For example, trends of declining salinity and stable salinity are both evident in records from the Swamp Creek cluster of alluvial monitoring bores. When a declining trend in salinity has been observed this may be related to depressurisation of the underlying Permian reducing the upward flow of Permian water. In contrast salinity appears more stable in water samples collected from bores installed within the Yorks Creek and Bowmans Creek alluvium, compared with Swamp Creek. The generally variable nature of salinity within the smaller tributaries of Bowmans Creek indicates relatively slow movement of groundwater, with low permeability areas retarding recharge and flushing of salts from the sediments. For these reasons Swamp Creek, Yorks Creek and Bettys Creek alluvium do not form highly productive aquifers as defined in the AIP, and therefore have not been exploited for any beneficial use. The occurrence of the salinity is due to evapo-concentration of rainfall recharge and flow of saline groundwater from the underlying Permian strata into the base of the Quaternary alluvium where the regional water table is above the base of alluvium, or has been in the past.

5.8.2 Chemistry and beneficial use

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 between 2017 and 2018. Samples were also taken from two standing pools in Bowmans Creek, which were determined to be windows to the water table (refer Section 5.6). Table 5-3 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 due to salinity. The concentration of total metals also exceeds guideline values for freshwater aquatic ecosystems. This is not uncommon in groundwater systems where trace elements can be naturally concentrated above guideline values for aquatic ecosystems that would rely on fresh water. 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. Consequently, 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

G1G74C
Groundwater Quality Results

Parameter	Units	LOR[#]	ANZECC GUIDELINES				NHMRC																			
Sample Location																										
Bore ID			Fresh Water Aquatic (95th)	Short term irrigation	Long Term irrigation	Stock Water	Drinking Water	ALV1 LARGE	ALV2 LARGE	ALV7 LARGE	BC-SP02	BC-SP02	BC-SP03	BC-SP03	BC-SP03	BC-SP06	BC-SP06	BC-SP07	BC-SP07	BC-SP07	BC-SP08	BC-SP08	BC-SP09	BC-SP09	BC-SP11	BC-SP11
Date Sampled								21-08-17	21-08-17	21-08-17	17-05-18	13-04-18	01-09-17	17-05-18	13-04-18	17-05-18	13-04-18	01-09-17	17-05-18	13-04-18	17-05-18	13-04-18	17-05-18	13-04-18	17-05-18	13-04-18
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]	7.3	7.7	7.4	7.16	7.4	7.8	7.48	7.64	7.32	7.55	7.7	7.35	7.47	7.47	7.73	7.38	7.63	6.94	7.11
Electrical conductivity	µS/cm	1	120 - 300	-		-	-	1120	2370	1680	5770	6200	8820	9210	10200	10500	11800	11500	11800	13000	14200	15800	11200	12200	5430	7160
Sodium Absorption Ration (SAR)	-	0.01		-		-	-	3.42	5.89	4.47	11.6	12.6	20.1	20.6	21.3	19.4	20.7	23.7	22.6	23.9	30.8	31.1	23.2	23.9	8.81	9.35
Total Dissolved Solids (calc)	mg/L	1.00		-		3000 - 13000*	600[b]	728.00	1540.00	1090.00	3750	4030	5730.00	5990	6630	6820	7670	7480.00	7670	8450	9230	10300	7280	7930	3530	4650
Total Hardness as $CaCO_3$	mg/L	1.00		-		-	200[b]	265.00	800.00	398.00	1010	1080	1130.00	1140	1220	1540	1640	1480.00	1550	1600	1550	1520	1360	1440	1120	1240
Hydroxide Alkalinity as $CaCO_3$	mg/L	1.00		-		-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1.00		-		-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1.00		-		-	-	186.00	447.00	314.00	491	504	681.00	718	757	793	852	922.00	934	987	1140	1150	1080	1120	497	573
Total Alkalinity as $CaCO_3$	mg/L	1.00		-		-	-	186.00	447.00	314.00	491	504	681.00	718	757	793	852	922.00	934	987	1140	1150	1080	1120	497	573
Major Ions																										
Sulfate as SO_4 - Turbidimetric	mg/L	1		-		1000 - 2000	500[a] / 250[b]	127	288	192	896	942	821	906	860	1080	1200	645	698	712	698	691	702	666	348	388
Chloride	mg/L	1			40	-	250[b]	160	313	255	1190	1190	2270	2660	2600	3130	3010	3280	3750	3680	4560	4510	3410	3260	1390	1740
Fluoride	mg/L	0.1		2.0	1.0	2	1.5[a]	0.2	0.4	0.3	0.5	0.8	1	1	1	0.7	0.8	0.8	0.8	0.8	1	1.1	0.7	0.8	0.3	0.5
Calcium	mg/L	1		-		1000	-	65	159	90	177	190	129	130	138	125	138	92	102	115	97	110	96	114	193	214
Magnesium	mg/L	1		-		-	-	25	103	42	137	147	196	198	212	297	315	304	314	319	318	303	271	280	155	172
Sodium	mg/L	1		-		-	180[b]	128	405	205	850	951	1550	1600	1710	1750	1930	2100	2040	2200	2790	2790	1960	2080	678	758
Potassium	mg/L	1		-		-	-	2	4	2	1	2	4	3	4	12	12	18	16	19	20	20	12	12	3	3
Total Anions	meq/L	0.01		-		-	-	10.9	23.8	17.5	62	63.2	94.7	108	106	127	127	124	139	138	166	164	132	128	56.4	68.6
Total Cations	meq/L	0.01		-		-	-	10.9	34.1	16.9	57.1	63	90.1	92.4	98.8	107	117	121	120	128	153	152	113	120	52	57.9
Ionic Balance	%	0.01		-		-	-	0.21	17.9	1.6	4.14	0.2	2.51	7.87	3.68	8.35	4.04	1.2	7.3	3.82	4.1	3.88	8.05	3.51	4.09	8.48
Nutrients																										
Ammonia as N	mg/L	0.01	0.9	-		-	0.5[b]	0.05	0.06	<0.01	0.02	0.02	<0.01	0.02	0.09	0.09	0.13	<0.01	0.13	0.12	0.02	0.15	0.13	0.05	0.02	0.02
Nitrite as N	mg/L	0.01		-		30	3[a]	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
Nitrate as N	mg/L	0.01	0.7	-		-	50[a]	0.02	0.09	0.04	0.03	0.05	0.13	0.08	0.1	0.04	0.07	0.16	0.07	0.1	0.05	0.06	0.03	0.05	0.06	0.09
Nitrite + Nitrate as N	mg/L	0.01		-		400	-	0.02	0.09	0.04	0.03	0.05	0.13	0.08	0.1	0.04	0.07	0.16	0.07	0.1	0.05	0.06	0.03	0.06	0.06	0.09
Total Kjeldahl Nitrogen as N	mg/L	0.1		-		-	-	<0.1	<0.1	<0.1	0.2	0.9	0.5	1.5	1	0.6	2.2	1.3	1.5	1	0.7	1.1	0.3	0.4	0.4	0.5
Total Nitrogen as N	mg/L	0.1		25 - 125	5	-	-	<0.1	<0.1	<0.1	0.2	1	0.6	1.6	1.1	0.6	2.3	1.5	1.6	1.1	0.8	1.2	0.3	0.5	0.5	0.6
Total Phosphorus as P	mg/L	0.01		0.8 - 12	0.05	-	-	0.09	0.04	0.04	0.18	0.54	0.26	1.03	1.2	0.17	0.49	1.01	1.92	1.37	0.53	0.74	0.36	0.31	0.42	0.36
Reactive Phosphorus as P	mg/L	0.01				-	-	<0.01	0.02	<0.01	0.08	0.08	0.12	0.12	0.12	0.06	0.06	0.01	0.02	0.01	0.02	0.01	<0.01	0.02	<0.01	<0.01
Total Metals																										
Aluminium	mg/L	0.01	0.055	5		5	0.2[b+]	0.58	0.31	1.51	5.76	9.71	18.4	94	77.4	6.4	21.5	87.9	95	72.9	34.8	32.2	19.5	13.2	23.5	13.4
Arsenic	mg/L	0.001	As (III) 0.024 As (V) 0.013	2.0	0.1	0.5	0.01[a]	<0.001	<0.001	0.003	0.004	0.009	0.005	0.024	0.019	0.001	0.005	0.026	0.026	0.025	0.027	0.028	0.021	0.014	0.009	0.007
Beryllium	mg/L	0.001		0.5	0.1	-	0.06[a]	<0.001	<0.001	<0.001	<0.001	0.002	0.001	0.006	0.007	<0.001	0.002	0.006	0.008	0.006	0.002	0.003	0.002	<0.001	0.002	<0.001
Barium	mg/L	0.001		-		-	2[a]	0.321	0.094	0.13	0.157	0.198	0.174	0.647	0.519	0.229	0.281	0.613	0.756	0.488	0.304	0.308	0.19	0.117	0.288	0.214
Cadmium	mg/L	0.0001	0.0002	0.05	0.01	0.01	0.002[a]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	0.0002	<0.0001	0.0003	0.0001	0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.001	CrIII – ID Cr(VI) 0.001	1.0	0.1	1.0	0.05[a]	<0.001	<0.001	<0.001	0.005	0.011	0.019	0.088	0.087	0.008	0.032	0.083	0.087	0.07	0.039	0.037	0.021	0.013	0.02	0.012
Cobalt	mg/L	0.001		0.10	0.05	1.0	-	<0.001	0.009	0.178	0.006	0.016	0.017	0.082	0.082	0.008	0.02	0.066	0.078	0.057	0.021	0.025	0.019	0.01	0.022	0.014
Copper	mg/L	0.001	0.0014	5.0	0.2	0.5 - 5^	2[a] / 1[b]	0.002	0.001	0.034	0.006	0.018	0.016	0.08	0.076	0.012	0.046	0.092	0.107	0.077	0.042	0.043	0.019	0.008	0.019	0.01
Lead	mg/L	0.001	0.0034	5.0	2.0	0.1	0.01[a]	<0.001	0.001	0.02	0.004	0.011	0.007	0.037	0.036	0.006	0.022	0.078	0.096	0.064	0.031	0.035	0.017	0.009	0.018	0.011
Manganese	mg/L	0.001	1.9	10.0	0.2	-	0.5[a] / 0.1[b]	0.23	0.398	4.22	1.78	2.39	0.798	2.88	3.06	0.544	0.681	3.42	4.15	3.07	0.605	0.876	0.564	0.311	1.33	0.796
Mercury	mg/L	0.0001	0.0006	0.002	0.002	0.002		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	0.0002	<0.0001	<0.0001	<0.0001	<0.0001
Molybdenum	mg/L	0.001	-	0.05	0.01	0.15	0.05[a]	<0.001	0.002	0.002	0.001	<0.001	0.003	0.002	<0.001	0.002	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel	mg/L	0.001	0.011	2.0	0.2	1	0.02[a]	<0.001	0.004	0.059	0.005	0.011	0.011	0.057	0.049	0.009	0.031	0.057	0.072	0.05	0.023	0.025	0.012	0.007	0.015	0.008
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	<0.01	0.01	0.02	<0.01	<0.01	0.01	0.02	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Strontium	mg/L	0.001			-	-	-	0.85	2.63	1.01	4.16	4.37	5.67	5.65	5.65	5.3	5.52	10.3	9.36	9.33	5.22	5.53	7.26	7.21	4.17	5.32
Vanadium	mg/L	0.01	-	0.5	0.1	-	-	<0.01	<0.01	<0.01	0.02	0.04	0.04	0.15	0.14	0.02	0.08	0.26	0.26	0.24	0.1	0.11	0.07	0.04	0.06	0.04
Zinc	mg/L	0.005	0.008	2.0	2.0	20	3[b]	0.007	0.007	0.277	0.03	0.073	0.057	0.281	0.258	0.043	0.157	0.354	0.437	0.314	0.112	0.103	0.093	0.05	0.086	0.049
Boron	mg/L	0.05	0.37	Refer to guideline	0.5	5.0	4[a]	0.06	0.08	0.07	0.08	0.07	0.1	0.06	<0.05	0.05	0.05	0.08	<0.05	<0.05	0.11	0.1	0.07	0.06	0.09	0.09
Iron	mg/L	0.05	-	10.0	0.2	-	0.3[b]	6.28	1.44	1.99	8	15.5	16.9	88.3	81	8.13	35.5	173	156	138	73.1	74.4	55.2	31.5	47.3	26.4

Key

#	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.

G1G74C

Groundwater Quality Results

Parameter	Units	LOR#	ANZECC GUIDELINES				NHMRC																				
Sample Location			Fresh Water Aquatic (95th)	Short term irrigation	Long Term irrigation	Stock Water	Drinking Water																				
Bore ID								BC-SP14	BC-SP14	BC-SP21	BC-SP22	BC-SP22	BC-SP22	DAM 17	GA2	GA2	GA2	GNP10 Pool	GNP10D	GNP10S	GNP11 Pool	GNP11D	GNP11S	GNP2 Pool	GNP9D	GNP9S	M49 BORE
Date Sampled								17-05-18	13-04-18	13-04-18	01-09-17	17-05-18	13-04-18	30-08-17	18-08-17	17-05-18	13-04-18	28-06-18	17-05-18	17-05-18	28-06-18	17-05-18	17-05-18	28-06-18	17-05-18	17-05-18	30-08-17
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]	7.44	7.66	7.65	7.8	7.55	7.69	8.4	7.2	7.29	7.47	7.86	7.57	7.41	7.35	7.43	7.23	7.93	10.6	7.52	8.1
Electrical conductivity	µS/cm	1	120 - 300	-		-	-	2500	3550	7820	17800	19000	20700	5510	3220	3210	3580	1720	983	1580	1300	2500	1200	1260	1270	1850	5330
Sodium Absorption Ration (SAR)	-	0.01		-		-	-	9.97	11.2	26.6	43.9	42.3	46.3	26.1	12.4	11.9	12		1.69	3.85		4.48	3.8		6.38	4.52	32.3
Total Dissolved Solids (calc)	mg/L	1.00		-		3000 - 13000*	600[b]	1620	2310	5080	11600.00	12400	13400	3580.00	2090.00	2090	2330		639	1030		1620	780		826	1200	3460.00
Total Hardness as $CaCO_3$	mg/L	1.00		-		-	200[b]	357	400	489	1360.00	1270	1380	323.00	358.00	362	453		323	360		566	296		156	445	253.00
Hydroxide Alkalinity as $CaCO_3$	mg/L	1.00		-		-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	31	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1.00		-		-	-	<1	<1	<1	<1	<1	<1	63.00	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	16	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1.00		-		-	-	375	425	750	964.00	1080	1110	1120.00	308.00	335	346	221	302	247	208	226	224	183	<1	310	1330.00
Total Alkalinity as $CaCO_3$	mg/L	1.00		-		-	-	375	425	750	964.00	1080	1110	1190.00	308.00	335	346	221	302	247	208	226	224	183	47	310	1330.00
Major Ions																											
Sulfate as SO_4 - Turbidimetric	mg/L	1		-		1000 - 2000	500[a] / 250[b]	81	105	352	721	774	800	322	359	343	385	267	36	199	151	113	112	144	156	228	170
Chloride	mg/L	1			40	-	250[b]	634	851	1820	5450	6210	5840	796	668	724	705	308	151	300	226	682	235	232	276	343	787
Fluoride	mg/L	0.1		2.0	1.0	2	1.5[a]	0.6	0.6	1	1.2	1.4	1.6	1	0.4	0.3	0.4		0.2	0.3		0.2	0.2		<0.1	0.4	1.2
Calcium	mg/L	1		-		1000	-	39	48	49	70	67	79	37	66	66	84	79	80	75	58	116	59	59	59	94	37
Magnesium	mg/L	1		-		-	-	63	68	89	288	267	286	56	47	48	59	48	30	42	34	67	36	30	2	51	39
Sodium	mg/L	1		-		-	180[b]	433	517	1350	3720	3460	3950	1080	542	520	589	191	70	168	142	245	150	143	183	219	1180
Potassium	mg/L	1		-		-	-	7	10	5	22	20	24	8	4	4	4	3	2	3	3	4	3	2	8	4	7
Total Anions	meq/L	0.01		-		-	-	27.1	34.7	73.6	188	213	204	52.9	32.5	34.2	34.8	18.7	11	17.5	13.7	26.1	13.4	13.2	12	20.6	52.3
Total Cations	meq/L	0.01		-		-	-	26.1	30.7	68.6	190	176	200	53.6	30.8	30	34.8	16.3	9.56	14.6	11.9	22.1	12.5	11.7	11.3	18.5	56.6
Ionic Balance	%	0.01		-		-	-	1.73	6.03	3.54	0.41	9.39	0.91	0.66	2.58	6.68	0.07	6.83	7.21	9.2	6.75	8.4	3.58	6.09	3.01	5.37	3.9
Nutrients																											
Ammonia as N	mg/L	0.01	0.9	-		-	0.5[b]	0.33	0.51	0.23	0.76	0.32	0.06	0.61	0.04	0.03	<0.01		0.09	0.02		0.03	0.04		0.05	0.02	1.56
Nitrite as N	mg/L	0.01		-		30	3[a]	<0.01	0.05	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
Nitrate as N	mg/L	0.01	0.7	-		-	50[a]	0.02	<0.01	0.05	0.07	0.03	0.16	0.96	0.33	0.15	0.13	0.02	<0.01	0.22	0.02	0.02	0.03	0.01	<0.01	0.04	0.1
Nitrite + Nitrate as N	mg/L	0.01		-		400	-	0.02	0.05	0.06	0.07	0.03	0.16	0.99	0.33	0.15	0.13	0.3	<0.01	0.22	0.3	0.02	0.03	0.2	<0.01	0.04	0.1
Total Kjeldahl Nitrogen as N	mg/L	0.1		-		-	-	1.3	2.5	3	6.3	1.4	2	0.9	0.1	0.2	<0.1	0.3	0.1	0.7	0.3	0.2	2.1	0.2	0.1	0.2	2.3
Total Nitrogen as N	mg/L	0.1		25 - 125	5	-	-	1.3	2.6	3.1	6.4	1.4	2.2	1.9	0.4	0.4	0.1	0.03	0.1	0.9	0.03	0.2	2.1	0.12	0.1	0.2	2.4
Total Phosphorus as P	mg/L	0.01		0.8 - 12	0.05	-	-	0.47	0.96	1.12	0.92	0.7	1.56	<0.01	0.05	0.04	0.02		0.02	0.29		0.03	2.27		0.02	0.14	0.02
Reactive Phosphorus as P	mg/L	0.01		-		-	-	0.01	0.02	0.02	0.13	0.19	0.18	<0.01	0.04	0.01	0.01		<0.01	<0.01		<0.01	<0.01		<0.01	<0.01	<0.01
Total Metals																											
Aluminium	mg/L	0.01	0.055	5		5	0.2[b+]	28.2	47.3	66.4	8.7	17	38.6	0.08	0.58	0.53	0.2	<0.001	0.29	19.3	<0.001	1.07	92.3	<0.001	0.53	2.38	<0.01
Arsenic	mg/L	0.001	As (III) 0.024 As (V) 0.013	2.0	0.1	0.5	0.01[a]	0.009	0.017	0.023	0.005	0.006	0.013	0.002	0.001	<0.001	<0.001		<0.001	0.005		0.004	0.016		<0.001	<0.001	<0.001
Beryllium	mg/L	0.001		0.5	0.1	-	0.06[a]	0.002	0.003	0.003	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001		<0.001	0.004		<0.001	<0.001	<0.001
Barium	mg/L	0.001		-		-	2[a]	0.318	0.378	0.961	0.213	0.258	0.389	0.197	0.048	0.053	0.048	<0.0001	0.351	0.188	<0.0001	0.25	1.18	<0.0001	0.233	0.101	0.159
Cadmium	mg/L	0.0001	0.0002	0.05	0.01	0.01	0.002[a]	<0.0001	0.0002	0.0001	0.0006	<0.0001	0.0006	<0.0001	<0.0001	<0.0001	<0.0001	<0.001	<0.0001	<0.0001	<0.001	<0.0001	0.0002	<0.001	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.001	CrIII – ID Cr(VI) 0.001	1.0	0.1	1.0	0.05[a]	0.025	0.044	0.068	0.01	0.02	0.054	<0.001	<0.001	0.001	<0.001		0.001	0.014		0.002	0.059		0.01	0.004	<0.001
Cobalt	mg/L	0.001		0.10	0.05	1.0	-	0.024	0.036	0.039	0.012	0.012	0.041	<0.001	0.001	0.002	0.001	0.001	<0.001	0.004	<0.001	0.002	0.07	0.003	<0.001	0.004	<0.001
Copper	mg/L	0.001	0.0014	5.0	0.2	0.5 - 5^	2[a] / 1[b]	0.03	0.047	0.041	0.014	0.021	0.063	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	0.009	<0.001	0.002	0.053	<0.001	<0.001	0.002	<0.001
Lead	mg/L	0.001	0.0034	5.0	2.0	0.1	0.01[a]	0.024	0.041	0.038	0.007	0.013	0.042	<0.001	0.002	<0.001	<0.001		<0.001	0.008		0.001	0.066		<0.001	0.002	<0.001
Manganese	mg/L	0.001	1.9	10.0	0.2	-	0.5[a] / 0.1[b]	2.41	2.82	1.66	1.38	0.861	1.48	0.039	0.139	0.087	0.079	<0.0001	0.046	0.128	<0.0001	0.459	7.09	<0.0001	0.019	0.76	0.016
Mercury	mg/L	0.0001	0.0006	0.002	0.002	0.002		<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001		<0.0001	0.0002		<0.0001	<0.0001	<0.0001
Molybdenum	mg/L	0.001	-	0.05	0.01	0.15	0.05[a]	<0.001	<0.001	0.002	0.002	0.002	0.001	0.006	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	<0.001	<0.001	0.004	0.002	<0.001
Nickel	mg/L	0.001	0.011	2.0	0.2	1	0.02[a]	0.023	0.039	0.035	0.011	0.017	0.04	0.001	<0.001	<0.001	<0.001		0.001	0.007		0.004	0.067		0.002	0.005	<0.001
Selenium	mg/L	0.01	Total – 0.011 SeIIV - ID	0.05	0.02	0.02	0.01[a]	<0.01	<0.01	<0.01	<0.01	<0.01	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			-	-	-	2.01	1.88	2.22	6.87	5.68	5.92	3.63	1.24	1.3	1.3		1.12	0.863		2.42	1.03		1.29	1.03	3.01
Vanadium	mg/L	0.01	-	0.5	0.1	-	-	0.06	0.12	0.13	0.03	0.06	0.15	<0.01	<0.01	<0.01	<0.01	<0.005	<0.01	0.03	<0.005	<0.01	0.17	0.02	<0.01	<0.01	<0.01
Zinc	mg/L	0.005	0.008	2.0	2.0	20	3[b]	0.33	0.55	0.37	0.096	0.078	0.217	<0.005	0.009	0.005	<0.005		0.022	0.086		0.119	0.55		0.021	0.204	<0.005
Boron	mg/L	0.05	0.37	Refer to guideline	0.5	5.0	4[a]	0.09	0.09	0.08	0.08	0.05	0.05	0.17	<0.05	<0.05	<0.05		<0.05	0.06		<0.05	0.05		<0.05	0.06	0.15
Iron	mg/L	0.05	-	10.0	0.2	-	0.3[b]	36.6	66	78.8	14.3	25.1	68.7	0.1	0.88	1.05	0.5		0.61	18.7		1.52	104		0.64	4.57	<0.05

Key

#	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.

5.9 Groundwater use

5.9.1 Private water users

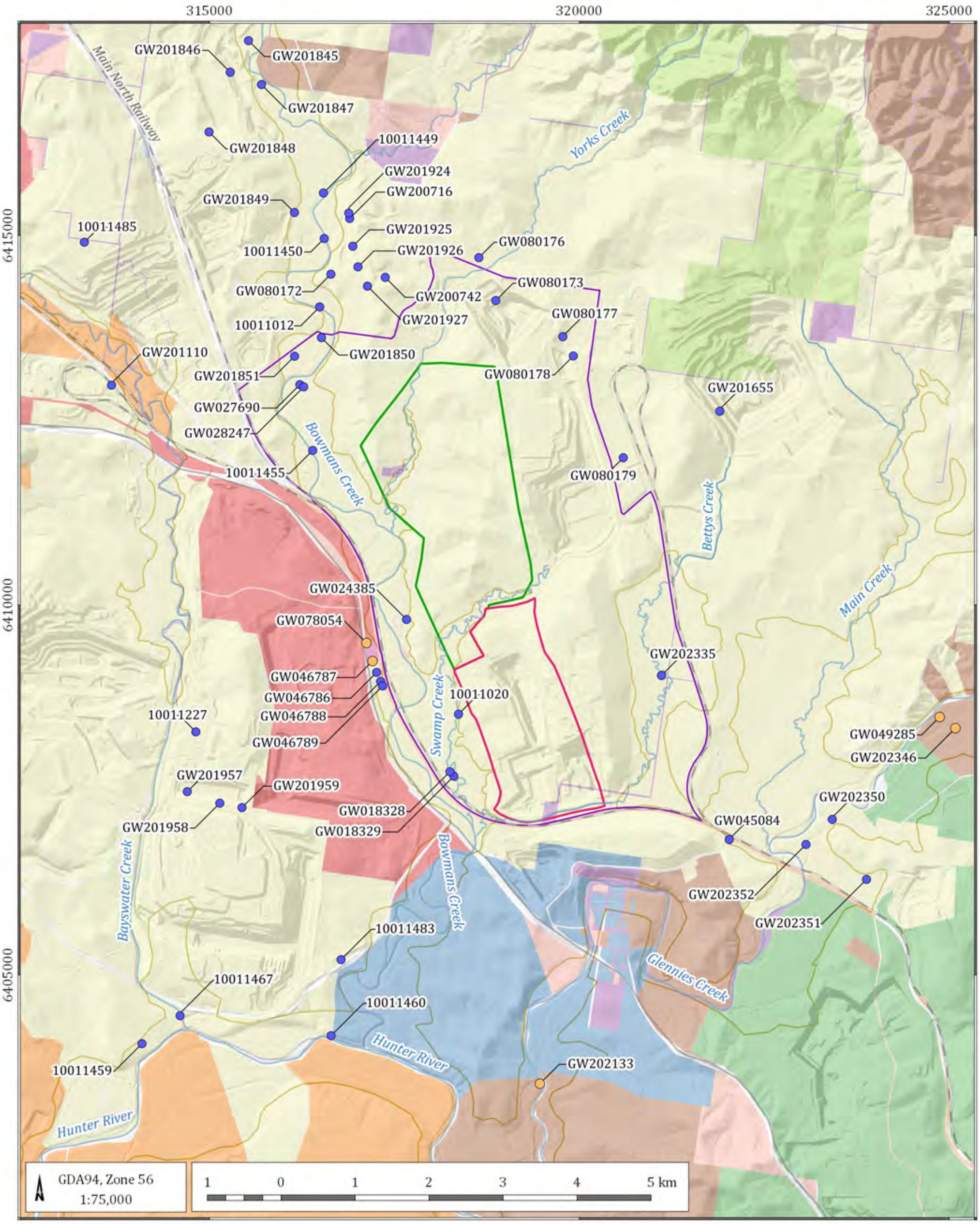
A search of the NSW State government groundwater bore database was conducted to identify the locations of any water supply bores in proximity to the Project. Figure 5-25 shows the locations of bores within the database and land parcels that are non mine-owned. The figure shows there are two bores from the database that are located on private property along Bowmans Creek which is part of the Jerrys Water Source. Both bores are on land which is managed by Daracon. This land is not presently used for agricultural or residential purposes.

The remainder of the private bores recorded in the NSW State government groundwater bore database are relatively distant from the Glendell Pit Extension, or 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 two registered bores located on private land in proximity to the Project.

Table 5-4 Registered bores on private lands

Registered number	Authorised/intended purpose	Date	Depth (m)	Casing type	Casing outside dia (mm)	Standing water level (m)	Yield (L/sec)
GW0788054	Stock and domestic	unknown	16.2	steel	168	6.9	1.12
GW046787	Domestic	unknown	6.2	well	1200	-	-

As can be seen from Table 5-4, the yield recorded for GW0788054 indicates that it is located on a less productive groundwater source.



LEGEND

- Road
- Rail
- Drainage
- Alluvium boundary
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Registered bores

- Bores on Glencore owned land
- Bores on Private land

Land Ownership

- AGL Macquarie
- Ashton Coal
- Bloomfield Collieries
- Crown Land
- Daracon Mining
- Energy Australia
- Glencore
- Government Authority
- HVO
- Private
- State Forest
- Telstra
- Unknown

Glendell Continued Operations GIA (G1874C)

Registered Groundwater Bores

AGE

DATE 21/11/2019

FIGURE No: **5-25**

Source: ELVIS LiDAR DEM (accessed April 2019); 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;
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5.9.2 Groundwater dependent ecosystems

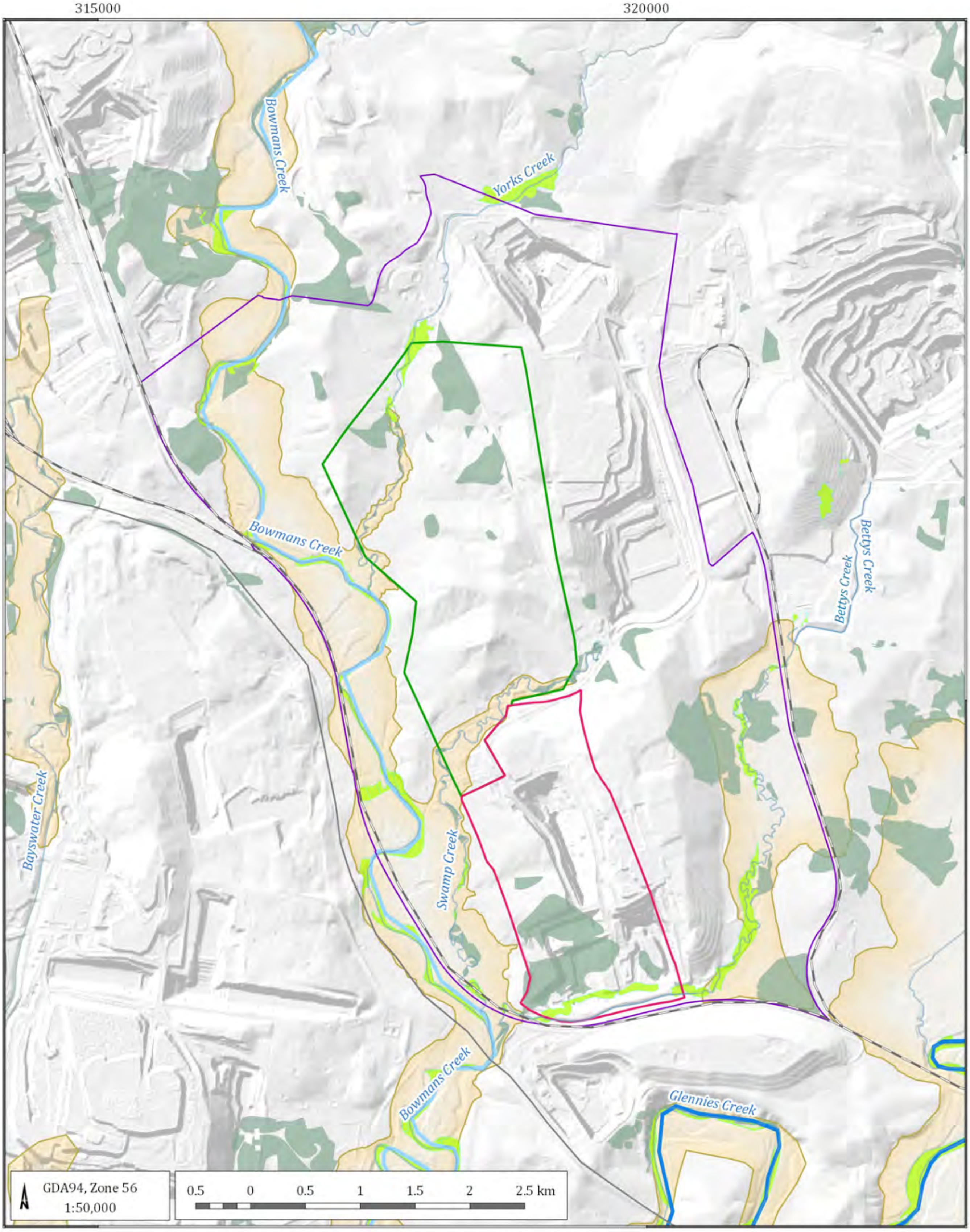
Macfarlane et al (2016) provides a register of water-dependent assets in the Hunter subregion prepared as a component of the Commonwealth Governments Bioregional Assessments Process. Water dependent assets are classified into three subgroups and seven classes. All landscape features such as aquifers, 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 located some 7 km from the Glendell Pit Extension is an alluvial aquifer asset, but the alluvial groundwater systems along Bowmans Creek, Glennies Creek, Main Creek and Bettys Creek are not noted as alluvial aquifer assets.

The register indicates riverine forests on flood plains associated with Bowmans Creek and Glennies Creek form potential GDEs. The Hunter Unregulated WSP does not indicate the presence of any high priority GDEs along Glennies Creek and Bowmans Creek.

A review of the Bureau of Meteorology Groundwater Dependent Ecosystems Atlas (GDE Atlas) shown on Figure 5-26 shows potential for aquatic and terrestrial GDEs to be present in the Project region. The GDE Atlas was developed as a national dataset of Australian GDEs to inform groundwater planning and management. The register indicates there are areas of low and high potential terrestrial GDE interaction along Yorks Creek, Bettys Creek, Swamp Creek and Bowmans Creek. There is moderate potential aquatic GDE along Bowmans Creek. The GDE Atlas indicates the presence of a high and low potential terrestrial GDE occurring along Bettys Creek within the existing Glendell Pit. Vegetation has been cleared from this area when Bettys Creek was diverted around the Glendell Pit, and therefore there is no GDE present in this area (refer Figure 3-3).

Much of the 'low potential GDE' mapped in Figure 5-26 aligns with remnant terrestrial vegetation occurring on Permian regolith outside the alluvial flood plains. Given the deeper water table outside the floodplain it is expected these vegetation communities would be unlikely to rely on deep groundwater (refer Umwelt 2019).

More detailed investigations were undertaken to identify the potential for groundwater dependent ecosystems and stygofauna to occur in the Project Area and surrounds. The reader should refer to the EIS (Umwelt 2019b), Assessment of Commonwealth Matters Report (Umwelt 2019), BDAR (Umwelt 2019a) and the Stygofauna Assessment (Eco Logical 2019) for more information.



LEGEND

- Road
- Rail
- Drainage
- Alluvium boundary
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

GDE Atlas - Aquatic

- High potential GDE
- Moderate potential GDE

GDE Atlas - Terrestrial

- High potential GDE
- Low potential GDE

Glendell Continued Operations GIA (G1874C)

Potential groundwater dependent ecosystems

AGE

DATE 21/11/2019

FIGURE No: **5-26**

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.; GDEs from BoM.;
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5.10 Conceptual model

5.10.1 Existing groundwater regime

This section summarises the processes that control and influence the storage and movement of groundwater in the hydrogeological systems occurring in the Glendell Pit Extension and the broader region. It is based on geological and hydrogeological data presented in the preceding sections.

The Quaternary alluvium along Bowmans Creek forms a thin aquifer system in the Project Area and adjacent to the Glendell Pit Extension. The Bowmans Creek alluvium is commonly less than 10 m in thickness with the most permeable part of the sequence being the deeper 'bed load' sand and gavels that readily transmit groundwater through the alluvium. Geological maps show alluvial sediments occur along the tributaries of Bowmans Creek, Bettys Creek, Swamp Creek and Yorks Creek. Field investigations have confirmed the alluvium occurring along these tributaries is thin, clayey and contains saline groundwater, meaning these tributaries do not form aquifers.

The Permian coal measures form less productive groundwater systems, when compared to the Bowmans Creek alluvium, with the coal seams being the most permeable lithology within the Permian sequences. The Project is situated along the hinge of an anticline structure with the sequence of coal seams dipping from the hinge axis towards the east and west where adjacent mining operations extract coal via open cut and underground methods. The Permian strata does not form a highly productive aquifer because of generally poor water quality and low yields that preclude any beneficial use.

The Bowmans Creek alluvium is the only geological strata in the region that has the potential to sometimes meet the NSW government criteria to be classified as a "highly productive" groundwater source, which requires TDS concentrations less than 1,500 mg/L and contain water supply works that can yield water at a rate greater than 5 L/s. All other formations are classified as 'less productive' including the areas of alluvial sediments occurring along Yorks Creek and Swamp Creek. All areas of alluvium proposed to be removed by mining are considered to be 'less productive'.

Permian sediments outcrop in the Project Area and are recharged via rainfall infiltrating through the soil cover and weathered Permian profile. Groundwater flows from areas of high head (pressure plus elevation) to low head via the most permeable and transmissive pathways. The groundwater flow path and discharge zone for the Permian groundwater system is influenced by the land use activities in the region. In the absence of mining activities, the main discharge mechanism for groundwater within the Permian strata is through slow upward flow to Quaternary alluvium deposited along creeks, particularly Bowmans Creek. Groundwater monitoring from the Project Area and surrounds shows that approved mining activities have depressurised the Permian groundwater systems and reduced the pressure within coal seams to the point where groundwater levels exist below the base of the Quaternary alluvium. This means the main discharge zone for groundwater within the Permian interburden and coal seams has changed from the alluvial aquifer to the surrounding mining operations, either closed or operating.

The alluvial sediments along Bowmans Creek are also recharged by rainfall, as well as by seepage of surface water through the bed of creeks, when they are flowing, where the stream bed sediments and the underlying groundwater levels promote this interconnectivity. The salinity of the groundwater within the Bowmans Creek alluvium varies from fresh to slightly brackish indicating relatively high recharge rates. The flow path within the Bowmans Creek alluvium is a reflection of the topography, with groundwater flowing 'downstream' in a south-westerly direction towards the Hunter River. Unlike the Permian strata, drawdown within the Bowmans Creek alluvium is not readily evident within available monitoring datasets. The fact that the Bowmans Creek alluvial aquifer shows no notable drawdown in response to the observed Permian depressurisation from open cut and underground mining indicates the volume of groundwater moving downwards to the Permian is limited and less than recharge rates from rainfall and streamflow that serve to buffer any losses.

The former Liddell underground mine is situated immediately to the north of the proposed Glendell Pit Extension and underlies the Bowmans Creek and Yorks Creek alluvium. Whilst the Permian Middle Liddell seam remains depressurised within this mine, the lack of detectable impact on groundwater levels within the overlying alluvium indicates the relatively low vertical permeability of the Permian strata and the lack of significant fracturing induced by the largely bord and pillar mining operation.

Bowmans Creek meanders through the flood plain and forms a window to the underlying alluvial aquifer. In dry periods the baseflow in Bowmans Creek is low and the creek reduces to a series of disconnected ponds which are a reflection of the underling interconnected water table. Bowmans Creek is therefore expected to form both a recharge and discharge zone for alluvial groundwater depending on prevailing climate conditions and location within the flood plain. The main water dependent assets are aquatic ecosystems within Bowmans Creek and riparian vegetation communities that potentially depend on shallow groundwater where the water table is shallow adjacent to the creek. Two private bores have also been identified adjacent to Bowmans Creek and the Glendell Pit Extension, and may to be used for industrial purposes, if not already decommissioned.

The main causal pathway for potential impacts from mining on the water dependent assets is depressurisation of the Permian strata resulting in drawdown within the Bowmans Creek alluvium. Climatic conditions also have the potential to impact upon water dependent assets. Baseline groundwater monitoring has shown to date that whilst the Permian strata depressurises in response to mining this does not necessary result in a detectable impact within the adjacent alluvial water source and at the water dependent assets. The outcome aligns with observations from the existing Glendell Pit, that despite being located adjacent to the Bowmans Creek alluvium, does not record significant groundwater inflows, with little sump pumping required during operations. Monitoring of the pools along Bowmans Creek indicates that variability in climatic conditions can have a significant impact on water dependent assets in the Project Area.

A block fault zone has been identified as crossing the Glendell Pit Extension. Whilst the potential to transmit groundwater through the fault 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. Observations of the block fault zone exposed within approved open cut mining areas do not suggest it is a source of significant groundwater ingress. An alternative conceptualisation is the block fault zone allows enhanced transmission of groundwater. Middlemis and Peeters (2018) indicate sources of uncertainty affecting groundwater models can be grouped as follows:

- structural/conceptual – geological structure and hydrogeological conceptualisation assumptions applied to derive a simplified view of a complex hydrogeological reality (any system aspect that cannot be changed in an automated way in a model);
- parameterisation – hydrogeological property values and assumptions applied to represent complex reality in space and time (any system aspect that can be changed in an automated way in a model via parameterisation);
- measurement error – combination of uncertainties associated with the measurement of complex system states (heads, discharges), parameters and variability (3D spatial and temporal) with those induced by upscaling or downscaling (site-specific data, climate data); and
- scenario uncertainties – guessing future stresses, dynamics and boundary condition changes (e.g. mining, climate variability, land and water use change).

Conceptual models always have some uncertainty regarding geology and structure as this cannot be seen but only inferred through drilling and modelling. The Project is unique in that the significant history of mining in the area means the geology has been investigated for a long period of time, and also is visually evident in the open cut mining areas. Exploration drilling within the Project Area has been undertaken at a 500 to 600 m spacing. For this reason, it is considered the surfaces for the key hydrostratigraphic units have a relatively low level of residual uncertainty compared to less developed or greenfield areas.

There is also residual uncertainty remaining around the behaviour of faults particularly the block fault zone that geological models indicate passes through the Glendell Pit Extension. Investigating the hydrogeological properties of faults through field investigations is challenging and therefore the influence of this uncertainty is investigated through numerical modelling.

Hydrogeological parameters (hydraulic conductivity and storage) assigned to the key geological units also have some residual uncertainty, however, due to the significant mining development within the Project region there is significant testing data, and previous numerical modelling efforts available to define appropriate ranges for hydrogeological parameters. Direct observations in mining areas coupled with observations of how the groundwater systems respond to the stresses induced by mining provide observations and data than can be used to identify ranges for hydraulic parameters.

Measurement error is inherent in all hydrogeological datasets. A key dataset utilised for the study is groundwater level measurements. Where groundwater monitoring bores are appropriately constructed and sealed within the target aquifer, the elevation of bore is accurately surveyed and water level measurement is via modern electronic water level meters it is considered the measurement error is relatively low, potentially less than 0.1 m. This is considered the case with the bulk of the available network which has been specifically constructed for groundwater monitoring. There is also an extended period of baseline monitoring available since 2012 which also enables the verification of results by comparison between different bores.

VWPs are also utilised in deeper coal seams to indicate depressurisation of coal measures. The groundwater elevations provided by the VWPs are potentially less certain than the stand pipe monitoring bores as they are grouted into boreholes and cannot be validated, or instrument drift detected. Despite these limitations the VWPs are considered an extremely valuable tool for developing conceptual models, when the limitations of the data provided is acknowledged. A nominal accuracy range of ± 10 m is considered appropriate to apply to VWPs.

Error in the measurement of groundwater inflow to mining areas is also considered significant. Groundwater entering open cut mining areas is commonly difficult to separate from sources of surface water runoff that all reports to the same sumps in the mining areas. Groundwater is also readily evaporated from mine faces or remains bound by capillary action to spoil and coal materials and therefore particularly where inflows are low, never flows to sumps for pumping where its volume can be measured. These inherent challenges in measuring groundwater inflow to mining areas means there is always some residual uncertainty associated with measurements of groundwater inflow to mining areas. This uncertainty cannot be practically reduced in many cases. Despite this inherent uncertainty observations from the existing Glendell Pit and Mount Owen mine show very limited 'free flowing' inflows, with little water reporting to pit sumps, and most evaporating directly from the pit face or adhering to lower strata material. These observations provide guidance on likely outcomes for the Glendell Pit Extension given it is proposed in the same geological and hydrogeological setting.

6 Numerical groundwater model

6.1 Previous model

Rust PPK conducted the first groundwater investigation at Glendell Mine in 1996 as part of the Statement of Environmental Effects for a modification to the Glendell Consent. The groundwater study included drilling, permeability testing (slug tests, pumping and injection tests and packer tests), groundwater monitoring and numerical groundwater modelling to simulate the groundwater flow and to estimate rates of seepage. The numerical groundwater model was used to simulate pit inflows and depressurisation over the 20-year mine development. The pit footprint assessed using the model was slightly larger proposing to mine more of Swamp Creek than ultimately approved. The modelling included two simulation scenarios; 1) pit seepage with leakage from the overlying alluvium and 2) pit seepage without leakage from the overlying alluvium. The model results included a prediction of net change in the alluvium leakage balance and potential drawdown impacts to local bores. It was noted that potential drawdown impacts were dependent on the recharge rates applied to the alluvium.

Modelled estimates of pit seepage into the Glendell Pit with no alluvium seepage to the mining area were approximately 1.3 ML/day, while modelled pit seepage which included leakage from the alluvium ranged from zero to 6 ML/day after 20 years of mining. Operational experience has indicated the seepage rates predicted by the modelling were conservative with actual inflow, whilst difficult to measure, expected to be less than 1 ML/day. The modelling indicated the coal seams would be depressurised to a distance in excess of one kilometre in all lateral directions. Leakage from the alluvium was determined to be limited to within 500 m of the pit workings, with the alluvium providing recharge to the underlying strata. Whilst provided by a relatively simplistic model, monitoring has shown these historical predictions were reasonable.

Because Glendell is surrounded by numerous other mining operations there have been more recent groundwater models developed to assess the impacts of adjacent operations that also cover Glendell to represent cumulative impacts. The most recent is the model developed to assess the impact of Mount Owen Continued Operations Project Modification 2 (AGE, 2018). The model covers the land where the Glendell Pit Extension is proposed, and represents the operating Glendell Mine and other mines including approved operations at Mount Owen, Integra Underground, Rix's Creek South/Rix's Creek North, Ravensworth East, Ravensworth Operations, Liddell Coal Operations, Ashton Open Cut/Underground, and Hunter Valley Operations (HVO) North Mine. Although the model does not simulate the Glendell Pit Extension, the predicted cumulative impacts cover the surrounding mine area and provide an indication of impacts from approved mining.

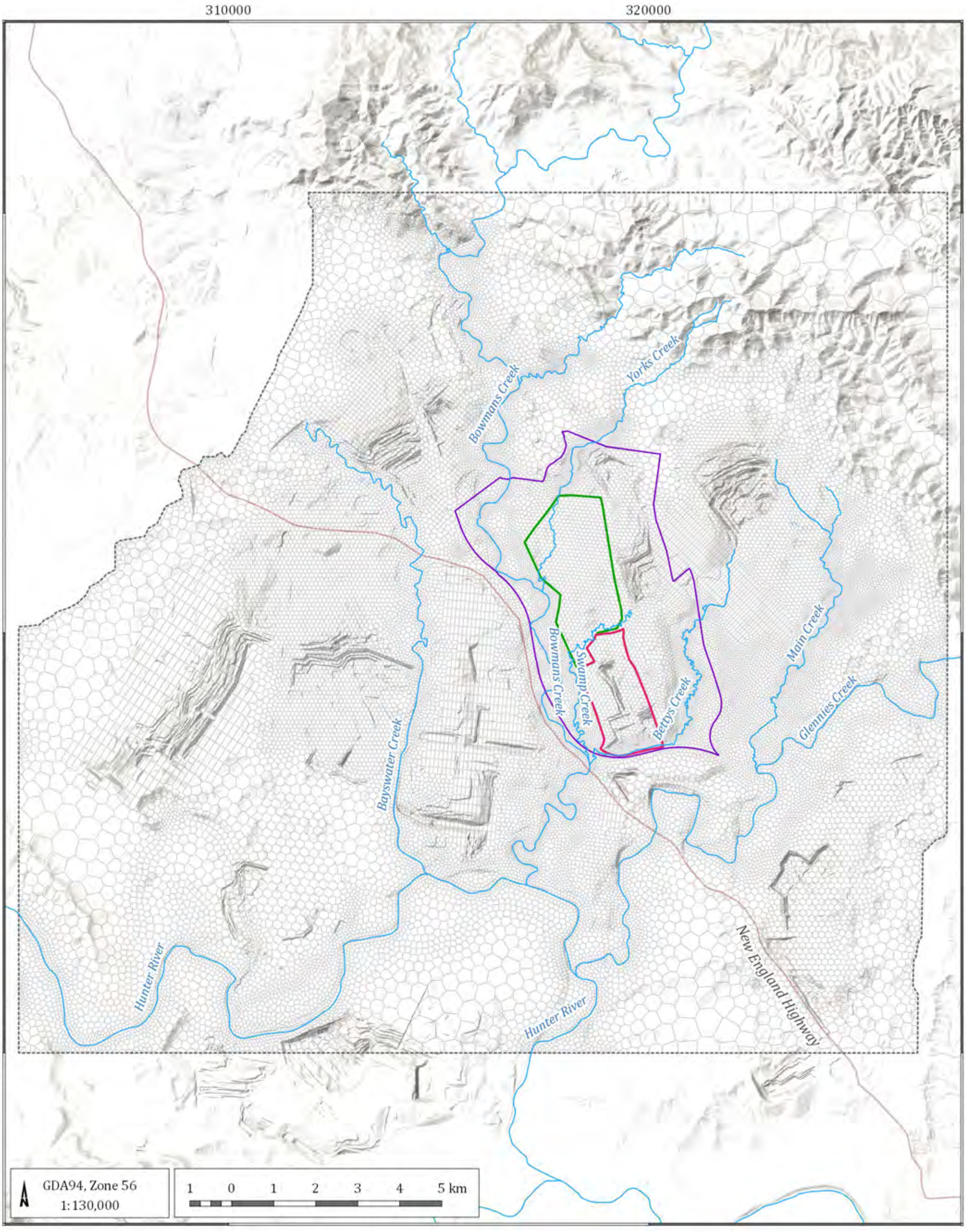
The Mount Owen Continued Operations Project Modification 2 model indicated a maximum of 0.5 m of drawdown within the Swamp Creek alluvium and around 0.2 m in the centre of the drainage due to cumulative impacts at closure of the Mount Owen Mine. Drawdown within Bowmans Creek alluvium generated by the cumulative impact of mining was estimated to be around 0.2 m. The limited drawdown predicted by the numerical model generally aligns with the lack of observed drawdown within alluvial groundwater systems surrounding Glendell Mine.

6.2 Overview of groundwater modelling

A 3D numerical groundwater flow model was developed for the Project using MODFLOW-USG. A detailed description of the modelling logic is provided in Appendix B. The model represents the key geological units as 21 layers extending approximately 22 km wide (west to east direction) and 20.5 km long (north to south direction). It comprises up to 51,132 cells per layer, making it spatially a large model (Figure 6-1).

The prevalence 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 first developed by Mackie Environmental Research (MER), then updated by Jacobs as described in Jacobs (2014), and finally updated by AGE for modifications at Integra Underground and Mount Owen North Pit (AGE 2017, 2018). This approach was undertaken to, as far as possible, 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 Glendell Pit Extension and the surrounding region. The model was updated as follows:

- development of new MODFLOW USG model mesh and layers;
- updating water level monitoring dataset;
- adjusting coal seam levels based on updated geological models;
- updating the thickness and extent of the Quaternary alluvium based on further field investigations described in Appendix A;
- recalibrating model to water level records and mine inflows;
- inclusion of heterogeneity of aquifer and recharge parameters using pilot points;
- using a parent/surrogate approach to calibrate the model;
- updating progression of approved and proposed mining; and
- predicting impacts on groundwater regime for the Project.



LEGEND

- Road
- Drainage
- Model boundary
- Model mesh
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Glendell Continued Operations GIA (G1874C)

Model extent

AGE

DATE 21/11/2019

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\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\06.01_G1874C_Model extent.qgs

Appendix B describes the evolution of the regional model over time and the changes made to quantify the impact of the Project. The model was used to identify the influence of the Project on the groundwater regime by comparing the impacts generated by the approved and proposed mine plans. Current approved and proposed (i.e. those for which an EIS has been submitted for assessment but not yet approved) mine plans within the region 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 B.

The model was calibrated using available groundwater level measurements from bores within the model domain that were considered reliable. As noted previously there is no measured groundwater inflow to the existing Glendell Pit as the low seepage is not pumpable and is readily removed by evaporation or bound to mined materials. Therefore, the volume of groundwater pumped from Integra Underground that has been recorded with a flow meter was used to guide the calibration of the model to mine inflows. A detailed description of the calibration procedure is provided in Appendix B. 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 4.7% 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). More importantly the model was able to replicate the observed depressurisation of the Permian occurring under the Bowmans Creek alluvium, whilst maintaining saturation within the alluvial aquifer.

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 Project, in accordance with the proposed mine plans. The influence of the Project on the groundwater regime was estimated by comparing the impacts predicted by the numerical model for the approved and proposed mine plans. Three model scenarios were run, and their results compared as follows:

1. No Glendell – this scenario included approved and foreseeable operations within the region, but no approved or proposed mining at Glendell Mine;
2. Approved – included the currently Approved Operations at Glendell Mine and approved and foreseeable operations within the region; and
3. Approved + Project – included approved and foreseeable operations as well as the proposed continuation of Glendell Mine.

Scenario 3 when examined provides an indication of the cumulative impacts from all approved and proposed mining in the model domain. The influence of the Project on the groundwater regime was determined by comparing the difference between the above model scenario 1 and scenario 2.

Commencement of mining at Glendell coincided with the commencement of the Hunter Unregulated WSP in 2009. The purpose of the Scenario 1 was to allow the volume of water taken from each water source and the drawdown since the WSP commenced to be estimated. This was achieved by comparing the water level predictions between Scenario 1 and Scenario 3.

The groundwater inflow from the North Coast Fractured and Porous Rock WSP to the Glendell Pit Extension was not calculated relative to the start of the WSP in 2016, and therefore represents a total water take, including previously approved mining impacts. This is likely to overstate the volume of licensable take from the North Coast Fractured and Porous Rock WSP due to the Project.

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 had the most influence on model predictions. The model parameters were adjusted to encompass the expected range of uncertainty. Appendix B 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 undertaken 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/uncertainty.

The peer review report prepared by HydroAlgorithmics is included within Appendix F.

7 Model predictions and impact assessment

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

- groundwater directly intercepted by mining from the Permian coal measures (Section 7.2);
- drawdown in groundwater levels in the Quaternary alluvium and Permian coal measures (Section7.2.2);
- change in alluvial and baseflow availability (Section 7.2.4);
- impact on private bores (Section 7.2.5);
- drawdown impact to potential GDEs (Section 7.2.6);
- cumulative impacts (Section 7.2.8); and
- post closure impacts (Section 7.3).

7.1 Impact of blasting on aquifer properties

Enviro Strata Consulting Pty Ltd (ESC 2019) assessed the potential for blasting to impact on the integrity of rock strata between Bowmans Creek and the Glendell Pit Extension. The assessment included a review of geological logs in the Project Area and rock strength testing data. The review indicated the Glendell Pit Extension is characterised by moderately strong to strong rock types with majority being above 30 MPa, which is a typical concrete strength value. The review indicated cracks are not readily transmitted through strong strata with a strength over 30 MPa and concluded the strata are resistant to fracturing induced by the adjacent open cut blasting. It is anticipated that increased permeability is limited to less than 30 m from the external blast face.

7.2 Operation stage groundwater predictions

7.2.1 Groundwater directly intercepted by mining

Figure 7-1 and Table 7-1 show the total inflow of groundwater to the drain cells within the model which represents the water intercepted from the Permian coal measures within the actively mined area of the Project. The table and figure show the volume of groundwater intercepted by the Approved Operations and the Project combined, and the proportion attributable to the mining within the extended footprint associated with the Project only.

For reference, the groundwater model simulates initial Project ground disturbance in 2020, with the first production of coal from the Barrett seam in 2021 (Year 1). Figure 7-1 shows the influence of the Project changes over the life of the Project with the volume of groundwater intercepted by mining increasing over time as the footprint of the Project increases and advances away from the Approved Operations.

The volume of groundwater intercepted from the Permian coal measures due to the combined effect of the Approved Operations and Project peaks in Year 17 at 249 ML. Section 7.2.8 provides information on water licences required to account for groundwater intercepted by the Approved Operations and the Project. Permian groundwater inflows for the Mount Owen Complex (Glendell, Ravensworth East and Mount Owen) reaches a peak of 552 ML in Year 12.

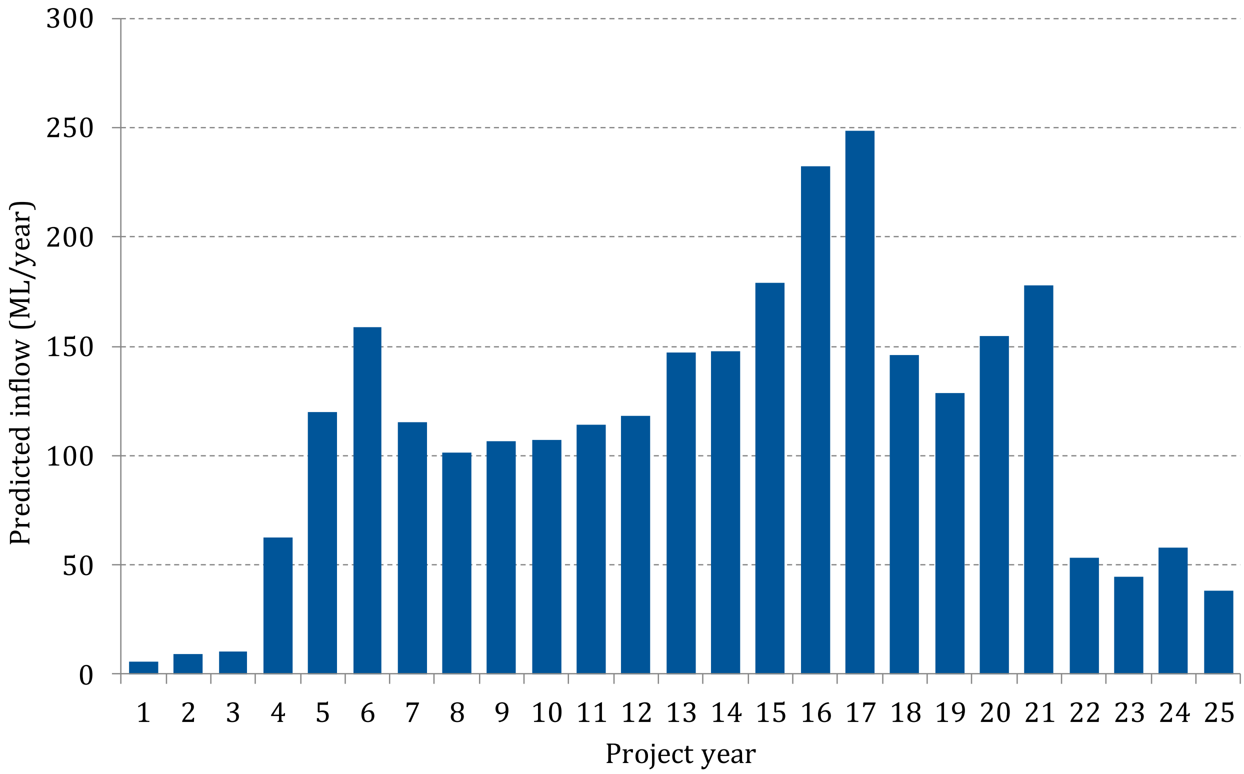


Figure 7-1 Groundwater intercepted from Permian coal measures

Table 7-1 Groundwater intercepted from Permian coal measures

Project Year	Predicted inflow (ML/year)				
	Approved Operations & Project	Project only	Ravensworth East	Mount Owen	Total Mount Owen Complex
1	70	6	125	217	412
2	56	9	55	326	437
3	39	10	29	312	380
4	91	62	0	296	387
5	120	120	0	361	481
6	159	159	0	295	454
7	115	115	0	216	331
8	101	101	0	116	217
9	107	107	0	101	208
10	107	107	0	135	242
11	114	114	0	134	248
12	118	118	0	434	552
13	147	147	0	362	509
14	147	147	0	285	432

Project Year	Predicted inflow (ML/year)				
	Approved Operations & Project	Project only	Ravensworth East	Mount Owen	Total Mount Owen Complex
15	179	179	0	177	356
16	232	232	0	80	312
17	249	249	0	31	280
18	146	146	0	26	172
19	129	129	0	0	129
20	154	154	0	0	154
21	178	178	0	0	178
22	53	53	0	0	53
23	45	45	0	0	45
24	58	58	0	0	58
25	38	38	0	0	38

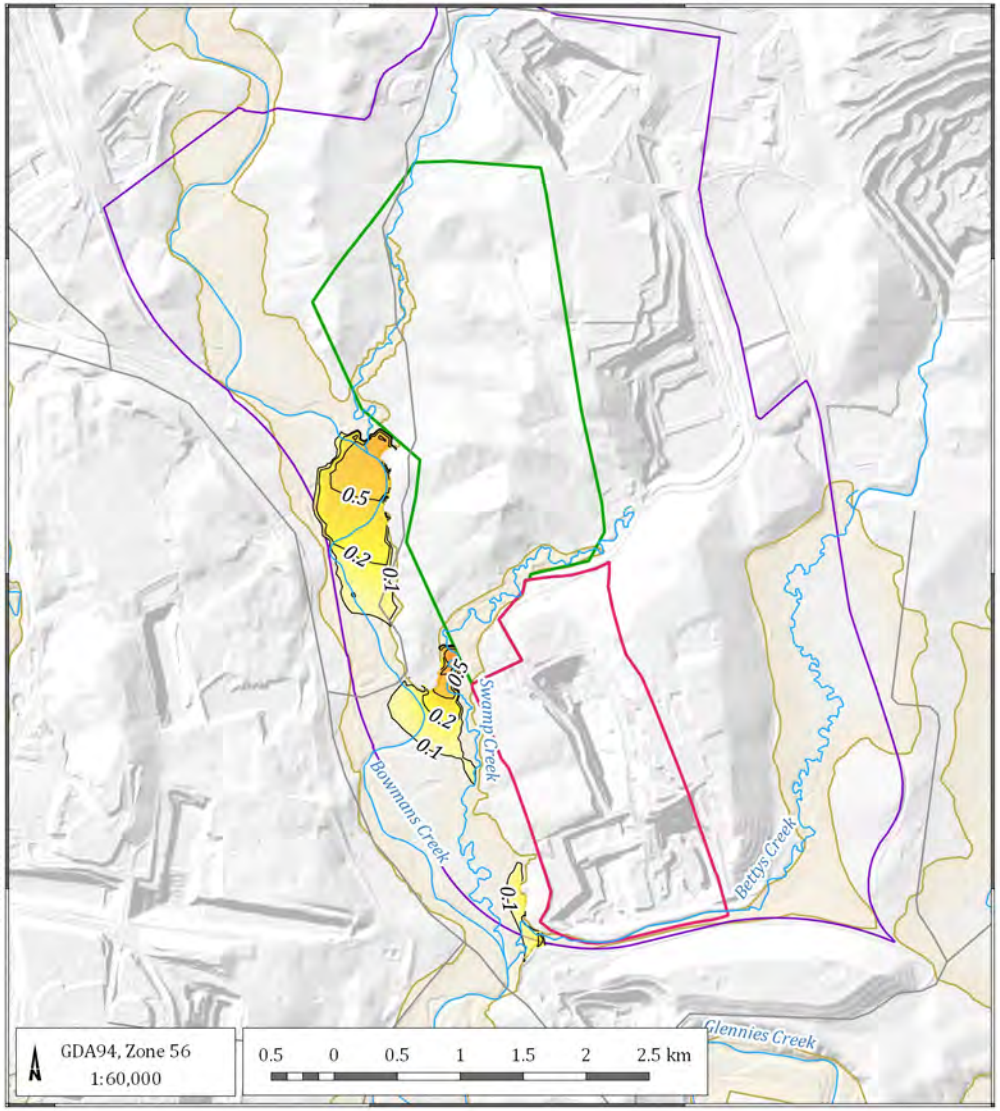
7.2.2 Drawdown and depressurisation during mining operations

Figure 7-2 shows the maximum drawdown predicted by the numerical model to occur within the Quaternary alluvium during the life of the Project. Two windows are included within the figure. The first window shows the predicted drawdown from the Approved Operations plus the additional drawdown generated by the Project. The second window shows the amount of drawdown contributed by the Project only (i.e. the Glendell Pit Extension results less the Approved Operations impact predictions). The drawdown within the Quaternary alluvium is calculated from the commencement of the Hunter Unregulated WSP in 2009.

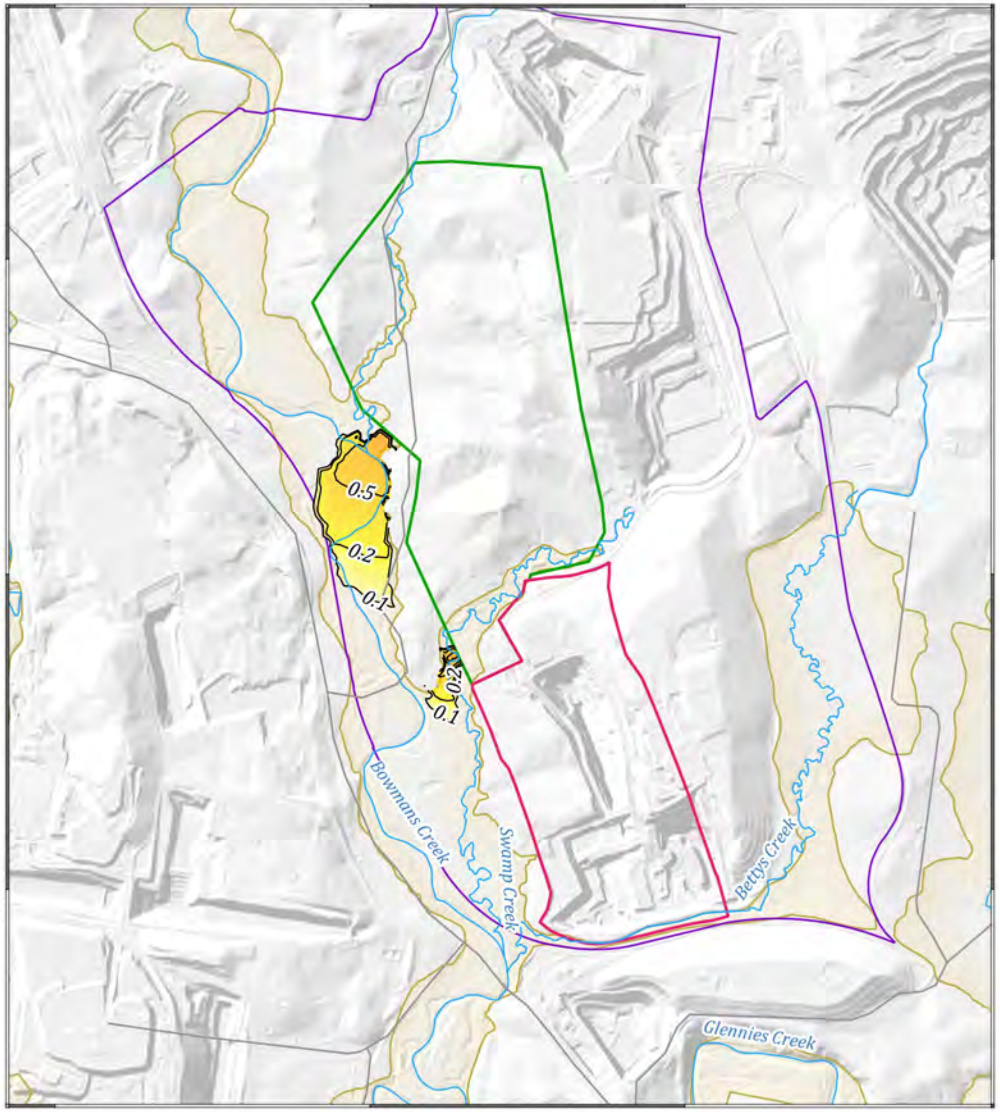
Figure 7-3 shows how the saturated thickness of the Bowmans Creek alluvial aquifer changes over the Project life due to cumulative impacts of approved mining, including the Project (i.e. Approved + Project modelling scenario). Figure 7-4 shows the level of saturation in the alluvium for the 'No Glendell' model scenario at various stages of the Project life to identify the relative contribution of the Approved Operations and Project to any predicted changes in saturation.

Figure 7-5 shows the maximum drawdown predicted to occur within the Middle Liddell seam during the life of the Project. The Middle Liddell seam was chosen as it is intercepted at all mining operations surrounding the Glendell Pit Extension. Two windows are included within the figure. The first window shows the predicted drawdown from the Approved Operations plus the additional drawdown generated by the Project. The second window shows the amount of drawdown contributed by the Project only (i.e. the Glendell Pit Extension results less the Approved Operations impact predictions).

Approved Operations and Project



Project only



LEGEND

- Drainage
- Road
- Alluvium boundary
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Drawdown (m)

- 0
- 0.1
- 0.2
- 0.5
- 1
- 2
- Drawdown contour

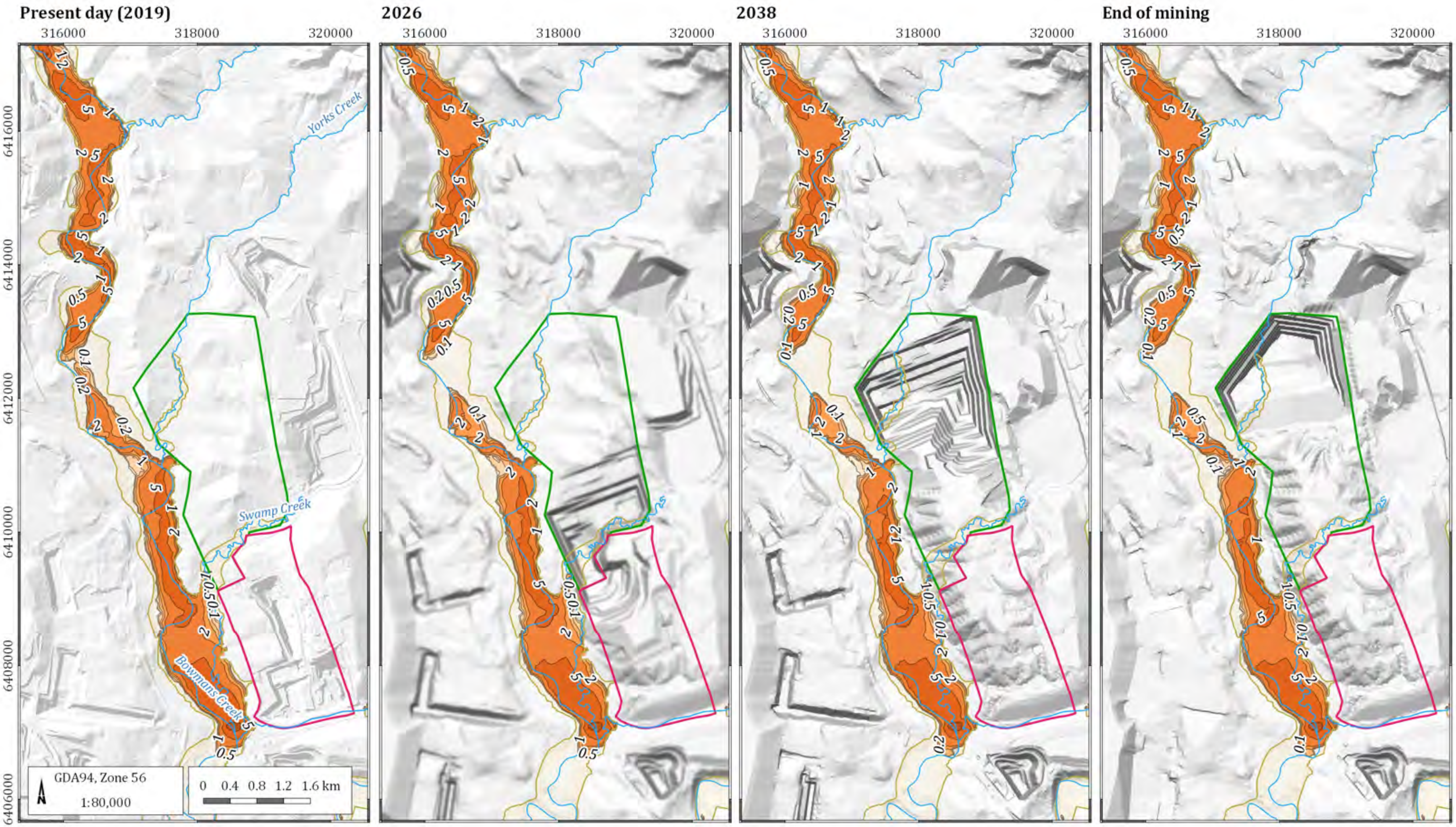
Glendell Continued Operations GIA (G1874C)

Maximum zone of drawdown during operations due to Project – Quaternary alluvium

DATE
21/11/2019

FIGURE No:
7-2

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\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\07.02_G1874C_Maximum zone of drawdown due to project - Qa.qgs



LEGEND

- Drainage
- Alluvium boundary
- Approved Glendell Pit
- Glendell Pit Extension

Saturated thickenss (m)

- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- 20 - 25
- Thickness contour

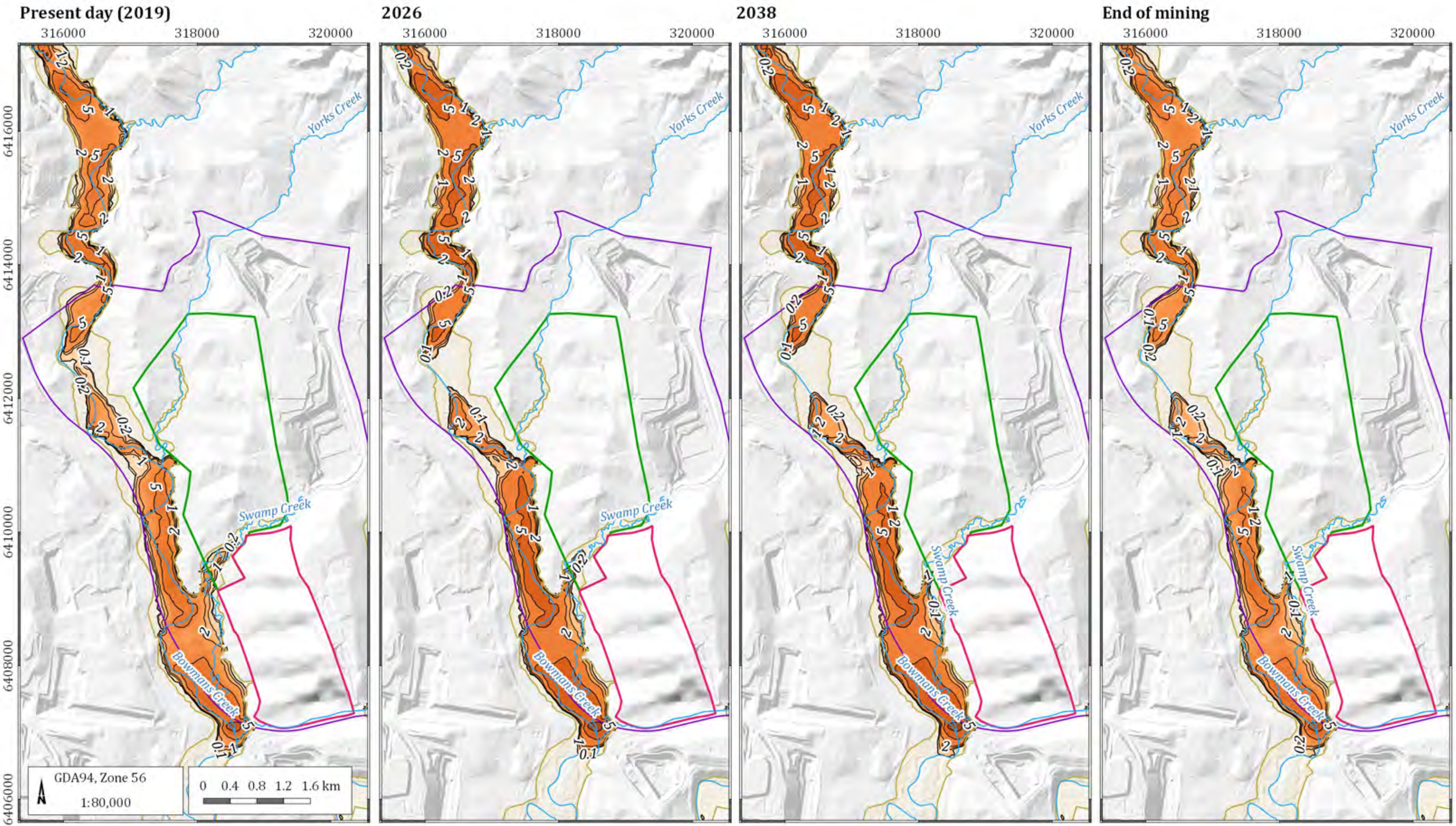
Glendell Continued Operations GIA (G1874C)

Saturated thickness of Quaternary alluvium over time - Cumulative Impacts (Approved + Project Scenario)

DATE
28/11/2019

FIGURE No:
7-3

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.; 2026 & 2036 landform data from client;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\07.03_G1874C_Saturated thickness during mining.qgs



LEGEND

- Drainage
- Alluvium boundary
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Saturated thickenss (m)

- 0.1 - 0.2
- 0.2 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- Thickness contour

AGE

Glendell Continued Operations GIA (G1874C)

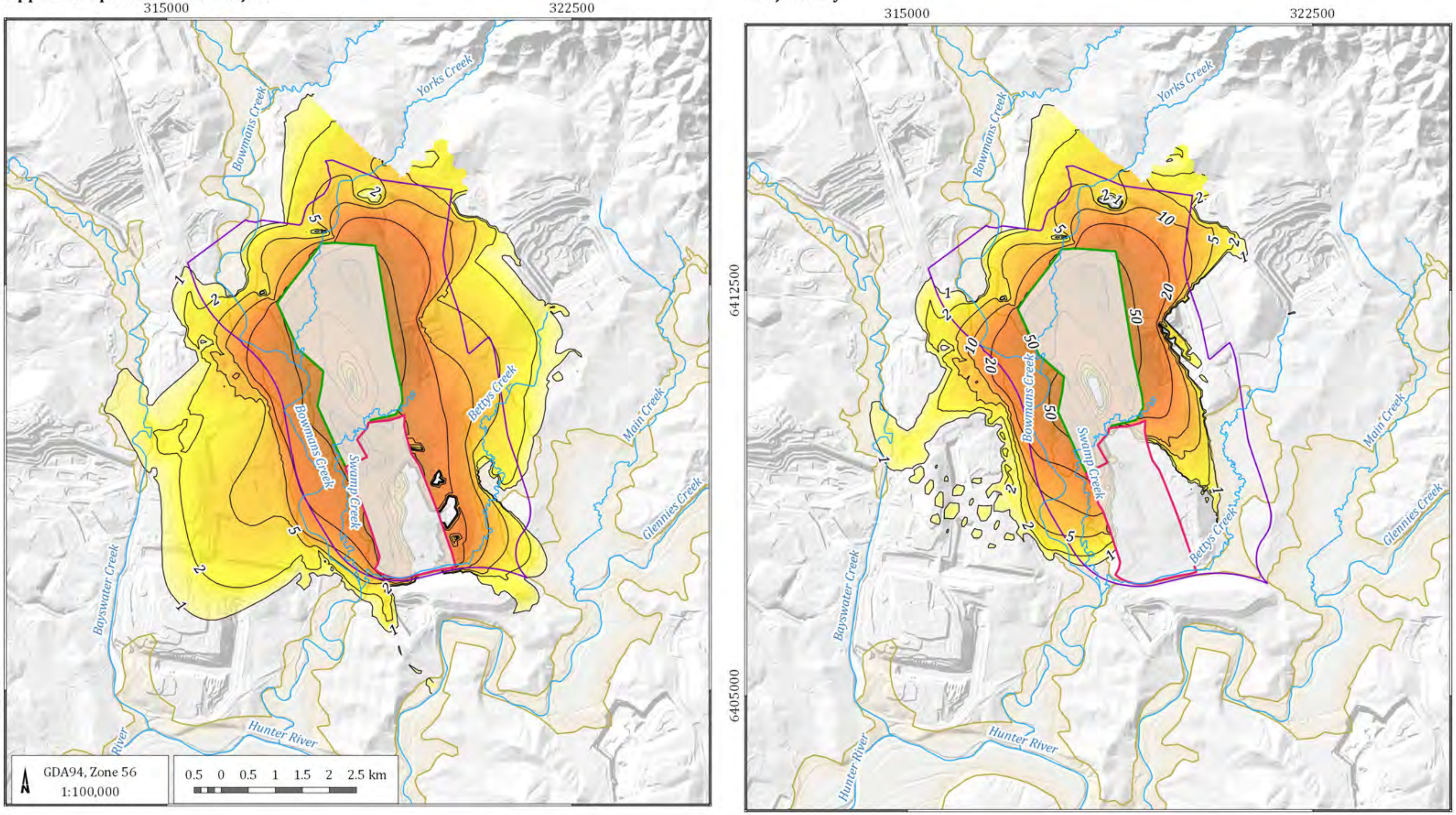
Saturated thickness of Quaternary alluvium over time - No Glendell Scenario

DATE
22/11/2019

FIGURE No:
7-4

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\07.04_G1874C_Saturated thickness during mining - noglen.qgs

Approved Operations and Project | **Project only**



LEGEND

- Drainage
- Alluvium boundary
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Drawdown (m)

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

Glendell Continued Operations GIA (G1874C)

AGE

Maximum zone of drawdown during operations due to Project – Middle Liddell seam

DATE
21/11/2019

FIGURE No:
7-5

The numerical model predicts several zones of drawdown less than 1 m occurring within the Bowmans Creek alluvium due to the Approved Operations plus the Project during the life of the Project. The zone of drawdown is relatively limited because the average rainfall recharge rate calibrated for the alluvium exceeds the losses induced by mining and therefore buffers the drawdown generated by the model. This aligns with current monitoring results that have not detected significant drawdown within the Bowmans Creek alluvial systems (refer to Section 5.5) outside the range of climatic fluctuations that can be attributed to mining. The model predictions indicate that the maximum drawdown of less than 1 m is relatively limited when compared with the climatic fluctuations that have recorded water level changes between 1 m and 4 m within the Bowmans Creek alluvium.

The potential for impact within the Quaternary alluvium depends on the changes in saturated thickness within the alluvial aquifer. Figure 7-3 shows the change in saturated thickness at intervals through the life of the Project due to the combined influence of the Approved Operations and the Project. The figure shows that there is commonly between 2 to 5 m of saturated thickness within the Bowmans Creek alluvium adjacent to the Approved Operations and Project. The changes predicted to occur in the saturated thickness are a function of the cumulative impacts generated by the surrounding approved mining and the Project where there is potential for the alluvium to become unsaturated due to already approved cumulative impacts from surrounding mines.

In Figure 7-3 the alluvium remains saturated adjacent to the Project, with the exception of an area to the west. As can be seen from Figure 7-4, the area of desaturated alluvium is predicted to arise as a result of the cumulative impacts of other mines irrespective of any contribution from Glendell (Approved Operations or the Project). A comparison between Figure 7-3 and Figure 7-4 indicates that the Project will have a negligible impact on the extent of saturation during the operational period. The predicted drawdown associated with the Project shown in Figure 7-2 does not appear to have any noticeable effect on the extent of desaturation within the alluvium during the operational period modelled.

There are multiple coal seams intersected by the mining operations associated with the Project. As noted above the drawdown predicted for the Middle Liddell seam was examined as this seam is being actively mined at the adjacent Ravensworth Operations, Integra Underground, Mount Owen, Liddell Coal Operations and Ashton Coal Mine and therefore is subject to significant cumulative impacts.

Figure 7-5 shows the maximum zone of depressurisation within the Middle Liddell seam generated by the Approved Operations and Project, and the contribution of the Project only. The two windows illustrate that the drawdown north of the Approved Operations where mining has not occurred is largely attributable to the Project as would be expected. Of interest is the drawdown within the Middle Liddell seam generated by the Project is not extensive as the seam is already depressurised at surrounding mining operations.

Whilst the modelling indicates the Middle Liddell seam will be depressurised by the Project, 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.

7.2.3 Cumulative drawdown and depressurisation during mining

Approved coal mines within the region operate below the water table in relatively close proximity to the Approved Operations 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 Project based on publicly available information.

The numerical groundwater model was used to assess the cumulative drawdown generated where zones of drawdown from other mines overlap. The surrounding mines included Integra Underground, Rix's Creek South/Rix's Creek North, Ravensworth East, Mount Owen, Ravensworth Operations, Liddell Coal Operations, Ashton Coal Mine and HVO North Mine.

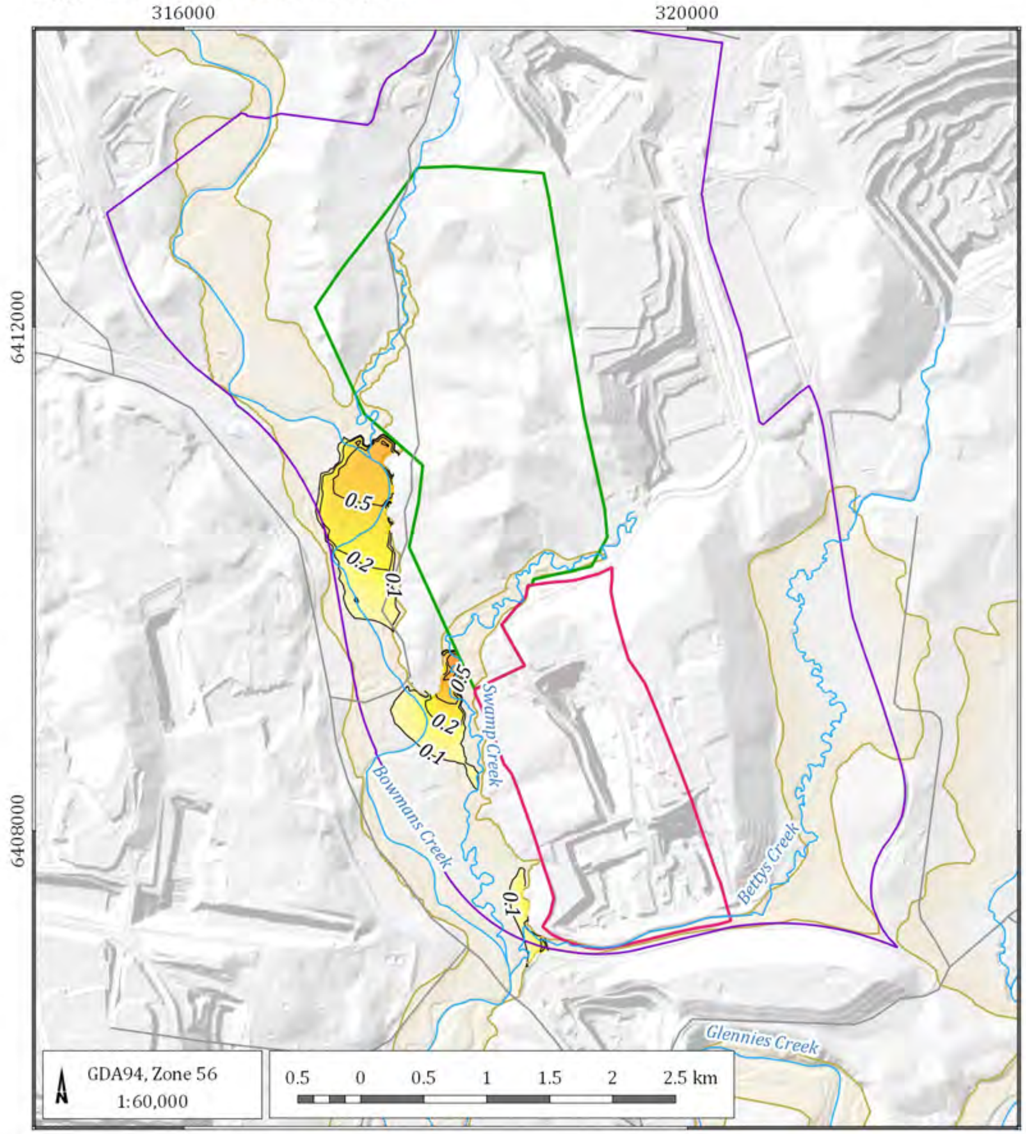
The simulation of mining at these sites using the numerical model was based on the AGE (2018) version of the numerical model which was updated to assess Mount Owen Continued Operations Project Modification 2. The progression of mining at Ravensworth Operations was updated based on information provided by Glencore.

Figure 7-6 and Figure 7-7 show the maximum zone of cumulative drawdown for the Quaternary alluvium and Middle Liddell seam during the life of the Project respectively. The cumulative drawdown is calculated assuming no mining development occurred within the region as baseline levels, and therefore represents the potential change in groundwater levels since 1980. Figure 7-6 compares the predicted drawdown within the Quaternary alluvium due to the influence of the Approved Operations and the Project at Glendell, with the cumulative impact from all surrounding mining. It highlights the cumulative impact of surrounding mining is predicted to induce up to about 2 m of drawdown within the Bowmans Creek alluvium.

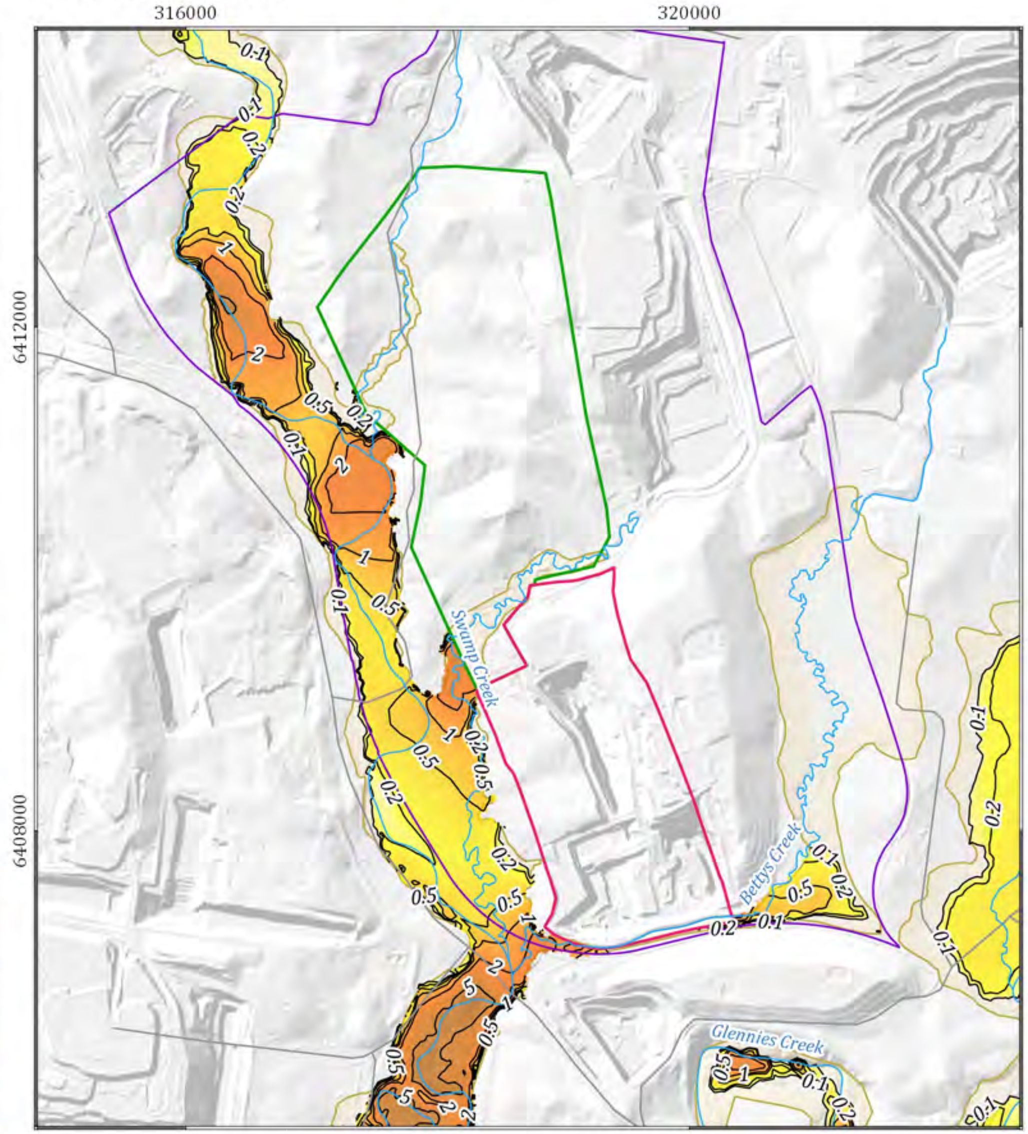
Figure 7-7 shows the Middle Liddell seam is predicted to be significantly depressurised in the region due to the cumulative impacts of mining operations. Whilst the drawdown occurs within the Middle Liddell seam, it is important to note this coal seam is deep, contains poor quality groundwater and therefore does not form a resource with any environmental value.

Figure 7-8 presents modelled cumulative drawdown since the commencement of the Hunter Unregulated WSP in 2009 to April 2019 conditions. For reference, the figure also shows cumulative drawdown over the same period for the Middle Liddell seam. The results indicate the majority of cumulative alluvial drawdown predicted from the commencement of the Hunter Unregulated WSP occurred within the last 10 years.

Approved Operations and Project



Cumulative drawdown



LEGEND

- Drainage
- Road
- Alluvium boundary
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Drawdown (m)

- 0
- 0.1
- 0.2
- 0.5
- 1
- 2
- 5
- 10
- Drawdown contour

Glendell Continued Operations GIA (G1874C)

AGE

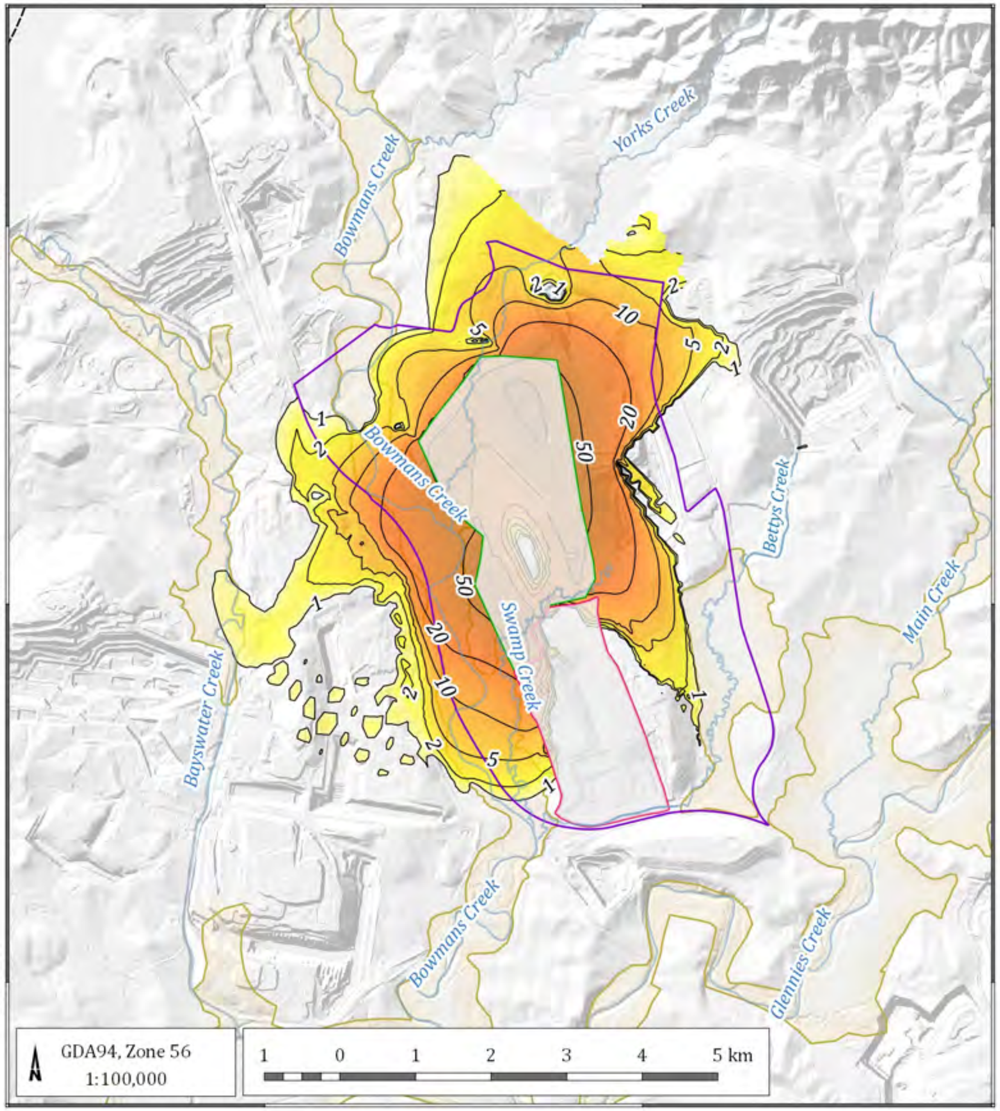
Maximum cumulative drawdown during operations – Quaternary alluvium

DATE
21/11/2019

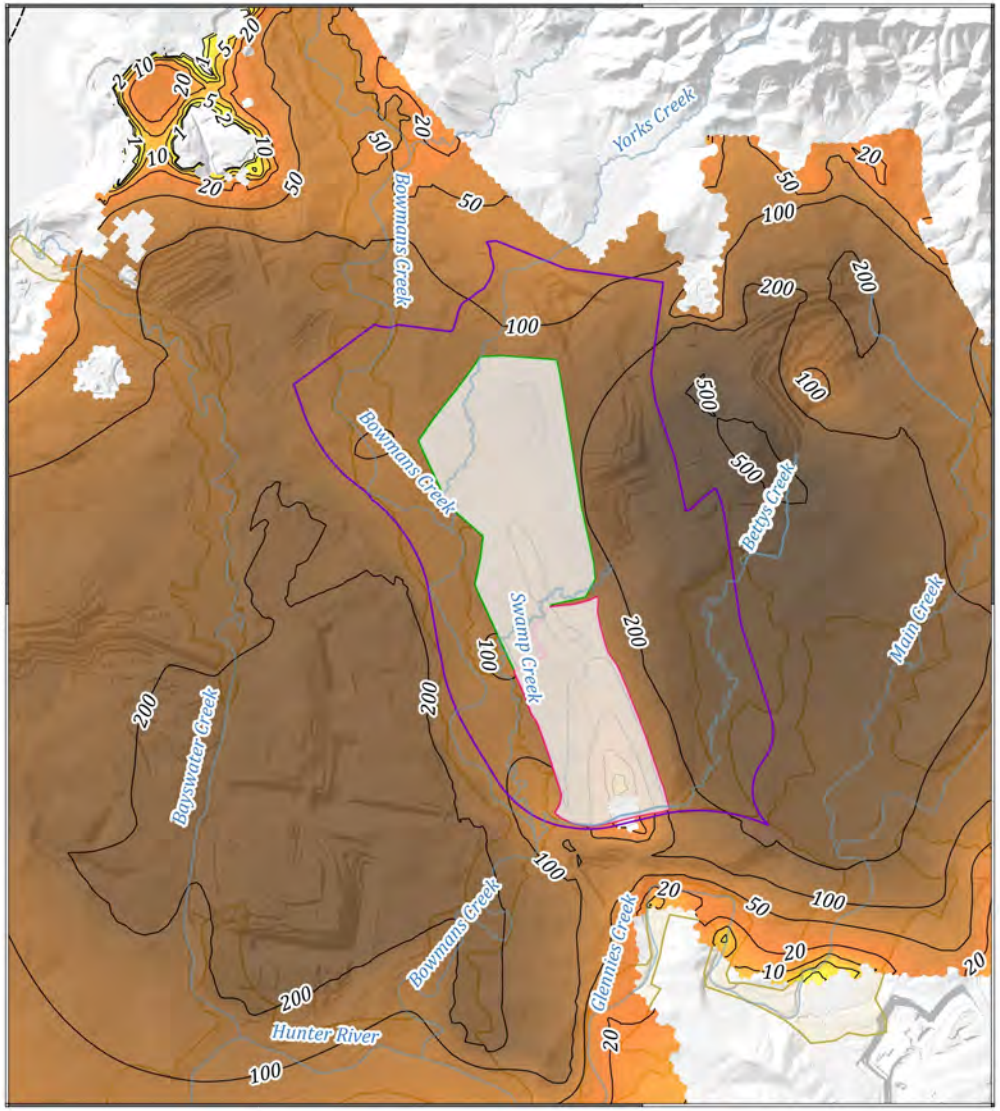
FIGURE No:
7-6

Source: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\07.06_G1874C_Cumulative drawdown - Quaternary alluvium.qgs

Approved Operations and Project



Cumulative drawdown



LEGEND

- Drainage
- Alluvium boundary
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Drawdown (m)

0, 1, 2, 5, 10, 20, 50, 100, 200, 500

— Drawdown contour

Glendell Continued Operations GIA (G1874C)

AGE

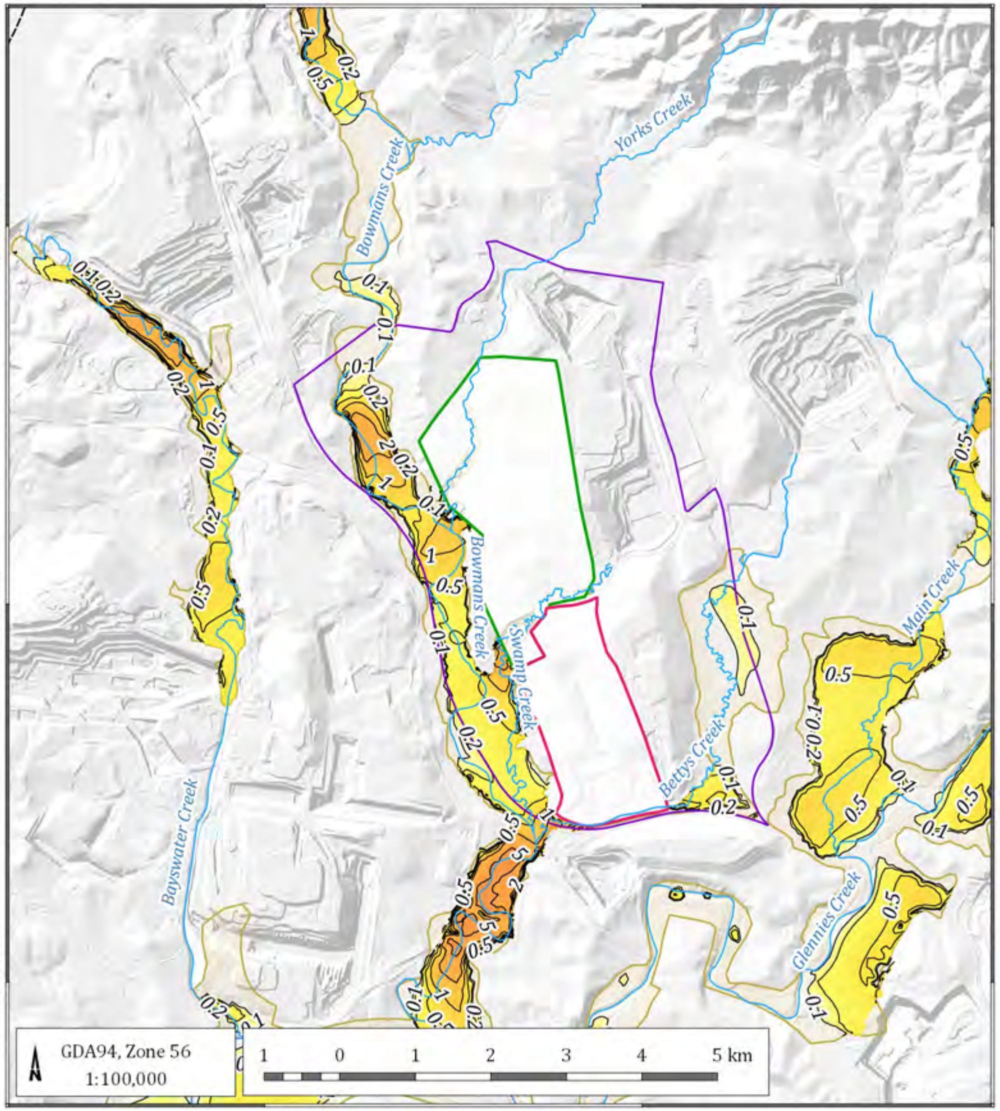
Maximum cumulative drawdown during operations – Middle Liddell Seam

DATE
21/11/2019

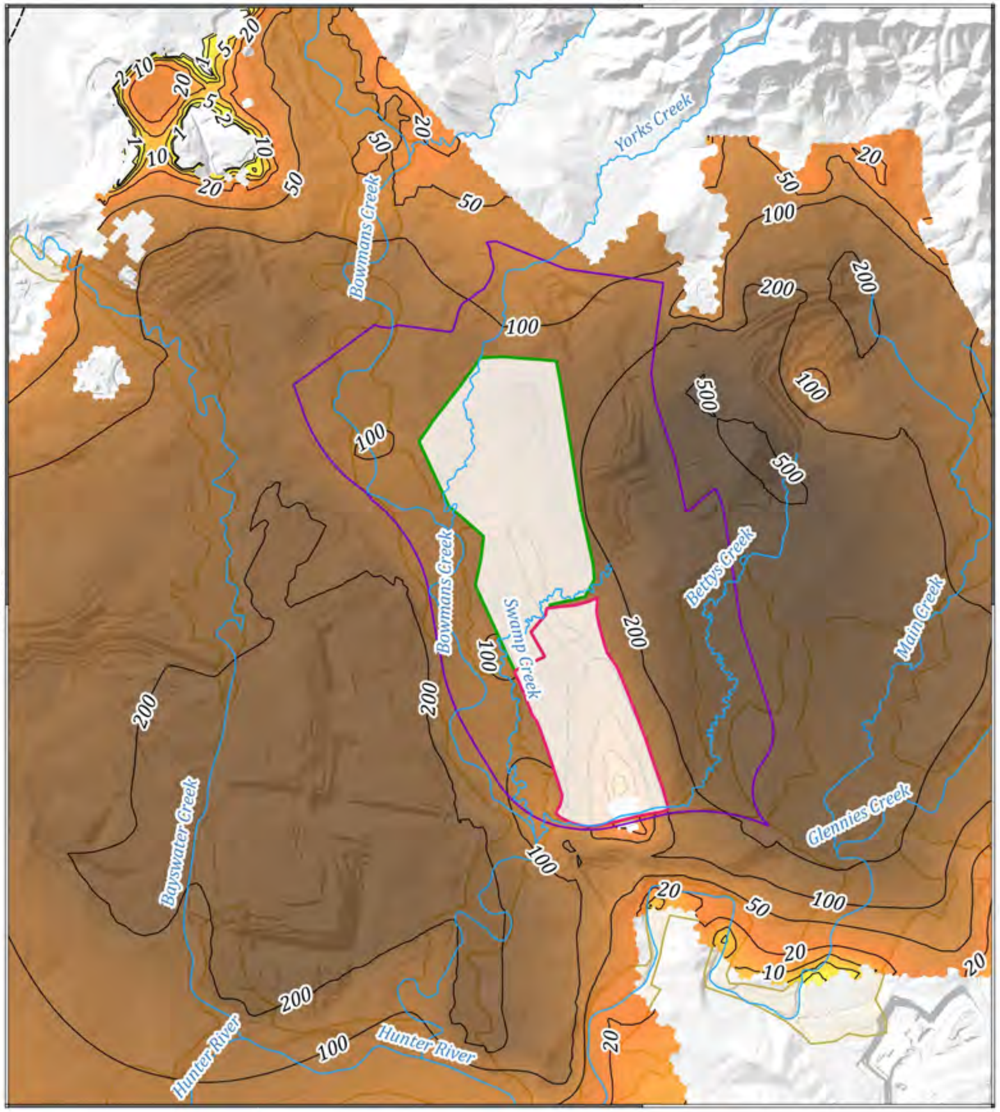
FIGURE No:
7-7

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\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\07.07_G1874C_Cumulative_drawdown- Middle Liddell.qgs

Alluvial drawdown



Middle Liddell drawdown



LEGEND

- Drainage
- Alluvium boundary
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Drawdown (m)

0.1	10
0.2	20
0.5	50
1	100
2	200
5	500

— Drawdown contour

AGE

Glendell Continued Operations GIA (G1874C)

Cumulative drawdown - 2009 to present

DATE
21/11/2019

FIGURE No:
7-8

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\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\07.08a_G1874C_Cumulative_drawdown- 2009-present.qgs

7.2.4 Change in alluvial and surface water flows

The model was used to determine the potential for mining to interfere with the alluvial groundwater systems and to provide estimates of indirect 'water take' in accordance with the AIP. Mining will only directly intercept alluvial aquifers where mining removes Swamp Creek and Yorks Creek. In these areas' groundwater inflow from the alluvial sediments will occur directly into the Glendell Pit Extension where the saturated areas of the alluvium are exposed in the mine face.

There is also a potential for indirect impact or 'water take' occurring as the Permian strata become depressurised and the volume of groundwater flowing from the Permian strata 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 strata 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 Project.

The peak change in flow to the Bowmans Creek Quaternary alluvium due to the Approved Operations and the Project during the mining phase was 10 ML/year. This limited impact on flow to the alluvium is expected because the model predicts only minimal drawdown within the alluvium. The change in flow of groundwater to the alluvium reduces the baseflow in Bowmans Creek predicted by the model by up to 5 ML/year. It is important to note that a change of 5 to 10 ML/year is negligible at the catchment scale and equivalent to approximately 0.15 to 0.3 L/sec.

Alluvium will also potentially be intercepted as part of the Hebden Road and Heavy Vehicle Access Road construction site near the confluence of Yorks and Bowmans Creek. This is outside the footprint of the Glendell Pit Extension and was therefore not represented in the groundwater model. The small footprint of these works and the transient nature means these construction works are likely to have only a localised impact if there is any interference with the water table.

7.2.5 Drawdown in private bores

Section 5.9.1 described groundwater usage in private bores in proximity to the Project. Two registered bores on the NSW government database are located on private property to the west of the Glendell Pit Extension and are assumed to be installed within the regolith. The AIP specifies a threshold for minimal impact on water supply works is a drawdown of 2 m cumulatively unless make good provisions should apply.

Figure 7-9 presents maximum groundwater drawdown at privately owned bores (GW046759 and GW078054). Results confirm groundwater drawdown at these locations are predicted to be less than the AIP threshold for minimal impact on water supply works.

