
APPENDIX K

Water Assessment

Appendix A

Groundwater Impact Assessment



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Report on

HVO Continuation Project Groundwater Impact Assessment

Prepared for
EMM Consulting Pty Ltd

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ageconsultants.com.au

ABN 64 080 238 642

Executive Summary

Hunter Valley Operations (HVO) is a multi-pit open cut mining complex located north-west of Singleton in the Hunter Valley, New South Wales. HVO comprises two mine sites, HVO North and HVO South which are separated by the Hunter River. HVO is owned by subsidiary companies of Yancoal and Glencore, and operated by the HVO Joint Venture (JV).

The HVO Continuation Project (the Project) proposes to extend the life of open cut mining to 2050 at HVO North and 2045 at HVO South. The continued mining across the HVO Complex will be predominantly located in previously mined areas and involves extracting coal from deeper seams at HVO North. The approved operation includes construction of a barrier wall across the Hunter River paleochannel at HVO North to limit groundwater migration from the Hunter River alluvium and Hunter River into the mining area. As part of the Project, the approved barrier wall will be constructed using clayey material emplaced on the highwall benches that intersect the Hunter River alluvium during mining, and keyed into the Permian bedrock. The construction methodology will be consistent with the approved and installed Carrington Pit barrier wall (i.e., after mining but prior to backfilling).

A Groundwater Impact Assessment (GIA) was undertaken to assess the potential impact of the Project on the groundwater regime and address the requirements of the NSW and Commonwealth government legislation, policies and guidelines. The GIA comprised an initial review of available data followed by a field investigation program to fill data gaps. A range of datasets were used to update the conceptual understanding of the groundwater regime in the Project area. Quaternary alluvium occurring in the Hunter River and Wollombi Brook floodplains is the main aquifer in the region. The Quaternary alluvium forms a thin meandering aquifer system which is commonly less than 20 m in thickness with the most permeable part of the sequence being the deeper 'bed load' sands and gravels that readily transmit groundwater.

The Quaternary alluvium is underlain by Permian strata that does not form a highly productive aquifer system because of generally poor water quality and low yields that preclude any beneficial use. The coal seams in the Permian are more permeable compared to the interburden and are therefore the most transmissive pathways along which groundwater movement occurs. The groundwater flow path and discharge zone for the Permian groundwater system is heavily influenced by mining activities in the region that have depressurised the Permian groundwater systems and reduced the water levels within coal seams to the point where groundwater levels occur below the base of the Quaternary alluvium adjacent mining areas. This means the main discharge zone for groundwater within the Permian interburden and coal seams is into mining operations. The alluvial aquifer is effectively disconnected from the Permian with water levels maintained within the alluvium by rainfall recharge and river leakage.

The main water dependent assets occurring in proximity to the HVO Complex are the Carrington Billabong (including river red gum communities), riparian vegetation along the Hunter River and Wollombi Brook, and stygofauna species within alluvium pore spaces. There are no private water supply bores in proximity to the HVO Complex. The main potential pathways for impacts on the water dependent assets occur via drawdown within the alluvium, where it will either be directly excavated from within the Hunter River paleochannel (under the approved development consent at HVO North), or indirectly effected via depressurisation of the underlying Permian strata.

A 3D numerical groundwater flow model was developed using MODFLOW-USG. The model represented the main hydrostratigraphic layers in the region including the Quaternary alluvium, and the coal seams/interburden of the Permian strata with a total of 33 layers. The model was regional in scale being 23 km x 28 km in dimension to allow representation of cumulative impacts associated with surrounding mining operations.

A significant network of monitoring bores exists within the model domain, particularly across the Hunter River floodplain which were used for model calibration. Nested installations occur at many sites with separate bores constructed within the alluvial aquifer and underlying coal seams and/or interburden strata. A common observation at these monitoring sites is that mining at HVO has lowered groundwater levels within coal seams which extend under adjacent creeks and rivers, but the overlying alluvial aquifers do not record detectable drawdown. The calibration of the numerical model focussed on replicating this key observed trend of depressurisation within the Permian strata adjacent mining areas, and lack of drawdown within the alluvial aquifers to ensure key processes occurring within the groundwater regime were represented by the numerical model.

Executive Summary

The numerical modelling was used to provide predictions of drawdown during mining and post mining. The modelling indicated the drawdown in the Hunter River alluvium would be most significant during mining adjacent to the area where approved mining will excavate alluvium within the Hunter River paleochannel. The modelling indicates that the extent and magnitude of drawdown will reduce after the barrier wall is constructed at HVO North and the mining area backfilled. The Wollombi Brook alluvium will not be directly excavated during mining. No additional drawdown in the Wollombi Brook alluvium is predicted. In contrast, the avoidance measure of removing mining in the South Lemington Pit 1 and 2 areas from the mine plan is predicted to result in a reduction in potential drawdown in the Wollombi Brook alluvium (in comparison to the approved operations).

The numerical model was used to provide an estimate of the predicted volume of groundwater that will incidentally enter the open cut mine areas over the life of the Project, and the volume of water indirectly taken from adjacent alluvial aquifers and connected surface waters. These predictions were utilised in the Water Assessment Report (Appendix K of the EIS) which outlines the water licensing strategy for the predicted take of groundwater and connected surface water due to the Project.

At the completion of mining, a final void will remain at HVO North and HVO South. These voids will slowly fill with water over time forming void lakes within the rehabilitated final landform. A water balance model prepared for the EIS Surface Water Impact Assessment (Engeny 2022) indicated the water level within the final voids will slowly recover stabilising at approximately -80 mAHD. Groundwater modelling predicts the final voids at HVO North and HVO South will act as strong sinks, with groundwater flow into the void lakes, rather than outwards. Post mining the maximum drawdown in the alluvium is predicted to remain in the same general locality as predicted during operations but will expand slightly in area due to the influence of the continuing evaporative pumping effect from the final voids.

An uncertainty analysis of model predictions indicated that alternative calibrated versions of the numerical model did not indicate impact at third-party bores, only minor change in the predicted extent of the 2 m drawdown contour, minor change to drawdown in groundwater dependent ecosystem areas, and that the alluvial aquifer will remain saturated and therefore able to host stygofauna habitat.

HVO has an existing water management plan prepared to address the existing consent conditions. HVO has established a substantial network of groundwater monitoring bores to monitor groundwater levels and quality at HVO. This monitoring network will be augmented by additional bores installed within the Hunter River alluvium in the area adjacent to the barrier wall where modelling indicates the potential for additional drawdown in the water table. A low permeability barrier monitoring and management plan for the Carrington West Wing barrier wall will be prepared in consultation with the NSW Government, including development of appropriate level and quality triggers to allow early warning of potential impacts that differ to those predicted. This will involve development of a trigger action response plan, identifying contingencies and mitigation measures to manage potential impacts greater than predicted.

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HVO Continuation Project

Groundwater Impact Assessment

1 Introduction

1.1 Background

Hunter Valley Operations (HVO) is a multi-pit open cut mining complex approximately 24 kilometres (km) north-west of Singleton in the Hunter Valley of New South Wales (NSW) Figure 1.1). HVO comprises two mine sites separated by the Hunter River, HVO North and HVO South. While the two mine sites are approved under separate development consents, they are operated as one complex with fully integrated environmental management systems.

The existing HVO North operation comprises the approved mining areas of West Pit, Mitchell Pit and Carrington Pit, as shown in Figure 1.2. It operates under development consent DA 450-10-2003 which allows extraction of up to 22 million tonnes per annum (Mtpa) of run-of-mine (ROM) coal until 12 June 2025.

HVO South operates under Project Approval (PA) 06_0261 and comprises the approved mining areas of Riverview Pit and Cheshunt Pit, where mining activities currently take place, and the Riverview South East Extension and South Lemington Pits 1 and 2. PA 06_0261 allows the extraction of up to 20 Mtpa of ROM coal until 24 March 2030.

Mining across HVO is undertaken using dragline and truck and shovel methods. ROM coal from HVO North and South is currently processed at the Hunter Valley (HV) Coal Preparation Plant (CPP) and/or the Howick CPP (both at HVO North), from which product coal is predominantly transported via overland conveyor to the HV load point (HVLN) or Newdell LP and via rail to the Port of Newcastle for export. The Lemington CPP (LCPP) and associated rail loop, which is approved under PA 06_0261 and would process and rail coal from HVO South, is yet to be constructed.

HVO is owned by subsidiary companies of Yancoal and Glencore, as participants in the unincorporated HVO Joint Venture (JV). HV Operations Pty Ltd is the appointed manager of the JV.

1.2 Project overview

The HVO Continuation Project (the Project) broadly comprises the continuation of the life of HVO North and HVO South, from the current approved mining completion dates of 2025 and 2030 respectively, to the end of 2050 at HVO North and 2045 at HVO South. The continuation of mining across the HVO Complex will increase resource recovery from the existing operation, predominantly by mining through previously mined areas and to the extent of existing mining tenements and extracting coal from deeper seams at HVO North.

At HVO South an extension to the life of the mine is proposed to facilitate improved mine sequencing outcomes and reduction in mining rate. The Project proposes a reduced mining footprint at HVO South compared to what is approved for extraction, with the previously approved coal extraction in the Riverview South East Extension area and South Lemington Pits 1 and 2 proposed to be removed from mine plan (and future approvals) for the Project. However, some rehabilitation works will be required to be undertaken in the South Lemington Pit 1 area, as part of the mine closure process. The approved shorter rail loop option associated with the LCPP has also been removed from the Project.

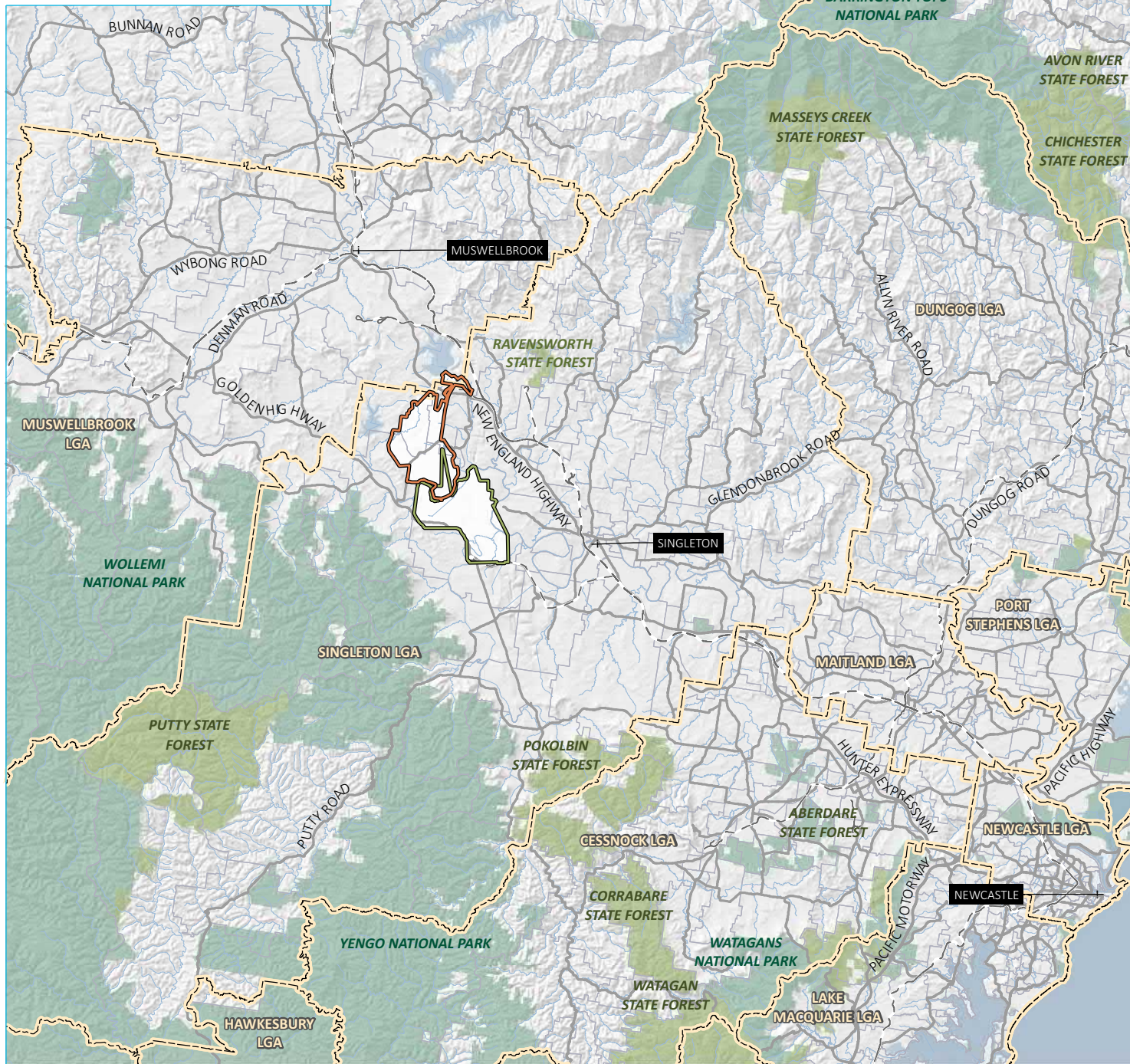
A number of infrastructure upgrades and changes are also required to facilitate the Project (and are included as part of it), including realignment of part of Lemington Road, relocation of transmission and telecommunication lines, an upgrade of the Newdell LP including construction of a new product stockpile and train loading bin, an upgrade of the HVLN product stockpile including an extension to the existing coal stockpile, and improvements to Lake James and Parnells Dam.

To enable the Project to proceed, two new State significant development (SSD) consents are required; one for HVO North and one for HVO South, under Part 4, Division 4.1 of the *NSW Environmental Planning and Assessment Act 1979* (EP&A Act). The Project will seek to maintain separate development consents for HVO North and South, as is currently the case. Given that the two mine sites operate as one complex, one Environmental Impact Statement (EIS) has been prepared to support the two development applications required for the Project.

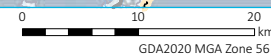
It is also likely that approval under Part 3, Division 1 of the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) will be required for the Project. A referral was submitted to the Department of Climate Change, Energy, Environment and Water (DCCEEW) for the Project regarding potential impacts to listed threatened species and ecological communities and water resources to determine if it is a controlled action under the EPBC Act. At the time of finalisation of this report, DCCEEW's determination is still pending.

This Groundwater Impact Assessment (GIA) forms part of the EIS and provides an assessment of the potential groundwater impacts of the Project. It also assesses the potential incremental impacts of the continuation of HVO North and HVO South given separate development consents are being sought for each operation. It documents the investigation/modelling methods and results, initiatives to avoid and minimise groundwater impacts and additional mitigation and management measures proposed to address residual impacts not able to be avoided.

The Project description is provided in Chapter 4 of the EIS (EMM 2022a). The key components of the Project as they relate to HVO North and HVO South are individually listed below. The proposed conceptual layout of the Project, inclusive of both HVO North and South, is provided in Figure 1.3.



Source: EMM (2022); HVO (2022); ABS (2021); DFSI (2020, 2021); GA (2011)

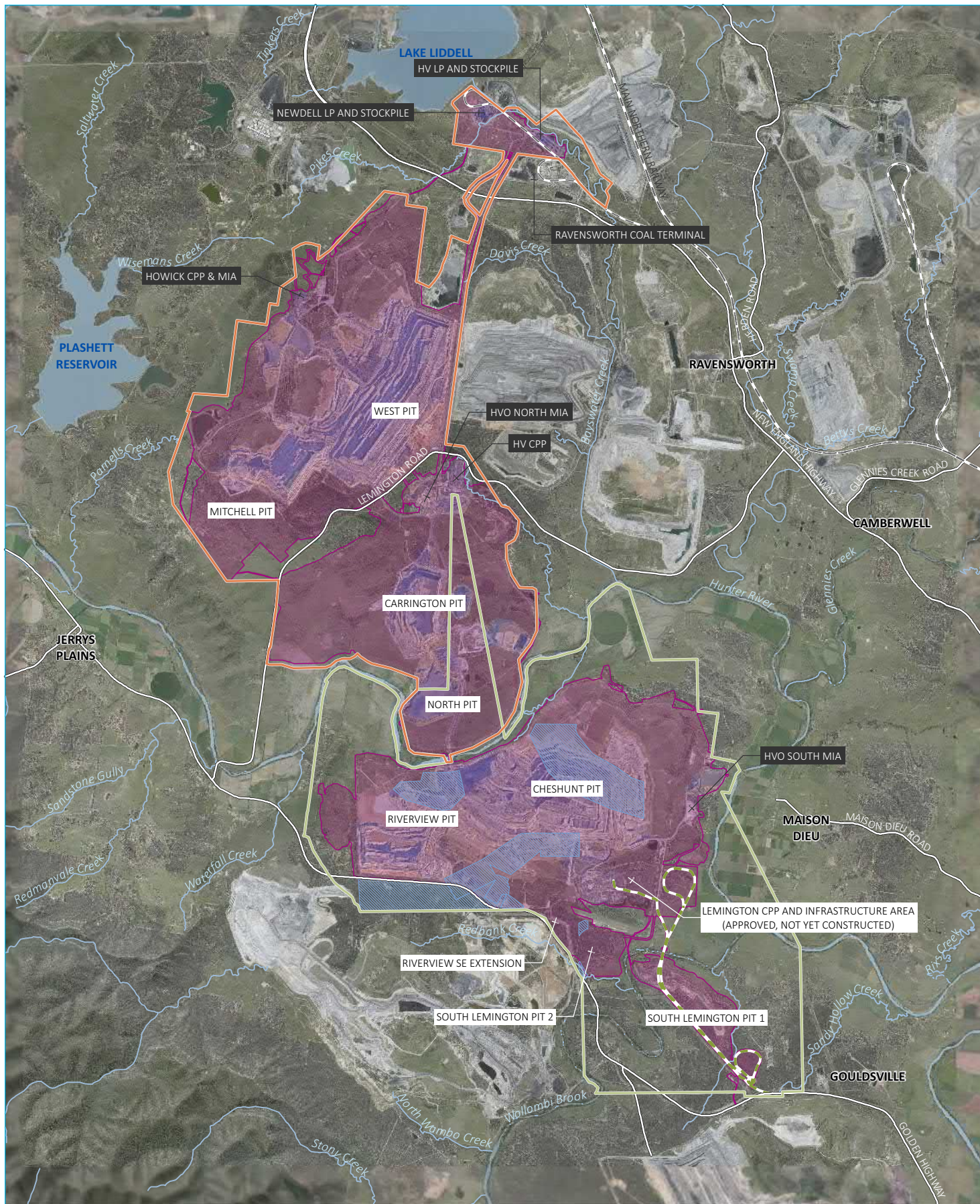


KEY

- Existing HVO North development consent boundary (DA 450-10-2003)
- Existing HVO South project approval boundary (PA 06-0261)
- Rail line
- Major road
- Named watercourse
- Named waterbody
- Suburb boundary
- Local government area
- NPWS reserve
- State forest

Locality plan

Hunter Valley Operations
HVO Continuation Project
Figure 1.1



Source: EMM (2022); HVO (2022); ESRI (2022); DFSI (2017); GA (2011)

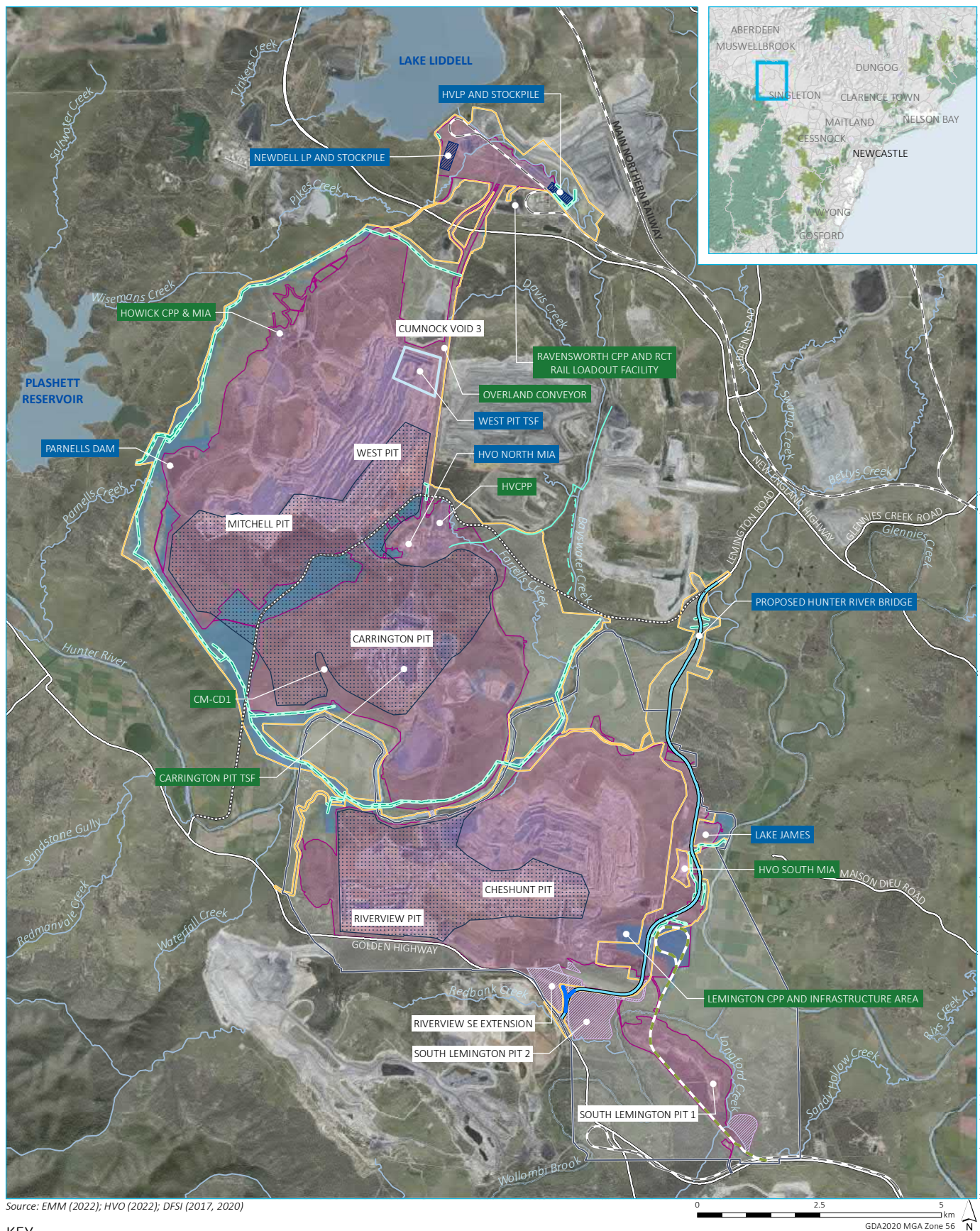
KEY

- Existing HVO North development consent boundary (DA 450-10-2003)
- Existing HVO South project approval boundary (PA 06-0261)
- Existing and approved disturbance area
- Approved highwall mining area
- South Lemington Rail Loop and haul route (approved, not yet constructed)

- Existing environment
- Rail line
- Major road
- Named watercourse
- Named waterbody

HVO existing environment

Hunter Valley Operations
HVO Continuation Project
Figure 1.2



KEY

- HVO North proposed development consent boundary
- HVO South proposed development consent boundary
- Existing and approved disturbance area
- Previously approved area not retained
- Existing HVO elements to be maintained
- South Lemington Rail Loop (approved, not yet constructed)

- Proposed HVO Continuation Project elements
- Lemington Road realignment
- Indicative location of public road closure
- Haul route to Ravensworth Operations
- Transmission line relocation
- Alternative Golden Highway intersection
- Proposed mining area
- Product stockpile
- Additional disturbance area
- West Pit TSF

- Existing environment
- Rail line
- Major road
- Ravensworth Operations access road
- Named watercourse
- Named waterbody
- NPWS reserve (refer to inset)
- State forest (refer to inset)

Project conceptual layout

Hunter Valley Operations
HVO Continuation Project
Figure 1.3



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1.2.1 HVO North

The key changes proposed by the Project to the approved HVO North operations include:

- an extension to the life of the mine until the end of 2050;
- extraction of coal to the base of the Barrett seam across the HVO North mining area. Existing operations are approved to extract coal to the base of the Barrett seam in the West Pit; however, are only approved to the base of the shallower Bayswater seam in Carrington Pit;
- extraction of an additional approximate 400 Million tonnes (Mt) of ROM coal through the extraction of coal from deeper seams and a small increase in the mining extent (between the existing West and Mitchell Pits and Carrington Pit);
- infrastructure upgrades, as listed below:
 - realignment of Lemington Road and new bridge over the Hunter River. While the proposed realigned corridor is partly within the HVO South development consent boundary, the realignment is required to enable the progression of mining from the Mitchell and West pits into the Carrington area at HVO North. The works associated with the road realignment therefore form part of the HVO North Project;
 - HVO North site access road relocation off the existing Lemington Road;
 - an increase in the capacity of Parnells Dam from approximately 1 gegalitres (GL) to 4 GL;
 - realignment of transmission and telecommunication lines that are currently within the proposed mining footprint;
 - HVO North Mine Infrastructure Area upgrade;
 - ancillary activities as required to facilitate operations;
 - access roads to facilitate service provider access;
 - use of demountable/temporary buildings in construction compounds as required;
 - upgrade of the existing Newdell LP train loading facility and construction of a new product stockpile; or
 - extension of the HVLP product coal stockpile, including the closure of a section of Liddell Station Road.
- coal haulage from the HVCPP to the Ravensworth ROM pad, via internal haul roads;
- revised tailings management strategy;
- amendments to the approved final landform;
- progressive rehabilitation throughout the mine life; and
- changes to the development consent boundary to incorporate the changes listed above.

Other than as set out above, all activities that are currently approved under the existing HVO North approval are intended to continue. Key aspects and outcomes of the approved development at HVO North that will remain the same under the Project include the following:

- the maximum allowable annual coal extraction and processing rate;
- annual operational workforce numbers and associated traffic generation;
- approved heights of overburden emplacement areas;
- receipt of ROM coal from HVO South via internal haul roads for processing at all CPP facilities approved for HVO North;
- continued avoidance of the Aboriginal heritage site known as Carrington Mine - Colluvial Deposit 1 (CM-CD1); and
- the ridge between Jerrys Plains and HVO North will remain, continuing to provide an effective amenity barrier.

Carrington West Wing barrier wall

As currently approved, a barrier wall is to be constructed in the western arm of the palaeochannel in the Carrington West Wing area to limit groundwater migration from the Hunter River (and associated alluvium) into the HVO North mining areas and potential migration of water from the mining area into the Hunter River alluvium. The current approval requires construction of the barrier wall prior to mining resuming within 100 m of the palaeochannel.

The barrier wall location and timing were considered as part of the Project design, and a suitable alternative approach has been identified to meet the same objectives. The proposed adjustment to the barrier wall location and timing has been discussed with NSW Department of Planning and Environment (DPE) and DPE-Water during consultation as part of the EIS.

The proposed approach will be consistent with the approved construction methodology of the existing Carrington Pit barrier wall (approved by the then NSW Department of Planning in 2008 and constructed in 2010):

- emplacement of clayey material on the highwall benches (clay compacted buttress) that intercept the Hunter River alluvium following mining and prior to backfilling the pit with overburden and interburden waste material;
- the barrier wall will be keyed into the Permian, consistent with the approach of the Carrington Pit barrier wall;
- designed to meet the existing consent requirements to have a permeability of 1×10^{-8} metres per second (m/sec), equivalent to 1×10^{-3} metres per day (m/day);
- the objectives of the barrier wall will remain the unchanged:
 - limit groundwater inflow from the Hunter River alluvium into the mined area;
 - limit potential drawdown in the alluvium due to groundwater inflows into the mined area;
 - limit the potential for seepage from the backfilled pit to the alluvium;
- the location of the proposed barrier wall differs slightly to the barrier presented in HVO North Mod 3 in 2010, as it will be constructed on the benches of the highwall that intercept alluvium, rather than excavating a trench across the inferred extent of the paleochannel alluvium.

The proposed approach has other benefits when compared to the barrier wall as per the current approval:

- by constructing the barrier wall on the highwall rather than excavating a trench closer to the Hunter River, the proposed location will result in reduced ground disturbance;
- by constructing the barrier wall after mining has moved through the area and prior to backfill, the proposed timing will result in:
 - lower noise impacts associated with construction activities (such as noise from mining equipment) as the activity will be conducted below natural ground level, with the highwall limiting the potential for noise to travel beyond the mine area;
 - greater control to isolate the paleochannel alluvium, as the extent of the alluvium will be exposed in the highwall, ensuring that the clayey material is placed across the full extent; and
 - reduced potential for disturbance of the barrier during mining and associated risk of affecting the integrity of the barrier.

1.2.2 HVO South

The key changes proposed by the Project to the existing approved operations at HVO South include:

- an extension of the life of the mine until the end of 2045;
- a reduction in the approved maximum ROM coal extraction rate from 20 Mtpa to 18 Mtpa;
- changes to the approved mine sequencing (although noting that mining within the two primary open cut pits; Riverview and Cheshunt, will remain generally within the same footprint as approved);
- removal of coal extraction from the mine plan from the Riverview South East Extension, South Lemington Pit 1 and South Lemington Pit 2 mining areas;

- infrastructure upgrades and changes to that currently approved, as listed below:
 - removal of the LCPP short rail loop option;
 - removal of the approved conveyor from HVO South to the HVCPP at HVO North (the conveyor has not been constructed);
 - construction of the Cheshunt and Riverview flood protection levees;
 - realignment of transmission lines;
 - enlargement of Lake James from approximately 0.7 GL to 2 GL;
 - additional tailings pipelines and pumps;
 - ancillary activities as required to facilitate operations;
 - access roads to facilitate service provider access; and
 - use of demountable/temporary buildings in construction compounds as required.
- revision and implementation of the tailings strategy; and
- amendments to final landform due to rescheduling and or infrastructure relocations, progressive rehabilitation will be undertaken throughout the mine life.

Other than as set out above, all activities that are currently approved under the existing HVO South approval are intended to continue.

Figure 1.5 shows the Project mining progression at yearly intervals. Mining in HVO North is proposed to continue from the existing West Pit towards Carrington Pit. Mining in HVO South is proposed to continue within its current mining footprint south of Hunter River (albeit at a slower rate than currently approved) while South Lemington Pits 1 and 2 are no longer proposed for the Project.

1.2.3 Existing approved operations

The location of the various approved mining areas is shown on Figure 1.4 and details about the HVO South and HVO North existing pits are included in Table 1.1.

Mining from the collective HVO North areas commenced at West Pit in 1949 and is currently approved to continue until 2025. Historical operations in North Pit and Alluvial Lands have since ceased and the North Pit void has previously been used for tailings emplacement. The mined Alluvial Lands footprint has since been fully rehabilitated. Mining from Carrington Pit has also ceased and is currently used to store tailings. Active mining currently occurs at West Pit while future mining is approved for Carrington West Wing.

The Cheshunt, Riverview, South Lemington open cut mines including the Lemington Underground operations south of the Hunter River are located within HVO South. Mining from the collective HVO South areas commenced in 1971 and is currently approved to continue until 2030. Historical operations in the north-eastern section of Cheshunt Pit and Lemington Underground have since ceased, while mining in the South Lemington Pits 1 and 2 has been put on hold. Active mining currently occurs only at the Cheshunt and Riverview pits.

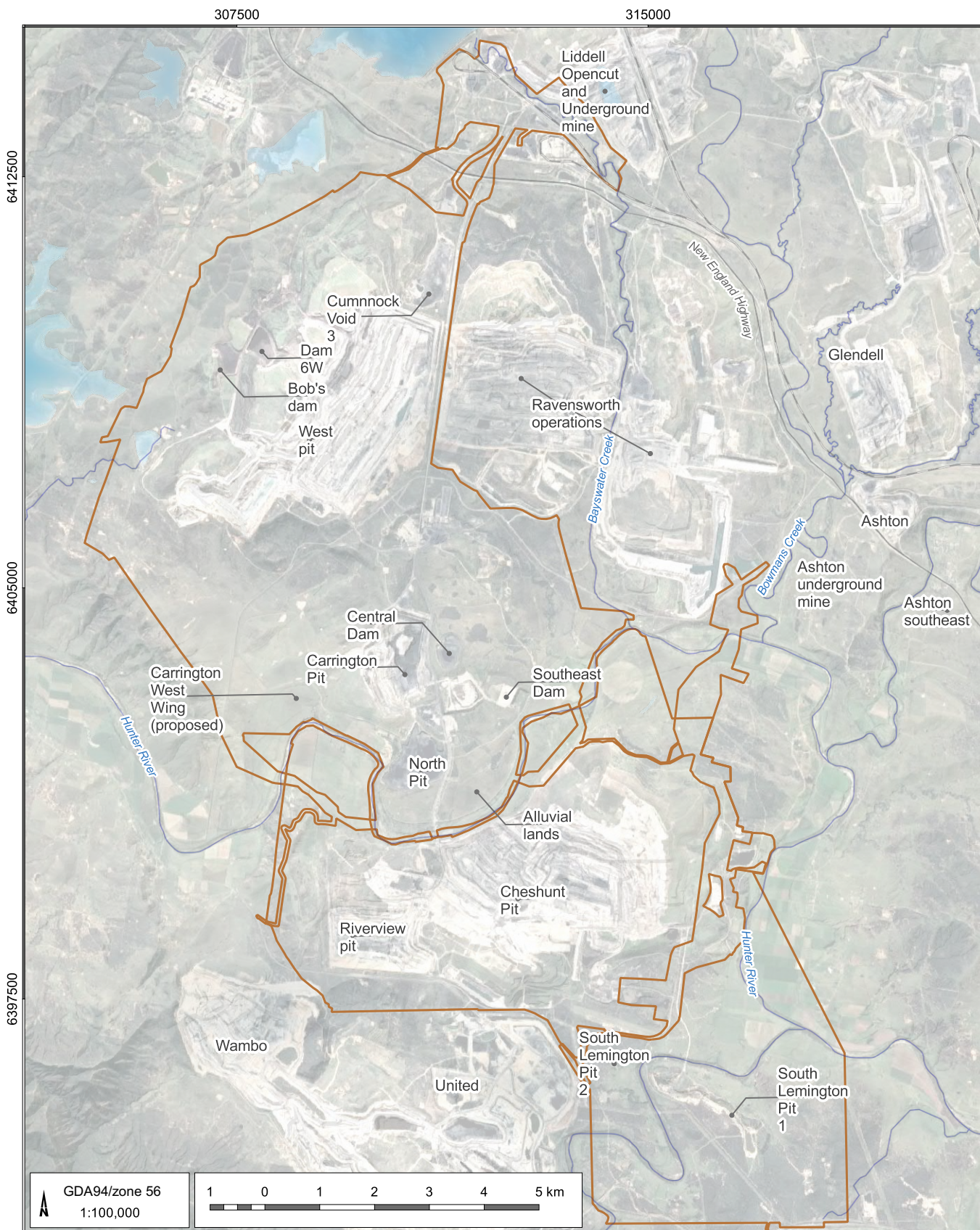
Fine rejects (tailings) have been emplaced in various approved tailings storage facilities (TSFs) across the complex. Currently, tailings are emplaced within approved TSFs in Carrington Pit as well as Cumnock Void 3 under agreement with Ravensworth Operations to utilise the void capacity. Tailings from the Howick CPP are currently pumped via a pipeline to Cumnock Void 3, while tailings from the HV CPP are pumped via a pipeline to the Carrington Pit TSF.

Intermittent deposition of tailings occurs in the Dam 6W TSF and Central TSF as part of ongoing management towards decommissioning. The South East TSF is currently in the capping phase. Prior to TSFs reaching capacity a detailed closure plan is developed for the individual facility to determine effective closure requirements including capping depth.

TSF locations are shown in Figure 1.4.

Table 1.1 Summary of approved mine workings and target seams

Reference name	Mine area	Basal coal seam	Start date	End date
HVO South	Cheshunt Pit (open cut)	Bayswater	2002	2030
	Riverview Pit (open cut)	Bayswater	1997	2030
	South Lemington Pit 1 (open cut)	Bowfield	1998	2024
	South Lemington Pit 2 (not yet mined)	Vaux	2015	2030
	Lemington mine (underground)	Mt Arthur	1971	1992
HVO North	North Pit (converted to tailings storage facility)	Vaux	1979	2003
	Alluvial Lands (rehabilitated)	Vaux	1993	2003
	Carrington Pit (open cut)	Bayswater	2000	2025
	West Pit (open cut)	Bayswater to Hebden	1949	2025
	Carrington west wing (not yet mined)	Bayswater	2023	2025



LEGEND

- Road
- Drainage
- Project Area

HVO Continuation (G1737J)

Approved mining operations in the Project



AGE

DATE
24/10/2022

FIGURE No:
1.4

1.3 Project terminology

The following key terms are used throughout this assessment to describe the Project:

- **HVO Complex** – comprises both HVO North and HVO South operations.
- **The Project** – the Project in its entirety, encompassing the continuation of the life of the complex; i.e., both HVO North and HVO South, within their respective proposed development consent boundaries, as illustrated in Figure 1.2.
- **Project area** – The area that is the subject of the two development applications, i.e., the proposed development consent boundary for HVO North and the proposed development consent boundary for HVO South.
- **Existing and approved disturbance area** – Areas that are disturbed and/or approved under the EP&A Act to be disturbed under the current development consents that apply to the HVO Complex.
- **Approved mining area** – The areas within the approved disturbance area that have been previously assessed and approved under the NSW EP&A Act for mining operations.
- **Additional disturbance area** – The areas that will be disturbed by the Project that are outside of both the existing and approved disturbance area for the HVO Complex and other neighbouring mines (Ravensworth Operations, United Wambo and Liddell Coal Operations (LCO)).
- **Previously approved areas not retained** - Areas that are disturbed and/or approved to be disturbed under the current development consents that apply to the HVO Complex, that will no longer be disturbed by the Project, such as the LCPP short rail loop, the Riverview South East Extension and South Lemington Pit 2 mining areas, and the approved temporary crossing across the Hunter River between HVO North and South.
- **Proposed mining area, HVO North** – Areas where coal extraction will take place for the Project at HVO North and includes:
 - areas already disturbed by mining that will be re-disturbed to facilitate coal extraction in the deeper Barrett seam;
 - areas not previously approved for mining (eg the area between the Mitchell Pit and Carrington Pit); and
 - areas approved but not yet disturbed (eg the Carrington West Wing area).
- **Proposed mining area, HVO South** – Comprises the Riverview Pit and Cheshunt Pit, where coal extraction will continue under the Project, down to the Bayswater seam. The HVO South proposed mining area does not include the previously approved South Lemington Pit 1, South Lemington Pit 2, or the Riverview South East Extension, as coal extraction is not proposed in these areas as part of the Project. However, rehabilitation activities will be required in some areas and form part of the Project.
- **Transmission line corridors** – Two categories of transmission line corridors have been defined for the purpose of quantifying the extent of disturbance for the Project:
 - realigned transmission lines (ie new transmission line easements) – the extent of disturbance will be limited to transmission line poles/towers and an access road for maintenance along the alignment, as well as vegetation management to maintain safe powerline clearance; and
 - existing transmission line easements to be decommissioned – disturbance will be confined to existing access tracks and cleared areas.
- **Realigned Lemington Road corridor** – The corridor extends from the Comleroi Road intersection with the Golden Highway at the southern end of the new alignment, along the Comleroi Road alignment around the south-eastern side of HVO South, and then extends in a northerly direction to join the existing Lemington Road at a point approximately 2.3 km south of the New England Highway/Lemington Road intersection. The corridor also allows for two options with respect to the connection to the Golden Highway; one assuming that the Golden Highway is realigned by United Wambo as approved under SSD 7142, and a second option that connects with the current alignment of the Golden Highway.
- **Project disturbance area** – this area is a combination of the additional disturbance area and the existing and approved disturbance area, minus the areas not being carried forward by the Project. If the Project is approved, this will become the 'approved disturbance area' under the new SSD consents

1.4 Assessment requirements

This assessment has been prepared in accordance with requirements of the DPE. These were set out in the Secretary's Environmental Assessment Requirements (SEARs) for the Project, issued on 11 March 2021. Table 1.2 lists individual requirements relevant to this GIA and where they are addressed in this report.

Table 1.2 Technical assessment (groundwater) related SEARs

Requirement	Section addressed
Key issues - Water – including:	
identification of any licensing requirements or other approvals under the Water Act 1912 and/or Water Management Act 2000;	Section 2 + Water Assessment Report (EMM 2022)
demonstration that water for the construction and operation of the proposed development can be obtained from an appropriately authorised and reliable supply in accordance with the operating rules of any relevant Water Sharing Plan (WSP) or water source embargo;	Sections 2.6, 8.3 & 9.5, Surface Water Impact Assessment Report (Engeny 2022) + Water Assessment Report (EMM 2022)
an assessment of the likely impacts of the development on the quantity and quality of existing surface and groundwater resources including a detailed assessment of proposed water discharge quantities and quality against receiving water quality and flow objectives;	Sections 8 & 9 + Surface Water Impact Assessment Report (Engeny 2022) + Water Assessment Report (EMM 2022)
an assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure, and other water users,	Section 8 & 9 + Surface Water Impact Assessment Report (Engeny 2022)

To inform the preparation of the SEARs, DPE invited other government agencies to recommend matters to be addressed in the EIS. DPE (Biodiversity and Conservation Branch, Water Knowledge Office, Resources Regulator) and NSW EPA raised matters relevant to the groundwater assessment. The matters raised are listed in Table 1.3 and have been taken into account in preparing this assessment, as indicated in the table. In addition, relevant matters raised during consultation with DPE Water agency as part of the preparation of the EIS are included within the table.

Table 1.3 Agency specific assessment recommendations

Requirement	Section addressed
Biodiversity and Conservation Branch	
The EIS must map the following features relevant to water and soils including:	
d. Groundwater	Section 6
e. Groundwater dependent ecosystems	Section 6.5.2
The EIS must describe background conditions for any water resource likely to be affected by the development, including:	
a. Existing surface and groundwater.	Section 6
c. Water Quality Objectives (as endorsed by the NSW Government http://www.environment.nsw.gov.au/ieo/index.htm) including groundwater as appropriate that represent the community's uses and values for the receiving waters	Section 6.4 + Water Assessment Report (EMM 2022)
d. Indicators and trigger values/criteria for the environmental values identified at (c) in accordance with the ANZECC (2000) Guidelines for Fresh and Marine Water Quality and/or local objectives, criteria or targets endorsed by the NSW Government	Section 6.4, approved WMP + Water Assessment Report (EMM 2022)
7. The EIS must assess the impacts of the development on water quality, including:	
a. The nature and degree of impact on receiving waters for both surface and groundwater, demonstrating how the development protects the Water Quality Objectives where they are currently being achieved, and contributes towards achievement of the Water Quality Objectives over time where they are currently not being achieved. This should include an assessment of the mitigating effects of proposed stormwater and wastewater management during and after construction.	Sections 8 & 9 + Surface Water Impact Assessment (Engeny 2022)
b. Identification of proposed monitoring of water quality.	Section 11 + Surface Water Impact Assessment (Engeny 2022)
The EIS must assess the impact of the development on hydrology, including:	
c. Effects to downstream water-dependent fauna and flora including groundwater dependent ecosystems.	Section 8.2.1 + Aquatic Ecology and GDE Assessment Report (ELA 2022)
Water Knowledge office	
Assessment of impacts on surface and ground water sources (both quality and quantity), related infrastructure, adjacent licensed water users, basic landholder rights, watercourses, riparian land, and groundwater dependent ecosystems, and measures proposed to reduce and mitigate these impacts.	Sections 8 & 9
Proposed surface and groundwater monitoring activities and methodologies.	Section 11
NSW EPA	
identify nearby water resources, the background water conditions (including river flow data, water flow/direction and quality data, the depth to groundwater, groundwater flow/gradient and quality data, reliance on water resources by surrounding users and by the environment) and relevant water quality objectives in line with relevant guidance/standards; and	Sections 6.1, 6.4 & 6.5
Identify existing impacts to water resources (including other industrial discharges);	Section 6.1

Requirement	Section addressed
identify potential impacts to surface and groundwater during both construction and operational stages and identify best practice mitigation measures (pollution control) and strategies to protect surface and groundwater resources, particularly erosion and sediment controls during the construction stage and the rehabilitation stage and the inclusion of permanent erosion and sediment controls where required and applicable;	Section 8, Surface Water Impact Assessment (Engeny 2022) and Water Assessment Report (EMM 2022)
identify the cumulative impacts of the proposed development in a local context.	Section 8.2 & 9.4
include a detailed proposal of any noise, air, water, land, waste, meteorological etc monitoring during construction and operation to ensure and assumptions, predictions, goals, criteria etc are achieved. The proposal should include a detailed description of the monitoring locations, sample analysis methods and the level of reporting proposed.	Section 11

Resources Regulator

Where a void is proposed to remain as part of the final landform, include:

- (iii) outcomes of the surface and groundwater assessments in relation to the likely final water level in the void. This should include an assessment of the potential for fill and spill along with measures required be implemented to minimise associated impacts to the environment and downstream water users.

Section 9, Surface Water Impact Assessment (Engeny 2022) and Water Assessment Report (EMM 2022)

DPE Water and NRAR

an assessment of the likely impacts of the development on the quantity and quality of existing surface and groundwater resources including a detailed assessment of proposed water discharge quantities and quality against receiving water quality and flow objectives; and	Section 8 and 9
an assessment of the likely impacts of the development on aquifers,	Section 8 and 9
Assessment of impacts on surface and ground water sources (both quality and quantity), related infrastructure, adjacent licensed water users, basic landholder rights, watercourses, riparian land, and groundwater dependent ecosystems, and measures proposed to reduce and mitigate these impacts.	Section 6, 8 and 9
Proposed surface and groundwater monitoring activities and methodologies.	Section 11
Consideration of relevant legislation, policies and guidelines, including the NSW Aquifer Interference Policy (2012), the Guidelines for Controlled Activities on Waterfront Land (2018) and the relevant Water Sharing Plans (available at https://www.industry.nsw.gov.au/water).	Section 2.4.2, 8, and 9, Surface Water Impact Assessment (Engeny 2022) and Water Assessment Report (EMM 2022)

1.5 Study area

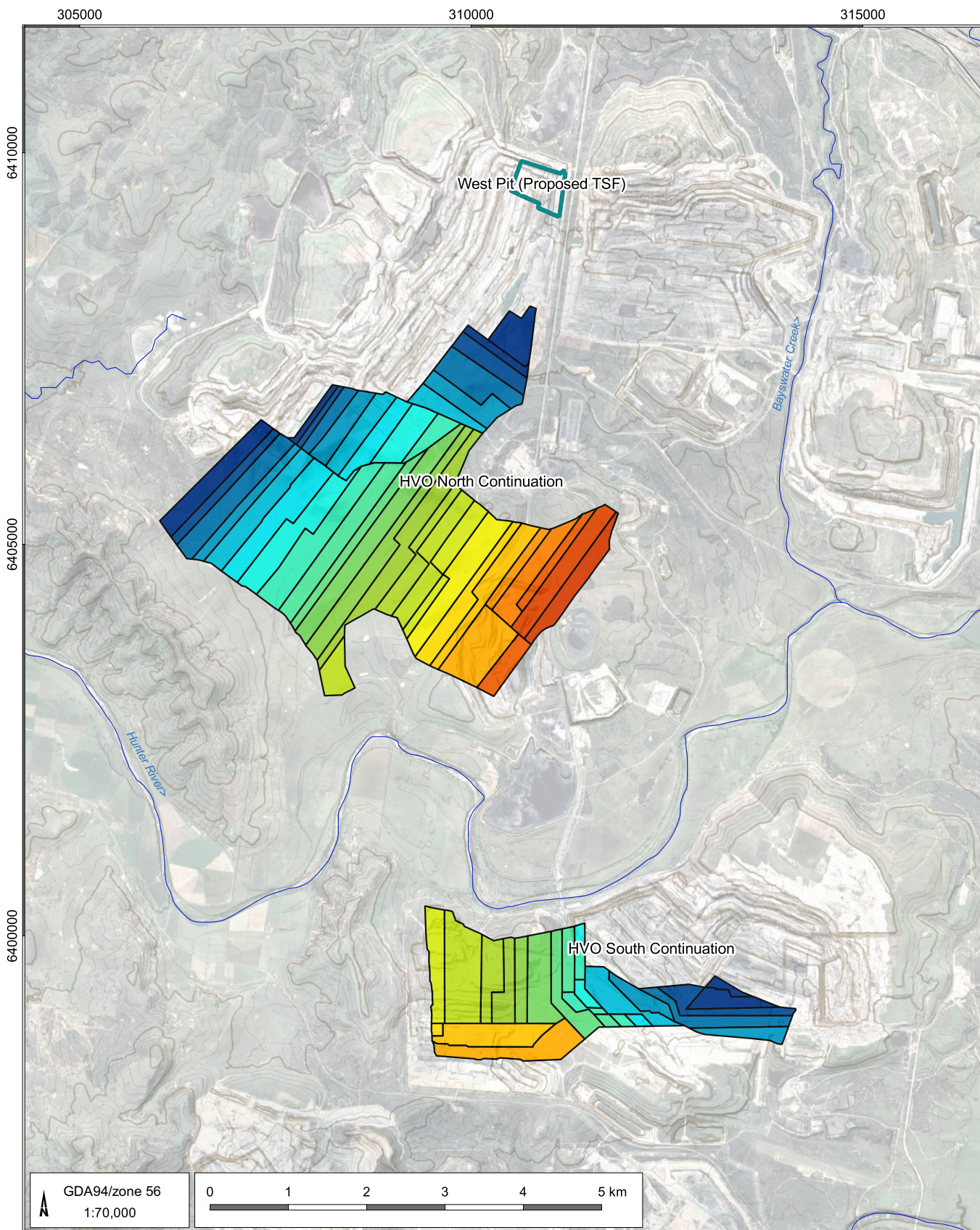
The Study area for the purposes of this assessment is focussed on the Project area that is the subject of the two development applications, for HVO North and HVO South, as well as surrounding mines that could directly or indirectly interact with the Project including Ravensworth Operations, Liddell, Mount Owen Complex, Ashton and Ulan/Wambo mine.

1.6 Objectives and scope of work

The objective of the GIA is to assess the potential impact of the Project on the groundwater regime and address the requirements of the NSW and Commonwealth government legislation and policies. The GIA comprises two parts: a description of the existing hydrogeological environment, and an assessment of the potential impacts of the Project on that environment. The impacts of the Project are detailed separately and related to the observed and modelled impacts of existing approved operations at HVO and the region more broadly to identify the extent of change in impacts on groundwater resources. The existing operations at HVO is discussed in Section 1.2.3.

The GIA includes:

- review of existing background data and previous hydrogeological investigations;
- field investigations to address data gaps (Appendix A);
- combining and updating the existing groundwater regional numerical models for the mid Hunter Region that was last utilised for HVO South Modification 5 (AGE 2015) and Glendell Continued Operations (AGE 2019) in accordance with the National Groundwater Modelling Guidelines (Barnett et.al., 2012) and relevant State and Commonwealth guidelines;
- assessment of impacts resulting from the Project, including impacts on regional groundwater levels and baseflow;
- assessment of potential impact pathways for groundwater dependent ecosystem (GDE) impacts resulting from short and/or long-term changes in groundwater;
- assessment of the potential third party impacts (i.e. private bores) resulting from changes to the regional groundwater system;
- assessment against the NSW Aquifer Interference Policy (2012) (although the Aquifer Interference Assessment Framework (checklist) is appended to the Water Assessment Report (EMM 2022));
- assessment of cumulative impacts;
- assessment of post mining recovery; and
- provision of recommendations for the management of groundwater impacts including monitoring.



LEGEND

- Road
- Drainage
- Elevation contour line
- West Pit (Proposed TSF)

Mine progression (Year)

2025	2034	2043
2026	2035	2044
2027	2036	2045
2028	2037	2046
2029	2038	2047
2030	2039	2048
2031	2040	2049
2032	2041	2050
2033	2042	

HVO Continuation (G1737J)

Proposed HVO Continuation Project – Mine Progression



AGE

DATE
23/08/2022

FIGURE No:
1.5

2 Regulatory framework

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

- NSW Government:
 - Legislation:
 - Water Management Act 2000 and the associated Water Sharing Plans.
 - Policy and Plans:
 - NSW Groundwater Quality Protection Policy (1998);
 - NSW Groundwater Dependent Ecosystems Policy (2002);
 - Aquifer Interference Policy (2012);
 - Strategic Regional Land Use Policy (2012);
 - Strategic Regional Land Use Plan – Upper Hunter (2012); and
 - Water Sharing Plans.
- Commonwealth Government:
 - Legislation:
 - Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).
- Guidelines and explanatory notes:
 - Information guidelines for proponents preparing coal seam gas and large coal mining development proposals (Commonwealth of Australia, 2018); and
 - Uncertainty analysis – Guidance for groundwater modelling within a risk management framework (Middlemis and Peeters, 2018).

A set of guidelines introduced by the NSW government during the course of this project was also considered. It includes the documents:

- Groundwater assessment toolbox for major projects in NSW – Overview document. NSW Government, January 2022.
- Guidelines for Groundwater Documentation for SSD/SSI projects. Technical Guideline. NSW Government, January 2022.
- Minimum Groundwater Modelling Requirements for SSD/SSI Projects. NSW Government, January 2022.
- Cumulative Groundwater Impact Assessment Approaches. NSW Government, January 2022.

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

2.1 NSW Groundwater Quality Protection Policy 1998

This policy (DLWC, 2002) provides a set of guiding principles to protect groundwater against pollution. The principles outline management intents of groundwater so that their most sensitive beneficial use is maintained. For new developments, the scale and scope of work required to demonstrate adequate groundwater protection shall be commensurate with the risk the development poses to the groundwater system and the value of the groundwater resource.

2.2 NSW Groundwater Dependent Ecosystems Policy 2002

This policy (DLWC, 2002) provides a set of guiding principles adopted by the state for protection of GDEs. The principles outline management of groundwater flow, levels and quality to minimise adverse impacts and maintain ecosystem function of GDEs.

2.3 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.

The *Water Management Act 2000* includes the concept of “no more than minimal harm” for both the granting of water access licences (WALs) and the granting of approvals. Aquifer interference approvals are not yet active/enacted under the *Water Management Act 2000*. To date, no proclamation has been made specifying that aquifer interference approvals are required in any part of NSW. As such, aquifer interference approvals are not required to be obtained for the Project.

The EP&A Act, sections 4.41 1(g) stipulates that SSD’s authorised by a development consent do not require a water use approval, a water management work approval, or an activity approval under the *Water Management Act 2000*.

2.4 State groundwater policy

2.4.1 NSW Strategic Regional Land Use Policy

The NSW Strategic Regional Land Use Policy applies to the Hunter Valley in which the Project area resides. Biophysical Strategic Agricultural Land (BSAL) is land considered to have high quality soil and water resources capable of sustaining high levels of productivity. BSAL occurs within the footprint of the Project area, along the Hunter River Flood plain Figure 2.1.

2.4.2 Aquifer interference policy

The *Water Management Act 2000* defines an aquifer interference activity as involving 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 because 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. A proponent must hold sufficient share components and water allocation to account for the actual take of water from the relevant water source when the take occurs.

The AIP states that a WAL 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, WALs 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.”*

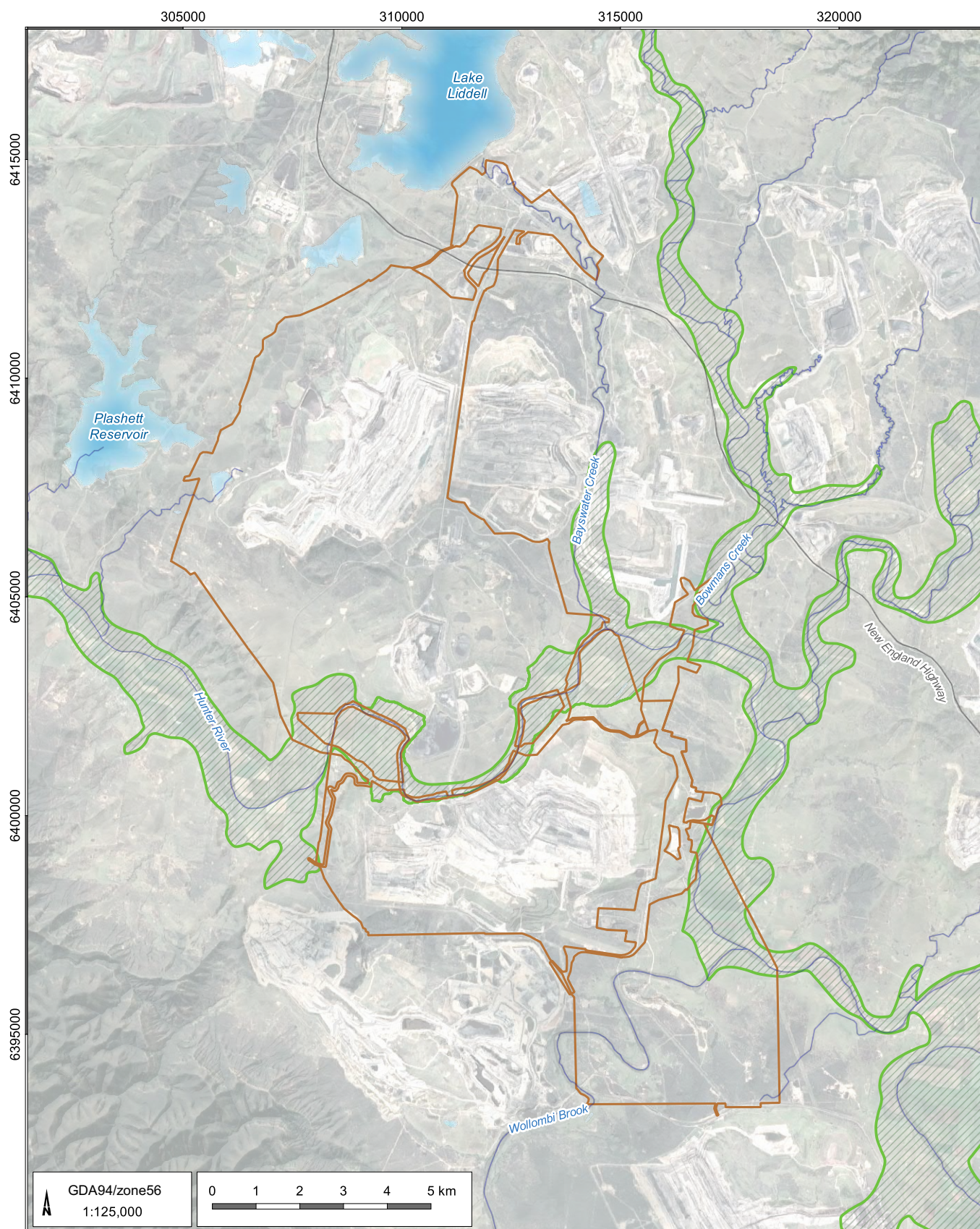
In particular, the AIP describes minimal impact considerations for aquifer interference activities based upon whether the water source is highly productive or less productive and whether the water source is alluvial or porous/fractured rock in nature. The AIP prescribes a maximum of 2 m cumulative decline at any water supply work. If this impact threshold is exceeded, make good provisions will apply for the impacted water supply work.

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 milligrams per litre (mg/L); and
- b) contains water supply works that can yield water at a rate greater than 5 litres per second (L/s).

Highly productive groundwater sources are further grouped by geology into alluvium, 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.

Figure 2.2 shows the mapped areas of groundwater productivity across the Project area and surrounds, which shows areas classified as either highly or less productive. The “highly productive” areas do not entirely overlap with the mapped alluvium extents from the NSW state-wide seamless geology data package (Colquhoun et al. 2019) and tend to exclude the fringe areas of the mapped alluvium. Consequently, alluvial bores fall within areas of “highly productive” or “less productive” water sources categories depending on their proximity to the main drainage lines. The Permian coal measures (porous and fractured rock) are categorised as “less productive”.



LEGEND

- Road
- Drainage
- Project Area
- Biophysical Strategic Agricultural Land (BSAL)

HVO Continuation (G1737J)

Biophysical Strategic Agricultural Land



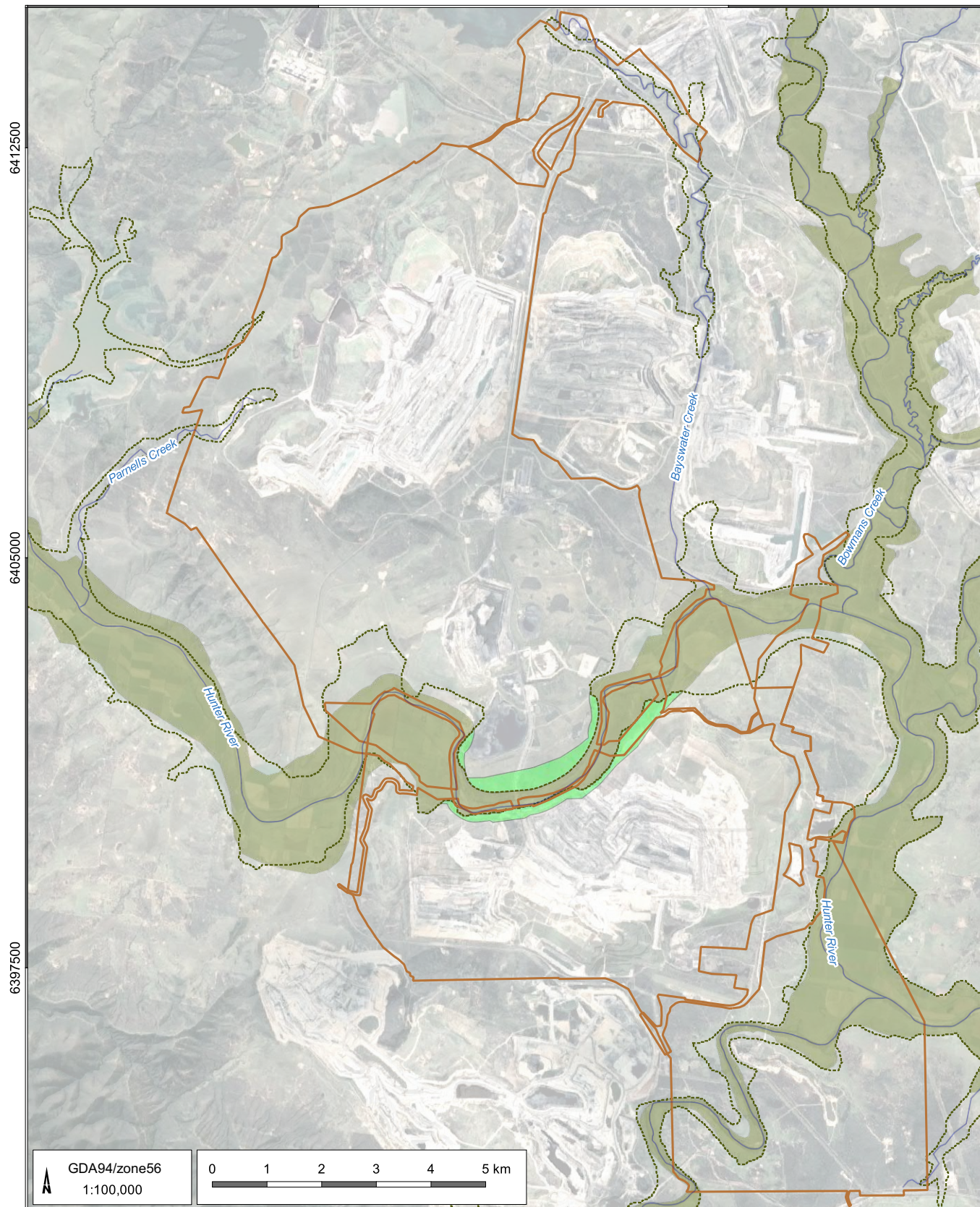
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24/10/2022

FIGURE No:
2.1

307500

315000



LEGEND

- Drainage
- Project Area
- Alluvium boundary
- Highly productive groundwater
- Highly productive groundwater area – previously mined

HVO Continuation (G1737J)

Highly productive groundwater**AGE**DATE
24/10/2022FIGURE No:
2.2

2.5 Commonwealth Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)* is administered by the Department of Climate Change, Energy, the Environment and Water (DCCEEW). The *EPBC Act* is designed to protect national environmental assets, known as Matters of National Environmental Significance (MNES). Under the 2013 amendment to the *EPBC Act*, significant impacts on water resources associated with coal mining and/or coal seam gas (CSG) developments were included as an MNES and are known as the ‘water trigger’.

The *Significant Impact Guidelines 1.3: Coal Seam Gas and Large Coal Mining Developments – Impacts on Water Resources* (Commonwealth Department of the Environment, 2013) has been developed in order to assist CSG and large coal mining development applicants determine whether a development is likely to have significant impacts on water resources.

The bilateral agreement under the *EPBC Act* with the NSW government notes that NSW should seek and consider expert advice from the Independent Expert Scientific Committee (IESC) in relation to CSG or large coal mining developments that are likely to have a significant impact on water resources. The Project has been referred to the Commonwealth for the assessment against the *EPBC Act*, and at the time this report was prepared, a reply was yet to be received. The assessments in this report have also considered recent IESC advice from the recent Glendell Continued Operations Project and extensions to the existing Bulga Coal Complex, located near the Project. The GIA also considered the following IESC guidance notes:

- Information guidelines for proponents preparing coal seam gas and large coal mining development proposals, 2018
- Uncertainty analysis—Guidance for groundwater modelling within a risk management framework, 2018

The IESC also released a Guidance Note for characterising and modelling of geological fault zones in March 2022. This guidance note was released after the characterisation and modelling work as part of the GIA was largely completed, and therefore it could not be fully considered during preparation of the GIA. Information on faults and structures and is presented in Section 4.4. Many of the faults and structures within the mining areas have already been intercepted and removed by approved mining of shallow coal seams. The proposed mining of deeper coal seams therefore has less potential to create additional connectivity with alluvial systems through faults or other structures.

2.6 Water sharing plans and licensing

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 NSW Government has progressively developed 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 Project – these are the WSP for the:

- Hunter Regulated River Water Source 2016 (Hunter Regulated WSP) – Hunter River surface water;
- Hunter Unregulated and Alluvial Water Sources 2022 (Hunter Unregulated WSP) – alluvial groundwater and tributaries to the Hunter River; and
- North Coast Fractured and Porous Rock Groundwater Sources 2016 (North Coast Fractured and Porous Rock WSP) – groundwater from Permian interburden and coal.

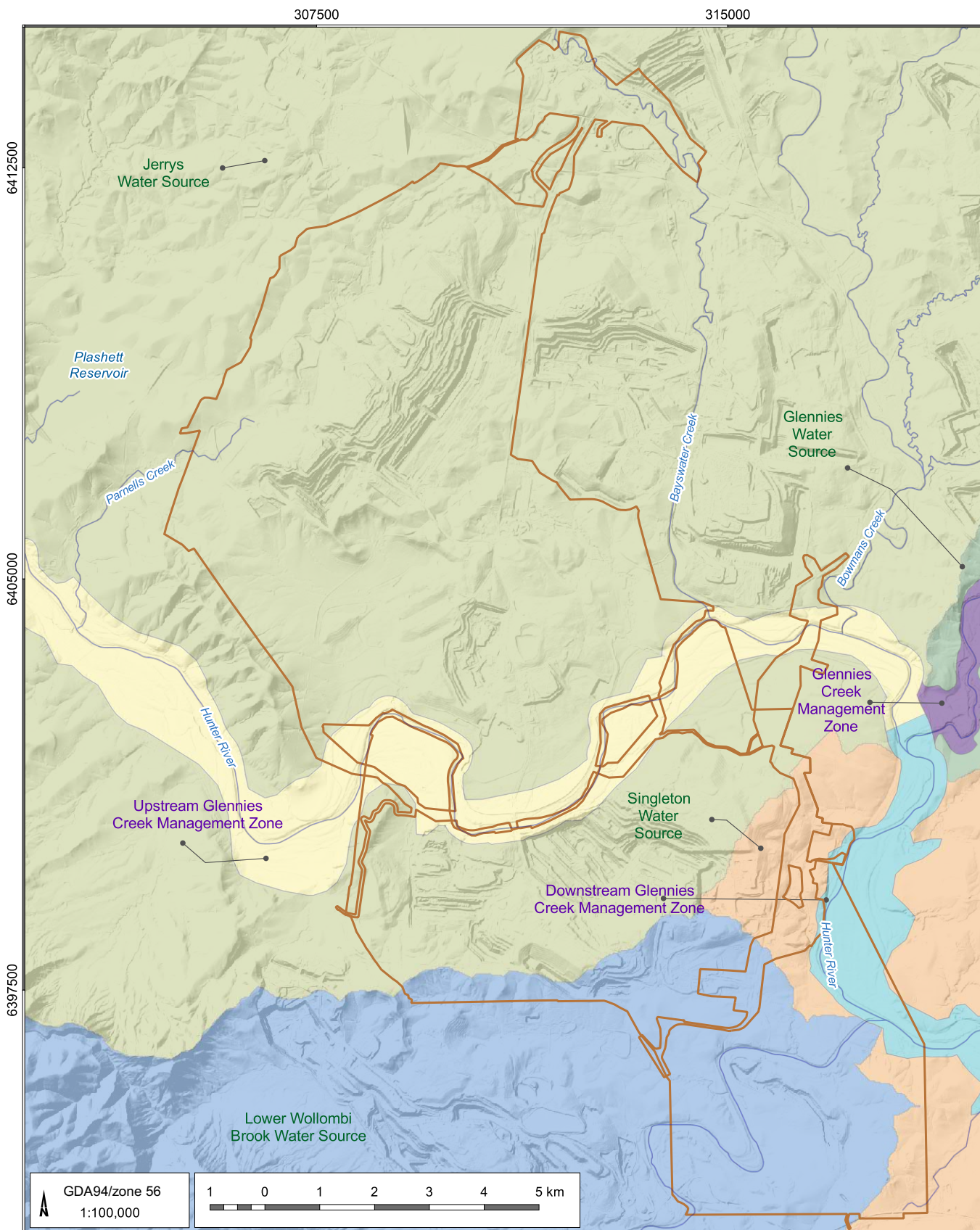
The boundaries of the respective WSP and water sources of the Hunter Regulated and Hunter Unregulated WSPs are shown in Figure 2.3 and Figure 2.4. The consolidated aquifers underlying the Hunter River Regulated and Hunter River Unregulated WSPs (not shown on the map) is wholly managed by the North Coast Fractured and Porous Rock WSP. HVO currently hold water entitlements from several water sources managed under different WSPs. Table 2.1 summarises the total number of WALs and the total entitlement for each management zone.

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

The Hunter 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. HVO is located within the Jerrys Water Source, Glennies Water Source, Singleton Water Source and the Lower Wollombi Brook Water Source areas.

The Hunter Regulated WSP covers the Hunter River surface water flows and highly connected alluvial aquifers within 40 m of the riverbanks of the Hunter River and Glennies Creek. The Hunter Regulated Water Source is divided into three management zones (Zone 1, Zone 2, and Zone 3). The zones are defined from a single common point, which is the junction of Glennies Creek with the Hunter River. The Hunter River within the Project area is managed by Zone 1B up to the Glennies Creek junction, Zone 2A up to the Wollombi Brook junction and Zone 2B for the remainder of the river until the downstream extent of the Hunter Regulated water source outside the Project area.

The WALs held by HVO for each management zone are presented on Table 2.1, and the total number of water access licences for the relevant water sources are presented on Table 2.2 below.



LEGEND

- Road
- Drainage
- Project Area

Water sources - Unregulated

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

Water sources - Unregulated - Alluvial

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

HVO Continuation (G1737J)

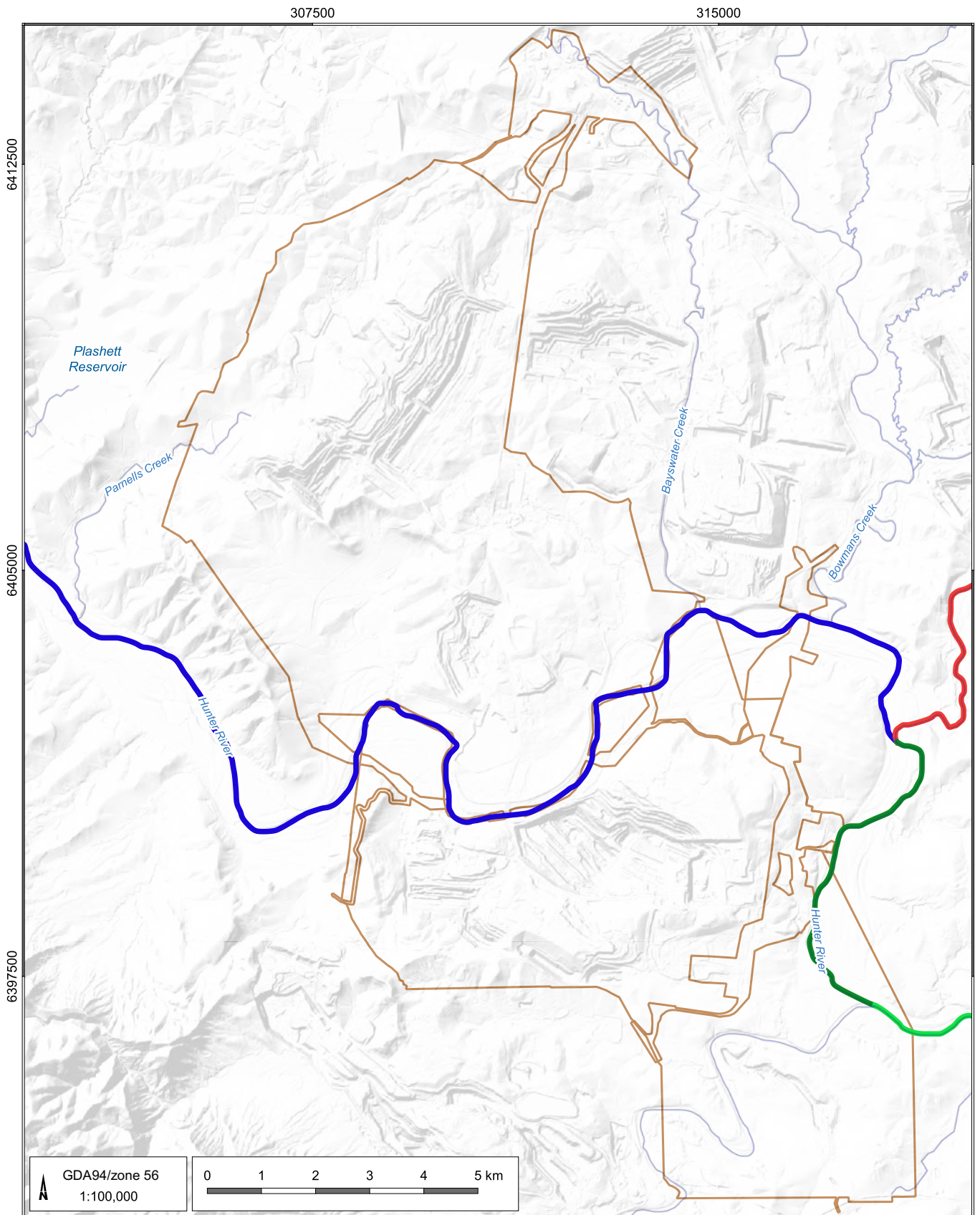
Water Sharing Plans - Unregulated



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FIGURE No:
2.3



LEGEND

— Drainage

— Project Area

Hunter Regulated River Water Source - Management Zones

— Management Zone 1B

— Management Zone 2A

— Management Zone 2B

— Management Zone 3A

HVO Continuation (G1737J)

Water sharing plans - Regulated



AGE

DATE
24/10/2022

FIGURE No:
2.4

Table 2.1 Water entitlements held by HVO in each water source

Water Sharing Plan	Water Source	Management Zone	Category	WALs	Allocation (units)
Hunter Regulated River Water Source 2016	Hunter Regulated River water source	Zone 1b (Hunter River from Goulburn river junction to Glennies Creek junction)	Domestic and stock	1	8
			General security	20	5244
			High security	6	3183
			Supplementary water	3	98
		Zone 2a (Hunter River from Glennies Creek junction to Wollombi Brook junction)	General security	4	1393
			High security	5	1506
			Supplementary water	2	302
		Zone 2b (Hunter River from Wollombi Brook junction to Oakhampton rail bridge)	Domestic and stock	2	16
			General security	4	613
			Supplementary water	2	128
Hunter Unregulated and Alluvial Water Sources 2022	Hunter Regulated River alluvial water source	D/S Glennies Creek management zone	Aquifer	3	289
		Glennies Creek management zone	Aquifer	0	
		U/S Glennies Creek management zone	Aquifer	2	448
	Jerrys water source	Jerrys management zone	Unregulated river	3	705
			Aquifer	1	120
	Lower Wollombi Brook water source	N/A	Aquifer	1	144
		N/A	Unregulated river	2	88
	Singleton water source	N/A	Aquifer	1	225
North Coast Fractured and Porous Rock Groundwater Sources 2016	Sydney Basin-North Coast groundwater source	N/A	Aquifer	6	5560

Table 2.2

Total number of water access licences and water usage for the relevant water sources (financial year 2022-2023)

Water Sharing Plan	Water Source	Category	No. of WALs	Total Share Component
Hunter Regulated River Water Source 2016	Hunter Regulated River water source	Domestic and stock	165	1562
		Domestic and stock [domestic]	63	147
		Domestic and stock [stock]	21	103
		Local water utility	5	10832
		Major utility [power generation]	1	36000
		Regulated river (general security)*	825	128544
		Regulated river (high security)*	155	21740
		Supplementary water*	239	48519.22
Hunter Unregulated and Alluvial Water Sources 2022	Hunter Regulated River alluvial water source	Aquifer*	226	24118
		Aquifer (general security)*	1	0
		Local water utility	5	4938
	Jerrys water source	Aquifer*	11	1246
		Domestic and stock	2	8
		Domestic and stock [domestic]	2	2
		Major utility	1	7700
		Unregulated river*	19	2097
	Lower Wollombi Brook water source	Aquifer*	42	3745
		Domestic and stock	12	48
		Domestic and stock [domestic]	1	1
		Domestic and stock [stock]	1	4
		Unregulated river*	97	6663
	Singleton water source	Aquifer*	2	230
		Domestic and stock	3	9
		Domestic and stock [domestic]	2	3
		Domestic and stock [stock]	1	1
		Unregulated river*	22	1170
North Coast Fractured and Porous Rock Groundwater Sources 2016	Sydney Basin-North Coast groundwater source	Aquifer*	172	67443.5
		Local water utility	9	1300

Notes: * = Access licence category assigned 1 ML per share.
The remaining access categories are "100% of share component".

2.7 Conditions of approval

The HVO North (DA 450-10-2003) and HVO South (PA 06_0261) development consents are managed by a Water Management Plan (WMP) (Water Management Plan, Hunter Valley Operations, Version 3.0, 2018) that complies with management conditions of the approvals. A draft update to the WMP is in review at the time this report was prepared. HV Operations currently holds all necessary water licences for the existing operations at HVO.

The WMP outlines how HV Operations 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 HV Operations business principles, policy, standards and all relevant licences and environmental approvals held by HVO. Section 11 outlines the content of the Groundwater Management Plan (GWMP) and how it will continue to be used for this Project in more detail.

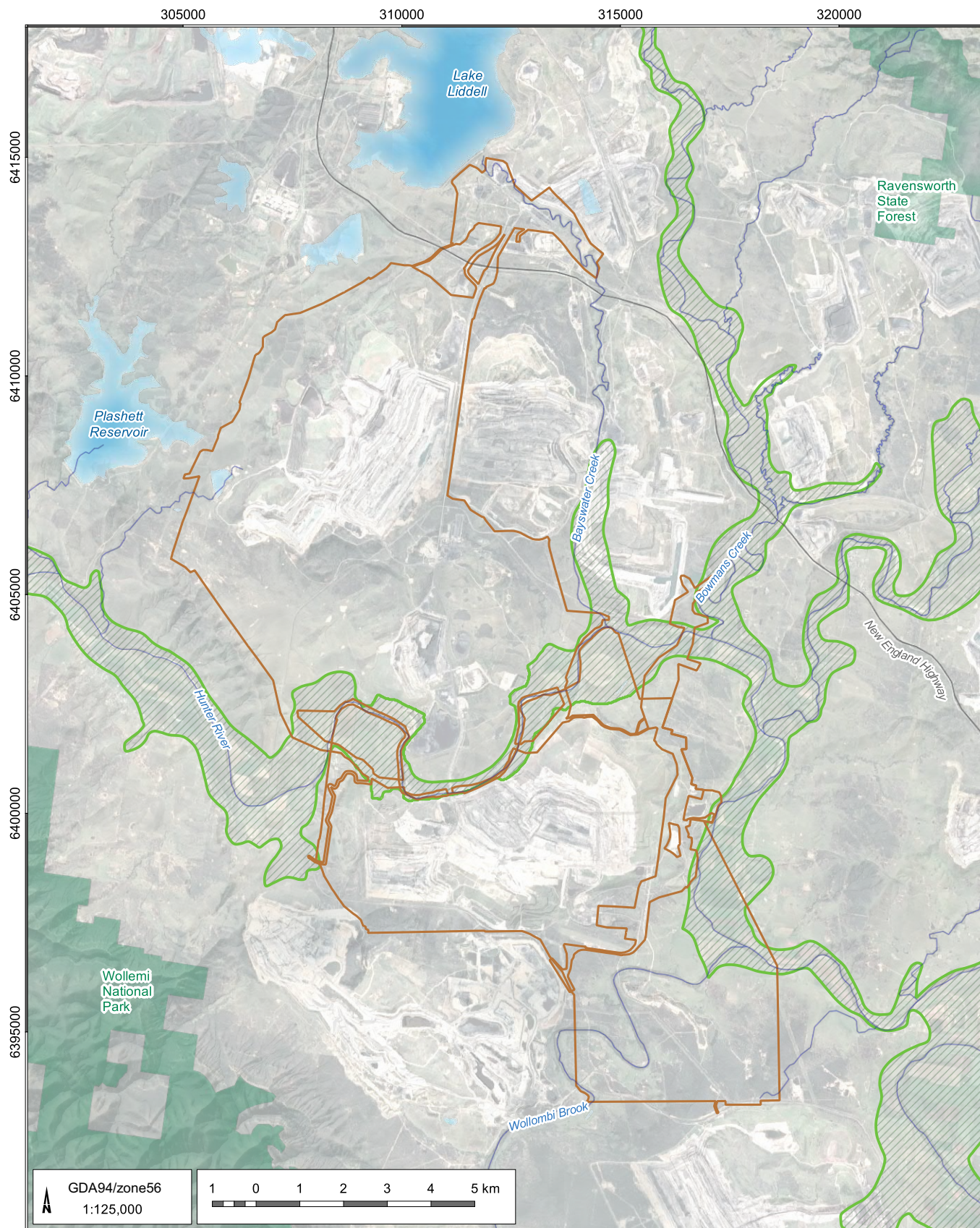
3 Environmental setting

3.1 Location and land use

The HVO Complex is located within the mid Hunter Valley coalfields. The mid Hunter Valley has a long history of mining the Permian Coal Measures dating back to 1800's. Land within the Project Area is currently used for coal mining and stock grazing. Surrounding land use in the region includes mining and mining related developments, the state-controlled Wollemi National Park to the south-west and agricultural activities such as grazing and cropping primarily along the Hunter River (Figure 3.1).

BSAL is land considered to have high quality soil and water resources capable of sustaining high levels of agricultural productivity (Section 2.4.1). BSAL has been mapped as occurring within the Hunter River floodplain, as shown in Figure 3.1. The regional mapping indicates that BSAL is present adjacent to the northern end of Riverview Pit and Cheshunt Pit, within the approved mine footprint. BSAL also existed within the footprint of the former Alluvial Lands project at HVO North, but has since been removed by mining.

Figure 3.2 shows the locations of the approved mines in the immediate area surrounding HVO. The mines are the United, Wambo and Mt Thorley Warkworth mine complex which are located directly south of HVO, while several other mining operations including Ravensworth Operations, Liddell and Glendell are located to the east and north-east. Most of the mines are developed using open cut but can also have underground operations. The closest underground mines to the Project are the Lemington Underground mine at HVO South and the Ravensworth Underground Mine to the north.



LEGEND

- Road
- Drainage
- Project Area
- Biophysical Strategic Agricultural Land (BSAL)
- National Park

HVO Continuation (G1737J)

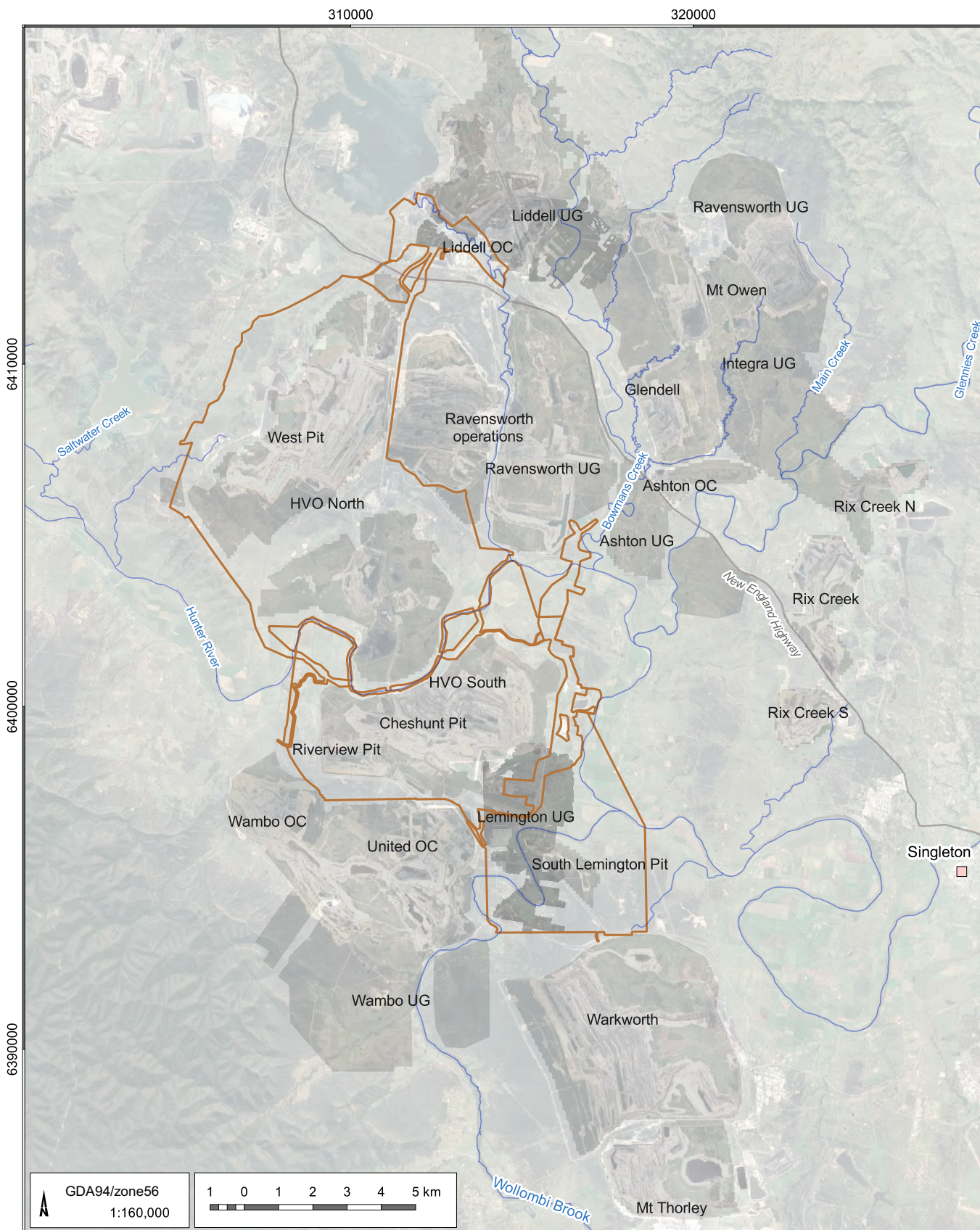
Land use



AGE

DATE
24/10/2022

FIGURE No:
3.1



LEGEND

- Populated place
- Road
- Drainage
- Project Area
- Underground workings

HVO Continuation (G1737J)

Historic and approved mining



AGE

DATE
02/11/2022

FIGURE No:
3.2

3.2 Climate

3.2.1 Rainfall and evapotranspiration

The climate in the region is characterised by hot summers and mild dry winters. Climate data was obtained from the Scientific Information for Land Owners (SILO)¹ database of historical climate records for Australia. This service interpolates climate records from available BoM weather stations with data gaps addressed through data processing to provide a spatially and temporally complete climate dataset. SILO data was downloaded for a point within the Project boundary (151.00°, -32.5° elevation 77 mAHD). The summarised rainfall and evaporation data from 1900 to 2022 for the Project location is provided in Table 3.1.

Table 3.1 Rainfall and evaporation averages

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Mean rainfall (mm)	73.1	69.8	65.3	44.9	38.7	46.2	41.1	35.2	39.8	49.7	61.7	68.1	633.7
Mean evaporation (mm)	203.5	159.0	141.3	102.2	72.4	55.0	64.3	88.4	119.2	156.5	177.9	207.4	1547.0
Evap minus rainfall	130.3	89.2	75.9	57.3	33.8	8.9	23.2	53.3	79.4	106.8	116.2	139.2	913.4

Based on the SILO dataset, average annual rainfall is 632 mm, with January being the wettest month (73 mm). Annual evaporation (1,511 mm/year) exceeds mean rainfall throughout the year, with the highest moisture deficit occurring during the summer months.

The Cumulative Rainfall Departure (CRD) since 1950 is provided in Figure 3.3. Monthly records from the SILO dataset were used to calculate the CRD, also referred to as the rainfall residual mass. The CRD is a summation of the monthly departure of rainfall from the long-term average monthly rainfall and provides a historical record of relatively wet and dry periods. A rising trend in slope in the CRD plot indicates periods of above average rainfall, whilst a declining slope indicates periods when rainfall is below average. A standard technique for assessing groundwater level trends is to compare the water level hydrographs with the CRD. The CRD can be used to assess if changes in groundwater levels are correlated with climatic conditions or other factors such as resource extraction, mining, irrigation etc.

¹ <https://www.longpaddock.qld.gov.au/silo/>.

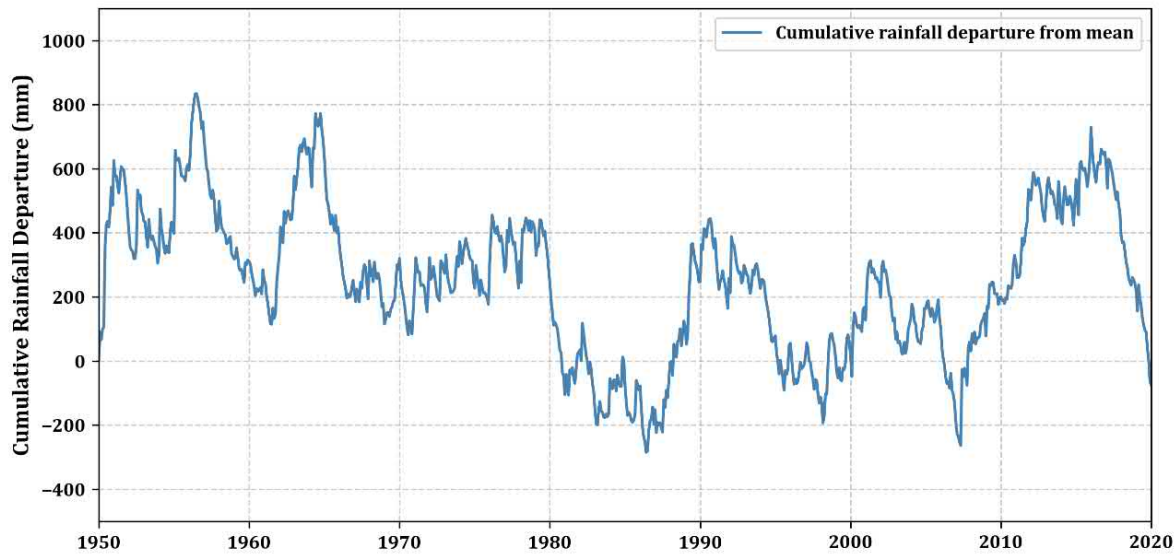


Figure 3.3 Cumulative Rainfall Departure (SILO)

Figure 3.3 shows the long-term variations in rainfall since mining in the Hunter region began in 1950. Four distinct periods can be observed from the CRD trends over the last 20 years:

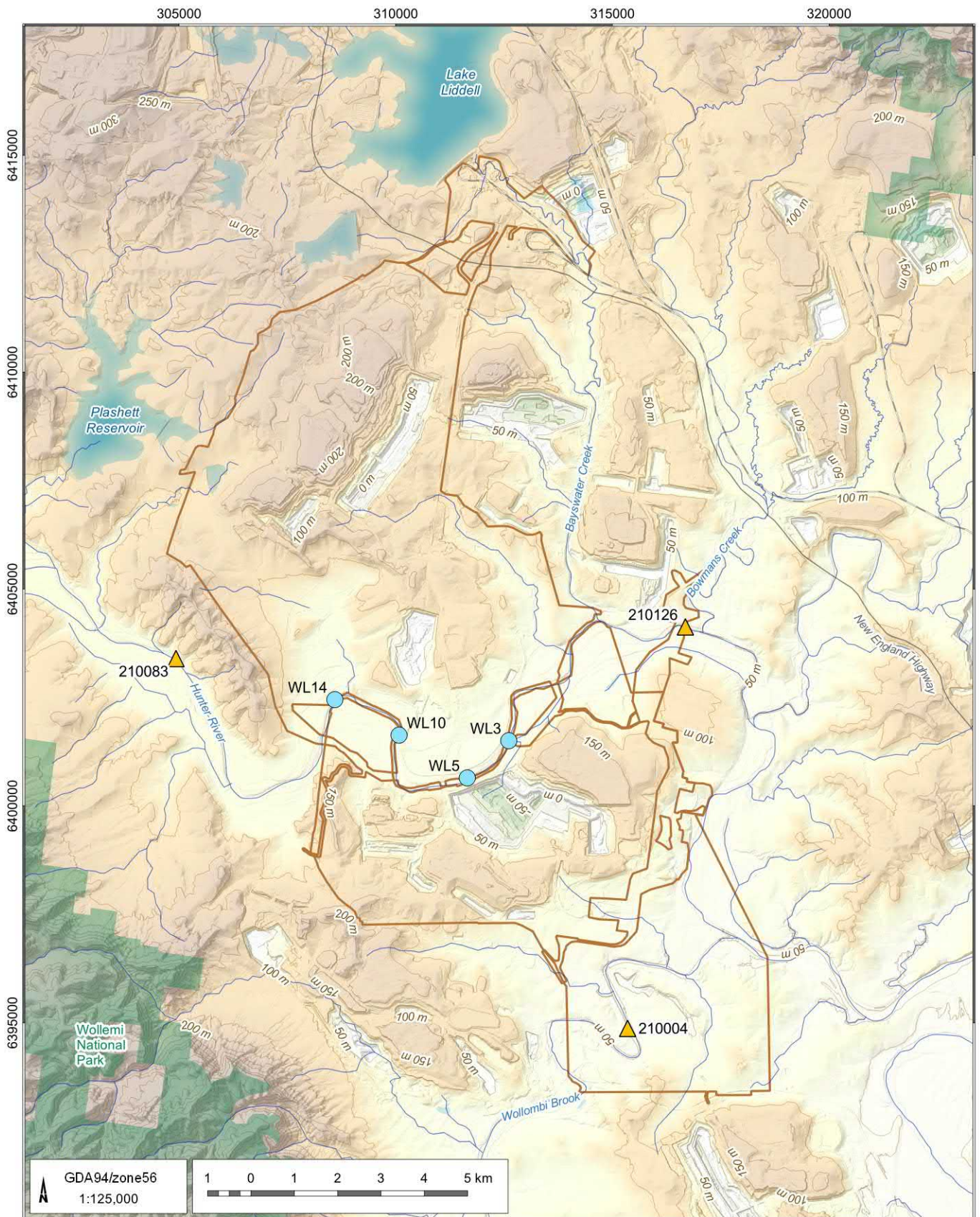
- 2000 - 2007 - during the Millennium drought where rainfall was commonly below average and El Niño events occurred;
- 2007 – 2012 - when rainfall was commonly above average and La Niña events occurred;
- 2012 to 2016 - when rainfall generally remained closer to historical averages, with a relatively neutral trend; and
- 2017 to 2020 – a period where rainfall was consistently below average, and the Hunter region was declared as drought affected by NSW DPI.

Since 2020 rainfall has been above average due to La Nina conditions. Groundwater levels within shallow groundwater systems decline naturally during the drier periods and recover during periods of enhanced rainfall recharge. Groundwater levels and climate are discussed further in Section 6.1.

3.3 Terrain

At a regional scale, the terrain is characterised by a steep and incised range to the south-west (> 300 mAHD), declining generally towards the lower lying floodplains of the Hunter River and Wollombi Brook (Figure 3.4). The main topographic highpoint within the region is located south-west of the Project within the Wollemi National Park. Mining in the region, including the Project occurs adjacent to the Hunter River floodplains where hilly terrain grades into flat alluvial plains. The ground levels in the Hunter River and Wollombi Brook alluvial lands and surrounding area are around 50 mAHD to 70 mAHD.

The floodplain in the Project Area is largely cleared of vegetation due to historical farming and mining. Some sparse riparian vegetation is present along the Hunter River and Wollombi Brook, including tree species such as the River Red Gum. Wollemi National Park is densely vegetated with various plant communities, including open forests dominated by eucalypt species.



LEGEND

- ▲ DPIE stream gauge
- HVO stream gauge
- Road
- Rail
- Drainage
- Elevation contour (mAHd)
- Project Area
- National Park
- Water area

Elevation (mAHd)

- 150
- 75
- 50
- 50
- 80
- 100
- 300
- 250

HVO Continuation (G1737J)

Terrain and drainage



DATE
24/10/2022

FIGURE No:
3.4

3.4 Drainage

The Hunter River is the primary surface water drainage in the Project Area. The river flows in an easterly direction immediately through the Project Area, then flowing in a southerly direction. The tributaries in the Project Area include Parnells Creek, Farrells Creek, Bayswater Creek, Bowmans Creek and Wollombi Brook. The Hunter River and Wollombi Brook are main surface water features directly adjacent to the HVO Complex and a focus of the GIA.

Figure 3.5 shows a photograph of Hunter River at Lemington road crossing. The Hunter River is a regulated river with flows controlled by releases from the Glenbawn Dam located approximately 35 km north of the HVO Complex. The dam supplies water into the Hunter River to meet the requirements of irrigation, stock and industry licence holders as well as allowances for environmental water. As a result, the river level and flow volumes vary according to climate, water release and annual water demand from water licence holders.

Figure 3.6 shows a photograph of Wollombi Brook looking upstream of the Warkworth River gauging station. Wollombi Brook flows in a north to north-easterly direction across HVO South, eventually joining with the Hunter River. Wollombi Brook is an ephemeral watercourse, with flows dependent on rainfall events.

Both HVO and the NSW state government monitor streamflow at gauging stations along the Hunter River and Wollombi Brook at the locations shown in Figure 3.4. The NSW gauging stations for each of the watercourse are:

- Hunter River at Liddell (210083);
- Hunter River upstream at Foybrook (210126); and
- Wollombi Brook - Wollombi Brook at Warkworth (210004).

Figure 3.7 to Figure 3.9 show the stream flow and estimated baseflow at these gauging stations. The figures show the estimated baseflow using the method developed by Lyne and Hollick (1979). The method assumes that the filtering of baseflow from quickflow is analogous to digital filtering used in signal analysis. The filter is run three times through the dataset (forward, backward, forward) to smooth out the data to separate out quickflow and baseflow components from the stream flow dataset. The method is not directly related to the underlying physical processes, but it is widely used because it provides objective and repeatable results.

The baseflow volumes were estimated at 25%, 23.1% and 10.3% for the gauging stations at Hunter River at Liddell, Hunter River upstream at Foybrook and Wollombi Brook respectively. The baseflow analysis show that baseflow contribution into Hunter River decreases slightly downstream. The baseflow is notably less in Wollombi Brook compared to the Hunter River and in the 2017 to 2019 drought Wollombi Brook ceased to flow.



Figure 3.5 Hunter River at Lemington road crossing (image from Google Maps)



Figure 3.6 Wollombi Brook at the Warkworth river gauge (BMT WBM, 2014)

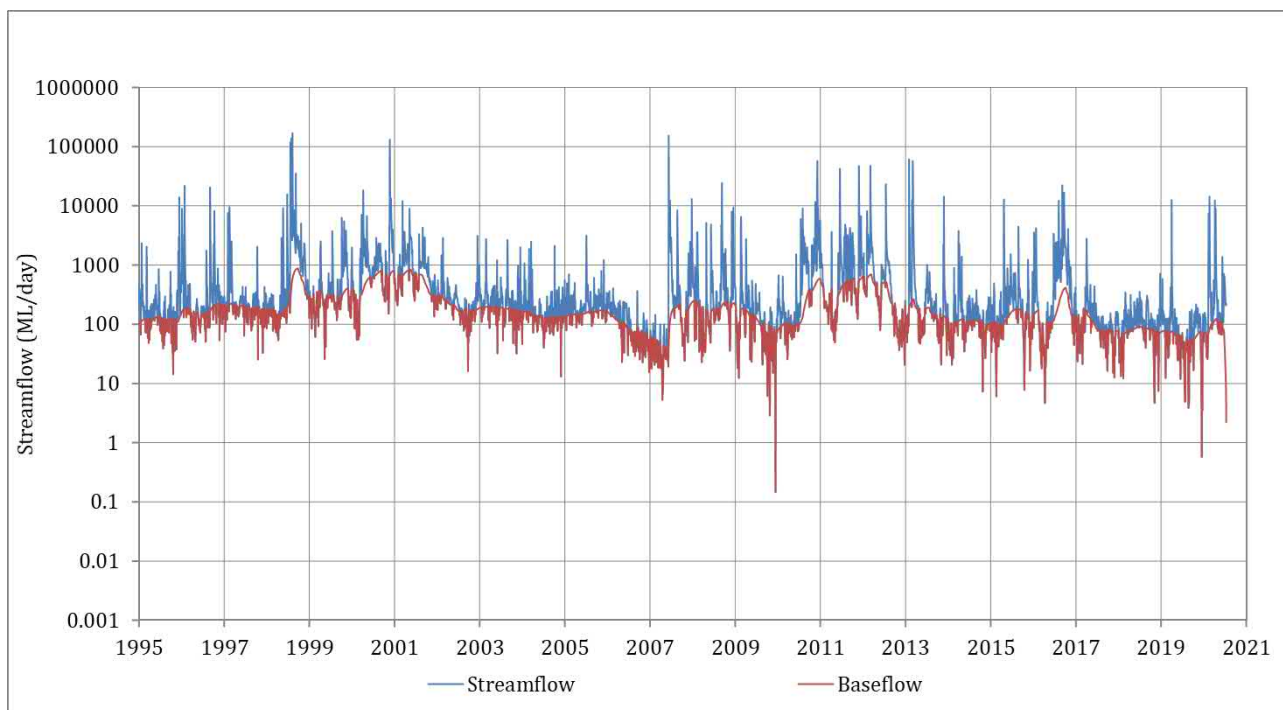


Figure 3.7 Baseflow in Hunter River at Liddell (210083)

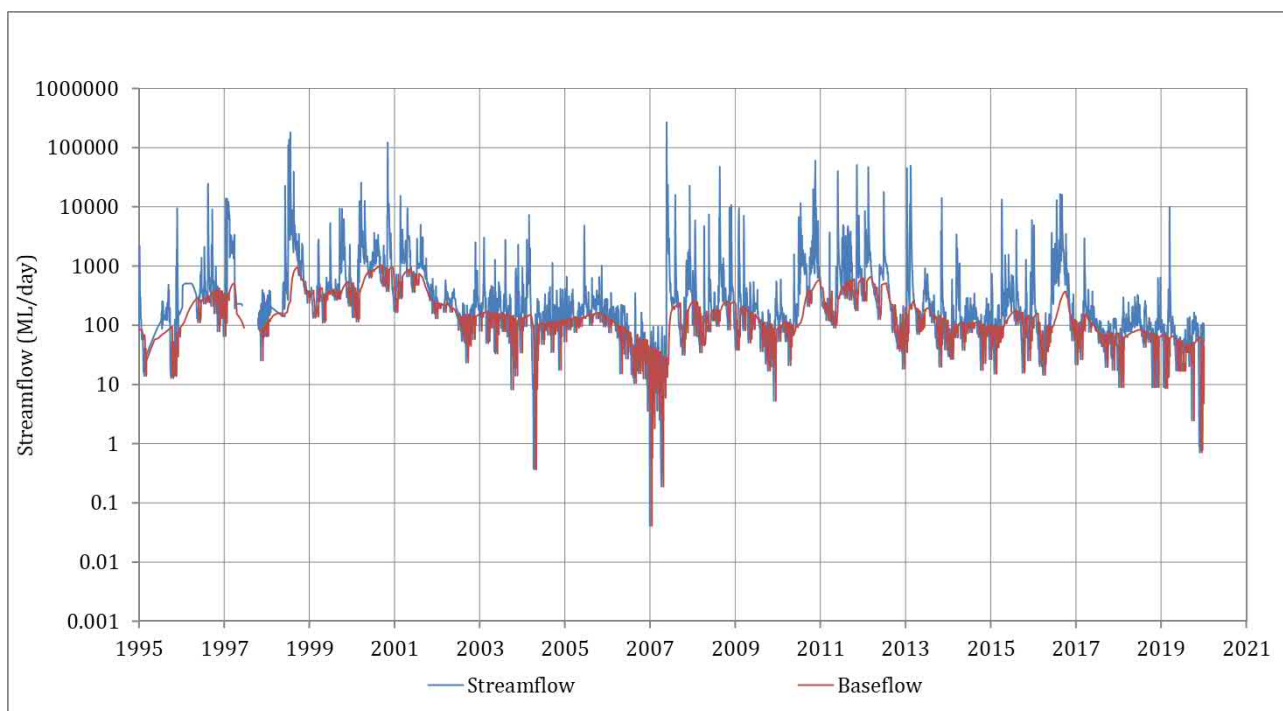


Figure 3.8 Baseflow in Hunter River at upstream of Foybrook (210126)

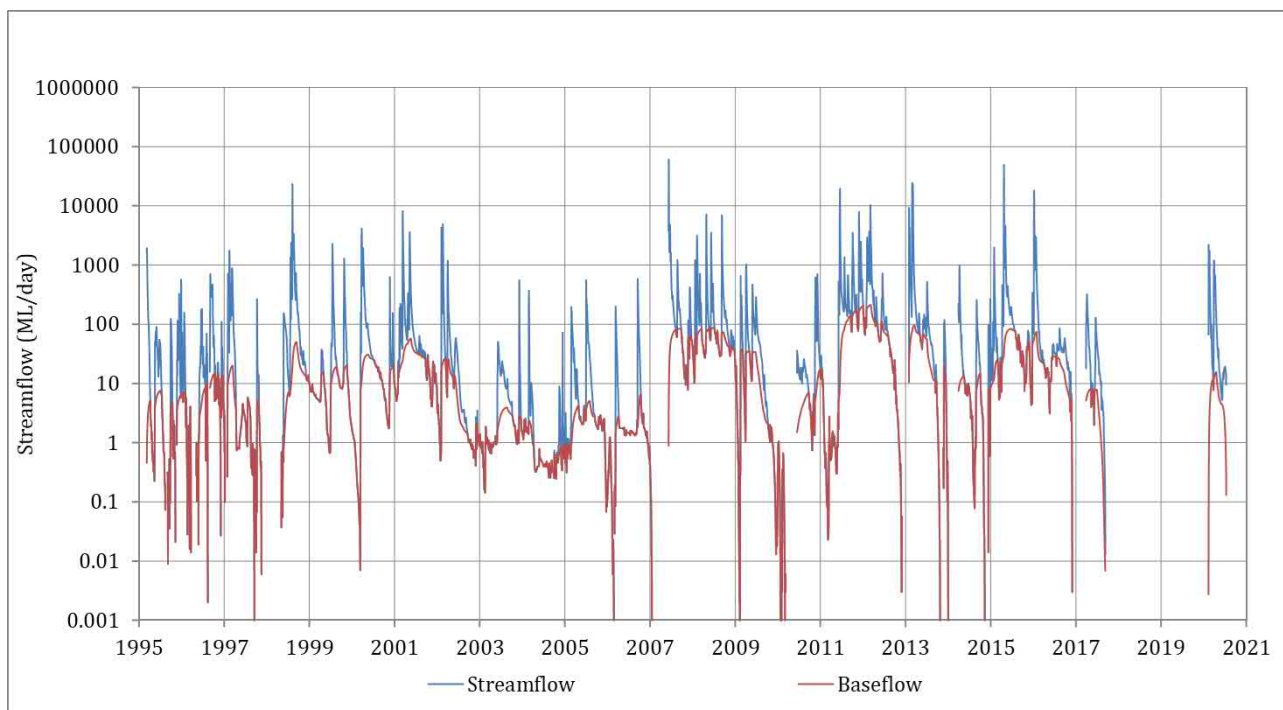


Figure 3.9 Baseflow in Wollombi Brook at Warkworth (210004)

4 Geological setting

There is a significant history of mining within and surrounding the HVO Complex which means the geology is well understood. Previous documents that describe the geology/hydrogeology include the Carrington West Wing Extension for HVO North (Modification 3; MER, 2010), HVO South Modification 5 (AGE, 2015), and also McVicar and others (2015) as part of Australian Government's Bioregional Assessment program. For this reason, it is considered the geological surfaces for the key hydrostratigraphic units have a relatively low level of residual uncertainty compared to less developed or greenfield areas.

4.1 Regional geology

The Project is located within the Hunter Coalfield towards the north-eastern margins of the Permian and Triassic Sydney Basin. The basin formed during a period of crustal thinning and igneous rifting in the Late Carboniferous to Early Permian and subsequently infilled with Permian and Triassic aged sediments. The basin is structurally bounded by the Hunter-Mooki Thrust Fault approximately six kilometres to the north-east, where the New England Block is thrust over Permian Sydney Basin sediments.

Table 4.1 provides a summary of the regional geology and relevant stratigraphic units within the Project area.

Table 4.1 Summary of regional geology

Age	Stratigraphic Unit	Description
Quaternary	Quaternary sediments – alluvium (Q_a, Q_al, Q_av, QH_al)	Shallow sequences of clay, silty sand and sand. Basal sands and gravels overlying surficial alluvium along major watercourses (i.e. Hunter River and Wollombi Brook).
	Aeolian dunes and associated sands (Cz_dds, Cz_aths)	Dune sand.
Tertiary	Cenozoic terrestrial deposits (Cz_athc, Cz_ag, Cz_aa, Cz_a)	Silt, sand and gravel.
	Volcanics (Jui__d, Mzui__k, Mzui__t)	Flows, sills and dykes.
Triassic	Narrabeen Group (Tn)	Sandstone, interbedded sandstone and siltstone, claystone. Localised at Wollemi National Park.
Permian	Newcastle Coal Measures (Pne)	Coal seams, claystone (tuffaceous), siltstone, sandstone and conglomerate.
	Watts Sandstone (Pihw)	Medium to coarse-grained sandstone.
	Jerrys Plains Sub-group (Pwj)	Cyclic coal seam sequence with dark-grey to black laminated shale and siltstone. Coal seams, in the order of increasing age and depth, include: • Whybrow Seam, • Redbank Creek Seam, • Wambo Seam, • Whynot Seam, • Blakefield Seam, • Glen Munro Seam, • Woodlands Hill Seam, • Arrowfield Seam, • Bowfield Seam, • Warkworth Seam, • Mt Arthur Seam, • Piercefield Seam, • Vaux Seam, • Broonie Seam and • Bayswater Seam.
	Wittingham Coal Measures	
Permian	Archerfield Sandstone	Bronze-coloured lithic sandstone.
	Vane Sub-group (Pwv)	Coal bearing sequences with wedges of sandstone and siltstone. Coal seams, in the order of increasing age and depth, include: • Lemington Seam, • Pikes Gully Seam, • Arties Seam, • Liddell Seam, • Barrett Seam and • Hebden Seam.
	Saltwater Creek Formation (Pwts)	Sandstone and siltstone, minor coaly bands, siltstone towards base.
	Maitland Group (Pmt)	Siltstone, claystone and minor fine-grained sandstone.

Figure 4.1 shows the regional surface geology across the site and surrounds, based on the NSW state-wide seamless geology data package (Colquhoun et al. 2019) which is in turn sourced from contemporary geological mapping (on a variety of scales) across NSW. The Permian coal measures are stratified (layered) sequences dipping in a general west to south-westerly direction and outcrop over most of the mapped extent. Regionally, the surface the coal measures is influenced by a series of fold structures. The Permian sediments are unconformably overlain by thin meandering lineaments of Quaternary alluvial sediments deposited along drainage line flood plains. A weathering profile is typically present as a thin heterogeneous layer of unconsolidated weathered material (regolith) grading through weathered rock to fresh bedrock.

4.2 Regional structures

The regional geology and major geological structures are shown in Figure 4.1. Major fold structures in the Project area and region include the:

- Bayswater Syncline that runs in a south-west direction through HVO South;
- Muswellbrook Anticline located to the west of HVO North;
- Camberwell Anticline located approximately 5 km north-east of the HVO Complex.

The Glendell mining operation targets shallow coal seams along the Camberwell Anticline. Mt Owen and Integra mining operations located on the eastern flank of the anticline are conceptualised to have limited interaction with mining operations on the western flank.

An extensive regional fault is the Hunter Valley Cross Fault, that passes to the south and west of the Project Area. Little is documented about the fault, but historic information suggests it is not large with a maximum displacement of approximately 10 m. An area locally named 'Block Fault Zone', is a zone of faults north-east of the Project Area some 250 m to 300 m wide with typical fault displacements of less than 12 m.

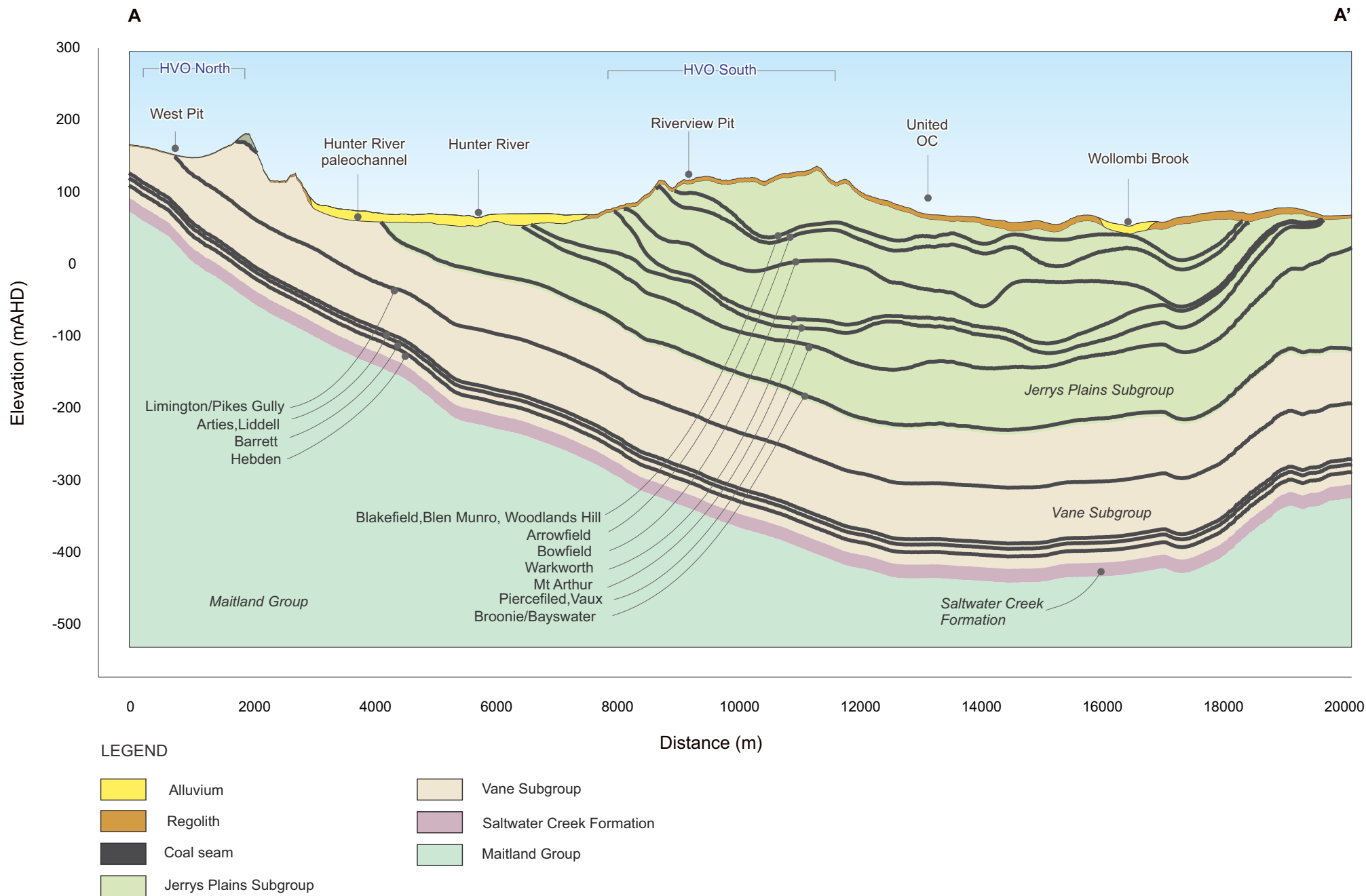
The most significant regional intrusion is the north-east trending Hunter Valley Dyke, which is a volcanic intrusion aligned with a regional fault structure that passes through HVO North and HVO South as shown on Figure 4.1, and is known to continue north to Liddell Mine along the alignment of the David Creek Fault.

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 Source: ELVIS LIDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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4.3 Local geology

The younger Permian and Triassic units above the Permian Wittingham Coal Measures have been largely eroded away in the Project area. Consequently, the geology surrounding HVO is now characterised by two distinct geological units, namely Quaternary alluvium occurring within the Hunter River floodplain and its tributaries, and the Permian Wittingham Coal Measures that form the bedrock.

Figure 4.2 shows a conceptual geological cross-section based in the Project area. The cross-sections show the relative distribution of key stratigraphic units across the Project.



Conceptualised geological cross-section A - A'

Figure - 4-2

HVO Continuation (G1737J)

4.3.1 Quaternary alluvium

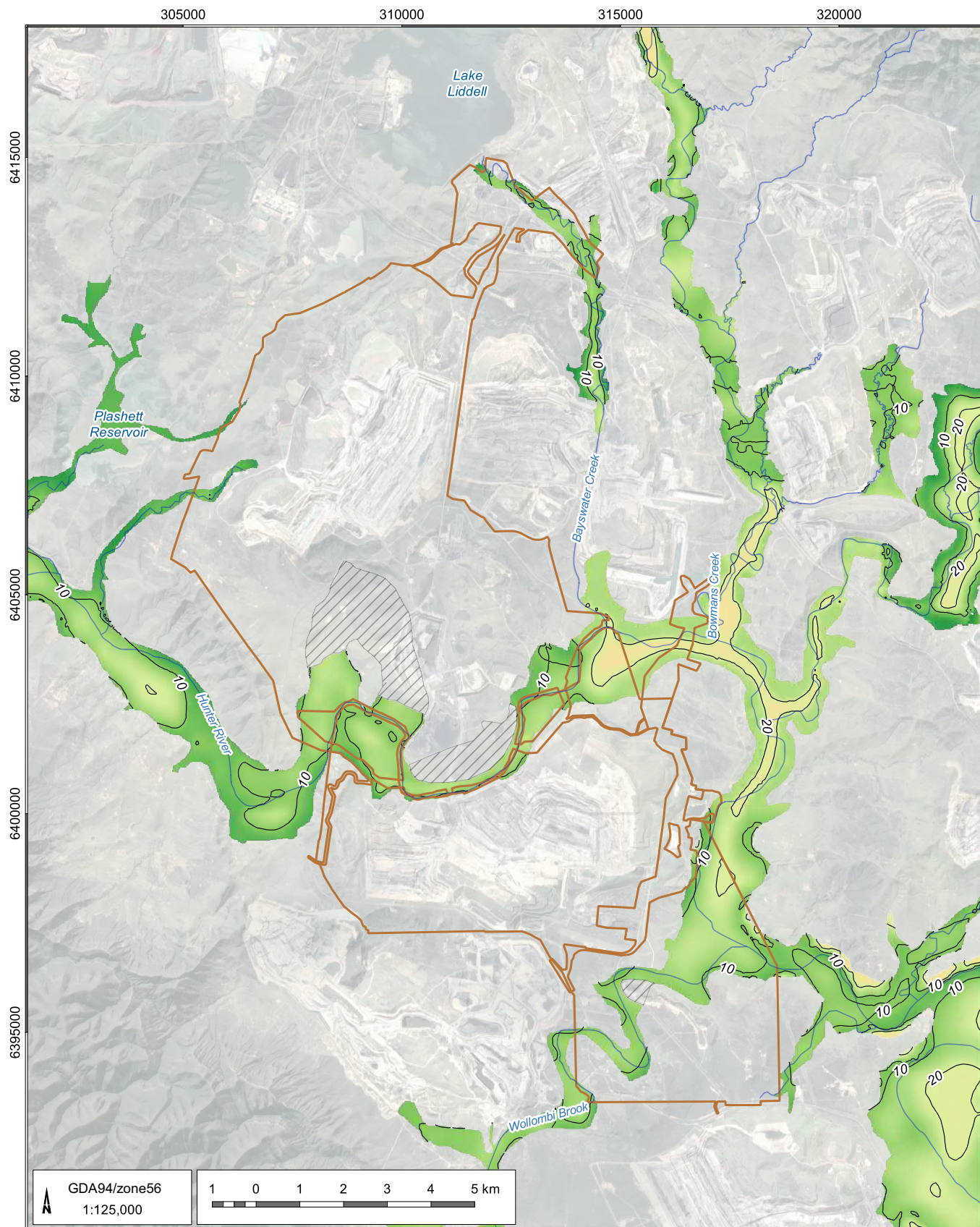
The Quaternary alluvium sediments along the Hunter River and Wollombi Brook flood plains comprise two distinct depositional units, a surficial fine-grained sediment and coarser basal material (Table 4.1). The alluvium in general comprises upward fining sequences of clay, sands and gravel. The thickness and extent of the alluvium is shown in Figure 4.3. Along the Hunter River and Wollombi Brook flood plains the productive basal sands are typically between 7 m and 20 m thick. The basal sands and gravel at the base of the Hunter River and Wollombi Brook alluvium form a 'highly productive' aquifer as defined in Section 2.4.2.

An ancient river meander carved into the underlying Permian sediments and infilled with alluvial sediments forms a palaeochannel to the north of the Hunter River near Carrington Pit (Figure 4.3). Previous studies conducted by previous owners Coal & Allied identified that the coarser gravels largely occur within the western limb of the palaeochannel (MER 2010). The initial extent of the palaeochannel extends three kilometres north of the river, but the eastern limb of the palaeochannel has since been removed by mining of Carrington Pit. A low permeability barrier wall (the Carrington Pit barrier wall) has been constructed across the eastern limb of the palaeochannel to reduce interaction with the Hunter River alluvium. As described in Section 1.5.1, future mining in the approved Carrington West Wing Pit will involve installing a barrier wall, consistent with the construction approach of the Carrington Pit barrier wall, which will restrict flow between the pit and the western limb of the palaeochannel soon after mining.

4.3.2 Aeolian deposits

Cenozoic dune sands (CZ_dds) and associated high level sand deposits (Cz_aths) mapped in the state geology dataset (Figure 4.1) is locally referred to as 'Warkworth Sands' in the Project Area. The feldspathic quartz aeolian sands are approximately 3 m thick and form a thin capping on the underlying Permian bedrock. The fine-grained sands overlie a low permeability base of residual clay associated with the underlying strata. The low permeability clays reduce vertical flow of groundwater and result in the formation of a thin perched water table at the base of the sand mass.

The aeolian sand's ability to store and slowly release water supports unique woodland known as the Warkworth Sands Woodland. The Warkworth Sands supports a woodland defined as the Warkworth Sands Woodland in the Sydney Basin Bioregion, that is classified as an endangered ecological community under the Biodiversity Conservation Act 2016 (BC Act) and critically endangered ecological community under the Commonwealth EPBC Act.



LEGEND

- Drainage
- Contour line
- Project Area
- Mined out former paleochannel

Thickness (m)

- 0
- 5
- 10
- 20
- 30

HVO Continuation (G1737J)

Alluvium thickness



AGE

DATE
02/11/2022

FIGURE No:
4.3

4.3.3 Permian Wittingham Coal Measures

The Permian Wittingham Coal Measures comprise economic coal seams, along with overburden and interburden consisting of sandstone, siltstone, tuffaceous mudstone and conglomerate. The coal measures occur at outcrop and are unconformably overlain by Quaternary sediments along drainage lines and spare patches of aeolian sediments. As a result, the upper Permian stratigraphy underwent a period of weathering, resulting in a thin, surficial weathering profile of unconsolidated and highly weathered material (regolith) overlying bedrock. The red outline in Figure 4.4 shows the approximate contact of weathering profile above fresh rock of the Permian Wittingham Coal Measures at Carrington Pit. The depth of weathering varies in the area and can extend to 50 m below surface.

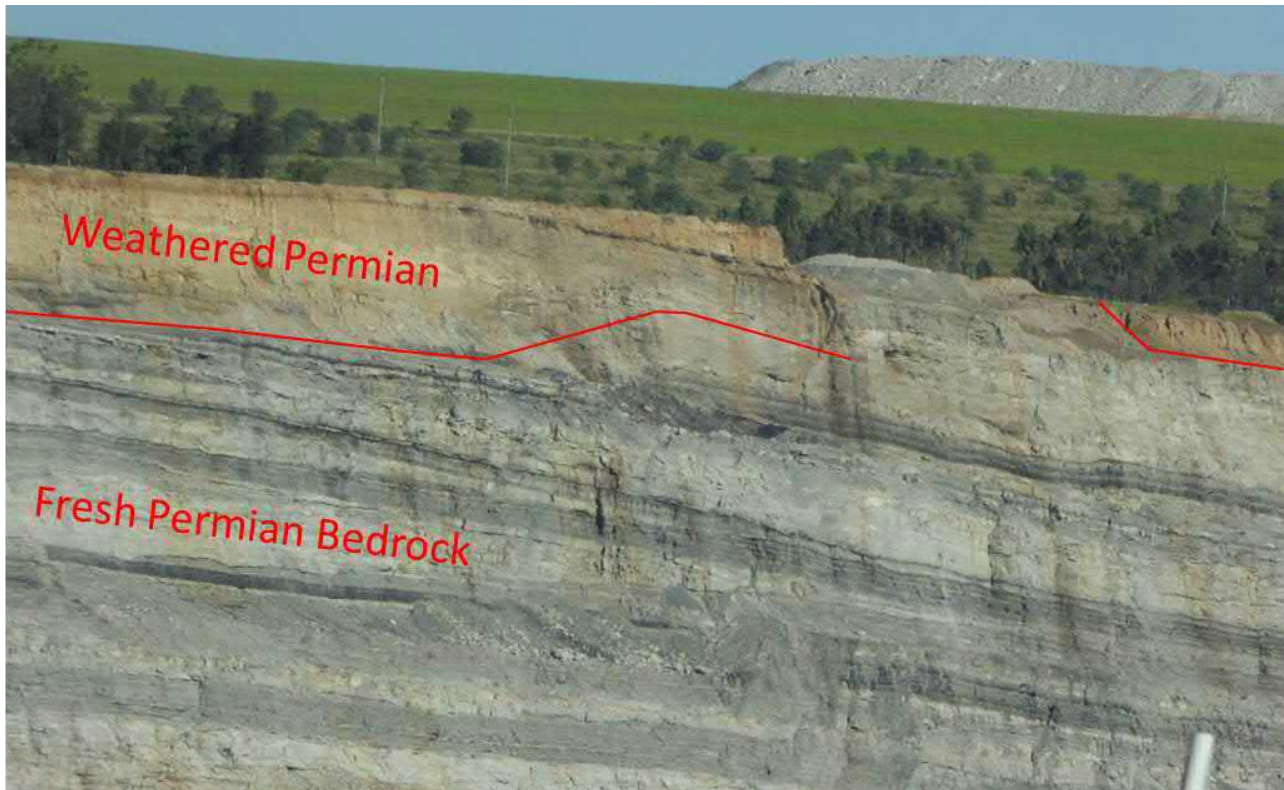


Figure 4.4 Weathering of the Permian Wittingham Coal Measures

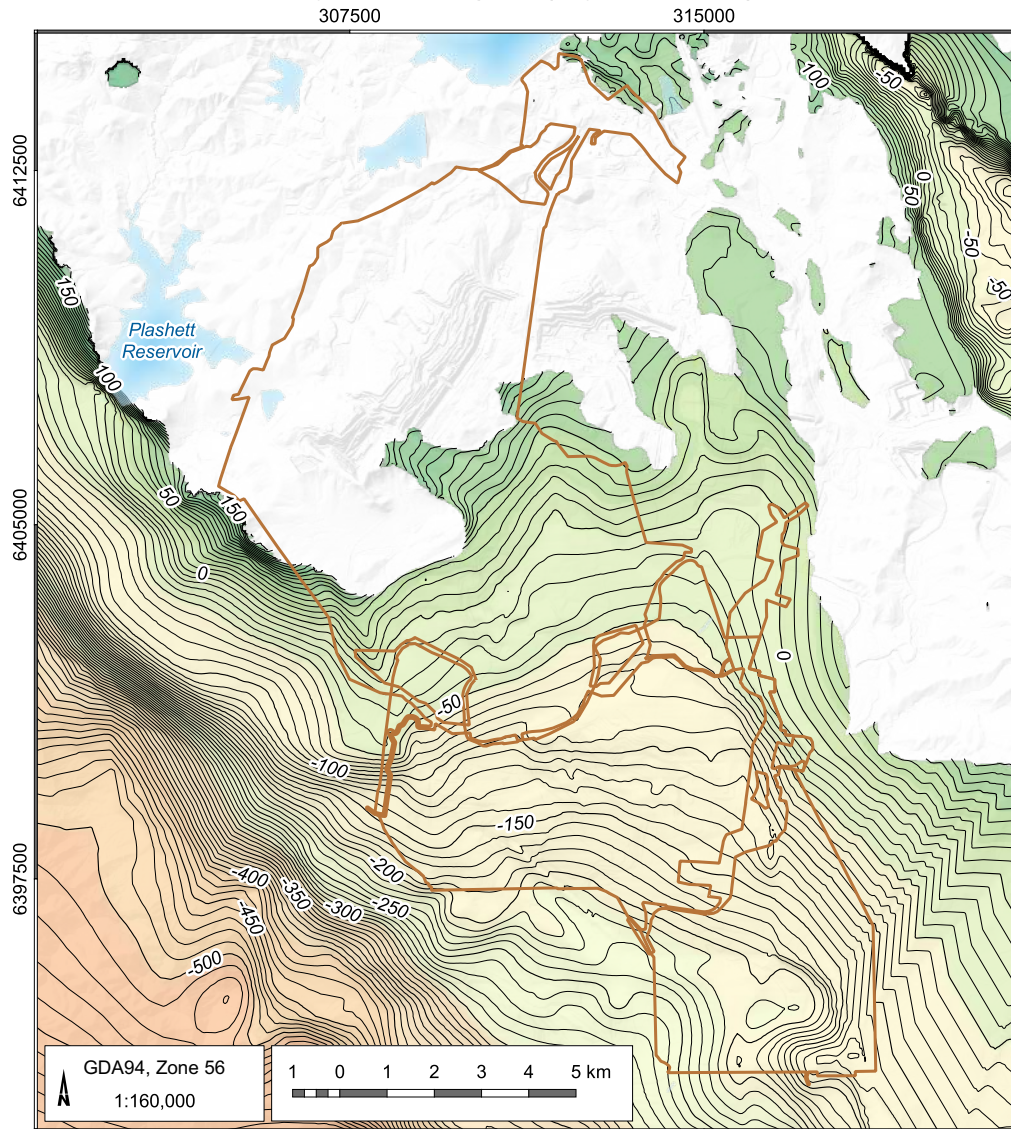
Mining at HVO South intercepts only the Jerrys Plains Subgroup (Pwj) of the Wittingham Coal Measures. The outcrop extent of the Jerrys Plains Subgroup is shown on Figure 4.1 while the thickness of the subgroup is shown on Figure 4.5. The Jerrys Plains Subgroup is absent in the northern area of HVO North, gradually thickens from its outcrop in the north and is up to 300 m thick at HVO South. Within the Jerrys Plains Subgroup there are 15 main coal seams that are mined across the Hunter Valley. Each coal seam occurs with various splits and plies but generally has a cumulative thickness of 5.5 m thick.

The Bayswater Seam is underlain by the Archerfield Sandstone of the Vane subgroup, which is a marker bed between the Jerrys Plains Subgroup and the underlying Vane Subgroup of the Wittingham Coal Measures. The sandstone unit consists of well-sorted quartz lithic sandstone and is distinguishable as a massive, light brown or honey coloured sandstone.

Mining in the Project Area has resulted in removal of the Permian interburden and coal which is then emplaced in the mining pit as spoil after recovery of coal. Spoil material exists within the mined footprint and rehabilitated areas, primarily along the western edge of West Pit and Alluvial Lands in HVO North, and around Cheshunt and Riverview pits in HVO South.

The outcrop extent of the Vane Subgroup (Pwv) is shown on Figure 4.1 while the thickness and bottom elevation of the subgroup is shown on Figure 4.6. The Vane subgroup gradually thickens from its outcrop in the north and is up to 500 m thick at HVO South. Coal seams of the Vane subgroup are currently mined from HVO North and other mines to the east where it occurs as outcrop. Each coal seam in the Vane subgroup generally has a cumulative thickness between 2 m to 12 m.

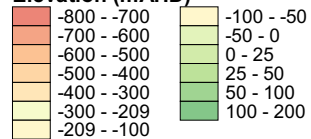
Bottom elevation of Jerrys Plains Subgroup (Bayswater Seam)



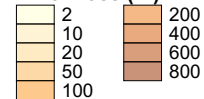
LEGEND

- Populated place
- Drainage
- Contour line
- Project Area

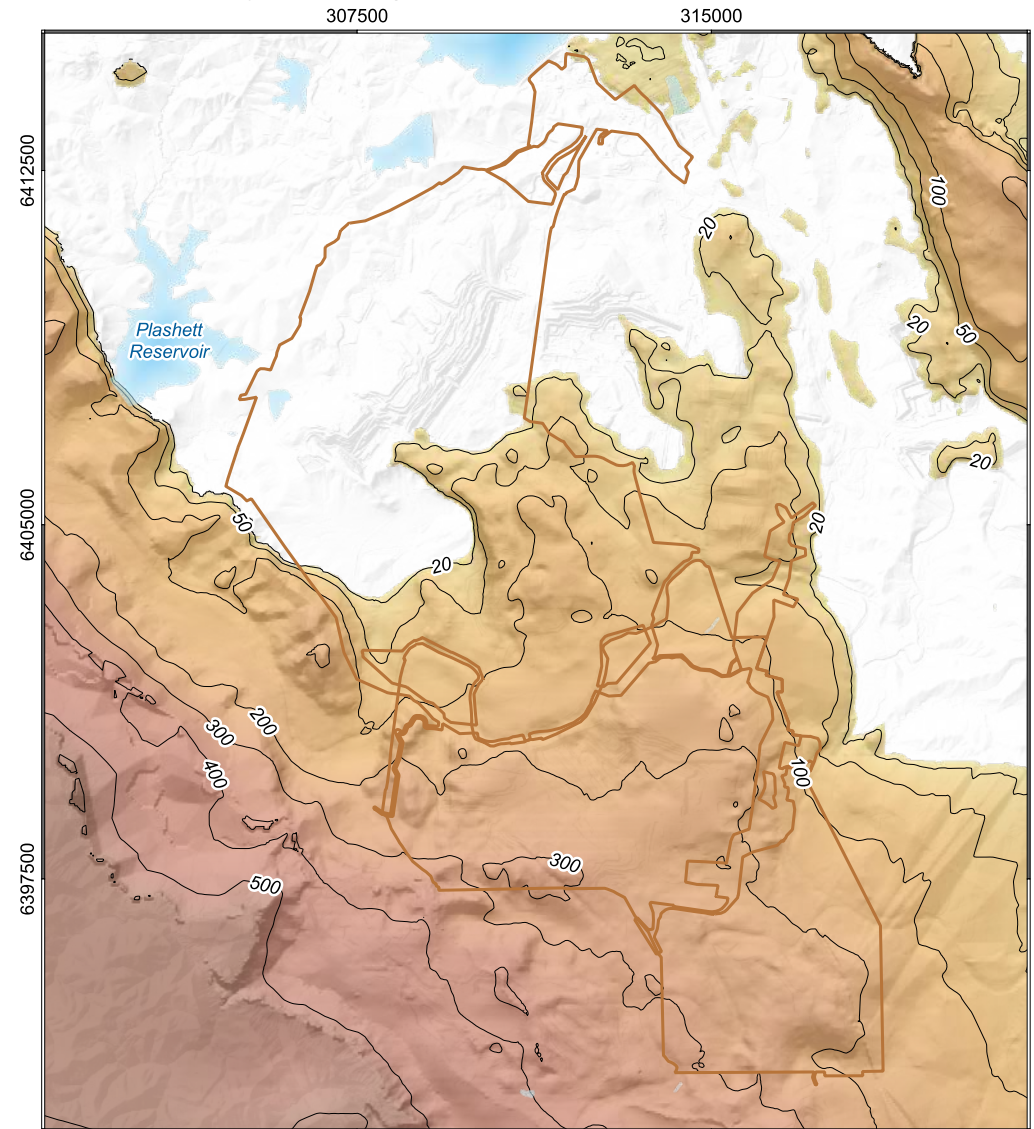
Elevation (mAHD)



Thickness (m)



Thickness of Jerrys Plain Subgroup



HVO Continuation (G1737J)



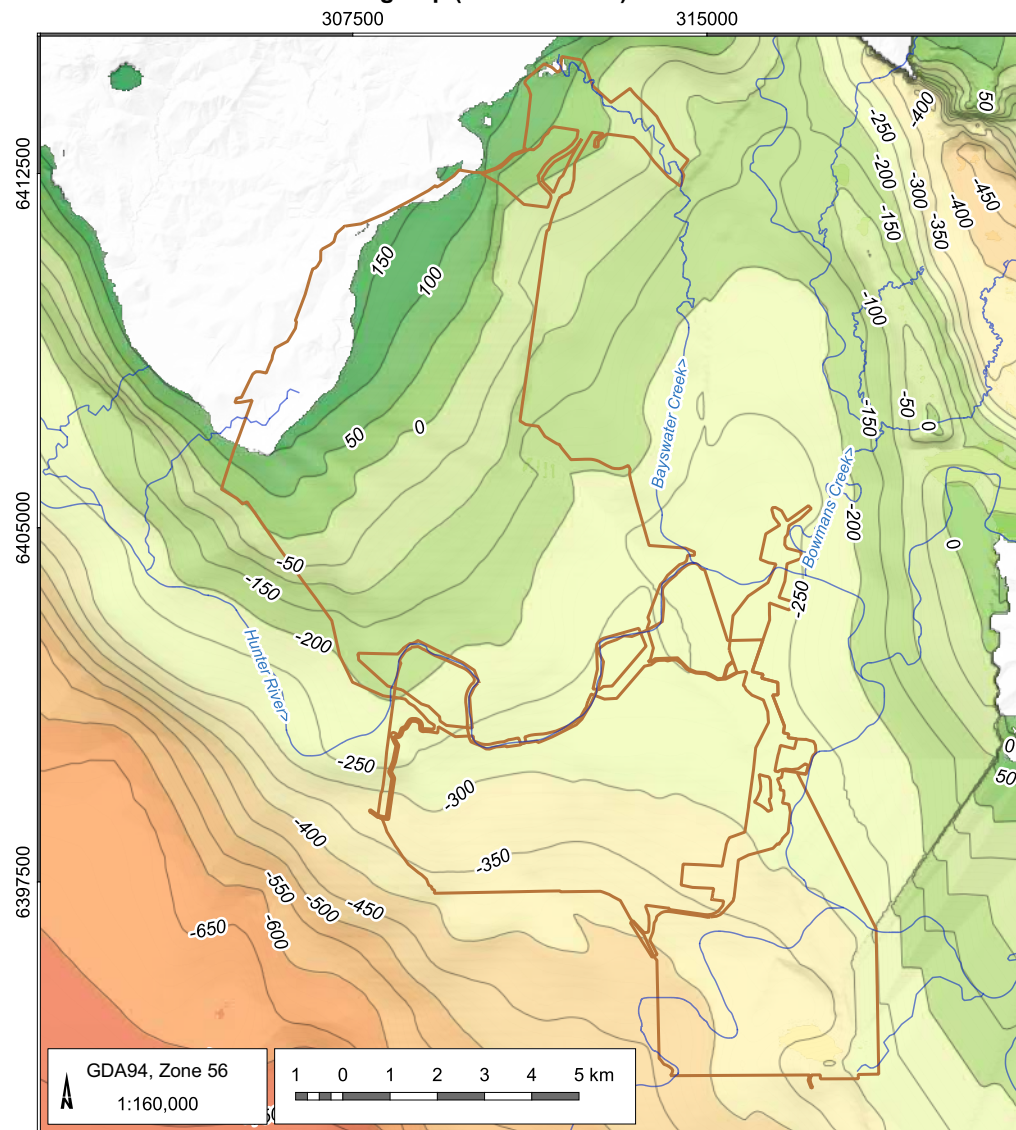
Elevation and thickness of the Jerrys Plains subgroup

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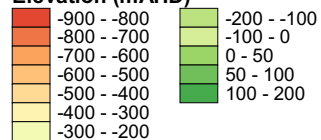
Bottom elevation of Vane Subgroup (Hebden Seam)



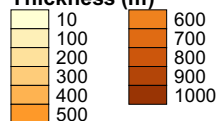
LEGEND

- Populated place
- Drainage
- Contour line
- Project Area

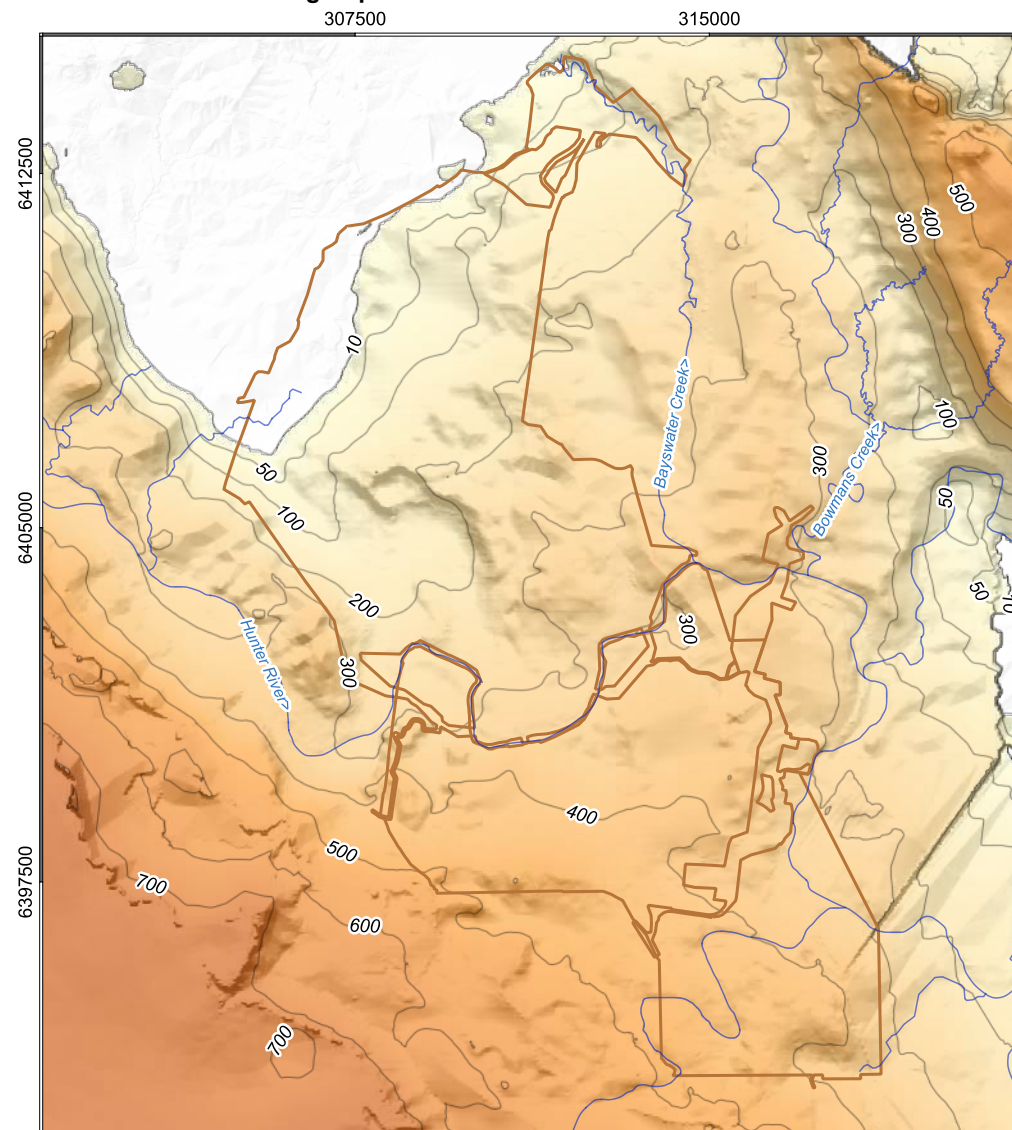
Elevation (mAHD)



Thickness (m)



Thickness of Vane Subgroup



HVO Continuation (G1737J)



Elevation and thickness of the Vane subgroup

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17/11/2022

FIGURE No:

4.6

4.4 Local structures

Figure 4.7 and Figure 4.8 show the folds, faults and dykes identified in the geotechnical studies by Encompass occurring at HVO North and HVO South respectively (2022a, 2022b). A description of these structures provided in the sections below is largely based on the Encompass geotechnical investigations, supplemented with photographs provided by site geologists.

4.4.1 Folding

The major fold structures in the Project area are the Bayswater Syncline and the Muswellbrook Anticline (Figure 4.7). West Pit/Wilton Pit and Mitchell Pit at HVO North are located on the eastern flank of the Muswellbrook Anticline. In this area coal seams dip south-eastward, towards the centre of the Bayswater Syncline, which has a North-South trending axis five to eight kilometres to the east. Localised steep bedding dips occur only near major faulting. A north-south trending anticline passes through the former North Pit, with a width of 200-300 metres, dips of up to 30 degrees on the limbs of the anticline and minor reverse faulting. The anticline flattens as it plunges towards the south. At HVO South the Cheshunt Pit / Riverview Pit are largely situated on the western limb of the Bayswater Syncline (Figure 4.8), with the southern end of the Muswellbrook Anticline three kilometres to the west.

4.4.2 Faulting

Fault orientations at HVO North are commonly aligned north-east/south-west and north-west/south-east reflecting the dominant joint directions. Two major east-west striking normal faults occur at West Pit, namely Parnell's Fault, which has a throw of approximately 20 metres, and the GRS Fault, which has a throw of up to 50 metres. Photographs of Parnell's Fault where exposed in West Pit are provided Figure 4.9 and Figure 4.10.

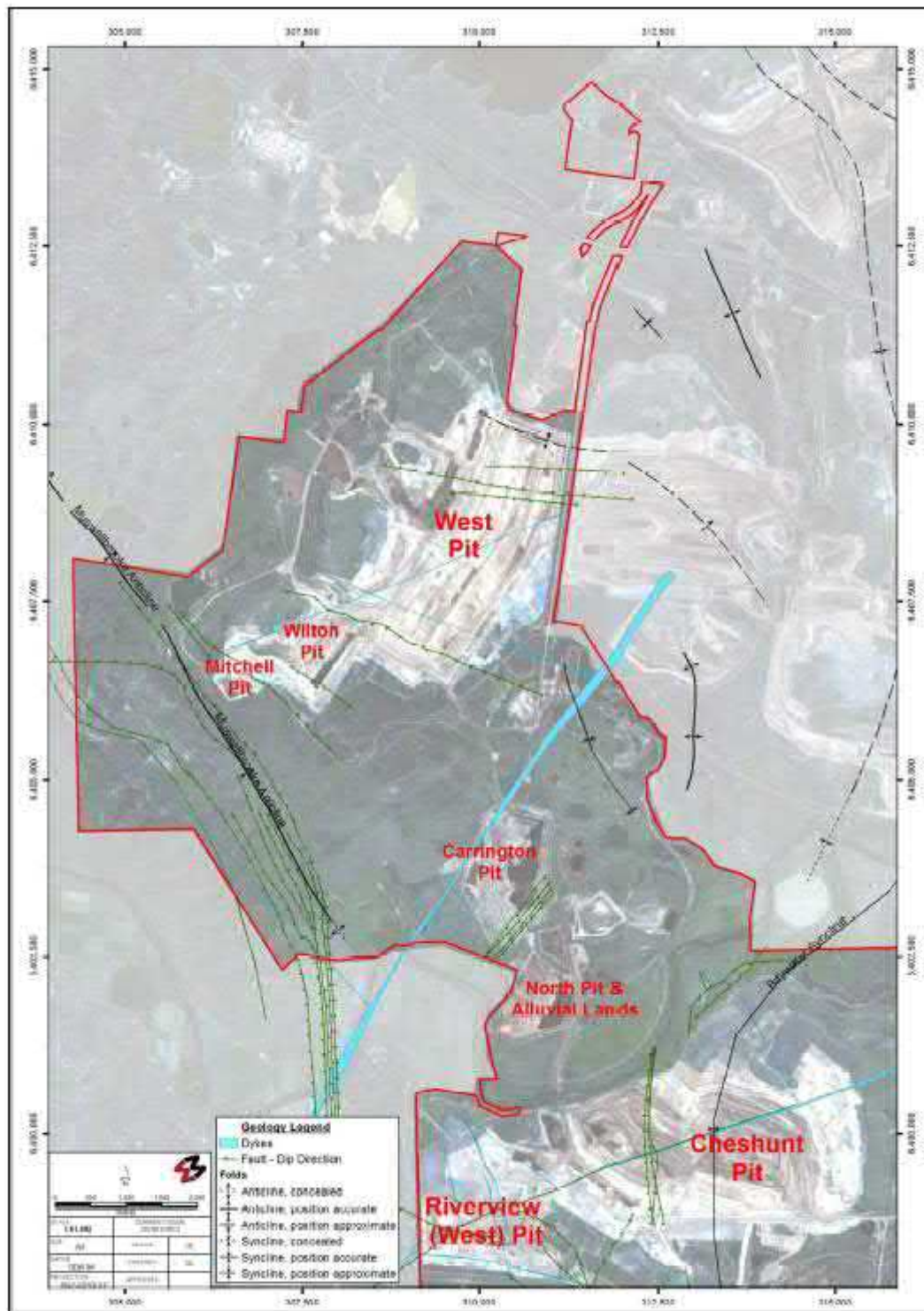
The Hunter Valley Fault Zone is exposed in Carrington Pit and is a closely-spaced horst and graben structure that extends for several kilometres and across several mine sites. This series of north-south trending normal faults have throws of one to five metres. Small-scale thrust faults that are associated with the Hunter Valley Fault Zone have been identified in the Carrington Pit, running in a north-east to south-west orientation. Photographs of fault structures in Carrington Pit walls are provided in Figure 4.11 to Figure 4.13.

At HVO South the normal, north-south striking Lemington Fault, bounds the eastern limit of the previously mined Lemington Underground and has a vertical displacement of 20 metres (Figure 4.8 and Figure 4.7).

The most significant intrusion in the Project area is the Carrington Dyke which is a regional north-east, south-west trending structure that cuts through the Carrington Pit. This dyke is 10 m to 20 m thick and has caused some silling of adjacent coal seams. The dyke is likely to exhibit lower permeability due to its thickness and localised alteration of geology, but also has associated localised fracturing which enhances groundwater storage (MER, 2009). Mining at the Carrington Pit has already removed a segment of the Carrington Dyke.

At HVO South a major dolerite dyke known as the Lemington Dyke passes through the Cheshunt Pit area in a north-easterly direction. This dyke is sub-vertical, 5 m to 10 m wide, and comprised of highly clay altered rock. It has caused minor silling of coal seams in its vicinity. The extent of heat affected coal extends up to five metres on either side of the dyke. There is also some very localised normal faulting evident at the contact with the dyke or by coal seam levels either side of the dyke.

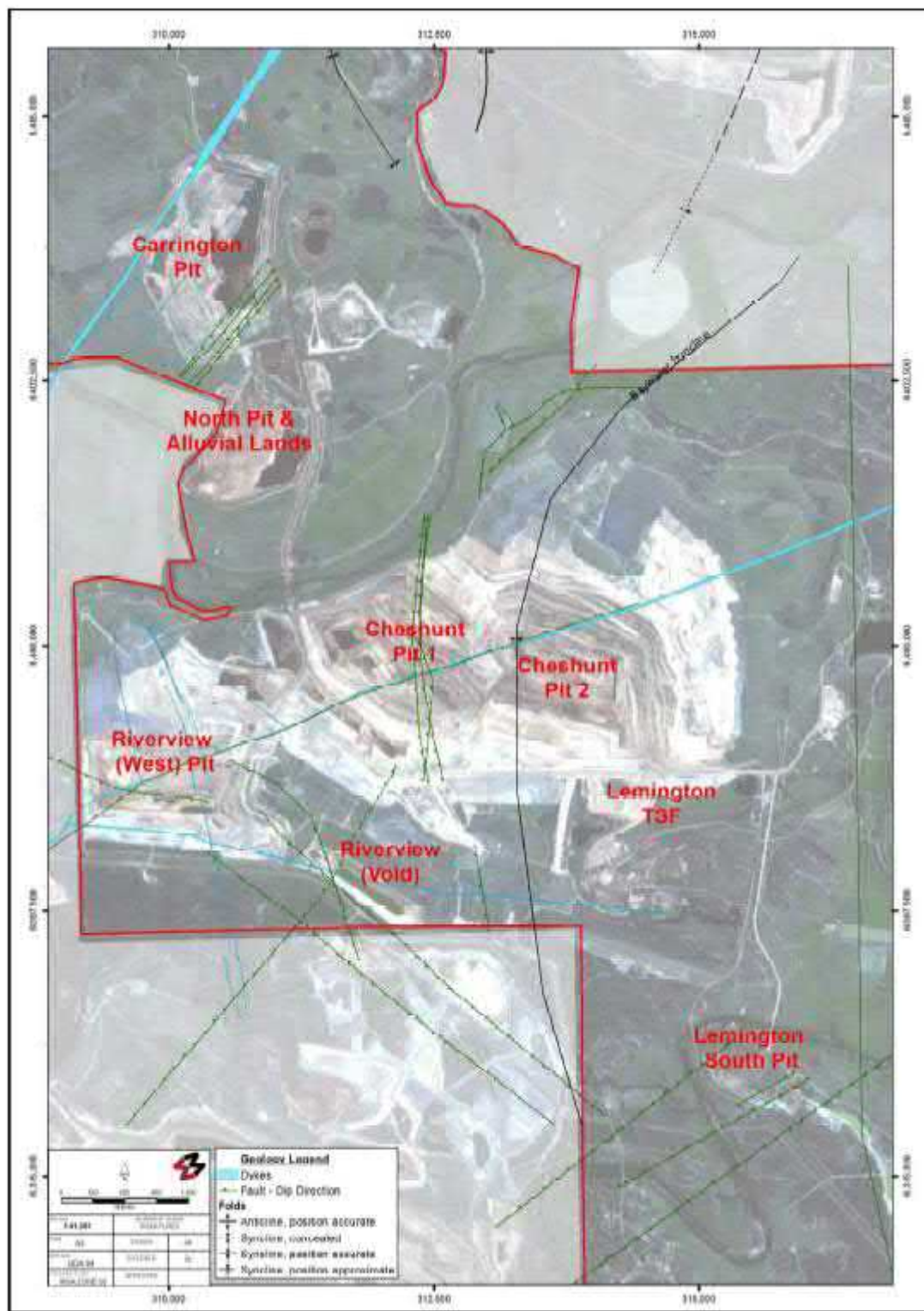
Some minor north-south dykes have also been intersected, particularly in the Riverview Pit. These are very thin at less than 1 metre in thickness, vertical and discontinuous. These dykes do not have silling extending into the coal seams beyond 2 metres locally.



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Figure 4.7 HVO North - Structural Geology (Reproduced from Encompass, 2022a)



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Figure 4.8 HVO South - Structural Geology (Reproduced from Encompass, 2022b)



Figure 4.9 West Pit - Parnell's Fault

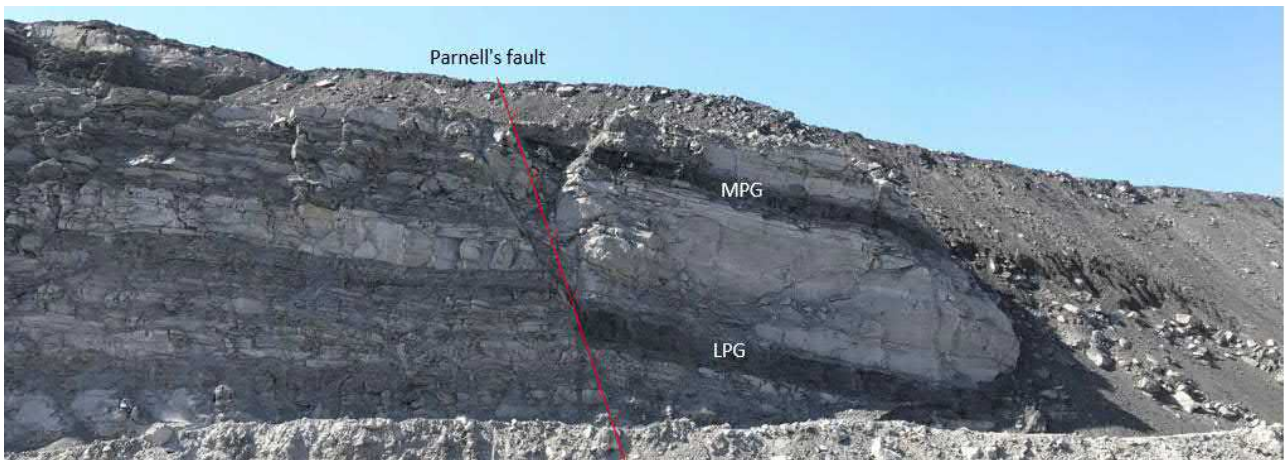


Figure 4.10 West Pit - Parnell's Fault



Figure 4.11 Carrington Pit Fault



Figure 4.12 Carrington Pit Fault



Figure 4.13 Carrington Pit Graben Structure

5 Monitoring network

The WMP outlines the details of the current groundwater monitoring locations, frequency and analytes for HVO. Historical monitoring data from the groundwater monitoring network is available from 1995 to present. Groundwater monitoring data is also available for monitoring networks maintained by surrounding Ravensworth, Glendell, Liddell, Mt Owen Complex, Integra, Mt Thorley Warkworth Complex, United and Wambo operations.

The alluvium, regolith and spoil monitoring bore locations are shown in Figure 5.1, with the Permian monitoring bores are shown in Figure 5.2. A summary of the number of monitoring bores for which data has been collated for the current study is presented in Table 5.1. Where information on the screened formation were not available, it has not been included in the summary, conceptualisation and/or model development since the formation cannot be estimated. Further construction details for each of the HVO monitoring points are presented in Appendix B.

