APPENDIX 9

Groundwater Impact Assessment

Australasian Groundwater and
Environmental Consultants Pty Ltd

Report on

Mount Owen Continued Operations Modification 2 – Groundwater Impact Assessment

Prepared for
Mount Owen Pty Limited

Project No. G1862A July 2018

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Australasian Groundwater and Environmental Consultants Pty Ltd

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Report on

Groundwater Impact Assessment Mount Owen Continued Operations – Modification 2

1 Introduction

The Mount Owen Complex is located within the Hunter Coalfields in the Upper Hunter Valley of New South Wales (NSW). It is located approximately 20 kilometres (km) north-west of Singleton, 24 km south-east of Muswellbrook and to the north of Camberwell. Mt Owen Pty Limited (Mount Owen), a subsidiary of Glencore Coal Pty Limited (Glencore), currently owns three existing open cut operations in the Mount Owen Complex; Mount Owen, Ravensworth East and Glendell (Figure 1-1).

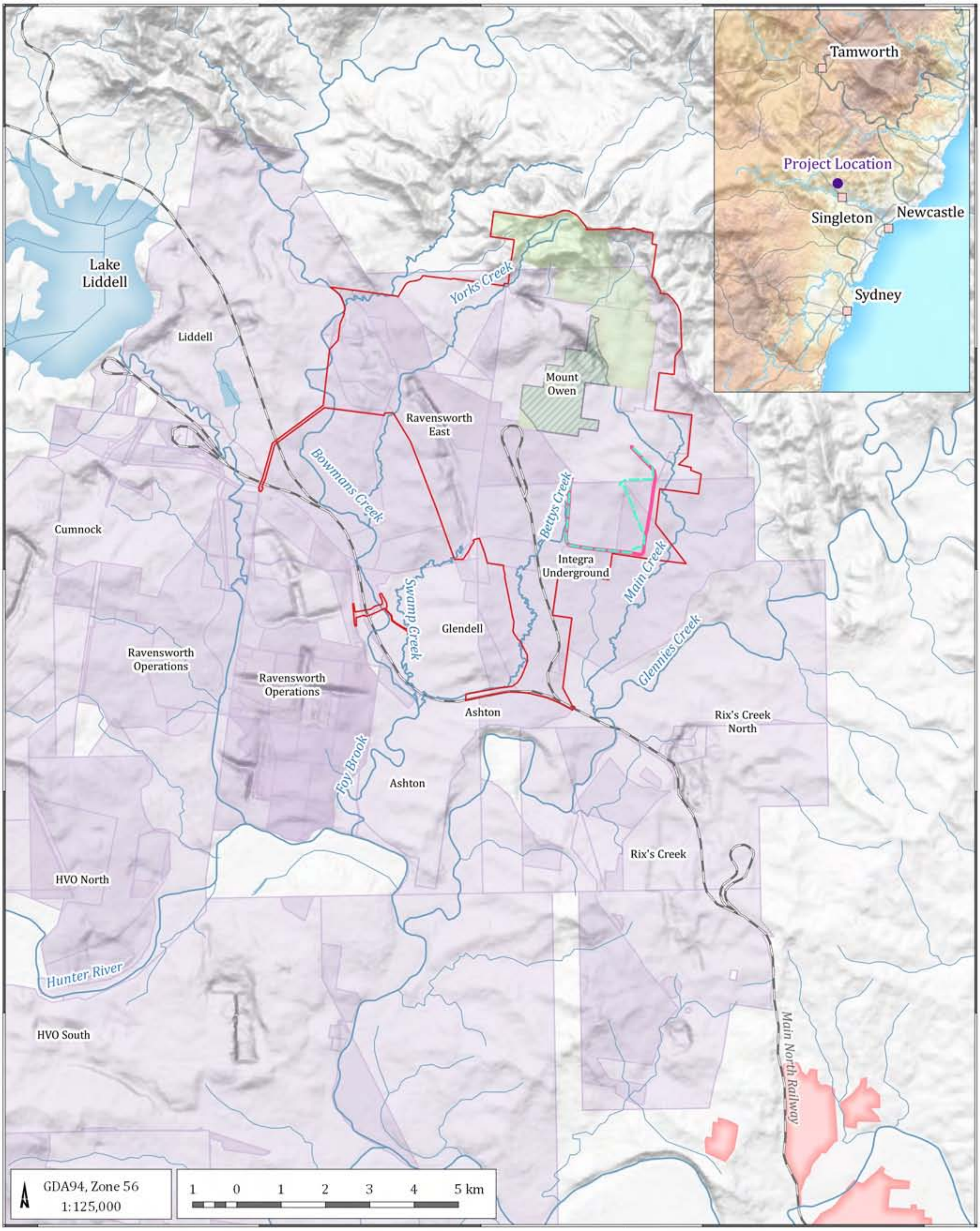
Mount Owen received development consent (SSD-5850) from the Planning Assessment Commission for the Mount Owen Continued Operations Project (Continued Operations Project) in November 2016. The Continued Operations Project development consent incorporates all previously approved operations at the Mount Owen Mine and Coal Handling and Preparation Plant (CHPP) and Ravensworth East Mine and allows for continued and expanded mining until 2031, now referred to as the 'Approved Operations'. Glendell Mine operates under a separate consent (DA 80/952) and does not form part of the Approved Operations.

In September 2017 Mount Owen modified SSD-5850 (Modification 1) to allow for the construction of a water pipeline from the Integra Underground Mine (IUG) to the Mount Owen Complex and allow the integration of the IUG into the Greater Ravensworth Area Water and Tailings Scheme (GRAWTS). Mount Owen now proposes to further modify development consent SSD-5850 to allow for the optimisation of the North Pit mine plan to access coal reserves from the mining tenements obtained by Glencore through its acquisition of the IUG (the Proposed Modification).

To facilitate this Mount Owen commissioned Umwelt Australia Pty Ltd to prepare a Statement of Environmental Effects (SEE) to support the Proposed Modification under Section 4.55(2) of the *Environmental Planning and Assessment Act 1979* (EP&A Act).

The Proposed Modification was also referred to the Commonwealth Department of Environment and Energy (DoEE) and was determined not to be a controlled action under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)

This groundwater assessment has been prepared by Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) to support the SEE for the Proposed Modification. The scope of the groundwater assessment has been designed to address the requirements of the New South Wales Aquifer Interference Policy (2012) (AIP) and information guidelines developed by the Independent Expert Scientific Committee (IESC) on Coal Seam Gas and Large Coal Mining Development). In addition, the groundwater assessment builds upon the assessment completed to support the Environmental Impact Statement (EIS) for the Continued Operations Project which reflected the guidelines and expectations of relevant approval authorities at both State and Commonwealth levels. This is consistent with the direction provided by the Department of Planning and Environment (DP&E) to review and update the technical assessments for the Continued Operations Project as part of the preparation of the SEE.



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Coal titles
- Built up area
- Water area
- Ravensworth State Forest - Undisturbed
- Ravensworth State Forest - Removed by mining
- Major drainage
- Minor drainage
- Major road
- Minor road
- Rail

Mount Owen (G1862A)

General location plan

AGE

DATE 12/06/2018

FIGURE No: **1-1**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/01.01_G1862A_General Location plan.qgs

1.1 Objectives and scope of work

The objective of the groundwater assessment was to assess the impact of the Proposed Modification on the groundwater regime and address the requirements of the NSW and Federal government legislation and policies. The groundwater assessment comprised two parts, a description of the existing hydrogeological environment, and an assessment of the impacts of the Proposed Modification on that environment. The impacts of the Proposed Modification are detailed separately and also related to the Approved Operations to identify the extent of change in impacts on groundwater resources.

The groundwater impact assessment included:

- review of existing background data and previous hydrogeological investigations;
- updating the existing groundwater regional numerical model for the mid Hunter Region that was last utilised for the Approved Operations (and recently updated for Integra Underground Mod 8) in accordance with the National Groundwater Modelling Guidelines (National Water Commission, 2012) and relevant State and Commonwealth guidelines (Appendix C);
- assessment of the impacts as a result of the Proposed Modification, including impacts on regional groundwater levels and baseflow;
- assessment of potential groundwater dependant ecosystem (GDE) impacts resulting from short and/or long term changes in groundwater;
- assessment of the potential third party impacts (i.e. private bores) as a result of changes to the regional groundwater system;
- assessment against the Aquifer Interference Policy (2012);
- assessment of cumulative impacts;
- assessment of post mining recovery; and
- provision of recommendations for the management of groundwater impacts including monitoring.

1.2 Proposed modification

The Proposed Modification will enable access to approximately 35 million tonnes (Mt) of additional run-of-mine (ROM) coal from the North Pit. Recovery of the additional coal reserves will result in approximately 46 hectares (ha) of additional disturbance (Proposed Disturbance Area) (refer to Figure 1-2), representing an increase of approximately 1.8 per cent to the total disturbance area currently approved, and require an increased depth in the North Pit to provide for mining down to the Hebden Seam. The change to the North Pit mine plan will require the extension of the mine life through to 2037 (an additional 6 years). Figure 1-3 shows the pit shell for the Proposed Modification.

Prior to the acquisition of the Integra Underground mining tenements, the mine plan design for the North Pit did not allow access to the deeper coal seams and was restricted to the east of the approved North Pit footprint. This resulted in the approved pit floor 'stepping up' as it progressed further southwards and the 'stepping in' of the mine plan along its eastern boundary. The acquisition of the Integra Underground Mine and associated mining tenements has removed this previous constraint and allows for deeper and extended coal extraction across the proposed modified North Pit.

The Proposed Disturbance Area extends further east from the Proposed Modification pit boundary to provide for additional infrastructure such as water management structures and access. In addition, the northern extent of the Proposed Disturbance Area is identified to provide for earthworks to shape and improve the final landform of the North Pit to tie into the surrounding topography, these works are located in proximity to the existing approved Bettys Creek diversion. It is not proposed to modify the existing Bettys Creek diversion in this area which continues through the South East Offset and South East Corridor Offset areas into Main Creek.

No changes are proposed to current mining methods, extraction limits, transportation methods, operational hours or workforce numbers. The Proposed Modification will utilise existing and approved infrastructure with the exception of proposed water management structures to manage water from the mining operation. Table 1-1 provides a comparison between the Approved Operations and the Proposed Modification.

Table 1-1 Comparison between the Approved Operations and the Proposed Modification

Component	Approved Operations	Proposed Modification
Mining Method	Truck and excavator	No change to mining methods
Target Seams	Down to Hebden Seam Down to approximately 300 m depth	No change to target seams Down to approximately 380 m depth (average 340 m)
Total Reserve Recovered	Total of 257 Mt ROM coal Ravensworth East – 48 Mt Mount Owen – 209 Mt	Additional approximately 35 Mt ROM coal over the life of the mine (approximately 13% of total approved reserve)
Disturbance Area	Approved Disturbance Area of 2534 ha	Additional 46 ha disturbance (increase of 1.8% of total Approved Disturbance Area) Modification to SSD-5850 consent boundary to include Proposed Disturbance Area
Annual Production	Ravensworth East – 4 Mtpa Mount Owen – 10 Mtpa	No change to annual production limit
Mine Life	2031	2037
CHPP Capacity	Up to 17 Mtpa	No change to CHPP capacity
Management of Mining Waste	Emplacement of waste in-pit and out-of-pit, up to maximum existing approved height of 230 m. Tailings emplacement in Ravensworth East voids (including West Pit), within in-pit tailings cells in North Pit and/or BNP, and transfer under the GRAWTS to Liddell (subject to relevant approvals)	Emplacement of waste in Approved Disturbance Areas (up to maximum existing approved height) Tailings emplacement within West Pit, in-pit tailings cells in North Pit and/or BNP, and transfer under the GRAWTS
Water Management	Upper and Middle Bettys Creek Diversions Management of water within the water management system and GRAWTS Works to provide flood attenuation for Yorks Creek	No changes to existing approved creek diversions Extension of water management system to Proposed Disturbance Area and continued management of water within the GRAWTS Proposed amendments to design of existing water management system to provide flood attenuation for Yorks Creek

Component	Approved Operations	Proposed Modification
Operational Workforce	Up to approximately 660 at Mount Owen and up to 260 at Ravensworth East	Continued employment of existing Mount Owen workforce (up to approximately 660) for an additional 6 years
Hours of Operation	24 hours, 7 days per week	No change to hours of operation
Interactions with Integra Underground Mine	Minimum 250 m separation subject to strict safety and operational controls	No change to minimum separation – implementation of safety and operational controls through integration of Glencore owned mining operations
Final Landform	Final voids at BNP and North Pit Final landform approved with commitments relating to landform design (including micro relief), conservation and water management considerations as part of further detailed mine design	No additional void in final landform Proposed changes to the final void arrangement in North Pit Final landform to be designed to incorporate detailed design commitments relating to landform design (including micro relief), conservation and water management considerations and be consistent with the existing progressive rehabilitation objectives in the development consent

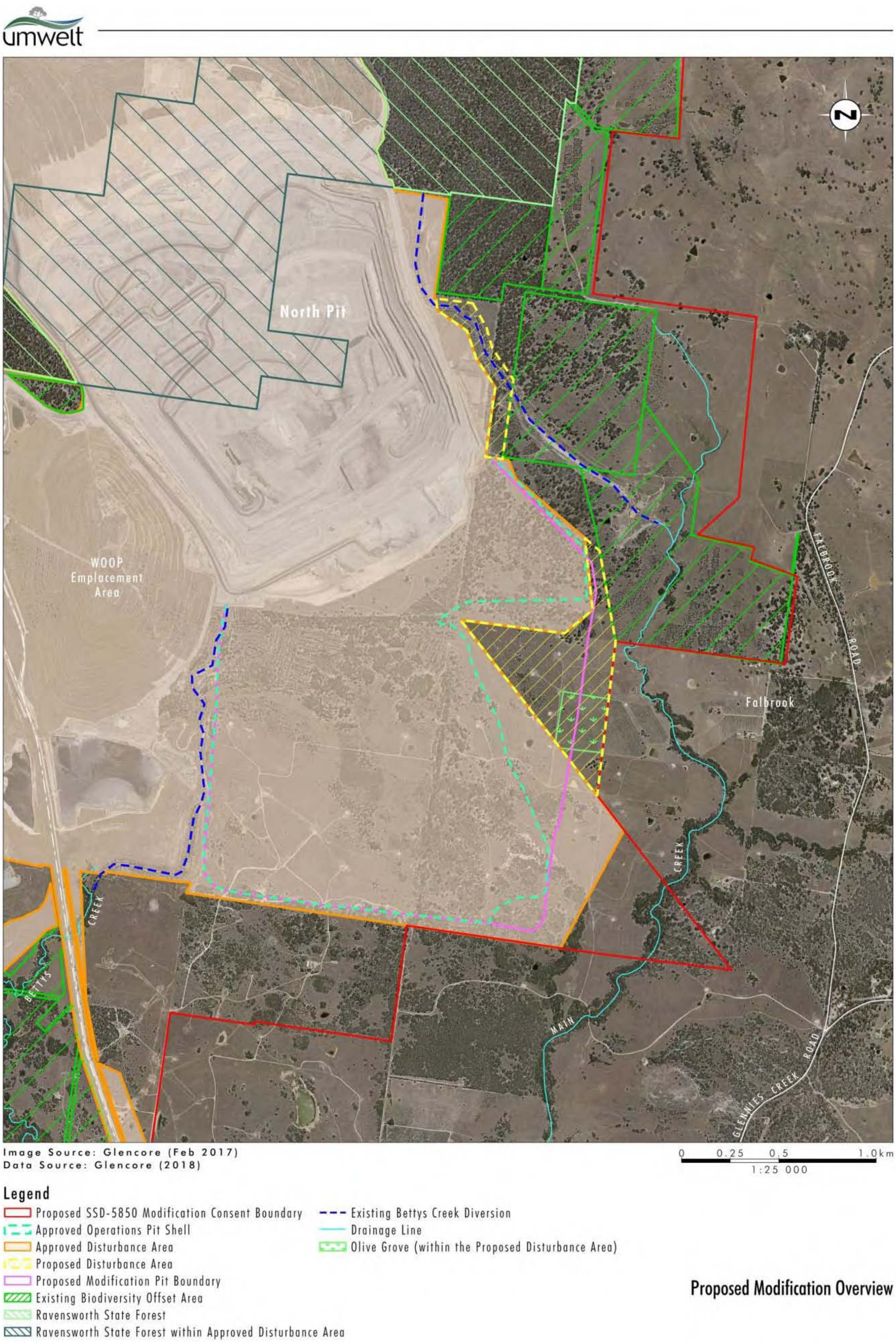
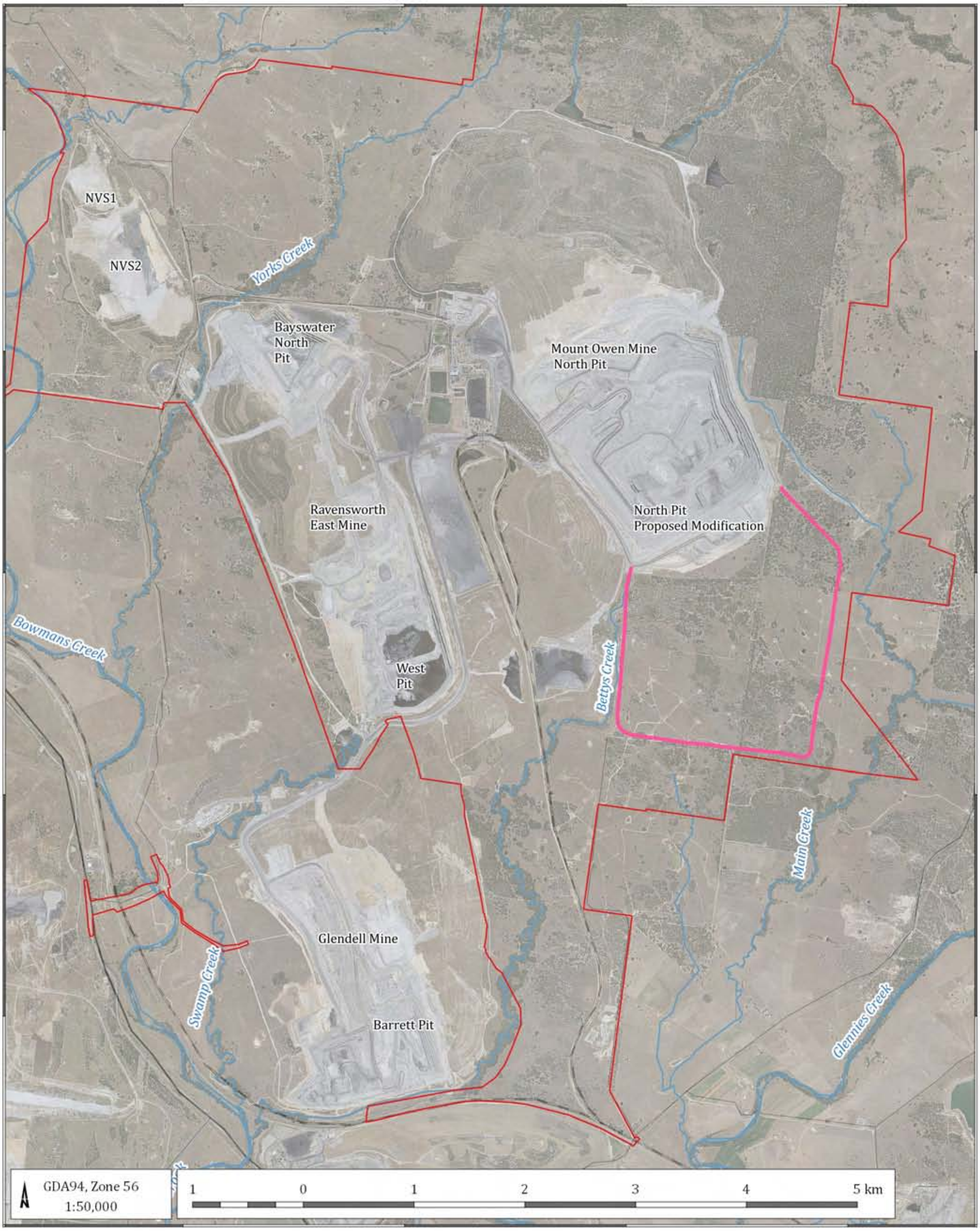


Figure 1-2 Proposed Modification Overview



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Proposed Modification pit shell
- Drainage
- Major road
- Minor road
- Rail

Mount Owen (G1862A)

Proposed Modification

AGE

DATE 12/06/2018

FIGURE No: **1-3**

Source: GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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1.3 Report structure

This report is structured as follows:

- Section 1 – Introduction: provides an overview of the Proposed Modification and the assessment scope.
- Section 2 – Regulatory framework: describes the regulatory framework relating to groundwater.
- Section 3 – Environmental setting: describes the environmental setting of the Proposed Modification 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 Proposed Modification.
- 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.
- Appendix A attaches a report that summarises investigations to define the limit of the alluvium along Main Creek adjacent to the Proposed Modification.
- Appendix B contains a table that provides key construction details for each monitoring bore.
- Appendix C provides a detailed description of the numerical modelling undertaken for the Proposed Modification, including details on model construction, calibration, validation and uncertainty, and the peer review report.
- Appendix D compares the impacts predicted for the Proposed Modification with State and Federal government policy and comments on compliance.

2 Regulatory framework

The Proposed Modification 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 Landuse Policy (2012); and
        - Strategic Regional Landuse Plan – Upper Hunter (2012).

- Commonwealth Government:
    - As noted in Section 1, the Proposed Modification is not a Controlled Action and does not require Commonwealth approval under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). As part of the assessment process, the Independent Expert Scientific Committee (IESC) information guidelines for coal seam gas (CSG) and large coal mining development proposals have been considered.

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

2.1 Water Management Act 2000

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

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

The *Water Management Act 2000* includes the concept of ensuring "no more than minimal harm" for both the granting of water access licences (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.

The *Environmental Planning And Assessment Act 1979* - Sect 89j 1(a) requires State significant development authorised by a development consent does not require a water use approval, a water management work approval or an activity approval, but does require an aquifer interference approval under the *Water Management Act 2000*. 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 Crown Lands and Water Division (CLWD) (formerly known as DPI Water) is progressively developing WSPs for rivers and groundwater systems across NSW following the introduction of the *Water Management Act 2000*. The purposes of 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 Proposed Modification - these are the WSP for the:

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

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

The Hunter Regulated WSP covers the Hunter River surface water flows and highly connected alluvials described in the plan. The Hunter Regulated Water Source is divided into three management zones (Zone 1, Zone 2, Zone 3). The zones are defined from a single common point, which is the junction of Glennies Creek with the Hunter River. The Proposed Modification 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 Proposed Modification occurs on the catchment divide that marks the boundary between the Jerrys Water Source and Glennies Water Source. The Hunter Regulated River Alluvial Water Source which covers the Quaternary alluvium associated with Glennies Creek and Station Creek is also a separate water source managed under the Hunter Unregulated WSP. The trading rules for the Jerrys Water Source and the Hunter Regulated River Alluvial Water Source allow conversion of surface water licences to aquifer access licences, subject to assessment.

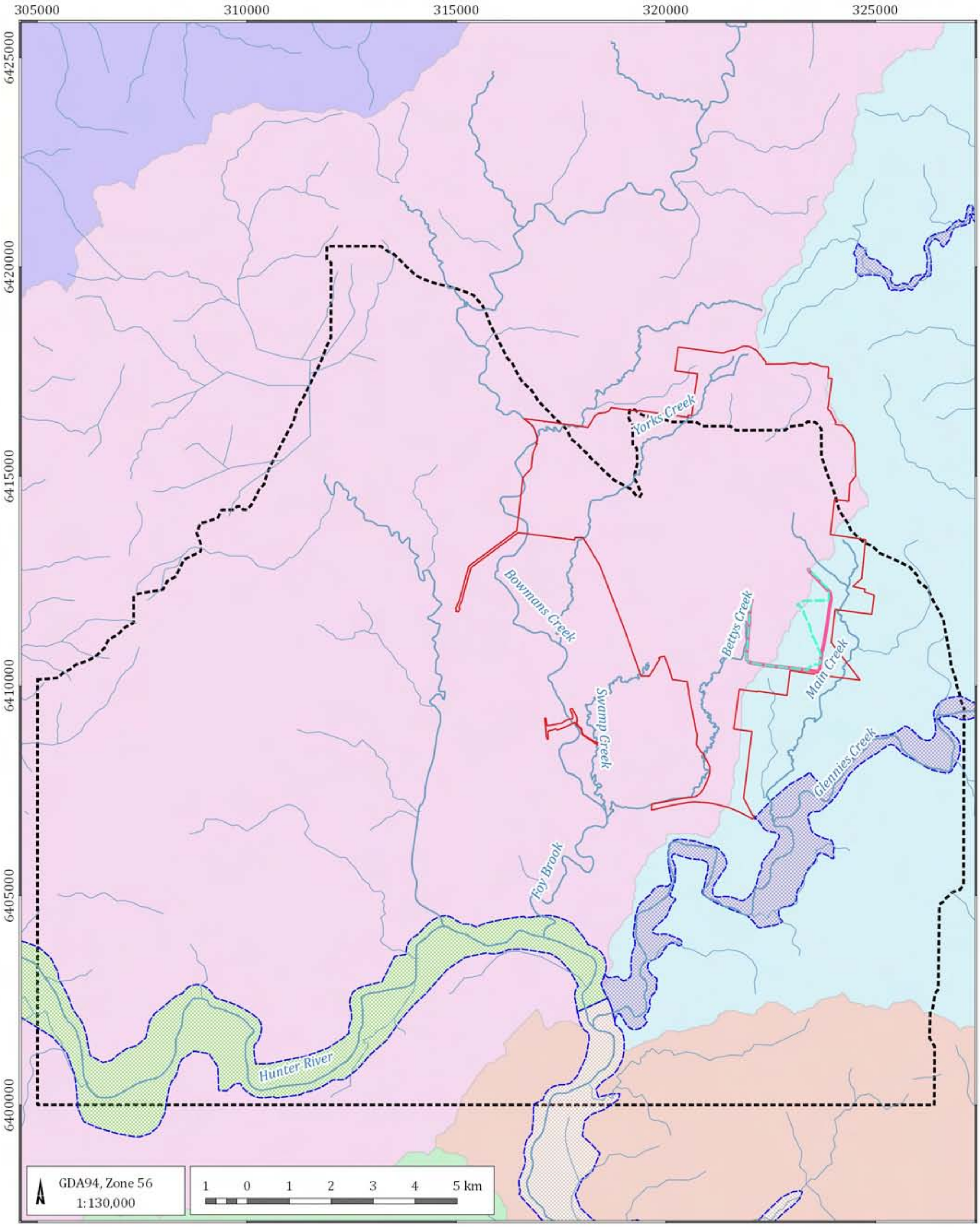
Figure 2-1 shows the water sources and management zones relevant to the Proposed Modification. Table 2-1 summarises the number of WALs and the surface water and aquifer licence shares available for each water source.

Table 2-1 Water licensing for each water source

Water source	Aquifer access licence units		Unregulated river surface water units	
	No. of WALs	Total units	No. of WALs	Total units
Jerrys	10	1,246	19	2097
Glennies	2	10	12	446
Hunter Regulated River Alluvial	221	24,108	n/a	n/a
Sydney Basin North Coast	182	69,932	n/a	n/a

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

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary

Hunter Regulated River Water Sharing Plan Water Sources

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

Hunter Unregulated and Alluvials Water Sharing Plan Water Sources

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

Mount Owen (G1862A)

Water Sharing Plan Water Sources

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DATE 12/06/2018

FIGURE No: **2-1**

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

2.3.1 Aquifer Interference Policy

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

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

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

The AIP 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 WAL must hold sufficient share component and water allocation to account for the take of water from the relevant water source when the take occurs. The requirement to hold appropriate WALs for relevant stages of the Approved Operations is reflected in the conditions of SSD-5850.

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.

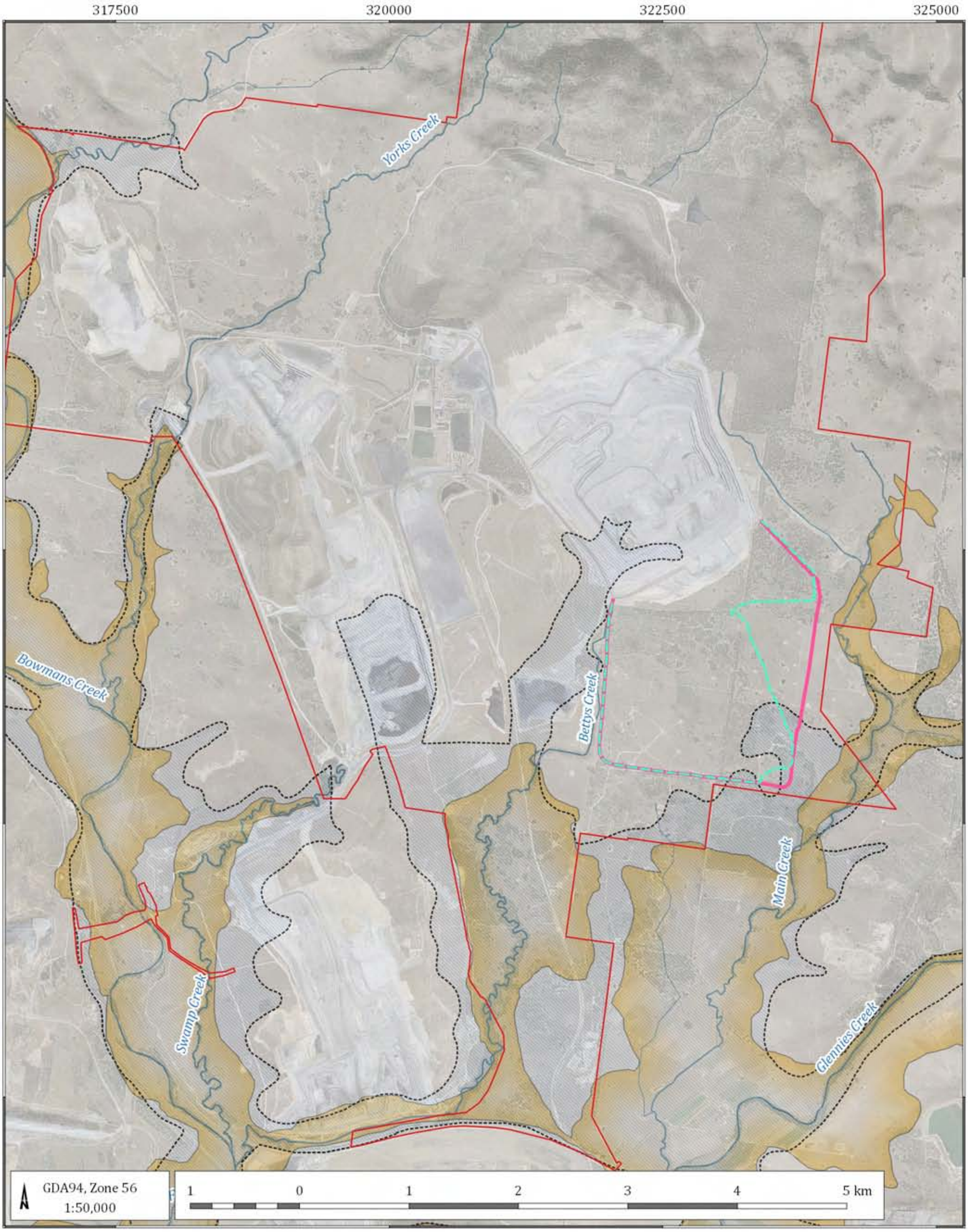
A "highly productive" groundwater source is defined by the AIP as a groundwater source which has been declared in regulations and datasets, based on the following criteria:

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.

CLWD has produced a map of groundwater productivity across NSW, which shows areas classified as either highly or less productive. The CLWD groundwater productivity map has been produced based on regional scale geological maps. Figure 2-2 shows the CLWD groundwater productivity map, which indicates the alluvium along Bettys Creek and Main Creek has been classified as highly productive. Investigations at the Mount Owen Complex have determined that the groundwater associated with Bettys Creek and Main Creek does not fulfil the definition of 'highly productive' due to TDS of groundwater exceeding 1,500 mg/L and the limited saturated thickness meaning yields from bores are low and do not exceed 5 L/s. The extent and characteristics of the Quaternary alluvium is further discussed in Section 4.2.1. Section 5.2 and Section 5.4 provide further information on the properties of the alluvial aquifers and why they are not classified as '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 with water table and groundwater pressure drawdown as well as groundwater and surface water quality changes. Section 7 presents the Proposed Modification impacts and compares these with the AIP thresholds. Appendix D notes where information required to address the AIP is presented within the report.



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Refined alluvium boundary
- Highly productive groundwater (DPI Water, 2012)
- Major drainage
- Minor drainage

Mount Owen (G1862A)

Highly productive groundwater

DATE 12/06/2018

FIGURE No: 2-2

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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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 Proposed Modification resides. Biophysical Strategic Agricultural Land (BSAL) is land with high quality soil and water resources capable of sustaining high levels of productivity. BSAL is mapped along parts of the Hunter River and the Glennies Creek flood plain on the regional mapping (Figure 3-2). There have been two Site Verification Certificates issued that certify that no BSAL exists within the Approved Disturbance Area for the Continued Operations Project and also within the Proposed Disturbance Area for the Proposed Modification.

2.4 Water licensing

Mount Owen 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. 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

Licence No.	Water source	Abstraction purpose	Units
20BL169337	Sydney Basin North Coast	dewatering of North Pit	140
20BL170294	Sydney Basin North Coast	dewatering of Eastern Rail Pit	220
20BL170295	Sydney Basin North Coast	dewatering of Ravensworth East Pits	800
		Total Sydney Basin North Coast	1,160

The North Pit 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. There are no permanent visible flows of groundwater into the North 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 it is largely evaporated or adheres to mined materials preventing it from accumulating on the pit floor.

Mount Owen have used two different methods to indirectly estimate the volume of groundwater entering the mining areas including North Pit, being numerical modelling and water balance modelling. Figure 2-3 show the estimates of groundwater inflow for the 2016 calendar year from both modelling methods. The numerical model developed by Jacobs (2014) for the Approved Operations indicates inflows of between 25 and 35 ML/month. In contrast the water balance model developed by HEC (2017) indicates no groundwater inflow occurred to North Pit. This difference is explained by the fact that the water balance method only estimates groundwater that is pumped into the mine water circuit, and cannot detect water that evaporates or adheres to mined material before entering the mine water circuit. In contrast the numerical modelling method provides an estimate of all groundwater that enters the mine including water removed by processes such as evaporation. The fact that no groundwater inflow was estimated using the water balance method suggests all 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).

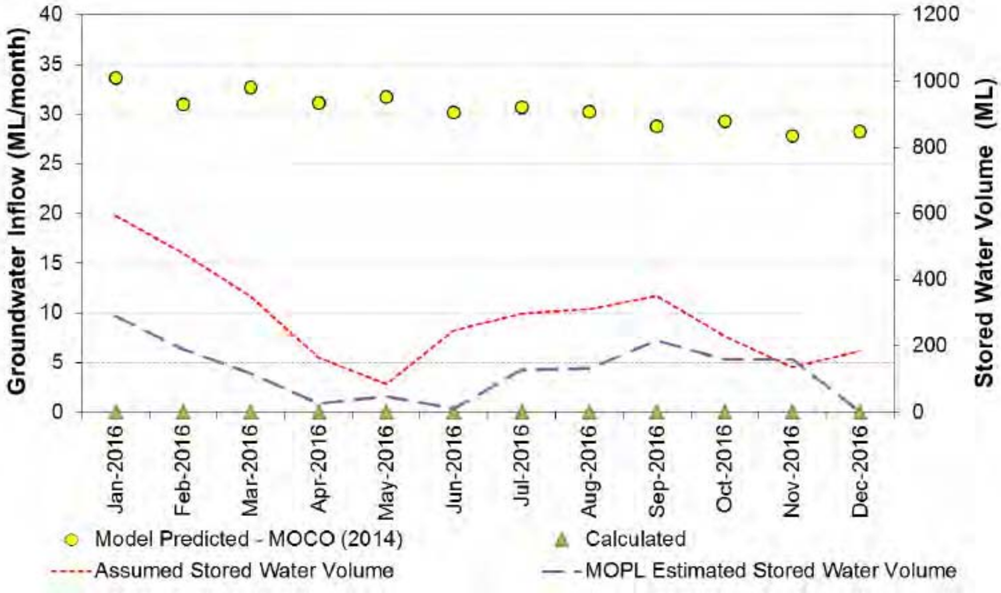


Figure 2-3 Estimated volume of groundwater entering North Pit 2016 calendar year (source HEC 2017)

Mount Owen 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, Mount Owen 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). Mount Owen'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

Development consent SSD-5850 requires development of a Water Management Plan (WMP) and Water Management Performance Measures for the Approved Operations. Schedule 3, Condition 26 (v) of SSD-5850 outlines the items to be addressed in a Groundwater Management and Monitoring Plan (GWMMP), which is a component of the overarching WMP. Condition 21 of SSD-5850 also requires Mount Owen to hold all necessary water licences for the Approved Operations.

Mount Owen last updated the GWMMP in October 2017 following approval for the construction of a water pipeline from IUG to the Mount Owen Complex (Modification 1). The WMP and GWMMP outlines how Mount Owen 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 Mount Owen. Section 8 outlines the content of the WMP and how it will continue to be used for this Proposed Modification in more detail.

2.6 Commonwealth Environment Protection and Biodiversity Conservation Act 1999

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

Detailed ecological and water resources assessments were undertaken to support the Proposed Modification which have concluded that the Proposed Modification would not have a significant impact on relevant MNES. The aspects of the Proposed Modification that are not the subject of the existing EPBC Act approval for the Continued Operations Project or are otherwise exempt from Act (Action), were referred to DoEE in October 2017 to determine whether or not the Action was a controlled action. In December 2017, the referred Action was determined not to be a controlled action and therefore does not require approval under the EPBC Act. As such no further assessment of MNES is required.

As noted, the Proposed Modification was declared not to be a controlled action, notwithstanding a summary of the IESC guidelines and where they are addressed within the report is included in Appendix D for consistency with, and to enable comparison to, the groundwater assessment outcomes for the Approved Operations.

3 Environmental setting

3.1 Location

The Mount Owen Complex is located in the Hunter Coalfields of the Sydney Basin and is entirely within the Singleton Local Government Area. It is approximately 20 km north-west of the Singleton town centre. The IUG lies immediately to the west and under part of the Mount Owen Complex whilst other surrounding mines include the Ashton Mine to the southwest and Rix's Creek and Rix's Creek North to the south. Surrounding land uses in the locality include mining and mining related development as well as agricultural activities such as cropping and grazing.

3.2 Climate

The climate in the region is temperate and is characterised by hot summers with regular thunderstorms and mild dry winters. Climate data was obtained from the Scientific Information for Land Owners (SILO) database of historical climate records for Australia (DSITI 2015). This service interpolates rainfall and evaporation records from available stations to a selected point which was selected as the adjacent IUG. Climatic data was obtained for the period between 01/01/1900 to 1/04/2017. 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)	78.9	75.0	65.6	53.5	44.8	52.4	43.8	37.7	41.7	50.6	61.3	69.4	674.7
	Mean evaporation (mm)	203.9	161.1	142.8	103.4	72.5	55.3	63.7	89.2	119.2	156.2	176.8	209.8	1553.7
	Evap minus rainfall	125.0	86.2	77.2	49.9	27.7	2.9	19.9	51.5	77.4	105.6	115.5	140.3	879.1

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

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

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

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

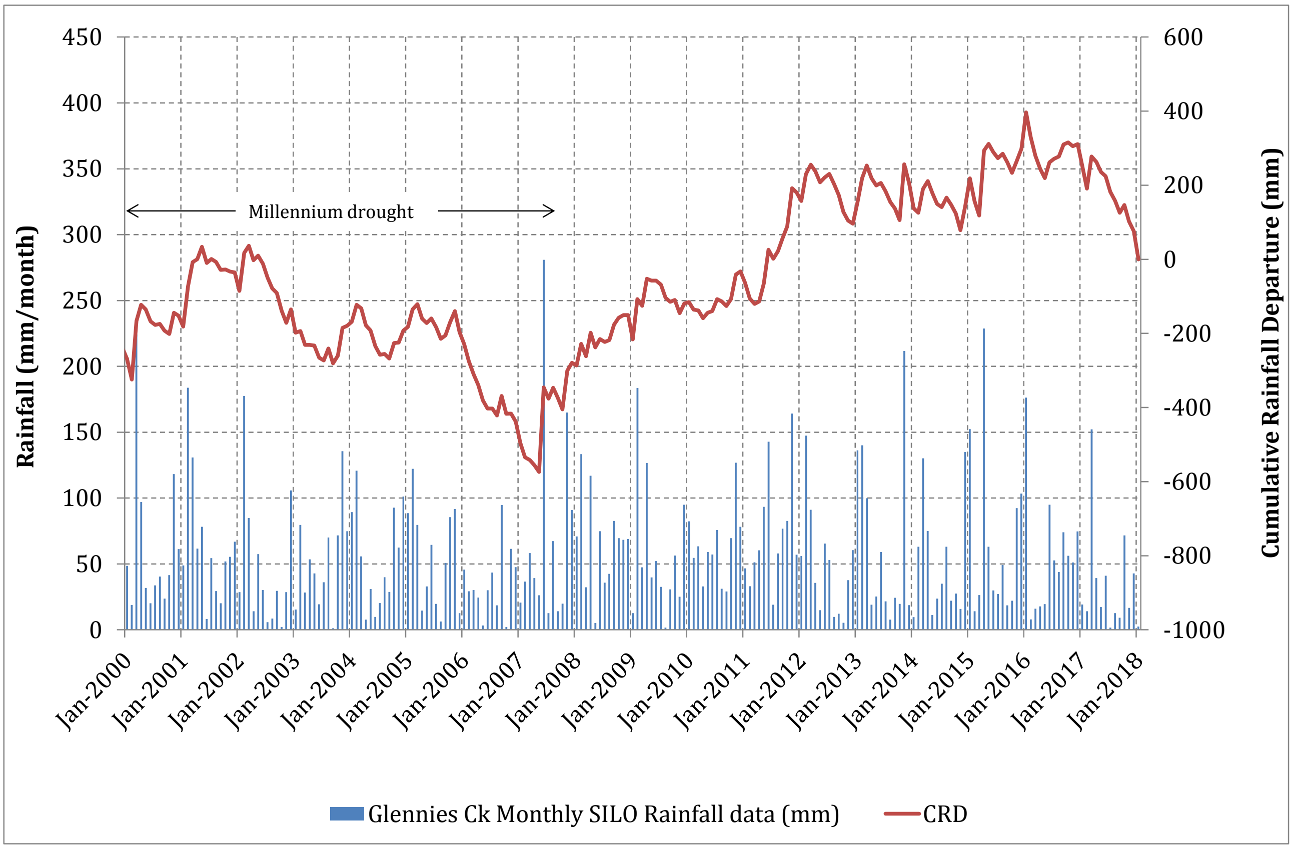


Figure 3-1 Cumulative Rainfall Departure (SILO) and monthly rainfall

The CRD trends are relevant because groundwater levels particularly in shallow aquifers tend to reflect the same trends, with declining groundwater levels when rainfall is below average and rising trends during periods of above average rainfall. Groundwater levels and climate are discussed further in Section 5.

3.3 Terrain and drainage

The approved North Pit mine is planned to advance through an area of gently inclined cleared land between Main Creek and the redirected Bettys Creek. The land elevation falls gently from the crest of the catchment divide at about 150 mAHD down to 110 mAHD along the Bettys Creek diversion and 100 mAHD at the Main Creek flood plain. Much of the revised North Pit mine plan occurs within the footprint of the approved mining, except for a triangular area of cleared land (Proposed Disturbance Area) covering some 37.4 ha to the east of the approved North Pit footprint within the Main Creek catchment. Figure 3-2 shows the terrain and the drainage within the region.

Main Creek is the closest water course to the Proposed Disturbance Area, the high bank of Main Creek is located 160 m from the eastern limit of the Proposed Modification pit boundary at the closest point. The shortest distance to the mapped Main Creek alluvium is 150 m (at the closest point) from the Proposed Modification pit boundary. Main Creek is ephemeral and only flows following rainfall. It has a northeast-southwest alignment and joins Glennies Creek some 7 km to the south. Glennies Creek is the most significant water course in the local area with perennial flows maintained by releases from Lake St Clair located about 13 km upstream of the mining areas.

The realigned Bettys Creek runs along the western boundary of North Pit returning to the original alignment some 700 m southwest of the Proposed Disturbance Area. Bettys Creek enters Bowmans Creek approximately 4 km to the south-east. Bowmans Creek is also an ephemeral creek located west of the Proposed Disturbance Area which joins the Hunter River approximately 8 km south-west.

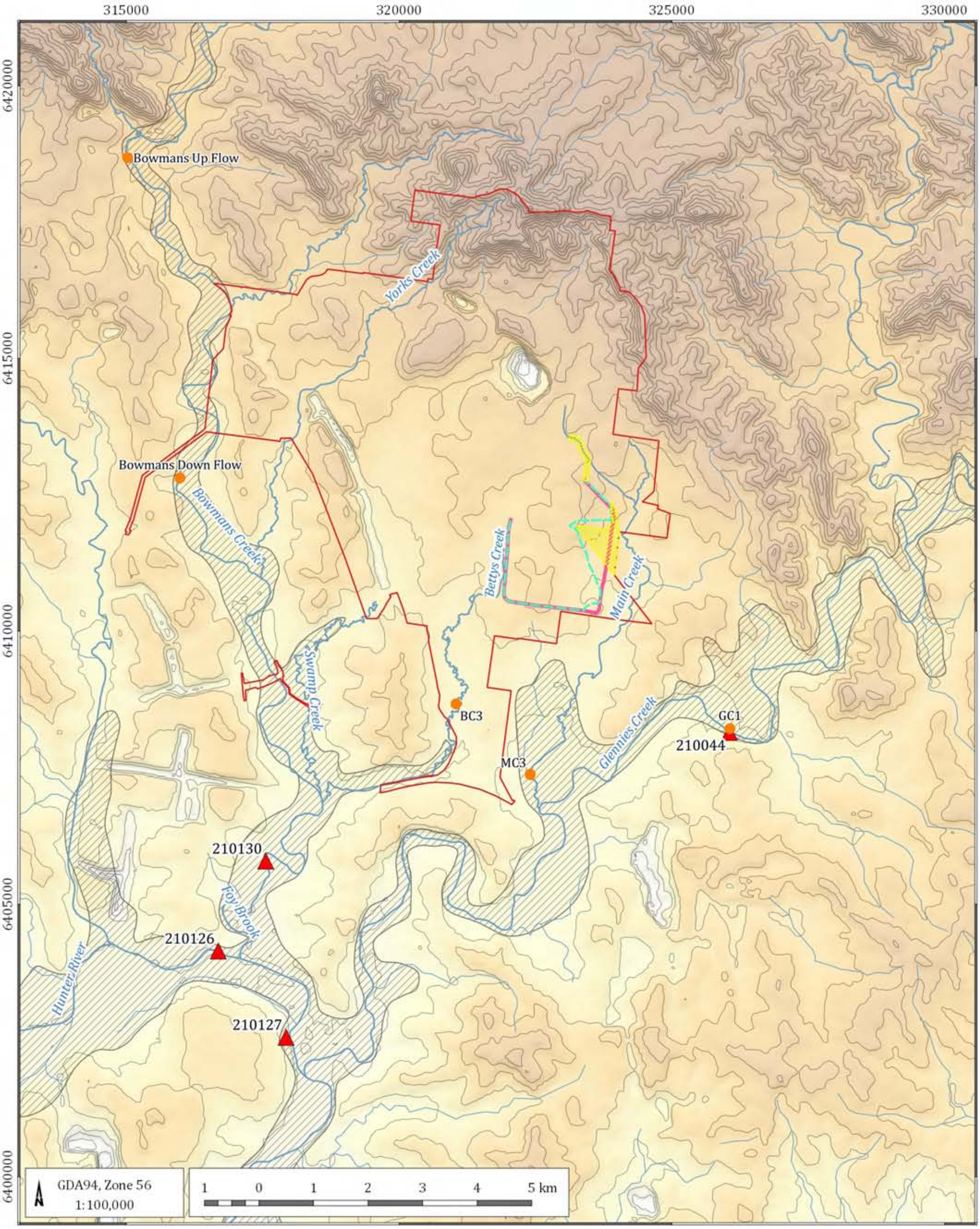
CLWD do not monitor stream flow within the smaller Bettys and Main Creeks, but do record streamflow and water quality on Glennies Creek, Bowmans Creek, and the Hunter River. Figure 3-2 shows the location of nearby gauging stations. The nearest gauging station along Glennies Creek is at Middle Falbrook (station 210044), which is southeast of the Proposed Disturbance Area. The nearest station on Bowmans Creek is at Bowmans Creek Bridge (210130), approximately 7 km from the Proposed Disturbance Area. There are two nearby stations on the Hunter River, Upstream Foybrook (210126), approximately 8 km southwest and Upstream Glennies (210127), 9 km from the Proposed Disturbance Area.

Stream flow records from the gauging stations were obtained and compared with daily rainfall data to assess the contribution of groundwater through baseflow to flows in Glennies Creek, Bowmans Creek, and the Hunter River. Figure 3-3, Figure 3-4 and Figure 3-5 show the total recorded stream flow for Glennies Creek, Hunter River, and Bowmans Creek respectively. The proportion of baseflow within was estimated and is shown on the graphs separated from the total flow.

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

Groundwater level measurements have recorded the regional water table is below the bed of Main Creek and Bettys Creek, indicating both creeks are largely disconnected from the regional water table and therefore do not receive any significant baseflow from groundwater. The adjacent IUG monitors water level and flow within Glennies Creek (GC1), Bettys Creek (BC3) and Main Creek (MC3). The monitoring site on Glennies Creek (GC1) is situated where the government gauge 210044 is located and therefore serves to supplement the flow data with additional chemical data. Figure 3-2 shows the location of gauging stations. Monitoring at MC3 and BC3 has confirmed creeks are ephemeral and only flow when rainfall is sufficient to generate runoff.

Figure 3-2 also shows the location of stream gauging sites in Bowmans Creek upstream and downstream of the Liddell Mine that are operated by Glencore.



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Proposed Disturbance Area
- Biophysical strategic agricultural land
- Major drainage
- Minor drainage
- River gauging stations
- Glencore gauging site

Elevation (mAHD)

- 40
- 80
- 120
- 200
- 400
- 600
- Contour (mAHD, 20m interval)

Mount Owen (G1862A)

Terrain and drainage

AGE

DATE 12/06/2018

FIGURE No: **3-2**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.; NSW Department of Planning & Infrastructure 2013, Strategic Agricultural Lands (Biophysical). Bioregional Assessment Dataset. Viewed 27 September 2017, http://data.bioregionalassessments.gov.au/dataset/42e2a51d-3c11-431f-ac62-f8511c859516.;
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/03.02_G1862A_Terrain and drainage.qgs

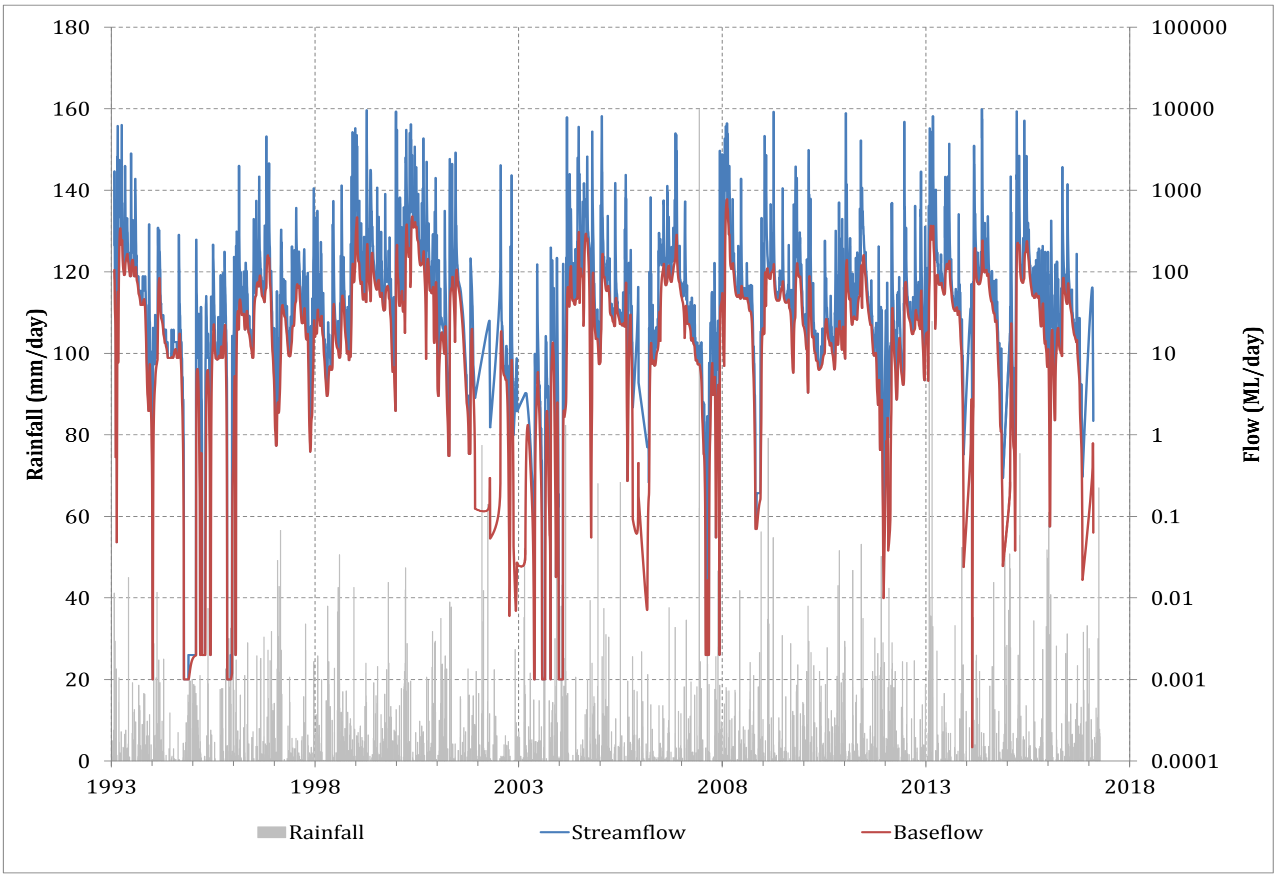


Figure 3-3 Baseflow in Glennies Creek at Middle Falbrook (210044)

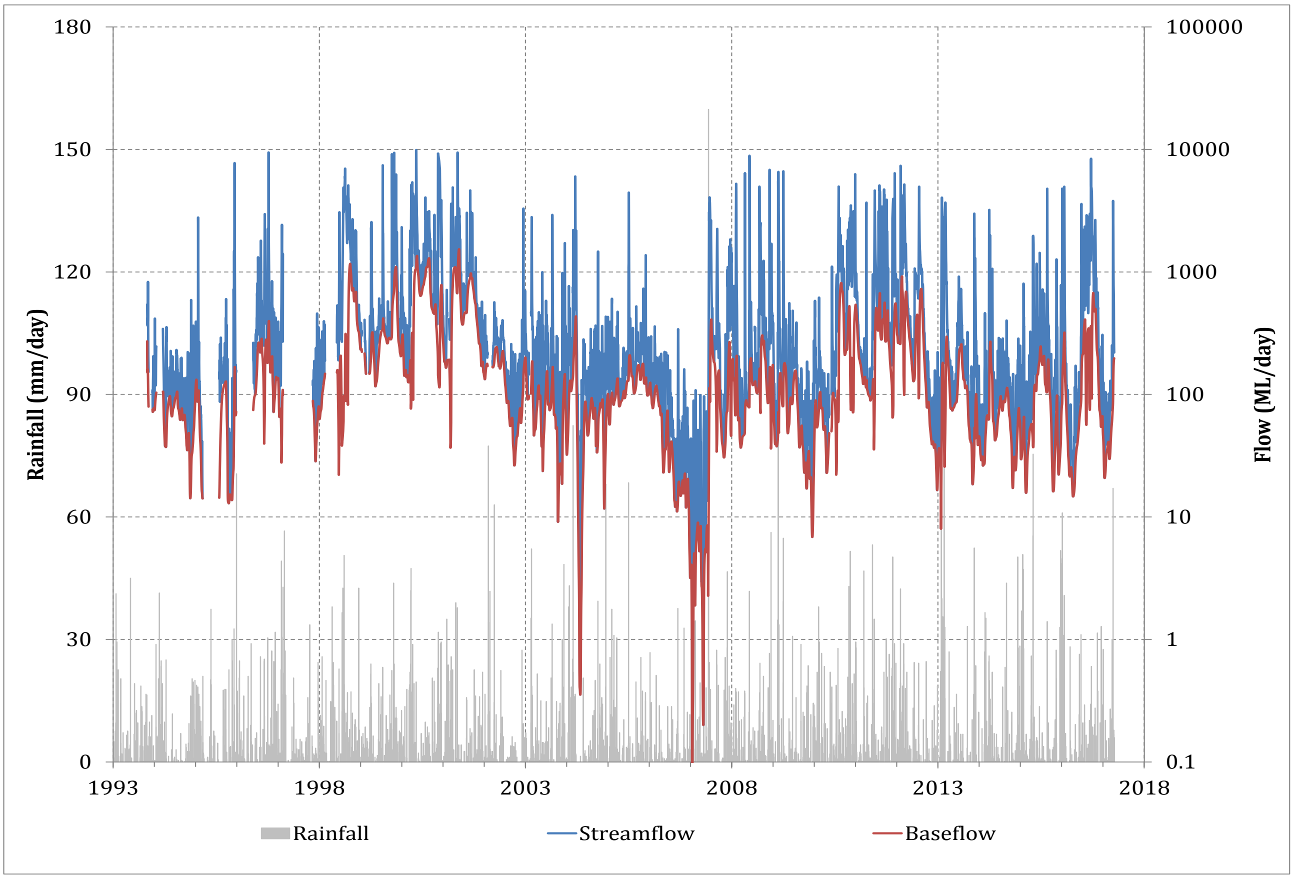


Figure 3-4 Baseflow in Hunter River at U/S Foybrook (210126)

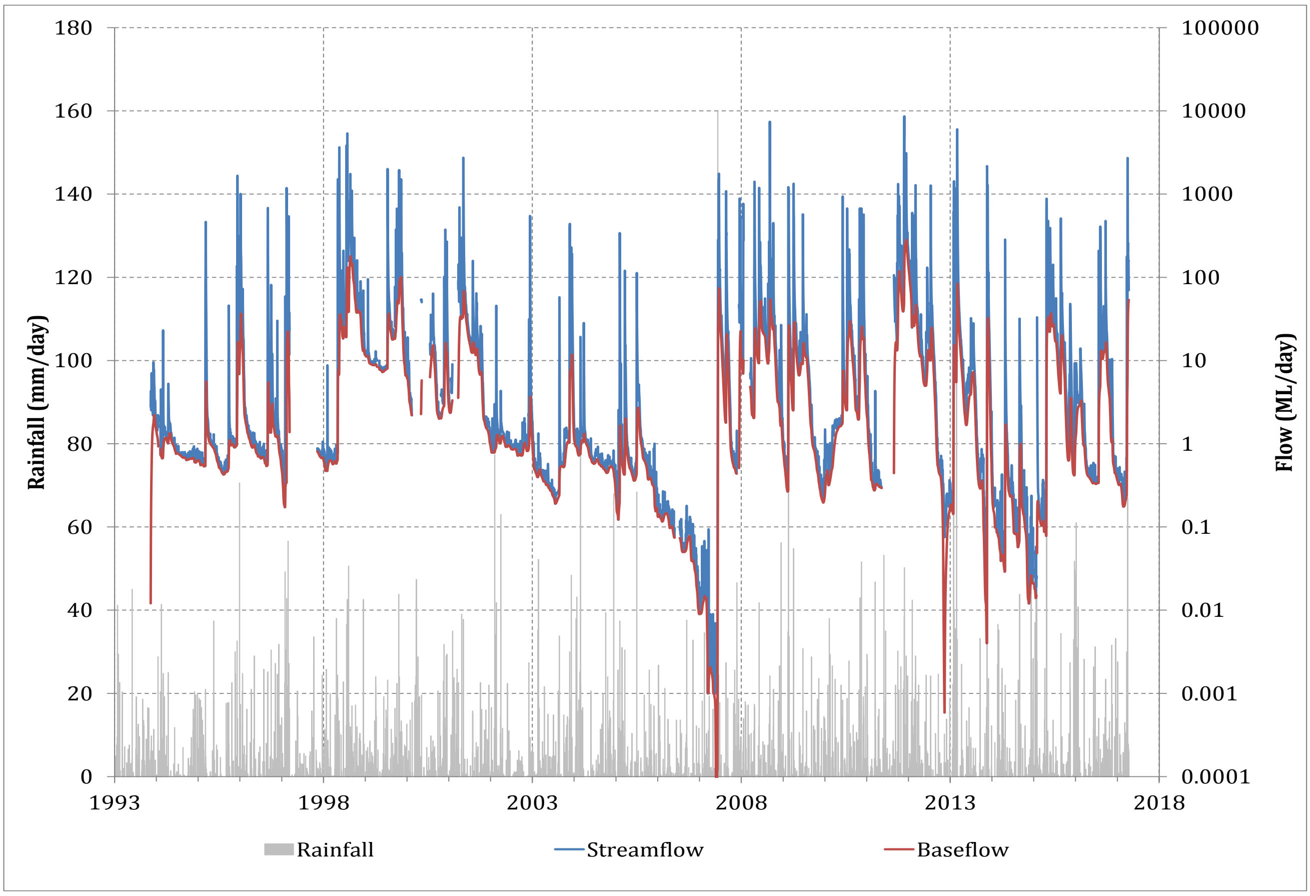


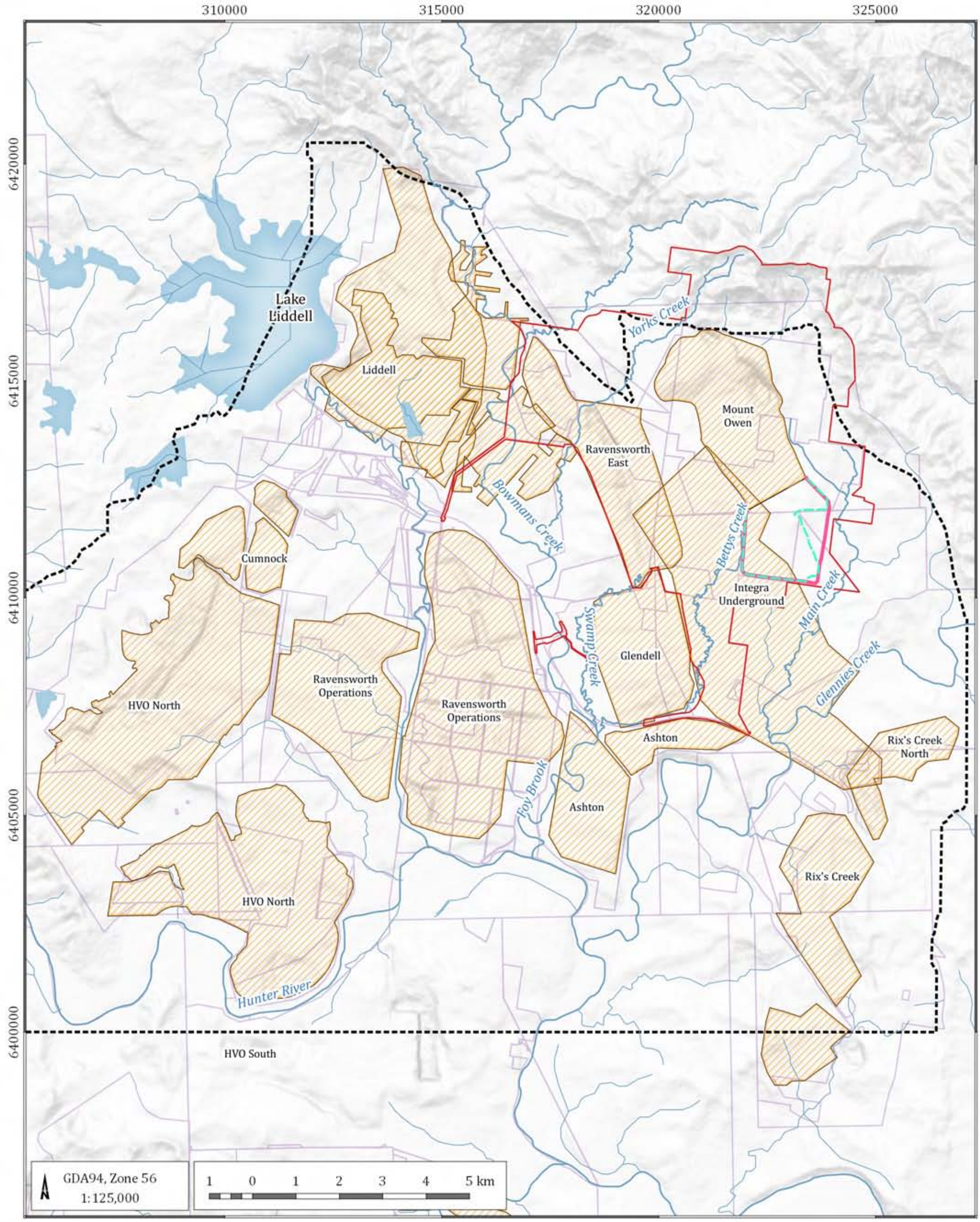
Figure 3-5 Baseflow in Bowmans Creek at Bowmans Creek Bridge (210130)

3.4 Land use

Land use within the vicinity of the Approved Operations is primarily coal mining and agriculture. Agricultural and environmental land use includes:

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

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



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Approximate historic and existing mining operations
- Model boundary
- Coal titles
- Water area
- Major drainage
- Minor drainage

Moint Owen (G1862A)

Historic and approved mining

AGE

DATE 12/06/2018

FIGURE No: **3-6**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/03.06_G1862A_Historic and approved mining.qgs

4 Geological setting

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

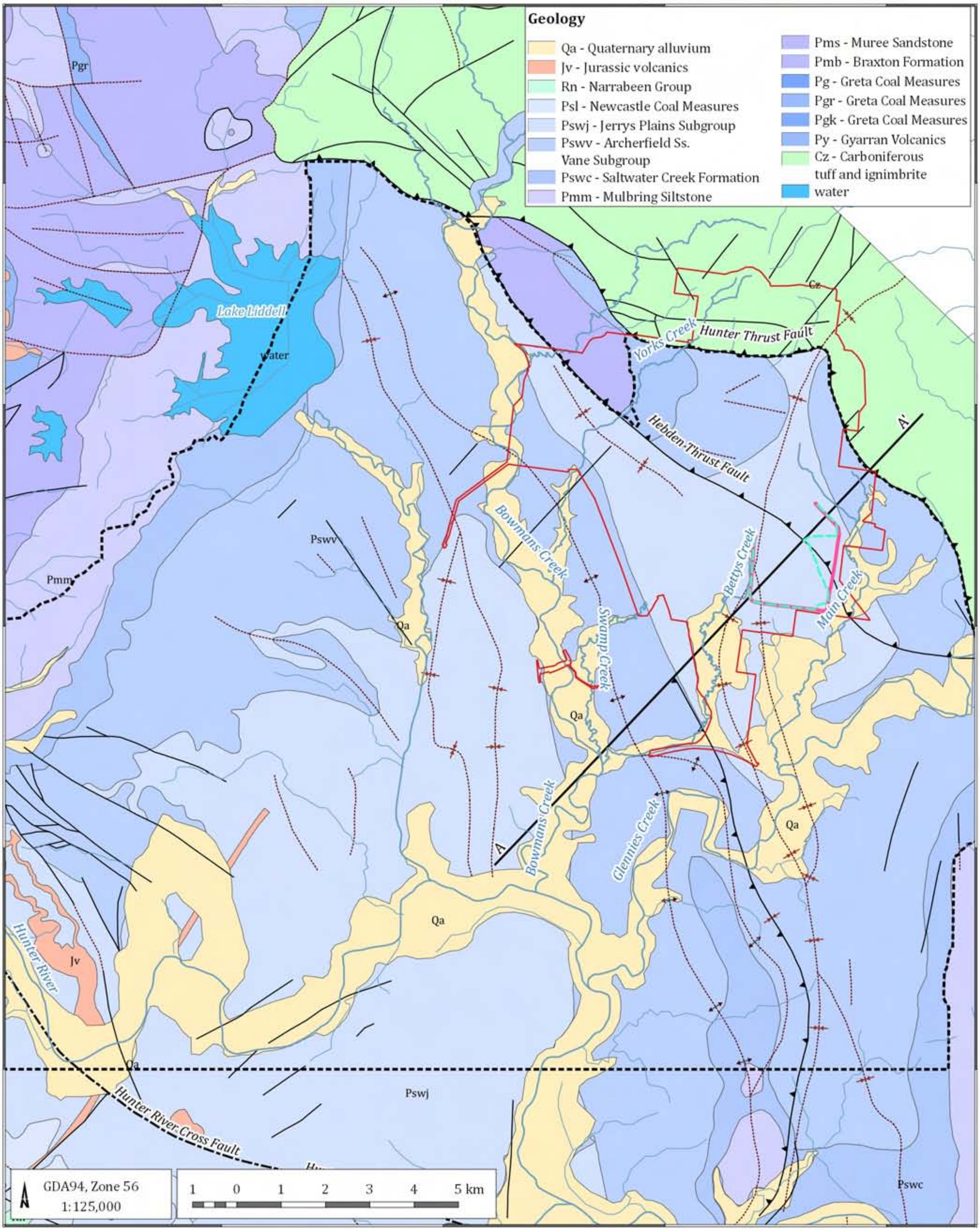
- publicly available geological maps (Hunter Coalfields map sheets) and reports;
- geological, geotechnical and hydrogeological reports and data prepared for Mount Owen Complex and IUG;
- publicly available geological and hydrogeological reports for surrounding mine operations; and
- hydrogeological data held on the CLWD 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 along Bettys Creek where mining has realigned the creek, and along Main Creek where localised studies have confirmed the extent of alluvial sediments. Table 4-1 provides a detailed summary of the regional geology and relevant stratigraphic units within the Mount Owen Complex and surrounds. Figure 4-2 provides a conceptual geological cross-section showing the relative distribution of key stratigraphic units across the Mount Owen Complex.

Table 4-1 Summary of regional geology

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



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Alluvium extent
- Cross section (A-A')
- Thrust fault
- Fault
- Anticline
- Syncline
- Fold
- Major drainage
- Minor drainage

Mount Owen (G1862A)

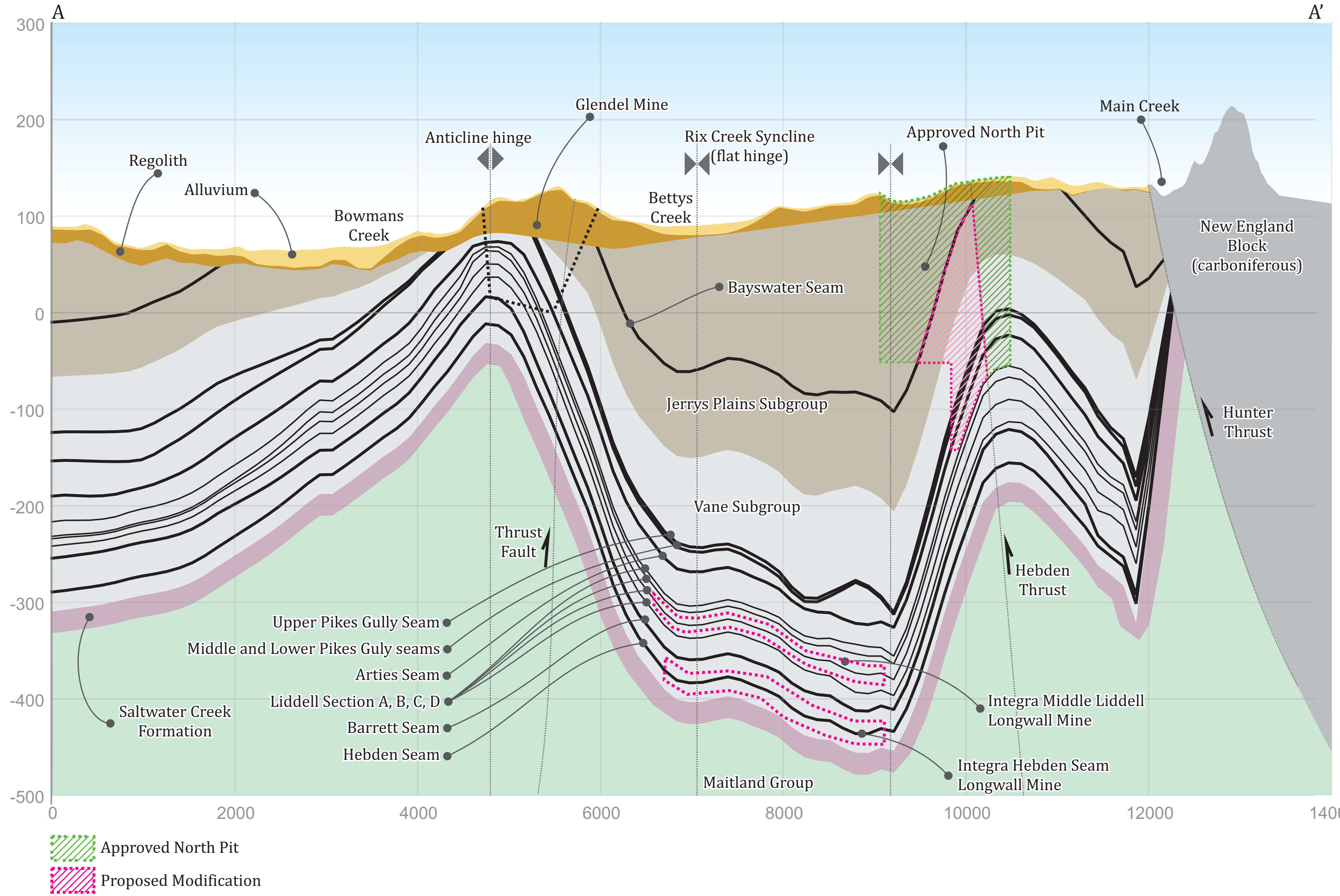
Regional surface geology

AGE

DATE 28/06/2018

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/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/04.01_G1862A_Regional surface geology.qgs



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

Figure 4-2

Integra (G1862A)

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

The Wittingham Coal Measures outcrop in the North Pit and are subdivided into the Vane Subgroup and the Jerrys Plains subgroup and contain the coal seams targeted by the Mount Owen Mine and adjacent mines. The underlying Vane Subgroup is separated into the Foybrook Coal Measures which contains the economic coal seams for the North Pit, and the Archerfield Sandstone, a well-sorted, quartz lithic sandstone. The Jerrys Plains Subgroup also contains numerous coal seams; claystone, tuff, siltstone, sandstone, and conglomerate. The Permian sediments dip in westerly direction towards the axis of an anticlinal structure along the western boundary of the North Pit.

The Permian sediments are unconformably overlain by thin Quaternary alluvial deposits along drainage line flood plains. These deposits comprise silt, sand, and gravel along the present day alignments of Glennies Creek, Main Creek and Bettys Creek. Surficial weathering occurs across the North Pit and the Proposed Disturbance Area. The 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 represents the boundary between the Carboniferous New England Block which has been thrust over Permian Sydney Basin sediments. The North Pit is located on the eastern limb of the Rix Creek Syncline with the coal seams dipping towards the west. The Hebden Thrust occurs within the North Pit raising the level of the coal seam on the eastern upthrust side of the fault. Figure 4-3 shows a photograph of the Permian sequence exposed in the highwall of the North Pit and highlights the folding of the coal seams but a general lack of significant fault structures.

Figure 4-3 Photo of Permian strata exposed in 'highwall' of North Pit looking towards the south

4.2 Local geology

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

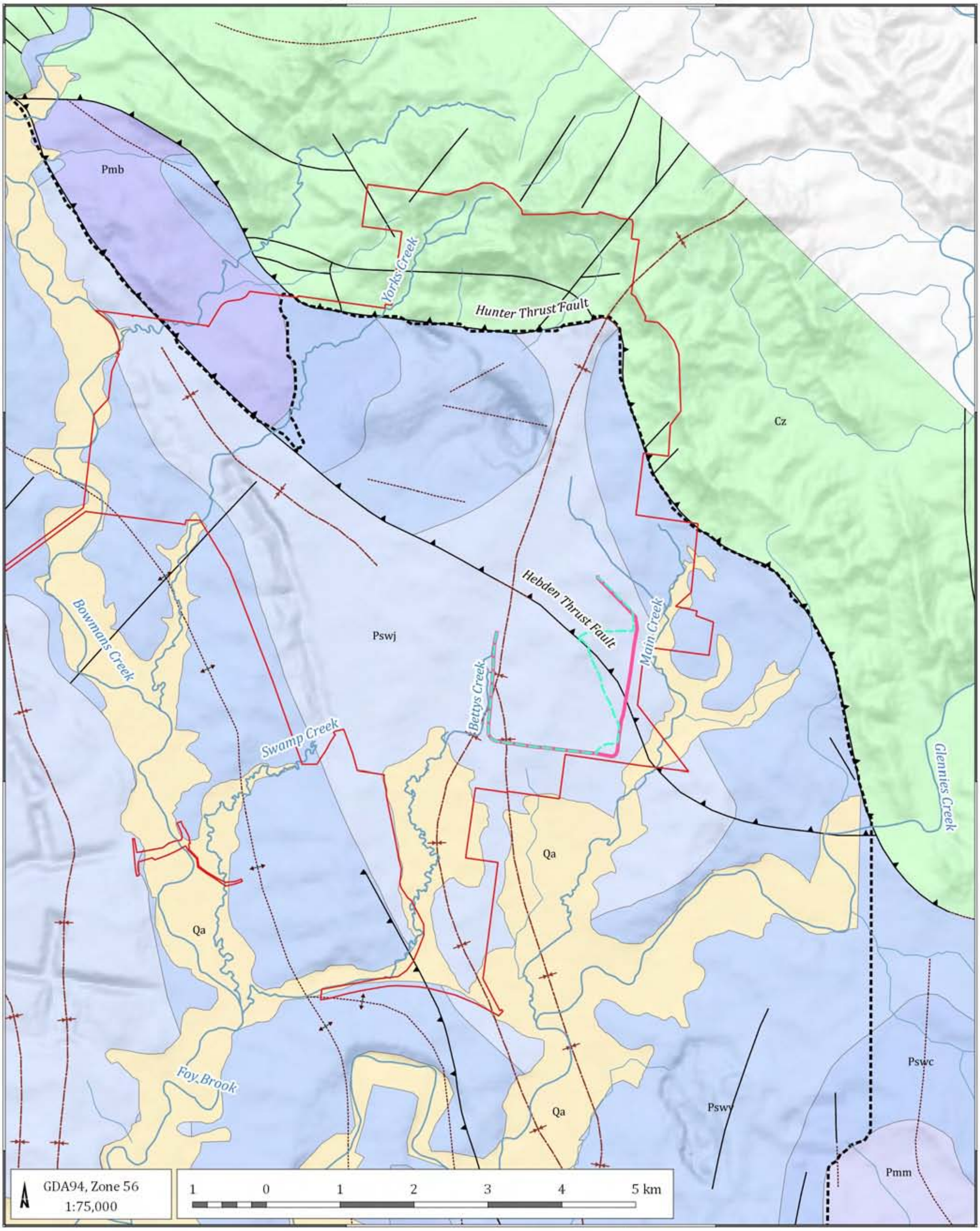
- Quaternary alluvium;
- Jerrys Plains Subgroup;
- Vane Subgroup;
- Saltwater Creek Formation; and
- Maitland Group.

Each of the main stratigraphic units is discussed in further detail below. Figure 4-4 shows the surface geology of the North Pit and immediate surrounds.

4.2.1 Quaternary alluvium

Quaternary alluvium (Qa) occurs within the flood plains of Main Creek and Bettys Creek in proximity to the North Pit. The alluvium typically comprises clay, silt and sand overlying basal clayey sands and gravels which unconformably overlie the Permian sediments. The Quaternary sediments are up to 5 m thick within the Bettys Creek flood plain and up to 10 m below Main Creek.

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



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Thrust fault
- Fault
- Anticline
- Syncline
- Fold
- Major drainage
- Minor drainage

Geology

- Qa - Quaternary alluvium
- Pswj - Jerrys Plains Subgroup
- Pswv - Archerfield Ss., Vane Subgroup
- Pswc - Saltwater Creek Formation
- Pmb - Braxton Formation
- Cz - Carboniferous tuff and ignimbrite

Mount Owen (G1862A)

Proposed Modification surface geology

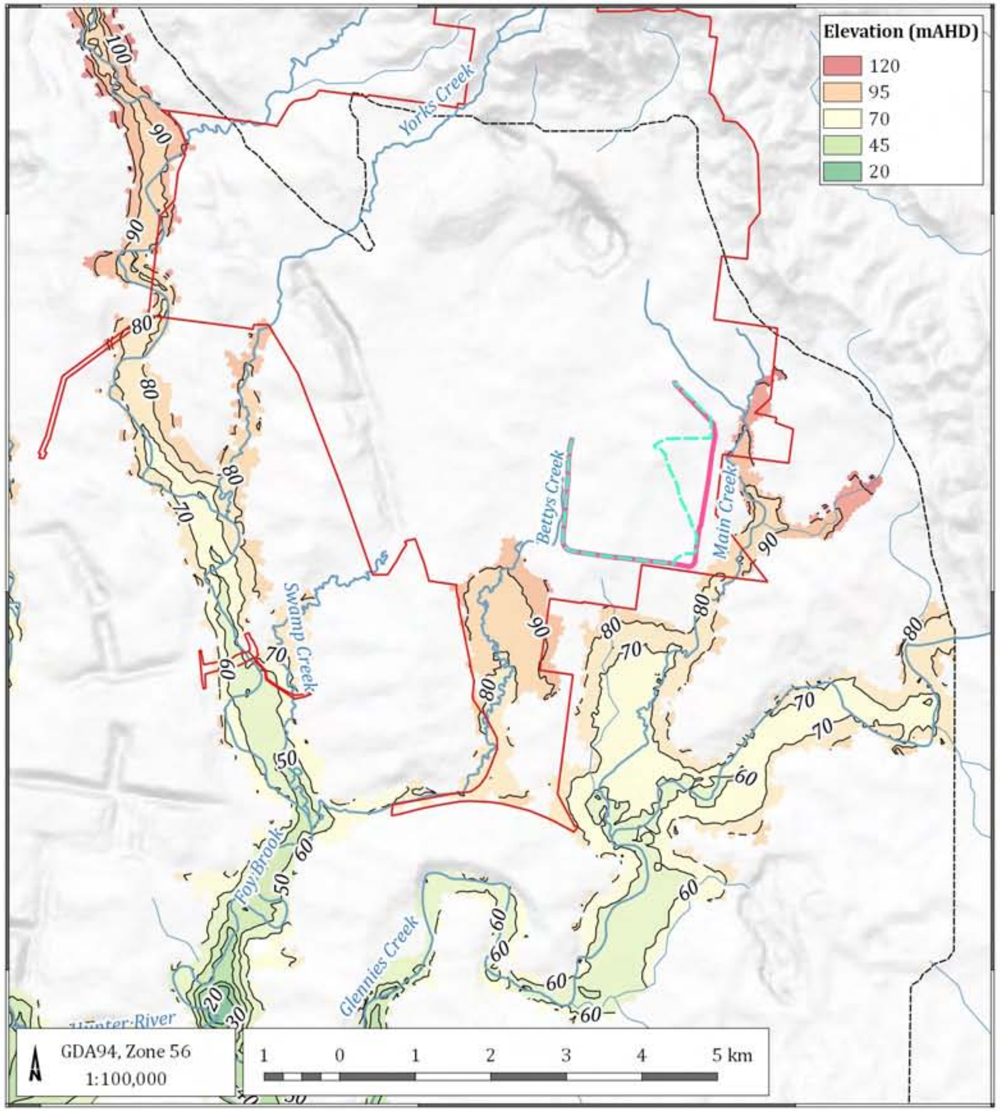
AGE

DATE 12/06/2018

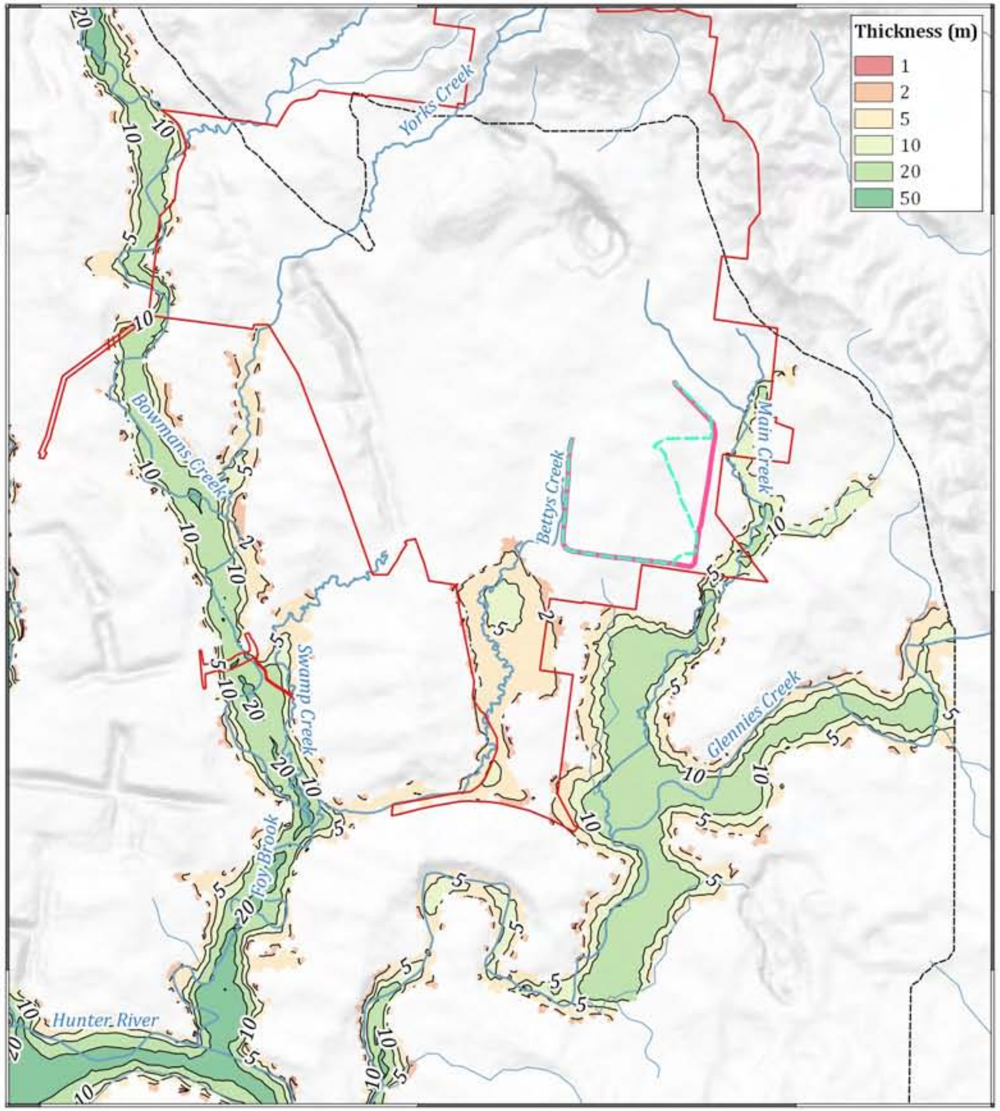
FIGURE No: **4-4**

Source: Glen R.A. and Beckett J., 1993, Hunter Coalfield Regional Geology 1:100 000, 2nd edition. Geological Survey of New South Wales, Sydney;
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/04.04_G1862A_Project site surface geology.qgs

Structure contours of the Quaternary alluvium



Thickness contours of the Quaternary alluvium



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Major drainage
- Minor drainage
- Contour line

Mount Owen (G1862A)

Structure and thickness contours of the Quaternary alluvium

DATE
12/06/2018

FIGURE No:
4-5

AGE

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/04.05_G1862A_Structure thickness contours Quaternary alluvium.qgs

4.2.2 Jerrys Plains Subgroup

The youngest of the Permian aged sediments within the North Pit are the Jerrys Plains Subgroup (Pswj), part of the Wittingham Coal Measures. The Jerrys Plains Subgroup outcrops within the North Pit (Figure 4-4) and subcrops below the Quaternary alluvium associated with Bettys Creek and Main Creek. 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. The Bayswater seam is the main economic seam within the Approved Operations.

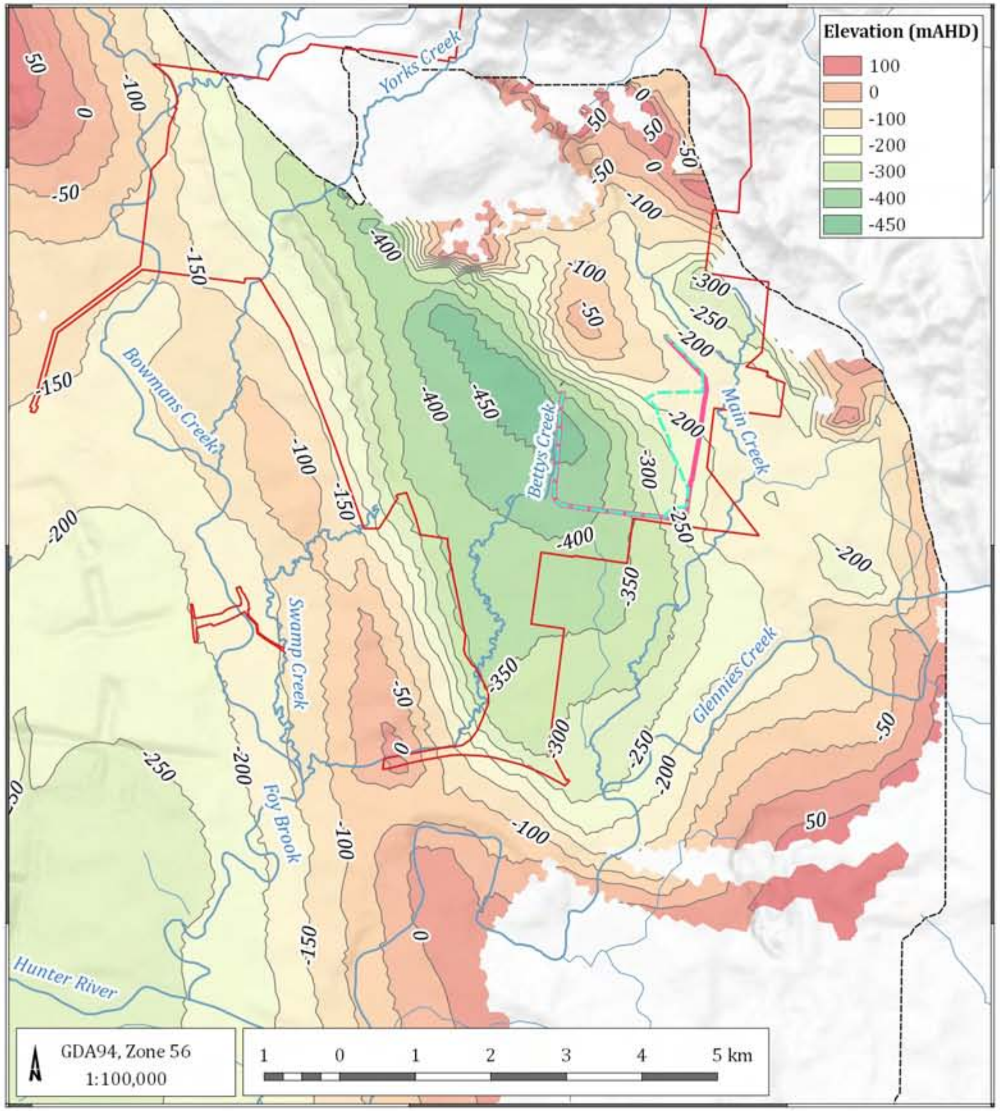
4.2.3 Vane Subgroup

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 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, Pikes Gully, Arties, Liddell, Barrett and Hebden Seams.

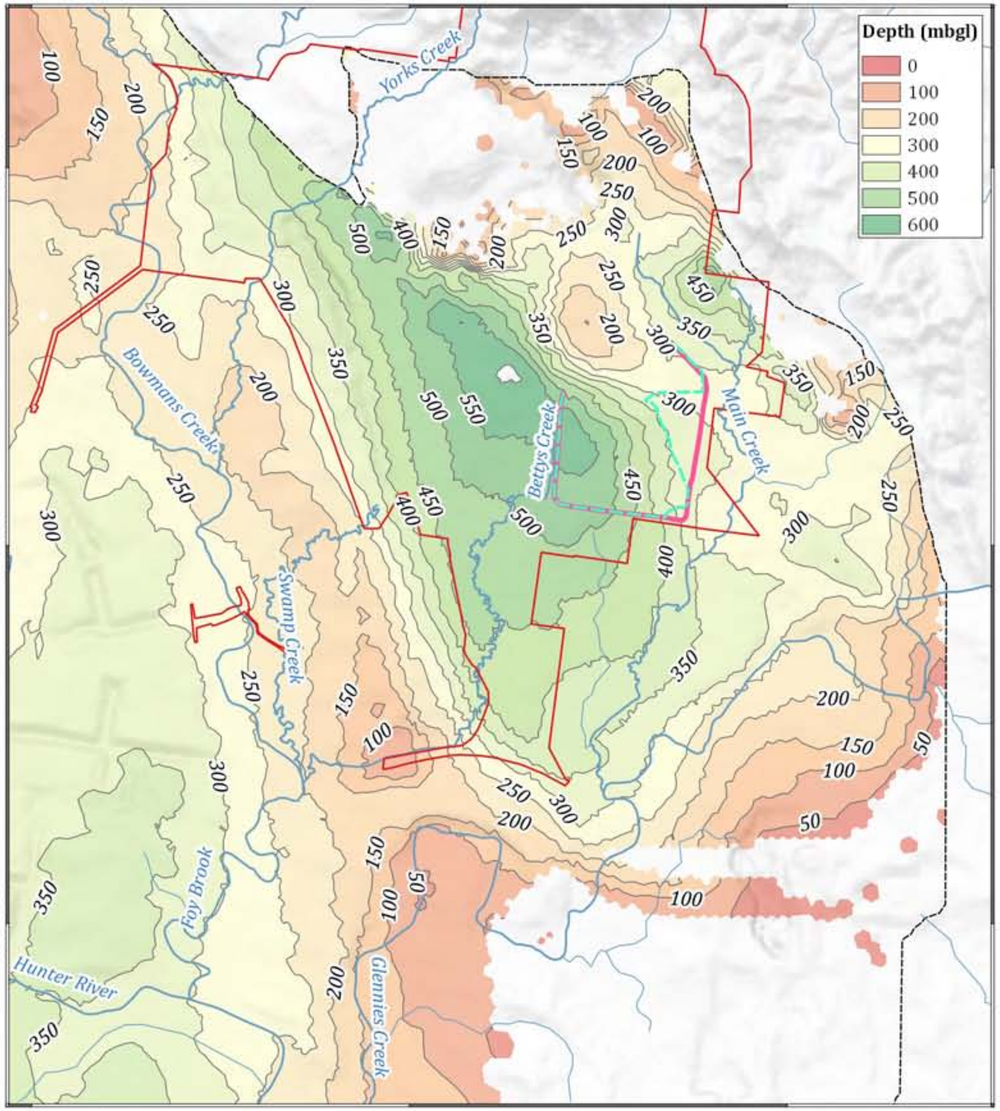
The Proposed Modification proposes additional mining of the Foybrook Formation coal seams down to the floor of the Hebden Seam which is up to 380 m below the current ground surface. Because the Foybrook Formation coal seams dip to the west and becomes too deep for economic open cut mining, the Proposed Modification pit shell is designed with a series of levels, with mining proposed to the Hebden Seam in the east where the seam is shallower and stepping up to the Lemington Seam in the western parts of the pit shell. The structure, distribution and depth to the Hebden Seam is presented in Figure 4-6.

A weathered profile up to 25 m occurs across the Permian strata that are exposed at the land surface. Figure 4-3 shows the Permian sequence exposed in the highwall of the North Pit and the thin brown weathered profile, overlying the grey and black un-oxidised Permian coal measures.

Structure contours of the Hebden Seam



Depth-below-surface contours of the Hebden Seam



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Major drainage
- Minor drainage
- Contour line

Mount Owen (G1862A)

Structure and depth below surface contours of the Hebden Seam

DATE
12/06/2018

FIGURE No:
4-6

AGE

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/04.06_G1862A_Structure and depth to base of Hebden Seam.qgs

5 Hydrogeology

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

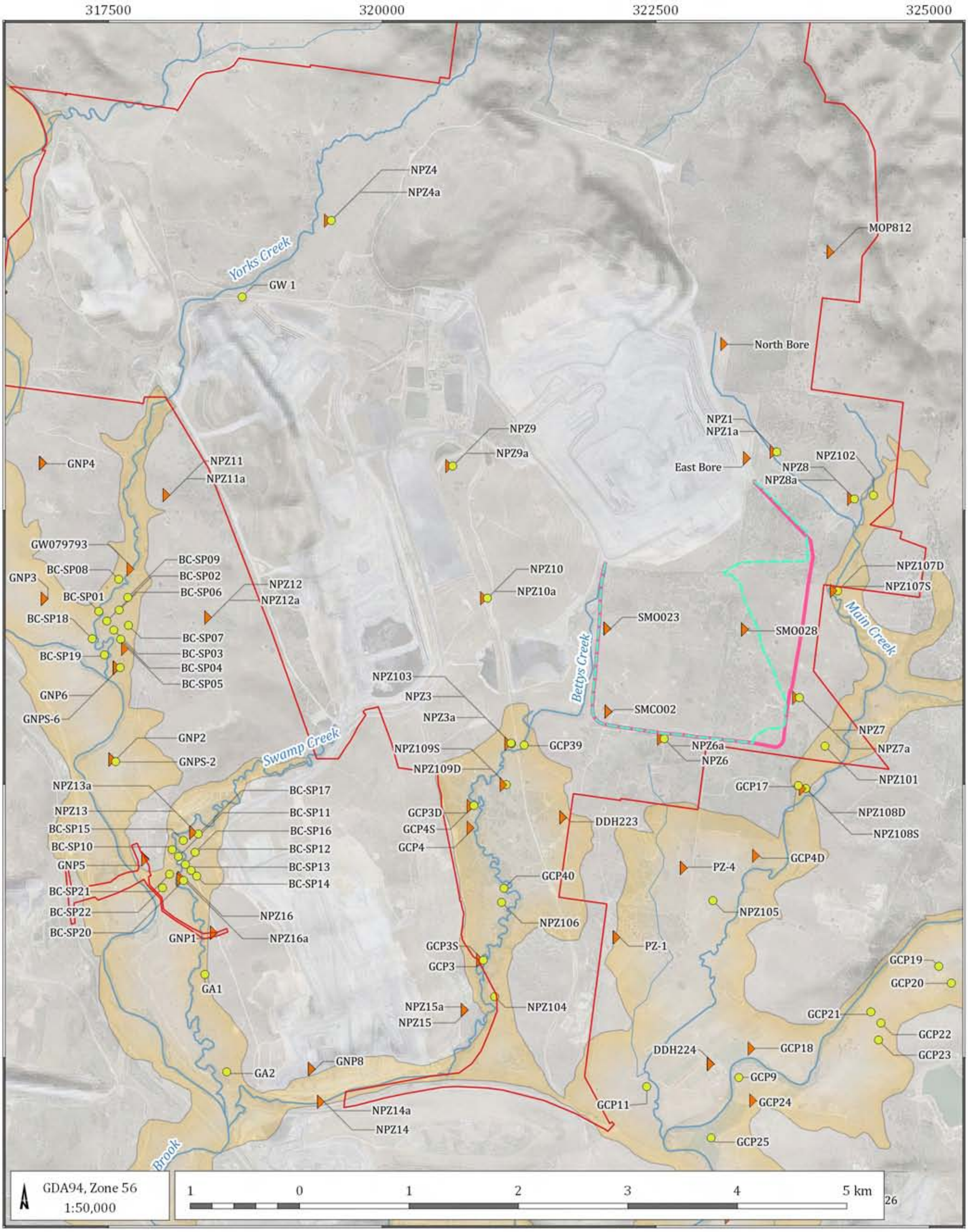
- Quaternary alluvium, which forms a relatively thin aquifer system where it occurs along drainage lines; and
- Permian sediments that can be divided into:
    - thin, generally dry and variably permeable weathered rock (regolith);
    - non coal interburden that forms aquitards; and
    - low to moderately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

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

5.1 Groundwater monitoring network

Glencore monitor groundwater levels within the Quaternary alluvium and Permian coal measures using a network of monitoring bores and vibrating wire piezometers (VWPs) installed across the mid Hunter region at each of its operations. Of relevance to the Proposed Modification are the monitoring networks at the Mount Owen Complex and at the adjacent IUG and Liddell Mines. The monitoring bores within the Quaternary alluvium are typically relatively shallow with standard uPVC casing. The Permian strata is monitored using a combination of monitoring bores and arrays of VWPs for the deeper strata within the geological sequence.

Figure 5-1 shows the locations of the monitoring bores and VWPs. The monitoring bores target the Quaternary alluvium deposited within the Bettys Creek, Main Creek, Bowmans Creek and Glennies Creek flood plains, as well as key coal seams and interburden units being mined. Tables within Appendix B summarise the construction details for each of the monitoring sites along with information on the aquifer thickness, recent static water levels and measurements of hydraulic conductivity.



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Alluvium extent
- Drainage

Monitoring bore stratigraphy

- Alluvium
- Permian

Mount Owen (G1862A)

Groundwater monitoring network

AGE

DATE 08/05/2018

FIGURE No: **5-1**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/05.01_G1862A_Groundwater monitoring location.qgs

5.2 Alluvial groundwater systems

5.2.1 Thickness and saturation

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

There are seven bores that have intersected the Bettys Creek alluvium. The borehole logs indicate the alluvium is defined by thin horizons usually no more than 2 m thick of clay, silt, sand, and gravel. Most layers are predominantly clay, with associated silt, sand, or gravel. Clays vary in colour across red, brown, and yellow to white and grey. Gravels are consistently rounded to sub-rounded, and sands vary from fine to coarse grained. The photograph in Figure 5-3 was taken where the North Pit has intersected the Bettys Creek alluvium and illustrates the horizons of silt and clay to gravel and coarse sand.

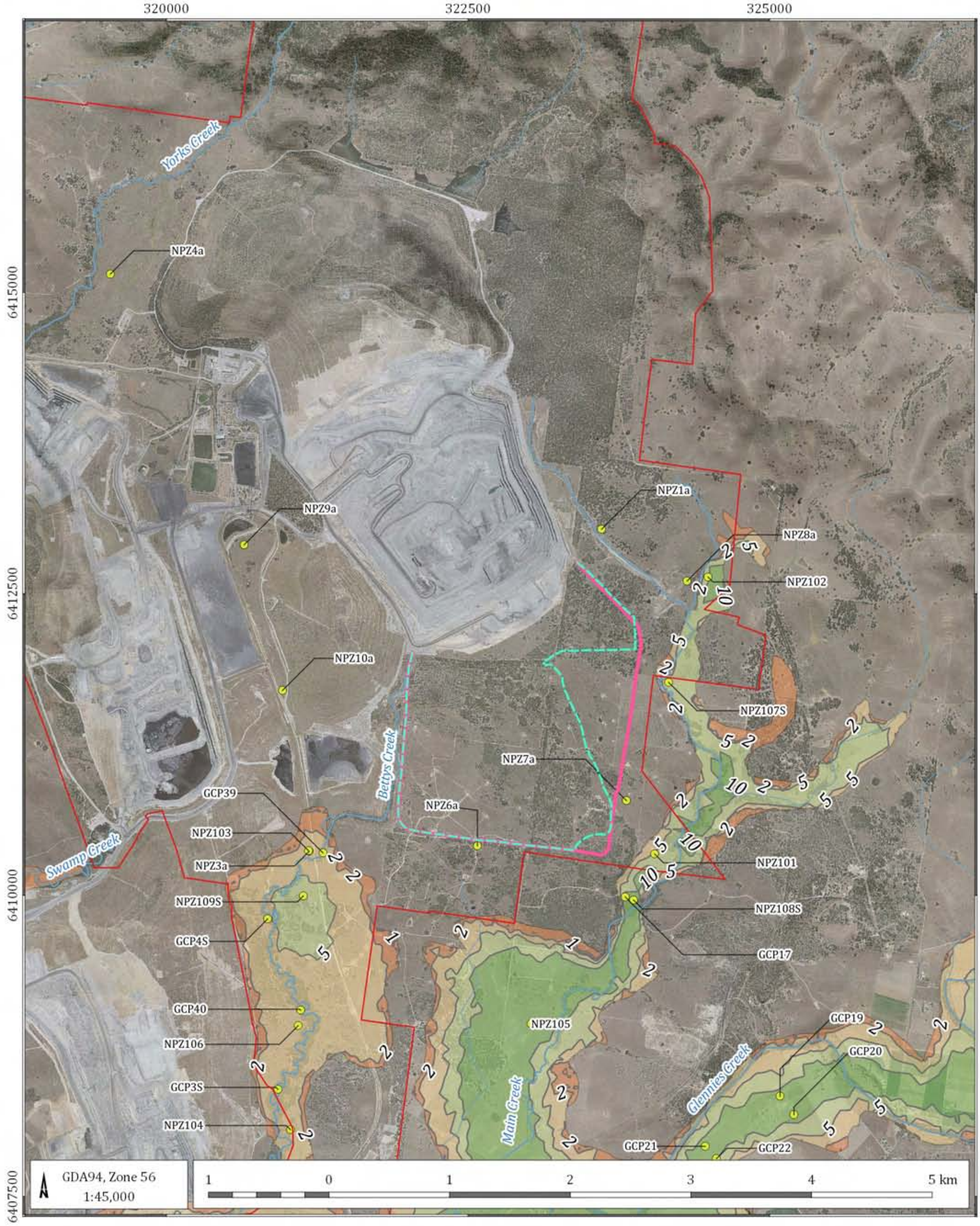
The saturated proportion of the Quaternary alluvium within the Bettys Creek alluvium is minimal. Bores NPZ104, NPZ106, and NPZ109S are dry, despite being screened to the base of the Quaternary alluvium. Bore NPZ103 has a saturated thickness of about 1 m, and the Quaternary alluvium at that location is 4 m thick. Bores GCP3S and GCP4S do not have drilling logs, and so the depth of the Quaternary alluvium and saturated thickness is not known. This information indicates Bettys Creek cannot be considered as a “highly productive” aquifer because the limited saturated thickness means it cannot yield flows of more than 5 L/sec from bores.

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

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

Whilst there is a greater saturated thickness within Main Creek it is still considered insufficient to yield more than 5 L/sec from a bore, and therefore does not meet the criteria to be classified as “highly productive”. This conclusion is supported by the observations of Jacobs (2017) who noted that monitoring bores installed in Main Creek alluvium (NPZ107S and NPZ108S) and Bettys Creek (NPZ109S) did not provide continuous flows of groundwater via airlifting. The monitoring bores could only be developed by hand bailing which indicates a very low sustainable yield well below 5 L/sec.

Umwelt (2015) investigated the connectivity between surface water in Main Creek/Bettys Creek and the underling shallow water table within the alluvial sediments. The work indicated the creek channels were typically less than 2 m in depth, and that all monitoring bores installed within the alluvium recorded groundwater depths below the level of the creeks. This indicates that the creeks are largely disconnected from the groundwater systems and the groundwater systems cannot contribute significant baseflow to Main Creek or Bettys Creek. This separation between the water table and the creek bed means there is a lack of connectivity and therefore any drawdown within the alluvium from mining activities would have no impact on surface flows in Main Creek and Bettys Creek.



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Contour line (m)
- Alluvium monitoring bores

Thickness (m)

- 0
- 2
- 5
- 10
- 20
- 30

Mount Owen (G1862A)

Interpolated thickness of Quarternary alluvium

AGE

DATE 25/06/2018

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/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/05.02_G1862A_Interpolated thickness of alluvium.qgs

Figure 5-3 Bettys Creek alluvium exposed in North Pit

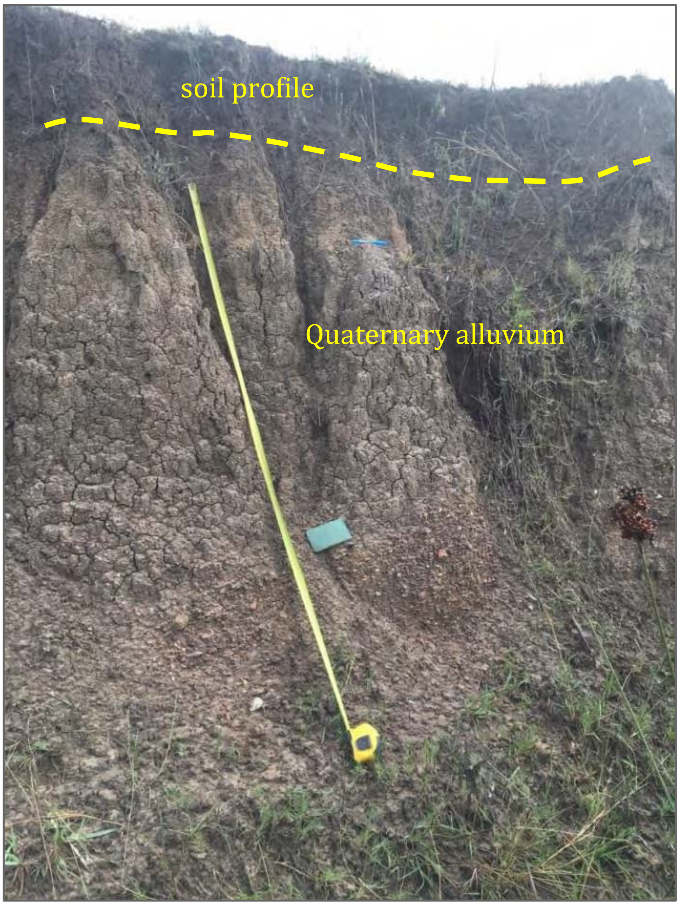
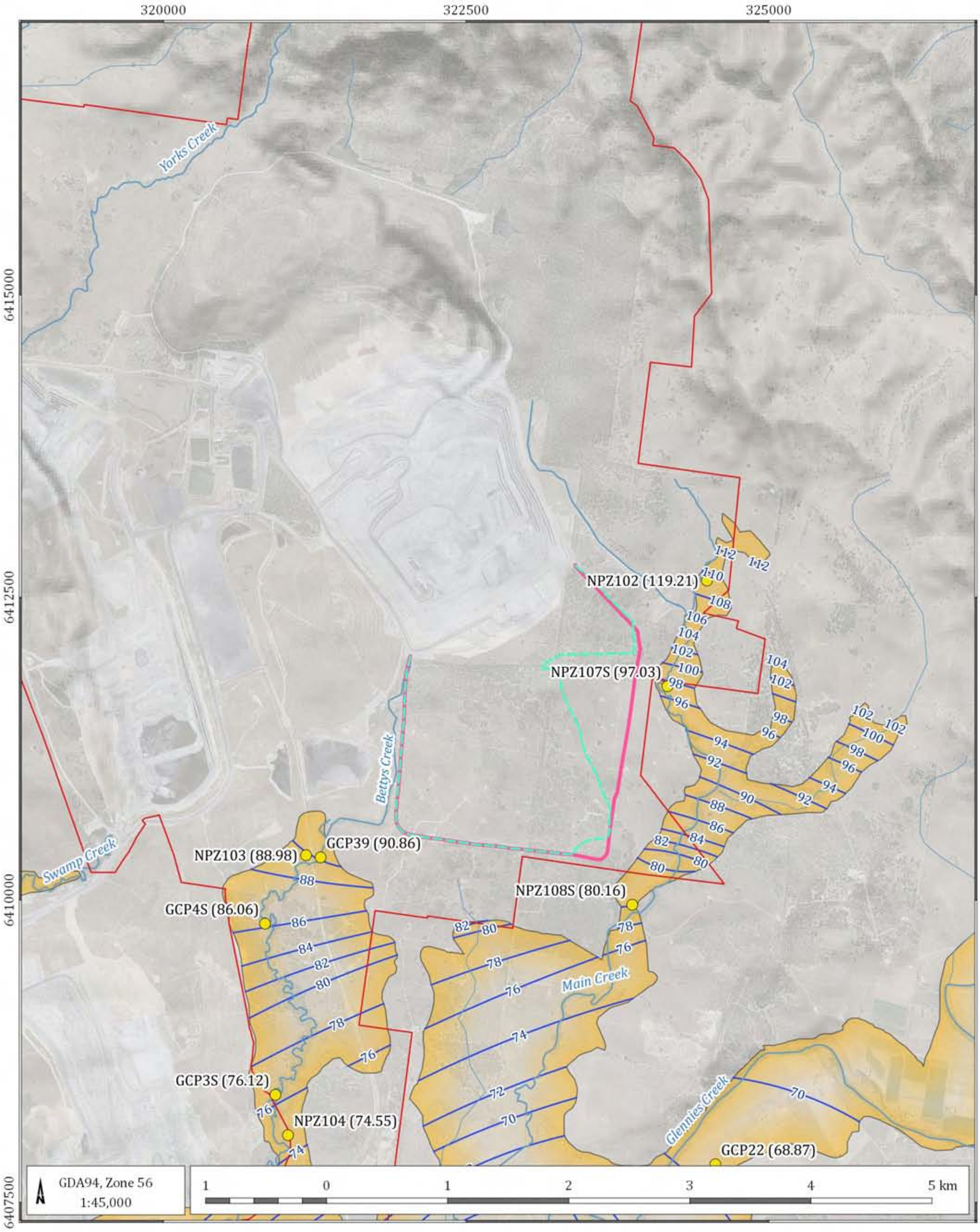


Figure 5-4 Main Creek alluvium from channel of Main Creek

5.2.2 Flow and water level fluctuations

Standing water level measurements from monitoring bores in the vicinity of North Pit indicate groundwater flow within the alluvial aquifers is a reflection of the surface topography. Figure 5-5 shows interpolated groundwater levels from the monitoring bores, and highlights the generally south to south-westerly trend in flow. The hydraulic gradients are relatively steep in Bettys Creek and Main Creek at about 1:100 to 1:200, whereas a gentler gradient occurs in Glennies Creek up to about 1:1000. This slighter hydraulic gradient within Glennies Creek appears due to the presence of more permeable sediments and a flatter terrain along the creek alignment. Long term groundwater level measurements have been recorded at each bore within the Quaternary alluvium adjacent to the Proposed Modification. These are presented in Figure 5-6 to Figure 5-10. The CRD is also included on the graphs to show climatic cycles and rainfall trends relative to long term averages. In general, groundwater levels within the Quaternary alluvium show a relationship to the CRD indicating the influence of climatic cycles on rainfall recharge. No significant drainage from the alluvial aquifers due to mining activities is obvious within the available datasets.



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Groundwater level contour
- Alluvium monitoring bores

Mount Owen (G1862A)

Interpolated groundwater levels within Quarternary alluvium 2017

AGE

DATE 08/05/2018

FIGURE No: **5-5**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/05.05_G1862A_Interpolated groundwater levels within alluvium 2017.qgs

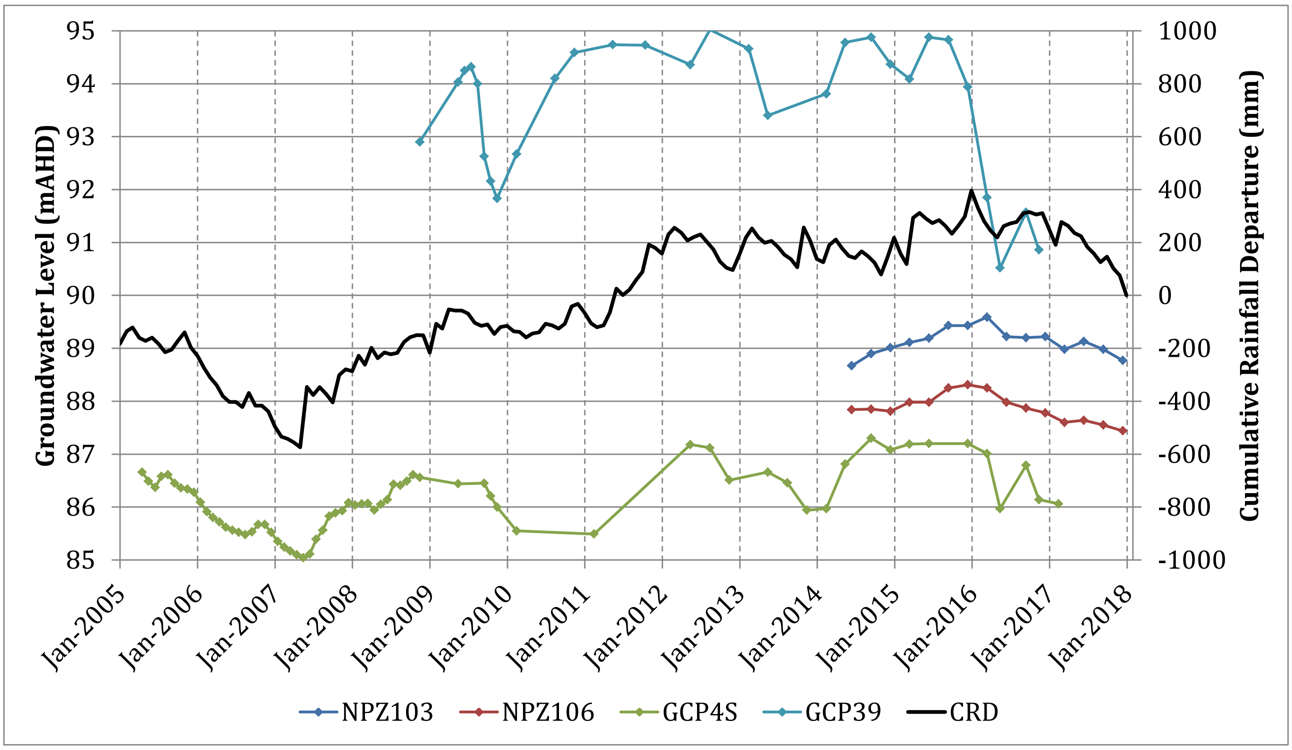


Figure 5-6 Bettys Creek alluvium hydrographs – northern bores

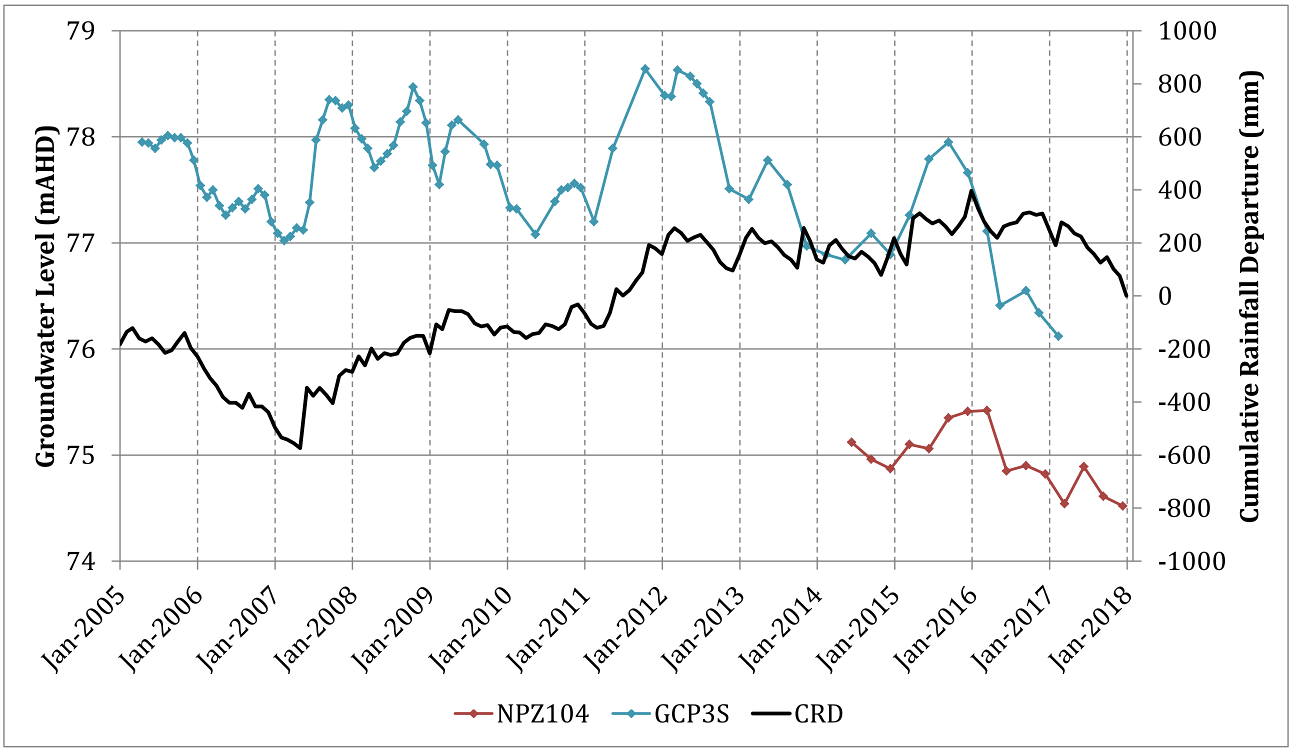


Figure 5-7 Bettys Creek alluvium hydrographs – southern bores

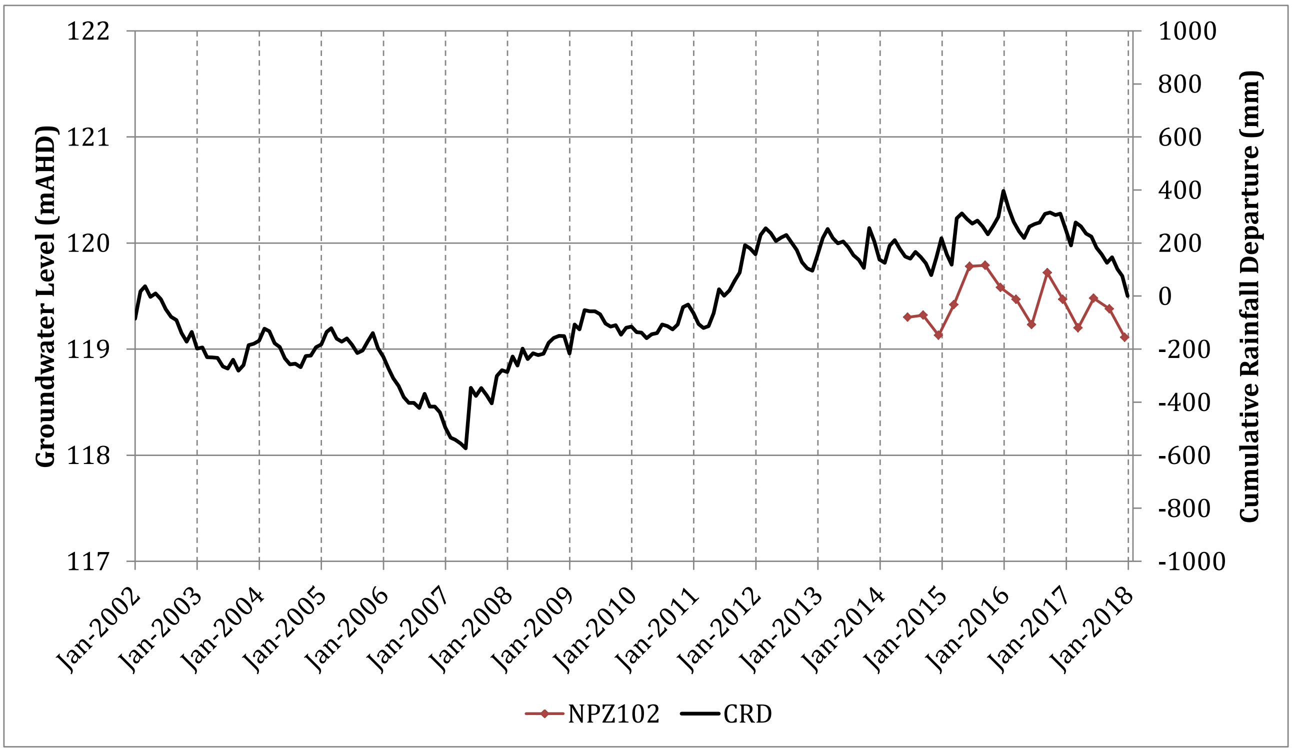


Figure 5-8 Main Creek alluvium hydrographs – northern bores

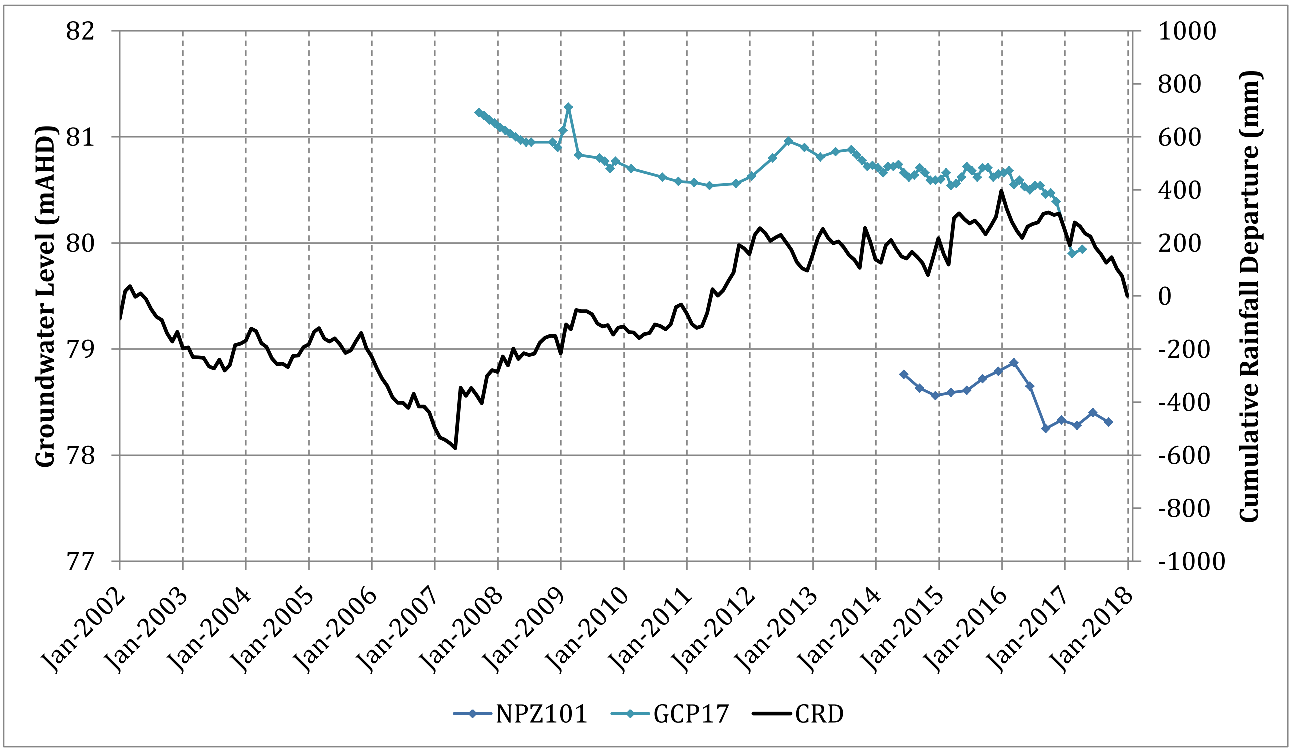


Figure 5-9 Main Creek alluvium hydrographs – midstream bores

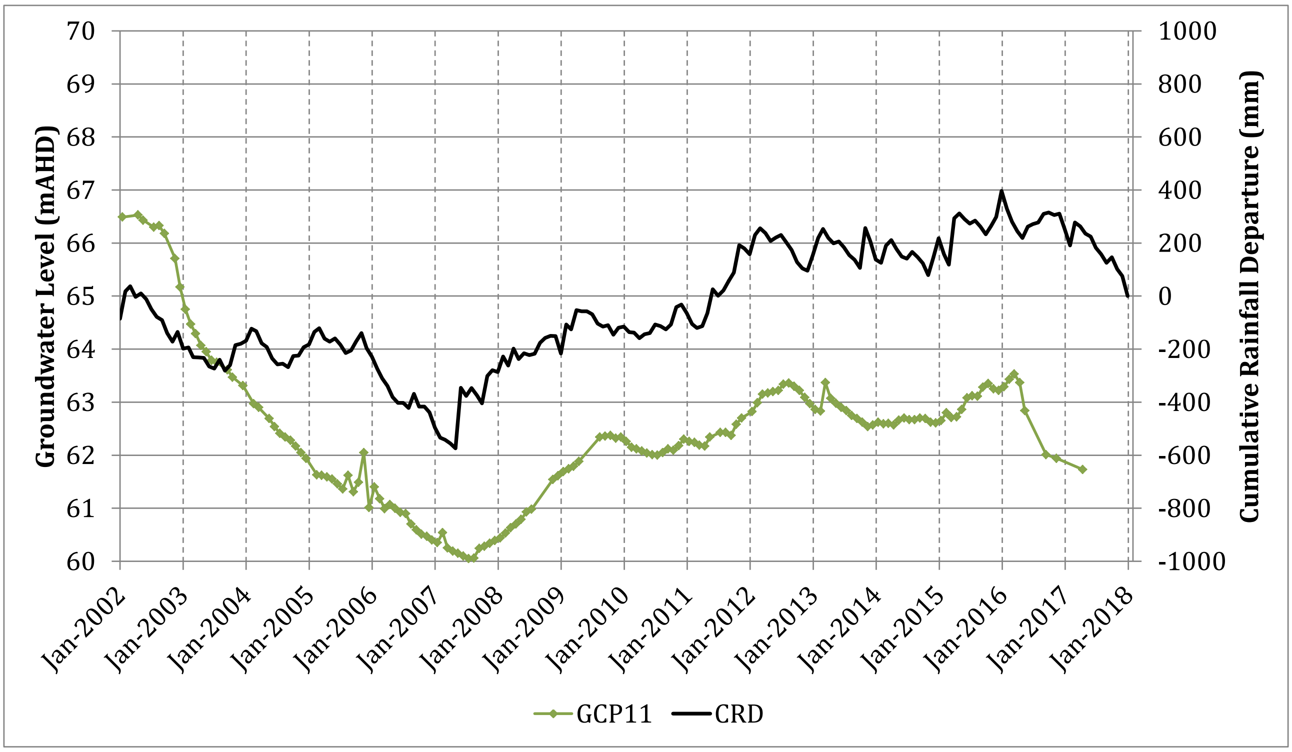


Figure 5-10 Main Creek alluvium hydrographs – southern bores

5.2.3 Hydraulic properties

The general dominance of clays within borehole logs for Bettys Creek and Main Creek alluvium suggests a moderate to low hydraulic conductivity for the alluvial sediments. This is confirmed by available hydraulic conductivity measurements for the alluvial sediments summarised in Appendix B, which indicate a hydraulic conductivity in the Main Creek alluvium of 0.06 m/day at bore GCP17. No measurements of hydraulic conductivity are available for Bettys Creek alluvium, but the lithology within the borehole logs suggests it would be similar to Main Creek, and therefore moderate to low for unconsolidated alluvial sediment.

5.3 Permian groundwater systems

5.3.1 Flow and water level fluctuations

Mining at Mount Owen Mine and the adjacent IUG is relatively deep and therefore suited to using arrays of VWPs to monitor changes in pore pressure and depressurisation. Three arrays of VWPs installed in exploration holes are located within the footprint of the approved North Pit (SMO023, SMO028 and SMCO02).

The arrays of VWPs are fitted with data loggers and therefore provide a continuous record of how pressure within Permian strata has responded to mining. Figure 5-11 to Figure 5-13 below show pressures recorded by each VWP sensor in equivalent Australian Height Datum (AHD) in the vicinity of the Mount Owen mine.

North Pit is also surrounded by the NPZ series of monitoring bores. These bores are comprised of two PVC pipes installed at different levels within the same borehole, with a shallow 50 mm PVC pipe typically less than 100 m deep and second deeper 25 mm PVC pipe within the same drill hole sometimes installed at depths greater than 100 m. Figure 5-14 to Figure 5-19 show hydrographs for selected bores and VWPs that are located within the Permian strata in the region of North Pit.

The closest VWP array, SMO023, is some 900 m from the active North Pit mine face and has recorded a gradual depressurisation within the Bayswater seam, but relatively stable pressures in the shallower overlying seams. In contrast the arrays of VWPs in SMO028 some 1.3 km from the North Pit highwall have recorded some cycles of drawdown, but followed by subsequent recovery in some of the VWPs. These hydrographs demonstrate the variability in the pressure response within the different seams. SMC002 is located some 1.7 km from North Pit highwall and installed within strata overlying the IUG. The sensors installed within the deeper Bayswater and Ravensworth seam between 135 m and 190 m deep have responded to mining at IUG, whereas the shallow sensors installed at depths less than 110 m show only a slight response, followed by recovery in pressure at depths above 56 m. The deeper sensors have been damaged by subsidence from the Integra Underground mine and have not provided data since 2014.

The hydrographs for the NPZ series of monitoring bores provide less detail than the arrays of VWPs, but record a gradual depressurisation in the deeper strata. The influence of mining is evident in many of the hydrographs with depressurisation resulting in a characteristic slow decline in groundwater levels within deeper Permian strata below 100 m depth over time. This is typical for relatively low permeability material that is slow to drain. In contrast, the groundwater levels within the shallow piezometers are more stable and do not suggest any significant depressurisation associated with mining.

In summary the monitoring network shows the cumulative impact of open cut and underground mining is depressurising strata within the Permian sequence around the Proposed Modification. The depressurisation is much less evident and less significant within the shallow strata less than 100 m deep. The higher pressures within the shallow strata means the cumulative impact of mining has not resulted in a detectable reduction in groundwater levels within the alluvial groundwater systems along Main Creek and Bettys Creek.

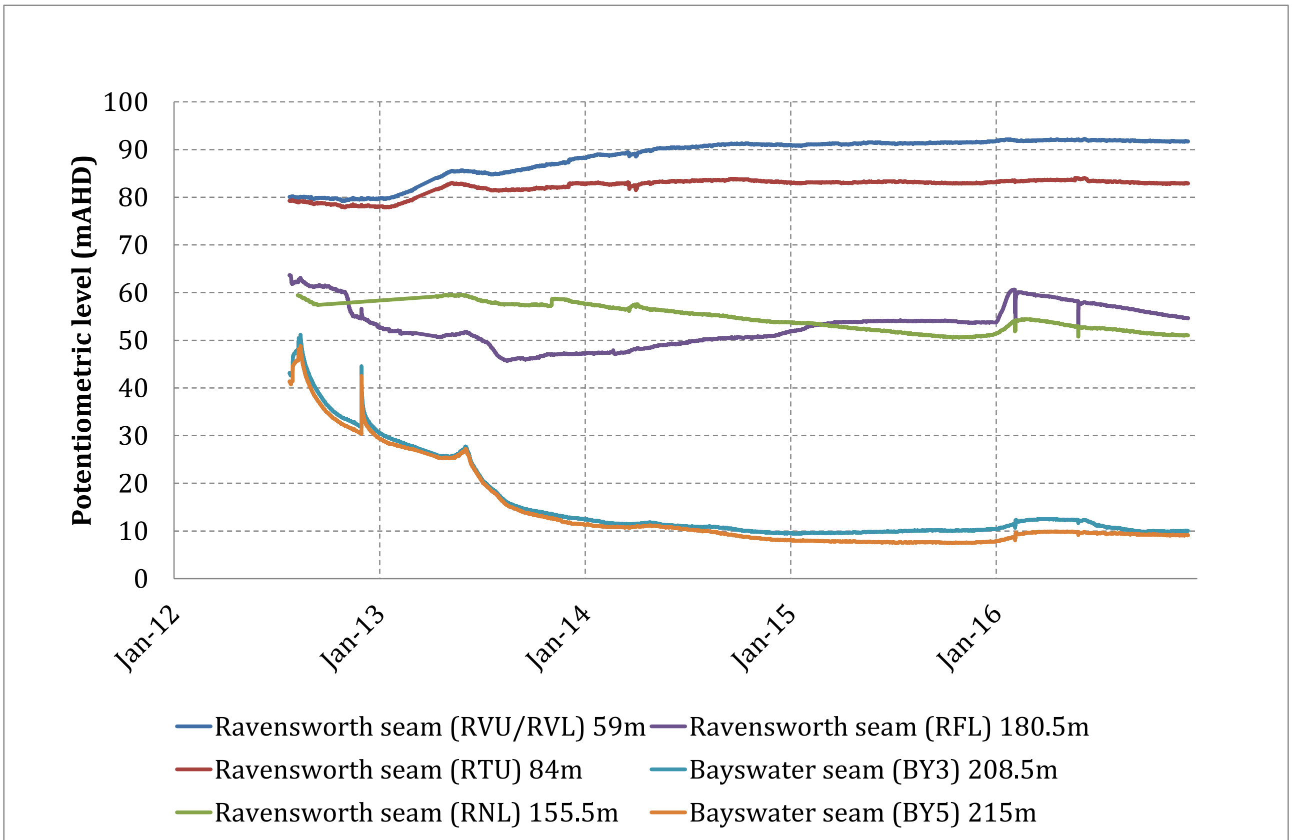


Figure 5-11 Hydrograph – SMO023

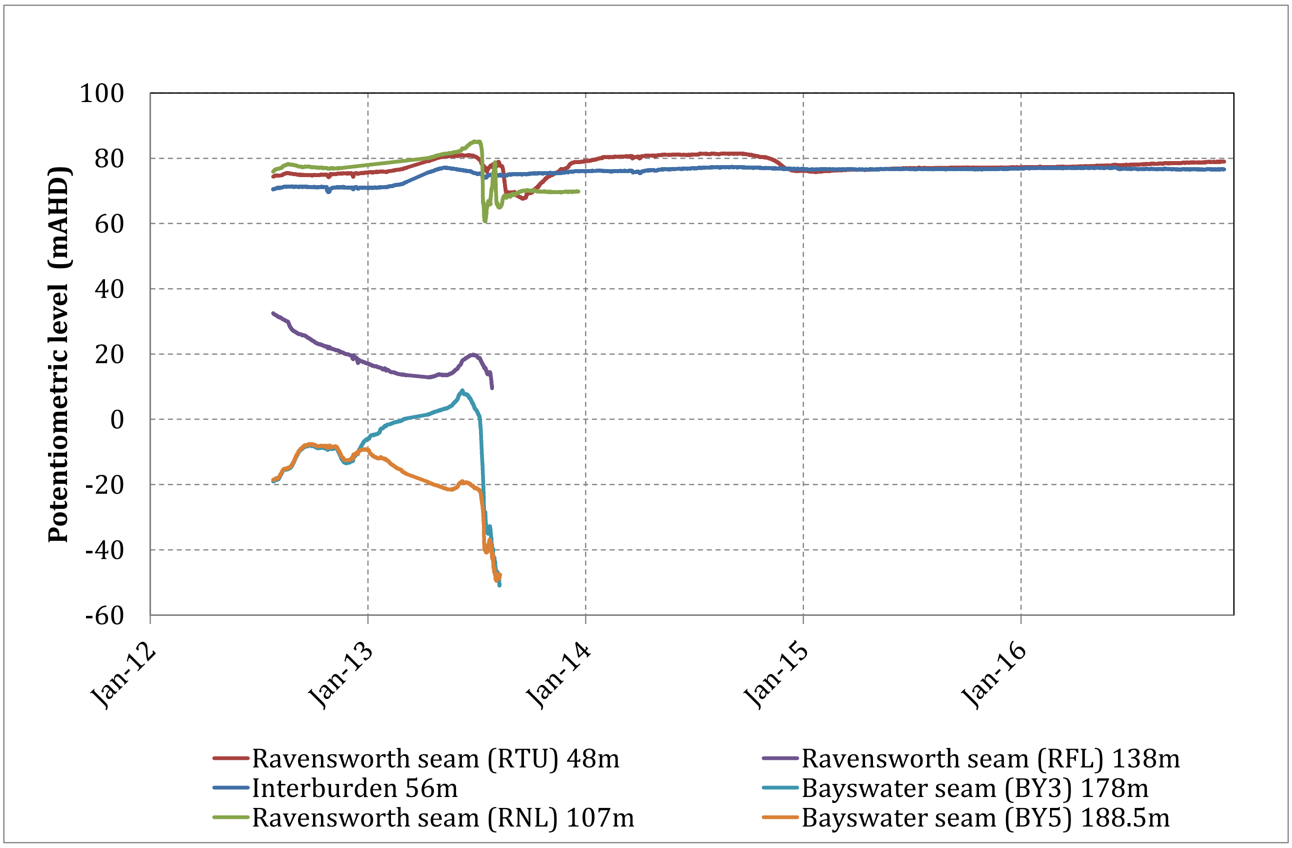


Figure 5-12 Hydrograph – SMC002

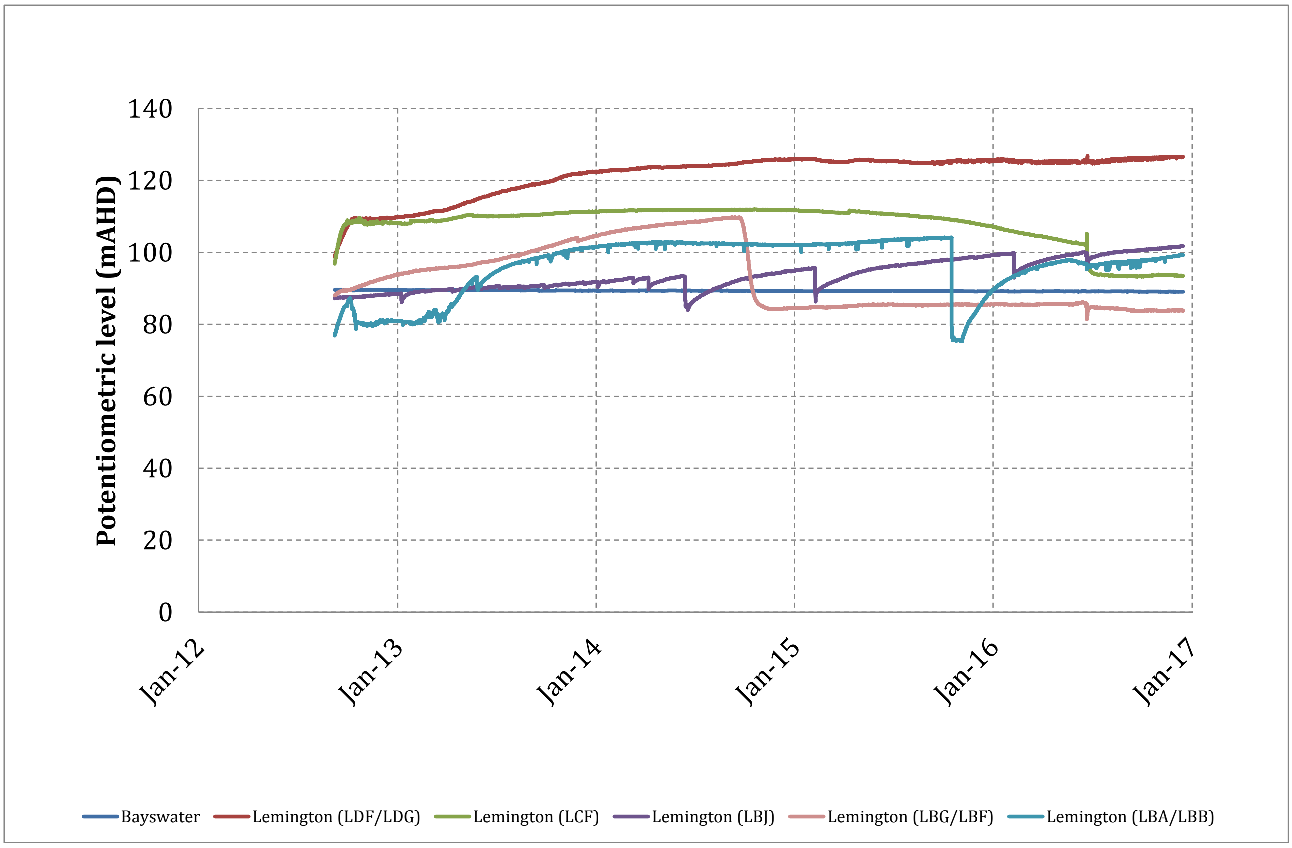


Figure 5-13 Hydrograph – SMO028

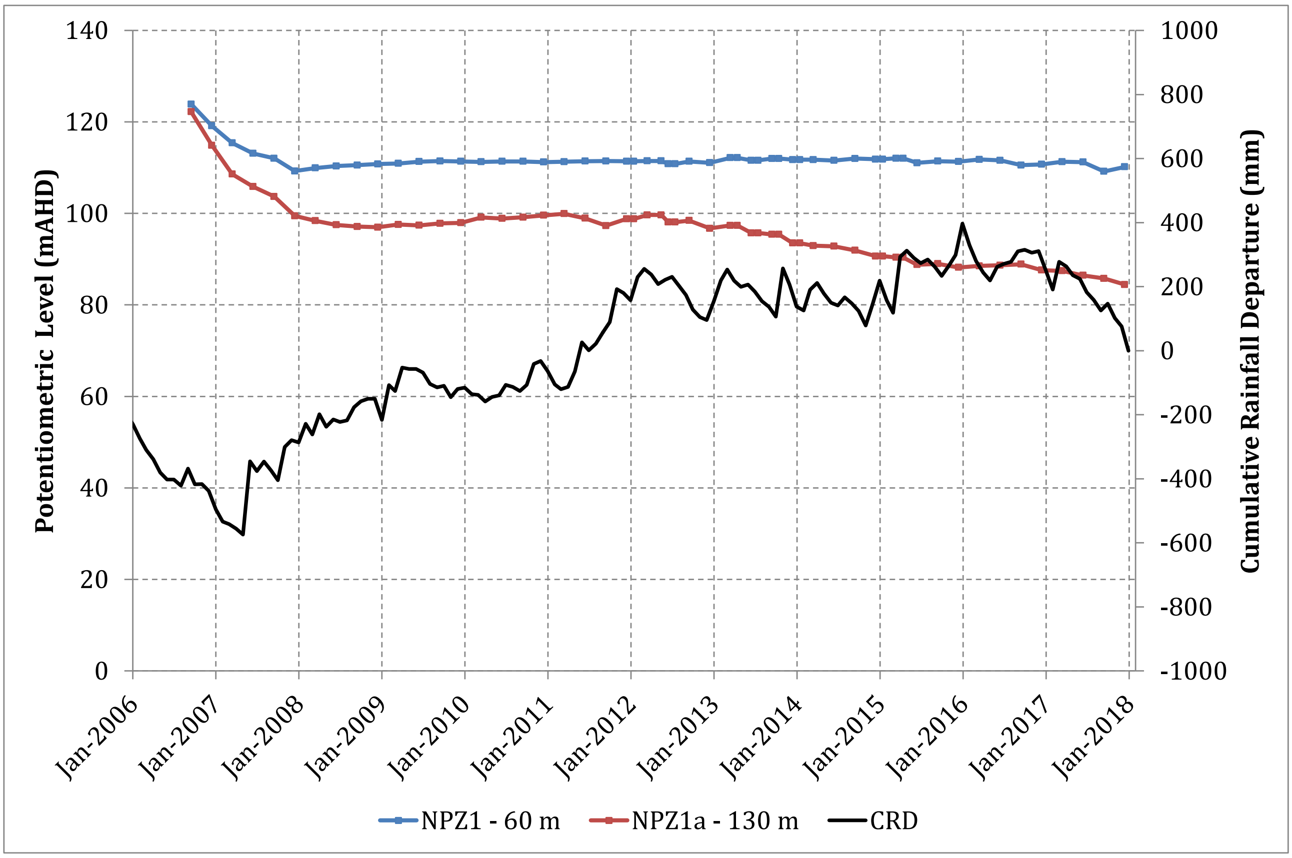


Figure 5-14 Hydrograph – NPZ1

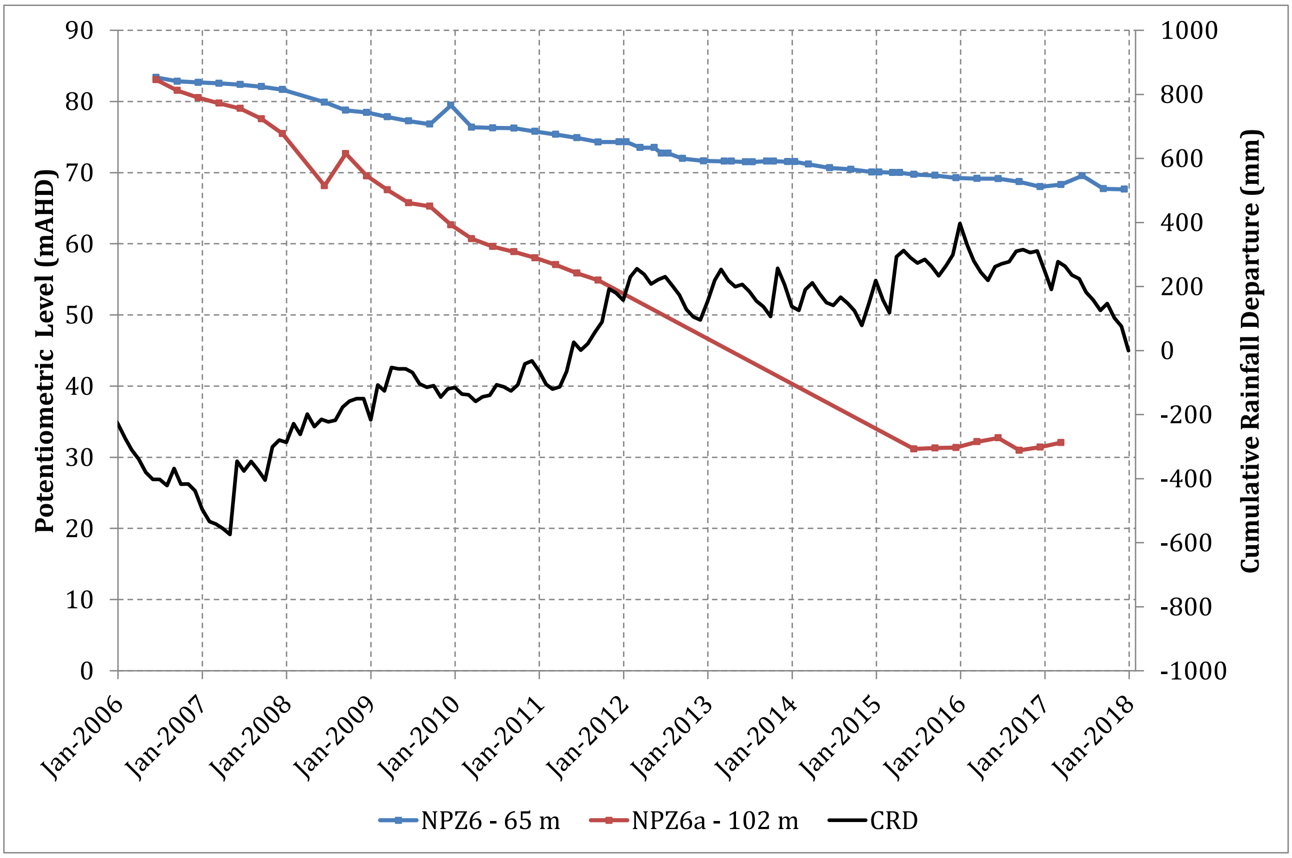


Figure 5-15 Hydrograph – NPZ6

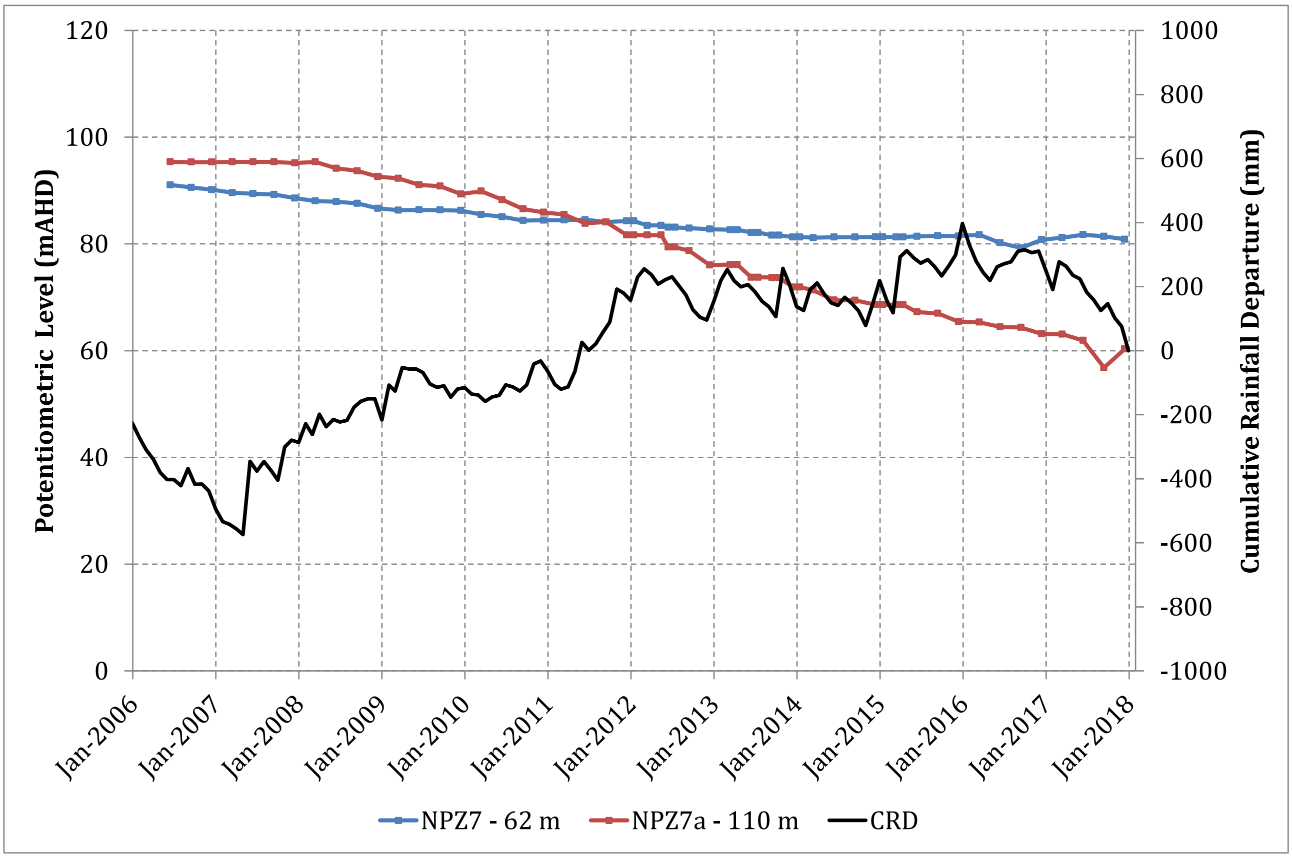


Figure 5-16 Hydrograph – NPZ7

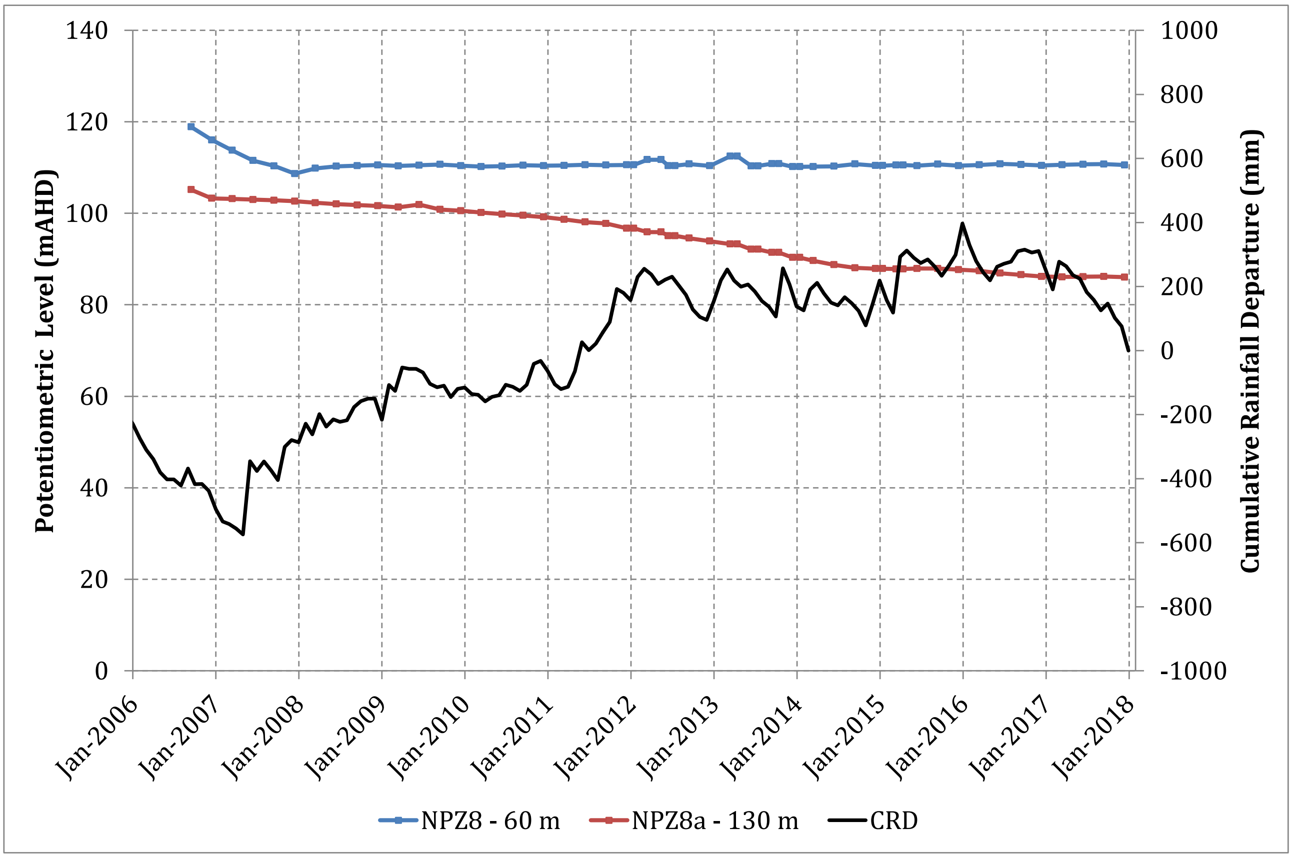


Figure 5-17 Hydrograph – NPZ8

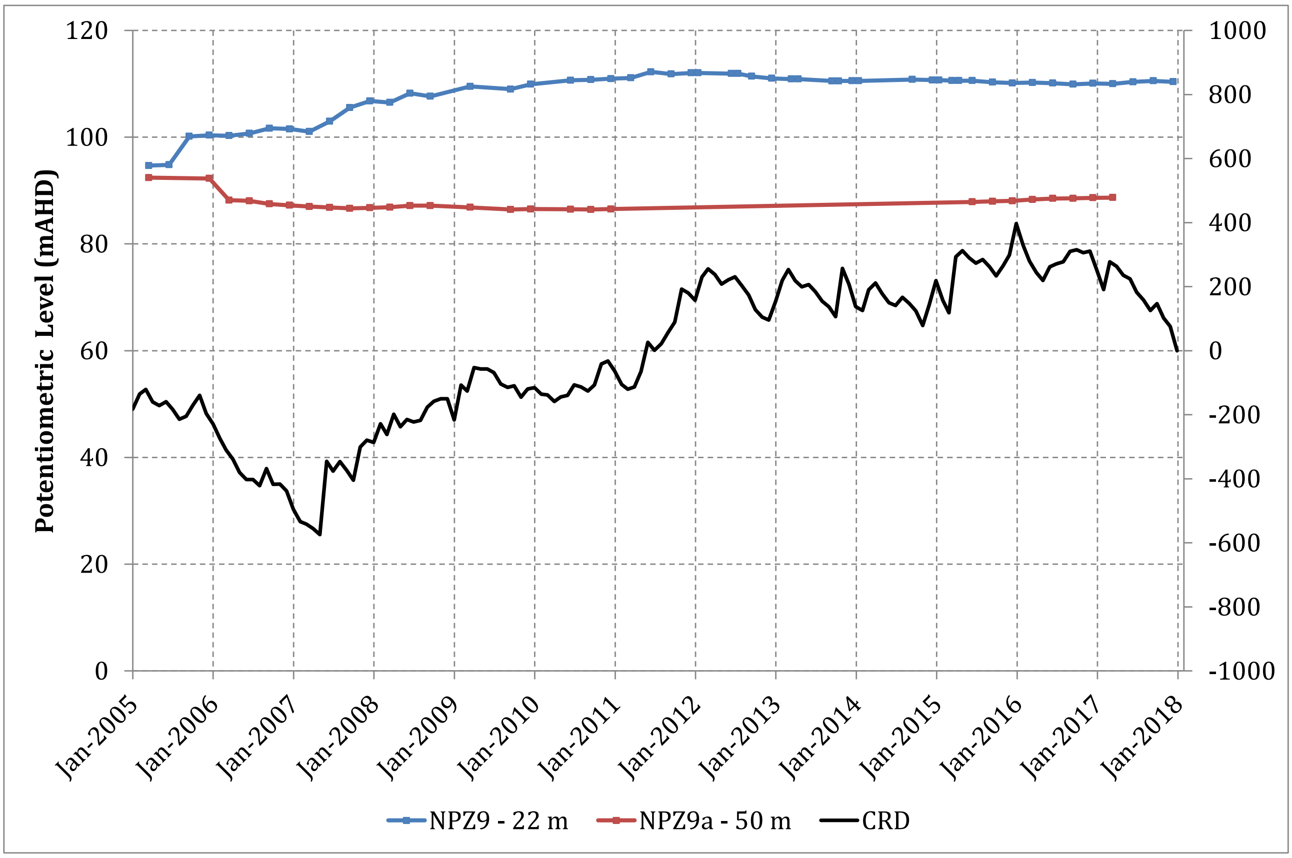


Figure 5-18 Hydrograph – NPZ9

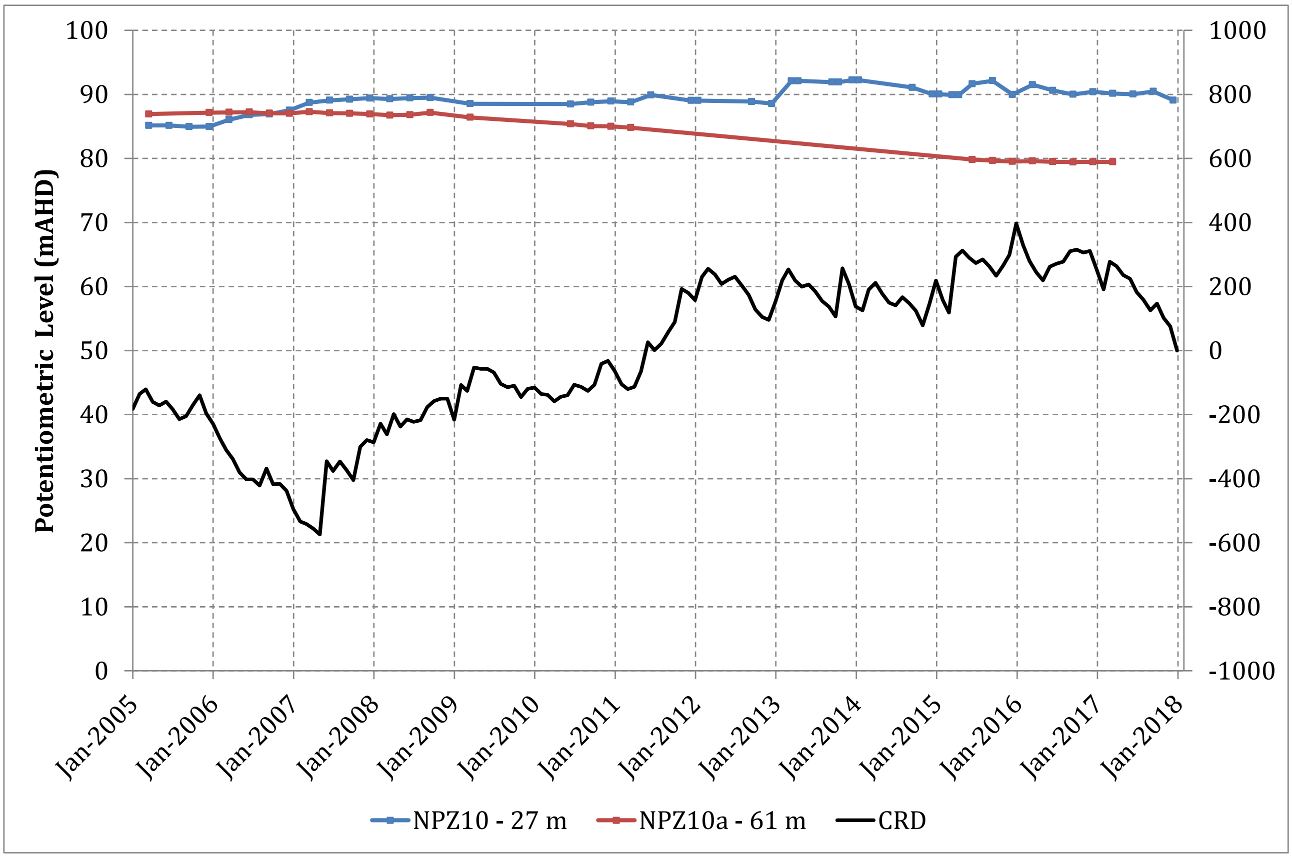


Figure 5-19 Hydrograph – NPZ10

5.3.2 Hydraulic parameters

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

Measurements of hydraulic conductivity within the Permian strata are available for many of the surrounding coal mines within the Hunter Valley region (e.g IUG) 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 Proposed Modification and from public domain reports for surrounding mining. The most relevant testing available is an extensive packer testing program within borehole DDH223, that comprised a total of 79 separate tests from near surface to around 480 m deep (SCT, 2008).