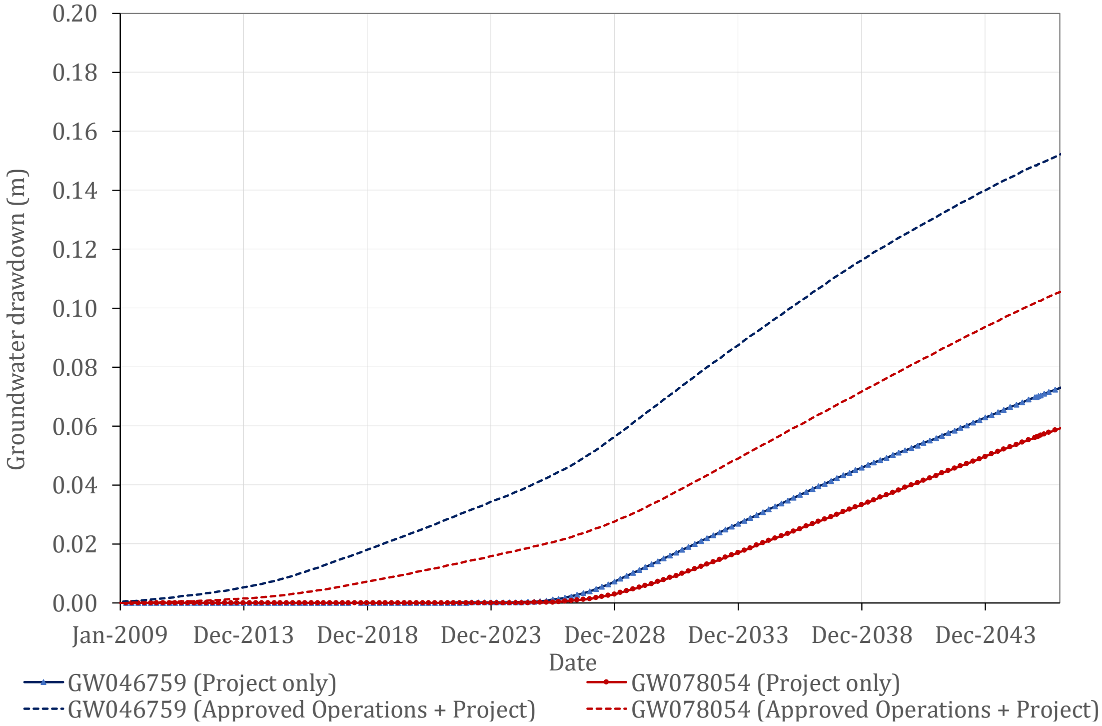


Figure 7-9 Drawdown at privately owned groundwater bores

7.2.6 Impact on groundwater dependent ecosystems

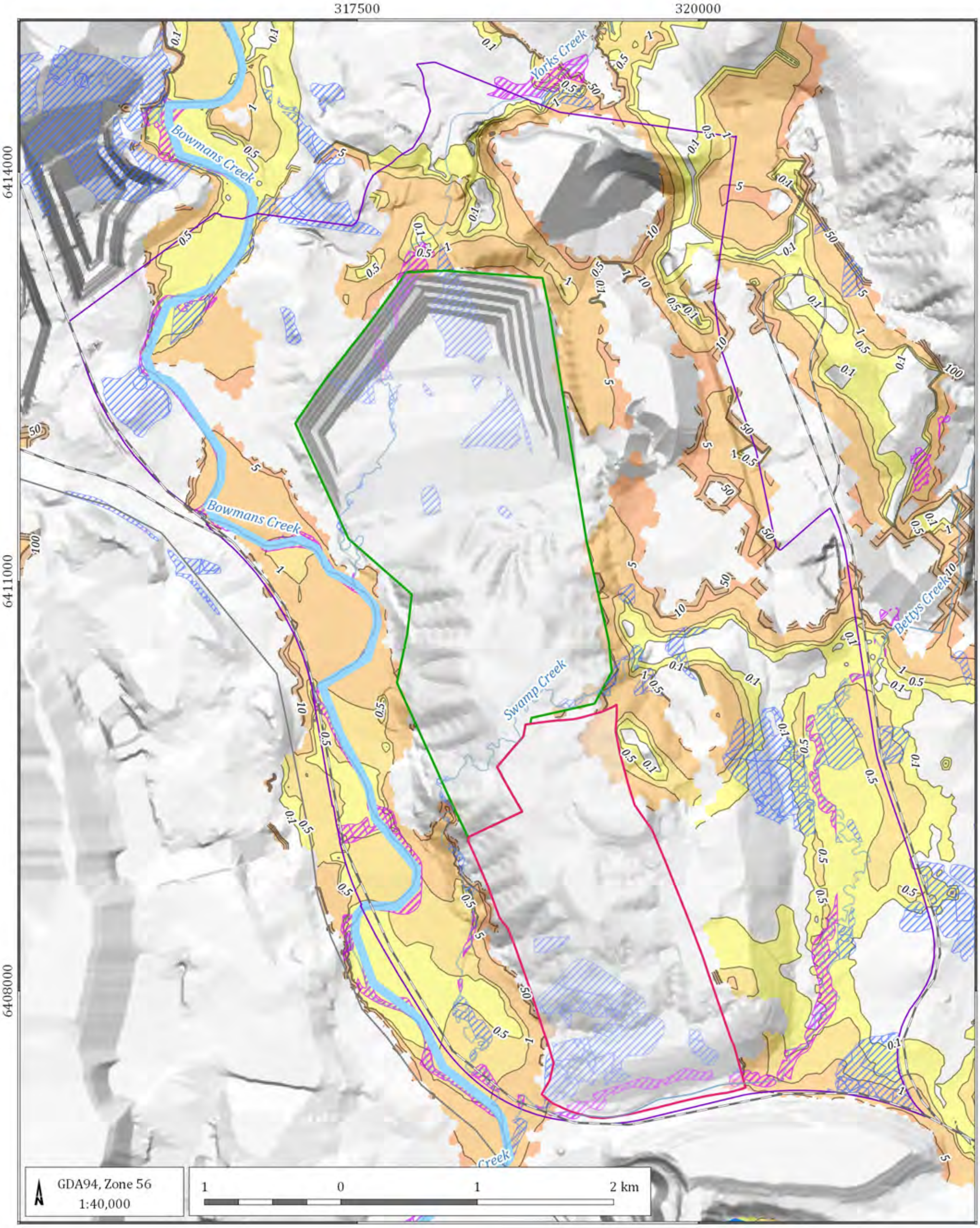
As detailed under Section 5.9.2, potential GDEs have been identified occurring mainly along Bowmans Creek. The riparian vegetation and aquatic ecosystems are considered potential GDEs.

As previously shown in Figure 7-2 the drawdown predicted to occur due to the Project is largely less than 1 m. Figure 7-10 shows the maximum cumulative watertable drawdown due to all approved mining operations over the life of the Project. The drawdown is only shown for areas where the water table in Layers 1 and 2 is within 10 m below the land surface and therefore more accessible by tree roots. The figure also shows the location of the potential GDEs identified by the BoM GDE Atlas. Figure 7-10 shows the cumulative impact from approved mining in the vicinity of the Project is more extensive with widespread drawdown between about 0.5 to 1 m within the Bowmans Creek alluvial aquifer.

The AIP specifies 'less than or equal to 10% cumulative variation in the water table, allowing for typical climatic post-water sharing plan variations, 40 m from any high priority groundwater dependent ecosystem. There are no high-priority GDEs listed in the relevant water sharing plans in the region of the Project. The Project therefore does not exceed the minimal impact thresholds and complies with the AIP. Further discussion on potential GDEs and impacts is provided in the Commonwealth Matters Report prepared for the EIS (Umwelt, 2019).

7.2.7 Impact on culturally significant sites

No high priority culturally significant sites are listed in the schedules of the relevant water sharing plans. An indigenous engraving site is located to the north-west of the Glendell Pit Extension within Bowmans Creek. The engraving is not listed in the Hunter Unregulated WSP.



LEGEND

- Drainage
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

GDE Atlas - Aquatic

- Moderate potential GDE

GDE Atlas - Terrestrial

- High potential GDE
- Low potential GDE

Drawdown (m)

- 0.1 - 0.5
- 0.5 - 1
- 1 - 5
- 5 - 10
- 10 - 50
- 50 - 100
- Contour line

Glendell Continued Operations GIA (G1874C)

Potential GDEs and predicted maximum cumulative water table drawdown

AGE

DATE 21/11/2019

FIGURE No: **7-10**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.; GDE Atlas © http://www.bom.gov.au/water/groundwater/gde/;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\07.10_G1874C_Potential GDEs and predicted maximum cumulative drawdown in Quaternary alluvium.qgs

7.2.8 Water licensing and water sharing plan rules

The AIP requires the accounting of 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 flows occurring within the Quaternary alluvium and rivers resulting from depressurisation of the underlying Permian strata 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 Project and the Approved Operations.

As discussed in Section 2, three WSPs apply to the aquifers and surface waters affected by the Project – these are the WSPs for the:

- Hunter Regulated River Water Source 2016 (Hunter Regulated WSP);
- Hunter Unregulated and Alluvial Water Sources 2009 (Hunter Unregulated WSP); and
- 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. The Project falls within the Jerrys Water Source (refer Figure 2-1). The predicted annual groundwater volumes required to be licensed to account for the peak water take over the life of mining for the Approved Operations and Project are summarised in Table 7-2.

Table 7-2 Groundwater licensing summary – during mining

Water sharing plan	Water source/ management zone	Type	Peak volume requiring licensing during mining (ML/year)	
			Approved Operations and Project	Project only
North Coast Fractured and Porous Rock WSP	Sydney Basin North Coast	groundwater	249 (Year 17)	249 (Year 17)
Hunter Unregulated WSP	Jerrys	groundwater	10 (Year 12 to 25)	5 (Year 22 to 25)
		surface water	5 (Year 22 to 25)	2 (Year 18 to 25)
	Glennies	groundwater	0	0
		surface water	0	0
	Hunter Regulated River Alluvium	groundwater	1 (Year 17 to 24)	0
Hunter Regulated WSP	Management Zone 3a - Glennies Creek & Station Creek surface water	surface water	0	0

The AIP requires proponents of aquifer interference activities to hold water licences at the time of the actual or predicted take. As reported in Section 2.4, Glencore has a total entitlement of 1,160 ML/year from the Sydney Basin North Coast Water Source under the North Coast Fractured and Porous Rock WSP. These licences are to account for groundwater intercepted at the Mount Owen Complex. The model predicts a maximum of 552 ML/year (Year 12) take from the Mount Owen Complex including the Project, therefore the current entitlements held by Glencore adequately cover the take under the North Coast Fractured and Porous Rock WSP.

There is predicted to be a small groundwater take from Jerrys Water Source during operations. This take is not predicted to peak until approximately Year 12 to 25. There are currently 1,246 units available for trade within the Jerrys Water Source and transfers between surface and groundwater systems are permitted under the trading rules. The predicted water take attributable to the Project should be able to be readily sourced on the market prior to the predicted take occurring.

There is also predicted to be a very small take of groundwater from the Hunter Regulated River Alluvium Water Source from the Glennies Creek alluvial aquifer peaking in Year 17 to 24. The predicted volume is 1 ML/year which is equivalent to 0.03 L/sec and considered negligible and undetectable at a catchment scale.

No take of groundwater from the Glennies Water Source is predicted during operations.

The Glennies Water Source and Jerrys Water Source have 'cease to pump' rules under the Hunter Unregulated WSP 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 40 m 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 the Jerrys Water Source due to the activity occurs only incidentally due to depressurisation of the underlying Permian coal measures, and not from direct extraction. This rule is therefore not applicable to the Project.

7.3 Post mining recovery conditions

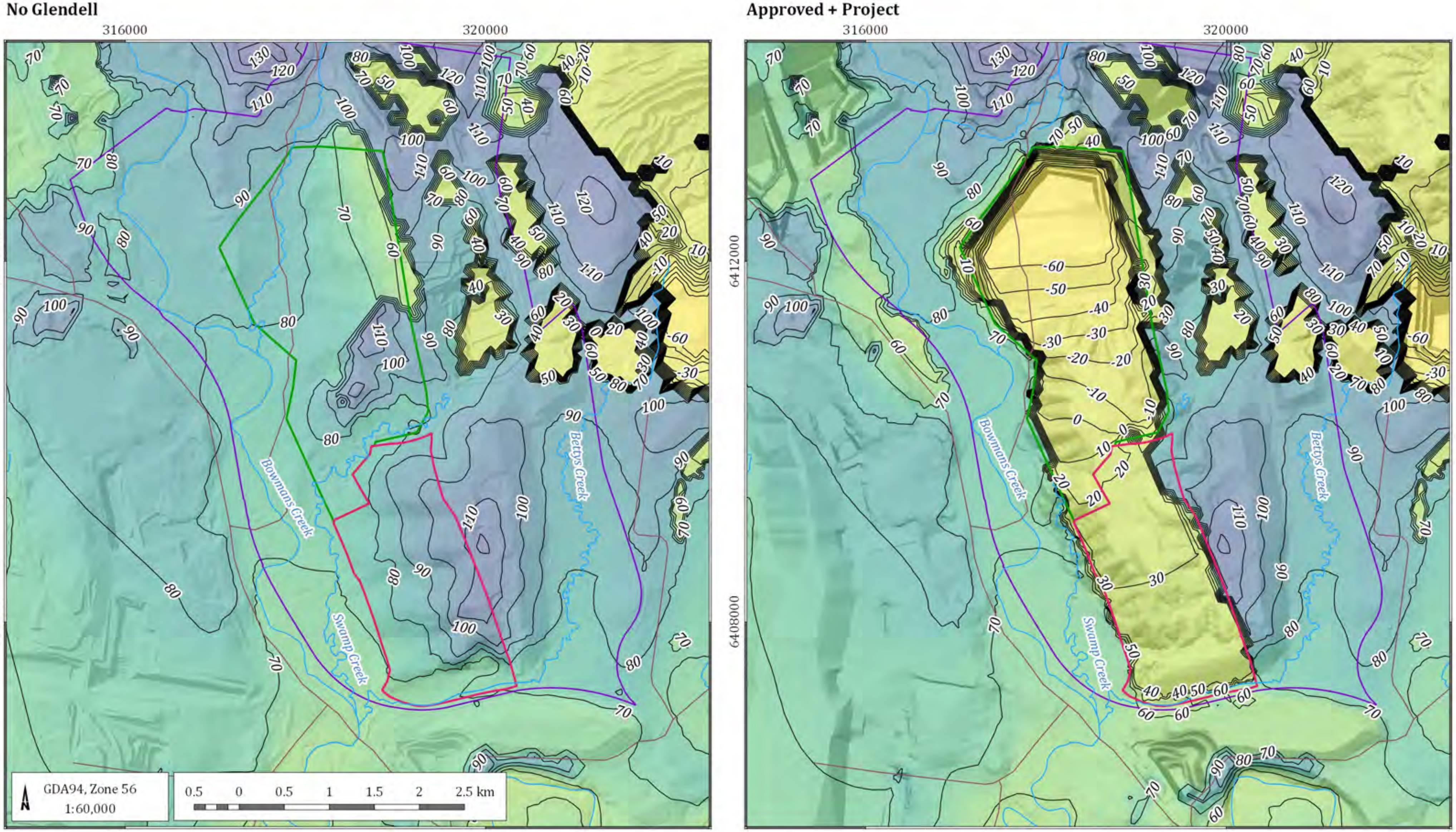
Post mining conditions were also simulated using the numerical model to determine how the final void lake associated with the Project would interact with the groundwater systems. Appendix B provides details of the model set up and the representation of post mining conditions. The sections below describe the post mining predictions of water levels, drawdown and changes in water quality.

7.3.1 Post closure groundwater recovery

The recovery rate and equilibrium water level within the final void lake is a function of direct rainfall to the lake surface, rainfall runoff from the surrounding catchment and groundwater inflow through spoils, evaporation, and undisturbed geological units. Because the groundwater flow model does not represent rainfall runoff and is not refined enough to represent the morphology of the final void accurately, information from a separate water balance model created by GHD (2019) was used to provide inputs to the groundwater model. The process to determine the final void water level recovery was as follows:

- firstly, a water balance model was used to assess the rate of net surface water flow in the final void from rainfall and runoff (minus evaporation), but excluding any input of groundwater;
- secondly the water level recovery curve predicted by the water balance model was then represented in the groundwater model and the net rate of groundwater inflow to the final void over time was calculated;
- thirdly the calculated groundwater inflow to the final void was entered into the water balance model and the water level recovery curve recalculated;
- finally, the water level recovery curve was represented in the groundwater model to allow prediction of long-term drawdown and water take.

This approach ensured consistency between the surface water and groundwater studies. The water balance model indicated the water level within the final void will slowly recover over a period of approximately 450 years stabilising at approximately -60 mAHD.



LEGEND

- Drainage
- Road
- Alluvium boundary
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Water table (m)

-70	150
-50	200
50	250
100	

— Contour line

Glendell Continued Operations GIA (G1874C)

AGE

Post mining water table

DATE
28/11/2019

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.;
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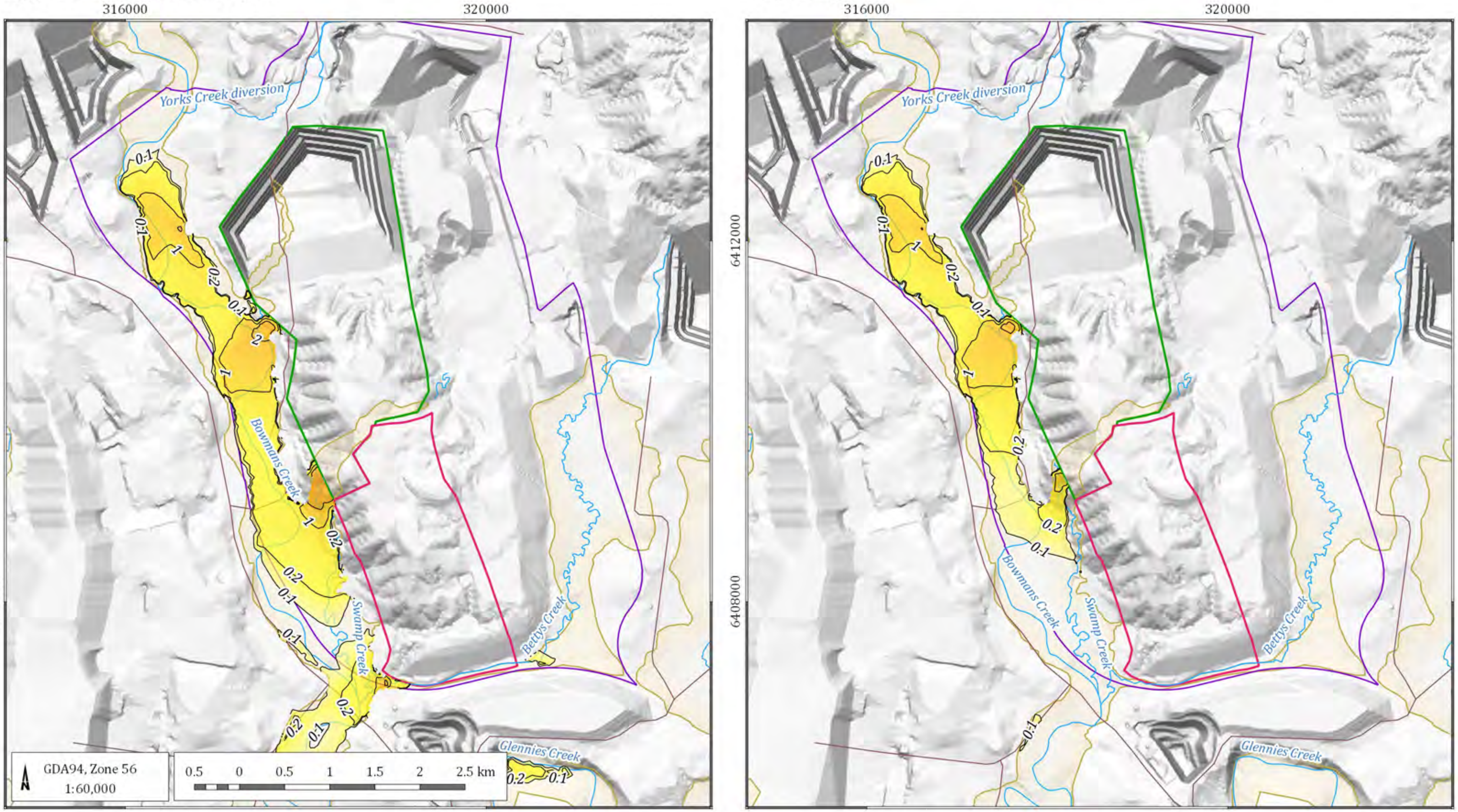
Approved Operations and Project | **Project only**



LEGEND

- Drainage
- Road
- Alluvium boundary
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Drawdown (m)

- 0.1
- 0.2
- 1
- 2
- Drawdown contour

Glendell Continued Operations GIA (G1874C)

AGE

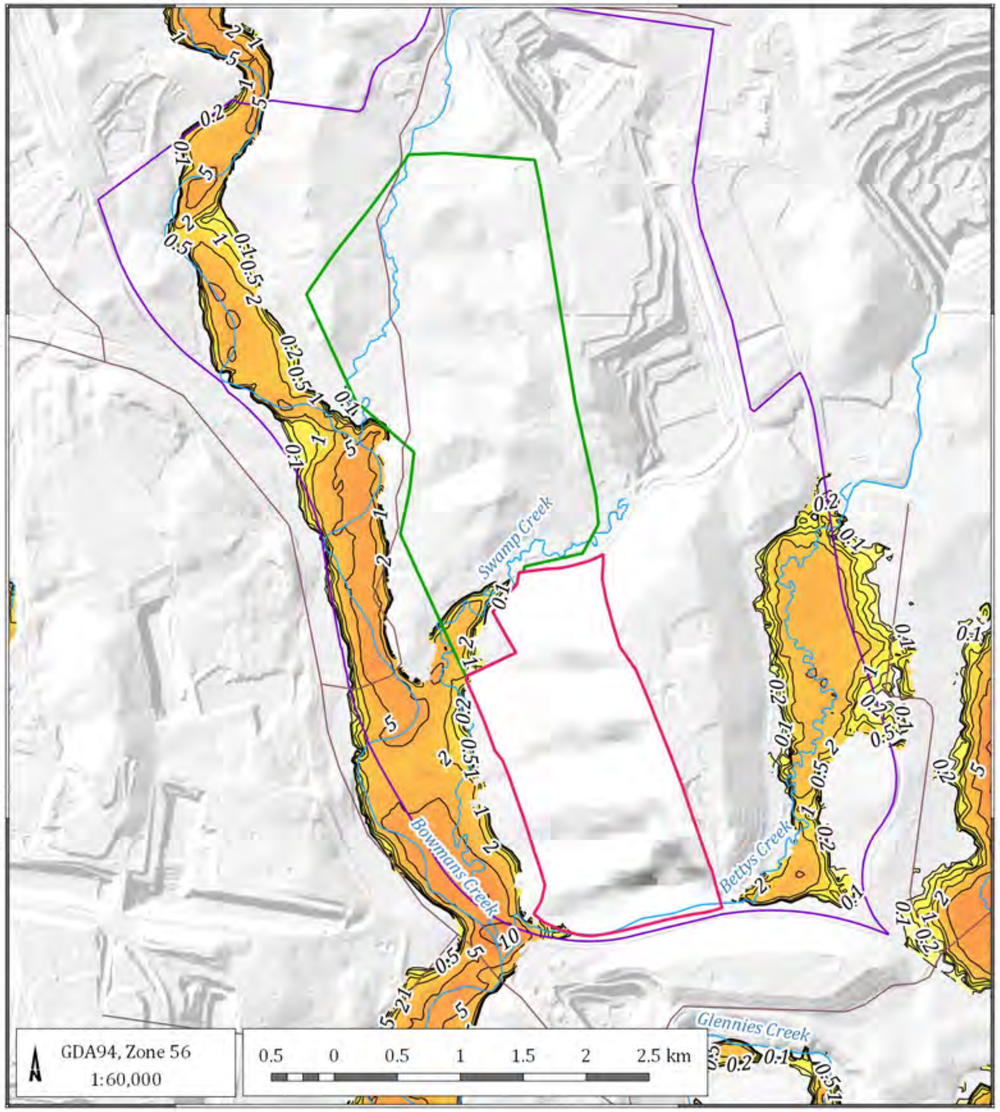
Post mining maximum drawdown – Quaternary alluvium

DATE
22/11/2019

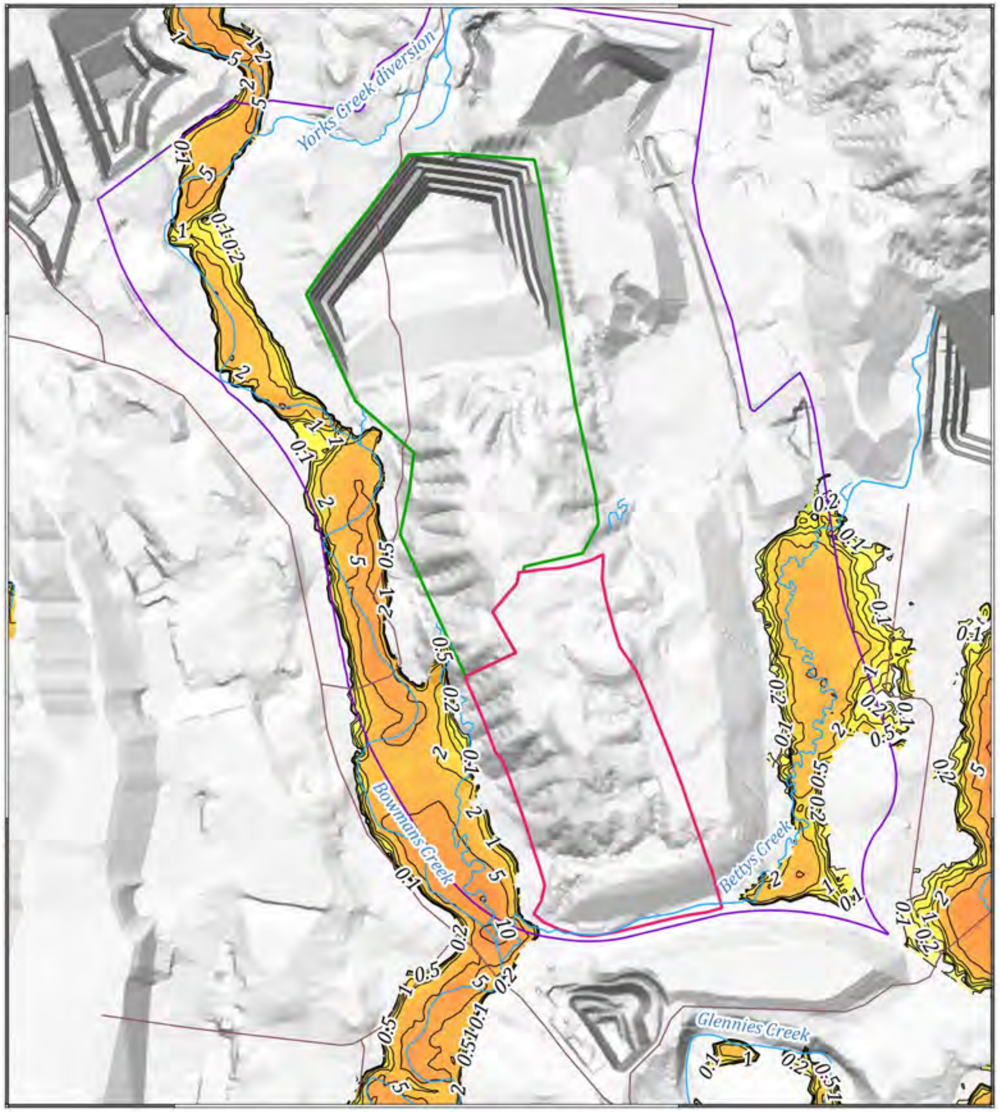
FIGURE No:
7-12

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\07.12_G1874C_Post mining maximum drawdown – Quaternary alluvium.qgs

No Glendell



Approved + Project



LEGEND

- Drainage
- Road
- Alluvium boundary
- Approved Glendell Pit
- Glendell Pit Extension
- Project Area

Saturation (m)

0.1	5
0.2	10
1	20
2	50

Glendell Continued Operations GIA (G1874C)

AGE

Post mining saturation – Quaternary alluvium

DATE
26/11/2019

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\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\07.13_G1874C_Post mining saturation - Quaternary alluvium.qgs

Figure 7-11 shows the regional groundwater table for the 'No Glendell' and 'Approved + Project' scenarios after 450 years of recovery. The model results indicate that groundwater will gradually seep into the void and the groundwater levels within the Permian strata will establish a new equilibrium level in response to the changes in landforms and the consequential increase in surface water and evaporation interactions. The final void lake water levels are predicted to be about 130 m below pre-mining groundwater levels, indicating that the void will act as a sink in perpetuity with no escape of contained void water.

Figure 7-12 and Figure 7-13 show the maximum zone of drawdown and saturation within the Quaternary alluvium that is predicted to occur during the post mining recovery phase. As can be seen by comparing Figures 7-12 and 7-13, the water table (depth of saturation) has increased in the alluvium over this recovery period. Accordingly, the predicted drawdown associated with the Approved Operations and the Project is relative to a recovering system with groundwater levels in the alluvium overall being higher than existing conditions. The drawdown attributable to the Approved Operations and the Project within the Quaternary alluvium are therefore unlikely to be detectable from seasonable fluctuations and the recovering system. The model predicts post mining drawdown will be greater than the maximum drawdown encountered during the operational phase. This is because drawdown in the alluvium and hard rock systems continues to propagate post mining due to the slow re-equilibration of the groundwater system to the presence of the final landform. In the model all the other mines that create a cumulative impact are also represented as closed and this results in a gradual recovery in the groundwater regime over time post mining increasing the area and thickness of saturated alluvium. So therefore, whilst more drawdown is predicted post mining it occurs within a system which is predicted to be less impacted due to the recovery generated by closure of the surrounding mining operations.

7.3.2 Change in alluvial and surface water flows

The model was used to determine the potential for mining to interfere with the alluvial groundwater systems and to provide estimates of indirect 'water take' during the recovery period post mining. The methodology was the same as outlined in Section 6.2 for the operational phase. The change in alluvial water resources was determined by comparing water budgets for alluvial zones using versions of the numerical model that contained Glendell post mining.

Figure 7-14 to Figure 7-16 below show the reduction in flow of groundwater from the Permian strata to each alluvial water sources post mining. These graphs show the cumulative impact of all approved mining on each water source, and the proportion attributable to the Approved Operations and the Project. For licensing purposes, the calculated water take from each water source was normalised to zero at the commencement of the Hunter Unregulated WSP. This removes the influence of historical mining on the groundwater regime.

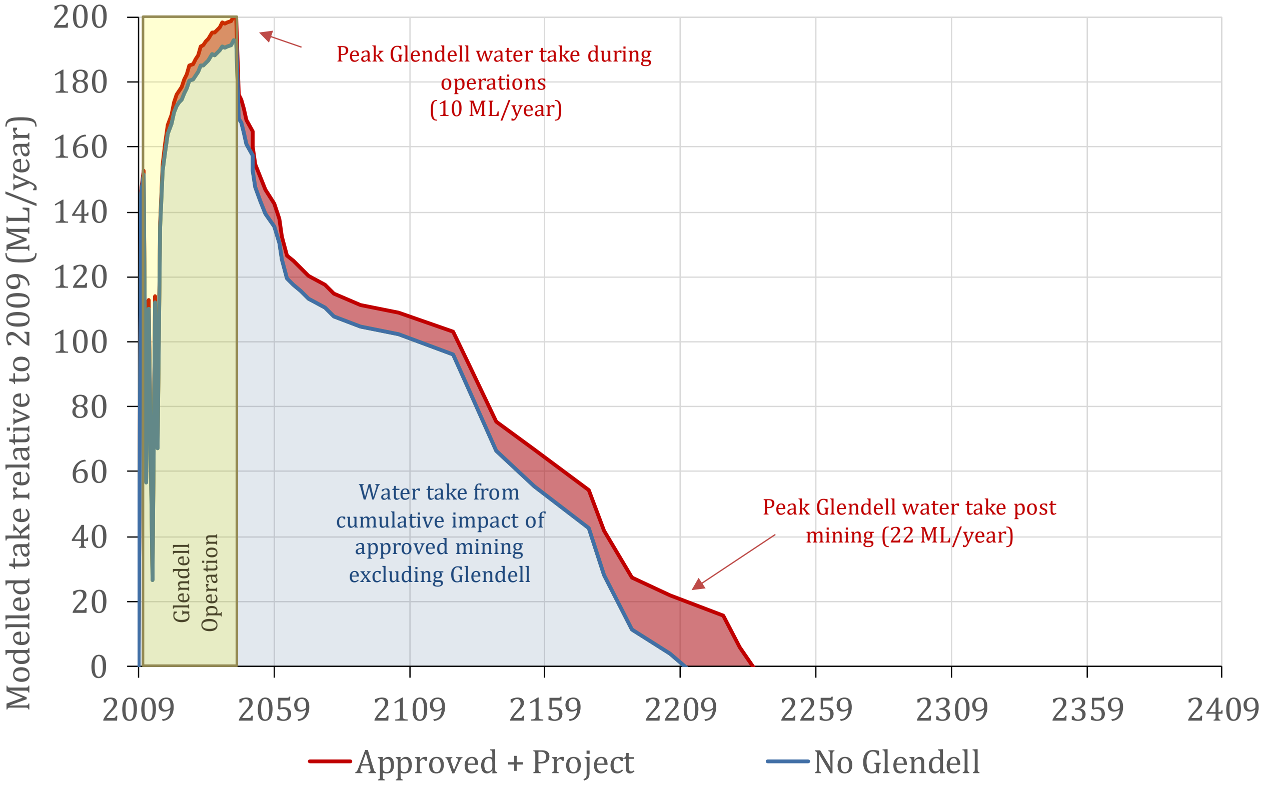


Figure 7-14 Reduction in groundwater flow to Jerrys Water Source alluvial aquifers

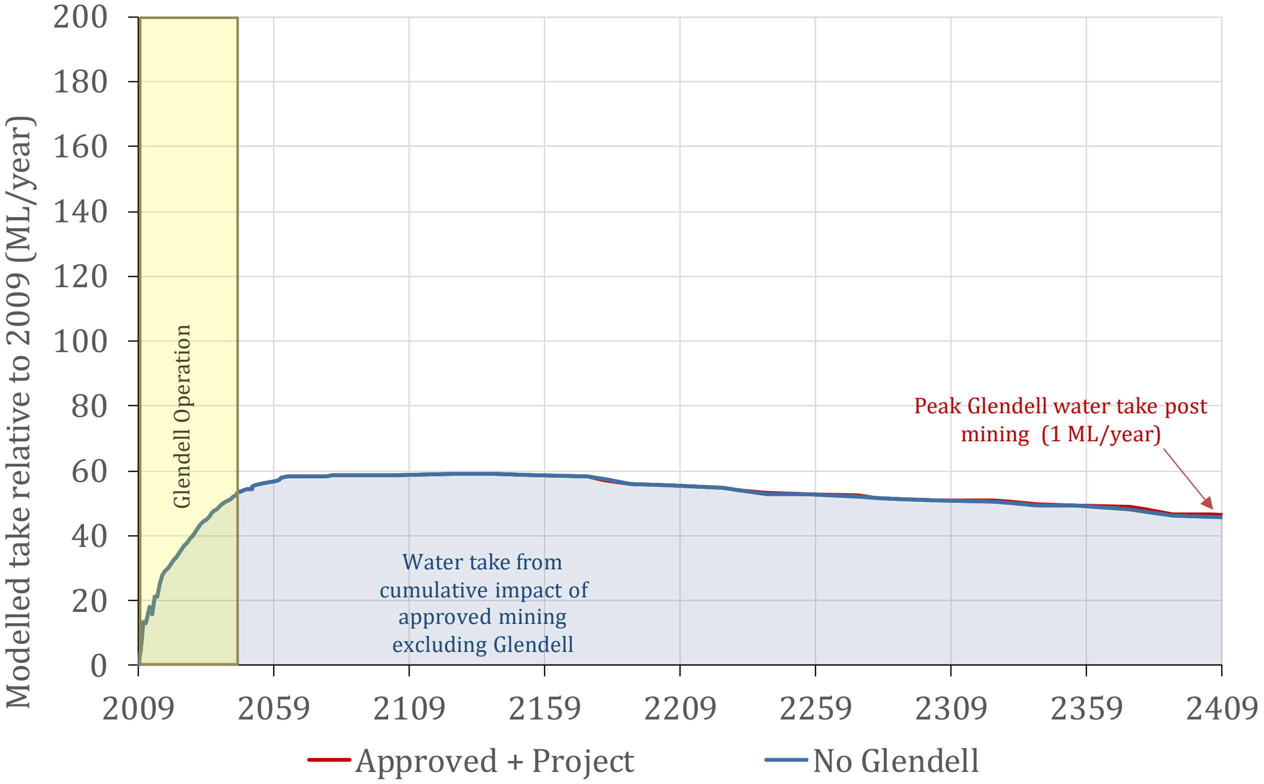


Figure 7-15 Reduction in groundwater flow to Glennies Water Source alluvial aquifers

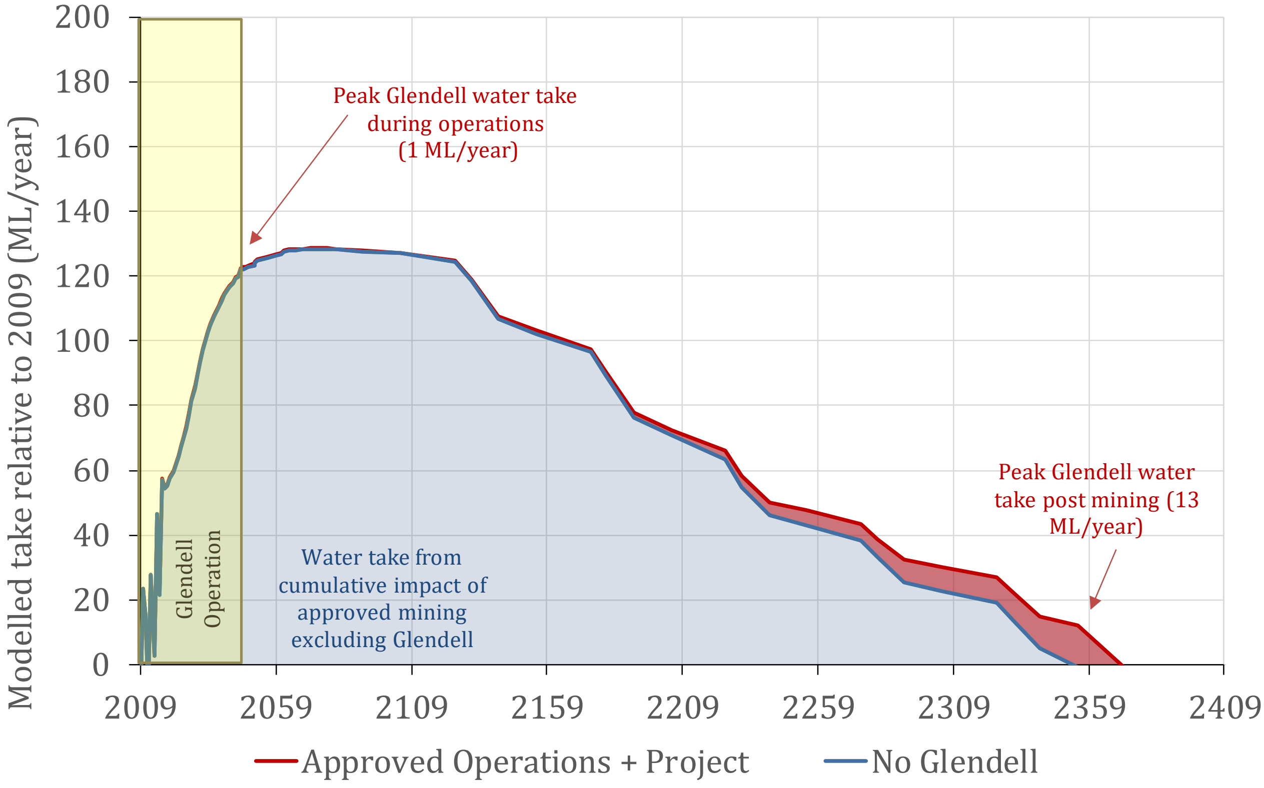


Figure 7-16 Reduction in groundwater flow to Hunter Regulated River Alluvium Water Source alluvial aquifers

Figure 7-14 shows the water take from Jerrys Water Source (Bowmans Creek, Yorks Creek, Swamp Creek, Bettys Creek alluvium) peaks during mining then slowly reduces post mining as the groundwater regime adjusts to the changed landforms and recovers to new equilibrium levels. The groundwater flow from the Permian strata to the Jerrys Water Source alluvium returns to 2009 conditions approximately 150 years post mining. Whilst flows to the Jerrys Water Source slowly recover post mining, the proportion of the residual water take attributable to the Approved Operations and the Project increases slightly over time. This is indicated by the diverging lines on Figure 7-14. The water take peaks at 22 ML/year approximately 150 years post mining. At this point the total groundwater flow to the Jerrys Water Source has returned to 2009 conditions. While the take attributable to the Project increases over time until this stabilisation is reached, overall take continues to decrease over this same period due to the general recovery of the system following the cessation of mining at other operations. Put another way, the Project does not result in any significant increase in cumulative take.

Figure 7-15 shows the predicted take from the Glennies Water Source (Main Creek alluvium) due to Glendell is undetectable, never exceeding 1 ML/year post mining.

The Hunter Regulated River Alluvium Water Source (Glennies Creek alluvium) is slower to recover than the Jerrys Water Source with flows returning to 2009 conditions approximately 300 years post mining. Similar to the Jerrys Water Source, the contribution of residual water take attributable to the Approved Operations and the Project increases slowly post mining, peaking at about 13 ML/year after 300 years when the water source has returned to 2009 conditions.

When considering the above results, it is important to note there is significant uncertainty in the predicted water take post mining. The model predictions are for relatively small volumes of water centuries into the future. The modelling also indicates that the cumulative impact from closure of other surrounding mines significantly complicates the recovery of the groundwater systems and suggests peaks in water take are influenced by recovery of surrounding operations.

Post mining the entire groundwater regime is recovering due to the closure of all open cut and underground mines represented in the groundwater model. This means that whilst ongoing impacts are predicted they occur within a less impacted groundwater regime due to the recovery of the other mining operations. This is particularly true for the underground mines that do not have residual open voids and allow the groundwater regime to recovery to a new equilibrium level, higher than levels during operations.

The numerical model indicates that post mining the flows from the Permian strata to the alluvium will slowly recover, and eventually could exceed the baseline levels prior to mining. This is predicted to occur due to the potential enhancement of recharge through spoil piles that cover a large percentage of the model domain. The charts of flow shown in Figure 7-14 to Figure 7-16 have been cut off to only show the flow loss, and not the post mining increase in groundwater flow due to the significant uncertainty associated with this prediction.

7.3.3 Drawdown in private bores

Figure 7-17 presents maximum groundwater drawdown at privately owned bores (GW046759 and GW078054) due to the Approved Operations and the Project. Results confirm groundwater drawdown at these locations are less than the AIP threshold for minimal impact on water supply works.

Little information exists regarding the construction details of these bores. The geological model indicates the base of the regolith at this location is at approximately 68 mAHD, while the cumulative model predicts a reduction in groundwater level to a minimum of approximately 72 mAHD. This indicates that cumulative groundwater drawdown will not significantly impact the ability for these bores to pump low volumes of groundwater.

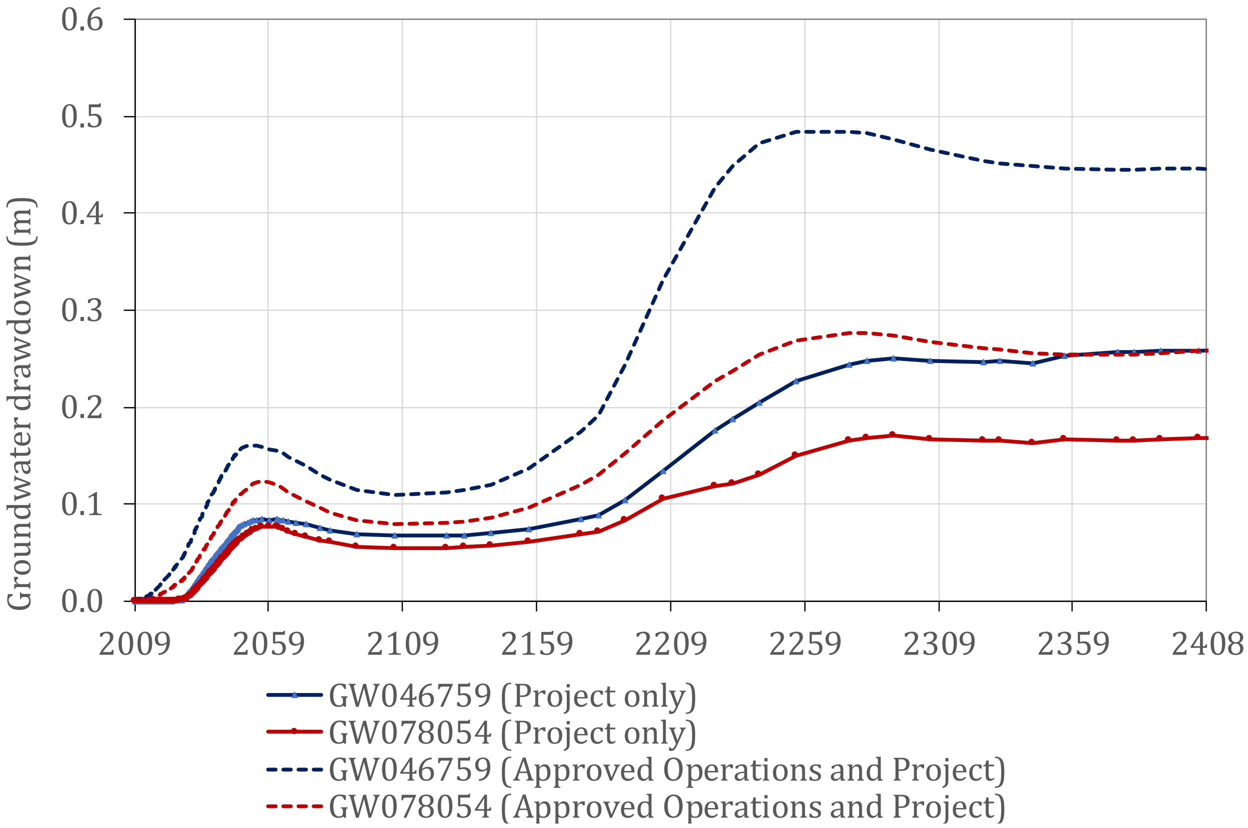


Figure 7-17 Drawdown at privately owned groundwater bores

7.3.4 Water licensing and water sharing plan rules

As noted previously in Section 7.2.8, the AIP requires the accounting of all groundwater take, either directly or indirectly from groundwater systems. The predicted annual groundwater volumes to account for the peak post mining water take for the Approved Operations and the Project are summarised in Table 7-3. All groundwater takes have been corrected for 'double accounting' by subtracting baseflow changes from the total alluvial flow change. The calculations to correct for double accounting is shown within the brackets in Table 7-3.

Table 7-3 Groundwater licensing summary – post mining for Approved Operations and the Project

Water sharing plan	Water source/ management zone	Type	Peak volume requiring licensing post mining (ML/year)
North Coast Fractured and Porous Rock WSP	Sydney Basin North Coast	groundwater	less than during mining
Hunter Unregulated WSP	Jerrys	groundwater	4 (22 minus 18)
		surface water	18
	Glennies	groundwater	1 (1 minus 0)
		surface water	0
	Hunter Regulated River Alluvium	groundwater	13
Hunter Regulated WSP	Management Zone 3a - Glennies Creek and Station Creek surface water	surface water	14

7.3.5 Groundwater quality changes

Post mining, water will evaporate from the void lake surfaces drawing in groundwater from the surrounding geological units and forming a sink in the groundwater regime. The water balance model (GHD, 2019) indicates the evaporation from the lake surface will concentrate salts in the pit lake slowly over time, with the pit lake salinity remaining below typical Permian strata salinity levels for the 500 year modelling period. The minimal impact considerations within the AIP require that:

1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.
2. 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.

The gradually increasing salinity will not pose a risk to highly connected surface water sources as the final void will remain a permanent sink with a steep hydraulic gradient between the mine and the surrounding Permian strata. This will mean that the evapo-concentrated salt will remain within the final void lake and therefore will not affect the beneficial use category of groundwater or the long-term average salinity in surface waters. The reduced groundwater flow from the Permian strata to the alluvium is expected to reduce the salt load to the Bowmans Creek alluvium resulting in an overall improvement in quality, despite the decline in quantity.

7.4 Uncertainty

The uncertainty in the model predictions introduced by model parameters was assessed using a nonlinear uncertainty analysis where numerous model parameters were changed at the same time. Appendix B presents the results of the uncertainty analyses. An uncertainty analysis involved changing model parameters to create 183 model realisations. A separate sensitivity analysis was also undertaken to assess the influence of uncertainty in spoil properties and the permeability of the block fault zone.

Predictive uncertainty analysis undertaken to assess the likelihood of groundwater inflow to the pit and impacts to groundwater receptors from mining induced drawdown concluded that the risk of significant impacts was low. Worse case predictions of groundwater take from the Permian and alluvial systems were less than WSP licences currently allocated to the Mount Owen Complex, with the exception of the unregulated alluvial Jerrys and Glennies Water Sources. It is unlikely the approved Glendell Pit and associated Glendell Pit Extension will have significant impacts on groundwater drawdown.

Sensitivity analysis was carried out by increasing the permeability of the block fault zone and revealed minimal sensitivity to groundwater drawdown and alluvial flow changes.

Post mining sensitivity analysis concluded equilibrium conditions within the Project Area are sensitive to the hydraulic and storage properties within the backfilled material. Extreme combinations of high recharge, low permeability and low storage promotes groundwater decant through the spoil into the surrounding strata. However, all scenarios predicted net sink conditions for the entire Glendell Pit Extension (i.e. groundwater gradients flow into the backfilled material and void).

8 Groundwater monitoring and management plan

The Mount Owen Complex operates in accordance with a Water Management Plan (WMP) which was prepared in consultation with NSW government agencies consistent with the requirements of the Glendell Consent and Mount Owen Consent. The WMP includes a standalone Groundwater Monitoring and Management Plan (GWMMP). The WMP describes the management of environmental and community aspects, impacts and performance relevant to the sites water management system.

The Mount Owen Complex already has an existing groundwater monitoring network as described in Section 5.2. The monitoring network is comprised of standard 50 mm or 25 mm PVC monitoring bores installed within the alluvial aquifers and the deeper Permian strata including coal measures. The network also includes arrays of VWPs cemented into selected drill holes to monitor pressure in deeper strata. This includes monitoring sites along Bowmans Creek, Yorks Creek, Bettys Creek and Swamp Creek installed within the alluvium and underlying Permian strata to compare to predictions of the numerical modelling.

Proposed mining activities will result in removal of existing groundwater monitoring bores that are within the Additional Disturbance Area. Glencore will determine appropriate replacement monitoring sites in liaison with DPIE Water post approval when updating the WMP to account for the Project.

Currently groundwater levels and field water quality (pH and EC) are measured in the monitoring bores on a monthly to quarterly basis, in addition to daily water level readings recorded by the dataloggers in selected monitoring bores and VWPs. 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 is 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.

Every six months samples are collected from a subset of bores for analysis of speciation, rare elements, and inorganics. The water quality analysis includes:

- pH, electrical conductivity (field measurements);
- Major ions - Ca, Cl, K, Na, Mg, SO_4, HCO_3;
- Alkalinity;
- Nutrients - Total P; and
- Total metals- Aluminium, Arsenic, Barium, Lithium, Manganese, Rubidium, Selenium, Strontium, Zinc, Boron.

Groundwater quality analysis should continue in the existing and any new bores to detect changes in groundwater quality during mining.

Like the water level monitoring, yearly reporting of the water quality results from the monitoring network should be included in the annual review. The Surface Water and Groundwater Response Plan currently provides triggers for pH and EC for selective bores within the network. The trigger levels have been calculated as the 80th percentile of baseline water quality data collected. The comparison of water quality measurements to the trigger levels will continue. The trigger levels are periodically reviewed, in consultation with relevant agencies, as additional monitoring information becomes available.

The WMP includes the requirement to monitor groundwater inflows to the mine and compare the results to the predicted inflow from groundwater modelling. The water balance method should be used to estimate the volume of free-flowing groundwater entering the mine workings. Additionally, every three years the validity of the numerical model predictions should be assessed and if the data indicates significant divergence from the model predictions, an updated groundwater model should be constructed for the simulation of mining.

9 Summary and conclusions

The groundwater assessment for the Project considered the impacts of extending the Glendell Pit towards the north into a previously unmined area. The only geological formation that is considered to constitute a potentially highly productive aquifer in the area of the Glendell Pit Extension is the Bowmans Creek alluvium, which is relatively thin but contains a permeable sand and gravel base that readily transmits fresh to slightly brackish groundwater. Bowmans Creek meanders through the flood plain adjacent to the Glendell Pit Extension and pools within the creek can form windows to the underlying water table. During drought conditions in 2018/2019 flow in Bowmans Creek has ceased and the water course reduced to a series of disconnected pools, interconnected through the alluvial groundwater system. Aquatic ecosystems in Bowmans Creek are therefore subject to this wetting and drying cycle imparted by climate. Vegetation occurs in a thin riparian zone along Bowmans Creek and potentially depends on the underlying alluvial water table where it is relatively shallow (<10 m below surface) immediately adjacent to the creek. There no known private bores extracting water from the Bowmans Creek alluvium in proximity to the Glendell Pit Extension, but potentially two bores installed within the underlying regolith strata.

The Project Area is surrounded by operating or completed open cut and underground mines targeting the same coal measures. The extensive mining history in the region means the geology of the area has been continually investigated and is well understood through drilling and observation in open cut and underground areas. Glencore operates many of the mining operations surrounding the Project and this allowed access to a range of datasets including geological models, groundwater monitoring and mine schedules for surrounding areas.

The existing groundwater monitoring network was supplemented with additional monitoring bores for the Project in 2012 and this has provided data to assess baseline conditions. It is evident in the datasets that the long history of mining and the close proximity of underground and open cut activities to the Project has resulted in the groundwater levels within the Permian coal measures being extensively depressurised. A cumulative impact on groundwater levels within the Permian strata is clearly evident. The depressurised coal seams occur in the Glendell Pit Extension and under the Bowmans Creek alluvial aquifer. Under the Bowmans Creek alluvium, the water level drawdown is sufficient to disconnect the Permian groundwater systems in coal seams from the overlying alluvium reversing hydraulic gradients from upwards to downwards. Despite downward gradients from the Quaternary alluvium to underlying Permian strata being established, there is no significant drawdown evident in water level records from the Quaternary alluvium that is readily attributable to mining. This is because vertical flows are expected to be small owing to limited vertical permeability through the interburden and the recharge to the alluvium from rainfall and river leakage readily makes up any vertical downward losses.

Quaternary alluvium also occurs along Yorks Creek and Swamp Creek which are tributaries of Bowmans Creek. These tributaries have small catchments and a significant alluvial plain has not formed in these areas. Compared to the Bowmans Creek floodplain, the alluvium is much thinner, comprised of less permeable sediments and of limited saturation or is dry. The Project proposes to remove alluvium associated with Yorks Creek and Swamp Creek. This will expose sections of alluvium in the western pit wall. Seepage from these areas into the Glendell Pit Extension is expected to be very low due to the limited saturated thickness in these areas. Similar areas of alluvium with limited saturated thickness have been mined through in Bettys Creek at North Pit and Glendell Pit without incident or impact. On this basis, and the modelled low levels of take, no engineering measures are considered warranted for control of seepages. Installing a barrier wall within the alluvium would not be effective due to the shallow depth of the alluvium proximal to the western limit of the Glendell Pit Extension, and the relatively thick permeable regolith underlying the alluvium. The barrier may have an impact on groundwater recharge through the shallow alluvium system, although the underlying regolith would hydraulically connect the shallow alluvial system to the disturbance area.

The existing information on the groundwater regime was used to calibrate a numerical groundwater flow model. The model was able to replicate the observed disconnection between the Permian coal seams and the alluvial groundwater systems that has resulted due to the cumulative impact of approved mining. Given the model replicated this key environmental process it was considered suitable for assessing the impact of the Project.

Numerical modelling indicates continuing the Glendell Pit to the north will further depressurise the coal seams targeted for mining. Localised areas of drawdown are predicted to occur within the Bowmans Creek alluvium in proximity to the areas where Yorks Creek and Swamp Creek will be removed. The predicted drawdown is up to 2 m in isolated areas. Monitoring indicates this is a fraction of the natural variability than has been measured up to 4 m. There are no known operating private water supply bores in the areas where the numerical modelling indicates the potential for drawdown.

Public domain datasets indicate riparian vegetation occurring along Bowmans Creek has the potential to depend on a shallow water table. This vegetation is not noted within the relevant water sharing plans as a significant groundwater dependent ecosystem and therefore the AIP thresholds do not apply. Potential impacts on terrestrial vegetation and aquatic ecosystems which may be impacted by changes in groundwater levels is considered further by Umwelt (2019).

Depressurisation generated by advancement of the Project will result in direct interception of groundwater in the coal measures and indirect influence on flows to the alluvial aquifers. The AIP requires the direct and indirect interception of groundwater to be accounted for with water licenses in each water source where take of water is predicted. The peak take from Jerrys Water Source is not predicated to occur until well into the operational phase of the Project and reaches 10 ML/year.

The open cut mining area will be gradually backfilled during mining. This will result in an elongated north south spoil pile with a residual open void situated at the northern extent of the Glendell Pit Extension. The spoils will slowly re-saturate with groundwater and rainfall seepage through the spoil surface forming a water table groundwater system in the mined area. Modelling indicates a northwards hydraulic gradient through the spoils to the open void at the north as the groundwater system rebounds to a new equilibrium condition. The evaporative pumping effect from the open void will exceed inputs from rainfall, runoff and groundwater, resulting in a water level in the open void remaining below the regional water table. The effect of this will be to draw in groundwater to the open void and create a permanent zone of residual drawdown. A residual direct and indirect take of groundwater will occur post mining due to the evaporative pumping effect of the void. Glencore holds sufficient water licenses to account for the long term take by permanent retirement of necessary units, with the exception of the unregulated Jerrys and Glennies Water Sources. The evaporative pumping effect in the final void will slowly concentrate salts, with the depressed water table preventing any outflow to the surrounding environment. Modelled salinity levels in the pit lake remain below salinity levels in the Permain aquifers for well over 500 years.

The limited impacts detected in monitoring to date, the limited future impact predicted by modelling, and the existing management plans and measures already in place at the Mount Owen Complex mean that no additional groundwater impact mitigation measures are recommended for the Project. An expansive network of monitoring bores already exists, and groundwater levels and quality should continue to be monitored in accordance with the approved WMP. 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 WMP protocols.

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11. Glossary and acronyms

AGE	Australasian Groundwater and Environmental Consultants Pty Ltd
AHD	Australian Height Datum
AIP	Aquifer Interference Policy
BSAL	Biophysical Strategic Agricultural Land
CRD	Cumulative Rainfall Departure
DoEE	Commonwealth Department of the Environment and Energy
DPIE	NSW Department of Planning, Industry and Environment
EIS	Environmental Impact Statement
GDE	Groundwater Dependent Ecosystem
Glencore	Glencore Coal Pty Limited
GWMMP	Groundwater Monitoring and Modelling Plan
IESC	Independent Expert Scientific Committee
ML	Megalitres
MNES	Matters of National Environmental Significance
Mount Owen	Mt Owen Pty Limited
Mtpa	Million tonnes per annum
Pinneena	Department of Primary Industries – Water supplied database of registered groundwater bores
The Proponent	Glendell Tenement Pty Ltd
SILO	SILO is a database of historical climate records for Australia
SRLU Policy	Strategic Regional Land Use Policy
VWP	Vibrating wire piezometer
WAL	Water access licence
WMP	Water management plan
WSP	Water Sharing Plan

Appendix A Limit of alluvium investigation

A 1 Objectives and scope

Figure A 2-1 shows the extent of Highly Productive Alluvium determined by DPI-Water for Aquifer Interference Activities (2012a, 2012b). The extent of Highly Productive Alluvium is defined based on public domain geology maps and requires ground truthing where mining is proposed in proximity. The first attempt to better define the extent of alluvial sediments was conducted by Jacobs (2014) as part of the Mount Owen Continued Operations Project. The groundwater assessment for the Glendell Continued Operations Project included further investigations to more accurately define the extent and thickness of alluvial sediments associated with Bowmans Creek, Swamp Creek and Yorks Creek in the vicinity of the proposed Glendell Pit Extension. The work program comprised review of public domain datasets that could indicate the extent and thickness of alluvial sediments, as well as field investigations in areas where further data collection was required.

A 2 Extent of alluvium

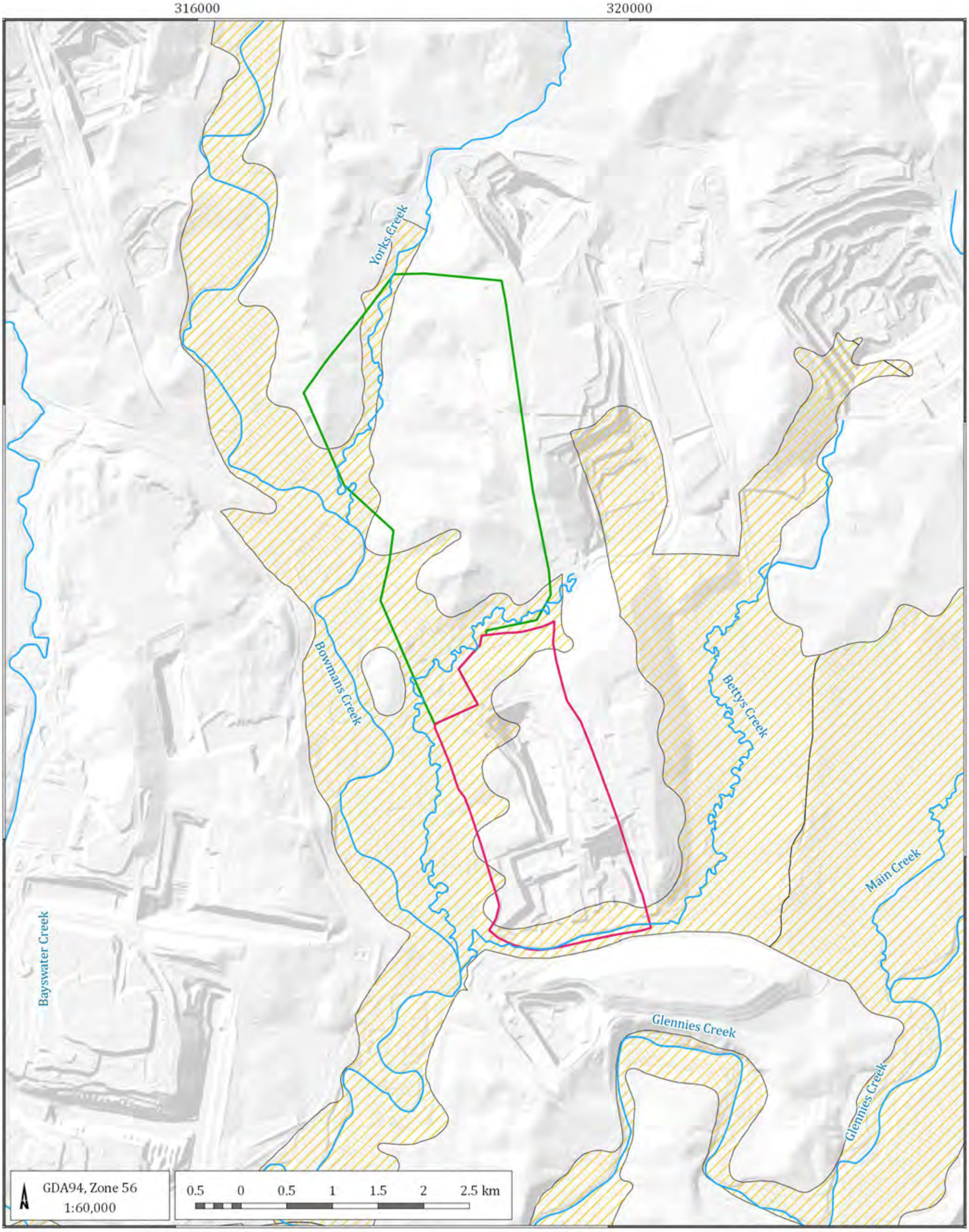
The work program comprised a desktop review, field investigations and re-interpretation of the limit of alluvium. The extent of alluvial sediments was assessed using datasets for soils and terrain elevation, supplemented with information from test pits excavated within and adjacent to the Glendell Pit Extension area.

A 2.1 Desktop review

An initial desktop review of the following data sources was conducted to gain an appreciation of the extent of the alluvial sediments. The following spatial information was reviewed:

- Commonwealth Scientific and Industrial Research Organisation (CSIRO) Soil Landscape Series that includes maps indicating the depth of regolith, Wilford *et al* (2015);
- Geoscience Australia (GSA) radiometric maps, GSA (2015);
- soil maps used to identify the extent of Biophysical Strategic Agricultural Land (BSAL), DPI (2012);
- Aquifer Interference Policy (AIP) highly productive alluvium maps, DPI-Water (2012b);
- Office of Environment and Heritage (OEH) maps, including:
    - Australian Soil Classification (ASC) Soil Type map of NSW;
    - Great Soil Group (GSG) Soil Type map of NSW;
    - Soil Landscape Regolith Stability of North-East New South Wales; and
    - Hydrologic Group of Soils in NSW, OEH (2017).
- monitoring bore lithology and construction logs;
- work conducted by Jacobs (2014) to define the limit of alluvium as part of the Mount Owen Continued Operations Groundwater Impact Assessment report; and
- LiDAR imagery supplied by Glencore.

The data review indicated a varying alluvial boundary depending on the data source, and therefore field investigations were undertaken to better define the limit of the alluvial sediments.



LEGEND

- Drainage
- Approved Glendell Pit
- Proposed Glendell Pit Extension
- Highly productive alluvium (DPI Water 2012)

Glendell Continued Operations GIA (G1874C)

Highly productive alluvium

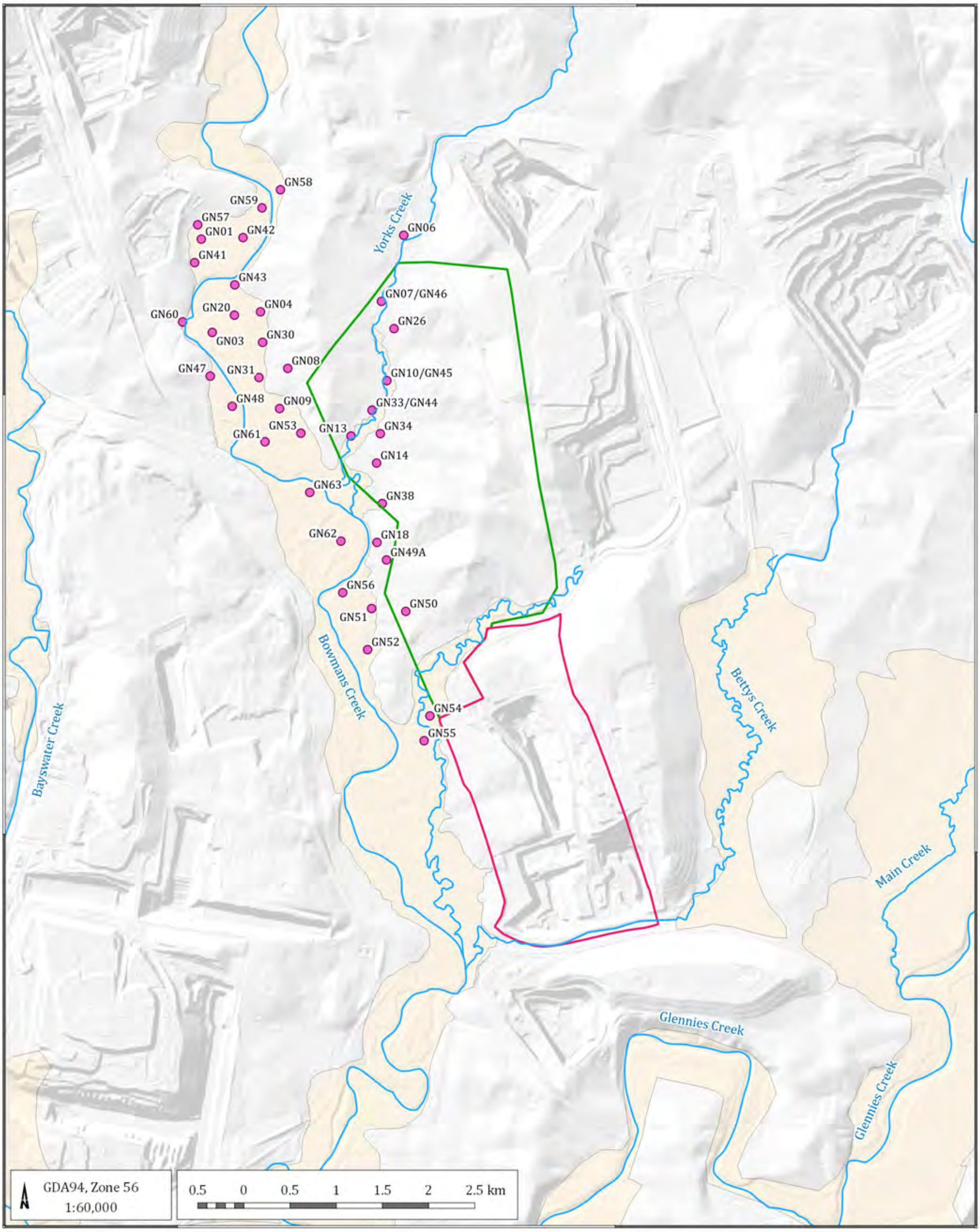
DATE 30/07/2019

FIGURE No: **A 2-1**

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\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\A2.1_G1874C_test pit locations.qgs

A 2.2 Field investigations

A series of 38 test pits were excavated to better define the occurrence and limit of the alluvial sediments within the Glendell Pit Extension area and surrounds. The spatial information from the desktop study and the limit of the alluvium determined by Jacobs (2014) was used to guide the locations of the test pits. The test pits were excavated between 23rd and 30th August 2017. A backhoe was used to excavate to a maximum depth of four metres below ground level (mbgl) or to refusal on bedrock. The excavated material was logged onsite with a summary of the intersect material provided in Table A 2-1. The locations of the test pits are shown on Figure A 2-2.



LEGEND

- Drainage
- Approved Glendell Pit
- Proposed Glendell Pit Extension
- Alluvium boundary
- Test pit

Glendell Continued Operations GIA (G1874C)

Test pit locations

AGE

DATE 30/07/2019

FIGURE No: **A 2-2**

Source: Glen R.A. and Beckett J., 1993, Hunter Coalfield Regional Geology 1:100 000, 2nd edition. Geological Survey of New South Wales, Sydney;
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Table A 2-1 Test pit details

Pit ID	soil type	Depth (mbgl)	alluvium details			
			interval (mbgl)	thickness (m)	saturation	water (mbgl)
GN01	alluvium	3.3	0.2 - 3.3	> 3.3	moist	-
GN03	alluvium	3	0.2 - 3	> 3	moist	-
GN04	alluvium	3.5	0.25 - 3.5	> 3.5	moist	-
GN06	colluvium	3.2	Nil	Nil	moist / wet	-
GN07/GN46	colluvium	3.6	Nil	Nil	dry	-
GN08	colluvium	2.1	Nil	Nil	dry	-
GN09	alluvium	3.6	0.4 - 3.6	> 3.6	dry	-
GN10/GN45	alluvium	3.2	0.3 - 2.6	2.6	moist / wet	3
GN13	alluvium	4	0.1 - 4	> 4	wet	3.8
GN14	colluvium	3.2	Nil	Nil	dry	-
GN18	colluvium	1.7	Nil	Nil	dry	-
GN20	alluvium	3.2	0.4 - 3.2	> 3.2	dry	-
GN26	colluvium	3.5	Nil	Nil	dry	-
GN30	alluvium	3.5	0.4 - 3.5	> 3.5	dry	-
GN31	alluvium	4	0.5 - 4	> 4	dry	-
GN33/GN44	alluvium	3.6	0.1 - 3.6	> 3.6	wet	3.55-3.6
GN34	colluvium	3	Nil	Nil	dry	-
GN38	colluvium	3.2	Nil	Nil	dry	-
GN41	alluvium	3.4	0.35 - 3.4	> 3.4	dry	-
GN42	alluvium	3.3	0.2 - 3.3	> 3.3	dry	-
GN43	alluvium	2.4	0.2 - 2.4	> 2.4	wet	2.1
GN47	alluvium	3.4	0.2 - 3.4	> 3.4	moist	-
GN48	alluvium	3.2	0 - 3.2	> 3.2	moist	-
GN49A	colluvium	3.6	nil	nil	dry	-
GN50	colluvium	3.5	nil	nil	dry	-
GN51	alluvium	3.5	0.1 - 3.5	> 3.5	wet	3.45 - 3.5
GN52	alluvium	3	1 - 3	> 3	wet	2.8
GN53	alluvium	4	0.4 - 4	> 4	moist	-
GN54	alluvium	3.5	0.15 - 3.5	> 3.5	moist	-
GN55	alluvium	3.5	0 - 3.5	> 3.5	moist	-
GN56	alluvium	3.3	0.4 - 3.3	> 3.3	moist	-

Pit ID	soil type	Depth (mbgl)	alluvium details			
			interval (mbgl)	thickness (m)	saturation	water (mbgl)
GN57	alluvium	3.2	1.5 - 3.2	> 3.2	dry / moist	-
GN58	alluvium	3.2	0.3 - 3.2	> 3.2	moist	-
GN59	alluvium	3.1	0.2 - 3.1	> 3.1	moist	-
GN60	alluvium	2.71	0 - 2.7	2.7	dry	-
GN61	alluvium	3.4	0.45 - 3.4	> 3.4	dry	-
GN62	alluvium	3.2	0.8 - 3.2	> 3.2	moist	-
GN63	alluvium	3.5	0.7 - 3.5	> 3.5	moist	-

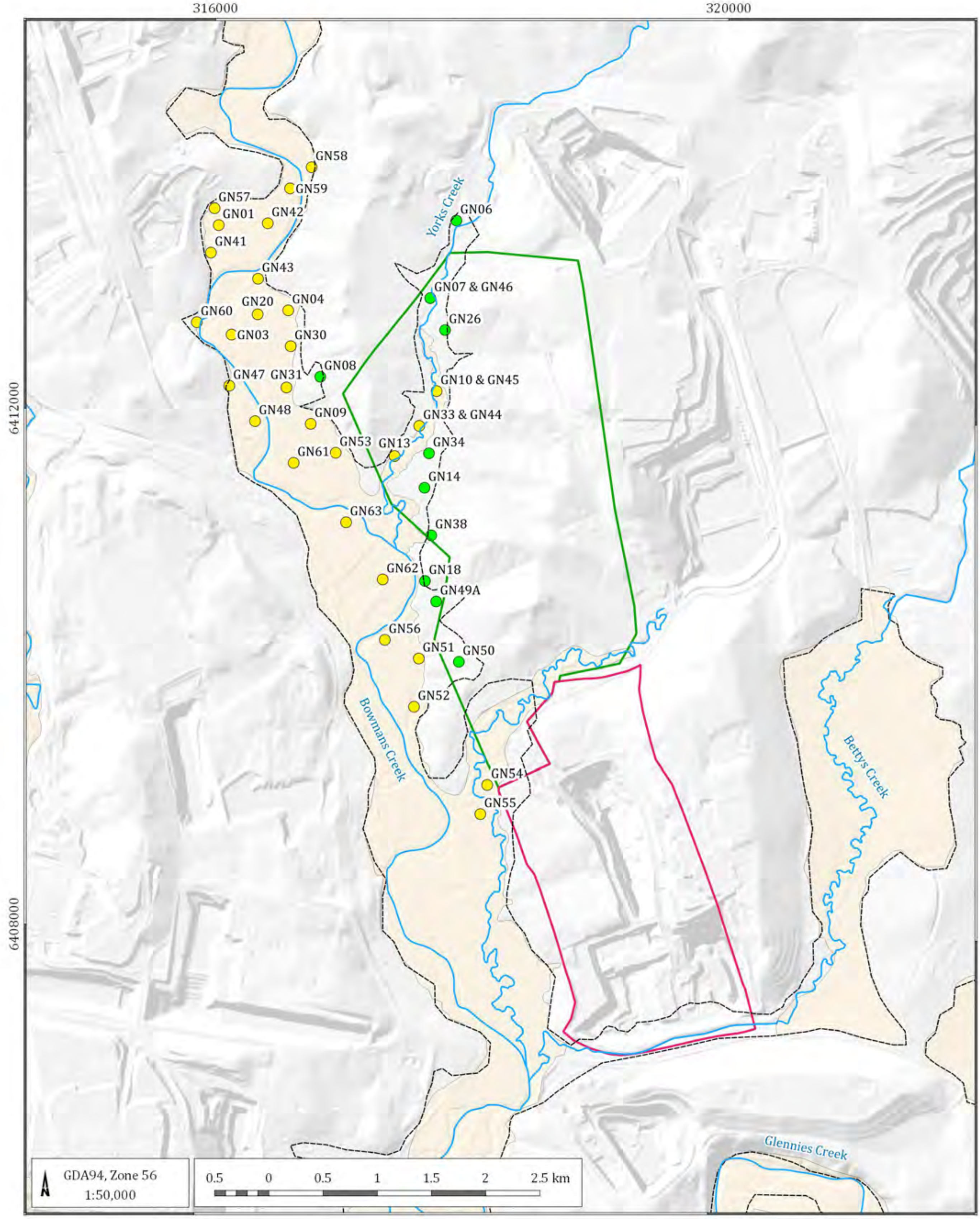
A 2.3 Interpretation

The information gathered from the test pits was used to either confirm the boundary of the alluvial sediments defined by Jacobs (2014), or to adjust the boundary where required. Borehole logs from previously drilled monitoring bores were also used to assist in defining the limit of alluvium. Figure A 2-3 shows the updated limit of alluvial sediments compared with that previously defined by Jacobs (2014).

The fieldwork indicated that the extent of the Bowmans Creek alluvial plain is similar that determined by Jacobs (2014). This was due a clear change in slope between the flood plain and the adjacent hillslopes where colluvial material occurs.

The desktop study suggested that Yorks Creek may not host any alluvium, however, test pits determined that a narrow strip of alluvium is present along the drainage only. The extent of the Yorks Creek alluvium was determined to be less extensive than determined by Jacobs (2014). The extent of alluvium narrows in the upstream areas of Yorks Creek, with the alluvial plain flanked by colluvial hillslopes and bedrock outcrops. Several alluvial terraces are visible towards the confluence with Bowmans Creek.

Two test pits were excavated in the lower areas of Swamp Creek towards the confluence with Bowmans Creek. The Swamp Creek alluvial extents were not refined based on fieldwork results, as they are part of a development consent boundary associated with Glendell Open Cut Mine and the area logistically available for test pitting was partially limited due to active mining operations. A more refined alluvium boundary, previously determined by Mackie Environmental Research as part of an internal Glencore review was used to update the Swamp Creek boundary. The boundary resulted in slightly extended, but thinner alluvial plain that excluded the Mining Infrastructure Area (MIA).



LEGEND

- Drainage
- Approved Glendell Pit
- Proposed Glendell Pit Extension
- Alluvium boundary as defined by LiDAR (Jacobs 2014)
- Revised alluvium extent (AGE 2018)

Test pit bores

- Alluvium
- Colluvium

Glendell Continued Operations GIA (G1874C)

Revised alluvial extent

AGE

DATE 30/07/2019

FIGURE No: **A 2-3**

Source: Glen R.A. and Beckett J., 1993, Hunter Coalfield Regional Geology 1:100 000, 2nd edition. Geological Survey of New South Wales, Sydney;
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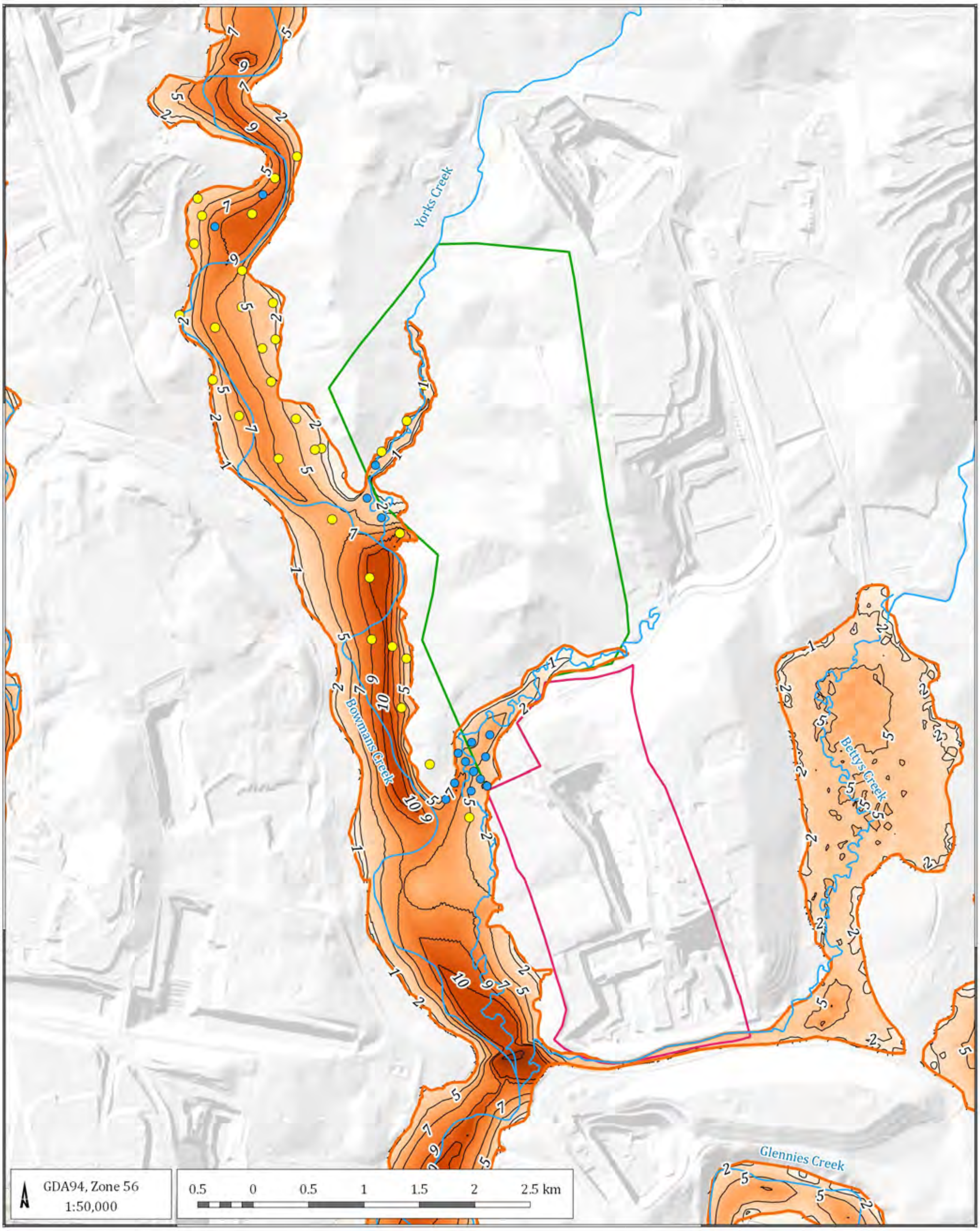
A 3 Thickness of alluvium

The thickness of the alluvial sediments was also reviewed for the purposes of updating the conceptual and numerical models of the groundwater regime. The thickness of the alluvium was determined using information from existing monitoring bores as well as the test pits where the base of alluvium was determined. Three additional monitoring bores were also installed within the Bowmans Creek alluvium in March 2018 by Jacobs (2018), and the information from these bores was also used to assess the thickness of the alluvium. A total of 61 drillhole or testpit locations were reviewed with 26 sites providing information on the thickness of the alluvium (23 bores and two alluvial test pits).

Figure A 3-1 shows the updated alluvial thickness. The figure shows the alluvium is typically up to 10 m thick within the Bowmans Creek flood plain and slightly thinner in Yorks and Swamp Creeks where it is up to 6 m to 8 m in thickness.

The saturated thickness within Bowmans Creek alluvium appears to be patchy and variable depending on location. 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.



LEGEND

- Drainage
- Approved Glendell Pit
- Proposed Glendell Pit Extension
- Revised alluvium extent (AGE 2018)

Test pits and bores

- Alluvial Test Pit
- Bore

Thickness (m)

- 1
- 2
- 5
- 7
- 9
- 10
- 15
- 20
- 25
- contour line

Glendell Continued Operations GIA (G1874C)

Interpolated thickness of alluvium

AGE

DATE 10/10/2019

FIGURE No: **A 3-1**

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\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\A2.1_G1874C_test pit locations.qgs

A 4 References

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Appendix B Numerical modelling

B 1 Objectives

Predictive numerical modelling was undertaken to assess the impact of the Project on the groundwater regime. The key objective was to allow the risks to the groundwater regime to be assessed using a groundwater model to systematically investigate the causal pathways for potential impacts on water resources and water-dependent assets. Outputs from this modelling process were:

- estimates of the volume and rate of groundwater directly intercepted by the mine workings as a function of mine position and timing;
- estimates of the volume of groundwater indirectly affected or intercepted from adjacent water sources outside the Project footprint;
- the amount water entitlements required to account for the water directly and indirectly intercepted by the Project;
- estimates of the extent and magnitude of drawdown in surrounding water sources and the potential for the Project to induce drawdown that exceeds the threshold levels of impact for receptors specified within in the AIP;
- the nature of changes to the groundwater regime post mining and the potential to exceed thresholds for water level and quality specified in the AIP for water sources and water dependent assets;
- areas of potential risk where groundwater impact mitigation/control measures may be necessary; and
- the influence of uncertainty in model parameters on the magnitude of impacts predicted by the model and the need for any further management and mitigation measures to ensure preparedness for uncertainty.

The key to the modelling exercise is robust conceptualisation of the groundwater regime that can be represented by a numerical model. 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 main report details the conceptual understanding of the hydrogeological regime at the project site. The purpose of this appendix is to describe the model setup, calibration, predictive scenarios and uncertainty analysis undertaken with the numerical model. The model predictions from the basecase model (the 'best' calibrated model) are summarised in the main report but not included here to ensure there is no duplication within the documents.

B 2 Model construction and development

B 2.1 Model version and update log

The significant development of mining in the region surrounding the Project means there have been many previous groundwater modelling efforts to estimate the impact of mining on the groundwater regime. The numerical model utilised for the Project was a further iteration of the numerical model previously developed for:

- Ravensworth underground (Mackie Environmental Research, 2011);
- Liddell mine (SKM, 2013);
- Mount Owen mine (Jacobs, 2014);
- Integra mine (AGE, 2017); and
- Mount Owen mine (AGE, 2018).

An existing numerical model was utilised to ensure the cumulative impacts from already approved surrounding operations were represented as consistently as possible with previous approvals. This approach aligns with the 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) provided 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 B 1 below summarises the model version and modifications undertaken since development of the model in 2011.

Table B 1 Model versions

Model version	Model build	Project	Description of modification(s)	Model version number
1	0	Ravensworth	• 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

Model version	Model build	Project	Description of modification(s)	Model version number
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
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
7	2	Liddell	• incorporation of Liddell base case into Version 7	7.2 Liddell

Model version	Model build	Project	Description of modification(s)	Model version number
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 • inclusion of additional alluvial monitoring data	8
8	1	Mount Owen	• predictive simulations for Mount Owen Continued Operations EIS	8.1 Mount Owen
9	0	Mount Owen Mine and Integra Underground Mine	• modelling taken over by AGE • converting model to MODFLOW USG including development of new model mesh and layers • refining model mesh along Bettys Creek and Main Creek alluvial aquifers • 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 mining at Mt Owen Mine • predicting impacts on groundwater regime for proposed mining at Integra Underground and Mount Owen	9
9	1	Mount Owen Mine and Integra Underground Mine	• Update of open cut mine plan at Mount Owen North Pit to extend to the end of 2036	9.1 Mount Owen

Model version	Model build	Project	Description of modification(s)	Model version number
9	2	Liddell Open Cut	• Reduce the depth of Liddell Open Cut to the base of the Barrett Seam (currently approved to the Hebden Seam) • update of the planned end of mining/beginning of recovery year to 2023 (instead of 2022) • introduction of the Davis Creek Fault and Dyke into the model, represented by the Horizontal Flow Barrier (HFB) package • representation of historical workings of Liddell Underground Mine in the groundwater model, using data from SKM's (2014) groundwater model and refinements • representation of coal barrier walls separating different areas of Liddell Underground Mine in the model • introduction of controlled water levels in the different areas of Liddell Underground Mine into the model, following detailed data provided by LCO	9.2 Liddell (unpublished version)
10	0	Glendell	• refinement of Glendell and Mount Owen approved mine sequences and plans • revision of alluvial thickness along Bowmans and Glennies Creek • review and updates to coal seam surfaces based on client's geological models • extending northern boundary to reduce potential for boundary condition to influence predictions • refinement of model cell resolution around the Glendell mining area and Bowman Creek • introduction of pilot point multipliers to improve calibration and uncertainty analysis (Kx, Kz, Sy, Ss, and recharge) • recalibration (steady state and transient) to extended calibration dataset using surrogate child/parent technique • updated stochastic predictive simulations of proposed operations	10

The sections below summarise the model set-up and calibration.

B 2.2 Model uncertainty

Middlemis and Peeters (2018) indicate sources of uncertainty affecting numerical modelling simulations can be grouped as follows:

- structural/conceptual – geological structure and hydrogeological conceptualisation assumptions applied to derive a simplified view of a complex hydrogeological reality (any system aspect that cannot be changed in an automated way in a model);
- parameterisation – hydrogeological property values and assumptions applied to represent complex reality in space and time (any system aspect that can be changed in an automated way in a model via parameterisation);
- measurement error – combination of uncertainties associated with the measurement of complex system states (heads, discharges), parameters and variability (3D spatial and temporal) with those induced by upscaling or downscaling (site-specific data, climate data); and
- scenario uncertainties – guessing future stresses, dynamics and boundary condition changes (e.g. mining, climate variability, land and water use change).

Each of these sources of uncertainty are discussed within this document within relevant sections below. Attempts are also made to identify inherent bias and transparently communicate this as recommended by Middlemis and Peeters (2018).

B 2.3 Model code

The model utilises the MODFLOW-USG code to simulate groundwater flow in the Project region. This model code was considered to remain suitable to meet the model objectives because it:

- allows use of an unstructured mesh where cells can be refined around localised features such as rivers, alluvial aquifers and mining, and larger cells used where refinement is 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 therefore the ability to conduct stochastic uncertainty analysis; and
- better represents flow transfer processes between systems such as bedrock and alluvial groundwater systems through the pinching out of layers.

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 (2018). The mesh was generated using Algomesh (HydroAlgorithmics, 2014).

B 2.4 Model design

B 2.4.1 Extent and boundaries

The Project is located in an area where a cluster of mining activities are situated and create a cumulative impact on the groundwater regime. The model domain was designed to cover the relevant mining activities, and also include a spatial buffer to ensure that the limits of the model domain were sufficiently remote from the mining activities to reduce the impact of assumed boundary conditions on the model outcomes. The model domain was approximately 22 km wide (west to east direction) and 20.5 km long (north to south direction) as shown in Figure B 1.

The shape of the model was aligned with key regional geological and hydrogeological features as follows:

- Northern boundary – set approximately 7 km north of the Project this boundary extends beyond the Hunter Thrust fault that separates the 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 western boundary – set approximately 7 km north-west of the Project, where the Wittingham Coal Measures outcrop and terminate; and
- Southern boundary – set at approximately 9 km south at a distance beyond the limit of influence of the Project.

Prior to version 9, 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 from up gradient catchments that occur to the north-east of the Project site. The revised model represents the non-coal strata east of the fault as a separate groundwater model layer. This layer does not laterally connect to the terminated strata at the fault, but flow occurs into the layers vertically. General head boundaries utilise a conductance rate calculated using the dimensions of the model cells, the distance to the neighbouring cell, and the calibrated horizontal hydraulic conductivity. Constant head cells were assigned where Lake Liddell occurs in an area on the north-western boundary of the numerical model. The general head and constant head boundary cells in the model are displayed in Figure B 1.

The uncertainty introduced to the model depends on the data used to develop the assigned boundary conditions. The boundary conditions are influenced by the ground surface in the model which is represented at the model extents using the publicly available 1 second SRTM dataset which is known to be vertically accurate to 6.0 m over Australia with 90% confidence[1]. This accuracy at the model boundaries is relatively low compared to the more accurate LIDAR dataset used within the Project area, and is expected to have introduced some uncertainty to the groundwater flows at the model extents. However, due to the distance of the model boundaries from the project area, the uncertainty introduced by the ground surface elevations is unlikely to significantly affect the uncertainty in impacts generated by the Project.

B 2.4.2 Grid

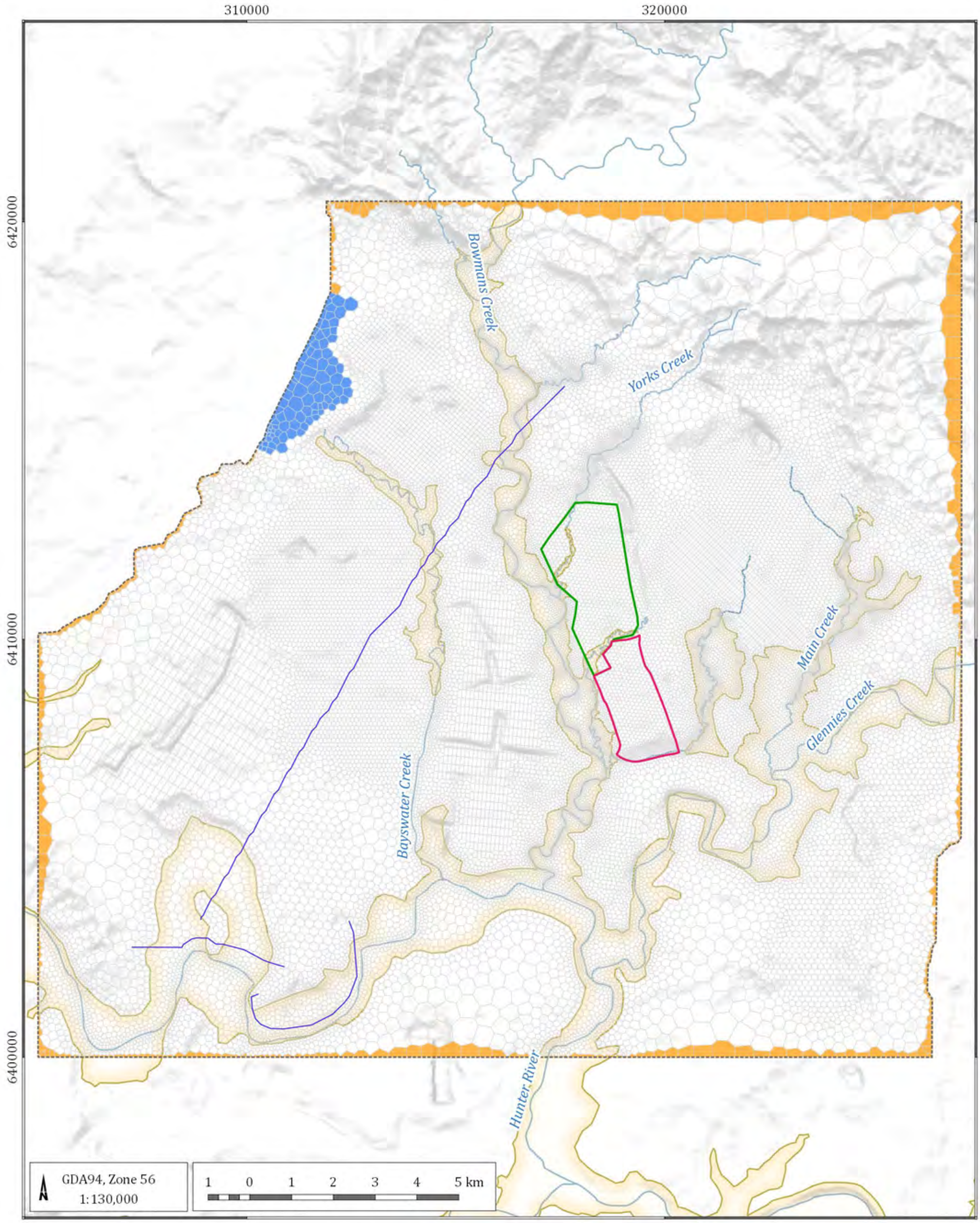
The model domain was discretised and arranged into 21 layers comprising up to 51,132 cell nodes in each layer with the dimensions of the cells varying according to the features that required representation. The following cells dimensions where adopted:

- longwall mining areas – 75 m x 150 m rectangular cells aligned to longwall panels where possible;
- open cut areas – 100 m x 100 m voronoi cells;
- streams and alluvial flood plains – varying from 20 m x 20 m to 150 m x 150 m; and
- potential GDEs within alluvial flood plains – 20 m x 20 m.

[1] NASA et al, The Shuttle Radar Topography Mission, *Data Validation and Applications*, June 14-16, 2005

Figure B 2 and Figure B 3 show the cell size adopted in the vicinity of the Project to reduce uncertainty associated with the scaling of field data to the model scale. The finer scale cells were created where more closely spaced monitoring bores occur within the alluvium associated with Bowmans, Yorks and Swamp Creeks to allowing some spatial variability in model parameters to be represented during the calibration process. A zone of model cells with a dimension of 60 m x 60 m was created between the proposed western edge of the Project and the Bowmans Creek alluvial aquifer. The purpose of these cells was to ensure sufficient simulation points existed in the model to represent a steep zone of depressurisation developing between the Project area and the adjacent alluvial water source if required.

Overall, the model comprised 590,771 cells across the 21 layers with a significantly reduced model run time than predecessors.



LEGEND

- Drainage
- Horizontal Flow Barrier (HFB)
- Model boundary
- Model mesh
- Approved Glendell Pit
- Proposed Glendell Pit Extension
- Constant Head Cells
- General Head Boundary Cells

Glendell Continued Operations GIA (G1874C)

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

AGE

DATE 30/07/2019

FIGURE No: **B 1**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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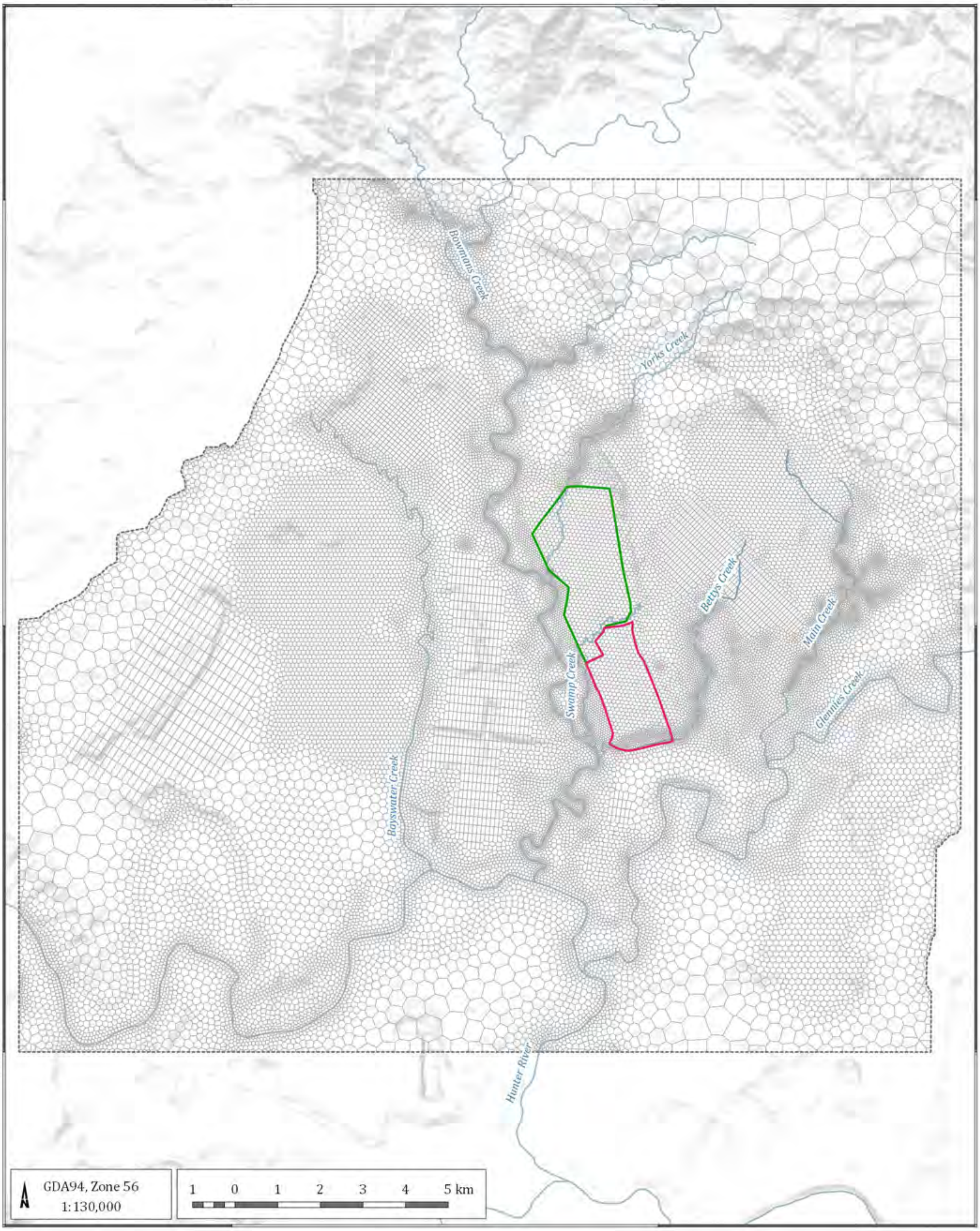
The model domain is extensive and therefore includes numerous known, and many likely unidentified faults. The properties of the faults are not known and are therefore not afforded any special treatment within the model. The exception was a significant fault that strikes in a north easterly orientation adjacent to the Liddell mine. Mining operations suggest this fault retards groundwater flow across it, and it was represented in the model using a horizontal flow barrier.

The model includes the full extents of the existing Glendell Mine as well as the full extents of:

- Mount Owen Mining Complex (including MOD2 that is being determined by the Independent Planning Commission at the time of writing);
- Integra Underground Mine;
- Rix Creek North Mine (formerly Integra Open cut);
- Liddell Mine;
- Ashton Open cut and Underground Mine;
- Ravensworth Operations; and
- Hunter Valley Operations (HVO) North.

The approved mining areas were encompassed within the model domain as most target equivalent coal seams proposed for mining at the Project site and are necessary to represent and assess the magnitude of cumulative impacts.



LEGEND
- Drainage
- Model boundary
- Model mesh
- Approved Glendell Pit
- Proposed Glendell Pit Extension

Glendell Continued Operations GIA (G1874C)

Grid layout

DATE 30/07/2019

FIGURE No: **B 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.;
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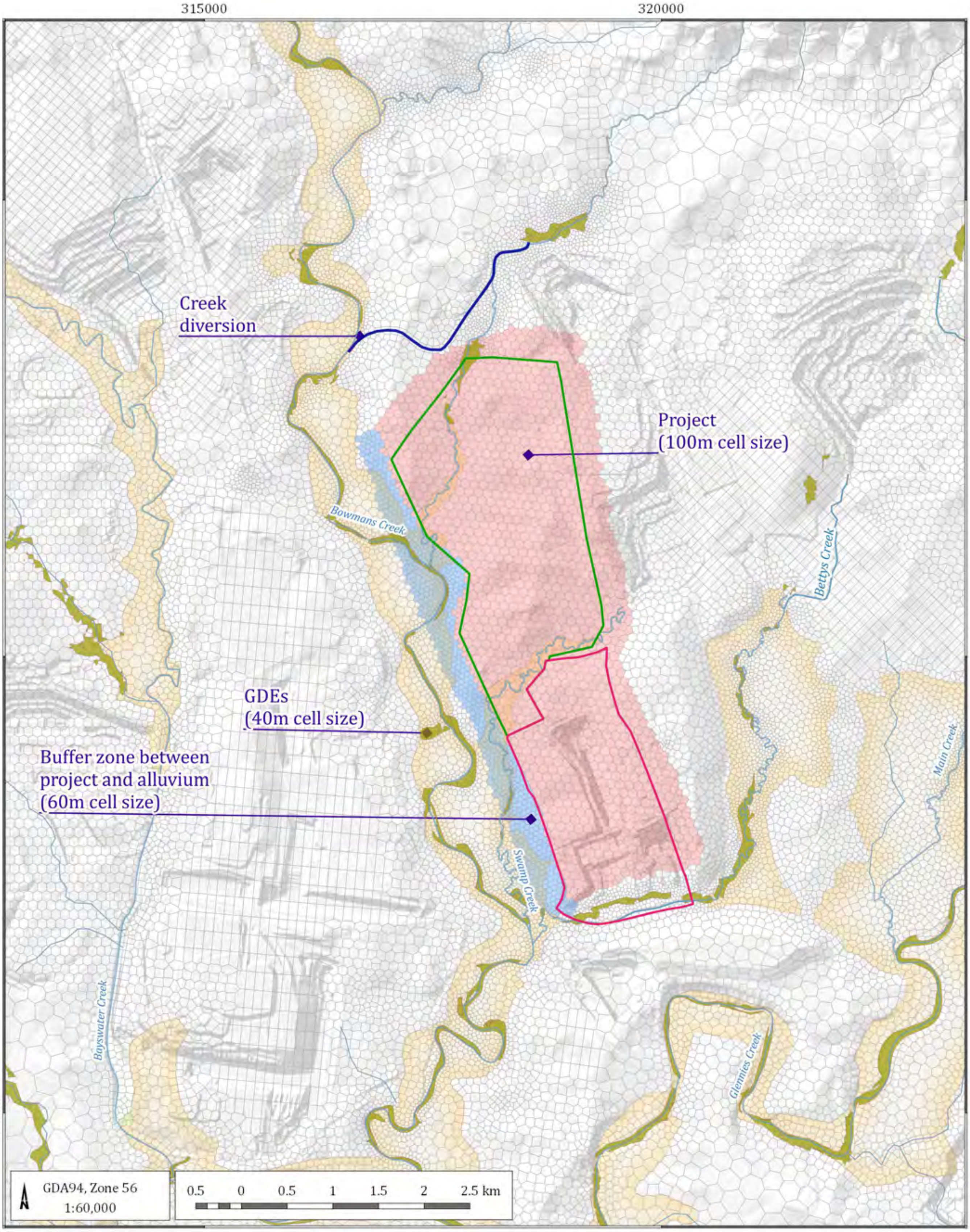

LEGEND
- Drainage
- Approved Glendell Pit
- Proposed Glendell Pit Extension
- Model mesh
- Project boundary
- Buffer zone between Glendell Pit Extension and Bowmans Creek alluvium
- High potential GDE - Terrestrial
- Alluvium boundary

Glendell Continued Operations GIA (G1874C)

Grid layout (Project area)

AGE

DATE 30/07/2019

FIGURE No: **B 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.;
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B 2.4.3 Model Layers

The key hydrostratigraphic units within the Quaternary and Permian formations identified in the conceptual model (refer main report) were represented in the numerical model with 21 separate layers (Table B 2). Model layers were created to separately represent the following hydrostratigraphic units:

- Quaternary alluvium;
- surficial weathered Permian formations;
- coal seams (groups of seam plys); and
- non-coal interburden strata that separating the coal seams.

Middlemis and Peeters (2018) describe the model surfaces as a structural and conceptual source of uncertainty in the numerical model that cannot be changed in an automated way in a model. The sources of data and uncertainty in the model surfaces are discussed for each hydrostratigraphic unit below.

Quaternary alluvium

The extent and thickness of the Quaternary alluvium in the numerical model was based on regional geology maps and refined in areas of the model where site specific data was available. Areas where site specific investigation data has been utilised to update the model are along Main Creek (AGE, 2018) and along Bowmans, York and Swamp Creek (refer Appendix A). The investigative work undertaken to refine the extent and depth of the alluvium along Bowmans Creek resulted in a significant reduction in the alluvial thickness being represented in the numerical model, from about 20 m along the deepest part of the paleochannel to typically less than 10 m over most of the flood plain area west of the Project (refer Section 4.2 in the main report).

The field investigations undertaken for the Project are considered to have reduced the uncertainty associated with the extent and thickness of the alluvial aquifer close to the mining area. Whilst the updated surfaces for the base of the Quaternary alluvium in the Project area were improved from previous realisations, there remains some inherent uncertainty in the exact thickness of alluvium where investigative drilling data is not available. This is of course an inherent uncertainty in all groundwater models. If in reality the Bowmans Creek alluvial sequence is thinner in some areas than represented in the numerical model the impact of the Project could be more significant, and likewise if the alluvium is thicker in some areas than represented in the numerical model the drawdown impact in reality could be less than predicted by the model.

Weathered Permian

Surficial weathering of outcropping Permian bedrock was represented in the model as a separate hydrostratigraphic unit. The depth of the weathering surface in the numerical model was based on geological models provided by the proponent for mining areas at Liddell mine, Ravensworth Operations and the Mount Owen Complex including Glendell. The weathering surface has been gradually updated over time as the model has been updated to assess the impact of surrounding Glencore (formerly Xstrata) Projects.

Because mining is active at all of the above sites the Permian weathered zone is readily observable in the open cut mining areas. The depth of weathering surface typically has a transitional, rather than a sharp well defined boundary to underlying unweathered fresh rock, and its inherent uncertainty is therefore higher than compared to for example a coal seam that commonly has a readily definable unambiguous boundary that can be measured to an accuracy of several centimetres. However, the direct observations of the weathering in the mines, along with large exploration drilling datasets is expected to have resulted in the weathering surface being readily identifiable to within an estimated accuracy of ±5 m to 10 m.

The top of the Permian weathering surface directly underlies the base of the Quaternary alluvium along Bowmans Creek and therefore has the potential to be a pathway for transmission of groundwater to the mining areas. If this were to result in impact upon the alluvial aquifer the weathered zone would be considered a causal pathway, which is defined by Middlemis and Peters (2018) as *"the logical chain of events either planned or unplanned that link coal resource development and potential impacts on water resources and water-dependent assets."* Variability in the thickness of the weathering surface would therefore be expected to influence the magnitude of the impact predicted upon the alluvial water sources and water dependent assets. However as noted the significant geological datasets available for the region, and readily observable weathered zone characteristics is surrounding mines means this uncertainty has been reduced to as low as practicably possible if compared to a greenfield region.

Permian coal seams and interburden

As noted previously the numerical model contains layers to represent the key interburden and coal seams intersected by mining operations within the model domain. In a similar process to the weathered zone the interburden and coal seams were sourced from geological models provided by the proponent which have been gradually updated over time as the model has been used to assess the impact of mining at Liddell, Ravensworth Operations, Integra and the Mount Owen Complex. A further review of the numerical model against updated geological models was conducted for the Project. Geological models for Liddell mine and Glendell mine were obtained and the surfaces for key coal seams compared to those existing in the groundwater model. Areas where differences were noted exceeding in the order of 10 m were updated in the numerical model to reflect the most recent geological models.

Similar to the weathered zone the surfaces for the key coal seams and intervening interburden are considered to be "relatively' accurate as they are informed by direct observation within mining areas and networks of exploration drill holes across the mining areas. The nature of these layers also means that the distinct transitions between the layers is readily identifiable to an accuracy of several centimetres. The accuracy of the coal seams and interburden surfaces becomes less certain in areas beyond the extent of the mining company geological models where the surfaces have been extrapolated based on less data. In proximity to the Project, these data poor areas occur only to the south, as the surfaces elsewhere are based on geological model data from Ravensworth Operations, Liddell and Mount Owen mine. The uncertainty in the Permian model layers is therefore considered to be have reduced as far as possible, and is significantly better than a greenfield area with limited mining history.

It is considered unlikely that any small inaccuracies in the Permian surfaces will introduce significant uncertainty to the model for a number of reasons. This is because the coal seams and interburden are confined layers and the response induced in these layers by mining activities is based on the layer transmissivity and the adopted specific storage. The coal seams and are also relatively deep compared to the Quaternary alluvium and weathered Permian strata and they remain confined until mining encroaches in close proximity. It is considered significant inaccuracy in the coal seam surfaces would need to exist before predictions would be significantly affected.

Figure B 4 and Figure B 5 show graphically the model layers in 3D oblique views. Figure B 4 shows the model viewed from the south looking to the north, with Figure B 5 providing a view into the model through a cut out into the Project area.

Table B 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 Plain 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 Barett 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

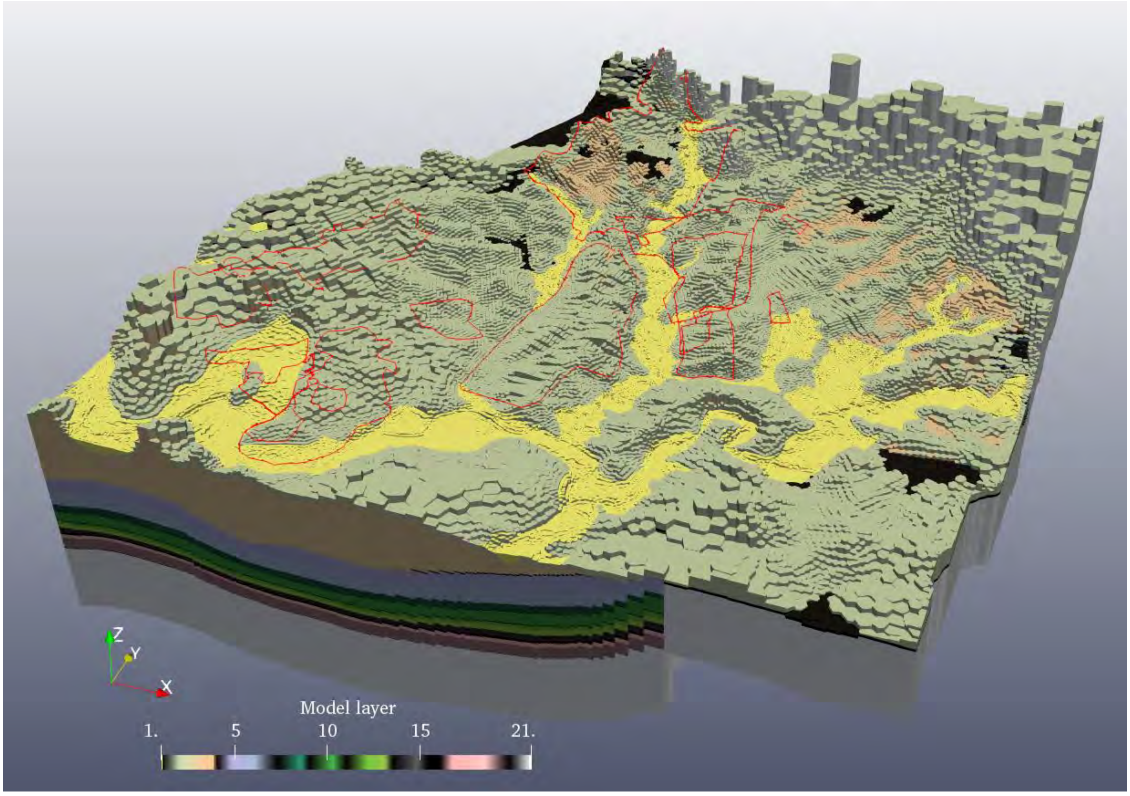


Figure B 4 Oblique view of model layers looking from south to north

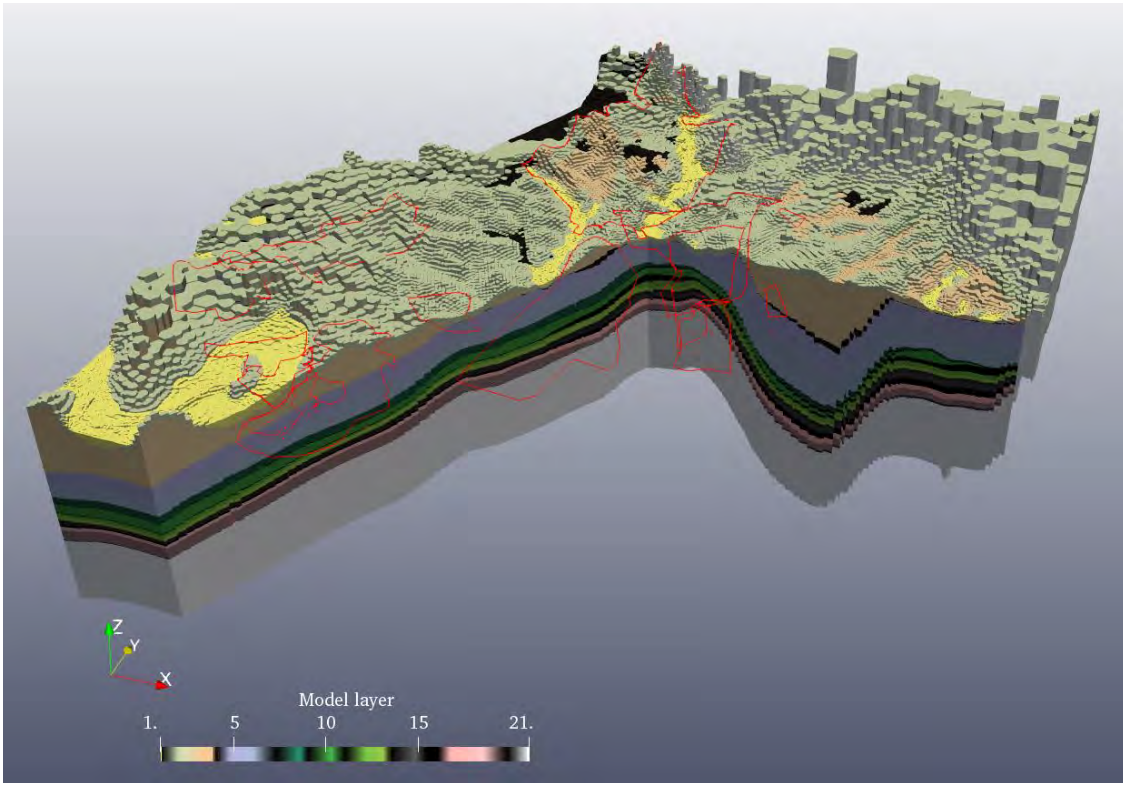


Figure B 5 Oblique view of model layers – cut through project area

B 2.4.4 Geological structures

The model domain is extensive and therefore includes some known, and many likely unidentified structures including intrusions and faults. The geological structures and the potential influence on the groundwater regime are discussed in the main report in Section 4.2.3. In the Project area the main geological structures are the:

- Camberwell Anticline which runs through the centre of the Project;
- Cutback Fault, which is west of the Camberwell Anticline and is reverse fault with an approximate 3 m to 5 m displacement;
- Block Fault Zone, is a zone of faults in the north of the Project area some 250 m to 300 m wide with typical fault displacements of less than 12m;
- Hunter Valley Dyke, which is north of the Project area with a typical intrusive thickness of up to 15 m; and
- Davis Creek Fault which separates the Liddell open cut mine for the adjacent abandoned Liddell underground mine.