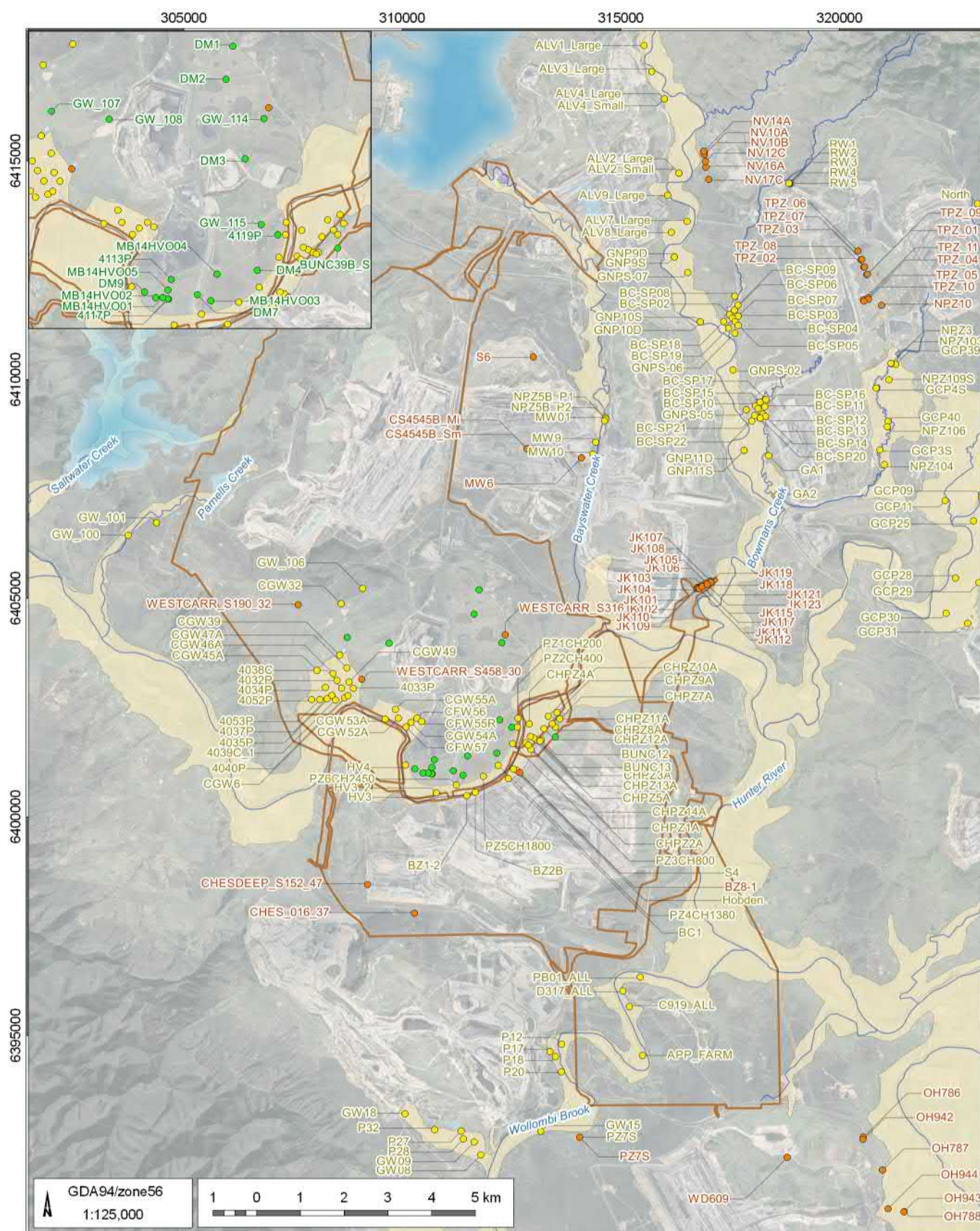
Table 5.1 Groundwater monitoring by lithological units and mines

Lithology	HVO	Other mines in Project area
Alluvium	60	100
Regolith/spoil	27	59
Coal seam	78	255
Interburden	28	87
Total	193	501

Figure 5.1 shows good spatial coverage for groundwater monitoring points within the alluvium across HVO North and HVO South. As shown in Table 5.1, data has been collated for 694 monitoring points from HVO and mines in the Project area. Around 24% of the bores are dedicated monitoring points in the alluvium along as the Hunter River and its major tributaries are primary areas of interest for monitoring for potential impacts. Similarly, most of the monitoring bores within Jerrys Plains coal seams are paired with alluvial bores to measure the deeper pressure response in the underlying Hunter River and Wollombi Brook alluvium.

The groundwater monitoring network includes Vibrating Wire Piezometers (VWP) sealed into boreholes with cement bentonite grout mixes. VWPs are utilised for deeper strata where installation of PVC becomes more difficult or where monitoring of multiple levels is required. The groundwater elevations provided by VWPs are potentially less reliable than the standpipe monitoring bores as they are grouted into boreholes and cannot be validated, or instrument drift detected. Despite these limitations, VWPs are valuable tools for developing conceptual models when the limitations of the data provided is acknowledged. A nominal accuracy range of ± 10 m is considered appropriate to apply to VWPs.

The coverage of the monitoring network in the Vane Subgroup coal measures within the Project area was initially limited. To address this data gap, monitoring data from the Ravensworth mine network have been included in this assessment. Further fieldwork was also undertaken to install VWPs and monitoring bores where data was limited. The data collection methods comprised drilling, measurement of groundwater levels and conducting in-situ permeability tests on the newly established bores. Details of the field investigation report to address data gaps for the Project are presented in Appendix A.



LEGEND

- Drainage
- Project Area
- Alluvium boundary

Monitoring location

- Alluvium
- Regolith
- Spoil

HVO Continuation (G1737J)

Alluvium, regolith and spoil groundwater monitoring locations



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FIGURE No:
5.1

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 Content: ELVIS LiDAR DEM (accessed April 2019 ; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
 G:\Projects\G1737J.HVO Continuation\3 GIS\Workspaces\002 Deliverable\2\05.02 G1737J Permian groundwater monitoring locations.qgs

6 Conceptual model

This section describes the main processes and interactions that define how groundwater moves in the natural and modified groundwater regime. The key components and interactions that govern the behaviour of groundwater system is simply referred to as the 'conceptual model' and is a simplified understanding of the natural groundwater system based on geological and hydrogeological data.

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

- Quaternary alluvium, which forms a relatively thin aquifer system where it occurs along the major creeks and rivers;
- Permian sediments that can be divided into:
 - thin and variably permeable weathered rock at the surface (regolith). They generally do not form aquifers due to limited saturated thickness;
 - non coal interburden that forms aquitards; and
 - low to moderately permeable coal seams that act as the most transmissive strata within the coal measures, but still relatively poorly transmissive aquifers.

The following sections describe the various components of the groundwater system from available monitoring data, previous groundwater studies undertaken in the region, as well as additional fieldwork conducted to gather data for the Project.

6.1 Groundwater levels and flow

6.1.1 Quaternary alluvium

The groundwater flow direction in the alluvium is largely controlled by surface topography and the water level within the Hunter River. The Hunter River is regulated by releases from the upstream Glenbawn Dam and therefore is a perennial system. The aquifer within the Quaternary alluvium interacts with the Hunter River via losing or gaining reaches along its alignment. Adjacent to mining areas some segments of the Hunter River are expected to leak to the underlying alluvial aquifer, forming a significant source of recharge and buffering fluctuations within the underlying water table. Figure 6.1 shows the interpolated recent groundwater level contours in the alluvium in the Project area.

The groundwater level contours indicate flow within the remnant palaeochannel sediments is towards the mined portion of the palaeochannel. However, a hydraulic gradient towards the HVO mining areas is not apparent in the Hunter River alluvium, where the alluvial deposit is narrower. Drawdown impact from the HVO open cuts in the Hunter River alluvium is not evident in the existing data.

The groundwater levels in the rehabilitated Alluvial Lands are lower than the groundwater levels in the Hunter River alluvium. The groundwater levels in the spoil suggest that the spoil groundwater is disconnected from the Hunter River alluvium but is connected to the active HVO South operations via coal seams under the Hunter River.

Groundwater levels in the Wollombi Brook alluvium also show flow heading downstream towards the Hunter River. A localised hydraulic gradient is evident around the mined South Lemington Pit 1. The South Lemington Pit 1 is used for water storage purposes and therefore will act as a local groundwater sink during periods when the water level within the residual void is maintained below the level of the alluvial water table.

6.1.1.1 Temporal trends

This section describes groundwater level trends in the alluvial aquifer at key sections of the Hunter River between HVO North and HVO South, including Wollombi Brook south of HVO South. Hydrographs of these key locations are presented with rainfall as CRD and measured river levels to review groundwater response to these two recharge sources. The locations of the bores in each hydrograph are as follows:

- Figure 6.2 – alluvial bores west of Carrington Pit;
- Figure 6.3 – alluvial bores south of Carrington Pit at HVO North;
- Figure 6.4 – alluvial bores north of Cheshunt Pit at HVO South; and
- Figure 6.5 - alluvium bores near Lemington South Pit 1 at HVO South.

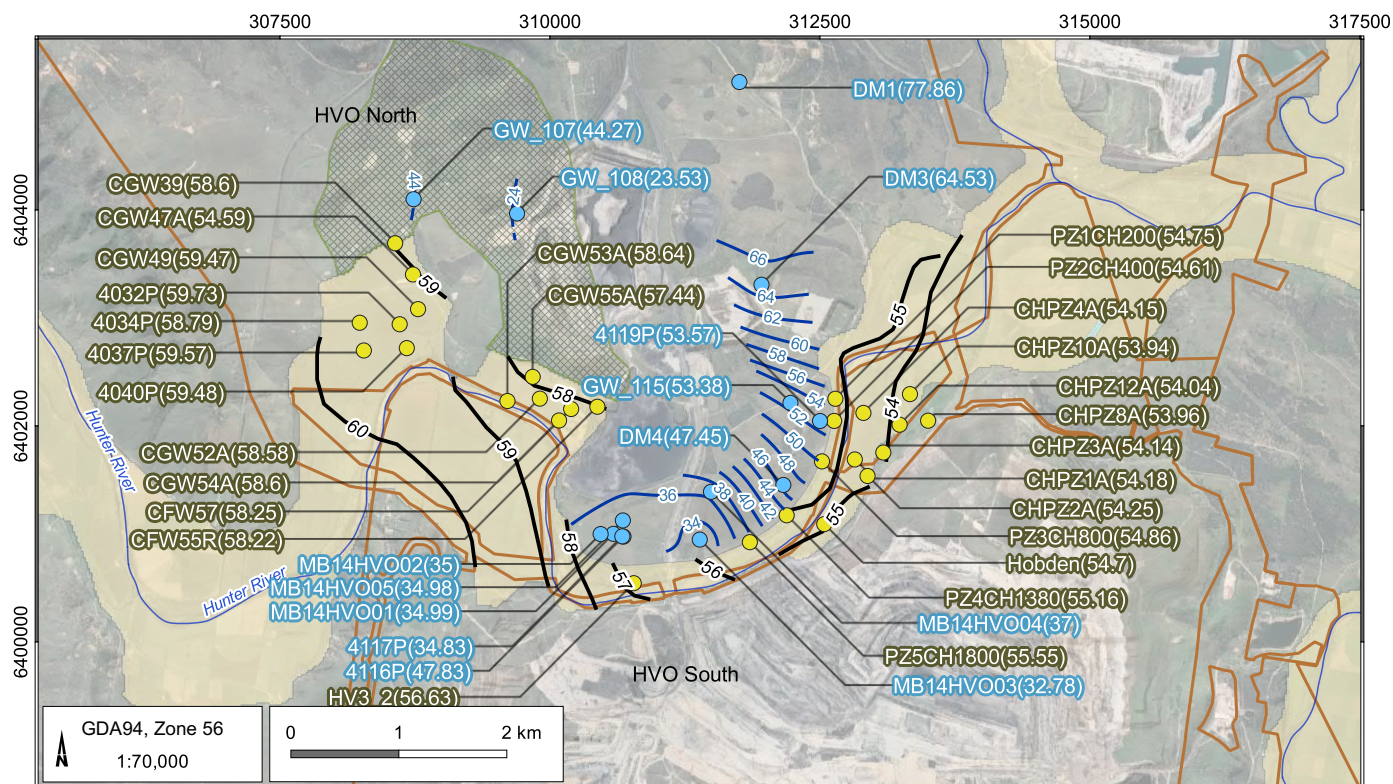
The hydrographs show a strong correlation between groundwater levels in the alluvium around HVO North and HVO South and the river level, indicating the Hunter River is an important recharge source for the alluvium occurring between HVO North and HVO South (Section 6.3). The effects of river recharge can be seen in recovery of groundwater levels when river levels rise during high flow events. This is particularly evident in mid 2016, when groundwater levels along the Hunter River rise in response to elevated river levels.

Groundwater levels within the alluvium slowly decline during the 2017 to 2019 drought due to low recharge from both the river and rainfall. During this period, water levels in the Hunter Regulated River remained at relatively stable levels due to release from the Glenbawn Dam whilst a slow decline in groundwater levels occurred. This indicates that rainfall is also an important source of recharge to maintain the level of the alluvial water table.

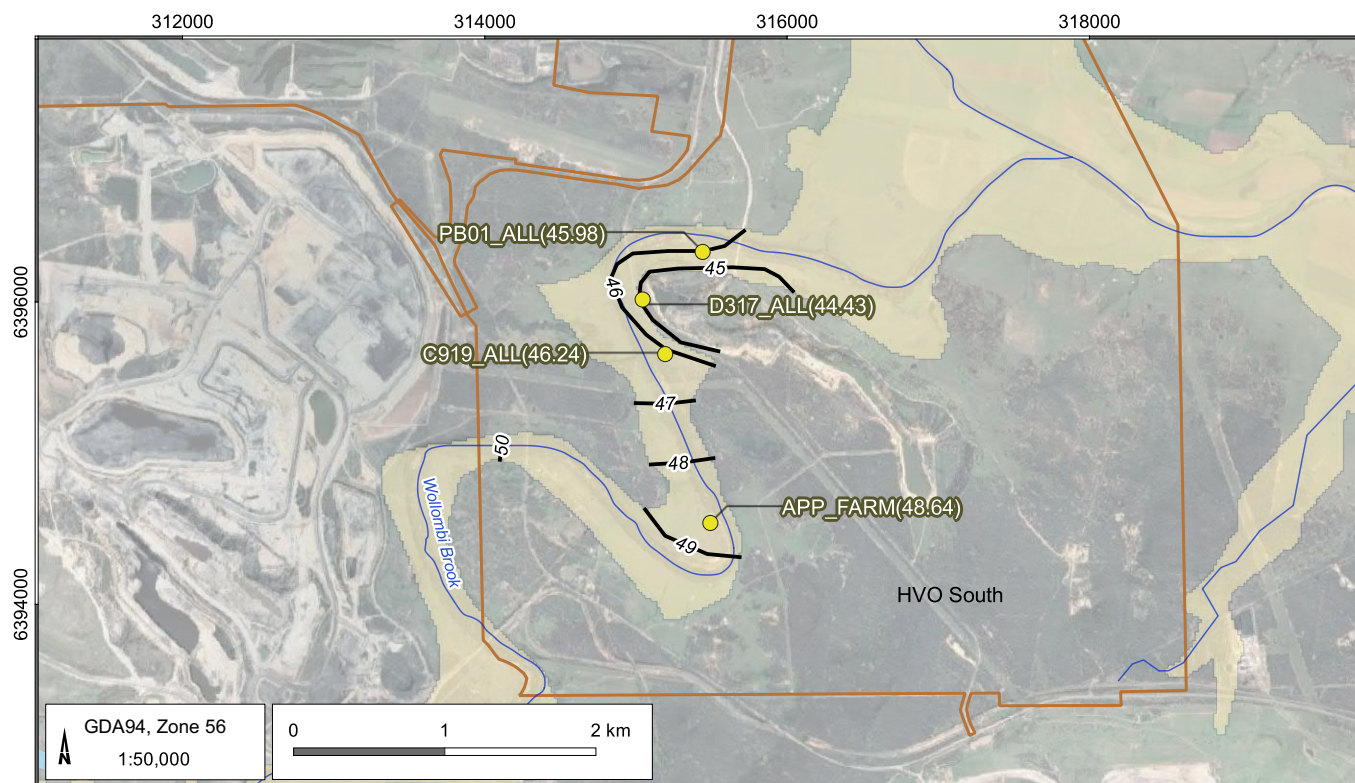
Figure 6.5 shows water levels in the area associated with Wollombi Brook. Groundwater levels in the Wollombi Brook alluvium are similarly correlated with stream water levels and rainfall. Wollombi Brook is an unregulated stream that becomes ephemeral during drought, and diffuse rainfall is considered more likely to be the dominant source of recharge for the adjacent alluvium.

Additional hydrographs of water level data grouped by their location and screened formation in the Project area is presented in Appendix C.

Groundwater contours - Hunter River



Groundwater contours - Wollombi Brook



LEGEND

- Drainage
- Interpolated 2019 groundwater level contours within Quaternary alluvium (mAHD)
- Interpolated 2019 groundwater level contours - Spoil (mAHD)
- Inferred 2019 groundwater level contours - Spoil (mAHD)
- Project Area
- Alluvium boundary
- Previous paleochannel extent
- Monitoring bore**
 - Alluvium
 - Spoil

HVO Continuation (G1737J)

Interpolated 2019 groundwater levels within Quaternary alluvium



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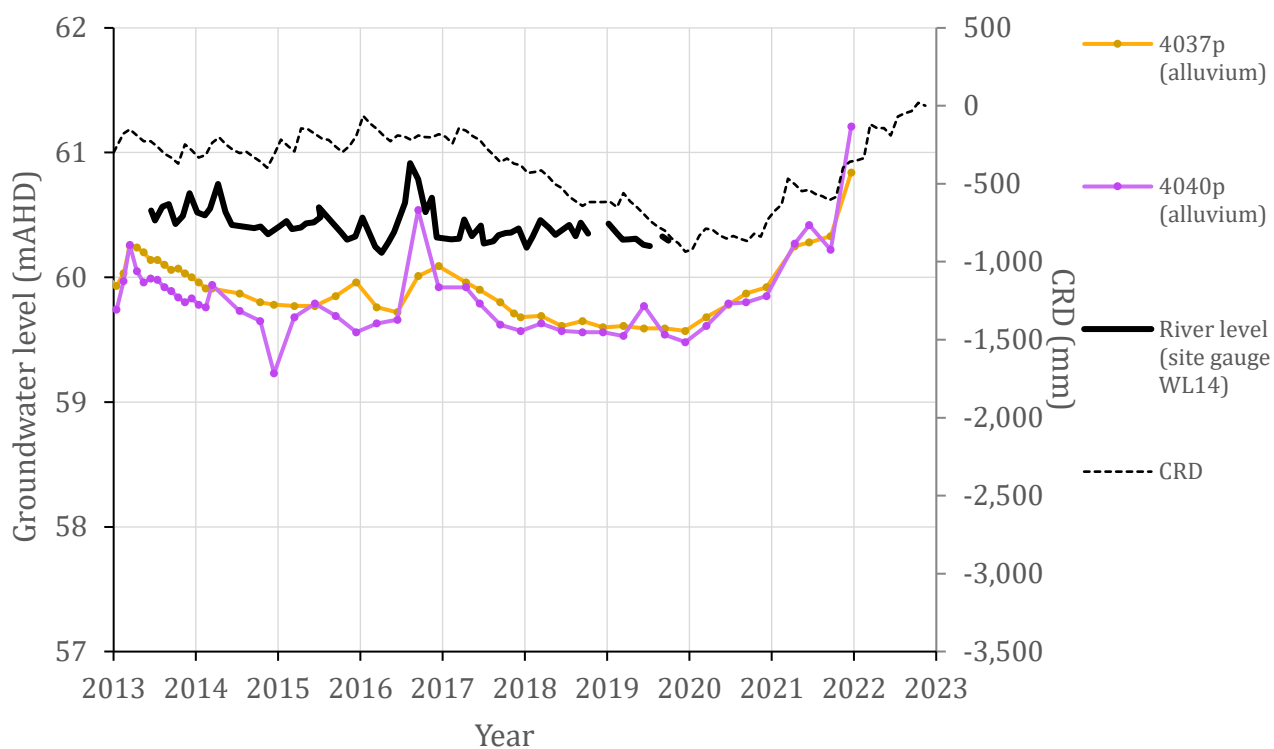


Figure 6.2 Water levels in the Hunter River and alluvium west of Carrington Pit

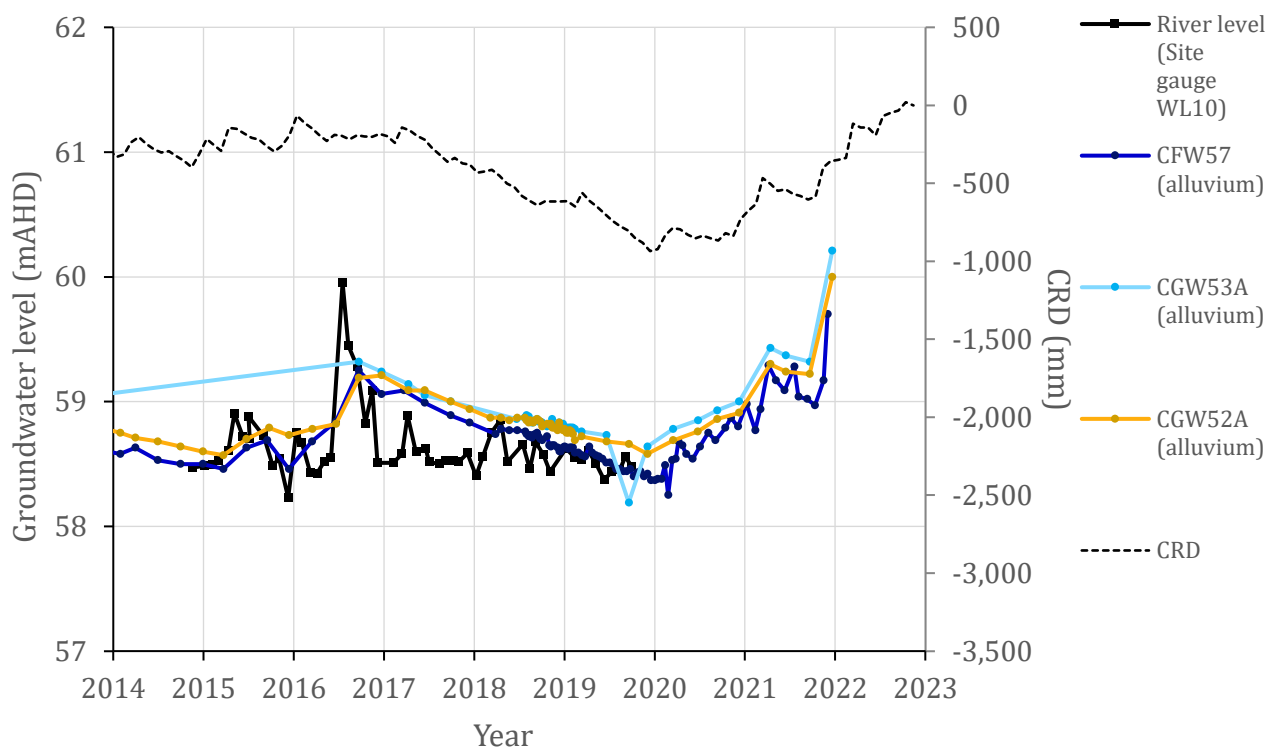


Figure 6.3 Water levels in the Hunter River and alluvium south of Carrington Pit

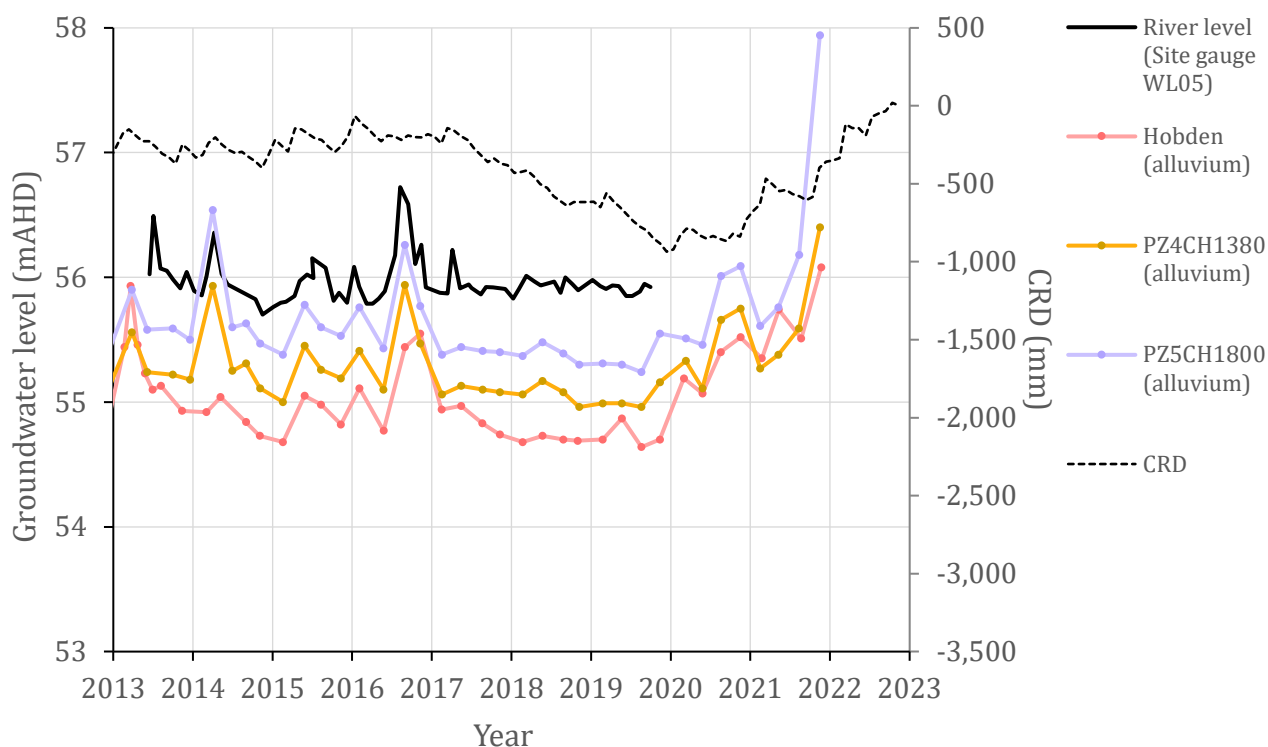


Figure 6.4 Water levels in the Hunter River and alluvium north of Cheshunt Pit

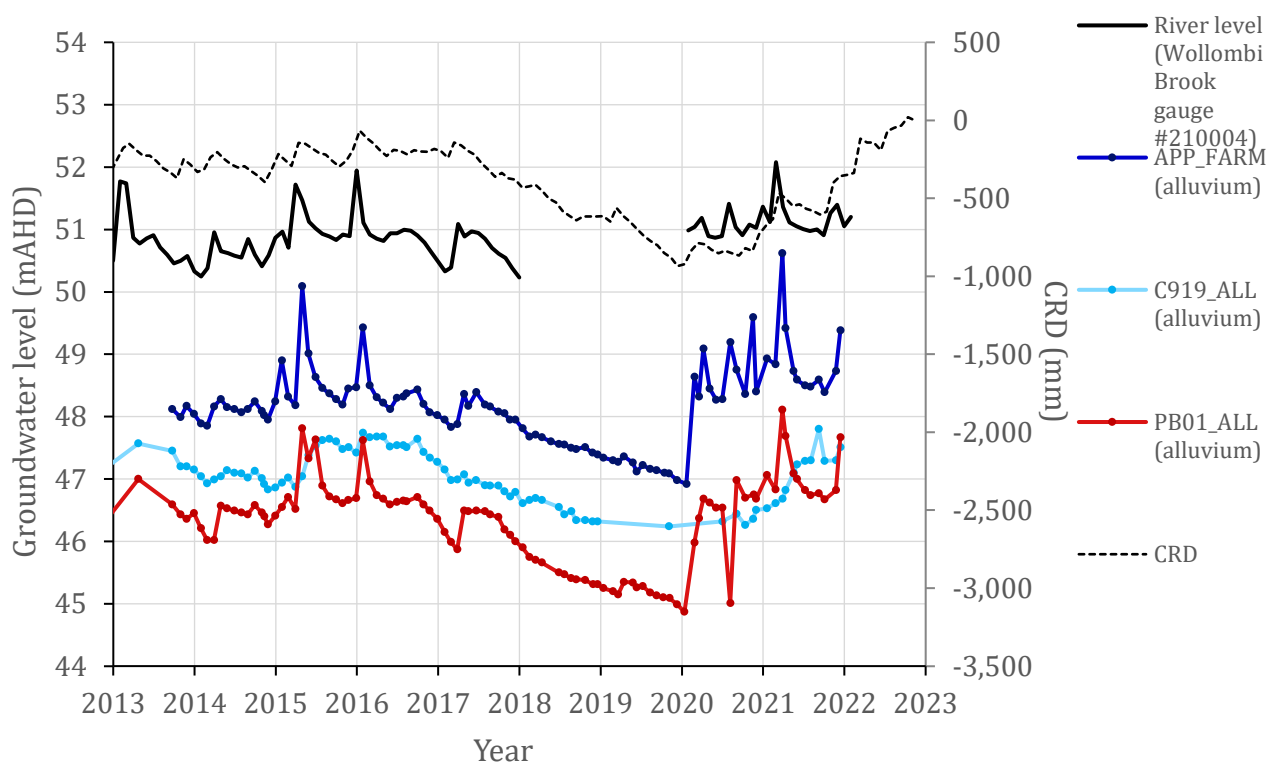


Figure 6.5 Water levels in the Wollombi Brook and alluvium near Lemington South Pit 1

6.1.2 Permian Coal Measures

Groundwater flow in the Permian in areas unaffected by mining largely follows the regional topography towards the Hunter River valley. During pre-mining conditions, groundwater in the Permian discharged into the Quaternary alluvium of the Hunter River. This discharge occurs where groundwater in the Permian has an upward head above the base of alluvium and where the permeability promotes upward vertical flow.

In the present day, various active mining areas in the Project area have depressurised the Permian coal seams within and surrounding their disturbance areas. As a result, groundwater discharge from the Permian into the overlying alluvium has reduced. In some areas along the Hunter River, groundwater heads in the Permian coal measures are fully reversed and occur below the base of the alluvium (Section 6.1.3). In these areas, Permian groundwater no longer discharges to the alluvium.

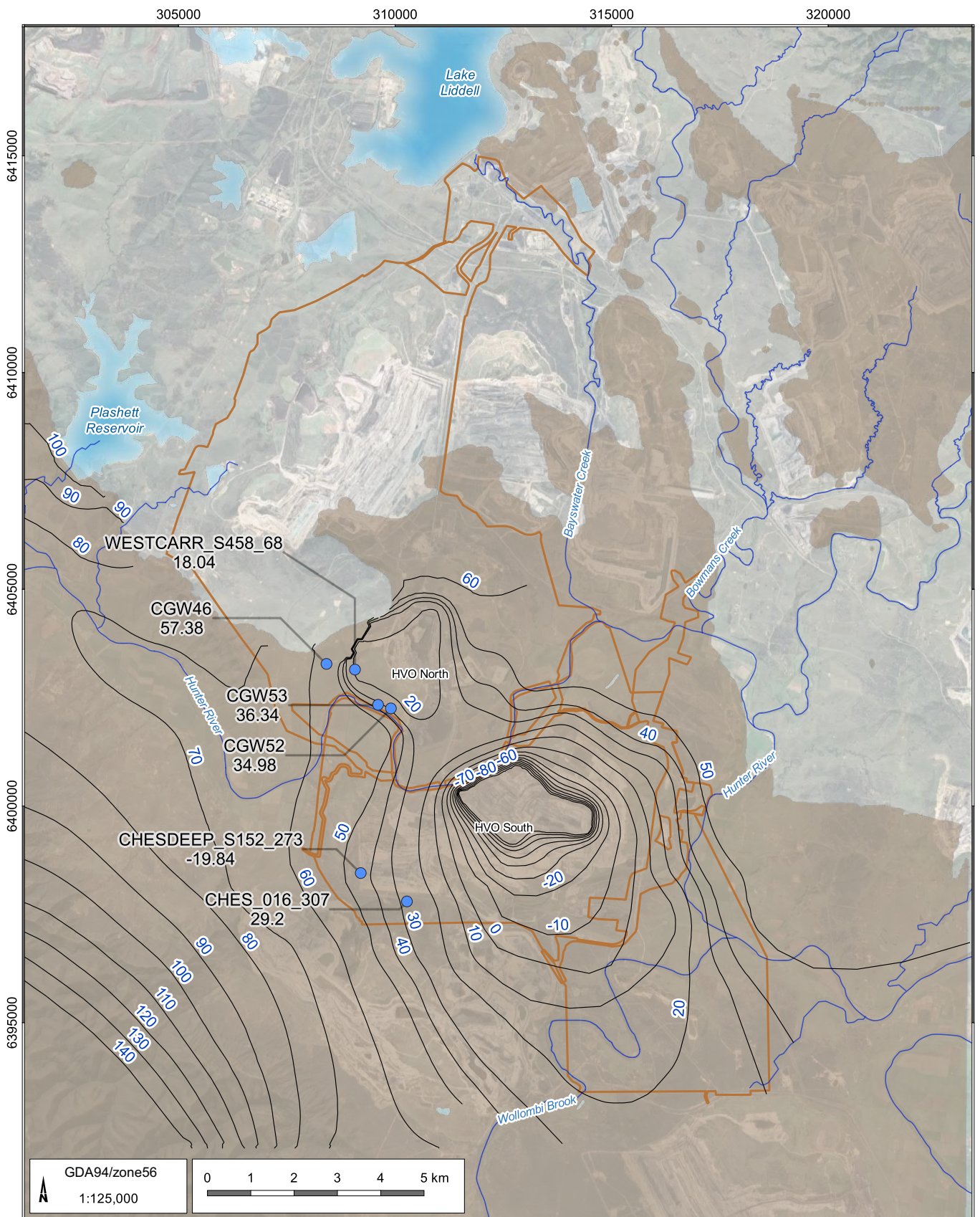
Figure 6.6 and Figure 6.7 show the groundwater contours for the Bayswater seam in Jerrys Plains subgroup and the Barrett seam in Vane subgroup. The deepest coal seam mined in the Project area is usually either the basal Bayswater or Barrett/Hebden seams and therefore the most significant drawdown occurs within these seams. The Vane subgroup has not been mined at HVO, but has been mined at operations to the north and east (Ravensworth Operations, Liddell, Ashton, Mount Owen Complex) and this is reflected in the water level contours.

Groundwater contours presented are conceptualised flow gradients in the Project area constrained by recent available monitoring data. Groundwater in the Jerrys Plains subgroup flows from the north-west recharge areas where it initially discharges into the Hunter River upstream of HVO. The contours also show mining pits in the Project area has depressurised the coal seams resulting in groundwater flow towards mined areas.

6.1.2.1 Groundwater discharge and mine voids

As discussed, groundwater from the Permian discharges into the open cut and underground mines. The discharge occurs as slow seepages through the more permeable coal seams. Seepage into the existing HVO mine pits is limited and is largely evaporated from the pit face (see Figure 6.8). Rates of groundwater seepage cannot be directly measured as the water reports to sumps at mining pit floors that also collect rainfall runoff. As a result, groundwater inflows are generally difficult to determine; it is however known that they are relatively low.

Error in the measurement of low volumes of groundwater inflow into mining areas is therefore considered significant. Inherent challenges in measuring groundwater inflow to mining areas means there is always some residual uncertainty. This uncertainty cannot be practically reduced in most cases. For these reasons, groundwater discharge into mine pits can only be estimated using numerical groundwater models. Groundwater inflow into West Pit at HVO North was estimated at 190 ML/year (MER, 2003), while inflows into Cheshunt and Riverview pits were estimated at 853 ML/year (AGE, 2015). Despite this inherent uncertainty, observations from the existing HVO mines show very limited 'free flowing' inflows, with little water reporting to pit sumps from mine faces, and most evaporating directly from the pit face or adhering to overburden material.



LEGEND

- Drainage
- Contour line
- Project Area
- Bayswater coal seam extent
- Water area

- Bayswater seam monitoring bore

HVO Continuation (G1737J)

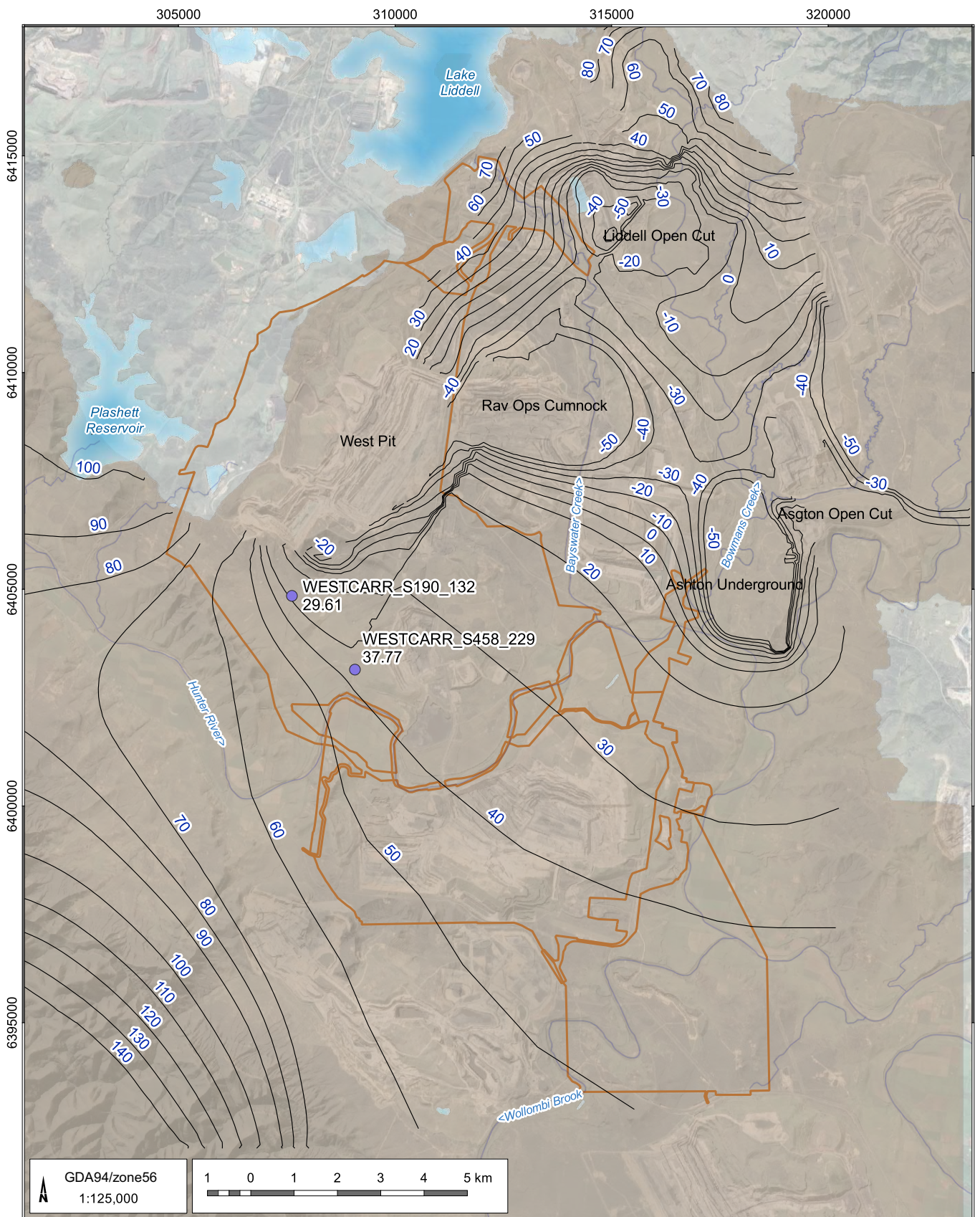
Groundwater head contours for the Bayswater seam



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FIGURE No:
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LEGEND

- Drainage
- Contour line
- Project Area
- Coal seam extent

● Barrett seam monitoring bore

HVO Continuation (G1737J)

Groundwater head contours for the Barrett seam



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FIGURE No:
6.7



Figure 6.8 Groundwater seepage from coal seams in Cheshunt Pit (left) and Carrington Pit (right)

6.1.3 Vertical gradients

One of the key potential risks associated with coal mining is the depressurisation of the Permian strata, potentially resulting in reduction of available water and groundwater drawdown in the Quaternary alluvium along the Hunter River and Wollombi Brook. Groundwater levels in the Permian and alluvium were therefore compared to determine if mining induced drawdown has detectably influenced groundwater levels within the alluvium.

Figure 6.9 and Figure 6.10 show groundwater levels in selected monitoring bores situated along the Hunter River between HVO North and HVO South installed within the Permian and alluvium. The hydrographs show that the groundwater level within the shallow Permian coal seams is generally 25 m to 30 m lower than the level within the alluvium along the Hunter River. The elevation of groundwater levels within the shallow coal seams is around 25 mAHD to 35 mAHD and is below the base of the alluvium along the Hunter River (between 55 mAHD to 57 mAHD). This indicates there is no discharge of Permian groundwater to the alluvium, and depressurisation from approved mining does not result in significant drawdown within adjacent alluvium.

Figure 6.11 shows groundwater levels in the Permian Bowfield seam declining to about 5 mAHD due to licensed groundwater use from the nearby Lemington Underground bore (SLR, 2019) since 2016. As a result, Permian water levels are now about 40 m below the base of the alluvium of 47 mAHD. Again, this indicates there is no discharge of Permian groundwater to the alluvium and mining induced drawdown does not result in significant drawdown within adjacent alluvium.

Further from mining areas, an upward vertical gradient from the Permian into the alluvium is expected to be maintained and Permian water will discharge into the alluvium. These areas are typically further from active mining where monitoring data becomes limited. Further depressurisation of the Permian strata at the HVO Complex is not expected to significantly impact groundwater levels within the Quaternary alluvium, as the Permian generally already has become disconnected and contributes little to no upward discharge into the alluvium in the Project area.

In areas adjacent to the Quaternary alluvium at HVO North, HVO only proposes to mine deeper seams of the Vane subgroup below the already depressurised upper coal seams of the Jerrys Plains subgroup. The seams within the Jerrys Plains subgroup are either in direct contact with the alluvium through subcrop areas, or indirectly through closer proximity to the alluvium below the surface. In contrast the deeper seams of the Vane subgroup do not subcrop in the vicinity of HVO and are significantly deeper. These factors are expected to reduce the connectivity between the alluvium and depressurisation of deeper coal seams created by the Project.

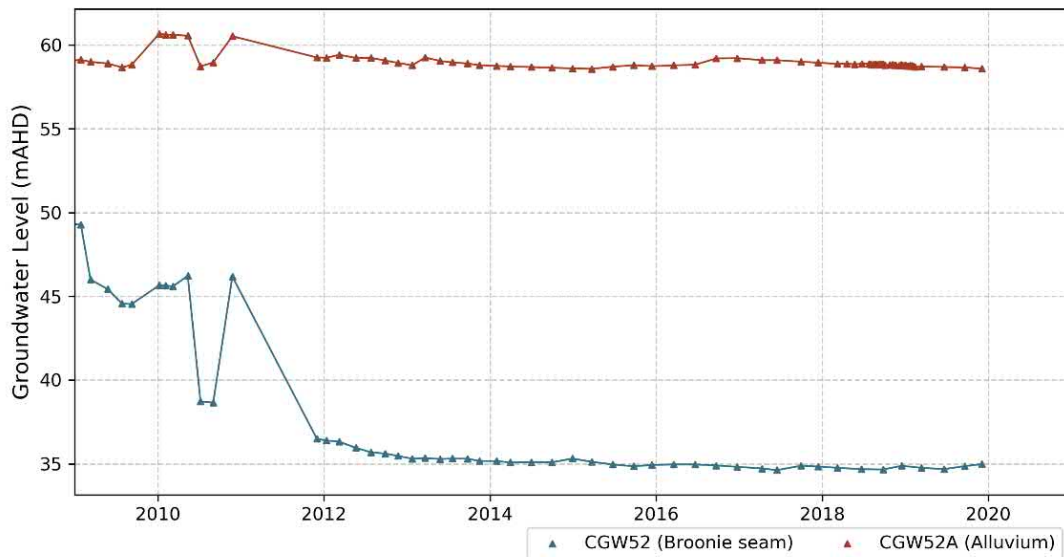


Figure 6.9 Water levels in the Hunter River alluvium near Carrington Pit and the underlying Permian coal seams

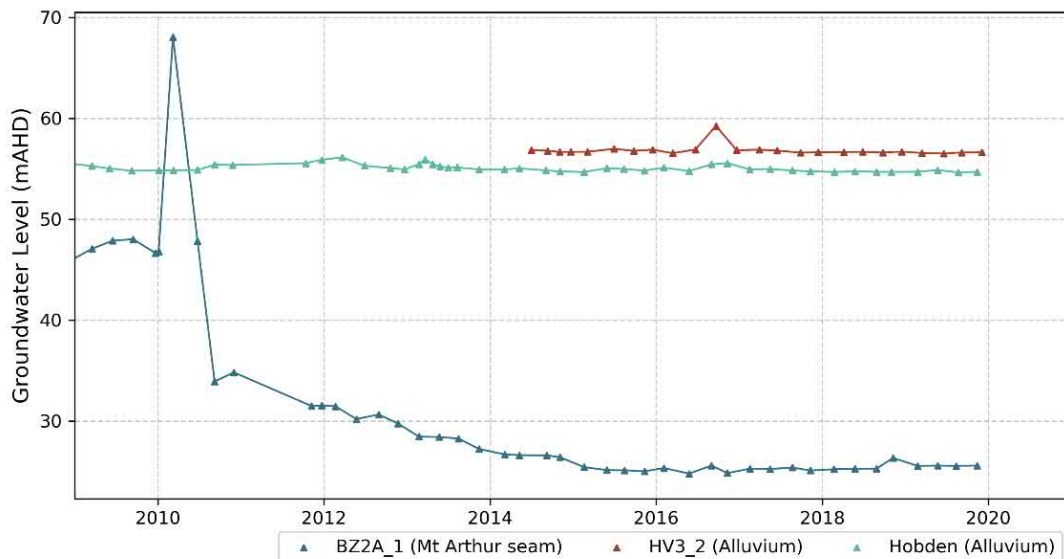


Figure 6.10 Water levels in the Hunter River alluvium near Cheshunt and Riverview pits and the underlying Permian coal seams

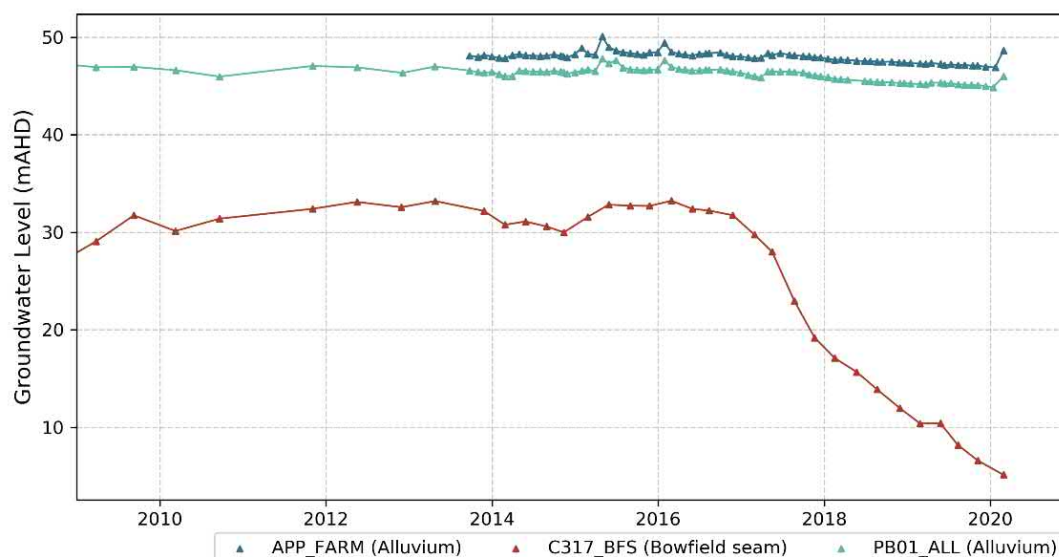


Figure 6.11 Water levels in Wollombi Brook alluvium and the underlying Permian coal seams

6.2 Aquifer hydraulic properties

6.2.1 Hydraulic conductivity measurements in the Hunter Valley

Extensive hydraulic testing has historically been undertaken across the Hunter Valley using field packer testing, lab core permeability testing and falling/rising head tests, with most readings compiled as part of a study across the Hunter Valley conducted by Mackie Environmental Research (MER, 2009). Test results from the study was also described by AGE (2015).

Alluvium hydraulic property data was largely collected from the Hunter River palaeochannel and “highly productive” alluvium (basal sands and gravels) along the Hunter River, with a total of 59 measurements recorded. Individual coal seams and interburden (siltstone and sandstone) within the Jerrys Plains Subgroup and Vane Subgroup were also tested. In total, there are more than 300 measurements available for the coal, and 151 measurements for the interburden material, which includes the Archerfield Sandstone.

Figure 6.12 shows the distribution in all available horizontal hydraulic conductivity results for the alluvium, Permian coal and interburden including spoil and fine rejects.

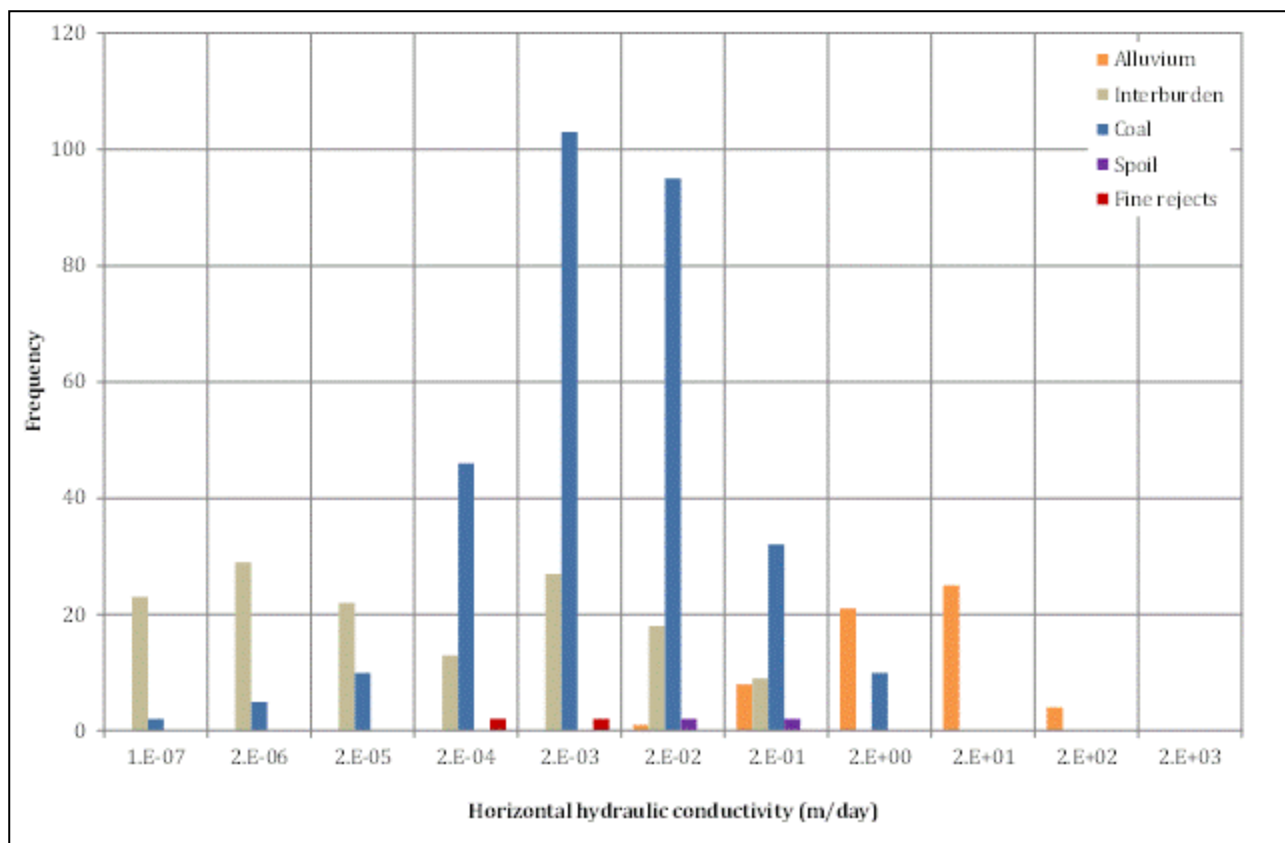


Figure 6.12 Histogram of hydraulic conductivity (Kh) distribution (AGE, 2017)

The hydraulic conductivity in the alluvium ranges between 5.3×10^{-2} m/day and 3.7×10^2 m/day. The distribution of the dataset shows a left skewed distribution, meaning that the alluvium has a relatively high hydraulic conductivity and will tend to be greater than 1 m/day which is logical given its sandy gravelly texture at depth.

The compiled coal conductivity data shows a normally distributed dataset, meaning that most (~200) of the tested conductivity values tend to be moderately permeable with values around 10^{-3} to 10^{-2} m/day. The distribution of the hydraulic conductivity data in the interburden material however shows low to moderate permeability ranges. The interburden can be generally considered less permeable than the coal seams, but permeabilities can be very variable, ranging between 2×10^{-7} m/day and 1 m/day. While only limited (< 10) hydraulic conductivity test data from the Archerfield Sandstone was available, the results indicate low permeabilities within the sandstone unit. The range of hydraulic conductivity of the Permian units predominantly varies with depth (Section 6.2.3), although higher conductivity may also indicate the predominance of fractures in the rock mass in a subset of the test dataset.

Spoil material and fine rejects from historical mining processes are also presently deposited around HVO in mining pits and TSFs. Emplaced spoil material from field tests of spoil at HVO North have estimated a hydraulic conductivity of between 0.7 m/day and 1.6 m/day (AGE, 2013; Mackie, 2009). The available data indicates that the hydraulic conductivity of fine rejects can range between 1.0×10^{-4} m/day and 1.0×10^{-2} m/day, which decreases with increased compaction/settlement (Aubertin *et al*, 1995; Wickland *et al*, 2010).

The difference in hydraulic conductivity for fine rejects and spoil material is largely due to consolidation behaviour and particle structure. In essence, the fine rejects have a particle size similar to silt and clay, whilst spoils can have a wider size particle range through from clay to gravel. When considering this information, it is important to note that whilst spoils are moderately permeable when initially placed, anecdotal evidence at HVO North within the backfilled Alluvial Lands area suggests physical compaction combined with physical and chemical weathering of the spoil sediments has reduced the porosity and permeability of the spoil significantly.

The physically dispersive nature of the spoils is visually evident where they are present at the surface on-site and this process is expected to promote the gradual clogging of porosity within the spoils. As a result, neither the spoil nor the fine rejects are expected to form productive aquifers in the long term. Post closure the spoils will be rehabilitated and covered with appropriately stable material according to the Rehabilitation Management Plan.

Packer testing was conducted within a borehole in HVO North to gather in-situ permeability data specifically for the Project. The test results indicate a notable range of permeability with hydraulic conductivity ranging from 3×10^{-3} m/day to 7×10^{-5} m/day within the Barrett Seam and around 2×10^{-3} m/day within the interburden and Pikes Gully Seam. Hydraulic conductivity results for the tests were within expected conductivity values for host rock in the Hunter Valley area (Mackie, 2009).

6.2.2 Barrier wall

Two sections of low permeability barrier wall were installed prior to mining of the Alluvial Lands at HVO North and the eastern limb of the palaeochannel south of Carrington Pit. The barrier walls were installed into the Permian to seal the alluvium to manage groundwater impacts to the adjacent Hunter River floodplain.

The current approval for mining at Carrington West Wing similarly requires a barrier wall to be constructed prior to mining. As detailed in Section 1.5.1, HVO proposes to construct the barrier wall after mining on the alluvial benches of the high wall and prior to backfilling, consistent with the construction approach for the Carrington Pit barrier wall. There is no proposed change to the other current consent conditions related to the Carrington West Wing barrier wall.

6.2.3 Correlation of hydraulic conductivity vs depth

In general, hydraulic conductivity of stratigraphic units decreases with depth due to increasing confining pressure that compacts or cements any interconnected pores, faults and fractures within a rock. As depth increases, the ability of faults and fractures of the rock to transmit water decreases until eventually permeability of the rock matrix dominates. AGC in 1984 first showed the correlation of hydraulic conductivity with depth in coal seams from the Upper Hunter Valley. Test data from other similar sedimentary basins within Australia confirms that the in-situ permeability of most strata tends to reduce with depth (OGIA, 2019). This is particularly true of coal seams since the permeability is derived almost entirely from small fractures or cleats which are particularly prone to closure as the weight of the material overlying increases.

The correlation between hydraulic conductivity and depth for coal seams is presented in Figure 6.13. The dataset indicates a log-linear reduction in coal hydraulic conductivity of around an order of magnitude every 100 m below the surface. Similarly, the comparison of the hydraulic conductivity and depth data for the interburden in Figure 6.14 also shows a reduction in hydraulic conductivity with depth. The permeability in the interburden decreases following a power trend (four orders of magnitude within the first 100 m depth range. This likely due to a combination of compaction forces as described above, in addition to the presence of a weathered profile contributing to higher permeabilities in the shallow <100 m) sections.

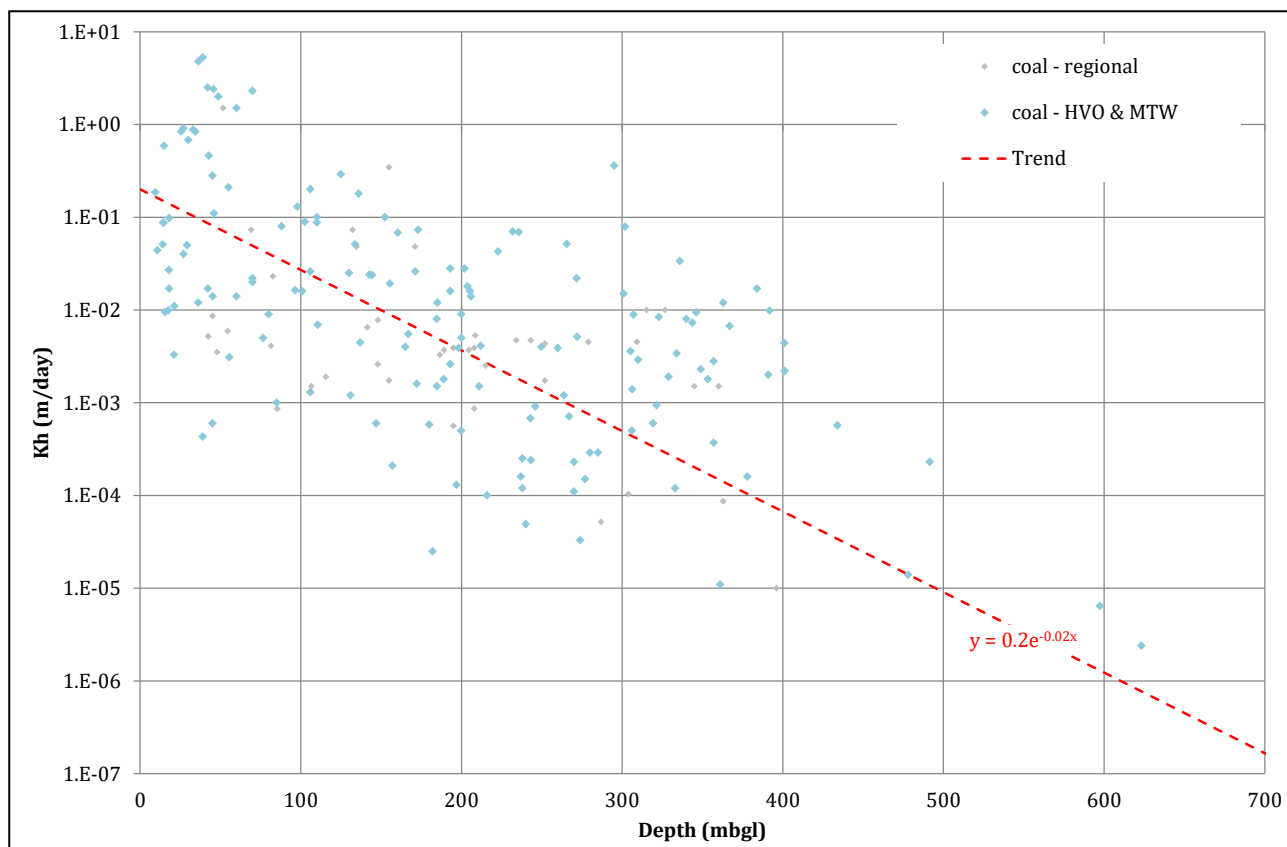


Figure 6.13 Hydraulic conductivity vs. depth – coal (AGE, 2017)

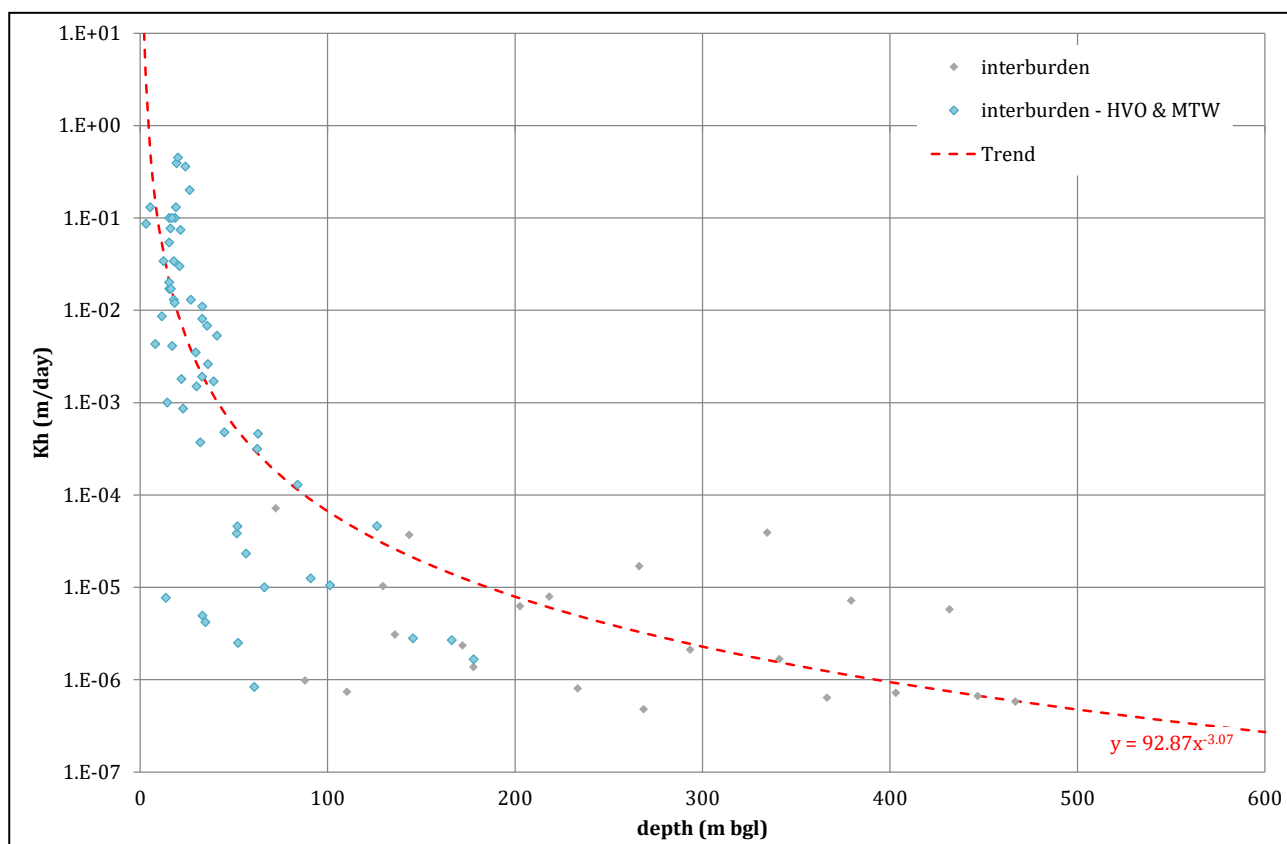


Figure 6.14 Hydraulic conductivity vs. depth – interburden (AGE, 2017)

6.2.4 Uncertainty in aquifer hydraulic conductivity

The range of hydraulic conductivity in the Permian varies by three to four orders of magnitude from the median, while the range of hydraulic conductivity in alluvium varies by about two. This indicates hydraulic behaviour of the alluvial groundwater system is less variable and is therefore less uncertain than the Permian. This is optimal as the alluvial groundwater systems host the main sensitive receptor in the Project area.

The large range of observed hydraulic conductivity in the Permian layers would suggest at first glance that there is a large uncertainty in the aquifer behaviour. However, there are more than 300 historical measurements in the Permian coal seams which show a normal distribution of hydraulic conductivity. The number and distribution of hydraulic conductivity data suggest that sufficient data have been collated showing the upper and lower bound of natural variability assuming a normal distribution, characterised around a median value. Furthermore, there is also adequate data showing a correlation to further constrain the hydraulic conductivity of the Permian formations with depth. The hydraulic conductivity of the Permian formations is therefore considered to be well understood and is less uncertain compared to most hydrogeological systems.

The number of hydraulic conductivity tests to characterise mine spoils is significantly less than available for the in-situ Permian formations. Given that the spoils emplacement is spatially extensive from historical mining in the Project area, hydraulic conductivity of spoils is a source of conceptual uncertainty for most mining operations, including for the Project. The uncertainty and estimated hydraulic conductivity of this material is addressed through calibration of hydrogeological parameters to water level responses in spoil material during numerical modelling (refer Appendix D). A separate sensitivity analysis was also undertaken by varying the properties of the spoil to determine how this could influence groundwater flow directions (Appendix D). Finally, the properties of the spoil were allowed to vary as part of the uncertainty analysis (Appendix D).

6.3 Groundwater recharge

As discussed previously, groundwater recharge in the Project area and region occurs through infiltration of diffuse rainfall and via river leakage.

The Quaternary alluvium is a shallow unconfined groundwater system that is recharged by rainfall infiltration, river leakage, flooding and in some areas also from upward leakage from the underlying stratigraphy. River leakage into the alluvium is an important recharge mechanism and can be up to four times greater than direct rainfall recharge (McVicar et. al. 2015).

Permian sediments outcrop primarily as regolith in the Project area and are recharged via rainfall infiltrating through the soil cover and weathered Permian profile. The Permian sediments are also recharged by the overlying Quaternary alluvium, particularly where mining in the Project area has lowered groundwater levels in the Permian (Section 6.1.3) to the point where Permian groundwater levels in some areas exist below the base of the Quaternary alluvium.

Diffuse rainfall recharge ranges from zero to 2% of annual rainfall based on previous studies the Upper Hunter Region (MER, 2006). Assuming an annual rainfall of 632 mm, the average annual recharge for the Project site is up to 12.6 mm. Estimates of mean annual recharge by Herron et.al. (2018) for the Hunter subregion have returned a similar value of 9 mm, or 1.5% of rainfall. The recharge method was primarily based on the chloride mass balance (CMB) method as described in Wood (1999), but also further considered variability of recharge from surface geology, vegetation and distribution of rainfall.

A simple soil moisture balance was used to estimate the timing and magnitude of recharge events for the Project area. The method uses historical rainfall datasets to calculate soil moisture and determine when the soil profile has reached saturation and subsequent deep drainage to the underlying water table occurs.

Averaged recharge rates across geology at land surface during pre-mining (pre-1970) and during mining (post 1970) are presented in Table 6.1 The results show that the post 1970 recharge values is consistent with the 1.5% recharge rate obtained using the CMB method by Herron et.al. (2018), noting that the dominant area where recharge is estimated are diffuse recharge through the Permian regolith.

Table 6.1 Diffuse groundwater recharge rates

Zone	Diffuse recharge rate – pre 1970 (% of annual)	Diffuse recharge rate – post 1970 (% of annual)	Diffuse recharge rate – pre 1970 (mm)	Diffuse recharge rate – post 1970 (mm)
Colluvium and less productive alluvium	5.4	4.5	33.1	29.5
Highly productive (basal) alluvium	12.0	9.9	73.6	64.9
Regolith	1.0	1.5	6.1	9.8
Spoil	-	3.3	-	21.6

Note: Assumes average yearly rainfall 612.9 mm and 656 mm in the periods 1900 to 1969 and 1970 to 2021 respectively.

6.4 Groundwater quality and beneficial use

6.4.1 Salinity

This section describes the groundwater salinity within the Permian Coal Measures, spoil, Hunter River alluvium and Wollombi Brook alluvium in the Project area. Salinity is often the key constraint to groundwater use and can be assessed through reference to total dissolved solid (TDS) concentrations and/or electrical conductivity (EC). EC can be used to estimate TDS concentrations by multiplying by 0.67 (ANZECC 2000). Salinity is commonly described on a scale ranging from fresh to extremely saline. Food and Agriculture Organization of the United Nations ('FAO') (2013) provide a useful set of categories for assessing salinity based on TDS concentrations, and is categorised here using EC as follows:

- Fresh water: <700 $\mu\text{S/cm}$
- Brackish (slightly saline): 700 to 2,000 $\mu\text{S/cm}$
- Moderately saline: 2,000 to 10,000 $\mu\text{S/cm}$
- Saline: 10,000 to 25,000 $\mu\text{S/cm}$
- Highly saline: 25,000 to 45,000 $\mu\text{S/cm}$
- Brine: >45,000 $\mu\text{S/cm}$

EC measurement data is collected routinely from groundwater quality monitoring in the Project area. Figure 6.15 presents EC measurements in monitoring bores from hydrostratigraphic units near the HVO Complex, the neighbouring Ravensworth and United mines and the Liddell mine. The EC measurements are presented as a box and whisker plot which shows the spread of the data and a range of statistics (including 5th and 95th percentiles, median, interquartile range (25th percentile to 75th percentile) excluding any outliers). The plot illustrates the distribution of salinity data within each formation. Summary statistics of the field EC data is also presented in Table 6.2.

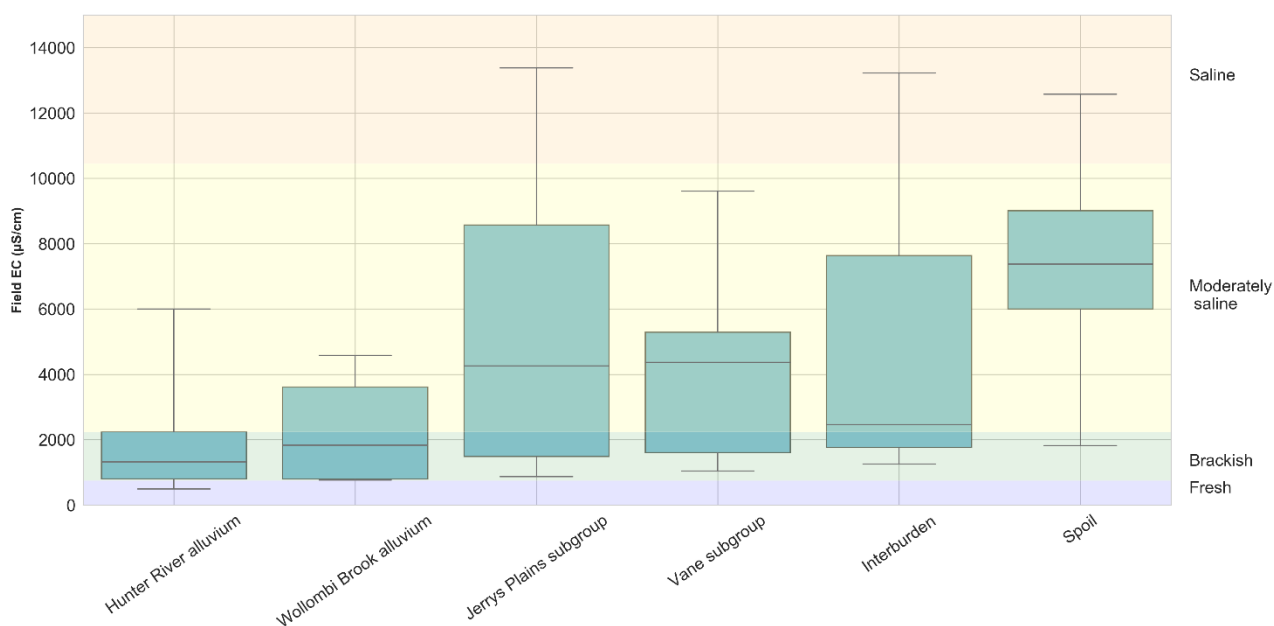


Figure 6.15 Distribution of groundwater field EC data by formation

Table 6.2 Summary statistics of field EC data by formation

Formation	No of tests	Field EC (µS/cm)					
		Mean	Min	25%	50%	75%	Max
Hunter River alluvium	1312	2185	117	801	1317	2240	27900
Wollombi Brook alluvium	57	2226	752	790	1824	3610	7450
Jerrys Plains subgroup	1328	5609	366	1481	4260	8570	21300
Vane subgroup	591	4348	283	1610	4370	5290	15740
Interburden	1201	4874	5	1760	2460	7640	32400
Spoil	374	7330	2839	1027	6000	7370	9008

All sub-surface strata will show some degree of variability since salinity can be affected by a range of factors including sampling depth, aquifer residence time and evapo-concentration processes occurring in near surface areas. Generally, higher permeability aquifer units that receive more rainfall recharge have lower groundwater salinity, whilst relatively high salinity and variability would normally be expected in lower permeability aquitard units that receive more varying recharge.

The alluvial aquifers in the Hunter River and Wollombi Brook are characterised by lower salinities and variability compared to Permian groundwater (Figure 6.15). The median EC for both aquifers is less than 2,200 µS/cm indicating mainly brackish water. Assuming an EC to TDS conversion factor of 0.67, the shallow groundwater systems meets the salinity criteria of 1,500 mg/L outlined Section 2.4.1 for a “highly productive” groundwater source, where basal gravel sections of the alluvium are present and can yield water at a rate greater than 5 L/s (as defined in the AIP).

The average surface water EC in the Hunter River (#210083, #210126) is around 730 µS/cm while average surface water EC in Wollombi Brook is 1,121 µS/cm. The higher groundwater EC in the alluvium along Wollombi Brook and the Hunter River may reflect increased contribution from upward flow of Permian water (Kellett et. al. 1989, ERM 2008).

Groundwater in Parnells Creek alluvium is consistently saline with median EC values about 10,000 µS/cm, noting that data was largely collected at bore GW-100. Groundwater salinity in Parnells Creek therefore does not meet the salinity criteria for a “highly productive” groundwater source.

Median EC values for the spoil and Permian units suggest moderately saline conditions on average. Groundwater in the Permian underneath the Hunter River can be brackish in some cases where it is locally recharged by the overlying Quaternary alluvium. However, the freshwater yields are likely to be limited due to the generally lower permeability and lower recharge ability to replenish freshwater.

Groundwater monitoring at HVO is conducted in accordance with the approved WMP. The WMP describes the groundwater monitoring frequency, parameters to be tested and groundwater triggers. The groundwater trigger values are assigned for EC and pH for different pit locations and geological units. The trigger values for pH are determined using the 5th and 95th percentile calculated from available groundwater monitoring datasets. The EC trigger value is based on the 95th percentile calculated from monitoring dataset. When results are lower than the 5th percentile or higher than the 95th percentile this triggers a review of the monitoring results which is documented within the Annual Review. The most recent annual review was conducted by EMM (2022b).

6.4.2 Beneficial use

A search of the National Groundwater Information System (NGIS) database indicates that the main use of groundwater in Project area is for stock, with minor irrigation. Groundwater use for irrigation is largely limited to the upstream side of HVO and downstream areas near the Singleton township. Most groundwater bores used for water supply are screened within the Hunter River alluvium.

Field crops such as wheat, barley, grain sorghum and canola are mainly irrigated in the Upper Hunter Region (DPI, 2013). Salinity tolerance for field crops vary, but for grain sorghum may be as low as 900 $\mu\text{S}/\text{cm}$ before a reduction in crop yield. Groundwater salinity in the Hunter River and Wollombi Brook alluvium is generally between 1,300 to 1,800 $\mu\text{S}/\text{cm}$, so its use for irrigation will vary according to local groundwater quality, co-use with fresher surface water and the type of irrigated crop.

The maximum salinity guidelines values from NSW DPI (2014) for various livestock threshold was compared against median salinity from the Permian formations presented in Table 6.2. Poultry farming generally requires the least saline groundwater, where EC values greater than 4,700 $\mu\text{S}/\text{cm}$ would result in loss of productivity. Based on this value, the median groundwater salinity in the Permian suggests that it is generally suitable for livestock use. However, the combination of variable groundwater salinity and limited yields in the fractured rock means that it is only reliable where higher local yields are encountered.

6.4.3 Trace element occurrence

Figure 6.16 shows a summary of trace metal concentrations within alluvium, Permian and spoils on a logarithmic scaled plot. Table 6.3, Table 6.4 and Table 6.5 presents the summarised statistics for groundwater quality samples across the Study area based on the same trace element dataset. The default guidelines values (DGVs) for toxicants in freshwater for the 95% level of species protection which is recommended for application to slightly to moderately disturbed ecosystems are also shown on the tables (ANZG 2018).

A number of these elements are generally below detection limit (e.g., beryllium, chromium, silver, lead, mercury, cesium, etc) but is displayed in the plot at the detection limit value. The concentration of trace metals in alluvium is generally lower and less variable when compared to the Permian and spoils. Overall, the range of trace metal concentrations between formations is generally within the same order of magnitude for most of the analytes, with a few exceptions such as aluminium and arsenic that may be influenced by oxidation of small amounts of pyrite minerals. The distinct trace metal ranges suggest that the alluvium is a relatively separate groundwater system with little interaction with other formations. This is as expected as the alluvium water table is hydraulically disconnected from the Permian and spoils in the Project area (Section 6.1).

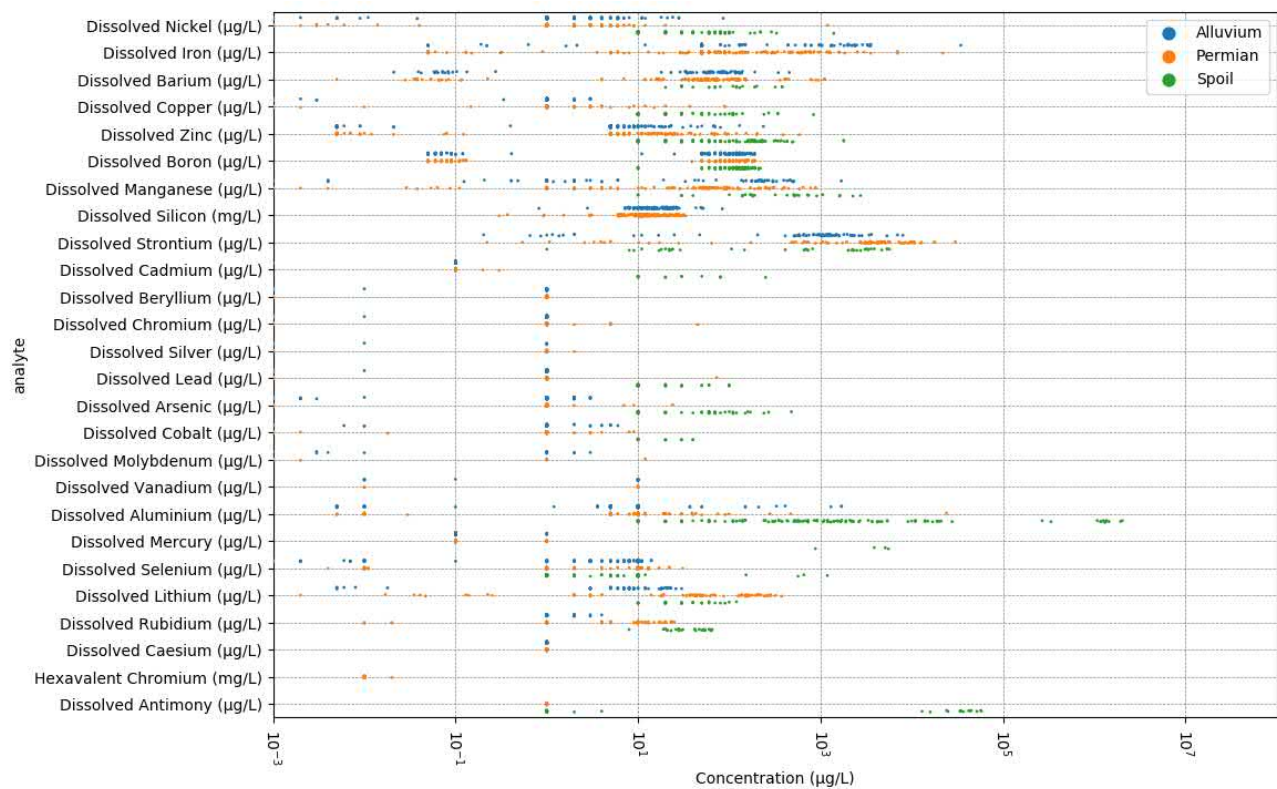


Figure 6.16 Trace element concentrations in groundwater

Table 6.3 Trace elements in regional alluvial groundwater

Trace metal	Freshwater water quality guideline value (ANZG, 2018)		No of tests	Dissolved concentration (µg/L) in alluvium groundwater				
	Value (µg/L)	Level of species protection (%)		Min	25%	50%	75%	Max
Aluminium	55 (pH>6.5) 0.8 (pH<6.5)	95 unknown	198	0.005	5	10	10	1700
Arsenic	As III – 24 As VI - 13	95 95	198	0.001	1	1	1	3
Barium	none	none	74	0.021	0.121	62.5	89.75	455
Beryllium	none	none	74	0.001	1	1	1	1
Boron	95	95	198	0.05	0.09	80	120	190
Cadmium	0.2	95	178	0.001	0.1	0.1	0.1	0.1
Caesium	none	none	54	1	1	1	1	1
Chromium	Cr III – 3.3 Cr VI - 1.0	unknown 95	74	0.001	1	1	1	1
Cobalt	1.4	Unknow	72	0.001	1	1	1	6
Copper	1.4	95	186	0.001	1	1	1	3
Iron	none	none	146	0.05	50	50	147.5	34500
Lead	3.4	95	198	0.001	1	1	1	1
Lithium	none	none	60	0.005	5	8	12.25	30
Manganese	1900	95	74	0.001	1	62	227.5	1690
Mercury	0.6	95	135	0.1	0.1	0.1	0.1	1
Molybdenum	34	unknown	14	0.001	0.0036	1	1	3
Nickel	11	95	198	0.001	1	1	3	86
Rubidium	none	none	54	1	1	1	2	4
Selenium	11	95	198	0.001	2	10	10	14
Silicon (mg/L)	none	none	138	0.82	10.84	15.3	21.6	84
Silver	0.05	95	8	0.001	0.001	0.0055	1	1
Strontium	none	none	74	0.203	328.6	1050	1427.5	8000
Vanadium	6	unknown	14	0.01	0.01	10	10	10
Zinc	8	95	198	0.005	5	5	7.75	237

Table 6.4 Trace element in regional Permian groundwater

Trace metal	Freshwater water quality guideline value (ANZG, 2018)		No of tests	Dissolved concentration (µg/L) in Permian groundwater				
	Value (µg/L)	Level of species protection (%)		Min	25%	50%	75%	Max
Aluminium	55 (pH>6.5) 0.8 (pH<6.5)	95 unknown	150	0.005	5	10	10	24000
Antimony	9	unknown	26	1	1	1	1	1
Arsenic	As III – 24 As VI - 13	95 95	126	0.001	1	1	1	24
Barium	none	none	116	0.005	12	54	91.5	1100
Beryllium	none	none	92	0.001	1	1	1	1
Boron	95	95	124	0.05	0.08	60	112.5	190
Cadmium	0.2	95	136	0.1	0.1	0.1	0.1	0.3
Caesium	none	none	77	1	1	1	1	1
Chromium	Cr III – 3.3	unknown	92	0.001	1	1	1	45
Cobalt	1.4	Unknow	92	0.001	1	1	1	9
Copper	1.4	95	134	0.001	1	1	1	89
Iron	none	none	240	0.05	50	50	130	22000
Lead	3.4	95	150	0.001	1	1	1	73
Lithium	none	none	84	0.002	3	44	150	375
Manganese	1900	95	116	0.001	3	55	100	890
Mercury	0.6	95	111	0.1	0.1	0.1	0.1	1
Molybdenum	34	unknown	7	0.001	0.0012	1	1	12
Nickel	11	95	150	0.001	1	1	3	1200
Rubidium	none	none	80	0.01	1	9.5	10	25
Selenium	11	95	150	0.004	1	10	10	31
Silicon (mg/L)	none	none	245	0.3	9.744	11.8	14.2	33.2
Silver	0.05	95	32	0.001	1	1	1	2
Strontium	none	none	91	0.221	635	3520	5380	30100
Vanadium	6	unknown	7	0.01	0.01	10	10	10
Zinc	8	95	150	0.005	5	6	18	585
Hexavalent Chromium (mg/L)	Cr VI - 1.0	95	129	0.01	0.01	0.01	0.01	0.02

Table 6.5 Trace element in spoil groundwater

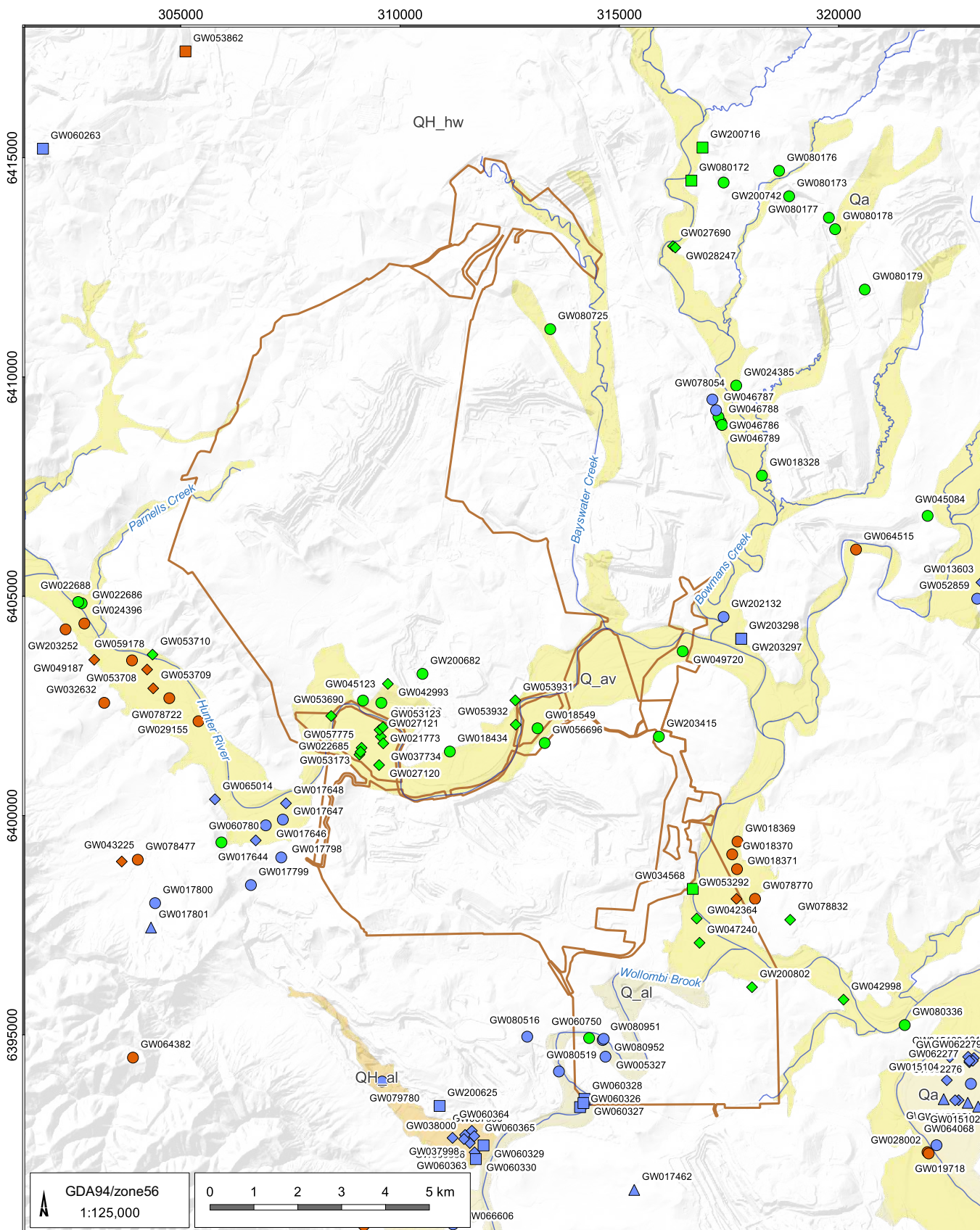
Trace metal	Freshwater water quality guideline value		No of tests	Dissolved concentration (µg/L) in spoil groundwater				
	Value (µg/L)	Level of species protection (%)		Min	25%	50%	75%	Max
Aluminium	55 (pH>6.5) 0.8 (pH<6.5)	95 unknown	129	10	60	730	4420	2040000
Antimony	9	unknown	36	1	1	1	34000	58000
Arsenic	As III – 24 As VI - 13	95 95	54	10	10	60	70	480
Barium	none	none	21	20	30	80	140	380
Boron	95	95	118	10	80	120	140	220
Cadmium	0.2	95	14	10	10	25	72.5	250
Cobalt	1.4	Unknow	12	10	10	20	30	40
Copper	1.4	95	59	10	10	30	85	840
Lead	3.4	95	39	10	10	10	30	100
Lithium	none	none	26	10	20	30	57.5	120
Manganese	1900	95	28	10	116	255	725	2750
Mercury	0.6	95	4	880	2686	4510	5235	5550
Nickel	11	95	105	10	10	30	70	1400
Rubidium	none	none	26	8	23	42	53.75	65
Selenium	11	95	119	1	1	2	10	1190
Strontium	none	none	36	1	22	726	3097.5	5700
Zinc	8	95	116	10	20	65	180	1800

6.5 Groundwater users

6.5.1 Private water users

A search of the NGIS database was conducted to identify the locations of any water supply bores in proximity to the Project. Figure 6.17 shows the location of the registered bores and land ownership details around the Project area. The search identified 117 registered bores located within the Project area, 22 of which are owned by private landholders. The remainder of the registered bores are located on land either owned by HVO or other mining companies.

Table 6.6 summarises the screened formations of these registered bores. For bores with no available lithological details, the surface geology map and lithological logs for nearby exploration and registered bores were used to infer the screened lithology. Most private landholder bores are primarily located upstream and downstream of the Project area along the Hunter River and are screened within the Hunter River alluvium.



LEGEND

— Drainage
 — Project Area

Owners

● Glencore
 ● Private
 ● Other mines

Water users

FTypeClass
 □ Commercial and Industrial
 ◇ Irrigation
 △ Stock and Domestic
 ○ Water supply or unknown use
 ○ Water Supply

Quaternary Alluvium (mapped)

Q a - Alluvium
 Q acw - Alluvial channel deposits
 Q al - overbank deposits
 Q av - Alluvial valley deposits
 QH al - Fluvially deposit

HVO Continuation (G1737J)

Private registered bores



AGE

DATE
 18/11/2022

FIGURE No:
6.17

Table 6.6 Private registered bores by stratigraphic unit

Screened unit	Owner		
	HVO	Other mines	Private
Alluvium	25	31	14
Permian	21	17	8
Total	46	49	22

Note: Monitoring, abandoned and destroyed bores have been excluded.

6.5.2 Groundwater dependent ecosystems

Groundwater Dependent Ecosystems (GDEs) are defined as ecosystems that rely in some part for their survival on groundwater. Dependence ranges from complete reliance for some systems to others that rely partially on groundwater, particularly during times of drought. Potential GDE occurrence around HVO is mapped in Figure 6.18. The map includes areas of low to high potential GDEs mapped in the National Atlas of Groundwater Dependent Ecosystems (the Atlas). The Atlas shows known and potential GDEs and is the most comprehensive inventory of the location and characteristics of potential GDEs in Australia. The areas of moderate and high potential GDEs are largely associated the Hunter River, Bowmans Creek, Glennies Creek and Wollombi Brook. When interpreting the GDEs identified in the Atlas it should be noted there is some uncertainty in the potential for the ecosystems to be reliant on groundwater. This is illustrated by the identification of some areas of potential GDEs situated within open cut mining areas.

A site specific GDE study by Eco Logical Australia (ELA; 2022) was undertaken for the Project. The study involved field surveys of four potential GDE areas that were identified from a desktop assessment and remote sensing analysis. The surveys were located in the Hunter River between HVO North and HVO South, Wollombi Brook and two sites representing terrestrial vegetation associated with the unconsolidated Warkworth Sands.

A biodiversity development assessment report (BDAR) has also been completed for the Project by Umwelt (Australia) Pty Ltd (Umwelt) and is included as Appendix L to the EIS. The BDAR focused on vegetation mapping within the Project Area, mainly on the additional disturbance areas. Umwelt (2022) conducted multiple field surveys in 2020 (March, June, August, September and October), 2021 (April and October), and 2022 (June, July and August). The landscape within and surrounding the Project Area is characterised by extensive historical clearing for agricultural, mining and rural development. As such, much of the land associated with the Project conforms to Category 1 – Exempt Land under the Local Land Services Act 2013, being lawfully cleared areas and low conservation vegetation not required to be assessed. Remaining areas of native vegetation and habitat have been surveyed for its biodiversity value and assessed in accordance with the biodiversity assessment method (NSW DPE 2020) in accordance with the BC Act. The results of vegetation mapping conducted by Umwelt (2022) was provided to ELA to inform the GDE assessment.

Locations of potential GDEs in the Project area include:

- Carrington Billabong (SLR 2019);
- River red gums along the Hunter River and Wollombi Brook (HVO, 2022);
- Stygofauna in alluvium along Hunter River, Bowmans Creek, Glennies Creek and Wollombi Brook (ELA, 2022);
- River Oak Grassy Riparian Woodland of the Hunter River riparian zone; and
- Warkworth Sands Woodlands (ELA, 2022).

The Carrington Billabong is an ephemeral freshwater wetland south of the mined Carrington Pit (SLR, 2019). An existing low permeability barrier wall separates the billabong and the pit, resulting in relatively stable groundwater levels supporting the billabong despite the historical mining. This GDE is maintained by river leakage into the alluvial groundwater system, rather than Permian groundwater due to the disconnect between the alluvium and Permian groundwater system previously described in Section 6.1.3. For this reason, the River Red Gum communities identified by Umwelt (2022) along Hunter River are also expected to be supported by groundwater occurring within the alluvium rather than the Permian strata.

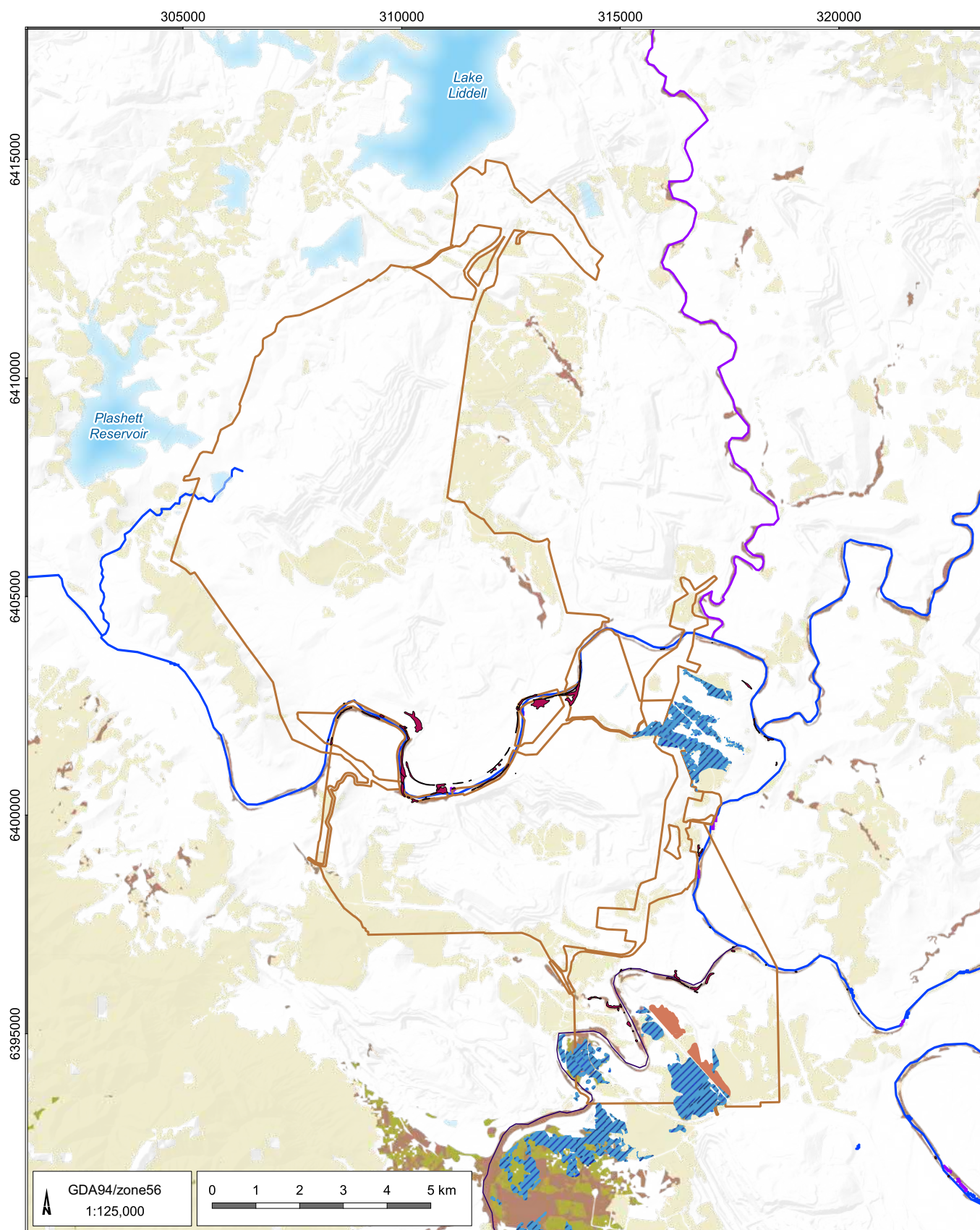
Stygofauna are known to occur in alluvial sediments in the Project area along the Hunter River, Bowmans Creek, Glennies Creek and Wollombi Brook (ELA, 2022). They may also occur in the shallow fractured rock up to 60 m depth where they colonise fracture networks of secondary porosity. The presence of stygofauna becomes increasingly uncommon in the deeper, unweathered rock where increasing groundwater salinity, and low dissolved oxygen levels limit their occurrence.

The Warkworth Sands Woodlands are largely associated with the unconsolidated aeolian sediments in the area. The recent study by ELA (2022) noted changes in NDVI associated with the terrestrial vegetation during the dry season, suggesting a degree of groundwater dependence. Cumberland Ecology (2014) also noted species indicative of a persistent water table can be found in dune swales suggesting some groundwater permanence.

The saturation in the sands can be variable. A 2021 groundwater monitoring bore installation program in the sands encountered dry soils at the time of installation (EMM, 2022c). A soil survey was undertaken by Lockwood (2007) in the Warkworth Sands approximately three months after an extreme rain event. The findings indicated nearly all deep sand profiles were moist close to the clay boundary, and many were saturated. Dataloggers installed in the monitoring bores show the Warkworth Sands Woodlands temporarily becomes a perched groundwater system (i.e., contains groundwater that is disconnected from the underlying formations) following high rainfall events (e.g., following the floods of March 2021 and 2022).

Nevertheless, some small seepages of groundwater occur from the Warkworth Sands at the break of slope created by the Wollombi Brook floodplain, while most of the perched water is likely to be removed from the aquifer by direct evapotranspiration through the vegetation (AGE, 2010). This implies that the water table formed at the base of the Warkworth Sands is perched and is not in direct hydraulic connection with the regional aquifer in the underlying Permian fractured rock. The Warkworth Sands aquifer is therefore considered to be perched above, and not directly connected to, the regional water table (AGE, 2014). Any potential lowering of pressure within the Permian strata will pose minimal risk to the water table within the sands and the associated terrestrial GDEs.

A conceptual graphic showing the key elements of the groundwater regime occurring within the Warkworth Sands Woodland is provided in Figure 6.19.



LEGEND

- Drainage
- Project Area

Aquatic GDE

- Known GDE - from regional studies
- High potential GDE - from national assessment
- Moderate potential GDE - from national assessment

Terrestrial GDE

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

Potential GDE – mapped from current and historical studies

- River Red Gum Area
- Warkworth Sands Woodland (EPBC Act)
- Warkworth Sands Woodland (TSC Act)
- ▨ Warkworth Sands Woodland (TSC Act)

HVO Continuation (G1737J)

Potential groundwater dependent ecosystems



AGE

DATE
04/11/2022

FIGURE No:
6.18

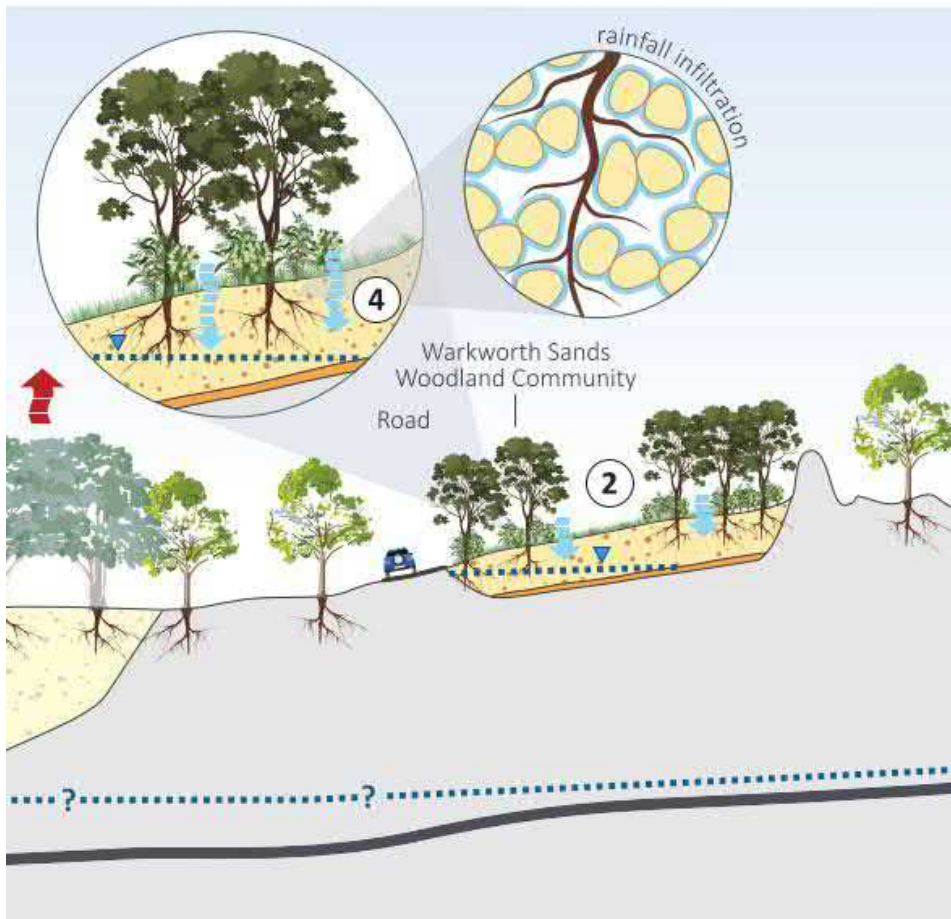


Figure 6.19 Conceptual model of Warkworth Sands Woodlands (source EMM 2022c)

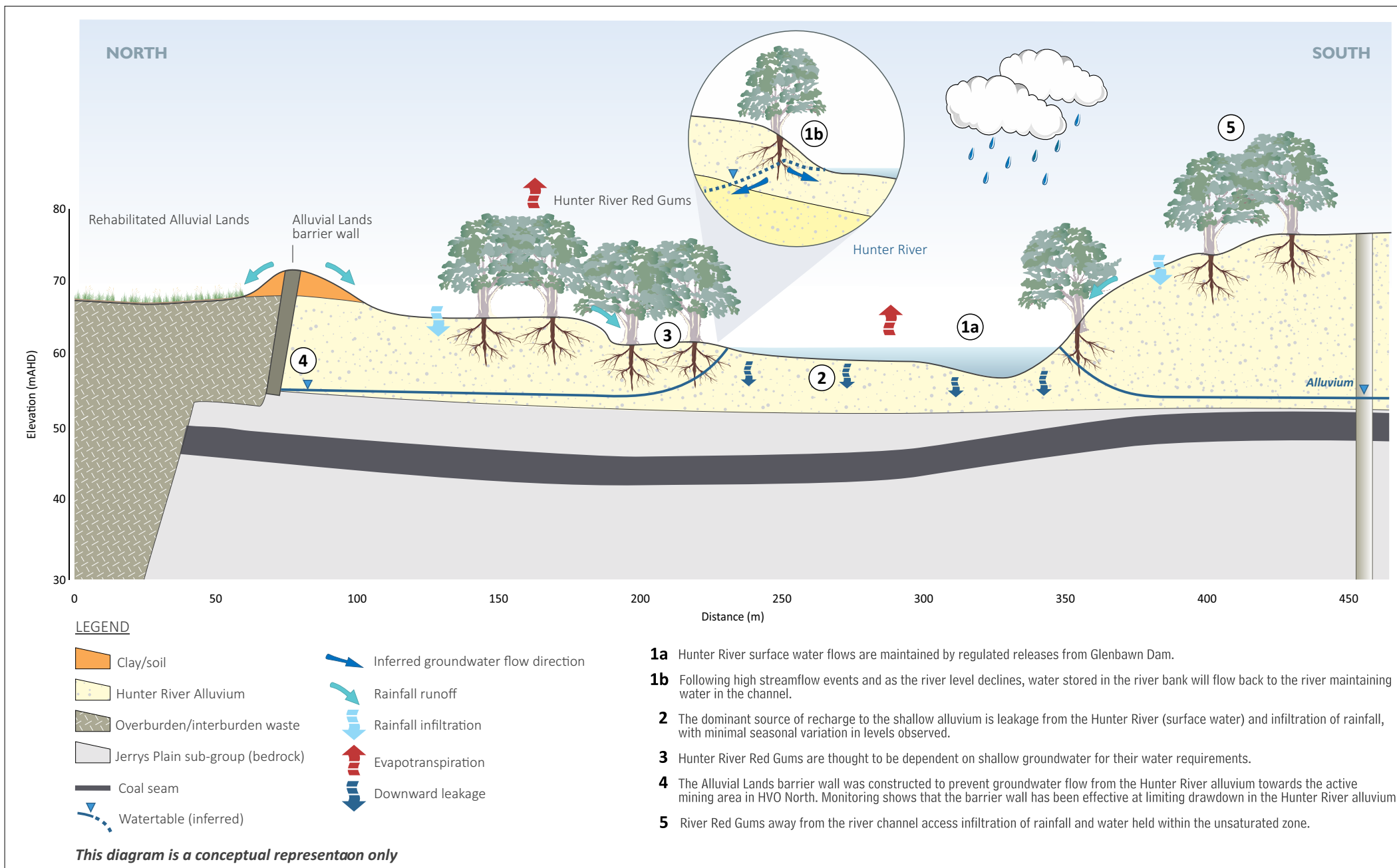
6.6 Summary of conceptual groundwater model

The HVO Complex is situated along the Hunter River floodplain where it has incised into the sequence of coal seams where adjacent mining operations extract coal via open cut and underground methods. The Quaternary alluvium along the Hunter River floodplain and Wollombi Brook forms a thin meandering aquifer system in the Project area. The Hunter River alluvium is commonly less than 20 m in thickness with the most permeable part of the sequence being the deeper 'bed load' sands and gravels that readily transmit groundwater.

The Permian layers do not form highly productive aquifers because of generally poor water quality and low yields that preclude any beneficial use. The coal seams in the Permian are more permeable compared to the interburden materials and are therefore the transmissive pathways where groundwater movement occurs. The groundwater flow path and discharge zone for the Permian groundwater system is primarily influenced by mining activities in the region.

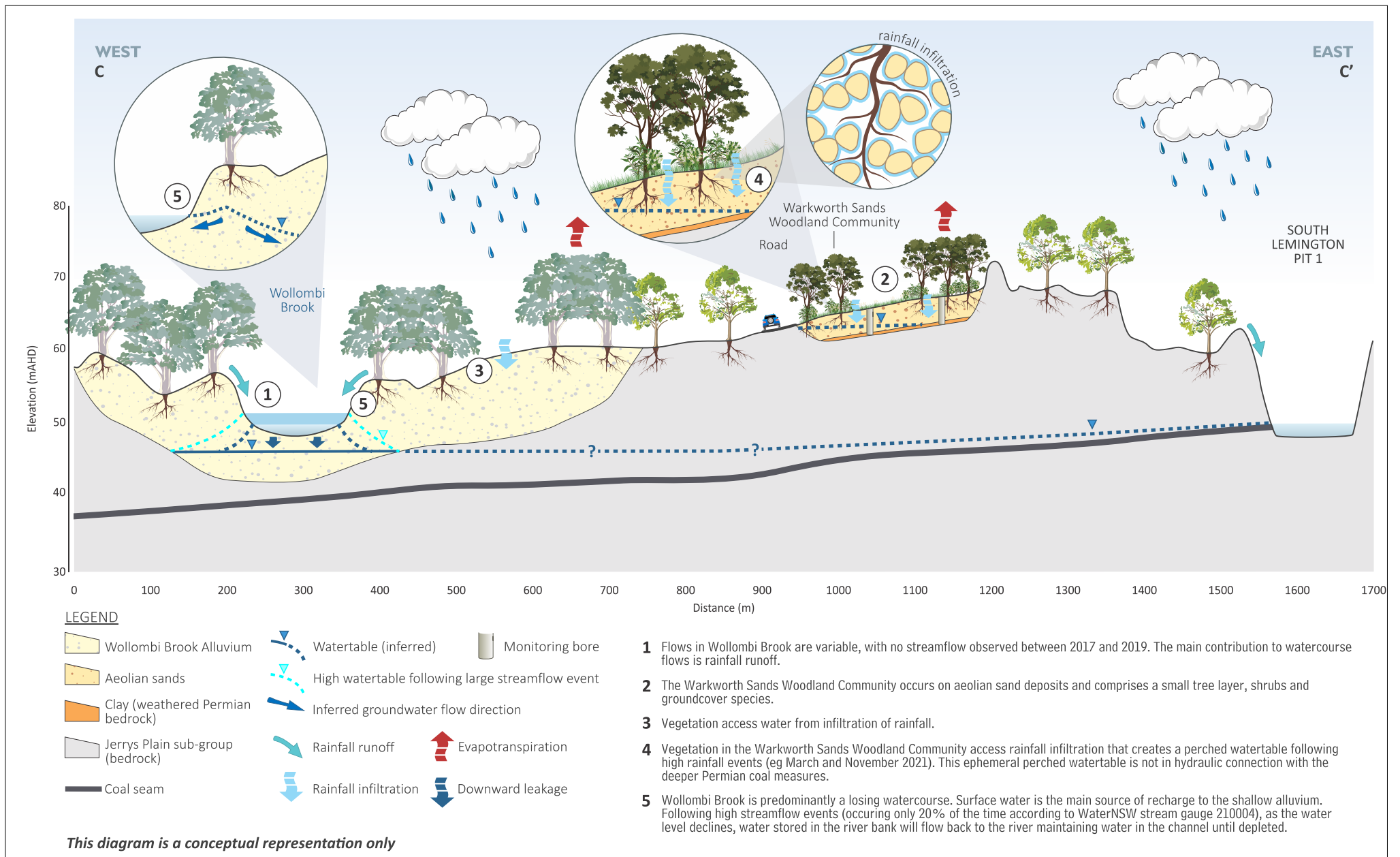
Prior to the occurrence of mining activities, the main discharge mechanism for groundwater within the Permian strata was through slow upward flow to Quaternary alluvium deposited along watercourses, particularly the Hunter River. In the present day, approved mining activities have depressurised the Permian groundwater systems and reduced the pressure within coal seams to the point where groundwater levels exist below the base of the Quaternary alluvium. This means the main discharge zone for groundwater within the Permian interburden and coal seams has changed from the alluvial aquifer to the surrounding mining operations, either closed or operating. The alluvial aquifer is effectively disconnected from the Permian with levels maintained primarily by river leakage.

The main causal pathway for potential impacts from mining on the water dependent assets is depressurisation of the Permian strata resulting in drawdown within the Hunter River and Wollombi Brook alluvium. However, as discussed above and in Section 6.1, the groundwater table in the alluvium is currently disconnected from the groundwater in the shallow coal seams which are already depressurised by historical mining. Further depressurisation of the deeper Barrett and Hebden seams is therefore not likely to significantly affect the shallow groundwater table within the alluvium based on the conceptualisation provided. As a result, groundwater risks to the Hunter River and its alluvial aquifers are expected to be minimal beyond already approved existing operations. Aspects of the conceptual model described above are shown graphically in Figure 6.20 and Figure 6.21.



Hunter River and River Red Gums Conceptual Model

HVO Continuation Project
Groundwater impact assessment
Figure 6.20



Receptor Conceptual Diagram – Warkworth Sands and Wollombi Brook

HVO Continuation Project
Groundwater impact assessment

Figure 6.21

7 Numerical groundwater model

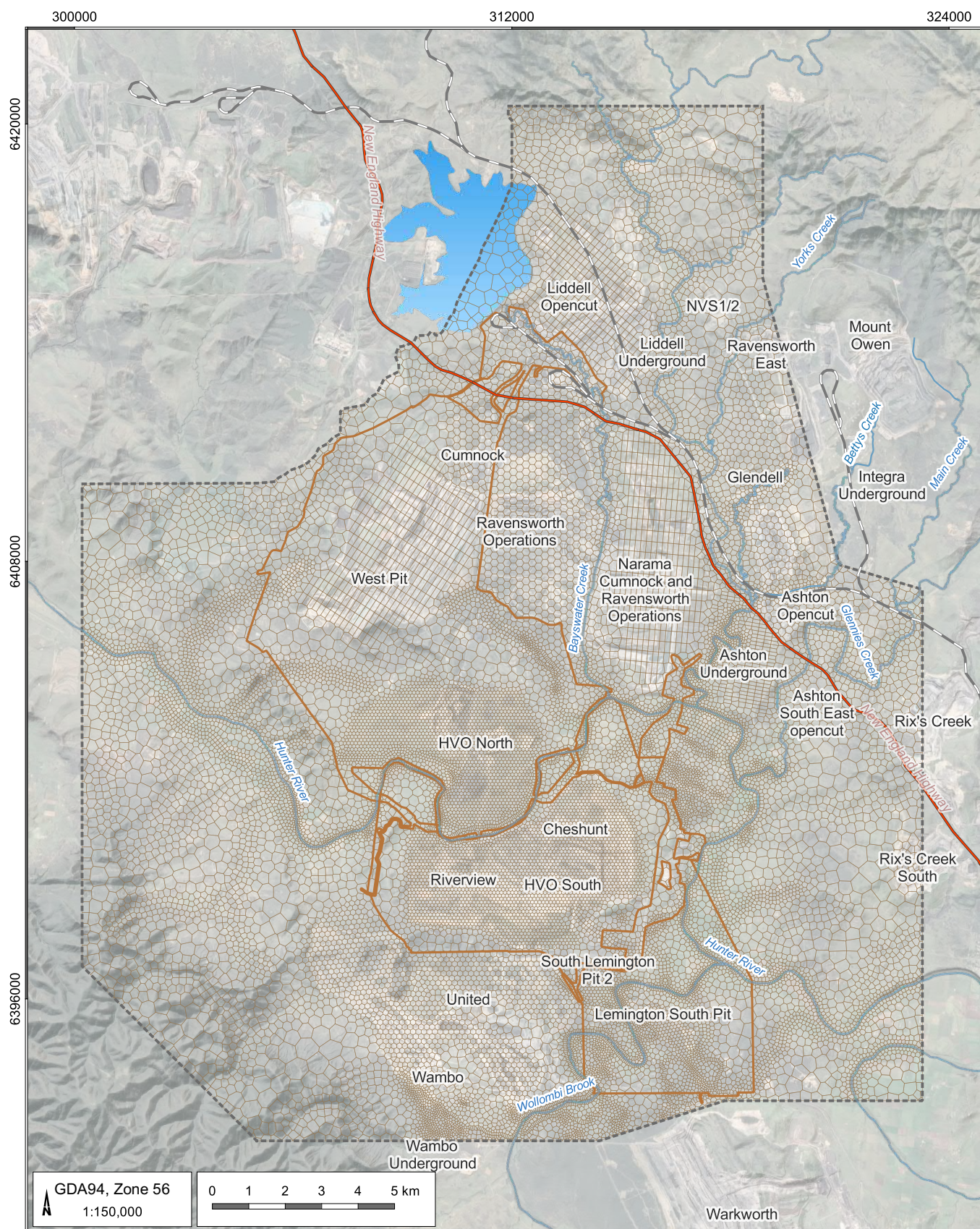
7.1 Overview of groundwater modelling

The prevalence of mining in the region means there have been many previous groundwater modelling efforts in the mid-Hunter Region. The most recent models in the Study area were prepared for HVO South MOD5 (AGE, 2015), and Glendell Continued Operations Project (AGE, 2019). These models were reviewed to determine if they would be suitable to assess the impact of the Project. It was concluded a new model should be constructed to cover the Project area using the most up to date elements of each model.

The 3D groundwater flow model was developed using MODFLOW-USG. A detailed description of the modelling is provided in the technical report included within Appendix D. The model represents the main hydrostratigraphic layers in the region which are the Quaternary alluvium, and the coal seams/interburden of the Vane Subgroup and Jerrys Plains Subgroup. The model is approximately 23 km wide in an east to west direction, and 28 km long north to south. It has 33 layers and comprises up to 22,577 cells per layer, making it spatially a large and complex model (Figure 7.1).

When constructing the new model, the approach was to create consistency with previous work as much as possible to represent the cumulative impacts of mining in the surrounding region as well as include the proposed new elements of the Project. Major components of the modelling included:

- updating the model layers including the Permian coal seams;
- updating the historical progression of mining and final void water levels;
- updating water level monitoring datasets and recalibrating the model;
- using pilot points to represent spatial heterogeneity in aquifer parameters;
- representing the proposed progression of mining for the Project;
- using the model to assess the impacts on the groundwater regime for the Project; and
- conducting sensitivity and uncertainty analysis.



LEGEND

- Drainage
- Road
- Rail
- Project Area
- Model extent
- Model grid

HVO Continuation (G1737J)

Model extent



AGE

DATE
25/10/2022

FIGURE No:
7.1

A significant network of monitoring bores exists within the model domain, particularly across the Hunter River and Bowmans Creek flood plains adjacent to mining areas which can be used for model calibration. Nested installations occur at many sites with separate bores constructed within the alluvial aquifer and underlying coal seams and/or interburden strata. A common observation at these monitoring sites is that mining induces depressurisation and lowering of water levels within coal seams which extend under adjacent creeks and rivers, but the overlying alluvial aquifers do not record detectable drawdown (refer hydrographs contained within Appendix C). This is the case within the Hunter River alluvium which has not recorded identifiable long term drawdown despite the close proximity of mining at HVO North and HVO South. This outcome is a function of several factors including, lack of direct connection between the alluvium and the mining areas, the aquitard properties of the interburden strata underlying the alluvium, relatively high recharge rates to the alluvium through the flood plain soils, and leakage from Hunter River which has its flow sustained by upstream releases from Glenbawn Dam. These factors combine to buffer any losses from the alluvium due to depressurisation of the Permian strata to a point where the influence of mining cannot be identified within the alluvial aquifers, and climate is the main driver of water level fluctuations.

The calibration of the numerical model focussed on replicating this key regional trend of depressurisation within the Permian strata adjacent mining areas, and lack of drawdown within the alluvial aquifers. In some areas, particularly the area between HVO North and HVO South, groundwater monitoring sites can occur relatively clustered together. In this circumstance it was not always possible for the model to replicate all observed water level trends due to the model cell size and spatial variability achievable in model parameters. In these areas the calibration focussed on replicating the overall trend of depressurisation within the Permian, and the observation of no detectable drawdown within the alluvium. The transient calibration achieved a 9.2% scaled root mean square (SRMS) error, which is within the guidance range of <10% recommended by the Australian Groundwater Modelling Guidelines (Barnett et al. 2012). The calibration is described in more detail in Appendix D.

The model was used to identify the impact of the Project on the groundwater regime by comparing the impacts generated by the approved and proposed mine plans. Current approved and proposed mine plans within the region were included in order to account for cumulative impacts. At the time of model development, this included projects for which an EIS had been submitted for assessment, but not yet approved, such as Glendell Continued Operations. Recently the application for the Glendell Continued Operations project was refused by the NSW Government, so the modelling is conservative.

The influence of the Project on the groundwater regime was estimated by comparing the impacts predicted by the numerical model for the approved and proposed mine plans. The following model scenarios were run:

1. “baseline” – this scenario included approved operations within the region, but no mining after 2009 which is when the Hunter Unregulated WSP commenced - this provided a ‘base-case’ for assessment of total impacts;
2. “approved” – included the currently approved operations at HVO North and HVO South and approved and foreseeable operations within the region; and
3. “proposed” – included approved and foreseeable operations as well as the proposed mine plans associated with the Project.

The prediction results from each model scenario were compared and the groundwater impact results are discussed in Section 8. The AIP requires that impacts due to aquifer interference activities are assessed both over the life of the activity and after closure of the activity. The impacts predicted by groundwater modelling post closure are summarised in Section 9.

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

7.2 Peer review

A peer review was conducted by Dr Doug Weatherill of EMM, who has over 20 years of experience in hydrogeological investigations and groundwater modelling. The review was undertaken in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al. 2012) and included input and involvement from Dr Weatherill over the three main stages of numerical groundwater modelling as follows:

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

The peer review report, along with others for the surface water assessment is appended to the Water Assessment report (Appendix K of the EIS).

8 Operational stage impacts

8.1 Impact of blasting on aquifer properties

A previous study by Enviro Strata Consulting Pty Ltd (ESC 2019) assessed the potential for blasting to impact on the integrity of Permian rock strata for the Glendell Continued Operations Project in the Hunter Valley. The assessment included a review of geological logs in the Glendell project area and rock strength testing data. The review indicated the Glendell Pit Extension is characterised by moderately strong to strong rock types with majority being above 30 MPa, which is a typical concrete strength value. The review further indicated that cracks are not readily transmitted through strong strata with a strength over 30 MPa and concluded the strata are resistant to fracturing induced by the adjacent open cut blasting. It is anticipated that increased permeability is limited to less than 30 m from the external blast face. Given the relatively close proximity of Glendell to HVO, and the same Permian strata are proposed for mining it is expected the fracture transmission would be similar at HVO.

Most of the additional mined disturbance area as part of the Project will mine the deeper seams below the base of Bayswater seam of the Jerrys Plains Subgroup underneath the existing Carrington Pit. As a result, blasting during mine operations was not considered to substantially change aquifer properties to warrant representation in the groundwater model.

8.2 Water table drawdown

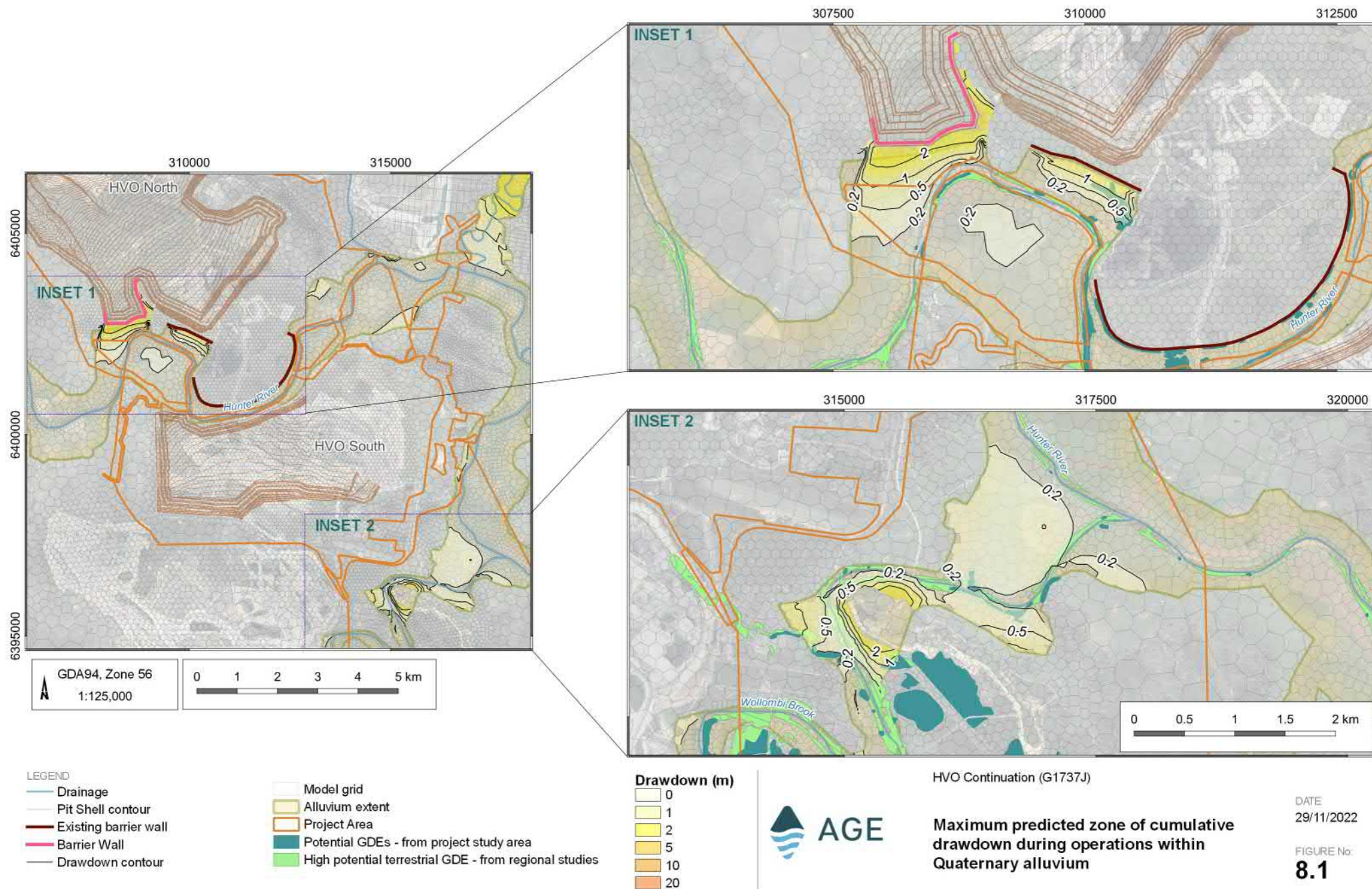
'Drawdown' is a reduction in hydraulic head within an aquifer in response to removal of water. Examples of activities that can induce drawdown include pumping from water supply bores, transpiration from vegetation, and excavations from open cut/underground mining. When the water table falls within an unconfined aquifer it is referred to as drawdown, whereas within a fully saturated confined aquifer such as a coal seam a decline in water level is referred to as depressurisation.

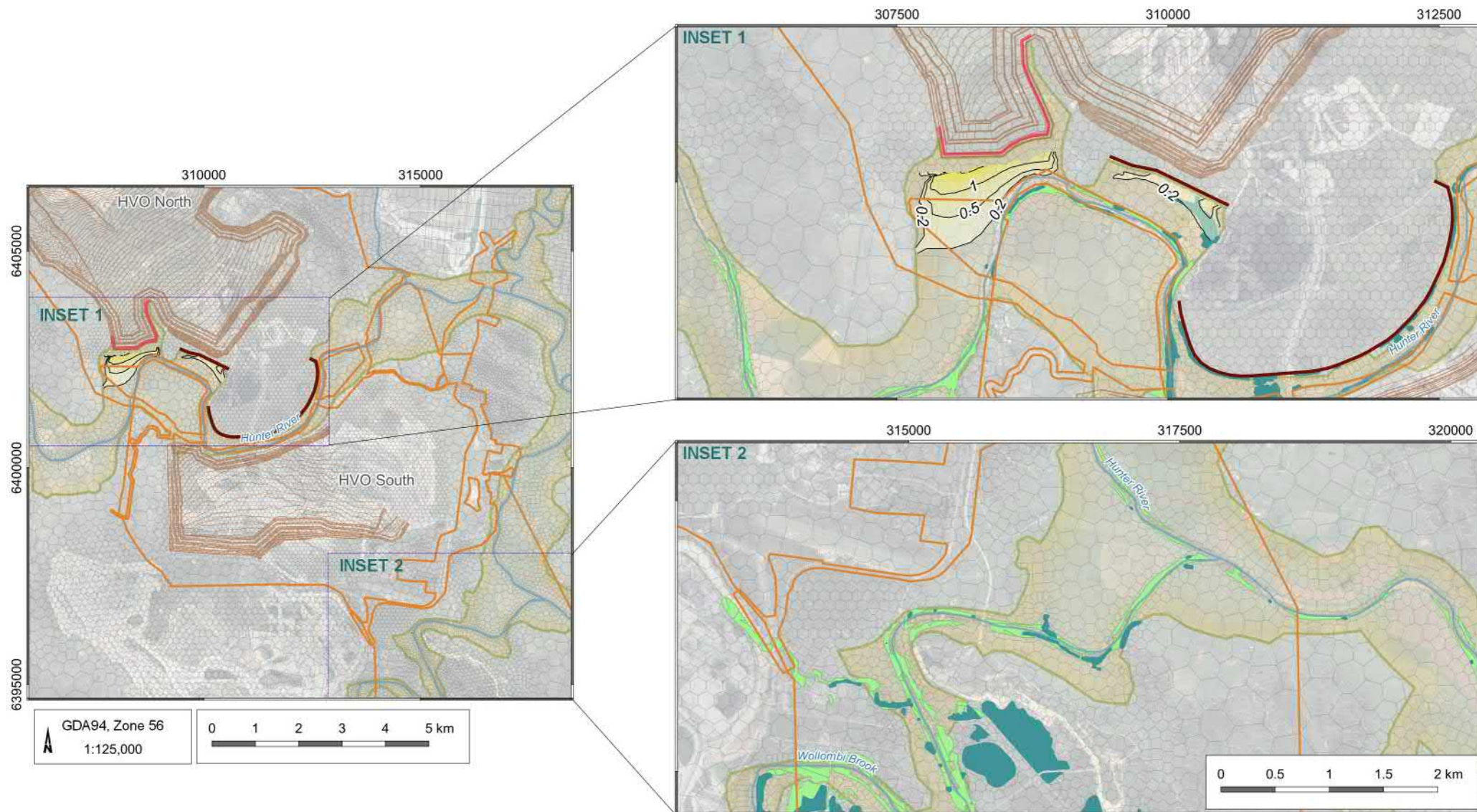
Figure 8.1 shows the maximum cumulative drawdown predicted to occur within the Hunter River Quaternary alluvium and the Wollombi Brook Quaternary alluvium during the operating life of the HVO Complex to 2050. This prediction is from the calibrated suite of models, with the uncertainty analysis predictions provided within Appendix D. The figure shows the maximum drawdown predicted to occur due to the cumulative impact of HVO North and HVO South and other mines in the region. This drawdown is calculated by comparing the "proposed" model scenario that includes all approved and proposed mining activities, with the "baseline" version of the model where mining in the region does not continue beyond 2009. This approach allows the cumulative impact of mining activities post commencement of the Hunter Unregulated WSP in 2009 to be established as required by the AIP.

The drawdown shown in the figures is a composite of the maximum drawdown predicted at each model cell over the operational life of the Project until year 2050. For drawdown that is predicted to occur within the Hunter River alluvium adjacent HVO North, the maximum drawdown occurs prior to construction of the barrier wall adjacent to the alluvium. After construction of the barrier wall, the drawdown reduces over the remainder of the mine life, but the maximum cumulative drawdown is shown on Figure 8.1.

Figure 8.1 shows the drawdown predicted to occur within the Wollombi Brook alluvium. The figure shows a peak cumulative drawdown of up to 5 m in magnitude in the area of the Lemington Underground Mine. Drawdown is predicted because a continued extraction of groundwater from the Lemington Underground Mine is represented in the "proposed" model scenario, creating lower groundwater levels compared to the "baseline" model scenario that simulates pumping from the Lemington Underground ceasing in 2009. There is also a small amount of drawdown of about 0.2 m predicted to occur further to the east of the Lemington Underground and downstream within the Wollombi Brook alluvium. This occurs as the coal seams intersected by Lemington Underground subcrop under the Wollombi Brook in this area and promote minor expansion of the zone of drawdown. The drawdown is therefore a cumulative impact and not generated from the proposed open cut mining at HVO North and HVO South.

Figure 8.2 shows the incremental drawdown predicted to occur within the Hunter River alluvium and Wollombi Brook alluvium respectively. This drawdown is calculated by comparing the drawdown predicted by the “proposed” model scenario that includes all approved and proposed mining activities, with an “approved only” scenario where only approved mining is represented. Figure 8.2 shows an incremental drawdown within the Hunter River alluvium similar to cumulative drawdown, indicating the majority of the impact within the Hunter River alluvium is attributable to the Project. It should be noted the maximum incremental drawdown is predicted to occur only for a short duration prior to the construction of the barrier wall. The predicted incremental drawdown is negligible following installation of the barrier wall. In contrast there is no additional incremental drawdown predicted to occur within the Wollombi Brook alluvium as mining is being reduced, not increased in this area with the South Lemington Pit 1 and 2 open cut mining being removed from the Project. In fact, an amount of drawdown is prevented due to the removal of future mining at Lemington South pits 1 and 2 from the proposed Project mine plan.





LEGEND

- Drainage
- Pit Shell contour
- Existing barrier wall
- Barrier Wall
- Drawdown contour
- Model grid
- Alluvium extent
- Project Area
- Potential GDEs - from project study area
- High potential terrestrial GDE - from regional studies

Drawdown (m)

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



HVO Continuation (G1737J)

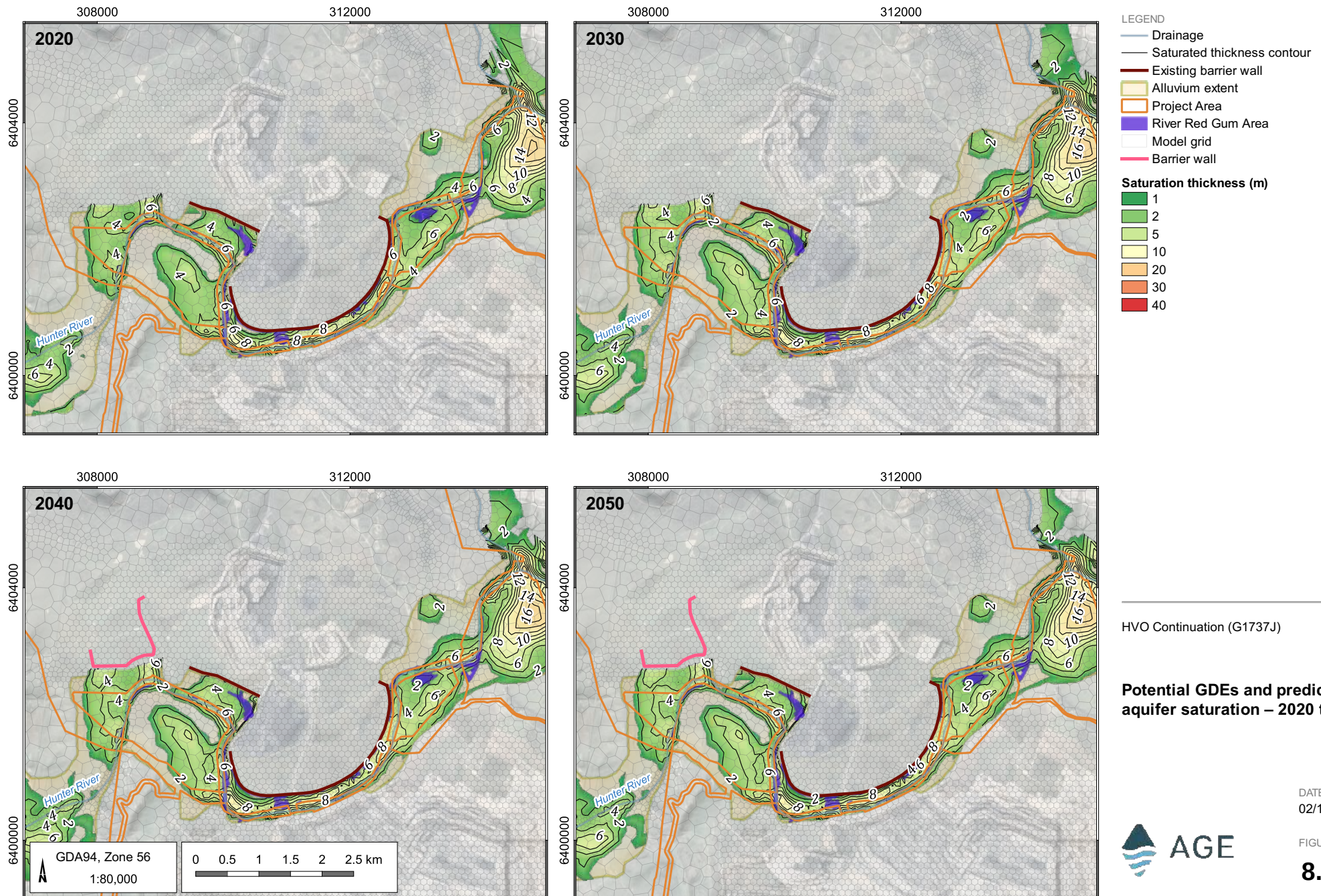
**Maximum predicted zone of
incremental drawdown during
operations within Quaternary alluvium**

DATE
29/11/2022

FIGURE No:
8.2

8.2.1 Changes to groundwater regime at groundwater dependent ecosystems

Figure 8.3 shows the predicted change in the saturated thickness within the alluvial aquifer over the operating life of the Project. The figures highlight that whilst the saturated thickness of the Hunter River alluvium can be limited in some areas there isn't an appreciable change in the extent of the saturated areas over time due to the Project. The areas where GDEs potentially occur are also not dewatered over the Project life. The potential impact of the Project on GDEs is discussed further in the Aquatic Ecology and GDE Assessment (ELA, 2022 in Appendix M of the main EIS document).



8.2.2 Drawdown at private water supply bores

Section 6.5.1 described groundwater usage in private water supply bores in proximity to the Project area. There are no known private water supply bores situated within the zone where the incremental drawdown is predicted to exceed the AIP threshold for minimal impact of 2 m.

8.2.3 Drawdown at culturally significant sites

No high priority culturally significant sites are listed in the schedules of the relevant water sharing plans.

8.3 Water take due to mining

All water taken by aquifer interference activities, regardless of its quality, needs to be accounted for within extraction limits set under WSPs. Water take can be classified as:

- **incidental water take** which is a category within the AIP for water encountered incidentally within mine workings and extracted for safety – this is also commonly referred to as direct water take;
- **indirect or passive water take** which refers to water that occurs in aquifers or connected rivers that are not directly excavated by the mining activities, but are predicted to experience some reduction in flow volume due to drawdown generated by the adjacent mining activity; and
- **consumptive water take** which occurs when water is pumped directly from a water source via bores in aquifers or pumps in rivers.

A water licence is required to account for all water taken incidentally, passively or consumptively. The sections below provide the predictions of incidental and passive water take. No groundwater is proposed to be extracted from water supply bores for consumptive use for the Project. The Water Assessment report contains information on water licensing strategy for the Project.

8.3.1 Incidental (direct) water take

Figure 8.4 shows the predicted volumes of groundwater that will incidentally enter the mine workings at HVO North and HVO South over the life of the mines for the approved operations and the Project. This includes all groundwater intercepted in all the open cut mining areas and the Lemington Underground, either through pit dewatering, excavation of material with entrained water storage, or evaporation. It does not reflect the water management requirements in the open cut operations. The total incidental water take for the Project peaks during Year 16 at 2,133 ML, then reduces after mining at HVO South ceases in Year 21. Predicted water take volumes are tabulated within the modelling report included as Appendix D.

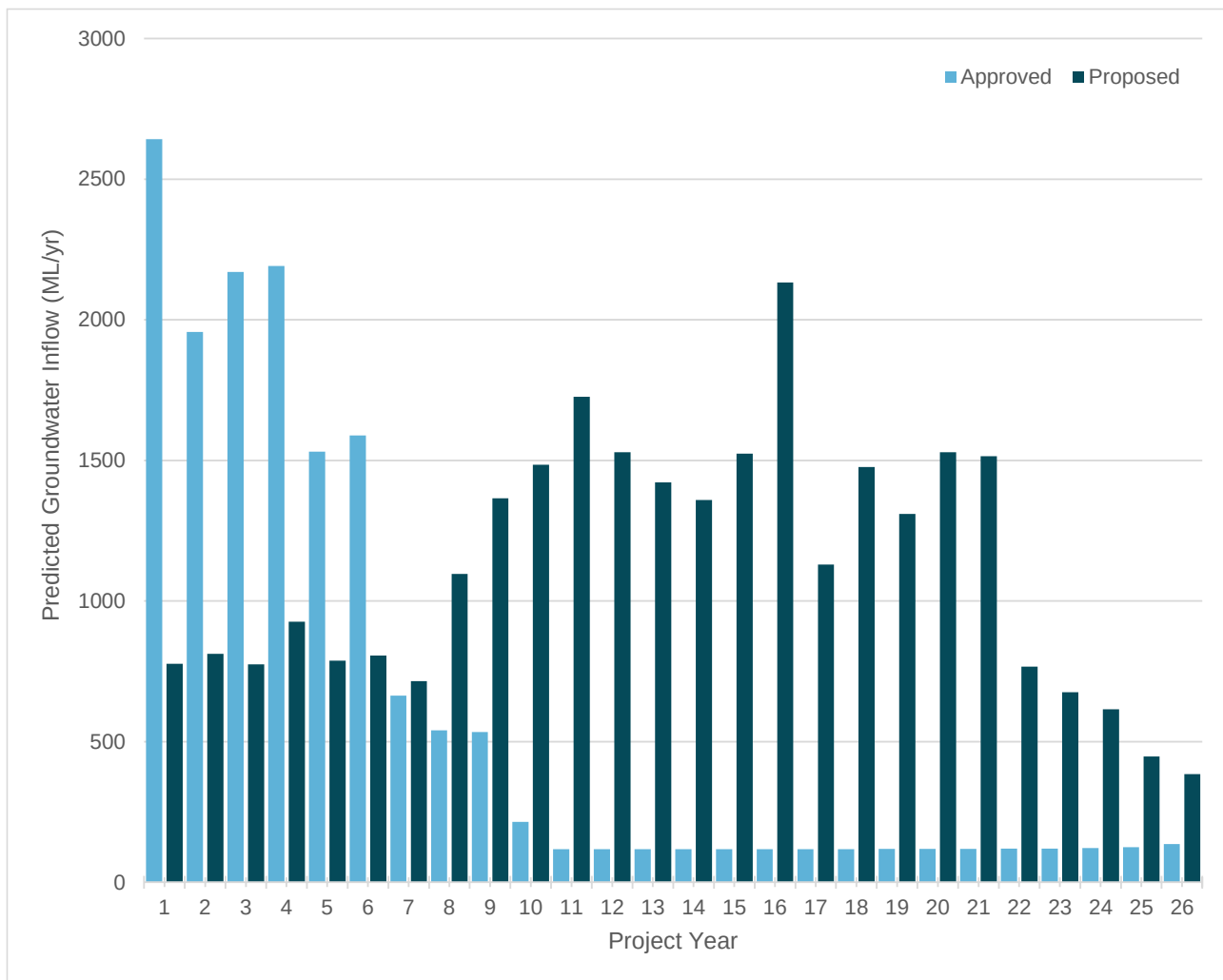


Figure 8.4 Predicted groundwater inflow to open cut mining areas

8.3.2 Groundwater surface water interactions (indirect take)

The numerical model was used to provide a prediction of the changes in groundwater flows to the alluvial aquifers and connected surface water. The modelling indicates that as the Permian strata becomes depressurised due to the Project the volume of groundwater flowing from the Permian to the adjacent Quaternary alluvium progressively reduces. This process reduces the volume of groundwater entering the Quaternary alluvium, as well as the piezometric surface under the alluvium. This creates steeper hydraulic gradients between the Quaternary alluvium and the underlying Permian resulting in a slight lowering of groundwater levels within the Quaternary alluvium, as well as reducing connected river baseflow and increasing river leakage. The predicted localised drawdown induced by this process is described in Section 8.2. The changes in flow occurring within each WSP area and water source are provided in Appendix D.

The predicted flow changes tabulated in Appendix D indicate the decrease in groundwater flow from the Permian bedrock into the Quaternary alluvium, creates a proportional reduction in baseflow in the connected surface waters of Hunter River and Wollombi Brook. This occurs because the main discharge zone for groundwater within the Quaternary alluvium is as baseflow to the surface water courses.

The most significant reduction in baseflow is predicted to occur in the area between HVO North and South, this is simply because mining associated with the Project is located immediately adjacent to this zone. A lesser reduction is predicted for the Wollombi Brook area as it is more distant from the mining areas. The reduction in baseflow also creates an increase in the rate of leakage from the surface water systems to the underlying groundwater regime, which is a response to slightly lowered groundwater levels. Modelling estimates of the increases in river leakage are also tabulated in Appendix D.

The EIS Surface Water Impact Assessment Report (Engeny 2022) addresses the impact of changes to baseflow and leakage on total streamflow for each relevant watercourse. The Water Assessment Report (EMM 2022c - Appendix K of the EIS.) outlines the water licensing strategy for the predicted take of groundwater and connected surface water due to the Project.

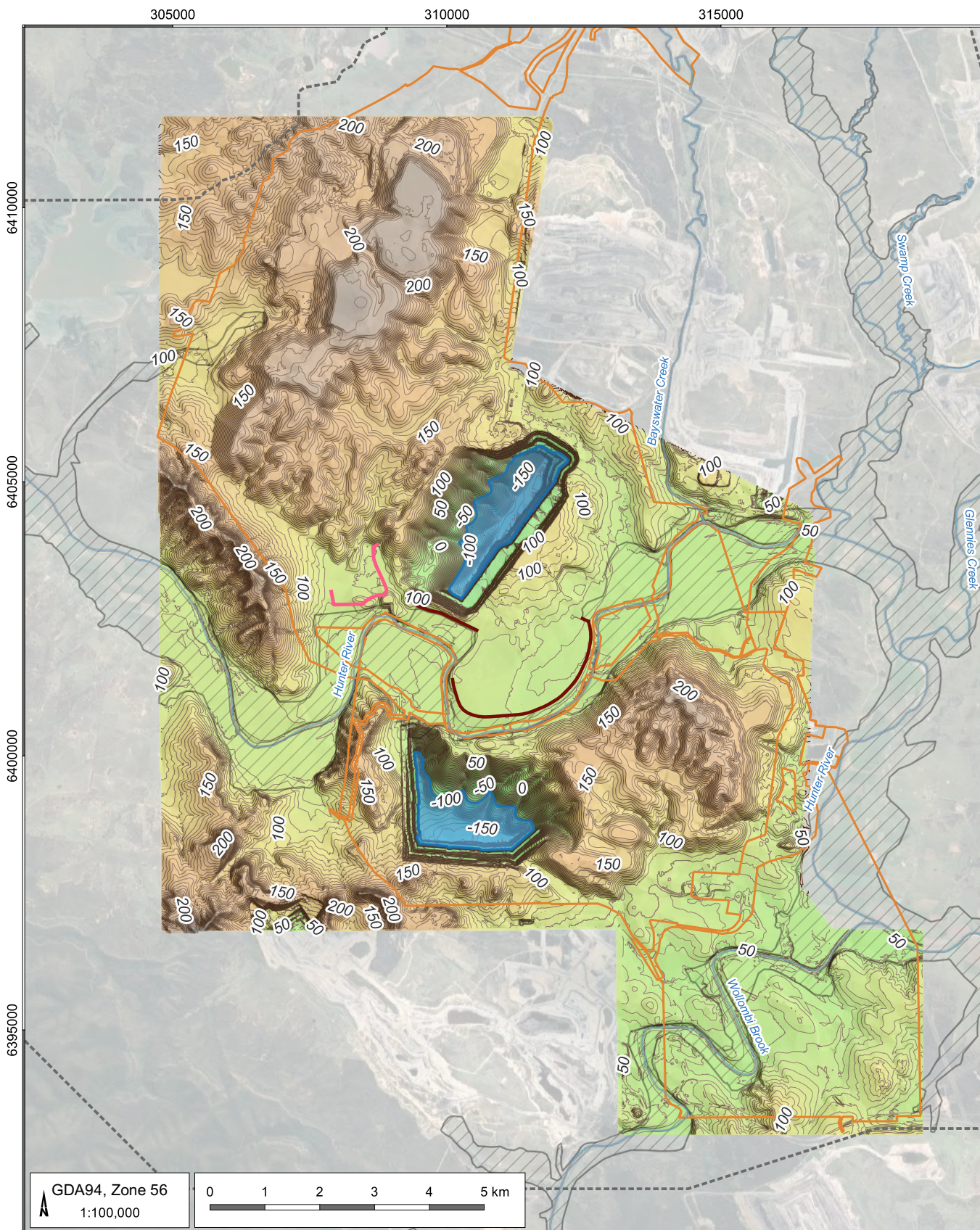
9 Post mining recovery

Post mining conditions were simulated using the numerical model to determine how the final void lakes associated with the Project would interact with the groundwater systems. Appendix D 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.

9.1 Void lake water levels

At the completion of mining, a final void will remain at HVO North and HVO South (see Figure 9.1). These voids will slowly fill with water over time forming void lakes within the rehabilitated final landform. The equilibrium water level within the final void lakes will be a function of the water inputs and outputs. Inputs to the void lakes will occur from direct rainfall to the void lake surfaces, runoff from the catchments, groundwater inflow through spoils, and groundwater inflow through undisturbed geological units. Outflow will occur via evaporation from the void lake surfaces.

Engeny (2022) used a water balance model to assess the rate of water level recovery and the final equilibrium level within the final void lakes at HVO North and HVO South. The predicted water level recovery is shown in Figure 9.2. The water balance model indicated the water level within the final voids will slowly recover over a period of approximately 600 years stabilising at approximately -80 mAHD. The surface area for the void lakes is predicted to be 212 ha for HVO North and 182 ha for HVO South. The stabilised water level within the final voids is about 165 m below the HVO North Pit crest and 150 m below the HVO South Pit crest, forming a final void lake about 110 m deep at HVO North and 80 m deep at HVO South.



LEGEND

- Drainage
- Barrier Wall
- Existing barrier wall
- Final Landform contour
- Project Area
- Alluvium extent
- Model boundary
- Final lake void

Final landform (mAHD)

- 195
- 100
- 100
- 150
- 200
- 250

HVO Continuation (G1737J)

Final landform and void lakes



AGE

DATE
04/11/2022

FIGURE No:
9.1

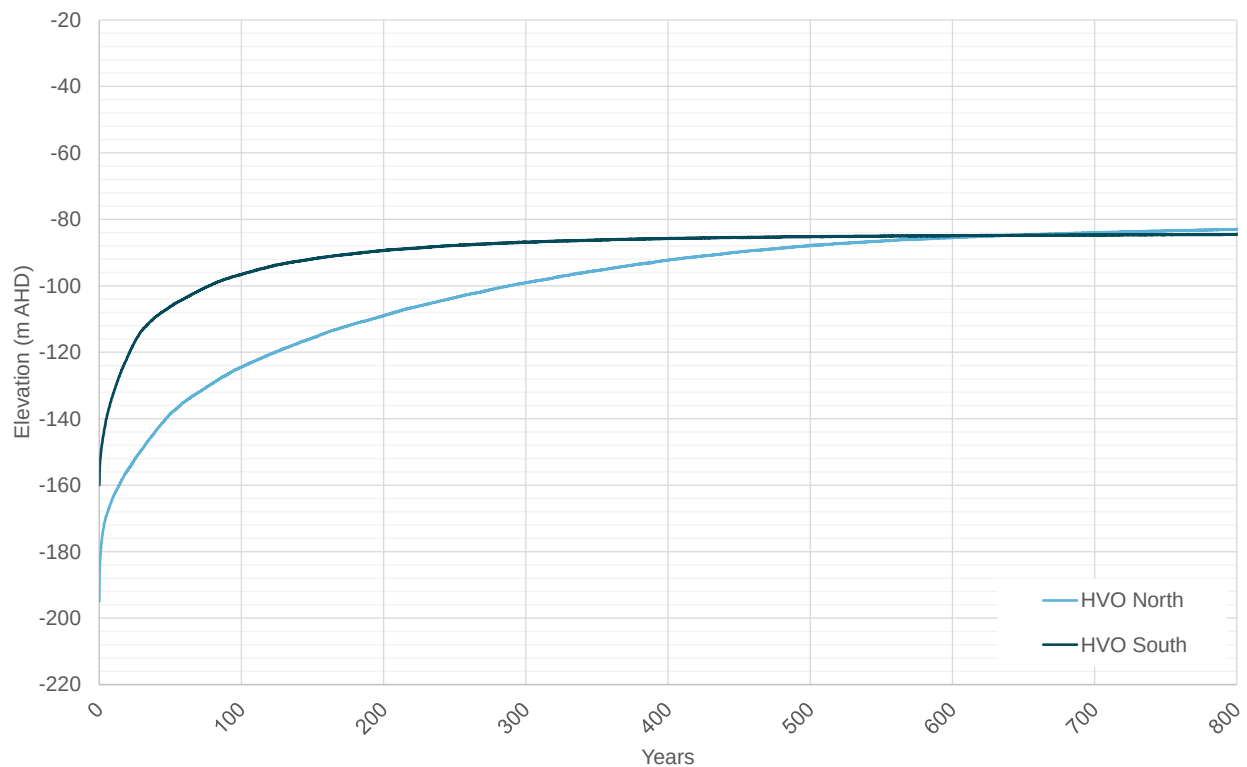
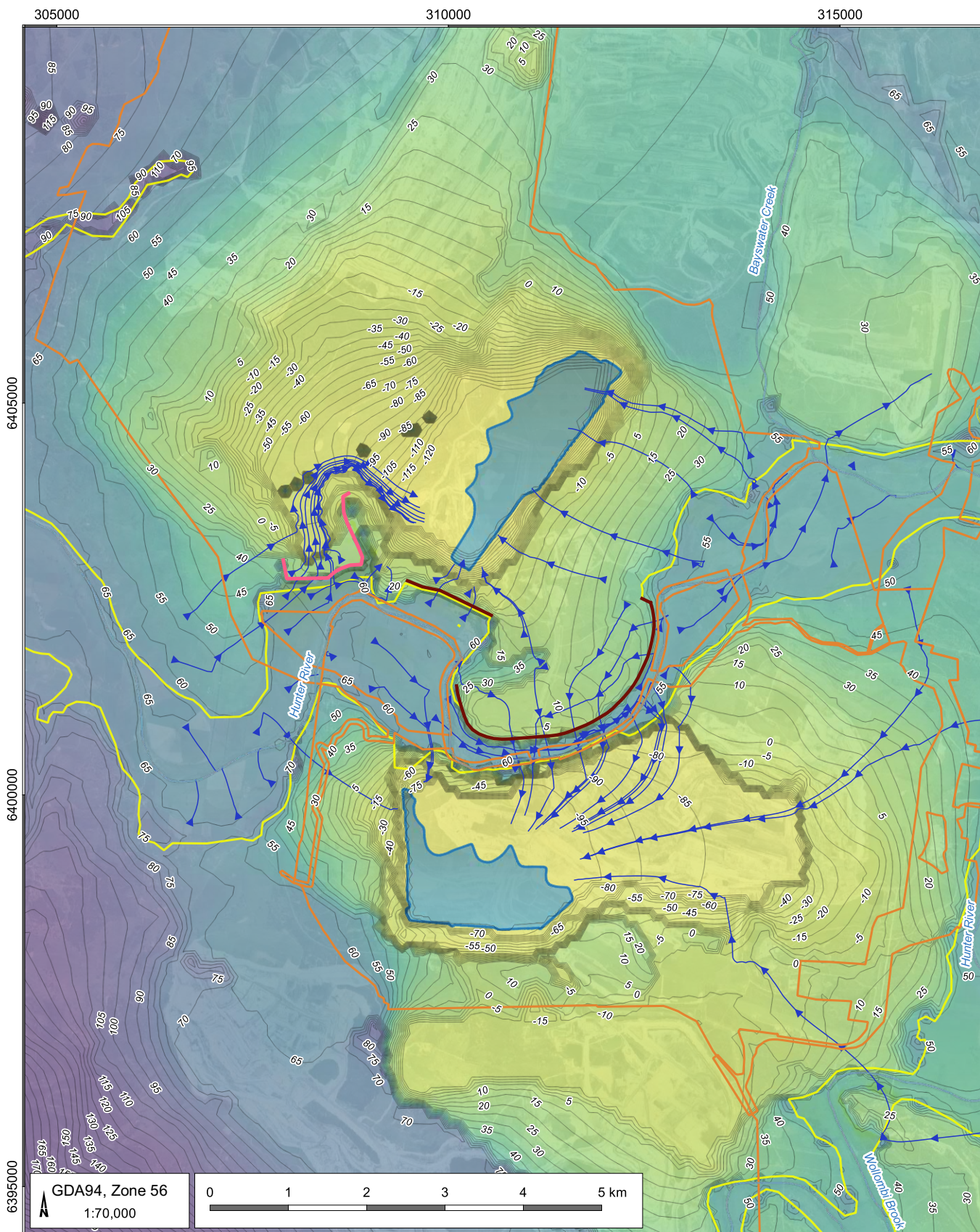


Figure 9.2 Simulated water level recovery in void lakes (Engeny 2022)

9.2 Water levels and flow direction

The void lake level recovery predicted by the water balance model was represented in the groundwater flow model as a series of fixed heads rising over time. The numerical flow model was then used to simulate recovery within the groundwater regime over a period of 1000 years. Figure 9.3 shows the simulated water table at 100 years after closure of HVO North. It also shows the flow path for particles released into the water table at mine closure in 2050. The figure shows the final voids in HVO North and HVO South act as sinks, with groundwater flow into the lakes, not outwards. This prediction is to be expected as the water levels within the final voids are well below groundwater levels within the rock mass surrounding the final voids.



AGE

DATE
02/11/2022

FIGURE No:
9.3

9.3 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, 2022) indicates the evaporation from the lake surface will concentrate salts in the pit lake slowly over time, with the pit lake salinity rising about 1000 mg/L to 1500 mg/L every 100 years within the final void lakes. The water within the void lakes will become brackish to saline 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.