Figure 5-20 and Figure 5-21 show the available hydraulic conductivity measurements for Permian coals and Permian interburden. The graphs illustrate the general decline in hydraulic conductivity with depth below the surface due to the closure of the fractures with increasing stratigraphic pressure, and possible infilling due to mineral precipitates. The site specific data from DDH223 is shown separately on the graphs.

Figure 5-20 shows the decline in the coal seam hydraulic conductivity with depth and the relationship determined by Mackie (2009) highlighted in light blue. The variability in hydraulic conductivity is also illustrated with up to four orders of magnitude variability. This is illustrated by the testing from DDH223 that recorded coal seam hydraulic conductivity ranging from 9 x 10^{-6} to 1 x 10^{-2} m/day.

Three to four orders of magnitude variability in hydraulic conductivity is also evident in the Permian non-coal interburden strata, as illustrated in the packer testing measurements recorded from DDH223 shown in Figure 5-21. The figure indicates the typically low hydraulic conductivity in the interburden ranging from 9 x 10^{-3} to 1 x 10^{-6} m/day in the measurements from DDH223.

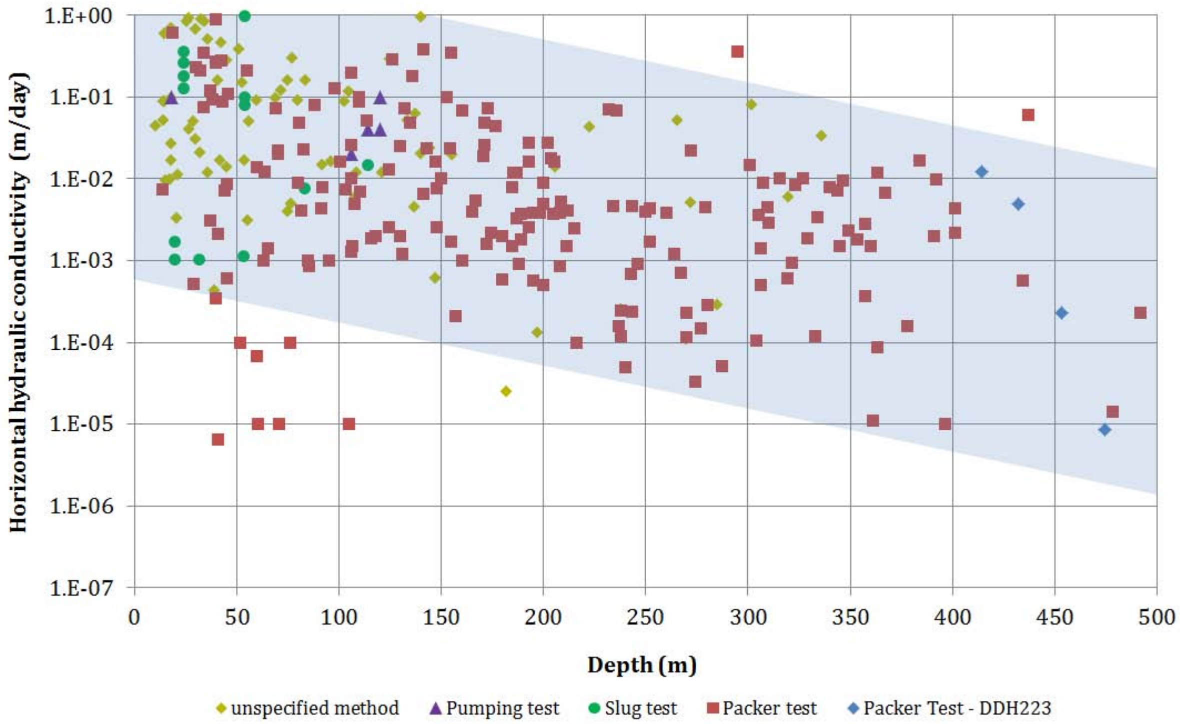


Figure 5-20 Hydraulic conductivity vs depth – Permian coal

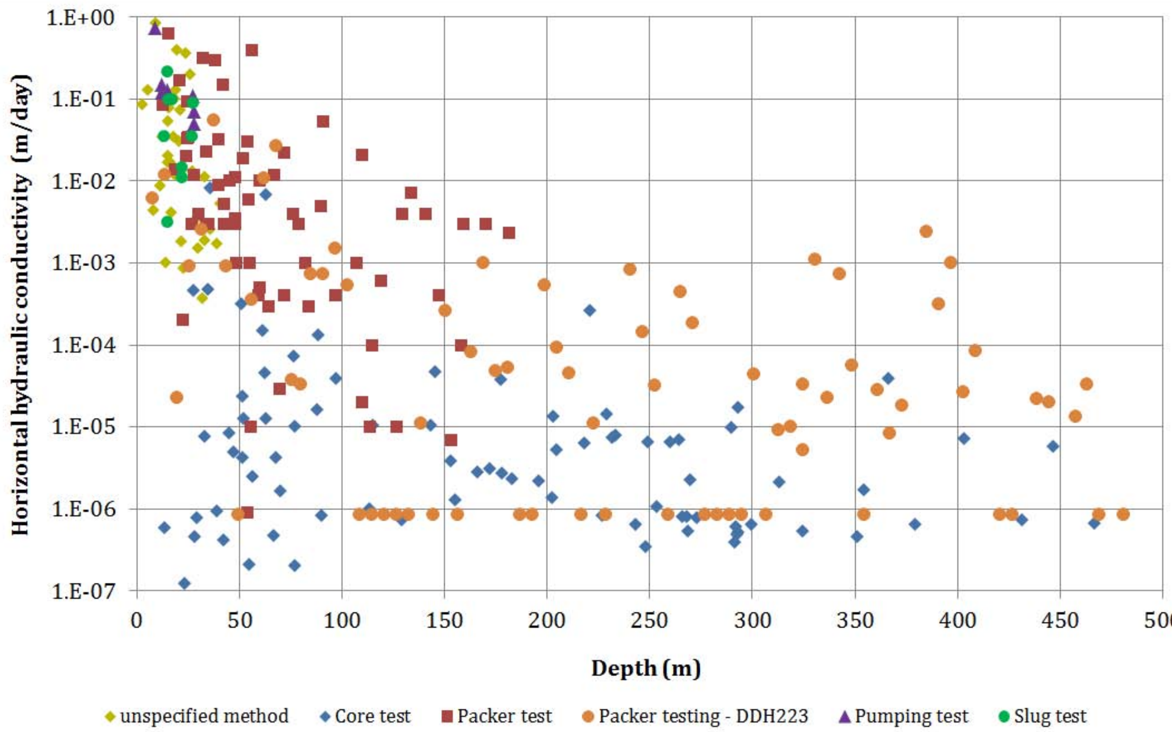


Figure 5-21 Hydraulic conductivity vs. depth – Permian interburden

5.4 Groundwater quality and beneficial use

5.4.1 Salinity

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

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

Electrical conductivity data is collected routinely from the monitoring bore network at the site and surrounds. Electrical conductivity can be used to estimate TDS concentrations by multiplying by 0.67 (ANZECC 2000). Figure 5-22 presents electrical conductivity measurements in monitoring bores from key geological units within the Proposed Modification area as a violin plot. A violin plot shows the density of data at different values and has been used to illustrate the density of data within each of the salinity categories above. The salinity categories described previously are shown with equivalent electrical conductivity measurements.

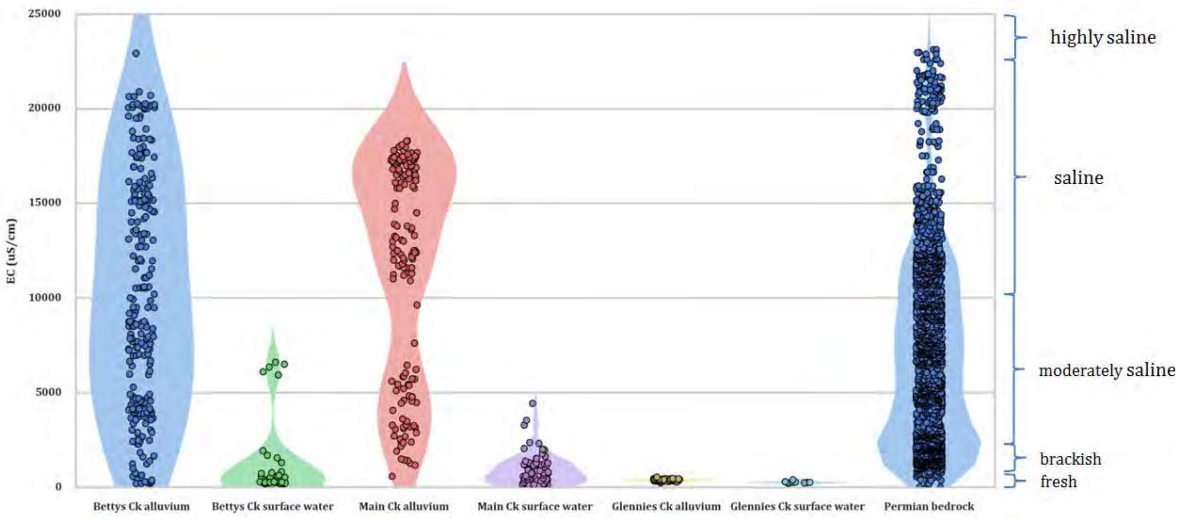


Figure 5-22 Electrical conductivity violin plot of monitoring data

The violin plot shows graphically a number of factors including the generally variable nature of salinity with the groundwater systems and the contrast between the surface water and the groundwater salinity. The plot shows samples collected from the monitoring bores installed within Bettys Creek alluvium and Main Creek alluvium yield samples with a wide range in salinity from fresh to saline. High level mapping by the NSW government has classified the Quaternary alluvium occurring along Main Creek and Bettys Creek as a “highly productive” groundwater source. To meet this criteria the groundwater system must yield groundwater with a TDS concentration less than 1500 mg/L. The available data, indicate high salinity, low transmissivity, and low saturated thickness, meaning that Main Creek and Bettys Creek alluvium do not meet the NSW government criteria of a highly productive groundwater source (refer Sections 5.2 for detail on permeability and transmissivity of alluvium). As noted previously this conclusion has been confirmed by attempts to airlift monitoring bores installed within the Main Creek alluvium and Bettys Creek alluvium that failed to provide a continuous flow of groundwater (Jacobs 2017). The bores could only be developed by hand bailing indicating a very slow seepage rate of groundwater into the bores well below the threshold level of 5 L/sec for “highly productive” groundwater sources.

Figure 5-22 shows the salinity of surface water within Main Creek and Bettys Creek also varies from fresh to brackish, depending on the location and climatic conditions during sample collection.

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

The violin plots show data from the Permian strata that are drawn from the Glencore mines within the mid Hunter Valley (Mount Owen, Liddell, Ravensworth, IUG). 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 processes in the recharge area. The shape of the violin shows the median for the dataset occurs within the brackish to moderately saline range. Of note is the similarity in the salinity range measured within the Permian compared with the alluvial groundwater from Bettys Creek alluvium and Main Creek alluvium. This similarity suggests that upwelling of Permian groundwater through the base and into the Quaternary alluvium occurs 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.

The violin plot combines salinity data over different time periods into a single graphic. To examine trends over time Figure 5-23 to Figure 5-25 were prepared, and show the variability in the salinity of samples collected over time from bores within the Main Creek and Bettys Creek alluvium and the Permian respectively.

Figure 5-23 to Figure 5-25 indicate a level of variability in the salinity of samples collected from each monitoring bore over time. Of note is the saline nature of groundwater samples collected from bores installed in the Main Creek alluvium immediately adjacent to the Proposed Modification (GCP17 and NPZ101). No uniform cycles are evident between monitoring bores within the Quaternary alluvium, whereas salinity trends appear more correlated between samples collected from the Permian bores. The generally variable nature of salinity within the alluvial groundwater systems suggests relatively slow movement of groundwater, with low permeability areas retarding the flushing of salts from the sediments. The limited transmissivity within Bettys Creek in particular appears to promote this high salinity. For these reasons Bettys Creek and Main Creek alluvium do not form 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 in the lower reaches of Main Creek where the regional water table is above the base of alluvium.

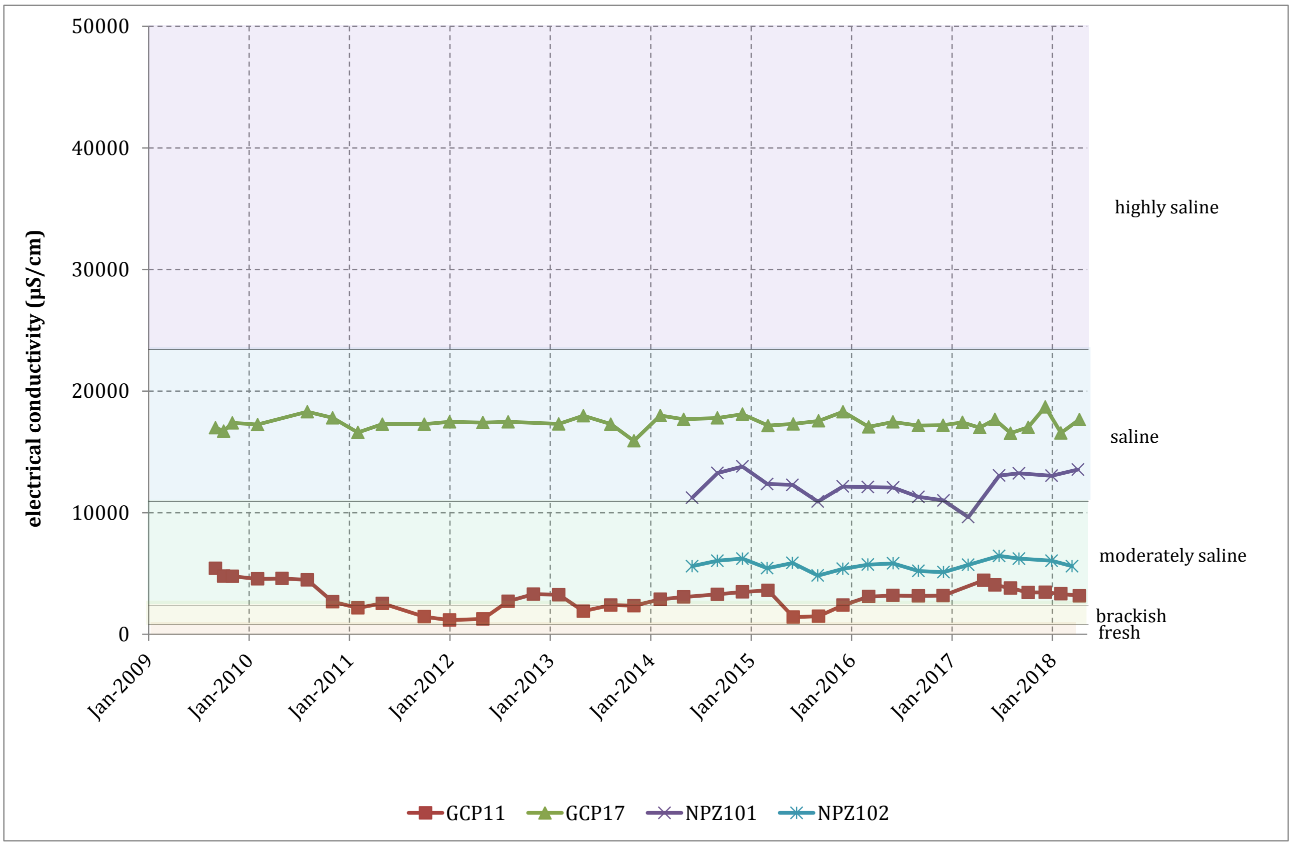


Figure 5-23 Electrical conductivity in Main Creek alluvium

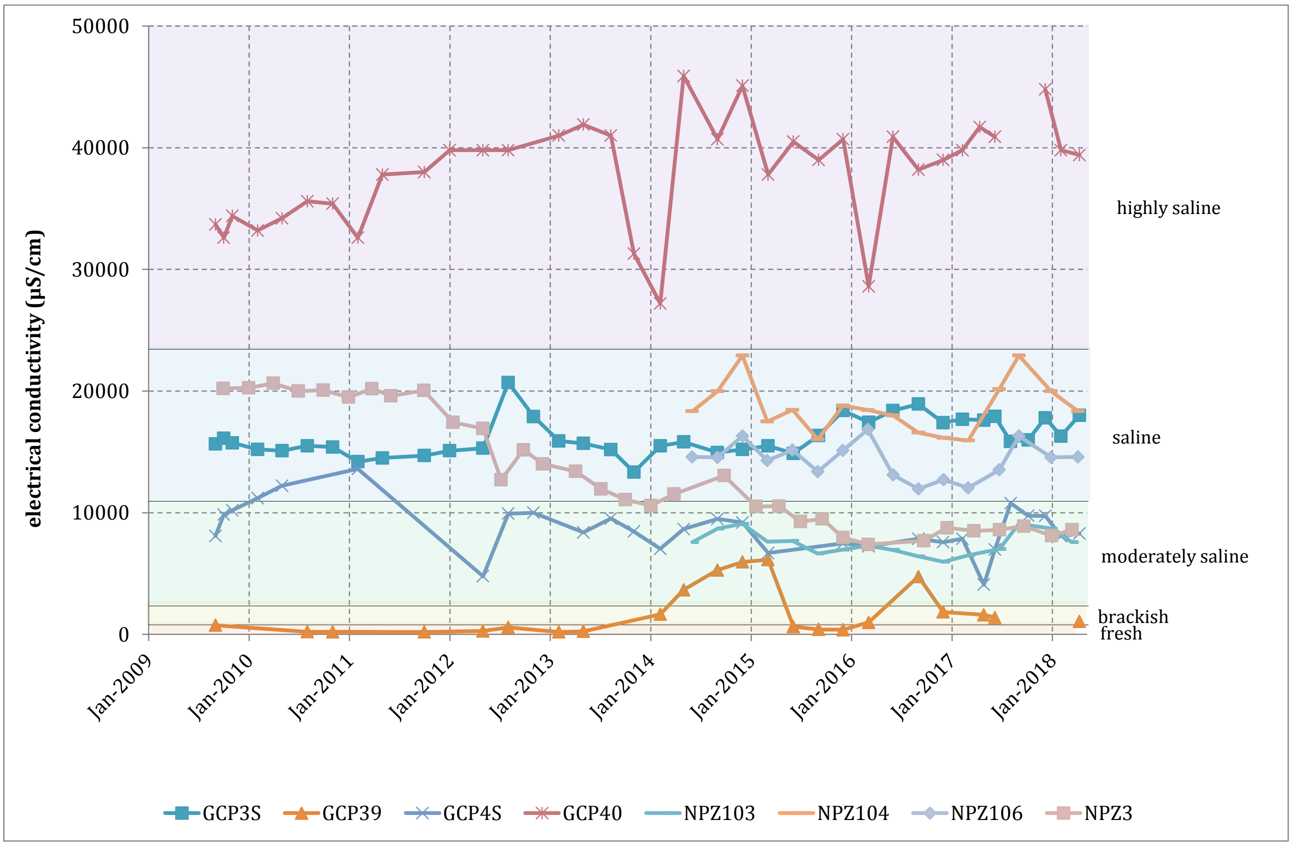


Figure 5-24 Electrical conductivity in Bettys Creek alluvium

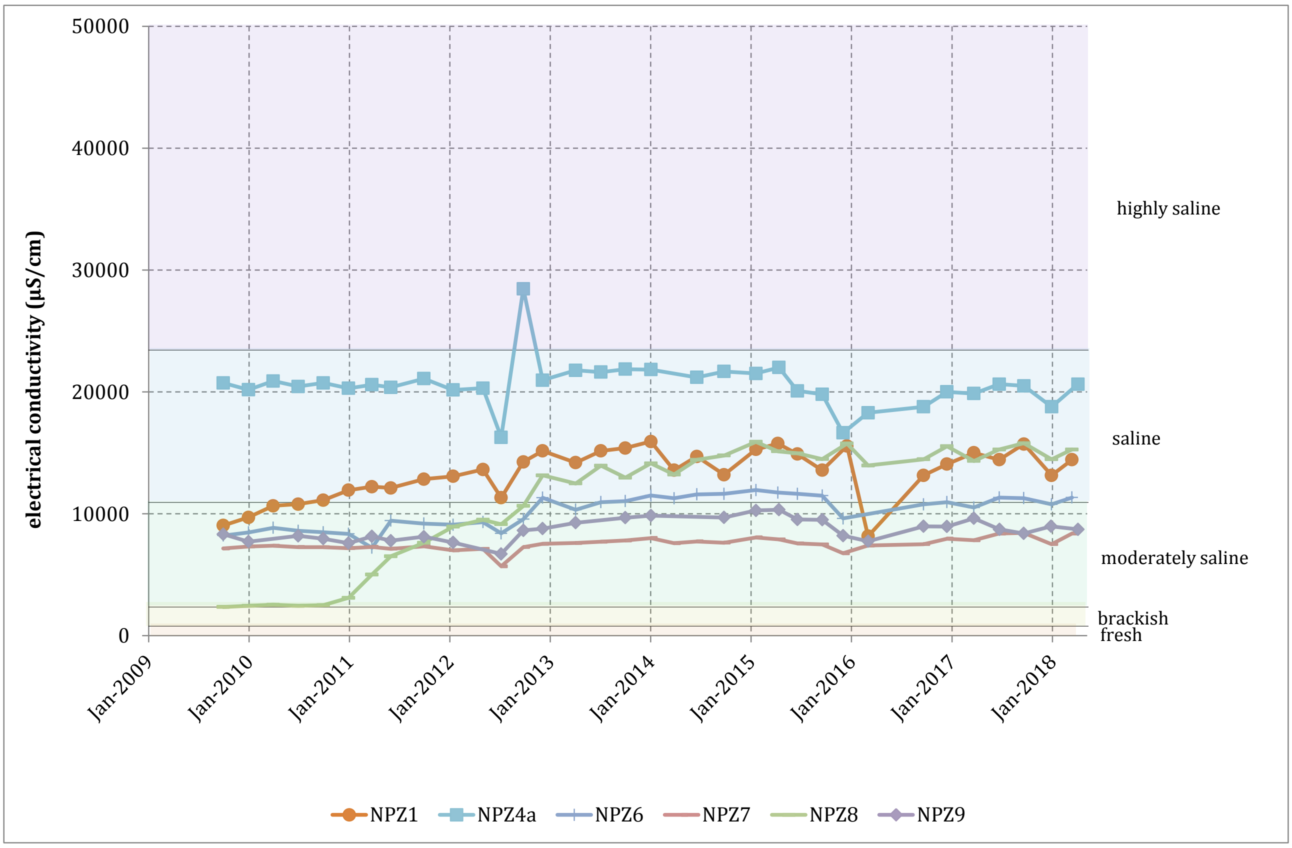


Figure 5-25 Electrical conductivity in selected Permian monitoring bores

5.4.2 Chemistry and beneficial use

In September 2017 groundwater samples were collected from selected monitoring bores installed within the Quaternary alluvium and Permian groundwater systems for a comprehensive laboratory analysis of water quality indicators. Table 5-1 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 indicates the groundwater in an undiluted state is not suitable for freshwater aquatic ecosystems. This guideline is not relevant as groundwater does not contribute baseflow to Main Creek and Bettys Creek as the water table is below the bed of the creeks. The data does suggest the groundwater from some areas within the Quaternary alluvium and Permian could be used for stock, but this use is variable and generally controlled by the salinity.

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

Table 5-1 Water quality in selected monitoring bores

Parameter	Units	LOR[#]	ANZECC GUIDELINES				NHMRC																							
Sample Location			**Fresh Water Aquatic (95th)**	**Short term irrigation**	**Long Term irrigation**	**Stock Water**	**Drinking Water**																							
Bore ID								NPZ4A	NPZ11A	NPZ101	NPZ102	NPZ103	NPZ104	NPZ107S	NPZ107D	NPZ108S	NPZ108D	NPZ109D	GCP09	GCP11	GCP17	GCP18	GCP19	GCP21	GCP24	GCP25	GCP27	GCP28	GCP36	GCP40
Date Sampled								1/09/2017	1/09/2017	1/09/2017	1/09/2017	1/09/2017	1/09/2017	10/08/2017	10/08/2017	10/08/2017	10/08/2017	10/08/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017	6/09/2017
Lithology																														
Physical Parameters																														
pH	pH Units	0.1	**6.5 - 8.5**	**6.0 - 8.5**	**6.0 - 8.5**	-	**6.5 - 8.5[b]**	7.7	8.3	7.8	7.7	7.7	7.9	7.0	8.2	7.7	8.1	8.2	7.5	7.9	7.6	7.5	7.6	7.8	8.0	7.2	11.5	7.5	8.1	7.6
Electrical conductivity	μS/cm	1	**120 - 300**	-		-	-	19800	9960	12800	6300	6860	19100	13303	8582	14983	10869	11167	411	3320	16700	590	3340	1360	2990	530	3530	496	990	38000
Sodium Absorption Ration (SAR)	-	0.01		-		-	-	42.3	76.3	27.7	11.1	13.1	34.7	-	-	-	-	-	1.33	18.6	23	8.27	7.06	4.12	17.1	1.4	44.7	1.57	4.98	24.2
Total Dissolved Solids (calc)	mg/L	1.00		-		**3000 - 13000***	**600[b]**	12900	6470	8320	4100	4460	12400	8637	5572	9727	7056	7250	267	2160	10800	384	2170	884	1940	344	2290	322	644	24700
Total Hardness as $CaCO_3$	mg/L	1.00		-		-	**200[b]**	1920	148	1460	1360	1190	2140	-	-	-	-	-	96	217	2420	35	604	272	164	105	25	117	135	8650
Hydroxide Alkalinity as $CaCO_3$	mg/L	1.00		-		-	-	<1	<1	<1	<1	<1	<1	<5	<5	<5	<5	<5	<1	<1	<1	<1	<1	<1	<1	<1	229.00	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1.00		-		-	-	<1	17.00	<1	<1	<1	<1	<5	<5	<5	<5	<5	<1	<1	<1	<1	<1	<1	<1	<1	373.00	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1.00		-		-	-	450	742	831	766	588	783	1100	990	1000	790	410	90	839	932	164	281	252	350	106	<1	105	244	785
Total Alkalinity as $CaCO_3$	mg/L	1.00		-		-	-	450	759	831	766	588	783	1100	990	1000	790	410	90	839	932	164	281	252	350	106	602	105	244	785
Major Ions																														
Sulfate as SO_4 - Turbidimetric	mg/L	1		-		**1000 - 2000**	**500[a] / 250[b]**	2520	21	1170	469	88	507	1200	330	1100	750	530	10	89	1250	24	55	40	54	21	59	11	22	1130
Chloride	mg/L	1			**40**	-	**250[b]**	5670	3030	3520	1400	1880	6220	2800	1700	3700	2400	2800	57	611	5110	63	889	294	737	82	516	80	181	13100
Fluoride	mg/L	0.1		**2.0**	**1.0**	**2**	**1.5[a]**	0.4	1.6	0.6	0.8	0.4	0.6	-	-	-	-	-	0.2	0.5	0.5	0.4	0.4	0.5	0.6	0.2	0.2	0.1	0.1	0.5
Calcium	mg/L	1		-		**1000**	-	311	36	103	95	137	166	200	99	130	220	120	22	39	238	4	110	61	36	25	10	27	32	991
Magnesium	mg/L	1		-		-	-	278	14	293	272	205	419	320	160	370	260	99	10	29	443	6	80	29	18	12	<1	12	17	1640
Sodium	mg/L	1		-		-	**180[b]**	4260	2130	2440	938	1040	3690	2900	1800	3500	2100	2700	30	628	2600	112	399	156	503	37	514	39	152	5180
Potassium	mg/L	1		-		-	-	18	6	7	2	3	30	12	13	13	15	13	<1	2	6	<1	2	1	8	2	87	2	2	11
Total Anions	meq/L	0.01		-		-	-	221	101	140	64.6	66.6	202	-	-	-	-	-	3.61	35.8	189	5.55	31.8	14.2	28.9	4.87	27.8	4.58	10.4	409
Total Cations	meq/L	0.01		-		-	-	224	95.8	136	68	69	204	-	-	-	-	-	3.22	31.7	162	5.56	29.5	12.2	25.4	3.9	25.1	4.08	9.66	410
Ionic Balance	%	0.01		-		-	-	0.62	2.7	1.7	2.58	1.78	0.59	12	12	12	12	16	5.68	6.14	7.76	0.1	3.84	7.27	6.53	11.1	5.16	5.78	3.88	0.16
Nutrients																														
Ammonia as N	mg/L	0.01	**0.9**	-		-	**0.5[b]**	4.62	2.18	<0.01	0.02	<0.01	0.03	-	-	-	-	-	<0.01	10.1	0.24	<0.01	1.51	<0.01	11.4	0.06	14.4	0.11	0.05	0.22
Nitrite as N	mg/L	0.01		-		**30**	**3[a]**	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	-	-	-	-	-	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	0.05	<0.01	9.11	0.04	0.05	<0.01
Nitrate as N	mg/L	0.01	**0.7**	-		-	**50[a]**	0.03	<0.01	0.1	0.04	0.11	0.1	-	-	-	-	-	0.89	0.04	0.04	3.62	1.6	0.17	<0.01	0.31	25.3	1.65	1.42	<0.01
Nitrite + Nitrate as N	mg/L	0.01		-		**400**	-	0.03	0.03	0.1	0.04	0.11	0.1	-	-	-	-	-	0.89	0.04	0.04	3.62	1.67	0.17	0.04	0.31	34.4	1.69	1.47	<0.01
Total Kjeldahl Nitrogen as N	mg/L	0.1		-		-	-	5.4	2.5	0.3	0.2	0.9	0.6	-	-	-	-	-	0.3	10.6	0.3	0.4	1.8	0.4	11.9	2.3	79	4.1	1.4	<0.5
Total Nitrogen as N	mg/L	0.1		**25 - 125**	**5**	-	-	5.4	2.5	0.4	0.2	1	0.7	-	-	-	-	-	1.2	10.6	0.3	4	3.5	0.6	11.9	2.6	113	5.8	2.9	<0.5
Total Phosphorus as P	mg/L	0.01		**0.8 - 12**	**0.05**	-	-	0.08	0.06	0.03	0.16	0.39	0.05	0.1	<0.05	0.6	<0.05	<0.05	0.5	0.75	0.03	0.36	0.36	0.05	0.77	1.45	11	0.41	0.14	<0.05
Reactive Phosphorus as P	mg/L	0.01				-	-	0.07	0.03	0.03	0.06	0.01	<0.01	-	-	-	-	-	<0.01	0.64	<0.01	0.34	0.24	0.04	0.66	0.01	1.73	0.05	0.04	<0.01
Total Metals																														
Aluminium	mg/L	0.01	**0.055**	**5**		**5**	**0.2[b +]**	0.48	1.09	0.38	5.45	4.23	1.66	-	-	-	-	-	1.31	1.62	3.29	1.22	0.42	0.33	<0.01	135	3.01	2.03	0.25	2.1
Arsenic	mg/L	0.001	**As (III) 0.024 As (V) 0.013**	**2.0**	**0.1**	**0.5**	**0.01[a]**	<0.001	0.002	0.001	0.005	0.002	0.002	0.003	<0.001	0.03	0.006	0.002	0.003	0.002	0.013	0.002	<0.001	<0.001	<0.001	0.032	0.004	0.001	0.002	0.01
Beryllium	mg/L	0.001		**0.5**	**0.1**	-	**0.06[a]**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.007	<0.001	<0.001	<0.001	<0.001
Barium	mg/L	0.001		-		-	**2[a]**	0.066	2.9	0.04	0.087	0.518	0.102	-	-	-	-	-	0.035	0.098	0.091	0.009	0.082	0.044	0.169	0.444	0.562	0.068	0.133	0.241
Cadmium	mg/L	0.0001	**0.0002**	**0.05**	**0.01**	**0.01**	**0.002[a]**	0.0002	<0.0001	0.0002	<0.0001	<0.0001	0.0002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	0.0005	0.0019	0.0002	0.0002	<0.0001
Chromium	mg/L	0.001	**CrIII – ID Cr(VI) 0.001**	**1.0**	**0.1**	**1.0**	**0.05[a]**	0.002	0.002	0.004	0.009	0.008	0.007	0.008	<0.001	0.044	0.001	0.004	0.001	0.001	0.006	<0.001	<0.001	<0.001	<0.001	0.131	0.01	0.004	0.001	0.038
Cobalt	mg/L	0.001		**0.10**	**0.05**	**1.0**	-	<0.001	0.002	<0.001	0.008	0.008	0.004	-	-	-	-	-	<0.001	0.001	0.016	<0.001	0.002	<0.001	<0.001	0.033	0.004	0.003	<0.001	0.024
Copper	mg/L	0.001	**0.0014**	**5.0**	**0.2**	**0.5 - 5^**	**2[a] / 1[b]**	0.005	0.014	0.002	0.006	0.01	0.01	0.008	<0.001	0.025	0.002	0.004	0.047	0.005	0.092	0.013	0.007	0.052	<0.001	0.383	0.387	0.035	0.029	9.96
Lead	mg/L	0.001	**0.0034**	**5.0**	**2.0**	**0.1**	**0.01[a]**	0.007	0.011	<0.001	0.004	0.006	0.004	0.004	<0.001	0.017	0.002	0.002	0.002	0.003	0.026	<0.001	0.002	<0.001	<0.001	0.197	0.07	0.021	0.012	0.011
Manganese	mg/L	0.001	**1.9**	**10.0**	**0.2**	-	**0.5[a] / 0.1[b]**	0.197	0.063	0.044	0.448	0.637	0.098	-	-	-	-	-	0.174	0.478	2.91	0.018	0.21	0.082	0.171	0.812	0.278	2.74	0.199	2.81
Mercury	mg/L	0.0001	**0.0006**	**0.002**	**0.002**	**0.002**		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0005	<0.0001	<0.0001	<0.0001	<0.0001
Molybdenum	mg/L	0.001	**-**	**0.05**	**0.01**	**0.15**	**0.05[a]**	0.01	0.003	<0.001	<0.001	<0.001	<0.001	-	-	-	-	-	<0.001	<0.001	0.004	<0.001	<0.001	<0.001	0.008	<0.001	0.054	0.001	<0.001	0.002
Nickel	mg/L	0.001	**0.011**	**2.0**	**0.2**	**1**	**0.02[a]**	0.007	0.007	0.005	0.009	0.008	0.008	0.007	<0.001	0.03	<0.001	0.003	0.002	0.002	0.011	0.001	0.004	0.001	0.002	0.068	0.03	0.014	0.109	0.235
Selenium	mg/L	0.01	**Total – 0.011 SeIIV - ID**	**0.05**	**0.02**	**0.02**	**0.01[a]**	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	-	-	-	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
Strontium	mg/L	0.001			-	-	-	22.9	8.85	8.3	4.76	6	11.7	-	-	-	-	-	0.25	2.34	20	0.169	2.89	0.953	3.96	1.27	2.8	0.395	0.496	37
Vanadium	mg/L	0.01	**-**	**0.5**	**0.1**	-	-	<0.01	<0.01	<0.01	0.02	0.02	<0.01	-	-	-	-	-	0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.3	<0.01	<0.01	<0.01	<0.01
Zinc	mg/L	0.005	**0.008**	**2.0**	**2.0**	**20**	**3[b]**	0.24	0.08	0.014	0.021	0.035	0.035	0.12	0.007	0.11	0.026	0.032	0.017	0.013	0.087	0.006	0.819	0.021	<0.005	0.56	11.1	0.537	0.636	0.123
Boron	mg/L	0.05	**0.37**	**Refer to guideline**	**0.5**	**5.0**	**4[a]**	0.7	0.25	0.06	0.17	0.09	0.08	-	-	-	-	-	<0.05	0.06	0.08	<0.05	<0.05	0.05	0.13	0.06	<0.05	<0.05	<0.05	0.07
Iron	mg/L	0.05	**-**	**10.0**	**0.2**	-	**0.3[b]**	1.08	2.24	0.65	6.58	5.59	2.36	-	-	-	-	-	7.9	2.83	16.3	1.22	0.73	0.6	0.87	167	6.68	5.35	1.49	12.9

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

5.5 Groundwater use

5.5.1 Private water users

A search of the NSW state government groundwater bore database was conducted to identify the locations of any non mine-owned water supply bores in proximity to the Proposed Modification. The search confirmed there are no water supply bores within the Main Creek alluvium, and only one private well within the Glennies Creek alluvium as described below.

Figure 5-26 shows the locations of bores within the database and land parcels that are non mine-owned. The figure shows there are three bores from the database that are located on private properties along Glennies Creek which is part of the Hunter Regulated River Alluvial Water Source. The remainder of the bores are located on land owned by mining companies and are used for monitoring the impact of mining, or are former water bores or wells no longer in use. Table 5-2 summarises the details within the NSW government database for the three registered bores located on private land.

Table 5-2 Registered bores on private lands

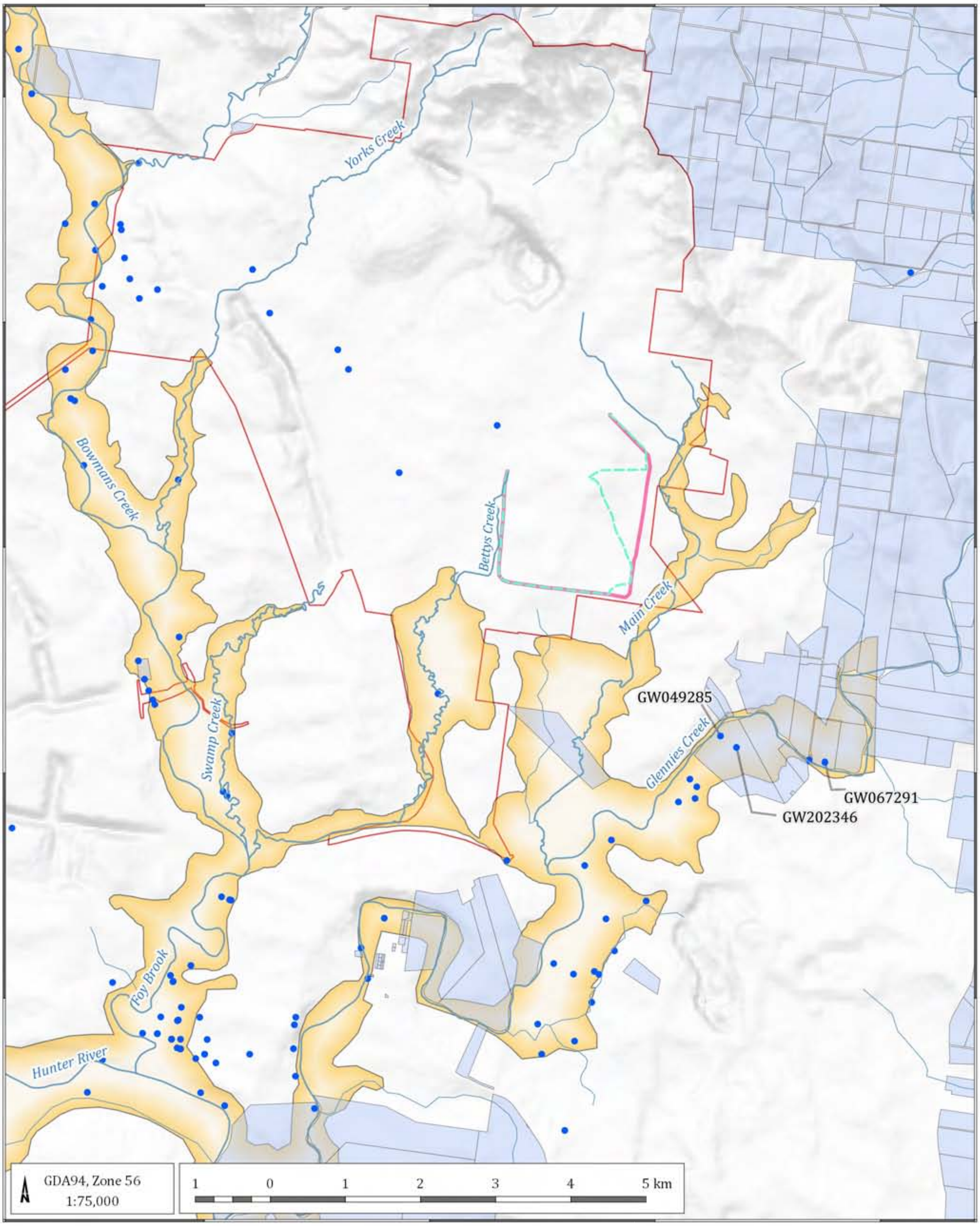
Registered number	Authorised purpose	Date	Depth (m)	Casing type	Casing dia (mm)	Standing water level (m)	Yield (L/sec)
GW067291	stock, domestic, farming	1981	10.1	concrete	1200	2	1
GW049285	farming	1979	-	-	-	-	-
GW202346	monitoring bore	2007		uPVC	50	8.45	1

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

Geoterra (2009) noted whilst preparing the groundwater assessment for underground mining within the Middle Liddell seam at IUG that whilst there are private bores and wells registered within proximity to the underground mine, none are active or present apart from GW067291, which is located on the north bank of Glennies Creek near the Middle Falbrook Road bridge. Recent discussions with the property owner indicate the bore remains actively used.

No detail on the construction of bore GW049285 is recorded within the database other than it was constructed as a well. Discussions with the property owners indicate the well has been filled in and is no longer in use.

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



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Quaternary alluvium
- Privately owned land
- Registered bore

Mount Owen (G1862A)

Groundwater use

AGE

DATE 12/06/2018

FIGURE No: **5-26**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.; Glen R.A. and Beckett J., 1993, Hunter Coalfield Regional Geology 1:100 000, 2nd edition. Geological Survey of New South Wales, Sydney;
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/05.26_G1862A_Groundwater use.qgs

5.5.2 Groundwater dependent ecosystems

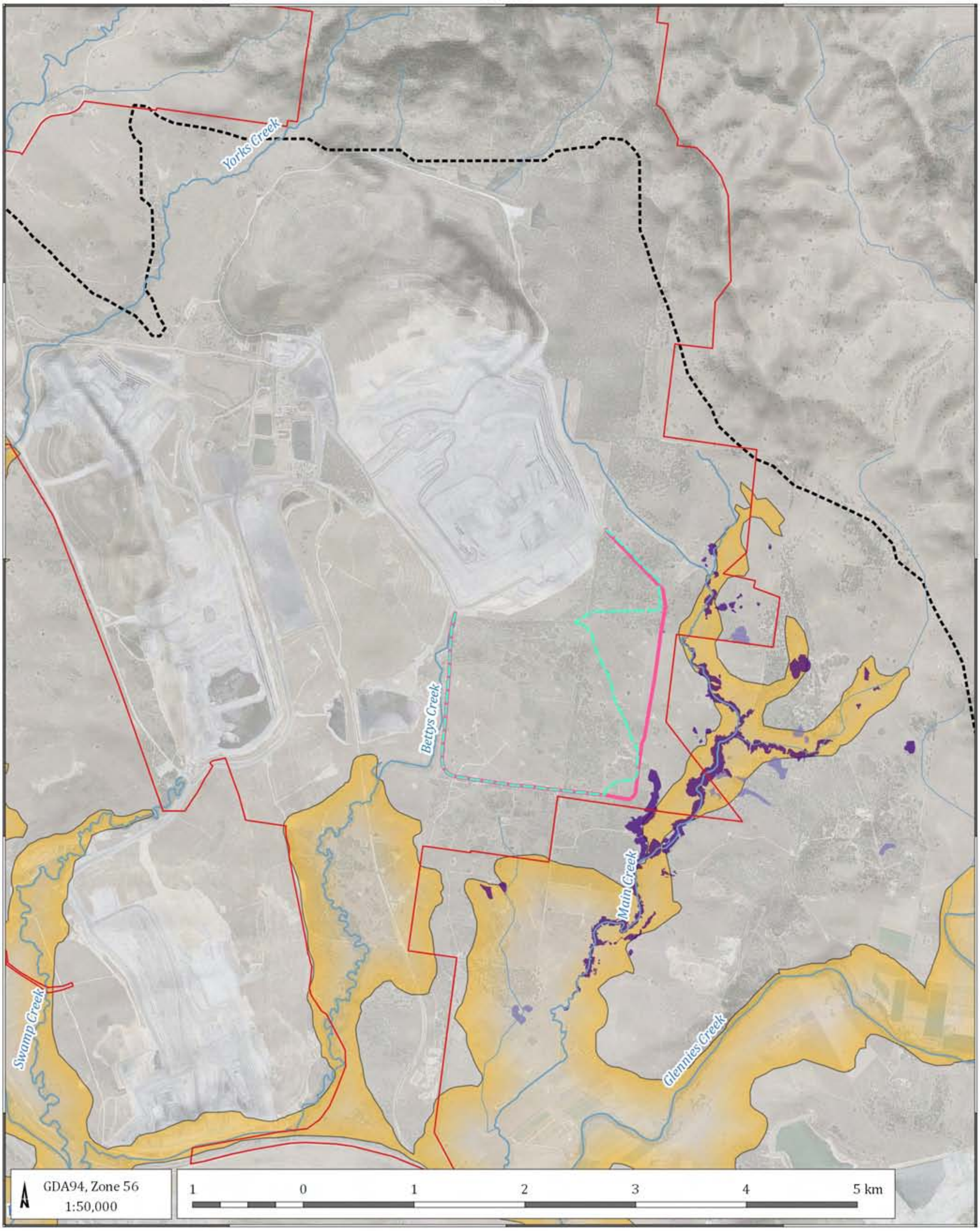
Macfarlane et al (2016) provides a register of water-dependent assets in the Hunter subregion prepared as a component of the Federal Governments Bioregional Assessments Process. Water dependent assets are classified into three subgroups and seven classes. All landscape features such as aquifers, rivers, lagoons, lakes, springs and wetlands, and the habitats dependent on them, are inherently water dependent; hence, all assets in the subgroups 'Surface water feature' and 'Groundwater feature (subsurface)' are included in the water-dependent asset register. Figures within the register indicate the Hunter River alluvium located some 9 km from the North Pit is an alluvial aquifer asset, but the alluvial groundwater systems along Glennies Creek, Main Creek and Bettys Creek are not noted as alluvial aquifer assets.

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

Umwelt (2015) discussed the ecological communities and potential impacts associated with the Continued Operations Project. They noted the Hunter Swamp Oak Forest and a small area of Hunter Lowland Red Gum Forest community (Figure 5-27) that were mapped as occurring within a thin riparian zone on Main Creek may possibly be groundwater dependent due to reliance in some circumstances on groundwater in periods of drought. However it was also noted these vegetation communities can also exist further upstream and in other creek systems where there is unlikely to be any significant alluvial groundwater present. This was particularly the case with the Hunter Lowland Red Gum Forest which is mapped as extending well into areas where there is little or no alluvium, and vegetation in these areas would be reliant on soil moisture and rainfall. On this basis the Umwelt (2015) study concluded that the Hunter Lowland Red Gum Forest where it occurs in proximity to Mount Owen did not constitute a GDE.

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

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



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Alluvium extent
- Model boundary

Vegetation (Unwelt, 2017)

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

Mount Owen (G1862A)

Potential groundwater dependent ecosystems

AGE

DATE 12/06/2018

FIGURE No: **5-27**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
Glen R.A. and Beckett J., 1993, Hunter Coalfield Regional Geology 1:100 000, 2nd edition. Geological Survey of New South Wales, Sydney;
GDE Atlas © State of NSW (DPI Water);
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/05.27_G1862A_Groundwater dependent ecosystems.qgs

5.6 Conceptual model

This section summarises the processes that control and influence the storage and movement of groundwater in the hydrogeological systems occurring in the vicinity to the Mount Owen Complex and the broader region. It is based on hydrogeological data presented in the preceding sections and figures and cross sections contained in Section 4.

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

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

Vegetation communities that potentially depend on shallow groundwater within the Quaternary alluvium occur in a riparian zone along Main Creek and Bettys Creek. Previous work has indicated that the depth of the water table along Main Creek and Bettys Creek is typically like to preclude direct connectivity, with the vegetation communities reliant on soil moisture (Umwelt, 2015). It was noted that there is the possibility of some sinker roots in larger trees extending to the alluvial groundwater particularly during wetter periods when the water table in the Quaternary alluvium is higher.

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

Groundwater flows from areas of high head (pressure plus elevation) to low head via the most permeable and transmissive pathways. The water table surface and flow direction within the alluvial sediments of Main, Bettys and Glennies Creeks is a reflection of the topography, with groundwater flowing 'downstream' in a south-westerly direction towards the Hunter River. The groundwater levels within the Permian are influenced by topography and the proximity of mining activities. No connectivity between the Permian and Quaternary alluvium groundwater is evident in more elevated upstream areas of Main Creek, however further downstream, water level measurements indicate Permian groundwater discharges to the Quaternary alluvium. Depressurisation of the deeper Permian strata is evident in the deeper strata typically below 100 m depth. The shallower Permian strata shows less impacts from mining and therefore has no detectable drawdown recorded within the monitoring bores installed within the alluvial aquifers because of this.

A series of thrust faults occur in the area including one within the North Pit and another adjacent to the IUG. Whilst the potential to transmit groundwater through the faults has not been established it is expected to be relatively limited, given the limited cross sectional area of the fault zone and the potential for the fault gouge sediment to retard groundwater flow. This conclusion is supported by observations during mining within North Pit that have indicated faults have not contributed notably to pit inflows.

6 Numerical groundwater model

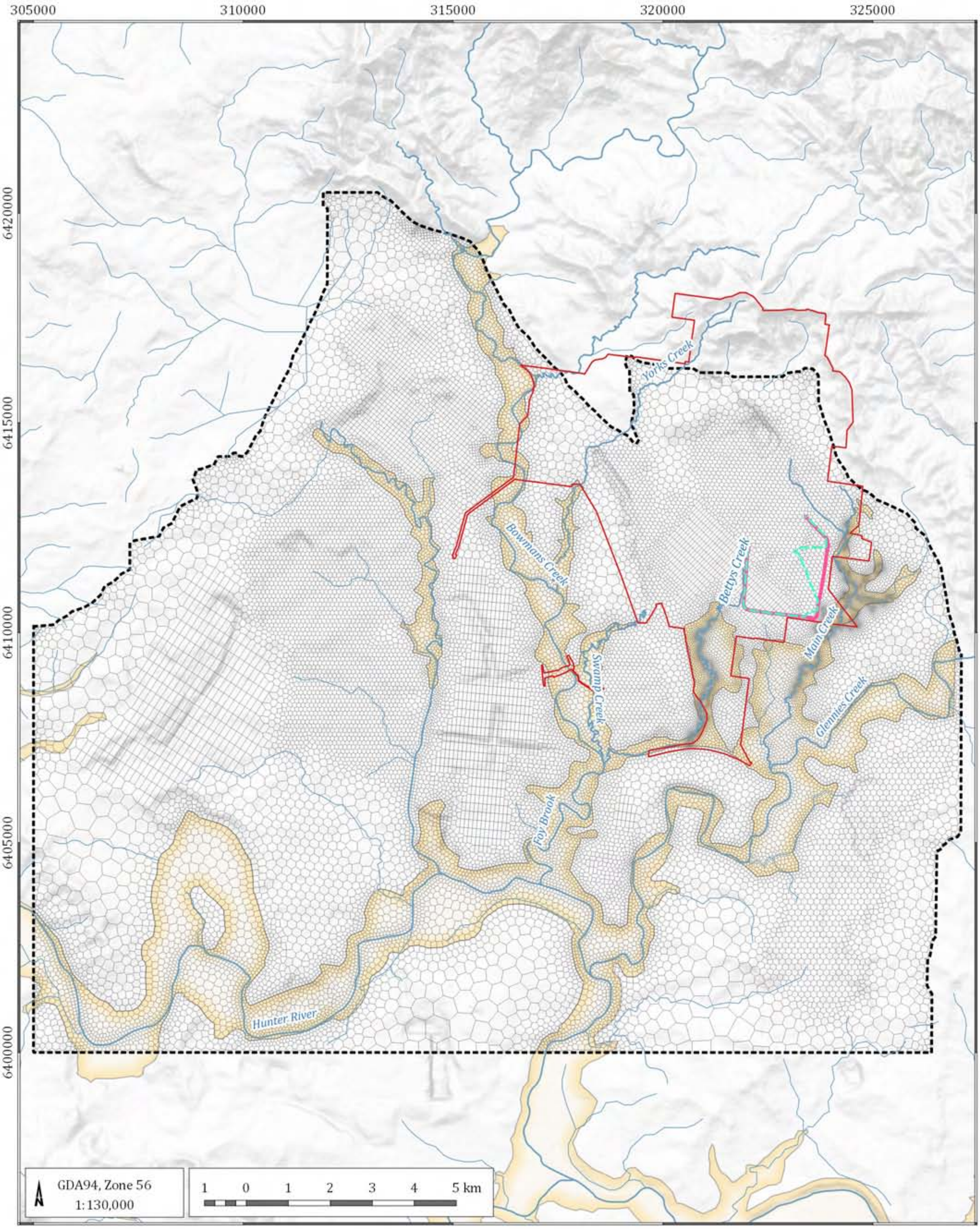
6.1 Overview of groundwater modelling

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

The model represents the key geological units as 21 layers extending approximately 25 km from west to east and 26 km long in the north to south direction. It comprises up to 32,212 cells per layer, making it spatially a large model (Figure 6-1).

The prevalence of mining in the region means there have been many previous groundwater modelling efforts. The numerical model developed for the Proposed Modification was built upon an existing large regional model first developed by Mackie Environmental Research (MER), then updated by Jacobs as described in Jacobs (2014). This approach was undertaken to as far as possible to create consistency with previous work, and also to continue to build upon the regional flow model to represent the cumulative impacts of mining in the North Pit and the surrounding region. The model was updated as follows, for both the IUG Modification 8 and the Proposed Modification:

- converting model to MODFLOW USG including development of new model mesh and layers;
- updating water level monitoring dataset;
- representing hydraulic conductivity as decreasing with depth in Permian model layers as indicated in field measurements from the region (consistent with adjacent IUG);
- adjusting coal seam levels based on an updated geological model from Mount Owen mine and new geological data that became available when Glencore acquired IUG;
- updating the thickness and extent of the Quaternary alluvium based on borehole logs and geophysical investigations at Mount Owen mine described in detail in the report contained within Appendix A;
- recalibrating model to water level records and mine inflows at IUG;
- inclusion of detailed mine plan progression for IUG into the regional model including the approved Modification 8;
- updating progression of approved and proposed mining at Mount Owen Mine and IUG;
- adding approved open cut mining at Rix's Creek North Mine (former Integra open cut); and
- predicting impacts on groundwater regime for Proposed Modification.



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh
- Alluvium extent
- Major drainage
- Minor drainage

Mount Owen (G1862A)

Model extent

DATE 12/06/2018

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/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/06.01_G1862A_Model extent_.qgs

Appendix C describes the evolution of the regional model over time and the changes made to quantify the impact of the Proposed Modification. The model was used to identify the influence of the Proposed Modification on the groundwater regime by comparing the impacts generated by the approved and proposed mine plans. Current approved and foreseeable mine plans within the region including the IUG extension (now approved Modification 8) 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 C.

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 North 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 IUG that has been recorded with a flow meter was used to guide the calibration of the model. A detailed description of the calibration procedure is provided in Appendix C. The objective of the calibration was to replicate the groundwater levels measured in the monitoring network, and the mine inflows in accordance with *Australian groundwater modelling guidelines* (Barnett *et al.* 2012). The transient calibration achieved a 6% scaled root mean square (SRMS) error, which is well within acceptable limits (i.e. 10%), recommended by the *Australian groundwater modelling guidelines* (Barnett *et al.* 2012).

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

- Approved - with the currently Approved Operations and foreseeable operations within the region (including a recently approved modification to IUG – Modification 8); and
- Approved Operations + Proposed Modification – which includes approved and foreseeable operations as well as the Proposed Modification of the North Pit mine plan.

The second model scenario when examined provides an indication of the cumulative impacts from all approved and proposed mining in the model domain. The influence of the Proposed Modification on the groundwater regime was determined by comparing the difference between the above model scenario results. Model scenarios were also developed, which excluded all future mining at Mount Owen from the commencement of each WSP. The purpose of this was to quantify the volume of water taken from each water source and the drawdown since each WSP commenced. To achieve these two additional models were run, one from 2009 for the Hunter Unregulated WSP, and a second from 2016 for the North Coast Fractured and Porous Rock WSP. The drawdown presented therefore represents the change in groundwater levels from the commencement of each WSP. The change in flow to the alluvial aquifers is also relative to baseline flows at the commencement of the Hunter Unregulated WSP in 2009. The groundwater inflow from the North Coast Fractured and Porous Rock WSP to the North Pit was not calculated relative to the start of the WSP, and therefore represents a total water take including previously approved mining impacts to ensure water licensing in adequate to account for all groundwater intercepted by North Pit.

It is important to note that the Approved Operations have been approved based on previously completed groundwater assessments (Jacobs 2014). An approach of continuous improvement in the groundwater model has been pursued since this time. This has included a refined model mesh and improved calibration. This has resulted in the model being refined for other projects (IUG) and the Proposed Modification. The general location and nature of the impacts predicted by the updated model are generally consistent with previous predictions, but there are some differences in the magnitude of impacts predicted by the updated model for the Approved Operations. These impacts described later in Section 7 are generally less than impacts indicated in previous versions of the model. These differences were created by changes to hydraulic parameters within the model determined during the calibration process that utilised a more extensive database of water level and mine inflow datasets. The water level records in the model region show a clear trend of drawdown occurring within the Permian strata, but no propagation of this drawdown into the alluvial groundwater systems. This water level observation data along with more groundwater inflow records to IUG were used to calibrate the model and resulted in a reduction in the hydraulic conductivity in some layers, most significantly within the regolith that underlies the alluvial aquifers.

Another change that influenced the predictions was a change in the representation of the recharge processes in the model. MODFLOW models provide two methods to represent movement of recharge to the water table. The first is the vadose zone method that represents water movement through the unsaturated vadose zone, the second being the pseudo soil model that routes recharge directly to the water table and does not represent unsaturated flow process. The Approved Operations model used the vadose zone method, whilst the Proposed Modification modelling used the pseudo soil model for recharge. Industry testing conducted since the Approved Operations modelling was conducted in 2012 to 2014 has indicated that the vadose zone method has the potential to over enhance the hydraulic connection occurring between alluvium and bedrock layers due to unsaturated zone flow. Modelling since this time has moved to the pseudo soil model that does not have this limitation and this difference is also expected to explain some of the difference between the models for the Approved Operations and the Proposed Modification.

When considering the differences in the numerical models it is important to understand that models used for mining operations inherently require continuous updates and revisions as new information and data is continually collected through monitoring networks. The on-going nature of the model development is a good example of best practice as defined by Middlemis (2004), which is *"the fundamental guiding principle for best practice modelling is 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."*

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

6.2 Peer review

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

- conceptualisation and model updates;
- model calibration; and
- model predictions.

The peer review report prepared by Hydroalgorithmics is included within Appendix C.

7 Model predictions and impact assessment

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

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

Cumulative impacts are outlined in Section 7.1.6, with post closure impacts discussed in Section 7.3.

7.1 Proposed Modification groundwater predictions

7.1.1 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 North Pit. The table and figure show the volume of groundwater intercepted by the Approved Operations and the Proposed Modification combined, and the proportion attributable to the mining within the extended footprint and deeper coal seams in the North Pit associated with the Proposed Modification only.

Figure 7-1 shows the influence of the Approved Operations compared with the Proposed Modification changes over time. This is due to differences in the sequence and depth of mining in the two models that represent the Approved Operations and the Proposed Modification. Generally the results show the proportion of groundwater intercepted by mining due to the Proposed Modification increases over time, although there are years when the influence of the Approved Operations dominates the water budget where mining is in the same location but timed to occur earlier than the Proposed Modification.

The volume of groundwater intercepted from the Permian coal measures due to the Proposed Modification peaks in Year 15 at 456 ML/year. Section 7.1.6 provides information on water licences required to account for groundwater intercepted by the Approved Operations and the Proposed Modification.

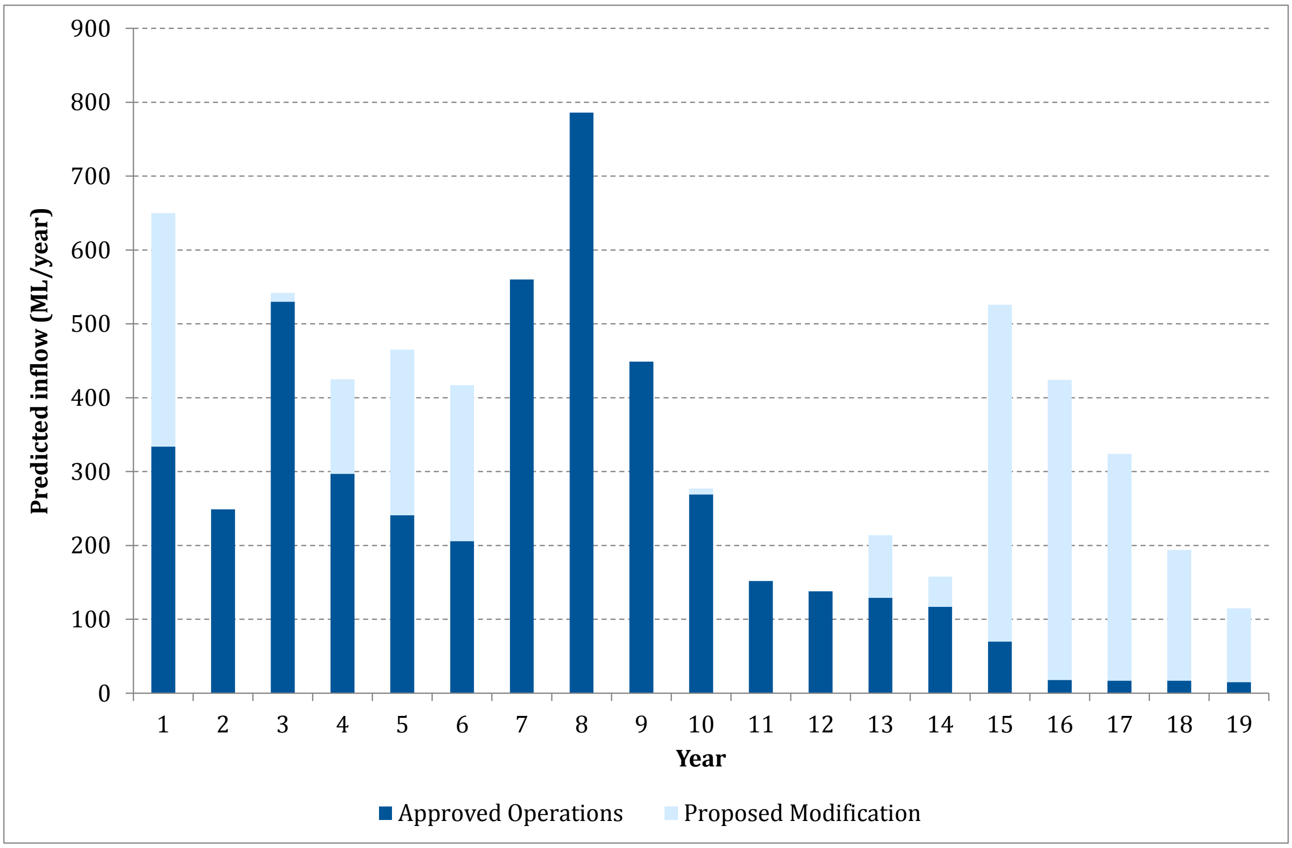


Figure 7-1 Groundwater intercepted from Permian coal measures – North Pit

Table 7-1 Groundwater intercepted from Permian coal measures

Year	Predicted inflow (ML/year)			
	North Pit		Bayswater North Pit	
	Approved Operations and Proposed Modification	Proposed Modification only	Approved Operations	Total
1	650	316	176	826
2	249	0	96	345
3	542	12	366	908
4	425	128	159	584
5	465	224	83	548
6	417	211	68	485
7	560	0	242	802
8	786	0	-	786
9	449	0	-	449
10	277	8	-	277

Year	Predicted inflow (ML/year)			
	North Pit		Bayswater North Pit	
	Approved Operations and Proposed Modification	Proposed Modification only	Approved Operations	Total
11	152	0	-	152
12	138	0	-	138
13	214	85	-	214
14	158	41	-	158
15	526	456	-	526
16	424	406	-	424
17	324	307	-	324
18	194	177	-	194
19	115	100	-	115

7.1.2 Drawdown and depressurisation during mining operations

Figure 7-2 and Figure 7-3 show the maximum drawdown predicted by the numerical model to occur during the life of the Proposed Modification. The figures show the drawdown predicted to occur within the Quaternary alluvium and the Middle Liddell seam layers within the numerical model. Two windows are included within each of the figures. The first window shows the predicted drawdown from the Approved Operations plus the additional drawdown generated by the larger footprint and deeper mining due to the Proposed Modification. The second window shows the amount of drawdown contributed by the Proposed Modification only. It should be noted the drawdown within the Quaternary alluvium is calculated from the commencement of the Hunter Unregulated WSP in 2009, whilst the Permian drawdown is from the start of the North Coast Fractured and Porous Rock WSP which commenced in 2016.

Figure 7-2 shows that the numerical model predicts only two small zones of drawdown within the Main Creek alluvium due to the Approved Operations plus the Proposed Modification, and that the Proposed Modification alone does not result in any further drawdown beyond that predicted for the Approved Operations. This is because the Proposed Modification is targeting deeper coal seams that are separated from the Quaternary alluvium by intervening interburden strata of limited permeability. The modelling indicates the recharge rate to the alluvium exceeds the losses through the base of the alluvium due to mining and therefore there is no significant drawdown predicted. This aligns with current monitoring results that have not detected any significant drawdown within the Main Creek and Bettys Creek alluvial systems (refer to Section 5.2.2).

When reviewing the impacts associated with the Proposed Modification it is clear the predicted drawdown is less than predicted by the model for the Continued Operations Project by Jacobs 2014 and further outlined in Umwelt 2015. The previous modelling predicted the potential for up to 3 m of drawdown where North Pit is adjacent to Main Creek alluvium and 2 m for Bettys Creek alluvium. Appendix C describes how the groundwater model was updated and recalibrated to improve the models ability to predict mine inflow and water level drawdown. The lesser impacts predicted by the updated model is due to the interaction of a number of factors including changes in hydraulic properties, recharge rates and the representation of fracturing above adjacent underground mining areas.

As noted in Section 2.4 the North Pit operates in relatively low permeability geological regime where groundwater is not problematic for mining and is commonly evident only as damp evaporating seeps in mine faces. Therefore the volume of groundwater intercepted at North Pit cannot be directly used to calibrate groundwater models. In contrast measuring groundwater inflows to underground mines is less problematic and provides a more accurate volumetric estimate of groundwater inflow through coal seams. The updated model benefitted from the availability of additional data from IUG including metered mine inflow data and additional water level measurements from monitoring bores and VWPs adjacent to the North Pit. The updated model for the Proposed Modification was recalibrated using the metered mine inflow from the adjacent IUG as well as additional water level measurements from bores and VWPs not available to the Continued Operations Project at the time the work was undertaken. This improved the models ability to replicate both measured mine inflow and observed drawdown within the Permian coal seams and interburden. The ability to represent cumulative impacts was also improved by updates to the fracturing above IUG. To achieve the improved calibration the updated model represented the Permian coal seams and interburden as becoming less permeable with depth below the surface as indicated by field measurements presented in Section 5.3.2. The recalibration also represented climatic cycles in recharge to improve the calibration of the water levels measured within the Quaternary alluvium that respond more readily to rainfall events than the Permian groundwater systems. These factors all combined to result in changes in the predictions described above. Given the additional datasets and improved calibration statistics the updated predictions are considered improved estimates of impacts compared to previous versions of the model.

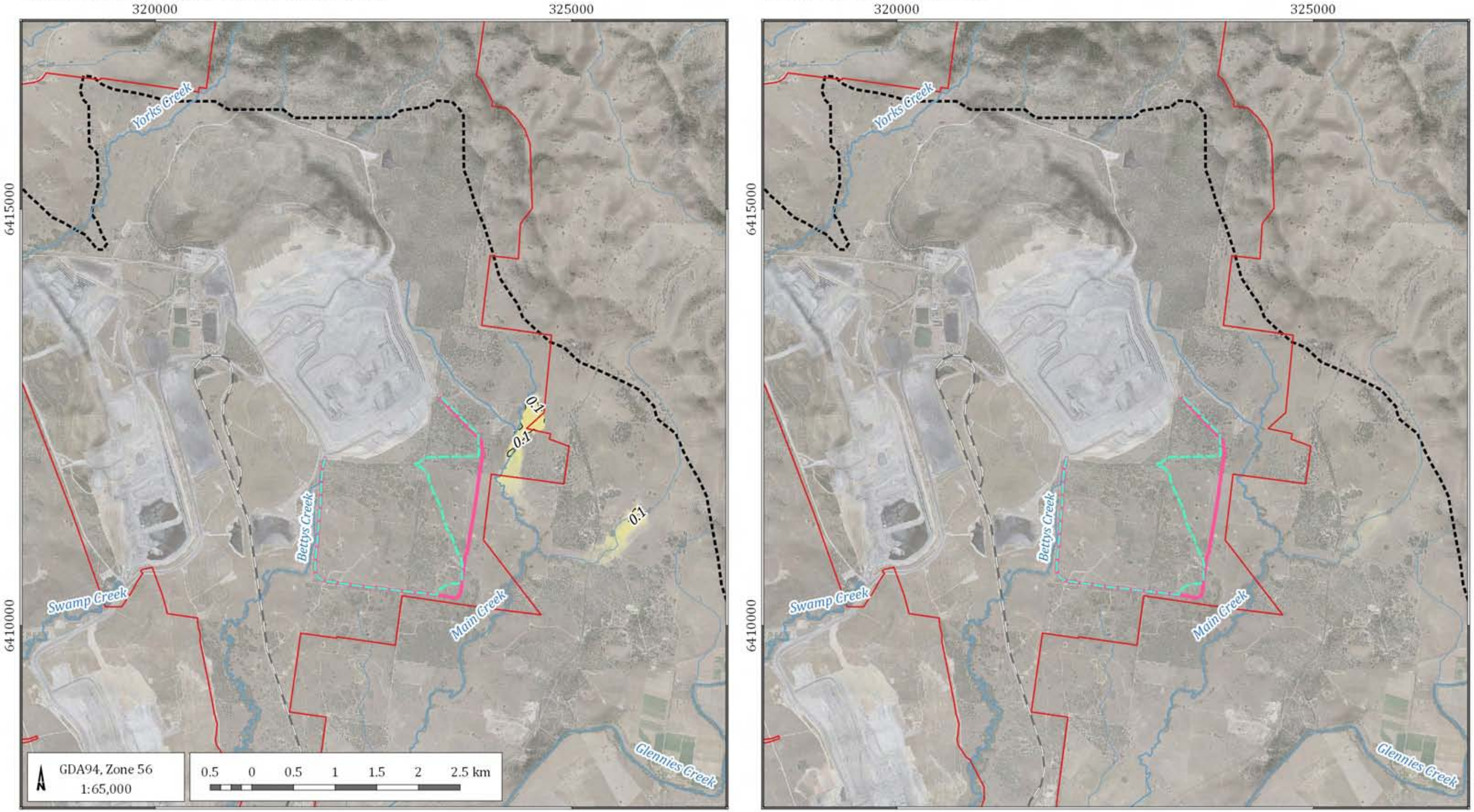
There are multiple coal seams intersected by the mining operations associated with the Proposed Modification. The Middle Liddell Seam was chosen to present the drawdown as it is also being actively mined at the adjacent IUG and also within the Mount Owen Complex and therefore illustrates cumulative impacts. Figure 7-3 shows the zone of depressurisation within the Middle Liddell Seam extends some 1 km to 1.5 km from the North Pit. The drawdown is similar in both windows within the figure indicating the drawdown is largely attributable to the Proposed Modification. This is because the Proposed Modification proposes mining down to the Hebden Seam across a greater extent of the North Pit than the Approved 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.

The total cumulative drawdown from the commencement of the model is shown within the figures included in Section 7.1.6.

Approved mining and Modification drawdown

Modification only drawdown



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Major drainage
- Minor drainage
- Major road
- Minor road
- Rail
- Drawdown contour (m)

Drawdown (m)

- 0.0
- 0.1
- 0.5

Mount Owen (G1862A)

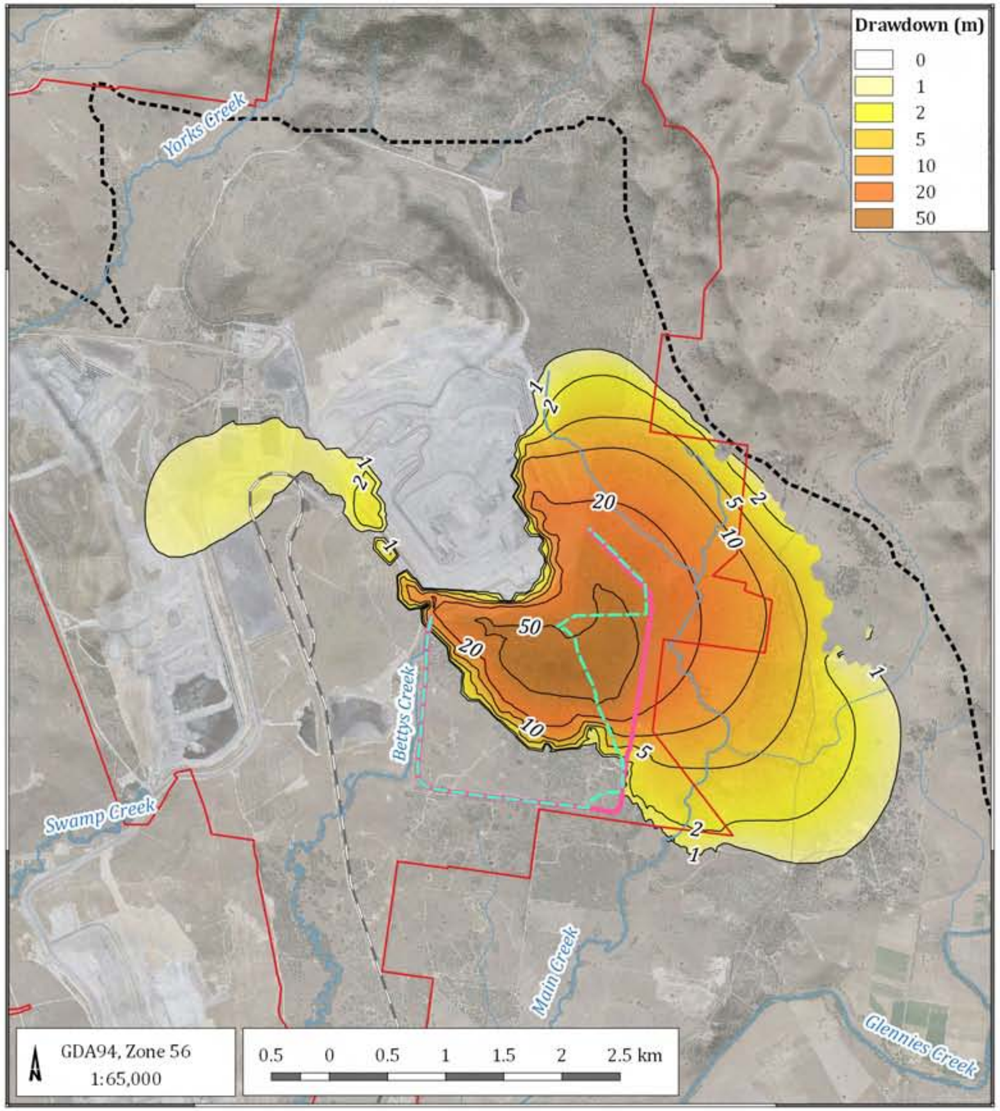
Maximum zone of drawdown due to Proposed Modification - Quaternary alluvium

DATE
12/06/2018

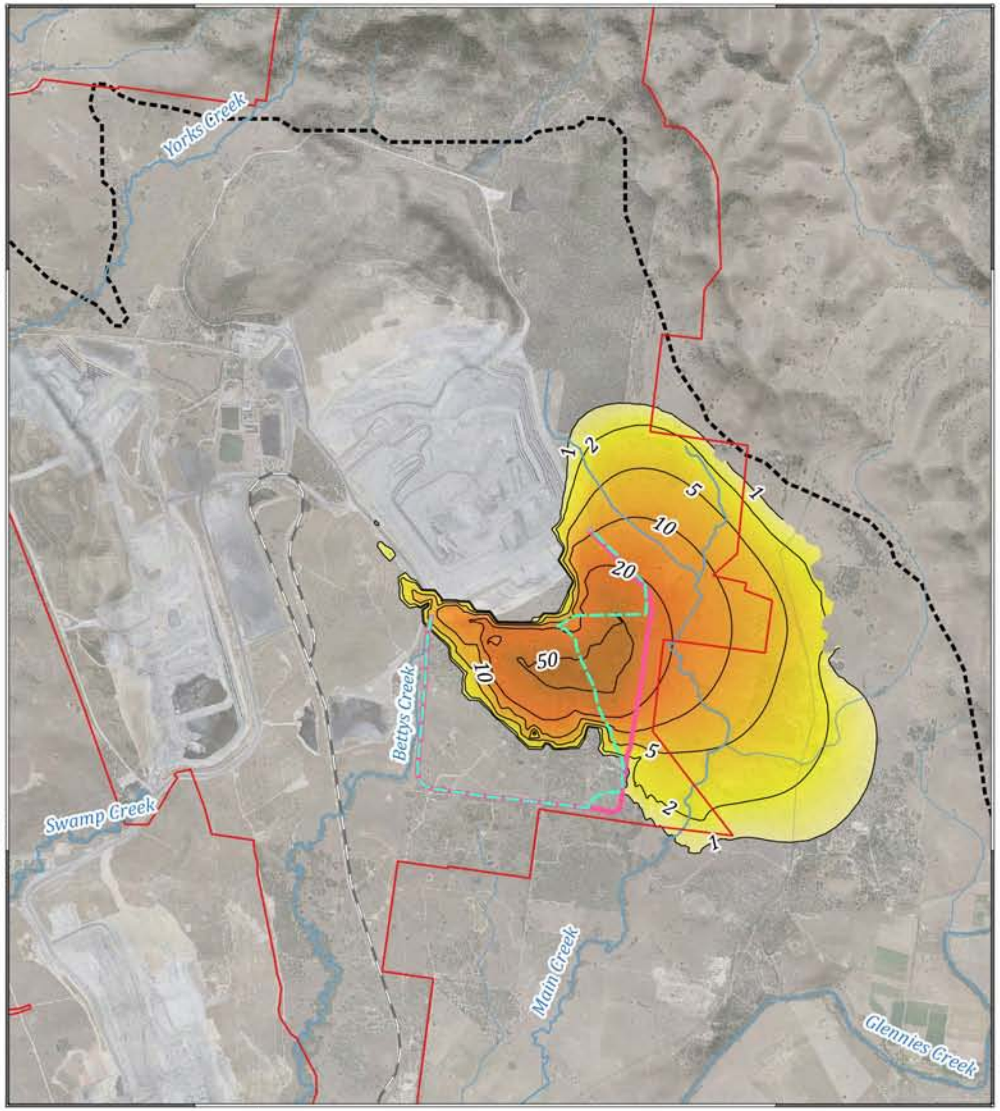
FIGURE No:
7-2

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/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/07.02_G1862A_Maximum zone of drawdown due to project - Quaternary Alluvium_.qgs

Approved mining and Modification drawdown



Modification only drawdown



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Major drainage
- Minor drainage
- Major road
- Minor road
- Rail
- Drawdown contour (m)

Mount Owen (G1862A)

AGE

Maximum zone of drawdown due to Proposed Modification - Middle Liddell Seam

DATE
12/06/2018

FIGURE No:
7-3

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/07.03_G1862A_Maximum zone of drawdown due to project - Middle Liddell_.qgs

7.1.3 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 not directly intercept alluvial aquifers, however, an indirect impact or 'water take' potentially occurs as the Permian strata become depressurised and the volume of groundwater flowing from the Permian to the Quaternary alluvium progressively reduces. Whilst this alluvial groundwater does not necessarily enter the mine workings, the volume of groundwater entering the alluvial groundwater systems is reduced by lower pressures within the Permian due to mining, and this has been considered 'water take' that needs to be accounted for with water licences except where negligible take occurs (AIP, 2012). The change in alluvial water resources was determined by comparing water budgets for alluvial zones using versions of the numerical model that contained and excluded the Proposed Modification.

The water budgets indicated very limited influence on the alluvial systems with a peak change in flow to the Main Creek Quaternary alluvium due to the Approved Operations and the Proposed Modification of 3 ML/year. This result excludes IUG to eliminate the potential for double counting. This very limited impact on the alluvial flow is expected because the model predicts only minimal drawdown within the alluvium. The change in flow of groundwater to the alluvium reduces the baseflow predicted by the model in Main Creek by 1 ML/year. When the change in flow attributable to the Proposed Modification only is calculated, which is the focus of this report, it represents less than 1 ML/year from each alluvial water source and is therefore negligible. Again this is expected given the lack of drawdown within the Main Creek and Bettys Creek alluvium predicted for the Proposed Modification.

7.1.4 Drawdown in private bores

Section 5.5.1 described groundwater usage in private bores in proximity to the North Pit. There are no private bores predicted to be impacted by the Approved Operations or Proposed Modification. 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. The numerical modelling indicates the Proposed Modification does not exceed this threshold and therefore complies with the policy.

7.1.5 Impact on groundwater dependent ecosystems

As detailed under Section 5.5.2, potential GDEs have been identified primarily in riparian vegetation along Bettys Creek and Main Creek. Figure 7-4 shows the location of the potential GDEs along with the maximum cumulative drawdown predicted within the Quaternary alluvium. Figure 7-4 also shows saturated thickness remaining within the alluvial sediments at the end of the simulated mining period.

When interpreting these figures it is important to note that the Proposed Modification is predicted to generate no detectable drawdown. The already approved cumulative impact is therefore provided as it represents the maximum impact on potential GDEs that could need management. The figures show that whilst the numerical model predicts the potential for a small amount of drawdown in the order of 0.1 m this is essentially undetectable and outside the expected accuracy of the model. The figures show the limited drawdown from the already approved cumulative impacts of mining does not dewater the alluvial sediments.

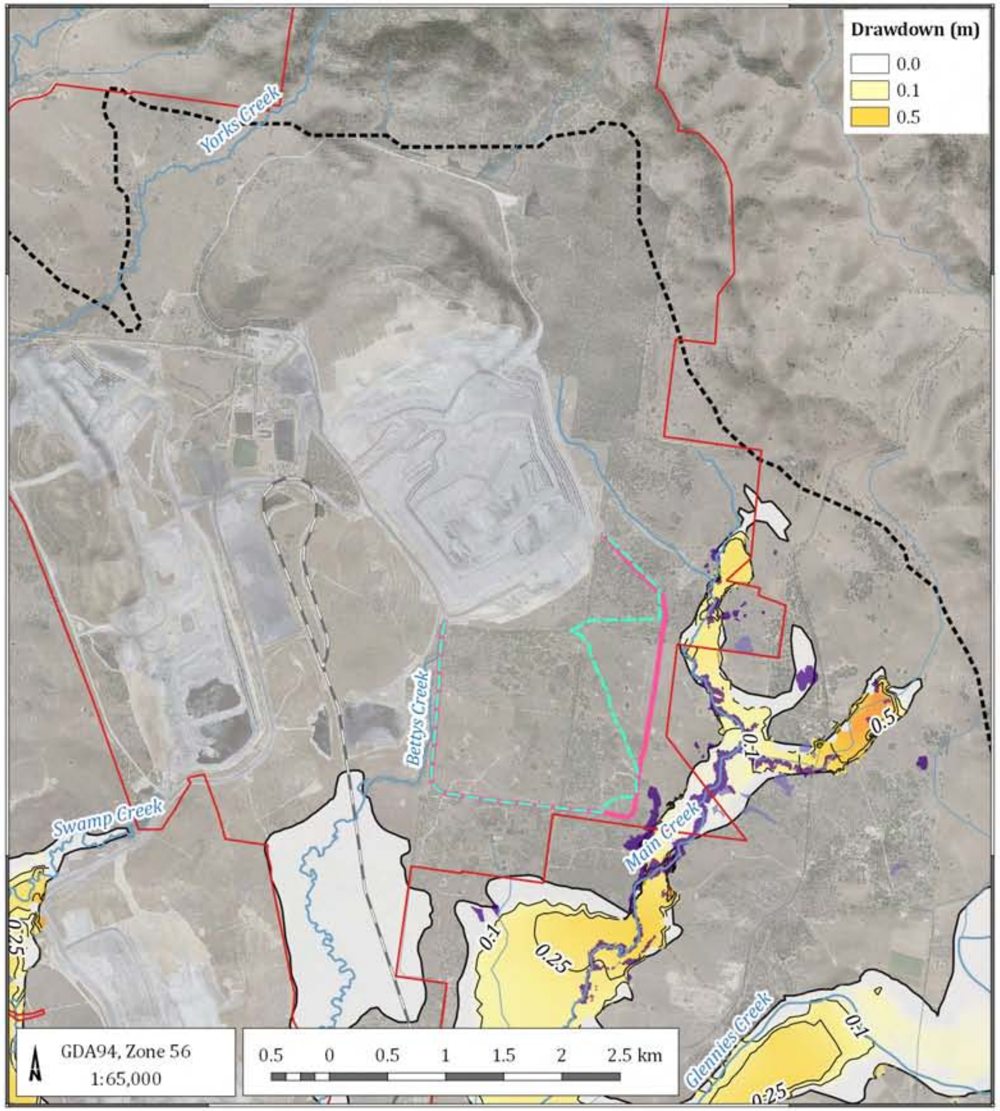
The AIP specifies 'less than or equal to 10% cumulative variation in the water table, allowing for typical climatic post-water sharing plan variations, 40 m from any:

a) high priority groundwater dependent ecosystem; or
b) high priority culturally significant site; and
c) listed in the schedule of the relevant water sharing plan.

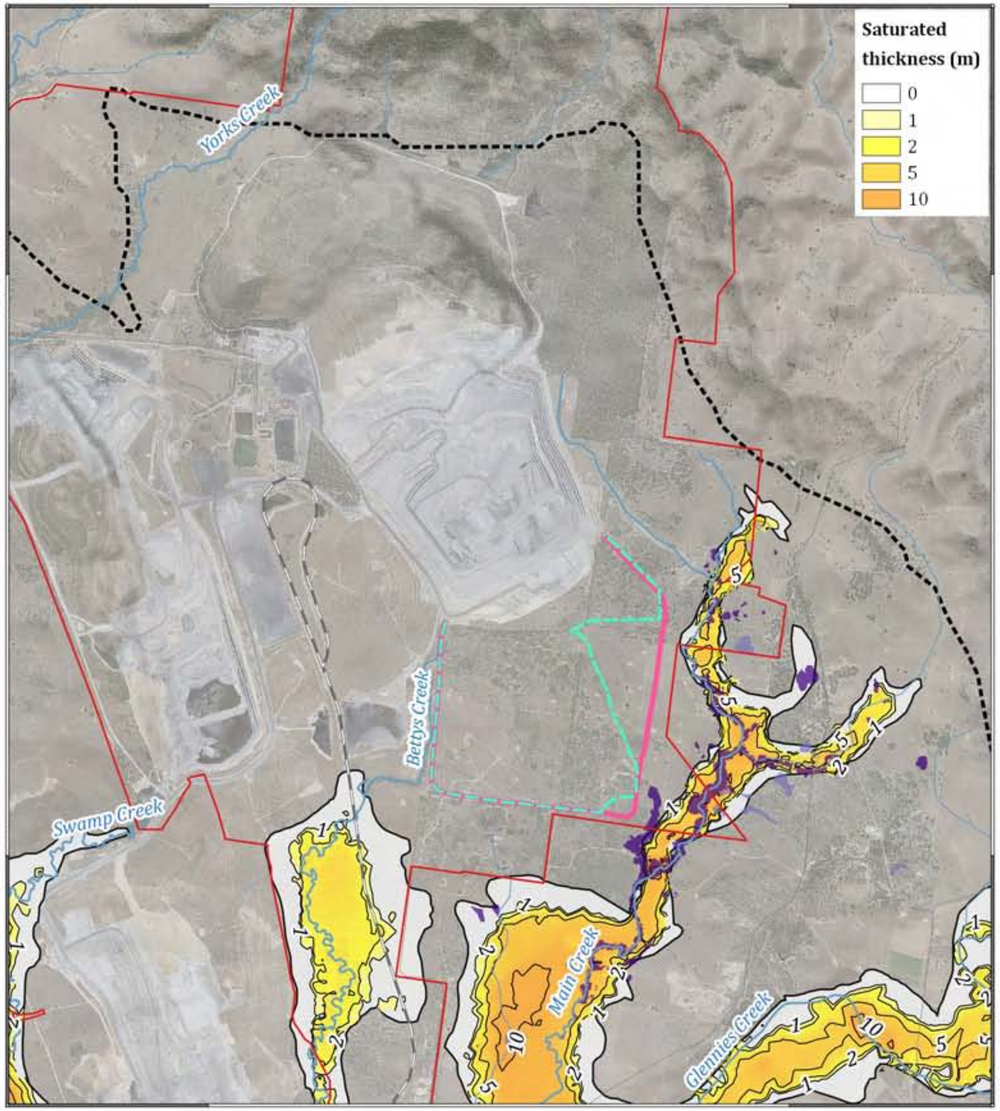
There are no high-priority GDEs or culturally significant sites in the region of the Proposed Modification. The Proposed Modification therefore does not exceed the minimal impact thresholds and complies with the AIP.

A survey of bores installed within the Bettys Creek and Main Creek alluvial aquifers did not detect the presence of stygofauna. Stygofauna were detected in Glennies Creek alluvium however the Proposed Modification will not impact upon this groundwater system (ELA 2018).

Cumulative drawdown



Saturated thickness within alluvium at end of mining



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Quaternary alluvium extent
- Drainage
- Major road
- Minor road
- Contour line (m)

Vegetation (Umwelt, 2017)

- Central hunter swamp oak forest
- Hunter lowland red gum forest

AGE

Mount Owen (G1862A)

Potential GDEs and predicted maximum cumulative drawdown in Quarternary alluvium

DATE
12/06/2018

FIGURE No:
7-4

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/07.05_G1862A_GDEs and predicted maximum cumulative drawdown - Alluvium_.qgs

7.1.6 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 is considered an indirect take. This section discusses the water licences required to account for the peak direct and indirect takes of groundwater and surface water due to the Proposed Modification and the Approved Operations.

As discussed in Section 2, three WSPs apply to the aquifers and surface waters affected by the Proposed Modification – 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 North Pit falls within the Jerrys Water Source and Glennies 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 Proposed Modification are summarised in Table 7-2. The volumes are calculated from the commencement of each of the WSPs.

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 Proposed Modification	Proposed Modification only
North Coast Fractured and Porous Rock WSP	Sydney Basin North Coast	groundwater	908 (Year 3)	456 (Year 15)
Hunter Unregulated WSP	Jerrys	groundwater	0	0
		surface water	0	0
	Glennies	groundwater	3 (Year 12)	1 (Year 18)
		surface water	1 (Year 7)	0
	Hunter Regulated River Alluvium	groundwater	0	0
Hunter Regulated WSP	Management Zone 3a - Glennies Creek & Station Creek surface water	surface water	0	0

As reported in Section 2.4, Mount Owen 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 North Pit, Ravensworth East pits (Bayswater North Pit and West Pit) and the Eastern Rail Pit. Mining in the West Pit and Eastern Rail Pit is completed and the peak inflow to Bayswater North Pit is 366 ML in Year 3, with mining ceasing after Year 7. The total peak licence requirement therefore is 908 ML occurring in Year 3 due to the combined influence of the Bayswater North Pit (366 ML) and the North Pit (542 ML). Therefore Mount Owen hold sufficient water licences to account for the influence of the Proposed Modification on the Sydney Basin North Coast Water Source.

When interpreting the predicted changes in flow due to the Proposed Modification it is important to consider the volumes in context. For the Approved Operations and Proposed Modification, the predicted peak groundwater volume intercepted from the Glennies Water Source peaks at 3 ML/year in Year 12 which is equivalent to 0.1 L/sec. The predicted peak groundwater volume intercepted from the Proposed Modification only, peaks at just 1 ML/year in Year 18. This change in flow due to both the Approved Operations and the Proposed Modification is distributed across a wide area which is undetectable and unmeasurable within the groundwater regime.

The Glennies Water Source and Jerrys Water Source have ‘cease to pump’ rules that require *“from year six of the plan, all licence holders must cease to pump when there is either no visible inflow to, or outflow from, the pumping pool. N.B. From year six of the plan the cease to pump condition will apply to aquifer access licences extracting from all alluvial aquifers within 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 Glennies 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 Proposed Modification.

7.2 Cumulative drawdown

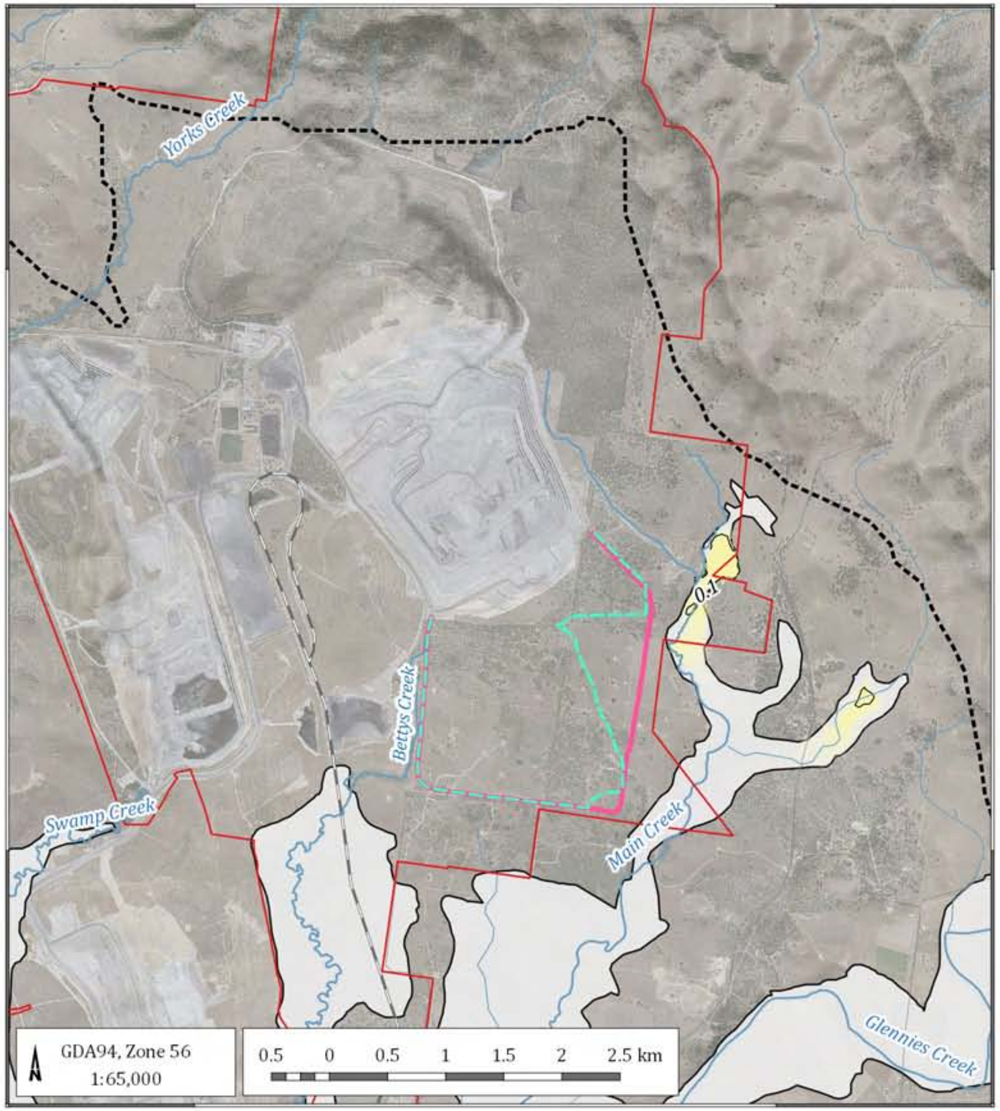
Approved coal mines within the region operate below the water table in relatively close proximity to the Approved Operations and therefore create a cumulative impact where the zones of drawdown overlap. No coal seam gas extraction projects are currently in operation or proposed in the vicinity of the Approved Operations 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 approved and foreseeable operations at IUG (including Modification 8), Rix’s Creek/Rix's Creek North, Ravensworth East, Glendell Mine, Ravensworth Operations, Liddell Mine, Ashton Underground, and Hunter Valley Operations (HVO) North Mine. The simulation of mining at these sites using the numerical model was based on the 2014 version of the numerical model which was updated to include the Proposed Modification as well as the recently approved IUG Modification 8.

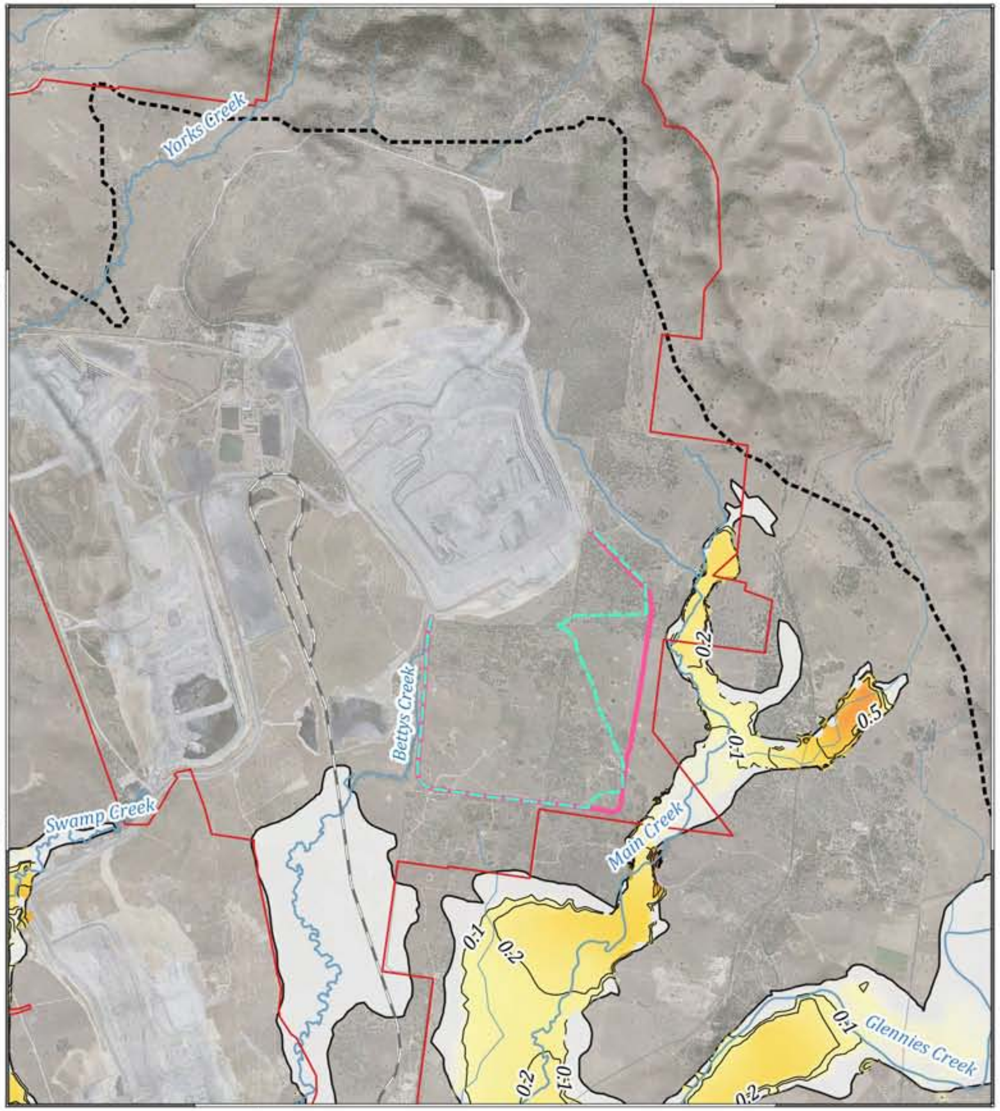
Figure 7-5 and Figure 7-6 show the maximum cumulative drawdown for the Quaternary alluvium and Middle Liddell Seam respectively. The cumulative drawdown is calculated assuming no mining development occurred within the region as baseline levels, and therefore represents the potential change in groundwater levels since 1980. Figure 7-5 compares the predicted drawdown within the Quaternary alluvium for the Approved Operations and Proposed Modification with the cumulative impact from all surrounding mining. It indicates the cumulative drawdown induced by all mining, ranges from 0.1 m to 0.5 m within the alluvial systems, which is unlikely to be detectable with monitoring.

Figure 7-6 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.

Approved mining and Modification drawdown



Cumulative drawdown



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Quaternary alluvium extent
- Major drainage
- Minor drainage
- Major road
- Minor road
- Contour line (m)

Drawdown (m)

- 0.0
- 0.1
- 0.5

AGE

Mount Owen (G1862A)

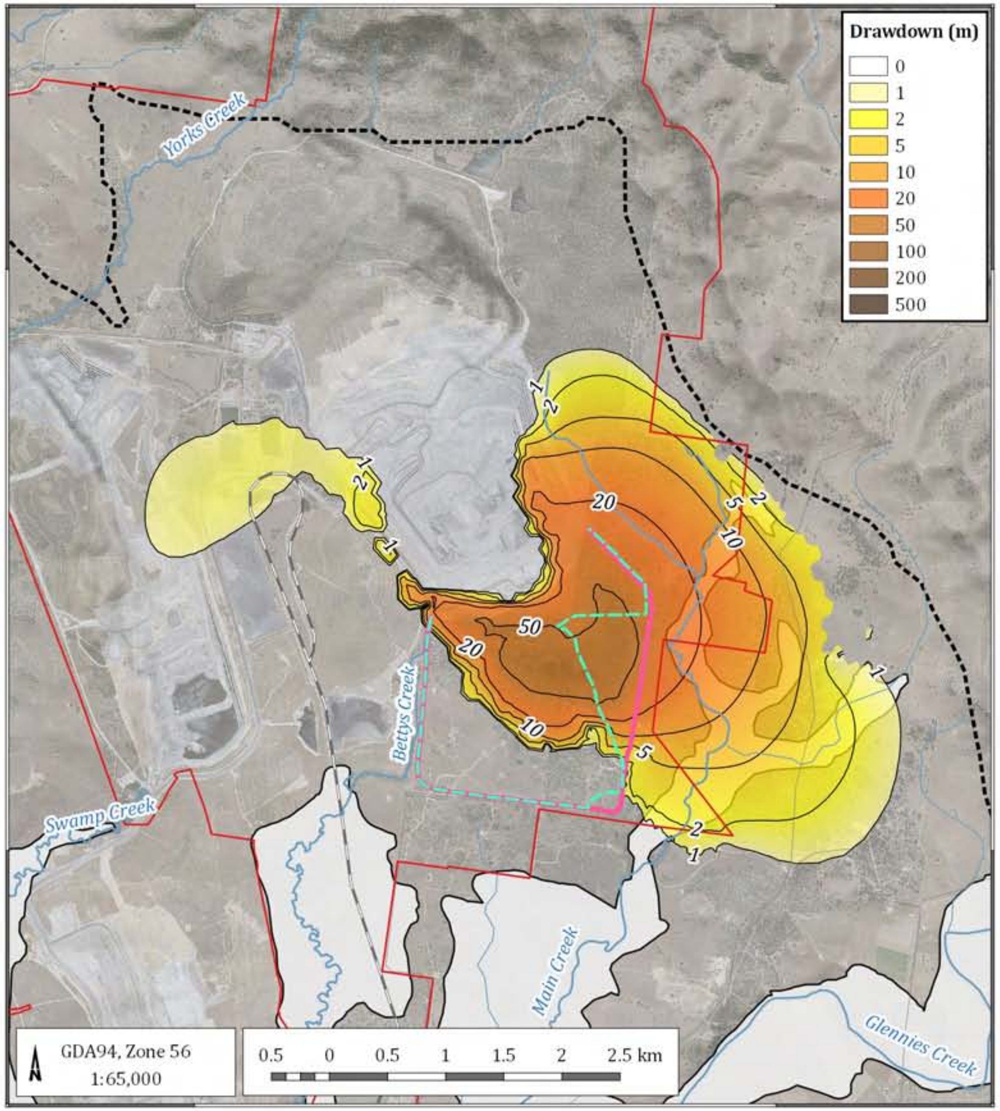
Cumulative drawdown - Quaternary alluvium

DATE
12/06/2018

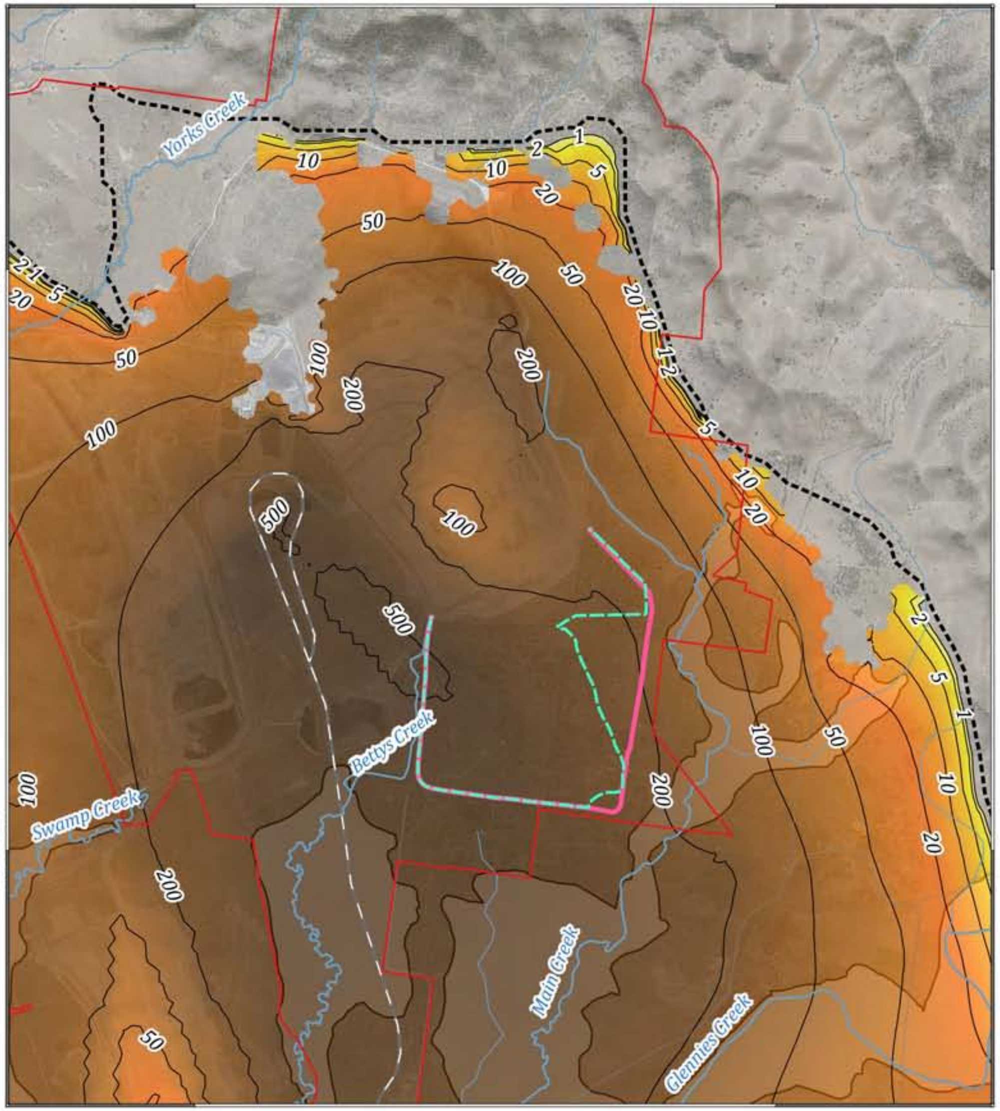
FIGURE No:
7-5

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/07.06_G1862A_Cumulative drawdown - Quaternary Alluvium.qgs

Approved mining and Modification drawdown



Cumulative drawdown



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Quaternary alluvium extent
- Major drainage
- Minor drainage
- Major road
- Minor road
- Rail
- Contour line (m)

Mount Owen (G1862A)

AGE

Cumulative drawdown - Middle Liddell Seam

DATE
12/06/2018

FIGURE No:
7-6

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/07.07_G1862A_Cumulative drawdown - Middle Liddell.qgs

7.3 Post mining recovery conditions

Post mining conditions were also simulated using the numerical model to determine how the final North Pit void lake associated with the Proposed Modification will interact with the groundwater systems. Appendix C 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.

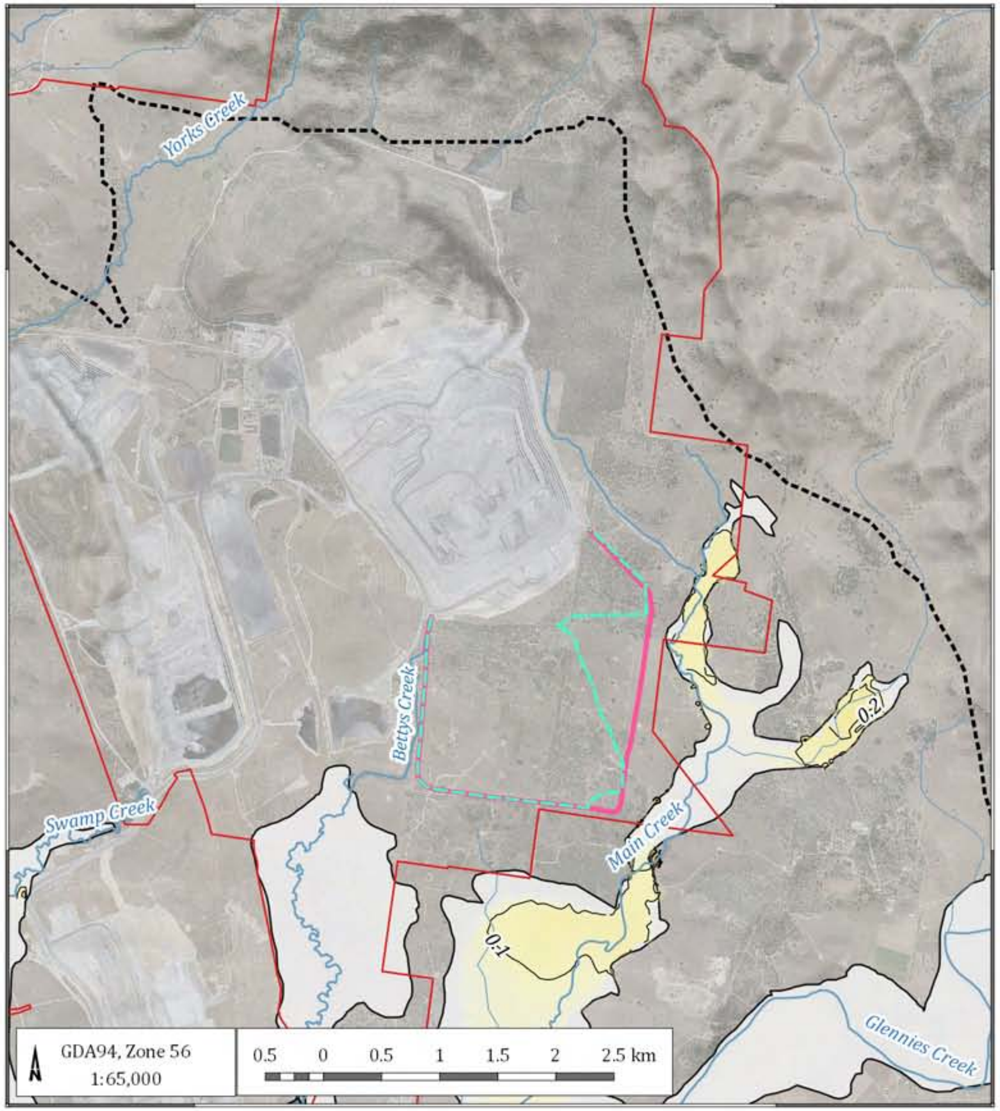
7.3.1 Post closure groundwater recovery

Groundwater inflows to the void during recovery were included in the Surface Water Impact Assessment as part of the development of a high-resolution water balance model (Engeny Water Management, 2018). Final void lake level recovery rates from the water balance model were reinstated into the groundwater model using a series of constant heads over time. This ensured consistency between the surface water and groundwater studies. The final landform was added to the recovery model, which determined the design and location of the proposed final void. The predicted recovery in the void lake levels from the surface water model were represented in the groundwater model with constant heads and simulations undertaken to assess equilibrium conditions.

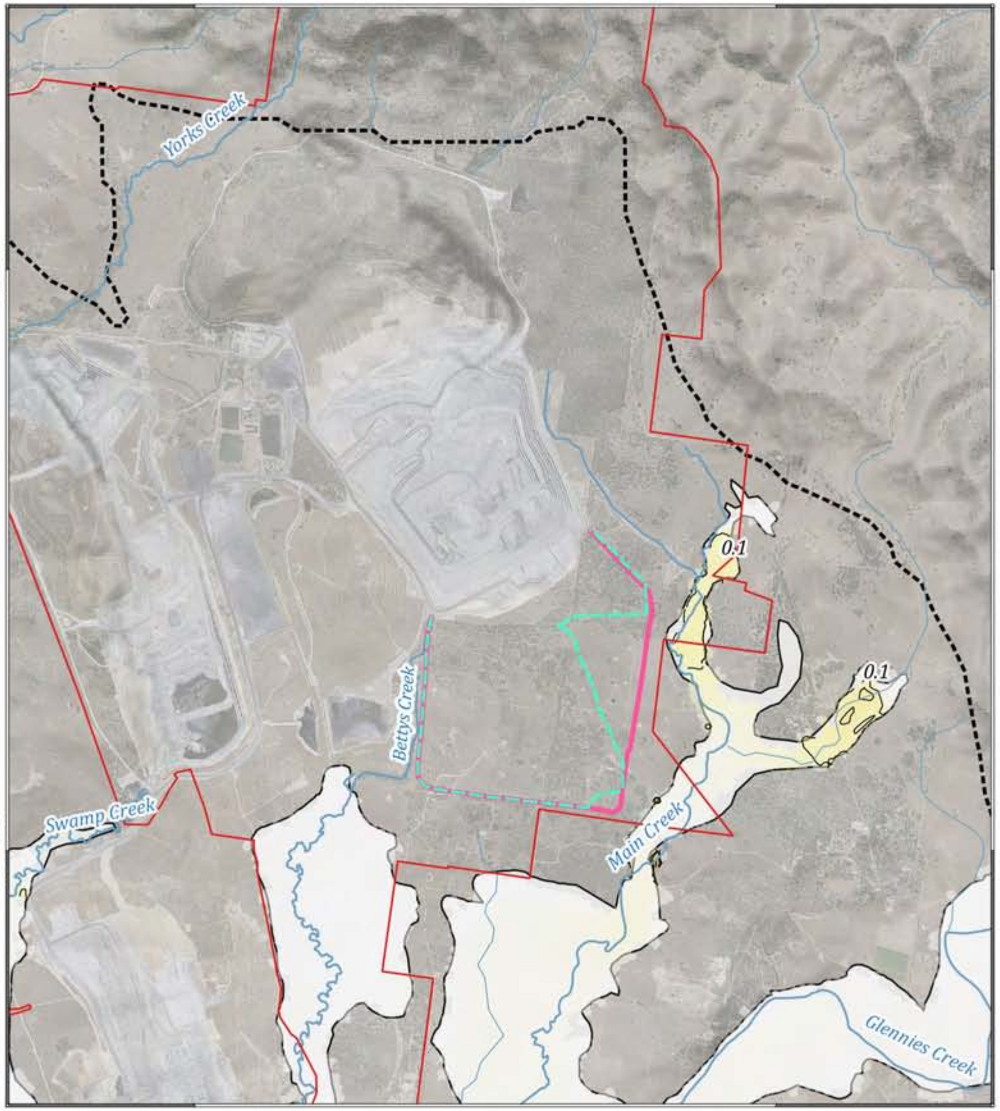
The water balance model indicated the water level within the final void will slowly recover over a period of approximately 320 years stabilising at approximately -65 mAHD. The model results indicate that groundwater will gradually seep into the void and the groundwater levels within the Permian strata will establish a new equilibrium level in response to the changes in landforms. The final void lake water levels are predicted to be about 120 m to 140 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 7-7 shows the maximum drawdown within the Quaternary alluvium that is predicted to occur during recovery. The magnitude of the drawdown within the Quaternary alluvium is relatively limited at generally less than 0.1 m which is considered undetectable from seasonal fluctuations.

Approved mining plus Modification post-mining drawdown



Modification only post-mining drawdown



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Alluvium extent
- Model boundary
- Major drainage
- Minor drainage
- Drawdown contour (m)

Drawdown (m)

- 0.0
- 0.1
- 0.5

Mount Owen (G1862A)

Post-mining maximum drawdown - Quaternary alluvium

DATE
12/06/2018

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/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/07.08_G1862A_Post-mining maximum drawdown - Quaternary alluvium.qgs

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 post mining recovery period in accordance with the AIP. The methodology was the same as outlined for the operational period as outlined in Section 7.1.3. 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 Proposed Modification post mining.

The water budgets indicate there is potential for the indirect take on the alluvial groundwater systems to increase post mining whilst the groundwater systems are recovering. Figure 7-8 below shows the groundwater flow to the alluvial groundwater systems post mining for the cumulative scenario where all approved and foreseeable mining operations are represented. The graph shows the overall recovery of the groundwater system is reached after approximately 500 years after mine closure.

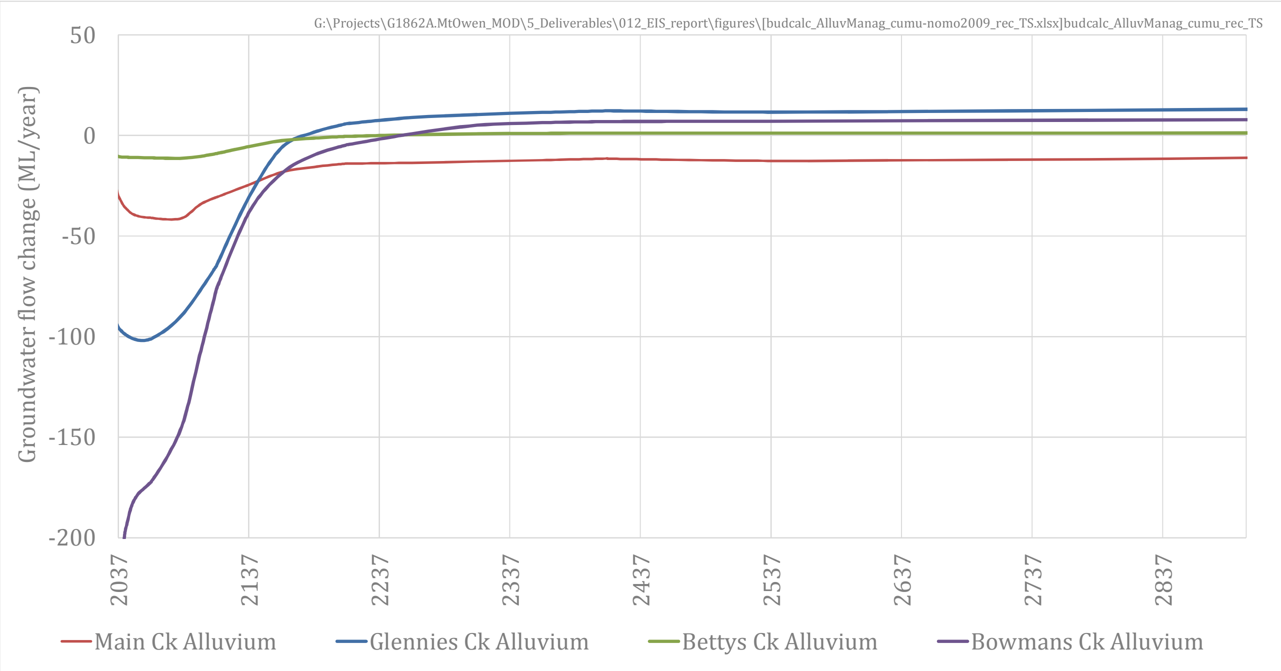


Figure 7-8 Post mining flux to alluvial systems for the cumulative scenario

Figure 7-9 shows the change in groundwater flow to the alluvial systems for both the Approved Operations and Proposed Modification. It shows the long term reduction in groundwater flow to the Main Creek alluvium stabilises at around 35 ML/year approximately 500 years post mining. The peak reduction in groundwater flow to the Main Creek alluvium due to the Proposed Modification only peaks at 13 ML/year approximately 800 years post mining.

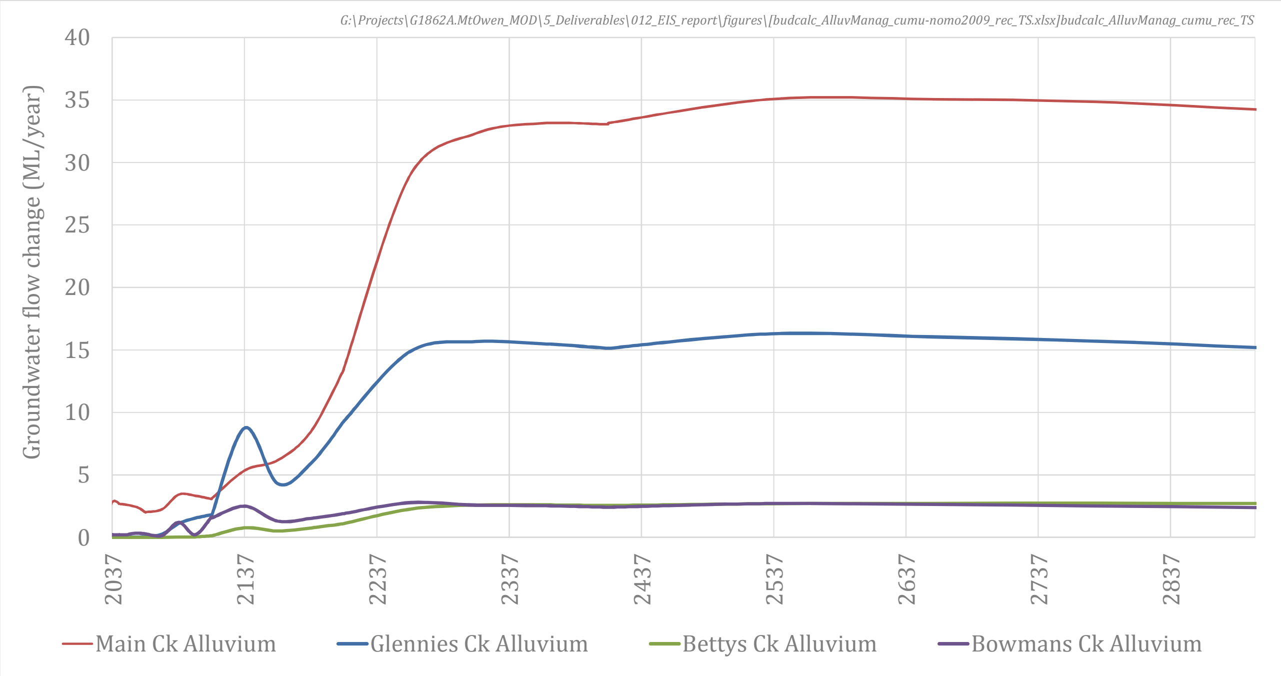


Figure 7-9 Post mining change in flux to alluvial systems due to Proposed Modification and Approved Operations

7.3.3 Water licensing and water sharing plan rules

As noted previously in Section 7.1.6, 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 Proposed Modification 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.

Table 7-3 Groundwater licensing summary – post mining

Water sharing plan	Water source/ management zone	Type	Peak volume requiring licensing post mining (ML/year)	
			Approved operations and proposed modification	Proposed Modification only
North Coast Fractured and Porous Rock WSP	Sydney Basin North Coast	groundwater	less than during mining	less than during mining
Hunter Unregulated WSP	Jerrys	groundwater	4 (6 minus 2)[1]	2 (3 minus 1)
		surface water	2	1
	Glennies	groundwater	27 (35 minus 8)	9 (13 minus 4)
		surface water	8	4

Water sharing plan	Water source/ management zone	Type	Peak volume requiring licensing post mining (ML/year)	
			Approved operations and proposed modification	Proposed Modification only
	Hunter Regulated River Alluvium	groundwater	2 (16 minus 14)	1 (7 minus 6)
Hunter Regulated WSP	Management Zone 3a - Glennies Creek & Station Creek surface water	surface water	14	6

Note : *Workings in brackets show the correction of groundwater take to remove surface water that would be otherwise double counted*

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 influenced by recovery of surrounding operations.

7.3.4 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 (Engeny Water Management, 2018) indicates the evaporation from the lake surface will concentrate salts in the pit lake slowly over time. 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.

7.4 Sensitivity

The uncertainty in the model predictions was assessed using a nonlinear uncertainty analysis where numerous model parameters were changed at the same time. Appendix C presents the results of the uncertainty analyses. An uncertainty analysis involved changing model parameters to create 225 model realisations. The uncertainty analysis did not predict any impacts to the alluvium due to the Proposed Modification that exceeded the minimal impact considerations within the AIP.

8 Groundwater monitoring and management plan

The Mount Owen Complex operates in accordance with a WMP which was prepared in consultation with NSW government agencies consistent with the requirements of the SSD-5850. The WMP includes a standalone GWMMP Plan that was last updated in October 2017 following approval for the construction of a water pipeline from IUG to the Mount Owen Complex (Modification 1). The WMP describes the management of environmental and community aspects, impacts and performance relevant to the sites water management system.

Given the updated numerical modelling indicates the impact of the Proposed Modification on alluvial groundwater systems and associated users will be negligible, no additional monitoring beyond that developed for the Approved Operations is considered necessary.

A total of 97 bore or VWP sites form the current groundwater monitoring network for Mount Owen. The monitoring network is comprised of standard 50 mm or 25 mm PVC monitoring bores installed within the alluvial aquifers and the coal measures and arrays of VWPs cemented into selected drill holes to monitor pressure in deeper strata. This includes a network of monitoring sites along Main Creek and Bettys Creek installed within the alluvium and underlying Permian strata to compare to predictions of the numerical modelling.

Currently groundwater levels and field water quality (pH and EC) are measured in the monitoring bores on a 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 22 bores for analysis and major ions and trace elements concentrations. The bores tested include the NPZ series of bores that are located along or adjacent to Main Creek and Bettys Creek. 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 will continue in order to detect any changes in groundwater quality during mining. The current monitoring is considered adequate to monitor the predicted impacts of the Proposed Modification on groundwater quality.

Similar to the water level monitoring, yearly reporting of the water quality results from the monitoring network will be included in the annual review. The WMP currently provides triggers for pH, EC for the standpipe bores within the network. The trigger levels have been calculated as the 80^{th} 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. Previous efforts to calculate the groundwater inflow to North Pit (HEC 2017) have indicated all the groundwater evaporates from the mine face or is bound to mined material before being pumped into the mine water circuit. The water balance method will therefore continue to be used to estimate the volume of free flowing groundwater entering the mine workings. In addition to this every three years the validity of the numerical model predictions will be assessed and if the data indicates significant divergence from the model predictions, an updated groundwater model will be constructed for the simulation of mining.

Post mining water levels in the final voids will be compared to surrounding groundwater bores. Investigation will be triggered if the water level in the final void exceeds the observed water level in any of the surrounding monitoring bores.

9 Summary and conclusions

The groundwater assessment for the Proposed Modification considered the impacts of increasing the mining footprint at Mount Owen by 46 ha and increasing the depth of mining across the extent of the North Pit to allow extraction of coal to the base of the Hebden Seam.

The Proposed Modification is located in an area that has had a long history of mining, and is therefore extensively depressurised. In this context, the Proposed Modification is comparatively minor in scale and the potential to influence cumulative groundwater impacts is very limited.

Alluvial aquifers are not present within the footprint of the North Pit and the adjacent Main Creek and Bettys Creek alluvium do not meet the criteria of highly productive aquifers. There are no private groundwater users within these groundwater systems due to variable water quality and low yields. Therefore from a groundwater perspective the Proposed Modification is not considered to occur within an environmentally sensitive area.

The prevalence of mining in the region means there have been many previous groundwater modelling efforts. The numerical model developed for the Proposed Modification has built upon an existing large regional model to create consistency with previous work and to represent the cumulative impacts in the surrounding region. The model was updated with additional water level and mine inflow data to improve the ability of the model to predict the impact of mining operations. The model was used to assess the incremental effects of the Proposed Modification and changes to approved impacts brought about through recalibration. Cumulative effects from neighbouring mines were also assessed. The key findings were:

- The Approved Operations along with the Proposed Modification will induce inflow that will directly intercept up to 908 ML/year of groundwater from the Permian coal measures – Mount Owen hold sufficient water licence entitlements to account for this.
- The inflow to the North Pit as a result of the Proposed Modification will generate a zone of drawdown within the Permian coal measures focussed around the North Pit footprint of up to 1.5 km – there are no private water bores or GDEs within this drawdown zone and this is within the predicted extent of drawdown in the Permian coal measures from historical mining operations within this area since 1980.
- The maximum net loss of groundwater from the Quaternary alluvium (3 ML/year) due to the Proposed Modification during operations is predicted to be negligible and undetectable.
- The Proposed Modification will not result in any detectable incremental drawdown within Quaternary alluvial aquifers – therefore private water bores and potential GDEs reliant on the alluvial systems will not be affected.
- At closure groundwater will gradually seep into the final North Pit void and re-pressurise the Permian strata slowly over time – a steep hydraulic gradient between the void and the groundwater systems will remain creating a permanent 'sink' for groundwater flow that will result in an undetectable drawdown from the Quaternary alluvial systems.

Given the limited impacts detected in monitoring to date and by numerical modelling for future activities no additional groundwater impact mitigation measures are required for the Proposed Modification. An expansive network of monitoring bores already exists and groundwater levels and quality will 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 would be conducted in accordance with the WMP protocols.

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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
CLWD	The Crown Lands and Water Division of Department of Industry (formerly known as DPI Water
DoEE	Department of the Environment and Energy
EIS	Environmental Impact Statement
GDE	Groundwater Dependent Ecosystem
Glencore	Glencore Coal Pty Limited
IESC	Independent Expert Scientific Committee
IUG	Integra Underground Mine
ML	Megalitres
MNES	Matters of National Environmental Significance
Mount Owen	Mt Owen Pty Ltd
Mtpa	Million tonnes per annum
Pinneena	Department of Primary Industries – Water supplied database of registered groundwater bores
SILO	SILO is a database of historical climate records for Australia
SRLU Policy	Strategic Regional Landuse Policy
VWP	Vibrating wire piezometer
WAL	Water access licence
WMP	Water management plan
WSP	NSW Water Sharing Plan

Appendix A

Limit of alluvium investigation (AGE 2017)

Australasian Groundwater and
Environmental Consultants Pty Ltd

Report on

Main Creek Alluvium Verification and Mapping

Mount Owen Continued Operations – Modification

Prepared for
Glencore Australia Pty Ltd

Project No. G1862 October 2017
www.ageconsultants.com.au ABN 64 080 238 642

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Report on

Main Creek Alluvium Verification and Mapping
Mount Owen Continued Operations – Modification

1 Introduction

The Mount Owen Complex is operated and owned by Mount Owen Pty Limited, a subsidiary of Glencore Coal Pty Ltd (Glencore). The Mount Owen Complex comprises of the Mount Owen (North Pit), Ravensworth East (West and Bayswater North Pits) and Glendell (Barrett Pit) open cut coal mines. The Complex is located approximately 20 km north-west of Singleton, NSW.

The Mount Owen Continued Operations – Modification (proposed modification) Project seeks to increase the life and extraction limit of Mount Owen Mine (North Pit) beyond that currently provided for by the development consent. The proposed modified North Pit shell intersects the alluvium of Main Creek as mapped in the Mount Owen Continued Operations Project Groundwater Impact Assessment (Jacobs, 2014). This document outlines the methodology and outcomes of investigations undertaken to verify this mapping of the alluvium of Main Creek in proximity to the approved and proposed North Pit extent.

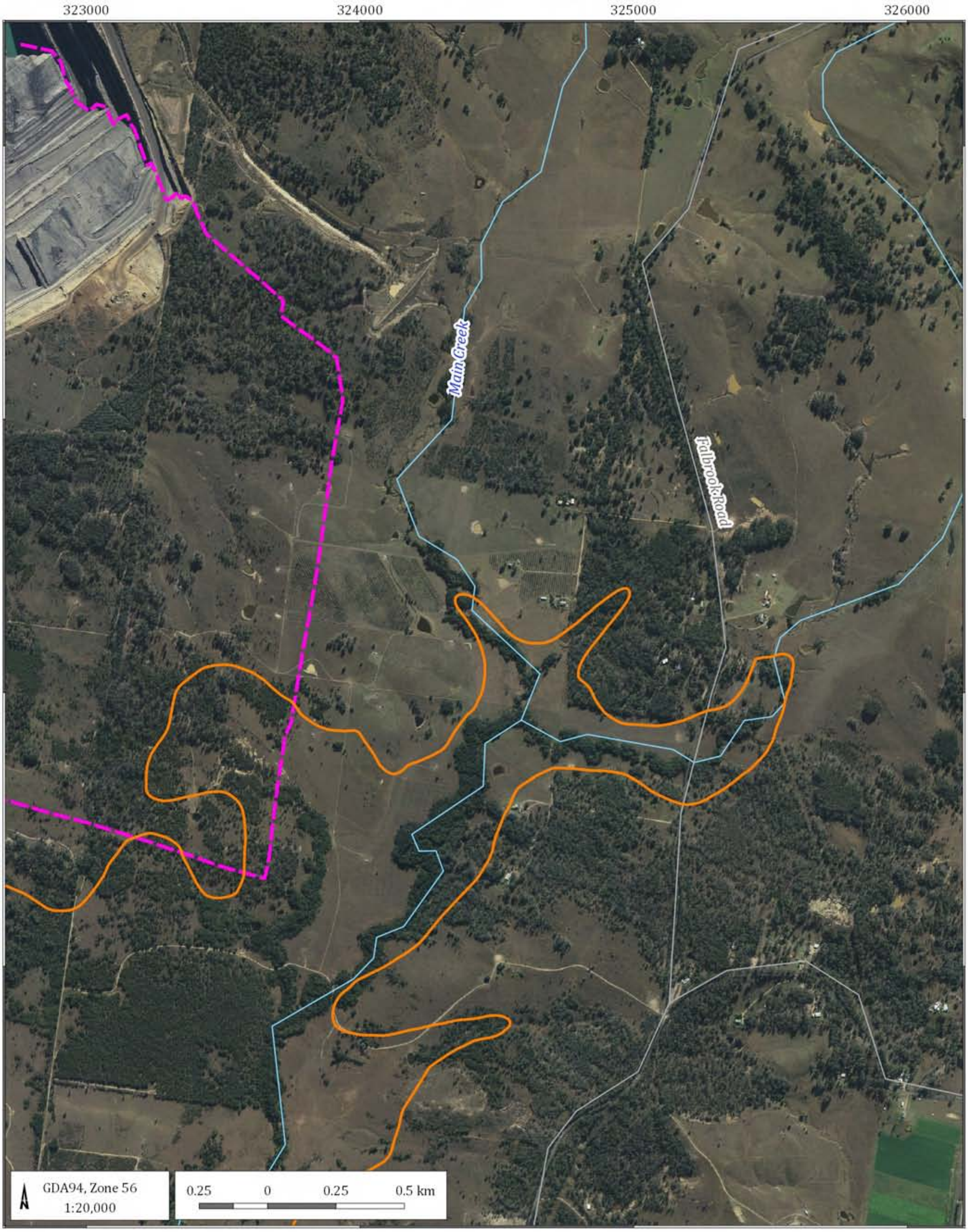
Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) prepared this document at the request of Mount Owen. It addresses the scope of work presented in the request for proposal (RFP) provided by Vicki McBride on 17 January 2017.

1.1 Objectives and scope of work

The objective of the Main Creek alluvium verification and mapping is to assess and refine, where necessary, the previously mapped alluvium extent of Main Creek in proximity to the approved and proposed North Pit extent. This will allow planning for the proposed modification to consider this potential constraint and identify appropriate locations for ongoing groundwater monitoring.

The previously mapped alluvium extent was initially established by the NSW Aquifer Interference Policy (AIP) highly productive alluvium maps (Figure 1.1). This was subsequently refined by Jacobs (2014) via the use of geospatial interpretation of LiDAR data as shown in Figure 1.2. To achieve the objective, the following scope was developed:

- Desktop study.
- Geophysical survey.
- Intrusive investigation.
- Reporting.



LEGEND

- Highly productive alluvium (AIP 2012)
- Proposed Modification Pit Shell
- Road
- Watercourse

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

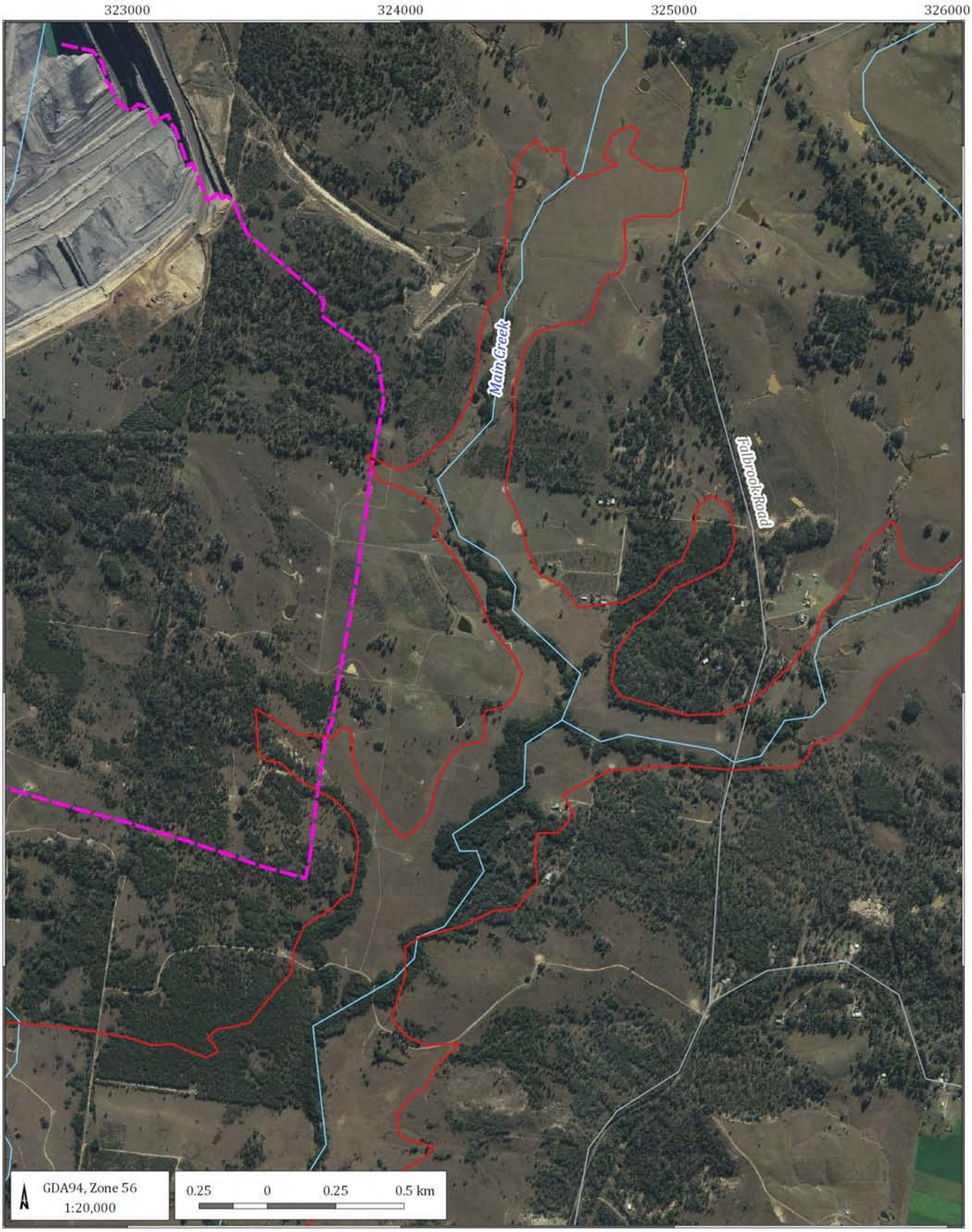
Highly Productive Alluvium (as per the 2012 AIP)

AGE

DATE 11/10/2017

FIGURE No: **1.1**

N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/01_02_G1862.Mt_Owen_AIP_highly_productive_alluvium.qgs



LEGEND

- Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)
- Proposed Modification Pit Shell
- Road
- Watercourse

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)

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FIGURE No: **1.2**

N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/01_03_G1862.Mt_Owen_MOOSE_LIDAR_alluvial_study.qgs

2 Background - Geology

Mount Owen is situated in the Hunter Valley of NSW. Land use surrounding the mine is primarily cattle grazing on open pastures, active open-cut mining and irrigation cropping adjacent Glennies Creek. Two major water courses sit astride the mine: Bowmans Creek to the east and Glennies Creek to the west. Both creeks flow in a southerly direction to the Hunter River.

Local geology consists of the Permian coal measures of the Vane and Jerrys Plains subgroups of the Sydney Basin. The site is overlain with a layer of weathered rock / regolith, with alluvium and colluvium accumulated in drainage lines at the surface. Ranges to the north are exposed Sydney Basin basement and consist of Carboniferous age sedimentary, marine and volcanic rocks of the New England Orogen.

The current design of the proposed modification pit extends to the base of the Jerrys Plains Subgroup – Burnamwood Formation - Bayswater Seam (Jacobs, 2014).

Numerous rock outcrops are present on site. A polymictic, poorly sorted, sub-rounded, conglomerate, and well sorted sandstone outcrop (Figure 2.1) and thin shallow coal seams were observed onsite. Faults of metre scale throw are known to occur within the Project area (pers. comm. Ben Kemp – 10 March 2017). Exposed Main Creek alluvium is dominantly light brown to yellow, dark brown, clay with graded sand, and variegated bed load gravel clast or clay matrix supported (Figure 2.2).

Figure 2.1 Polymictic conglomerate outcrop (scale 14 cm)

Figure 2.2 Main Creek alluvium in creek bank (GDA94 z56 324182, 6411535)

3 Methodology

As discussed in Section 1, the scope comprised the following tasks:

1. Desktop study.
2. Geophysical survey.
3. Test pit intrusive investigation.
4. Reporting.

3.1 Desktop study

The desktop study included a range of published data sets to estimate the presence / absence and limits of alluvial sediments, including:

- Commonwealth Scientific and Industrial Research Organisation (CSIRO) regolith maps, Wilford *et al* (2015);
- Geoscience Australia (GSA) radiometric maps, (2015);
- Aquifer Interference Policy (AIP) highly productive alluvium maps NOW (2013);
- 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, all from the Office of Environment and Heritage (2017); and
- Mount Owen Continued Operations Groundwater Impact Assessment, Jacobs (2014).

Published data and previous interpretation indicated the presence of alluvium along Main Creek and its tributaries to the east and west. The extent of alluvium was delineated using geospatial methods for the Mount Owen Continued Operations Project – Groundwater Impact Assessment (Jacobs, 2014). LiDAR was interpreted to identify low flat alluvial topography as alluvium (Figure 1.2). The LiDAR alluvium extent refines those from the AIP (2012) dataset.

3.2 Fieldwork

3.2.1 Geophysical survey

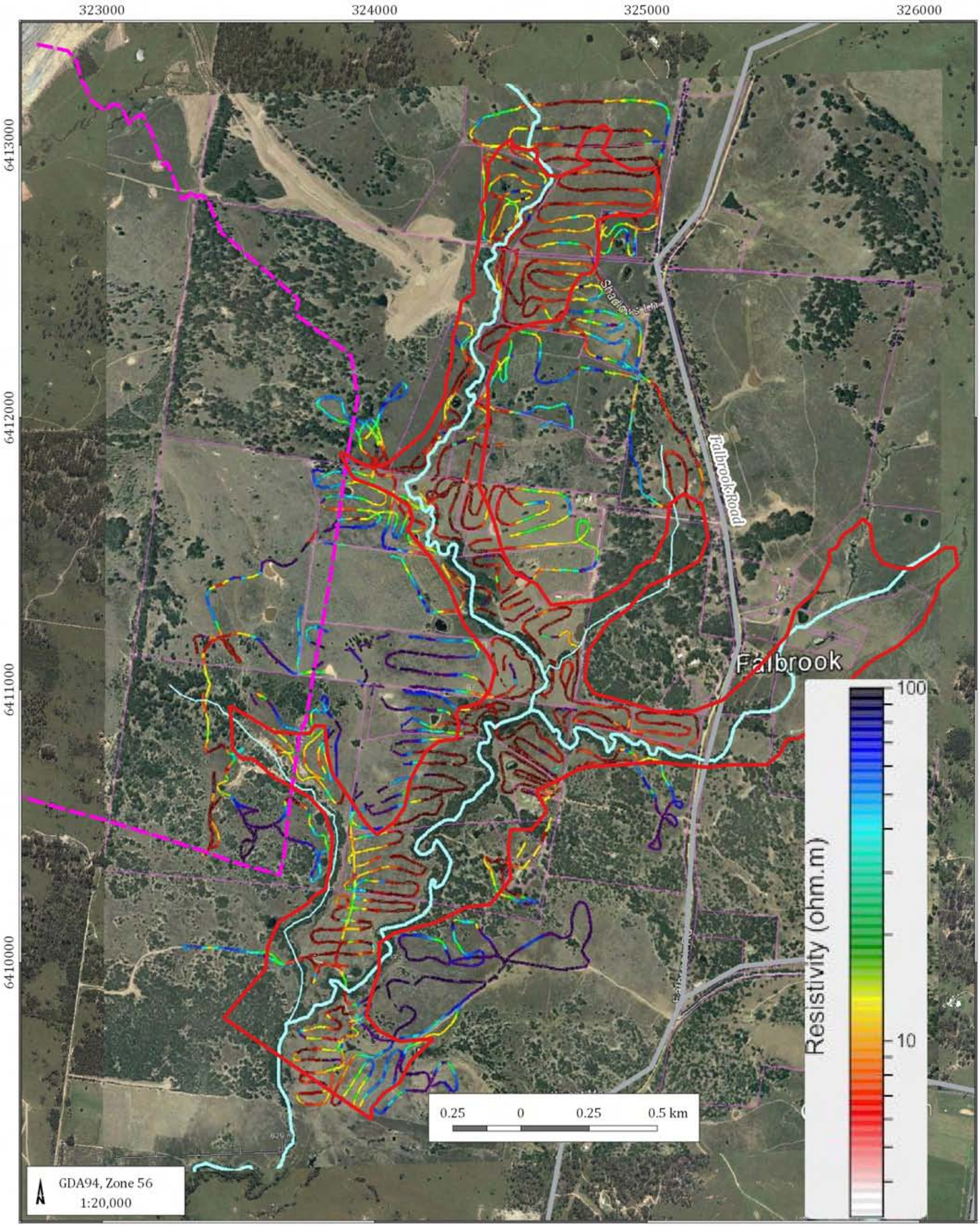
Following the desktop study, a geophysical survey was undertaken to delineate alluvium associated with Main Creek and a number of its tributaries. The primary objective of the survey was to assess the western extent of the Main Creek alluvium, which is the extent closest to the mine. The geophysical survey trace extended parallel to the proposed modification disturbance boundary on both sides of Main Creek (Figure 3.1).

The geophysical survey was performed by Dr David Allen of Groundwater Imaging on 15 and 16 February 2017. The AgTEM geophysical survey technique was used and comprises a continuous electrical resistivity / conductivity measurement (Figure 3.2). A non-metallic cart with conductive transmitter loops is towed behind a vehicle. Electrical current is pulsed through the loops which induce electrical fields beneath the cart within the ground. The induced electrical field rate of decay is measured within receiver loops on the cart and provides inference on the resistivity of materials present.

Typically, low electrical conductivity (high resistance) and high electrical conductivity (low resistance) values can infer groundwater and / or rock and composition of bulk sediments (Groundwater Imaging 2017) (Table 3.1). Conductivity was measured to a depth of 20 m. The geophysical survey traces were conducted at spacings of 40 m, where possible given the terrain and obstacles (Groundwater Imaging 2017). The discrete survey data were subsequently reduced with a gridding software package (using kriging and nearest neighbour alogorithms) to produce the interpretation of the data (pers. comm. David Allen - Groundwater Imaging April 2017). The geophysical survey was undertaken by a qualified professional using standard industry practices.

Table 3.1 Electrical resistivity survey response

Low electrical conductivity	High electrical conductivity
Lack of clay	Clays
Low saturation	High saturation
Fresh pore water	Saline pore water
Impervious rock	Weathered rock



LEGEND

- Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)
- Proposed Modification Pit Shell
- Watercourse

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

AgTEM survey trace

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FIGURE No: **3.1**

Source: Groundwaterimaging (2017), AgTEM Alluvium and Subcrop Investigation at Mt Owen for Glencore - Singleton;
N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/03_01_G1862.Mt_Owen_AgTEM_survey_trace.qgs

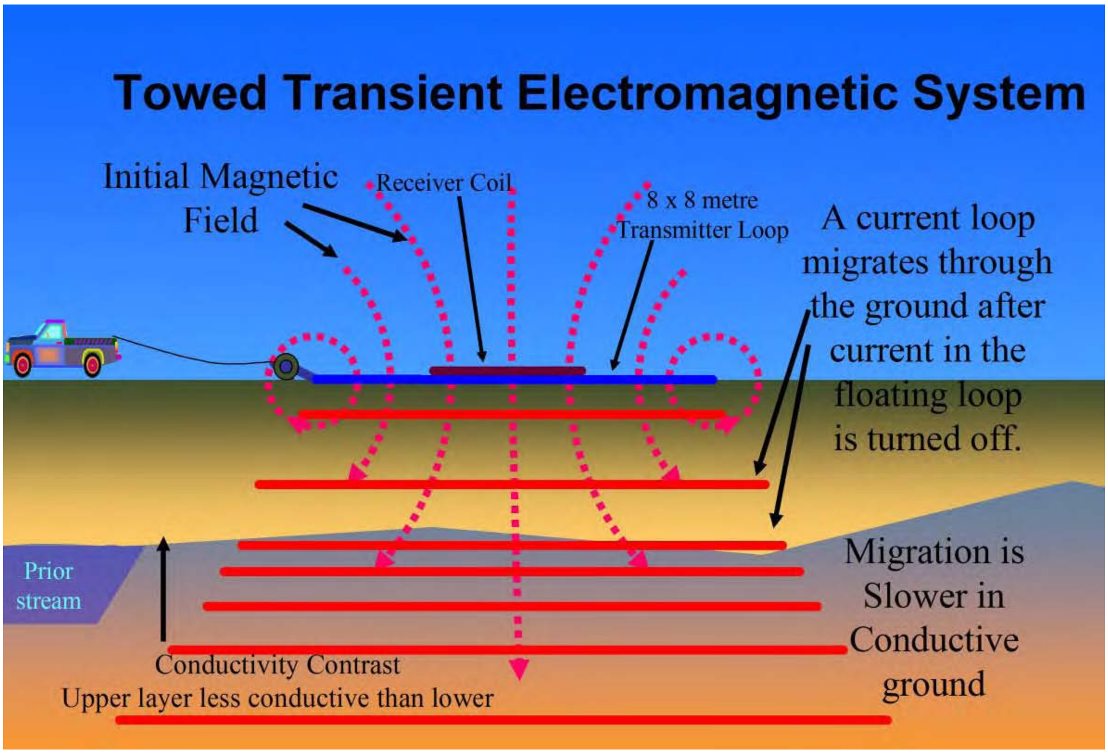


Figure 3.2 Diagram of geophysical electrical conductivity method, towed transient electromagnetic system, Groundwater Imaging (2017)

3.2.2 Intrusive investigations - Test pits

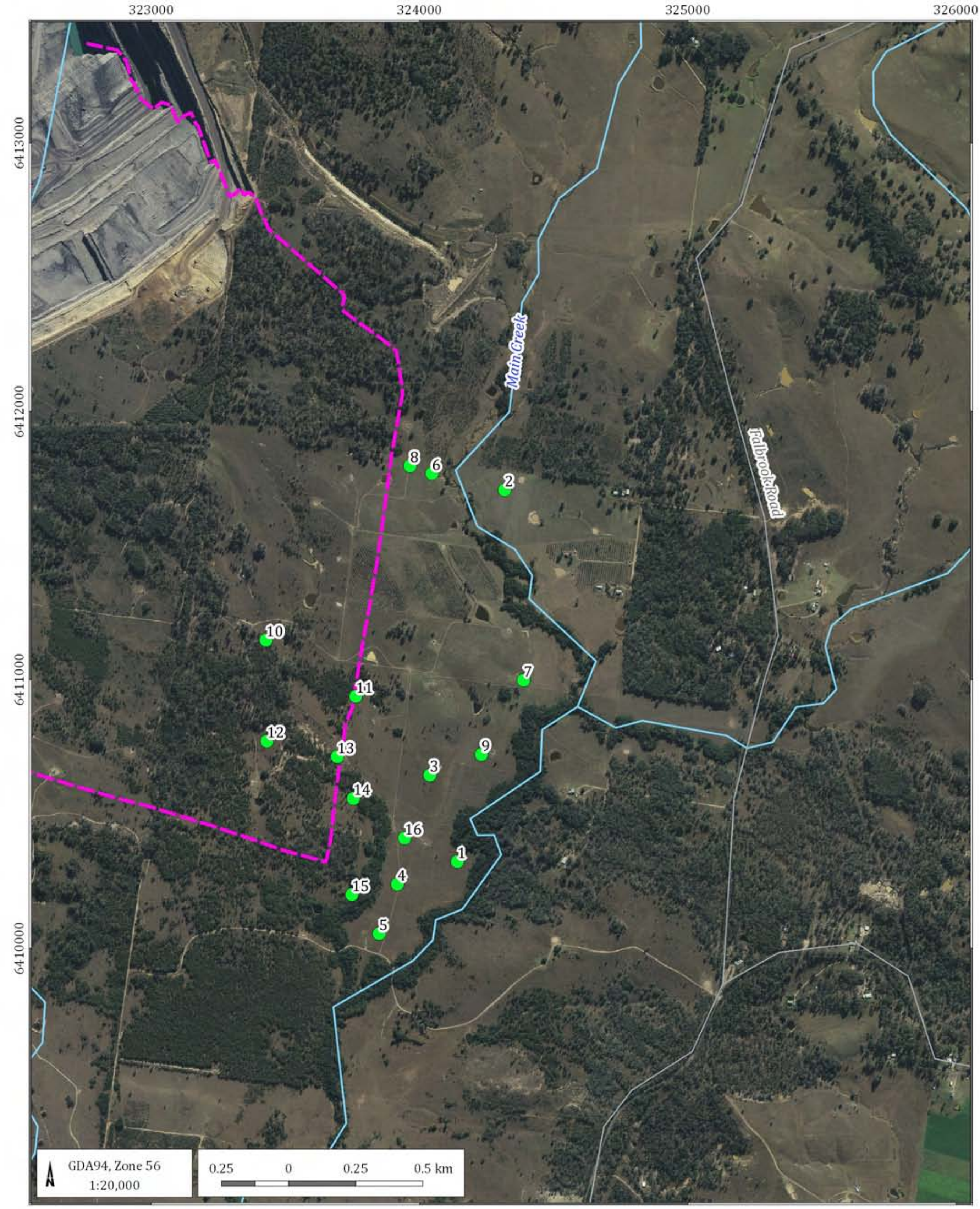
The results of the geophysical survey were verified through the excavation of a series of test pits. The locations were selected on the basis of their geophysical responses. Locations interpreted to be representative of alluvium, colluvium, thin colluvium (thin clay bound sediments) and weathered rock were chosen.