The structures are shown in Figure 4-7 in the main report. The Camberwell Anticline structure is represented within the numerical model through the Permian model layers defined in the Glendell geological model.

The Davis Creek Fault and an un-named dyke identified at Liddell Mine were also represented in the numerical model. At Liddell Mine these structures have been observed to act as barriers to groundwater flow and were therefore included in previous updates to the groundwater model represented with the Horizontal Flow Barrier (HFB) Package.

The Cutback Fault, the Block Fault Zone or the Hunter Valley Dyke were not represented within the model as no explicit evidence exists as to their influence on the groundwater regime. Whilst the faults were not represented directly in the basecase model the influence of the faults was evaluated through a sensitivity analysis (refer Section B 5.4).

B 2.4.5 Timing

The model timing was updated to more finely divide time allowing improved representation of the progress of mining and the seasonal variability in groundwater levels from climate. The calibration involved an initial steady state calibration to obtain pre-mining conditions, followed by a transient history matching using water level measurements from the monitoring network. 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 2045 – 148 x quarterly stress periods.

Quarterly stress periods were introduced to the model so that some 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 being active for 3.5 years to reflect the advancement of the mine face and the progressive backfilling of the open-cuts with spoils, or goafing of longwall mining areas.

An additional version of the model was developed for simulating recovery after mining ceased at the Project in 2045. Both models were combined into a single, continuous simulation with one finishing and the other starting at the beginning 2045. The timing for the recovery model was set up as a 24 exponentially increasing transient stress periods, aligning with a surface water balance model being used to simulate recovery of water with the final void. The ATS (Adaptive Time Stepping) function was used applying a 1.4x multiplier/divisor, with an initial time-step length of 10% of the total stress period length.

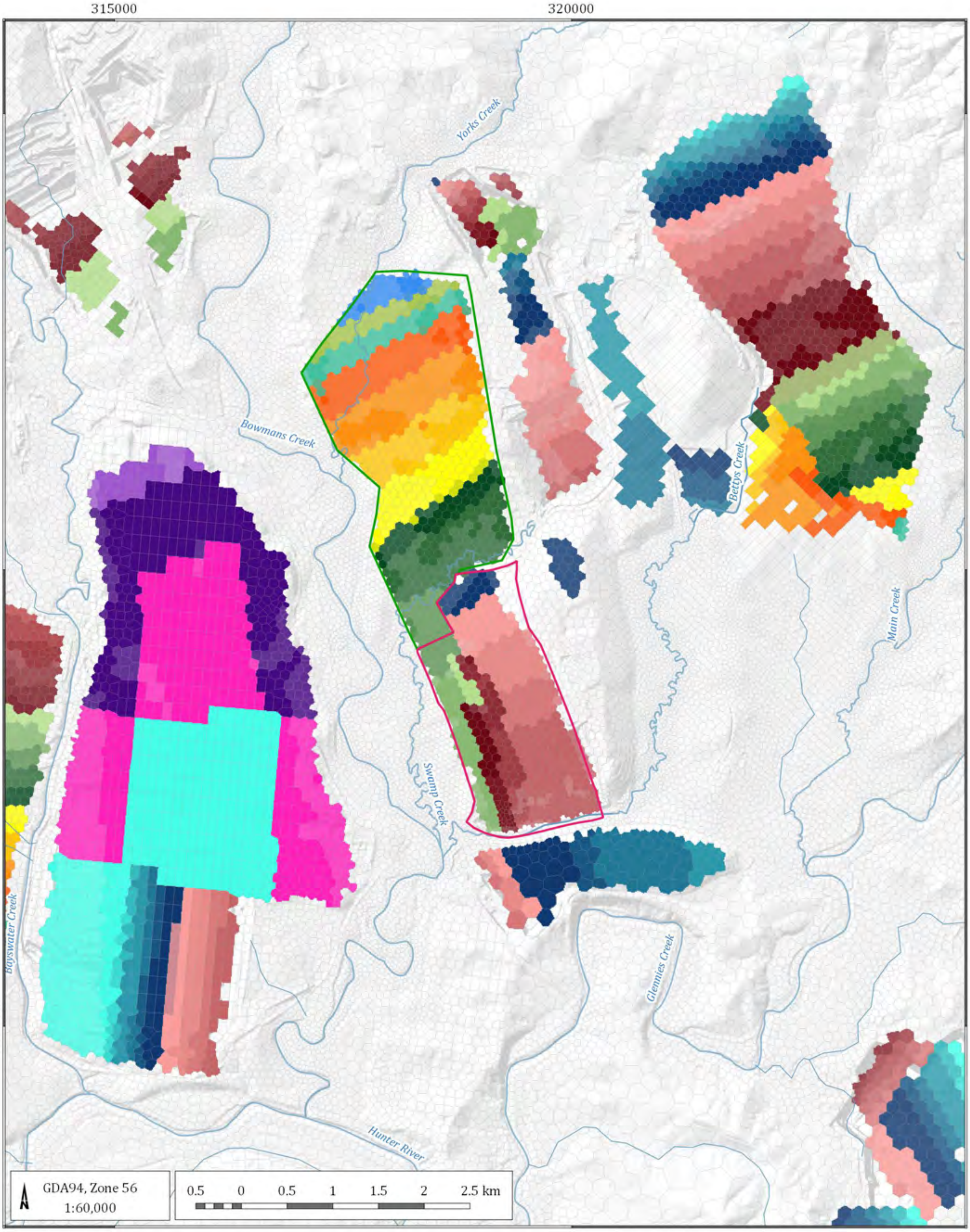
B 2.4.6 Mining progression

As noted previously there are numerous mining operations situated within the model domain. The representation of approved mining in the model was based on the detailed mine schedules introduced to the model for previous projects. This approved and planned future mining was reviewed and updated for the Glencore operations. The 3D staged plans for the Project area were used to create an annual mine progression for the Project. Table B 3 indicates the coal seams targeted at each mining operation within the model domain and the corresponding model layer. The simulation of approved mining in the model was based on the mine schedules developed for approval of surrounding operations and updated with using staged plans developed for the Project area using pit shells and schedules provided by Glencore.

Table B 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																									

Figure B 6, Figure B 7 and Figure B 8 show the footprint and timing of the Project, as well as the cumulative mining surrounding the Project.



LEGEND

- Drainage
- Model mesh
- Proposed Glendell Pit Extension
- Proposed Glendell Pit Extension

Mine start year

1980	2007	2017	2034
1984	2009	2018	2036
1989	2010	2020	2038
1994	2011	2022	2040
2000	2012	2024	2042
2002	2013	2026	2043
2003	2014	2028	2045
2005	2015	2030	
2006	2016	2032	

Glendell Continued Operations GIA (G1874C)

Predictive mine progression for the Project – Regolith & Bayswater seam

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FIGURE No: **B 6**

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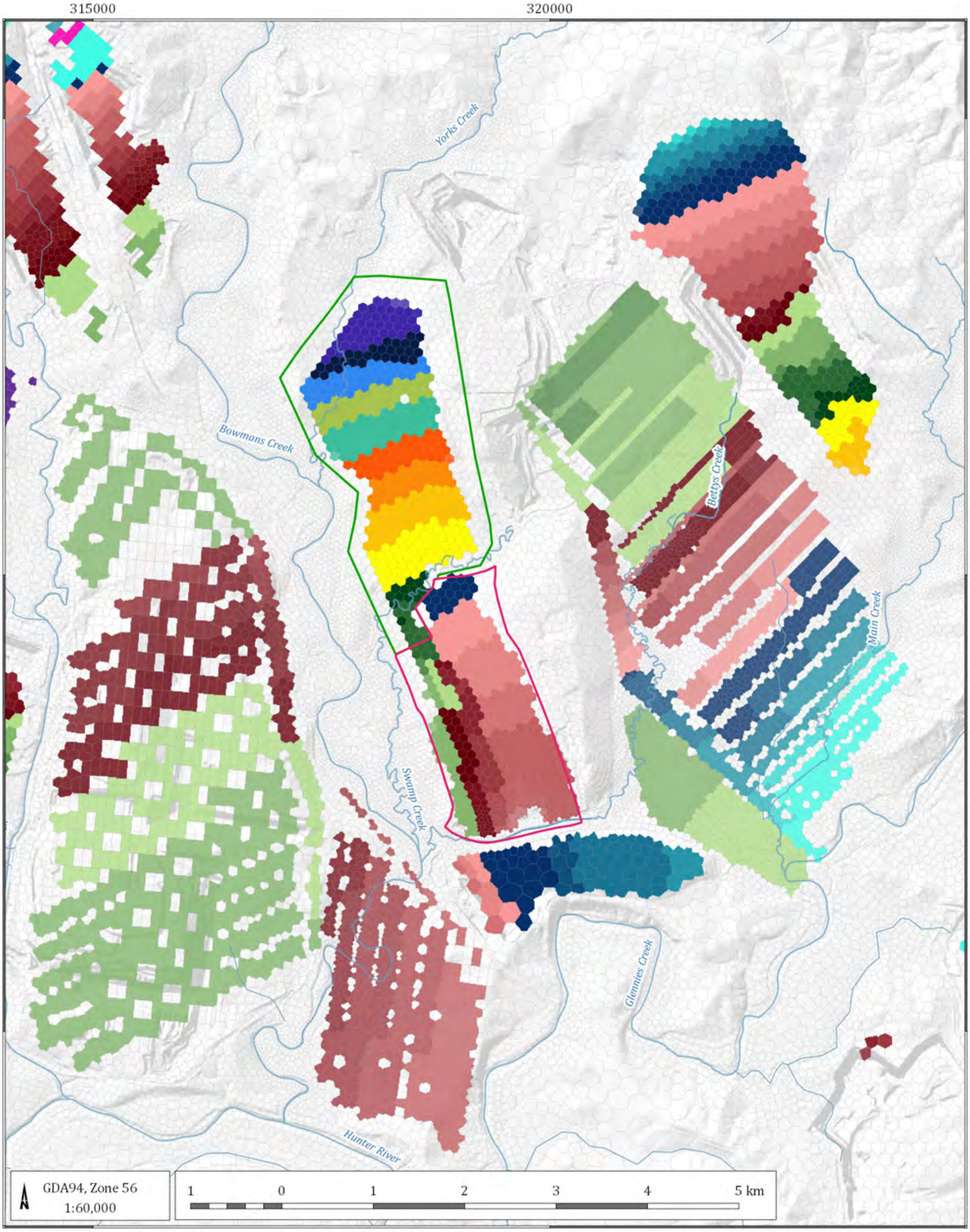

LEGEND

- Drainage
- Model mesh
- Approved Glendell Pit
- Proposed Glendell Pit Extension

Mine start year

1980	2007	2017	2034
1984	2009	2018	2036
1989	2010	2020	2038
1994	2011	2022	2040
2000	2012	2024	2042
2002	2013	2026	2043
2003	2014	2028	2045
2005	2015	2030	
2006	2016	2032	

Glendell Continued Operations GIA (G1874C)

Predictive mine progression for the Project – Middle Liddell seam

AGE

DATE 30/07/2019

FIGURE No: **B 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.;
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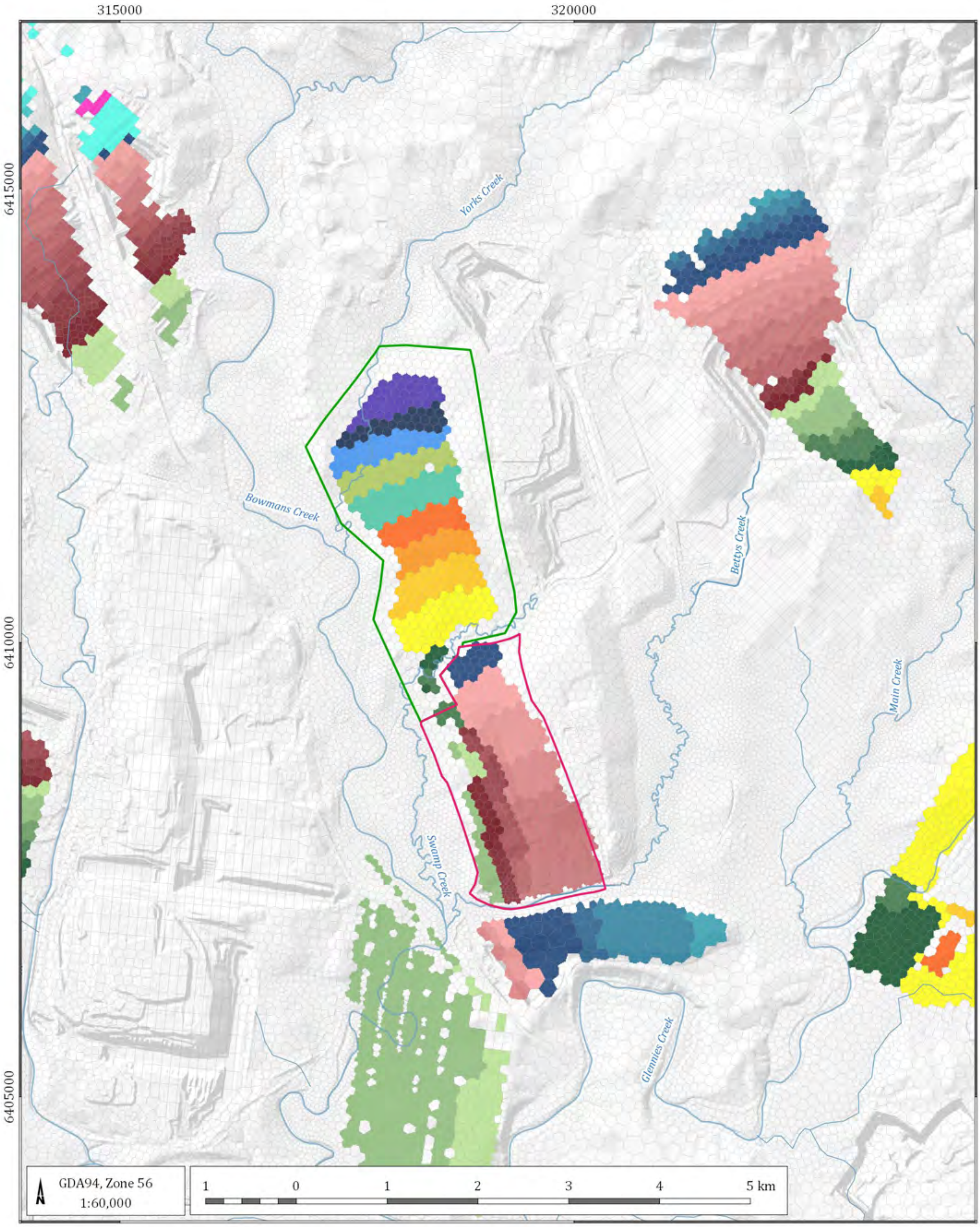

LEGEND

- Drainage
- Model mesh
- Approved Glendell Pit
- Proposed Glendell Pit Extension

Mine start year

1980	2007	2017	2034
1984	2009	2018	2036
1989	2010	2020	2038
1994	2011	2022	2040
2000	2012	2024	2042
2002	2013	2026	2043
2003	2014	2028	2045
2005	2015	2030	
2006	2016	2032	

Glendell Continued Operations GIA (G1874C)

Predictive mine progression for the Project – Barrett seam

AGE

DATE 30/07/2019

FIGURE No: **B-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.;
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The timing and location of mining represented within the numerical model contains an unavoidable element of uncertainty. Middlemis and Peeters (2018) categories this as 'scenario uncertainty'. This is because records of historical mining can be difficult to obtain, and assumptions on the progress of mining operations, particularly older operations are therefore required. The exact advancement of future mining operations is also uncertain as all mining operations are subject to market conditions that can alter the economics of projects. The historical and future mining represented within the numerical model should therefore be considered a guide rather than highly accurate. Despite these unavoidable limitations, the model is considered to largely have mining represented where it has occurred historically and is approved to occur in the future; it is only the timing and elevation of the mining that has a level of uncertainty. The uncertainty in the location and progression of mining has potential to influence the calibration of the model in areas where water level calibration points are situated in close proximity to mining activities. In areas more distant from mining activities the uncertainties in the historical progression of mining obviously become less influential on the model predictions. The NSW and Commonwealth approval process allows for this inherent uncertainty in future mining schedules by typically requiring three or five yearly updates to numerical models during operations to allow any changes in schedules to be represented in the model and also allow for validation of predictions or further calibration utilising new monitoring and parameter datasets.

B 2.5 System stresses

B 2.5.1 Recharge

The MODFLOW USG recharge package (RCH) was used to represent diffuse rainfall recharge. The upstream weighting function with the CONSTANTCV option was selected and therefore flow through the vadose zone was not simulated in the model.

Recharge to the groundwater systems occurs through diffuse infiltration of rainfall through the soil profile and subsequent deep drainage to underlying groundwater systems. A simple SWAT model (Arnold, 2012) covering the model domain catchment area was developed to guide the groundwater recharge rates for the calibration process. Global FAO soil and static land use data were assumed, and weather was applied using interpolated SILO climate data. SWAT provided estimates of recharge rates to the alluvium of about 112 mm/year for the Quaternary alluvium, and 6 mm/year for the Permian groundwater systems.

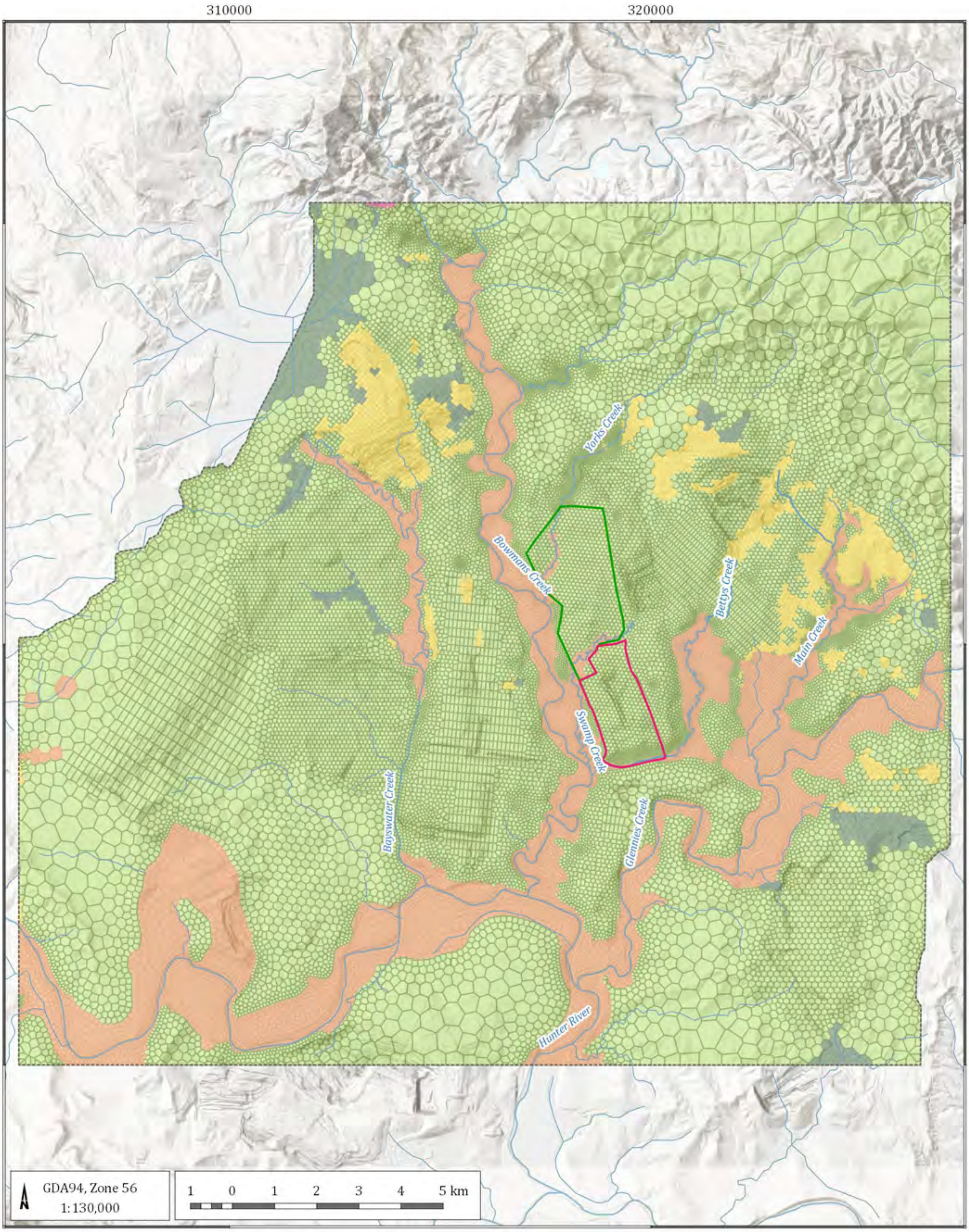
In addition to this a spreadsheet-based soil moisture calculation was used to estimate the timing and magnitude of recharge events used in the model. The simple soil moisture balance was used to evaluate when the soil profile had likely reached field capacity following rainfall and when subsequent deep drainage to the underlying water table occurs based on historical rainfall datasets.

Groundwater recharge was represented in the numerical model using zones based on geology occurring at the land surface. Figure B 9 shows the recharge zones represented in the groundwater model. Variability in recharge rates across these zones was represented with a pilot point multiplying field across the model. Timing of transient recharge during the calibration period was obtained from the soil moisture balance. The amount of recharge was determined using a multiplier on the initial estimate from the soil moisture balance.

Table B 4 summaries the calibrated rate of recharge for each geological unit. The recharge rates were reduced lower than indicated by the SWAT model to achieve the final calibration. Recharge for the predictive and recovery phases (2019+) adopted constant steady state recharge rates based on long-term average rainfall.

Table B 4 Modelled recharge rates

Zone	Diffuse recharge rate – steady state				
	Average (mm/year)	% of annual rainfall	Minimum (mm/year)	Maximum mm/year)	STDEV (mm/year)
Alluvium	49.5	7.5%	0.04	118.8	14.2
Permian regolith	2.1	0.3%	0.04	4.4	0.5
Permian overburden	0.4	0.1%	0.2	0.6	0.05
Permian unweathered	0.6	0.1%	0.3	0.8	0.14
Saltwater Creek Formation	0.1	0.01%	0.1	0.1	0.00



LEGEND

- Drainage
- Model boundary
- Model mesh
- Approved Glendell Pit
- Proposed Glendell Pit Extension

Recharge zones

- 1 - Quaternary alluvium
- 2 - Permian regolith
- 3 - Permian overburden
- 4 - Permian interburden
- 21 - Salt Water Creek Formation

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Recharge zones

AGE

DATE 30/07/2019

FIGURE No: **B 9**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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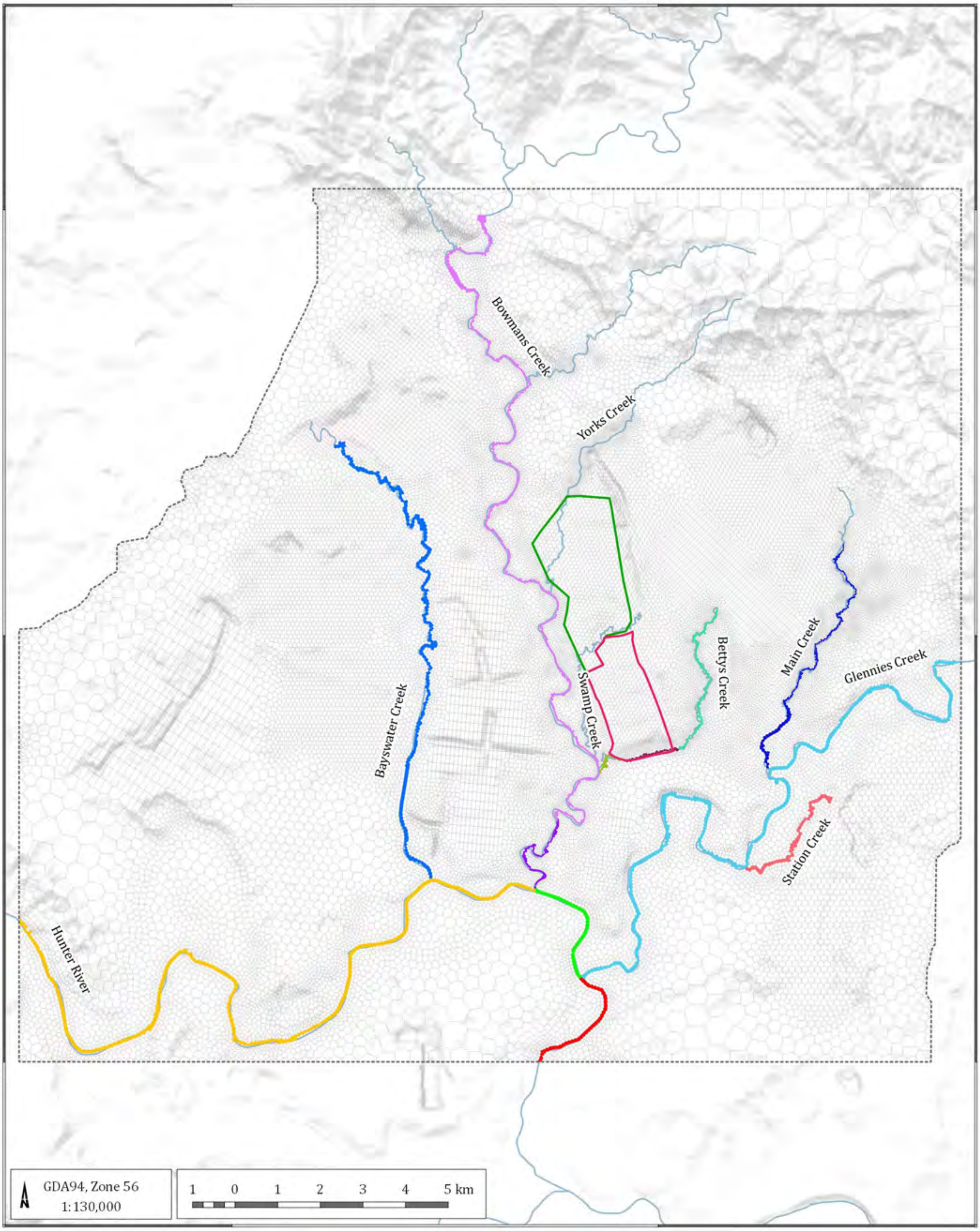
The rate of rainfall recharge is an inherently uncertain parameter in the numerical model, as it cannot be directly measured, only inferred from changes in groundwater levels within monitoring bores. Rainfall recharge also varies spatially depending on a large range of factors including soils, land-use, geology, topography and depth to water table. Whilst the numerical model represents some of these elements it cannot be expected to provide highly accurate values of rainfall recharge, and the rainfall recharge rates determined during the calibration process are considered to be one potential realisation. Given the uncertainty in this model parameter it was varied in the uncertainty analysis to determine the influence on the model predictions. The uncertainty analysis for model parameters is described in Section B 5.

B 2.5.2 Surface drainage

Groundwater interaction with surface drainage was simulated using either the stream package (STR), or the river package (RIV) of MODFLOW. The cells assigned to these packages in the model were divided by zones to represent each of the drainage systems and are displayed on Figure B 10.



LEGEND

- Drainage
- Model boundary
- Model mesh
- Approved Glendell Pit
- Proposed Glendell Pit Extension

River/stream zones

- Hunter River (1)
- Hunter River (2)
- Hunter River (2)
- Bowmans Creek (1)
- Bowmans Creek (1)
- Glennies Creek
- Bayswater creek
- Bettys Creek (1)
- Bettys Creek (2)
- Bettys Creek (3)
- Main Creek
- Station Creek

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River and surface drainage cells

AGE

DATE 30/07/2019

FIGURE No: **B 10**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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Major streams systems, including the Hunter River, Bowmans Creek, and Glennies Creek were represented using the stream package, whereas minor drainage systems were simulated using the river package.

The stream package requires the level of the river bed and the measured flow of surface water. The river bed conductance was calculated from river width, length, riverbed thickness, and an estimated vertical hydraulic conductivity of the riverbed material. The vertical hydraulic conductivity of the riverbed was then adjusted during the calibration process. 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 from flow gauging data from NSW government stream gauges (NSW DPI, 2017). 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 B 5 summarises the stream and river cell parameters in the model.

The water level above the river bed was set at 0 m for all minor ephemeral streams and creeks within the model domain. The locations 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.

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

Segment 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	0.05	5.0	4	0.004	1.5	0.03
2	Bowmans Creek Seg2	0.09	5.0	4	0.004	1.5	0.03
3	Hunter River Seg1	0.04	7.0	6	0.0005	2.0	0.03
4	Hunter River Seg2	0.08	7.0	6	0.0007	2.0	0.03
5	Glennies Creek	0.12	7.0	6	0.0015	2.0	0.03
6	Hunter River Seg3	0.09	7.0	6	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	-

Uncertainty in the representation of the rivers and creeks is introduced to the model through the adopted stream bed conductance and stream flow timing and rates. The stream bed conductance, which represents the connectivity of surface water with groundwater was not measured, but was determined during the calibration process and also varied as part of the predictive uncertainty analysis. Surface water flow was represented in the model downstream of NSW government flow gauges using the stream package. The closest stream flow gauge to the Project is located on Bowmans Creek downstream of the Glendell Mine (refer main report Section 3.3). This means no surface water runoff water was represented in the model upstream of the government gauge through the Project area. The model therefore represents groundwater that enters Bowmans Creek as baseflow and flows downstream. The lack of surface water flow in the model upstream of the government gauge is expected to reduce streambed recharge during rainfall events and result in the model compensating with increased recharge from other sources such as diffuse rainfall.

B 2.5.3 Evapotranspiration

The evapotranspiration was guided by the results of the SWAT model that indicated an areal potential evaporation rate averaging 448 mm/year. Evapotranspiration from the water table was represented in the numerical model with the evapotranspiration package (EVT). Evapotranspiration occurred from the upper most model cells across the model domain at a maximum rate of 440mm/year, decreasing linearly to a maximum depth of 2 m below the surface.

Evapotranspiration, like recharge also varies spatially and is a function of similar factors including soils, land-use, geology, topography and depth to water table. Whilst there is inherent uncertainty in the volume of water removed by evapotranspiration from the water table, the process is only represented in the numerical model where the water table is within 2 m of the land surface. The water table is only close to the land surface in the numerical model in a thin riparian zone adjacent to the main rivers and creeks, and therefore only influences groundwater levels in these narrow zones. In these zones depth of the river/creek bed and the nature of the stream (losing/gaining) exerts significant control on the groundwater level, and in some areas is expected to override the influence of the evapotranspiration on groundwater levels. Therefore, whilst the evapotranspiration is inherently uncertain, it was not varied in the model calibration or assessed in the uncertainty analysis due to an expected limited influence on the groundwater regime where the Project is proposed.

B 2.5.4 Abstraction

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

B 2.5.5 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 layers 2 and 21 which are the only layers present underlying the lake. Whilst the actual water level in Lake Liddell is expected to vary according to climatic conditions and usage from the Liddell power station, a static water level was considered sufficient as the lake is some 6 km from the Project area, and not expected to significantly influence the groundwater system at this distance.

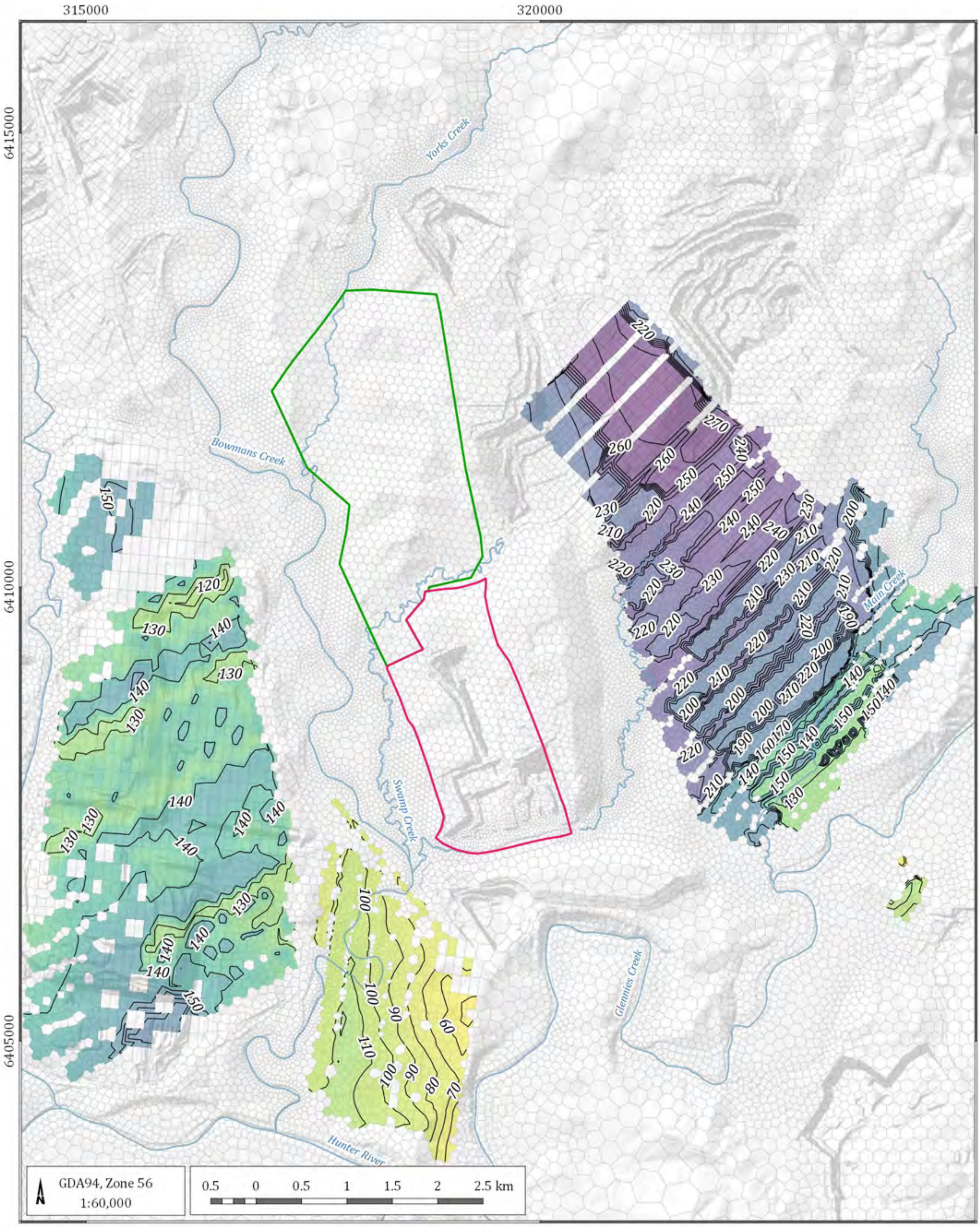
B 2.5.6 Mining

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 provided by Glencore. 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 Glendell mining area and other 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. The progressive backfilling of the open-cuts with spoils was represented by progressively changing the hydraulic properties of mined cells (Kx, Kz, Sy and Ss) behind the active open cut mining areas after the drains were removed.

Recharge rates to the spoil were not enhanced as the spoil is conceptualised to be very free draining during operations and infiltration readily flows to sumps within mining areas without mounding within the spoil heaps. The captured water within the mining areas does not represent water take 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 B 3.5.2.

Goafing and fracturing above longwall panels in the underground mine was simulated using a connected linear network fracture methodology described by AGE (2017). This method represents the fracture network using “stacked drains” and calculates the conductance empirically calculated based on the intensity of fracturing at any given model cell. Figure B 11 shows the 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 displaying the maximum fracture height value.



LEGEND

- Drainage
- Model mesh
- Approved Glendell Pit
- Proposed Glendell Pit Extension

Fracture height above seam (m)

- 50
- 100
- 150
- 200
- 300
- Contour line

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Modelled fracture height

AGE

DATE 30/07/2019

FIGURE No: **B 11**

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A separate model run was built to simulate recovery of the groundwater system once all mining was complete. In this model, the drain cells above longwall mines were removed and the hydraulic conductivity enhanced to represent the residual fracture network, ensuring equivalent mine inflows prior to commencement of recovery. This approach is previously described by AGE (2017). Changes to the horizontal and vertical hydraulic conductivity were applied to the 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).

An equation was developed, which respects the fracture network (A_p), the host material hydraulic conductivity, and 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:

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

where,

ct = adjustable constant (0.2)

h = height above longwall panel (m)

Kz = in-situ vertical hydraulic conductivity

A second equation was also 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:

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

Table B 6 presents the aquifer parameters applied to the post mining underground workings.

Table B 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 x 10^{-6}	0.1
Bord and Pillar	100	100	5 x 10^{-6}	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.

B 3 Model calibration

B 3.1 Calibration method

The groundwater model was calibrated with a pre-mining steady state run and a transient run (1980 to 2018) 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_HP, Doherty 2018) were used to determine optimal hydraulic parameters and recharge rates to achieve the best history match to the available water level measurements from monitoring bores.

As with all models the resulting calibration is non-unique, that is an alternative set of parameters could produce an equally valid calibration, especially where simulations are sensitive to parameter combinations that lie within the calibration null space. The calibration null space refers to the model parameters and parameter combinations that are not informed by the available observed measurements. A model calibrated in this way is classified as conditionally calibrated (verified) in that it has not yet been falsified by tests against observational data (Middlemis & Peeters, 2018).

B 3.2 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 402 monitoring points were used to calibrate the model, comprising:

- 402 monitoring points from the Glendell, 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;
- 48 monitoring points across the model domain that screen the alluvium from monitoring wells;
- 122 monitoring points that screen the Permian coal measures and interburden from monitoring wells; and
- 155 monitoring points from vibrating wire piezometers.

Middlemis & Peeters (2018) suggest groundwater assessments consider the uncertainty around measurements used during the modelling process. The groundwater levels within the monitoring network are measured manually with electronic water level dippers and the water level converted to an elevation based on surveyed levels at measurement point which is usually the top of bore casing. Modern electronic water level dippers are expected to be accurate to within ±1 cm, and with the measurement point elevation also ±1 m to 10 cm depending on the method of surveying. The measurement of water levels within the monitoring network is therefore considered unlikely to have introduced any significant uncertainty to the model predictions. Vibrating wire piezometers in contrast measure pore pressure which is converted to a potentiometric surface based on the elevation of the VWP sensor. The VWPs are sealed with cement grout within the boreholes and therefore cannot be validated, or the data loggers checked for instrument drift. Therefore the measurement error for the VWPs is considered higher than monitoring bores and possibly in the range of ±5 m to 10 m. Despite the potential for a larger measurement error in the VWP data, when used with caution it is still considered a useful additional dataset to understand the groundwater regime and guide the calibration of the numerical model where the observed pressure changes are considered conceptually sound.

Figure B 12 presents the observation bores that were used in the calibration process. The installation details for a number of bores could not be determined and were therefore not included within the model. For model calibration purposes the observation bore water level records were weighted as follows:

- obviously anomalous results were removed;
- datalogger data was reduced to a monthly frequency; and
- datapoints for each location were weighted according to the formula:

weight of datapoint = 1/ √ (number of points for that site).

Using this method bores with longer records have a lower weighting per datapoint, but a higher overall weighting in the combined dataset.

The model was calibrated to the observed water level datasets, with the 'best calibrated' model returning the lowest objective function (phi) value i.e., the lowest statistical difference between the observed and modelled values across the chosen dataset.

B 3.3 Pilot points

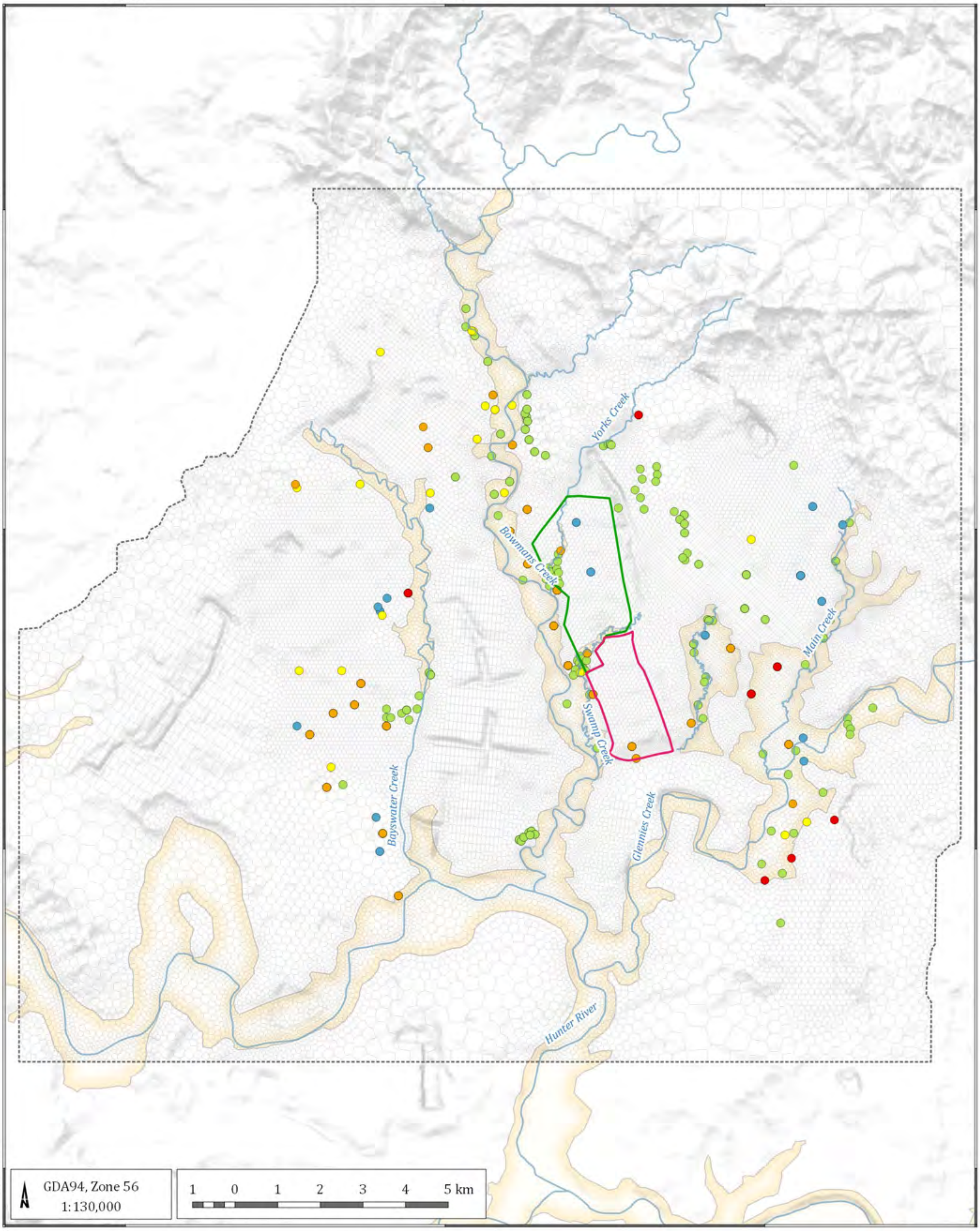
The model domain contains a significant network of monitoring bores and water level datasets. The water level responses recorded in the monitoring bores (as discussed in the main report Section 5.5) vary depending on a range of factors including geology, location, climatic conditions and mining activities. Water levels recorded in the monitoring bores indicate heterogeneous hydraulic properties and recharge rates. To represent heterogeneity within the model domain and provide a degree of flexibility during the calibration, a series of pilot points were added to each model layer. The locations of the pilot points in each model layer are shown in Figure B 13. Pilot points distal to the Project area were fixed to ensure consistency with neighbouring groundwater impact reports, namely the Integra Underground operations and Mt Owen Complex. The calibration process therefore focused on observations from monitoring bores and vwps in the Project area where the pilot points remained adjustable.

The pilot points were interpolated across the model domain in each layer of the model using ordinary automatic Kriging through PLPROC (Watermark Numerical Computing, 2015). Horizontal and vertical conductivity were then adjusted, and the absolute values were capped to ensure maximum and minimum values did not exceed appropriate ranges for each units. Specific storage values are constrained by literature ranges derived from regional studies of similar strata, using the relationship between bulk modulus, Poisson's ratio, and effective porosity, to calculate a physically possible value. Table B 7 presents the general parameter constraints applied to all layers.

Table B 7 General parameter constraints

Unit	Min Kx (m/day)	Max Kx (m/day)	Min Kz (m/day)	Max Kz (m/day)	Min Sy (%)	Max sy (%)	Min_Ss (m^{-1})	Max_Ss (m^{-1})	Max Kz/Kx
Alluvium	1×10^{-5}	100	1×10^{-5}	10	1	40	1×10^{-5}	1×10^{-3}	0.5
Regolith	1×10^{-5}	10	1×10^{-5}	1	1	20	1×10^{-6}	1×10^{-3}	0.5
Interburden	1×10^{-7}	1×10^{-2}	1×10^{-8}	5×10^{-3}	0.1	6	7×10^{-7}	1×10^{-4}	0.5
Coal	1×10^{-7}	$1 X 10^{-1}$	$8.6 X 10^{-6}$	1×10^{-1}	0.1	5	2×10^{-6}	$1 X 10^{-4}$	1

To calibrate the model, the pilot point multipliers for Kx were allowed to vary ±1 orders of magnitude from the starting point. The starting point for all multipliers was assumed to be 1.



LEGEND
- Drainage
- Model boundary
- Model mesh
- Approved Glendell Pit
- Proposed Glendell Pit Extension
- Alluvium boundary

Model Layer
- 1 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 21

Glendell Continued Operations GIA (G1874C)

Observation target locations

DATE 30/07/2019

FIGURE No: **B 12**

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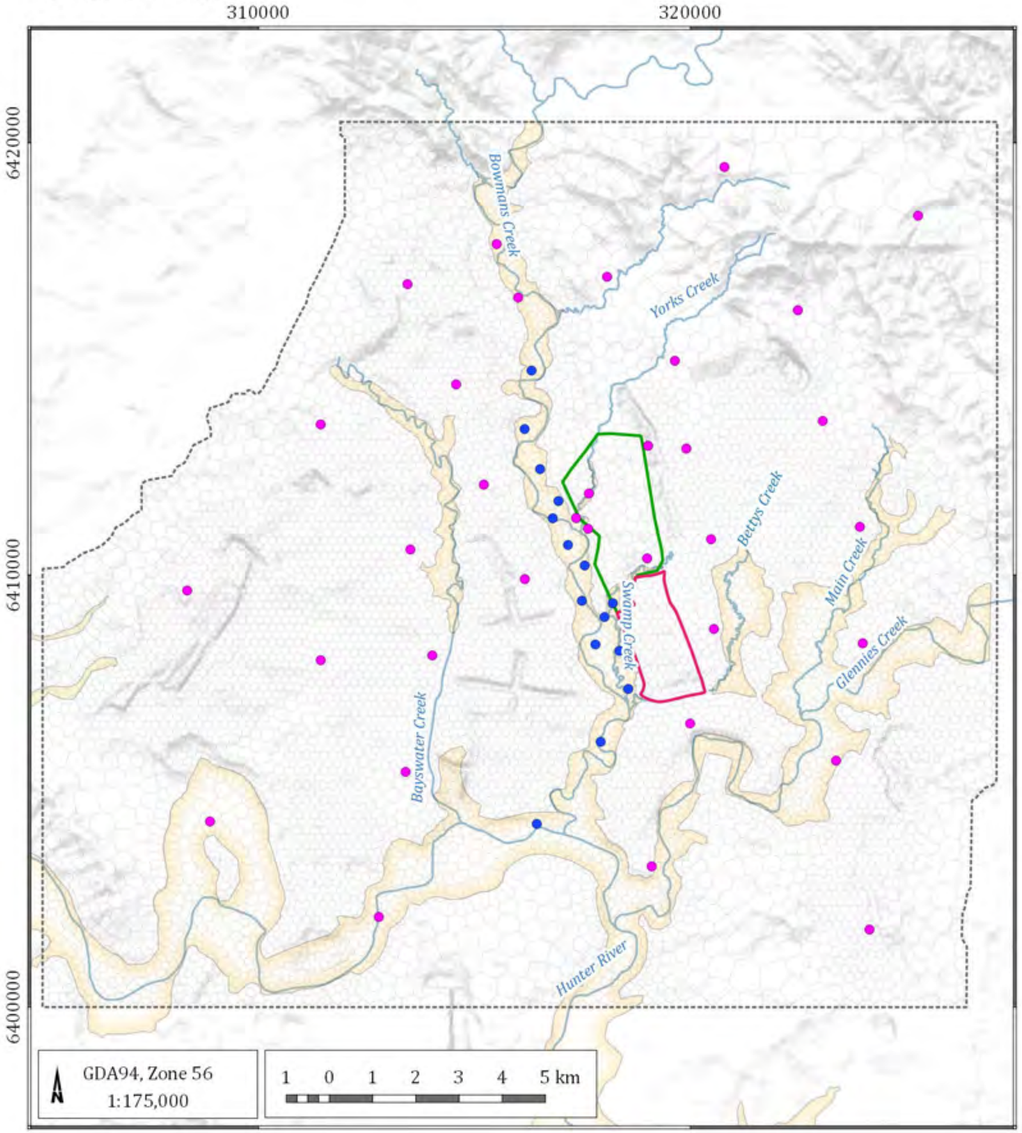
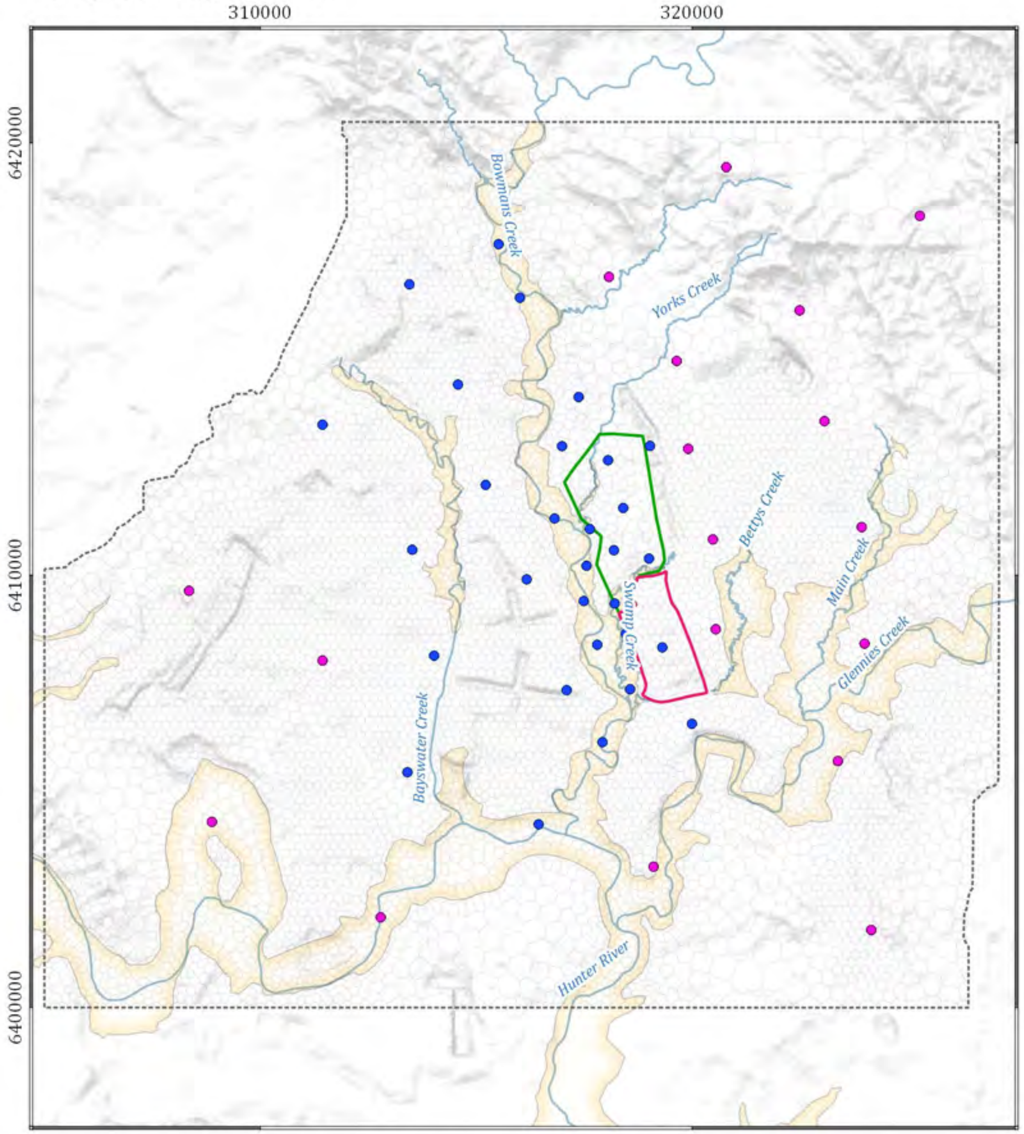
Pilot points - Layer 01



Pilot points - Layer 02 to 21



LEGEND

- Drainage
- Model boundary
- Model mesh
- Approved Glendell Pit
- Proposed Glendell Pit Extension

Pilot points

- Adjustable pilot point
- Fixed pilot point

AGE

Glendell Continued Operations GIA (G1874C)

Locations of pilot points

DATE
30/07/2019

FIGURE No:
B 13

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B 3.4 Surrogate calibration approach

The groundwater model contains approximately half a million cells and runs over 56 stress periods to simulate historic mining. The complexity of the model and stresses occurring within the groundwater system during the simulation significantly slows down the model run time.

Standard gradient based calibration techniques require deriving of the Jacobian matrix at each step in the optimisation process. To do this, each adjustable parameter and pilot point in the model requires its own model simulation. The Glendell groundwater model contains 2,442 adjustable parameters, meaning the Jacobian matrix alone requires thousands of hours of CPU processing time to prepare.

To combat the common issue with slow model runtimes and a high number of parameters, a lower resolution 'surrogate' model was developed. The surrogate model was identical to the 'parent' model in every way, the only difference being the resolution of the model cells.

The 'surrogate' model domain also contained 21 layers but was discretised into 8,245 cell nodes in each layer with the dimensions of the cells varying according to the features that required representation. The surrogate model grid is presented in Figure B 14. The following cells dimensions were adopted:

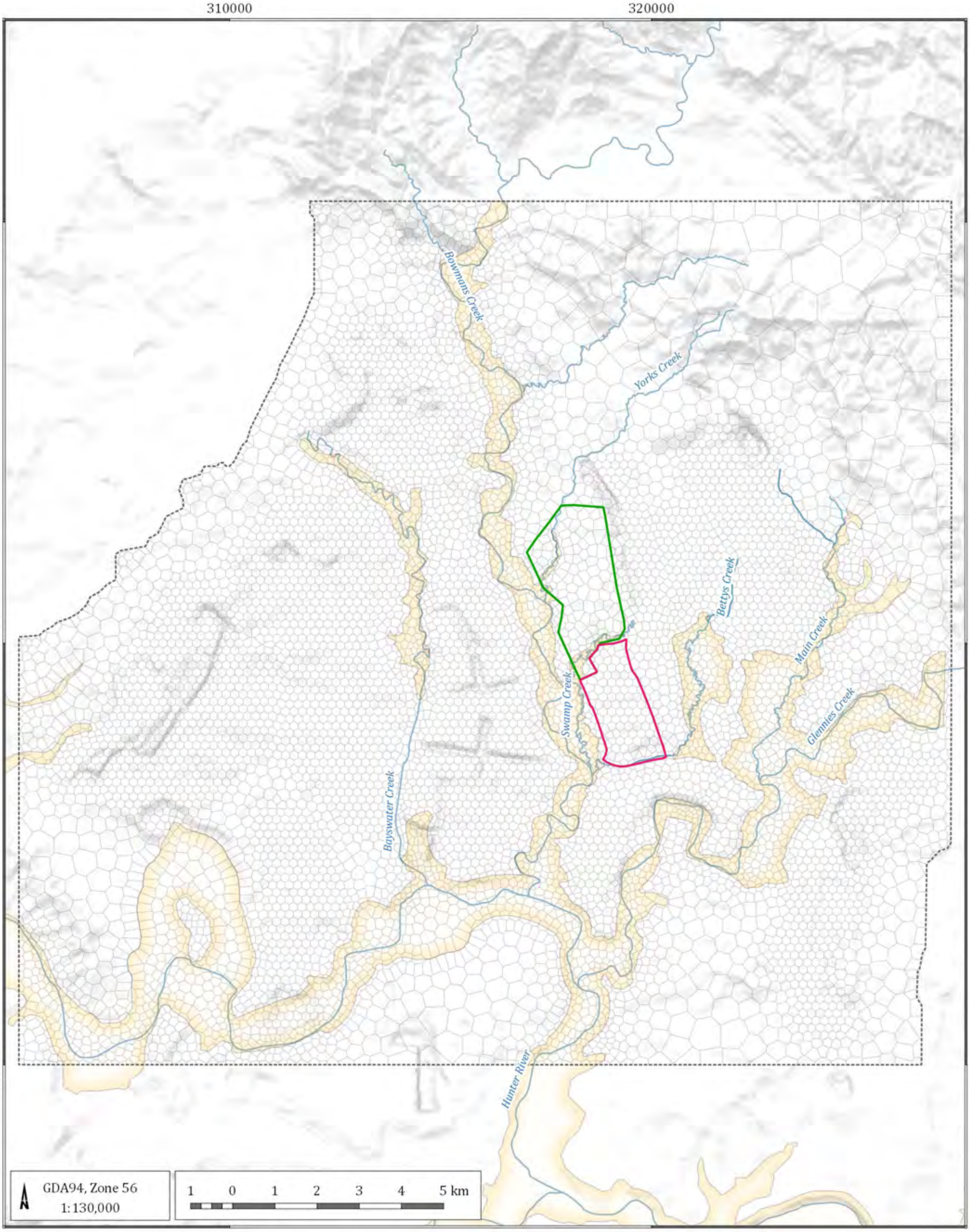
- open cut and longwall mining areas – 200 m x 200 m hexagonal cells;
- streams and alluvial flood plains – from 150 m x 150 m Voronoi cells; and
- vegetation communities within alluvial flood plains – 150 m x 150 m.

Overall, the model comprised 134,092 cells across the 21 layers. Model runtimes of the surrogate model were 6 minutes, compared to 90 minutes for the parent model.

To maintain the integrity of the model calibration and predictions, the calibration process firstly used the surrogate model to derive parameter sensitivities to groundwater level observations (Jacobian matrix) at the start of each optimisation step. The information from the surrogate Jacobian matrix was then used to optimise the parent model. This optimising step required far less CPU resources, and enabled rapid calibration with little compromise. The surrogate model produced near identical calibration statistics to the parent model. This allowed the use of the surrogate model calibration results within the more refined parent model which was more refined around environmental and mining features.

B 3.5 Calibration results

Figure B 15 presents the observed and simulated groundwater levels determined from the calibration in a scattergram. Figure B 16 shows the relationship between the observed water levels and the residuals. The results show more clearly that the observations above 50 mAHD are more closely matched by the model, whilst the observations from deeper VWPs and monitoring bores that have recorded mining induced depressurisation and not replicated as closely. Most of these discrepancies are generally related to timing offsets in drawdown response, as opposed to the model misrepresenting drawdown.



LEGEND
- Drainage
- Model boundary
- Model mesh
- Approved Glendell Pit
- Proposed Glendell Pit Extension

Glendell Continued Operations GIA (G1874C)

Surrogate Model Grid

AGE

DATE 30/07/2019

FIGURE No: **B 14**

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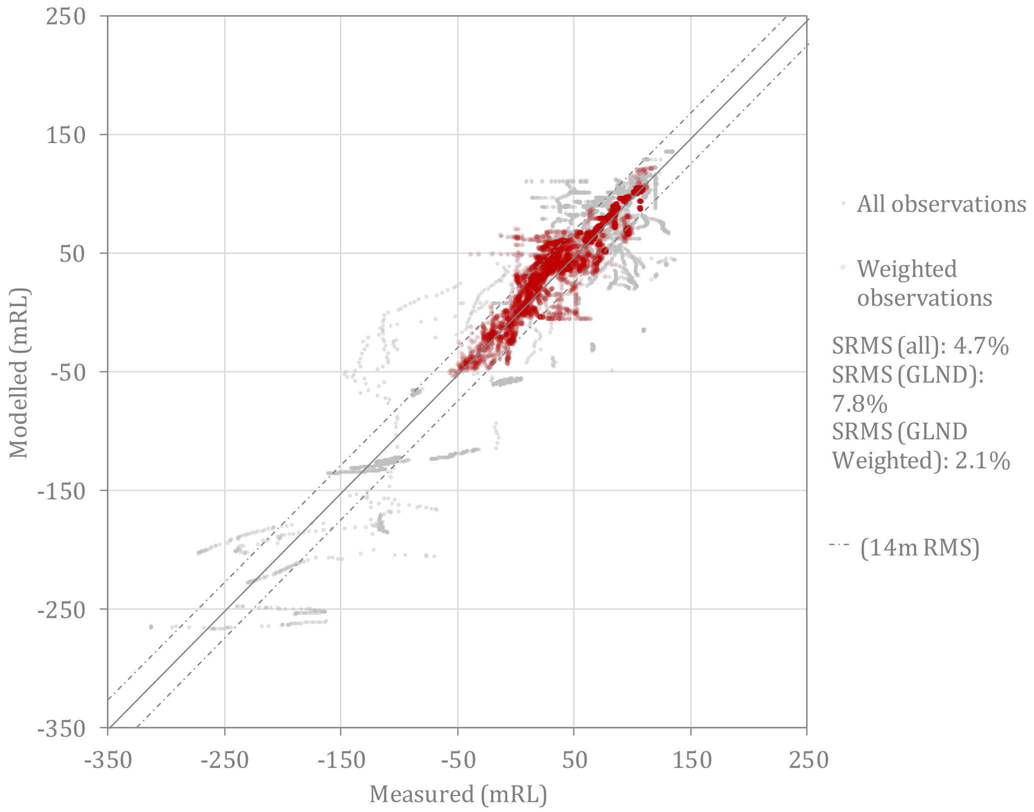


Figure B 15 Transient calibration – modelled vs observed groundwater levels

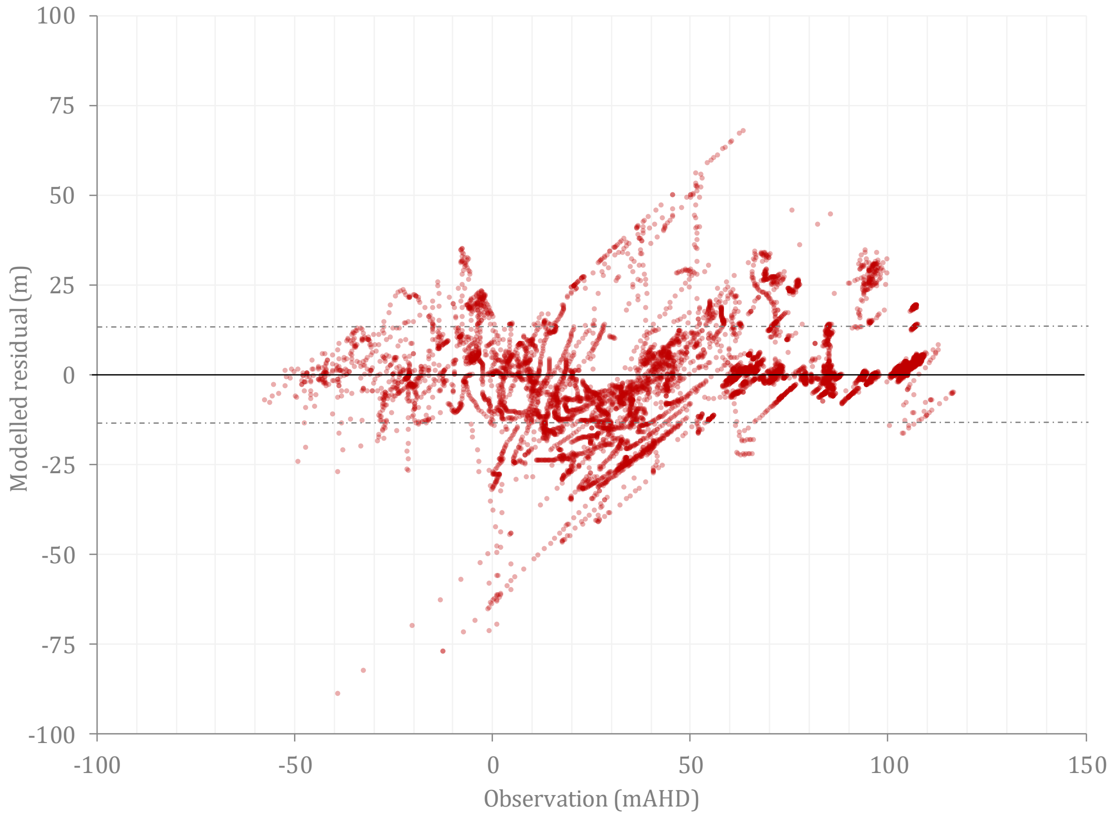


Figure B 16 Observations versus residuals (Glendell)

Table B 8 presents the unweighted statistics for the transient calibration model.

Table B 8 Statistical analysis

Calibration performance measure	Unweighted value (Glendell only)	Unweighted value (All)
Sum of Residuals (SR) (m)	-4047	-3844
Mean Sum of Residuals (MSR) (m)	-0.42	-0.20
Scaled Mean Sum of Residuals (SMSR) (%)	-0.24	-0.04
Sum of Squares (SSQ) (m2)	1751507	8493231
Mean Sum of Squares (MSSQ) (m2)	182	444
Root Mean Square (RMS) (m)	13.5	21.1
Root Mean Fraction Square (RMFS) (%)	496535	578607
Scaled RMFS (SRMFS) (%)	147442	66576
Scaled RMS (SRMS) (%)	7.8	4.7

The root mean square (RMS) error calculated for the calibrated model was 21.1 m. The total measured head change across the model domain was 449.0 m, with a standardised unweighted RMS (SRMS) of 4.7%, indicating a good match for the type of system being modelled.

Appendix B-1 presents the historic calibration hydrographs, showing the fit between modelled and observed groundwater levels from 1980 to April 2018. The appendix also presents a table with the location and the model misfit for each bore utilised to update the calibration of the model.

An analysis of simulated vs. measured vertical pressures in available key VWPs to the east of the Glendell Project was also carried out to assess the ability of the model to simulate vertical gradients. The result is displayed on Figure B 17. The results indicate the groundwater model appropriately simulates vertical gradients at key VWP locations proximal to the project area.

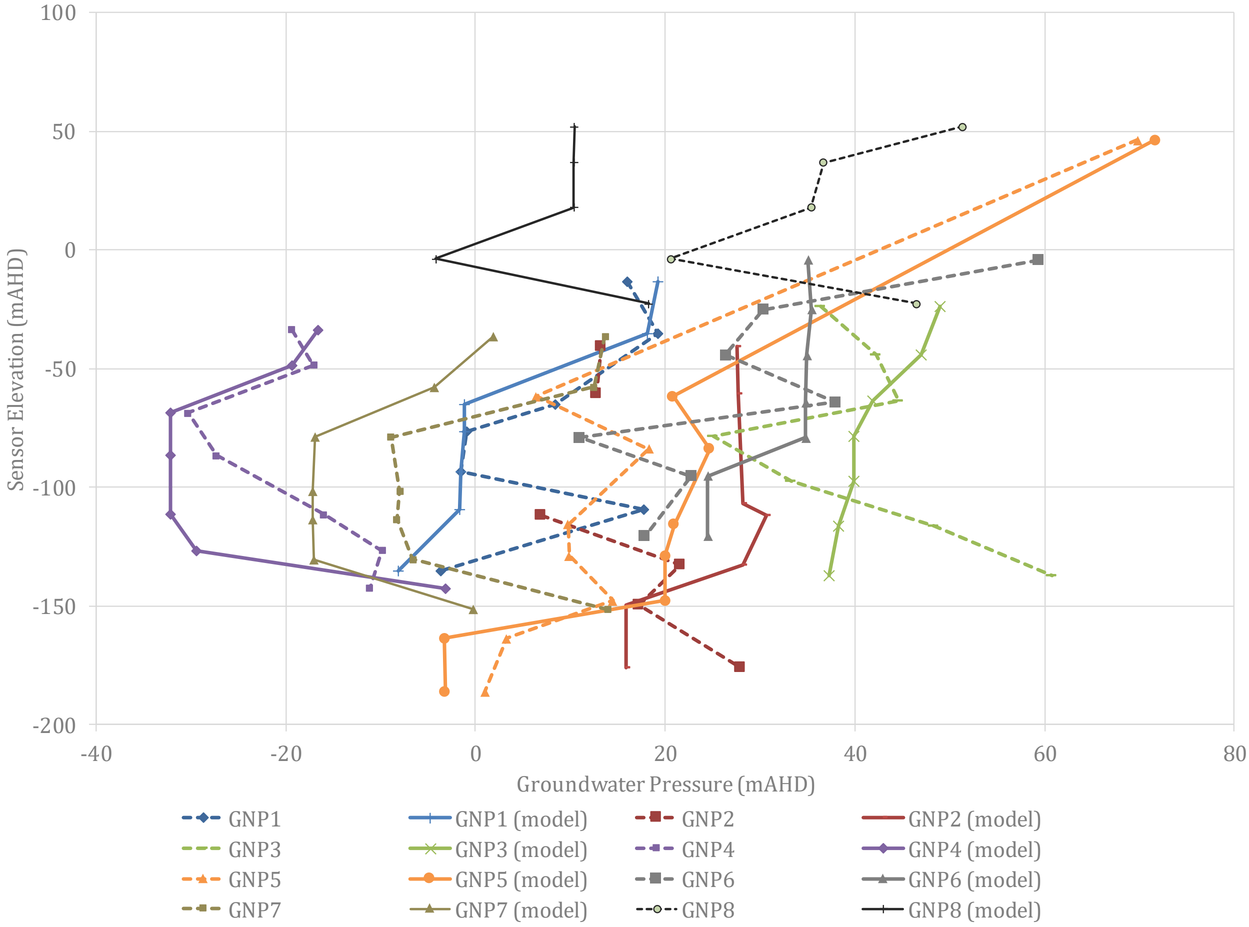


Figure B 17 Modelled versus observed vertical pressures at key VWP locations

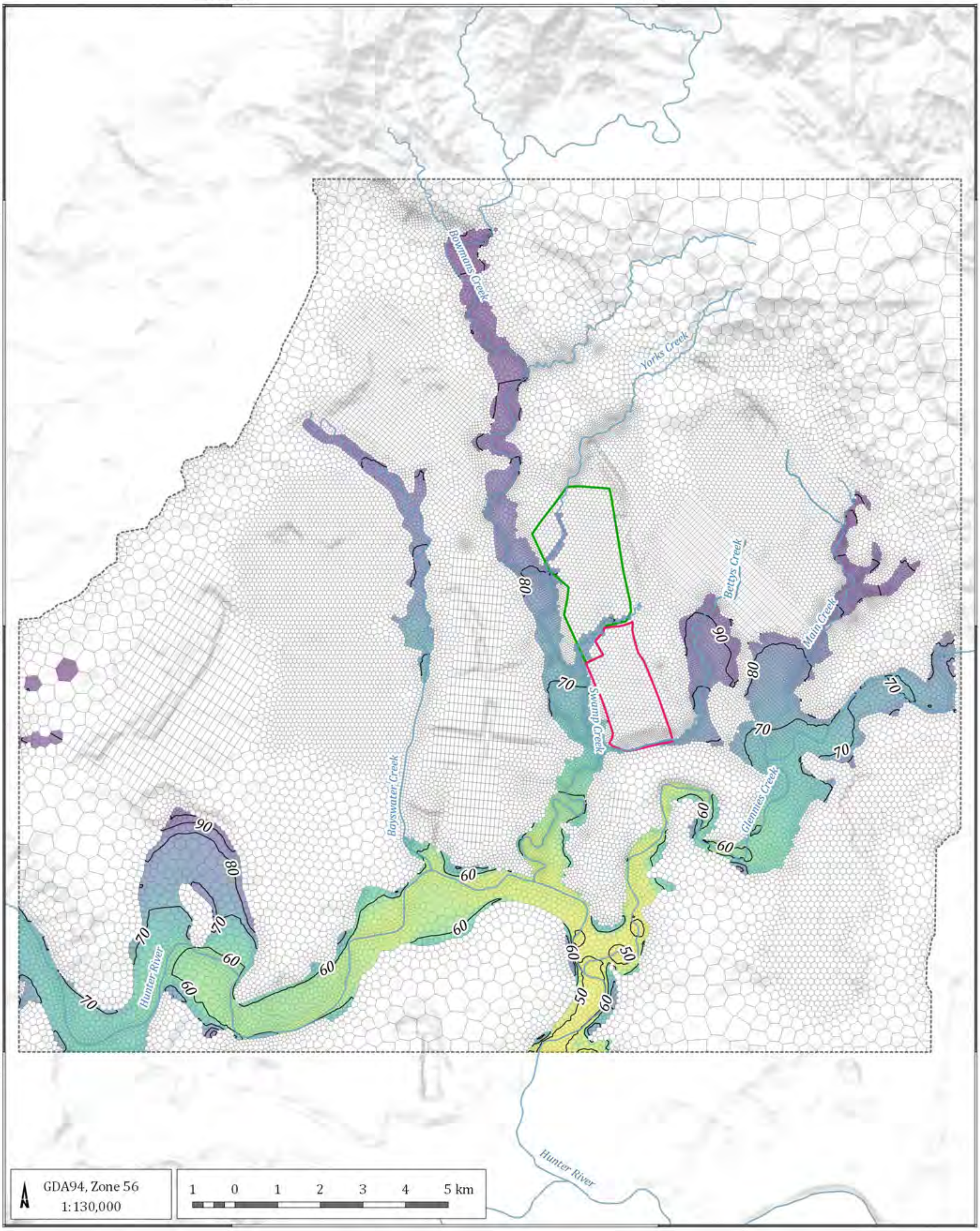
As it can be seen in the figure, although absolute values are not replicated exactly, simulated vertical pressure gradients replicate the trends measured in the VWPs indicating vertical gradients are replicated by the model.

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.

B 3.5.1 Calibration heads

The calibrated heads from the steady state calibration model for the unconsolidated sediments (alluvium and regolith) are presented in Figure B 18 with the coal seams water levels (Middle Liddell and Barrett respectively) in Figure B 19 and Figure B 20. 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 in 2018 within the unconsolidated sediments (alluvium and regolith) are shown in Figure B 21, with the coal seam water levels in Figure B 22 and Figure B 23. Groundwater levels representing 2018 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

- Drainage
- Model boundary
- Model mesh
- Approved Glendell Pit
- Proposed Glendell Pit Extension

Groundwater level (mAHD)

- 50
- 60
- 70
- 80
- 90
- 100
- Groundwater level contour (mAHD)

Glendell Continued Operations GIA (G1874C)

Predicted pre-mining groundwater levels - Alluvium and regolith

AGE

DATE 30/07/2019

FIGURE No: **B 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.;
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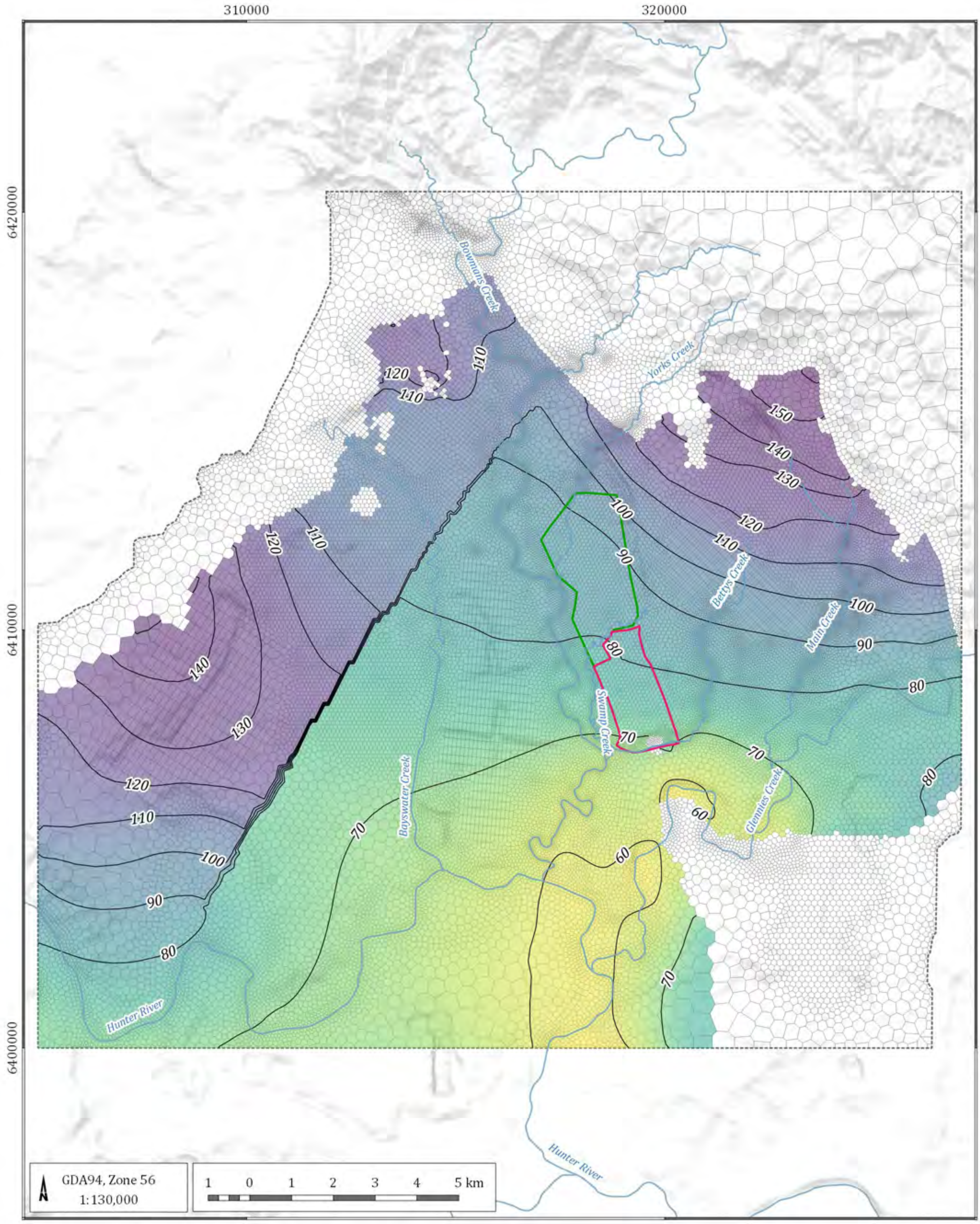

LEGEND

- Drainage
- Model boundary
- Model mesh
- Approved Glendell Pit
- Proposed Glendell Pit Extension

Groundwater level (mAHD)

50	120
60	130
70	140
80	150
90	160
100	

— Groundwater level contour (mAHD)

Glendell Continued Operations GIA (G1874C)

Predicted pre-mining groundwater levels – Middle Liddell Seam

AGE

DATE 30/07/2019

FIGURE No: **B 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.;
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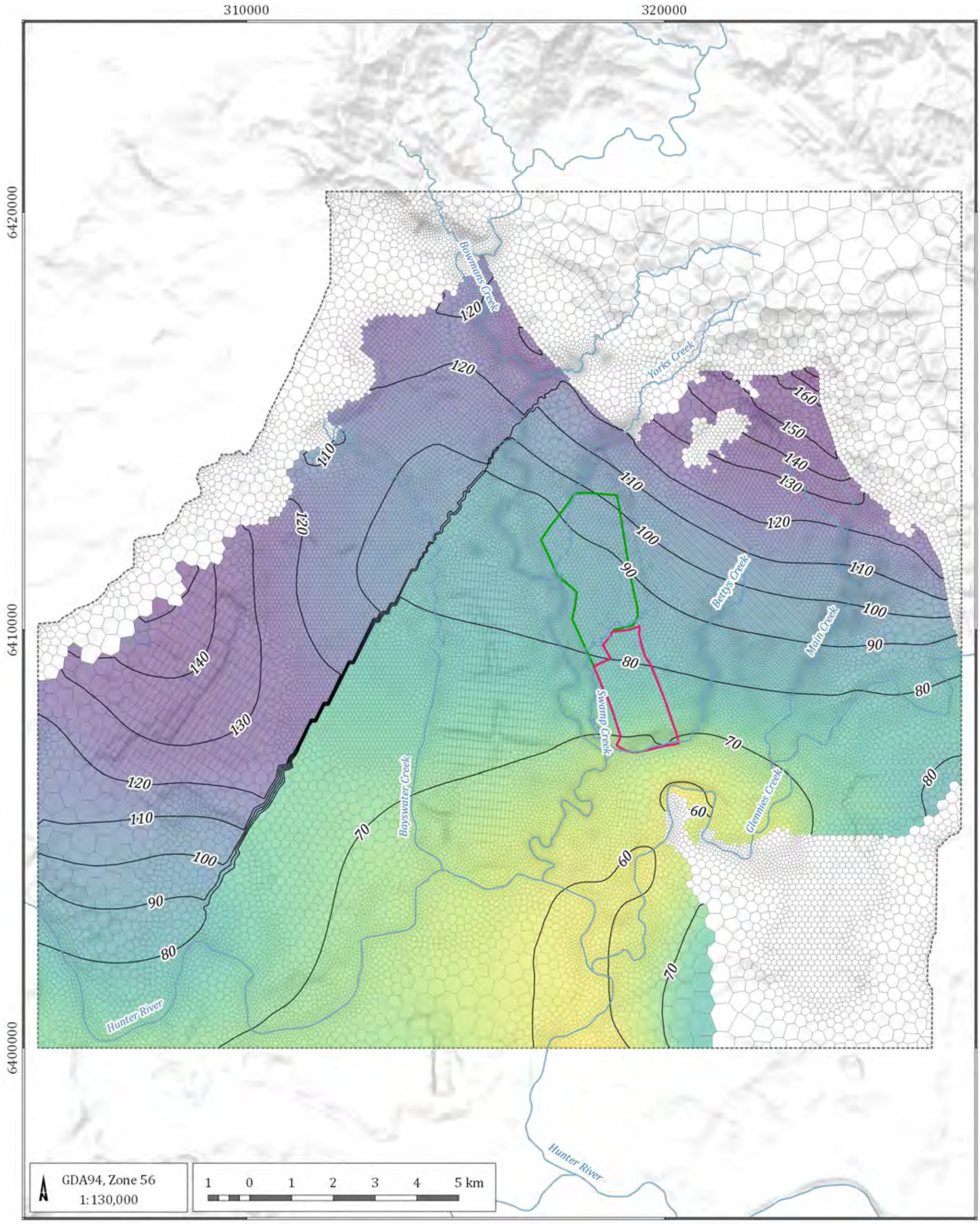

LEGEND

- Drainage
- Model boundary
- Model mesh
- Approved Glendell Pit
- Proposed Glendell Pit Extension

Groundwater level (mAHD)

50	130
70	150
90	170
110	190

— Groundwater level contour (mAHD)

Glendell Continued Operations GIA (G1874C)

Predicted pre-mining groundwater levels – Barrett Seam

AGE

DATE 30/07/2019

FIGURE No: **B 20**

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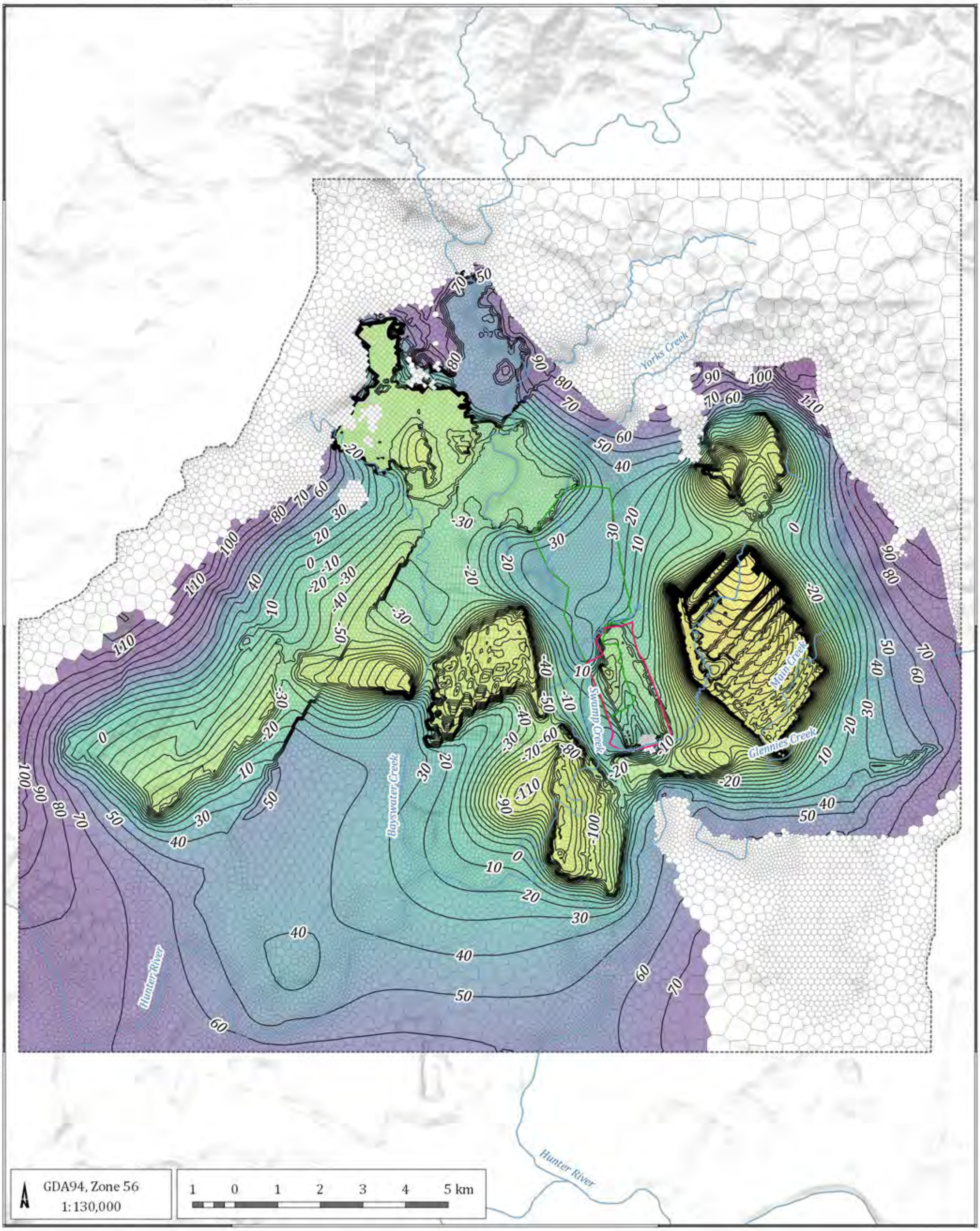

LEGEND

- Drainage
- Model boundary
- Model mesh
- Approved Glendell Pit
- Proposed Glendell Pit Extension

Groundwater level (mAHD)

-400	50
-300	75
-200	100
-100	125
0	150
25	

— Groundwater level contour (mAHD)

Glendell Continued Operations GIA (G1874C)

Predicted groundwater levels (2018) – Middle Liddell Seam

AGE

DATE 30/07/2019

FIGURE No: **B 22**

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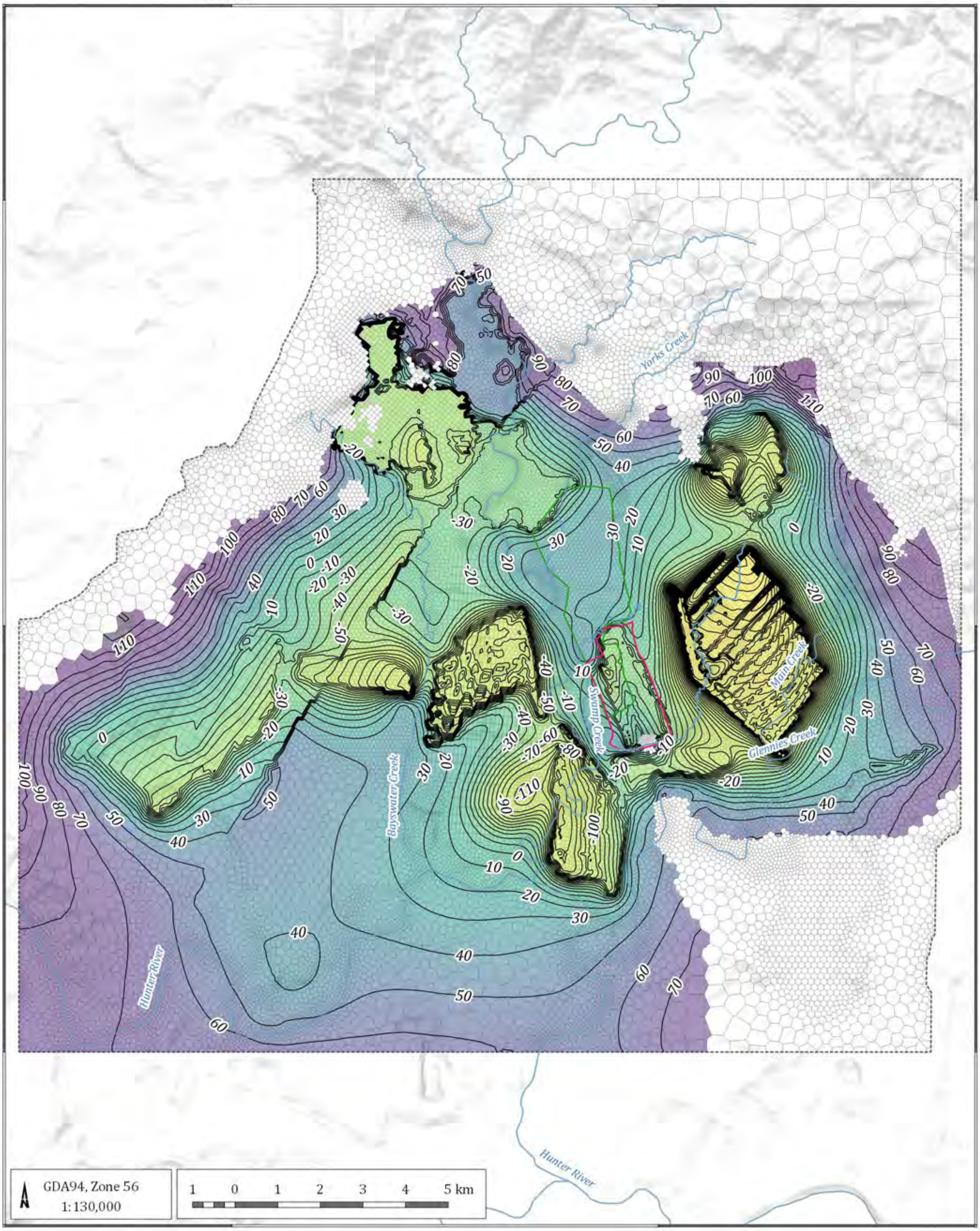

LEGEND

- Drainage
- Model boundary
- Model mesh
- Approved Glendell Pit
- Proposed Glendell Pit Extension

Groundwater level (mAHD)

-400, -300, -200, -100, 0, 25, 50, 75, 100, 125, 150

Groundwater level contour (mAHD)

Glendell Continued Operations GIA (G1874C)

Predicted groundwater levels (2018) – Middle Liddell Seam

AGE

DATE 30/07/2019

FIGURE No: **B 22**

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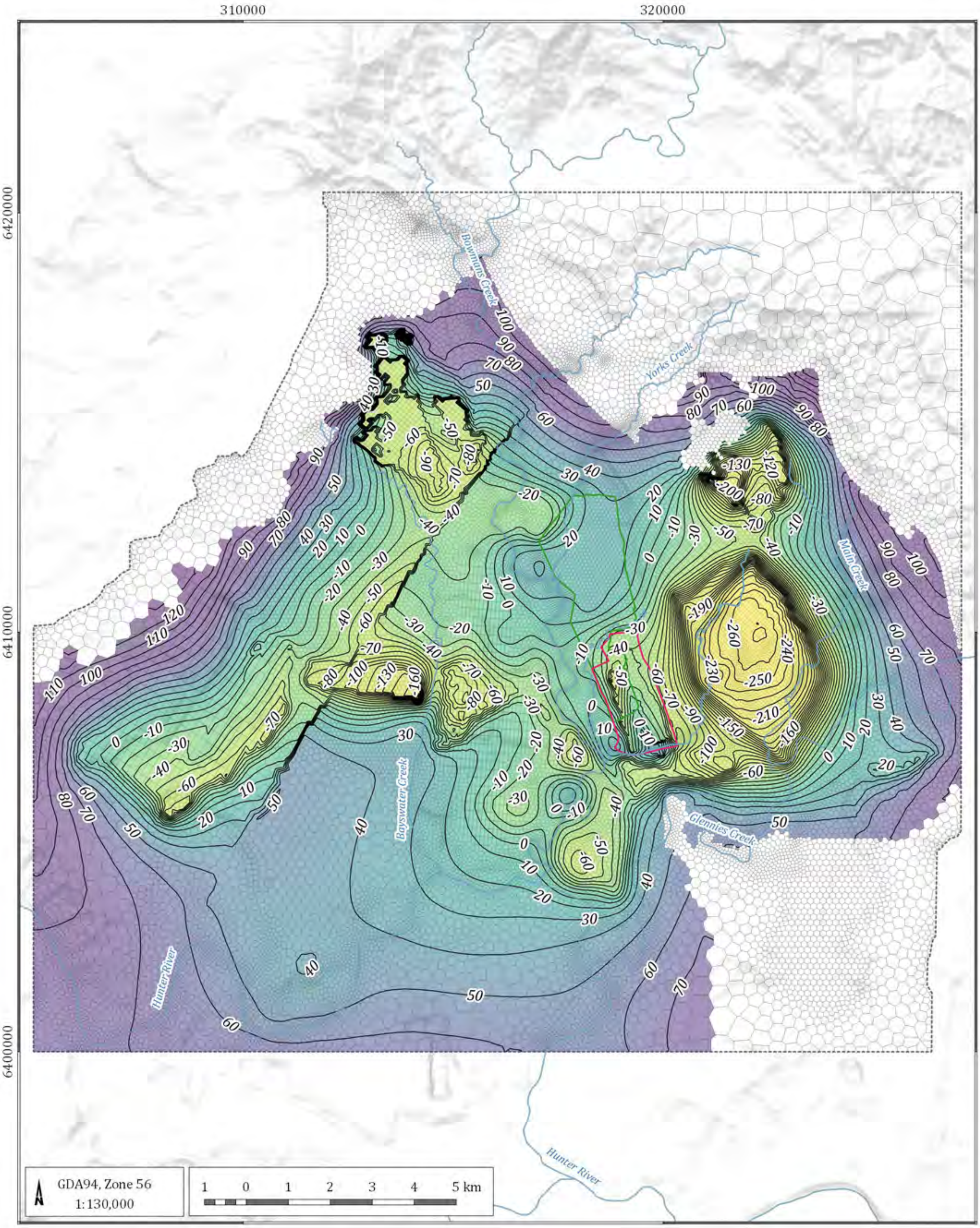

LEGEND

- Drainage
- Model boundary
- Model mesh
- Approved Glendell Pit
- Proposed Glendell Pit Extension

Groundwater level (mAHD)

-300	50
-200	100
-100	150
0	200

— Groundwater level contour (mAHD)

Glendell Continued Operations GIA (G1874C)

Predicted groundwater levels (2018) – Barrett Seam

DATE 30/07/2019

FIGURE No: **B 23**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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B 3.5.2 Hydraulic parameters

Table B 9 summarises the calibrated average hydraulic conductivity value for each of the hydrostratigraphic units within the model domain for a set of depth ranges for each layer. The values presented are the basecase value for each layer. Table B 7 General parameter constraints. The relationship with depth is further discussed below.

Table B 9 Calibrated hydraulic conductivity values

Model layer	Lithology	Average horizontal hydraulic conductivity Kx (m/day)*	Average vertical hydraulic conductivity factor (Kz/Kx)
1	Alluvium (Qa)	4.90×10^{0}	0.02
2	Regolith	7.80×10^{-3}	0.14
3	Overburden	0-100m: 1.55×10^{-4} 100-300m: 1.28×10^{-4}	0.01
4	Bayswater Seam	0-100m: 9.93×10^{-2} 100-300m: 9.27×10^{-2}	1.0
5	Interburden	0-100m: 2.05×10^{-3} 101-300m: 2.04×10^{-3}	0.05 – 0.06
6	Interburden	0-100m: 2.24×10^{-3} 101-300m: 2.60×10^{-3} 301-700m: 4.03×10^{-4}	0.1 – 0.17
7	Upper Pikes Gully Seam	0-100m: 8.13×10^{-2} 101-300m: 1.09×10^{-2} 301-700m: 1.83×10^{-4}	1.0
8	Interburden	0-100m: 1.54×10^{-3} 101-300m: 1.36×10^{-3} 301-700m: 3.04×10^{-4}	0.1 – 0.15
9	Middle and Lower Pikes Gully Seam	0-100m: 8.74×10^{-3} 101-300m: 4.77×10^{-4} 301-700m: 1.23×10^{-5}	0.09
10	Interburden	0-100m: 4.26×10^{-3} 101-300m: 1.78×10^{-3} 301-700m: 2.19×10^{-4}	0.01 – 0.11
11	Arties Seam	0-100m: 7.15×10^{-2} 101-300m: 6.67×10^{-3} 301-700m: 1.68×10^{-4}	1.0
12	Interburden	0-100m: 1.18×10^{-3} 101-300m: 1.03×10^{-3} 301-700m: 7.64×10^{-4}	0.1 – 0.2
13	Liddell Seam Section A	0-100m: 3.05×10^{-3} 101-300m: 2.11×10^{-4} 301-700m: 9.73×10^{-6}	1.0
14	Liddell Seam Section B	0-100m: 1.72×10^{-3} 101-300m: 2.58×10^{-4} 301-700m: 8.63×10^{-6}	1.0

Model layer	Lithology	Average horizontal hydraulic conductivity Kx (m/day)*	Average vertical hydraulic conductivity factor (Kz/Kx)
15	Liddell Seam Section C	0-100m: 6.37×10^{-2} 101-300m: 1.01×10^{-2} 301-700m: 1.88×10^{-4}	9.9×10^{-1} to 1×10^{0}
16	Liddell Seam Section D	0-100m: 2.31×10^{-2} 101-300m: 2.72×10^{-3} 301-700m: 6.58×10^{-4}	4.5×10^{-1}
17	Interburden	0-100m: 7.67×10^{-4} 101-300m: 1.19×10^{-3} 301-700m: 6.72×10^{-4}	2.0×10^{-2} to 1.0×10^{-1}
18	Barrett Seam	0-100m: 5.15×10^{-2} 101-300m: 4.67×10^{-3} 301-700m: 2.16×10^{-4}	1.0×10^{0}
19	Interburden	0-100m: 6.92×10^{-4} 101-300m: 4.46×10^{-4} 301-700m: 1.24×10^{-4}	1.5×10^{-1} to 3.0×10^{-1}
20	Hebden Seam	0-100m: 3.42×10^{-2} 101-300m: 3.10×10^{-3} 301-700m: 7.80×10^{-5}	1.0×10^{0}
21	Saltwater Creek Formation	1.0×10^{-3}	2.4×10^{-1}
-	Liddell Underworkings	2.49×10^{-3}	1.0×10^{0}
-	Spoil	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 (refer main report Section 5.7). Because the decrease of hydraulic conductivity within the interburden rock units is driven by an increase in overburden pressure, the relationship between Kx 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 1×10^{-1} m/day and the interburden at a maximum of 1×10^{-3} m/day. Both coal and interburden were also capped at a lower bound of 8.64×10^{-6} m/day generally aligning with field measurements described in the main report (Section 5.7).

The *slope* and HC_0 parameters in the depth dependence equations were adjusted for each individual model layer during the calibration process. Following this equation, the output values are adjusted at each of the pilot points within the bounds previously presented in Table B 7.

The Kx vs. depth relationship for the individual coal seams and interburden units are presented in Figure B 24 and Figure B 25. As shown in Figure B 24 and Figure B 25, the calibrated hydraulic conductivity decline with depth for the various coal and interburden layers remains generally within the trend zone identified for the available field data described with the main report. The hydraulic conductivity for the interburden layers in the model calibrated at the upper end of the field measurements.

Figure B 26 and Figure B 27 provide cumulative exceedance plots for the calibrated hydraulic conductivity within the model layers representing coal seams and interburden. The plots use data from a regularised 200 m grid covering the model domain rather than model cell centres. This approach has been used to remove the effect of different cell sizes, which could bias the outputs.

In order to demonstrate the application of the depth dependence function and pilot point approach, the spatial distribution of hydraulic conductivity values is presented in Figure B 28 for the Barrett Seam. Figure B 28 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).

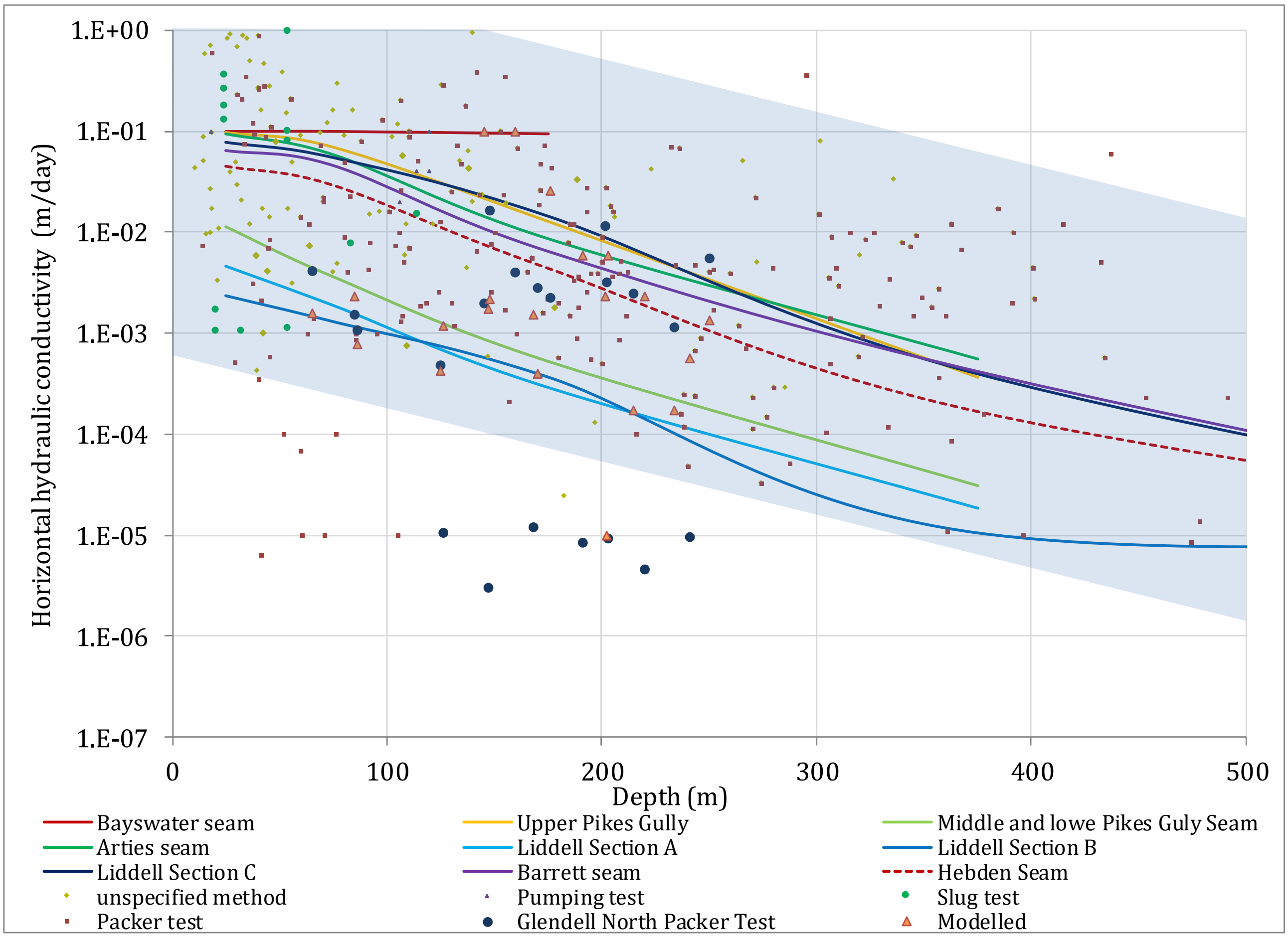


Figure B 24 Coal hydraulic conductivity distribution graph

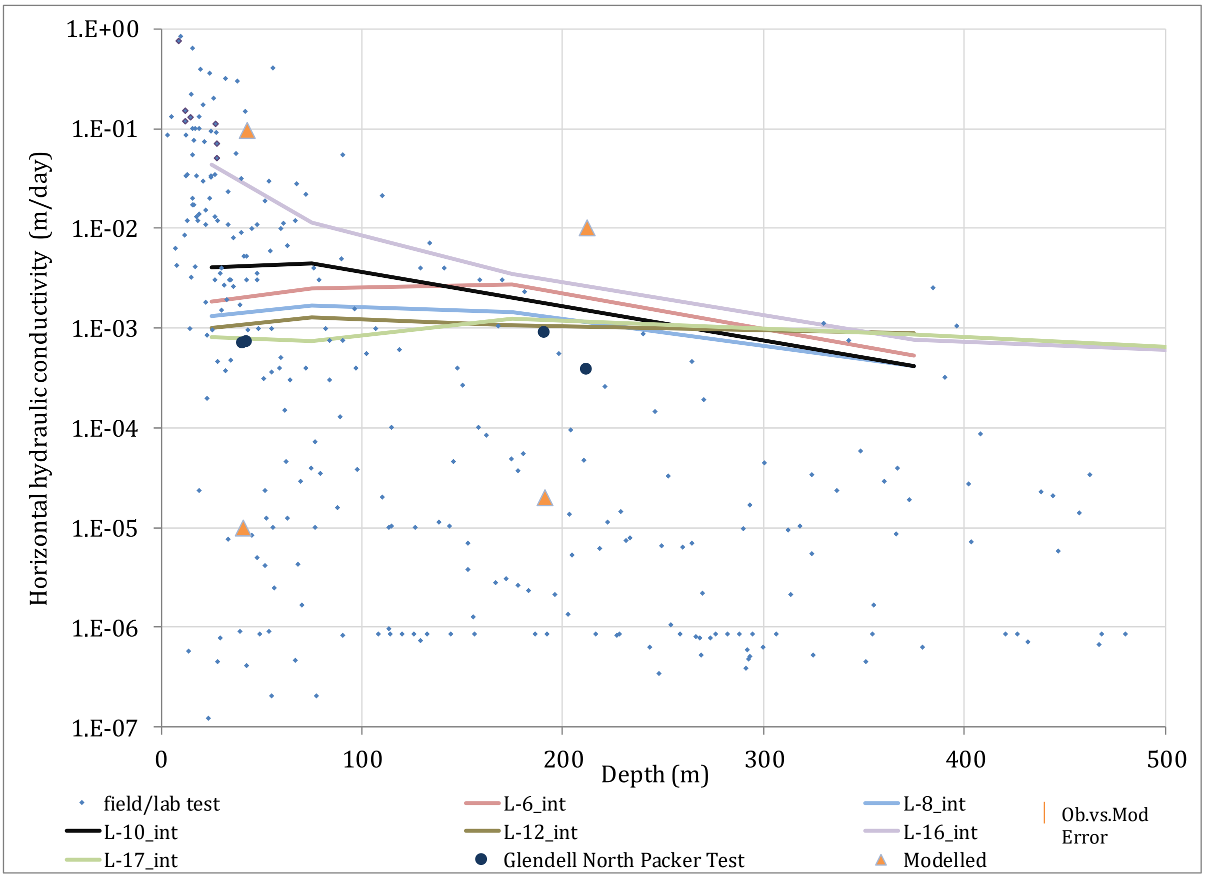


Figure B 25 Interburden hydraulic conductivity distribution graph

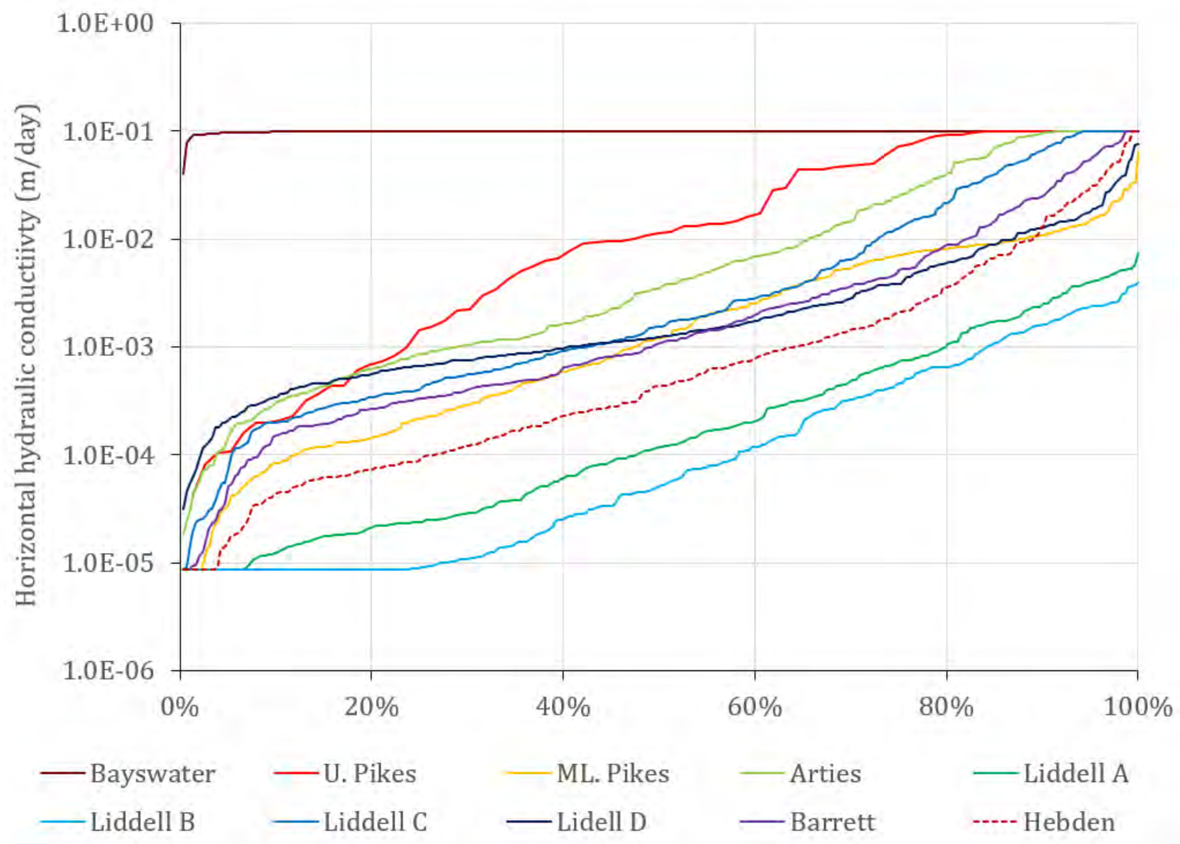


Figure B 26 Calibrated coal seam hydraulic conductivity ranges

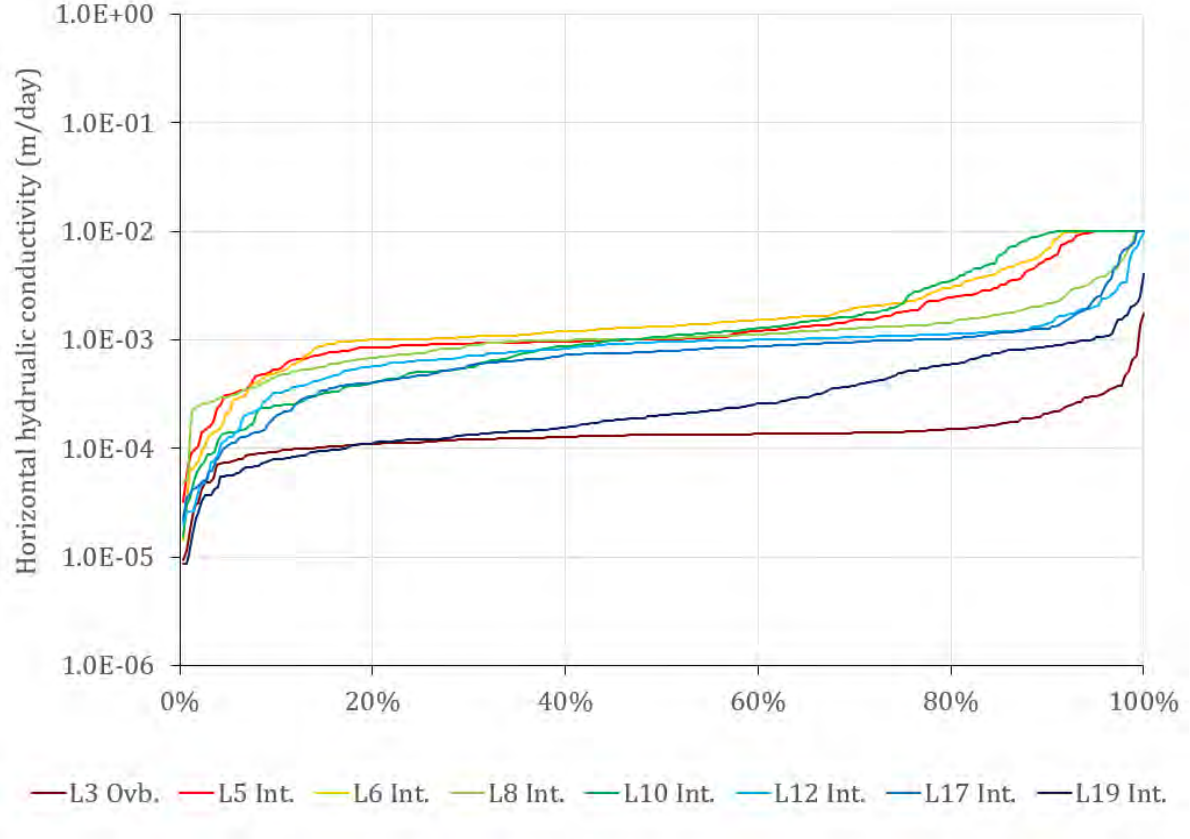
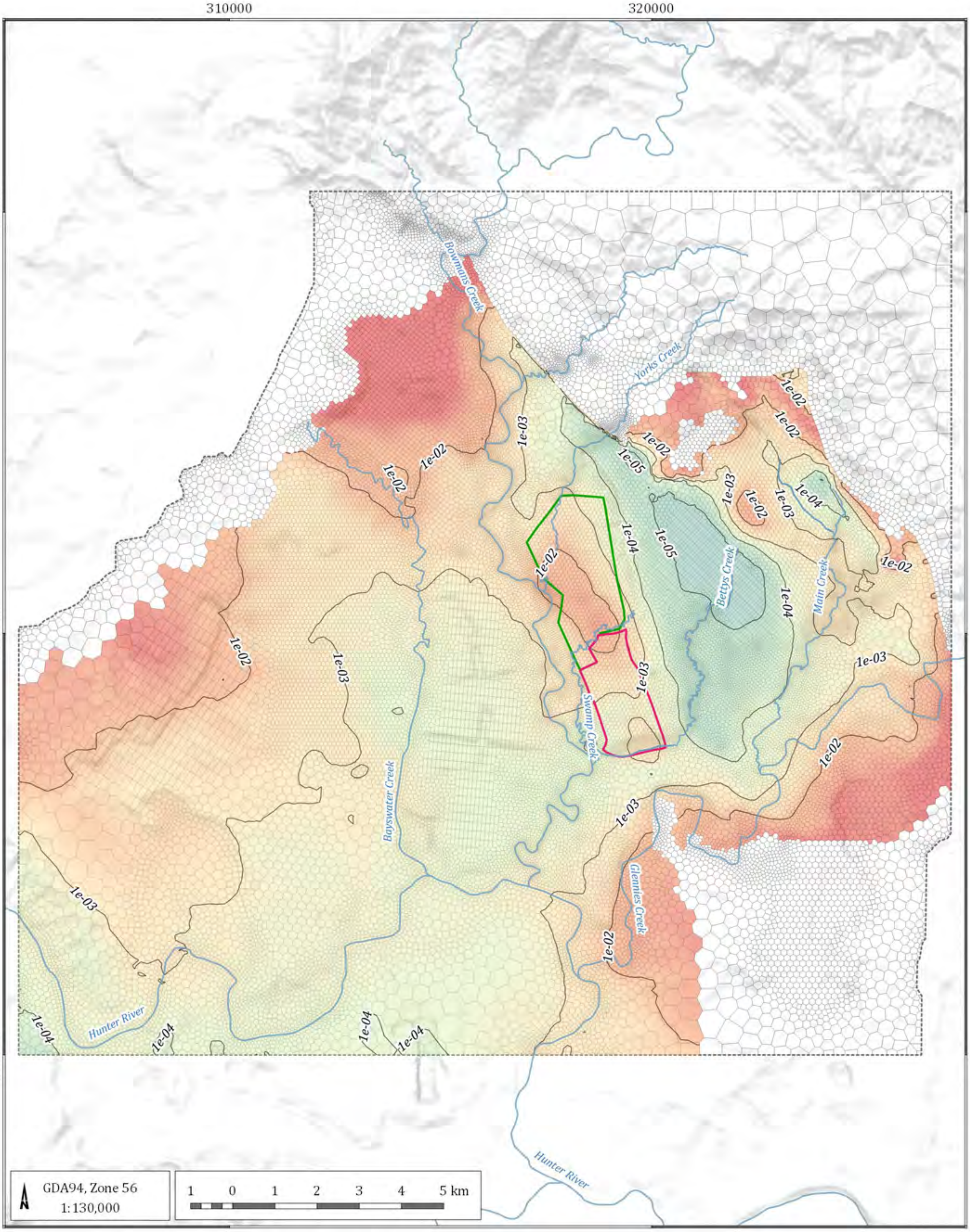


Figure B 27 Calibrated interburden seam hydraulic conductivity ranges



LEGEND

- Drainage
- Model boundary
- Model mesh
- Approved Glendell Pit
- Proposed Glendell Pit Extension

Hydraulic conductivity (m/day)

- 1e-06
- 1e-05
- 1e-04
- 1e-03
- 1e-02
- 1e-01

— Hydraulic conductivity contour

Glendell Continued Operations GIA (G1874C)

Modelled hydraulic conductivity of the Barrett Seam

AGE

DATE 30/07/2019

FIGURE No: **B 28**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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B 3.5.3 Storage properties

Table B 10 summarises the calibrated values for specific storage and specific yield.