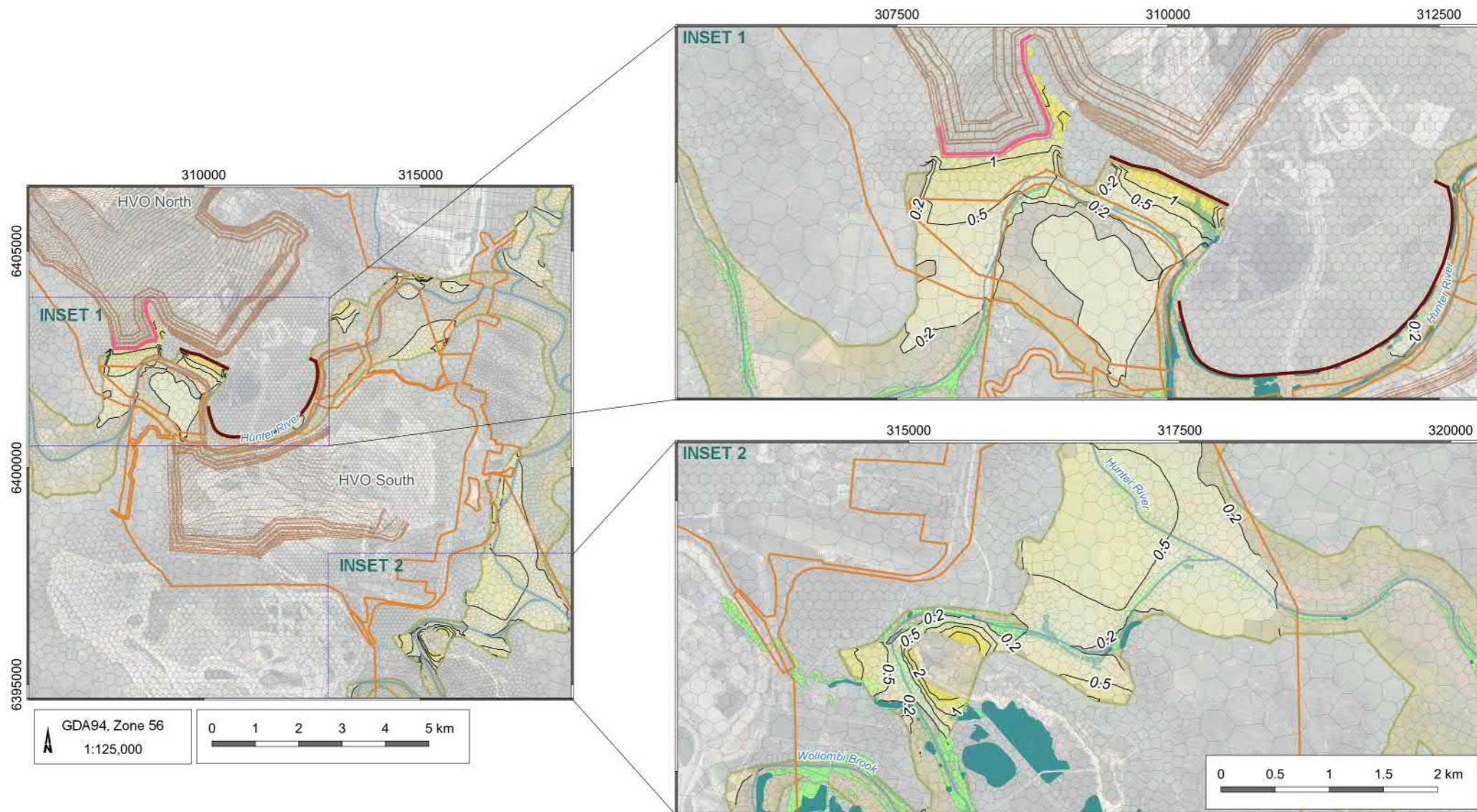
The gradually increasing salinity will not pose a risk to highly connected surface water sources as the final void will remain a permanent sink with an inward hydraulic gradient between the mine and the surrounding Permian strata. This will mean that the evapo-concentrated salt will remain within the final void lake and therefore will not affect the beneficial use category of groundwater or the long-term average salinity in surface waters. Water within the backfilled mine areas (including spoils) will also report to the final void lakes. The reduced groundwater flow from the Permian strata to the alluvium is expected to reduce the salt load to the Hunter River and Wollombi Brook potentially resulting in an overall improvement in groundwater quality within the alluvium, despite the minor decline in quantity.

There is no predicted change to the water quality or beneficial use category of the alluvial groundwater or connected surface water sources.

9.4 Water table drawdown

Figure 9.4 shows the maximum cumulative drawdown predicted to occur within the Hunter River alluvium and the Wollombi Brook alluvium after closure of the Project. The figure shows maximum drawdown is predicted to remain in the same general locality as predicted during operations but will expand slightly in area. This is due to the influence of the continuing evaporative pumping effect from the final voids post mining whilst the groundwater regime reaches a new equilibrium.

Figure 9.5 shows the incremental drawdown predicted to occur within the Hunter River alluvium and Wollombi Brook alluvium after closure of the Project. As noted in Section 8.2, this drawdown is calculated by comparing the drawdown predicted by the “proposed” model scenario that includes all approved and proposed mining activities, with an “approved only” scenario where only approved mining is represented. Figure 9.5 shows the post mining incremental drawdown within the Hunter River alluvium is relatively limited and occurs primarily along the alignment of the barrier wall, indicating similar long term impacts for the proposed and approved operations. In contrast there is no additional incremental drawdown predicted to occur within the Wollombi Brook alluvium in the area of the South Lemington Pit 1 as mining is being reduced, not increased in this area with the South Lemington Pit 1 and 2 open cut mining both being removed from the Project. There is a predicted zone of incremental drawdown to the east of HVO South along the fringe of the Hunter River alluvium, and at the confluence Hunter River and Wollombi Brook. This is attributed to the subcrop of Permian Mt Arthur coal seams under the Hunter River alluvium in this area.



LEGEND

- Drainage
- Pit Shell contour
- Existing barrier wall
- Barrier Wall
- Drawdown contour
- Model grid
- Alluvium extent
- Project Area
- Potential GDEs - from project study area
- High potential terrestrial GDE - from regional studies

Drawdown (m)

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

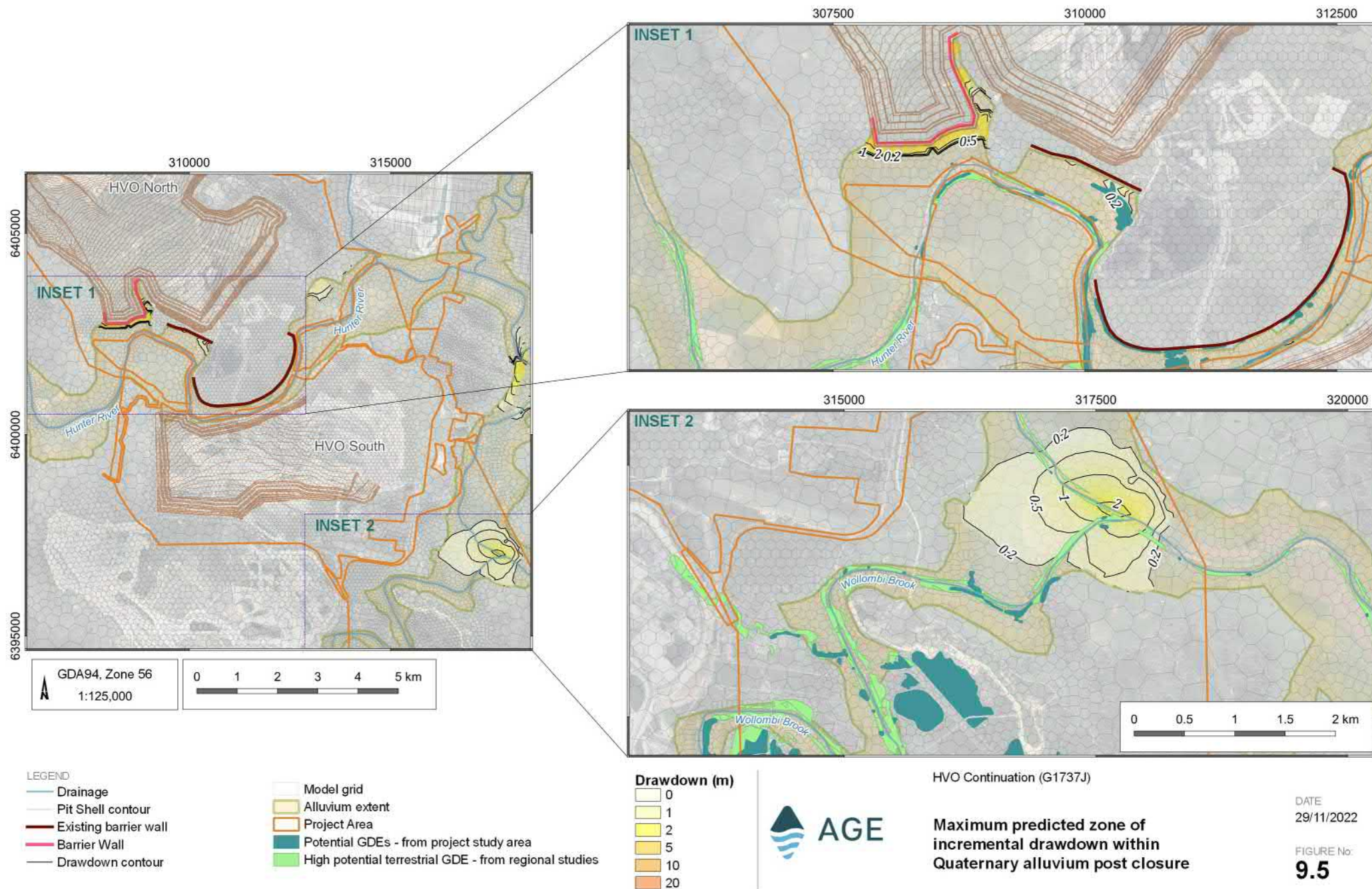


HVO Continuation (G1737J)

Maximum predicted zone of cumulative drawdown within Quaternary alluvium post closure

DATE
29/11/2022

FIGURE No:
9.4



9.5 Changes in groundwater flow post mining

Post mining, it was assumed there will be no active pumping from the open cut mine workings and therefore no consumptive take. There will however be changes in groundwater flow to the adjacent alluvium and connected surface water due to the evaporative pumping effect created by the final void lakes. The numerical model indicates the evaporative pumping effect of the void will stabilise at between about 1,200 ML/year and 1,300 ML/year. The impact of this process will be a zone of residual drawdown in groundwater levels within the adjacent alluvium as described in Section 9.4.

The evaporative pumping effect and associated drawdown will change groundwater flow to the adjacent Quaternary alluvium. The changes in flow occurring within each WSP area and water source are provided in Appendix D. The mechanisms are the same as described in Section 8.3 whereby reduced flow from the Permian to the alluvium results in reducing baseflow and increasing leakage from the Hunter River and Wollombi Brook. The modelling indicates baseflow in the Hunter River is predicted to gradually reduce after mining and stabilise about 200 years post mining as a new equilibrium condition becomes established in the groundwater regime. An increase in the river leakage rate is also predicted due to the predicted downward gradient created by Permian depressurisation. The EIS Surface Water Report (Engeny 2022) addresses the impact of changes to baseflow and leakage on total streamflow in each relevant watercourse. The Water Assessment Report (EMM 2022c - Appendix K of the EIS.) outlines the water licensing strategy for the predicted take of groundwater and connected surface water due to the Project.

10 Predictive uncertainty analysis

The uncertainty in the model predictions introduced by model parameters was assessed using a nonlinear uncertainty analysis where numerous model parameters were changed at the same time. Appendix D presents the results of the uncertainty analyses. An uncertainty analysis involved changing model parameters to create 93 model realisations. A separate sensitivity analysis was also undertaken to assess the influence of climate change. The results of the uncertainty analysis did not indicate any impact to third party bores and displayed only minor changes to the predicted extent of cumulative alluvial drawdown. The extent of drawdown in GDE areas (river red gums) also reported minor changes, with no significant changes predicted in the extent of saturation within the Quaternary alluvium.

11 Groundwater monitoring and management plan

HVO has an existing WMP prepared to address the consent conditions and describes the groundwater monitoring processes for determining:

- water take from water sources;
- effectiveness of the low permeability barrier walls;
- impacts on private groundwater bores;
- impacts on GDEs;
- seepage/leachate from water storages;
- alluvial lands area management; and
- validation of the groundwater model.

The WMP will be updated in consultation with DPE Water to ensure the impact of the Project is effectively monitored and where necessary mitigated.

11.1 Water take from water sources

Direct measurement of water take is not possible in the geological setting of the Project area. This is because groundwater inflow rates are low, and not all groundwater intercepted by the mining activities reports to sumps for pumping. A significant proportion of groundwater intercepted by the mining activities evaporates from the pit face, or is entrained in coal or spoils, later being lost to evaporation. Indirect water take from adjacent alluvial aquifers also cannot be directly measured, only inferred from groundwater level changes.

Under the WMP leakage of groundwater from the target coal seams and alluvial aquifers is estimated on an annual basis with the results provided in the Annual Review. Two methods are utilised to estimate the direct and indirect water take. An operational water balance is used to estimate the volume of groundwater pumped from active mining areas, whilst the groundwater flow model is used to provide estimates of the total direct and indirect takes from Quaternary alluvium and Permian groundwater regime. This process will continue to provide appropriate estimates of water take over the Project life.

11.2 Groundwater monitoring network

HVO has established a substantial network of groundwater monitoring and testing bores to monitor groundwater levels and quality at HVO. The network is monitored in accordance with Appendix D of the WMP. Monitoring activities include:

- groundwater level monitoring;
- field water quality measurement: pH and EC;
- submission of water quality samples for laboratory analysis, which includes:
 - standard analytical suite:
 - TDS,
 - calcium, chloride (Cl), carbonate (CO₃), potassium (K), magnesium (Mg), sodium (Na), sulfate (SO₄), and alkalinity (total, carbonate, bicarbonate and hydroxide); or
 - aluminium (Al), arsenic (As), boron (B), cadmium (Cd), copper (Cu), mercury (Hg), magnesium (Mg), nickel (Ni), lead (Pb), selenium (Se), zinc (Zn); or
 - alternate analytical suite:
 - TDS,
 - Al, As, B, Be, Ca, Cd, Cl, CO₃, Co, Cu, F, Fe, Hg, K, Mg, Mn, Na, Ni, rubidium (Rb), antimony (Sb), Se, SO₄, silicon dioxide (SiO₂), strontium (Sr), Zn, and alkalinity (total, carbonate, bicarbonate and hydroxide);
 - ammonia (NH₃), nitrite (NO₂), nitrate (NO₃), phosphorus (P), Pb,
 - or alkalinity/acidity.

Drawdown impacts predicted to occur due to the Project occur in an area of the Hunter River alluvium south of the Carrington West Wing barrier wall where the existing groundwater monitoring network is currently limited. It is proposed additional monitoring bores will be installed within the zone of predicted drawdown to monitor impacts in this area. A network of eight nested monitoring bores will be installed in this area, with separate bores screened with the Quaternary alluvium and Permian strata. The locations and designs will be determined in consultation with the DPE – Water during updates to the WMP. Indicative locations are provided on Figure 11.1. The additional monitoring sites will be equipped with electronic water level loggers to provide daily measurements of groundwater level behaviour over time in response to mining and climatic and river conditions. The bores will be installed approximately one year prior to mining commencing in the remnant palaeochannel to allow collection of background groundwater level trends prior to the effects of mining.

A network of monitoring bores already exists along the Wollombi Brook where cumulative drawdown is predicted due to the extraction from the Lemington Underground, and no additional monitoring sites are likely to be necessary in this location.

Results of the groundwater monitoring at HVO are reported in the Monthly Environmental Monitoring Report, Annual Review and to the Community Consultative Committee (CCC).

11.3 Performance criteria and trigger levels

Trigger values are provided within the GWMP as a measurable basis for identifying adverse water related impacts and are the basis on which to consider implementing contingency measures, provided there is a large enough data set for statistically robust values. Key analytes with triggers specified are;

- pH (acidity / alkalinity)
- EC
- Total Suspended Solids (TSS).
- Standing Water Level (SWL) (specific groundwater sites only)

In the absence of licence or applicable ANZG (2018) criteria, the 95th percentile of the available validated data record for a monitoring station is adopted as the basis for a water quality management guideline trigger value. The calculated trigger values are incorporated into quarterly reviews of monitoring data. Specific groundwater impact assessment criteria are also derived and give consideration to minimal impact considerations in the AIP. Performance against these assessment criteria is reported in the Annual Review. The performance criteria and the trigger levels will be reviewed and updated when the GWMP is updated, and the low permeability barrier (LPB) monitoring and management plan (MMP) is prepared (refer Section 11.6).

11.4 Private water supply bore monitoring

It is not anticipated the Project will result in any unreasonable loss of groundwater yield at existing privately owned water bores in the local area. The existing network of groundwater monitoring bores, covering both the coal seams and the alluvium, is expected to be sufficient to ascertain whether a change in groundwater level at a private water bore could be attributed to the HVO operation.

11.5 Impacts of Groundwater Dependent Ecosystems

GDEs with the potential to be affected by the Project are limited to river red gum stands along the Hunter River and Wollombi Brook. It is not anticipated that groundwater drawdown as a result of the Project will result in stress to the associated vegetation communities (refer Appendix M of the EIS). Whilst the species utilises shallow groundwater that is recharged by surface water leakage, it relies on flooding regimes for recruitment. Current flooding regimes are not predicted to be significantly affected as a result of the Project (Engeny 2022).

The HVO River Red Gum Rehabilitation and Restoration Strategy outlines the management and monitoring regime to ensure these communities are maintained. The HVO River Red Gum Rehabilitation and Restoration Strategy (HVO 2022) stipulates that groundwater monitoring data will be made available to the persons undertaking the ecological monitoring in order to assess the impact that fluctuating groundwater levels may have on the health of the Carrington Billabong and the Priority Sites listed in the strategy document.

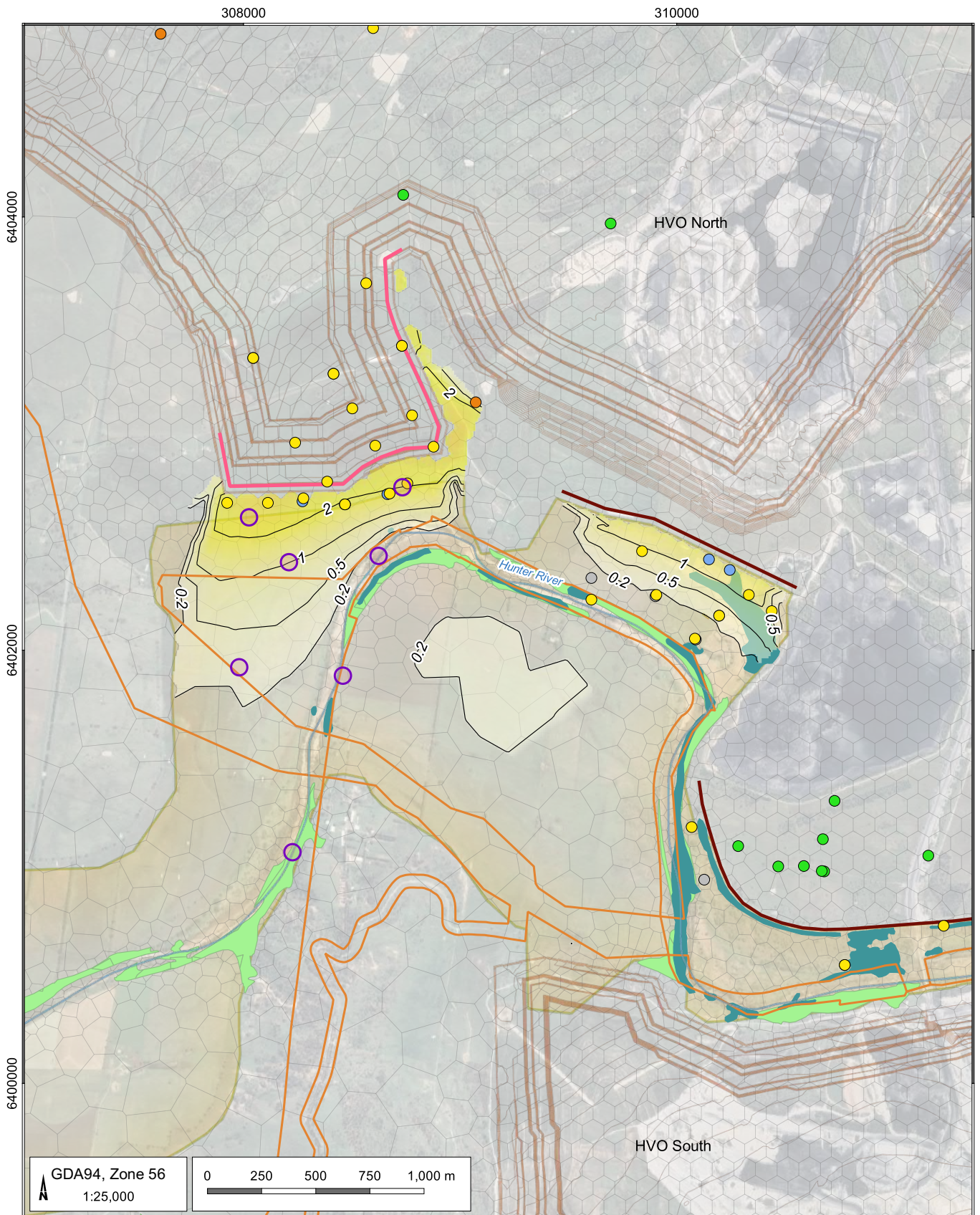
11.6 Effectiveness of low permeability barrier

A low permeability barrier (LPB) monitoring and management plan (MMP) for the Carrington West Wing barrier wall will be prepared in consultation with DPE – Water, including development of appropriate level and quality triggers to allow early warning of potential impacts that differ to those predicted. This will involve development of a trigger action response plan, identifying contingencies and mitigation measures to manage potential impacts greater than predicted.

Performance of the existing Carrington Pit and Alluvial Lands Barriers is assessed regularly through a series of piezometers along the length of the barriers and reported in the Annual Review.

11.7 Numerical model validation

Every three years HVO conducts an independent review of the groundwater model. This includes validation of the model predictions against observed water take and groundwater level changes. If the review indicates observations divergence significantly from the model predictions, the model will be updated and forward predictions reassessed. The years for these reviews are based on the dates of the latest Environmental Assessments where the groundwater models were reviewed.



LEGEND

- Drainage
- Pit Shell contour
- Existing barrier wall
- Barrier Wall
- Drawdown contour
- Model grid
- Alluvium extent
- Project Area
- Potential GDEs - from project study area
- High potential terrestrial GDE - from regional studies

Groundwater monitoring

Quaternary alluvium

- Alluvium
- Regolith
- Spoil

Permian

- Coal seam
- Interburden

○ Indicative location of additional monitoring sites

Drawdown (m)

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

HVO Continuation (G1737J)

Indicative additional groundwater monitoring sites



AGE

DATE
17/11/2022

FIGURE No:
11.1

12 References

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Appendix A

Field investigation report

HVO Field Investigation Program

A 1 Introduction

The fieldwork program included the:

- installation of five vibrating wire piezometers (VWPs);
- installation of one monitoring bore;
- permeability testing (rising/falling head and packer testing); and
- core sampling.

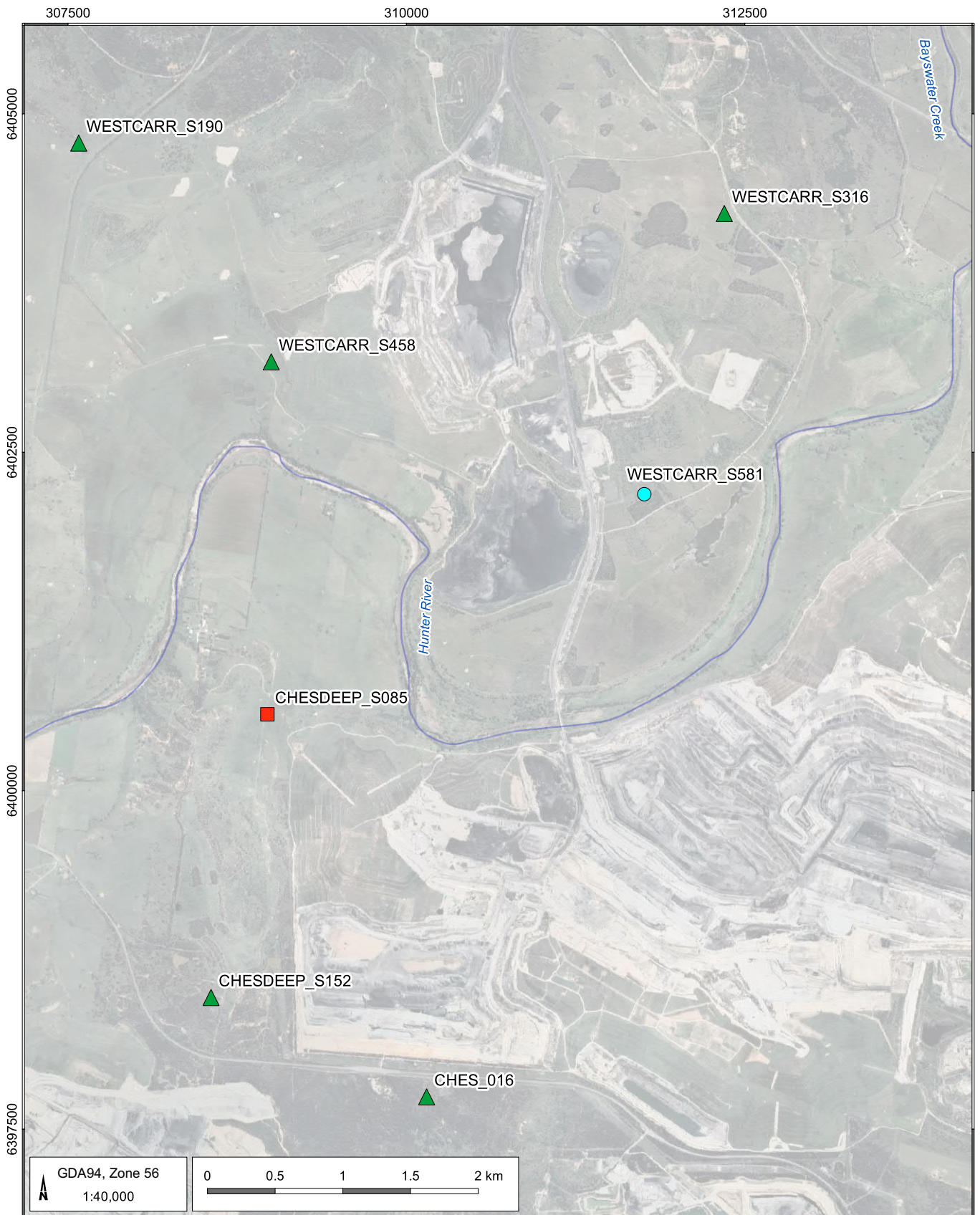
This report summarises the results of the fieldwork program, completed between December 2019 and September 2020.

A 2 Drilling and monitoring network

The VWP, monitoring bore and core/packer test hole locations are shown on Figure A 2.1. Monitoring network locations and details are summarised in Table A 2.1.

The field program involved drilling at seven sites at HVO and:

- installing vibrating wire piezometers at:
 - three locations at HVO North (WESTCARR_S190, WESTCARR_S316, WESTCARR_S490);
 - two locations at HVO South (CHES_016, CHESDEEP_S152).
- installing a monitoring bore at CHESDEEP_S085;
- conducting packer testing in WESTCARR_S581; and
- collecting core samples from WESTCARR_S581 for density laboratory measurement of permeability, and specific storage.



LEGEND

— Drainage

Hole locations

- ▲ Vibrating wire piezometer
- Monitoring bore
- Core/packer

HVO Groundwater Program - Stage 1 (G1810B)

WWP & monitoring bore locations



AGE

DATE
17/11/2022

FIGURE No:
A 2.1

Table A 2.1 Monitoring network locations and details 2 Monitoring network locations and details

Hole ID	Easting (GDA94 z56)	Northing (GDA94 z56)	Ground elevation (mAHD)	PVC collar elevation (mAHD)	Total depth (mBGL)	Works type	Target strata	Completion date
CHES_016	310272.81	6397794.35	139.91	-	337	VWP	Regolith, Woodlands Hill Seam, Bowfield Seam, Piercefield Seam, Bayswater Seam	06/07/2020
CHESDEEP_S152	309206.05	6398449.68	119.97	--	284	VWP	Regolith, Woodlands Hill Seam, Warkworth Seam, Piercefield Seam, Bayswater Seam	07/05/2020
WESTCARR_S190	307616.82	6404845.55	87.68	-	140	VWP	Regolith, Upper Arties Seam, Barrett Seam	23/01/2020
WESTCARR_S316	312352.96	6404162.08	92.59	-	350	VWP	Regolith, Bayswater Seam, Upper Arties Seam, Barrett Seam	21/09/2020
WESTCARR_S458	309071.91	6403144.36	69.40	-	248	VWP	Regolith, Bayswater Seam, Lemington Seam, Upper Arties Seam, Barrett Seam	19/12/2019
CHESDEEP_S085	309125.14	6400440.48	73.96	74.94	146.7	Monitoring bore	Bayswater Seam	24/04/2020
WESTCARR_S581	311719.32	6402152.47	69.00	-	349	Packer testing only – no permanent installation	Barrett Seam	20/08/2020

Notes: GDA94z56: Geocentric Datum of Australia 1994, zone 56.

mAHD: metres Australian Height Datum.

mBGL: metres Below Ground Level.

Completion date: For monitoring bore refers to the date by which construction and development were completed. For VWP's this refers to the date the borehole was grouted back to surface. For packer testing this refers to the date on which the final packer test was completed.

A 2.1 VWP drilling and installation

The function of a VWP is to measure the pore water pressure of a target stratum. Typically, a VWP is embedded in a borehole sealed with bentonite grout. The depth of the VWP is indicative of the representative stratum. The benefits of installing a nested VWP are that multiple piezometers can be installed in one hole and to greater depths than a conventional standpipe monitoring bore.

A piezometer operates by converting water pressure to a frequency signal. This is achieved when an electromagnetic coil in the instrument vibrates a wire element connected to a diaphragm. A change in the wires natural frequency signal is detected and recorded in a data logger installed at the surface.

All VWPs were drilled with biodegradable, inert polymers using the mud rotary drilling technique. Each VWP borehole was drilled with a PQ size polycrystalline diamond bit (PCD) and reamed out to 152 mm hole diameter.

All VWP boreholes were geophysically logged prior to instrumentation installation. The proposed sensor intervals were revised to reflect observed geology from the geophysical survey. All sensor depths were based on strata and coal seam picks provided by HVO.

Prior to commencing each VWP installation:

- all piezometers were checked; and
- the initial calibrated pressure value in kilopascals (kPa) of each piezometer was recorded.

VWP targets, installation depths and pre-installation sensor results are summarised in Table A 2.3.

Sensor depths were double checked in the field prior to installation by writing the VWP ID, installation depth, serial number, and date on duct tape. An example of the duct tape labels and sensor serial numbers is presented in Figure A 2.2.

The VWP arrays were constructed on the surface and consisted of two tremie lines for grouting, with piezometers and cables attached by duct tape, and a weighted object (usually a star picket) taped to the end to balance and straighten the array. The array was then lowered down the hole and suspended with a sling from the wireline on the rig prior to grouting.

Grout was prepared on site and mixed in open top rainwater tanks using the manufacturer's recommended ratios for VWP installations. An example VWP grout batch is shown in Figure A 2.3. Table A 2.4 lists the material quantities used to mix the grout slurry for each individual VWP. An additional 10% grout was prepared in excess of the calculated total bore volume to allow for loss to formation.

Each VWP borehole was grouted through the tremie lines to which the sensors were taped to, with all piezometers and geological units sealed to prevent vertical water movement and cross aquifer contamination within the borehole. Top up grout batches were mixed by hand and delivered around the tremie lines from surface where required. After each grout batch, the VWP sensors were connected to a data logger to check functionality and to ensure all sensors were grouted in place.

Table A 2.3 VWP targets and installation depths

VWP ID	Sensor no.	Target strata	Installation depth (mBGL)	VWP sensor serial no.	Brand	Pressure rating (kPa)	Pre-install check
CHES_016	1	Regolith	37	S3043	HMA	700	Pass
	2	Woodlands Hill Seam	94	S2888	HMA	2,000	Pass
	3	Bowfield Seam	129	S2891	HMA	2,000	Pass
	4	Piercefield Seam	236	S3077	HMA	5,000	Pass
	5	Bayswater Seam	307	S3080	HMA	5,000	Pass
CHESDEEP_S152	1	Regolith	47	S3042	HMA	700	Pass
	2	Woodlands Hill Seam	59	S2913	HMA	1,000	Pass
	3	Warkworth Seam	122.5	S3122	HMA	3,000	Pass
	4	Piercefield Seam	181.5	S3124	HMA	3,000	Pass
	5	Bayswater Seam	273	S3078	HMA	5,000	Pass
WESTCARR_S190	1	Regolith	32	S3046	HMA	700	Pass
	2	Upper Arties Seam	84	S2887	HMA	2,000	Pass
	3	Barrett Seam	132	S2890	HMA	2,000	Pass
WESTCARR_S316	1	Regolith	36	S3045	HMA	700	Pass
	2	Bayswater Seam	101.5	S2886	HMA	2,000	Pass
	3	Upper Arties Seam	217.5	S3125	HMA	3,000	Pass
	4	Barrett Seam	323	S3079	HMA	5,000	Pass
WESTCARR_S458	1	Regolith	30	S3044	HMA	700	Pass
	2	Bayswater Seam	68	S2914	HMA	1,000	Pass
	3	Lemington Seam	107	S2889	HMA	2,000	Pass
	4	Upper Arties Seam	164	S3123	HMA	3,000	Pass
	5	Barrett Seam	229	S3076	HMA	5,000	Pass

Notes: mBGL: metres Below Ground Level.

Table A 2.4 VWP grout mix summary

VWP ID	Water (L)	Cement (kg)	Bentonite (kg)	Total grout volume (L) (10% contingency)
CHES_016	5,845	2,195	584	6,762
CHESDEEP_S152	4,926	1,850	492	5,699
WESTCARR_S190	2,428	912	242	2,809
WESTCARR_S316	6,071	2,279	606	7,023
WESTCARR_S458	4,301	1,615	430	4,976

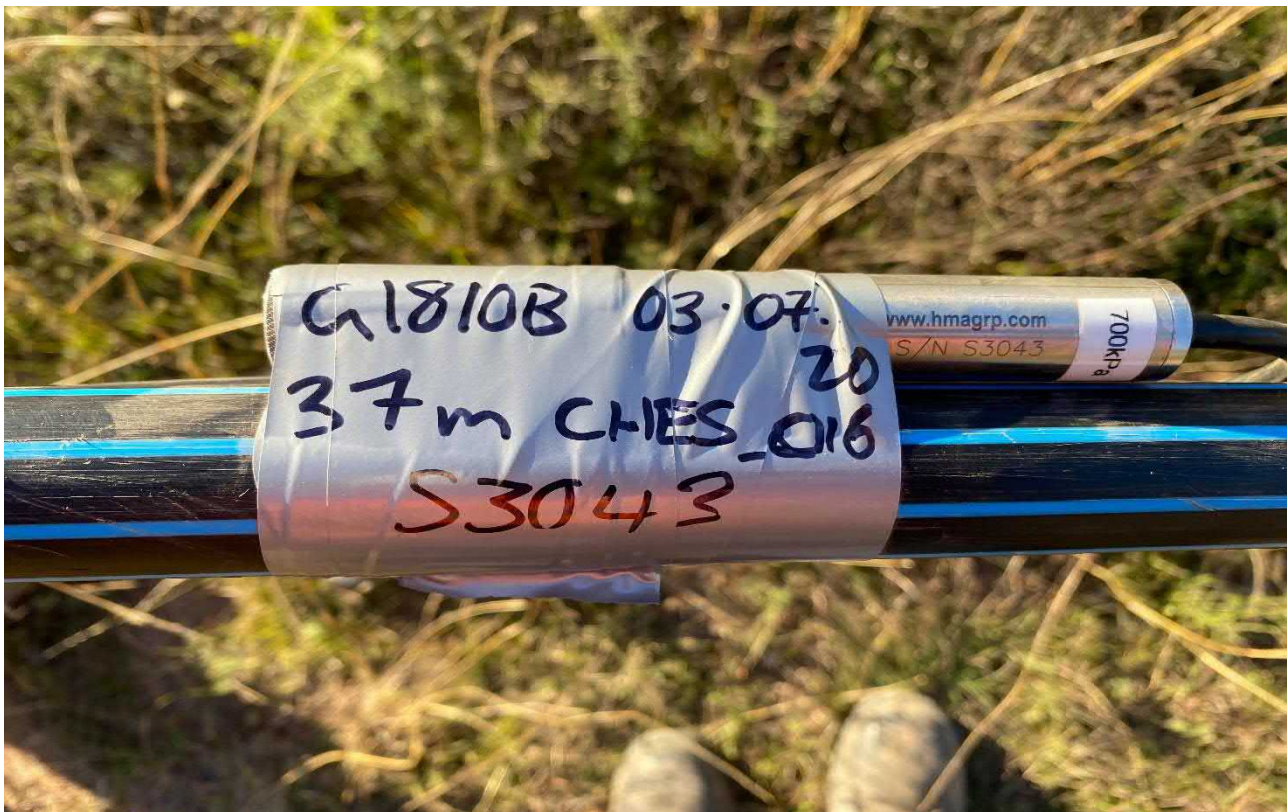


Figure A 2.2 VWP sensor marked up prior to installation



Figure A 2.3 VWP grout mix consistency (VWP CHES_016 grout mix shown)

A 2.2 VWP telemetry installation

An Ontoto brand telemetric data logger was connected to each VWP array following grouting. The data logger is housed inside a steel enclosure that is mounted on a post above the VWPs. During the installation process, the hole was topped up with grout as required, and a cement pad was installed to secure the post. To minimise data errors, the terminals inside each enclosure have been labelled with their serial numbers and installation depths. An example VWP enclosure is shown in Figure A 2.4.



Figure A 2.4 telemetric VWP showing labelled cables (VWP CHESDEEP_S152 shown)

A 2.3 Monitoring bore drilling, installation and construction

Monitoring bore construction conforms to the *Minimum Construction Requirements for Water Bores in Australia* (NUDLC, 2020). One monitoring bore (CHESDEEP_S085) was completed as part of the Stage 1 fieldwork program. This bore was drilled under the supervision of a licensed Class 3 (WaterNSW) driller.

The monitoring bore was drilled with a 152 mm diameter PCD bit using biodegradable, inert polymers via the mud rotary drilling technique. The monitoring bore (and VWP) construction diagrams are shown in Appendix A 1.

The bore was constructed with 50 mm diameter, flush threaded, Class 18 unplasticised polyvinyl chloride (uPVC) casing with threaded joints, O-ring seals and a 1 mm aperture, uPVC machine slotted screen. A gravel filter pack of 3 to 5 mm diameter, washed, rounded, quartz gravel was placed in the annulus to a level above the screened interval.

Bentonite pellets were placed above the filter gravel to seal and hydraulically isolate the screened interval. Material emplacement depth was measured downhole using a tag line. The remainder of the annulus was grouted with a cement, water and 5% bentonite powder slurry using high density polyethylene (HDPE) tremie pipe. Following grouting of the annulus, the bore was airlifted using an air compressor until the bore returned clear water, the gravel pack had been sufficiently developed and fines were purged from the formation.

Headworks and a monument were planned to be installed at the bore; however, a significant amount of subsurface gas was liberated from the hole a short time after development was completed. A continuous stream of gas continued to issue from the monitoring bore months later. For this reason, the bore has since been decommissioned. For the sake of completeness, monitoring bore construction details are shown in Table A 2.5. For the sake of completeness, monitoring bore construction details are shown in Table A 2.5.

Table A 2.5 Monitoring bore construction details – CHESDEEP_S085

Bore ID	Target	Screen depth (mBGL)	Gravel pack (mBGL)	Bentonite seal (mBGL)	Grout seal (mBGL)	Stick up height (m)	Groundwater level (mBGL)	Date of water level
CHESDEEP_S085	Bayswater Seam	132.55-135.55	130.88-136.95	127.95-130.88	0-127.95	0.98	43.42	24/04/2020

Notes: mAHD: metres above Australian Height Datum.
mBGL: metres Below Ground Level.

A 3 VWP data monitoring

A 3.1 Initial configuration

The calibration factors for all VWP sensors were obtained from the HMA VW Piezometer Calibration Certificates. The calibration factors were used to configure the factory pressure and temperature readings for all piezometers with the associated data logger. The data loggers were configured for two VWP pressure and temperature wires for each sensor.

Each data logger was programmed to record piezometer frequencies continuously every 6 hours, on the hour, until the logger is full. The logger will then overwrite the data when the memory is full. Sensor data are stored in flash memory as a backup in the event of telecommunications failure. Long range antennas can be fitted to the VWP enclosures if mobile coverage is intermittent.

Note that the recorded data is a measure of the pore water pressure in “B” units (that convert to Hertz [Hz]), which can then be translated to mH₂O and temperature (°C). The mH₂O data can then be converted into groundwater level elevations (mAHD) using the ground level (collar) and individual sensor depths.

A 4 Aquifer hydraulic testing

A 4.1 Methodology

Hydraulic testing using water injection methods down the borehole, also known as Lugeon testing or Packer testing, allows for estimation of the bulk hydraulic conductivity of the adjacent rock mass. Water is injected at specific pressure 'steps' and the resulting flow rate is recorded when the flow has reached a quasi-steady state condition. The steps are ramped up and down through a calculated pressure range.

Inflatable pneumatic straddle packers were used to test the hydraulic conductivity of multiple lithologies in borehole WESTCARR_S581 (99 mm diameter HQ cored hole). The depth and thicknesses of the test seams in the borehole were determined from the geophysical logs. The geophysical logs and core samples were reviewed to assess wall rock conditions for identifying appropriate locations to seat the packers above and below the targeted strata. The packer was lowered to the assigned depth and inflated to isolate the test intervals. The packer inflation pressure was calculated to ensure an effective seal throughout the test.

Clean water was injected through the drill string in five pressure steps - three increasing steps, followed by two decreasing steps. The constant pressures for each of the steps were calculated as a fraction of the maximum determined test pressure for the downhole interval. For each step, water was injected at a constant pressure and a stabilised flow rate was measured over a 12-minute period. The maximum water pressure was determined so that it did not exceed the rock overloading (confinement) stress at the test depth as this could cause permanent hydro-fracturing which would be detrimental to test results.

A 4.2 Lugeon test results

Five successful lugeon (packer) tests were completed in cored borehole WESTCARR_S581. Successfully targeted intervals include the Pikes Gully Coal Seam, interburden, Lower Barrett Coal Seam, Barrett Coal Seam to end of hole (EOH) and underburden strata. Several other tests were abandoned, due to sub-surface conditions (joints/faults and unsuitable lithology) causing leakage around the packers. Those results are not considered representative and are not presented here.

The borehole interval specifications and inflow rates from the pressure steps were analysed using the 'Aquifer Test Version 9.0' software package (Waterloo Hydrogeologic, 2020) to obtain an estimate of permeability (hydraulic conductivity) for each interval. The results of the software analyses, which provide step pressures, flow rates, flow patterns, calculated Lugeon units and hydraulic conductivity for the 5-step water injection tests are provided in Appendix A 2. The results of the packer tests are summarised below in Table A 4.1.

The test results indicate a wide range of permeability in WESTCARR_S581, with hydraulic conductivity varying from 3.00×10^{-3} m/day (Lower Barrett Seam) to 7.10×10^{-5} m/day (Barrett Seam to EOH). Hydraulic conductivity results for the Pikes Gully and Lower Barrett Seams were within expected ranges (Mackie, 2009). Lower hydraulic conductivity values were observed for the interburden and underburden strata, as well as from the Barrett Seam down to EOH. These observations align with expected hydraulic conductivity values for similar lithologies in the Hunter Valley area (SCT, 2008; AGE, 2017).

Variable Lugeon value flow patterns for the 5 pressure steps were interpreted using the Houlby method (refer Table A 4.1).

The Pikes Gully Seam displayed a dilation type flow pattern. Dilation flow is characterised by similar hydraulic conductivities at low and medium water pressures, with much greater conductivities recorded at higher (or sometimes intermediate) pressures. This behaviour occurs when the water pressure applied is greater than the minimum principal stress of the rock mass, thus causing a temporary dilatancy of the fissures/joints within the rock mass. Dilatancy causes an increase in the cross-sectional area available for water to flow, and therefore increases the hydraulic conductivity.

The Lower Barrett Seam exhibited a turbulent flow pattern. Turbulent flow is characterised by a decrease in rock mass hydraulic conductivity with increasing water pressure. This behaviour is often characteristic of rock masses exhibiting partly open to moderately wide cracks/joints.

The interburden and strata from the Barrett Seam to EOH (primarily sandstone and siltstone) exhibited a void filling flow pattern. Void filling is characterised by decreasing hydraulic conductivities independent of water pressure. Such behaviour indicates that either: (1) water progressively fills isolated discontinuities, (2) swelling occurs in these discontinuities, or (3) fines mobilise into the discontinuities and build up a cake layer that clogs them.

The underburden strata (predominantly sandstone) demonstrated laminar flow conditions. Under a laminar flow pattern, conductivity values are observed to be relatively equal regardless of water pressure. This indicates smooth water passage into target strata, without turbulence and little influence of secondary permeability, providing representative conductivity values of the formation being assessed.

No washout type flow patterns were observed in the test results. Washouts indicate seepage induced hydrofracturing and result in irreparable damage to the rock mass. The results from such test results are artificial and not indicative of in-situ rock mass hydraulic conductivities. The absence of washout type flow patterns in the five successful lugeon tests at WESTCARR_S581 indicate that the hydraulic conductivities obtained are representative.

Table A 4.1 Summary of packer test results – WESTCARR_S581

Test No.	Test date	Test interval (mBGL)	Test zone length (m)	Stratigraphy	Flow pattern	Hydraulic conductivity (m/day)	Hydraulic conductivity (m/s)
5	20/08/2020	218-224	6	MPG/LPG Seam	Dilation	2.60×10^{-3}	3.01×10^{-8}
4	20/08/2020	270.4-275.4	5	Interburden	Void filling	1.20×10^{-3}	1.39×10^{-8}
3	19/08/2020	314-319	5	LLB Seam	Turbulent	3.00×10^{-3}	3.47×10^{-8}
2	19/08/2020	326-347.5	21.5	Barrett to EOH	Void filling	7.10×10^{-5}	8.21×10^{-10}
1	17/08/2020	343-347.5	4.5	Underburden	Laminar	1.92×10^{-3}	2.22×10^{-8}

Notes: m/day: metres per day.
m/s: metres per second.
EOH: end of hole.

A 5 Core testing

Six core samples collected from drillhole WESTCARR_S581 were selected for laboratory analysis of bulk density, permeability and specific storage. Samples were chosen based on composition (sandstone) and depth, with samples selected at regular depth intervals to provide an indicative range of permeability down hole. The lab analysis was completed by Stratum Reservoir in QLD, and the results of testing are detailed in Table A 5.1. Samples were chosen based on composition (sandstone) and depth, with samples selected at regular depth intervals to provide an indicative range of permeability down hole. The lab analysis was completed by Stratum Reservoir in QLD, and the results of testing are detailed in Table A 5.1. The original lab results are attached in Appendix A 3.

Density for the sandstone samples averaged 2.51 g/cm³ over a range of 2.33 g/cm³ to 2.83 g/cm³. Majority of the samples fall within the typical density range of 2.0-2.6 g/cm³ for sandstone (Vitz et al., 2020).

Air permeability values were obtained from six vertical core plugs and six horizontal core plugs. Summary results for WESTCARR_S581 are provided in Figure 6.1 as permeability (milliDarcies [mD]) and as hydraulic conductivity (m/day), which was calculated assuming Darcy is equivalent to 0.831 m/day. Vertical air permeability values range from 3.32×10^{-6} m/day to 3.99×10^{-5} m/day. Horizontal air permeability values range from 3.32×10^{-6} m/day to 5.15×10^{-5} m/day. Horizontal and vertical permeability results are within expected ranges.

Youngs Modulus and Poisson's Ratio were determined via uniaxial compressive strength (UCS) testing. As expected, rock strength increases with depth and correlates strongly with reduced permeability. UCS results are shown in Figure A 5.1 to Figure A 5.7.

Table A 5.1 Sample and results summary WESTCARR_S581

Sample ID	Depth (mBGL)		Lithology	Grain density (g/cm³)	Compressive strength (psi)	Static Young's Modulus (x10 ⁶ psi)	Static Poisson's Ration	Permeability to Air				Testing comments
								Millidarcies (mD)		m/day		
	Horizontal	Vertical						Horizontal	Vertical	Horizontal	Vertical	
HYD04	47.54	47.59	Sandstone	2.37	22.04	0.56	0.29	0.032	0.014	2.659E-05	1.163E-05	Short plug, lamination
HYD15	115.73	115.79	Sandstone	2.33	20.01	1.28	0.17	0.062	0.048	5.152E-05	3.989E-05	-
HYD25	179.66	179.62	Sandstone	2.83	53.64	1.55	0.30	0.009	0.007	7.479E-06	5.817E-06	Short plug, lamination
HYD33	226.1	226.05	Sandstone	2.54	77.55	1.72	0.21	0.004	0.004	3.324E-06	3.324E-06	Lamination
HYD41	274.26	274.21	Sandstone	2.47	54.48	0.83	1.72	0.005	0.004	4.155E-06	3.324E-06	Lamination
HYD51	334.48	334.52	Sandstone	2.53	83	1.89	1.89	0.006	0.004	4.986E-06	3.324E-06	Short plug, lamination

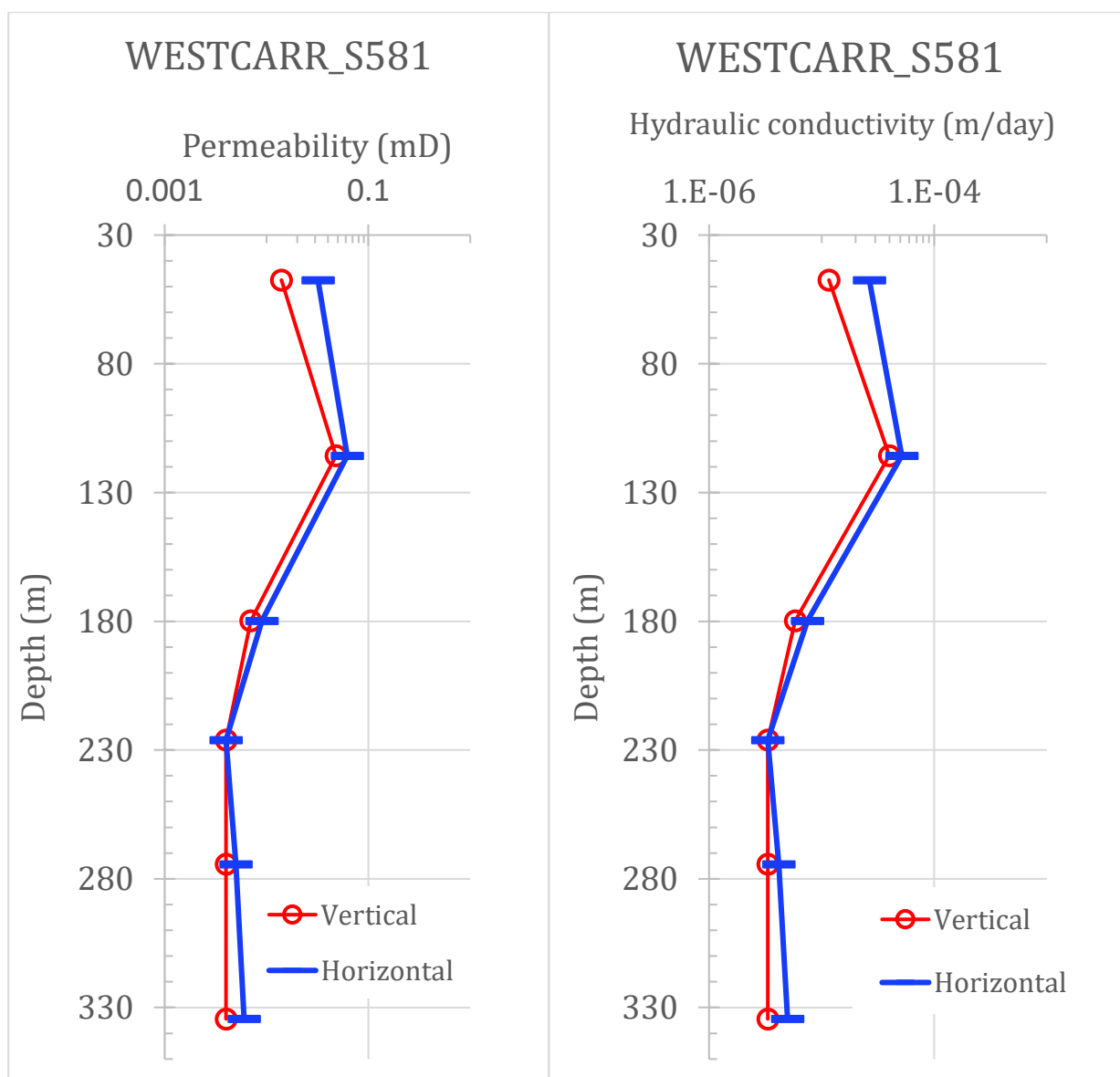


Figure A 5.1 Vertical & horizontal permeability (left)/hydraulic conductivity (right)

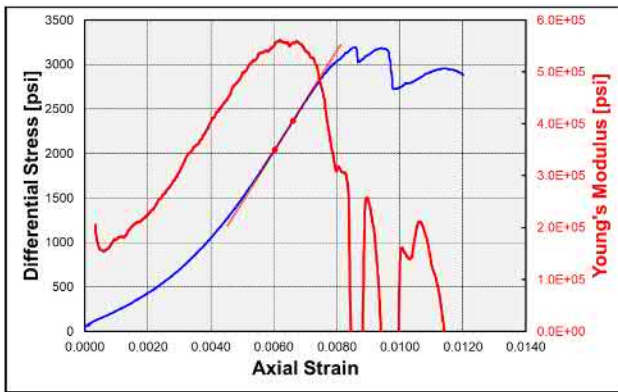


Figure A 5.2 HYD04 UCS results

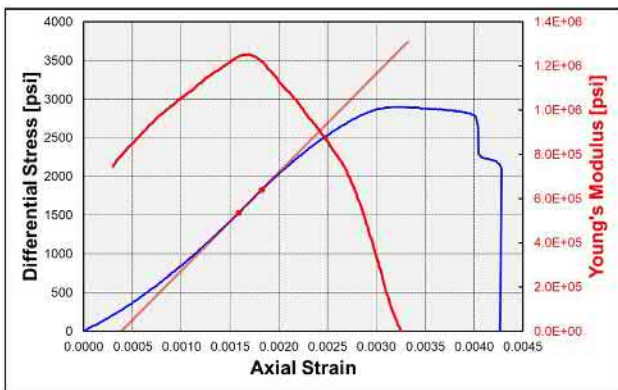
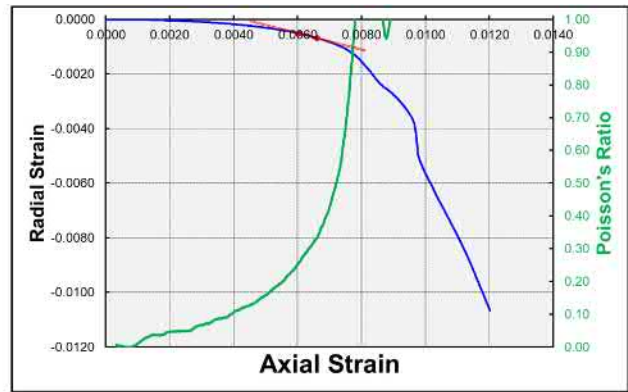


Figure A 5.3 HYD15 UCS results

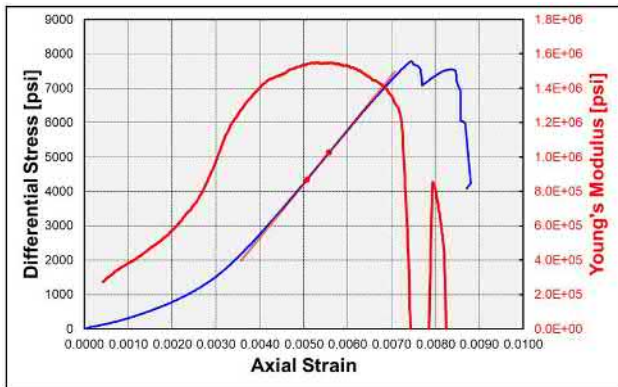
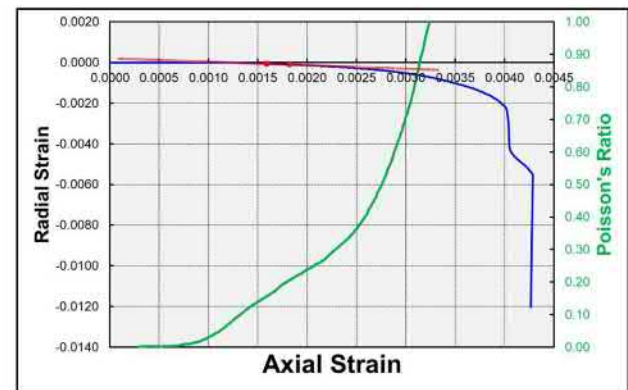


Figure A 5.4 HYD25 UCS results

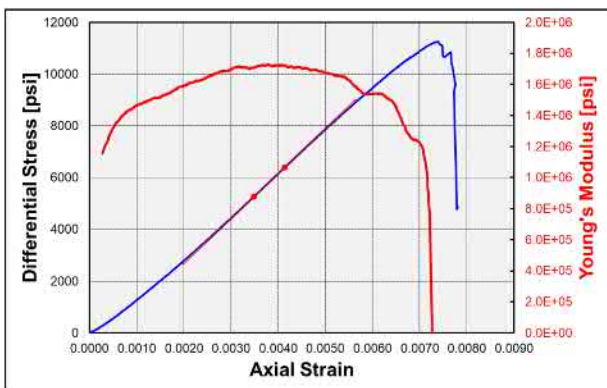
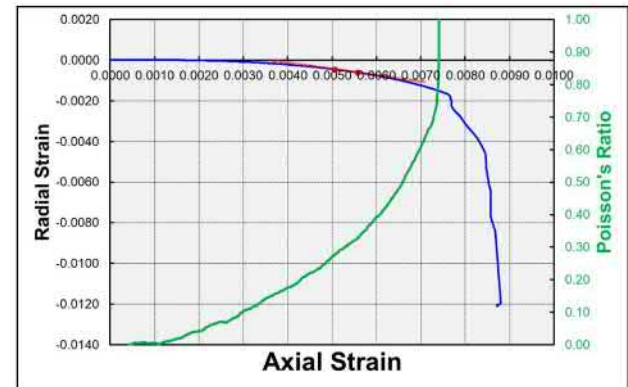
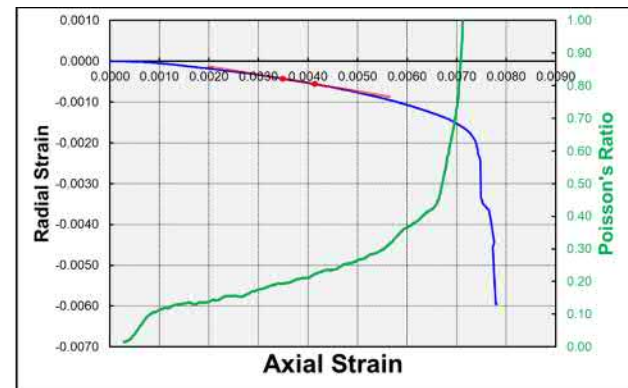


Figure A 5.5 HYD33 UCS results



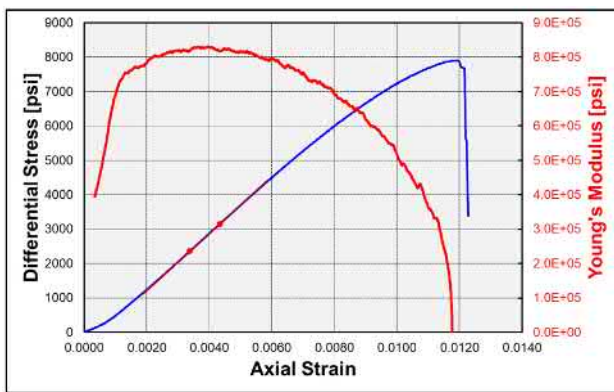


Figure A 5.6 HYD41 UCS results

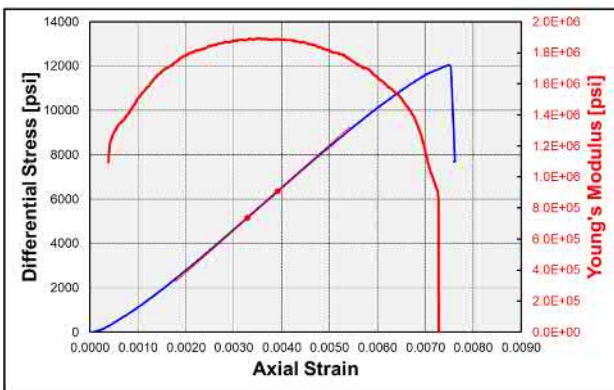
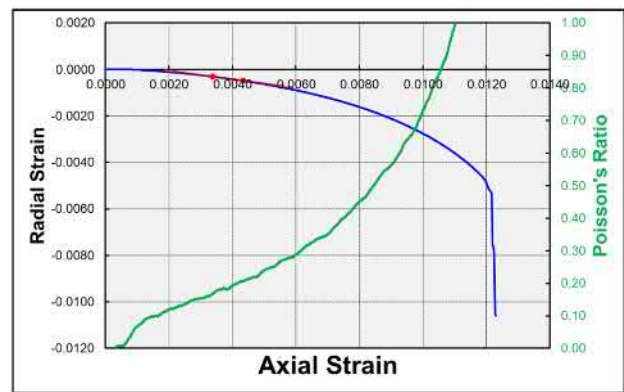
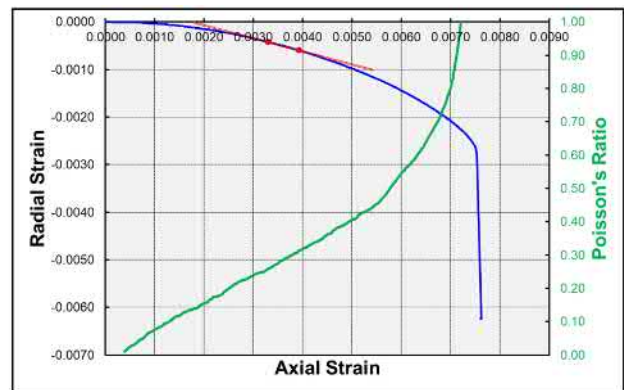


Figure A 5.7 HYD51 UCS results



A 6 Summary

AGE supervised the groundwater monitoring network expansion installed between December 2019 and September 2020. Boreholes were drilled with biodegradable, inert polymers using the mud rotary drilling technique. Each borehole was drilled with a PQ size polycrystalline diamond bit (PCD) and reamed out to 152 mm hole diameter. Monitoring bore construction conforms to the *Minimum Construction Requirements for Water Bores in Australia* (NUDLC, 2020). Boreholes were drilled under the supervision of a licensed Class 3 (WaterNSW) driller.

The VWP boreholes were geophysically logged prior to instrumentation installation. The proposed sensor intervals were revised to reflect observed geology from the geophysical survey. All sensor depths were based on strata and coal seam picks provided by HVO. Each VWP borehole was grouted, with all piezometers and geological units sealed to prevent vertical water movement and cross aquifer contamination within the borehole. The VWP sensors measure the in-situ groundwater level/pressure head. Data is recorded by a telemetric data logger, with data available for download from Ontoto's website.

One monitoring bore was installed during Stage 1 (CHESDEEP_S085). Monitoring bore CHESDEEP_S085 is screened in the Bayswater Seam and was decommissioned due to excess gas issuing from the bore post-development.

Packer testing was conducted at five intervals within WESTCARR_S581 to gather in-situ permeability data. Successfully targeted intervals include the Pikes Gully Coal Seam, interburden, Lower Barrett Coal Seam, Barrett Coal Seam to end of hole (EOH) and underburden strata. The test results indicate hydraulic conductivity is within expected ranges, varying from 3.00×10^{-3} m/day (Lower Barrett Seam) to 7.10×10^{-5} m/day (Barrett Seam to EOH) (Section 5.2).

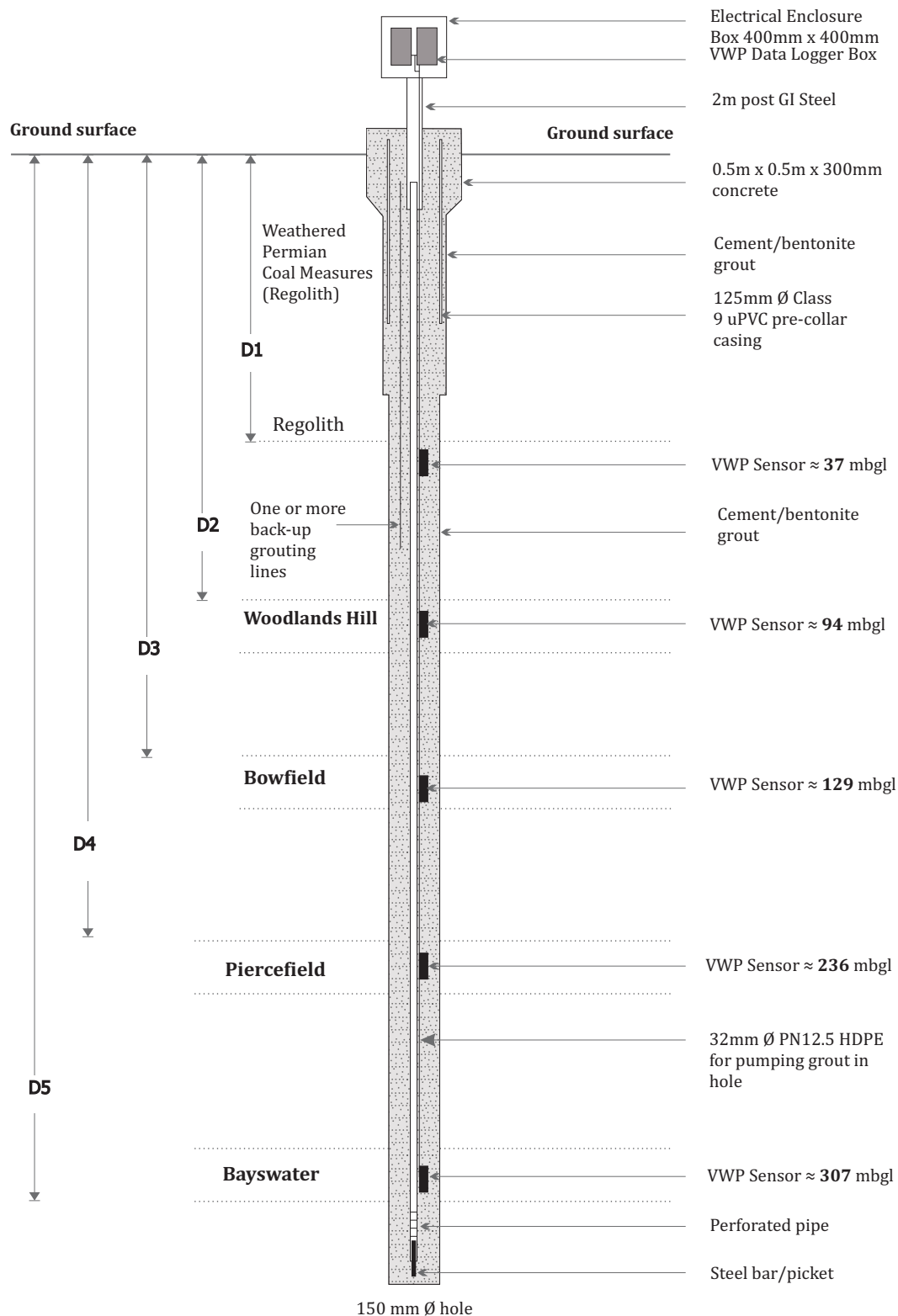
Core samples from WESTCARR_S581 were analysed for density, permeability, porosity and UCS in the laboratory. Vertical and horizontal permeability values were within expected ranges. Permeability generally decreased with depth, displaying an inverse relationship to rock mass strength, which increased with depth.

A 7 References

- Australasian Groundwater and Environmental Consultants Pty Ltd, AGE (2017). *Integra Underground Groundwater Impact Assessment*. AGE Report No G1285A submitted to HV Coaking Coal Pty Ltd 4 December 2017.
- Mackie, C. D. 2009. *Hydrogeological characterisation of coal measures and overview of impacts of coal mining on groundwater systems in the Upper Hunter Valley of NSW*. University of Technology, Sydney, January 2009.
- National Uniform Drillers Licensing Committee (NUDLC), (2020). *Minimum Construction Requirements for Water Bores in Australia – Fourth Edition*. <https://www.adia.com.au/documents/item/458>.
- SCT Operations (2008). *Packer test summary hole DDH223*.
- Vitz, E., Moore, J. W., Shorb, J., Prat-Resina, X., Wendorff, T. & Hahn, A. 2020. *Density of Rocks and Soils*. Chemical Education Digital Library, Libretexts. https://chem.libretexts.org/Bookshelves/Ancillary_Materials/Exemplars_and_Case_Studies/Exemplars/Geology/Density_of_Rocks_and_Soils.
- Waterloo Hydrogeologic (2020). *Aquifer Test Version 9.0*.

Appendix A 1

Bore logs



Vibrating wire piezometer - CHES_016

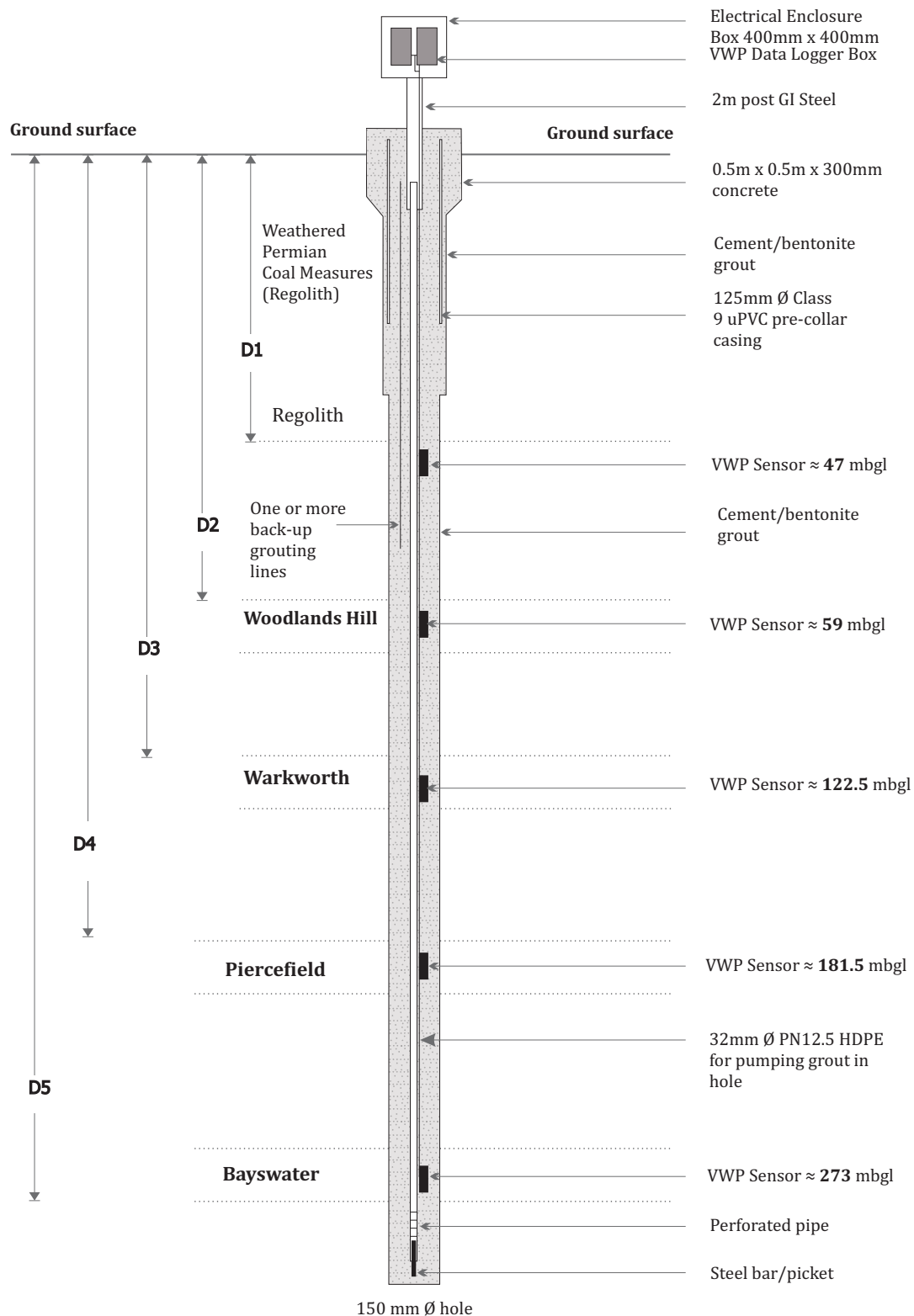
Coal Seams	Depth (D)	Installation depths (mbgl)	HVO Exploration Site Name
Regolith	D1	37	CHES_016
Woodlands Hill	D2	94	
Bowfield	D3	129	
Piercefield	D4	236	
Bayswater	D5	307	

Not to Scale

Vibrating wire piezometer installation - CHES_016

HVO Groundwater Program - Stage 1 (G1810B)





Vibrating wire piezometer - CHESDEEP_S152

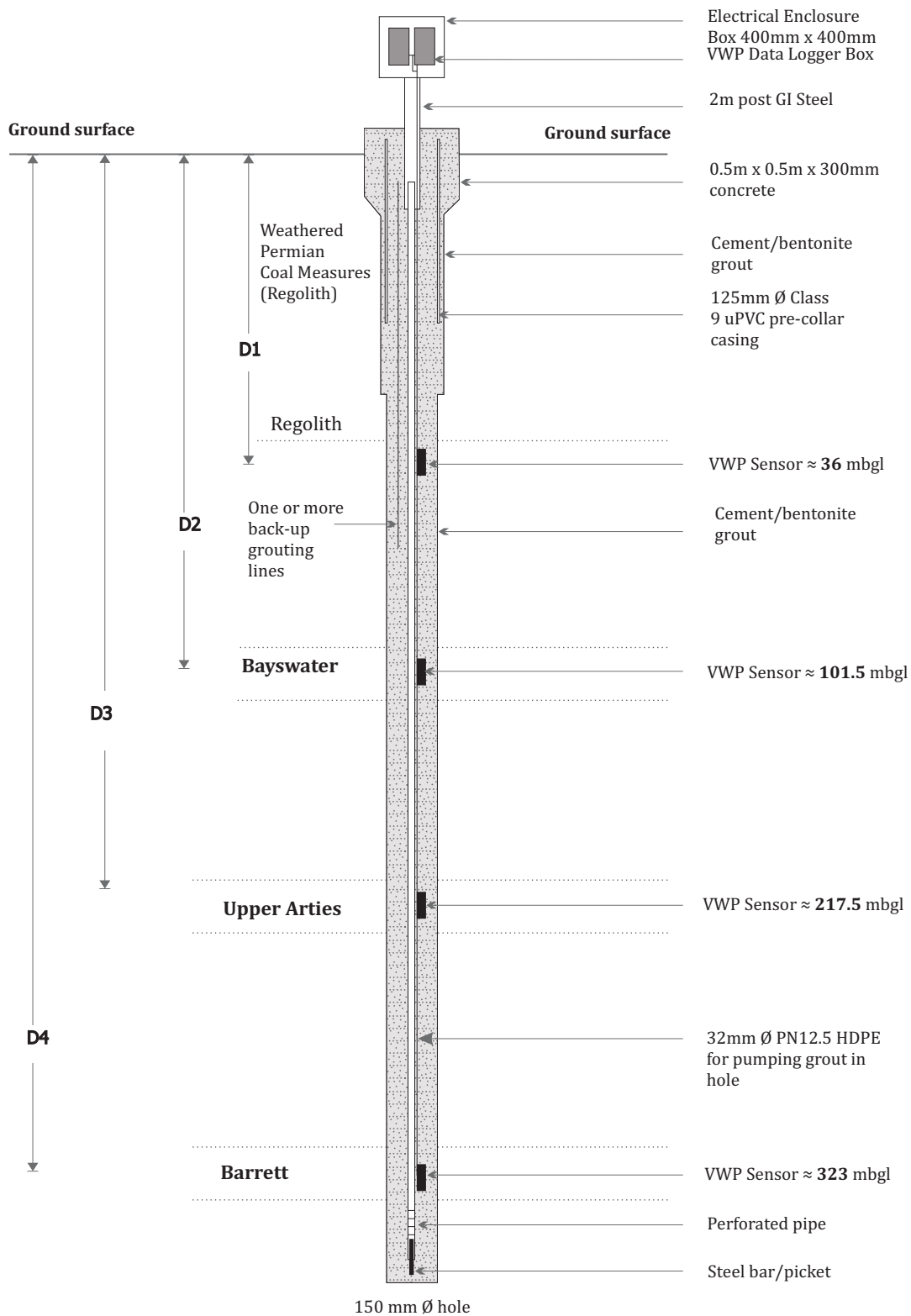
Coal Seams	Depth (D)	Installation depths (mbgl)	HVO Exploration Site Name
Regolith	D1	47	CHESDEEP_S152
Woodlands Hill	D2	59	
Warkworth	D3	122.5	
Piercefield	D4	181.5	
Bayswater	D5	273	

Not to Scale

Vibrating wire piezometer installation - CHESDEEP_S152

HVO Groundwater Program - Stage 1 (G1810B)





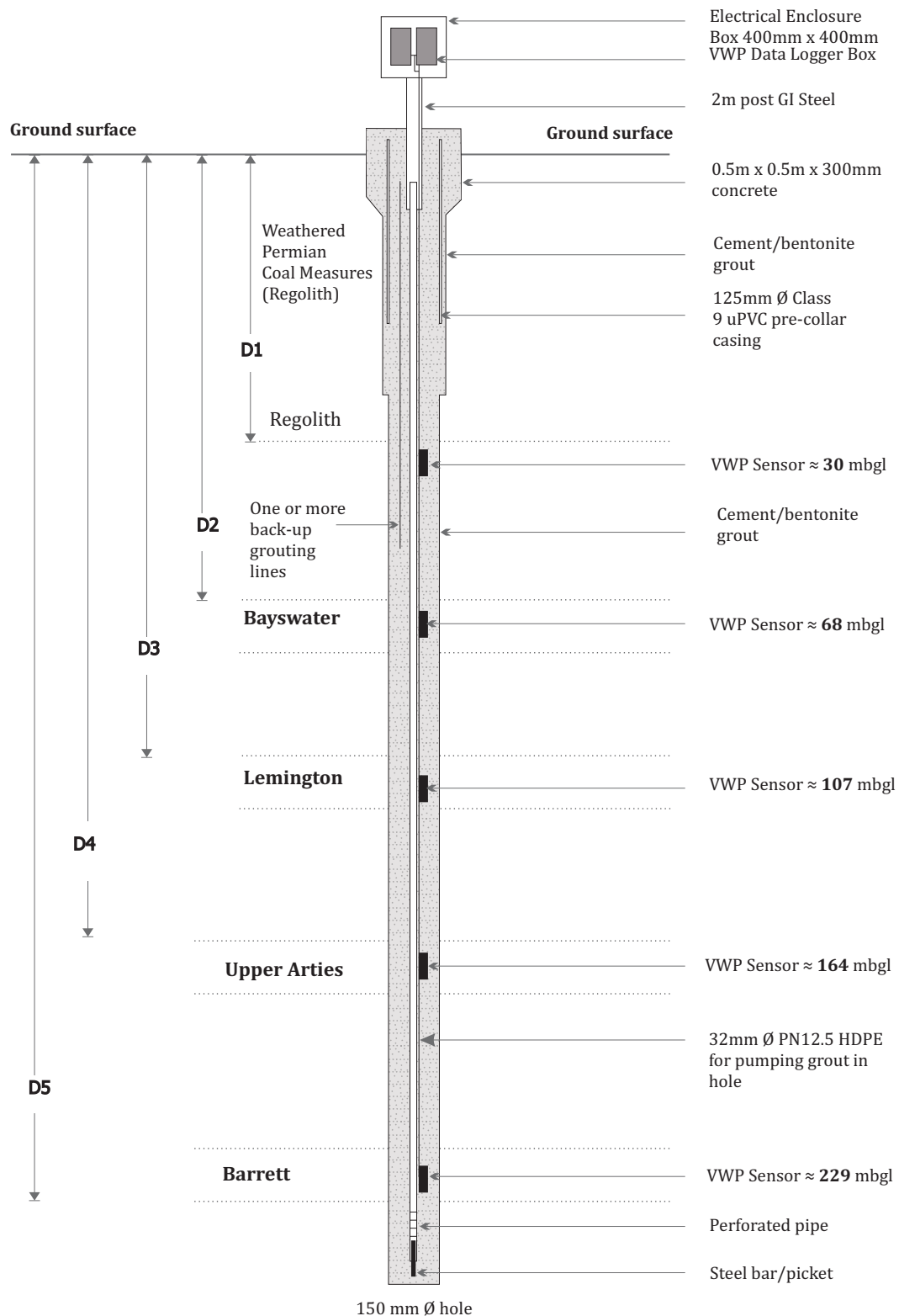
Vibrating wire piezometer - **WESTCARR_S316**

Coal Seams	Depth (D)	Installation depths (mbgl)	HVO Exploration Site Name
Regolith	D1	36	WESTCARR_S316
Bayswater	D2	101.5	
Upper Arties	D3	217.5	
Barrett	D4	323	

Not to Scale

Vibrating wire piezometer installation - WESTCARR_S316

HVO Groundwater Program - Stage 1 (G1810B)



Vibrating wire piezometer - **WESTCARR_S458**

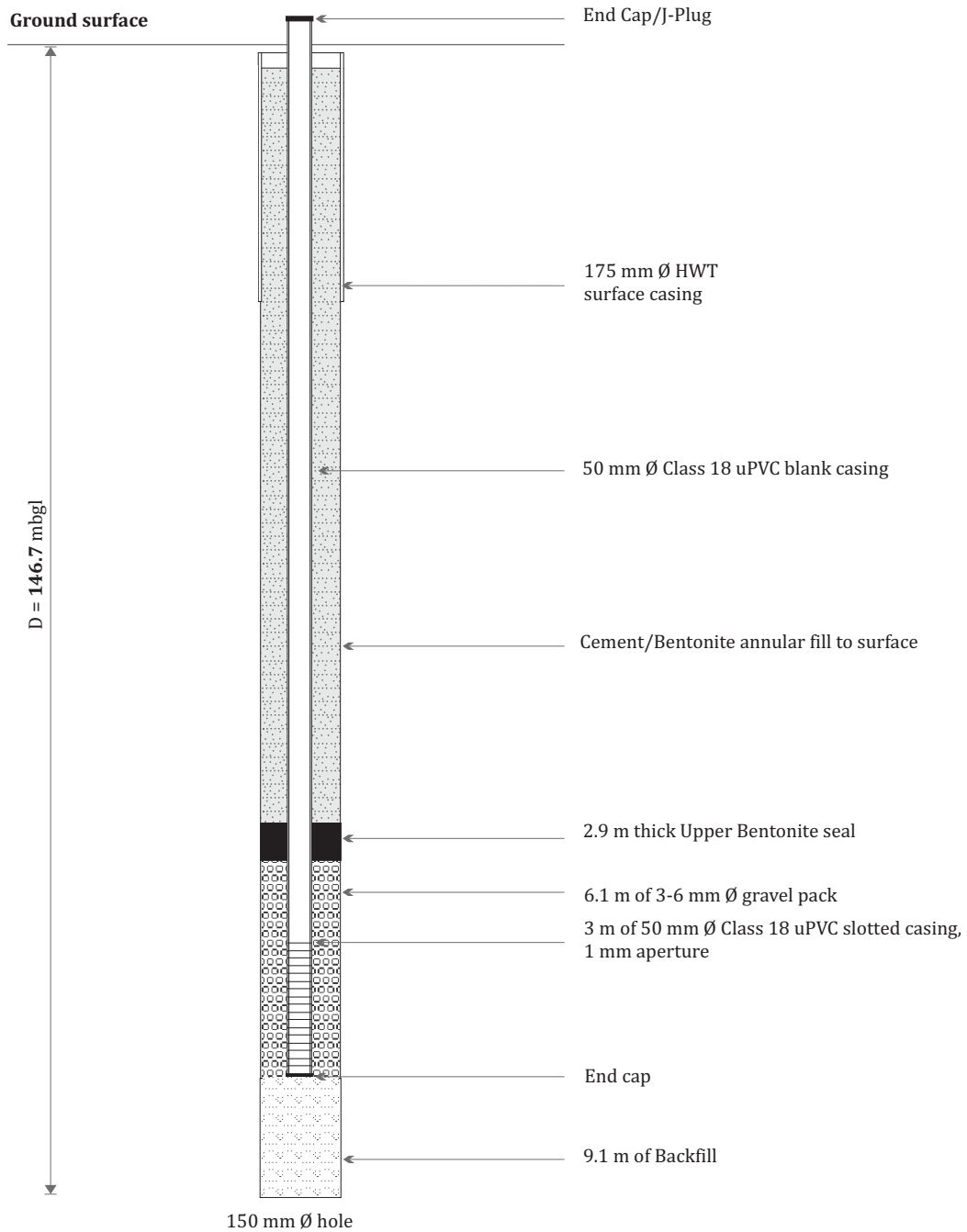
Coal Seams	Depth (D)	Installation depths (mbgl)	HVO Exploration Site Name
Regolith	D1	30	WESTCARR_S458
Bayswater	D2	68	
Lemington	D3	107	
Upper Arties	D4	164	
Barrett	D5	229	

Not to Scale

Vibrating wire piezometer installation - WESTCARR_S458

HVO Groundwater Program - Stage 1 (G1810B)





Monitoring bore - CHESDEEP_S085

Not to Scale

LEGEND

-  Grout
-  Gravel pack
-  Bentonite seal
-  Backfill

Target	Screen depth (mbgl)	Gravel pack (mbgl)	Bentonite seal (mbgl)	Grout seal (mbgl)	HVO Exploration Site Name
Bayswater Seam	132.55-135.55	130.88-136.95	127.95-130.88	0-127.95	CHESDEEP_S085

Monitoring bore installation - CHESDEEP_S085

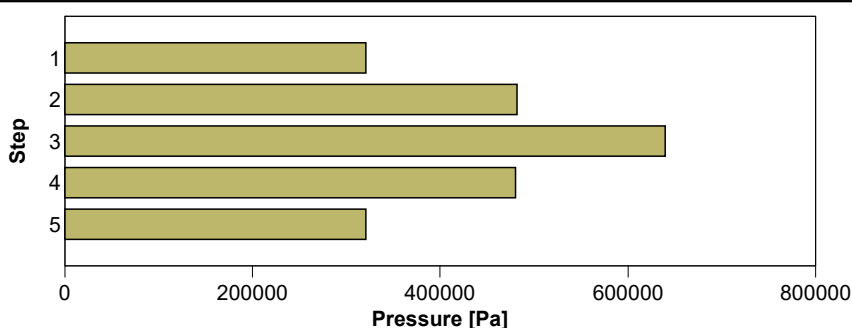
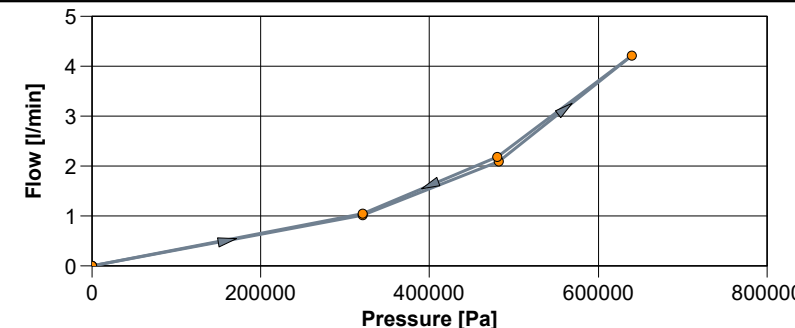
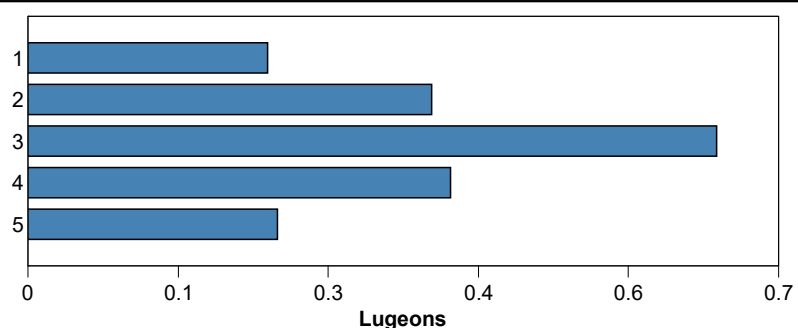
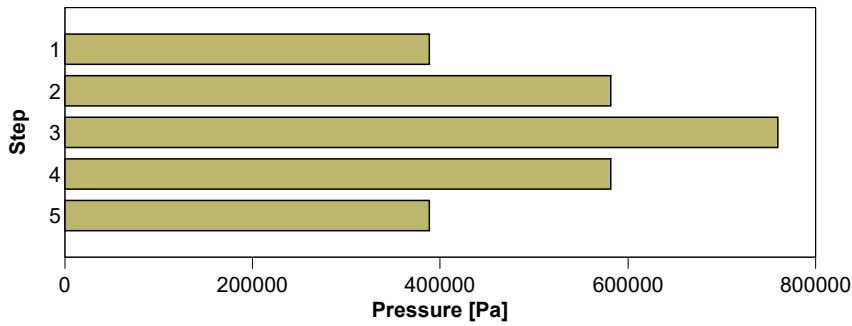
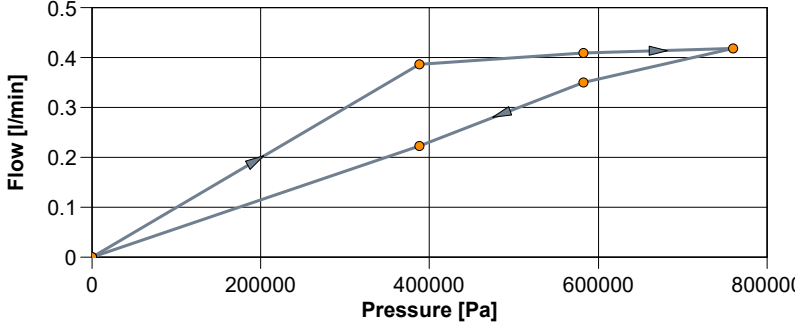
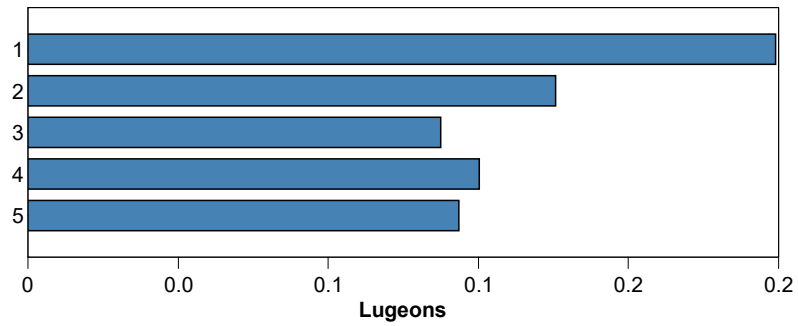
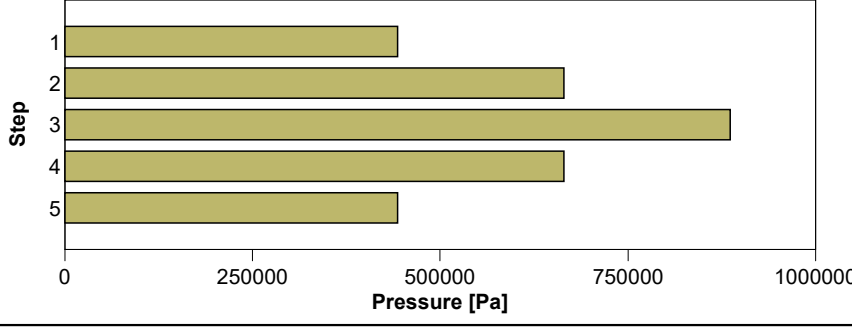
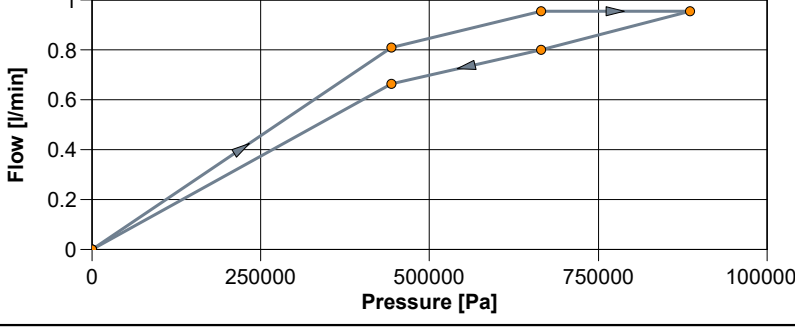
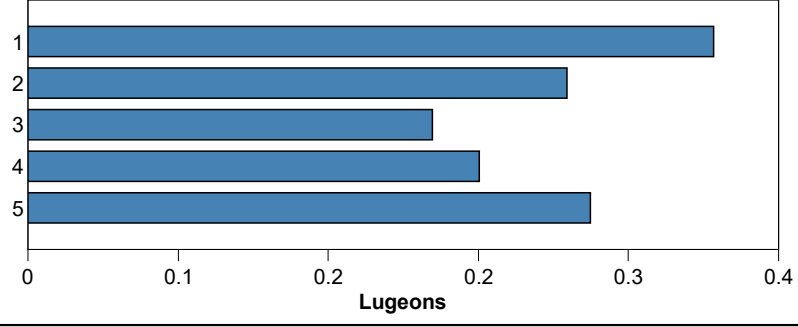
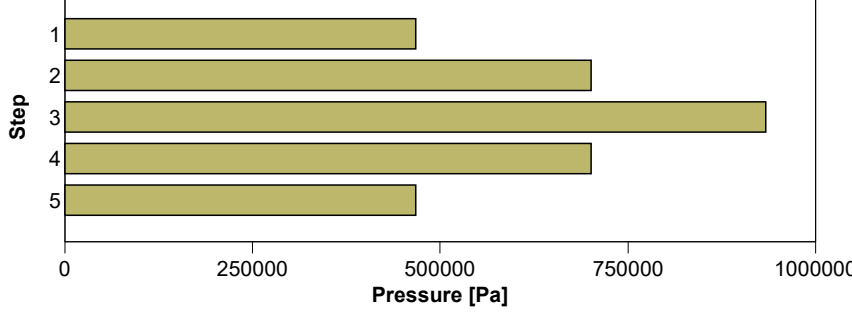
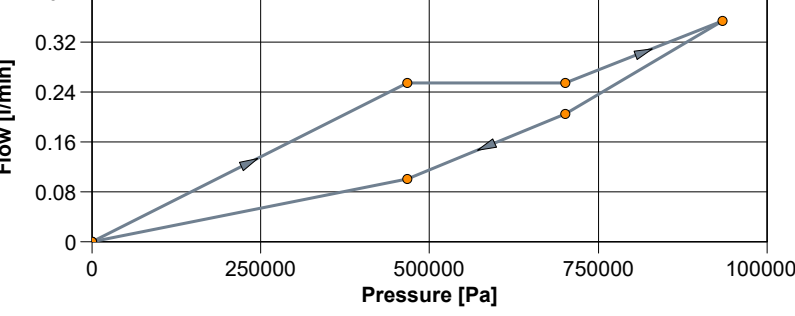
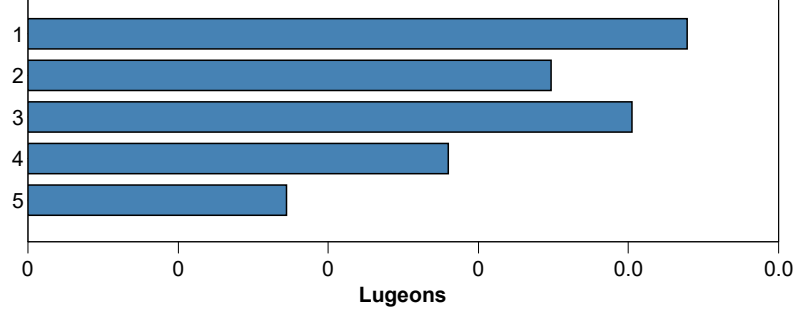
HVO Groundwater Program - Stage 1 (1810B)

Appendix A 2

Packer test analysis

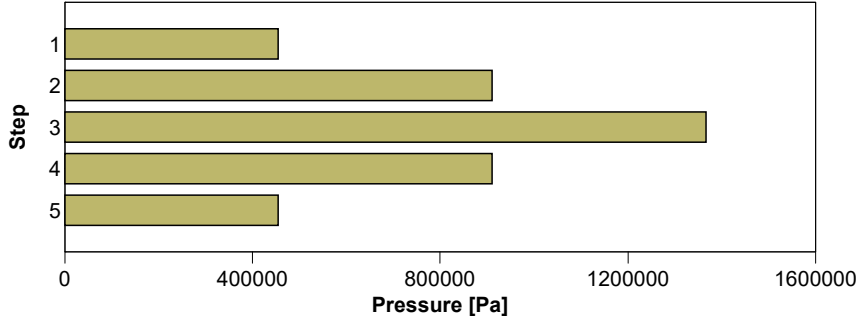
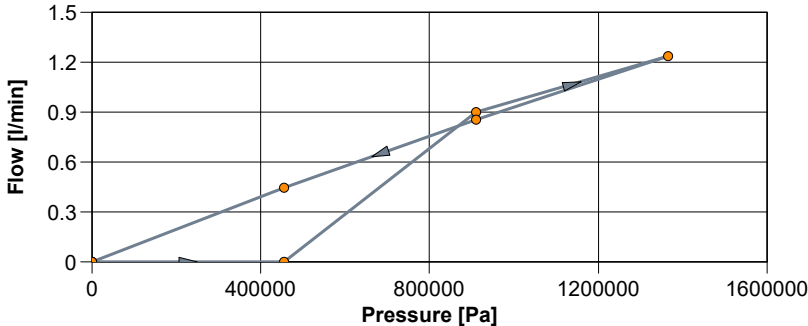
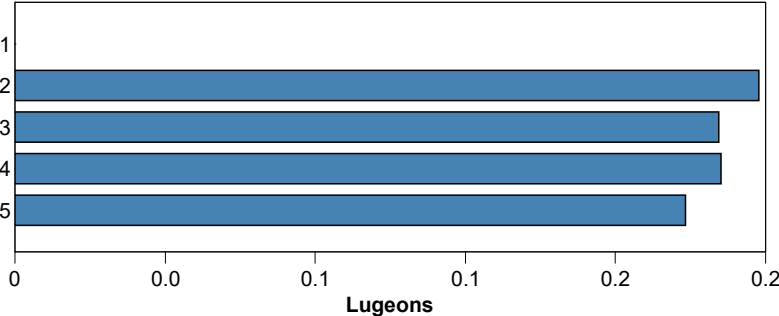


Lugeon Test Summary - WESTCARR_S581		
Project: HVO Groundwater Program - Stage 1		
Number: G1810B		
Client: Glencore		

Test Interval Top Bottom	Graphs			Result																																						
218.000 m 224.000 m	 <table><caption>Pressure vs Step Data (218.000 m to 224.000 m)</caption><tr><th>Step</th><th>Pressure [Pa]</th></tr><tr><td>1</td><td>320000</td></tr><tr><td>2</td><td>480000</td></tr><tr><td>3</td><td>640000</td></tr><tr><td>4</td><td>480000</td></tr><tr><td>5</td><td>320000</td></tr></table>	Step	Pressure [Pa]	1	320000	2	480000	3	640000	4	480000	5	320000	 <table><caption>Flow vs Pressure Data (218.000 m to 224.000 m)</caption><tr><th>Pressure [Pa]</th><th>Flow [l/min]</th></tr><tr><td>0</td><td>0</td></tr><tr><td>160000</td><td>0.5</td></tr><tr><td>320000</td><td>1.0</td></tr><tr><td>480000</td><td>1.5</td></tr><tr><td>640000</td><td>2.0</td></tr><tr><td>800000</td><td>2.5</td></tr></table>	Pressure [Pa]	Flow [l/min]	0	0	160000	0.5	320000	1.0	480000	1.5	640000	2.0	800000	2.5	 <table><caption>Lugeons vs Step Data (218.000 m to 224.000 m)</caption><tr><th>Step</th><th>Lugeons</th></tr><tr><td>1</td><td>0.24</td></tr><tr><td>2</td><td>0.36</td></tr><tr><td>3</td><td>0.64</td></tr><tr><td>4</td><td>0.36</td></tr><tr><td>5</td><td>0.24</td></tr></table>	Step	Lugeons	1	0.24	2	0.36	3	0.64	4	0.36	5	0.24	Dilation Lugeon: 0.24 Hydraulic Conductivity: 3.01E-8 m/s Hydraulic Conductivity: 0.0026 m/d
Step	Pressure [Pa]																																									
1	320000																																									
2	480000																																									
3	640000																																									
4	480000																																									
5	320000																																									
Pressure [Pa]	Flow [l/min]																																									
0	0																																									
160000	0.5																																									
320000	1.0																																									
480000	1.5																																									
640000	2.0																																									
800000	2.5																																									
Step	Lugeons																																									
1	0.24																																									
2	0.36																																									
3	0.64																																									
4	0.36																																									
5	0.24																																									
270.400 m 275.400 m	 <table><caption>Pressure vs Step Data (270.400 m to 275.400 m)</caption><tr><th>Step</th><th>Pressure [Pa]</th></tr><tr><td>1</td><td>400000</td></tr><tr><td>2</td><td>580000</td></tr><tr><td>3</td><td>760000</td></tr><tr><td>4</td><td>580000</td></tr><tr><td>5</td><td>400000</td></tr></table>	Step	Pressure [Pa]	1	400000	2	580000	3	760000	4	580000	5	400000	 <table><caption>Flow vs Pressure Data (270.400 m to 275.400 m)</caption><tr><th>Pressure [Pa]</th><th>Flow [l/min]</th></tr><tr><td>0</td><td>0</td></tr><tr><td>160000</td><td>0.2</td></tr><tr><td>320000</td><td>0.4</td></tr><tr><td>480000</td><td>0.6</td></tr><tr><td>640000</td><td>0.8</td></tr><tr><td>800000</td><td>1.0</td></tr></table>	Pressure [Pa]	Flow [l/min]	0	0	160000	0.2	320000	0.4	480000	0.6	640000	0.8	800000	1.0	 <table><caption>Lugeons vs Step Data (270.400 m to 275.400 m)</caption><tr><th>Step</th><th>Lugeons</th></tr><tr><td>1</td><td>0.11</td></tr><tr><td>2</td><td>0.15</td></tr><tr><td>3</td><td>0.17</td></tr><tr><td>4</td><td>0.19</td></tr><tr><td>5</td><td>0.18</td></tr></table>	Step	Lugeons	1	0.11	2	0.15	3	0.17	4	0.19	5	0.18	Void filling Lugeon: 0.11 Hydraulic Conductivity: 1.39E-8 m/s Hydraulic Conductivity: 0.0012 m/d
Step	Pressure [Pa]																																									
1	400000																																									
2	580000																																									
3	760000																																									
4	580000																																									
5	400000																																									
Pressure [Pa]	Flow [l/min]																																									
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2	0.15																																									
3	0.17																																									
4	0.19																																									
5	0.18																																									
314.000 m 319.000 m	 <table><caption>Pressure vs Step Data (314.000 m to 319.000 m)</caption><tr><th>Step</th><th>Pressure [Pa]</th></tr><tr><td>1</td><td>450000</td></tr><tr><td>2</td><td>650000</td></tr><tr><td>3</td><td>850000</td></tr><tr><td>4</td><td>650000</td></tr><tr><td>5</td><td>450000</td></tr></table>	Step	Pressure [Pa]	1	450000	2	650000	3	850000	4	650000	5	450000	 <table><caption>Flow vs Pressure Data (314.000 m to 319.000 m)</caption><tr><th>Pressure [Pa]</th><th>Flow [l/min]</th></tr><tr><td>0</td><td>0</td></tr><tr><td>160000</td><td>0.4</td></tr><tr><td>320000</td><td>0.8</td></tr><tr><td>480000</td><td>1.2</td></tr><tr><td>640000</td><td>1.6</td></tr><tr><td>800000</td><td>2.0</td></tr></table>	Pressure [Pa]	Flow [l/min]	0	0	160000	0.4	320000	0.8	480000	1.2	640000	1.6	800000	2.0	 <table><caption>Lugeons vs Step Data (314.000 m to 319.000 m)</caption><tr><th>Step</th><th>Lugeons</th></tr><tr><td>1</td><td>0.29</td></tr><tr><td>2</td><td>0.25</td></tr><tr><td>3</td><td>0.22</td></tr><tr><td>4</td><td>0.20</td></tr><tr><td>5</td><td>0.27</td></tr></table>	Step	Lugeons	1	0.29	2	0.25	3	0.22	4	0.20	5	0.27	Turbulent Lugeon: 0.29 Hydraulic Conductivity: 3.47E-8 m/s Hydraulic Conductivity: 0.003 m/d
Step	Pressure [Pa]																																									
1	450000																																									
2	650000																																									
3	850000																																									
4	650000																																									
5	450000																																									
Pressure [Pa]	Flow [l/min]																																									
0	0																																									
160000	0.4																																									
320000	0.8																																									
480000	1.2																																									
640000	1.6																																									
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Step	Lugeons																																									
1	0.29																																									
2	0.25																																									
3	0.22																																									
4	0.20																																									
5	0.27																																									
326.000 m 347.500 m	 <table><caption>Pressure vs Step Data (326.000 m to 347.500 m)</caption><tr><th>Step</th><th>Pressure [Pa]</th></tr><tr><td>1</td><td>480000</td></tr><tr><td>2</td><td>700000</td></tr><tr><td>3</td><td>920000</td></tr><tr><td>4</td><td>700000</td></tr><tr><td>5</td><td>480000</td></tr></table>	Step	Pressure [Pa]	1	480000	2	700000	3	920000	4	700000	5	480000	 <table><caption>Flow vs Pressure Data (326.000 m to 347.500 m)</caption><tr><th>Pressure [Pa]</th><th>Flow [l/min]</th></tr><tr><td>0</td><td>0</td></tr><tr><td>160000</td><td>0.12</td></tr><tr><td>320000</td><td>0.24</td></tr><tr><td>480000</td><td>0.36</td></tr><tr><td>640000</td><td>0.48</td></tr><tr><td>800000</td><td>0.60</td></tr></table>	Pressure [Pa]	Flow [l/min]	0	0	160000	0.12	320000	0.24	480000	0.36	640000	0.48	800000	0.60	 <table><caption>Lugeons vs Step Data (326.000 m to 347.500 m)</caption><tr><th>Step</th><th>Lugeons</th></tr><tr><td>1</td><td>0.005</td></tr><tr><td>2</td><td>0.007</td></tr><tr><td>3</td><td>0.009</td></tr><tr><td>4</td><td>0.008</td></tr><tr><td>5</td><td>0.005</td></tr></table>	Step	Lugeons	1	0.005	2	0.007	3	0.009	4	0.008	5	0.005	Void filling Lugeon: 0.005 Hydraulic Conductivity: 8.21E-10 m/s Hydraulic Conductivity: 0.000071 m/d
Step	Pressure [Pa]																																									
1	480000																																									
2	700000																																									
3	920000																																									
4	700000																																									
5	480000																																									
Pressure [Pa]	Flow [l/min]																																									
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4	0.008																																									
5	0.005																																									



Lugeon Test Summary - WESTCARR_S581	
Project: HVO Groundwater Program - Stage 1	
Number: G1810B	
Client: Glencore	

Test Interval Top Bottom	Graphs			Result																																										
343.000 m 347.500 m	 <table><caption>Pressure Data by Step</caption><tr><th>Step</th><th>Pressure [Pa]</th></tr><tr><td>1</td><td>~450,000</td></tr><tr><td>2</td><td>~900,000</td></tr><tr><td>3</td><td>~1,300,000</td></tr><tr><td>4</td><td>~900,000</td></tr><tr><td>5</td><td>~450,000</td></tr></table>	Step	Pressure [Pa]	1	~450,000	2	~900,000	3	~1,300,000	4	~900,000	5	~450,000	 <table><caption>Flow vs Pressure Data</caption><tr><th>Step</th><th>Pressure [Pa]</th><th>Flow [l/min]</th></tr><tr><td>1</td><td>~450,000</td><td>~0.45</td></tr><tr><td>2</td><td>~900,000</td><td>~0.90</td></tr><tr><td>3</td><td>~1,300,000</td><td>~1.25</td></tr><tr><td>4</td><td>~900,000</td><td>~0.90</td></tr><tr><td>5</td><td>~450,000</td><td>~0.45</td></tr></table>	Step	Pressure [Pa]	Flow [l/min]	1	~450,000	~0.45	2	~900,000	~0.90	3	~1,300,000	~1.25	4	~900,000	~0.90	5	~450,000	~0.45	 <table><caption>Lugeon Data by Step</caption><tr><th>Step</th><th>Lugeons</th></tr><tr><td>1</td><td>~0.05</td></tr><tr><td>2</td><td>~0.22</td></tr><tr><td>3</td><td>~0.18</td></tr><tr><td>4</td><td>~0.18</td></tr><tr><td>5</td><td>~0.15</td></tr></table>	Step	Lugeons	1	~0.05	2	~0.22	3	~0.18	4	~0.18	5	~0.15	Laminar Lugeon: 0.19 Hydraulic Conductivity: 2.22E-8 m/s Hydraulic Conductivity: 0.00192 m/d
Step	Pressure [Pa]																																													
1	~450,000																																													
2	~900,000																																													
3	~1,300,000																																													
4	~900,000																																													
5	~450,000																																													
Step	Pressure [Pa]	Flow [l/min]																																												
1	~450,000	~0.45																																												
2	~900,000	~0.90																																												
3	~1,300,000	~1.25																																												
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5	~450,000	~0.45																																												
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1	~0.05																																													
2	~0.22																																													
3	~0.18																																													
4	~0.18																																													
5	~0.15																																													



Lugeon Test Analysis Report

Project: HVO Groundwater Program - Stage 1

Number: G1810B

Client: Glencore

Location: Lemington

Lugeon Test: 5 - MPG/LPG Seam

Tested bore: WESTCARR_S581

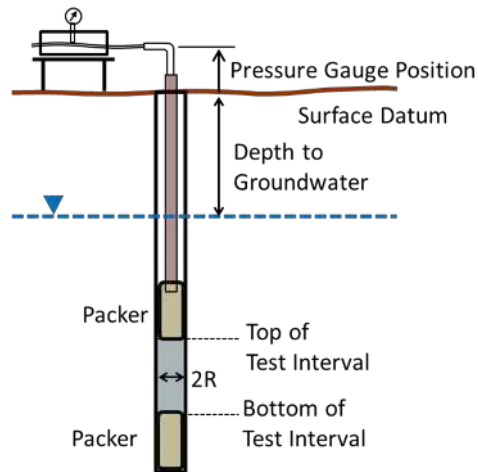
Test Conducted by: TW

Test Date: 20/08/2020

Analysis Performed by: WR

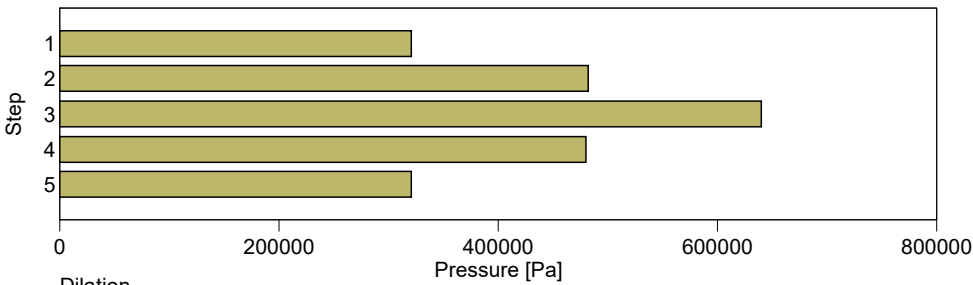
Analysis Date: 20/08/2020

Lithology: Pikes Gully Seam

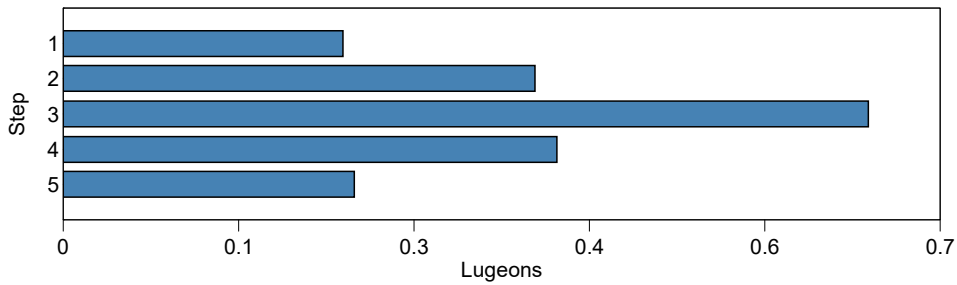
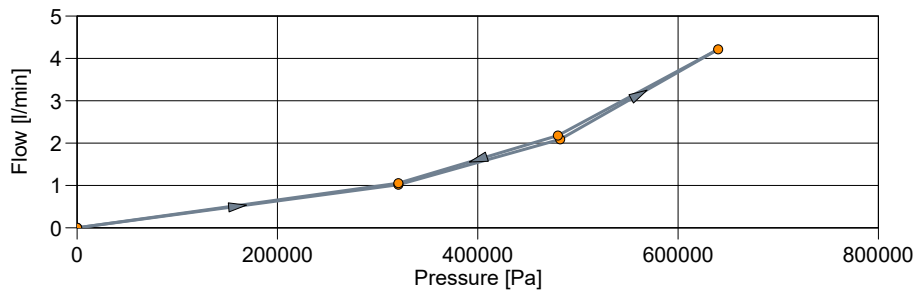


Top of Test Interval: 218.000 m
Bottom of Test Interval: 224.000 m
Length of Test Interval: 6.000 m
Gauge Position: 0.800 m
Depth to Groundwater: 38.080 m
Radius of Test Section: 0.048 m
Dip of bore: 90° from vertical
Vertical Top of Test Interval: 0.000 m
Vertical Bottom of Test Interval: 0.000 m

Step	Pressure [Pa]	Flow Meter Readings [l]												Average Flow Rate [l/min]	Hydraulic Conductivity		
		1	2	3	4	5	6	7	8	9	10	11	12		[m/s]	[m/d]	Lugeon
1	321000	872.9	874.2	875.2	876.3	877.4	878.4	879.4	880.3	881.3	882.2	883.1	884.0	1.0	3.01×10^{-8}	0.00260	0.239
2	482000	889.1	891.3	893.4	895.6	897.8	899.9	902.0	904.0	906.1	908.3	910.1	912.1	2.1	5.07×10^{-8}	0.00438	0.404
3	640000	926.5	930.9	935.2	939.5	943.7	948.0	952.1	956.3	960.5	964.6	968.8	972.9	4.2	8.65×10^{-8}	0.00747	0.688
4	480000	977.1	979.3	981.5	983.8	986.0	988.2	990.4	992.5	994.7	996.9	999.0	1001.1	2.2	5.30×10^{-8}	0.00458	0.422
5	321000	1003.6	1004.6	1005.7	1006.8	1007.9	1008.9	1009.9	1011.0	1012.0	1013.0	1014.1	1015.1	1.1	3.13×10^{-8}	0.00270	0.249
Average															5.03×10^{-8}	0.00435	0.401



Dilation
Lugeon: 0.24
Hydraulic Conductivity: 3.01×10^{-8} m/s
Hydraulic Conductivity: 0.0026 m/d





Lugeon Test Analysis Report

Project: HVO Groundwater Program - Stage 1

Number: G1810B

Client: Glencore

Location: Lemington

Lugeon Test: 4 - Interburden

Tested bore: WESTCARR_S581

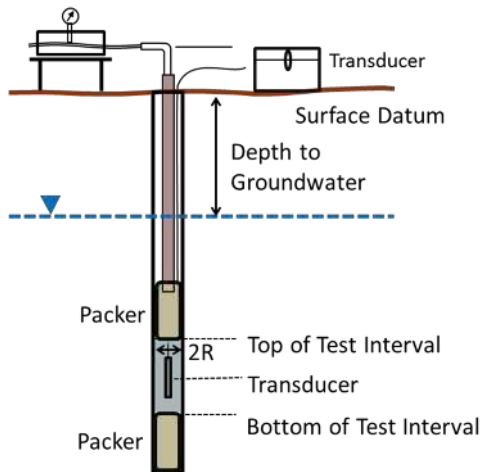
Test Conducted by: TW

Test Date: 20/08/2020

Analysis Performed by: WR

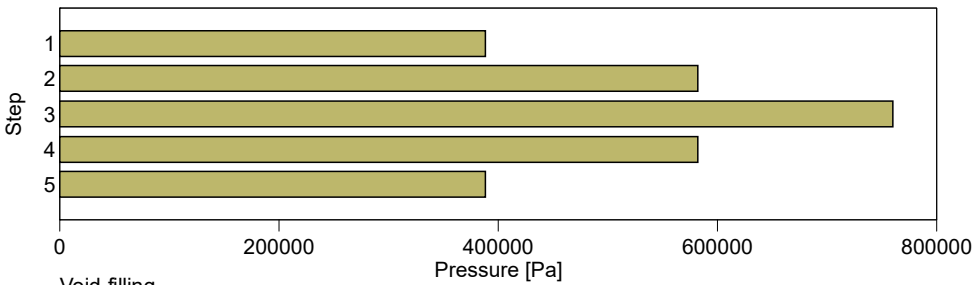
Analysis Date: 20/08/2020

Lithology: Interburden

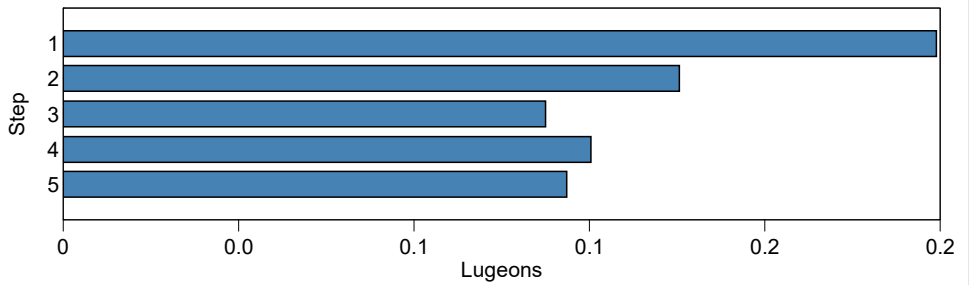
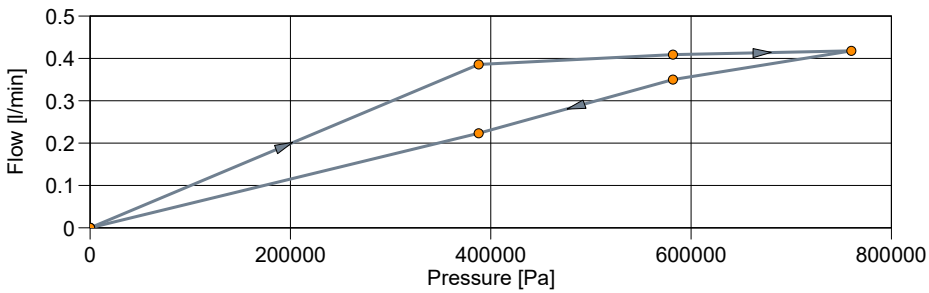


Top of Test Interval: 270.400 m
Bottom of Test Interval: 275.400 m
Length of Test Interval: 5.000 m
Depth to Groundwater: 36.390 m
Radius of Test Section: 0.048 m
Dip of bore: 90° from vertical
Vertical Top of Test Interval: 0.000 m
Vertical Bottom of Test Interval: 0.000 m

Step	Pressure [Pa]	Flow Meter Readings [l]												Average Flow Rate [l/min]	Hydraulic Conductivity		
		1	2	3	4	5	6	7	8	9	10	11	12		[m/s]	[m/d]	Lugeon
1	388000.0	567.0	567.5	568.0	568.4	568.7	569.1	569.5	569.9	570.2	570.5	570.9	571.2	0.4	2.41×10^{-8}	0.00208	0.199
2	582000.0	572.7	573.2	573.6	574.0	574.5	574.9	575.3	575.7	576.0	576.5	5576.8	577.2	0.4	1.70×10^{-8}	0.00147	0.141
3	760000.0	578.7	579.1	579.5	580.0	580.4	580.8	581.2	581.6	582.0	582.5	582.9	583.3	0.4	1.33×10^{-8}	0.00115	0.110
4	582000.0	583.9	584.2	584.6	584.9	585.3	585.6	586.0	586.3	586.7	587.0	587.4	587.7	0.4	1.45×10^{-8}	0.00126	0.120
5	388000.0	588.1	588.3	588.6	588.8	589.1	589.3	589.5	589.7	589.9	590.2	590.3	590.6	0.2	1.39×10^{-8}	0.00120	0.115
Average															1.66×10^{-8}	0.00143	0.137



Void filling
Lugeon: 0.11
Hydraulic Conductivity: 1.39×10^{-8} m/s
Hydraulic Conductivity: 0.0012 m/d





Lugeon Test Analysis Report

Project: HVO Groundwater Program - Stage 1

Number: G1810B

Client: Glencore

Location: Lemington

Lugeon Test: 3 - LLB Seam

Tested bore: WESTCARR_S581

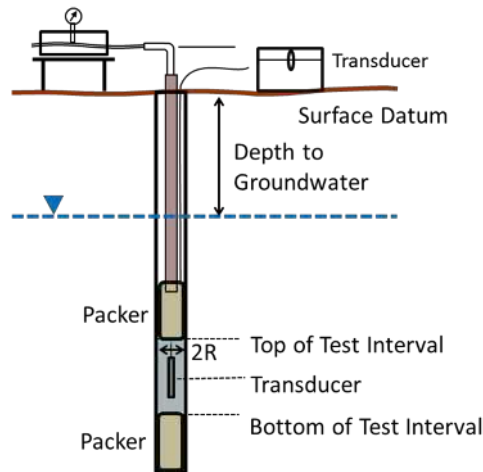
Test Conducted by: TW

Test Date: 19/08/2020

Analysis Performed by: WR

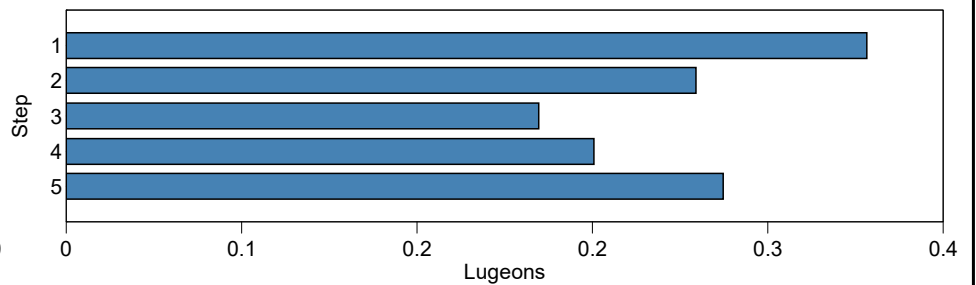
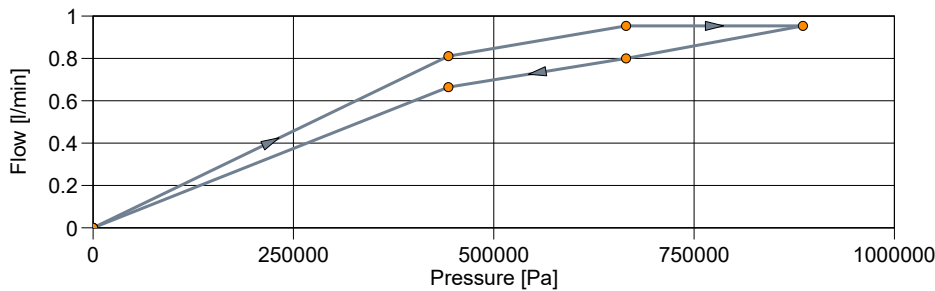
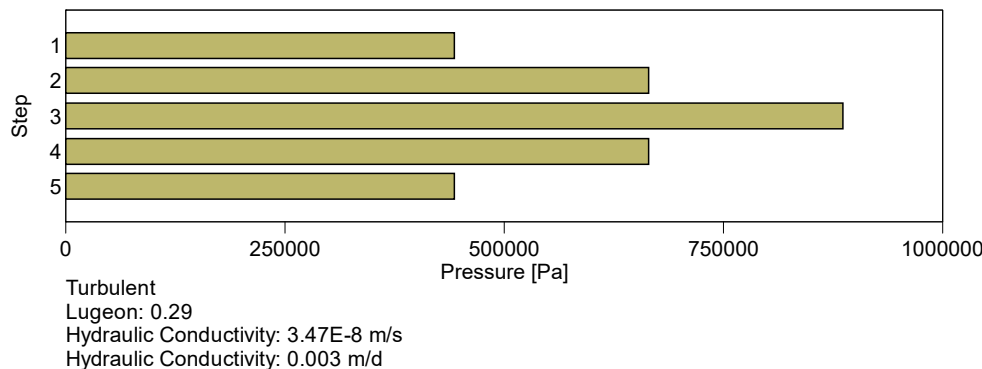
Analysis Date: 19/08/2020

Lithology: LLB Seam



Top of Test Interval: 314.000 m
Bottom of Test Interval: 319.000 m
Length of Test Interval: 5.000 m
Depth to Groundwater: 33.690 m
Radius of Test Section: 0.048 m
Dip of bore: 90° from vertical
Vertical Top of Test Interval: 0.000 m
Vertical Bottom of Test Interval: 0.000 m

Step	Pressure [Pa]	Flow Meter Readings [l]												Average Flow Rate [l/min]	Hydraulic Conductivity		
		1	2	3	4	5	6	7	8	9	10	11	12		[m/s]	[m/d]	Lugeon
1	443000.0	297.3	298.1	298.8	299.6	300.4	301.2	302.0	302.8	303.7	304.5	305.4	306.2	0.8	4.41×10^{-8}	0.00381	0.365
2	665000.0	309.2	310.1	311.1	312.1	313.0	313.9	314.9	315.8	316.8	317.7	318.7	319.7	1.0	3.47×10^{-8}	0.00300	0.287
3	886000.0	323.8	324.8	325.8	326.8	327.8	328.8	329.6	330.5	331.5	332.4	333.3	334.3	1.0	2.60×10^{-8}	0.00225	0.215
4	665000.0	336.7	337.5	338.5	339.2	340.8	341.1	341.6	342.4	343.1	343.9	344.7	345.5	0.8	2.91×10^{-8}	0.00251	0.241
5	443000.0	346.7	347.4	348.1	348.8	349.5	350.1	350.8	351.4	352.0	352.7	353.4	354.0	0.7	3.62×10^{-8}	0.00313	0.300
Average															3.40×10^{-8}	0.00294	0.282





Lugeon Test Analysis Report

Project: HVO Groundwater Program - Stage 1

Number: G1810B

Client: Glencore

Location: Lemington

Lugeon Test: 2 - Barrett to EOH

Tested bore: WESTCARR_S581

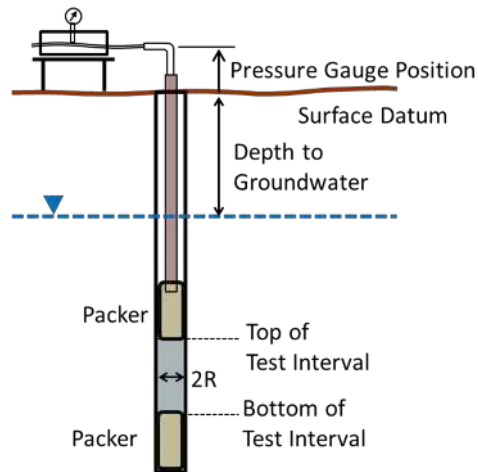
Test Conducted by: TW

Test Date: 19/08/2020

Analysis Performed by: WRR

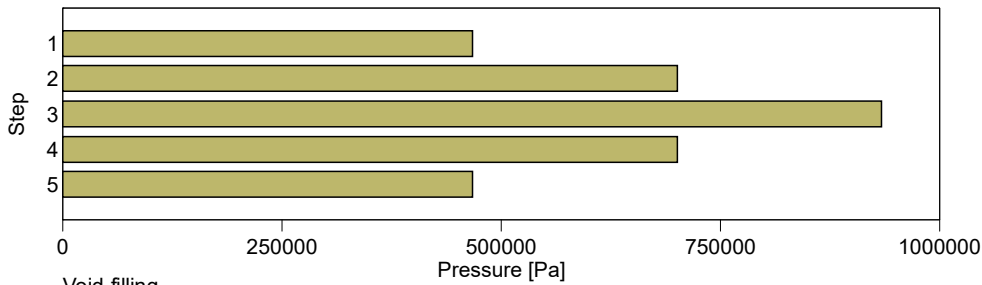
Analysis Date: 19/08/2020

Lithology: Barrett Seam to EOH

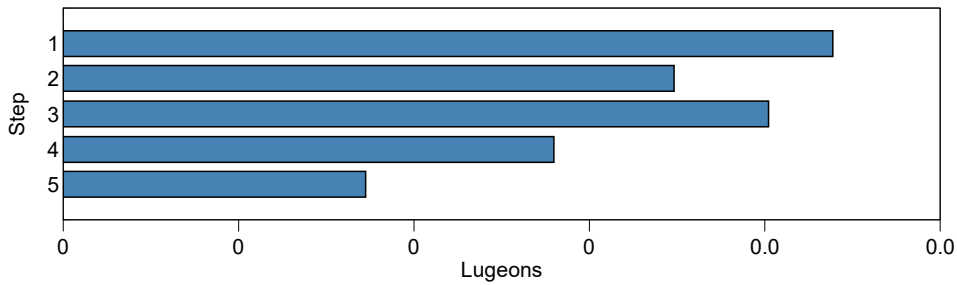
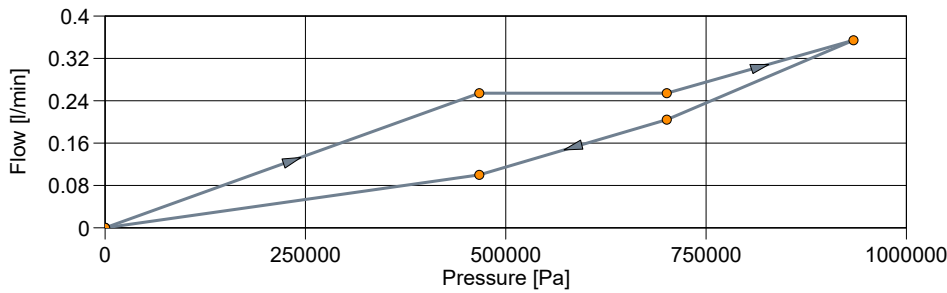


Top of Test Interval: 326.000 m
Bottom of Test Interval: 347.500 m
Length of Test Interval: 21.500 m
Gauge Position: 0.800 m
Depth to Groundwater: 43.265 m
Radius of Test Section: 0.048 m
Dip of bore: 90° from vertical
Vertical Top of Test Interval: 0.000 m
Vertical Bottom of Test Interval: 0.000 m

Step	Pressure [Pa]	Flow Meter Readings [l]												Average Flow Rate [l/min]	Hydraulic Conductivity		
		1	2	3	4	5	6	7	8	9	10	11	12		[m/s]	[m/d]	Lugeon
1	467000	37.5	37.8	38.1	38.4	38.6	38.9	39.1	39.3	39.6	39.8	40.1	40.3	0.3	2.09×10^{-9}	0.000181	0.013
2	701000	41.1	41.3	41.6	41.9	42.2	42.5	42.7	43.0	43.2	43.5	43.7	43.9	0.3	1.66×10^{-9}	0.000143	0.010
3	934000	44.2	45.1	45.4	45.7	46.1	46.3	46.6	46.9	47.2	47.5	47.8	48.1	0.4	1.92×10^{-9}	0.000166	0.012
4	701000	48.8	49.1	49.3	49.5	49.7	49.9	50.1	50.3	50.5	50.7	50.9	51.1	0.2	1.33×10^{-9}	0.000115	0.008
5	467000	51.6	51.7	51.8	51.9	52.0	52.1	52.2	52.3	52.4	52.5	52.6	52.7	0.1	8.21×10^{-10}	0.000071	0.005
Average															1.56×10^{-9}	0.000135	0.010



Void filling
Lugeon: 0.005
Hydraulic Conductivity: 8.21×10^{-10} m/s
Hydraulic Conductivity: 0.000071 m/d





Lugeon Test Analysis Report

Project: HVO Groundwater Program - Stage 1

Number: G1810B

Client: Glencore

Location: Lemington

Lugeon Test: 1 - Basement

Tested bore: WESTCARR_S581

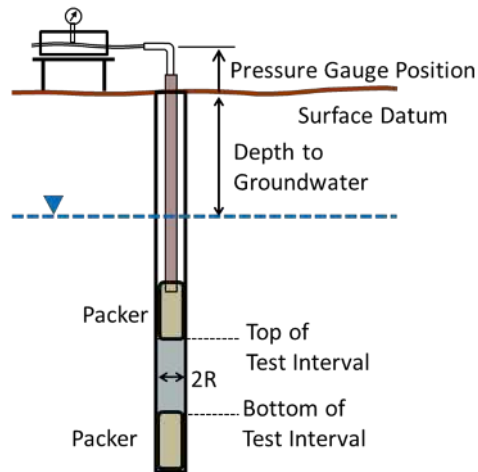
Test Conducted by: TW

Test Date: 17/08/2020

Analysis Performed by: WR

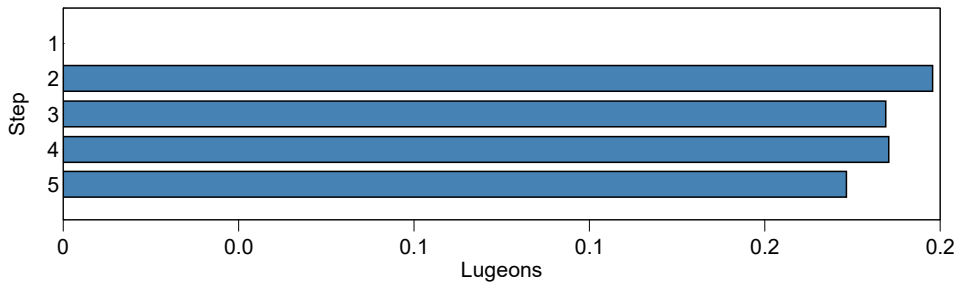
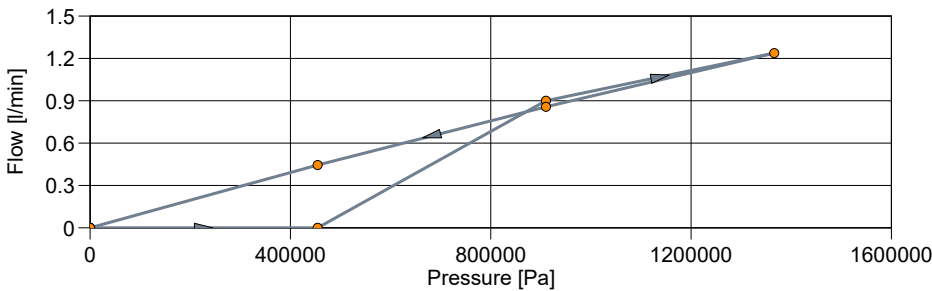
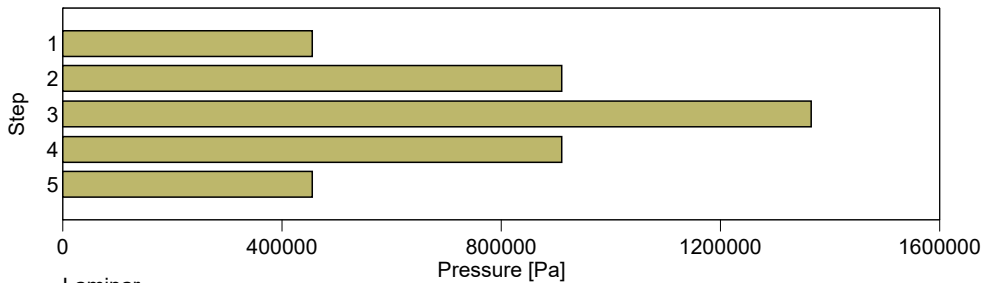
Analysis Date: 17/08/2020

Lithology: Basement



Top of Test Interval: 343.000 m
Bottom of Test Interval: 347.500 m
Length of Test Interval: 4.500 m
Gauge Position: 0.800 m
Depth to Groundwater: 9.300 m
Radius of Test Section: 0.048 m
Dip of bore: 90° from vertical
Vertical Top of Test Interval: 0.000 m
Vertical Bottom of Test Interval: 0.000 m

Step	Pressure [Pa]	Flow Meter Readings [l]												Average Flow Rate [l/min]	Hydraulic Conductivity		
		1	2	3	4	5	6	7	8	9	10	11	12		[m/s]	[m/d]	Lugeon
1	455000																
2	910000	115.5	116.2	117.0	117.8	118.4	120.0	120.8	121.6	123.0	123.6	124.2	125.4	0.9	2.34×10^{-8}	0.00202	0.198
3	1366000	128.4	129.2	130.6	131.8	133.2	134.5	135.8	137.0	138.3	139.8	140.8	142.0	1.2	2.22×10^{-8}	0.00191	0.188
4	910000	143.6	144.6	145.6	146.6	147.5	148.2	149.0	149.9	150.7	151.5	152.2	153.0	0.9	2.22×10^{-8}	0.00192	0.188
5	455000	154.4	155.0	155.3	155.8	156.3	156.8	157.2	157.8	158.2	158.6	158.9	159.3	0.4	2.11×10^{-8}	0.00182	0.179
Average															2.22×10^{-8}	0.00192	0.188



Laminar
Lugeon: 0.19
Hydraulic Conductivity: 2.22×10^{-8} m/s
Hydraulic Conductivity: 0.00192 m/d

Appendix A 3

Laboratory results

CORE ANALYSIS REPORT

Client : AGE Consultants
Well : G1810B - HVO Groundwater

Date : 19/11/2020
File : AB-107189
Cleaning Method : Chloro-meth
Drying Method : Humidity dry

Sample Number	Depth (m)	Dir	Permeability to Air (mD)	Remarks
HYD04_H	47.54	H	0.032	=
HYD04_V	47.59	V	0.014	S.P, lam
HYD15_H	115.73	H	0.062	
HYD15_V	115.79	V	0.048	
HYD25_V	179.62	V	0.007	S.P, lam
HYD25_H	179.66	H	0.009	
HYD33_V	226.05	V	0.004	
HYD33_H	226.10	H	0.004	lam
HYD41_V	274.21	V	0.004	
HYD41_H	274.26	H	0.005	lam
HYD51_H	334.48	H	0.006	
HYD51_V	334.52	V	0.004	S.P, lam

lam lamination
S.P short plug (length < diameter)

ROCK MECHANICS FINAL REPORT



STRATUM
RESERVOIR

UNCONFINED COMPRESSIVE TEST G1810B

(47.48 – 334.41 m)

Coretrac Project N°: AB-107189

Client:
AGE



20 November, 2020

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PAGE 07 | SECTION 02 | RESULTS

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1.1 OPERATIONAL EXCELLENCE POLICY OF STRATUM RESERVOIR

Stratum Reservoir is committed to achieving the highest performance in Operational Excellence. This will be achieved through demonstrated leadership, ethical behavior and adherence to Stratum Reservoir standards. Stratum Reservoir will endeavor to conduct all operations in a manner to protect the environment, communities and the integrity of the company's human, physical and financial resources and ensure alignment with our strategic direction.

Consistent with this policy, **Stratum Reservoir will:**

- Place Quality, Health and Safety, Security and protection of the Environment as core values while never intentionally placing employees, our processes, customers or the communities in which we live and work at risk of loss.
- Aim for zero events and seek continual improvement in Quality, Health and Safety, Security and protection of the Environment, while managing responsible care, process vulnerabilities, public, customer and employee inputs, scientific knowledge and technology and best business practices to exceed customer expectations.
- Provide consistent framework for establishing and executing Quality, Health and Safety, Security and Environmental objectives.
- Demonstrate personal commitment to seek the prevention and elimination of employee injury, ill health and non-productive time while holding our managers and employees accountable for performance in their area(s) of responsibility.
- Communicate and consult with our employees, interested parties and our customers on Quality, Health and Safety, Security and protection of the Environment.
- Actively seek ways to mitigate and minimize identified service-related product risks, workplace hazards, process inefficiencies, process variance and the prevention of pollution associated with our products and services.
- Comply with our Rules to Live By and all applicable laws, regulations, standards and other requirements that the organization subscribes. Where adequate laws do not exist, we will apply standards reflecting our commitment to Quality, Health and Safety, Security, protection of the Environment and customer satisfaction.
- Set, review and act upon our Key Performance Indicators, objectives and targets.
- Commit to continually improve the Quality, Health and Safety, Security and Environmental Management System through the integration of risk-based thinking, lessons learned, and management philosophy.

01

1.1 Sample preparation

1.2 Equipment

1.3 Procedure

1.1 SAMPLE PREPARATION

AB-107189 called for unconfined compressive strength testing on six samples recovered from a depth range of 47.48 m to 334.41 m. The sample preparation and testing procedures are described in detail below.

A total of six vertically oriented samples were collected from separate depths for compressive strength testing. In all six cases 1" diameter plugs were trimmed to length (ideally 2"+, min. 1.4") and their ends were ground square, flat, and parallel using 60-grit sandpaper before being finished with 220-grit paper. Samples were determined to be ready for testing when the ends were flat to a precision of $\pm 0.001"$. After preparation the dimensions and mass of the samples were recorded, and the nominal density calculated (Table 1).

Sample No.	Depth (m)	Test Type	Mass (g)	Length (in)	Diameter (in)	L:D Ratio	Nominal Density (g/cc)
HYD04	47.48	UCS	63.52	2.1040	0.9945	2.12	2.37
HYD15	115.67	UCS	62.79	2.1151	0.9955	2.12	2.33
HYD25	179.80	UCS	63.80	2.0548	0.9946	2.07	2.83
HYD33	226.08	UCS	63.54	1.9648	0.9938	1.98	2.54
HYD41	274.33	UCS	51.89	1.6503	0.9943	1.66	2.47
HYD51	334.41	UCS	68.27	2.1233	0.9936	2.14	2.53

Table 1: Experimental samples used for UCS testing as part of this study.

1.2 EQUIPMENT

All tests were conducted in a **GCTS RTR-1000** style triaxial deformation apparatus using experimental setups and methods described in detail below.

GCTS RTR-1000 SPECIFICATIONS:

- 20,000 psi (140 MPa) confining pressure/pore pressure
- 225,000 lbf (1000 kN) axial load
- 200°C temperature
- 1.5" y 1" dia. loading platens w/ & w/o Ultrasonic (ULT) Velocity Capability
- Axial & Circumferential Deformation Measurement



1.3 UNCONFINED COMPRESSIVE STRENGTH TEST (UCS)

- **Goal**
 - To determine the compressive strength and static elastic parameters of tested sample
- **Sample Description**
 - 1" dia. x 2" long (1.4" min.)
 - 1.5" dia. x 3" long (2.1" min.)
 - Note: Minimum recommended sample lengths are set at a L:D ratio of 1.4:1 to avoid the influence of friction end effects on the results of the test. Ultimately the stringency/leniency of L:D ratio are determined by the client.
 - During preparation samples are determined to be ready for testing when their ends are parallel to +/- 0.001".
 - By default measurements are conducted on vertically oriented plugs, however testing on horizontal or oblique samples is equally possible.
- **Default Testing Conditions**
 - Strain Rate
 - Default: $5 \times 10^{-6} \text{ s}^{-1}$
 - Optional: $1 \times 10^{-6} \text{ s}^{-1}$, $5 \times 10^{-7} \text{ s}^{-1}$, ultimately strain rate is determined by the client's wishes and time/budget constraints
 - Saturation.
 - Default: As-Received
 - Optional:
 - Saturation w/ 7% KCl brine solution
 - Saturation w/ lab created approximation of in-situ brine
 - Saturation w/ other fluid, to be discussed w/ client
- **Testing Procedure**
 - Sample Assembly & Test Setup
 - Sample is fitted with heat shrink collars at top and bottom in order to affix the sample to the loading platens, but is not fully jacketed.
 - Axial LVDTs are mounted to the loading platens & circumferential deformation chain is wrapped around the mid-point of the length of the sample.
 - Fully instrumented sample is inserted into the load frame.
 - Pressure vessel wall is lowered over the sample to ensure that it is centered underneath the axial loading ram, and to ensure self-similarity of loading orientation with Triaxial Compressive Strength tests.
 - Sample Loading
 - Once fitted into the load frame with the vessel wall lowered, recording is initiated at a rate of 0.5-5 Hz. Ultimately the recording rate is up to the client, however this rate is more than sufficient to capture the mechanical properties of interest.
 - The axial loading ram is advanced at a rate of 0.1"/hour until it is seated onto the sample, and a load of ~150 lbf is acting on the sample.

- At this point the deformation feedback is switched to the two axial LVDTs directly monitoring deformation of the sample, and the sample is deformed at the previously defined strain rate (default: $5 \times 10^{-6} \text{ s}^{-1}$). Loading continues at this constant rate until the sample fails.
 - Following sample failure, the axial loading ram is retracted at a rate of 0.25"/min. for 1 minute to remove the axial load. Following removal of axial load, data recording is halted.
- Post-test Procedure
 - Following testing the pressure vessel is lifted, the deformation sensors are removed from the sample, and the sample is removed from the testing apparatus and returned to storage. (Optional: if post-test photography/CT are requested, sample will be forwarded to those departments).
- **Deliverables**
 - Unconfined Compressive Strength (peak total axial stress)
 - Static Young's modulus
 - Based on average measurement of 2 axial LVDTs
 - Measured over a data range of 10% of compressive strength of sample, where slope of Differential Stress v. Axial Strain curve is at its maximum
 - Static Poisson's ratio
 - Based on circumferential strain measurement made using chain gauge device.

Q2

2.1 UCS Results

2.2 Plots

2.3 Summary

2.1 UCS RESULTS

Six vertically oriented samples were collected from a depth range of 47.48 m to 334.41 m, and subjected to unconfined compressive strength testing. Samples HYD33 (226.08m) and HYD51 (334.41m) were by far the strongest of the samples tested, exhibiting a compressive strength of 11,241 psi and 12,038 psi respectively, while sample HYD15 (115.67 m) was the weakest sample with a compressive strength of 2,902 psi (Table 2). In addition to being the strongest sample, HYD51 was also the stiffest sample tested, exhibiting a static Young's modulus (that as measured by physical deformation of the sample) of 1.89×10^6 psi. The sample HYD04 (47.48) showed the most elastic behavior with a static Young's modulus of 0.56×10^6 psi. Static Poisson's ratio of the five samples ranged from 0.17 to 0.30.

Sample No.	Depth (m)	Rock Type	Confining Pressure (psi)	Compressive Strength (psi)	Static Young's Modulus ($\times 10^6$ psi)	Static Poisson's Ratio
HYD04	47.48	Sandstone	0	3197	0.56	0.29
HYD15	115.67	Sandstone	0	2902	1.28	0.17
HYD25	179.80	Sandstone	0	7780	1.55	0.30
HYD33	226.08	Clayey Siltstone	0	11247	1.72	0.21
HYD41	274.33	Clayey Siltstone	0	7901	0.83	0.19
HYD51	334.41	Clayey Siltstone	0	12038	1.89	0.28

Table 2: Results of UCS test conducted on samples tested as part of this study. Color coding refers to the color of the data points in Figures 2-4.

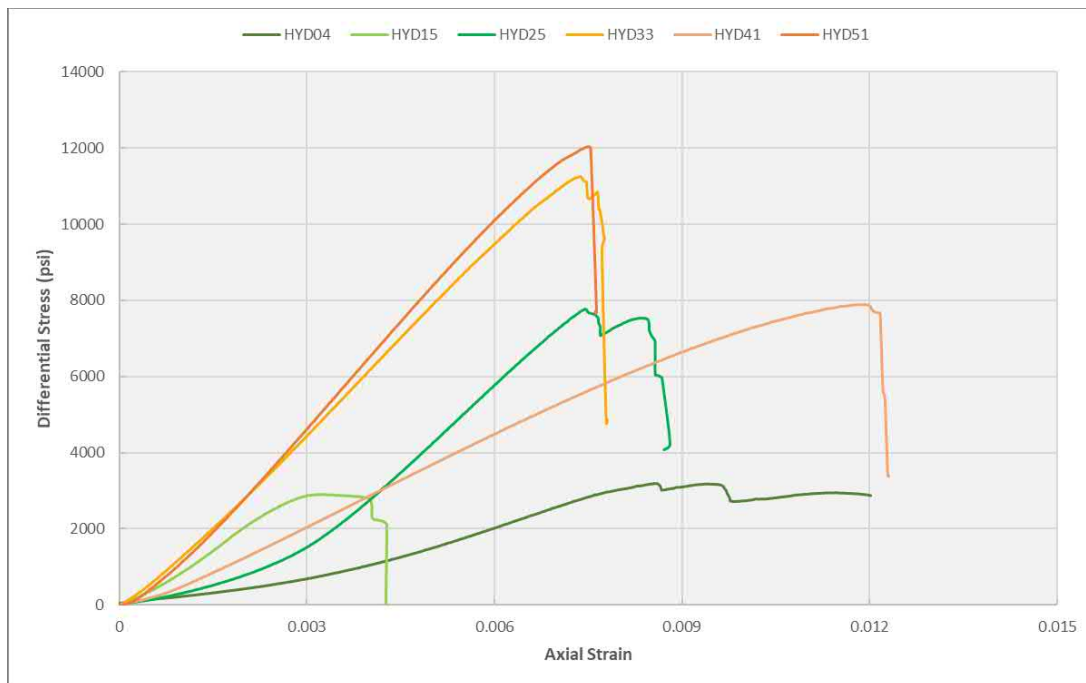
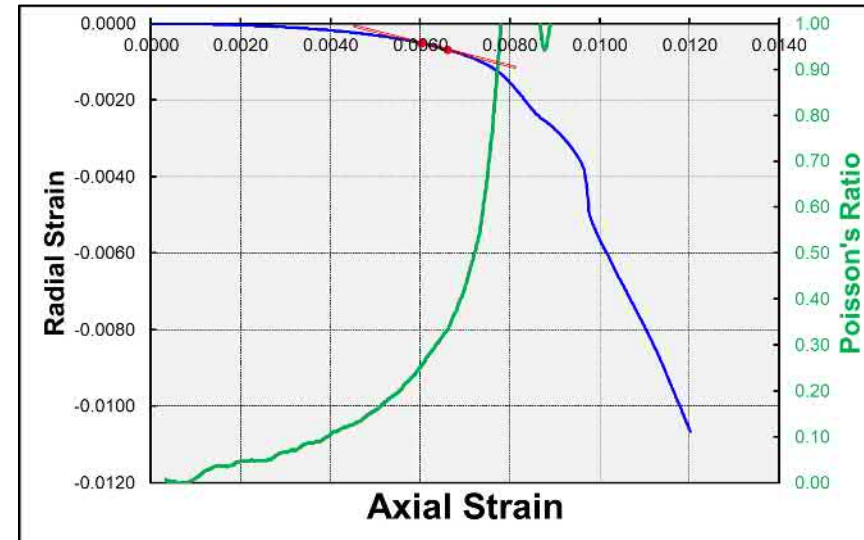
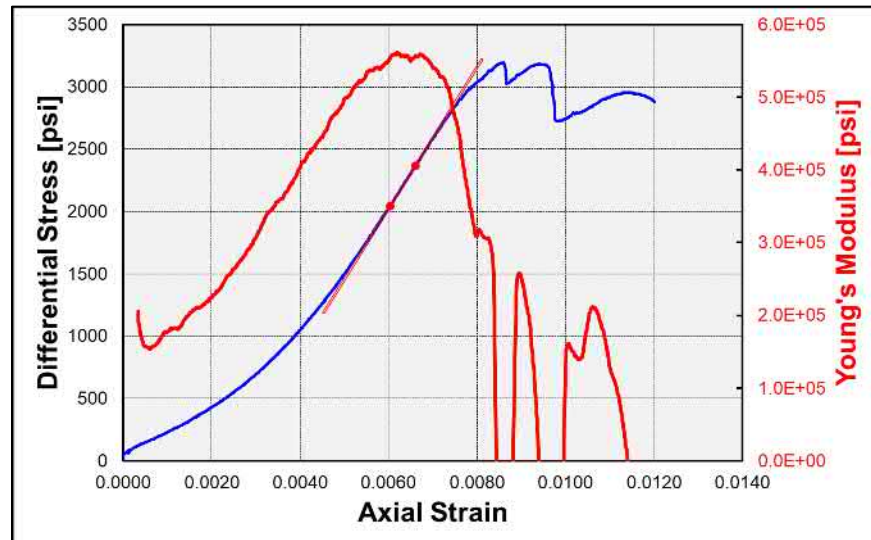
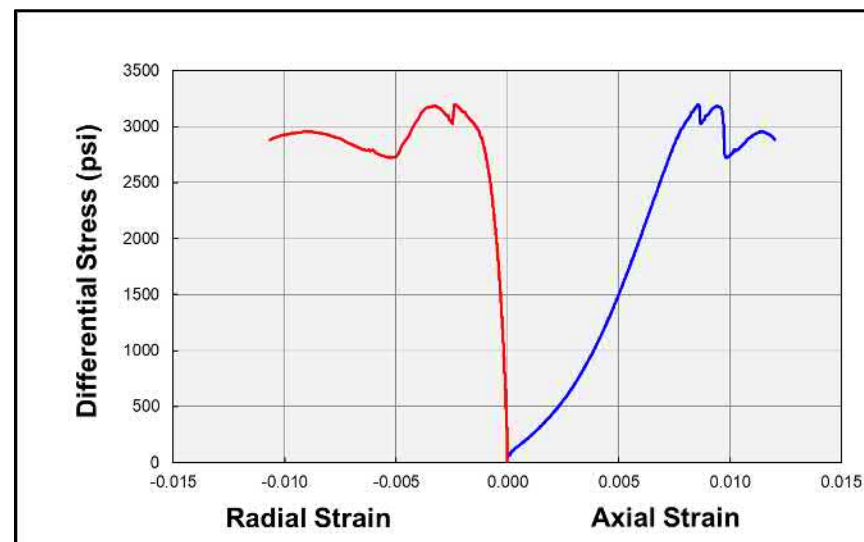


Figure 1: Stress-Strain curves of UCS tests conducted as part of this study. Results of testing on Sandstones are in shades of blue, results of tests on Siltstones are in shades of orange.