The test pits were excavated between 9 and 10 May 2017. The location coordinates are summarised in Table 3.2 and shown on Figure 3.3. The test pitting was undertaken by an experienced AGE field hydrogeologist. All AGE qualified professionals and undertake project tasks in line with standard industry practices and internal standard operating procedures.

A backhoe was utilised to excavate to a depth of 3.5 m or refusal. The excavated material was logged onsite by an AGE hydrogeologist. Detailed logs are provided in Appendix A.

Table 3.2 Test pit locations

Pit no	East (GDA94z56)	North(GDA94z56)	Date/time
1	324141	6410322	10/03/2017 14:41
2	324317	6411707	10/03/2017 8:00
3	324038	6410645	10/03/2017 12:41
4	323917	6410238	10/03/2017 15:47
5	323849	6410054	9/03/2017 10:40
6	324046	6411768	9/03/2017 16:30
7	324388	6410997	10/03/2017 11:40
8	323964	6411796	9/03/2017 15:40
9	324230	6410720	10/03/2017 13:00
10	323427	6411147	9/03/2017 13:00
11	323762	6410937	10/03/2017 10:46
12	323431	6410770	9/03/2017 14:10
13	323693	6410712	10/03/2017 9:36
14	323753	6410558	9/03/2017 15:04
15	323747	6410199	9/03/2017 8:44
16	323944	6410411	10/03/2017 13:49



LEGEND

- Test pit locations
- Proposed modification pit shell
- Road
- Watercourse

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

Test pit locations

AGE

DATE 11/10/2017

FIGURE No: **3.3**

N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/03_01_G1862.Mt_Owen_MOOSE_property_Main_Creek_MOOSE_test_pits.qgs

4 Results

4.1 Desktop study interpretation

The desktop study was completed to assess the presence / absence of alluvium through the review of published datasets. The datasets are presented graphically with the original alluvium extents in Figure 4.1 to Figure 4.8. Details of the desktop study findings are outlined in the paragraphs below.

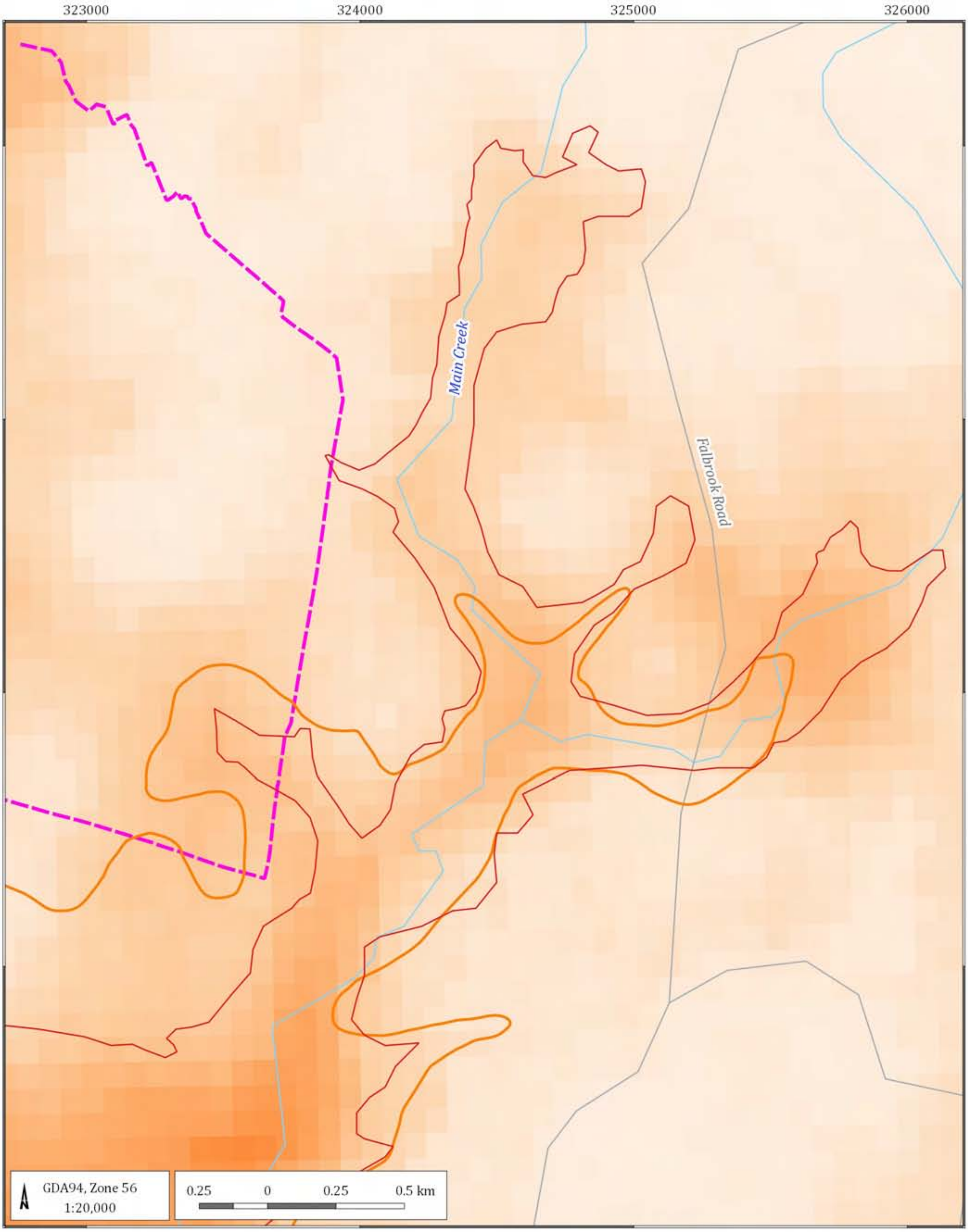
In 2015, the CSIRO published regolith maps indicating likely thicknesses of regolith across Australia. Regolith is considered to be the weathered and permeable rock profile that most likely to contribute recharge to the underlying and / or adjacent rock units. Alluvium can often be detected in the CSIRO regolith maps; however, the regolith maps often show the combined thickness of alluvium and the underlying weathered rock. Figure 4.1 shows the estimated thickness of regolith along Main Creek. Up to 7 m of regolith was estimated in the northern parts of Main Creek and up to 13 m in the south (Wilford *et al* 2015)**.** The data also shows areas of thicker regolith (up to a thickness of 10 m) extending to the northwest from Main Creek, toward the mine and a second area of regolith between 5 m and 10 m thick can be seen on the eastern side of Main Creek (Figure 4.1).

In 2015, radiometric surveys were repeated in greater detail by Geoscience Australia. The results of the surveys are publically available and filtered potassium, thorium and uranium data were plotted on Figure 4.2, Figure 4.3 and Figure 4.4, respectively (Geoscience Australia, 2015). The radiometric domains of potassium, thorium and uranium are higher in concentration at locations of higher relief and represent fresh outcrop. Concentrations are lower along Main Creek and south to south-west of the proposed modification disturbance boundary which coincide with low lying flat topography or forested locations. The low domain represents moist ground and areas of accumulated sediments derived from weathered rock. Weathered rock and sediments are low in potassium, thorium and uranium as these elements have been leached respective to fresh rock. Whilst this data correlated to the location of the creek, the results were not sufficiently detailed to refine the extent of the alluvium.

In 2017, the Office of Environment and Heritage (OEH) published the Australia Soil Classification (ASC) and Great Soil Group types (GSG) datasets. These datasets characterise the soils in the vicinity of Main Creek as sodosols or solodic soils (Figure 4.5 and Figure 4.6 respectively). These soil types are defined as having a strong texture contrast between the A and B horizons, and these horizons tend to be acid and alkaline, respectively. These soils tend to be dispersive and can be used to highlight areas of alluvium as it is material that has already been transported / dispersed.

In 2017, the OEH also published the Soil Landscape Regolith Stability (SLRS) map which shows the potential coherence potential of soils. Figure 4.7 shows that in the vicinity of Main Creek, the areas of higher topographic elevation consist of high coherence soils with high sediment delivery. Low coherence (when wet) soils can be indicative of alluvium, as both tend to lack a clay / silty component. In the case of alluvium, the clayey / silty material has been partially or wholly removed mechanically (eg via creek flow). The lower lying areas associated with Main Creek and the easterly tributary comprises low coherence soil, with very high fine sediment delivery potential. Hydrological Soil Groups (HGS) categorise soils based on their potential infiltration rates. Infiltration rates can be indicative of alluvium as it tends to have low clay / silt content making the material more permeable. The HGS mapping characterise Main Creek and the proposed modification disturbance areas as category D soils (Figure 4.8). OEH (2017) describes category D soils as:

"soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission."



LEGEND

Depth of regolith (m)

- 0
- 4
- 7.5
- 11
- 15
- 19
- 23
- 26
- 30

- Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)
- Proposed modification pit shell
- Road
- Watercourse

Groundwater productivity

- Highly productive alluvium (AIP 2012)

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

Depth of regolith

AGE

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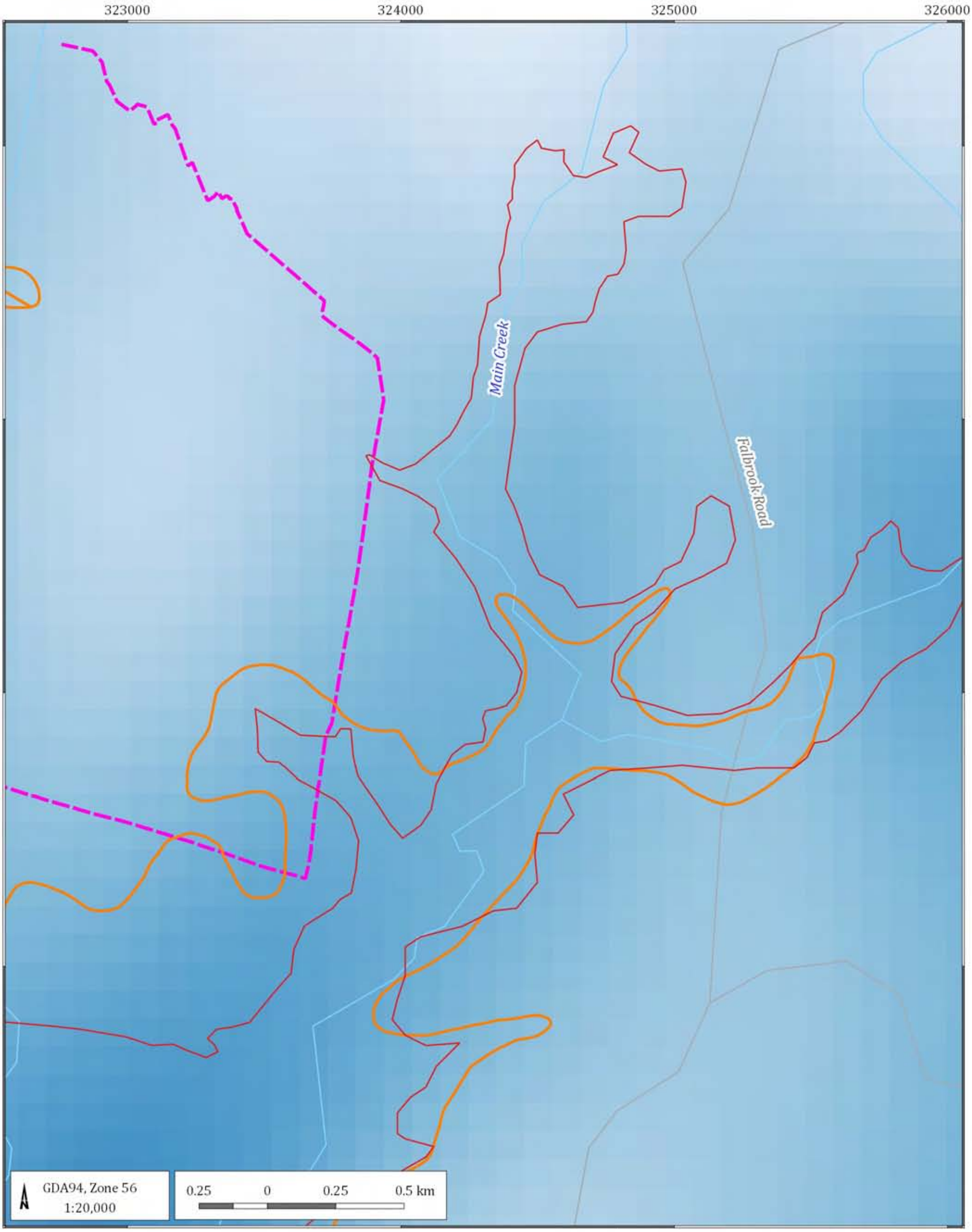
FIGURE No: **4.1**

N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/04_01_G1862.Mt_Owen_CSIRO_depth_regolith_m.qgs



LEGEND

Filtered potassium (%)

- 0.10
- 0.35
- 0.60
- 0.85
- 1.10
- 1.35
- 1.60
- 1.85
- 2.10
- 2.40

- Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)
- Proposed modification pit shell
- Fences
- Road
- Watercourse

Groundwater productivity

- Highly productive alluvium (AIP 2012)

Mount Owen Continued Operations - Modification 2
(Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

Potassium radiometric response

AGE

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FIGURE No: **4.2**

Source: Minty, B.R.S., Franklin, R., Milligan, P.R., Richardson, L.M. and Wilford, J., 2010., Radiometric Map of Australia (Second Edition), scale 1:15 000 000, Geoscience Australia, Canberra.;
N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/04_02_G1862.Mt_Owen_MOOSE_radiometric_response_KThU.qgs

LEGEND

Filtered thorium (ppm)

- 2.0
- 3.5
- 5.0
- 6.5
- 7.5
- 9.0
- 10.5
- 12.0
- 13.5
- 15.0

- Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)
- Proposed modification pit shell
- Fences
- Road
- Watercourse

Groundwater productivity

- Highly productive alluvium (AIP 2012)

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

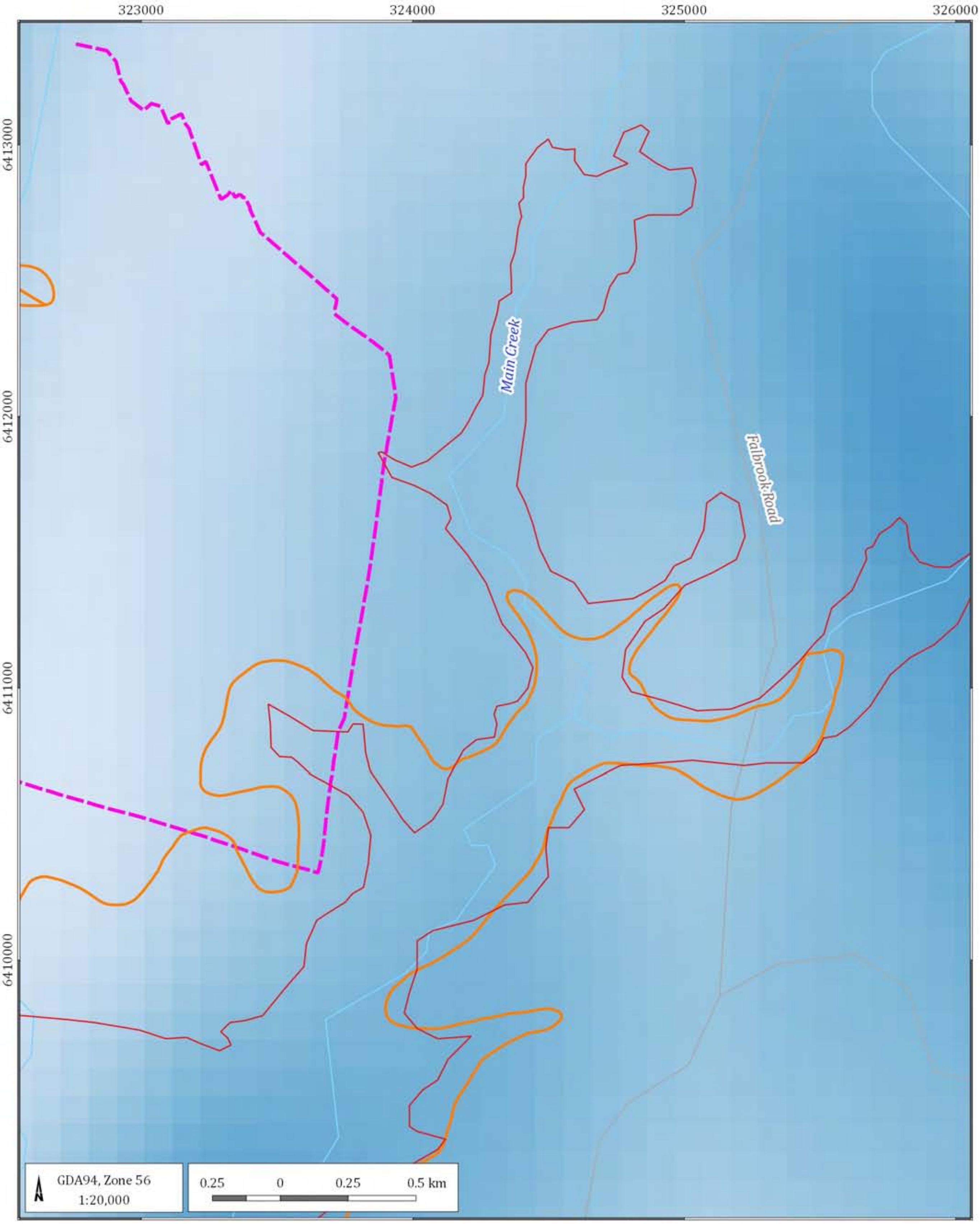
Thorium radiometric response

AGE

DATE 11/10/2017

FIGURE No: **4.3**

Source: Minty, B.R.S., Franklin, R., Milligan, P.R., Richardson, L.M. and Wilford, J., 2010., Radiometric Map of Australia (Second Edition), scale 1:15 000 000, Geoscience Australia, Canberra.;
N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/04_02_G1862.Mt_Owen_MOOSE_radiometric_response_KThU.qgs



LEGEND

Filetered uranium (ppm)

- 0.35
- 0.55
- 0.75
- 1.00
- 1.20
- 1.45
- 1.65
- 1.85
- 2.10
- 2.30

- Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)
- Proposed modification pit shell
- Fences
- Road
- Watercourse

Groundwater productivity

- Highly productive alluvium (AIP 2012)

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

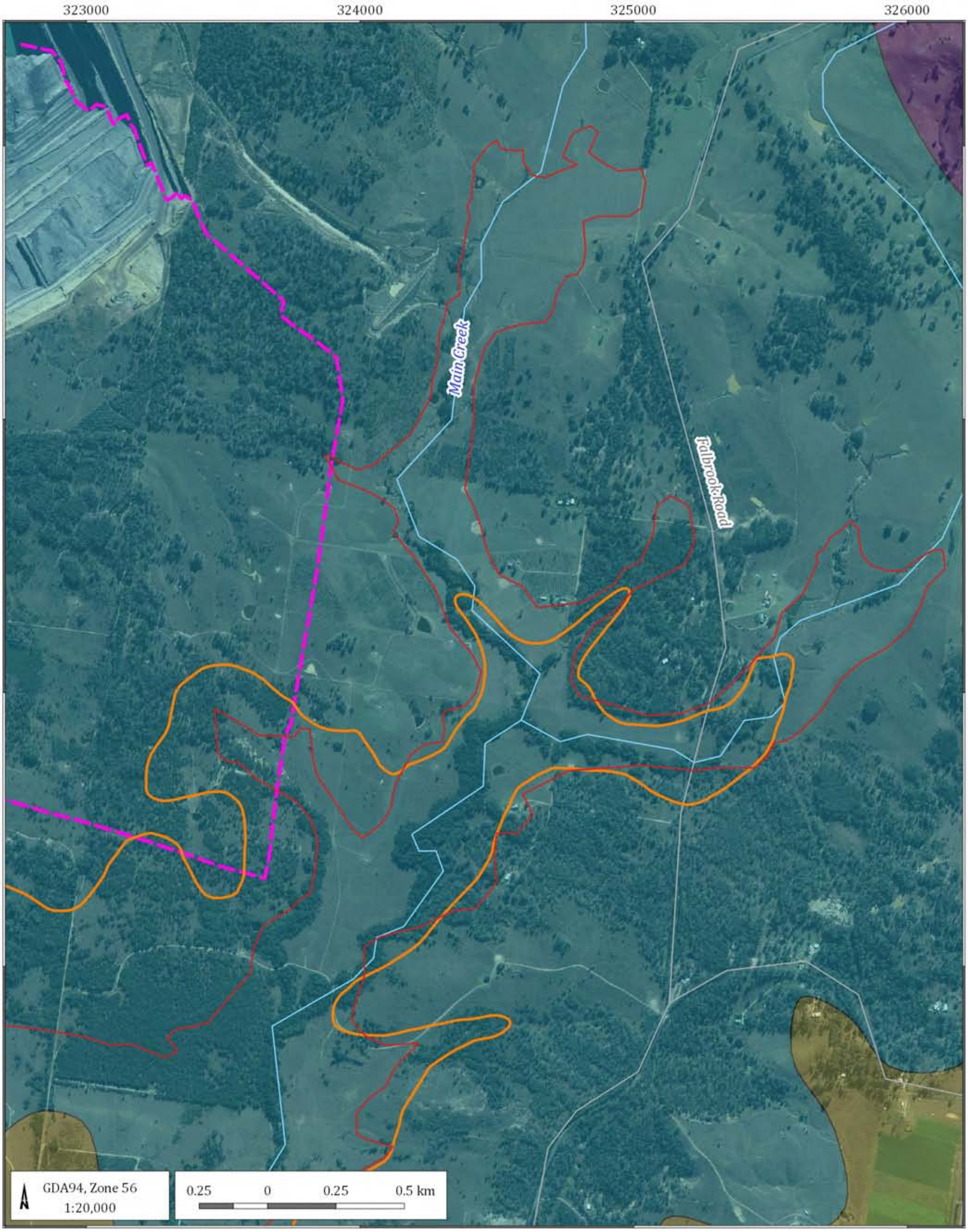
Uranium radiometric response

AGE

DATE 11/10/2017

FIGURE No: **4.4**

Source: Minty, B.R.S., Franklin, R., Milligan, P.R., Richardson, L.M. and Wilford, J., 2010., Radiometric Map of Australia (Second Edition), scale 1:15 000 000, Geoscience Australia, Canberra.;
N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/04_02_G1862.Mt_Owen_MOOSE_radiometric_response_KThU.qgs



LEGEND

ASC Soil Types

- Dermosols
- Sodosols
- Tenosols (Alluvial)

Groundwater productivity

- Highly productive alluvium (AIP 2012)
- Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)
- Proposed modification pit shell
- Road
- Watercourse

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

Australian Soil Classification (ASC)

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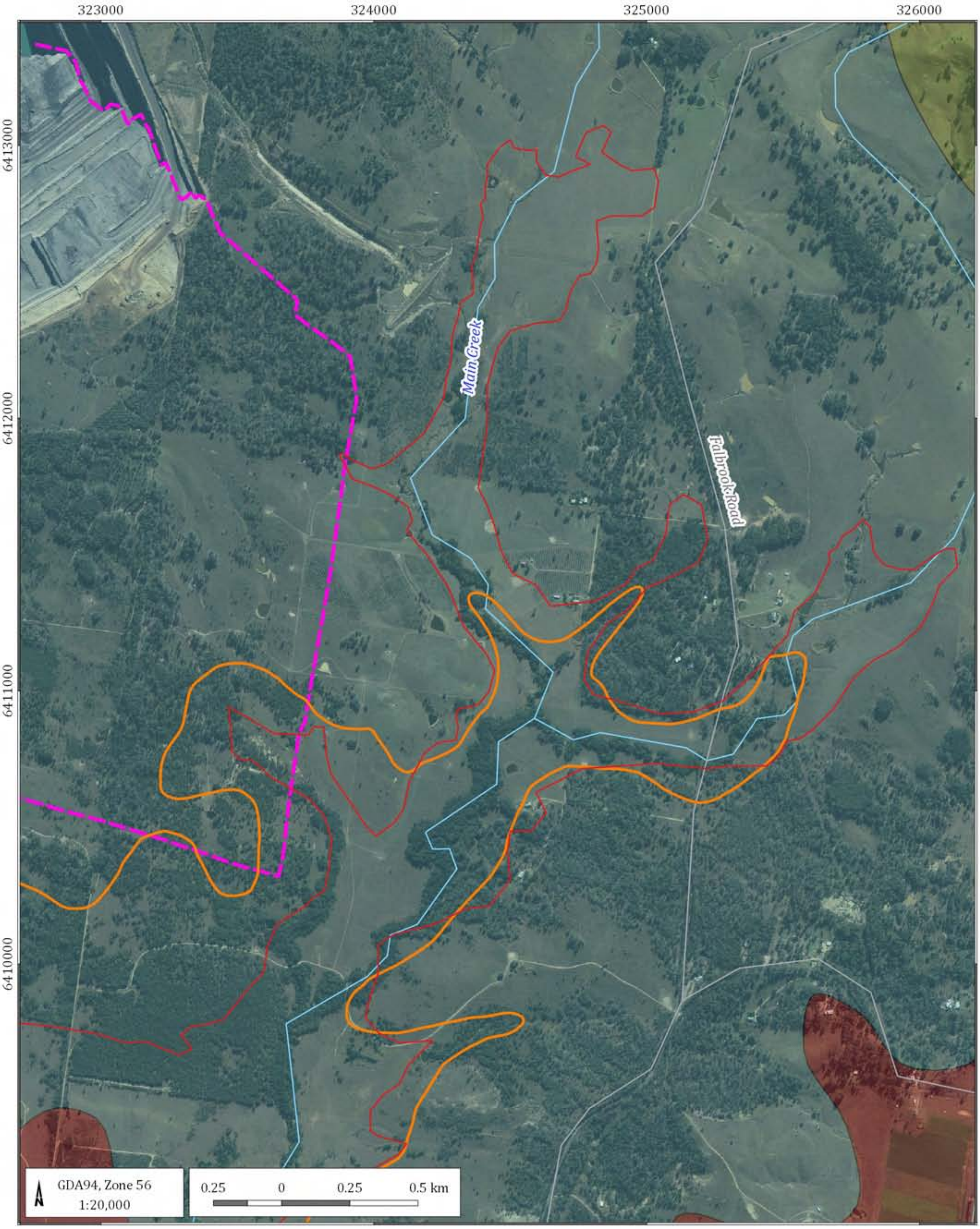
FIGURE No: **4.5**



LEGEND

Great Soil Groups (GSG)

- Alluvial Soils - Medium Textured (Loams, Clay Loams)
- Red Podzolic Soils - more fertile (volcanics and granodiorites)
- Solodic Soils

Groundwater productivity

- Highly productive alluvium (AIP 2012)
- Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)
- Proposed modification pit shell
- Road
- Watercourse

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

Great Soil Groups (GSG)

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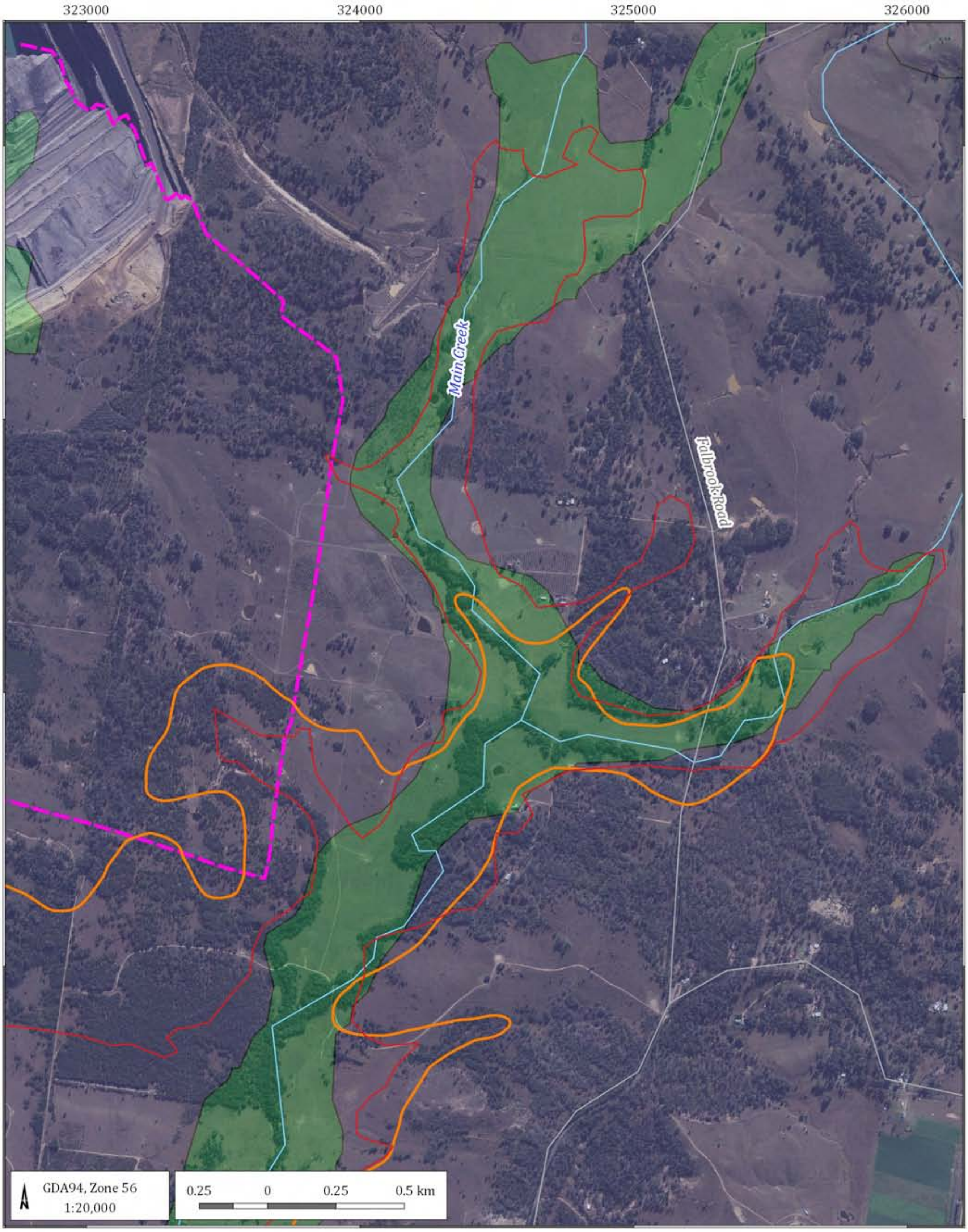
FIGURE No: 4.6

N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/04_06_G1862.Mt_Owen_Great_Soil_Groups.qgs



LEGEND

Regolith Soil Landscape

High coherence soils with high sediment delivery potential

Low coherence soils (when wet), with very high fine sediment delivery potential

Groundwater productivity

Highly productive alluvium (AIP 2012)

Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)

Proposed modification pit shell

Road

Watercourse

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

Regolith/Soil Erodibility Landscape

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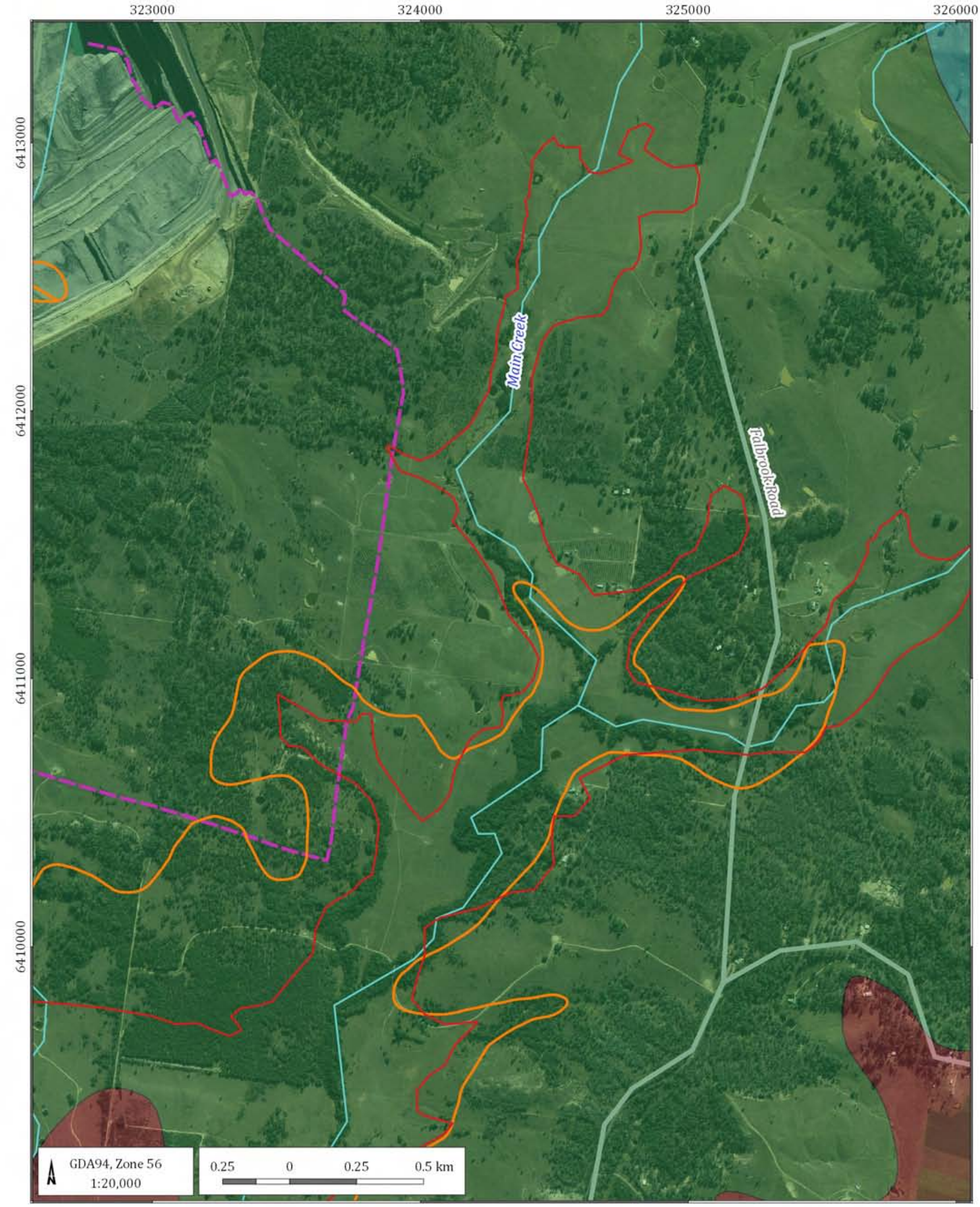
FIGURE No: **4.7**

N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/04_07_G1862.Mt_Owen_Regolith_Soil_Erodibility_Landscapes.qgs



LEGEND

Hydrological Soil Groups

- B - Moderate infiltration
- C - Slow infiltration
- D - Very slow infiltration

Groundwater productivity

- Highly productive alluvium (AIP 2012)
- Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)
- Proposed modification pit shell
- Road
- Watercourse

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

Hydrological Soil Groups - estimated infiltration rates

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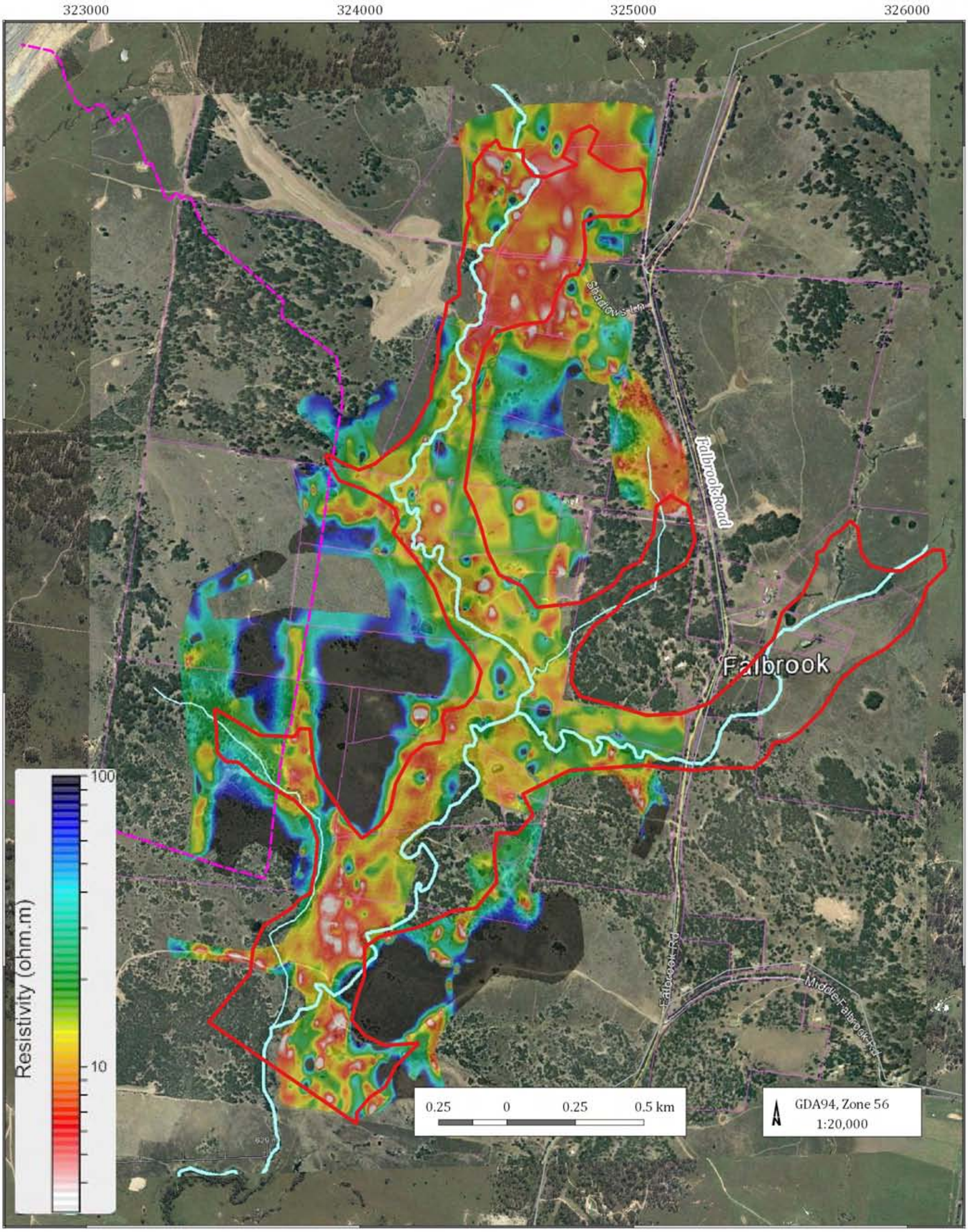
FIGURE No: **4.8**

N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/04_08_G1862.Mt_Owen_MOOSE_Hydrological_Soil_Groups.qgs

4.2 Geophysics interpretation

The AgTEM survey simultaneously assesses the electrical conductivity potential of the substrate at varying depths. In the case of the survey undertaken, the depths used to assess the thickness of the alluvium included: 0.3 m, 1 m, 2 m, 4 m, 7 m, 12 m and 20 m below ground level (mbgl). The results of the AgTEM survey for these depths are plotted on Figure 4.9 to Figure 4.15. Groundwater Imaging (2017) made the following observations based on the site visit and the survey results:

- Several metres of alluvium are exposed in the bed of Main Creek (adjacent test pit location 2). Modelled AgTEM data indicates a corresponding low resistivity layer along the length and sides of the creek. It is most likely this modelled layer corresponds to brackish ground moisture in both the alluvium and intense weathered strata immediately beneath. That is, alluvium is present adjacent the creek in most locations and is likely to be hydraulically connected with the underlying weathered rock.
- Low resistivity features exist in the data corresponding to occurrences of brackish springs and moist soil patches. These features extend deeply along the strike of strata suggesting upward groundwater flow through permeable strata and possibly co-incident fracture planes. These potential fracture planes are most noticeable within the northern portion of site (refer Figure 4.16). The areas of moist soil corresponding to areas of groundwater "upwelling" are shown 3D interpreted resistivity projections in the Groundwater Imaging report (2017) attached as Appendix B.
- A high, deep, resistive feature coincides with the hills of outcropping rock (refer Figure 4.16). Directly south and on the eastern side of Main Creek, a similar high, deep resistive feature is coincident with hills of outcropping rock. The high, deep, resistive features represent hard dry rock (refer Figure 4.16).
- The primary tributary located to the west of Main Creek (refer to test pit locations 10-14) has greatly limited depth at its confluence with Main Creek as at test pit location 16). An inferred hard rock layer has been attributed for the reduced alluvium thickness at this location.
- The alluvium also extends along the tributaries to the east of Main Creek. The geophysical survey focussed primarily on the western extents of the alluvium and only a qualitative assessment was undertaken over the eastern extents.



LEGEND

- Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)
- Proposed modification pit shell
- Watercourse
- Road

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

AgTEM survey results at 0.3 m depth

AGE

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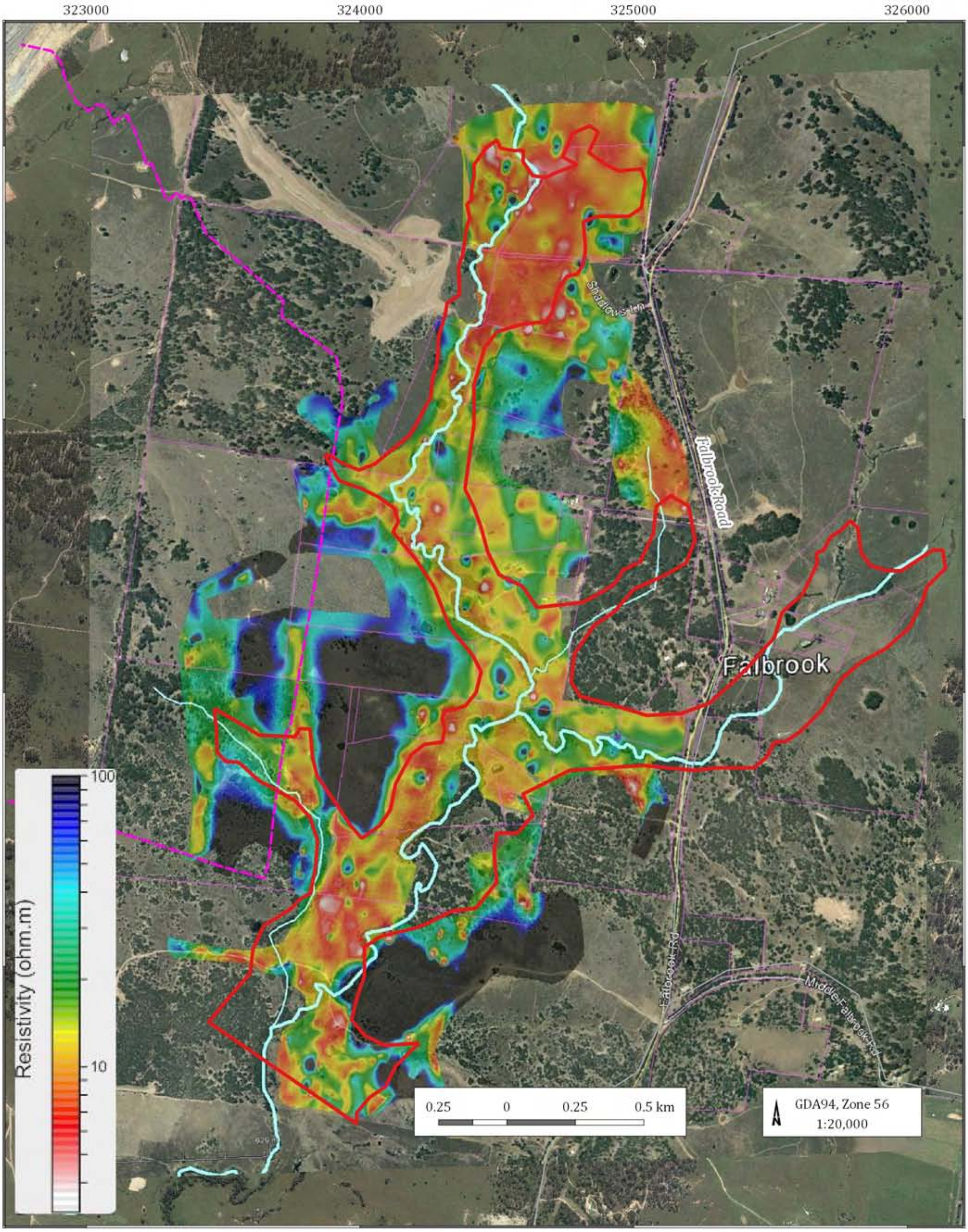
FIGURE No: **4.9**

Source: Groundwaterimaging (2017), AgTEM Alluvium and Subcrop Investigation at Mt Owen for Glencore - Singleton;
N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/04_09_G1862.Mt_Owen_MOOSE_geophysical_response_04_05__03_01.qgs



LEGEND

Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)
Proposed modification pit shell
Watercourse

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

AgTEM survey results at 1 m depth

AGE

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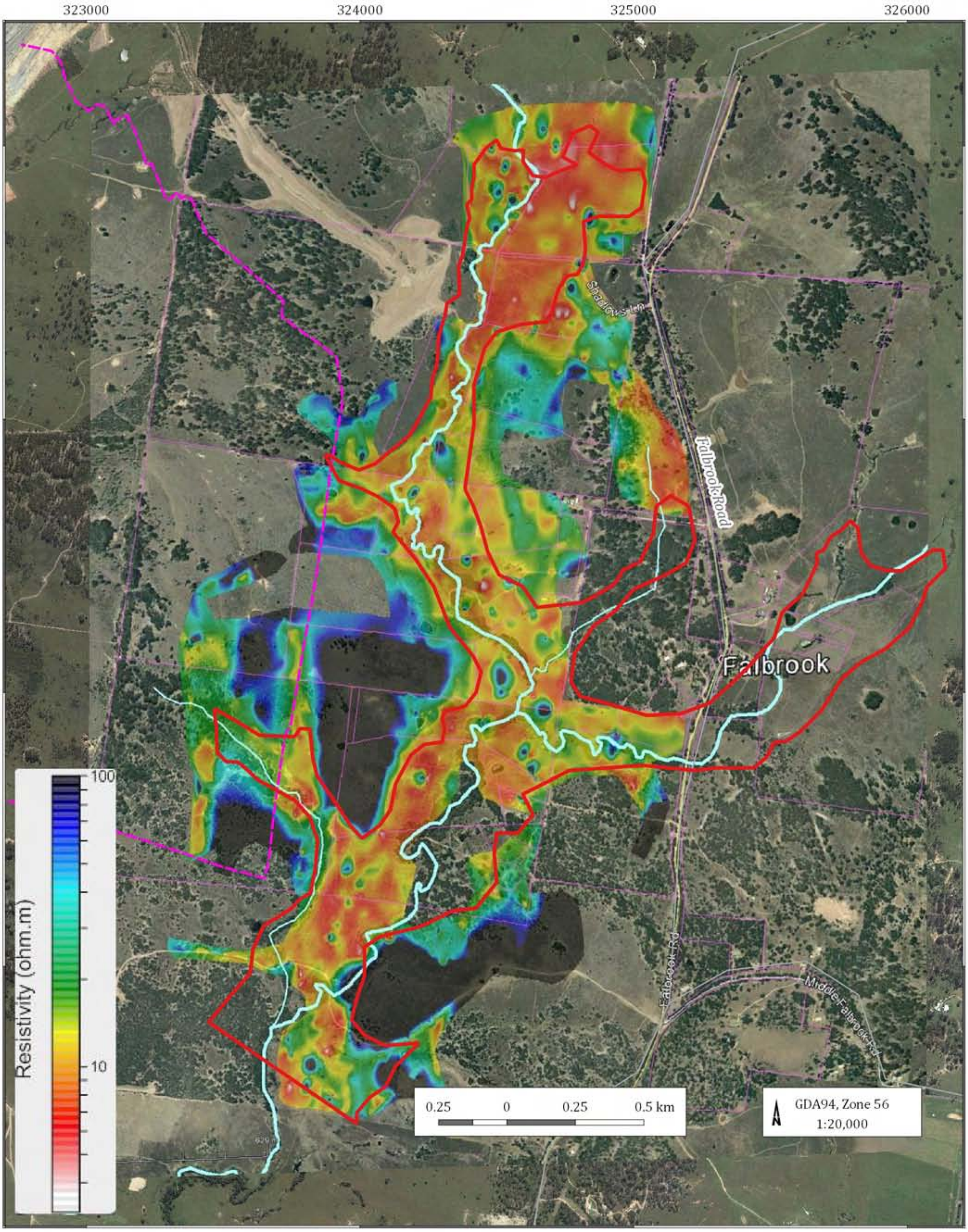
FIGURE No: **4.10**

Source: Groundwaterimaging (2017), AgTEM Alluvium and Subcrop Investigation at Mt Owen for Glencore - Singleton;
N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/04_09_G1862.Mt_Owen_MOOSE_geophysical_response_04_05__03_01.qgs



LEGEND

- Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)
- Proposed modification pit shell
- Road
- Watercourse

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

AgTEM survey results at 2 m depth

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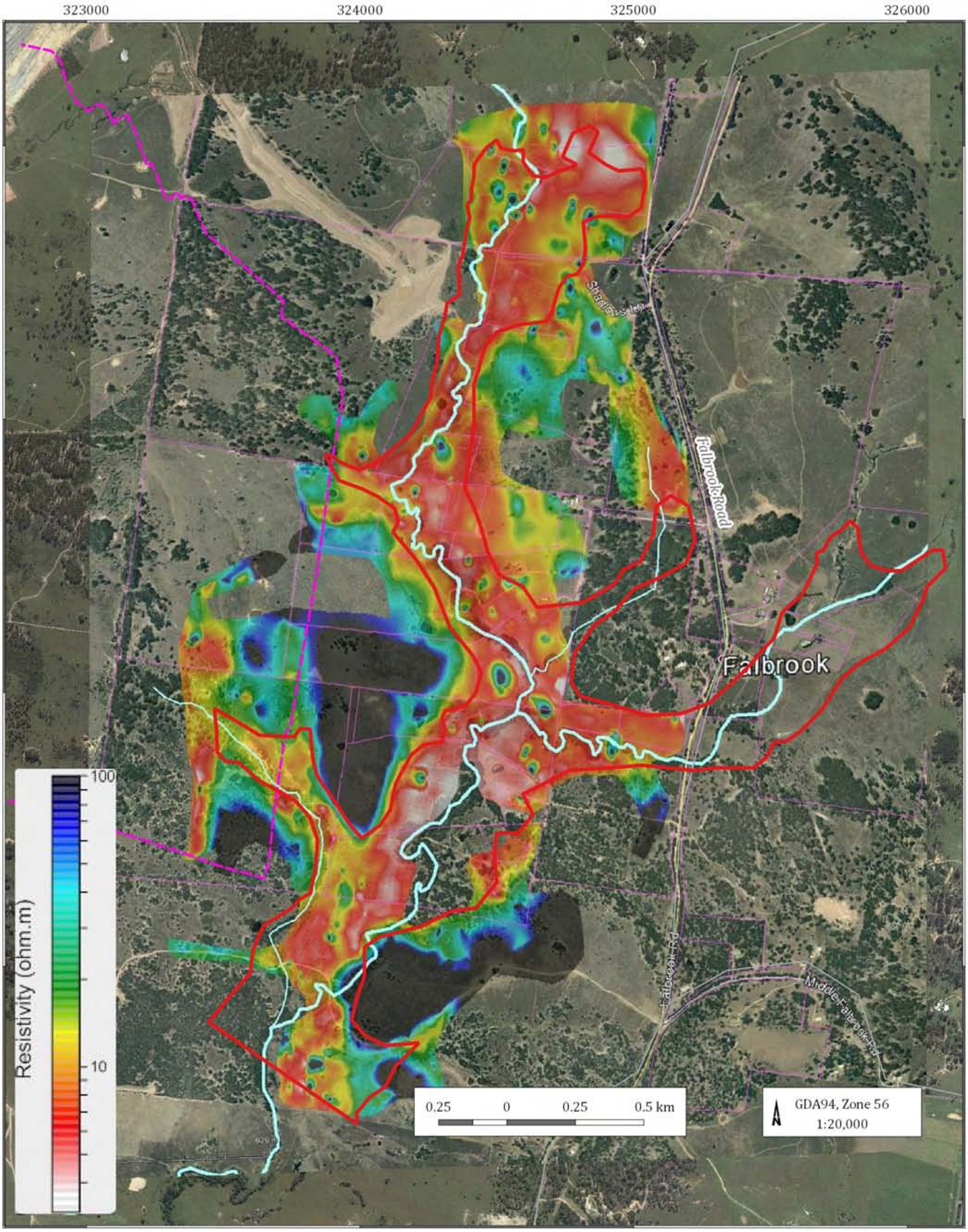
FIGURE No: **4.11**

Source: Groundwaterimaging (2017), AgTEM Alluvium and Subcrop Investigation at Mt Owen for Glencore - Singleton;
N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/04_09_G1862.Mt_Owen_MOOSE_geophysical_response_04_05__03_01.qgs



LEGEND

- Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)
- Proposed modification pit shell
- Watercourse
- Road

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

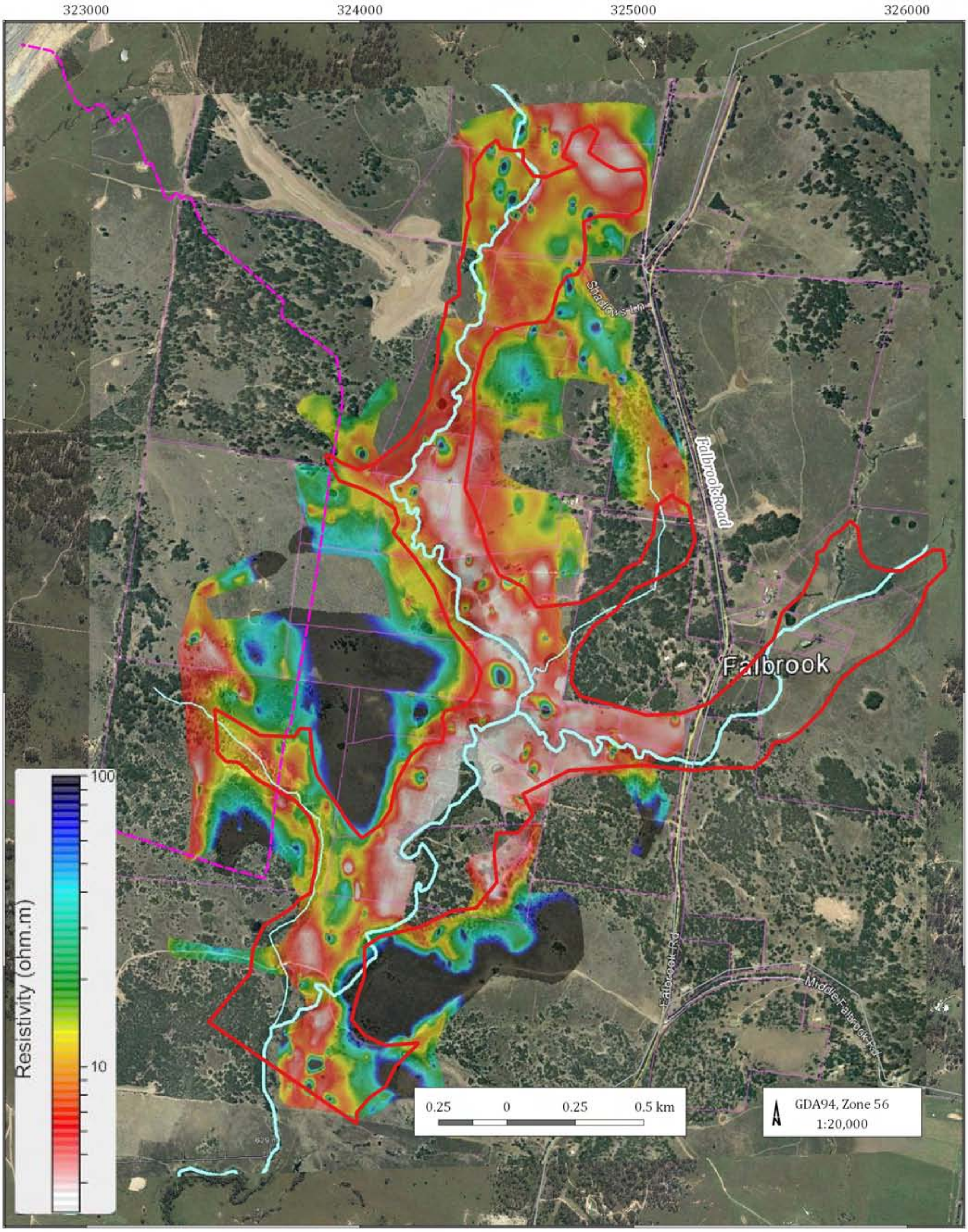
AgTEM survey results at 4 m depth

AGE

DATE 11/10/2017

FIGURE No: **4.12**

Source: Groundwaterimaging (2017), AgTEM Alluvium and Subcrop Investigation at Mt Owen for Glencore - Singleton;
N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/04_09_G1862.Mt_Owen_MOOSE_geophysical_response_04_05__03_01.qgs



LEGEND

- Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)
- Proposed modification pit shell
- Watercourse
- Road

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
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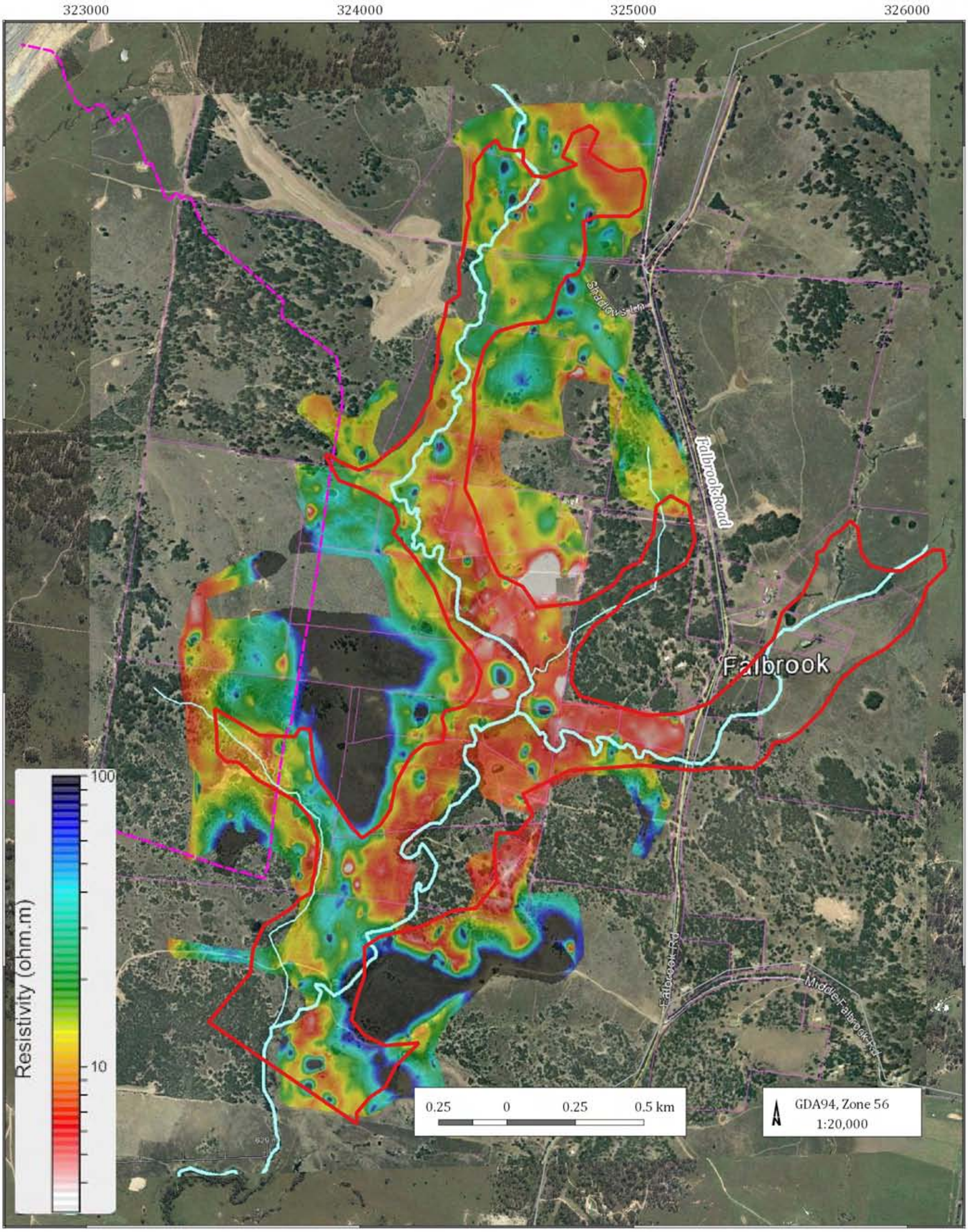
AgTEM survey results at 7 m depth

DATE 11/10/2017

FIGURE No: **4.13**

Source: Groundwaterimaging (2017), AgTEM Alluvium and Subcrop Investigation at Mt Owen for Glencore - Singleton;
N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/04_09_G1862.Mt_Owen_MOOSE_geophysical_response_04_05__03_01.qgs



LEGEND

- Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)
- Proposed modification pit shell
- Fences
- Road
- Watercourse

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

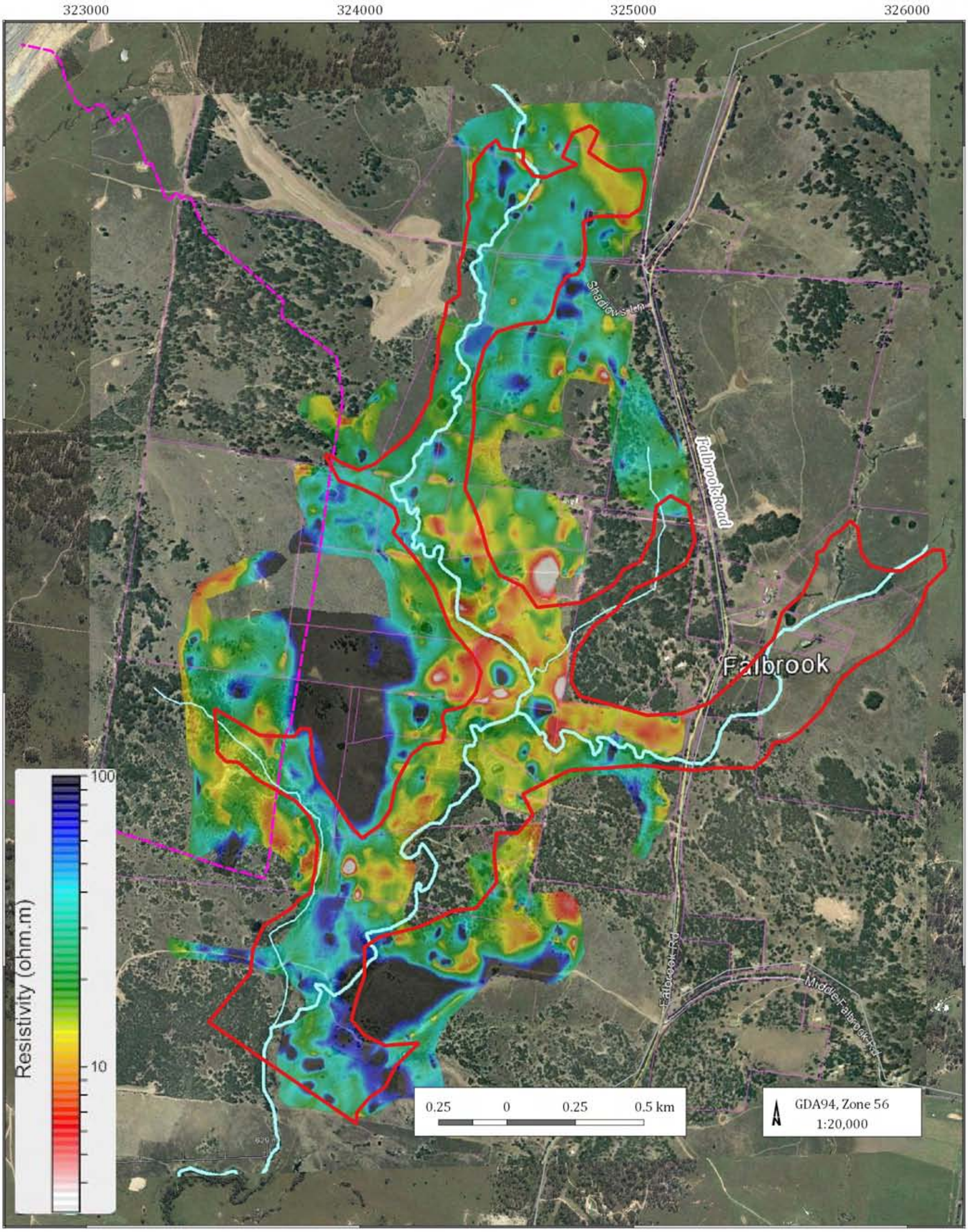
AgTEM survey results at 12 m depth

AGE

DATE 11/10/2017

FIGURE No: **4.14**

Source: Groundwaterimaging (2017), AgTEM Alluvium and Subcrop Investigation at Mt Owen for Glencore - Singleton;
N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/04_09_G1862.Mt_Owen_MOOSE_geophysical_response_04_05__03_01.qgs



LEGEND

- Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)
- Proposed modification pit shell
- Watercourse
- Road

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

AgTEM survey results at 20 m depth

DATE 11/10/2017

FIGURE No: **4.15**

Source: Groundwaterimaging (2017), AgTEM Alluvium and Subcrop Investigation at Mt Owen for Glencore - Singleton;
N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/04_09_G1862.Mt_Owen_MOOSE_geophysical_response_04_05__03_01.qgs

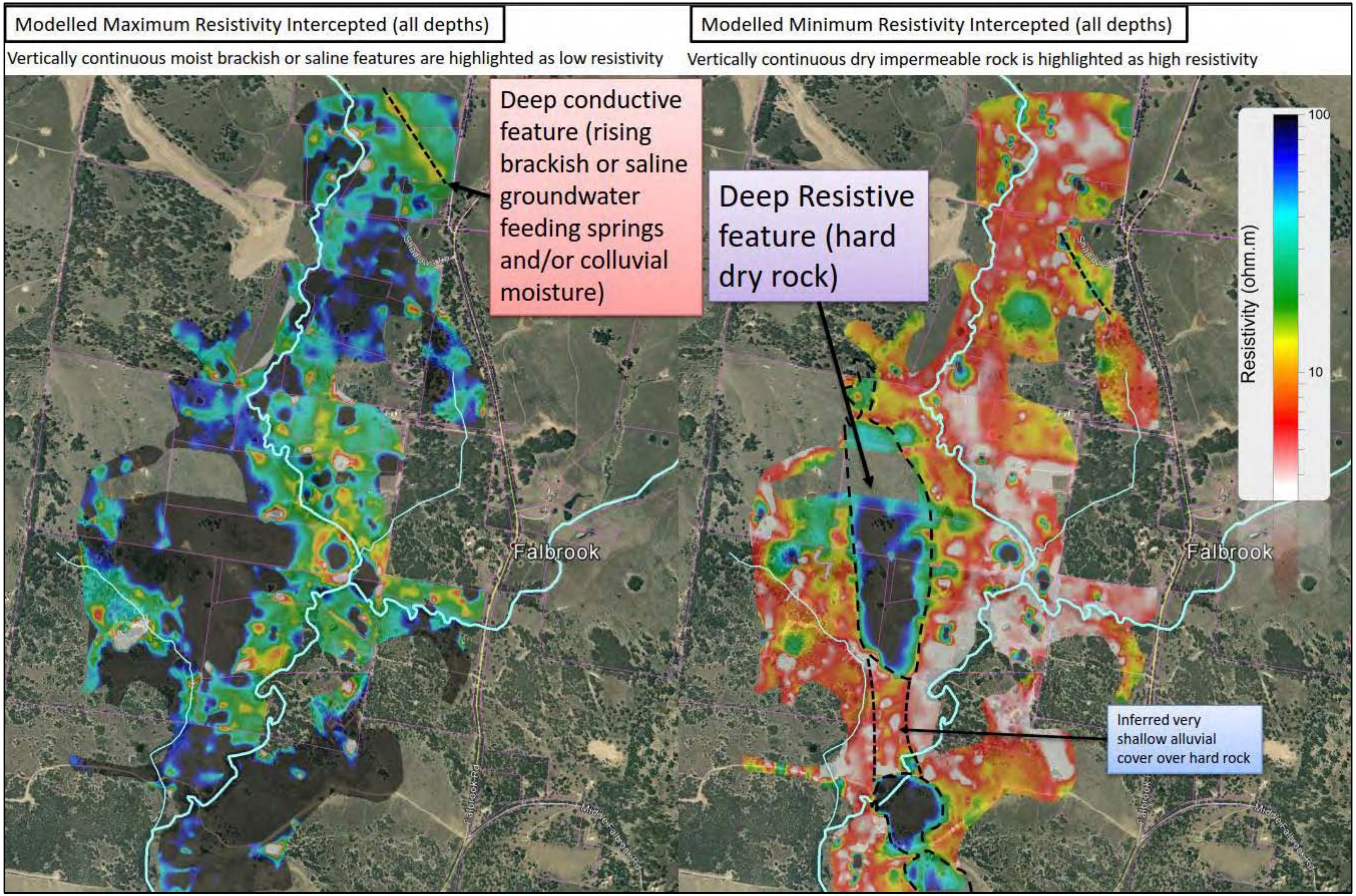


Figure 4.16 AgTEM interpretation of fractures and shallow rock (Groundwater Imaging 2017 refer Appendix B)

4.3 Intrusive test pit interpretation

Sixteen test pits were excavated to confirm the results of the geophysical survey. For the purposes of the test pitting task, alluvium was defined as water transported sediment that showed water flow and / or transport structures. Colluvium is material that was transported / deposited by rain-wash and / or slope creep. Colluvium tends to be low permeability material that collects at the base of slopes and / or in surface depressions.

Based on the results of the geophysical survey and the test pits, areas that were considered to be of very low permeability and groundwater storage potential were excluded from the alluvium. The results of the test pitting are tabulated in Table 4.1 and the geology types are plotted on Figure 4.17. Detailed test pit logs and photos are attached in Appendix A.

Table 4.1 Test pit lithology classification

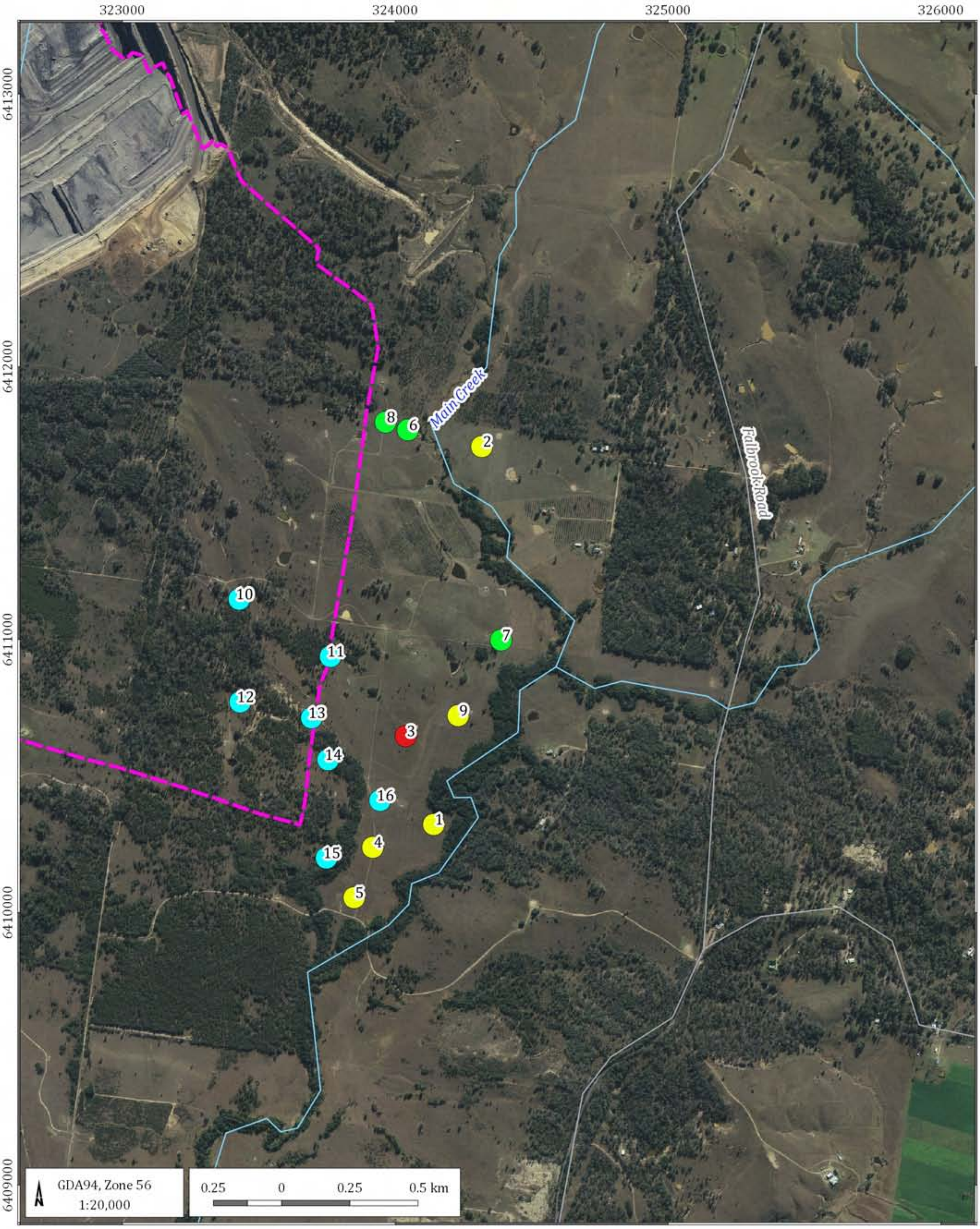
Pit no	Classification	Alluvium (Yes/No?)
1	Alluvium	Yes
2	Alluvium	Yes
3	Rock	No
4	Alluvium	Yes
5	Alluvium	Yes
6	Colluvium	No
7	Colluvium	No
8	Colluvium	No
9	Alluvium	Yes
10	Thin clayey Colluvium	No
11	Thin clayey Colluvium	No
12	Thin clayey Colluvium	No
13	Thin clayey Colluvium	No
14	Thin clayey Colluvium	No
15	Thin clayey Colluvium	No
16	Thin clayey Colluvium	No

The geophysical survey results were utilised to locate the potential limit of alluvium. Test pits were subsequently used to verify the geophysical survey results. The geology of test pit locations 10 to 16 were found to be predominantly thin, clay bound sediments with minimal bedding structure. These sediments are likely to contribute minimally to the recharge of the alluvial aquifer that is located down hydraulic gradient.

Elsewhere, the geophysical survey results were used to revise the alluvium boundary. In these areas, the geophysical surveyed alluvium results were more conclusive and distinct, and this was confirmed with alluvium comprising of graded and bedded clay, sand and gravel intersected by test pits 1, 2, 4 and 5. Groundwater Imaging (2017) interpreted thin alluvium at the location of test pit 4. This was confirmed with thin clay, then alluvial sands terminated by sandstone at 2.1 m and conglomerate which was damp to a depth of 3.4 m.

An area of LiDAR mapped alluvium on the west side of Main Creek (refer to test pit locations 6 and 8) was also refined. LiDAR had interpreted potential alluvium whilst geophysical survey had excluded alluvium in this location. Test pits 6 and 8 confirmed the presence of thin colluvial sand silty, clay and saprolite.

In the area of test pits 7 and 9, the boundary was revised to coincide with the LiDAR survey limits. The geophysical survey and the test pits confirmed that the LiDAR boundary was accurate in this area. At test pit 7, colluvial gravel and clay was found to overlay siltstone. Geophysical grids 0.3 m to 2 m indicated higher resistivity whilst 4 m to 20 m depths indicated lower resistivity. The lower resistivity at >4 m depth coincides with presumed saline water and confirmed dampness within the siltstone and a thin westerly dipping coal seam. Just east of this test pit the alluvium boundary is identifiable from field topographic inspection which coincides with the LiDAR and geophysical interpreted alluvial extent. Test pit 7 is significant as it indicates likely connectivity between alluvium and proposed mined and depressurised westerly dipping coal seams. At test pit 9, clay and bedded alluvial damp sand with clay were identified. The geophysical survey, test pits and site inspection of topography showed that the LiDAR boundary was accurate in the vicinity of test pit 9.



LEGEND

Test pit locations

- Alluvium
- Colluvium
- Rock
- Thin clay bound sediments

- Proposed modification pit shell
- Road
- Watercourse

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

Test pit lithology classification

AGE

DATE 11/10/2017

FIGURE No: **4.17**

5 Discussion

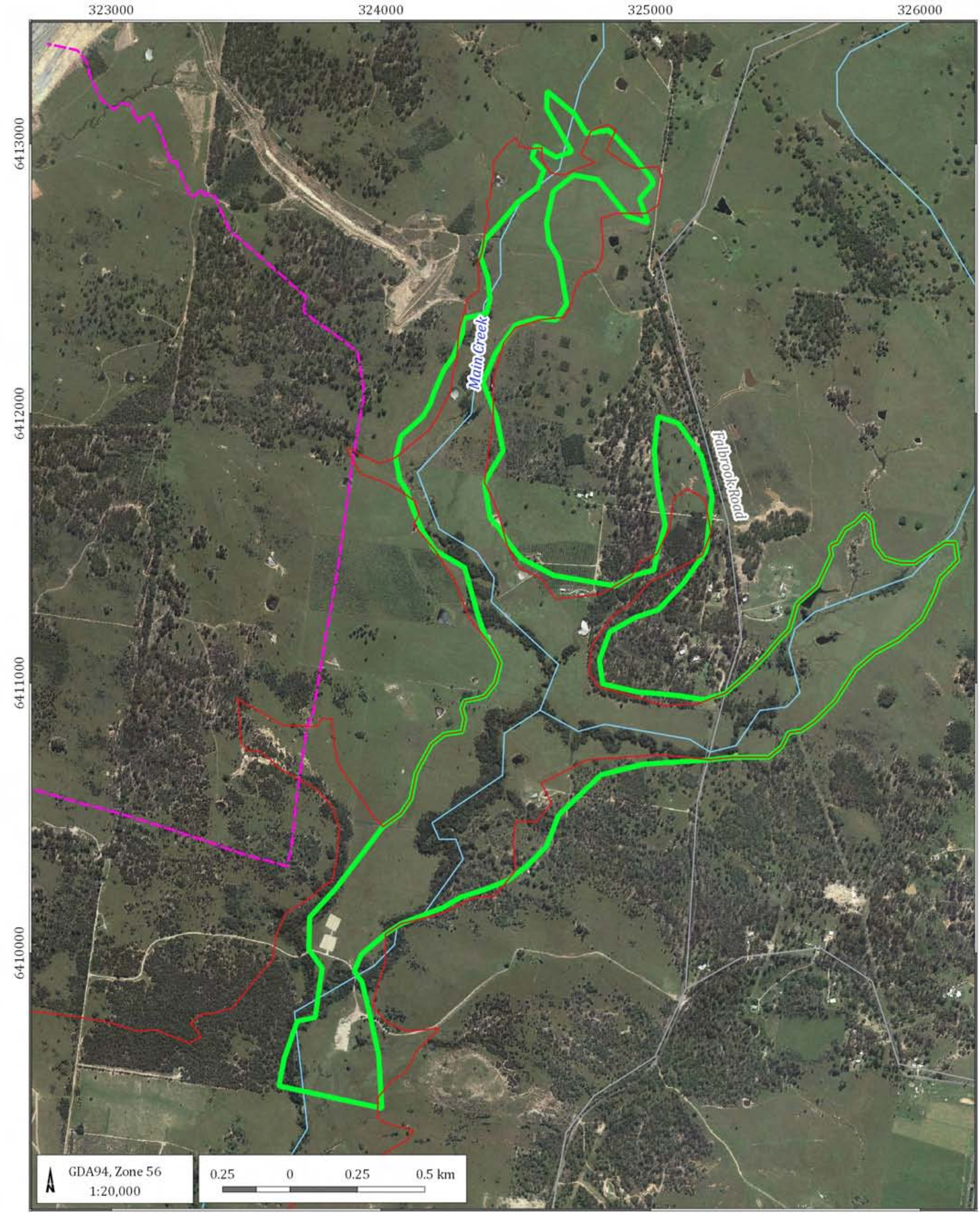
The revised alluvium extent boundary shown on Figure 5.1 was derived following reviews of the following:

- LiDAR survey by Jacobs (2014).
- AgTEM geophysical survey by Groundwater Imaging Pty Ltd.
- Results of 16 test pits excavated on 9-10 March 2017.
- Observations in the field of alluvial deposits and creek bank.
- Australia Soil Classification maps published by OEH (2017), including ASC, GSG, SLRS and HGS datasets.
- Soil and Landscape Grid. National Soil Attributes – depth of soil / regolith data base (CSIRO 2015).
- Radiometric Maps of Australia. Potassium, Thorium and Uranium Radiometric Responses (Geoscience Australia 2015).

The geophysical survey results were utilised to locate the potential limit of alluvium. Test pits were subsequently used to verify the geophysical survey results. Areas that were considered to be of very low permeability and storativity were excluded from the alluvium; that is, the geology of test pit locations 10 to 16 were found to be predominantly thin, clay bound colluvium with minimal bedding structure. These sediments are likely to contribute minimally to the recharge of the alluvial aquifer that is located down hydraulic gradient.

In the area of test pits 7 and 9, the boundary was confirmed to coincide with the LiDAR survey limits. The geophysical survey and the test pits showed that the LiDAR boundary was accurate in this area. Elsewhere, the geophysical survey results were used to revise the alluvium boundary. In these areas, the geophysical survey results were more conclusive and distinct, and this was confirmed with alluvium being intersected by test pits 1, 2, 4 and 5.

In general, the geophysical survey reduced the alluvium extent adjacent to the southern extent of the proposed modification pit shell on the western side of Main Creek (refer Figure 5.1). The survey expanded the alluvial extent on the eastern side of Main Creek; however, if this area is deemed critical, the alluvium should be verified with further test pitting.. In the north, the geophysical survey constrained the alluvial extent in close proximity to the western side of Main Creek and reduced the overall extent. In this area, the colluvium overlies an upwelling of brackish groundwater fed springs, which is likely discharge from the underlying Permian fractured hard rock geology.



LEGEND

- Updated potentially productive alluvium boundary
- Main Creek Alluvium as delineated by LiDAR (Jacobs 2014)
- Proposed modification pit shell
- Watercourse
- Road

Mount Owen Continued Operations - Modification 2 (Proposed Modification)
G1862 - Main Creek Alluvium Verification and Mapping

Revised alluvium extent vs alluvium as delineated by LiDAR

AGE

DATE 11/10/2017

FIGURE No: **5.1**

Source: Groundwaterimaging (2017), AgTEM Alluvium and Subcrop Investigation at Mt Owen for Glencore - Singleton;
N:/Groundwater Jobs/G1862.Mt Owen Optimisation Project Main Creek/3_GIS/Workspaces/05_01_G1862.Mt_Owen_MOOSE_revised_alluvial_extents.qgs

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Appendix A Test pit logs

Hole ID	E	N	From	To	Facie	Description	Photo
Test pit 1	324141	6410322	0	0.1	Soil	Clayey soil, light brown, rare (<5%) weathered pebbles, organics and rootlets.	
			0.1	1.1	Clay	Clay, brown, dark to lighter brown, plastic to dry, and damp to dry at depth respectively, with rare (<5%), white, subangular, pebbles (20-50mm), weathered, and rootlets.	
			1.1	1.5	Alluvium	Sand with clay, lighter brown than above, very fine (<0.02 mm) sand (75%), clay (25%) matrix, rounded grain (2mm) black organics, rootlets, soft and flaking texture.	
			1.5	2	Alluvium	Sand, brown, well sorted (0.1 - 0.2mm) sand.	
			2	2.7	Alluvium	Sand, brown, fining up, moderately sorted, fine (<0.2mm) sand (70%) to pebbles (30%) (7-15mm), unweathered and hard; increase depth, basal, subangular to subrounded coarse (≥2mm) sand (60%) to pebbles (40%) (45mm), increase mode towards gravel.	
			2.7	3.2	Alluvium	Gravel, brown to variegated, poorly sorted fine (<0.2mm) sand (~40-45%), subrounded pebbles (~35-40%) (≤60mm), clay (25%), grey, clast supported.	
			3.2	3.3	Clay	Clay with sand, grey with yellow mottles, clay (90%), well sorted fine (<1mm) sand (<10%) dispersed throughout, crumbly and damp.	

Hole ID	E	N	From	To	Facie	Description
Test pit 2	324317	6411706.9	0	0.1	Soil	Clay soil, moderate brown, soft and friable with rootlets.
			0.1	0.6	Clay	Clay, highly plastic, moderate stiffness, almost pure, minor (<10%) sand and pebbles (1-4mm).
			0.6	0.9	Clay	Clay with sand, brown, clay (60%), moderately sorted, very fine to coarse (1mm) sand (35%), white weathered subrounded pebble clasts (30mm).
			0.9	1.7	Alluvium	Clay with sand, mottled brown and orange, clay (50%), well sorted, very fine to (1mm) sand (50%), smooth consistency, crumbly bolus.
			1.7	2.1	Alluvium	Gravel, poorly sorted, clast supported, very fine (0.1mm) to coarse (2mm) sand (75%), polymictic, variegated, subrounded to subangular pebble (4mm) to cobble (35mm).
			2.1	3.3	Clay	Clay, lighter to darker brown with depth, clay (80%) massive, brown, stiff and dense, minor (20%) very fine grained (<1mm) sand dispersed throughout clay, dark brown lineation of clay indicating bedding.

Hole ID	E	N	From	To	Facie	Description
Test pit 3	324038	6410645	0	0.1	Soil	Soil, brown, with minor soil and pebbles.
			0.1	0.2	Colluvium/saprolite	Gravel with clay, gravel (85%), variegated, poorly sorted (0.1-11cm), polymictic, clay (15%), grey and orange, moist.
			0.2	0.5	Conglomerate	Conglomerate, variegated, poorly sorted, polymictic, dry, hard, refusal.

Hole ID	E	N	From	To	Facie	Description
Test pit 4	323917	6410238.5	0	0.05	Soil	Clayey soil, light brown, rare (<5%) weathered pebbles, organics and rootlets.
			0.05	0.8	Clay	Clay, brown, dark to lighter brown, plastic to dry, and damp to dry at depth respectively, rare dispersed (<5%) sand, pebbles and rounded organics (2-4mm), with increasing sand at depth, and rootlets.
			0.8	2.1	Alluvium	Sand, fining up, mottled to banded yellow and brown, moderate to well sorted, fine (0.2mm) sand (90%), rounded to subrounded pebbles (10%) (4-15mm) with abundance increasing with depth; coarse (0.5-1mm) sand (80%), subangular to subrounded pebbles (2-20mm), slight damp towards base.
			2.1	3	Sandstone	Sandstone, light grey, well sorted fine grained (~1mm) sandstone (90%), lense of minor subrounded (4-8mm) pebbles (10%), hard, and dry.
			3	3.3	Conglomerate	Conglomerate with clay matrix, bedded three with three components observed, clay grey comprising red angular clasts (1-6mm), a gravel, poorly sorted comprising very fine sand (<0.1mm) to subrounded to subangular pebble (2-15mm), clast support, and sandstone comprising, grey, very fine sand (<0.1mm), hard-medium strength and friable. All three units wet to damp, not as hard as overlying.

Hole ID	E	N	From	To	Facie	Description
Test pit 5	323849	6410054	0	0.3	Soil	Clayey soil, brown, organic rootlets and charcoal.
			0.3	0.7	Clay	Clay, brown, hard, stiff.
			0.7	2.4	Clay	Clay with sand, brown, hard, stiff, minor sand, and rare (<10%) weathered white clasts, subrounded.
			2.4	2.6	Alluvium	Clay with sand, orange and brown lenses, clay (70%), minor (30%) fine to coarse sand and pebbles (1-5mm), pebbles weathered to clay, rough textured.
			2.6	3	Alluvium	Clay with sand, light grey with red, orange and black laminations, clay (70%), very fine (<0.1mm) sand (30%), laminar bedding, soft texture.
			3	3.3	Alluvium	Clay with sand and gravel, grey clay (70%) matrix, fine (<1mm) sand (20%), orange, brown red and white, subrounded to subangular (1-4mm) pebbles (10%), clast supported, rough texture.
			3.3	3.5	Clay	Sand with clay, mottled light brown and orange with black/iron stained clast spots, well sorted, very fine grained (<0.1mm) sand (40-60%), clay (45-50%), rare (<5%) subrounded cobbles (35mm).

Hole ID	E	N	From	To	Facie	Description	
Test pit 6	324046	6411768	0	0.2	Soil	Sandy soil, red and brown, moist with rootlets.	
			0.2	0.8	Sand silty	Sandy soil, light brown, well sorted, very fine grained (<0.2mm) sand (70%), moderate (20%) silt, minor (<10%) pebbles, dry and friable.	
			0.8	2	Clay	Clay with minor sand and pebbles, dark brown to yellow mottles, fining up, very fine grained sand to subangular chipped red, hard lithics, clay matrix supported, dry.	
			2	3.2	Saprolite	Clay with sand and pebbles, grey clay, yellow minor very fine grained sand pockets, weathered sandstone pebble clasts, matrix supported.	
			3.2	3.3	Saprolite	Sandstone, light grey, well sorted, friable and damp.	

Hole ID	E	N	From	To	Facie	Description
Test pit 7	324388	6410997.1	0	0.2	Soil	Sandy clayey soil, light brown, well sorted, very fine grained (<1mm) sand (75%), clay (25%), damp, with rootlets.
			0.2	0.4	Colluvium	Gravel, light brown, poorly sorted, well rounded pebbles, colluvium.
			0.4	1.3	Clay	Clay, grey with yellow mottles, clay (75%) stiff, hard, crumbly and damp, minor (25-30%) sand and gravel dispersed, larger clasts weathered red.
			1.3	2.5	Siltstone - dry	Siltstone, white, moderately hard, fossils and iron staining, dry.
			2.5	3.3	Siltstone - damp	Siltstone, white with red stains, leaf fossils, soft, crumbly and damp, contain thin (~5cm) coal seam at ~3mBGL.

Hole ID	E	N	From	To	Facie	Description
Test pit 8	323964	6411796.4	0	0.2	Soil	Sandy soil, red and brown, moist with rootlets.
			0.2	0.35	Sand silty	Sand silty, light brown, well sorted, very fine grained sand (<0.2mm), dry and friable.
			0.35	0.7	Sand silty	Sand silty, light brown, poorly sorted, sand to small cobbles.
			0.7	0.8	Clay	Clay, dark brown and hard.
			0.8	1.9	Clay	Clay with sand, red and brown, stiff, minor (10-20%) mottled very find sand dispersed throughout.
			1.9	2.7	Saprolite	Clay with cobbles, clay matrix mottled grey to yellow, cobbles of well sorted red sandstone which are hard.
			2.7	3.3	Saprolite	Clay, light grey to brown mottled, increasing weathered rock.

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Hole ID	E	N	From	To	Facie	Description
Test pit 9	324230	6410720.1	0	0.2	Soil	Clayey soil, light brown, rare (<5%) weathered pebbles, organics and rootlets.
			0.2	2.3	Clay	Clay, brown, clay (70%)moderate plasticity, stiff, hard, crumbly, rare to minor (<10 - 15%), white, ovate subrounded cobble (50mm) to subangular pebble (20-25mm) clasts with increasing depth, composition remanent moderately sorted sandstone, clasts concentration and rare sand (5-15%) dispersed increasing with depth, damp at 0.8 - 0.9mBGL.
			2.3	3.3	Alluvium	Sand with clay, light brown, moderately sorted, sand (60%) very fine to predominantly coarse (<2mm), clay (20%), pebbles (19%), subrounded to subangular (2-10mm), rare (1%) polymictic conglomerate boulder (14cm), sub-parallel fine laminations colour orange and black within the clay, moist to almost damp at end of hole depth limit.

Hole ID	E	N	From	To	Facie	Description
Test pit 10	323427	6411147.2	0	0.2	Soil	Soil, brown with rootlets.
			0.2	0.6	Clay	Clayey soil with very fine sand, white, hard and friable.
			0.6	1.7	Clay	Clay with fining up sand and gravel, sand (0.5-1mm) moderately sorted, occasional pebble, red/brown, to very fine sand and gravel (80mm), poorly sorted subrounded to angular with clay matrix, excavated pile dried white.
			1.7	2.6	Saprolite	Gravel with clay matrix, grey and brown mottles.
			2.6	3.3	Saprolite	Rock, partially clayey, grey, with iron stain nodules and clasts.

Hole ID	E	N	From	To	Facie	Description
Test pit 11	323762	6410937	0	0.3	Soil	Sandy clayey soil, brown, well sorted, very fine grained (<1mm) sand (75%), clay (25%), and rootlets
			0.3	1.2	Clay	Clay and sand, fining up, mottled, dark brown, yellow and light brown, minor (<10%) very fine dispersed sand, dry, cracked, and rootlets; increasing with depth very fine (<0.1mm) sand (75%) and clay (25%), crumbly and soft.
			1.2	1.4	Saprolite	Sandstone, white, well sorted (0.5mm mode) and hard.
			1.4	2.2	Saprolite	Clay and weathered sandstone, clay (90%) yellow and grey with organics, minor sandstone (<10%) white, well sorted, hard.
			2.2	2.3	Rock	Siltstone, fissile with fossils and siderite.

Hole ID	E	N	From	To	Facie	Description
Test pit 12	323431	6410770.1	0	0.25	Soil	Soil, brown with pebbles.
			0.25	1.2	Clay	Clay, brown, initially pure, stiff, with rare pebbles, grading to crumbly textured clay with red, angular, chip pebbles (8mm).
			1.2	2.5	Clay	Clay with minor sand, yellow to brown, increasing initial grey and brown mottles, then to grey with depth, clay grey, sand increases (brown) to mid-facie then decreases (grey), very fine sand (0.1-1mm), well sorted, soft feel.
			2.5	3.3	Saprolite	Clay with weathered rock, grey clay matrix, and iron stained nodules and clast.

Hole ID	E	N	From	To	Facie	Description
Test pit 13	323693	6410712	0	0.2	Clay	Clayey sandy soil, brown, clay (60%), well sorted very fine sand (40%), damp.
			0.2	0.7	Clay	Clay, yellow and brown mottled, clay stiff, hard, moderate plasticity, with rare (5%) fine sand and subangular pebbles (8mm).
			0.7	1.3	Clay	Clay, yellow and brown mottled, clay (90%) stiff, hard, rough texture with rare (10%) very fine (<1mm) sand, and rootlets.
			1.3	1.7	Sand clayey	Sand with clay, light brown to yellow, well sorted, very fine grained (<0.2mm) sand (75%), clay (25%), soft friable and crumbly.
			1.7	2.1	Gravel	Gravelly sand with clay, light brown, laminated contacts between gravelly sand and clay, brown and red poorly sorted, subangular very fine sand to subrounded pebbles (40mm), clast supported with depth, clay matrix grey, gravel grades to clast supported, noted red clasts and grey matrix.
			2.1	3.3	Clay	Clay with gravel, clay grey (70%), brown, subrounded to rounded (5-45mm) pebbles (20%), very fine (<0.1mm) sand (10%), matrix supported.

Hole ID	E	N	From	To	Facie	Description
Test pit 14	323753	6410558.3	0	0.2	Soil	Soil, brown with rootlets.
			0.2	0.4	Clay	Clayey soil, mottled dark brown to rarer light brown, rare very fine sand to small pebbles, clay moderate plasticity and stiff.
			0.4	0.9	Clay	Clay, light grey to brown, white fine sand grains (2mm) dispersed throughout, hard and friable.
			0.9	1.6	Sandstone	Sandstone, weathered, white, well sorted, initially soft and friable becoming hard with iron staining until refusal.

Hole ID	E	N	From	To	Facie	Description
Test pit 15	323747	6410199.4	0	0.4		Soil, brown, with rootlets.
			0.4	0.8	Soil	Clay with sand, light white to brown, very fine (<0.1mm) sand (70%), clay (30%).
			0.8	2.5	Clay	Clay with minor sand, light brown with orange mottles towards base, very fine (<0.1mm) sand, grading to clay with depths, black organic fines randomly dispersed throughout.
			2.5	3	Colluvium	Sand to cobbles, light brown and variegated, poorly sorted, fine sand (30%), subrounded to lesser subangular pebbles to cobbles (≤15mm) (70%), clasts weathered.
			3	3.3	Saprolite	Sand with clay, light grey, moderately sorted, rare red pebbles, siderite, organics and rootlets.
			3.3	3.6	Saprolite	Gravel with clay, brown, yellow and orange mottles, clast supported, poorly sorted angular to subangular pebbles, grey clay matrix, weathered conglomerate.
			3.6	4.5	Saprolite	Sand with clay, mottled light brown and yellow, very fine grained (<1mm) sand (50-60%), moderate (40-50%) clay, clast supported, weathered sandstone.

Hole ID	E	N	From	To	Facie	Description
Test pit 16	323944	6410410.6	0	0.26	Soil	Soil with sand and clay, light brown, clay (50%), well sorted, very fine sand (50%), crumbly.
			0.26	2.6	Clay	Clay with sand, light brown to dark with depth, fining up, clay (75-60%) decreasing with depth, hard, highly plastic becoming crumbly, well sorted, very fine (<0.5mm) sand (25-40%) increasing with depth, damp, with rootlets.
			2.6	3.1	Sand clayey	Sand with clay and pebbles, dark brown to mottled brown and orange, well sorted, very fine (<0.2mm) sand (65%), clay (25%), pebbles (5mm) to cobbles (30-65mm) (15%), white, well rounded to subrounded, weathered white or siliceous clasts non-weathered, size increasing with depth to proportions of sand and gravel (70%) and clay (30%).
			3.1	3.3	Clay	Clay with gravel, clay (65%), grey, yellow and lesser purple mottles, very fine (<0.1mm) sand and pebbles (3-10mm) (35%).

Appendix B Geophysical Survey Report (Groundwater Imaging February 2017)

AgTEM Alluvium and Subcrop Investigation at Mt Owen

for Glencore – Singleton.

December 2016

For Glencore as arranged by AGE Consultants P/L

Dr David Allen. David@GroundwaterImaging.com.au 0418964097

Executive Summary

- Background:
  - This site is entirely hosted within the Permian Singleton Coal Measures (sandstone, shale, mudstone, conglomerate and coal seams). Just to the north exist Carboniferous Wallaringa Formation (conglomerate acid tuffs and lithic red sandstones). The site is on the east side of the Glennies Creek Syncline. This means that strata are expected to be dipping slightly to the south of west resulting in creek alluvium with north-south trends and abrupt western boundaries. Creek segments in other orientations are anticipated to be fault controlled and crossing dipping strata.
- This survey:
  - Bulk ground electrical (EC) conductivity survey was conducted in three dimensions using AgTEM cart. EC is a measure principally of salinity of ground moisture, but, obviously, if ground saturation is low or rock porosity is low then EC will be lowered compared to EC of any moisture present. On land, AgTEM survey passed currents through the ground in controlled and measured ways to map bulk EC of the ground. EC of metal objects is very high and, where possible, data affected by metal objects in or on the ground was rejected.
  - Survey was conducted, where possible, at 40m line spacing and to a depth of around 20m robustly (40m to some extent) using a null mutual coupled receiver loop on the AgTEM cart but no external slingram loop (this would have reduced productivity but improved deeper investigation).
- Findings:
  - Several metres of alluvium were identified in exposure in the bed of main creek and the modelled AgTEM data indicates a corresponding low resistivity layer along the sides of the length of the creek. It is most likely that this modelled layer corresponds to brackish ground moisture in both the alluvium and intense weathering of the strata immediately beneath.
  - In the south it is inferred that the the top of the alluvium there drains freely to a lower standing water level because the modelled low resistivity layer does not extend to the surface.
  - The alluvium also extends along the tributaries to the east.
  - Other low resistivity features exist in the data corresponding to known occurrence of brackish springs and moist soil patches. These features extend deeply along the strike of strata suggesting upward groundwater flow through permeable strata and possibly co-incident fracture planes.
  - A tributary enters from the southwest however an inferred hard rock layer has greatly limited depth of alluvium at the confluence. To the north the hard rock bounds the west side of Main Creek Alluvium, while to the south of the confluence it bounds the east side of main Creek Alluvium and further south this alluvium opens out into the Glennies Creek alluvium.

Contents

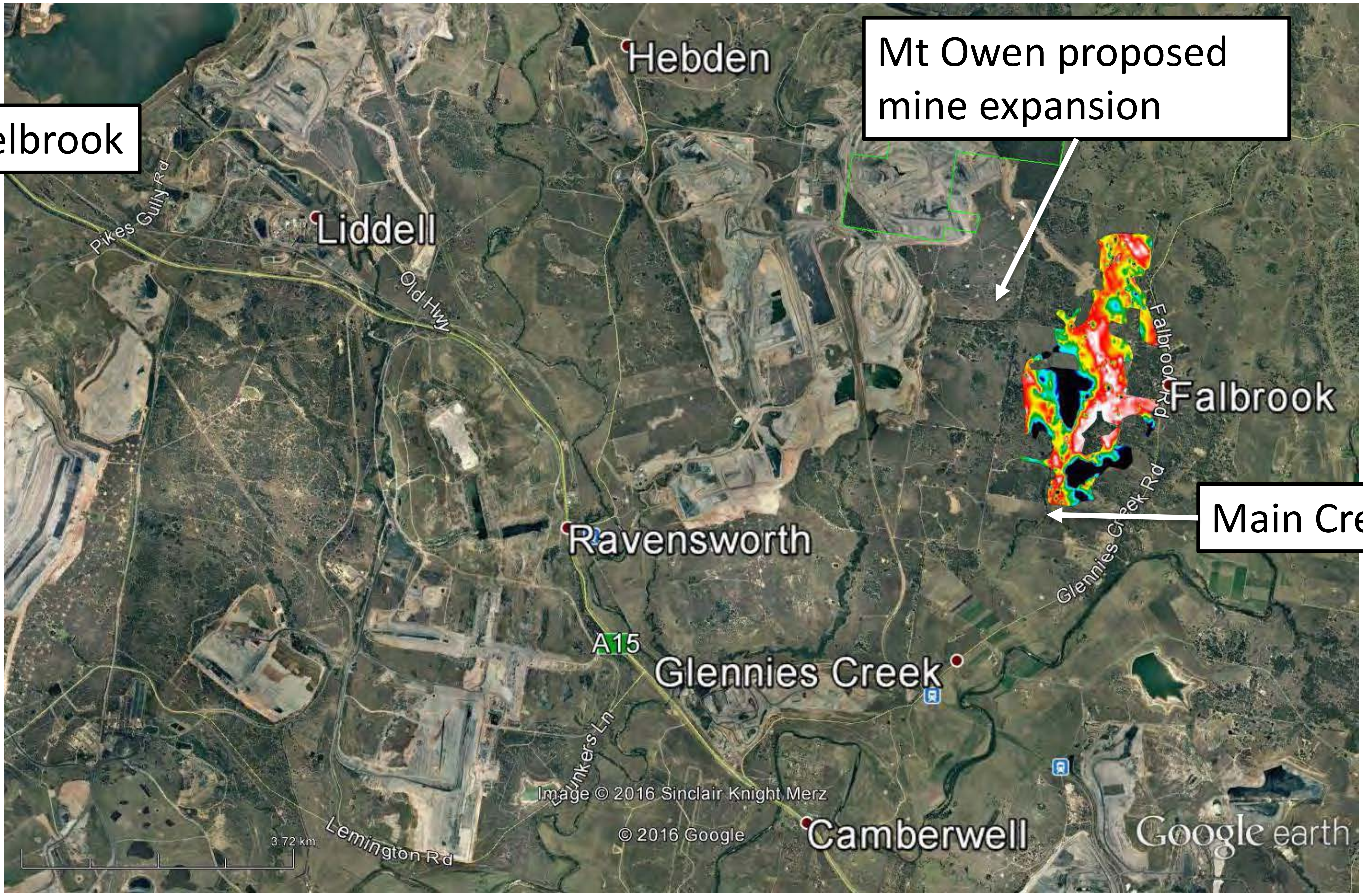
Context and Aim

- Delineation of Alluvium and connected groundwater flow pathways using surface geophysics.
- Aim – Improvement of definition of the alluvium boundary and connected groundwater flow pathways along Main Creek within the Mt Owen site.

Method Summary

- Variation in the depth, lithology, saturation and groundwater salinity of the geological facies at the site has been mapped using towed transient electromagnetics, drill chip lithology, outcrop, soils and float rock appraisal. 3D graphics has been applied to relate the various sources of information.

Location


Hebden
Mt Owen proposed mine expansion
To Muswelbrook
Liddell
Pikes Gully Rd
Old Hwy
Falbrook
Falbrook Rd
Main Creek
Glennies Creek Rd
Ravensworth
A15
Glennies Creek
Bunkers Ln
Image © 2016 Sinclair Knight Merz
© 2016 Google
Camberwell
Google earth
3.72 km
Lemington Rd
To Singleton

Geophysical Methods Introduction

- A quick and comprehensive way of looking at a shallow (0 to 100m deep) groundwater resource is to image it with towed transient electromagnetic devices. The resultant EC image will reveal, in a blurred manner, the proportion of ions in solution in the groundwater and rock at various depth – usually this means that dry ground, good aquifers and fresh basement rock show as electrically resistive and contrast with clays and saline aquifers that show as electrically conductive. Determining exactly what each feature represents is then a matter of interpretation which is usually solved by comparison with borehole logs and a bit of logic (eg. basement rock will be at the base, an unsaturated zone will be at the top and prior river channels will be shaped concave-up).

Why use Electrical Conductivity Imaging for Groundwater Investigation

- reveal spatial details not observable by any more economically viable means
- EC responds clearly and conclusively to recharge pathways and saline groundwater.

LOW EC
- Lack of Clays
- Low Saturation
- Fresh pore water
- Impervious fresh rock

HIGH EC
- Clays
- High Saturation
- Saline pore water
- Weathered rock

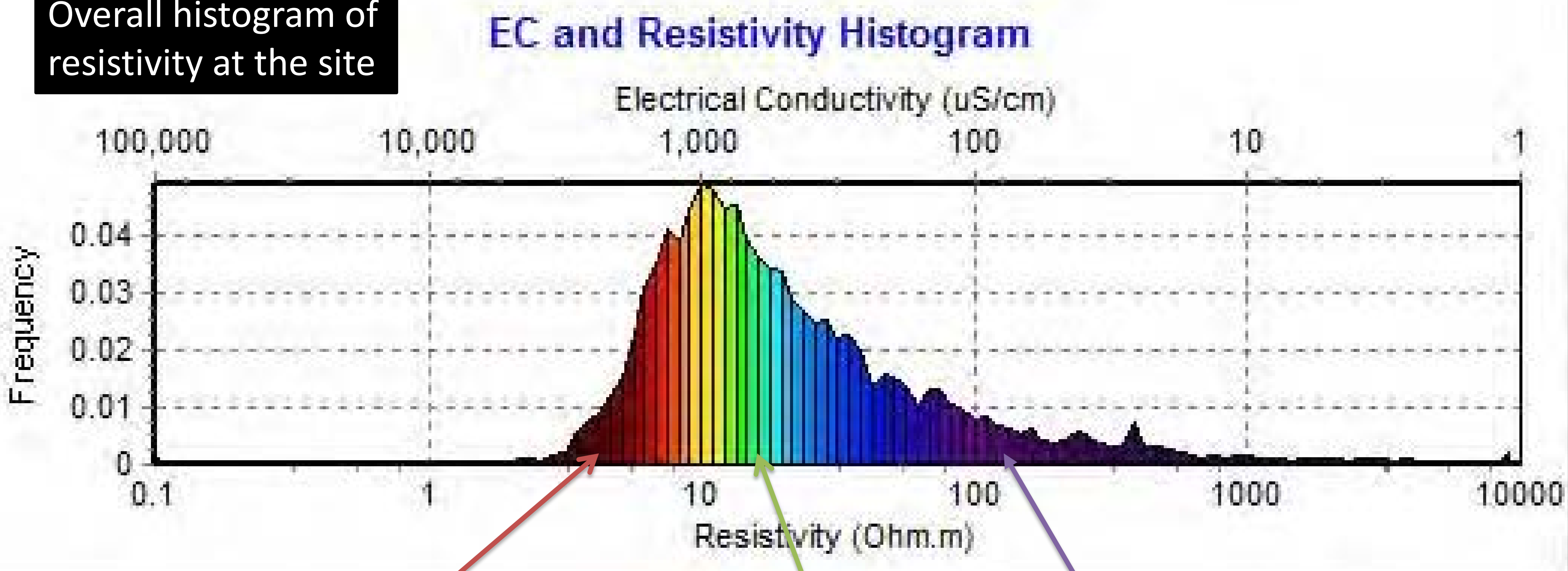
Results Presentation

- TEM data has been presented as depth slices in Google Earth
- In Google Earth 3D oblique orientation, other data is presented in combination with the TEM depth slices including outcrop photos, lithology logs and TEM transects. Interpretation comments are added.
- 3D presentations of data at individual sites along with bore lithology graphics and photos are presented.

Resistivity scale used in Google Earth Images

The inverse of Resistivity is Electrical Conductivity (EC).

Overall histogram of resistivity at the site



Saline moisture typically in weathered rock and clay

Fresh ground moisture typically in sand and gravel

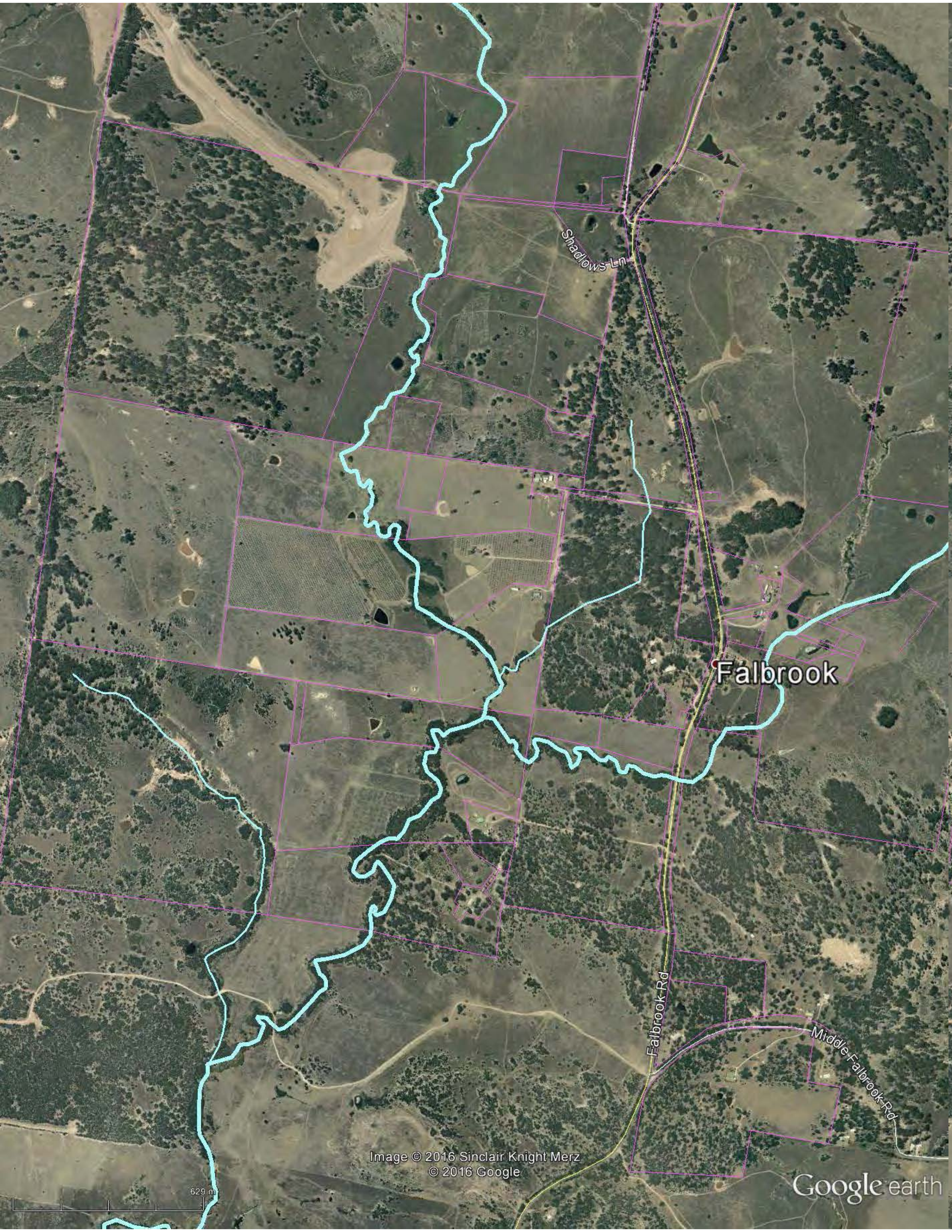
Hard rock such as granite, quartzite and limestone. Sediments void of moisture.

Treat modelled resistivities in these datasets as relative, not absolute.

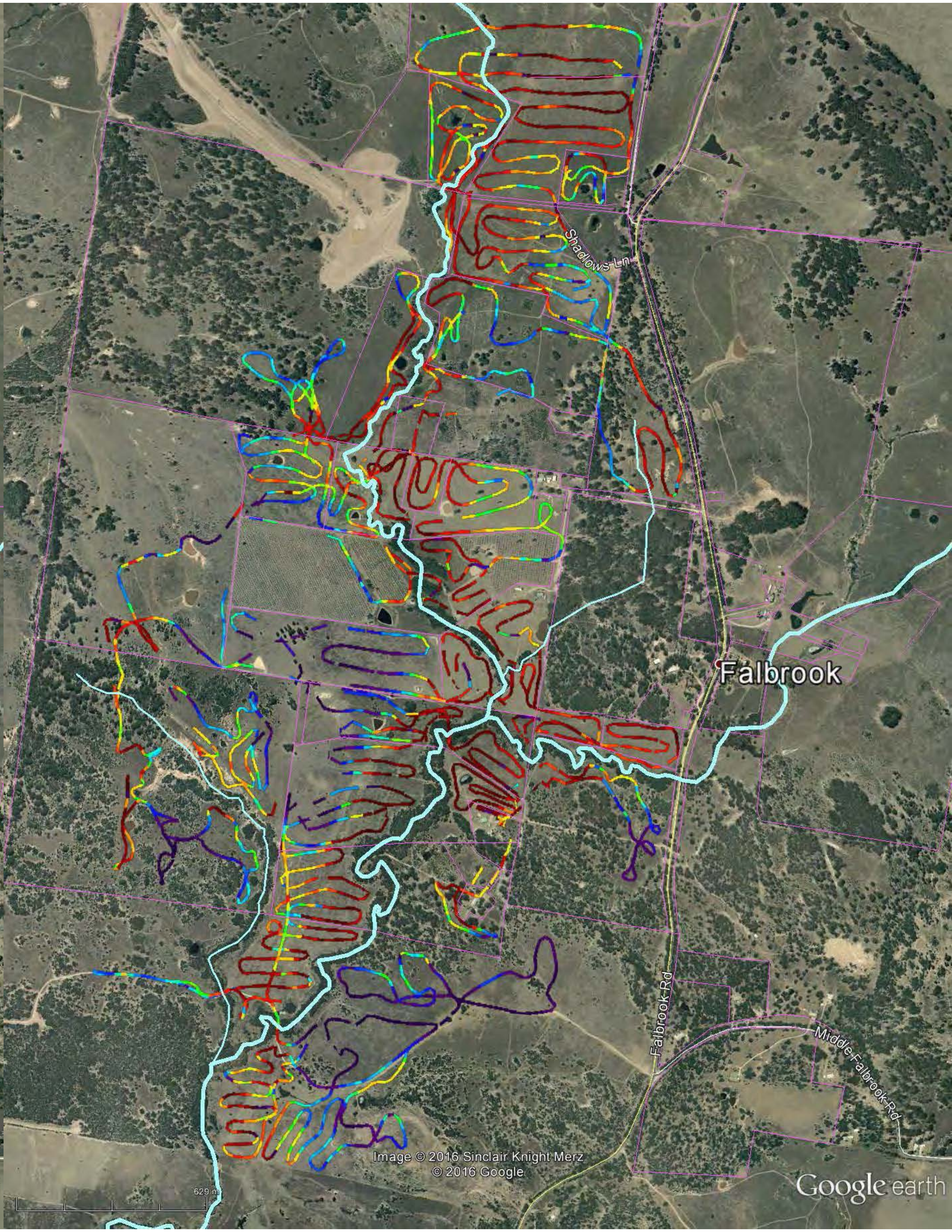
Full set of depth slices with common colour stretch

The AgTEM4 prototype 2016

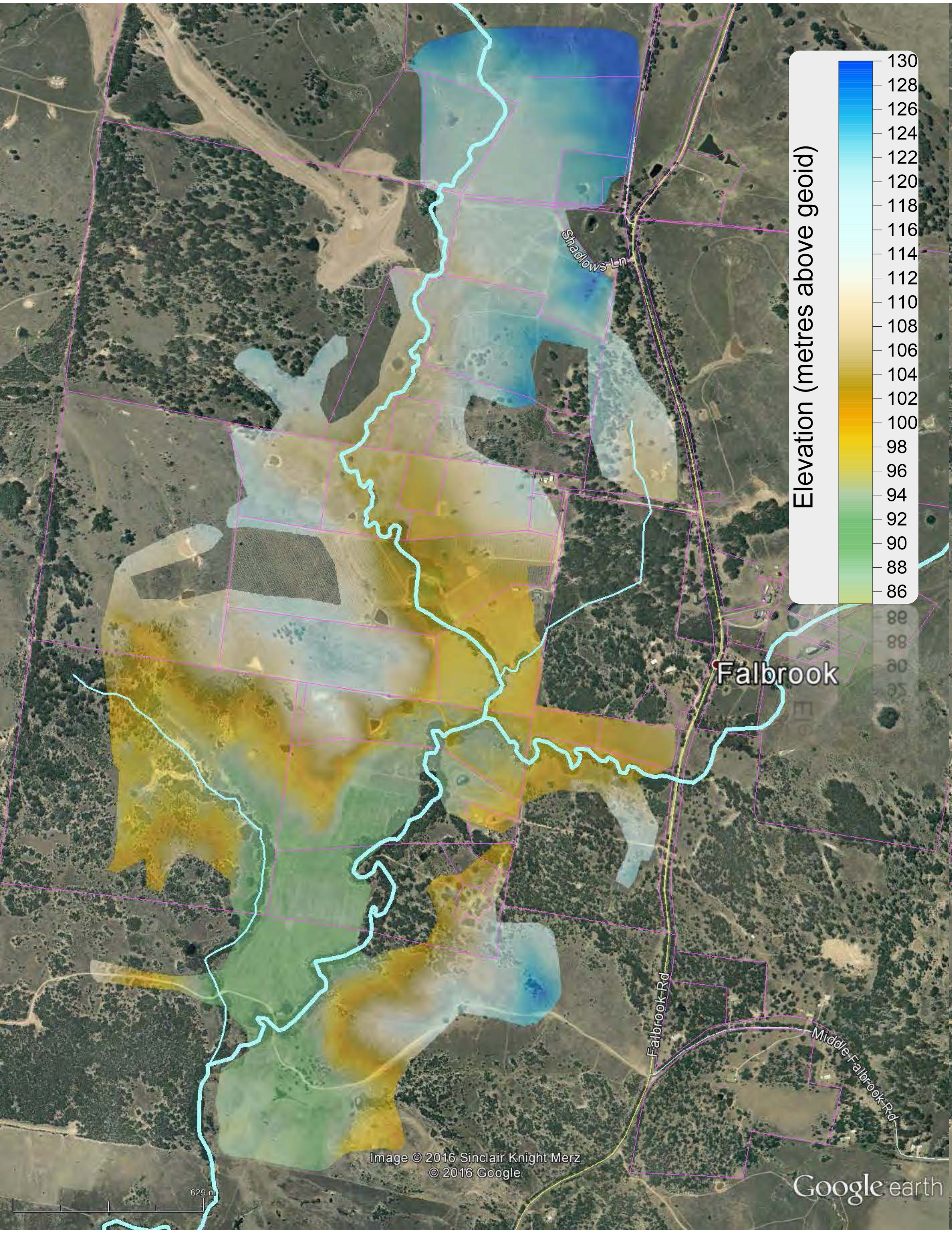
Main Creek and Tributaries



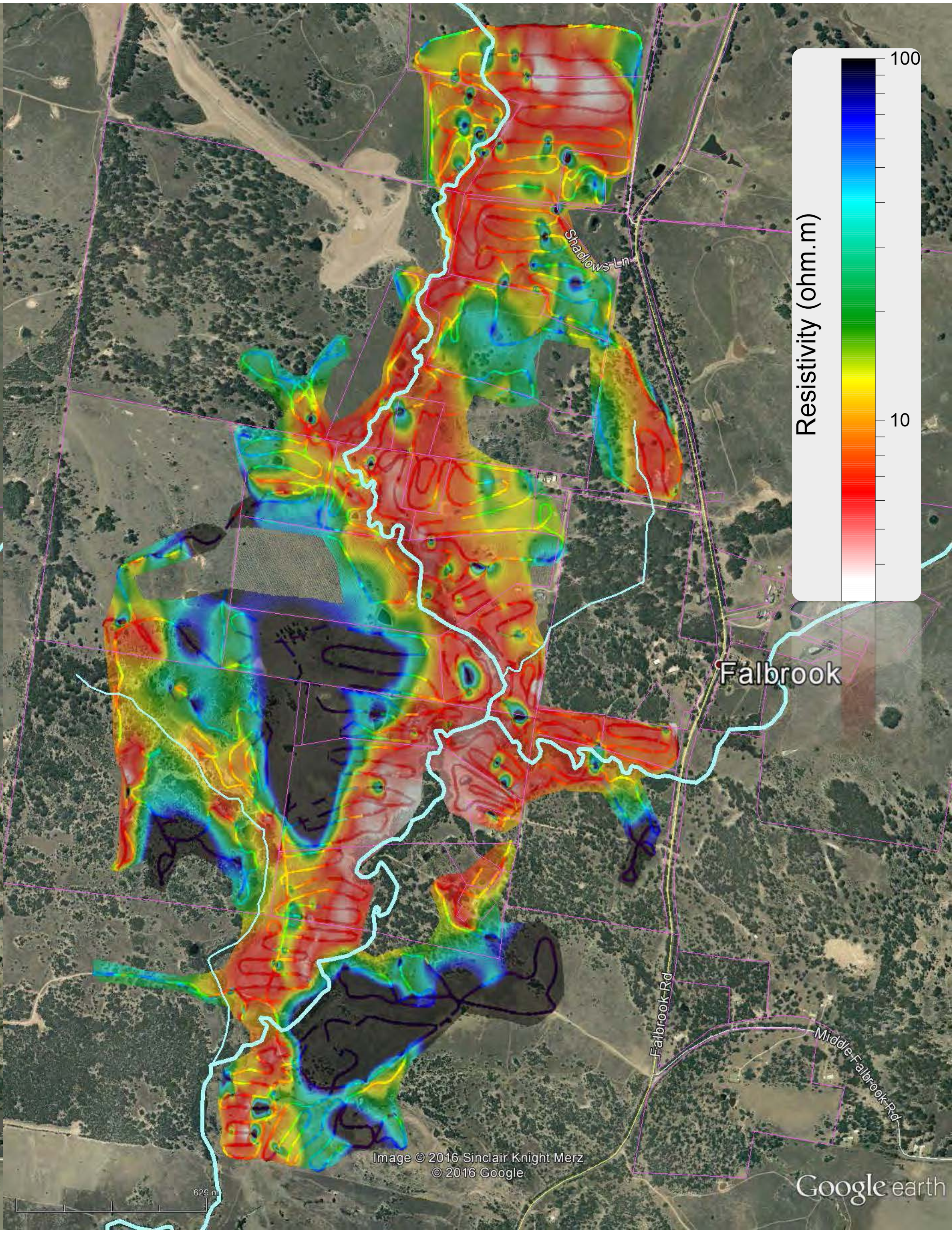
AgTEM survey track – modelled resistivity at 4m deep



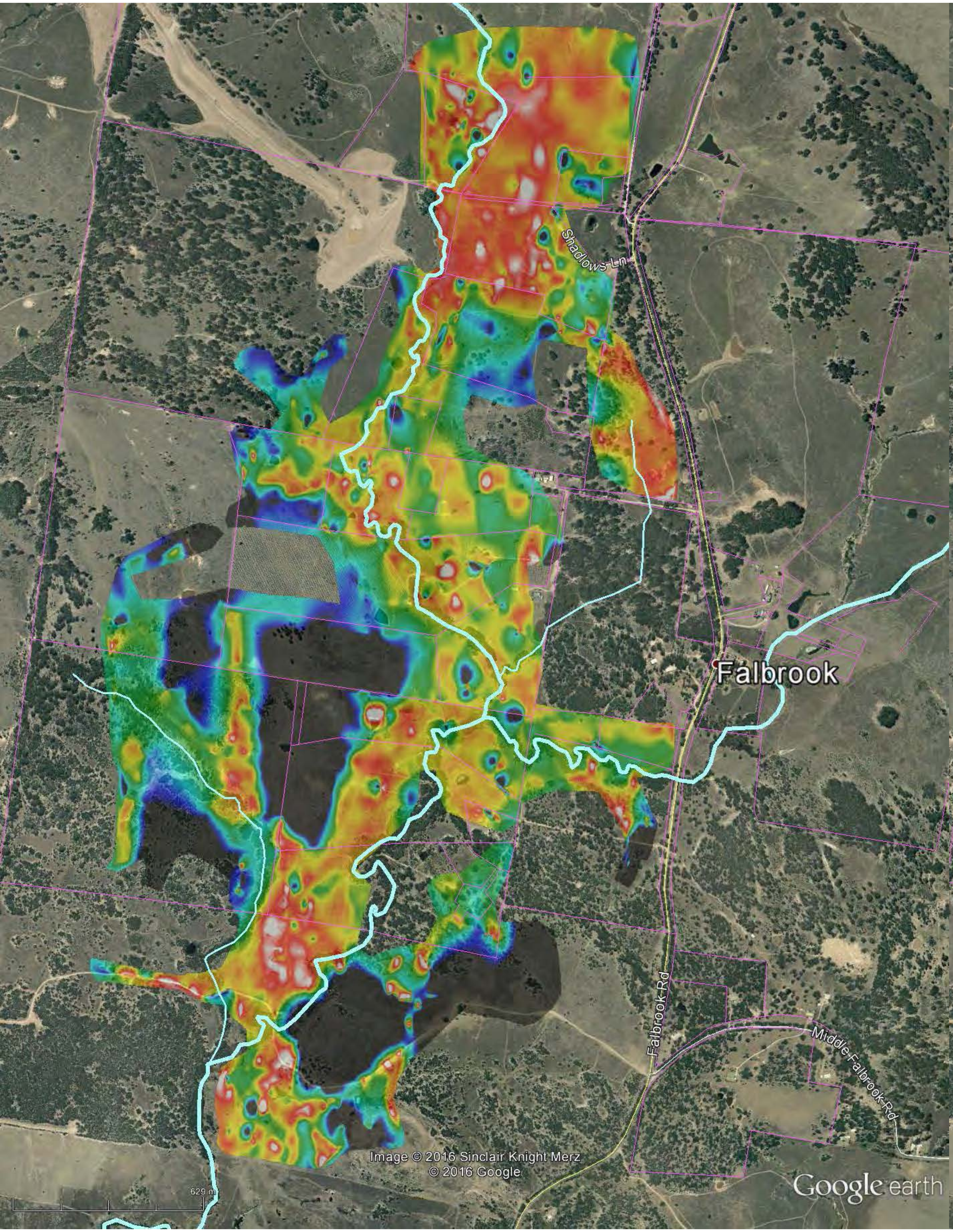
Elevation



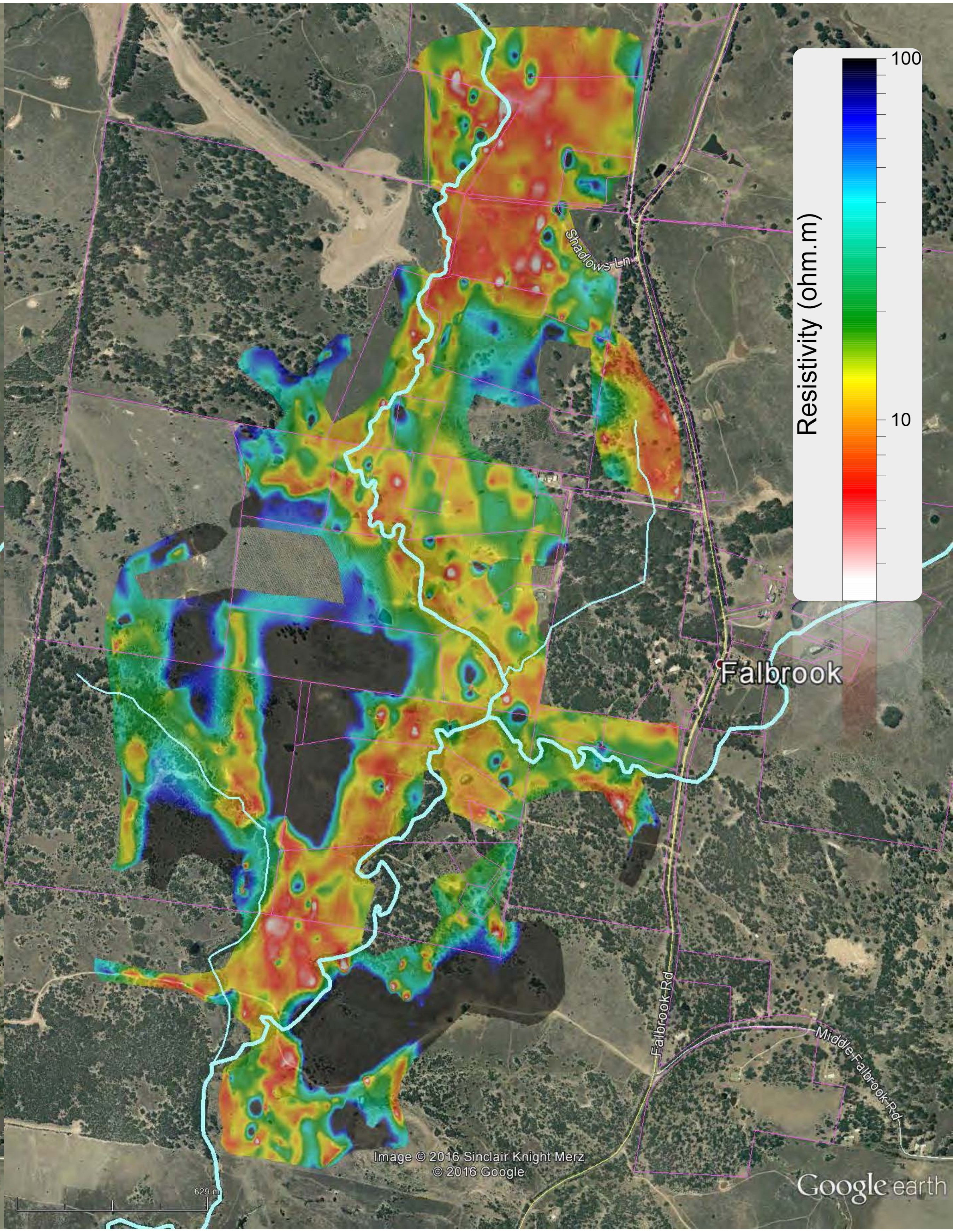
Modelled Resistivity at 4m Deep – with survey track overlay



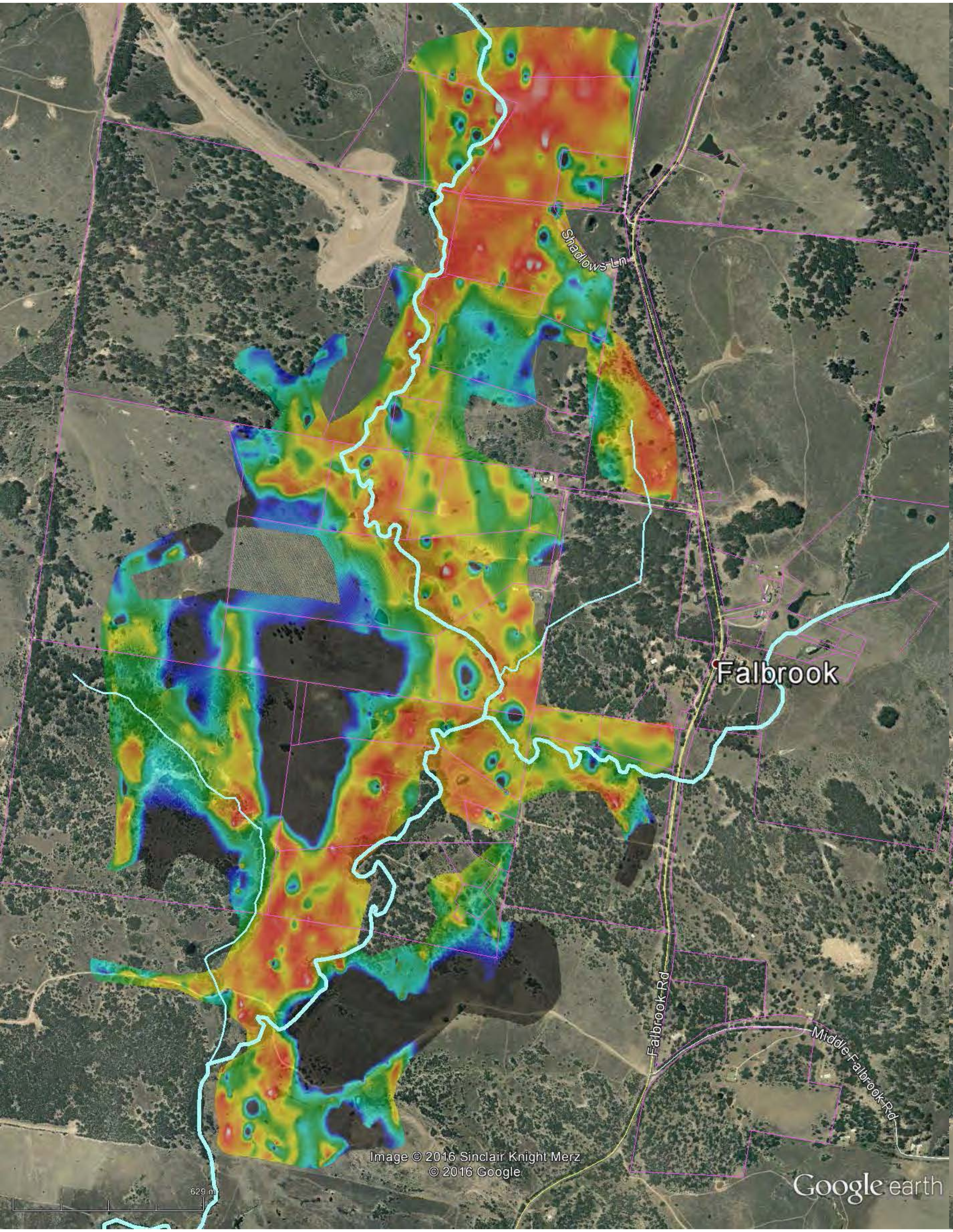
Modelled Resistivity at 0.3m Deep



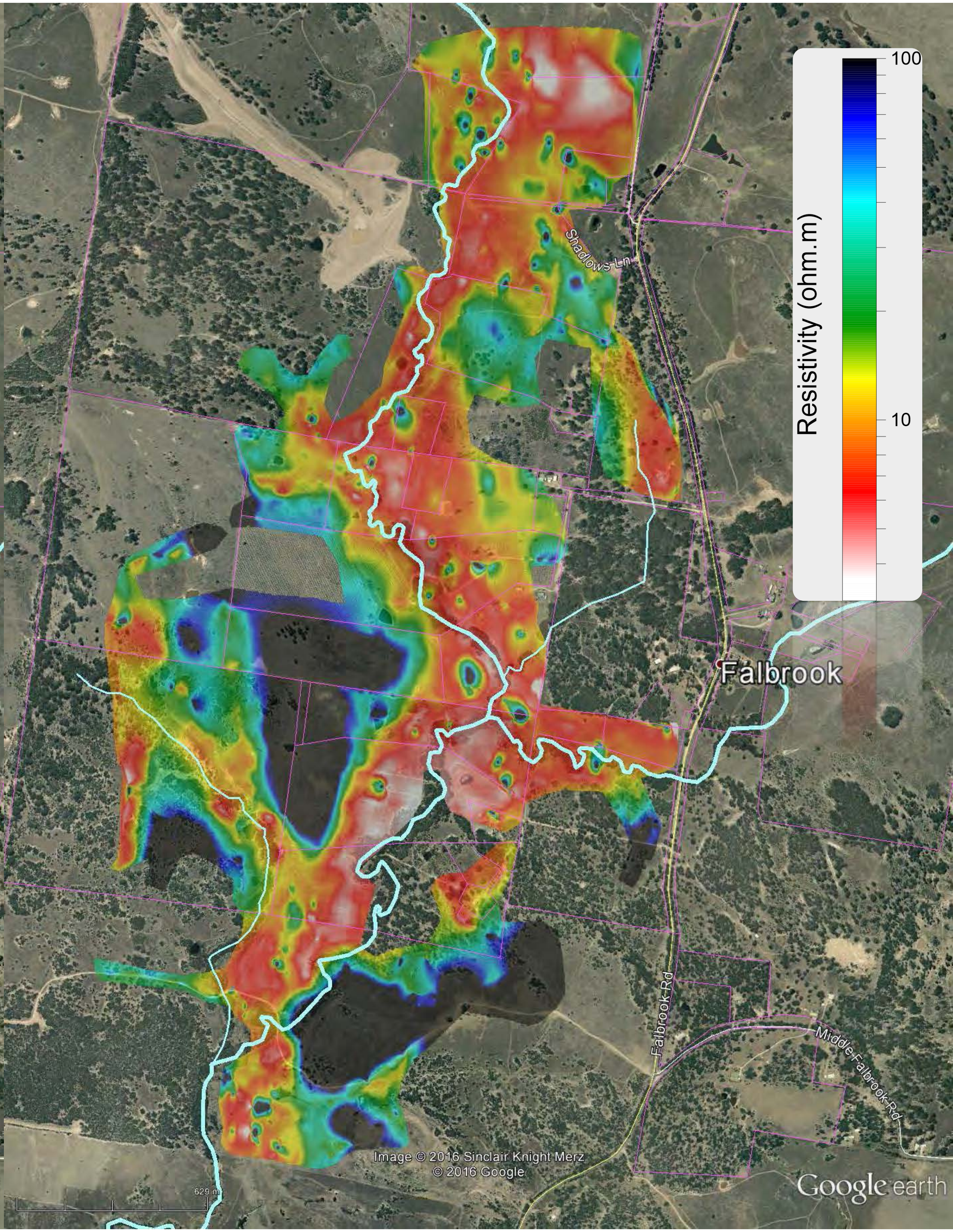
Modelled Resistivity at 1m Deep



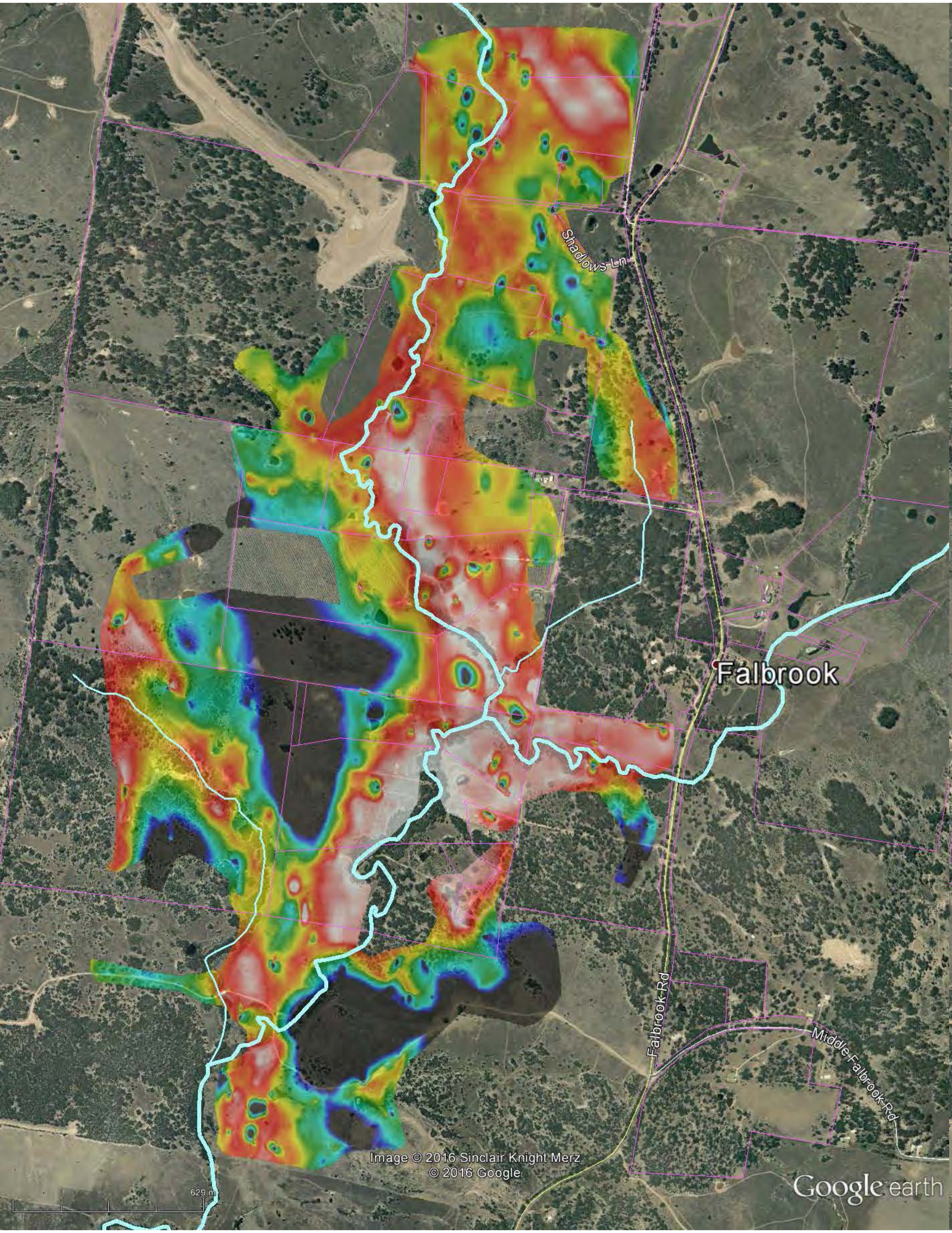
Modelled Resistivity at 2m Deep



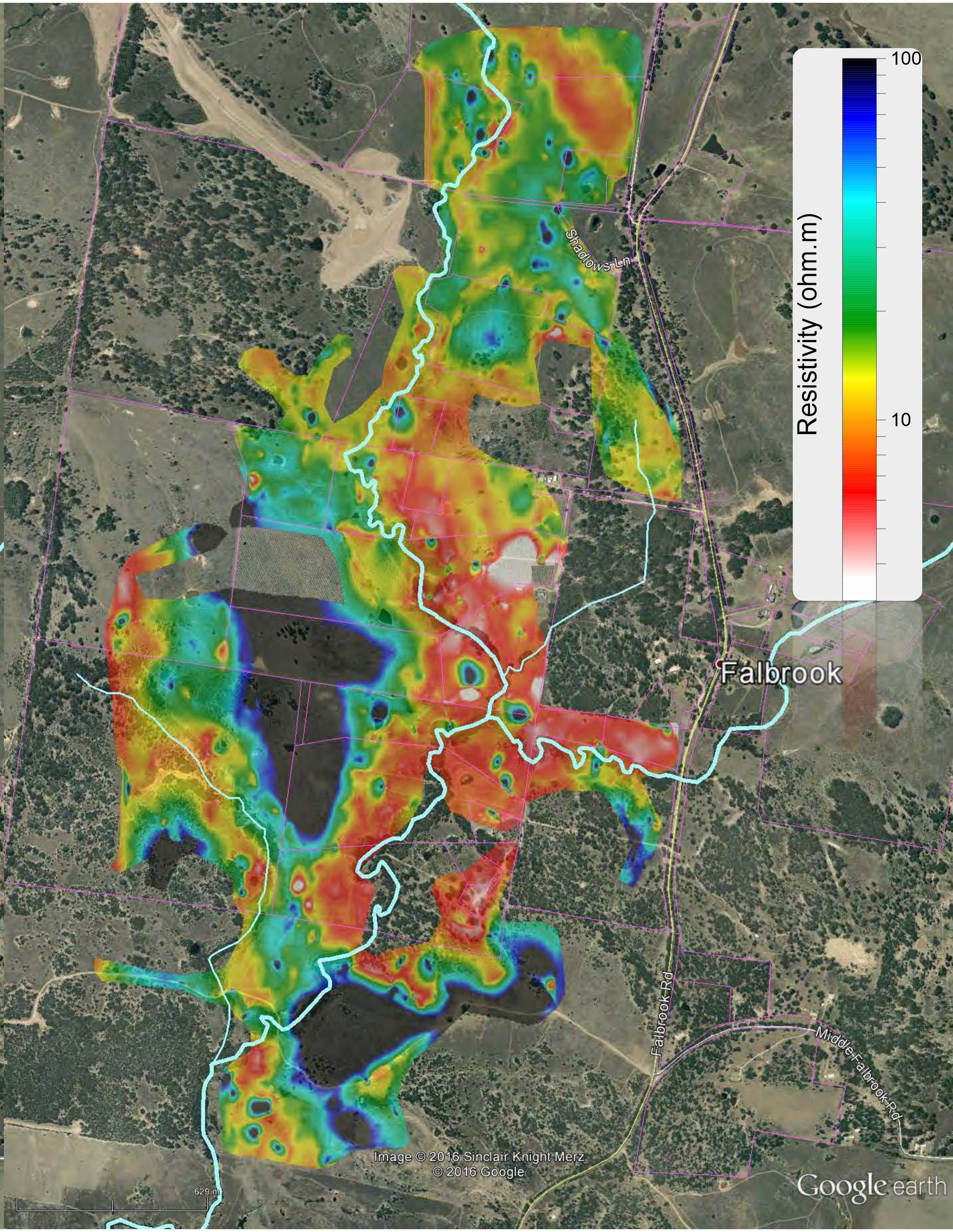
Modelled Resistivity at 4m Deep



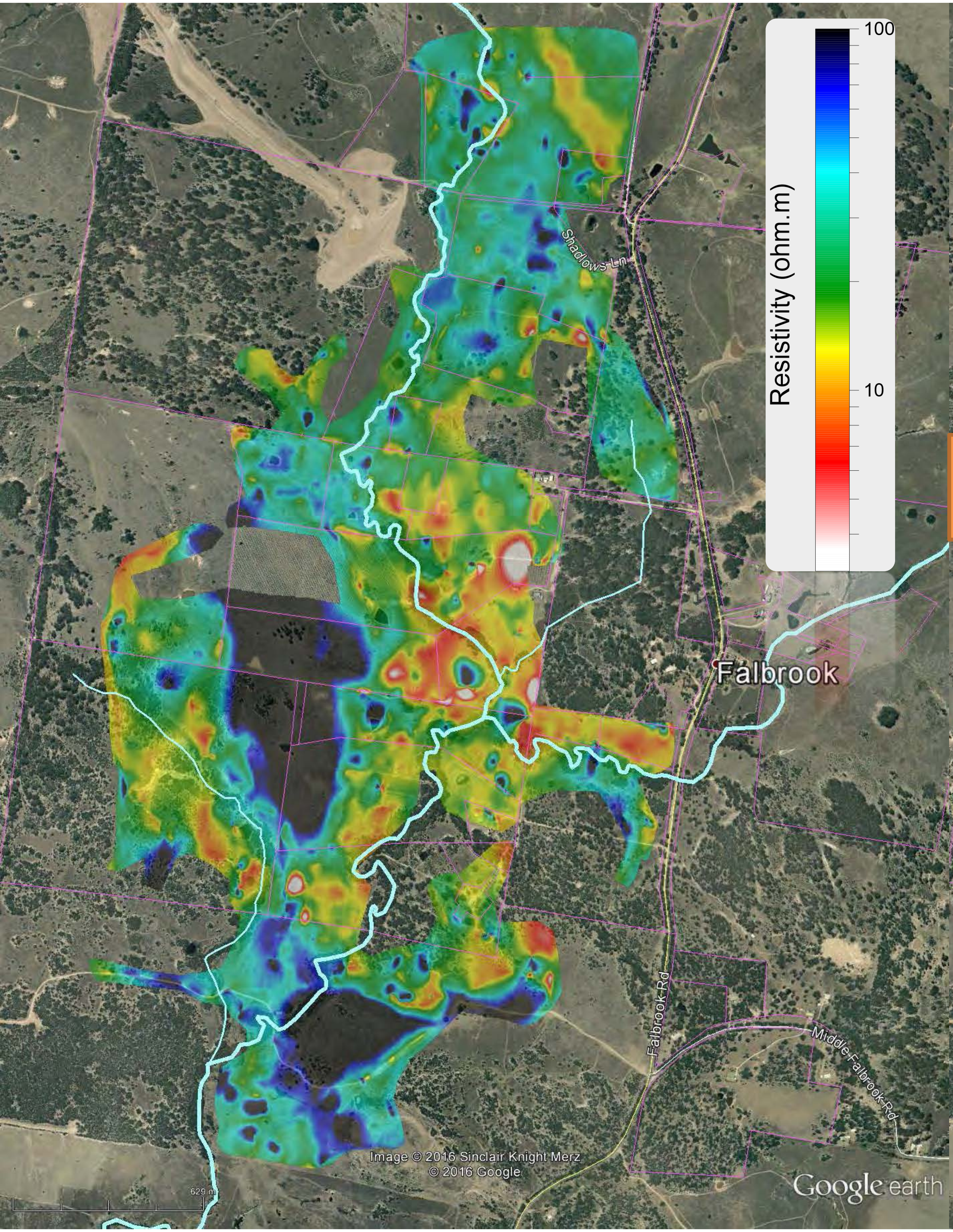
Modelled Resistivity at 7m Deep



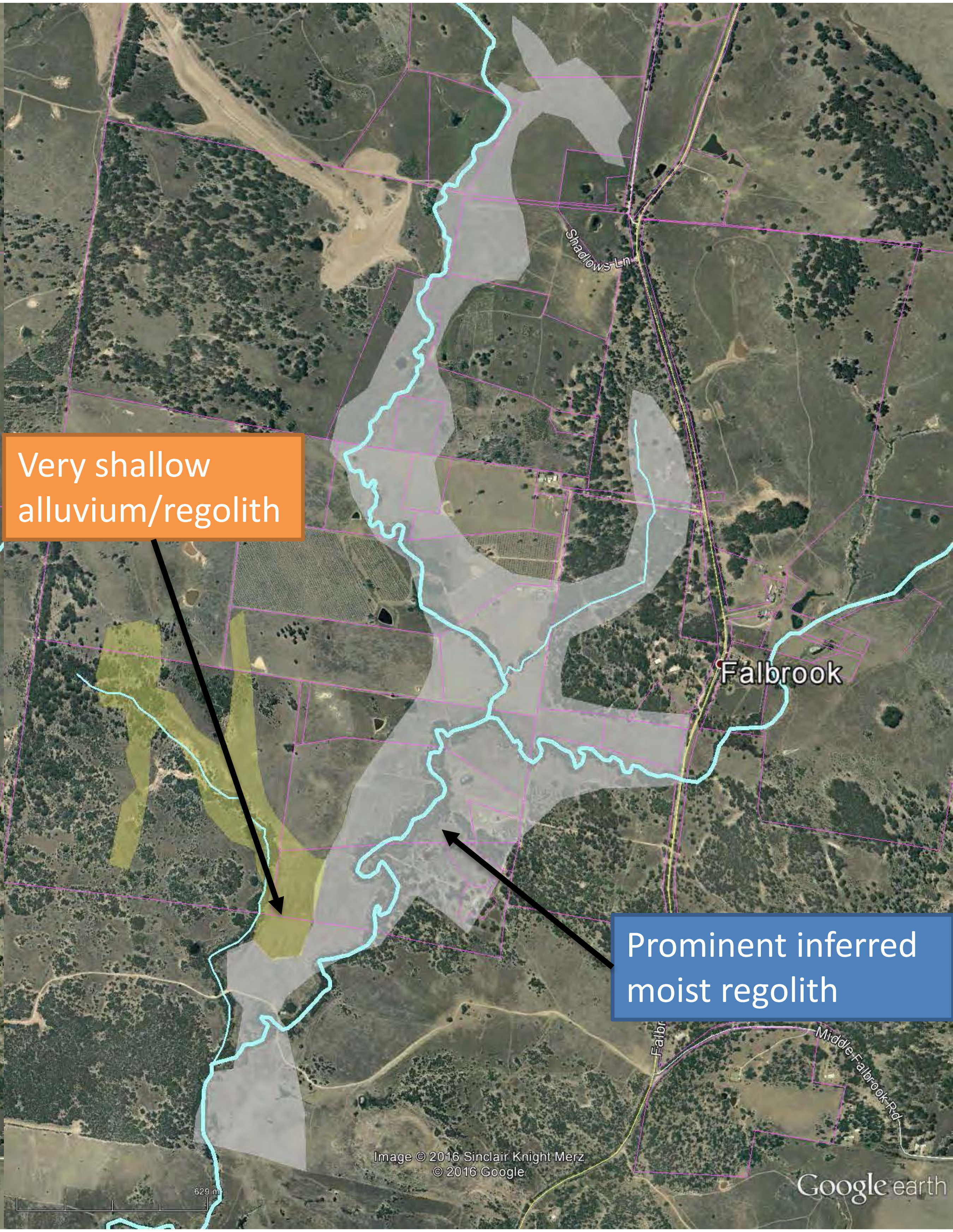
Modelled Resistivity at 12m Deep



Modelled Resistivity at 20m Deep

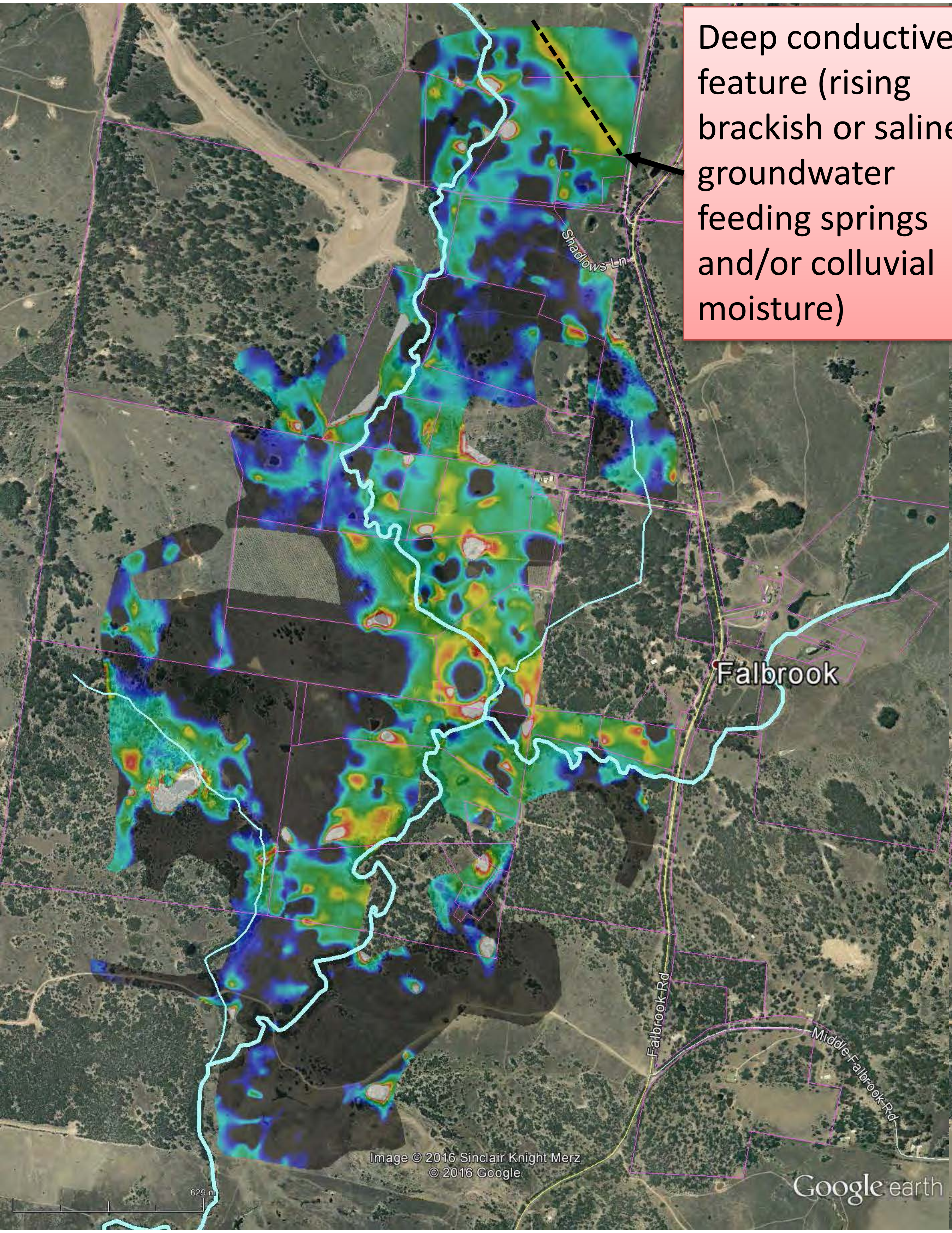


Prominent inferred moist regolith



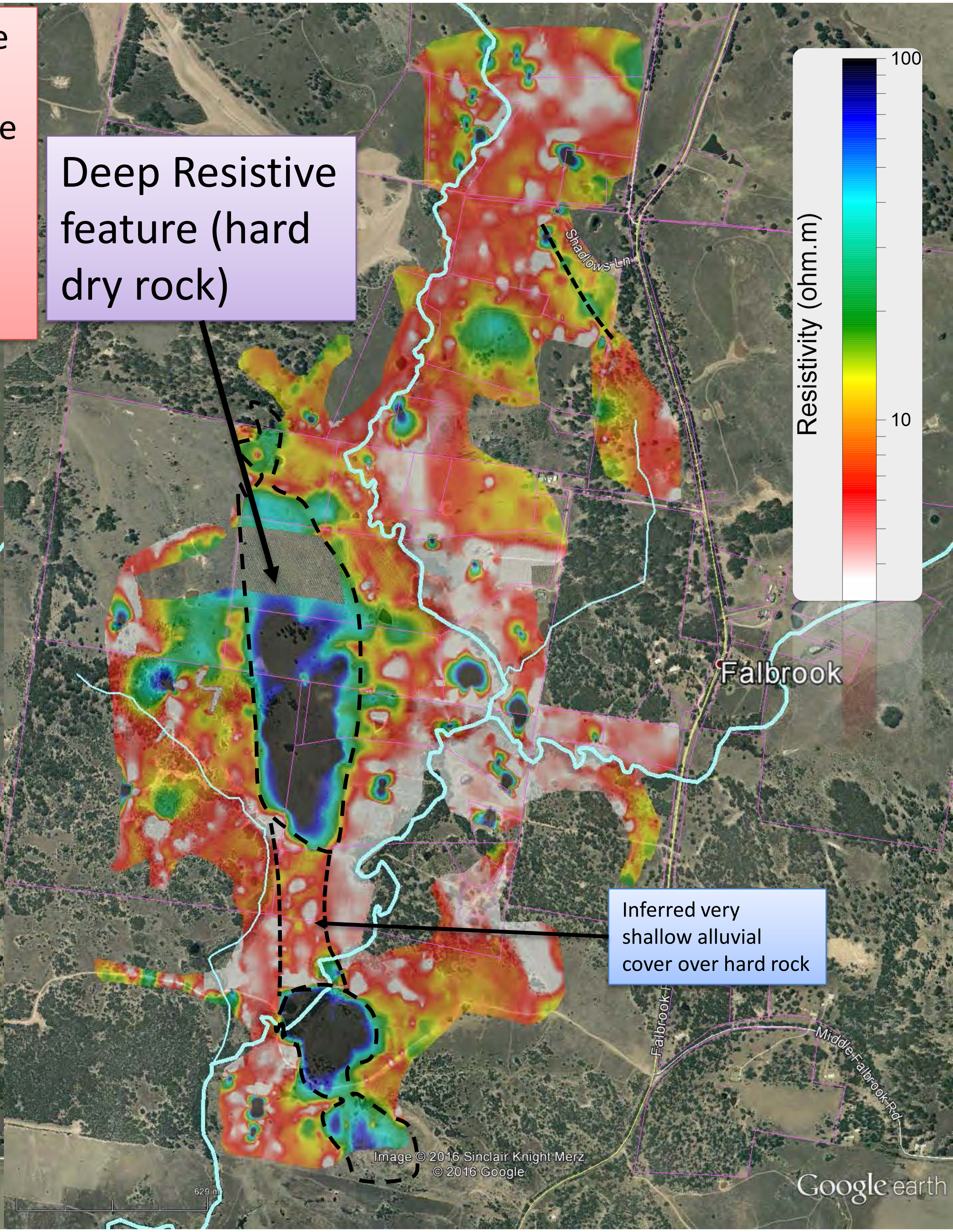
Modelled Maximum Resistivity Intercepted (all depths)

Vertically continuous moist brackish or saline features are highlighted as low resistivity



Modelled Minimum Resistivity Intercepted (all depths)

Vertically continuous dry impermeable rock is highlighted as high resistivity



Photos and geological observations

Erosion in Main Creek reveals 4 metres of mud impregnated gravel alluvium on top of inferred mudstone saprolite. Photo taken just north of the olive orchards.