Table B 10 Model layer storage properties

Model layer	Lithology	Specific yield - Sy	Specific storage - Ss (m^{-1})
1	Alluvium (Qa)	4.97×10^{-2}	-
2	Regolith	1.35×10^{-2}	1.0×10^{-3}
3	Overburden	1.01×10^{-2}	1.0×10^{-4}
4	Bayswater Seam	3.15×10^{-2}	5.07×10^{-6}
5	Interburden	5.5×10^{-2}	3.56×10^{-6}
6	Interburden	1.0×10^{-3}	9.89×10^{-7}
7	Upper Pikes Gully Seam	1.0×10^{-3}	3.28×10^{-6}
8	Interburden	1.0×10^{-3}	2.62×10^{-6}
9	Middle and Lower Pikes Gully Seam	1.1×10^{-3}	6.66×10^{-6}
10	Interburden	1.0×10^{-3}	7.0×10^{-7}
11	Arties Seam	1.0×10^{-3}	1.52×10^{-6}
12	Interburden	1.0×10^{-3}	7.0×10^{-7}
13	Liddell Seam Section A	1.0×10^{-3}	1.48×10^{-6}
14	Liddell Seam Section B	1.0×10^{-3}	2.15×10^{-6}
15	Liddell Seam Section C	1.0×10^{-3}	9.0×10^{-7}
16	Liddell Seam Section D	1.0×10^{-3}	9.0×10^{-7}
17	Interburden	1.0×10^{-3}	7.0×10^{-7}
18	Barrett Seam	1.39×10^{-3}	2.98×10^{-6}
19	Interburden	1.0×10^{-3}	1.12×10^{-6}
20	Hebden Seam	1.0×10^{-3}	3.65×10^{-6}
21	Saltwater Creek Formation	1.0×10^{-3}	7.0×10^{-7}
-	Liddell Underground	4.85×10^{-1}	4.59×10^{-6}
-	Spoil	1.0×10^{-1}	1.0×10^{-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. Rau et al (2018) provides limits based on poroelastic theory which indicates that specific storage is restricted to the range of 2.3×10^{-7} m^{-1} and 1.3×10^{-5} m^{-1}. The calibrated parameters for coal were guided by these bounds, although some flexibility was allowed for improvement of the calibration results.

B 3.5.4 Parameter sensitivity and identifiability

Identifiability is a term used to describe the capability of a model calibration to constrain parameters used by a model and ultimately reduce the uncertainty in predictions made by the model. An identifiability value of one means that the range in the model parameter can be constrained through the calibration process and hence the parameter is highly estimable. In contrast, an identifiability value of zero indicates that the parameter range cannot be constrained by calibration and hence its uncertainty is not reduced through the calibration process.

To further investigate this issue the PEST utility GENLINPRED was used to provide an estimate of parameter identifiability. GENLINPRED provides an identifiability value for each model parameter. Table B 11 shows the identifiability of groundwater model parameter zones for Kx, Kz, Sy and Ss in respect to the groundwater level observation dataset. Figure B 29 presents a visual representation of the most sensitive parameter field, horizontal hydraulic conductivity.

Table B 11 Average parameter identifiability

Model layer	Lithology	Horizontal hydraulic K (Kx)	Vertical hydraulic K (Kz)	Specific storage - Ss (m^{-1})	Specific yield - Sy
1	Alluvium (Qa)	0.21	<0.005	<0.005	0.06
2	Regolith	0.23	0.09	0.02	0.11
3	Overburden	0.07	0.05	<0.005	0.03
4	Bayswater Seam	0.06	0.01	<0.005	0.01
5	Interburden	0.20	0.17	0.06	0.13
6	Interburden	0.17	0.13	<0.005	<0.005
7	U Pikes Gully Seam	0.02	0.01	<0.005	<0.005
8	Interburden	0.06	0.03	<0.005	<0.005
9	M/L Pikes Gully Seam	0.04	0.04	<0.005	0.04
10	Interburden	0.20	0.17	<0.005	<0.005
11	Arties Seam	0.14	<0.005	<0.005	<0.005
12	Interburden	0.09	0.08	<0.005	<0.005
13	Liddell Seam Section A	0.12	0.05	0.01	<0.005
14	Liddell Seam Section B	0.12	0.04	0.05	<0.005
15	Liddell Seam Section C	0.06	0.01	<0.005	<0.005
16	Liddell Seam Section D	0.12	0.03	<0.005	<0.005
17	Interburden	0.18	0.19	<0.005	<0.005
18	Barrett Seam	0.03	<0.005	<0.005	<0.005
19	Interburden	0.16	0.11	0.04	<0.005
20	Hebden Seam	0.02	<0.005	<0.005	<0.005

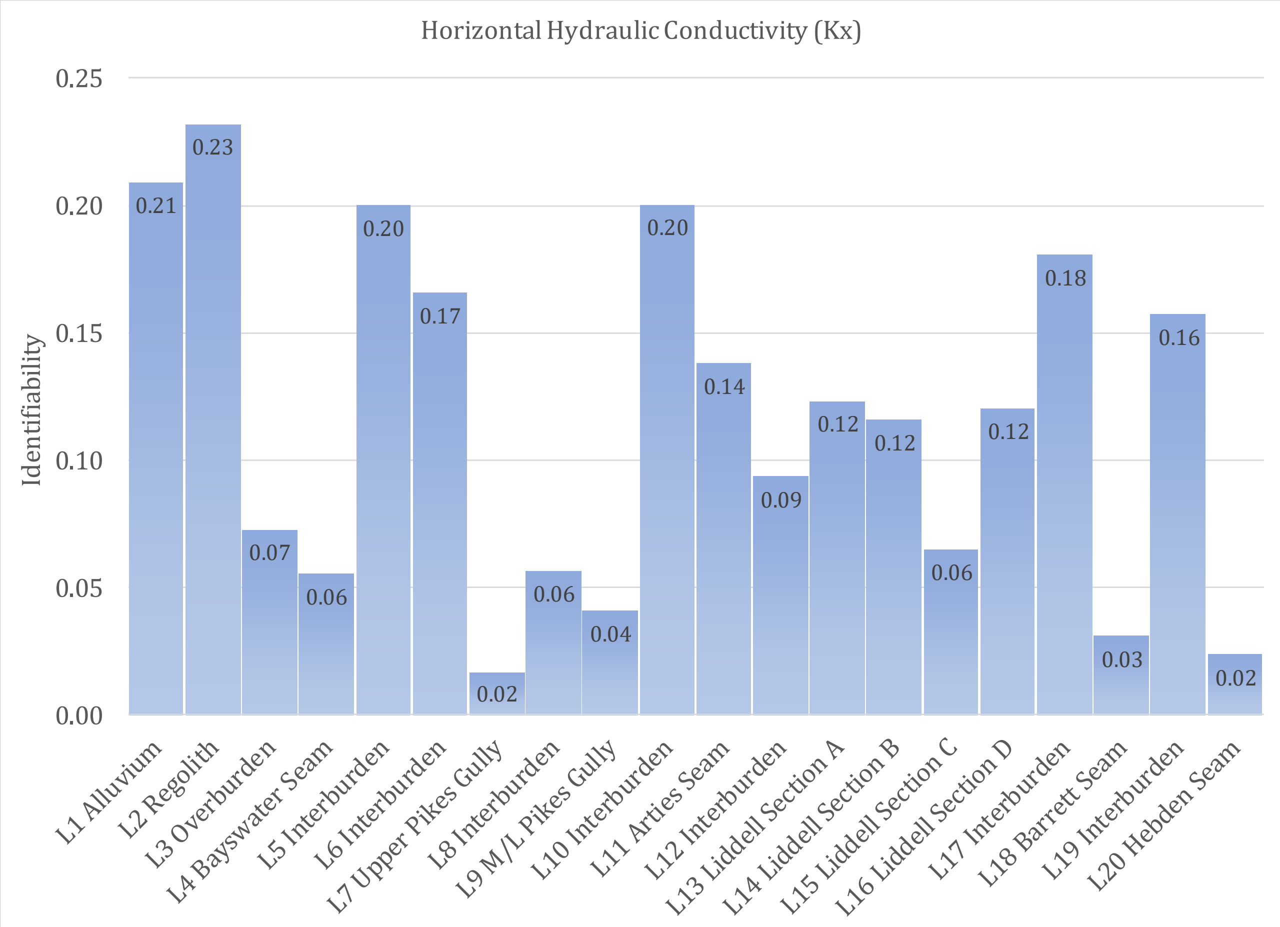


Figure B 29 Parameter identifiability – Horizontal hydraulic conductivity

There are five Kx parameter zones with an identifiability of ~0.2 or higher, meaning that the modelled heads are highly sensitive to parameters within these zones and therefore 'identifiable'. The identifiability of Kz zones is highest in the same sensitive layers to Kx changes, although the values are typically half as sensitive on average.

The results indicate that storage is the least identifiable parameter. The identifiability is low because the magnitude of change in the parameter to derive the Jacobian matrix did not induce significant changes in groundwater levels compared to hydraulic conductivity. Specific storage is most identifiable in the regolith, interburden, and Middle Liddle B seam model layers.

The average identifiability from the alluvial and regolith recharge pilot point multipliers was 0.28 and 0.13 respectively. Stream bed conductance of Bowmans creek had a similar identifiability of 0.27.

Identifiability is only a qualitative indicator and should not be over-interpreted. However, it can provide some insight into calibrated model behaviour. Parameters with high identifiability can be interpreted as important controls on model performance. Identifiable parameters indicate where the groundwater and conceptual models are suitably constructed to replicate measured processes.

The analysis indicates that model parameters affecting the alluvial groundwater systems were relatively identifiable during the calibration process. This is an optimal outcome as the alluvial groundwater systems are the main sensitive receptors in the Project area. The calibration process was less successful in identifying appropriate model parameters for the coal seams, but as the coal seams are not sensitive environmental receptors, their uncertainty in parameter values is less significant.

The results from the identifiability analysis are used to derive the posterior distributions for the uncertainty analysis. If not managed properly parameters that are highly identifiable can have a narrow posterior distribution when conducting uncertainty analysis. Parameters with low identifiability could imply the parameter is insensitive to the measurement data, or there are no observation data to inform the parameter. In this instance, the range of parameters explored in the uncertainty analysis is broad. This is discussed in Section B 5.2.2.

B 3.5.5 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 B 12 shows the water budget for the steady state (pre-mining) model and the averages from the transient model for the period 1979 to 2018.

Table B 12 Model budgets (ML/day)

Parameter	Steady state model			Transient model average		
	in	out	in - out	in	out	in - out
storage				16.6	5.9	10.6
rainfall	10.6	-	10.6	10.8	-	10.8
river	-	0.01	-0.01	-	0.01	-0.01
stream	1.3	6.0	-4.7	1.6	5.4	-3.8
evapotranspi	-	6.5	-6.5	-	4.9	-4.9
general head	0.7	0.2	0.5	0.9	0.1	0.8
constant head	0.03	0.0	0.03	0.4	0.0	0.4
drains				-	13.9	-13.9
Total	**12.7**	**12.7**	**0.0**	**30.3**	**30.3**	**0.0**

The steady state water budget indicates that recharge to the groundwater system within the model averages 10.6 ML/day, with approximately 4.7 ML/day being discharged via surface drainage, and 6.5 ML/day lost to evapotranspiration in areas where the water table is within 2 m of the land surface. Regional through flow from the general head boundary contributes 4% of the total input to the groundwater model, whereas the constant head boundary, which represents Lake Liddell, contributes little to the overall water budget.

The transient model water budget departs from steady state conditions because of extensive mining in the model domain. Mining dewatering represented by drain cells indicates regional dewatering intercepts 13.9 ML/day on average, which indirectly reduces stream baseflow, evapotranspiration rates, and increases inflows from the general and constant head boundaries. Recharge from rainfall and river leakage increases very slightly within the transient model due to the use of actual climatic data during the transient calibration period from 1980 to 2018.

The calibrated model water budget represents the optimal balance PEST arrived at using the groundwater levels and baseflow as a target. There is significant uncertainty in these volumes as the majority of the budget components are not directly measurable in the field. Variations of the model water budgets are indirectly explored through the predictive uncertainty analysis, as described in Section B 5.

B 3.5.6 Baseflow verification

Figure B 30 shows the baseflow calculated for the Bowmans Creek downstream of the Project (station 210130), compared with the baseflow simulated by the numerical model during the calibration period.

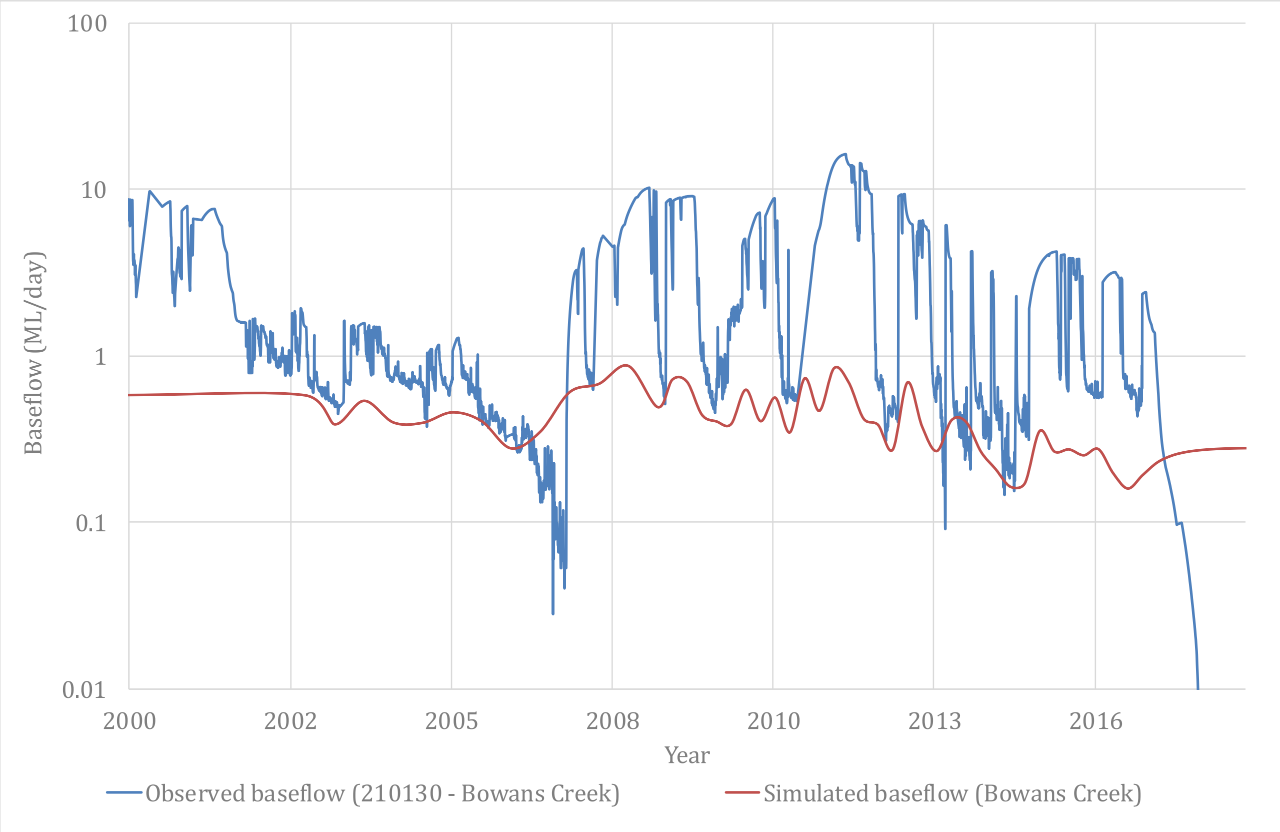


Figure B 30 Modelled vs observed baseflow analysis at Bowmans Creek

The results show the model generally replicates the calculated baseflow levels and climatically controlled trends in Bowmans Creek in a subdued manner compared to the baseflow calculated using the method of Lyne and Hollick (1979). This suggests some of the interflow processes that occur on a daily scale and are captured in the stream gauging are not replicated in the numerical model due to the quarterly stress periods adopted.

B 3.5.7 Mine inflow verification

Observable and pumpable groundwater inflow to the existing Glendell workings is essentially zero (refer main report Section 2.4). It is therefore not possible to verify the mine inflow predicted by the numerical model aligns with field measurements.

Groundwater inflow to neighbouring mines is discussed by AGE (2017) who concluded the model generally replicated inflows to the Integra underground mine. To verify that this latest model is consistent with previous groundwater estimations to the mine working area, groundwater inflow budgets were extracted during the calibration period. Figure B 31 presents the raw inflow predictions to the drain cells in the groundwater model. The results indicate good agreement with expected inflows at Glendell Pit (Barrett Pit) and Integra Underground.

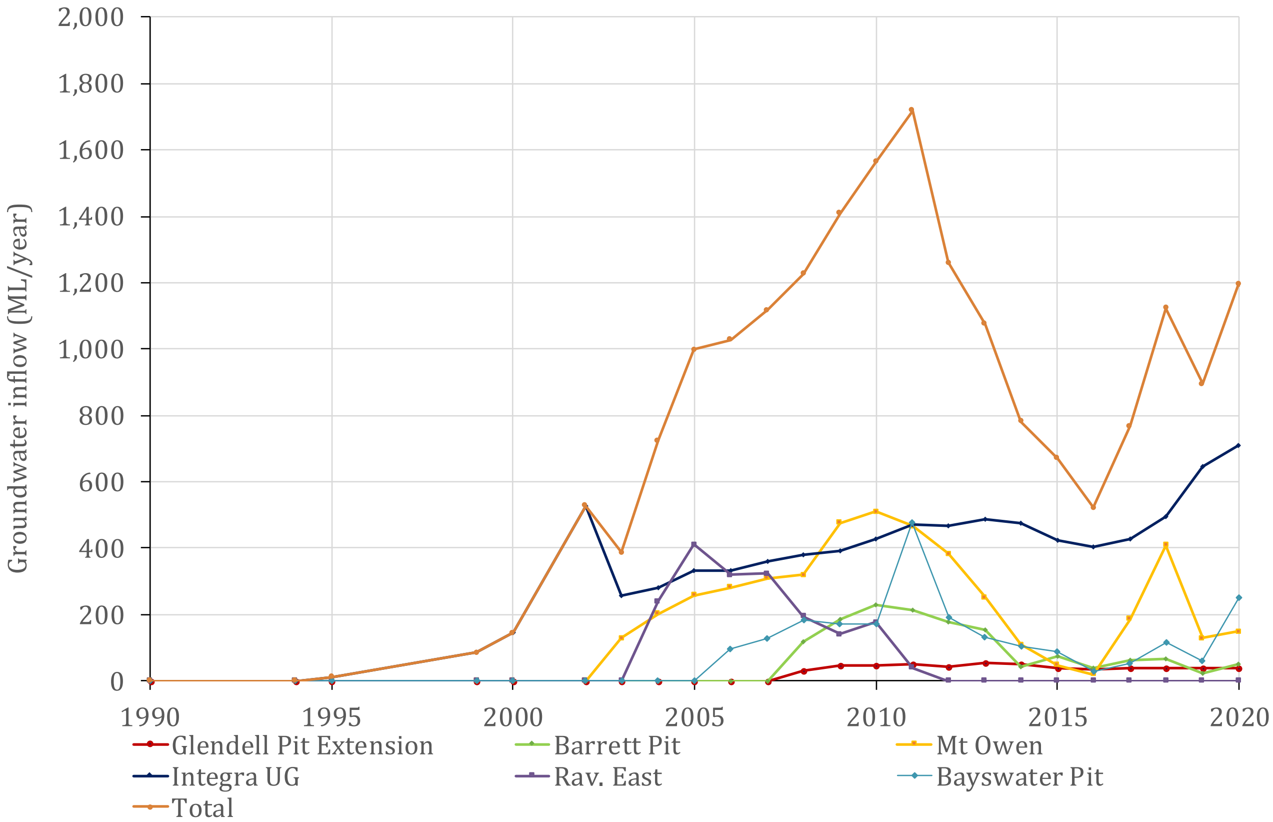


Figure B 31 Simulated inflow to mining areas (1990 – 2020)

B 3.5.8 Model confidence level classification

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. Several factors are considered in determining the model confidence-level:

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

A Class 3 model is often referred to as an aquifer simulator, in that it encapsulates a very detailed and well understood conceptualisation. Despite the use of all available data for the model inputs, it is difficult to obtain all of the Class 3 descriptors, and an appropriate and achievable level is commonly somewhere between an aquifer simulator and an impact model. Barnett *et al*., (2012) consistently suggest "*it is not expected that any individual model will have all the defining characteristics of Class 1, 2 or 3 models*". Comparison against the performance indicators for individual model classes are presented in Table B 13.

This shows the Project groundwater model is classified between a Class 2 and Class 3 model. That is, the model classification identifies:

- 2 out 18 (11%) performance indicators align with a Class 1 model;
- 10 out 22 (45%) performance indicators align with a Class 2 model; and
- 15 out 21 (71%) performance indicators align with a Class 3 model.

Table B 13 Model confidence level classification

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

Class	Data		Calibration		Prediction		Quantitative Indicators	
3 (Complex Simulator)	~	Local climate data	✓	Most seasonal matches ok.	~	Good validation	✓	Mass balance < 0.5%
	✓	Kx, Kz & Sy measurements from range of tests	~	Present day data targets	✓	Calibration & prediction consistent (transient or steady state).	~	Properties ~field measurements
	~	High resolution DEM all areas.	✓	Head & Flux targets used to constrain calibration	✓	Similar stresses to those in calibration.	✓	No coarse discretisation in key areas (grid or time)
	✓	Good aquifer geometry.					✓	Review by experienced Modeller

B 4 Recovery simulations

A separate transient model was built to simulate recovery of the groundwater system once all mining is complete. At the completion of mining, any remaining drain cells were removed, and the model was adjusted to simulate post-mining conditions. This included an increase in permeability in the mining areas to represent the spoils used to backfill open cut mining areas, and enhanced recharge rates to the spoil heaps to simulate their enhanced recharge capacity. In addition, an evaporative boundary condition was applied over the mining landforms with the exception of the pit lake areas. Final voids remain in both the Glendell Project, Ravensworth Operations, and Mt Owen mines. Because the groundwater flow model does not represent rainfall runoff and is not refined enough to represent the morphology of the final voids accurately information from a separate water balance model created by GHD (2019) was used to provide inputs to the groundwater model. The process to determine the final void water level recovery was as follows:

- firstly, the water balance model was used to assess the rate of net surface water flow in the final void from rainfall and runoff (minus evaporation), but excluding any input of groundwater;
- secondly the water level recovery curve predicted by the water balance model was then represented in the groundwater model and the net rate of groundwater inflow to the final void over time was calculated;
- thirdly the calculated groundwater inflow to the final void was entered into the water balance model and the water level recovery curve recalculated; and
- finally, the water level recovery curve was represented in the groundwater model to allow prediction of long-term drawdown and water take.

This approach ensured consistency between the surface water and groundwater studies. The water balance model indicated the water level within the final void will slowly recover over a period of approximately 500 years stabilising at approximately -64 mAHD. The recovery simulation was run for 550 years, thus allowing the groundwater levels in the backfilled spoil, final void lake, unmined coal seams, and the overlying water-bearing strata to recover to a long-term post mining equilibrium.

Model cells representing backfilled spoil were assigned a higher horizontal (0.3 m/day) and vertical (0.1 m/day) conductivity than the bedrock units, and a porosity (specific yield) of 0.1. Recharge rates to the spoil were also increased to 2% of average annual rainfall. There are few reported measurements of the influence of gradual consolidation and rehabilitation on spoil hydraulic properties and rainfall recharge rates post mining. The hydraulic properties adopted in the modelling assume the spoils form a relatively permeable aquifer system with relatively high rates of recharge.

Model cells located within the final voids were assigned a high horizontal and vertical hydraulic conductivity (1,000 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.

Outputs from the recovery modelling are presented in Section 7.3 of the main report.

B 5 Uncertainty analysis

The preceding sections highlight uncertainties in model inputs and the necessary simplifications made within the model to represent the natural system. The sections below describe the methodology and results of the uncertainty analysis completed for the Project.

B 5.1 Methodology

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

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

A Null-space Monte Carlo uncertainty analysis was undertaken (option 3) to quantify the magnitude of uncertainty in the future impacts predicted by the model. This type of analysis produces probability distributions for predictive impacts by assessing a composite likelihood of an impact occurring through assessing and ranking the predictions from hundreds of models 'realisations'. 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.

This uncertainty analysis was essentially a three-part process. Firstly, the valid range for the parameters (i.e. pre-calibration range) was determined, and then 250 model realisations were created, each having differing values of model parameters. Realisations were then constrained using calibration datasets.

The constrained realisations were tested and the models that failed to converge or could not achieve adequate calibration were rejected, leaving the output from 183 successful models for uncertainty analysis. Models were considered to have an acceptable calibration if they had less than a 100% increase in the model phi. This output was analysed to provide a statistical distribution of the predictive impacts.

Outputs from the uncertainty modelling were processed in accordance with the risk-based calibrated language proposed in Middlemis & Peeters (2018). The ranges adopted are shown in Table B 14.

It is important to note that the ranges include outputs from all model runs that are deemed to be within an acceptable calibration. There may be one outlier model run within the dataset that produces the extremities of the ranges on the charts.

Table B 14 Calibrated uncertainty modelling language

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

B 5.2 Parameter generation

B 5.2.1 Prior ranges

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. Table B 15 to Table B 20 shows the 'prior' range explored during the uncertainty analysis simulations. This represents the 95th confidence interval on prior information of the likely range of the model parameters. 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 250 models were generated using a random parameter generator to produce 'realisations' to assess predictive impacts.

Table B 15 Prior range – horizontal hydraulic conductivity

Model layer	Lithology	Horizontal hydraulic conductivity (m/day)		
		lower	mean	upper
1	Alluvium (Qa)	5.0×10^{-2}	5.0×10^{0}	$1.0 \times 10^{+1}$
2	Regolith	1.0×10^{-4}	2.44×10^{-3}	1.2×10^{-1}
3	Overburden	1.0×10^{-6}	1.37×10^{-4}	1.0×10^{-3}
4-20	Coal seam limit (Kcap)	8.0×10^{-3}	1.0×10^{-1}	1.0×10^{0}
5-19	Interburden limit (Kcap)	1.0×10^{-4}	1.0×10^{-3}	1.0×10^{-2}
21	Saltwater Creek Formation	1.0×10^{-5}	1.0×10^{-3}	5.0×10^{-3}
1-21	Pilot point multiplier	0.01x	0.01-100x	100x

Table B 16 Prior range – vertical hydraulic conductivity factor

Model layer	Lithology	Vertical hydraulic conductivity factor (Kz/Kx)		
		Lower	Mean	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

Model layer	Lithology	Vertical hydraulic conductivity factor (Kz/Kx)		
		Lower	Mean	Upper
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
1-21	Pilot point multiplier	0.01x	0.01-50x	50x

Table B 17 Prior range – Specific yield

Model layer	Lithology	Specific yield – Sy		
		Lower	Mean	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%
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%
1-21	Pilot point multiplier	0.1x	0.3 – 9x	50x

Table B 18 Prior range – specific storage

Model layer	Lithology	Specific storage m^{-1}		
		Lower	Mean	Upper
1	Alluvium (Qa)	1.0×10^{-4}	9.67×10^{-4}	5.0×10^{-3}
2	Regolith	1.0×10^{-5}	9.57×10^{-4}	1.0×10^{-3}
3	Overburden	5.0×10^{-7}	1.92×10^{-4}	5.0×10^{-4}
4	Bayswater Seam	5.0×10^{-7}	5.04×10^{-6}	5.0×10^{-5}
5	Interburden	5.0×10^{-7}	3.44×10^{-6}	5.0×10^{-5}
6	Interburden	5.0×10^{-7}	1.07×10^{-6}	5.0×10^{-5}
7	Upper Pikes Gully Seam	5.0×10^{-7}	3.36×10^{-6}	5.0×10^{-5}
8	Interburden	5.0×10^{-7}	3.08×10^{-6}	5.0×10^{-5}
9	Middle and Lower Pikes Gully Seam	5.0×10^{-7}	1.02×10^{-5}	5.0×10^{-5}
10	Interburden	5.0×10^{-7}	5.0×10^{-7}	5.0×10^{-5}
11	Arties Seam	5.0×10^{-7}	1.55×10^{-6}	5.0×10^{-5}
12	Interburden	5.0×10^{-7}	5.0×10^{-7}	5.0×10^{-5}
13	Liddell Seam Section A	5.0×10^{-7}	1.16×10^{-6}	5.0×10^{-5}
14	Liddell Seam Section B	5.0×10^{-7}	1.3×10^{-6}	5.0×10^{-5}
15	Liddell Seam Section C	5.0×10^{-7}	6.33×10^{-7}	5.0×10^{-5}
16	Liddell Seam Section D	5.0×10^{-7}	6.97×10^{-7}	5.0×10^{-5}
17	Interburden	5.0×10^{-7}	5.0×10^{-7}	5.0×10^{-5}
18	Barrett Seam	5.0×10^{-7}	2.85×10^{-6}	5.0×10^{-5}
19	Interburden	5.0×10^{-7}	7.44×10^{-7}	5.0×10^{-5}
20	Hebden Seam	5.0×10^{-7}	3.55×10^{-6}	5.0×10^{-5}
21	Saltwater Creek Formation	5.0×10^{-7}	5.0×10^{-7}	5.0×10^{-5}
2-21	Pilot point multiplier	0.01x	0.2 – 5x	50x

Table B 19 Prior range – recharge factor

Model layer	Lithology	Recharge rate (mm/year)		
		Lower	Mean	Upper
1	Alluvium (Qa)	2.3	55.6	92.6
2	Regolith	0.1	2.4	9.3
3	Overburden	0.1	0.4	9.3
4-20	Permian interburden and coal seams	0.1	0.6	9.3
21	Saltwater Creek Formation	0.1	0.1	0.9

Table B 20 Prior range – streambed vertical hydraulic conductivity (m/day)

Unit	Lithology	Vertical hydraulic conductivity (m/day)		
		Lower	Mean	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

B 5.2.2 Posterior ranges

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.

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.

As pilot points are present in each layer, reviewing the basecase prior and posterior ranges is not sufficient to show full distribution in parameters for each layer. Instead the posterior distribution of parameters was analysed using regularised (200 m) cumulative distribution function (CDF) plots with uncertainty ranges added. Example plots are provided as Figure B 32 and Figure B 33 for Kx in layer 1 (Quaternary Alluvium) and Kx in layer 15 (Middle Liddell seam).

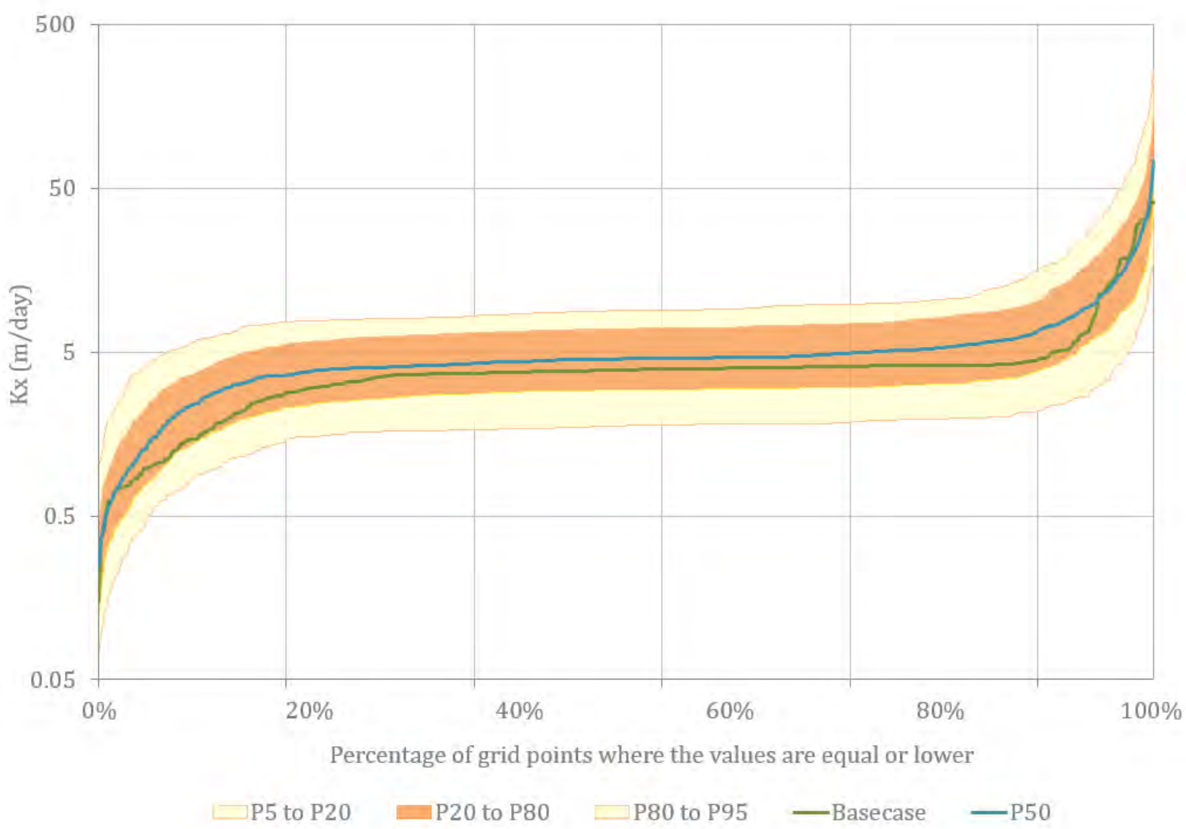


Figure B 32 Cumulative distribution function plot for Kx layer 1 – Quaternary alluvium

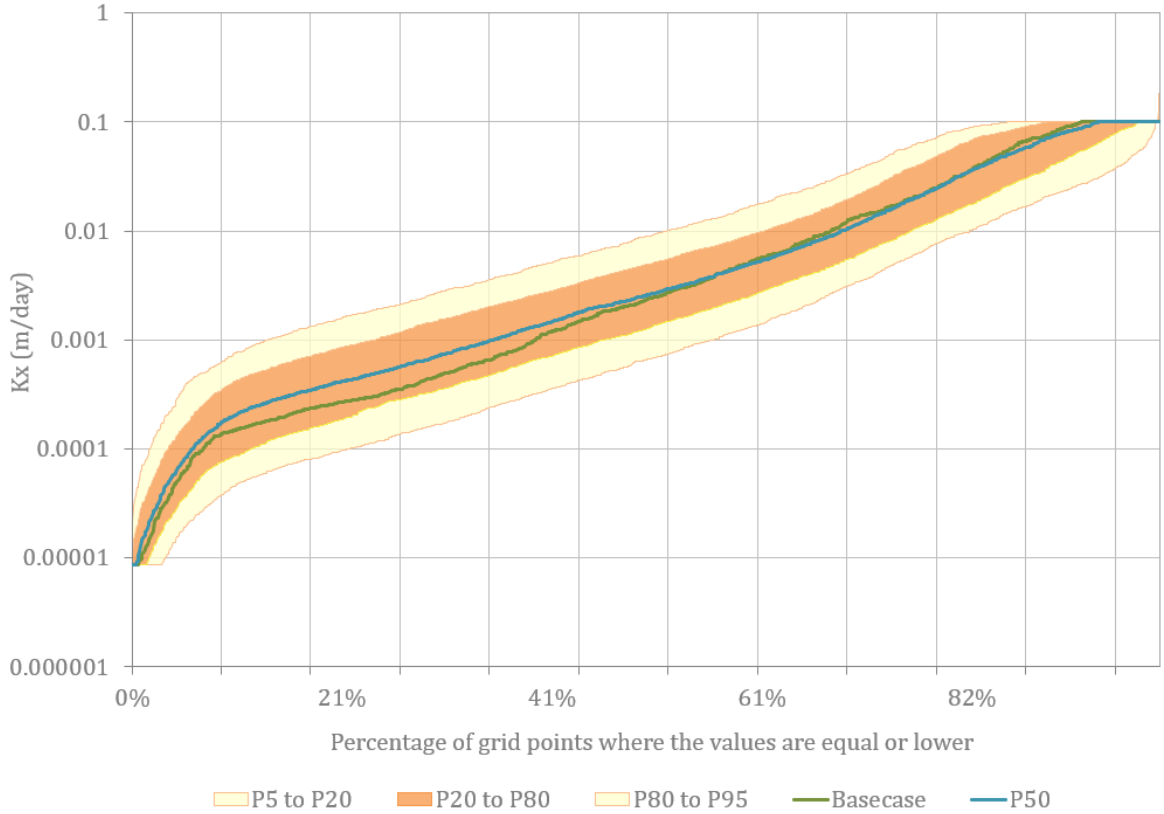


Figure B 33 Cumulative distribution function plot for Kx layer 15 – Middle Liddell Seam

The plots show that the 50th percentile (P50) parameter values adopted for the uncertainty analysis is similar to the basecase model, and the basecase model is therefore a more likely version of the model parameters. In layer 15 the highest Kx values in the basecase model reached the upper limit prescribed for coal seams (0.1 m/day – see Section B 3.5.2) at less than 10% of grid points. However, in the most permeable uncertainty models this limit was reached at 20% of the grid points. If this cap were not present the permeability would have increased to unrealistically high values.

The uncertainty bands for each layer show that the average Kx varied by approximately 0.5 to 1 order of magnitude across the 183 realisations, while the pilot points varied by as much as 0.05-50x the average Kx from the depth dependence equation (where applicable). This represents the variation in the average transmissivity of the entire unit in the model commensurate with the field testing data ranges. This is considered to be a suitable range in conditions to properly simulate uncertainty, but could be expanded if the calibration criteria were allowed to vary by more than 100% of the basecase model phi.

The variability of recharge to the system assessed in the uncertainty analysis is equivalent to the 95th confidence interval of calculated yearly recharge rates from the soil-moisture bucket model (see Section B 2.5.1) from 1900 to 2018. This is equivalent to a modelled alluvial recharge rate of approximately 1 to 120 mm/year. Therefore, any expected dry/wet climate cycles have been conservatively simulated, considering the recharge factor is applied for the entire life of the Project, not just isolated dry years.

B 5.3 Results

B 5.3.1 Number of model runs

As noted previously, a total of 250 models were generated and set to run. Solver settings were allowed to adjust if model convergence was not achieved with the original criteria. i.e. SMS convergence criteria was initially set to 0.005 m but relaxed to 0.01 m if the initial model did not converge. If convergence was still not achieved with the relaxed solver settings, then the model run was rejected. Of the 250 models run only 39 models did not converge, and 28 models did not produce acceptable calibration statistics, leaving 183 models for the uncertainty calculations.

As the number of models contributing to the uncertainty analysis increases, the difference in the output ranges reduces, until the addition of further models has little influence on the results. Figure B 34 shows the number of model simulations contributing to the uncertainty analysis and the range in the outputs produced. The figure shows the results are similar after 183 models are combined. The number of models contributing to the Project uncertainty analysis (183) is therefore sufficient to fully explore parameter uncertainty.

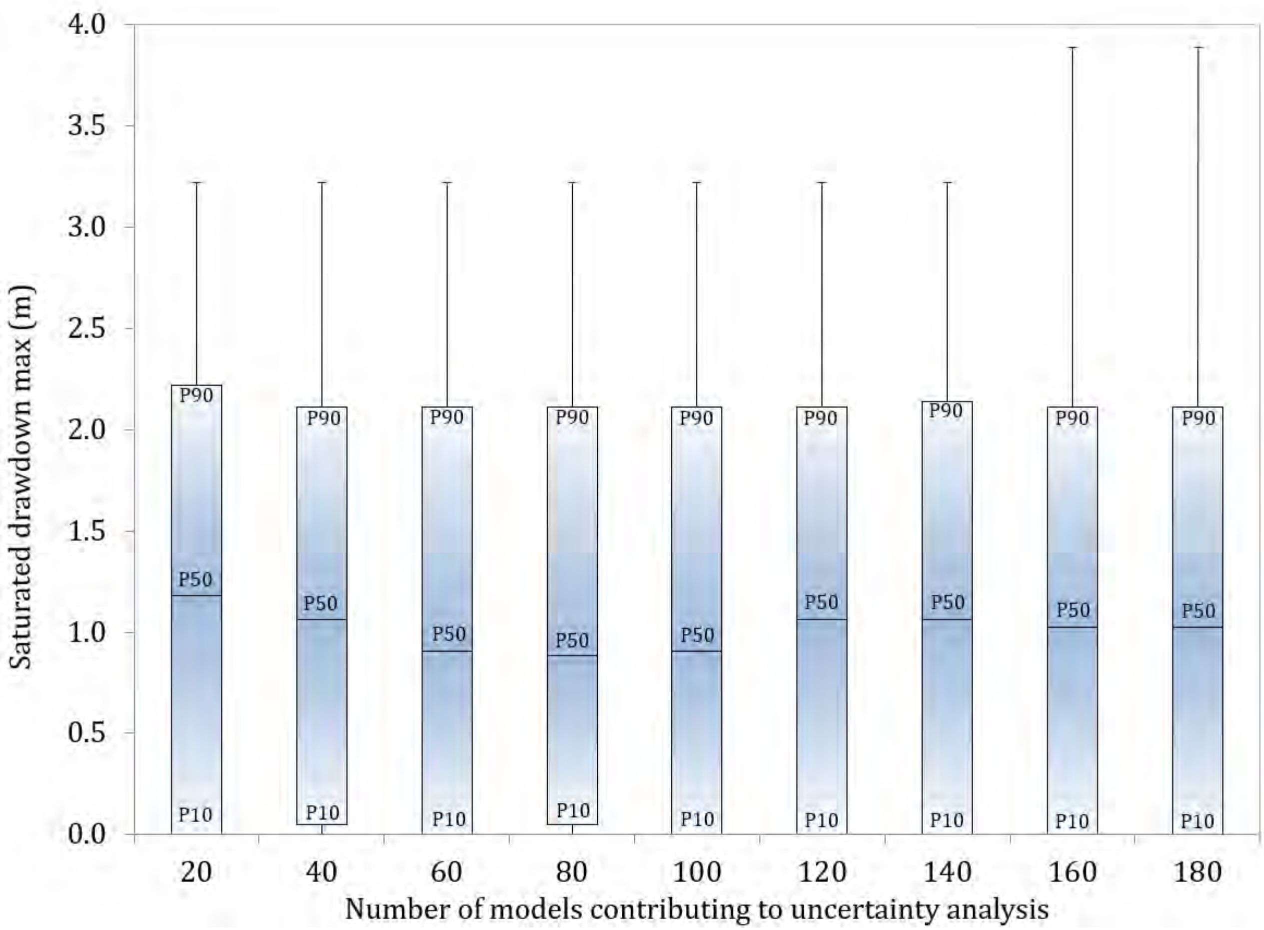


Figure B 34 Model convergence check points (Box and whisker)

A summary of the calibration performance and predictive response to mining is provided in Appendix B-2 The hydrographs show the composite distribution of the heads across all 183 realisations and indicate that the majority of the models are acceptably calibrated.

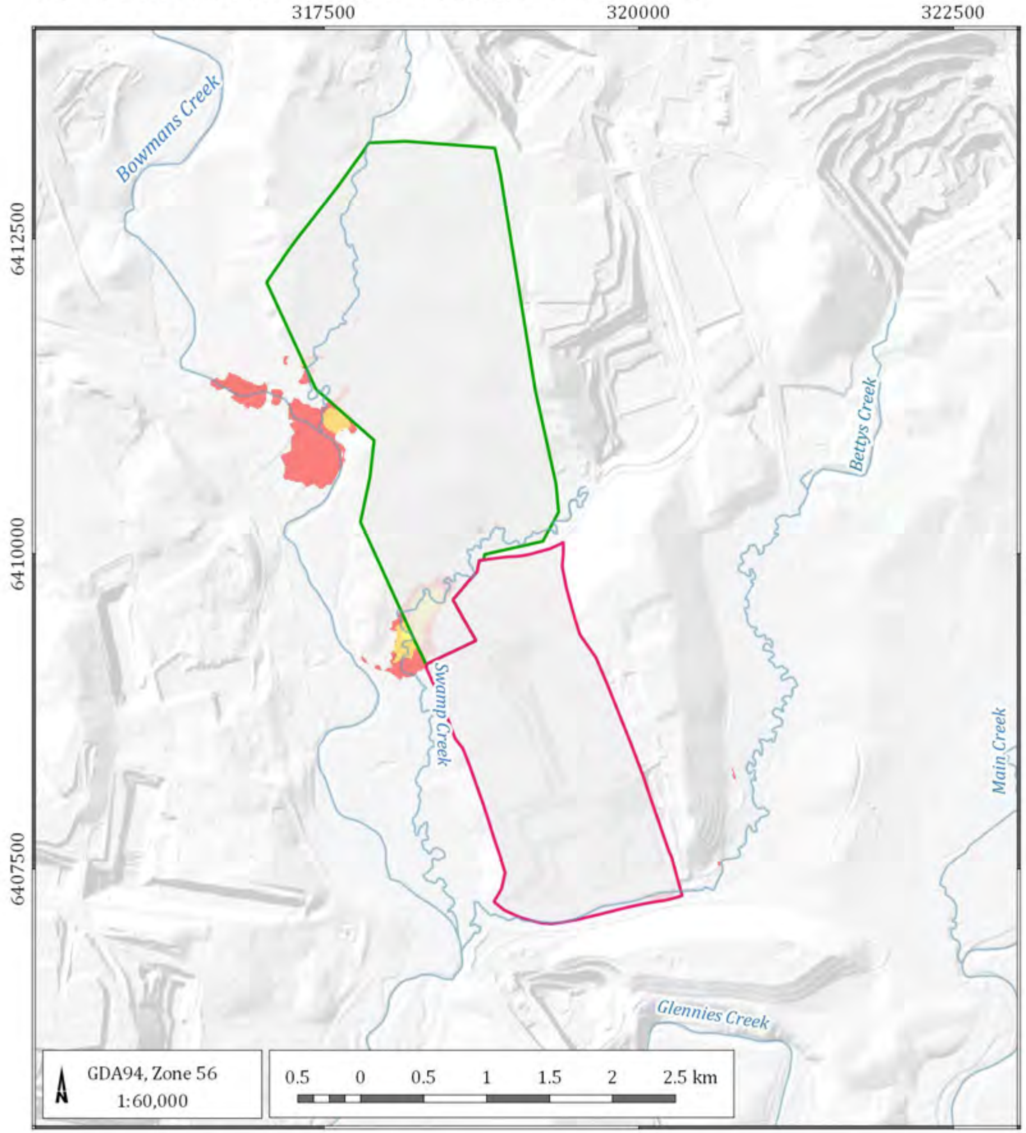
B 5.3.2 Uncertainty in drawdown

Drawdown predicted by the calibrated model is provided within the main report for the alluvium (Layer 1), Middle Liddell Seam (Layer 15), and Barrett Seam (layer 18). Figure B 35 and Figure B 36 show the likelihood of the maximum drawdown at any time during mining exceeding 2 m within the alluvium and Barrett Seam. The figures use the calibrated language to describe uncertainty as detailed in Section B 5.1

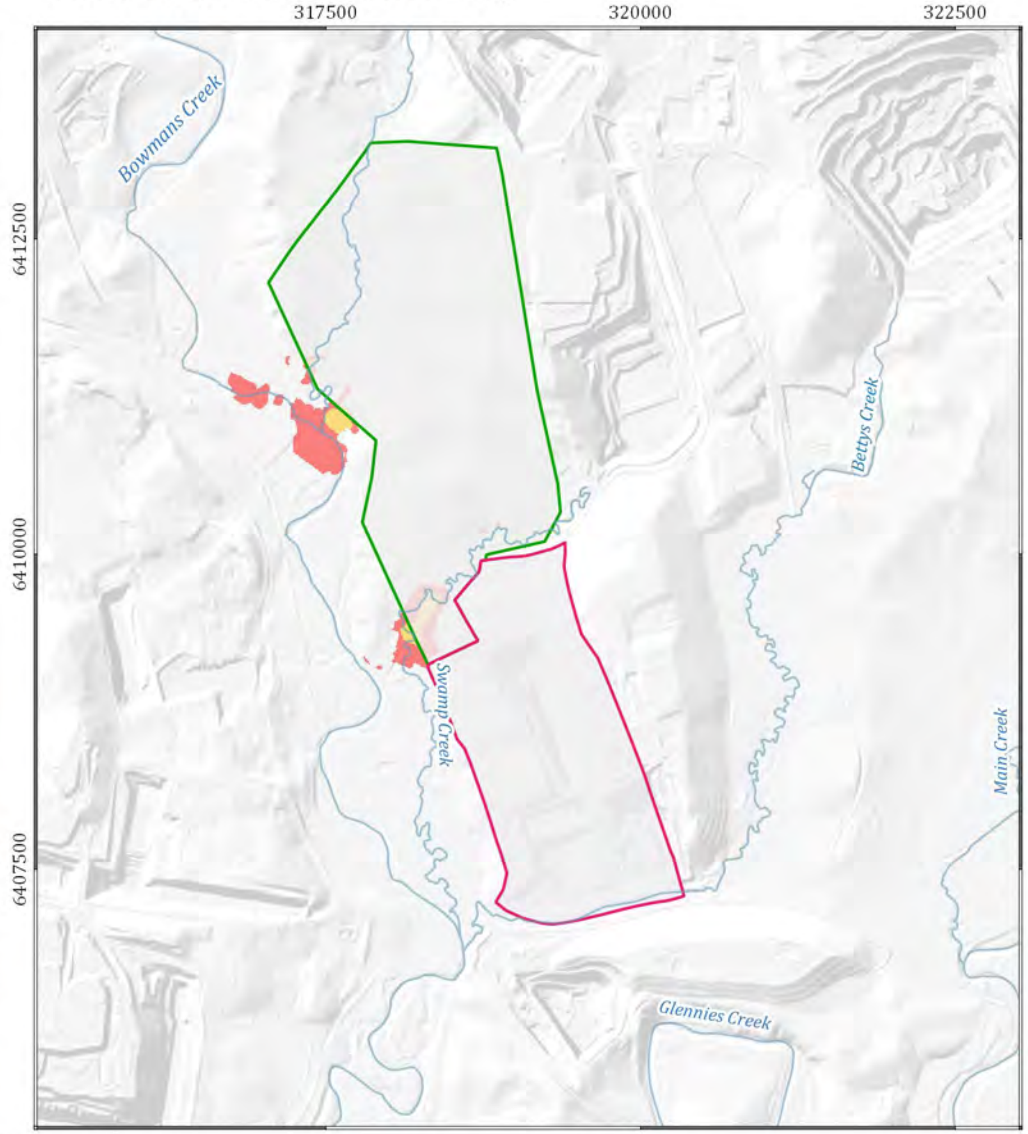
Figure B 35 shows that within the two shallowest model layers there are only limited areas where drawdowns of over 2 m occur and are ranked as 'very unlikely' to 'unlikely'. The uncertainty analysis indicates that there are no areas within the Bowmans Creek alluvium where drawdown is 'likely' or 'very likely' to exceed 2 m during the active Project life. This is because the indirect loss of groundwater from the base of the alluvium to the depressurised underlying Permian aquitards is less than the recharge rate to the alluvial groundwater system across the majority of the model realisations.

In the deeper model layers the spatial extents of drawdown are greater and, as expected, radiate out in decreasing likelihood from the active mining area. Although the deeper layers show a larger area of drawdown this is not transmitted to the shallower layers.

Likelihood of drawdown - Approved mining and Modification



Likelihood of drawdown - Modification only



LEGEND

- Dainage
- Model boundary
- Approved Glendell Pit
- Proposed Glendell Pit Extension

Exceedance probability (%)

- 0-10% (Very unlikely)
- 10-33% (Unlikely)
- 33-67% (About as likely as not)
- 67-90% (Likely)
- 90-100% (Very likely)

Glendell Continued Operations GIA (G1874C)

AGE

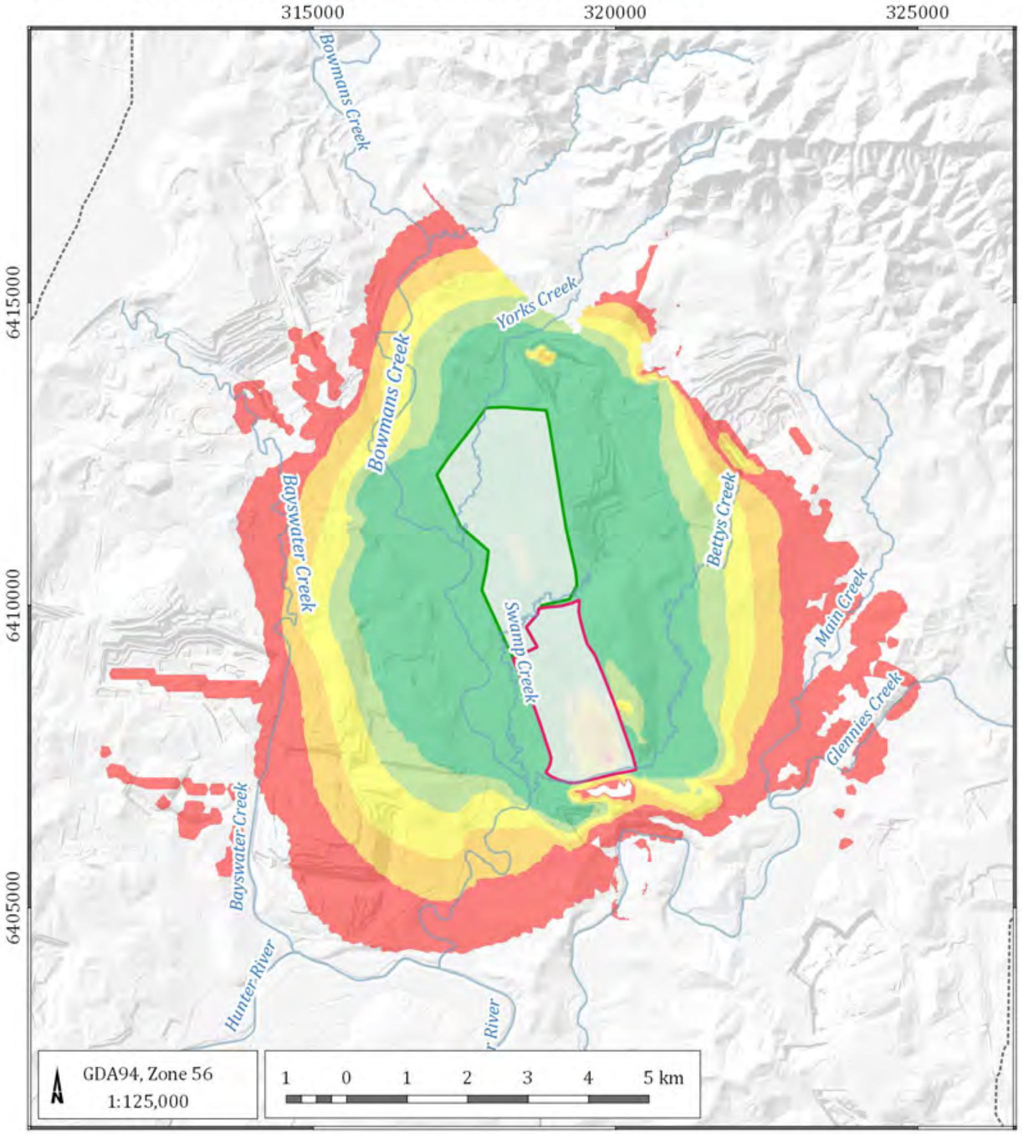
Likelihood of 2m drawdown due to Proposed Modification – Quaternary alluvium

DATE
30/07/2019

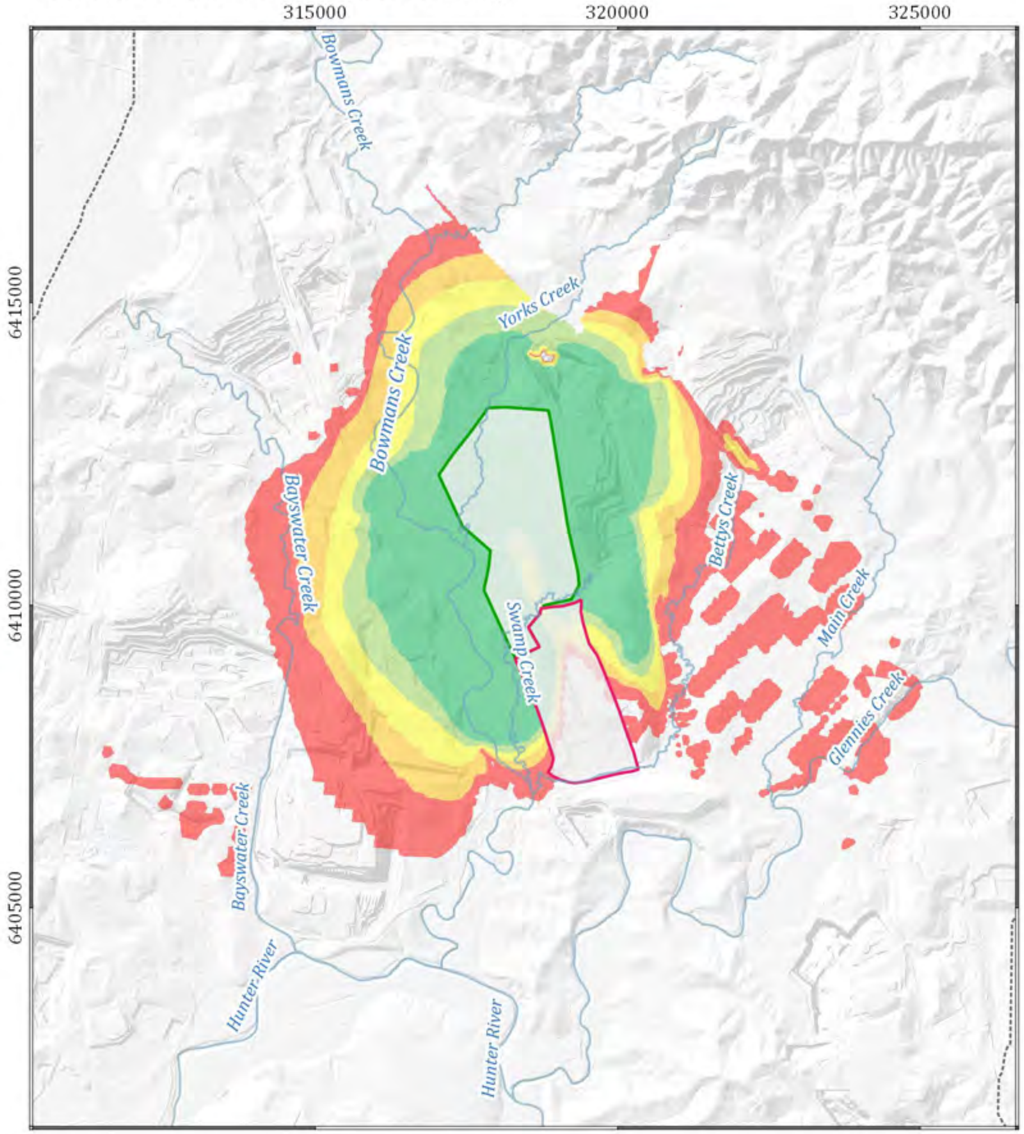
FIGURE No:
B 35

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\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\B35-B36_G1874C_Likelihood drawdown.qgs

Likelihood of drawdown - Approved mining and Modification



Likelihood of drawdown - Modification only



LEGEND

- Dainage
- Model boundary
- Approved Glendell Pit
- Proposed Glendell Pit Extension

Exceedance probability (%)

- 0-10% (Very unlikely)
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- 67-90% (Likely)
- 90-100% (Very likely)

Glendell Continued Operations GIA (G1874C)

AGE

Likelihood of 2m drawdown due to Proposed Modification – Barrett Seam

DATE
30/07/2019

FIGURE No:
B 36

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\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\B35-B36_G1874C_Likelihood drawdown.qgs

B 5.4 Sensitivity analysis

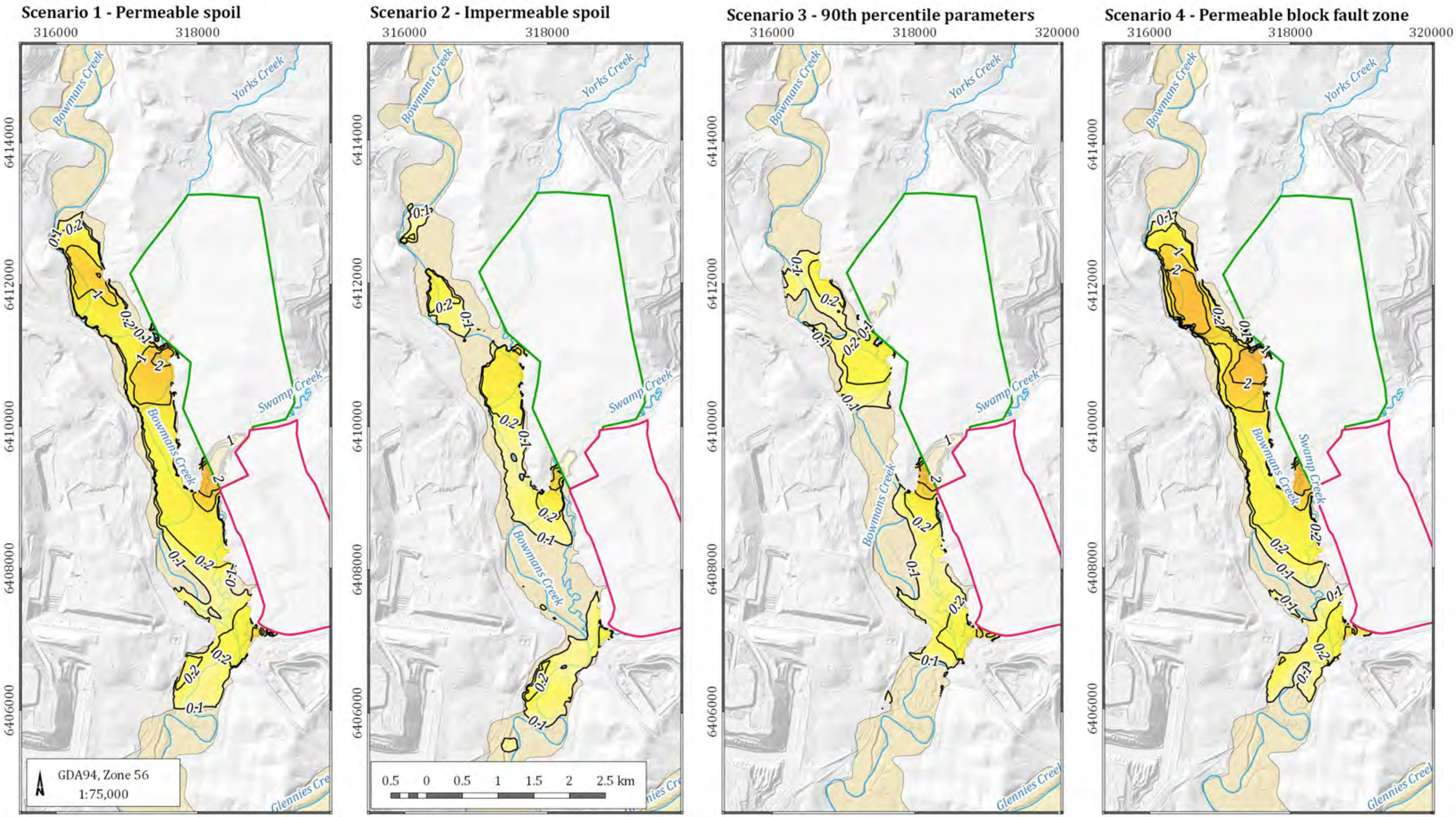
The uncertainty analysis explored the influence of the model parameters on predictions. A separate sensitivity analysis was undertaken to evaluate the uncertainty associated with specific aspects of the groundwater regime include mine spoil properties and the block fault zone in the northern part of the Project area. Four additional model scenarios were run:

- Scenario 1: Permeable spoil (1 m/day) with low recharge (1% annual rainfall) to simulate low water levels;
- Scenario 2: Less permeable spoil (0.05 m/day) with high recharge (5% annual rainfall) to simulate high water levels;
- Scenario 3: model parameters obtained from the 90th percentile of the uncertainty analysis with the peak alluvial water take during the mining phase; and
- Scenario 4: Moderately permeable block fault zone (0.001 m/day).

Figure B 37 presents the predicted drawdown post mining within the Quaternary Alluvium when the groundwater regime reaches a new equilibrium due to the Project. The results show the sensitivity of the model predictions to the properties of the spoils within the mined areas. Scenario 1 shows that where the spoils are permeable, but not well replenished by rainfall recharge the drawdown becomes more extensive within the Bowmans Creek alluvium. This is because groundwater levels within the mined pit shell are lower under this scenario. In contrast, under Scenario 2 there is little long term drawdown within the Bowmans Creek alluvium when the mine spoils are less permeable but with a relatively high rate of rainfall recharge. This is due to the mounding of groundwater within the mine shell that reduces long-term drawdown within the adjacent alluvial aquifer.

Counter-intuitively, the drawdown generated by Scenario 3 is less than the base case prediction (refer main report Section 7.3.1). This is a likely a result of a more transmissive system represented in this scenario, in combination with higher recharge rates than the base case, sustaining groundwater levels within the alluvial system.

Scenario 4 represents a moderately enhanced hydraulic conductivity occurring along the strike of the block fault located in the northern part of the Project area. It was created to evaluate the potential effect of a zone of enhanced hydraulic conductivity between the Permian coal measures and Quaternary alluvium. The results from this model scenario indicate the potential for slightly more extensive drawdown within the Bowmans Creek alluvium to occur under this conceptualisation. Because Scenario 4 indicated impacts greater than predicted by the base case model post closure a further model run was conducted with a moderately permeable block fault during proposed mining operations. Figure B 38 shows the maximum drawdown predicted to occur within the Quaternary alluvium and Middle Liddell Seam during the life of the Project due to the approved and proposed at Glendell. The figure shows the presence of the fault, shown in red, has minimal impact to the extent of drawdown within the Middle Liddell seam. This is due to a number of complicating factors, including the prevalence of cumulative impacts proximal to the project area, together with the buffering effect the fault appears to have by connecting the depressurised areas with higher pressure groundwater systems.



LEGEND

- Drainage
- Approved Glendell Pit
- Proposed Glendell Pit Extension
- Alluvium boundary

Drawdown (m)

- 0.1
- 0.2
- 1
- 2
- Contour line

Glendell Continued Operations GIA (G1874C)

AGE

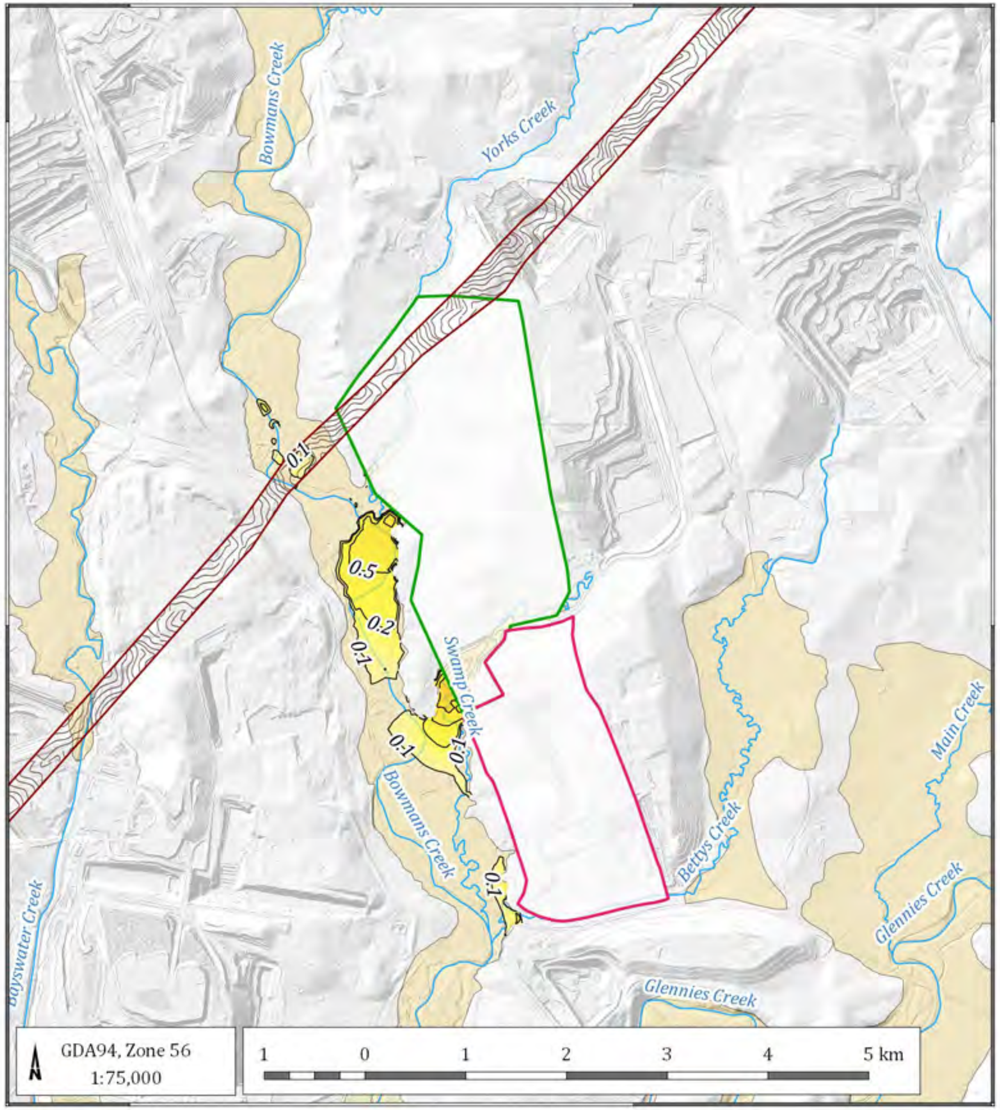
Post-mining equilibrated drawdown sensitivity (Scenario 1 – 4)

DATE
30/07/2019

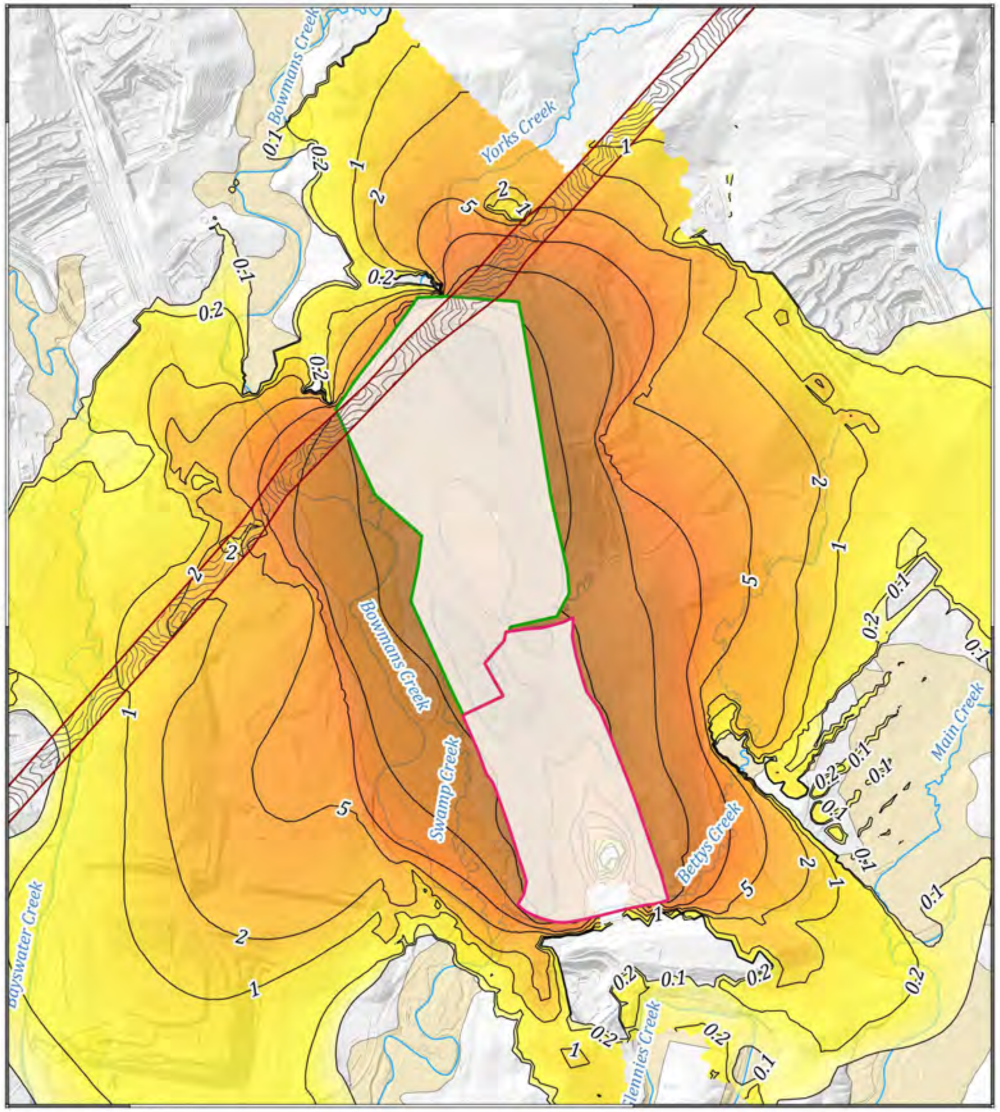
FIGURE No:
B 37

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\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\B37_G1874C_Post-mining equilibrated drawdown sensitivity (Scenario 1 – 4).qgs

Alluvium drawdown



Middle Liddell Seam



LEGEND

- Drainage
- Approved Glendell Pit
- Proposed Glendell Pit Extension
- Alluvium boundary
- Block fault

Drawdown (m)

0	10
1	20
2	50
5	100

Drawdown contour (m)

Glendell Continued Operations GIA (G1874C)

AGE

Mining phase drawdown sensitivity (Scenario 4)

DATE
30/07/2019

FIGURE No:
B 38

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\G1874C.Glendell North EIS GIA\3_GIS\Workspaces\001_Deliverable1\B38_G1874C_Mining phase drawdown sensitivity (Scenario 4).qgs

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Appendix B 1 Calibration details and hydrographs

Bore	Easting	Northing	Layer	Average residual	Range in residuals	
	(GDA94 Z56)	(GDA94 Z56)			Minimum	Maximum
64CT	314485	6414900	16	-47.2	-77.2	-27.3
8-South-2	314598	6414413	16	-18.1	-88.7	5.3
ALV1_Large	315486	6417679	1	3.0	0.6	4.5
ALV1_Small	315486	6417679	5	4.1	0.7	6.0
ALV2_Large	316299	6414733	1	-0.9	-3.5	0.0
ALV2_Small	316299	6414733	2	-0.2	-4.7	1.0
ALV3_Large	315695	6417043	1	-0.1	-2.1	1.3
ALV3_Small	315695	6417043	5	2.0	-0.7	4.3
ALV4_Large	315998	6416437	2	1.3	-1.1	2.8
ALV4_Small	315998	6416437	2	0.7	-1.9	2.2
ALV7_Large	316513	6413614	1	-0.7	-1.5	0.2
ALV7_Small	316513	6413614	5	-2.1	-6.5	2.6
ALV8_Large	316152	6413318	1	-1.2	-5.3	0.5
ALV8_Small	316152	6413318	5	6.2	-2.6	14.1
BC-SP02	317462	6411496	2	-0.5	-2.1	0.7
BC-SP03	317603	6411396	2	-1.1	-2.0	-0.2
BC-SP04	317645	6411305	1	-1.0	-1.9	-0.2
BC-SP05	317686	6411214	2	-0.7	-1.4	0.0
BC-SP06	317620	6411568	2	-1.7	-2.8	-0.6
BC-SP07	317661	6411477	2	-1.7	-2.6	-0.8
BC-SP08	317653	6411913	2	1.5	0.5	2.4
BC-SP09	317637	6411740	1	-1.2	-2.2	0.0
BC-SP10	318101	6409408	2	1.9	0.9	2.5
BC-SP11	318144	6409354	1	0.8	-0.3	1.9
BC-SP12	318192	6409266	1	1.1	0.2	2.4
BC-SP13	318247	6409223	1	6.8	0.4	18.1
BC-SP14	318288	6409175	1	9.2	0.1	20.1
BC-SP15	318176	6409513	1	0.2	-1.5	2.5
BC-SP16	318317	6409413	1	11.1	-0.8	25.8
BC-SP17	318333	6409585	1	3.5	-2.7	19.9
BC-SP18	317368	6411329	1	3.3	2.2	4.1
BC-SP19	317446	6411166	1	4.4	4.2	4.5
BC-SP20	318165	6409127	1	0.2	-0.7	2.3
BC-SP21	318053	6409199	1	-0.4	-1.4	1.7
BC-SP22	318010	6409068	1	-2.0	-2.6	-1.4
Borehole_P	313421	6410674	8	19.1	10.5	28.3
CS4536_HF7	312571	6409174	15	27.6	16.8	33.8
CS4545_S4	312871	6408374	11	-17.9	-32.2	14.3
CS4545B	312871	6408374	15	-20.9	-26.4	-18.2
CS4545B_Mi	312871	6408374	2	-8.0	-15.7	-2.9
CS4545B_Sm	312871	6408374	2	-5.3	-7.7	-1.6
CS4545C	312871	6408374	18	23.4	22.2	24.2

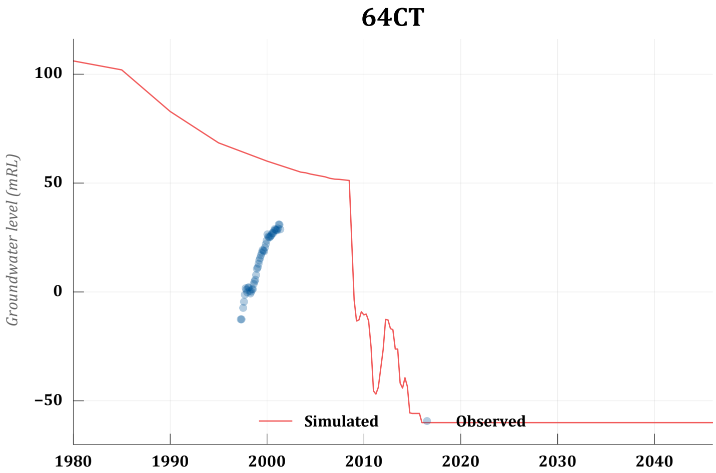
Bore	Easting	Northing	Layer	Average residual	Range in residuals	
	(GDA94 Z56)	(GDA94 Z56)			Minimum	Maximum
CS4545D	312871	6408374	20	25.2	22.9	26.4
CS4641C	313521	6410474	15	4.3	-24.9	50.4
CS4655-Bay	313621	6407874	5	14.2	12.2	17.2
CS4655-Brt	313621	6407874	18	-22.8	-26.5	-13.5
CS4655-LLd	313621	6407874	14	-24.9	-31.3	-14.6
CS4655-LmA	313621	6407874	6	-10.7	-14.2	-2.2
CS4655-LmH	313621	6407874	6	-5.8	-8.4	3.4
CS4655-UAr	313621	6407874	10	-21.0	-26.9	-12.1
CS4655-ULd	313621	6407874	14	-21.7	-26.3	-13.9
CS4655-UPG	313621	6407874	8	-16.1	-20.7	-8.1
CS4656-Brt	313021	6408874	18	-6.6	-22.9	8.9
CS4656-LLd	313021	6408874	14	-22.9	-27.3	-16.3
CS4656-LmA	313021	6408874	6	-9.2	-18.3	-2.8
CS4656-LmF	313021	6408874	6	3.5	-4.6	6.1
CS4656-LmH	313021	6408874	6	10.4	9.6	14.0
CS4656-UPG	313021	6408874	8	-33.3	-46.5	-20.0
CS4656-UAr	313021	6408874	10	-25.0	-34.7	-11.8
CS4656-ULd	313021	6408874	14	-24.5	-29.1	-18.1
DUR2	313479	6416657	15	-5.7	-16.3	8.2
GA1	318356	6408263	1	-0.1	-1.4	3.7
GA2	318569	6407359	1	-2.2	-3.0	2.2
GNP1-Art	318471	6408616	11	-3.6	-7.4	1.1
GNP1-Brt	318471	6408616	18	3.9	-15.8	19.4
GNP1-Heb	318471	6408616	20	-3.9	-13.5	4.5
GNP1-LLd	318471	6408616	15	-5.4	-10.8	1.9
GNP1-MLd	318471	6408616	14	-6.5	-12.6	1.0
GNP1-PG	318471	6408616	9	-8.3	-13.0	-3.2
GNP1-ULd	318471	6408616	14	1.4	-5.6	9.8
GNP2-Art	317547	6410228	11	-21.8	-25.6	-14.9
GNP2-Bar	317547	6410228	18	-3.5	-6.4	1.3
GNP2-Heb	317547	6410228	20	12.6	6.0	18.7
GNP2-LLd	317547	6410228	15	-12.2	-17.3	-6.5
GNP2-MLd	317547	6410228	14	-23.6	-24.8	-22.4
GNP2-PG	317547	6410228	9	-20.3	-23.1	-14.3
GNP3-Art	316935	6411682	11	-1.4	-14.3	4.6
GNP3-Brt	316935	6411682	18	4.5	-11.9	11.6
GNP3-Heb	316935	6411682	20	11.9	-5.1	23.5
GNP3-LLd	316935	6411682	15	-5.2	-13.6	-3.0
GNP3-MLd	316935	6411682	15	-14.7	-15.1	-14.0
GNP3-PG	316935	6411682	9	-14.3	-16.1	-12.1
GNP3-ULd	316935	6411682	14	0.7	-2.9	3.0
GNP4-Art	316925	6412962	11	-7.3	-18.6	2.3

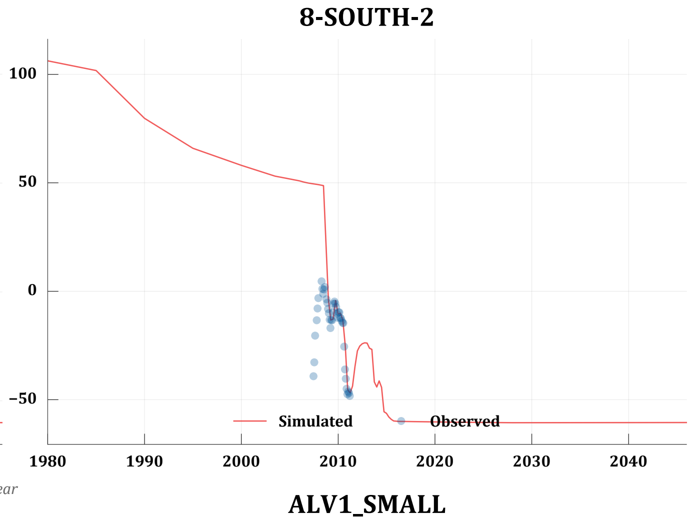
Bore	Easting	Northing	Layer	Average residual	Range in residuals	
	(GDA94 Z56)	(GDA94 Z56)			Minimum	Maximum
GNP4-Brt	316925	6412962	18	21.5	9.2	35.2
GNP4-Heb	316925	6412962	20	-6.4	-11.8	0.0
GNP4-LLd	316925	6412962	15	14.2	0.6	23.7
GNP4-MLd	316925	6412962	15	4.0	-3.0	13.1
GNP4-PG	316925	6412962	9	-5.8	-13.7	2.8
GNP4-ULd	316925	6412962	14	3.5	-6.1	14.8
GNP5-Art	317884	6409295	11	-8.9	-10.2	-6.4
GNP5-Bar	317884	6409295	18	0.4	-2.6	6.6
GNP5-Heb	317884	6409295	20	1.0	-6.0	8.2
GNP5-Int	317884	6409295	4	-1.8	-2.3	-1.1
GNP5-LLd	317884	6409295	15	-10.4	-15.2	-5.5
GNP5-MLd	317884	6409295	15	-14.0	-16.8	-9.9
GNP5-PG	317884	6409295	9	-24.7	-32.0	-14.4
GNP5-ULd	317884	6409295	14	-13.8	-16.1	-11.0
GNP6-Art	317628	6411064	11	-8.5	-10.6	-5.1
GNP6-Bar	317628	6411064	18	-7.3	-13.3	-1.8
GNP6-Heb	317628	6411064	20	-4.9	-10.0	0.1
GNP6-LLd	317628	6411064	15	-22.5	-24.0	-18.3
GNP6-MLd	317628	6411064	15	-0.4	-19.7	13.5
GNP6-PG	317628	6411064	9	8.4	-5.9	24.3
GNP6-ULd	317628	6411064	14	-12.4	-15.1	-8.5
GNP7-Art	316516	6412447	11	6.9	-3.3	16.8
GNP7-Brt	316516	6412447	18	13.2	4.1	23.2
GNP7-Heb	316516	6412447	20	8.4	-14.2	15.0
GNP7-LLd	316516	6412447	15	12.0	2.9	21.3
GNP7-MLd	316516	6412447	15	13.1	4.7	23.0
GNP7-PG	316516	6412447	9	5.0	-7.8	11.8
GNP7-ULd	316516	6412447	14	11.6	3.7	20.0
GNP8-Bar	319383	6407394	18	9.4	-30.5	27.3
GNP8-Heb	319383	6407394	20	16.4	-12.8	29.4
GNP8-LLd	319383	6407394	15	-0.5	-41.1	36.9
GNP8-MLd	319383	6407394	15	9.5	-27.3	41.0
GNP8-ULd	319383	6407394	14	22.1	-16.2	55.8
GNPS-02	317547	6410228	1	-0.8	-1.1	-0.4
GNPS-05	317884	6409295	2	-0.7	-1.2	0.1
GNPS-06	317628	6411064	1	0.9	-1.1	2.2
GNPS-07	316516	6412447	1	0.8	0.8	0.8
GW079793	317711	6411994	16	-0.2	-1.7	1.7
JK101	316736	6405214	2	2.4	0.1	4.3
JK102	316736	6405214	2	2.2	1.7	3.1
JK103	316846	6405275	2	-0.6	-1.9	0.6
JK104	316846	6405275	2	0.9	0.8	1.0

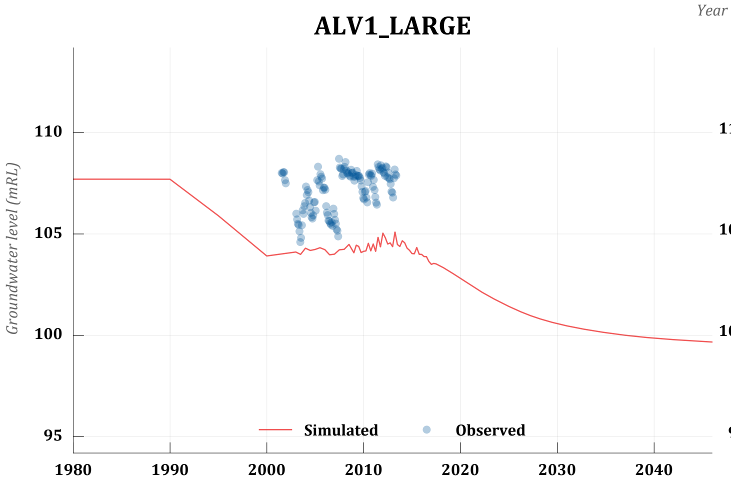
Bore	Easting	Northing	Layer	Average residual	Range in residuals	
	(GDA94 Z56)	(GDA94 Z56)			Minimum	Maximum
JK105	316963	6405387	2	1.6	1.1	2.0
JK106	316992	6405324	2	1.0	-0.5	2.3
JK107	317023	6405417	2	0.7	0.6	0.7
JK108	317023	6405417	2	4.4	4.3	4.7
JK109	316736	6405214	2	1.6	-0.6	3.6
JK110	316736	6405214	2	3.0	2.7	3.4
JK113	316785	6405185	2	1.7	0.6	2.5
JK115	316846	6405275	2	-1.6	-2.7	-0.6
JK118	317110	6405340	2	1.7	0.0	3.1
JK119	317110	6405340	2	5.5	5.3	5.8
JK121	316992	6405324	2	-1.1	-3.0	-0.1
JK123	316992	6405324	2	-1.2	-2.1	-0.3
LBH_Coal	315482	6417253	5	4.1	2.2	5.6
LC1	315748	6414612	15	1.3	-57.9	25.8
M49	316387	6413353	15	-3.6	-65.0	8.6
MiddleLidd	315238	6413724	5	-2.9	-27.2	12.8
MLD_1	314648	6413349	15	-3.9	-26.6	4.5
MLD_3	314638	6412994	9	-11.1	-26.4	-4.0
Mt_Owen_2	316577	6414477	16	-2.9	-71.3	9.3
MW01	314657	6409076	2	0.8	0.6	1.4
MW1	314094	6408249	3	1.6	1.0	2.4
MW10	314339	6408276	2	4.6	3.3	5.5
MW12	314151	6408017	5	21.1	20.3	21.6
MW2	314094	6408249	3	-2.3	-2.7	-2.1
MW3	314094	6408249	3	-3.1	-3.1	-3.1
MW4	313979	6408173	3	-4.8	-4.9	-4.7
MW5	314094	6408249	3	-2.6	-2.7	-2.6
MW6	314094	6408249	2	8.8	8.8	8.8
MW9	314387	6408584	2	-5.0	-5.4	-4.7
NPZ1_Mid	313464	6404940	5	3.9	-5.1	11.0
NPZ1_Tall	313464	6404940	6	5.2	1.2	11.5
NPZ11	318076	6412655	2	-4.8	-7.3	-3.1
NPZ11a	318076	6412655	7	-0.9	-22.3	10.9
NPZ12	318416	6411491	2	-5.9	-8.1	-3.7
NPZ12a	318416	6411491	7	-0.8	-18.5	44.6
NPZ13	318333	6409585	16	12.7	4.6	22.0
NPZ13a	318333	6409585	13	-16.2	-19.9	-9.9
NPZ14	319482	6407113	16	-27.5	-36.3	6.1
NPZ14a	319482	6407113	20	-18.8	-26.5	3.1
NPZ16	318202	6409145	13	25.1	17.6	34.3
NPZ16a	318165	6409127	14	-1.4	-14.7	45.7
NPZ2-120	313376	6405741	6	-9.5	-13.7	-6.2

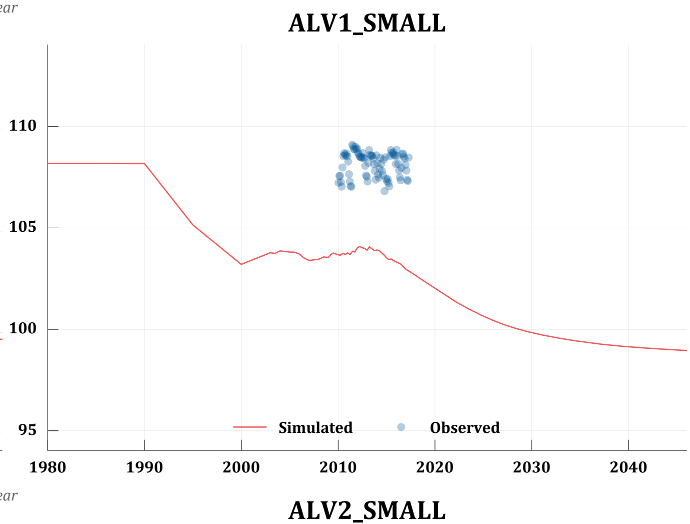
Bore	Easting	Northing	Layer	Average residual	Range in residuals	
	(GDA94 Z56)	(GDA94 Z56)			Minimum	Maximum
NPZ5B_P1	314621	6409128	2	-4.1	-6.4	-0.7
NPZ5B_P2	314657	6409076	2	0.9	-1.4	1.4
PGW5_Large	316168	6415304	15	25.4	13.0	34.7
PGW5_Small	316168	6415304	2	-1.0	-4.9	0.9
RNVW1-Bay	313901	6403900	3	-12.3	-13.5	-11.4
RNVW1-Brt	313901	6403900	18	10.6	4.7	15.4
RNVW1-LLd	313901	6403900	11	-9.6	-20.9	7.6
RNVW1-LmA	313901	6403900	5	-11.5	-14.2	1.6
RNVW1-LmH	313901	6403900	5	14.0	2.3	20.5
RNVW1-UAr	313901	6403900	6	7.2	4.6	12.3
RNVW1-ULd	313901	6403900	10	-2.2	-8.3	6.5
RNVW1-UPG	313901	6403900	6	-4.0	-5.3	0.5
RNVW2-Brt	313533	6405363	18	-2.5	-4.5	0.5
RNVW2-LLd	313533	6405363	14	-3.3	-7.7	0.1
RNVW2-LmA	313533	6405363	5	-16.9	-19.0	-7.4
RNVW2-LmH	313533	6405363	5	16.8	14.6	18.9
RNVW2-UAr	313533	6405363	6	-7.2	-9.7	-3.7
RNVW2-ULd	313533	6405363	10	-4.8	-9.9	0.2
RNVW2-UPG	313533	6405363	6	-6.3	-8.4	-2.9
RNVW4-Brt	314129	6410997	21	-6.6	-20.7	6.0
RNVW4-LLd	314129	6410997	19	-4.9	-13.4	4.2
RNVW4-UAr	314129	6410997	10	-1.6	-8.9	4.1
RNVW4-ULd	314129	6410997	14	1.6	-11.8	13.1
RNVW4-UPG	314129	6410997	10	3.8	-9.2	13.8
SDH16	313635	6410877	9	44.7	31.2	67.8
SDH18	313471	6410574	9	-7.2	-44.4	30.2
WPP1	311520	6413468	11	18.8	17.6	19.5
WPP2	311483	6413549	17	13.3	12.4	13.9

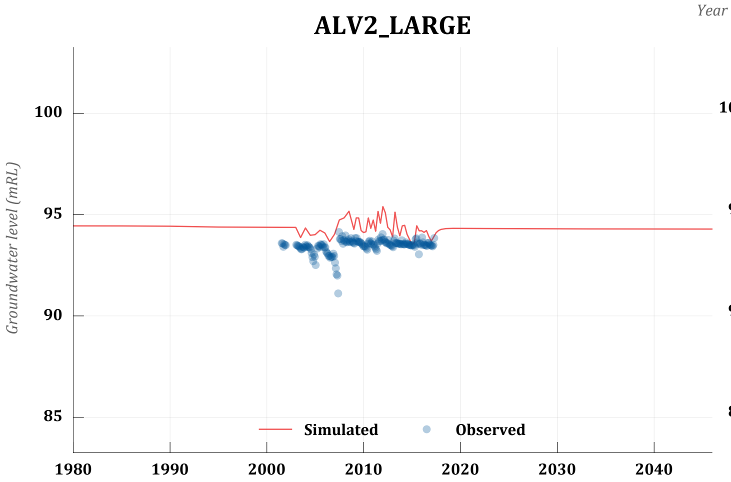
Appendix B 2 Predictive uncertainty hydrographs

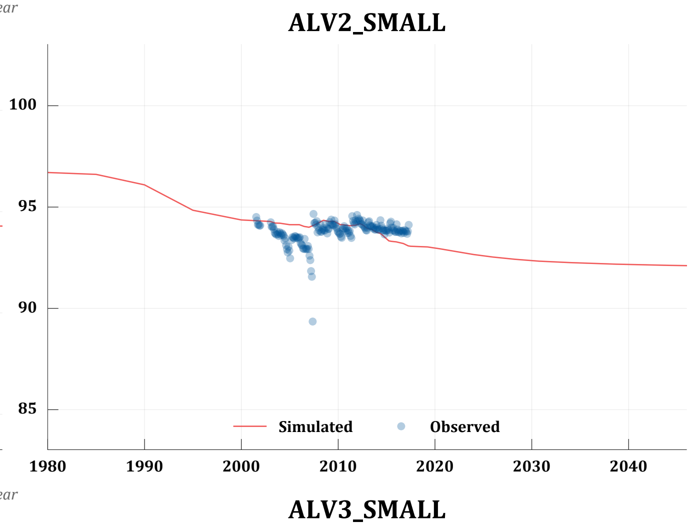

64CT
Groundwater level (mRL)
100
50
0
−50
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040

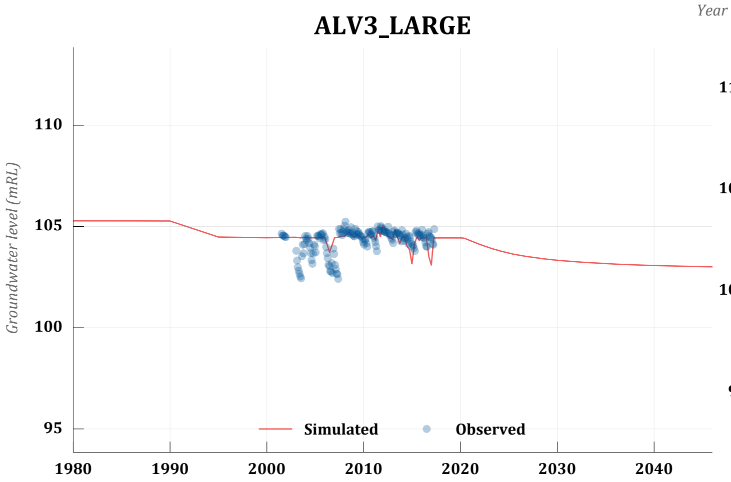

8-SOUTH-2
100
50
0
−50
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040
Year

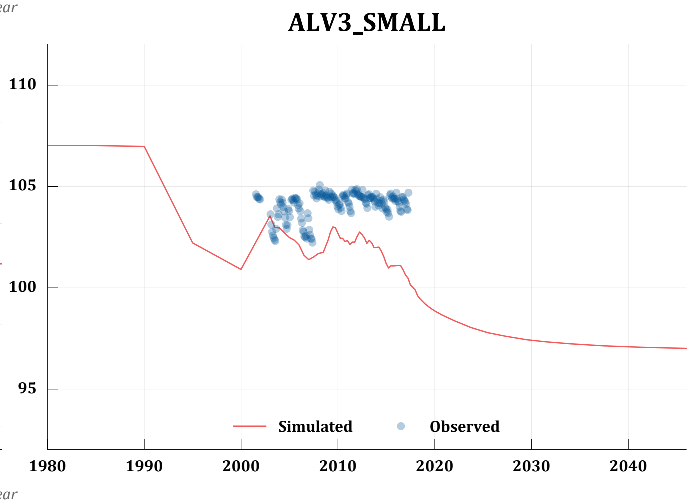

ALV1_LARGE
Groundwater level (mRL)
110
105
100
95
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040

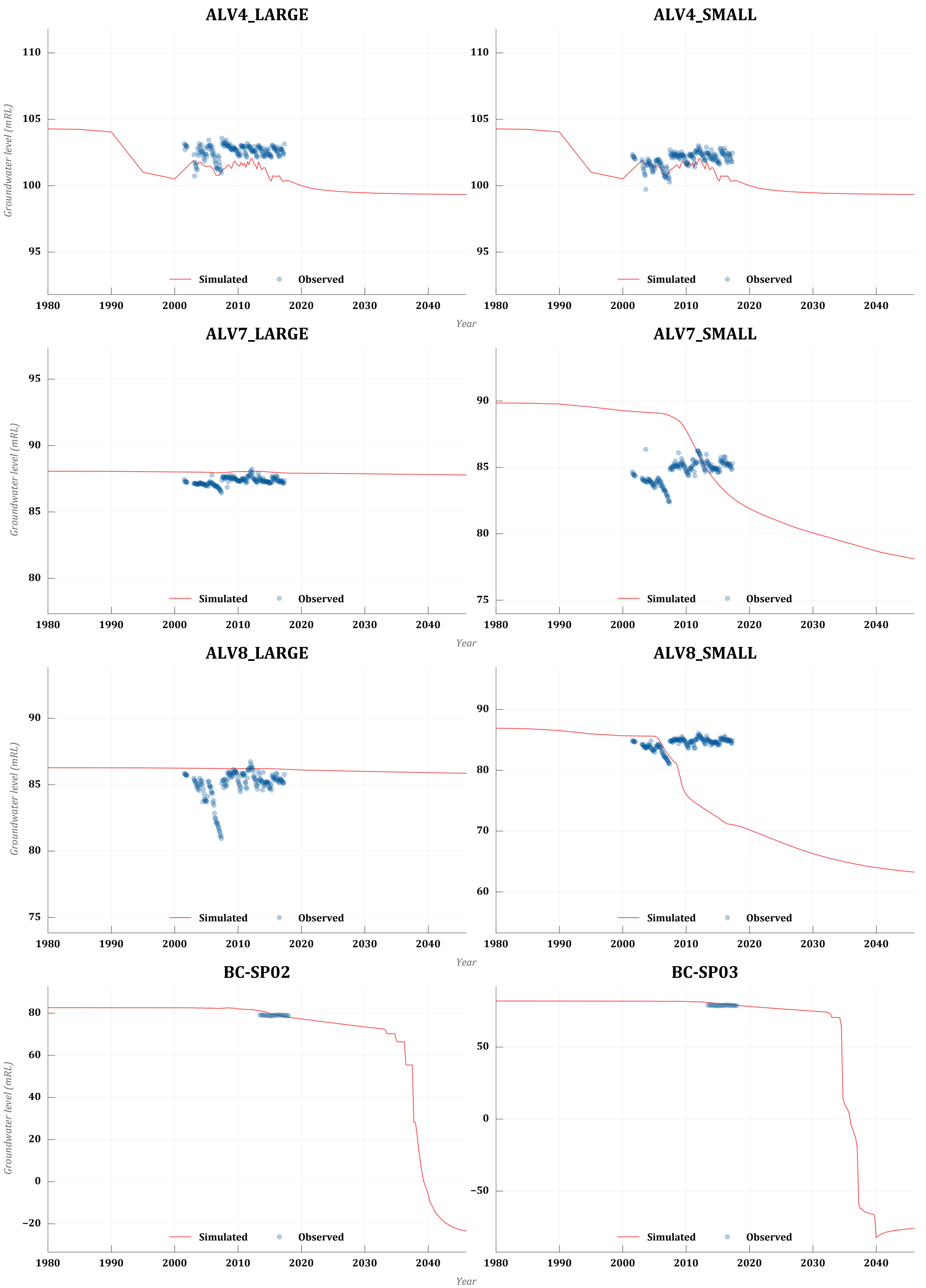

ALV1_SMALL
110
105
100
95
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040
Year

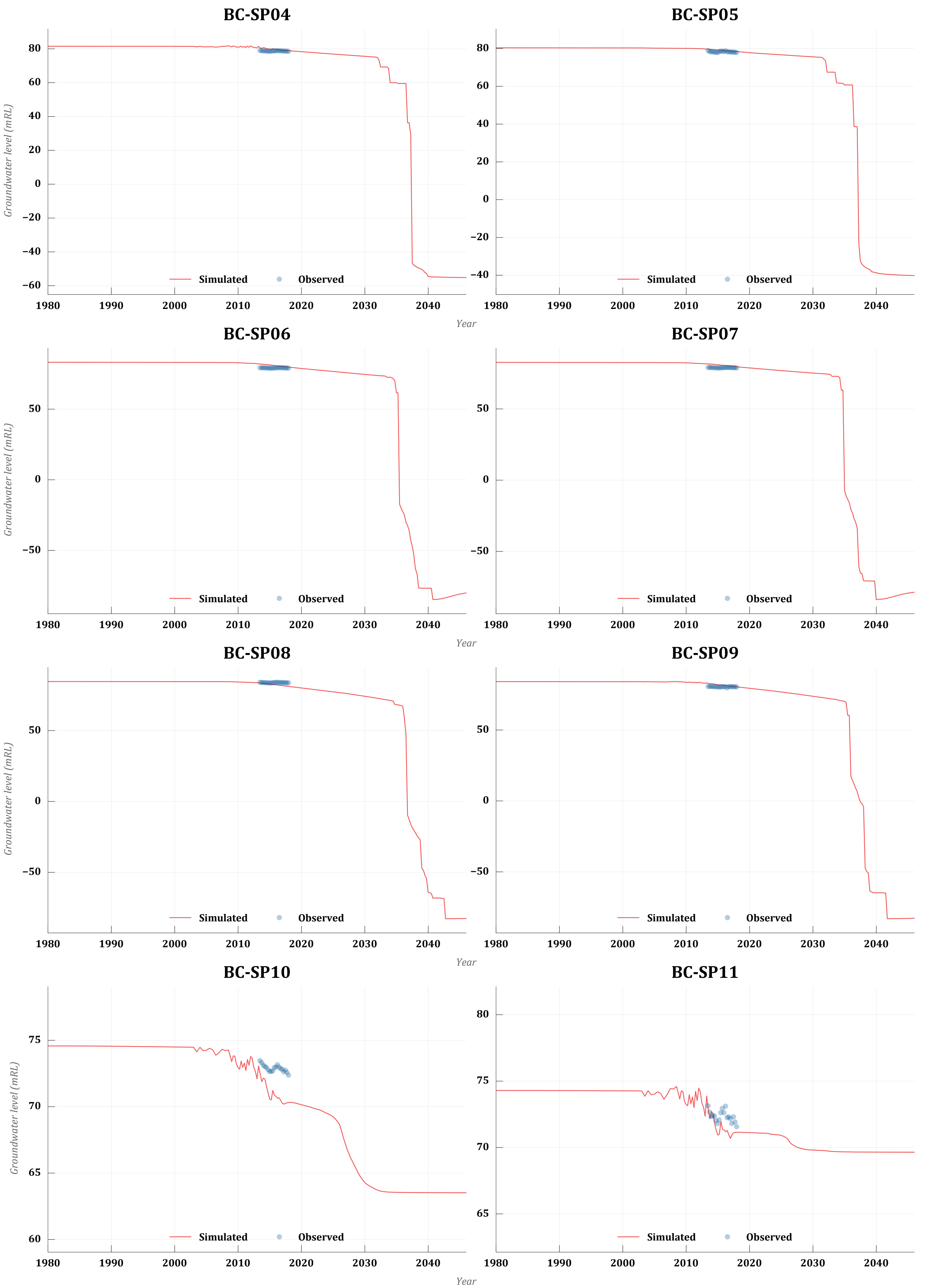

ALV2_LARGE
Groundwater level (mRL)
100
95
90
85
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040