2.2 PLOTS

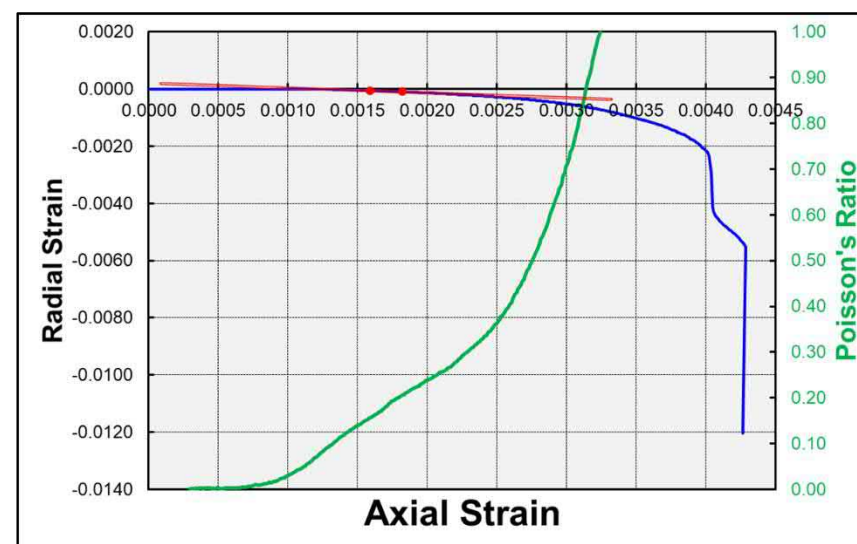
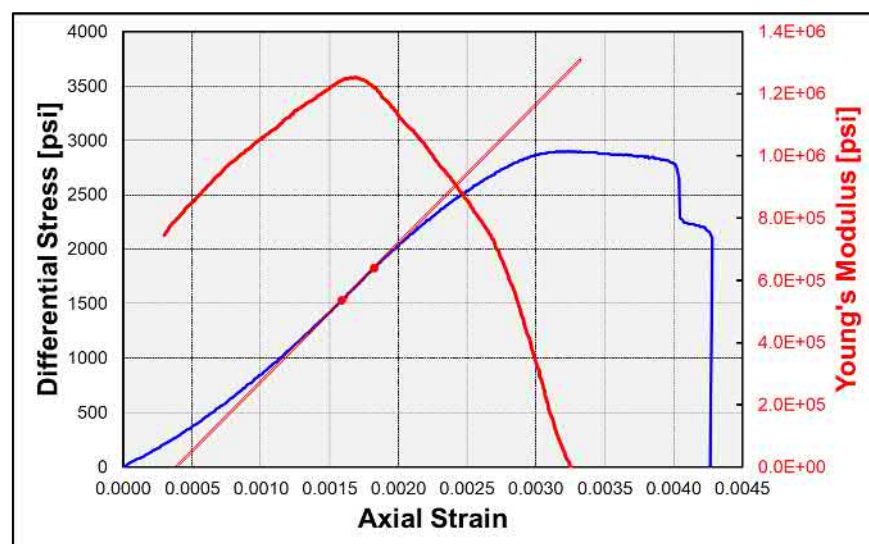
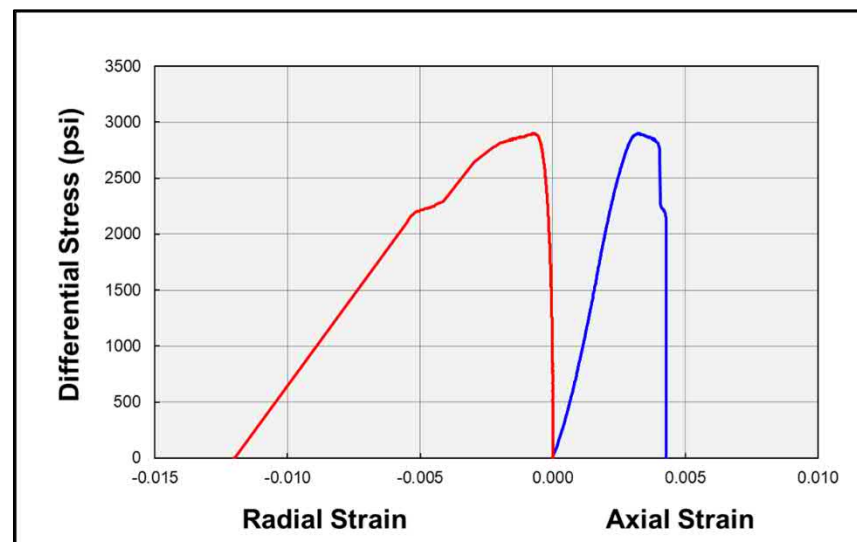
HYD04

		Data Range	
Company	AGEC	Young's Modulus (10^6 psi)	0.56 64%
Project	G1810B - HVO Groundwater	Poisson's Ratio	0.29 74%
Sample No.	HYD04	Young's Modulus (10^6 psi)	0.44 33%
Depth (m)	47.48	Poisson's Ratio	0.12 43%
Length (in)	2.1040	Young's Modulus (10^6 psi)	0.55 57%
Diameter (in)	0.9945	Poisson's Ratio	0.24 67%
L:D Ratio	2.12		
Bulk Density (g/cc)	2.37		
Confining Pressure (psi)	0		
Compressive Strength (psi)	3197		
Saturation State	As Is		



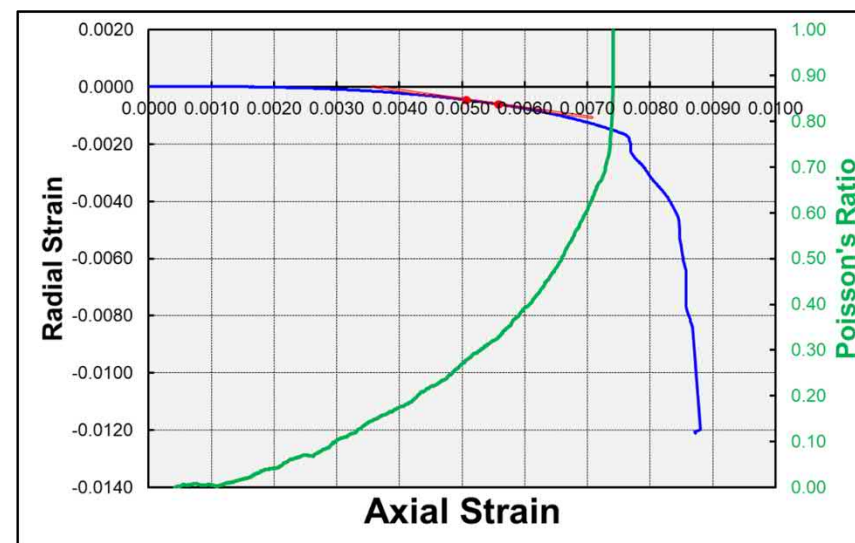
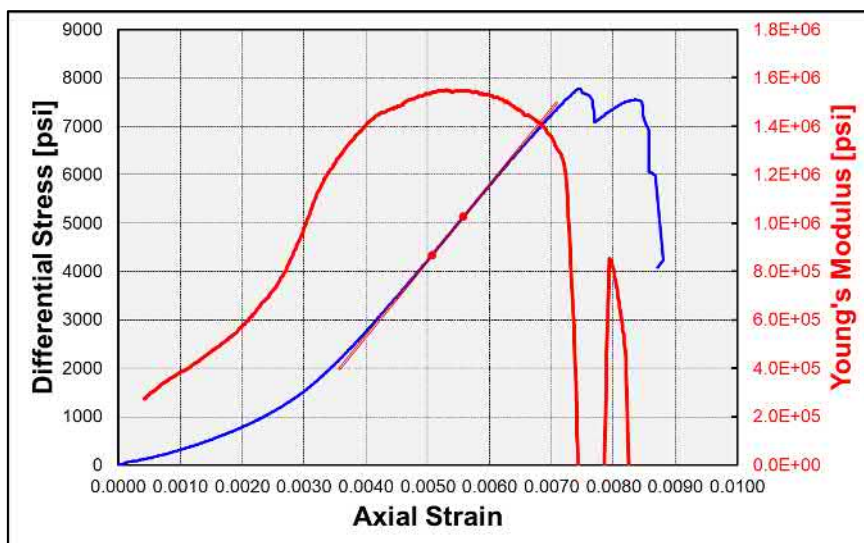
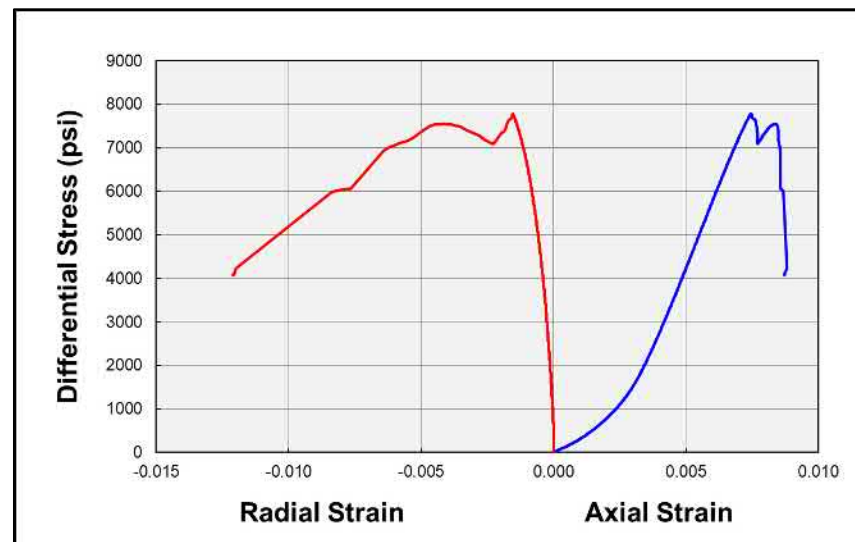
HYD15

		Data Range	
Company	AGEC	Young's Modulus (10^6 psi)	1.28 53%
Project	G1810B - HVO Groundwater	Poisson's Ratio	0.17 63%
Sample No.	HYD15	Young's Modulus (10^6 psi)	1.14 33%
Depth (m)	115.67	Poisson's Ratio	0.07 43%
Length (in)	2.1151	Young's Modulus (10^6 psi)	1.24 57%
Diameter (in)	0.9955	Poisson's Ratio	0.20 67%
L:D Ratio	2.12		
Bulk Density (g/cc)	2.33		
Confining Pressure (psi)	0		
Compressive Strength (psi)	2902		
Saturation State	As Is		



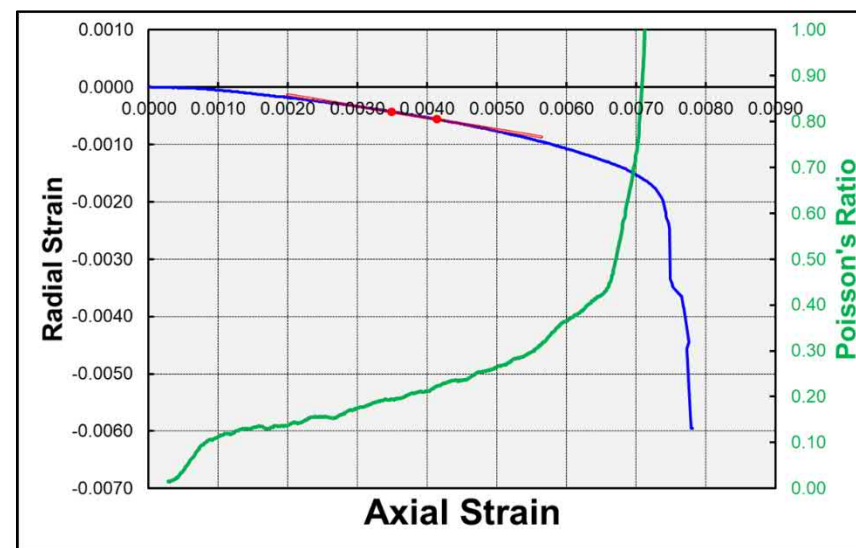
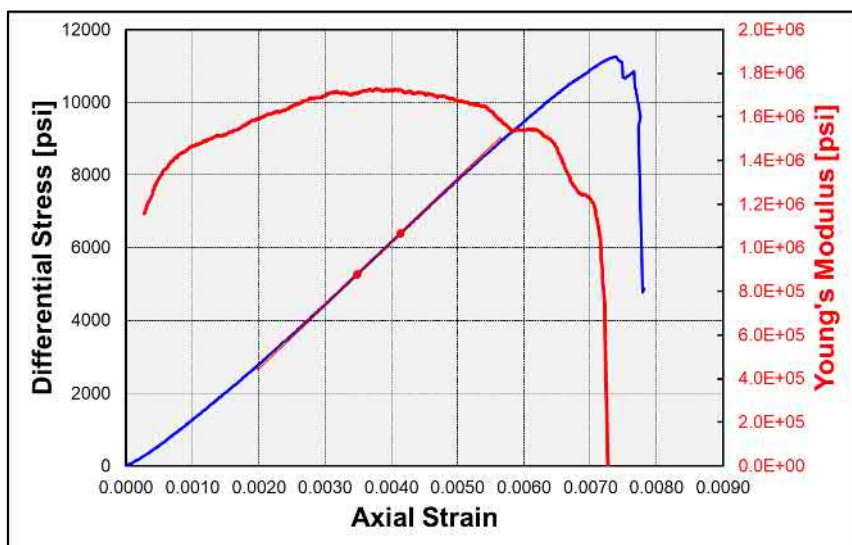
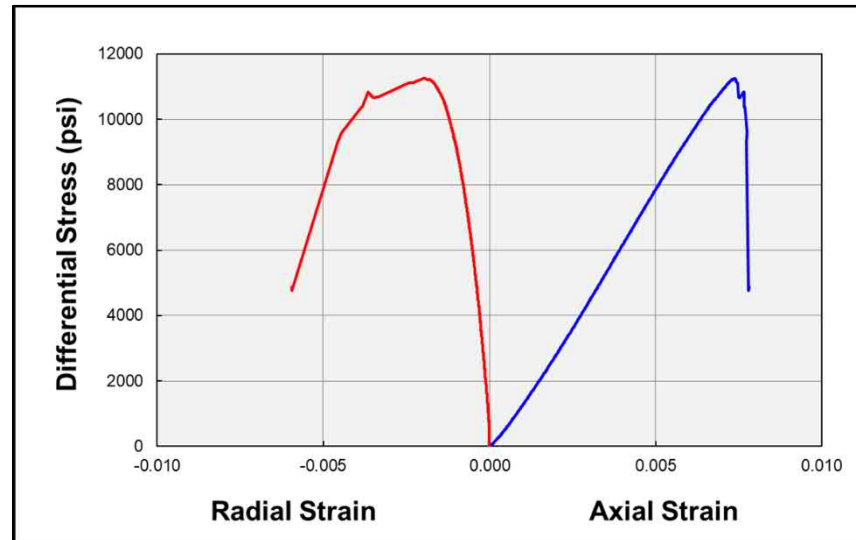
HYD25

			Data Range	
Company	AGEC	Young's Modulus (10 ⁶ psi)	1.55	56%
Project	G1810B - HVO Groundwater	Poisson's Ratio	0.30	66%
Sample No.	HYD25	Young's Modulus (10 ⁶ psi)	1.43	33%
Depth (m)	179.80	Poisson's Ratio	0.18	43%
Length (in)	2.0548	Young's Modulus (10 ⁶ psi)	1.54	57%
Diameter (in)	0.9240	Poisson's Ratio	0.31	67%
L:D Ratio	2.22			
Bulk Density (g/cc)	2.83			
Confining Pressure (psi)	0			
Compressive Strength (psi)	7780			
Saturation State	As Is			



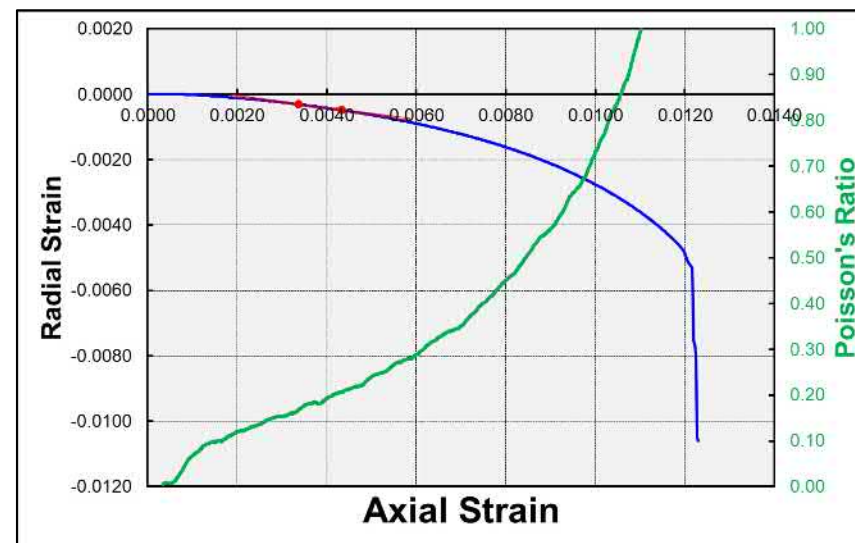
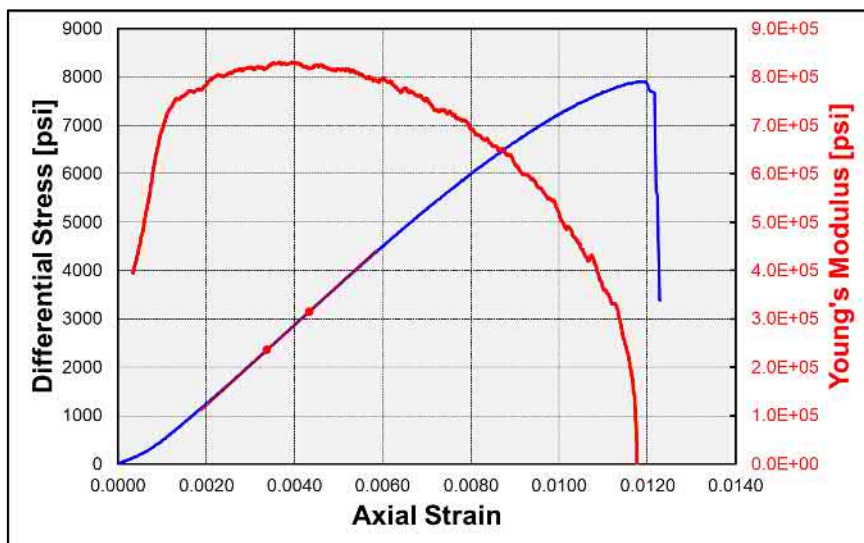
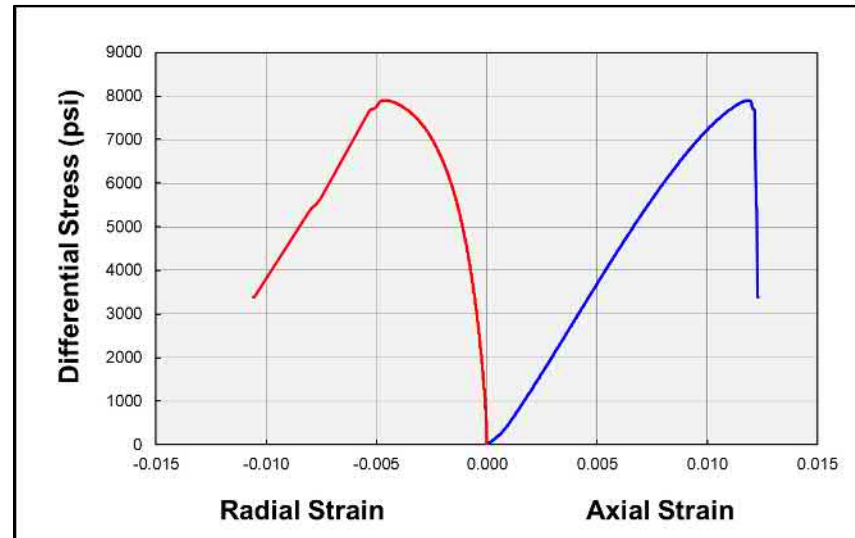
HYD33

			Data Range	
Company	AGEC	Young's Modulus (10^6 psi)	1.72	47%
Project	G1810B - HVO Groundwater	Poisson's Ratio	0.21	57%
Sample No.	HYD33	Young's Modulus (10^6 psi)	1.69	33%
Depth (m)	226.08	Poisson's Ratio	0.17	43%
Length (in)	1.9648	Young's Modulus (10^6 psi)	1.71	57%
Diameter (in)	0.9938	Poisson's Ratio	0.24	67%
L:D Ratio	1.98			
Bulk Density (g/cc)	2.54			
Confining Pressure (psi)	0			
Compressive Strength (psi)	11247			
Saturation State	As Is			



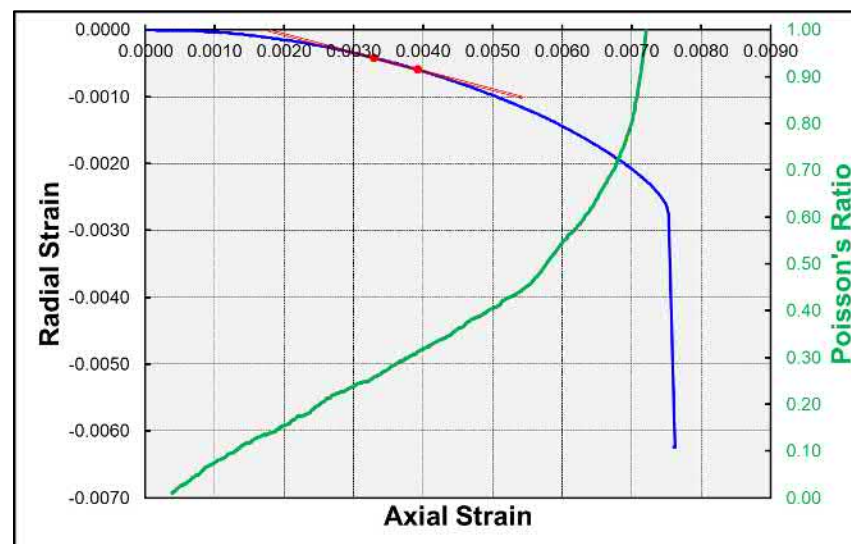
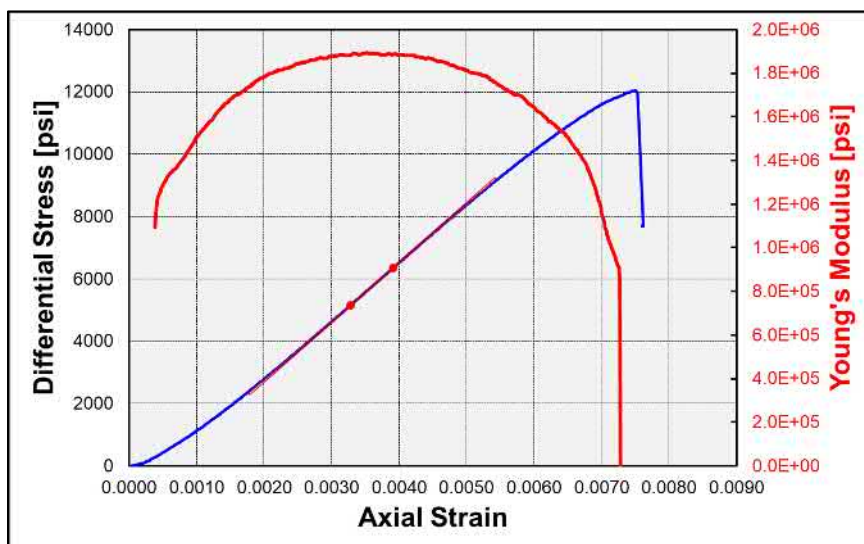
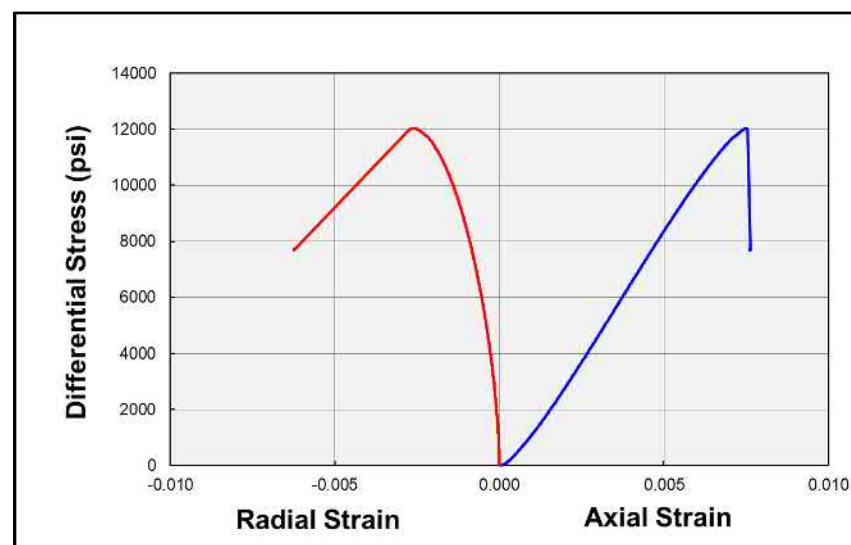
HYD41

		Data Range	
Company	AGEC	Young's Modulus (10^6 psi)	0.83 30%
Project	G1810B - HVO Groundwater	Poisson's Ratio	0.19 40%
Sample No.	HYD41	Young's Modulus (10^6 psi)	0.82 33%
Depth (m)	274.33	Poisson's Ratio	0.20 43%
Length (in)	1.6503	Young's Modulus (10^6 psi)	0.77 57%
Diameter (in)	0.9943	Poisson's Ratio	0.32 67%
L:D Ratio	1.66		
Bulk Density (g/cc)	2.47		
Confining Pressure (psi)	0		
Compressive Strength (psi)	7901		
Saturation State	As Is		



HYD51

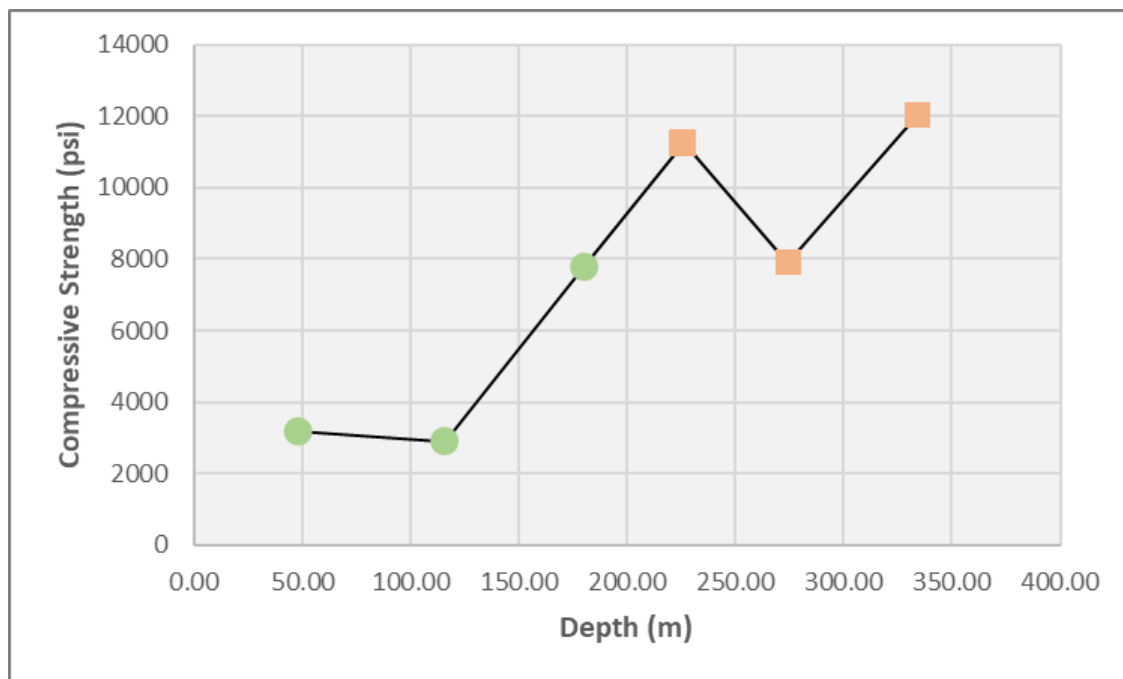
		Data Range		
Company	AGEC	Young's Modulus (10 ⁶ psi)	1.89	43%
Project	G1810B - HVO Groundwater	Poisson's Ratio	0.28	53%
Sample No.	HYD52	Young's Modulus (10 ⁶ psi)	1.88	33%
Depth (m)	334.41	Poisson's Ratio	0.23	43%
Length (in)	2.1233	Young's Modulus (10 ⁶ psi)	1.86	57%
Diameter (in)	0.9936	Poisson's Ratio	0.36	67%
L:D Ratio	2.14			
Bulk Density (g/cc)	2.53			
Confining Pressure (psi)	0			
Compressive Strength (psi)	12038			
Saturation State	As Is			



2.3 SUMMARY

The six tested samples can be lithological described as either sandstones (HYD04, HYD15, & HYD25) or clayet siltstones (HYD33, HYD41, HYD51). Unconfined compressive strength tests were conducted on all six samples, with measurements of UCS, static Young's modulus, and static Poisson's ratio. In addition to the data presented above our results are summarized as follows.

The compressive strength of the tested samples ranged from 2,902 psi to 12,038 psi, and indicates a general increase in UCS with increasing depth (Figure 2 – Top). With exception of sample HYD41 (0.83×10^6 psi) which shows a low Young's modulus value, we see an increase in static Young's modulus with increasing sample depth (Figure 2 – Middle). And with the exception of samples HYD04 (0.56×10^6 psi) and HYD41 (0.83×10^6 psi) which present a low Young's moduli values, all the other samples show a Young's modulus in the range of 1.28×10^6 psi to 1.89×10^6 psi. Static Poisson's ratio ranged from 0.17 (low PR) to 0.30 (which is quite typical), and showed no clear trend with depth (Figure 2 – Bottom).



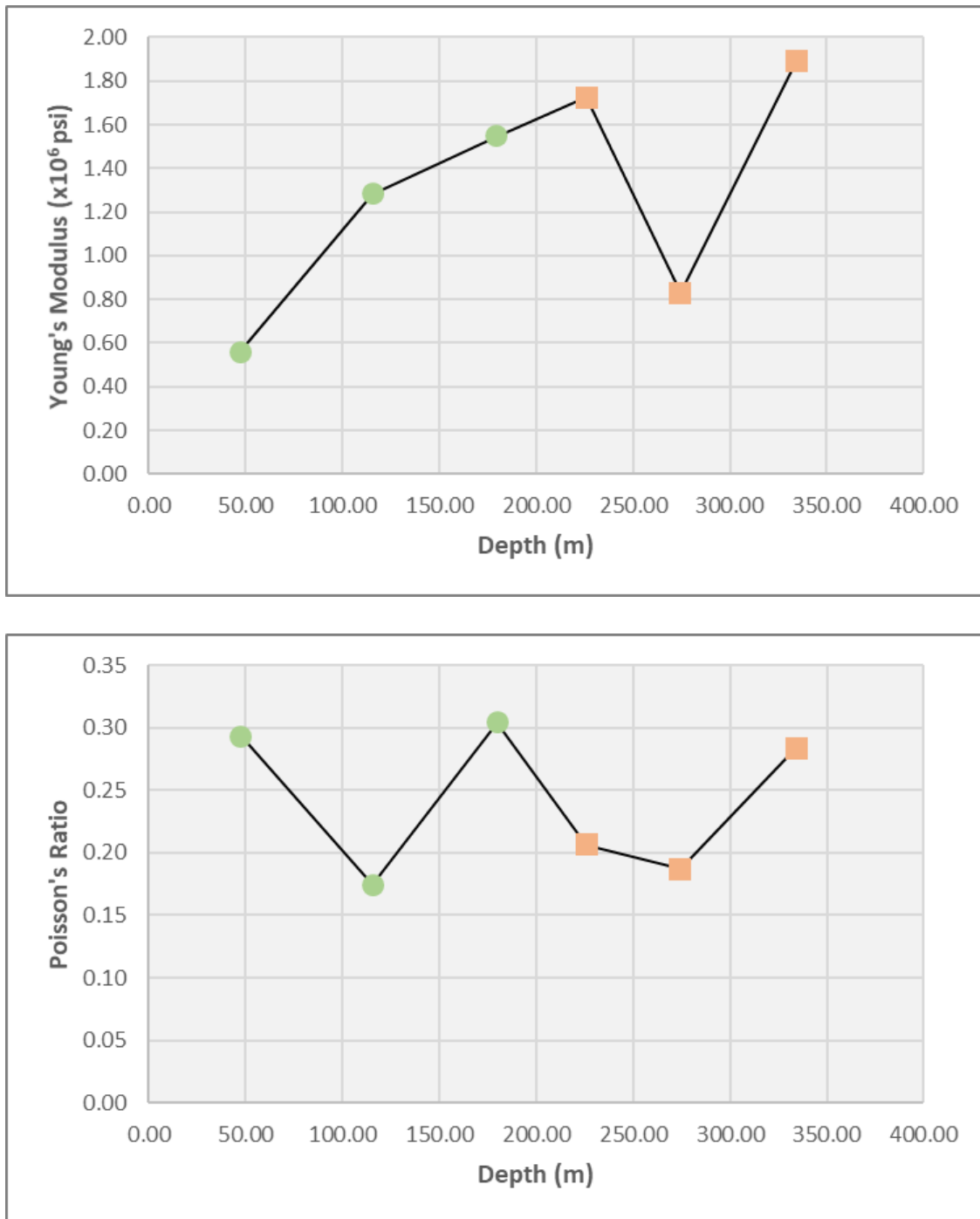


Figure 2: Compressive strength (Top), static Young's modulus (Middle), and static Poisson's ratio (Bottom) as a function of depth for the samples tested as part of this study.

03

3.1 Personnel Involved

3.2 Contacts

3.1 PERSONNEL INVOLVED

- Evelyn Azuaje (Mexico Lab Manager)
- Geraldine Pedrero (Mexico Technical Sales & Rock Mechanics)
- Juan D. Jacinto (Rock Mechanics)

3.2 CONTACTS

Evelyn Azuaje

Mexico Lab Manager

Stratum Reservoir México | Av Antimonio Lote 2 S/N | Ciudad Industrial | Villahermosa, Tabasco | Mexico |
C.P. 86010 | Main: + 52.993.3581900 Ext. 702405 | Mobile: +52 (993)-177 6782
evelyn.azuaje@stratumreservoir.com | www.stratumreservoir.com

Geraldine Pedrero

Mexico Rock Mechanics BD

Stratum Reservoir México | Av Antimonio Lote 2 S/N | Ciudad Industrial | Villahermosa, Tabasco | Mexico |
C.P. 86010 | Main: + 52.993.3581900 Ext. 702393 | Mobile: + 52 (993)- 1474350
geraldine.pedrero@stratumreservoir.com | www.stratumreservoir.com



Appendix B

HVO Groundwater monitoring network

Table B 1 HVO Groundwater monitoring network

Bore ID	Easting	Northing	Top of casing (mAHD)	Ground elevation (mAHD)	Bore depth (mBGL)	Screen elevation (mBGL)	Formation
BC1	312421	6400874	66.38	66.08	8.51	-	Alluvium
4038C	308502	6403116	71	70	13	6 - 12	Alluvium
CHPZ11A	313429	6402129	62.9	61.9	10.6	7.2-10.6	Alluvium
BZ1-2	311472	6400483	71.8	71.39	9.73	7 - 10	Alluvium
4052P	307924	6402680	73.7	72.6	15.6	8.4-14.4	Alluvium
CHPZ14A	312883	6401639	66.4	66	16	12.8-16	Alluvium
CHPZ5A	312926	6401838	65.8	65.4	15.5	12.9-15.5	Alluvium
HV3	310776	6400546	68.64	67.7	16.6	-16.7	Alluvium
4035P	308386	6402778	71.5	70.5	12.8	5.7-11.7	Alluvium
4033P	308877	6402939	70.9	69.9	10.1	7 - 17	Alluvium
CGW6	308756	6402770	70.9	70.1	21.8	-	Alluvium
CGW45A	308044	6403349	72.65	72.18	13.97	-	Alluvium
CGW46A	308415	6403276	71.95	71.95	11.52	-	Alluvium
4053P	308112	6402680	72.6	71.6	15.8	8.8-14.8	Alluvium
CHPZ9A	313538	6402383	62.5	62.1	11.2	8-11.2	Alluvium
CHPZ7A	313600	6402238	60.4	60.3	11.2	8 - 11	Alluvium
GW_101	304373	6406727	100.54	-	12	9 - 12	Alluvium
BZ1-1	311472	6400483	71.79	71.39	20.99	21-24	Alluvium
GW_106	309091	6405223	82.26	-	30	24-27	Alluvium
CHPZ8A	313502	6402051	60.85	60.05	6.25	4 - 6	Alluvium
GW_100	303728	6406435	89.55	-	6	4 - 6	Alluvium
CHPZ2A	312941	6401539	65.78	65.14	15.73	12.6-15.6	Alluvium
CHPZ1A	312823	6401692	65.89	64.86	16.23	13.2-16.2	Alluvium
CGW32	308598	6404872	79.06	78.48	22.52	14-23	Alluvium
BUNC45A	313667	6402055	73.2	72.9	21.2	17.3-20.3	Alluvium
4037P	308276	6402701	71.77	70.74	14.37	8.28-14.28	Alluvium
CFW57	310084	6402053	71.5	70.8	16.4	8.4-15.4	Alluvium
PZ1CH200	312643	6402254	62.16	62.21	10.59	8.9-11.1	Alluvium
D317_ALL	315044	6396018	59.34	59.05	14.65	9.2-12.2	Alluvium
4034P	308238	6402958	71.46	71.15	14.69	5.6-14.6	Alluvium
4040P	308674	6402723	70.13	69.16	11.94	5.9-11.9	Alluvium
4032P	308608	6402944	70.29	69.35	13.46	7.44-13.44	Alluvium
C919_ALL	315193	6395657	58.24	57.94	11.46	7.5-13.5	Alluvium
CFW55R	310439	6402180	70.28	69.78	16.1	10.4-15.4	Alluvium
CHPZ3A	313087	6401756	63.86	63.18	13.88	10.9-13.9	Alluvium

Bore ID	Easting	Northing	Top of casing (mAHD)	Ground elevation (mAHD)	Bore depth (mBGL)	Screen elevation (mBGL)	Formation
S4	312614	6401065	67.42	66.32	11.74	-	Alluvium
PZ3CH800	312519	6401674	64.15	64.2	10.52	-	Alluvium
APP_FARM	315492	6394540	54.7	53.88	8.71	-	Alluvium
CFW56	310333	6402255	-	69.9		-	Alluvium
PZ4CH1380	312192	6401175	65.03	65.11	14.66	-	Alluvium
CGW53A	309606	6402233	70.53	69.83	14.04	-	Alluvium
Hobden	312540	6401093	67.2	66.52	13.93	-	Alluvium
CGW49	308778	6403084	69.57	69.05	12.78	-	Alluvium
S6	312994	6410517	-	69	-	-	Alluvium
HV4	310069	6401183	-	67	-	13	Alluvium
PZ6CH2450	311233	6400727	67.2	67.1	14.1	>14.5-15	Alluvium
CHPZ13A	313009	6401801	66.3	65.5	15.3	10.6-15.3	Alluvium
BZ2B	311668	6400560	-	71.3	-	-	Alluvium
BZ8-1	312685	6401010	-	67.8	-	-	Alluvium
BUNC12	313180	6401753	-	75.9	-	-	Alluvium
BUNC13	313145	6401730	-	78.6	-	-	Alluvium
PZ2CH400	312632	6402049	62.63	62.68	11.22	9.9 - 11.2	Alluvium
NPz3_HVO	307024	6407896	147.04	146.38	99.14	93.6-96.6	Alluvium
HG2	312469	6400886	67.4	66.77	15.49	1 - 17	Alluvium
CGW39	308566	6403694	70.84	70.31	12.92	5 - 14	Alluvium
CHPZ10A	313334	6402297	63.37	62.57	12.04	9.5-12.5	Alluvium
CHPZ12A	313238	6402014	63.43	63.13	11.55	9.5-12.5	Alluvium
CHPZ4A	312903	6402123	66.19	65.45	12.66	9.5-12.5	Alluvium
PB01_ALL	315441	6396333	54.61	54.37	10	9.5-12.5	Alluvium
CGW54A	310196	6402159	70.8	70	17.1	-	Alluvium
HV3_2	310776	6400546	67.67	67.22	16.55	-	Alluvium
CGW47A	308731	6403405	71	70.39	16.03	-	Alluvium
PZ5CH1800	311851	6400926	66.2	66.28	15.08	-	Alluvium
4039C_1	308468	6402673		70.7		-	Alluvium
BZ3-1	311840	6400640	70.29	69.97	26.18	-	Alluvium
CGW55A	309840	6402457	71.04	70.56	17.98	-	Alluvium
CGW52A	309906	6402255	71.36	70.61	17.8	-	Alluvium
GW9702	316436	6401479	-	98.6	-	-	Coal seam
GW9701	315901	6401798	-	93.6	-	-	Coal seam
F1_WF533	316607	6398247	56	-	-	-	Coal seam
H5038_5	309950	6398920	-	111.7	-	-	Coal seam
CFW57A	310088	6402049	71.8	70.9	7.9	1.5-6	Coal seam

Bore ID	Easting	Northing	Top of casing (mAHD)	Ground elevation (mAHD)	Bore depth (mBGL)	Screen elevation (mBGL)	Formation
H5032_5	309960	6398320		116.3	-	-	Coal seam
C1_WJ039	317142	6400707	70.26	71.2	-	-	Coal seam
GW9710	316700	6400486		82.6	-	-	Coal seam
D317_WDH	315044	6396018	59.5	-	-	-	Coal seam
D406_WDH	313931	6396074	-	57	-	-	Coal seam
4039C_2	308468	6402673	-	70.7	-	-	Coal seam
SR002	319079	6394620	57.38	56.99	11.21	-	Coal seam
E5038_5	309650	6398915	-	122.4	-	-	Coal seam
BZ8-3	312685	6401010	-	67.8	-	-	Coal seam
BZ5-2	312192	6400804	-	66.9	-	-	Coal seam
BZ5-1	312192	6400804	-	66.9	-	-	Coal seam
CHPZ13D	313014	6401801	65.4	65.1	17.3	23.4-20.5	Coal seam
BUNC46D	313328	6401782	66	65.8	24	21-24	Coal seam
BUNC39A_D	313499.9	6401823	66.792	66.792	19.9	16.6-19.9	Coal seam
BUNC44D	313601	6401922	65.9	65.2	16.4	13-16	Coal seam
CGW47	308731	6403405	70.83	70.39	14.76	-	Coal seam
CGW45	308044	6403349	72.18	72.18	28.6	-	Coal seam
CGW54	310196	6402159	69.22	69.95	36.58	-	Coal seam
CHPZ14D	312891	6401639	66.2	65.9	18.8	28.8-25.6	Coal seam
BZ1-3	311472	6400483	71.79	71.39	55.25	53-56	Coal seam
D406_BFS	313932	6396075	57.68	57.36	61.33	51-57	Coal seam
BZ2A_1	311671	6400561	71.72	71.17	49.71	49.1-52.1	Coal seam
C621_BFS	315431	6395316	58.69	58.37	57.45	47-56	Coal seam
CHPZ8D	313508	6402047	61.1	59.89	8.84	6 - 9	Coal seam
D010_BFS	314356	6395688	56.33	55.94	68.05	60-66.5	Coal seam
B334_BFS	316693	6394083	73.67	73.37	65.3	58.5-64.5	Coal seam
C130_BFS	316409	6394911	63.32	63.36	65.27	55.5-64.5	Coal seam
C630_BFS	316387	6395302	69.15	68.81	49.1	40.3-48.3	Coal seam
D317_BFS	315044	6396019	59.97	59.64	45.27	39-44.2	Coal seam
BZ4A_2	312029	6400705	74.47	73.88	41.41	38-41	Coal seam
D807_BFS	314003	6396485	60.29	59.94	41.37	36-41	Coal seam
D2_WH236	314769	6395832	57	56.67	53.47	43-52.5	Coal seam
C130_AFS1	316409	6394911	63.56	63.23	42.16	42-44	Coal seam
BZ3-3	311840	6400640	70.33	69.97		41.5-44.5	Coal seam
SR011	317699	6394412	87.31	86.82	46.91	41.4-47.4	Coal seam
D612_AFS	314526	6396315	62.55	62.16	24.01	-	Coal seam
D612_BFS	314526	6396315	62.44	62.1	35.06	-	Coal seam

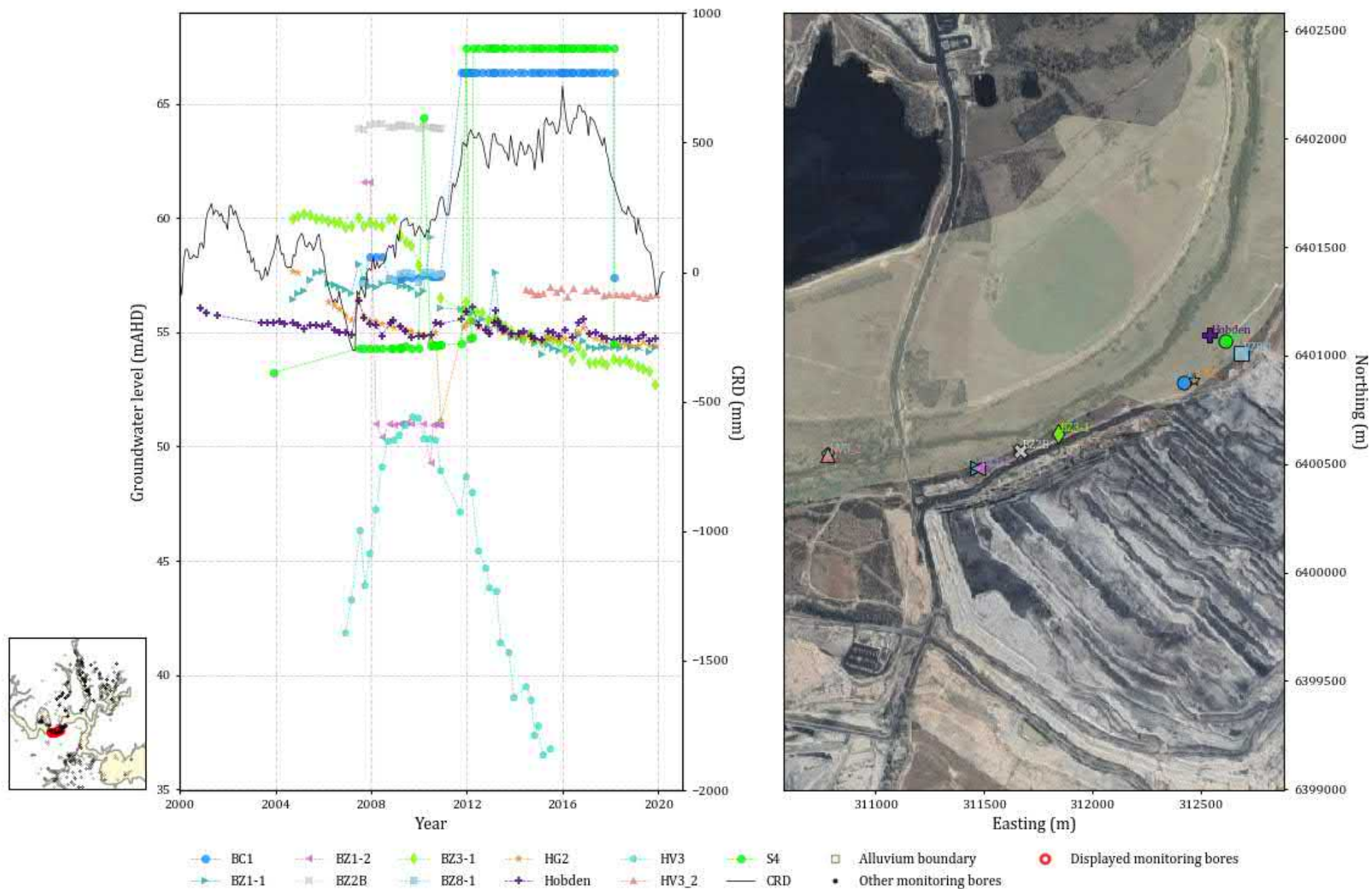
Bore ID	Easting	Northing	Top of casing (mAHD)	Ground elevation (mAHD)	Bore depth (mBGL)	Screen elevation (mBGL)	Formation
SR004	318994	6395506	78.92	78.15	39.87	-	Coal seam
CGW53	309606	6402333	71.1	70.5	43	-	Coal seam
GA3	310127	6400940	67.02	67.02	12	-	Coal seam
CGW46	308415	6403276	71.95	71.95	12.28	-	Coal seam
4039C_3	308468	6402673	-	70.7	-	-	Coal seam
BC1a	312421	6400874	66.36	66.08	21.7	-	Coal seam
B925_BFS	315930	6394599	62.82	62.45	87.03	81-87	Coal seam
B631_BFS	316434	6394314	72.44	72.11	86.03	78-84	Coal seam
C613_BFS	314689	6395244	63.95	63.64	85.49	77-85	Coal seam
C317_BFS	315064	6395002	60.74	60.38	76.16	70-76.5	Coal seam
CGW52	309902	6402249	71.4	70.7	44.55	-	Coal seam
SR001	319146	6394094	59.26	58.44	59.18	-	Coal seam
C122_BFS	315501	6395007	58.74	58.44	61.3	-	Coal seam
SR003	318863	6394864	61.89	61.33	63.88	-	Coal seam
CHPZ3D	313093	6401756	63.6	62.96	22.07	19.2-22.2	Coal seam
CHPZ12D	313237	6402020	63.51	63.26	15.85	15-16	Coal seam
C809_WDH	314208	6395494	59.44	59.13	38.69	28-38	Coal seam
BUNC45D	313677	6402060	73.72	73.36	30.73	25.9-28.9	Coal seam
HG2A	312469	6400886	66.82	66.24	27.84	25.8-28	Coal seam
D510_AFS	314381	6396142	55.31	54.99	30.35	25.5-30.5	Coal seam
D510_BFS	314381	6396142	55.28	54.98	38.78	34-38	Coal seam
C317_WDH	315064	6395002	60.33	60.12	33.89	31-33.5	Coal seam
B425_WDH	316020	6395019	58.19	57.88	36.19	31.5-35.5	Coal seam
SR009	319338	6394746	53.81	53.26	35.85	30.4-36.4	Coal seam
C130_WDH	316409	6394911	63.52	63.14	21.55	19-21.5	Coal seam
C122_WDH	315511	6395003	58.73	58.44	22.69	19.6-22.6	Coal seam
D010_WDH	314356	6395688	56.26	55.93	16.97	19.5-22.5	Coal seam
D010_GM	314356	6395688	56.26	55.95	22.96	19.5-22.5	Coal seam
D406_AFS	313932	6396075	57.73	57.41	28.18	24-27.5	Coal seam
SR010	317319	6395338	58.88	58.26	29.98	24.6-30.6	Coal seam
SR008	319290	6395111	56.44	55.84	29.8	24.4-30.4	Coal seam
B631_WDH	316425	6394322	72.25	71.98	30.73	23.8-32.3	Coal seam
BZ2A_2	311671	6400561	72.3	71.7	20.9	-	Interburden
BZ8-2	312685	6401010	67.79	67.36	20.97	18-21	Interburden
SR005	318831	6396128	66.05	65.36	26.39	-	Interburden
SR012	318354	6393926	76.49	76.02	29.03	23.4-29.4	Interburden
HG1	312390	6400882	66.8	66.1	14.7	-	Interburden

Bore ID	Easting	Northing	Top of casing (mAHD)	Ground elevation (mAHD)	Bore depth (mBGL)	Screen elevation (mBGL)	Formation
CFW59	310245	6402370	69.4	68.9	16	7.5-13.3	Interburden
C130_ALL	316409	6394911	63.42	63.1	16.98	15-17	Interburden
CGW51A	310149	6402419	70.21	70.04	17.01	-	Interburden
NPz1_HVO	305240	6406100	138.9	138.1	59	56-59	Interburden
NPz2_HVO	308715	6411207	191.06	190.44	61.9	57-60	Interburden
NPz4_HVO	309624	6406493	135.97	135.22	77	71-74	Interburden
SR006	318555	6395732	84.12	83.31	91.44	-	Interburden
4051C	308664	6402720	69.9	68.92	30.53	31.75-32.75	Interburden
4036C	308272	6402687	71.78	70.7	34.12	33.1-34.1	Interburden
SR007	318281	6395675	82.17	81.58	36.91	31.5-37.5	Interburden
NPz5_HVO	310326	6406955	114.49	113.76	43.37	40-43	Interburden
BZ4B	312029	6400705		74.1			Interburden
BZ4A_1	312029	6400705		74.4			Interburden
BUNC14	313115	6401693		80.8			Interburden
BZ3-2	311840	6400640	70.6	70.3	11.7		Interburden
HG3	312541	6400940		66.8			Interburden
BUNC39B_S	313499.9	6401823	66.872	66.872	13.5	10.5-13.5	Spoil
DM9	310284	6401095	70.8	69.6			Spoil
DM2	311639	6404634	105.65				Spoil
DM7	311162	6401051	70.39	69.26			Spoil
4113P	310729	6401304	70.41	69.08	65.21	62.9-69.54	Spoil
GW_114	312272	6403981	98.19		33	27-30	Spoil
MB14HVO02	310469	6401001	70.9		91	70-91	Spoil
MB14HVO05	310675	6401127	71.67		85	69-90	Spoil
MB14HVO03	311387	6400950	67.14		80	69-90	Spoil
MB14HVO01	310587	6401003	71.29		90	69-90	Spoil
DM1	311754	6405187	103.05	102.73	28.83		Spoil
DM3	311959	6403310	94.97	94.14	40.67		Spoil
DM4	312161	6401456	65.69	64.85	54.91		Spoil
4117P	310670	6400980	71.43	70.21	89.78	87-89.64	Spoil
4116P	310681	6400978	71.48	70.17	24.49	20.9-23.54	Spoil
4119P	312501	6402048	64.74	63.51	17.31	14.9-17.54	Spoil
GW_108	309695	6403970	84.39		61.5	52.5-58.5	Spoil
MB14HVO04	311491	6401392	67.06		55	33-54	Spoil
GW_107	308737	6404102	73.47		28.63	24.2-27.2	Spoil
GW_115	312227	6402216	68.32		28.7	22.2-28.2	Spoil

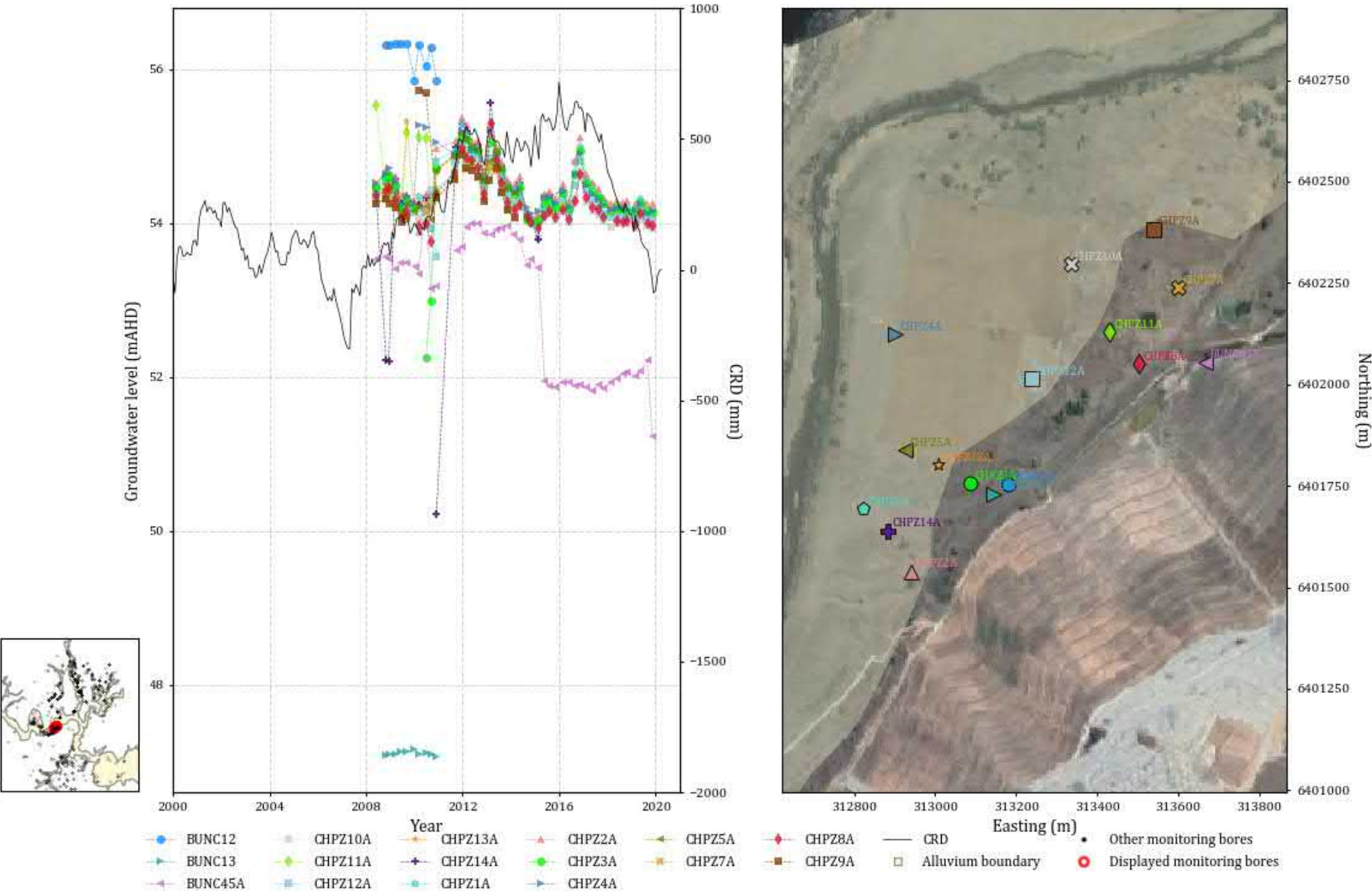
Appendix C

Hydrographs

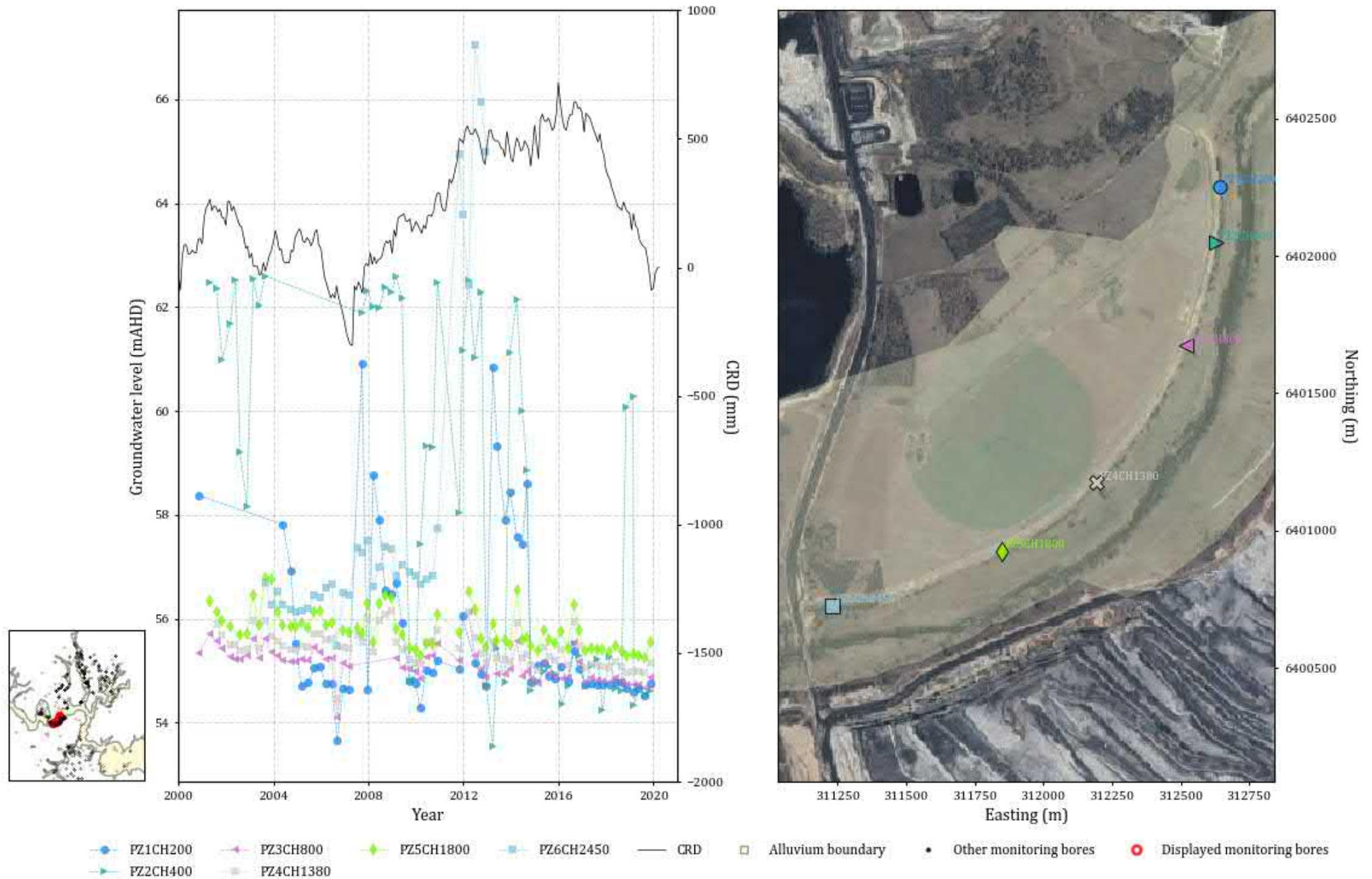
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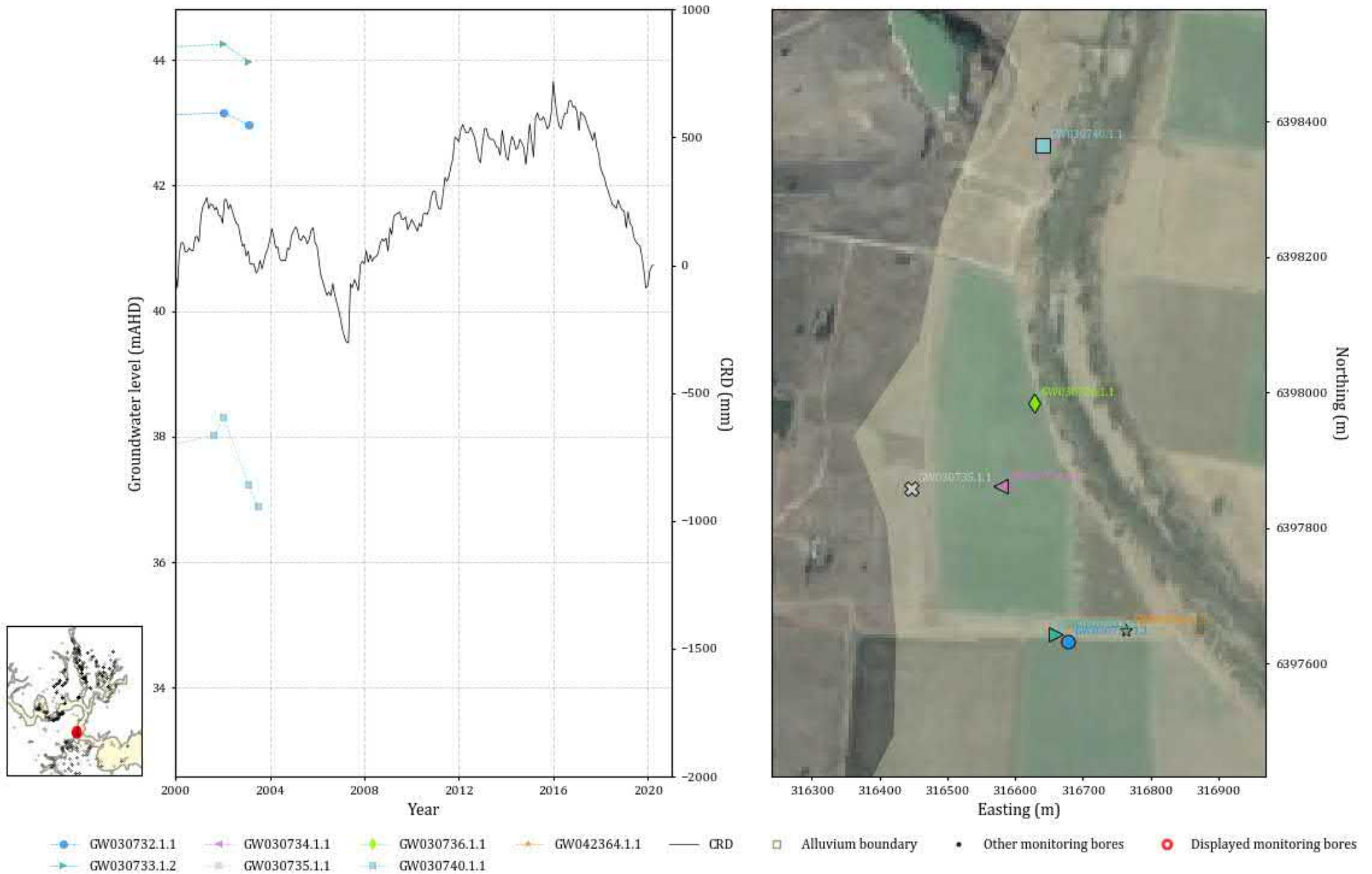
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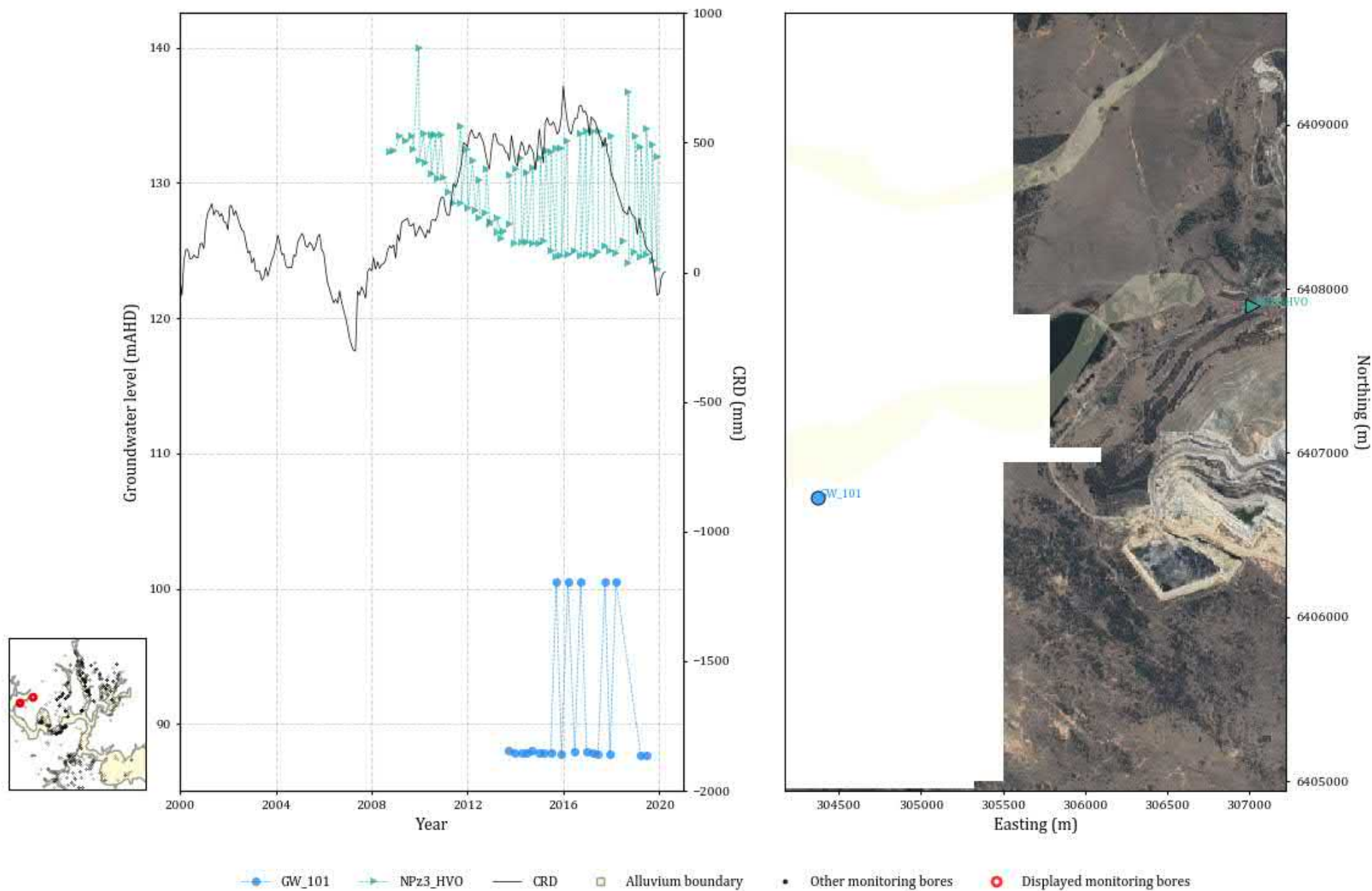
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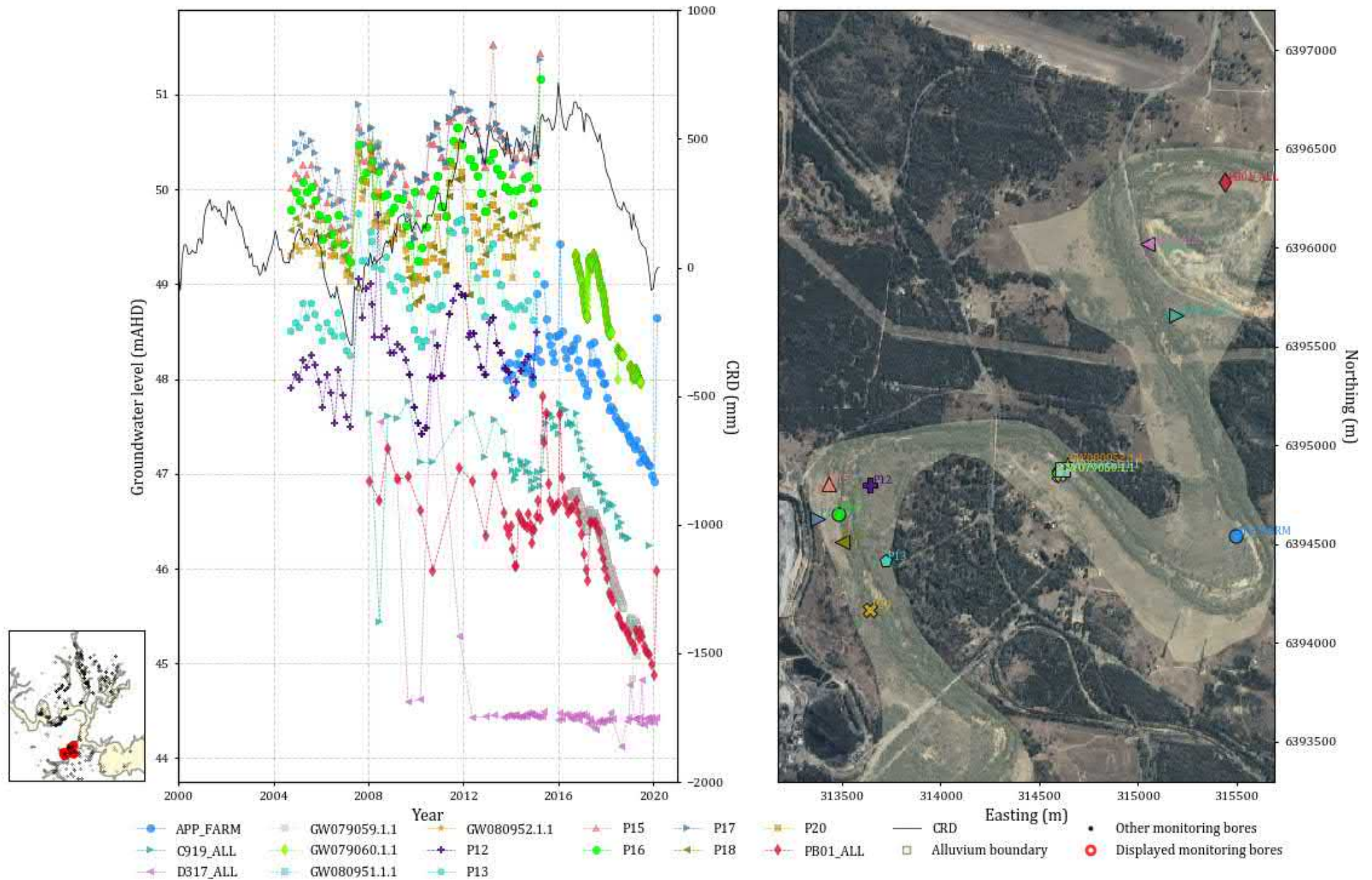
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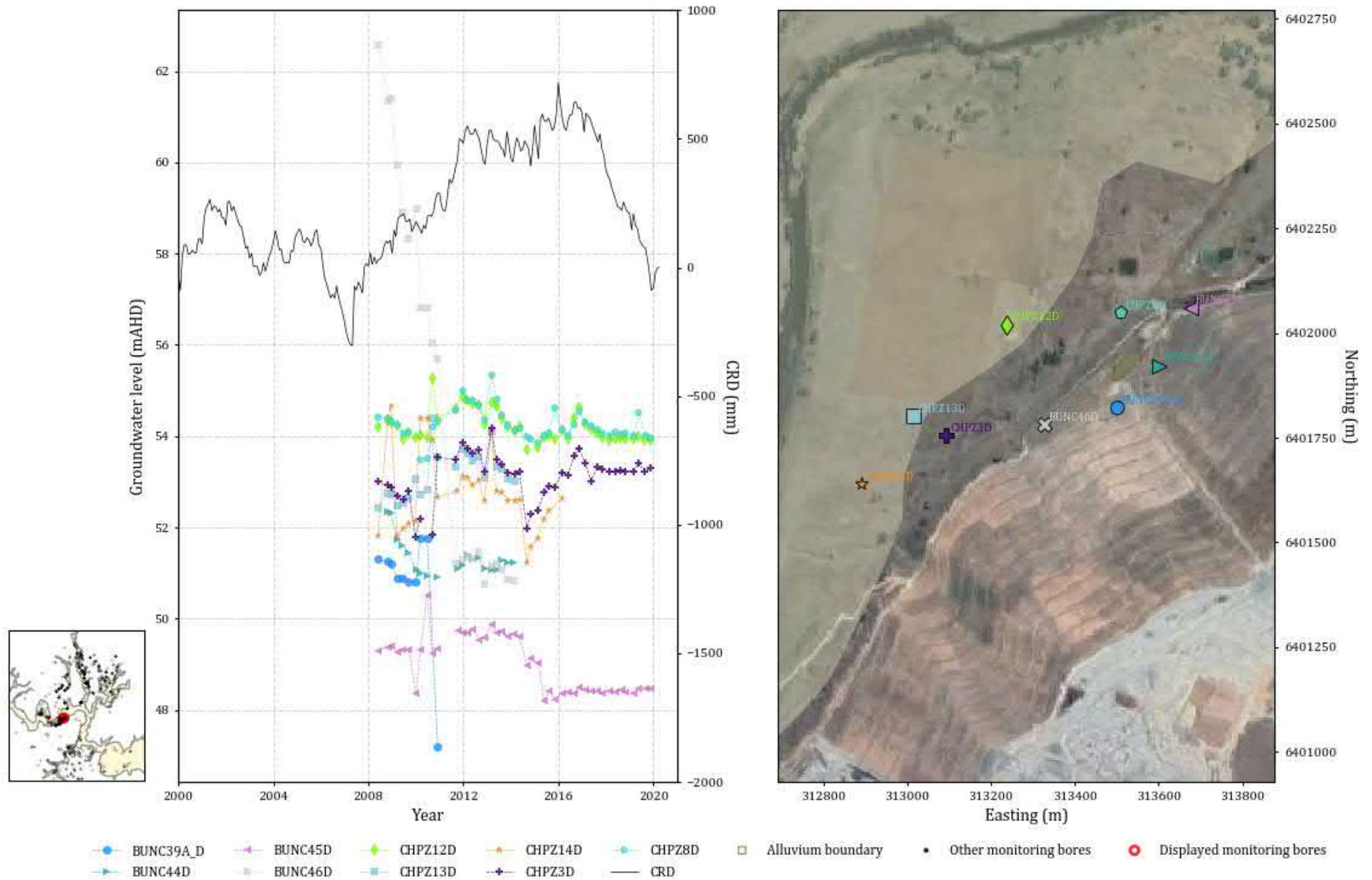
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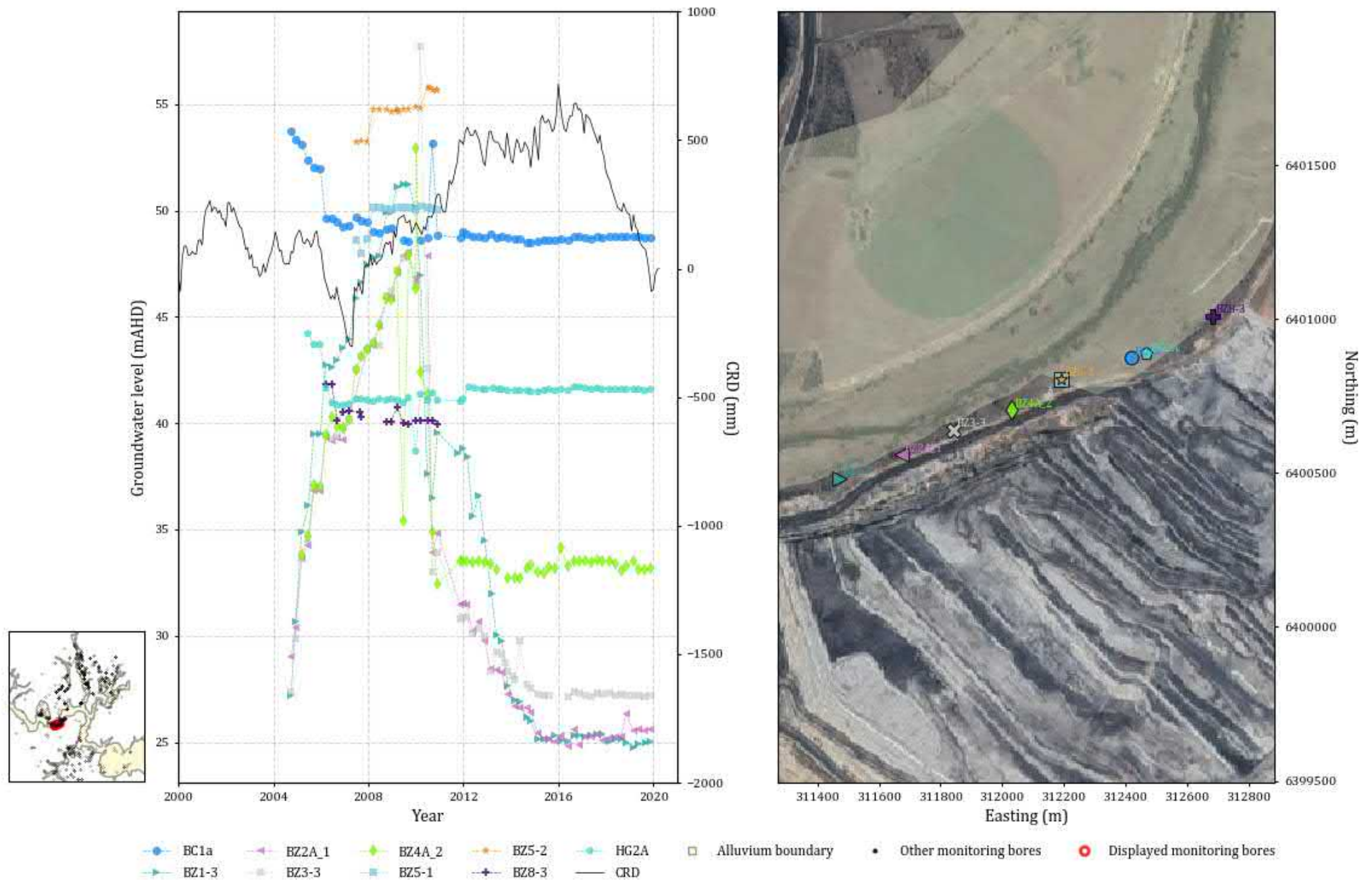
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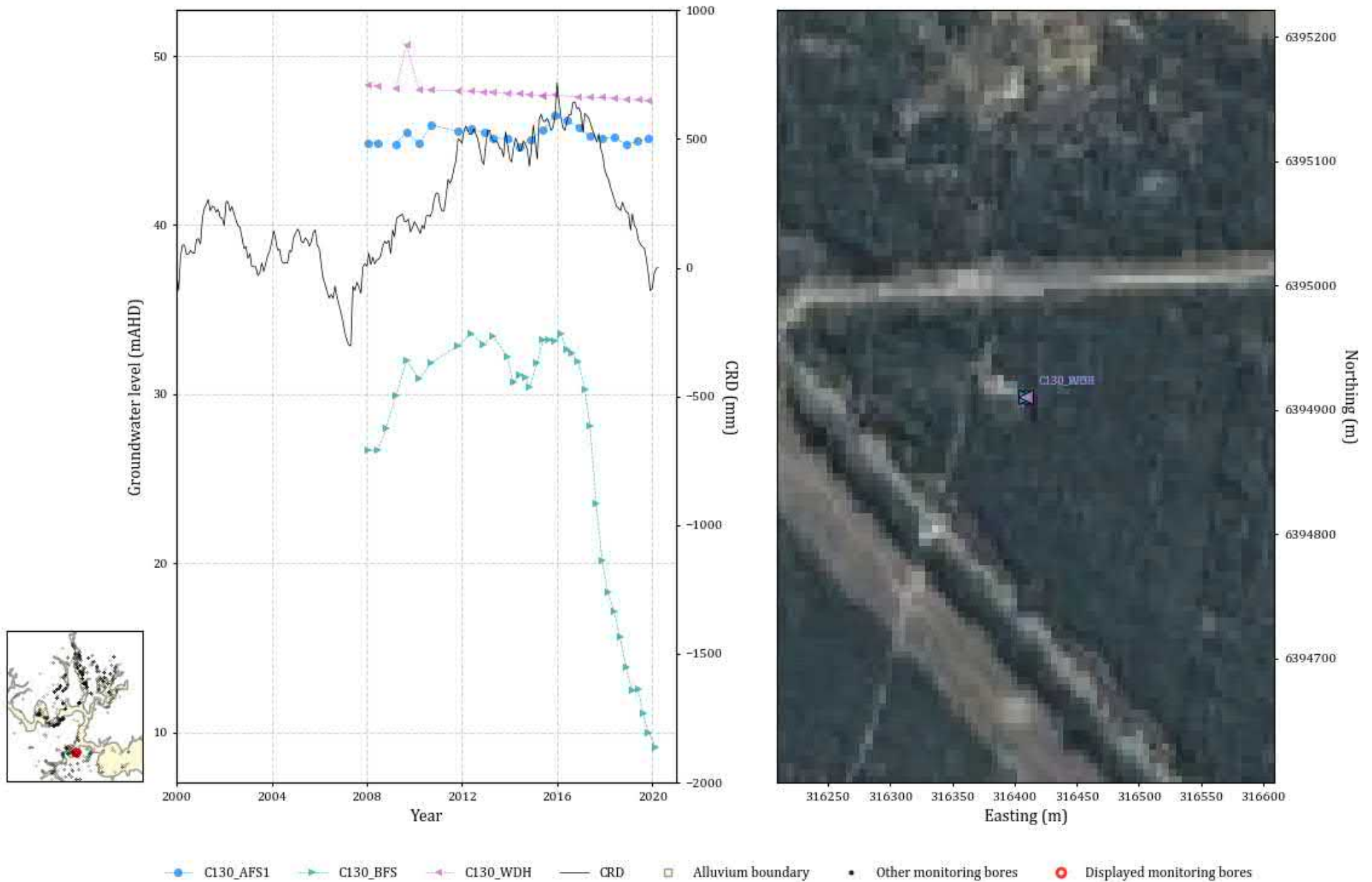
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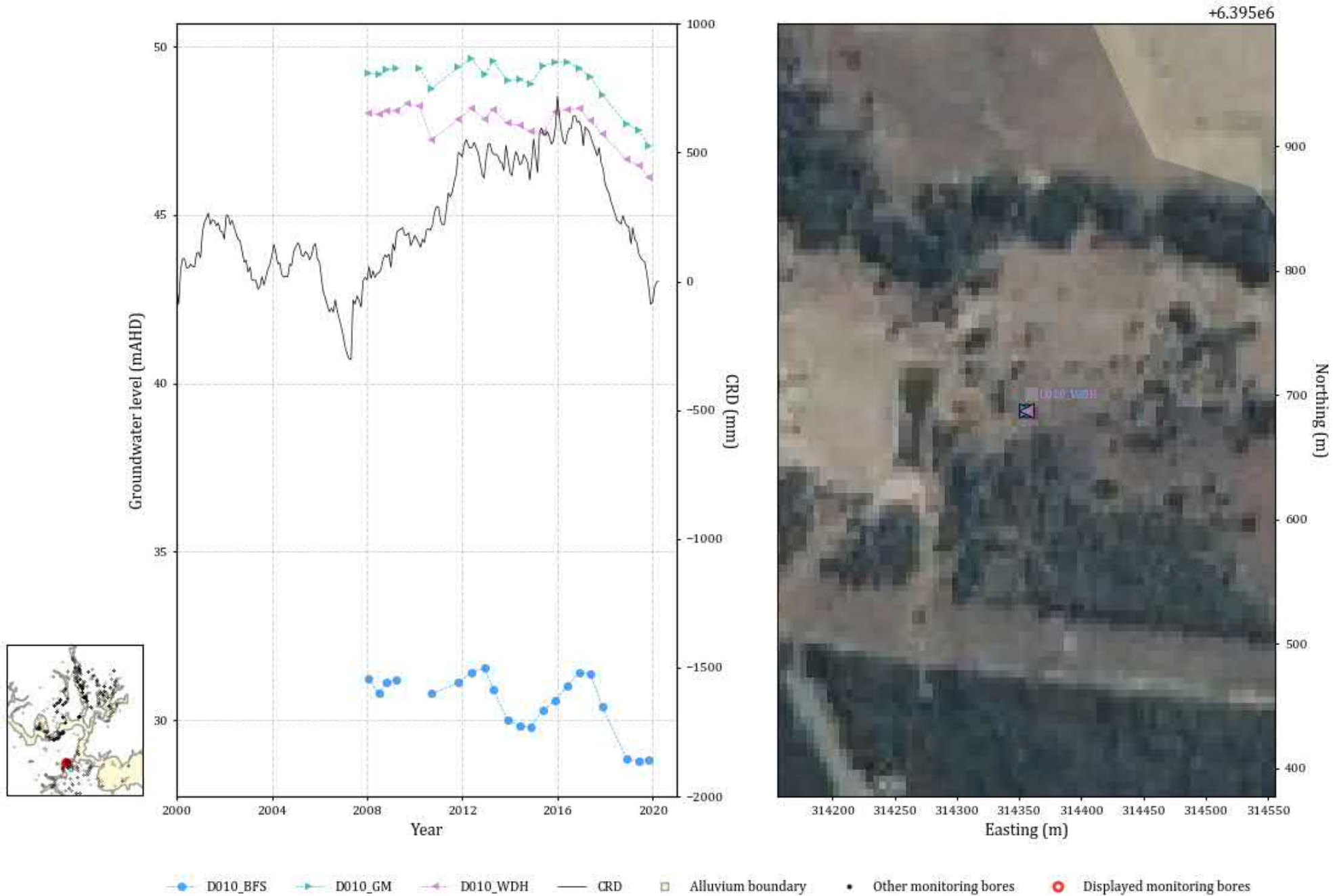
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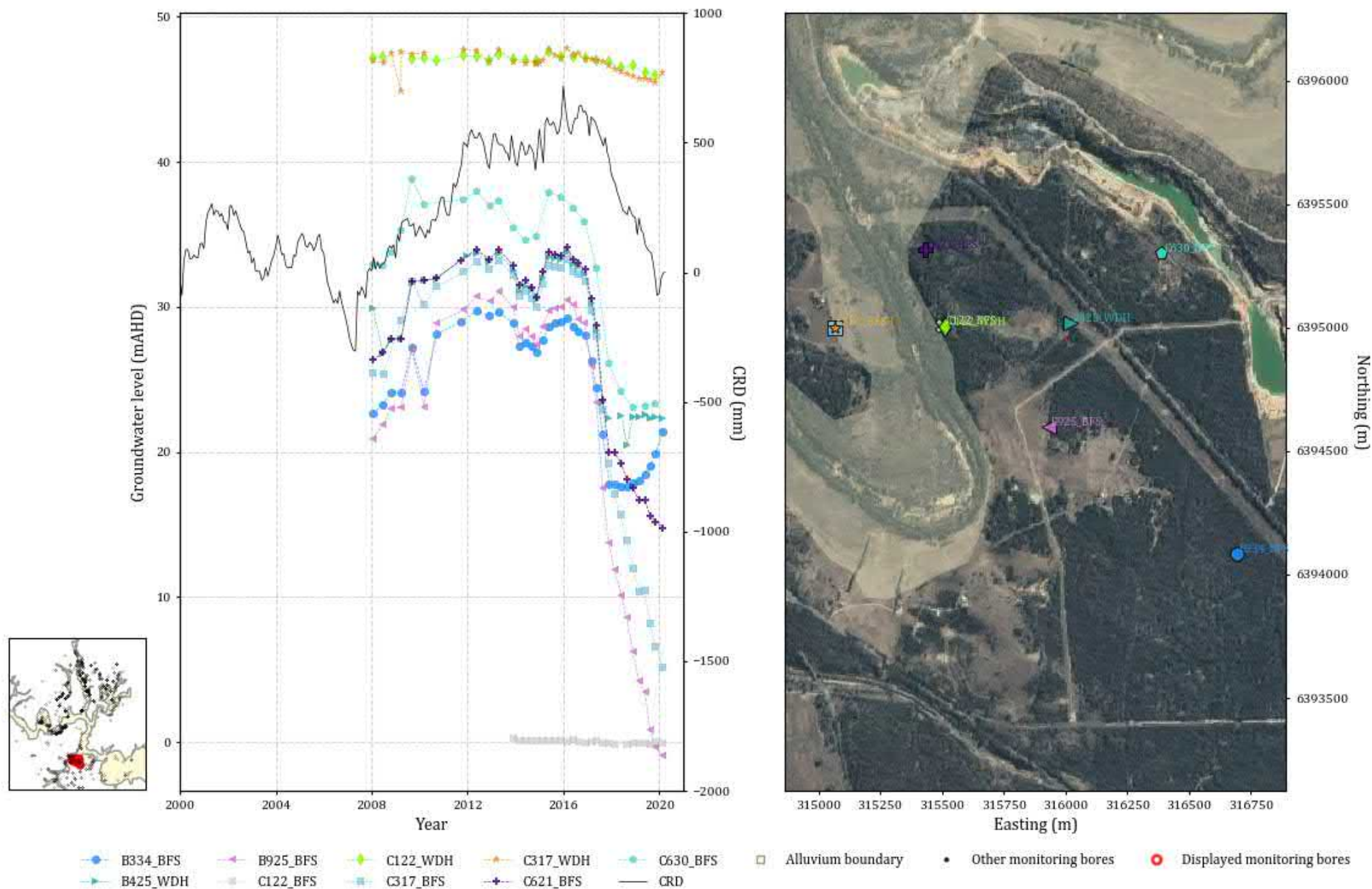
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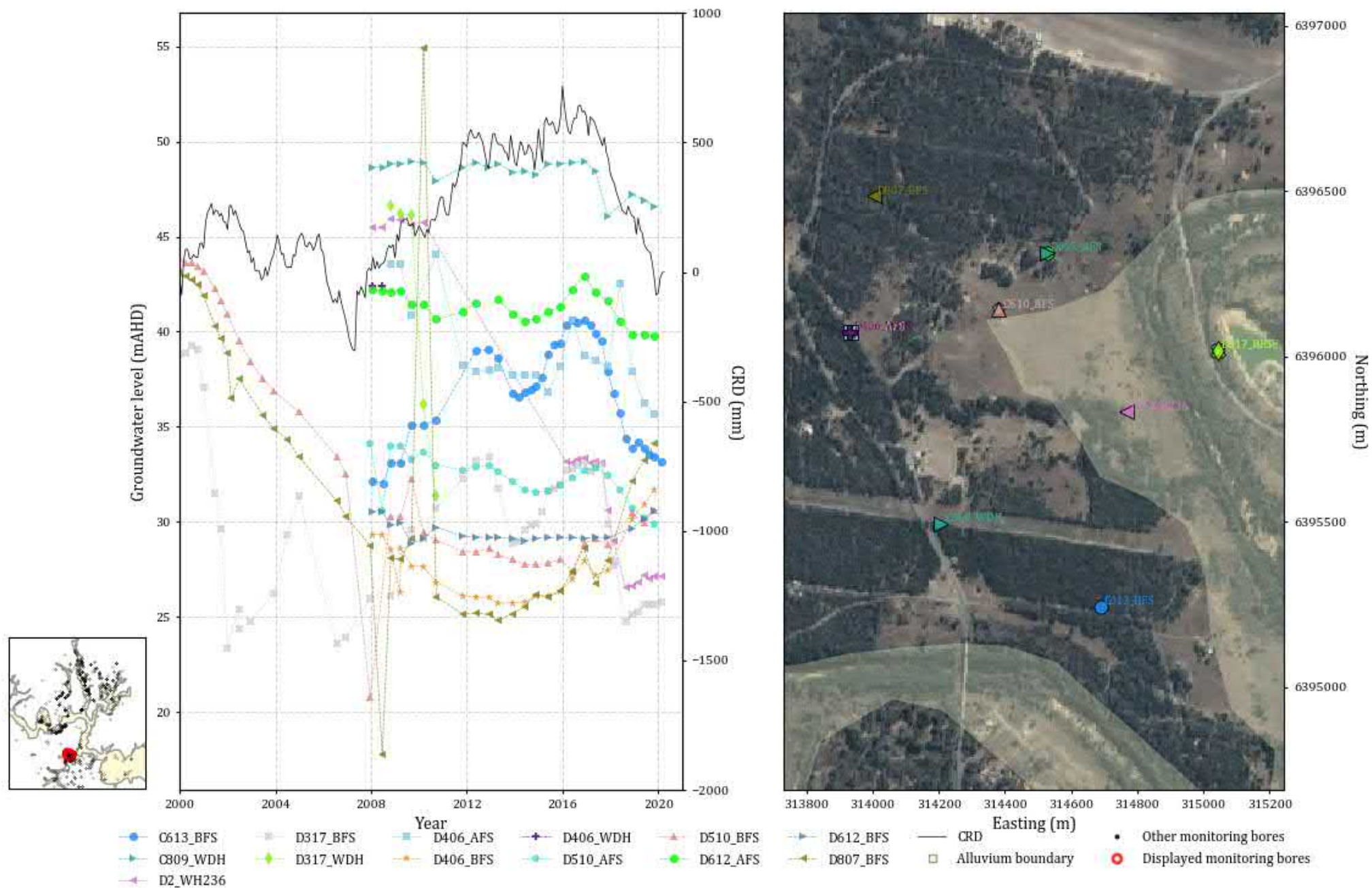
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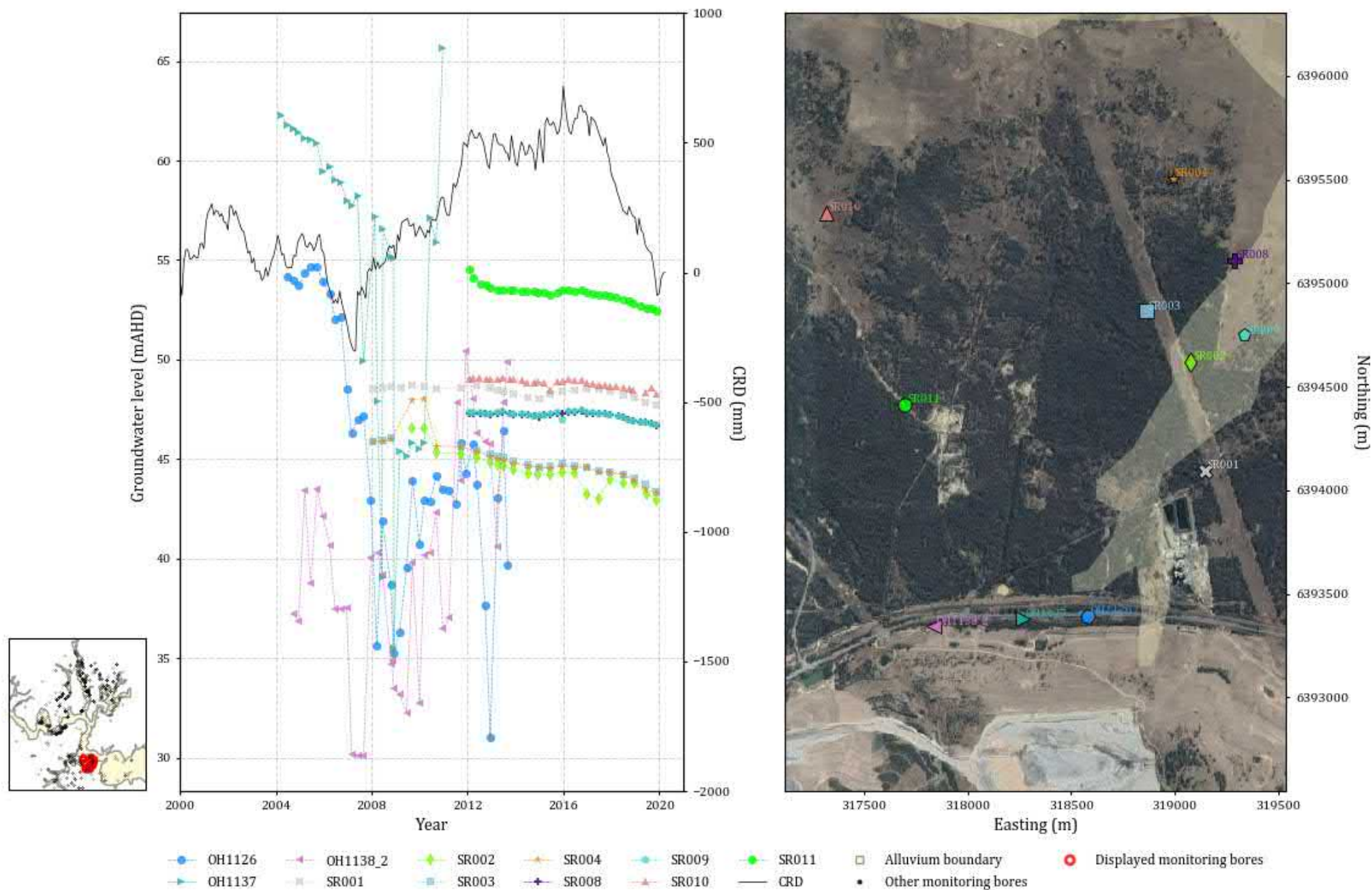
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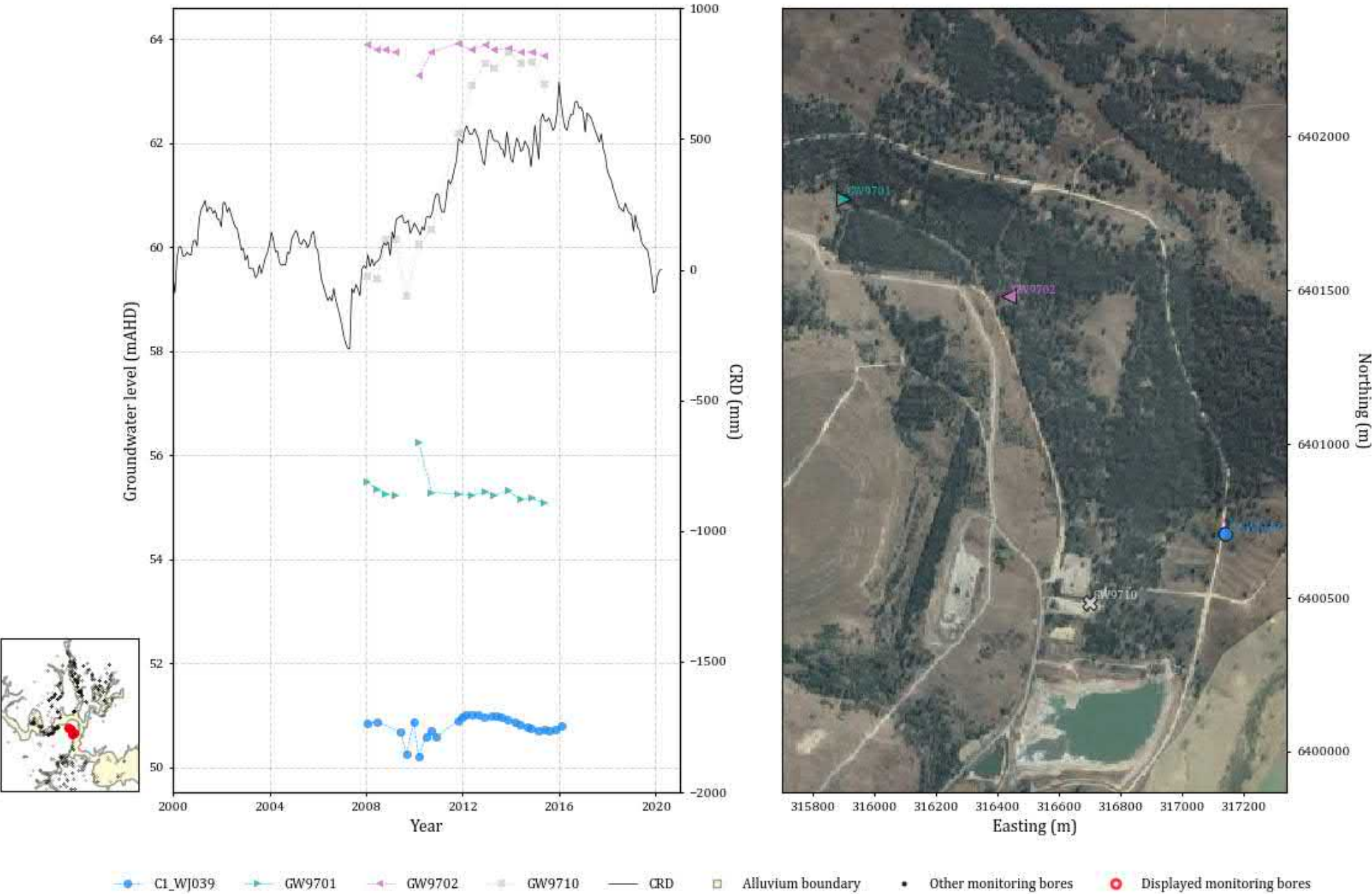
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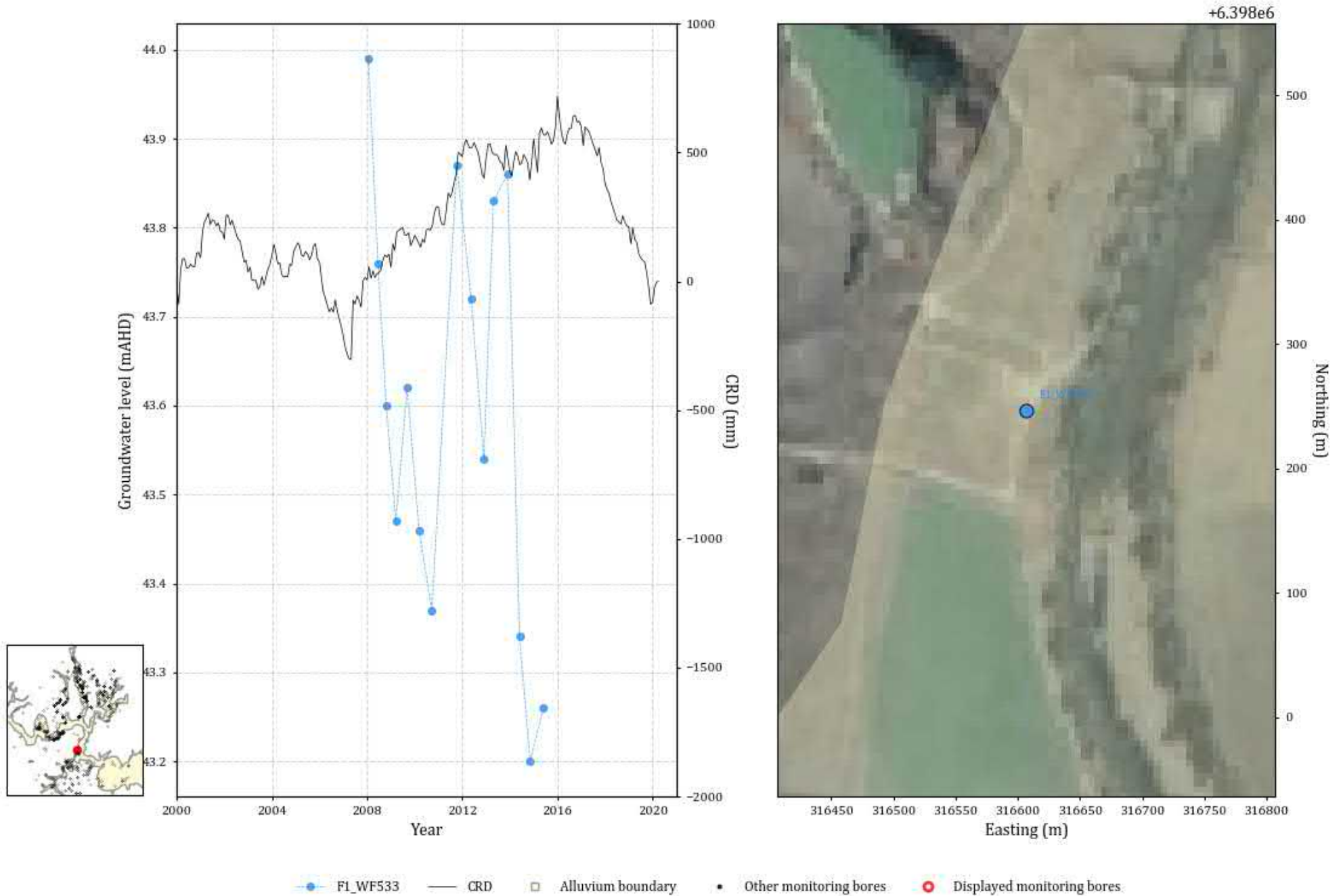
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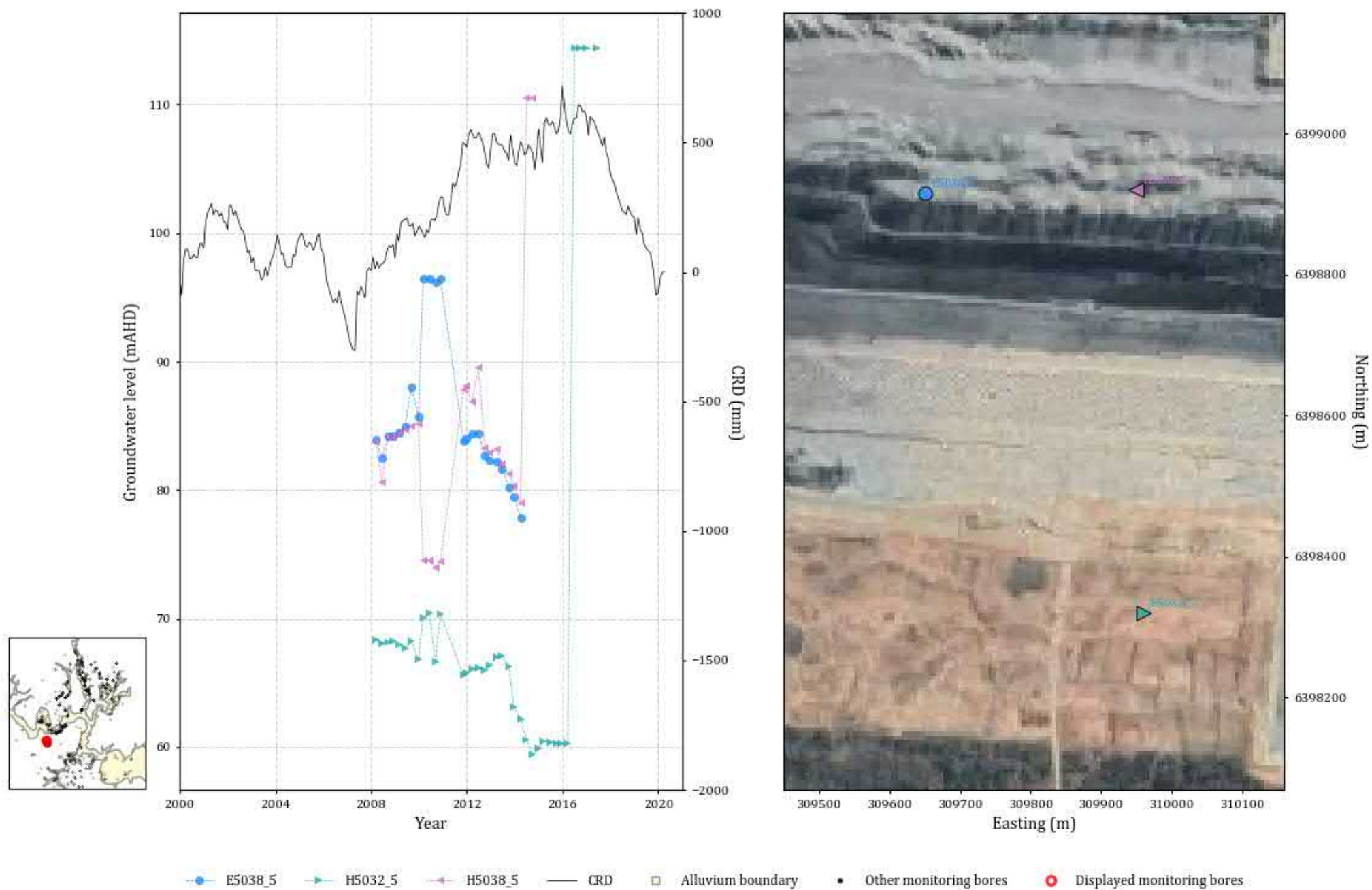
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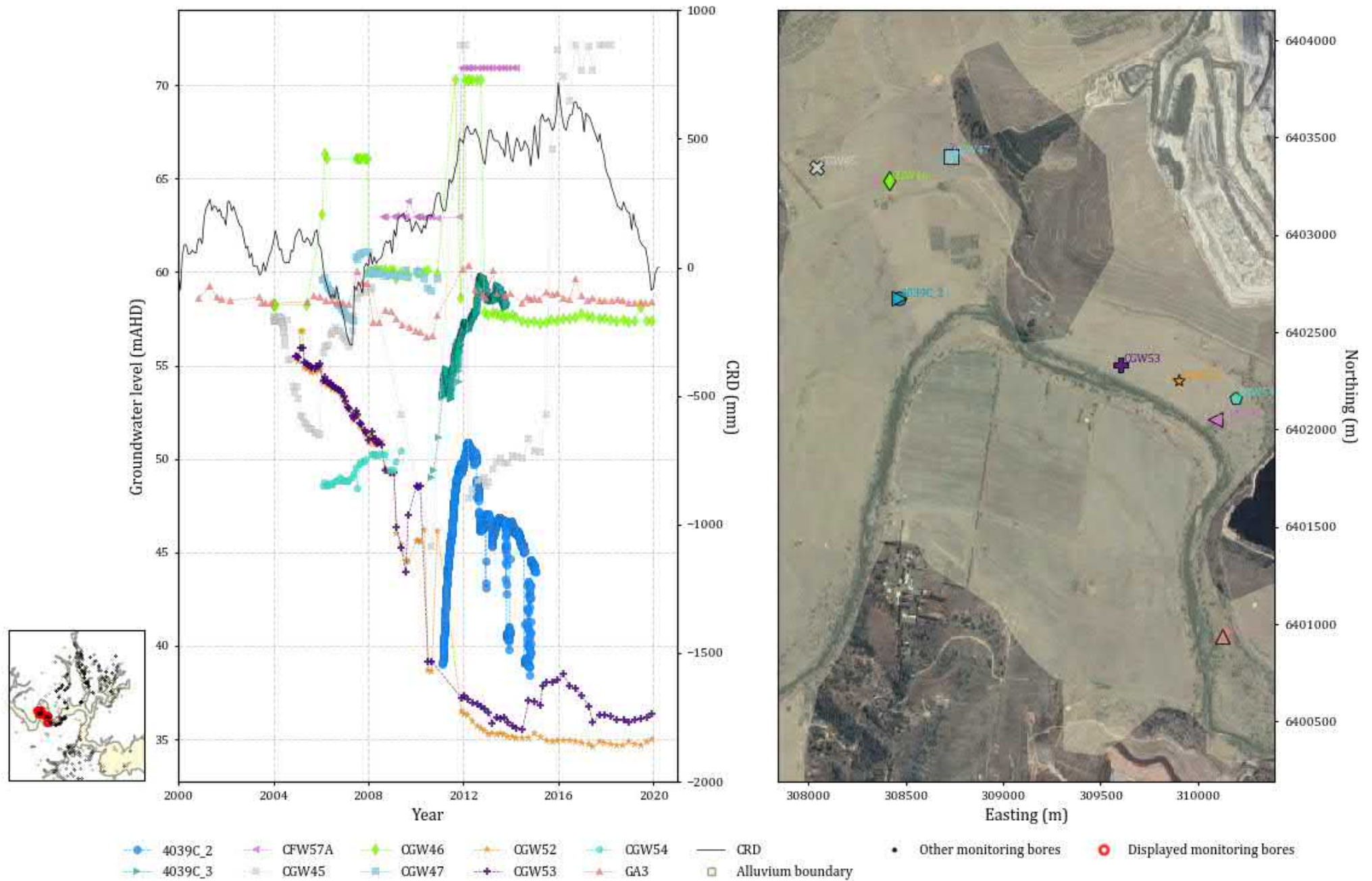
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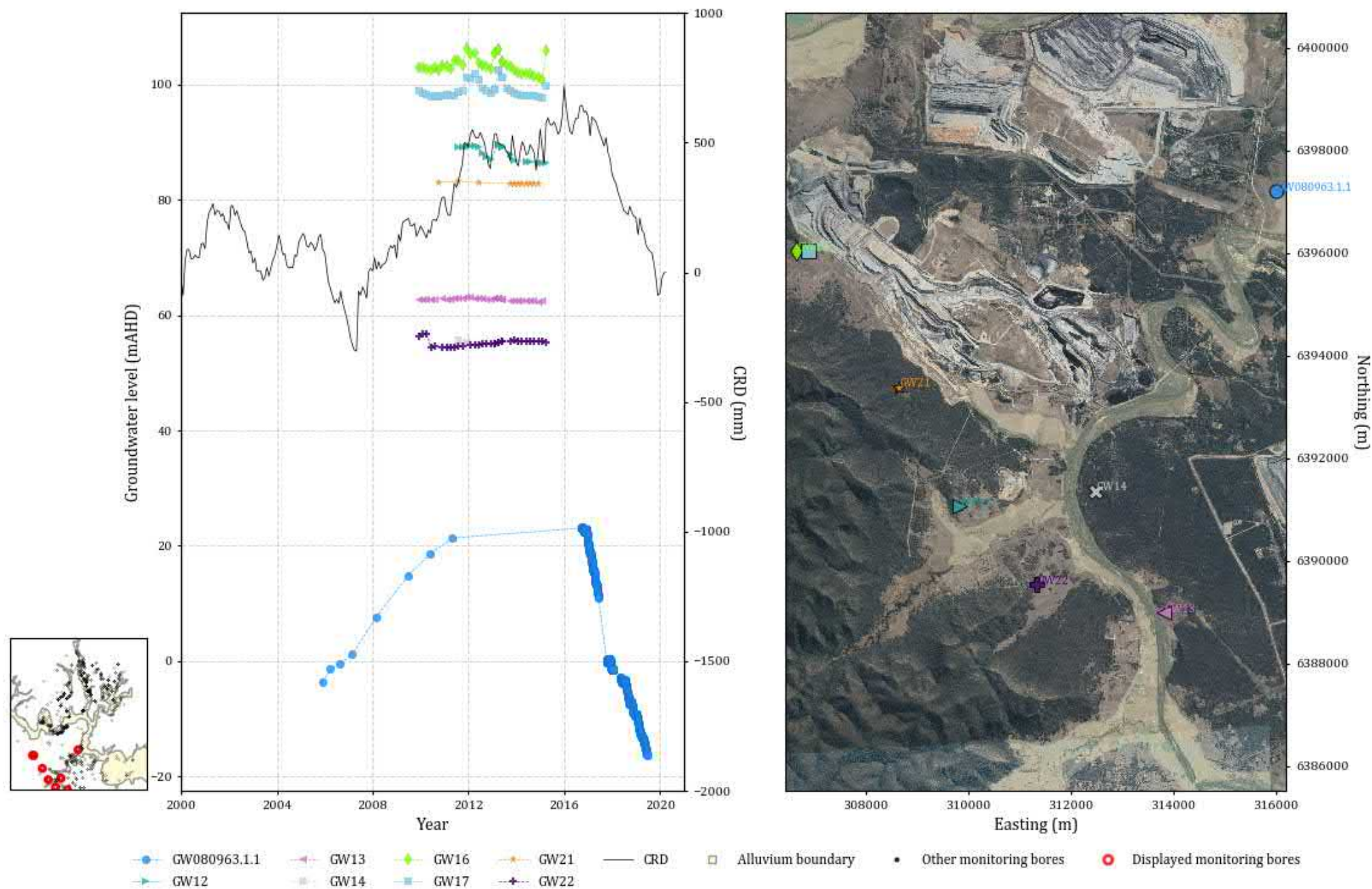
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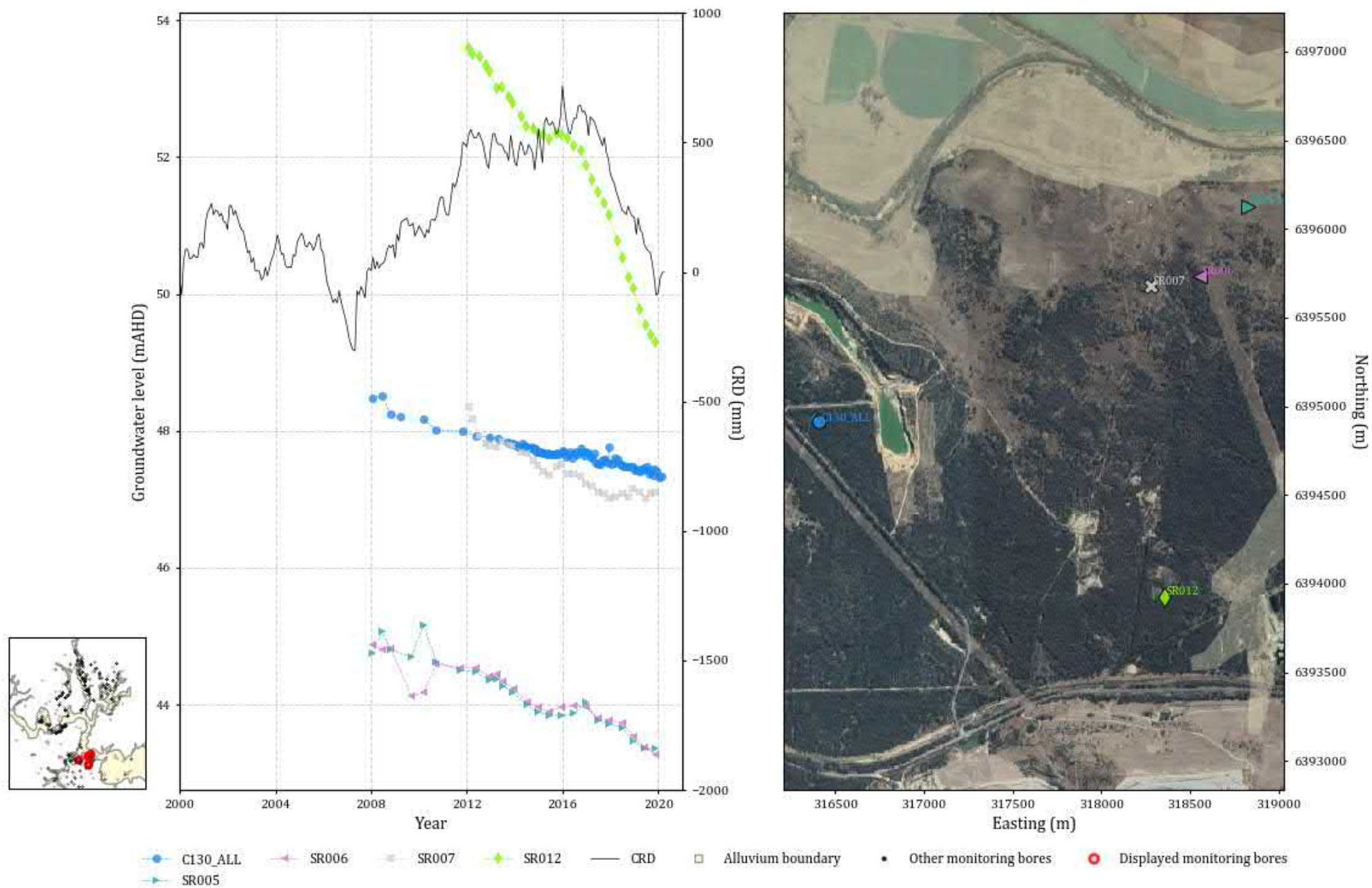
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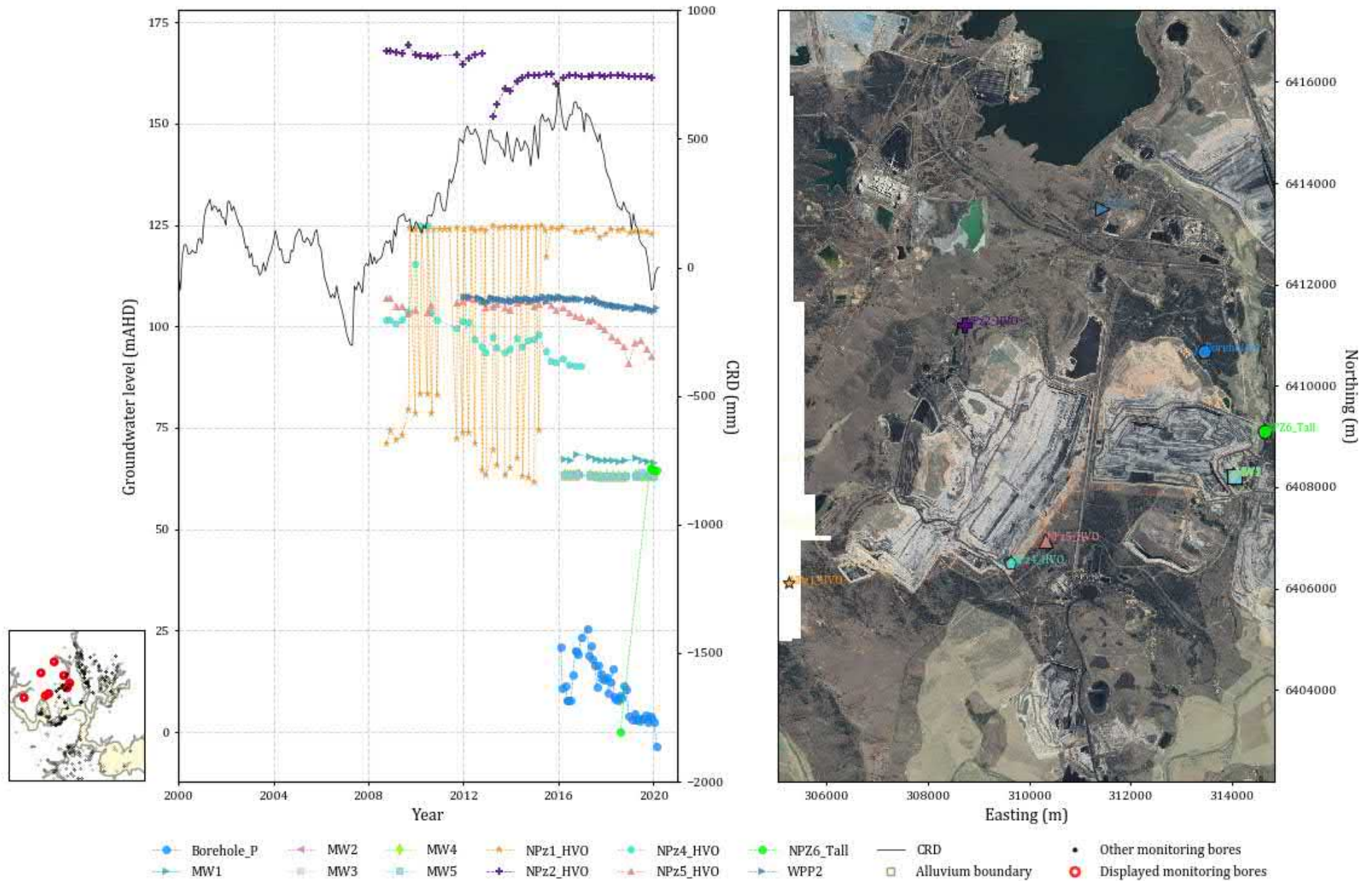
coal_seam_wambo_oc_bores



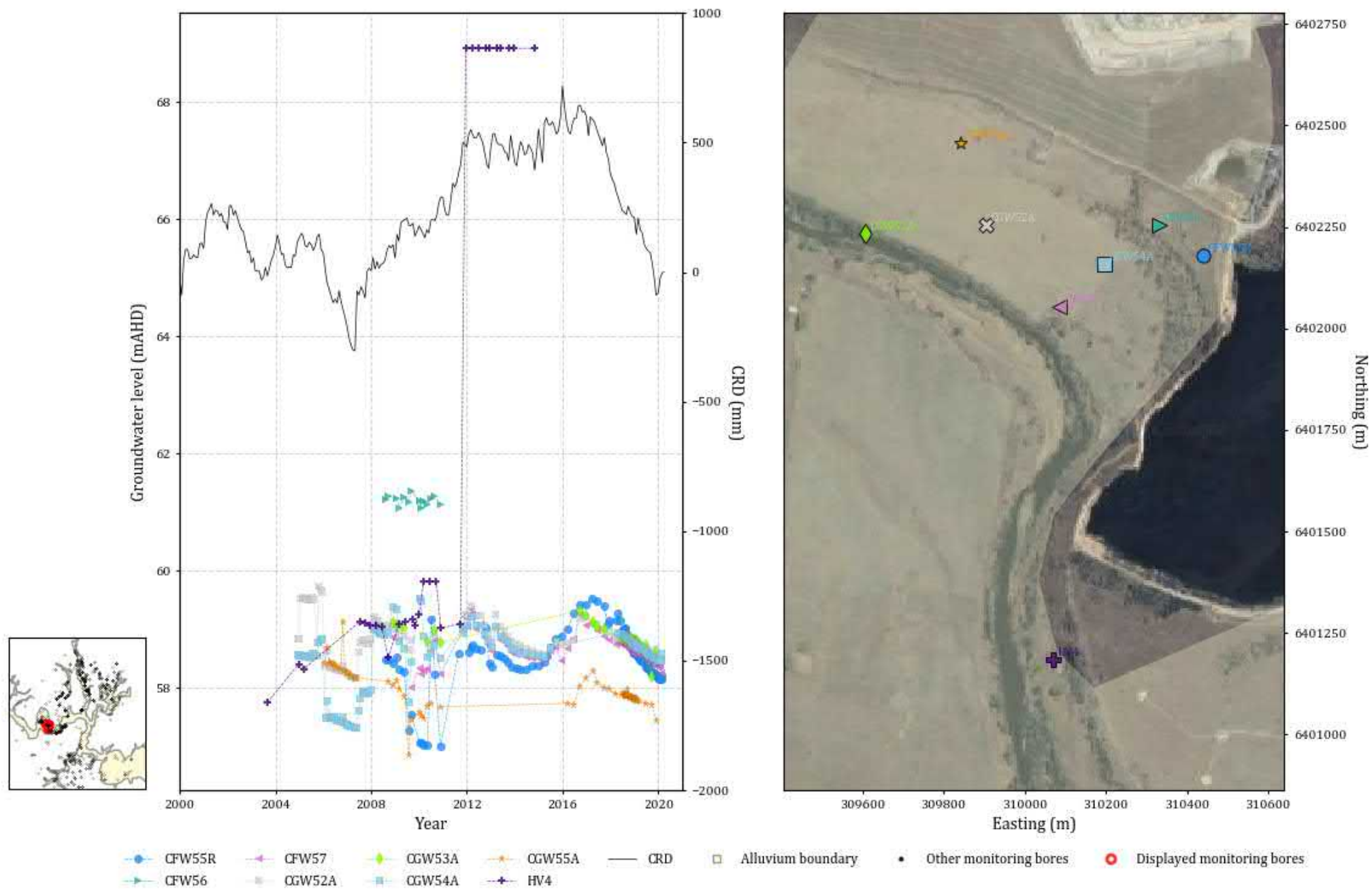
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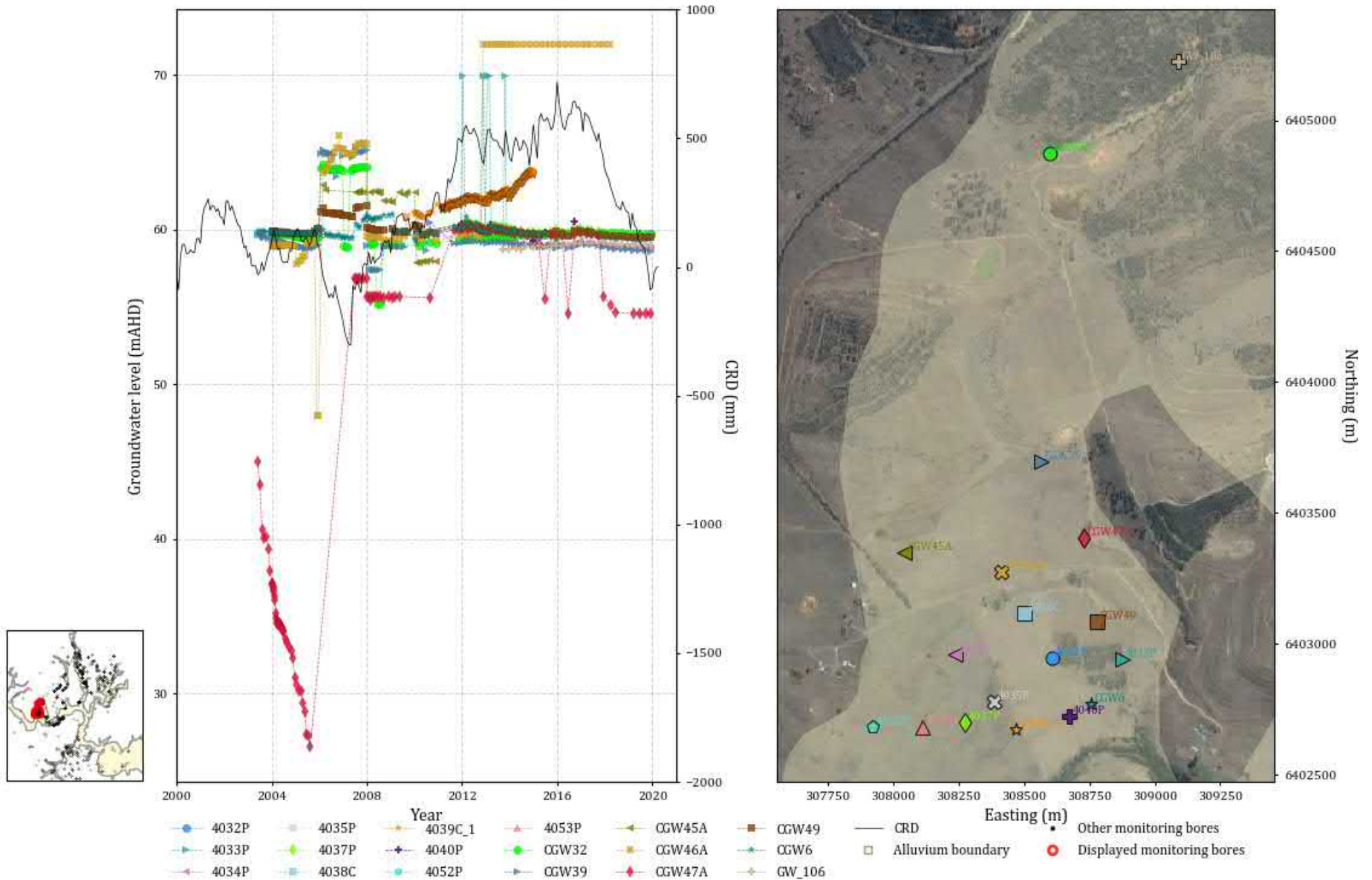
interburden_rav_bores



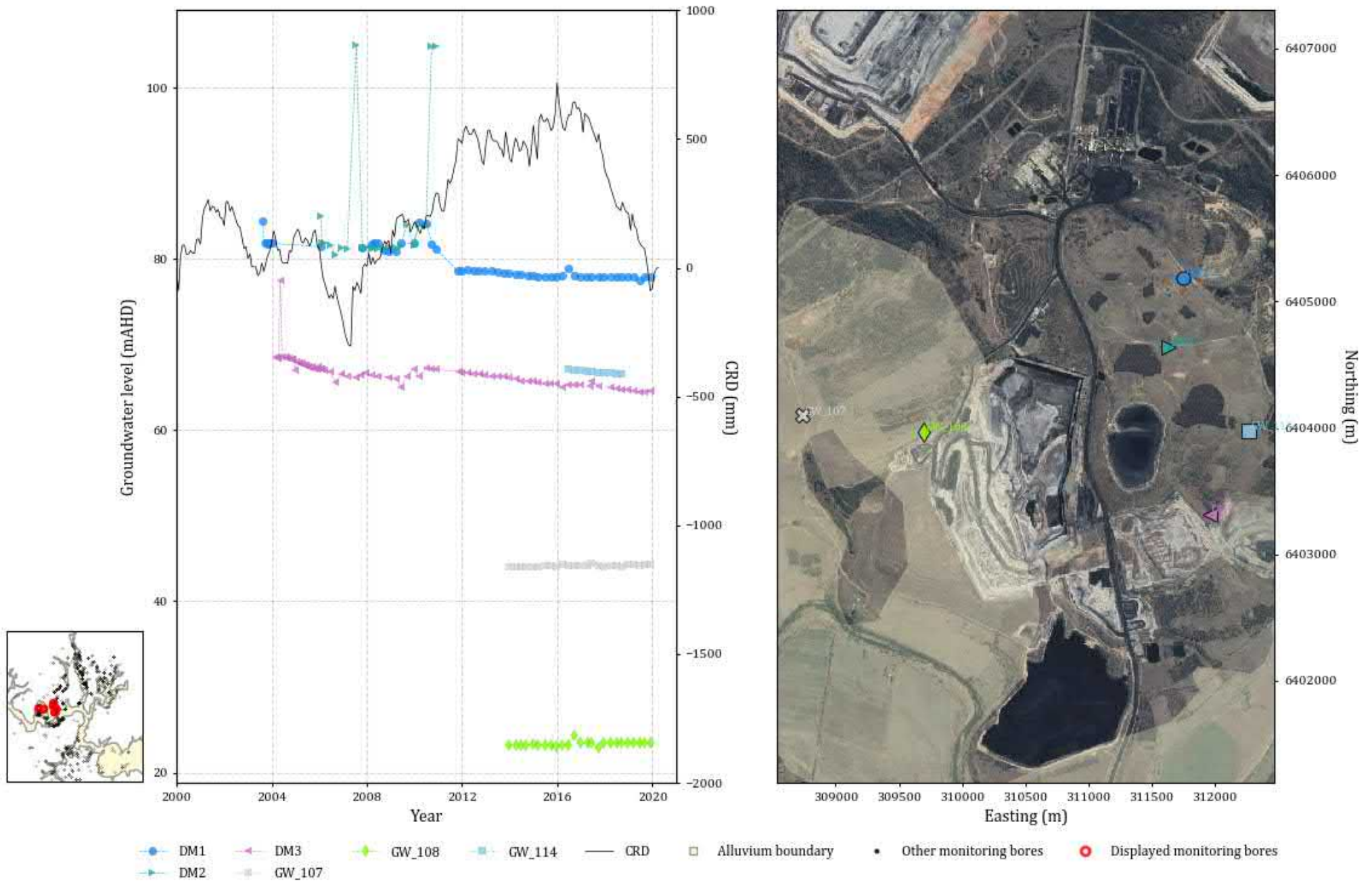
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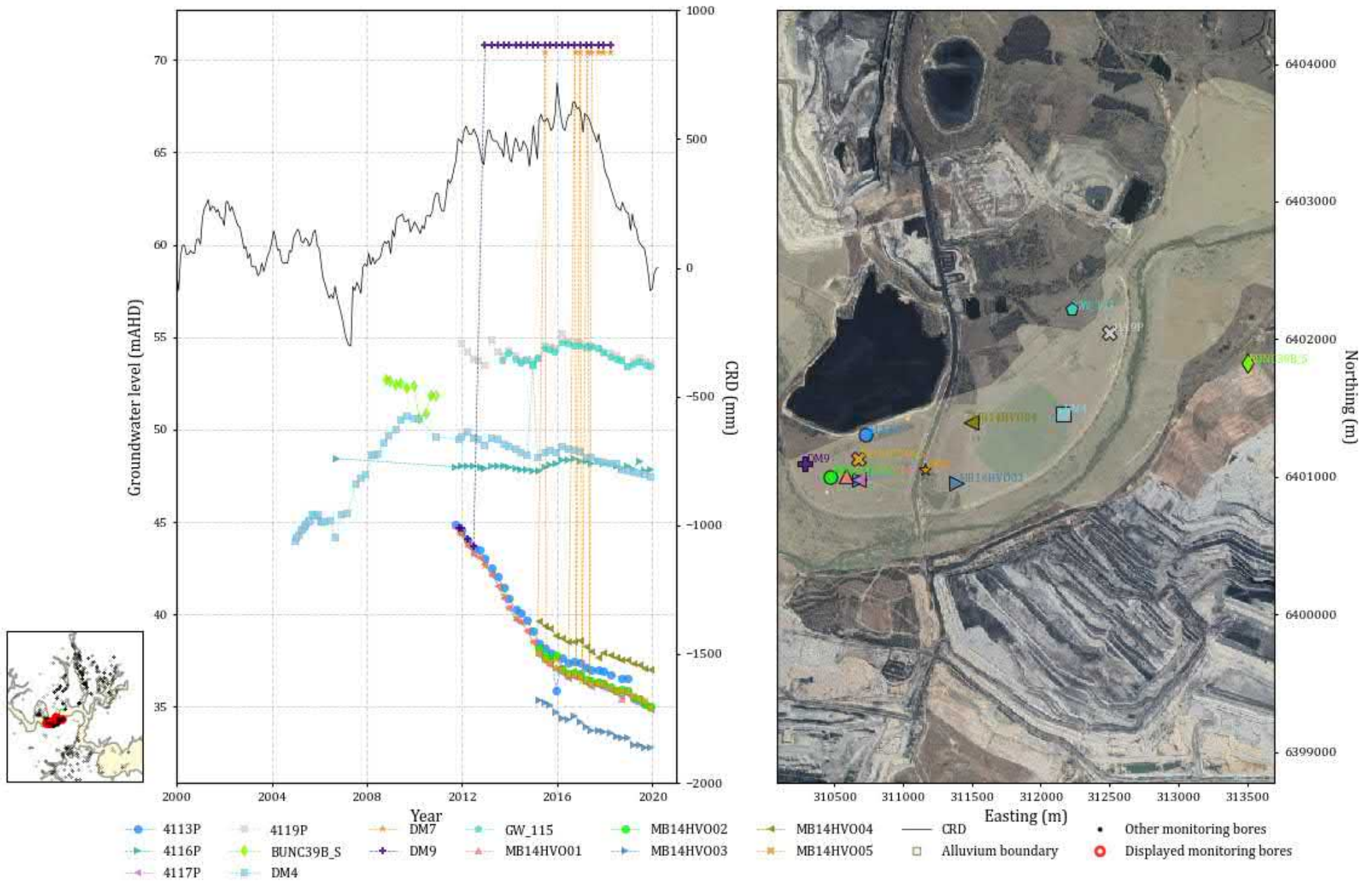
palaeoalluvium_western_limb_bores



spoil_north_hvo_bores



spoil_west_hvo_bores



Appendix D

Groundwater modelling technical report

HVO Continuation Project

Numerical Modelling Report

D1 Objectives

Numerical groundwater modelling was undertaken to predict the impact of the Project on the groundwater regime. The key objective was to predict in detail the potential impact and pathways for impact on water resources and water-dependent assets. The specific objectives of the modelling were to:

- predict the volume and rate of groundwater directly intercepted by the mine workings as a function of mine position and timing (incidental take);
- predict the volume of groundwater indirectly affected or intercepted from adjacent water sources outside the Project disturbance area (passive take);
- predict water directly and indirectly intercepted by the Project to inform the water licensing strategy (within the water assessment report, EMM 2022);
- predict the extent and magnitude of drawdown in surrounding water sources and the potential for the Project to induce drawdown that exceeds the threshold levels of impact for receptors specified within in the AIP;
- predict changes to the groundwater regime post-mining and the potential to exceed thresholds for water level and quality specified in the AIP for water sources and water dependent assets;
- predict areas of potential risk where groundwater impact mitigation/control measures may be necessary; and
- quantify the influence of uncertainty in model parameters on the magnitude of impacts predicted by the model.

An important aspect of the modelling exercise is robust conceptualisation of the groundwater regime that is represented in a simplified manner by a numerical model. The conceptual model is an interpretation of how the groundwater system operates given the available data and is an idealised and simplified representation of the natural system. The main report details the conceptual understanding of the hydrogeological regime in the Project area. The purpose of this appendix is to describe the numerical model setup, calibration, predictive scenarios and uncertainty analysis undertaken with it. The model predictions from the base-case model (the 'best' calibrated model) are summarised in the main report but not included here to ensure there is no duplication within the documents.

D2 Model construction and development

D2.1 Model version and update log

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

- Glendell mine (AGE, 2019);
- Liddell open cut mine (AGE, 2018a);
- Mt Owen and Integra mines (AGE 2018b, AGE 2017b);
- HVO South mine, MOD5 (AGE, 2017a);
- United-Wambo open cut mine (AGE, 2016);
- Mount Thorley-Warkworth mine (AGE, 2014); and
- Ravensworth underground (Mackie Environmental Research, 2011).

The numerical model was built specifically for the Project and based upon previous numerical models to ensure the cumulative impacts from already approved surrounding operations were represented as consistently as possible with previous approvals. This approach aligns with the fundamental guiding principle described by Middlemis (2004) that *“...model development is an on-going process of refinement from an initially simple representation of the aquifer system to one with an appropriate degree of complexity. Thus, the model realisation at any stage is neither the best nor the last, but simply the latest representation of our developing understanding of the aquifer system.”*

Jacobs (2014) provided a model version naming protocol and update log to identify the version of the ‘base’ model used for various projects. Although the model extent, grid and layers of the numerical models often change from project to project, every new model in the Greater Ravensworth Area has been largely based on the previous models, trying to maintain consistency in approved neighbour operations, and updating the assumptions and predictions of the project being studied. Therefore, they could be considered iterations of a an overall “Greater Ravensworth Area” model, being progressively updated in local areas. A new version number is assigned to each new iteration, usually including changes such as model structure, calibration, approved current or future mining operations. Table D 1 below summarises the model version and modifications undertaken since development of the initial model in 2011.

Table D 1 Greater Ravensworth area model versions

Model version	Model build	Project	Description of modification(s)	Model version number	Year Released
1	0	Ravensworth	- Initial model setup. - Model calibration.	1	2011
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 Horizontal Flow Barrier package (HFB) for faults regionally.	6	-
6	1	Liddell	Updated stochastic predictive simulations of proposed operations.	6.1 Liddell	-

Model version	Model build	Project	Description of modification(s)	Model version number	Year Released
7	0	Liddell	- Representation of Glennies Creek and Main Creek alluvium based upon LIDAR data. - Refinement of Glendell and Mount Owen approved mine sequences and plans. - Incorporation of Integra Underground mine. - Modification of hydrogeological parameters to account for enhanced conductivity above former underground workings and according to depth of overburden. - Modification of model size and stress periods to accommodate updated mine sequencing. - Recalibration (steady state and transient) to extended calibration dataset. - Updated stochastic predictive simulations of proposed operations.	7	-
7	1	Mount Owen	Recalibration to refine specific yields.	7.1 Mount Owen	-
7	2	Liddell	Incorporation of Liddell base case into Version 7.	7.2 Liddell	-
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; and - 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	2017

Model version	Model build	Project	Description of modification(s)	Model version number	Year Released
9	1	Mount Owen Mine and Integra Underground Mine	Update of open cut mine plan at Mount Owen North Pit to extend to the end of 2036.	9.1 Mount Owen	2018
9	2	Liddell Open Cut	- Reduce the depth of Liddell Open Cut to the base of the Barrett Seam (currently approved to the Hebden Seam). - Update of the planned end of mining/beginning of recovery year to 2023 (instead of 2022). - Introduction of the Davis Creek Fault and Dyke into the model, represented by the Horizontal Flow Barrier (HFB) package. - Representation of historical workings of Liddell Underground Mine in the groundwater model, using data from SKM's (2014) groundwater model and refinements. - Representation of coal barrier walls separating different areas of Liddell Underground Mine in the model. - Introduction of controlled water levels in the different areas of Liddell Underground Mine into the model, following detailed data provided by LCO.	9.2 Liddell (unpublished version)	2018
10	0	Glendell	- Refinement of Glendell and Mount Owen approved mine sequences and plans. - Revision of alluvial thickness along Bowmans and Glennies Creek. - Review and updates to coal seam surfaces based on Glencore's geological models. - Extending northern boundary to reduce potential for boundary condition to influence predictions. - Refinement of model cell sizes around the Glendell mining area and Bowman Creek. - Introduction of pilot point multipliers to improve calibration and uncertainty analysis (Kx, Kz, Sy, Ss, and recharge) - Recalibration (steady state and transient) to extended calibration dataset using surrogate child/parent technique. - Updated stochastic predictive simulations of proposed operations.	10.0	2019

Model version	Model build	Project	Description of modification(s)	Model version number	Year Released
11	0	HVO	- Combined model layers from the existing Glendell and HVO South MOD5 numerical models to create layers for updated model. - Reduced the extent of the model, and centered it on HVO, to reduce numerical burden. The model excluded MTW to the south and Mt Owen/Integra to the east, but used boundary conditions at these locations to represent previously modelled impacts from these mining operations. - Updated historical mine sequences at HVO. - Revised the extent of Quaternary alluvium along Hunter River north of Cheshunt Pit. - Added pit lake areas in South Lemington Pit 1, Carrington Pit, Carrington Remnant Void. - Added controlled water levels to represent ongoing dewatering of the Lemington Underground Mine. - Adjusted river depth along Hunter River. - Recalibrated using pilot points (steady state and transient).	11.0	(This report)

D2.2 Model uncertainty

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

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

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

D2.3 Model code

The model was built using MODFLOW-USG, selected because it:

- allows use of an unstructured mesh where cells can be refined around localised features such as rivers, alluvial aquifers and mining, and larger cells used where refinement is not required;
- does not need layers to be continuous over the model domain, allowing layers to stop where geological units pinch out or outcrop such as coal seams and alluvium;
- effectively reduces the number of cells with the refinement and pinching options that allow faster model run times, therefore improving the ability to conduct stochastic uncertainty analysis; and
- better represents flow transfer processes between systems such as bedrock and alluvial groundwater systems through the pinching out of layers.

The input files for the MODFLOW-USG model were created using custom Fortran code and a MODFLOW-USG edition of the Groundwater Data Utilities by Watermark Numerical Computing (2019). The model's unstructured 3D mesh was generated using Algomesh (HydroAlgorithmics, 2014).

D2.4 Model design

D2.4.1 Extent and boundaries

HVO is located in the Upper Hunter Valley in New South Wales, where a cluster of mining activities are situated and create a cumulative impact on the groundwater regime. The model includes the full extents of the existing and proposed HVO North and South mines as well as the full extent of:

- Liddell Mine;
- Glendell Mine (including the proposed Glendell Continued Operations Project);
- Ravensworth Operations;
- Ashton Open cut and Underground Mine; and
- United and Wambo open cut mines.

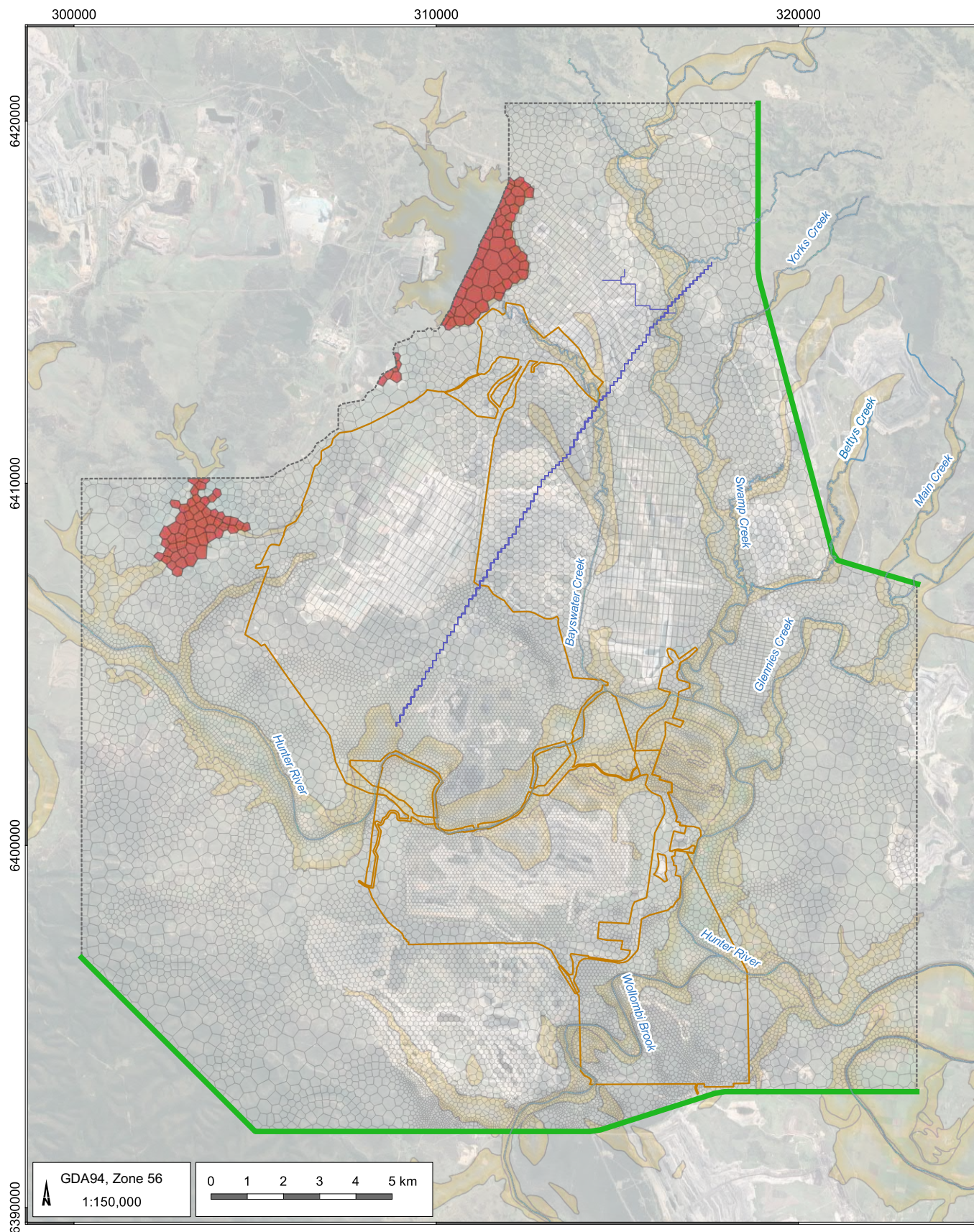
The approved mining areas were encompassed within the model domain as most target the same coal seams proposed for mining at HVO and are necessary to represent and assess the magnitude of cumulative impacts. Cumulative impact areas from the previous groundwater impact assessments relevant to HVO were reviewed to ensure the NSW Aquifer Interference Policy (AIP) minimal impact considerations (drawdown threshold) of 2 m for assessing potential impacts on third party water supply bores and approximately 0.2 m in the alluvium could be represented in the Project area.

The model domain was also designed to include a spatial buffer to ensure that the outline of the model domain was sufficiently remote from the mining activities to reduce any overly constraining influence of boundary conditions on the model outcomes.

The resulting model domain is approximately 23 km wide (west to east direction) and 28 km long (north to south direction) as shown on Figure D 1. The shape of the model was aligned with key regional geological and hydrogeological features as follows:

- North-western boundary – set approximately 3 km north-west of HVO, where the mined Wittingham Coal Measures outcrop and terminate.
- Northern boundary – set approximately 10 km north of HVO, this boundary extends beyond the Hunter Thrust fault that separates the non-coal bearing Carboniferous sediments against the Permian coal measures of the Hunter Valley (refer to Geological Map in Section 4 of main report).
- North-east boundary – set approximately 10 km north-east of HVO, this boundary is aligned with the Camberwell anticline, where the basement of the Wittingham Coal measures is closer to the surface. Due to the basement high, the groundwater system in the eastern basin of the anticline has limited interaction with western basin and was excluded from the model. A “general head” boundary condition was applied as shown on Figure D 1, using heads extracted from the model developed for the Glendell Continuation project.
- Southern boundary – set to the south of Wollombi Brook to include United and Wambo mine open cut operations and final voids. A “general head” boundary condition was applied to this boundary as seen on Figure D 1.

The ground surface in the model was represented using the publicly available 1 second SRTM dataset, known to be vertically accurate to 6.0 m over Australia with 90% confidence. Around the Project area and along surface drainages, more accurate LiDAR data was used where available.



LEGEND

- Drainage
- Project Area
- Alluvium Boundary
- Model extent
- Model grid

- Horizontal Flow Barrier (HFB) walls
- General Head Boundary
- Constant head cells

HVO Continuation (G1737J)

Model mesh and boundaries



AGE

DATE
03/11/2022

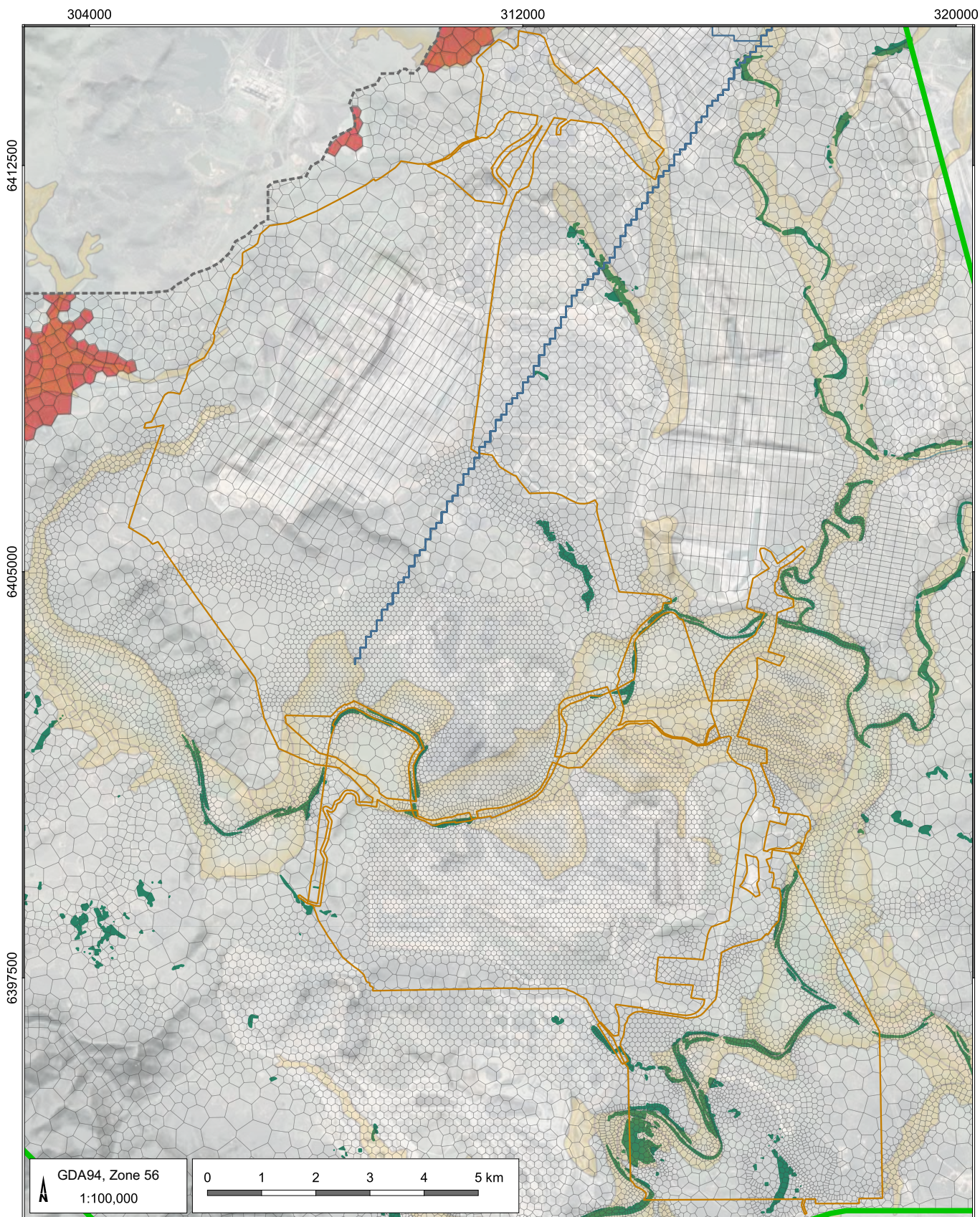
FIGURE No:
D 1

D2.4.2 Mesh

The model domain was discretised and arranged into 33 layers comprising up to 22,577 cell nodes in each layer. The dimensions of the cells vary according to the features that required representation, with the highest level of detail around the Project Area. The following cell dimensions were adopted:

- longwall mining areas – 100 m x 200 m to 150 m x 300 m rectangular cells aligned to longwall panels where possible;
- open cut areas – varying polygons and dimensions from 100 m to 200 m hexagonal Voronoi cells, and 150 m x 200 m to 150 m x 300 m rectangular cells;
- streams and alluvial flood plains – varying from 50 m x 50 m to 200 m x 200 m Voronoi cells; and
- potential groundwater dependent ecosystems (GDEs) within alluvial flood plains – 50 m x 50 m Voronoi cells.

Figure D 2 shows the cell sizes. Finer scale cells were created at important components of the model such as GDEs, rivers/creeks, alluvial aquifers and mining areas particularly near the Hunter River. The purpose of these cells was to ensure sufficient simulation points existed in the model to represent a steep zone of depressurisation developing between the Project area and the adjacent alluvial water source if required. The cell refinements also allow spatial variability in model parameters to be represented during the calibration process. Overall, the model comprised 415,385 cells across the 33 layers.



LEGEND

- Drainage
- Horizontal Flow Barrier (HFB) walls
- General Head Boundary
- Project Area
- Constant head cells
- Model extent
- Model grid
- Alluvium extent
- High potential terrestrial GDE - from regional studies

HVO Continuation (G1737J)

Model mesh and boundaries (Project area)



AGE

DATE
03/11/2022

FIGURE No:
D 2

D2.4.3 Model Layers

The key hydrostratigraphic units within the Quaternary and Permian formations identified in the conceptual model (refer main report) were represented in the numerical model via 33 separate layers (Table D 2). Model layers were created to separately represent the following hydrostratigraphic units:

- Quaternary alluvium (shallow and deep);
- surficial weathered Permian strata;
- coal seams (groups of seam plys); and
- non-coal, overburden and interburden strata that separate the coal seams.

The model layers from the Greater Ravensworth and HVO South models were combined for the current model build. The number of layers in each model is different, with the layers focussed on different hydrostratigraphic units. The HVO model included all coal seam layers within the Wittingham Coal Measures, as well as interburden, overburden, alluvium and regolith. The dimensions of the model layers were generally retained from each of the source models where possible. Some layers were spliced to maintain their vertical dimensions. Others required further interpolation or extrapolation within the model domain. A number of model layers representing split seams originally imported from the Greater Ravensworth model were merged to a single layer to reduce the number of cells and numerical burden. Some interburden layers with significant thickness (>80m) were subdivided to improve vertical resolution through the strata.

As noted by Middlemis and Peeters (2018), the model surfaces are a structural and conceptual source of uncertainty in the numerical model that cannot be changed in an automated way during the calibration process. The sources of data and uncertainty in the model surfaces are discussed for each hydrostratigraphic unit below.

Quaternary alluvium

The extent and thickness of the Quaternary alluvium in the numerical model was based on the CSIRO (2015) soil and landscape grid, regional geology maps and site specific data where it was available. The areas where site specific investigation data was utilised to update the model are along the Hunter River and Wollombi Brook (AGE, 2017a), Main Creek (AGE, 2018) and along Bowmans, York and Swamp Creek (AGE, 2019). A recent re-examination of geological logs that made part of the model development resulted in further updates to the extent of the Hunter River alluvial aquifer north of the Cheshunt Pit.

As detailed within the main report, the Quaternary alluvium contains a basal gravel unit overlain by finer grained alluvial sediments. Therefore, two alluvial layers were created in the numerical model:

- an upper layer with a maximum thickness of 8 m in general (but up to 28 m in a deep section of the Hunter River) that represents shallow and less productive silty sands and clays; and
- a second layer representing the deeper, coarser, more productive sands and gravels at the base of the alluvium.

The iterative refinements are considered to have reduced the uncertainty associated with the extent and thickness of the alluvial aquifer, particularly close to HVO. Whilst the updated surfaces for the base of the Quaternary alluvium in the Project area were improved from previous realisations, there remains some inherent uncertainty in the exact thickness of alluvium where investigative drilling data is not available. This is of course an inherent uncertainty in all groundwater models. If the Hunter River alluvial sequence is thinner in some areas than represented in the numerical model, the impact of the Project on the 'total saturated thickness of alluvium' could be more significant, and likewise if the alluvium is thicker in some areas than represented in the numerical model, the actual drawdown impact as a proportion of the 'total saturated thickness of alluvium' could be less than predicted by the model.

Table D 2 Model layers

Geological age	Stratigraphic unit		Model layer
Quaternary	Shallow alluvium / regolith		1
	Deep alluvium		2
Permian (Wittingham Coal Measures)	Overburden		3
	Newcastle Coal Measures	Newcastle seam	4
	Jerrys Plain sub-group	Whybrow seam	4
		Interburden	5
		Wambo seam	6
		Interburden	7
		Whynot seam	8
		Interburden	9
		Blakefield, Glen Munro and Woodlands Hill seams	10
		Interburden	11
		Arrowfield seam	12
		Interburden	13
		Bowfield seam	14
		Interburden	15
		Warkworth seam	16
		Interburden	17
		Mt Arthur seam	18
		Interburden	19
		Piercefield, Vaux seams	20
		Interburden	21
		Broonie, Bayswater seam	22
	Vane sub-group	Interburden	23
		Interburden	24
		Lemington, Pikes Gully seams	25
		Interburden	26
		Interburden	27
		Arties, Liddell seams	28
		Interburden	29
		Barrett seam	30
		Interburden	31
		Hebden seam	32
	Saltwater Creek Formation		33

Weathered Permian

Surficial weathering of outcropping Permian bedrock was represented in the model as a separate hydrostratigraphic unit. The depth of the weathering surface in the numerical model was based on geological models provided by the proponent for mining areas at HVO, Liddell and Ravensworth Operations, and the CSIRO (2015) soil and landscape grid. The weathering surface has been gradually updated over time as the model has been updated to assess the impact of mining in the region.

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

Permian coal seams and interburden

As noted previously, the numerical model contains layers to represent the key interburden and coal seams intersected by mining operations within the model domain. In a similar process to the weathered zone, the interburden and coal seams were sourced from geological models provided by the proponent which have been gradually updated over time.

Similar to the weathered zone, the surfaces for the key coal seams and intervening interburden are considered to be “relatively” accurate as they are informed by direct observation within mining areas and networks of exploration drill holes across the mining areas. The nature of these layers also means that the distinct transitions between the layers is readily identifiable to an accuracy of several centimetres. The accuracy of the coal seams and interburden surfaces becomes less certain in areas beyond the extent of the mining company geological models where the surfaces have been extrapolated based on less data. However, these areas are limited in the model due to the prevalence of coal mining in the region. The uncertainty in the Permian model layers is therefore considered to have been reduced as far as possible and is significantly better than a greenfield area with no mining history.