Springs in the north of the survey site

- Main Creek is fed from the north by springs and rising groundwater entering alluvium and colluvium. The sedge in the foreground indicates where risen groundwater breaks out of alluvium to commence flow along the creek. Along the side of the hill some strata are evident however the strata principally hosting rising groundwater are receded within the topography and covered by colluvium into which they recharge.

Abrupt west edge of alluvium

- In the mid-north of the survey site the creek passes right up against the west side of the alluvium – seen here in this west looking photo.

Creek cut into alluvium

- North of the olive groves the creek cuts into the alluvium

Alluvium of gravels and mud.

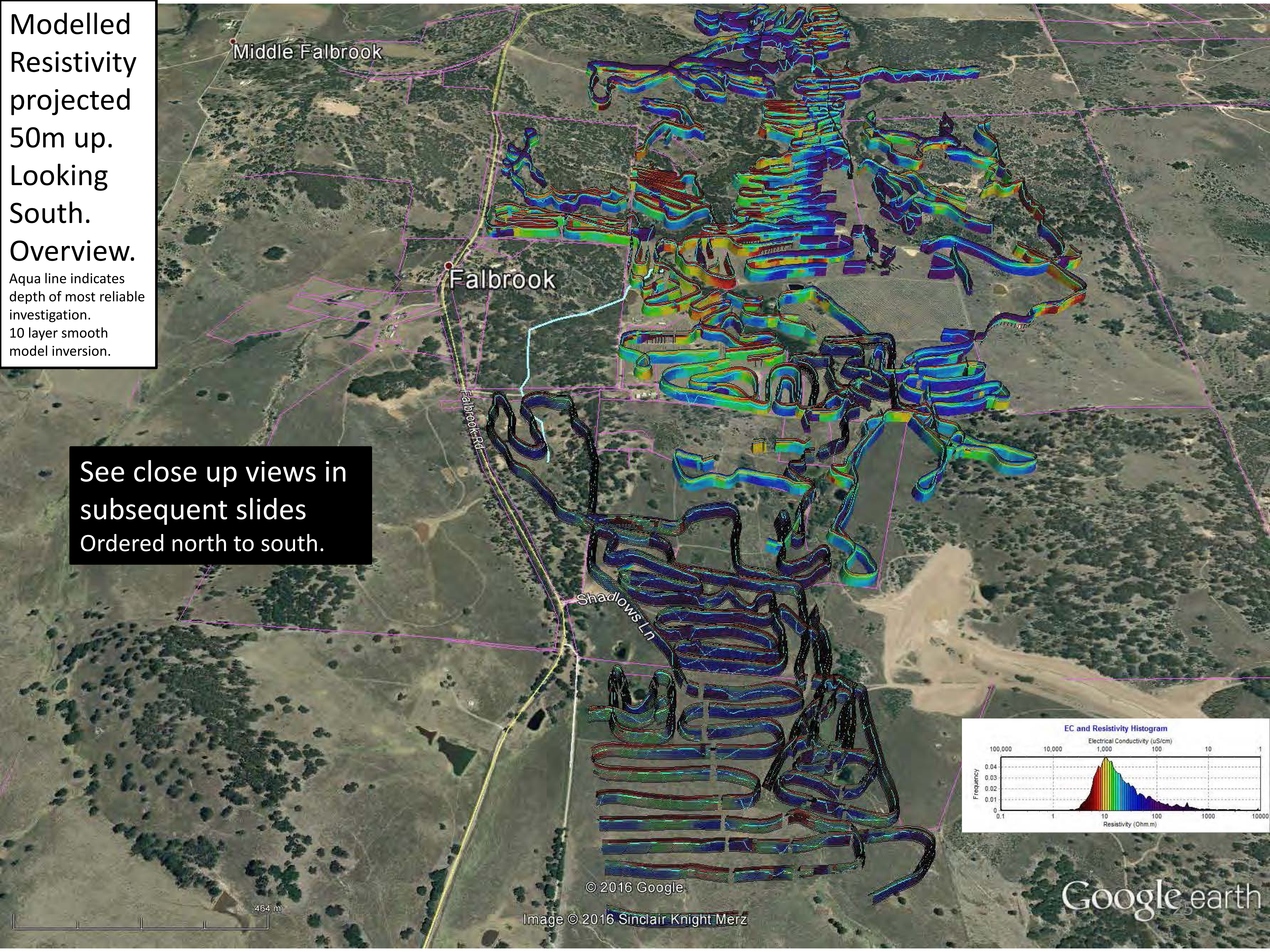
- The alluvium consists principally of gravels (bedload) impregnated with mud (suspended load). At the top it grades into an established soil without gravel.

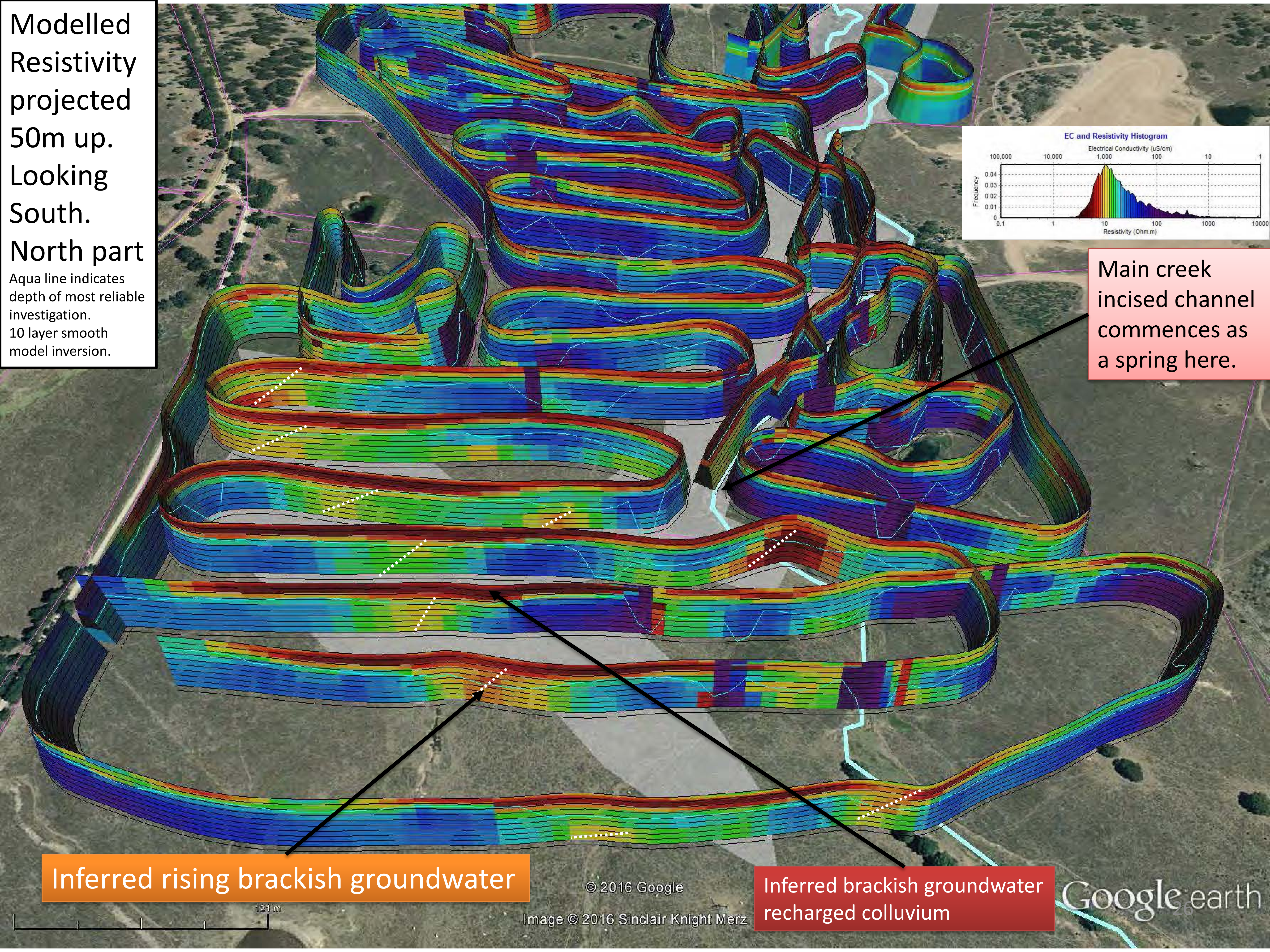
The electrically resistive feature.

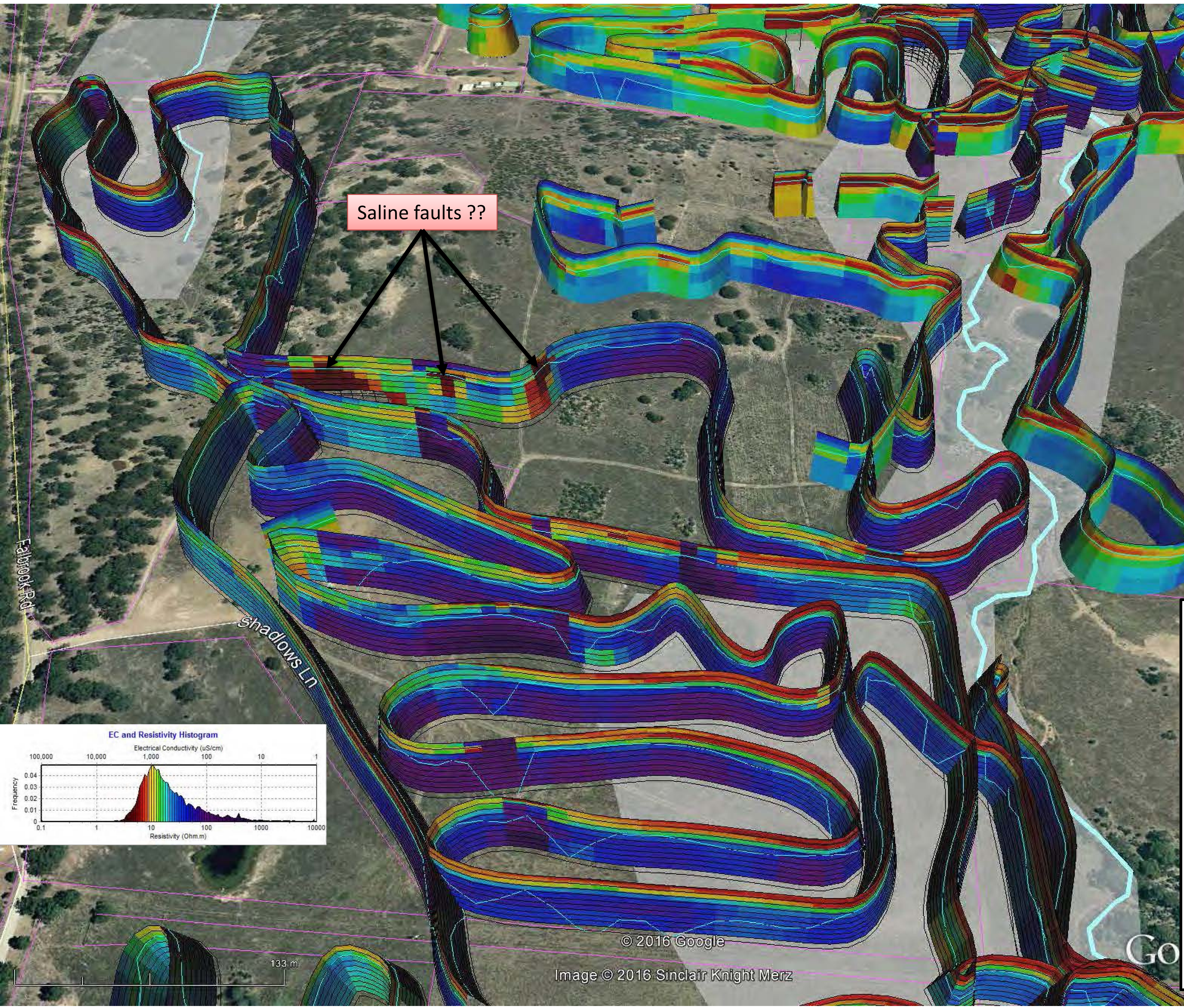
- Conglomerate exposed at the south end of the survey site within the deep resistive feature – inferred to be a westerly dipping silicified facies including such conglomerate layers. The conglomerate is polymictic, subrounded and poorly sorted.

Three dimensional presentation

- In order to understand the TEM data, it has been plotted in 3D. This helps with observation of the geometry of features in vertical transects.
- The curtain images are simply projected 50m up from the Google Earth DEM. The data is plotted against depth but draped over the Google Earth DEM.

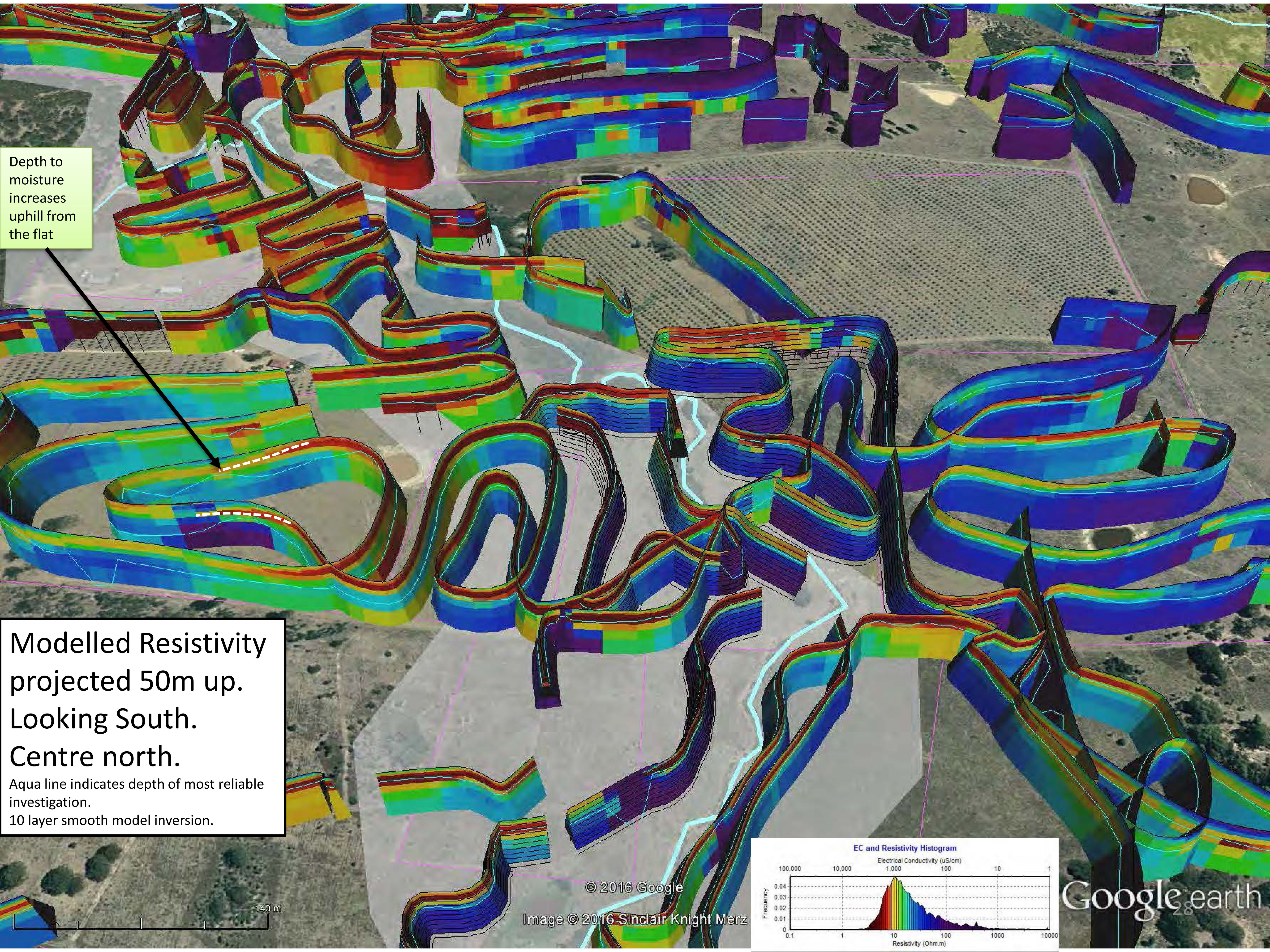

Modelled Resistivity projected 50m up. Looking South. Overview.
Aqua line indicates depth of most reliable investigation.
10 layer smooth model inversion.
Middle Falbrook
Falbrook
Falbrook Rd
Shadlows Ln
See close up views in subsequent slides
Ordered north to south.
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
100,000
10,000
1,000
100
10
1
Frequency
0.04
0.03
0.02
0.01
0
0.1
1
10
100
1000
10000
Resistivity (Ohm.m)
464 m
© 2016 Google
Image © 2016 Sinclair Knight Merz
Google earth

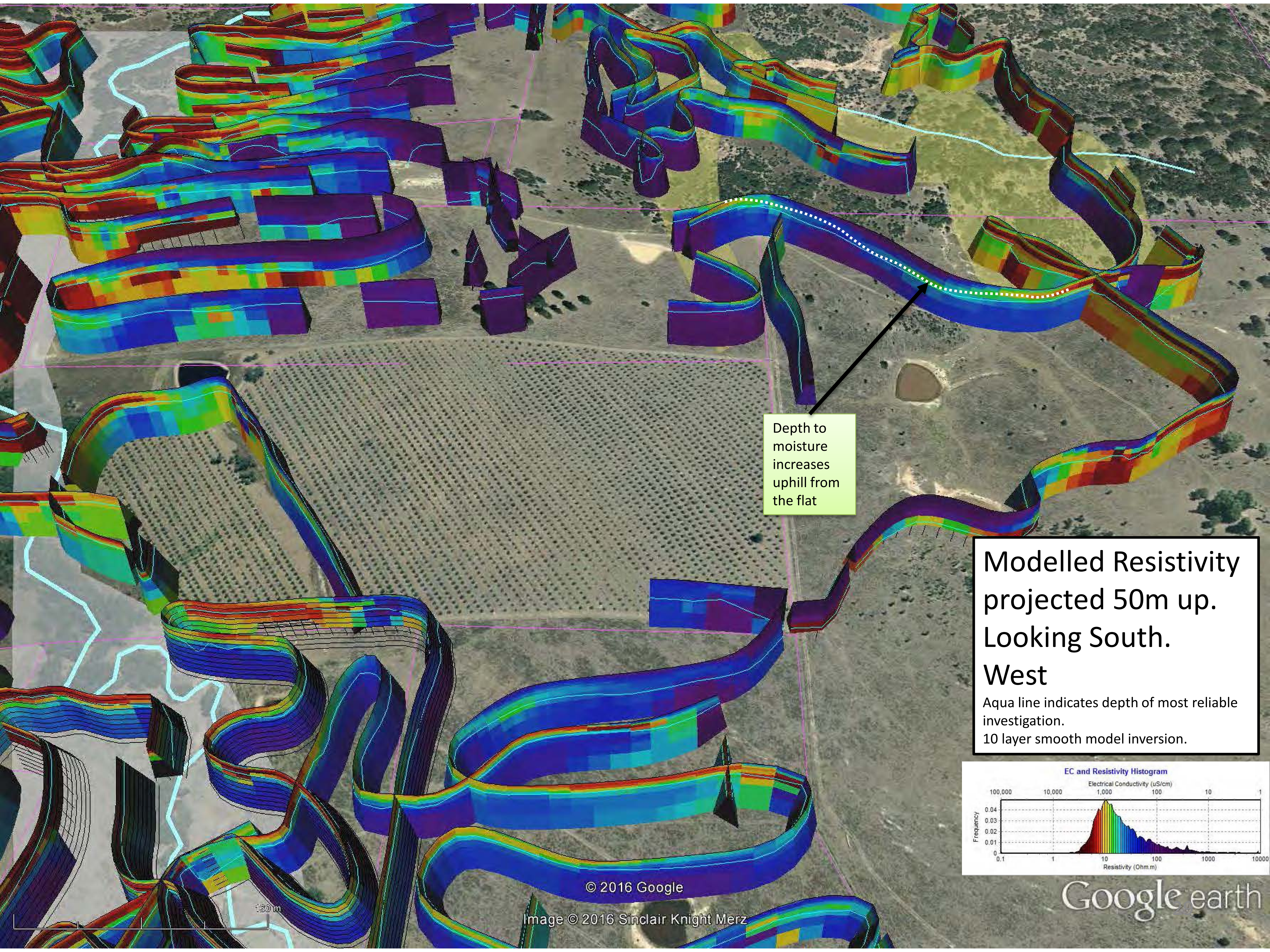

Modelled Resistivity projected 50m up. Looking South. North part
Aqua line indicates depth of most reliable investigation.
10 layer smooth model inversion.
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
100,000 10,000 1,000 100 10 1
Frequency
0.04 0.03 0.02 0.01 0
0.1 1 10 100 1000 10000
Resistivity (Ohm.m)
Main creek incised channel commences as a spring here.
Inferred rising brackish groundwater
Inferred brackish groundwater recharged colluvium
121 m
© 2016 Google
Image © 2016 Sinclair Knight Merz
Google earth

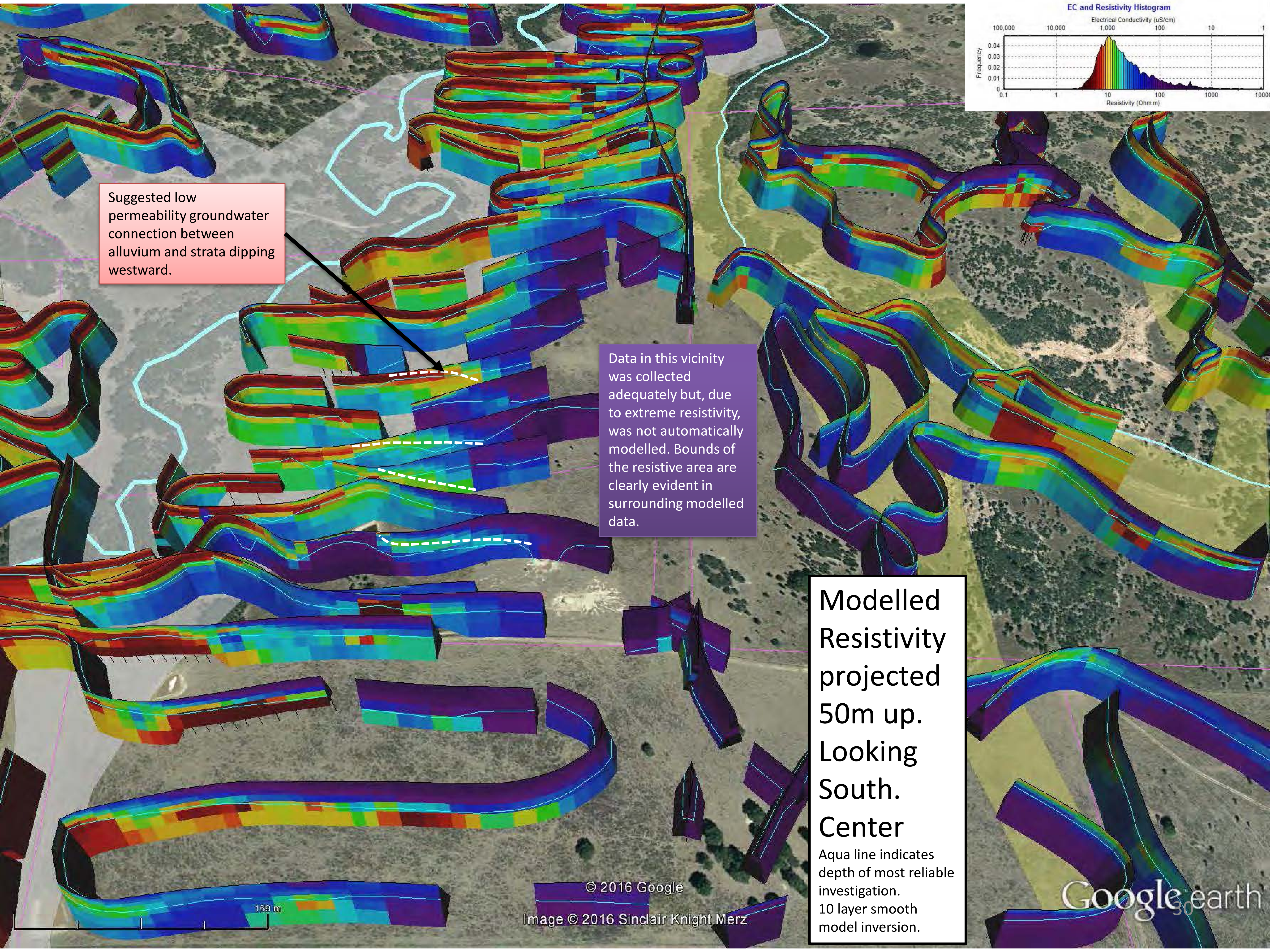


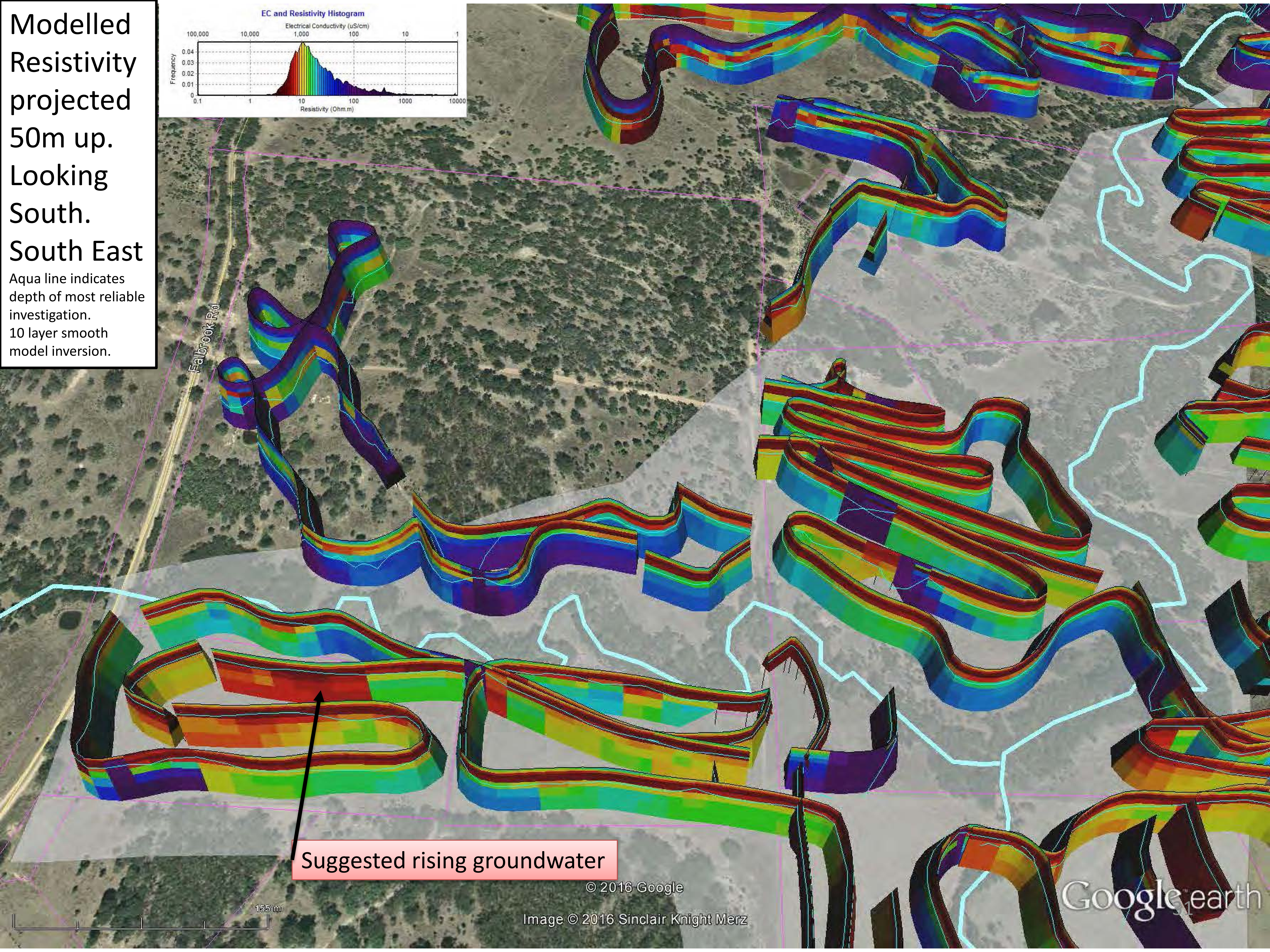
Modelled Resistivity projected 50m up. Looking South. Mid North

Aqua line indicates depth of most reliable investigation.
10 layer smooth model inversion.

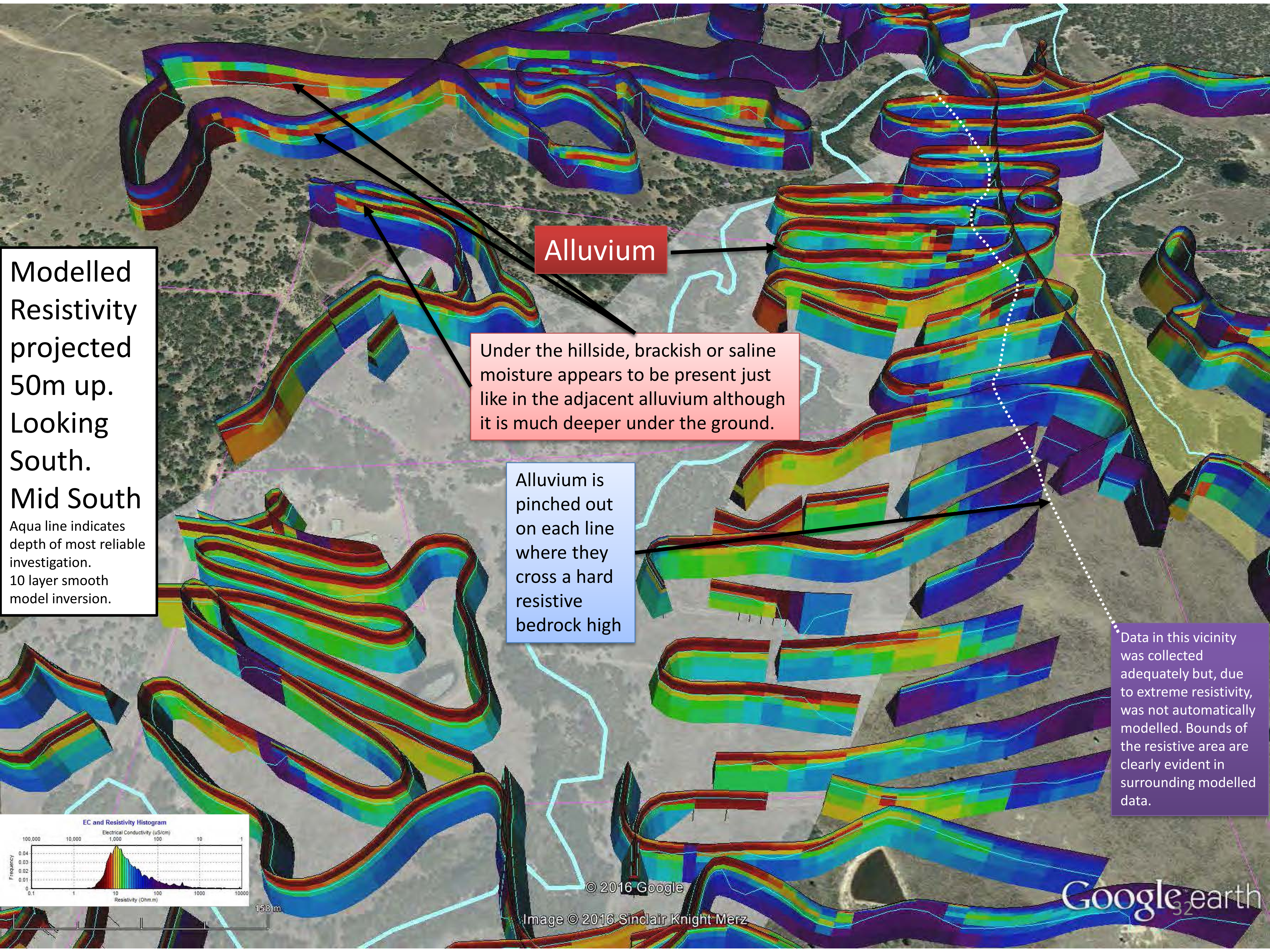

Depth to moisture increases uphill from the flat
Modelled Resistivity projected 50m up.
Looking South.
Centre north.
Aqua line indicates depth of most reliable investigation.
10 layer smooth model inversion.
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
Frequency
Resistivity (Ohm.m)
© 2016 Google
Image © 2016 Sinclair Knight Merz
140 m
Google earth


Depth to moisture increases uphill from the flat
Modelled Resistivity projected 50m up. Looking South. West
Aqua line indicates depth of most reliable investigation.
10 layer smooth model inversion.
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
100,000
10,000
1,000
100
10
1
Frequency
0.04
0.03
0.02
0.01
0
0.1
1
10
100
1000
10000
Resistivity (Ohm.m)
© 2016 Google
Image © 2016 Sinclair Knight Merz
Google earth

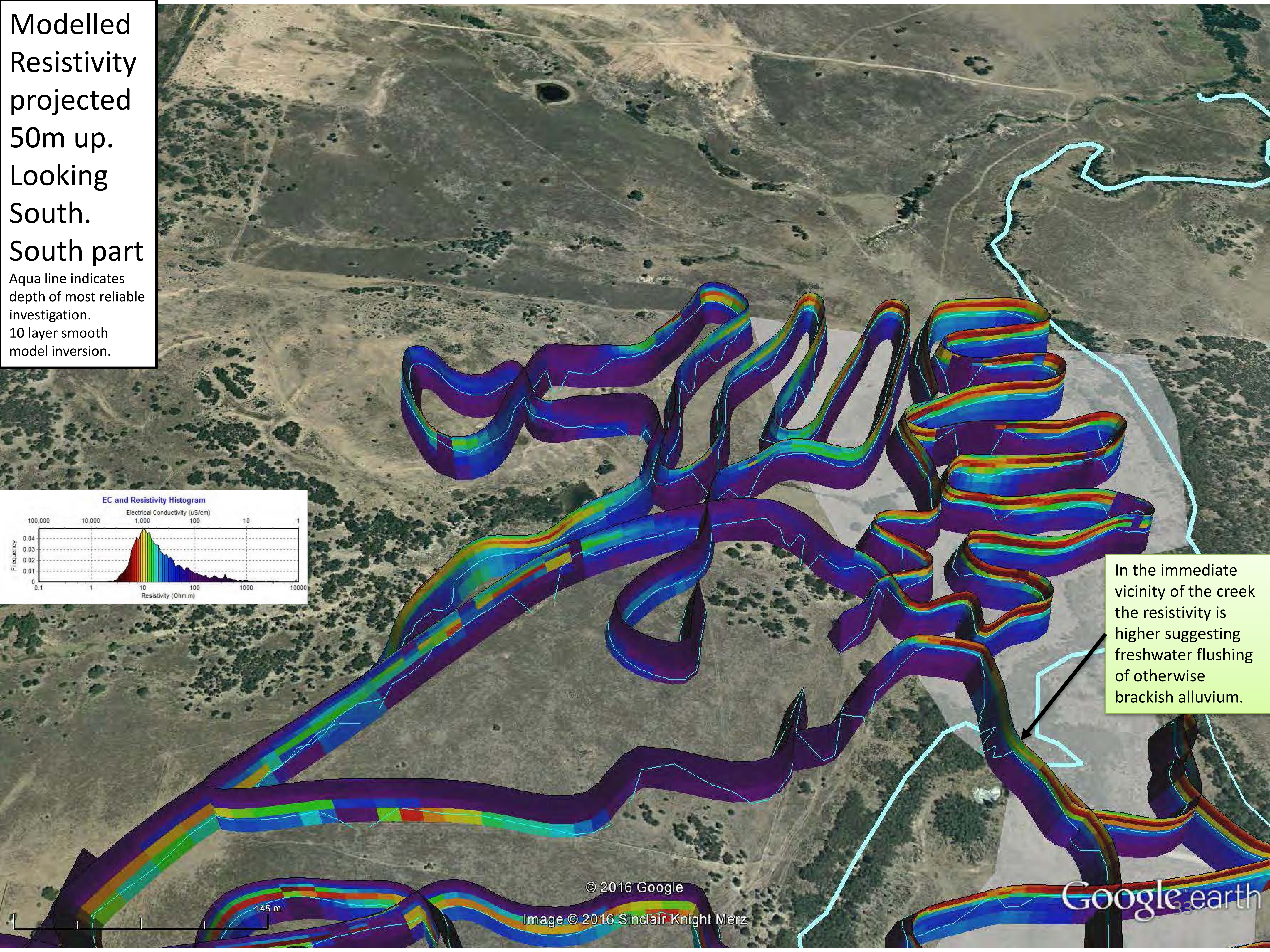

EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
100,000
10,000
1,000
100
10
1
Frequency
0.04
0.03
0.02
0.01
0
0.1
1
10
100
1000
10000
Resistivity (Ohm.m)
Suggested low permeability groundwater connection between alluvium and strata dipping westward.
Data in this vicinity was collected adequately but, due to extreme resistivity, was not automatically modelled. Bounds of the resistive area are clearly evident in surrounding modelled data.
Modelled Resistivity projected 50m up. Looking South. Center
Aqua line indicates depth of most reliable investigation.
10 layer smooth model inversion.
169 m
© 2016 Google
Image © 2016 Sinclair Knight Merz
Google earth



Modelled Resistivity projected 50m up. Looking South. South East
Aqua line indicates depth of most reliable investigation.
10 layer smooth model inversion.
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
100,000
10,000
1,000
100
10
1
Frequency
0.04
0.03
0.02
0.01
0
0.1
1
10
100
1000
10000
Resistivity (Ohm.m)
Fallbrook Rd
Suggested rising groundwater
© 2016 Google
Image © 2016 Sinclair Knight Merz
Google earth
155 m



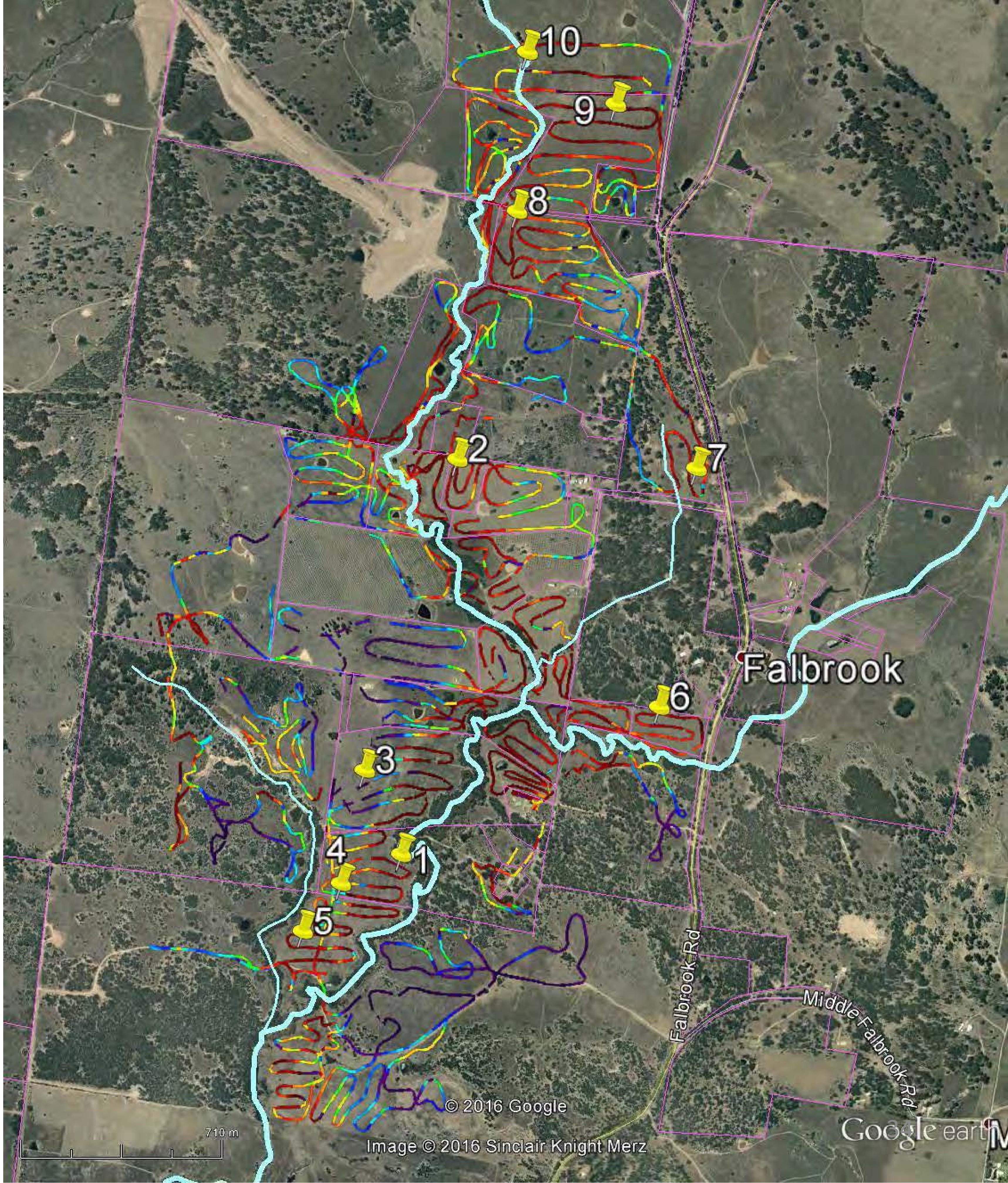
Alluvium
Under the hillside, brackish or saline moisture appears to be present just like in the adjacent alluvium although it is much deeper under the ground.
Modelled Resistivity projected 50m up. Looking South. Mid South
Aqua line indicates depth of most reliable investigation.
10 layer smooth model inversion.
Alluvium is pinched out on each line where they cross a hard resistive bedrock high
Data in this vicinity was collected adequately but, due to extreme resistivity, was not automatically modelled. Bounds of the resistive area are clearly evident in surrounding modelled data.
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
Frequency
Resistivity (Ohm.m)
158 m
© 2016 Google
Image © 2016 Sinclair Knight Merz
Google earth


Modelled Resistivity projected 50m up. Looking South. South part
Aqua line indicates depth of most reliable investigation.
10 layer smooth model inversion.
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
100,000
10,000
1,000
100
10
1
Frequency
0.04
0.03
0.02
0.01
0
0.1
1
10
100
1000
10000
Resistivity (Ohm.m)
In the immediate vicinity of the creek the resistivity is higher suggesting freshwater flushing of otherwise brackish alluvium.
145 m
© 2016 Google
Image © 2016 Sinclair Knight Merz
Google earth

Suggested pit sampling sites.

See kmz file for coordinates.

1. Deep alluvium/regolith
2. Deep alluvium/regolith
3. Impermeable dry strata
4. Shallow alluvium over impermeable dry strata
5. Deep alluvium/regolith west of the divide
6. Alluvium/regolith – eastern tributary
7. Alluvium/regolith – NE tributary
8. Alluvium/regolith – North
9. Colluvium over rising groundwater source
10. Main creek on northern colluvium



Conclusion

- Mud clogged gravel alluvium is present along Main Creek and its tributaries at depths between nil, in the north, to many metres, in the south.
- A north-south impermeable westerly dipping strata outcrops and subcrops adjacent to main creek alluvium, to the west in the north, and to the east in south. Where Main Creek crosses this strata, at the confluence with a creek entering from the west, the alluvium is very thin – the impermeable strata appears to be a barrier to groundwater flow.
- Rising brackish groundwater recharges colluvium and alluvium along linear features – the most prominent one being in the far north at a break of slope on the hillside.
- A list of pit sampling sites is given for recommended enhancement of interpretation of the geophysical data.

Appendices

- Production Report
- Identifying depths on ribbon images
- Towed Transient Electromagnetic schematic
- TEM platform configuration schematics
- TerraTEM specifications

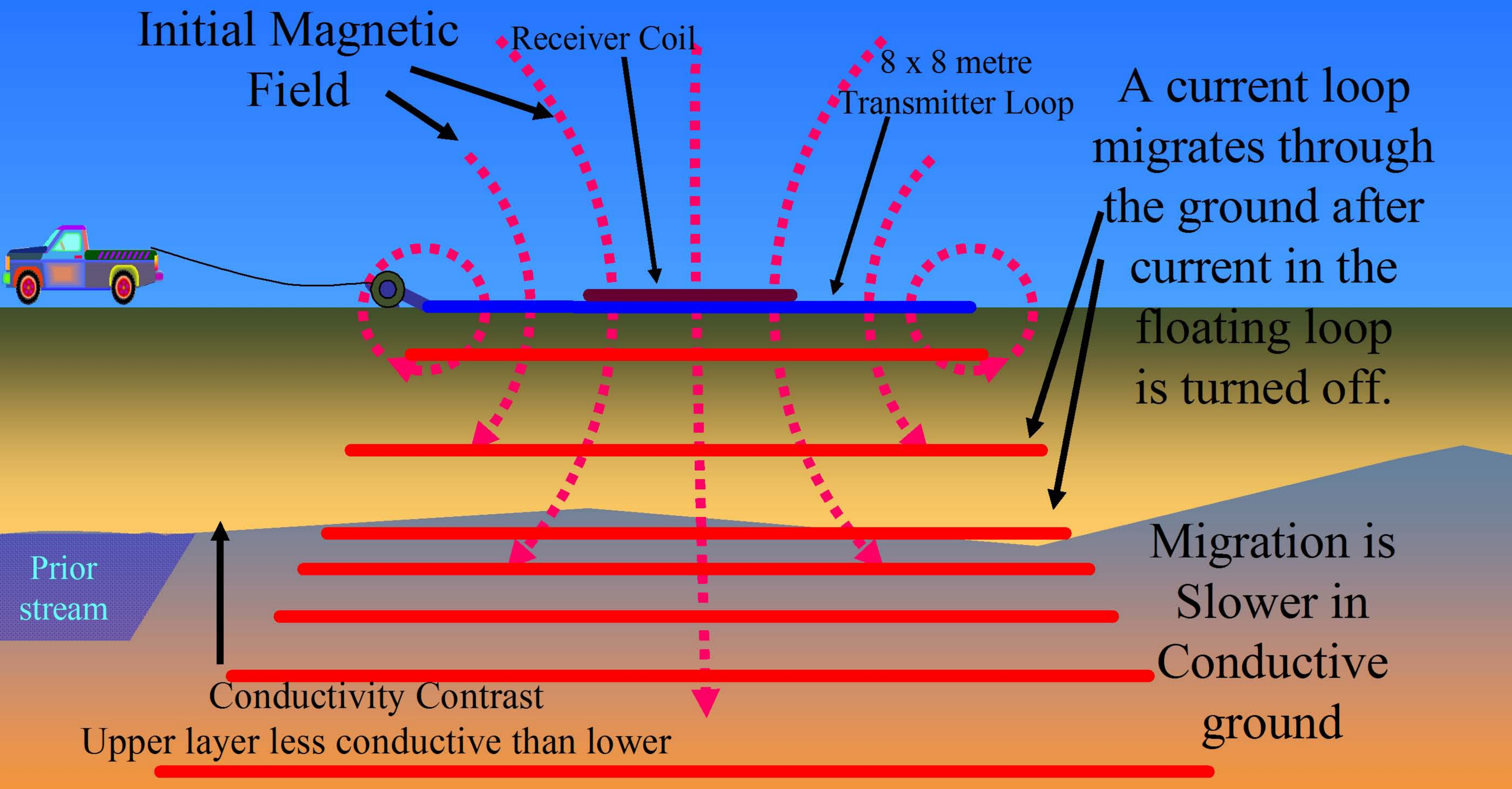
Production Report

Date	Charge	Details
14/02/2017	Induction/ Mobilization	Travel Dubbo to Mudgee for Generic Induction. Continue to Singleton via Lue due to multiple road blockages by separate bushfires.
15/02/2017	Production	7.30 am site induction. Proceed to site 9.00 am. Setup. Lose 3 hours due to CMOS battery failure. Survey in late afternoon. Bogged at 5.30pm and departed by 9pm. Production – survey north area. Decide to charge full production due to long day.
16/02/2017	Production	AgTEM survey of Central Area. 6.30am to 5.00pm
17/02/2017	Production/ Demobilization	AgTEM survey of South then roving infill survey. 6.30am to 6pm (returned key). Required offsite by 5pm and not return during weekend due to supervisory limitations. No accommodation available over weekend due to local Bruce Springsteen concert. Remaining infill and eastern extension abandoned. One hour lost due to stop work and depart requirement during thunderstorm at mid-day. Violent thunderstorm in early evening – local bushfire risk. Golden Highway open again with bushfire now under control – demobilize overnight.

Total TEM production distance excluding gaps >40m and data excluded due to metallic interference = 75 km

Only the central nulled receiver loop was fitted, slingram being omitted to improve productivity and due to lack of need for deeper data.

Towed Transient Electromagnetic System



Small AgTEM prototype for shallower surveys

USA patented.

The trailer must be largely non-metallic for TEM survey.

Booms holding the large horizontal transmitter loop are held in place by elastic cords that yield and spring back upon tree or rock impact.

The drawbar is an arrangement of fibreglass tube and tensioned kevlar ropes.

TEM Method Details

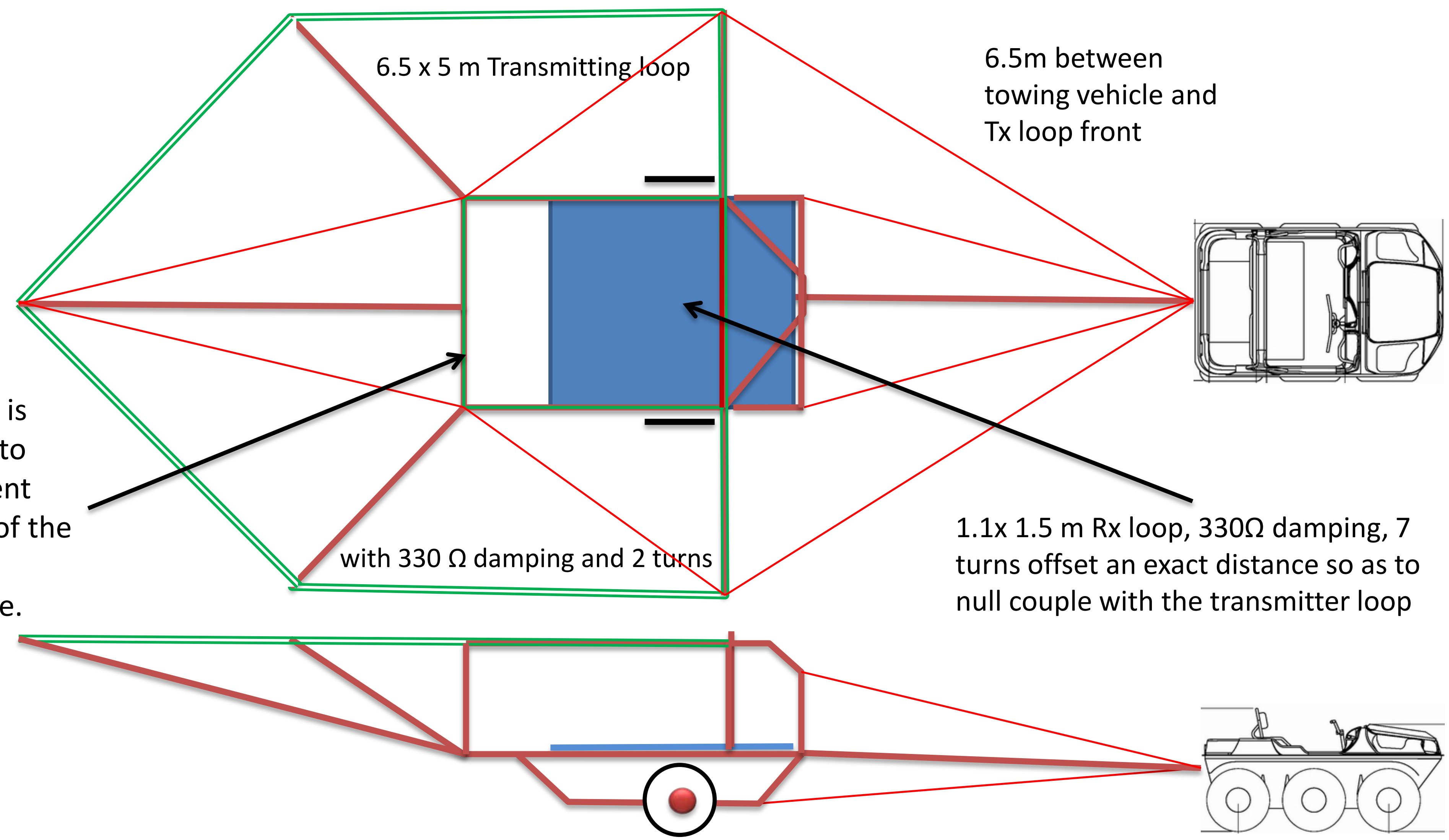
- A schematic of a towed transient electromagnetic survey system is provided on the next slide. Electrical current is pulsed through a large transmitter loop and each pulse induces a 'smoke ring' of current in the ground below as it turns on and off. As the 'smoke ring' dissipates out into the ground its magnetic field decays and it is the decay of this magnetic field, along with the decay of the magnetic field resulting from the transmitter loop, that is detected by various receiver loops. The decay is abated by conductive layers and enhanced by resistive layers in the substrate.
- The system used on this job, photographed on the previous page, had a 2 turn 6.5 x 5m transmitter loop with a centrally located receiver loop under the indented front of the transmitter loop and in a null coupled arrangement. The system was operated using a Monash Geoscope TerraTEM with an accelerated transmitter (to see shallower features) called TEMTx32, the continuous acquisition option, a Trimble AgGPS114 receiving Omnistar DGPS corrections and several truck batteries for power supply. The system was towed by a Landrover Defender separated from the equipment by a 5.5m fibreglass boom and rope assembly. The receiver loop had a 330 ohm damping resistor across it as did the transmitter loop and 16.5 Amps was driven though the two turn Tx loop. The receiver also had a pre-amp with a 60 kHz low pass filter invoked.
- Processing of this data involves numerous steps presented in a the next slides. The main steps are removal of movement noise, primary field stripping, cleaning of the data (removal of data mainly affected by metallic objects etc.), spatial smoothing, modeling to transform the voltage versus time data to smoothness constrained layers of resistivity versus depth, more data cleaning, gridding and presentation. The principle step is the transformation (matrix inversion) which is carried out using the Aarhus Hydrogeophysics Group algorithm EM1DInv.

Transient EM equipment configuration

6.5 x 5 m transmitting loop towed TEM system

Plan view

Vertical section



Exact loop dimensions

To avoid intellectual property loss, the exact loop dimensions have been displayed separately in a file SoilImagerJustTheLoops.png which is not openly distributed.

Transmitter loop suspension arms are attached elastically to prevent attrition upon impact with trees. Arms may be raised from the towing vehicle and fold inwards for obstacle avoidance and for compact transport when not surveying. The trailer draw-bar is detached for between-job transport. The trailer is lightweight and can be lifted by one person. Attrition is also avoided by addition of a breakaway pin. **Australian Patent Pending.**

General Processing Sequence

Define System Geometry

–

1. Quality control and data parsing during acquisition
    1. At the beginning of each day, select a reference sounding and plot it along with all incoming data.
    2. Watch all incoming data constantly making comparison with the reference sounding.
    3. Cancel acquisition or note problems as noise sources, metal artefacts, or equipment malfunctions are encountered. Alter course across ground to both more clearly define noise and artefacts and to subsequently avoid them.
    4. Each night, convert BIN file into TEM and TXT files and back them up.
    5. Each night, display selected channels of the data in plan view to appraise layout of geological features and any present geophysical artefacts.
2. Acquire system response from data obtained (stacked then averaged) in a very resistive area. If a very resistive area is not available then a larger hand laid loop is laid, ideally at the most resistive low horizontal gradient location in the survey area, a sounding taken (generally in slingram mode to avoid in-loop enhanced effects such as system response itself, induced polarization and super-para-magnetic effect. Then data from that loop is inverted to give a modelled response which is then used to calculate the equivalent response for the cart configuration. That response is then subtracted from the actual measured cart response at that site to give approximate system response of the cart.
3. Determine EM1DInv inversion software initial model, constrains and control parameters.
4. –
5. Operations performed on TEM files
    1. Basetrend removal (optional – only possible on moderately to highly resistive areas). This removes movement noise from the receiver coil moving through the magnetic field of the earth slowly. Some large mat receiver loops and other structures that do not vibrate do not create much movement noise. Basetrend removal is conducted by using a timebase of acquisition much longer than necessary so as to sample basetrend during acquisition by regression analysis of the part of the stacked records beyond where the decays drop well into the noise envelope.
    2. Adjust magnitude according to primary field response (optional). This is not appropriate and not done with nulled coils but is useful when using slingram coils.
    3. Reject records with low or high primary field response as they are clearly suffering from equipment malfunction (eg. Receiver loop blown over by wind) (optional). This may be conducted automatically or manually by visualizing a primary field channel on a map display and culling all soundings showing anomalous primary field.
6. Convert TEM file into a relational voltage database (*Volt.DBF, *XVolt.DBF,*YVolt.DBF)
7. Normalize data using average magnitude of log10(data) from a small receiver placed directly on the transmitter loop wires (*YVolt.DBF) (This is optional as the data is already normalized according to current monitored (every 10 soundings in 2014 version of TerraTEM firmware)).
8. Remove system response, optionally taking magnitude of transmitted data (proportional to *YVolts.DBF) into account for every sounding - again this option is not appropriate for nulled coils.
9. –
10. Display voltage data, in map view, coloured to represent magnitude of a particular channel. Simultaneously view decay plots of picked soundings, along with a reference sounding.
    1. Interactively remove geophysical artefacts by clicking on points or data segments.
    2. Display automatically updates - repeat a.
    3. Repeat a,b. until satisfied that data is suitably cleaned.
    4. Interactively clip channel count on soundings with procedure as for a., b. and c. (optional).
11. Smooth voltage data horizontally. Trapezoidal filtering is ideal (optional). Note well that this step is conducted after removal of artefacts which would have spread their mess throughout the data if

(eg. Voxler).

35. Grid and display depth slices, stacked if required in 3D space (Surfer).
36. Organize and refine KML files in Google Earth and select enhanced snapshot views. Combine into a folder and collectively output as a new KMZ file. The KMZ files are compact - Email to interested parties.
37. Collect all graphics in MS Powerpoint (A3 resolution!) and create a report. Make a summary report in MS Word (optional). Generate PDF report.
38. Package job DVD and printing, mailing etc.

Transient EM equipment specifications

Alpha GeoInstruments

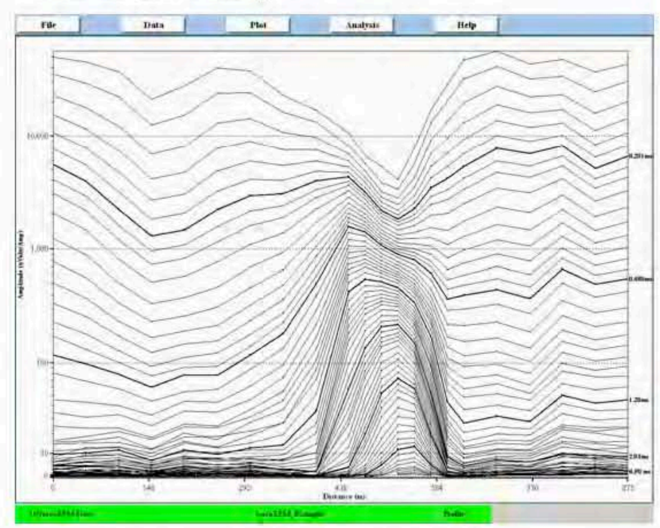
terraTEM
Time-Domain EM
Surveying System

terraTEM Features

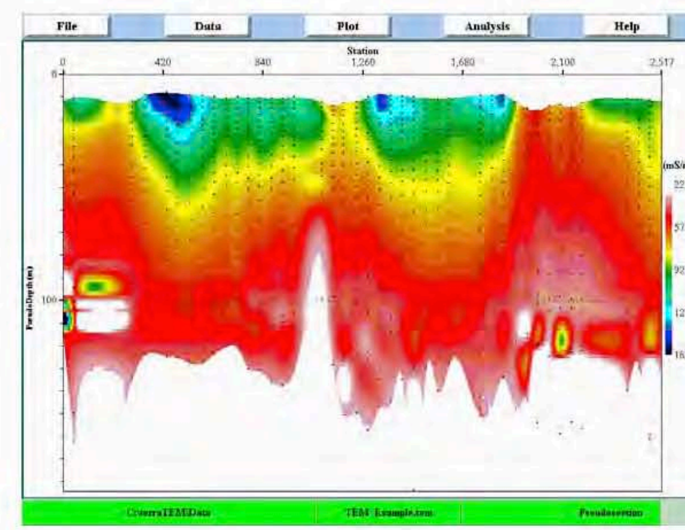
- Transmitter and receiver in one unit
- Single or 3 channel receiver with 10 amp. transmitter
- High speed sampling at 500 kHz for superior near surface resolution
- Easy to use touch screen with auto set-up and smart menus
- Large 15" LCD display for data visualisation
- Fast and easy data transfer via USB port
- Integrated 12 channel GPS system for seamless station positioning (option)
- Integrated PC for data visualisation, data processing, and interpretation in field using built-in software
- Rugged construction with external 24 V battery power pack and charger
- Several optional extras to broaden capability
- Designed and built in Australia

Screen Dumps

The following are a number of screen views from the **terraTEM** system.



Full control of all aspects of data display, post-survey filtering, and decay curve analysis



Multiple display formats, including gridding and raster images (options)

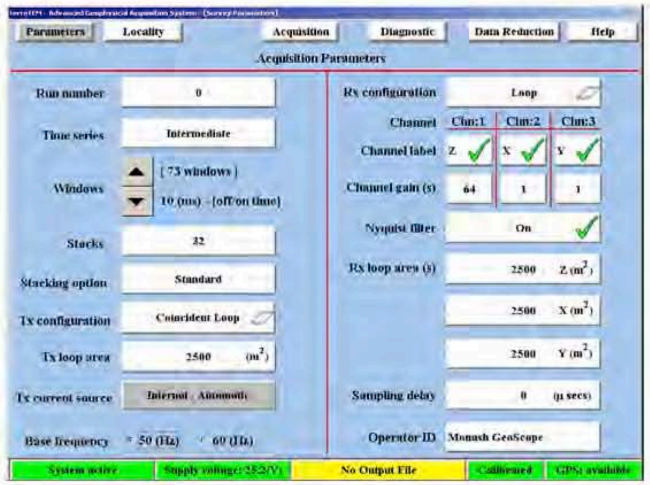
The **terraTEM** is designed, developed and manufactured by **Monash GeoScope**

Monash GeoScope

Applications

The **terraTEM** can be used for various applications including the following:

- Mineral exploration
- Near surface including geo-technical and engineering investigations
- Groundwater and salinity studies
- Environmental surveys



Easy access to all parameters, multiple binning and stacking options; smart menu system.

Internal GPS, for positional accuracy (option)

General Specifications

	terraTEM	Options
Transmitter Output	10 Amps. (max.)	**Enhanced Transmitter**
Receivers	1 Channel	**3 Channels (simultaneous)**
High Resolution Sampling Rates	500 kHz	-
User Selectable Multiple Time Gates	-	**Option**
Data Visualisation and Processing in field	Standard Software	**Enhanced Software**
Storage Device – 1 GB Flash Disk	Standard	-
GPS Receiver – 12 channel	-	**Option**
Communications – Port for Data Transfer	USB and RS-232 Standard	-
External Synchronisation	-	**Option**
Continuous Recording (with external GPS Interface)	-	**Option**
Extra Stacking Options and Gain Functions	**10 Selectable Gain Settings from 1 to 8,000**	**Auto Gain**
Vectem 3 Interface Module (for down-hole surveying)	-	**Option**
Interface Options (third party devices)	-	**Option**
Dimensions: Console: 530 x 350 x 160 mm. 13 kg. Battery Box: 280 x 250 x 180 mm. 12 kg.		
Operating Temperature: -10 to 40 degrees C.		

Further Information

For further information regarding this product, either technical or sales, please contact:

Alpha GeoInstruments

Unit 1, 43 Stanley Street, Peakhurst. N.S.W. 2210. Australia
Phone +61 (0) 2 9584 7555 **Fax** +61 (0) 2 9584 7599
e-mail info@alpha-geo.com **website** www.alpha-geo.com

Your Distributor:

terraTEM
Technical Specifications

Transmitter

Output	15 Amp. (max.)
On/Off Period	Adjustable 10 ms (50 Hz) or 8.33 ms (60 Hz) increments

Receiver

Sampling	500 kHz per channel, fixed
Inputs	+/- 40 V maximum continuous voltage
Gain	User selectable fixed gains Other Gains Optional
Resolution	Maximum 28 bits, effective
Functions Measured	Tx/Rx loop resistance, Tx current, Tx turn-off time, battery voltage, automatic gain/offset calibration, transient response

Console

Display	LCD TFT, 15 inch
Touch Screen	Splashproof
Storage	1 GB flash RAM

External Interfaces

Communications	USB and Serial port for data transfer

Equipment Supplied

- Console
- Loop connectors
- Battery Pack (24 volts), complete with connector cable (overseas batteries not included)
- Battery charger
- USB flash disk (for data transfer)
- Operations manual

Sensor Attachments Available

Surface Receiver	RVR-1 or cable loop
Downhole	Vectem 3 or equivalent

Physical

Housing	Aluminium "Zero" case
Console: Weight	13 kgs.
Dimensions	530 x 350 x 160 mm.
Battery Pack: Weight	12 kgs.
Dimensions	280 x 250 x 180 mm.
Operating Temperature	-10 to 40 degrees C.

Options

GPS Receiver	12 channel receiver
Multi-channel Receiver	3 channel simultaneous A/D
External Transmitter Interface	External synchronisation option (for use with TEMTX-32, Zonge high powered transmitters)
Vectem 3 Interface	Internal interface module
Continuous Recording	Continuous recording of unit with external GPS interface using NMEA standard
Software Packages	Extra Stacking Options, Sferics Rejection and Gains, Spectral Analysis and Digital Signal Processing User-defined time series

Further Information

For further information regarding this product, either technical or sales, please contact:

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e-mail info@alpha-geo.com **website** www.alpha-geo.com

Your Distributor:

Alpha Geoinstruments is a division of Alpha Geoscience Pty. Ltd. (ABN 14 080 819 209)
The above Technical Specifications could change without notice.

How do I interpret the imaging

Image types and the common colour scale

Imagery has been presented as both 3D ribbons and 2D map views. Both are presented with and without satellite imagery backgrounds. The same EC colour scale has been used for all the imagery so that it is all directly comparable. This scale was derived by binning all the data in a histogram of EC and then spreading the colour evenly over the histogram (equal area colour distribution).

2D map imagery is of three types:

- EC slices at constant depth below the canal water surface;
- EC slices at constant depth below the canal bed; and
- Maximum EC of any layer intersected. This type is designed to give, **as low EC anomalies**, a rough indication of the most likely prolific seepage pathways.

Background satellite imagery has been added to many images using Google Earth. It is useful for locating seepage pathways in relation to features on the ground. For instance, particular types of trees, or anomalous crop vigore may indicate groundwater seeped from a nearby seepage pathway. Salinity scalds, evident on the imagery, may also be related to seepage pathways.

Files have been supplied so that users can image the data themselves in Google Earth, HydroGeoImager (available from the author), ESRI products or other products capable of reading dBase files, ESRI Shapefiles or CSV ASCII files.

Hints on use of these images

This document is a Microsoft Powerpoint Presentation supplied on the attached CD. Cutting and pasting these images from this document to other computer programs is best done by selecting the actual images rather than the slides because powerpoint desamples cut and pasted slides. Alternatively you may print to a hi-res PDF file.

In powerpoint, you will get an animation effect as you page through the depth slice image slides (back and forth as you please). It is much easier to compare the slices using this animation effect than it is on paper.

Data files and GIS integration

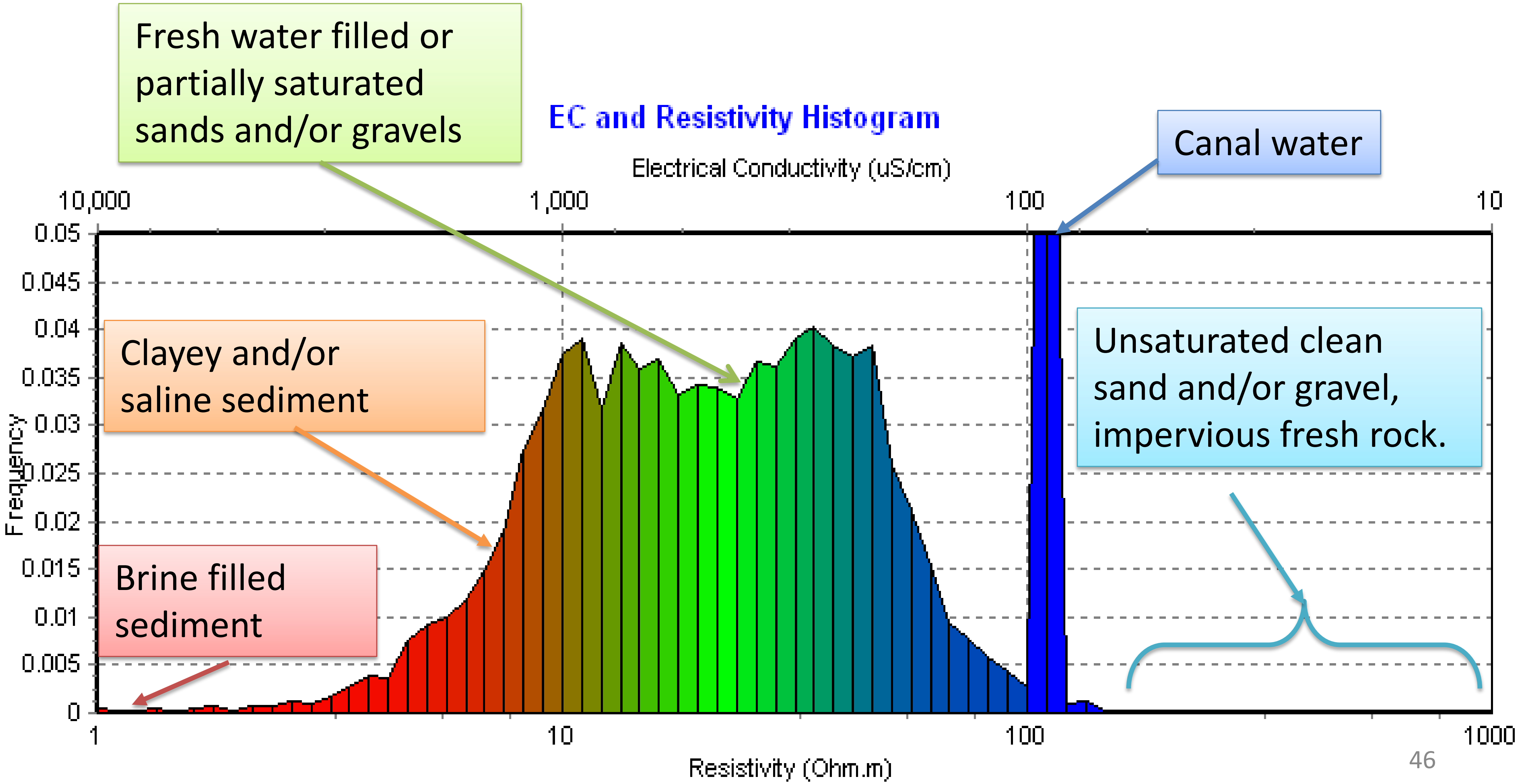
Accompanying data files in dBase IV format can be loaded in and out of MS Excel. The format has been chosen because it is easy to load into ESRI ArcView products. The final data is labelled *Ohmm.dbf and is of course in units of Ohm.m, the reciprocal of Siemens per metre. Each resistivity column is accompanied by a depth column indicating the base of the layer of that resistivity. Simple queries can be used to make a multitude of meaningful themes for adding to GIS images. Google Maps and Google Earth may be used for viewing some themes in the KMZ files supplied (zipped KML files). CSV (Comma Separated Variable) files of depth below bed slices also are supplied and may readily be loaded into most packages including Golden Software Surfer and ESRI ArcMap.

Where exactly am I looking?

In most cases, data may be located by identifying features such as fences and trees on the satellite imagery, however, accurate locations may be attained by loading files into Google Maps, Google Earth, ESRI products such as ArcMap or free ArcExplorer or even by loading the dBase files into Microsoft Excel. The viewer will find functions in most of these products that allow them to save sites they click with the mouse to a text file of co-ordinates which can then be loaded into a GPS receiver or printed as a list.

Imagery color scale and histogram calculated for all data collected from all canals in the Irrigation Scheme

EC has been represented by a colour scale ranging from red, through green to blue with red representing the higher EC values. A histogram of EC values of all the data collected was generated and colour was distributed across that histogram so that each colour in the colour scale representing EC filled an equal area of the histogram. This has resulted in all important features in the datasets being visible.

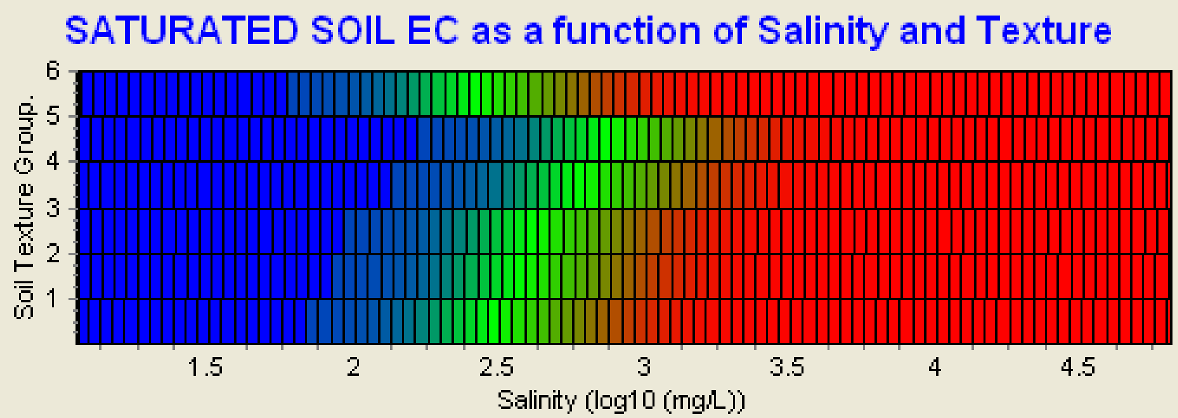


Understanding the 3D graphics

Sediment texture and Pore Water Salinity

6: Water
5: Sands <10%Clay
4: Sandy Loams 10-25% Clay
3: Loams 25-30% Clay
2: Clay Loams, Light Clay 30-45% Clay
1: Medium, Heavy Clays >45% Clay

For any histogram of EC, we can show what colour is generated by various combinations of soil texture and salinity in saturated sediment using an empirically derived algorithm.



and using a Salinity conversion factor mg/L / uS/cm of 0.64.
After Slavich & Petterson - Aust J. Soil Res., 1993, 31, 73-81

Bore Lithology Graphics

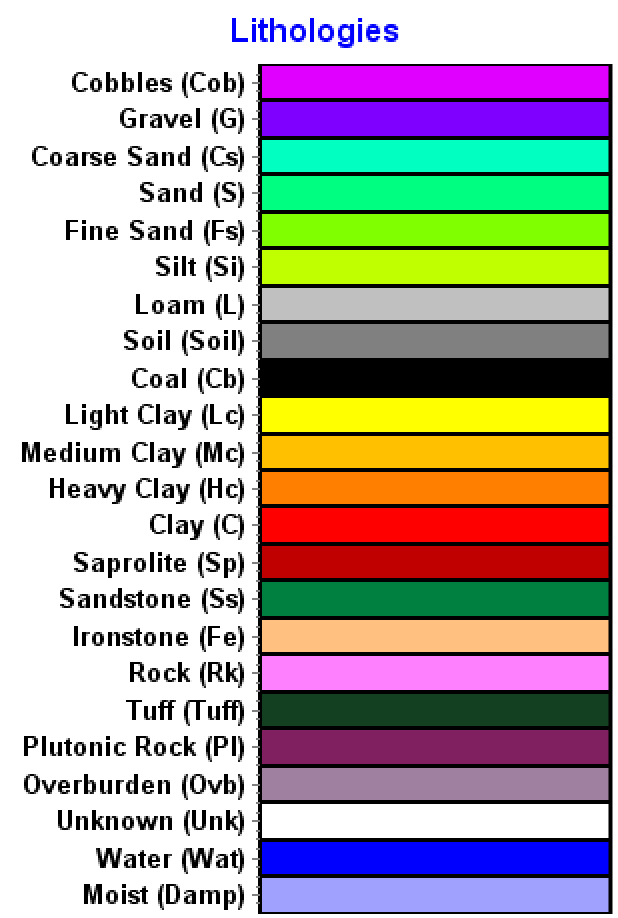
In the images, bore logs are displayed graphically using lithology keys such as the one given here.

Lithologies have been extracted from drillers written logs using an automated text interpreter. Due regard to the limitations and quality of this source of data and the interpretation process must be given.

Many lithologies have been presented with composite codes – eg. a Sandy Light Clay hosting water would display the codes for Sand, Light Clay and Water. Alternatively the driller may have given a water level. In this case the water level would be displayed at a horizontal blue plane.

Beware that the images are either not elevation corrected, or, if displayed in Google Earth, corrected only using the coarse Google Earth DEM. Because rivers are normally incised, imagery beneath them should normally be compared to lithologies about 10m lower in the bore logs.

In Google Earth, you can turn the icons and lithology key on/off. If you click on an Icon it displays a text box of any available bore details (water level, salinity, lithologies etc.).

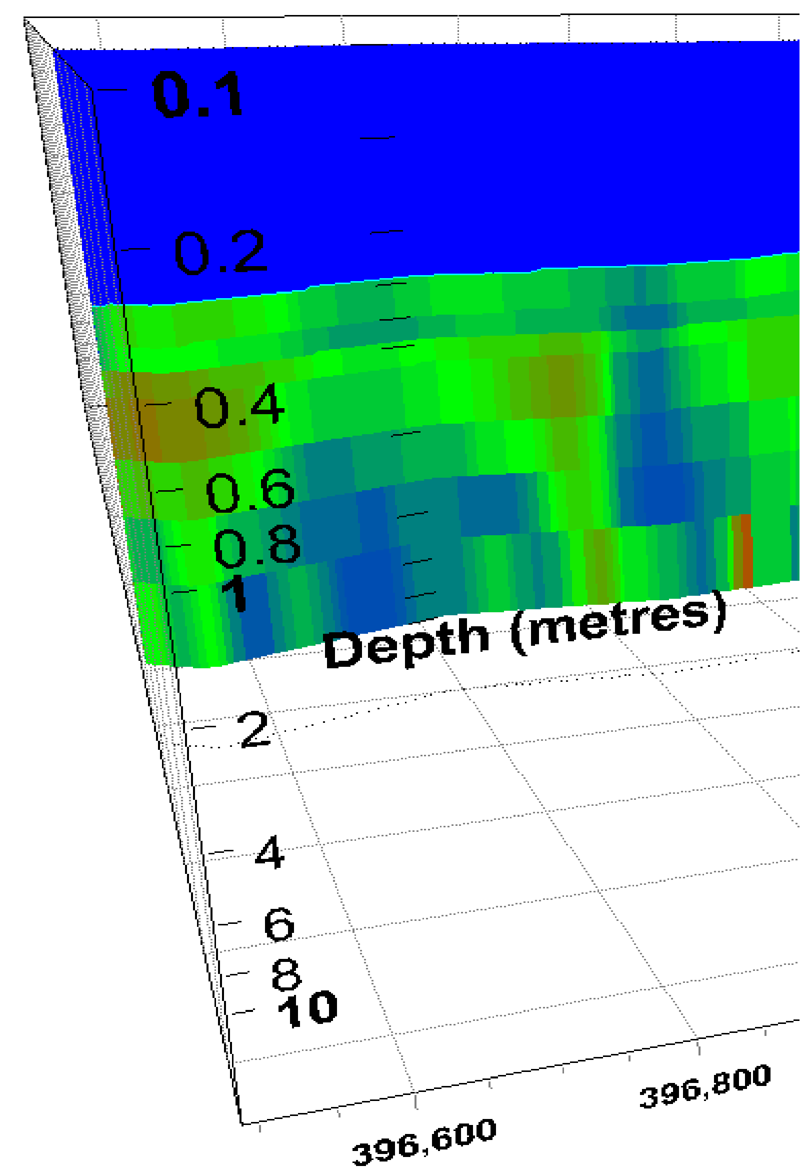


Identifying depths on ribbons

The 3D imagery may have either linear or log (as shown here) depth scales. It is labelled on the south-west corner of the 3D viewing space (as shown). Notice here that the increments are logarithmic. Logarithmic depth plotting is often used so that deep data can be examined at the same time as detailed shallow (near canal bed) data. The geophysical data loses resolution with increasing depth and so this type of depth scale presents all the data in a way that is easy to see.

Look on the ribbon behind the depth scale and you will see a column of black ticks. These correspond to the ticks on the annotated depth scale. Notice that they bunch up at 1m. Black dots mark the projection of the ribbon onto the base plane of the viewing space which is 20 m below the surface. When lithological logs are also displayed, a linear depth scale is preferred as the lithology does not blur out with depth.

The canal bed is marked with an aqua line.



Appendix B

Monitoring bore construction details

Table B-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		
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	-	-	-	-	-	-

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)
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	-	-	-	-	-	-	-	-
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	-	-

1. *Source Geoterra (2009)*

Table B-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
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

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
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
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

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-LLd	317604.6	6411061	Coal	80.81		-	31.482	15/12/2016
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
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

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
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
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

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-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
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

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

Appendix C

Numerical modelling report and peer review report

Mount Owen Mine
Numerical Modelling Report

C1 Introduction

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

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

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

- geological and topographical maps;
- geological models developed by the proponent;
- revision and update of the existing regional groundwater model developed in 2004 with key revisions in 2014; and
- results from previous hydrogeological investigations including relevant data from the publicly available datasets.

The main report details the conceptual understanding of the hydrogeological regime at the project site. The purpose of appendix is to describe the model setup, calibration and predictive scenarios undertaken with the numerical model. The model predictions are summarised in the main report but not included here to ensure there is no duplication within the documents.

C2 Model construction and development

C2.1 Model version and update log

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

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

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

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

Table C 1 Model versions

Model version	Model build	Project	Description of modification(s)	Model version number
1	0		• initial model setup; • model calibration	1
1	1	Liddell	• stochastic predictive simulations of proposed operations	1.1 Liddell
2	0		• refined historic mining and backfill sequencing at Ravensworth East, Glendell and Mount Owen operations; • updated geology models for Mount Owen and Ravensworth areas	2
2	1	Ravensworth East	• stochastic predictive simulations of proposed RERR operations	2.1 Rav
2	2	Liddell	• updated stochastic predictive simulations of proposed operations	2.2 Liddell
3	0		• refinement of historic Liddell open cut operations; Inclusion of additional coal barriers around Hazeldene workings	3
3	1	Liddell	• updated stochastic predictive simulations of proposed operations	3.1 Liddell
4	0		• inclusion of historic dewatering operations at Liddell underground workings; • conversion of Bowmans Creek "River" boundary conditions to "Stream" cells; • refinement of top and bottom elevations for Bowmans Creek alluvium based upon new LIDAR; • recalibration (steady state and transient); Creation\selection of new input datasets for stochastic simulations	4
4	1	Liddell	• updated stochastic predictive simulations of proposed operations	4.1 Liddell
5	0		• modification to underground working at Liddell; Addition of new dewatering bore at Middle Liddell underground workings	5
5	1	Liddell	• updated stochastic predictive simulations of proposed operations	5.1 Liddell
6	0		• refined model progression for mining and backfill sequencing based upon peer review comments; • updated HFB for faults regionally	6

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

Model version	Model build	Project	Description of modification(s)	Model version number
	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

A key improvement made to the model was the refinement of the model mesh where the Bettys Creek and Main Creek alluvium occur. Advice from the IESC on the Continued Operations Project noted that the scale the groundwater model was regional and that the mesh used did not enable an accurate assessment of the potential impacts on water dependent ecological assets which may rely on the groundwater in the Bettys Creek and Main Creek alluvium. To address this issue for the Continued Operations Project a new smaller and more refined groundwater model with a cells size of 20 m x 20 m was developed for the Bettys Creek and Main Creek area to provide a more refined assessment of impacts. A new smaller separate model was developed because at the time refining the regional model would have significantly slowed the simulation times to an impractical extent. The improvement in computer processors since the Continued Operations Project and the transfer to MODFLOW USG meant it was possible to further refine the regional model along Main Creek and Bettys Creek and remain within practical simulation times. The numerical model was refined to a cells size of 20 m x 20 m to ensure previous work for the Continued Operations Project was represented with the updated model for the Proposed Modification.

C2.2 Model code

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

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

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

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

C2.3 Model design

C2.3.1 Model grid

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

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

- North east – set approximately 2 to 3 km north-east of the Proposed Modification where the coal seams are terminated by the presence of the Hunter Thrust fault that abuts non coal bearing Carboniferous sediments against the Permian coal measures of the Hunter Valley (refer to Geological Map in Section 4 of main report).
- North west – set approximately 12 km north-west of the Proposed Modification, where the Whittingham Coal Measures outcrop and terminate.
- South – set at approximately 10 km south of the Proposed Modification beyond the limit of depressurisation from the Project.

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

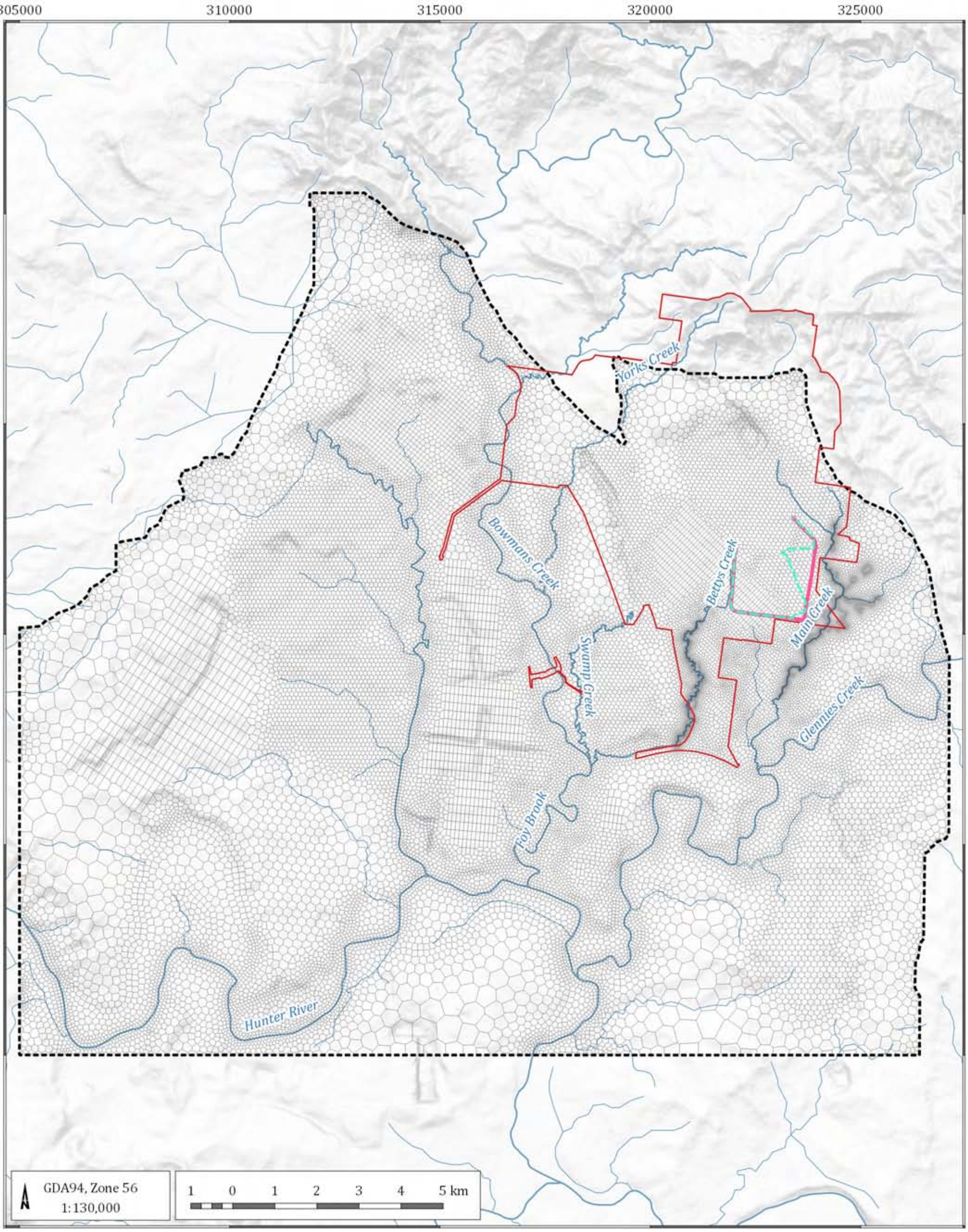
- longwall mining areas - 75 m x 150 m rectangular cells aligned to longwall panels;
- open cut areas - 100 x 100 m voronoi cells;
- streams and alluvial flood plains - from 50 x 50 m to 150 x 150 m; and
- groundwater dependent ecosystems (GDEs) within alluvial flood plains - 20 x 20 m.

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

As shown in Figure C 1, the model includes the full extents of the existing Mount Owen Complex (including the Mount Owen North Pit), as well as the:

- Integra Underground Mine, including a proposal to modify the current approval that is on exhibition at the time of writing;
- Rix Creek North Mine (formerly Integra Open cut);
- Liddell Mine;
- Ashton Underground Mine;
- Ravensworth Operations; and
- Hunter Valley Operations (HVO) North.

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



LEGEND
- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh
- Major drainage
- Minor drainage

Mount Owen (G1862A)

Grid layout

DATE 12/06/2018

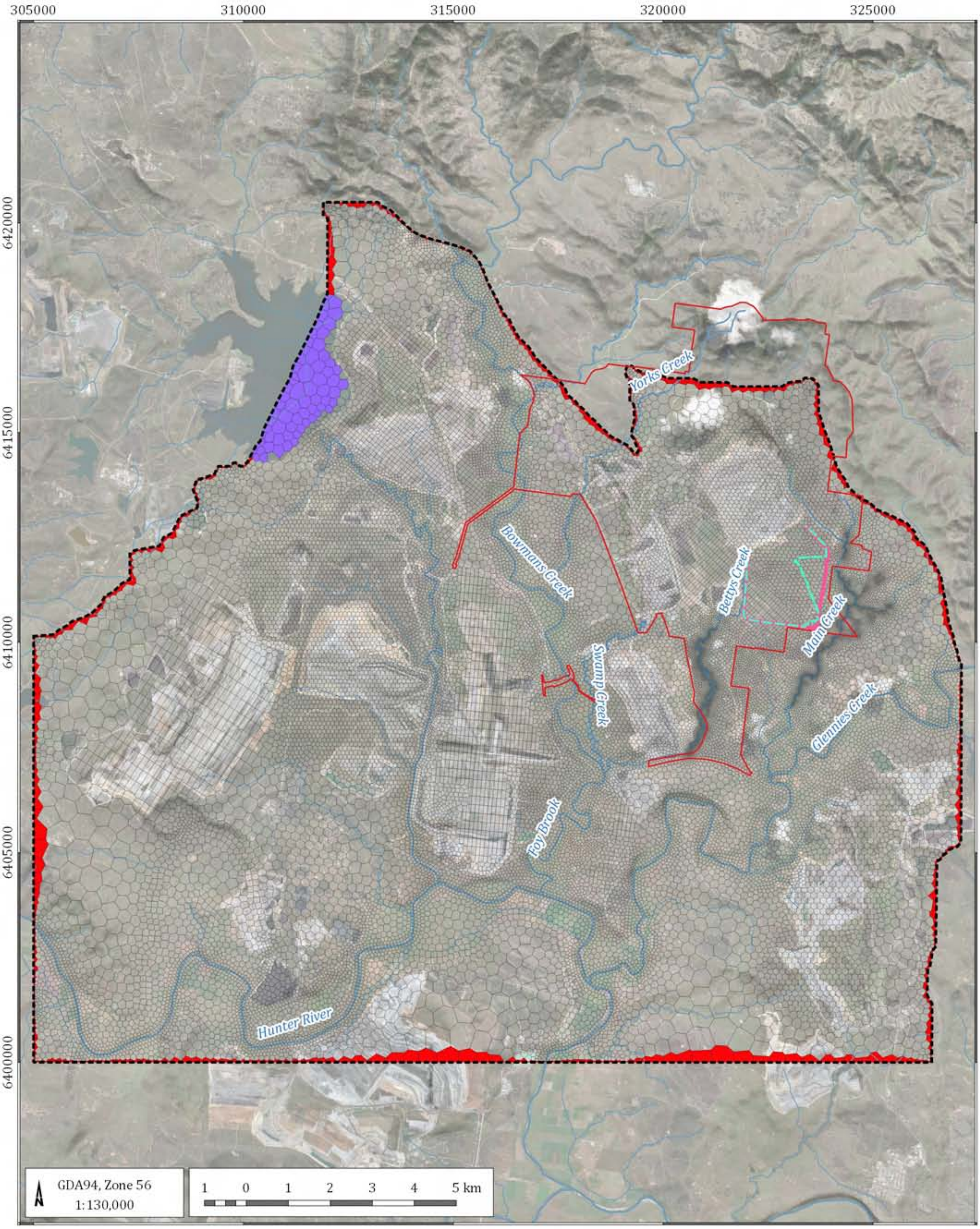
FIGURE No: **C-1**

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/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/C-01_G1862A.qgs

C2.3.2 Model boundary conditions

Previous versions of the model represented the model boundaries including the Hunter Thrust fault where the coal seams terminate to the north-east of the Project site with a 'no flow' boundary condition. Whilst coal seams are terminated at this fault, it was considered there is potential for groundwater flow into the model domain to occur through surficial layers from up topographic gradient catchments that occur to the north-east of the Project site. The 'no flow' boundaries were therefore converted to a general head boundary to allow groundwater to enter the model from the up-gradient catchments. The general head boundary cells in the model are displayed in Figure C 2.

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



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh
- Major drainage
- Minor drainage
- Constant Head Cells
- General Head Boundary Cells

Mount Owen (G1862A)

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

AGE

DATE 12/06/2018

FIGURE No: **C-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/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/C-01_G1862A.qgs

C2.3.3 Model layers

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

Table C 2 Model layers

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

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

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

C2.3.4 Timing

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

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

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

- Last day of 1979 - steady state stress period;
- 1980 to 1999 - 4 x five yearly stress periods (transient here and after);
- 2000 to 2002 – 1 x three yearly stress period;
- 2003 to 2008 – 12 x six monthly stress periods; and
- 2009 to 2036 – 112 x quarterly stress periods.

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

An additional version of the model was developed for simulating recovery after mining ceased at the Project in 2037. Both models were combined into a single, continuous simulation with one finishing and the other starting at the beginning 2037. The timing for the recovery model was set up as a single transient stress period with 900 years duration to align 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.

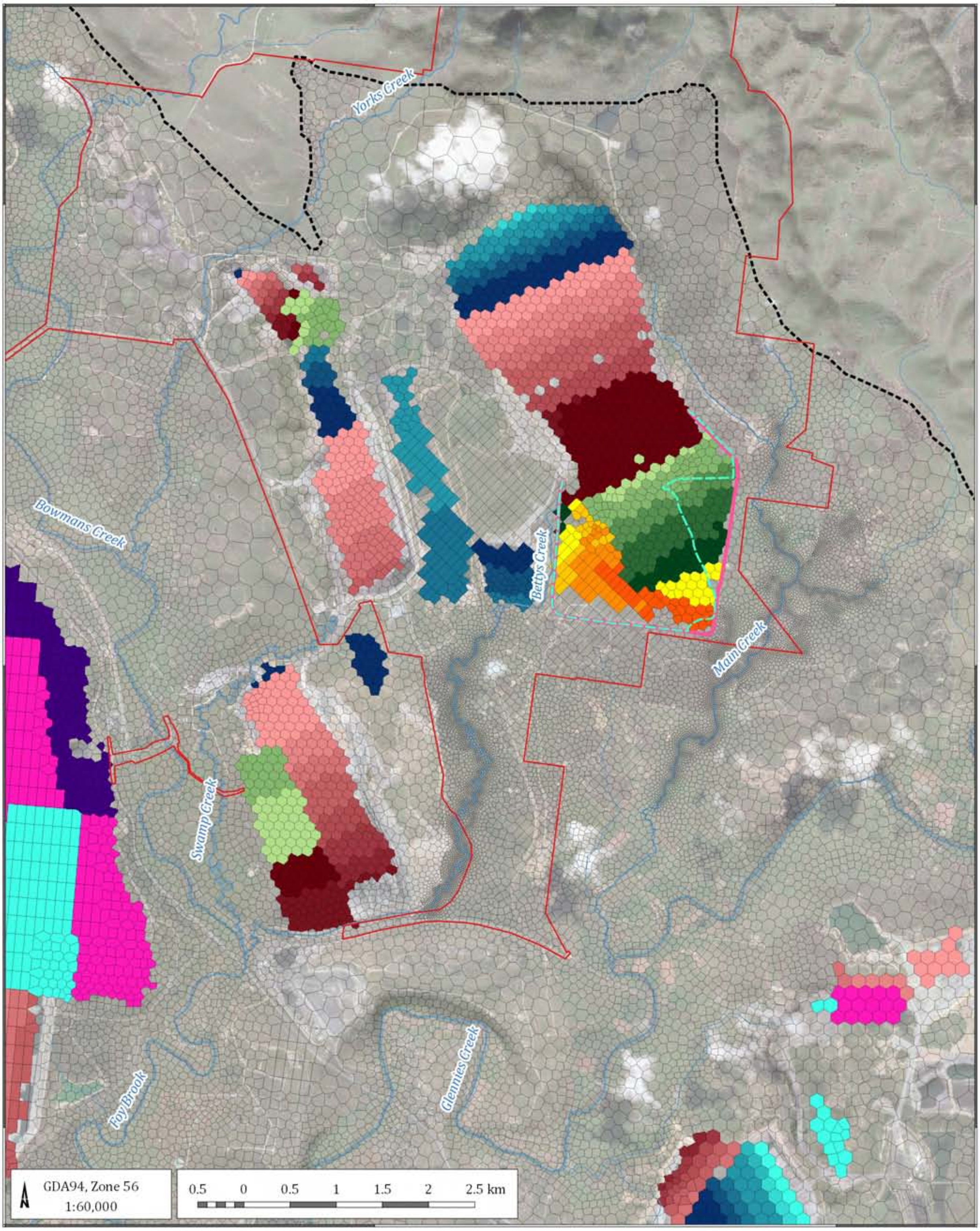
C2.3.5 Mining progression

The pit shell for the Proposed Modification has three separate zones with differing floor elevation. The deeper part of the pit extends to the Hebden seam in the Eastern, with a central area terminating at the floor of the Middle Liddell seam, with the shallowest area on the western boundary extracting down to the Lemington seam. Figure C 2 and Figure C 6 show the footprint and timing of the Proposed Modification, as well as the cumulative mining surrounding the Project.

Future mining at surrounding mines and their corresponding model layers detailed in Table C 3. The simulation of approved mining in the model was based on the detailed mine schedules described by Jacobs (2014) and updated with using 3D staged plans for the Proposed Modification area using pit shells and schedules provided by Mount Owen.

Table C 3 Model domain historic and approved mine progression

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



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh
- Major drainage
- Minor drainage

Mine start year

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

Mount Owen (1862A)

Predictive mine progression for the Project – Regolith & Bayswater seam

AGE

DATE 12/06/2018

FIGURE No: **C-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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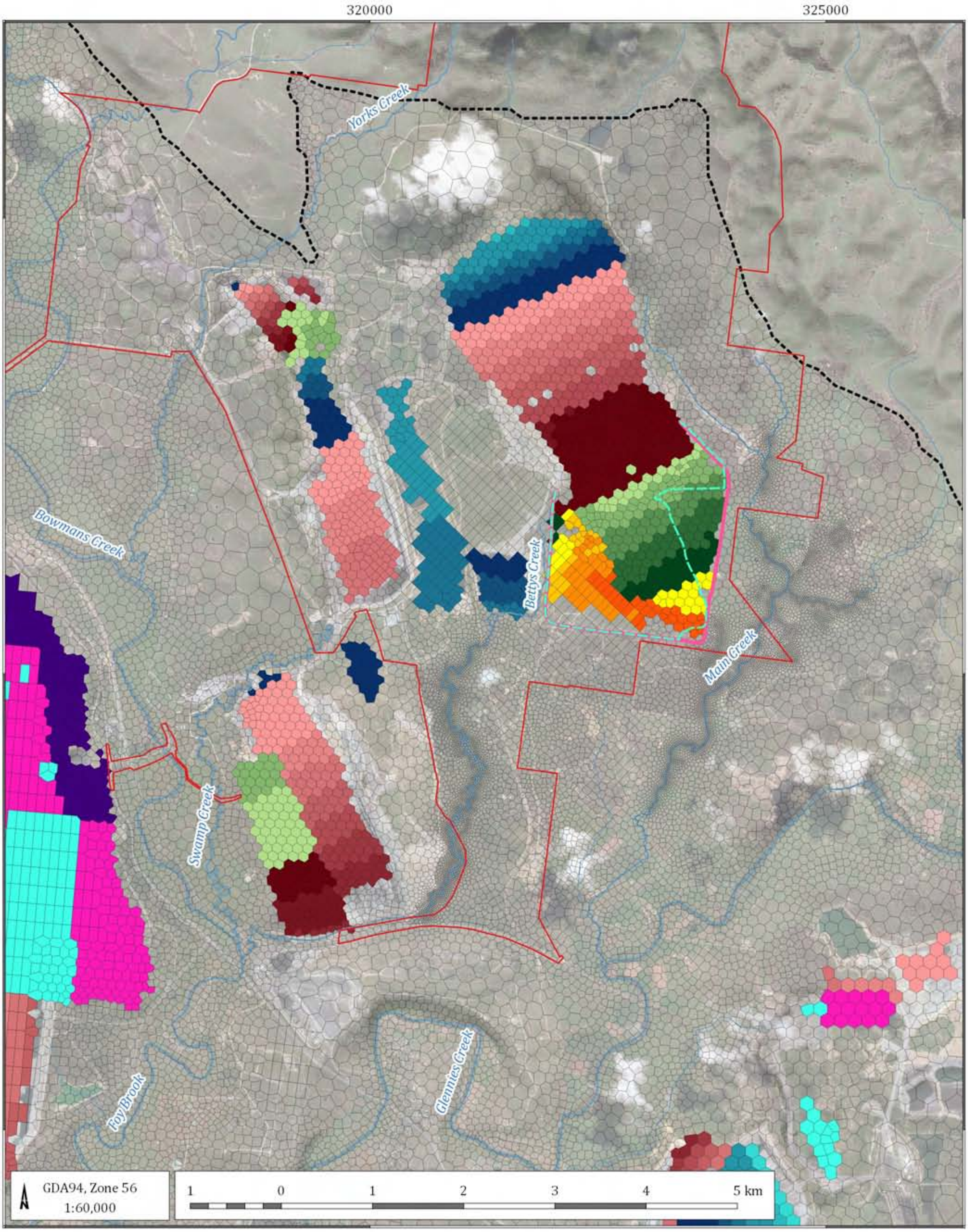

LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh
- Major drainage
- Minor drainage

Mine start year

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

Mount Owen (G1862A)

Predictive mine progression for the Project - Middle Liddell Seam

DATE 12/06/2018

FIGURE No: **C-4**

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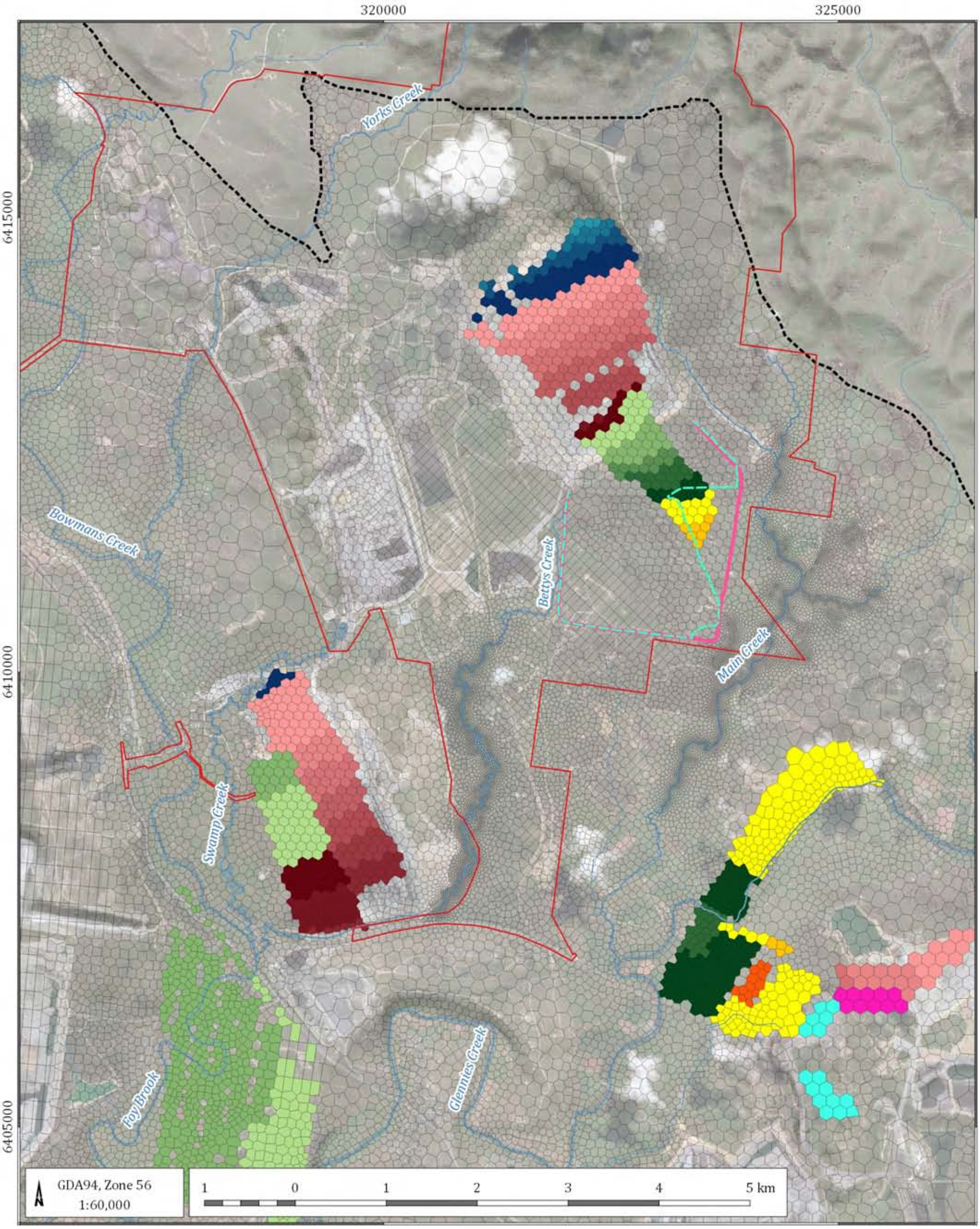

LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh
- Major drainage
- Minor drainage

Mine start year

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

Mount Owen (G1862A)

Predictive mine progression for the Project - Barrett Seam

AGE

DATE 12/06/2018

FIGURE No: **C-5**

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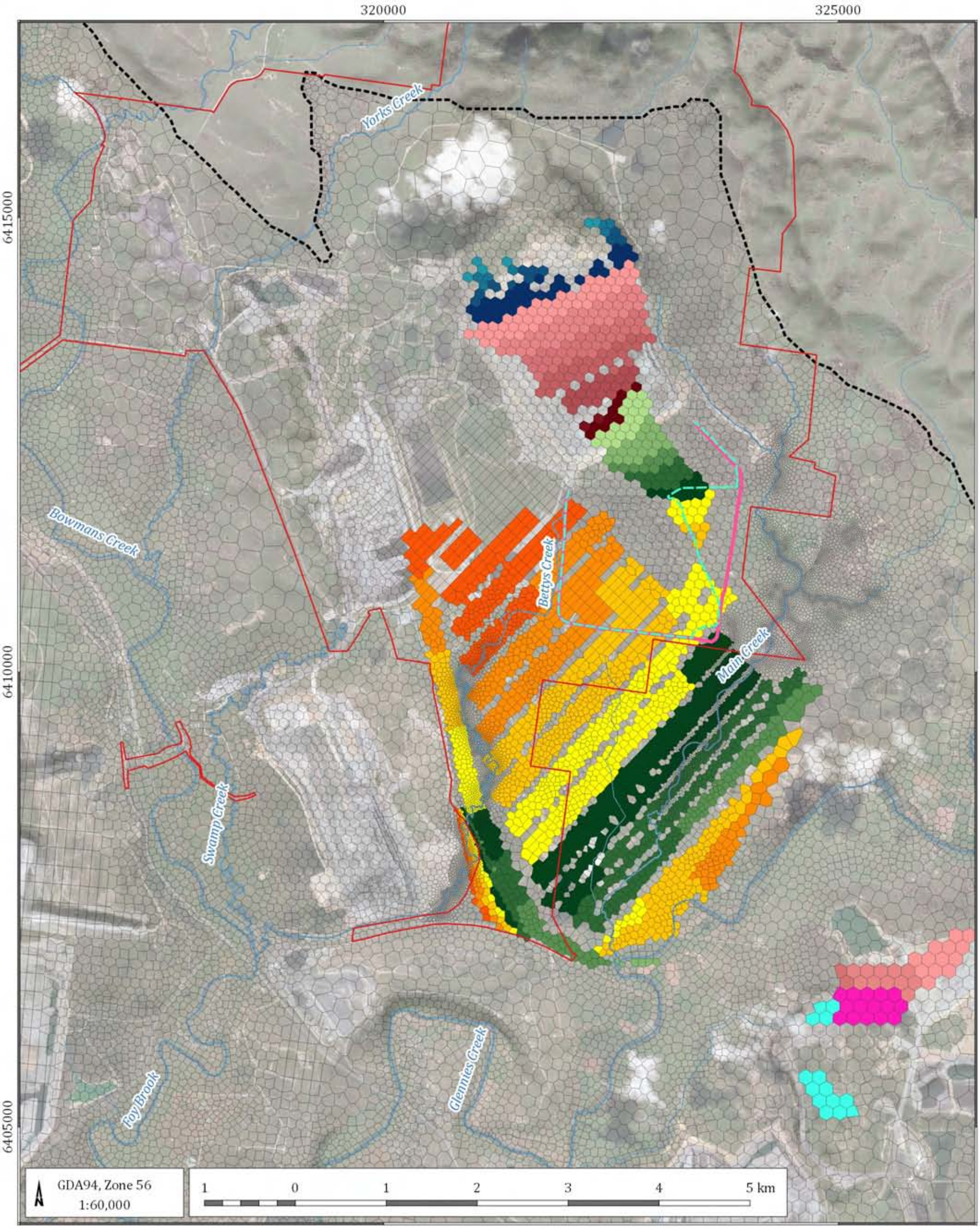

LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh
- Major drainage
- Minor drainage

Mine start year

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

Mount Owen (G1862A)

Predictive mine progression for the Project - Hebden Seam

AGE

DATE 12/06/2018

FIGURE No: **C-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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C2.4 System stresses

C2.4.1 Recharge

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

The dominant mechanism for recharge to the groundwater system is through diffuse infiltration of rainfall through the soil profile and subsequent deep drainage to underlying groundwater systems. Investigation in the region suggests the Main Creek and Bettys Creeks can be classified as 'losing' allowing transfer of surface water to the underlying aquifers.

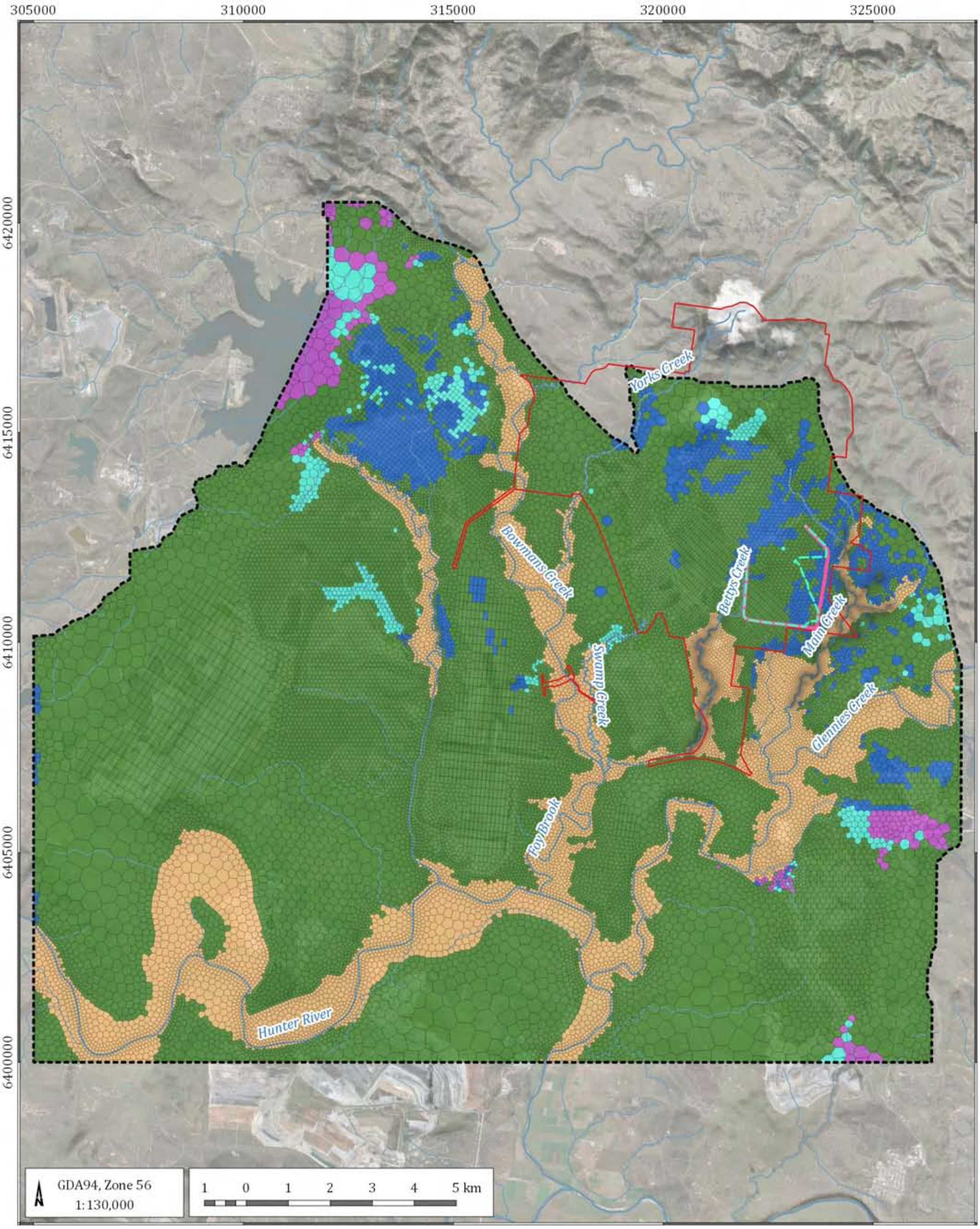
A simple SWAT model (Arnold, 2012) covering the model domain catchment area was developed to guide the groundwater recharge rates for the calibration process. Global FAO soil and static land use data were assumed, and weather was applied using interpolated SILO climate data. SWAT estimated recharge rates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

In addition to this a spreadsheet based soil moisture deficit calculation was used to estimate the timing and magnitude of recharge events used in the model. The simple soil moisture balance was used to estimate when the soil profile had reached field capacity following rainfall and when subsequent deep drainage to the underlying water table occurs. The recharge rates were reduced lower than indicated by the SWAT model to achieve the final calibration. Table C 4 represents the calibrated rate of recharge for each geological unit. Figure C 7 shows the recharge distribution zones.

Table C 4 Modelled recharge rates

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

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



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh
- Major drainage
- Minor drainage

Recharge zones

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

Mount Owen (G1862A)

Recharge zones

DATE 12/06/2018

FIGURE No: **C-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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C2.4.2 Evapotranspiration

Evapotranspiration from shallow water tables was represented with the evapotranspiration package (EVT). Evapotranspiration occurred from the upper most model cells across the model domain at an areal potential evaporation rates (440mm/year) decreasing linearly to a maximum depth of 2 m below the surface. The results from the SWAT modelling correlated well with the areal potential evaporation datasets, producing an average of 448 mm/year.

C2.4.3 Abstraction

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

C2.4.4 Surface drainage

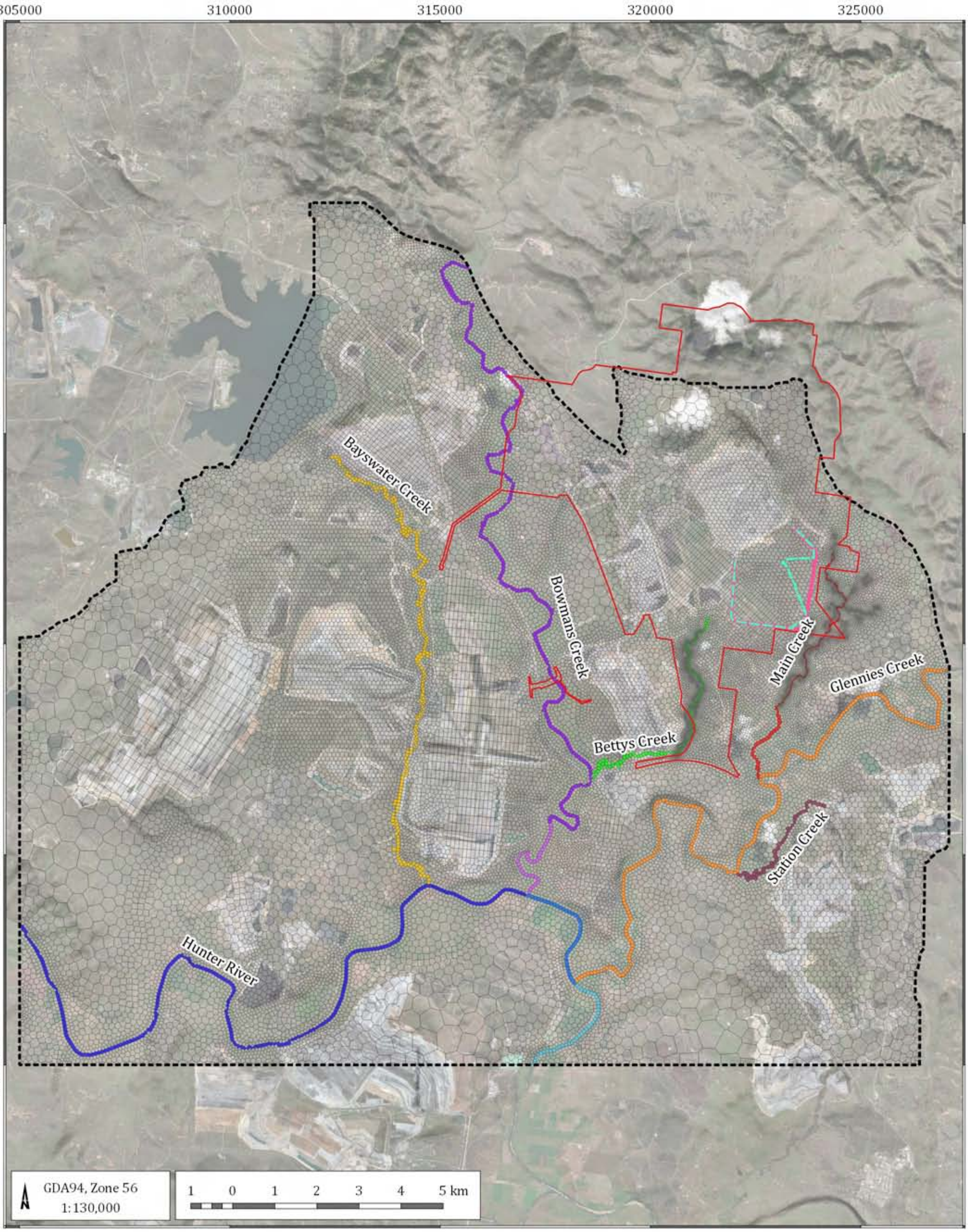
Groundwater interaction with surface drainage was modelled using the stream package (STR) and the river package (RIV) of MODFLOW. The cells assigned to these packages in the model were divided by zones to represent each creek systems and are displayed on Figure C 8.

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

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

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

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



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh

River Zones

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

Stream Zones

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

Mount Owen (G1862A)

River and surface drainage cells

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FIGURE No: **C-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 water level above the river bed was set at 0 m for all minor ephemeral streams and creeks within the model domain including Main Creek and Bettys Creek in proximity to the proposed Modification. The location of the river cells in the groundwater model were assigned to the highest active layer in the model, which was generally layer 1 or layer 2.

C2.4.5 Lakes and dams

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

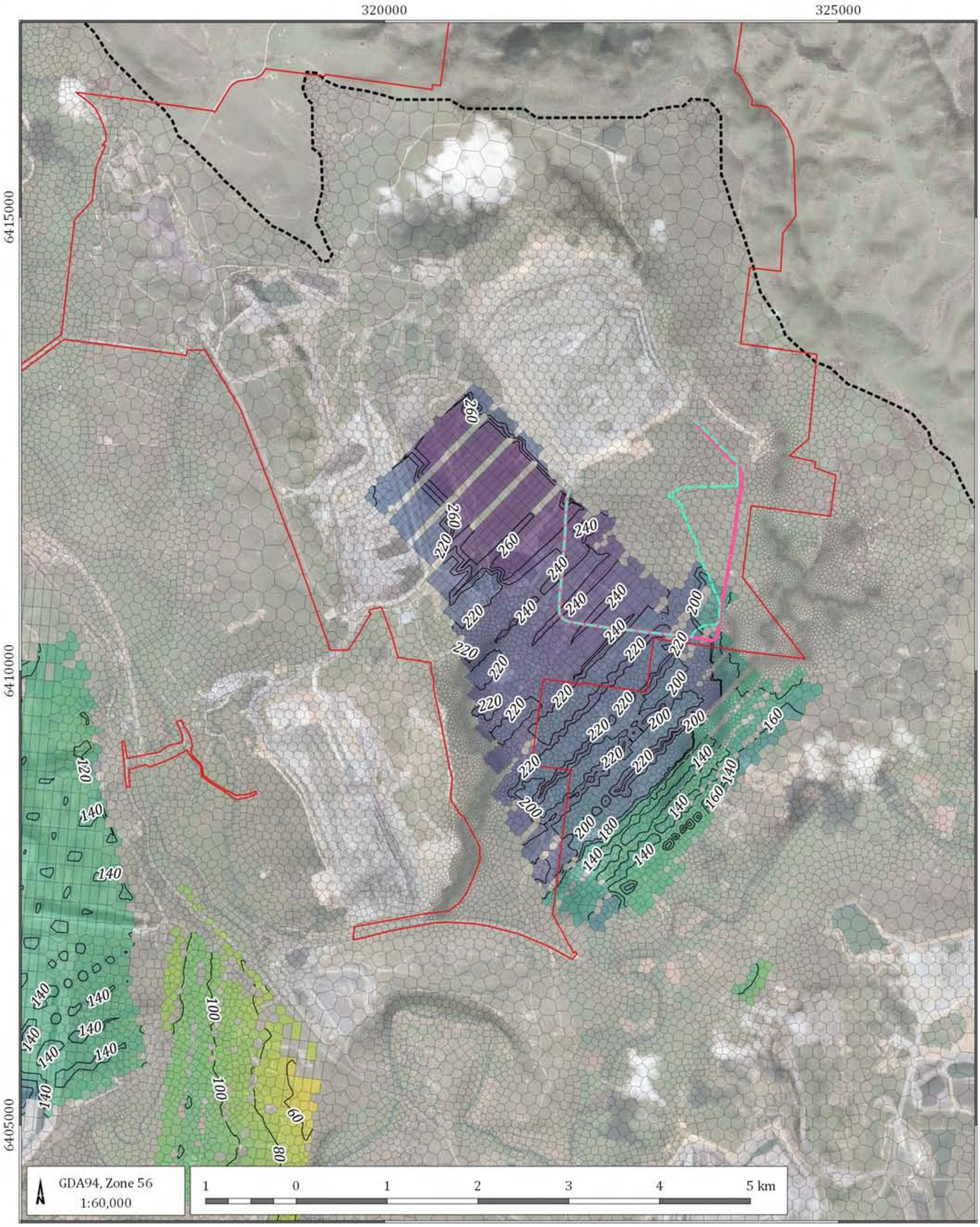
C2.4.6 Mining

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

Within the Mount Owen North Pit 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 and converted to represent the in-pit spoil piles. This timing was selected, based on an assessment of the mining plan. This way, the model represented the growth of spoil piles for the open-cut by progressively changing the hydraulic properties of mined cells (Kh, Kv, Sy and Ss) behind the active open cut mining area once the drains became inactive.

Recharge rates to the spoil were not enhanced as deep drainage of rainfall through the spoil is captured within the mining areas and does not represent water from the groundwater systems. This was a conservative approach implemented to represent the gradual rewetting of the unsaturated spoil over time. Storage was changed in a step-wise manner above the mined seam to avoid creating water in partly saturated layers. Further details about the calibrated hydraulic parameters are included in C3.2.2

Goafing and fracturing above longwall panels in the underground mine was simulated using an equivalent fracture network methodology described by AGE (2017b). Figure C 9 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 in a single map, displaying the maximum height value from the three input maps.



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh
- Major drainage
- Minor drainage
- Contour line (m)

Fracture height above seam (m)

175	50
200	75
225	100
250	125
300	150

Mount Owen (G1862A)

Modelled fracture height

AGE

DATE 12/06/2018

FIGURE No: **C-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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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; and final voids and were represented using void or spoil properties where appropriate. Changes to the horizontal and vertical hydraulic conductivity were applied to the single stress period recovery model. Specific yield and specific storage parameters representing highly fractured goaf zones were applied to mined coal seam layers only (layers 4, 14, 15, 18, and 20). Table C 6 presents the aquifer parameters applied to the post mining underground workings.

Table C 6 Recovery model underground parameters

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

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

C3 Model calibration

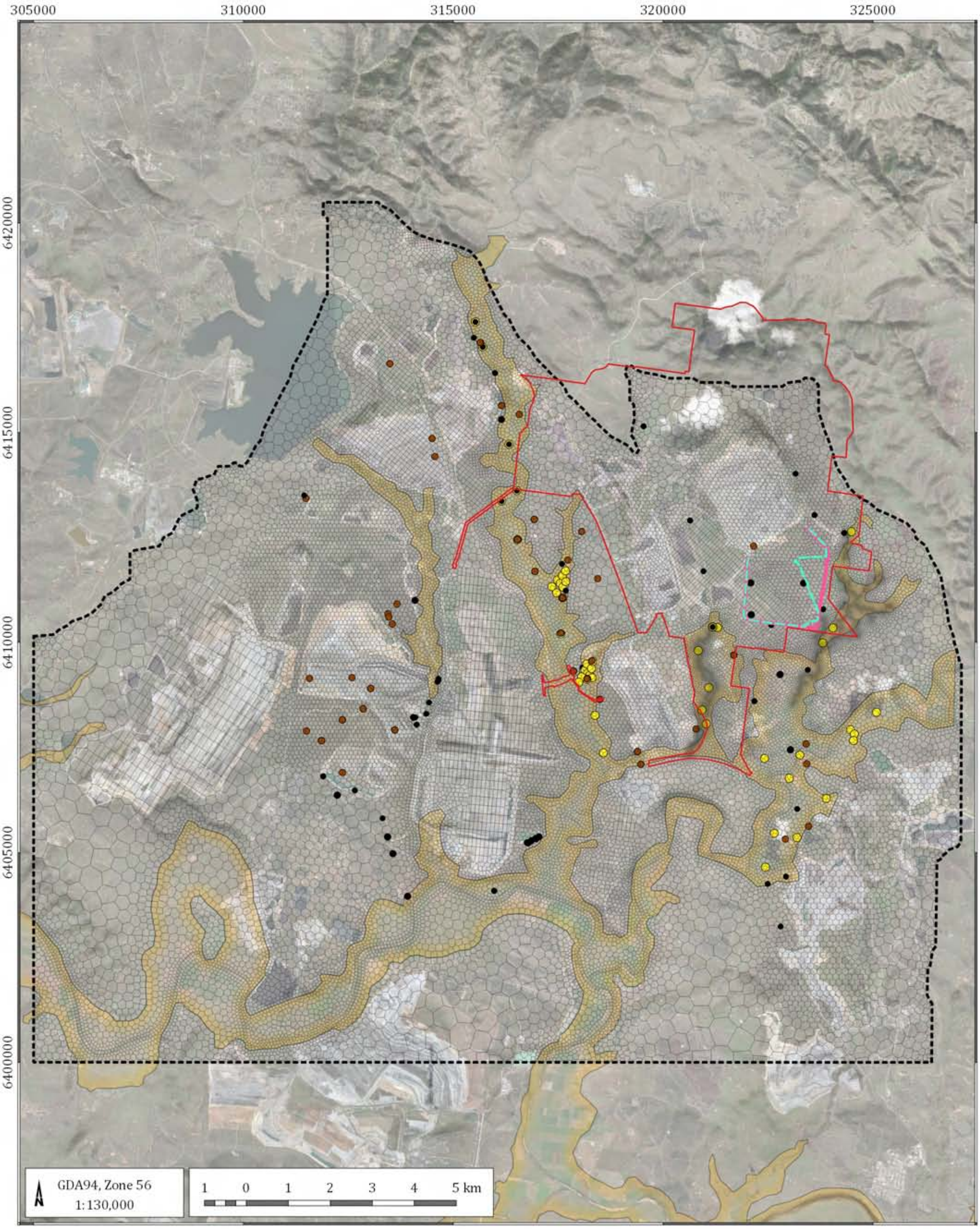
The groundwater model was calibrated with a pre-mining steady state run and a transient run (1980 to 2017) using available groundwater level data and documented mine inflows. The model was calibrated by adjusting aquifer parameters and stresses to produce the best match between the observed and simulated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

C3.1 Calibration targets

The steady state and transient model simulated water levels in all available monitoring bores within the bedrock and alluvial aquifers. A total of 254 monitoring points monitoring points were used to calibrate the model, and a further 72 were used as a verification. In total, 326 monitoring points were utilised, comprising:

- 325 monitoring points from the Integra, Mt Owen, Ravensworth and Liddell monitoring network, which included bores and VWPs that screen the alluvium and Permian coal measures;
- 1 private registered bore with available water level data, which intersects Quaternary alluvium;
- 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.

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



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh
- Alluvium extent
- Major drainage
- Minor drainage

Observation bores

- Alluvium
- Coal
- Interburden

Mount Owen (G1862A)

Observation target locations

AGE

DATE 12/06/2018

FIGURE No: **C-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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C3.2 Calibration results

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

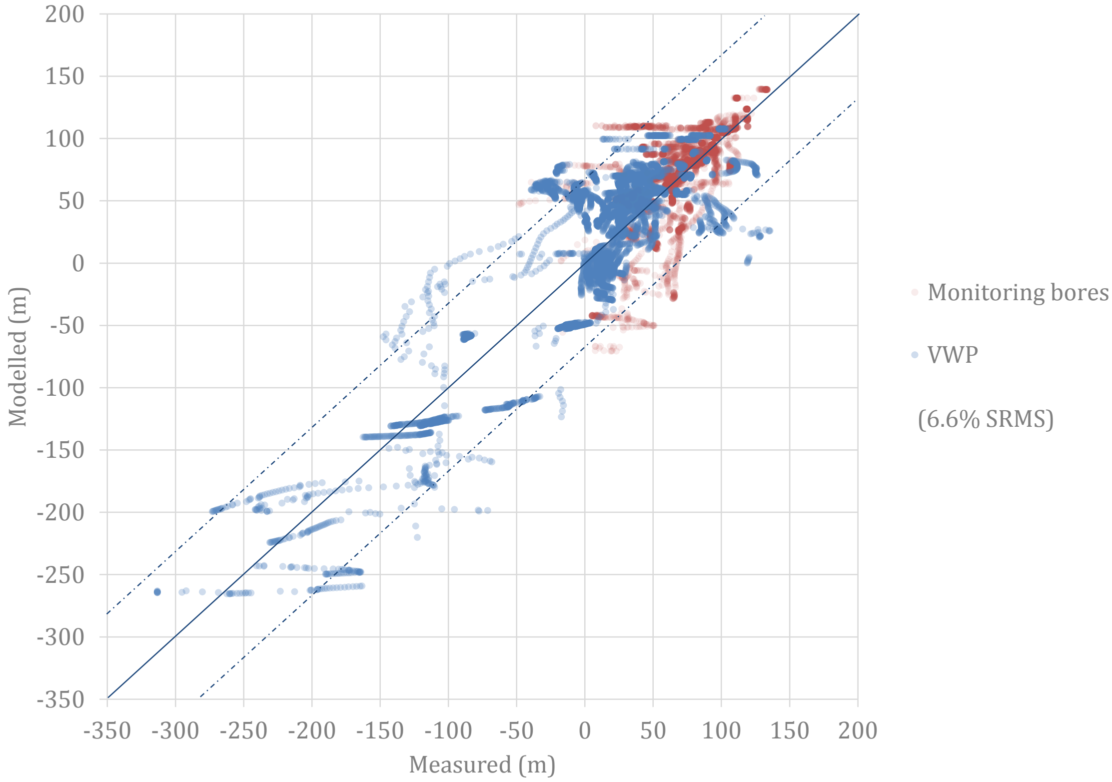


Figure C 11 Transient calibration and verification – modelled vs observed groundwater levels

Table C 7 presents the unweighted statistics for the transient calibration model.

Table C 7 Statistical analysis

Calibration performance measure	Unweighted value
Sum of Residuals (SR) (m)	-68472
Mean Sum of Residuals (MSR) (m)	-4.3
Scaled Mean Sum of Residuals (SMSR) (%)	-1.0
Sum of Squares (SSQ) (m2)	13790644
Mean Sum of Squares (MSSQ) (m2)	865.9
Root Mean Square (RMS) (m)	29.4
Root Mean Fraction Square (RMFS) (%)	789440
Scaled RMFS (SRMFS) (%)	83384
Scaled RMS (SRMS) (%)	6.6

The root mean square (RMS) error calculated for the calibrated model was 29.4 m. The total measured head change across the model domain was 449.0 m, with a standardised unweighted RMS (SRMS) of 6.6%, indicating a relatively good match for the type of system being modelled.

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

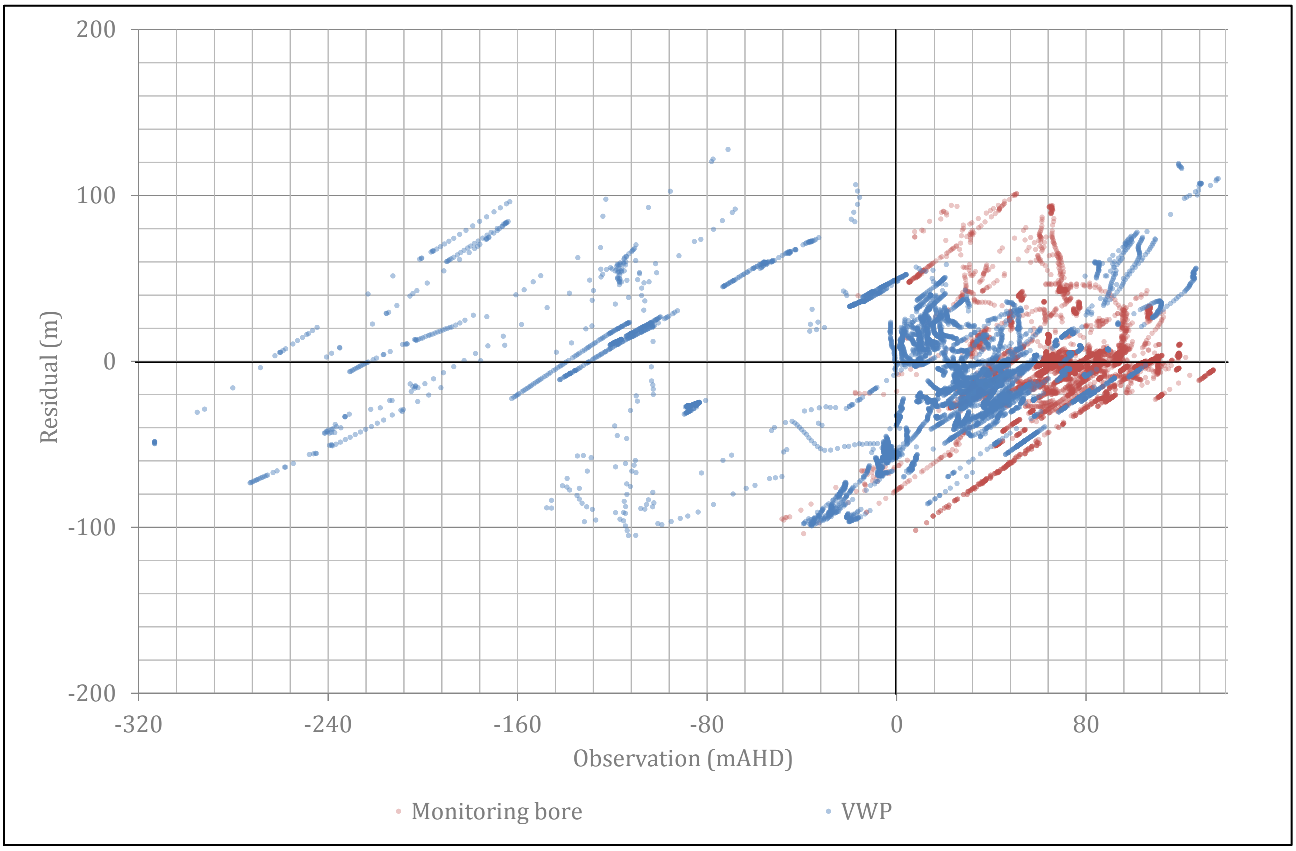


Figure C 12 Observations versus residuals

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

An analysis of simulated vs. measured vertical pressures in available key VWPs was also carried out to assess the ability of the model to simulate vertical gradients. The result is displayed on Figure C 13.

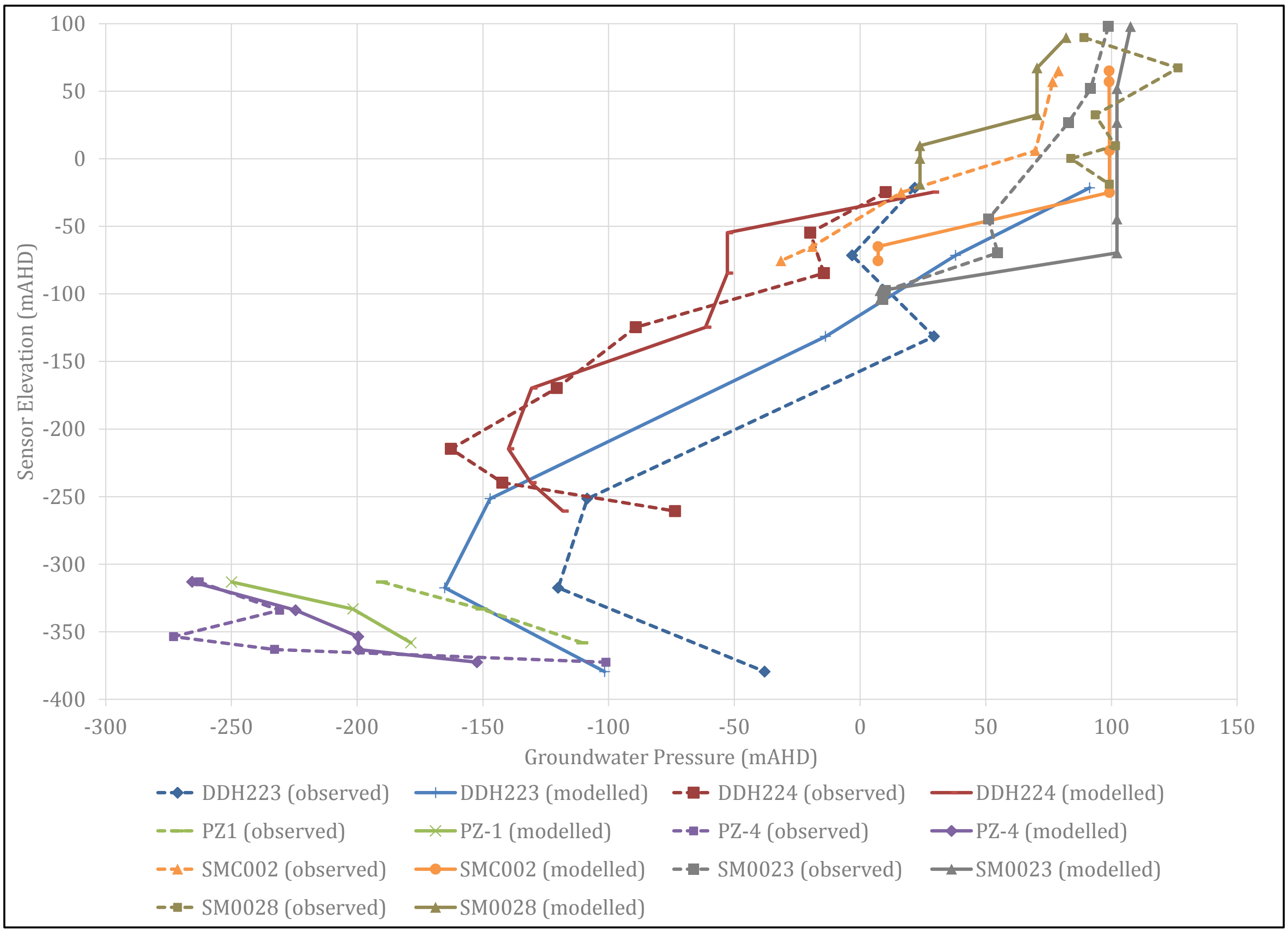


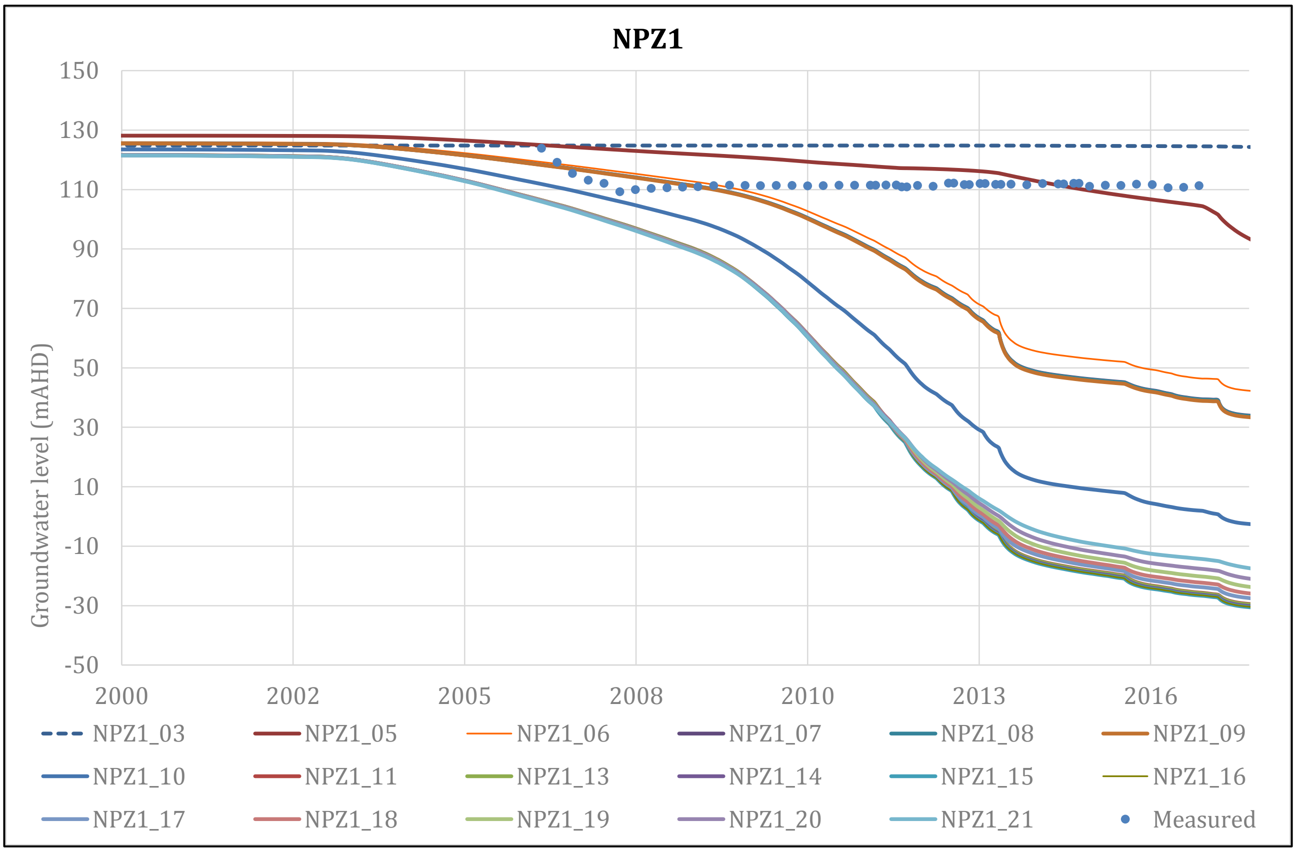
Figure C 13 Modelled versus observed vertical pressures at key VWP locations

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. In some instances, the model does not replicate water level changes in the groundwater system. This is most likely due to reliance on a simple formula to generate the spatial distribution of hydraulic conductivity adopted for each layer. The resolution of the model layering may also hinder model calibration, particularly within thick models layers, such as layer 5 and 6, where the level of fracturing, or host permeability may vary significantly.

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

There are a number of observation wells in the model that potentially screen multiple aquifer/aquitards – this is particularly true to the NPZ/a series of bores that have a 50mm and 25mm PVC pipe installed in a single drill hole therefore limit annulus around the casing to install seals. The ability of the model to simulate water levels recorded in these bores will be reduced where there is uncertainty about the exact layered monitored by the bore. Figure C 14 to Figure C 17 illustrates this issue by plotting groundwater levels from all model layers along with the measured groundwater levels. The figures show the strong vertical hydraulic gradients that exist within the groundwater model in the area of these bores. The dashed line indicates the model layer assigned to the monitoring bore. The blue/green dots represent the measured data used during the calibration process.