ALV2_SMALL
100
95
90
85
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040
Year


ALV3_LARGE
Groundwater level (mRL)
110
105
100
95
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040

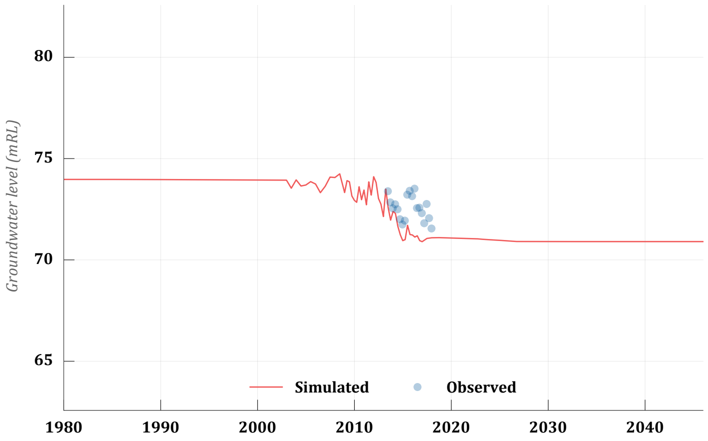

ALV3_SMALL
110
105
100
95
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040
Year


ALV4_LARGE
ALV4_SMALL
ALV7_LARGE
ALV7_SMALL
ALV8_LARGE
ALV8_SMALL
BC-SP02
BC-SP03
Groundwater level (mRL)
Year
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040
110
105
100
95
90
85
80
75
70
60
50
40
20
0
−20
−50

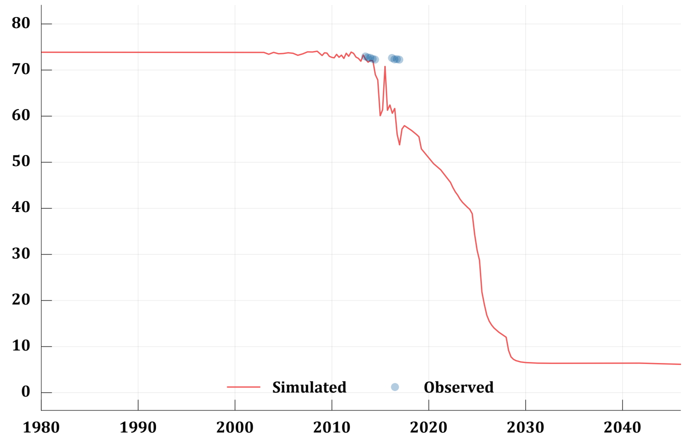


BC-SP04
BC-SP05
BC-SP06
BC-SP07
BC-SP08
BC-SP09
BC-SP10
BC-SP11
Groundwater level (mRL)
Year
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040

BC-SP12

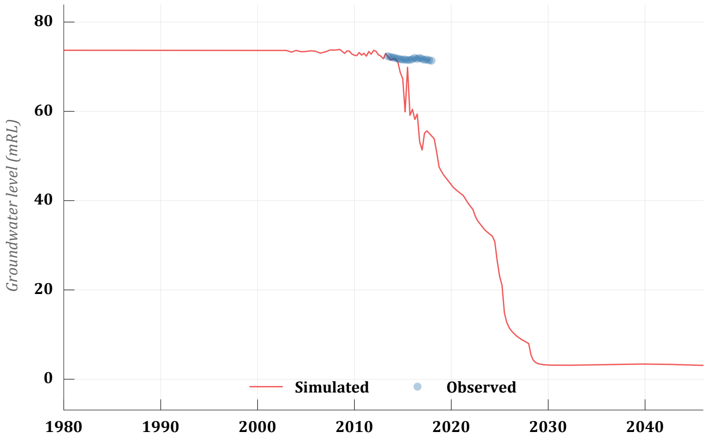


BC-SP13

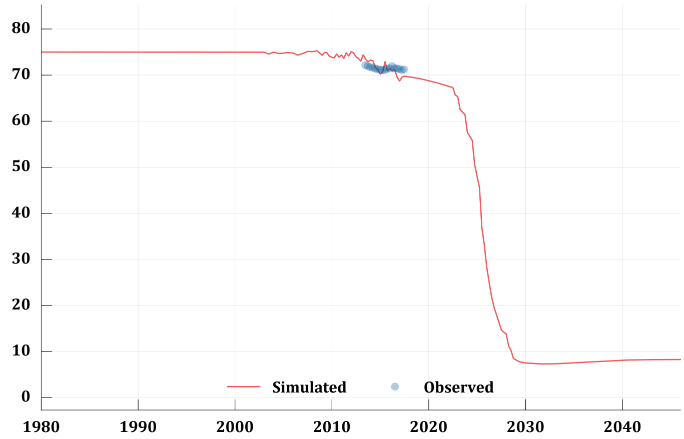


Year

BC-SP14

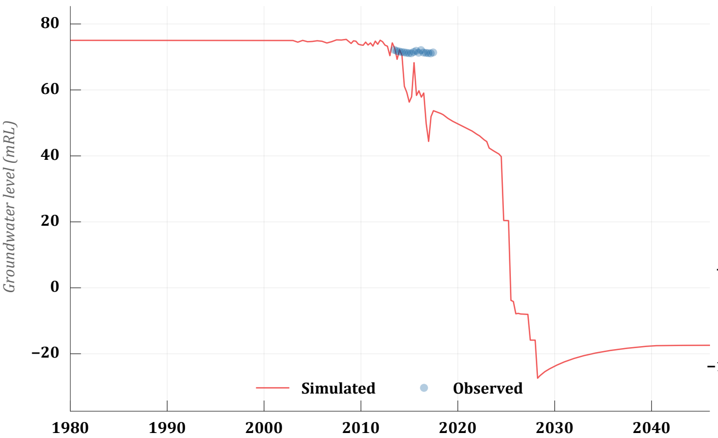


BC-SP15

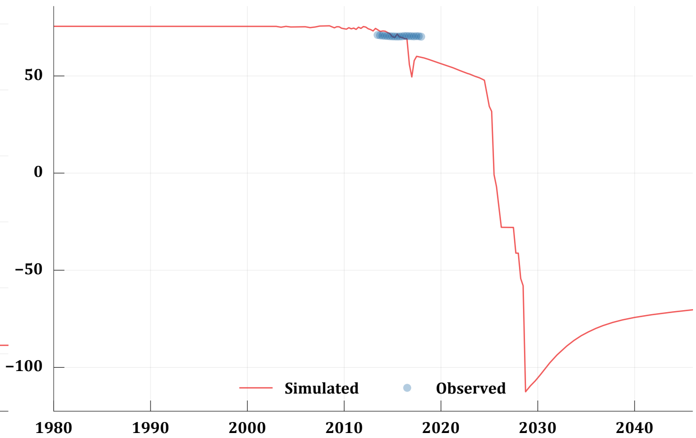


Year

BC-SP16

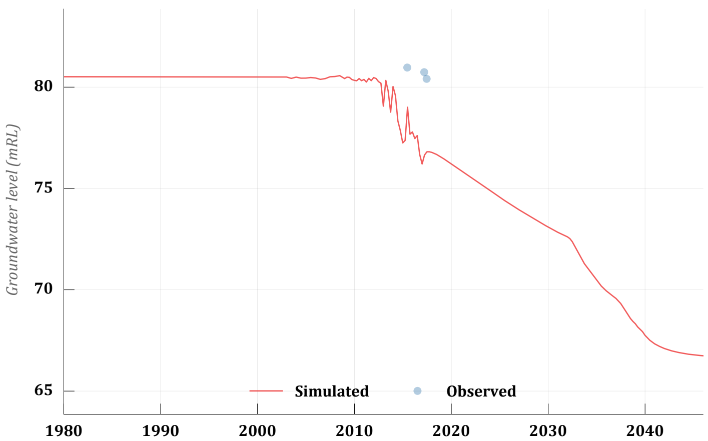


BC-SP17

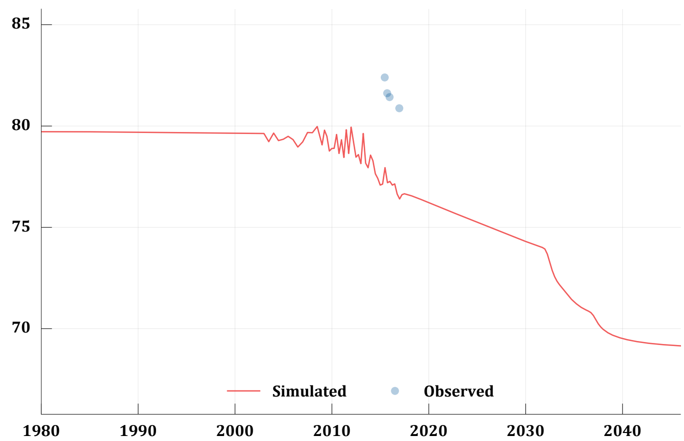


Year

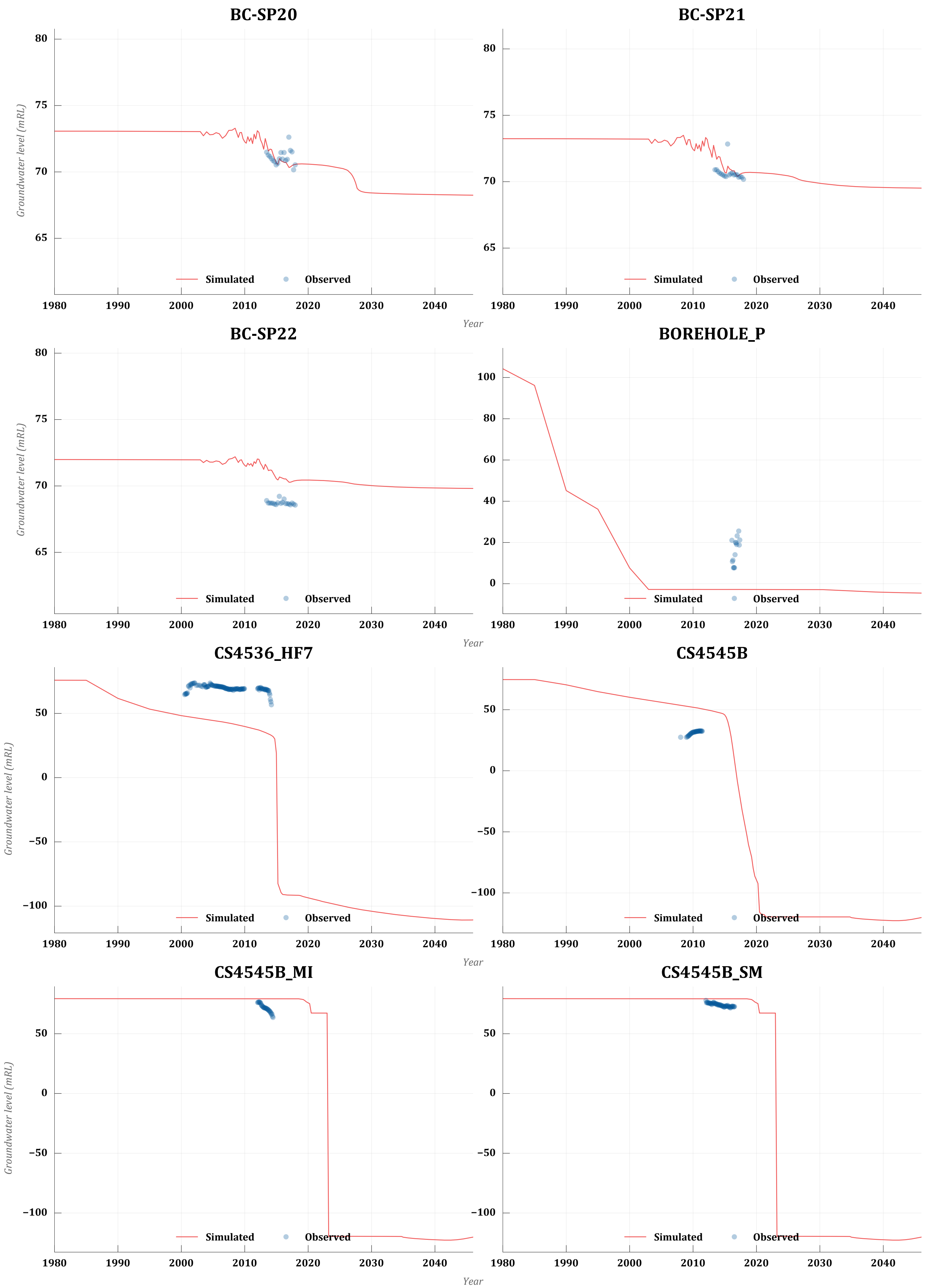
BC-SP18

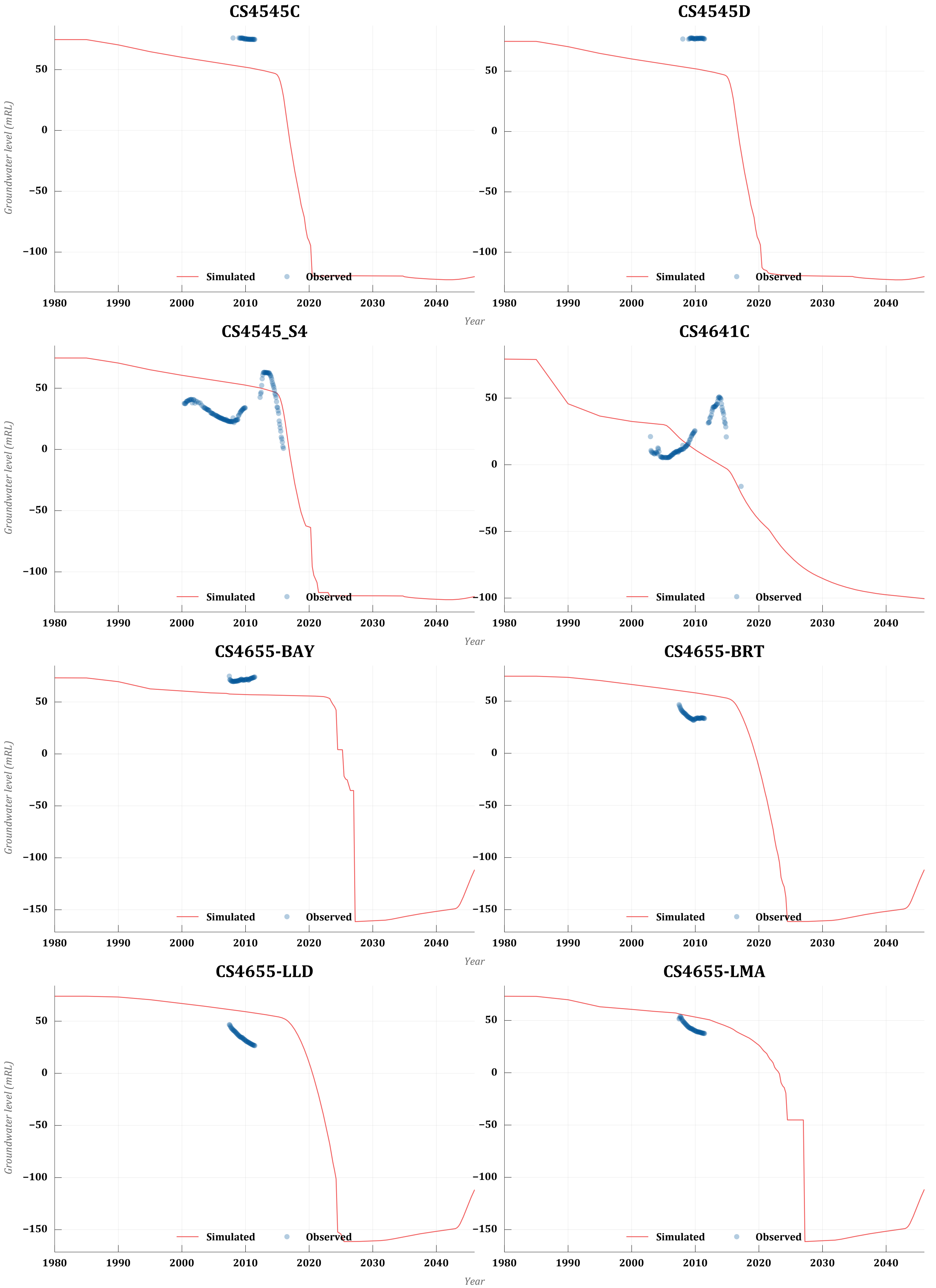


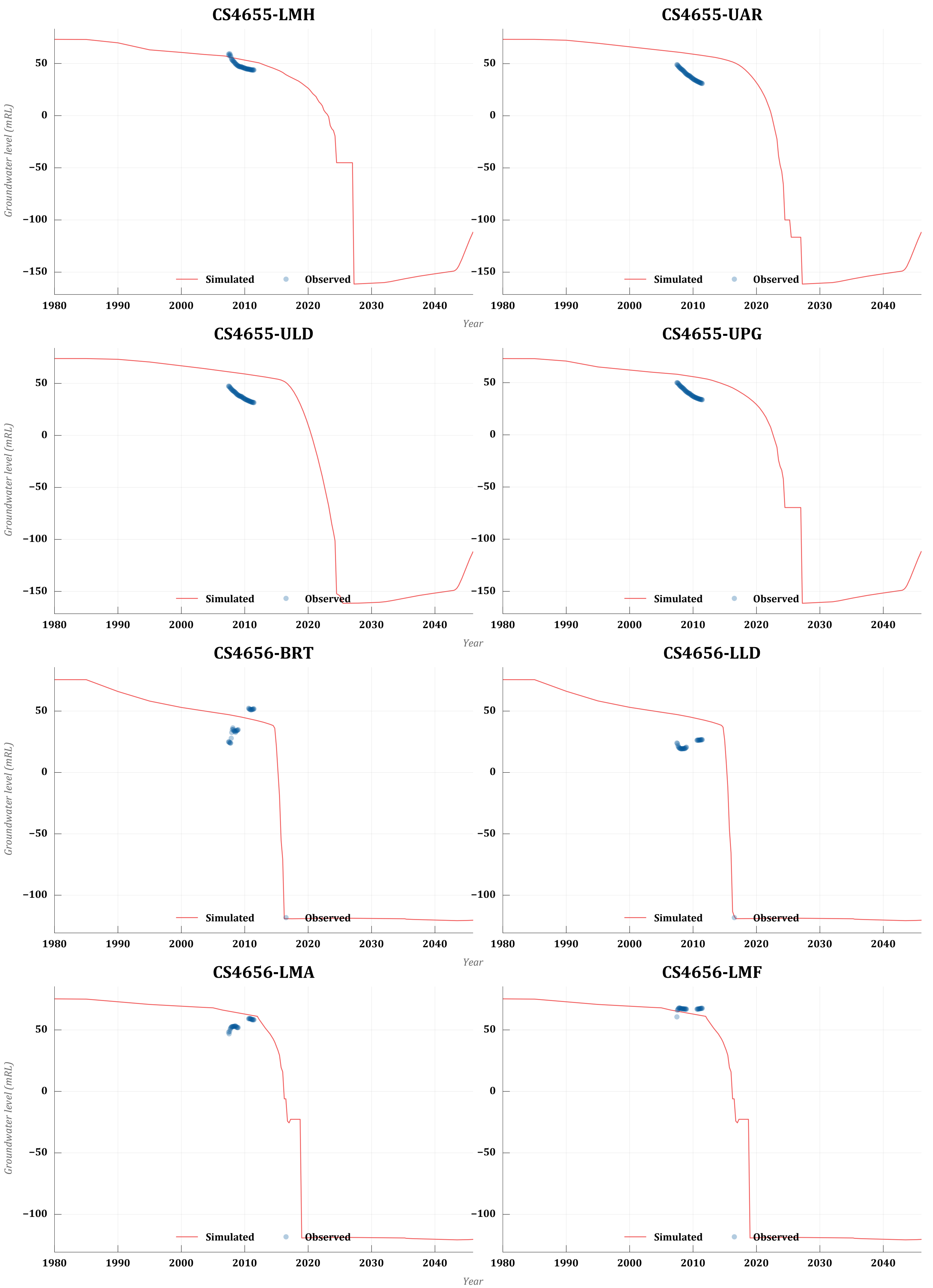
BC-SP19

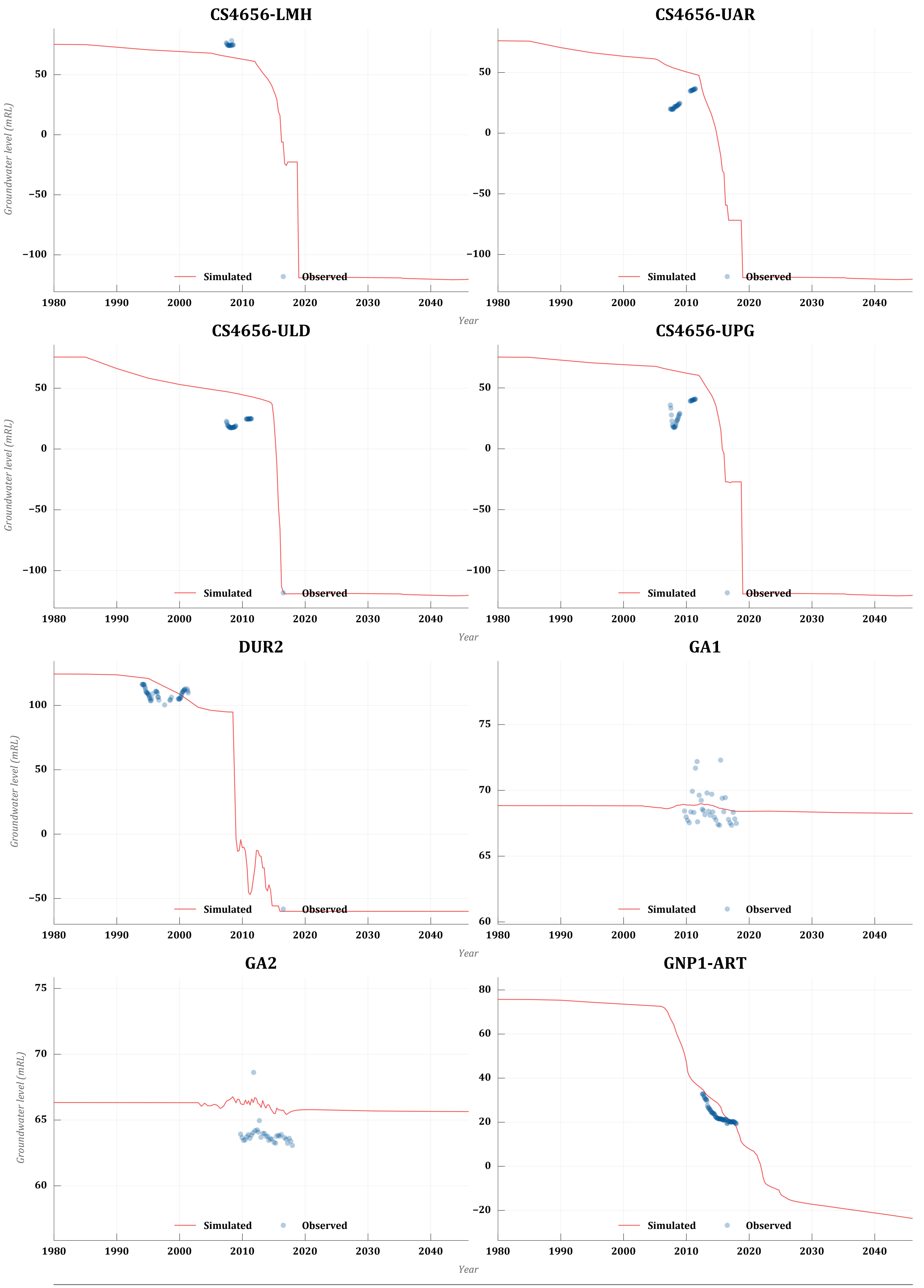


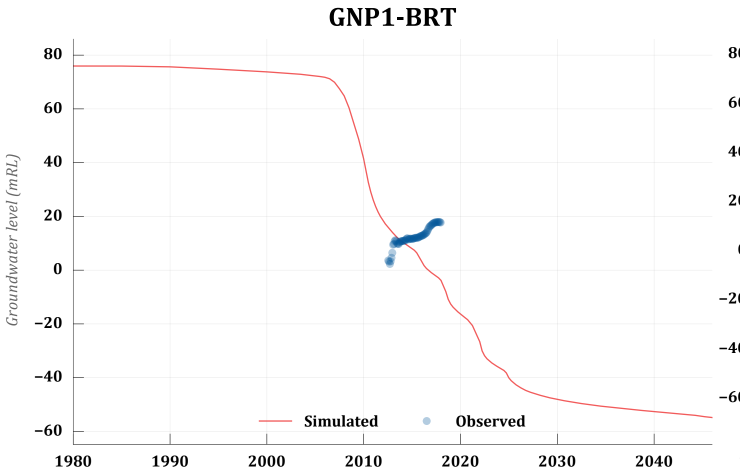
Year

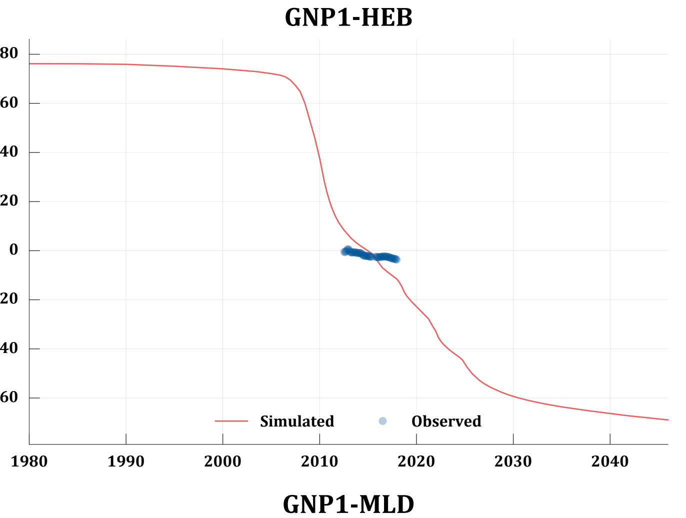

BC-SP20
BC-SP21
BC-SP22
BOREHOLE_P
CS4536_HF7
CS4545B
CS4545B_MI
CS4545B_SM
Groundwater level (mRL)
Year
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040
80
75
70
65
100
60
40
20
0
50
−50
−100

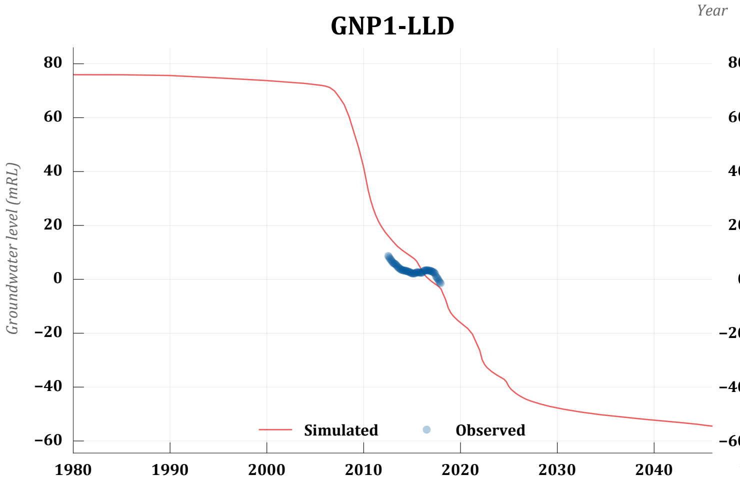

CS4545C
CS4545D
CS4545_S4
CS4641C
CS4655-BAY
CS4655-BRT
CS4655-LLD
CS4655-LMA
Groundwater level (mRL)
Year
Simulated
Observed
50
0
−50
−100
−150
1980
1990
2000
2010
2020
2030
2040

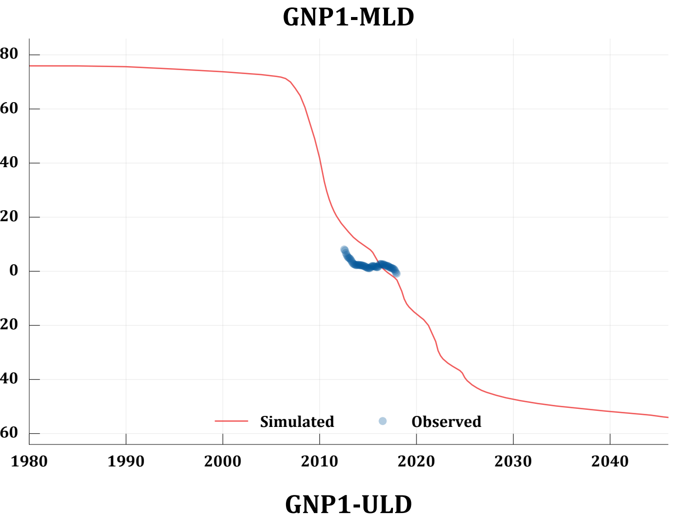

CS4655-LMH
CS4655-UAR
CS4655-ULD
CS4655-UPG
CS4656-BRT
CS4656-LLD
CS4656-LMA
CS4656-LMF
Groundwater level (mRL)
Year
Simulated
Observed
50
0
−50
−100
−150
1980
1990
2000
2010
2020
2030
2040

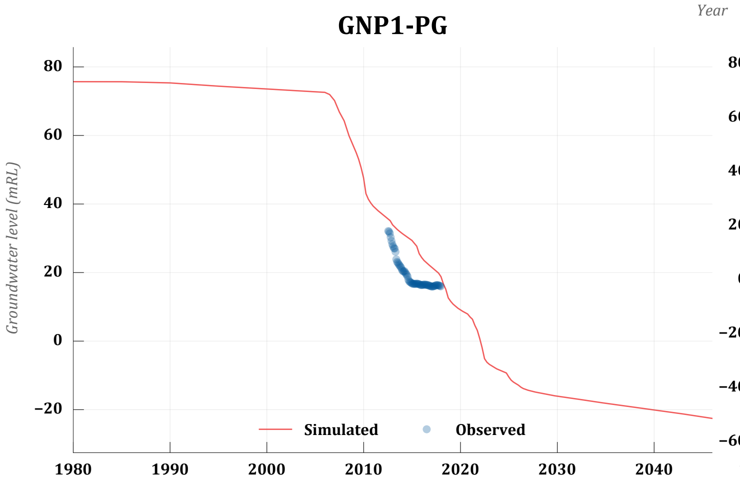

CS4656-LMH
CS4656-UAR
CS4656-ULD
CS4656-UPG
DUR2
GA1
GA2
GNP1-ART
Groundwater level (mRL)
Year
Simulated
Observed

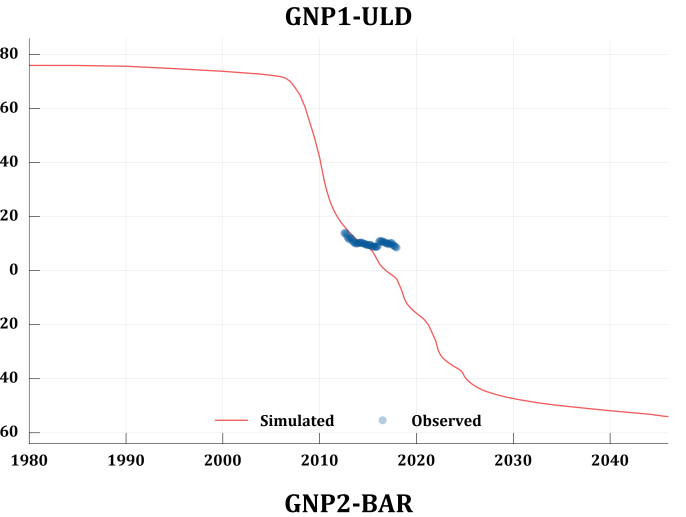

GNP1-BRT
Groundwater level (mRL)
80
60
40
20
0
−20
−40
−60
1980
1990
2000
2010
2020
2030
2040
Simulated
Observed

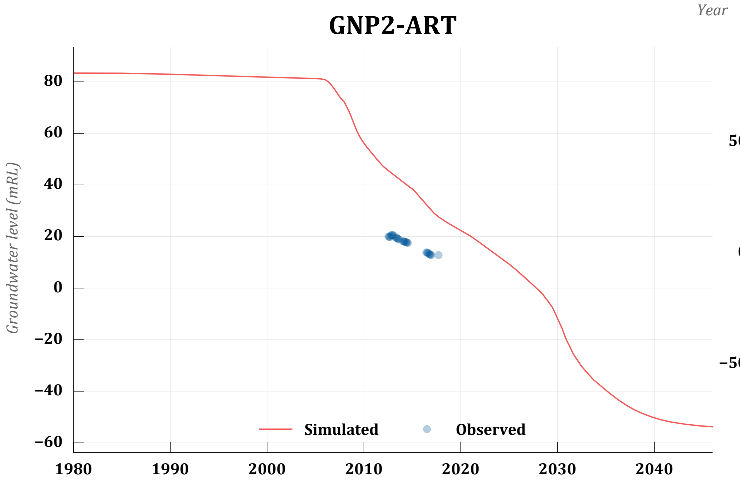

GNP1-HEB
80
60
40
20
0
−20
−40
−60
1980
1990
2000
2010
2020
2030
2040
Simulated
Observed
Year

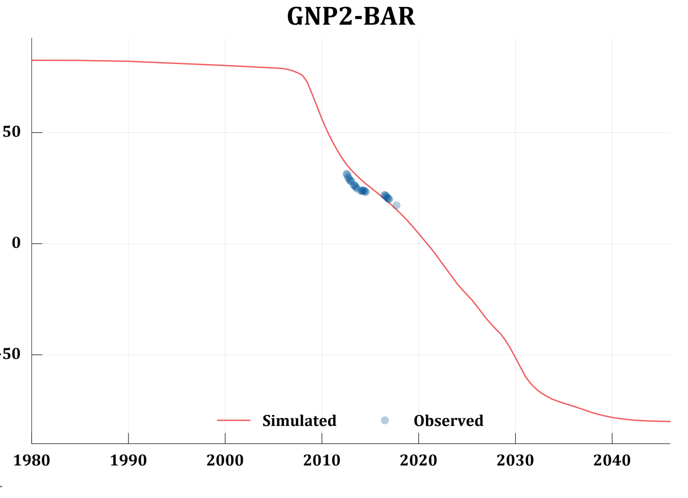

GNP1-LLD
Groundwater level (mRL)
80
60
40
20
0
−20
−40
−60
1980
1990
2000
2010
2020
2030
2040
Simulated
Observed

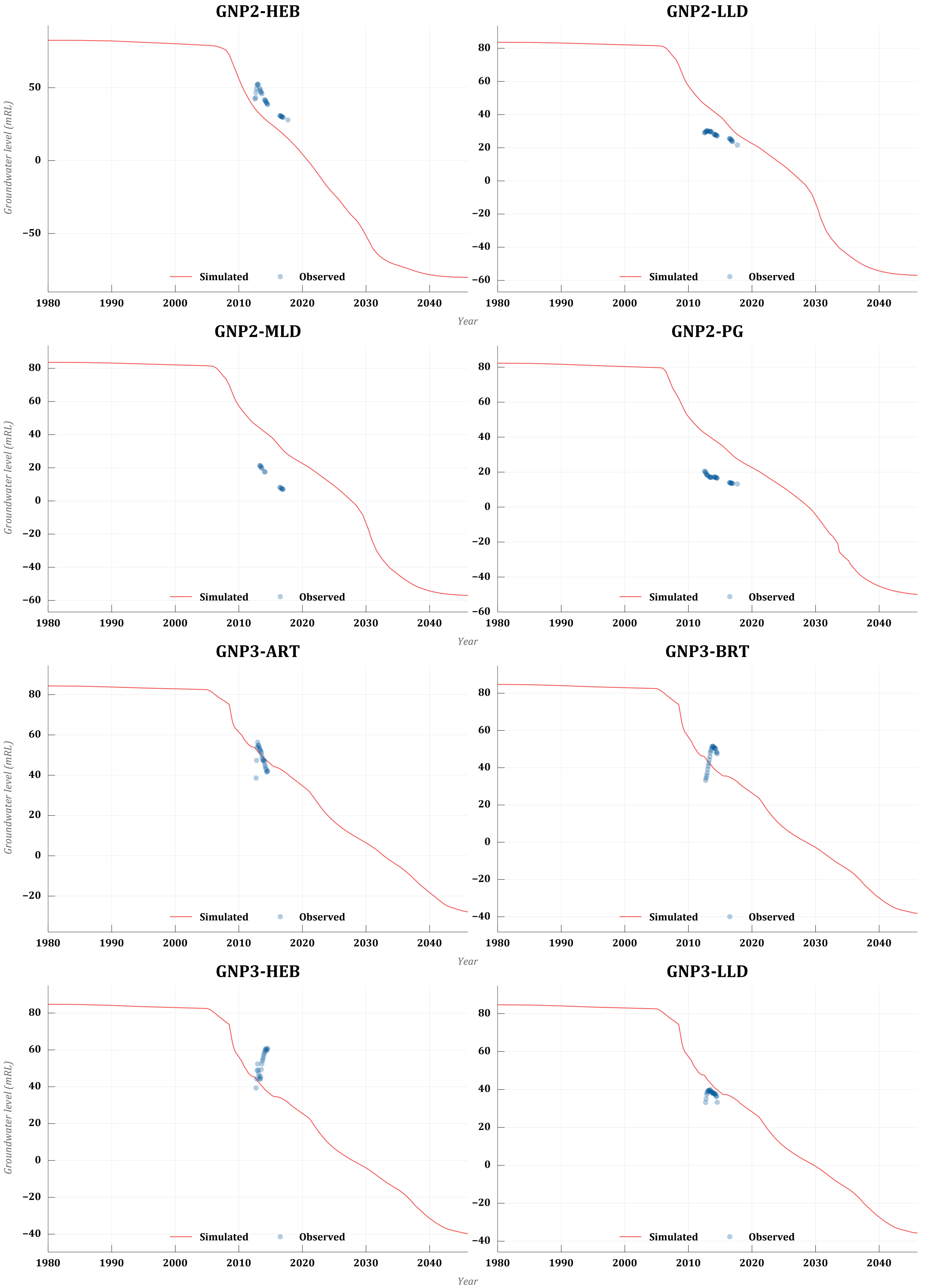

GNP1-MLD
80
60
40
20
0
−20
−40
−60
1980
1990
2000
2010
2020
2030
2040
Simulated
Observed
Year


GNP1-PG
Groundwater level (mRL)
80
60
40
20
0
−20
1980
1990
2000
2010
2020
2030
2040
Simulated
Observed

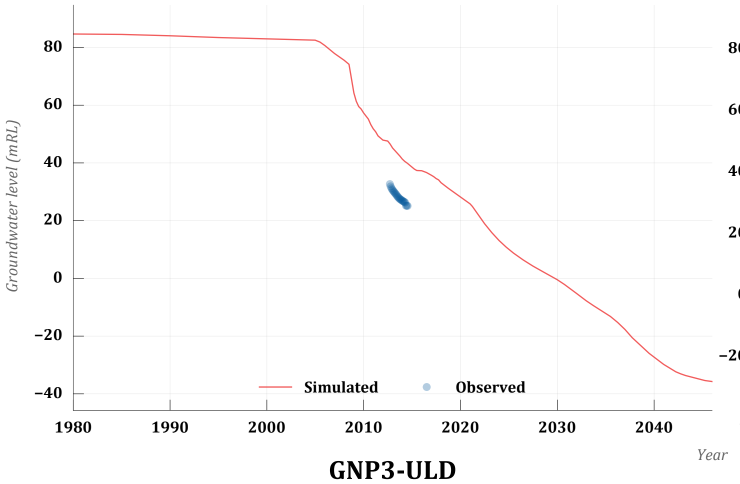

GNP1-ULD
80
60
40
20
0
−20
−40
−60
1980
1990
2000
2010
2020
2030
2040
Simulated
Observed
Year


GNP2-ART
Groundwater level (mRL)
80
60
40
20
0
−20
−40
−60
1980
1990
2000
2010
2020
2030
2040
Simulated
Observed

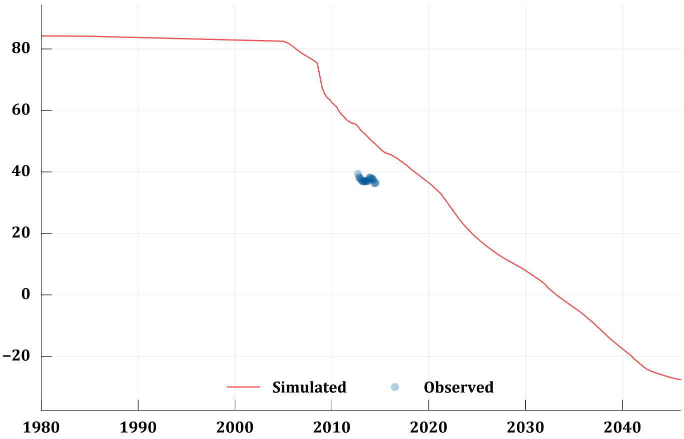

GNP2-BAR
50
0
−50
1980
1990
2000
2010
2020
2030
2040
Simulated
Observed
Year


GNP2-HEB
GNP2-LLD
GNP2-MLD
GNP2-PG
GNP3-ART
GNP3-BRT
GNP3-HEB
GNP3-LLD
Groundwater level (mRL)
Year
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040
−60
−50
−40
−20
0
20
40
50
60
80

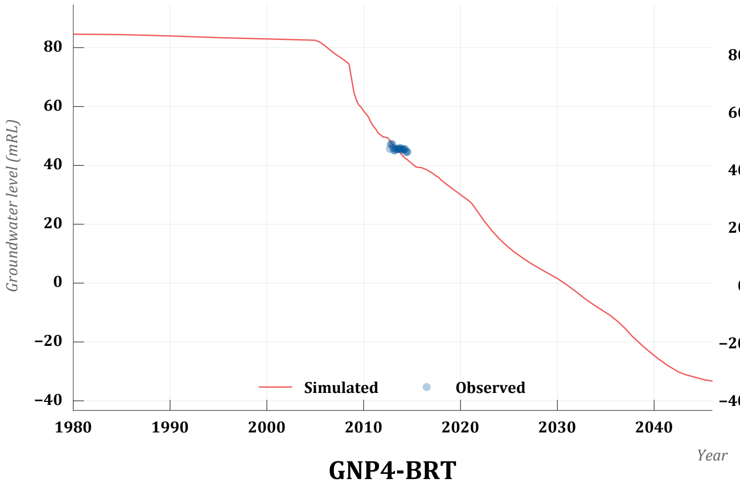
GNP3-MLD



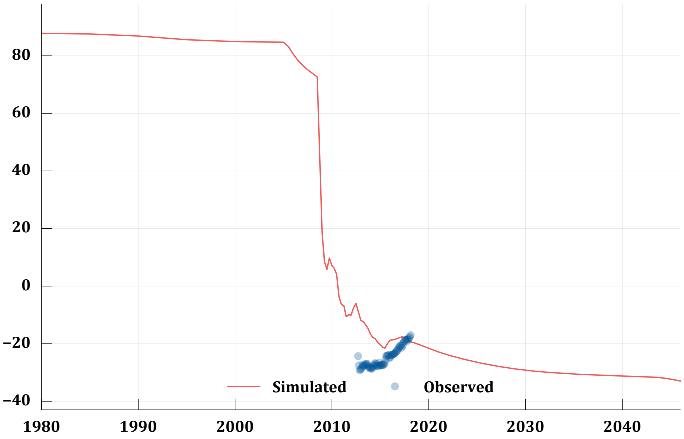
GNP3-PG



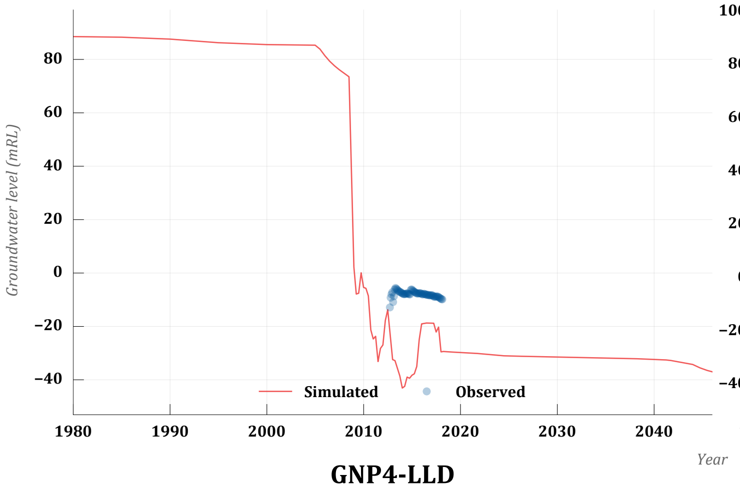
GNP3-ULD



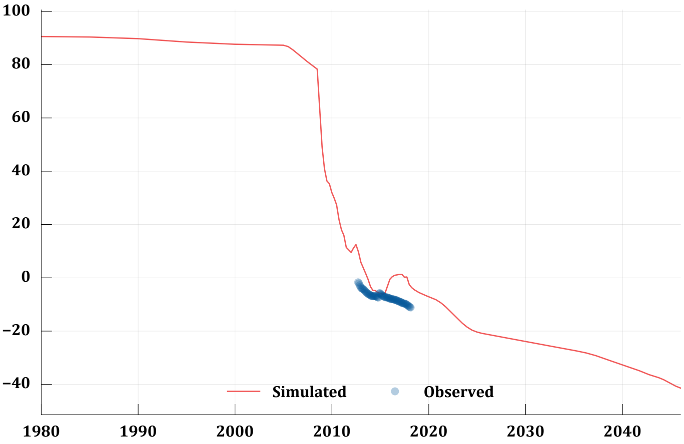
GNP4-ART



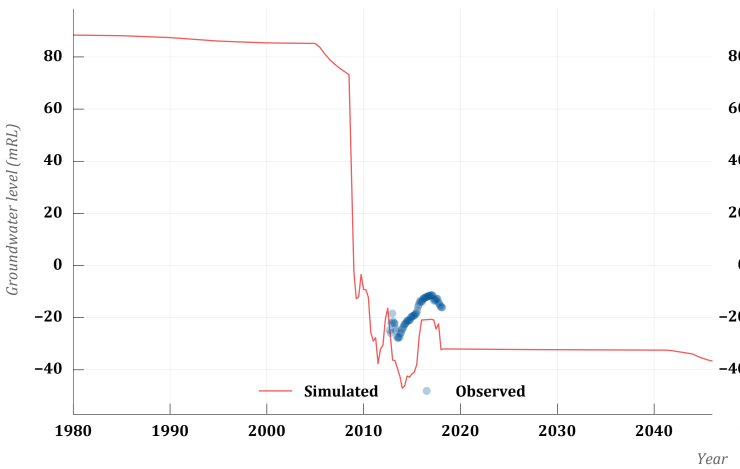
GNP4-BRT



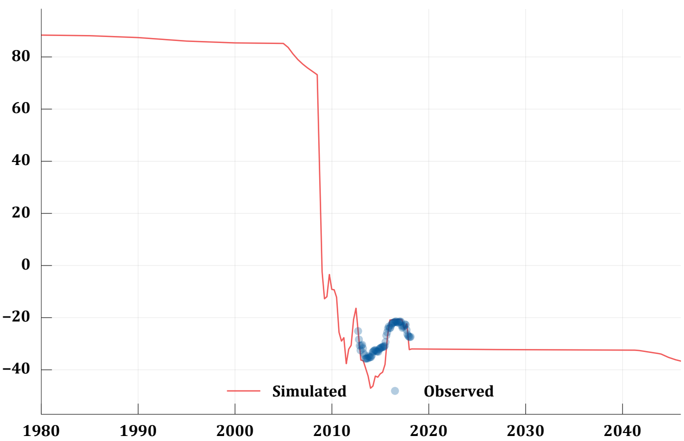
GNP4-HEB

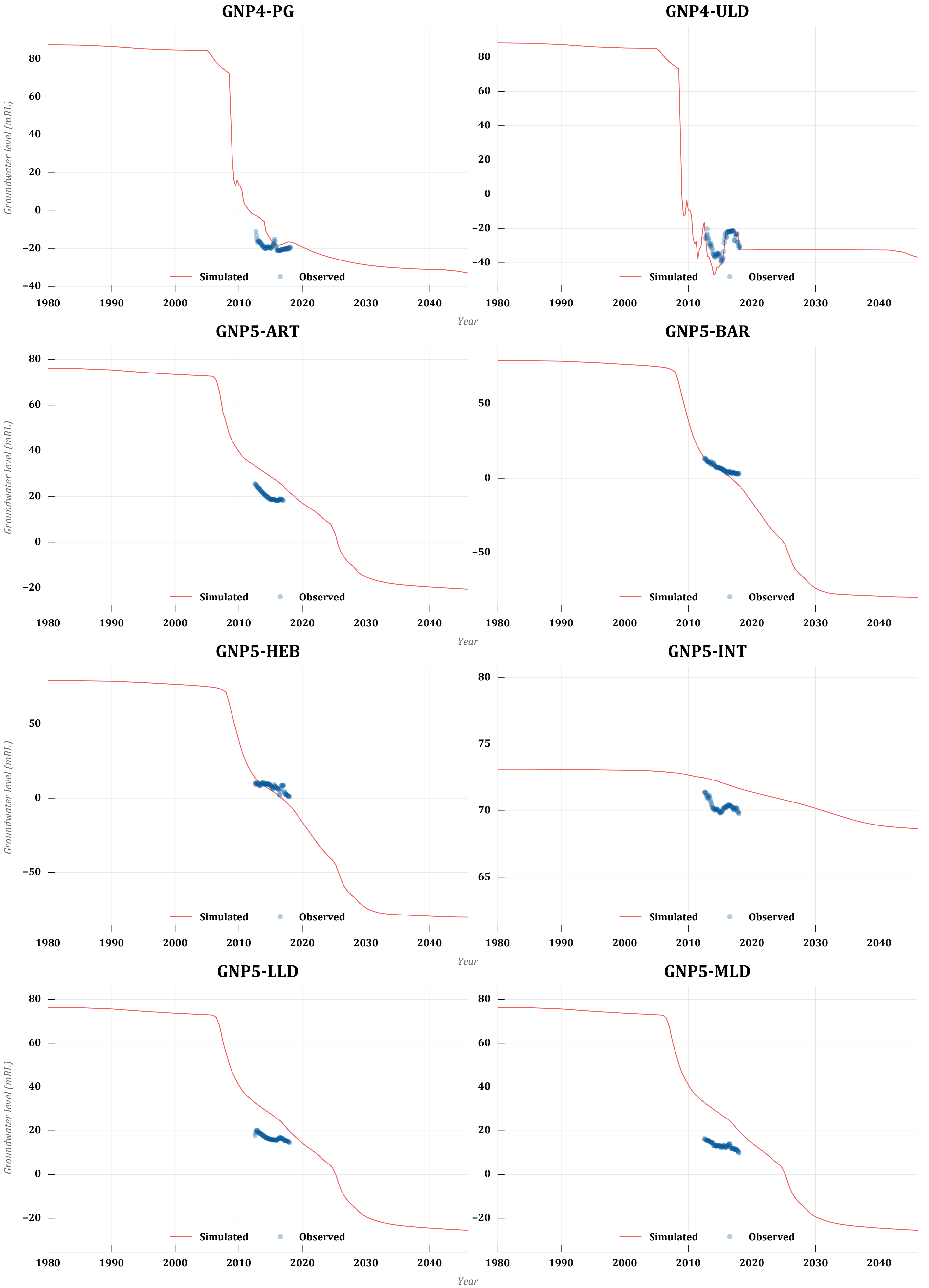


GNP4-LLD

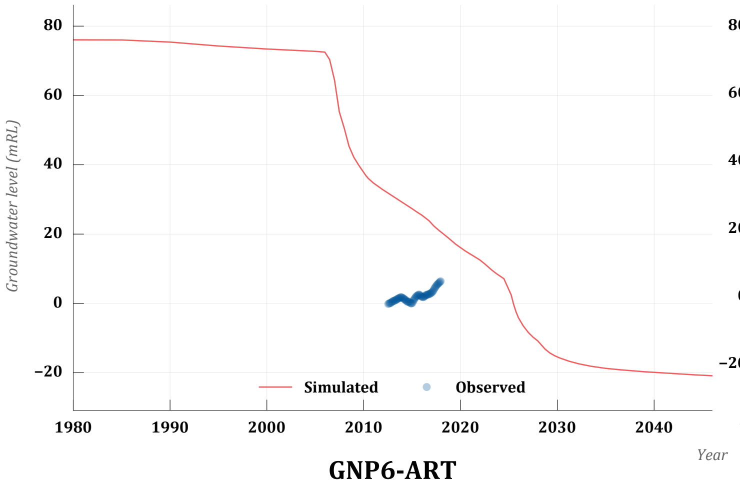


GNP4-MLD

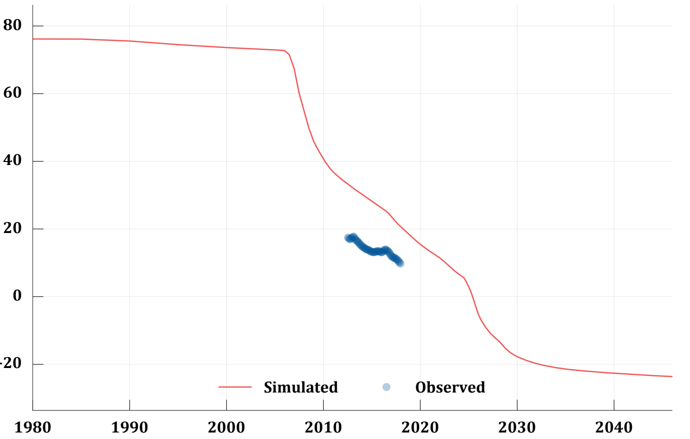



GNP4-PG
GNP4-ULD
GNP5-ART
GNP5-BAR
GNP5-HEB
GNP5-INT
GNP5-LLD
GNP5-MLD
Groundwater level (mRL)
Year
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040

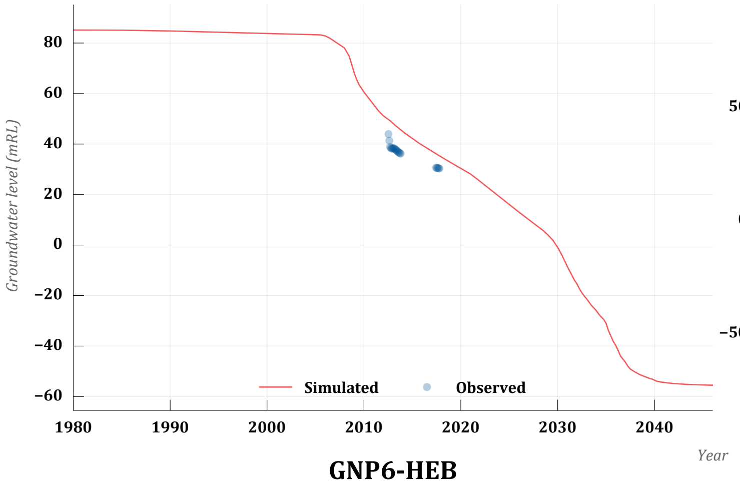
GNP5-PG



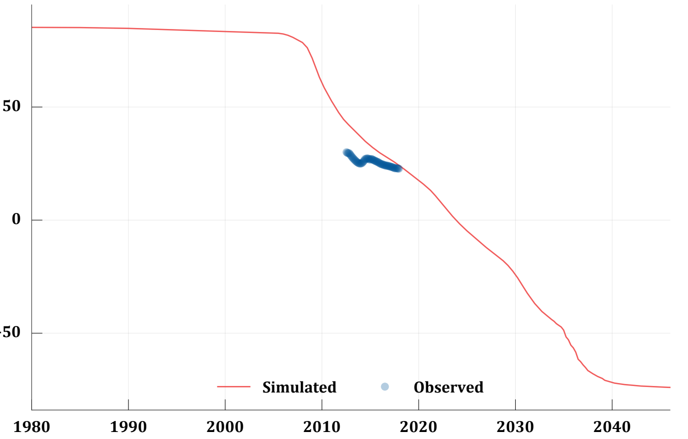
GNP5-ULD



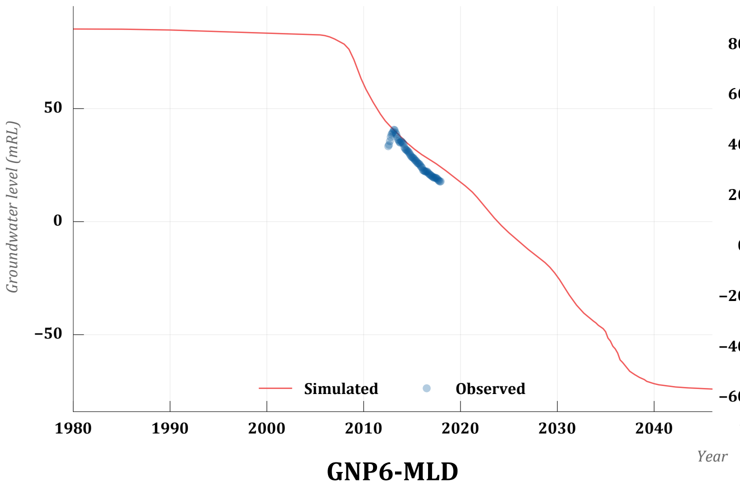
GNP6-ART



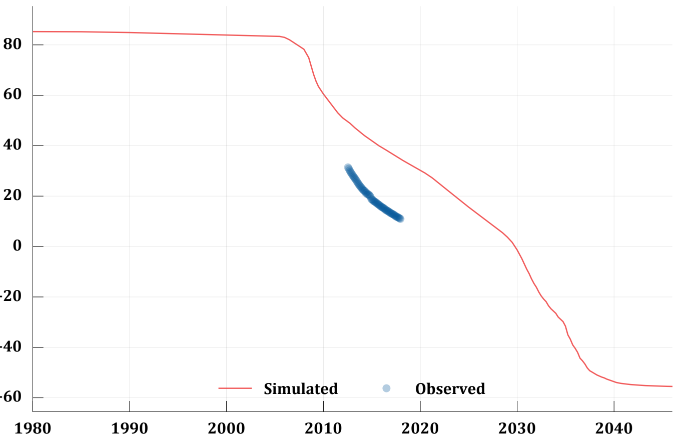
GNP6-BAR



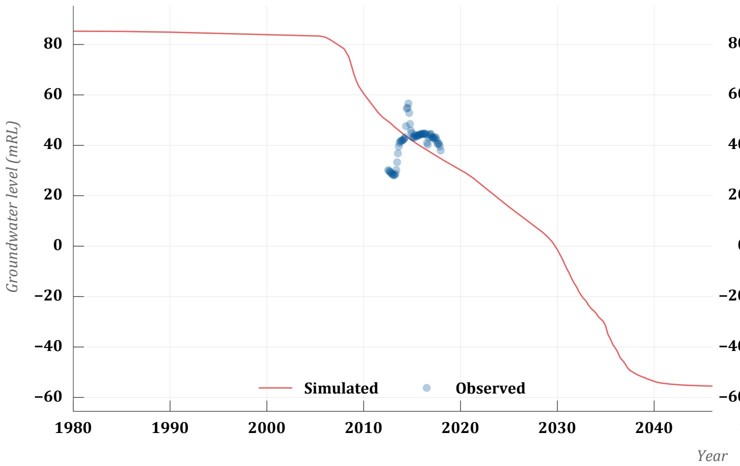
GNP6-HEB



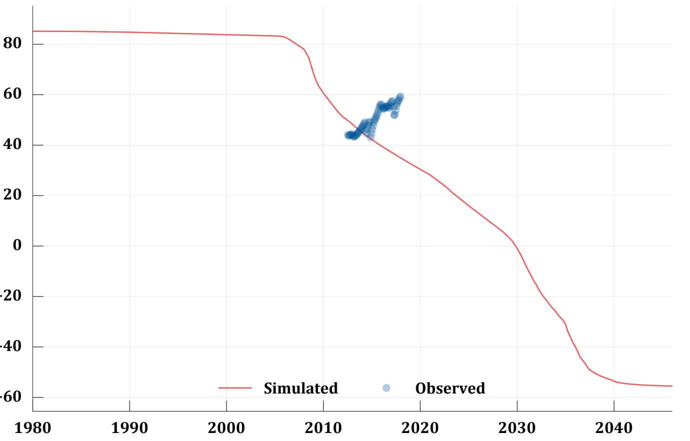
GNP6-LLD



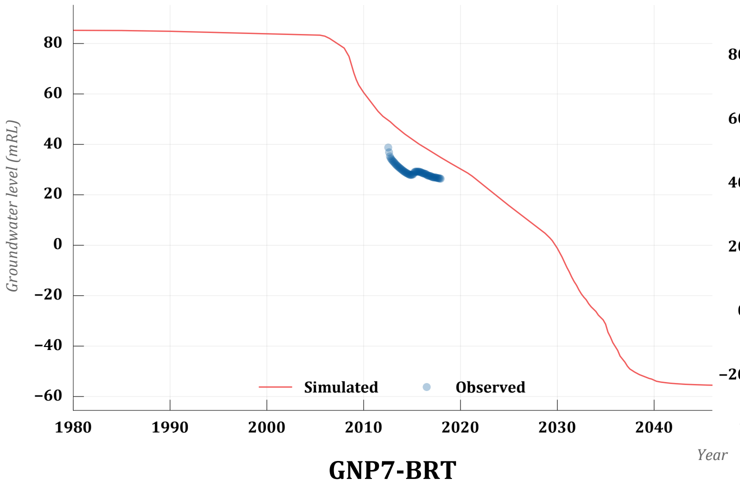
GNP6-MLD



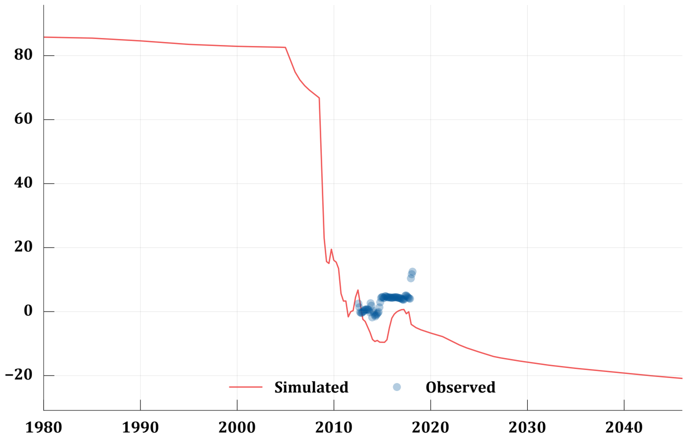
GNP6-PG



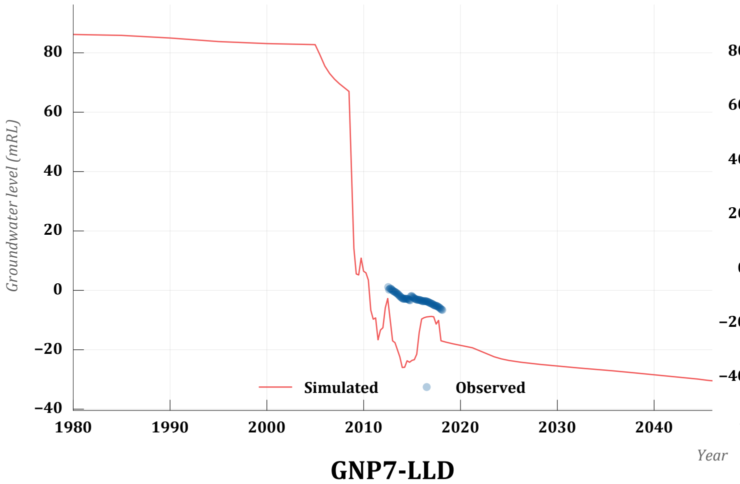
GNP6-ULD



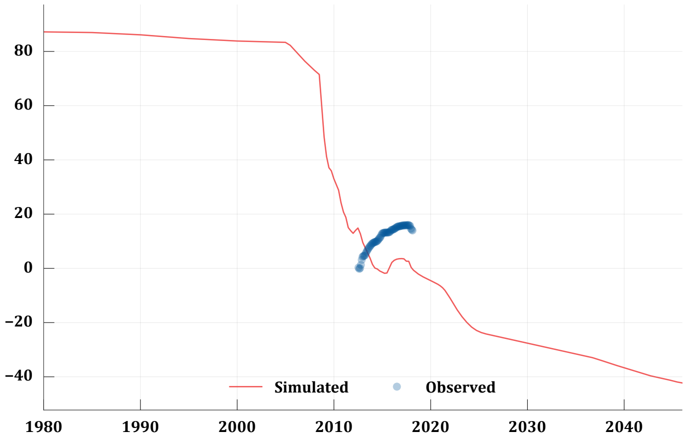
GNP7-ART



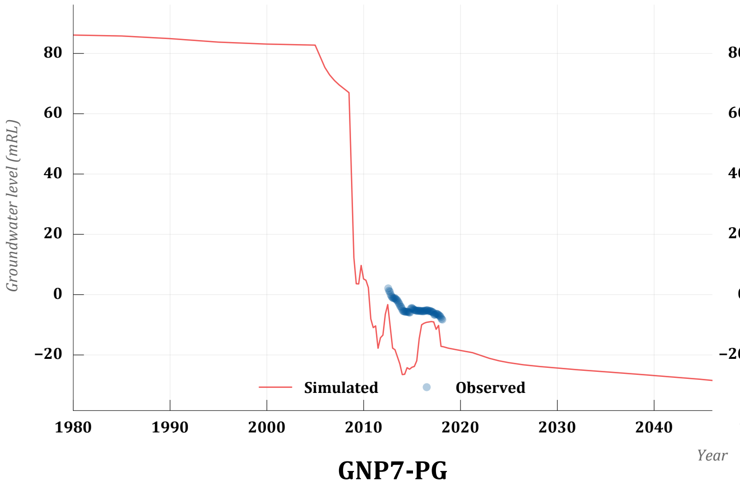
GNP7-BRT



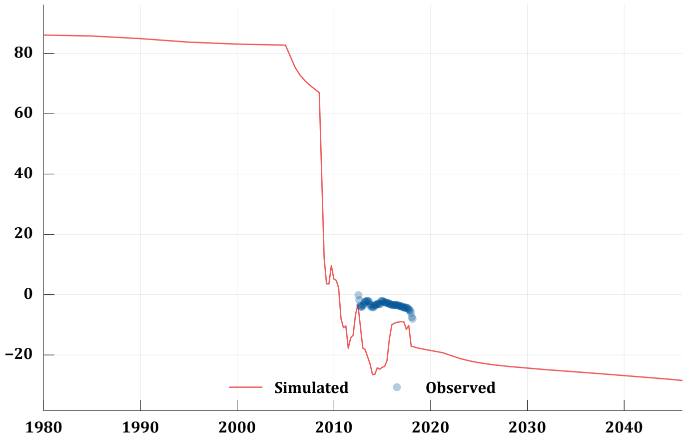
GNP7-HEB



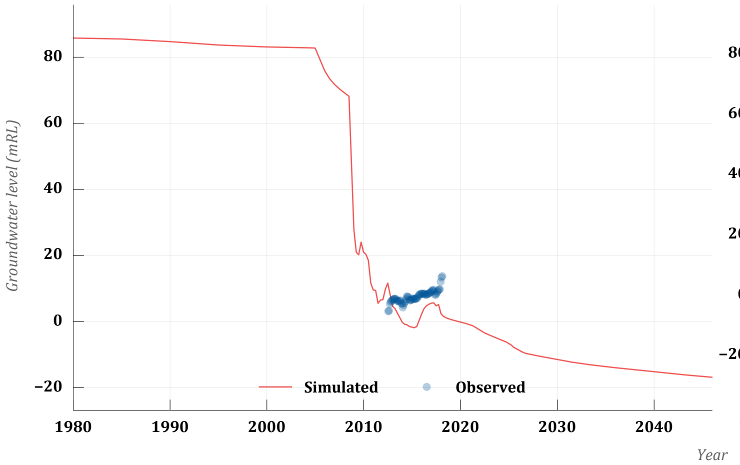
GNP7-LLD



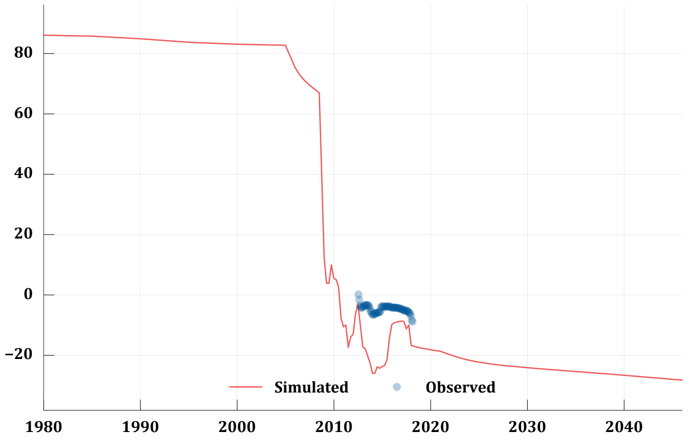
GNP7-MLD



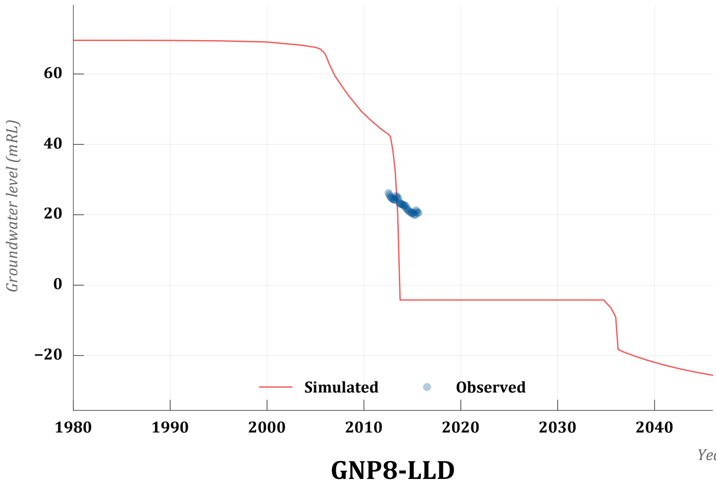
GNP7-PG



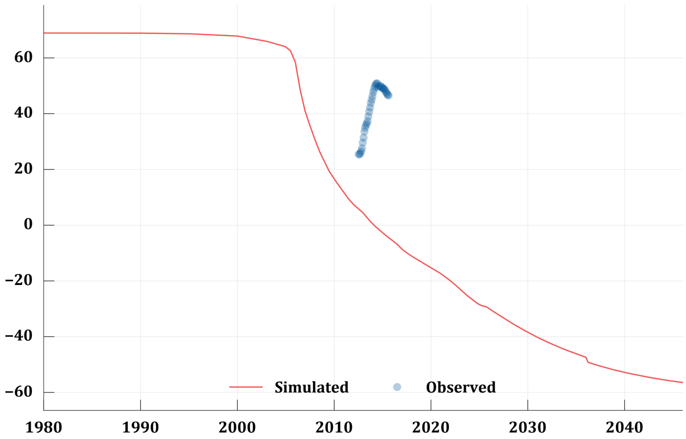
GNP7-ULD



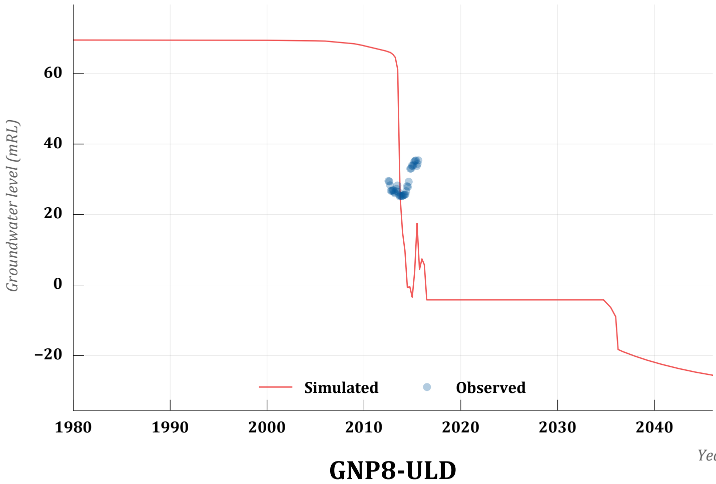
GNP8-BAR



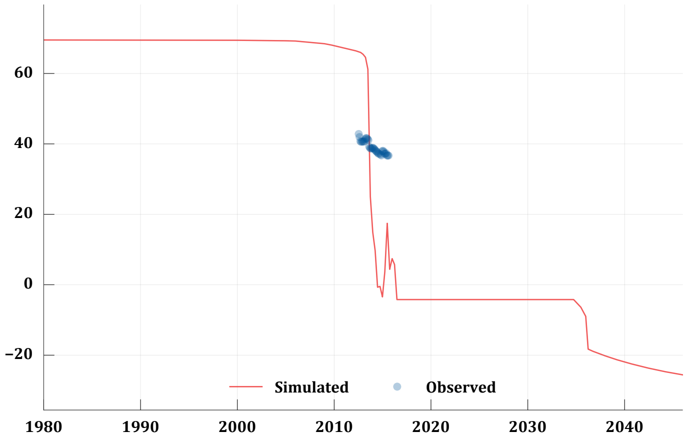
GNP8-HEB



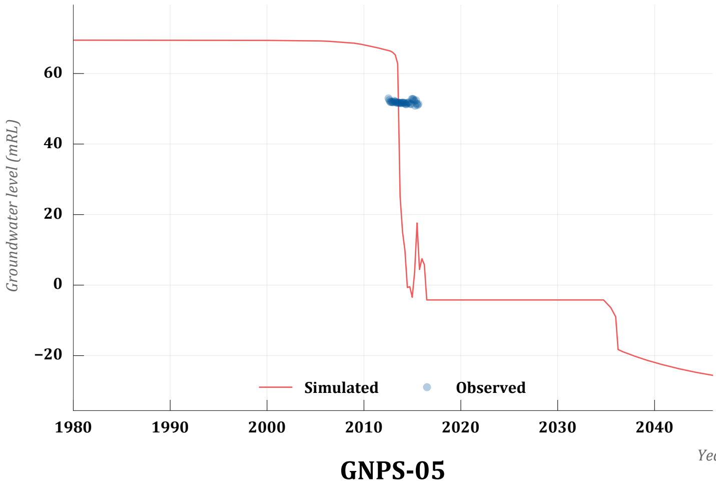
GNP8-LLD



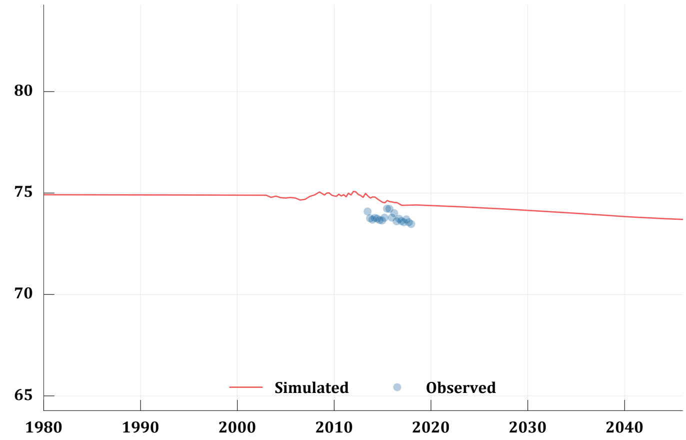
GNP8-MLD



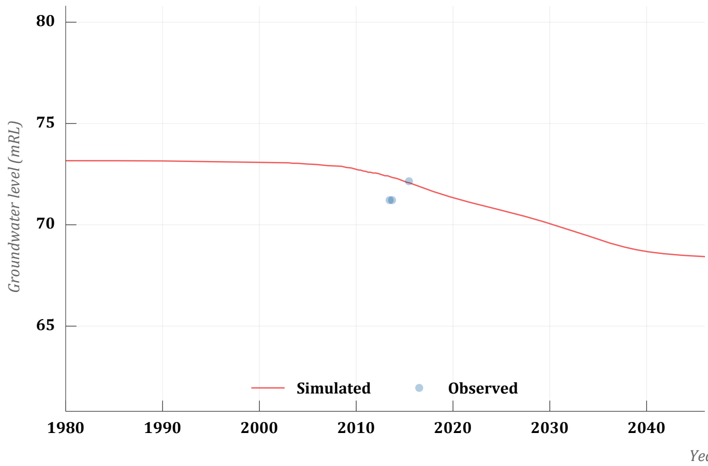
GNP8-ULD



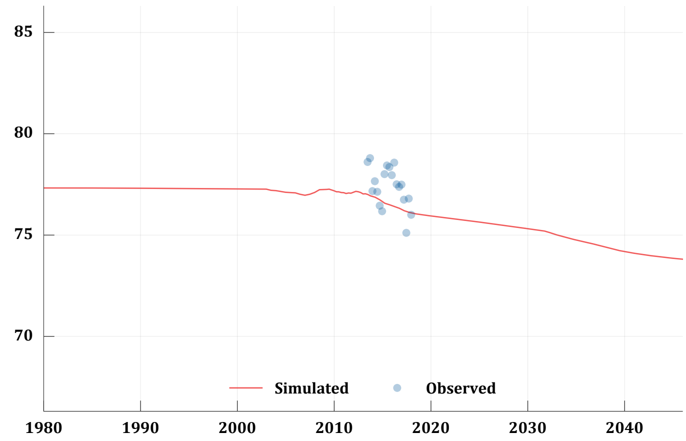
GNPS-02

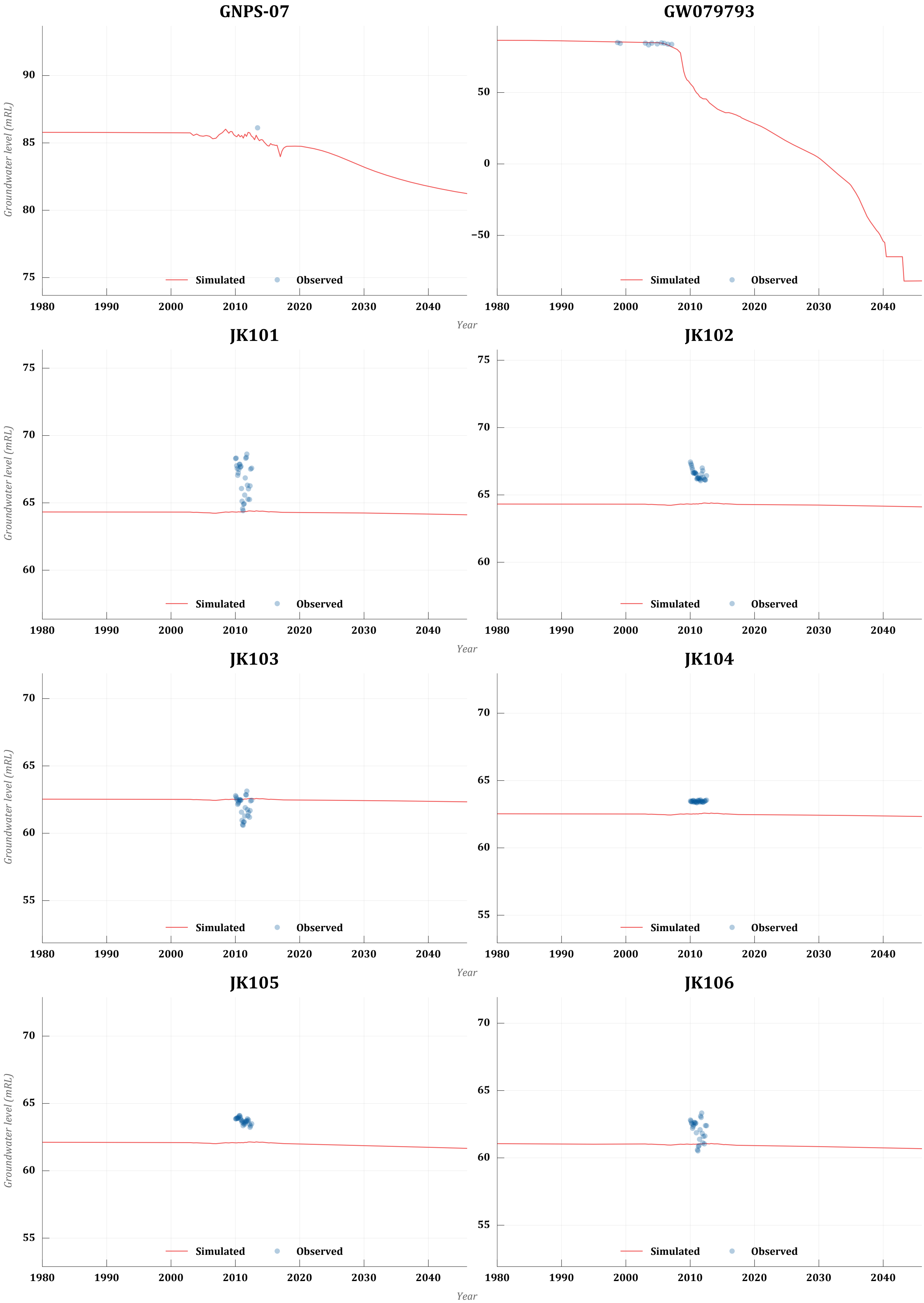


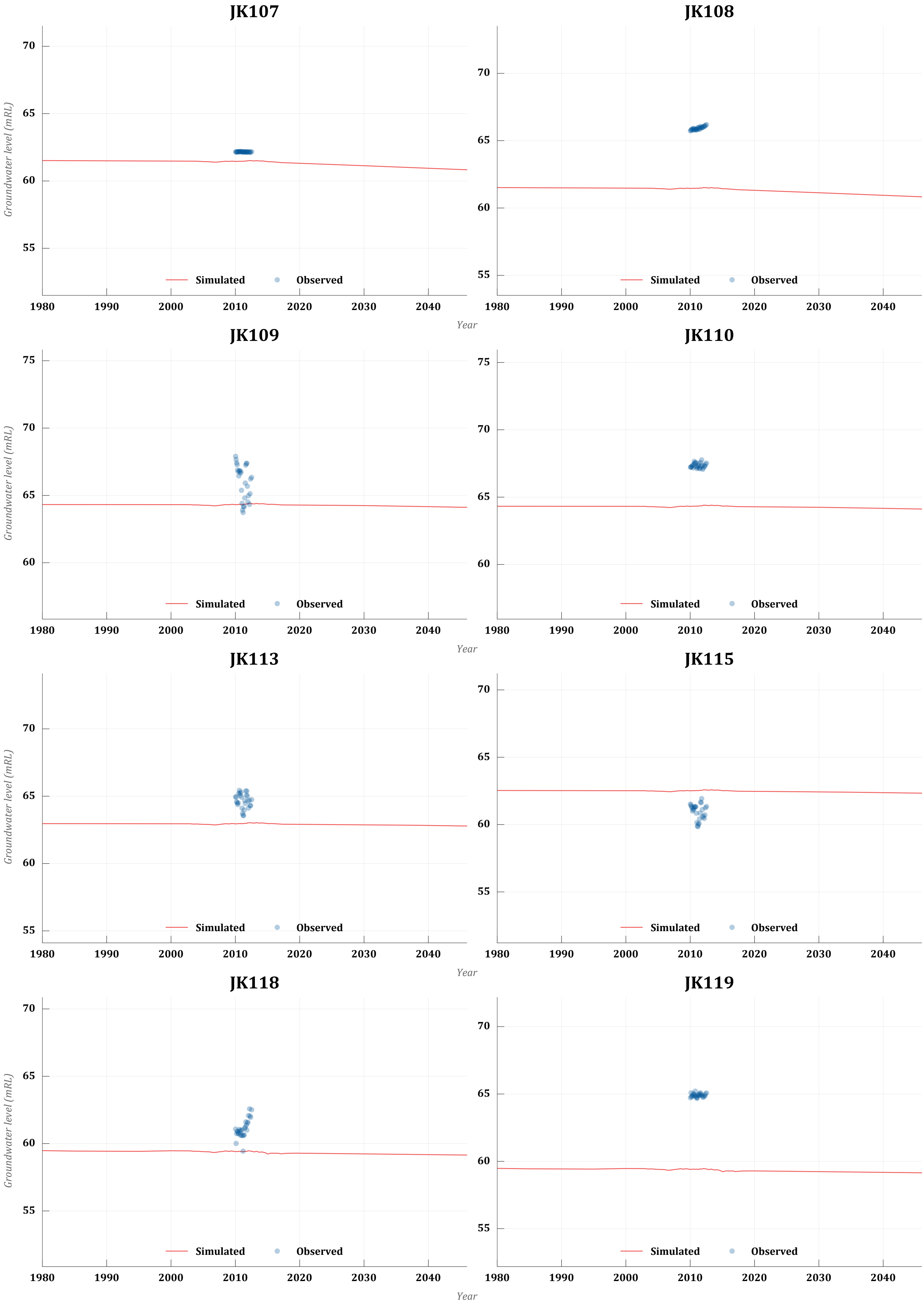
GNPS-05



GNPS-06




GNPS-07
GW079793
JK101
JK102
JK103
JK104
JK105
JK106
Groundwater level (mRL)
Year
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040


JK107
JK108
JK109
JK110
JK113
JK115
JK118
JK119
Groundwater level (mRL)
Year
Simulated
Observed
1980
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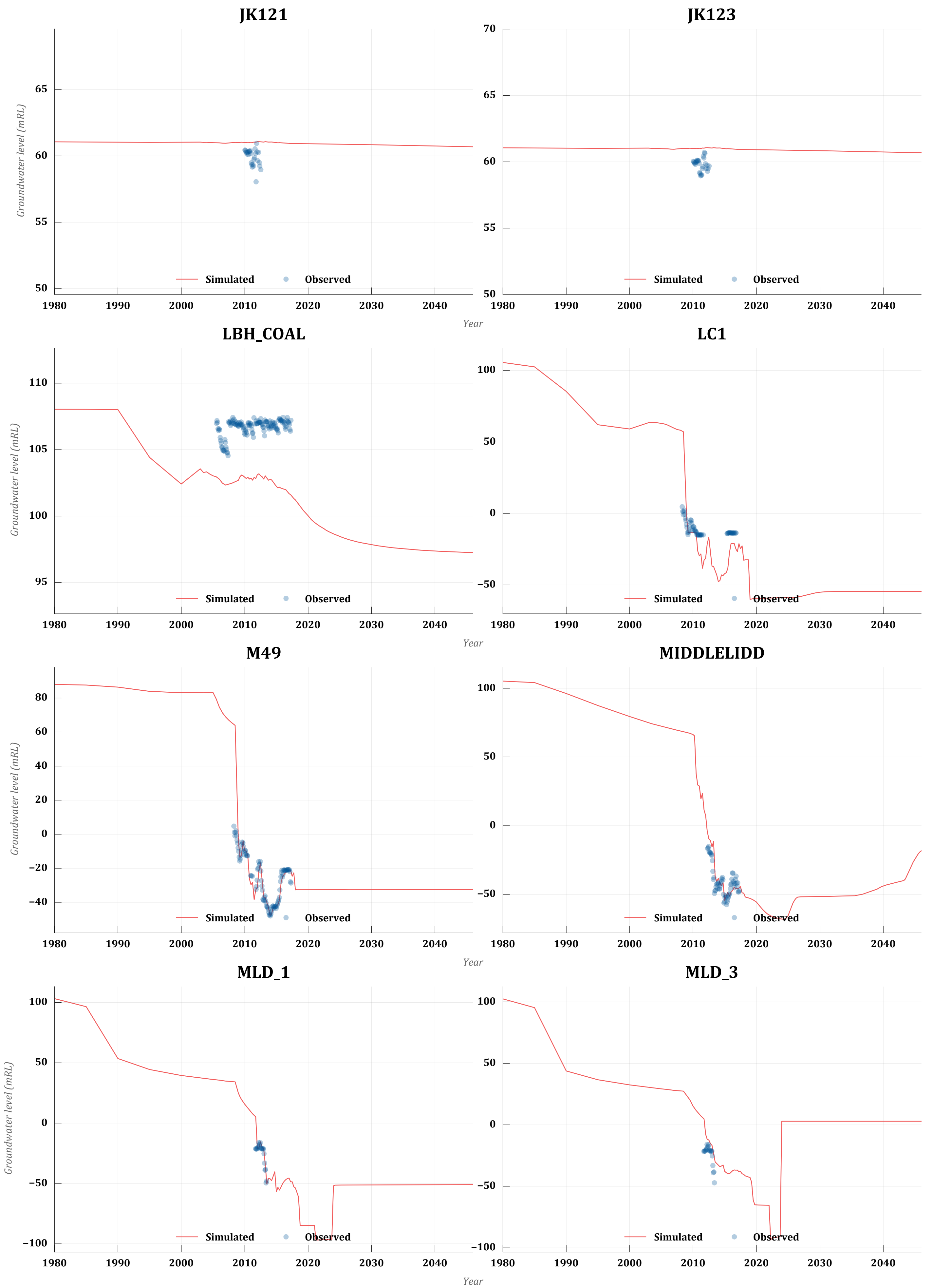
2030
2040
55
60
65
70
75


JK121
JK123
LBH_COAL
LC1
M49
MIDDLELIDD
MLD_1
MLD_3
Groundwater level (mRL)
Year
Simulated
Observed
1980
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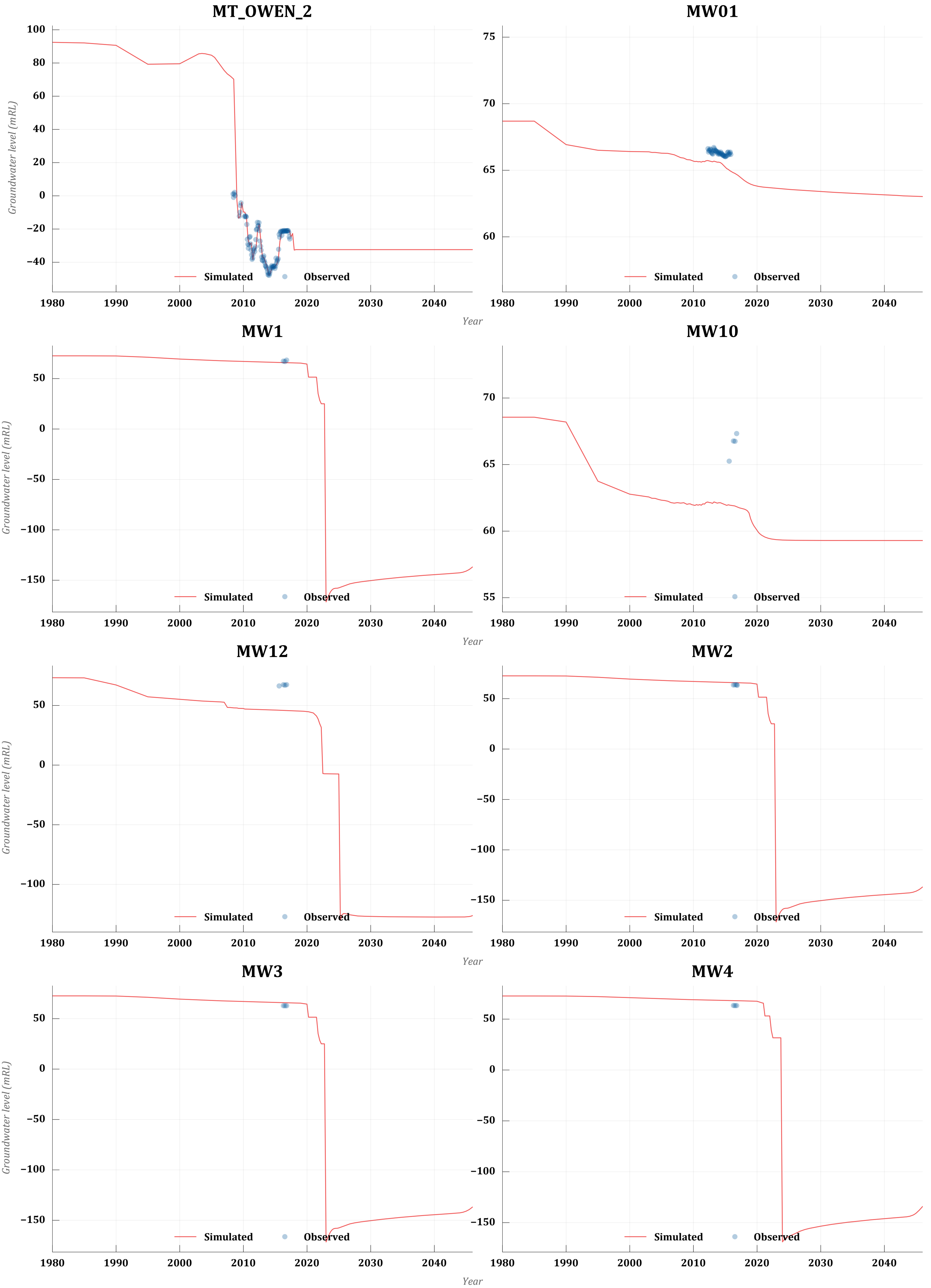
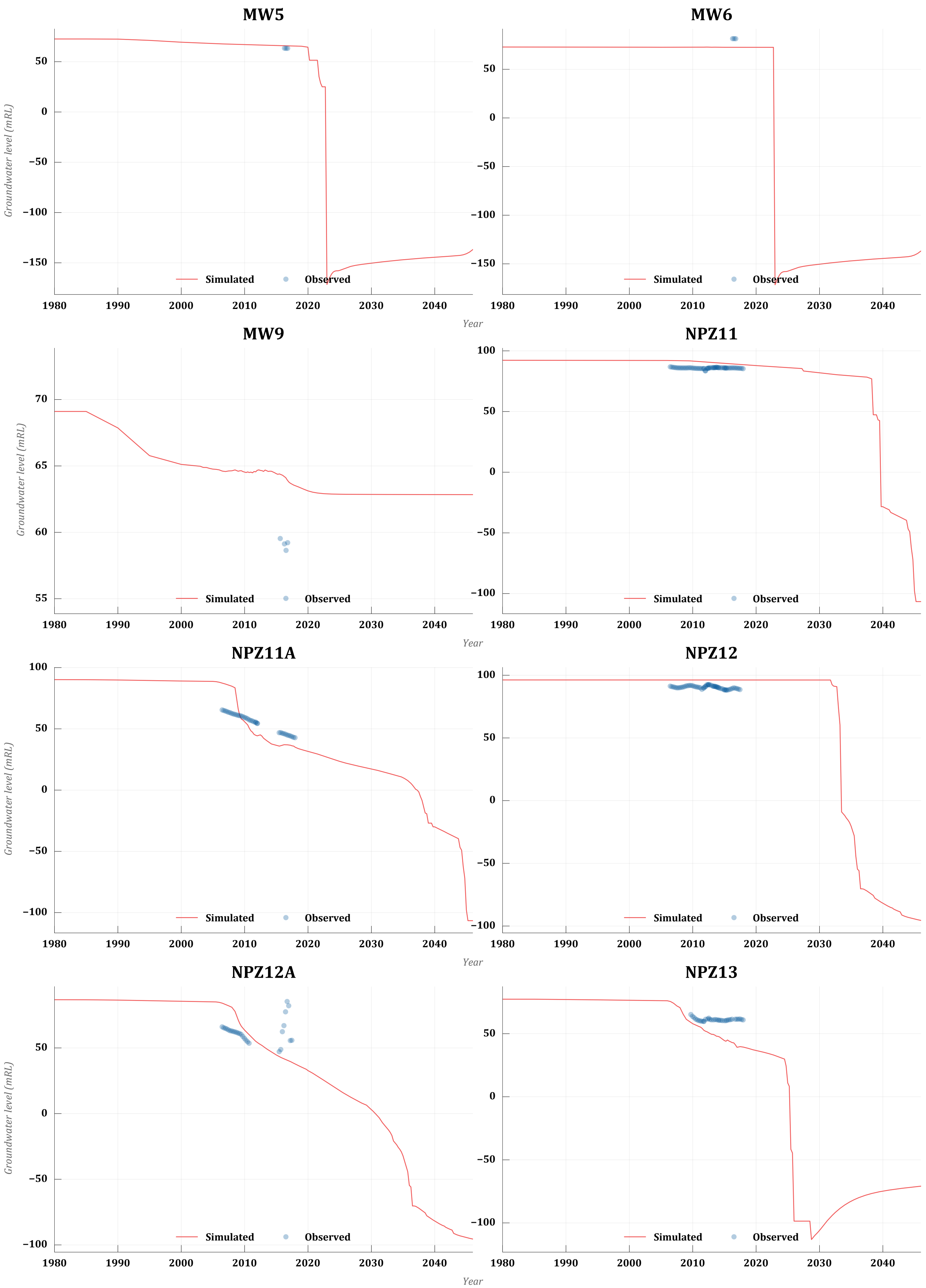
2000
2010
2020
2030
2040



MT_OWEN_2
MW01
MW1
MW10
MW12
MW2
MW3
MW4
Groundwater level (mRL)
Simulated
Observed
Year
1980
1990
2000
2010
2020
2030
2040


MW5
MW6
MW9
NPZ11
NPZ11A
NPZ12
NPZ12A
NPZ13
Groundwater level (mRL)
Year
Simulated
Observed
1980
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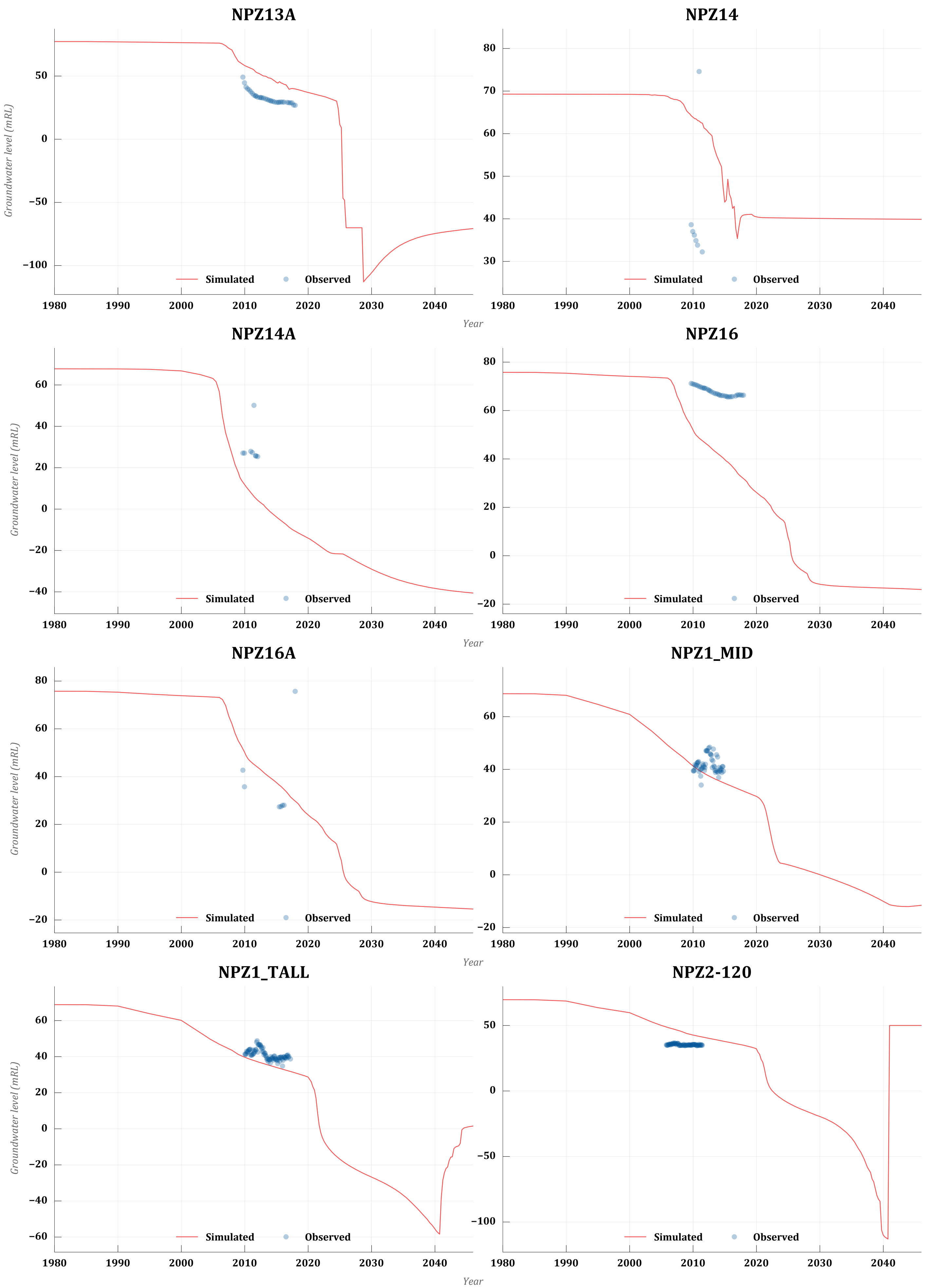
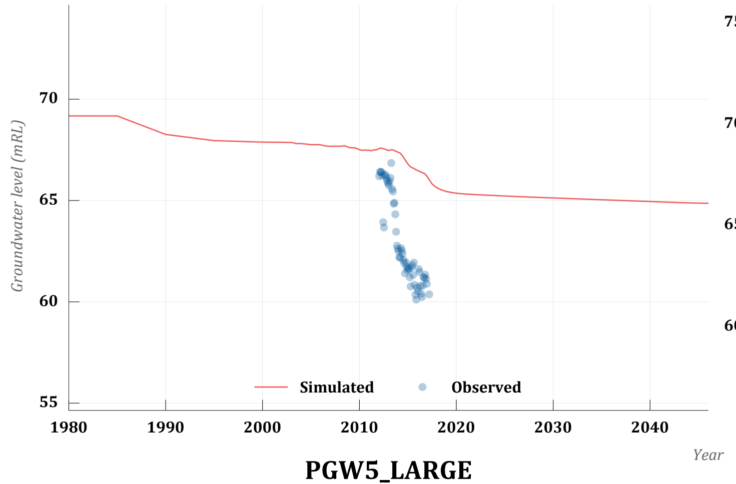
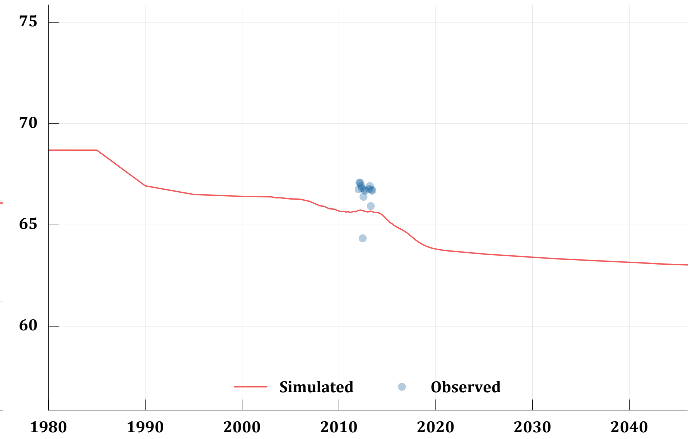
2000
2010
2020
2030
2040


NPZ13A
NPZ14
NPZ14A
NPZ16
NPZ16A
NPZ1_MID
NPZ1_TALL
NPZ2-120
Groundwater level (mRL)
Year
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040

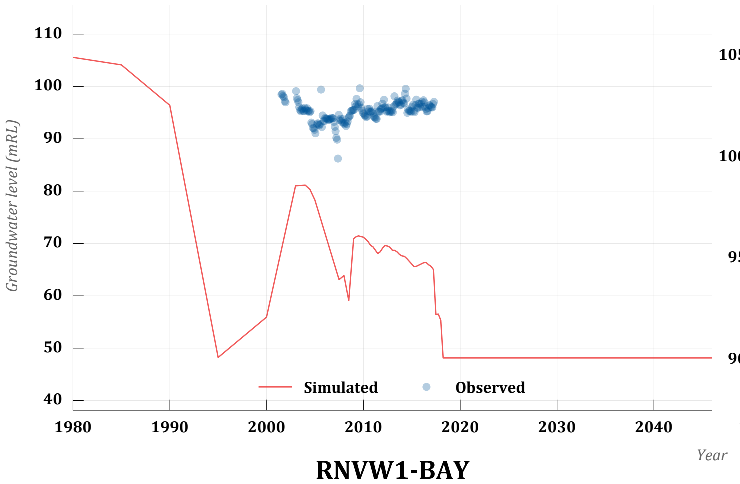
NPZ5B_P1



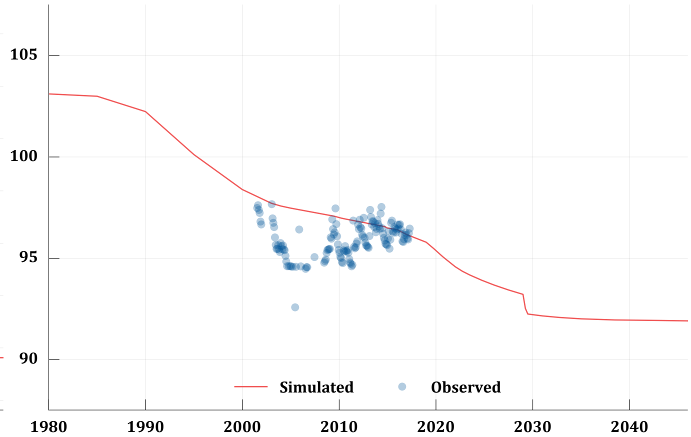
NPZ5B_P2



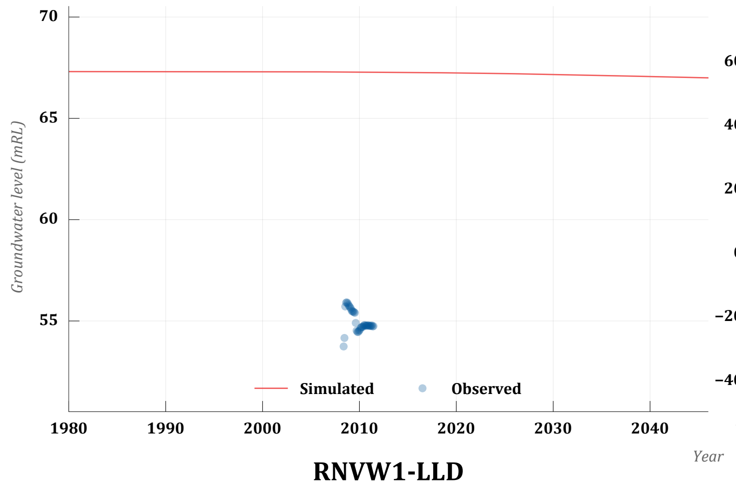
PGW5_LARGE



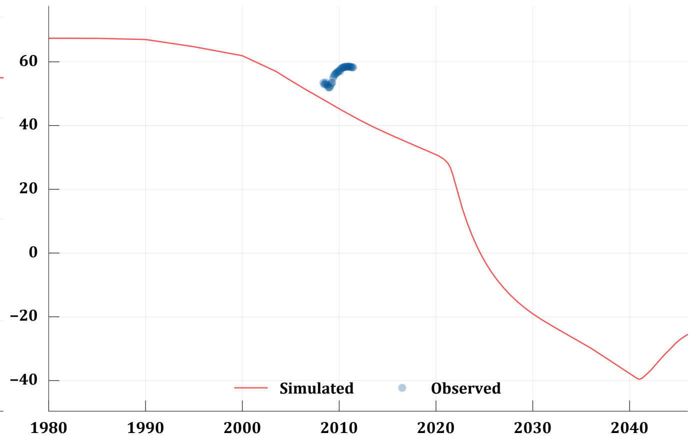
PGW5_SMALL



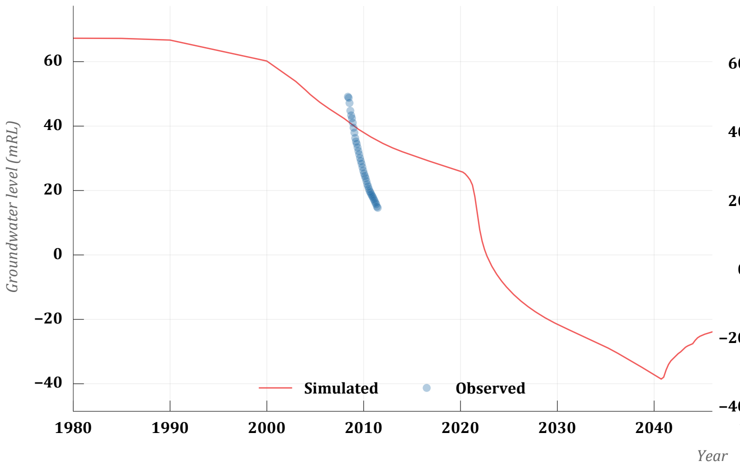
RNVW1-BAY



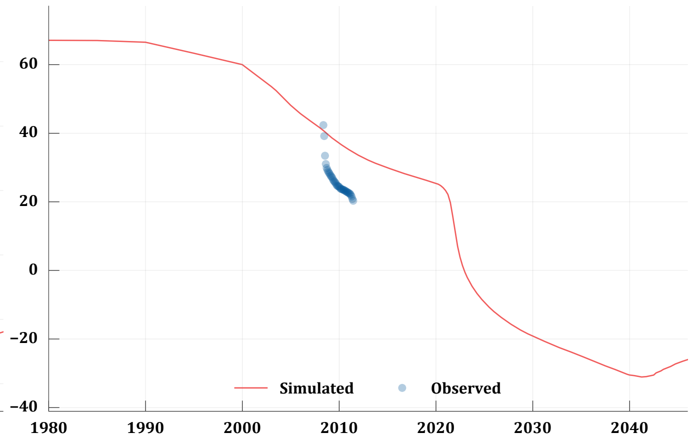
RNVW1-BRT

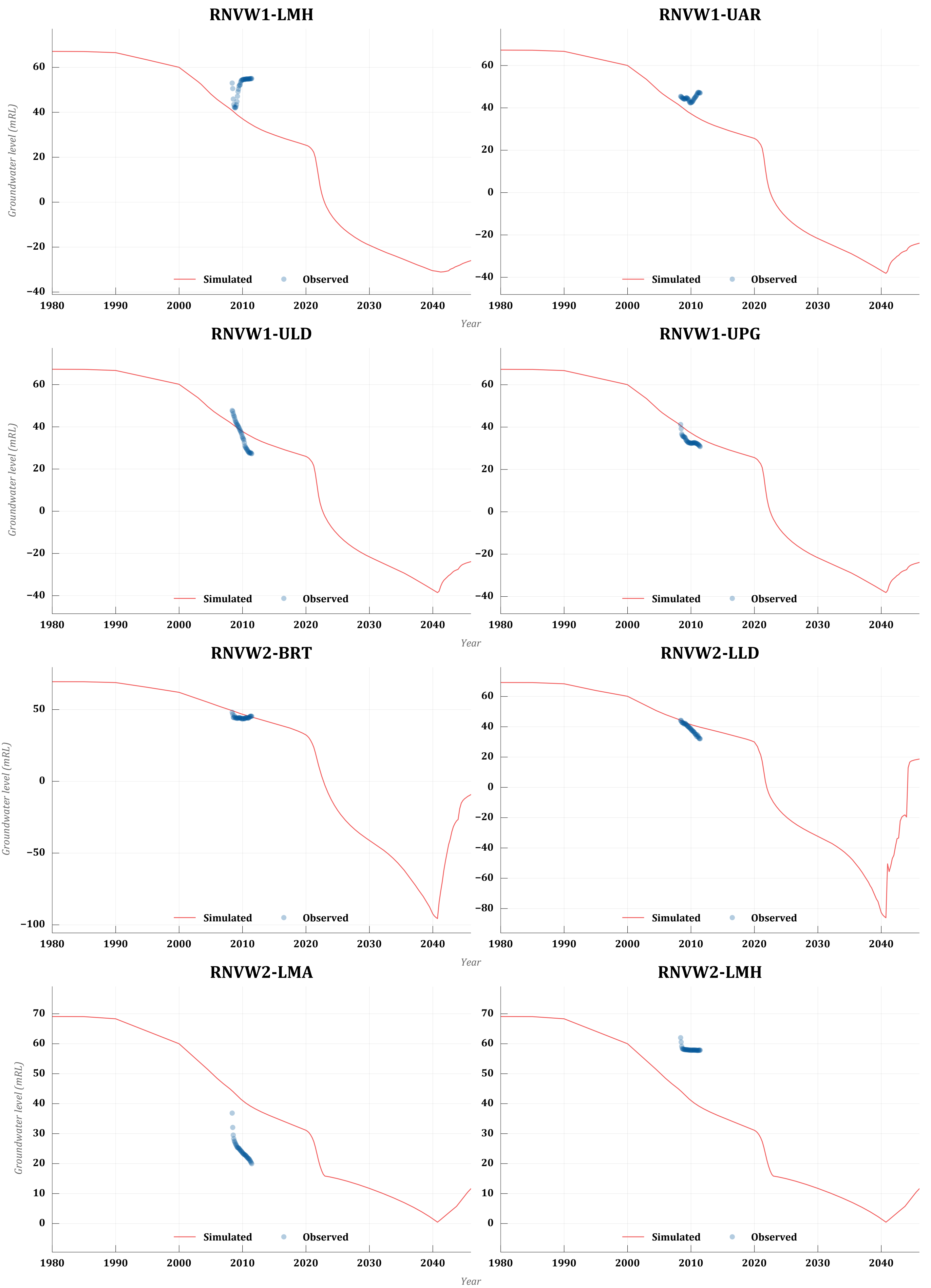


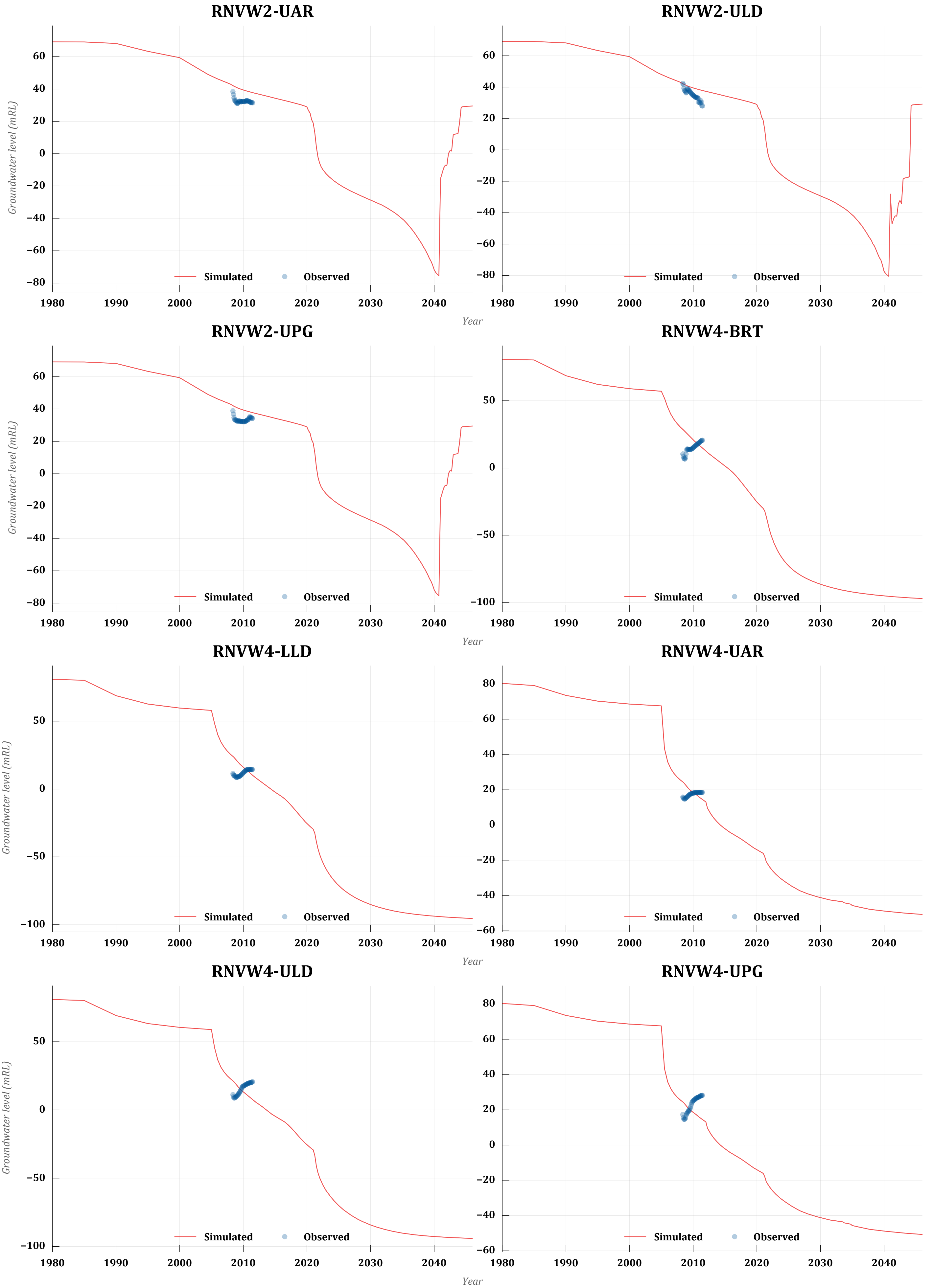
RNVW1-LLD

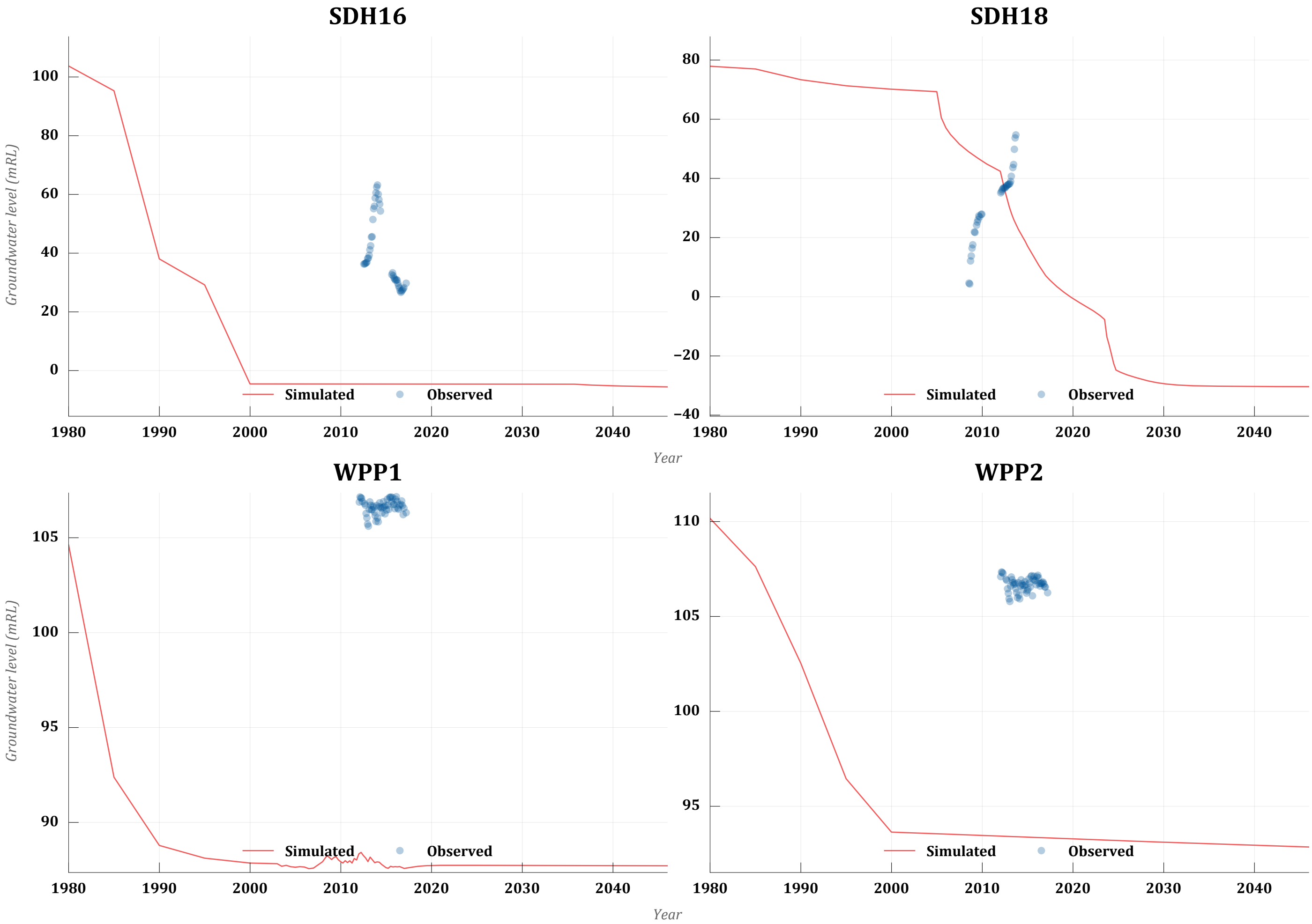


RNVW1-LMA

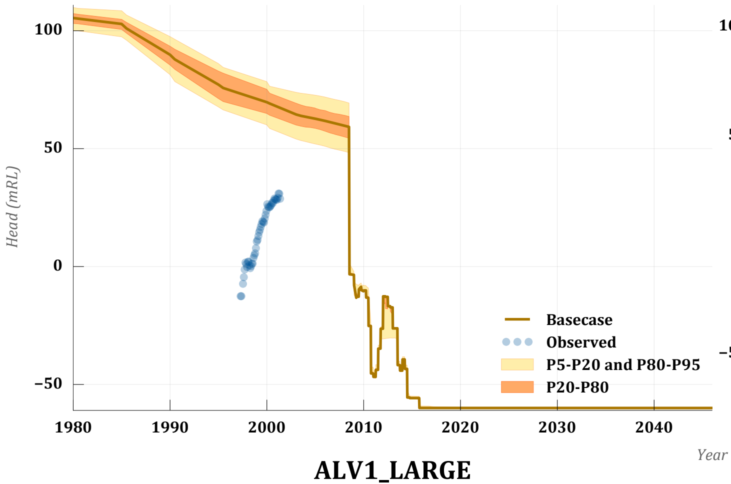



RNVW1-LMH
RNVW1-UAR
RNVW1-ULD
RNVW1-UPG
RNVW2-BRT
RNVW2-LLD
RNVW2-LMA
RNVW2-LMH
Groundwater level (mRL)
Year
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040