Figure D 3 and Figure D 4 show 3D representations of the model mesh and layers from oblique views. Figure D 3 shows the model viewed from the south looking to the north, and Figure D 4 provides a “sliced” view of the model, exploring the 3D representation of the Project area.

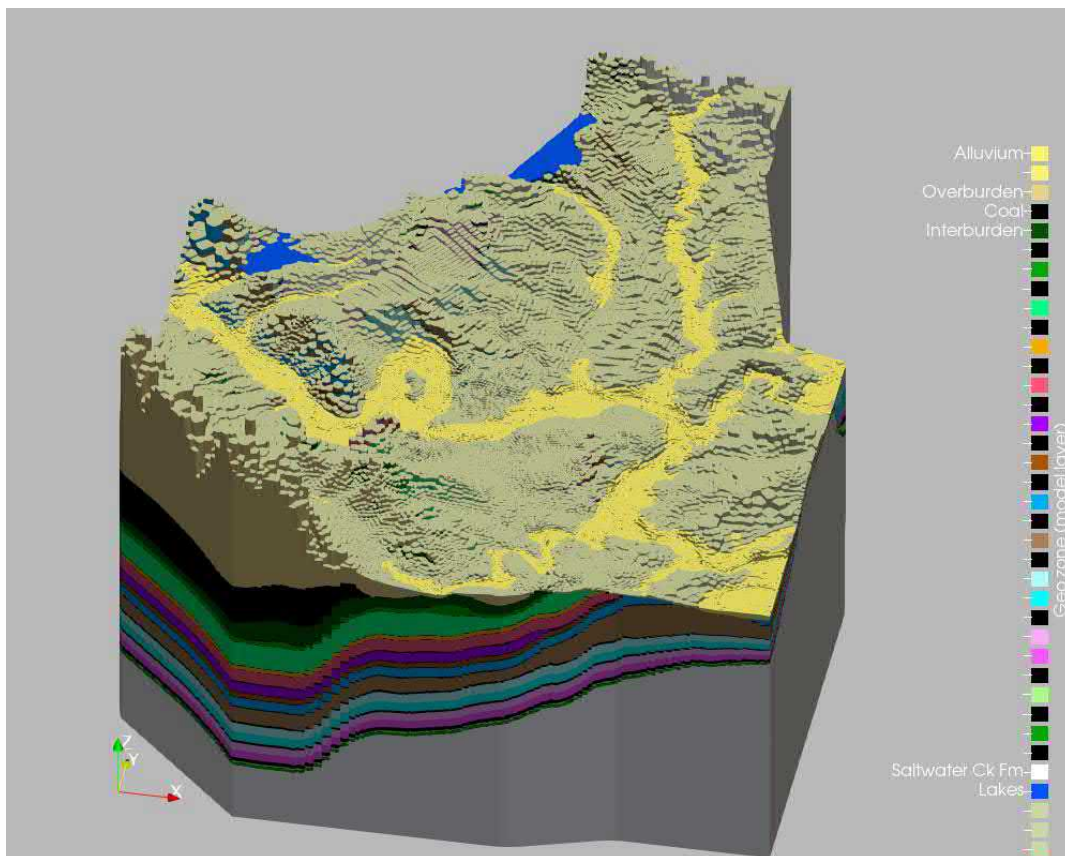


Figure D 3 3D representation of the model mesh and layers - oblique view looking from south towards north

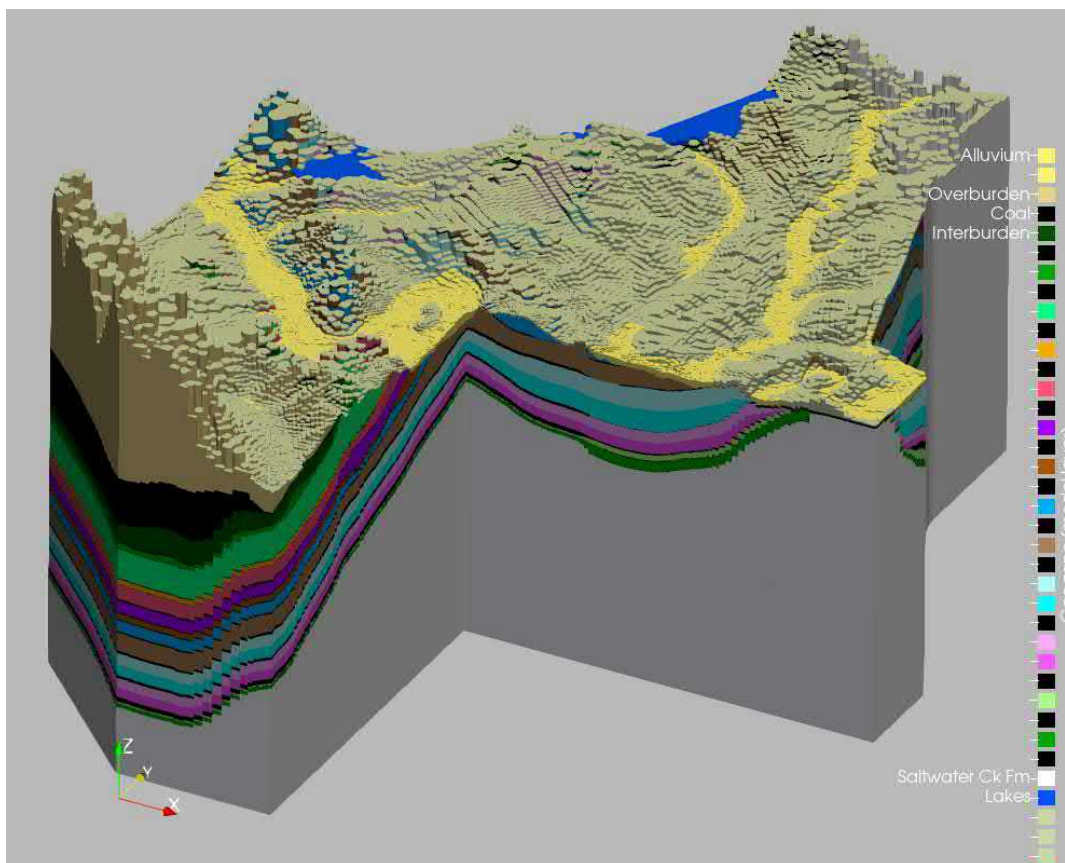


Figure D 4 3D representation of the model mesh and layers - oblique view, "sliced"

D2.4.4 Geological structures

The model domain includes some known and many likely unidentified structures including intrusions and faults. The geological structures and the potential influence on the groundwater regime are discussed in the main report in Section 4. In the Project area the main geological structures are the:

- Camberwell Anticline which runs along a northwest to southeast alignment near the northeast boundary of the model domain;
- Block Fault Zone, is a zone of faults perpendicular to the Camberwell Anticline east of the Project Area some 250 m to 300 m wide with typical fault displacements of less than 12 m;
- Davis Creek Fault which separates the Liddell open cut mine for the adjacent abandoned Liddell underground mine;
- Hunter River Cross Fault which occurs to the south of HVO South; and
- Hunter Valley Dyke, which is north of the Project area with a typical intrusive thickness of up to 15 m.

The structures are shown in Section 4 in the main report. The Camberwell Anticline structure is represented within the numerical model through the Permian model layers in the Glendell mine area. There are numerous mapped minor faults associated with the Hunter-Mooki Fault system within the model domain. The properties of most faults, including the Block Fault Zone or the Hunter Valley Dyke were not represented within the model as no explicit evidence exists as to their influence on the groundwater regime.

The exception to this is the Davis Creek Fault that strikes in a north easterly orientation adjacent to the Liddell mine which then continues through to the Ravensworth Operations (see Section 4 main report). The Davis Creek Fault and an un-named dyke identified were also represented in the numerical model. At Liddell Mine these structures have been observed to act as barriers to groundwater flow and were therefore included in previous updates to the groundwater model and represented with the Horizontal Flow Barrier (HFB) Package.

D2.4.5 Stress periods

The calibration involved an initial steady state calibration to obtain pre-mining conditions, followed by a transient history matching using water level measurements from the monitoring network. The transient numerical simulation was designed with stress periods of different intervals. At the beginning of the simulation where less monitoring data is available and less detail is required, longer stress periods were used; and in more recent times, where more monitoring data is available and more refined model outputs are required, shorter stress periods were used. The transient model was set up as follows:

- Last day of 1969 – steady state stress period (transient here and after);
- 1970 to 1979 – one 10-year stress period;
- 1980 to 1999 – 4 x five yearly stress periods;
- 2000 to 2002 – 1 x three yearly stress period;
- 2003 to 2008 – 12 x six monthly stress periods;
- 2009 to 2035 – 108 x quarterly stress periods; and
- 2036 to 2050 – 30 x six monthly stress periods.

Quarterly stress periods were introduced to the model so that some seasonal variability in recharge and stream flows could be represented where data was available for the calibration period. The drains representing mining were advanced in quarterly intervals and turned off after being active for 3.5 years to reflect the advancement of the mine face and the progressive backfilling of the open cut mines with spoils, or goafing of longwall mining areas (where applicable).

An additional version of the model was developed for simulating recovery after mining ceased at HVO in 2050. Both models were combined into a single, continuous simulation with one finishing and the other starting at the beginning 2050. The timing for the recovery model was set up as follows:

- 2051 – 1 x year stress period;
- 2052 to 2055 – 1 x 4 year stress period;
- 2056 to 2060 – 1 x 5 year stress period;
- 2061 to 2080 – 2 x 10 year stress periods;
- 2081 to 2100 – 1 x 20 year stress period;
- 2101 to 2100 – 1 x 20 year stress period;
- 2101 to 2300 – 4 x 50 year stress periods;
- 2301 to 3000 – 7 x 100 year stress periods; and
- 3001 to 4000 – 2 x 500 year stress periods.

The inputs/outputs of the recovery model were aligned with a surface water balance model being used to simulate recovery of water with the final void (Engeny 2022). MODFLOW's ATS (Adaptive Time Stepping) function was used applying a 3x multiplier and 1.3x divisor, with an initial time-step length of 20% of the total stress period length.

D2.4.6 Mining progression

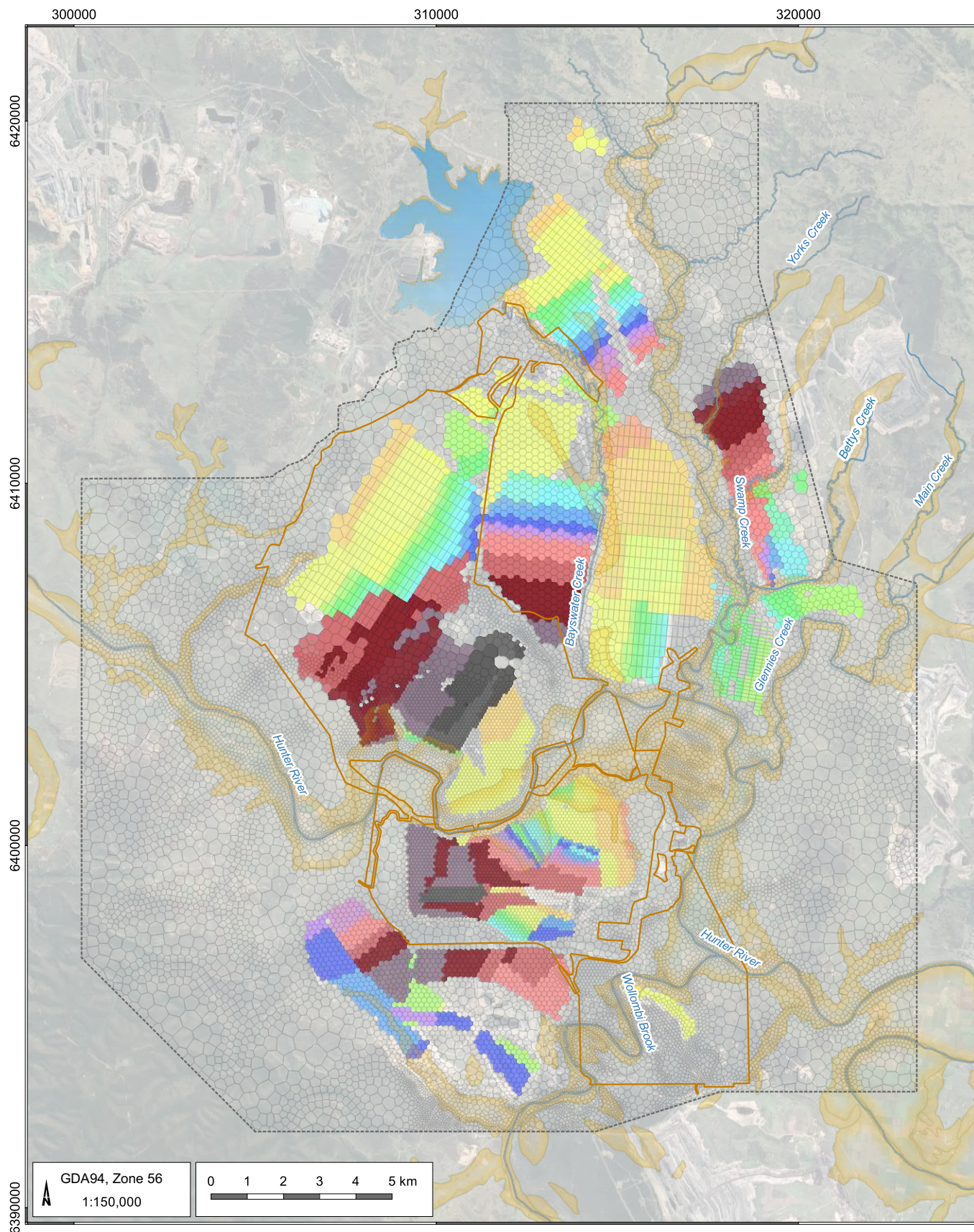
There are numerous mining operations situated within the model domain, generating complex interactions between them. The representation of mining in the model was based on mine schedules used in previous groundwater assessments and was updated using data provided by Glencore.

The mines represented in the model are summarized in Table D 3 below.

Figure D 5 and Figure D 6 show the footprint and timing of the project, as well as the cumulative mining surrounding the HVO Complex.

Table D 3 Mining progression (layers) – Proposed mining scenario

		Mine	HVO North	HVO South	Lemington South 1	Lemington UG	HVO West Pit	Rav Ops - Narama	Rav Ops - Rav North	Rav UG	Rav Ops - Cumnock OC	Rav Ops - Cumnock UG	Wambo Pit	Wambo OC	United OC	Glendell	Liddell
		Years active	1979 - 2050	1997- 2045	1998- 2006; 2019-2024	1971-1992	1952- 2025	1991-1998	pre1980-2013	2007- 2024	1949-2008	1949-2008	1974- 2017	2017- 2039	2017- 2039	2008- 2044	1990- 2022
Permian	Jerrys Plains Subgroup	Whybrow											Mined	Mined	Mined		
		Redbank											Mined	Mined	Mined		
		Wambo											Mined	Mined	Mined		
		Whynot											Mined	Mined	Mined		
		Blakefield		Mined										Approved	Approved		
		Glen Munro		Mined	Mined									Approved	Approved		
		Woodlands Hill		Mined	Mined									Approved	Approved		
		Arrowfield		Mined	Mined									Approved	Approved		
		Bowfield		Mined	Mined	Mined								Approved	Approved		
		Warkworth		Mined										Approved	Approved		
		Mt Arthur	Mined	Mined		Mined									Approved		
		Piercefield	Mined	Mined											Approved		
		Vaux	Mined	Mined			Mined	Mined	Mined		Mined				Approved		
		Broonie	Mined	Mined			Mined	Mined	Mined		Mined						
		Bayswater	Mined	Mined			Mined	Mined	Mined		Mined					Mined	
	Vane Subgroup	Lemington	Mined (future)				Mined		Mined		Mined					Mined	Mined
		Pikes Gully	Mined (future)				Mined		Mined	Mined		Mined				Mined	Mined
		Arties	Mined (future)				Mined		Mined							Mined	Mined
		Liddell	Mined (future)				Mined			Approved		Mined				Mined	Mined
		Barrett	Mined (future)				Mined					Mined				Mined	Mined
		Hebden					Mined										Mined



LEGEND

- Drainage
- Project Area
- Alluvium Boundary
- Model extent
- Model grid

Mine progression

 1970	 2016
 1984	 2017
 1994	 2019
 2004	 2024
 2007	 2029
 2009	 2035
 2011	 2040
 2013	 2045
 2015	 2050

HVO Continuation (G1737J)

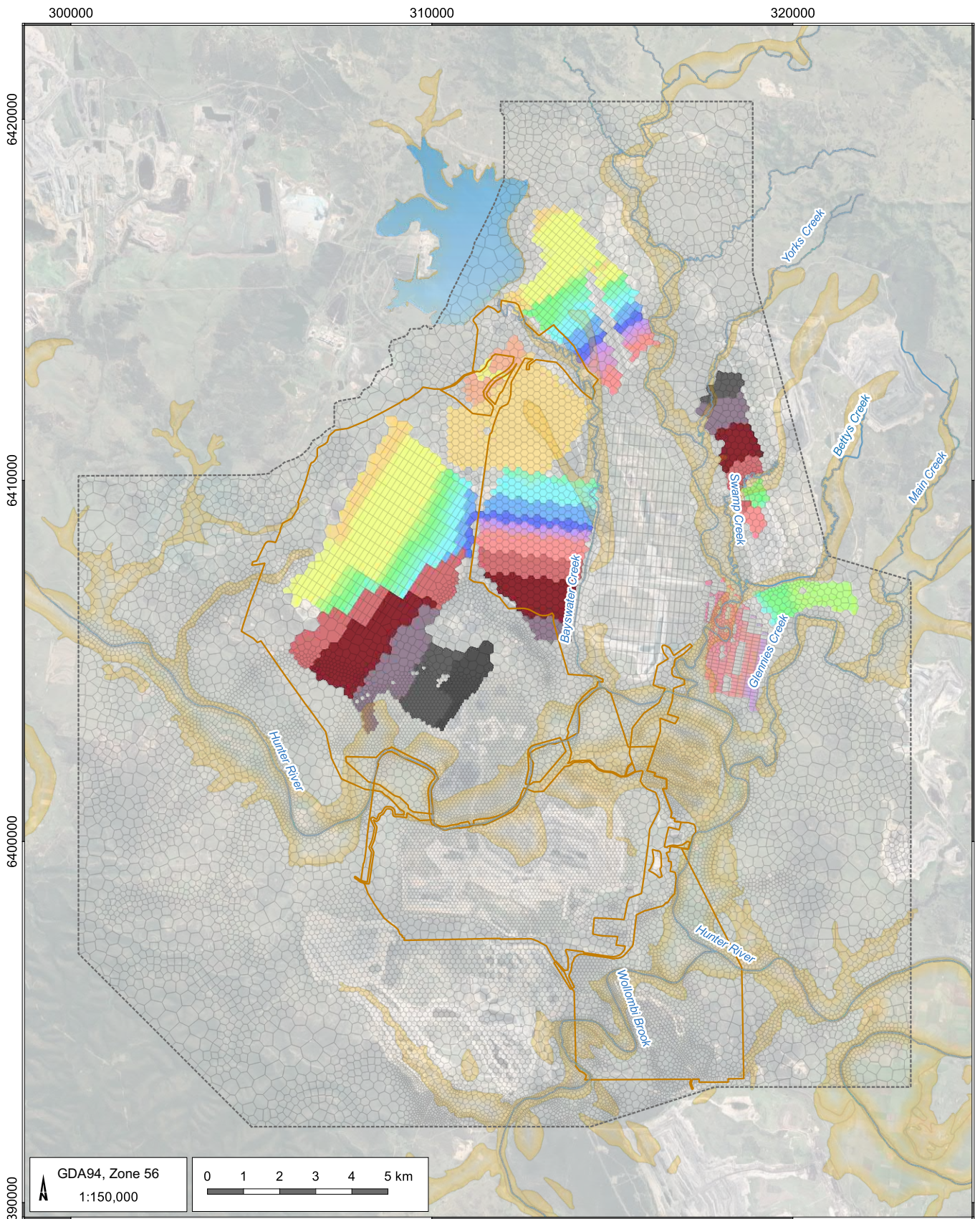
Predictive mine progression for the Project – Regolith, Lemington and Pikes Gully Seams



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FIGURE No:
D 5



LEGEND

- Drainage
- Project Area
- Alluvium Boundary
- Model extent
- Model grid

Mine progression

 1970	 2016
 1984	 2017
 1994	 2019
 2004	 2024
 2007	 2029
 2009	 2035
 2011	 2040
 2013	 2045
 2015	 2050

HVO Continuation (G1737J)

Predictive mine progression for the Project –Liddell and Barrett seams



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FIGURE No:
D 6

The timing and location of mining represented within the numerical model contains an unavoidable element of uncertainty; Middlemis and Peeters (2018) categorize this as 'scenario uncertainty'. This is because records of historical mining can be difficult to obtain, and assumptions on the progress of mining operations, particularly older operations are therefore required. The exact advancement of future mining operations is also uncertain as all mining operations are subject to market conditions that can alter the advancement of projects. The historical and future mining represented within the numerical model should therefore be considered a guide rather than highly accurate.

Despite these unavoidable limitations, the model is considered to largely have mining represented where it has occurred historically and is approved to occur in the future; it is only the timing and elevation of the mining (especially in historical mines) that has a level of uncertainty. The uncertainty in the location and progression of mining has potential to influence the calibration of the model in areas where water level calibration points are situated in close proximity to mining activities. In areas more distant from mining activities the uncertainties in the historical progression of mining obviously become less influential on the model predictions. The NSW and Commonwealth approval process allows for this inherent uncertainty in future mining schedules by typically requiring three or five yearly updates to numerical models during operations to allow any changes in schedules to be represented in the model and also allow for validation of predictions or further calibration utilising new monitoring and parameter datasets.

D2.5 System stresses

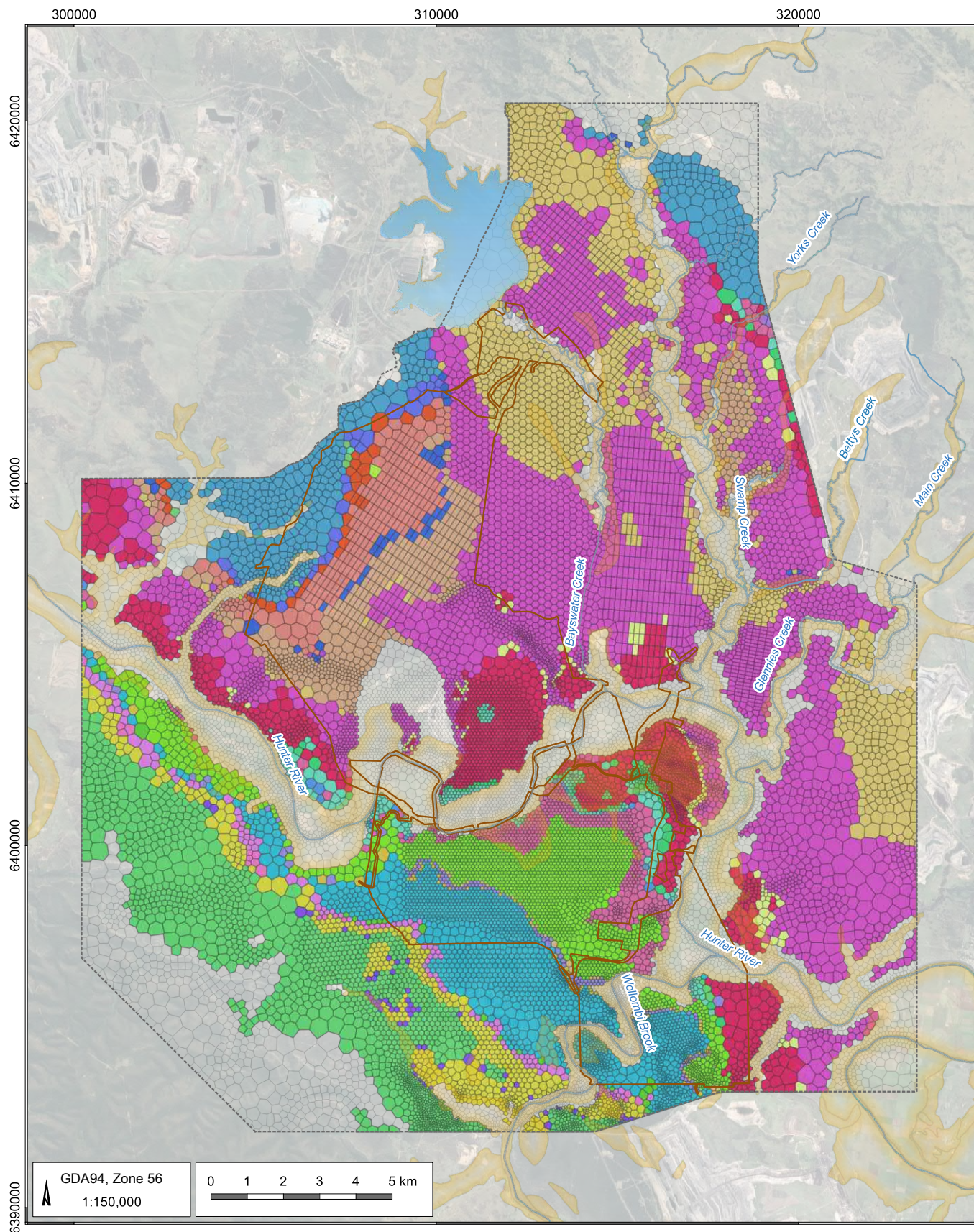
D2.5.1 Recharge

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

Recharge to the groundwater systems occurs through diffuse infiltration of rainfall through the soil profile and subsequent deep drainage to underlying groundwater systems. A spreadsheet-based soil moisture calculation was used to estimate the timing and magnitude of recharge events used in the model. The simple soil moisture balance was used to evaluate when the soil profile had likely reached field capacity following rainfall and when subsequent deep drainage to the underlying water table occurs based on historical rainfall datasets.

Groundwater recharge was represented in the numerical model using zones based on geology occurring at the land surface. Figure D 7 and Figure D 8 show the recharge zones represented in the groundwater model. Timing of transient recharge during the calibration period was obtained from the soil moisture balance calculation. The amount of recharge for each zone was determined using an individual factor which acts as a multiplier on the soil moisture balance calculation.

Table D 4 summarises the calibrated rate of recharge for each geological unit. Recharge for the predictive and recovery phases (after 2021) adopted a constant recharge rate based on the long-term average rainfall.



LEGEND

- Drainage
- Project Area
- Alluvium Boundary
- Model extent
- Model grid

Recharge zones

3	11	19	27
4	12	20	28
5	13	21	29
6	14	22	30
7	15	23	31
8	16	24	33
9	17	25	
10	18	26	

HVO Continuation (G1737J)

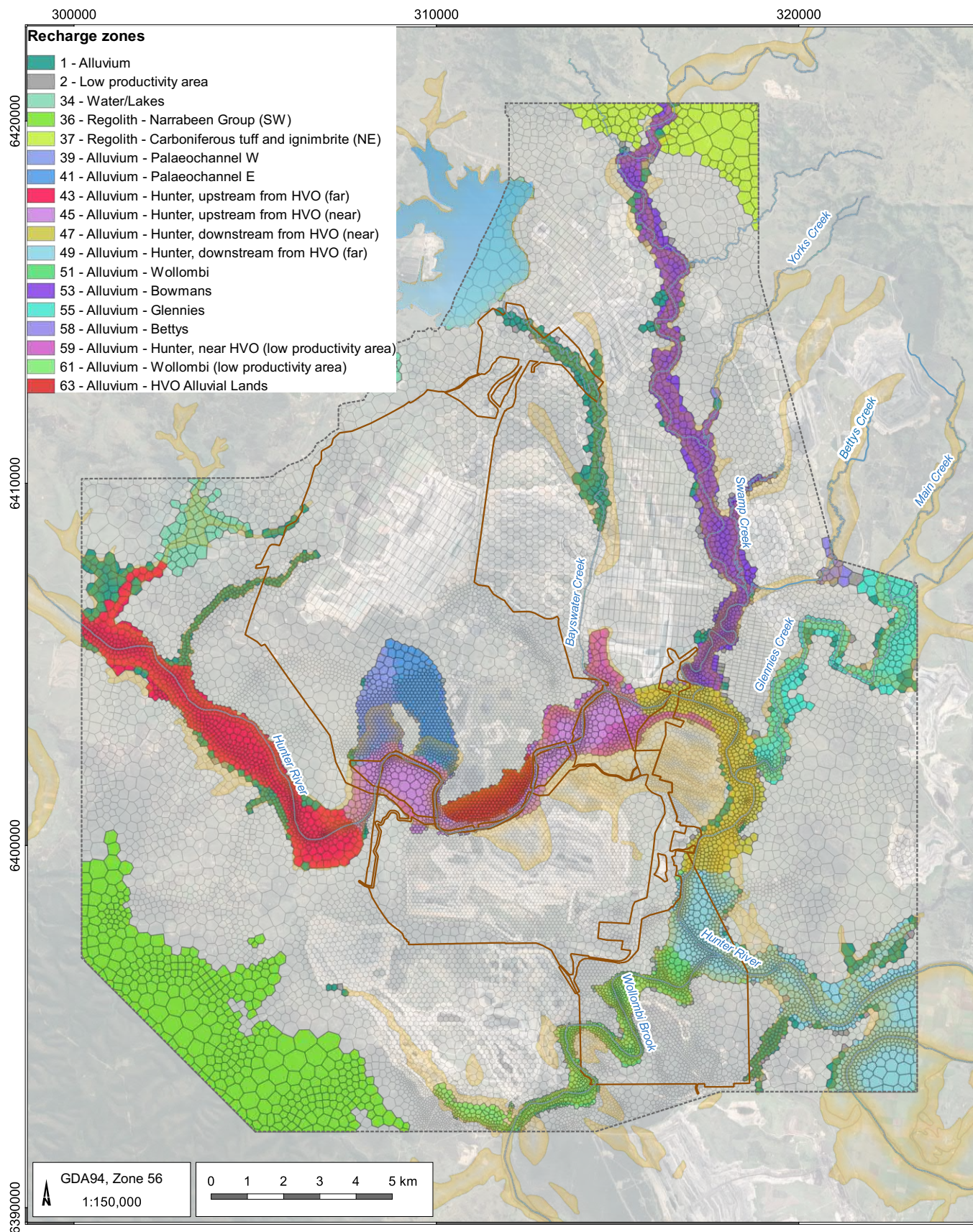
Recharge zones (Permian regolith)



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FIGURE No:
D 7



LEGEND

- Drainage
- Project Area
- Alluvium Boundary
- - - Model extent
- Model grid

HVO Continuation (G1737J)

Recharge zones (Alluvium and other zones)



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FIGURE No:
D 8

Table D 4 Modelled recharge rates

Zone		Diffuse recharge rate – steady state	
		Average (mm/year)	% of annual rainfall
1, 2	Alluvium, low productivity area	57.49	10.396%
3	Subcrop: Overburden	0.27	0.049%
4	Subcrop: Newcastle, Whybrow Seams	0.06	0.012%
5	Subcrop: Interburden	0.10	0.018%
6	Subcrop: Wambo Seam	0.45	0.082%
7	Subcrop: Interburden	0.20	0.036%
8	Subcrop: Whynot Seam	0.26	0.046%
9	Subcrop: Interburden	0.33	0.059%
10	Subcrop: Blakefield, GlenMunro, WoodlandsHill Seams	0.06	0.012%
11	Subcrop: Interburden	0.39	0.070%
12	Subcrop: Arrowfield Seams	0.22	0.039%
13	Subcrop: Interburden	0.09	0.015%
14	Subcrop: Bowfield, BowfieldSplit Seams	0.13	0.023%
15	Subcrop: Interburden	0.30	0.054%
16	Subcrop: Warkworth Seam	0.39	0.071%
17	Subcrop: Interburden	0.65	0.117%
18	Subcrop: MtArthur Seam	0.30	0.053%
19	Subcrop: Interburden	0.06	0.012%
20	Subcrop: Piercefield, Vaux Seams	0.44	0.080%
21	Subcrop: Interburden	0.07	0.013%
22	Subcrop: Broonie, Bayswater Seams	0.10	0.017%
23	Subcrop: Interburden	0.29	0.052%
24	Subcrop: Interburden	0.44	0.080%
25	Subcrop: Lemington, PikesGully Seams	0.13	0.024%
26	Subcrop: Interburden	0.10	0.018%
27	Subcrop: Interburden	0.43	0.078%
28	Subcrop: Arties, Liddell Seams	0.13	0.023%
29	Subcrop: Interburden	0.45	0.081%
30	Subcrop: Barrett Seam	0.09	0.016%
31	Subcrop: Interburden	0.43	0.078%
32	Subcrop: Hebden Seam	0.25	0.046%
33	Subcrop: SaltwaterCkFm	0.38	0.069%

Zone		Diffuse recharge rate – steady state	
		Average (mm/year)	% of annual rainfall
34	Water/Lakes	0.43	0.078%
36	Regolith - Narrabeen Group (SW)	0.03	0.006%
37	Regolith - Carboniferous tuff and ignimbrite (NE)	0.03	0.006%
39	Alluvium - Palaeochannel W	64.65	11.690%
41	Alluvium - Palaeochannel E	32.32	5.845%
43	Alluvium - Hunter, upstream from HVO (far)	64.65	11.690%
45	Alluvium - Hunter, upstream from HVO (near)	64.65	11.690%
47	Alluvium - Hunter, downstream from HVO (near)	32.32	5.845%
49	Alluvium - Hunter, downstream from HVO (far)	50.84	9.193%
51	Alluvium - Wollombi	64.65	11.690%
53	Alluvium - Bowmans	64.65	11.690%
55	Alluvium - Glennies	43.64	7.892%
58	Alluvium - Bettys	43.64	7.892%
59	Alluvium - Hunter, near HVO (low productivity area)	28.18	5.095%
61	Alluvium - Wollombi (low productivity area)	41.61	7.524%
63	Alluvium - HVO Alluvial Lands	0	0%

The rate of rainfall recharge is an inherently uncertain parameter in the numerical model, as it cannot be directly measured, only inferred from changes in groundwater levels within monitoring bores. Rainfall recharge also varies spatially depending on a large range of factors including soils, land-use, geology, vegetation cover, topography and depth to water table. Whilst the numerical model represents some of these elements, it cannot be expected to provide highly accurate values of rainfall recharge, and the rainfall recharge rates determined during the calibration process are considered to be one potential realisation. Given the uncertainty in this model parameter, it was included in the uncertainty analysis (the variable was allowed to vary) to determine the influence on the model predictions. The uncertainty analysis for model parameters is described in Section D7.

D2.5.2 Evapotranspiration

Evapotranspiration from the water table was represented in the numerical model within the soil moisture balance calculation prepared to estimate the applied recharge. Therefore, the evapotranspiration package (EVT) of MODFLOW was not needed. This approach greatly reduced the numerical burden of the simulation, allowing a more efficient calibration of parameters and estimation of uncertainty.

D2.5.3 Model outline boundaries

The general head boundary (GHB) package was used to represent groundwater exchange inside/outside of the model. The model extent was designed to make sure that impact from HVO (drawdown contour 1 m) did not extend to the model outline, and the GHB cells are not believed to influence the mining predictions. They act as a regional condition, and in some areas include cumulative impact not directly linked to HVO.

Groundwater elevations used for the GHB package were extracted from previous groundwater models (Glendell, HVO South) and reused. These included influence from Mount Thorley/Warkworth, Mount Owen/Integra and Ravensworth East. The GHB conductance was based on the conductance of the formation for each cell.

D2.5.4 Surface drainage

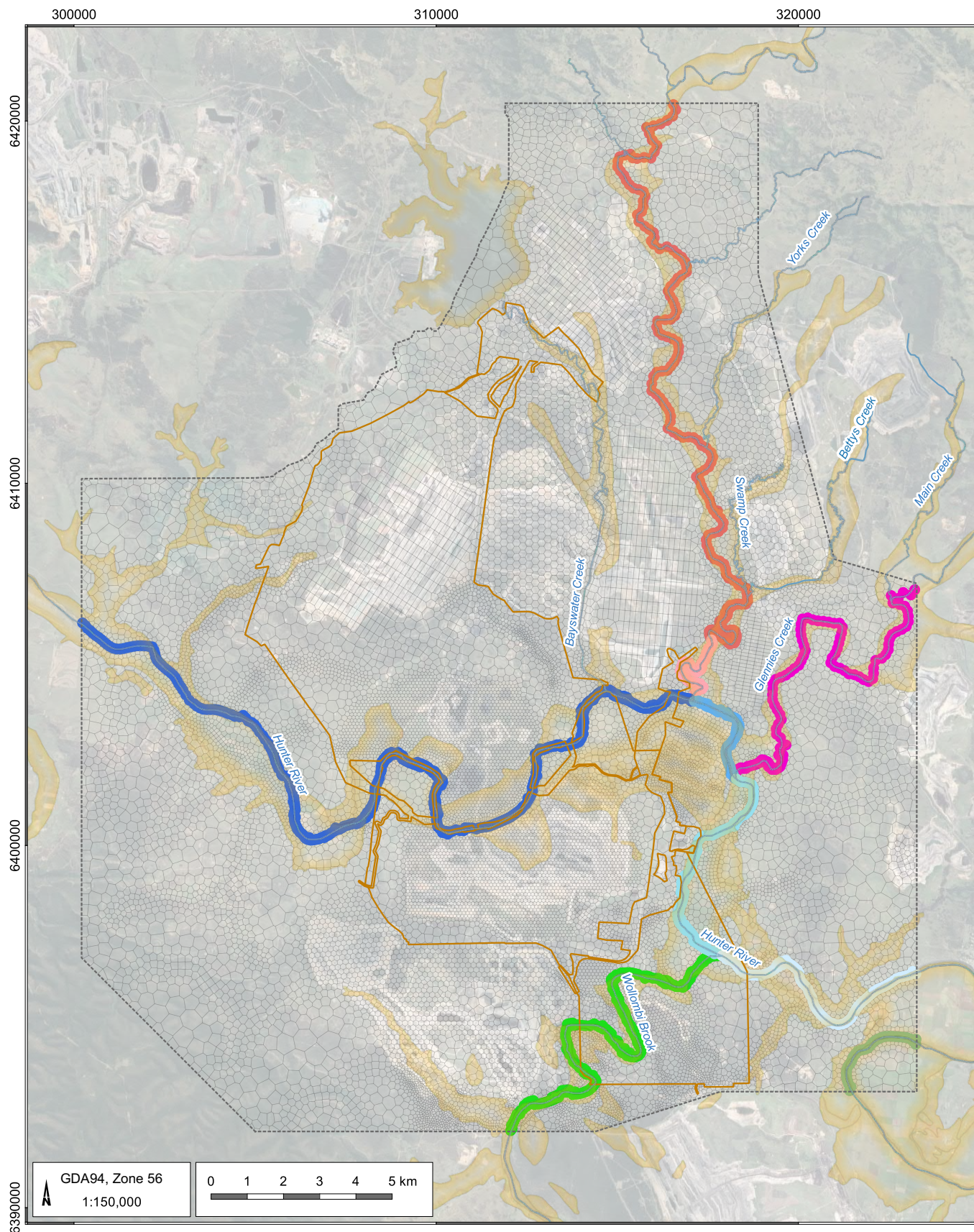
Groundwater interaction with surface drainage was simulated using either the stream package (STR), or the river package (RIV) of MODFLOW. The cells assigned to these packages in the model were divided by zones to represent each of the drainage systems and are displayed on Figure D 9 and Figure D 10.

Major streams systems, including the Hunter River, Bowmans Creek, Glennies Creek and Wollombi Brook were represented using the stream package, whereas minor drainage systems were represented using the river package (with no head of water, allowing them to only drain water from the groundwater system).

The stream package requires the level of the river bed, and for streams where there is flow of water “entering” the model, the measured flow of surface water. Flow “entering” the model was assigned for the Hunter River, Glennies Creek and Wollombi Brook, based on data from nearby gauging stations. For the predictive period, the average flow per gauging station between 2009 and 2019 was used as the water input.

The stream bed conductance was calculated from river width, length, riverbed thickness, and an estimated vertical hydraulic conductivity of the riverbed material. The vertical hydraulic conductivity of the stream bed was then adjusted during the calibration process. The stage height for rivers and creeks where flow “enters” the model (Hunter River, Glennies Creek and Wollombi Brook) was internally calculated by MODFLOW-USG. 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 D 5 and Table D 6 summarise the stream and river cell parameters in the model.

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



LEGEND

- Drainage
- Project Area
- Alluvium Boundary
- - - Model extent
- Model grid

Stream zones

- 1 - Bowmans Creek
- 2 - Bowmans Creek
- 3 - Glennies Creek
- 4 - Wollombi Brook
- 5 - Hunter River
- 6 - Hunter River
- 7 - Hunter River
- 8 - Hunter River
- 9 - Hunter River

HVO Continuation (G1737J)

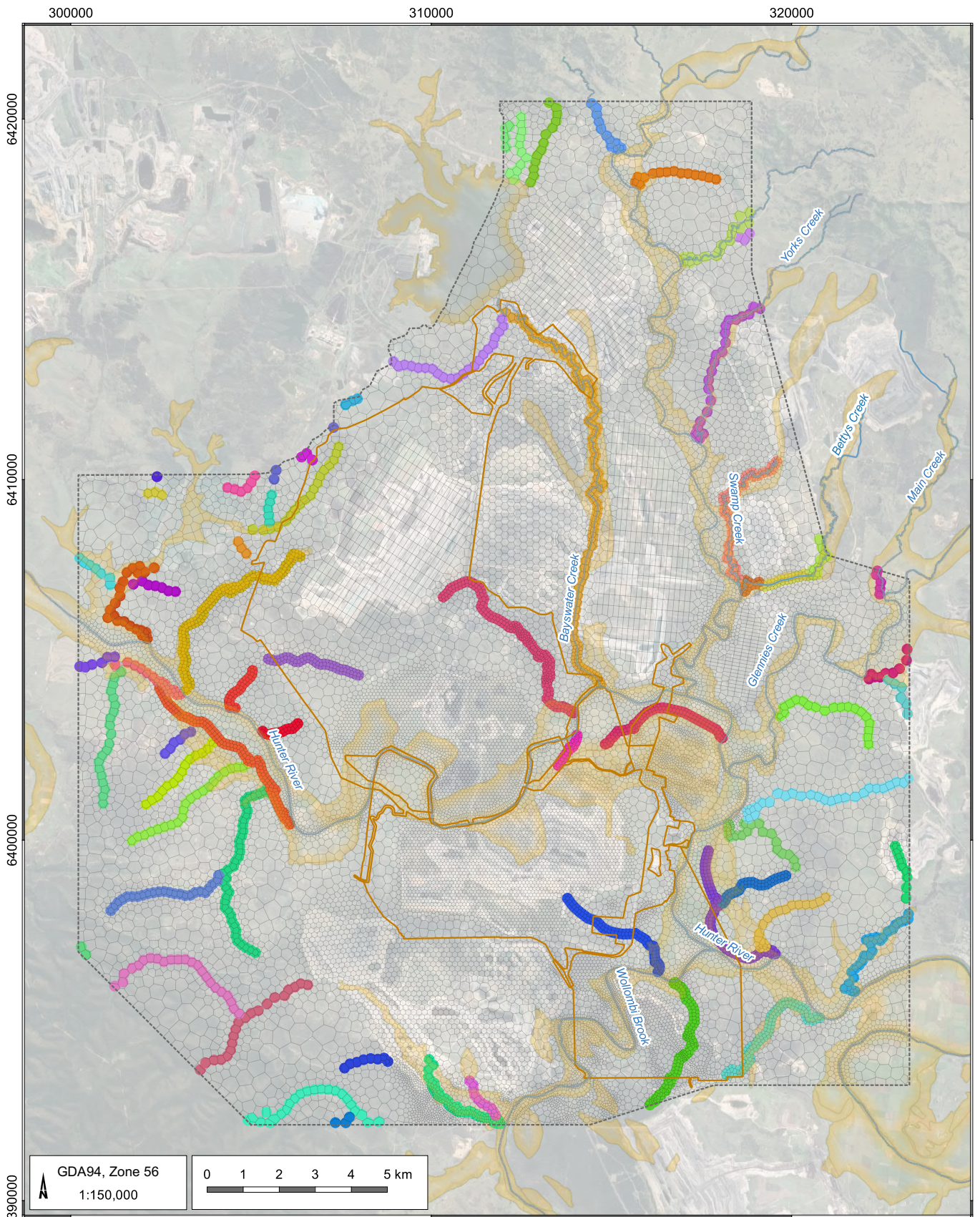
Drainage cells represented with the STR package



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FIGURE No:
D 9



LEGEND

- Drainage
- Project Area
- Alluvium Boundary
- Model extent
- Model grid

River zones

● 1	● 12	● 23	● 34	● 45	● 56
● 2	● 13	● 24	● 35	● 46	● 57
● 3	● 14	● 25	● 36	● 47	● 58
● 4	● 15	● 26	● 37	● 48	● 59
● 5	● 16	● 27	● 38	● 49	● 60
● 6	● 17	● 28	● 39	● 50	● 61
● 7	● 18	● 29	● 40	● 51	● 62
● 8	● 19	● 30	● 41	● 52	● 63
● 9	● 20	● 31	● 42	● 53	● 64
● 10	● 21	● 32	● 43	● 54	● 65
● 11	● 22	● 33	● 44	● 55	

HVO Continuation (G1737J)

Drainage cells represented with the RIV package



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FIGURE No:
D 10

Table D 5 Modelled stream (STR) cell parameters

Segment No.	Segment name	Vertical hydraulic conductivity Kv (m/day)	Width (m)	Incised depth (m)	Bed thickness (m)	Slope	Manning's coefficient
1	Bowmans Ck	0.011	5	4	1.5	0.004	0.03
2	Bowmans Ck	0.016	5	4	1.5	0.004	0.03
3	Glennies Ck	0.022	7	6	2	0.0015	0.03
4	Wollombi Brook	0.021	30	1.2	2	0.001	0.03
5	Hunter River	10.0	15	1	2	0.001	0.03
6	Hunter River	10.0	15	1.1	2	0.001	0.03
7	Hunter River	10.0	15	1.5	2	0.0006	0.03
8	Hunter River	10.0	15	1.5	2	0.0006	0.03
9	Hunter River	10.0	15	1.1	2	0.0006	0.03

Table D 6 Modelled river (RIV) cell parameters

Segment No.	Segment name	Vertical hydraulic conductivity Kv m/day)	Width (m)	Incised depth (m)	Bed thickness (m)
1	Main Ck	0.1	7	2.5	1
2	Bettys Ck	0.087	10	2.5	1
3	Bettys Ck	0.072	10	2.5	1
4	Bettys Ck	0.111	5	2.5	1
5	Swamp Ck	0.011	5	2.5	1
6	Yorks Ck	0.116	5	2.5	1
7	(No name)	0.081	5	2.5	1
8	(No name)	0.100	5	2.5	1
9	(No name)	0.087	5	2.5	1
10	(No name)	0.081	5	2.5	1
11	Bayswater Ck	0.096	8	2.5	1
12	Saltwater Ck	0.008	10	2.5	1
13	(No name)	0.01	5	2.5	1
14	(No name)	0.098	5	2.5	1
15	(No name)	0.081	5	2.5	1
16	(No name)	15.047	5	2.5	1
17	(No name)	0.067	5	2.5	1
18	(No name)	0.114	5	2.5	1
19	(No name)	0.1	5	2.5	1
20	(No name)	0.081	5	2.5	1
21	North Wambo Ck	0.141	10	2.5	1
22	North Wambo Ck	0.103	10	2.5	1

Segment No.	Segment name	Vertical hydraulic conductivity Kv m/day)	Width (m)	Incised depth (m)	Bed thickness (m)
23	North Wambo Ck	0.1	7	2.5	1
24	North Wambo Ck	0.033	10	2.5	1
25	North Wambo Ck	0.120	10	2.5	1
26	Wambo Ck	0.087	30	2.5	1
27	Stony Creek	0.060	10	2.5	1
28	Stony Creek	0.1	7	2.5	1
29	(No name)	0.1	8	2.5	1
30	(No name)	0.1	8	2.5	1
31	(No name)	0.1	12	2.5	1
32	Station Ck	0.097	8	2.5	1
33	Station Ck	0.028	10	2.5	1
34	Main Ck	0.083	8	2.5	1
35	(No name)	0.051	20	2.5	1
36	Bayswater Ck	0.1	5	2.5	1
37	Bayswater Ck	0.06	10	2.5	1
38	(No name)	1.127	7	2.5	1
39	(No name)	0.087	8	2.5	1
40	(No name)	0.079	10	2.5	1
41	(No name)	0.107	8	2.5	1
42	(No name)	0.120	10	2.5	1
43	(No name)	0.094	8	2.5	1
44	(No name)	0.081	6	2.5	1
45	(No name)	0.1	9	2.5	1
46	(No name)	0.1	5	2.5	1
47	(No name)	0.066	5	2.5	1
48	(No name)	0.083	5	2.5	1
49	(No name)	0.135	10	2.5	1
50	(No name)	0.169	7	2.5	1
51	(No name)	0.079	10	2.5	1
52	Parnells Ck	0.094	6	2.5	1
53	Saltwater Ck	0.1	7	2.5	1
54	Saltwater Ck	0.059	10	2.5	1
55	Saltwater Ck	0.091	5	2.5	1
56	Saltwater Ck	0.1	6	2.5	1
57	Saltwater Ck	0.1	7	2.5	1
58	Saltwater Ck	0.1	7	2.5	1

Segment No.	Segment name	Vertical hydraulic conductivity Kv m/day)	Width (m)	Incised depth (m)	Bed thickness (m)
59	Saltwater Ck	0.1	6	2.5	1
60	Saltwater Ck	0.1	5	2.5	1
61	Saltwater Ck	0.1	10	2.5	1
62	Saltwater Ck	0.1	15	2.5	1

Figure D 11 and Figure D 12 show the measured streamflow for the BoM Station *Hunter River at Liddell* (station number 210083) and the Station *Wollombi Brook at Warkworth* (station number 210004) compared with the streamflow used as an input for the numerical model during the calibration period.

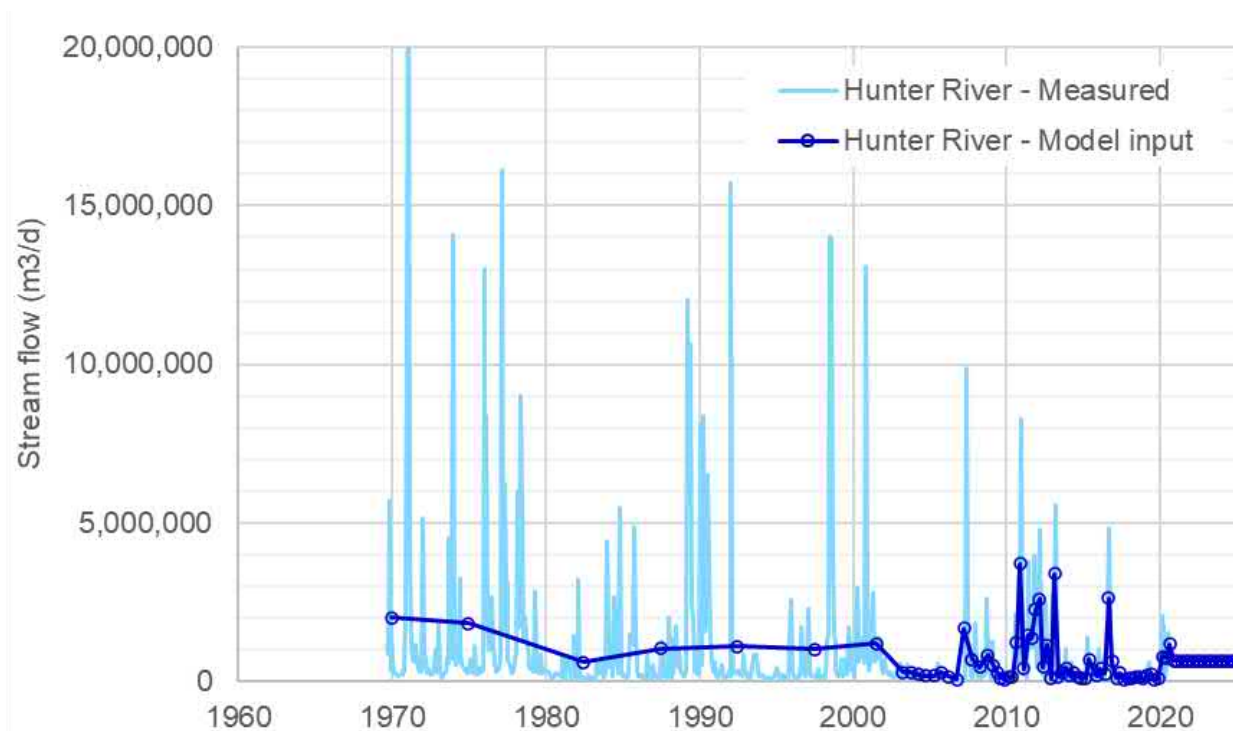


Figure D 11 Modelled vs observed streamflow analysis at Hunter River

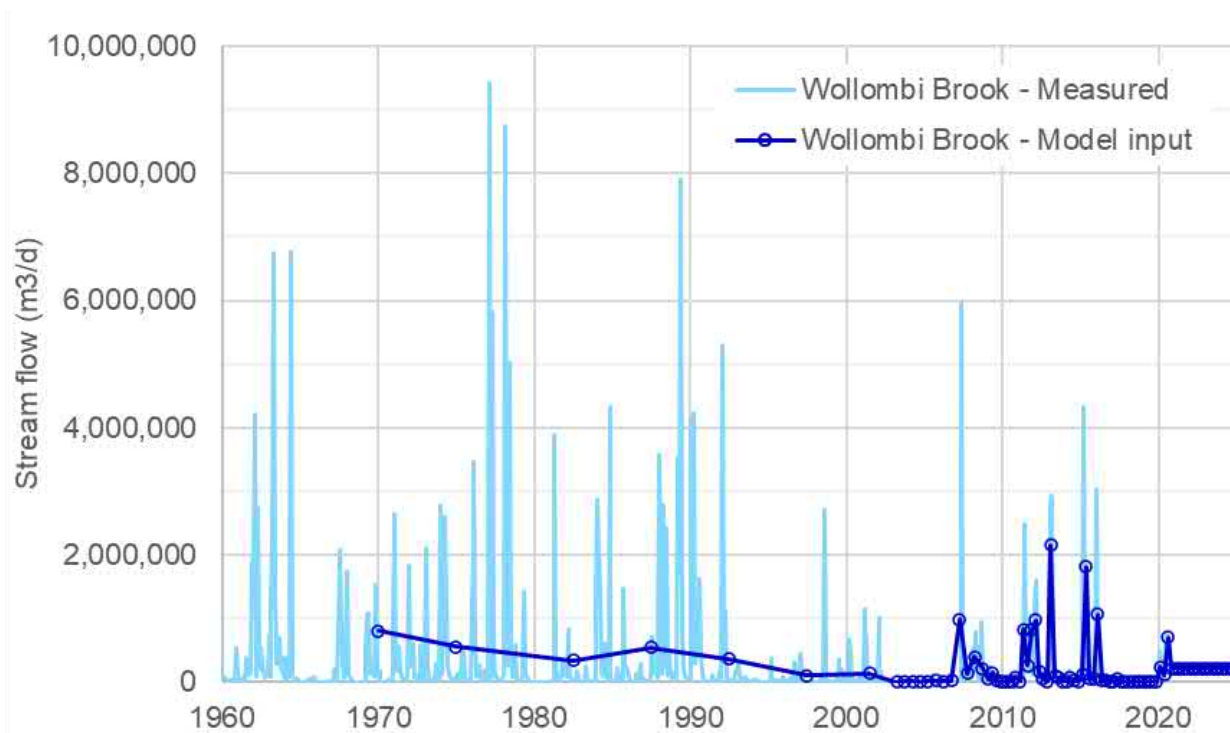


Figure D 12 Modelled vs observed streamflow analysis at Wollombi Brook

Uncertainty in the representation of the rivers and creeks is introduced to the model through the adopted stream bed conductance and stream flow timing and rates. The stream bed conductance, which represents the connectivity of surface water with groundwater was not measured but was estimated during the calibration process and also varied as part of the predictive uncertainty analysis.

D2.5.5 Groundwater abstraction

Mining activities are the major groundwater user in the region, not through pumping from bores, but from incidental abstraction from within mining areas for safety reasons. Abstraction from landholder pumping wells in comparison is comparatively limited in the region and was not included in the model simulation.

Abstraction from the Lemington underground workings was simulated using the drain (DRN) package, using the levels recorded in observation bores around the underground workings, and applying them as the DRN elevation in the simulation. Groundwater abstraction from the historical Liddell underground mines was simulated in a similar way, using the available levels recorded in bores monitoring the water levels in the workings and applying them in the model as drains.

D2.5.6 Lakes and dams

Lake Liddell, Plashett Reservoir and the Bayswater Power Station ash lake are located along the north-western boundary of the model and were represented in the model using the constant head package (CHD). Table D 7 below summarises the fixed heads applied to each lake. The elevations for each lake were sourced from the LiDAR elevations captured in February 2020.

Table D 7 Constant heads used for lakes and dams

Lakes	Head (mAHD)
Lake Liddell	127.8
Plashett Reservoir	119.9
Bayswater Power Station ash lake	170.15

The fixed heads were applied to layer 1. Whilst the actual water level in lakes is expected to vary according to climatic conditions and usage and discharge from the Liddell power station, a static water level was considered sufficient as the lakes are relatively distant from HVO and are not expected to significantly influence the deeper Permian groundwater system being assessed for the Project.

D2.5.7 Mining

The progression of mining over time was represented based on the schedules provided by HVO, as well as publicly available satellite images where company information was not available. The changes of hydraulic properties in model cells in response to mining (e.g. open cut voids, underground longwall goafing and spoil emplacement) were represented using a combination of MODFLOW's DRN and time varying materials (TVM) packages.

Within the Project area and other open-cut mine areas, drain cells were applied to all intersected model cells, at reference elevations set to the floor of each cell down to the target coal seam. The drains were setup to remain active within the open cut mining areas for 3.5 years after mined, before being turned off. The progressive backfilling of the open cuts with spoils was represented by progressively changing the hydraulic properties of mined cells (K_h , K_v , S_y and S_s) behind the active open cut mining areas after the drains were removed.

Recharge rates to the spoil were not enhanced as the spoil is conceptualised to be very free draining during operations and observations in the region indicates rainfall infiltration through the dumps readily flows to sumps within mining areas without mounding within the spoil heaps. The captured water within the mining areas does not represent water take from the groundwater systems. This was a conservative approach implemented to represent the gradual rewetting of the unsaturated spoil over time. Storage was changed in a step-wise manner above underground mined seams to avoid "creating" water in partly saturated layers. Further details about the calibrated hydraulic parameters are included in Section D3.

Goafing and fracturing above underground longwall panels were simulated using a connected linear network fracture methodology described by AGE (2017b). This method represents the fracture network using "stacked drains" and calculates the conductance empirically calculated based on the intensity of fracturing at any given model cell.

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

Bord and pillar and main/access underground roads were simulated using drain cells with a drain conductance of 100 m²/day, which lowered the heads to the drain stage values. Upon completion, bord and pillar and main road cells were converted to replicate void properties with high hydraulic conductivity and storage (using a hydraulic conductivity of 1000 m/day a specific yield of 100%, and a specific storage of 5×10^{-6}).

D3 Model Calibration

D3.1 Calibration method

The groundwater model was calibrated with an initial, pre-mining steady state stress period (to end of 1969) and a transient run (1970 to 2020) using available groundwater level data. The model was calibrated by adjusting aquifer parameters and stresses to produce the best match between the observed and simulated water levels and mine inflows. Manual testing and automated parameterisation software (PEST_HP, Doherty, 2018) were used to determine optimal hydraulic parameters and recharge rates to achieve the best history match to the available water level measurements from monitoring bores and inflow data.

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

D3.2 Calibration targets

The steady state and transient model simulated water levels in all available monitoring bores within the bedrock and alluvial aquifers. A total of 377 monitoring points were used to calibrate the model (Figure D 13), out of which 374 belong to the HVO, Glendell, United, Ravensworth and Liddell monitoring network. The 377 points are comprised of:

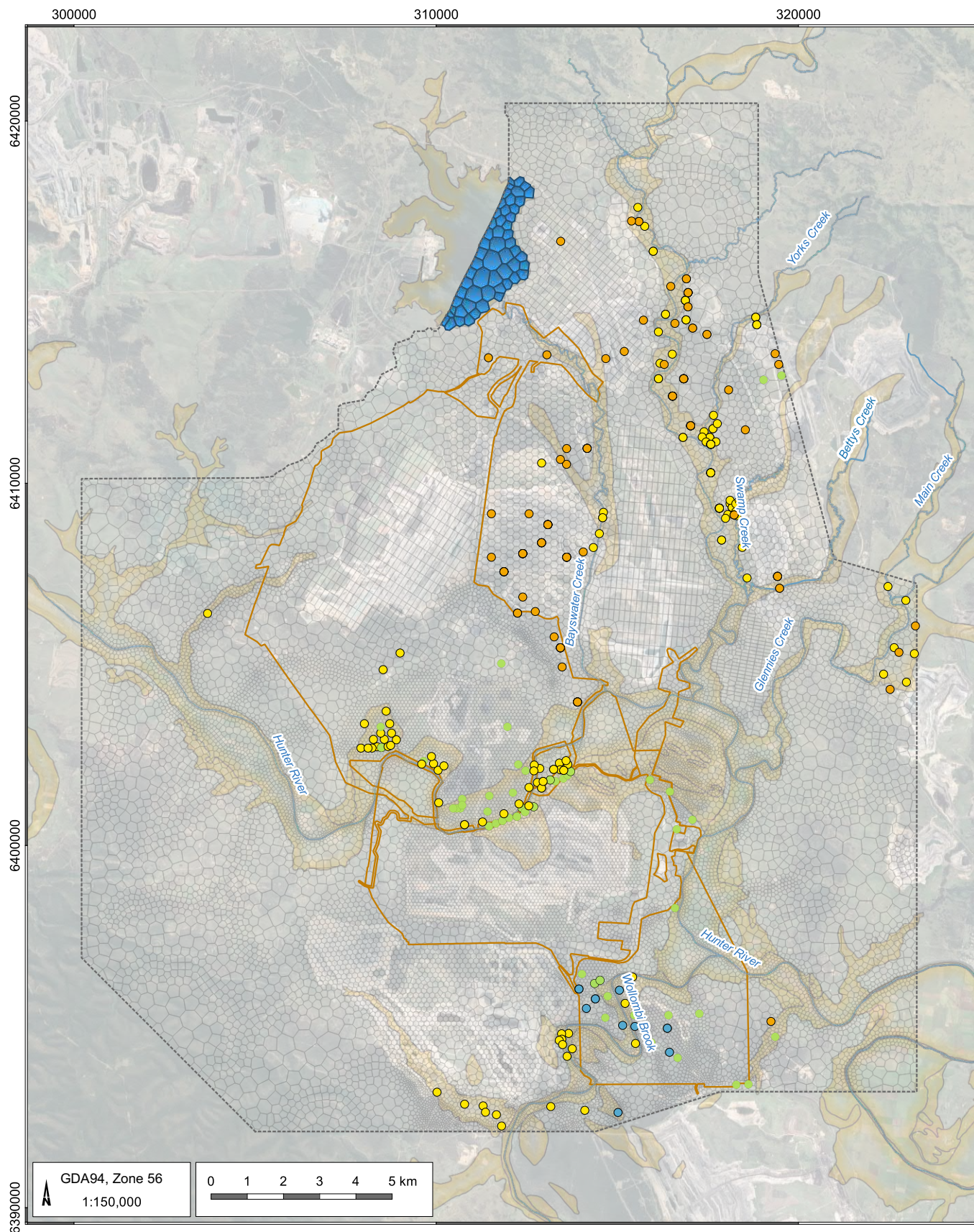
- 104 monitoring points across the model domain that screen the alluvium;
- 32 monitoring points screening the regolith;
- 229 monitoring points screening the Permian coal measures and interburden; and
- 12 bores screening other materials, like spoil.

Regarding the type of monitoring points, they consist of 269 bores and 108 VWP sensors.

Middlemis & Peeters (2018) suggest groundwater assessments consider the uncertainty around measurements used during the modelling process. The groundwater levels within the monitoring network are measured manually with electronic water level dippers and the water level converted to an elevation based on surveyed levels at reference point which is usually the top of bore casing. Modern electronic water level dippers are expected to be accurate to less than 1 cm, and with the measurement point elevation also ± 1 m to 10 cm depending on the method of surveying. The measurement of water levels within the monitoring network is therefore considered unlikely to have introduced any significant uncertainty to the model predictions.

VWPs in contrast measure pore pressure which is converted to a potentiometric surface based on the elevation of the VWP sensor. The VWPs are sealed with cement grout within the boreholes and therefore cannot be validated, or the data loggers checked for instrument drift. Therefore, the measurement error for the VWPs is considered higher than monitoring bores. Despite the potential for a larger measurement error in the VWP data, when used with caution it is still considered a useful additional dataset to understand the groundwater regime and guide the calibration of the numerical model where the observed pressure changes are considered conceptually sound.

Figure D 13 presents the location of observation bores that were used in the calibration process.



LEGEND

- Drainage
- Project Area
- Alluvium Boundary
- Model extent
- Model grid
- Lake Liddell

Model layers

- 1 - 2 (Alluvium, regolith)
- 3 - 13 (Overburden to Arrowfield Seam)
- 14 - 22 (Bowfield to Bayswater Seams)
- 23 - 32 (Lemington to Hebden Seams)

HVO Continuation (G1737J)

Observation target locations



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FIGURE No:
D 13

The installation details for some bores in the initial dataset could not be determined and therefore these bores were not included in the dataset used for calibration. For model calibration purposes, the observation bore water level records were weighted as follows:

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

Using this method, different monitoring locations have comparable weights, regardless of the number of points. During the calibration process, the weight of some locations was adjusted to focus the calibration in certain key areas of the system (around the project area for example). This was an iterative process during the calibration.

At the end of the process, the model was calibrated to the observed water level datasets, with the 'best calibrated' model returning the lowest difference between observed and simulated water levels and inflows (all measured using an objective function (ϕ)).

D3.3 Pilot points

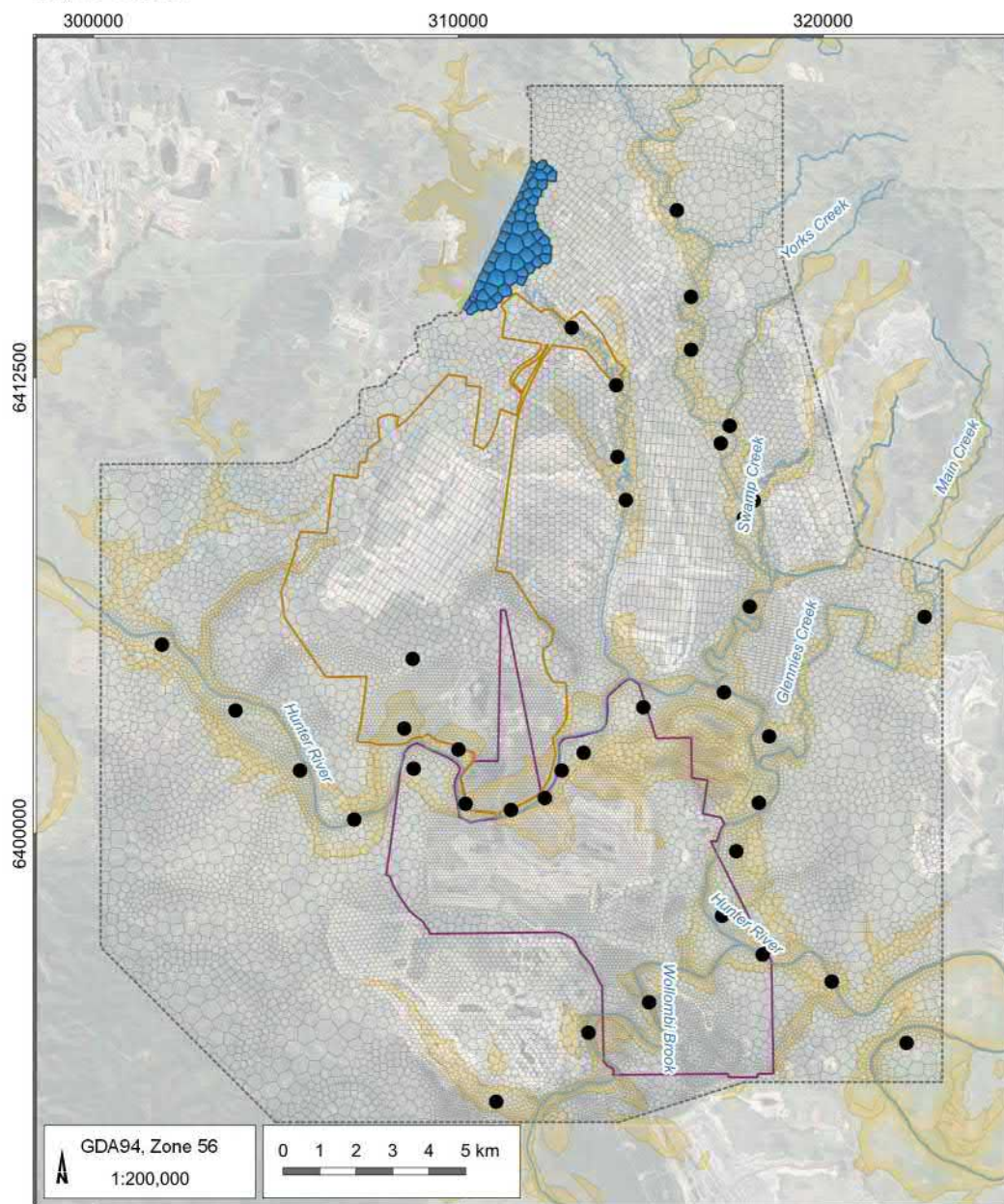
The model domain contains a significant network of monitoring bores and water level datasets. The water level responses recorded in the monitoring bores (as discussed in the main report Section 5.5) vary depending on a range of factors including geology, location, climatic conditions and mining activities, which may vary spatially over long or short distances. Water levels recorded in the monitoring bores suggest the presence of heterogeneous hydraulic properties and recharge rates. To represent heterogeneity within the model domain and provide a degree of flexibility during the calibration, a series of pilot points was added to model layers 1, 2, 10, 12, 14, 18, 22, 25 and 28. The location of the pilot points in the model layer is shown in Figure D 14.

For each layer with pilot points, the pilot points were interpolated across the model domain using ordinary Kriging through the PC utility PLPROC (Watermark Numerical Computing, 2015). Horizontal and vertical conductivity were then adjusted, and the absolute values were capped to ensure maximum and minimum values did not exceed appropriate ranges for each unit. Specific storage values were constrained by literature ranges physically possible values. Table D 8 presents the general parameter constraints applied to all layers.

Table D 8 General parameter constraints

Unit	Min Kx (m/day)	Max Kx (m/day)	Min Kz (m/day)	Max Kz (m/day)	Min Sy (%)	Max sy (%)	Min_Ss (m ⁻¹)	Max_Ss (m ⁻¹)	Max Kz/Kx
Alluvium	1×10^{-5}	1000	1×10^{-5}	10	1	40	2.2×10^{-7}	1×10^{-5}	0.5
Regolith	1×10^{-5}	10	1×10^{-5}	1	1	20	2.2×10^{-7}	1×10^{-5}	0.5
Overburden	1×10^{-5}	1	1×10^{-5}	1	0.1	20	2.2×10^{-7}	1×10^{-5}	1
Interburden	1×10^{-7}	1×10^{-2}	1×10^{-8}	5×10^{-3}	0.1	6	2.2×10^{-7}	1×10^{-5}	0.5
Coal	5×10^{-5}	1×10^{-1}	8.6×10^{-6}	1×10^{-1}	0.1	5	2.2×10^{-7}	1×10^{-5}	1

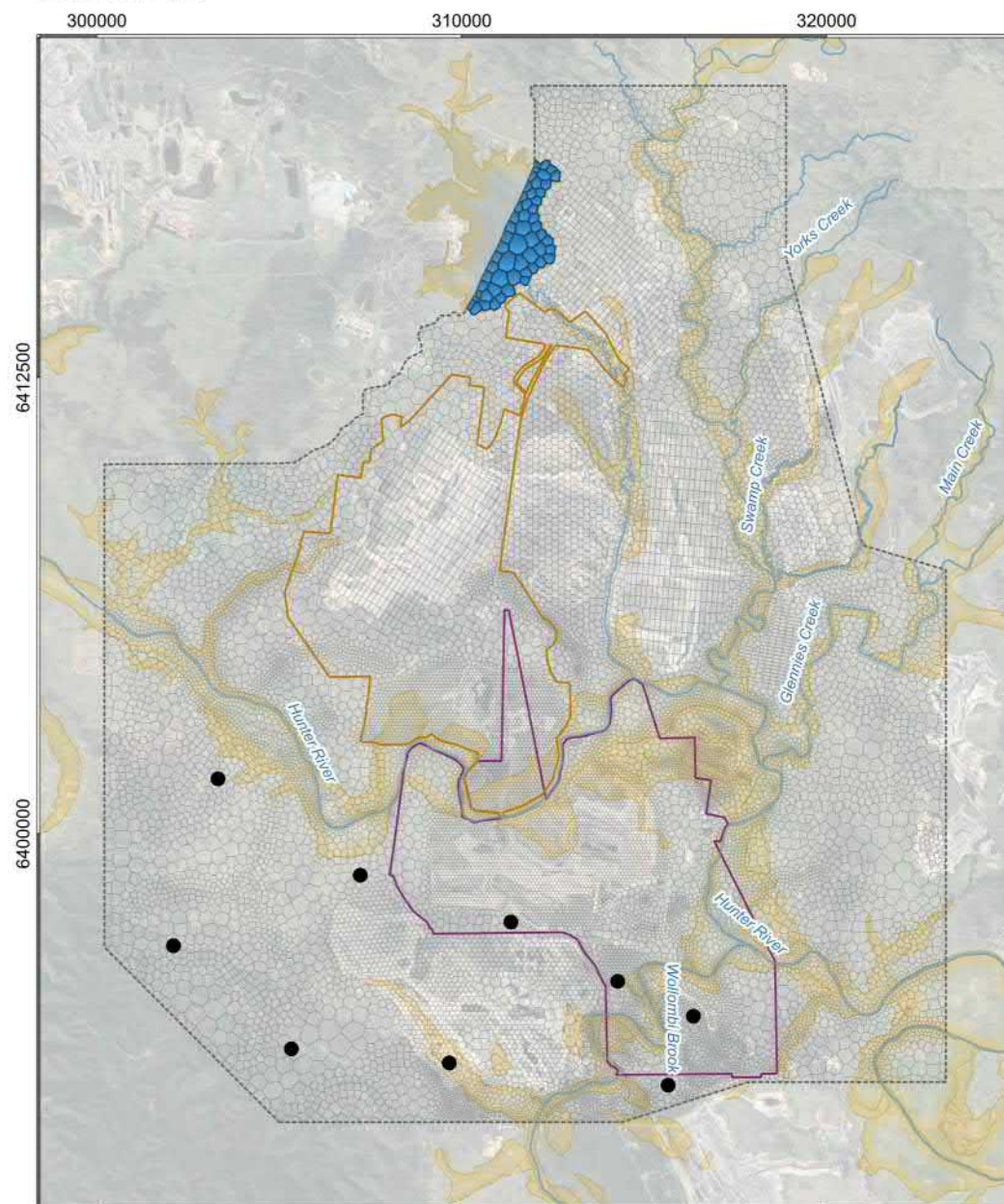
Layer 1 and 2



LEGEND

- Pilot points
- Drainage
- HVO North Boundary
- HVO South Boundary
- Model extent
- Model grid
- Lake Liddell
- Alluvium Boundary

Layer 10,12,14



HVO Continuation (G1737J)

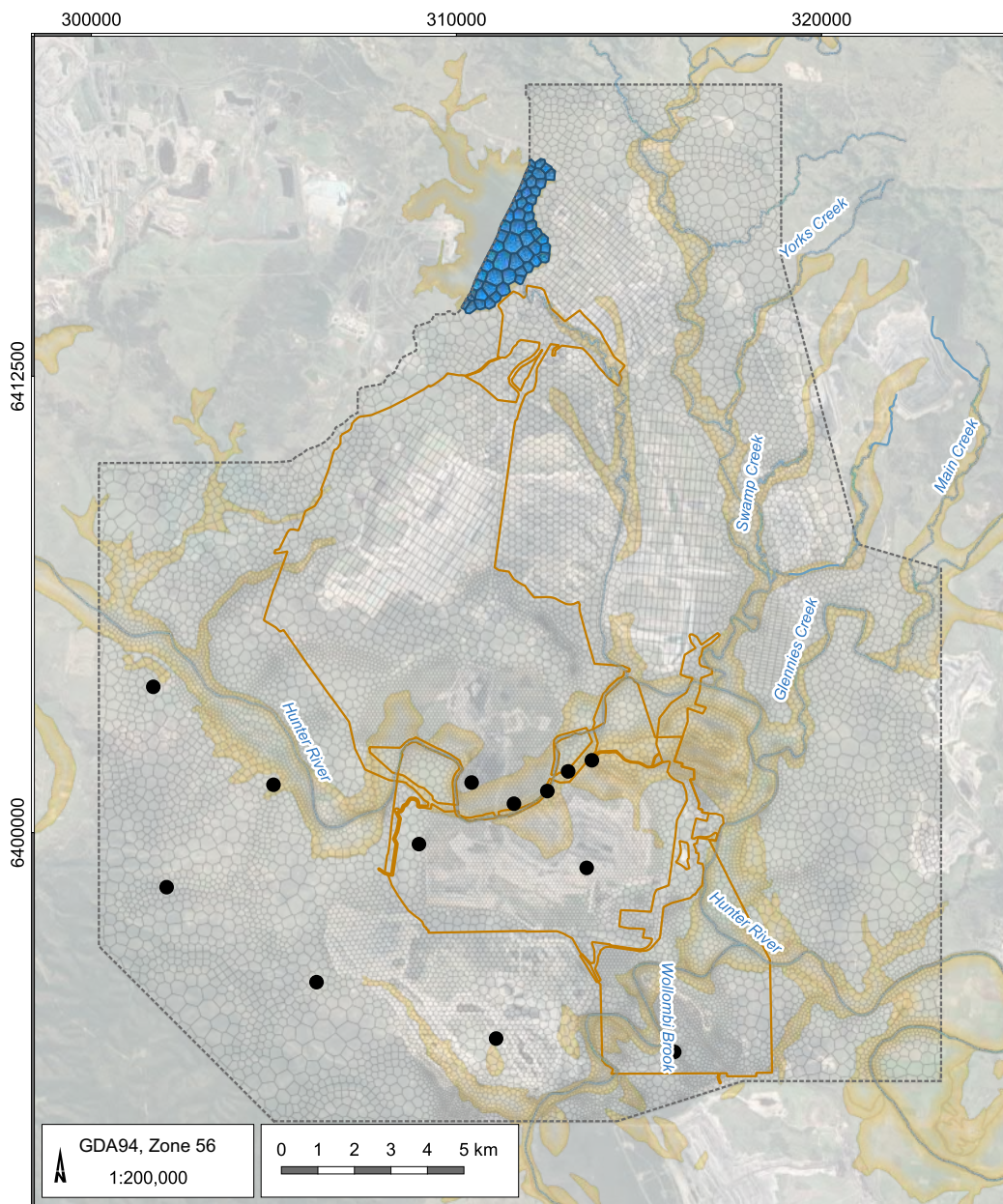


Locations of pilot points – Layers 1, 2, 10, 12, 14

DATE
14/09/2022

FIGURE No:
D 14

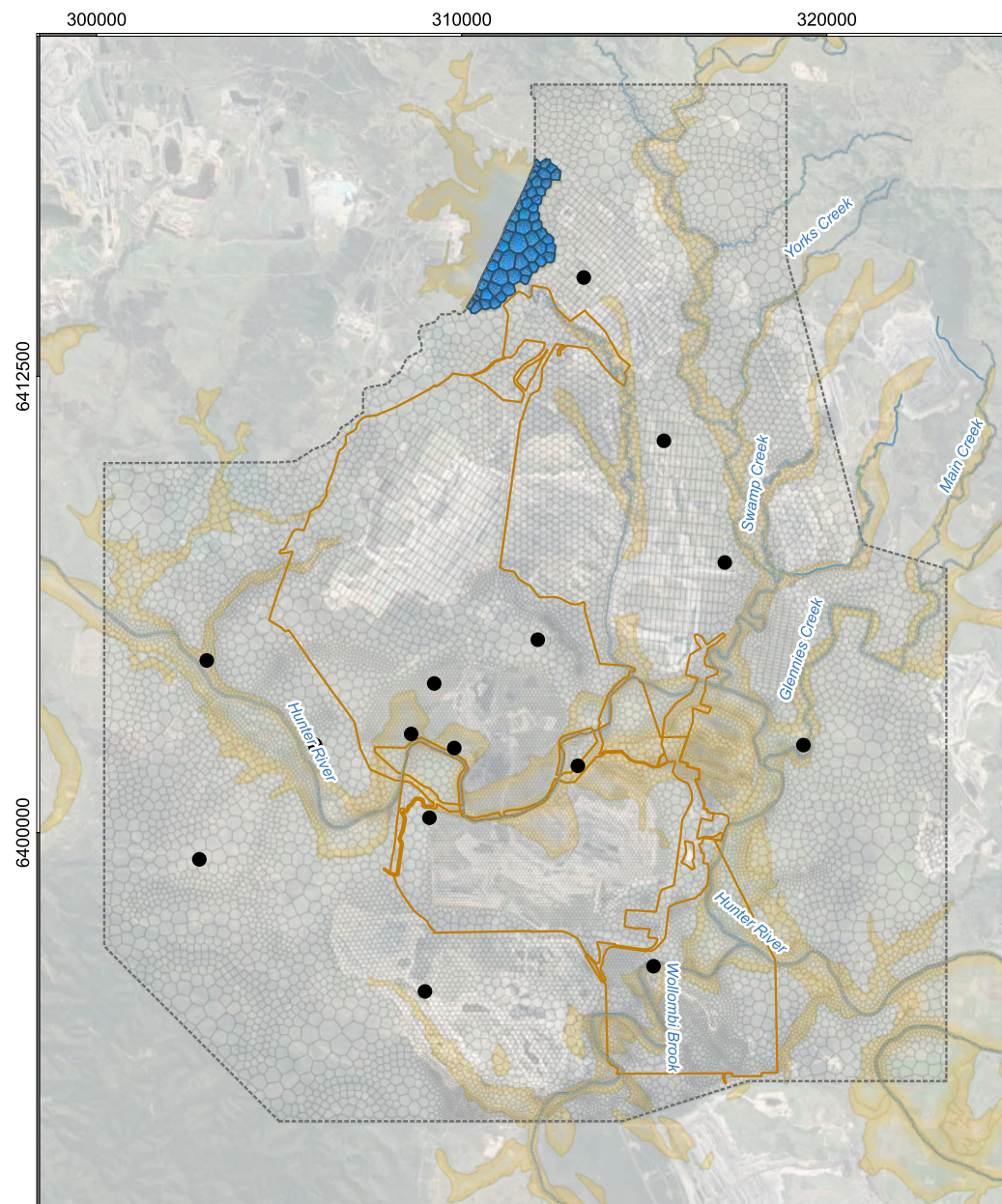
Layer 18



LEGEND

- Pilot points
- Drainage
- Project Area
- - - Model extent
- Model grid
- Lake Liddell
- Alluvium Boundary

Layer 22



HVO Continuation (G1737J)

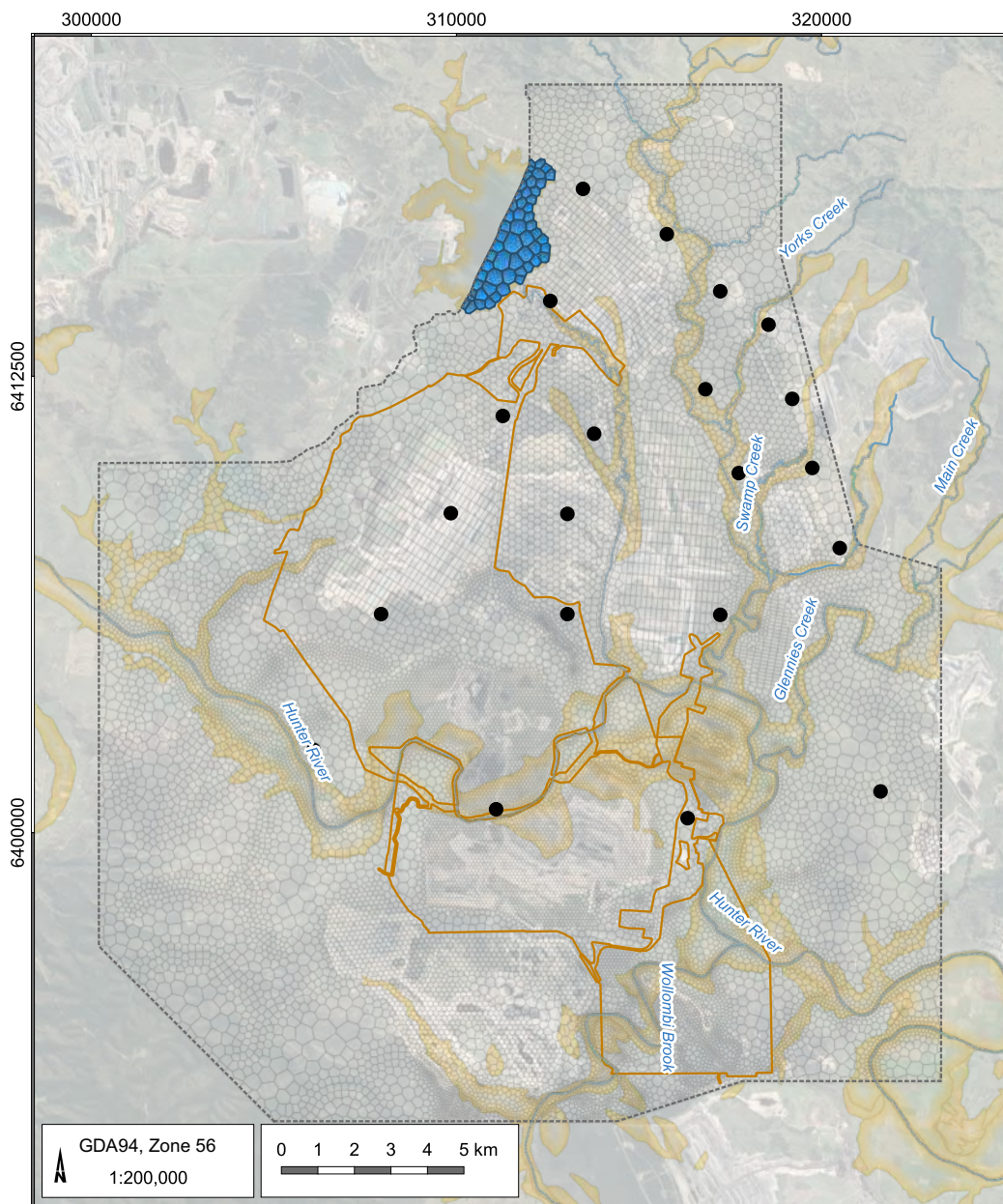


Locations of pilot points – Layers 18,
22

DATE
03/11/2022

FIGURE No:
D 15

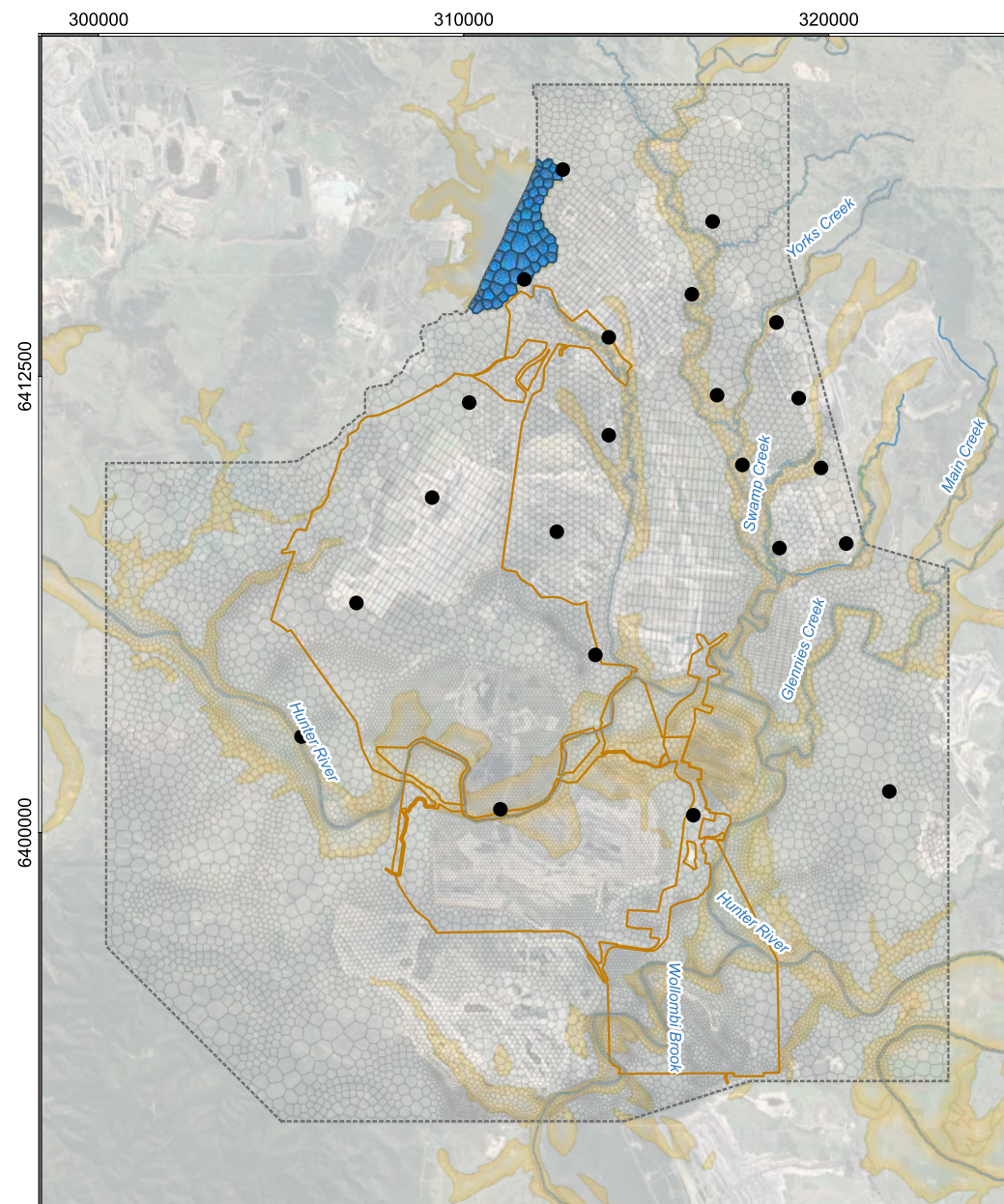
Layer 25



LEGEND

- Pilot points
- Drainage
- Project Area
- Model extent
- Model grid
- Lake Liddell
- Alluvium Boundary

Layer 28



HVO Continuation (G1737J)



Locations of pilot points – Layers 25,
28

DATE
03/11/2022

FIGURE No:
D 16

D3.4 Calibration results

Figure D 17 presents a scattergram with the observed and simulated groundwater heads that resulted from the calibration. Additional modelled vs observed scattergrams for key layers in the model are presented in Figure D 18.

The results show that the observations above 60 mAHD are more closely matched by the model, whilst the observations from deeper VWPs and monitoring bores where mining depressurisation has occurred have slightly wider discrepancies. Most of these discrepancies are generally related to timing offsets in drawdown response, as opposed to the model misrepresenting drawdown.

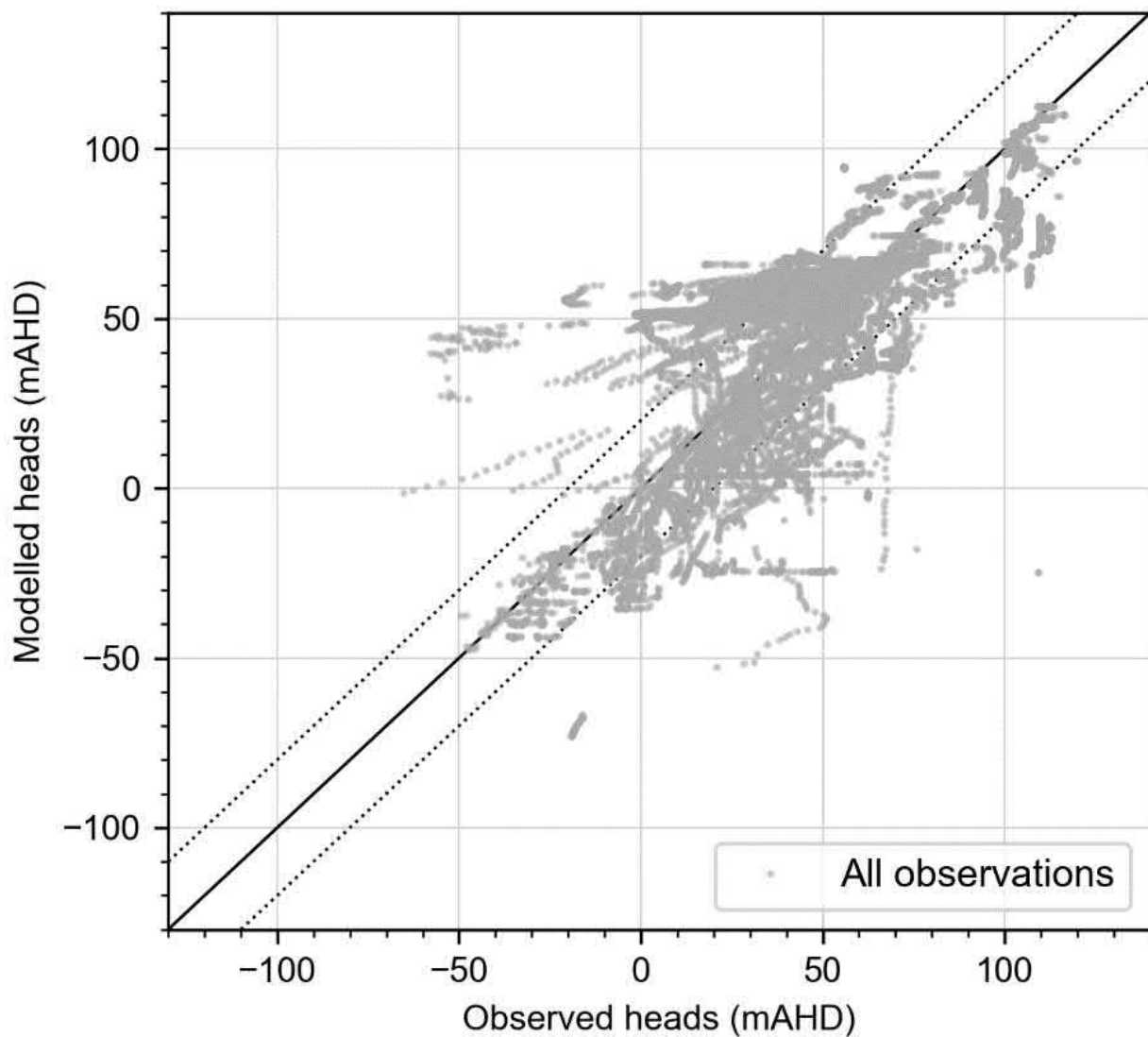


Figure D 17 Transient calibration – modelled vs observed groundwater levels (all layers)

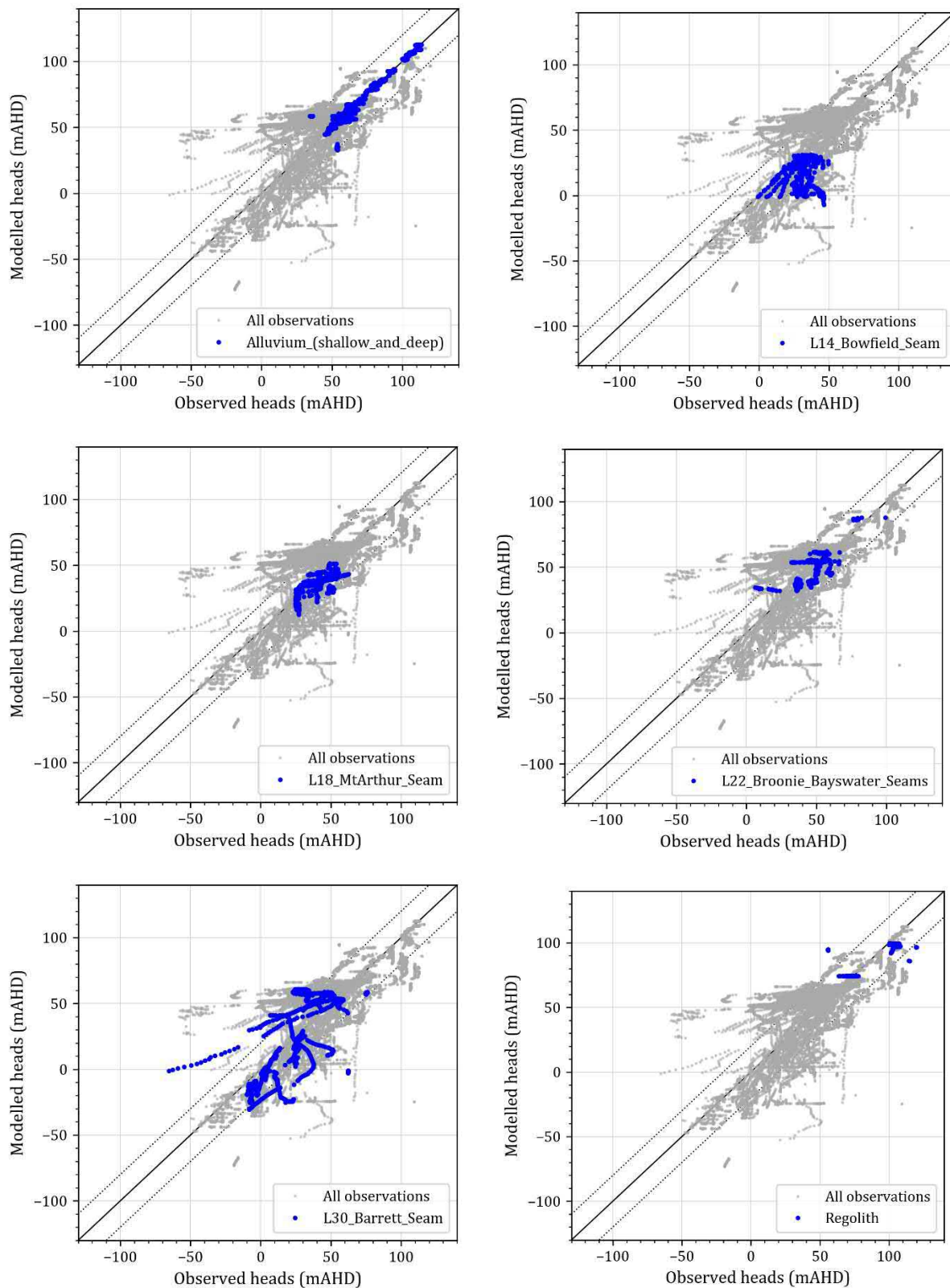


Figure D 18 Transient calibration – modelled vs observed groundwater levels (for selected layers, see individual legends)

Table D 9 presents the unweighted statistics for the transient calibration model.

Table D 9 Statistical analysis of calibrated model

Calibration performance measure	Unweighted value (HVO only)	Unweighted value (All)
SR - Sum of Residuals (m)	8650	166481
MSR - Mean Sum of Residuals (m)	3.0	10.8
SMSR - Scaled Mean Sum of Residuals (%)	7.3	5.9
RMS - Root Mean Square (m)	5.4	16.8
SRMS - Scaled RMS (%)	13.0	9.2

The SRMS around the HVO Complex (13%) is slightly higher than the general SRMS (9.2%). This is expected, since the range of heads for the whole model (dH) is 181.8m, vs 41.8 m for the bores around HVO, making the SRMS grow. Additionally, there are monitoring bores very close to the walls of HVO South and HVO North with very different behaviours within short distances, caused probably by small scale heterogeneities in the formation and mining progressions, and this level of detail is not captured by the model, which reproduces the system at a more regional scale.

The RMS error calculated for the calibrated model was 16.8 m. The total measured head change across the model domain was 181.8 m, with a scaled unweighted RMS (SRMS) of 9.2%, indicating a good match for the type of system being modelled.

Appendix D 1 presents the historic calibration hydrographs, showing the fit between modelled and observed groundwater levels from 1970 to 2020. The appendix also includes a table of the bore locations.

An analysis of simulated vs. measured vertical pressures in available key monitoring bores around the Project area was also carried out to assess the ability of the model to simulate vertical gradients. The result is displayed on Figure D 19 to Figure D 21. Although absolute values are not replicated exactly, the simulated heads generally replicate the trends and the observed vertical gradients between hydrostratigraphic units. This indicates that the model has replicated in a simple way the complex response to the numerous mining activities seen in the monitoring data over the calibration period.

Vertical gradient (Carrington)

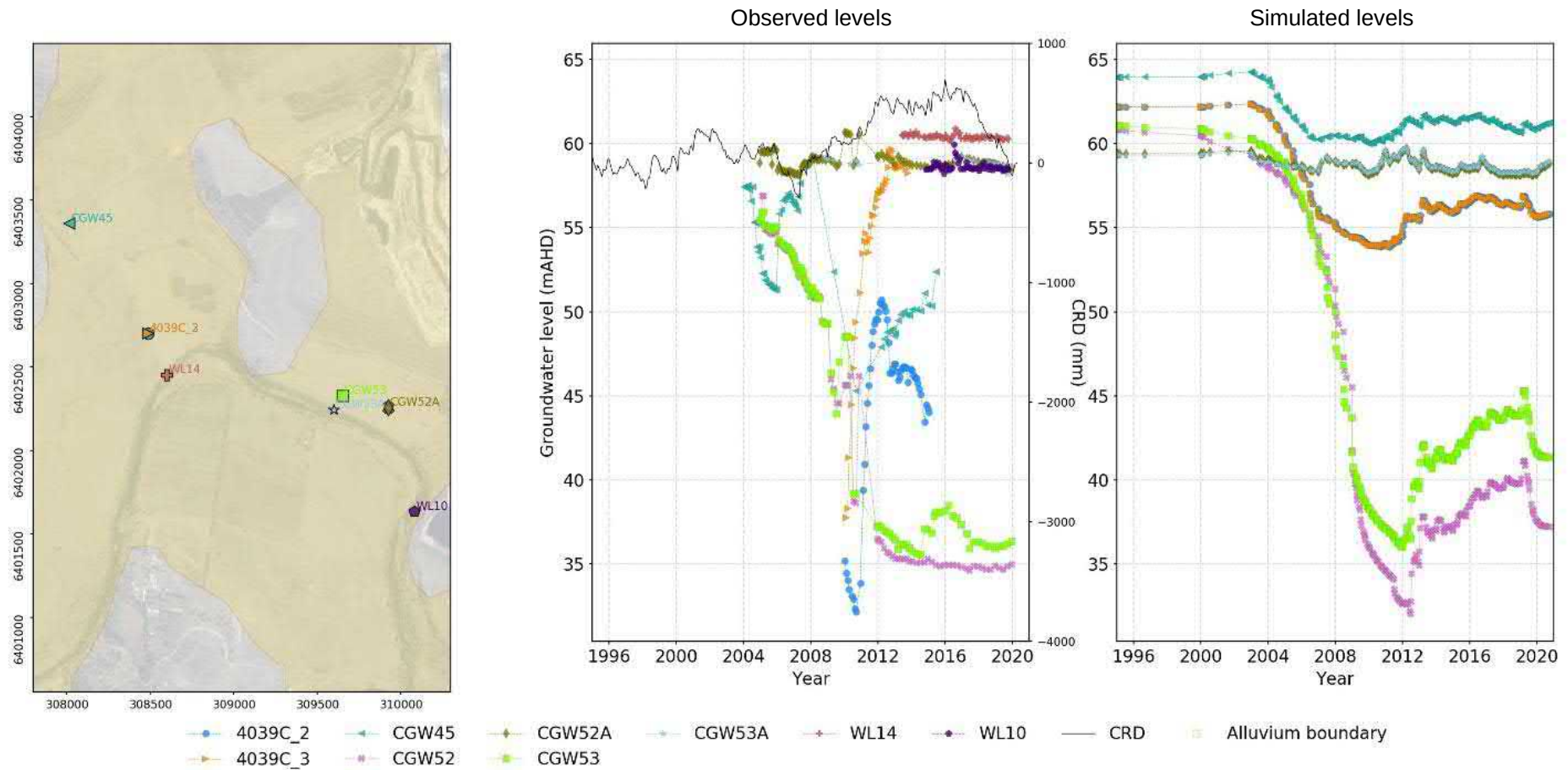


Figure D 19 Modelled versus observed vertical head gradients at Hunter River near HVO North (Carrington)

Vertical gradient (Cheshunt)

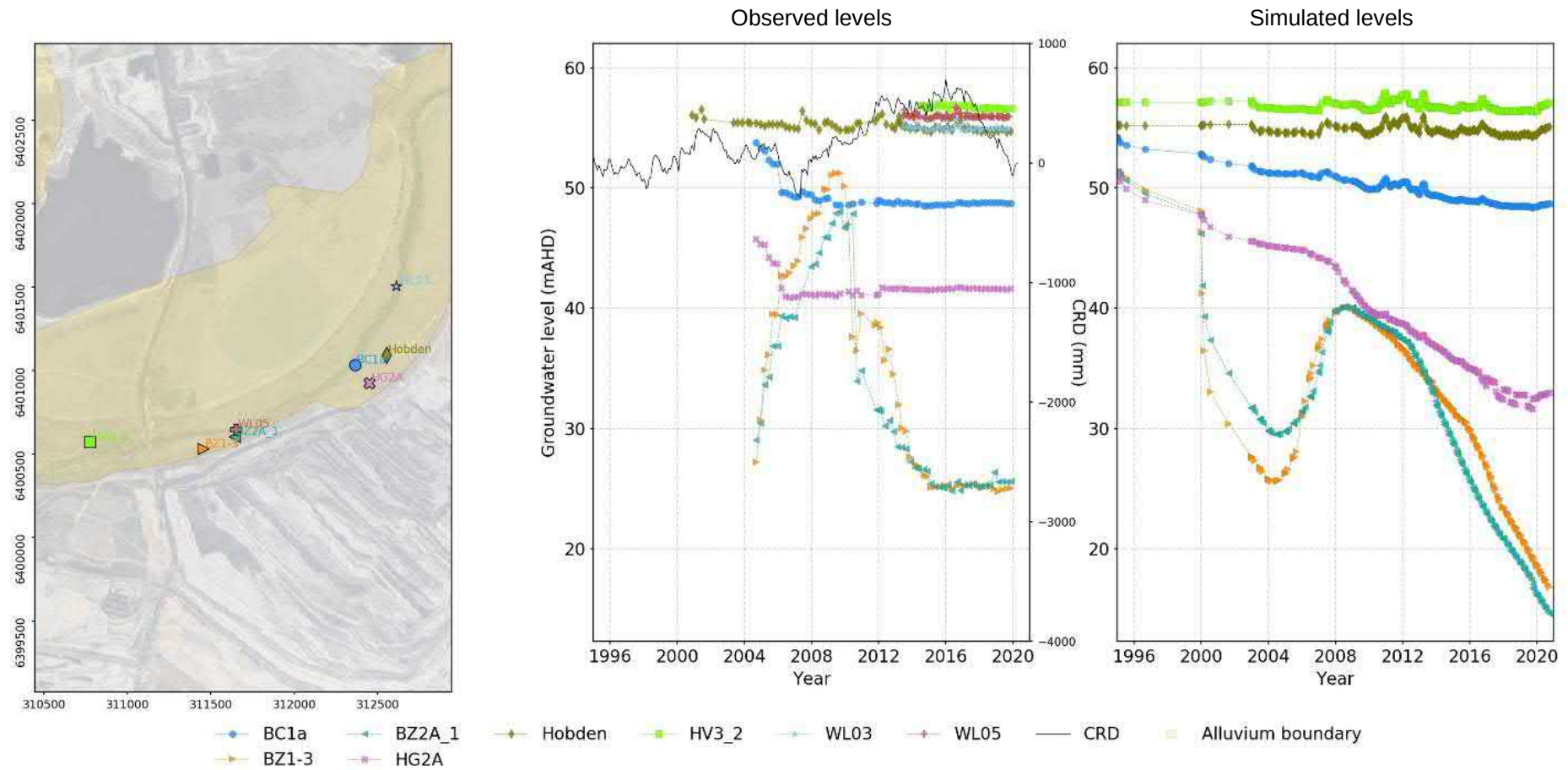


Figure D 20 Modelled versus observed vertical head gradients at Hunter River near HVO South

Vertical gradient (Wollombi Brook)

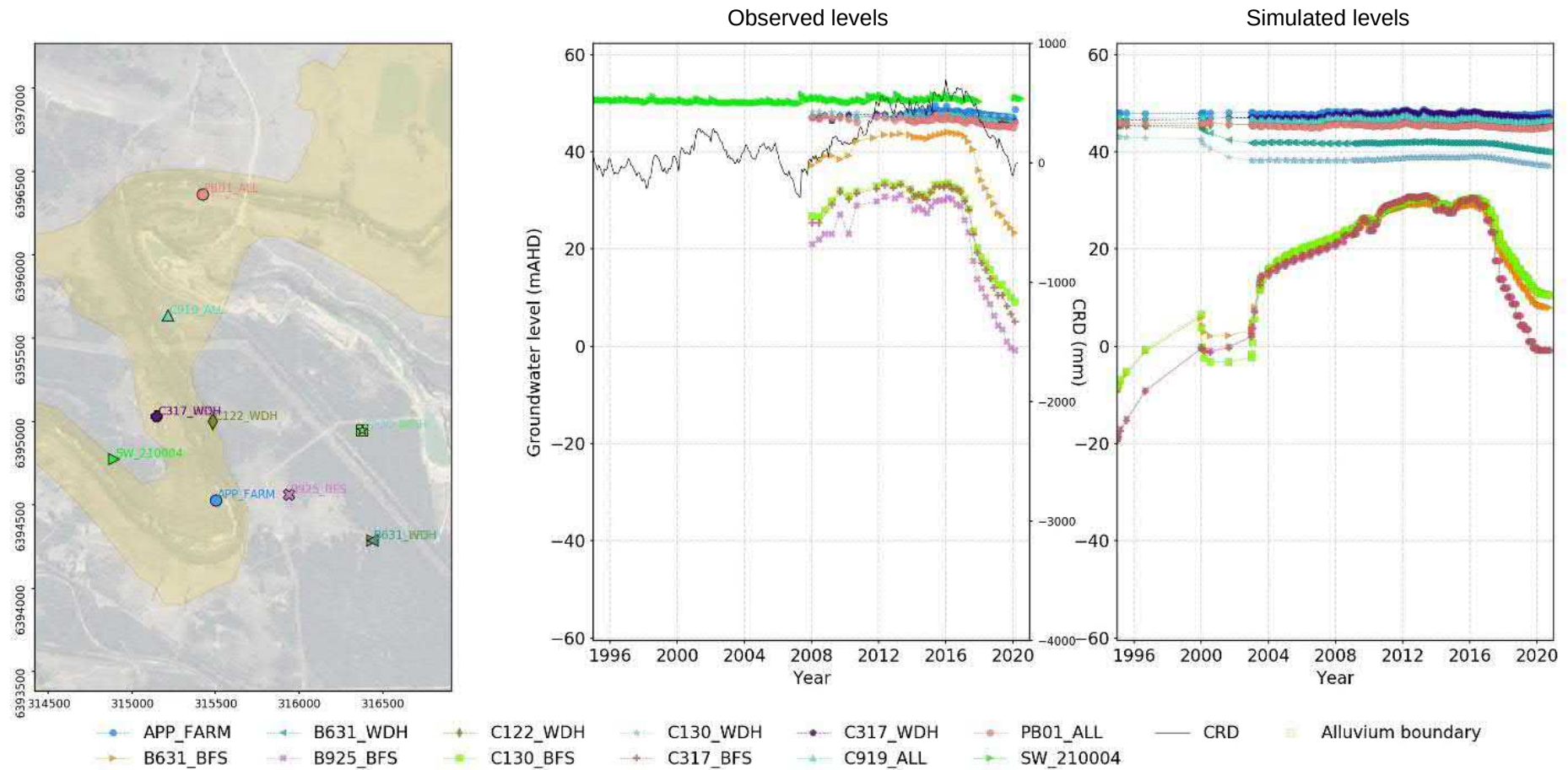
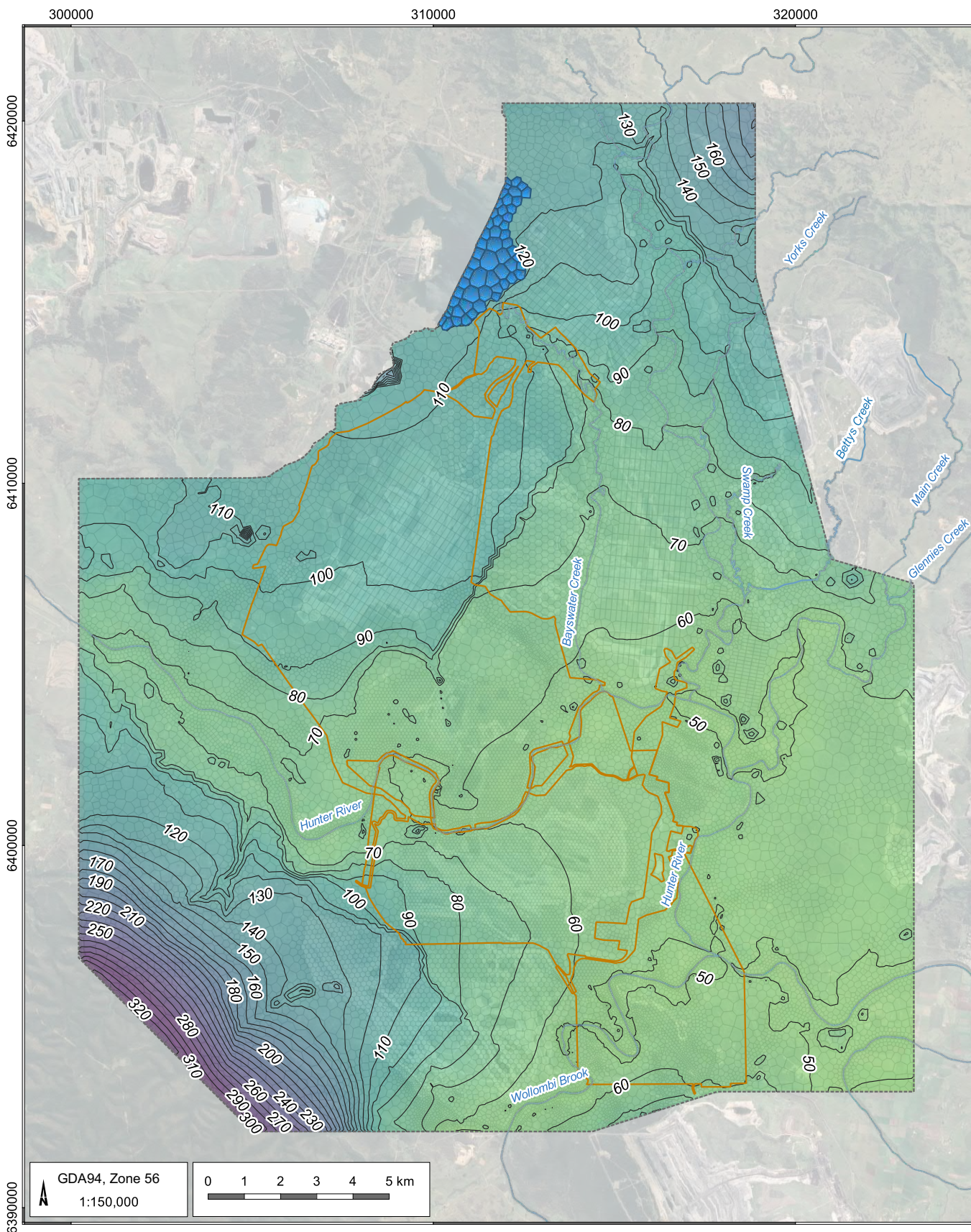


Figure D 21 Modelled versus observed vertical head gradients at Wollombi Brook

D3.4.1 Simulated heads

The simulated water table from the calibrated model in the steady state period (pre-1970) is presented in Figure D 22, while the coal seam water heads for the Liddell and Barrett seams are presented in Figure D 23 and Figure D 24 respectively. The figures show that in steady state, the regional groundwater gradient is towards the south-east, following the main local drainage systems.

The calibrated heads for the unconsolidated sediments (alluvium and regolith) at the end of the transient calibration period in 2020 are shown in Figure D 25, while the coal seam water levels for the Middle Liddell and Barrett seams are presented in Figure D 26 and Figure D 27. Groundwater levels representing 2020 conditions show the depressurised zones within the potentiometric surface caused by the advancement of mining. Depressurisation within the Liddell Seam reflects the advance of works at HVO West Pit, Ravensworth, Liddell, Ashton and Mt Owen/Integra.



LEGEND

- Drainage
- Contour line
- Project Area
- - - Model extent
- Model grid
- Lake Liddell

Groundwater level (mAH)

- 150
- 100
- 50
- 0
- 50
- 100
- 150
- 200
- 250
- 300

HVO Continuation (G1737J)

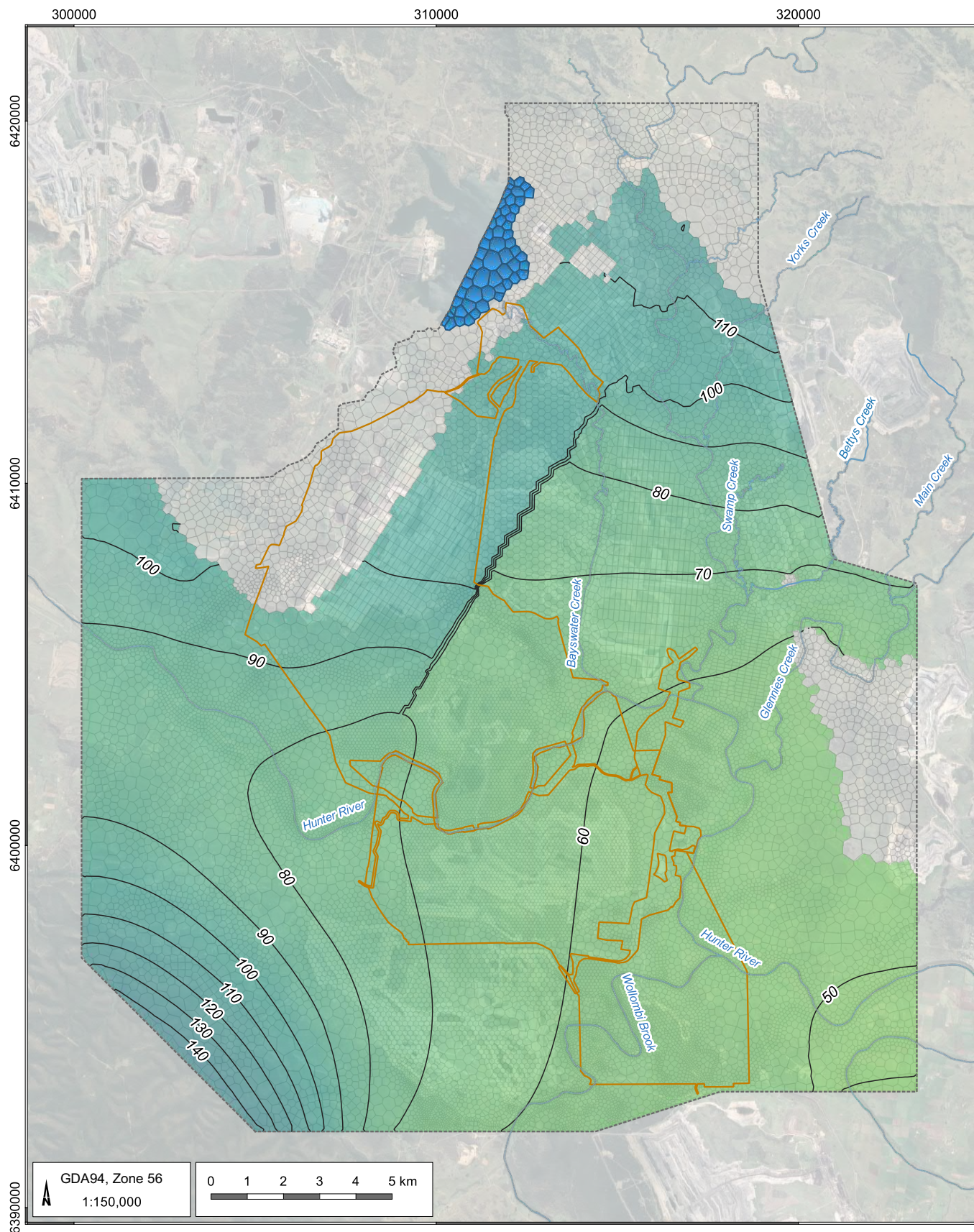
Simulated steady state groundwater levels – water table



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FIGURE No:
D 22



LEGEND

- Drainage
- Contour line
- Project Area
- - - Model extent
- Model grid
- Lake Liddell

Groundwater level (mAHd)

- 150
- 100
- 50
- 0
- 50
- 100
- 150
- 200
- 250
- 300

HVO Continuation (G1737J)

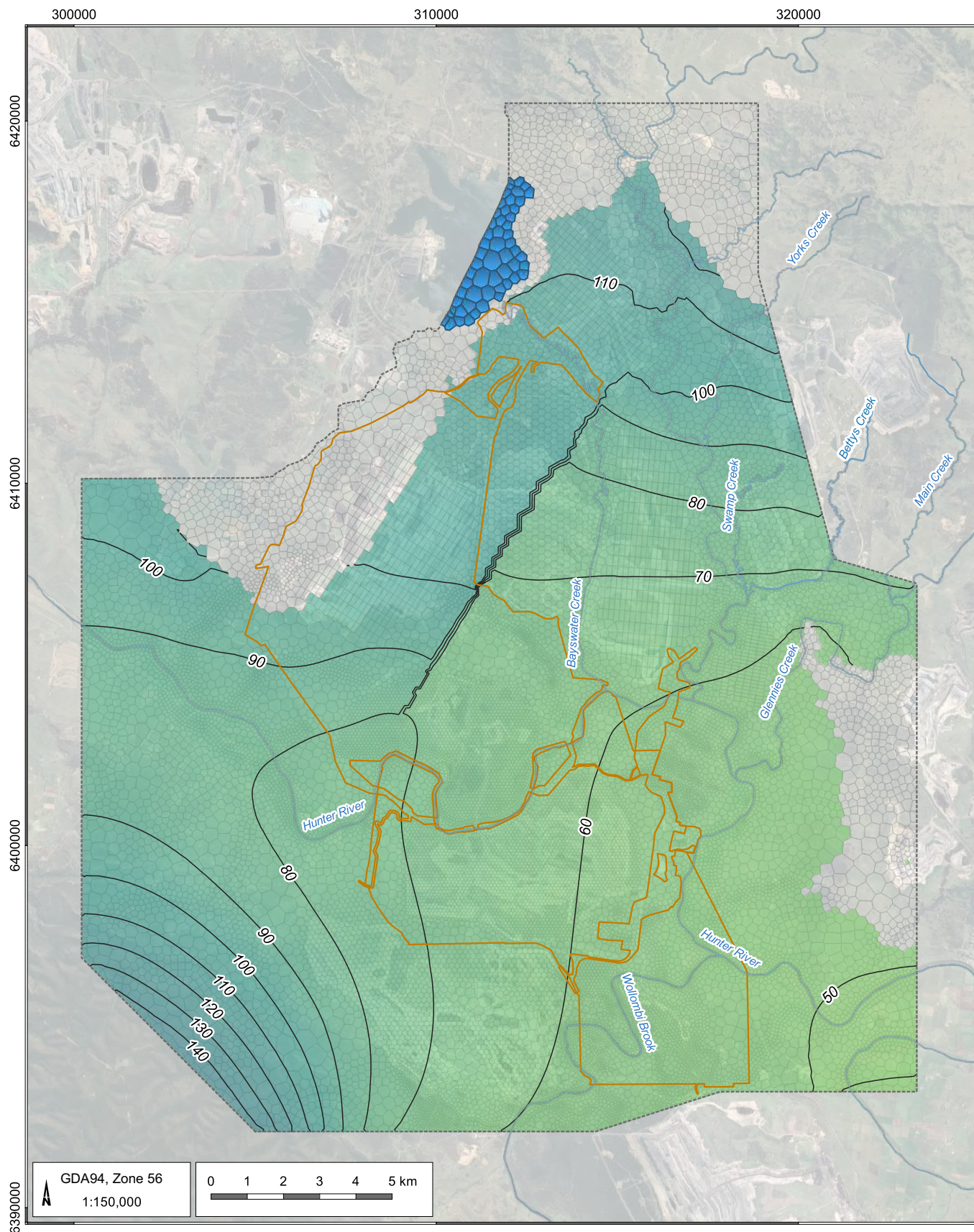
Simulated steady state groundwater levels – Middle Liddell Seam



AGE

DATE
03/11/2022

FIGURE No:
D 23



LEGEND

- Drainage
- Contour line
- Project Area
- - - Model extent
- Model grid
- Lake Liddell

Groundwater level (mAH)

- 150
- 100
- 50
- 0
- 50
- 100
- 150
- 200
- 250
- 300

HVO Continuation (G1737J)

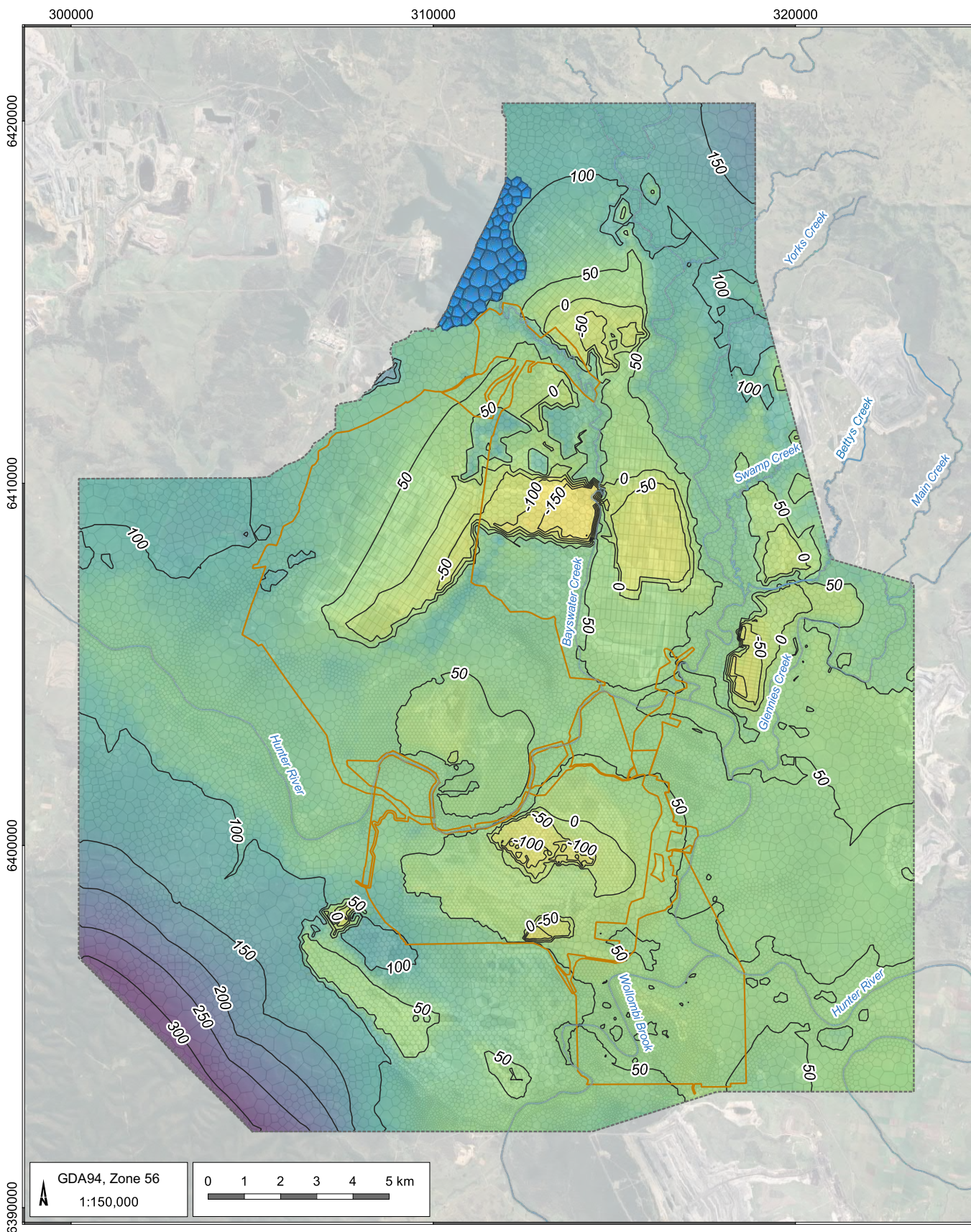
Simulated steady state groundwater levels – Barrett seam



AGE

DATE
03/11/2022

FIGURE No:
D 24



LEGEND

- Drainage
- Project Area
- Contour line
- Model extent
- Model grid
- Lake Liddell

Groundwater level (mAH)

- 150
- 100
- 50
- 0
- 50
- 100
- 150
- 200
- 250
- 300

HVO Continuation (G1737J)

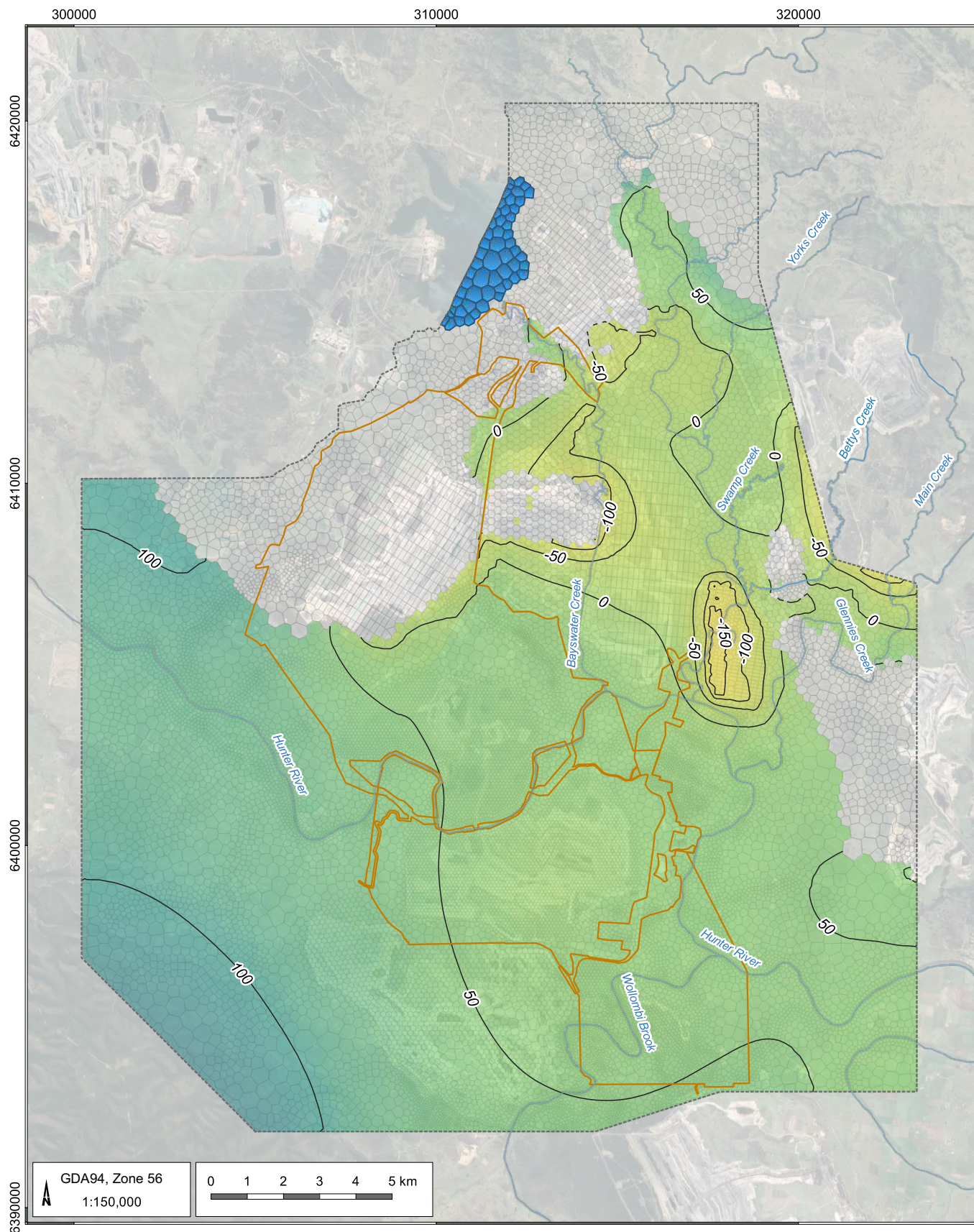
Simulated 2020 groundwater levels – water table



AGE

DATE
03/11/2022

FIGURE No:
D 25



LEGEND

- Drainage
- Contour line
- Project Area
- Model extent
- Model grid
- Lake Liddell

Groundwater level (mAH)

- 150
- 100
- 50
- 0
- 50
- 100
- 150
- 200
- 250
- 300

HVO Continuation (G1737J)

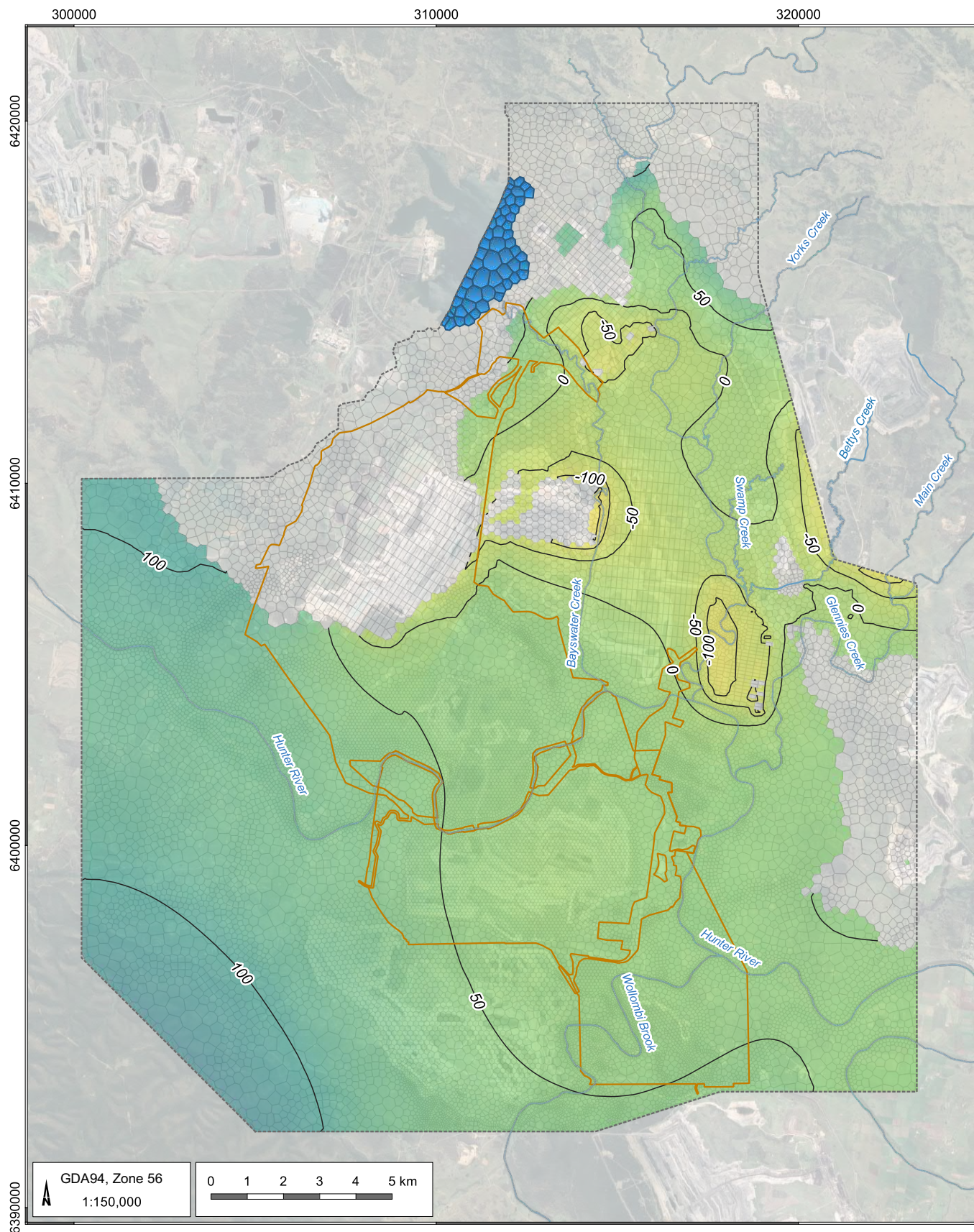
Simulated 2020 groundwater levels – Liddell seam



AGE

DATE
03/11/2022

FIGURE No:
D 26



LEGEND

- Drainage
- Contour line
- Project Area
- - - Model extent
- Model grid
- Lake Liddell

Groundwater level (mAHD)

- 150
- 100
- 50
- 0
- 50
- 100
- 150
- 200
- 250
- 300

HVO Continuation (G1737J)

Simulated 2020 groundwater levels – Barrett seam



AGE

DATE
03/11/2022

FIGURE No:
D 27

D3.4.2 Hydraulic parameters

Table D 10 summarises the calibrated hydraulic conductivity values for each hydrostratigraphic unit or layer within the model domain (before applying pilot point multipliers in the layers where they exist). Within the Permian layers, the hydraulic conductivity values vary with depth as explained below the table.

Table D 10 Calibrated hydraulic conductivity values

Model layer	Lithology	Horizontal hydraulic conductivity K_x (m/day)*	Average vertical hydraulic conductivity factor (K_z/K_x)
1	Regolith	2.65×10^{-3} to 6.8×10^{-3}	0.01
1	Shallow Alluvium (Qa)	High prod: 1.5 to 19 Low prod: 2.5 to 3.9	High prod: 0.6 Low prod: 0.01
2	Deep Alluvium (Qa)	High prod: 2.9 to 85 Low prod: 0.53 to 2.2	High prod: 0.05 Low prod: 0.01
3	Overburden	2.73×10^{-3}	0.09
4	Newcastle, Whybrow Seams	0-100m: 8.20×10^{-2} 100-300m: 8.38×10^{-3} 300-600m: 1.08×10^{-4}	0.02
5	Interburden	0-100m: 1.00×10^{-1} 100-300m: 3.77×10^{-2} 300-600m: 7.87×10^{-4}	0.05
6	Wambo Seam	0-100m: 9.36×10^{-4} 100-300m: 1.92×10^{-4} 300-600m: 1.95×10^{-5}	0.02
7	Interburden	0-100m: 1.00×10^{-1} 100-300m: 3.38×10^{-2} 300-600m: 4.37×10^{-4}	0.03
8	Whynot Seam	0-100m: 8.08×10^{-4} 100-300m: 8.36×10^{-5} 300-600m: 8.49×10^{-6}	0.01
9	Interburden	0-100m: 1.00×10^{-1} 100-300m: 3.16×10^{-2} 300-600m: 3.71×10^{-4}	0.07
10	Balkefiled, Glen Munro, Woodlands Hill Seams	0-100m: 1.00×10^{-3} 100-300m: 6.12×10^{-4} 300-600m: 1.01×10^{-4}	0.02
11	Interburden	0-100m: 9.66×10^{-2} 100-300m: 2.15×10^{-2} 300-600m: 3.31×10^{-4}	0.04
12	Arrowfield Seam	0-100m: 5.97×10^{-4} 100-300m: 3.05×10^{-5} 300-600m: 3.09×10^{-6}	0.02
13	Interburden	0-100m: 1.00×10^{-1} 100-300m: 5.74×10^{-2} 300-600m: 2.50×10^{-3}	0.08
14	Bowfield Seam	0-100m: 8.78×10^{-4} 100-300m: 1.33×10^{-4} 300-600m: 1.35×10^{-5}	0.01
15	Interburden	0-100m: 1.00×10^{-1} 100-300m: 6.87×10^{-2} 300-600m: 4.10×10^{-3}	0.02

Model layer	Lithology	Horizontal hydraulic conductivity Kx (m/day)*	Average vertical hydraulic conductivity factor (Kz/Kx)
16	Warkworth Seam	0-100m: 1.00×10^{-3} 100-300m: 1.00×10^{-3} 300-600m: 7.79×10^{-4}	0.02
17	Interburden	0-100m: 9.23×10^{-2} 100-300m: 1.72×10^{-2} 300-600m: 3.67×10^{-4}	0.01
18	Mt Arthur Seam	0-100m: 1.00×10^{-3} 100-300m: 6.50×10^{-4} 300-600m: 1.29×10^{-4}	0.12
19	Interburden	0-100m: 1.00×10^{-1} 100-300m: 6.42×10^{-2} 300-600m: 3.47×10^{-3}	0.5
20	Piercefield, Vaux Seams	0-100m: 9.89×10^{-4} 100-300m: 3.18×10^{-4} 300-600m: 3.23×10^{-5}	0.13
21	Interburden	0-100m: 8.77×10^{-2} 100-300m: 1.08×10^{-2} 300-600m: 1.29×10^{-4}	0.22
22	Broonie, Bayswater Seams	0-100m: 1.00×10^{-3} 100-300m: 9.08×10^{-4} 300-600m: 3.58×10^{-4}	1
23	Interburden	0-100m: 1.00×10^{-3} 100-300m: 1.00×10^{-3} 300-600m: 5.98×10^{-4}	0.03
24	Interburden	0-100m: 2.70×10^{-3} 100-300m: 2.24×10^{-4} 300-600m: 5.00×10^{-5}	0.17
25	Lemington, Pikes Gully Seams	0-100m: 1.00×10^{-3} 100-300m: 1.00×10^{-3} 300-600m: 8.14×10^{-4}	0.02
26	Interburden	0-100m: 1.00×10^{-3} 100-300m: 1.00×10^{-3} 300-600m: 7.91×10^{-4}	0.01
27	Interburden	0-100m: 8.72×10^{-2} 100-300m: 1.18×10^{-2} 300-600m: 1.93×10^{-4}	0.01
28	Arties, Liddell Seams	0-100m: 1.00×10^{-3} 100-300m: 1.00×10^{-3} 300-600m: 7.88×10^{-4}	1
29	Interburden	0-100m: 5.53×10^{-2} 100-300m: 4.50×10^{-3} 300-600m: 9.46×10^{-5}	0.04
30	Barrett Seam	0-100m: 1.00×10^{-3} 100-300m: 4.69×10^{-4} 300-600m: 9.64×10^{-5}	1
31	Interburden	0-100m: 5.31×10^{-2} 100-300m: 3.47×10^{-3} 300-600m: 6.69×10^{-5}	0.19
32	Hebden Seam	0-100m: 1.00×10^{-1} 100-300m: 3.77×10^{-2} 300-600m: 7.87×10^{-4}	1

Model layer	Lithology	Horizontal hydraulic conductivity Kx (m/day)*	Average vertical hydraulic conductivity factor (Kz/Kx)
33	Saltwater Creek Formation	1.1×10^{-3}	0.5
-	Liddell Underground works	11.4	1
-	Spoil	1.23	0.1
-	Tailings	8.3×10^{-5}	0.02

Note: * n layers with depth-dependent Kh, depth ranges and average Kh within the ranges are displayed.

The hydraulic conductivities of Permian layers in the model reduce with depth to reflect similar trends observed in field data gathered from the site and surrounding regional mines (refer main report Section 5.7). The increase in overburden pressure affects both the coal seams and interburden reducing their hydraulic conductivity at slightly different rates. Based on observed data and previous studies in the Hunter Valley, those different rates can be replicated using the following equations:

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

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

Where: *HC* is horizontal hydraulic conductivity at specific depth.

HC₀ is horizontal hydraulic conductivity at depth of 0m (intercept of the curve).

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

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

After using the depth-dependence equations, the horizontal hydraulic conductivity of the coal was capped at a maximum of 1×10^{-1} m/day and a minimum of 5×10^{-5} m/day. The interburden was capped at a maximum of 1×10^{-3} m/day and a minimum of 1×10^{-7} m/day.

The *slope* and *HC₀* parameters in the depth dependence equation were adjusted for each individual model layer during the calibration process. After the hydraulic conductivity of each cell was calculated using the equation, the value was adjusted by a factor determined by pilot points, and then capped within the maximum and minimum range.

Graphs of the Kx vs. depth relationship for the individual coal seams and interburden units are displayed on Figure D 28 and Figure D 29. As shown in these figures, calibrated hydraulic conductivity trend (decline with depth) for the various coal and interburden layers remains generally within the trend zone identified in the available field data, as described with the main report. The hydraulic conductivity for the interburden layers in the model calibrated at the upper end of the field measurements.

Appendix D 2 provides plots of depth vs horizontal hydraulic conductivity for the cells in each layer or subzone. In the appendix, each cell is represented with a dot. The graphs illustrate hydraulic conductivity distributions and how the range caps were applied.

The spatial distribution of hydraulic conductivity values for the Barrett Seam are presented in Figure D 30. The figure shows how the depth dependence function and pilot point approach influence the hydraulic conductivity in the coal seams. The figure shows a decline in hydraulic conductivity in the deepest part of the Barrett Seam within the model extent, to the south-west of the model and also east of the Camberwell Anticline.

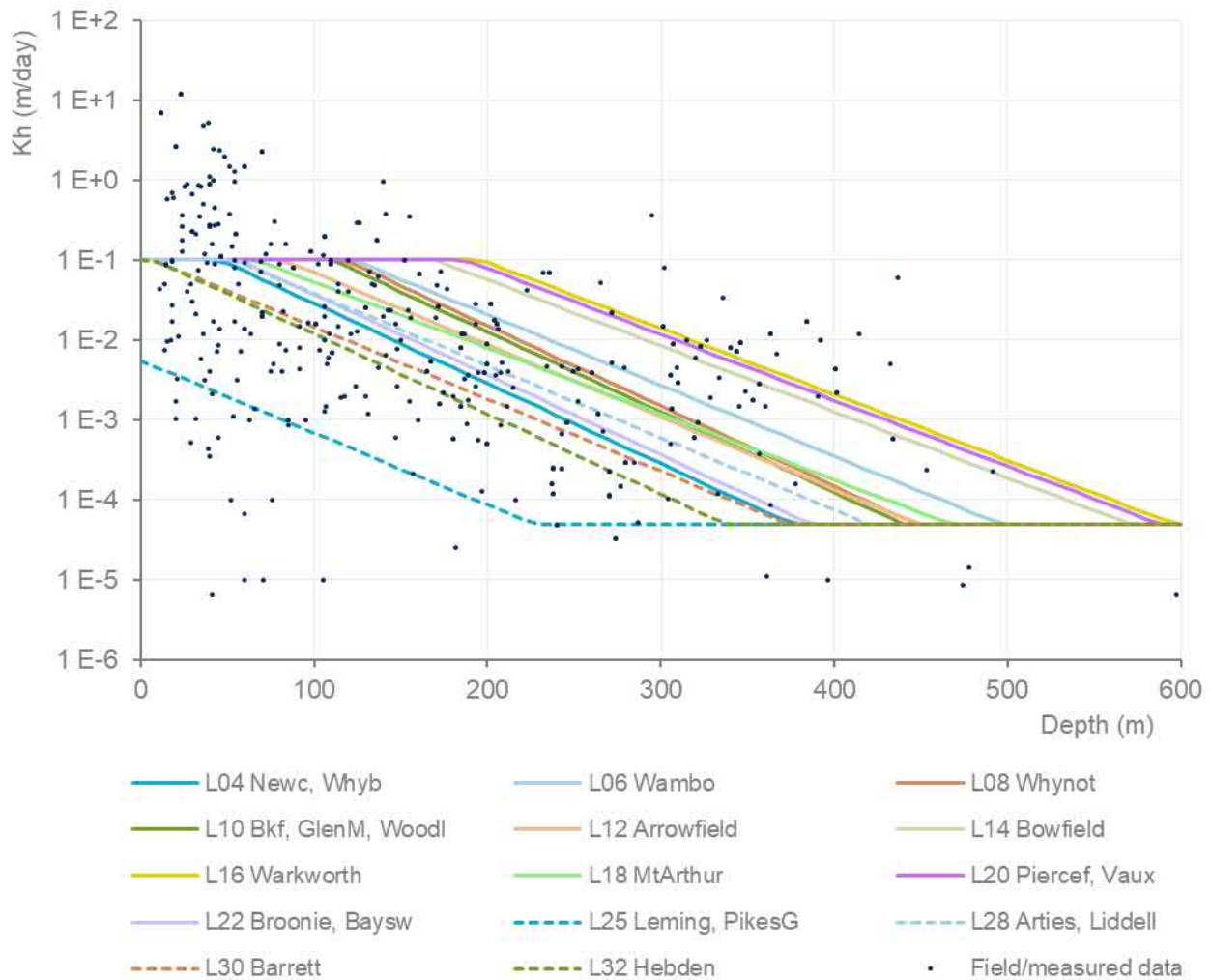


Figure D 28 Coal hydraulic conductivity distribution (before applying pilot point multipliers)

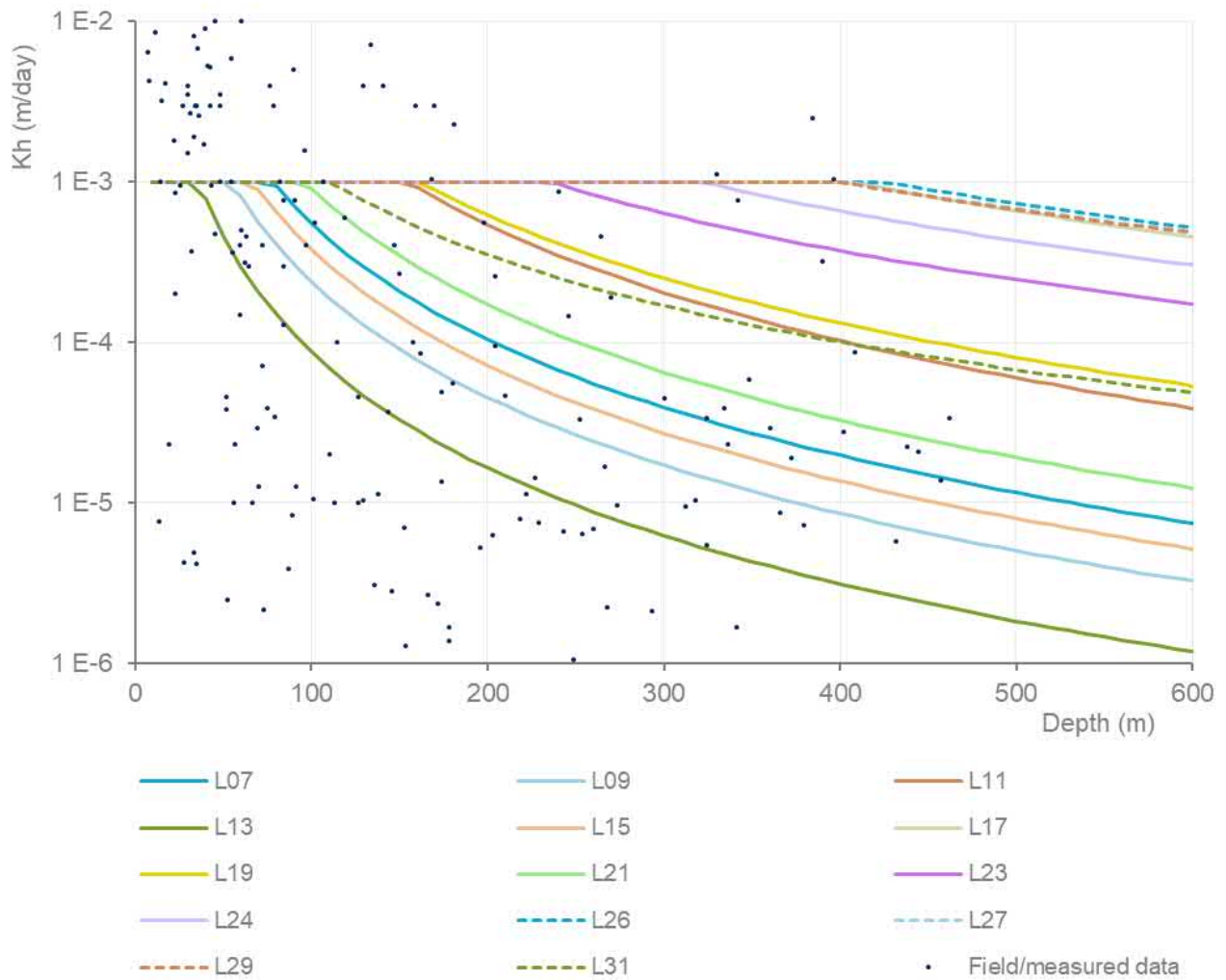
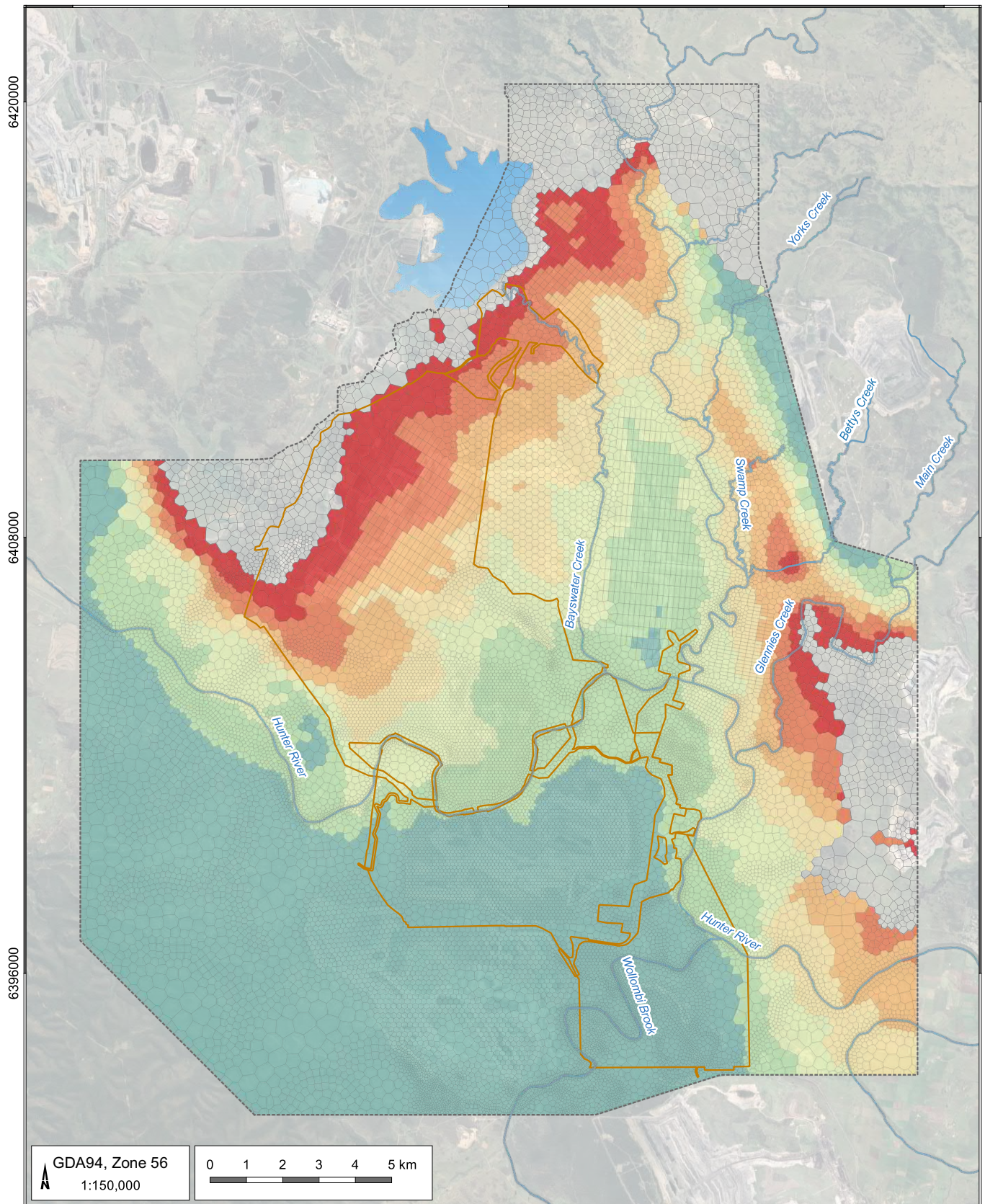


Figure D 29 Interburden hydraulic conductivity distribution

300000

312000

324000



LEGEND

- Drainage
- Project Area
- - - Model extent
- Model grid
- Lake Liddell

Hydraulic properties (m/day)

- 10⁻⁵ - 10^{-4.5}
- 10^{-4.5} - 10⁻⁴
- 10⁻⁴ - 10^{-3.5}
- 10^{-3.5} - 10⁻³
- 10⁻³ - 10^{-2.5}
- 10^{-2.5} - 10⁻²
- 10⁻² - 10^{-1.5}
- 10^{-1.5} - 10⁻¹

HVO Continuation (G1737J)

Modelled hydraulic conductivity of the Barrett Seam



AGE

DATE
03/11/2022FIGURE No:
D 30

D3.4.3 Storage properties

Table D 11 summarises the calibrated values for specific storage and specific yield.

Table D 11 Model layer storage properties

Model layer	Lithology	Specific yield Sy	Specific storage Ss (m ⁻¹)
1	Regolith	1% to 8%	1.2 x 10 ⁻⁵ to 1.3 x 10 ⁻⁵
1	Shallow Alluvium (Qa)	5% to 19%	1.3 x 10 ⁻⁵
2	Deep alluvium (Qa)	4% to 25%	1.0 x 10 ⁻⁵ to 1.3 x 10 ⁻⁵
3	Overburden	2.5%	1.3 x 10 ⁻⁵
4	Newcastle, Whybrow	0.7%	1.3 x 10 ⁻⁵
5	Interburden	1.8%	1.3 x 10 ⁻⁵
6	Wambo	0.07%	1.04 x 10 ⁻⁵
7	Interburden	0.7%	7.61 x 10 ⁻⁶
8	Whynot seam	0.5%	9.13 x 10 ⁻⁶
9	Interburden	1%	1.3 x 10 ⁻⁵
10	Blakefield, GlenMunro, WoodlandsHill	1%	1.3 x 10 ⁻⁵
11	Interburden	1%	9.1 x 10 ⁻⁶
12	Arrowfield	0.2%	1.3 x 10 ⁻⁵
13	Interburden	0.6%	4.48 x 10 ⁻⁶
14	Bowfield, BowfieldSplit	0.5%	1.3 x 10 ⁻⁵
15	Interburden	0.4%	8.68 x 10 ⁻⁶
16	Warkworth	0.7%	1.3 x 10 ⁻⁵
17	Interburden	1%	8.83 x 10 ⁻⁶
18	MtArthur	0.1%	1.3 x 10 ⁻⁵
19	Interburden	1%	3.74 x 10 ⁻⁶
20	Piercefield, Vaux	0.1%	1.3 x 10 ⁻⁵
21	Interburden	1%	7.55 x 10 ⁻⁶
22	Broonie, Bayswater	2.4%	8.97 x 10 ⁻⁷
23	Interburden	0.1%	2.43 x 10 ⁻⁶
24	Interburden	0.01%	7.27 x 10 ⁻⁷
25	Lemington, PikesGully	0.1%	1.06 x 10 ⁻⁵
26	Interburden	0.02%	5 x 10 ⁻⁷
27	Interburden	0.02%	5 x 10 ⁻⁷
28	Arties, Liddell	0.02%	6.33 x 10 ⁻⁷
29	Interburden	0.01%	5 x 10 ⁻⁷
30	Barrett	1%	2.3 x 10 ⁻⁶
31	Interburden	0.03%	7.75 x 10 ⁻⁷
32	Hebden	0.02%	2.74 x 10 ⁻⁶

Model layer	Lithology	Specific yield Sy	Specific storage Ss (m ⁻¹)
33	SaltwaterCkFm	0.02%	5 x 10 ⁻⁷
-	Liddell Underground	2%	2.4 x10 ⁻⁷
-	Spoil	0.1%	4.1 x 10 ⁻⁶
-	Tailings	5%	9.3 x 10 ⁻⁷

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.