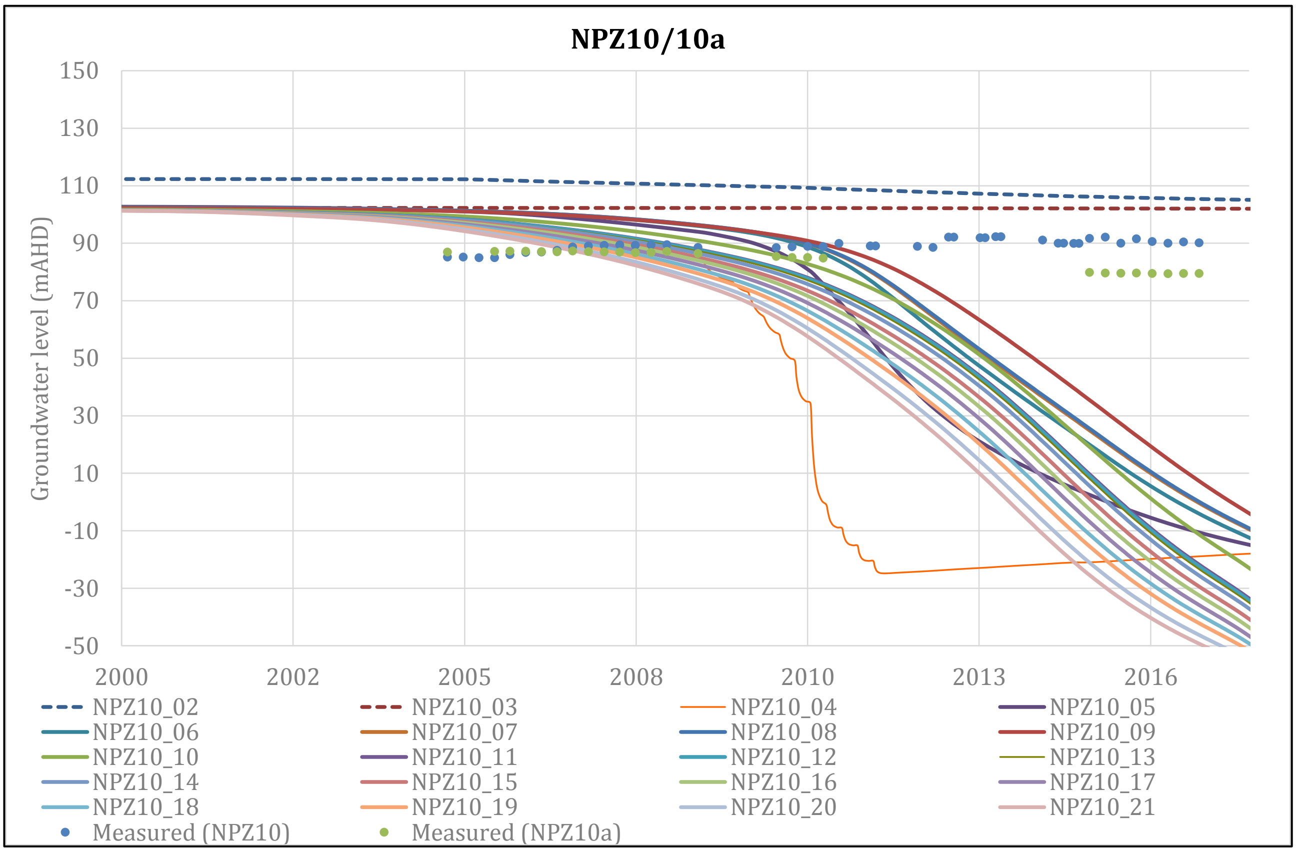
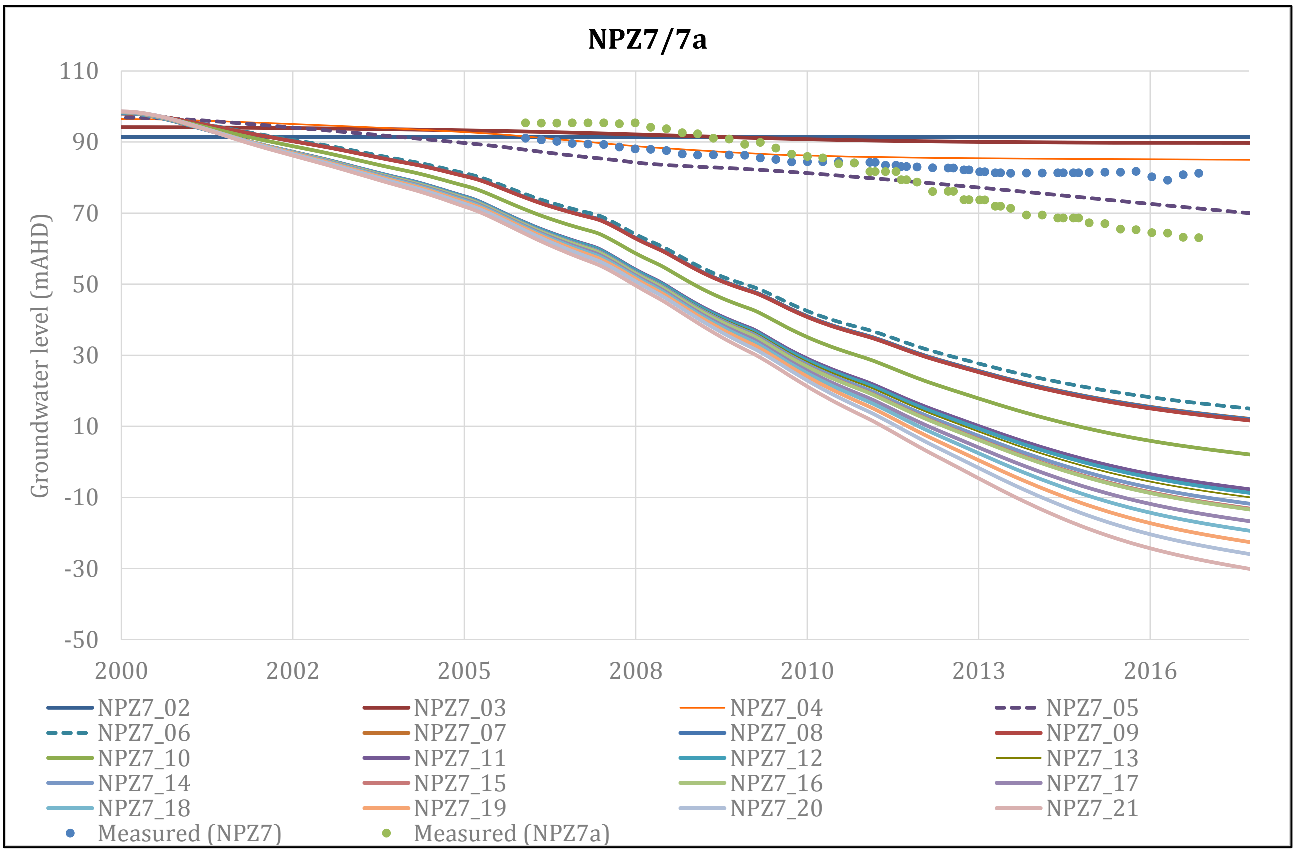


Figure C 14 NPZ1 – NPZ 10/10a modelled versus measured hydrographs



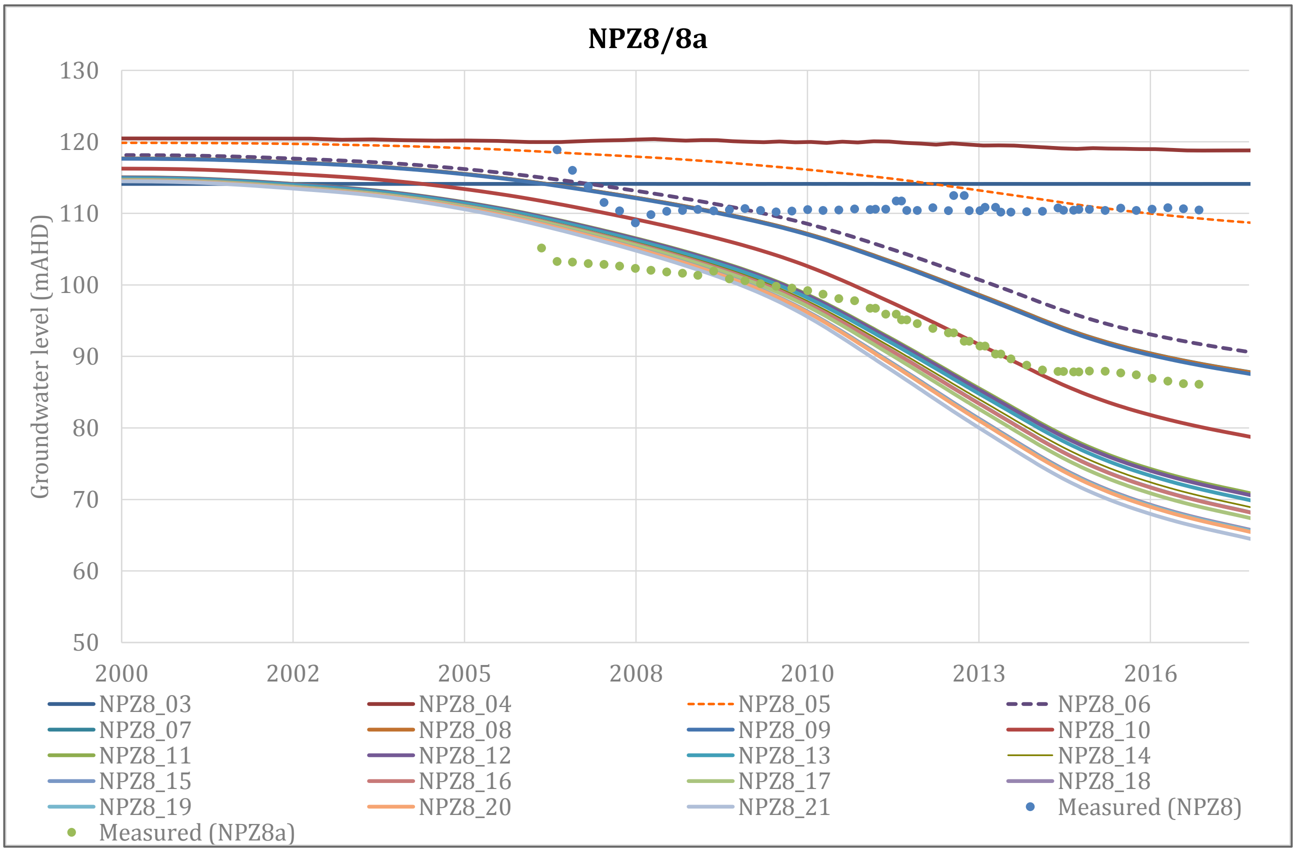
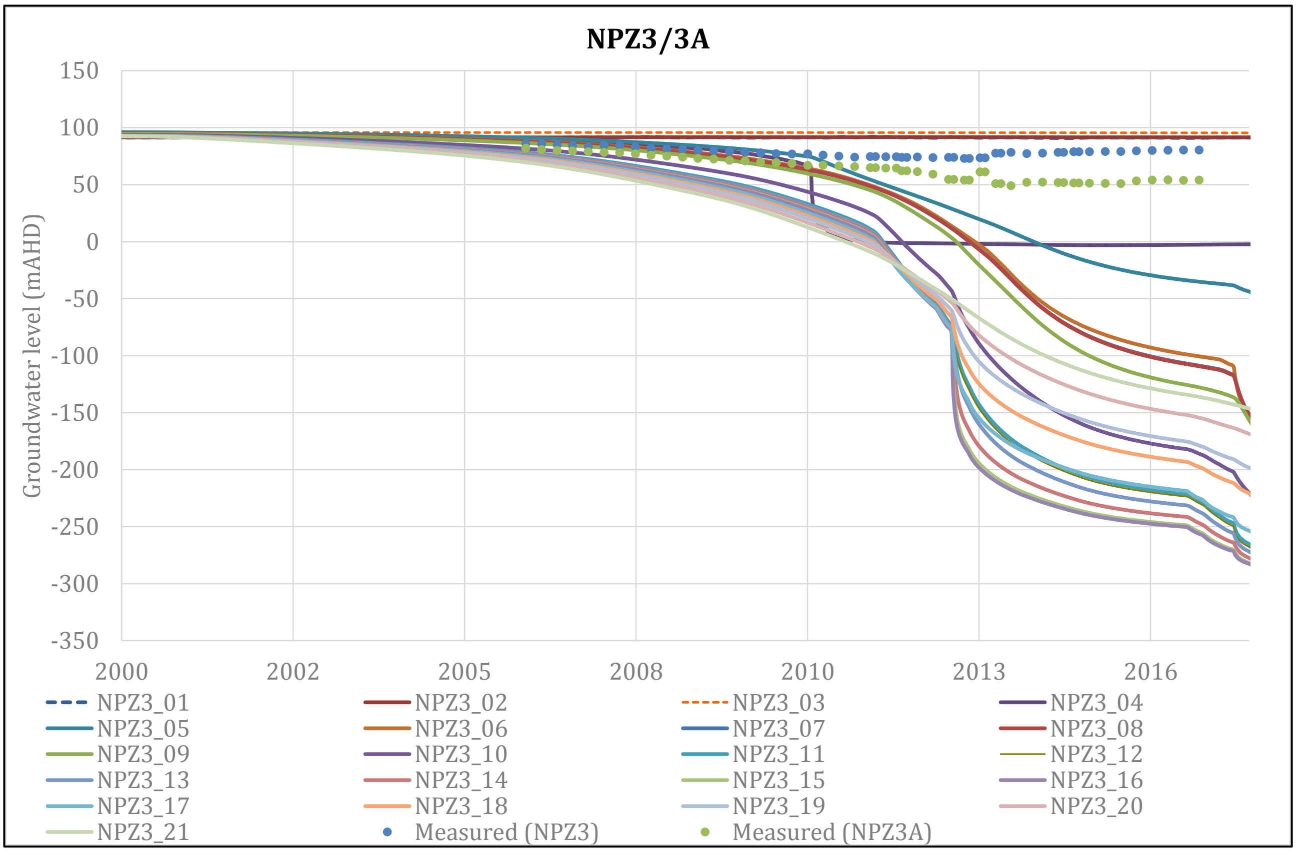


Figure C 15 NPZ7/7a – NPZ8/8a modelled versus measured hydrographs



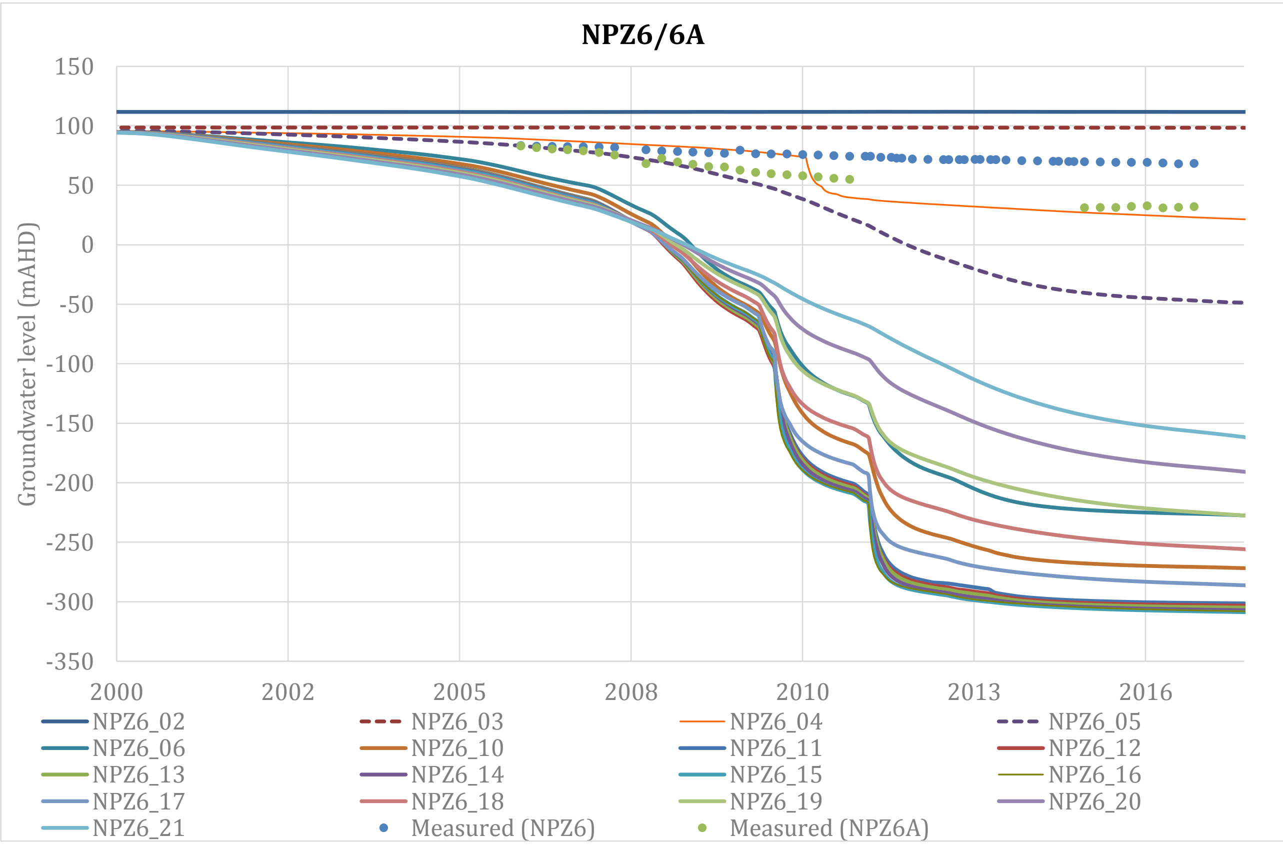


Figure C 16 NPZ3/3a – NPZ 6/6a modelled versus measured hydrographs

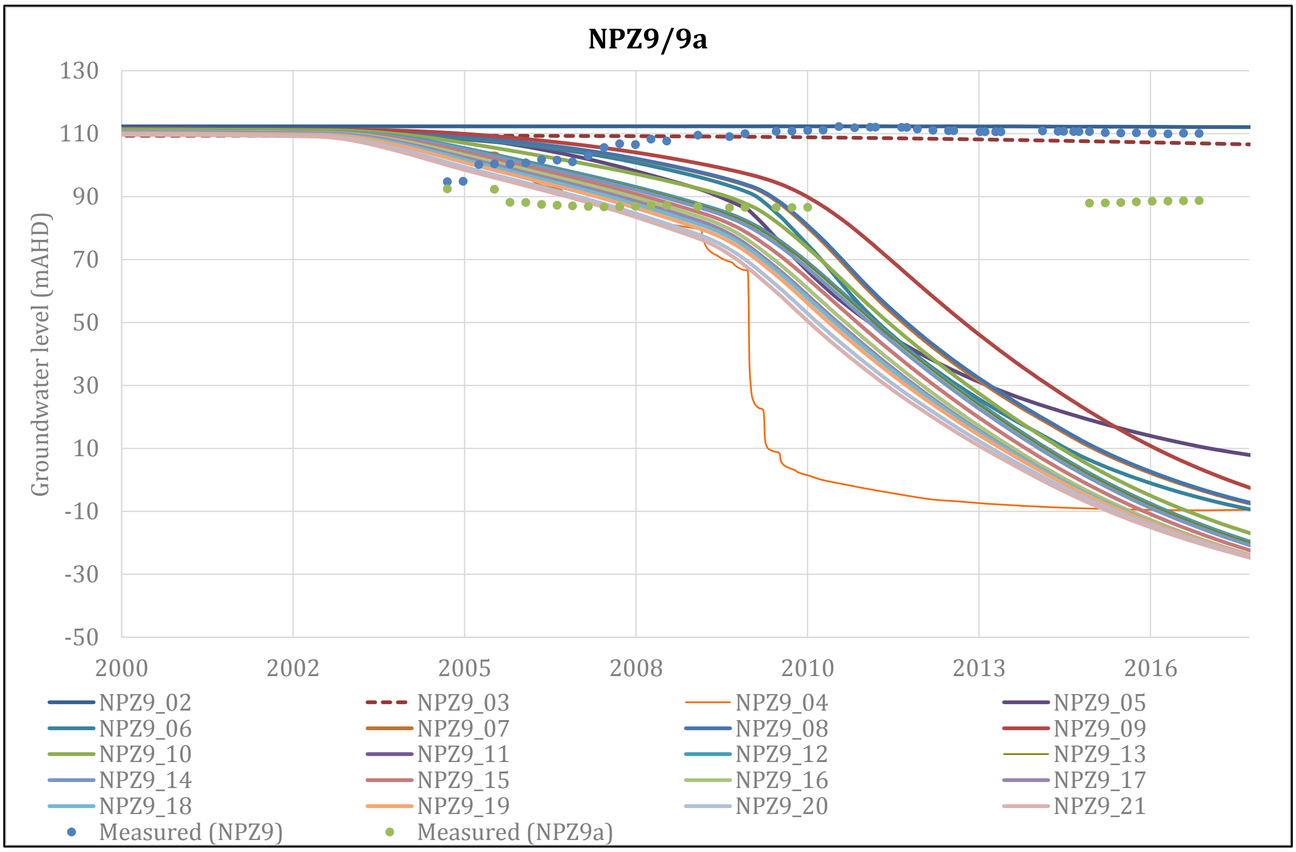


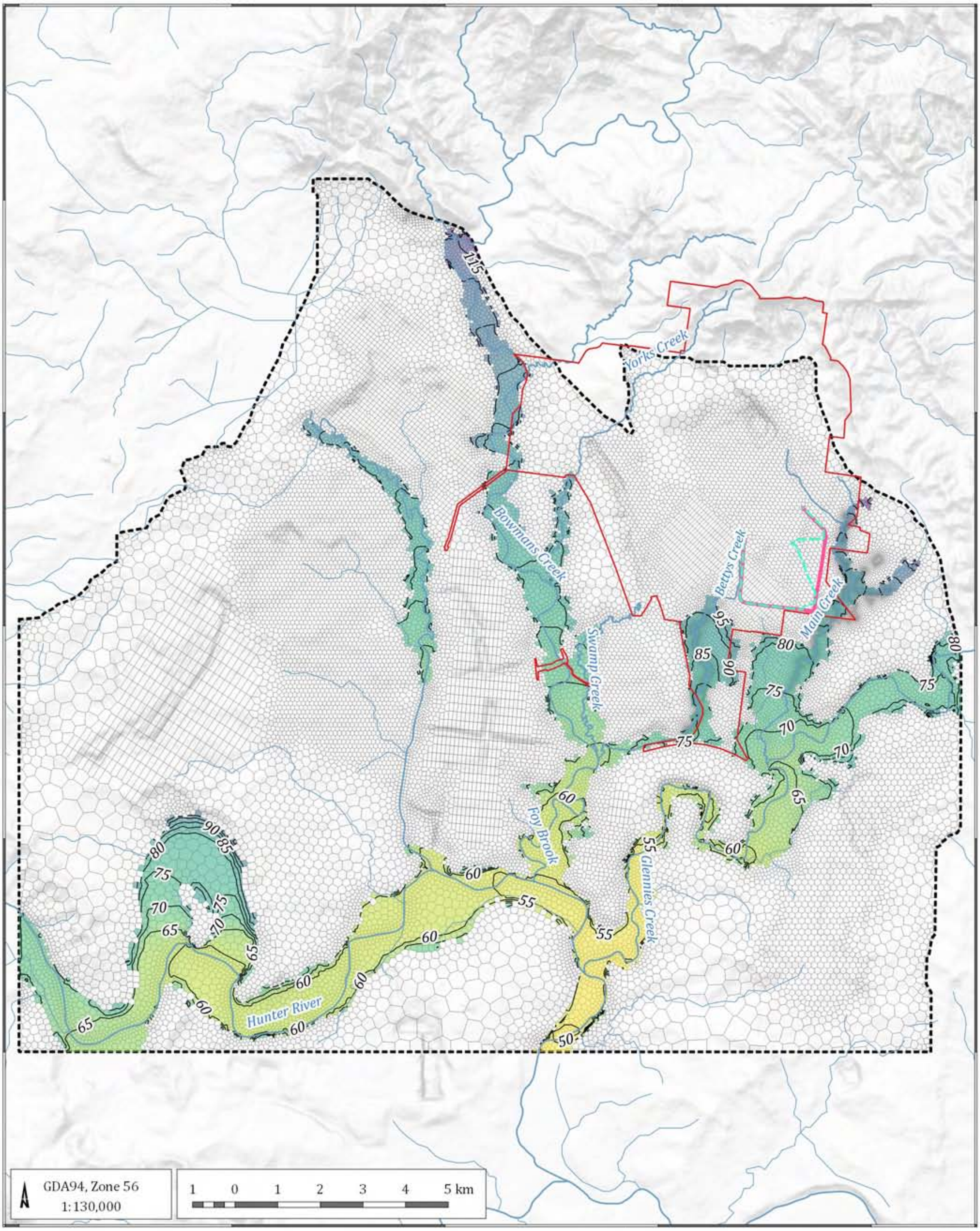
Figure C 17 NPZ9/9a modelled versus measured hydrographs

The results show the variability of groundwater levels with time as a result of mining activities associated with Mt Owen and Integra. Because the construction details regarding the placement of the screen and the integrity of the seal at these locations is limited, there is potential the measured data points represent a composite groundwater level from several model layers, rather than an isolated layer output which was assumed during the calibration. Despite the uncertainty in the bore construction the performance of the model appears to be reasonable at these locations.

C3.2.1 Calibration heads

The calibrated heads from the steady state calibration model are presented in Figure C 18, Figure C 19and Figure C 20 for the unconsolidated sediments (alluvium and regolith) and coal seams (Middle Liddell and Barrett respectively). The figures show groundwater generally flows southeast to the local drainage systems without the presence of active open-cut and longwall mining.

The calibrated heads at the end of the transient calibration model (2017) are presented in Figure C 22 and Figure C 23 for the unconsolidated sediments (alluvium and regolith) and coal seams (Middle Liddell and Barrett) respectively. Groundwater levels representing 2017 conditions show the depressurised zones within the potentiometric surface caused by the advancement of mining. Depressurisation within the Middle Liddell Seam reflects the advance of works at the West Pit, Ravensworth, Liddell, Ashton, Glendell, Mount Owen and Integra Underground mines.



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh
- Major drainage
- Minor drainage
- Groundwater level contour (mAHD)

Groundwater level (mAHD)

50
60
70
80
90
100
110
120
130

Mount Owen (G1862A)

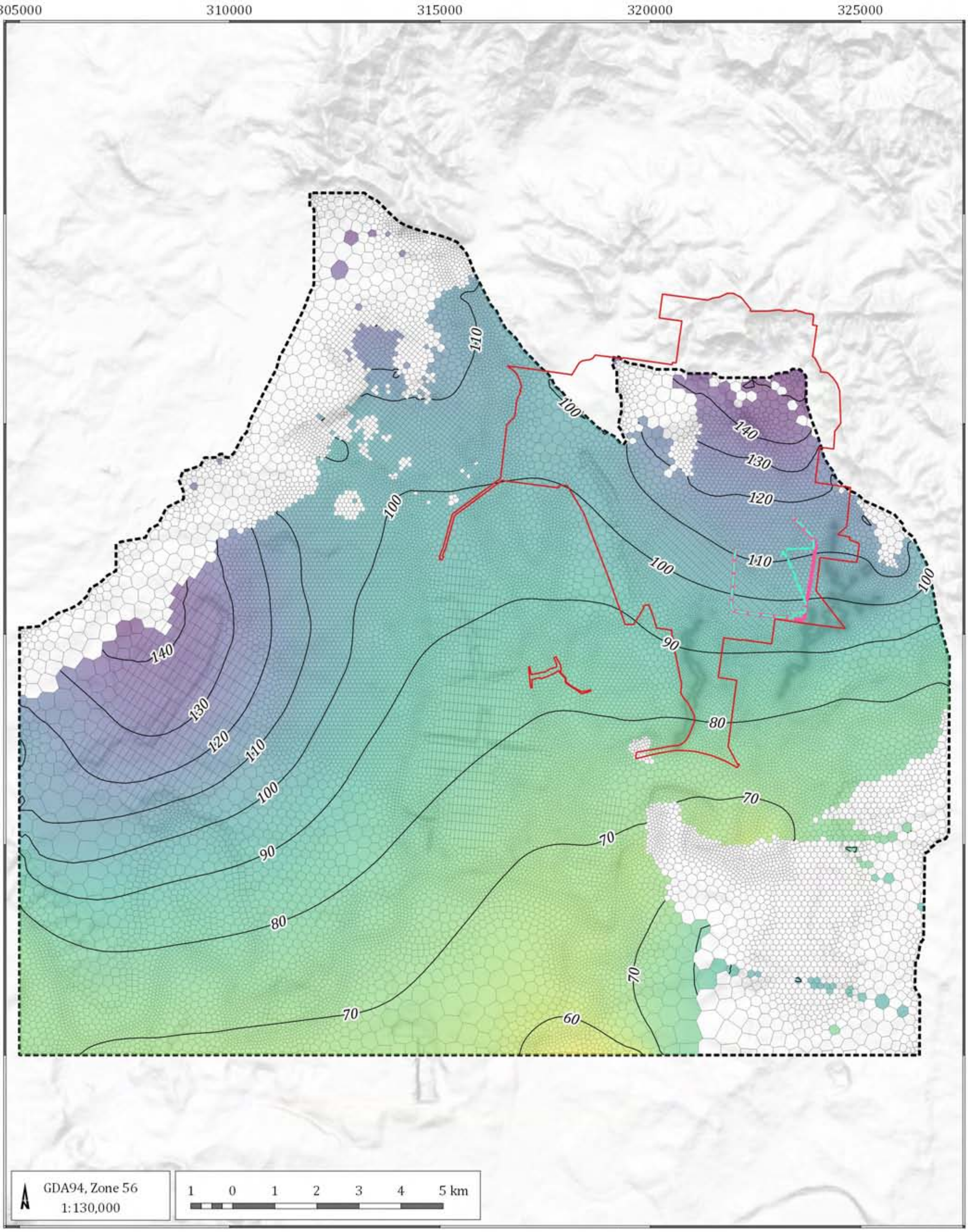
Predicted pre-mining groundwater levels - Alluvium and regolith

AGE

DATE 12/06/2018

FIGURE No: **C-18**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/C-17-26_G1862A Predicted_Premining Groundwater levels.qgs



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh
- Groundwater level contour (mAHD)

Groundwater level (mAHD)

50
60
70
80
90
100
110
120
130
140
150

Mount Owen (G1862A)

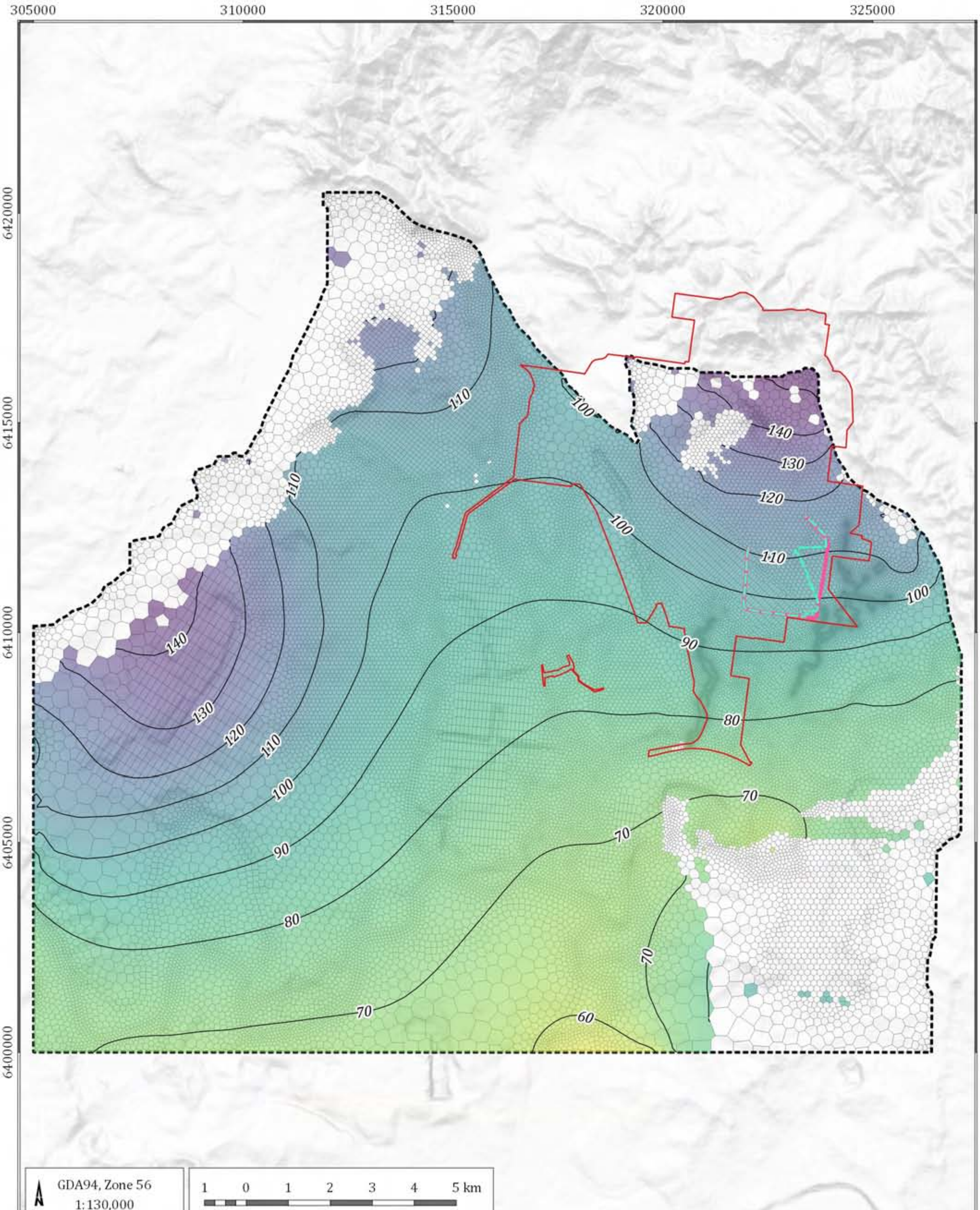
Predicted pre-mining groundwater levels - Middle Liddell Seam

AGE

DATE 12/06/2018

FIGURE No: **C-19**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/C-17-26_G1862A Predicted_Premining Groundwater levels.qgs



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh
- Groundwater level contour (mAHD)

Groundwater level (mAHD)

50
60
70
80
90
100
110
120
130
140
150

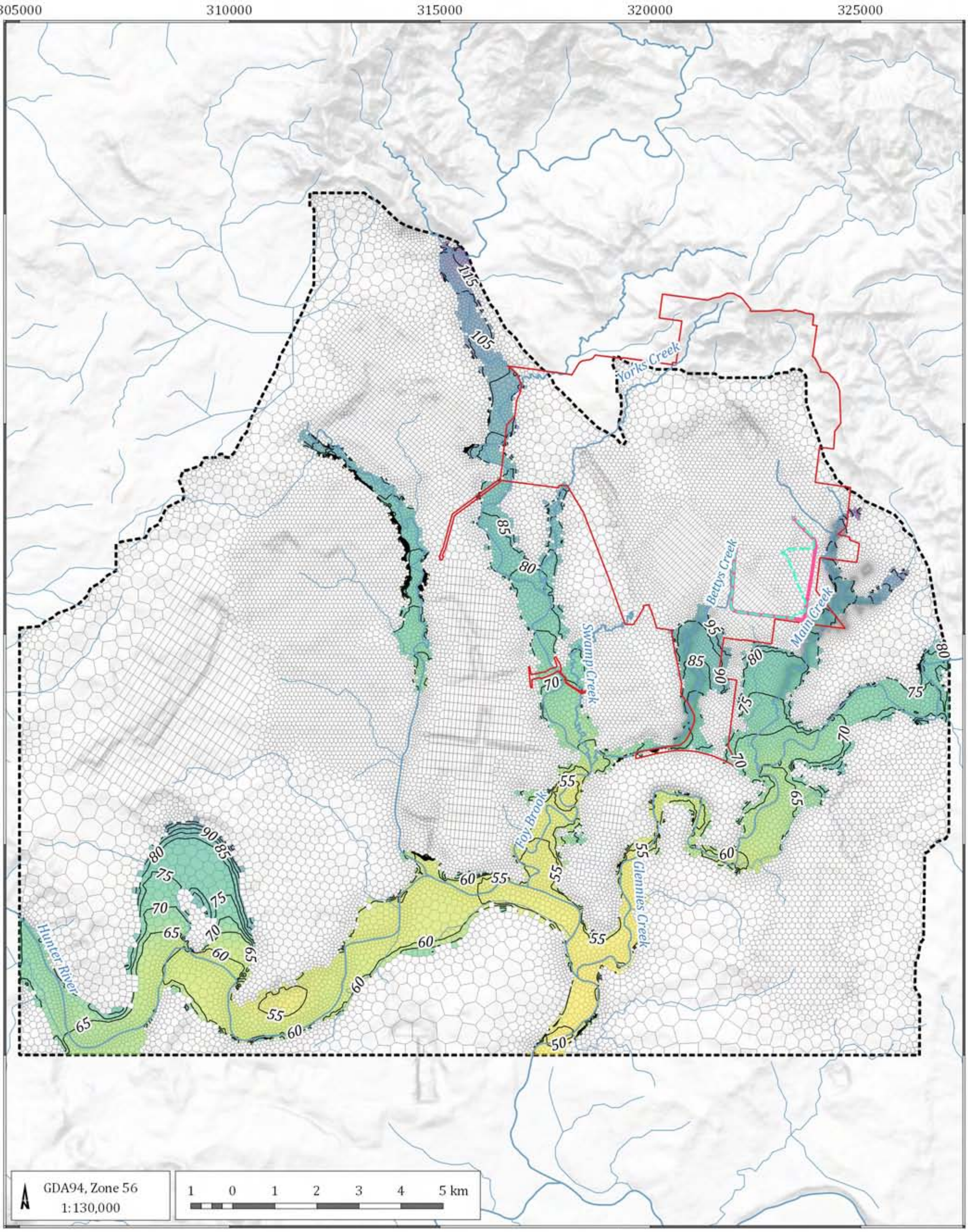
Mount Owen (G1862A)

Predicted pre-mining groundwater levels - Barrett Seam

DATE
12/06/2018

FIGURE No:
C-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.;
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/C-17-26_G1862A Predicted_Premining Groundwater levels.qgs



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh
- Groundwater level contour (mAHD)
- Major drainage
- Minor drainage

Groundwater level (mAHD)

50
60
70
80
90
100
110
120
130

Mount Owen (G1862A)

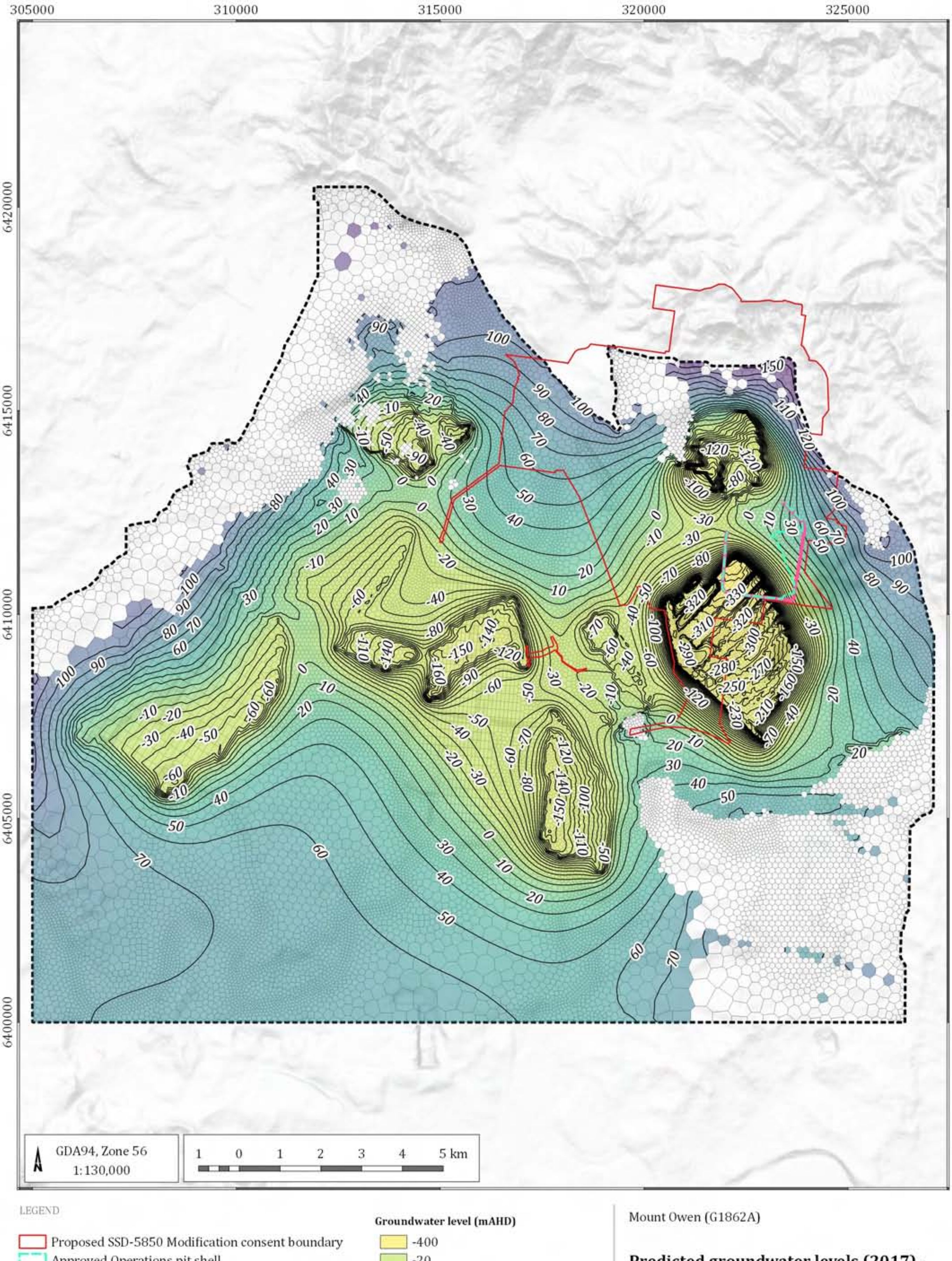
Predicted groundwater levels (2017) - Alluvium and regolith

AGE

DATE 12/06/2018

FIGURE No: **C-21**

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/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/C-17-26_G1862A Predicted_Premining Groundwater levels.qgs



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh
- Groundwater level contour (mAHD)

Groundwater level (mAHD)

-400
-20
0
20
40
60
80
100
120
140
160

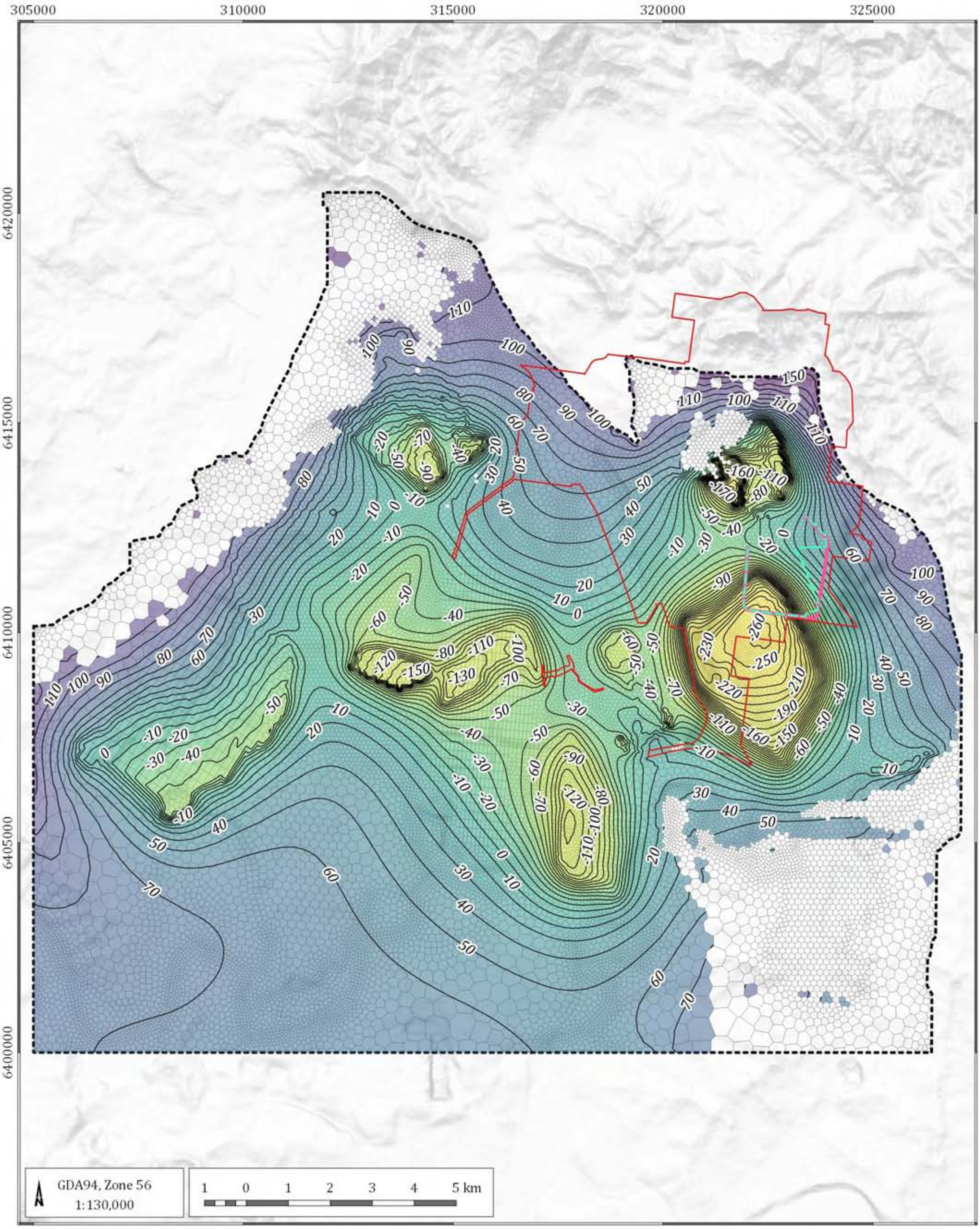
Mount Owen (G1862A)

Predicted groundwater levels (2017) - Middle Liddell Seam

DATE 12/06/2018

FIGURE No: **C-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.;
G:/Projects/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/C-17-26_G1862A Predicted_Premining Groundwater levels.qgs



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh
- Groundwater level contour (mAHD)

Groundwater level (mAHD)

-270
-75
-50
-25
0
25
50
75
100
125
150

Mount Owen (G1862A)

Predicted groundwater levels (2017) - Barrett Seam

AGE

DATE 12/06/2018

FIGURE No: **C-23**

C3.2.2 Hydraulic parameters

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

Table C 8 Calibrated hydraulic conductivity values

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

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

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

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

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

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

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

Where: HC is horizontal hydraulic conductivity at specific depth.

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

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

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

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

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

The Kh vs. depth relationship for the individual coal seams and interburden units are presented in Figure C 24 and Figure C 25. As shown in Figure C 24 and Figure C 25, the calibrated depth dependence trends for the various coal and interburden layers largely follow the averaged trend identified for the available field data described with the main report. The relationship used for the interburden in the model was skewed towards the more permeable measurements in the field data below 150 m, indicating the base model is conservative.

In order to demonstrate the application of the depth dependence function, the spatial distribution of hydraulic conductivity values is presented in Figure C 26 for the Barrett Seam. Figure C 26 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).

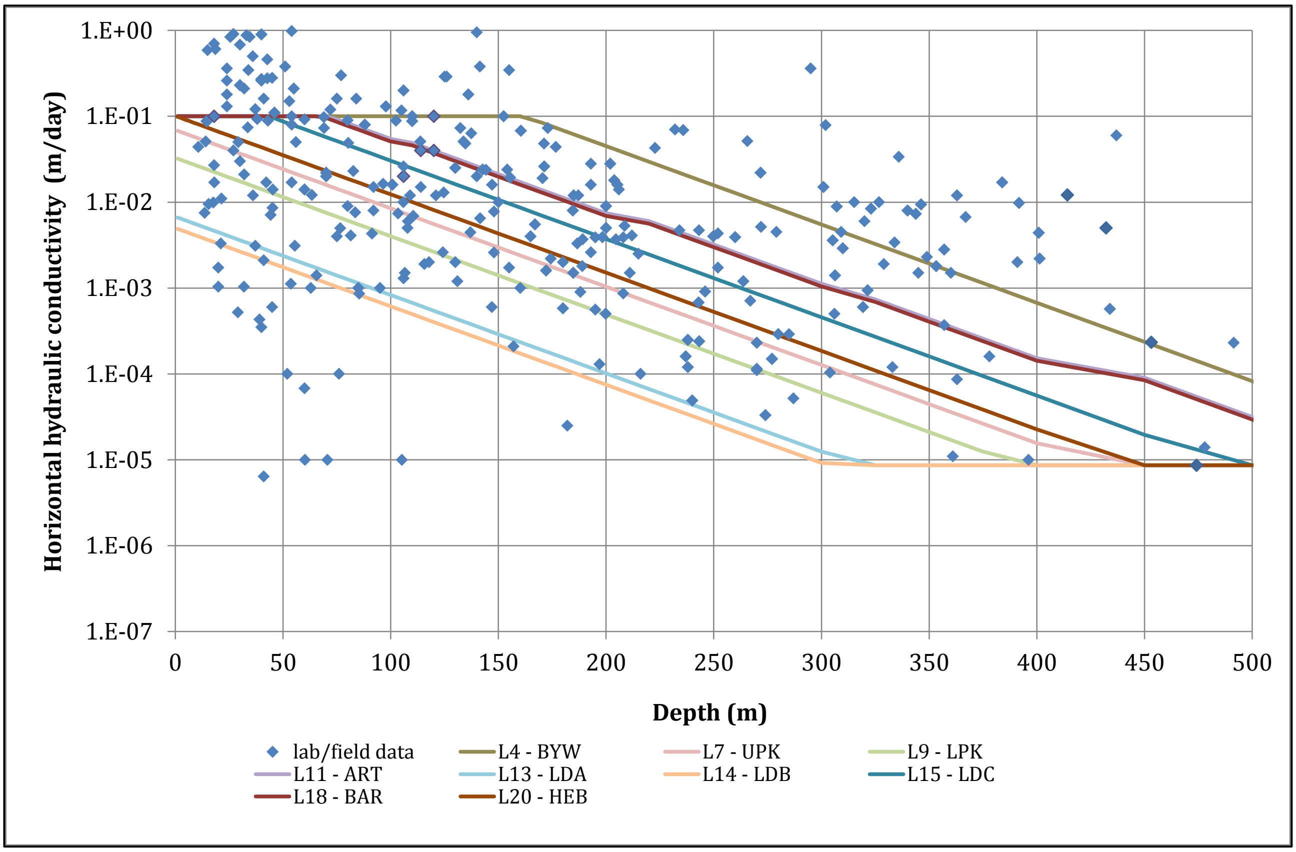


Figure C 24 Coal hydraulic conductivity distribution graph

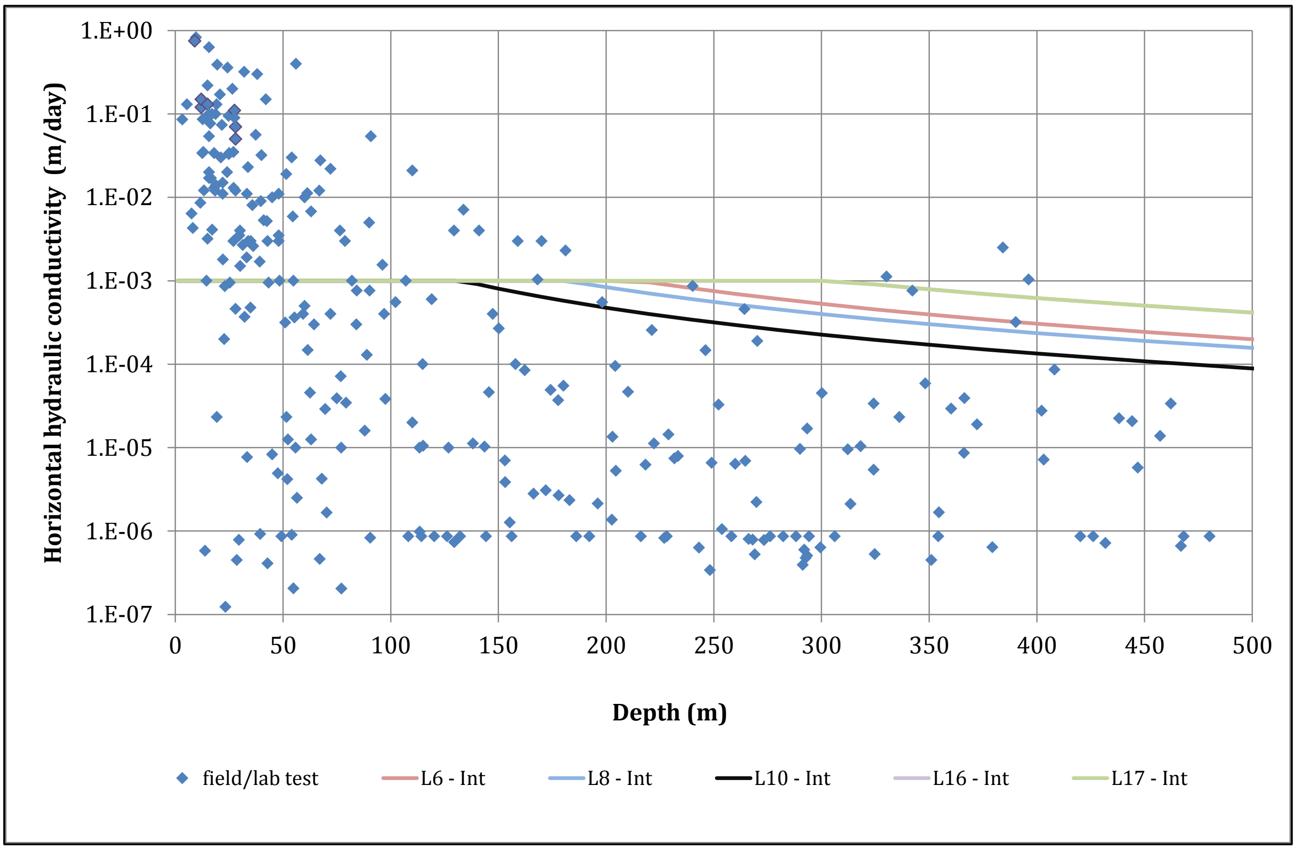
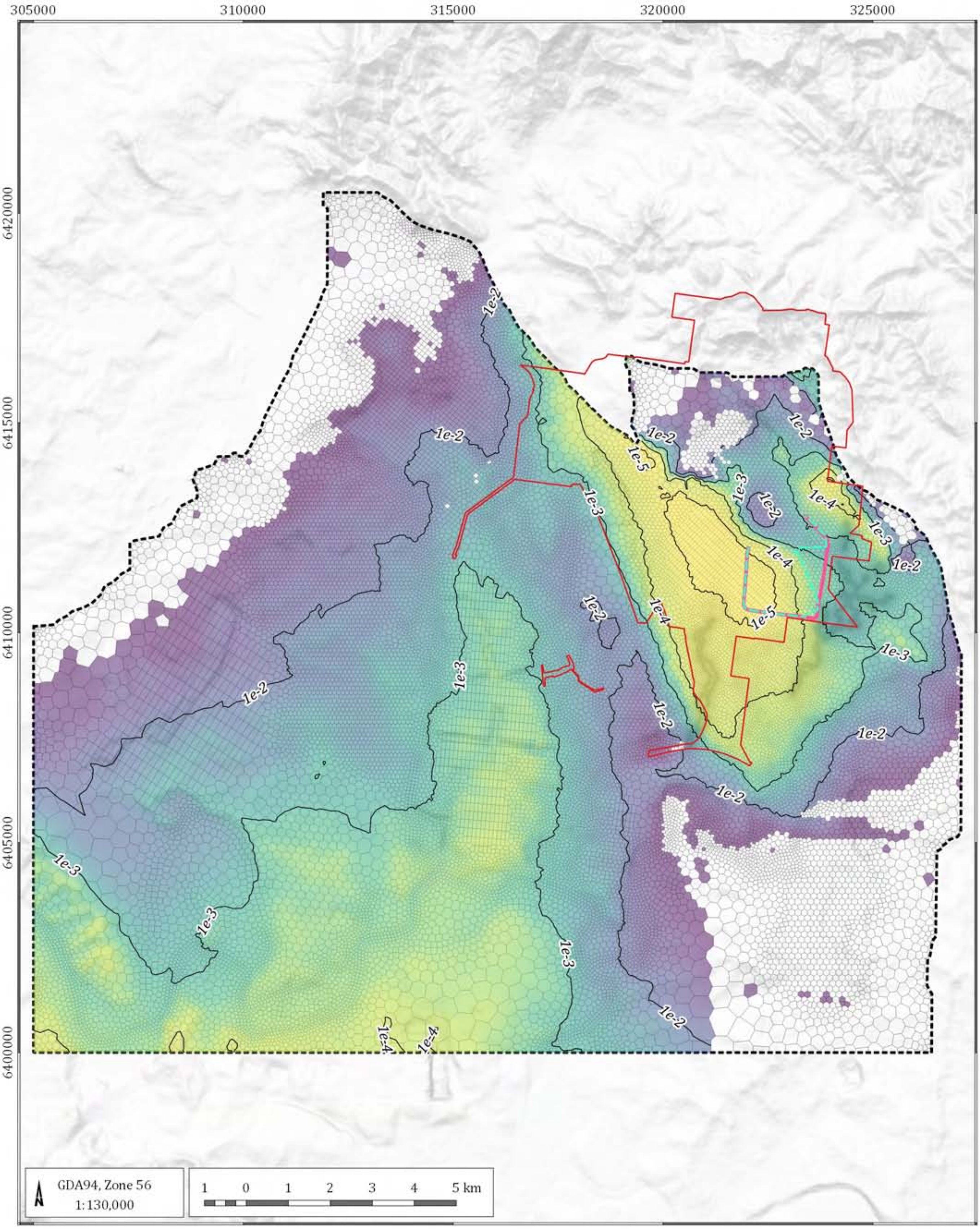


Figure C 25 Interburden hydraulic conductivity distribution graph



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Model mesh
- Groundwater level contour (mAHD)

Hydraulic conductivity (m/day)$_{f}$

- 1e-5
- 1e-4
- 1e-3
- 1e-2
- 1e-1

Mount Owen (G1862A)

Modelled hydraulic conductivity of the Barrett Seam

DATE 12/06/2018

FIGURE No: **C-26**

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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C3.2.3 Storage properties

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

Table C 9 Model layer storage properties

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

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

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

C3.2.4 Parameter sensitivity

The parameters used to calibrate the model to the observation dataset displayed varying levels of insensitivity to model responses. A linear analysis was undertaken to provide an identifiability value for each parameter ranging between 0 and 1. An identifiability value of one means that the parameter can be well constrained through the calibration process and hence the parameter is highly estimable. In contrast, an identifiability value of zero indicates that the parameter cannot be supported by the calibration datasets and hence its uncertainty does not reduce through the calibration process. Figure C 27 and Figure C 28 show the identifiability of a parameter in respect to the groundwater level observation data.

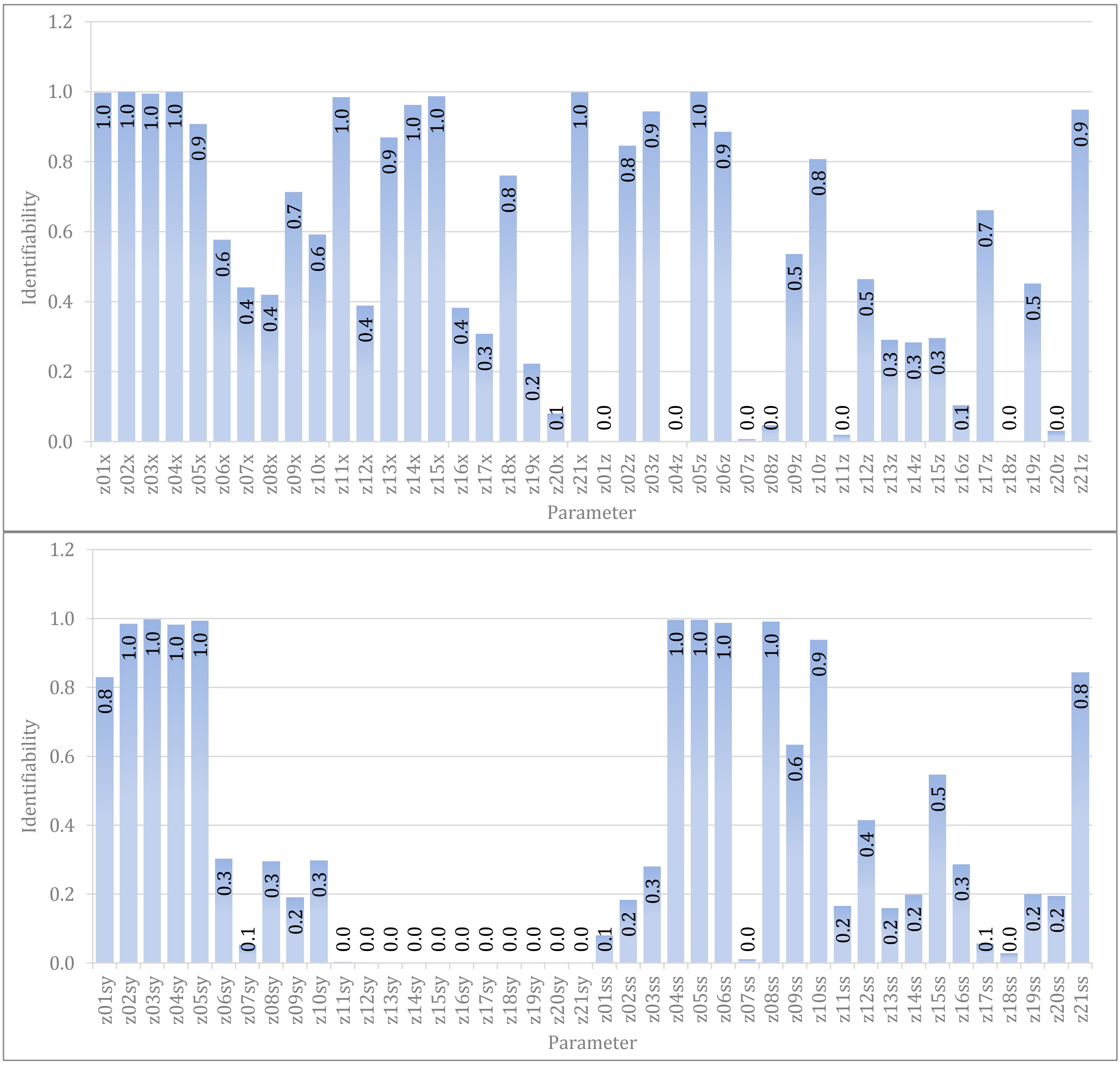


Figure C 27 Parameter identifiability – hydraulic conductivity and storage

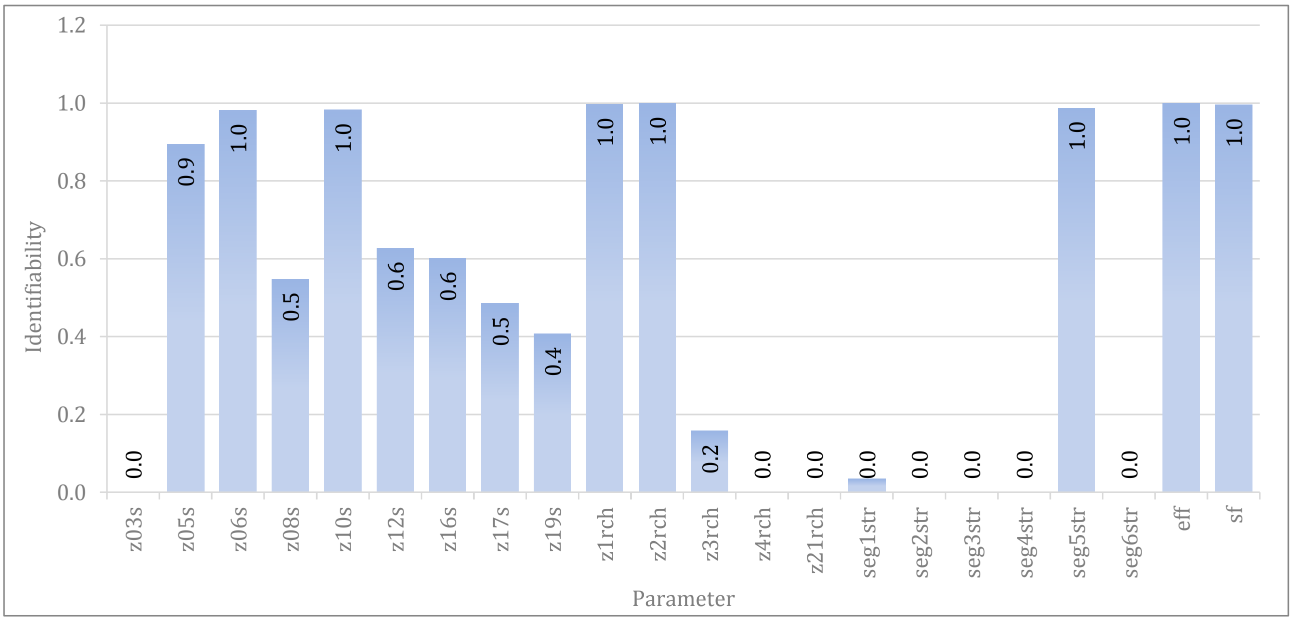


Figure C 28 Parameter identifiability – other

The results indicate that there are numerous parameters that are considered 'identifiable', and are associated with:

- horizontal hydraulic conductivity of the shallow aquifer units (z01-5x) and Liddell coal seams (z13-15x);
- vertical hydraulic conductivity of the shallow aquifer units and upper interburden (z02-3x, z05-6x);
- specific yield of the shallow aquifer system (z01-5sy);
- specific storage of the upper interburden (z04-6sy);
- slope, which determines horizontal hydraulic conductivity of the upper interburden (z05-6s, z10s);
- recharge to the alluvium and regolith (z1-2rch);
- vertical hydraulic conductivity of Glennies Creek streambed (seg5str); and
- application of hydraulic fracturing above the longwall panels (eff, sf).

It is important to note that the high identifiability values are likely a result of the lack of parameterisation within the groundwater model. Linear analysis is best applied to highly parameterised models, whereby many pilot points are applied across the model domain to introduce heterogeneity and un-constrain parameters to observation records distal to the pilot point. Hence, these parameter sensitivities should be used as a guide.

C3.2.5 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 C 10 shows the water budget for the steady state (pre-mining) model.

Table C 10 Model budgets – steady state

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

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

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

Table C 11 Model budgets – transient calibration

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

The water budget indicates that the groundwater system slightly departs from steady state conditions because of extensive mining in the model domain. Recharge (rainfall and river leakage) within the model averages 10.7 ML/day, with approximately 4.6 ML/day being discharged via surface drainage surface. The differences between the steady state recharge rates are due to different climatic conditions during the transient calibration period (1980 to 2017) when compared to the annual average (steady state). Table C 11 shows regional dewatering extracts at 9.8 ML/day on average, which indirectly reduces surface drainage, evaporation rates, and increases inflows from the general and constant head boundaries.

C3.2.6 Baseflow verification

Figure C 29 shows estimated observed baseflow at Bowmans Creek downstream of the mine (station 210004), compared to simulated baseflow. Flow out of the model domain is displayed as a negative value and observed baseflow was calculated using a search algorithm adopted from Arnold and Allen (1999) via the 'SWAT Bflow' executable (Texas A&M University, 2014).

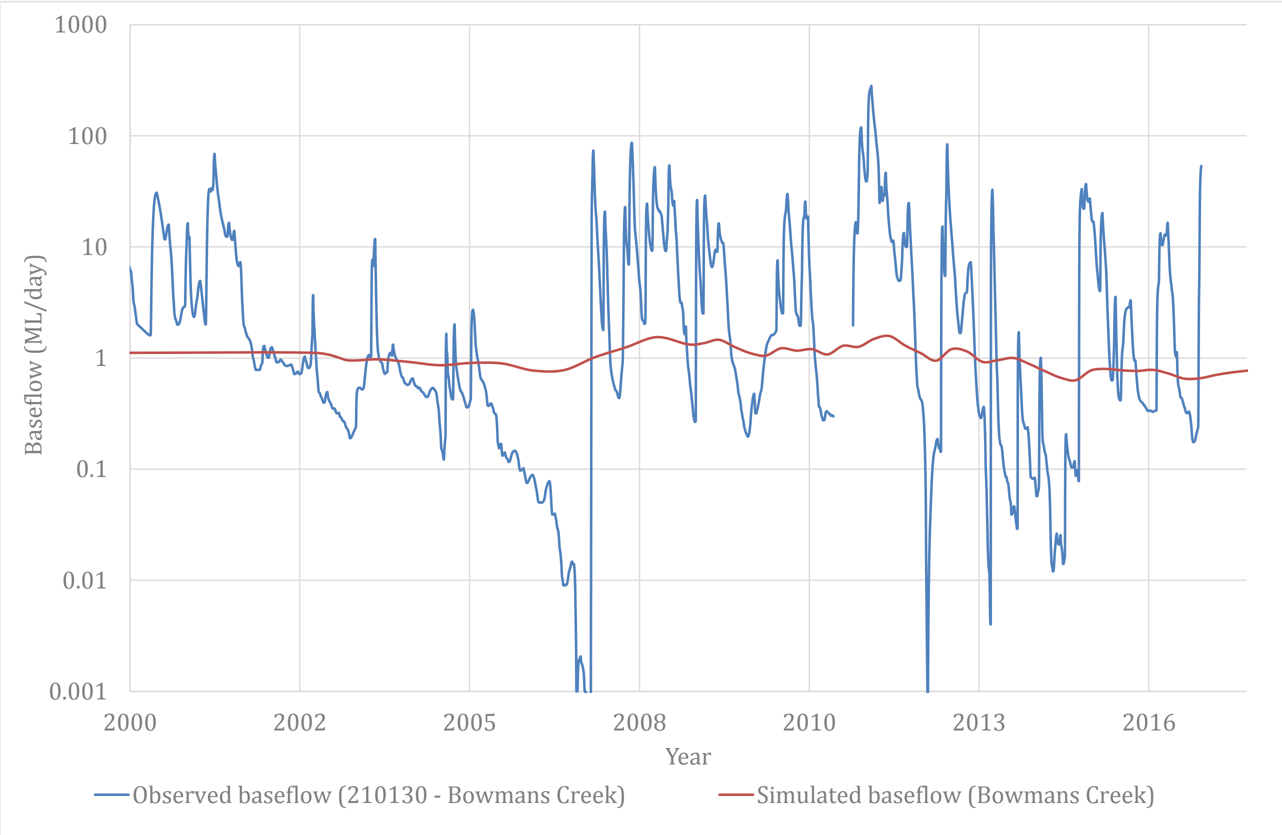


Figure C 29 Modelled vs observed baseflow analysis at Bowmans Creek

The results show the model generally replicates the calculated baseflow levels and climatically controlled trends in a subdued manner. Figure C 30 the baseflow calculated for the Glennies Creek station that is just outside the model domain (station 210044), compared to baseflow within the model domain.

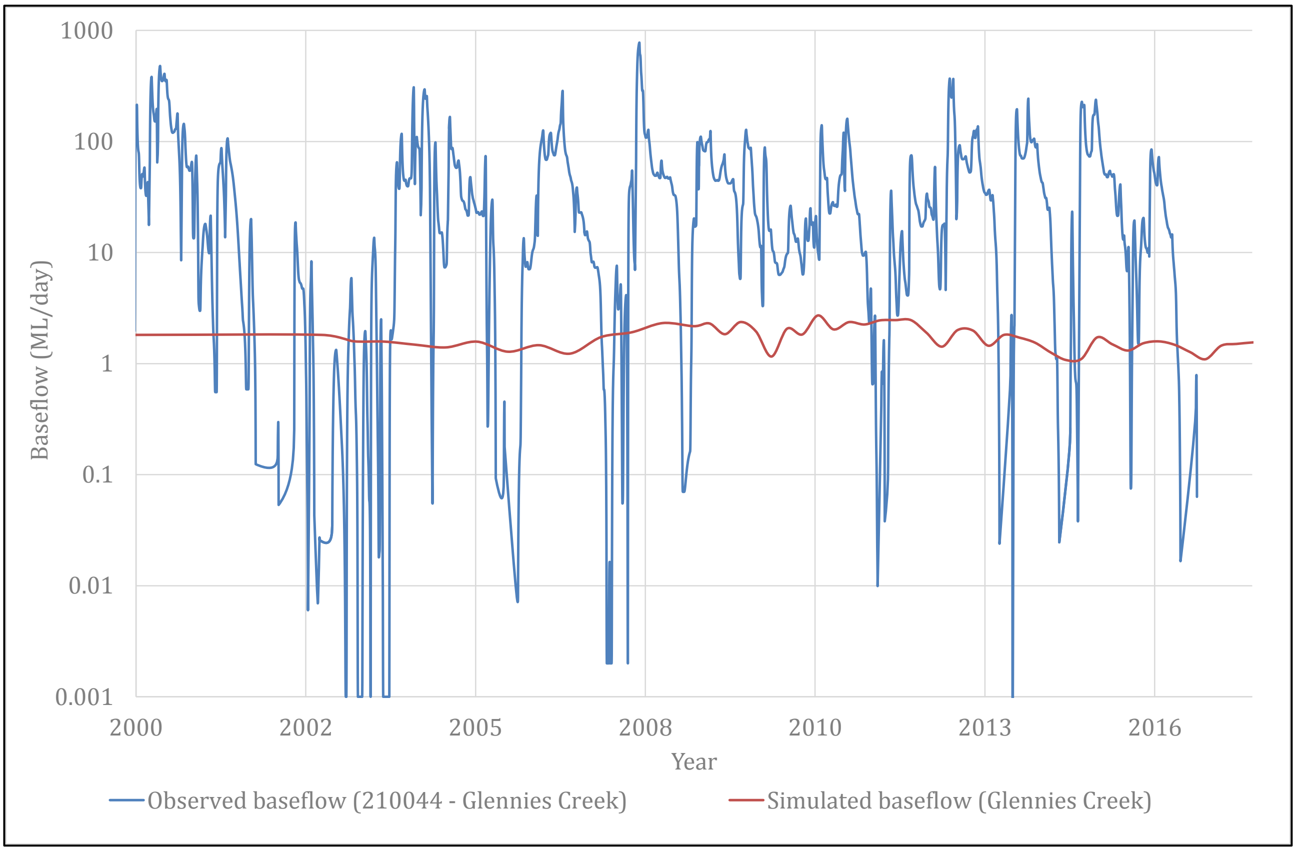


Figure C 30 Modelled vs observed baseflow analysis at Glennies Creek

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

C3.2.7 Mine inflow verification

Observable and pumpable groundwater inflow to the North Pit is essentially zero, therefore a verification using the groundwater model is not possible. The underground workings at Integra are estimated to have received average inflows in the order of 0.8 ML/day at the sumps between 2015 and 2017. The calibrated numerical model predicted approximately 1.2 ML/day entering the Integra Underground mine which is considered an acceptable match given losses that occur underground.

C3.2.8 Model confidence level classification

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

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

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

Table C 12 Model confidence level classification

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

C4 Recovery simulations

At the completion of mining, drain cells were removed and the model simulated post-mining conditions, which includes final voids within the Mt Owen complex. A transient model was created to ascertain post-mining impacts. A recovery simulation was run, with all drain cells removed, thus allowing the groundwater levels in the coal seams and the overlying water-bearing strata to recover. Model cells located within the final voids were assigned constant head cells, using a pit-lake recovery curve based on the surface water assessment (Engeny, 2017). Seven stress periods were used to replicate the steadily increasing pit lake following the completion of the Proposed Modification.

C5 Uncertainty analysis

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

C5.1 Methodology

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

C5.2 Parameter generation

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

Figure C 31 and Table C 13 to Table C 18 shows the 'prior' range explored during the uncertainty analysis simulation. This represents the 95th confidence interval best on prior information of the likely range of the model parameters prescribed to an entire homogenous unit. All parameters were assumed to possess a log-normal distribution using a mean value, or the most probable value, derived from the calibration exercise. The rainfall recharge rates for each unit were adjusted to cover the natural cycles of wet and dry years indicated in the 117 year historical dataset.

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

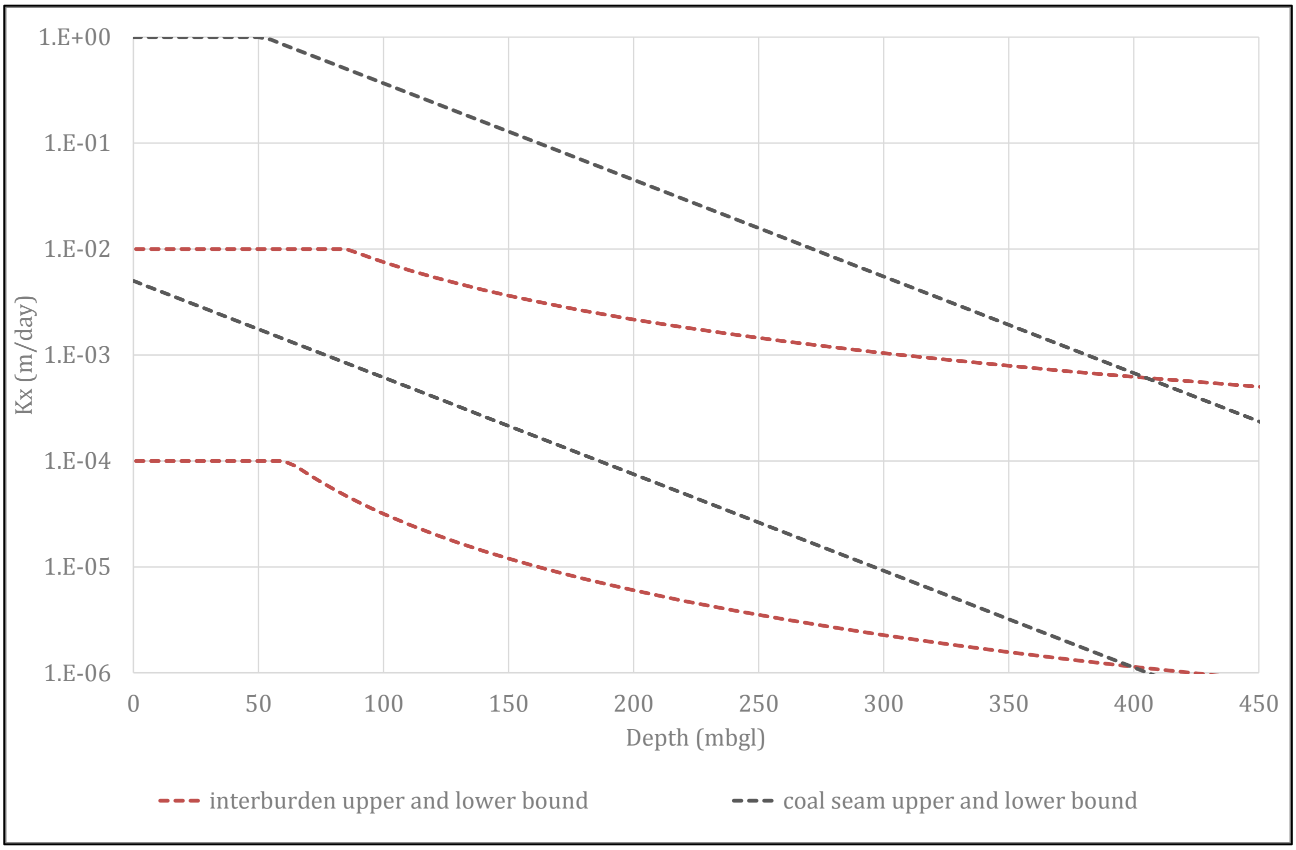


Figure C 31 Prior uncertainty range – Kx coal and interburden

Table C 13 Prior homogenous uncertainty range - Kx

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

Table C 14 Prior range – Kz factor

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

Table C 15 Prior range – Specific yield

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

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

Table C 16 Prior range – Specific storage

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

Table C 17 Prior range – recharge

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

Table C 18 Prior range – streambed Kz

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

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

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

The variability of recharge to the system assessed in the uncertainty analysis is equivalent to the 95th confidence interval of climate conditions on a yearly basis from 1900 to 2017. This is equivalent to a modelled alluvial recharge rate of 2.3 to 109.4 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.

C5.3 Results

A total of 225 models achieved model convergence and produced acceptable calibration statistics. Objective function values (i.e. sum of the squared weighted residuals) across the 225 model realisations ranged from an 11% improvement from the basecase model performance, to a 22% 'de-calibration' performance in the worst case. A summary of the calibration performance and predictive response to mining is provided within Appendix C-3. The hydrographs show the composite distribution of the heads across all 225 realisations and indicate that the majority of the models are acceptably calibrated.

C5.3.1 Permian Groundwater inflow

Figure C 32 presents the uncertainty of Permian groundwater inflow into the approved mining and the Proposed Modification into North Pit combined from 2009 to 2035.

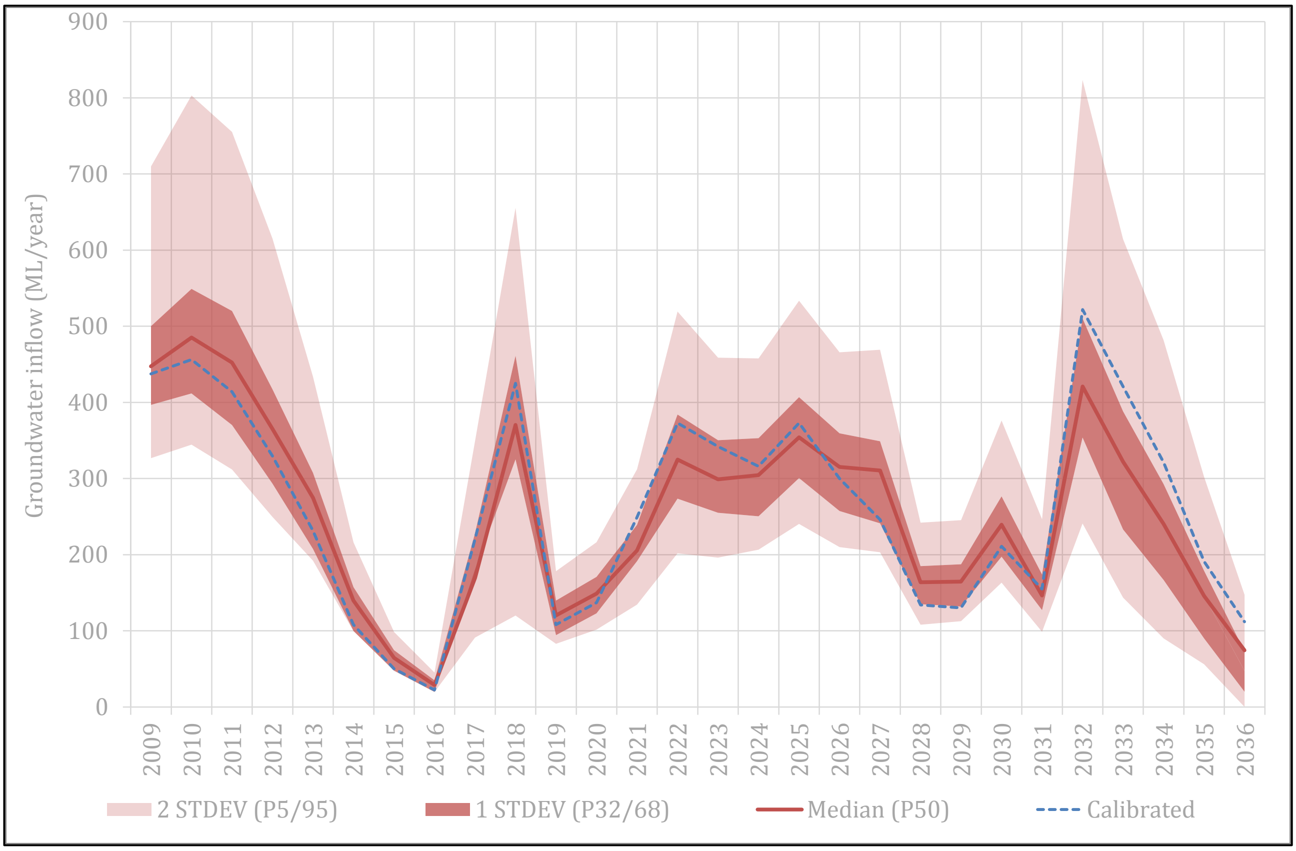


Figure C 32 Continued Operations Project + Proposed Modification - North Pit groundwater inflow uncertainty

The uncertainty analysis indicated future inflows up to 510 ML/year at 1 standard deviation in year 2032.

C5.3.2 Alluvial groundwater and surface water 'take'

Figure C 33 to Figure C 36 present the change in flux to the alluvial systems for the approved Continued Operations and the Proposed Modification. Due to the negligible influence from the Proposed Modification, these graphs represent the uncertainty in the impact from the approved Continued Operations Project.

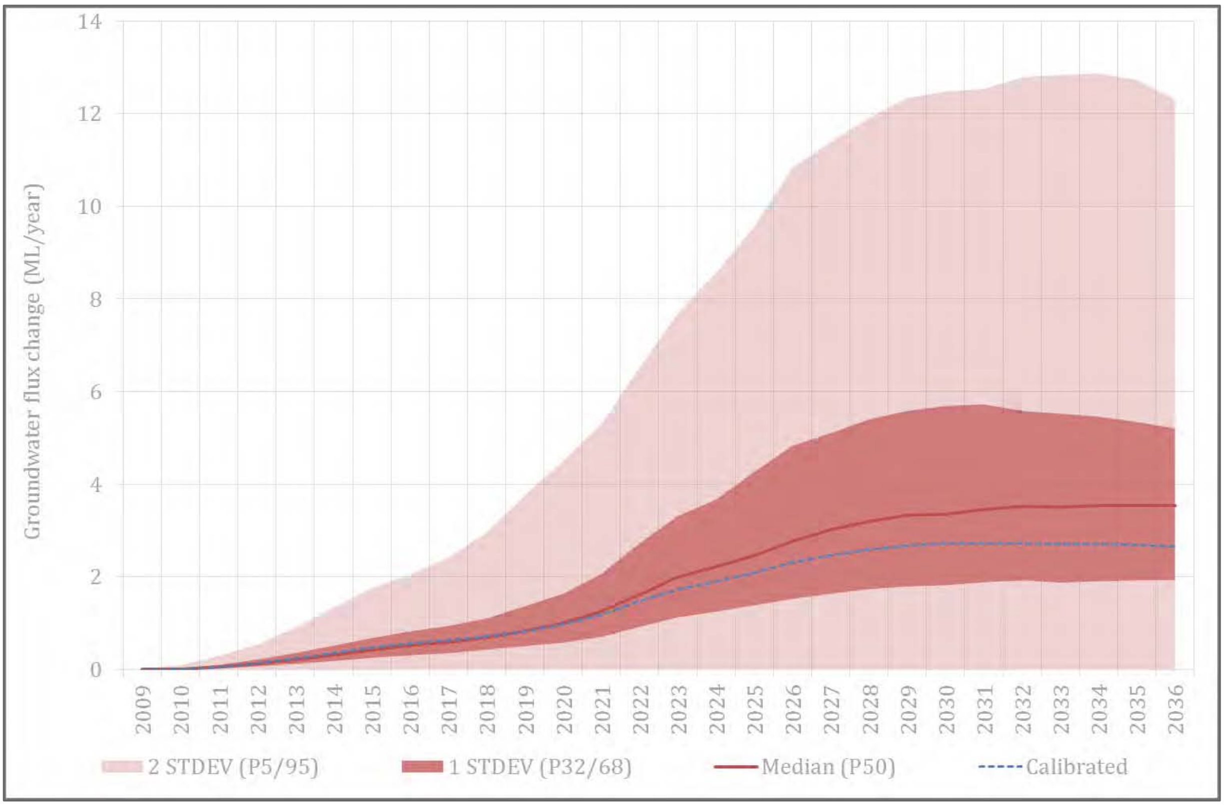


Figure C 33 Uncertainty in alluvial flux change - Continued Operations Project + Proposed Modification - Main Creek alluvium

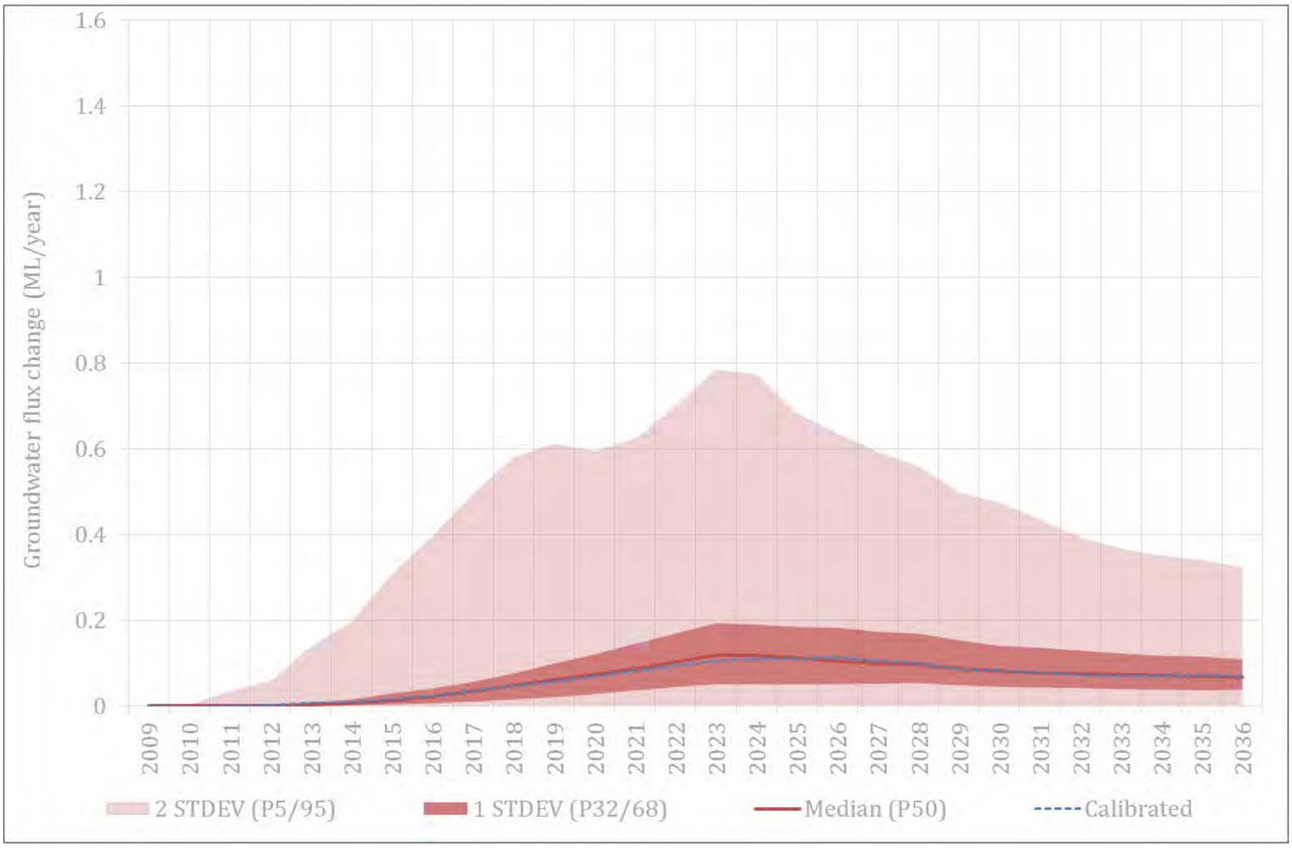


Figure C 34 Uncertainty in alluvial flux change - Continued Operations Project + Proposed Modification - Glennies Creek alluvial take

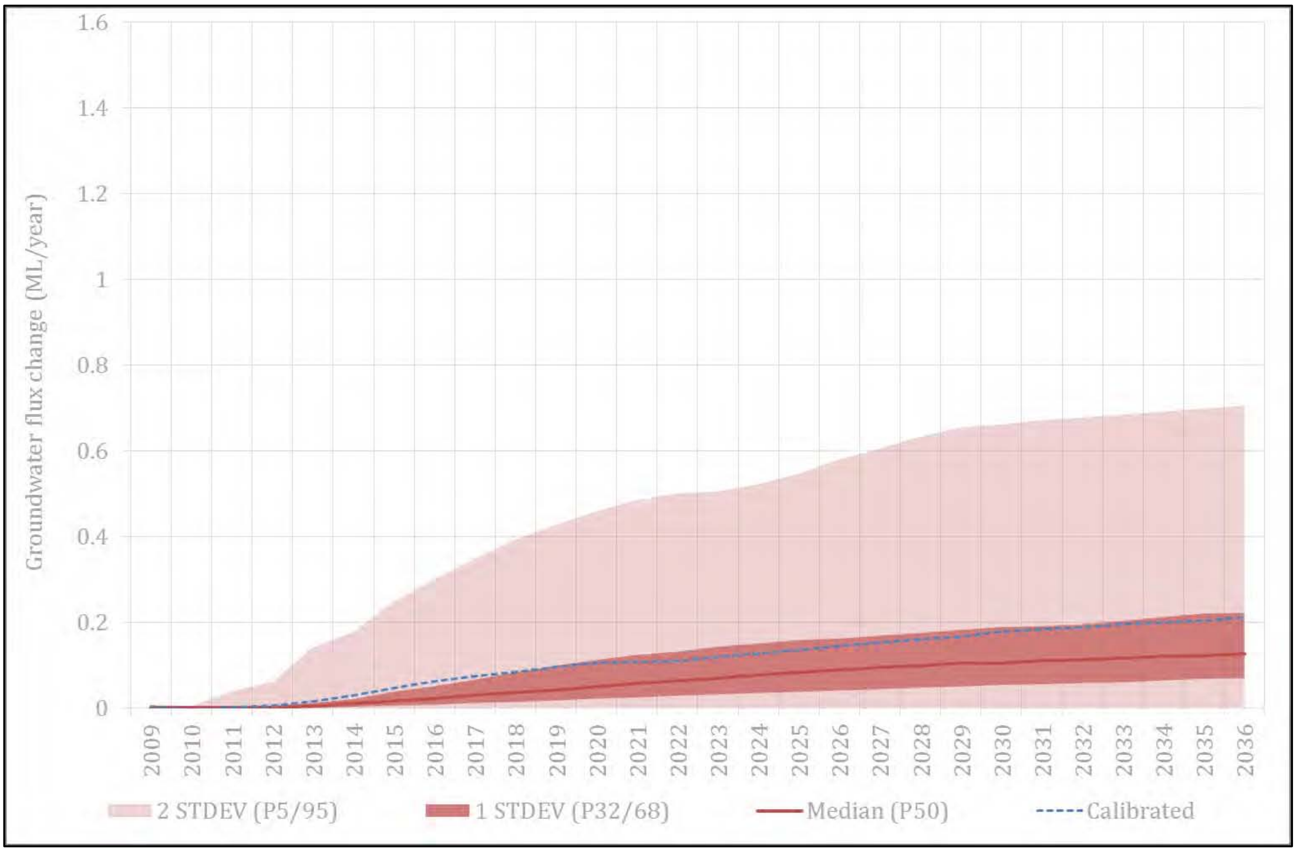


Figure C 35 Uncertainty in alluvial flux change - Continued Operations Project + Proposed Modification - Bowmans Creek alluvial take

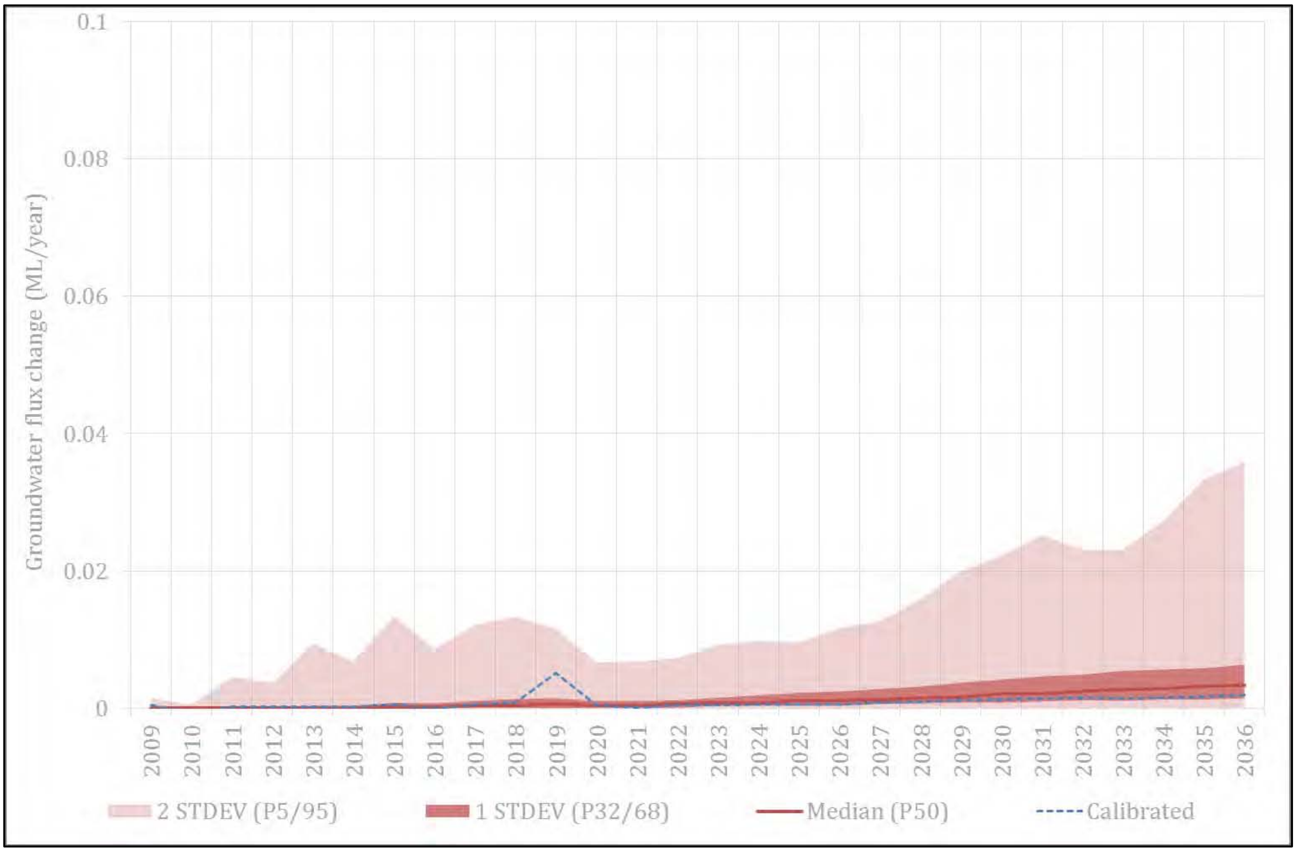


Figure C 36 Uncertainty in alluvial flux change - Continued Operations Project + Proposed Modification - Bettys Creek alluvial take

Table C 19 shows the change in flux to the alluvial groundwater systems and the resultant change in stream baseflow due to the Continued Operations Project and Proposed Modification for the +1 standard deviation outcome from the uncertainty analysis. The alluvial takes have been corrected for double-accounting by subtracting the incremental baseflow change from the corresponding raw alluvial flux change where the groundwater and surface water are within the same water source and WSP. The Glennies Creek flux changes were not corrected as the groundwater and surface water are regulated under different WSPs.

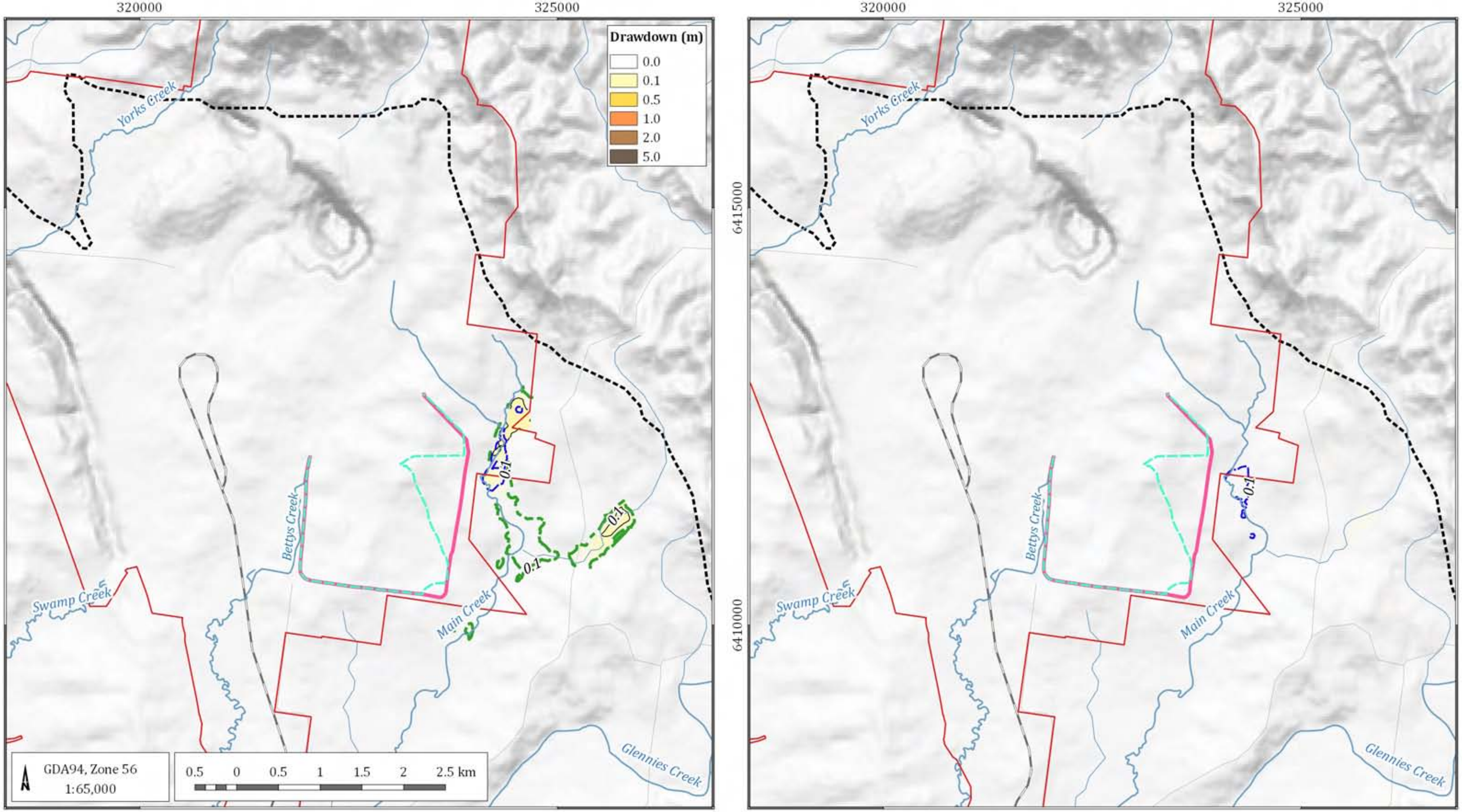
Table C 19 Maximum likely (+1 STDEV) alluvial and surface water takes

Year	Main Creek alluvium (ML)	Main Creek (ML)	Glennies Creek alluvium (ML)	Glennies Creek (ML)	Bowmans Creek alluvium (ML)	Bowmans Creek (ML)	Bettys Creek alluvium (ML)	Bettys Creek (ML)
2009	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2011	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2012	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2013	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0
2014	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0
2015	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0
2016	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0
2017	0.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0
2018	0.8	0.3	0.1	0.1	0.1	0.0	0.0	0.0
2019	0.9	0.4	0.1	0.1	0.1	0.0	0.0	0.0
2020	1.0	0.4	0.1	0.1	0.1	0.0	0.0	0.0
2021	1.2	0.5	0.1	0.1	0.1	0.0	0.0	0.0
2022	1.6	0.7	0.1	0.1	0.1	0.0	0.0	0.0
2023	2.0	0.9	0.1	0.1	0.1	0.1	0.0	0.0
2024	2.3	1.1	0.1	0.1	0.1	0.1	0.0	0.0
2025	2.5	1.3	0.1	0.1	0.1	0.1	0.0	0.0
2026	2.9	1.4	0.1	0.1	0.1	0.1	0.0	0.0
2027	3.1	1.6	0.1	0.1	0.1	0.1	0.0	0.0
2028	3.3	1.8	0.1	0.1	0.1	0.1	0.0	0.0
2029	3.5	1.9	0.0	0.1	0.1	0.1	0.0	0.0
2030	3.6	2.0	0.0	0.1	0.1	0.1	0.0	0.0
2031	3.6	2.1	0.0	0.1	0.2	0.1	0.0	0.0
2032	3.7	2.2	0.0	0.1	0.2	0.1	0.0	0.0
2033	3.7	2.2	0.0	0.1	0.2	0.1	0.0	0.0
2034	3.7	2.2	0.0	0.1	0.2	0.1	0.0	0.0
2035	3.7	2.3	0.0	0.1	0.2	0.1	0.0	0.0
Max	**3.7**	**2.3**	**0.1**	**0.1**	**0.2**	**0.1**	**0.0**	**0.0**

C5.3.3 Groundwater drawdown

Figure C 37 presents the uncertainty in maximum groundwater drawdown at any time within the Quaternary alluvium due to the Continued Operations Project and Proposed Modification. The results show that the majority of the models do not predict significant impacts to the alluvium during the mining. The maximum drawdown value (median + 2 standard deviations) predicted for the Continued Operations Project and Proposed Modification was 0.7 m and 0.2m, respectively. These values occur at isolated cells along Main Creek and Glennies Creek. For comparison, the maximum drawdown encountered from the median result +1 standard deviation was 0.2 m and 0.04 m for the Continued Operations Project and Proposed Modification respectively.

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



LEGEND

- Proposed SSD-5850 Modification consent boundary
- Approved Operations pit shell
- Proposed Modification pit shell
- Model boundary
- Major drainage
- Minor drainage
- Major road
- Minor road
- Rail
- Drawdown contour (m)
- +2 STDEV drawdown contour (0.1 m)
- Median drawdown contour (0.1 m)
- -2 STDEV drawdown contour (0.1 m)

Mount Owen (G1862A)

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

DATE
12/06/2018

FIGURE No:
C-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/G1862A.MtOwen_MOD/3_GIS/Workspaces/002_Deliverable2/C-37-38 uncert v2.qgs

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Appendix C-1

Calibration details and hydrographs

Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
64CT	314495	6414857	16	-61.9	-91.0	-39.8
8-South-2	314558.57	6414427.57	16	-74.0	-103.9	-59.6
ALV1_Large	315528.04	6417638.23	1	0.0	-2.5	1.4
ALV1_Small	315528.04	6417638.23	5	0.1	-3.3	1.7
ALV2_Large	316328.48	6414721.06	1	-1.2	-3.6	-0.5
ALV2_Small	316328.48	6414721.06	2	-0.8	-5.1	0.2
ALV3_Large	315703.61	6417043.79	1	-0.9	-2.9	-0.2
ALV3_Small	315703.61	6417043.79	5	-2.4	-4.3	-1.2
ALV4_Large	315994.63	6416420.77	2	-2.0	-3.9	-0.9
ALV4_Small	315994.63	6416420.77	2	-2.6	-4.9	-1.6
ALV7_Large	316513.72	6413617.33	1	-0.9	-1.9	-0.2
ALV7_Small	316513.72	6413617.33	5	-3.7	-7.2	1.3
ALV8_Large	316151.35	6413366.67	1	-1.9	-5.9	-0.7
ALV8_Small	316151.35	6413366.67	5	-0.7	-5.4	4.9
BC-SP02	317483	6411487	1	-3.9	-4.5	-3.4
BC-SP03	317547	6411405	1	5.8	5.3	6.2
BC-SP04	317610	6411320	1	-7.3	-7.5	-7.1
BC-SP05	317680	6411232	2	-3.2	-3.6	-2.6
BC-SP06	317596	6411588	1	-3.6	-4.2	-3.1
BC-SP07	317681	6411448	1	-4.7	-5.1	-4.4
BC-SP08	317592	6411869	2	-1.7	-2.0	-1.4
BC-SP09	317675	6411703	1	-2.4	-3.2	-2.0
BC-SP10	318080	6409400	2	-1.6	-1.9	-1.1
BC-SP11	318137	6409337	1	-0.9	-1.3	-0.2
BC-SP12	318201	6409265	1	-0.1	-0.7	0.9
BC-SP13	318253	6409210	1	-0.1	-0.5	0.2
BC-SP14	318305	6409158	1	-0.6	-0.9	-0.3
BC-SP15	318182	6409484	1	-2.4	-2.7	-1.9
BC-SP16	318290	6409376	1	-2.1	-2.6	-1.5
BC-SP17	318319	6409543	1	-4.6	-4.9	-4.4
BC-SP18	317350	6411325	1	-0.9	-0.9	-0.9

Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
BC-SP19	317462	6411178	1	-0.2	-0.8	0.5
BC-SP20	318184	6409118	1	-0.5	-1.2	1.3
BC-SP21	318057	6409176	1	-1.1	-1.7	1.1
BC-SP22	317992	6409051	1	-1.9	-2.4	-1.3
Borehole_P	313445	6410681	8	85.0	74.8	93.9
CS4536_HF7	312585.7	6409157.98	15	44.4	26.6	64.8
CS4539A_S2	311501.4	6407889.26	9	-14.0	-22.0	-3.2
CS4545_S4	312852.4	6408418.3	11	-9.8	-28.4	31.4
CS4545B	312852.37	6408414.35	15	-15.8	-22.3	-12.1
CS4545B_Mi	312852.37	6408414.35	2	-9.1	-16.8	-4.0
CS4545B_Sm	312852.37	6408414.35	2	-6.4	-8.8	-2.7
CS4545C	312852.37	6408414.35	18	29.8	27.4	31.7
CS4545D	312852.37	6408414.35	20	33.4	29.7	35.7
CS4547C	312360.37	6406896.61	15	-13.9	-18.5	-8.7
CS4556	311576	6409139	15	16.3	-29.7	25.8
CS4641C	313549	6410436	15	65.1	39.5	101.0
DUR2	313488	6416643	15	7.7	-6.3	29.6
GA1	318378.8	6408259	1	-1.6	-3.1	1.9
GA2	318578.1	6407367	1	-1.2	-2.1	-0.3
GCP09	323259	6407315	1	-2.4	-3.1	-1.7
GCP11	322417	6407232	1	-6.2	-8.6	-2.2
GCP17	323803	6409986	1	-4.1	-4.7	-3.7
GCP18	323406	6407580	7	91.8	88.9	94.0
GCP19	325086	6408333	1	-2.9	-3.9	0.0
GCP21	324466	6407916	1	-1.1	-2.0	0.2
GCP22	324558	6407814	1	-0.9	-1.8	-0.1
GCP23	324535	6407659	1	-0.2	-1.5	0.9
GCP24	323421	6407105	7	39.1	36.5	42.1
GCP25	323005	6406764	1	-1.1	-1.7	-0.3
GCP26	323888	6406292	1	-3.2	-3.9	-2.8
GCP27	323197	6406037	18	35.8	35.4	36.1

Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
GCP28	322651	6405459	1	0.0	-1.4	0.4
GCP29	323191	6405356	1	0.8	0.2	1.6
GCP30	322438	6404649	1	1.8	1.4	2.1
GCP31	322930	6404424	3	-2.2	-2.3	-2.1
GCP32	322491	6404250	21	-0.9	-1.5	-0.4
GCP34	322800	6403235	2	-35.1	-42.3	-29.6
GCP36	322915	6405320	14	4.2	3.0	5.6
GCP38	323468	6405626	11	13.6	10.7	16.2
GCP39	321297	6410352	1	1.9	-1.2	3.4
GCP3D	320838	6409800	3	-32.9	-51.6	-15.8
GCP3S	320924	6408389	1	-0.8	-2.1	0.0
GCP4D	323447	6409344	2	0.9	-2.7	6.2
GCP4S	320838	6409804	1	-1.1	-2.3	0.3
GNPS-02	317564	6410201	1	-4.1	-4.4	-3.7
GNPS-05	317865	6409311	2	-5.2	-5.7	-4.4
GNPS-06	317605	6411062	1	-3.2	-4.4	-2.0
GNPS-07	316530	6412448	1	0.8	0.8	0.8
GW079793	317730	6411962	16	1.2	-0.3	3.4
Haz_1	316148.43	6415645.15	16	-9.3	-32.1	5.6
Haz_1_2	316148.43	6415645.15	16	-6.9	-11.7	-4.1
Haz_3	315650	6417145	15	-52.7	-101.9	-6.4
Haz_4	315638.92	6417147.89	15	-55.6	-101.9	-4.9
Haz_6	316574.2	6415431.05	15	-30.3	-33.5	-25.1
JK101	316752.8	6405243.4	2	0.6	-1.7	2.4
JK102	316751.9	6405243	2	0.4	-0.1	1.3
JK103	316852.8	6405292.7	2	-1.3	-2.6	-0.1
JK104	316853.63	6405293.39	2	0.2	0.1	0.3
JK105	316956.53	6405345.42	2	0.0	-0.6	0.4
JK106	316955.34	6405344.59	2	-0.4	-1.9	0.9
JK107	317046.6	6405388.45	2	0.0	-0.1	0.0
JK108	317047.15	6405388.81	2	3.8	3.6	4.0

Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
JK109	316757.46	6405223.97	2	-0.2	-2.4	1.8
JK110	316758.51	6405224.28	2	1.2	0.8	1.6
JK112	316788.29	6405215.43	2	19.0	2.6	40.7
JK113	316787.63	6405215.96	2	0.0	-1.1	0.8
JK115	316862.24	6405266.24	2	-2.3	-3.4	-1.3
JK117	316863.43	6405266.9	2	11.8	1.0	42.5
JK118	317057.53	6405364.65	2	-1.1	-2.7	0.3
JK119	317058.06	6405364.94	2	2.7	2.5	3.1
JK121	316973.66	6405312.27	2	-2.5	-4.4	-1.5
JK123	316975.55	6405313.99	2	-2.7	-3.5	-1.8
LBH_Coal	315490.28	6417260.36	5	-0.7	-2.8	0.3
MW01	314624	6409058	2	-0.8	-1.0	-0.5
MW1	314063.86	6408205.96	3	-6.7	-7.3	-5.9
MW10	314356	6408296.51	2	-4.9	-6.2	-4.1
MW12	314126.15	6408038.72	5	30.7	29.2	31.6
MW2	314055.91	6408197.14	3	-10.6	-11.0	-10.4
MW3	314046.77	6408196.04	3	-11.4	-11.4	-11.4
MW4	314036.47	6408206.96	3	-15.8	-15.8	-15.7
MW5	314041.76	6408221.49	3	-10.9	-11.0	-10.8
MW6	314095.2	6408208.4	2	-0.9	-1.0	-0.9
MW9	314422.69	6408565.37	2	-14.3	-14.7	-13.9
North	323156.2	6414021	3	-7.5	-11.7	-5.2
NPZ1	323606	6413034	3	-20.5	-23.1	-8.4
NPZ1_Mid	313562.4	6404972.1	4	0.7	-7.0	7.3
NPZ1_Tall	313562.4	6404972	6	-5.6	-10.3	1.1
NPZ10	320961	6411696	2	-19.4	-27.2	-14.0
NPZ101	324046	6410343	1	-9.3	-9.6	-9.1
NPZ102	324489	6412637	1	10.0	9.4	10.3
NPZ103	321177	6410370	1	-2.0	-2.6	-1.7
NPZ104	321028	6408055	1	-1.7	-2.2	-1.4
NPZ106	321091	6408918	1	6.1	5.8	6.4

Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
NPZ10a	320961	6411696	3	-17.8	-22.6	-15.0
NPZ11	318059.4	6412639	2	-10.3	-12.7	-9.3
NPZ1-122	313562	6404972	6	-3.3	-14.2	3.8
NPZ11a	318059.4	6412639	7	-27.0	-27.7	-26.0
NPZ12	318440.4	6411519	2	-22.4	-24.6	-20.3
NPZ12a	318440.4	6411519	7	-16.0	-25.4	24.1
NPZ13	318302.4	6409556	16	70.6	52.2	86.8
NPZ13a	318302.4	6409556	13	40.3	33.5	51.9
NPZ14	319470.6	6407093	16	-22.6	-24.2	-20.3
NPZ14a	319470.6	6407093	20	-21.6	-30.1	-16.5
NPZ15	320784.3	6407934	2	-56.1	-56.7	-54.1
NPZ15a	320784.3	6407934	16	-17.9	-20.0	-8.1
NPZ16	318193.4	6409141	13	66.9	38.4	86.0
NPZ16a	318184	6409127	14	39.5	37.6	41.6
NPZ1-91	313562	6404972	5	7.7	4.0	13.0
NPZ1a	323606	6413034	6	-3.8	-19.1	8.8
NPZ2-120	313315	6405816	6	-18.5	-20.8	-16.7
NPZ3	321182	6410365	1	-13.2	-18.6	-5.1
NPZ3-110	312654	6406480	6	-7.0	-8.4	-4.1
NPZ3-64	312654	6406480	6	0.2	-13.1	3.9
NPZ3a	321182	6410365	3	-32.5	-46.6	-13.8
NPZ4	319534	6415151	3	-4.7	-5.4	-4.2
NPZ4-90	311899	6406810	21	4.8	1.9	5.5
NPZ4a	319534	6415151	21	3.8	2.1	4.9
NPZ5B_P1	314645	6409132	2	-4.7	-7.4	-1.0
NPZ5B_P2	314646	6409100	2	-0.7	-3.0	-0.3
NPZ6	322577	6410410	3	-24.3	-30.4	-15.2
NPZ6-70	314647	6409099	3	1.5	0.5	2.3
NPZ6a	322577	6410410	5	26.6	-3.6	78.9
NPZ6B-12	314646.7	6409098.8	2	-0.6	-0.9	-0.3
NPZ6B-24	314646.7	6409098.8	3	2.8	1.8	3.5

Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
NPZ7	323812.2	6410786	5	4.8	2.8	9.9
NPZ7_Mid	315973	6404086	5	25.0	18.7	30.2
NPZ7_Small	315973	6404086	5	10.0	2.6	17.9
NPZ7_Tall	315973	6404086	5	13.6	7.1	20.0
NPZ7a	323812.2	6410786	6	41.3	20.1	47.2
NPZ8	324314.4	6412607	5	-3.5	-9.4	1.3
NPZ8a	324314.4	6412607	6	-9.1	-11.5	-5.7
NPZ9	320643	6412905	3	-0.4	-14.7	3.5
NPZ9a	320643	6412905	3	-20.8	-22.6	-16.9
PGW5_Large	316148.86	6415312.19	15	12.0	-2.5	32.3
PGW5_Small	316148.86	6415312.19	2	-4.6	-8.1	-2.9
SDH16	313660	6410914	9	59.4	42.3	82.1
SDH18	313460	6410602	9	46.4	13.8	80.6
South	322157.2	6412294	15	3.9	-12.6	28.7
WPP1	311490	6413429	11	32.0	29.0	33.2
WPP2	311447	6413503	17	27.8	23.5	29.8
CS4655-Bay	313604.6	6407913	4	16.3	14.4	19.5
CS4655-Brt	313604.6	6407913	18	-13.4	-17.3	-6.1
CS4655-LLd	313604.6	6407913	14	-15.0	-18.1	-6.6
CS4655-LmA	313604.6	6407913	6	-10.6	-13.2	-2.6
CS4655-LmH	313604.6	6407913	6	-5.6	-7.9	3.0
CS4655-UAr	313604.6	6407913	10	-12.9	-15.7	-5.9
CS4655-ULd	313604.6	6407913	14	-11.8	-13.9	-5.9
CS4655-UPG	313604.6	6407913	8	-13.3	-16.1	-6.4
CS4656-Brt	313030.6	6408900.9	18	4.4	-12.5	21.1
CS4656-LLd	313030.6	6408900.9	14	-13.5	-18.4	-5.9
CS4656-LmA	313030.6	6408900.9	6	-2.6	-11.3	3.7
CS4656-LmF	313030.6	6408900.9	6	10.2	2.4	12.8
CS4656-LmH	313030.6	6408900.9	6	17.2	16.4	20.7
CS4656-UAr	313030.6	6408900.9	10	-18.0	-26.8	-5.4
CS4656-ULd	313030.6	6408900.9	14	-15.2	-20.2	-7.7

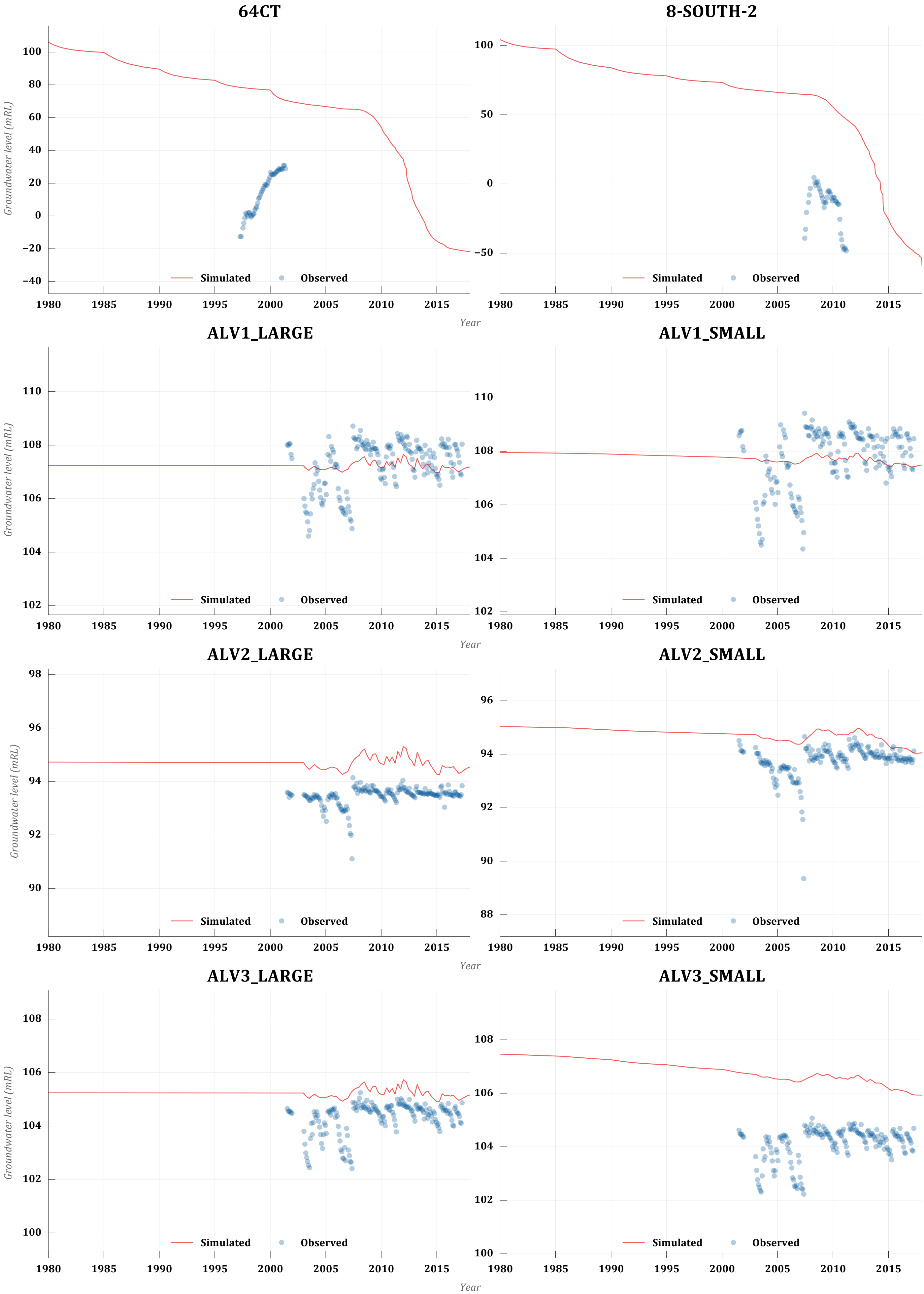
Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
CS4656-UPG	313030.6	6408900.9	8	-25.2	-38.3	-12.0
CS4657-Brt	312358.7	6408151.5	19	-24.4	-27.8	-20.3
CS4657-LLd	312358.7	6408151.5	15	-26.1	-28.7	-22.3
CS4657-LmA	312358.7	6408151.5	6	-24.8	-29.7	-13.4
CS4657-LmF	312358.7	6408151.5	6	3.8	-1.5	4.9
CS4657-LmH	312358.7	6408151.5	6	8.2	5.9	9.5
CS4657-LPG	312358.7	6408151.5	8	-24.7	-29.4	-18.6
CS4657-UAr	312358.7	6408151.5	10	-21.7	-25.4	-16.7
CS4657-ULd	312358.7	6408151.5	14	-20.4	-28.4	-13.4
CS4658-Bay	311860	6407655.5	4	-8.4	-9.1	-4.8
CS4658-Brt	311860	6407655.5	19	-35.6	-39.0	-32.0
CS4658-LLd	311860	6407655.5	15	-37.7	-41.1	-34.1
CS4658-LmA	311860	6407655.5	6	-26.1	-30.6	-21.8
CS4658-LmH	311860	6407655.5	6	-6.8	-11.6	-4.2
CS4658-UAr	311860	6407655.5	10	-34.4	-39.5	-29.3
CS4658-ULd	311860	6407655.5	14	-33.9	-37.7	-30.2
CS4658-UPG	311860	6407655.5	8	-34.8	-41.1	-31.0
DDH223-120	321684	6409694	3	-49.1	-69.6	-30.4
DDH223-170	321684	6409694	4	-43.1	-53.0	-37.1
DDH223-230	321684	6409694	5	-12.1	-35.9	42.8
DDH223-290	321684	6409694	6	-45.2	-89.1	20.4
DDH223-350	321684	6409694	10	-60.1	-105.1	70.1
DDH223-416	321684	6409694	15	-40.8	-96.7	97.7
DDH223-478	321684	6409694	20	44.4	8.5	106.4
DDH224-100	323034	6407439	5	-22.6	-24.8	-19.0
DDH224-130	323034	6407439	6	36.7	33.0	48.4
DDH224-160	323034	6407439	6	45.4	38.5	52.3
DDH224-200	323034	6407439	7	-27.0	-31.9	-23.7
DDH224-245	323034	6407439	13	16.6	9.8	26.7
DDH224-290	323034	6407439	16	4.9	-22.5	23.5
DDH224-315	323034	6407439	17	8.0	-11.1	30.4

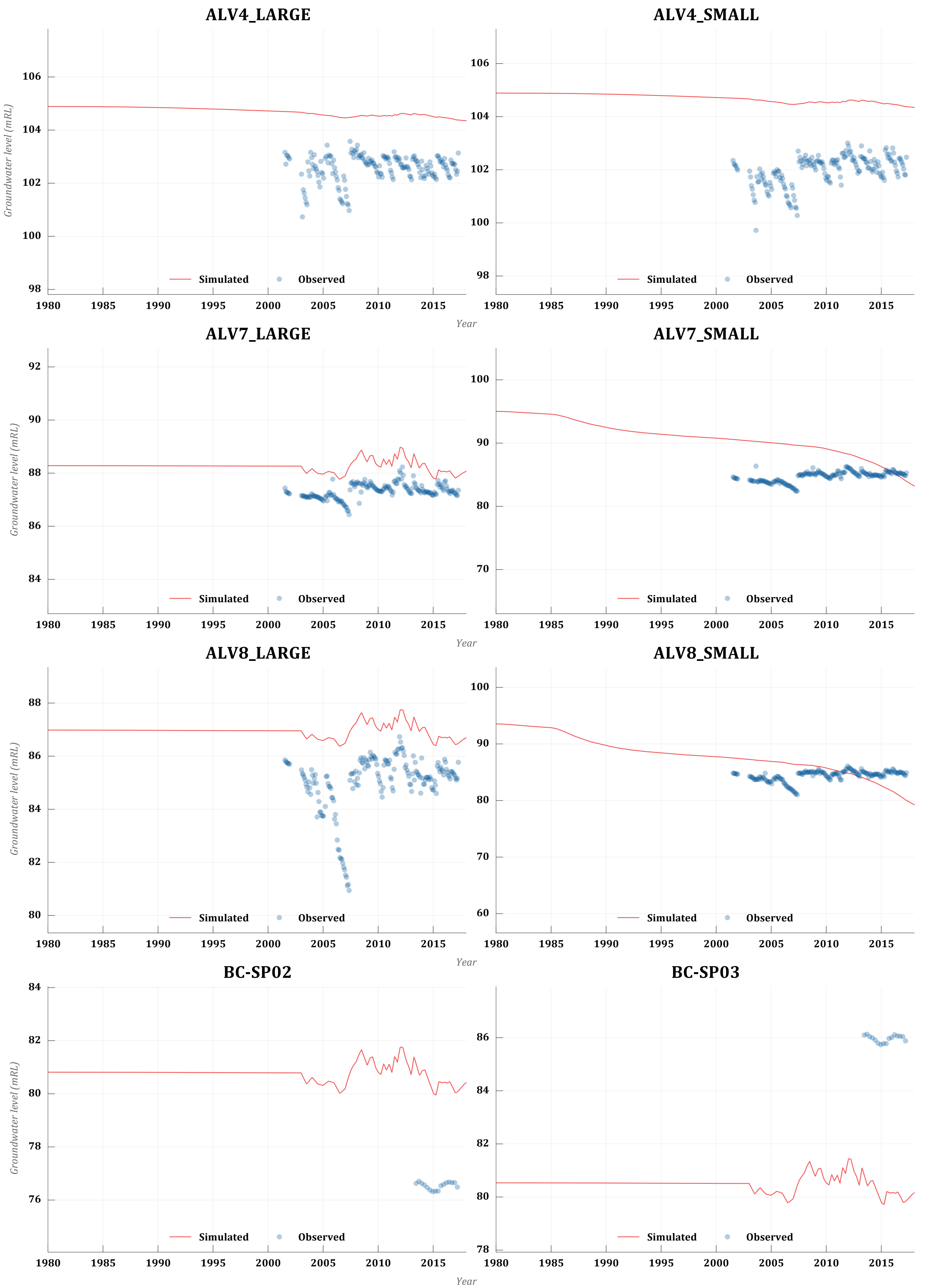
Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
DDH224-336	323034	6407439	18	59.7	44.8	74.5
GNP1-Art	318491.9	6408641	11	25.2	20.3	32.8
GNP1-Brt	318491.9	6408641	18	21.0	-2.3	39.8
GNP1-Heb	318491.9	6408641	20	9.5	-5.1	23.6
GNP1-LLd	318491.9	6408641	15	8.7	-0.5	19.8
GNP1-MLd	318491.9	6408641	14	7.3	-1.9	18.4
GNP1-PG	318491.9	6408641	9	-24.9	-27.4	-18.8
GNP1-ULd	318491.9	6408641	14	15.1	4.5	26.5
GNP2-Art	317563.6	6410220	11	-1.8	-8.5	10.8
GNP2-Bar	317563.6	6410220	18	11.3	5.6	26.0
GNP2-Heb	317563.6	6410220	20	29.2	19.5	38.0
GNP2-LLd	317563.6	6410220	15	10.0	1.6	24.1
GNP2-MLd	317563.6	6410220	14	0.7	-4.5	7.1
GNP2-PG	317563.6	6410220	9	-32.3	-34.4	-28.4
GNP2-ULd	317563.6	6410220	14	106.7	78.2	119.2
GNP3-Art	316945.5	6411691	11	0.3	-11.9	6.5
GNP3-Brt	316945.5	6411691	18	0.8	-14.6	7.3
GNP3-Heb	316945.5	6411691	20	8.3	-7.7	19.6
GNP3-LLd	316945.5	6411691	15	-9.3	-16.6	-7.6
GNP3-MLd	316945.5	6411691	15	-18.7	-19.6	-17.0
GNP3-PG	316945.5	6411691	9	-27.0	-28.2	-25.6
GNP3-ULd	316945.5	6411691	14	-1.5	-4.2	0.3
GNP4-Art	316930.7	6412932	11	-86.4	-95.1	-73.8
GNP4-Brt	316930.7	6412932	18	-66.0	-77.7	-58.4
GNP4-Heb	316930.7	6412932	20	-64.2	-67.5	-58.0
GNP4-LLd	316930.7	6412932	15	-78.6	-91.2	-62.8
GNP4-MLd	316930.7	6412932	15	-88.7	-99.3	-73.0
GNP4-PG	316930.7	6412932	9	-94.1	-96.7	-89.3
GNP4-ULd	316930.7	6412932	14	-88.9	-98.4	-73.0
GNP5-Art	317864.7	6409317	11	18.4	13.3	31.1
GNP5-Bar	317864.7	6409317	18	12.9	6.8	25.4

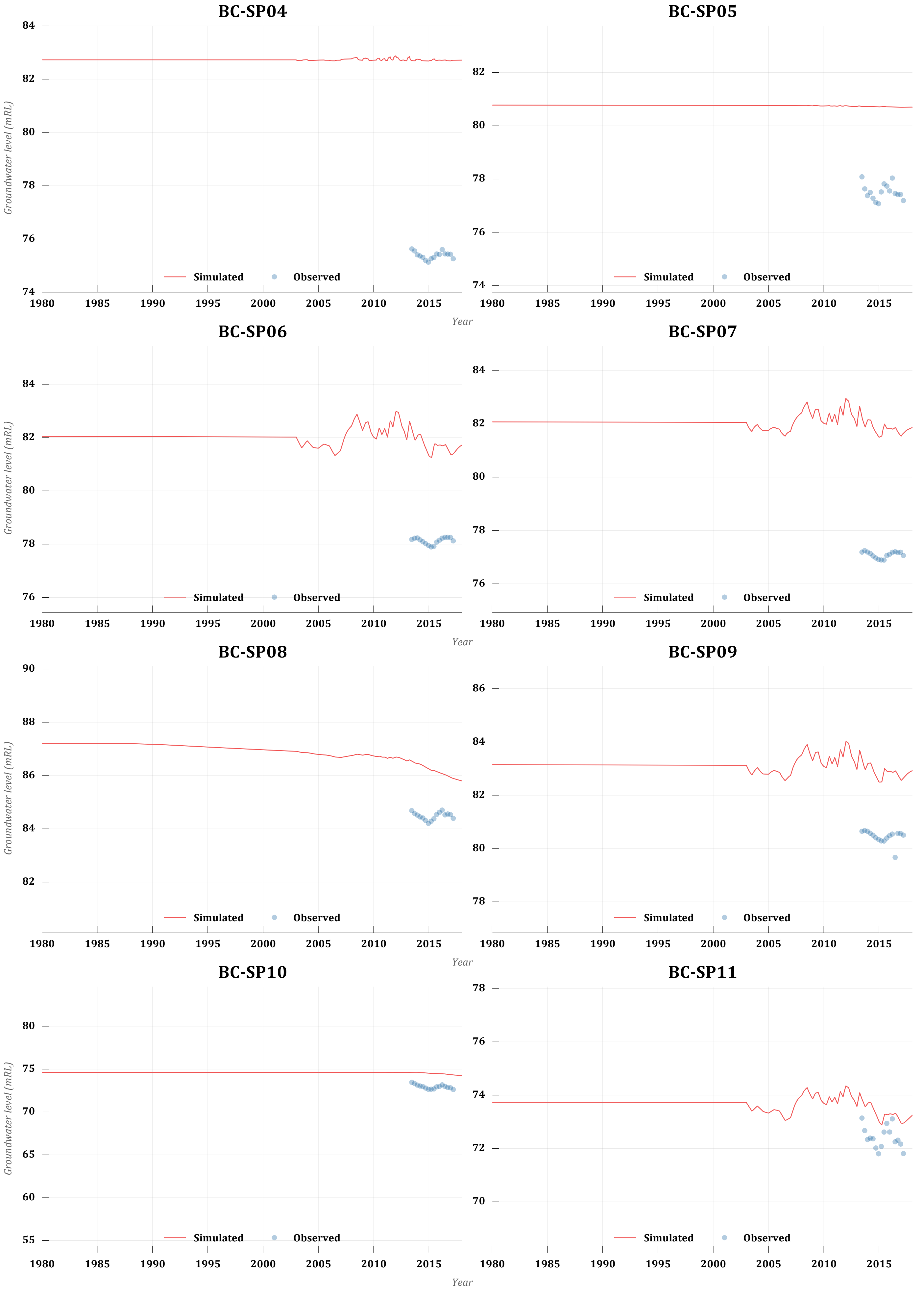
Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
GNP5-Heb	317864.7	6409317	20	15.5	4.2	32.6
GNP5-Int	317864.7	6409317	2	-6.3	-6.8	-5.5
GNP5-LLd	317864.7	6409317	15	18.5	8.3	32.9
GNP5-MLd	317864.7	6409317	15	15.1	6.9	28.4
GNP5-PG	317864.7	6409317	9	-31.5	-38.9	-22.5
GNP5-ULd	317864.7	6409317	14	15.4	7.5	28.3
GNP6-Art	317604.6	6411061	11	-5.1	-6.2	-1.7
GNP6-Bar	317604.6	6411061	18	-7.3	-12.8	2.6
GNP6-Heb	317604.6	6411061	20	-2.1	-8.2	1.6
GNP6-LLd	317604.6	6411061	15	-15.7	-18.3	-11.8
GNP6-MLd	317604.6	6411061	15	4.7	-14.8	19.4
GNP6-PG	317604.6	6411061	9	-13.0	-22.0	-0.6
GNP6-ULd	317604.6	6411061	14	-6.6	-10.2	2.1
GNP7-Art	316530.7	6412452	11	-50.2	-58.5	-40.2
GNP7-Brt	316530.7	6412452	18	-52.1	-56.1	-45.3
GNP7-Heb	316530.7	6412452	20	-38.5	-55.8	-24.1
GNP7-LLd	316530.7	6412452	15	-55.5	-59.2	-48.6
GNP7-MLd	316530.7	6412452	15	-54.5	-61.2	-46.9
GNP7-PG	316530.7	6412452	9	-62.4	-69.7	-56.2
GNP7-ULd	316530.7	6412452	14	-55.9	-61.4	-47.8
GNP8-Bar	319387.7	6407393	18	-1.8	-11.4	8.4
GNP8-Heb	319387.7	6407393	20	18.8	-11.2	35.9
GNP8-LLd	319387.7	6407393	15	-1.2	-15.7	14.9
GNP8-MLd	319387.7	6407393	15	8.8	-2.6	16.2
GNP8-ULd	319387.7	6407393	14	21.6	7.6	30.9
PZ-1-395	322172.84	6408597.57	17	60.9	2.5	84.2
PZ-1-415	322172.84	6408597.57	19	76.1	26.9	127.7
PZ-1-440	322172.84	6408597.57	21	58.5	34.4	91.6
PZ-4-395.5	322786.68	6409232.79	17	29.7	-49.8	96.1
PZ-4-416.5	322786.68	6409232.79	19	9.3	-6.3	27.8
PZ-4-436	322786.68	6409232.79	20	-50.6	-73.3	9.7

Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
PZ-4-445.5	322786.68	6409232.79	20	-10.5	-43.3	58.6
PZ-4-455	322786.68	6409232.79	21	23.9	5.4	47.9
RNVW1-Bay	313911	6403955.7	3	-14.9	-16.1	-14.0
RNVW1-Brt	313911	6403955.7	18	-2.7	-7.7	0.8
RNVW1-LLd	313911	6403955.7	11	-28.3	-41.0	-9.1
RNVW1-LmA	313911	6403955.7	3	-43.9	-49.5	-27.5
RNVW1-LmH	313911	6403955.7	3	-18.4	-27.9	-14.8
RNVW1-UAr	313911	6403955.7	6	-2.3	-4.6	1.1
RNVW1-ULd	313911	6403955.7	10	-16.7	-24.1	-6.1
RNVW1-UPG	313911	6403955.7	6	-13.5	-15.3	-7.0
RNVW2-Brt	313433.9	6405371.8	18	-13.3	-14.7	-10.9
RNVW2-LLd	313433.9	6405371.8	14	-18.5	-23.4	-14.2
RNVW2-LmA	313433.9	6405371.8	4	-16.1	-20.6	-4.0
RNVW2-LmH	313433.9	6405371.8	3	-23.1	-23.4	-19.3
RNVW2-UAr	313433.9	6405371.8	6	-15.7	-17.6	-10.8
RNVW2-ULd	313433.9	6405371.8	10	-17.8	-23.6	-11.6
RNVW2-UPG	313433.9	6405371.8	6	-14.8	-16.3	-10.2
RNVW3-Brt	312235.3	6406367.4	19	-23.4	-26.3	-18.1
RNVW3-LLd	312235.3	6406367.4	14	-20.5	-23.5	-12.2
RNVW3-LmA	312235.3	6406367.4	4	-23.6	-33.5	-10.7
RNVW3-UAr	312235.3	6406367.4	6	-27.7	-33.7	-17.7
RNVW3-ULd	312235.3	6406367.4	10	-27.6	-33.9	-18.0
RNVW3-UPG	312235.3	6406367.4	6	-22.8	-29.6	-12.9
RNVW4-Brt	314086.9	6411001.5	21	33.2	23.5	40.8
RNVW4-LLd	314086.9	6411001.5	19	36.0	31.9	40.1
RNVW4-UAr	314086.9	6411001.5	10	25.4	21.9	27.5
RNVW4-ULd	314086.9	6411001.5	14	44.4	36.8	50.5
RNVW4-UPG	314086.9	6411001.5	10	30.8	21.8	37.2
SMC002-BY3	322098.3	6410658	4	-16.8	-53.4	-0.4
SMC002-BY5	322098.3	6410658	4	-25.5	-54.7	-15.8
SMC002-int	322098.3	6410658	3	-23.5	-28.6	-21.9

Bore	Easting (GDA94 Z56)	Northing (GDA94 Z56)	Layer	Average residual	Range in residuals	
					Minimum	Maximum
SMC002-RFL	322098.3	6410658	3	-79.6	-86.0	-67.1
SMC002-RNL	322098.3	6410658	3	-24.0	-30.6	-15.7
SMC002-RTU	322098.3	6410658	3	-21.6	-30.6	-17.8
SMO023-Ban	322088.1	6411418	2	-7.3	-9.5	-2.5
SMO023-BY3	322088.1	6411418	4	4.1	-1.7	30.1
SMO023-BY5	322088.1	6411418	4	2.7	-3.1	28.0
SMO023-RFL	322088.1	6411418	3	-49.1	-56.2	-39.6
SMO023-RNL	322088.1	6411418	3	-47.7	-51.5	-42.8
SMO023-RTU	322088.1	6411418	3	-20.0	-24.2	-18.5
SMO023-RVU	322088.1	6411418	3	-13.8	-22.7	-10.2
SMO028-Bay	323345.7	6411410	4	7.2	6.6	7.4
SMO028-LBA	323345.7	6411410	6	60.0	27.9	75.3
SMO028-LBG	323345.7	6411410	6	56.4	35.1	73.7
SMO028-LBJ	323345.7	6411410	6	57.5	33.5	77.8
SMO028-LCF	323345.7	6411410	5	31.1	22.0	36.4
SMO028-LDF	323345.7	6411410	5	45.1	20.9	56.1


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


ALV4_LARGE
ALV4_SMALL
ALV7_LARGE
ALV7_SMALL
ALV8_LARGE
ALV8_SMALL
BC-SP02
BC-SP03
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015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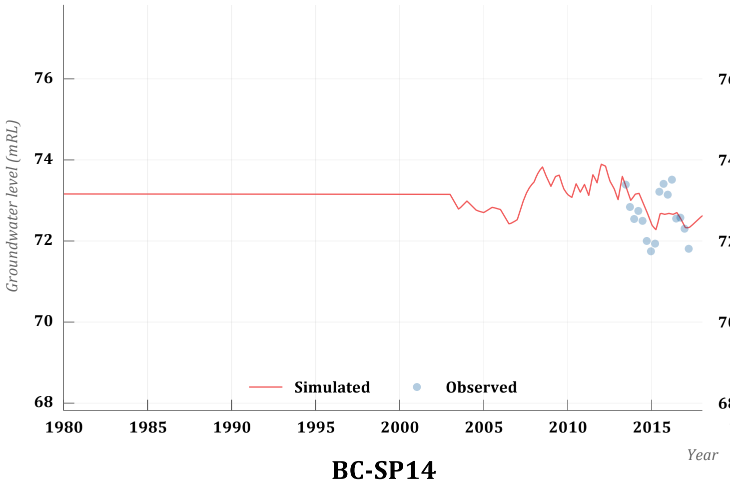
BC-SP05
BC-SP06
BC-SP07
BC-SP08
BC-SP09
BC-SP10
BC-SP11
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

BC-SP12



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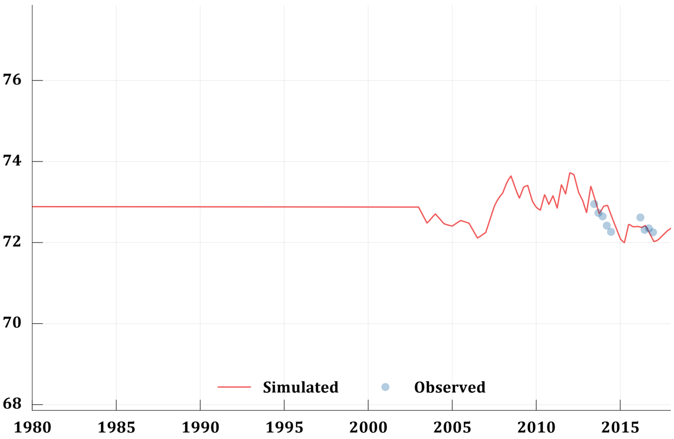

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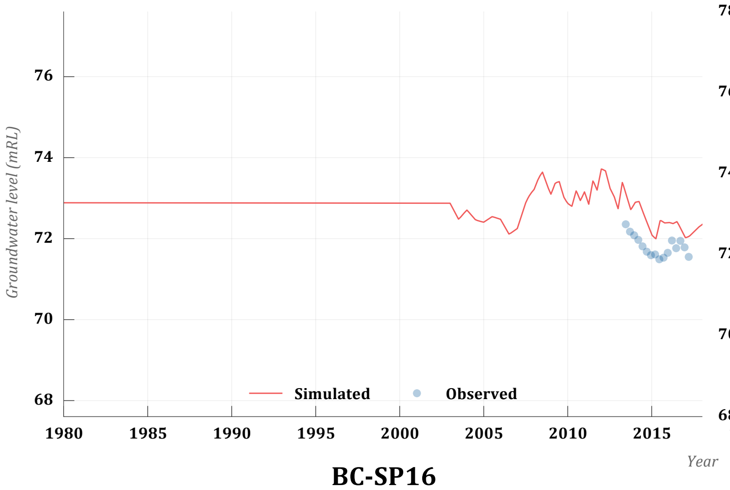

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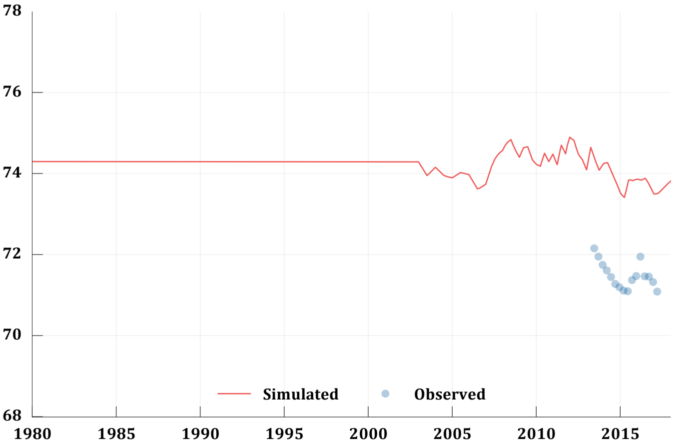

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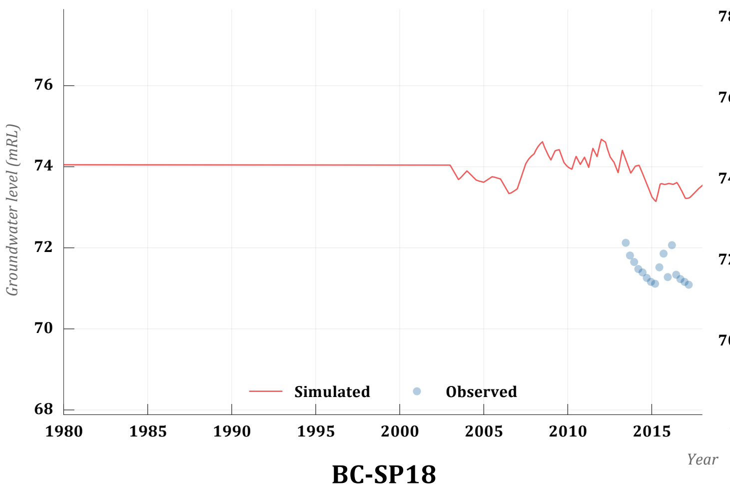

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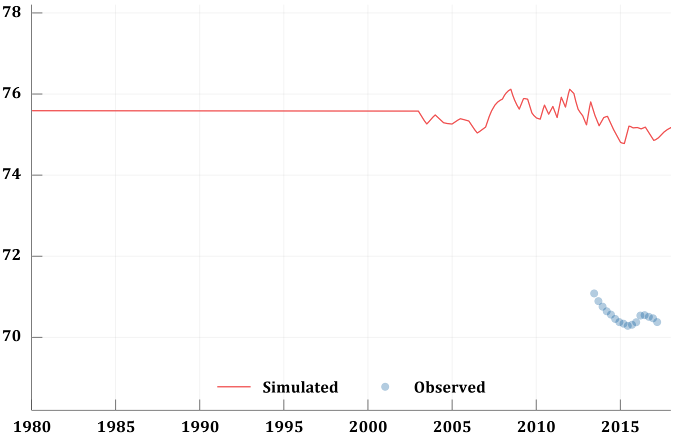

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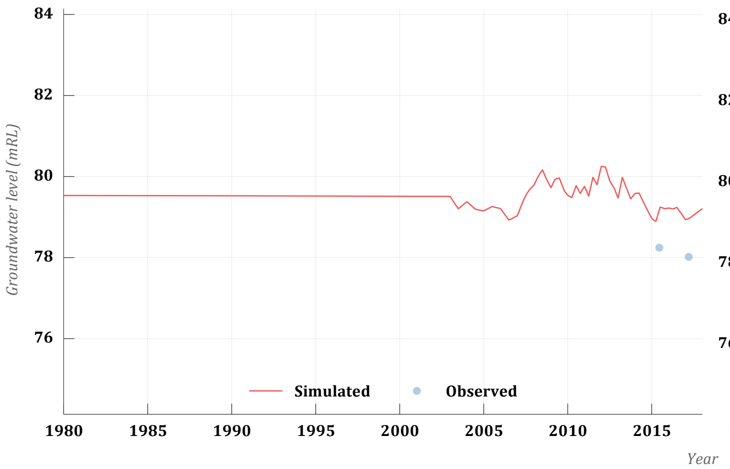

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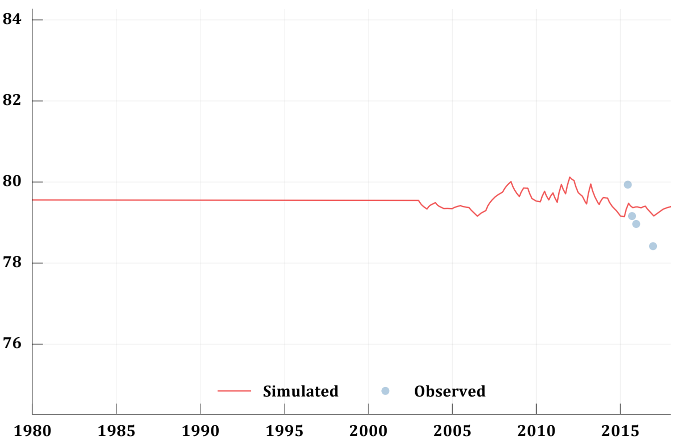
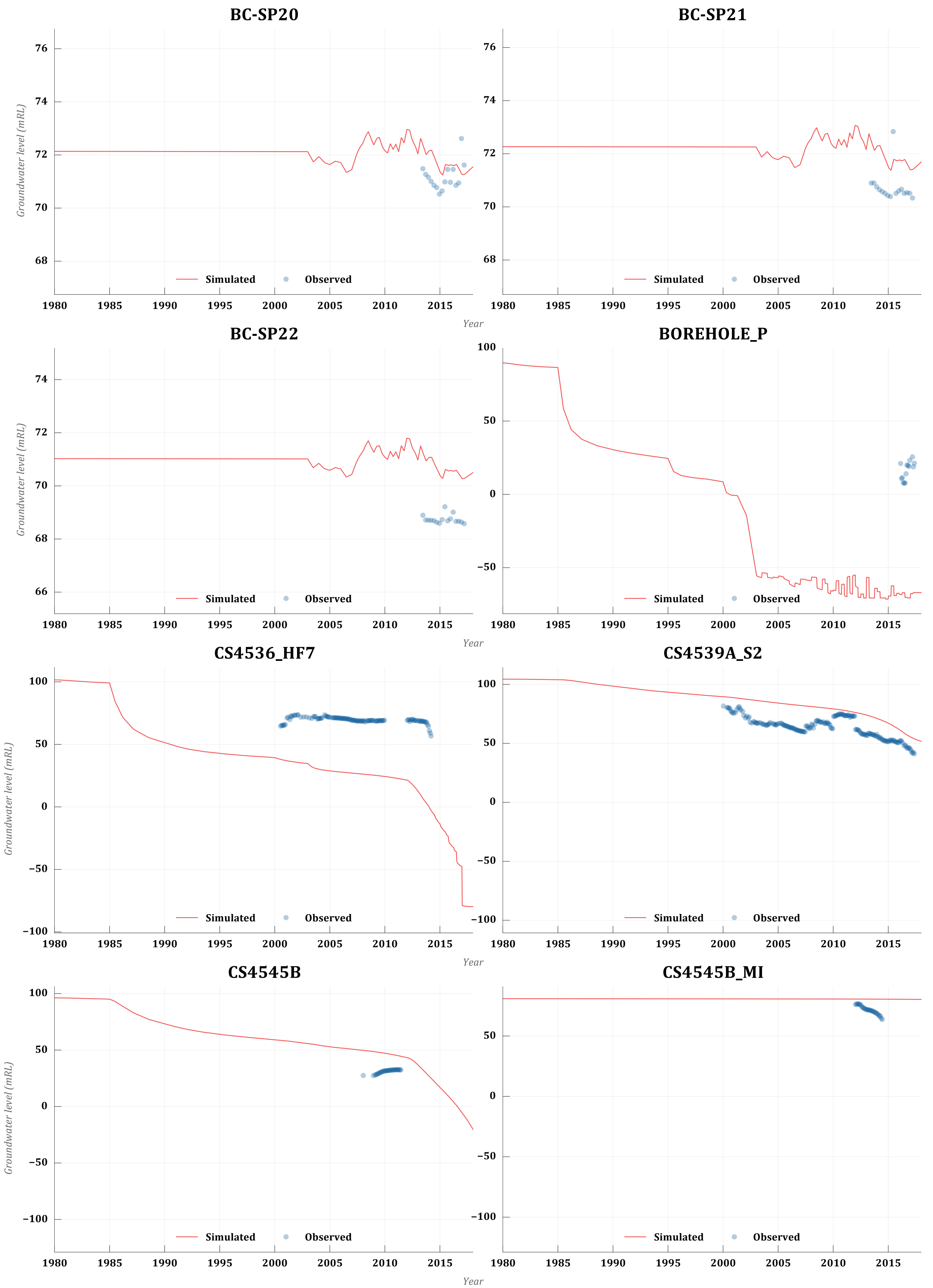
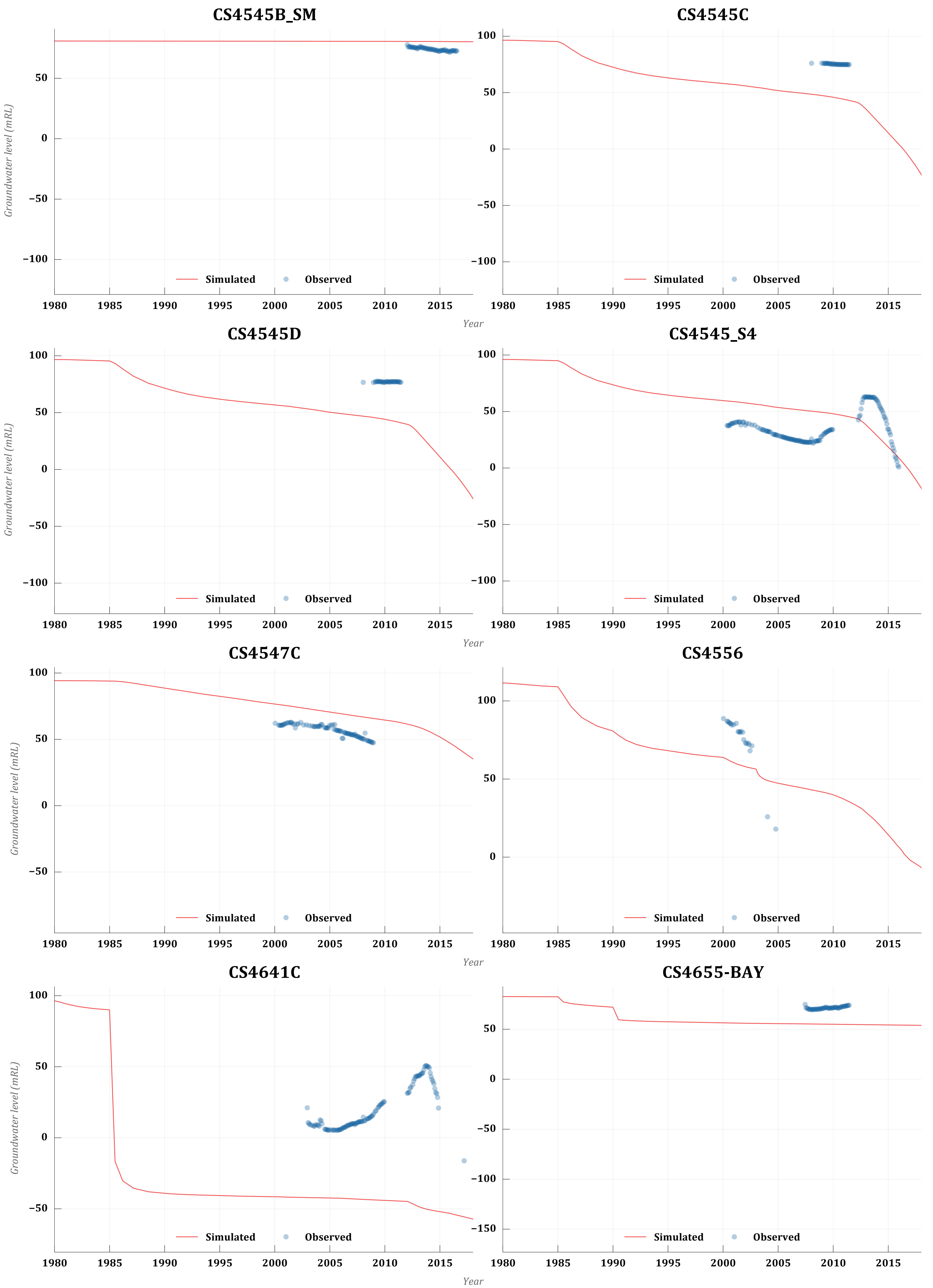



BC-SP20
BC-SP21
BC-SP22
BOREHOLE_P
CS4536_HF7
CS4539A_S2
CS4545B
CS4545B_MI
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015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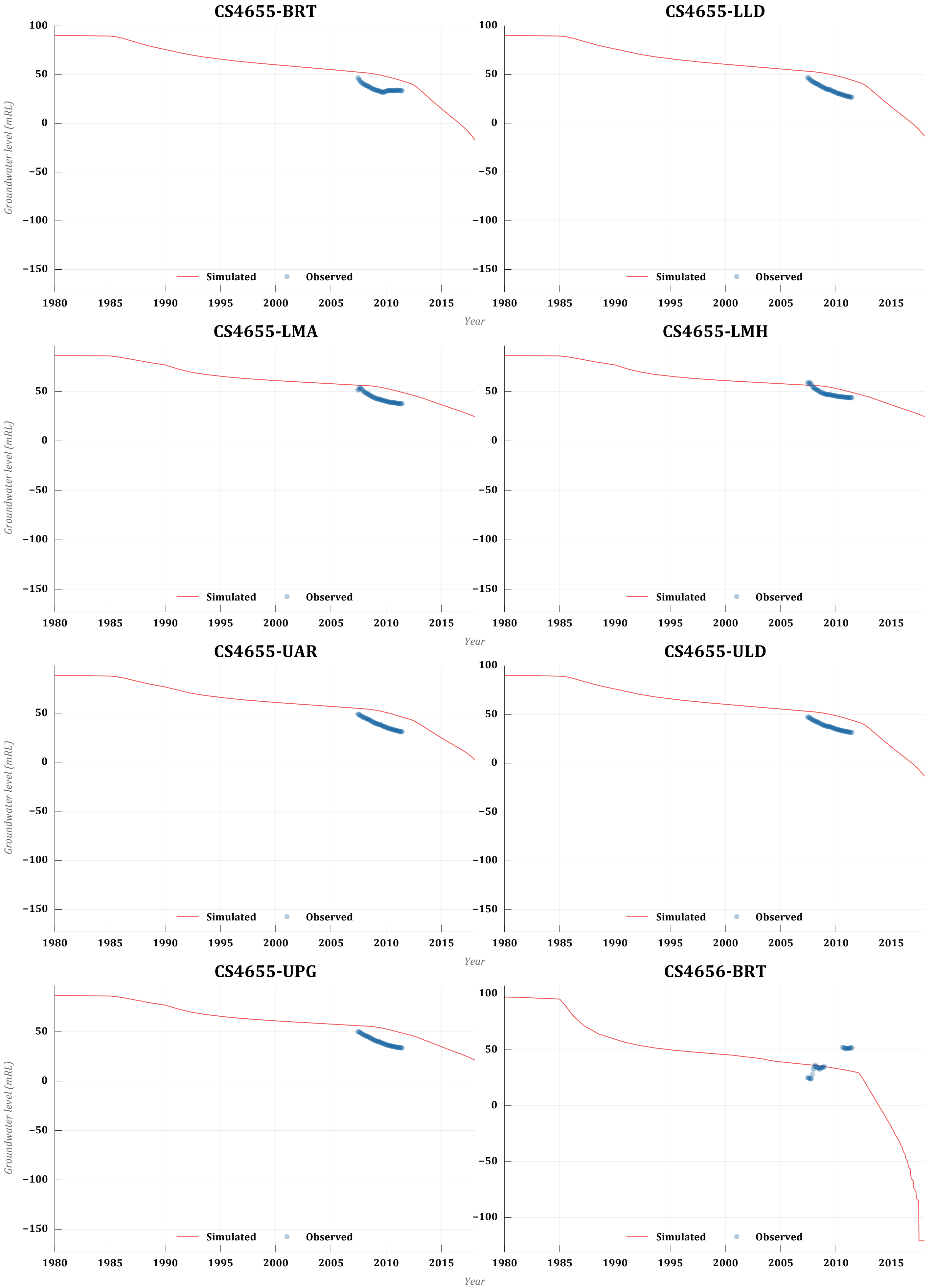
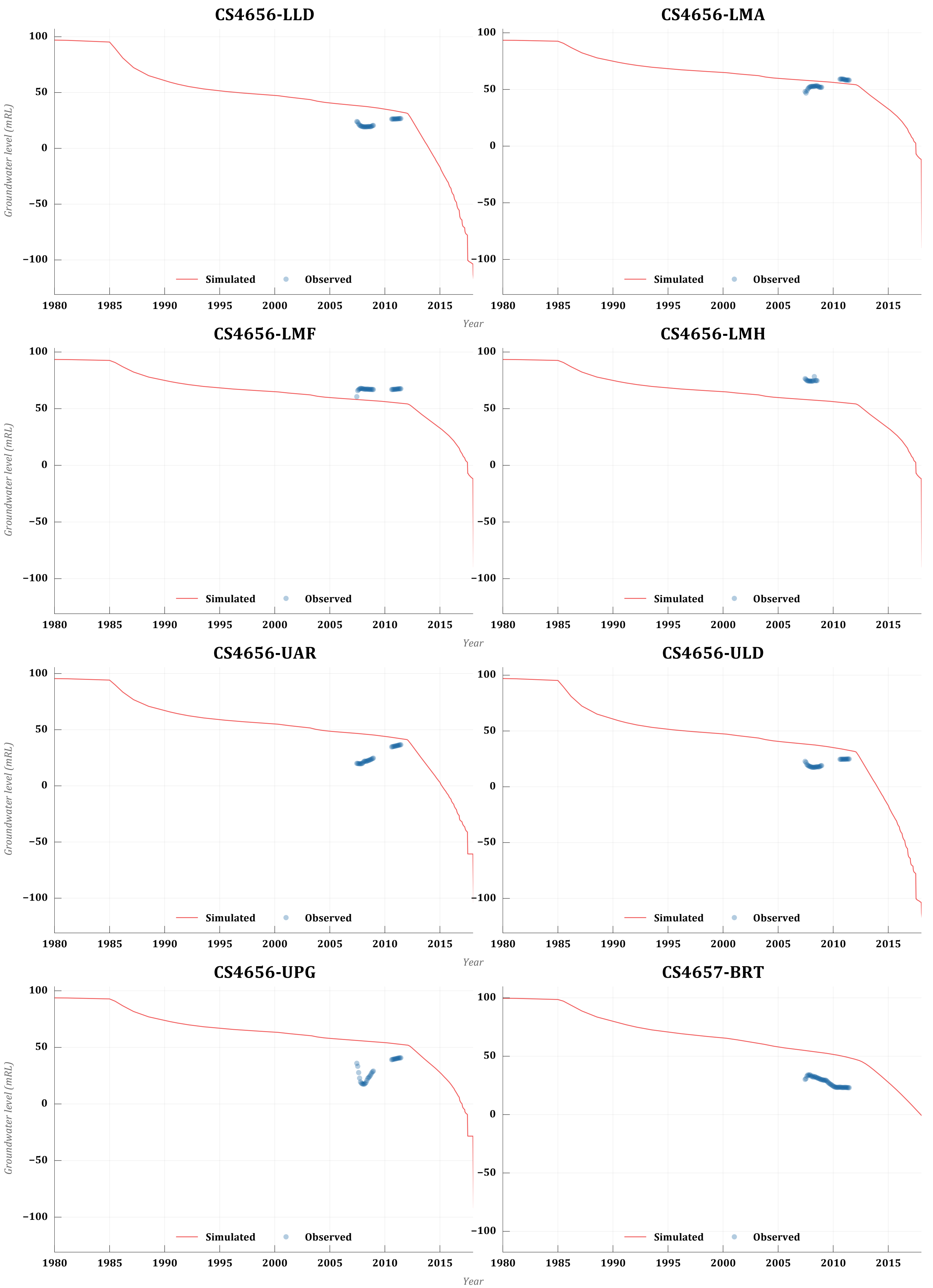
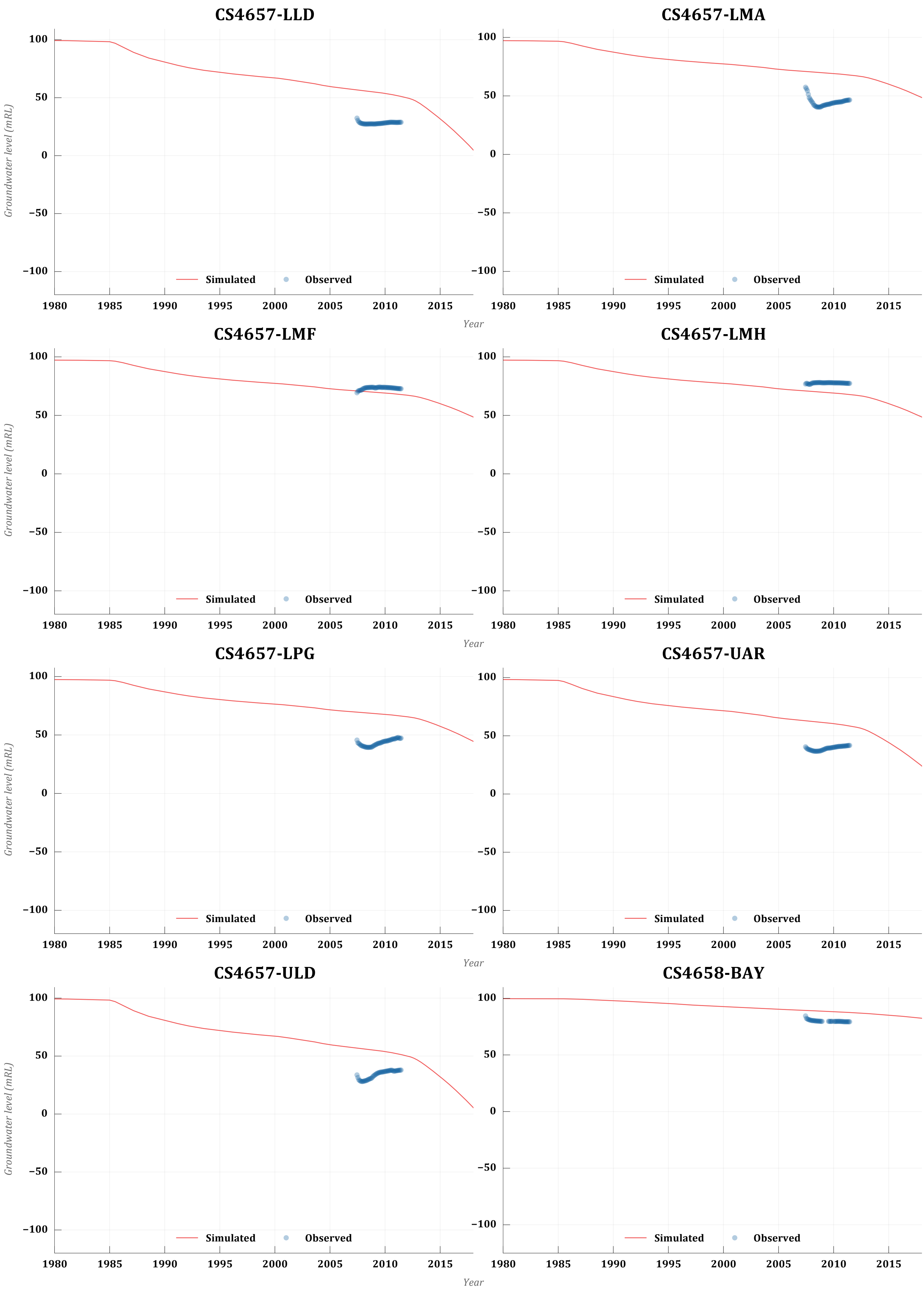
CS4545C
CS4545D
CS4545_S4
CS4547C
CS4556
CS4641C
CS4655-BAY
Groundwater level (mRL)
Year
Simulated
Observed