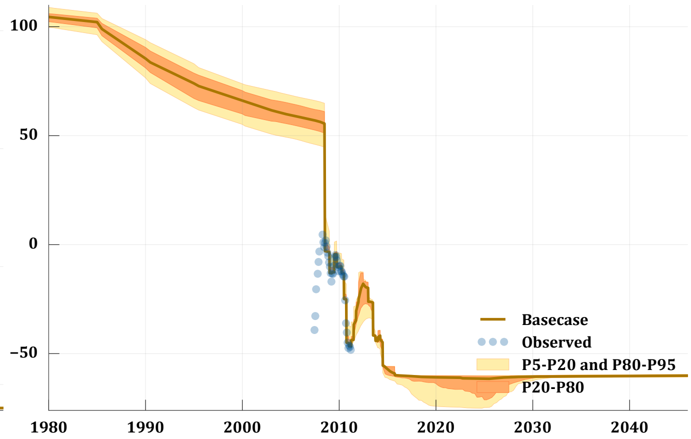

RNVW2-UAR
RNVW2-ULD
RNVW2-UPG
RNVW4-BRT
RNVW4-LLD
RNVW4-UAR
RNVW4-ULD
RNVW4-UPG
Groundwater level (mRL)
Year
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040


SDH16
SDH18
WPP1
WPP2
Groundwater level (mRL)
Year
Simulated
Observed
1980
1990
2000
2010
2020
2030
2040

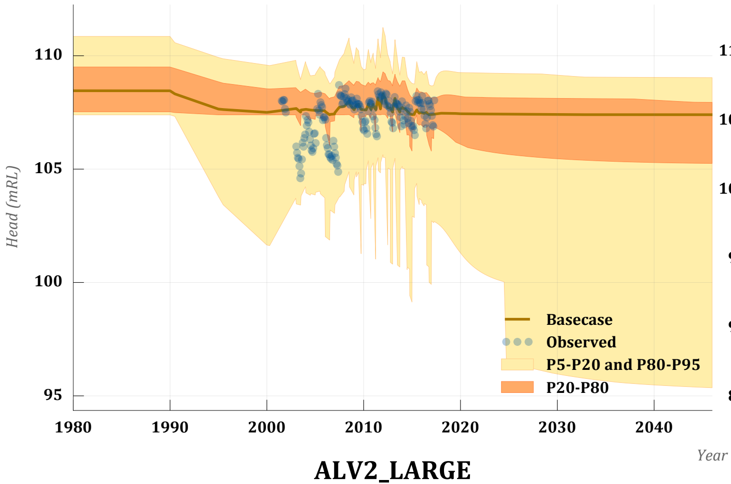
64CT



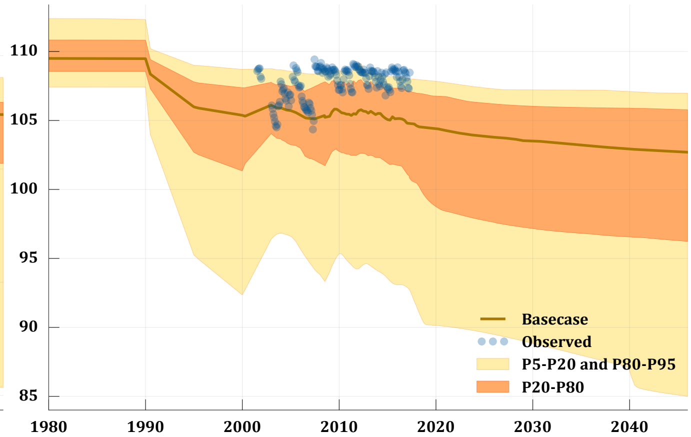
8-SOUTH-2



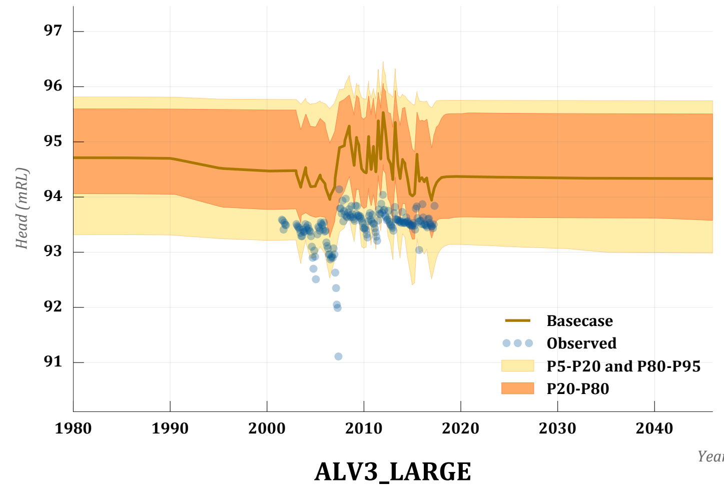
ALV1_LARGE



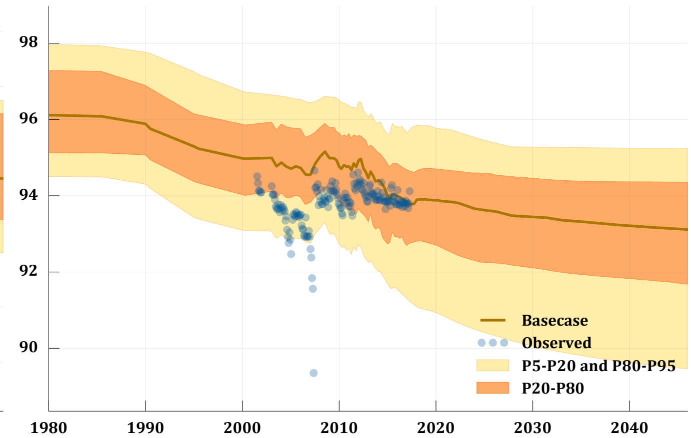
ALV1_SMALL



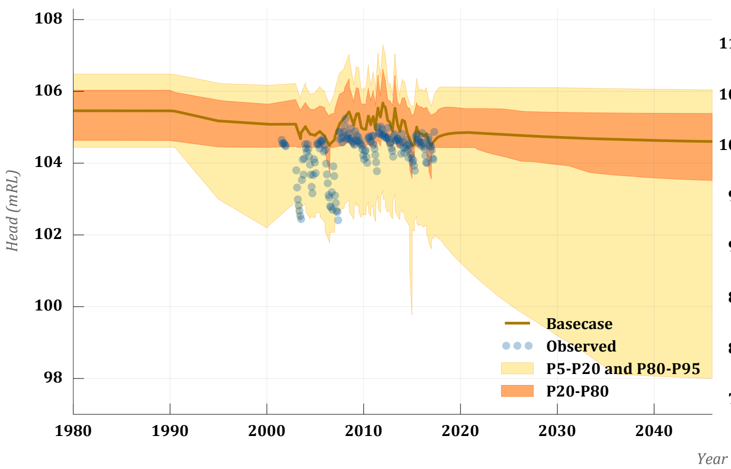
ALV2_LARGE



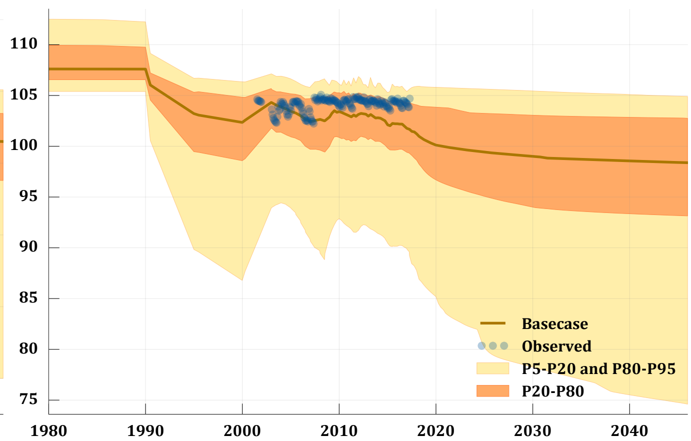
ALV2_SMALL

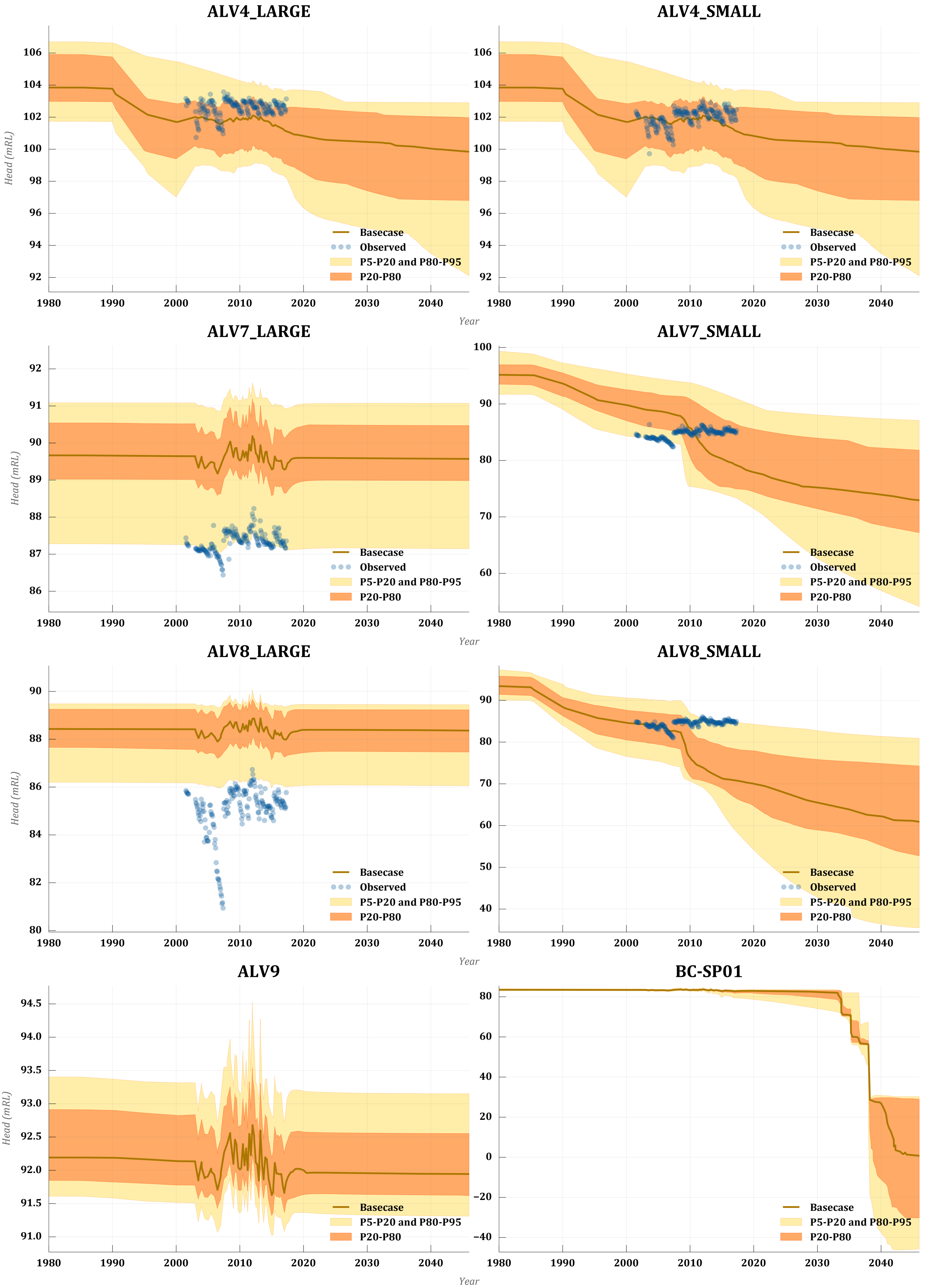


ALV3_LARGE

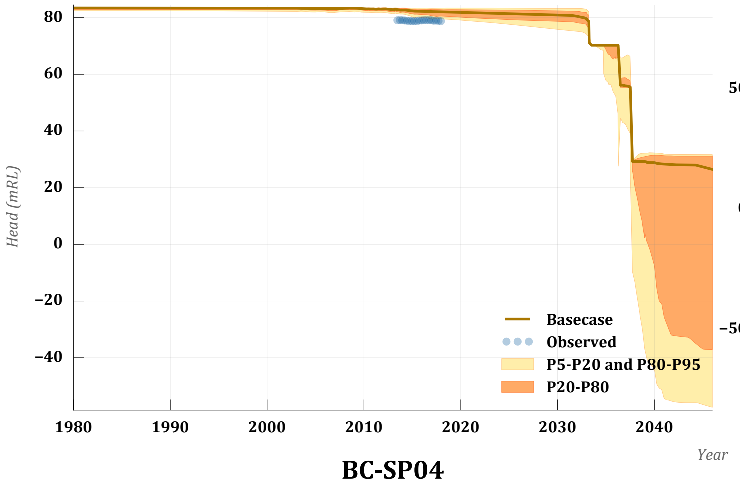


ALV3_SMALL

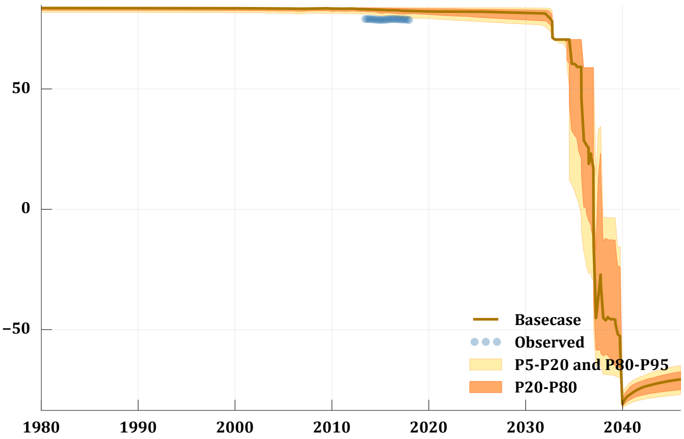



ALV4_LARGE
ALV4_SMALL
ALV7_LARGE
ALV7_SMALL
ALV8_LARGE
ALV8_SMALL
ALV9
BC-SP01
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
1980
1990
2000
2010
2020
2030
2040

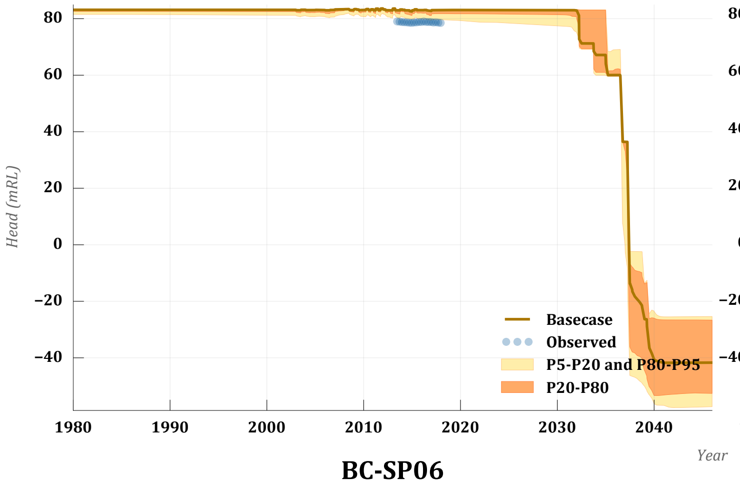
BC-SP02



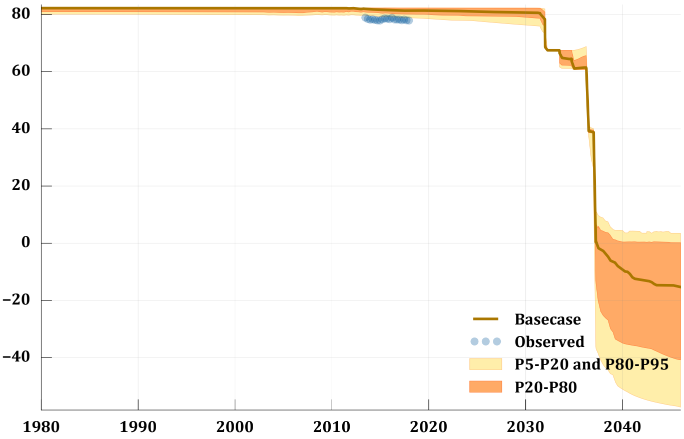
BC-SP03



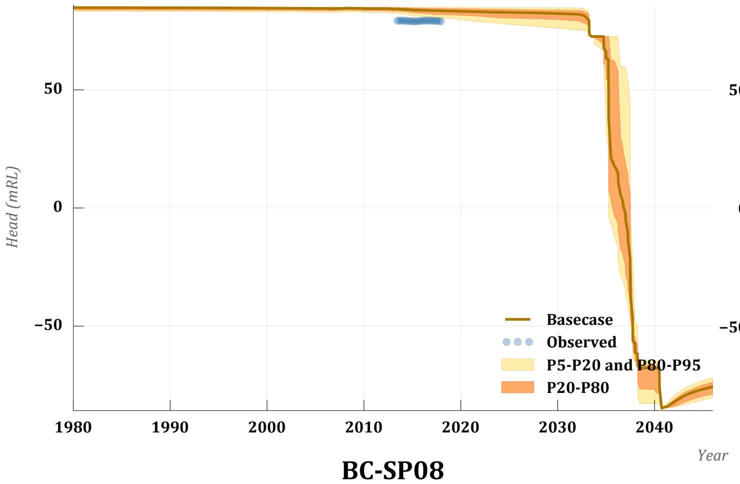
BC-SP04



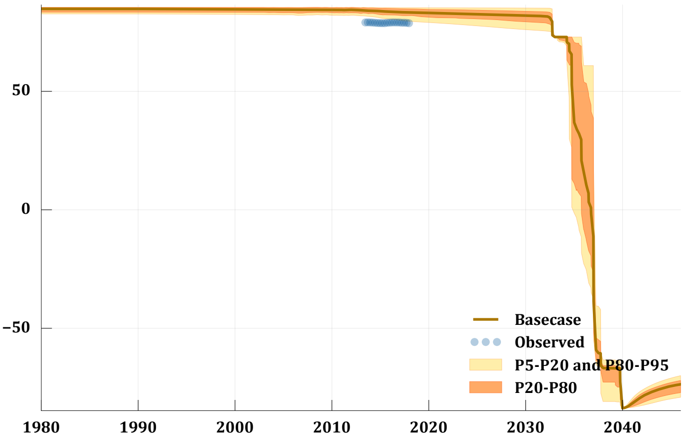
BC-SP05



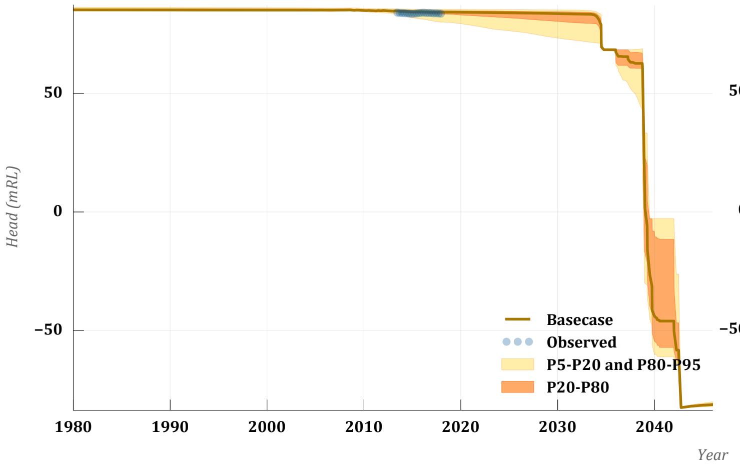
BC-SP06



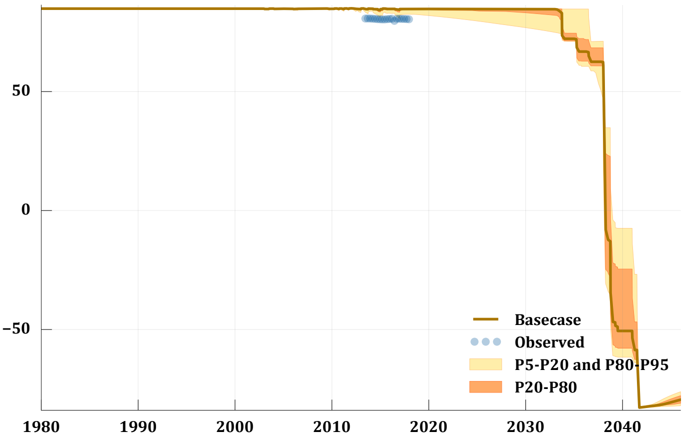
BC-SP07

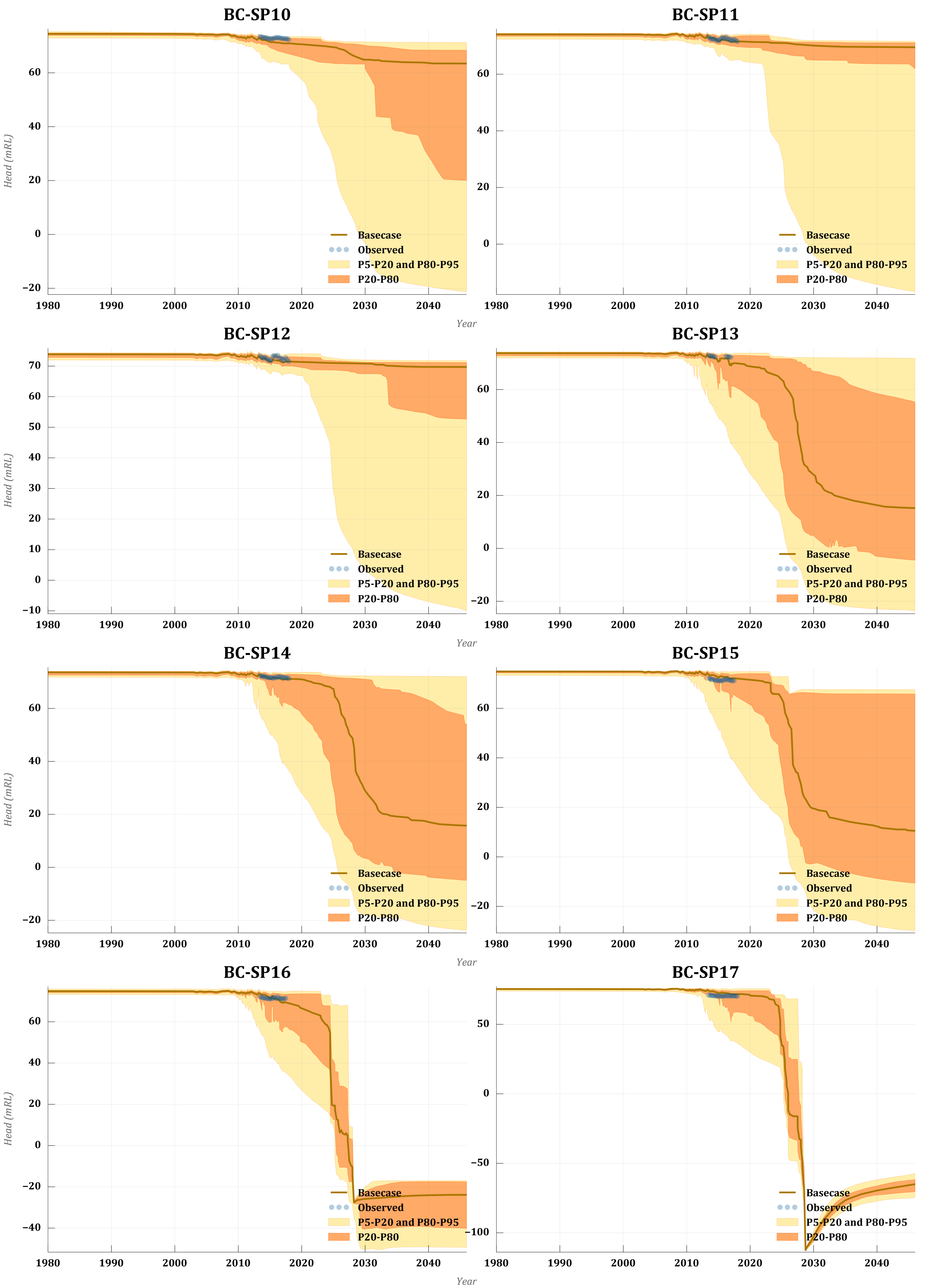


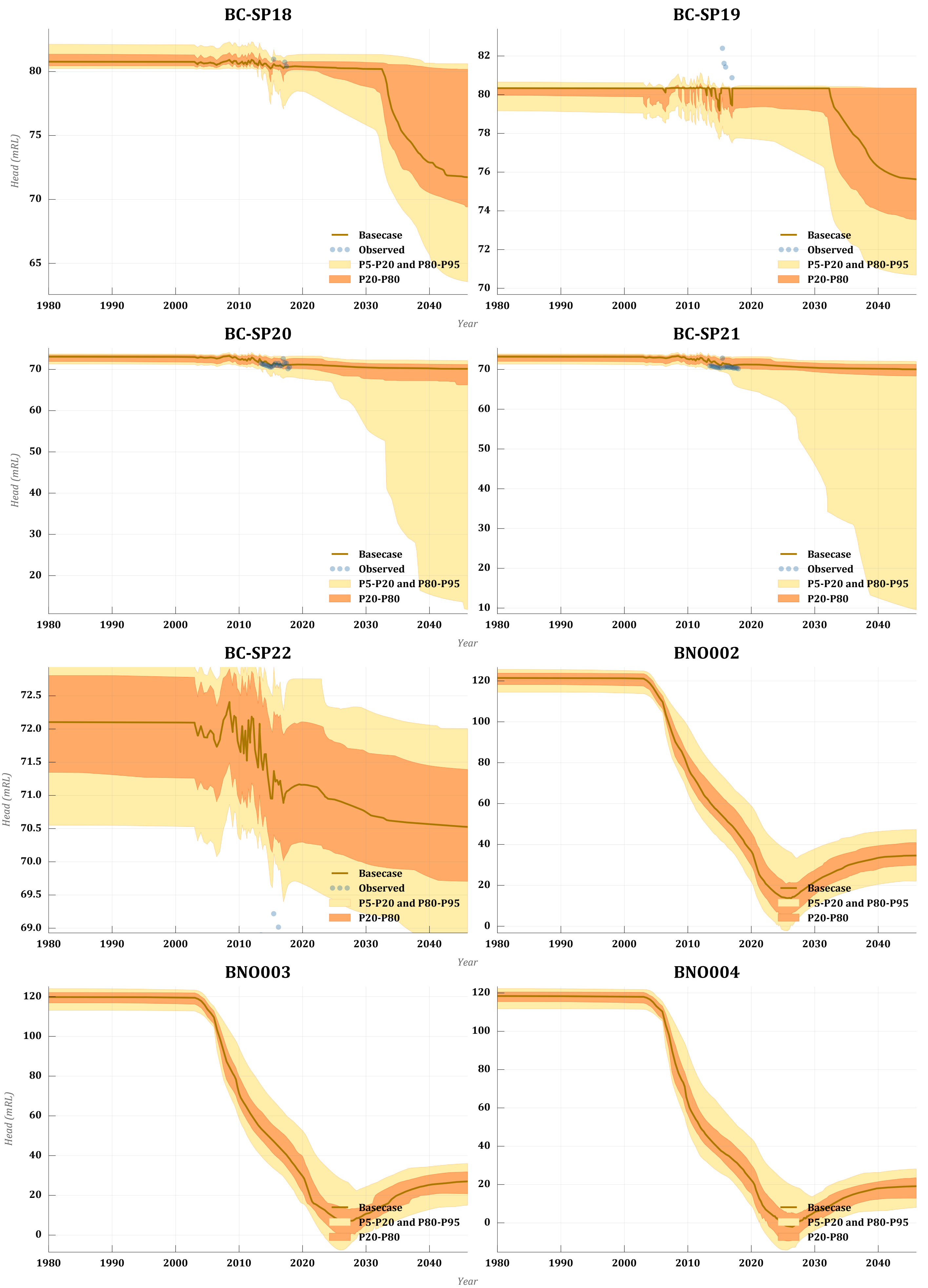
BC-SP08

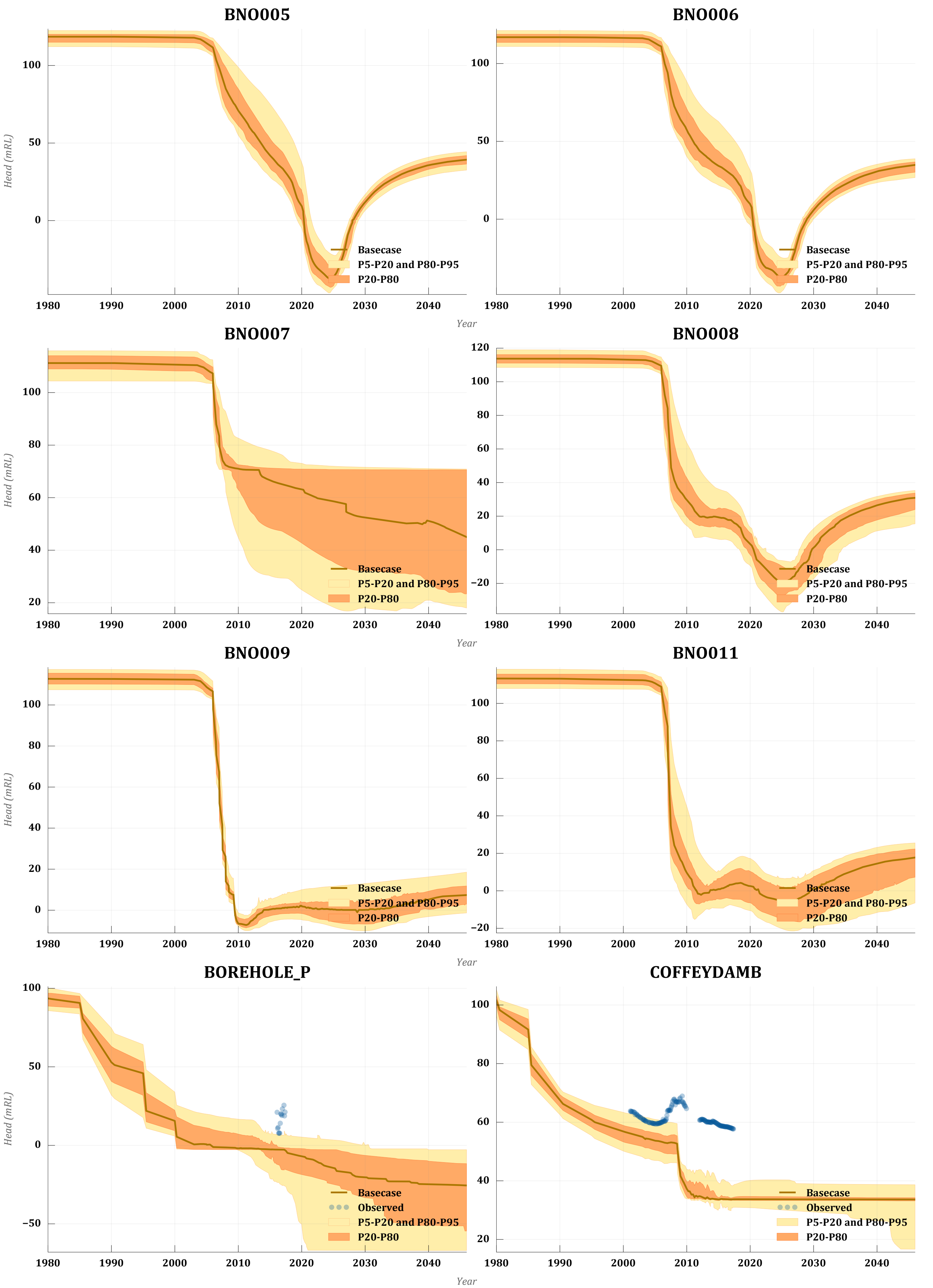


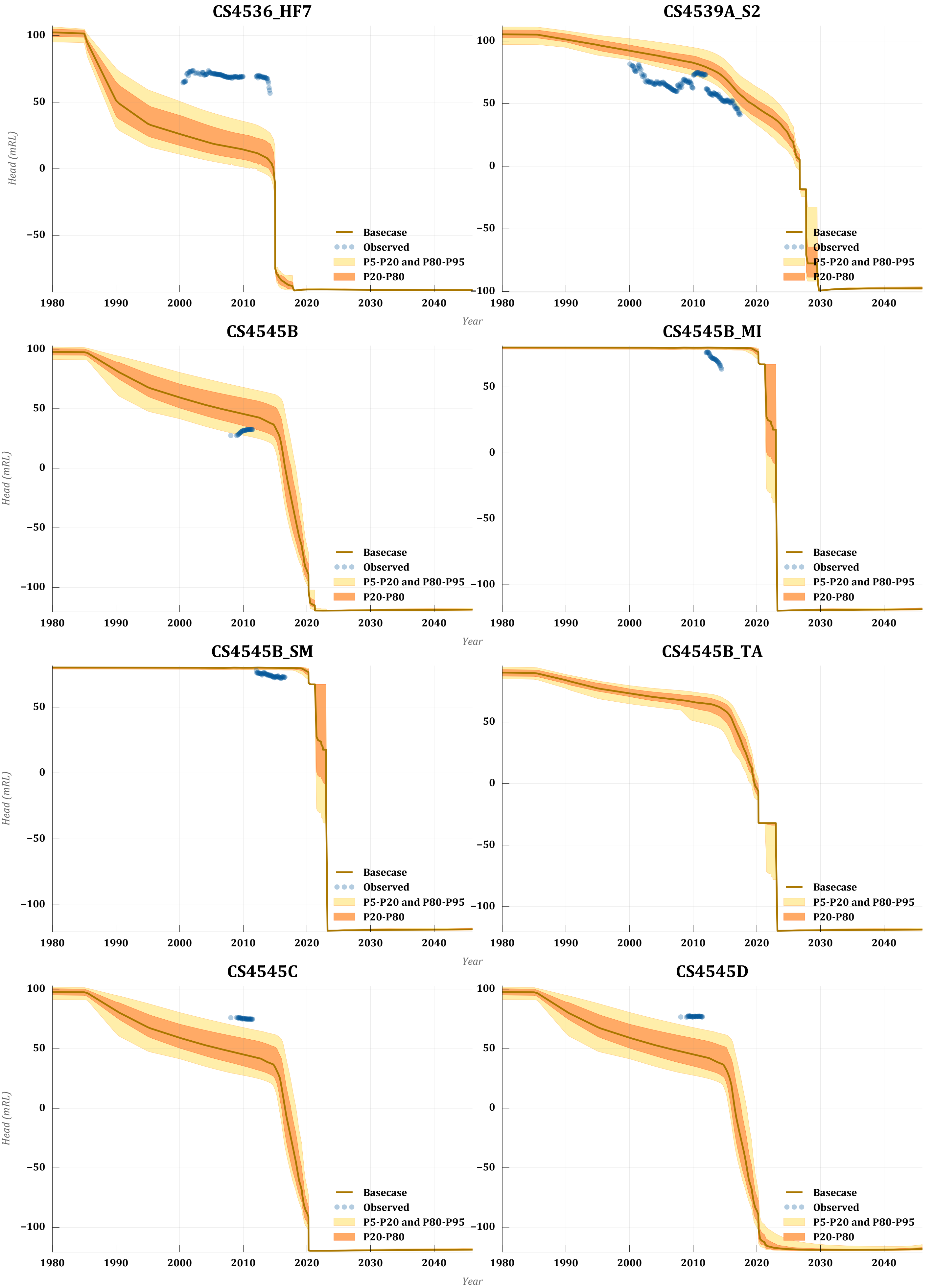
BC-SP09

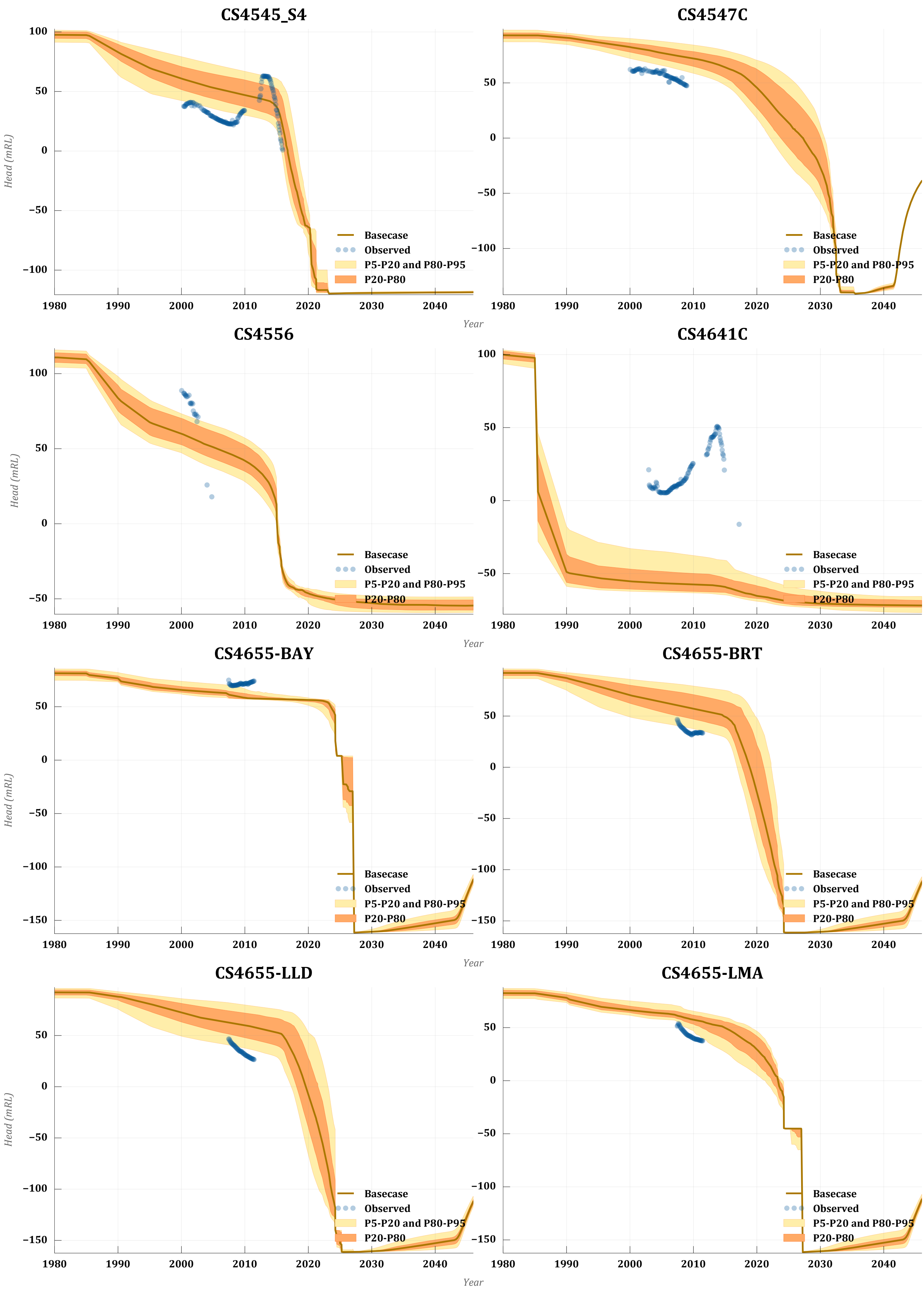



BC-SP10
BC-SP11
BC-SP12
BC-SP13
BC-SP14
BC-SP15
BC-SP16
BC-SP17
Head (mRL)
Year
1980
1990
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80

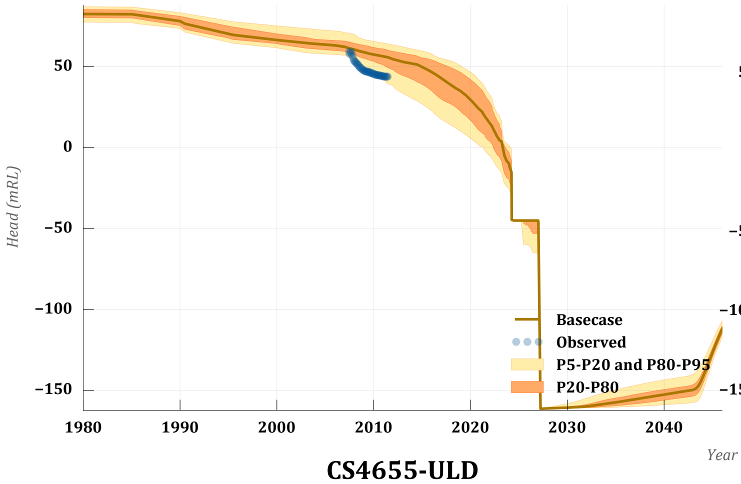

BC-SP18
BC-SP19
BC-SP20
BC-SP21
BC-SP22
BNO002
BNO003
BNO004
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80


BNO005
BNO006
BNO007
BNO008
BNO009
BNO011
BOREHOLE_P
COFFEYDAMB
Head (mRL)
Year
1980
1990
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80

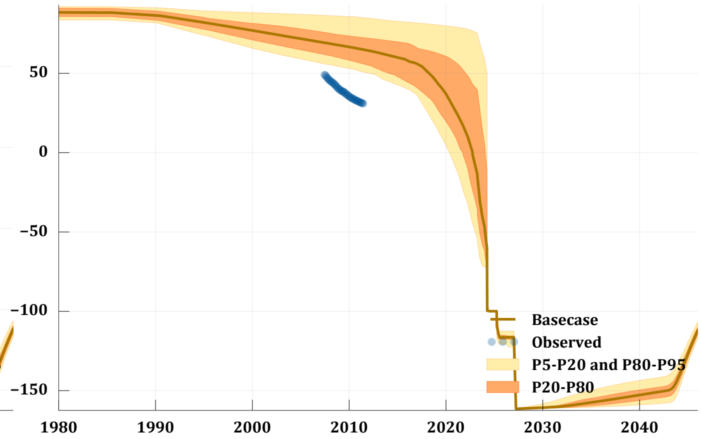

CS4536_HF7
CS4539A_S2
CS4545B
CS4545B_MI
CS4545B_SM
CS4545B_TA
CS4545C
CS4545D
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80


CS4545_S4
CS4547C
CS4556
CS4641C
CS4655-BAY
CS4655-BRT
CS4655-LLD
CS4655-LMA
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
1980
1990
2000
2010
2020
2030
2040
100
50
0
−50
−100
−150

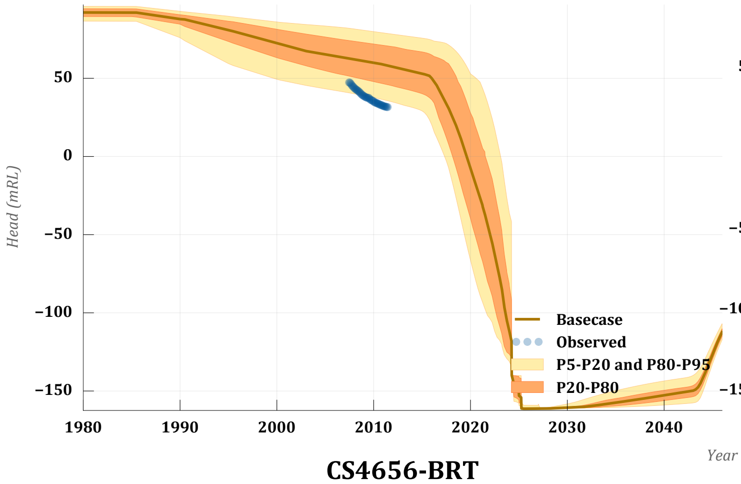
CS4655-LMH



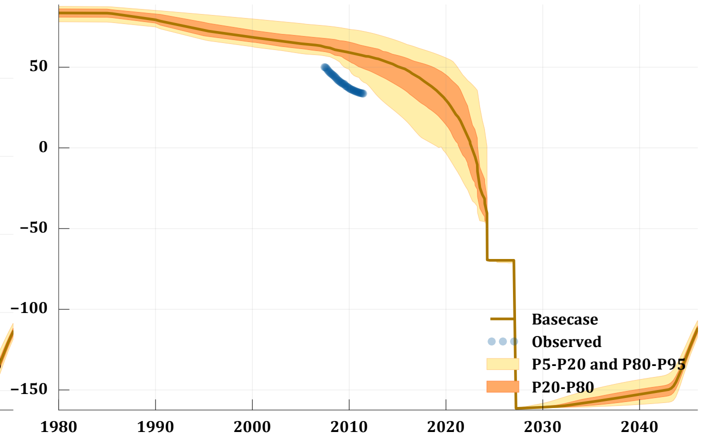
CS4655-UAR



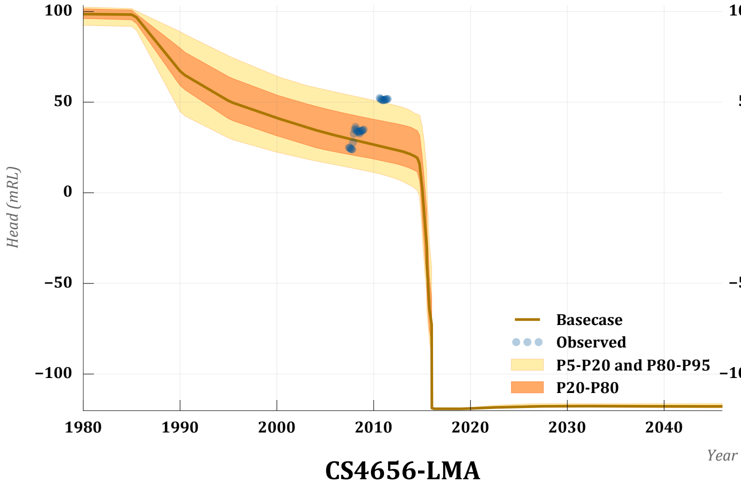
CS4655-ULD



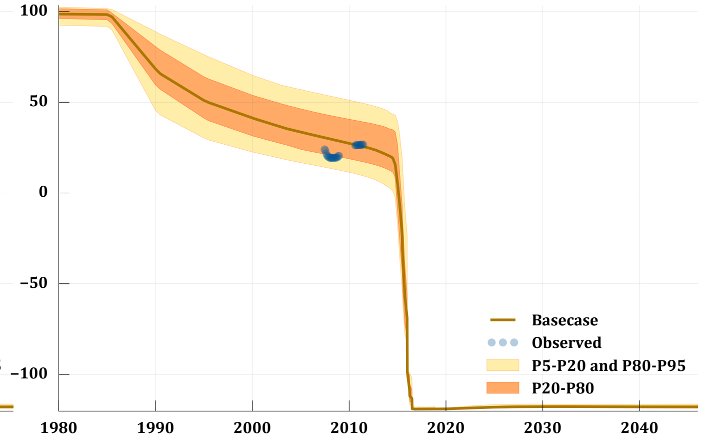
CS4655-UPG



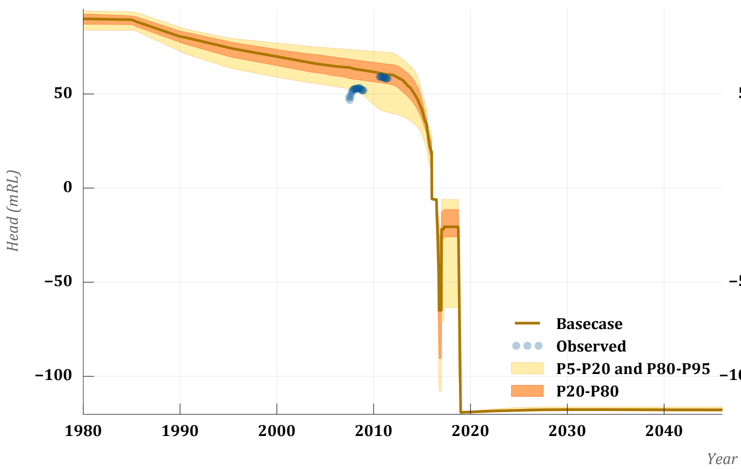
CS4656-BRT



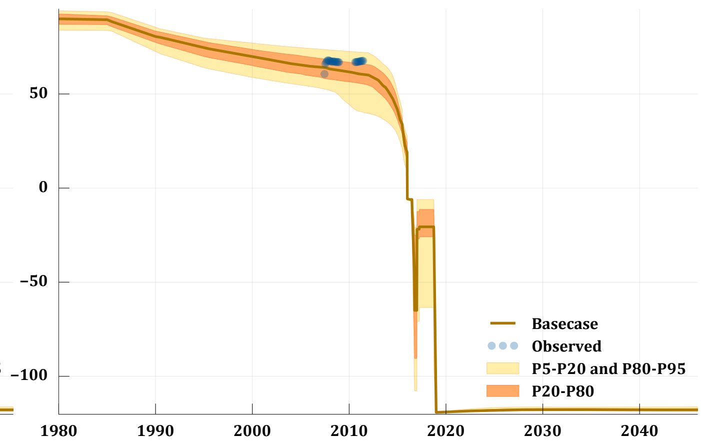
CS4656-LLD

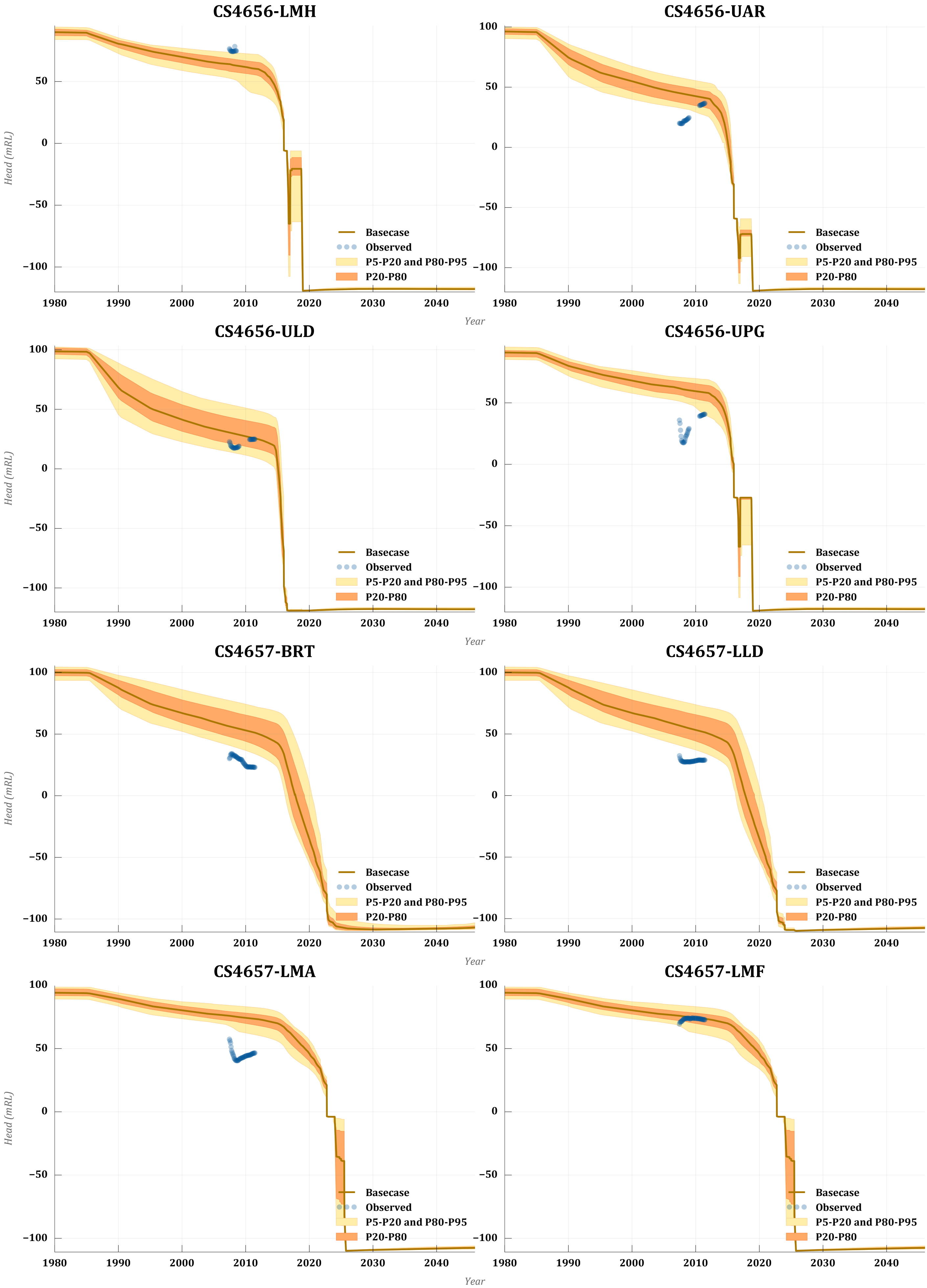


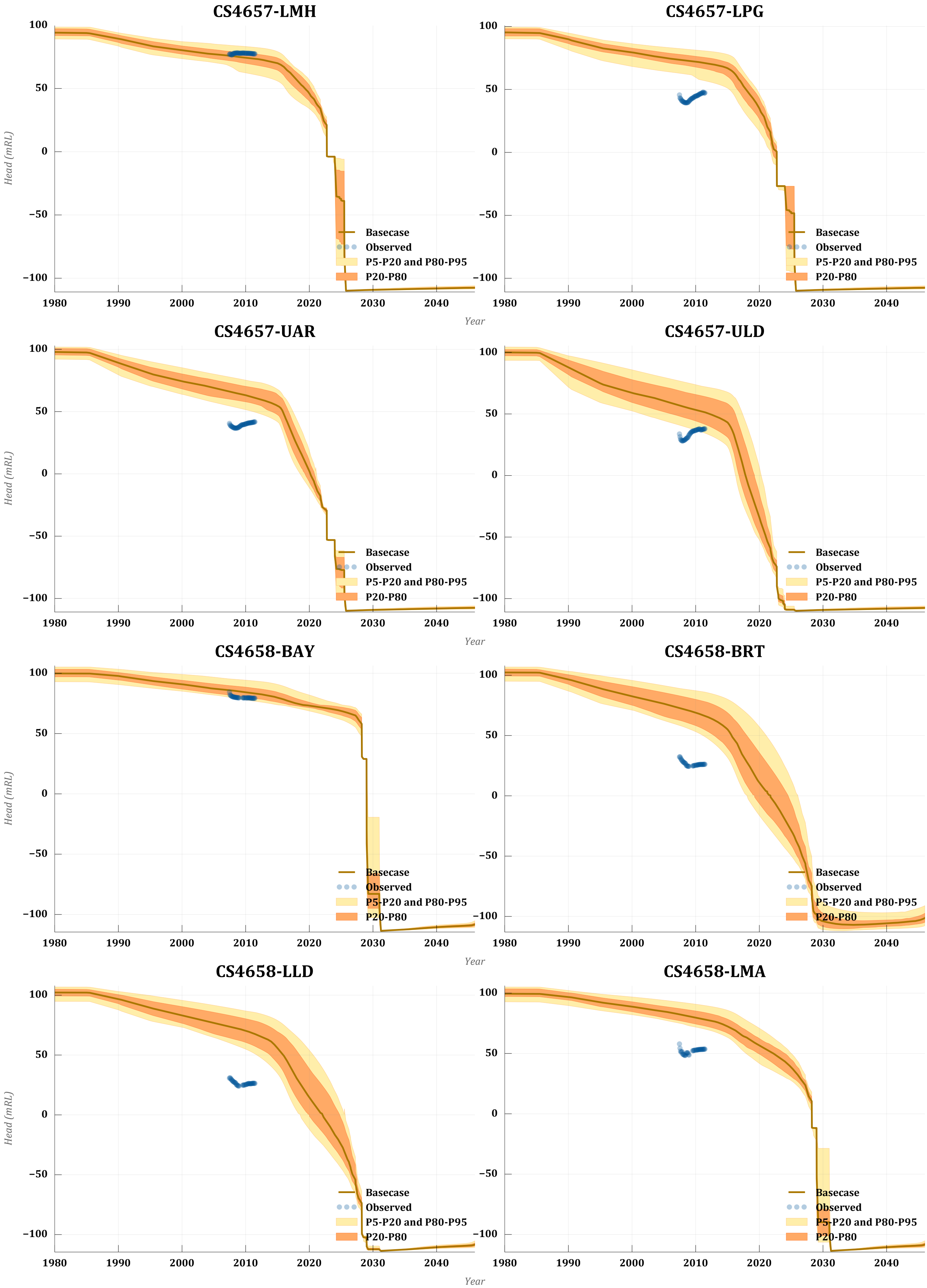
CS4656-LMA

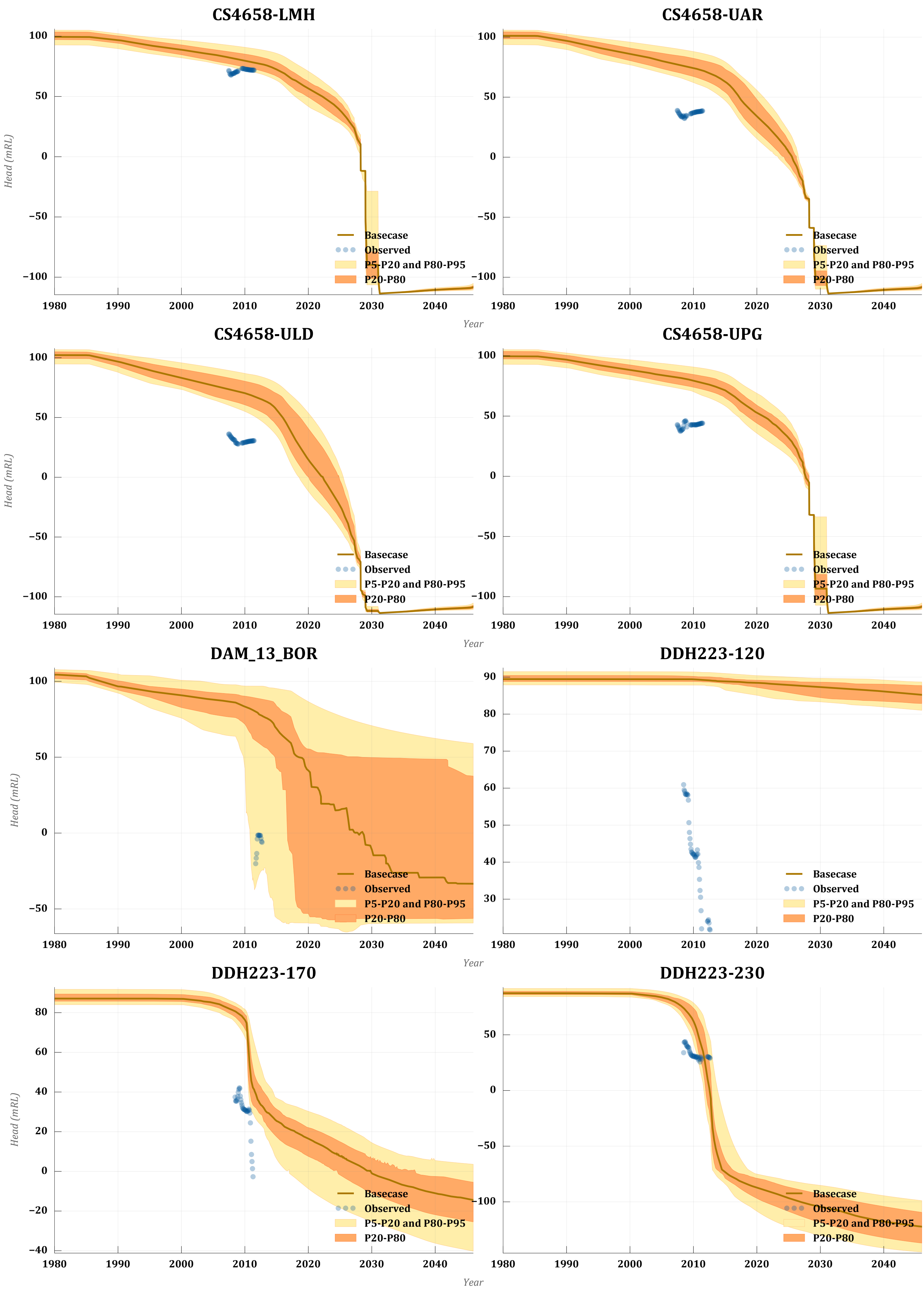


CS4656-LMF

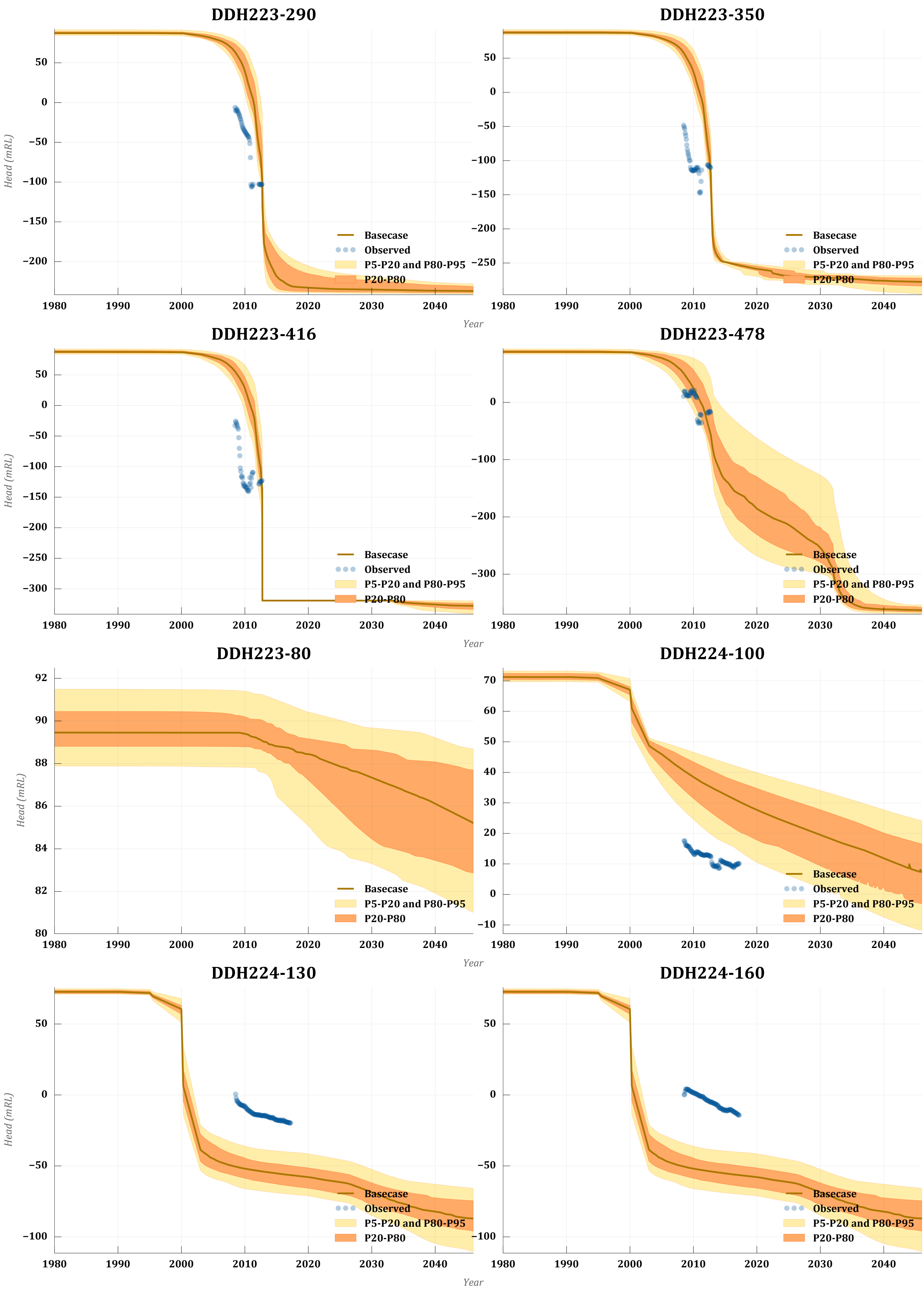


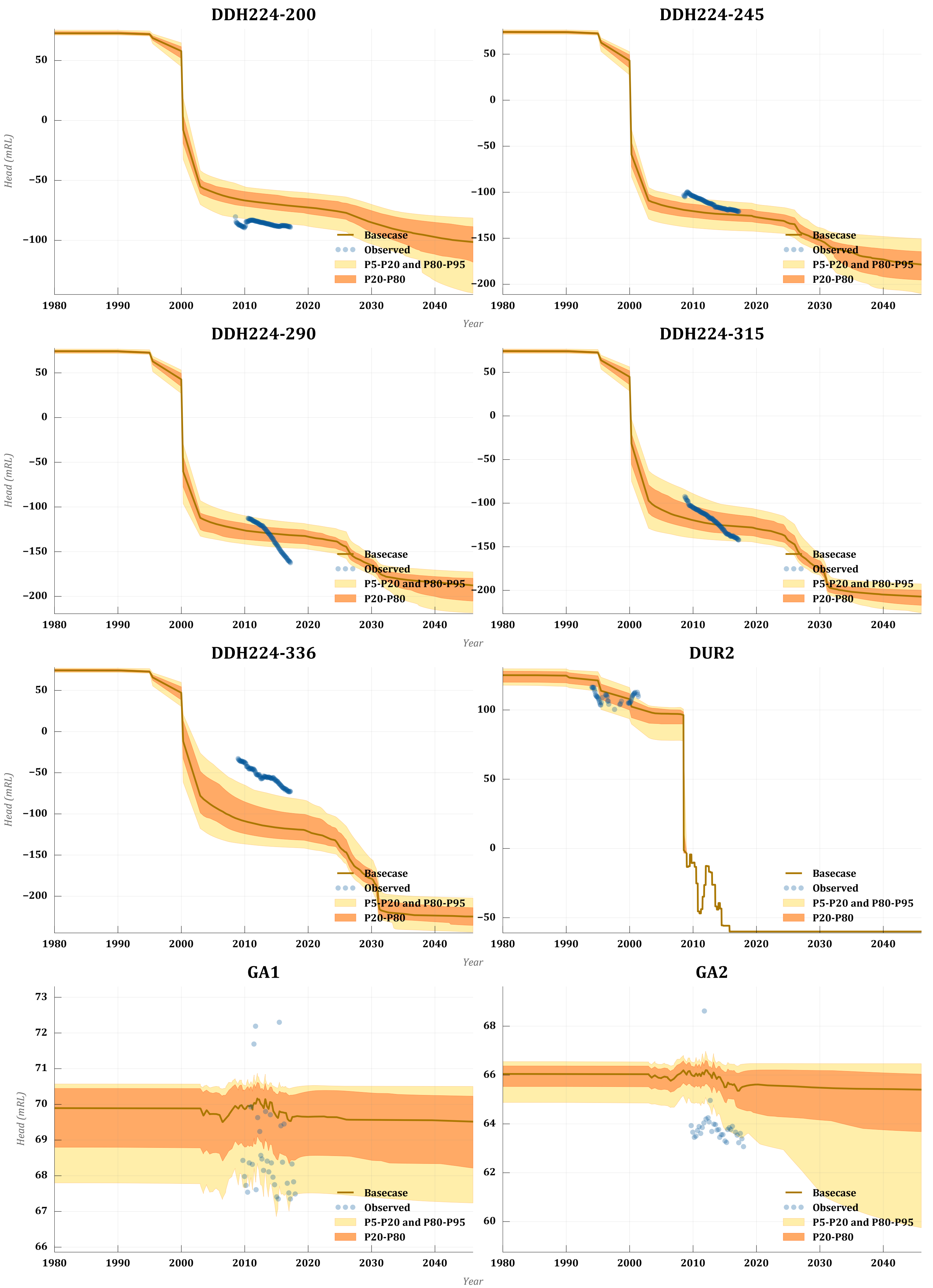

CS4656-LMH
CS4656-UAR
CS4656-ULD
CS4656-UPG
CS4657-BRT
CS4657-LLD
CS4657-LMA
CS4657-LMF
Head (mRL)
Year
100
50
0
−50
−100
1980
1990
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80

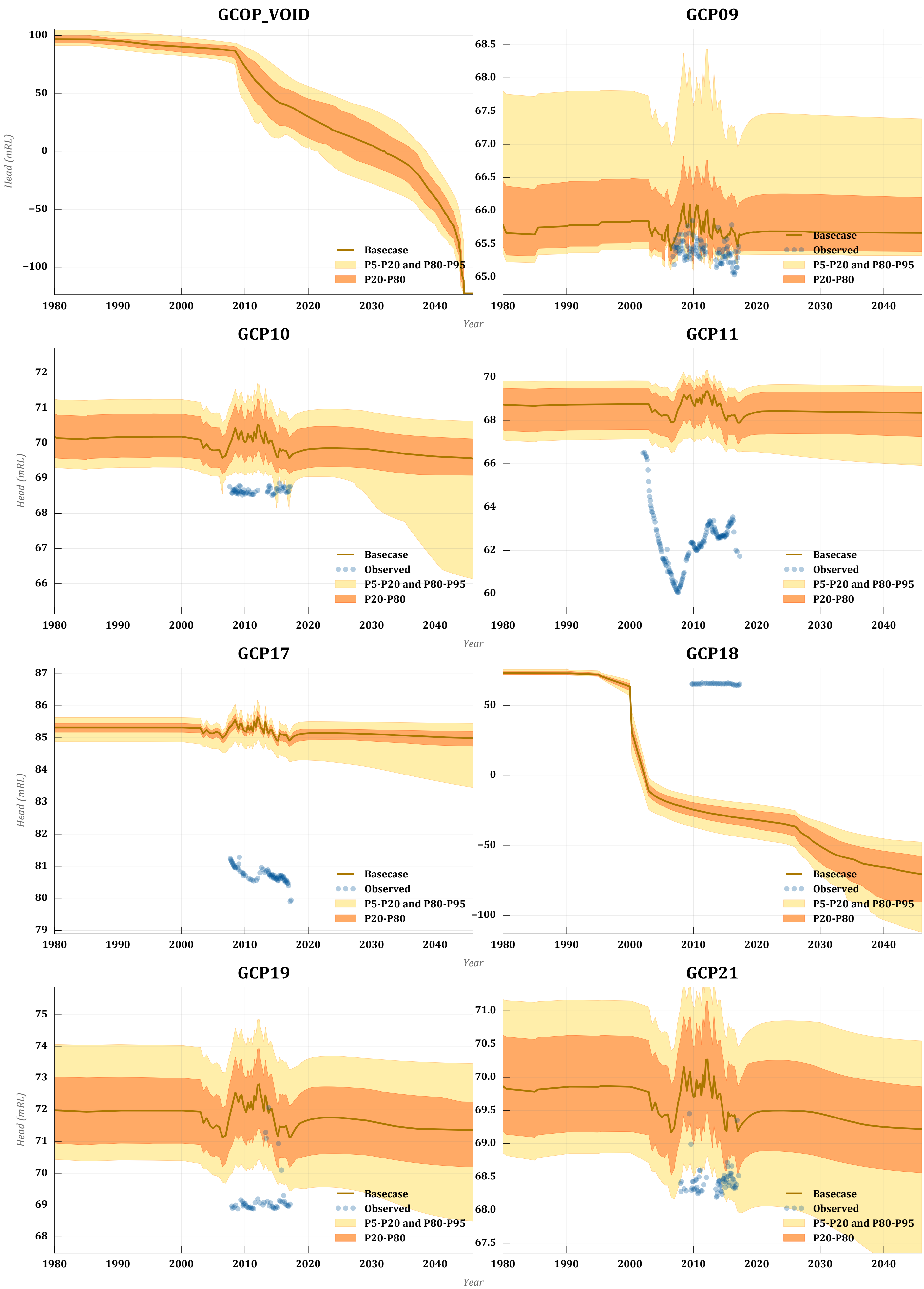

CS4657-LMH
CS4657-LPG
CS4657-UAR
CS4657-ULD
CS4658-BAY
CS4658-BRT
CS4658-LLD
CS4658-LMA
Head (mRL)
Year
100
50
0
−50
−100
1980
1990
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80



CS4658-LMH
CS4658-UAR
CS4658-ULD
CS4658-UPG
DAM_13_BOR
DDH223-120
DDH223-170
DDH223-230
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
1980
1990
2000
2010
2020
2030
2040


DDH223-290
DDH223-350
DDH223-416
DDH223-478
DDH223-80
DDH224-100
DDH224-130
DDH224-160
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80


DDH224-200
DDH224-245
DDH224-290
DDH224-315
DDH224-336
DUR2
GA1
GA2
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80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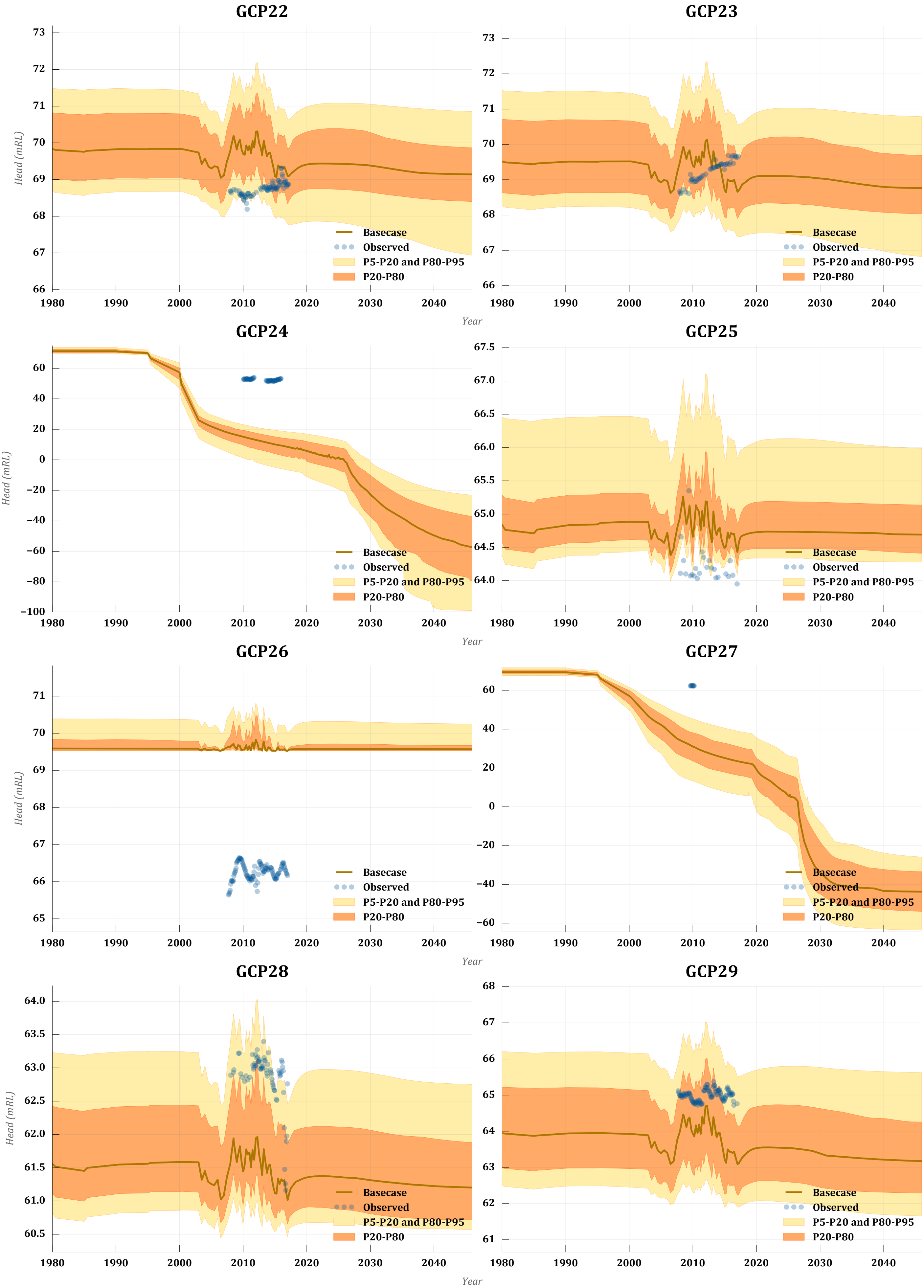
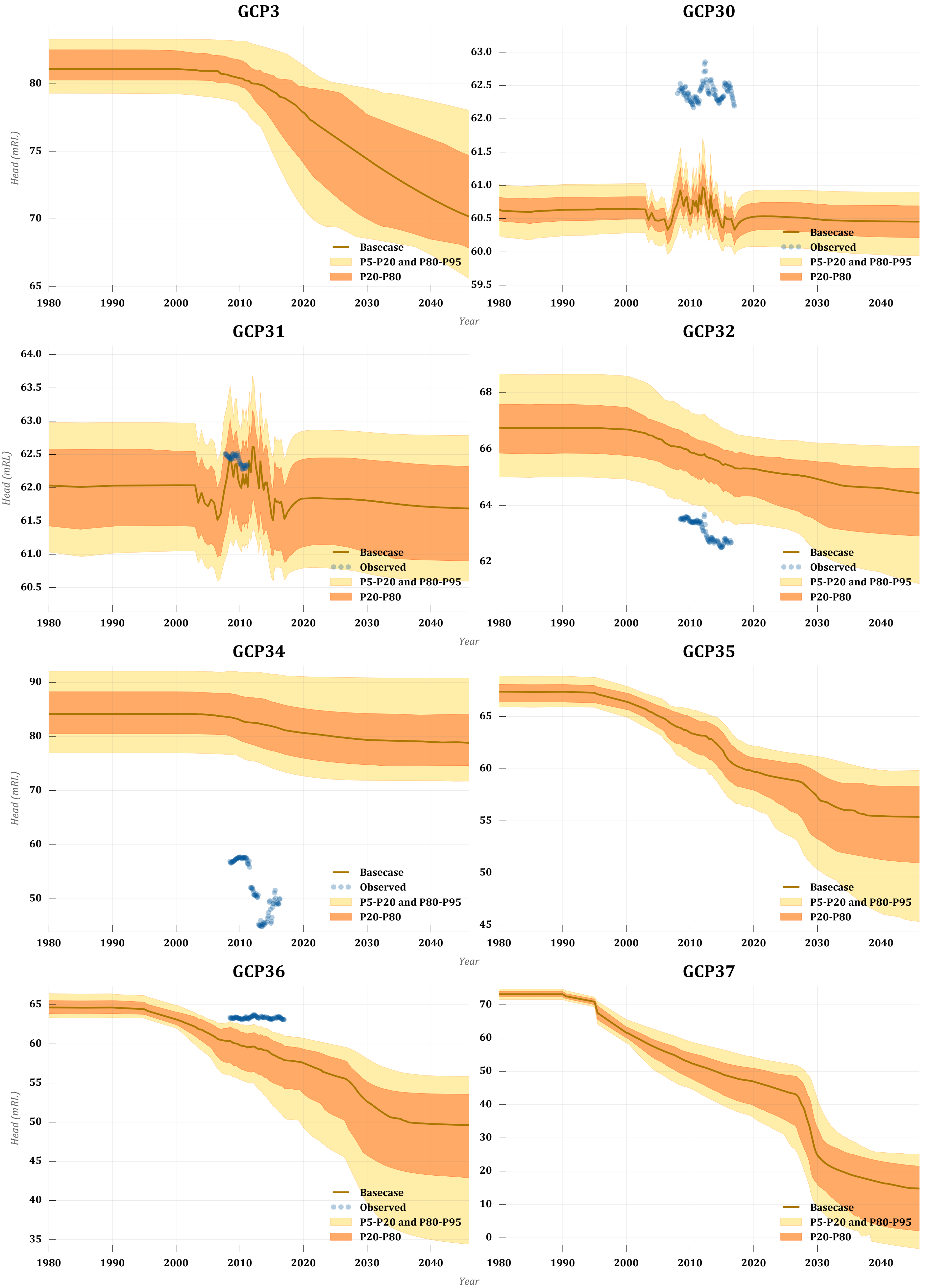
GCP09
GCP10
GCP11
GCP17
GCP18
GCP19
GCP21
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
1980
1990
2000
2010
2020
2030
2040


GCP22
GCP23
GCP24
GCP25
GCP26
GCP27
GCP28
GCP29
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80


GCP3
GCP30
GCP31
GCP32
GCP34
GCP35
GCP36
GCP37
Head (mRL)
Year
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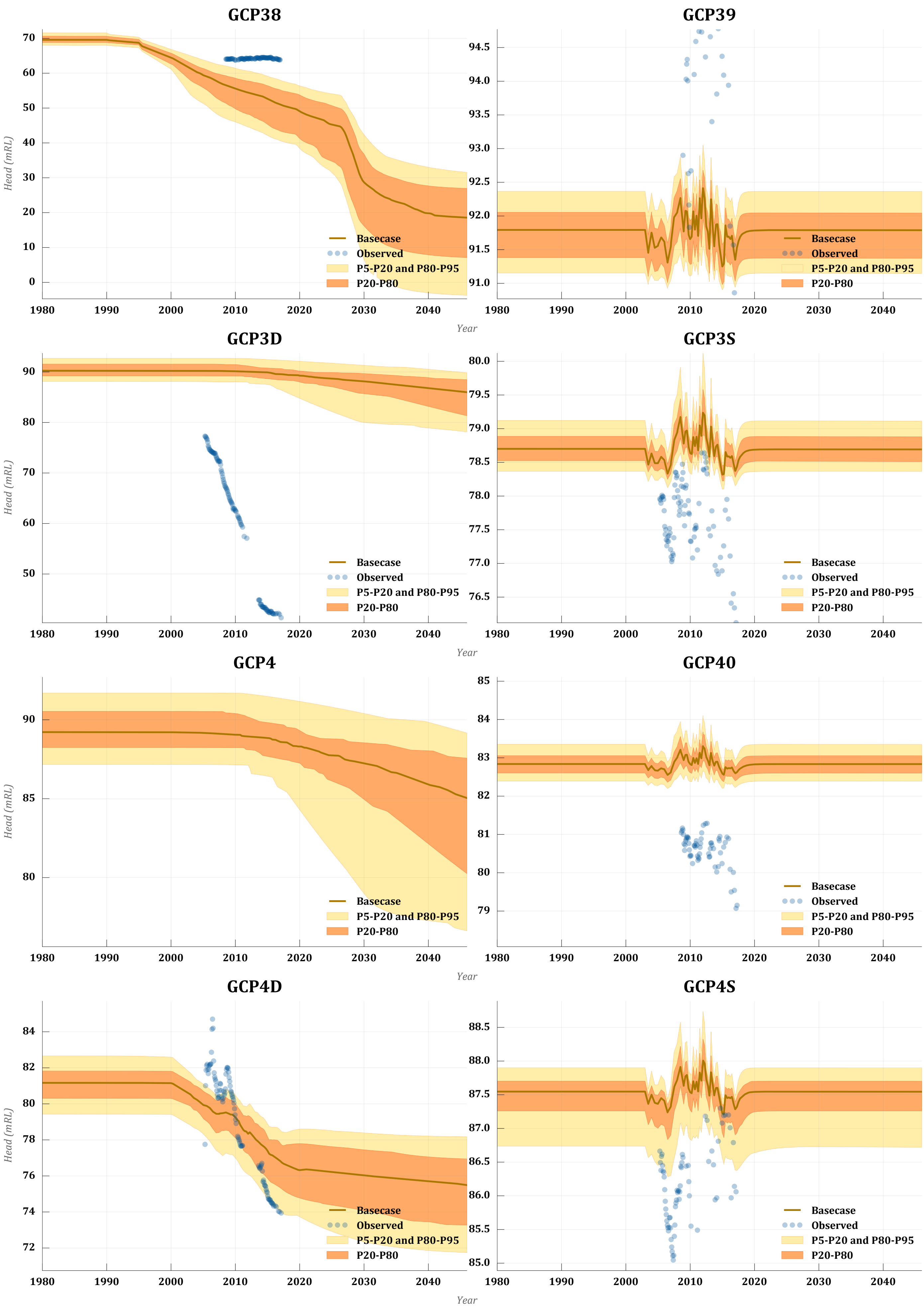
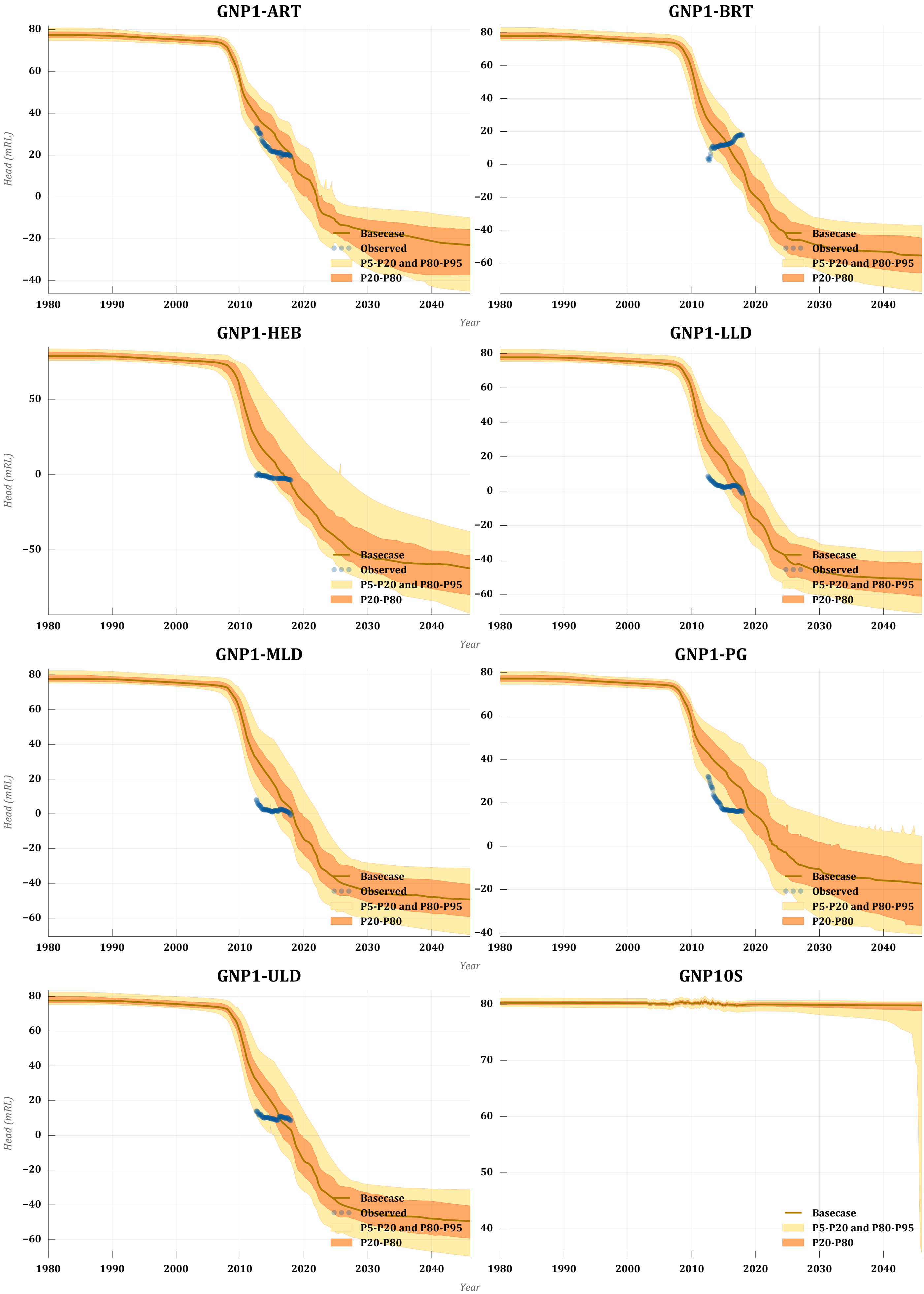
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80


GCP38
GCP39
GCP3D
GCP3S
GCP4
GCP40
GCP4D
GCP4S
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80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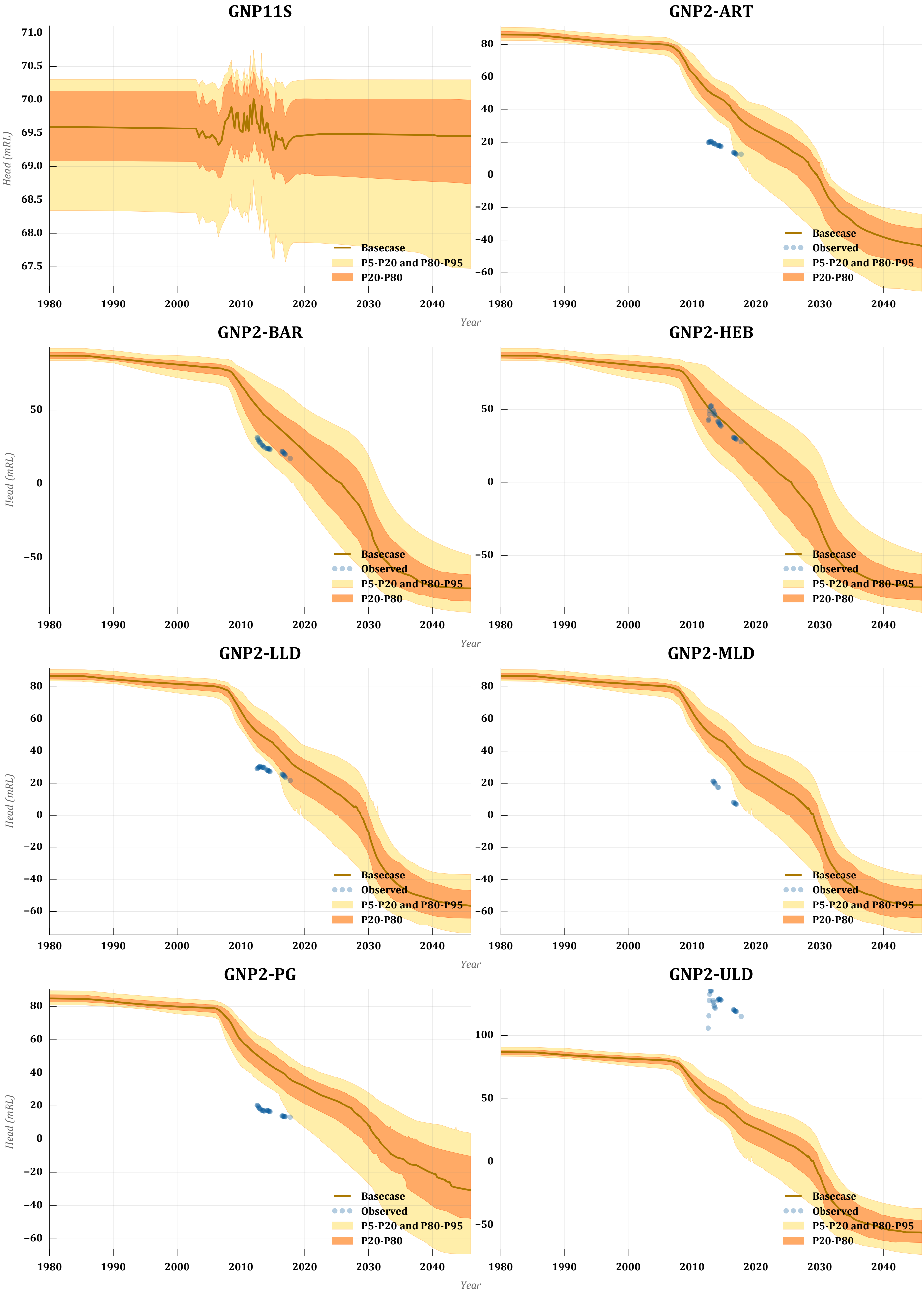
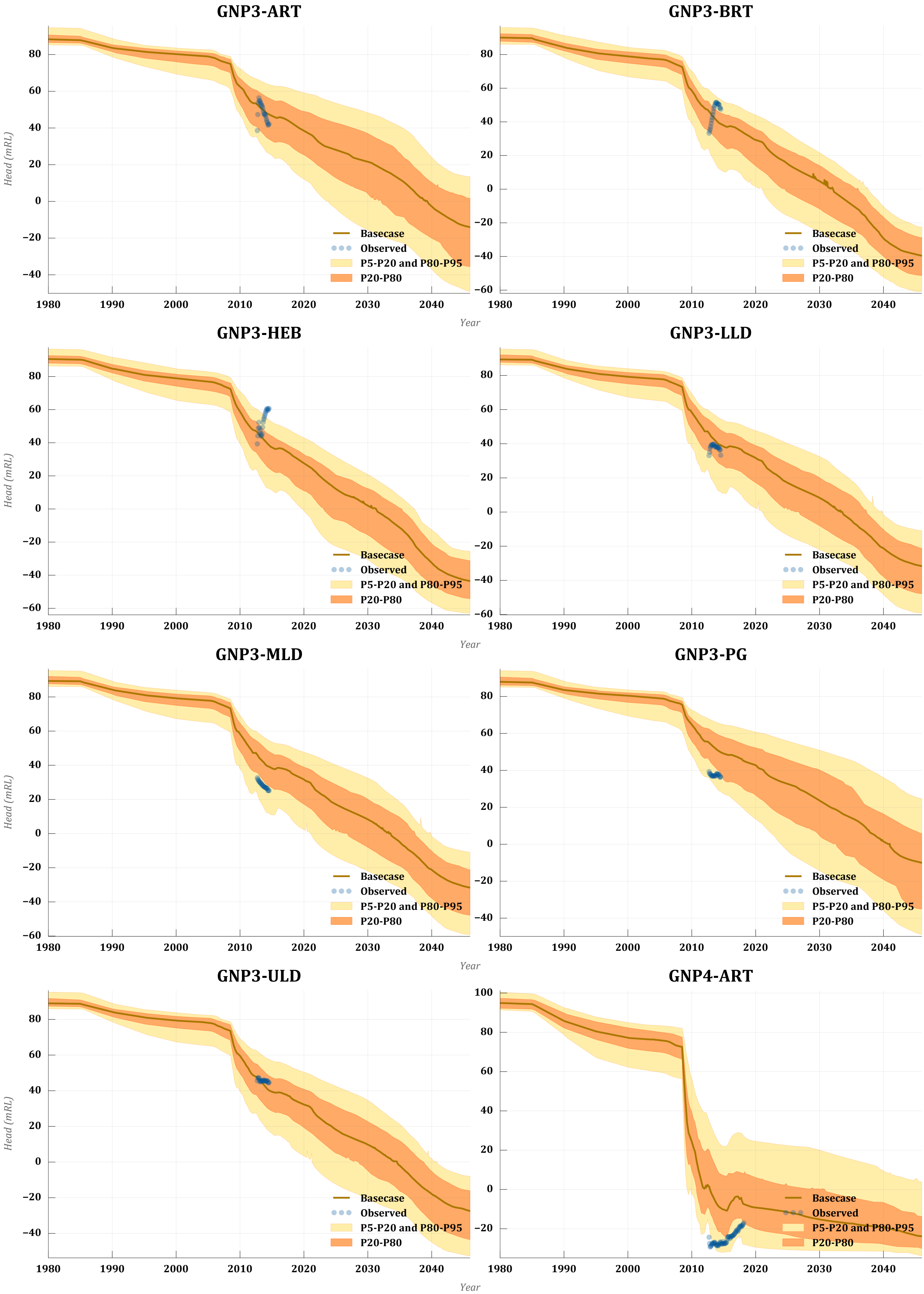
GNP1-BRT
GNP1-HEB
GNP1-LLD
GNP1-MLD
GNP1-PG
GNP1-ULD
GNP10S
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80


GNP11S
GNP2-ART
GNP2-BAR
GNP2-HEB
GNP2-LLD
GNP2-MLD
GNP2-PG
GNP2-ULD
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80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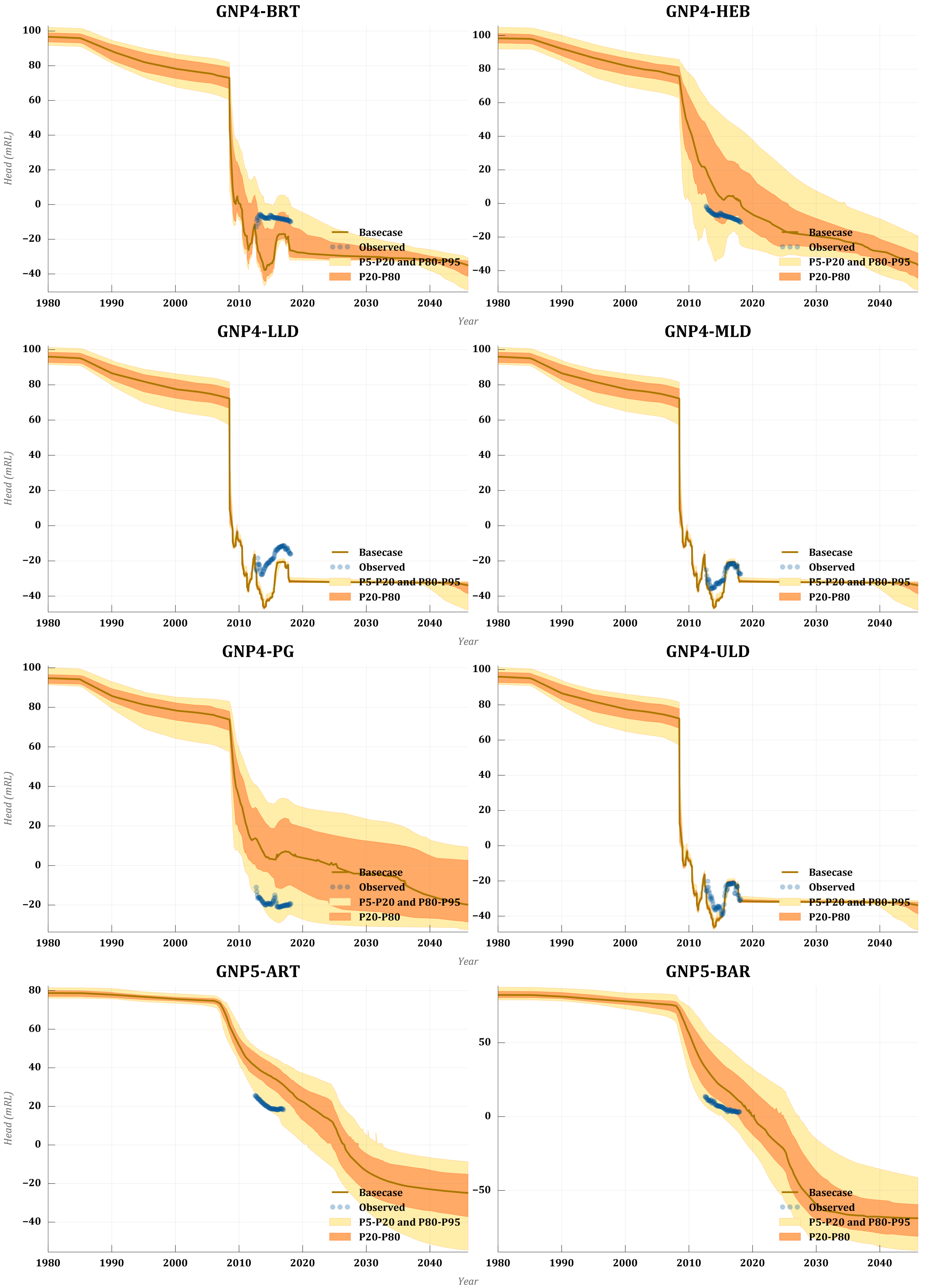
GNP3-BRT
GNP3-HEB
GNP3-LLD
GNP3-MLD
GNP3-PG
GNP3-ULD
GNP4-ART
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
1980
1990
2000
2010
2020
2030
2040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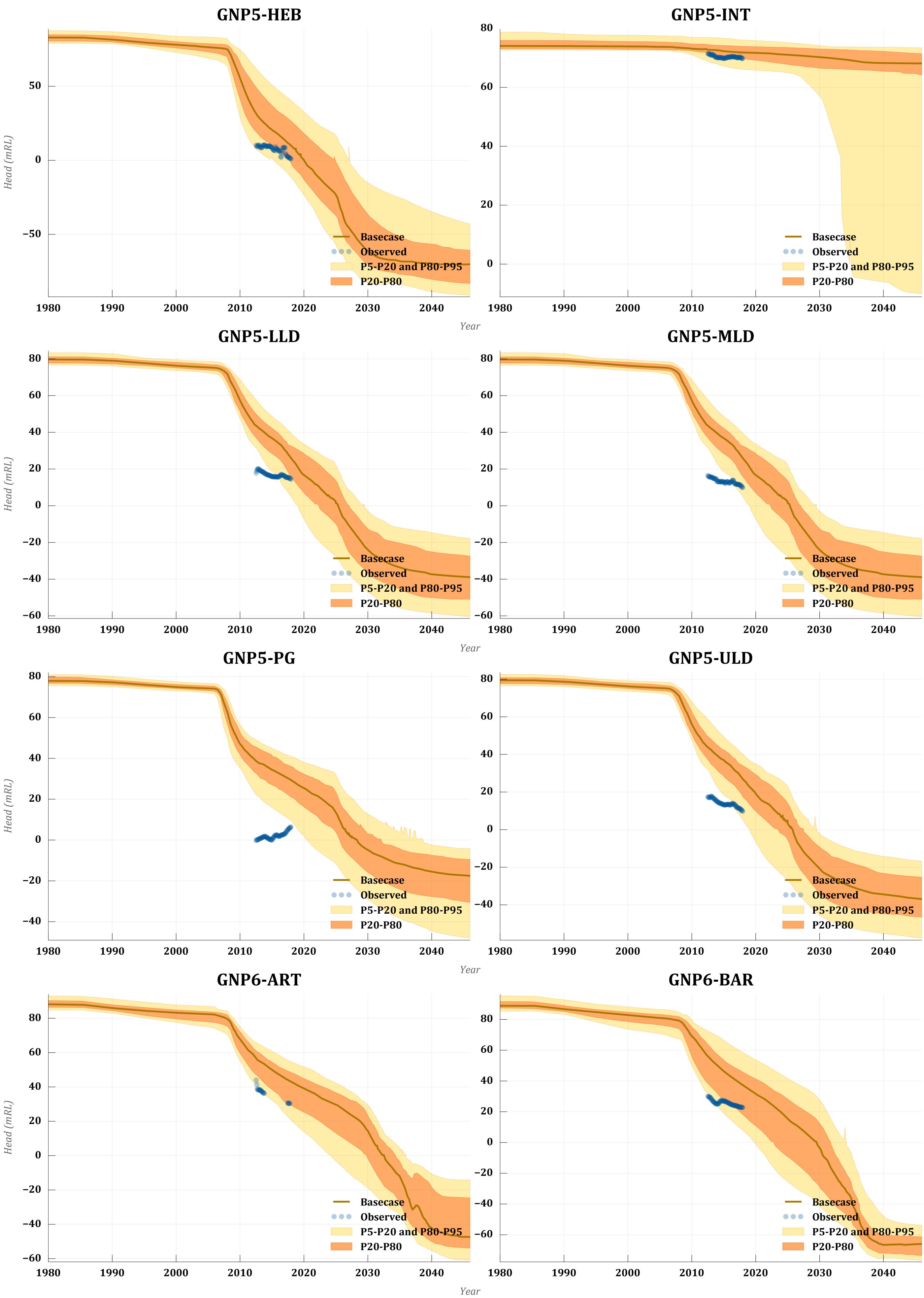
GNP4-LLD
GNP4-MLD
GNP4-PG
GNP4-ULD
GNP5-ART
GNP5-BAR
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
1980
1990
2000
2010
2020
2030
2040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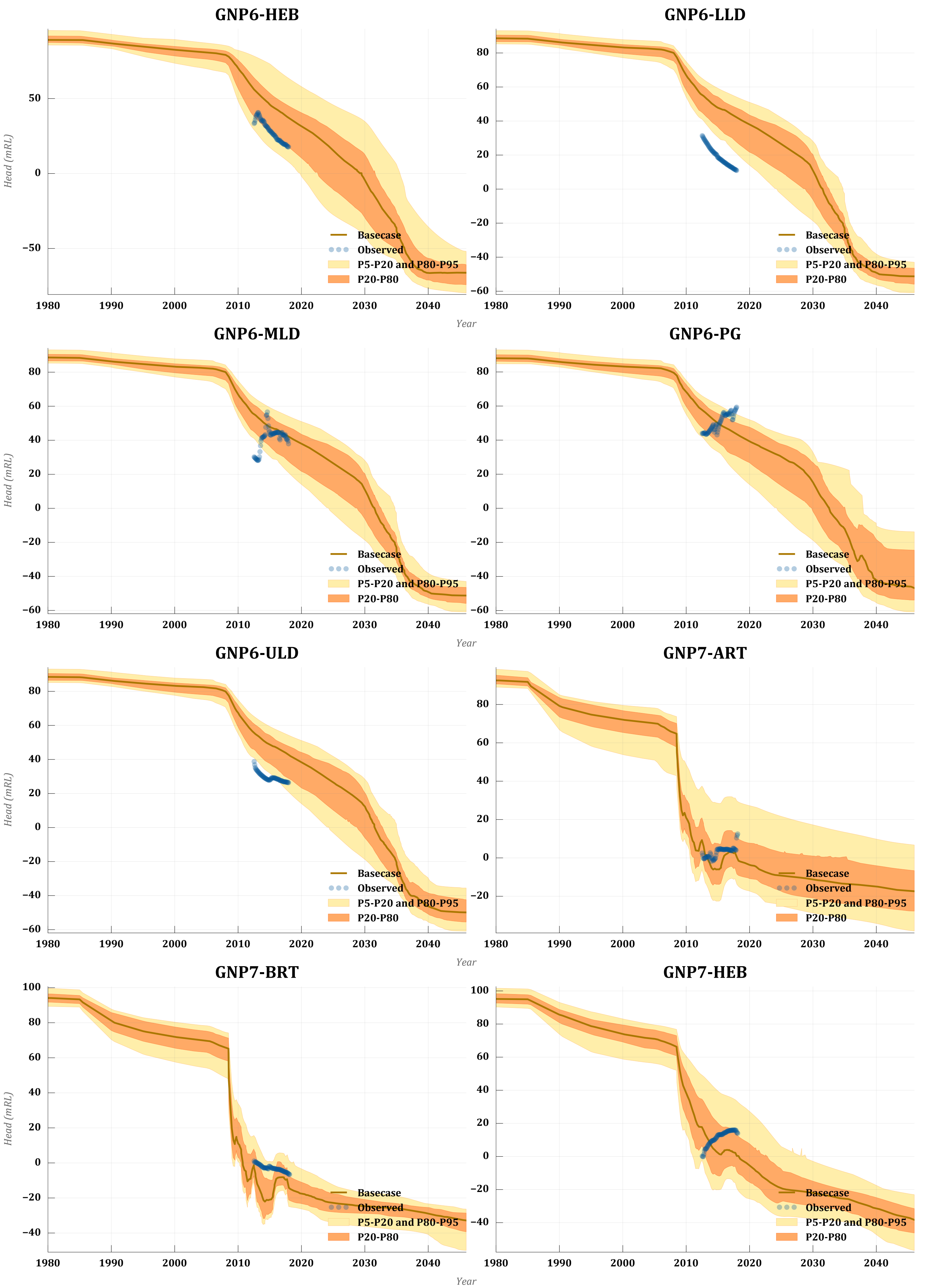
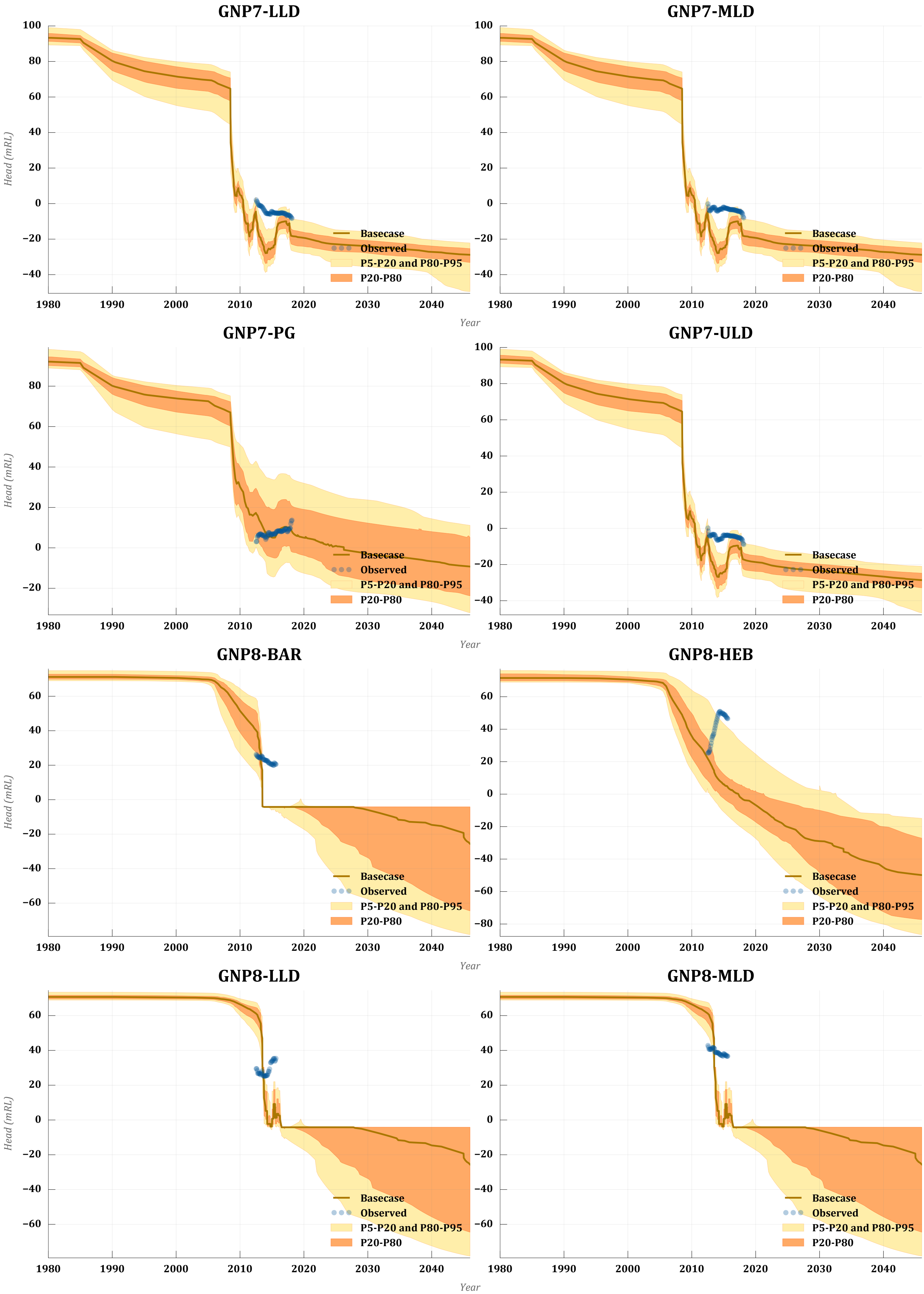
GNP5-INT
GNP5-LLD
GNP5-MLD
GNP5-PG
GNP5-ULD
GNP6-ART
GNP6-BAR
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80