Specific storage (Ss) data of coal seams or interburden obtained via direct testing is generally not available. Rau et al (2018) provide limits based on poroelastic theory which indicates that specific storage is restricted to the range of $2.3 \times 10^{-7} \text{ m}^{-1}$ and $1.3 \times 10^{-5} \text{ m}^{-1}$. The calibrated parameters for coal were guided by these bounds, although some flexibility was allowed for improvement of the calibration results.

D3.4.4 Parameter sensitivity and identifiability

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

The PEST utility GENLINPRED was used to calculate the parameter identifiability for each model parameter using the results of the automatic calibration process. Table D 12 shows the identifiability of groundwater model parameter zones for Kh, Kv, Sy, Ss and some other parameters in respect to the groundwater level observation dataset. Figure D 31 presents a visual representation of the identifiability of those parameters.

Table D 12 Parameter identifiability

Parameter(s)	Average identifiability	Identifiability range (Min – Max)
GHB_cond_TSF	6.4×10^{-1}	$4.5 \times 10^{-1} - 7.3 \times 10^{-1}$
Kh_L01_alluv_shallow	3.7×10^{-1}	$2.8 \times 10^{-1} - 5.4 \times 10^{-1}$
Kh_L01_regolith	4.9×10^{-1}	$4.0 \times 10^{-1} - 6.4 \times 10^{-1}$
Kh_L02_alluv_deep	4.0×10^{-1}	$2.8 \times 10^{-1} - 5.3 \times 10^{-1}$
Kh_L03_overburden	5.4×10^{-1}	-
Kh_L04_coal	3.6×10^{-1}	-
Kh_L05_interburden	5.8×10^{-1}	-
Kh_L06_coal	4.6×10^{-1}	-
Kh_L07_interburden	2.3×10^{-1}	-
Kh_L08_coal	5.1×10^{-1}	-
Kh_L09_interburden	2.8×10^{-1}	-
Kh_L10_coal	4.0×10^{-1}	-
Kh_L11_interburden	3.7×10^{-1}	-
Kh_L12_coal	4.6×10^{-1}	-

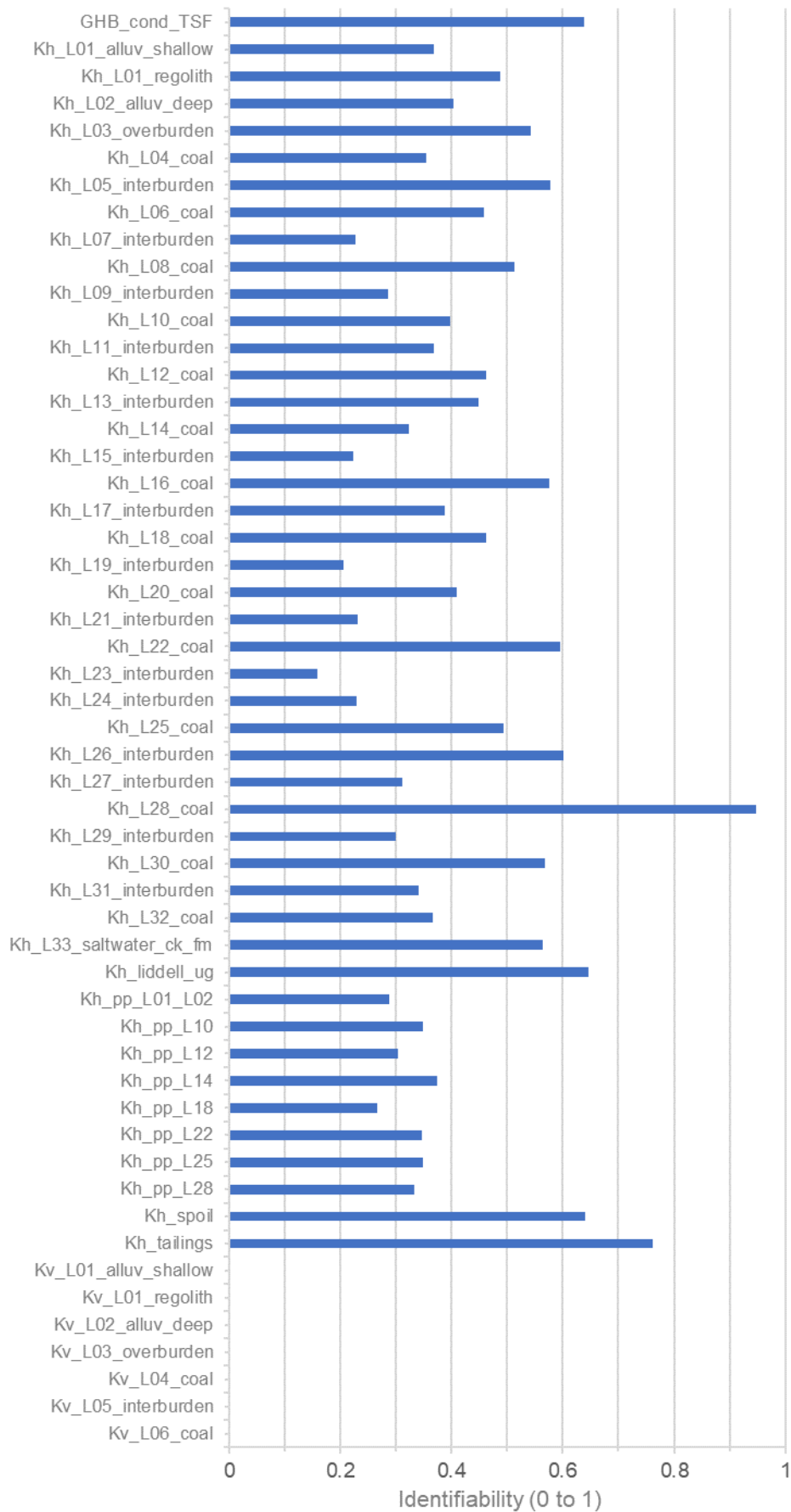
Parameter(s)	Average identifiability	Identifiability range (Min – Max)
Kh_L13_interburden	4.5×10^{-1}	-
Kh_L14_coal	3.2×10^{-1}	-
Kh_L15_interburden	2.2×10^{-1}	-
Kh_L16_coal	5.8×10^{-1}	-
Kh_L17_interburden	3.9×10^{-1}	-
Kh_L18_coal	4.6×10^{-1}	-
Kh_L19_interburden	2.1×10^{-1}	-
Kh_L20_coal	4.1×10^{-1}	-
Kh_L21_interburden	2.3×10^{-1}	-
Kh_L22_coal	6.0×10^{-1}	-
Kh_L23_interburden	1.6×10^{-1}	-
Kh_L24_interburden	2.3×10^{-1}	-
Kh_L25_coal	4.9×10^{-1}	-
Kh_L26_interburden	6.0×10^{-1}	-
Kh_L27_interburden	3.1×10^{-1}	-
Kh_L28_coal	9.5×10^{-1}	-
Kh_L29_interburden	3.0×10^{-1}	-
Kh_L30_coal	5.7×10^{-1}	-
Kh_L31_interburden	3.4×10^{-1}	-
Kh_L32_coal	3.7×10^{-1}	-
Kh_L33_saltwater_ck_fm	5.6×10^{-1}	-
Kh_liddell_ug	6.5×10^{-1}	-
Kh_pp_L01_L02	2.9×10^{-1}	$1.6 \times 10^{-1} - 3.8 \times 10^{-1}$
Kh_pp_L10	3.5×10^{-1}	$2.6 \times 10^{-1} - 5.0 \times 10^{-1}$
Kh_pp_L12	3.0×10^{-1}	$1.9 \times 10^{-1} - 4.0 \times 10^{-1}$
Kh_pp_L14	3.7×10^{-1}	$3.3 \times 10^{-1} - 4.0 \times 10^{-1}$
Kh_pp_L18	2.7×10^{-1}	$1.8 \times 10^{-1} - 3.6 \times 10^{-1}$
Kh_pp_L22	3.5×10^{-1}	$1.7 \times 10^{-1} - 4.9 \times 10^{-1}$
Kh_pp_L25	3.5×10^{-1}	$2.6 \times 10^{-1} - 5.2 \times 10^{-1}$
Kh_pp_L28	3.3×10^{-1}	$2.0 \times 10^{-1} - 4.3 \times 10^{-1}$
Kh_spoil	6.4×10^{-1}	-
Kh_tailings	7.6×10^{-1}	-
Kv_L01_alluv_shallow	1.6×10^{-5}	$0.0 \times 10^{+0} - 2.1 \times 10^{-4}$
Kv_L01_regolith	0.0	-

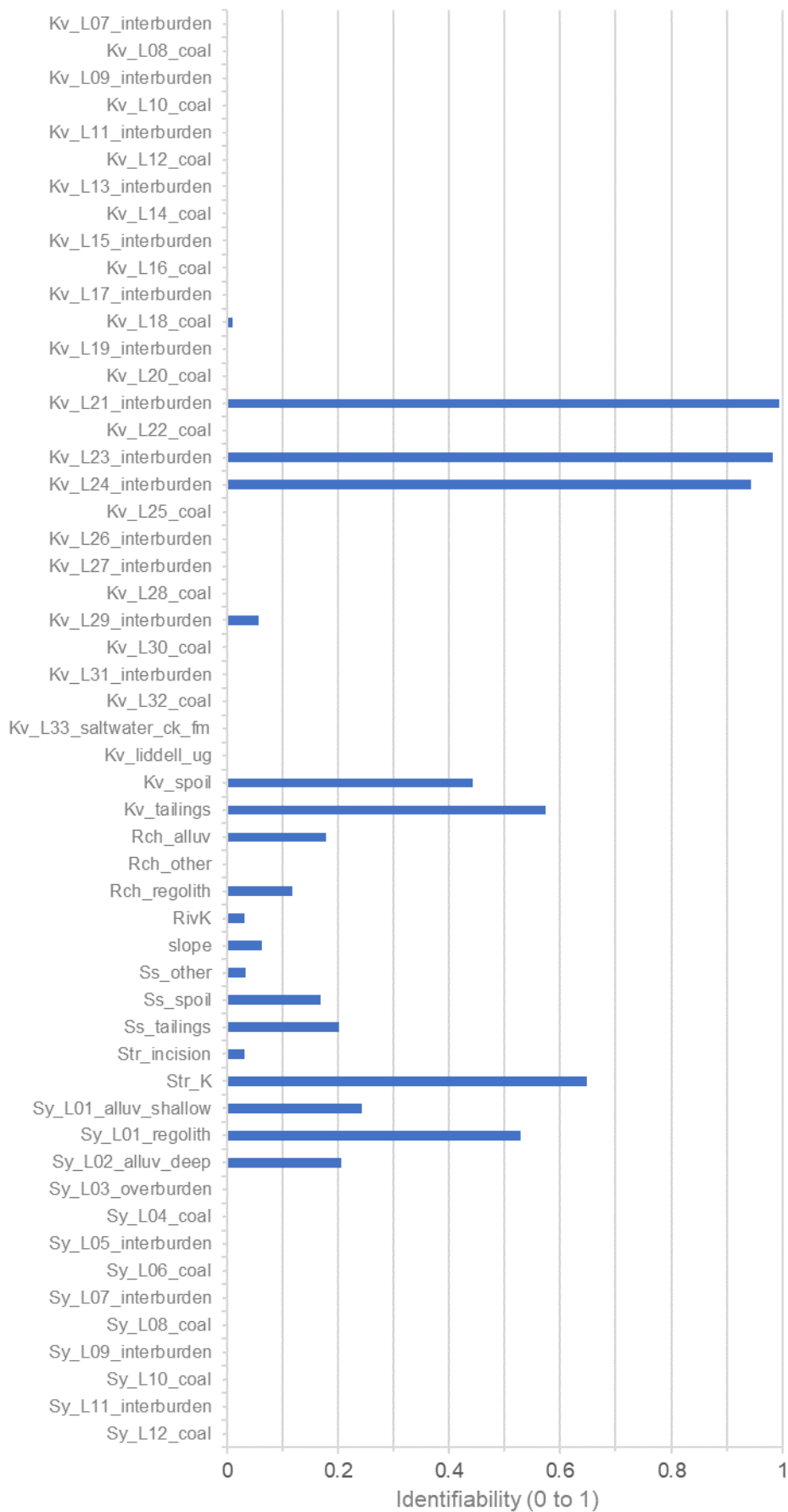
Parameter(s)	Average identifiability	Identifiability range (Min – Max)
Kv_L02_alluv_deep	2.1×10^{-4}	$0.0 - 1.7 \times 10^{-3}$
Kv_L03_overburden	0.0	-
Kv_L04_coal	0.0	-
Kv_L05_interburden	0.0	-
Kv_L06_coal	0.0	-
Kv_L07_interburden	0.0	-
Kv_L08_coal	0.0	-
Kv_L09_interburden	0.0	-
Kv_L10_coal	0.0	-
Kv_L11_interburden	0.0	-
Kv_L12_coal	0.0	-
Kv_L13_interburden	0.0	-
Kv_L14_coal	0.0	-
Kv_L15_interburden	0.0	-
Kv_L16_coal	0.0	-
Kv_L17_interburden	0.0	-
Kv_L18_coal	9.3×10^{-3}	-
Kv_L19_interburden	0.0	-
Kv_L20_coal	0.0	-
Kv_L21_interburden	9.9×10^{-1}	-
Kv_L22_coal	0.0	-
Kv_L23_interburden	9.8×10^{-1}	-
Kv_L24_interburden	9.4×10^{-1}	-
Kv_L25_coal	0.0	-
Kv_L26_interburden	0.0	-
Kv_L27_interburden	0.0	-
Kv_L28_coal	0.0	-
Kv_L29_interburden	5.8×10^{-2}	-
Kv_L30_coal	0.0	-
Kv_L31_interburden	0.0	-
Kv_L32_coal	0.0	-
Kv_L33_saltwater_ck_fm	0.0	-
Kv_liddell_ug	0.0	-
Kv_spoil	4.4×10^{-1}	-

Parameter(s)	Average identifiability	Identifiability range (Min – Max)
Kv_tailings	5.7×10^{-1}	-
Rch_alluv	1.8×10^{-1}	0.0 E+0 - 6.6×10^{-1}
Rch_other	0.0	-
Rch_regolith	1.2×10^{-1}	0.0 E+0 - 9.8×10^{-1}
RivK	3.2×10^{-2}	0.0 E+0 - 1.0
slope	6.3×10^{-2}	0.0 E+0 - 9.4×10^{-1}
Ss_other	3.2×10^{-2}	0.0 E+0 - 1.0
Ss_spoil	1.7×10^{-1}	-
Ss_tailings	2.0×10^{-1}	-
Str_incision	3.2×10^{-2}	1.2×10^{-2} - 8.9×10^{-2}
Str_K	6.5×10^{-1}	5.5×10^{-1} - 7.4×10^{-1}
Sy_L01_alluv_shallow	2.4×10^{-1}	1.0×10^{-1} - 6.0×10^{-1}
Sy_L01_regolith	5.3×10^{-1}	0.0 - 1.0
Sy_L02_alluv_deep	2.1×10^{-1}	1.2×10^{-1} - 4.1×10^{-1}
Sy_L03_overburden	6.6×10^{-4}	-
Sy_L04_coal	3.6×10^{-5}	-
Sy_L05_interburden	4.5×10^{-7}	-
Sy_L06_coal	1.7×10^{-7}	-
Sy_L07_interburden	0.0	-
Sy_L08_coal	0.0	-
Sy_L09_interburden	0.0	-
Sy_L10_coal	0.0	-
Sy_L11_interburden	0.0	-
Sy_L12_coal	0.0	-
Sy_L13_interburden	0.0	-
Sy_L14_coal	0.0	-
Sy_L15_interburden	0.0	-
Sy_L16_coal	0.0	-
Sy_L17_interburden	0.0	-
Sy_L18_coal	0.0	-
Sy_L19_interburden	0.0	-
Sy_L20_coal	9.7×10^{-2}	-
Sy_L21_interburden	9.8×10^{-1}	-
Sy_L22_coal	0.0	-

Parameter(s)	Average identifiability	Identifiability range (Min – Max)
Sy_L23_interburden	0.0	-
Sy_L24_interburden	0.0	-
Sy_L25_coal	0.0	-
Sy_L26_interburden	0.0	-
Sy_L27_interburden	0.0	-
Sy_L28_coal	0.0	-
Sy_L29_interburden	0.0	-
Sy_L30_coal	0.0	-
Sy_L31_interburden	0.0	-
Sy_L32_coal	0.0	-
Sy_L33_saltwater_ck_fm	0.0	-
Sy_liddell_ug	5.4×10^{-1}	$4.3 \times 10^{-1} - 6.4 \times 10^{-1}$
Sy_pp_L01_L02	1.4×10^{-1}	$6.0 \times 10^{-2} - 3.8 \times 10^{-1}$
Sy_spoil	6.9×10^{-1}	-
Sy_tailings	3.5×10^{-1}	-

Note: Range presented for rows made of subgroups of parameters (e.g. layer broken down in different zones).





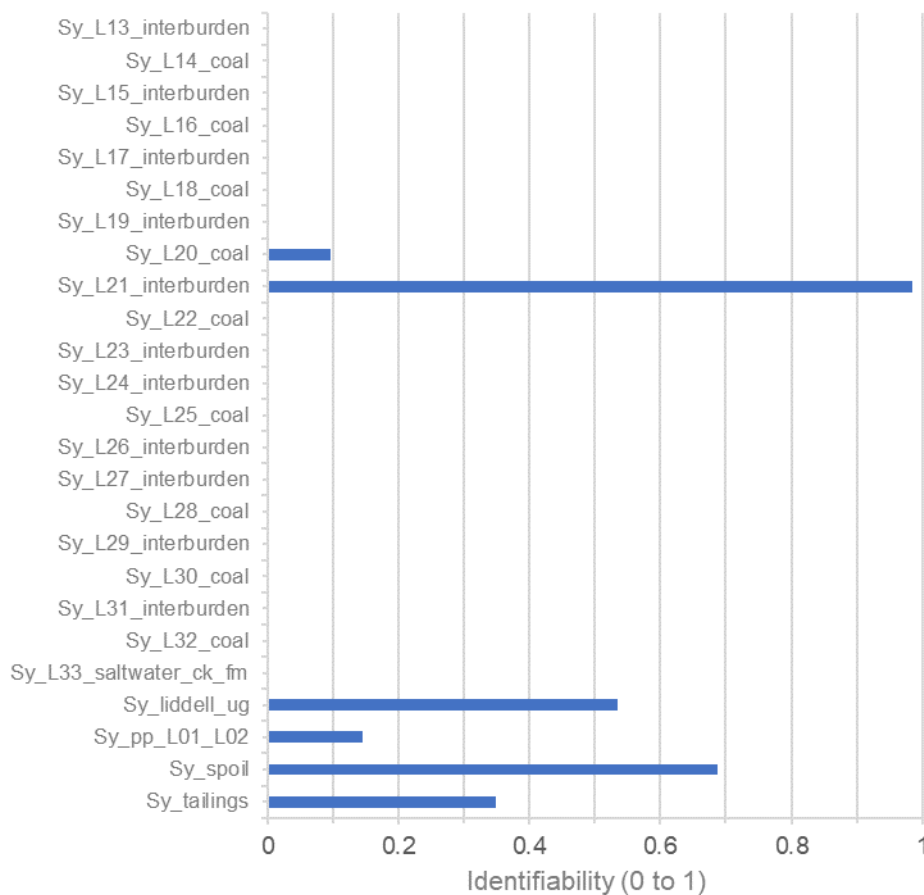


Figure D 31 Parameter identifiability

Most of the Kh parameters display an identifiability of ~0.2 or higher, meaning that the modelled heads are highly sensitive to the model parameter, and the calibrated values are highly 'identifiable'. In general, the main Kh parameter for each layer is more identifiable than the pilot points, as the main parameter affects all the observations on a given layer, but individual pilot points usually affect just a few. However, depending on the location of pilot points (say near observation points) and the scale of the pilot point multiplier vs the scale of the parameter range, the identifiability of the pilot points can end up being higher.

The identifiability of Kv zones is highest in layers 21, 23 and 24 (interburden layers above and below the Bayswater Seam). These layers are active during mining at HVO and include or are in close proximity to monitoring points, making them highly identifiable. Kh and Kv of the spoil and tailings are highly identifiable too, as they appear over time within the mined areas and are surrounded by monitoring locations, somewhat controlling their response.

The specific yield is highly identifiable in the alluvium, regolith, Piercefield/Vaux Seams and underlying interburden, and in Liddell Underground. These are layers where the saturation level of cells oscillates in close proximity to monitoring points, making the parameters highly identifiable. In the spoil and tailings, the specific yield is also highly identifiable.

Specific storage has relatively low identifiability for the layers in general, but it is highly identifiable for spoil and tailings. As explained before, spoil and tailings appear over time within the mined areas and are surrounded by monitoring locations, and their storage properties influence their response to oscillations in water levels generated by mining activities.

Recharge had an identifiability close to 0.2 in alluvium and close to 0.1 for the regolith of different rocks, indicating the different recharge coefficients for most of the model are identifiable. Smaller areas like lakes had individual recharge coefficients, and these were not identifiable as they did not have many observation points around them.

The bed conductance applied to the river package (RIV) of Modflow, used to represent smaller creeks with no head of water, was somewhat identifiable, as was the incision depth used in the setup of the stream (STR) package. However, the bed conductance of the stream package was highly identifiable, mainly because it controls the exchange of water between the channel and alluvium for the Hunter River.

In summary, the horizontal hydraulic conductivity was the group of parameters with the highest overall identifiability, with the vertical hydraulic conductivity and specific yield identifiable mostly in selected layers. The specific storage had an overall low (but not null) identifiability, and the river and stream parameters were identifiable.

Most of the parameters associated with spoil and tailings were highly identifiable, indicating the behaviour of the groundwater system is sensitive to their hydraulic properties. The model parameters associated to alluvial groundwater systems were also relatively identifiable during the calibration process. This is an optimal outcome as the alluvial groundwater systems are the main sensitive receptors in the Project area.

The results from the identifiability analysis are used to derive the posterior distributions for the uncertainty analysis. If not managed properly, parameters that are highly identifiable can have a very narrow posterior distribution when conducting uncertainty analysis. Parameters with low identifiability could imply the parameter is insensitive to the measurement data, or there are no observation data to inform the parameter. In this instance, the range of parameters explored in the uncertainty analysis was broad. This is discussed in Section D7.

D3.4.5 Water budget

Table D 13 below presents a summary of the water budget from the groundwater model for steady state, and average for the rest of the calibration simulation with transient stress periods.

Table D 13 Model budgets (ML/day)

	Steady state (ML/year)			Transient average (ML/year)		
	In	Out	In - Out	In	Out	In - Out
Storage	0.0	0.0	0.0	7899.7	2881.0	5018.7
Head dependent boundaries	1541.6	599.8	941.8	1608.9	894.1	714.8
Constant head boundaries	31.9	0.2	31.7	58.6	0.2	58.3
Drains	0.0	0.0	0.0	0.0	5635.8	-5635.8
River leakage	0.0	1971.2	-1971.2	0.0	1712.4	-1712.4
Stream leakage	1794.2	5703.4	-3909.1	1885.2	5991.3	-4106.1
Recharge	4906.8	0.0	4906.8	5661.5	0.0	5661.5
Total	8274.5	8274.6	-0.1	17113.9	17114.8	-1.0
Percent discrepancy	-	-	0.0%	-	-	0.0%

As expected, the main water input in the steady state simulation is recharge, followed by stream leakage (from the Hunter River, Bowmans Creek, Glennies Creek and Wollombi Brook) and head dependent boundaries (set mainly around the perimeter of the model extent). The main output in steady state is stream leakage, followed by river leakage. A smaller portion of the budget exits the system via head dependent boundaries.

The transient model water budget departed from steady state conditions due to mining operations in the model domain, as observed mainly in the Drain (DRN) budget. This loss is compensated for mostly by water extracted from storage, as observed in the table. During the transient period the input from recharge was slightly higher than that observed in the steady state period, keeping the output via stream leakage and river leakage relatively stable.

The average mass balance error, that is, the difference between calculated model inflows and outflows at the completion of the steady state calibration was 0.0% for both the steady state and transient parts of the simulation. The greatest error for a single stress period in the model was 0.13%, followed by 0.03%. This indicates that the model was stable during the calibration period and achieved an accurate numerical solution.

The calibrated model water budget represents the optimal balance PEST arrived at using the groundwater levels and baseflow as a target. There is significant uncertainty in these volumes as the majority of the budget components are not directly measurable in the field.

D3.4.6 Mine inflow verification

Groundwater seepage from the Permian is typically not distinguishable from spoil recharge and mine runoff as the three inflow components report to and are recorded at the base of the pit sump. It was therefore not possible to verify the mine inflow predicted by the numerical model aligns with field measurements.

Figure B 31 presents the inflow predictions to the drain cells in the groundwater model. The simulation predicts an average inflow of 1325 ML/year during 2019 for HVO North, HVO South and West Pit combined. The results indicate a general agreement with expected combined inflows of 1606 ML/year during the year 2019 (estimated using Glencore's site water balance data).

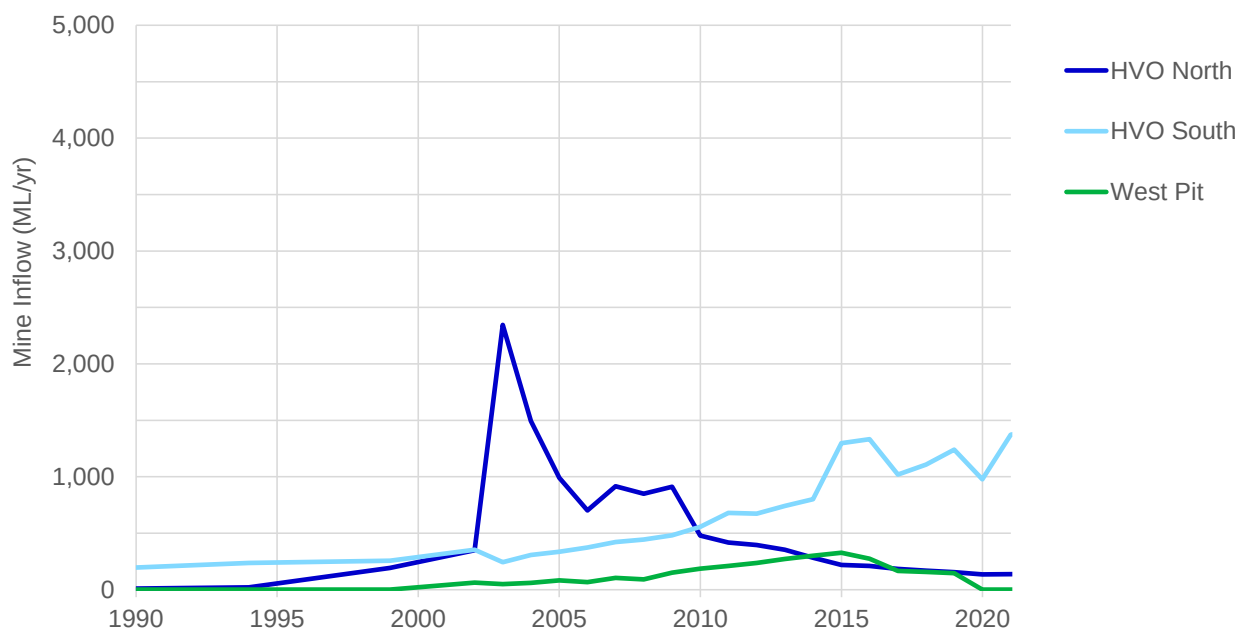


Figure D 32 Simulated inflow to mining areas (1990 – 2020)

D3.4.7 Model confidence level classification

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

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

A Class 3 model is considered to encapsulates a very detailed and well understood conceptualisation. Despite the use of all available data for the model inputs, it is difficult to fulfill every single criterion for a Class 3 model; thus, most models considered appropriate for this level are commonly somewhere between a Class 3 and a Class 2 impact model.

Barnett et al. (2012) consistently suggest *“it is not expected that any individual model will have all the defining characteristics of Class 1, 2 or 3 models”*. Comparison against the performance indicators for individual model classes are presented in Table D 14.

This shows the Project groundwater model is classified between as a Class 3 model with some characteristics of a Class 2 model. That is, the model classification identifies:

- 23 out of 29 (79%) performance indicators align with a Class 3 model;
- 3 out of 22 (14%) performance indicators align with a Class 2 model; and
- 1 out of 22 (5%) performance indicators align with a Class 1 model.

Table D 14 Model confidence level classification

Class	Data	Calibration	Prediction	Quantitative Indicators
Class 3	✓ <i>Spatial and temporal distribution of groundwater head observations adequately define groundwater behaviour, especially in areas of greatest interest and where outcomes are to be reported. Adequate coverage.</i>	✓ <i>Adequate validation is demonstrated. The model was calibrated against multiple "calibration success criteria", which were achieved before the model was deemed as calibrated.</i>	× <i>Length of predictive model is not excessive compared to length of calibration period. The length of the predictive model is large compared to the calibration period.</i>	✓ <i>Key calibration statistics are acceptable and meet agreed targets. The SRMS and other statistics are acceptable. More importantly, the model replicated key features of the conceptual system.</i>
	✓ <i>Spatial distribution of bore logs and associated stratigraphic interpretations clearly define aquifer geometry. Partial coverage of logs, aquifer geometry is reasonably accurate as it is was compiled from geological models used by different mines.</i>	✓ <i>Scaled RMS error or other calibration statistics are acceptable. The SRMS was lower than 10%, which is normally considered as acceptable.</i>	✓ <i>Temporal discretisation used in the predictive model is consistent with the transient calibration. The length of each stress period in the predictive period is the same or longer than those used during the calibration period (3 months or longer). The model is not intended to reproduce short-term responses of the system (hours, days or weeks).</i>	× <i>Model predictive time frame is less than 3 times the duration of transient calibration. The calibration model starts in 1970 and ends in 2020, but most of the calibration dataset is post-2000. The calibration period is about 20 years. The predictive timeframe is 2020 to 2050 for mining, and 2050 to 2150 for post-mining. Therefore, the prediction period "during mining" is within the "3 times" limit, but the post-mining period is beyond it.</i>
	N/A <i>Reliable metered groundwater extraction and injection data. No extraction with metered usage is present in the model area.</i>	✓ <i>Long-term trends are adequately replicated where these are important. The model could replicate key long term trends in different spatial areas, with relatively good matches for levels for climatic variations and mining stress variations. Vertical gradients were also reasonably well reproduced overall.</i>	✓ <i>Level and type of stresses included in the predictive model are within the range of those used in the transient calibration. The stresses used during the prediction phase are of similar nature to those used during calibration.</i>	✓ <i>Stresses are not more than 2 times greater than those included in calibration. The stresses simulated during prediction are of similar magnitude than those simulated during calibration.</i>
	✓ <i>Rainfall and evaporation data is available. A long history of records from multiple stations is available.</i>	✓ <i>Seasonal fluctuations are adequately replicated where these are important. (See above)</i>	× <i>Model validation suggests calibration is appropriate for locations and/or time outside the calibration model. Validation was not undertaken (the entire observation dataset was used for calibration).</i>	✓ <i>Temporal discretisation in predictive model is the same as that used in calibration. The temporal discretisation used during calibration and during prediction are consistent.</i>
	✓ <i>Aquifer-testing data to define key parameters. The model parameters were calibrated and constrained by local testing data.</i>	✓ <i>Transient calibration is current, i.e. uses recent data. The calibration used data that was current at the time of calibrating (beginning of 2020).</i>	N/A <i>Steady-state predictions used when the model is calibrated in steady-state only. Steady state predictions were not used.</i>	✓ <i>Mass balance closure error is less than 0.5% of total. The closure error was less than 0.5% of the total.</i>
	✓ <i>Streamflow and stage measurements are available with reliable baseflow estimates at a number of points. Streamflow measurements are available at some monitoring stations across the model extent.</i>	✓ <i>Model is calibrated to heads and fluxes. Yes, it is calibrated to both heads and fluxes.</i>		✓ <i>Model parameters consistent with conceptualisation. The model parameters were constrained during the calibration and are considered to be consistent with the conceptualisation.</i>
	✓ <i>Reliable land use and soil mapping data available. The data is available, although general geological mapping was used to define the model.</i>	✓ <i>Observations of the key modelling outcomes dataset is used in calibration. The model was calibrated to heads and influx, with special attention to heads, vertical gradients and general trends around the project.</i>		✓ <i>Appropriate computational methods used with appropriate spatial discretisation to model the problem. MODFLOW-USGT, a version of the standard computer code for numerical groundwater models was used. The model grid and layer discretisation fit the nature of the system being modelled.</i>
	N/A <i>Reliable irrigation application data (where relevant) is available. Not applicable.</i>			✓ <i>The modelled has been reviewed and deemed fit for purpose by an experienced, independent hydrogeologist with modelling experience. Multiple hydrogeologists with modelling experience participated in the development of the numerical model. An independent reviewer experienced in numerical modelling also provided feedback at multiple stages during the development of the numerical model, and their advice was incorporated in the modelling exercise.</i>

Class	Data		Calibration		Prediction		Quantitative Indicators	
	✓	Good quality and adequate spatial coverage of digital elevation model to define ground surface elevation. Lidar and SRTM data with relatively high resolution was used.						
	x	Groundwater head observations and bore logs are available but may not provide adequate coverage throughout the model domain.	✓	Validation is either not undertaken or is not demonstrated for the full model domain. Validation using a part of the observation dataset not used during calibration was not undertaken. All the observation dataset was used for calibration.	✓	Transient calibration over a short time frame compared to that of the prediction. The length of the predictive model is large compared to the calibration period.	x	Key calibration statistics suggest poor calibration in parts of the model domain.
	N/A	Metered groundwater extraction data may be available but spatial and temporal coverage may not be extensive.	x	Calibration statistics are generally reasonable but may suggest significant errors in parts of the model domain. Significant errors in parts of the model were not observed in the calibrated model.	x	Temporal discretisation used in the predictive model is different from that used in transient calibration.	✓	Model predictive timeframe is between 3 and 10 times the duration of transient calibration. The calibration model starts in 1970 and ends in 2020, but most of the calibration dataset is post-2000. The calibration period is about 20 years. The predictive timeframe is 2020 to 2050 for mining, and 2050 to 2150 for post-mining. Therefore, the prediction period "during mining" is within the "3 times" limit, but the post-mining period is beyond it.
Class 2	x	Streamflow data and baseflow estimates available at a few points.	x	Long term trends not replicated in all parts of the model domain.	x	Level and type of stresses included in the predictive model are outside the range of those used in the transient calibration.	x	Stresses are between 2 and 5 times greater than those included in calibration.
	N/A	Reliable irrigation-application data available in part of the area or for part of the area for part of the model duration.	x	Transient calibration to historic data but not extending to the present day.	N/A	Validation* suggests relatively poor match to observations when calibration data is extended in time and/or space. Model validation was not undertaken.	x	Temporal discretisation in predictive model is not the same as that used in calibration.
			x	Seasonal fluctuations not adequately replicated in all parts of the model domain. Seasonal fluctuations in alluvial aquifers were replicated.			x	Mass balance closure error is between 0.5% and 1% of total.
			x	Observations of the key modelling outcome data set are not used in calibration.			x	Not all model parameters consistent with conceptualisation.
							x	Spatial refinement too coarse in key parts of the model domain.
							x	The model has been reviewed and deemed fit for purpose by an independent hydrogeologist (no modelling experience).
	x	Few or poorly distributed existing wells from which to obtain reliable groundwater and geological information.	x	No calibration is possible.	✓	Predictive model time frame far exceeds that of calibration. The recovery period of the simulation (2050 to 2150) far exceeds the length of the calibration period.	x	Model is uncalibrated or key calibration statistics do not meet agreed targets.
Class 1	x	Observations and measurements unavailable or sparsely distributed in areas of greatest interest.	x	Calibration illustrates unacceptable levels of error especially in key areas.	x	Temporal discretisation is different to that of calibration.	x	Model predictive time frame is more than 10 times longer than transient calibration period. The model predictive timeframe is 130 years including the mining and post-mining periods. The calibration period is in the order of 15 to 20 years.
	N/A	No available records of metered groundwater extraction or injection.	x	Calibration is based on an inadequate distribution of data.	x	Transient predictions are made when calibration is in steady state only.	x	Stresses in predictions are more than 5 times higher than those in calibration.

Class	Data		Calibration		Prediction		Quantitative Indicators	
	x	Climate data only available from relatively remote locations.	x	Calibration only to datasets other than that required for prediction.	N/A	Model validation suggests unacceptable errors when calibration dataset is extended in time and/or space. Model validation was not undertaken.	x	Stress period or calculation interval is different from that used in calibration.
	x	Little or no useful data on land-use, soils or river flows and stage elevations.					x	Transient predictions made but calibration in steady state only.
							x	Cumulative mass-balance closure error exceeds 1% or exceeds 5% at any given calculation time.
							x	Model parameters outside the range expected by the conceptualisation with no further justification.
							x	Unsuitable spatial or temporal discretisation.
							x	The model has not been reviewed.

D4 Model Predictions

D4.1 Mine Inflow

Table D 15 shows the total inflow of groundwater to the drain cells within the model which represents the water directly drained and also excavated in the material from the rock formation (mainly from Permian coal measures) within the actively mined area of the Project. The table shows the volume of groundwater intercepted by the Approved Operations (Approved column), and Project (Proposed column).

For reference, the groundwater model assumes the proposed Project activities begin in 2025 (Year 1) and the Approved Operations will have ceased at HVO North by Year 1.

The volume of groundwater intercepted from the Permian coal measures due to the combined effect of the Approved Operations and Project peaks in Year 16 at 2133 ML. The water assessment report (EMM 2022) provides information on the water licensing strategy for groundwater intercepted by the mining operations.

Table D 15 Simulated mine inflow

Year		HVO North		HVO South		South Lemington Open Cuts		Lemington Underground		Total	
Mining Year	Cal	Approved ML/yr	Proposed ML/yr	Approved ML/yr	Proposed ML/yr	Approved ML/yr	Proposed ML/yr	Approved ML/yr	Proposed ML/yr	Approved ML/yr	Proposed ML/yr
1	2025	0	136	1888	458	631	0	124	183	2643	777
2	2026	0	99	1421	537	286	0	250	176	1956	812
3	2027	0	130	1756	473	204	0	211	171	2171	775
4	2028	0	128	1843	630	222	0	127	168	2192	926
5	2029	0	193	1367	428	107	0	57	166	1531	788
6	2030	0	257	1471	384	9	0	109	164	1589	806
7	2031	0	187	546	366	0	0	118	162	664	715
8	2032	0	549	422	386	0	0	118	161	540	1096
9	2033	0	785	416	421	0	0	118	160	534	1365
10	2034	0	911	97	414	0	0	118	159	214	1484
11	2035	0	1217	0	350	0	0	118	158	118	1726
12	2036	0	548	0	823	0	0	118	158	118	1529
13	2037	0	580	0	685	0	0	118	157	118	1422
14	2038	0	610	0	593	0	0	118	157	118	1359
15	2039	0	583	0	785	0	0	118	156	118	1524
16	2040	0	619	0	1358	0	0	118	156	118	2133
17	2041	0	584	0	390	0	0	118	155	118	1129
18	2042	0	820	0	501	0	0	118	155	118	1476
19	2043	0	654	0	501	0	0	118	155	118	1310
20	2044	0	645	0	730	0	0	118	154	118	1529
21	2045	0	592	0	769	0	0	119	154	119	1515
22	2046	0	611	0	0	0	0	119	156	119	767
23	2047	0	517	0	0	0	0	120	158	120	676

Year		HVO North		HVO South		South Lemington Open Cuts		Lemington Underground		Total	
Mining Year	Cal	Approved ML/yr	Proposed ML/yr	Approved ML/yr	Proposed ML/yr	Approved ML/yr	Proposed ML/yr	Approved ML/yr	Proposed ML/yr	Approved ML/yr	Proposed ML/yr
24	2048	0	454	0	0	0	0	121	161	121	615
25	2049	0	284	0	0	0	0	125	163	125	447
26	2050	0	220	0	0	0	0	136	165	136	385
27	2051	-	1083	-	655	-	0	-	0	-	1739
28	2052	-	771	-	452	-	0	-	0	-	1223
32	2056	-	820	-	399	-	0	-	0	-	1219
37	2061	-	833	-	376	-	0	-	0	-	1209
47	2071	-	833	-	368	-	0	-	0	-	1200
57	2081	-	829	-	378	-	0	-	0	-	1207
77	2101	-	825	-	412	-	0	-	0	-	1237
127	2151	-	822	-	443	-	0	-	0	-	1265

D4.2 Change in alluvial and surface water flows

The model was used to determine the potential for mining to change surface water-groundwater interaction and to provide estimates of indirect or passive 'water take' in accordance with the AIP. The estimated change in river leakage and baseflow is presented on Table D 16.

Table D 16 Estimated change in surface water-groundwater interaction (flow) –the Project

Year		Hunter Regulated River - Upstream Glennies (Zone 6)			Hunter Regulated River - Downstream Glennies (Zone 8)					Jerrys Water Source (Zone 2)		
Mining Year	Cal	Baseflow	Leakage	Groundwater	Baseflow (zone 2A)	Leakage (zone 2A)	Baseflow (zone 2B)	Leakage (zone 2B)	Groundwater	Baseflow	Leakage	Groundwater
		ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML
1	2025	138	63	135	12	7	0	0	8	0	0	1
2	2026	142	65	140	12	7	1	0	8	0	0	1
3	2027	146	67	143	12	7	0	0	8	0	0	0
4	2028	150	68	147	11	6	0	0	8	0	0	0
5	2029	154	69	150	11	6	1	0	8	0	0	0
6	2030	156	70	153	11	6	-1	0	9	0	0	1
7	2031	159	71	156	11	6	1	0	9	0	0	1
8	2032	162	72	158	11	6	1	0	9	0	0	1
9	2033	183	79	190	11	6	0	0	9	1	0	1
10	2034	236	131	254	12	6	1	0	9	1	0	1
11	2035	277	288	324	12	6	1	0	10	1	0	2
12	2036	277	233	157	12	6	2	0	10	1	0	2
13	2037	232	101	225	12	6	2	1	10	1	0	2
14	2038	232	102	230	12	6	2	1	10	2	0	2
15	2039	237	104	236	12	6	0	0	11	2	0	3
16	2040	242	107	242	12	6	2	0	11	2	0	3
17	2041	248	109	247	12	6	1	0	11	2	0	3
18	2042	253	111	251	13	6	2	0	11	3	0	4
19	2043	256	111	253	13	7	2	1	11	3	0	5

Year		Hunter Regulated River - Upstream Glennies (Zone 6)			Hunter Regulated River - Downstream Glennies (Zone 8)					Jerrys Water Source (Zone 2)		
Mining Year	Cal	Baseflow	Leakage	Groundwater	Baseflow (zone 2A)	Leakage (zone 2A)	Baseflow (zone 2B)	Leakage (zone 2B)	Groundwater	Baseflow	Leakage	Groundwater
		ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML
20	2044	258	111	255	13	6	1	0	11	3	0	4
21	2045	260	111	258	13	6	1	0	12	3	0	4
22	2046	263	112	259	12	6	-1	0	13	4	0	5
23	2047	267	113	263	13	7	0	0	13	4	0	5
24	2048	271	115	267	14	7	2	0	12	4	0	5
25	2049	274	116	270	14	7	-1	0	14	4	0	6
26	2050	277	117	272	15	8	2	1	13	5	0	6
27	2051	226	38	329	8	1	1	0	21	5	0	7
28	2052	343	46	359	16	2	-3	0	19	6	0	8
32	2056	378	48	378	17	2	2	0	19	7	0	9
37	2061	397	51	398	17	2	3	0	20	9	0	9
47	2071	416	54	414	18	2	3	0	22	12	0	15
57	2081	432	56	429	20	3	3	0	24	15	0	18
77	2101	450	59	448	24	3	4	0	29	17	0	21
127	2151	468	63	462	28	3	5	0	33	18	0	23

Notes:

- Baseflow column: reduction in baseflow.
- Leakage column: increase in leakage.
- Groundwater column: Water take from alluvial groundwater (flow from alluvium to Permian).
- The baseflow, leakage and groundwater estimates have been separated to prevent "double accounting".
- ML: Megalitres (all units are in megalitres).

Table D 17 Estimated change in surface water-groundwater interaction (flow) – the Project (cont.)

Year		Glennies Water Source (Zones 3+4)			Wollombi Brook Water Source (Zone 7)			Singleton Water Source (Zone 5)		
Mining Year	Cal	Baseflow ML	Leakage ML	Groundwater ML	Baseflow ML	Leakage ML	Groundwater ML	Baseflow ML	Leakage ML	Groundwater ML
1	2025	0	0	0	26	1	26	0	0	3
2	2026	0	0	0	24	1	25	0	0	3
3	2027	0	0	0	23	1	24	0	0	3
4	2028	0	0	0	22	1	23	0	0	3
5	2029	0	0	0	22	1	23	0	0	3
6	2030	0	0	0	21	1	23	0	0	3
7	2031	0	0	0	21	1	23	0	0	3
8	2032	0	0	0	21	1	22	1	0	3
9	2033	0	0	0	21	1	22	1	0	3
10	2034	0	0	0	20	1	22	1	0	3
11	2035	0	0	0	20	1	22	1	0	3
12	2036	0	0	0	20	1	22	1	0	3
13	2037	0	0	0	20	1	22	1	0	3
14	2038	0	0	0	20	1	22	1	0	3
15	2039	0	0	0	20	1	22	1	0	3
16	2040	0	0	0	20	1	22	1	0	3
17	2041	0	0	0	20	1	21	1	0	3
18	2042	0	0	0	20	1	21	1	0	3
19	2043	0	0	0	20	1	21	1	0	4
20	2044	0	0	0	20	1	21	1	0	4

Year		Glennies Water Source (Zones 3+4)			Wollombi Brook Water Source (Zone 7)			Singleton Water Source (Zone 5)		
Mining Year	Cal	Baseflow	Leakage	Groundwater	Baseflow	Leakage	Groundwater	Baseflow	Leakage	Groundwater
		ML	ML	ML	ML	ML	ML	ML	ML	ML
21	2045	0	0	0	20	1	21	1	0	4
22	2046	0	0	0	20	1	22	1	0	4
23	2047	0	0	0	20	1	23	1	0	4
24	2048	0	0	1	21	1	23	1	0	4
25	2049	0	0	1	22	1	25	1	0	4
26	2050	0	0	1	23	1	26	1	0	4
27	2051	1	0	1	24	1	26	1	0	4
28	2052	2	0	1	25	1	23	1	0	4
32	2056	1	0	1	23	0	21	1	0	4
37	2061	1	0	1	22	0	19	1	0	4
47	2071	2	0	2	21	0	19	2	0	5
57	2081	2	0	2	22	0	21	2	0	5
77	2101	3	0	3	26	0	23	2	0	6
127	2151	3	0	3	27	0	25	2	0	6

- Notes:**
- Baseflow column: reduction in baseflow.
 - Leakage column: increase in leakage.
 - Groundwater column: Water take from alluvial groundwater. (water flow from alluvium to Permian)
 - The baseflow, leakage and groundwater estimates have been separated to prevent "double accounting".
 - ML: Megalitres (all units are in megalitres).

D5 Recovery simulations

A separate transient model was built to simulate recovery of the groundwater system once all mining is complete. At the completion of mining, any remaining drain cells were removed, and the model was adjusted to simulate post-mining conditions. This included an increase in permeability in the mining areas to represent the spoils used to backfill open cut mining areas, and enhanced recharge rates to the spoil heaps (2.9 mm/year, 0.45% of average rainfall) to simulate their enhanced recharge capacity. In addition, boundaries for the simulation of pit lake recovery were enforced in the neighbouring mines where the recovery curves had been determined as part of previous assessments.

Within the model extent, final voids remain in HVO North and South, Liddell Entrance Pit and South Cut, Ravensworth East, Glendell Continuation, Ravensworth Narama, Ravensworth West Pit and United Mine. Because the groundwater flow model does not represent rainfall runoff and is not refined enough to represent the morphology of the final voids accurately, information from a separate water balance model created by Engeny (2022) was used to provide inputs to the groundwater model. The process to determine the final void water level recovery was as follows:

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

This approach ensured consistency between the surface water and groundwater studies.

The recovery simulation was run for 1,950 years, thus allowing the groundwater levels in the backfilled spoil, final void lake, unmined coal seams, and the overlying water-bearing strata to recover to a long-term post mining equilibrium. The final water balance model indicated the water level within the HVO final voids will slowly recover, and after a period of 100 years (year 2150) their level will be -124.5 mAHD at HVO North and -96.6 mAHD at HVO South.

Model cells representing backfilled spoil were assigned a higher horizontal (1.23 m/day) and vertical (0.1 m/day) conductivity than the bedrock units, and a specific yield of 0.1%. Recharge rates to the spoil were also increased to 0.45% of average annual rainfall. The hydraulic properties adopted in the modelling assume the spoils form a relatively permeable aquifer system with slightly high rates of recharge, but low storage.

Model cells located within the final voids were assigned a high horizontal and vertical hydraulic conductivity (1,000 m/day) and storage parameters (specific yield of 1.0, storage coefficient of 5.0×10^{-6}), to simulate free water movement within the void. This approach is often referred to as a 'high-k' lake.

Outputs from the recovery modelling are presented in Section 9 of the main report.

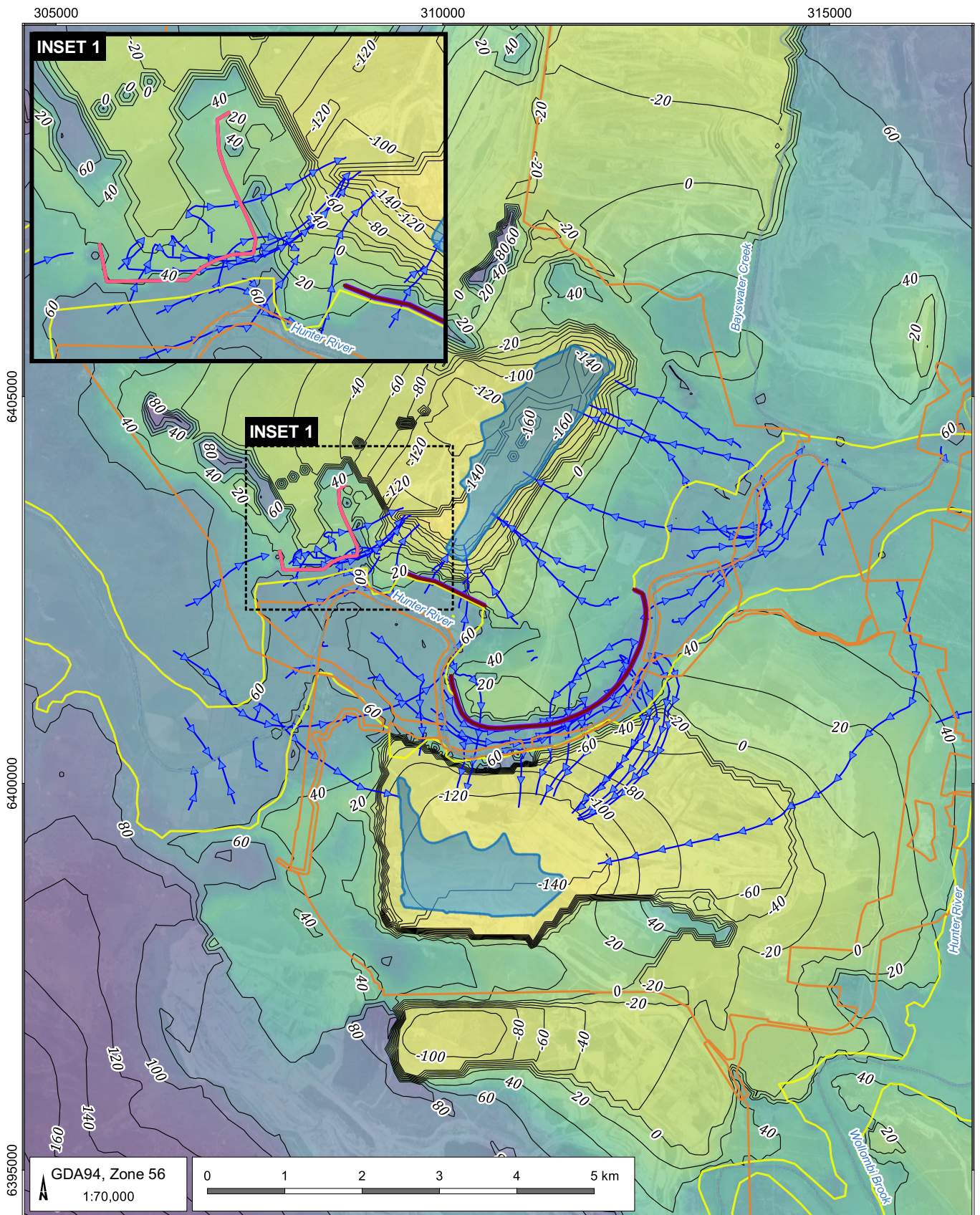
D6 Sensitivity analysis

D6.1 Hydraulic properties of spoils

A sensitivity analysis was undertaken to determine if changes to the hydraulic properties and recharge rates to the in-pit mine spoils at HVO could result in groundwater flow within the spoils not being captured by the final void and migrating towards the Hunter River alluvium. A number of model scenarios were run with the hydraulic conductivity and storage properties of the spoil reduced and the rainfall recharge rate increased to enhance water table mounding within the in-pit spoils to examine the potential to create groundwater flow towards the Hunter River alluvium. Scenarios that resulted in unrealistic mounding within the HVO North Alluvial Lands area where a water table has already formed and is measured by an existing network of monitoring bores were rejected. The estimated lower bound to the in-pit spoils that could enhance the mounding was:

- horizontal hydraulic conductivity - reduced from 1.23 m/day in the base case to 1×10^{-1} m/day;
- vertical hydraulic conductivity - reduced from 1.3×10^{-1} m/day in the base case to 1×10^{-1} m/day;
- specific storage - reduced from 4.1×10^{-6} m⁻¹ in the base case to 1×10^{-6} m⁻¹;
- rainfall recharge rate increased from 0.008 mm/year in the base case to 0.052 mm/year.

Figure D 33 shows the simulated water table at 100 years after closure of HVO North with the updated spoil properties. It also shows the flow path for particles released into the water table at mine closure in 2050. The figure shows the final voids in HVO North and HVO South continue to act as sinks, with groundwater flow towards the lakes from the spoil, not outwards indicating the potential for a shallow water table to develop within in-pit spoils and migrate to the Hunter River alluvial aquifer is low.



LEGEND

- Drainage
- ParticleTracking
- Barrier Wall
- Existing barrier wall
- Final Landform contour
- Project Area
- Alluvium extent
- Final void lake

Watertable table (m AHD)

- 180
- 12
- 24
- 39
- 47
- 52
- 61
- 70
- 89
- 120
- 329

HVO Continuation (G1737J)

Post mining water levels and particle paths 100 years after mining – spoil sensitivity analysis



AGE

DATE
29/11/2022

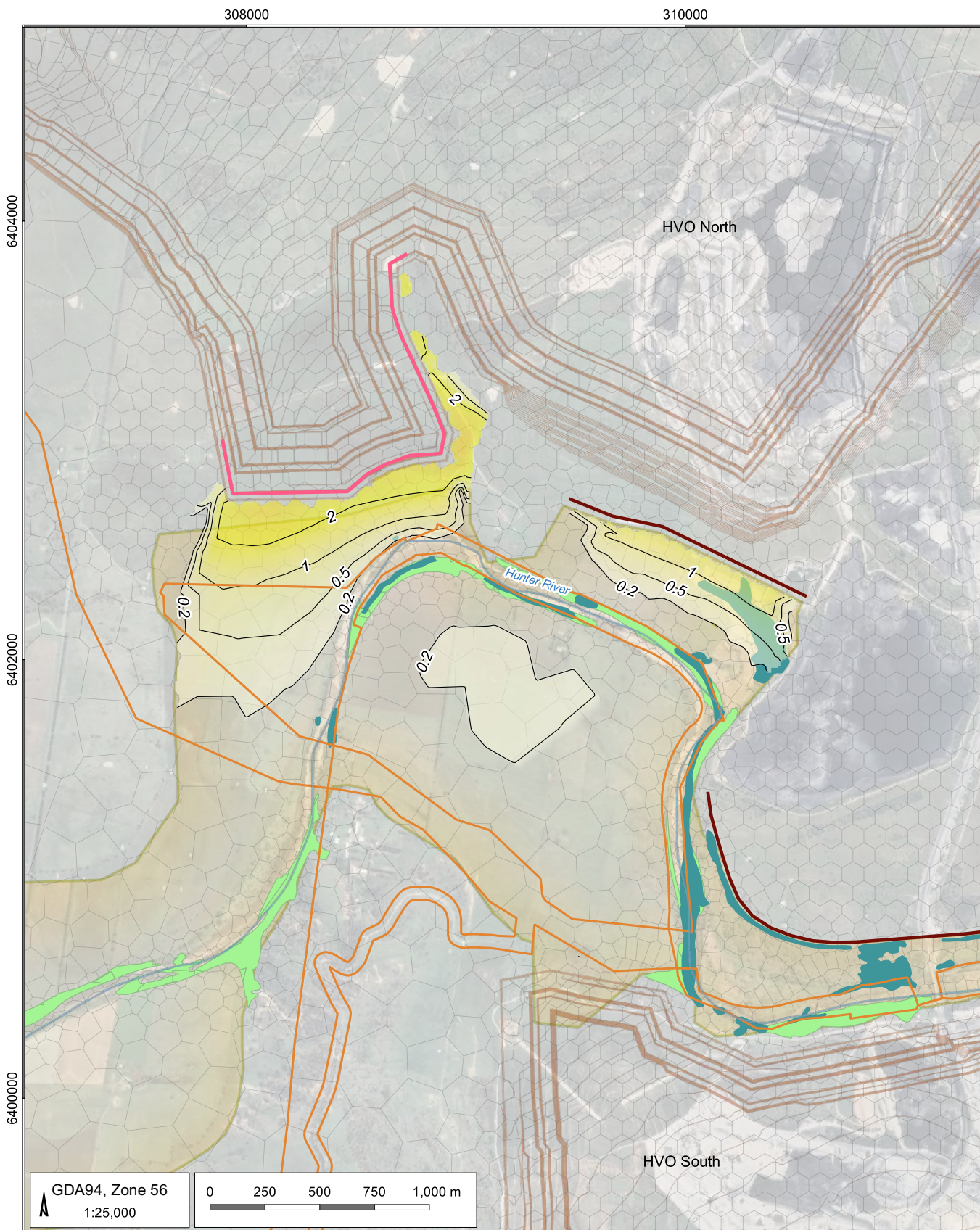
FIGURE No:
D 33

D6.2 Climate change

A sensitivity analysis was undertaken to evaluate the uncertainty associated with climate change, setting a specific climate trend for future years and assessing the model's predictions under those circumstances. The simulation was set based on the RCP8.5 climate change scenario¹, where rainfall is 15.4% lower than the yearly historical trend, while evapotranspiration is 15.2% higher. While the long term alluvial recharge for future predictions was 0.207 mm/day for the base case scenario (no climate change), the alluvial recharge since 2025 was set at 0.144 mm/day for the climate change scenario. The recharge was adjusted using the same proportion for every other recharge zone in the model.

The maximum cumulative drawdown results displayed on Figure D34, Figure D35, Figure D36 and Figure D37 show the sensitivity of the model predictions to a climatic variation as defined in RCP8.5. The scenario shows little difference in the alluvial drawdown on the Hunter River and Wollombi Brook, as the main control for alluvial replenishment is the river. The simulation indicates that the river or brook buffer most of the effects of reduced recharge/enhanced evapotranspiration under the climate change scenario.

¹ Based on the 'Climate Change Australia' website (<https://www.climatechangeinaustralia.gov.au>), using the maximum consensus projection for 2090, model ACCESS1-0.



LEGEND

- Drainage
- Pit Shell contour
- Existing barrier wall
- Barrier Wall
- Drawdown contour
- Model grid
- Alluvium extent
- Project Area
- Potential GDEs - from project study area
- High potential terrestrial GDE - from regional studies

Drawdown (m)

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

HVO Continuation (G1737J)

Maximum predicted zone of drawdown during operations within Hunter River Quaternary alluvium (climate change scenario)



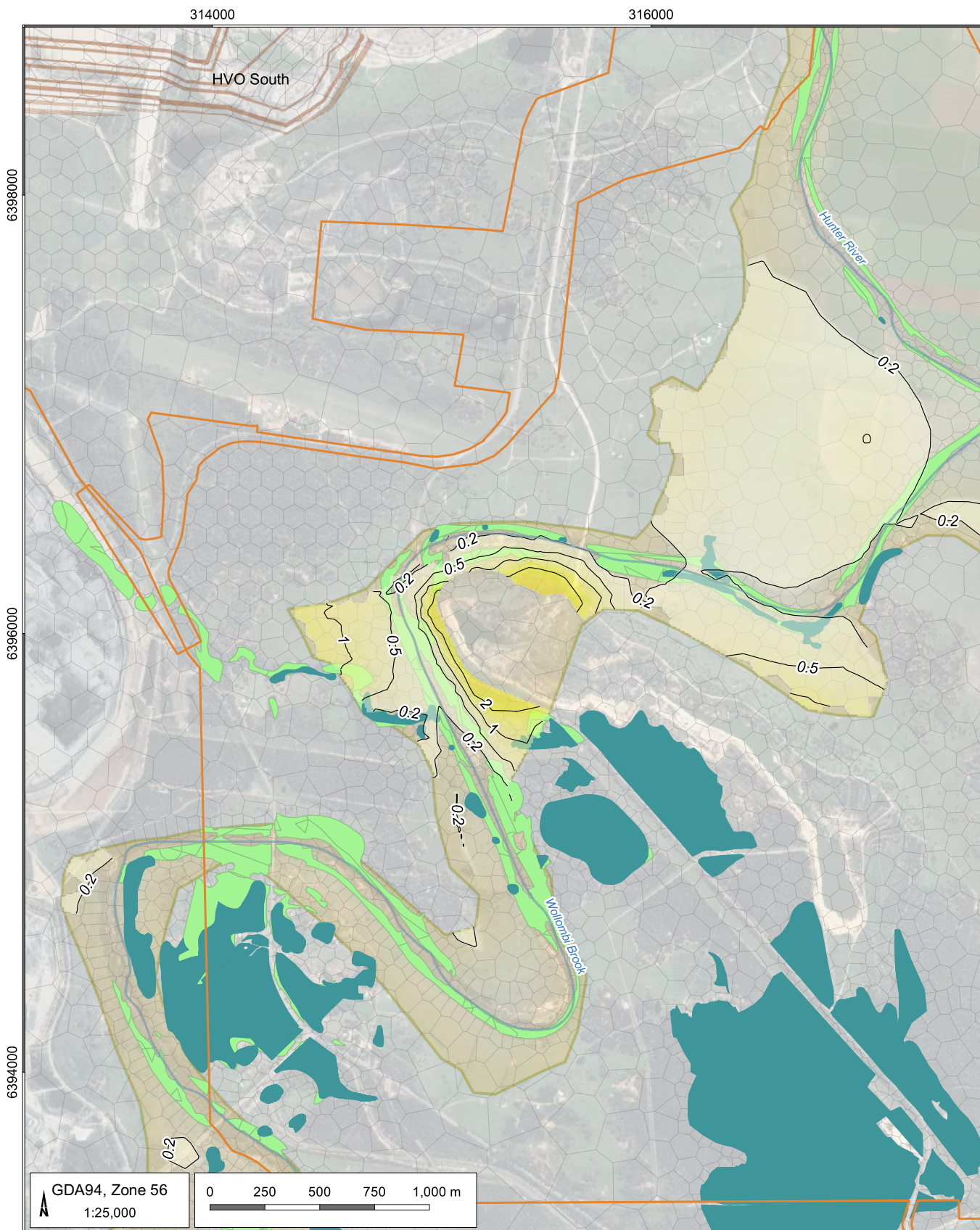
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FIGURE No:

D 34



LEGEND

- Drainage
- Pit Shell contour
- Drawdown contour
- Model grid
- Alluvium extent
- Project Area
- Potential GDEs - from project study area
- High potential terrestrial GDE - from regional studies

Drawdown (m)

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

HVO Continuation (G1737J)

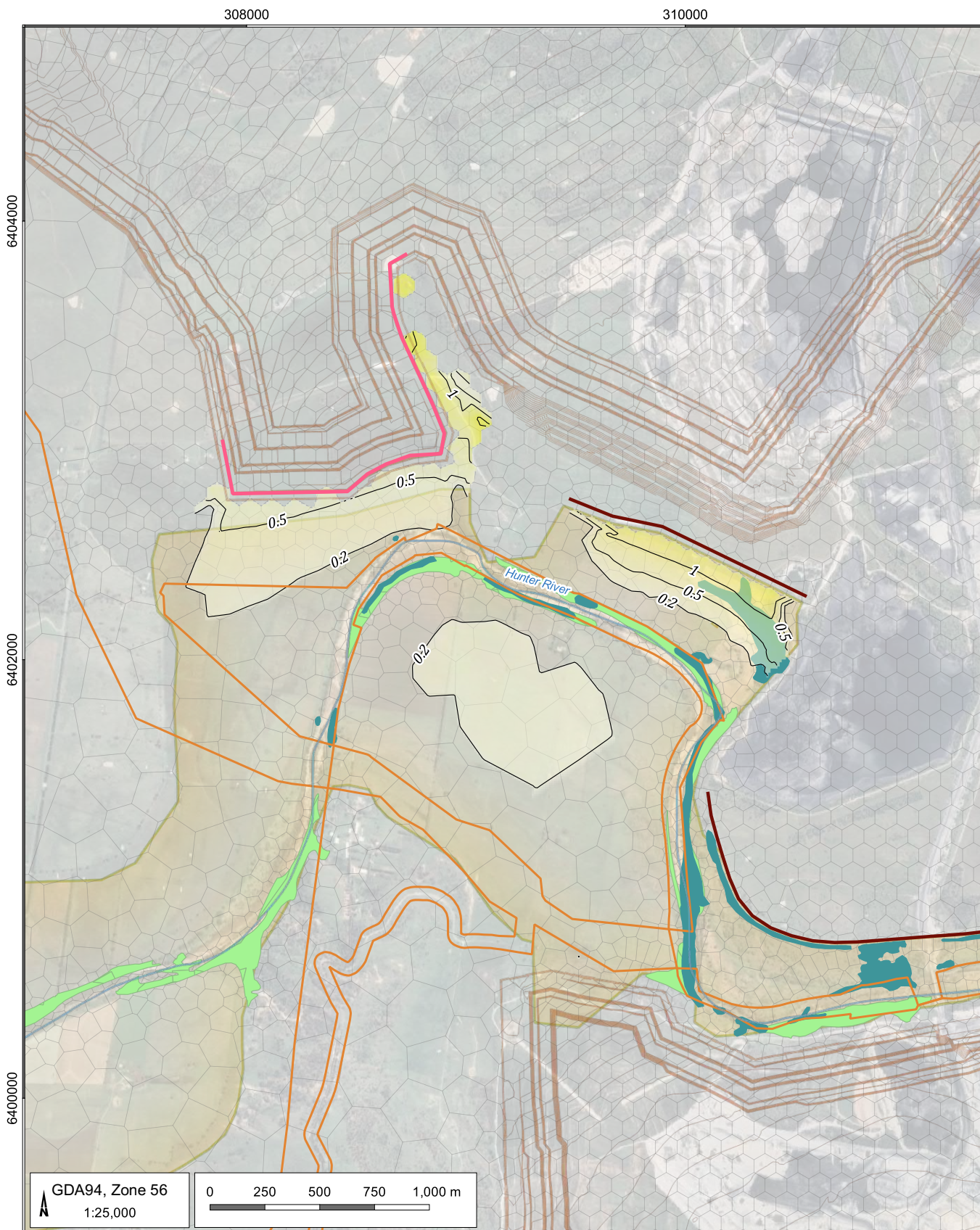
Maximum predicted zone of cumulative drawdown during operations within Wollombi Brook Quaternary alluvium (climate change scenario)



AGE

DATE
03/11/2022

FIGURE No:
D 35



LEGEND

- Drainage
- Pit Shell contour
- Existing barrier wall
- Barrier Wall
- Drawdown contour
- Model grid
- Alluvium extent
- Project Area
- Potential GDEs - from project study area
- High potential terrestrial GDE - from regional studies

Drawdown (m)

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

HVO Continuation (G1737J)

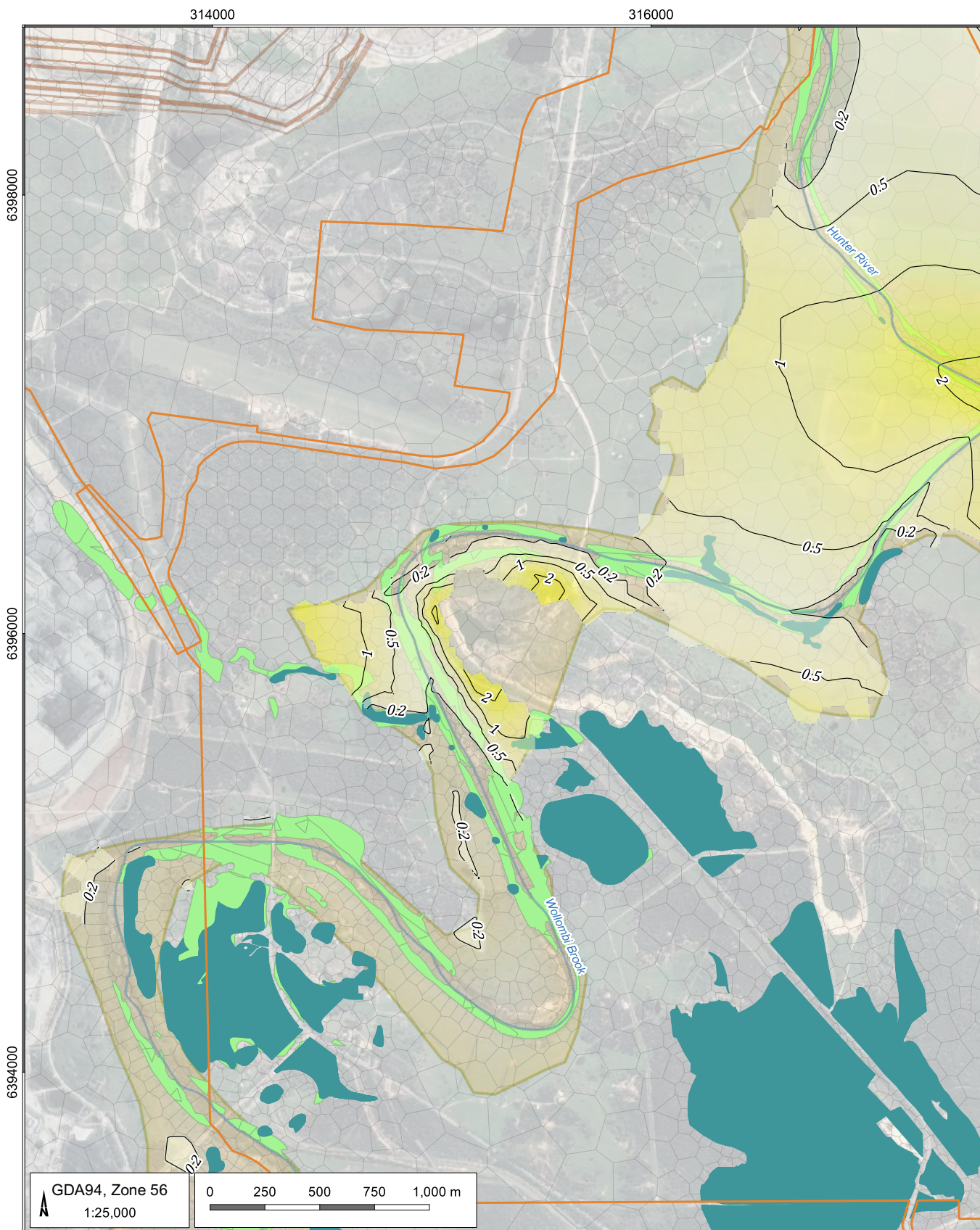
Maximum predicted zone of cumulative drawdown post-mining within Hunter River Quaternary alluvium (climate change scenario)



AGE

DATE
03/11/2022

FIGURE No:
D 36



LEGEND

- Drainage
- Pit Shell contour
- Drawdown contour
- Model grid
- Alluvium extent
- Project Area
- Potential GDEs - from project study area
- High potential terrestrial GDE - from regional studies

Drawdown (m)

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

HVO Continuation (G1737J)

Maximum predicted zone of cumulative drawdown post-mining within Wollombi Brook Quaternary alluvium (climate change scenario)



AGE

DATE
03/11/2022

FIGURE No:
D 37

D7 Uncertainty analysis

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

D7.1 Methodology

Middlemis and Peeters (2018) outline three general approaches to analysing parameter uncertainty in increasing order of complexity and the level of resources required for each of them. They are:

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

For this study a Null-space Monte Carlo uncertainty analysis (option 3) was undertaken to quantify the magnitude of uncertainty in the potential impacts predicted by the numerical model. This type of analysis produces probability distributions for predictive impacts by assessing a composite likelihood of an impact occurring through assessing and ranking the predictions from hundreds of models 'realisations'. Each model realisation is informed by the observation dataset by estimating statistics between observed and simulated features, and by assessing how those statistics change with perturbations of each parameter in the groundwater model.

This uncertainty analysis was a multi-stage process. Firstly, the valid range for the parameters (i.e. pre-calibration range) was determined. Secondly, using statistics derived from the automatic model calibration, the range of each parameter was further constrained (where necessary), especially in parameters the calibration was sensitive to, to avoid having parameter sets that generate simulations 'too far from the calibrated model'. It is this extra-step what sets apart a 'Null-space Montecarlo' approach, versus a regular Montecarlo where no further parameter constraints are made.

Based on the valid ranges of each parameter, 378 model realisations were ran, each having differing values for each parameter.

The constrained realisations were tested and the models that failed to converge or could not achieve adequate calibration statistics were rejected, leaving the output from 93 successful models for uncertainty analysis. Models were considered to have an acceptable calibration if they had less than a 65% increase in the model phi (with upper threshold for acceptance of 11,000, vs a calibrated phi value of 6,668). The distribution of the phi values of the model runs used for uncertainty is displayed on Figure D 38. This output was analysed to provide a statistical distribution of the predictive impacts.

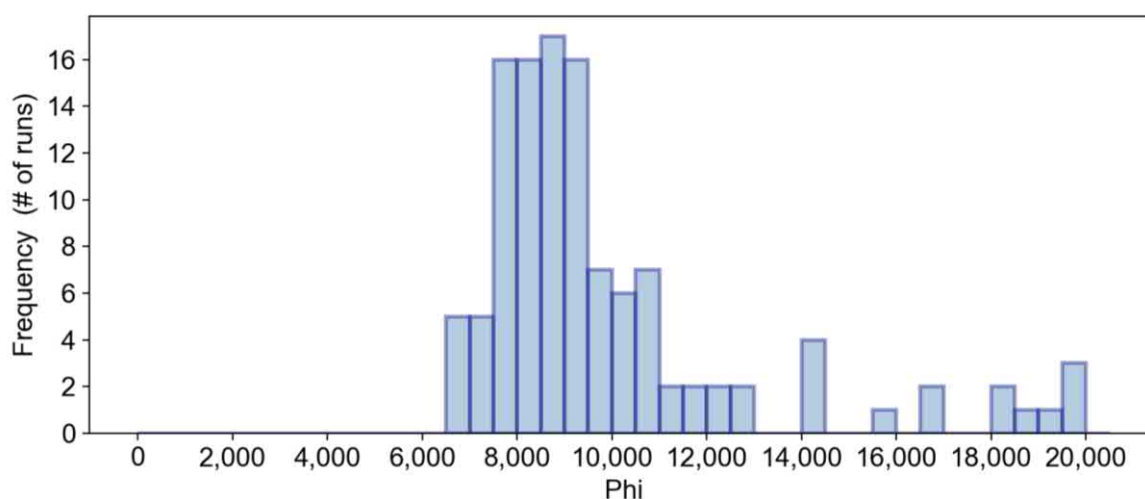


Figure D 38 Distribution of phi values in uncertainty runs (values over 20,000 not displayed)

Outputs from the uncertainty modelling were processed in accordance with the risk-based calibrated language proposed in Middlemis & Peeters (2018). The ranges adopted are shown in Table D 17.

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

Table D 17 Calibrated uncertainty modelling language

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

D7.2 Parameter generation

D7.2.1 Prior ranges

To undertake this type of analysis it is necessary to firstly assess the response of the calibration statistics to changes in the parameters in the groundwater model using a 'prior' or pre-calibration range. Table D 18 to Table D 23 show the 'prior' range explored during the uncertainty analysis simulations. This represents the 95th confidence interval on prior information of the likely range of the model parameters. All parameters were assumed to possess a log-normal distribution using a mean value, or the most probable value, derived from the calibration exercise. The rainfall recharge rates for each unit were adjusted to cover the natural cycles of wet and dry years indicated in the historical rainfall dataset.

A total of 378 models were generated using a random parameter generator to produce 'realisations' to assess predictive impacts.

Table D 18 Horizontal hydraulic conductivity (Kh0) – prior range

Lithology	Horizontal hydraulic conductivity (m/day)		
	lower	mean	upper
Alluvium, high productivity	1	18.3	100
Alluvium, low productivity	0.1	2.2	10
Coal seam	5×10^{-3}	1.2	5
Interburden (other)	2	62.8	180
Interburden L05	1×10^{-3}	8E-2	40
Overburden	1×10^{-6}	2.7×10^{-3}	1×10^{-2}
Regolith	1×10^{-4}	3.3×10^{-3}	0.12
Saltwater Ck Fm	1×10^{-5}	1.1×10^{-3}	5×10^{-3}
Spoil	1×10^{-4}	1.2	100
Tailings	1×10^{-7}	8.3×10^{-5}	100
Pilot points, Kh, L01 L02	1×10^{-1}	1.3	100
Pilot points, Kh, L10	0.1	0.7	100
Pilot points, Kh, L12	0.1	1.6	100
Pilot points, Kh, L14	0.1	3.5	100
Pilot points, Kh, L18	0.1	1.1	100
Pilot points, Kh, L22	0.1	1.5	100
Pilot points, Kh, L25	0.1	1.2	100
Pilot points, Kh, L28	0.1	2.3	100

Table D 19 Vertical hydraulic conductivity – prior range

Lithology	Vertical hydraulic conductivity factor (Kz/Kx)		
	Lower	Mean	Upper
Kv factor, Alluvium, high productivity	0.01	0.3	0.8
Kv factor, Alluvium, low productivity	1×10^{-2}	1×10^{-2}	0.8
Kv factor, Coal seam	1×10^{-2}	0.31	1
Kv factor, Interburden	1×10^{-2}	1.3×10^{-1}	1
Kv factor, Overburden	1×10^{-2}	9.2×10^{-2}	1
Kv factor, Regolith	1×10^{-2}	1×10^{-2}	0.8
Kv factor, Saltwater Ck Fm	0.2	1	1
Kv, Spoil	1×10^{-3}	0.13	100
Kv, Tailings	1×10^{-7}	2×10^{-6}	1

Table D 20 Specific yield – Prior range

Lithology	Specific yield – Sy		
	Lower	Mean	Upper
Alluvium, high productivity	5×10^{-2}	0.11	0.25
Alluvium, low productivity	1×10^{-2}	9.4×10^{-2}	0.25
Coal seam	2.3×10^{-4}	5.3×10^{-3}	3×10^{-2}
Interburden (other)	5.5×10^{-5}	4.9×10^{-3}	1×10^{-2}
Interburden (L05)	5.5×10^{-5}	1.8×10^{-2}	3.2×10^{-2}
Overburden	7.4×10^{-4}	2.5×10^{-2}	3×10^{-2}
Regolith	8.8×10^{-4}	4.2×10^{-2}	8.8×10^{-2}
Saltwater Ck Fm	5.5×10^{-5}	2×10^{-4}	1×10^{-2}
Spoil	1×10^{-3}	1×10^{-3}	0.1
Tailings	1×10^{-3}	5×10^{-2}	0.1
Pilot points, Sy, L01 L02	0.5	1.2	3

Table D 21 Specific storage – prior range

Lithology	Specific storage m^{-1}		
	Lower	Mean	Upper
Alluvium, high productivity	2.3×10^{-7}	1.3×10^{-5}	1.3×10^{-5}
Alluvium, low productivity	2.3×10^{-7}	1.3×10^{-5}	1.3×10^{-5}
Coal seam	2.3×10^{-7}	9.1×10^{-6}	1.3×10^{-5}
Interburden (other)	2.3×10^{-7}	4.9×10^{-6}	1.3×10^{-5}
Interburden (L05)	2.3×10^{-7}	1.3×10^{-5}	1.3×10^{-5}
Overburden	2.3×10^{-7}	1.3×10^{-5}	1.3×10^{-5}
Regolith	2.3×10^{-7}	1.2×10^{-5}	1.3×10^{-5}
Saltwater Ck Fm	2.3×10^{-7}	5.0×10^{-7}	1.3×10^{-5}
Spoil	2.3×10^{-7}	4.1×10^{-6}	1.3×10^{-5}
Tailings	2.3×10^{-7}	9.3×10^{-7}	1.3×10^{-5}

Table D 22 Recharge factor – prior range

Lithology	Recharge rate (mm/year)		
	Lower	Mean	Upper
Alluvium, high productivity	0.5	0.83	1
Alluvium, low productivity	0.4	0.66	1
Regolith - Permian subcrops (coal, interburden)	1×10^{-3}	3.9×10^{-3}	1×10^{-2}
Regolith - Narrabri Fm	5×10^{-4}	5×10^{-4}	1×10^{-2}
Regolith - Saltwater Ck Fm	5×10^{-4}	5.9×10^{-3}	1×10^{-2}
Regolith - Tuff	5×10^{-4}	5×10^{-4}	1×10^{-2}

Table D 23 Stream bed - vertical hydraulic conductivity (m/day) – prior range

Lithology	Vertical hydraulic conductivity (m/day)		
	Lower	Mean	Upper
Bowmans Creek	1×10^{-5}	1.4×10^{-2}	10
Glennies Creek	1×10^{-5}	2.2×10^{-2}	10
Hunter River	1×10^{-5}	8.7×10^{-2}	10
Wollombi Brook	1×10^{-5}	2.1×10^{-2}	10

D7.2.2 Posterior ranges

For the generation of a 'posterior distribution' of parameters, it was necessary to firstly calibrate the model using the 'prior range' of parameters, and assess the calibration statistics including how they change with small changes in individual parameters. This information was automatically calculated during the calibration and stored in a 'Jacobian matrix'.

In the posterior distribution of parameters, the range for each parameter was constrained (reduced) using information from the Jacobian matrix, in a way that maximises the number of "calibrated" versions of the model or in other words, minimises the number of uncalibrated models obtained from the Monte Carlo model runs. The ranges are minimised using information from the Jacobian matrix. If parameter ranges were constrained by more than 50%, the range was kept to a reduction of 50% as a limit.

The posterior distribution of parameters was plotted in violin plots and is included in Appendix D 3.

The plots in Appendix D 3 show that the 50th percentile (P50) parameter values adopted for the uncertainty analysis is similar to the base case model, and the base case model is therefore a more likely version of the model parameters.

D7.3 Results

D7.3.1 Number of model runs

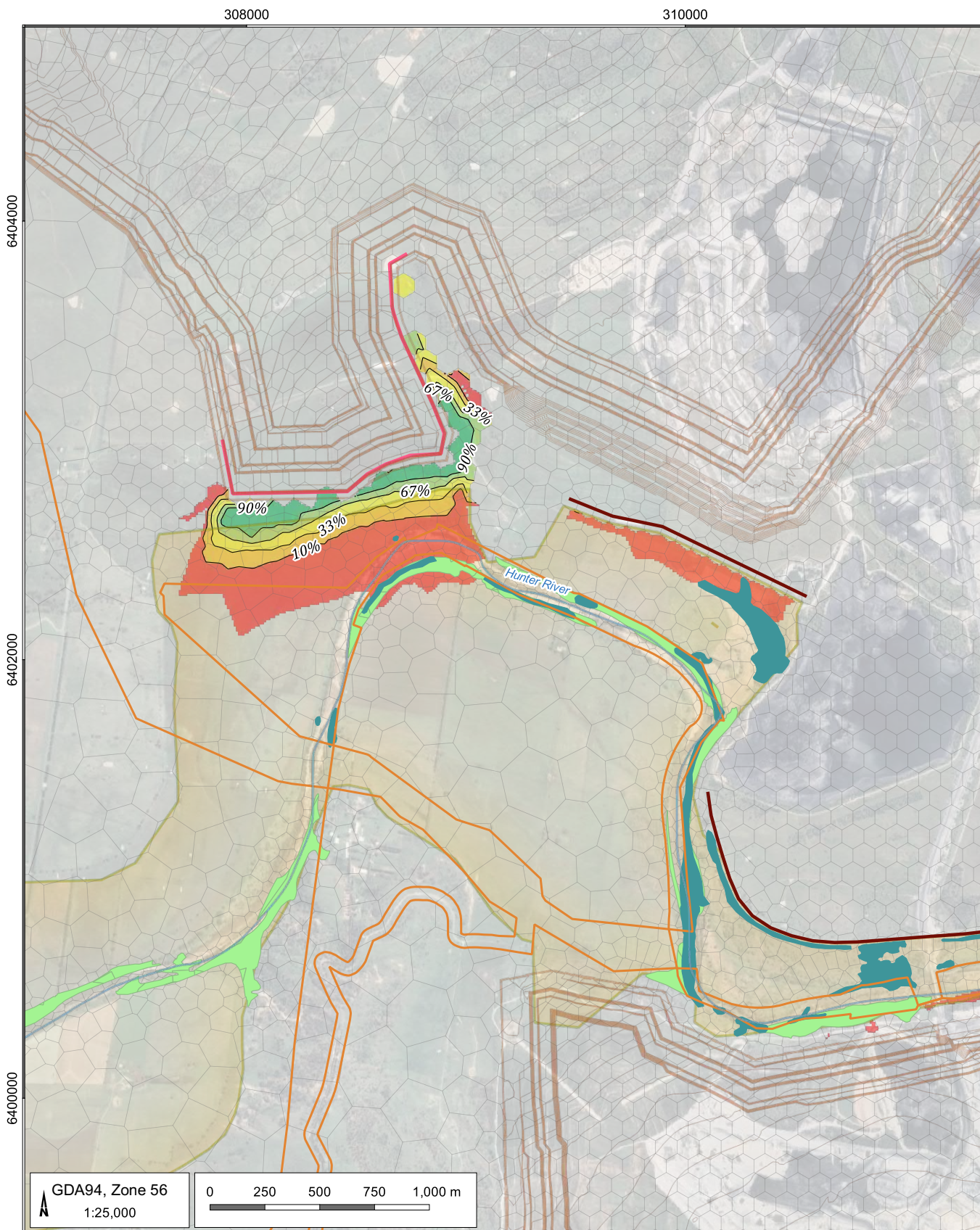
As noted previously, a total of 378 models were generated and set to run. On some runs where convergence was not achieved, the model run was rejected. Of the 378 models run, 149 model runs converged, and 56 model runs did not produce acceptable calibration statistics, leaving 93 model runs, which is believed to be an acceptable number of runs for the uncertainty calculations.

D7.3.2 Uncertainty in cumulative drawdown

Alluvial drawdown predicted by the calibrated model is provided within the main report. Figure D 39 and Figure D 40 show the likelihood of the maximum cumulative drawdown at any time during mining exceeding 2 m within the alluvium. In the figure, the language used for description of uncertainty detailed in Section D7.1 is used.

Figure D 39 shows that in the Hunter River alluvium, the area where the cumulative drawdown is likely to exceed 2 m is limited to the immediate vicinity of the HVO North Pit in the western palaeochannel, with an extension of up to 150 m from the pit. The area classified 'about as likely as not' extends up to 200m from the pit boundary, and beyond that the likelihood of more than 2 m of drawdown is 'unlikely' to 'very unlikely'. This is because the loss of alluvial groundwater to the pit and depressurised underlying Permian aquitards is less than the recharge rate from the river channel and rainfall to the alluvial groundwater system across the majority of the model realisations.

Figure D 40 shows that in the Wollombi Brook, the area where cumulative drawdown impact from Lemington Underground is likely to exceed 2 m is predominantly where the mine underlies the Wollombi Brook alluvium. There are small areas of drawdown exceeding 2 m at the fringes of the alluvium more distant from the mining area, however these are classified 'very unlikely'. The relatively limited zone of drawdown indicates that the loss of alluvial groundwater to the depressurised Permian strata is less than the recharge rate from the stream channel and rainfall to the alluvial groundwater system across the majority of the model realisations.



LEGEND

- Drainage
- Pit Shell contour
- Existing barrier wall
- Barrier Wall
- Drawdown contour
- Model grid
- Alluvium extent
- Project Area
- Potential GDEs - from project study area
- High potential GDE - from regional studies

Exceedance probability (%)

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

HVO Continuation (G1737J)

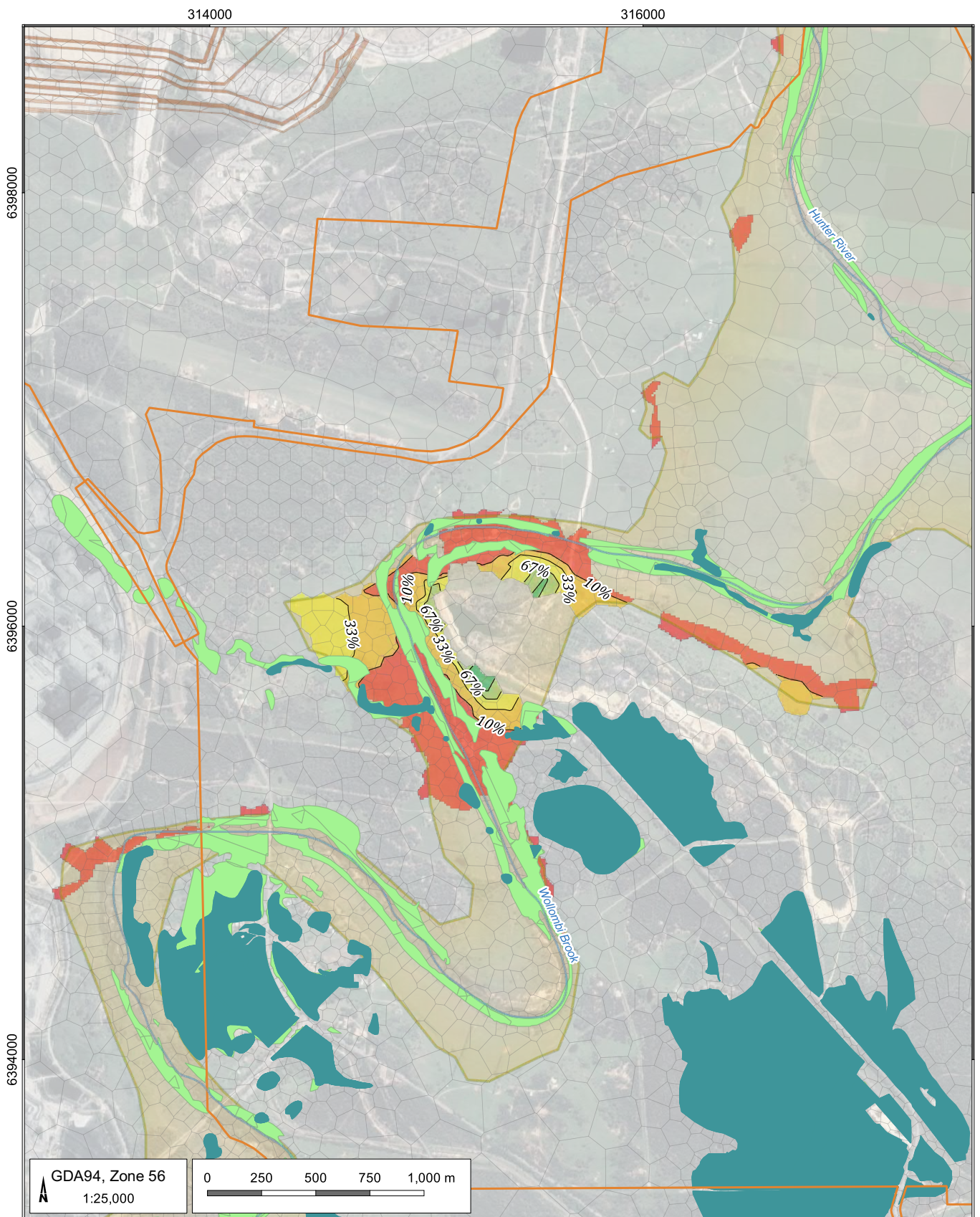
**Cumulative alluvial drawdown -
Likelihood of 2m drawdown due to
Approved and Proposed Project -
Hunter River**



AGE

DATE
29/11/2022

FIGURE No:
D 39



LEGEND

- Drainage
- Pit Shell contour
- Drawdown contour
- Model grid
- Alluvium extent
- Project Area
- Potential GDEs - from project study area
- High potential GDE - from regional studies

Exceedance probability (%)

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

HVO Continuation (G1737J)

**Cumulative alluvial drawdown -
Likelihood of 2m drawdown due to
Approved and Proposed Project –
Wollombi Brook**



AGE

DATE
29/11/2022

FIGURE No:
D 40

D8 References

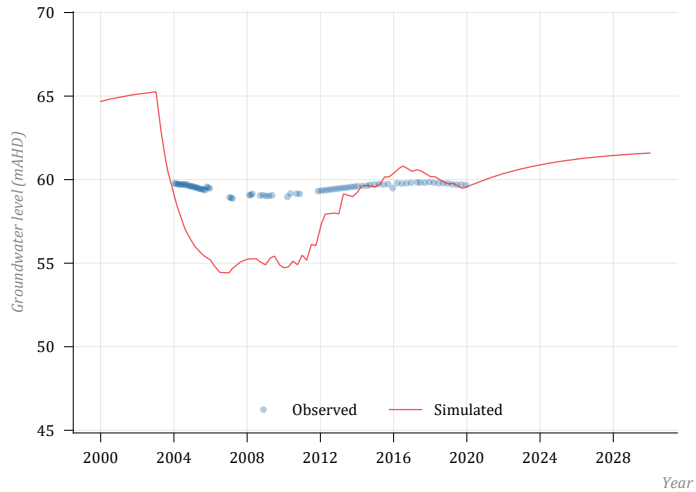
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Appendix D 1

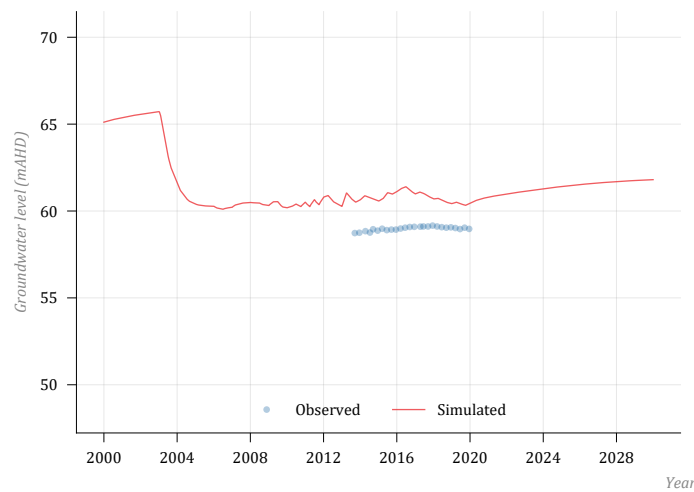
Historic calibration hydrographs

Alluvium_Palaeochannel_N

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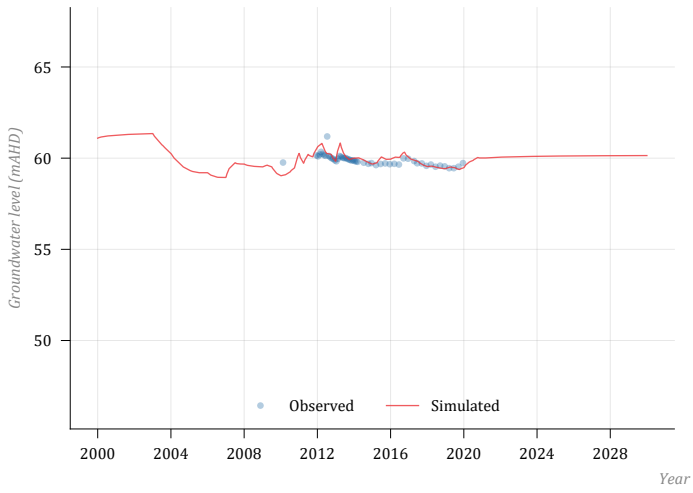


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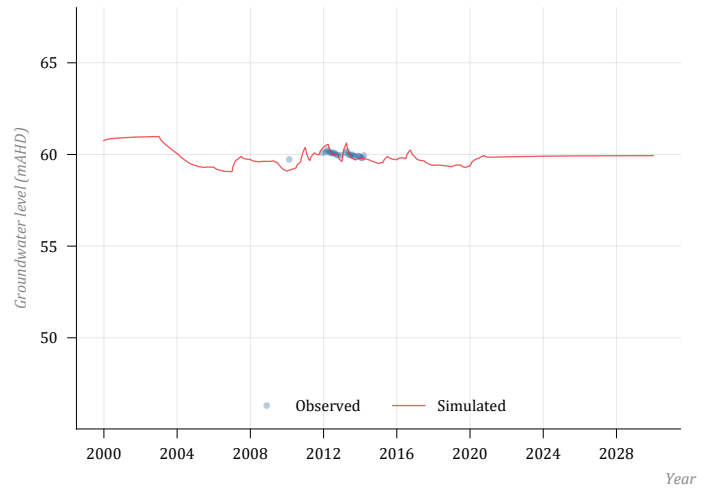


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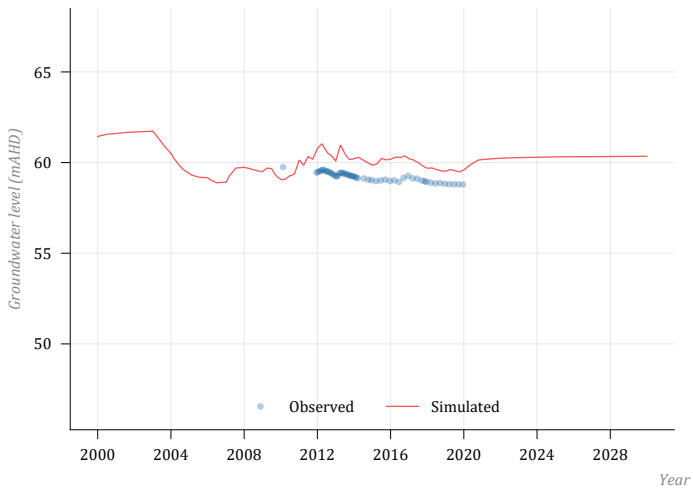
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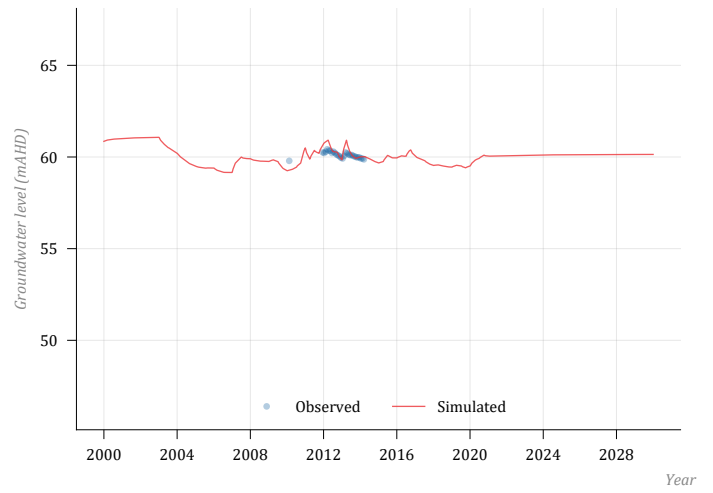
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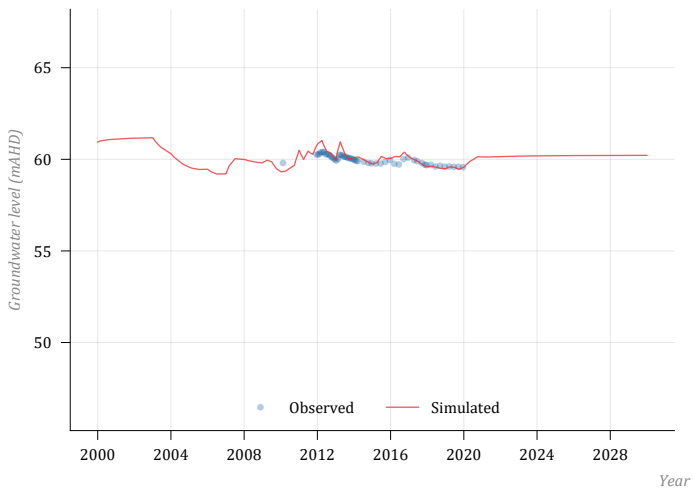
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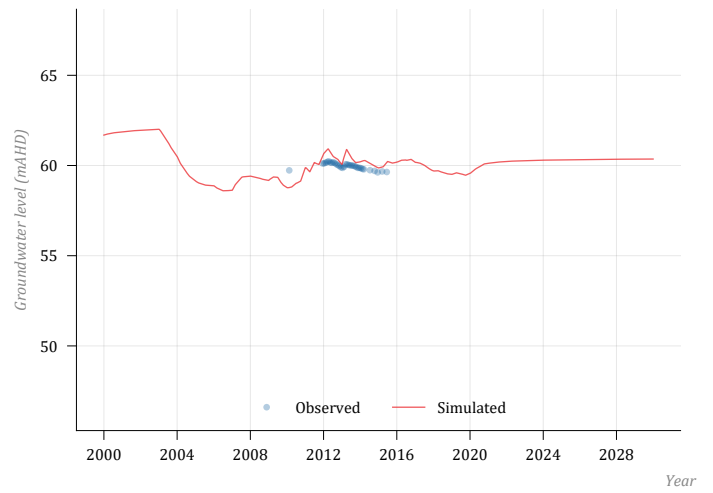
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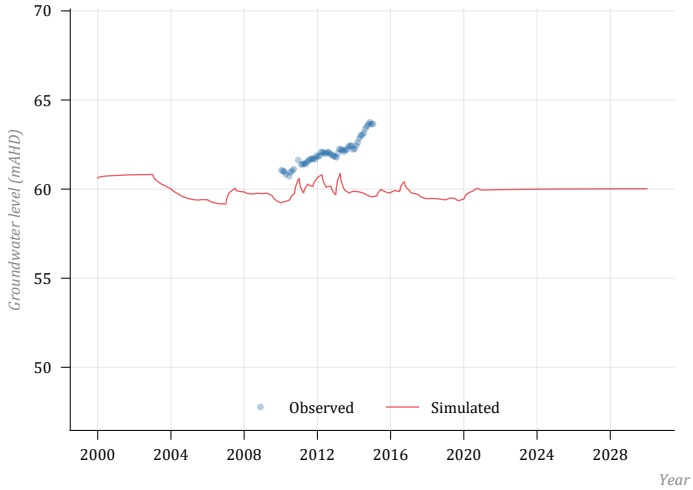
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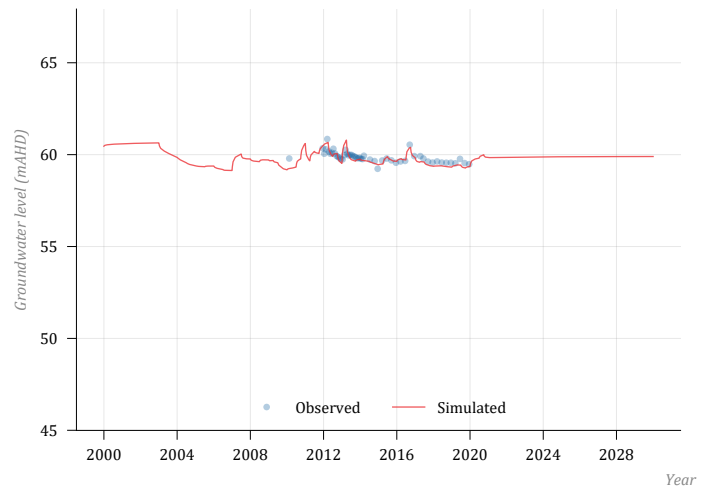
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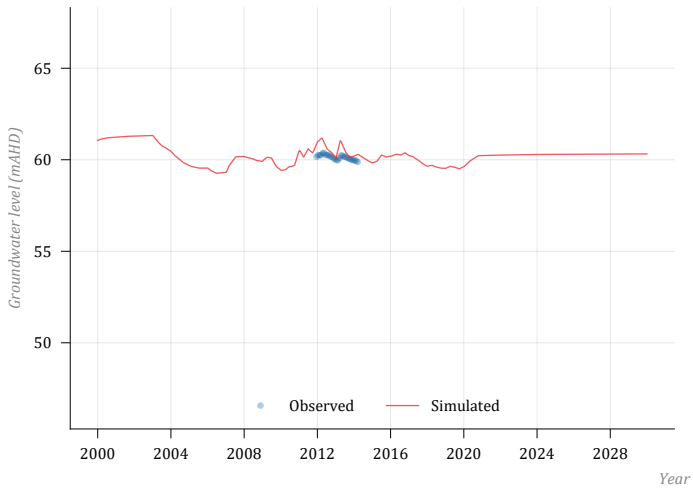


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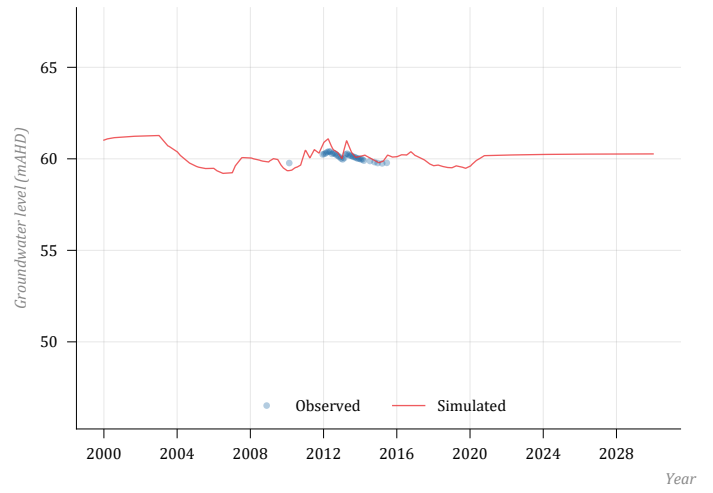


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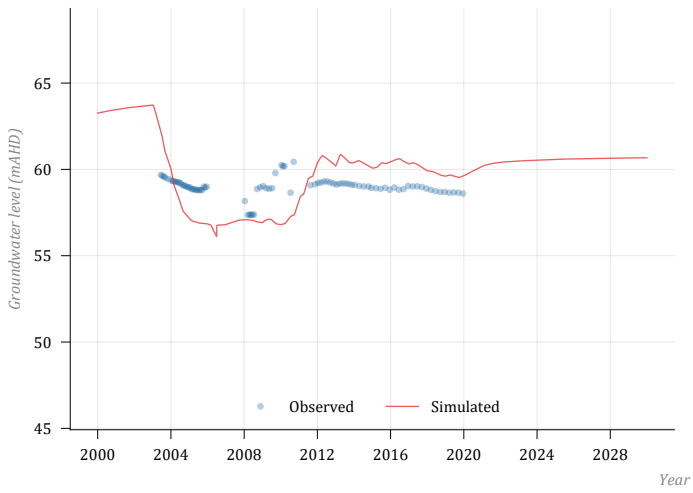
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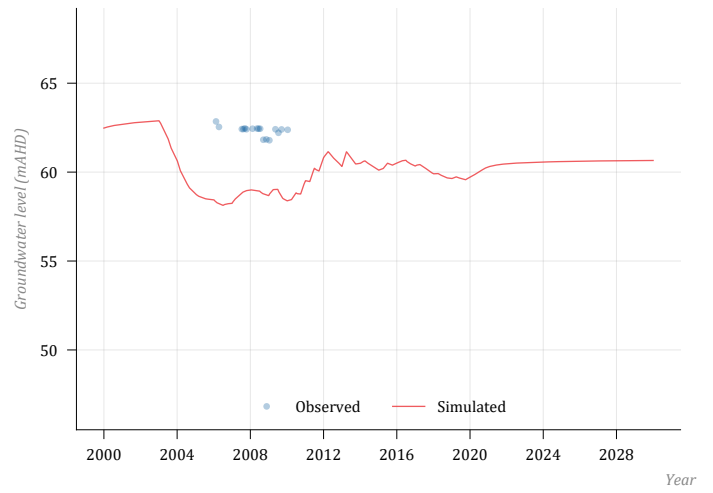
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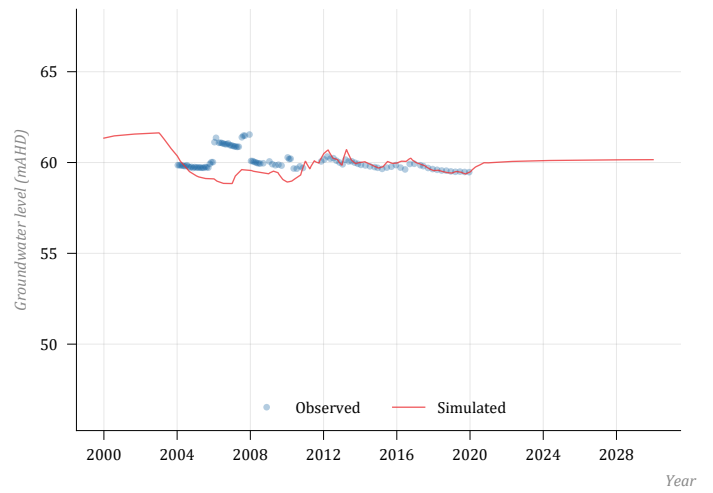
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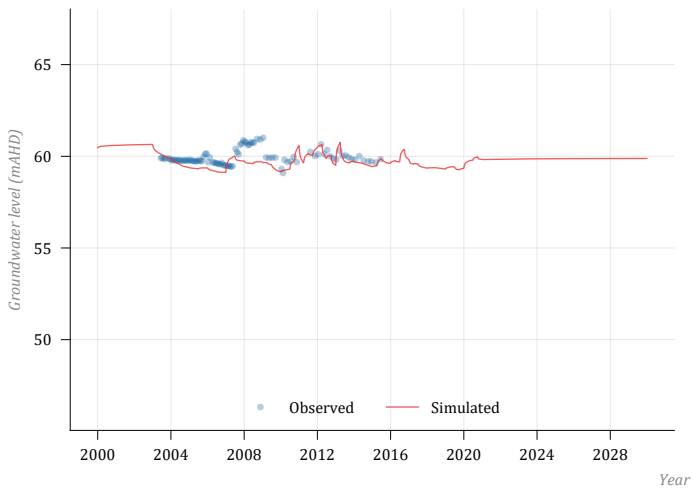
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CGW49

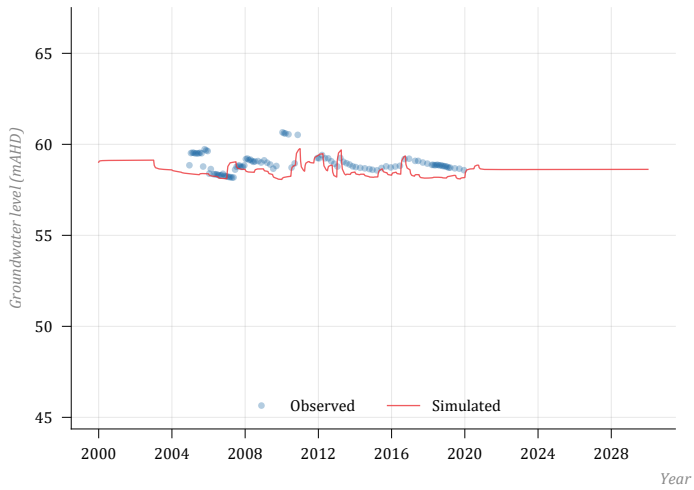


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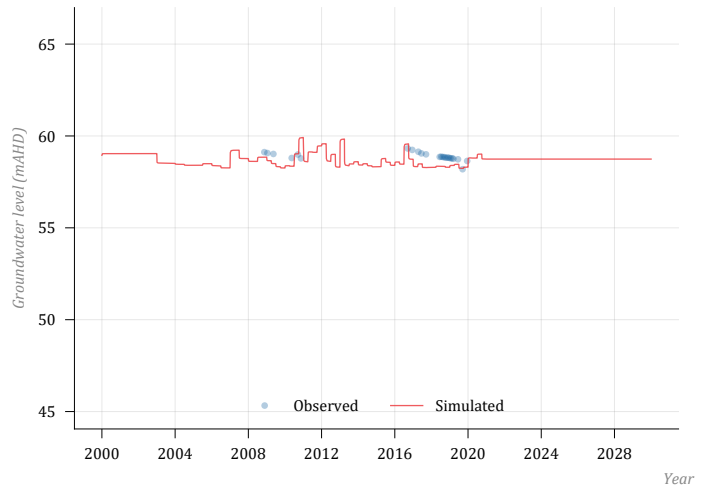


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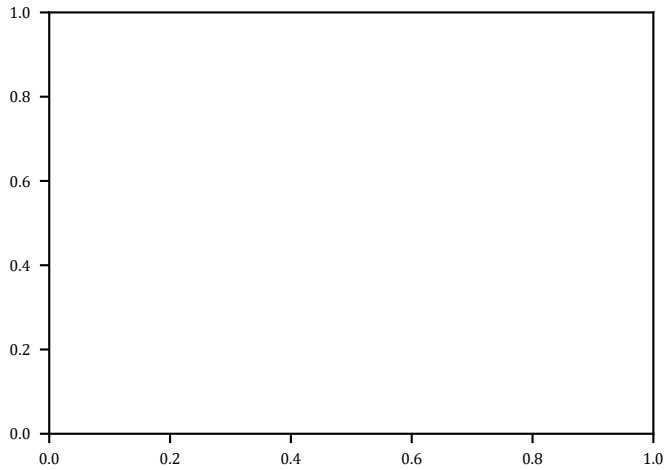
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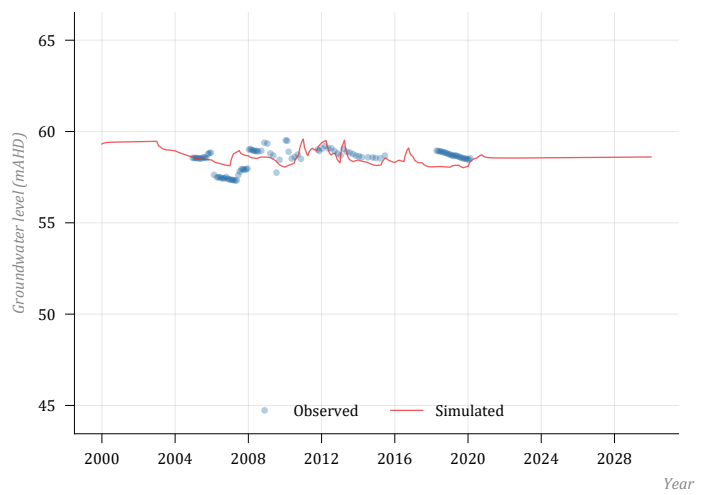
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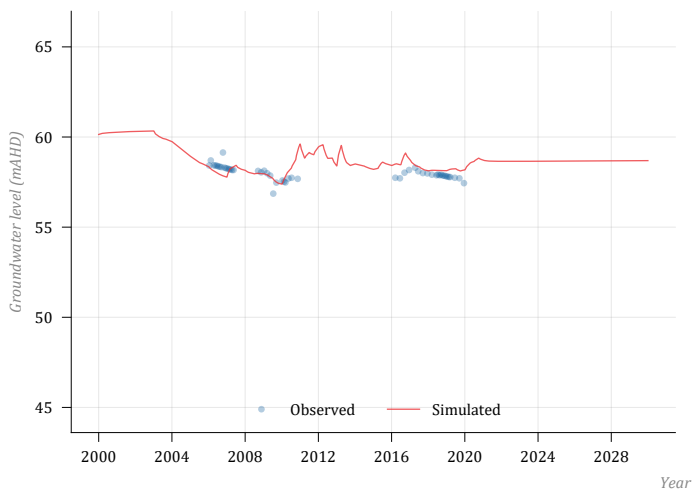
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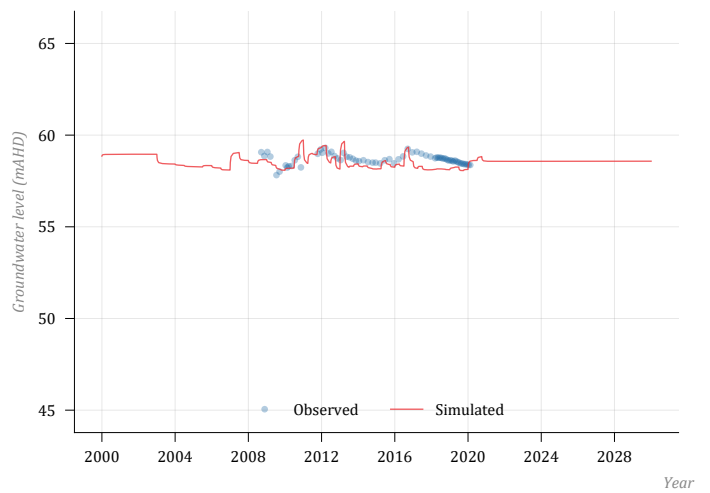
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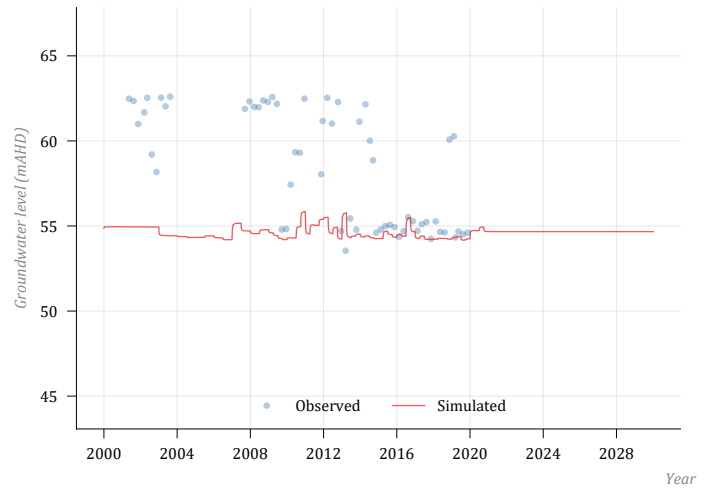


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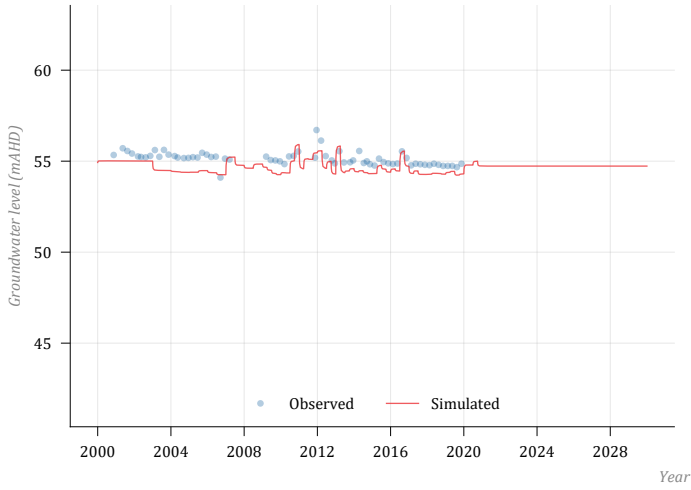
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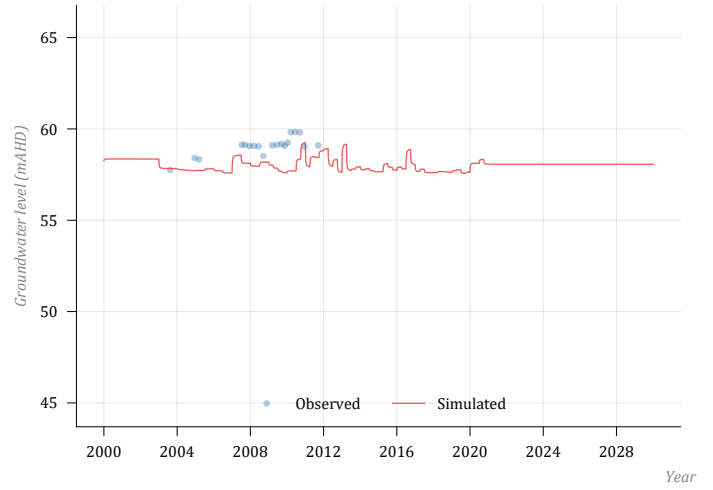
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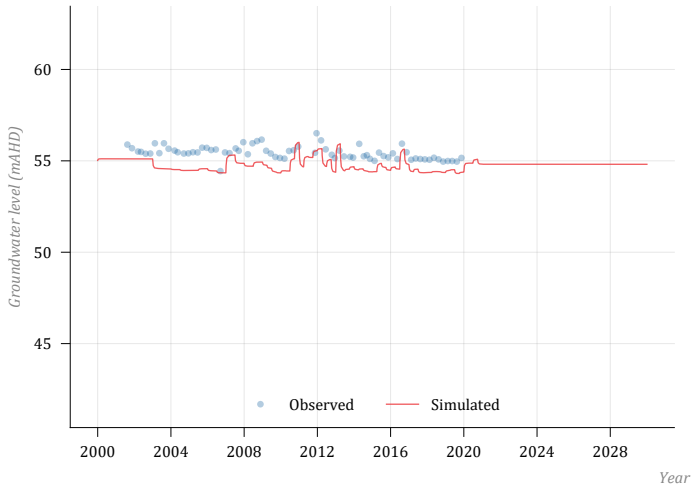
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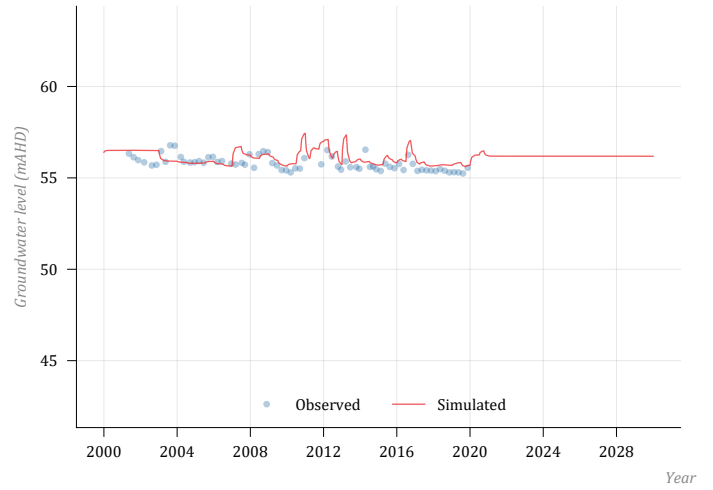
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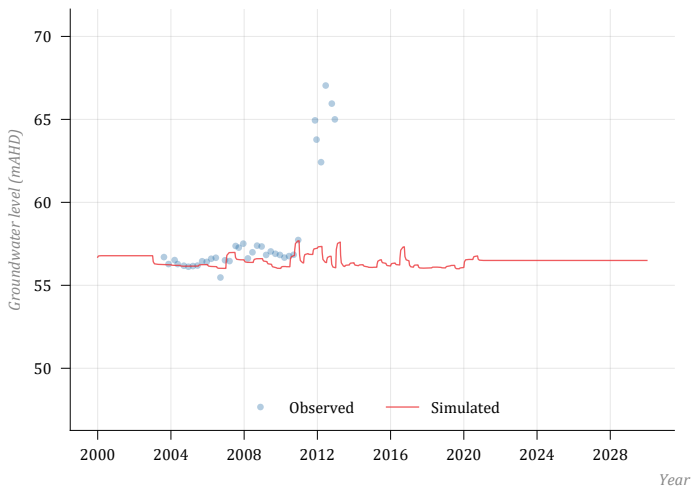
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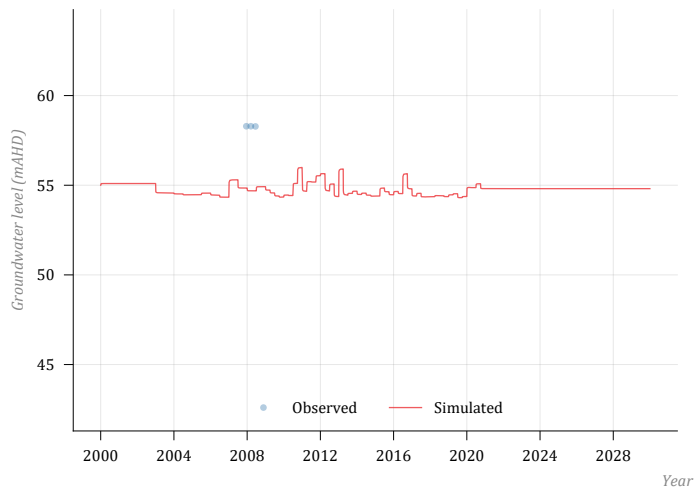


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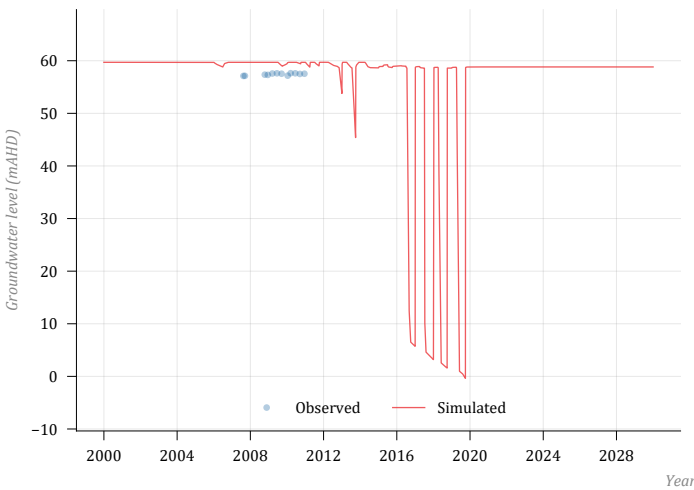


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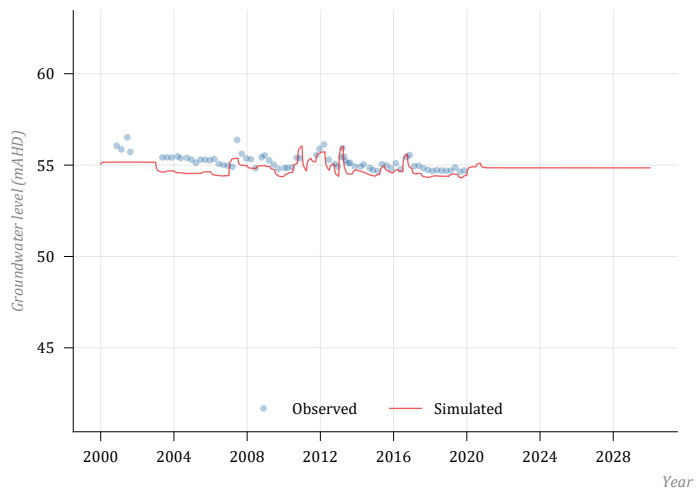
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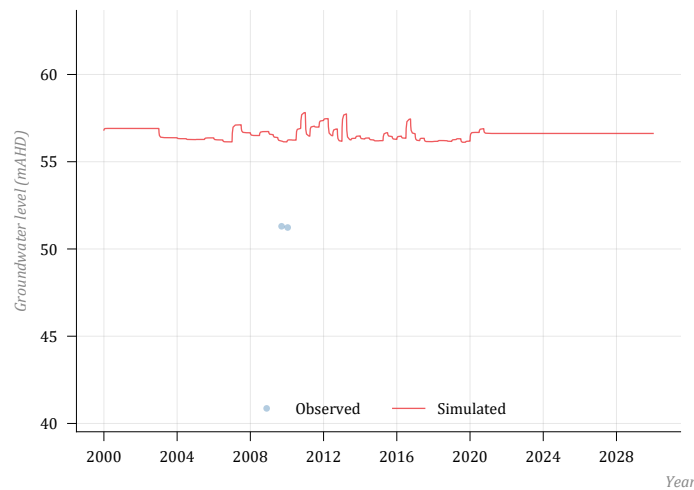
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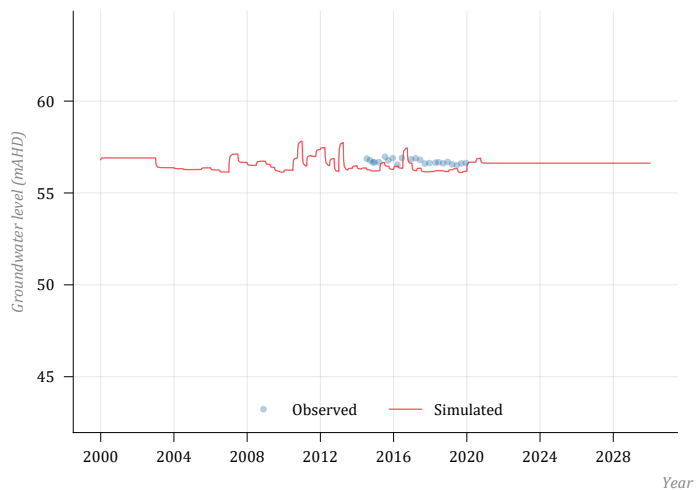
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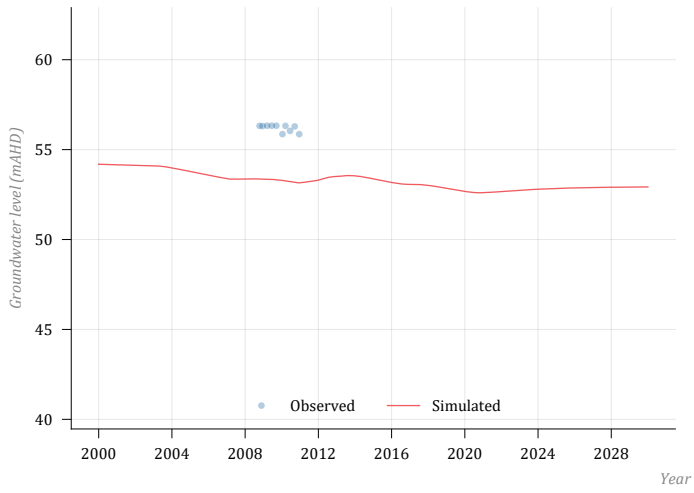


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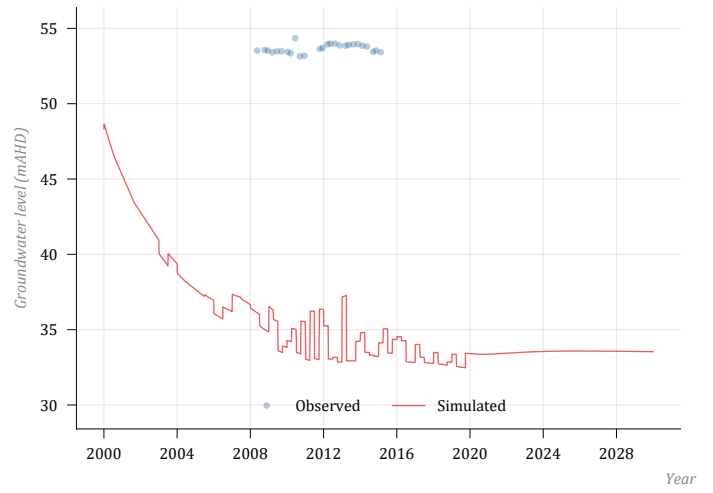


Alluvium_Hunter_HVO_downstream

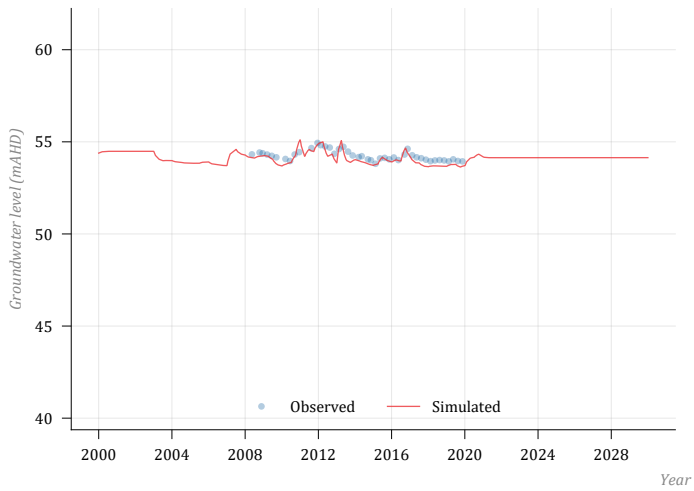
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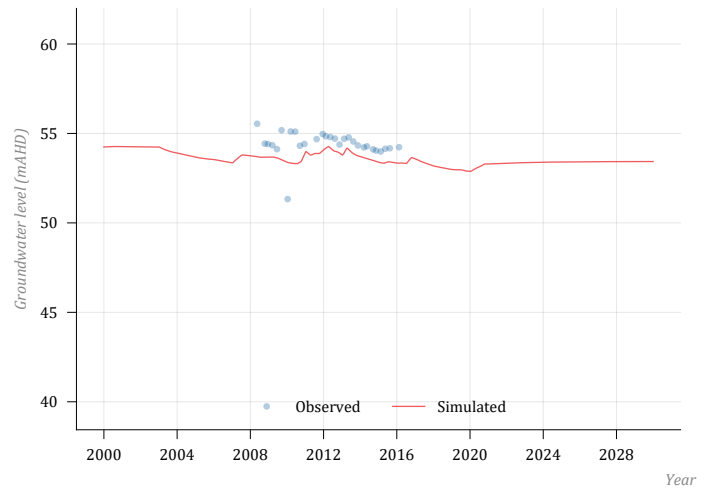
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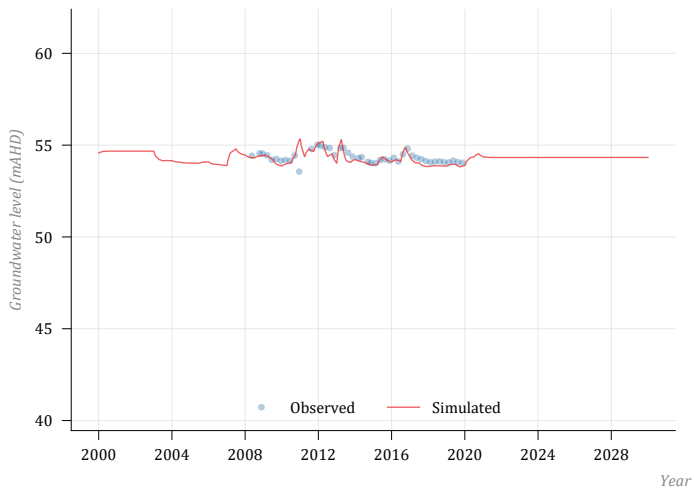
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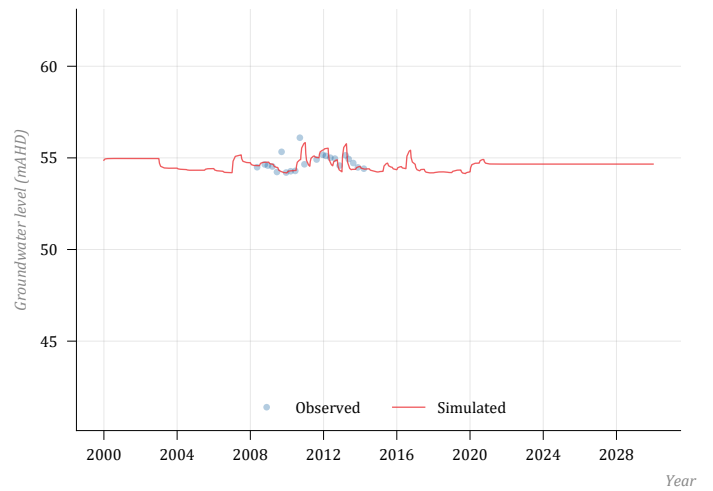
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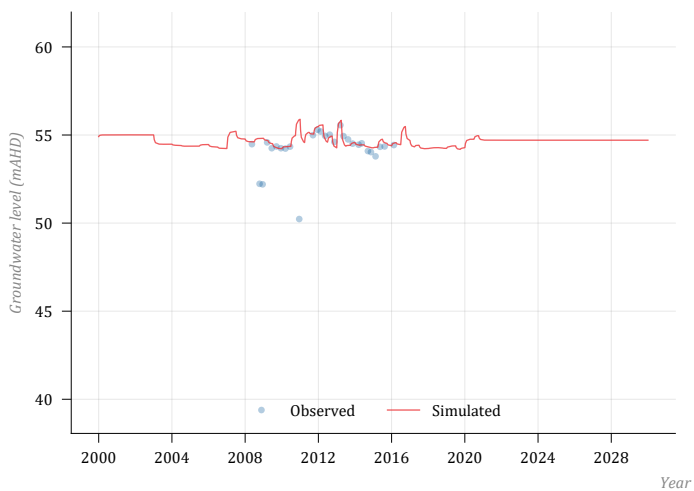
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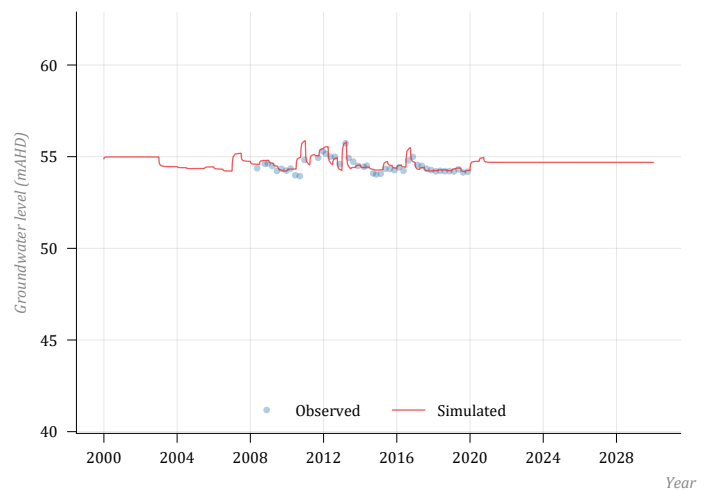
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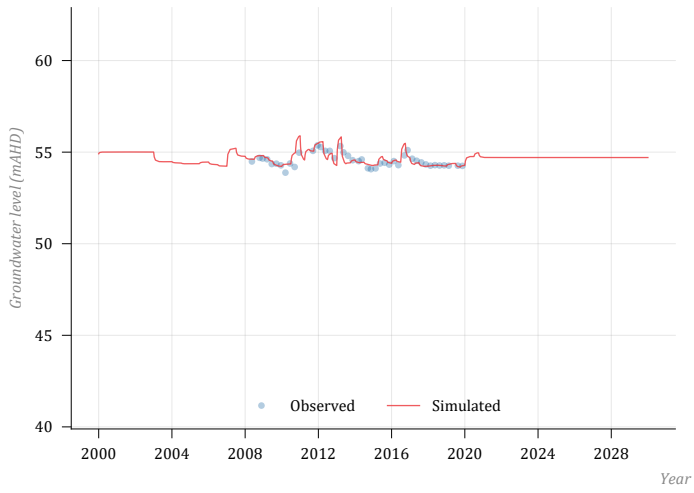


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Alluvium_Hunter_HVO_downstream

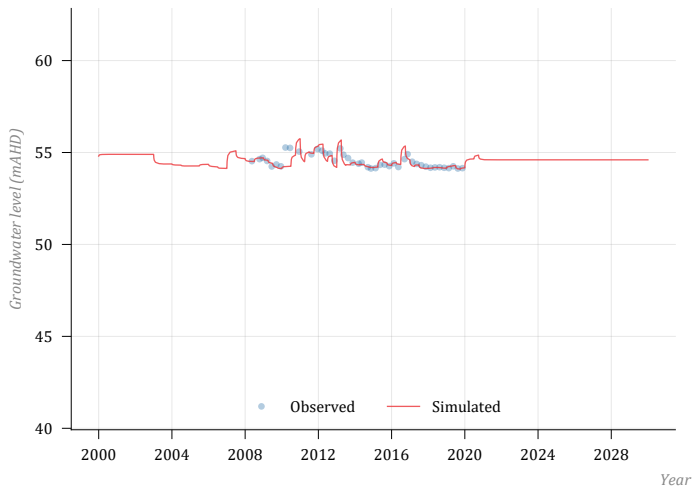
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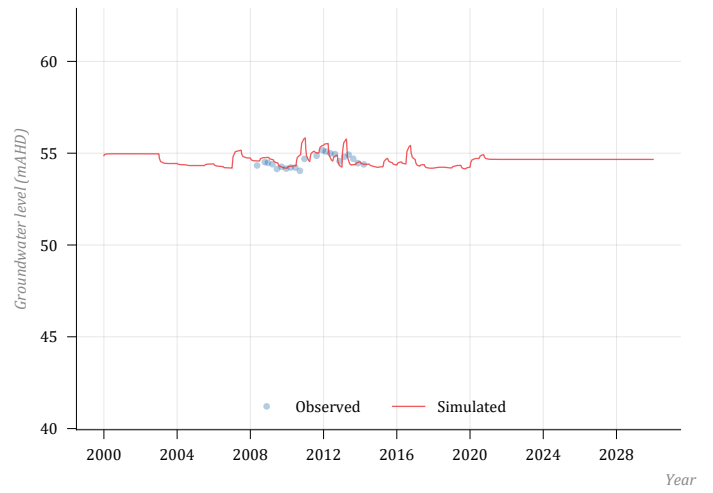
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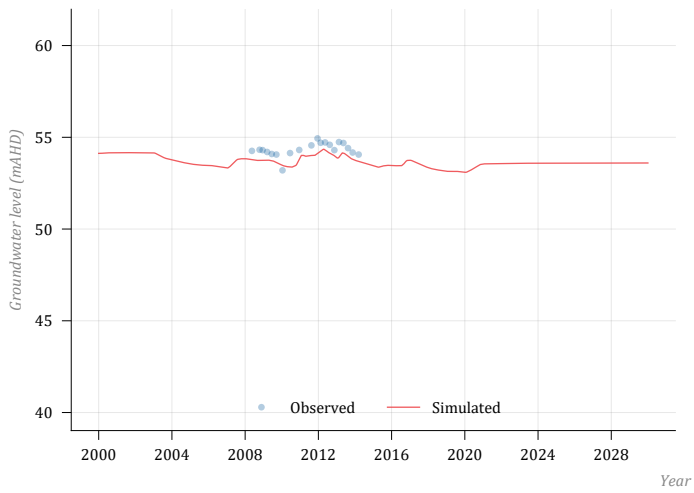
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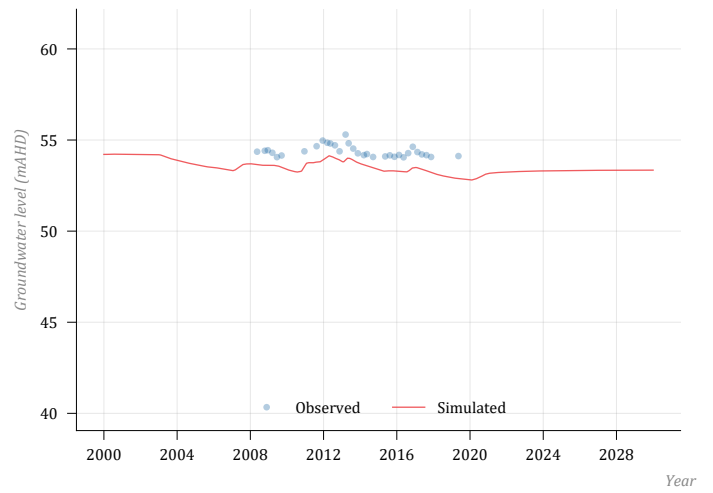
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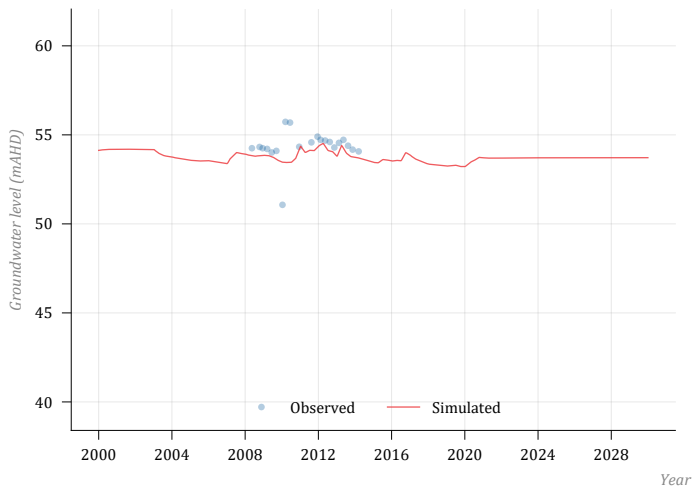
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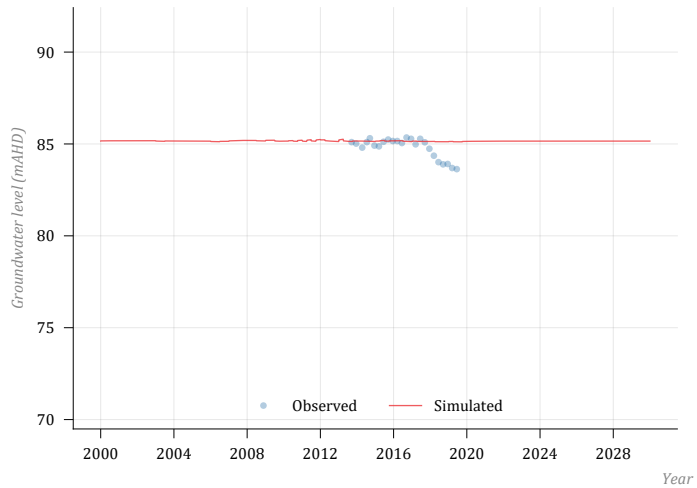


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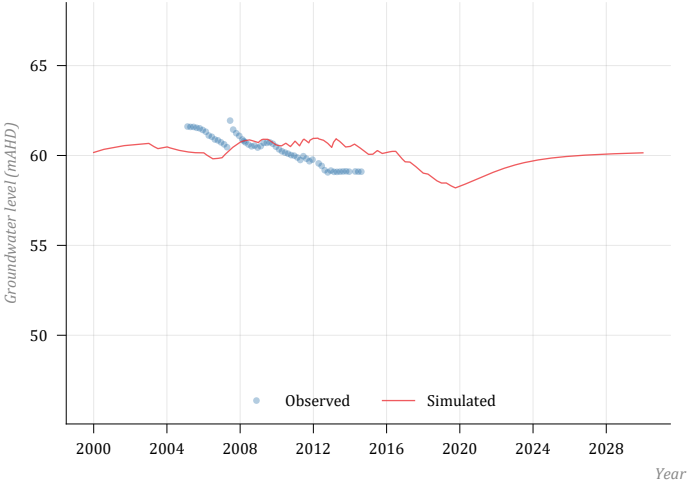
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GW_100

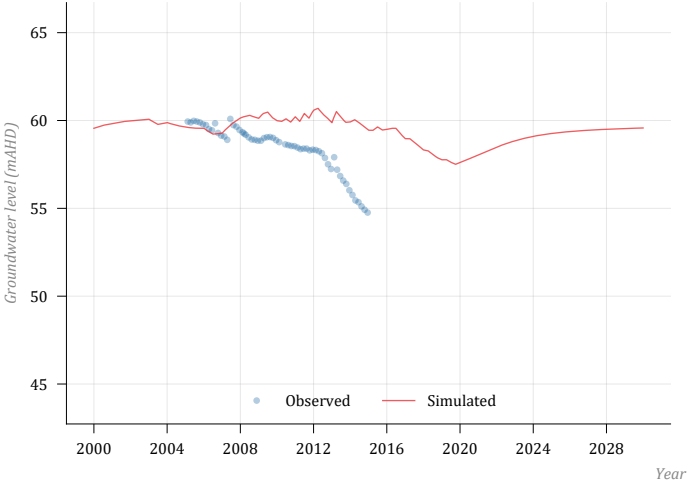


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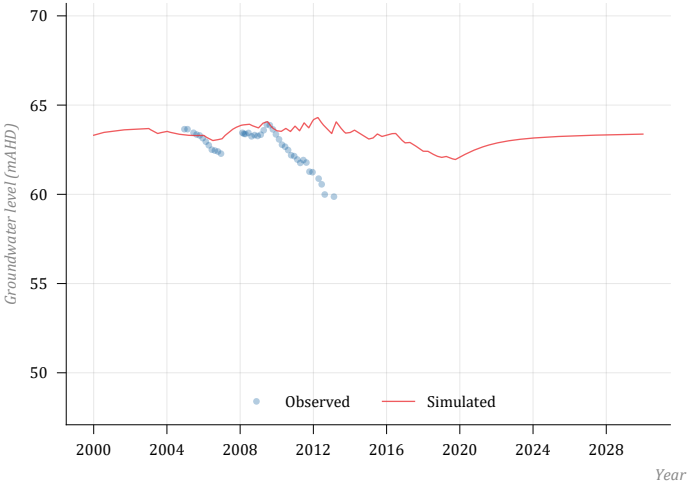
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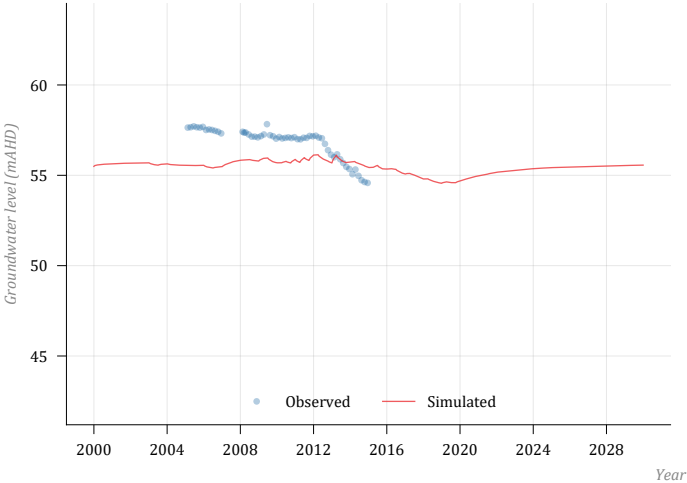
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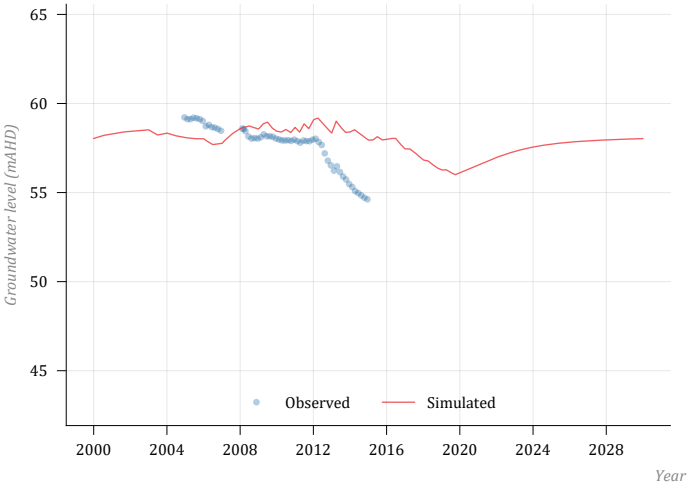
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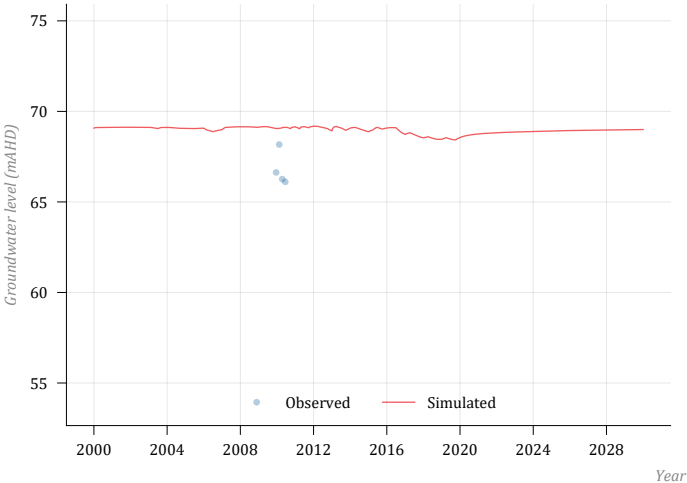
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GW09

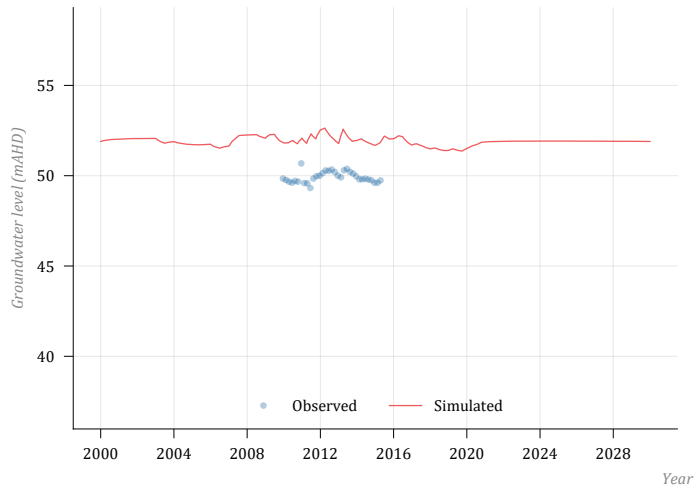


GW18



Alluvium_Wollombi_upstream

GW15

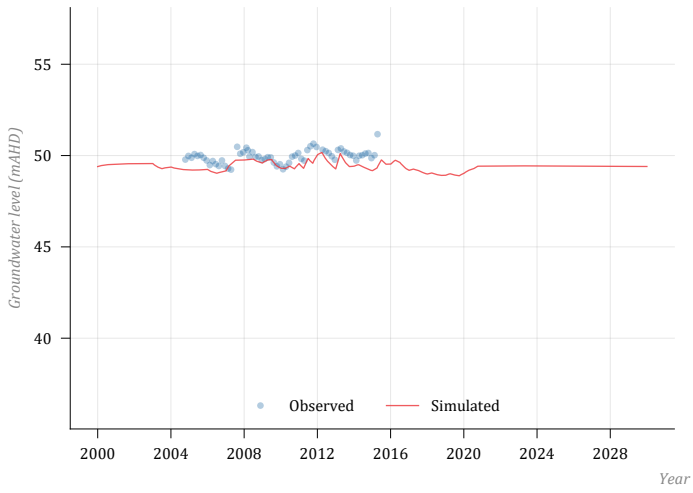


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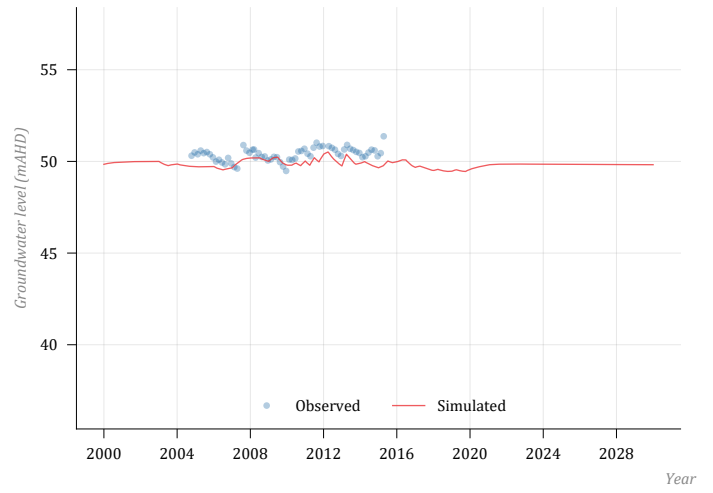