CS4655-BRT
CS4655-LLD
CS4655-LMA
CS4655-LMH
CS4655-UAR
CS4655-ULD
CS4655-UPG
CS4656-BRT
Groundwater level (mRL)
Year
Simulated
Observed
100
50
0
−50
−100
−150
1980
1985
1990
1995
2000
2005
2010
2015


CS4656-LLD
CS4656-LMA
CS4656-LMF
CS4656-LMH
CS4656-UAR
CS4656-ULD
CS4656-UPG
CS4657-BRT
Groundwater level (mRL)
Year
Simulated
Observed
100
50
0
−50
−100
1980
1985
1990
1995
2000
2005
2010
2015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CS4657-LMA
CS4657-LMF
CS4657-LMH
CS4657-LPG
CS4657-UAR
CS4657-ULD
CS4658-BAY
Groundwater level (mRL)
Year
Simulated
Observed
100
50
0
−50
−100
1980
1985
1990
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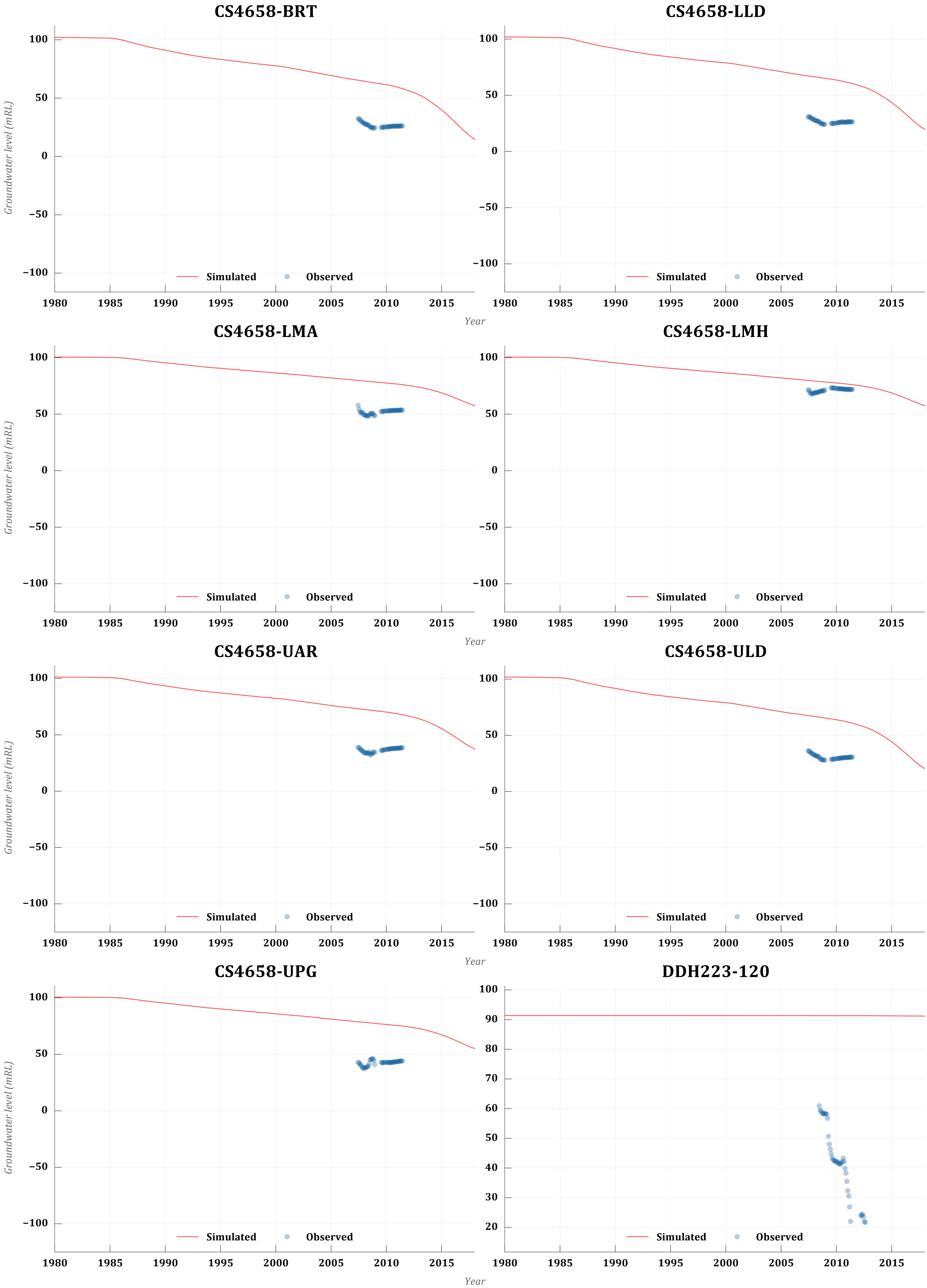
2000
2005
2010
2015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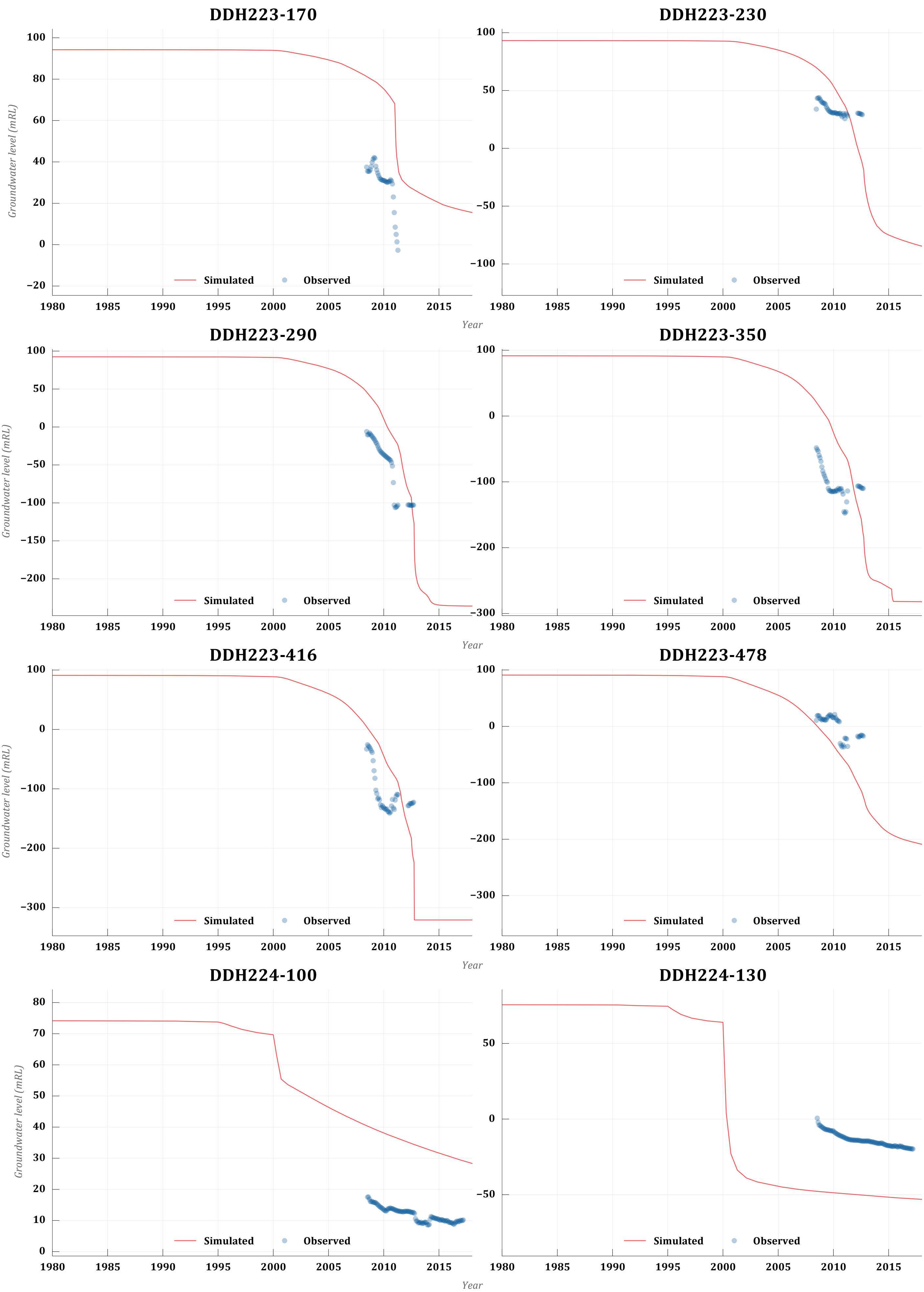
Groundwater level (mRL)
Year
Simulated
Observed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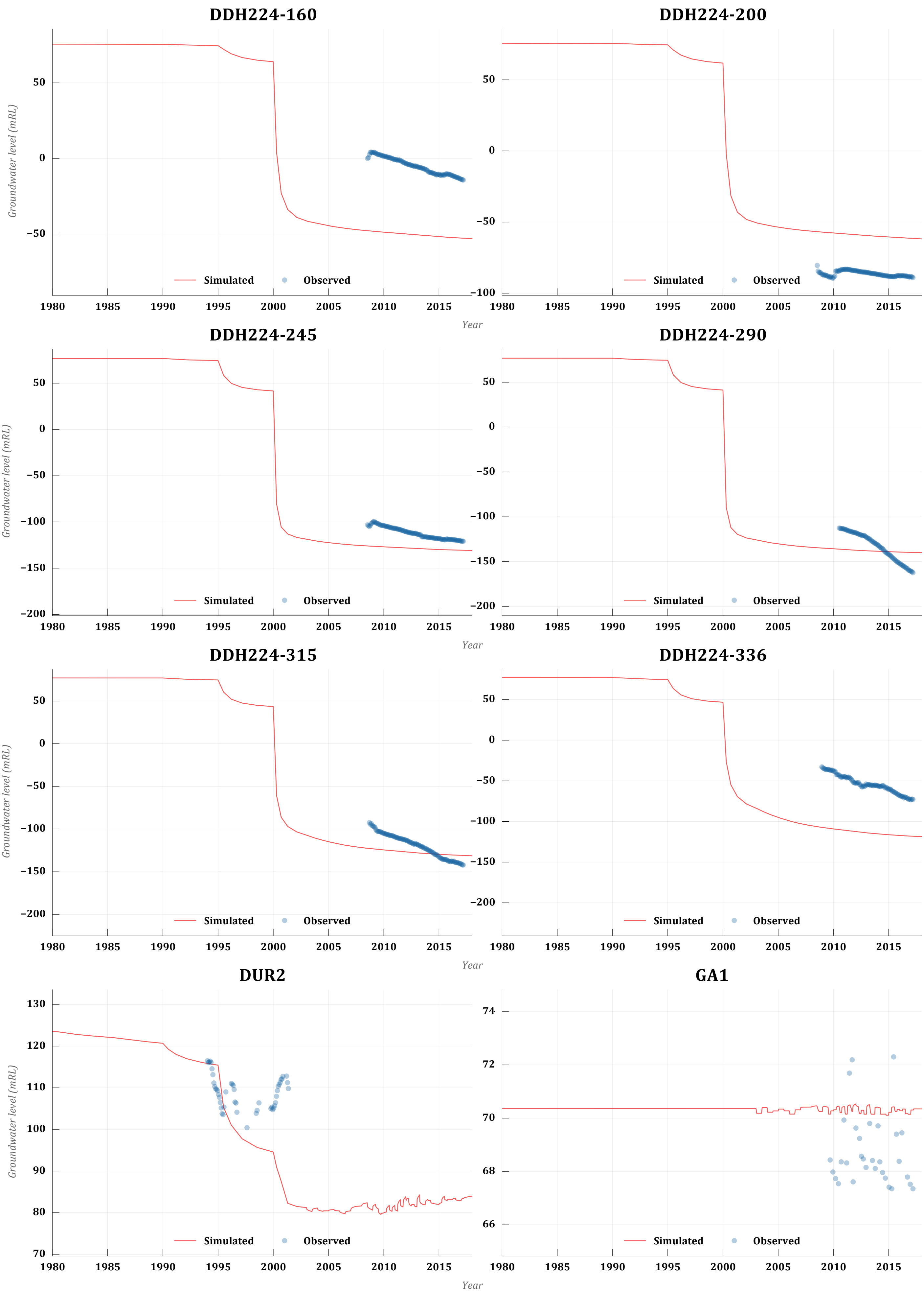
DDH223-230
DDH223-290
DDH223-350
DDH223-416
DDH223-478
DDH224-100
DDH224-130
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015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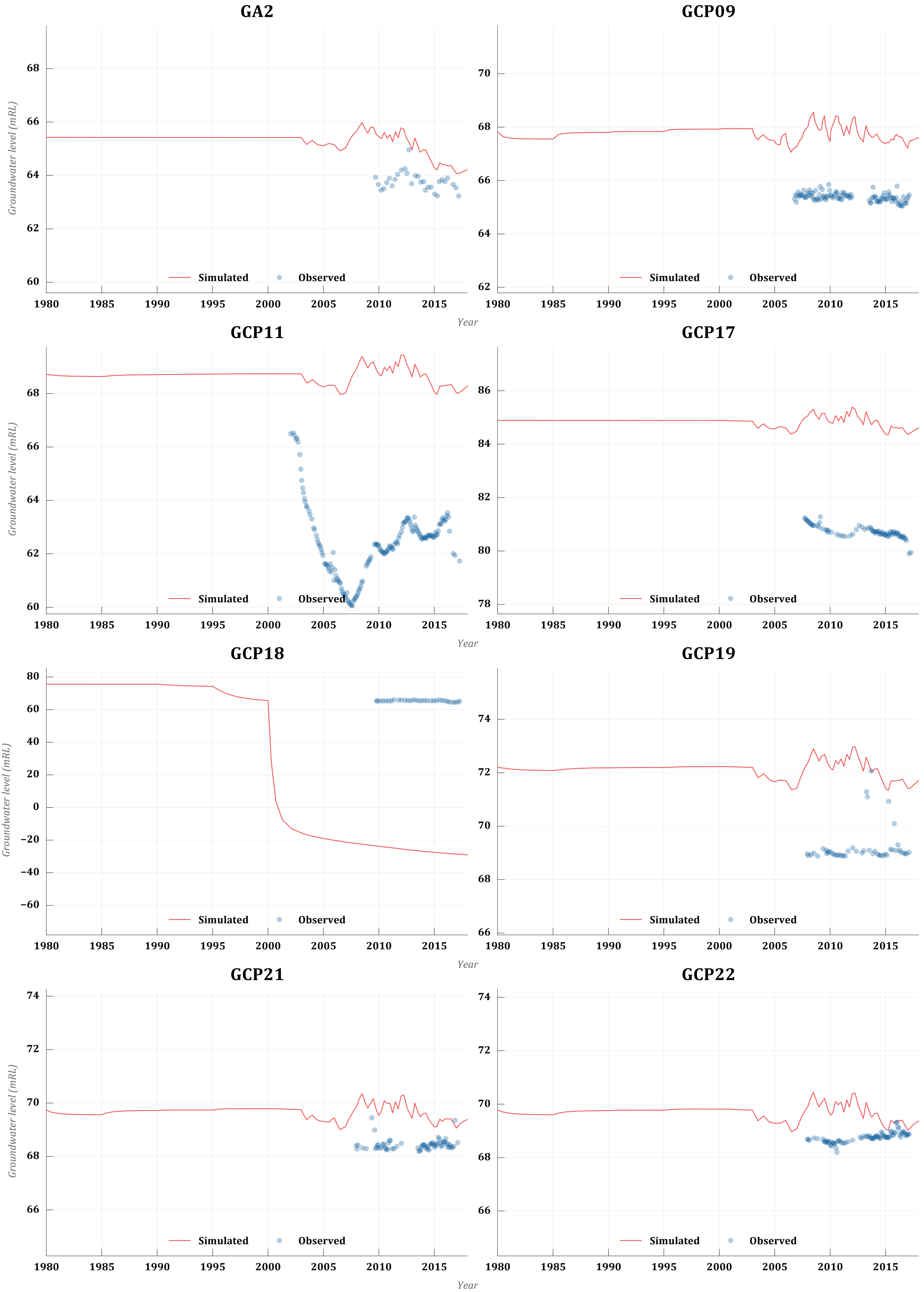
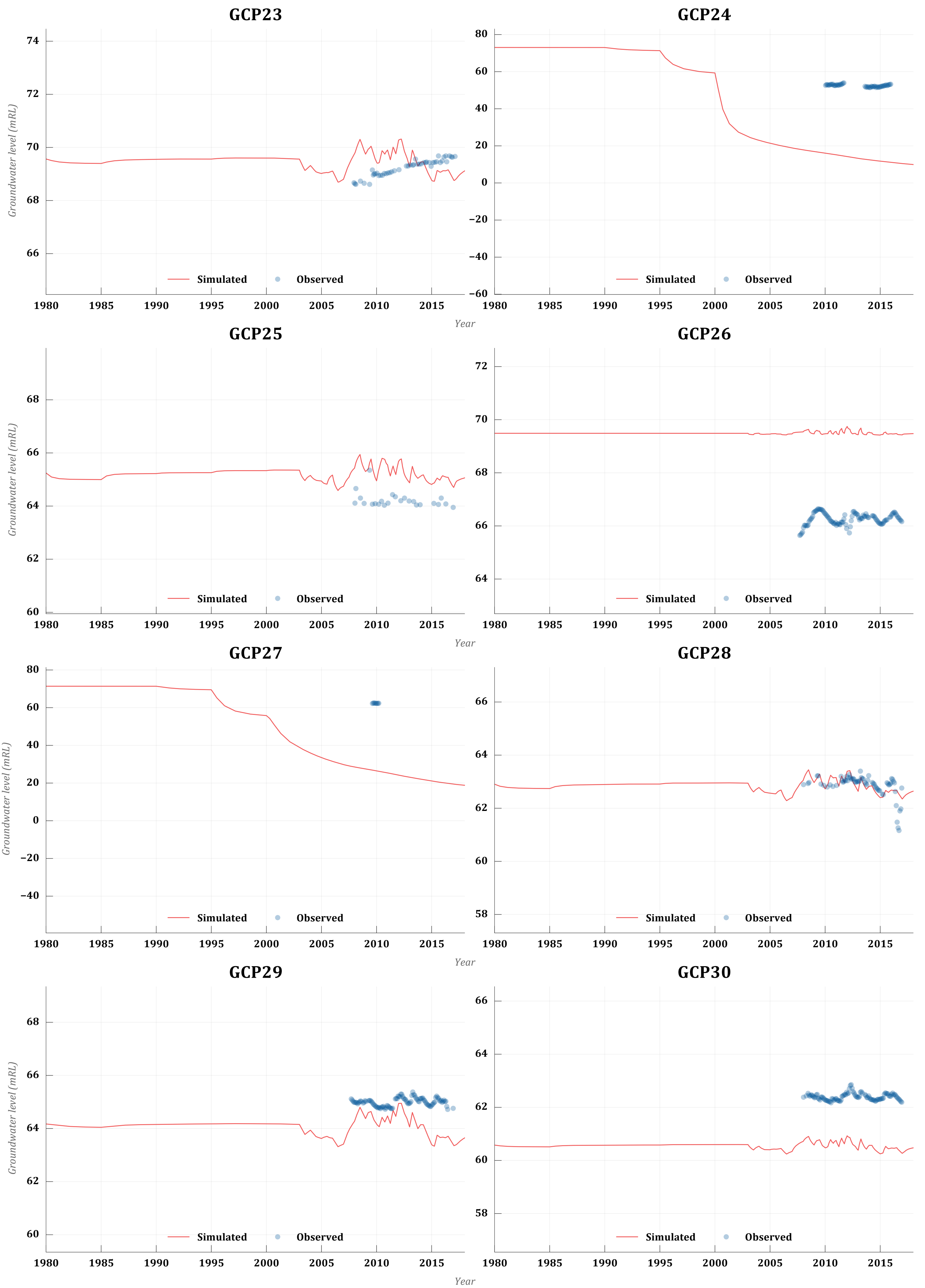
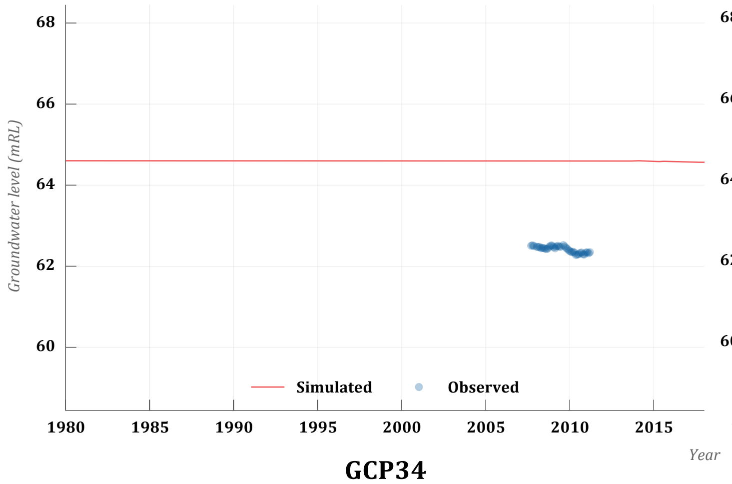
DDH224-200
DDH224-245
DDH224-290
DDH224-315
DDH224-336
DUR2
GA1
Groundwater level (mRL)
Year
Simulated
Observed
1980 1985 1990 1995 2000 2005 2010 2015


GA2
GCP09
GCP11
GCP17
GCP18
GCP19
GCP21
GCP22
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015


GCP23
GCP24
GCP25
GCP26
GCP27
GCP28
GCP29
GCP30
Groundwater level (mRL)
Year
Simulated
Observed

GCP31



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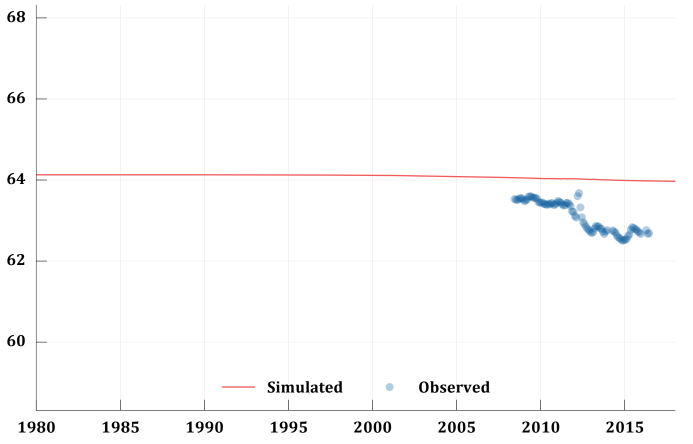

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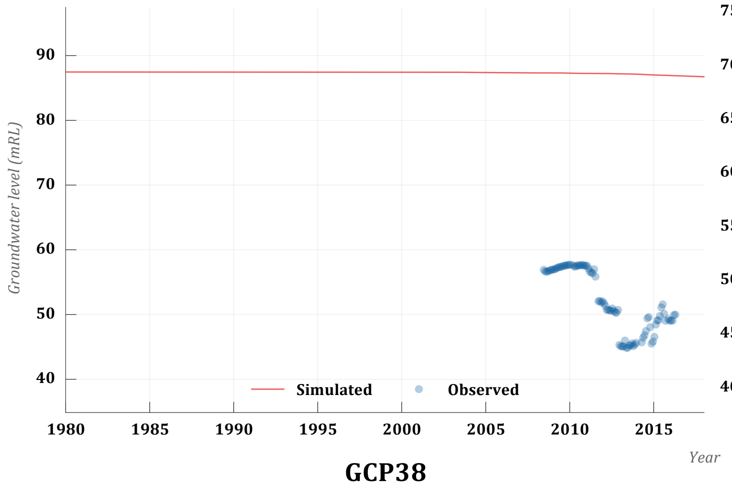

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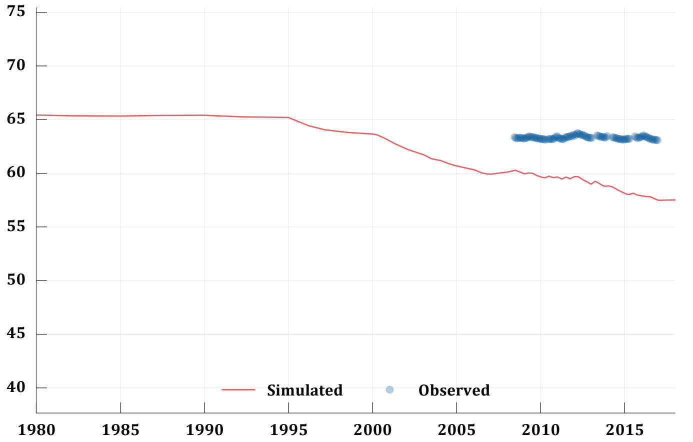

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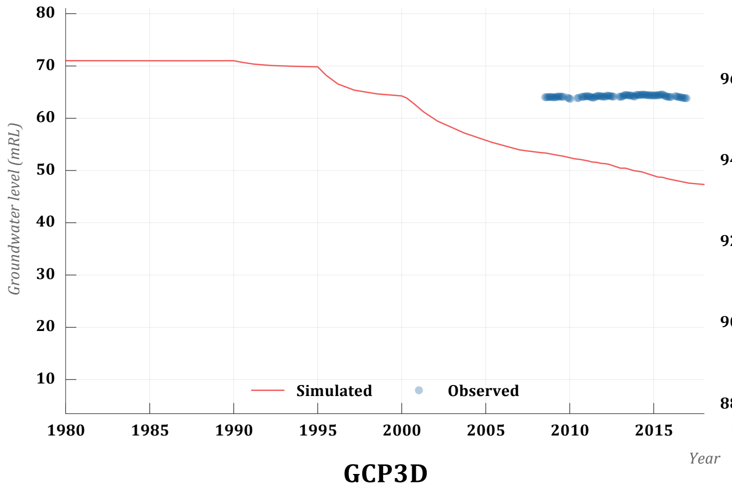

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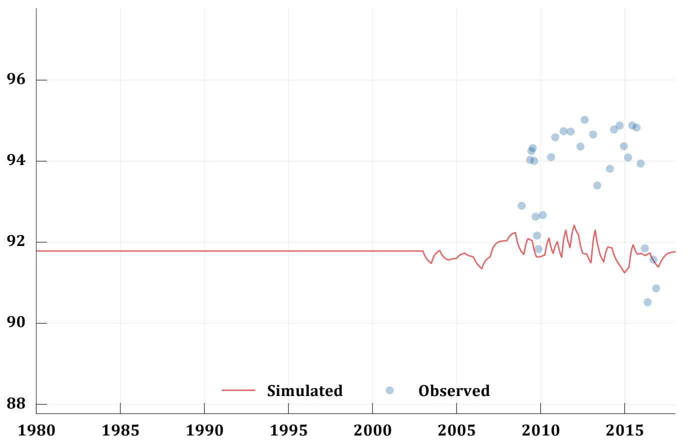

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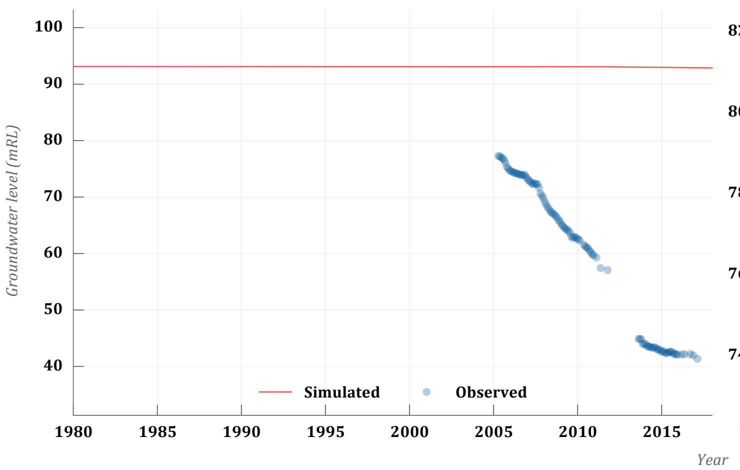
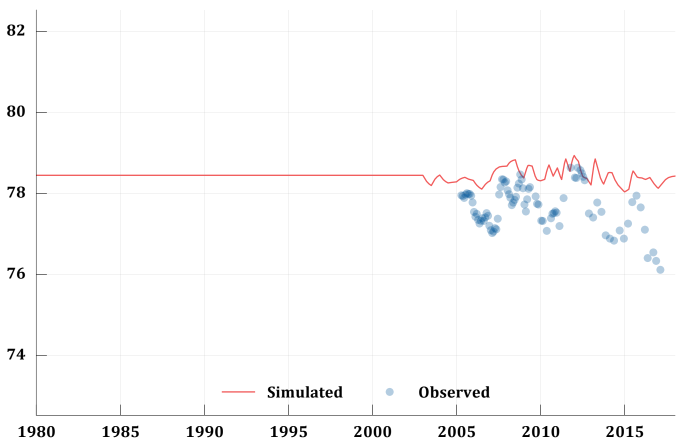
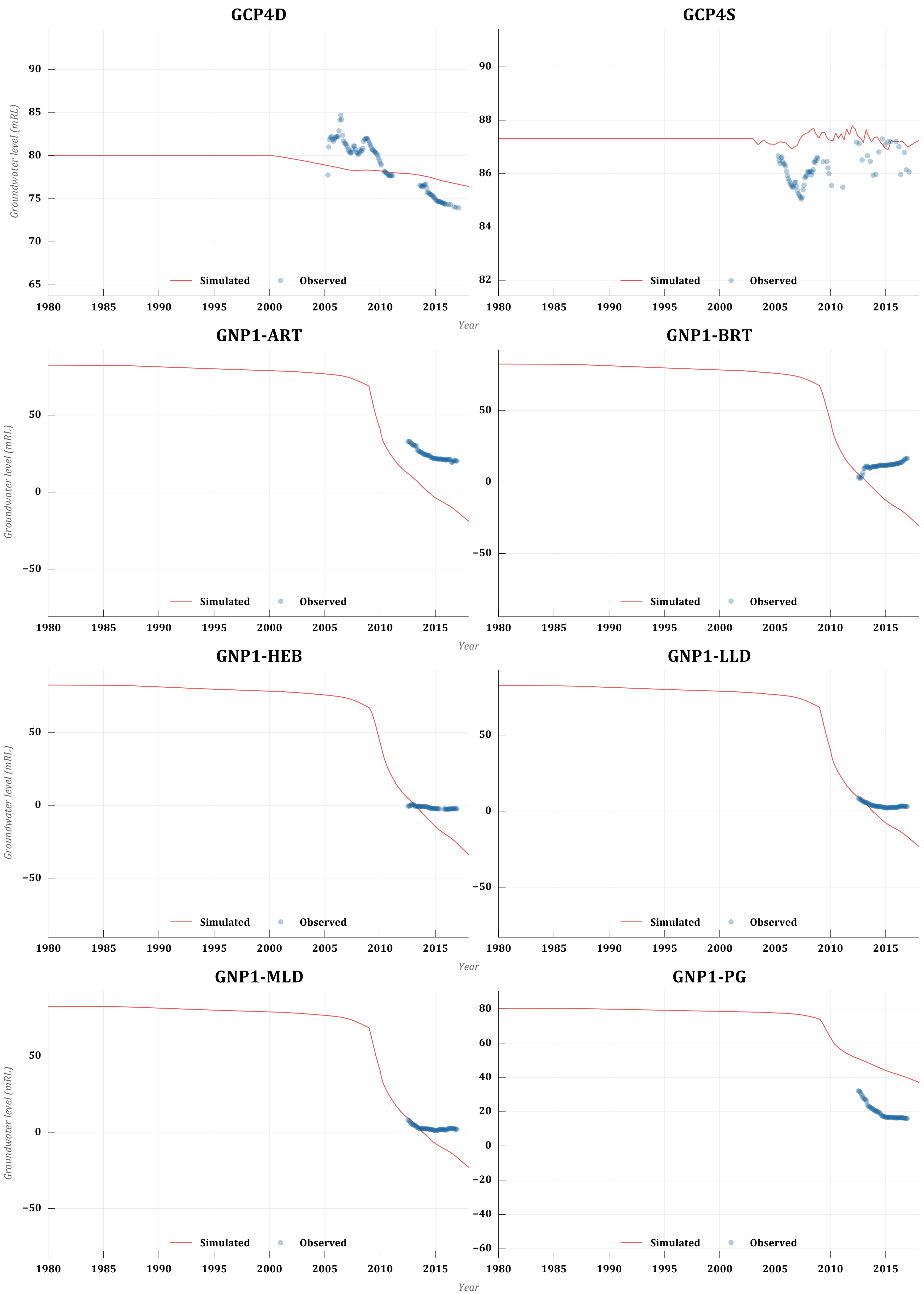
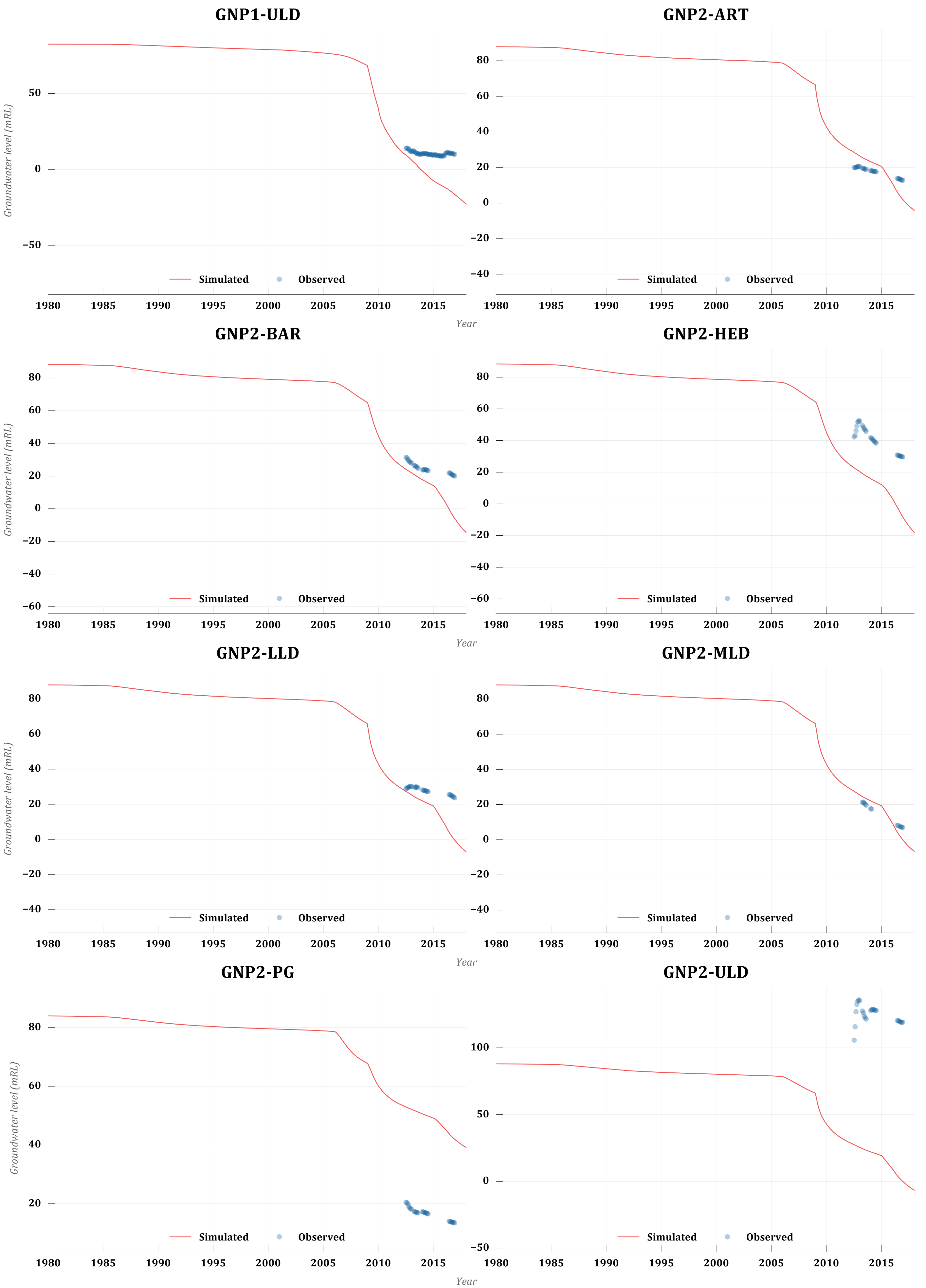


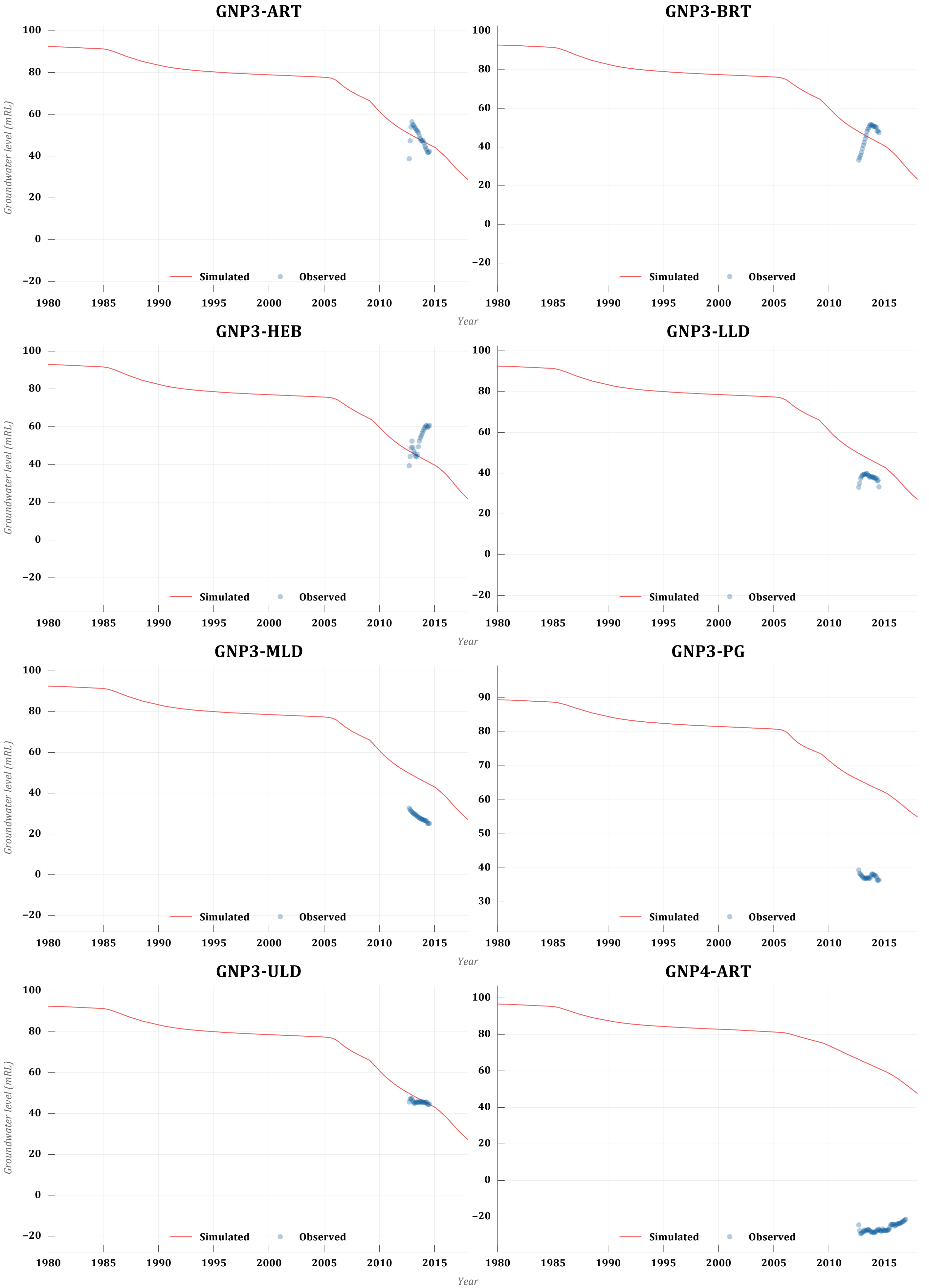
GCP3S

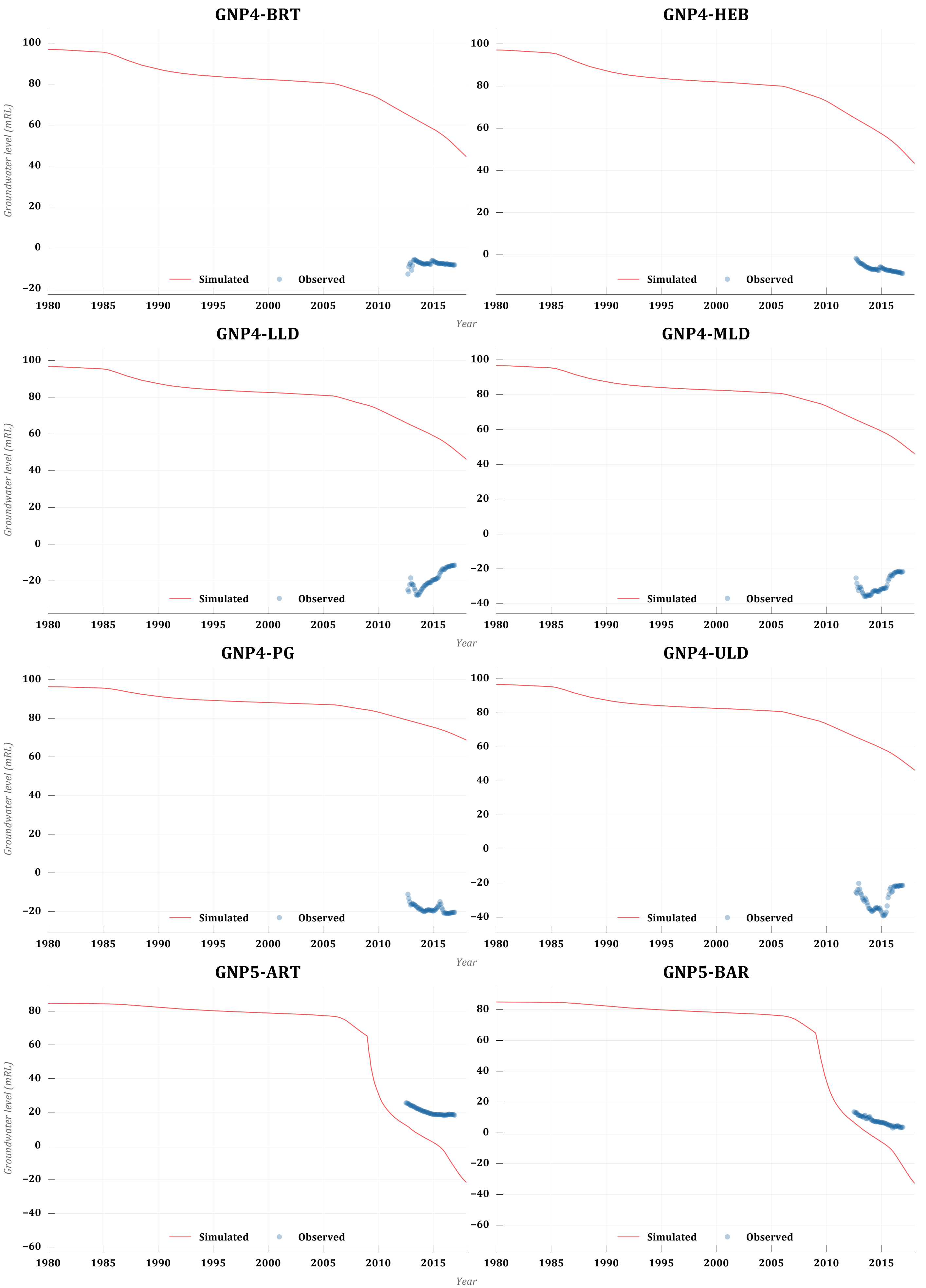


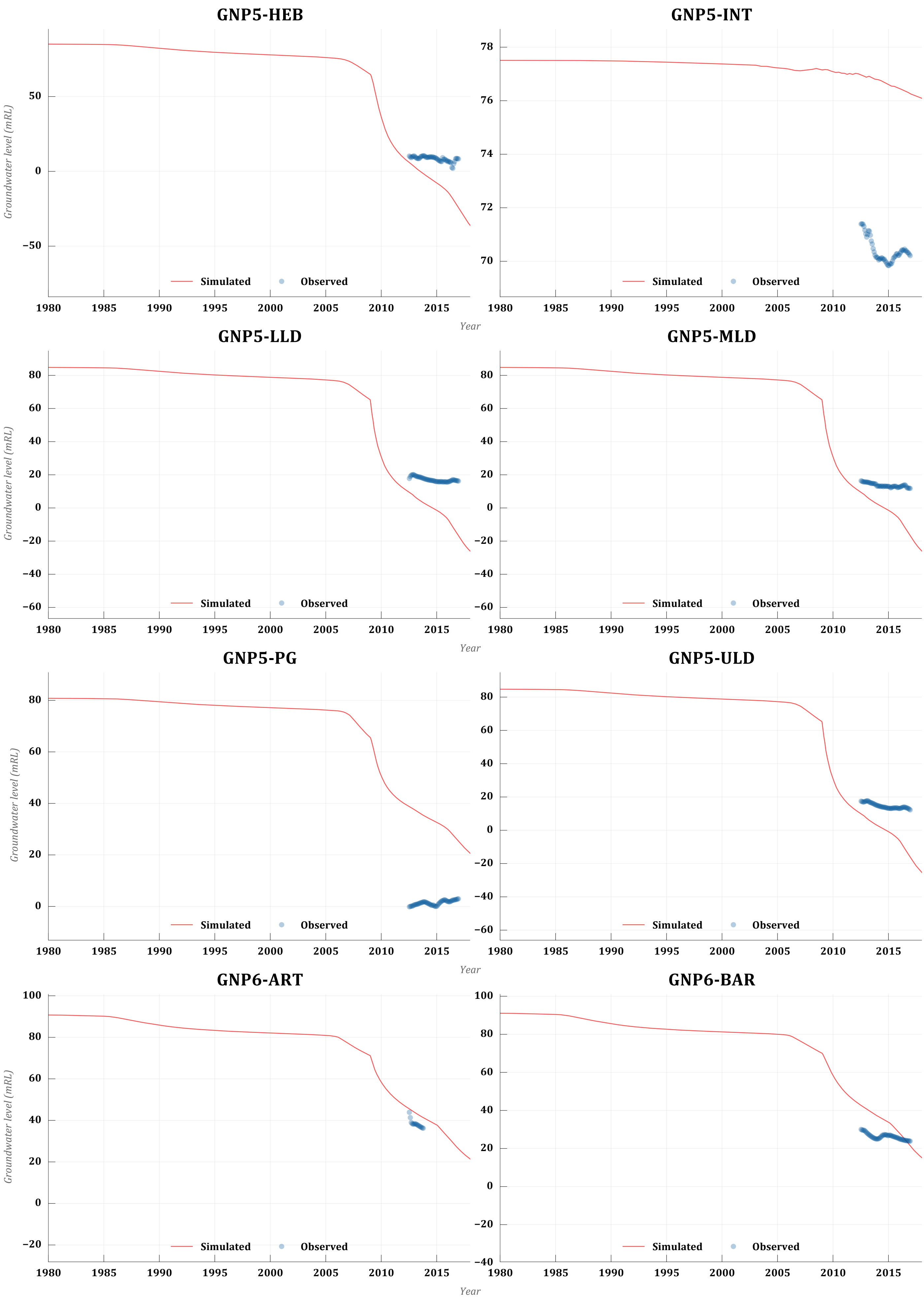

GCP4D
GCP4S
GNP1-ART
GNP1-BRT
GNP1-HEB
GNP1-LLD
GNP1-MLD
GNP1-PG
Groundwater level (mRL)
Year
1980
1985
1990
1995
2000
2005
2010
2015
Simulated
Observed

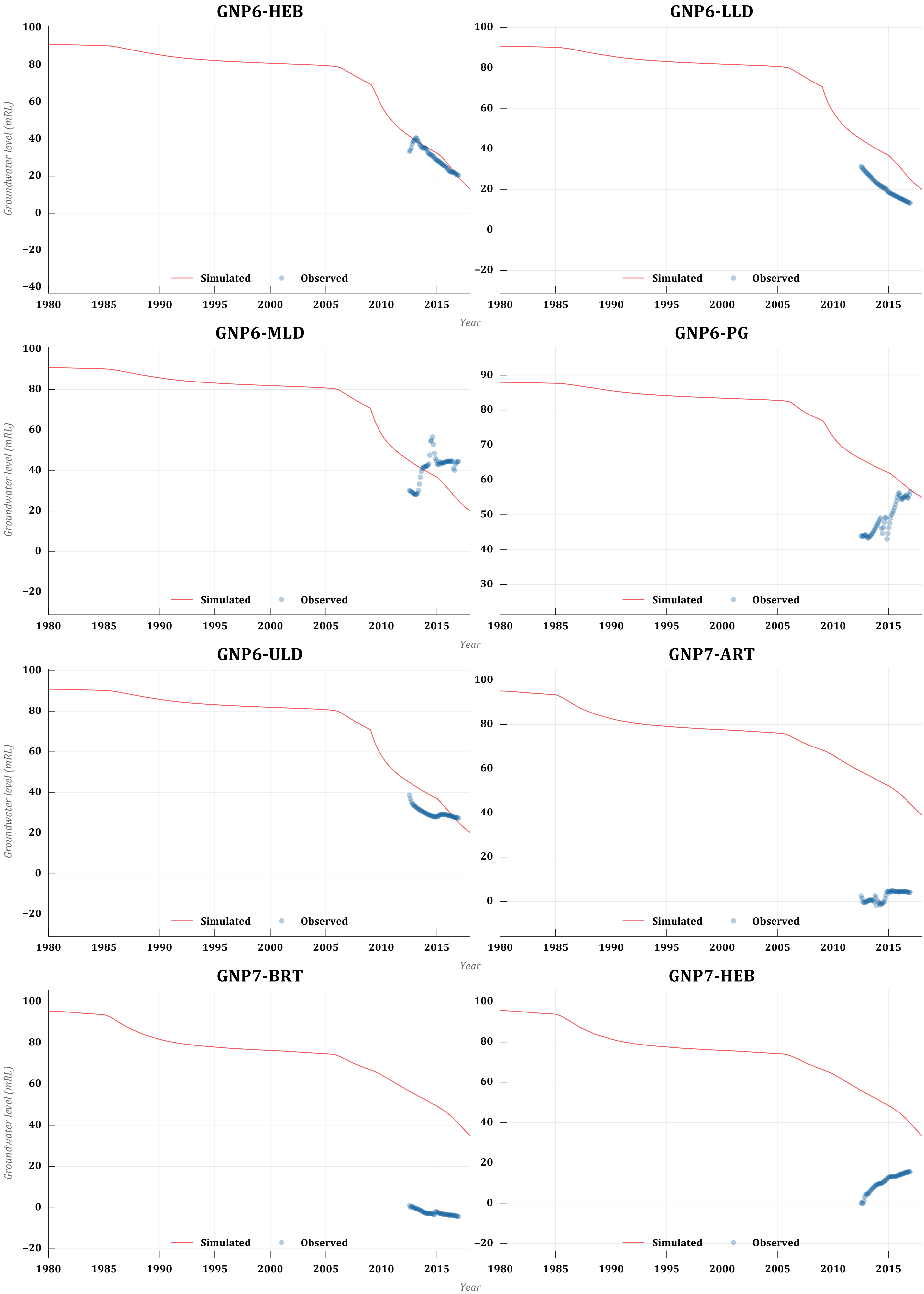


GNP1-ULD
GNP2-ART
GNP2-BAR
GNP2-HEB
GNP2-LLD
GNP2-MLD
GNP2-PG
GNP2-ULD
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

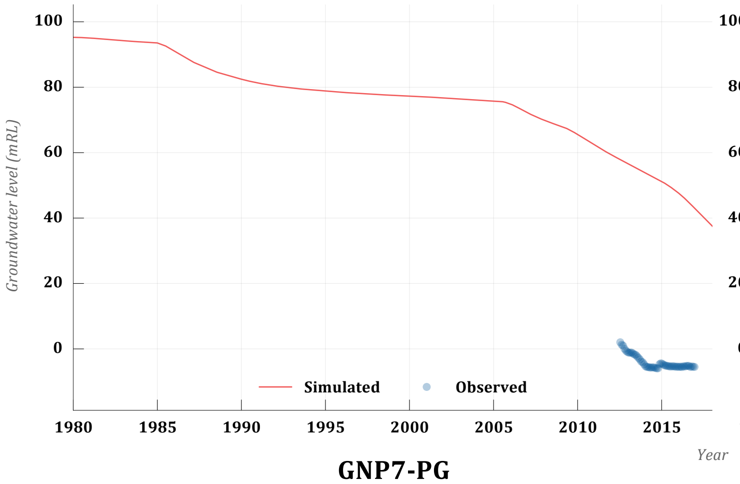

GNP3-ART
GNP3-BRT
GNP3-HEB
GNP3-LLD
GNP3-MLD
GNP3-PG
GNP3-ULD
GNP4-ART
Groundwater level (mRL)
Simulated
Observed
Year
1980
1985
1990
1995
2000
2005
2010
2015
100
80
60
40
20
0
−20
90
70
50
30


GNP4-BRT
GNP4-HEB
GNP4-LLD
GNP4-MLD
GNP4-PG
GNP4-ULD
GNP5-ART
GNP5-BAR
Groundwater level (mRL)
Year
Simulated
Observed

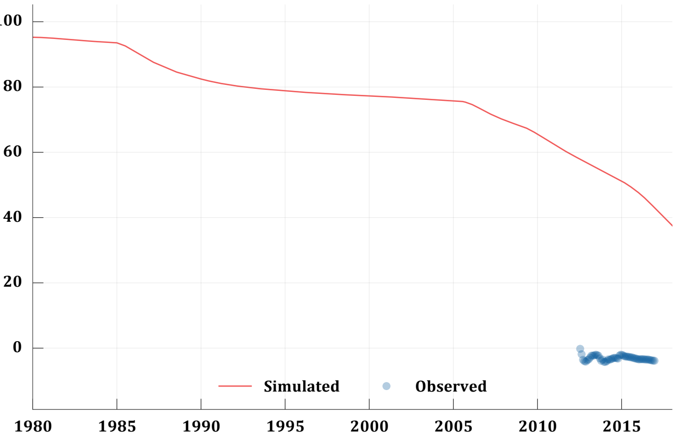

GNP5-HEB
GNP5-INT
GNP5-LLD
GNP5-MLD
GNP5-PG
GNP5-ULD
GNP6-ART
GNP6-BAR
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015


GNP6-HEB
GNP6-LLD
GNP6-MLD
GNP6-PG
GNP6-ULD
GNP7-ART
GNP7-BRT
GNP7-HEB
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015
100
80
60
40
20
0
−20
−40
90
70
50
30

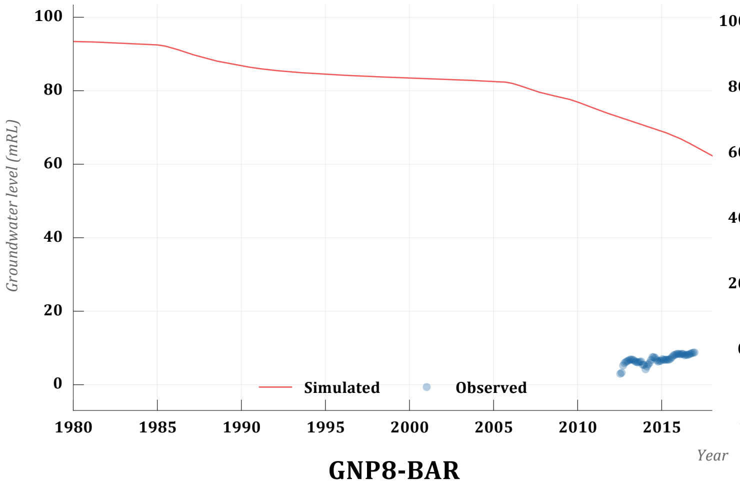
GNP7-LLD



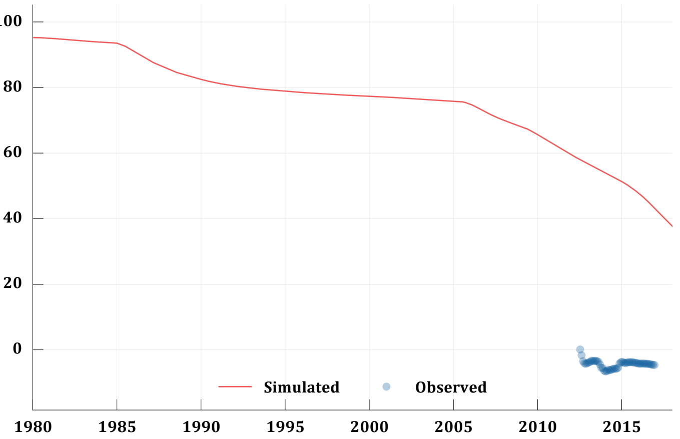
GNP7-MLD



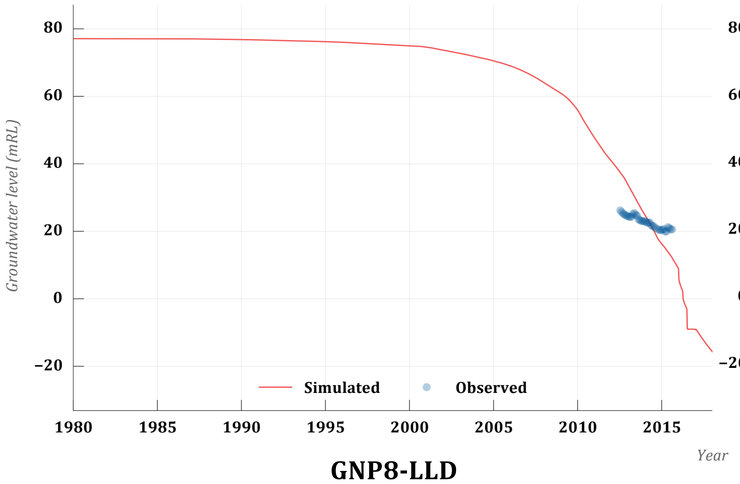
GNP7-PG



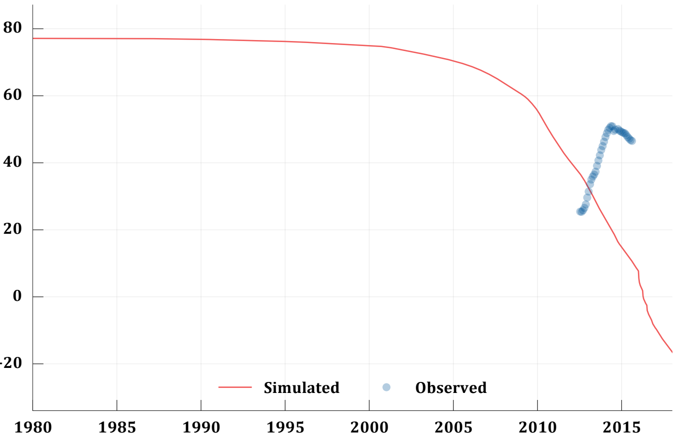
GNP7-ULD



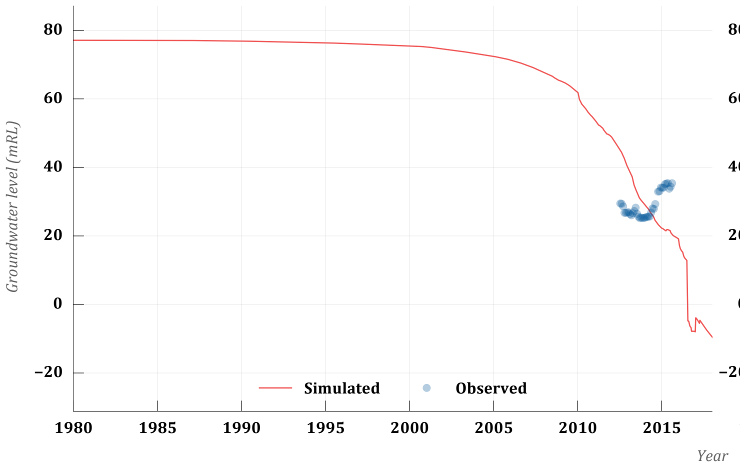
GNP8-BAR



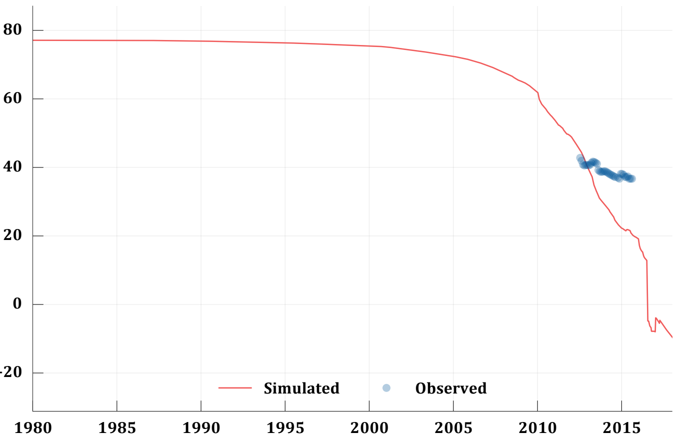
GNP8-HEB

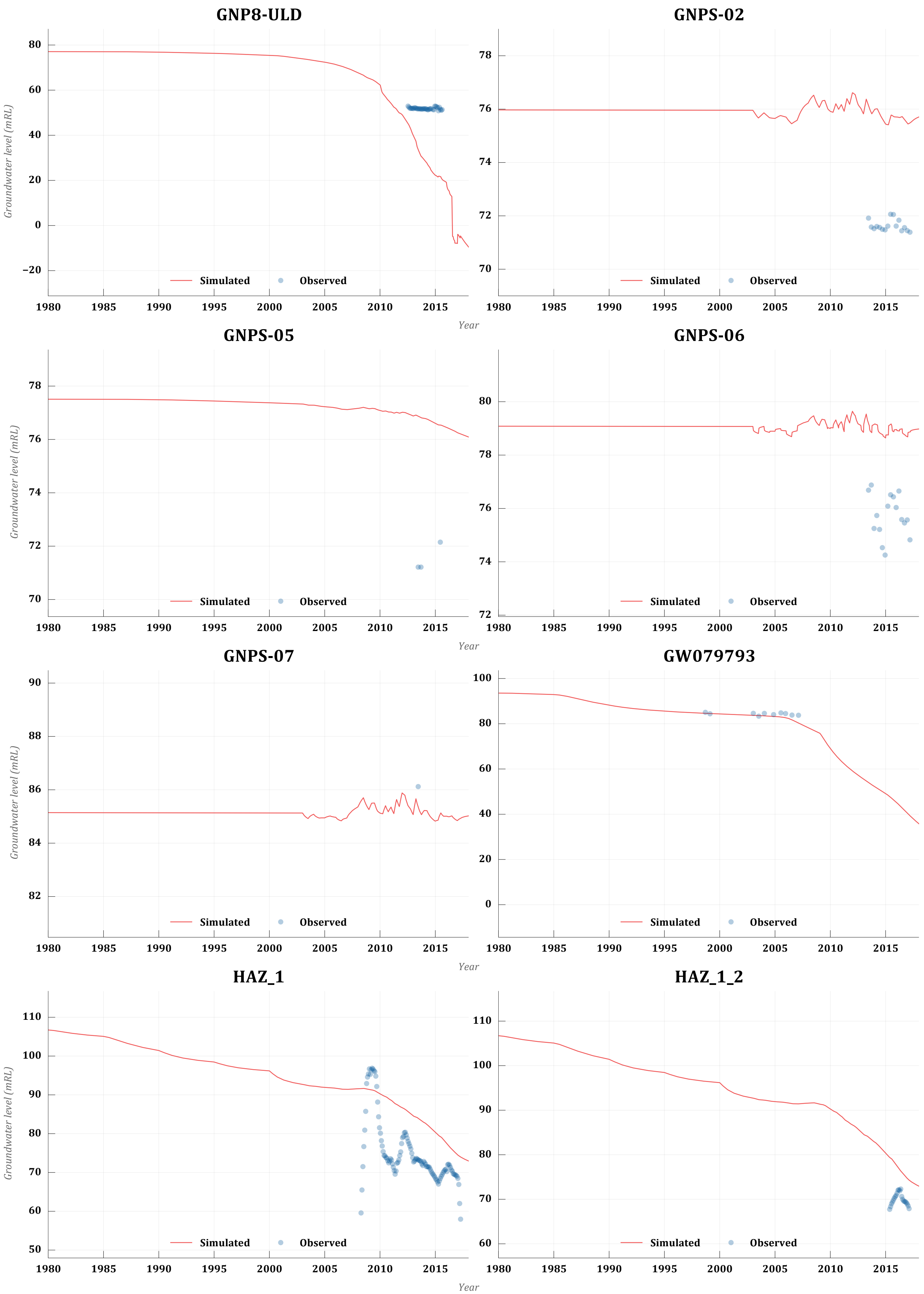


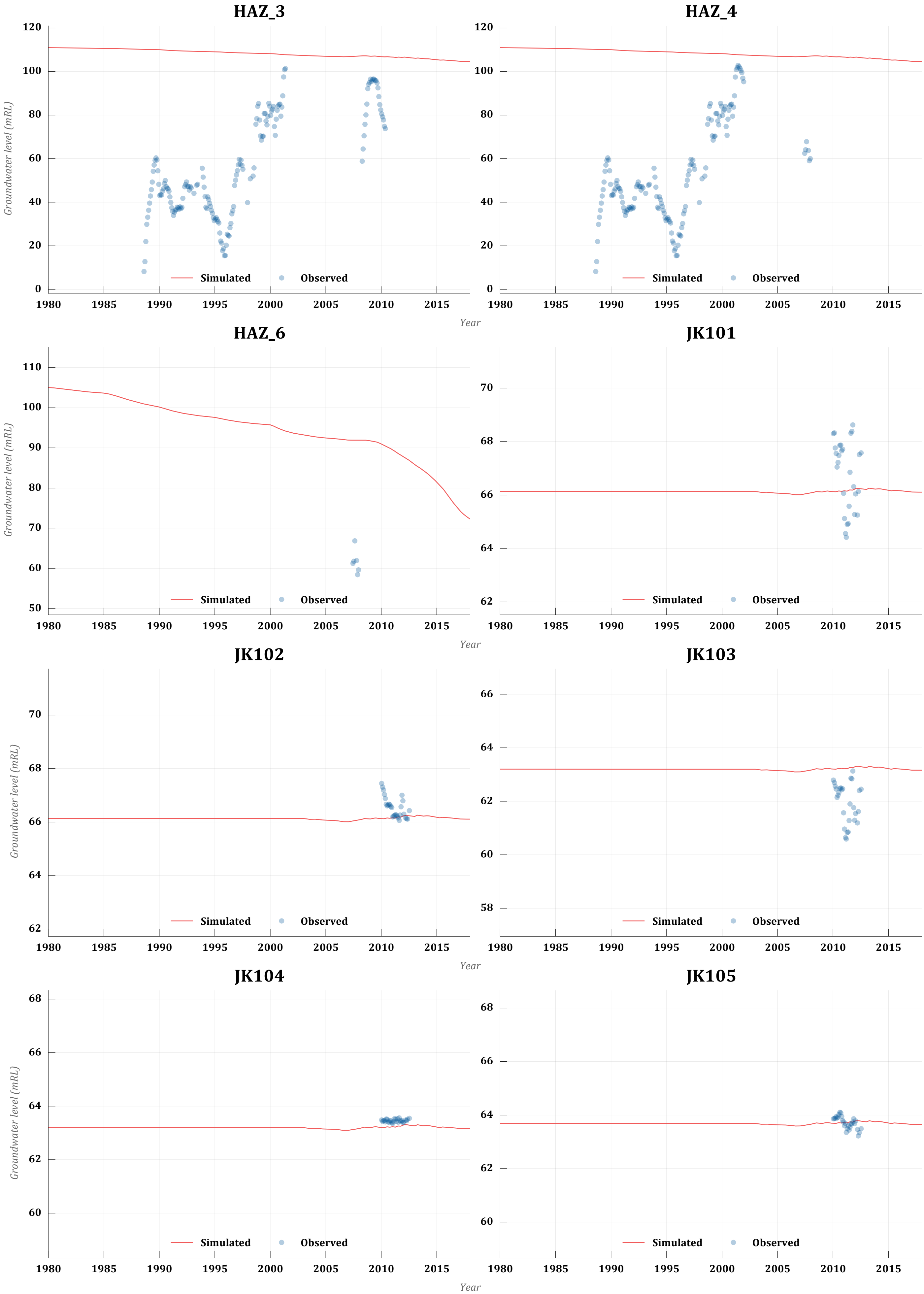
GNP8-LLD



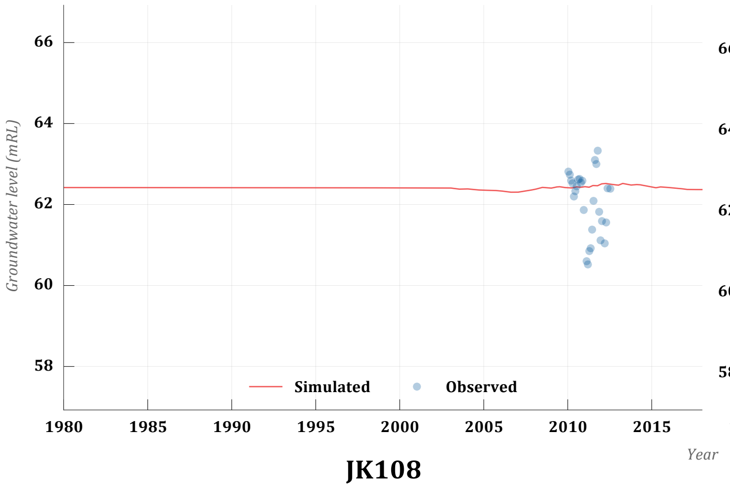
GNP8-MLD



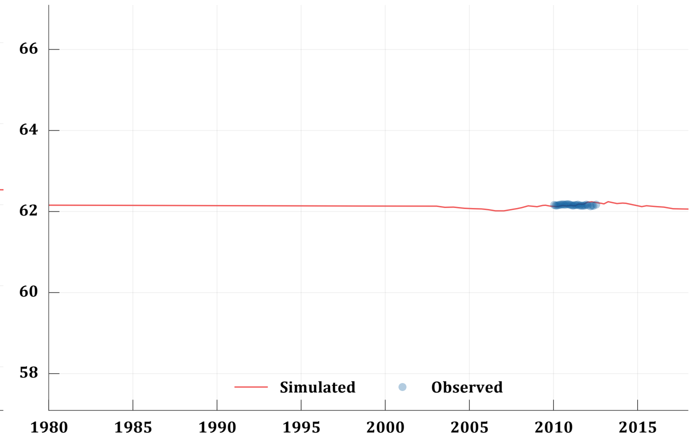

GNP8-ULD
GNPS-02
GNPS-05
GNPS-06
GNPS-07
GW079793
HAZ_1
HAZ_1_2
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015


HAZ_3
HAZ_4
HAZ_6
JK101
JK102
JK103
JK104
JK105
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

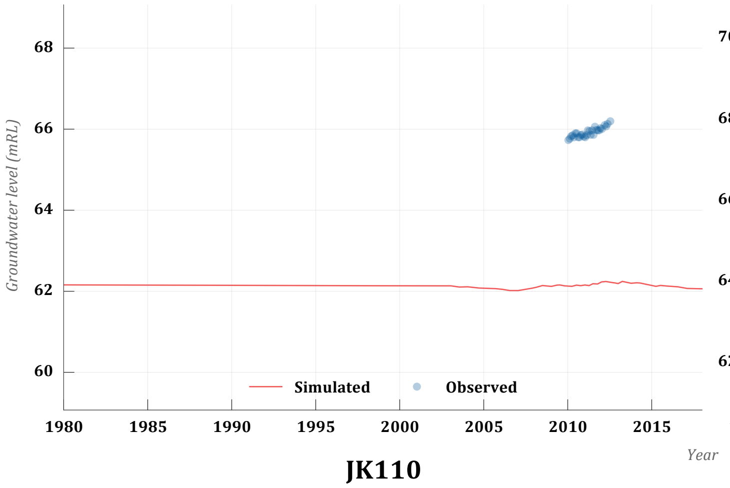
JK106



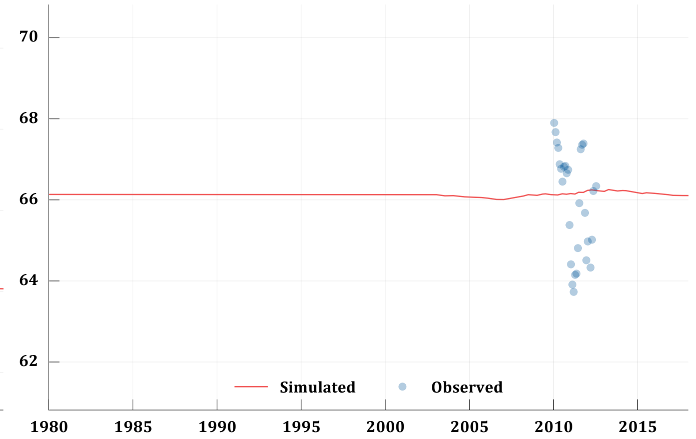
JK107



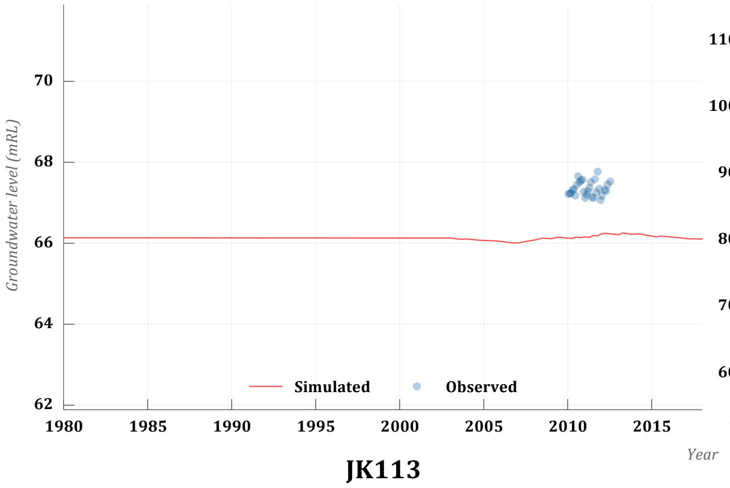
JK108



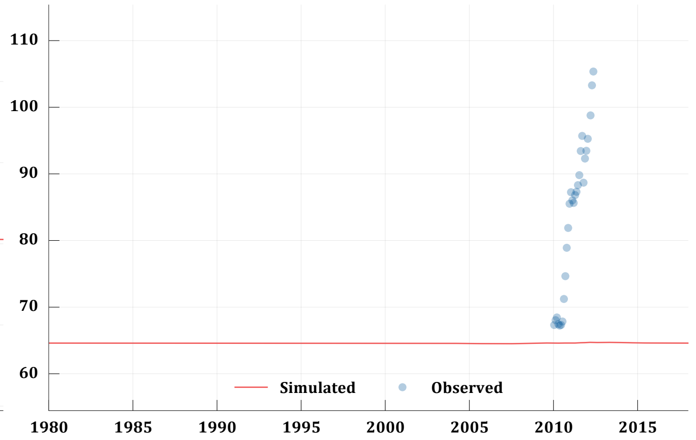
JK109



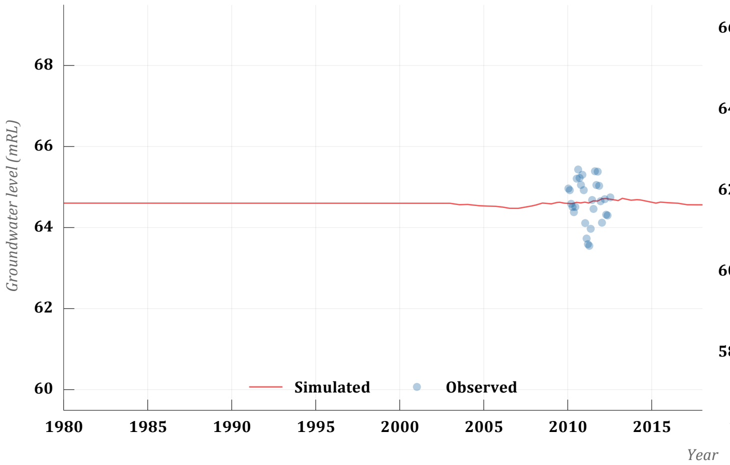
JK110



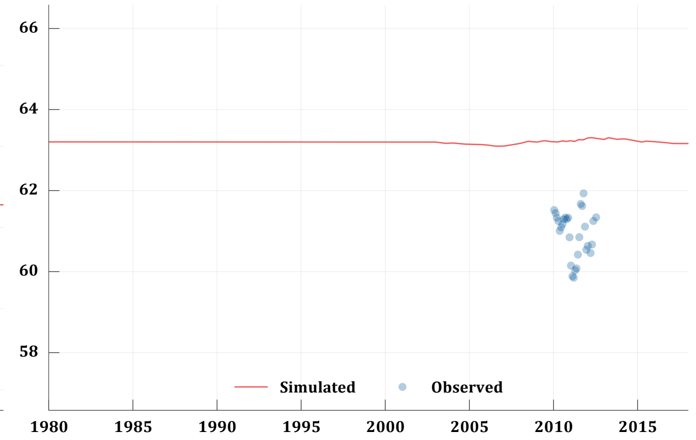
JK112

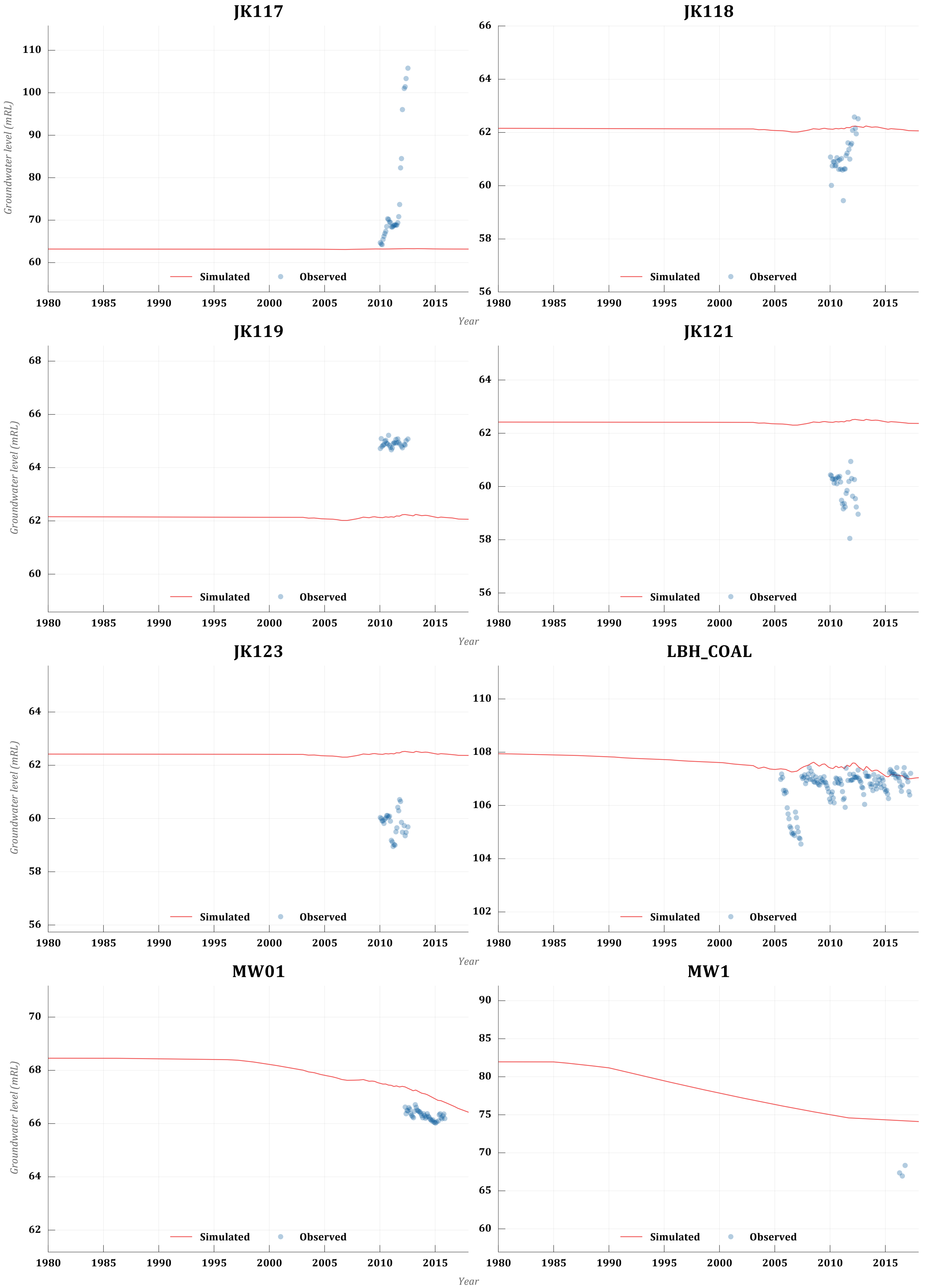


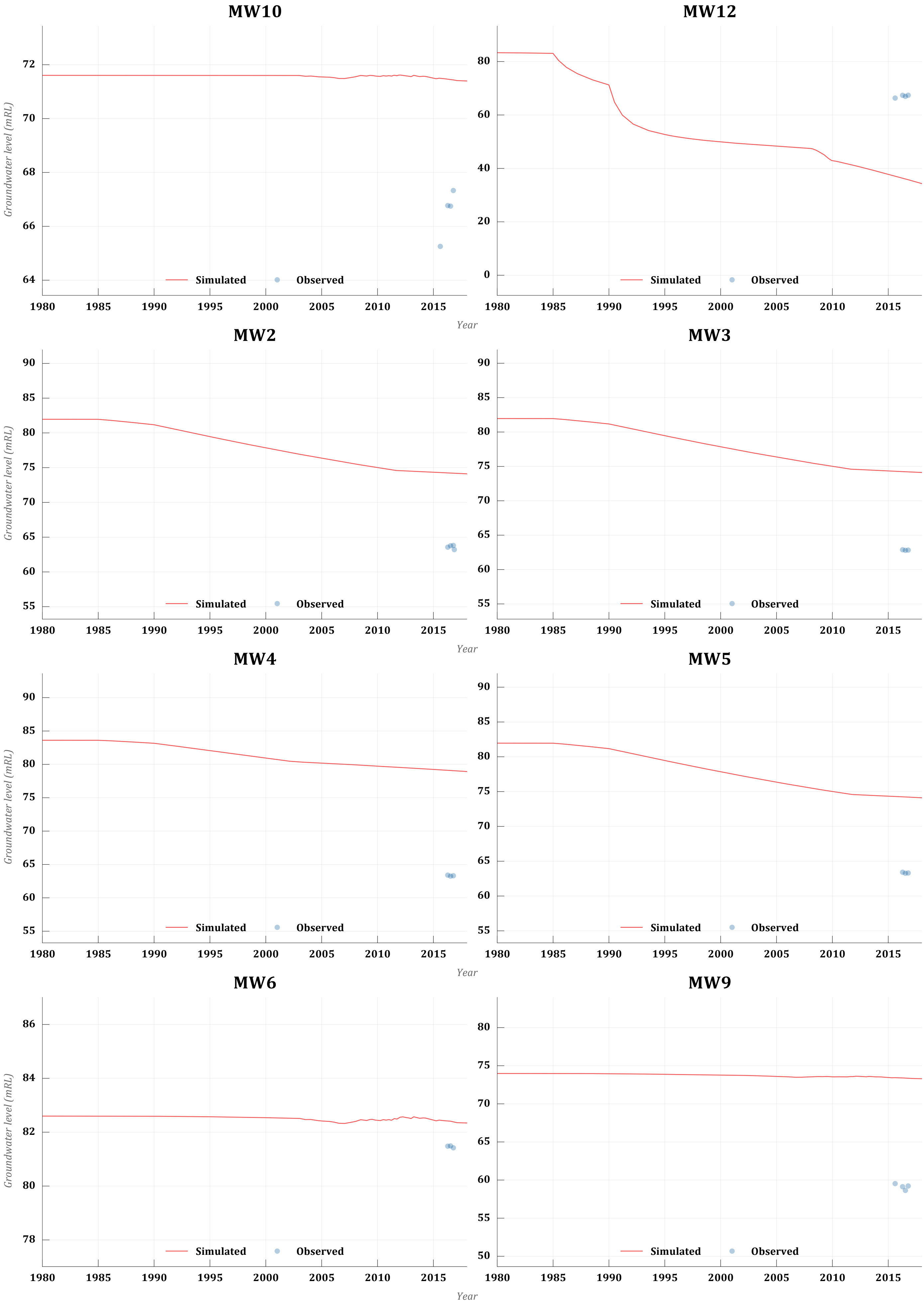
JK113

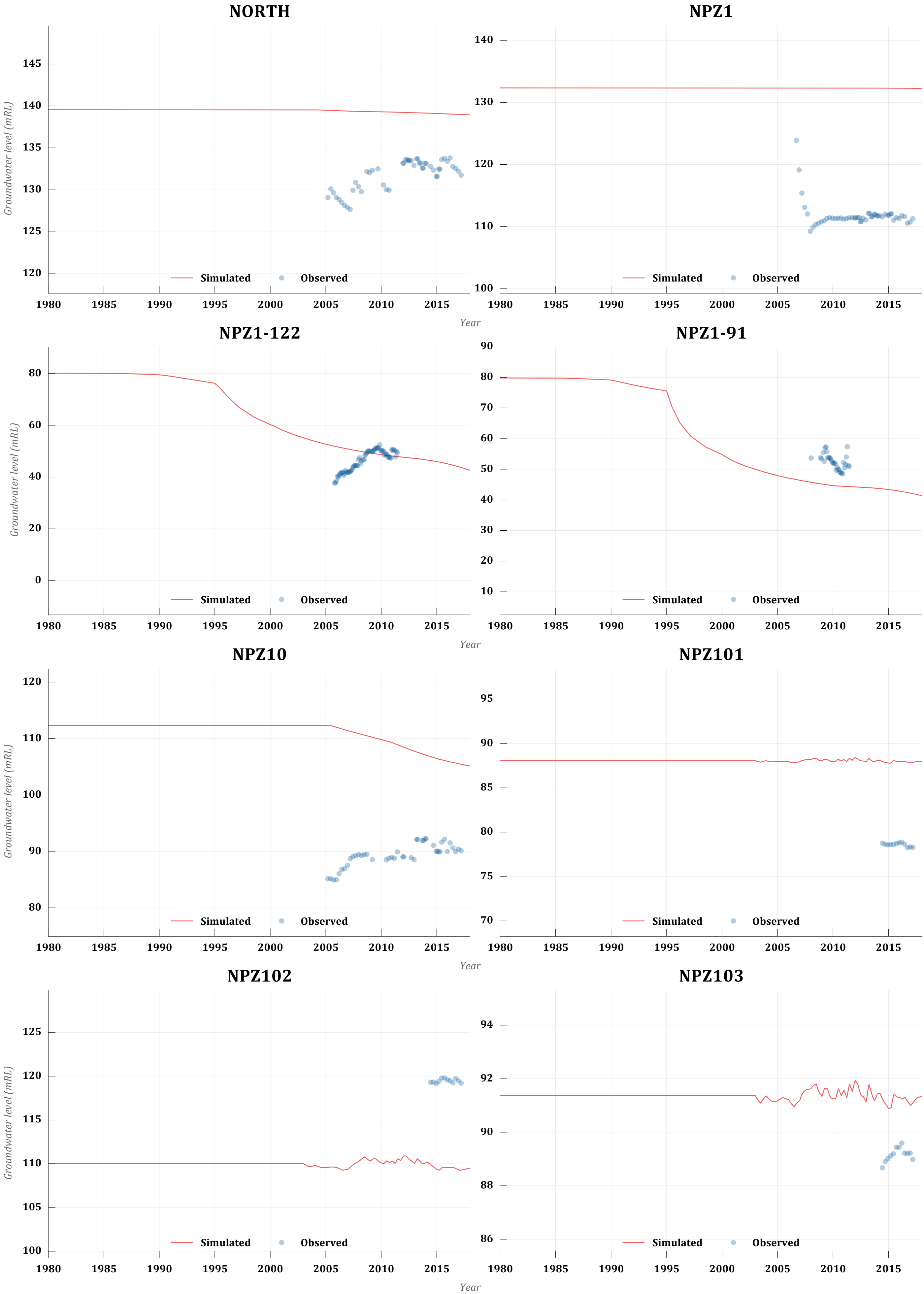


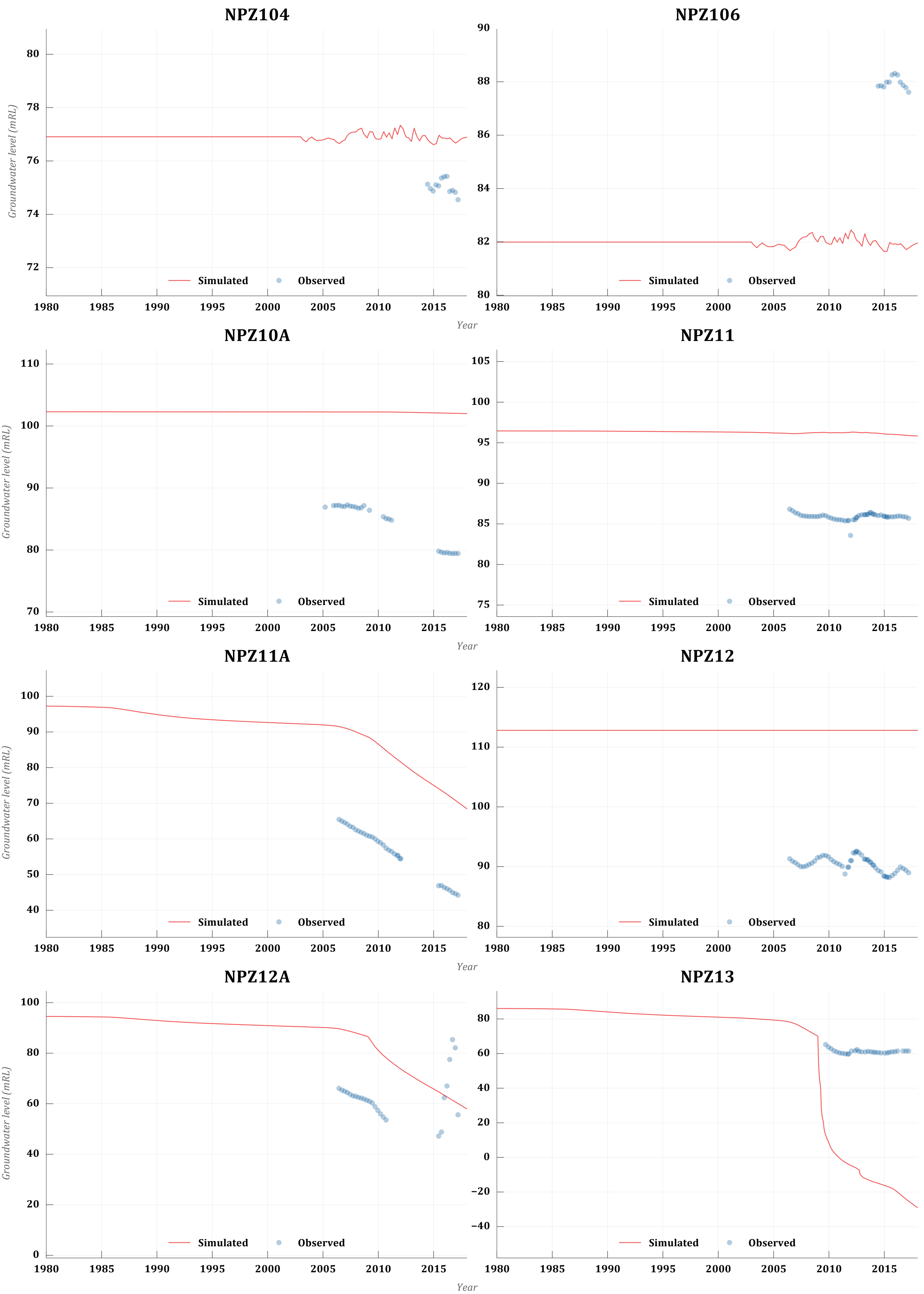
JK115

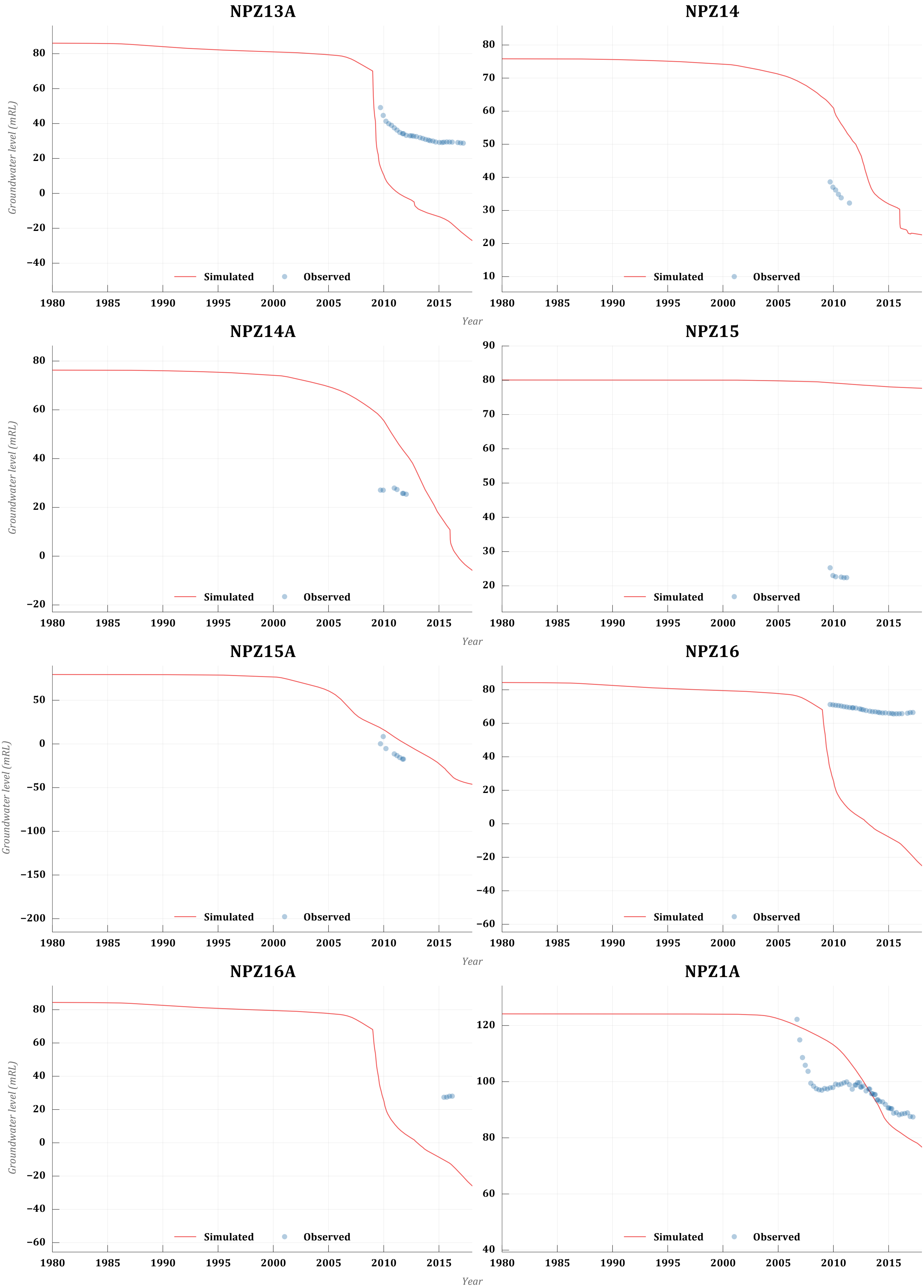


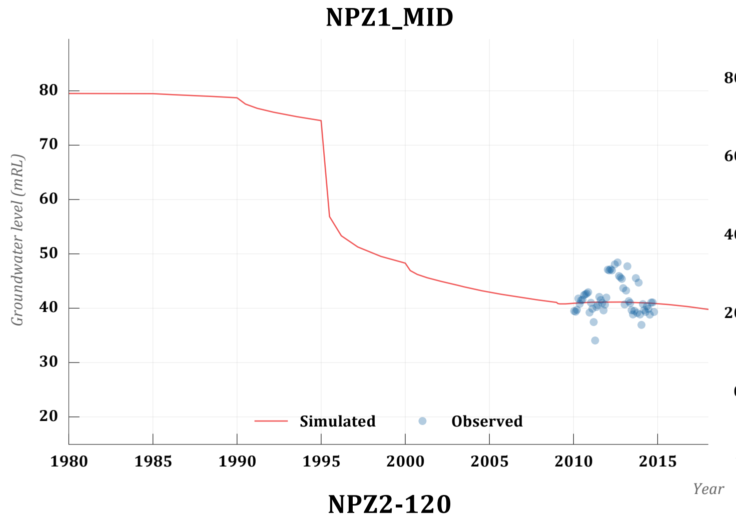

JK117
JK118
JK119
JK121
JK123
LBH_COAL
MW01
MW1
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

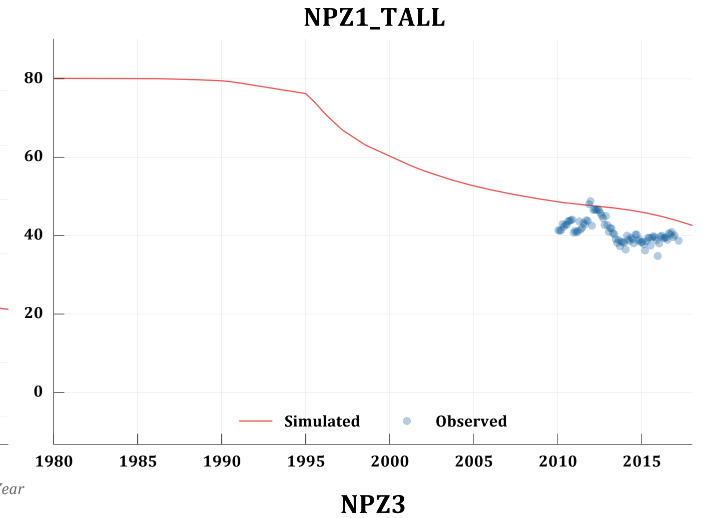

MW10
MW12
MW2
MW3
MW4
MW5
MW6
MW9
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

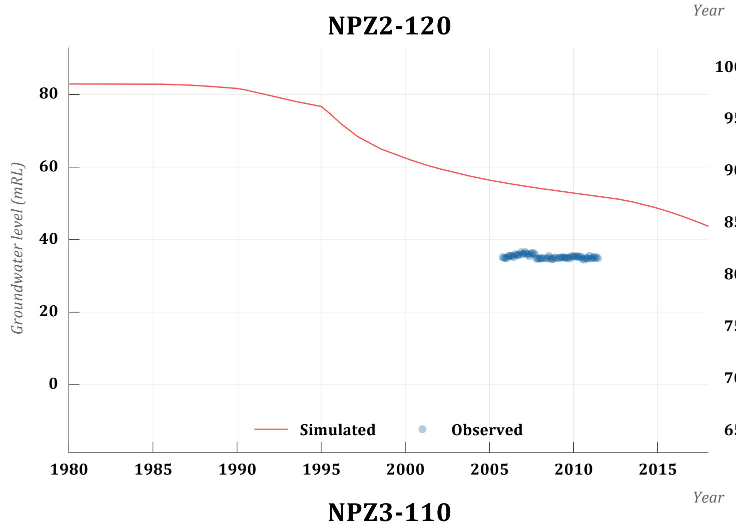

NORTH
NPZ1
NPZ1-122
NPZ1-91
NPZ10
NPZ101
NPZ102
NPZ103
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

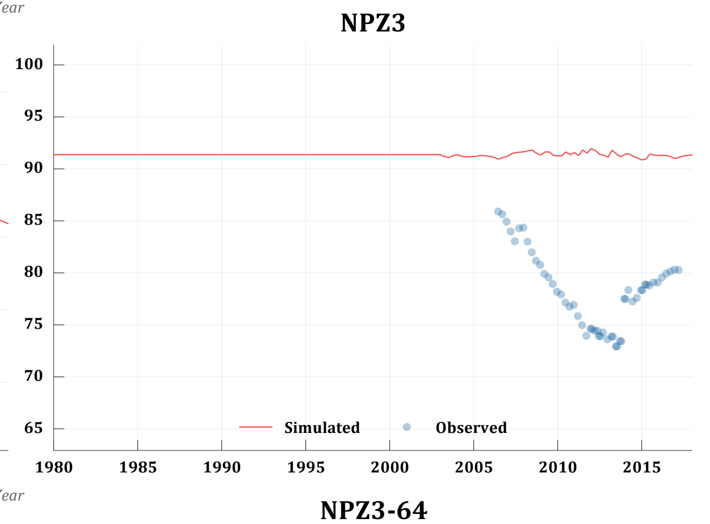

NPZ104
NPZ106
NPZ10A
NPZ11
NPZ11A
NPZ12
NPZ12A
NPZ13
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

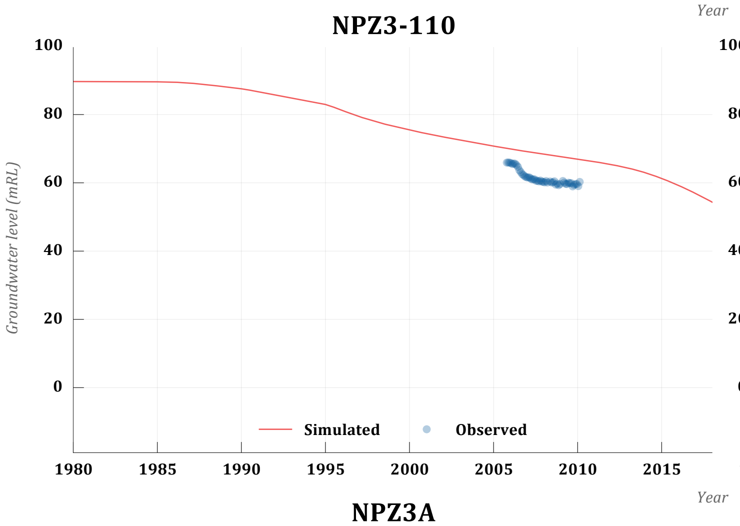

NPZ13A
NPZ14
NPZ14A
NPZ15
NPZ15A
NPZ16
NPZ16A
NPZ1A
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

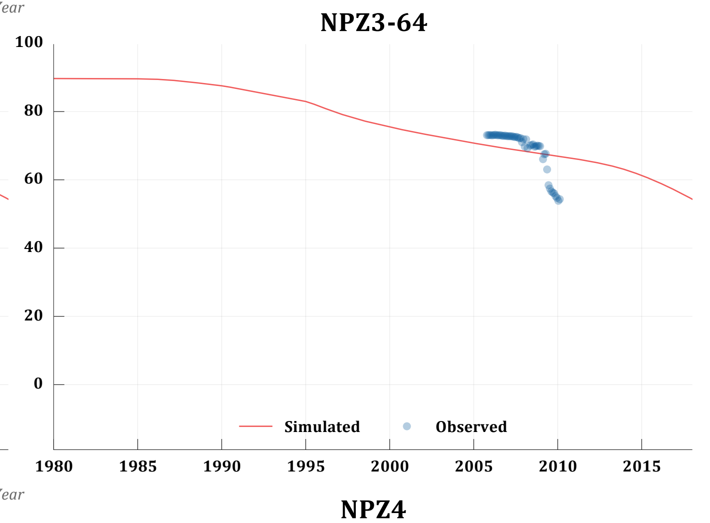

NPZ1_MID
Groundwater level (mRL)
Simulated
Observed

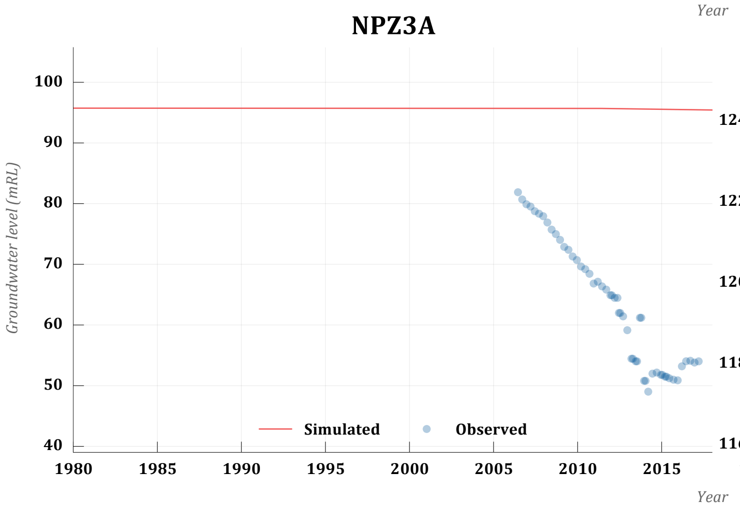

NPZ1_TALL
Simulated
Observed
Year

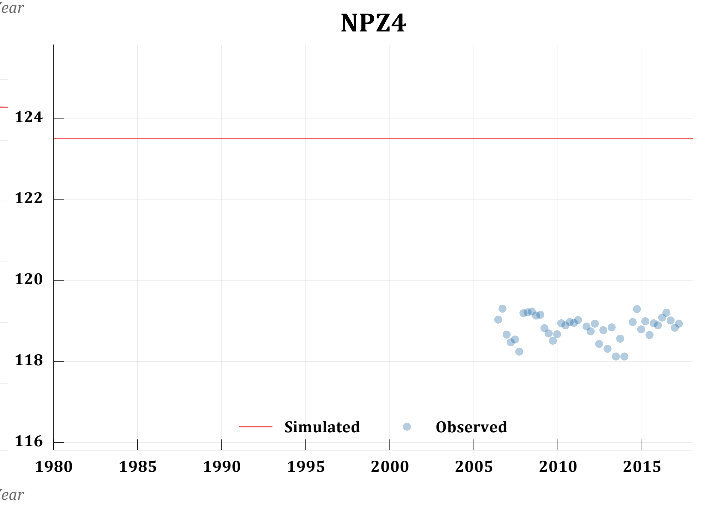

NPZ2-120
Groundwater level (mRL)
Simulated
Observed

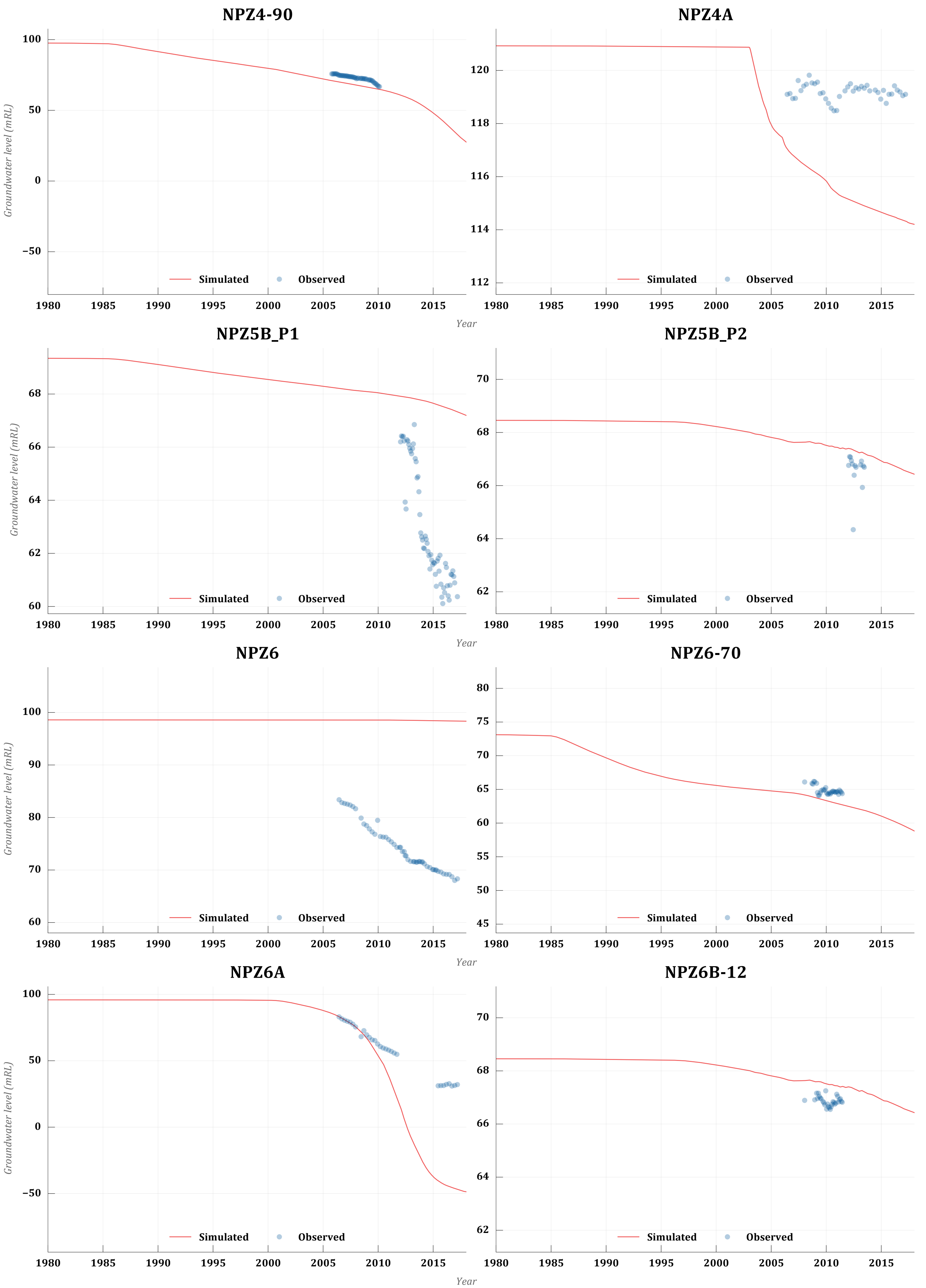

NPZ3
Simulated
Observed
Year

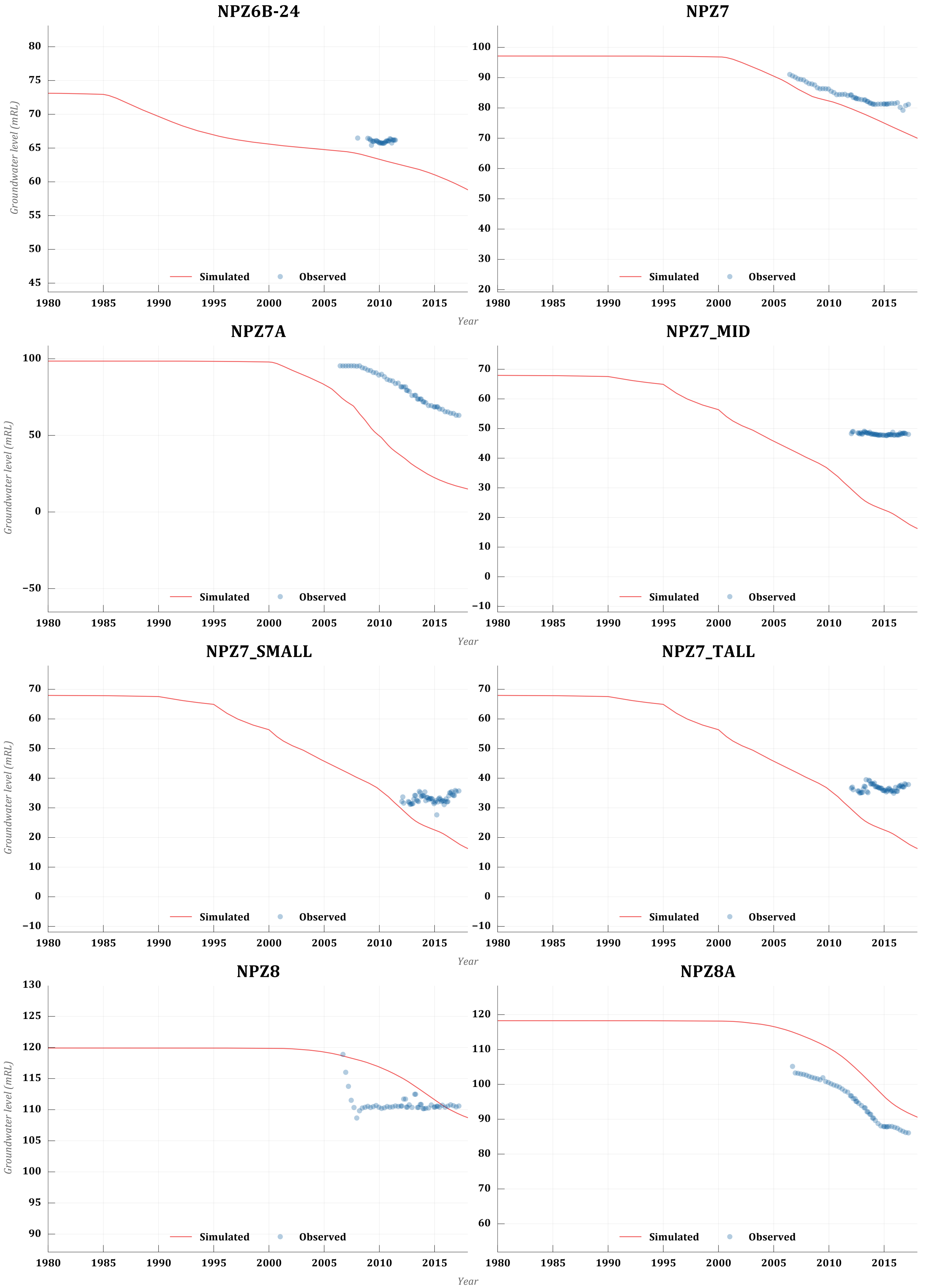

NPZ3-110
Groundwater level (mRL)
Simulated
Observed

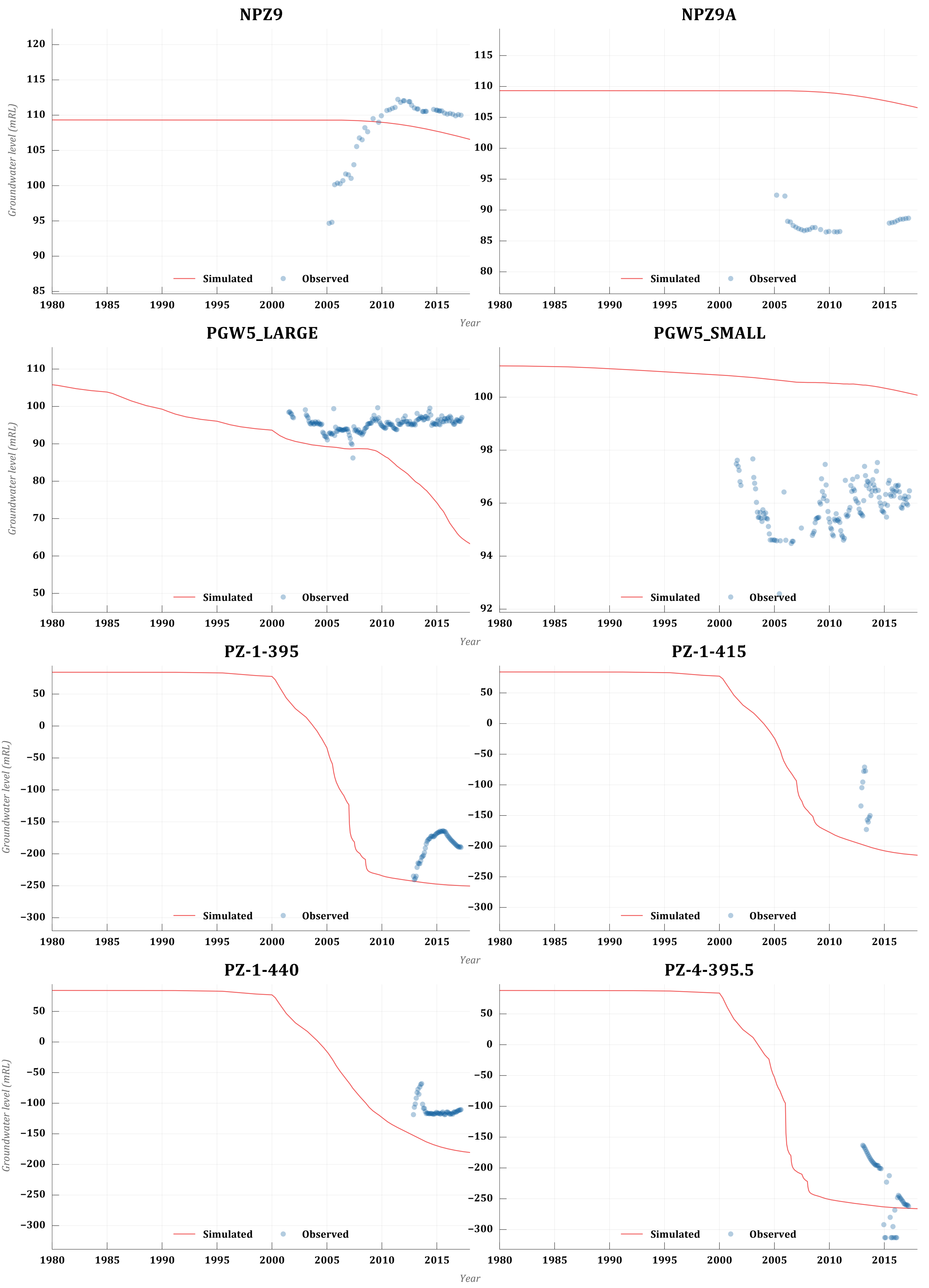

NPZ3-64
Simulated
Observed
Year

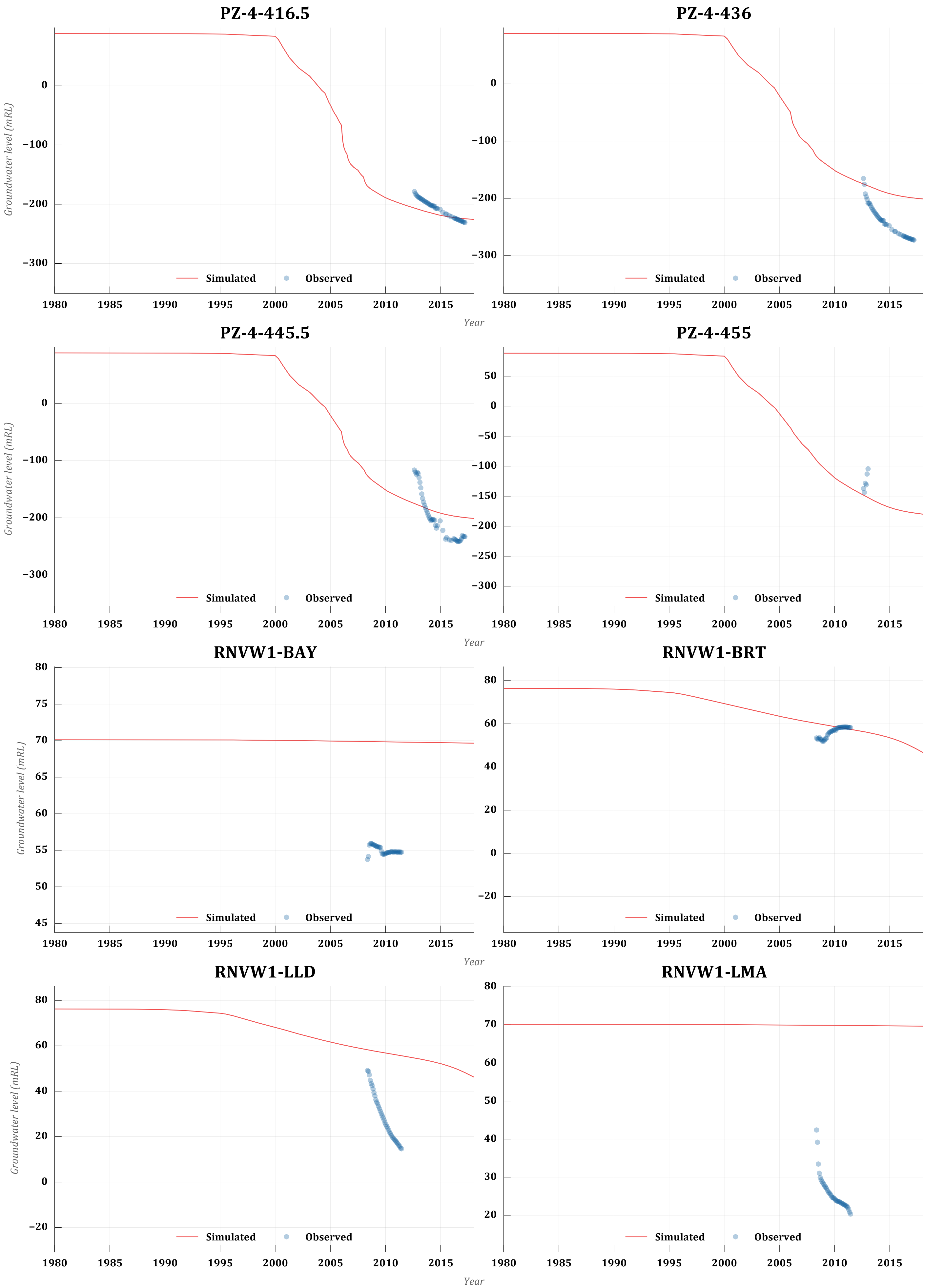

NPZ3A
Groundwater level (mRL)
Simulated
Observed

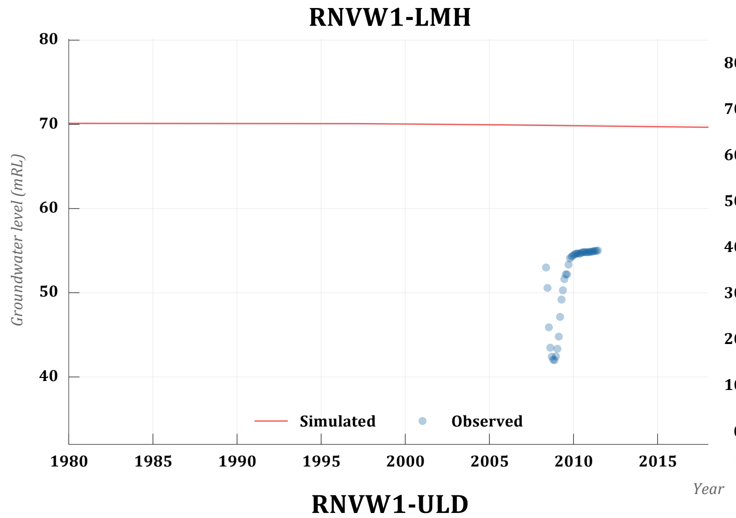

NPZ4
Simulated
Observed
Year

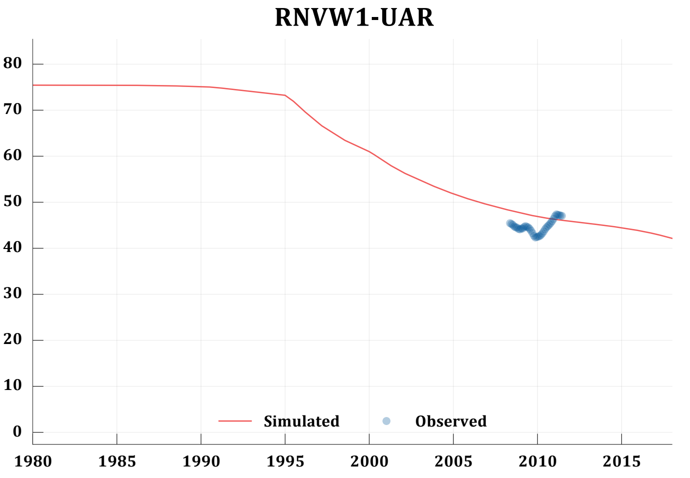

NPZ4-90
NPZ4A
NPZ5B_P1
NPZ5B_P2
NPZ6
NPZ6-70
NPZ6A
NPZ6B-12
Groundwater level (mRL)
Year
Simulated
Observed

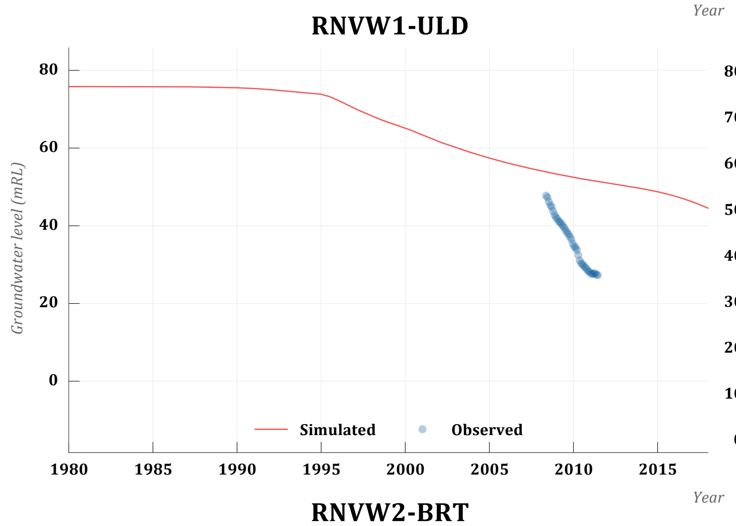

NPZ6B-24
NPZ7
NPZ7A
NPZ7_MID
NPZ7_SMALL
NPZ7_TALL
NPZ8
NPZ8A
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

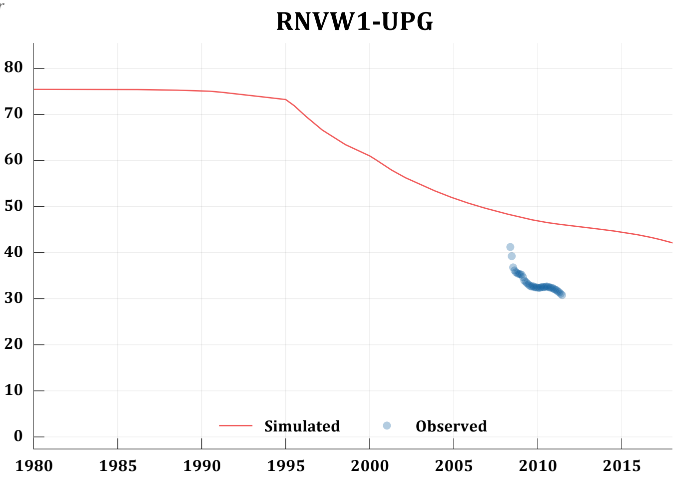

NPZ9
NPZ9A
PGW5_LARGE
PGW5_SMALL
PZ-1-395
PZ-1-415
PZ-1-440
PZ-4-395.5
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

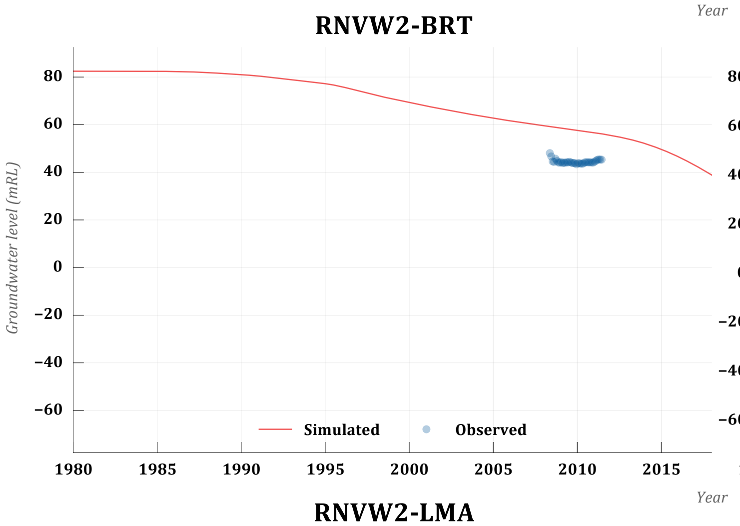

PZ-4-416.5
PZ-4-436
PZ-4-445.5
PZ-4-455
RNVW1-BAY
RNVW1-BRT
RNVW1-LLD
RNVW1-LMA
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

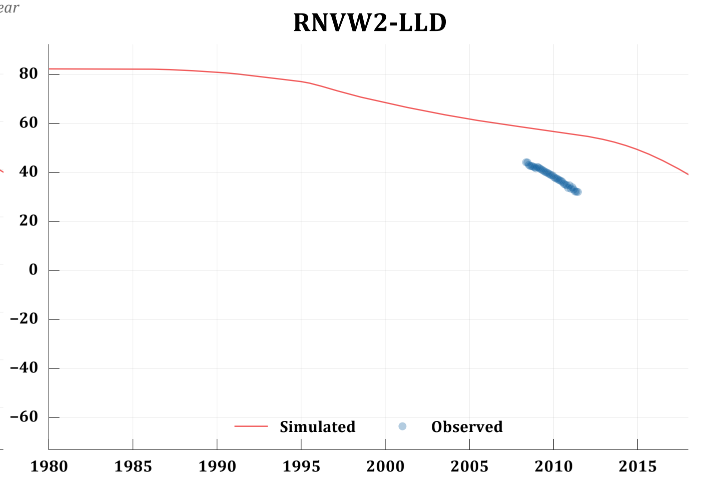

RNVW1-LMH
Groundwater level (mRL)
Simulated
Observed
Year

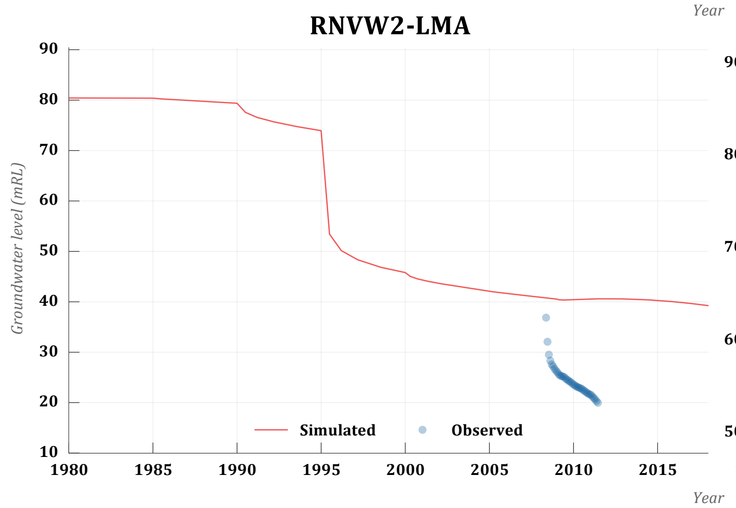

RNVW1-UAR
Simulated
Observed

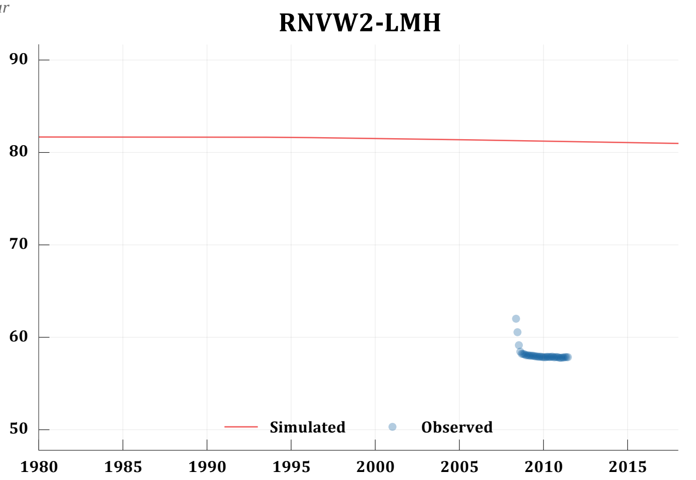

RNVW1-ULD
Groundwater level (mRL)
Simulated
Observed
Year

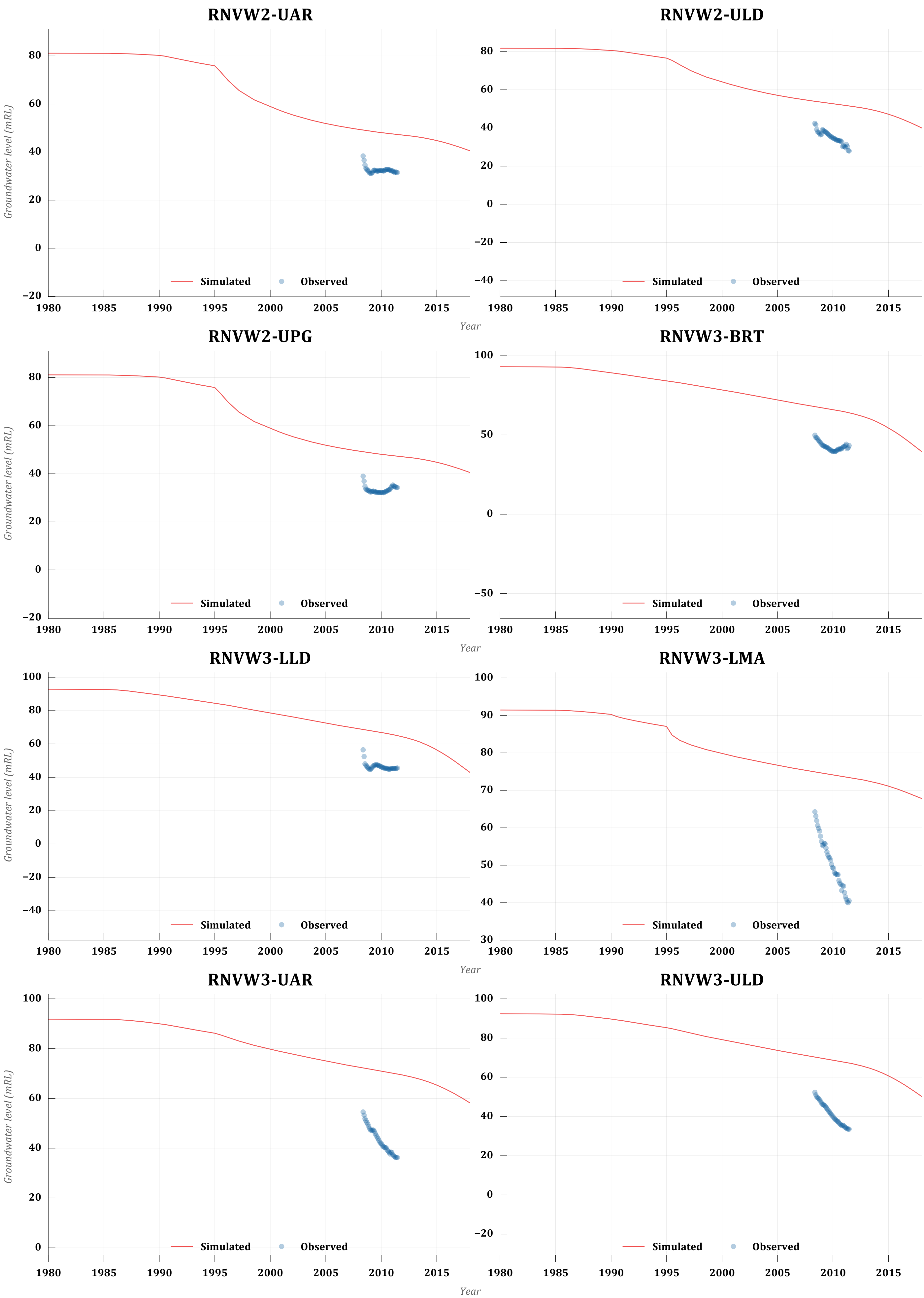

RNVW1-UPG
Simulated
Observed

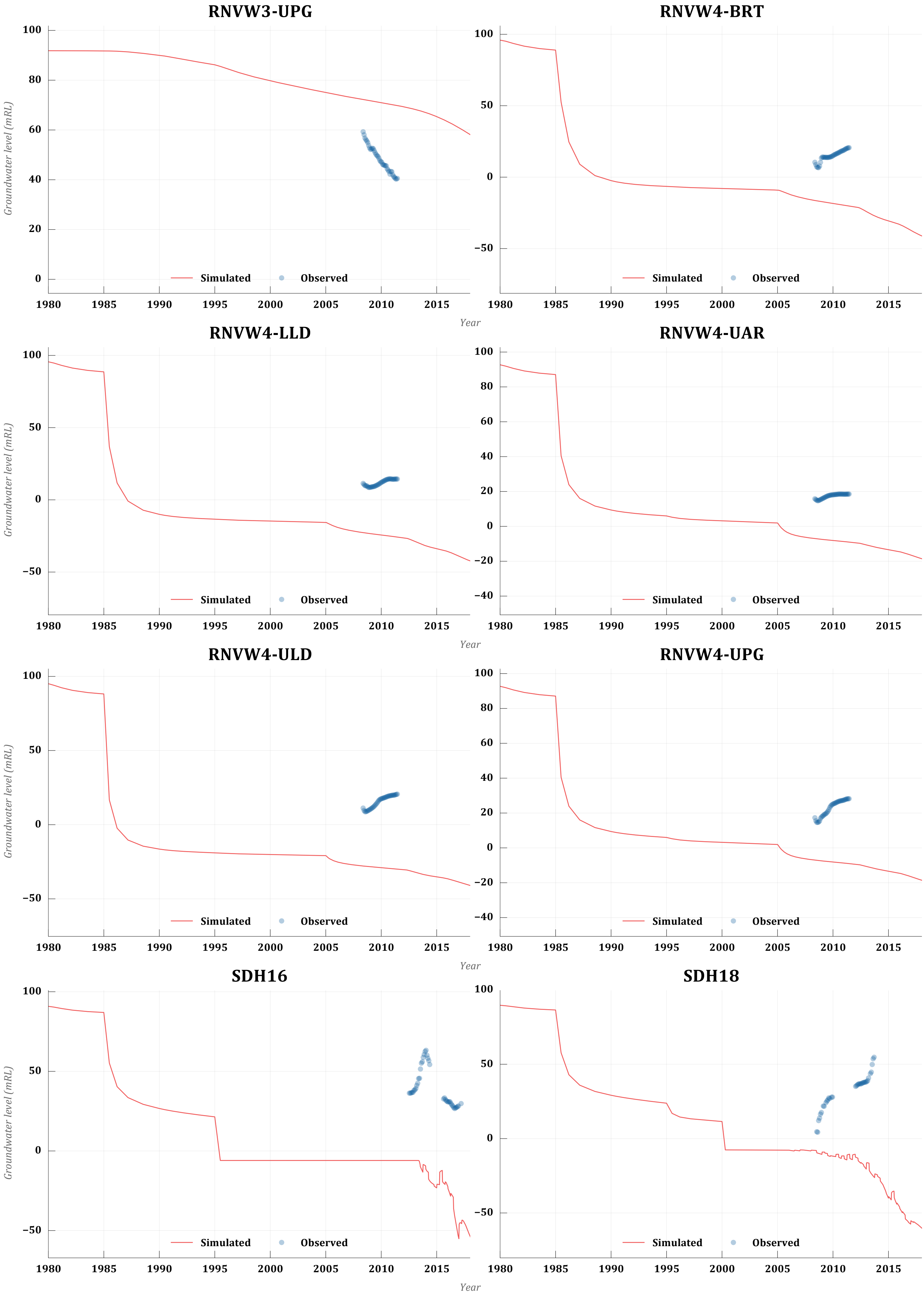

RNVW2-BRT
Groundwater level (mRL)
Simulated
Observed
Year

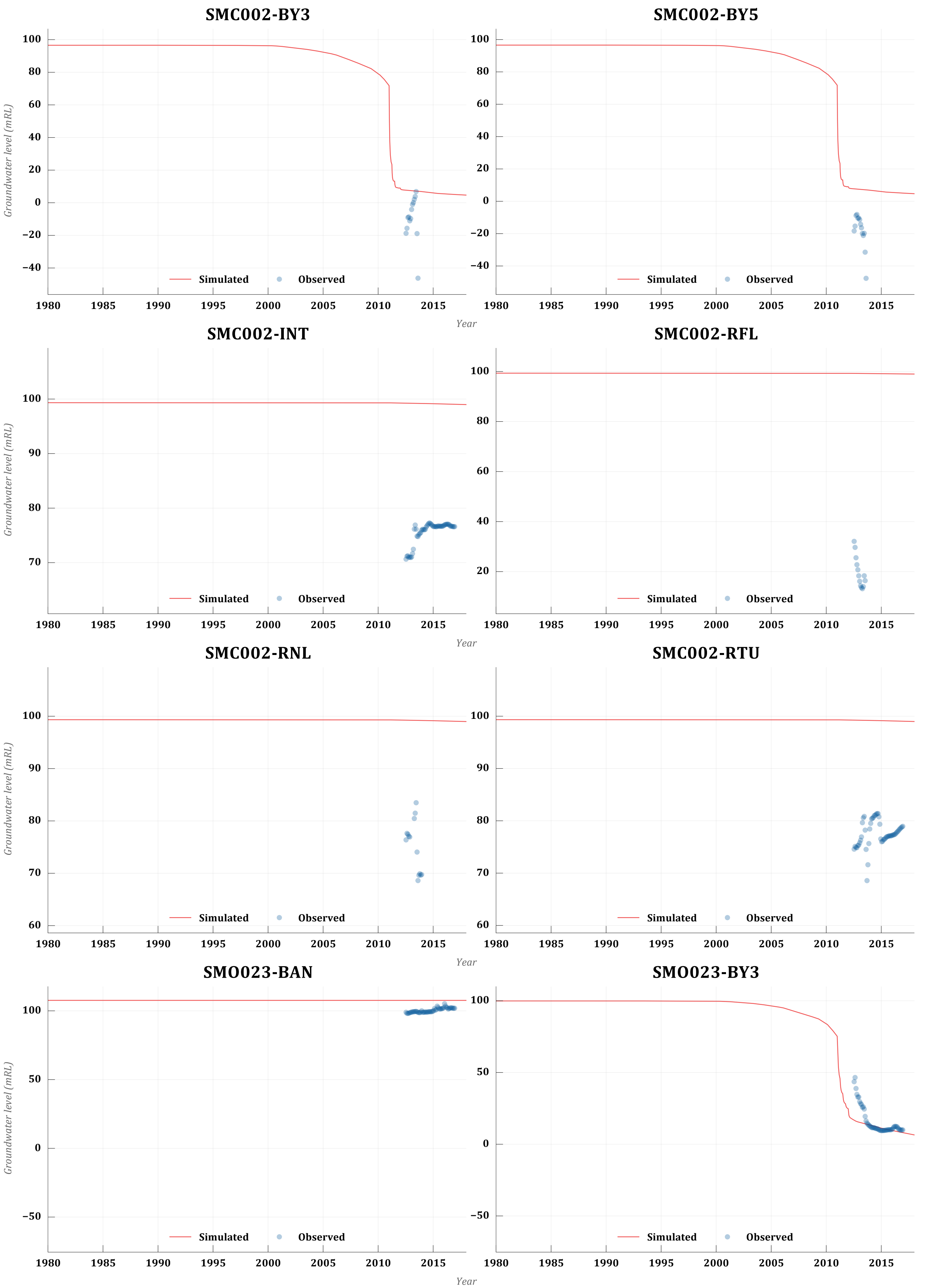

RNVW2-LLD
Simulated
Observed


RNVW2-LMA
Groundwater level (mRL)
Simulated
Observed
Year

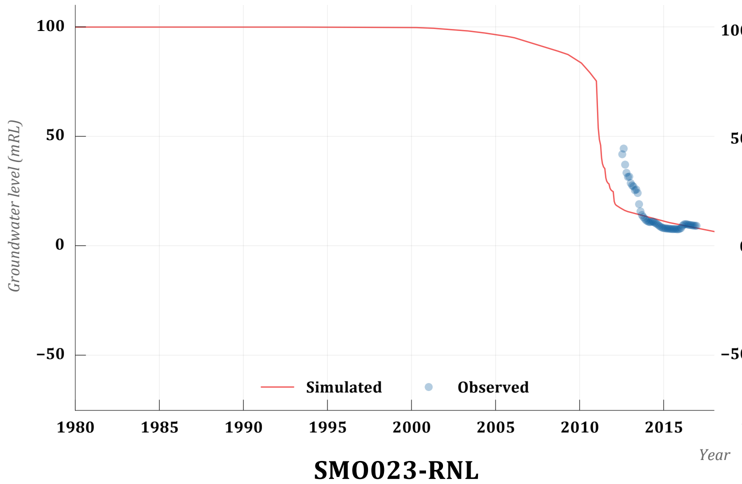

RNVW2-LMH
Simulated
Observed


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

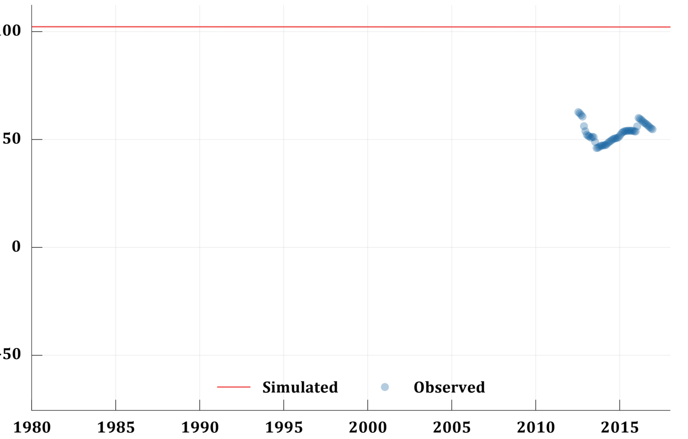

RNVW3-UPG
RNVW4-BRT
RNVW4-LLD
RNVW4-UAR
RNVW4-ULD
RNVW4-UPG
SDH16
SDH18
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015
100
80
60
40
20
0
−20
−40
50
−50


SMC002-BY3
SMC002-BY5
SMC002-INT
SMC002-RFL
SMC002-RNL
SMC002-RTU
SMO023-BAN
SMO023-BY3
Groundwater level (mRL)
Year
Simulated
Observed
1980
1985
1990
1995
2000
2005
2010
2015

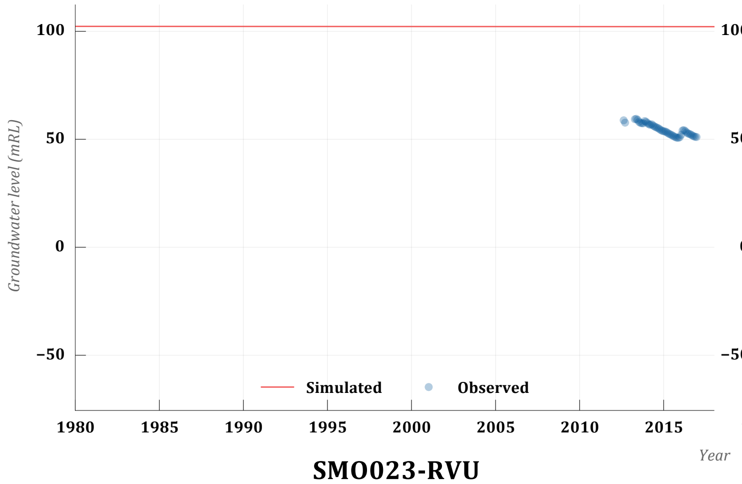
SMO023-BY5



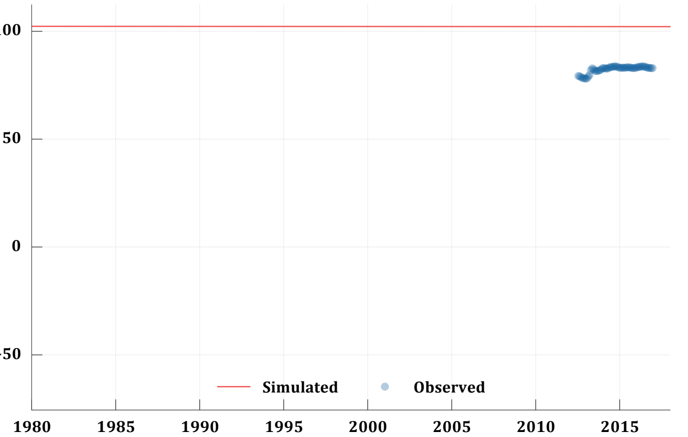
SMO023-RFL



SMO023-RNL



SMO023-RTU



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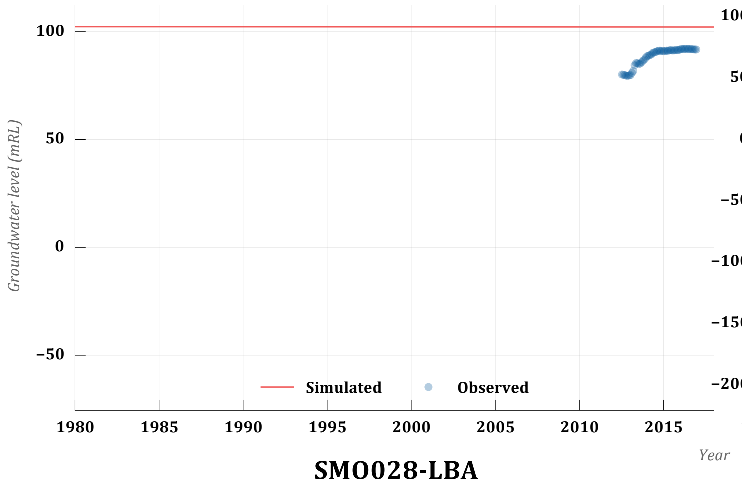

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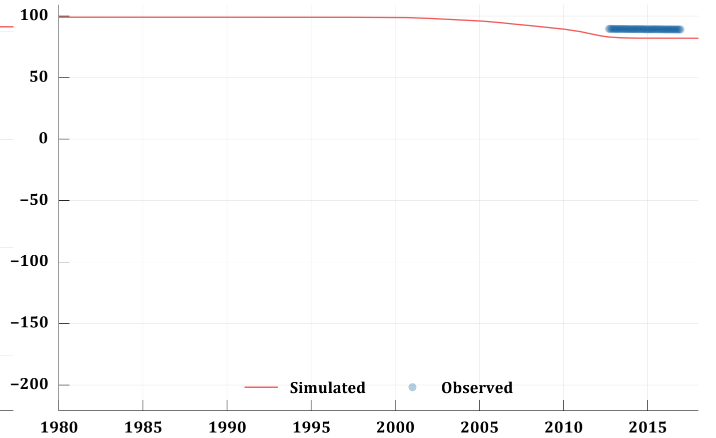

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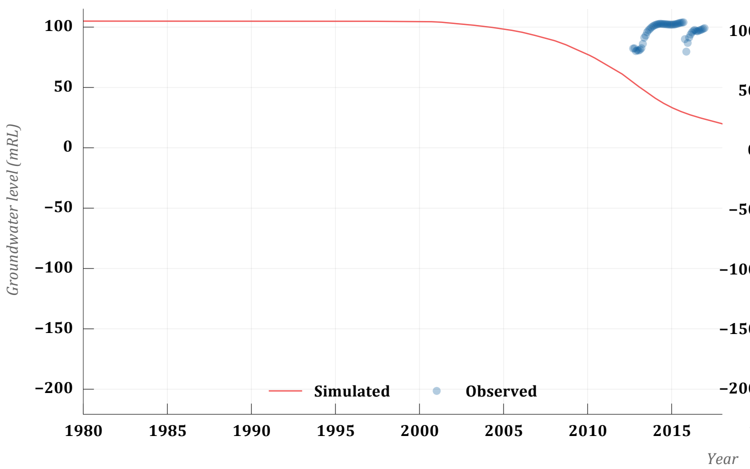

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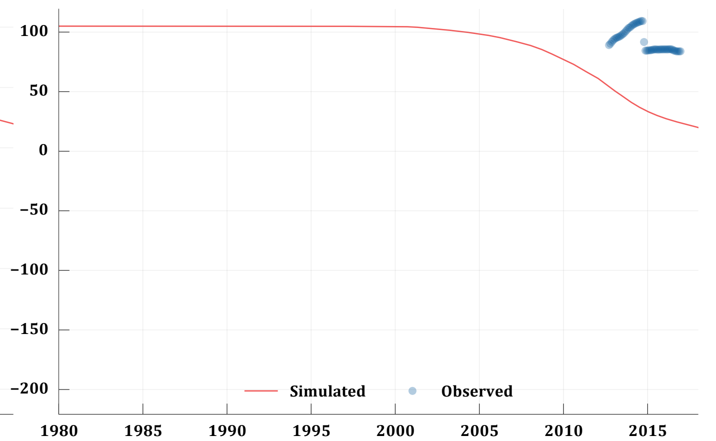
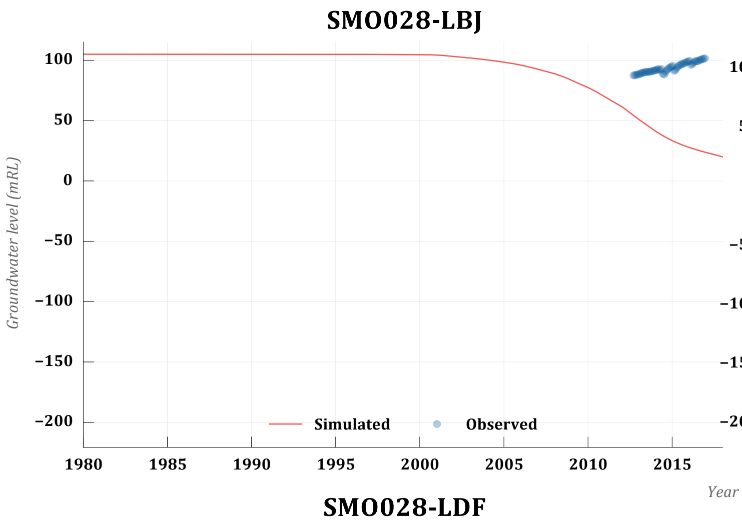
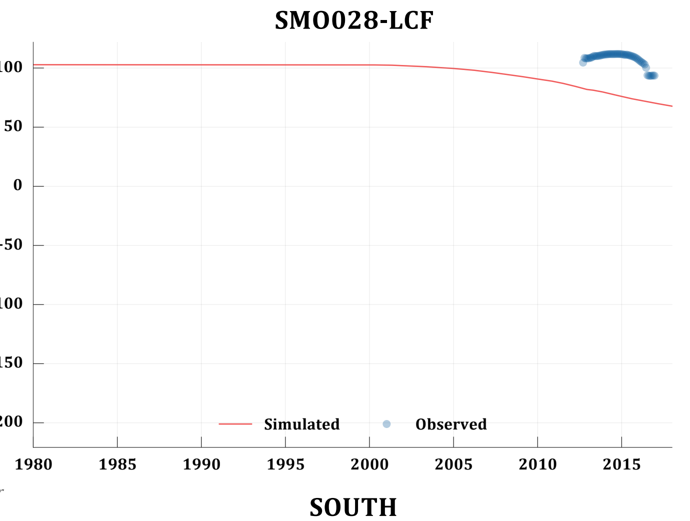



SMO028-LBJ
Groundwater level (mRL)
Simulated
Observed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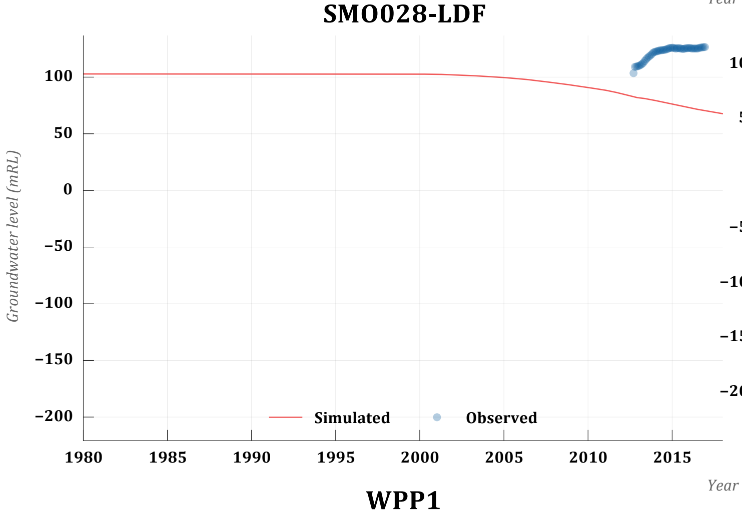
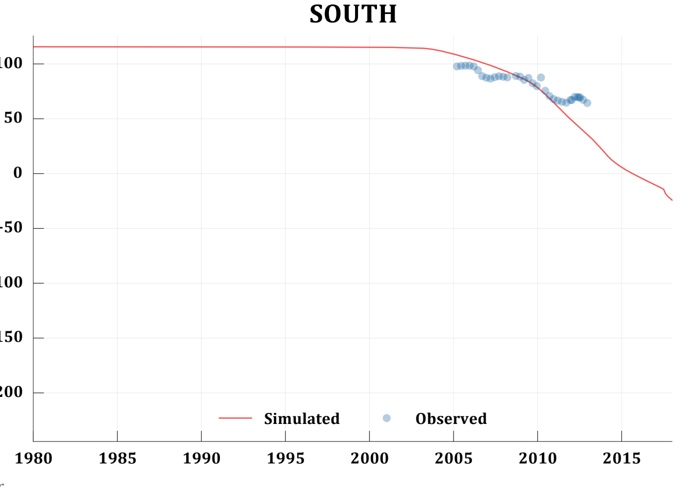
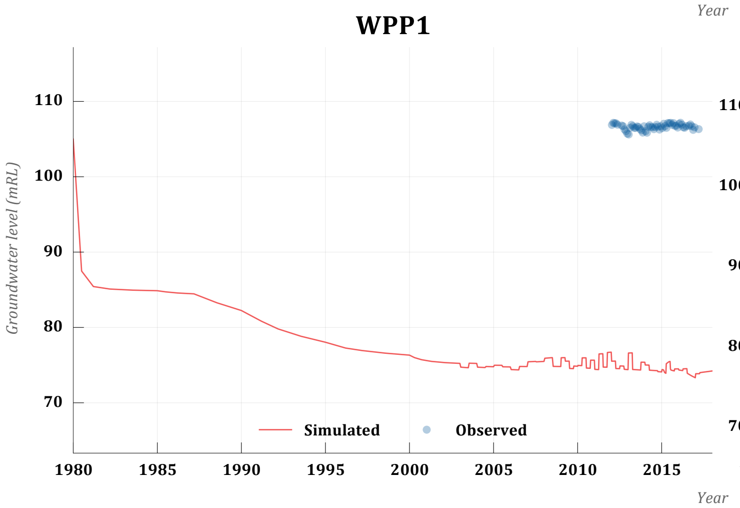
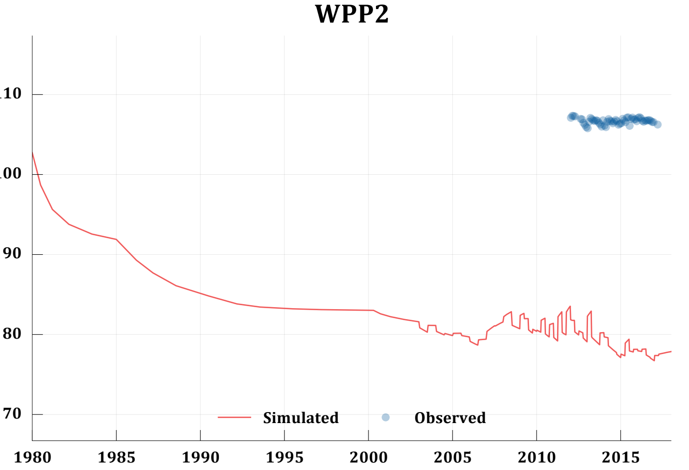
Simulated
Observed
Year