GNP6-HEB
Head (mRL)
50
0
−50
1980
1990
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80
GNP6-LLD
80
60
40
20
0
−20
−40
−60
Year
GNP6-MLD
GNP6-PG
GNP6-ULD
GNP7-ART
GNP7-BRT
100
GNP7-HEB



GNP7-LLD
GNP7-MLD
GNP7-PG
GNP7-ULD
GNP8-BAR
GNP8-HEB
GNP8-LLD
GNP8-MLD
Head (mRL)
Year
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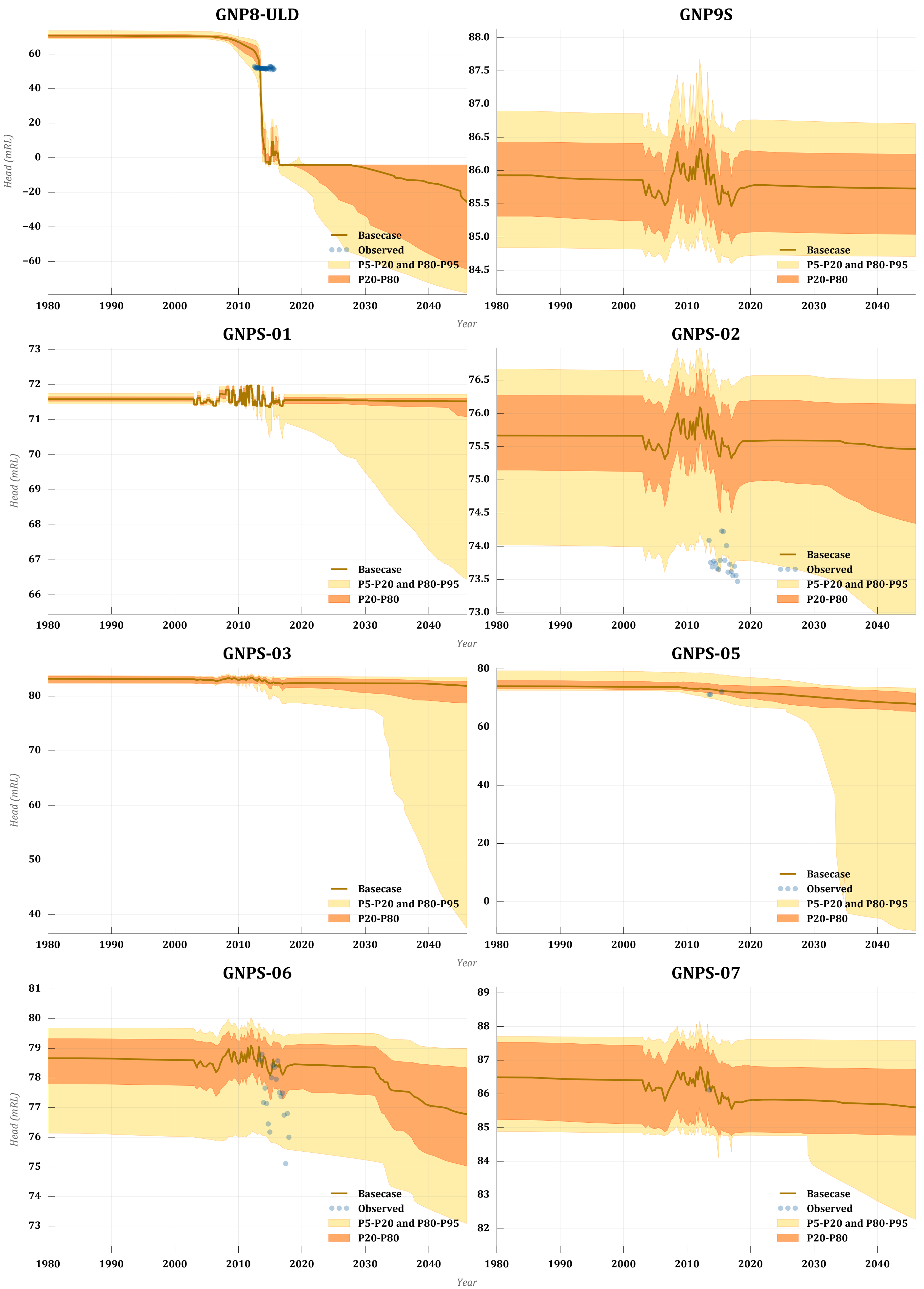
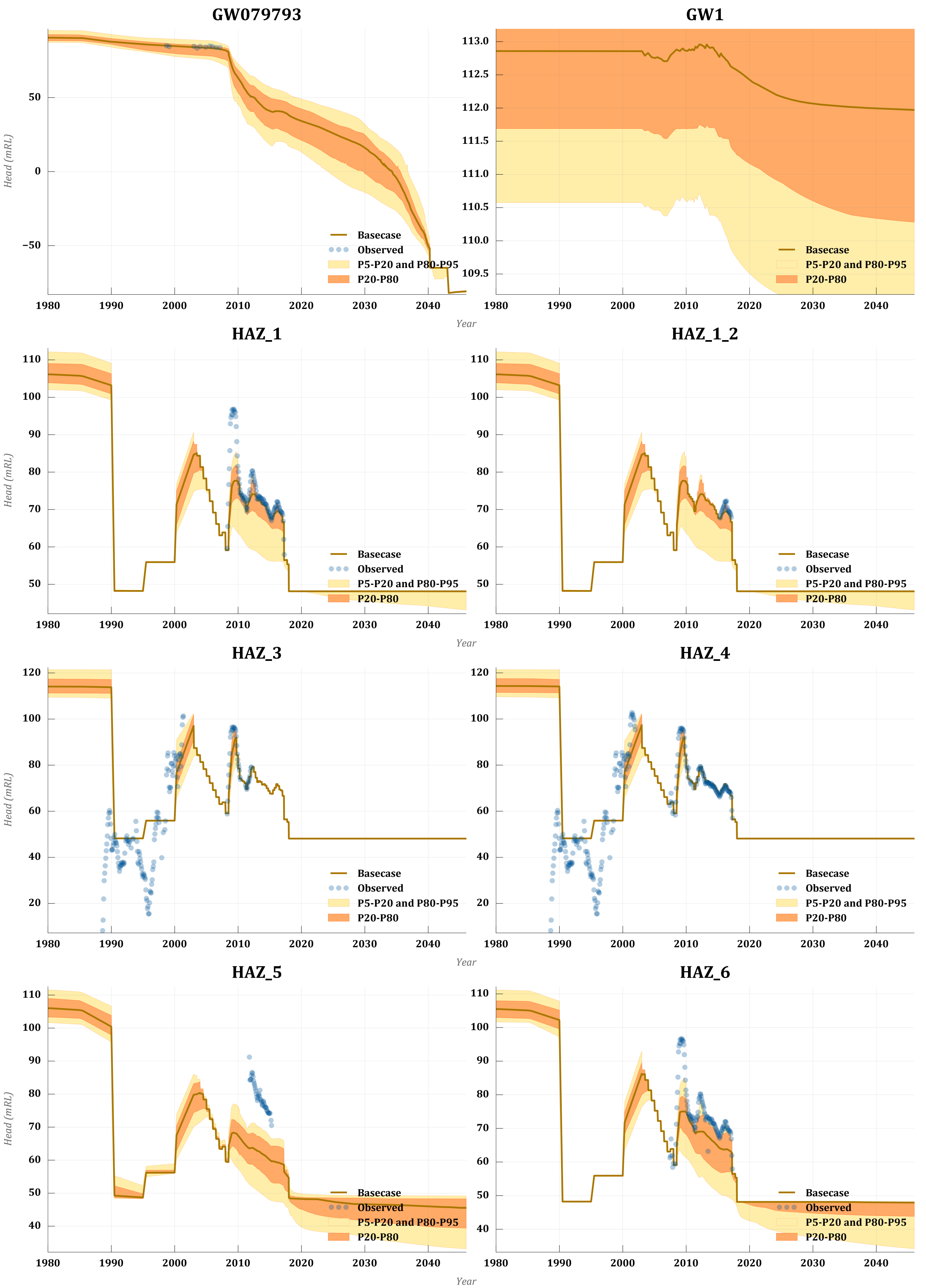
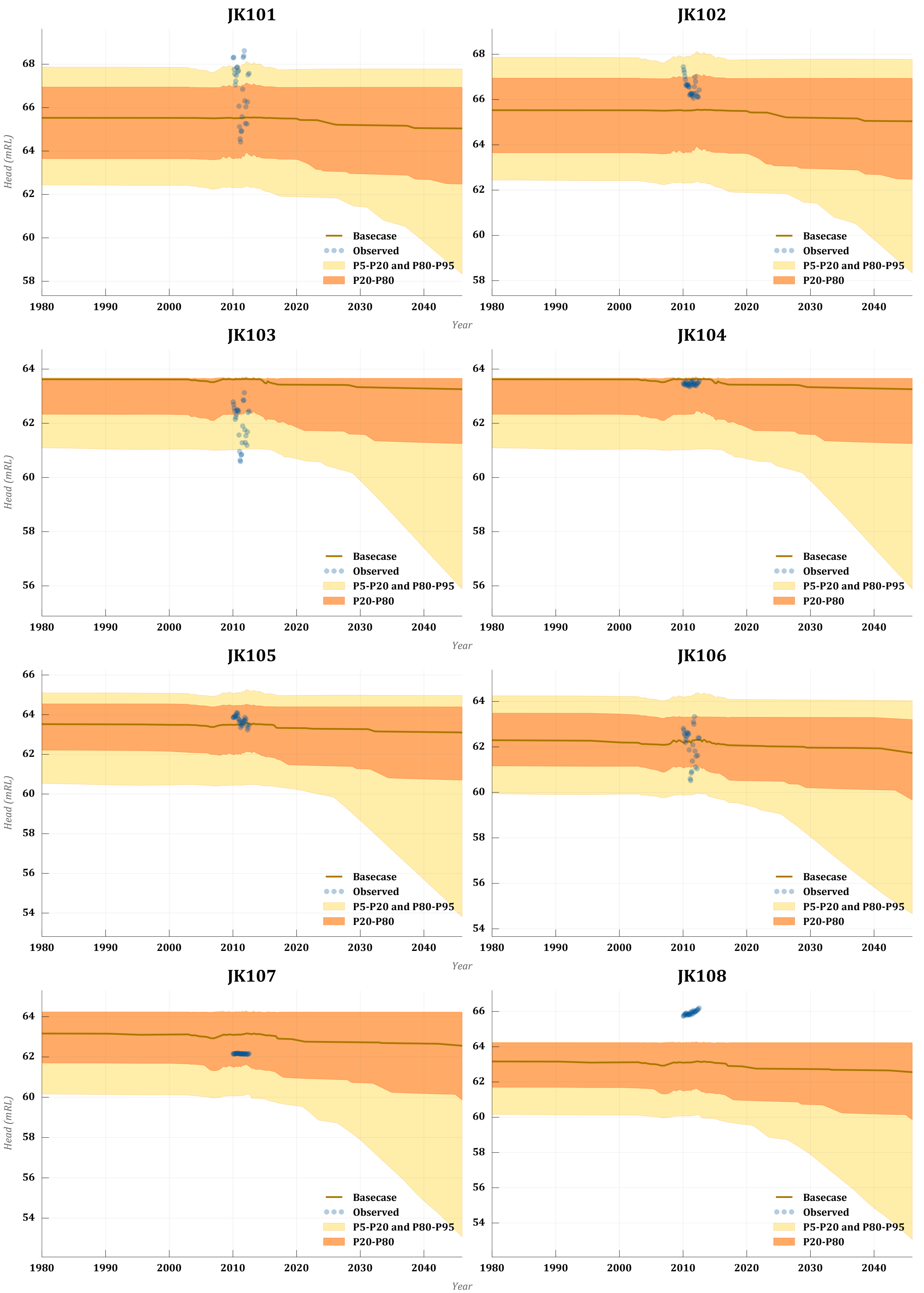
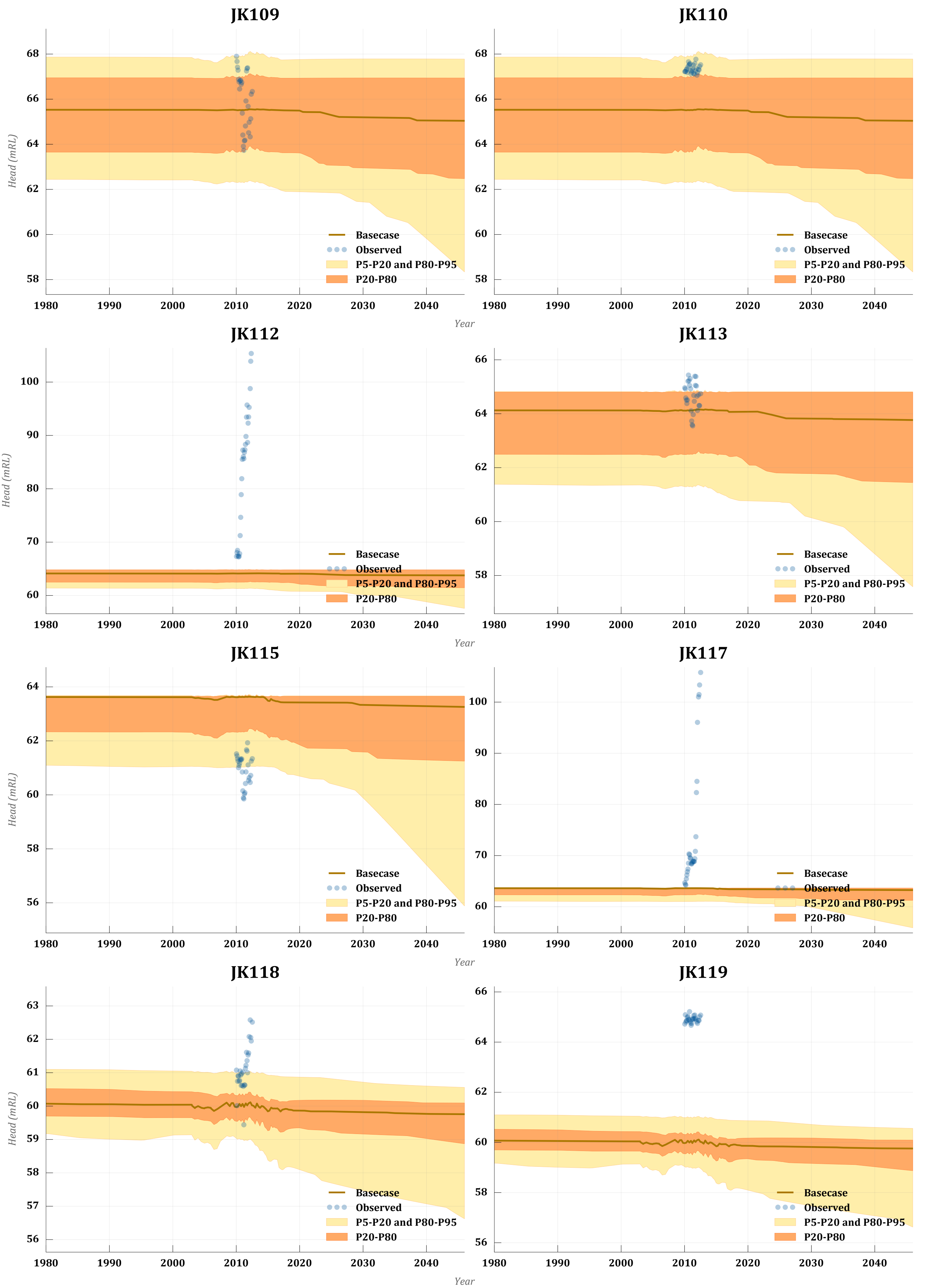
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80


GNP8-ULD
GNP9S
GNPS-01
GNPS-02
GNPS-03
GNPS-05
GNPS-06
GNPS-07
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
1980
1990
2000
2010
2020
2030
2040

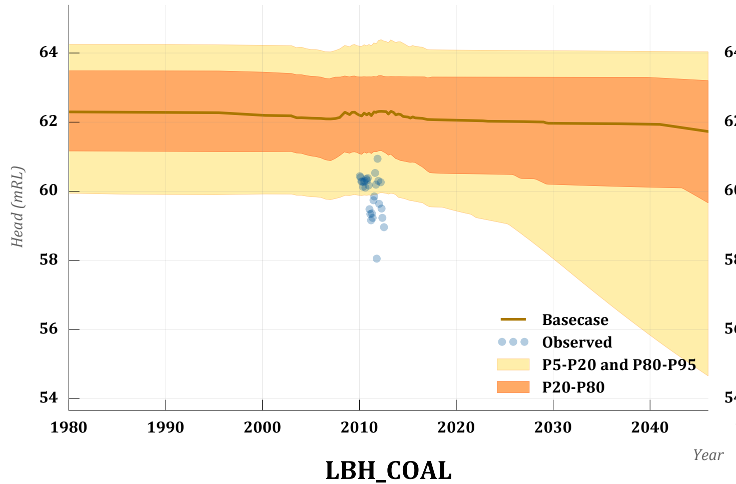

GW079793
GW1
HAZ_1
HAZ_1_2
HAZ_3
HAZ_4
HAZ_5
HAZ_6
Head (mRL)
Year
1980
1990
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80


JK101
JK102
JK103
JK104
JK105
JK106
JK107
JK108
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
1980
1990
2000
2010
2020
2030
2040

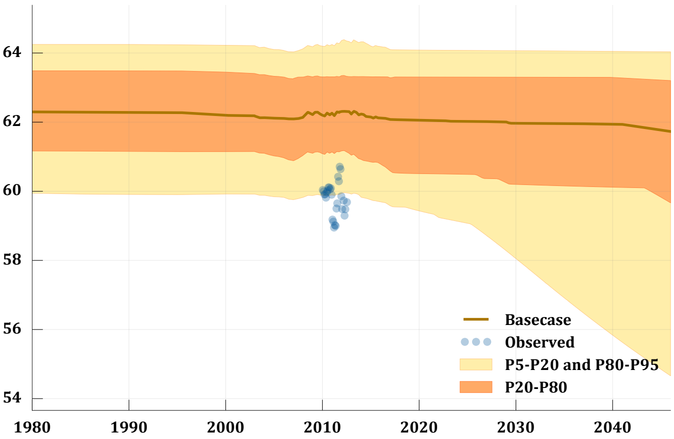


JK109
JK110
JK112
JK113
JK115
JK117
JK118
JK119
Head (mRL)
Year
1980
1990
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80

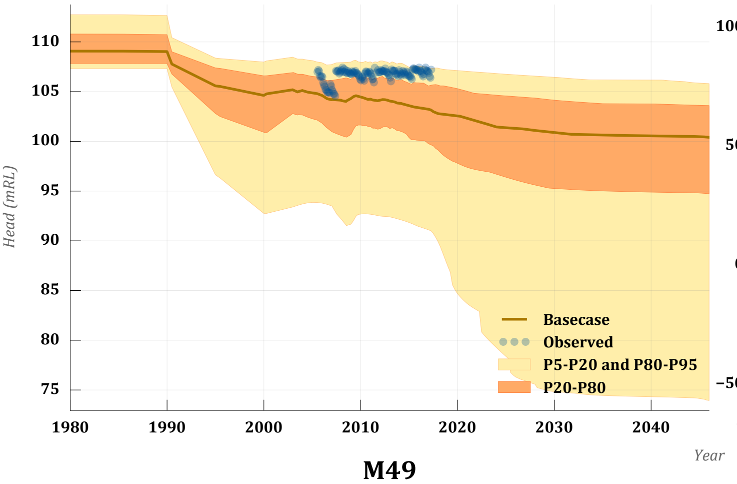
JK121



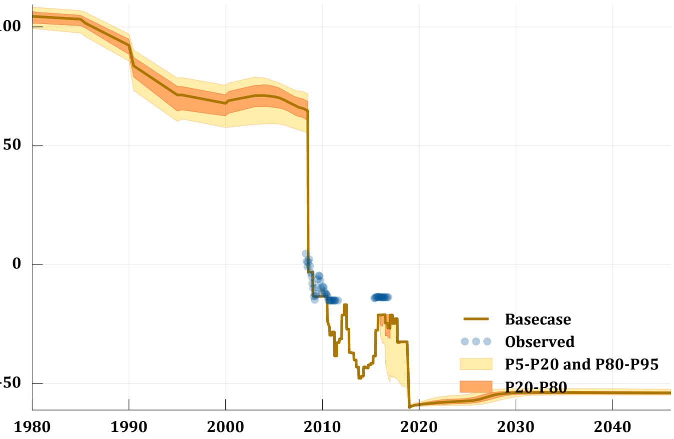
JK123



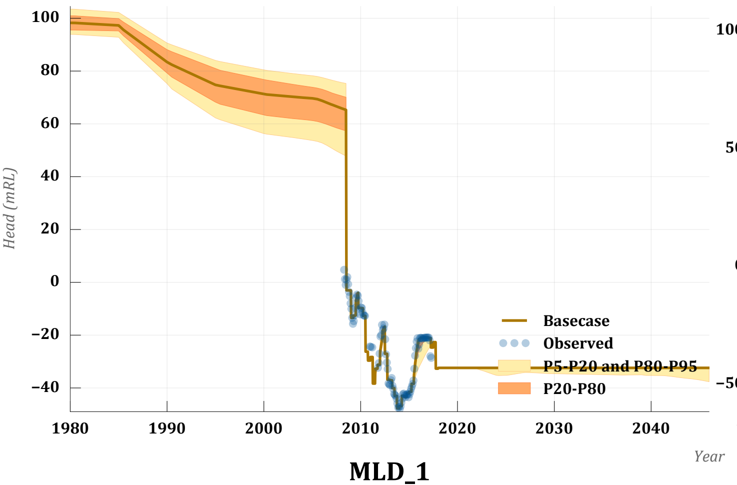
LBH_COAL



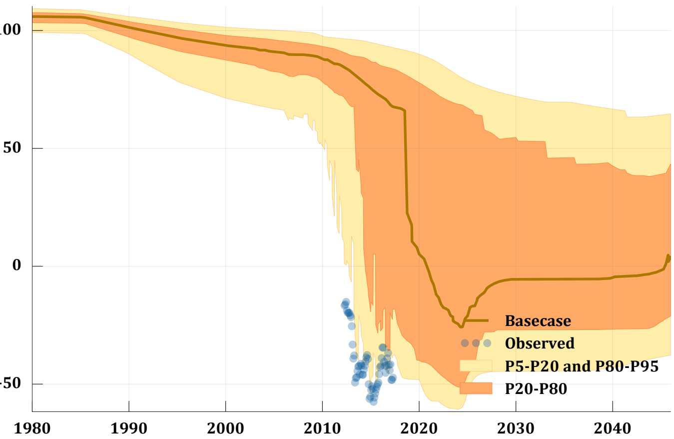
LC1



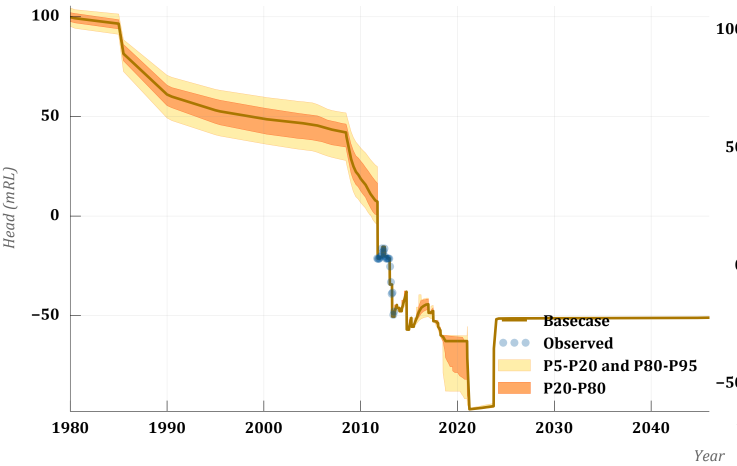
M49



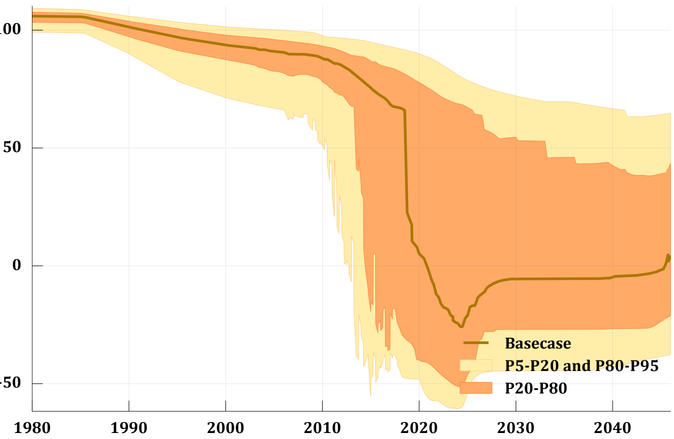
MIDDLELIDD

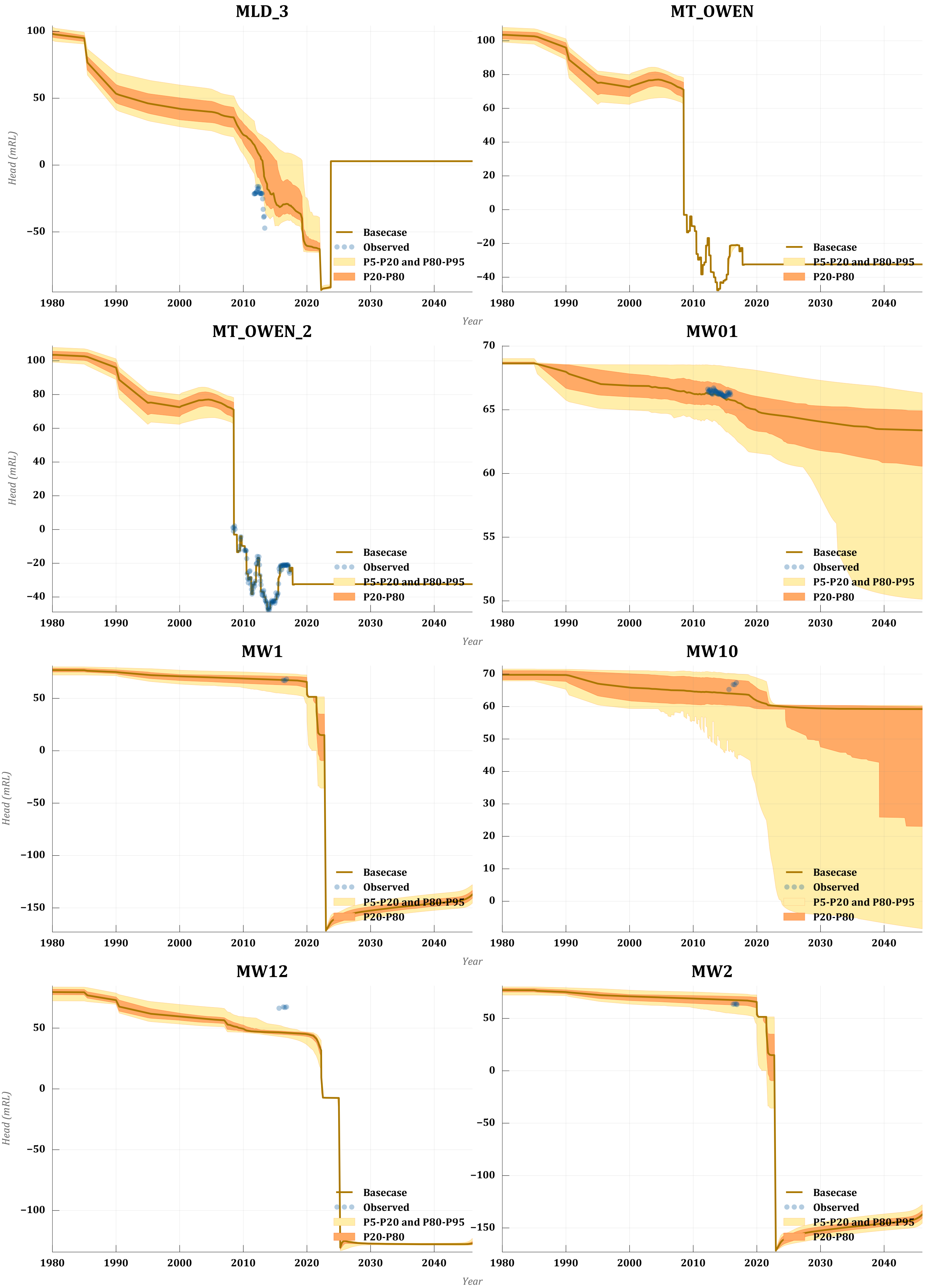


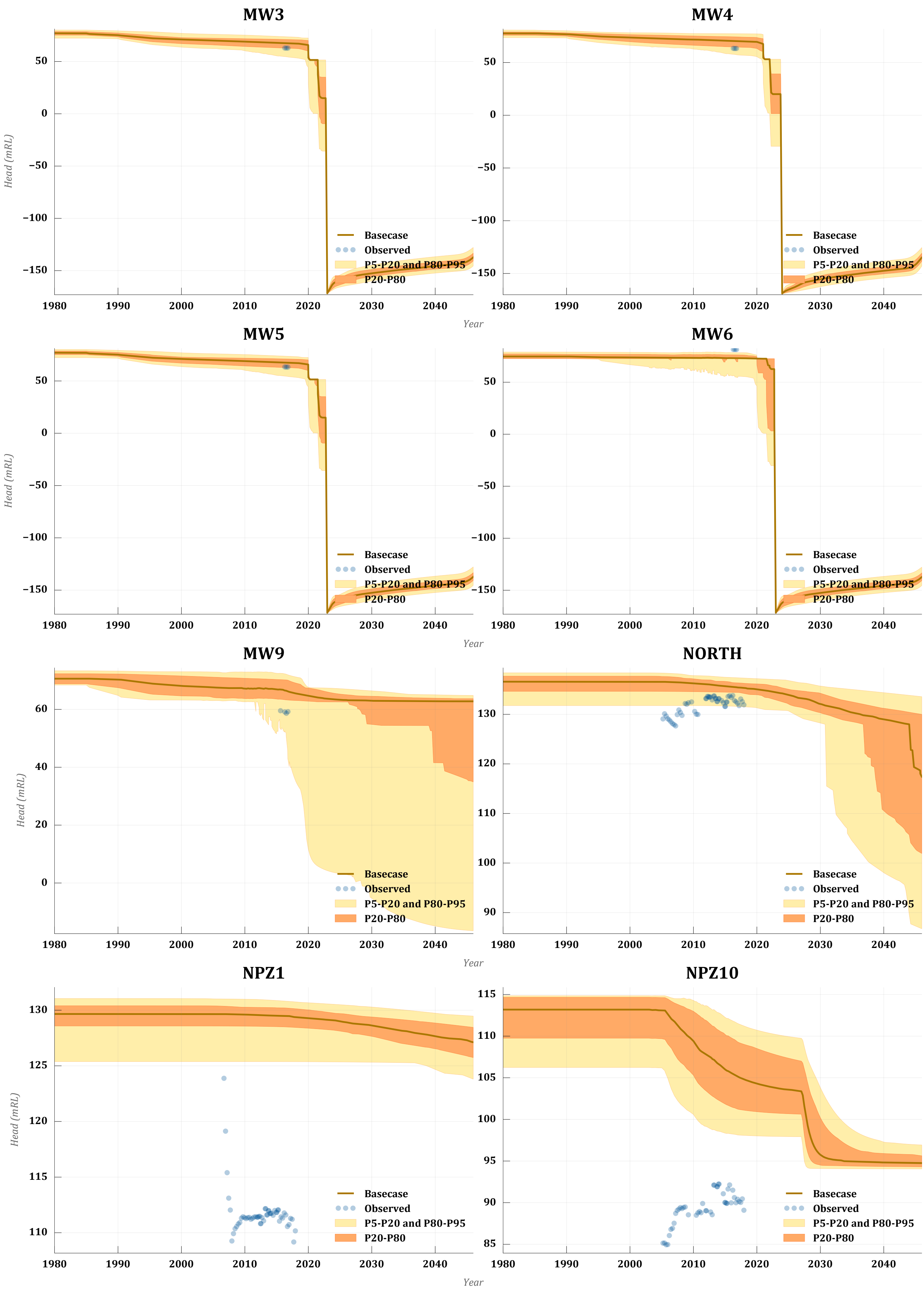
MLD_1

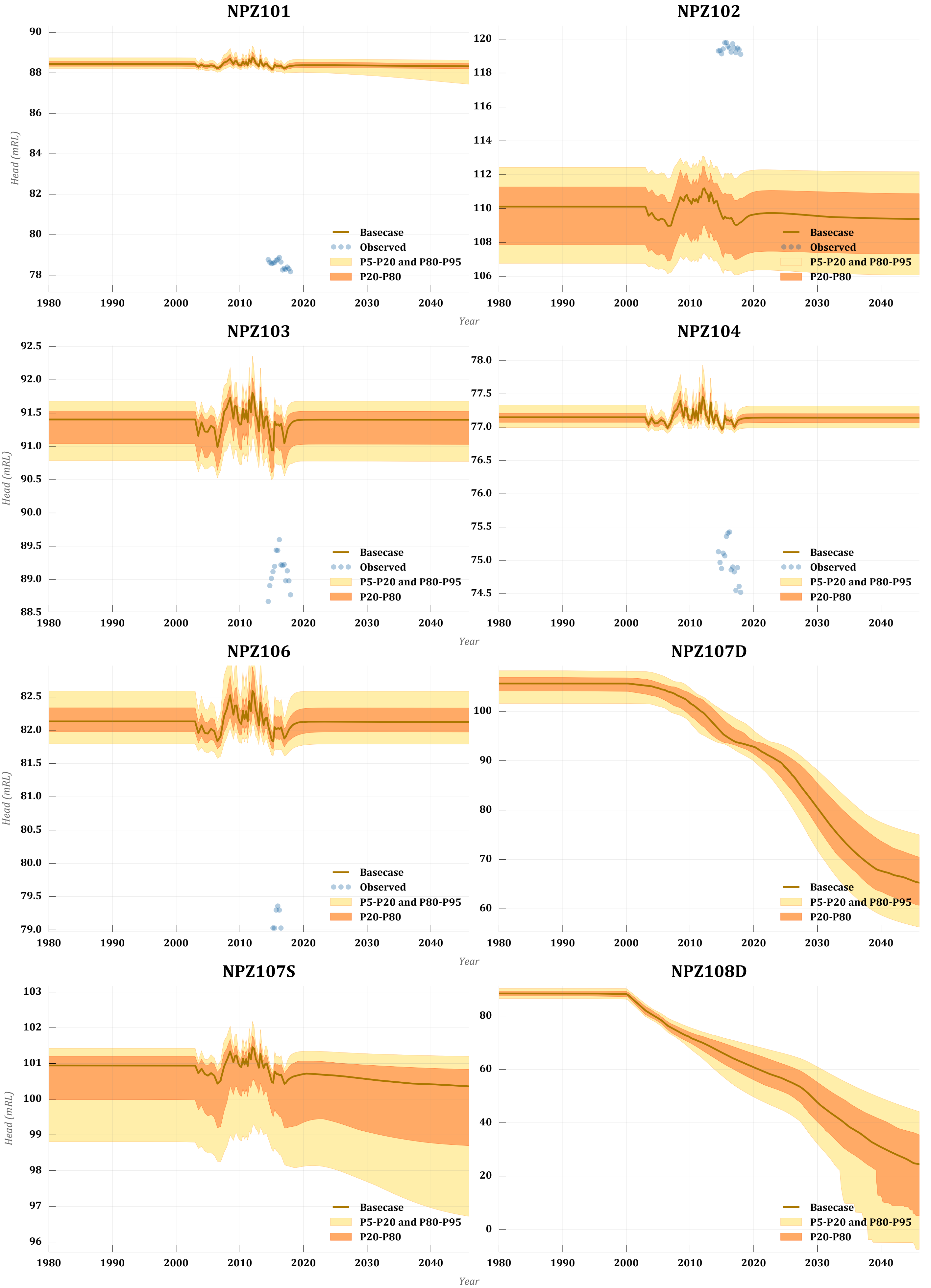


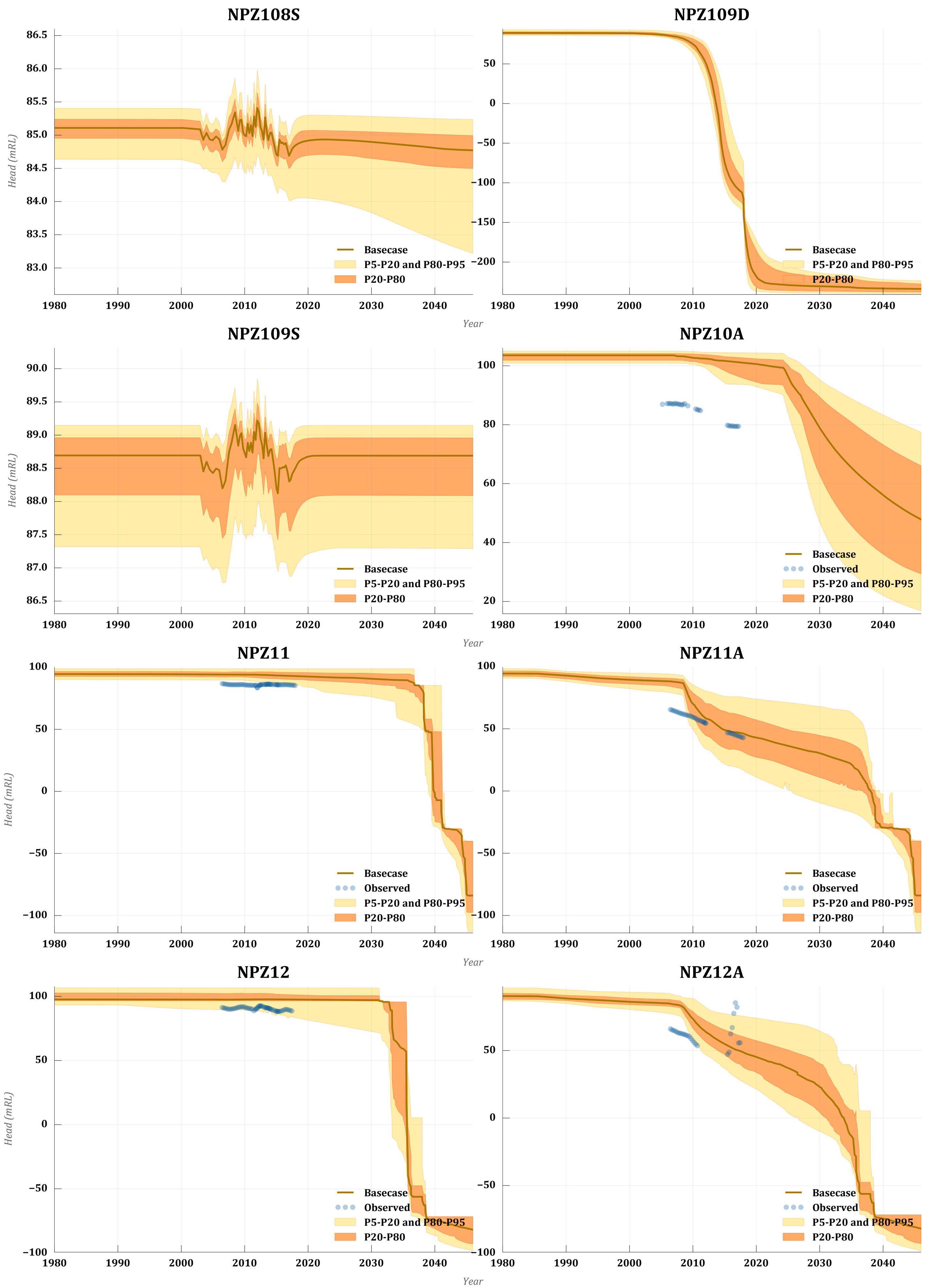
MLD_2




MLD_3
MT_OWEN
MT_OWEN_2
MW01
MW1
MW10
MW12
MW2
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
1980
1990
2000
2010
2020
2030
2040


MW3
MW4
MW5
MW6
MW9
NORTH
NPZ1
NPZ10
Head (mRL)
Year
1980
1990
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80


NPZ101
NPZ102
NPZ103
NPZ104
NPZ106
NPZ107D
NPZ107S
NPZ108D
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80


NPZ108S
NPZ109D
NPZ109S
NPZ10A
NPZ11
NPZ11A
NPZ12
NPZ12A
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
1980
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2030
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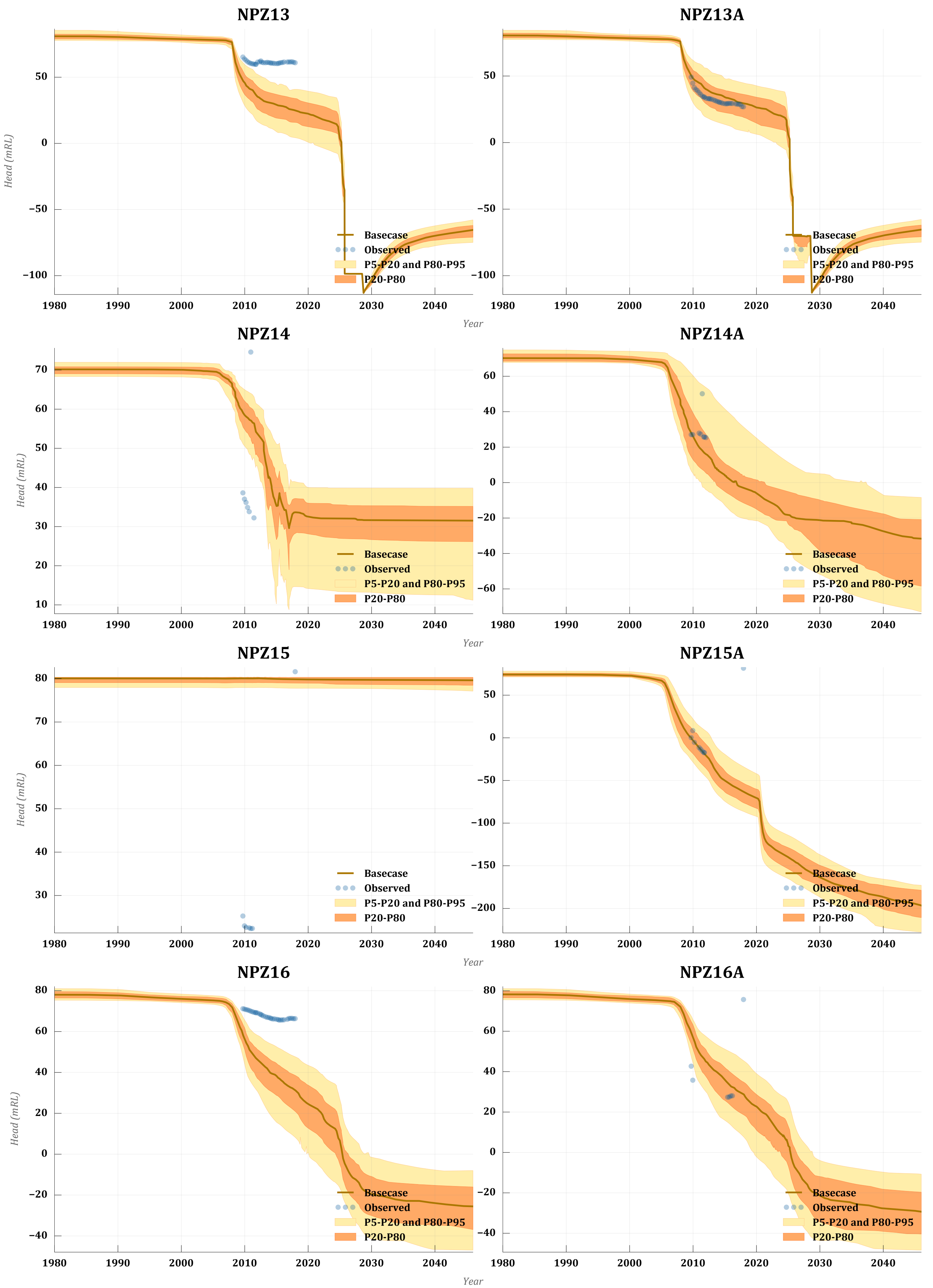
NPZ13
NPZ13A
NPZ14
NPZ14A
NPZ15
NPZ15A
NPZ16
NPZ16A
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
1980
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2000
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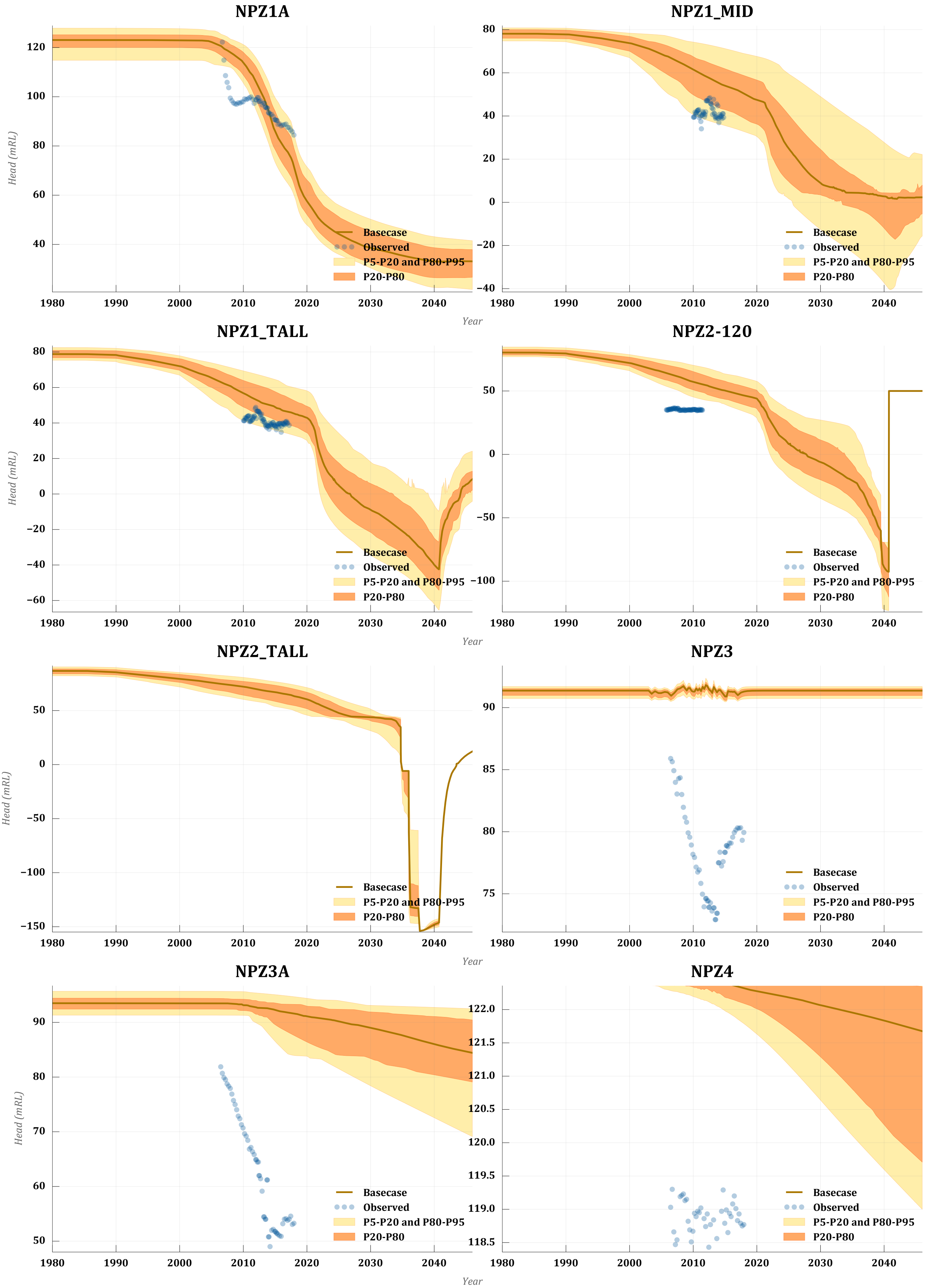
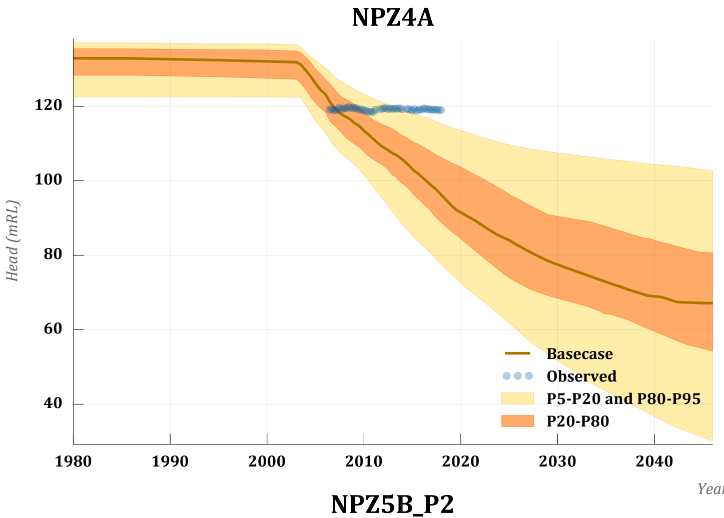
2030
2040



NPZ1A
Head (mRL)
Basecase
Observed
P5-P20 and P80-P95
P20-P80
NPZ1_MID
Year
NPZ1_TALL
NPZ2-120
NPZ2_TALL
NPZ3
NPZ3A
NPZ4


NPZ4A
Head (mRL)
120
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2010
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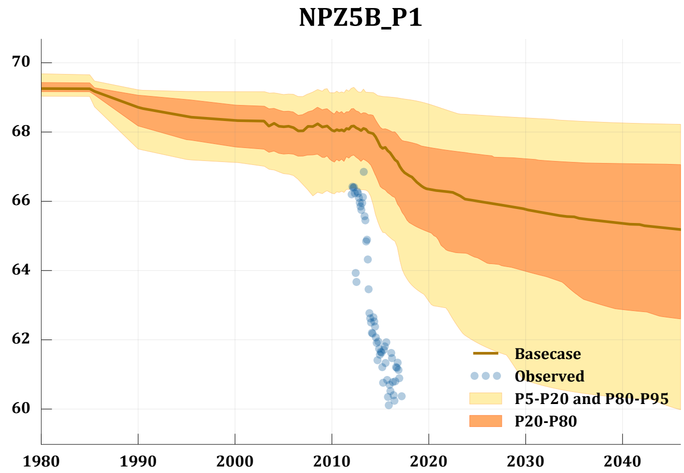
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80


NPZ5B_P1
70
68
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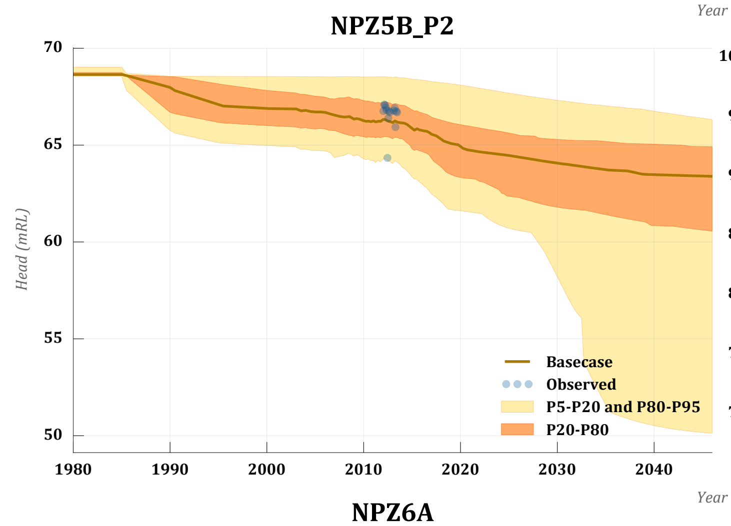
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80


NPZ5B_P2
Head (mRL)
70
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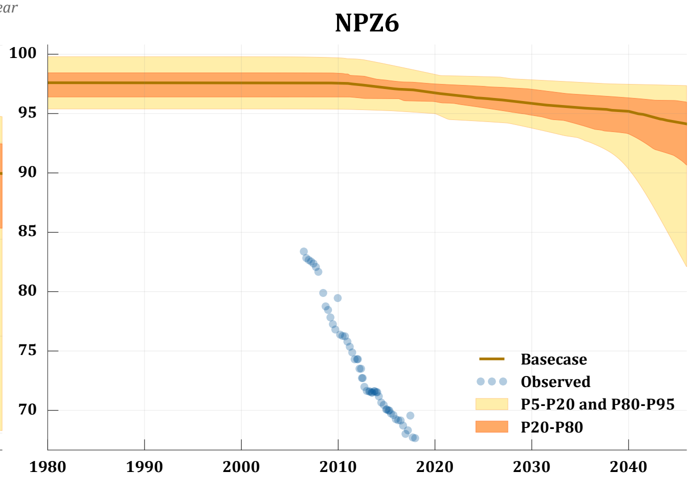
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80


NPZ6
100
95
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85
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75
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2000
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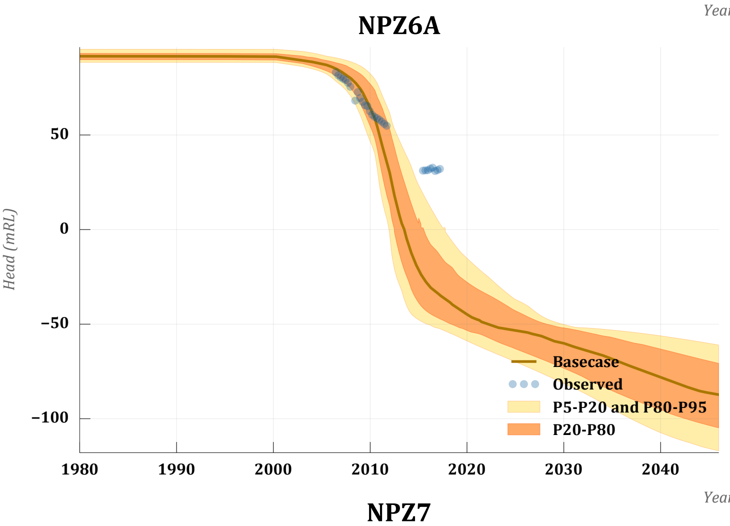
2030
2040
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80


NPZ6A
Head (mRL)
50
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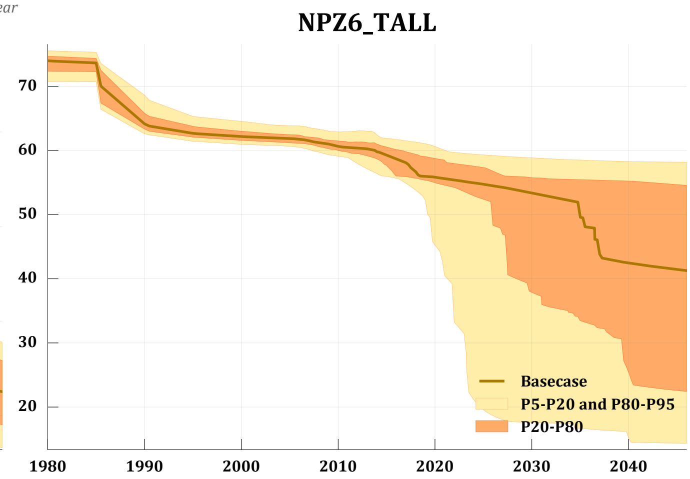
1990
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80


NPZ6_TALL
70
60
50
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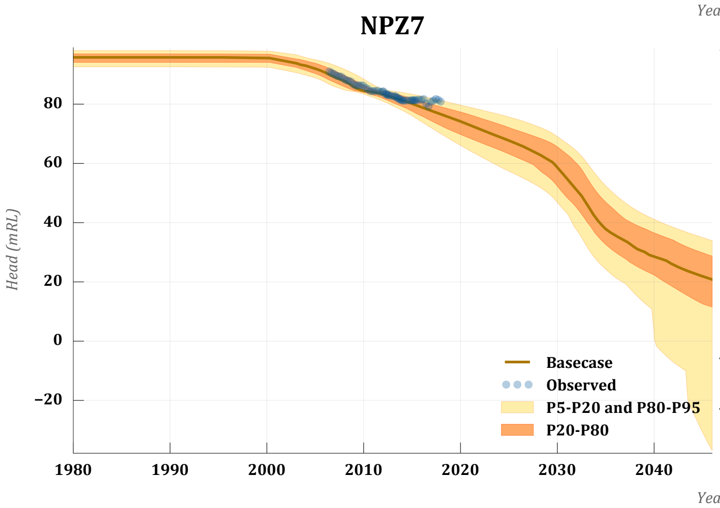
30
20
1980
1990
2000
2010
2020
2030
2040
Year
Basecase
P5-P20 and P80-P95
P20-P80


NPZ7
Head (mRL)
80
60
40
20
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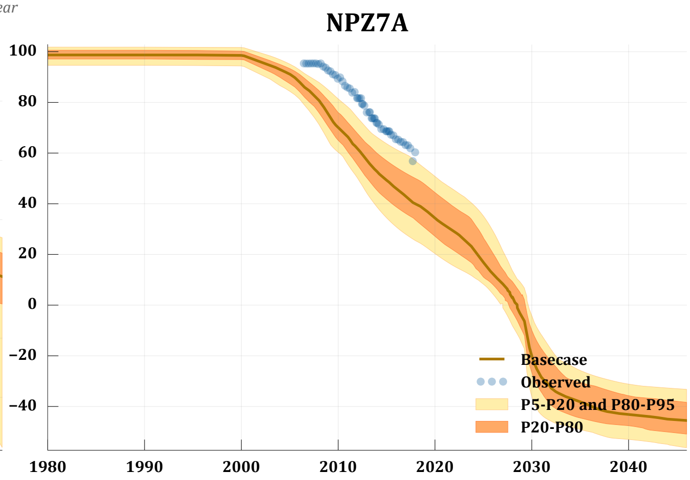
1990
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80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100
80
60
40
20
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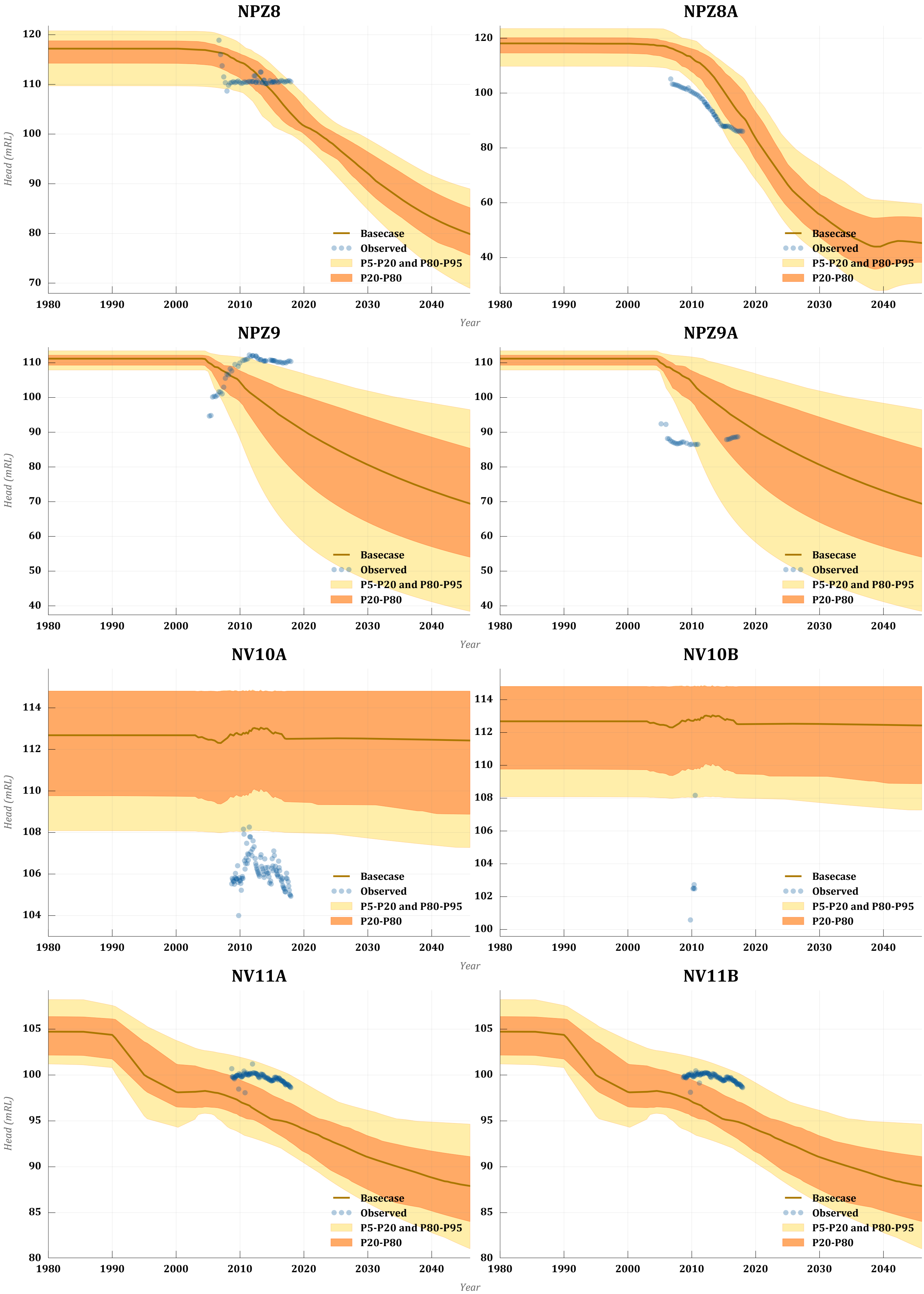
2040
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80


NPZ8
NPZ8A
NPZ9
NPZ9A
NV10A
NV10B
NV11A
NV11B
Head (mRL)
Year
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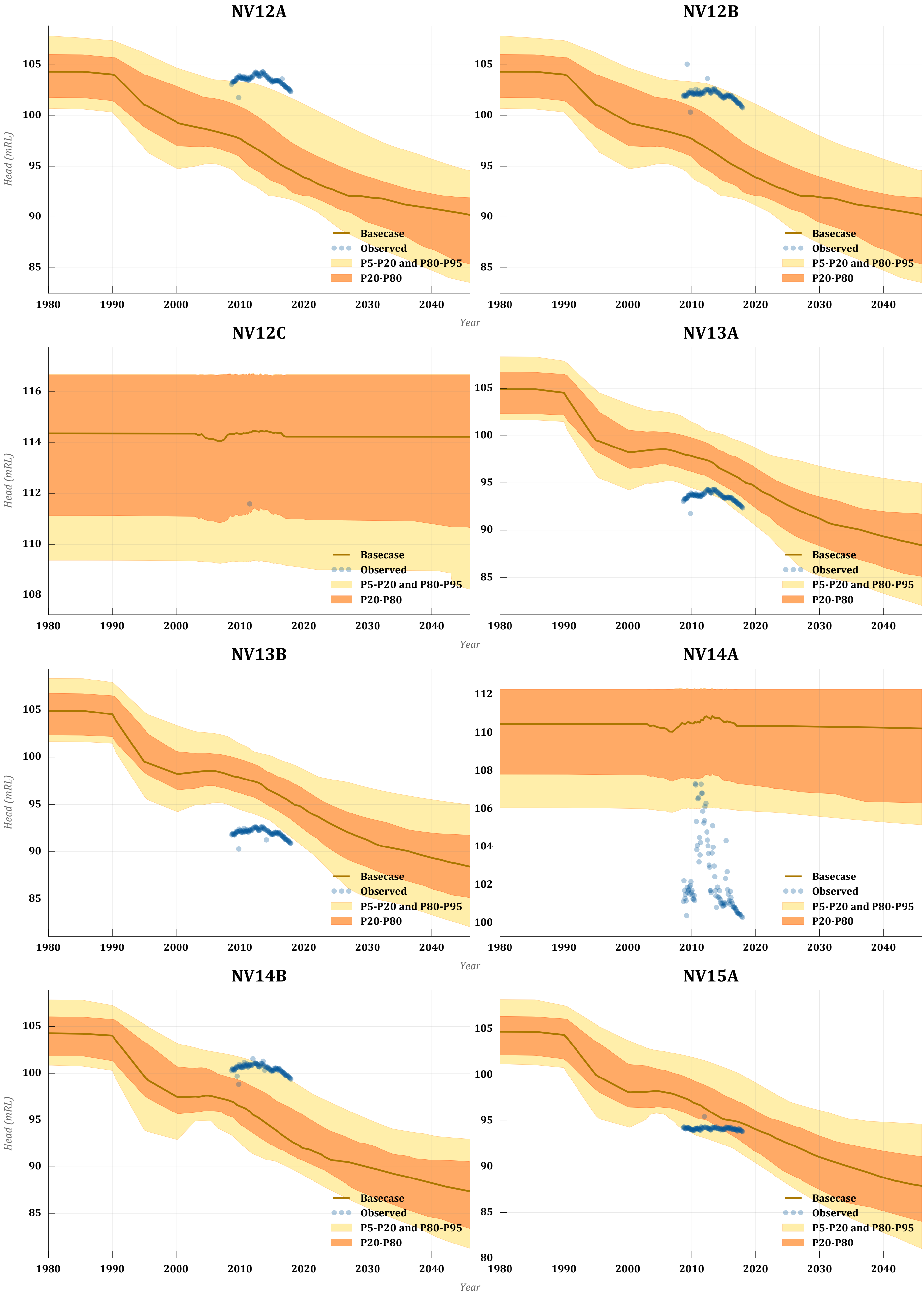
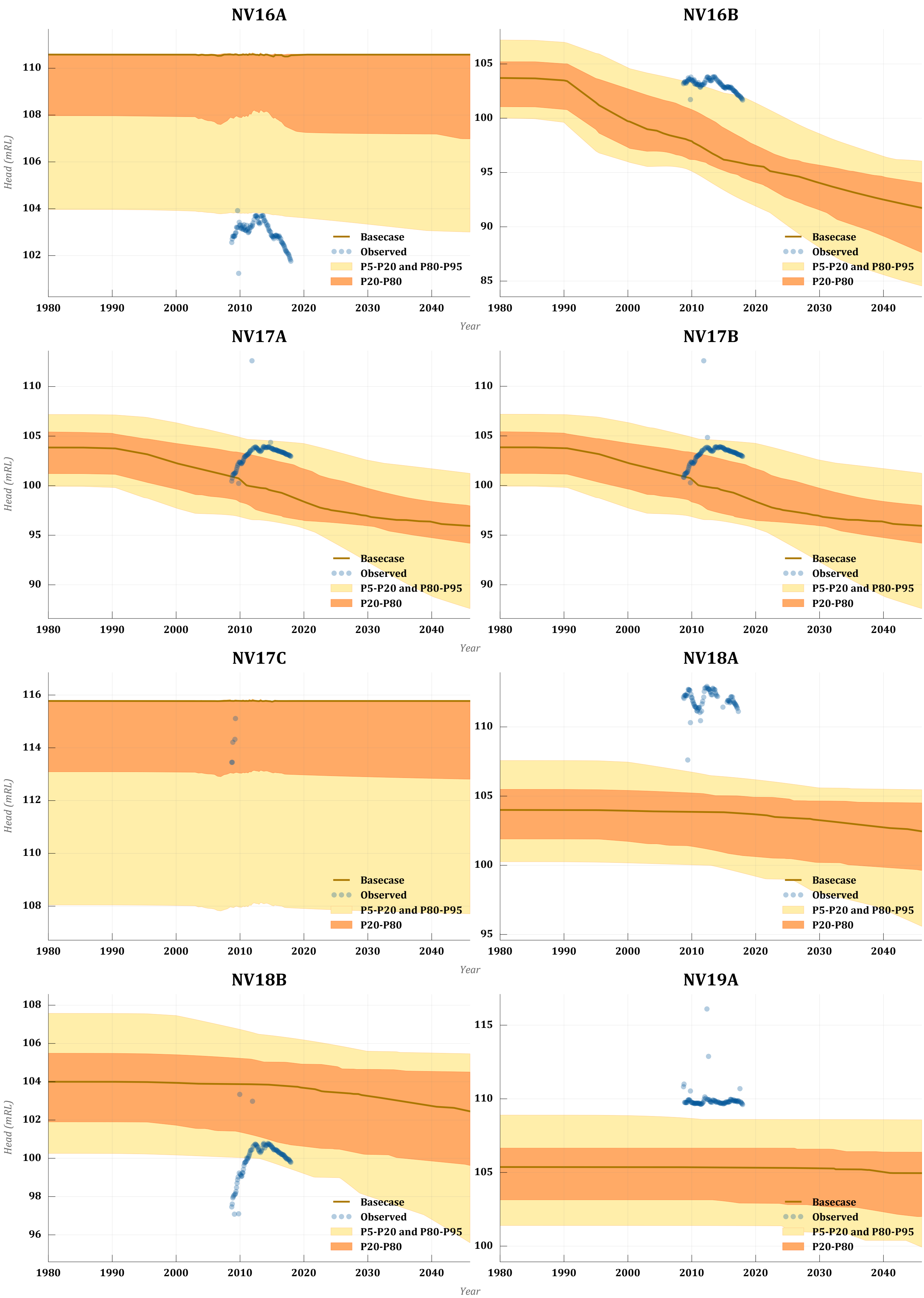
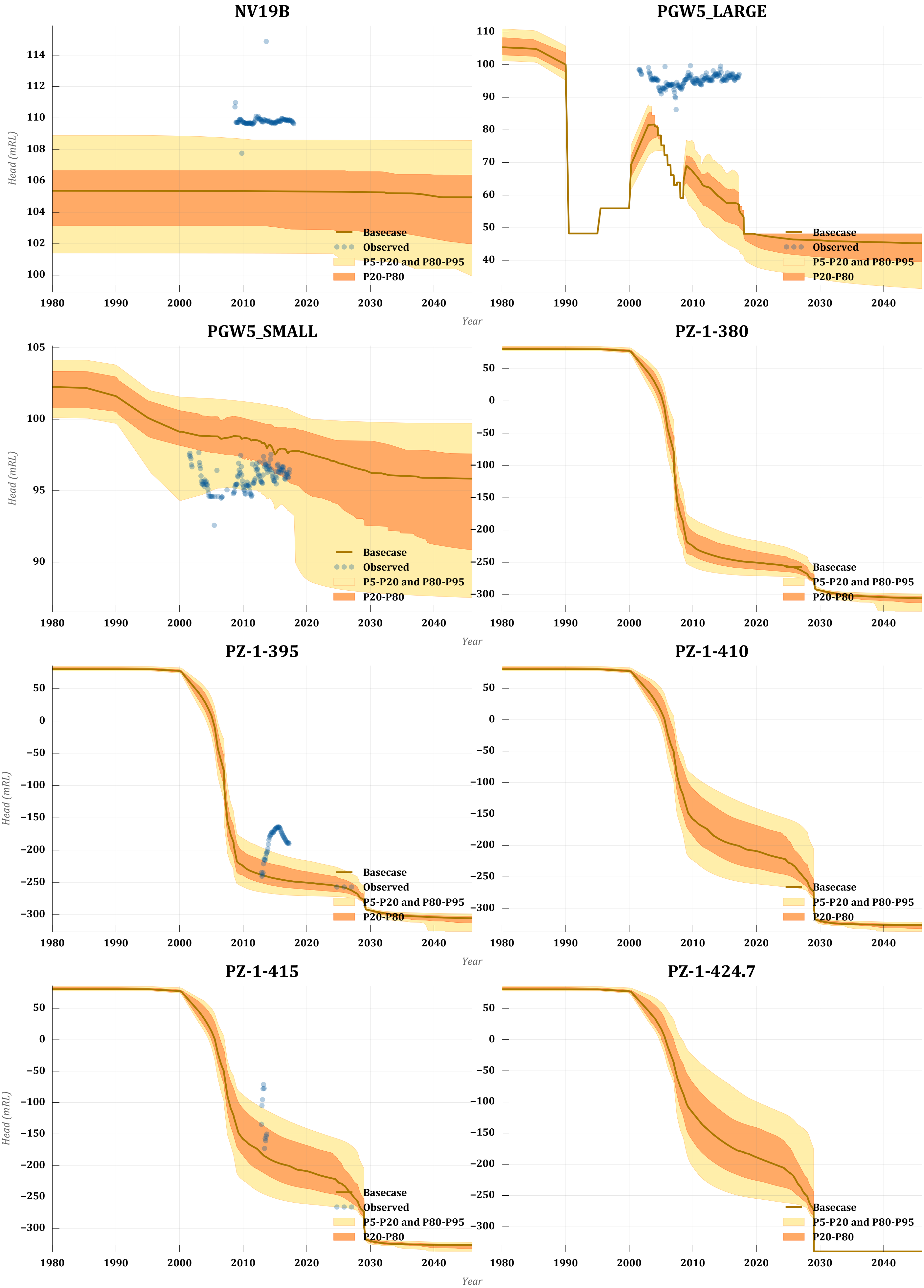
1990
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80


NV12A
NV12B
NV12C
NV13A
NV13B
NV14A
NV14B
NV15A
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
1980
1990
2000
2010
2020
2030
2040


NV16A
NV16B
NV17A
NV17B
NV17C
NV18A
NV18B
NV19A
Head (mRL)
Year
1980
1990
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80


NV19B
PGW5_LARGE
PGW5_SMALL
PZ-1-380
PZ-1-395
PZ-1-410
PZ-1-415
PZ-1-424.7
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
1980
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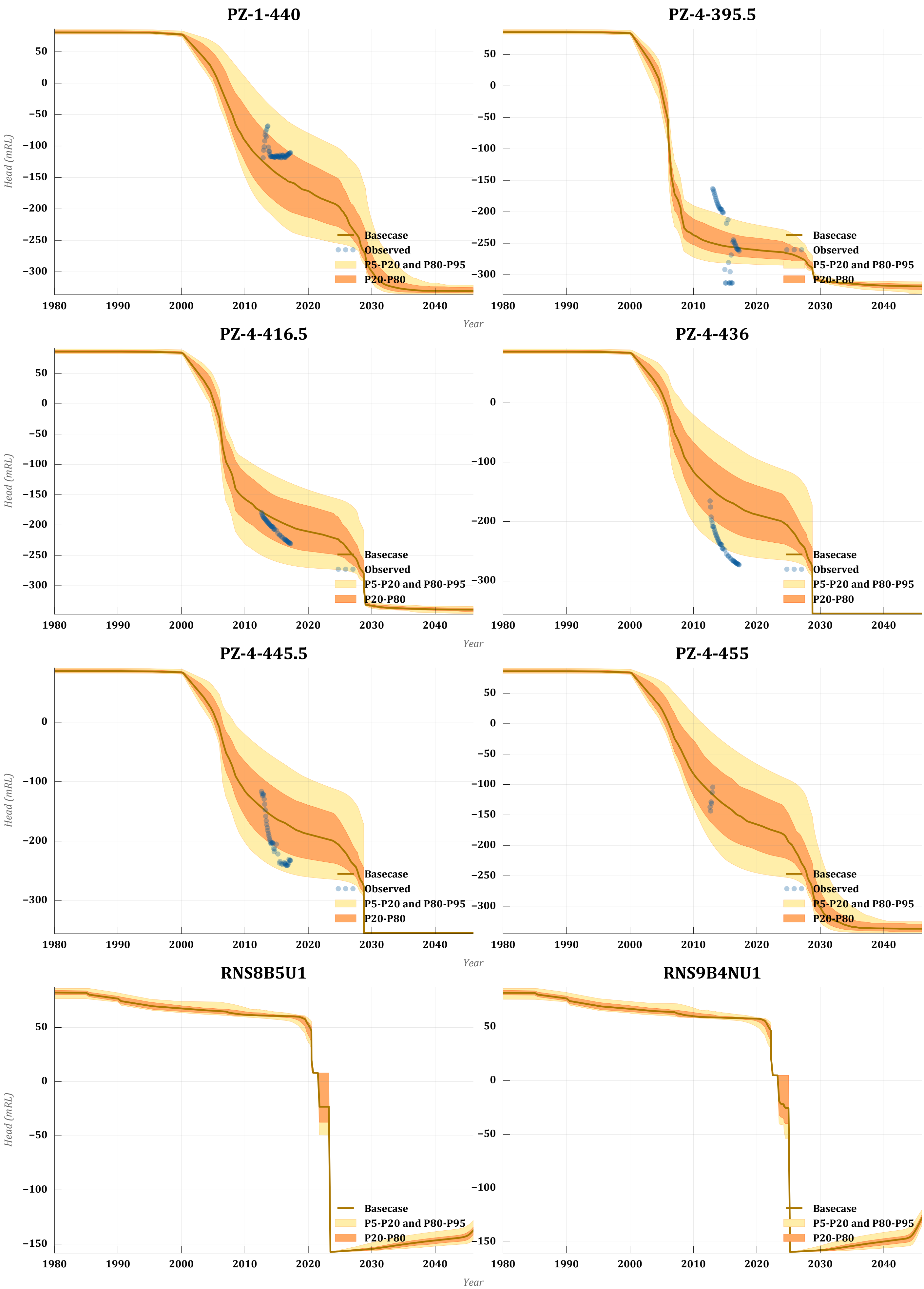
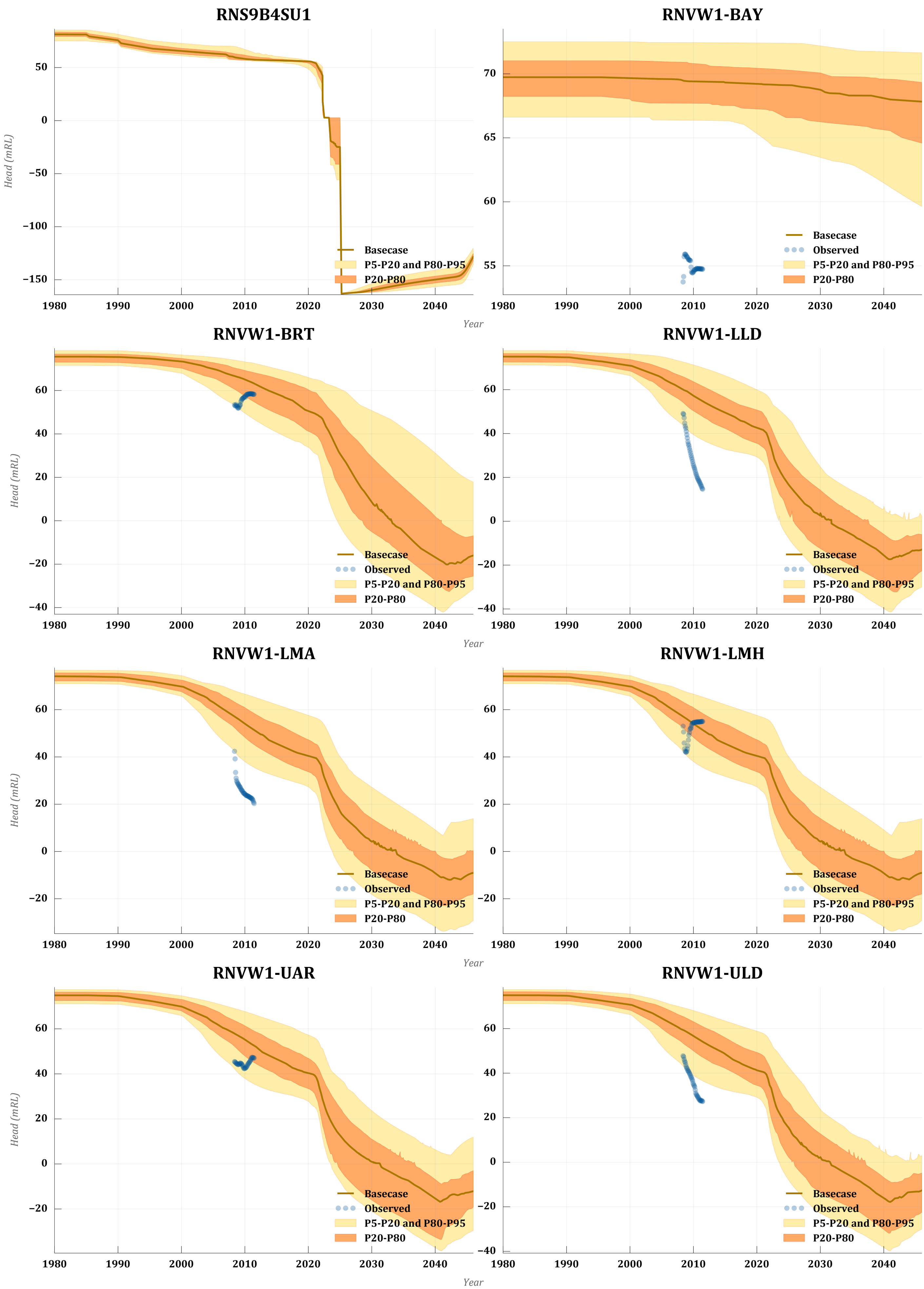
2040



PZ-1-440
PZ-4-395.5
PZ-4-416.5
PZ-4-436
PZ-4-445.5
PZ-4-455
RNS8B5U1
RNS9B4NU1
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80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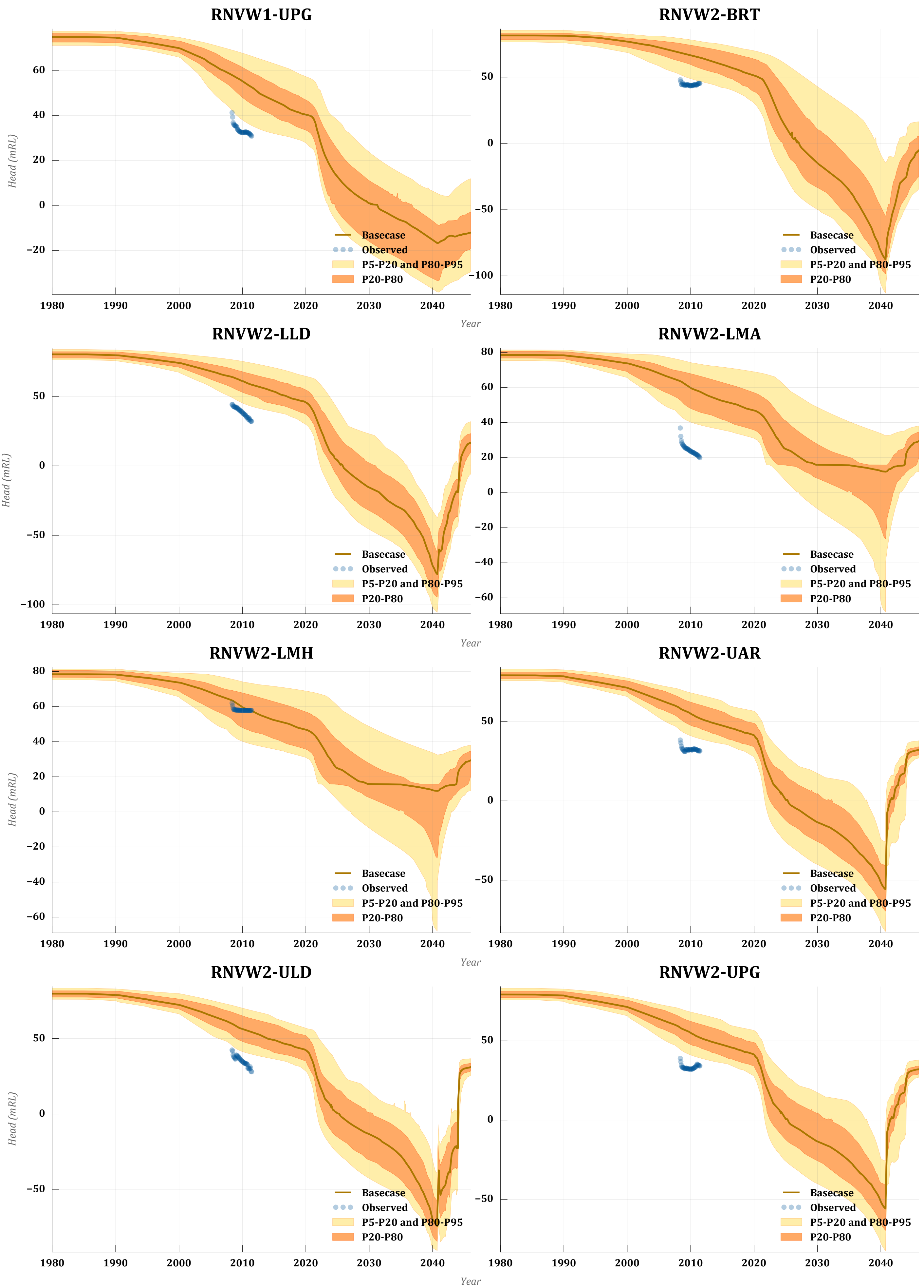
RNVW1-BRT
RNVW1-LLD
RNVW1-LMA
RNVW1-LMH
RNVW1-UAR
RNVW1-ULD
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
1980
1990
2000
2010
2020
2030
2040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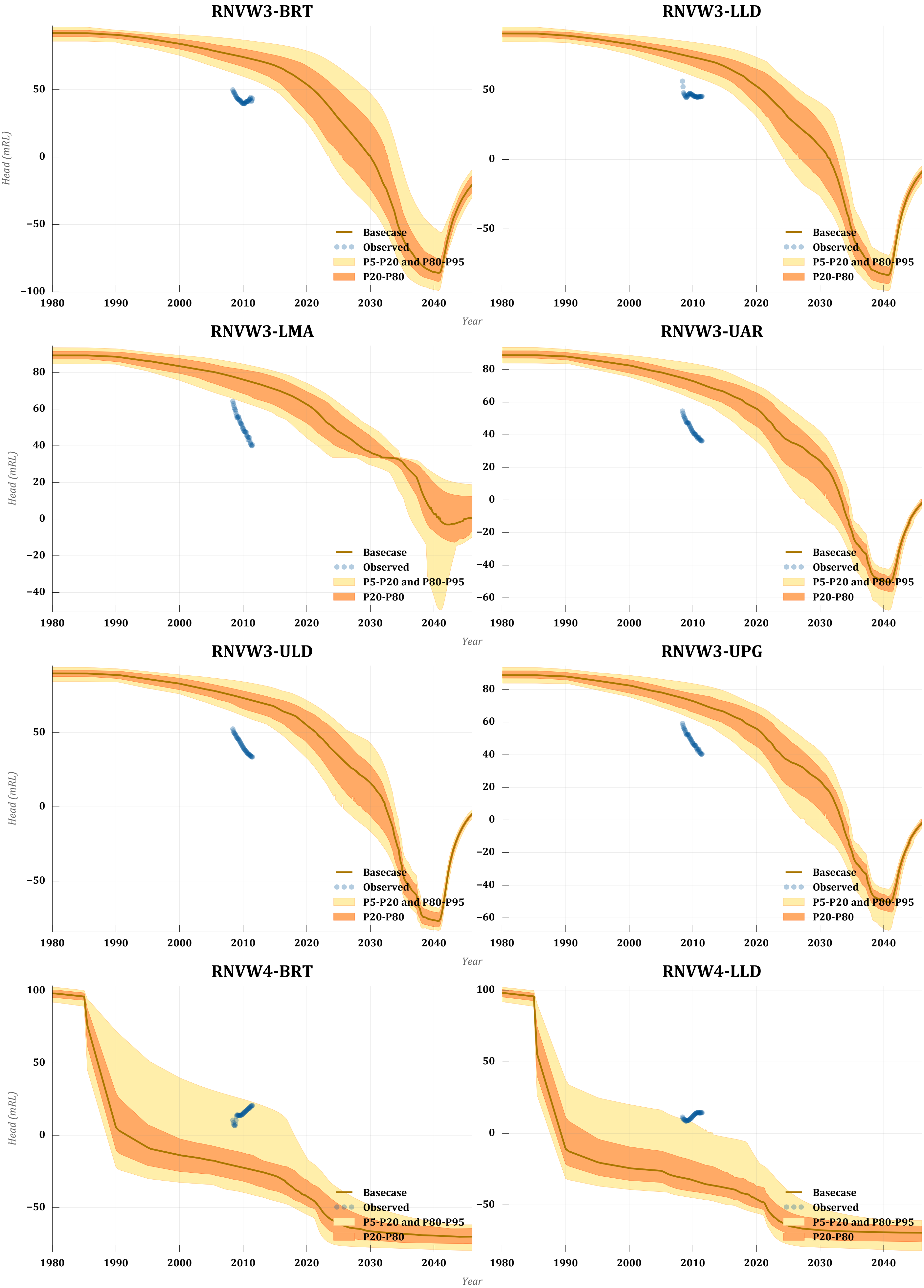
RNVW2-BRT
RNVW2-LLD
RNVW2-LMA
RNVW2-LMH
RNVW2-UAR
RNVW2-ULD
RNVW2-UPG
Head (mRL)
Year
1980
1990
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80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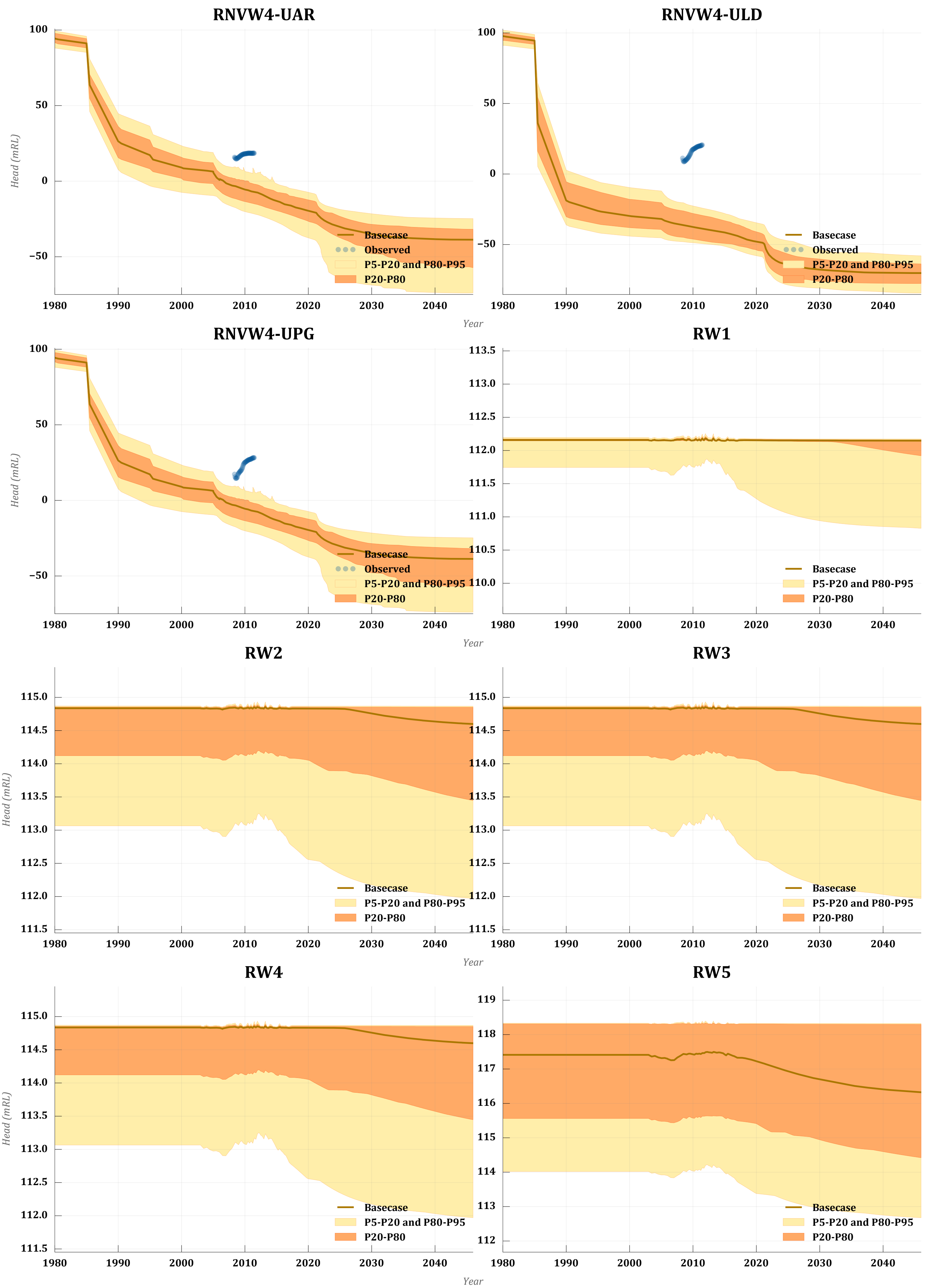
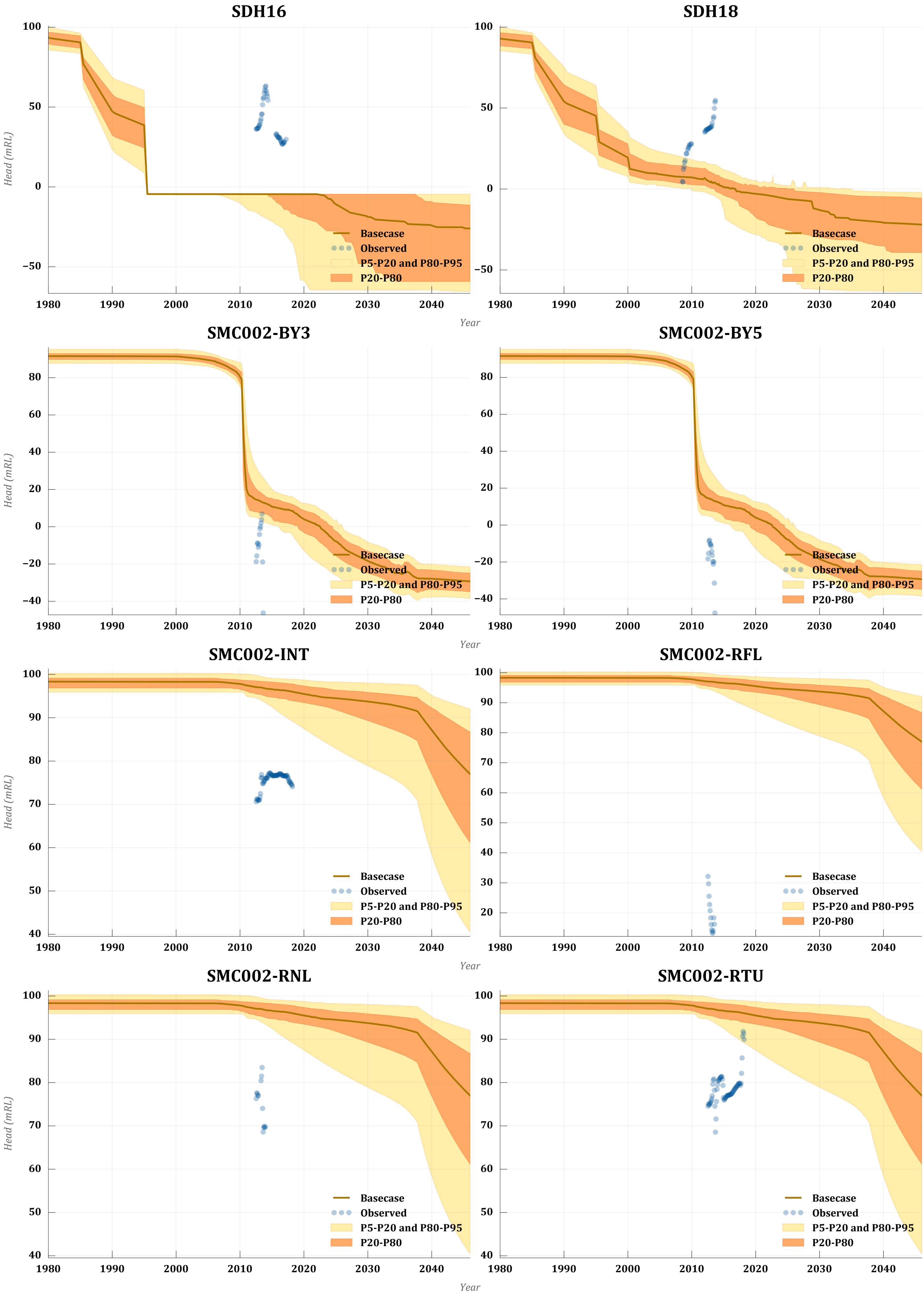
RNVW3-LLD
RNVW3-LMA
RNVW3-UAR
RNVW3-ULD
RNVW3-UPG
RNVW4-BRT
RNVW4-LLD
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
1980
1990
2000
2010
2020
2030
2040


RNVW4-UAR
RNVW4-ULD
RNVW4-UPG
RW1
RW2
RW3
RW4
RW5
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80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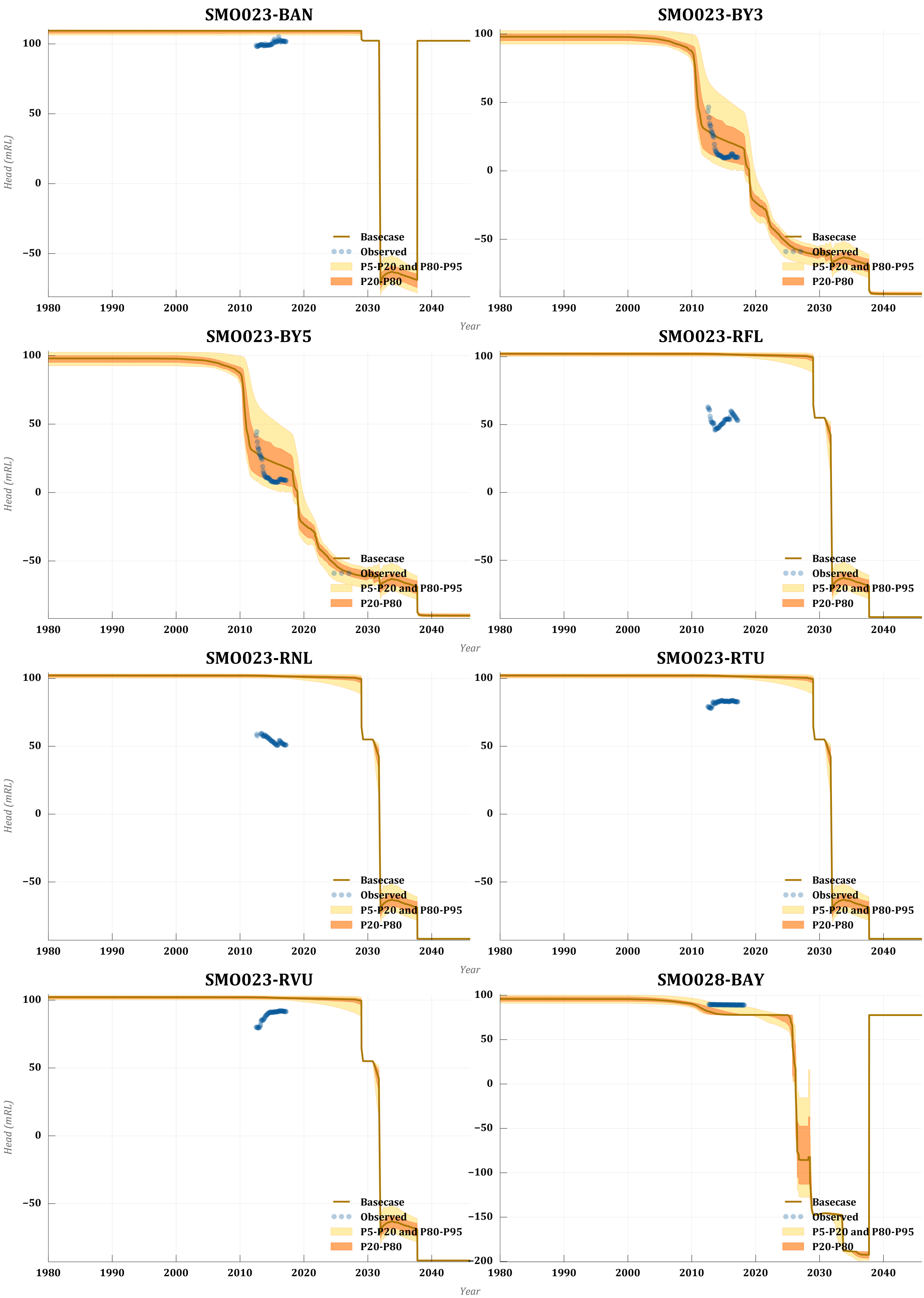
SDH18
SMC002-BY3
SMC002-BY5
SMC002-INT
SMC002-RFL
SMC002-RNL
SMC002-RTU
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
1980
1990
2000
2010
2020
2030
2040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SMO023-BY5
SMO023-RFL
SMO023-RNL
SMO023-RTU
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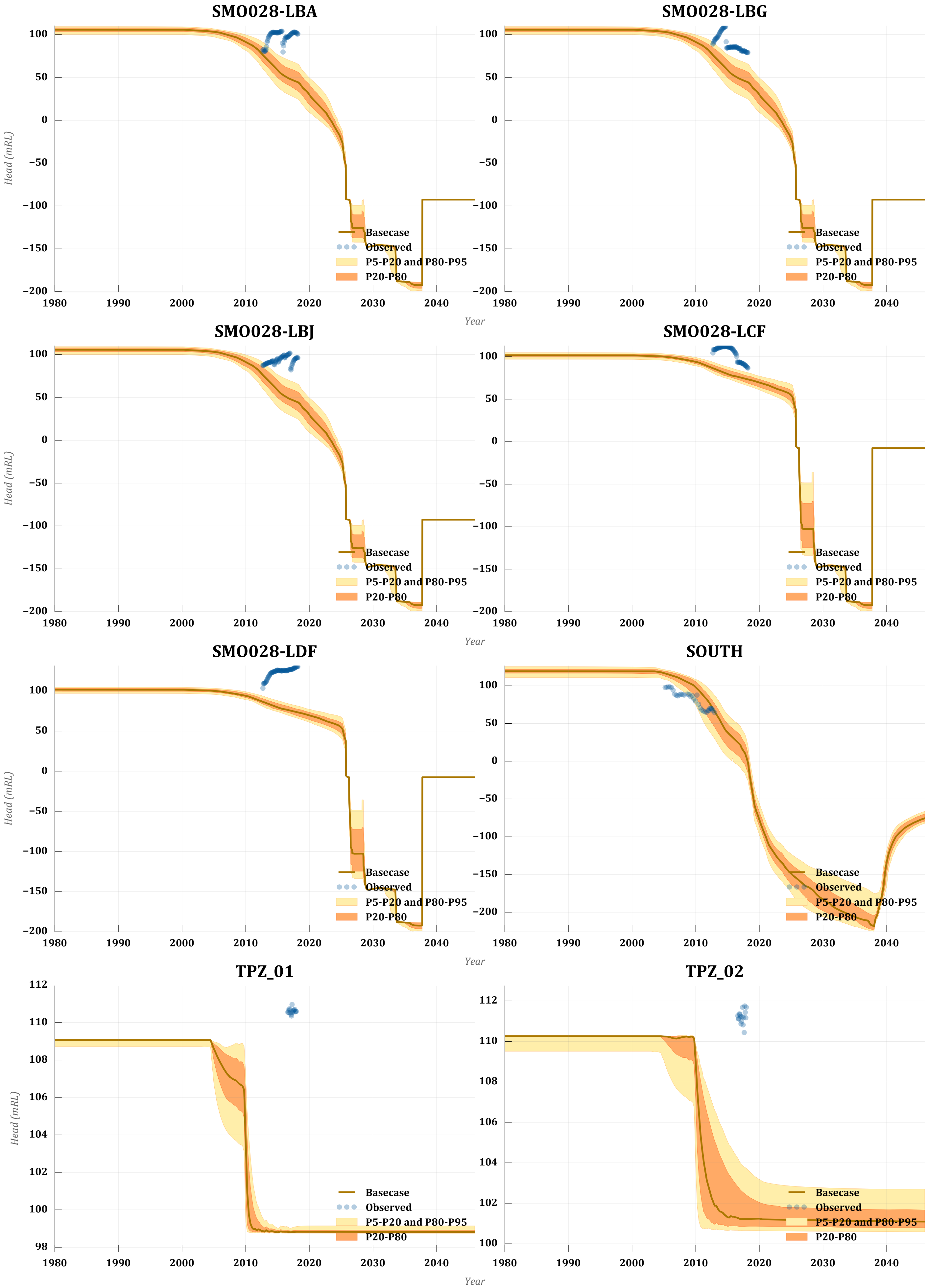
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80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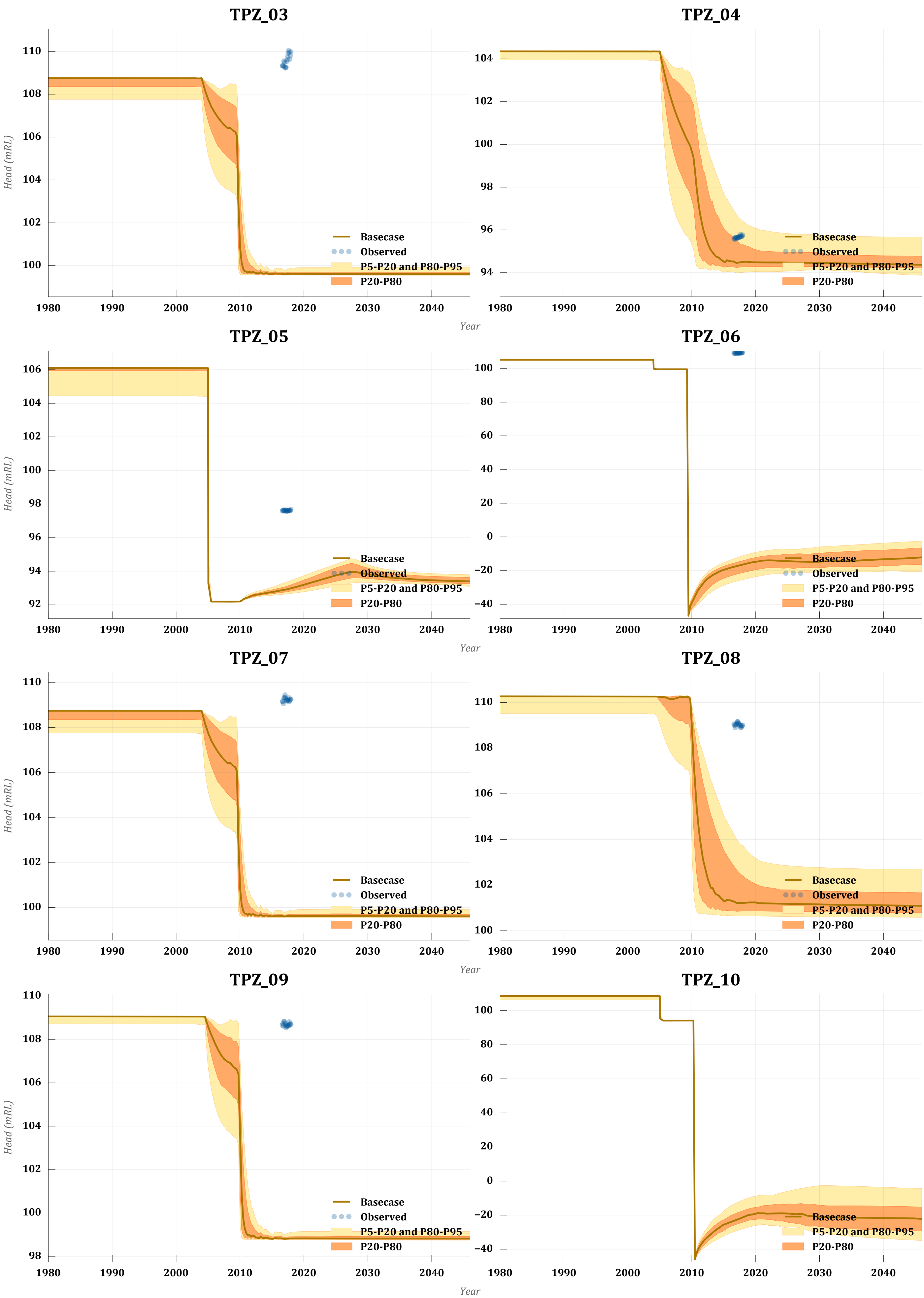
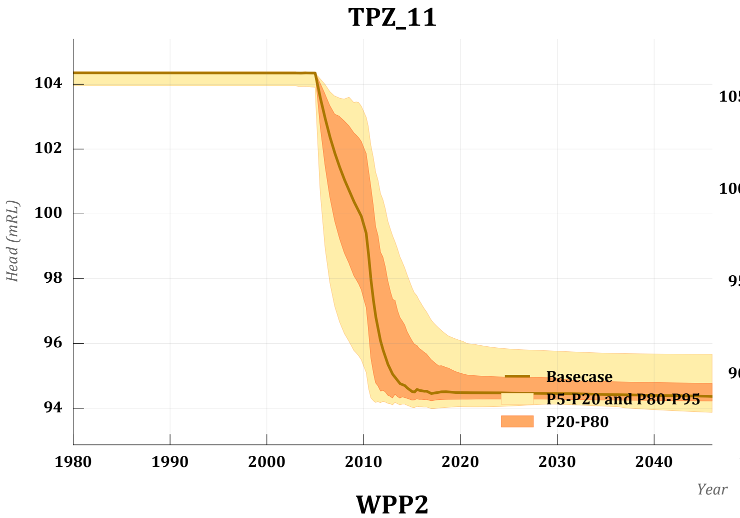
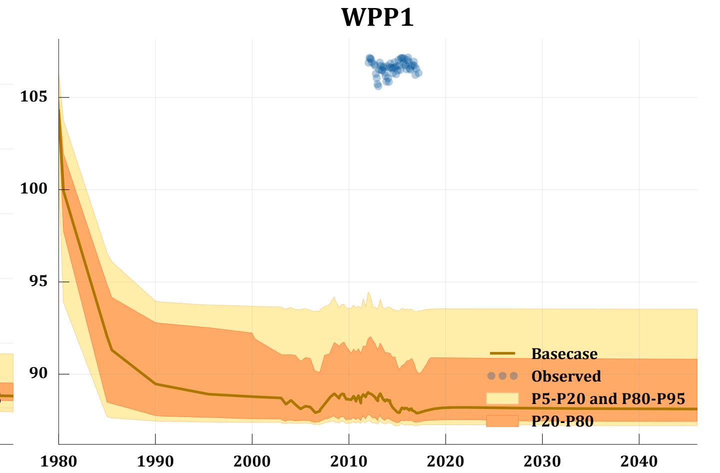
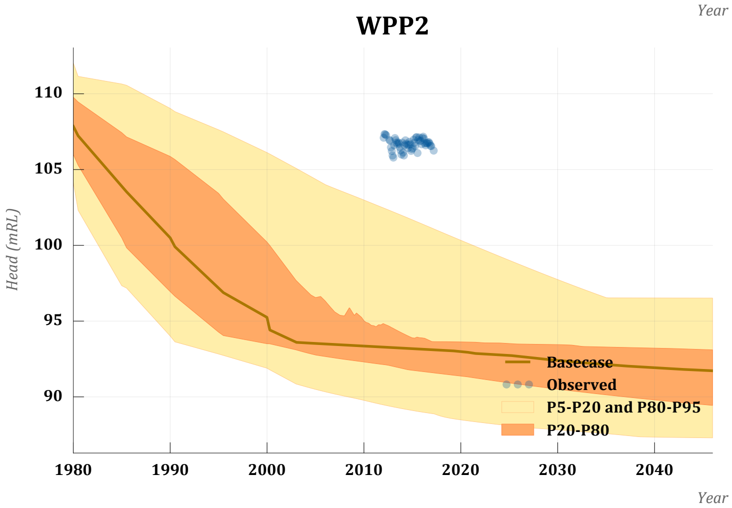
SMO028-LBG
SMO028-LBJ
SMO028-LCF
SMO028-LDF
SOUTH
TPZ_01
TPZ_02
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80