Alluvium_Wollombi_midstream

P16



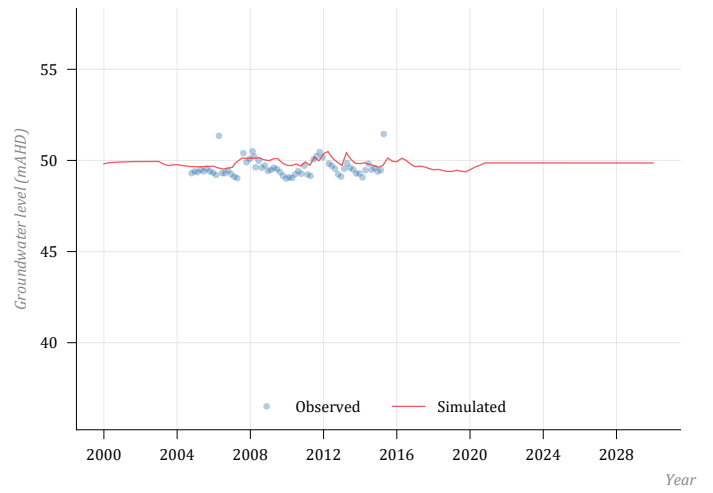
P17



P18



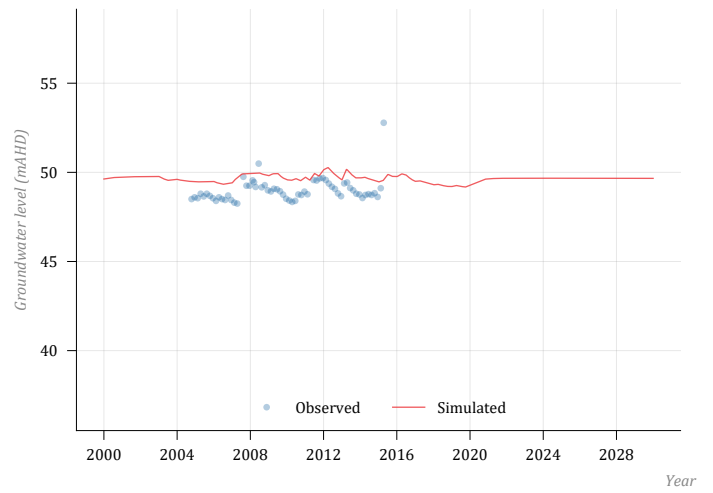
P20



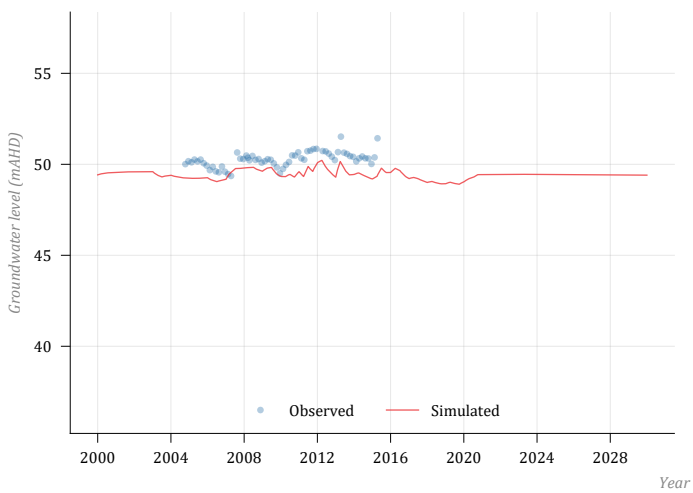
P12



P13

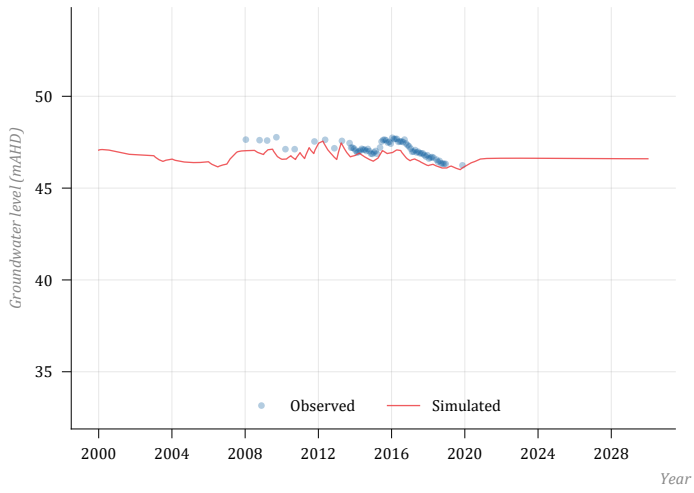


P15

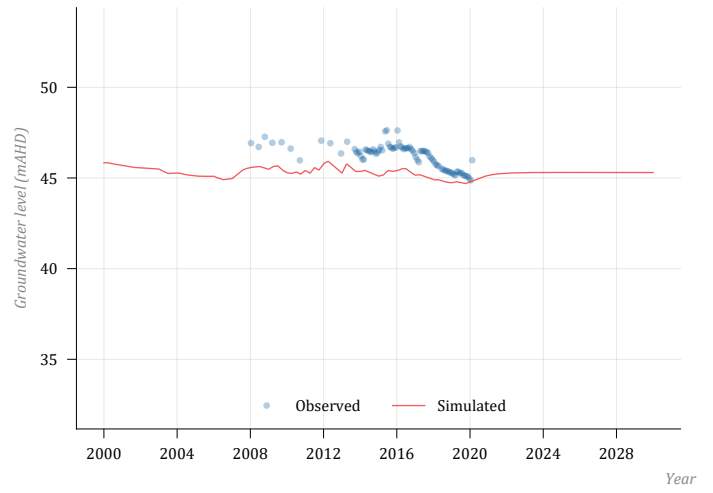


Alluvium_Wollombi_downstream

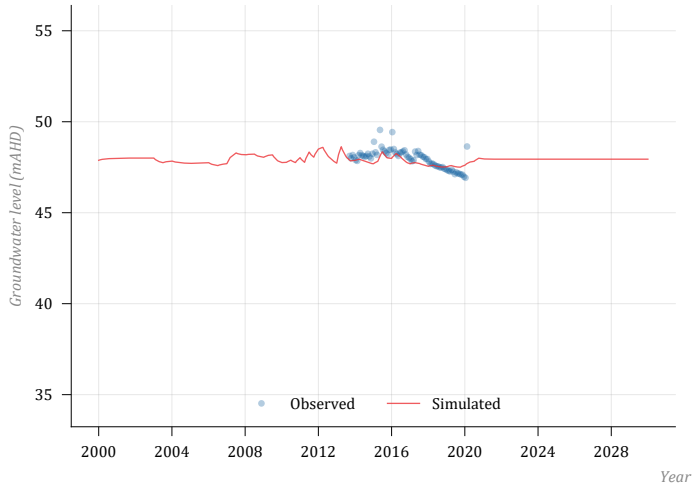
C919_ALL



PB01_ALL

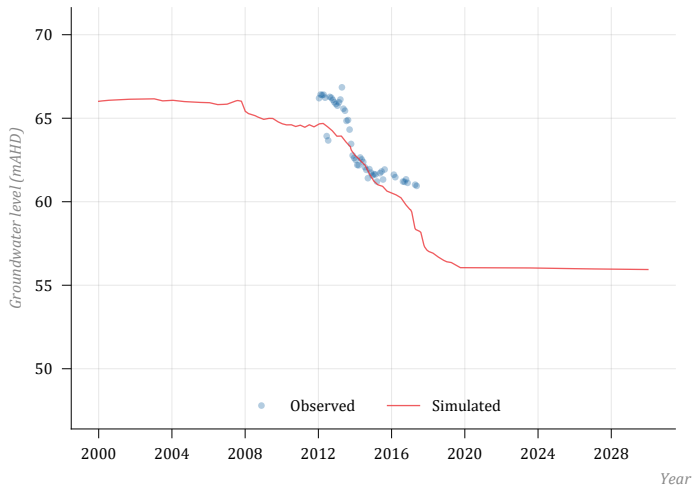


APP_FARM

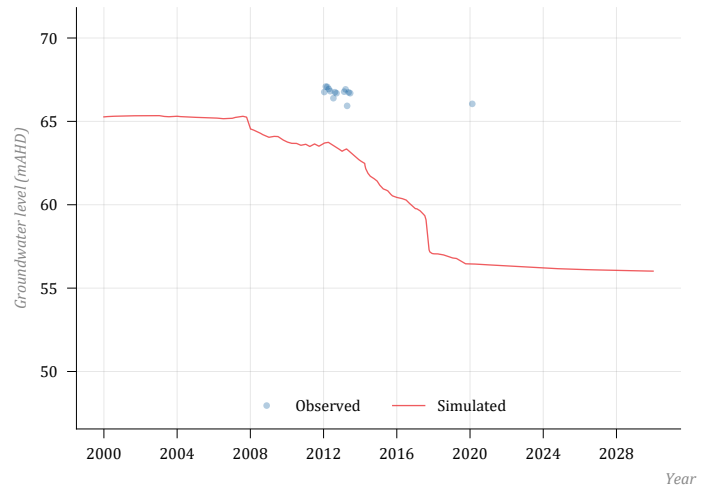


Alluvium_Bayswater_Ck

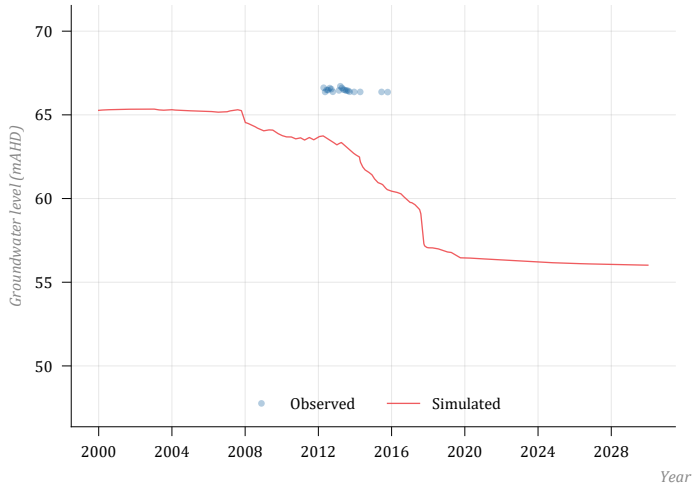
NPZ5B_P1



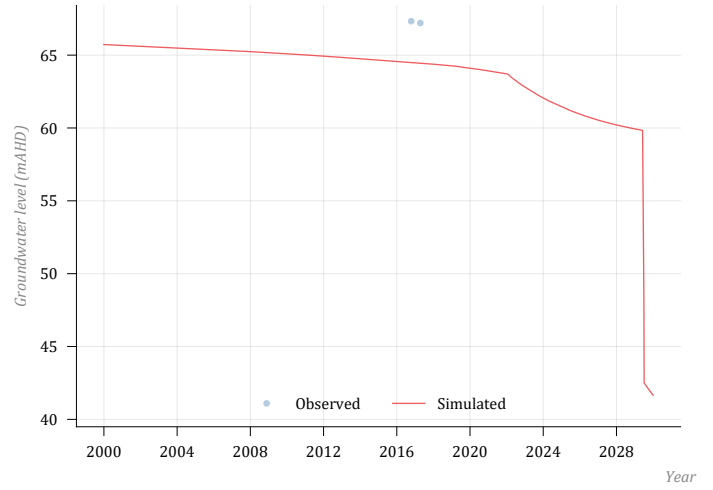
NPZ5B_P2



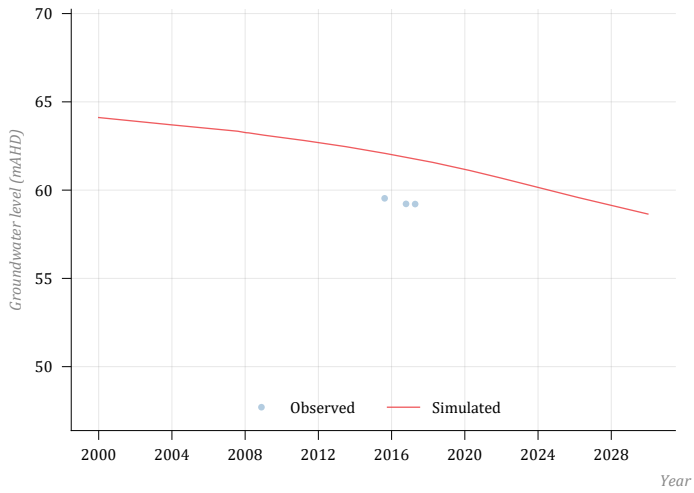
MW01



MW10

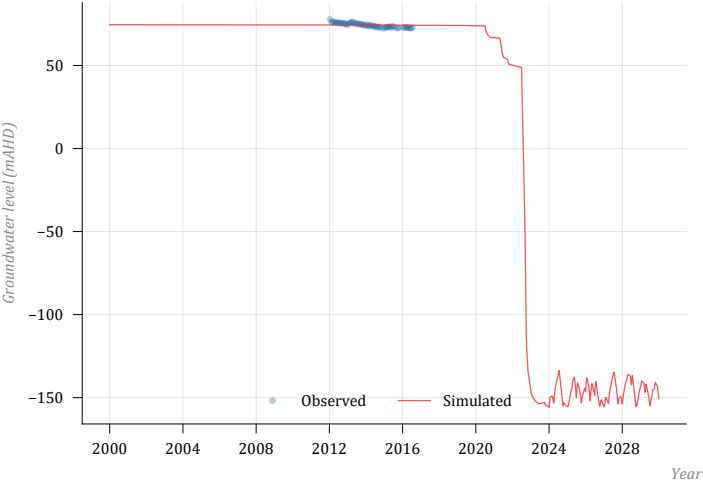


MW9

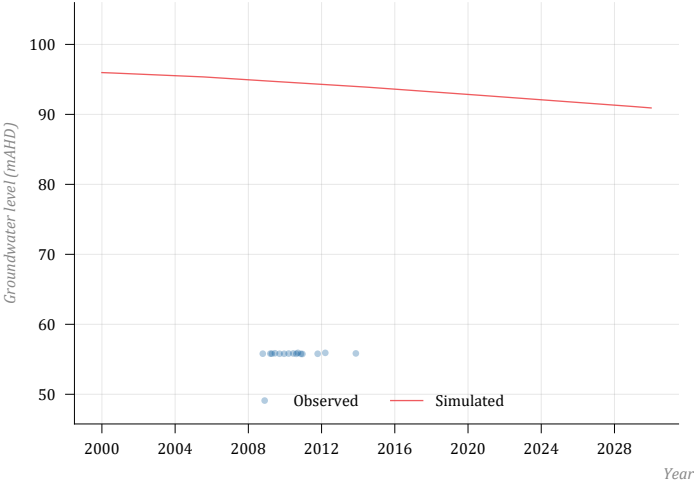


Regolith_West_of_Bayswater_Ck

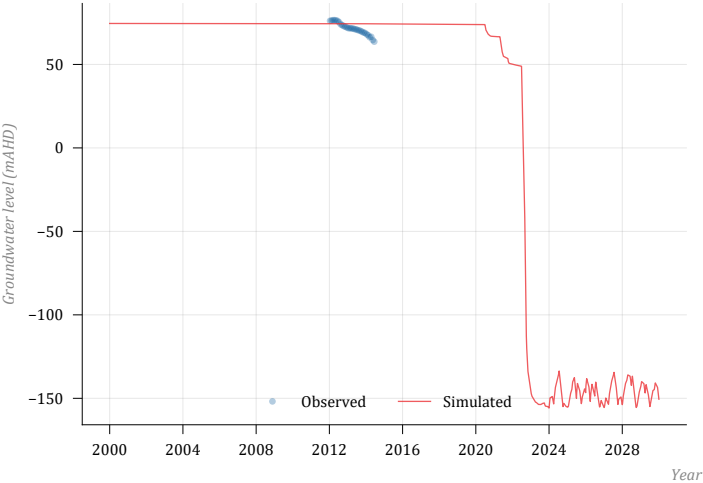
CS4545B_SM



S6

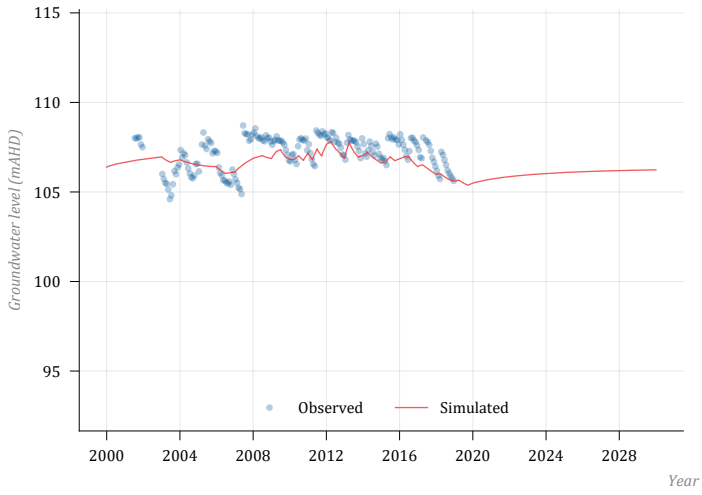


CS4545B_MI

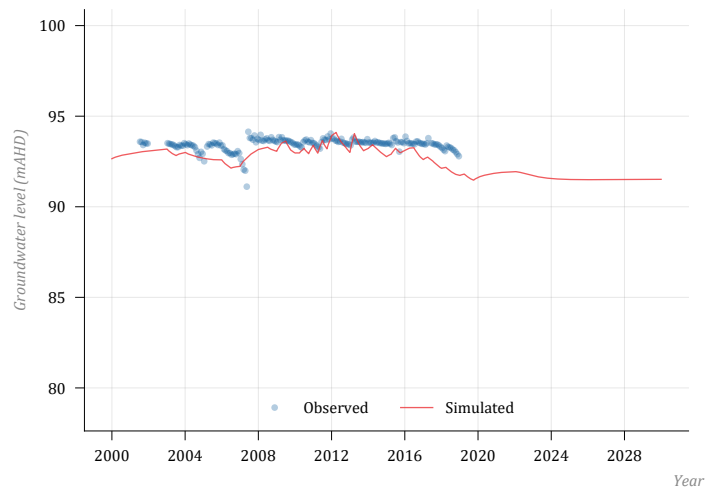


Alluvium_Bowmans_Ck_upstream

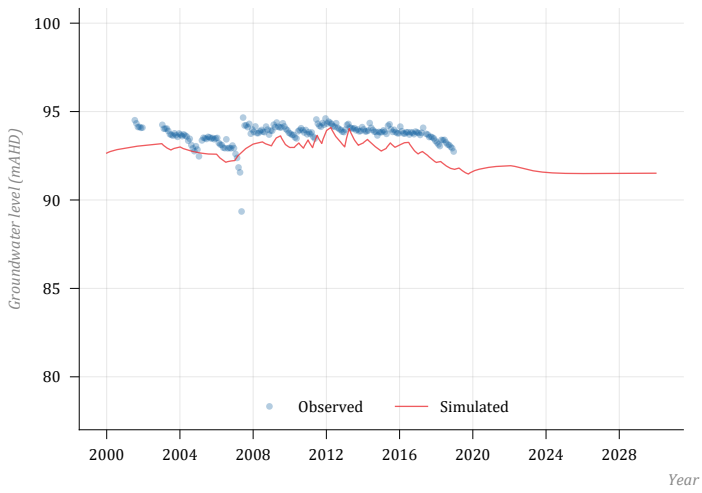
ALV1_LARGE



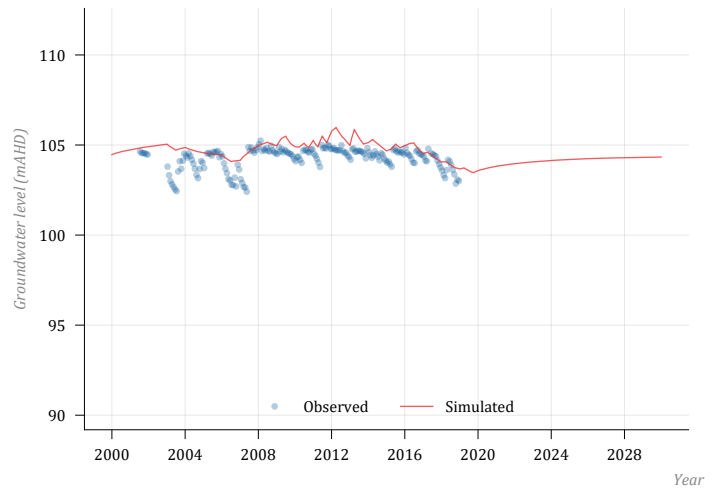
ALV2_LARGE



ALV2_SMALL



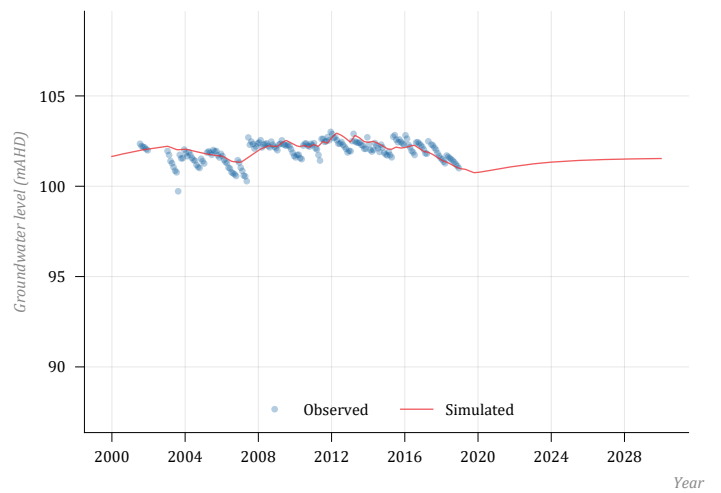
ALV3_LARGE



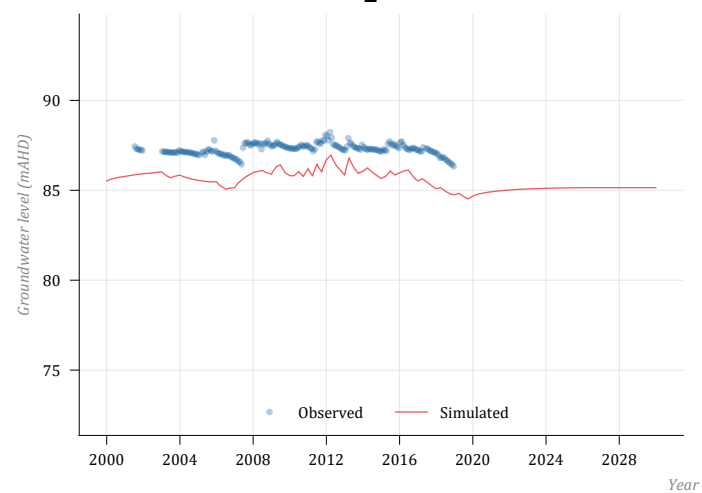
ALV4_LARGE



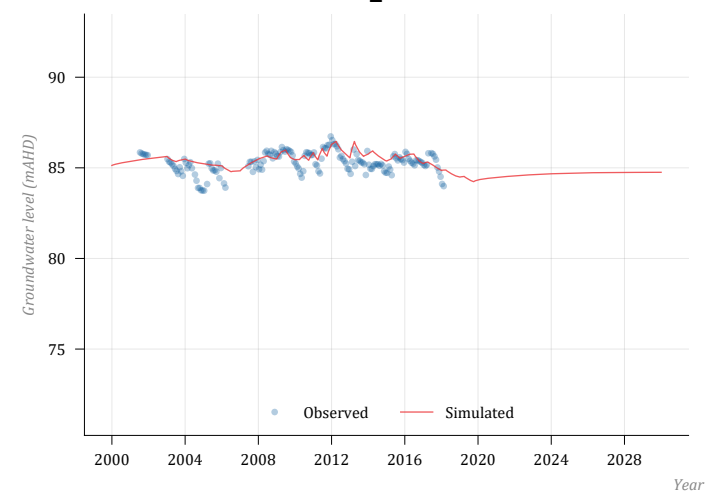
ALV4_SMALL



ALV7_LARGE

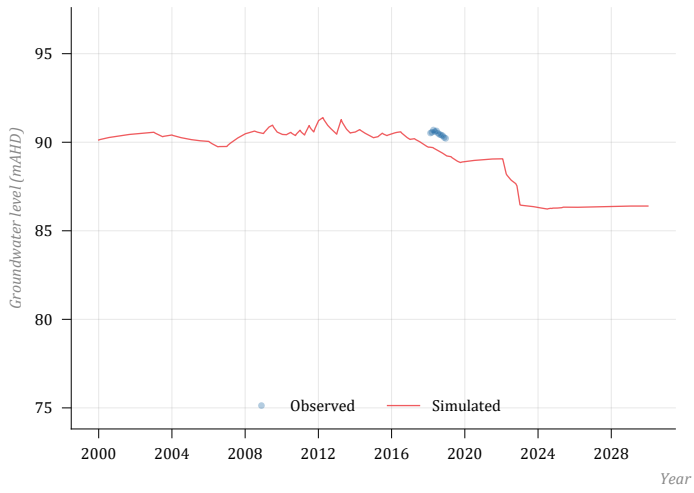


ALV8_LARGE

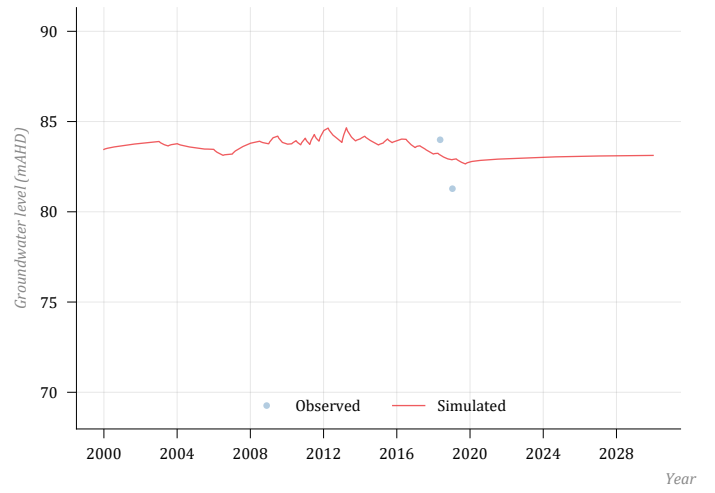


Alluvium_Bowmans_Ck_upstream

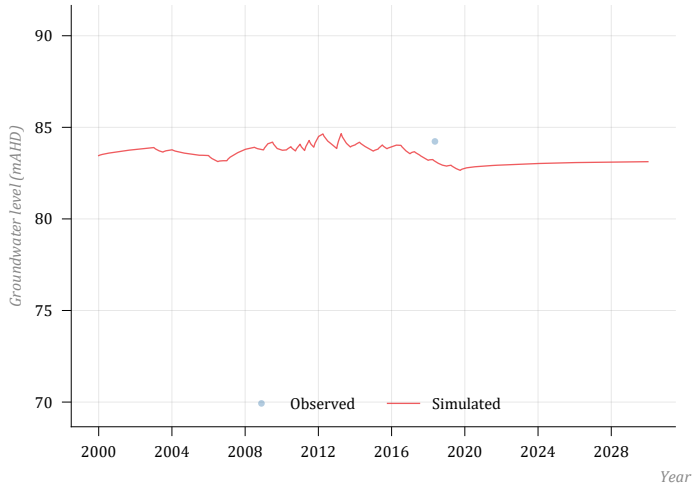
ALV9_LARGE



GNP9D

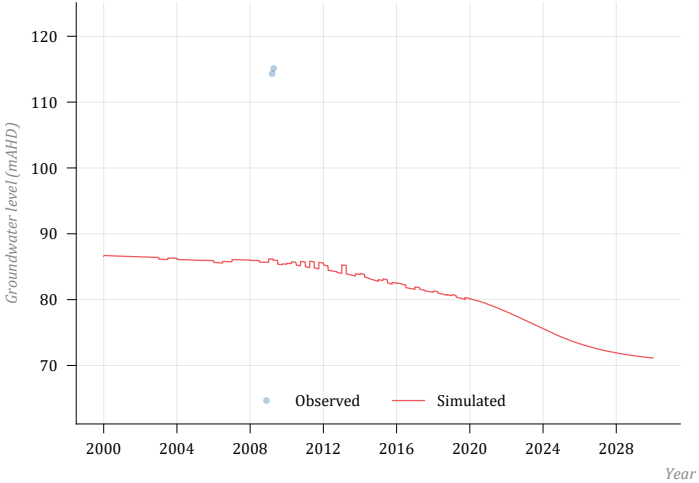


GNP9S

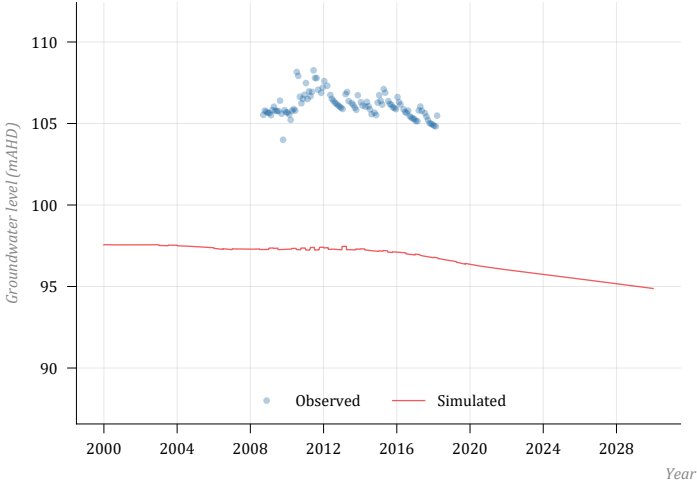


Regolith_Bowmans_Ck_upstream

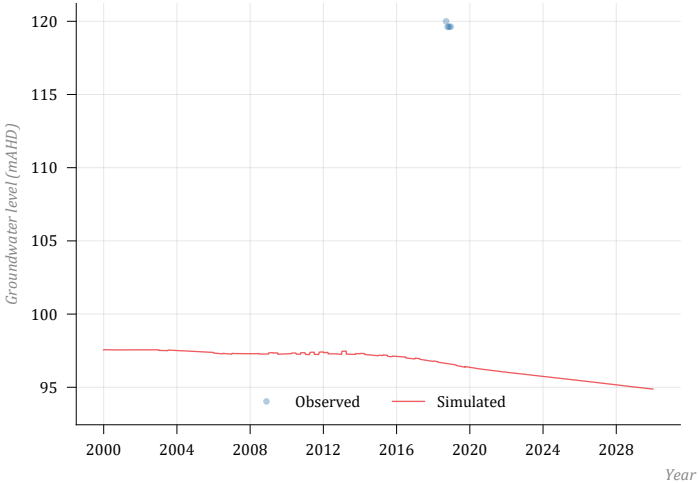
NV17C



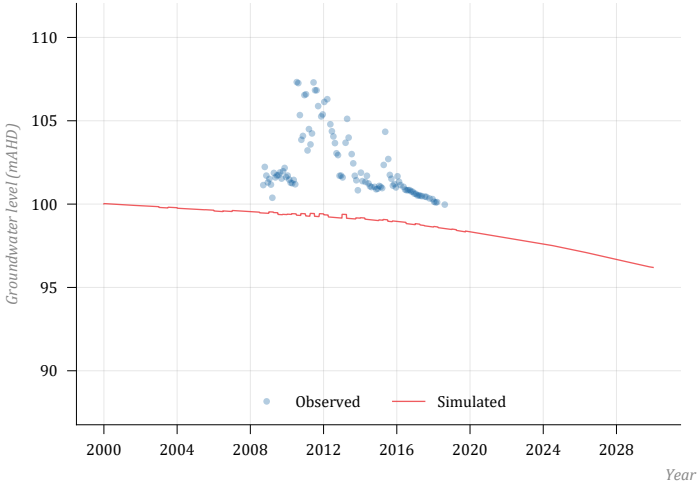
NV10A



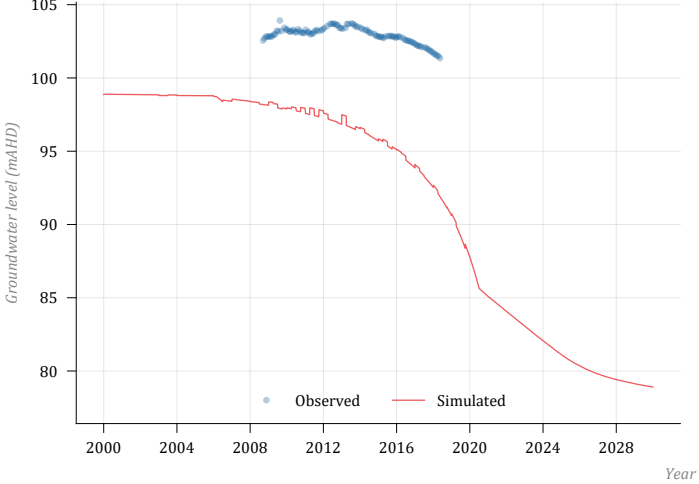
NV12C



NV14A

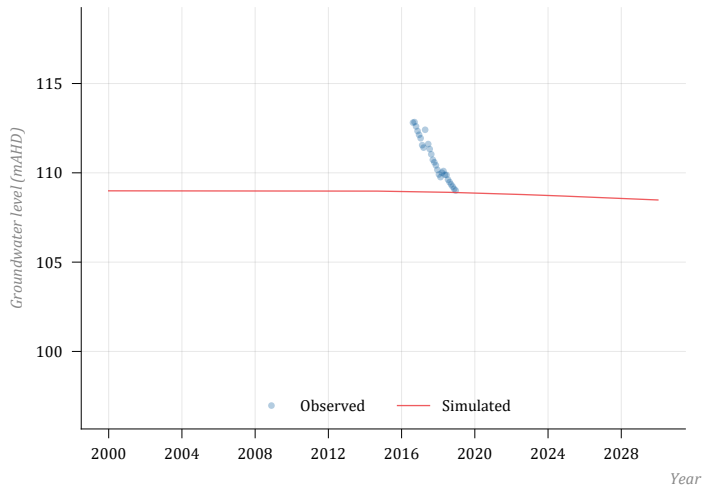


NV16A

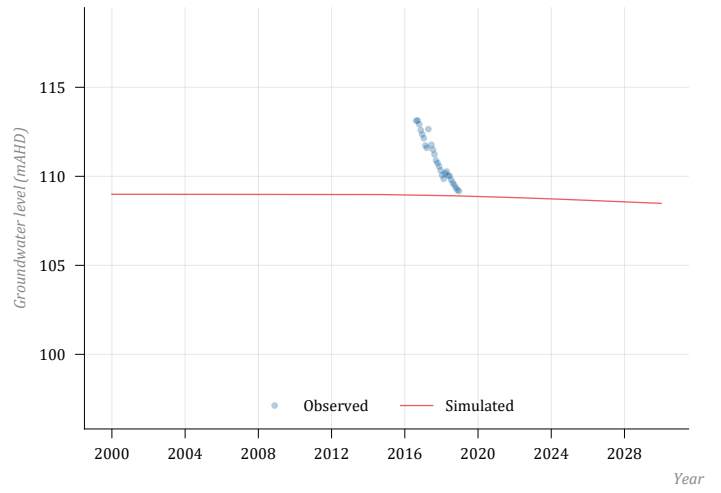


Alluvium_Yorks_Ck_upstream

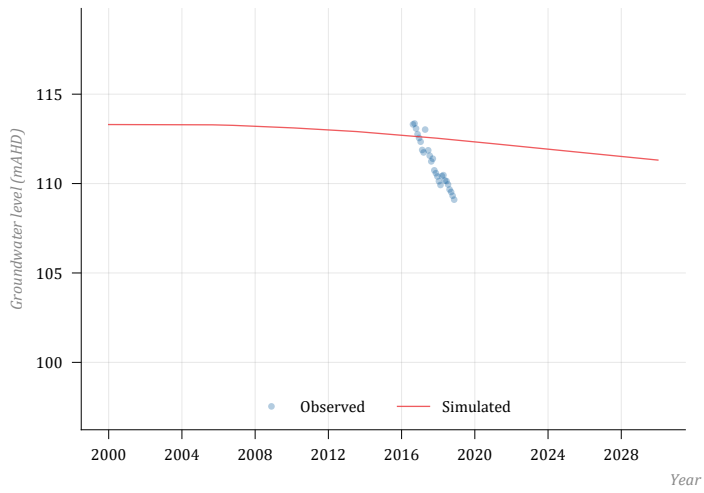
RW1



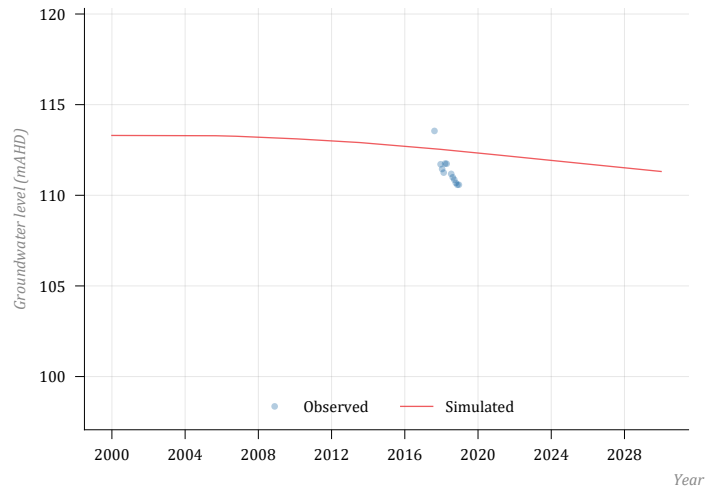
RW2



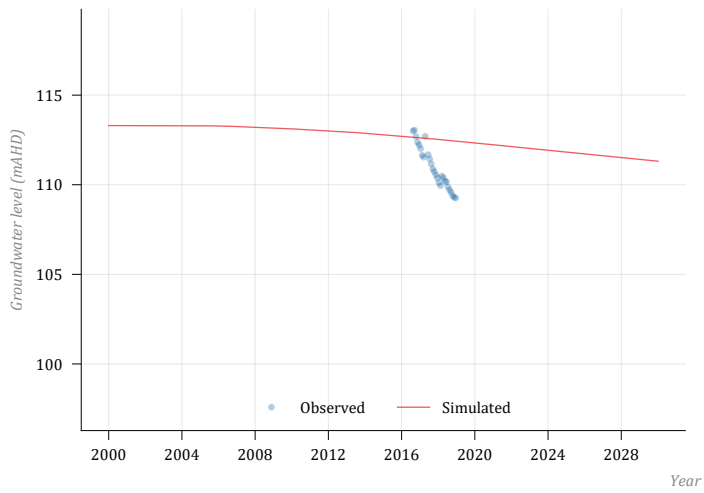
RW3



RW4

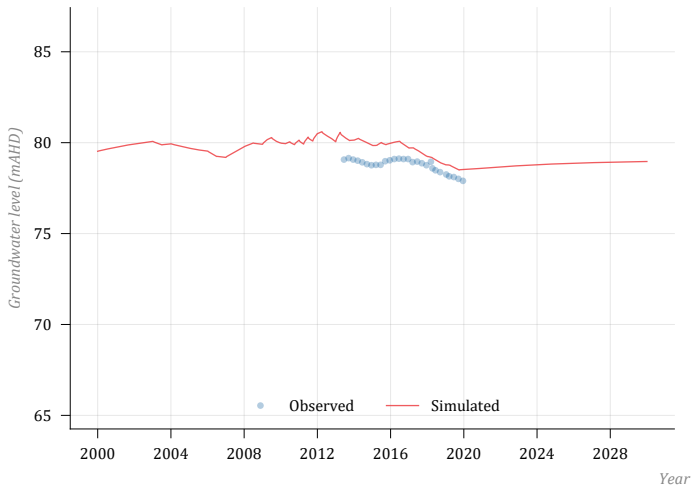


RW5

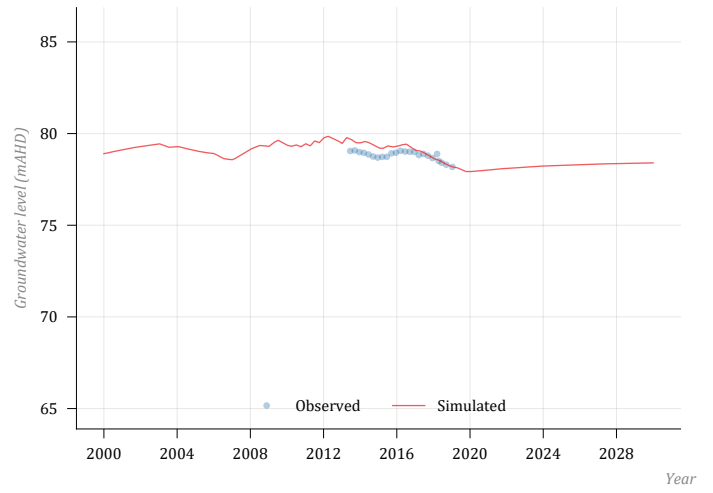


Alluvium_Yorks_Ck

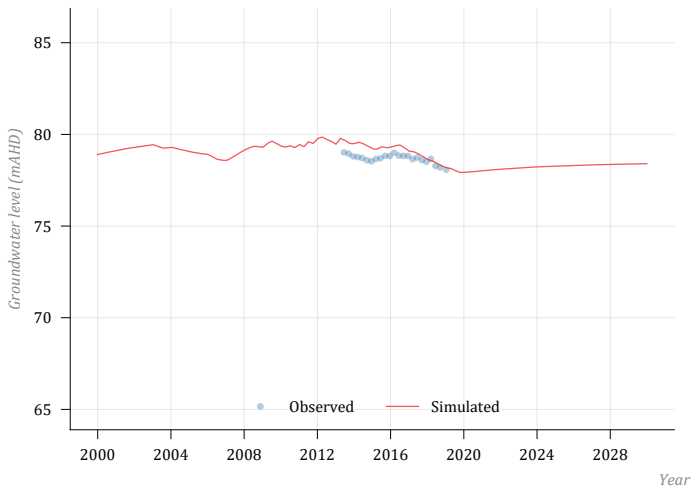
BC-SP02



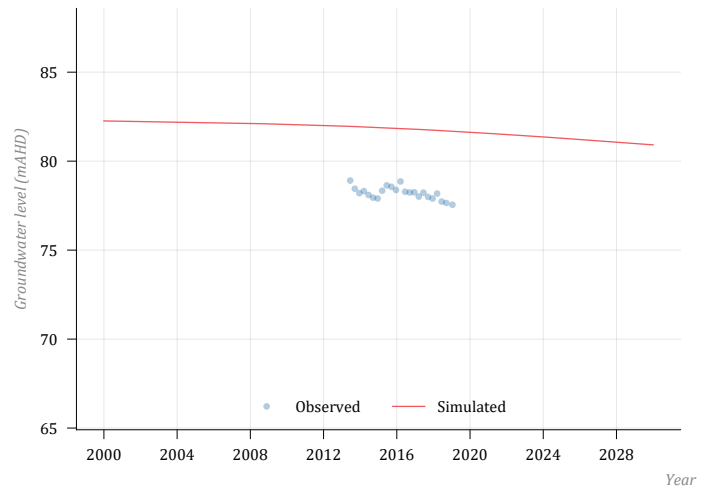
BC-SP03



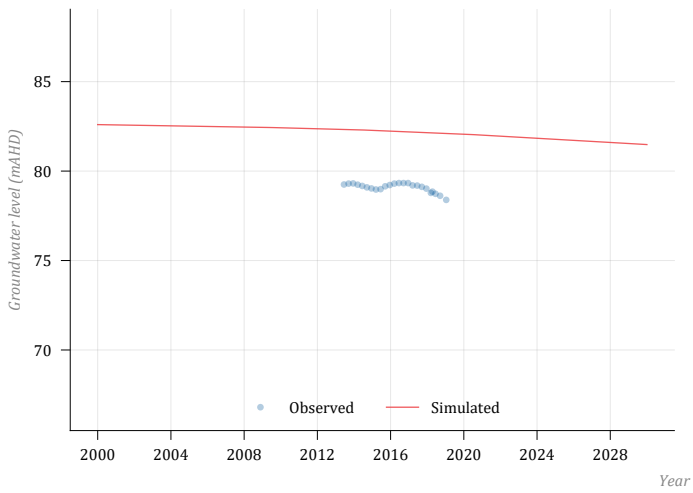
BC-SP04



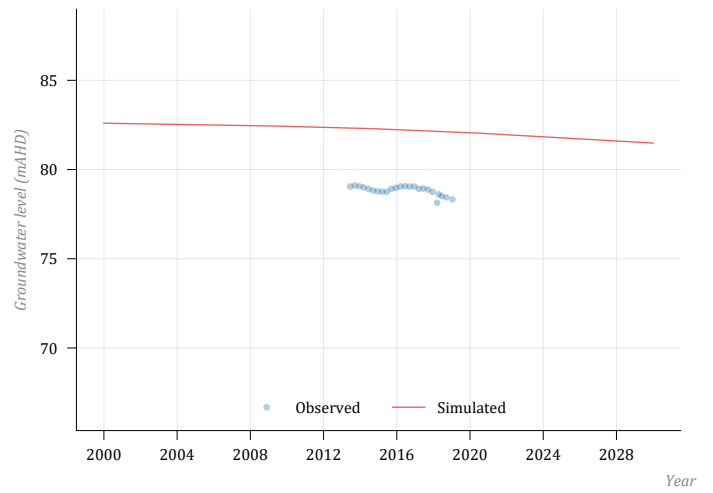
BC-SP05



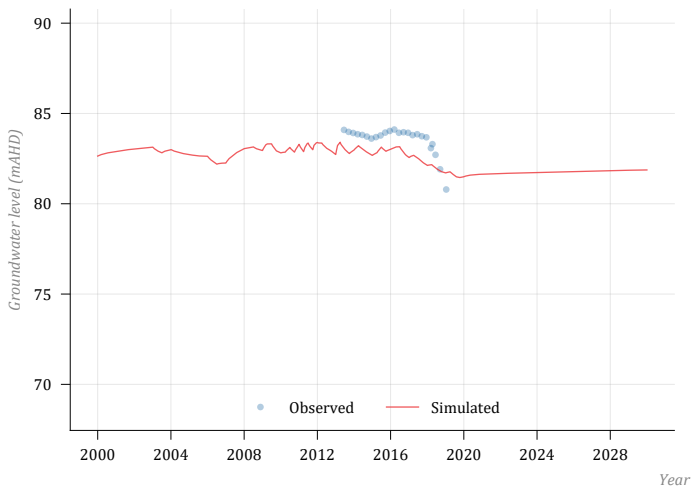
BC-SP06



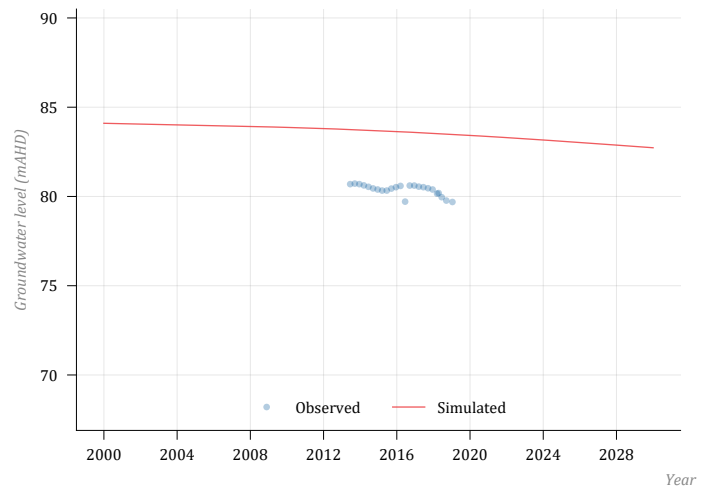
BC-SP07



BC-SP08

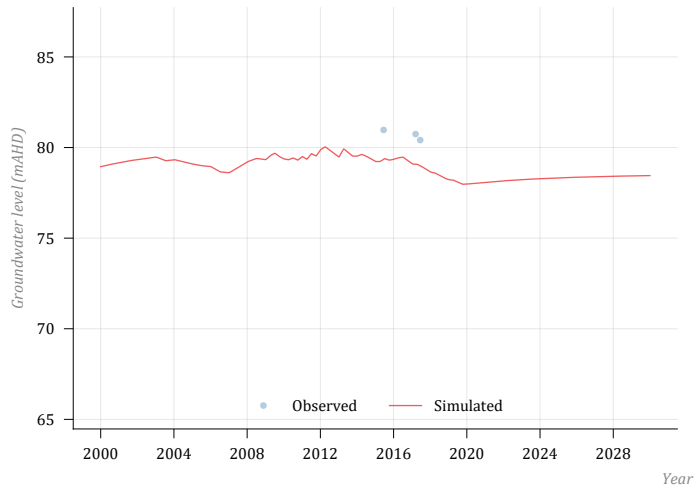


BC-SP09

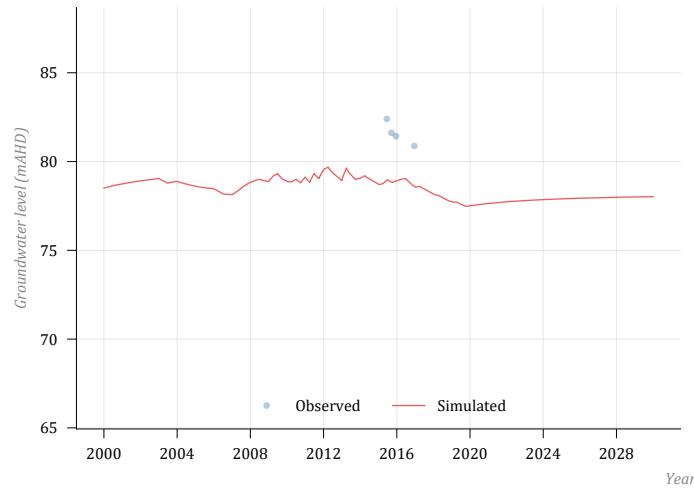


Alluvium_Yorks_Ck

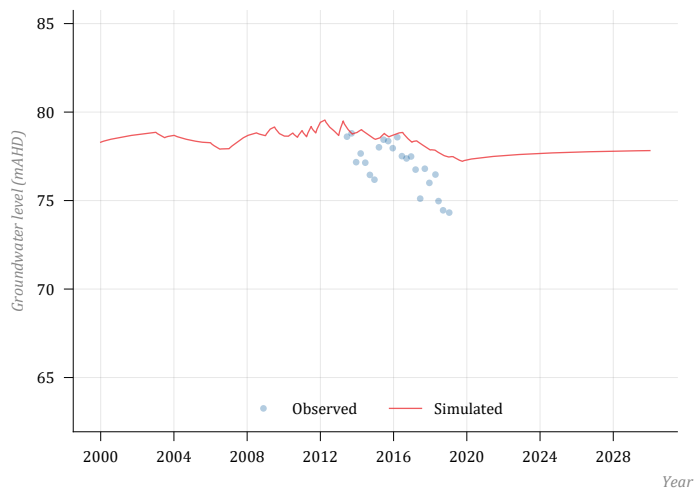
BC-SP18



BC-SP19

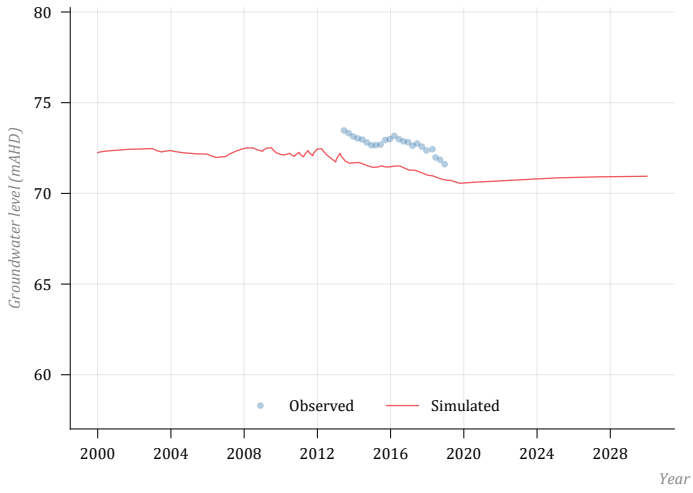


GNPS-06

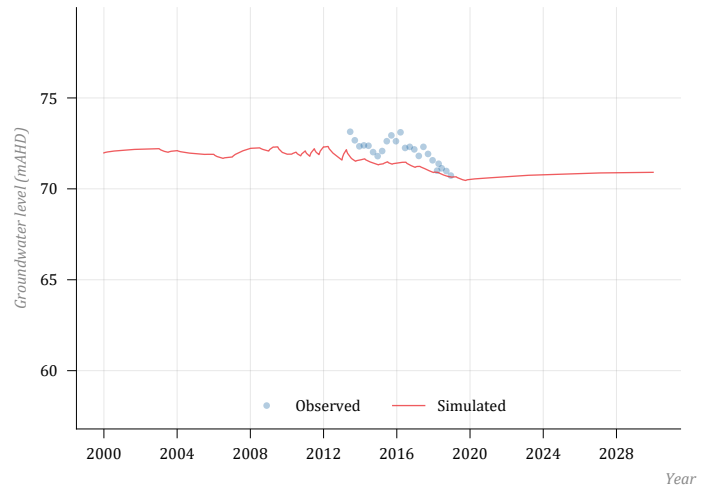


Alluvium_Swamp_Ck

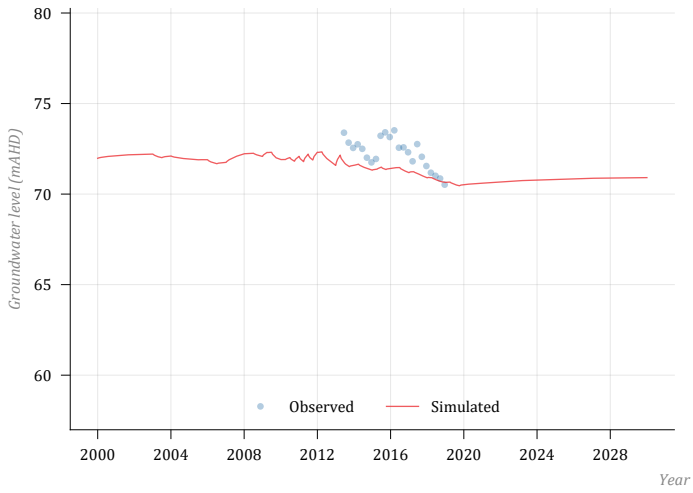
BC-SP10



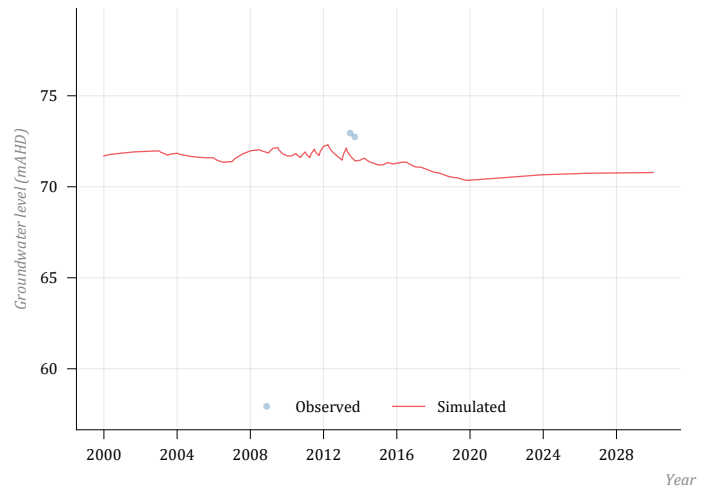
BC-SP11



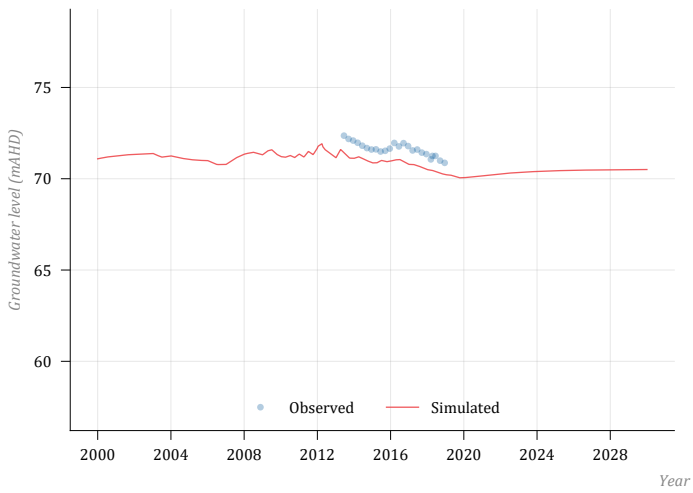
BC-SP12



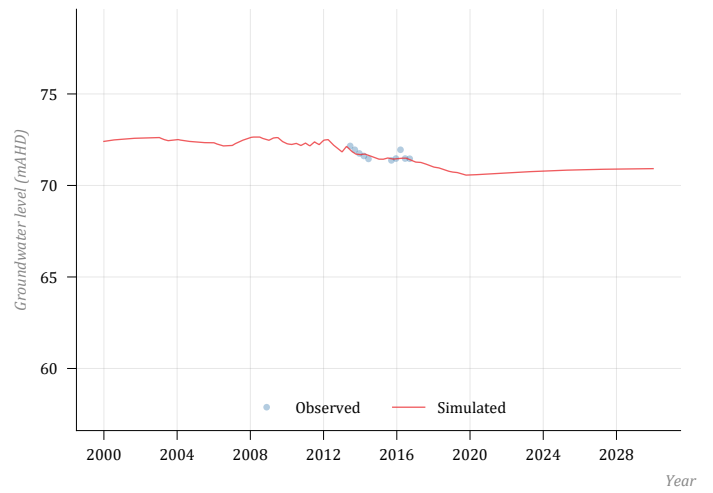
BC-SP13



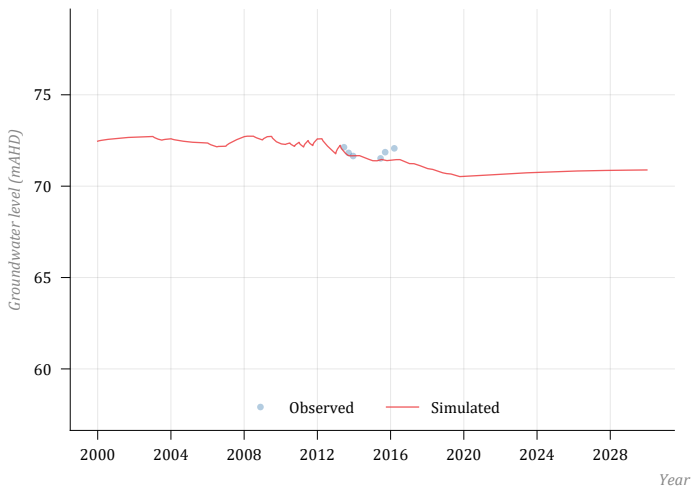
BC-SP14



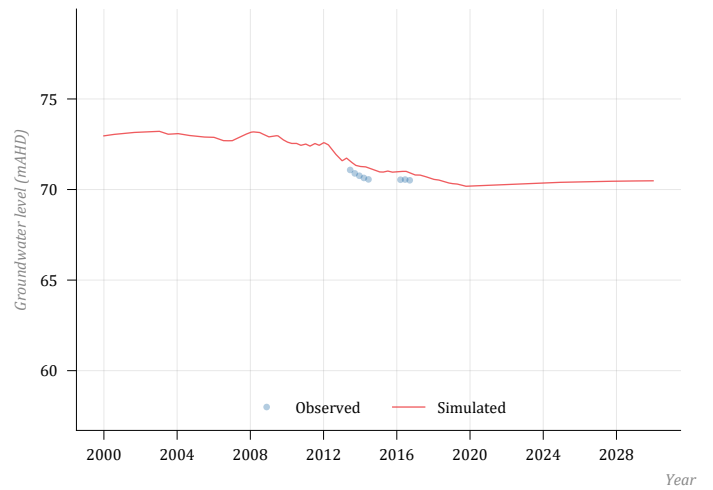
BC-SP15



BC-SP16

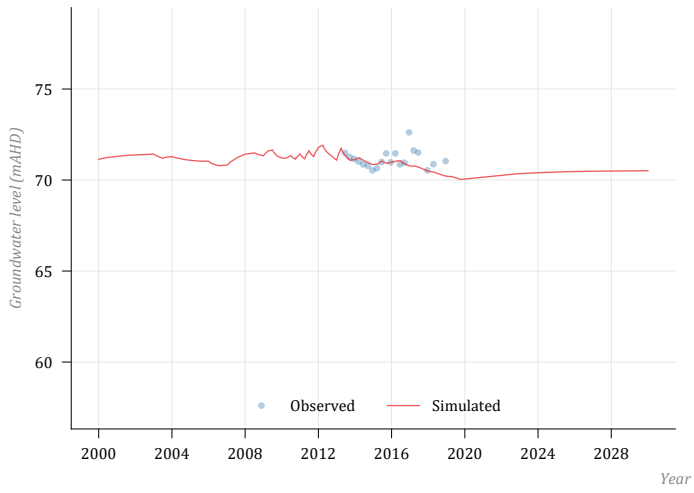


BC-SP17

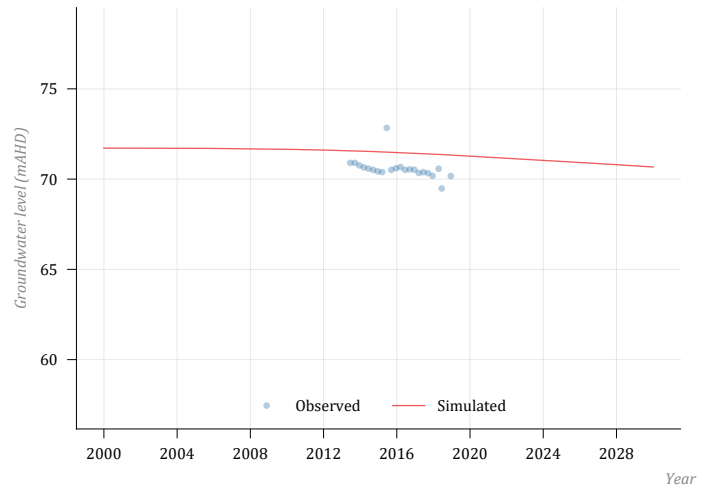


Alluvium_Swamp_Ck

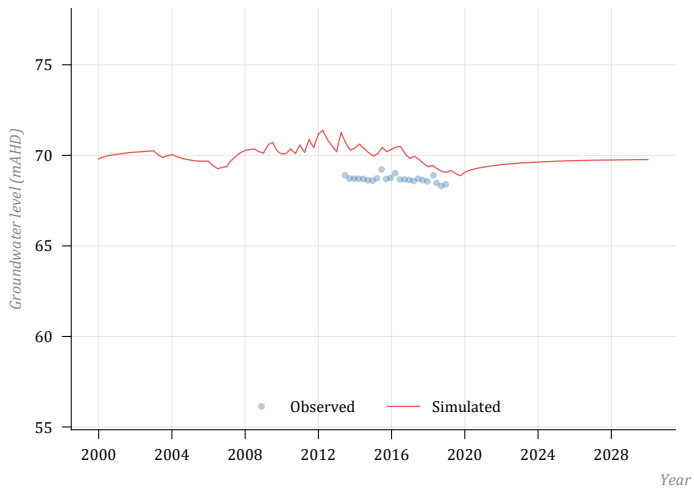
BC-SP20



BC-SP21



BC-SP22

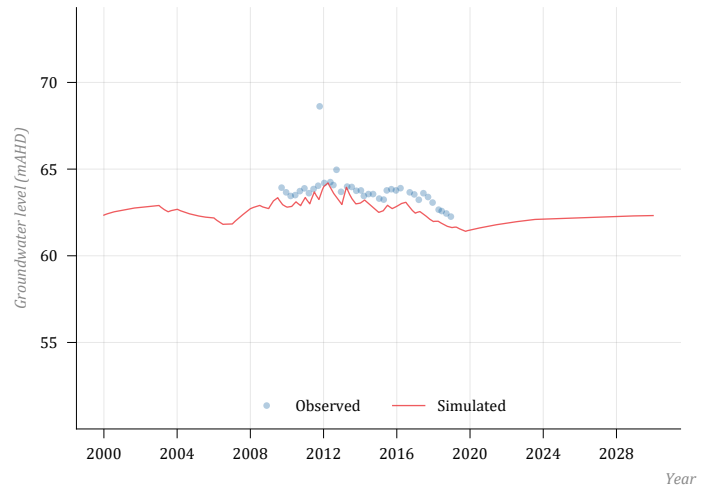


Alluvium_Bowmans_Ck_midstream

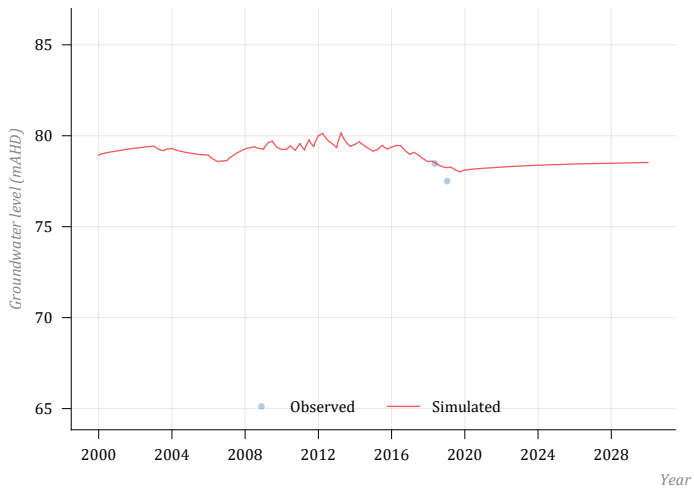
GA1



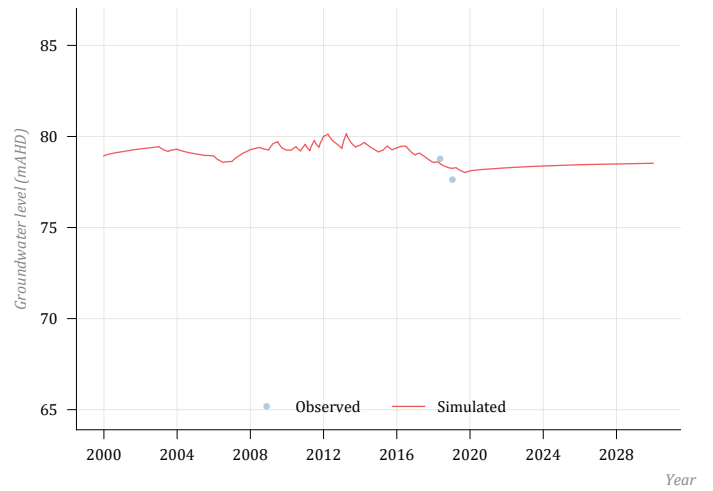
GA2



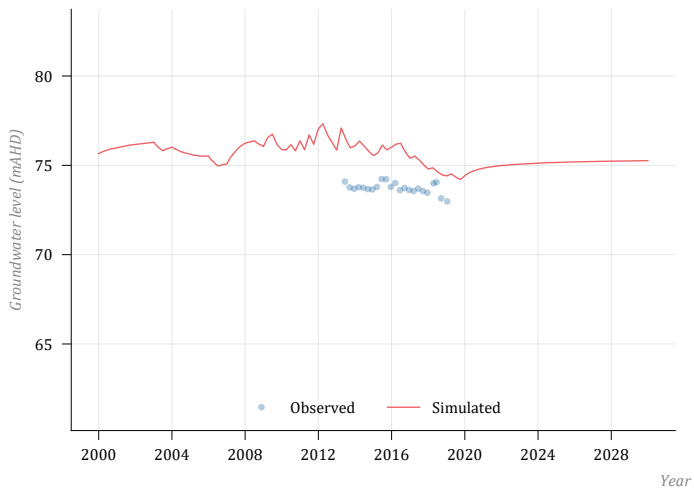
GNP10D



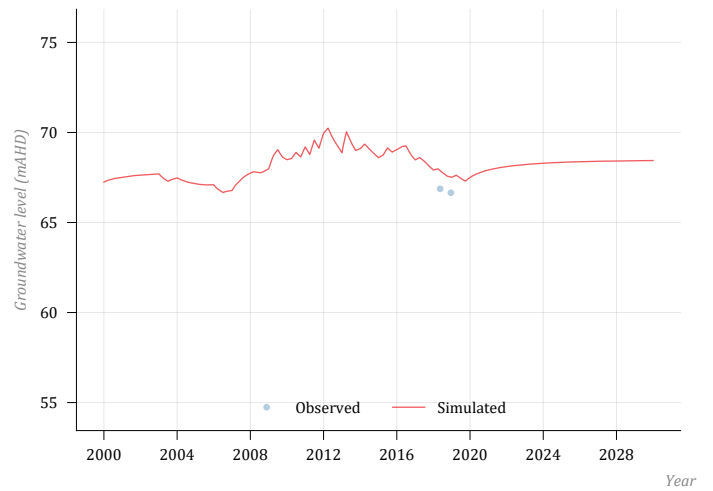
GNP10S



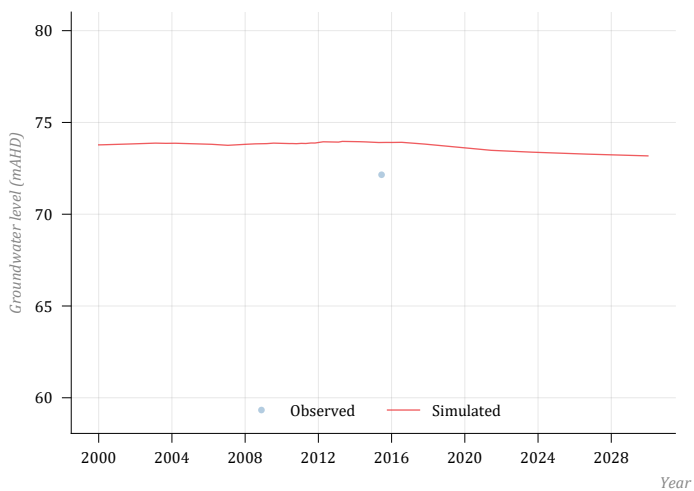
GNPS-02



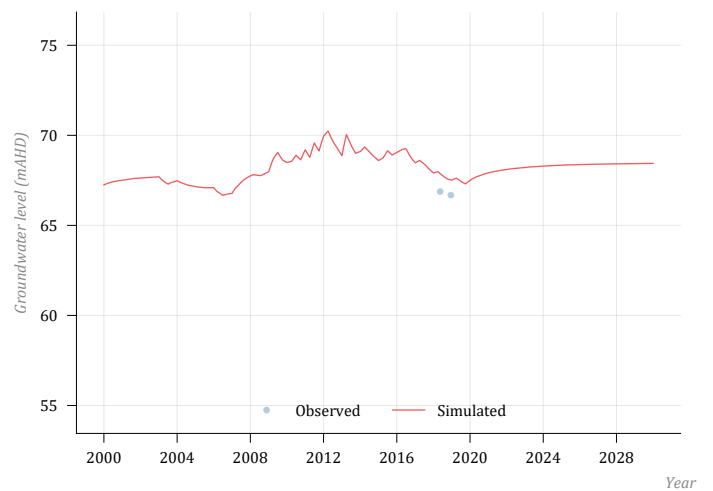
GNP11D



GNPS-05

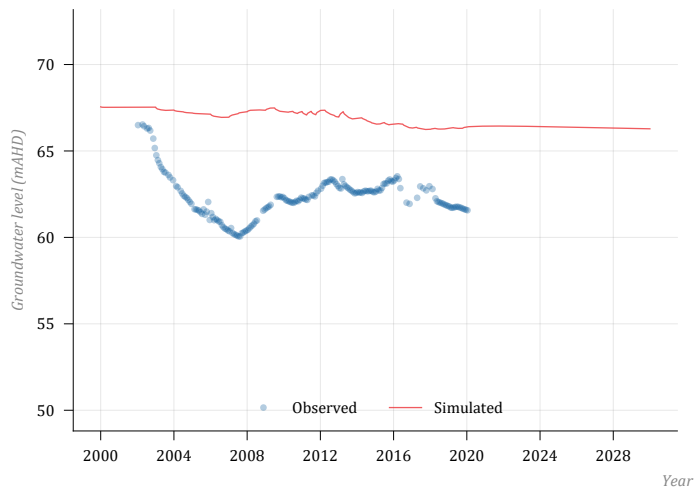


GNP11S

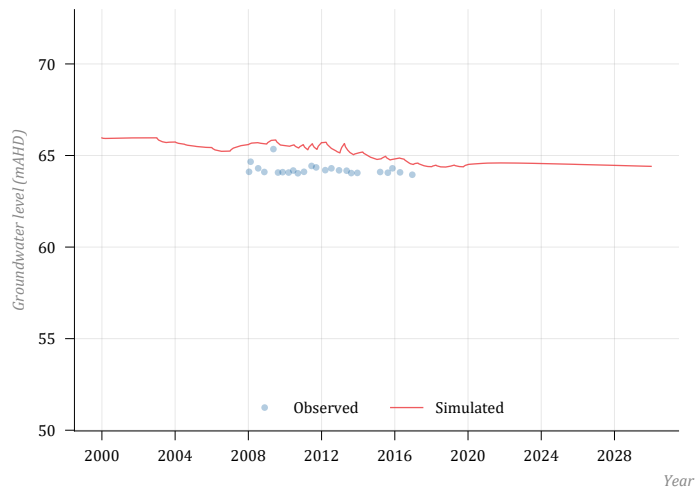


Alluvium_MainCk_StationCk_GlenniesCk

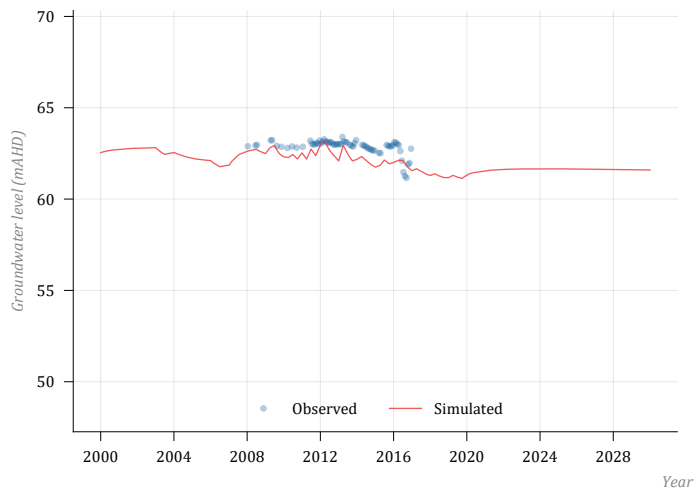
GCP11



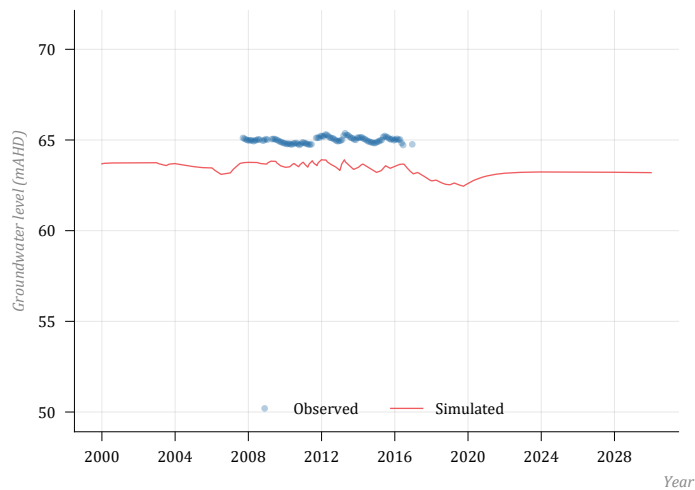
GCP25



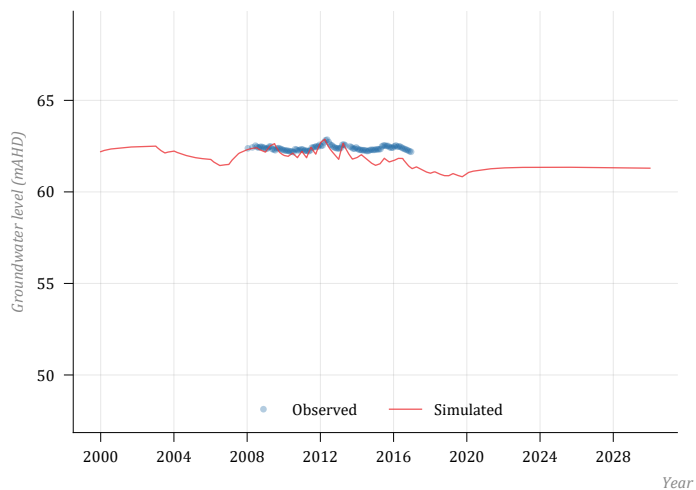
GCP28



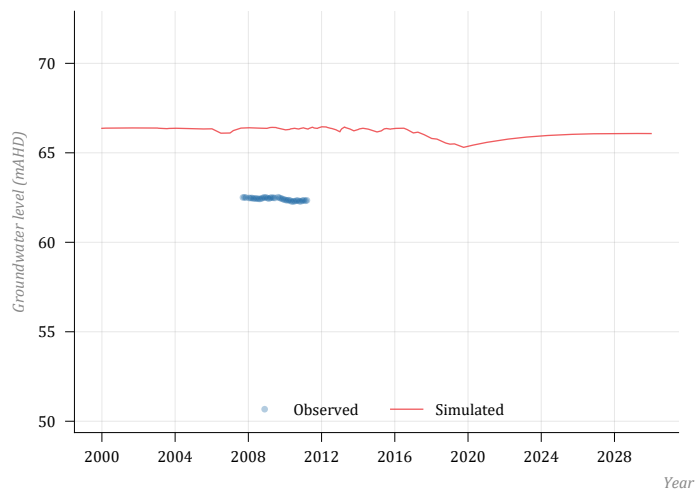
GCP29



GCP30

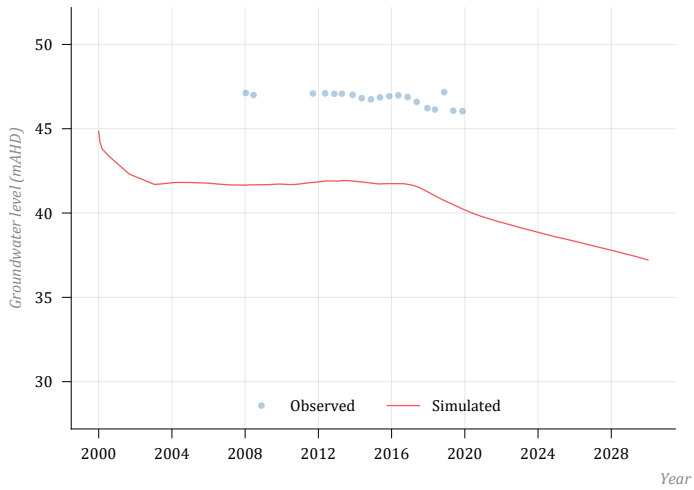


GCP31

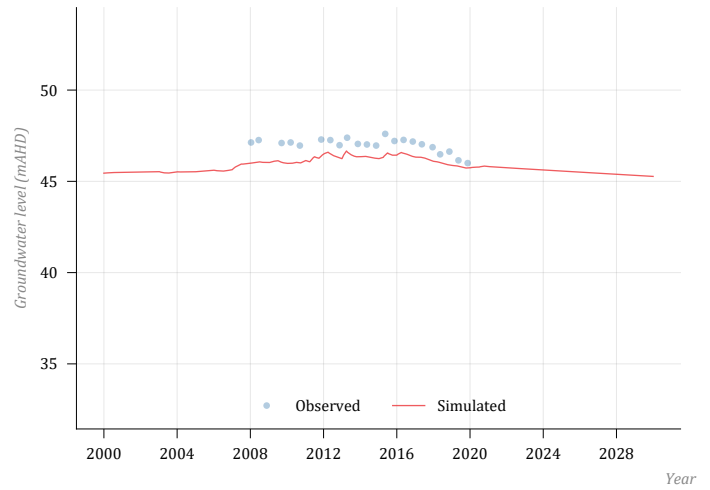


L10_Coal_Blakef_GlenM_WoodH_South

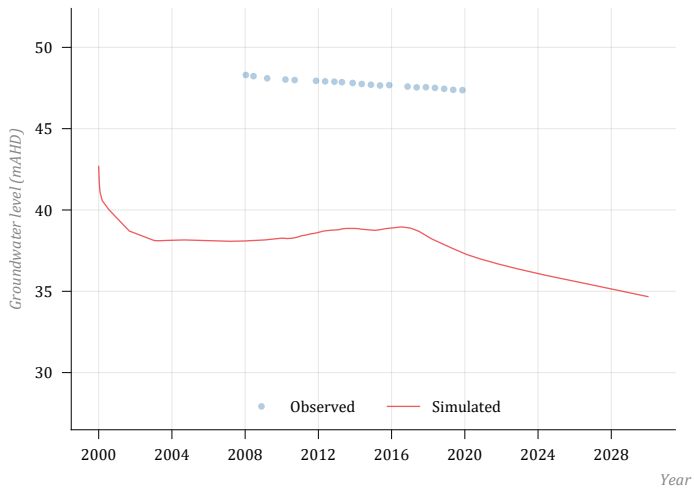
B631_WDH



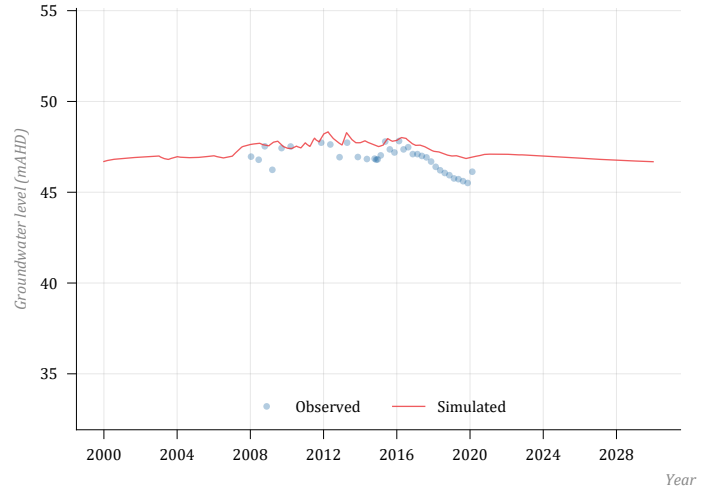
C122_WDH



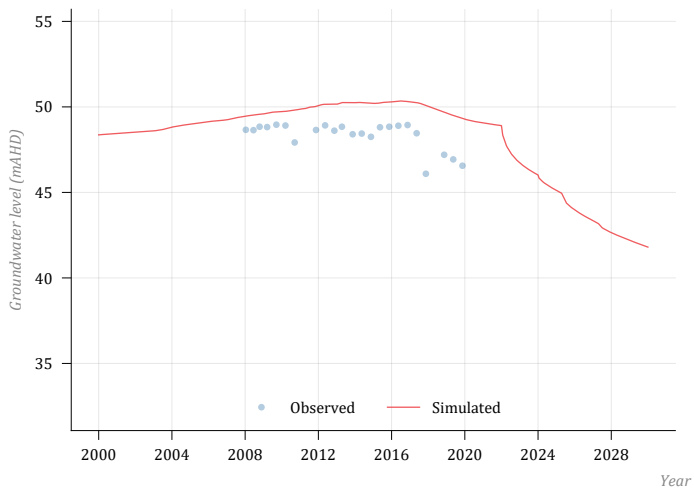
C130_WDH



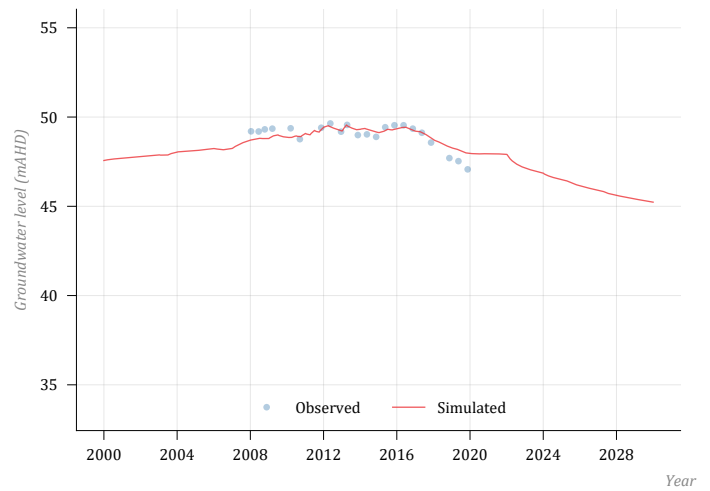
C317_WDH



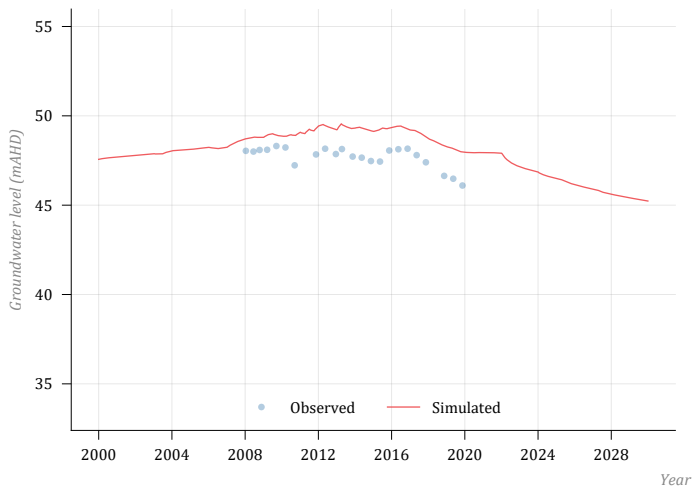
C809_WDH



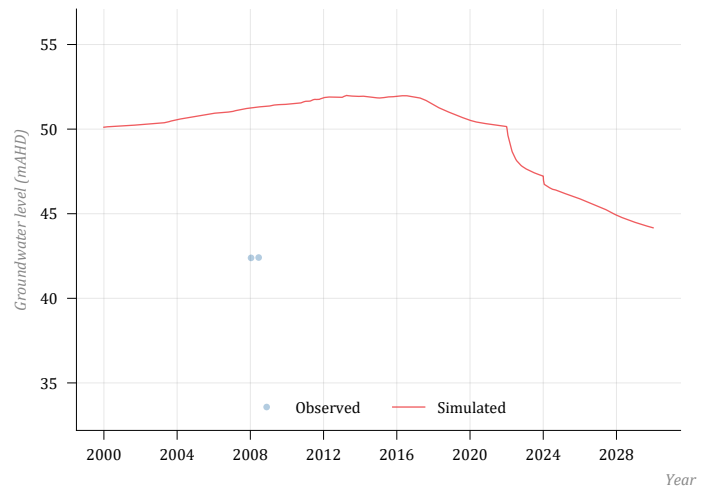
D010_GM



D010_WDH

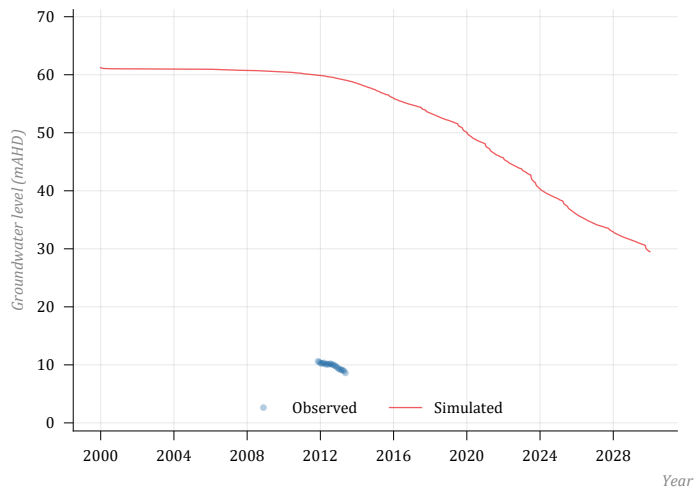


D406_WDH



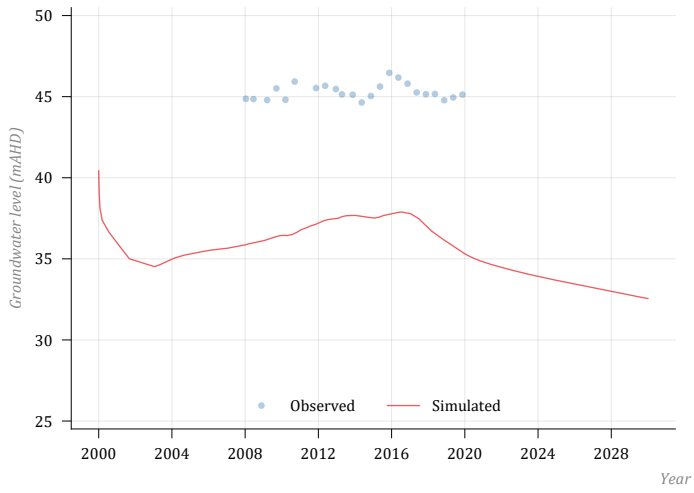
L10_Coal_Blakef_GlenM_WoodH_South

WOH2141B

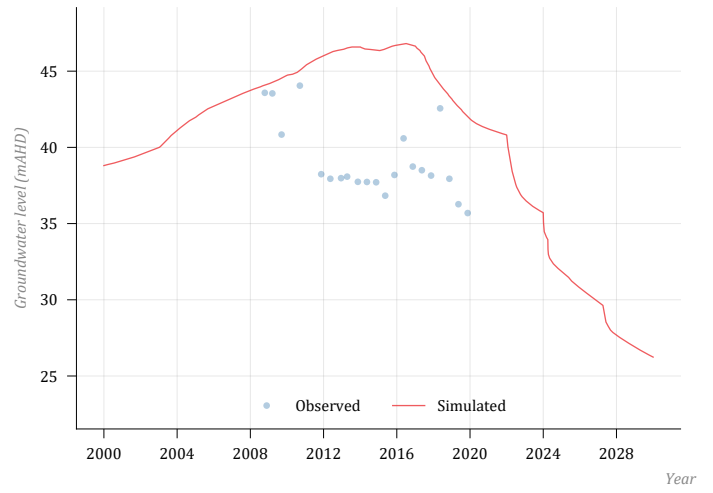


L12_Coal_Blakef_GlenM_WoodH_South

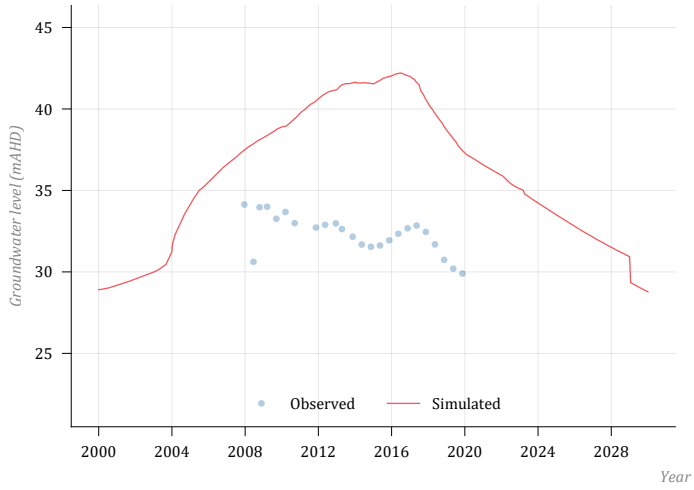
C130_AFS1



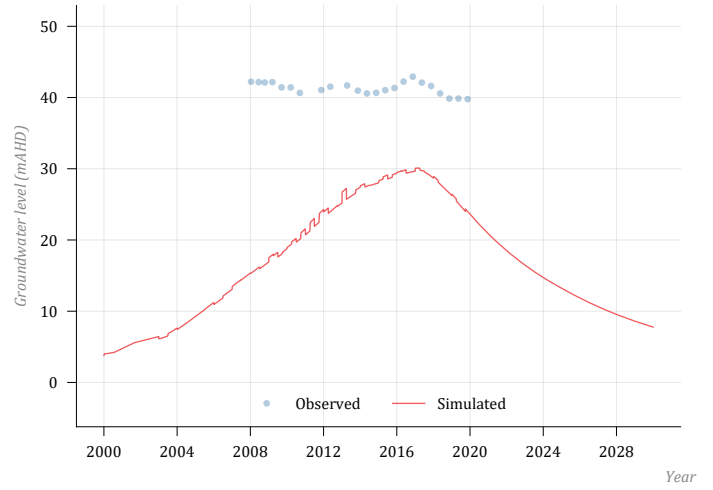
D406_AFS



D510_AFS

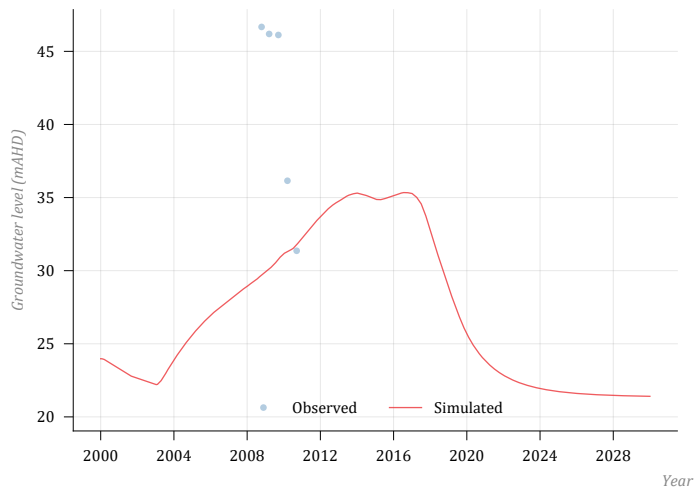


D612_AFS



L13_Coal_Blakef_GlenM_WoodH_South

D317_WDH

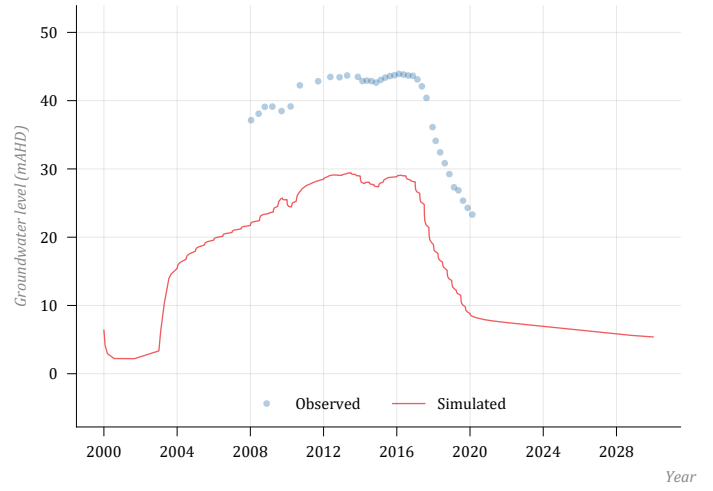


L14_Coal_Bowfield_South

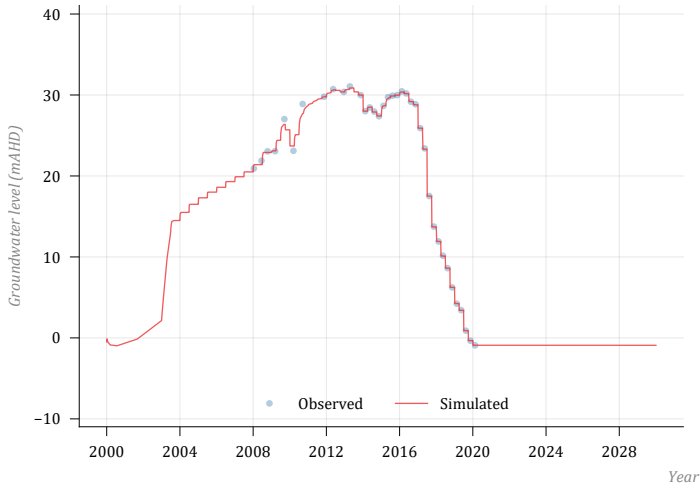
B334_BFS



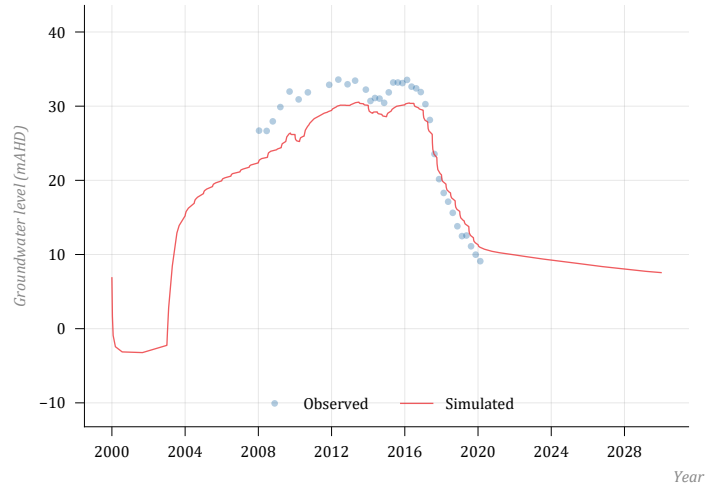
B631_BFS



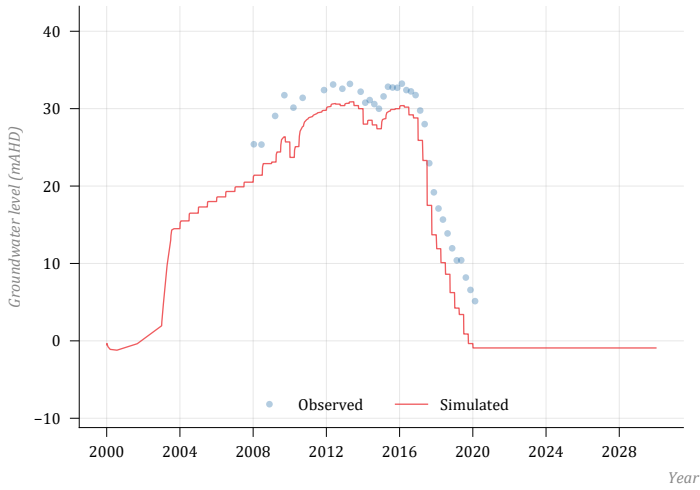
B925_BFS



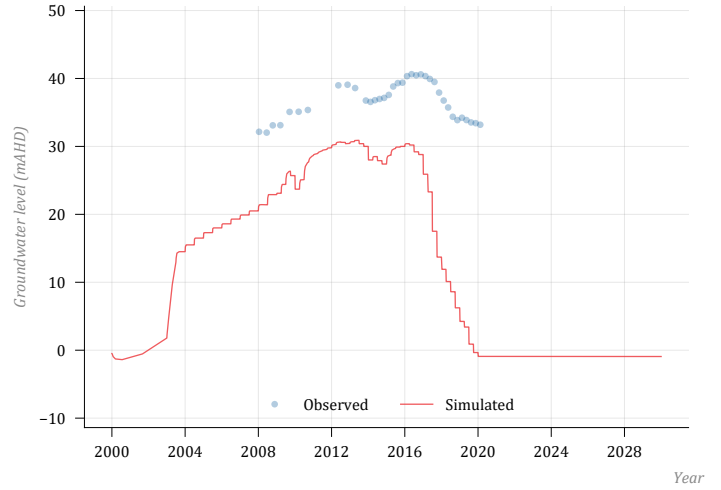
C130_BFS



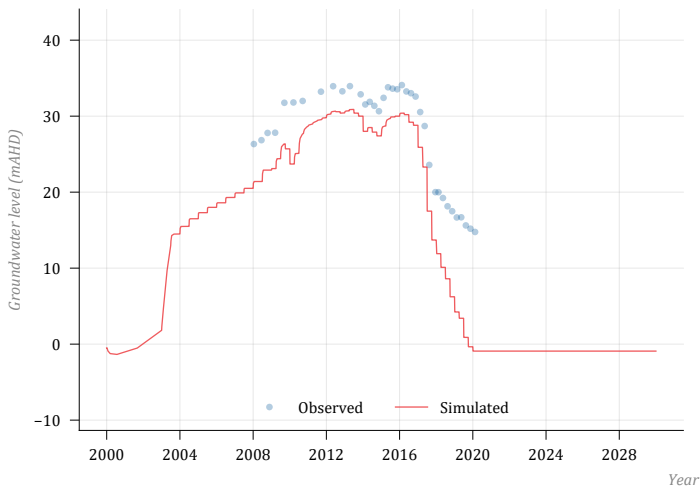
C317_BFS



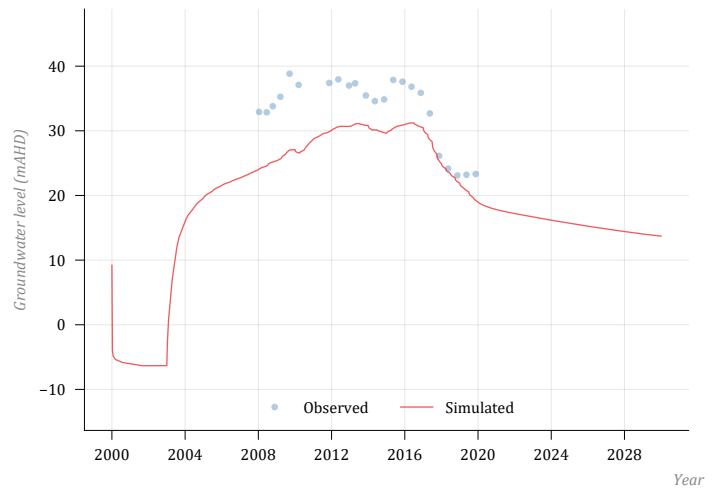
C613_BFS



C621_BFS

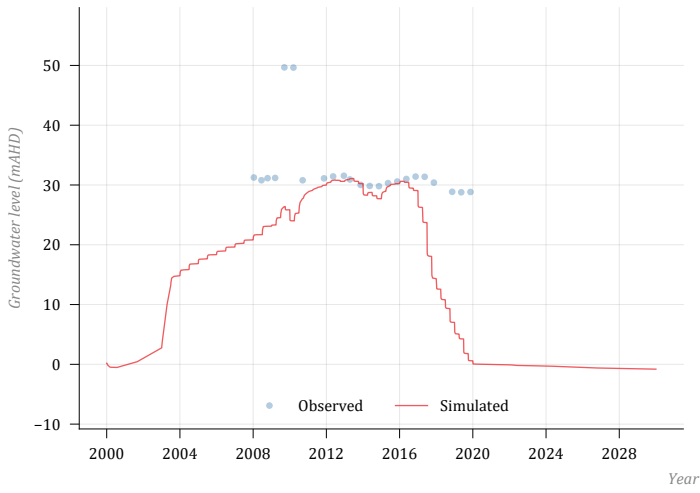


C630_BFS

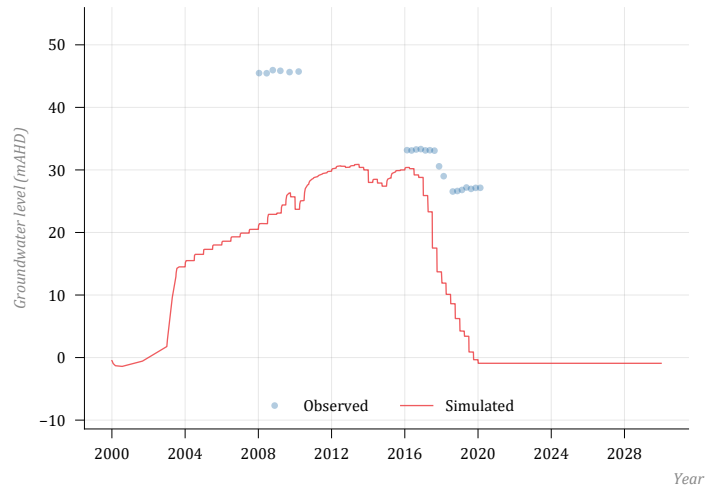


L14_Coal_Bowfield_South

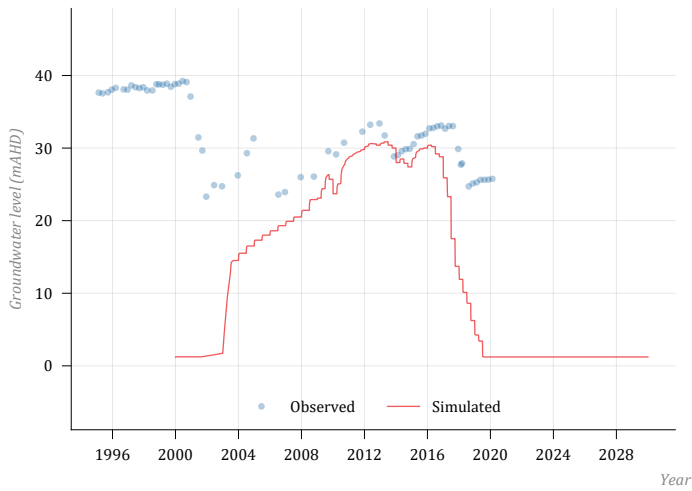
D010_BFS



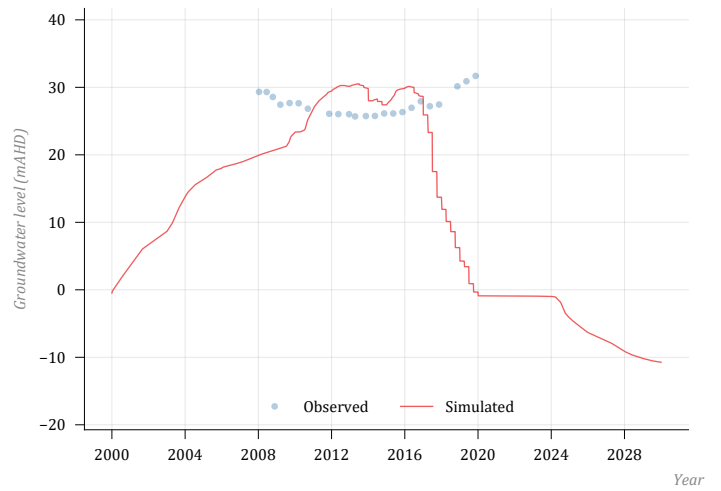
D2_WH236



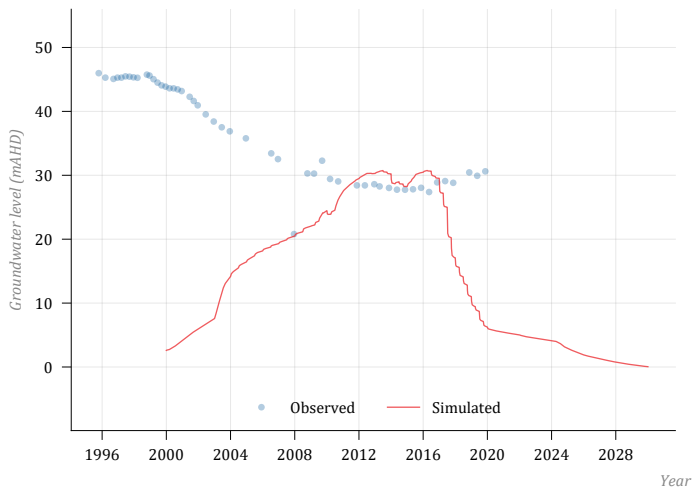
D317_BFS



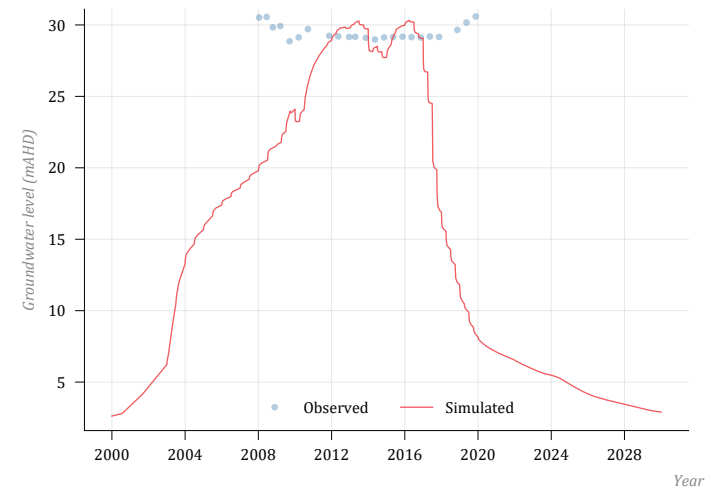
D406_BFS



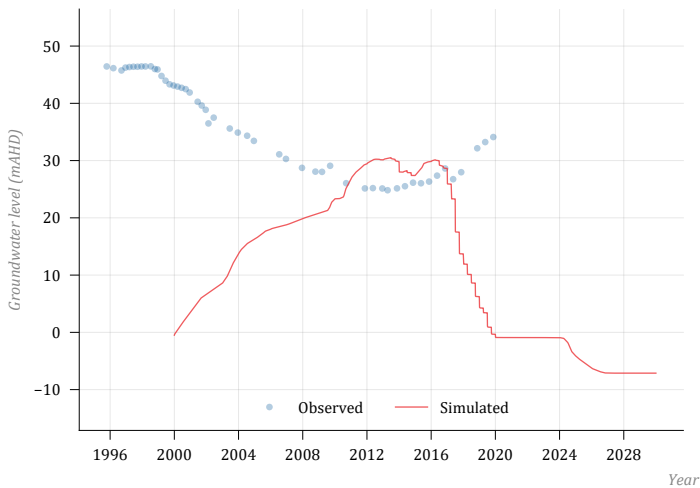
D510_BFS



D612_BFS

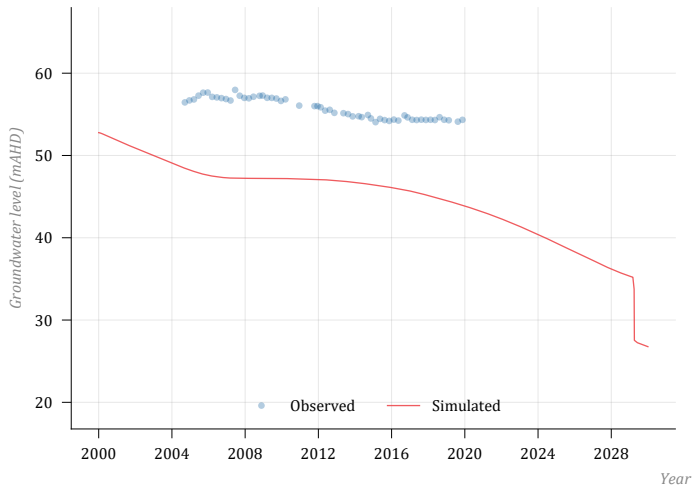


D807_BFS

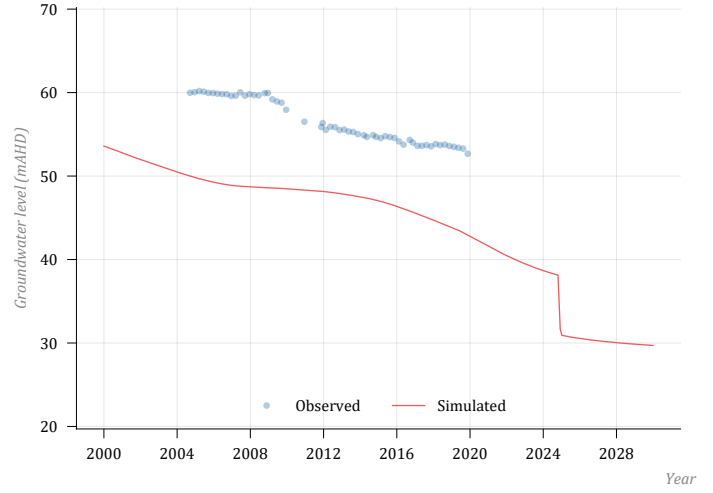


L17_Interburden_aboveMtArthur_HVO

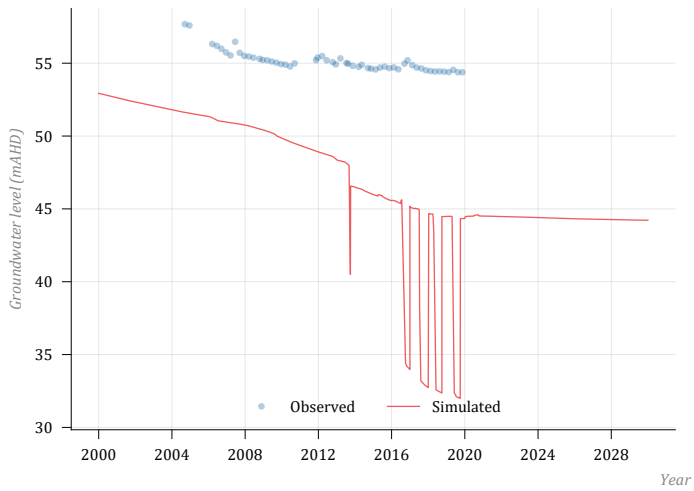
BZ1-1



BZ3-1



HG2

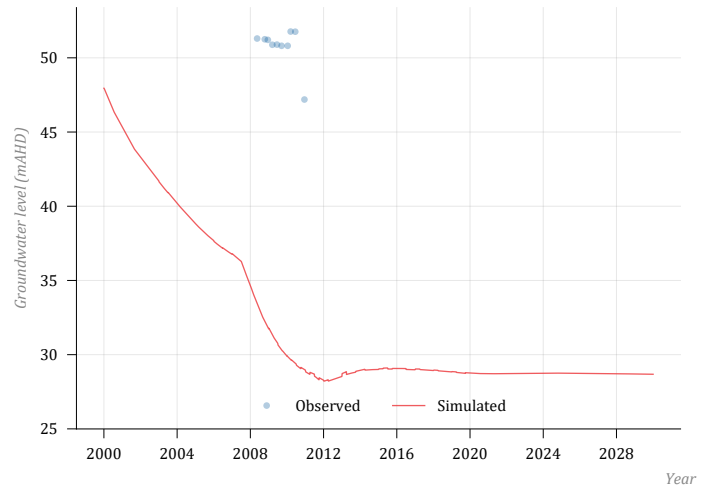


L18_Coal_MtArthur_HVO

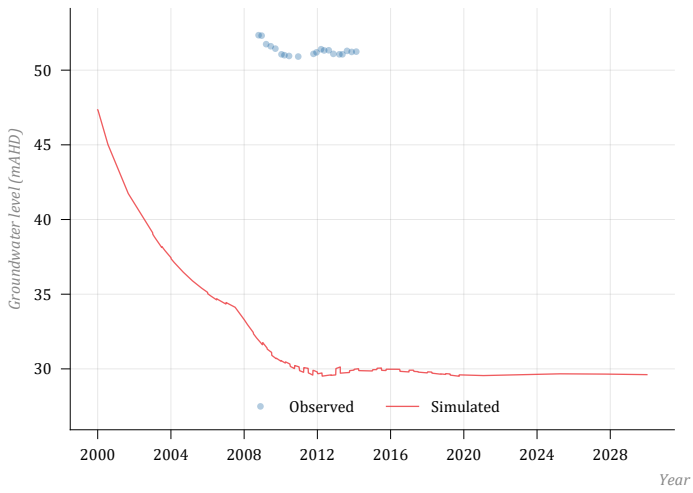
BC1A



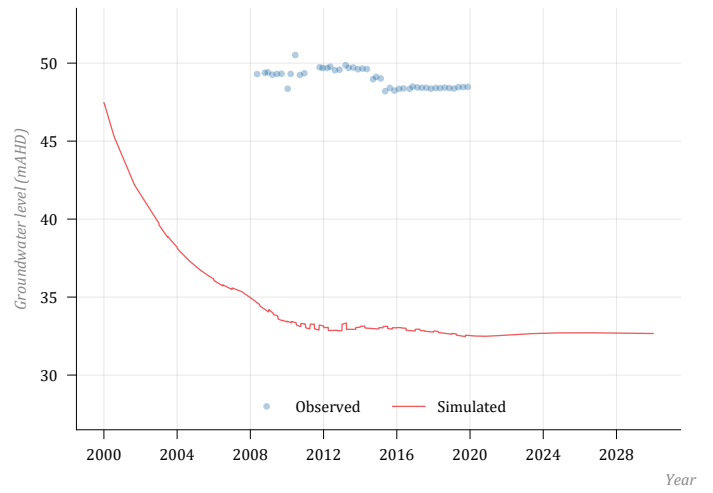
BUNC39A_D



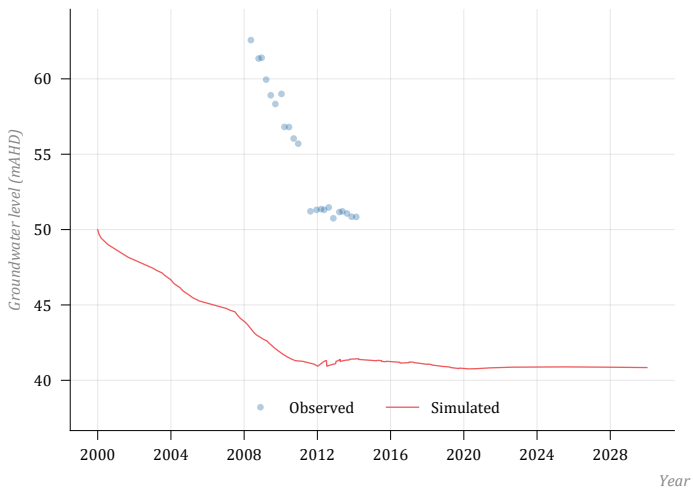
BUNC44D



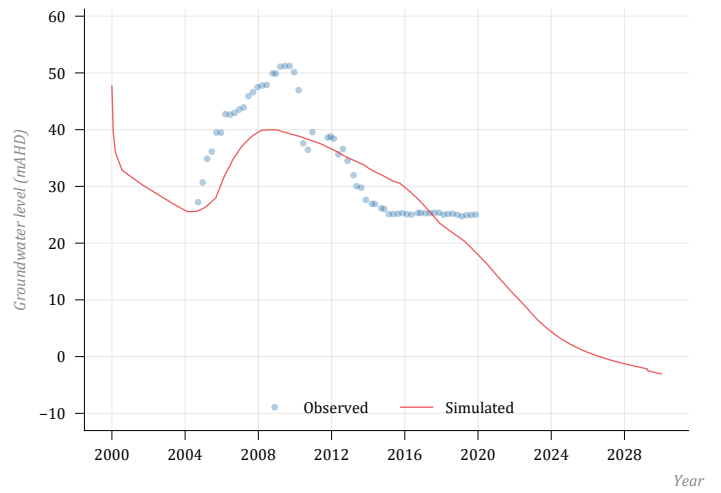
BUNC45D



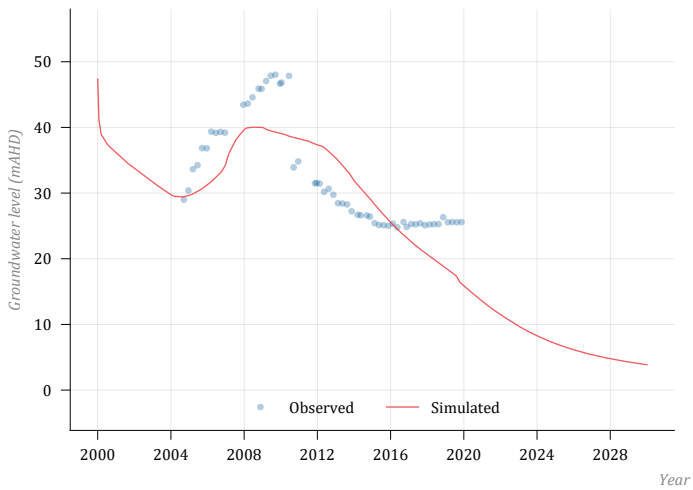
BUNC46D



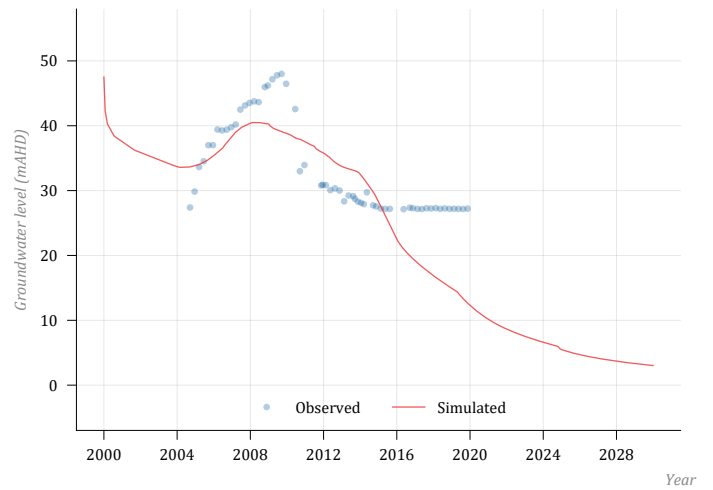
BZ1-3



BZ2A_1

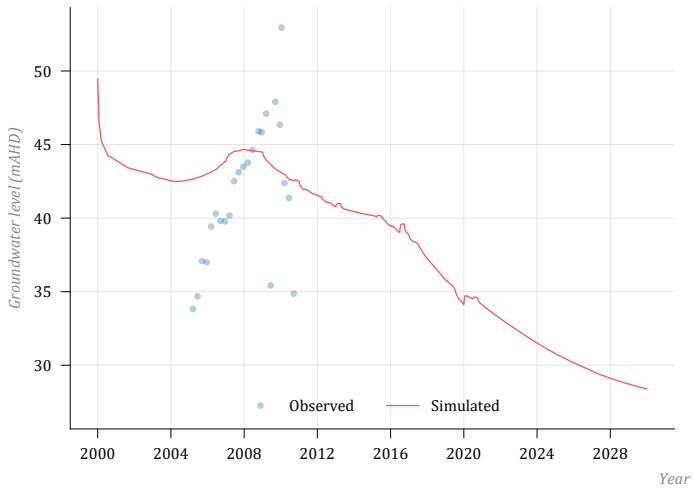


BZ3-3

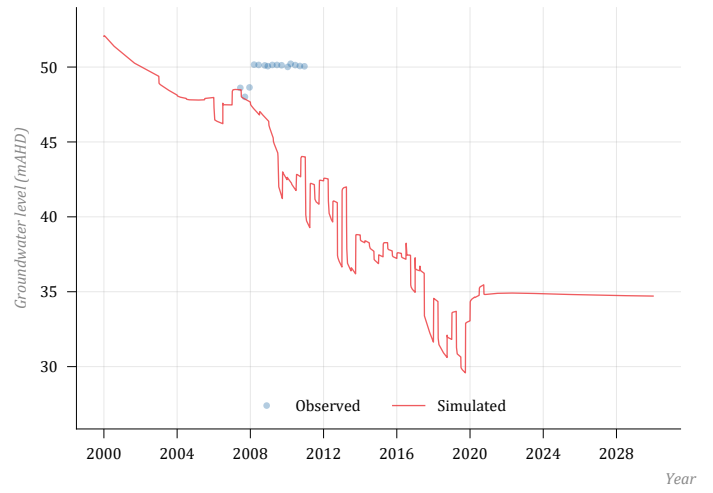


L18_Coal_MtArthur_HVO

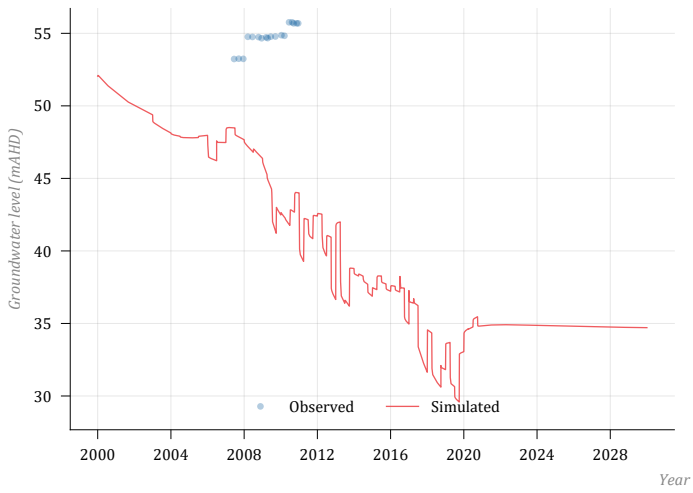
BZ4A_2



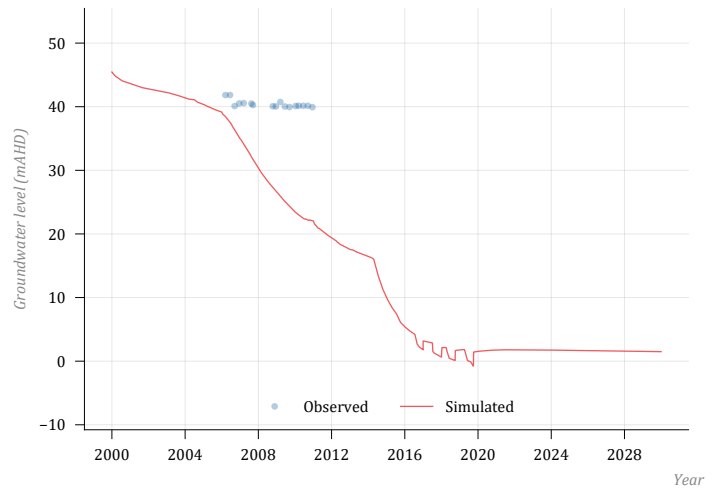
BZ5-1



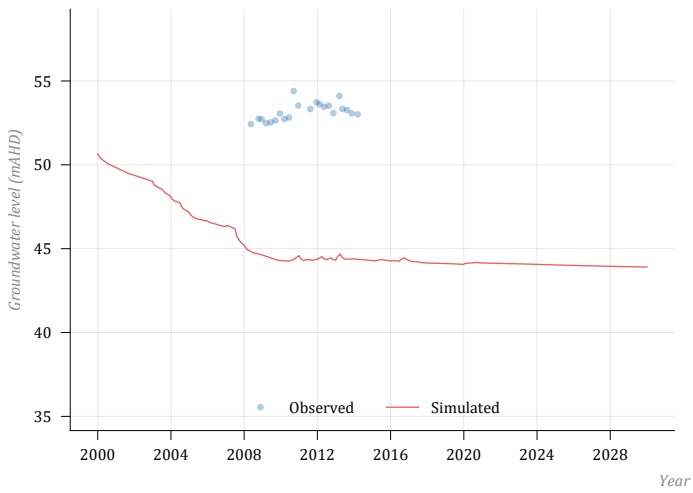
BZ5-2



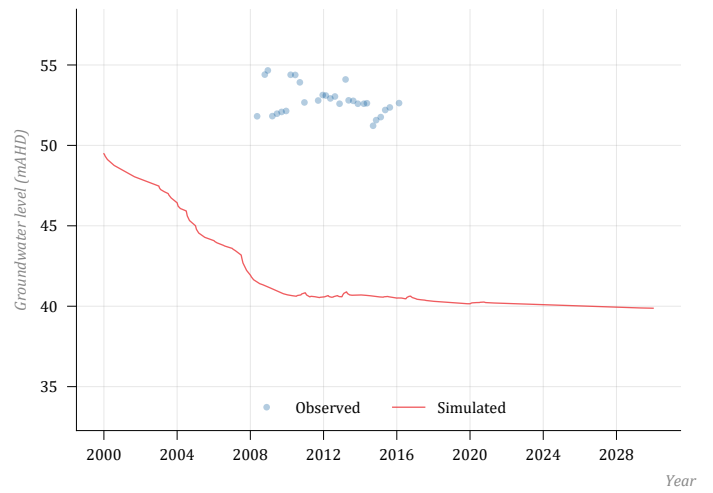
BZ8-3



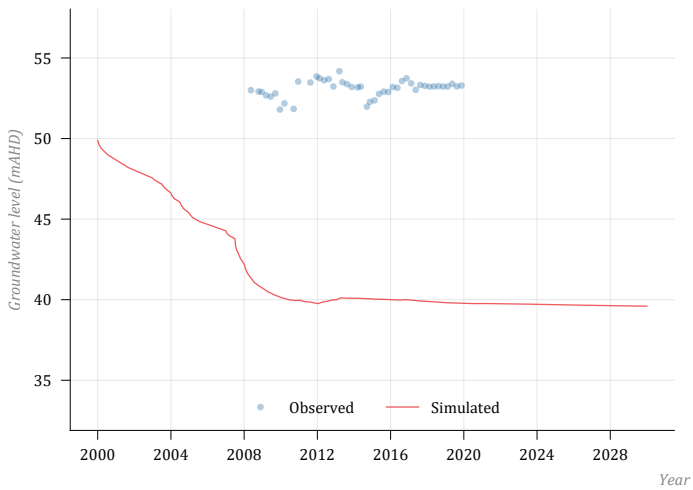
CHPZ13D



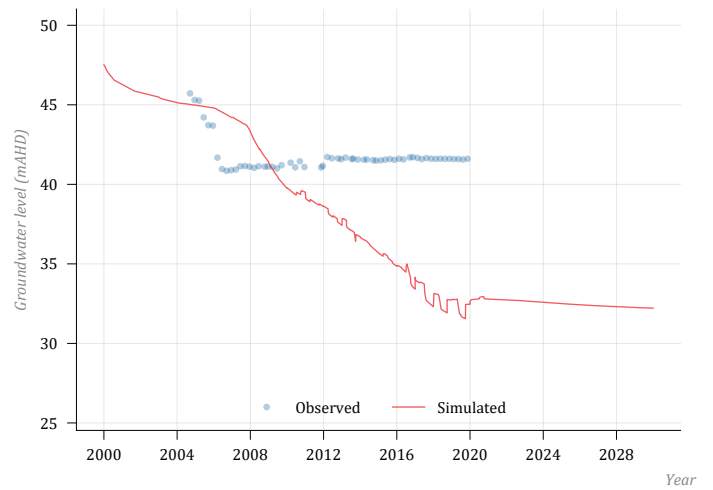
CHPZ14D



CHPZ3D

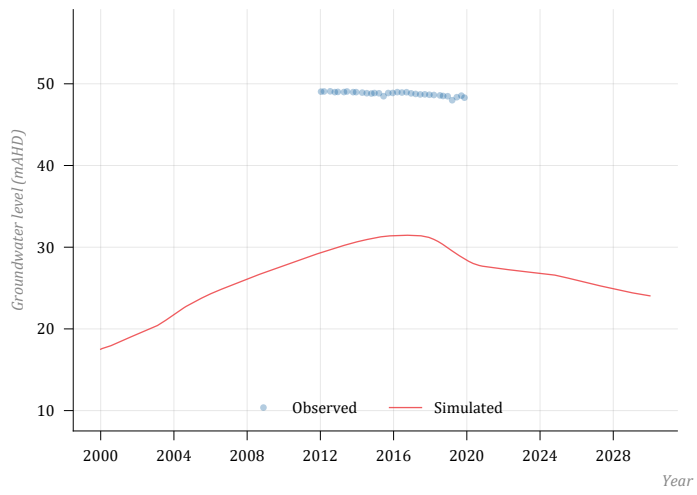


HG2A



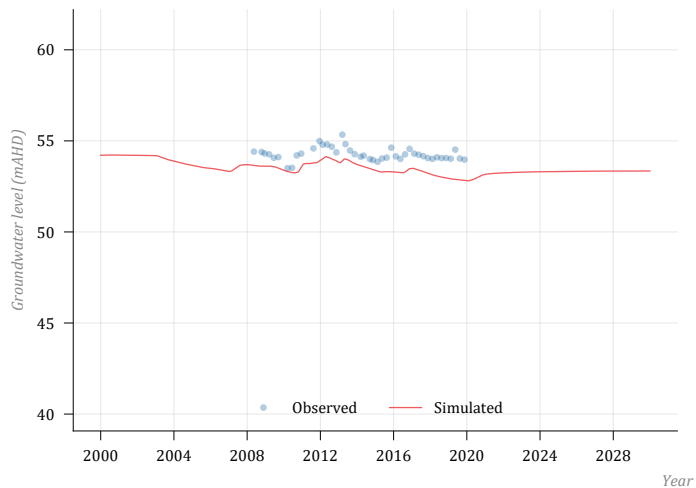
L18_Coal_MtArthur_South

SR010

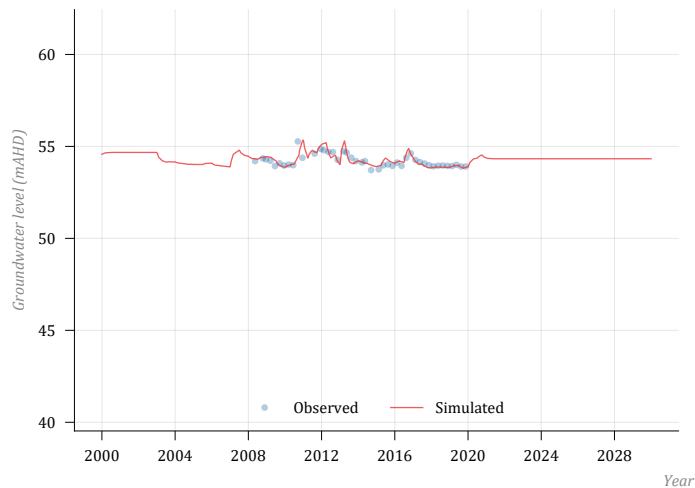


L19_Interburden_abovePiercefield_HV0

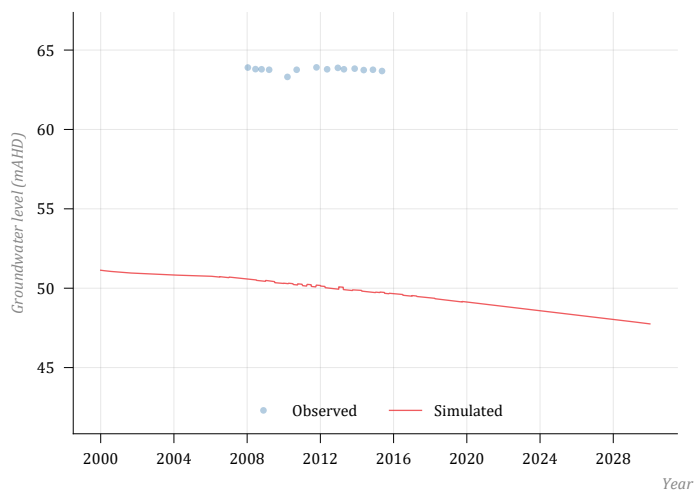
CHPZ8D



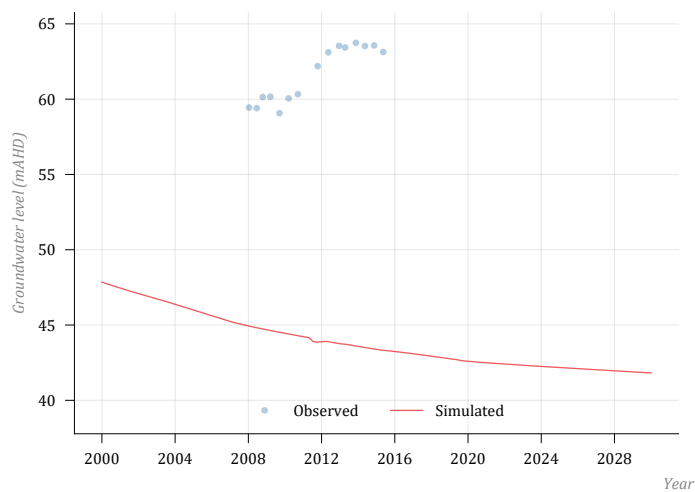
CHPZ12D



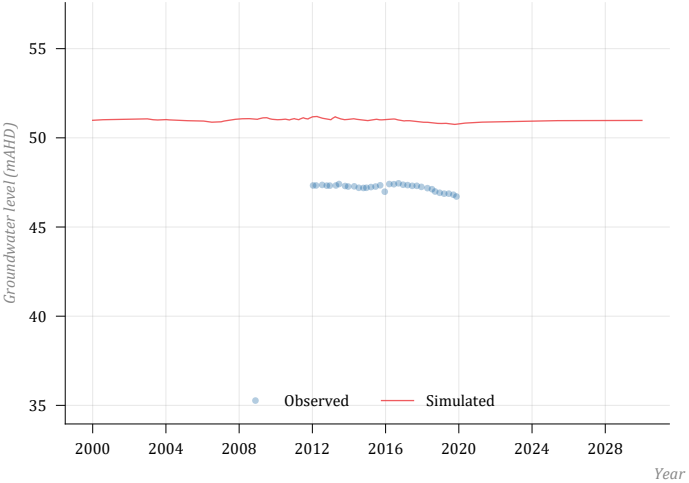
GW9702



GW9710

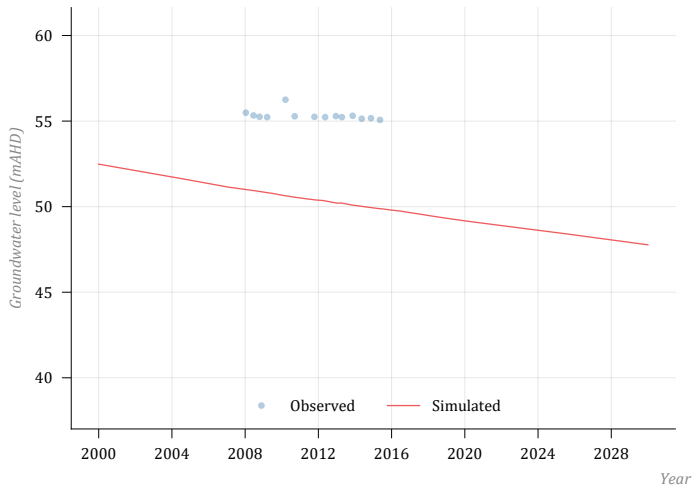


L19_Interburden_abovePiercefield_Sotheast
SR009

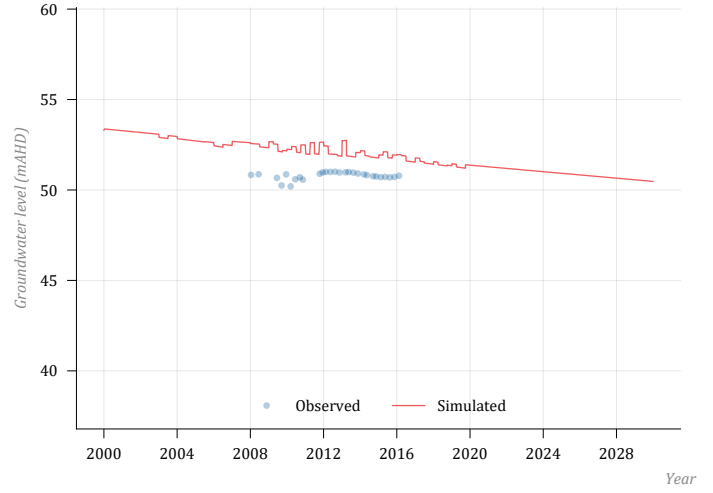


L20_Coal_Piercefield_Vaux_HVO

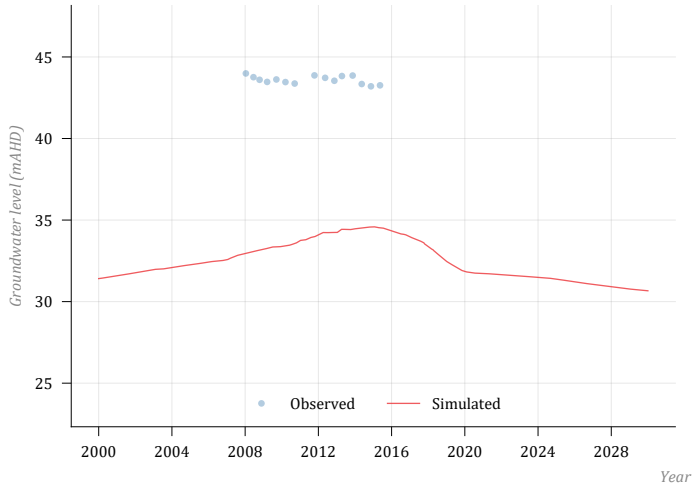
GW9701



C1_WJ039

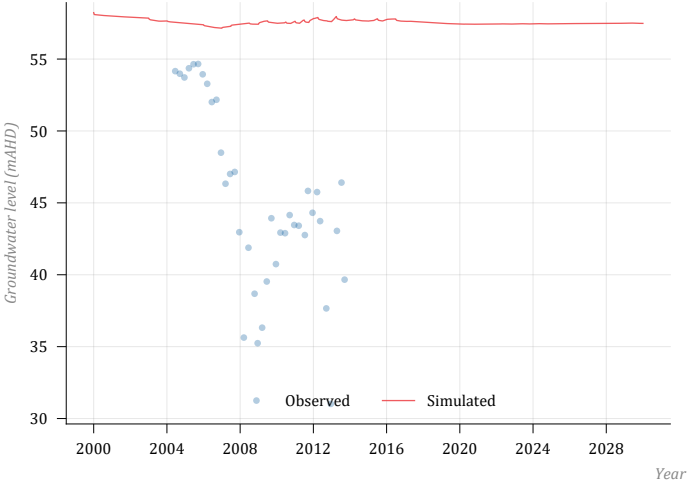


F1_WF533

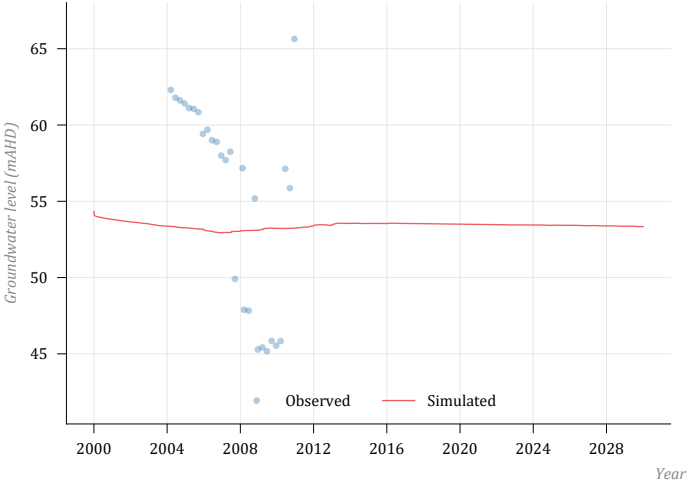


L20_Coal_Piercefield_Vaux_South

OH1126

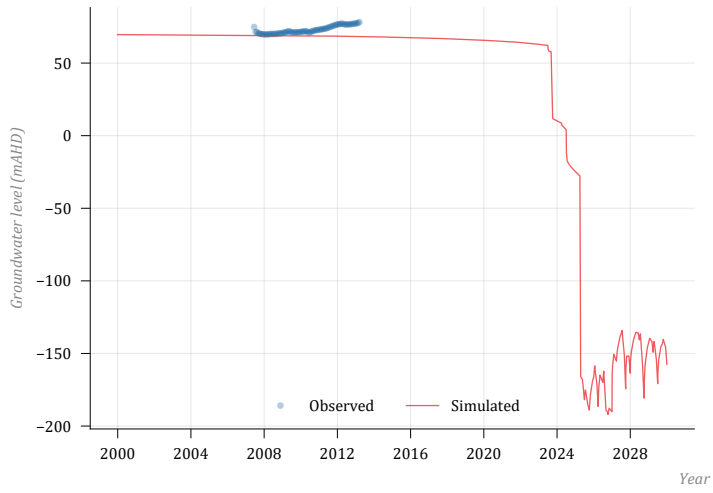


OH1137

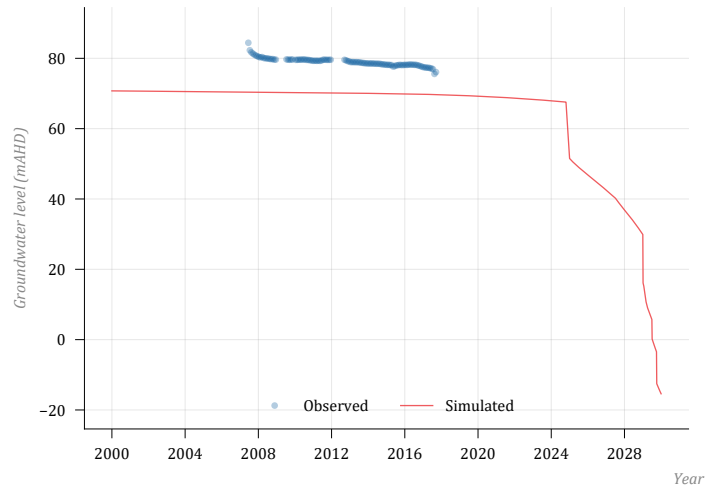


L21_Interburden_aboveBroonie_MidNorth

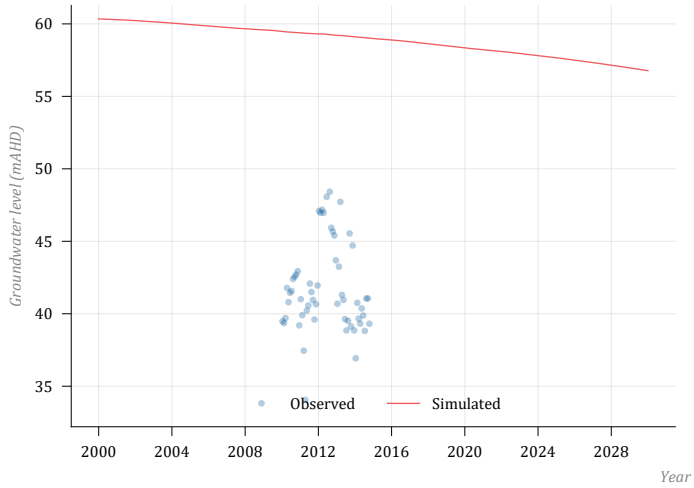
CS4655-BAY



CS4658-BAY

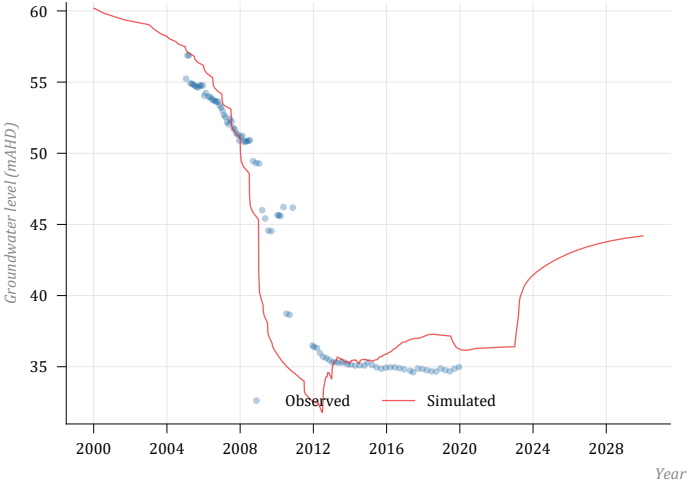


NPZ1_MID

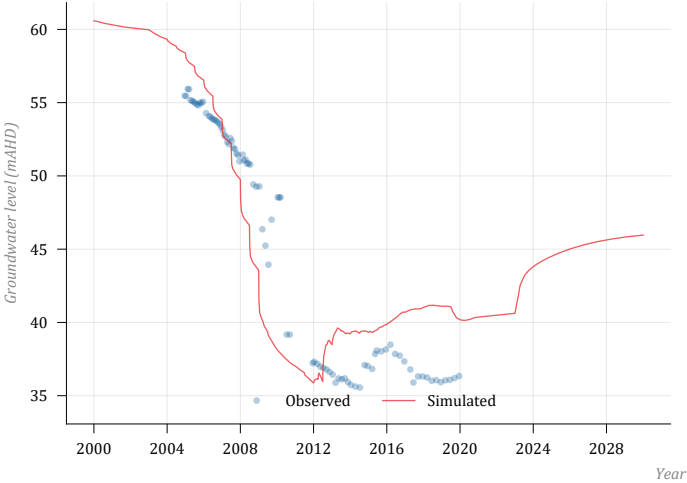


L22_Coal_Broonie_Bayswater_HV0

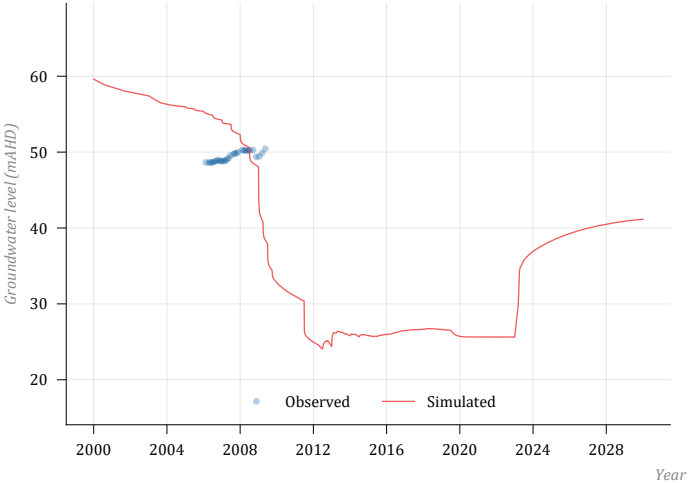
CGW52



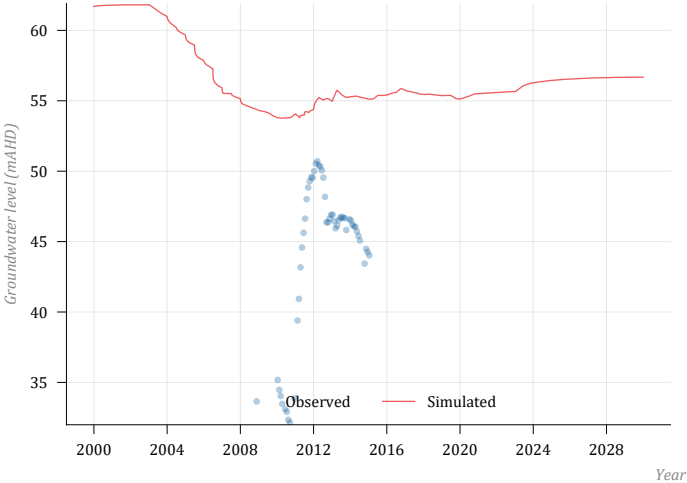
CGW53



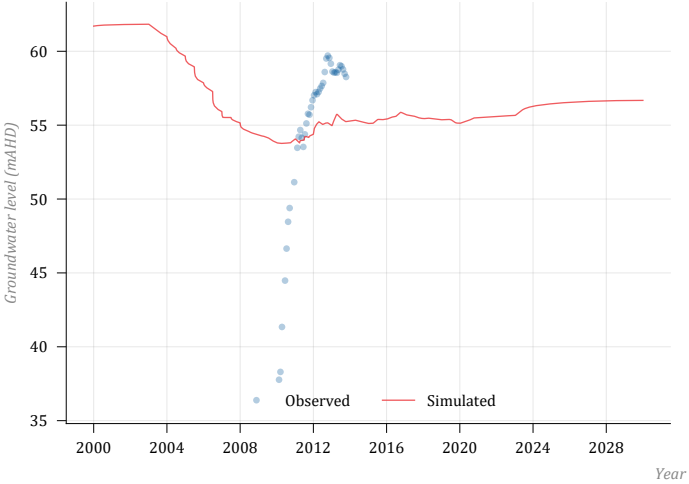
CGW54



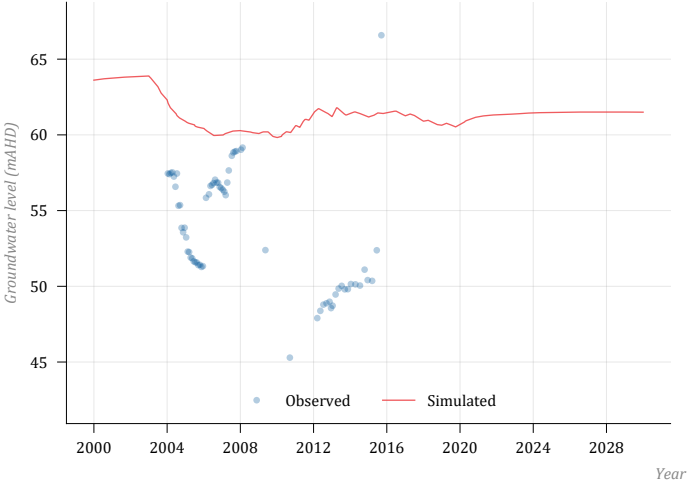
4039C_2



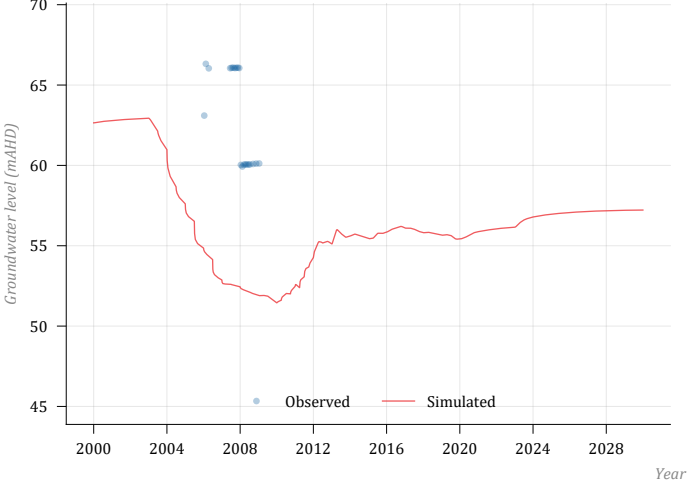
4039C_3



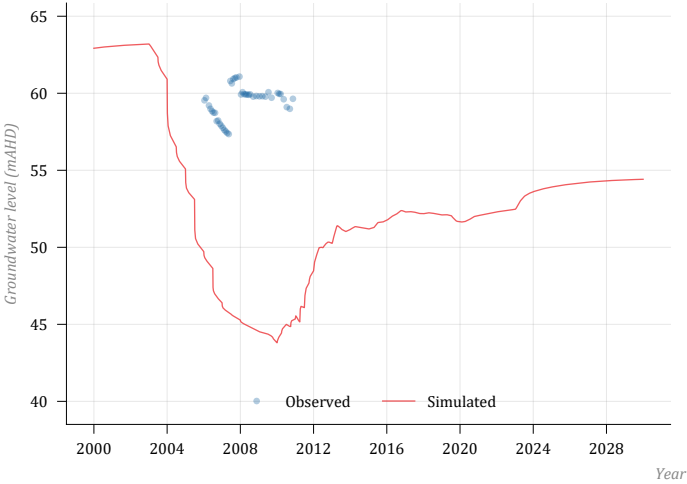
CGW45



CGW46

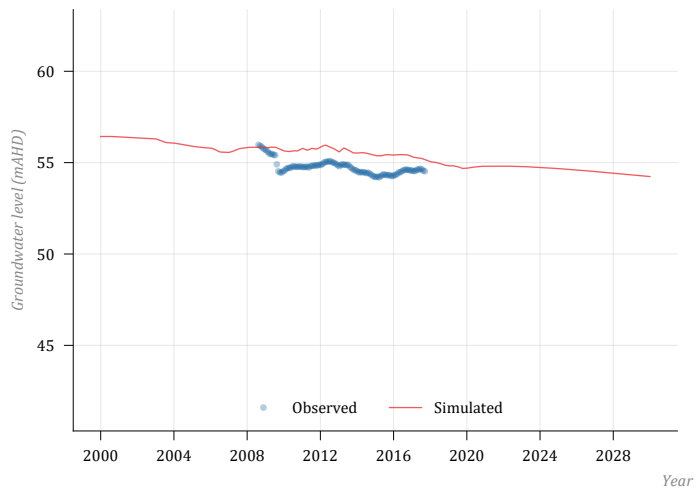


CGW47



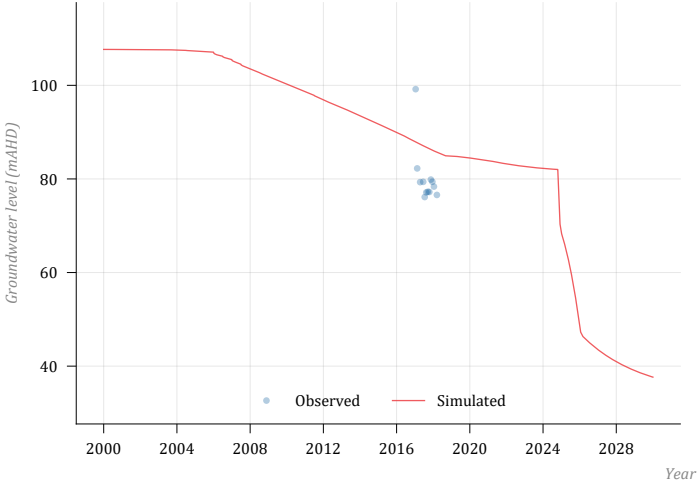
L22_Coal_Broonie_Bayswater_MidEast

RNVW1-BAY

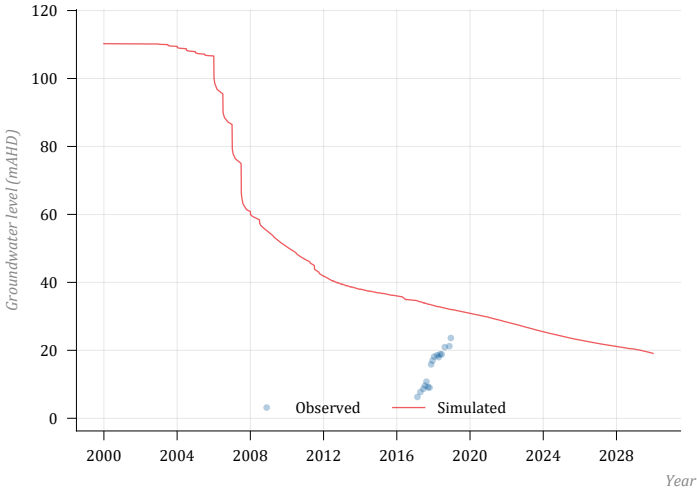


L22_Coal_Broonie_Bayswater_RavEast

BN0007

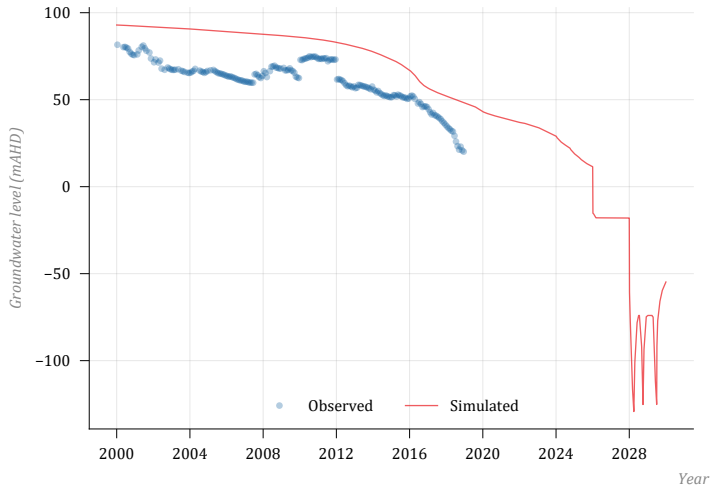


BN0009



L25_Coal_Lemington_PikesG_RavMid

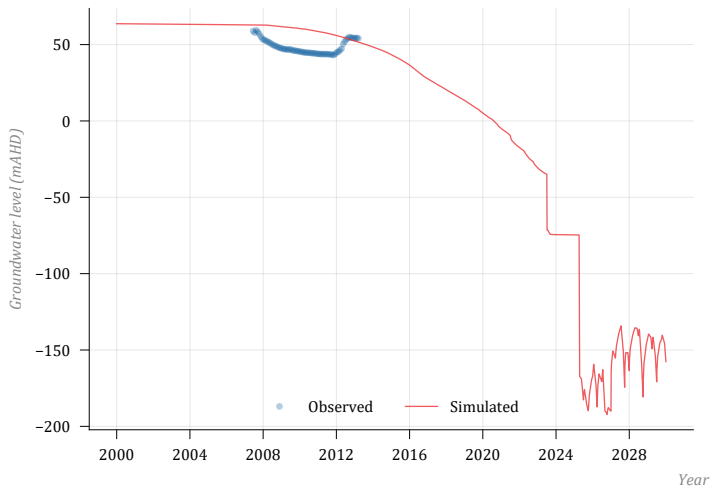