SMO028-LDF
Groundwater level (mRL)
Simulated
Observed

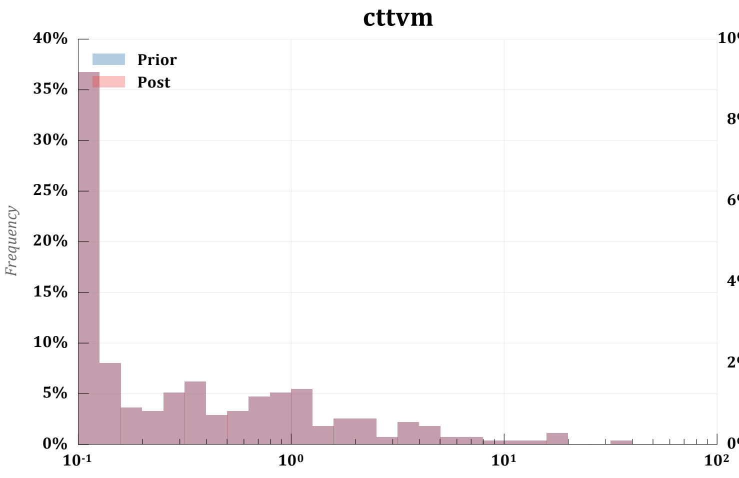

SOUTH
Simulated
Observed
Year


WPP1
Groundwater level (mRL)
Simulated
Observed


WPP2
Simulated
Observed
Year

Appendix C-2

Prior and posterior parameter confidence distributions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Post
Frequency
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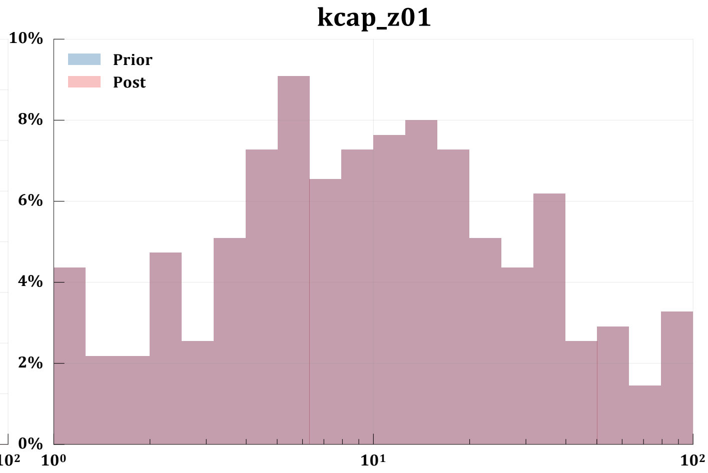
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Prior
Post
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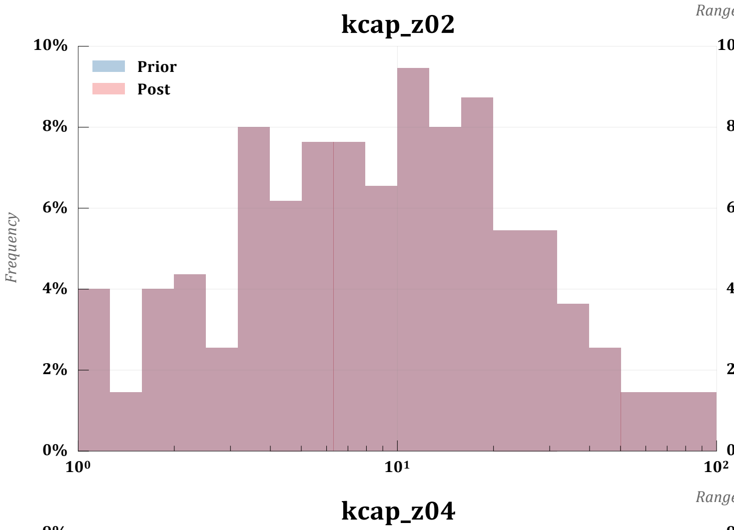
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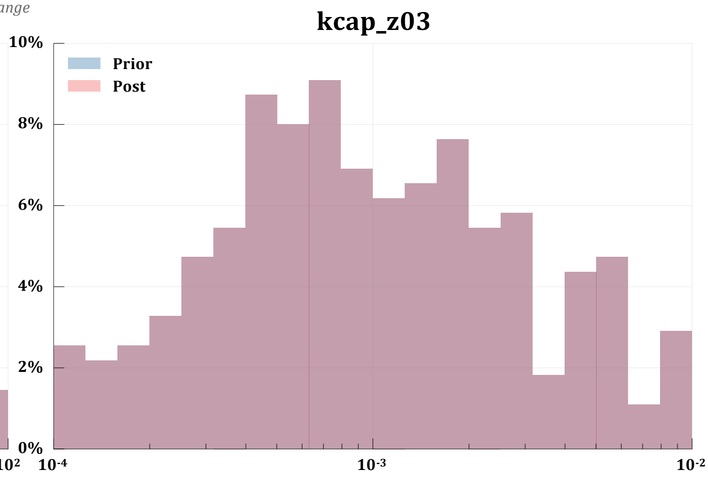
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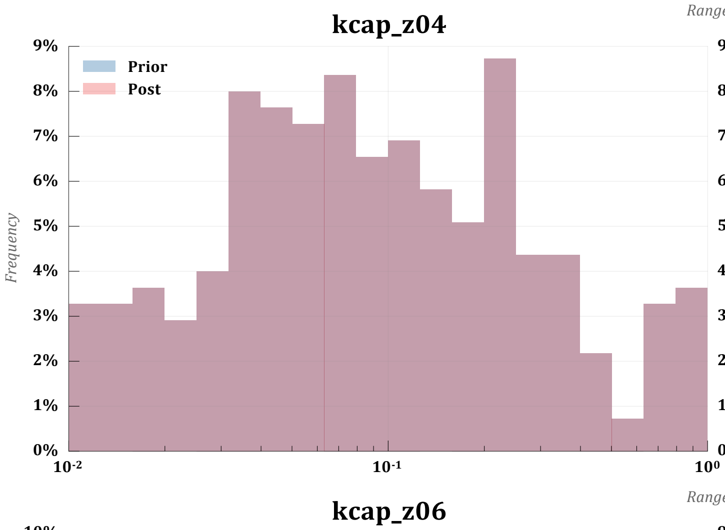
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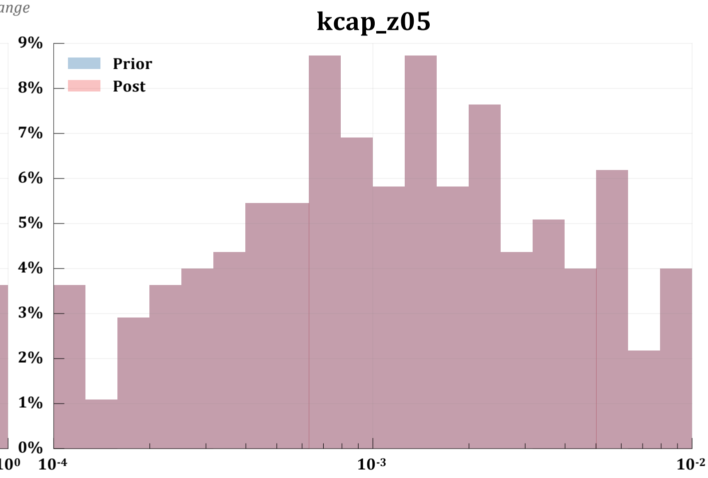
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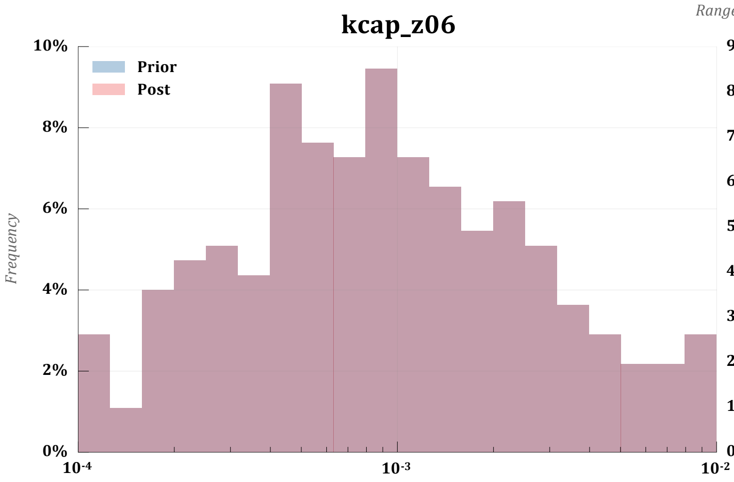
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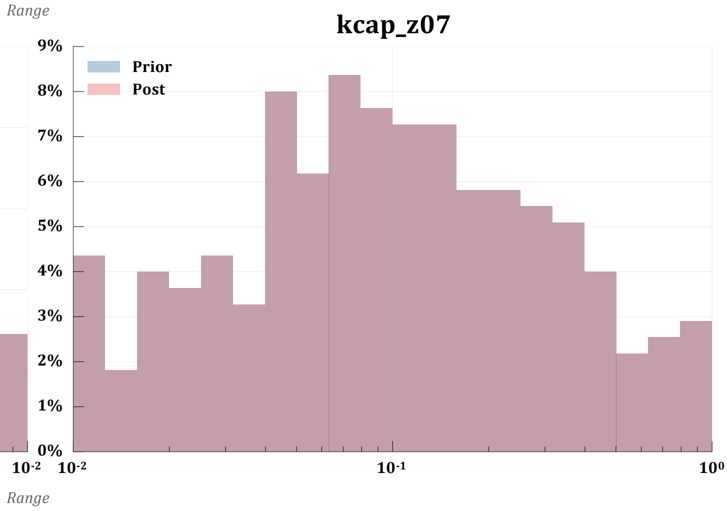
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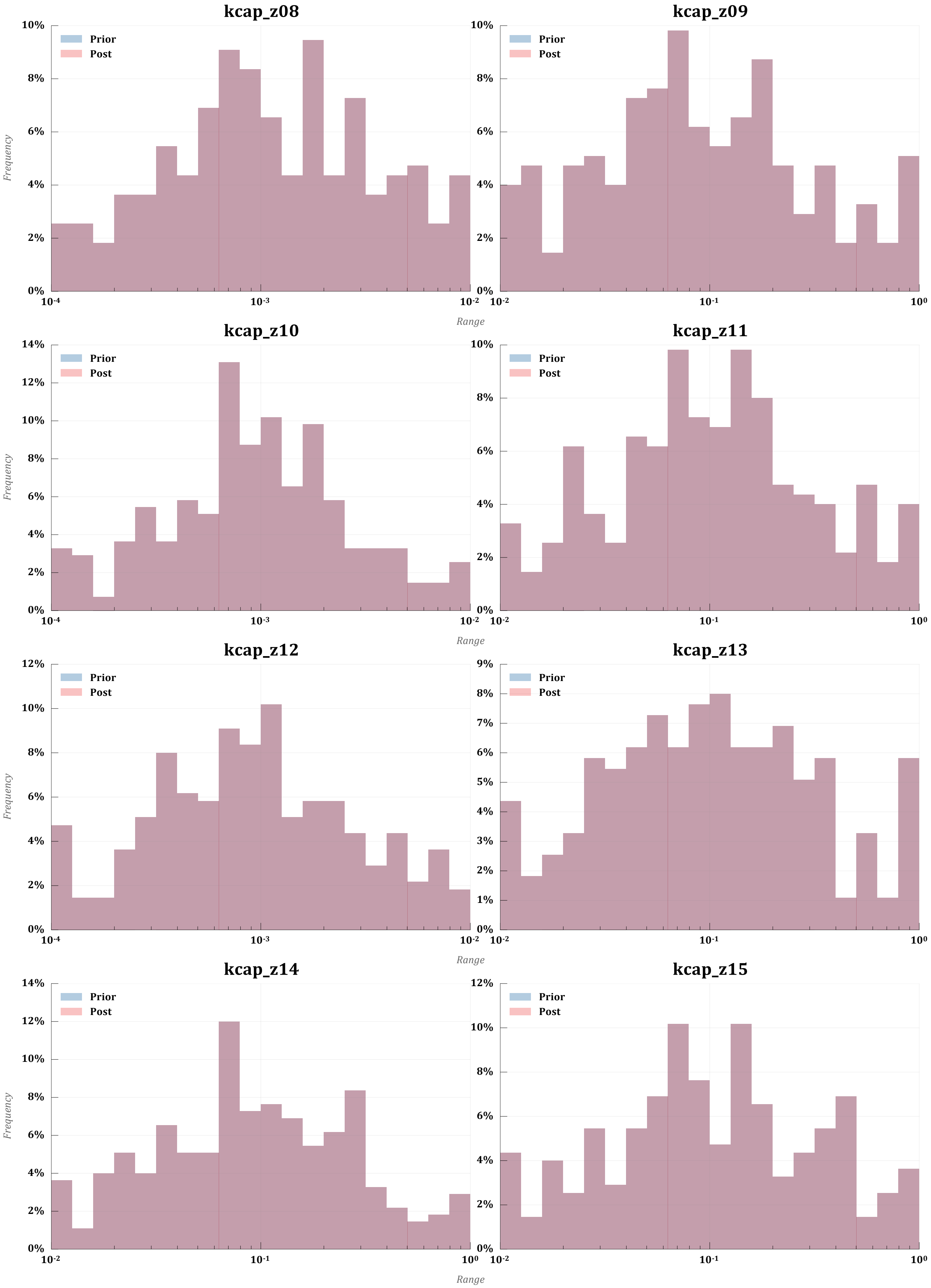
kcap_z08
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Post
Frequency
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8%
6%
4%
2%
0%
10-4
10-3
10-2
kcap_z09
Prior
Post
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8%
6%
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2%
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10-2
10-1
100
Range
kcap_z10
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Range
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Range
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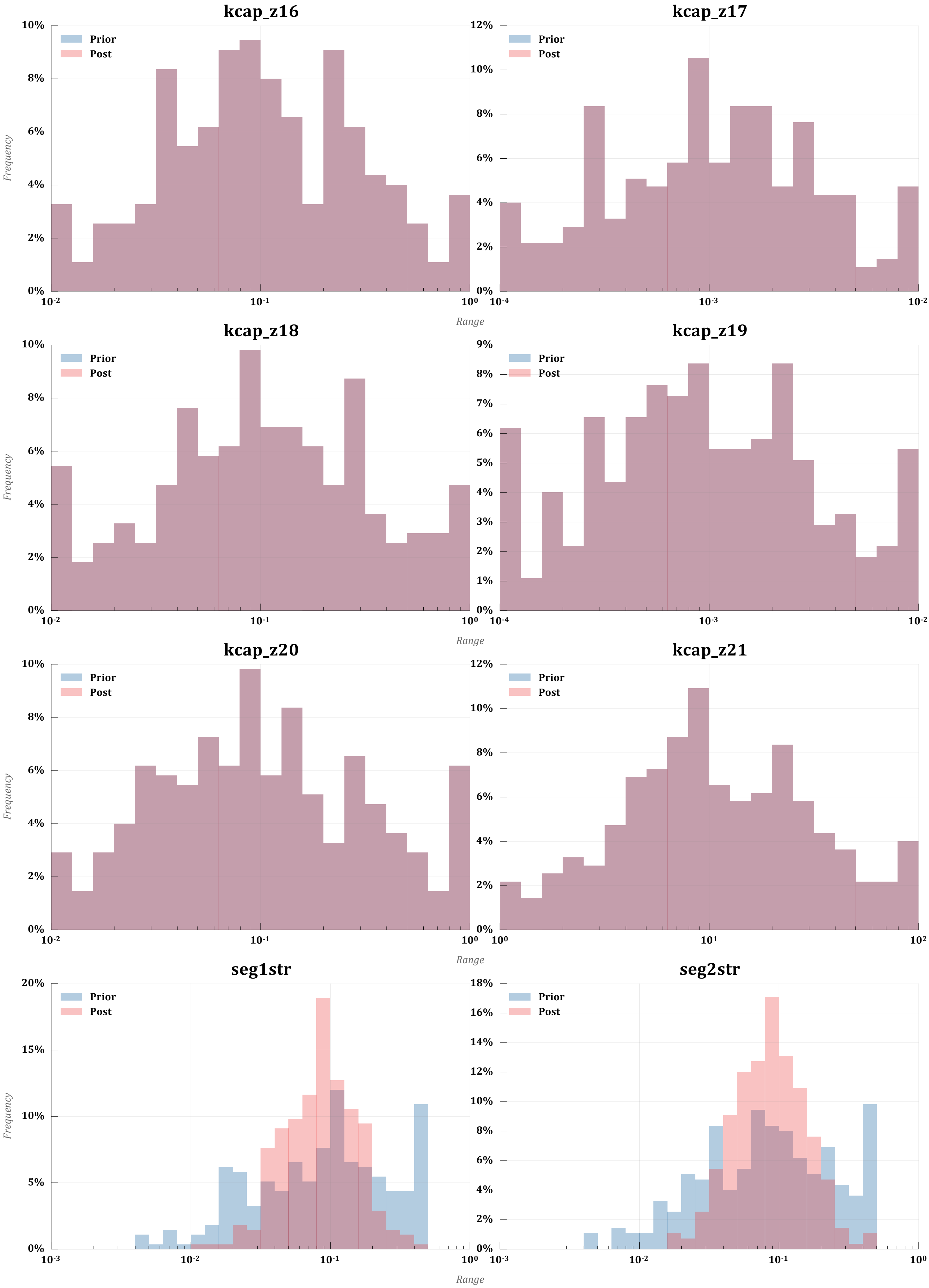
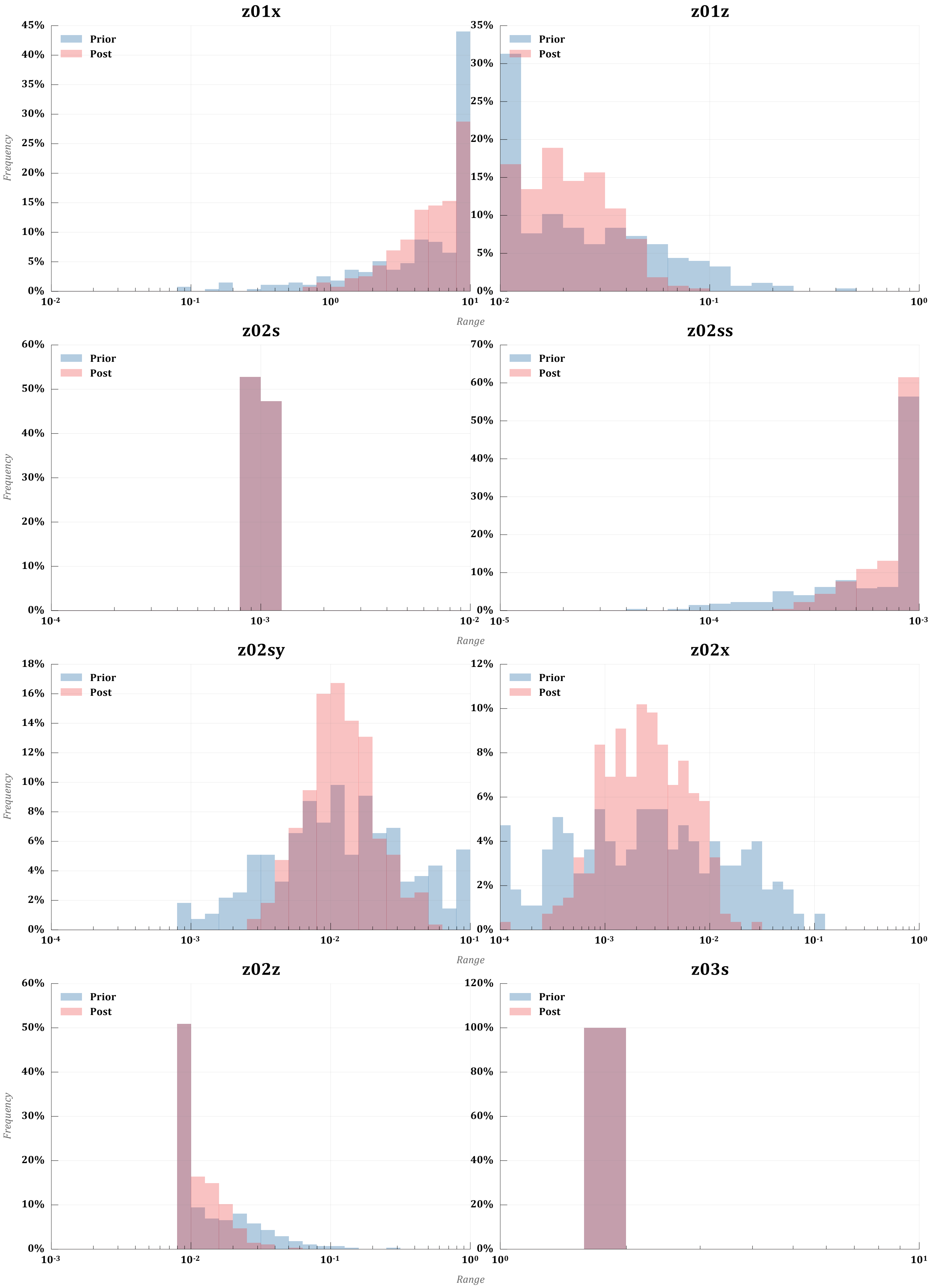

kcap_z16
kcap_z17
kcap_z18
kcap_z19
kcap_z20
kcap_z21
seg1str
seg2str
Prior
Post
Frequency
Range


seg3str
seg4str
seg5str
seg6str
sf
z01s
z01ss
z01sy
Prior
Post
Frequency
Range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z02ss
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Prior
Post
Frequency
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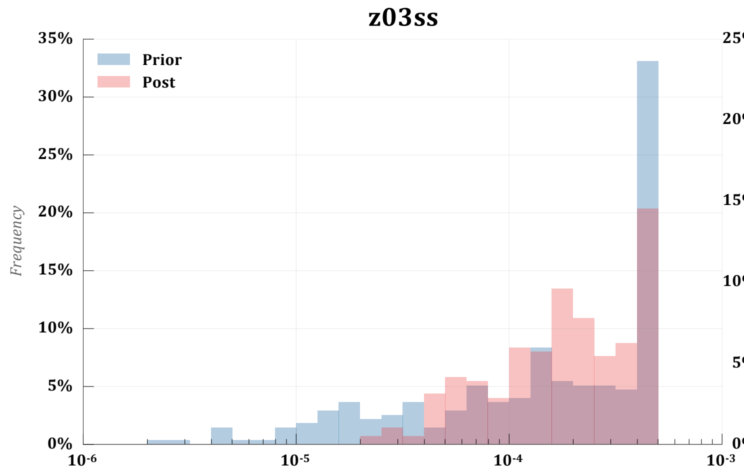
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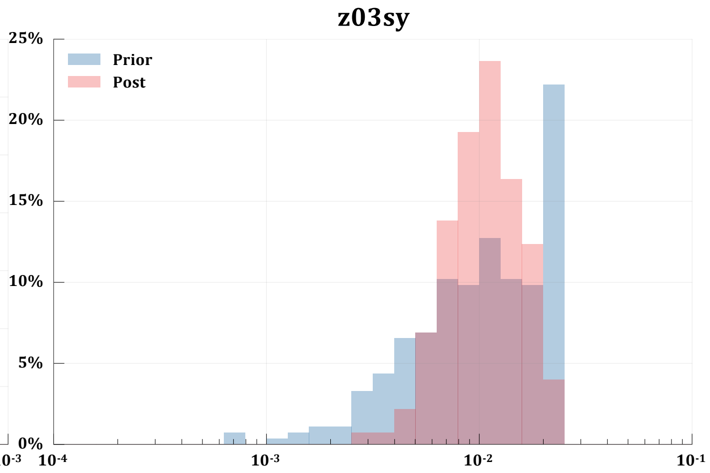
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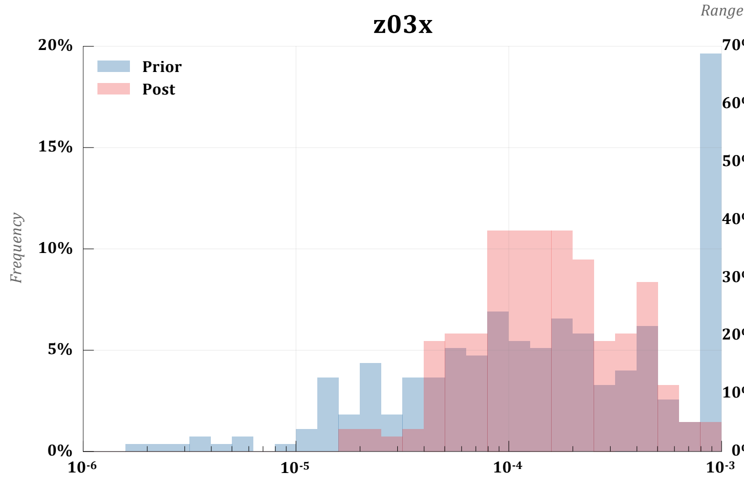
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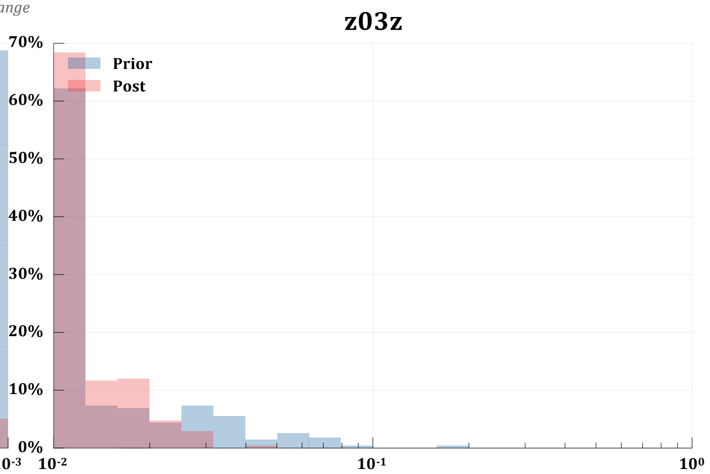
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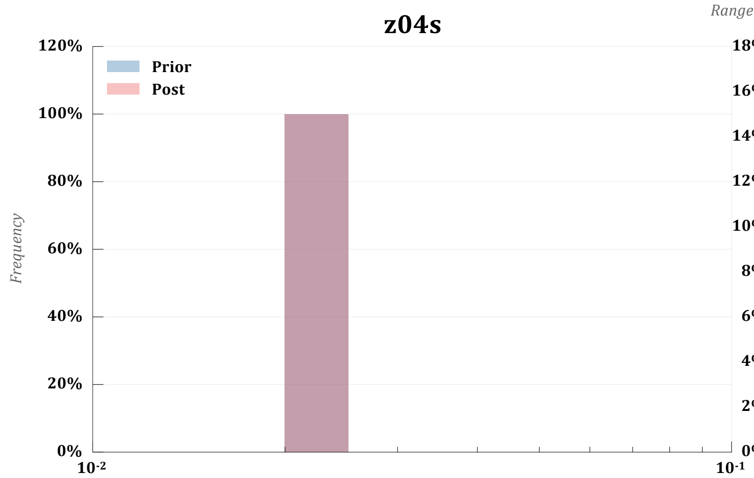
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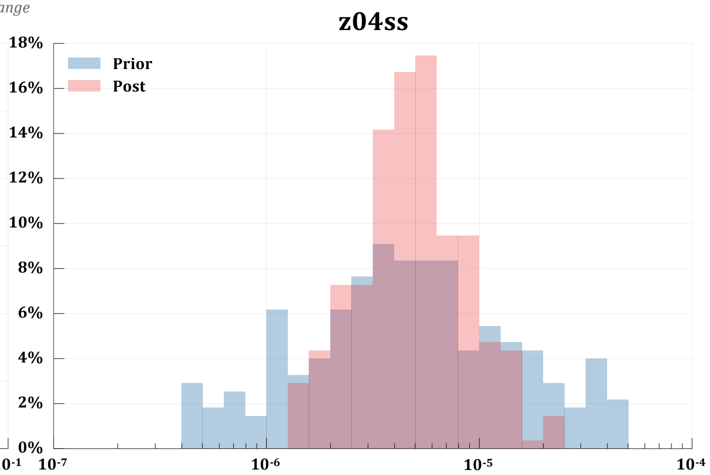
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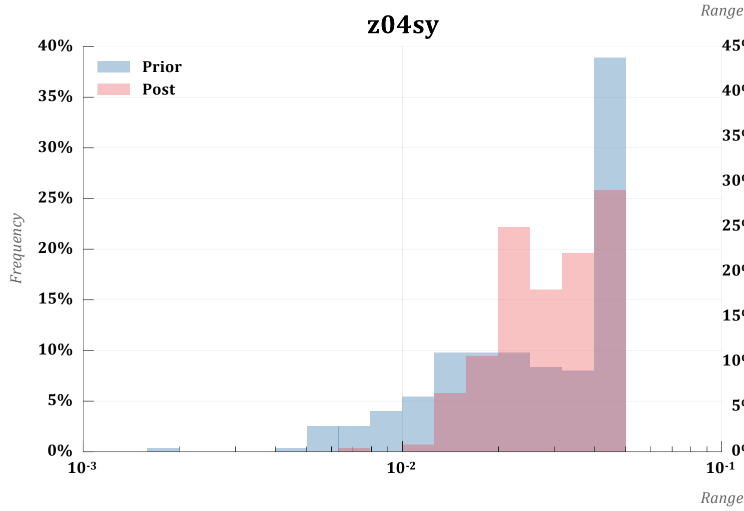
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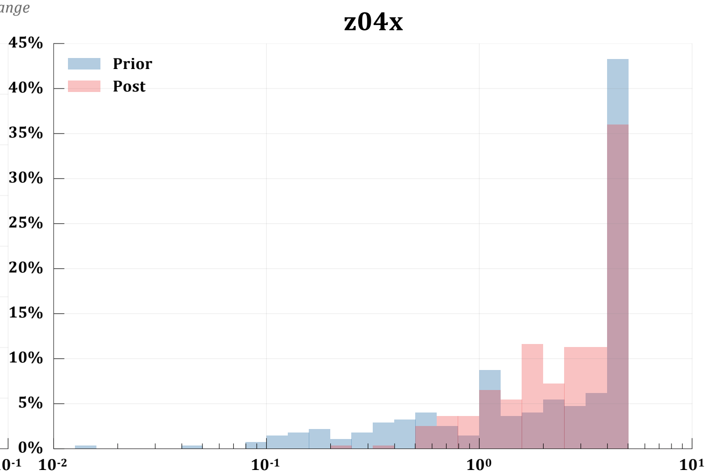
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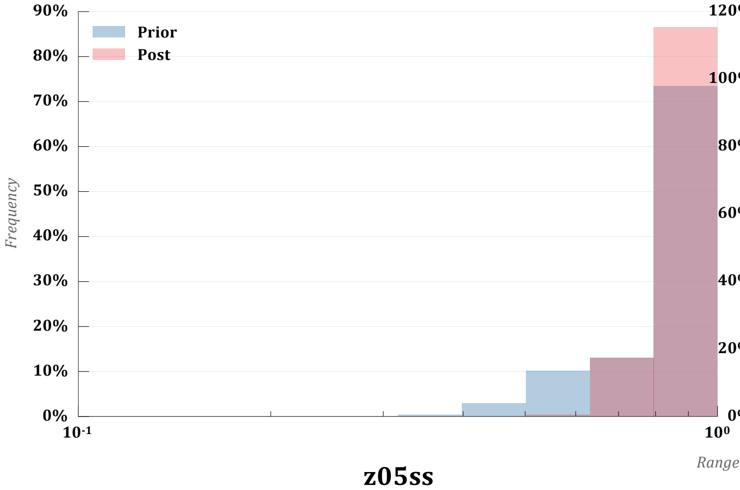
z04z



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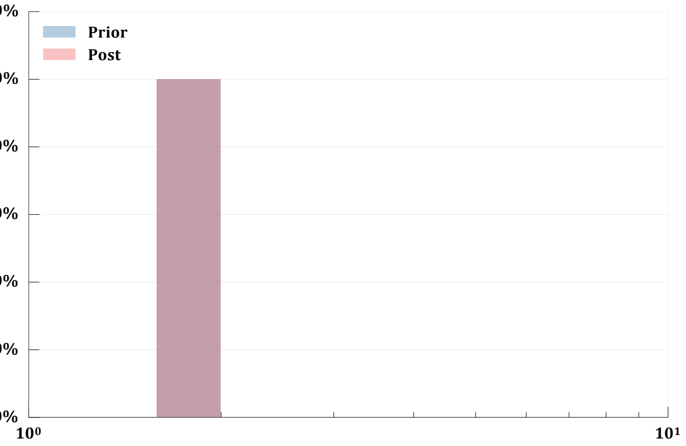

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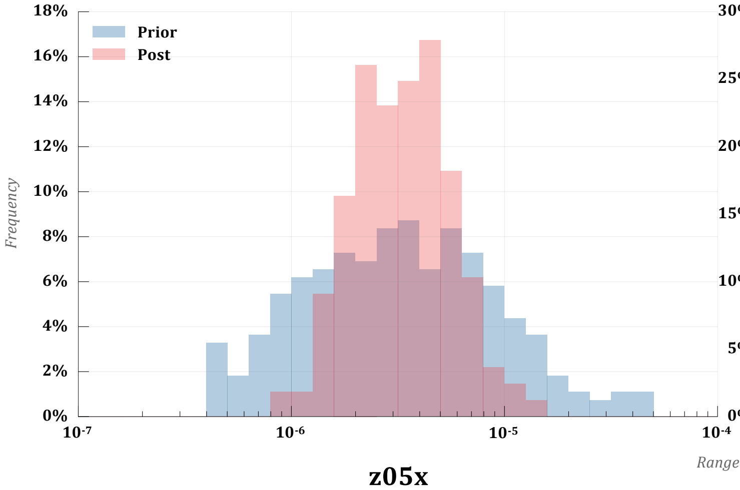

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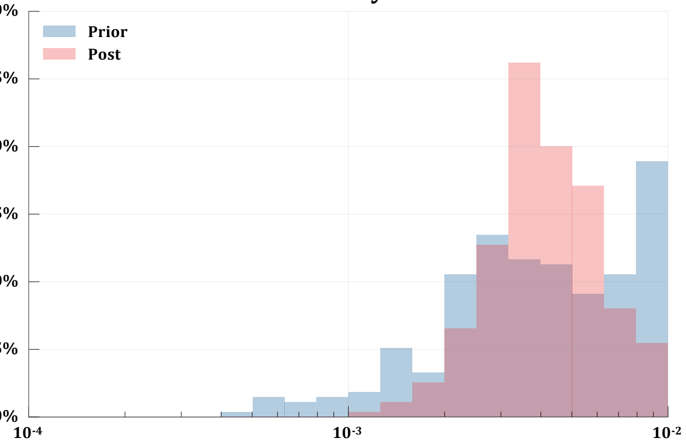

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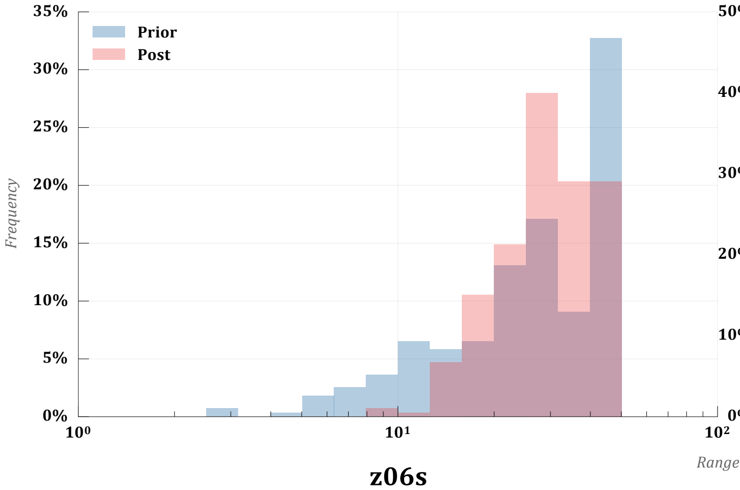

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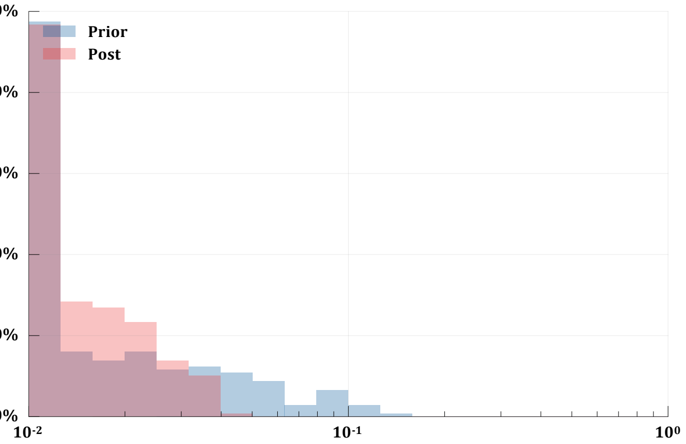

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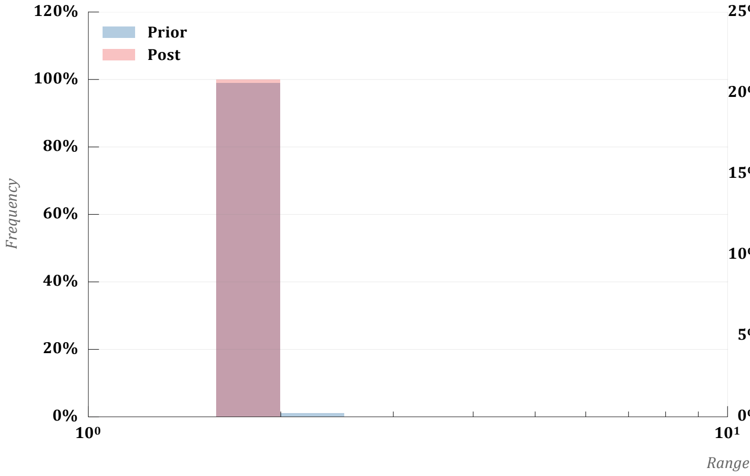

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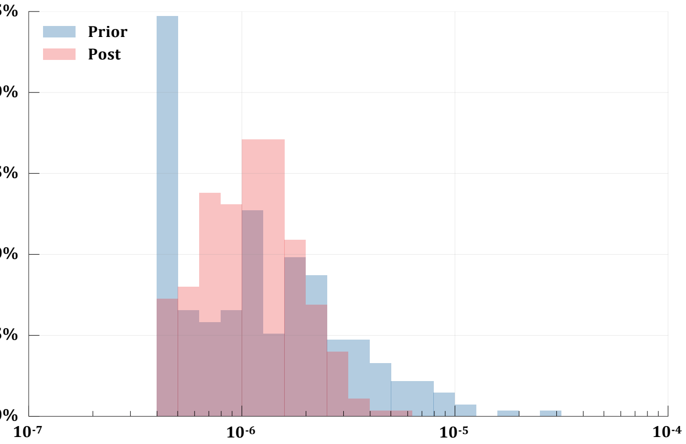

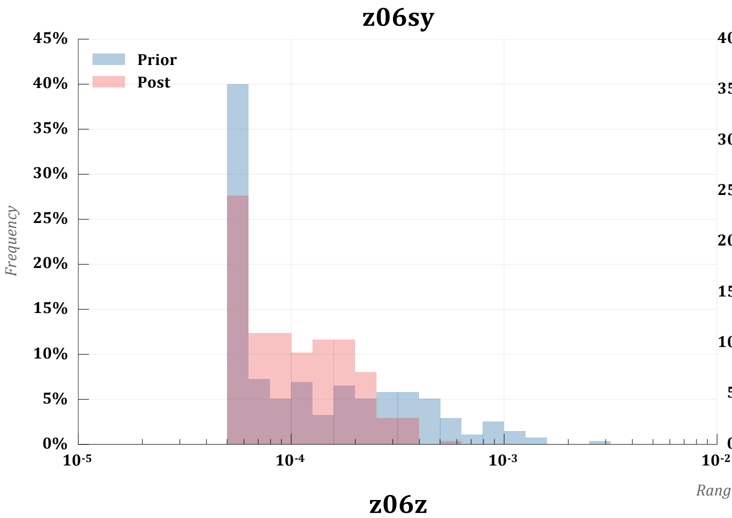
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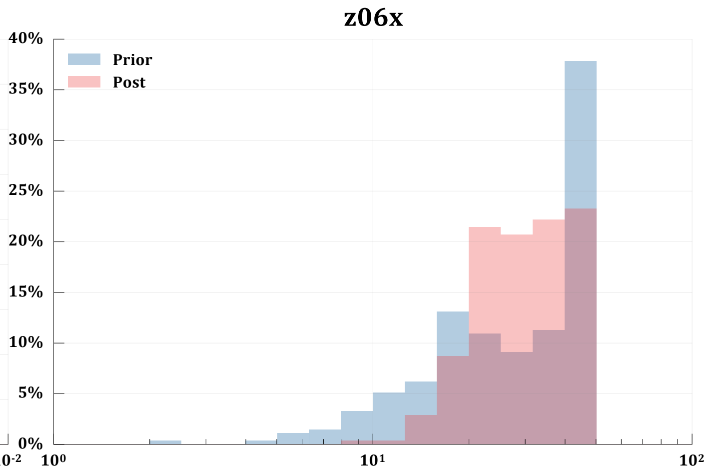
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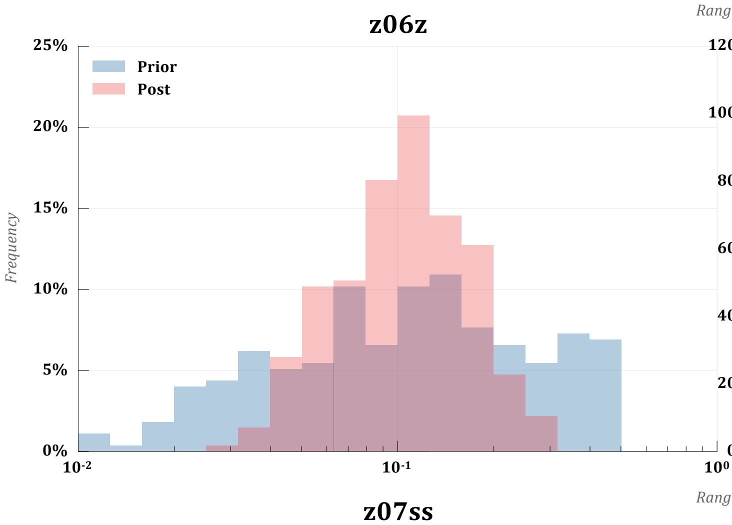
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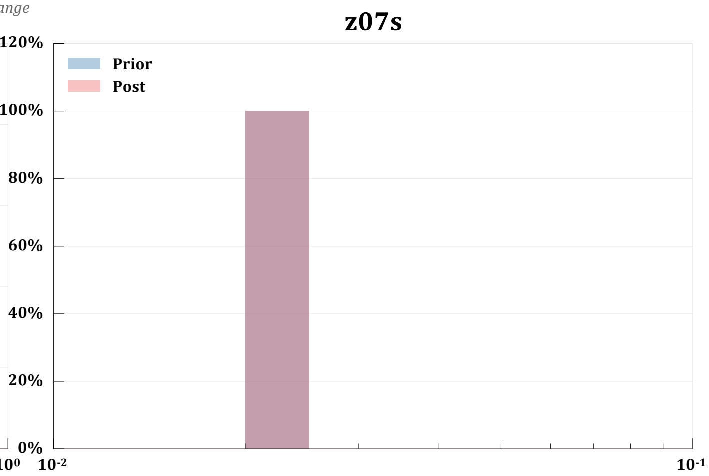
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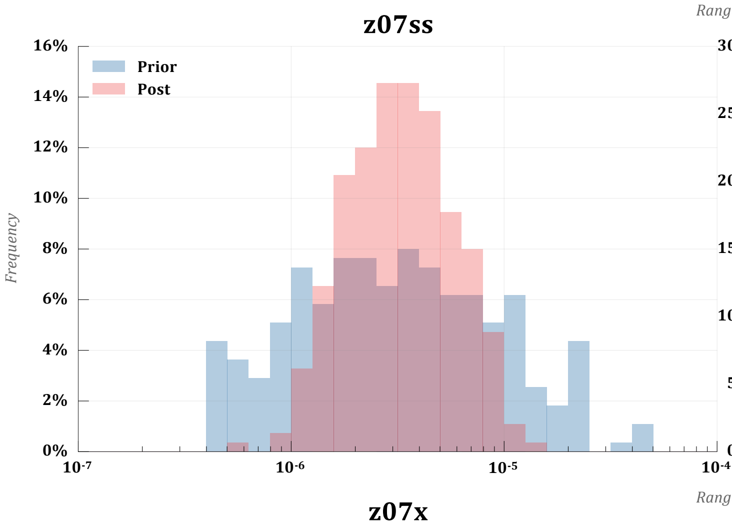
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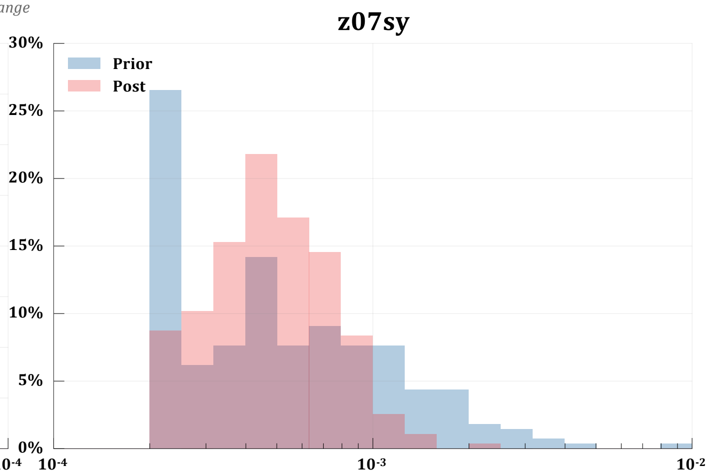
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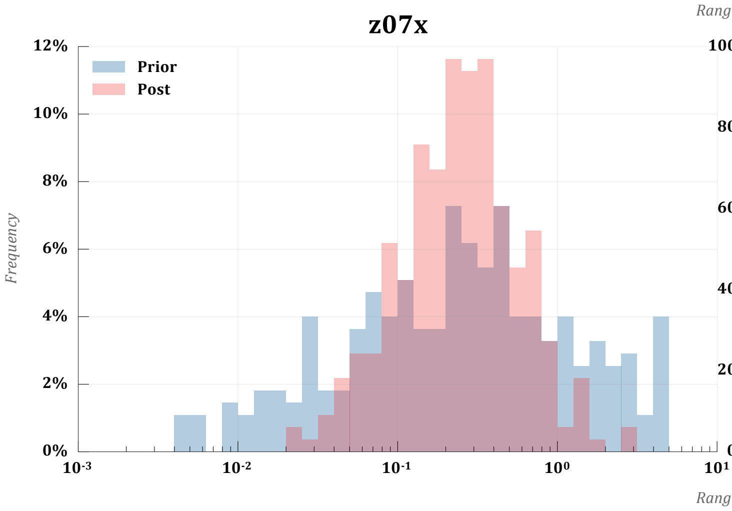
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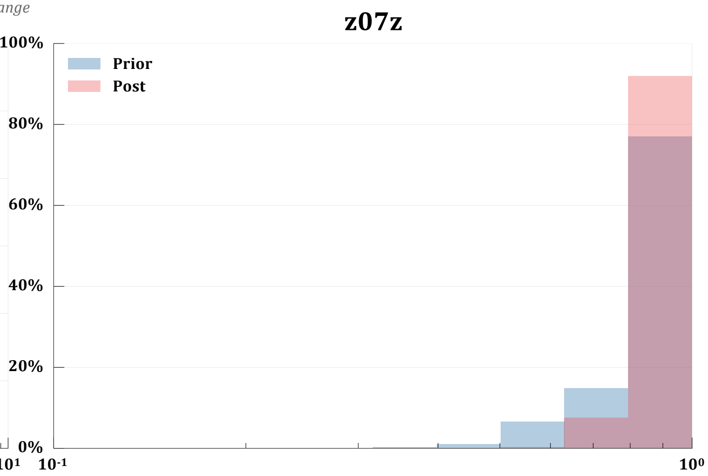
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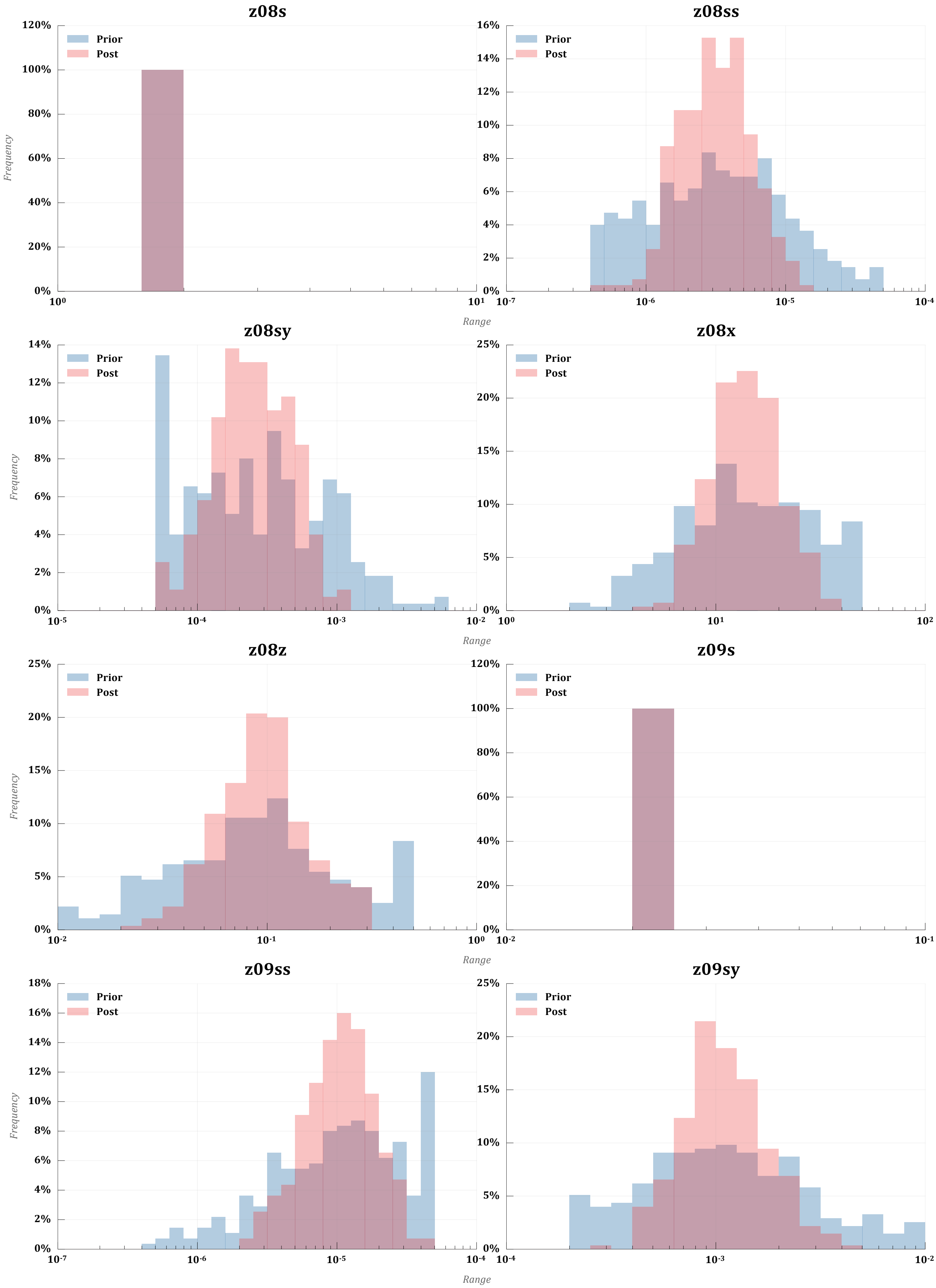
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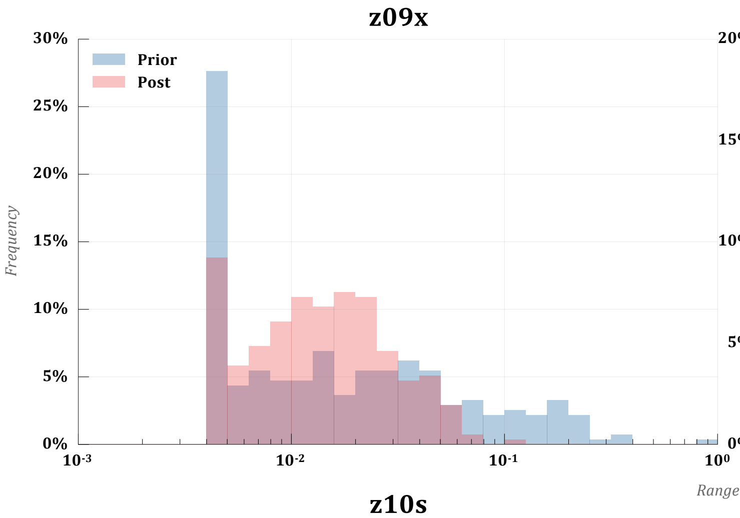
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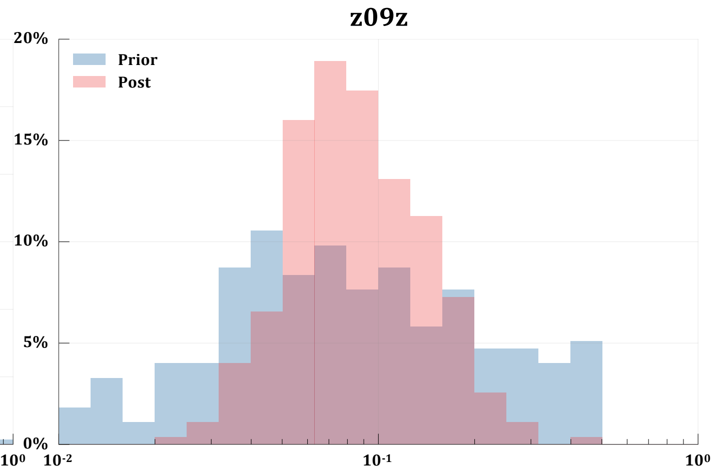
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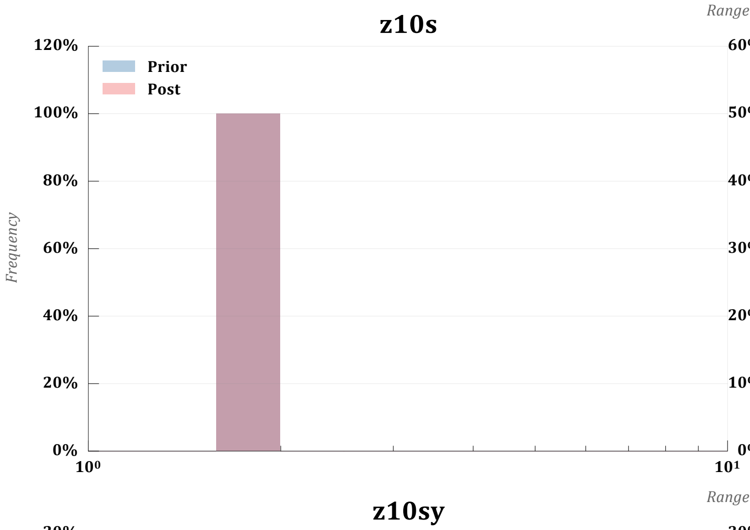
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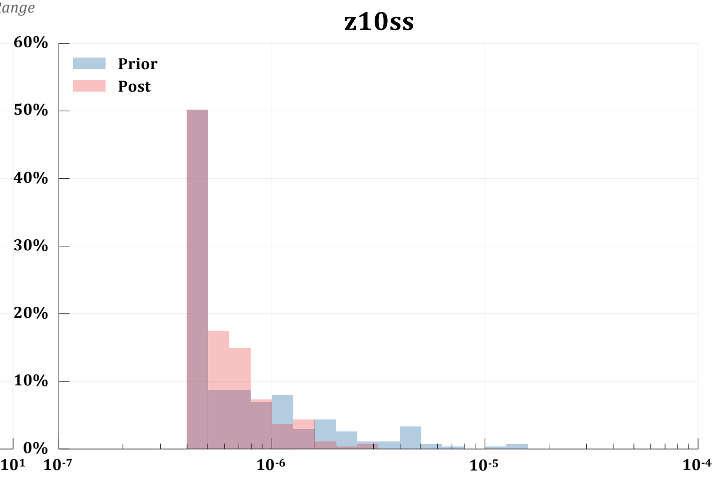
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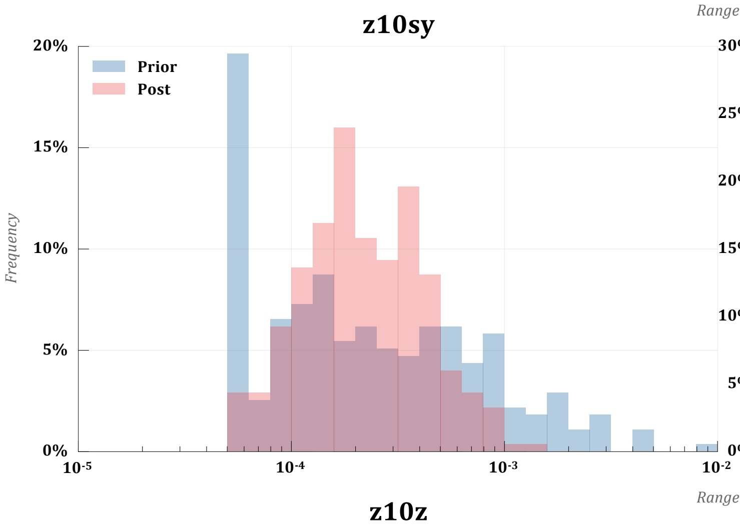
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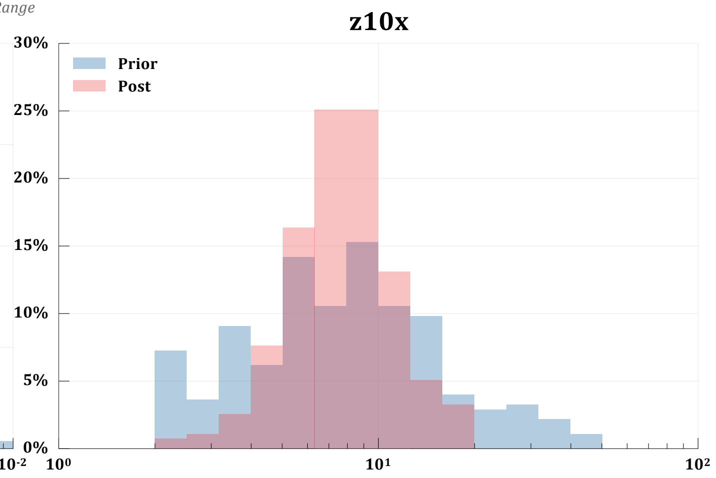
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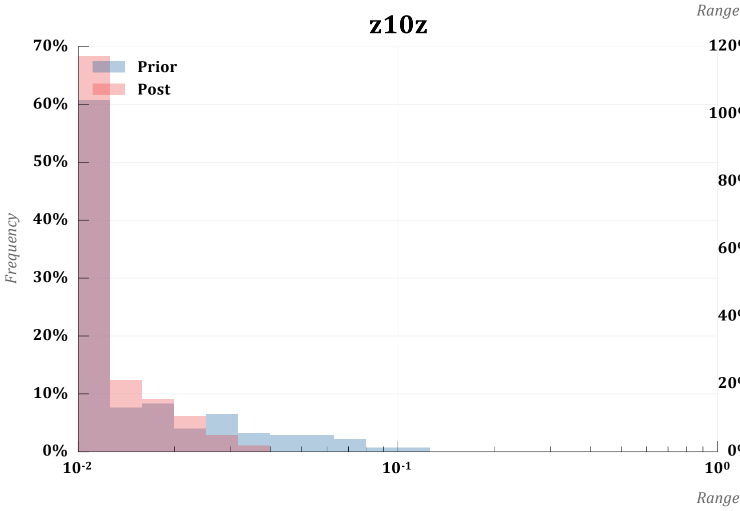
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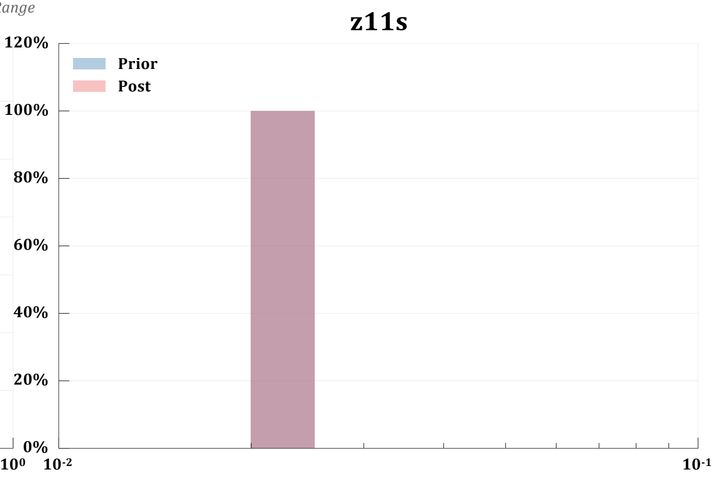
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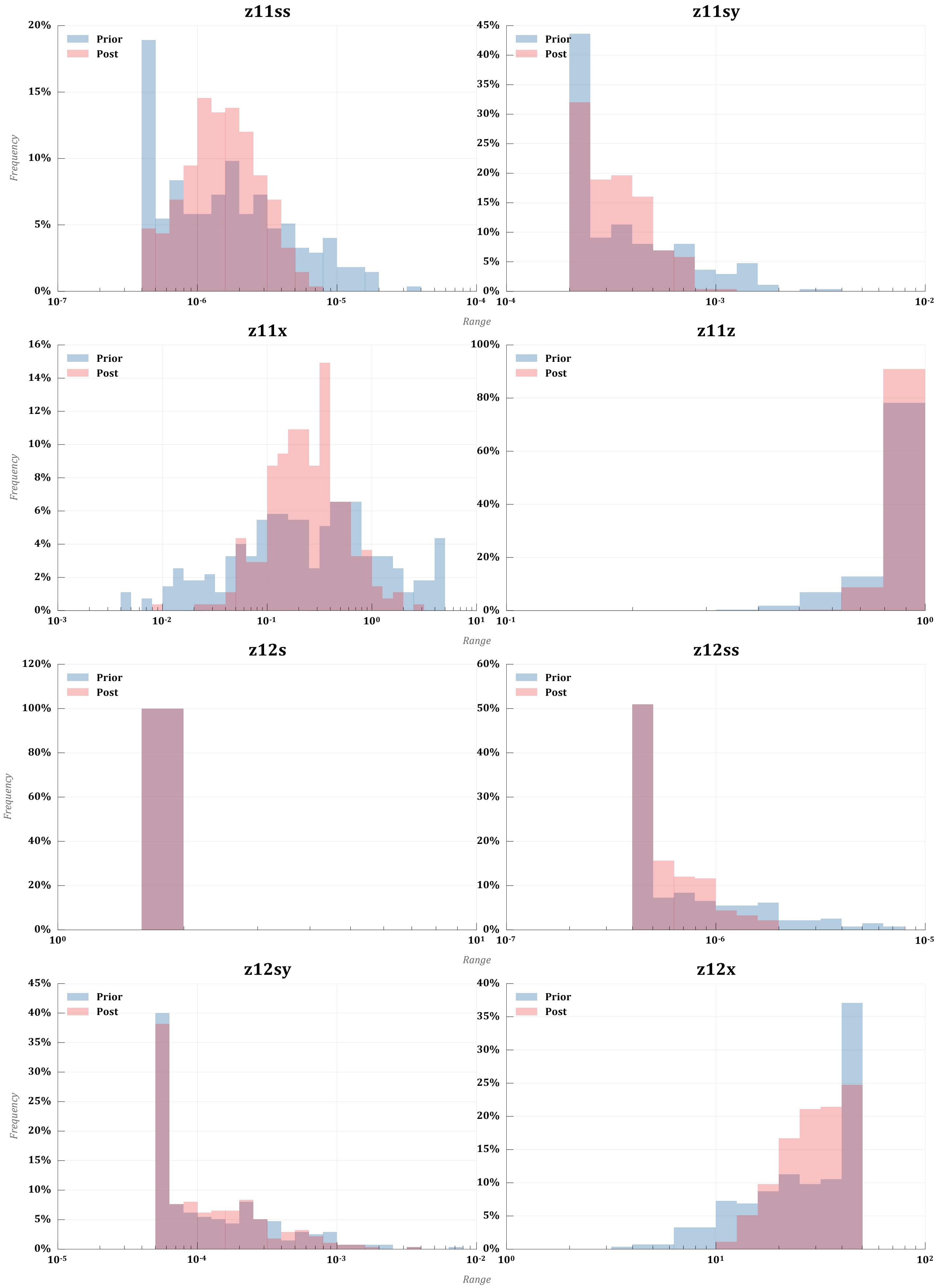
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z11sy
z11x
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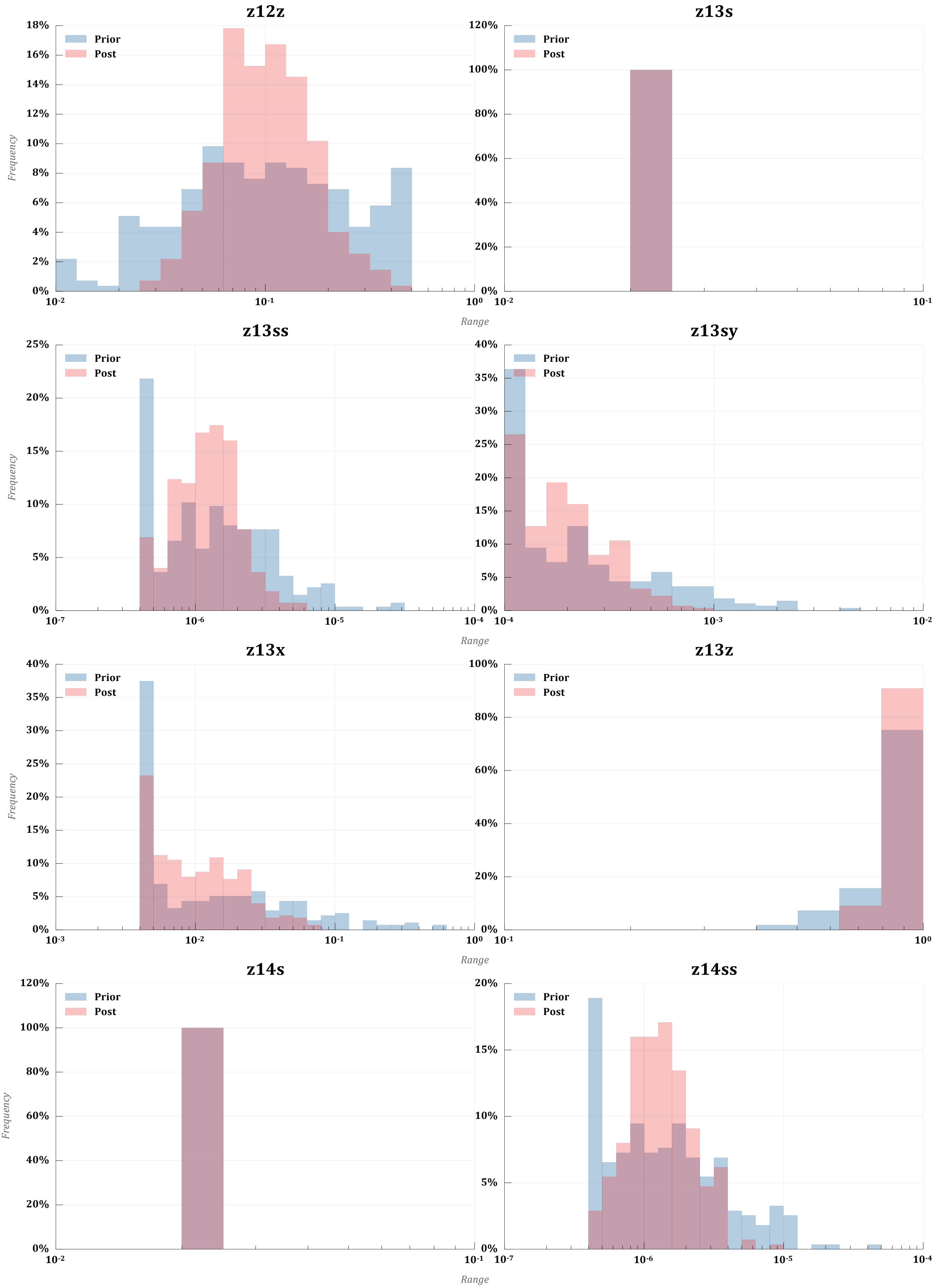
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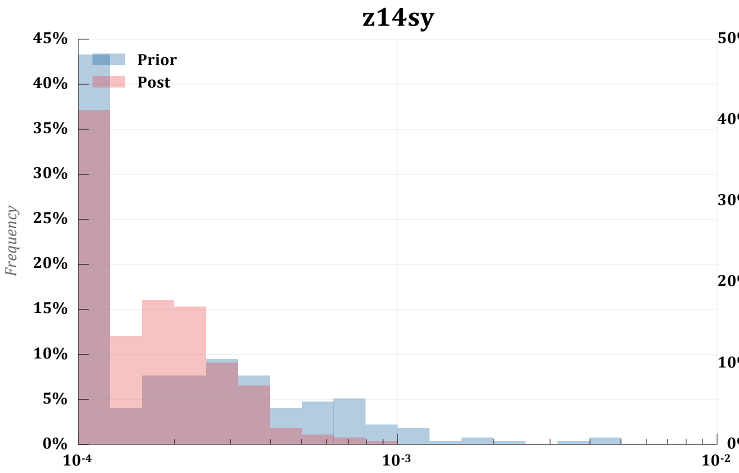
Prior
Post
Frequency
Range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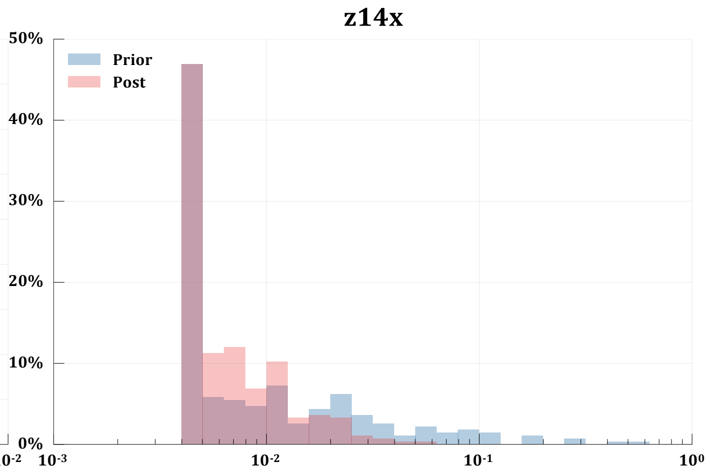
Prior
Post
Frequency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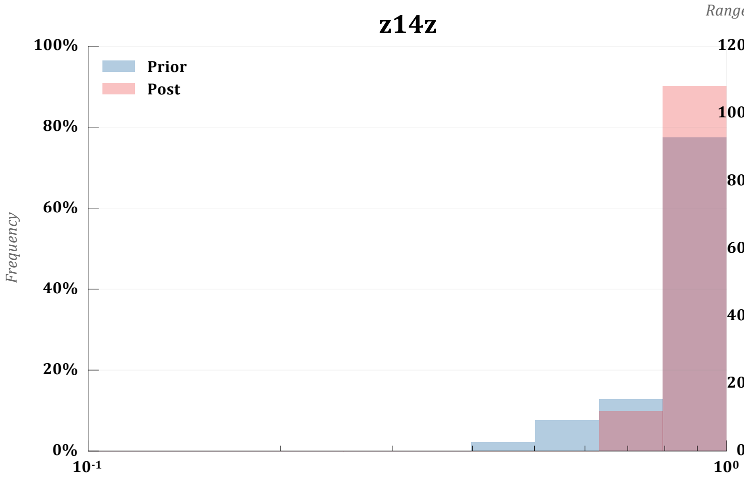
Prior
Post
Range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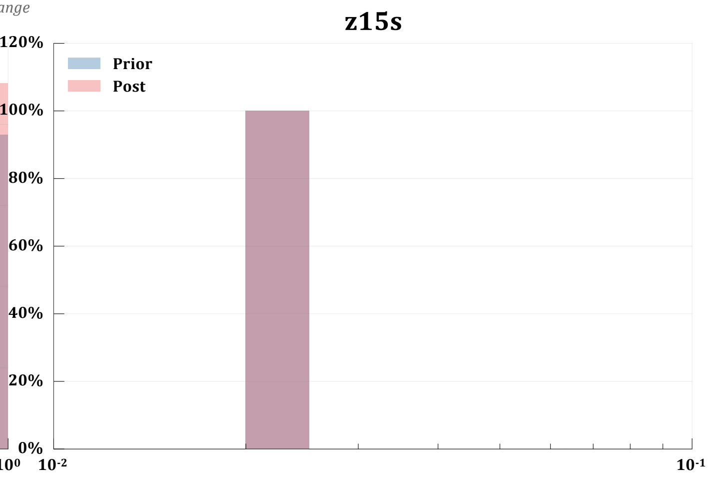
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Post
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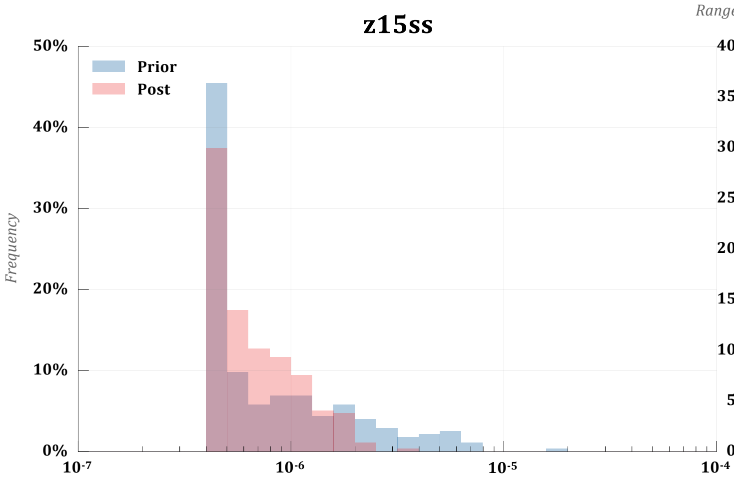
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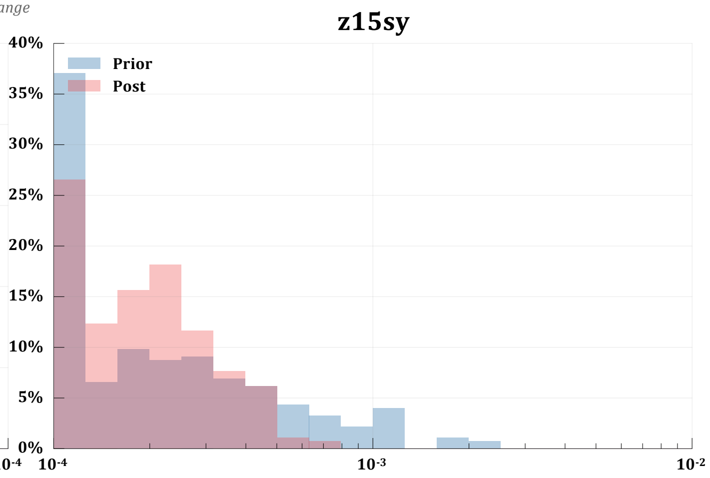
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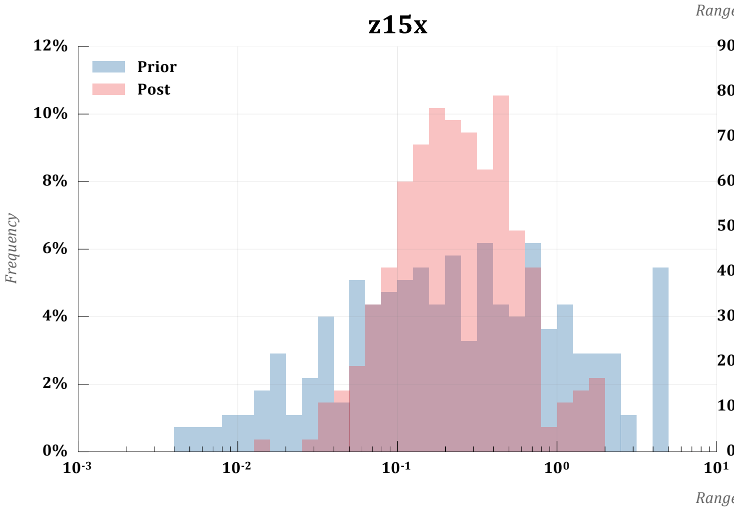
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Prior
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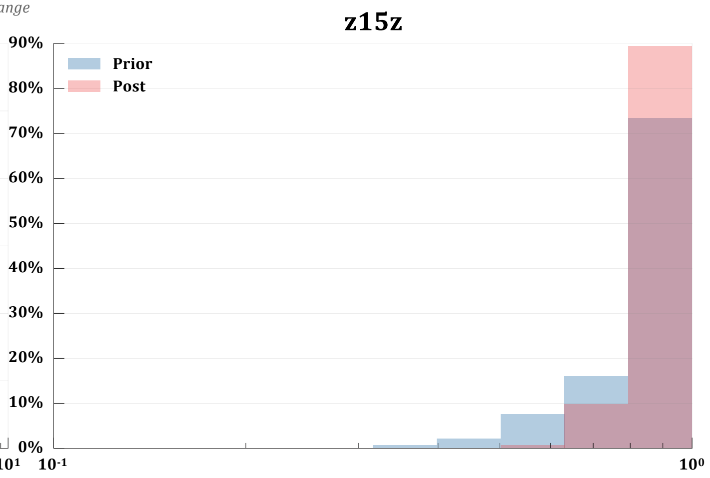
Frequency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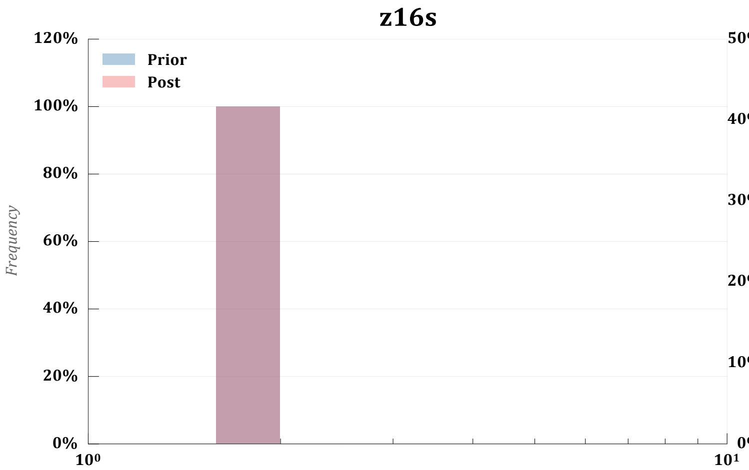
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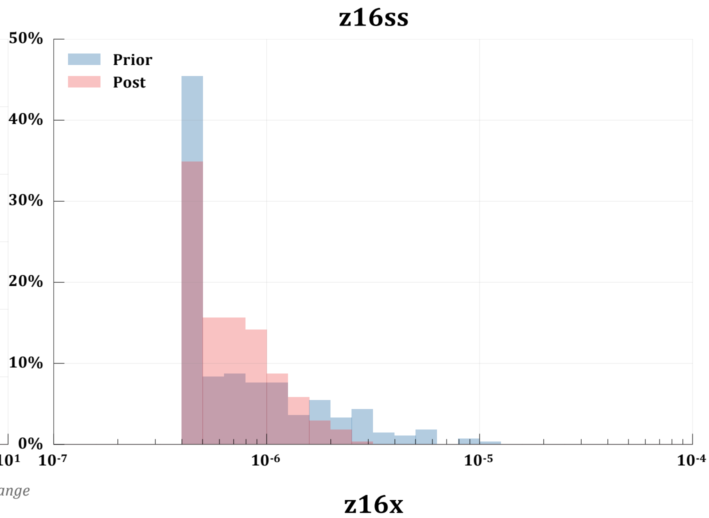
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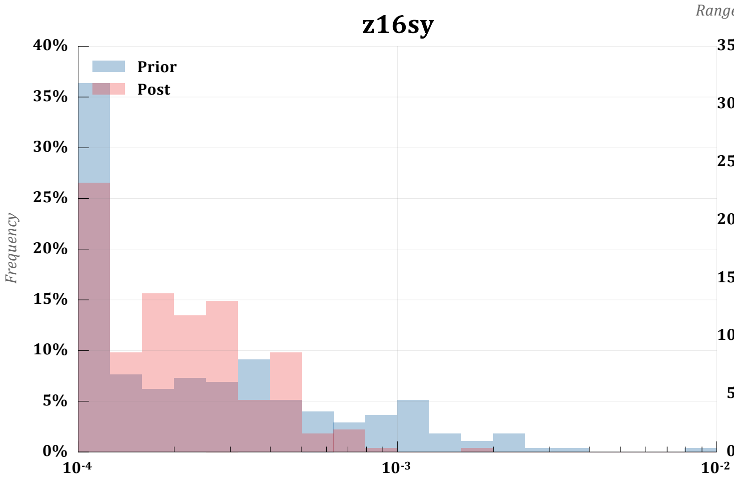
10^{-5}
10^{-4}
Range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0%
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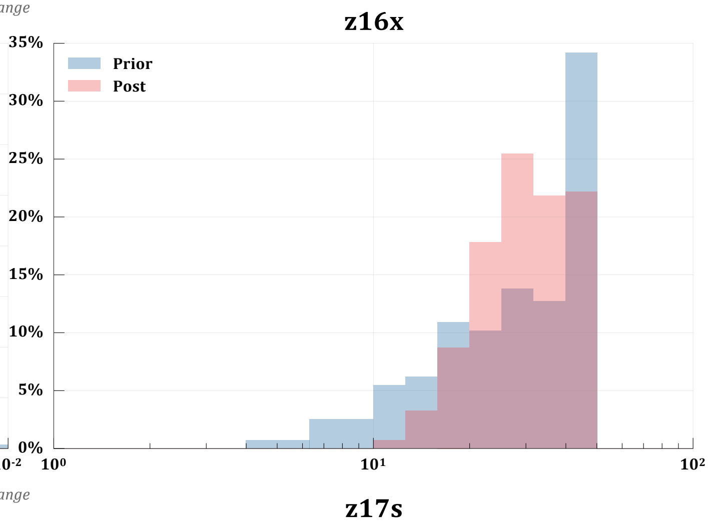
10^{-3}
10^{-2}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30%
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0%
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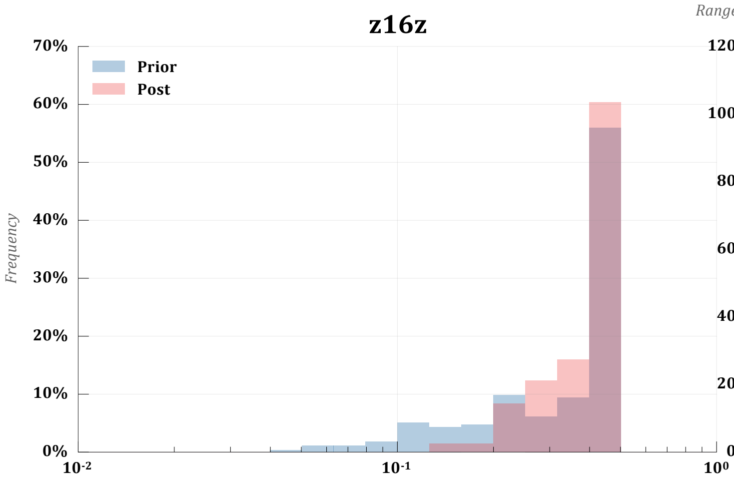
10^1
10^2
Range


z16z
Prior
Post
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40%
30%
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10%
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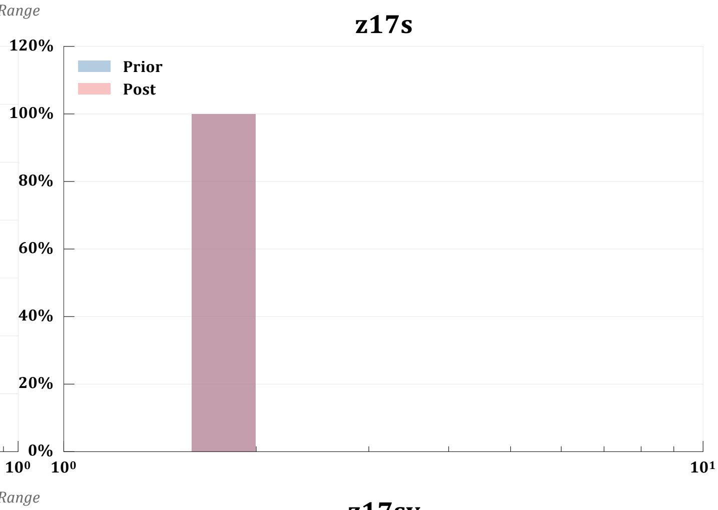
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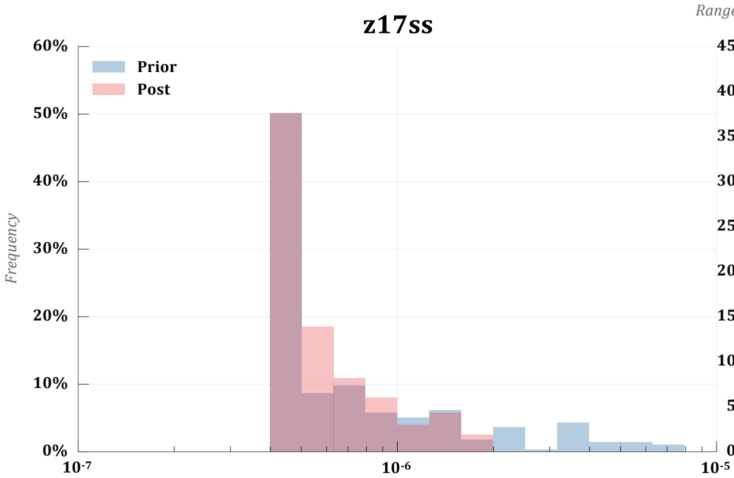
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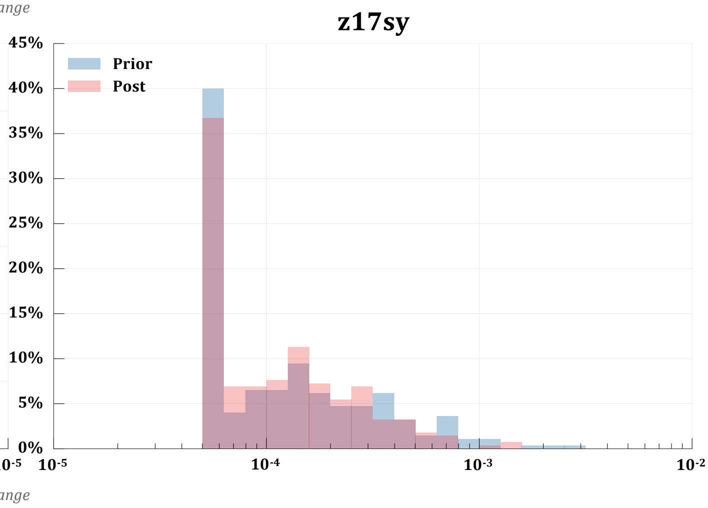
z17sy
Prior
Post
45%
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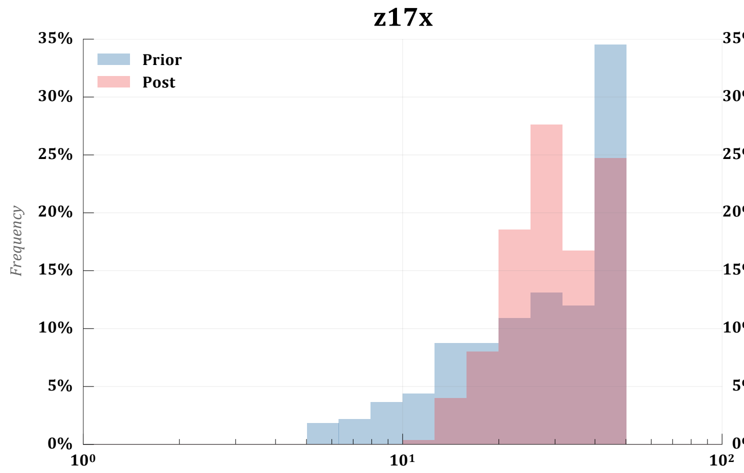
10^{-3}
10^{-2}
Range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Prior
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Frequency
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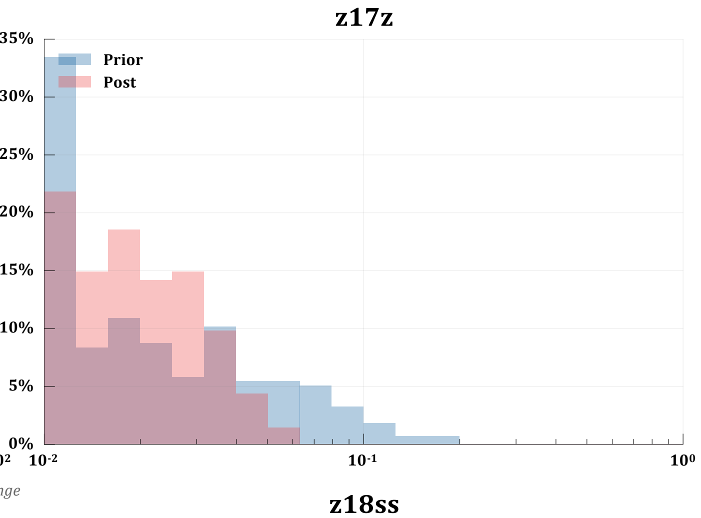
5%
0%
10^0
10^1
10^2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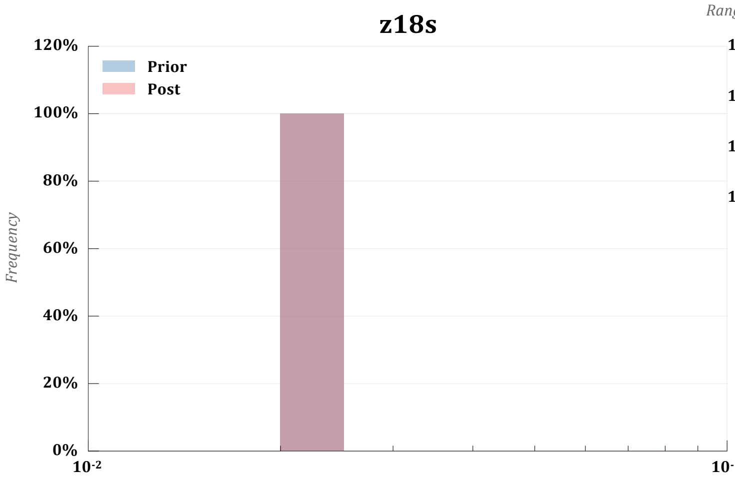
10^0
Range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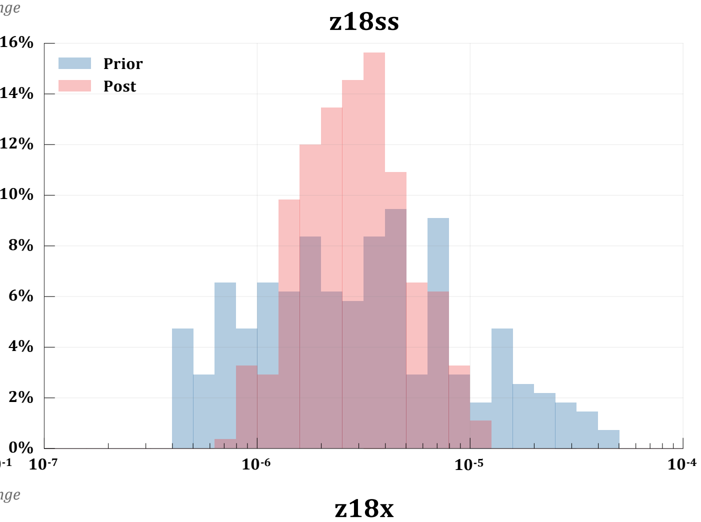
10^{-2}
10^{-1}


z18ss
Prior
Post
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14%
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8%
6%
4%
2%
0%
10^{-7}
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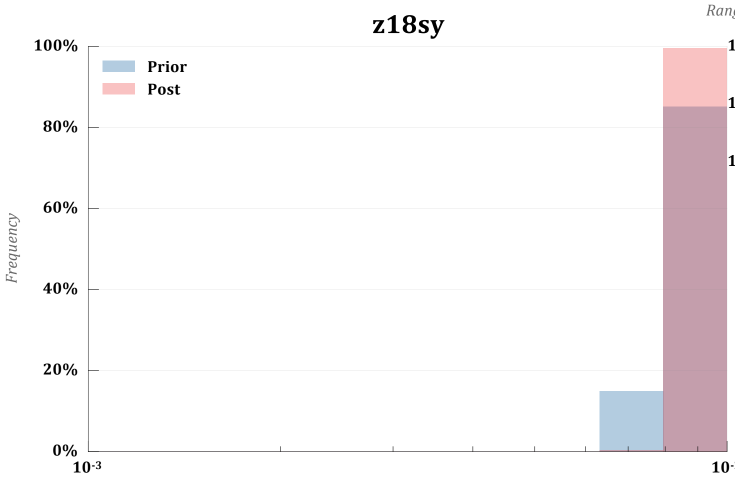
10^{-4}
Range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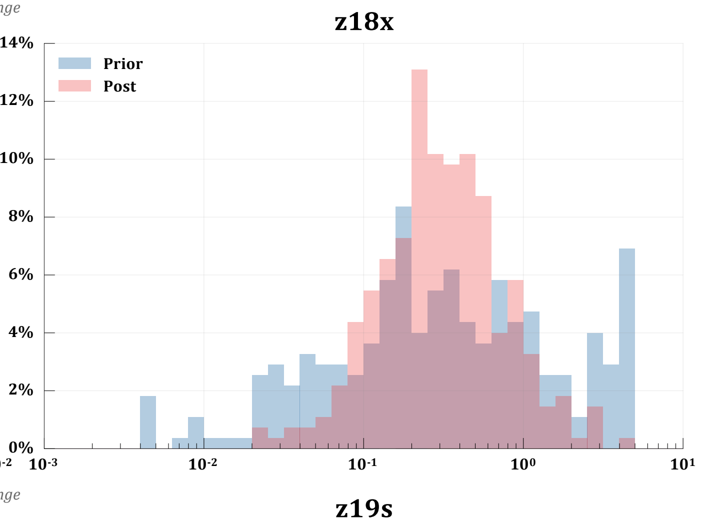
z18x
Prior
Post
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12%
10%
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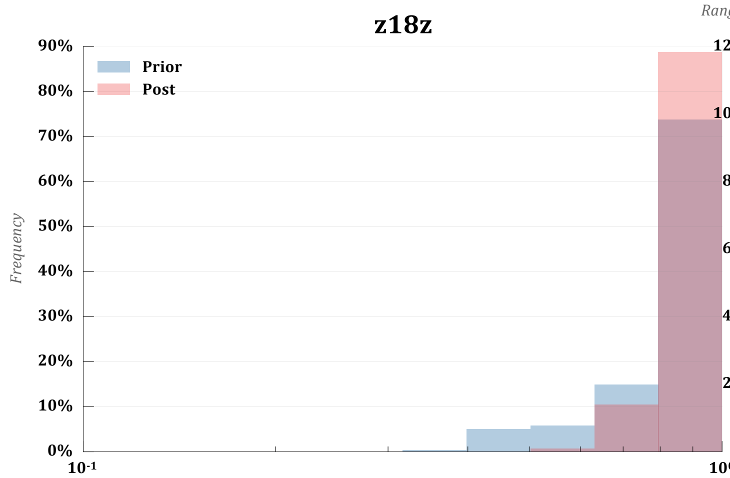
6%
4%
2%
0%
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
Range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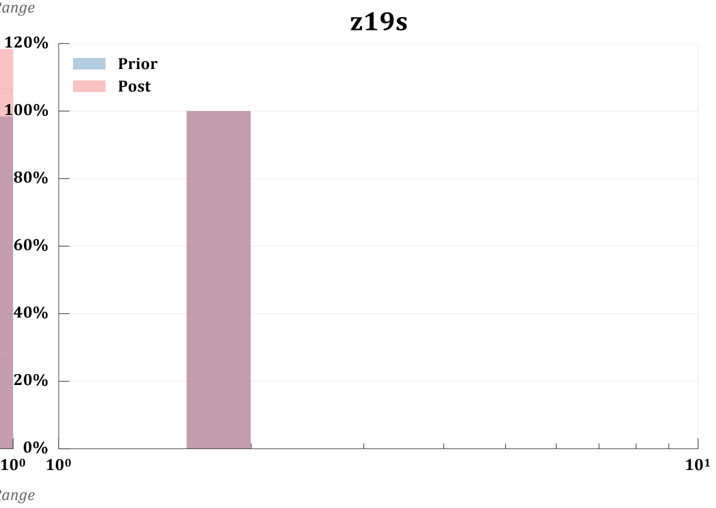
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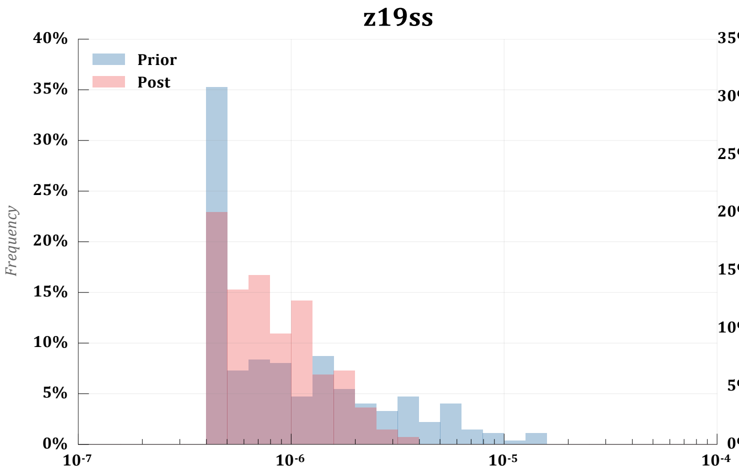
10^0
10^1
Range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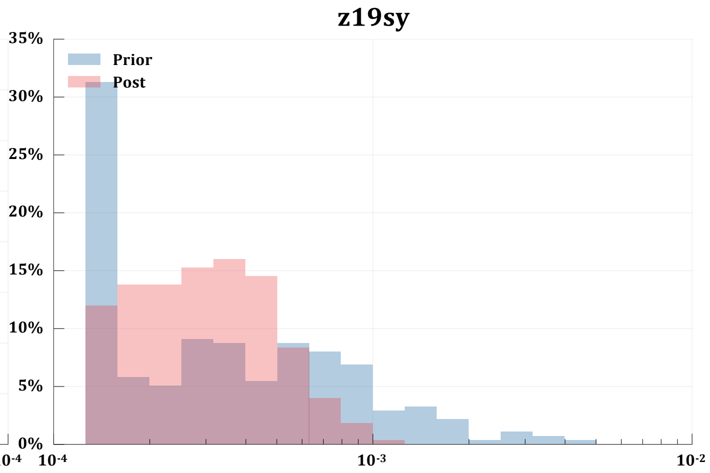
10-6
10-5
10-4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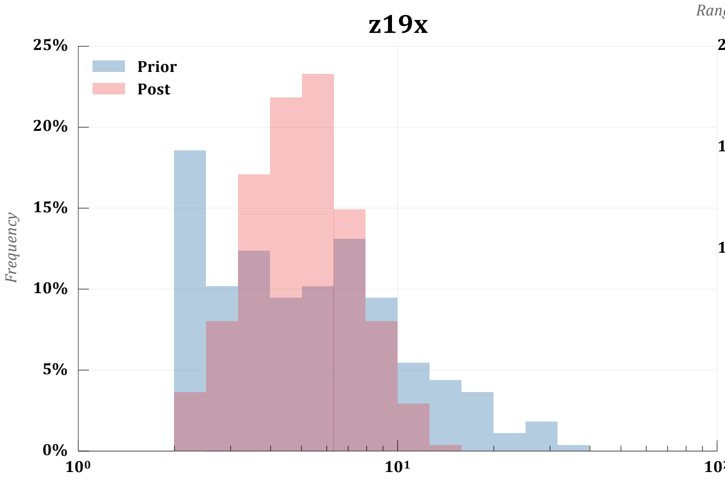
10-4
10-3
10-2
Range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10^0
10^1
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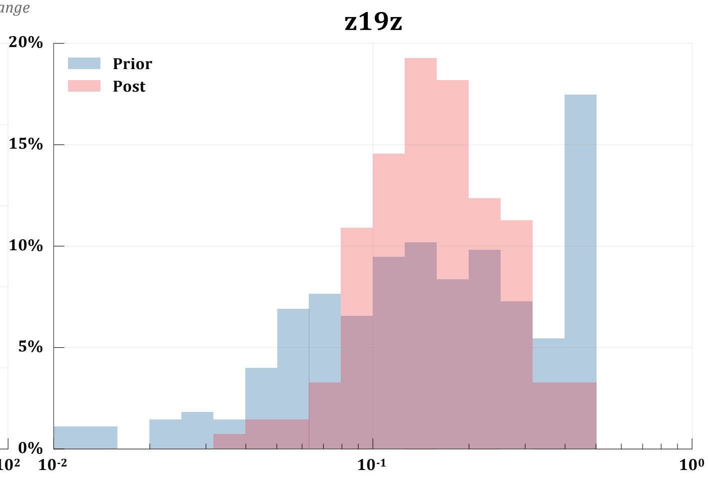
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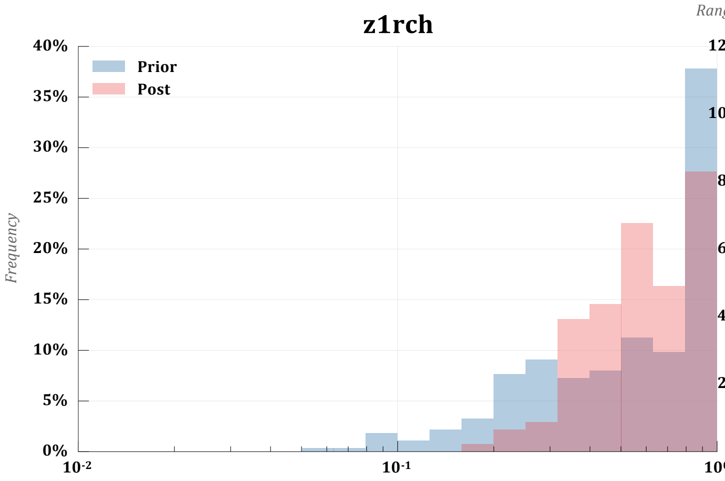
z1rch
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5%
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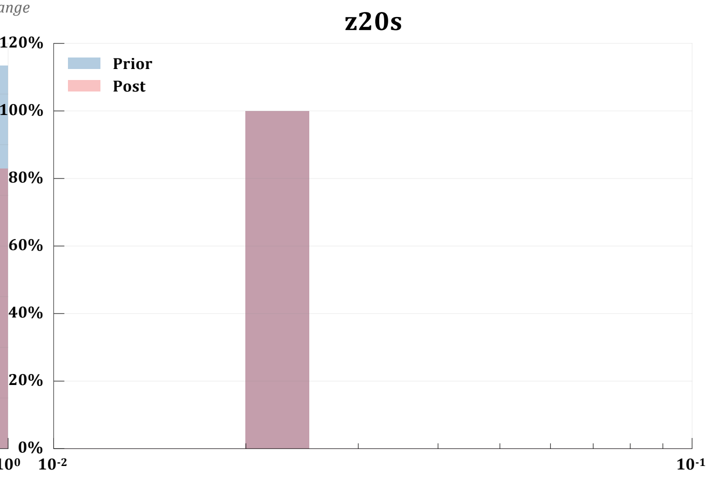
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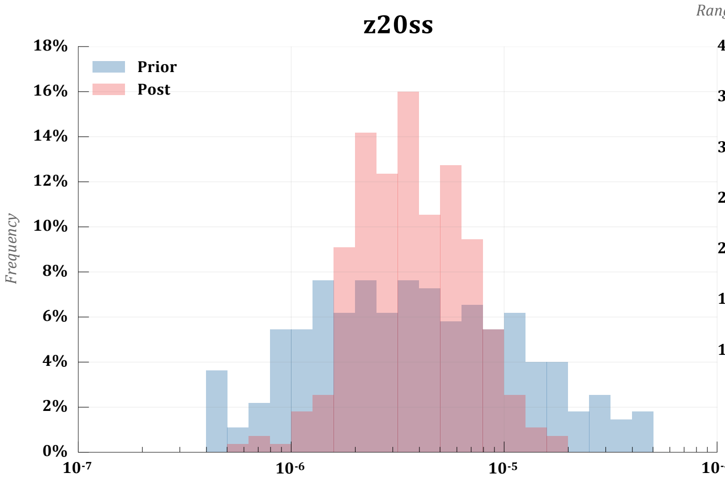
Range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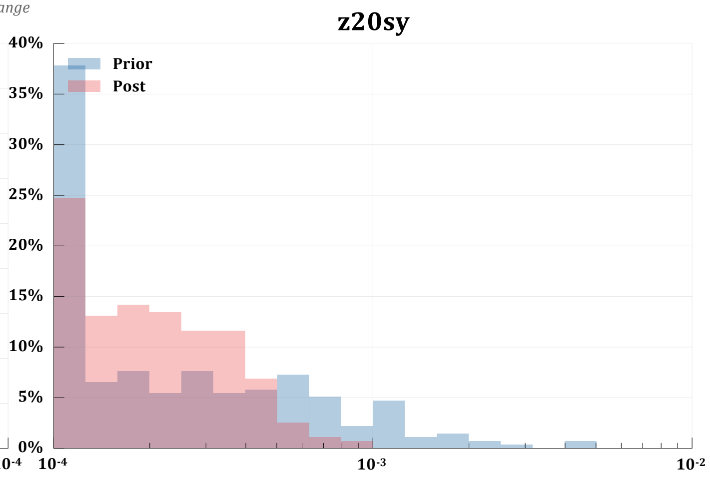
10-4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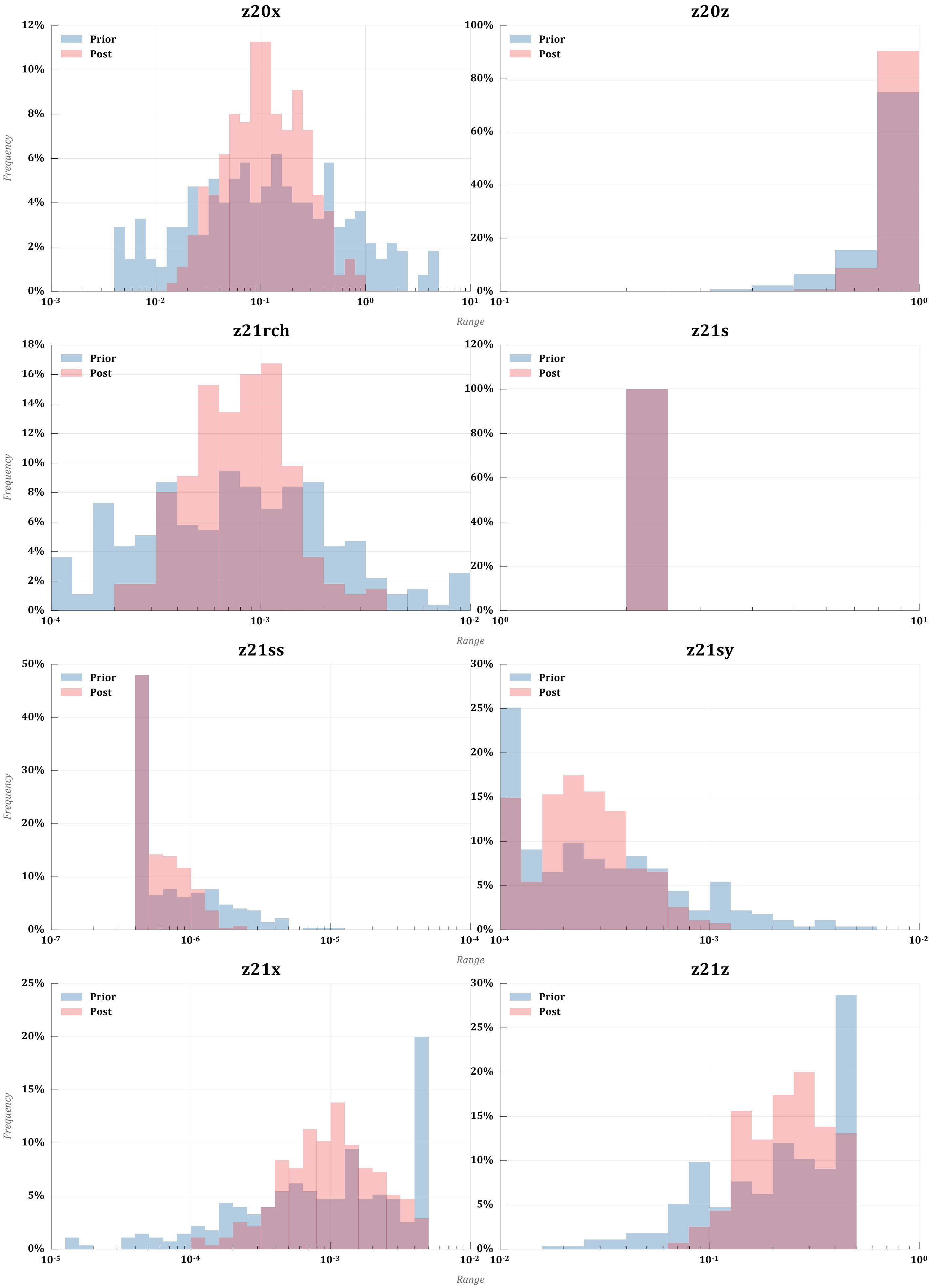
Range


z20x
z20z
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z21s
z21ss
z21sy
z21x
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Prior
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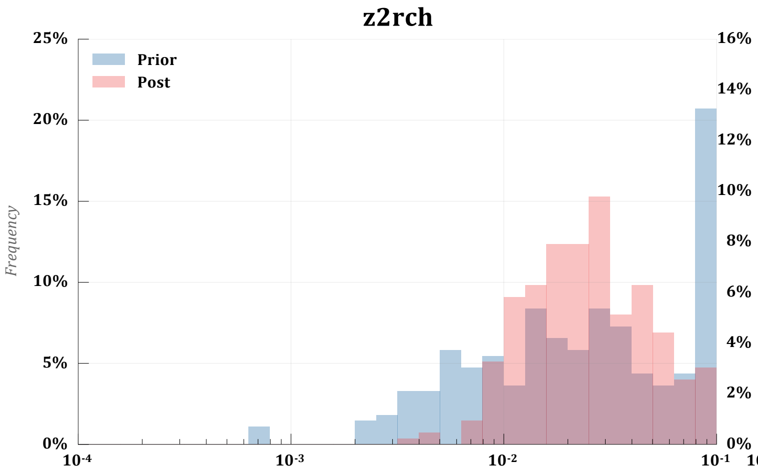
Frequency
Range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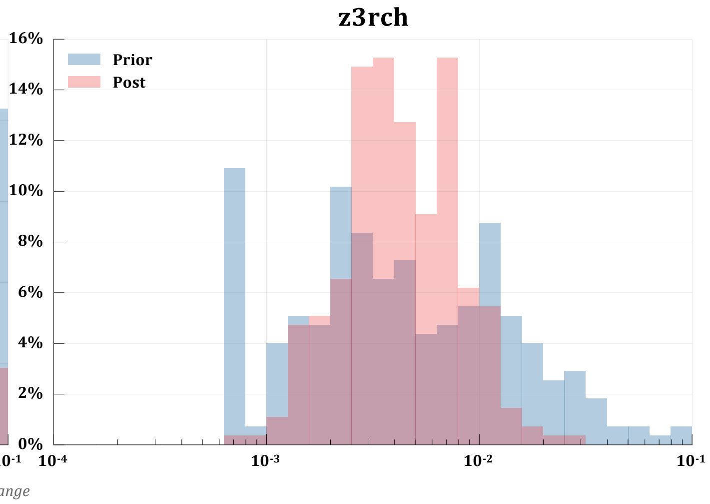
10-1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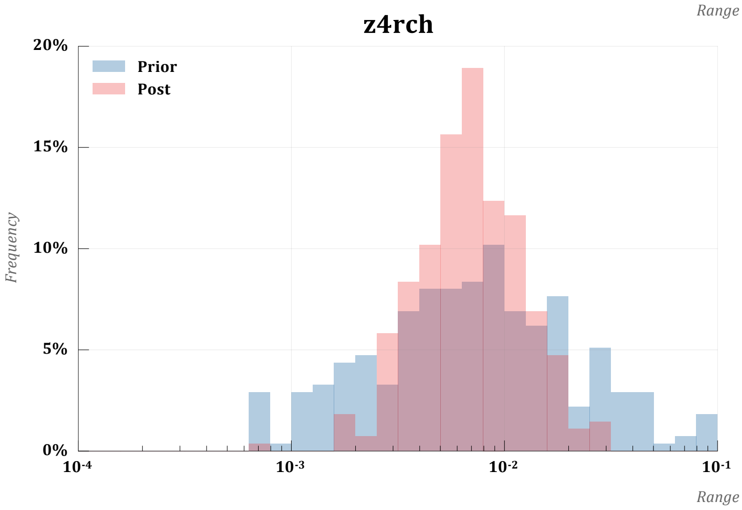
10-3
10-2
10-1
Range


z4rch
Prior
Post
Frequency
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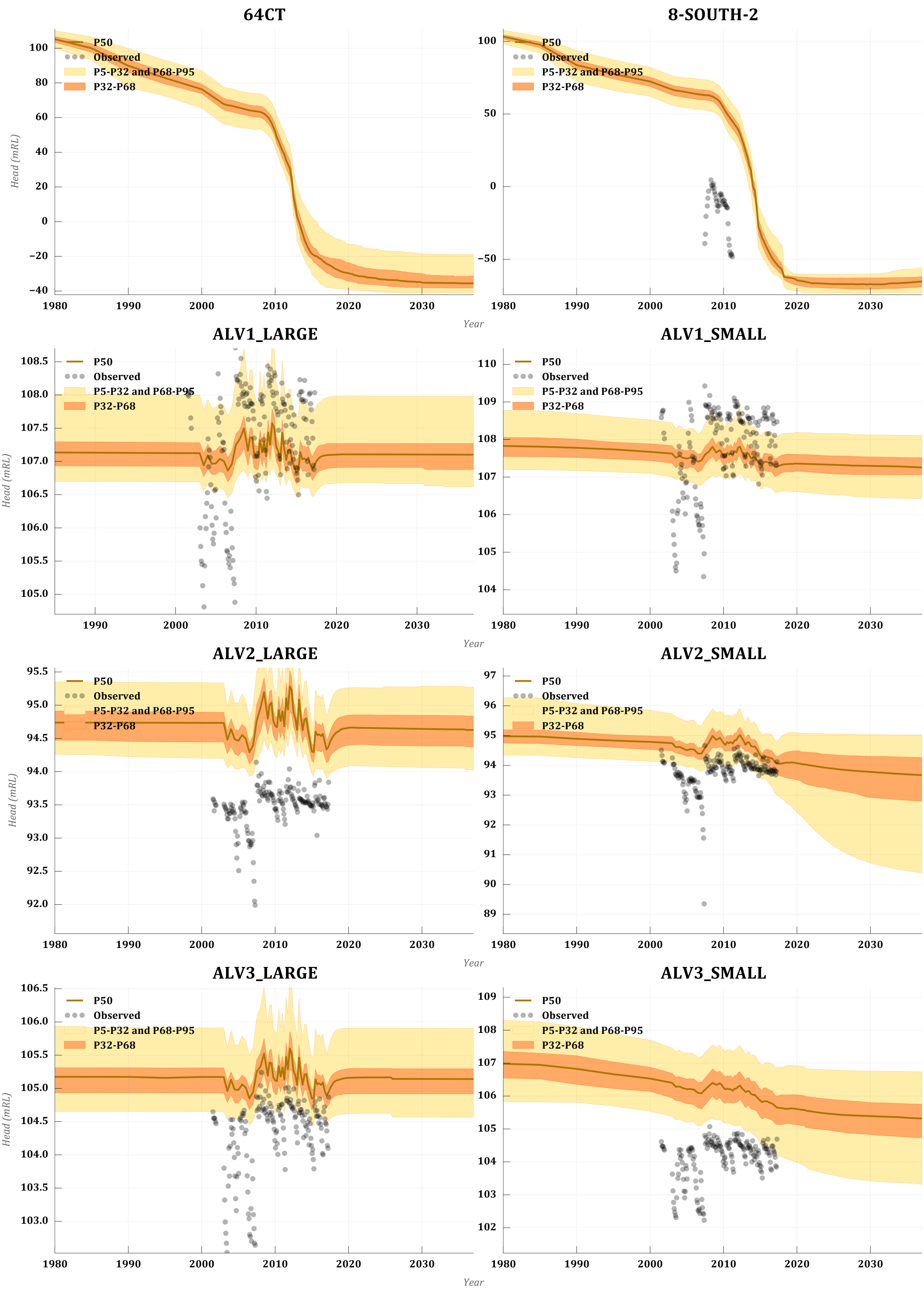
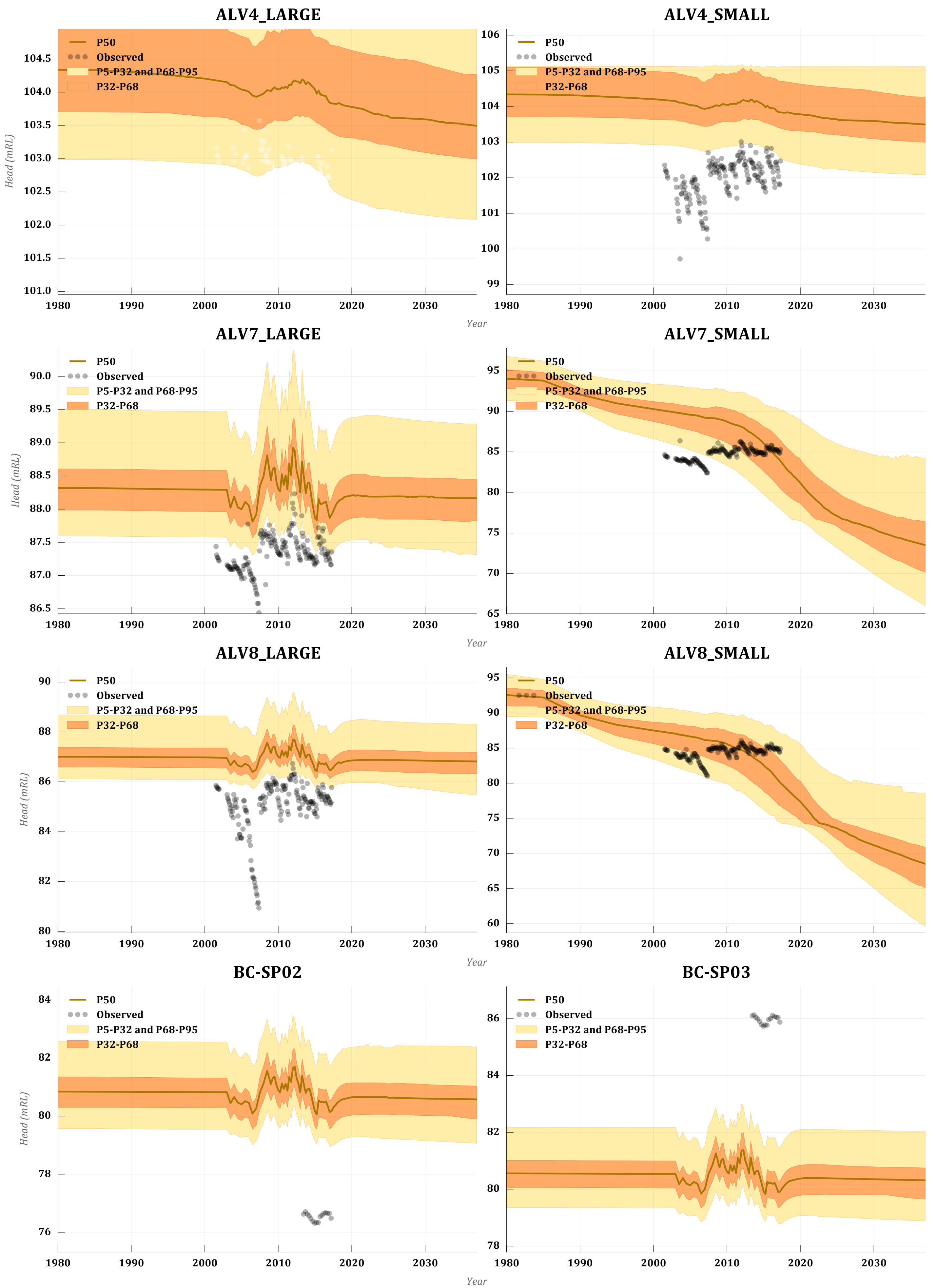
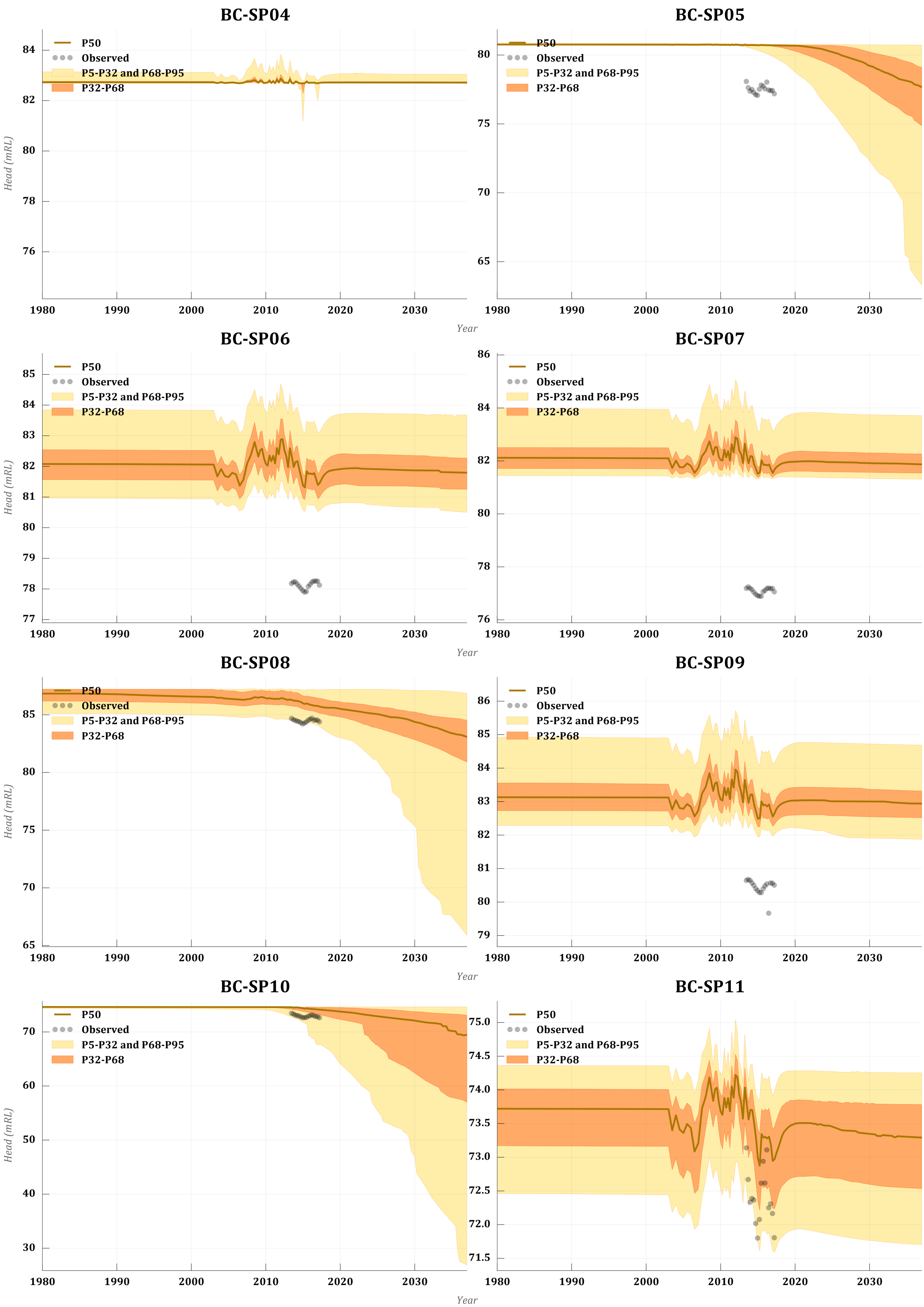
10-4
10-3
10-2
10-1
Range

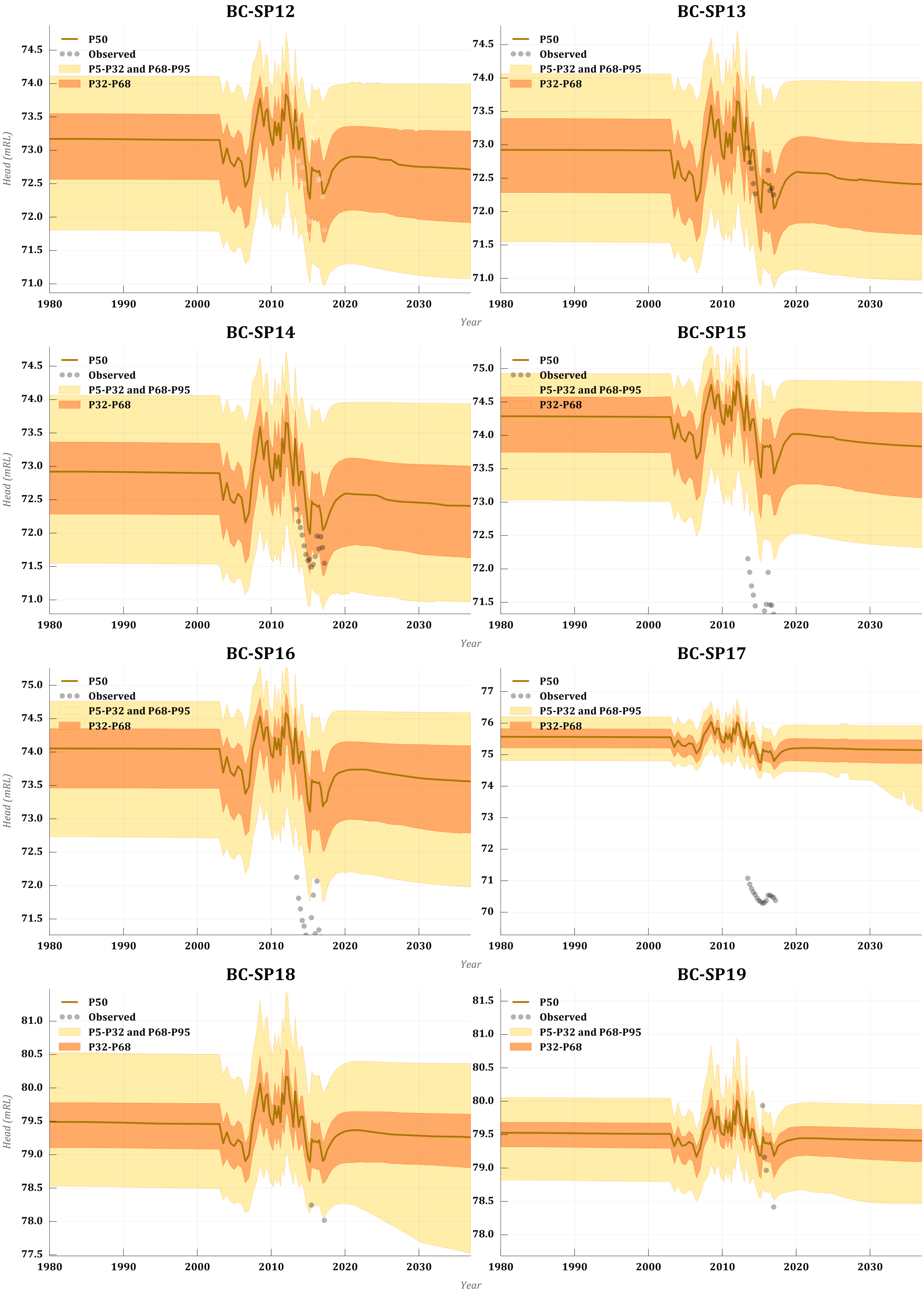
Appendix C-3

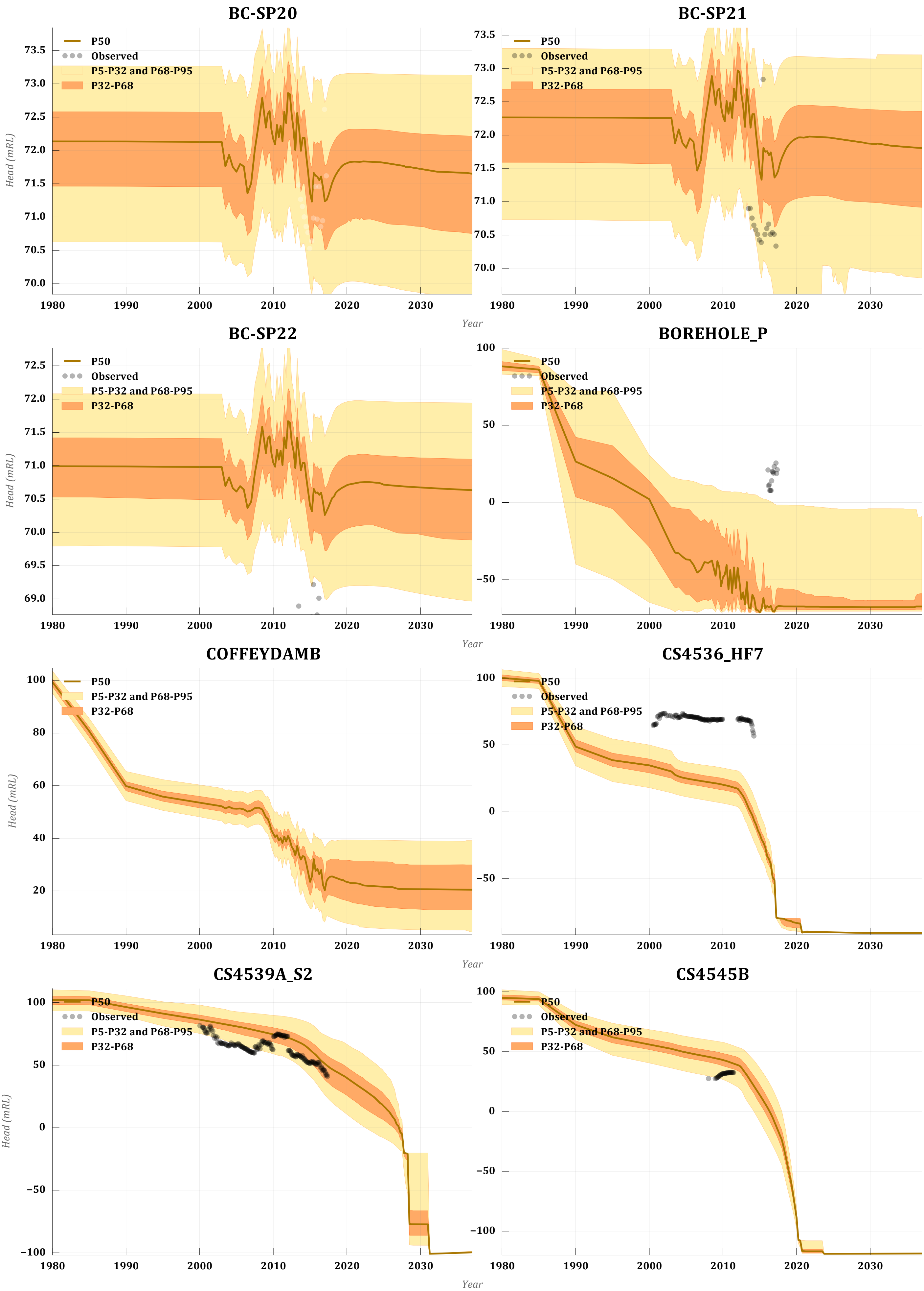
Predictive uncertainty hydrographs

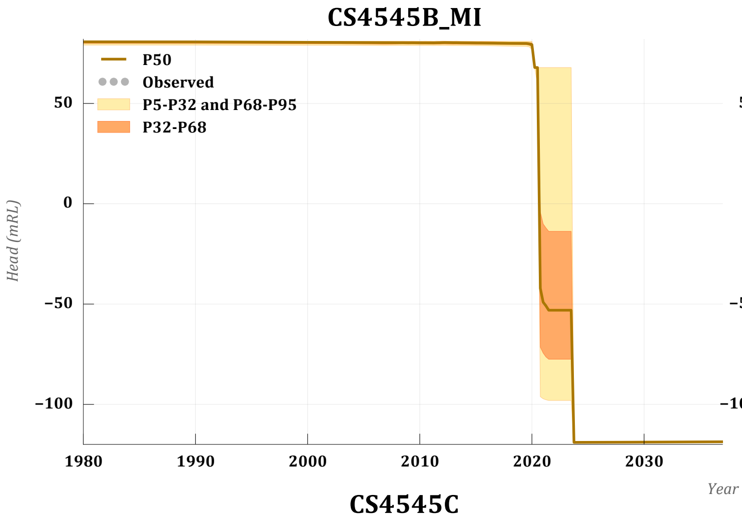

64CT
8-SOUTH-2
ALV1_LARGE
ALV1_SMALL
ALV2_LARGE
ALV2_SMALL
ALV3_LARGE
ALV3_SMALL
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year

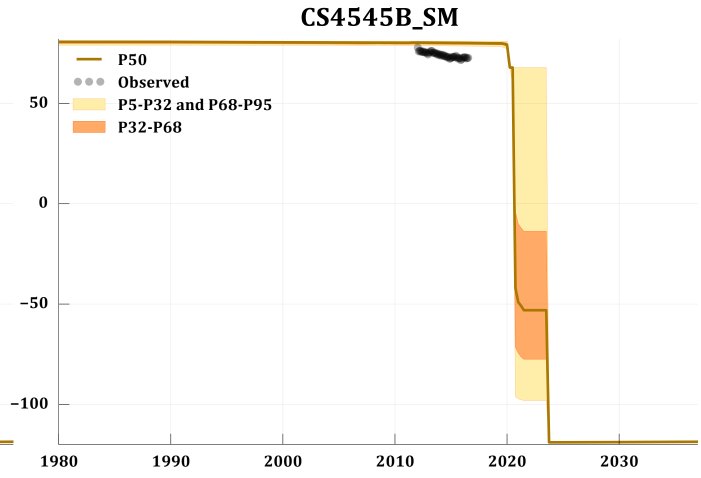

ALV4_LARGE
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
104.5
104.0
103.5
103.0
102.5
102.0
101.5
101.0
1980
1990
2000
2010
2020
2030
ALV4_SMALL
P50
Observed
P5-P32 and P68-P95
P32-P68
106
105
104
103
102
101
100
99
1980
1990
2000
2010
2020
2030
Year
ALV7_LARGE
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
90.0
89.5
89.0
88.5
88.0
87.5
87.0
86.5
1980
1990
2000
2010
2020
2030
ALV7_SMALL
P50
Observed
P5-P32 and P68-P95
P32-P68
95
90
85
80
75
70
65
1980
1990
2000
2010
2020
2030
Year
ALV8_LARGE
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
90
88
86
84
82
80
1980
1990
2000
2010
2020
2030
ALV8_SMALL
P50
Observed
P5-P32 and P68-P95
P32-P68
95
90
85
80
75
70
65
60
1980
1990
2000
2010
2020
2030
Year
BC-SP02
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
84
82
80
78
76
1980
1990
2000
2010
2020
2030
BC-SP03
P50
Observed
P5-P32 and P68-P95
P32-P68
86
84
82
80
78
1980
1990
2000
2010
2020
2030
Year


BC-SP04
BC-SP05
BC-SP06
BC-SP07
BC-SP08
BC-SP09
BC-SP10
BC-SP11
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year


BC-SP12
BC-SP13
BC-SP14
BC-SP15
BC-SP16
BC-SP17
BC-SP18
BC-SP19
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030


BC-SP20
BC-SP21
BC-SP22
BOREHOLE_P
COFFEYDAMB
CS4536_HF7
CS4539A_S2
CS4545B
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030


CS4545B_MI
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
50
0
−50
−100
1980
1990
2000
2010
2020
2030
Year


CS4545B_SM
P50
Observed
P5-P32 and P68-P95
P32-P68
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0
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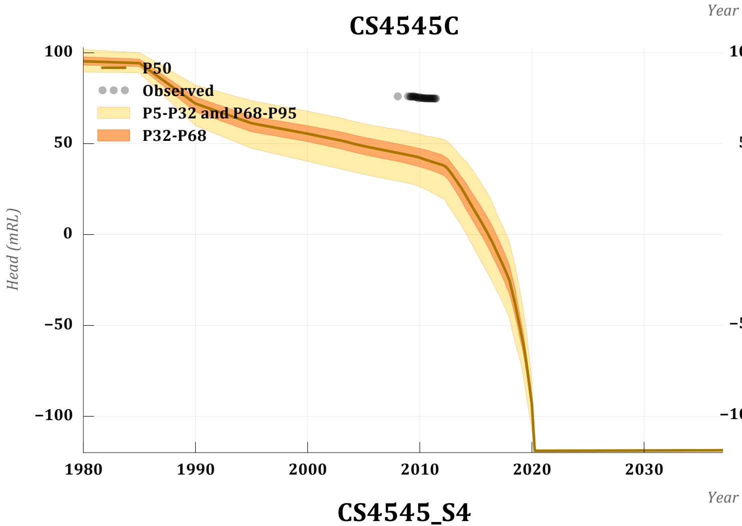
−100
1980
1990
2000
2010
2020
2030


CS4545C
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
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50
0
−50
−100
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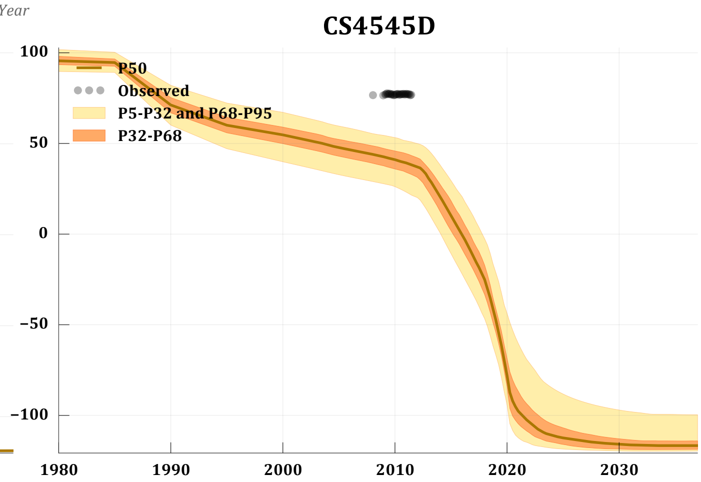
2000
2010
2020
2030
Year


CS4545D
P50
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P5-P32 and P68-P95
P32-P68
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50
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−50
−100
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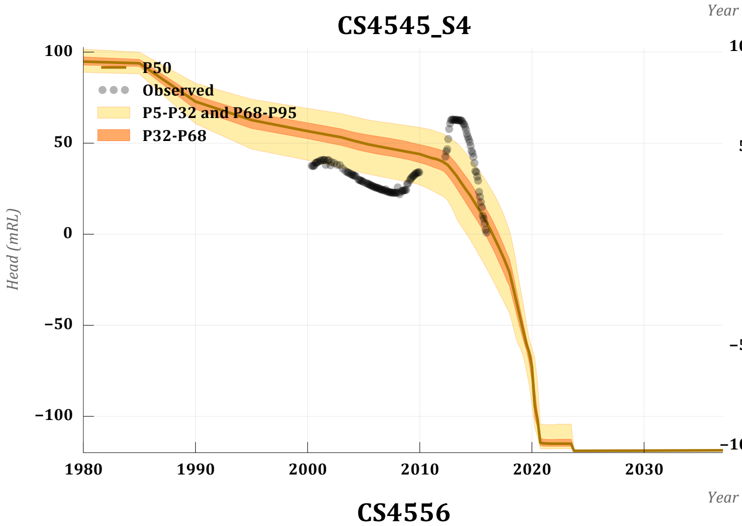
1990
2000
2010
2020
2030


CS4545_S4
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
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−50
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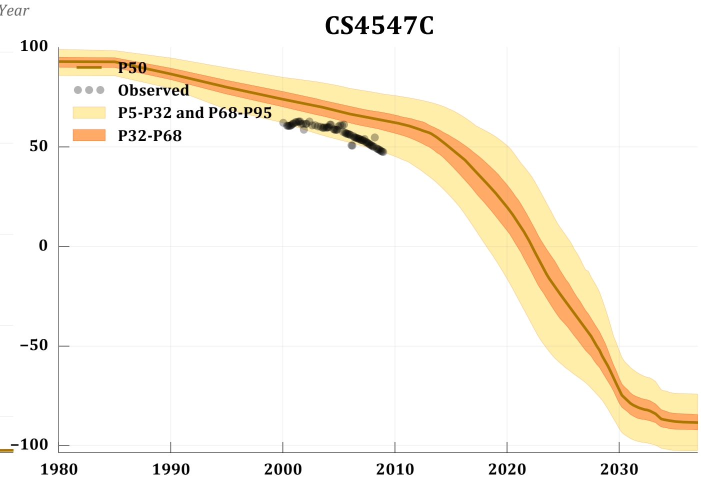
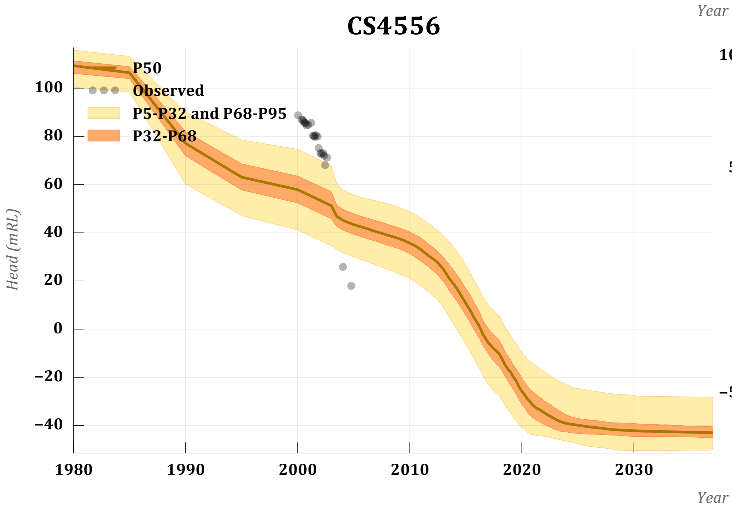
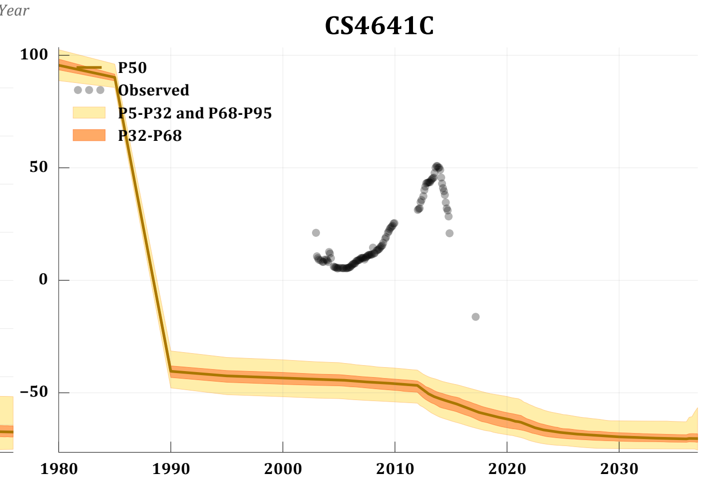
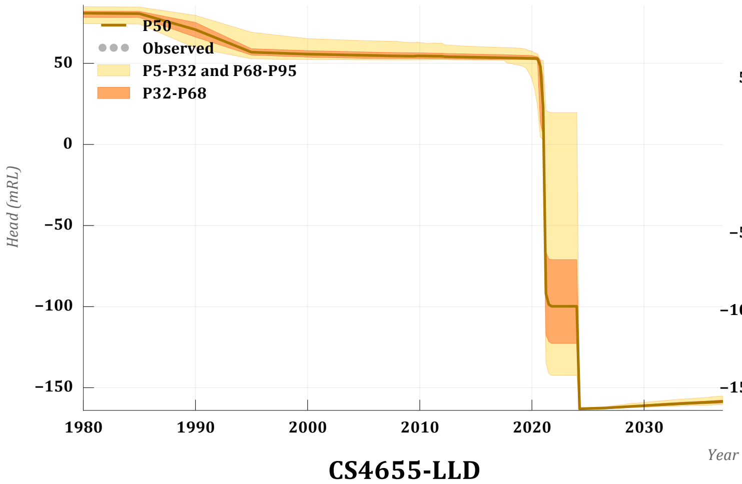
2000
2010
2020
2030
Year


CS4547C
P50
Observed
P5-P32 and P68-P95
P32-P68
100
50
0
−50
−100
1980
1990
2000
2010
2020
2030

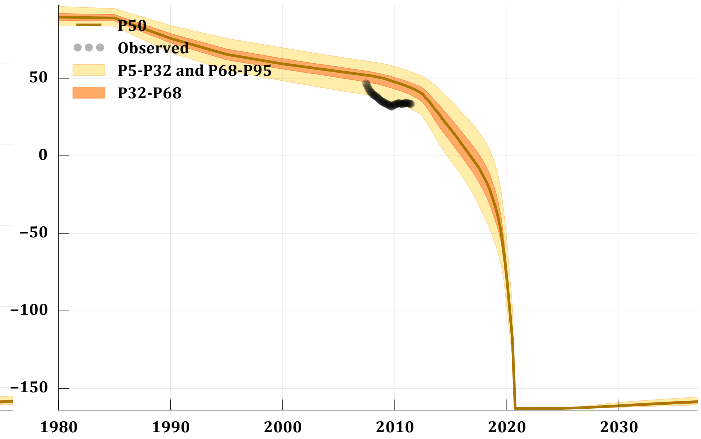

CS4556
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
100
80
60
40
20
0
−20
−40
1980
1990
2000
2010
2020
2030
Year


CS4641C
P50
Observed
P5-P32 and P68-P95
P32-P68
100
50
0
−50
1980
1990
2000
2010
2020
2030

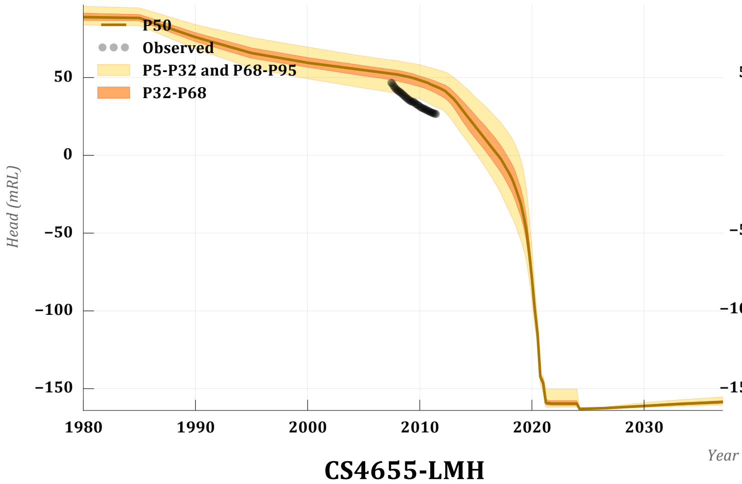
CS4655-BAY



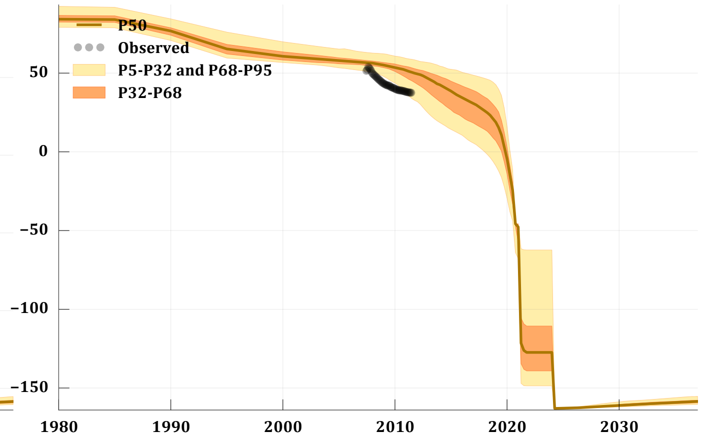
CS4655-BRT



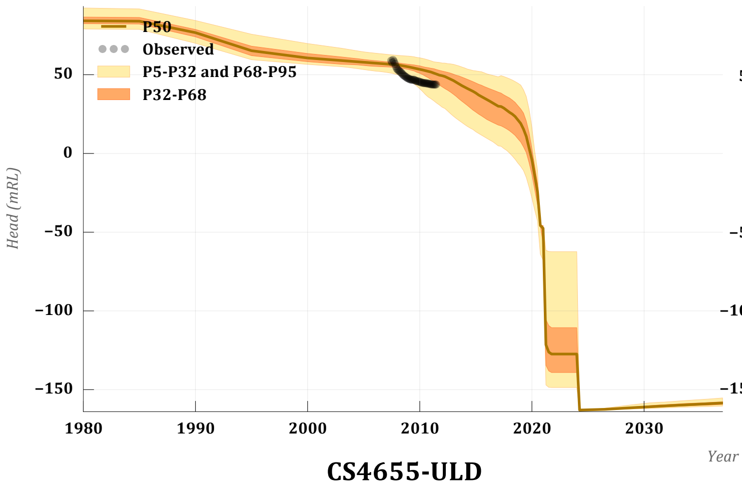
CS4655-LLD



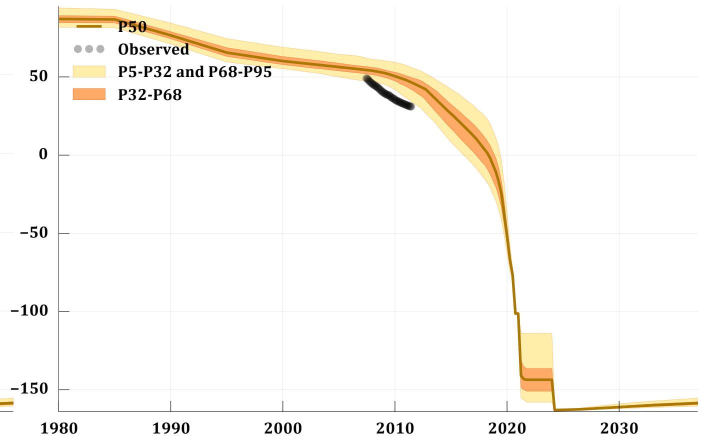
CS4655-LMA



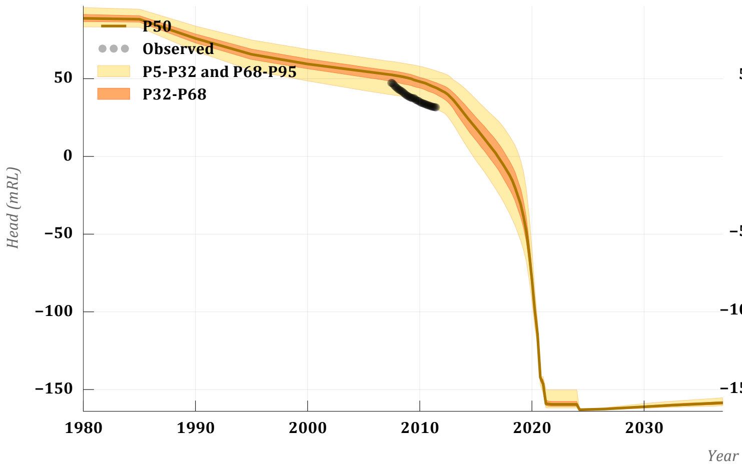
CS4655-LMH



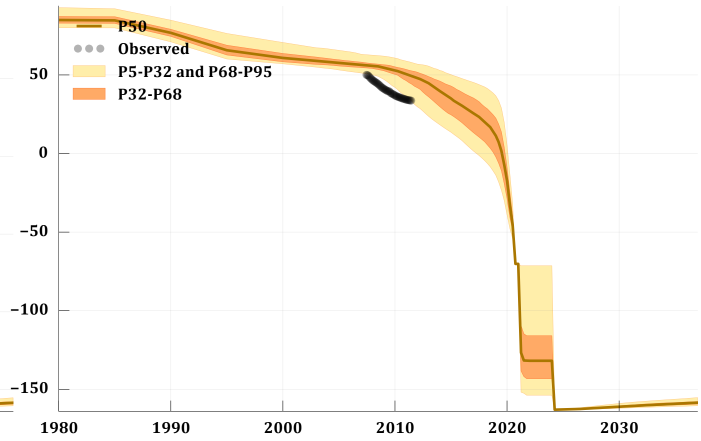
CS4655-UAR

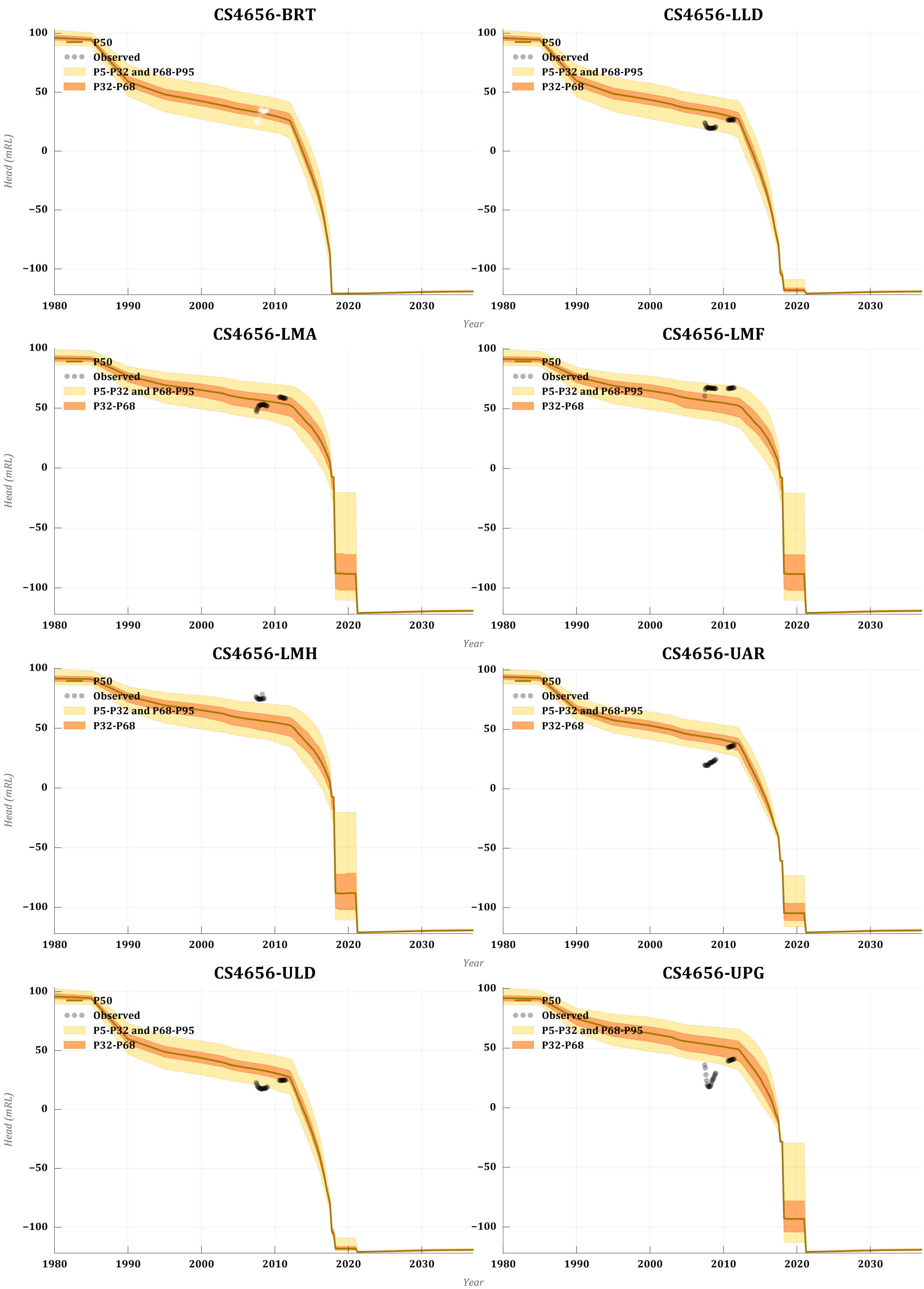


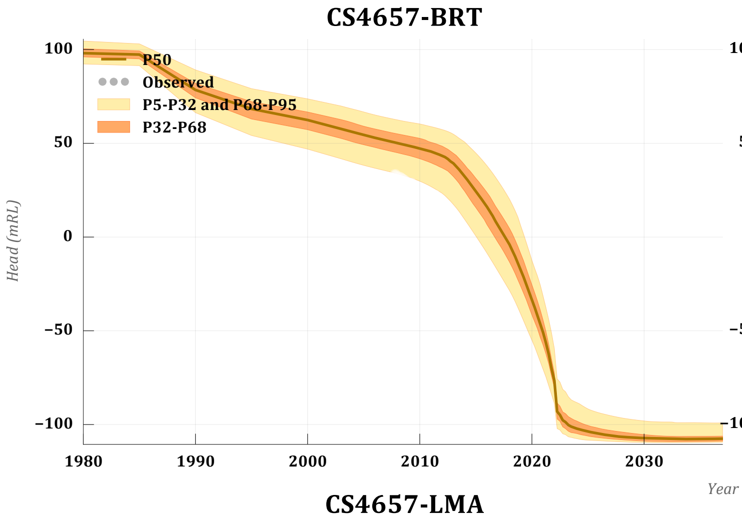
CS4655-ULD

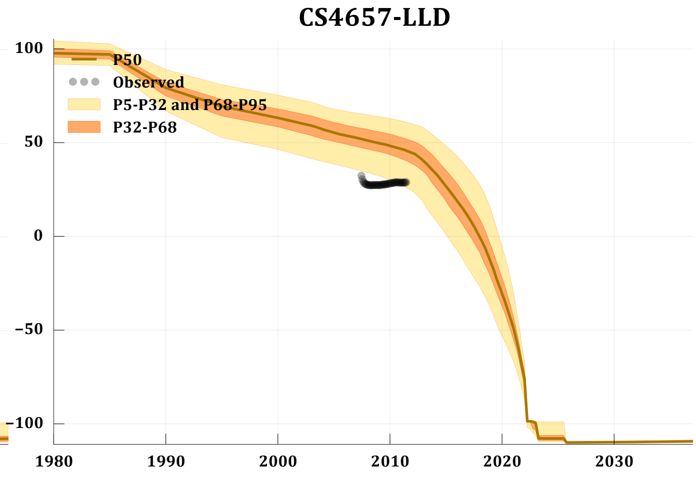


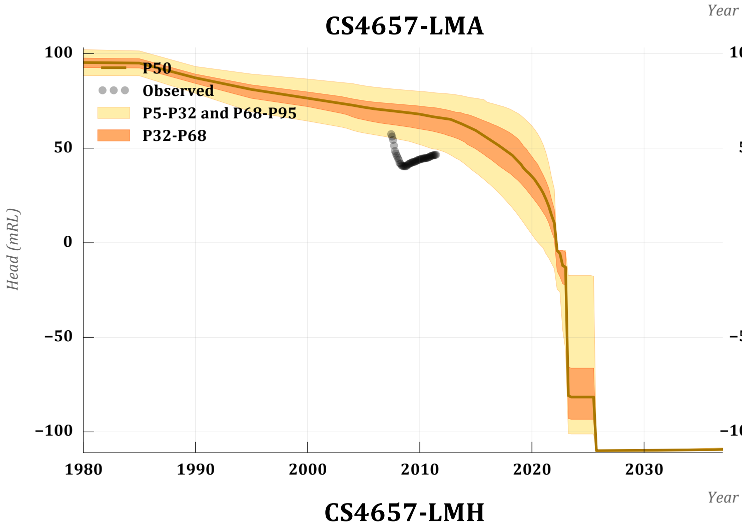
CS4655-UPG

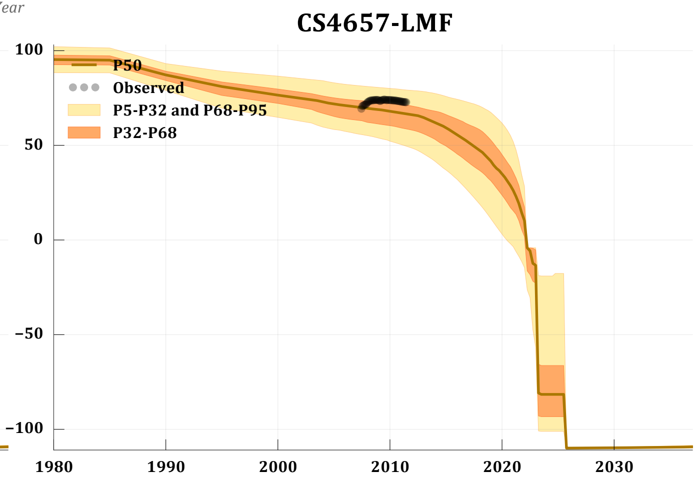


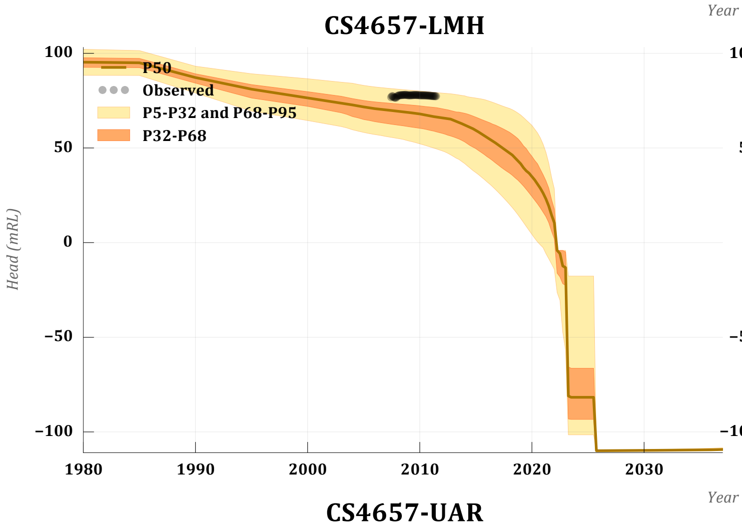

CS4656-BRT
CS4656-LLD
CS4656-LMA
CS4656-LMF
CS4656-LMH
CS4656-UAR
CS4656-ULD
CS4656-UPG
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
100
50
0
−50
−100
1980
1990
2000
2010
2020
2030