TPZ_03
TPZ_04
TPZ_05
TPZ_06
TPZ_07
TPZ_08
TPZ_09
TPZ_10
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80


TPZ_11
Head (mRL)
104
102
100
98
96
94
1980
1990
2000
2010
2020
2030
2040
Basecase
P5-P20 and P80-P95
P20-P80
Year


WPP1
105
100
95
90
1980
1990
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80


WPP2
Head (mRL)
110
105
100
95
90
1980
1990
2000
2010
2020
2030
2040
Basecase
Observed
P5-P20 and P80-P95
P20-P80
Year

Appendix C Monitoring bore construction details

Table C 1 Quaternary alluvium groundwater monitoring bores

Bore ID	Easting (m) GDA94 Zone 56	Northing (m) GDA94 Zone 56	Alluvial aquifer	Ground level (mAHD)	Bore depth (mbgl)	Thickness alluvium (mbgl)	Screened interval (mbgl)	SWL (mAHD)	Date SWL measured	Saturated alluvium thickness (m)	Kh[1] (m/day)
BC-SP02	317483	6411487	Yorks Ck	83.51	8.7			76.675	1/03/2017		
BC-SP03	317547	6411405	Yorks Ck	92.94	7.5			86.099	1/03/2017		
BC-SP04	317610	6411320	Yorks Ck	82.27	8.9			75.63	1/03/2017		
BC-SP05	317680	6411232	Yorks Ck	84.36	9			78.083	1/03/2017		
BC-SP06	317596	6411588	Yorks Ck	85.71	9.3			78.178	1/03/2017		
BC-SP07	317681	6411448	Yorks Ck	86.28	10.2			77.189	1/03/2017		
BC-SP08	317592	6411869	Yorks Ck	88.68	8.5			84.683	1/03/2017		
BC-SP09	317675	6411703	Yorks Ck	87.12	8.2			80.647	1/03/2017		
BC-SP10	318080	6409400	Swamp Ck	77.43	6			73.462	1/03/2017		
BC-SP11	318137	6409337	Swamp Ck	76	9.4			73.14	1/03/2017		
BC-SP12	318201	6409265	Swamp Ck	76.18	6.3			73.39	1/03/2017		
BC-SP13	318253	6409210	Swamp Ck	76.18	3.5			72.95	1/12/2016		
BC-SP14	318305	6409158	Swamp Ck	76.06	5.9			72.355	1/03/2017		
BC-SP15	318182	6409484	Swamp Ck	76.35	5			72.153	1/03/2017		
BC-SP16	318290	6409376	Swamp Ck	76.1	4.6			72.124	1/03/2017		
BC-SP17	318319	6409543	Swamp Ck	77	6.5			71.079	1/03/2017		
BC-SP18	317350	6411325	Swamp Ck	82.08	3.8			78.244	1/03/2017		
BC-SP19	317462	6411178	Swamp Ck	80.9	2.1			79.935	1/12/2016		
BC-SP20	318184	6409118	Swamp Ck	74.87	4.5			71.482	1/03/2017		

Bore ID	Easting (m) GDA94 Zone 56	Northing (m) GDA94 Zone 56	Alluvial aquifer	Ground level (mAHD)	Bore depth (mbgl)	Thickness alluvium (mbgl)	Screened interval (mbgl)	SWL (mAHD)	Date SWL measured	Saturated alluvium thickness (m)	Kh[1] (m/day)
BC-SP21	318057	6409176	Swamp Ck	76.08	6.7			70.896	1/03/2017		
BC-SP22	317992	6409051	Bowmans Ck	74.15	6			68.893	1/03/2017		
GA1	318378.8	6408259	Alluvium	73.1	6.35			68.43	22/03/2017		
GA2	318578.1	6407367	Alluvium	69.53	10.03			63.93	22/03/2017		
GCP09	323259	6407315	Glennies Ck	69.9	9	8	5.8 - 8.8	63.65	1/11/2016	1.75	>0.2
GCP11	322417	6407232	Main Ck	70.5	-	-	N/A - 12	61.73	15/04/2017	-	-
GCP17	323803	6409986	Main Ck	87.5	7.5	7	4.0 - 7.5	79.94	15/04/2017	0	0.06
GCP19	325086	6408333	Glennies Ck	77.5	12	11.5	8.5 - 12.0	69.02	5/02/2017	3.02	-
GCP20	325201	6408179	Glennies Ck	82	8.2	-	-	-	-	-	-
GCP21	324466	6407916	Glennies Ck	76	11	10.5	6.0 - 11.0	68.52	5/02/2017	3.02	0.16
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
GCP39	321297	6410352	Bettys Ck	96	3.2	3	2.5-3.0	90.86	30/11/2016	0	-
GCP3S	320924	6408389	Bettys Ck	81	5.4	-	3.4-5.4	76.12	8/02/2017	-	-
GCP40	321112	6409047	Bettys Ck	-	6.0	-	-	-	-	-	-
GCP4S	320838	6409804	Bettys Ck	90	6.1	-	4.0-6.1	86.06	8/02/2017	-	-
GNPS-02	317564	6410201	Bowmans Ck	76.82	9.2	-	-	71.915	1/03/2017	-	-
GNPS-06	317605	6411062	Yorks Ck	79.55	9.9	-	-	76.685	1/03/2017	-	-
GW1	318720	6414452	Yorks Ck	-	-	-	-	-	-	-	-

Bore ID	Easting (m) GDA94 Zone 56	Northing (m) GDA94 Zone 56	Alluvial aquifer	Ground level (mAHD)	Bore depth (mbgl)	Thickness alluvium (mbgl)	Screened interval (mbgl)	SWL (mAHD)	Date SWL measured	Saturated alluvium thickness (m)	Kh[1] (m/day)
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	-
NPZ105	323022	6408934	Main Ck	84	9	-	-	-	-	-	-
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	-
NPZ3	321182	6410365	Bettys Ck	93.53	6	-	-	78.93	22/03/2017	-	-
GNP09S	316224	6412805	Bowmans Ck	89.93	6.6	>6.60	3.60 - 6.60	84.93	4/05/2018	0.00	-
GNP09D	316223	6412806	Bowmans Ck	90.00	14.36	7.60	8.36 – 14.36	85.00	4/05/2018	-	5.03E-04
GNP10S	316818	6411319	Bowmans Ck	82.42	7.13	>7.13	4.13 – 7.13	77.52	4/05/2018	>3.13	2.13E-04
GNP10D	316817	6411318	Bowmans Ck	82.43	15.96	7.60	9.96 – 15.96	77.53	4/05/2018	-	3.84E-05
GNP11S	317817	6408381	Bowmans Ck	71.80	5.38	>5.38	2.38 – 5.38	67.30	4/05/2018	>0.58	4.34E-07
GNP11D	317818	6408381	Bowmans Ck	71.77	11.12	5.60	8.12 – 11.12	67.27	4/05/2018	-	5.21E-05

Note: *1. Source Geoterra (2009)*

Table C 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
East Bore	323332	6412810	Interburden	153.49	-	-	-	-
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
GCP3	320924	6408389	Interburden	81	49.2	-	-	-
GCP3D	320838	6409800	Interburden	81	48.5	-	41.35	15/02/2017

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
GCP4	320838	6409600	Interburden	90	36	-	-	-
GCP4D	323447	6409344	Interburden	90	36	-	73.94	15/02/2017
GNP1-Art	318491.9	6408641	Coal	76.75		-	32.571	15/12/2016
GNP1-Brt	318491.9	6408641	Coal	76.75		-	3.645	15/12/2016
GNP1-Heb	318491.9	6408641	Coal	76.75		-	-0.392	15/12/2016
GNP1-LLd	318491.9	6408641	Coal	76.75		-	8.664	15/12/2016
GNP1-MLd	318491.9	6408641	Coal	76.75		-	8.077	15/12/2016
GNP1-PG	318491.9	6408641	Coal	76.75		-	32.008	15/12/2016
GNP1-ULd	318491.9	6408641	Coal	76.75		-	13.67	15/12/2016
GNP2-Art	317563.6	6410220	Coal	78.26		-	19.977	15/12/2016
GNP2-Bar	317563.6	6410220	Coal	78.26		-	31.451	15/12/2016
GNP2-Heb	317563.6	6410220	Coal	78.26		-	42.23	15/12/2016
GNP2-LLd	317563.6	6410220	Coal	78.26		-	29.021	15/12/2016
GNP2-MLd	317563.6	6410220	Coal	78.26		-	21.714	10/12/2016
GNP2-PG	317563.6	6410220	Coal	78.26		-	20.46	15/12/2016
GNP2-ULd	317563.6	6410220	Coal	78.26		-	107.063	15/12/2016
GNP3-Art	316945.5	6411691	Coal	84.96		-	33.897	25/07/2014
GNP3-Brt	316945.5	6411691	Coal	84.96		-	32.828	25/07/2014
GNP3-Heb	316945.5	6411691	Coal	84.96		-	39.087	25/07/2014
GNP3-LLd	316945.5	6411691	Coal	84.96		-	33.296	25/07/2014
GNP3-MLd	316945.5	6411691	Coal	84.96		-	33.072	25/07/2014

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
GNP3-PG	316945.5	6411691	Coal	84.96		-	39.901	25/07/2014
GNP3-ULd	316945.5	6411691	Coal	84.96		-	43.77	25/07/2014
GNP4-Art	316930.7	6412932	Coal	111.44		-	-25.445	15/12/2016
GNP4-Brt	316930.7	6412932	Coal	111.44		-	-16.832	15/12/2016
GNP4-Heb	316930.7	6412932	Coal	111.44		-	-1.608	15/12/2016
GNP4-LLd	316930.7	6412932	Coal	111.44		-	-21.18	15/12/2016
GNP4-MLd	316930.7	6412932	Coal	111.44		-	-21.453	15/12/2016
GNP4-PG	316930.7	6412932	Coal	111.44		-	-8.641	15/12/2016
GNP4-ULd	316930.7	6412932	Coal	111.44		-	-22.341	15/12/2016
GNP5-Art	317864.7	6409317	Coal	86.26		-	25.381	15/12/2016
GNP5-Bar	317864.7	6409317	Coal	86.26		-	12.781	15/12/2016
GNP5-Heb	317864.7	6409317	Coal	86.26		-	9.63	15/12/2016
GNP5-Int	317864.7	6409317	Interburden	86.26	40	-	71.358	15/12/2016
GNP5-LLd	317864.7	6409317	Coal	86.26		-	17.801	15/12/2016
GNP5-MLd	317864.7	6409317	Coal	86.26		-	16.342	15/12/2016
GNP5-PG	317864.7	6409317	Coal	86.26	148	-	-0.223	15/12/2016
GNP5-ULd	317864.7	6409317	Coal	86.26		-	17.487	15/12/2016
GNP6-Art	317604.6	6411061	Coal	80.81		-	44.286	4/10/2013
GNP6-Bar	317604.6	6411061	Coal	80.81		-	30.062	15/12/2016
GNP6-Heb	317604.6	6411061	Coal	80.81		-	33.282	15/12/2016
GNP6-LLd	317604.6	6411061	Coal	80.81		-	31.482	15/12/2016

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
GNP6-MLd	317604.6	6411061	Coal	80.81		-	30.238	15/12/2016
GNP6-PG	317604.6	6411061	Coal	80.81		-	44.128	15/12/2016
GNP6-ULd	317604.6	6411061	Coal	80.81		-	39.005	15/12/2016
GNP8-Bar	319387.7	6407393	Coal	82.89		-	26.326	31/08/2015
GNP8-Heb	319387.7	6407393	Coal	82.89		-	25.404	31/08/2015
GNP8-LLd	319387.7	6407393	Coal	82.89		-	29.876	31/08/2015
GNP8-MLd	319387.7	6407393	Coal	82.89		-	42.991	31/08/2015
GNP8-ULd	319387.7	6407393	Coal	82.89		-	53.262	31/08/2015
GW079793	317730	6411962	Interburden			-	85.04	13/02/2007
MOP812-26	324128	6414863	Interburden	199.73	300	26	-	-
MOP812-35	324128	6414863	Interburden	199.73	300	35	-	-
MOP812-45	324128	6414863	Interburden	199.73	300	45	-	-
MOP812-73	324128	6414863	Interburden	199.73	300	73	-	-
MOP812-91	324128	6414863	Interburden	199.73	300	91	-	-
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
NPZ107D	324157.61	6411763.18	Coal	104.04	39	-	-	-
NPZ108D	323873.68	6409957.07	Coal	87.82	44	-	-	-
NPZ109D	321139.35	6409992.6	Coal	91.17	64	-	-	-
NPZ10	320961	6411696	Interburden	116.62	27	-	90.13	15/03/2017
NPZ10a	320961	6411696	Interburden	116.62	61	-	79.44	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
NPZ11	318059.4	6412639	Interburden	100.68	61	-	86.02	22/03/2017
NPZ11a	318059.4	6412639	Coal	100.68	102	-	60.02	22/03/2017
NPZ12	318440.4	6411519	Interburden	112.25	48	-	91.86	22/03/2017
NPZ12a	318440.4	6411519	Coal	112.25	97	-	58.82	1/03/2017
NPZ13	318302.4	6409556	Interburden	77.98	70	-	65.23	22/03/2017
NPZ13a	318302.4	6409556	Interburden	77.98	134	-	49.15	22/03/2017
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
NPZ16	318193.4	6409141	Interburden	75.7	60	-	71.2	22/03/2017
NPZ16a	318184	6409127	Coal	75.7	173	-	27.37	2/03/2016
NPZ1a	323213	6413286	Interburden	126.2	130	-	97.82	22/03/2017
NPZ3a	321182	6410365	Interburden	93.53	30	-	54.01	15/03/2017
NPZ4	319534	6415151	Interburden	124.84	60	-	119.03	1/03/2017
NPZ4a	319534	6415151	Interburden	124.84	110	-	119.1	1/03/2017
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

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
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
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
PZ-4-455	322786.68	6409232.79	Interburden	82.4	455	-	-124.379	17/01/2013
SMC002-BY3	322098.3	6410658	Coal	113.01	178	-	-19	11/08/2013
SMC002-BY5	322098.3	6410658	Coal	113.01	188.5	-	-18.524	12/08/2013
SMC002-int	322098.3	6410658	Interburden	113.01	56	-	70.517	15/12/2016
SMC002-RFL	322098.3	6410658	Interburden	113.01	138	-	32.547	30/07/2013
SMC002-RNL	322098.3	6410658	Interburden	113.01	107	-	75.88	23/12/2013
SMC002-RTU	322098.3	6410658	Interburden	113.01	48	-	74.349	15/12/2016
SMO023-Ban	322088.1	6411418	Interburden	110.85	13	-	99.454	15/12/2016
SMO023-BY3	322088.1	6411418	Coal	110.85	208.5	-	43.176	15/12/2016
SMO023-BY5	322088.1	6411418	Coal	110.85	215	-	41.39	15/12/2016
SMO023-RFL	322088.1	6411418	Interburden	110.85	180.5	-	63.662	15/12/2016

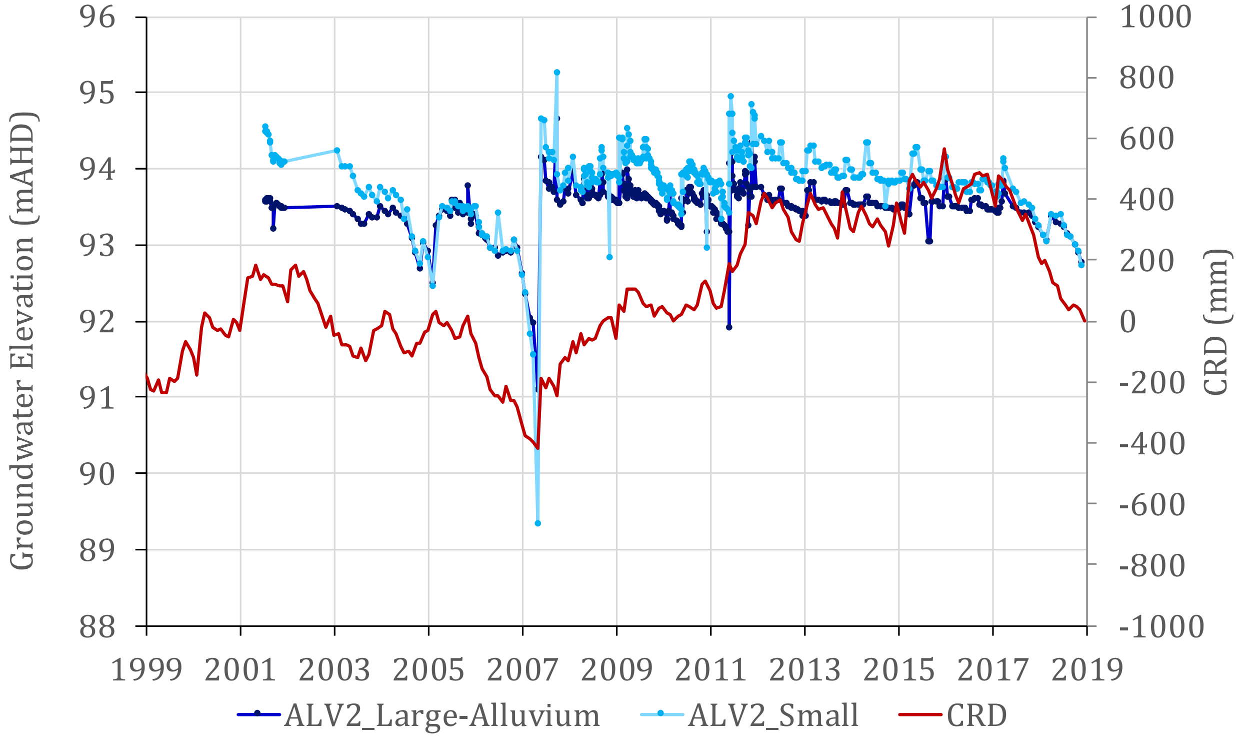
Bore ID	Easting (m) GDA94 Zone 56	Northing (m) GDA94 Zone 56	Aquifer	Ground elevation (mAHD)	Bore depth (mbgl)	Screened interval (mbgl)	SWL (mAHD)	Date SWL measured
SMO023-RNL	322088.1	6411418	Interburden	110.85	155.5	-	59.451	15/12/2016
SMO023-RTU	322088.1	6411418	Interburden	110.85	84	-	79.27	15/12/2016
SMO023-RVU	322088.1	6411418	Interburden	110.85	59	-	80.074	15/12/2016
SMO028-Bay	323346	6411410	Interburden	109.65	183	20	89.079	15/12/2016
SMO028-LBA	323346	6411410	Interburden	109.6485	183	128.5	99.263	15/12/2016
SMO028-LBG	323346	6411410	Interburden	109.6485	183	109.5	83.840	15/12/2016
SMO028-LBJ	323346	6411410	Interburden	109.6485	183	100	101.733	15/12/2016
SMO028-LCF	323346	6411410	Interburden	109.6485	183	77.2	93.493	15/12/2016
SMO028-LDF	323346	6411410	Interburden	109.6485	183	42.5	126.605	15/12/2016
GNOH030_S836	317765	6410554	Coal	84.6	196	196	-	-
GNOH030_316-584	317765	6410554	Interburden	84.6	187	187	-	-
GNOH030_316-583	317765	6410554	Coal	84.6	156.5	156.5	-	-
GNOH030_316-582	317765	6410554	Coal	84.6	94.5	94.5	-	-
GNOH030_316-653	317765	6410554	Coal	84.6	66.4	66.4	-	-
GNOH030_316-652	317765	6410554	Interburden	84.6	50	50	-	-
GNOH031_S858	319347	6410706	Coal	95.2	216	216	-	-
GNOH031_S827	319347	6410706	Interburden	95.2	195	195	-	-
GNOH031_S815	319347	6410706	Coal	95.2	147	147	-	-
GNOH031_316-656	319347	6410706	Interburden	95.2	95	95	-	-
GNOH031_316-655	319347	6410706	Coal	95.2	80.5	80.5	-	-
GNOH031_316-654	319347	6410706	Coal	95.2	44.5	44.5	-	-
GNOH032_S860	318066	6409354	Interburden	75.7	200	200	-	-
GNOH032_S830	318066	6409354	Coal	75.7	171.5	171.5	-	-

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
GNOH032_S831	318066	6409354	Interburden	75.7	157.5	157.5	-	-
GNOH032_S876	318066	6409354	Coal	75.7	95.75	95.75	-	-
GNOH032_S875	318066	6409354	Interburden	75.7	82.5	82.5	-	-
GNOH032_S874	318066	6409354	Coal	75.7	48.4	48.4	-	-
SMO076R_316-462	323968	6412102	Coal	121.8	298	298	-	-
SMO076R_316-461	323968	6412102	Interburden	121.8	270	270	-	-
SMO076R_316-460	323968	6412102	Coal	121.8	218	218	-	-
SMO076R_316-577	323968	6412102	Coal	121.8	185	185	-	-
SMO076R_316-446	323968	6412102	Coal	121.8	119.3	119.3	-	-
SMO076R_316-651	323968	6412102	Interburden	121.8	80	80	-	-
SMO057_316-447	323895	6411588	Interburden	116.9	274	274	-	-
SMO057_316-375	323895	6411588	Coal	116.9	217.5	217.5	-	-
SMO057_316-315	323895	6411588	Coal	116.9	115	115	-	-
SMO057_316-301	323895	6411588	Interburden	116.9	73	73	-	-
SMO063_316-448	323850	6411141	Coal	107.35	300	300	-	-
SMO063_316-376	323850	6411141	Coal	107.35	240.7	240.7	-	-
SMO063_316-317	323850	6411141	Coal	107.35	202.6	202.6	-	-
SMO063_316-316	323850	6411141	Coal	107.35	133	133	-	-
SMO063_316-302	323850	6411141	Interburden	107.35	92.5	92.5	-	-
GNC021_S1467	319000	6413123	Coal	161.7	377.5	377.5	-	-
GNC021_S1466	319000	6413123	Interburden	161.7	280	280	-	-
GNC021_S1465	319000	6413123	Coal	161.7	260	260	-	-
GNC021_S1359	319000	6413123	Interburden	161.7	190	190	-	-
GNC021_S1358	319000	6413123	Coal	161.7	170	170	-	-

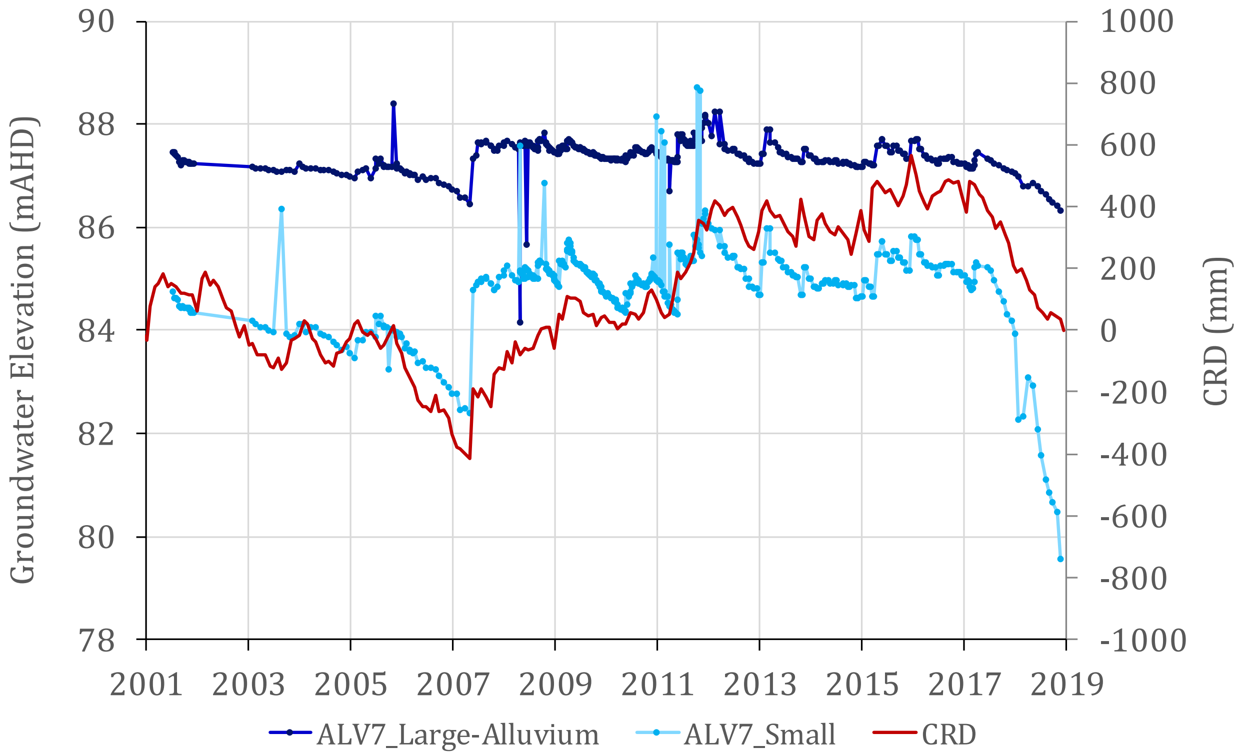
Bore ID	Easting (m) GDA94 Zone 56	Northing (m) GDA94 Zone 56	Aquifer	Ground elevation (mAHD)	Bore depth (mbgl)	Screened interval (mbgl)	SWL (mAHD)	Date SWL measured
GNC022_S1464	317906	6412655	Coal	96.2	229	229	-	-
GNC022_S1463	317906	6412655	Interburden	96.2	220	220	-	-
GNC022_S1351	317906	6412655	Coal	96.2	191	191	-	-
GNC022_S1357	317906	6412655	Coal	96.2	148	148	-	-
GNC022_S1356	317906	6412655	Coal	96.2	127	127	-	-
GNC022_S1355	317906	6412655	Coal	96.2	98.15	98.15	-	-
GNC022_S1346	317906	6412655	Interburden	96.2	75	75	-	-
GNC023_S1812	318122	6413294	Coal	101.5	285	285	-	-
GNC023_S1620	318122	6413294	Interburden	101.5	276	276	-	-
GNC023_S1619	318122	6413294	Coal	101.5	245	245	-	-
GNC023_S1570	318122	6413294	Coal	101.5	204	204	-	-
GNC023_S1569	318122	6413294	Coal	101.5	176	176	-	-
GNC023_S1568	318122	6413294	Coal	101.5	160	160	-	-
GNC023_S1567	318122	6413294	Interburden	101.5	142	142	-	-

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

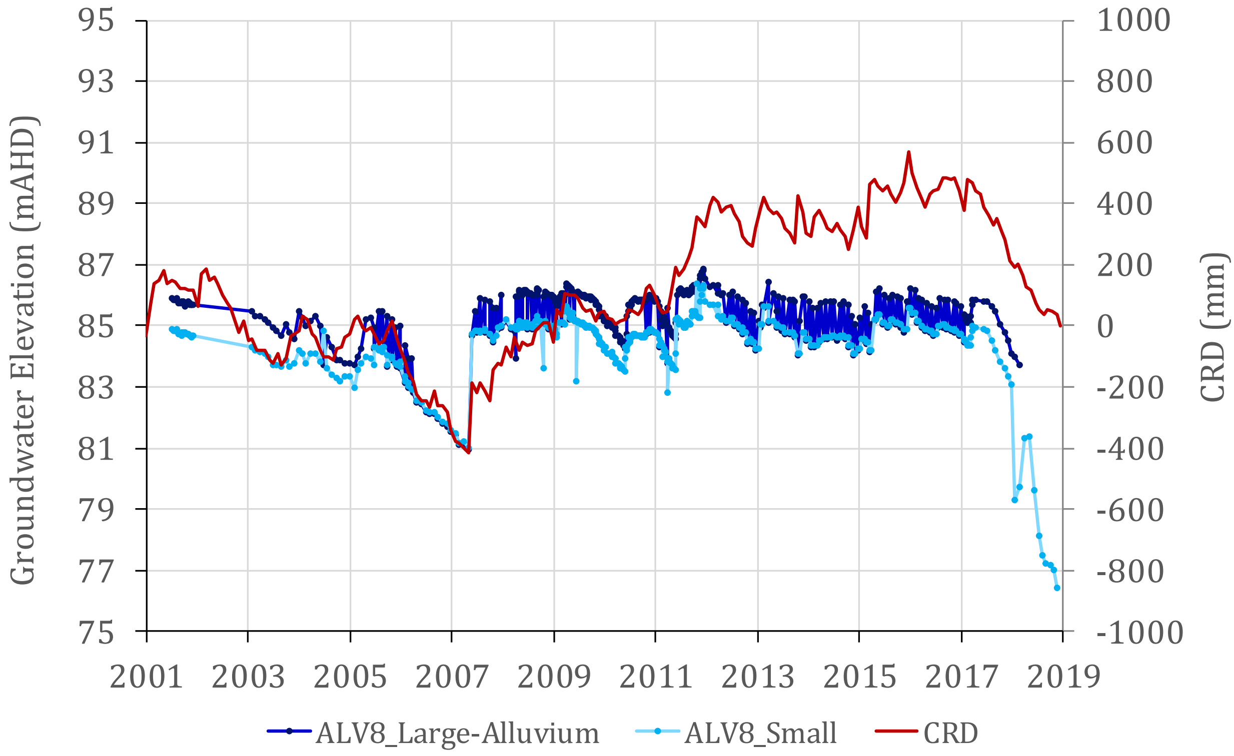
Appendix D Groundwater level hydrographs



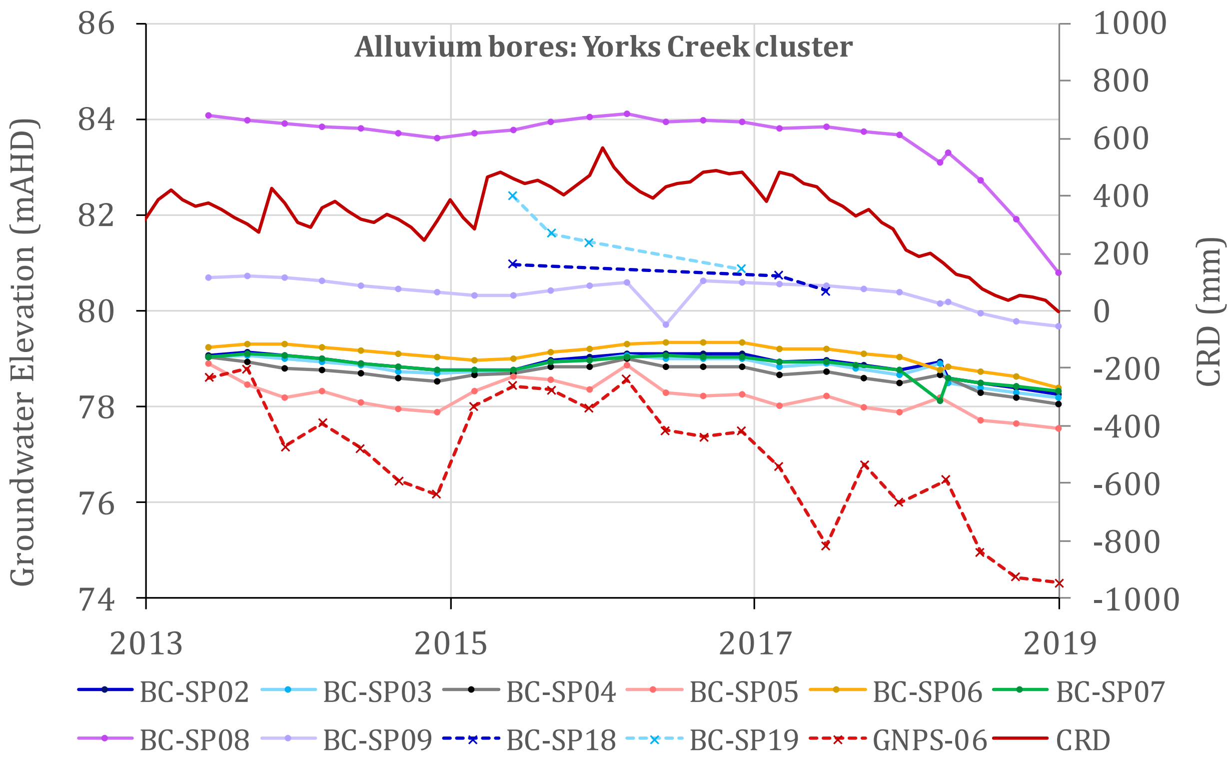
96
95
94
93
92
91
90
89
88
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Groundwater Elevation (mAHD)
CRD (mm)
1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019
ALV2_Large-Alluvium
ALV2_Small
CRD



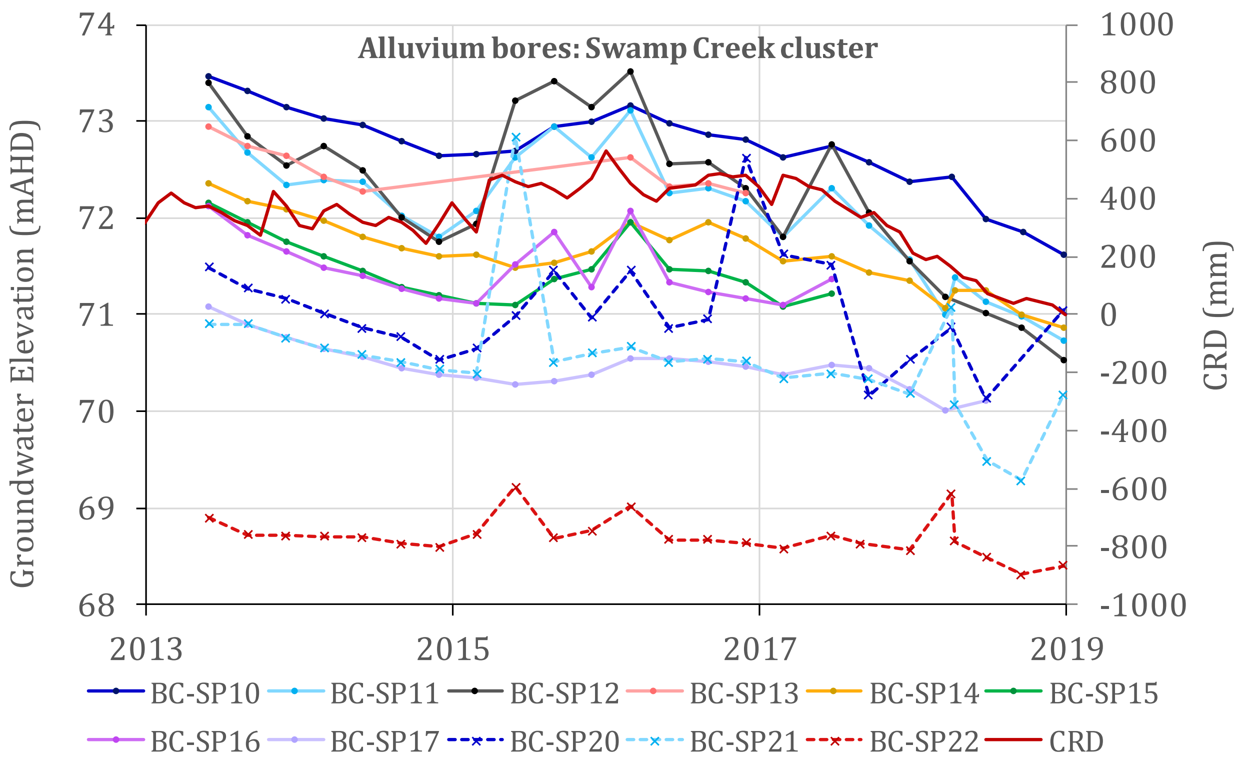
90
88
86
84
82
80
78
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Groundwater Elevation (mAHD)
CRD (mm)
2001 2003 2005 2007 2009 2011 2013 2015 2017 2019
ALV7_Large-Alluvium
ALV7_Small
CRD

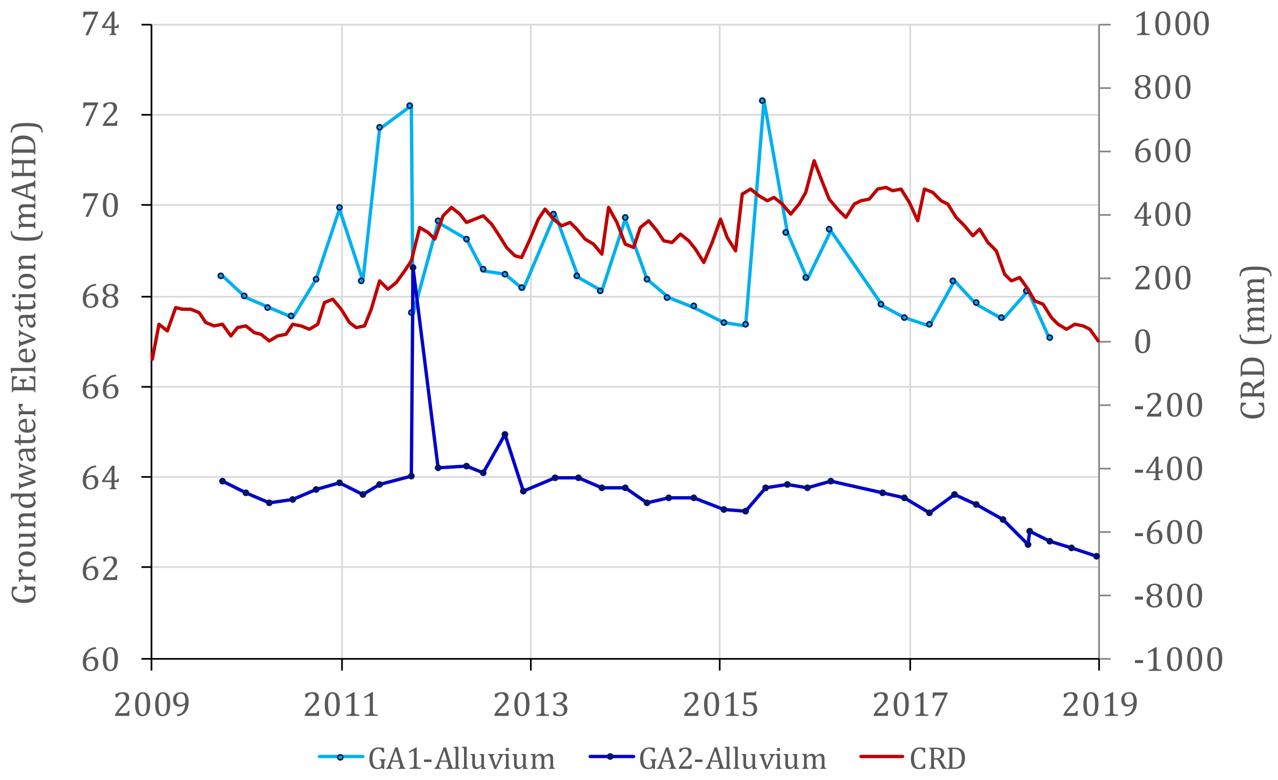


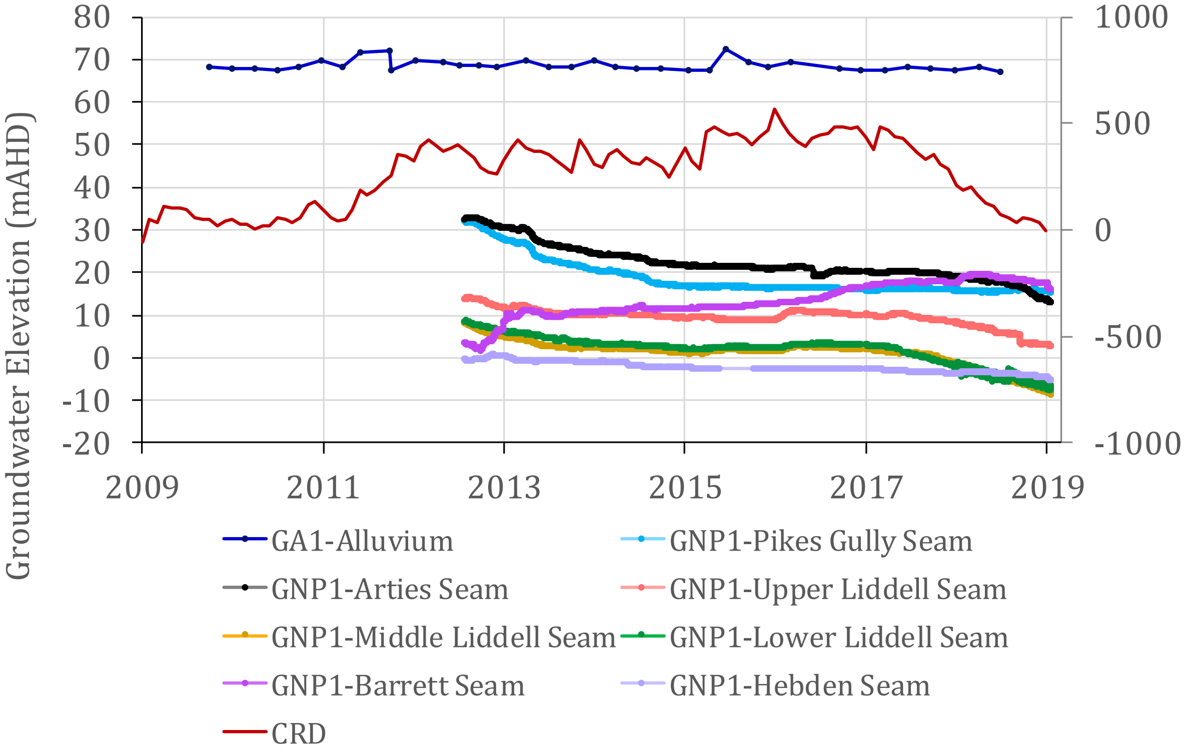
95
93
91
89
87
85
83
81
79
77
75
Groundwater Elevation (mAHD)
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
CRD (mm)
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
ALV8_Large-Alluvium
ALV8_Small
CRD



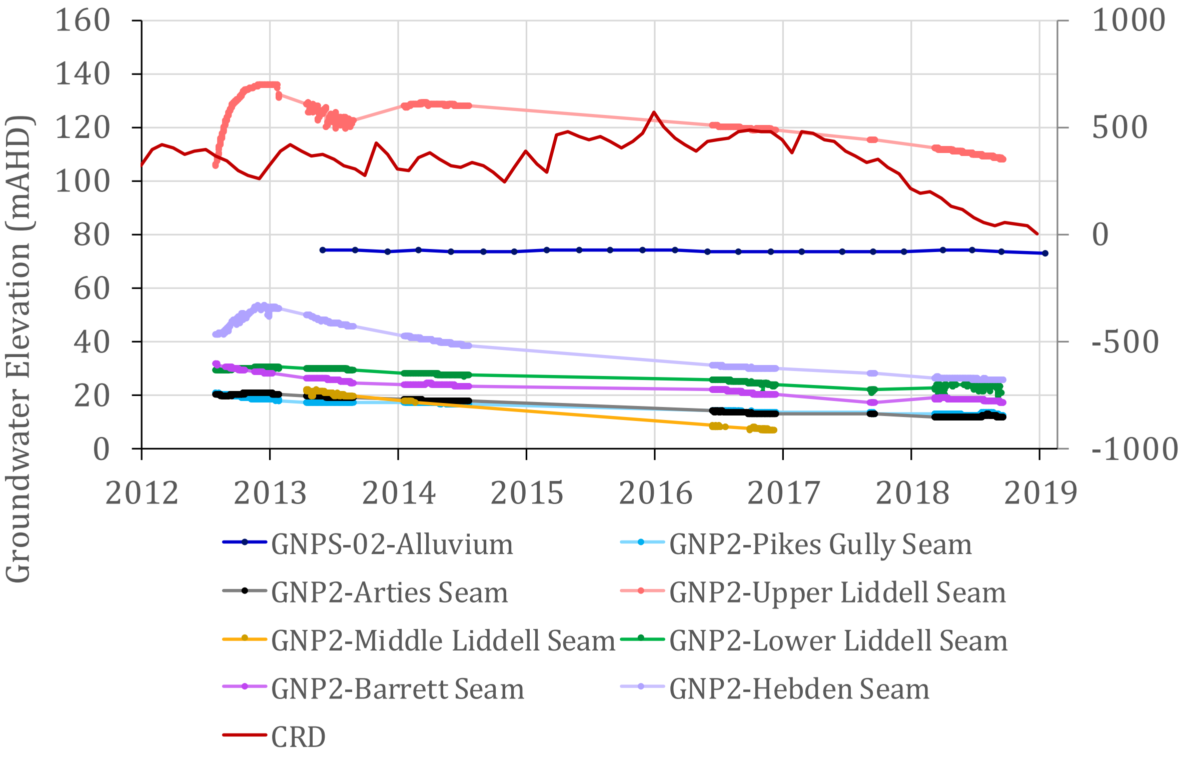
Alluvium bores: Yorks Creek cluster
86
84
82
80
78
76
74
Groundwater Elevation (mAHD)
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
CRD (mm)
2013
2015
2017
2019
BC-SP02
BC-SP03
BC-SP04
BC-SP05
BC-SP06
BC-SP07
BC-SP08
BC-SP09
BC-SP18
BC-SP19
GNPS-06
CRD


Alluvium bores: Swamp Creek cluster
Groundwater Elevation (mAHD)
CRD (mm)
74
73
72
71
70
69
68
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
2013
2015
2017
2019
BC-SP10
BC-SP11
BC-SP12
BC-SP13
BC-SP14
BC-SP15
BC-SP16
BC-SP17
BC-SP20
BC-SP21
BC-SP22
CRD

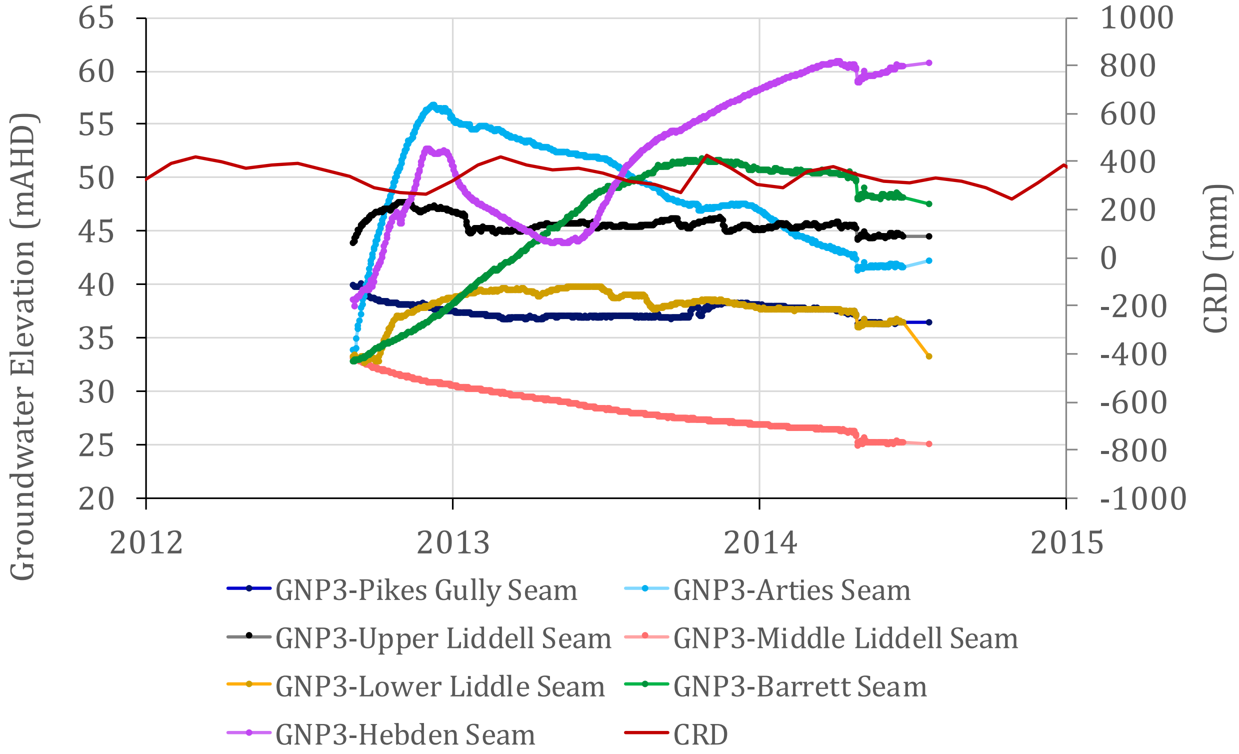

Groundwater Elevation (mAHD)
CRD (mm)
74
72
70
68
66
64
62
60
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
2009
2011
2013
2015
2017
2019
GA1-Alluvium
GA2-Alluvium
CRD



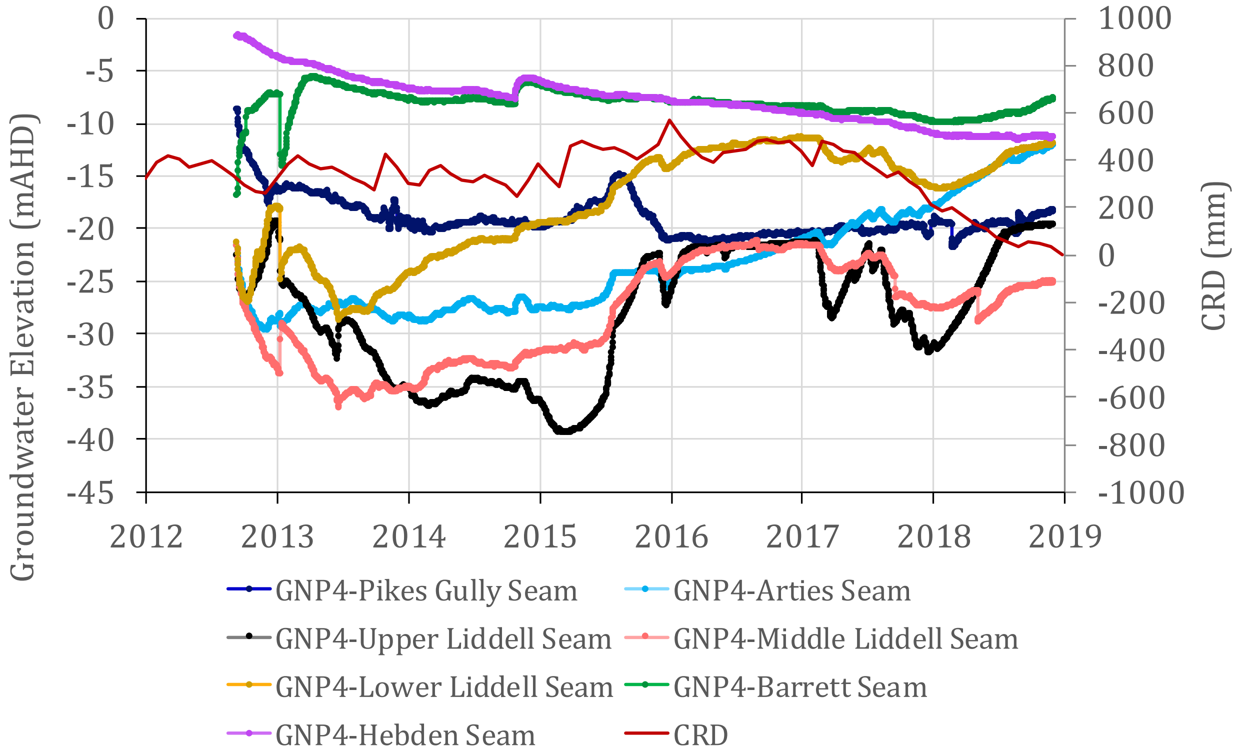
Groundwater Elevation (mAHD)
CRD (mm)
80
70
60
50
40
30
20
10
0
-10
-20
1000
500
0
-500
-1000
2009
2011
2013
2015
2017
2019
GA1-Alluvium
GNP1-Pikes Gully Seam
GNP1-Arties Seam
GNP1-Upper Liddell Seam
GNP1-Middle Liddell Seam
GNP1-Lower Liddell Seam
GNP1-Barrett Seam
GNP1-Hebden Seam
CRD



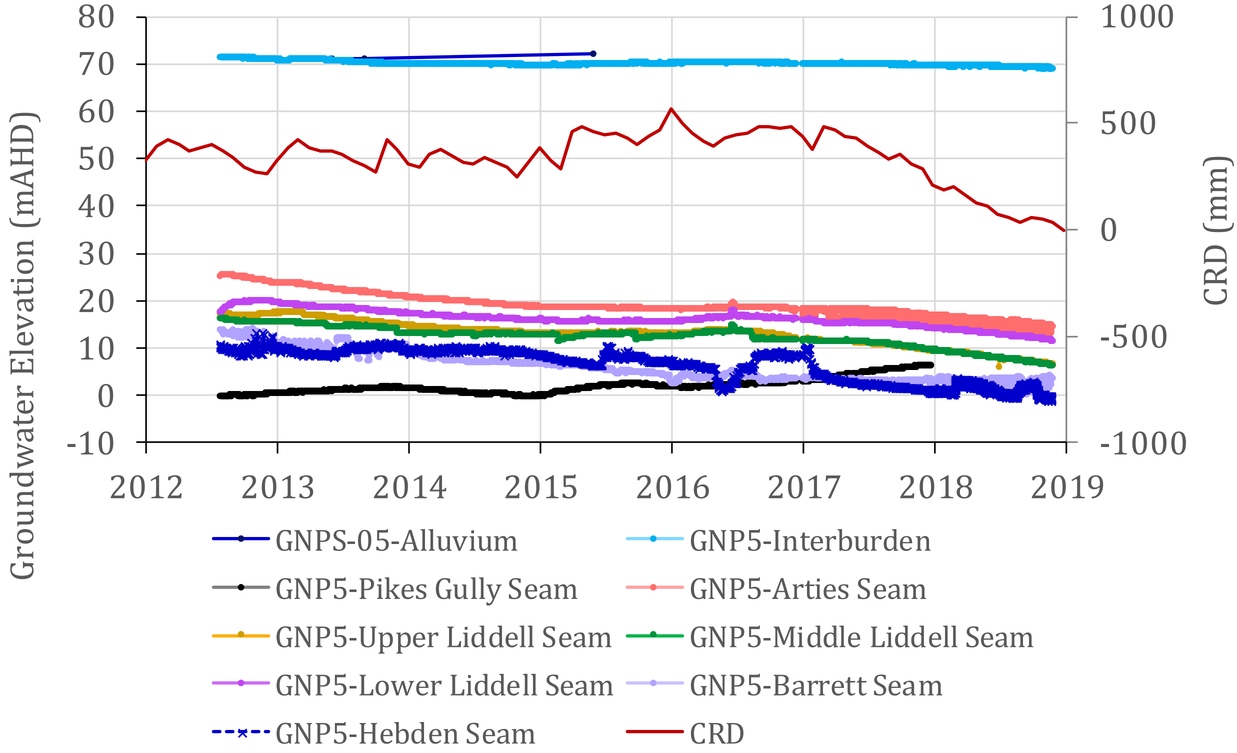
Groundwater Elevation (mAHD)
CRD (mm)
160
140
120
100
80
60
40
20
0
1000
500
0
-500
-1000
2012
2013
2014
2015
2016
2017
2018
2019
GNPS-02-Alluvium
GNP2-Pikes Gully Seam
GNP2-Arties Seam
GNP2-Upper Liddell Seam
GNP2-Middle Liddell Seam
GNP2-Lower Liddell Seam
GNP2-Barrett Seam
GNP2-Hebden Seam
CRD

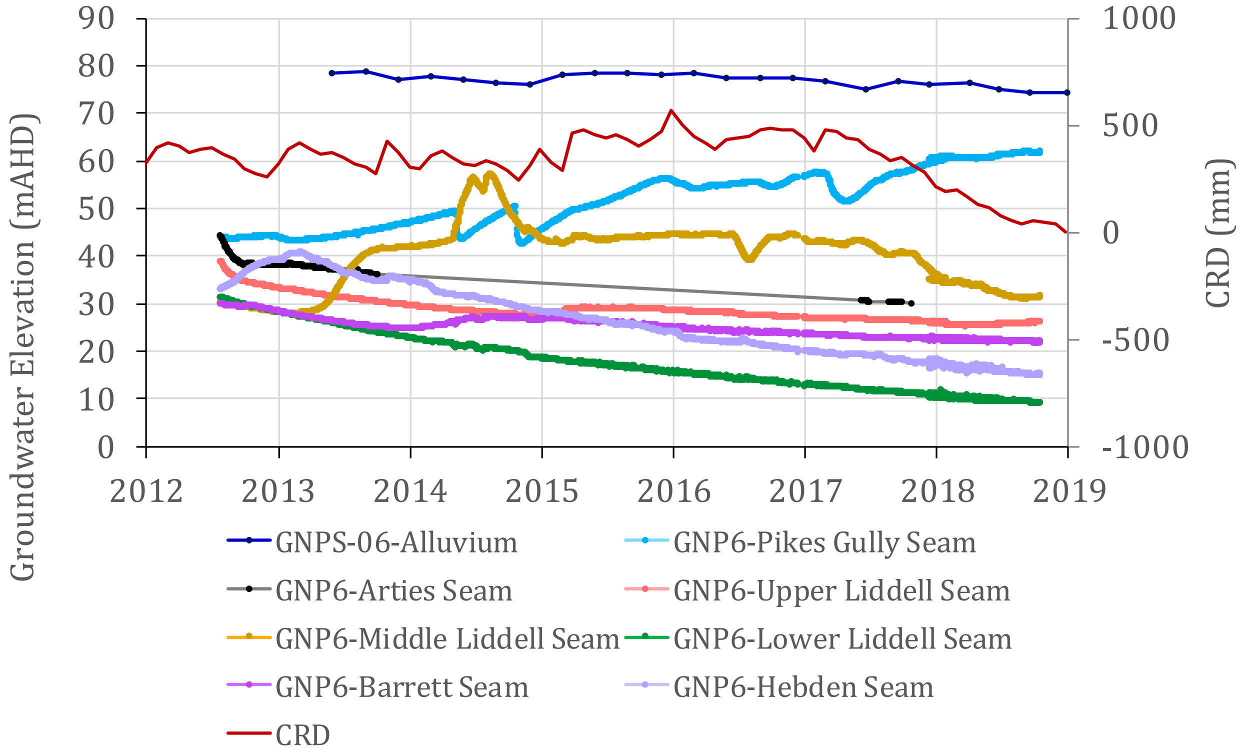


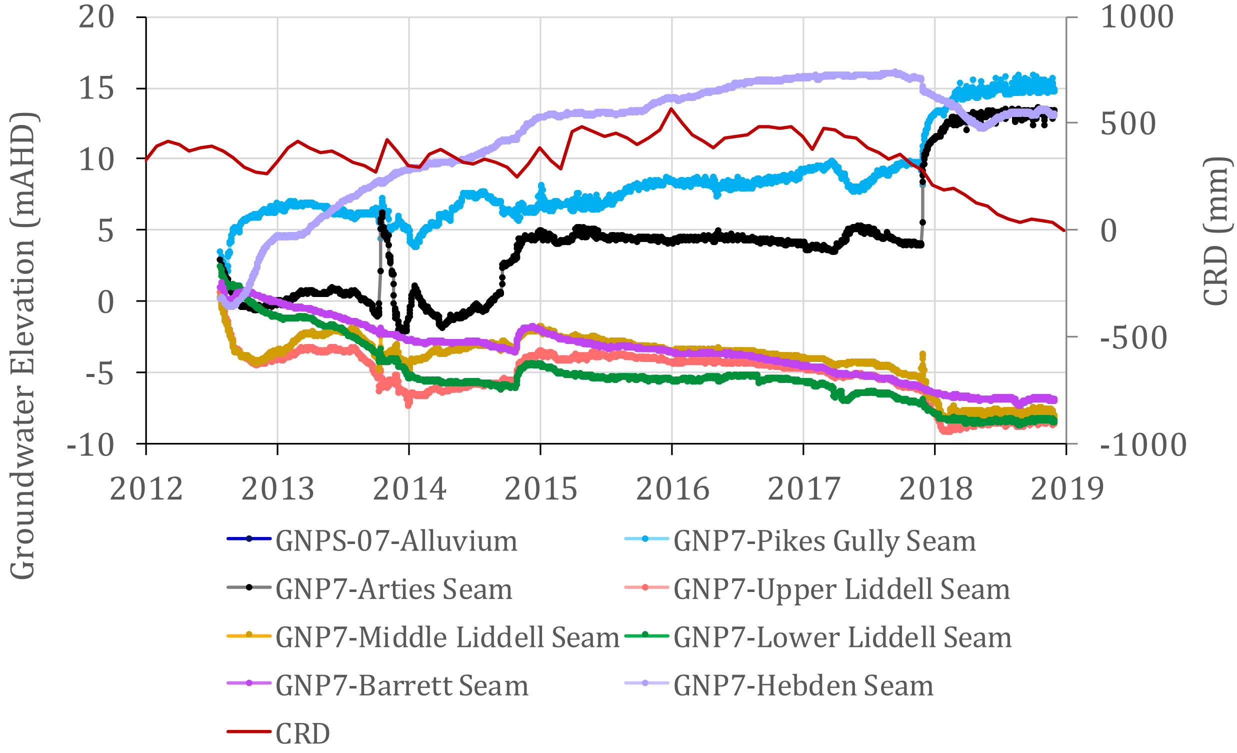
Groundwater Elevation (mAHD)
CRD (mm)
65
60
55
50
45
40
35
30
25
20
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
2012
2013
2014
2015
GNP3-Pikes Gully Seam
GNP3-Arties Seam
GNP3-Upper Liddell Seam
GNP3-Middle Liddell Seam
GNP3-Lower Liddle Seam
GNP3-Barrett Seam
GNP3-Hebden Seam
CRD

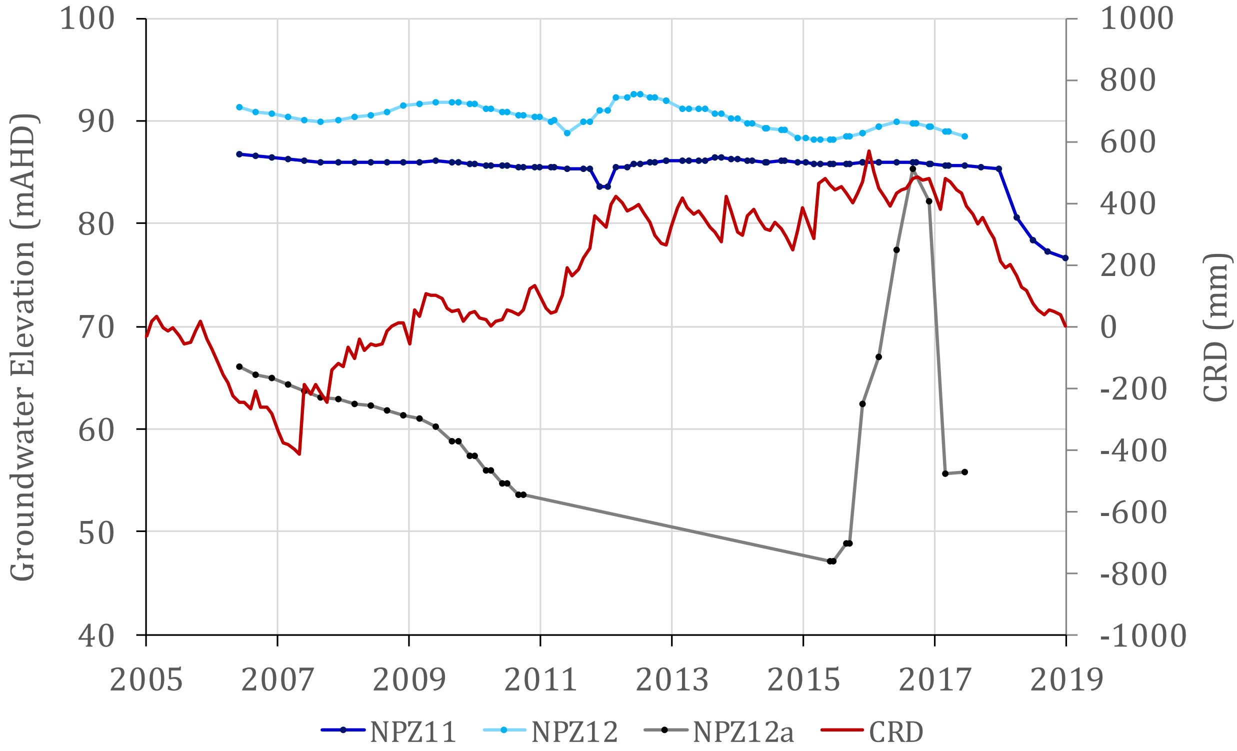


Groundwater Elevation (mAHD)
CRD (mm)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
2012
2013
2014
2015
2016
2017
2018
2019
GNP4-Pikes Gully Seam
GNP4-Arties Seam
GNP4-Upper Liddell Seam
GNP4-Middle Liddell Seam
GNP4-Lower Liddell Seam
GNP4-Barrett Seam
GNP4-Hebden Seam
CRD


80
70
60
50
40
30
20
10
0
-10
Groundwater Elevation (mAHD)
1000
500
0
-500
-1000
CRD (mm)
2012
2013
2014
2015
2016
2017
2018
2019
GNPS-05-Alluvium
GNP5-Interburden
GNP5-Pikes Gully Seam
GNP5-Arties Seam
GNP5-Upper Liddell Seam
GNP5-Middle Liddell Seam
GNP5-Lower Liddell Seam
GNP5-Barrett Seam
GNP5-Hebden Seam
CRD


90
80
70
60
50
40
30
20
10
0
Groundwater Elevation (mAHD)
1000
500
0
-500
-1000
CRD (mm)
2012
2013
2014
2015
2016
2017
2018
2019
GNPS-06-Alluvium
GNP6-Pikes Gully Seam
GNP6-Arties Seam
GNP6-Upper Liddell Seam
GNP6-Middle Liddell Seam
GNP6-Lower Liddell Seam
GNP6-Barrett Seam
GNP6-Hebden Seam
CRD


Groundwater Elevation (mAHD)
CRD (mm)
20
15
10
5
0
-5
-10
1000
500
0
-500
-1000
2012
2013
2014
2015
2016
2017
2018
2019
GNPS-07-Alluvium
GNP7-Pikes Gully Seam
GNP7-Arties Seam
GNP7-Upper Liddell Seam
GNP7-Middle Liddell Seam
GNP7-Lower Liddell Seam
GNP7-Barrett Seam
GNP7-Hebden Seam
CRD


Groundwater Elevation (mAHD)
CRD (mm)
100
90
80
70
60
50
40
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
2005
2007
2009
2011
2013
2015
2017
2019
NPZ11
NPZ12
NPZ12a
CRD

Appendix E Compliance with government policy

E1 Compliance with NSW government policy

This section discusses the ability of the Glendell Pit Extension to comply with the AIP. Table E 1-1 to Table E 1-3 below compare the groundwater impact predictions for the Glendell Pit Extension against the requirements under the AIP.

Table E 1-1 Accounting for or preventing the take of groundwater

AIP requirement		Proponent response
1	Described the water source (s) the activity will take water from?	Section 2.2 describes the water sources in the area of the activity which are: • Sydney Basin North Coast Water Source • Jerrys Water Source • Glennies Water Source • Hunter Regulated River Alluvial 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 7-2 summarises the peak take of surface water and groundwater from each water source due to the impacts from approved mining and the additional incremental effect of the Glendell Pit Extension on groundwater systems. Table 7-1 provides estimates of water taken on an annual basis as a con sequence of the Project's impacts on groundwater systems.
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?	Table 7-3 summarises the peak take of surface water and groundwater from each water source after closure of the activity associated with the Project's impacts on aquifer systems.
4	Made these predictions in accordance with Section 3.2.3 of the AIP? (page 27)	Based on 3D numerical modelling including approved and foreseeable cumulative impacts.
5	Described how and in what proportions this take will be assigned to the affected aquifers and connected surface water sources?	Table 7-2 and Table 7-3 summarise the peak take of surface water and groundwater from each water source due to the impacts of the approved mining and the additional incremental effect of the Glendell Pit Extension on groundwater systems.
6	Described how any licence exemptions might apply?	Not necessary, no exemptions sought in relation to groundwater take.
7	Described the characteristics of the water requirements?	Refer to surface water assessment.

AIP requirement		Proponent response
8	Determined if there are sufficient water entitlements and water allocations that are able to be obtained for the activity?	Licences are required to be held at the time of actual or predicted take. Section 2. includes a list of the entitlements currently held by Glencore in relation to the Mount Owen Complex. These entitlements also relate to predicted take associated with approved operations at Mount Owen which are not considered in this assessment. Section 7.2.7 and 7.3.4 summarises the peak predicted water take during operations and post closure. It indicates the current entitlements adequately account for the predicted water take from the North Coast Fractured and Porous Rock WSP by the proposed activity. There is predicted to be a small groundwater take from Jerrys Water Source during operations. This take is not predicted to occur until approximately year 12. There are currently 1246 units available for trade within the Jerrys water source and transfers between surface and groundwater systems are permitted under the trading rules. The predicted water take attributable to the Project should be able to be readily sourced on the market prior to the predicted take occurring. There is also predicted to be a very small take of groundwater from the Hunter Regulated River alluvium (Zone 3) occurring post mining. The volume is considered also small compared to the units available for trade within the water source. Again, the predicted water take attributable to the Project should be able to be readily sourced on the market prior to the predicted take occurring.

AIP requirement		Proponent response
9	Considered the rules of the relevant water sharing plan and if it can meet these rules?	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 40 m of an unregulated river, except for Domestic and Stock access licences and Local Water Utilities Access licences."* The predicted take of water from the Jerrys and Glennies Water Source 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 relevant as it is designed for active pumping sites.
10	Determined how it will obtain the required water?	Via seepage to the mine face – a majority will be removed as moisture in coal or evaporation and will not enter the site water circuit (Refer to section 7.2.1)

AIP requirement		Proponent response
11	Considered the effect that activation of existing entitlement may have on future available water determinations?	Future available water determinations are a matter for the NSW government. The following WALs and share components are available for each of the water sources to be impacted by the approved and proposed activity: • Sydney Basin North Coast Water Source - 164 WALs and 63575.5 aquifer licence shares • Jerrys Water Source – 10 WALs and 1,246 aquifer licence shares • Glennies Water Source – 2 WALs and 10 aquifer licence shares • Hunter Regulated River alluvial water source – 224 WALs and 24118 aquifer license shares The volume of water estimated to be taken by the activity, is considered an insignificant component of the existing entitlement of the Sydney Basin North Coast Water Source and the Jerrys Water Source. There is predicted to be a very small take of groundwater from the Glennies Water Source occurring post mining associated with the approved and proposed mining at Glendell (approximately 1 ML/year). This predicted impact will be subject to further validation as mining progresses, to determine if there is a need to secure a water license from the Glennies Water Source. It is also noted that the Hunter Unregulated WSP is currently under review and the anomaly regarding the low number of aquifer units in the Glennies waster source and the inability to transfer between surface and alluvial licence shares has been identified in submissions made during this review process.
12	Considered actions required both during and post-closure to minimise the risk of inflows to a mine void as a result of flooding?	Refer to the Surface Water Impact Assessment (GHD, 2019) for further information.

AIP requirement		Proponent response
13	Developed a strategy to account for any water taken beyond the life of the operation of the Project?	The strategy is to allocate existing and future water entitlements to the Glendell Pit Extension water takes as required to account for take of water after closure of the activity. Further detailed groundwater modelling will be undertaken prior to mine closure to confirm the likely take having regard to any changes to groundwater systems that may have occurred between now and then as aa consequence of any changes to approved mining.
	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 amount of mining has occurred in the Glendell Pit and in the surrounding region, and monitoring has not detected any unforeseen impacts on the environment or authorised water users. Given this, the identified 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?	A blasting assessment by Enviro Strata Consulting Pty Ltd (2019) concluded the proposed open cut mining will not generate fractures that extend a significant distance (less than 30 metres) beyond the pit shell. Any fracturing is predicted to be very small and would selfheal over time, limiting any risks associated with increased permeability that may occur soon after blasting.
15	Quantified any other uncertainties in the groundwater or surface water impact modelling conducted for the activity?	Sources of uncertainty identified and discuss in Section B2.2. Includes uncertainty introduced through geology, parameters, measurement error and scenarios. An uncertainty analysis was completed to identify model features and parameters that influence in the nature of model 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 will be undertaken as outlined in the operations Water Management Plan.

Table E 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 E 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 specifically for the Glendell Pit Extension since 2012. 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?	There are no high-priority GDEs in the region of the Glendell Pit Extension.
6	Potential for increased saline or contaminated water inflows to aquifers and highly connected river systems?	The final void will act as a 'groundwater sink' with the salinity balance indicating the salinity will slowly rise but remain lower that the salinity levels within Permian strata over the modelling period.
7	Potential to cause or enhance hydraulic connection between aquifers?	Only open cut mining is proposed which is not expected to generate significant fracturing beyond the pit shell.
8	Potential for river bank instability, or high wall instability or failure to occur?	Geotechnical studies have been undertaken to inform the mine design. Further detailed geotechnical studies will be undertaken prior to the Project reaching its full extent to confirm final landform high wall design to avoid instability risk. Refer to Surface Water Impact Assessment (GHD, 2019) and Rehabilitation Strategy (Umwelt 2019).
9	Details of the method for disposing of extracted activities (for CSG activities)?	Not applicable to the proposed activity.

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 consideration thresholds will not be exceeded.

E2 Compliance with Commonwealth government policy

As noted in Section 2.6, the Project was referred to DoEE to determine whether it should be categorised as a 'controlled action'. At the time of referral, detailed surface and groundwater studies had not been finalised. In the absence of study results, the Project was identified as having potential to significantly impact on water resources. The EPBC Act referral was placed on exhibition for public comment on 12 April 2019. On 10 July 2019, the referred action was determined to be a controlled action and therefore requires approval under the EPBC Act.

This section of the report considers the impact of the Glendell Pit Extension on groundwater resources, and if these impacts are significant according to the "Significant impact guidelines 1.3, Commonwealth of Australia 2013". It compares the predicted impacts against the DoE guidelines to determine if the Glendell Pit Extension 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 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 Glendell Pit Extension 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 Glendell Pit Extension, not the impact of the approved operations.

E2.1.1 Water availability to users

There is very limited groundwater usage via bores and wells in the area of the Glendell Pit Extension. This is generally due to the water quality in the aquifers in the area and the low flow rates in bores. The NSW government water bore database indicate there are two registered bores located on private property to the west of the Glendell Pit Extension. The numerical modelling indicates the Glendell Pit Extension will not generate significant drawdown (>0.2 m) at the locations of these bores.

E2.1.2 Water availability to the environment

Baseline groundwater monitoring data collected to date indicates that depressurisation of the Permian strata due to the approved mining in the region has reduced the flow of groundwater to the alluvial aquifer along Bowmans Creek. The numerical modelling indicates the depressurisation due to the Glendell Pit Extension will further reduce the flow of Permian groundwater to the alluvial aquifers during mining. This reduction in groundwater flow will result in a zone of drawdown occurring within the Bowmans Creek alluvial aquifer that is largely less than 1 m. This drawdown may be difficult to discern from climatic influences and impacts from approved surrounding mining. Whilst drawdown is predicted, the alluvial aquifer will remain saturated and any riparian vegetation occurring along Bowmans Creek that depends on groundwater will have continuing access to the water table, albeit at a slightly deeper level.

Whilst the level of vegetation dependence is not known, the water level fluctuations observed within the monitoring network exceed the level of drawdown predicted from the Glendell Pit Extension, and therefore a long term impact on the vegetation is considered improbable. This conclusion is supported by the lack of obvious impact to vegetation from the mining conducted to date that has depressurised the Permian strata and resulted in the potentiometric surface with the coal measures falling below the base of the alluvium.

E2.1.3 Water quality

The post mining pit lake water levels are predicted to recover to a new equilibrium level approximately 130 m below pre-mining groundwater levels, indicating that the voids will act as a sink in perpetuity with no escape of contained void water. The groundwater level will also recover within the backfilled spoil deposited with the pit shell, but the water table will remain below surrounding groundwater levels, promoting an inward gradient.

E2.1.4 Cumulative impacts

Cumulative impacts of existing and approved mining in the region of the Glendell Pit Extension are significant. Large mines targeting the same coal seams surround the Glendell Pit Extension and all depressurise the Permian strata. Logically the drawdown that is most attributable to the Glendell Pit Extension is that adjacent to the open cut mining area, with the zone of influence reducing with distance. The location of the mining in the Glendell Pit along the hinge of the Camberwell anticline will also limit the Project's impacts on adjacent alluvial groundwater systems. The impact assessment has concluded the Glendell Pit Extension will only add a very limited 'water take' and drawdown compared to the already approved mines. Maximum impacts on water table drawdown in the model are attributed to other mining operations except in areas immediately adjacent to the Glendell Pit. Post mining the groundwater regime will slowly recover and develop a new equilibrium in response to the changed landforms. The Projects impacts on alluvial aquifer systems are effectively limited to a delay in the rate of recovery of these systems rather than any change to the magnitude of impacts.

E2.1.5 Avoidance or mitigation measures

The groundwater seepage from Permian aquifers to the mining areas cannot be prevented or avoided and must be removed to ensure safe operating conditions within the mining areas. The use of low permeability barriers in the alluvium in Yorks Creek and Swamp Creek downstream of the intersection of the Glendell Pit Extension has been modelled with no material improvement in terms of reduced take. Given the generally low levels of predicted take and the Project's negligible impact on watertable levels relative to approved operations, the use of low permeability barriers is not considered to be necessary.

There are no private groundwater users predicted to be measurably impacted within proximity to the Glendell Pit Extension and therefore mitigation measures or make good measures with affected land owners are not required.

E2.1.6 Tabulated impacts

Table E 2-1 and Table E 2-2 summarise the conclusions compared against the Commonwealth guidelines for significant impacts:

Table E 2-1 Summary of impacts to the hydrology of the water resource compared to the significant impact 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 during operations with some peaks 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 negligible small compared to surface water flows within the creek systems. Reductions in baseflows are not predicted to have a measurable effect on flows in Bowmans Creek (GHD 2019)
recharge rates?	Recharge rates may be altered due to mine spoil heaps – this has been assessed using numerical modelling.
aquifer pressure or pressure relationships between aquifers?	Pressures will reduce in coal measures 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. The impact of existing approved operations is predicted to result in a lowering of groundwater levels in the alluvium with the project predicted to have no impact on the magnitude of this lowering of watertables other than in a limited area immediately adjacent to the Glendell Pit Extension. The Projects impacts on the water table in alluvial systems is effectively limited to a slowing of the rate of recovery.
groundwater/surface interactions?	Water table drawdown within the Quaternary alluvium will be unlikely to produce detectable changes in base flow to or from interconnected streams relative to approved conditions.
river/floodplain connectivity?	Alluvial tributaries of Swamp Creek and Bowmans Creek that flow to the Bowmans Creek alluvium will be removed by mining. Monitoring indicates limited saturation within the alluvium where the mining is proposed and therefore inflow rates from the exposed alluvium will be low.
inter-aquifer connectivity?	No significant fracturing is considered likely outside pit shell.
coastal processes?	Not applicable
large scale subsidence?	Only open cut mining is proposed.
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 will develop a licencing strategy for potential minor alluvial water take in later phases of the operations.
cumulative impact?	Yes - extensive mining within the Permian strata has been assessed using a regional groundwater model.

Table E 2-2 Summary of impacts to the water quality of the water resource compared to the significant impact 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?	Evaporation will concentrate salts in the final void lake. The Void will operate as a long term hydraulic sink and will maintain sufficient freeboard in the pit lake to avoid surface discharge into the downstream environment. Long term recovery modelling indicates that watertable levels within the in-pit spoil areas directly connected to the pit lake will not reach levels above the low point in the pit crest.
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?	Evaporation will concentrate salt in the final void lake.
cumulative impact?	Cumulative impacts have been estimated using a numerical model – the project will not significantly exacerbate already approved cumulative impacts.
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

A summary of the IESC information guidelines and where they are addressed within the groundwater assessment report is provided below.

Table E 2-3 IESC Information Guidelines

Information requirement	Addressed in Sections
Description of the proposal	1
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, 5
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, 7
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.	4.1, .1, .2
definitions of any significant geological structures (e.g. faults) in the area and their influence on groundwater, in particular, groundwater flow, discharge or recharge	4.2.3, 5.10
Values for hydraulic parameters (e.g. vertical and horizontal hydraulic conductivity and storage characteristics) for each hydrogeological unit.	5.7
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.	5.4, 5.8 Appendix D

Information requirement	Addressed in Sections
Description of the likely recharge, discharge and flow pathways for all hydrogeological units likely to be impacted by the proposed development.	5.10
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, 5.6
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.	B 2
Undertaken in accordance with the Australian Groundwater Modelling Guidelines, including peer review	Appendix B and Appendix F
Calibration with adequate monitoring data, ideally with calibration targets related to model prediction (e.g. use baseflow calibration targets where predicting changes to baseflow).	B 3
Representations of each hydrogeological unit, the thickness, storage and hydraulic characteristics of each unit, and linkages between units, if any.	B 2.4.3
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.	B 2.5.1, B 2.5.6
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.	7
Identification of the volumes of water predicted to be taken annually with an indication of the proportion supplied from each hydrogeological unit.	7.2.1, 7.2.4
An explanation of the model conceptualisation of the hydrogeological system or systems, including key assumptions and model limitations, with any consequences described.	5.10
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.	B 2.5
Sensitivity analysis of boundary conditions and hydraulic and storage parameters, and justification for the conditions applied in the final groundwater model.	B 3.5

Information requirement	Addressed in Sections
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.	B2.2
A programme for review and update of the models as more data and information become available, including reporting requirements.	8
Information on the time for maximum drawdown and post-development drawdown equilibrium to be reached.	7.2.2, 7.3.1
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.	7.2.2, 7.2.3, 7.2.4
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.	7.2.5, 7.2.6
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.	B 2.5.6, B 3.5
Consideration of possible fracturing of and other damage to confining layers.	B 2.5.6
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.	7.2, 7.3
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.	7.2.4, 7.2.5, 7.2.6

Information requirement	Addressed in Sections
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.	Surface water assessment
An assessment of the cumulative impact of the proposal on groundwater when all developments (past, present and/or reasonably foreseeable) are considered in combination.	7.2.3
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.	5.7, 5.8.1
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.	5.2, 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.	5.2, 5.5, 5.8
Water quality monitoring complying with relevant National Water Quality Management Strategy (NWQMS) guidelines and relevant legislated state protocols.	5.2, 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.	5.9.2
Public health, recreation, amenity, Indigenous, tourism or agricultural values for each water resource.	N/a

Information requirement	Addressed in Sections
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.	Ecology report and 5.9.2
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.	Ecology report
An estimation of the ecological water requirements of identified GDEs and other water-dependent assets.	Ecology report
Identification of the hydrogeological units on which any identified GDEs are dependent.	Ecology report
An outline of the water-dependent assets and associated environmental objectives and the modelling approach to assess impacts to the assets.	5, B 2.4
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.	7.2.6
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.	7.2.5
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.	7.3.1
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.	Ecology report and 7.3
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.	Ecology report
An assessment of the overall level of risk to water-dependent assets that combines probability of occurrence with severity of impact.	Ecology report

Information requirement	Addressed in Sections
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.	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.	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.	5.2
Concurrent baseline monitoring from unimpacted control and reference sites to distinguish impacts from background variation in the region (e.g. BACI design).	5.2
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.	Ecology report
Regular reporting, review and revisions to the monitoring programme.	8
Ecological monitoring complying with relevant state or national monitoring guidelines.	Ecology report
Cumulative Impacts	
Context and conceptualisation	
Cumulative impact analysis with sufficient geographic and time boundaries to include all potentially significant water-related impacts.	7.2.3
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.	7.2.3
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.	7.2.3

Information requirement	Addressed in Sections
A description of the current condition and quality of water resources and information on condition trends.	5
Identification of ecological characteristics, processes, conditions, trends and values of water resources.	Ecology report and 5.9.2
Adequate water and salt balances.	Surface water report
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).	7.2, 7.3
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.	Ecology report and 7
An assessment of impacts considered at all stages of the development, including exploration, operations and post closure / decommissioning.	7.2, 7.3
An assessment of impacts, utilising appropriately robust, repeatable and transparent methods.	7, B 2-B 7
Identification of the likely spatial magnitude and timeframe over which impacts will occur, and significance of cumulative impacts.	7.2, 7.3
Identification of opportunities to work with others to avoid, minimise or mitigate potential cumulative impacts.	7.2.3
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

Appendix F Peer review

HydroAlgorithmics Pty Ltd ● ABN 25 163 284 991
PO Box 241, Gerringong NSW 2534. Phone: (+61 2) 4234 3802

noel.merrick@hydroalgorithmics.com

DATE: 28 November 2019

TO: David Holmes
Principal Environmental Consultant
Umwelt (Australia) Pty Limited
75 York Street
Teralba NSW 2284

FROM: Dr Noel Merrick

RE: Glendell Continued Operations Project – Groundwater Peer Review

YOUR REF: 41668

OUR REF: HA2019/16a

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1. Introduction

This report provides a peer review of the groundwater impact assessment (GIA) and associated modelling for the Glendell Continued Operations Project, located to the north-west of Singleton, NSW. The GIA has been prepared by Australasian Groundwater and Environmental Consultants (AGE) under the project management of Umwelt, for the client Glendell Tenements Pty Ltd, a subsidiary of Glencore Coal Pty Ltd. The existing open cut Glendell Mine is part of the Mount Owen Complex in the Upper Hunter Valley.

The main elements of the Glendell Pit Extension (the Project) that are relevant to groundwater assessment are:

- Extension of the open cut pit to the north (by about 3 km).
- Mining down to the base of the Hebden Seam.
- Extended mine life to 2044 (an additional 20 years).
- Overburden emplacement in-pit to the south as operations progress to the north.

As with the *Approved* Glendell Pit, the *Proposed* Glendell Pit Extension is to run approximately parallel to Bowmans Creek. It also will intercept the alluvia associated with Yorks Creek and Swamp Creek.

The reviewer conducted previous groundwater peer reviews in March 2018 on the Mount Owen Continued Operations Project Modification 2 to the east of Glendell, and in December 2017 for the Integra Underground Modification 8 to the south-east of Glendell.

2. Documentation

The review is based on the following report:

1. AGE, 2019, Groundwater Impact Assessment Glendell Continued Operations Project. Project G1874C Final report prepared for Umwelt (Australia) Pty Limited, 28 October 2019. 120p (main) + 5 Appendices.

Groundwater modelling details are in Appendix B of Document #1:

2. AGE, 2019, Numerical Modelling. Appendix B, 161p.

Document #1 has the following major sections:

1. Introduction
2. Regulatory framework
3. Environmental setting
4. Geological setting
5. Conceptual model of groundwater regime
6. Numerical groundwater model
7. Model predictions and impact assessment
8. Groundwater monitoring and management plan
9. Summary and conclusions
10. References
11. Glossary and acronyms

The Appendices are:

A. Limit of alluvium investigation
B. Numerical modelling
C. Monitoring bore construction details
D. Groundwater level hydrographs
E. Compliance with government policy

Document #2 is structured as follows:

1. Objectives
2. Model construction and development
3. Model calibration
4. Recovery simulations
5. Uncertainty analysis
6. References.

The Appendices are:

1. Calibration details and hydrographs
2. Predictive uncertainty hydrographs

3. Review Methodology

While there are no standard procedures for peer reviews of entire groundwater assessments, there are two accepted guides to the review of groundwater models: the Murray-Darling Basin Commission (**MDBC**) Groundwater Flow Modelling Guideline[1], issued in 2001, and guidelines issued by the National Water Commission (**NWC**) in June 2012 (Barnett *et al.*, 2012[2]). Both guides also offer techniques for reviewing the non-modelling components of a groundwater impact assessment.

The NWC national guidelines were built upon the original MDBC guide, with substantial consistency in the model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details.

The NWC guide promotes the concept of "model confidence level", which is defined using a number of criteria that relate to data availability, calibration, and prediction scenarios. The NWC guide is

[1] MDBC (2001). Groundwater flow modelling guideline. Murray-Darling Basin Commission. URL: www.mdbc.gov.au/nrm/water_management/groundwater/groundwater_guides

[2] 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 82, National Water Commission, Canberra.

almost silent on coal mine modelling and offers no direction on best practice methodology for such applications. There is, however, an expectation of more effort in uncertainty analysis, although the guide is not prescriptive as to which methodology should be adopted.

Guidelines on uncertainty analysis for groundwater models were issued by the Independent Expert Scientific Committee (**IESC**) on Coal Seam Gas and Large Coal Mining Development in February 2018 in draft form and finalised in December 2018[3].

The groundwater guides include useful checklists for peer review. This groundwater impact assessment has been reviewed according to the 36-question Model Appraisal checklist[4] in MDBC (2001). This checklist has questions on (1) The Report; (2) Data Analysis; (3) Conceptualisation; (4) Model Design; (5) Calibration; (6) Verification; (7) Prediction; (8) Sensitivity Analysis; and (9) Uncertainty Analysis. Non-modelling components of the groundwater impact assessment are addressed by the first three sections of the checklist.

The review has also considered whether compliance with the minimal harm considerations of the NSW *Aquifer Interference Policy* (AIP) (NSW Government, 2012[5]) has been addressed adequately.

This review has been conducted progressively, with involvement of the peer reviewer at all stages of model development and application. The interaction was conducted through:

- One face-to-face meeting at AGE premises in Brisbane.
- Eight teleconferences with Glencore, Umwelt and AGE.
- Two Skype sessions with AGE.

Previous verbal and written review comments have been addressed satisfactorily, the latest review comments being advised on 28 October 2019.

A detailed assessment has been made in terms of the peer review checklists in **Table 1** and **Table 2**. **Table 1** addresses reporting, data analysis, conceptualisation and model design. **Table 2** addresses calibration, verification, prediction, sensitivity analysis and uncertainty analysis. Supplementary comments are offered in the following sections.

4. Report Matters

The GIA report is a high-quality document of about 330 pages length, including a number of appendices that contain more detail on field investigations, bore details, and numerical modelling. It is well-structured, well-written and the graphics are of exceptionally high quality and designed to ease understanding by readers. The report serves well as a standalone document, with no undue dependence on earlier work.

The modelling report occupies one-third of the full GIA report; the remainder is taken up with Appendices. Similarly, it is structured appropriately with sufficient detail and disclosure of method and results. Document #2 is not a standalone report because it completely omits the setup of basecase prediction scenarios, and all basecase prediction results. Instead, that material is in the GIA report.

Previous review comments on factual and editorial matters, on both reports, have been considered and have been accommodated in revisions of the reports.

The objectives are stated clearly in the GIA at the outset (Section 1.1): "*to assess the impact of*

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[3] Middlemis H and Peeters LJM (2018) *Uncertainty analysis—Guidance for groundwater modelling within a risk management framework*. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy, Commonwealth of Australia 2018.

[4] The NWC guidelines include a more detailed checklist with yes/no answers but without the graded assessments of the MDBC checklist, which this reviewer regards as more informative for readers.

[5] NSW Government, 2012, NSW Aquifer Interference Policy – NSW Government policy for the licensing and assessment of aquifer interference activities. Office of Water, NSW Department of Primary Industries, September 2012.

the Project on the groundwater regime and address the requirements of the NSW and Commonwealth government legislation and policies". The text of the report and its Conclusion sufficiently address those objectives.

The modelling objectives are itemised in Section B1 of Appendix B as outputs from the modelling process to address the key objective: "*to allow the risks to the groundwater regime to be assessed using a groundwater model to systematically investigate the causal pathways for potential impacts on water resources and water-dependent assets*". The model has been constructed and applied to address this objective.

Overall, there are no significant matters of concern in the reports as to structure or depth of coverage, and there is a clear focus on regulatory requirements.

5. Data Matters

Considerable effort has been put into resolving different interpretations of alluvial extent along Bowmans Creek and its tributaries, making use of test pits, CSIRO regolith inference, LiDAR and bore logs. A distinction has been made between alluvium and colluvium in areas officially held to be "highly productive" alluvium. The investigation is reported in Appendix A.

Data from several mine monitoring networks have been combined for cause-and-effect analysis and model calibration (Figure 5-1). The datasets are substantial, but the GIA report does not give numbers of standpipes and vibrating wire piezometer (VWP) installations. Bores are generally coded with a name that reflects the year of installation, the earliest being 2001. The duration of baseline monitoring data is extensive, with some data collection commencing in the early years of the 2000-2009 decade. Document #2 reports the use of 402 monitoring sites for calibration.

Groundwater flow directions can be inferred from groundwater head contours for alluvium (Figure 5-3) and the Middle Liddell Seam (Figure 5-4).

Surveying and water chemistry along Bowmans Creek for the length of the Glendell Pit Extension have demonstrated good surface water-groundwater connectivity, with mild gaining conditions at the northern end and mild losing conditions in the centre and at the southern end. Measured hydraulic gradients are less than 0.5% between creek water and groundwater. Baseflow analysis has been conducted on streamflow records for three watercourses using the Lyne-Hollick method (Figures 3-5 to 3-7). No flow-duration curves are presented; these often provide an indication of baseflow magnitude at the 10th (or lower) percentile.

Hydraulic conductivity estimates for modelling are informed primarily by 26 packer tests on targets intervals in four boreholes, mostly across coal seams, with two measurements in interburden. An unspecified number of slug tests has been conducted in the Bowmans Creek alluvium. These measurements supplement a large database of values recorded in many prior studies in a coalfield with a great many historical mines. Overall, there is good knowledge of permeability magnitudes, with a clear expression of decrease with depth (Figures 5-12, 5-13).

The geology, though complex, is well known. The axis of the Glendell Pit Extension follows an anticline, with steep dips on either side. At the northern end of the extension is a block fault zone about 250-300 m wide in the direction of mining (Figures 4-11, 4-14, 4-15). Based on photographic evidence, it does not appear to host much water.

Groundwater inflow to the existing Glendell pit is very low: "…*groundwater is not problematic for mining and is commonly evident only as damp evaporating seeps in mine faces (Figure 2-3). There are no permanent flows of groundwater into the approved Glendell Mine which require continuous pumping and therefore the volume of groundwater intercepted by the mining operations cannot be directly measured*".

6. Model Matters

The GIA report gives the impression that the applied model is a simple update of previous models developed by MER and Jacobs. As they used a structured grid and the applied model uses an unstructured grid of Voronoi cells of different sizes, the model is in fact a complete re-build. It is, however, an update of the models previously applied by AGE for Integra and Mount Owen modifications. The model development path is made clear in Appendix B.

The reviewer concurs with the entire modelling methodology described in Document #2 and recognises it as "state-of-art".

Key features of the modelling approach are:

- MODFLOW-USG plus AlgoMesh software platform for better mass balance and better spatial resolution;
- use of an equivalent pseudo-soil representation of unsaturated zones;
- use of a surrogate model to speed up calibration (essentially by adopting a coarser Voronoi mesh temporarily);
- application of an identifiability procedure to replace sensitivity analysis by perturbation, in which many more model properties can be included, and relative sensitivities are produced as a matter of course; the downside is an absence of reporting on calibration performance (if a sensitive parameter were varied) and on the magnitude of model outputs (if a sensitive parameter were varied); and
- a *monte carlo* style rigorous procedure for uncertainty analysis.

In terms of model confidence level classifications, Document #2 states:

> *"...the Project groundwater model is classified between a Class 2 and Class 3 model."*

An annotated classification table of attributes from the IESC guide has been included as Table B13. While it is never possible to assign a unique class number to any model, some quantification of the classification level can be indicated by taking counts of the ticks for each set of attributes. When this is done, the model can be said to be 7% Class 1, 37% Class 2 and 56% Class 3.

During operations, it is noted that "*Recharge rates to the spoil were not enhanced as the spoil is conceptualised to be very free draining*…". More realistically, infiltration is likely to be enhanced, but then the model would report extra pit inflow to be licensed as "take" when the water is really rainfall that is exempt from licensing. By ignoring extra infiltration, the model would estimate longer groundwater level recovery times than would probably occur. In this sense, it is a conservative stance when predicting long-term impacts. Enhanced recharge of 2% of rain is applied during the recovery period.

A stacked-drains approach has been used to represent the fracture zones of adjacent longwall mines. This is convenient to implement but has the disadvantage of being inapplicable for post-mining recovery simulation, as uncalibrated enhanced permeabilities must be applied into the future. AGE has correctly checked that the adopted permeabilities give matching pit inflows at end of mining and commencement of recovery.

AGE is to be commended for the innovation of a surrogate model to facilitate more rapid model calibration using PEST software. By using coarser discretisation, with a total of 0.13 million cells, individual runtimes were improved by a factor of 15 and the scale of the Jacobian sensitivity array was not compromised in the process.

Calibration performance statistics of 7.8 %RMS and 14 mRMS for Glendell monitoring sites are acceptable for such a complex mining precinct. Regionally, the statistics are 4.7 %RMS and 21 mRMS. The scattergram (Figure B15) is generally linear across a wide range, with no perceptible bias indicated in the residuals diagram (Figure B16). Replication of vertical head profiles (Figure B17) is quite good.

A comprehensive IESC-compliant Type-3 uncertainty analysis has been undertaken by means of a null-space *monte carlo* technique, using 183 alternative calibrated realisations out of a trial set of 250 selections. The rejected 27% of models either failed to converge (58% of cases) or had sum-of-squares more than double the target value (42% of cases). A convergence test, as encouraged by the IESC draft Explanatory Note on Uncertainty Analysis in Groundwater Modelling, is offered for what seems to be the maximum loss of saturated alluvial thickness (Figure B34). It should be noted that this example does not guarantee convergence at the same rate for other outputs of interest.

Table B14 has misleading terminology that was erroneous in the draft IESC Explanatory Note on Uncertainty Analysis that has been corrected in the final version. The words “to occur” should be replaced by “to be exceeded”. However, the legends for Figures B35 and B36 correctly refer to exceedance probabilities.

The formal uncertainty analysis is preceded in Section B2.2 by an informative analysis of qualitative uncertainty, as recommended by the IESC guide.

The reviewer considers that the adopted specific yields for Permian model layers are at the low end of what is physically reasonable, generally 0.1%. The sensitivity analysis in Table B11 indicates mild Sy identifiability for layers 1-5 (Sy values 1-5%) and virtually no Sy identifiability for deeper layers. Physical values of effective porosity in excess of 0.1% but generally less than 10% are to be expected; a more probable range should be 1-3%, which could be substantiated by core measurements. The adoption of low Sy values would have the effect of underestimating mine inflow, overestimating near-field environmental effects, and overestimating the spatial extent of drawdown. Therefore, the adopted Sy values would be conservative in terms of environmental effects.

Recovery in the presence of a final void has been modelled using the “high-K” lake approach, initially with presumably time-varying constant heads provided by a separate water balance model to generate a stage-discharge table, and finally as advised by the updated outputs from the surface water model (see Section 7.3.1 in the GIA report). The reviewer endorses deference to surface water modelling for a more robust analysis of final void behaviour than is readily achievable in a groundwater model.

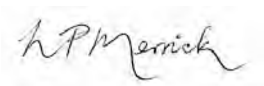
7. Conclusion

The reviewer is of the opinion that the documented groundwater assessment is best practice and concludes that the model is *fit for purpose*, where the purpose is defined by the objectives stated in Document #1 and Document #2:

- *“to assess the impact of the Project on the groundwater regime and address the requirements of the NSW and Commonwealth government legislation and policies’; and*
- *“to allow the risks to the groundwater regime to be assessed using a groundwater model to systematically investigate the causal pathways for potential impacts on water resources and water-dependent assets”.*

With regard to the second part of the second objective, the reviewer warns against expecting the groundwater model to reliably give the 0.1-0.2 m accuracy (derived from 10% of natural fluctuation) required by the Aquifer Interference Policy for a tolerable impact on a groundwater-dependent ecosystem. The display of simulated water table drawdown, where depth to water is less than 10 m, as in Figure 7-10, is a better indicator of potential impacts.

The groundwater modelling has been conducted to a very high standard. The only identified concern is the adoption of Permian specific yield (effective porosity) values that are at the low end of what is likely, in the opinion of the reviewer. However, use of lower than normal values can be considered as a conservative approach in terms of environmental effects.



Dr Noel Merrick

Table 1. Model Review (Part A)

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
1.0	THE REPORT								**A: Main Report & B: Appendix B**
1.1	Is there a clear statement of project objectives in the modelling report?		Missing	Deficient	Adequate	Very Good			A: Agency requirements: Section 1.1, Table 1-2. B: Modelling objectives at Appendix B, Section B1.
1.2	Is the level of model complexity clear or acknowledged?		Missing	No	Yes				Mixture of Class 1 (7%), Class 2 (37%) and Class 3 (56%).
1.3	Is a water or mass balance reported?		Missing	Deficient	Adequate	Very Good			Table B12: steady-state and transient calibration averages – mining 13.9 ML/day. Not shown for prediction.
1.4	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	Very Good			Addressed objectives.
1.5	Are the model results of any practical use?			No	Maybe	Yes			Addressed objectives.
2.0	DATA ANALYSIS								
2.1	Has hydrogeology data been collected and analysed?		Missing	Deficient	Adequate	Very Good			Alluvium definition (CSIRO regolith, soils maps, LiDAR, bore logs, test pits). Alluvium thickness and saturation thickness maps. Structure contours and depth of cover for Barrett and Middle Liddell Seams (Figs. 4-8, 4-9). 26 packer tests + slug tests. Water quality analysis violin plot (Fig.5-14). Good EC analysis (Section 5.8).
2.2	Are groundwater contours or flow directions presented?		Missing	Deficient	Adequate	Very Good			Alluvium (Fig.5-3) and Middle Liddell (Fig.5-4).
2.3	Have all potential recharge data been collected and analysed? (rainfall, streamflow, irrigation, floods, etc.)		Missing	Deficient	Adequate	Very Good			SILO rainfall. Streamflow presented in graphical form for three streams. Surveyed levels to determine gaining/losing status of Bowmans Creek. Excess water is stored in u/g Liddell workings; locations of 4 injection bores not clear.

2.4	Have all potential discharge data been collected and analysed? (abstraction, evapotranspiration, drainage, springflow, etc.)		Missing	Deficient	Adequate	Very Good			Baseflow analysis S3.3 – Lyne & Hollick (1979) method. Only 2 private bores (Section 5.9).
2.5	Have the recharge and discharge datasets been analysed for their groundwater response?		Missing	Deficient	Adequate	Very Good			CRD comparison. Evident regional mining depressurisation effects at depth but not in alluvium. Vertical head difference examined at paired bores. Good sw/gw connectivity.
2.6	Are groundwater hydrographs used for calibration?			No	Maybe	Yes			Appendix C. Hydrographs + CRD: alluvium; interburden; individual coal seams. Regional multi-mine monitoring networks.
2.7	Have consistent data units and standard geometrical datums been used?			No	Yes				
3.0	CONCEPTUALISATION								
3.1	Is the conceptual model consistent with project objectives and the required model complexity?		Unknown	No	Maybe	Yes			
3.2	Is there a clear description of the conceptual model?		Missing	Deficient	Adequate	Very Good			A: Section 10.
3.3	Is there a graphical representation of the modeller's conceptualisation?		Missing	Deficient	Adequate	Very Good			Geology X-Sections Figs.4-2, 4-3 with mine cutouts but no flow indicators: 3 marked faults.
3.4	Is the conceptual model unnecessarily simple or unnecessarily complex?			Yes	No				
4.0	MODEL DESIGN								Several prior models
4.1	Is the spatial extent of the model appropriate?			No	Maybe	Yes			22km (E-W) x 20.5km (N-S). 21 layers. Max 51k cells/layer (less pinchouts). Total 0.59 million cells. Minimum cell size 20m. Cell size 60m between pit and Bowmans Creek alluvium – to track steep hydraulic gradient. 100m cells in pit (Fig.B3). Many neighbouring mines included.
4.2	Are the applied boundary conditions plausible and unrestrictive?		Missing	Deficient	Adequate	Very Good			Justified in Section B2.4.1.

4.3	Is the software appropriate for the objectives of the study?			No	Maybe	Yes			MF-USG unstructured + AlgoMesh Voronoi cells. Upstream weighting = pseudo-soil. FORTRAN bespoke code.

Table 2. Model Review (Part B)

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
5.0	CALIBRATION								Steady-state 1979. Transient 1980 - 2018 (39 years); mostly 7 years data.
5.1	Is there sufficient evidence provided for model calibration?		Missing	Deficient	Adequate	Very Good			402 monitoring sites with proper QA and weighting - good spread (x,y,z) (Fig.B12). Scattergram; residuals x-y plot; vertical profiles (Fig.B17); hydrographs (App.B1). No residuals (x,y) map.
5.2	Is the model sufficiently calibrated against spatial observations?		Missing	Deficient	Adequate	Very Good			Scattergram generally linear across a wide range. Good vertical head profiles (Fig.B17). Good agreement between field and simulated head contours: Alluvium Fig.5-3 cf. Fig.B21; Middle Liddell Fig.5-4 cf. Fig.B22.
5.3	Is the model sufficiently calibrated against temporal observations?		Missing	Deficient	Adequate	Very Good			Quarterly stress periods from 2009. No systematic bias (fig.B16). Appendix B1: generally good match to absolute levels; most trends are replicated; some mining effects are not captured.
5.4	Are calibrated parameter distributions and ranges plausible?		Missing	No	Maybe	Yes			K(z) depth functions: coal K lies within field bandwidth (Fig.B24); interburden K at upper end of field bandwidth (Fig.B25). Specific Yield (Sy) at depth is at the low end of expected values, generally 0.1% in Permian below Layer 5. Specific storage is reasonable (insensitive anyway, so some higher values are of no concern). Five diffuse rainfall recharge zones: soil moisture model.
5.5	Does the calibration statistic satisfy agreed performance criteria?		Missing	Deficient	Adequate	Very Good			7.8%RMS, 14 mRMS - local. 4.7%RMS, 21 mRMS - regional.
5.6	Are there good reasons for not meeting agreed performance criteria?		Missing	Deficient	Adequate	Very Good			Mining complexity; some thick layers (assumed single head).
6.0	VERIFICATION								Optional for heads subset

6.1	Is there sufficient evidence provided for model verification?		Missing	Deficient	**Adequate**	Very Good			Baseflow verification Fig.B30 (Bowmans mis-spelled). UG Mine inflow at Integra u/g and Barrett pit said to agree well.
6.2	Does the reserved dataset include stresses consistent with the prediction scenarios?	N/A	Unknown	No	Maybe	Yes			
6.3	Are there good reasons for an unsatisfactory verification?	N/A	Missing	Deficient	Adequate	Very Good			
7.0	PREDICTION								2019-2045 (27 years)
7.1	Have multiple scenarios been run for climate variability?		Missing	Deficient	**Adequate**	Very Good			A: Long-term average during basecase prediction and recovery models. Climate variability is accommodated through uncertainty analysis by setting 95th percentile limits (based on 117 years of rain).
7.2	Have multiple scenarios been run for operational /management alternatives?		Missing	Deficient	**Adequate**	Very Good			Single mine plan - normal practice.
7.3	Is the time horizon for prediction comparable with the length of the calibration / verification period?		Missing	No	**Maybe**	**Yes**			Calib: 7-19 yrs, Pred:27yrs. Ratio Pred/Calib = 1.4 to 4.
7.4	Are the model predictions plausible?			No	Maybe	**Yes**			Negligible drawdown in alluvium matches observation. Minimal pit inflow matches observation.
8.0	SENSITIVITY ANALYSIS								Identifiability approach
8.1	Is the sensitivity analysis sufficiently intensive for key parameters?		Missing	Deficient	**Adequate**	Very Good			Table B11, Fig.B29. All properties assessed. Sensible findings: Kx is most important; also alluvial rain recharge; Ss is least identifiable; Sy not identifiable below layer 5.
8.2	Are sensitivity results used to qualify the reliability of model calibration?	N/A	Missing	Deficient	Adequate	Very Good			Not possible with identifiability approach.
8.3	Are sensitivity results used to qualify the accuracy of model prediction?		Missing	Deficient	**Adequate**	Very Good			Usual sensitivity analysis done for spoil and block fault zone.
9.0	UNCERTAINTY ANALYSIS								
9.1	If required by the project brief, is uncertainty quantified in any way?		Missing	No	Maybe	**Yes**			Substantial work. 183 realisations (Kx, Kz, Sy, Ss, RCH, RIV). Sy at depth limited to 1% max (could be higher). Pseudo Null-space Monte Carlo. Prior and posterior distributions.

9.2	Are uncertainty results used to qualify the reliability of model calibration?		Missing	Deficient	Adequate	Very Good			73% calibrated (183 of 250). Acceptability statistic is 2 x phi. Evidence is provided that one output has converged sufficiently with acceptable runs [new requirement of IESC Explanatory Note].
9.3	Are uncertainty results used to qualify the accuracy of model prediction?		Missing	Deficient	Adequate	Very Good			Uncertain outputs of interest: hydrographs; maximum drawdown (x,y) for alluvium, Middle Liddell Seam, Barrett Seam. Not reported for mine inflow, alluvium take, or surface water take.
NEW	As required by IESC, is qualitative uncertainty summarised?		Missing	Deficient	Adequate	Very Good			Very good qualitative uncertainty discussion (Section B2.2).
	TOTAL SCORE								PERFORMANCE: %