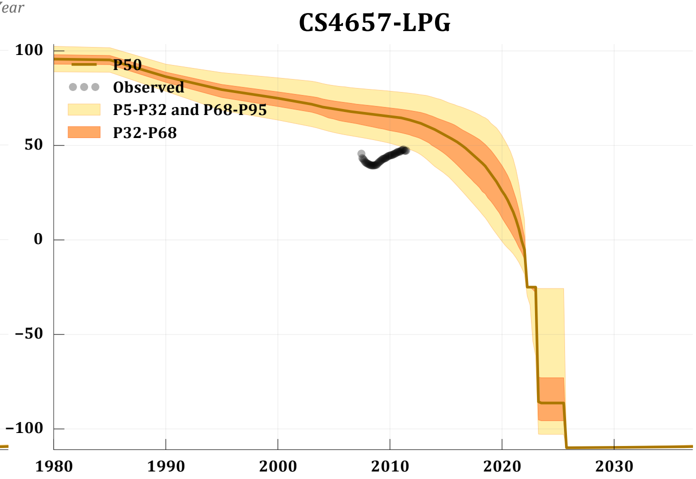

CS4657-BRT
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year

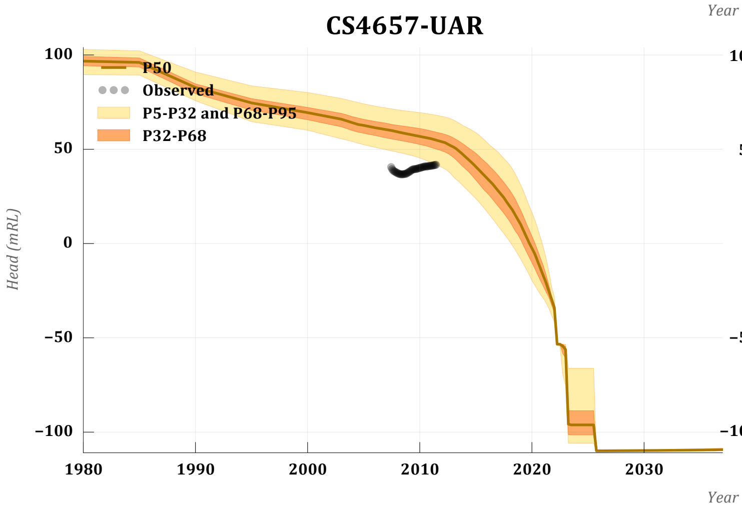

CS4657-LLD
P50
Observed
P5-P32 and P68-P95
P32-P68

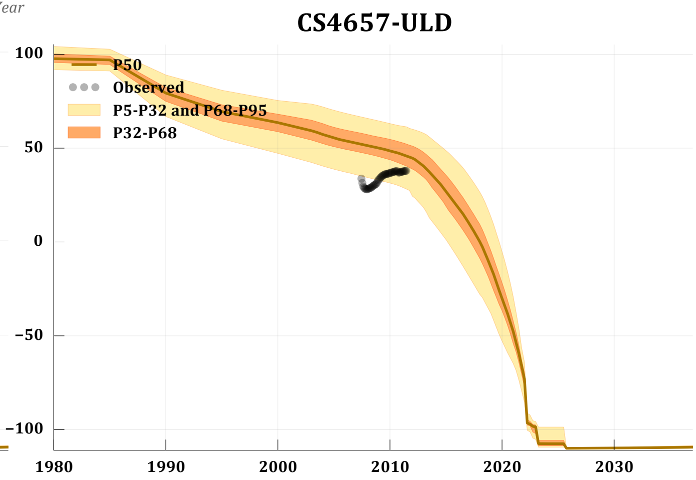

CS4657-LMA
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year

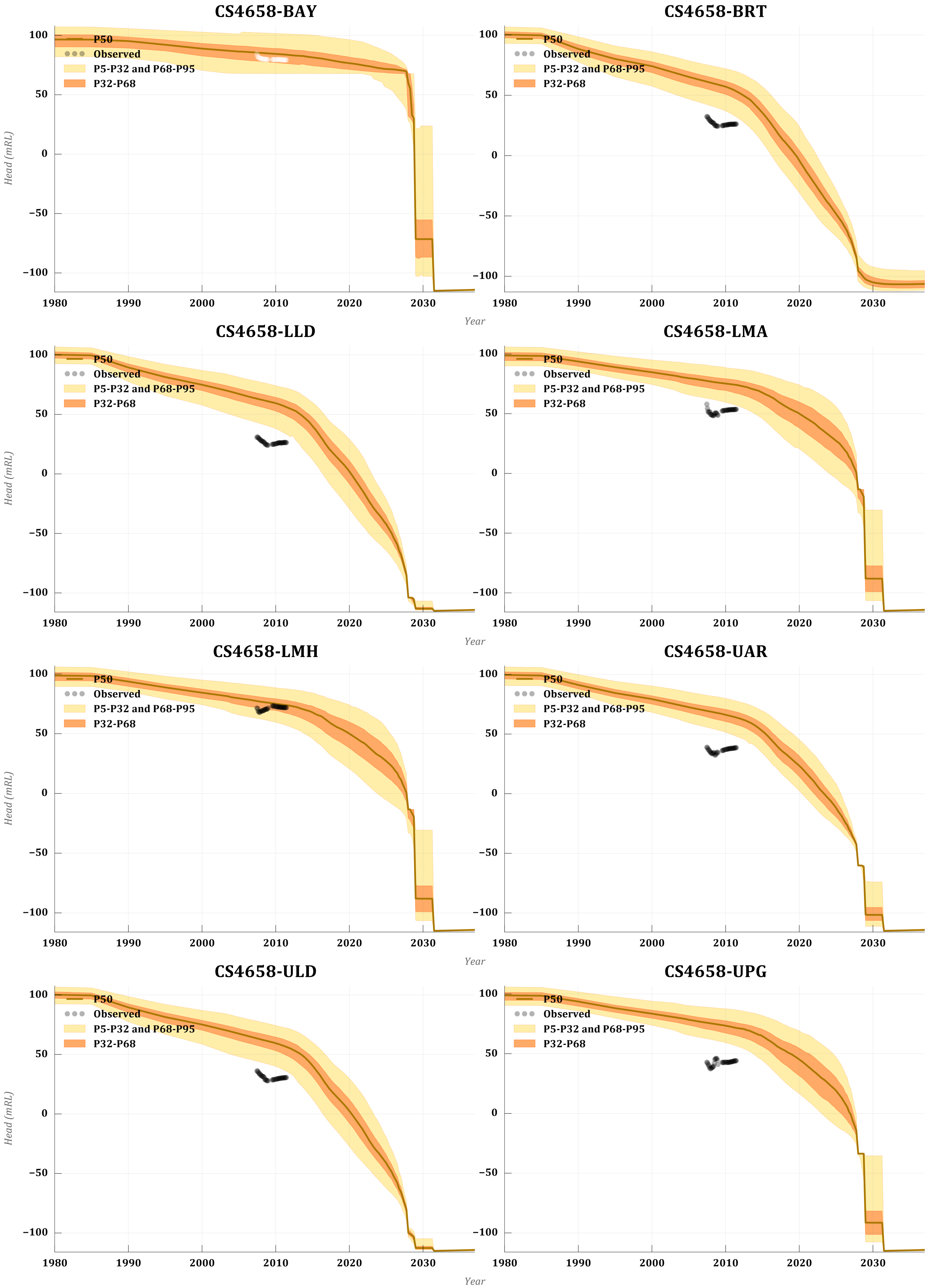

CS4657-LMF
P50
Observed
P5-P32 and P68-P95
P32-P68

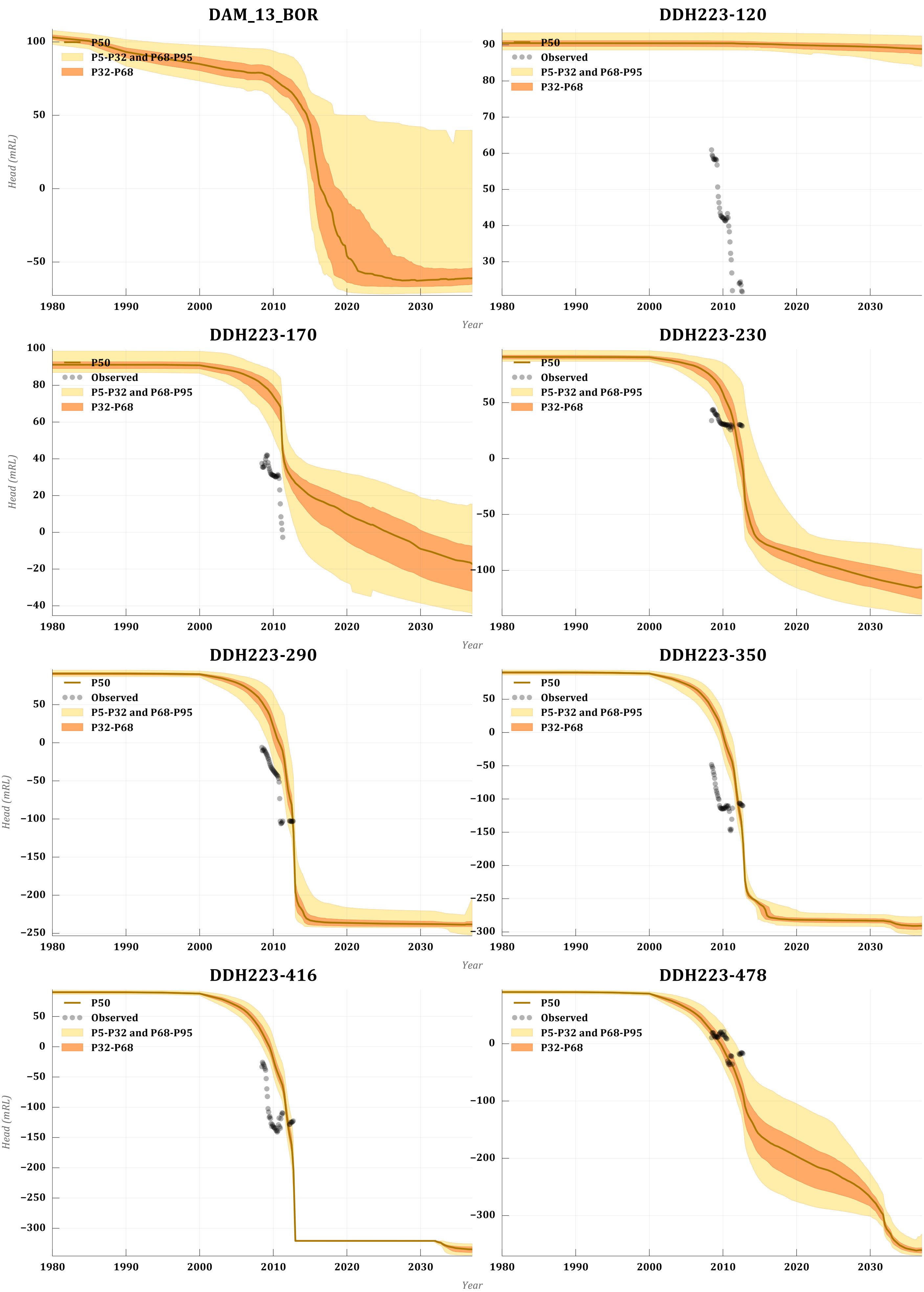

CS4657-LMH
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year


CS4657-LPG
P50
Observed
P5-P32 and P68-P95
P32-P68


CS4657-UAR
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year


CS4657-ULD
P50
Observed
P5-P32 and P68-P95
P32-P68


CS4658-BAY
CS4658-BRT
CS4658-LLD
CS4658-LMA
CS4658-LMH
CS4658-UAR
CS4658-ULD
CS4658-UPG
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
100
50
0
−50
−100
1980
1990
2000
2010
2020
2030


DAM_13_BOR
DDH223-120
DDH223-170
DDH223-230
DDH223-290
DDH223-350
DDH223-416
DDH223-478
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030
100
50
0
−50
90
80
70
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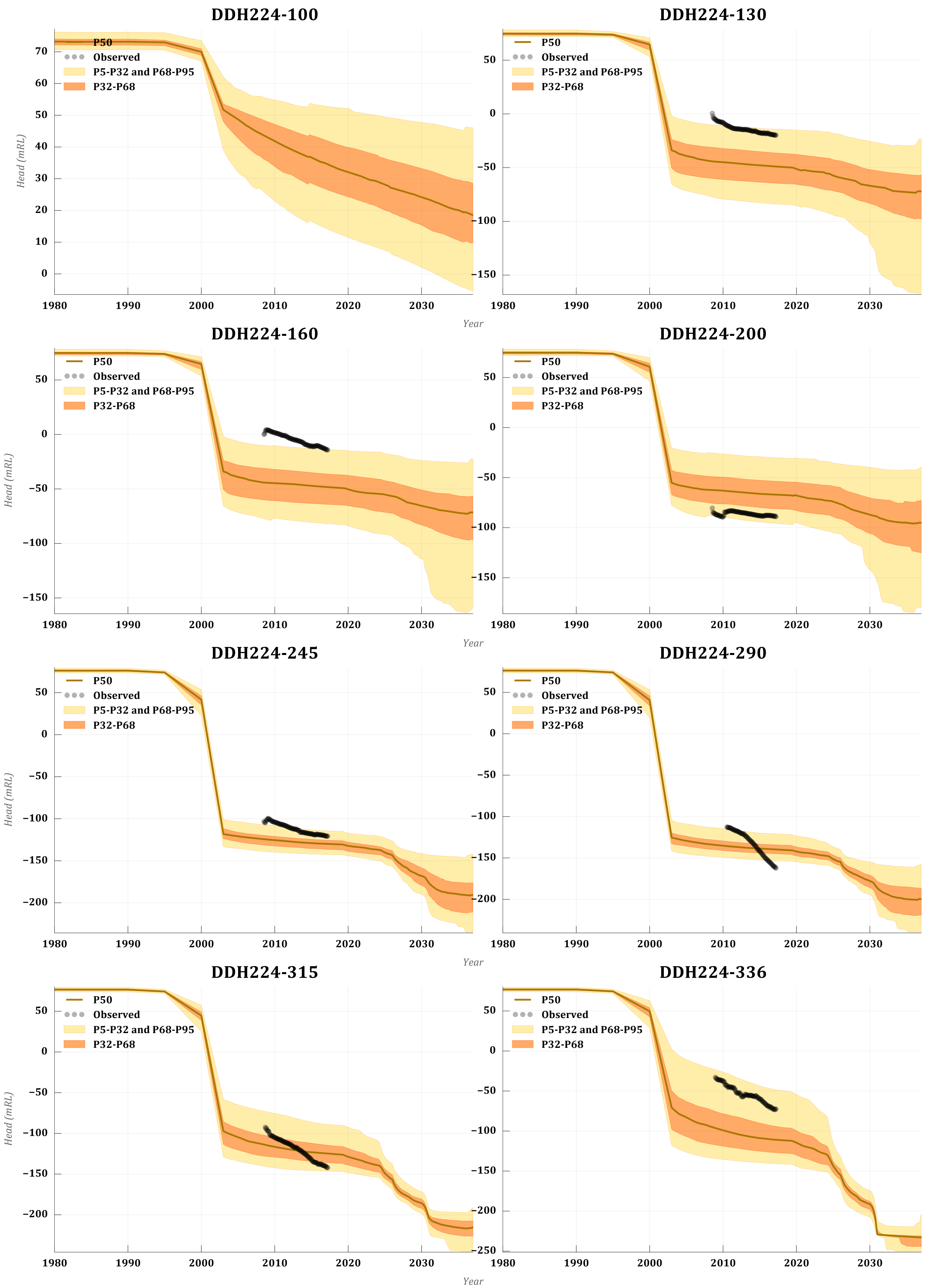
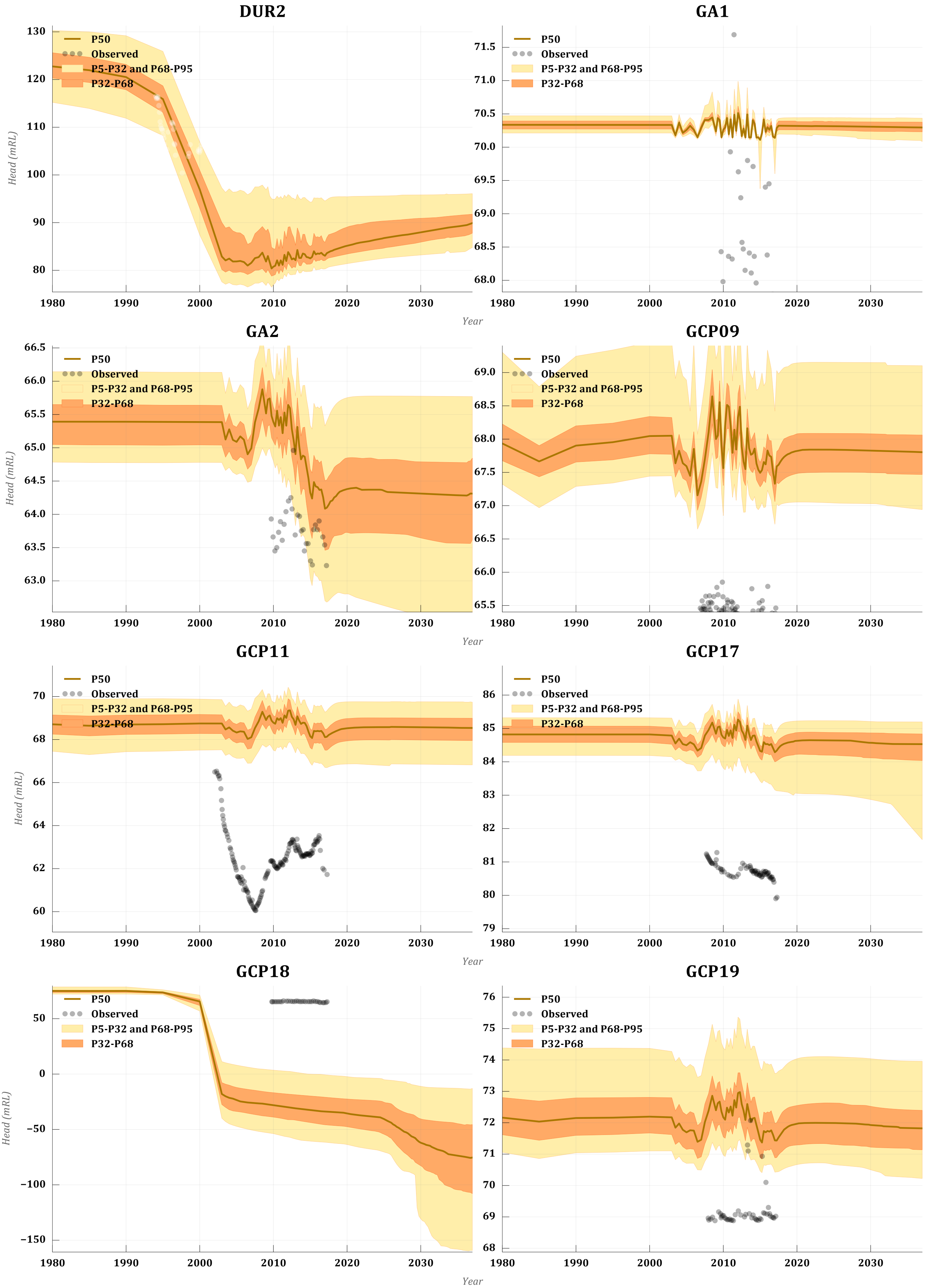
40
30
20
−20
−40
−100
−150
−200
−250
−300


DDH224-100
DDH224-130
DDH224-160
DDH224-200
DDH224-245
DDH224-290
DDH224-315
DDH224-336
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030


DUR2
GA1
GA2
GCP09
GCP11
GCP17
GCP18
GCP19
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
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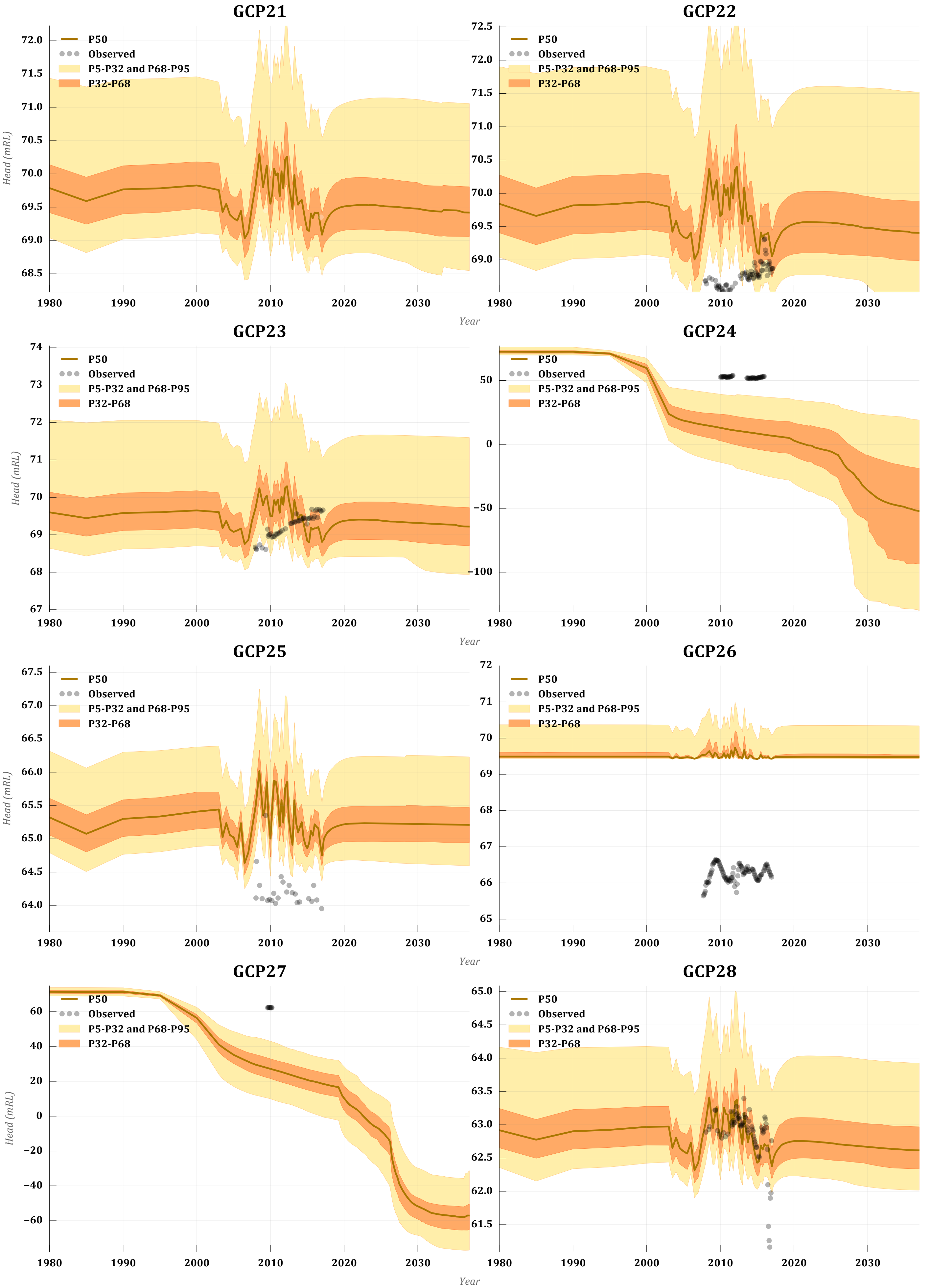
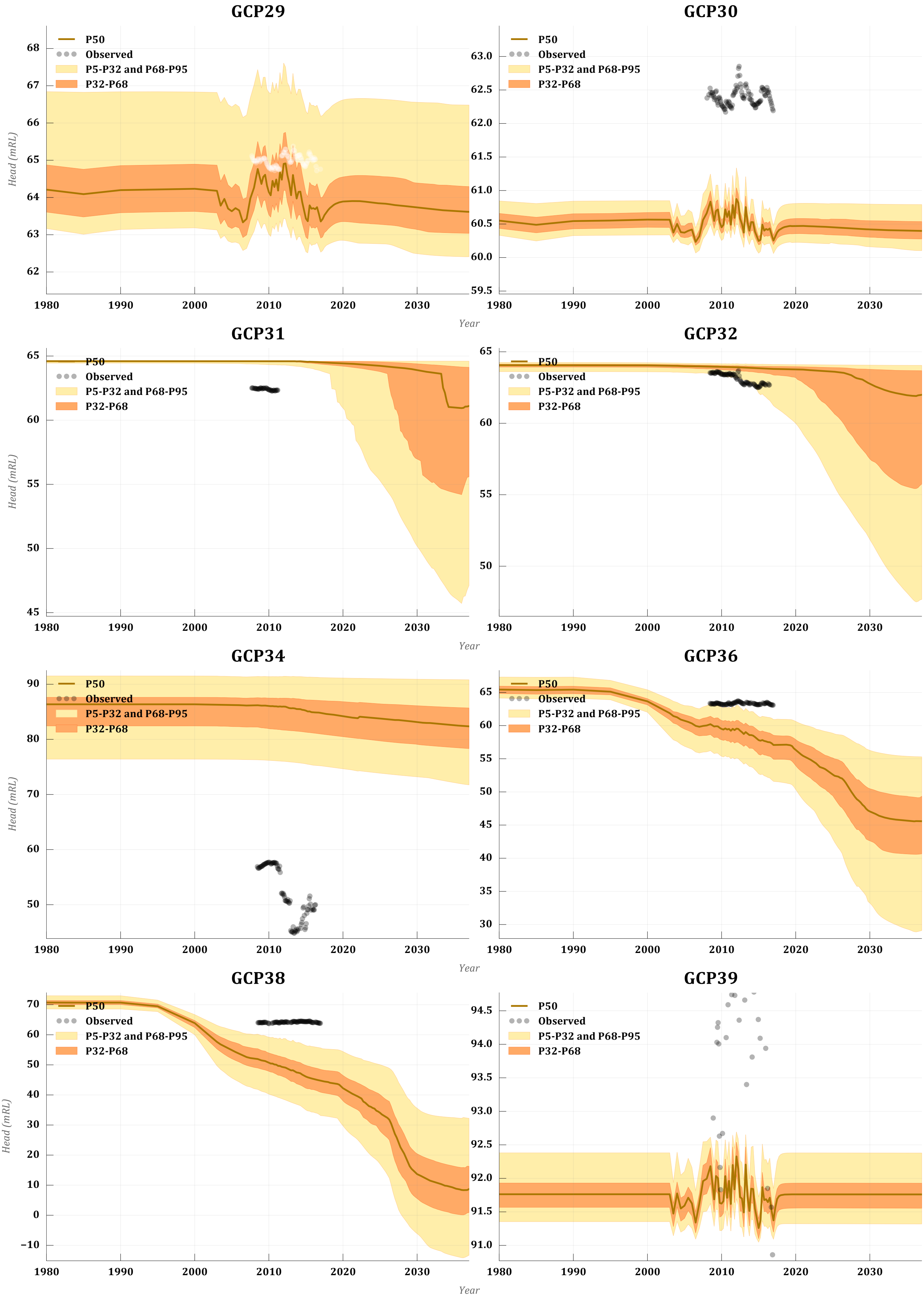
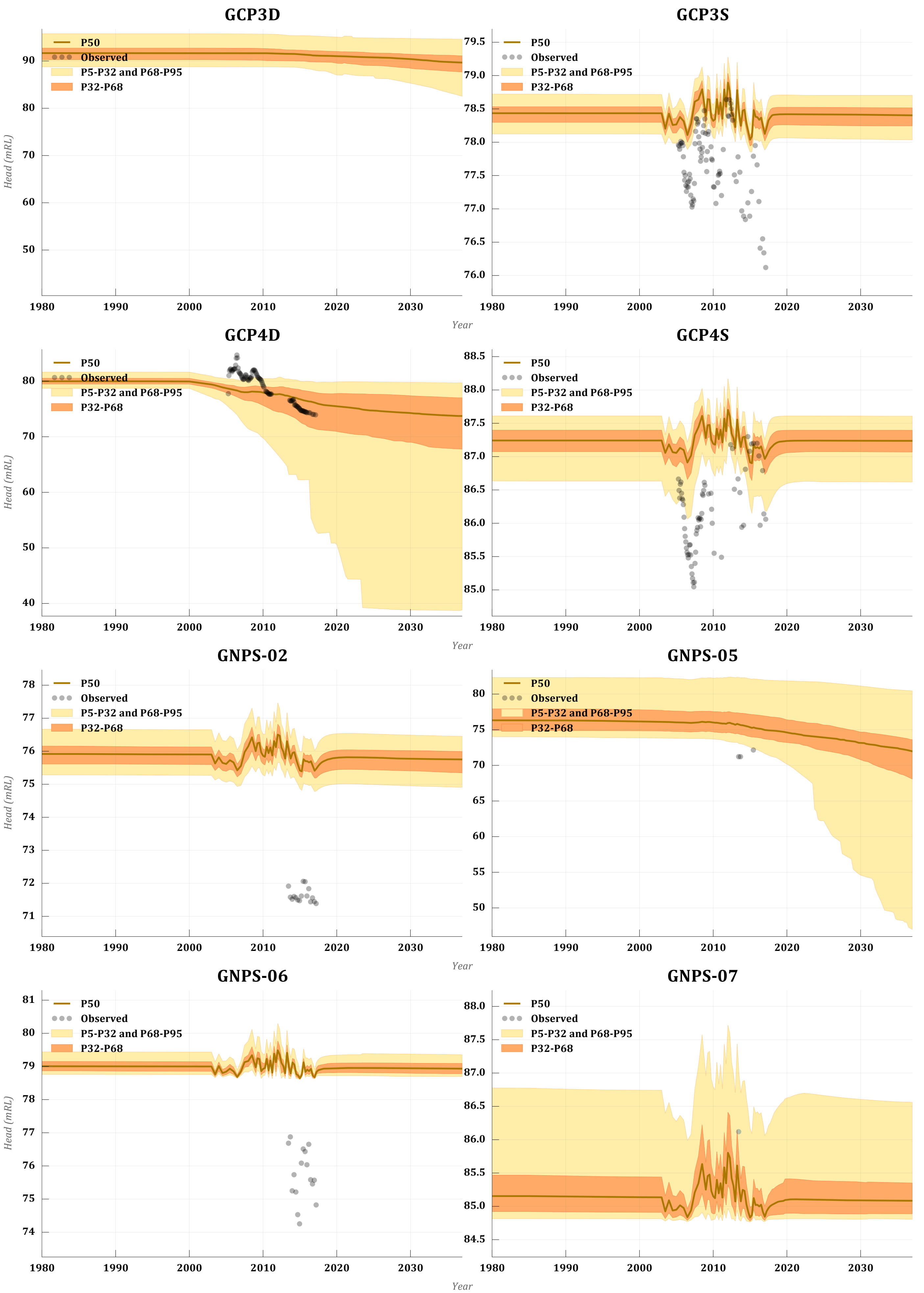
2010
2020
2030


GCP21
GCP22
GCP23
GCP24
GCP25
GCP26
GCP27
GCP28
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030


GCP29
GCP30
GCP31
GCP32
GCP34
GCP36
GCP38
GCP39
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year


GCP3D
GCP3S
GCP4D
GCP4S
GNPS-02
GNPS-05
GNPS-06
GNPS-07
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
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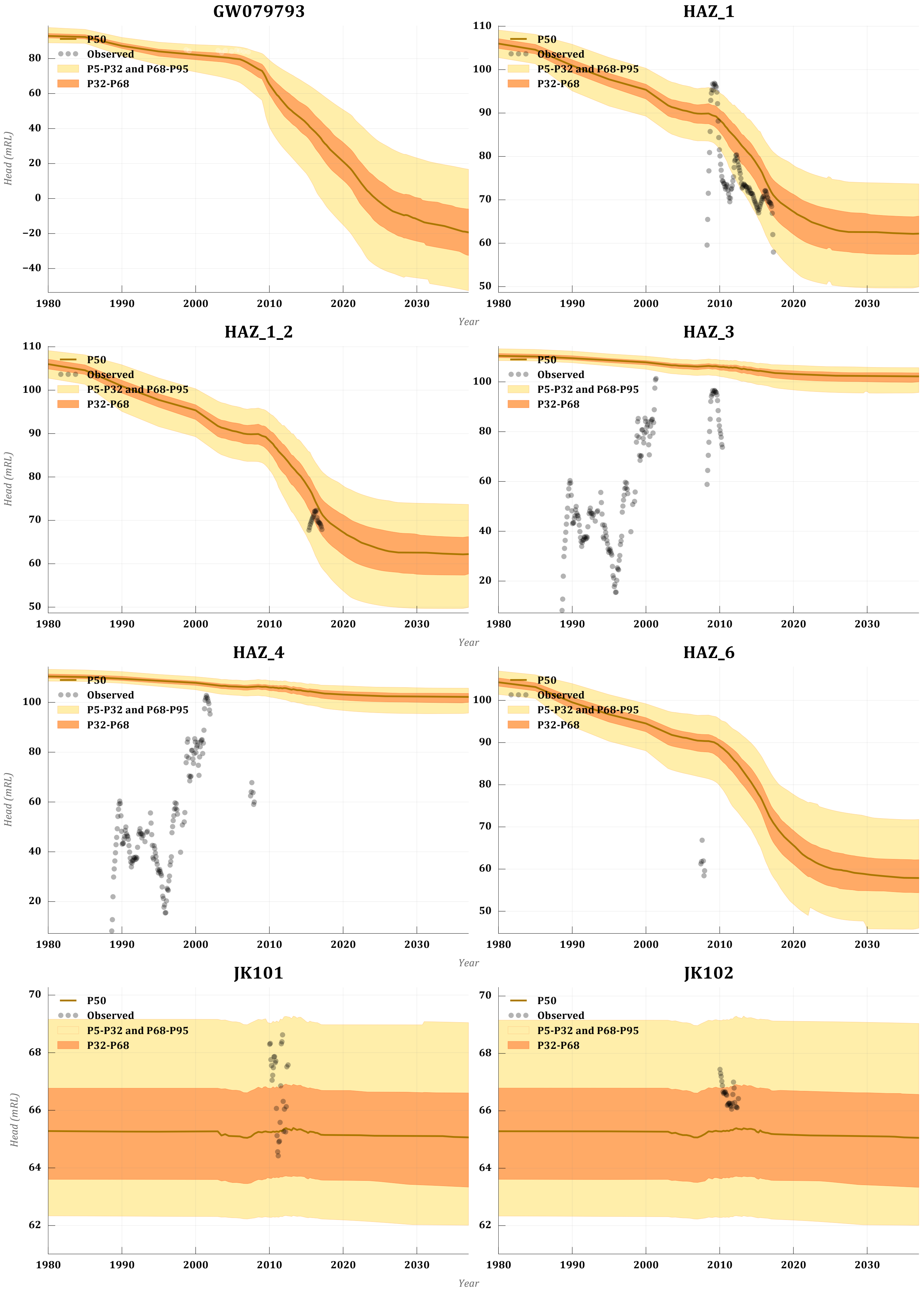
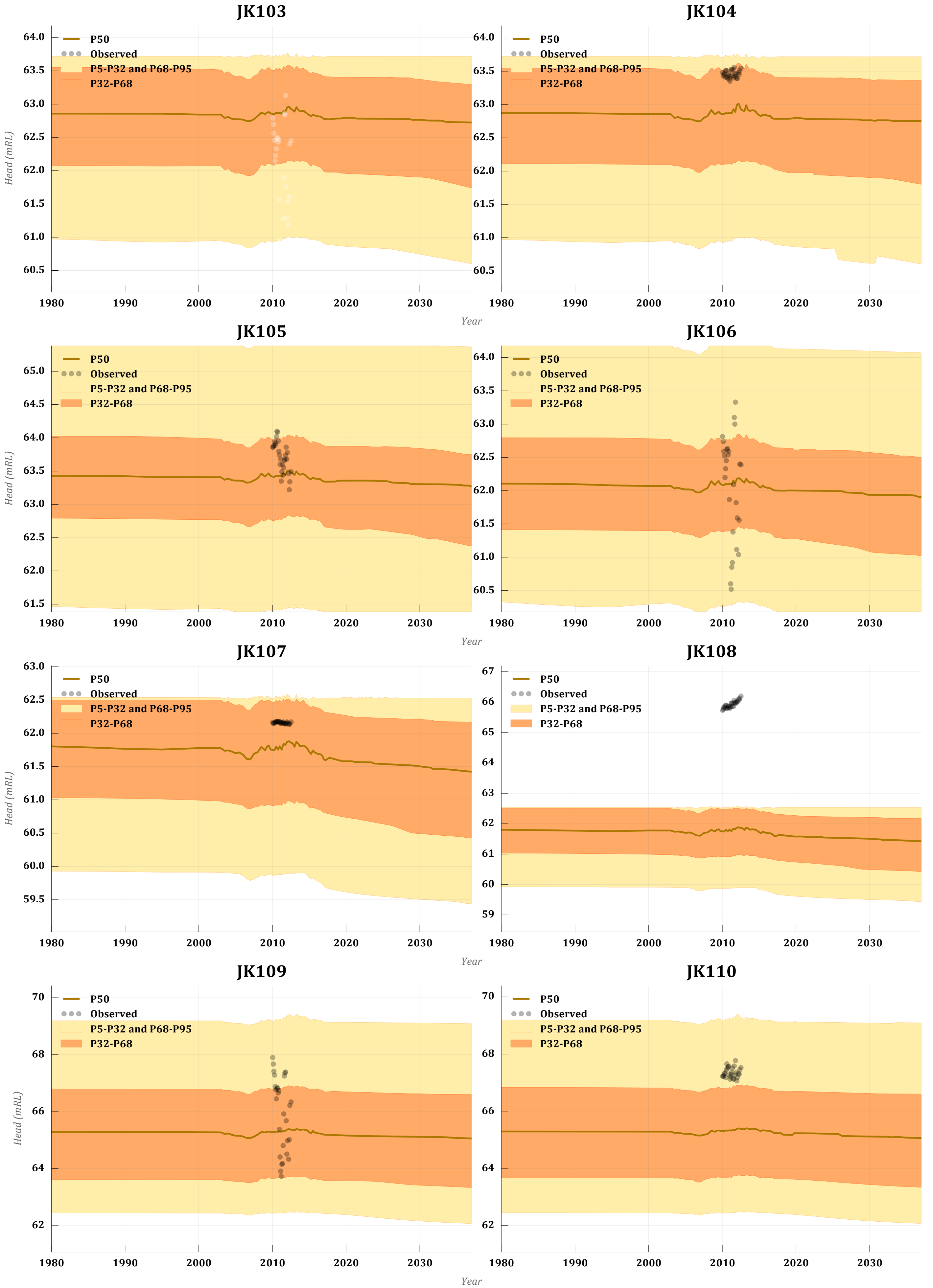
2000
2010
2020
2030


GW079793
HAZ_1
HAZ_1_2
HAZ_3
HAZ_4
HAZ_6
JK101
JK102
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030


JK103
JK104
JK105
JK106
JK107
JK108
JK109
JK110
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
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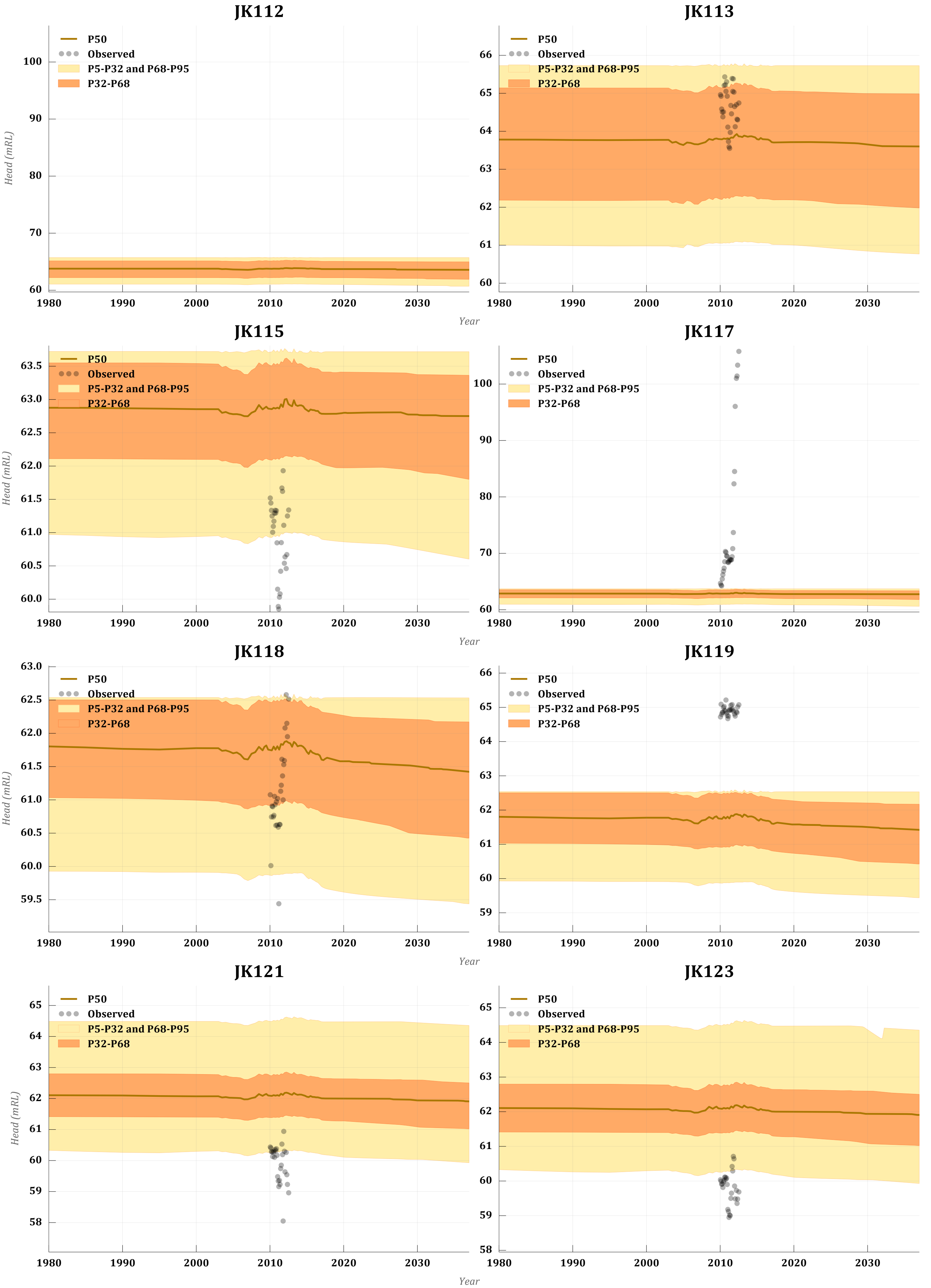
1990
2000
2010
2020
2030


JK112
JK113
JK115
JK117
JK118
JK119
JK121
JK123
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
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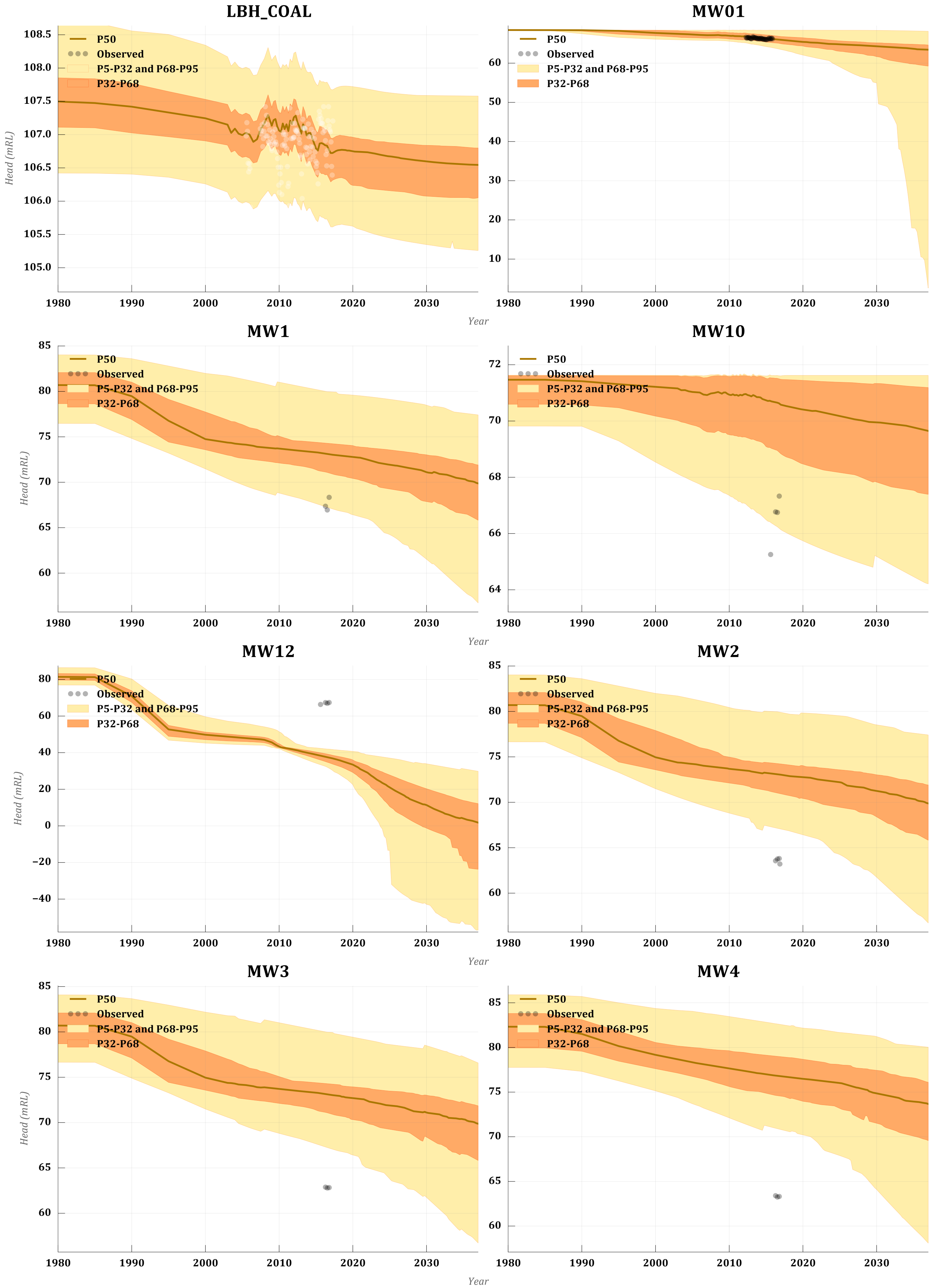
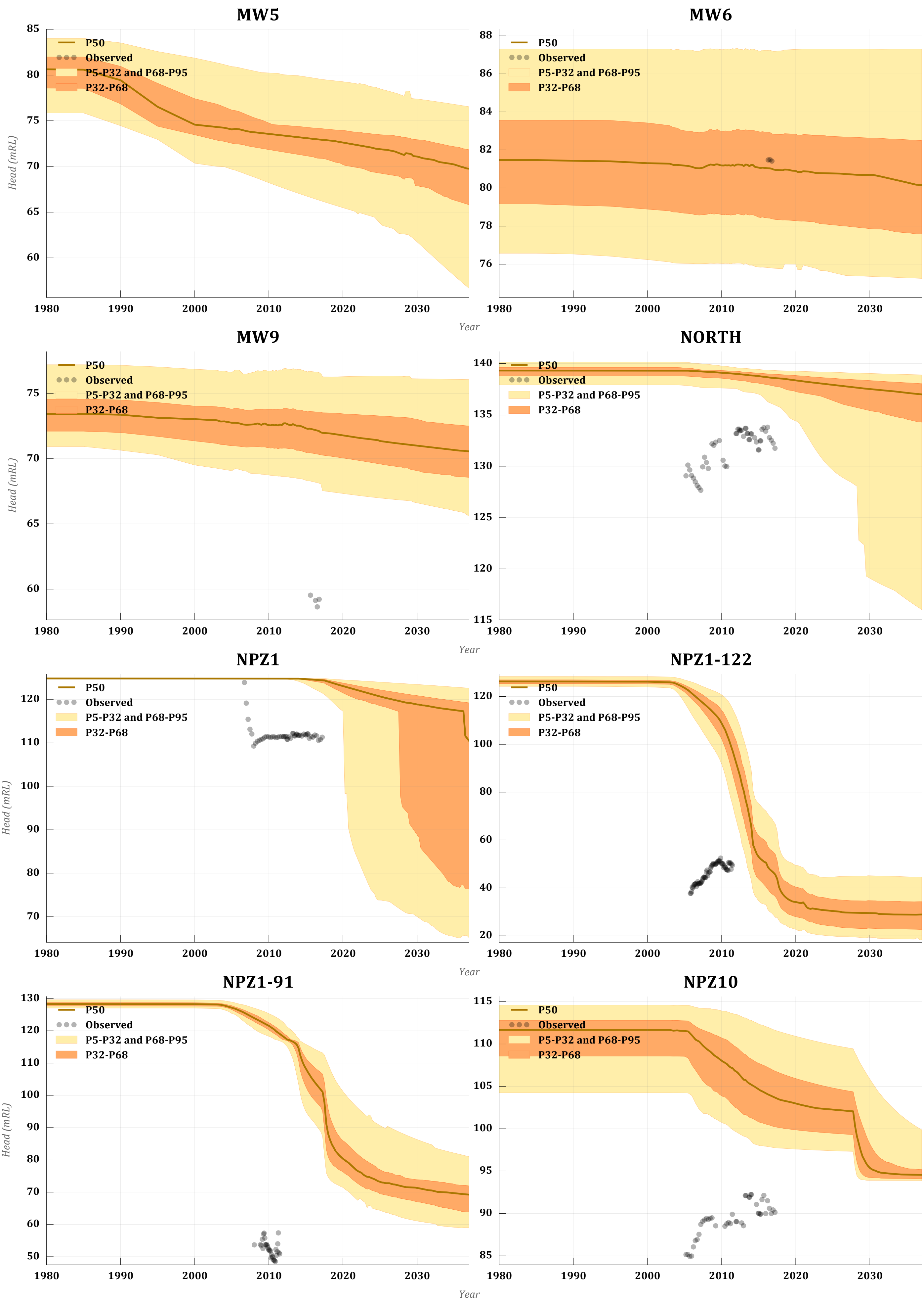
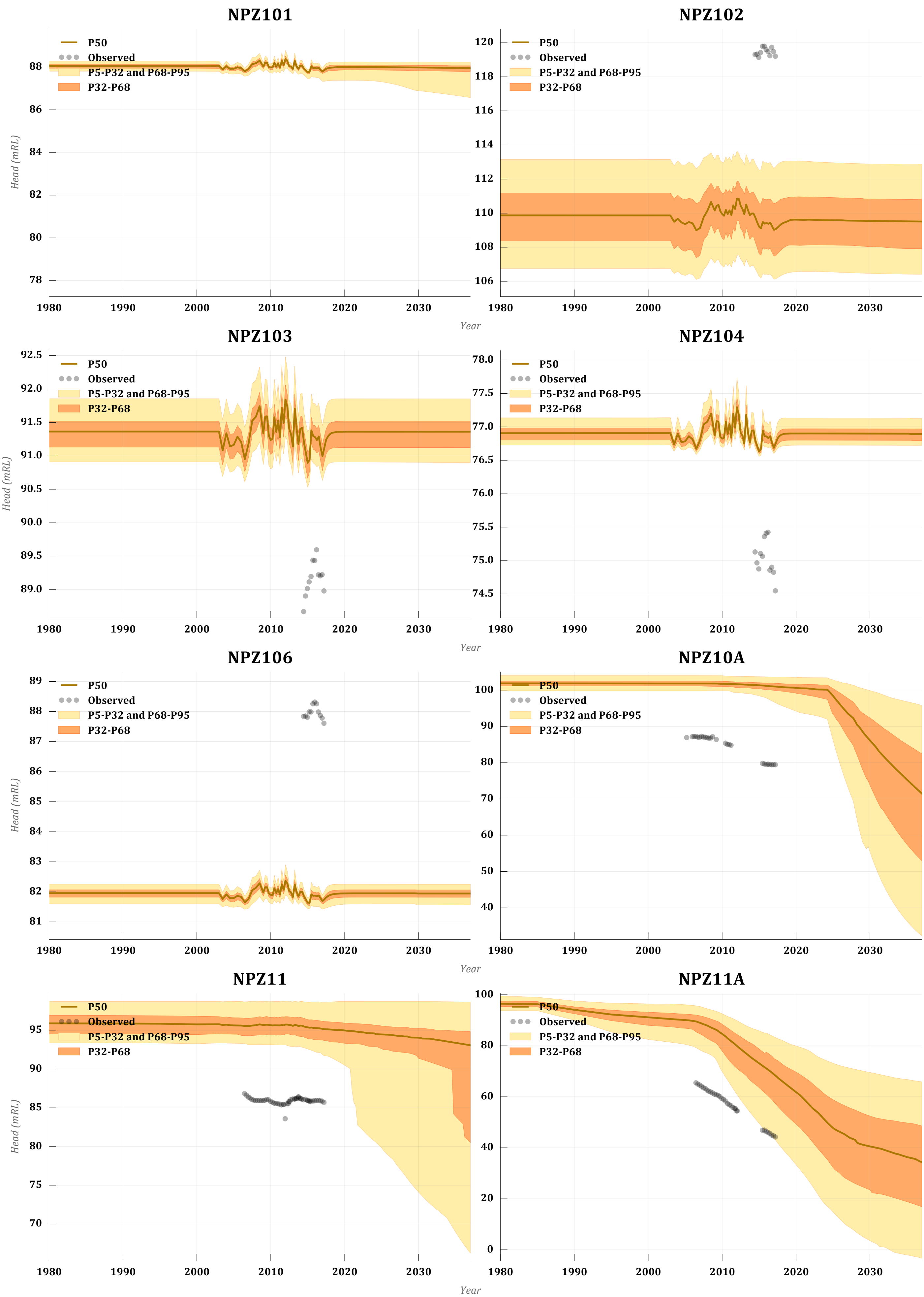
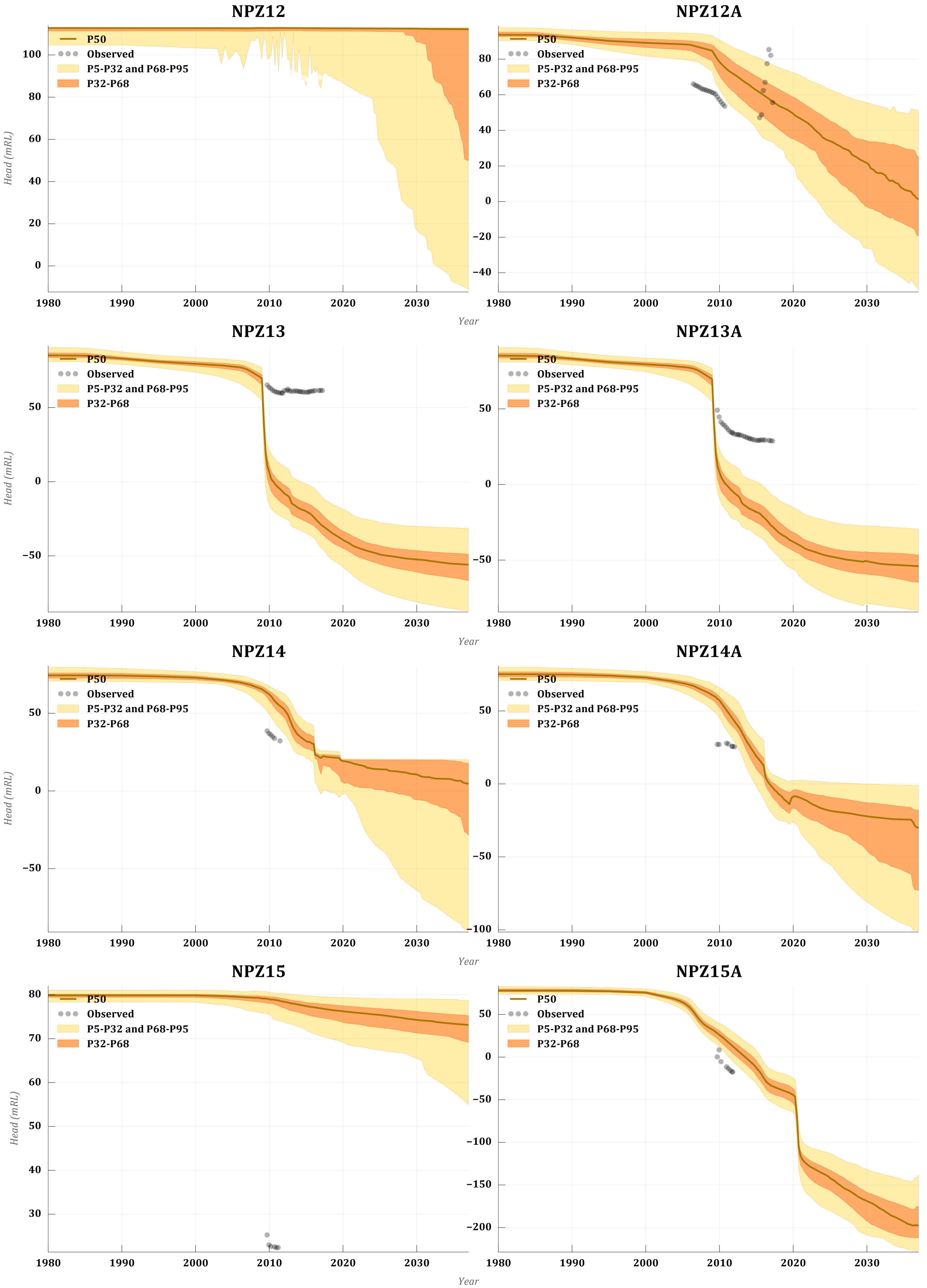
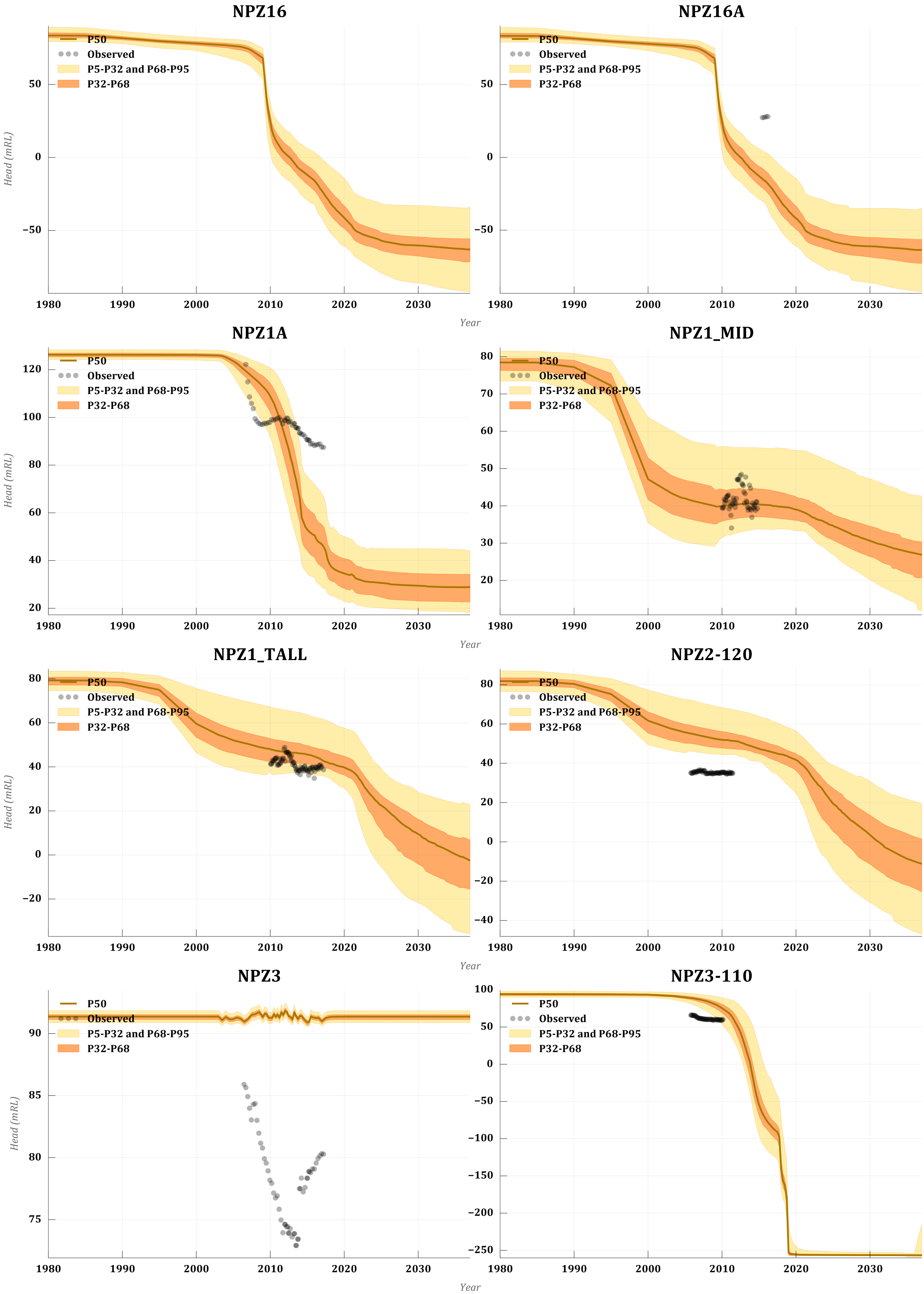
2010
2020
2030


LBH_COAL
MW01
MW1
MW10
MW12
MW2
MW3
MW4
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030

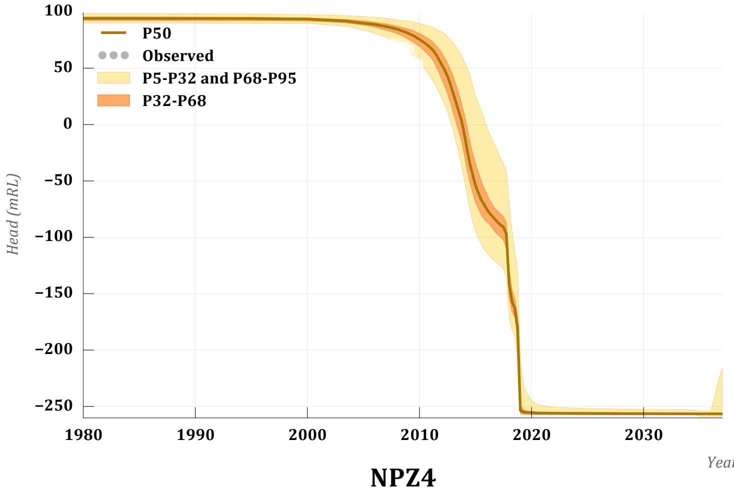

MW5
MW6
MW9
NORTH
NPZ1
NPZ1-122
NPZ1-91
NPZ10
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030


NPZ101
NPZ102
NPZ103
NPZ104
NPZ106
NPZ10A
NPZ11
NPZ11A
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030

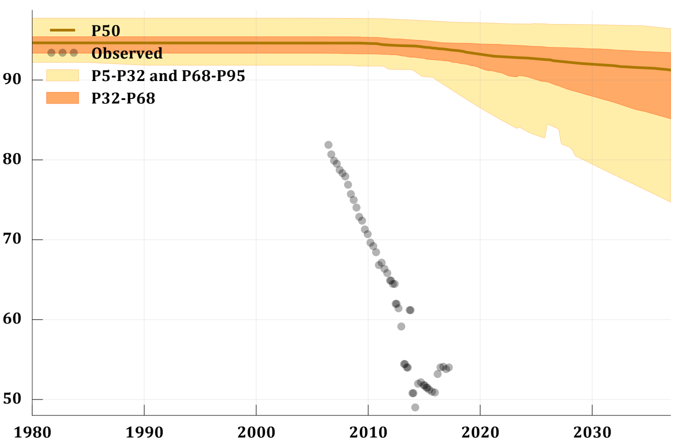

NPZ12
NPZ12A
NPZ13
NPZ13A
NPZ14
NPZ14A
NPZ15
NPZ15A
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030


NPZ16
NPZ16A
NPZ1A
NPZ1_MID
NPZ1_TALL
NPZ2-120
NPZ3
NPZ3-110
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030

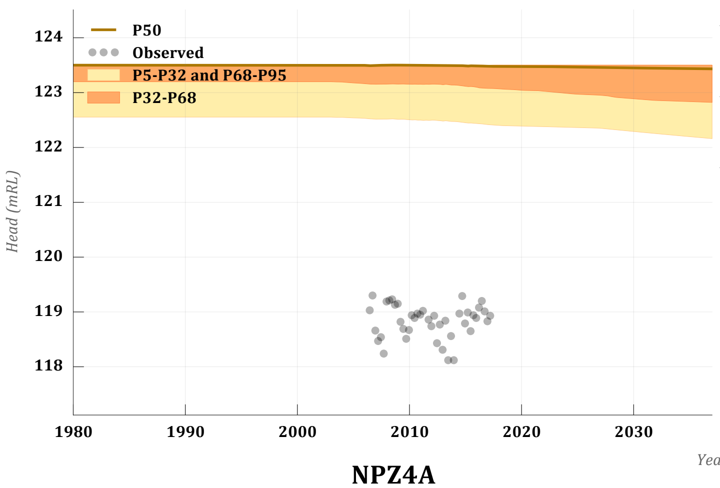
NPZ3-64



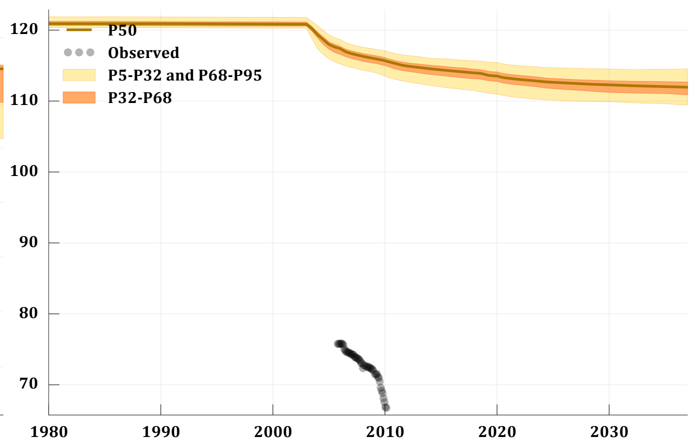
NPZ3A



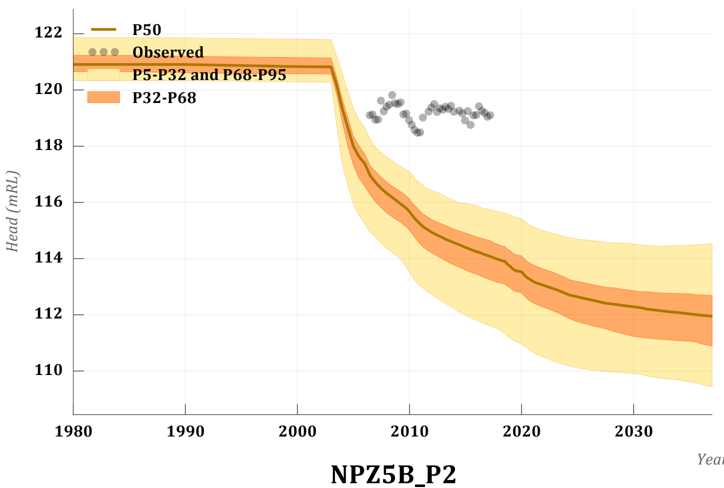
NPZ4



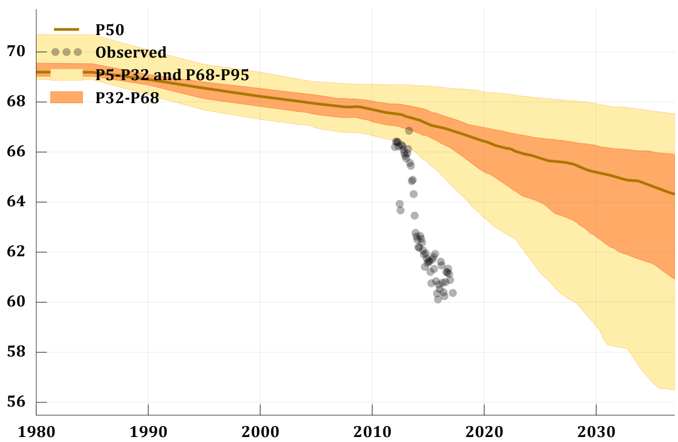
NPZ4-90



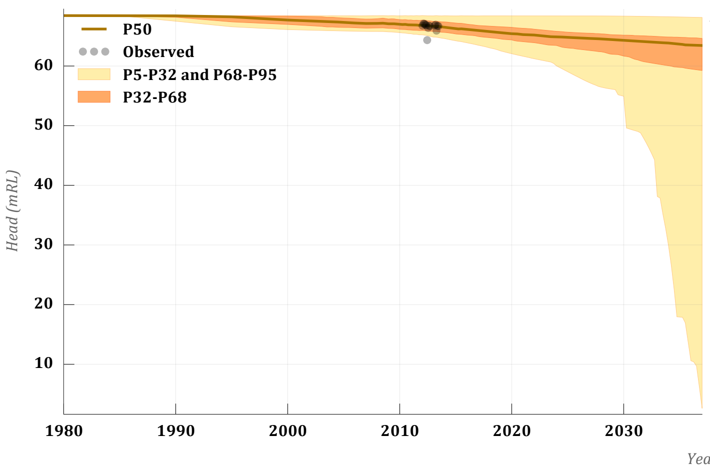
NPZ4A



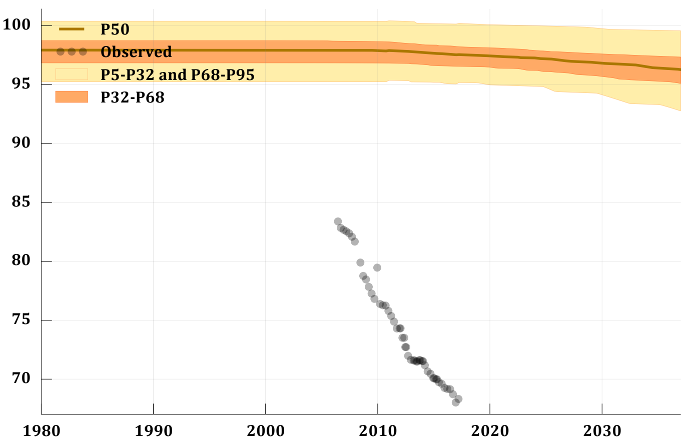
NPZ5B_P1

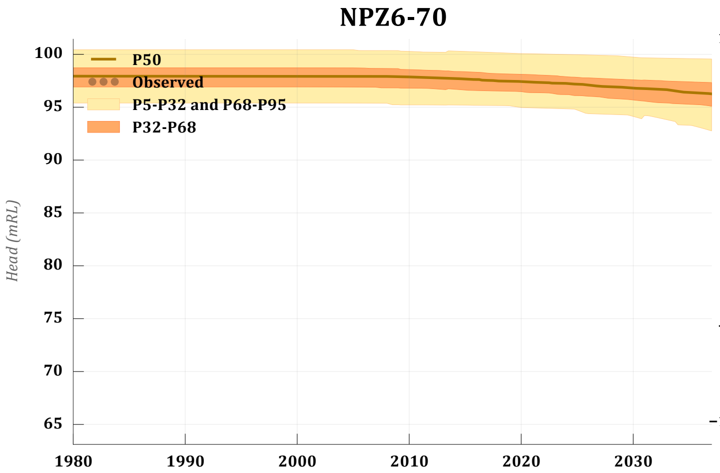


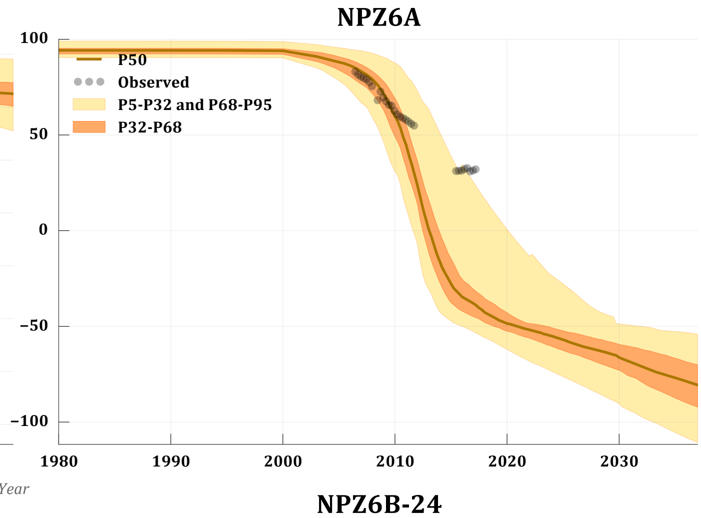
NPZ5B_P2



NPZ6




NPZ6-70
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
100
95
90
85
80
75
70
65
1980
1990
2000
2010
2020
2030


NPZ6A
P50
Observed
P5-P32 and P68-P95
P32-P68
100
50
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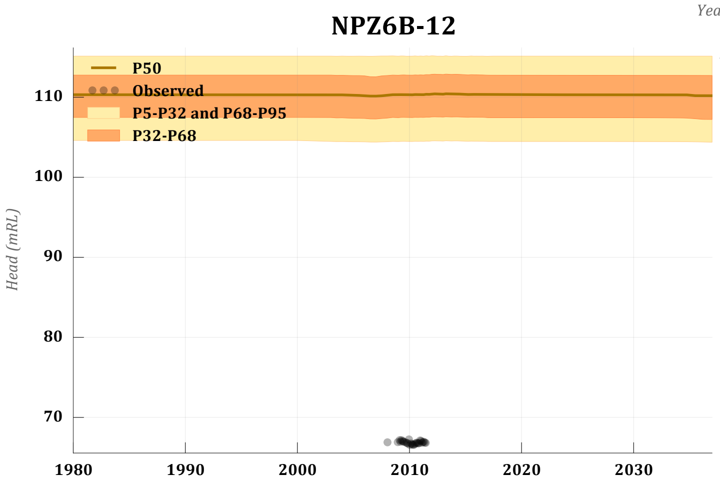
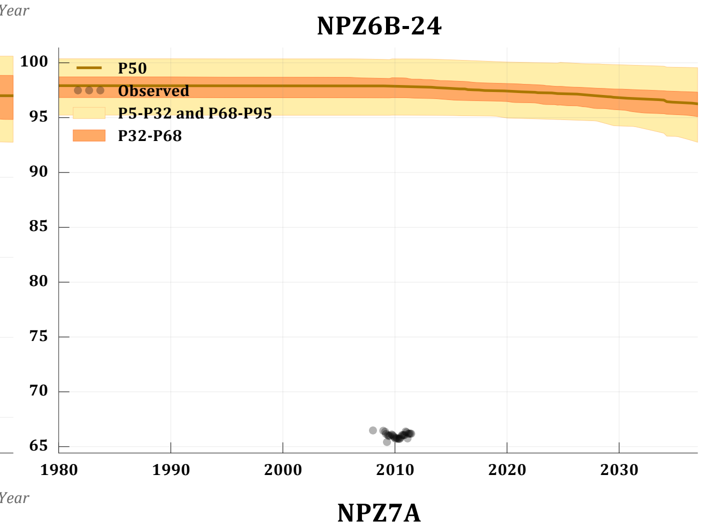
1980
1990
2000
2010
2020
2030
Year


NPZ6B-12
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
110
100
90
80
70
1980
1990
2000
2010
2020
2030


NPZ6B-24
P50
Observed
P5-P32 and P68-P95
P32-P68
100
95
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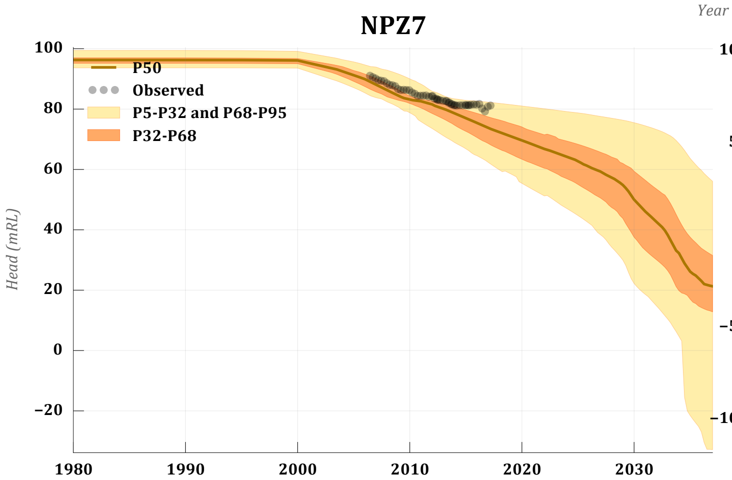
2020
2030
Year


NPZ7
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
100
80
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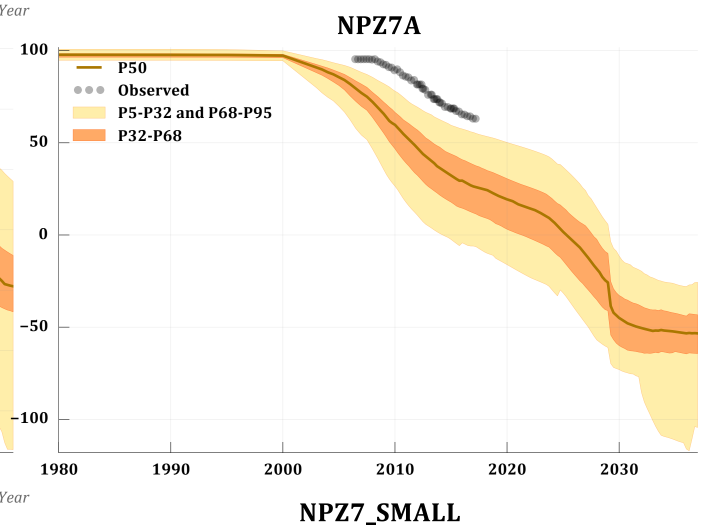
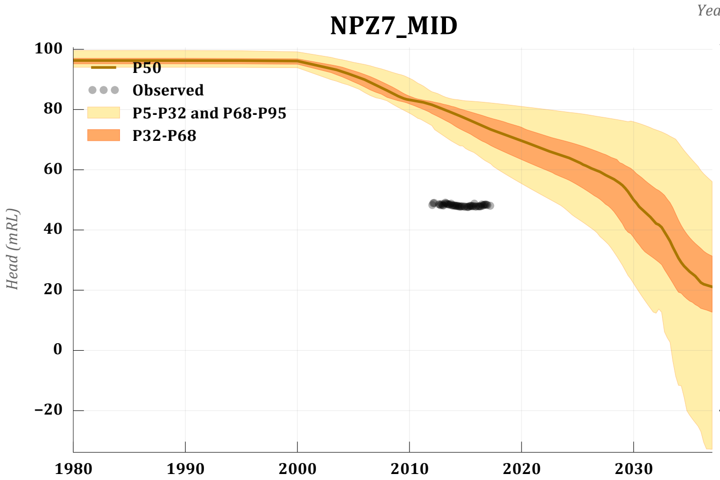
1990
2000
2010
2020
2030


NPZ7A
P50
Observed
P5-P32 and P68-P95
P32-P68
100
50
0
−50
−100
1980
1990
2000
2010
2020
2030
Year


NPZ7_MID
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
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20
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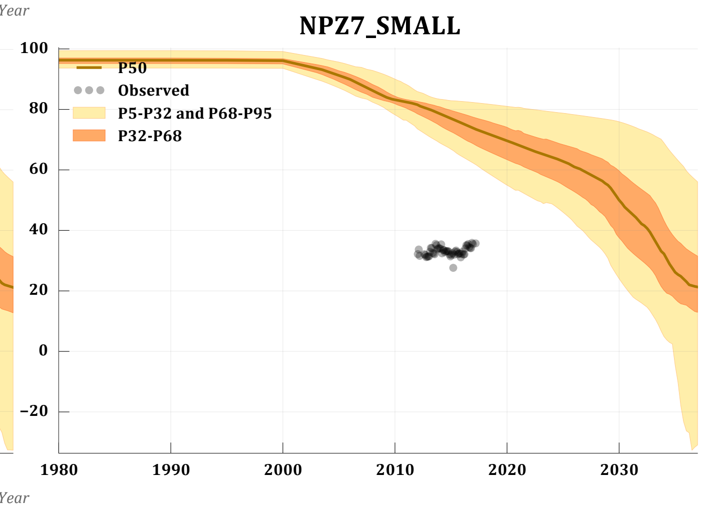
1990
2000
2010
2020
2030


NPZ7_SMALL
P50
Observed
P5-P32 and P68-P95
P32-P68
100
80
60
40
20
0
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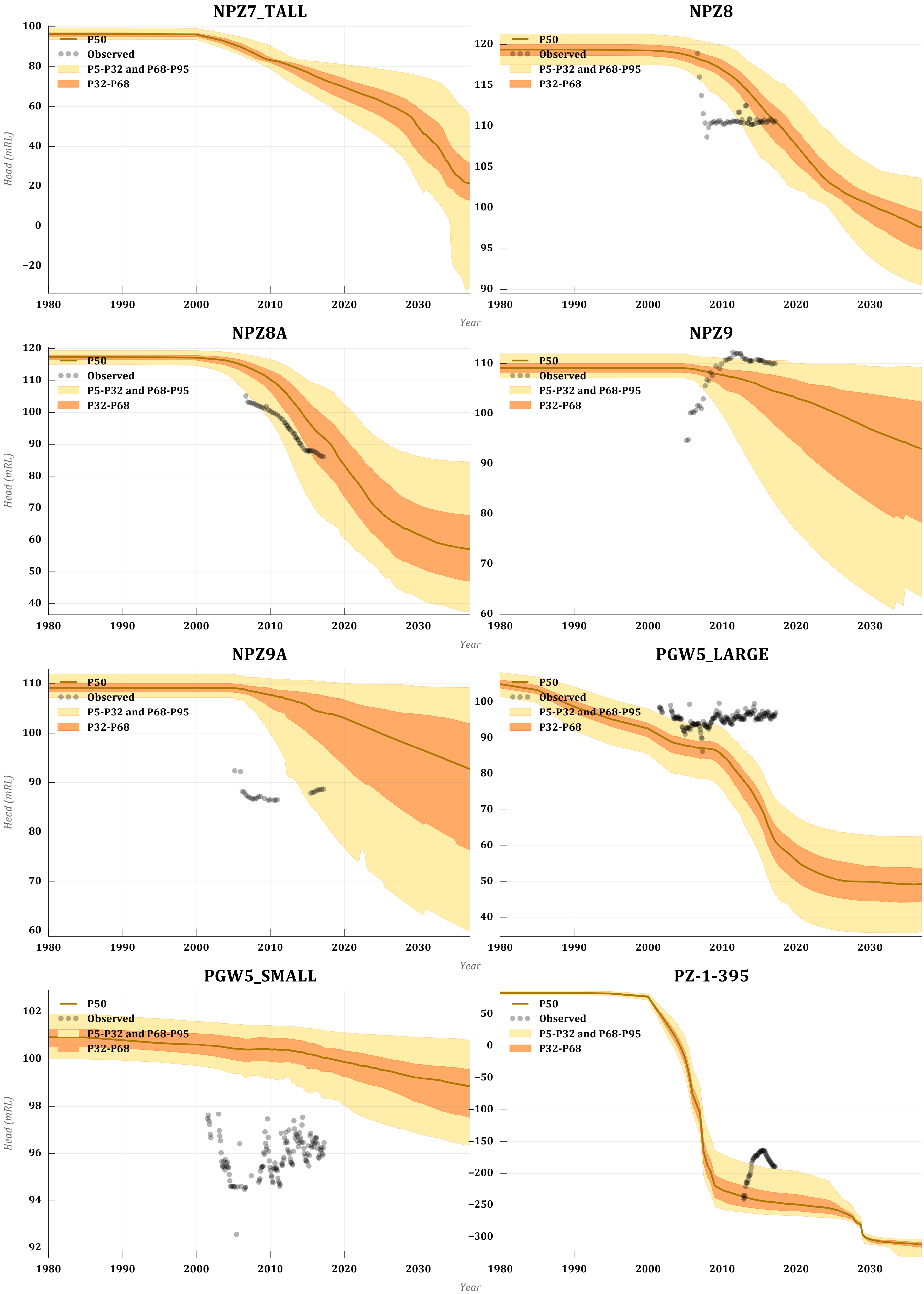
1980
1990
2000
2010
2020
2030
Year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NPZ8A
NPZ9
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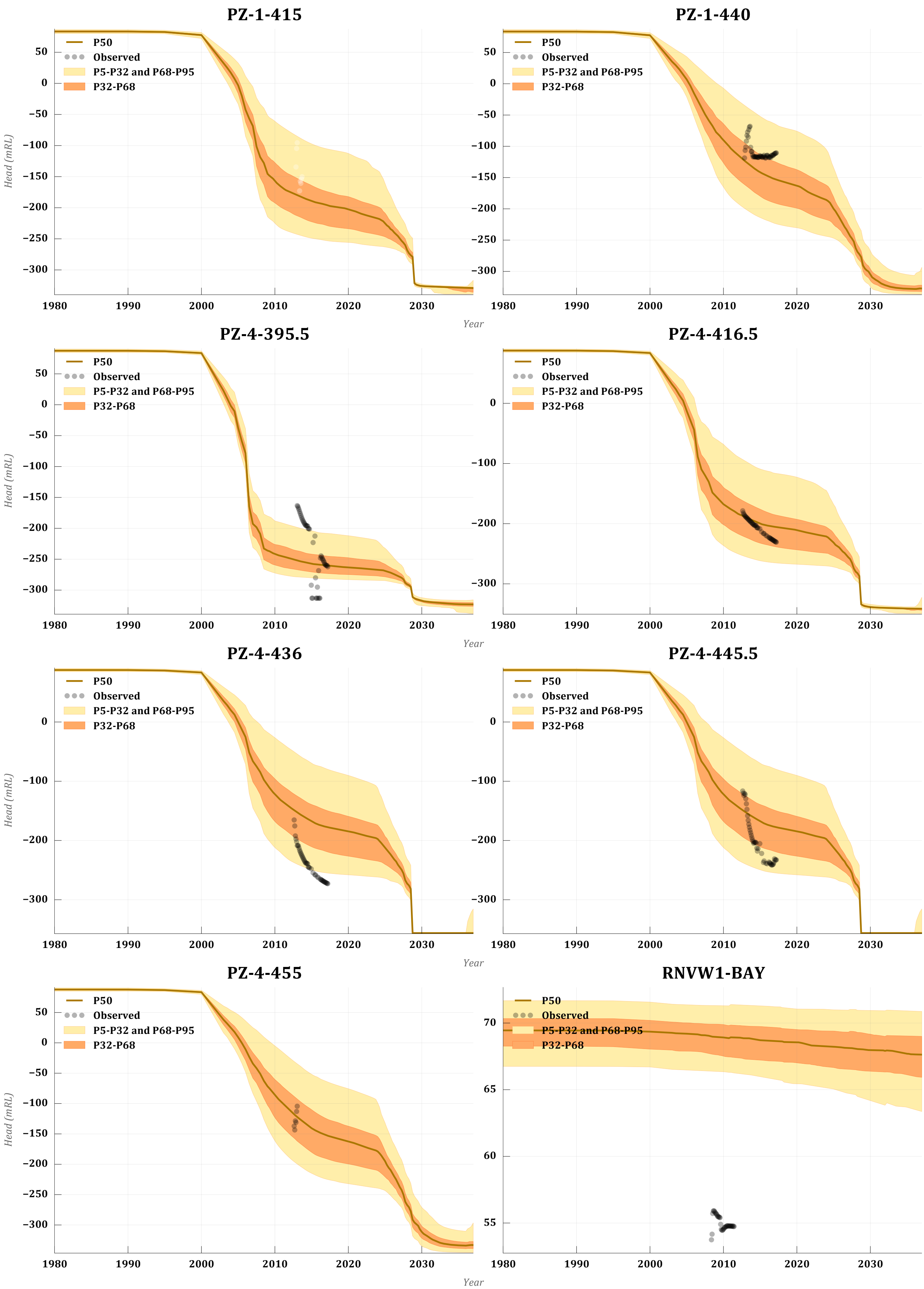
PZ-1-395
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030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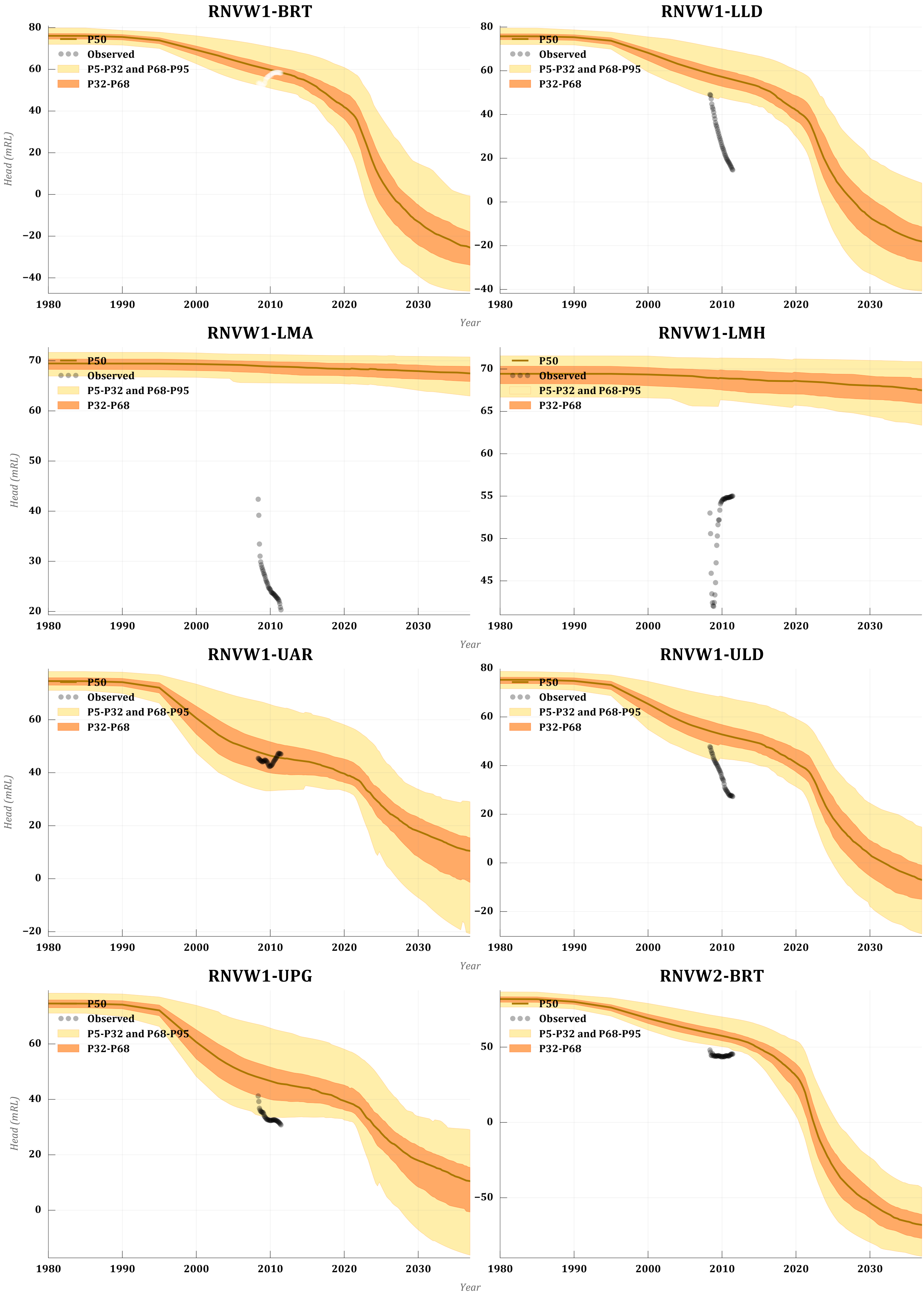
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year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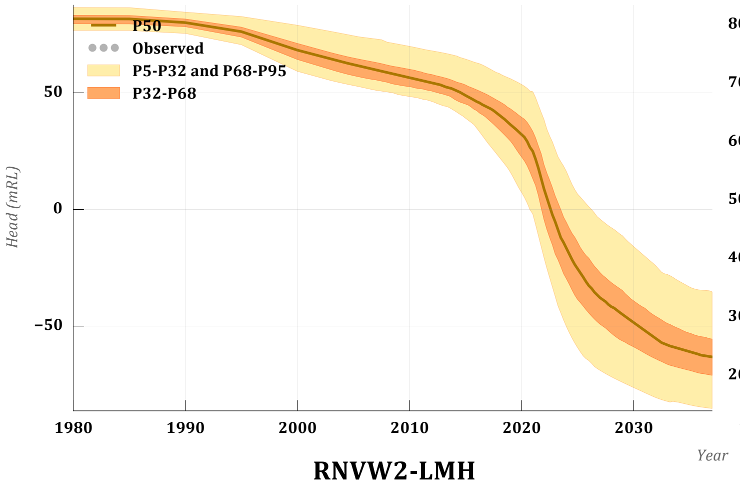
RNVW1-LLD
RNVW1-LMA
RNVW1-LMH
RNVW1-UAR
RNVW1-ULD
RNVW1-UPG
RNVW2-BRT
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030

RNVW2-LLD



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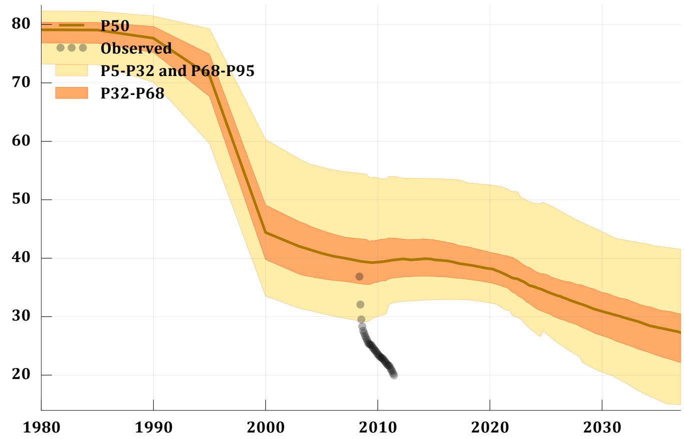

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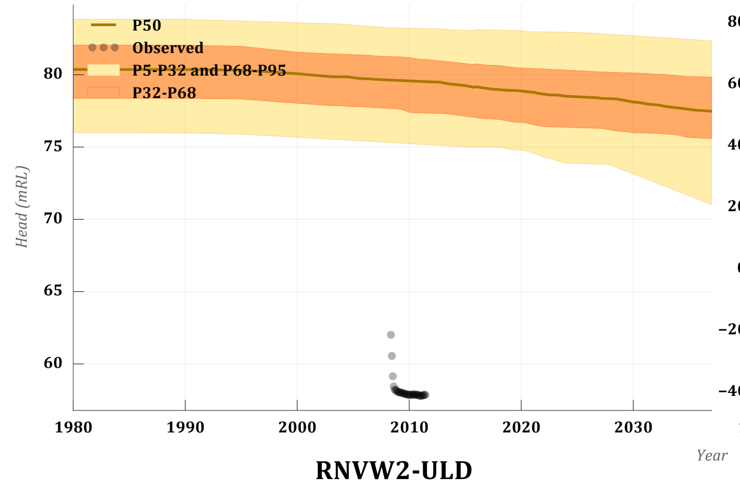

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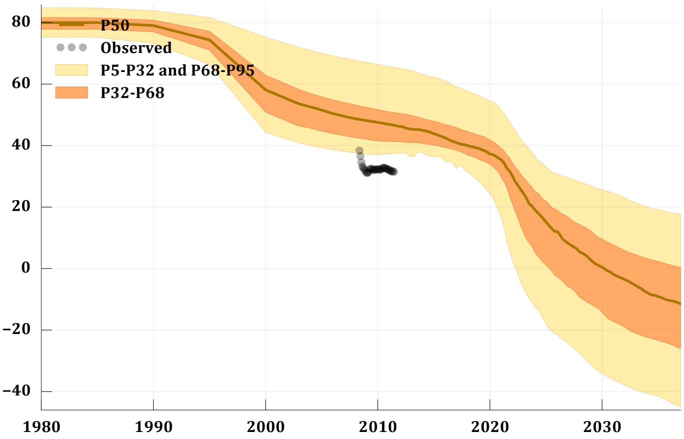

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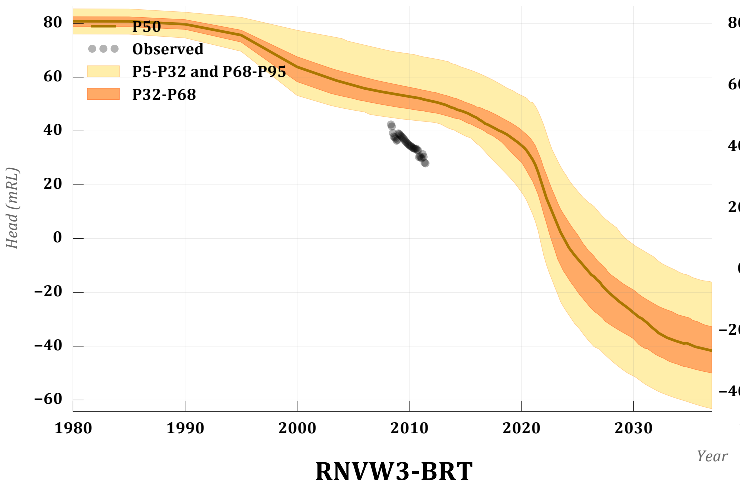

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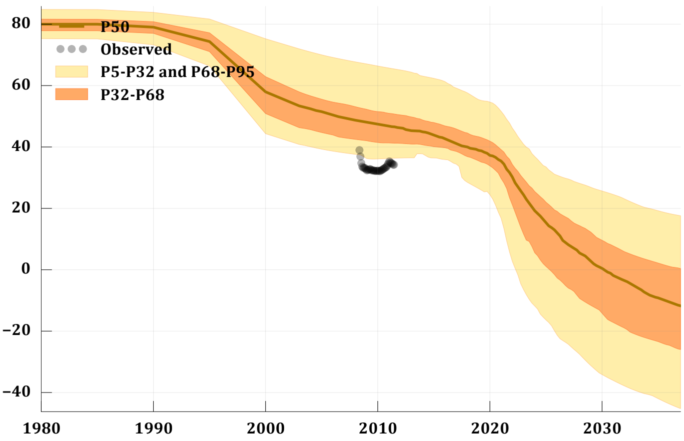

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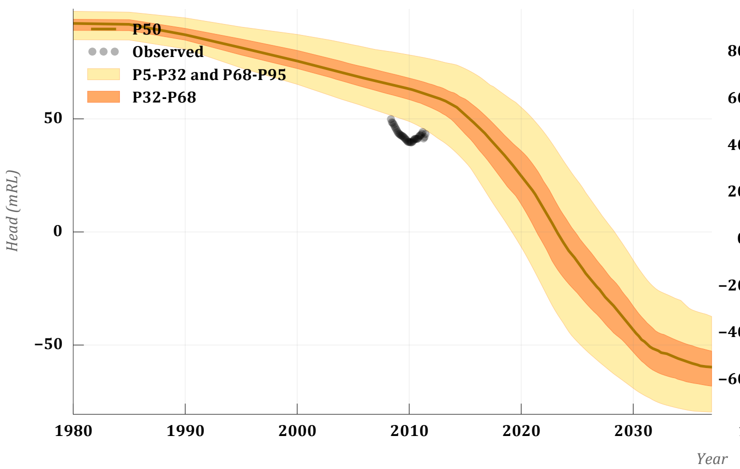

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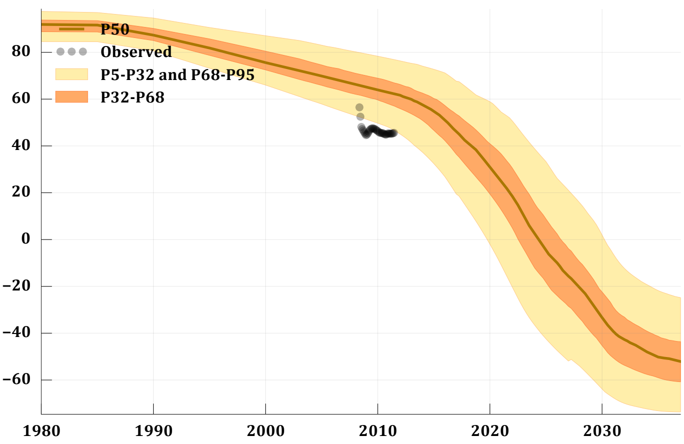

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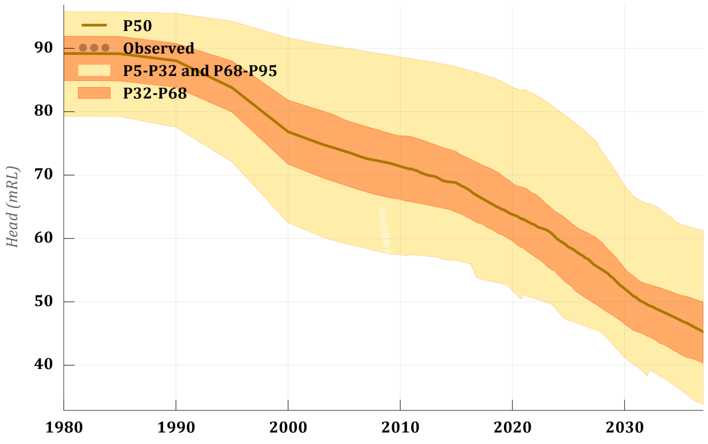

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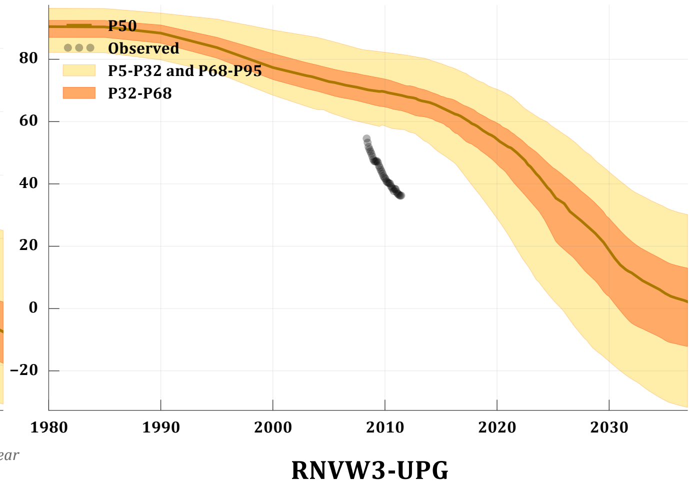

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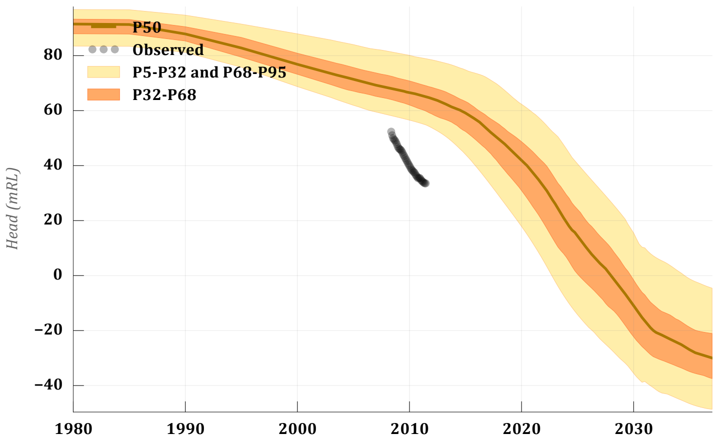

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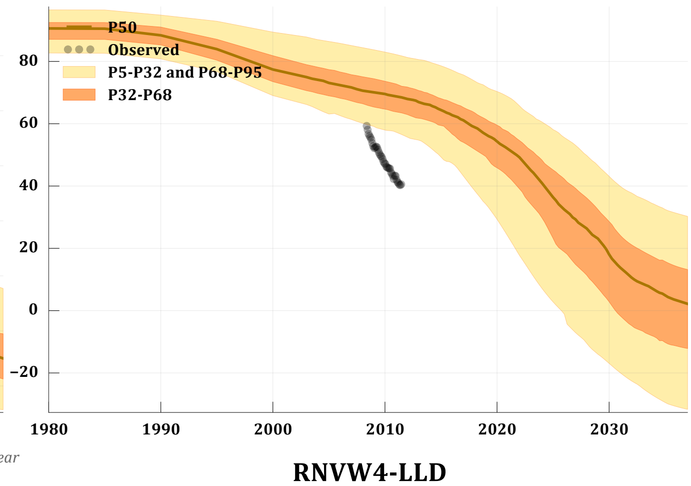

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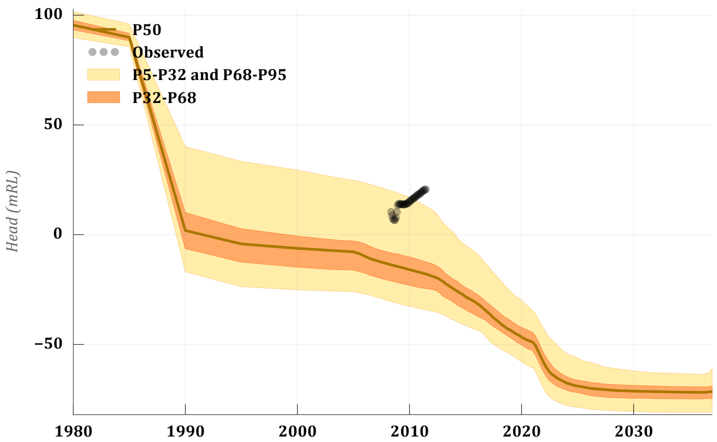

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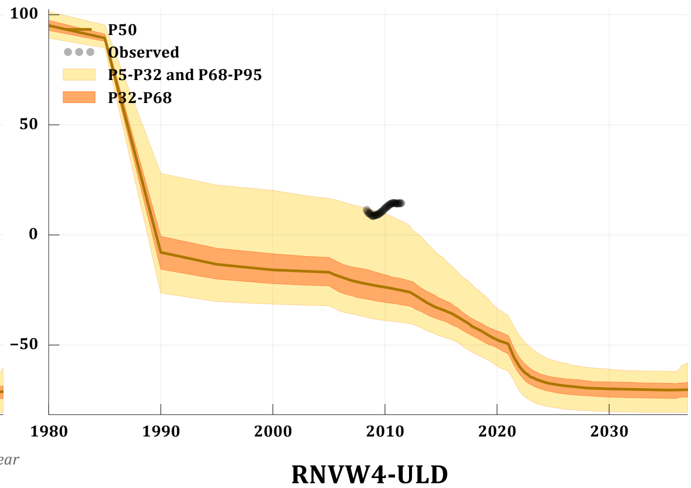

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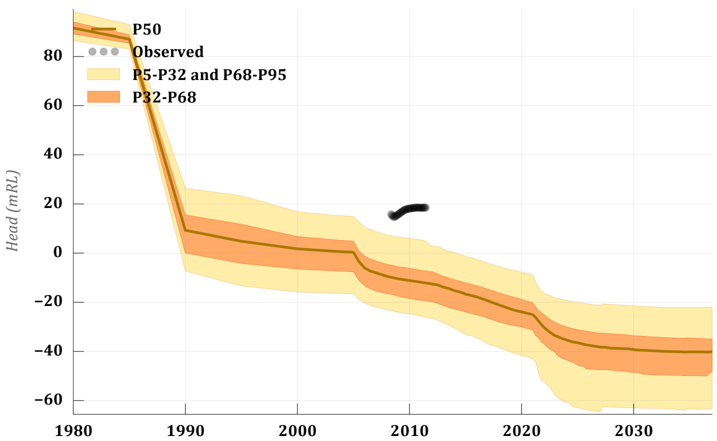

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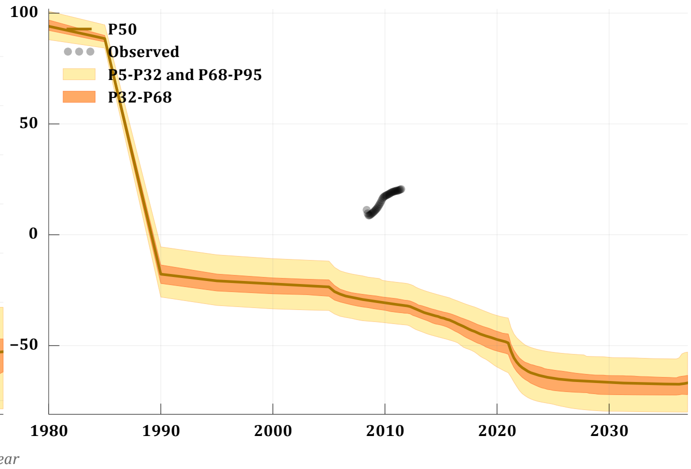
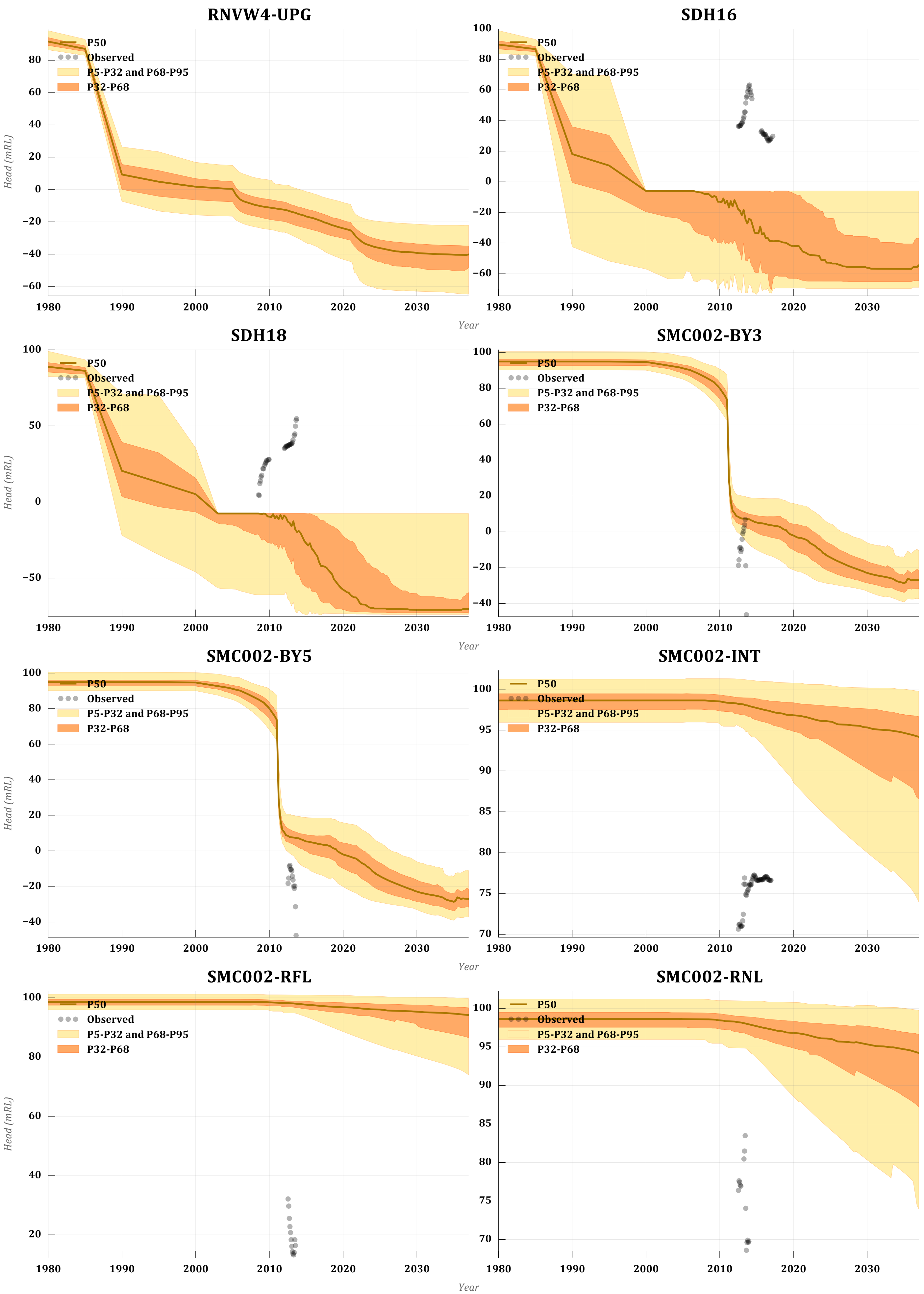
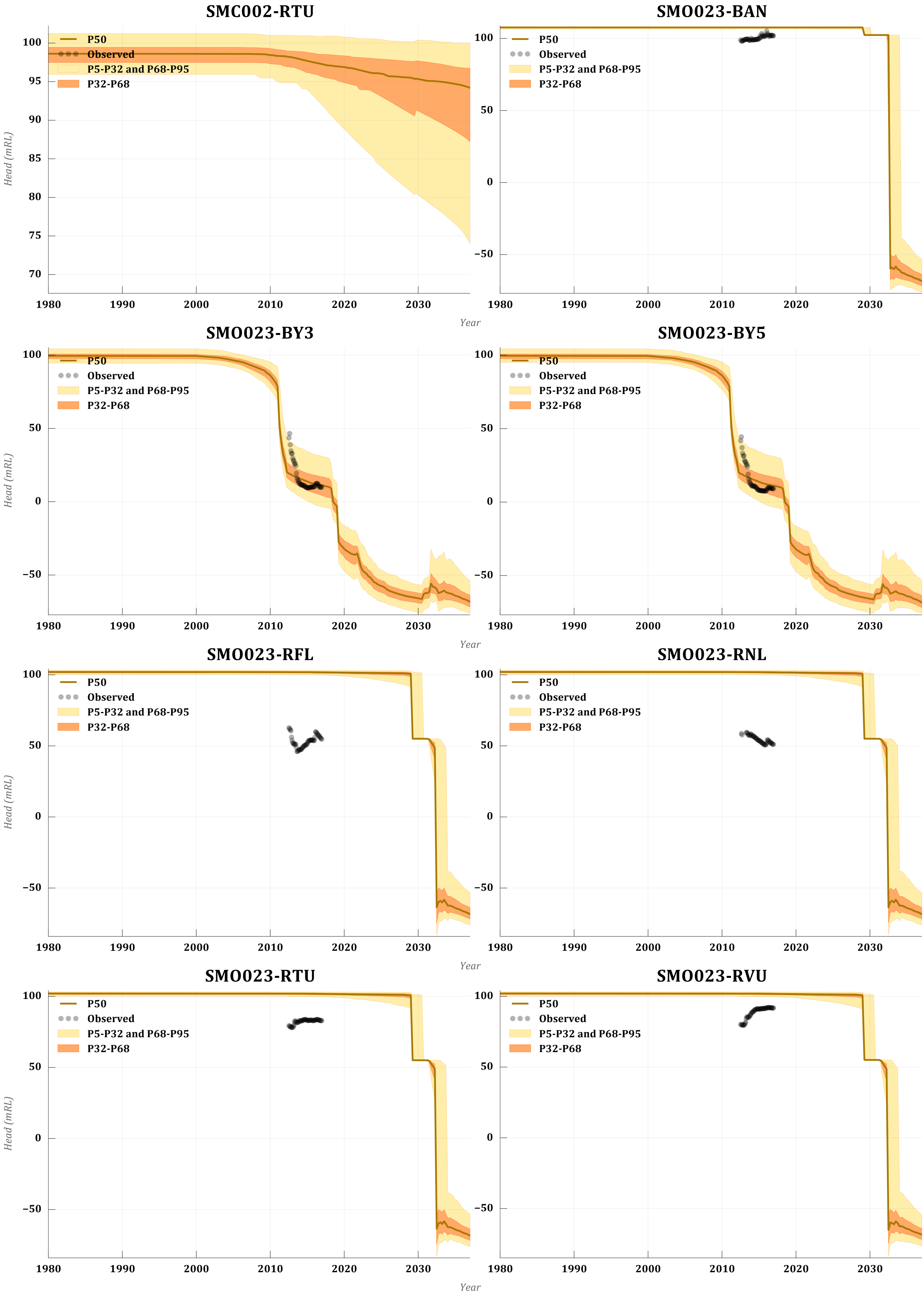



RNVW4-UPG
SDH16
SDH18
SMC002-BY3
SMC002-BY5
SMC002-INT
SMC002-RFL
SMC002-RNL
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year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SM0023-BAN
SM0023-BY3
SM0023-BY5
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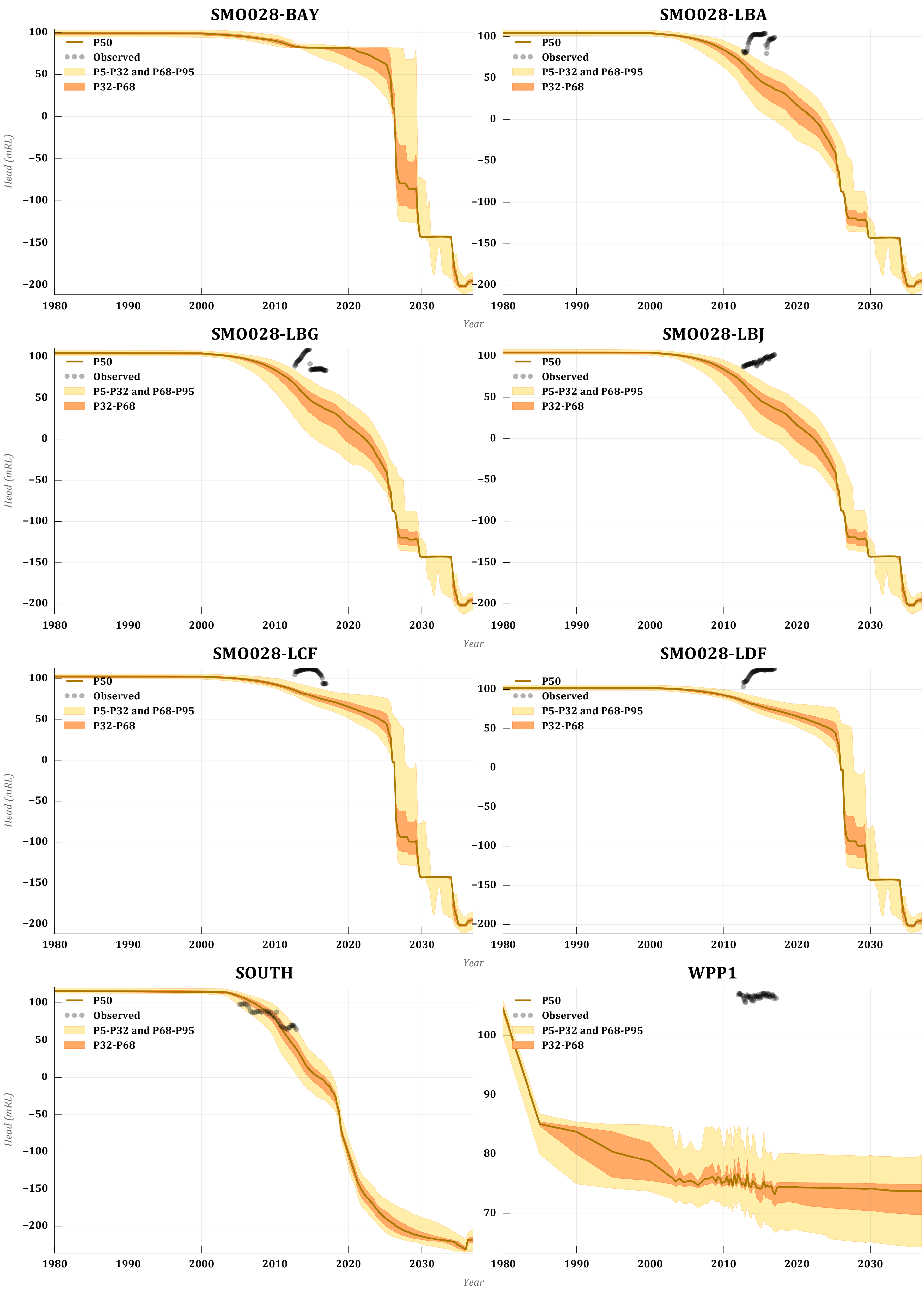
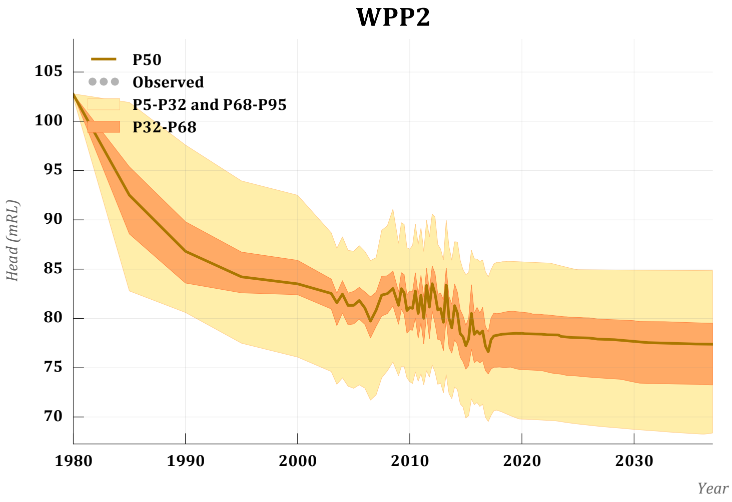
SM0023-RNL
SM0023-RTU
SM0023-RVU
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
1980
1990
2000
2010
2020
2030


SMO028-BAY
SMO028-LBA
SMO028-LBG
SMO028-LBJ
SMO028-LCF
SMO028-LDF
SOUTH
WPP1
P50
Observed
P5-P32 and P68-P95
P32-P68
Head (mRL)
Year
100
50
0
−50
−100
−150
−200
90
80
70
1980
1990
2000
2010
2020
2030


WPP2
P50
Observed
P5-P32 and P68-P95
P32-P68
105
100
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90
85
80
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70
Head (mRL)
1980
1990
2000
2010
2020
2030
Year

Table C 1-1 presents the comments from the peer review report prepared by Hydroalgorithmics and describes how these have been addressed in the final version of the groundwater assessment report.

Table C 1-1 Peer review comments and response

	Review comment	Actions to address comment
1	Consistent spelling of "licence" when used as a noun.	• all occurrences of “license” replaced with “licence” when used as a noun
2	Reference to inflow rather than flux, which is flow per unit area.	• all occurrences of “flux” changed to “flow” when referring to changes in the water budgets for the alluvial groundwater systems. • all occurrences of “flux” changed to “inflow” when referring to drain cell water budgets
3	Figure 4-6: correction to caption - depth to base of Hebden Seam, not seam thickness.	• changed caption to “structure and depth to base of Hebden seam”
4	Table 7-1: delete North Pit from the caption, as other pits are included; correct the spelling of Bayswater.	• deleted North Pit from caption • corrected spelling of “Bayswater”
5	Section 7.4: correction - 179 --> 225 realisations (as in Appendix C).	• changed “179 model realisations” to “225 model realisations” in Section 7.4
6	References: Engengy --> Engeny.	• changed “Engengy” to “Engeny” as required
7	Table C7: add tick in Class 3 for "Timeframe <3 x"	• added tick to “Table C 12 Class 3 adjacent to "Timeframe <3 x"
8	Section 5.3: A-3 --> C-3	• changed “Appendix A-3” to “Appendix C-3” within Section C5.3
9	Figure C25: hydraulic --> hydraulic conductivity	• changed Figure c 25 caption to “Interburden hydraulic conductivity distribution graph”
10	Figure C29: Bowans --> Bowmans.	• Changed “Bowans” to “Bowmans in legend of Figure C29
11	There is no mention in the report as to whether the model treats the other faults in any special way, or whether the throw for the Hebden Thrust Fault is sufficient to warrant simulated discontinuity of the coal seams across the fault.	• added the following text to Section C2.2.1 “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.”

	Review comment	Actions to address comment
12	An annotated classification table of attributes from the guidelines has been included as Table C 12. An additional tick should be placed against "Timeframe <3 x" in the Class 3 row. 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 22% Class 2 and 78% Class 3.	• added tick to "Table C 12 Class 3 adjacent to "Timeframe <3 x"
13	A substantial uncertainty analysis has been undertaken using a null-space monte carlo technique, using 225 alternative calibrated realisations out of a trial set of 275 selections. The acceptability criterion should be stated.	• added text within Section C5.3 discussing the realisation results – an acceptability criterion was not required as the null space methodology only produces calibrated realisations
14	Section C3.2 of Document #2 cites "the homogeneous hydraulic conductivity adopted for each layer" as a reason for occurrences of poor hydrographic calibration. This cannot be a reason, as it is clear that each layer has spatial variability as a consequence of using a decay function (hydraulic conductivity reducing with depth). However, the reliance on a simple formula to generate the spatial distributions is a valid reason. There are other incorrect references to layer homogeneity at Section C3.2.4 ("introduce heterogeneity") and Section C5.2 ("an entire homogenous unit").	• In Section C3.2 added sentence "This is most likely due to simplifying assumptions such as the reliance on a simple formula to generate the spatial distribution of hydraulic conductivity adopted for each layer"

	Review comment	Actions to address comment
15	The reviewer is of the view that the adopted specific yields for Permian model layers are too low. The sensitivity analysis in Figure C 27 indicates high Sy identifiability for layers 1-5 (Sy values 0.4-5%), poor Sy identifiability for layers 6-10 (values 0.01-0.11%), and no Sy identifiability for layers 11-21 (values 0.01-0.028%; 0.92% in Barrett Seam). 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, this approach would be conservative in terms of environmental effects	• reviewers comment noted, but no changes made to report

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PO Box 241, Gerringong NSW 2534. Phone: (+61 2) 4234 3802

noel.merrick@hydroalgorithmics.com

DATE: 19 March 2018

TO: Penelope Williams
Senior Environmental Planner
Umwelt (Australia) Pty Limited
75 York Street
Teralba NSW 2284

FROM: Dr Noel Merrick

RE: Mount Owen Continued Operations Project Modification – Groundwater Peer Review

YOUR REF: 3810F/TC/PW/300517

OUR REF: HA2018/5

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1. Introduction

This report provides a peer review of the groundwater impact assessment (GIA) and associated modelling for the Mount Owen Continued Operations Project S.96 Modification to SSD-5850, located to the north-west of Singleton. The GIA has been prepared by Australasian Groundwater and Environmental Consultants (AGE) under the project management of Umwelt, for the client Mount Owen Pty Ltd, a subsidiary of Glencore Coal Pty Ltd.

The main elements of the Modification that are relevant to groundwater assessment are:

- Increased mining footprint (by 46 ha).
- Deeper mining down to the base of the Hebden Seam (extra 80 m maximum).
- Extended mine life (by 4 years).

The reviewer conducted a previous groundwater peer review in October 2014 on the Mount Owen Continued Operations (MOCO) Project, and also in December 2017 for the neighbouring Integra Underground MOD8 Project.

2. Documentation

The review is based on the following report:

1. AGE, 2018, Groundwater Impact Assessment Mt Owen Mine. Project G1862A report prepared for Mount Owen Pty Limited, v02.01, 16 February 2018. 84p + 4 Appendices.

Groundwater modelling details are in Appendix C of Document #1:

2. AGE, 2018, Numerical Modelling Report, 61p + 3 Appendices.

Document #1 has the following major sections:

1. Introduction
2. Regulatory framework
3. Environmental setting
4. Geological setting
5. Hydrogeology
6. Numerical groundwater model
7. Model predictions and impact assessment
8. Groundwater monitoring and management plan
9. Summary and conclusions
10. References

The Appendices are:

A. Limit of alluvium investigation
B. Monitoring bore construction details
C. Numerical modelling report
D. Compliance with government policy

Document #2 is structured as follows:

1. Introduction
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. Prior and posterior parameter confidence distributions
3. 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 the newer guidelines issued by the National Water Commission 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 2012 national guidelines build on the 2001 MDBC guide, with substantial consistency in model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details. The new guide is 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. Recently (early March 2018), the Independent Expert Scientific Committee (IESC) released a draft Explanatory Note on Uncertainty Analysis in Groundwater Modelling, seeking feedback before finalisation (Middlemis & Peeters, 2018[3]).

The groundwater impact assessment has been reviewed according to the 2-page Model Appraisal

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[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.

[3] Middlemis, H. & Peeters, L. (2018) Explanatory Note, Uncertainty Analysis in Groundwater Modelling. Report prepared for IESC on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy.

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.

It should be recognised that the effort put into the modelling component of a groundwater impact assessment is very dependent on possible timing and budgetary constraints that are generally not known to a reviewer. However, this is less of an issue with a progressive review.

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 phone/email correspondence and a series of three teleconferences.

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 nearly 400 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 high quality. The report serves well as a standalone document, with no undue dependence on earlier work.

Previous review comments after conceptualisation and model design stages have been addressed satisfactorily. Although some editorial corrections are warranted, they are not the focus of this review.

Overall, there are no significant matters of concern in the report as to structure or depth of coverage, and there is a clear focus on regulatory requirements.

The objectives are stated clearly at the outset (Section 1.1), and the text of the report and its Conclusion sufficiently address those objectives.

The report would benefit from the following amendments:

- Consistent spelling of "licence" when used as a noun..
- Reference to inflow rather than flux, which is flow per unit area.
- Figure 4-6: correction to caption - depth to base of Hebden Seam, not seam thickness.
- Table 7-1: delete North Pit from the caption, as other pits are included; correct the spelling of Bayswater.
- Section 7.4: correction - 179 --> 225 realisations (as in Appendix C).
- References: Engengy --> Engeny.
- Table C7: add tick in Class 3 for "Timeframe <3 x"
- Section 5.3: A-3 --> C-3
- Figure C25: hydraulic --> hydraulic conductivity
- Figure C29: Bowans --> Bowmans.

[4] The newer guidelines include a more detailed checklist with yes/no answers but without the graded assessments of the 2001 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.

5. Data Matters

Data from several mine monitoring networks have been combined for cause-and-effect analysis and model calibration. The datasets are substantial, with 49 alluvial sites and 277 Permian sites. The cause-and-effect analysis reveals mining effects at depth but not in alluvium.

Considerable effort has been put into resolving different interpretations of alluvial extent, making use of test pits, CSIRO regolith inference, and geophysics. A transient electromagnetic method (TEM) survey has been particularly useful in giving better definition of the alluvium.

Baseflow analysis has been conducted on streamflow records for several streams using the Arnold-Allen method.

Hydraulic conductivity estimates for modelling are informed primarily by 79 packer tests, a substantial number, with support coming from 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.

The geology, though complex, is well known. Of the several structural faults noted in the report, the Hunter Thrust Fault is used as an impermeable model boundary on the north-eastern side (except near land surface where water exchange is allowed). There is no mention in the report as to whether the model treats the other faults in any special way, or whether the throw for the Hebden Thrust Fault is sufficient to warrant simulated discontinuity of the coal seams across the fault.

6. Model Matters

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;
- a novel 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 model generally achieves aspects of Class 2 and Class 3 confidence level criteria."*

An annotated classification table of attributes from the guidelines has been included as Table C 12. An additional tick should be placed against "Timeframe <3 x" in the Class 3 row. 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 22% Class 2 and 78% Class 3.

Calibration performance statistics of 6.6 %RMS and 29 mRMS are acceptable for such a complex mining precinct. The scattergram (Figure C 11) is generally linear across a wide range, but there is some remaining bias due to underestimation at high heads and overestimation at low heads. This also is evident in the residuals diagram (Figure C 12). Replication of vertical head profiles (Figure C 13) is generally good.

The model predictions differ from those reported with the previous MOCO model, but more confidence should be placed in the current model as it is superior in design and application.

A substantial uncertainty analysis has been undertaken using a null-space *monte carlo* technique, using 225 alternative calibrated realisations out of a trial set of 275 selections. The acceptability criterion should be stated. While this approach is still state-of-art, there will soon be an expectation of "proof" that the reported outputs for each percentile level are sufficiently converged for the chosen number of realisations. This test is encouraged by the IESC draft Explanatory Note on Uncertainty Analysis in Groundwater Modelling.

Section C3.2 of Document #2 cites "the homogeneous hydraulic conductivity adopted for each layer" as a reason for occurrences of poor hydrographic calibration. This cannot be a reason, as it is clear that each layer has spatial variability as a consequence of using a decay function (hydraulic conductivity reducing with depth). However, the reliance on a simple formula to generate the spatial distributions is a valid reason. There are other incorrect references to layer homogeneity at Section C3.2.4 ("introduce heterogeneity") and Section C5.2 ("an entire homogenous unit").

The reviewer is of the view that the adopted specific yields for Permian model layers are too low. The sensitivity analysis in Figure C 27 indicates high Sy identifiability for layers 1-5 (Sy values 0.4-5%), poor Sy identifiability for layers 6-10 (values 0.01-0.11%), and no Sy identifiability for layers 11-21 (values 0.01-0.028%; 0.92% in Barrett Seam). 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, this approach would be conservative in terms of environmental effects.

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 #2:

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

The 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 too low, 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								Main Report & Appendix C
1.1	Is there a clear statement of project objectives in the modelling report?		Missing	Deficient	Adequate	Very Good			Agency requirements: Section 1.1. Modelling objectives at Appendix C, Section C1.
1.2	Is the level of model complexity clear or acknowledged?		Missing	No	Yes				Mixture of Class 2 (22%) and Class 3 (78%). Missing tick for "Timeframe <3x" on Table C12.
1.3	Is a water or mass balance reported?		Missing	Deficient	Adequate	Very Good			Tables C10, C11.
1.4	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	Very Good			
1.5	Are the model results of any practical use?			No	Maybe	Yes			
2.0	DATA ANALYSIS								
2.1	Has hydrogeology data been collected and analysed?		Missing	Deficient	Adequate	Very Good			Alluvium definition (CSIRO regolith, test pits and TEM). Weathering & alluvium photos. Structure and cover depth contours. 79 packer tests. Water quality analysis violin plot (Fig.5-22).
2.2	Are groundwater contours or flow directions presented??		Missing	Deficient	Adequate	Very Good			Alluvium (Fig.5-5).
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.
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 – Arnold & Allen (1979) method. Only 3 private bores.
2.5	Have the recharge and discharge datasets been analysed for their groundwater response?		Missing	Deficient	Adequate	Very Good			CRD comparison. Evident mining effects at depth but not in alluvium.
2.6	Are groundwater hydrographs used for calibration?			No	Maybe	Yes			Hydrographs: alluvium (Figs.5-6 to 5-10); Permian (Figs.5-11 to 5-19). Monitoring networks: alluvium (49 sites); Permian (277 sites).

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			Inferences from dh/dx and water quality. Section 5.6.
3.3	Is there a graphical representation of the modeller's conceptualisation?		Missing	Deficient	Adequate	Very Good			Geology X-Section Fig.4-2 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			25km x 26km. 21 layers. Max 32k cells/layer (less pinchouts). Total 0.54million cells. Confinement by Hunter Thrust fault not far from mining. Minimum cell size 20m. Many neighbouring mines included. Subdivided Liddell Seam.
4.2	Are the applied boundary conditions plausible and unrestrictive?		Missing	Deficient	Adequate	Very Good			Justified in Section C2.2.2.
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.

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 - 2017 (38 years).
5.1	Is there sufficient evidence provided for model calibration?		Missing	Deficient	Adequate	Very Good			326 monitoring sites - good spread (x,z). Scattergram; residuals x-y plot; vertical profiles; hydrographs.
5.2	Is the model sufficiently calibrated against spatial observations?		Missing	Deficient	Adequate	Very Good			Scattergram generally linear across a wide range. Acceptable vertical head profiles (Fig.C13). Plausible head contours Figs.C18-C23.
5.3	Is the model sufficiently calibrated against temporal observations?		Missing	Deficient	Adequate	Very Good			Quarterly stress periods from 2009. Consistent bias: sim<obs (high head) and sim>obs (low head).
5.4	Are calibrated parameter distributions and ranges plausible?		Missing	No	Maybe	Yes			Specific Yield (Sy) at depth lower than expected physically; generally 0.01% to 0.05% in Permian below Layer 5.
5.5	Does the calibration statistic satisfy agreed performance criteria?		Missing	Deficient	Adequate	Very Good			6.6%RMS, 29 mRMS.
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 Figs.C29, C30. UG Mine inflow 1.2 ML/d cf. actual 0.8 ML/d.
6.2	Does the reserved dataset include stresses consistent with the prediction scenarios?	N/A	Unknown	No	Maybe	Yes			Section C3.2presents combined calibration and verification but the demarcation is not clear.
6.3	Are there good reasons for an unsatisfactory verification?	N/A	Missing	Deficient	Adequate	Very Good			
7.0	PREDICTION								2018-2036 (19 years)
7.1	Have multiple scenarios been run for climate variability?		Missing	Deficient	Adequate	Very Good			Long-term average during prediction and recovery. Climate variability is accommodated through uncertainty analysis by varying recharge factors..

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:38 yrs, Pred:19yrs. Ratio Pred/Calib = 0.5 (implies high "confidence")
7.4	Are the model predictions plausible?			No	Maybe	**Yes**			Negligible drawdown in alluvium matches observation.
8.0	SENSITIVITY ANALYSIS								Identifiability approach
8.1	Is the sensitivity analysis sufficiently intensive for key parameters?		Missing	Deficient	**Adequate**	Very Good			Usual sensitivity analysis on model properties done differently by linear analysis. Sensible findings.
8.2	Are sensitivity results used to qualify the reliability of model calibration?		**Missing**	Deficient	Adequate	Very Good			
8.3	Are sensitivity results used to qualify the accuracy of model prediction?		Missing	Deficient	**Adequate**	Very Good			Usual sensitivity analysis outputs done differently by uncertainty analysis .
9.0	UNCERTAINTY ANALYSIS								
9.1	If required by the project brief, is uncertainty quantified in any way?		Missing	No	Maybe	**Yes**			Substantial work. 275 realisations (Kx, Kz, Sy, Ss, RCH, RIV. Sy at depth limited to 1% max. 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**			82% calibrated (225 of 275). Acceptability statistic is not stated. No evidence provided that outputs have converged sufficiently with acceptable runs [new requirement of draft 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); mine inflow (median close to base case); alluvium take; surface water take.
	TOTAL SCORE								PERFORMANCE: %

Appendix D

Compliance with government policy

D1 Compliance with NSW government policy

This section discusses the ability of the Proposed Modification to comply with the AIP. Table D 1-1 to Table D 1-3 below compare the groundwater impact predictions for the Proposed Modification against the requirements under the AIP.

Table D 1-1 Accounting for or preventing the take of water

AIP requirement		Proponent response
1	Described the water source (s) the activity will take water from?	Section 2.3.1 describes the volume of water taken from the: • Sydney Basin North Coast Water Source • Jerrys Water Source • Glennies Water Source • Hunter Regulated River Alluvial Water Source • Hunter Regulated River Water Source
2	Predict the total amount of water that will be taken from each connected groundwater or surface water source on an annual basis as a result of the activity?	Table 7-2 summarises the peak take of surface water and groundwater from each water source due to the approved mining and the additional incremental effect of the Modification.
3	Predicted the total amount of water that will be taken from each connected groundwater or surface water source after the closure of the activity?	Section 7.3 describes post mining impacts.
4	Made these predictions in accordance with Section 3.2.3 of the AIP? (page 27)	Based on 3D numerical modelling.
5	Described how and in what proportions this take will be assigned to the affected aquifers and connected surface water sources?	Table 7-2 summarises the peak take of surface water and groundwater from each water source due to the approved mining and the additional incremental effect of the Proposed Modification.
6	Described how any licence exemptions might apply?	Not necessary.
7	Described the characteristics of the water requirements?	Refer to surface water assessment.
8	Determined if there are sufficient water entitlements and water allocations that are able to be obtained for the activity?	Section 2.4 describes the entitlements held by the proponent and indicates these are sufficient to account for water taken from the Sydney Basin North Coast Water Source. There is a very small predicted water take from the Glennies Water Source which peaks in Year 12 of mining, determined to be negligible and undetectable in a catchment context. In accordance with current development consent requirements, the proponent will obtain all necessary water licences for the development

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 40m of an unregulated river, except for Domestic and Stock access licences and Local Water Utilities Access licences."* The predicted take of water from the Glennies 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 7.1.1).
11	Considered the effect that activation of existing entitlement may have on future available water determinations?	The following WALs and share components are available for each of the water sources to be impacted by the approved and proposed activity: • Glennies Water Source – 2 WALs and 10 aquifer licence shares • Jerrys Water Source – 10 WALs and 1,246 aquifer licence shares • Hunter Regulated River – 221 WALs and 24,108 aquifer licence shares • Sydney Basin North Coast Water Source - 182 WALs and 69932.5 aquifer licence shares Future available water determinations are a matter for the NSW government. The volume of water taken by the activity, is considered an insignificant component of the existing entitlement of the Sydney Basin North Coast Water Source. The very small predicted water take from the Glennies Water Source which peaks in Year 12 of mining has been determined to be negligible and undetectable in a catchment context, but subject to further validation as mining progresses, and future entitlement availability closer to that time, has a potential need to secure a material component of the Glennies Water Source entitlements. Source - http://www.water.nsw.gov.au/water-licensing/registers (refer to Section 2.2)
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 (Engeny Water Management, 2018) for further information.
13	Developed a strategy to account for any water taken beyond the life of the operation of the Project?	Allocate existing and future water entitlements to the Proposed Modification water takes to license take of water as necessary. Strategy to account for alluvial water take beyond the life of the operation is proposed to include consideration of available water entitlements at that time, and as necessary refinement of the final landform catchment to return a greater volume of surface water to the relevant water sources (refer to the Surface Water Impact Assessment, Engeny Water Management 2018)

AIP requirement		Proponent response
	Will uncertainty in the predicted inflows have a significant impact on the environment or other authorised water users? Items 14-16 must be addressed if so.	There is inherent uncertainty in the predictions of groundwater models as the 'water take' predictions are difficult to measure and validate. Despite this fact, a significant portion of the North Pit has already been completed and monitoring has not detected any unforeseen impacts on the environment or authorised water users. The North Pit is not in a sensitive area and remote from the existing alluvial aquifers, GDEs and authorised users. Given this, some uncertainty in the predictions is not expected to have a significant impact on the outcomes of the proposed activity.
14	Considered any potential for causing or enhancing hydraulic connections, and quantified the risk?	Open cut mining is not expected to generate significant fracturing beyond the pit shell.
15	Quantified any other uncertainties in the groundwater or surface water impact modelling conducted for the activity?	An uncertainty analysis has been completed to identify model features and parameters that create changes in the predictions.
16	Considered strategies for monitoring actual and reassessing any predicted take of water throughout the life of the Project, and how these requirements will be accounted for?	Ongoing monitoring and verification of modelling.

Table D 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 D 1-3 Determining water predictions

AIP requirement		Proponent response
1	Establishment of baseline groundwater conditions?	Refer Section 5. Water quality and level data has been collected at the Proposed Modification area since 2005 for some of the key groundwater units and tested for a selection of analytes. Extensive water quality and level data has been collected at neighbouring mines.
2	A strategy for complying with any water access rules?	Not applicable as water is taken in an indirect passive manner.
3	Potential water level, quality or pressure drawdown impacts on nearby basic landholder rights water users?	No private bores are predicted to be impacted >2 m.

AIP requirement		Proponent response
4	Potential water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources?	No private bores are predicted to be impacted >2 m.
5	Potential water level, quality or pressure drawdown impacts on groundwater dependent ecosystems?	No significant drawdown is predicted at the sites of the potential groundwater dependent ecosystems.
6	Potential for increased saline or contaminated water inflows to aquifers and highly connected river systems?	The final void will act as a 'groundwater sink' therefore no saline or contaminated water inflows to aquifers and highly connected river systems will occur.
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?	Refer to Surface Water Impact Assessment (Engeny Water Management, 2018)
9	Details of the method for disposing of extracted activities (for CSG activities)?	N/A

There are two levels of minimal impact considerations specified in the AIP. If the predicted impacts are less than the Level 1 minimal impact considerations, then these impacts will be considered as acceptable. Where the predicted impacts are greater than the Level 1 minimal impact considerations then the AIP requires additional studies to fully assess these predicted impacts. If this assessment shows that the predicted impacts do not prevent the long-term viability of the relevant water-dependent asset, then the impacts will be considered to be acceptable. The modelling indicates the Level 1 minimal impact consideration thresholds will not be exceeded.

D2 Compliance with Commonwealth government policy

As noted in Section 2.6, detailed ecological and water resources assessments were undertaken to support the Proposed Modification which have concluded that the Proposed Modification would not have a significant impact on relevant MNES. In December 2017, the DoEE determined the Proposed Modification not to be a controlled action and therefore does not require approval under the EPBC Act.

A summary of the IESC guidelines and where they are addressed within the report is included here for consistency with, and to enable comparison to, the groundwater assessment outcomes for the Approved Operations.

This section of the report considers the impact of the Proposed Modification on groundwater resources, and if these impacts are significant according to the guidelines. It compares the predicted impacts against the DoE guidelines to determine if the Proposed Modification could have a significant impact on water resources. It also considers the potential for cumulative impacts with other developments. Again, it should be noted that the DoEE determined the Proposed Modification not to be a controlled action. This assessment against the DoE guidelines has therefore been included only for completeness.

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 Proposed Modification must have '*a real or not remote chance or possibility that it will directly or indirectly result in a change to*' the '*hydrology*' or '*water quality*' of the water resource. This change must be of '*sufficient scale or intensity as to reduce the current or future utility of the water resource for third party users*'. Third party users can include '*environmental and other public benefit outcomes, or to create a material risk of such reduction in utility occurring*'. Furthermore, '*whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the water resource which is impacted, and upon the intensity, duration, magnitude and geographic extent of the impacts*'.

The discussion below focusses on the incremental impact of the Proposed Modification, not the impact of the Approved Operations which is subject EPBC Act Approval EPBC 2013/6978.

D2.1.1 Water availability to users

There is only one known operating private bore within proximity to the North Pit, which is constructed as a well extracting from the Glennies Creek alluvial aquifer. This bore is currently monitored by the adjacent Rix's Creek North mine which is closer to the well than the North Pit. The results do not indicate the potential for any drawdown at this bore due to the Proposed Modification.

D2.1.2 Water availability to the environment

The numerical modelling indicates the depressurisation due to the Proposed Modification will not significantly reduce the flow of Permian groundwater to the alluvial aquifers during mining. Therefore, during mining there is not predicted to be any detectable drawdown occurring within the alluvial aquifers in proximity to the mine. Riparian vegetation occurring along Main Creek has been identified as having the potential to depend on groundwater. Whilst the level of dependence is not known, the water level fluctuations observed within the monitoring network significantly exceed the level of drawdown predicted for the Proposed Modification, and therefore a long term impact on the vegetation is considered improbable.

D2.1.3 Water quality

The post mining pit lake water levels are predicted to recover to a new equilibrium level approximately 120 m to 140 m below pre-mining groundwater levels, indicating that the voids will act as a sink in perpetuity with no escape of contained void water.

D2.1.4 Cumulative impacts

Cumulative impacts of existing and approved mining in the region of the Proposed Modification are significant. Large mines targeting the same coal seams surround the North Pit and all depressurise the Permian strata. Logically the drawdown that is most attributable to the Proposed Modification is that adjacent to the North Pit mining area, with the zone of influence reducing with distance. Previous sections that outline the cumulative impacts suggest the Proposed Modification will only add a negligible 'water take' and drawdown compared to the already approved mines.

D2.1.5 Avoidance or mitigation measures

The proposed mine plan avoids the flood plain and does not intersect existing alluvial aquifers. The impacts on the alluvial aquifers are therefore indirect, and occur through the depressurisation of the underlying Permian coal measures. Locating the mining outside the alluvial flood plain effectively mitigates the impact upon the alluvial aquifer and connected streams. The groundwater seepage to the mining areas cannot be prevented, and must be removed to ensure safe operating conditions within the mining areas. There are no private groundwater users possessing a water supply work within proximity to the North Pit and therefore mitigation measures or make good measures with affected land owners are not required.

D2.1.6 Tabulated impacts

Table D 2-1 and Table D 2-2 summarise the conclusions compared against DoE guidelines:

Table D 2-1 Summary of impacts to the hydrology of the water resource compared to the DoE guidelines

Is there a substantial change to the hydrology of the water resource for:	Comment relating to Modification
flow volume?	Modelling predicts changes in flows of groundwater from Permian bedrock to the alluvial aquifers, but this does not create, flow on effects for private water bores or GDEs.
flow timing?	Impacts are predicted to gradually increase and peak post mining as system re-equilibrates to the changed conditions resulting from mining.
flow duration and frequency of water flows?	Volumes of baseflow removed are negligible small compared to surface water flows within the creek systems.
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.
groundwater/surface interactions?	Water table drawdown within the Quaternary alluvium will not produce detectable changes in base flow to or from interconnected streams.
river/floodplain connectivity?	No impact as no mining proposed in flood plain. There is indirect connectivity through the Permian aquifer to the base of the Quaternary alluvium and river system.
inter-aquifer connectivity?	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 developing 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 D 2-2 Summary of impacts to the water quality of the water resource compared to the DoE guidelines

Is there a substantial change in water quality of the water resource:	Comment
create risks to human or animal health or the condition of the natural environment?	No
substantially reduce the amount of water available for human consumptive uses or for other uses dependent on water quality?	No
cause persistent organic chemicals, heavy metals, salt or other potentially harmful substances to accumulate in the environment?	Evaporation will concentrate salt in the final void lake.
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 mode - modelling will not 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

D2.1.7 IESC Information Guidelines

Information requirement	Addressed in Sections
Description of the proposal	
A regional overview of the proposed project area including a description of the geological basin, coal resource, surface water catchments, groundwater systems, water-dependent assets, and past, current and reasonably foreseeable coal mining and CSG developments.	3, 4, 5, 6
A description of the statutory context, including information on the proposal's status within the regulatory assessment process and on any water management policies or regulations applicable to the proposal	2
A description of the proposal's location, purpose, scale, duration, disturbance area, and the means by which it is likely to have a significant impact on water resources and water-dependent assets	1.1
A description of how impacted water resources are currently being regulated under state or Commonwealth law, including whether there are any applicable standard conditions	2
Groundwater	
Context and conceptualisation	
Descriptions and mapping of geology at an appropriate level of horizontal and vertical resolution including:	
• definition of the geological sequence/s in the area, with names and descriptions of the formations with accompanying surface geology and cross-sections.	4
• definitions of any significant geological structures (e.g. faults) in the area and their influence on groundwater, in particular, groundwater flow, discharge or recharge	4.1
Values for hydraulic parameters (e.g. vertical and horizontal hydraulic conductivity and storage characteristics) for each hydrogeological unit.	5.2.3, 5.3.2
Data to demonstrate the varying depths to the hydrogeological units and associated standing water levels or potentiometric heads, including direction of groundwater flow, contour maps, hydrographs and hydrochemical characteristics (e.g. acidity/alkalinity, electrical conductivity, metals, major ions). Time series data representative of seasonal and climatic cycles.	4.2, 5.2.2, 5.3.1
Description of the likely recharge, discharge and flow pathways for all hydrogeological units likely to be impacted by the proposed development.	5
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.	5.6
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.	Appendix C
Undertaken in accordance with the Australian Groundwater Modelling Guidelines , including peer review	Appendix C
Calibration with adequate monitoring data, ideally with calibration targets related to model prediction (e.g. use baseflow calibration targets where predicting changes to baseflow).	Appendix C
Representations of each hydrogeological unit, the thickness, storage and hydraulic characteristics of each unit, and linkages between units, if any.	Appendix C
Representation of the existing recharge/discharge pathways of the units and the changes that are predicted to occur upon commencement, throughout, and after completion of the development activities.	Appendix C

Information requirement	Addressed in Sections
Incorporation of the various stages of the proposed development (construction, operation and rehabilitation) with predictions of water level and/or pressure declines and recovery in each hydrogeological unit for the life of the project and beyond, including surface contour maps.	Appendix C
Identification of the volumes of water predicted to be taken annually with an indication of the proportion supplied from each hydrogeological unit.	7.1.1
An explanation of the model conceptualisation of the hydrogeological system or systems, including key assumptions and model limitations, with any consequences described.	5.6
Consideration of a variety of boundary conditions across the model domain, including constant head or general head boundaries, river cells and drains, to enable a comparison of groundwater model outputs to seasonal field observations.	Appendix C
Sensitivity analysis of boundary conditions and hydraulic and storage parameters, and justification for the conditions applied in the final groundwater model.	Appendix C
An assessment of the quality of, and risks and uncertainty inherent in, the data used to establish baseline conditions and in modelling, particularly with respect to predicted potential impact scenarios.	Appendix C
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.	7.3
Impacts to water resources and water-dependent assets	
An assessment of the potential impacts of the proposal, including how impacts are predicted to change over time and any residual long-term impacts:	
• Description of any hydrogeological units that will be directly or indirectly dewatered or depressurised, including the extent of impact on hydrological interactions between water resources, surface water/groundwater connectivity, inter-aquifer connectivity and connectivity with sea water.	7.1
• 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
• Description of potential impacts on hydraulic and storage properties of hydrogeological units, including changes in storage, potential for physical transmission of water within and between units, and estimates of likelihood of leakage of contaminants through hydrogeological units.	Appendix C
• Consideration of possible fracturing of and other damage to confining layers.	Appendix C
• 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
For each potentially impacted water resource, a clear description of the impact to the resource, the resultant impact to any water-dependent assets dependent on the resource, and the consequence or significance of the impact.	7
Description of existing water quality guidelines and targets, environmental flow objectives and other requirements (e.g. water planning rules) for the groundwater basin(s) within which the development proposal is based.	2

Information requirement	Addressed in Sections
An assessment of the cumulative impact of the proposal on groundwater when all developments (past, present and/or reasonably foreseeable) are considered in combination.	7.1.6
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
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, 8
Long-term groundwater monitoring, including a comprehensive assessment of all relevant chemical parameters to inform changes in groundwater quality and detect potential contamination events.	8
Water quality monitoring complying with relevant National Water Quality Management Strategy (NWQMS) guidelines and relevant legislated state protocols.	8
Water dependent assets	
Context and conceptualisation	
Identification of water-dependent assets, including:	
• Water-dependent fauna and flora supported by habitat, flora and fauna (including stygofauna) surveys.	5.5.2, 7.1.5
• Public health, recreation, amenity, Indigenous, tourism or agricultural values for each water resource.	N/a
Identification of GDEs in accordance with the method outlined by Eamus et al. (2006). Information from the GDE Toolbox and GDE Atlas may assist in identification of GDEs.	5.5.2
Conceptualisation and rationale for likely water-dependence, impact pathways, tolerance and resilience of water-dependent assets. Examples of ecological conceptual models can be found in Commonwealth of Australia (2015)2.	7.1.5
An estimation of the ecological water requirements of identified GDEs and other water-dependent assets.	7.1.5
Identification of the hydrogeological units on which any identified GDEs are dependent.	5.5.2
An outline of the water-dependent assets and associated environmental objectives and the modelling approach to assess impacts to the assets.	7.1.5
A description of the process employed to determine water quality and quantity triggers and impact thresholds for water-dependent assets (e.g. threshold at which a significant impact on an asset may occur).	N/a
Impacts, risk assessment and management of risks	
An assessment of direct and indirect impacts on water-dependent assets, including ecological assets such as flora and fauna dependent on surface water and groundwater, springs and other GDEs.	7.1.5
A description of the potential range of drawdown at each affected bore, and a clear articulation of the scale of impacts to other water users.	5.5.1, 7.1.4
Indication of the vulnerability to contamination (for example, from salt production and salinity) and the likely impacts of contamination on the identified water-dependent assets and ecological processes.	7.3.2

Information requirement	Addressed in Sections
Identification and consideration of landscape modifications (for example, voids, onsite earthworks, roadway and pipeline networks) and their potential effects on surface water flow, erosion and habitat fragmentation of water-dependent species and communities.	See Ecology report
Estimates of the impact of operational discharges of water (particularly saline water), including potential emergency discharges due to unusual events, on water-dependent assets and ecological processes.	See Ecology report
An assessment of the overall level of risk to water-dependent assets that combines probability of occurrence with severity of impact.	See Ecology report
The proposed acceptable level of impact for each water-dependent asset based on the best available science and site-specific data, and ideally developed in conjunction with stakeholders.	See Ecology report
Proposed mitigation actions for each identified impact, including a description of the adequacy of the proposed measures and how these will be assessed.	See Ecology report
Data and monitoring	
Sampling sites at an appropriate frequency and spatial coverage to establish pre-development (baseline) conditions, and test hypothesised responses to impacts of the proposal.	5, 8
Concurrent baseline monitoring from unimpacted control and reference sites to distinguish impacts from background variation in the region (e.g. BACI design).	5, 8
Monitoring that identifies impacts, evaluates the effectiveness of impact prevention or mitigation strategies, measures trends in ecological responses and detects whether ecological responses are within identified thresholds of acceptable change.	See Ecology report
Regular reporting, review and revisions to the monitoring programme.	8
Ecological monitoring complying with relevant state or national monitoring guidelines.	See Ecology report
Cumulative Impacts	
Context and conceptualisation	
Cumulative impact analysis with sufficient geographic and time boundaries to include all potentially significant water-related impacts.	7.1.6
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.	7.1.6
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.	7.1.6
• 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.	5.5
• Adequate water and salt balances.	See surface water assessment
• Identification of potential thresholds for each water resource and its likely response to change and capacity to withstand adverse impacts (e.g. altered water quality, drawdown).	8
An assessment of cumulative impacts to water resources which considers:	
• The full extent of potential impacts from the proposed development, including alternatives, and encompassing all linkages, including both direct and indirect links, operating upstream, downstream, vertically and laterally.	7

Information requirement	Addressed in Sections
• An assessment of impacts considered at all stages of the development, including exploration, operations and post closure / decommissioning.	7
• An assessment of impacts, utilising appropriately robust, repeatable and transparent methods.	7, Appendix C
• Identification of the likely spatial magnitude and timeframe over which impacts will occur, and significance of cumulative impacts.	7
• Identification of opportunities to work with others to avoid, minimise or mitigate potential cumulative impacts.	7.1.6
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