CS4539A_S2



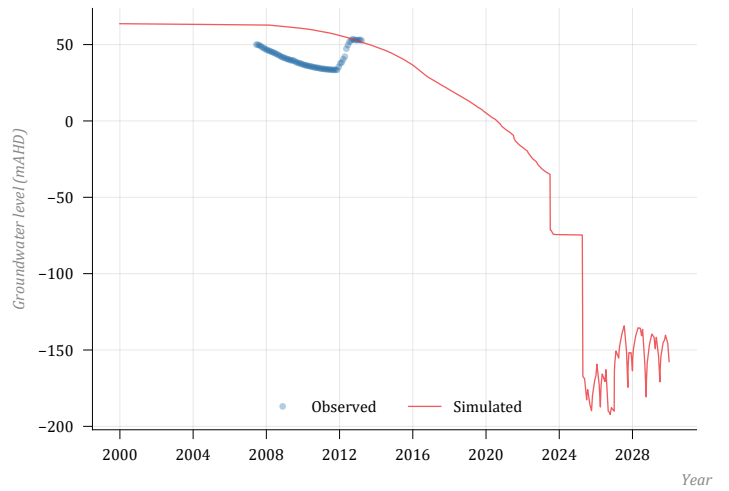
CS4655-LMA



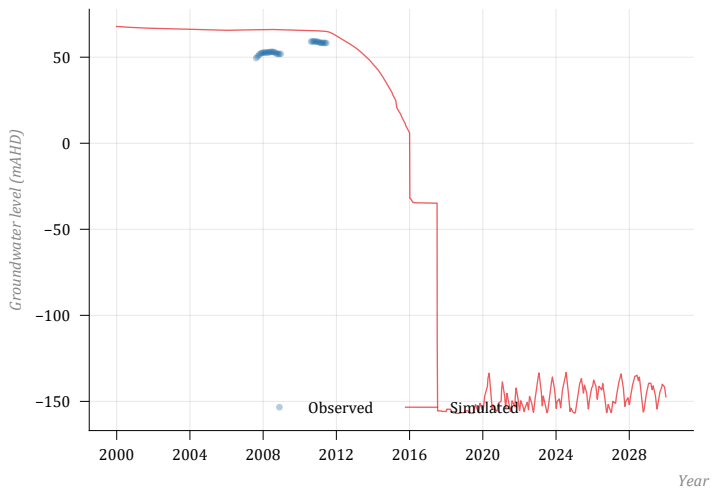
CS4655-LMH



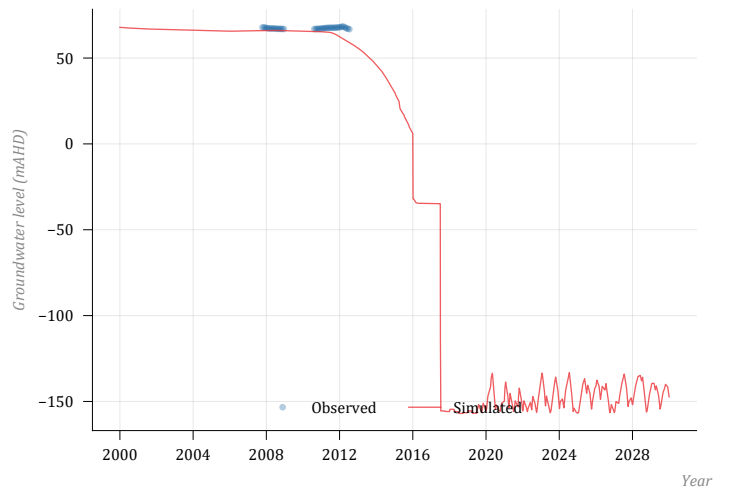
CS4655-UPG



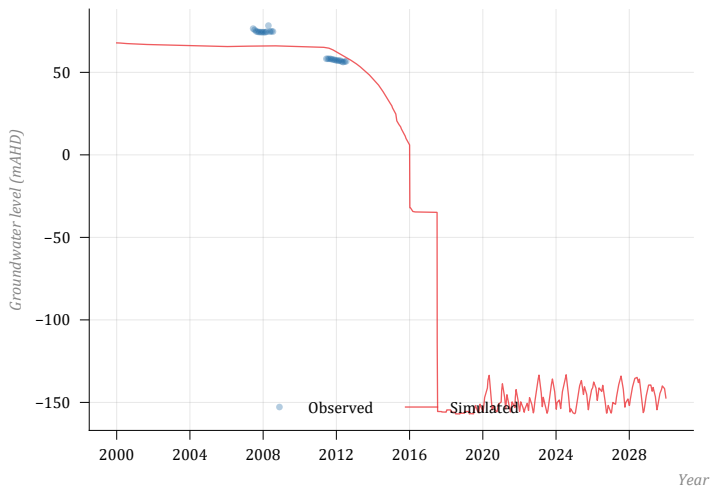
CS4656-LMA



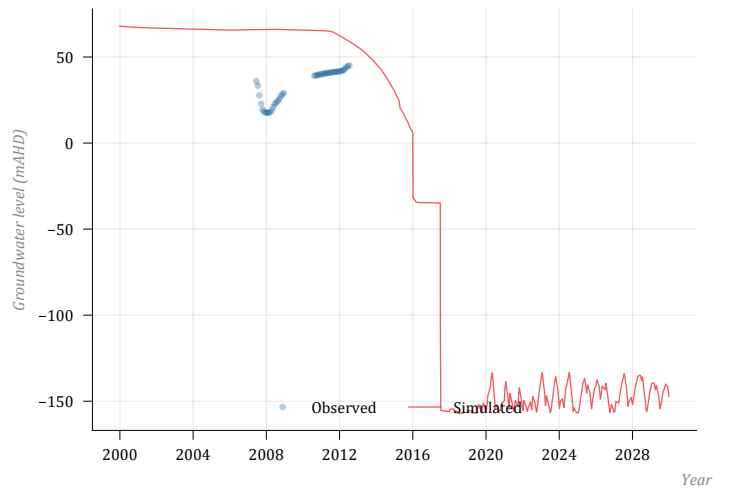
CS4656-LMF



CS4656-LMH

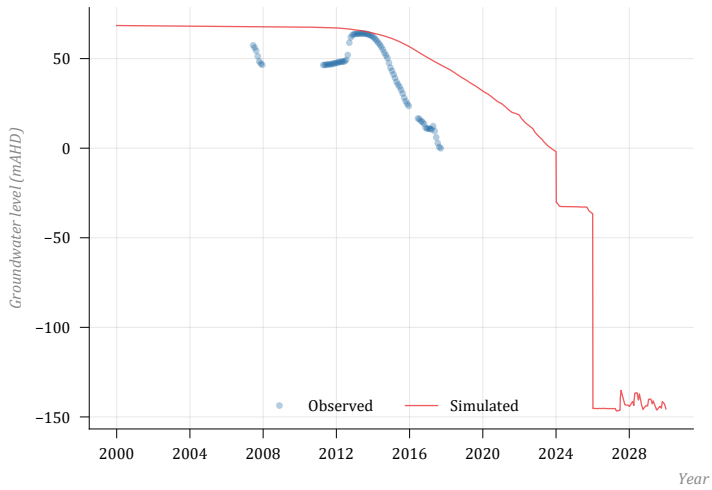


CS4656-UPG

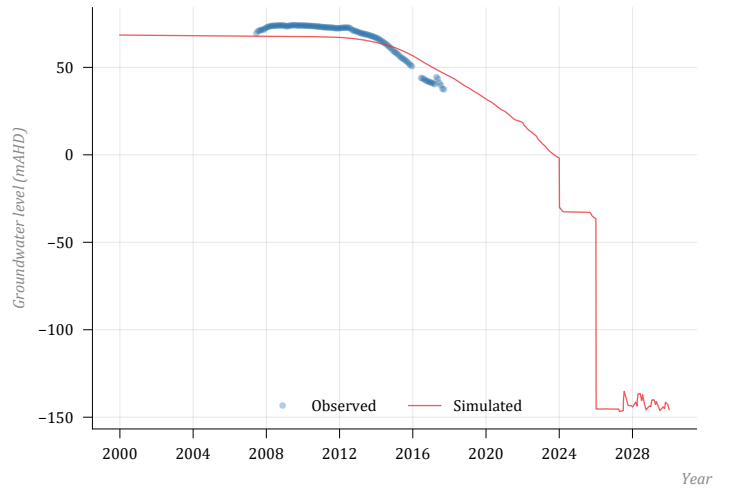


L25_Coal_Lemington_PikesG_RavMid

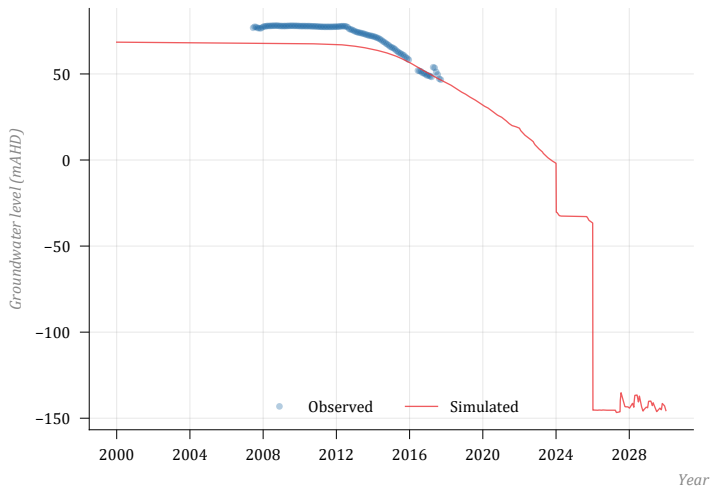
CS4657-LMA



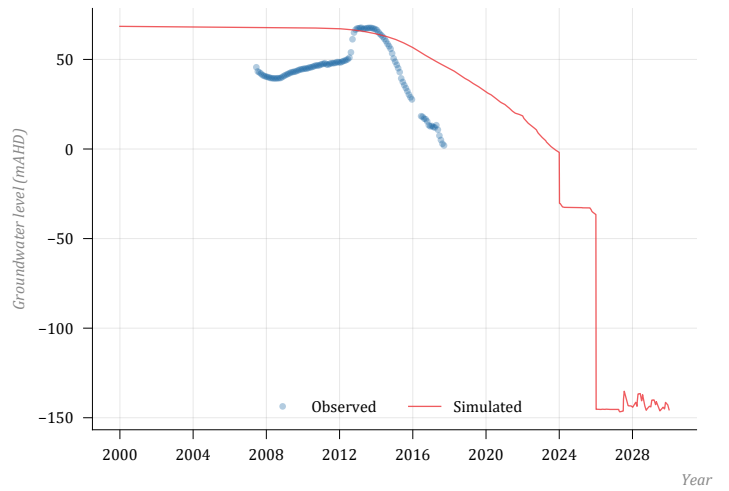
CS4657-LMF



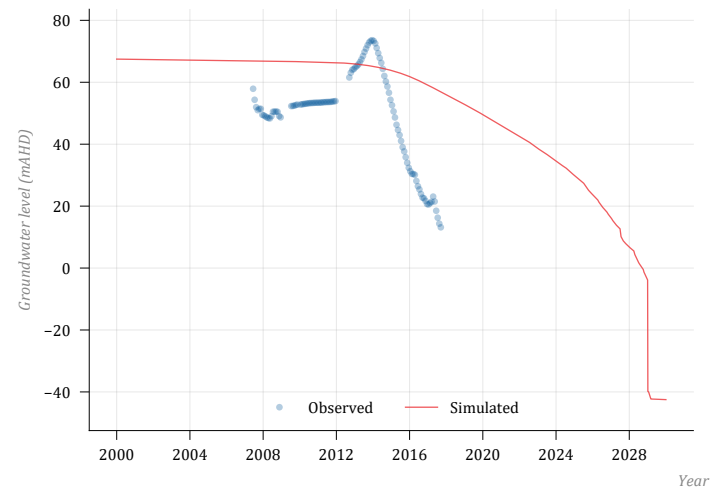
CS4657-LMH



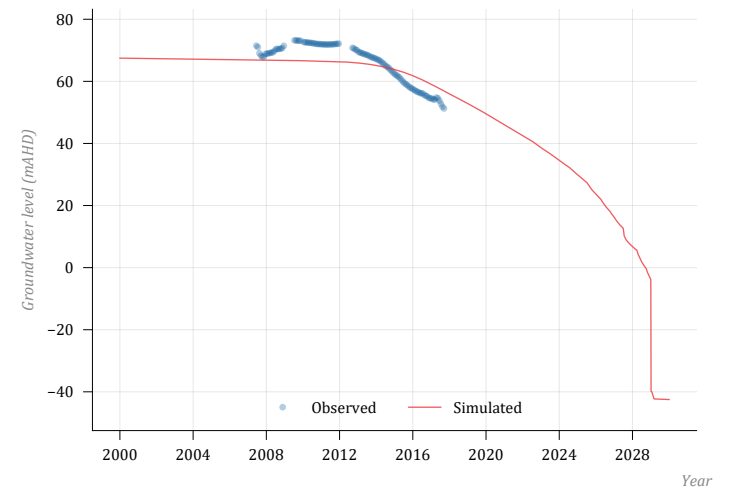
CS4657-LPG



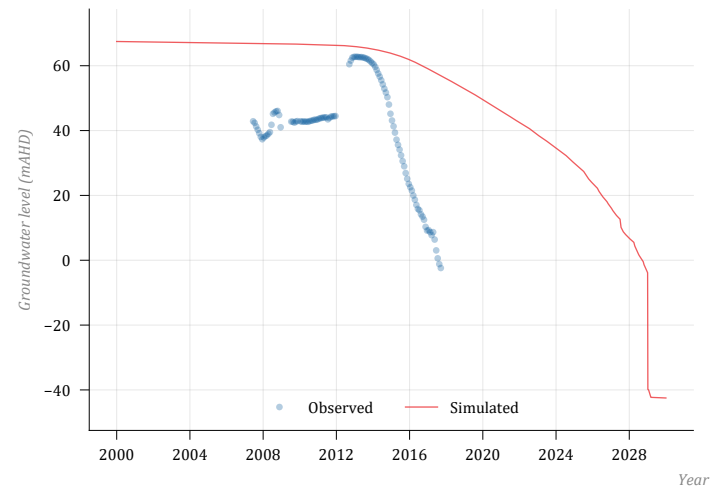
CS4658-LMA



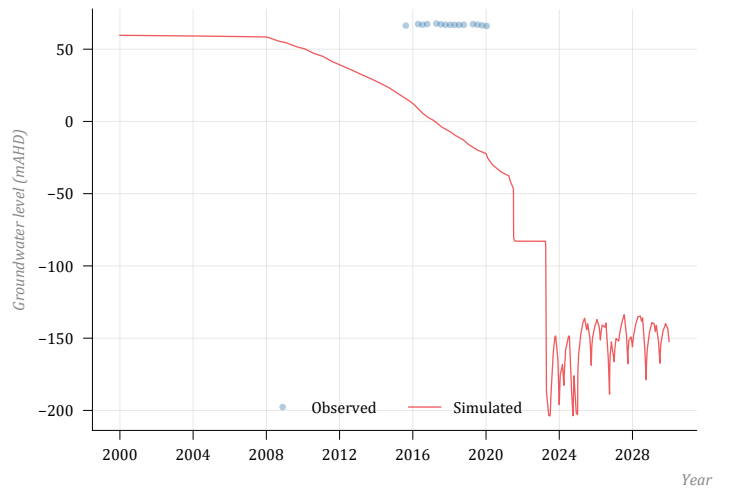
CS4658-LMH



CS4658-UPG

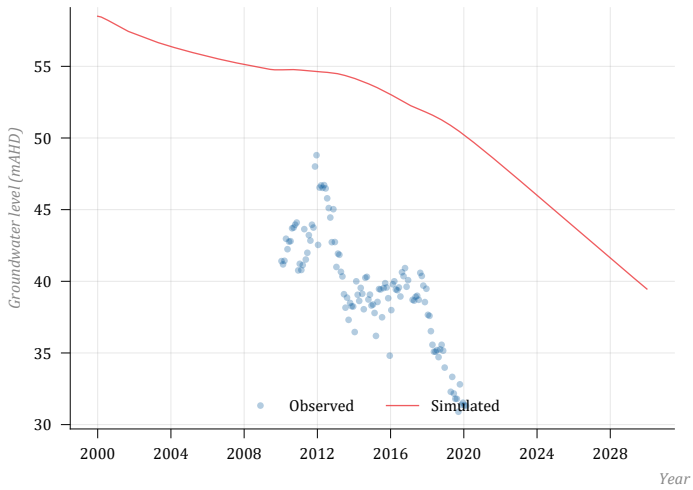


MW12

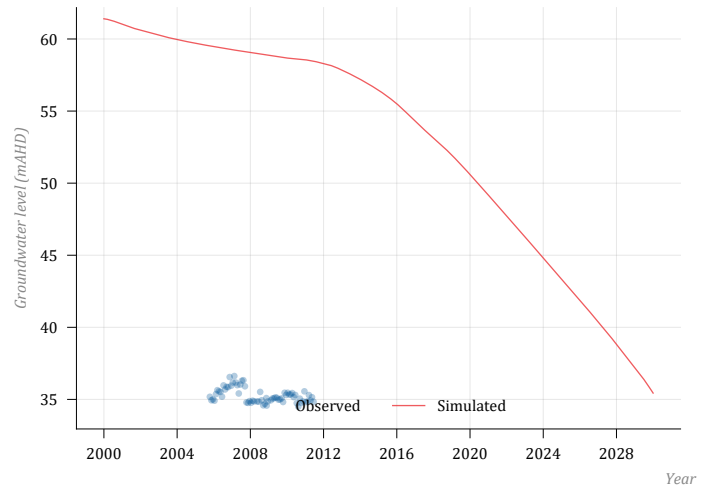


L25_Coal_Lemington_PikesG_RavMid

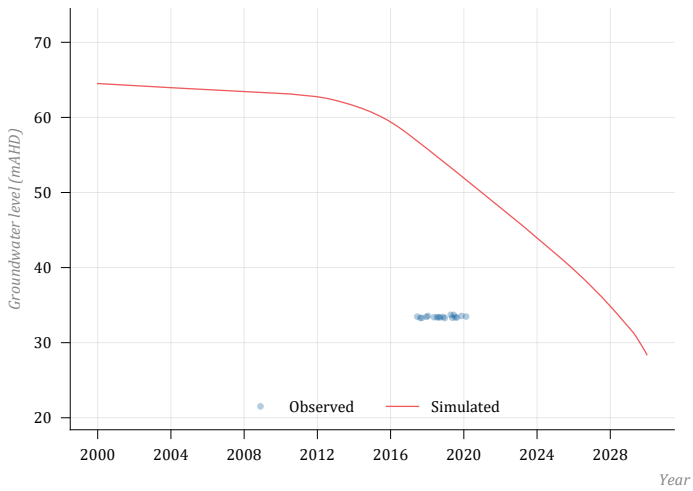
NPZ1_TALL



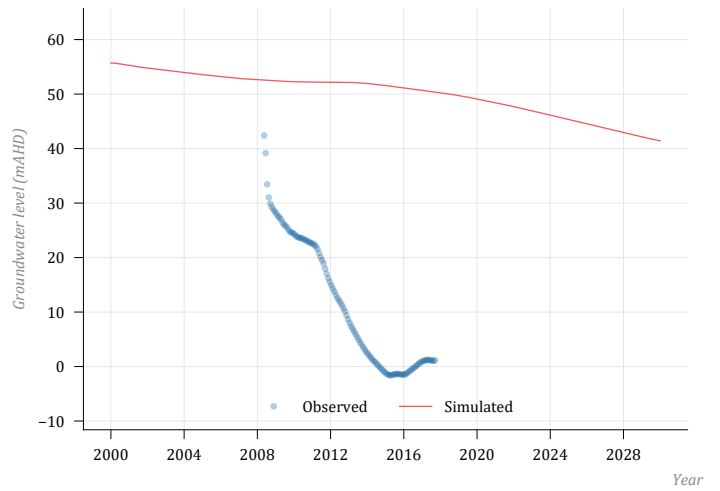
NPZ2-120



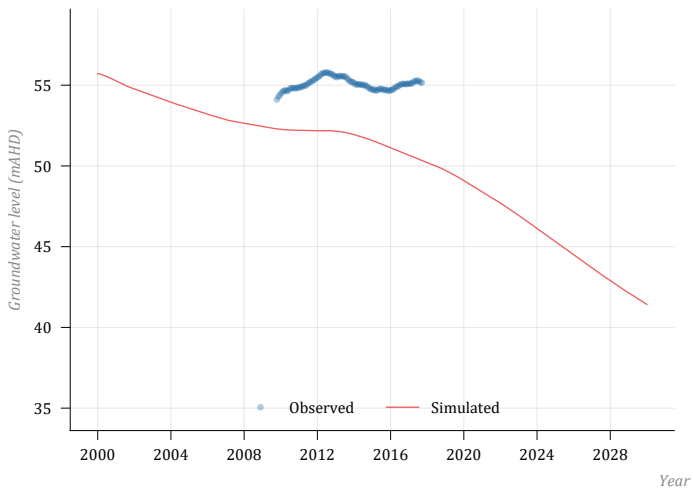
NPZ2_TALL



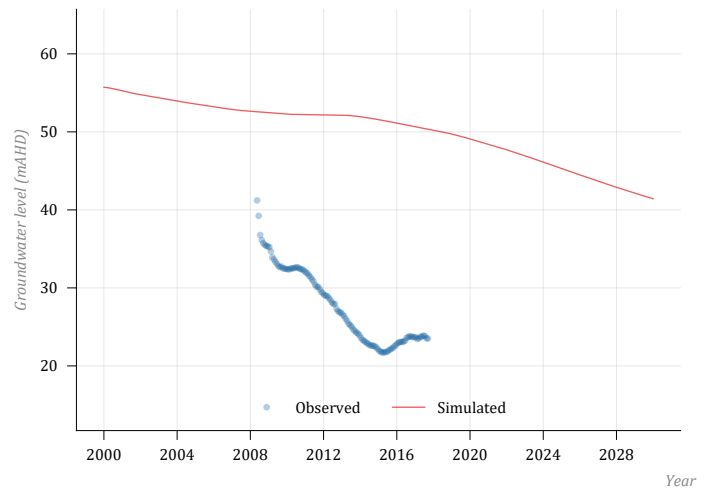
RNVW1-LMA



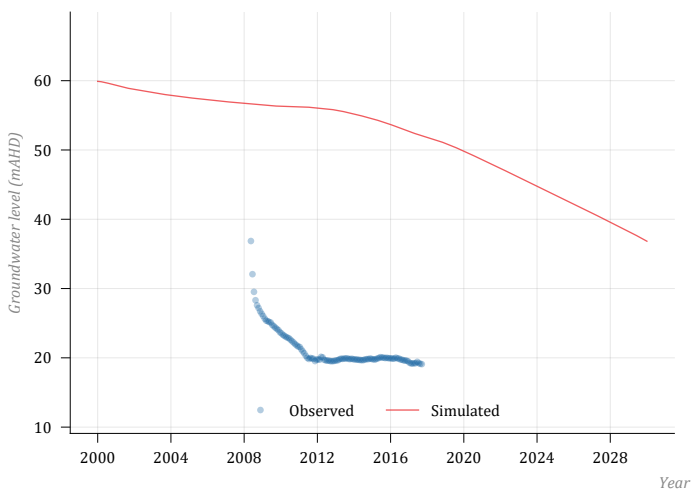
RNVW1-LMH



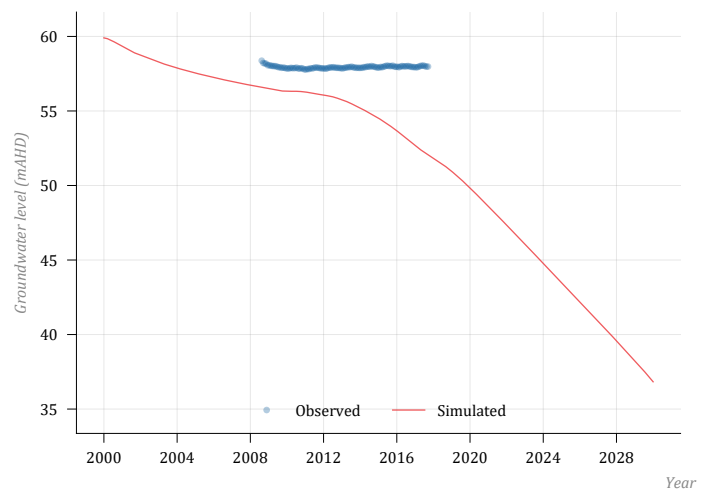
RNVW1-UPG



RNVW2-LMA

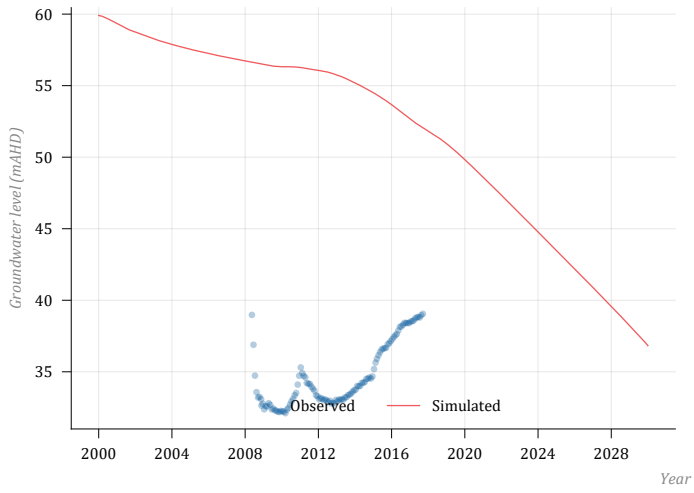


RNVW2-LMH

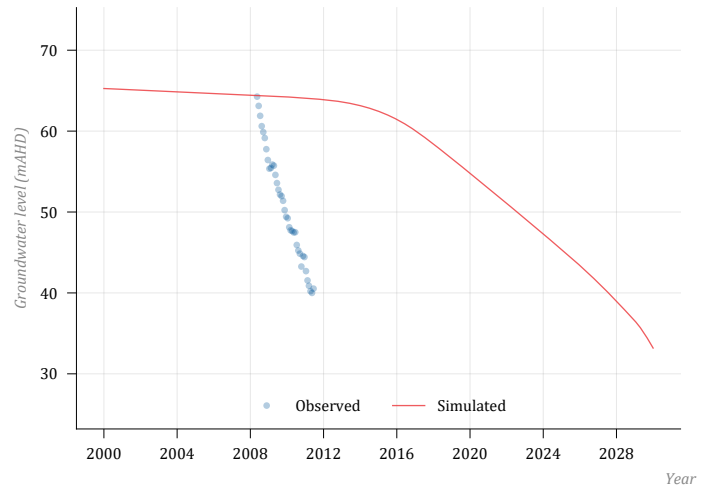


L25_Coal_Lemington_PikesG_RavMid

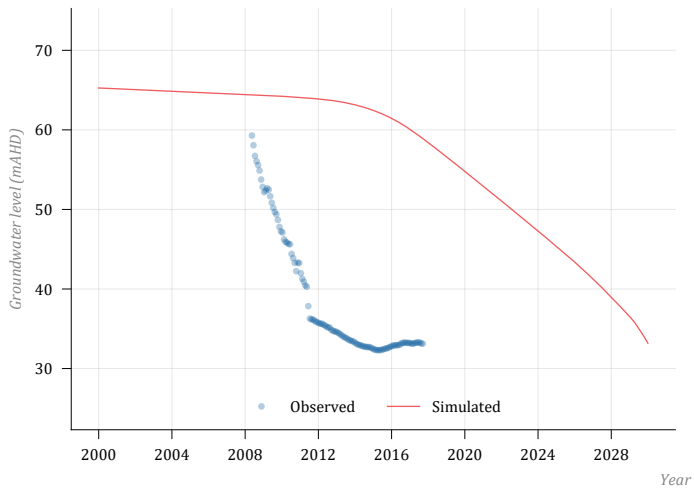
RNVW2-UPG



RNVW3-LMA

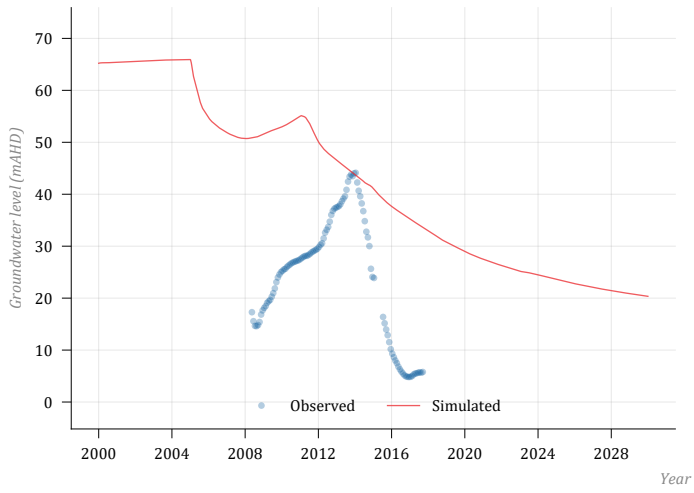


RNVW3-UPG

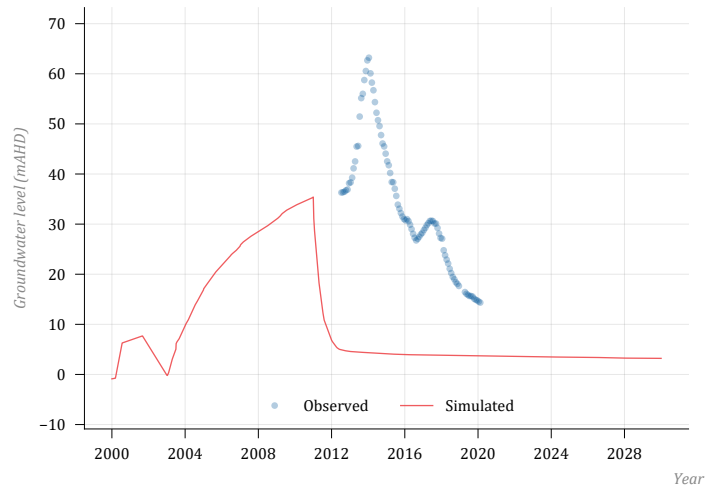


L25_Coal_Lemington_PikesG_RavNorth

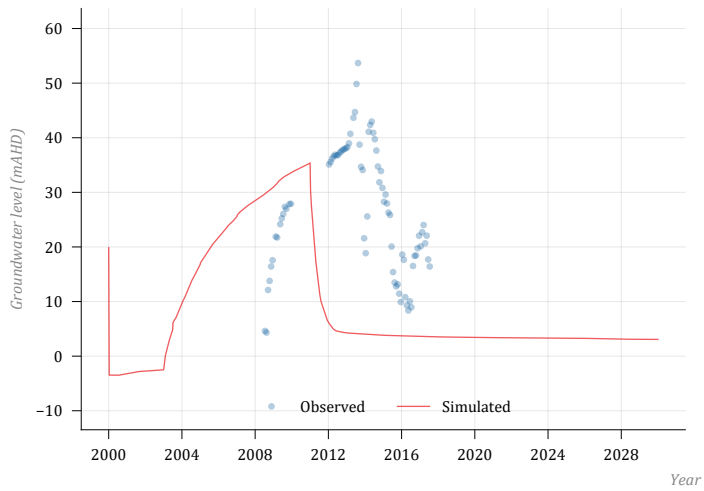
RNVW4-UPG



SDH16

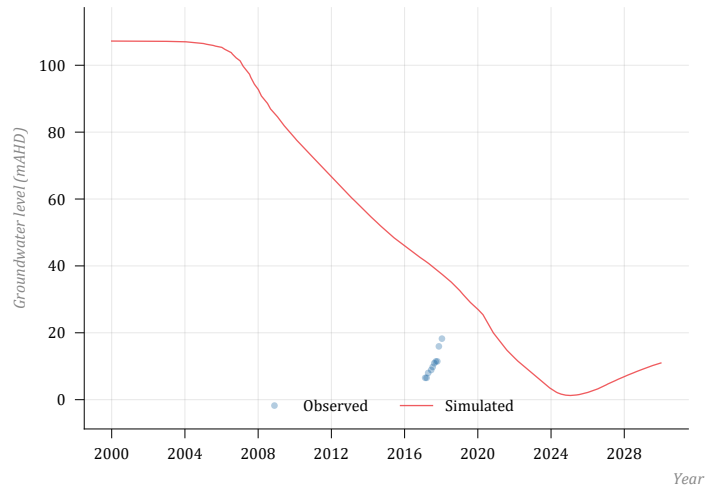


SDH18

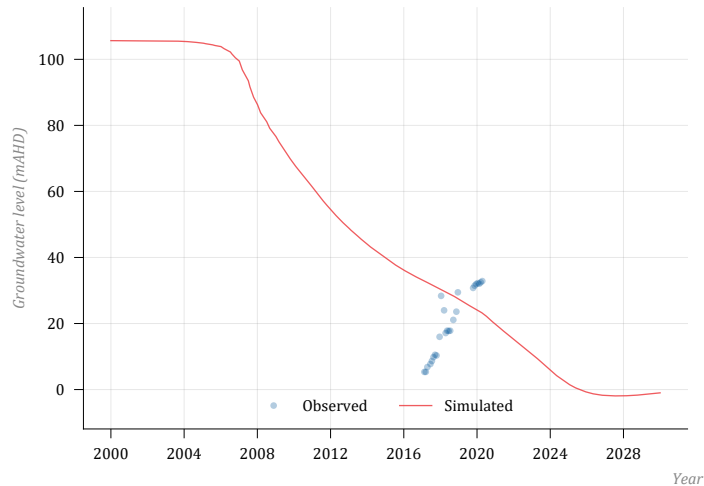


L25_Lemington_PikesG_BowmansCk

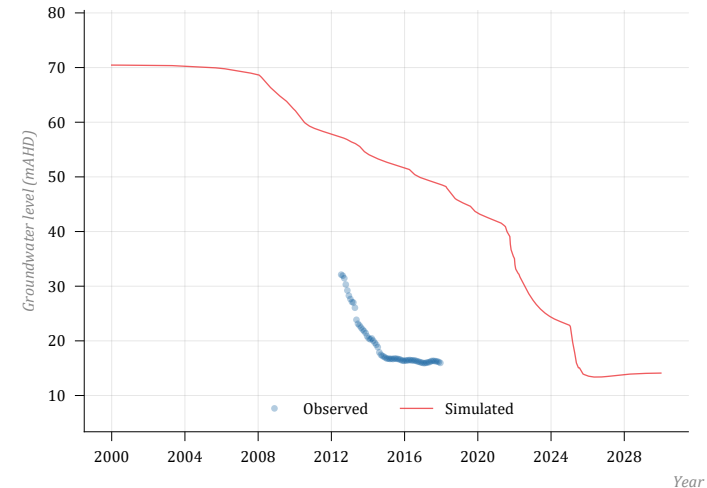
BN0008



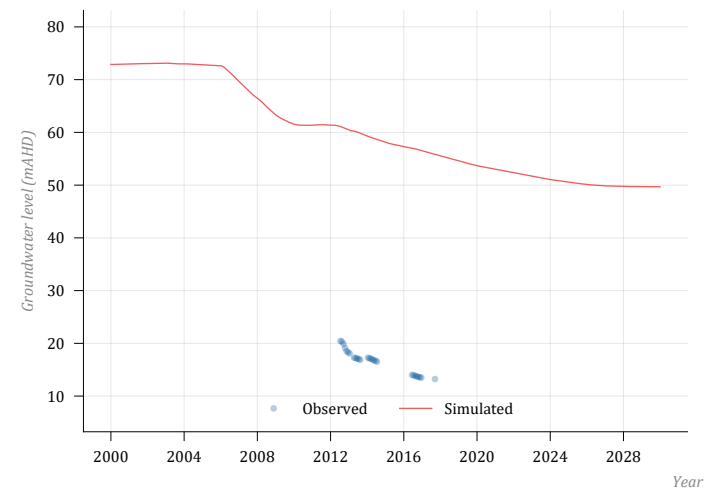
BN0011



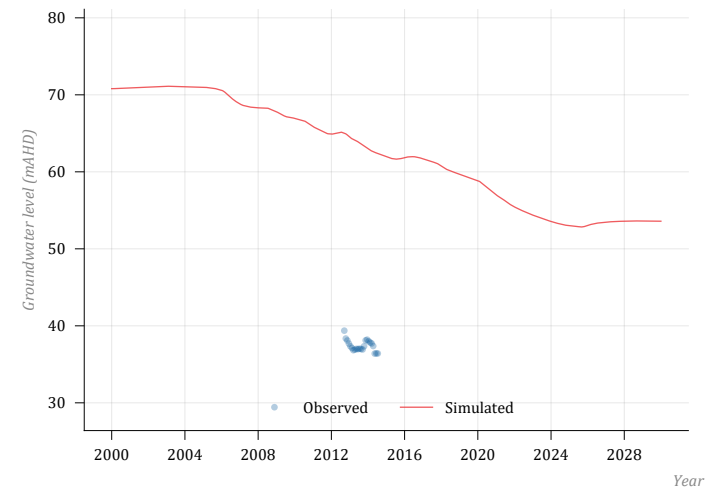
GNP1-PG



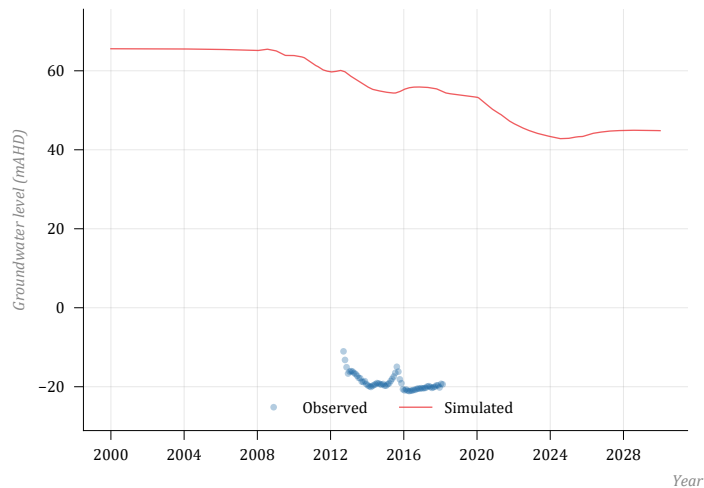
GNP2-PG



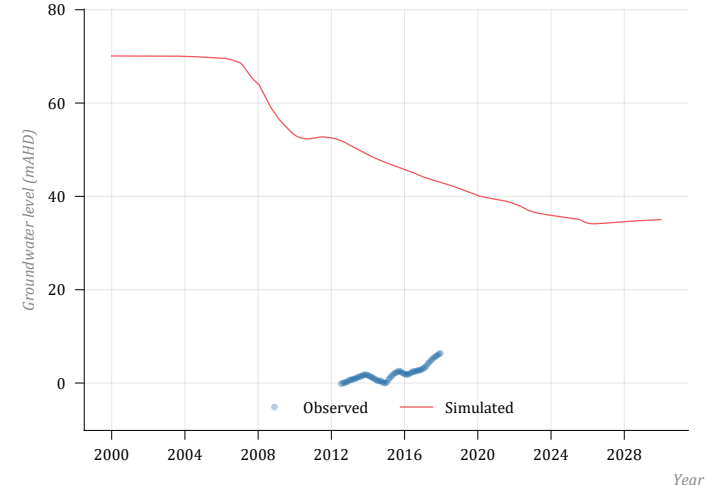
GNP3-PG



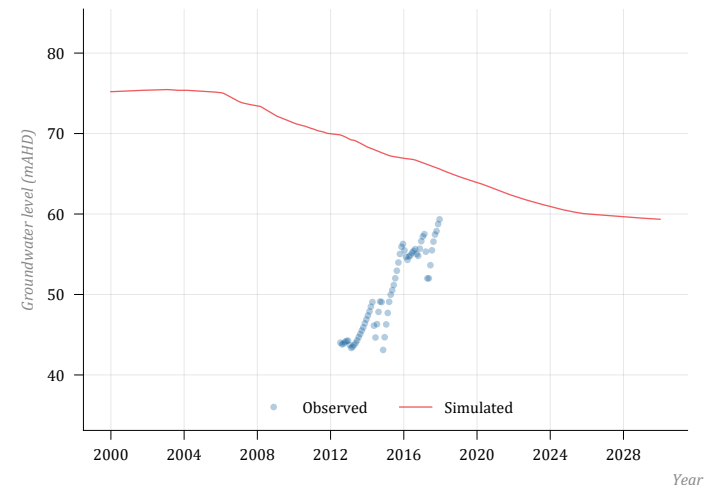
GNP4-PG



GNP5-PG

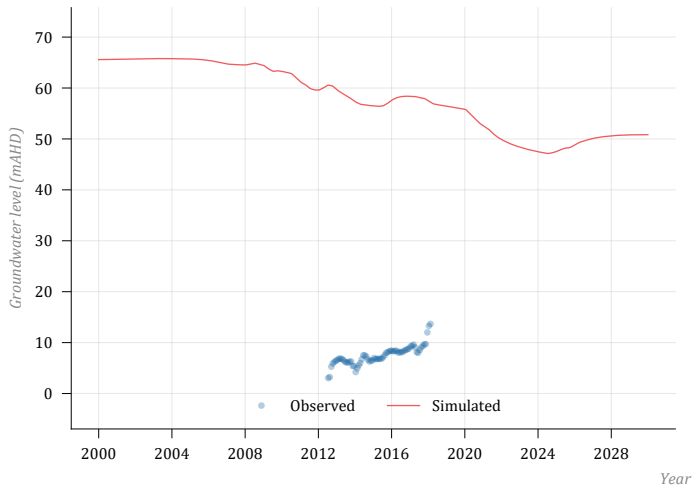


GNP6-PG

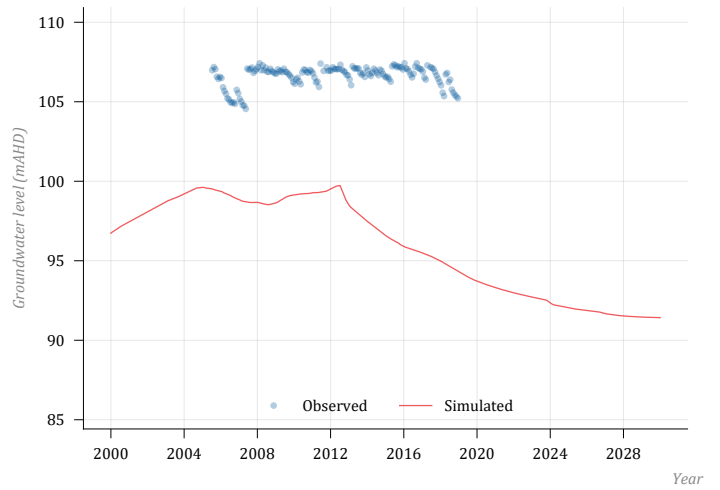


L25_Lemington_PikesG_BowmansCk

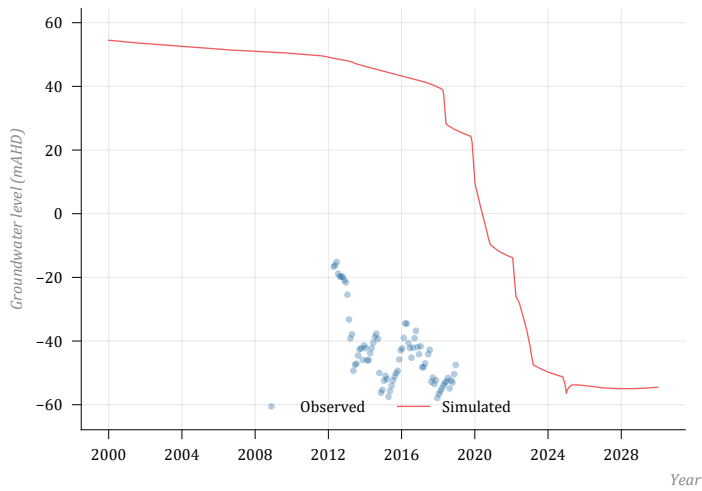
GNP7-PG



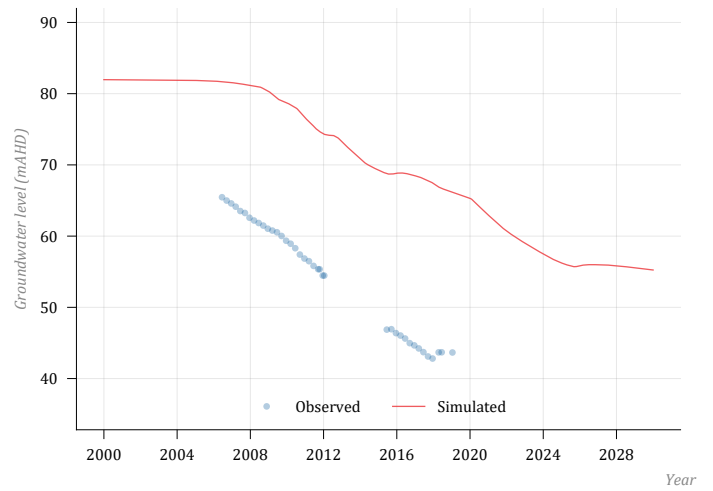
LBH_COAL



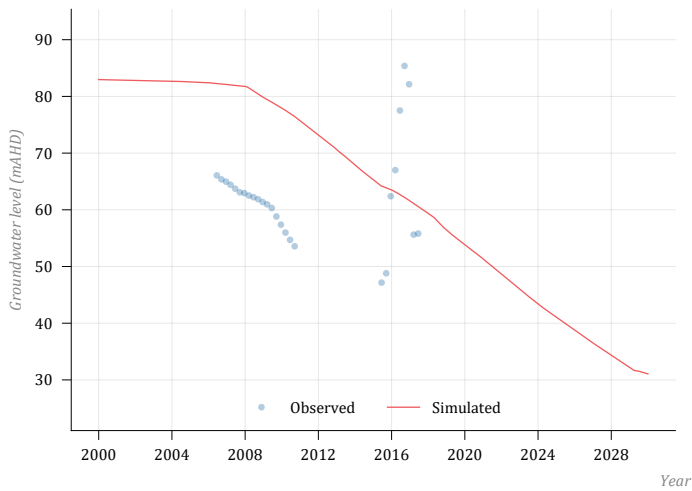
MIDDLELIDD



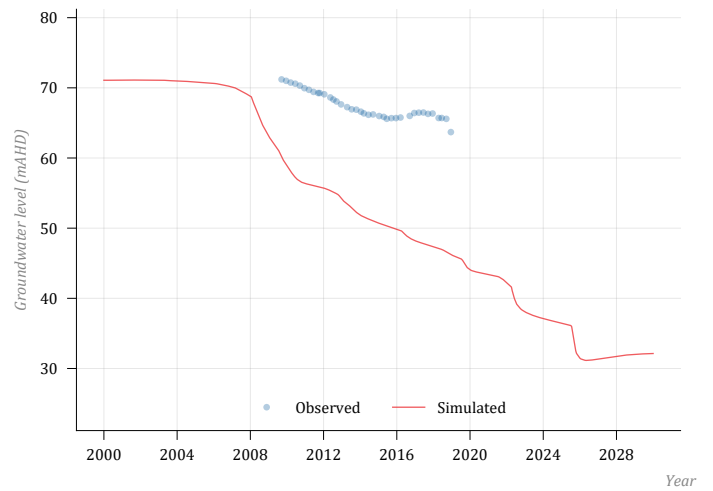
NPZ11A



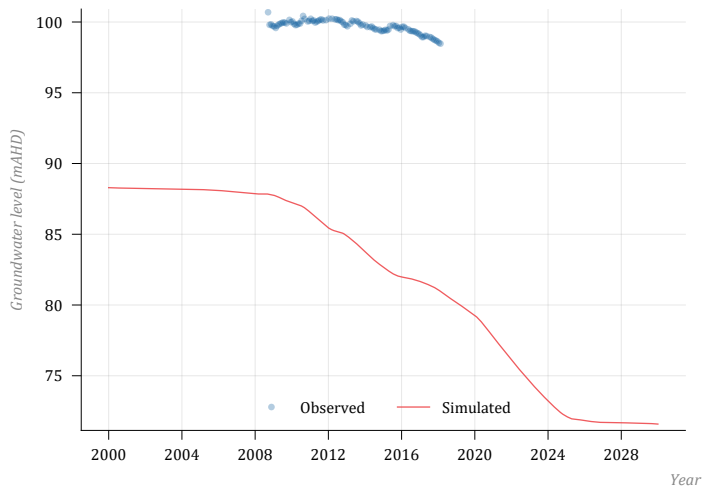
NPZ12A



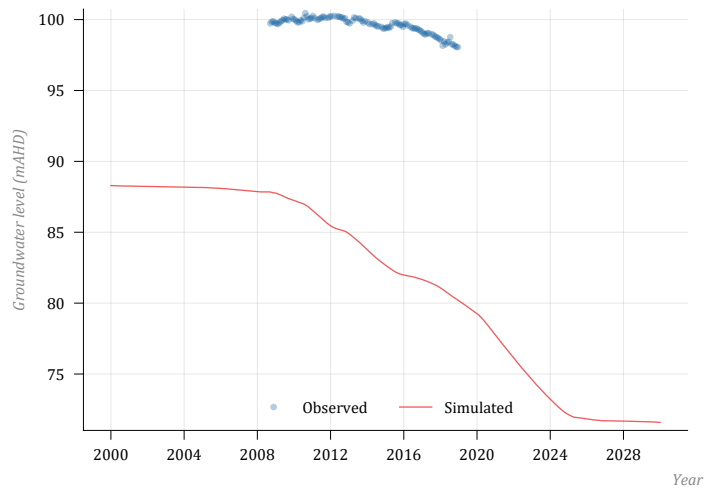
NPZ16



NV11A

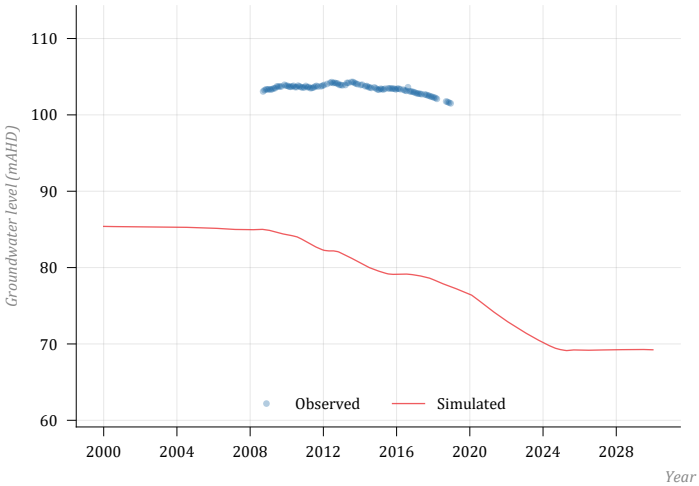


NV11B

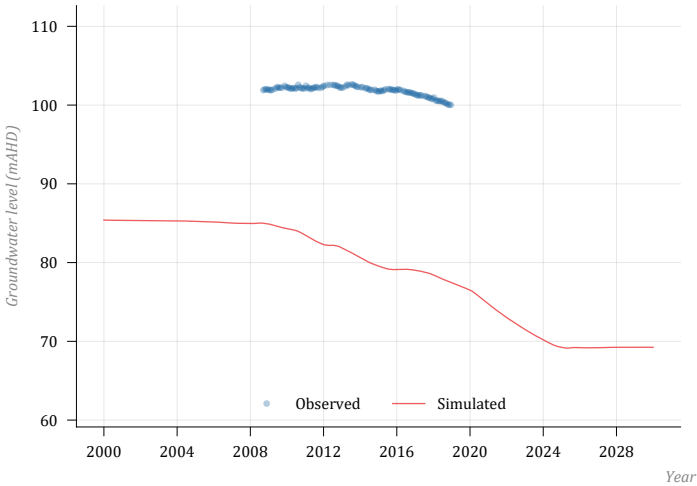


L25_Lemington_PikesG_BowmansCk

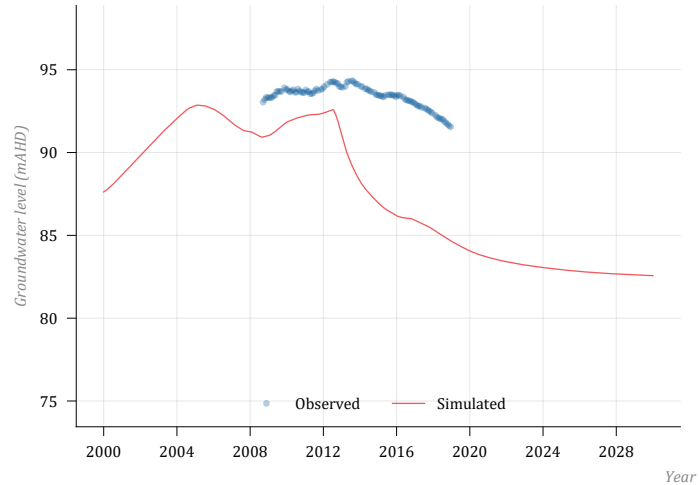
NV12A



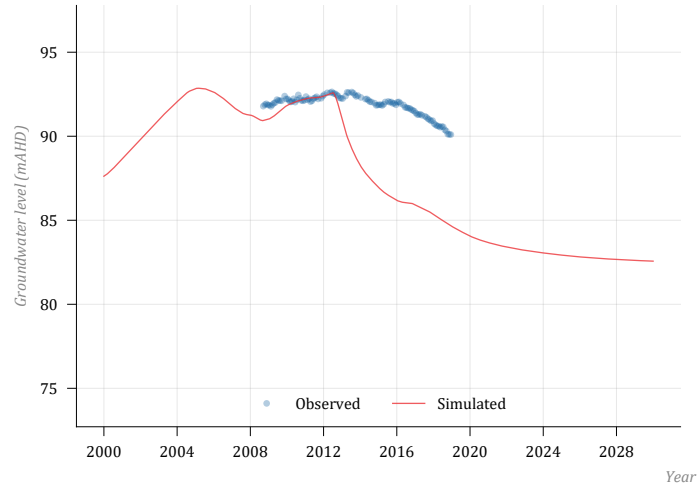
NV12B



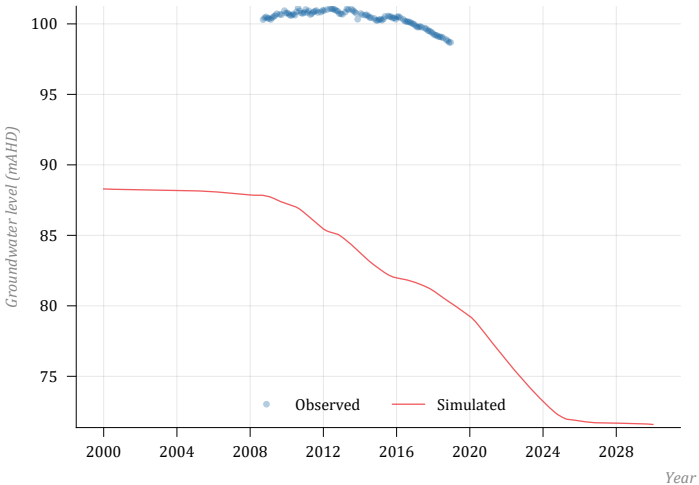
NV13A



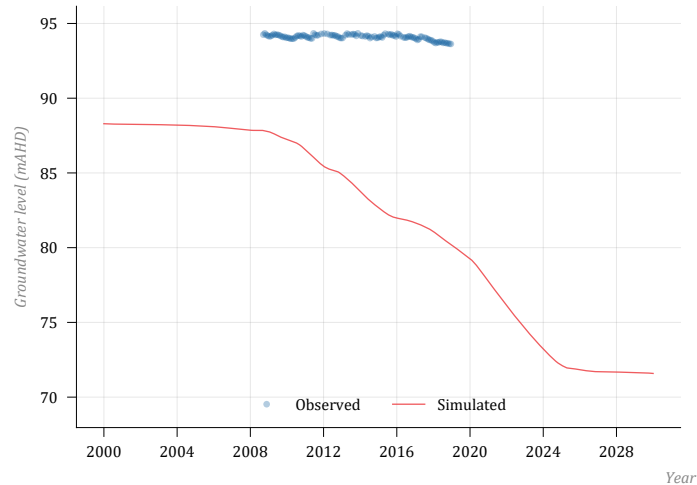
NV13B



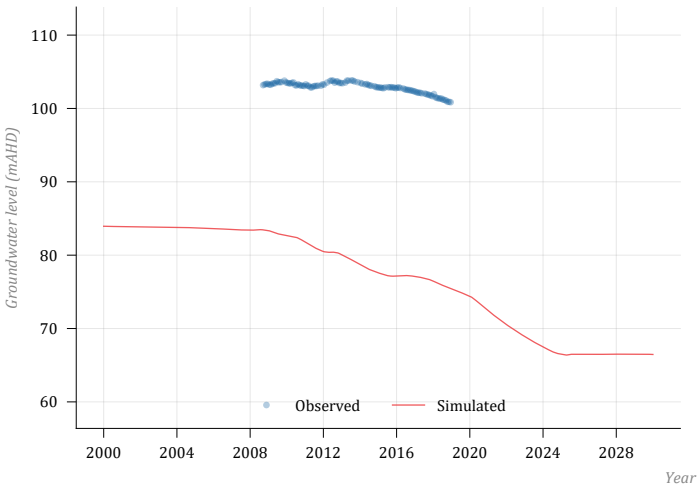
NV14B



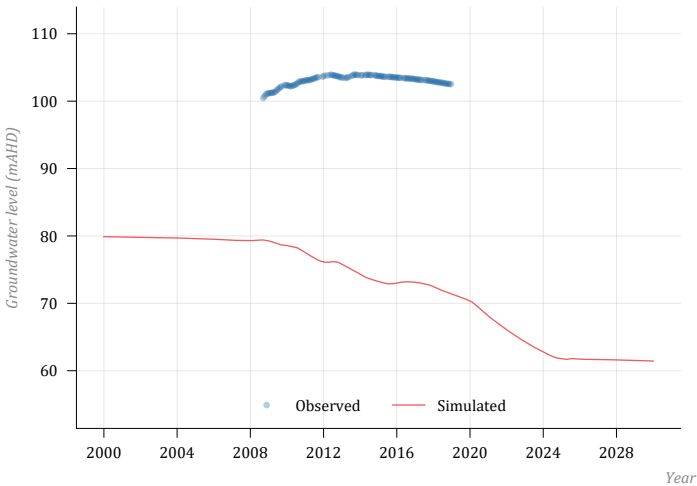
NV15A



NV16B

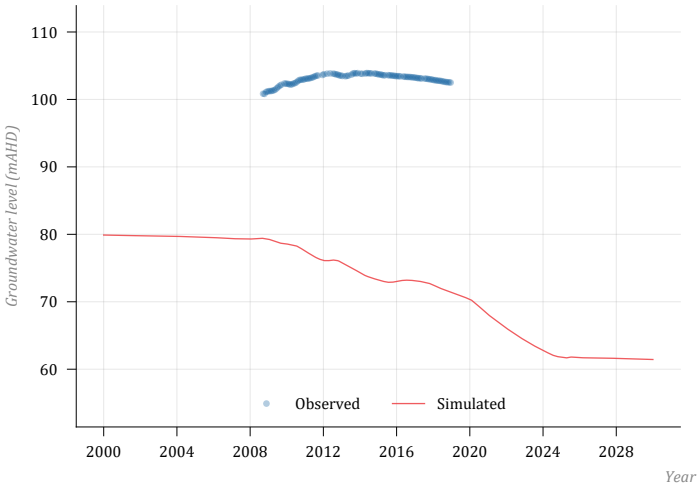


NV17A

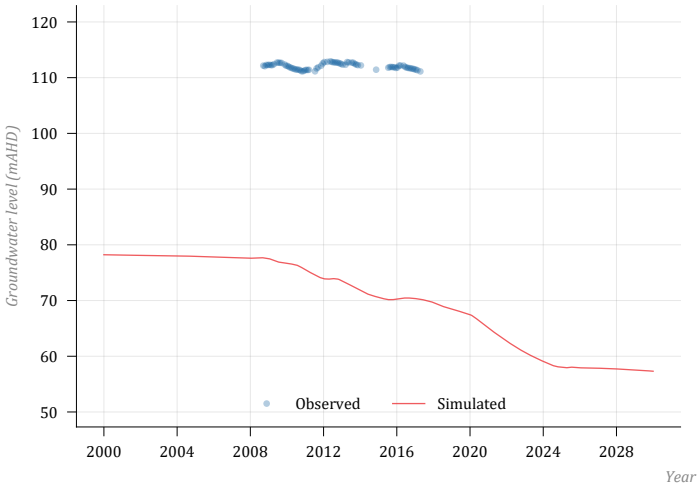


L25_Lemington_PikesG_BowmansCk

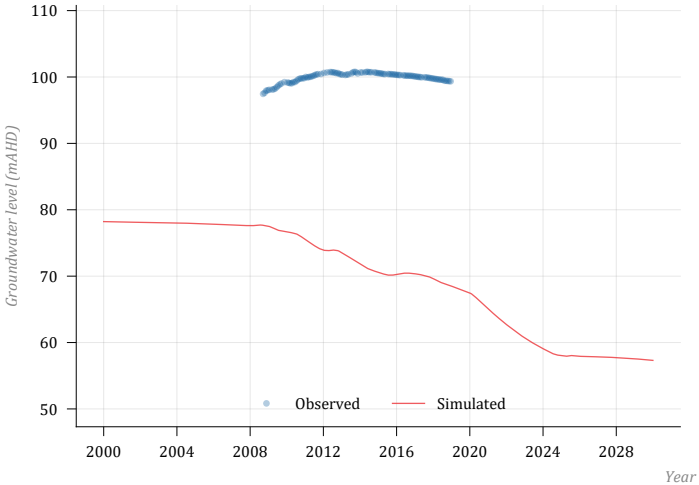
NV17B



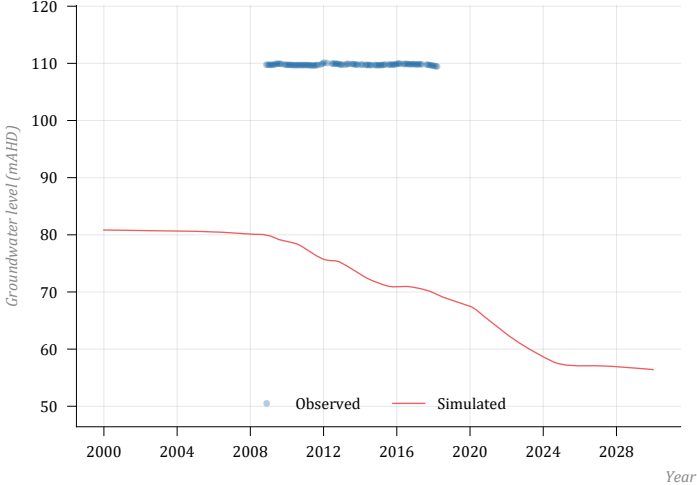
NV18A



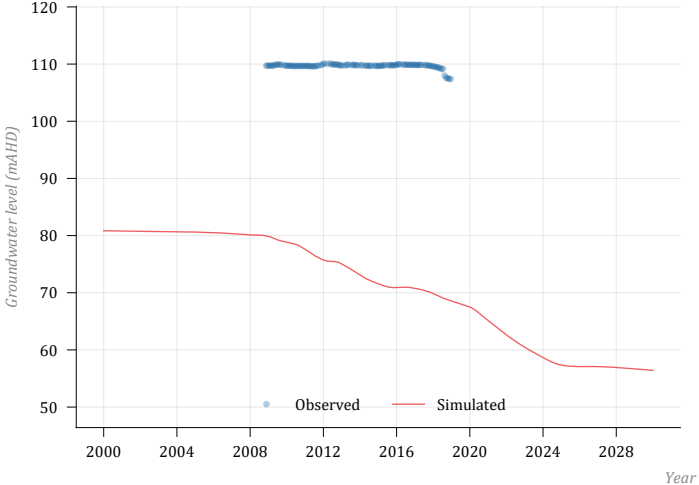
NV18B



NV19A

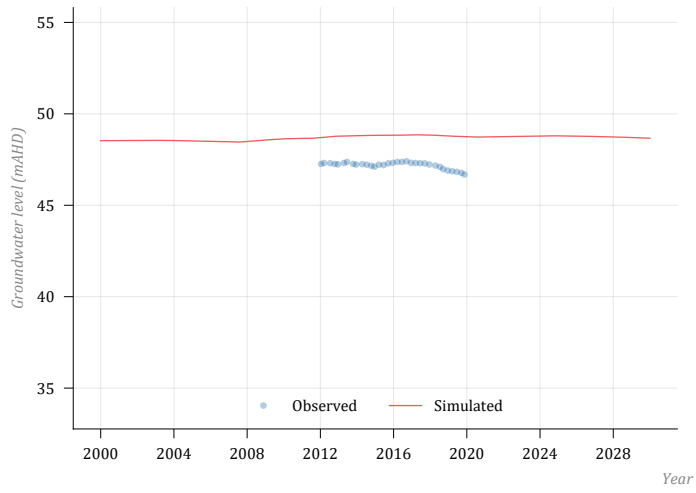


NV19B



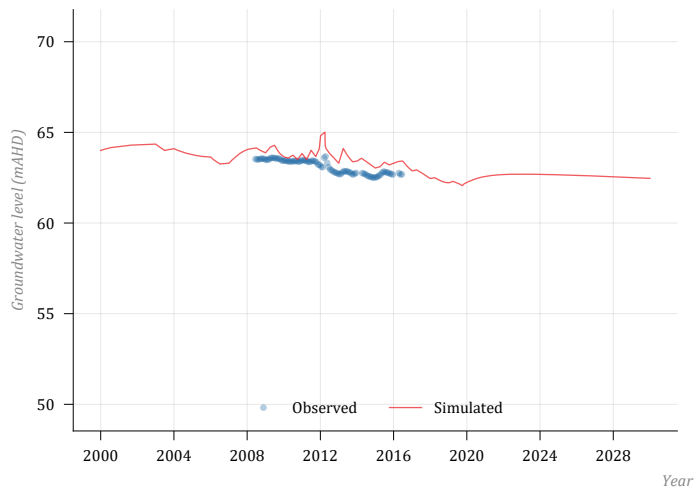
L25_Coal_Lemington_PikesG_Southeast

SR008



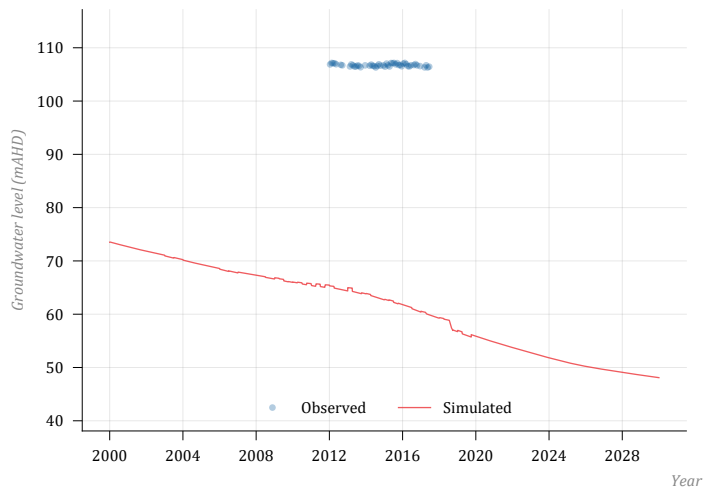
L25_Lemington_PikesG_StationCk

GCP32



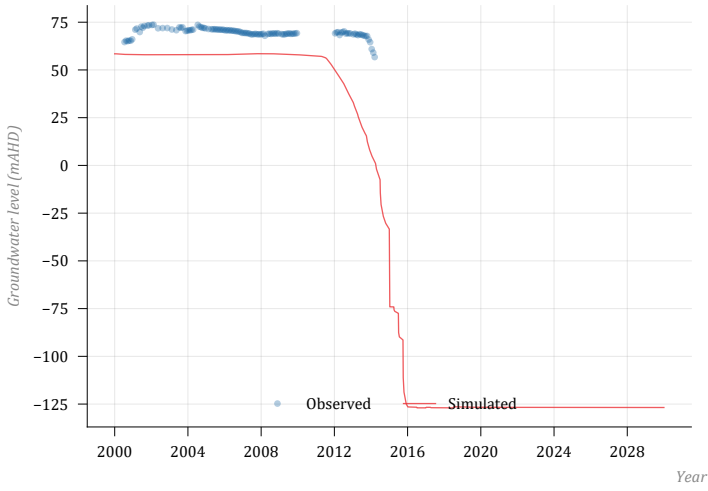
L27_Interburden_aboveArties_RavNorth

WPP1

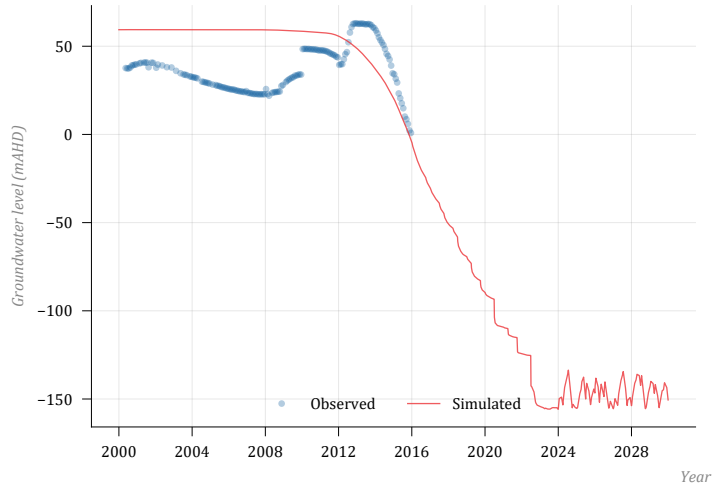


L28_Coal_Arties_Liddell_RavMid

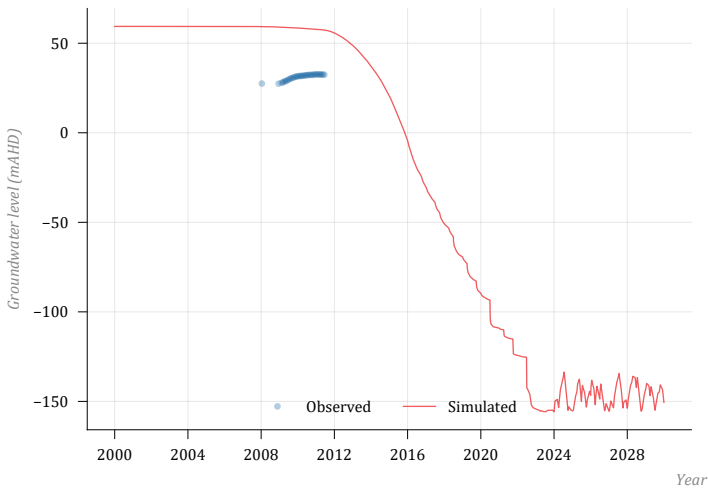
CS4536_HF7



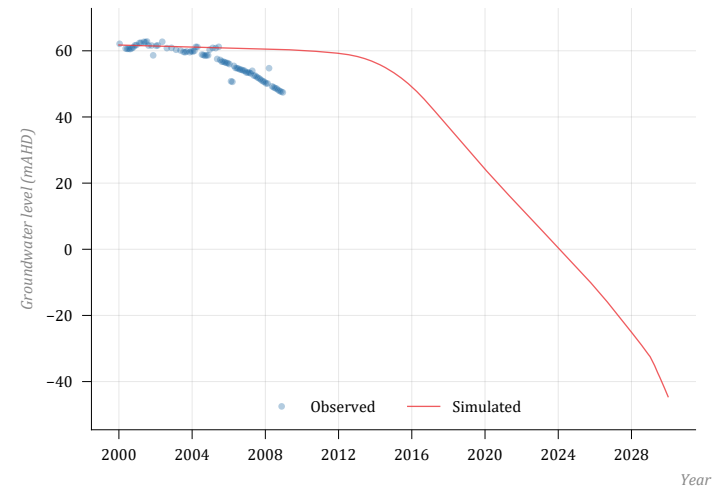
CS4545_S4



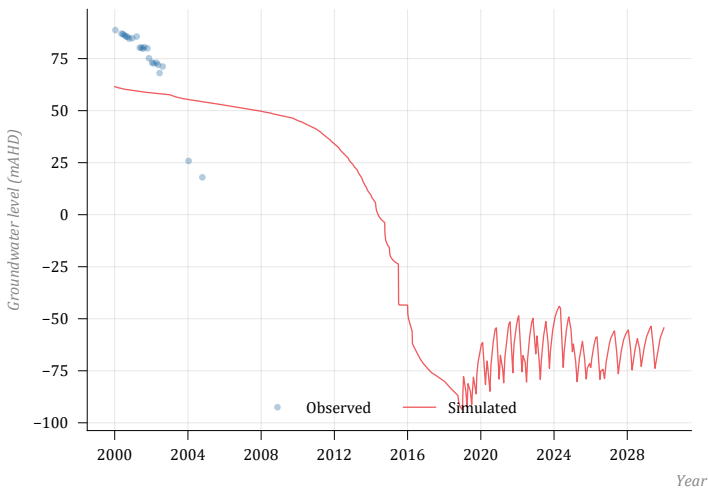
CS4545B



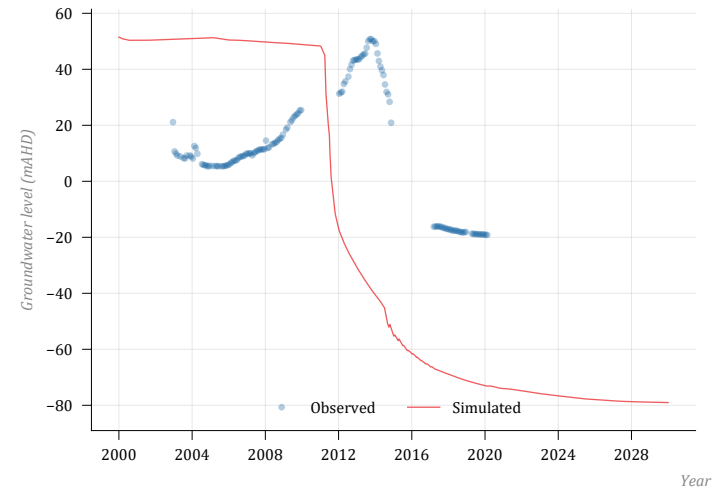
CS4547C



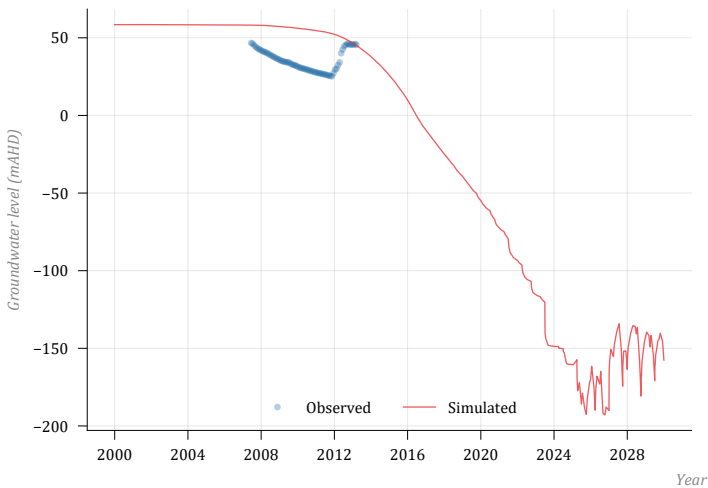
CS4556



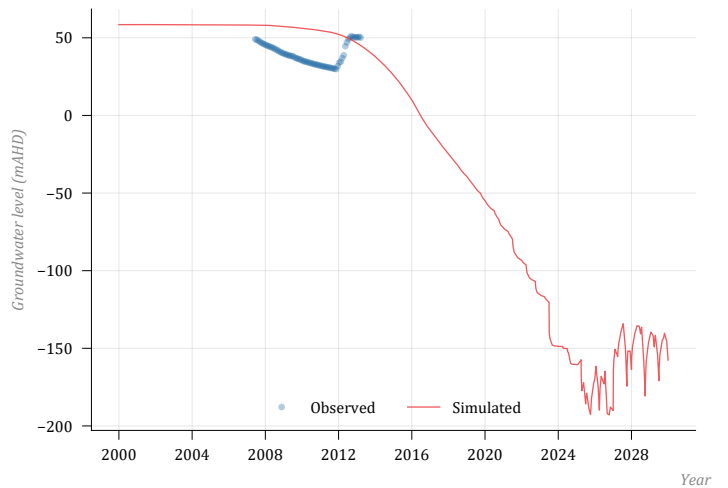
CS4641C



CS4655-LLD

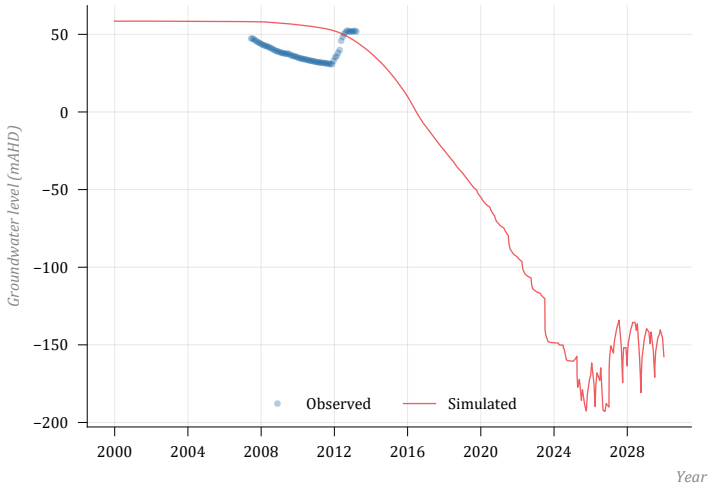


CS4655-UAR

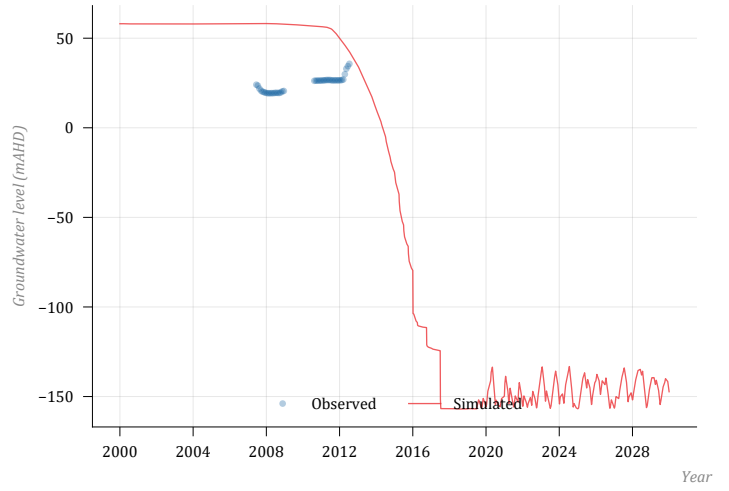


L28_Coal_Arties_Liddell_RavMid

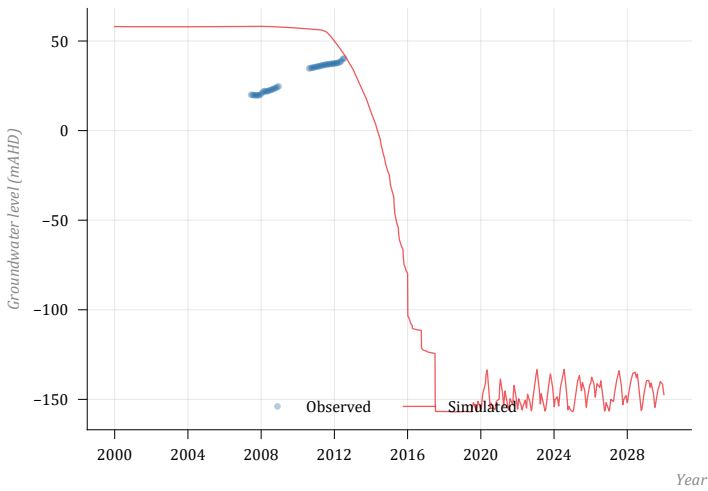
CS4655-ULD



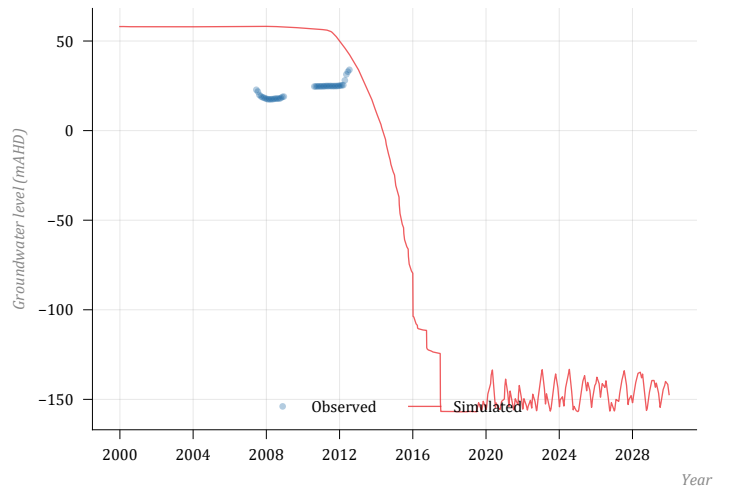
CS4656-LLD



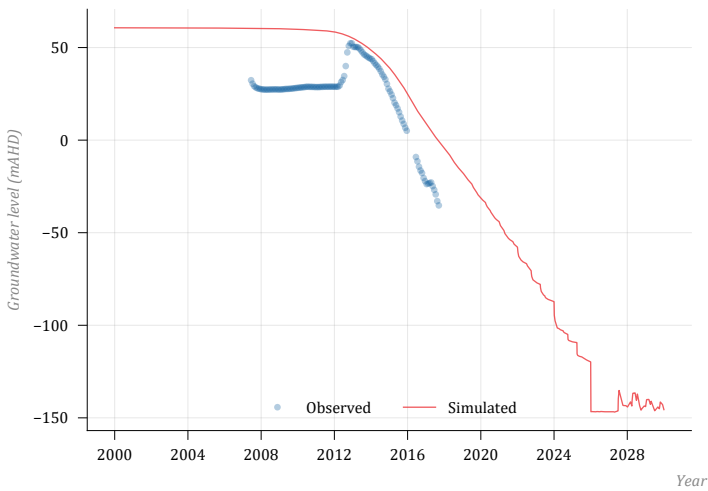
CS4656-UAR



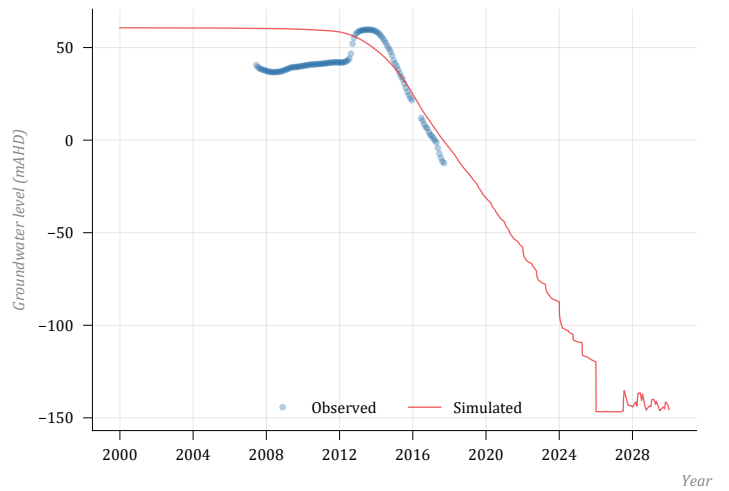
CS4656-ULD



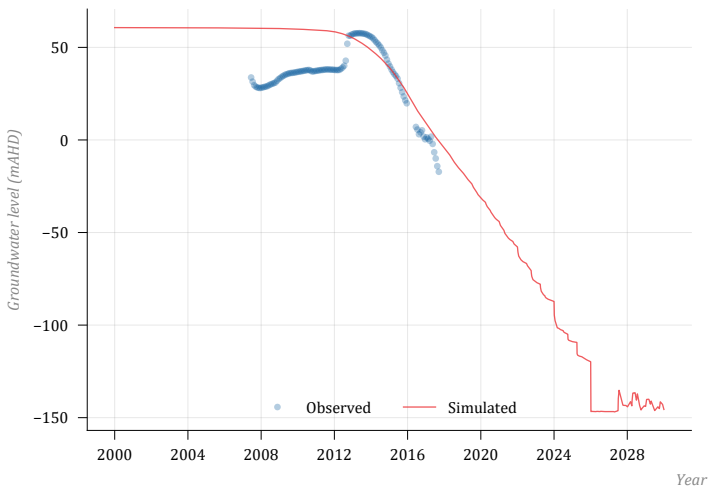
CS4657-LLD



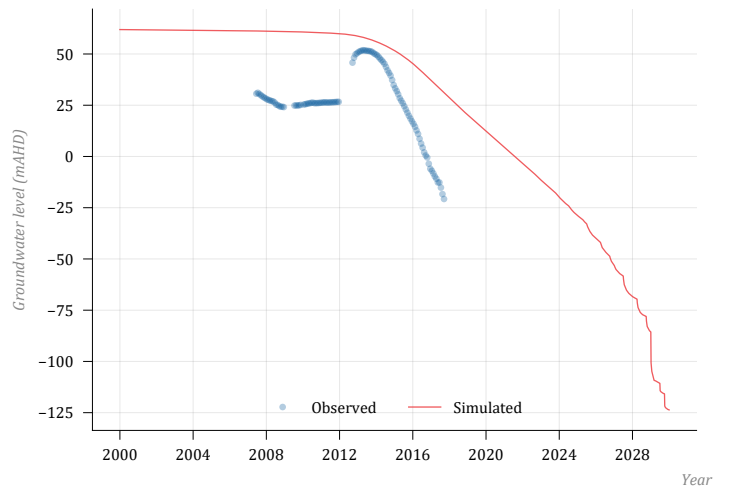
CS4657-UAR



CS4657-ULD

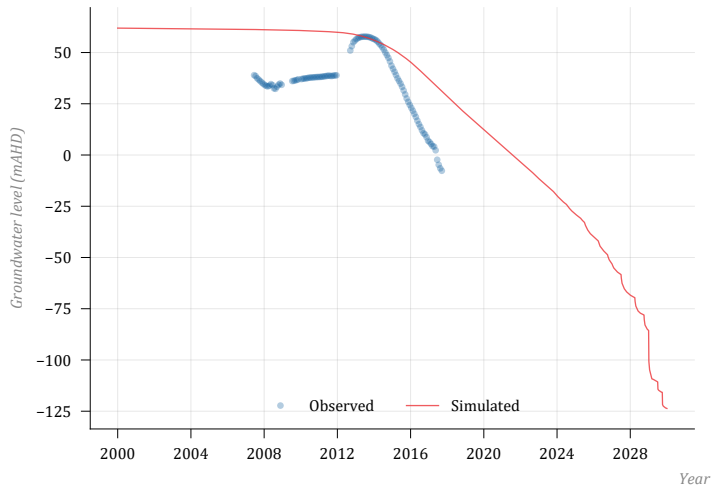


CS4658-LLD

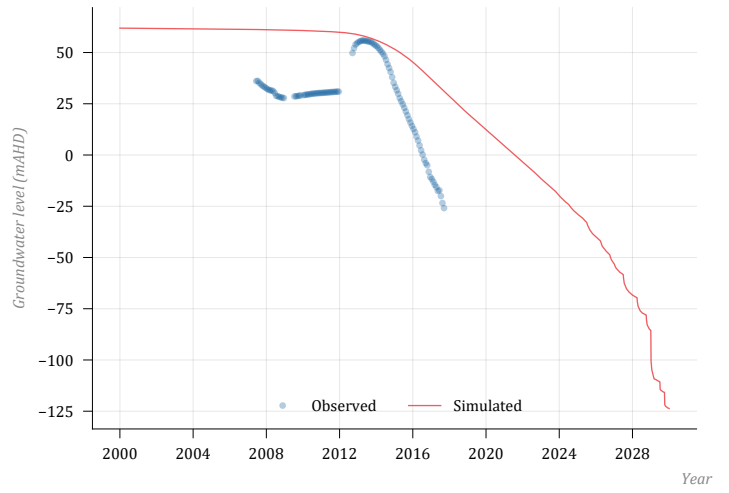


L28_Coal_Arties_Liddell_RavMid

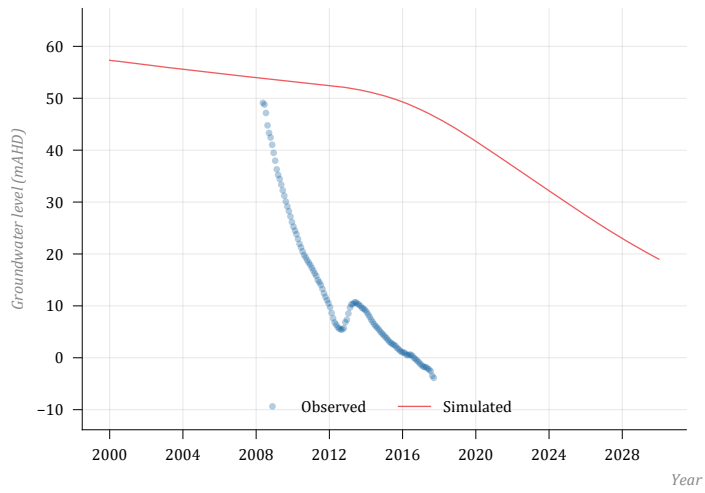
CS4658-UAR



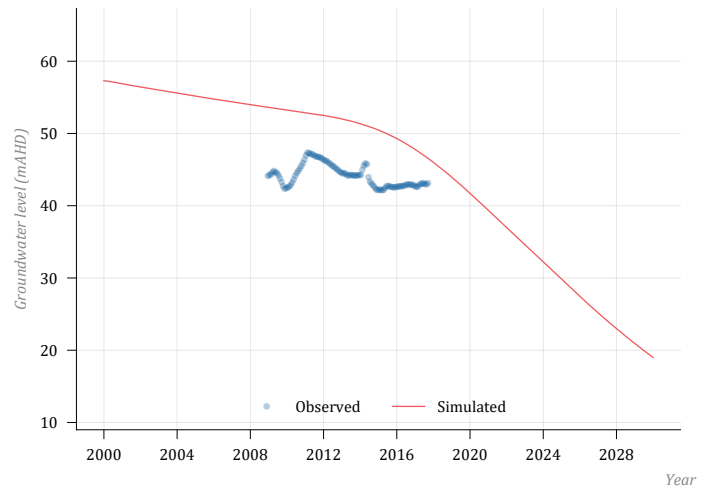
CS4658-ULD



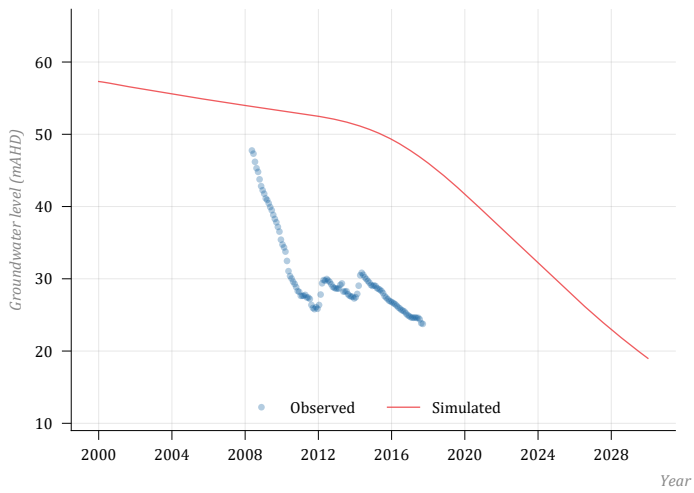
RNVW1-LLD



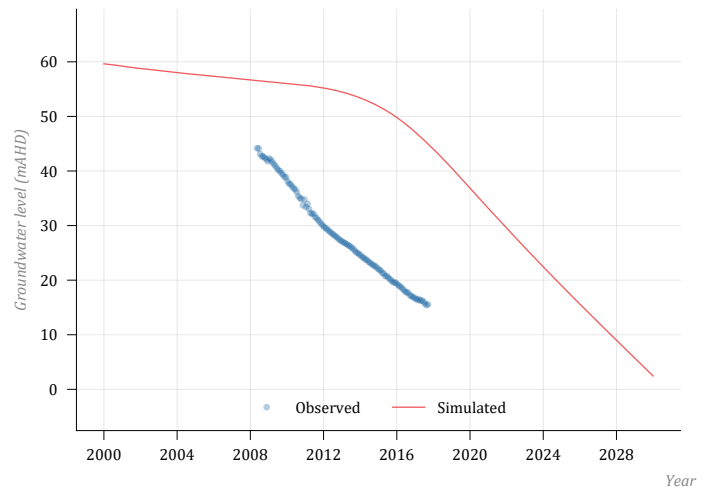
RNVW1-UAR



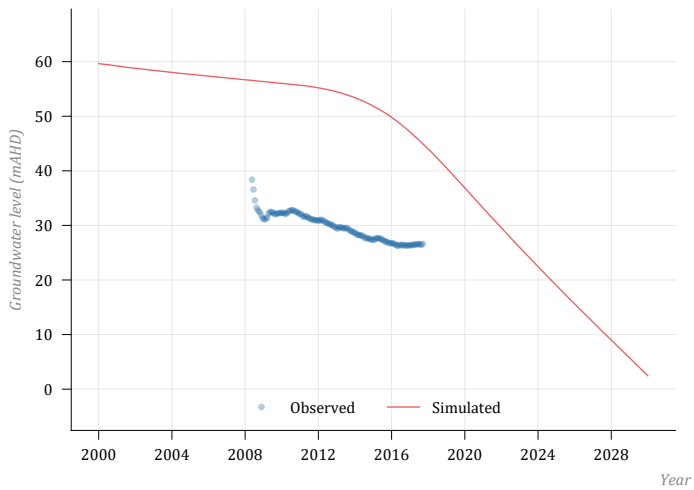
RNVW1-ULD



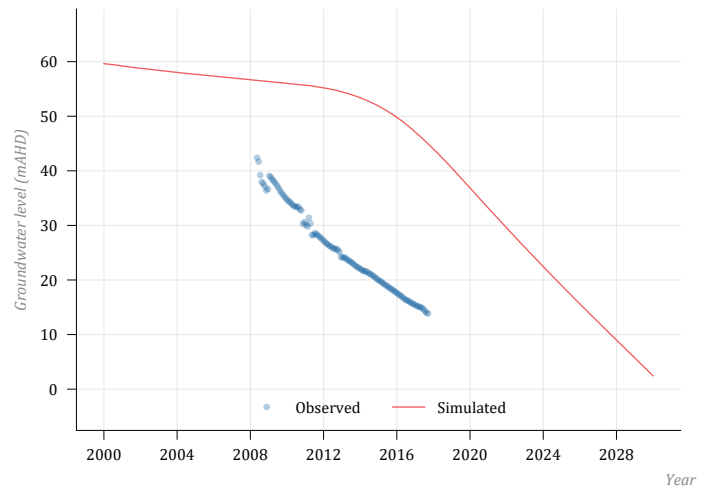
RNVW2-LLD



RNVW2-UAR

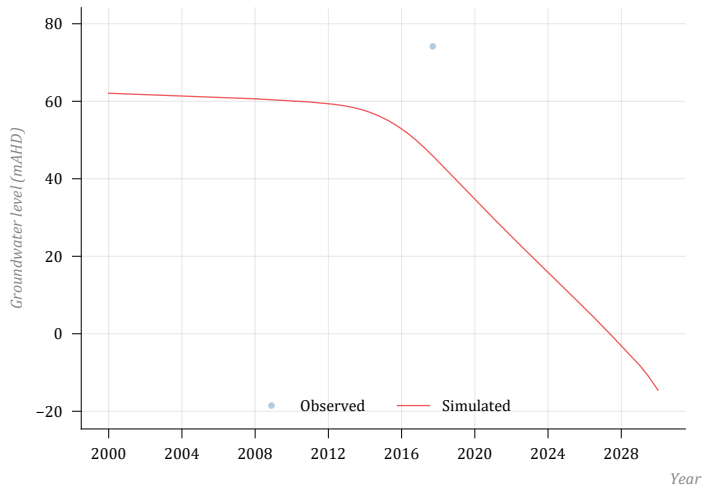


RNVW2-ULD

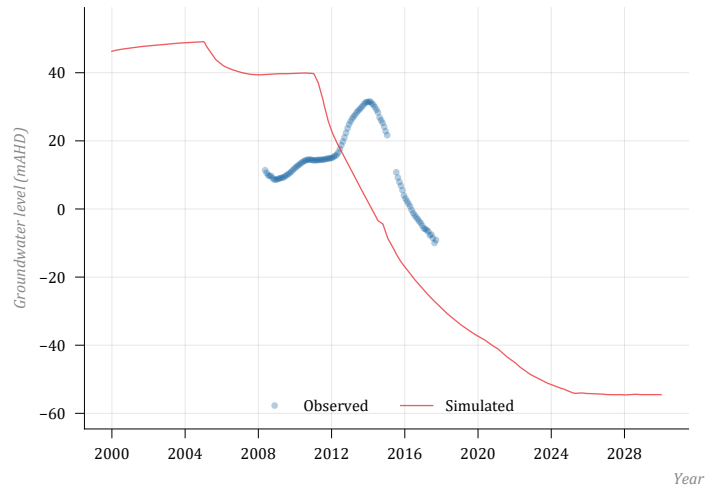


L28_Coal_Arties_Liddell_RavMid

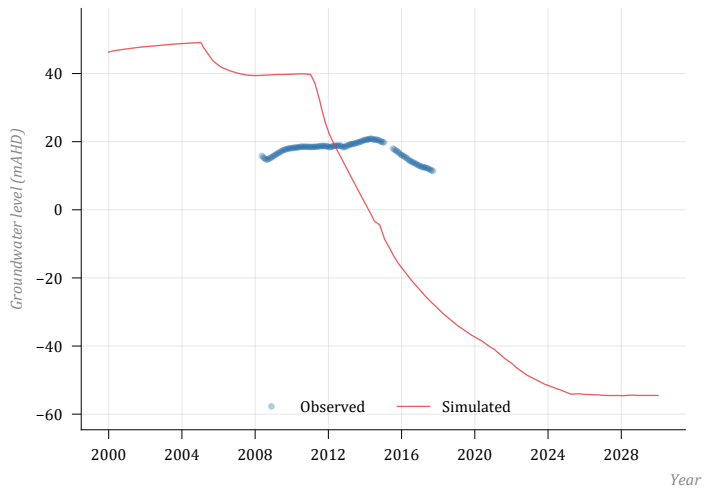
RNVW3-UAR



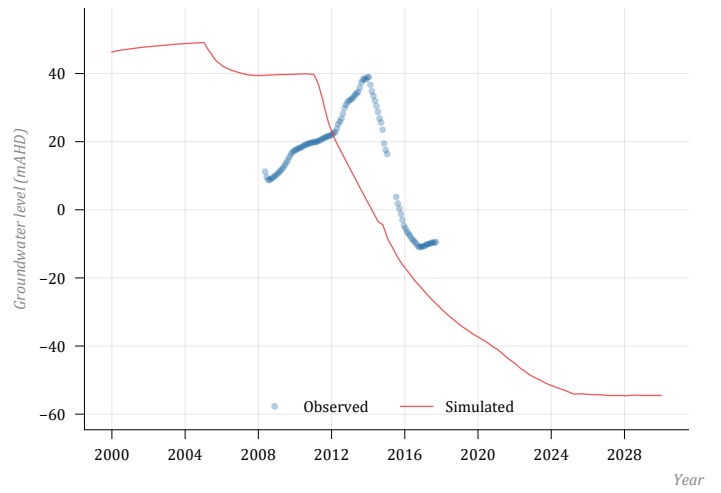
RNVW4-LLD



RNVW4-UAR



RNVW4-ULD

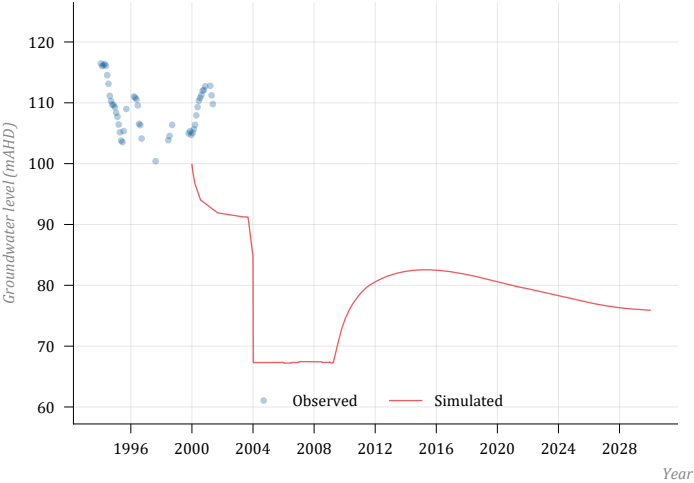


L28_Coal_Arties_Liddell_LiddellOC

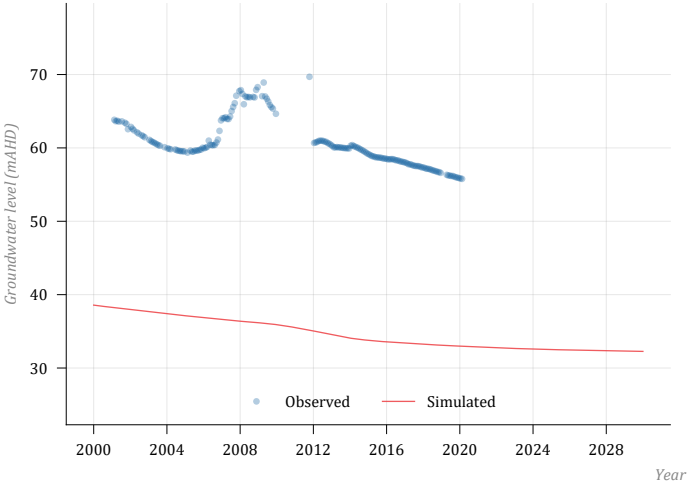
MLD_1



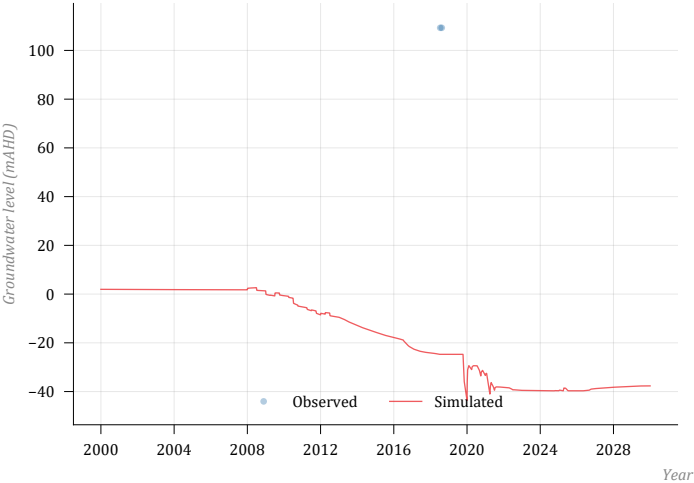
DUR2



COFFEYDAMB

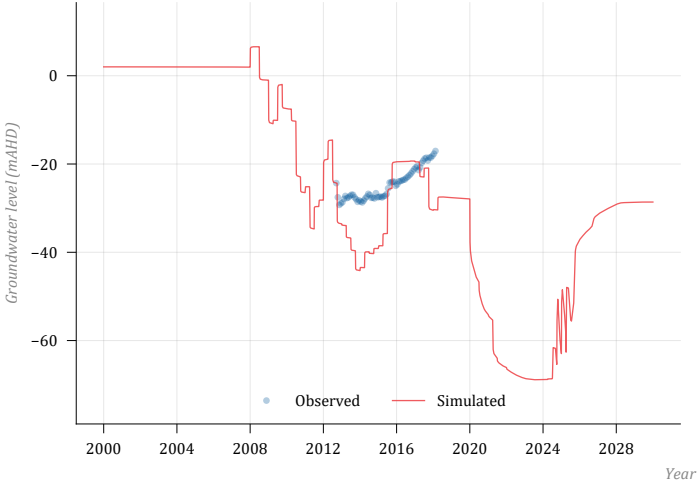


LC1

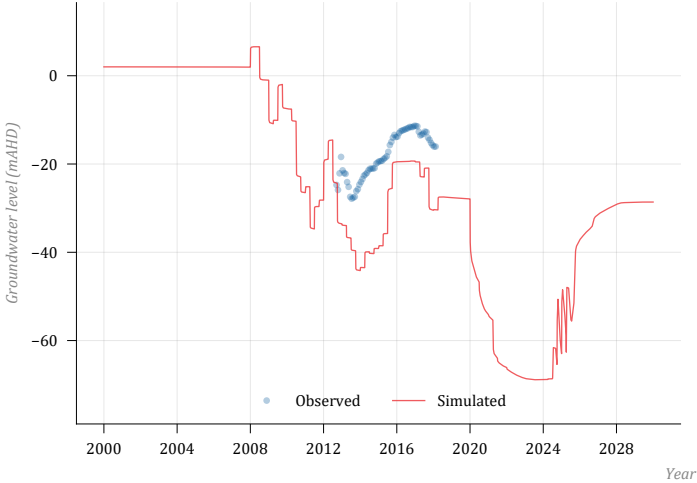


L28_Coal_Arties_Liddell_BowmansCk_upstream

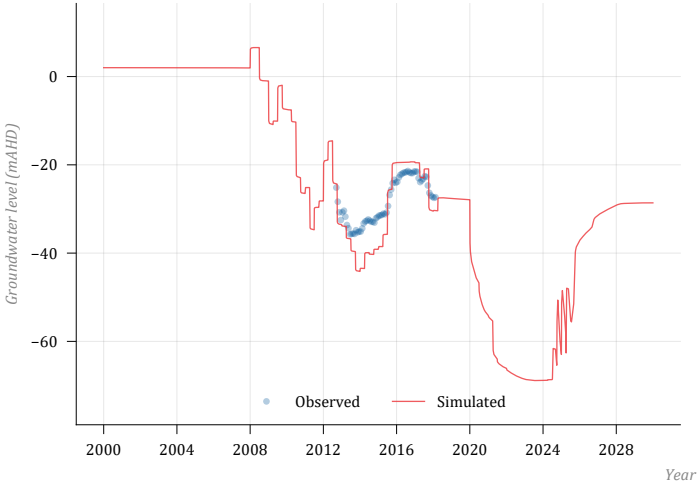
GNP4-ART



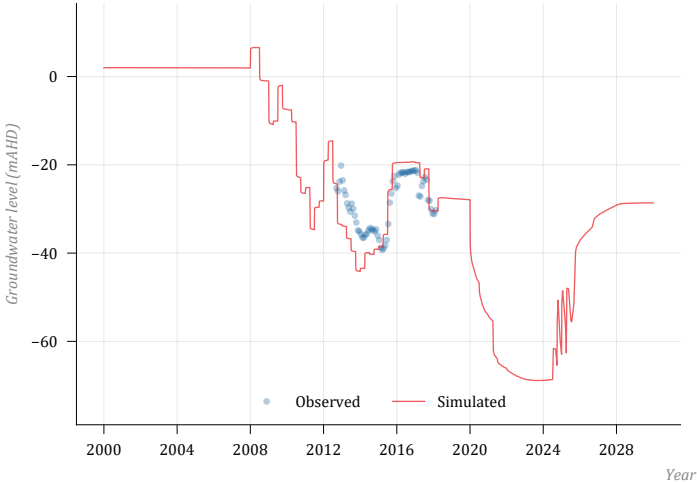
GNP4-LLD



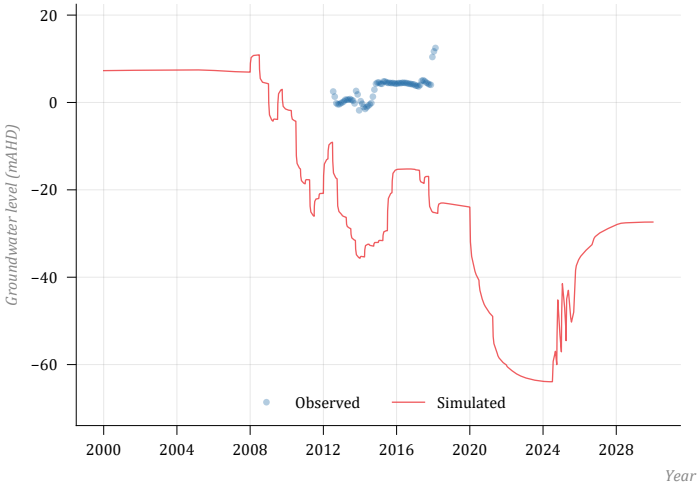
GNP4-MLD



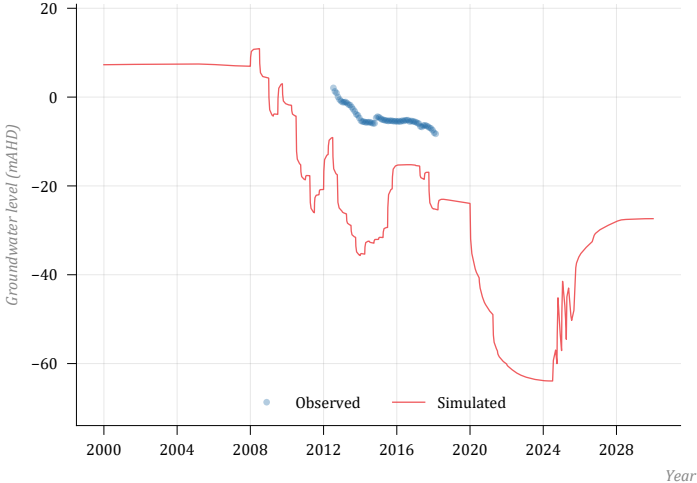
GNP4-ULD



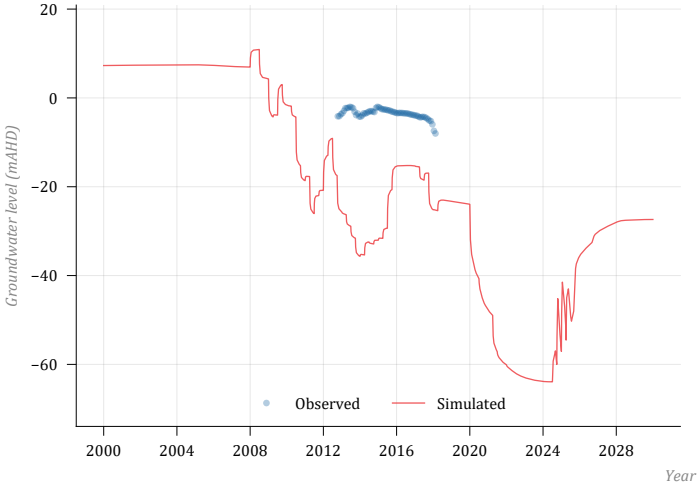
GNP7-ART



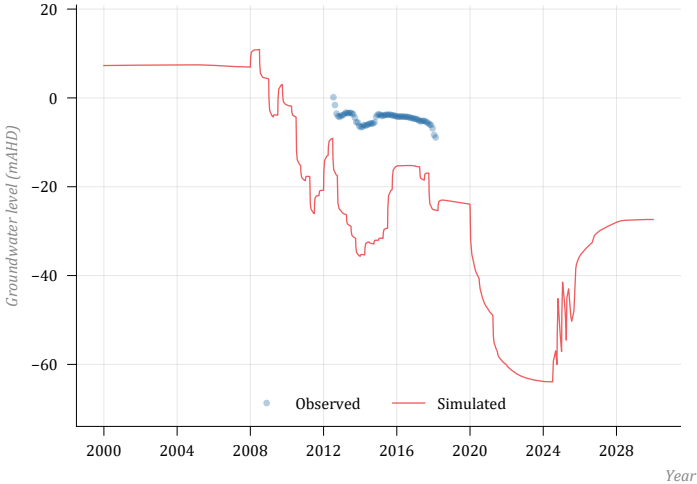
GNP7-LLD



GNP7-MLD

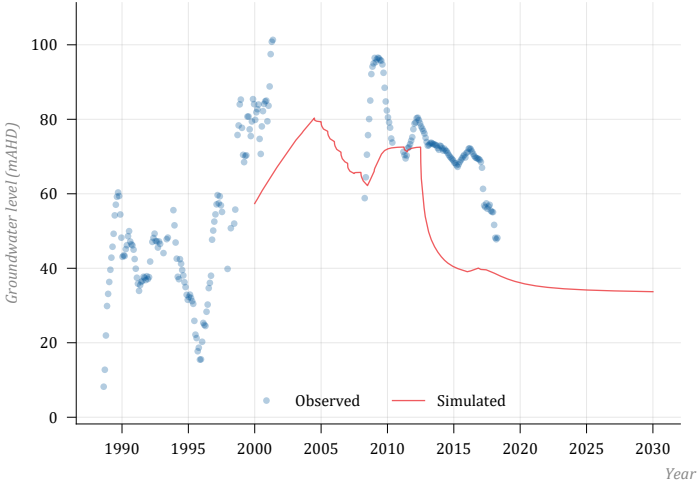


GNP7-ULD

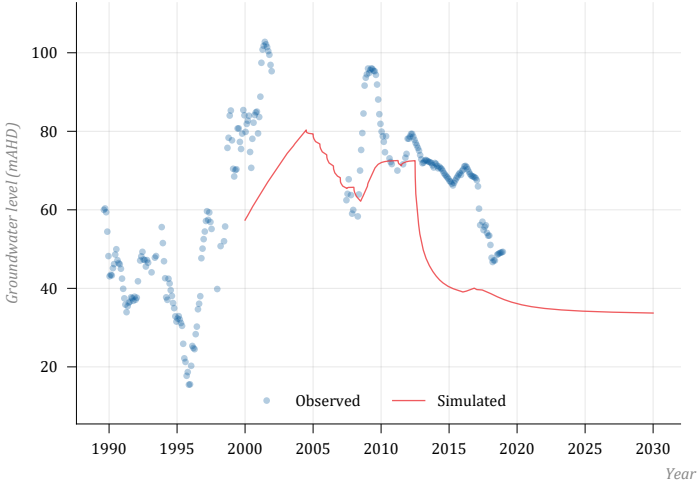


L28_Coal_Arties_Liddell_BowmansCk_upstream

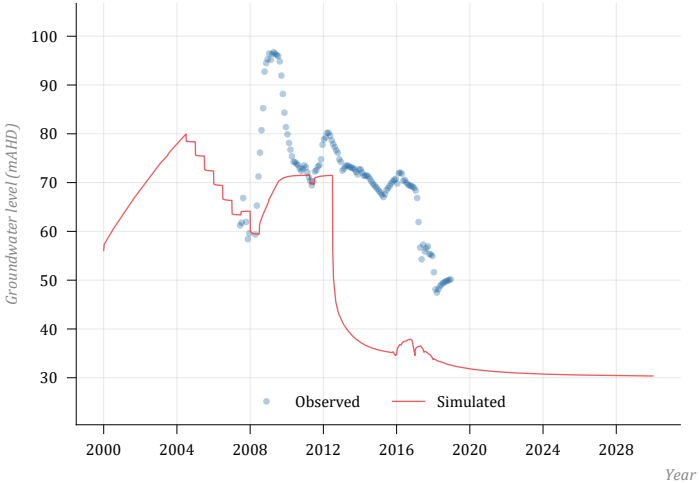
HAZ_3



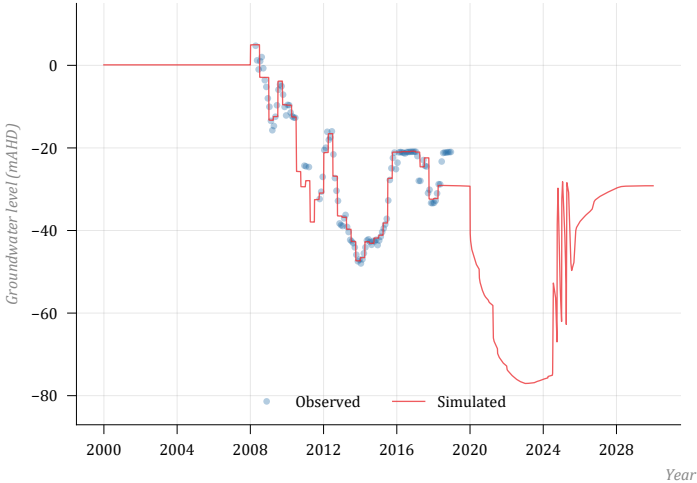
HAZ_4



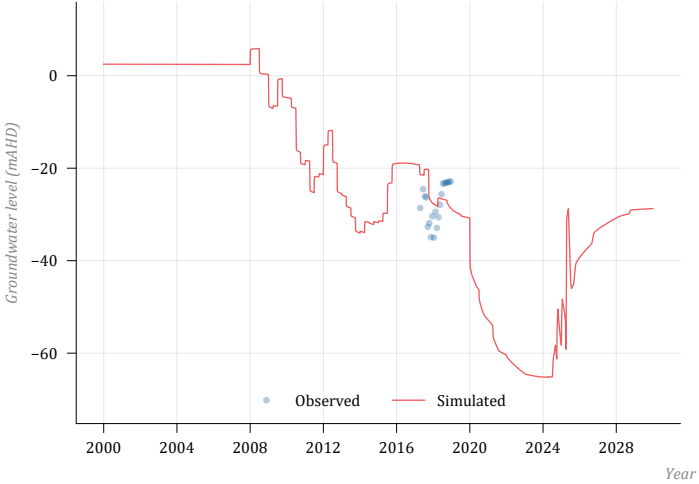
HAZ_6



M49

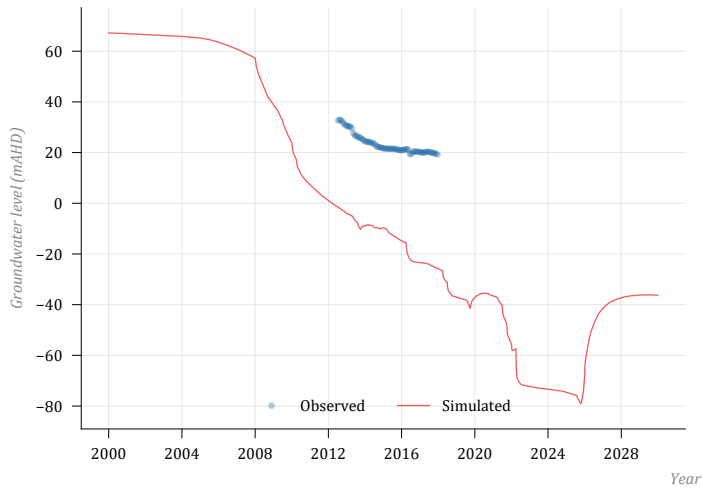


MT_OWEN

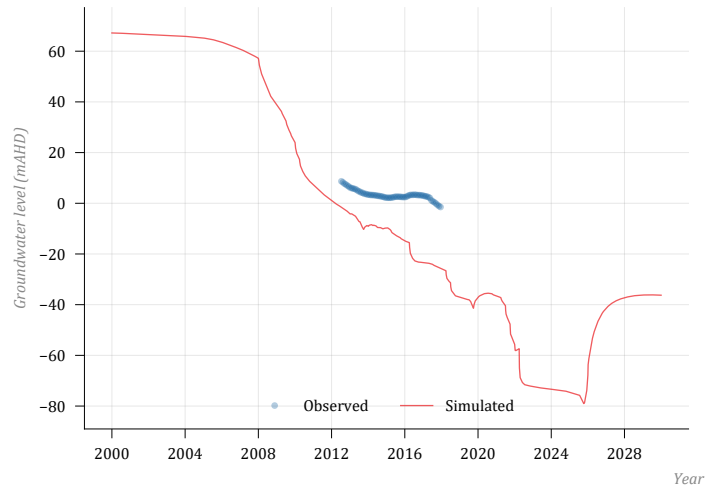


L28_Coal_Arties_Liddell_BowmansCk_downstream

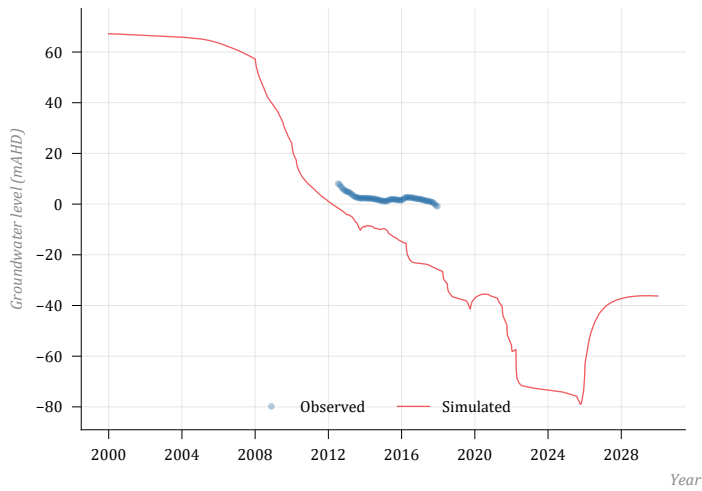
GNP1-ART



GNP1-LLD



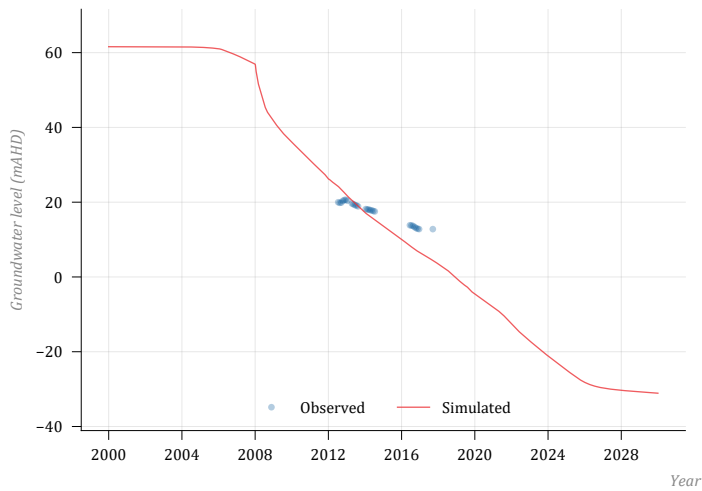
GNP1-MLD



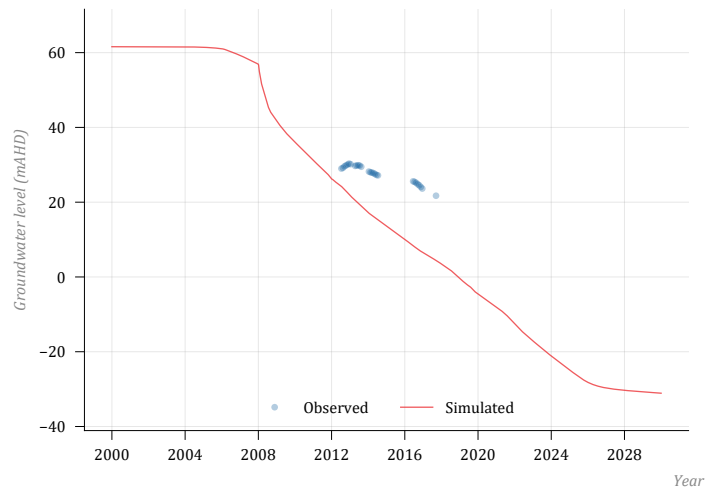
GNP1-ULD



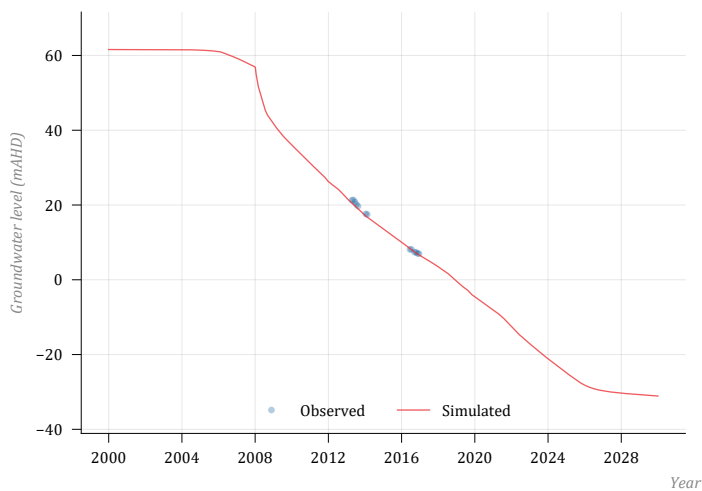
GNP2-ART



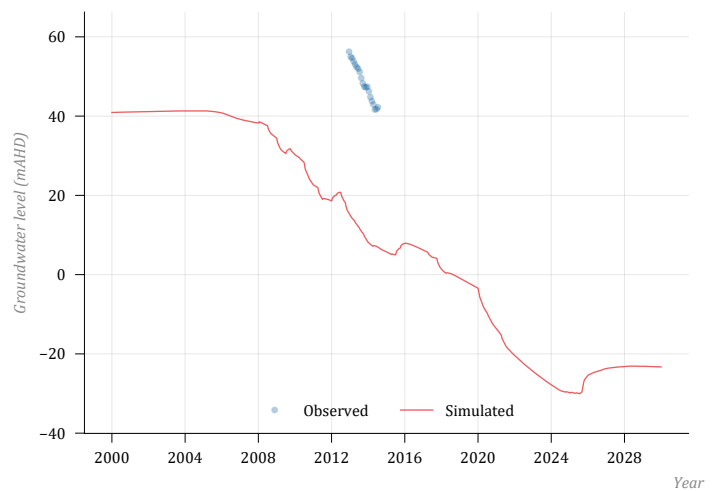
GNP2-LLD



GNP2-MLD

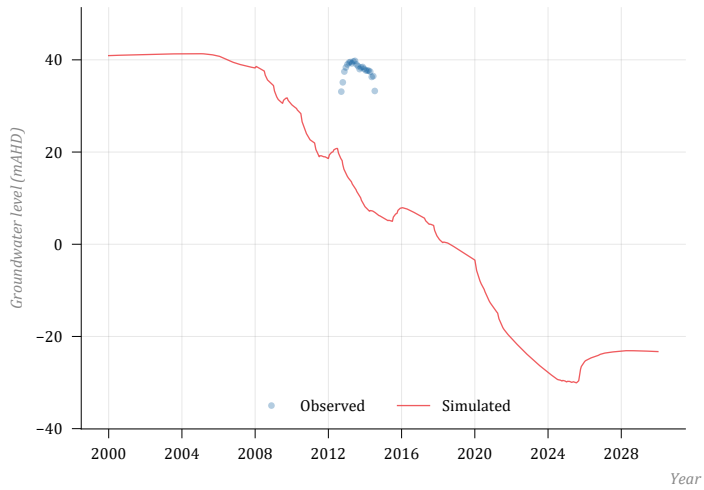


GNP3-ART

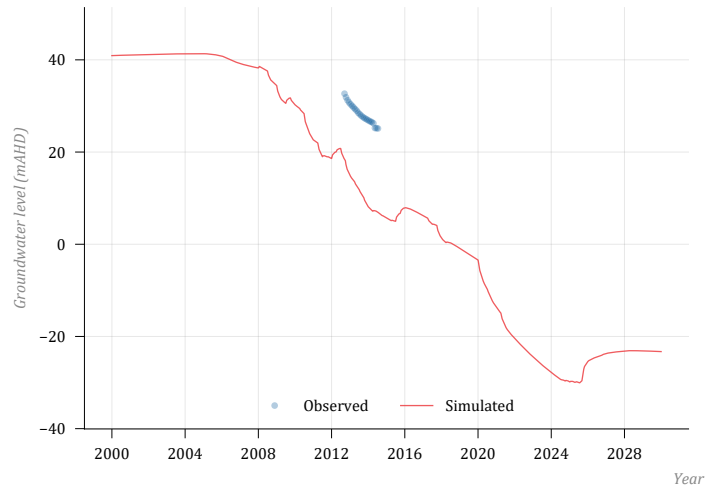


L28_Coal_Arties_Liddell_BowmansCk_downstream

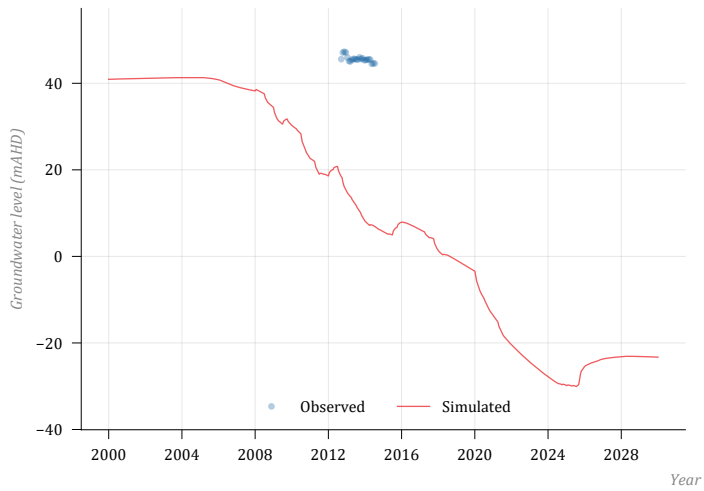
GNP3-LLD



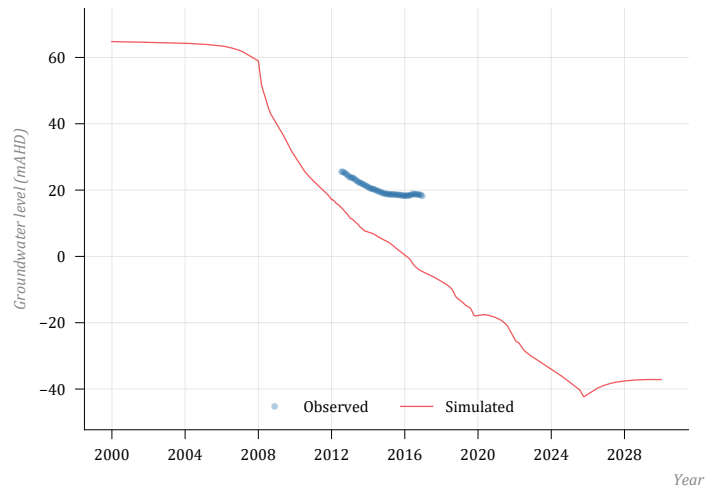
GNP3-MLD



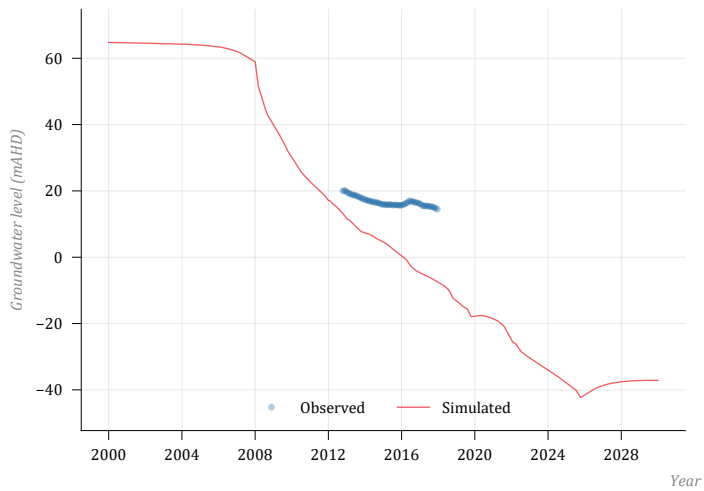
GNP3-ULD



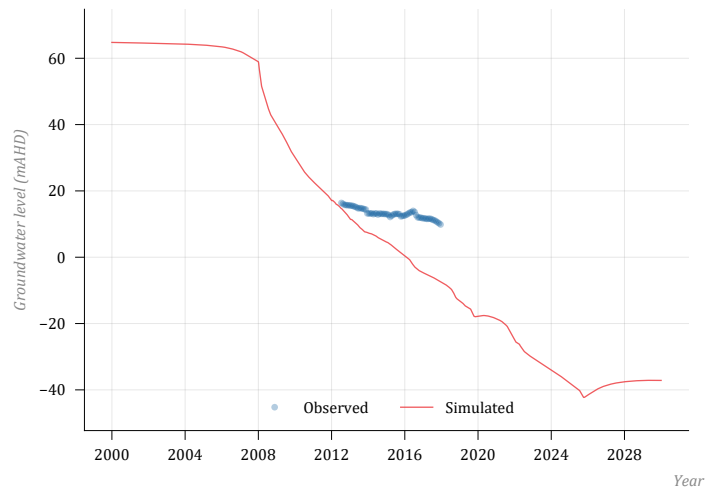
GNP5-ART



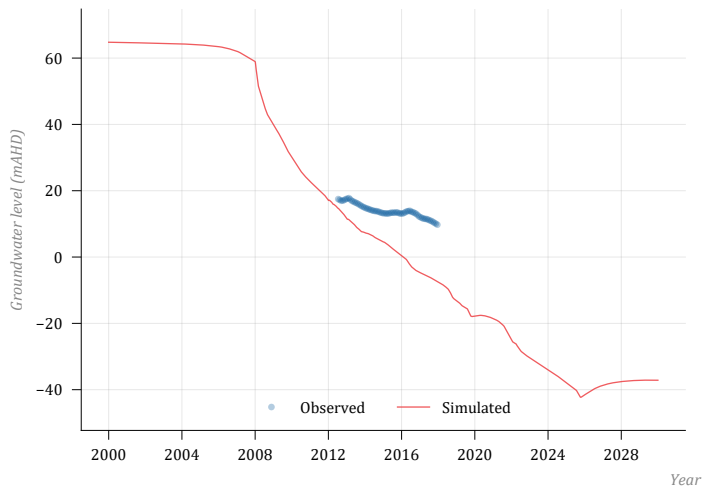
GNP5-LLD



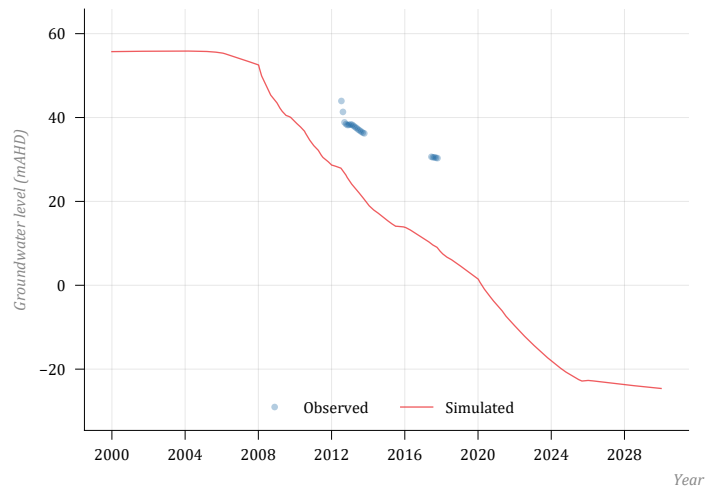
GNP5-MLD



GNP5-ULD

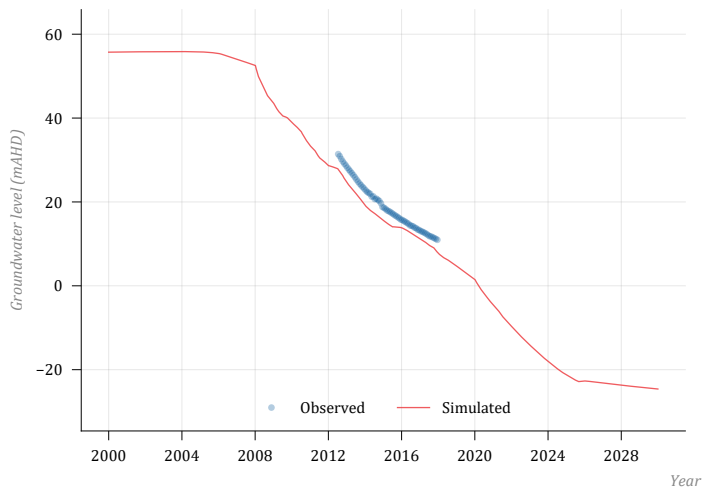


GNP6-ART

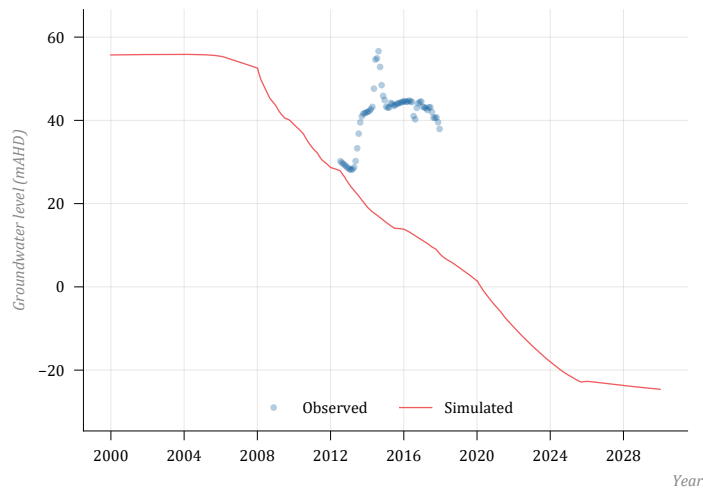


L28_Coal_Arties_Liddell_BowmansCk_downstream

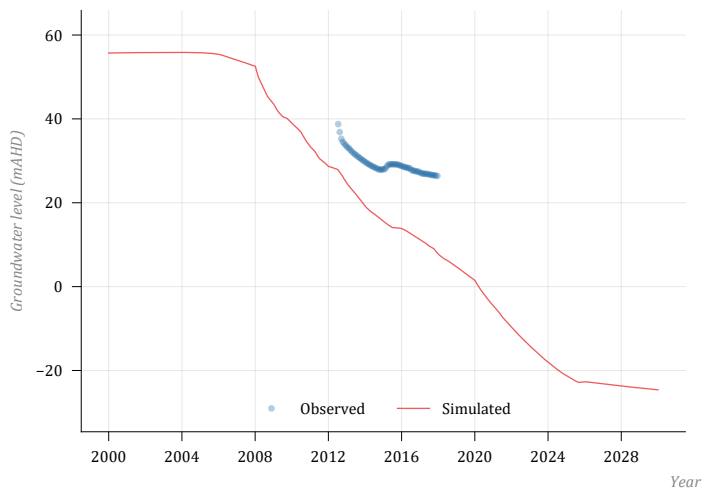
GNP6-LLD



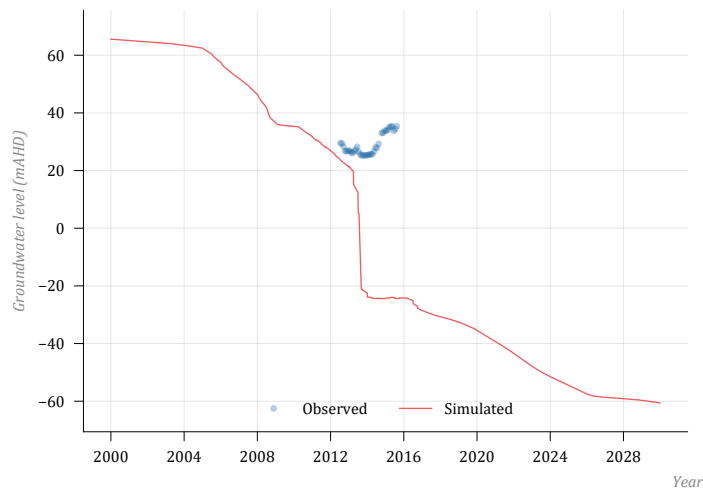
GNP6-MLD



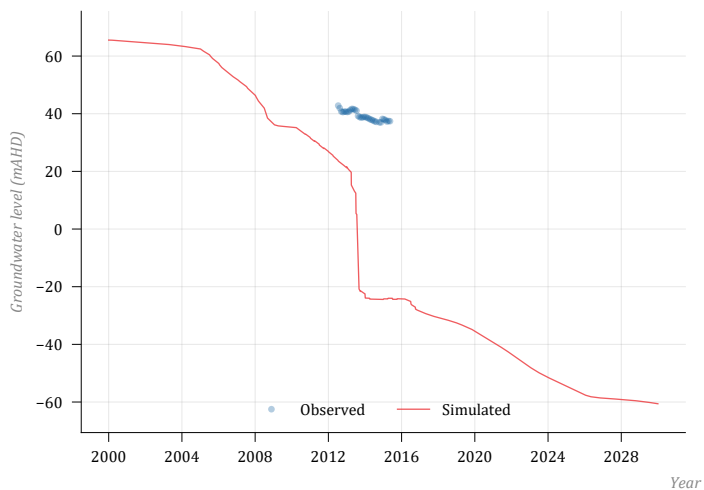
GNP6-ULD



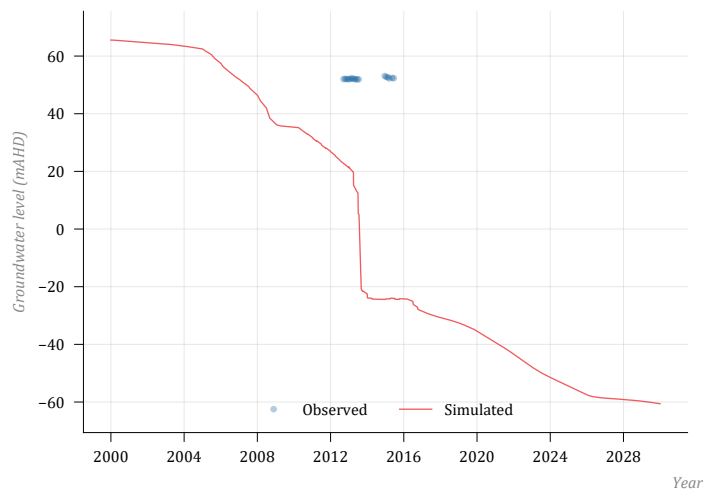
GNP8-LLD



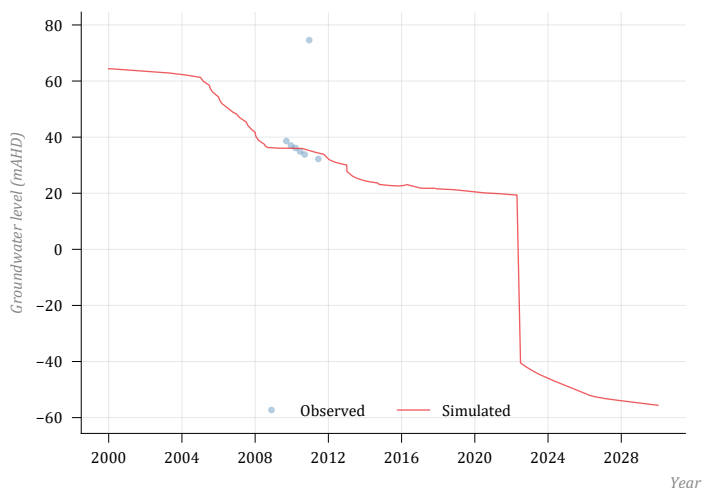
GNP8-MLD



GNP8-ULD



NPZ14

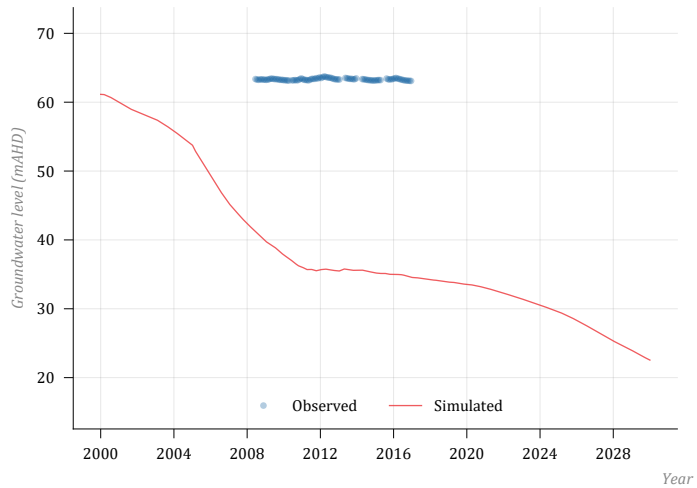


NPZ16A



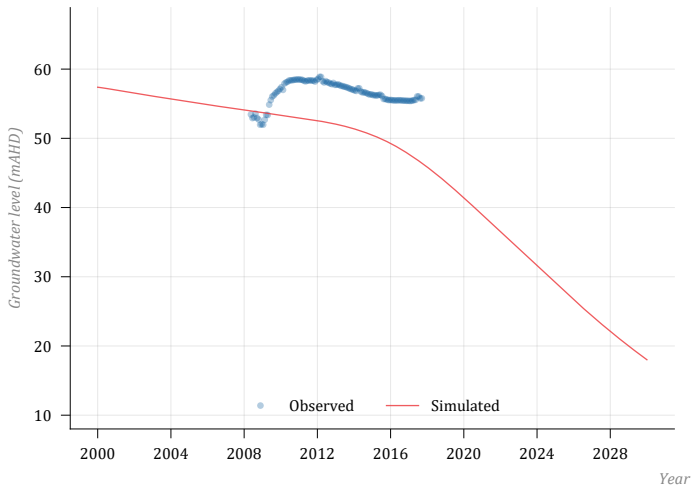
L28_Coal_Arties_Liddell_StationCk

GCP36

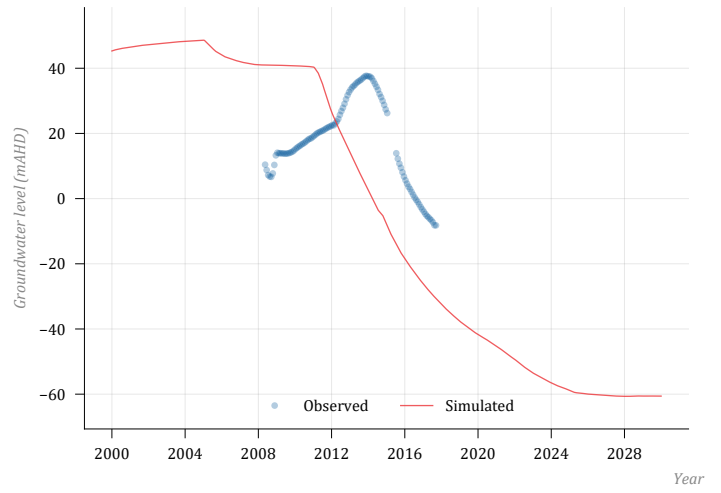


L30_Coal_Barrett_RavMid

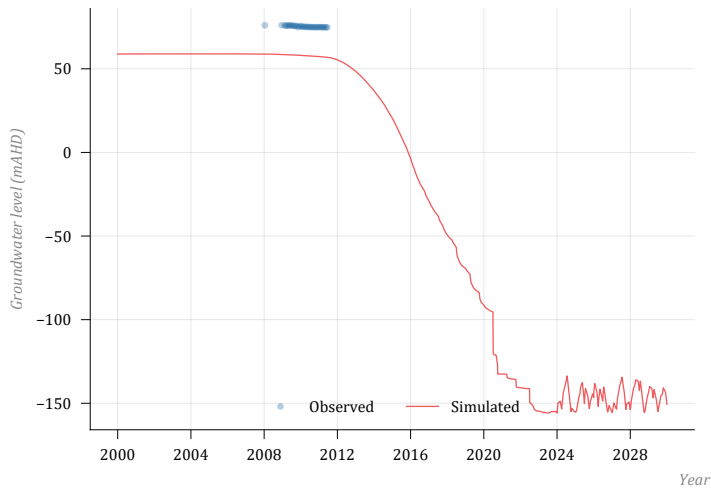
RNVW1-BRT



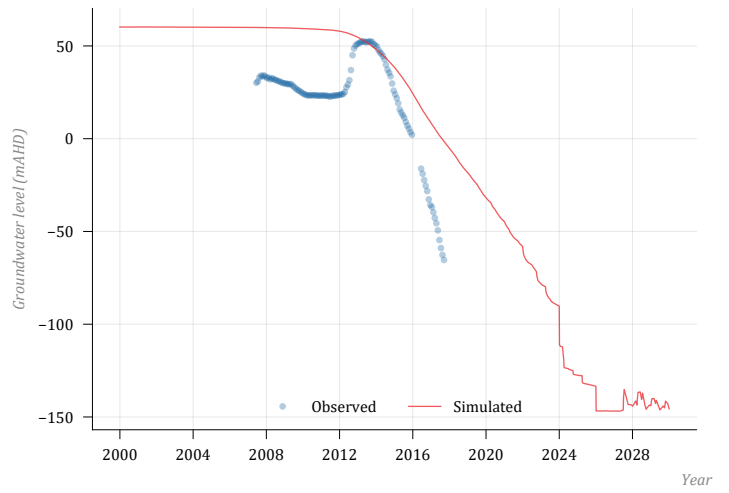
RNVW4-BRT



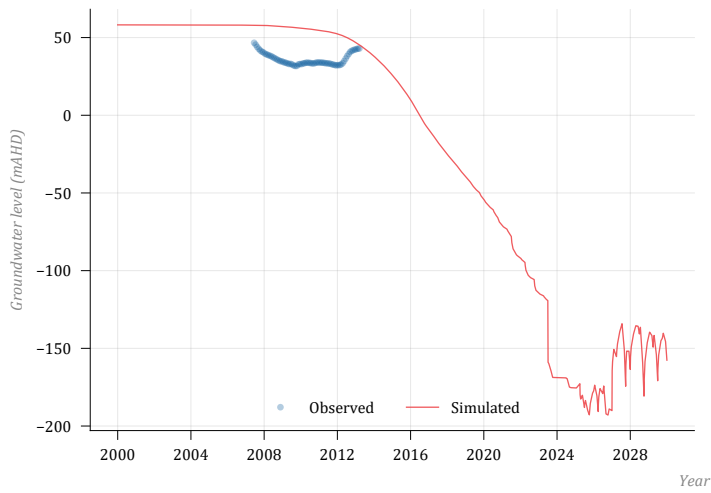
CS4545C



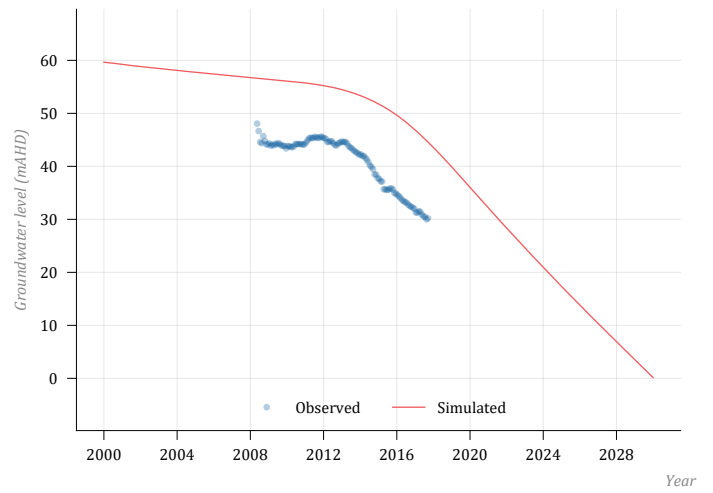
CS4657-BRT



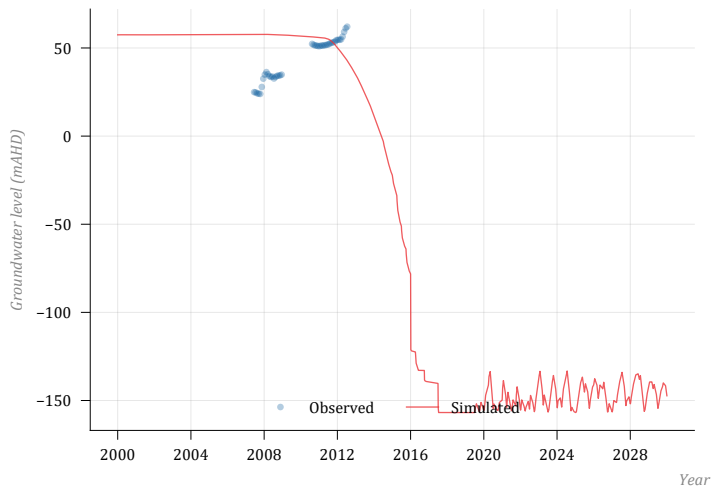
CS4655-BRT



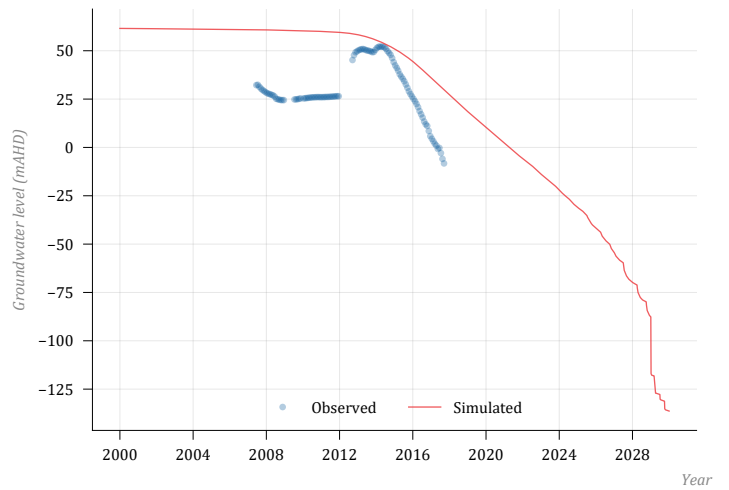
RNVW2-BRT



CS4656-BRT

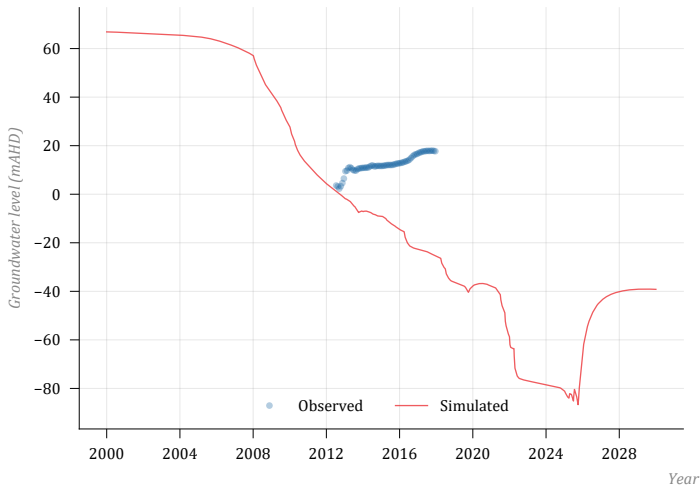


CS4658-BRT

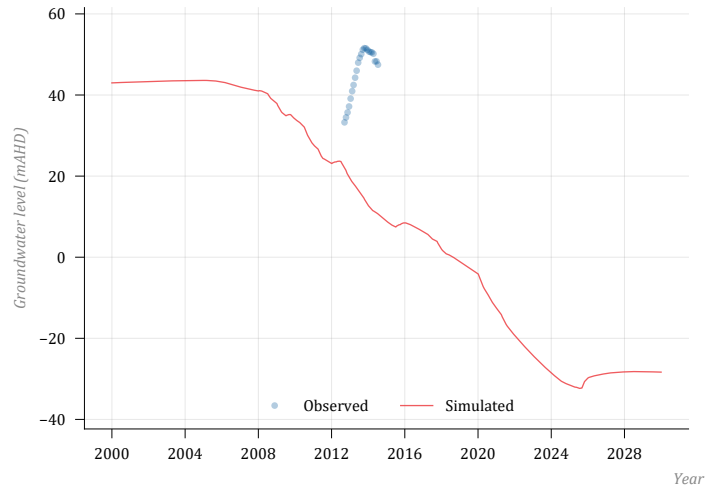


L30_Coal_Barrett_BowmansCk

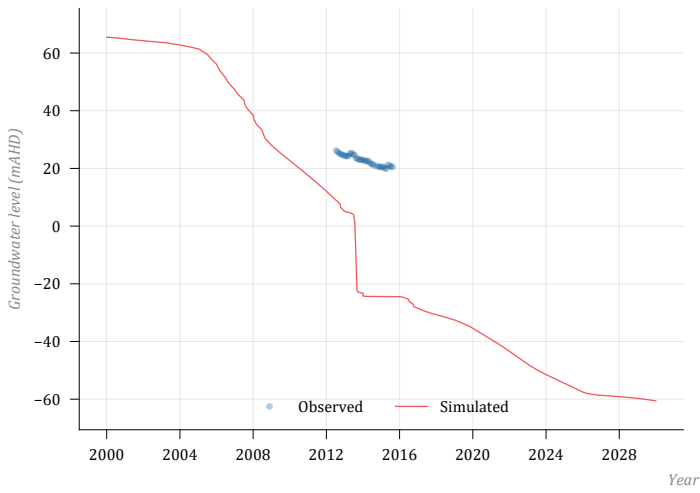
GNP1-BRT



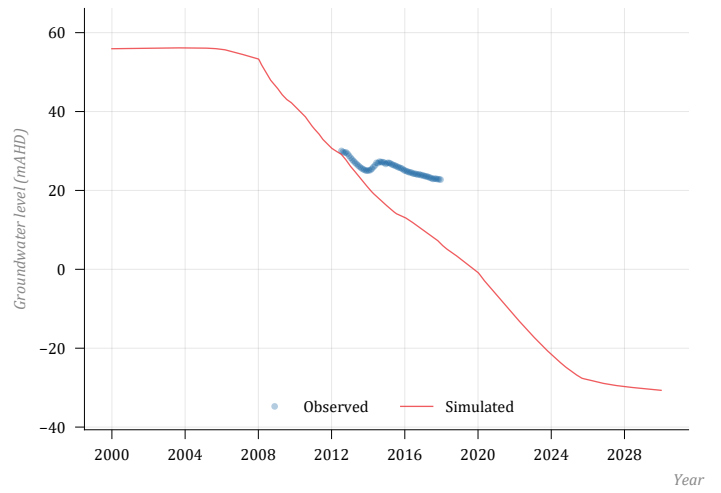
GNP3-BRT



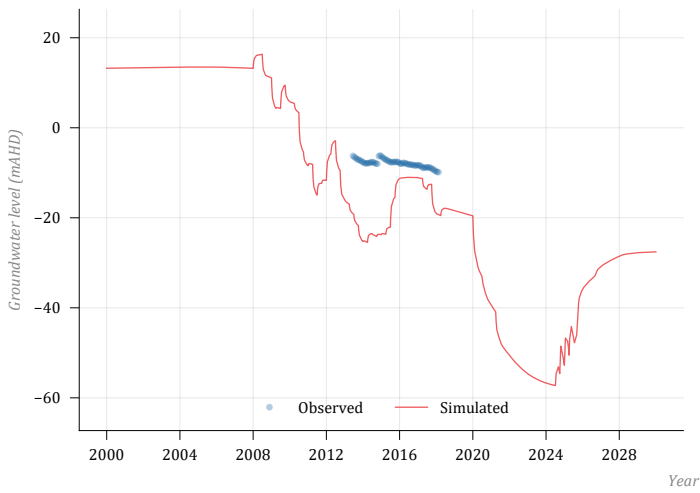
GNP8-BAR



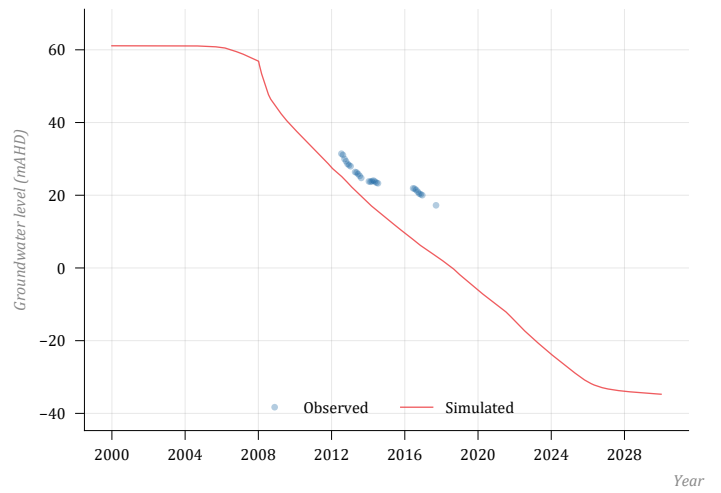
GNP6-BAR



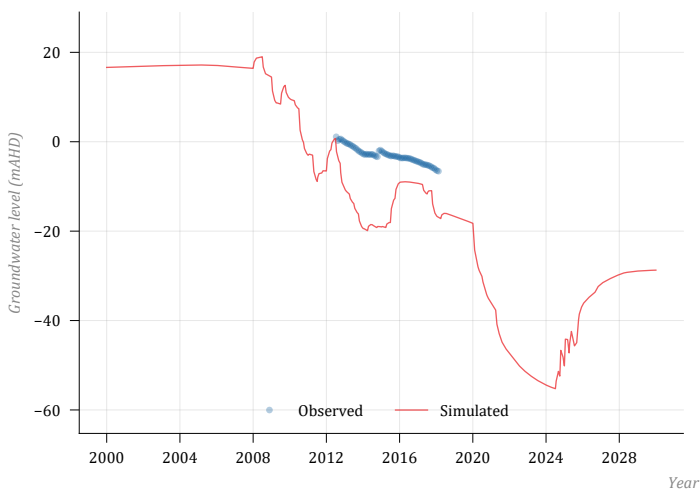
GNP4-BRT



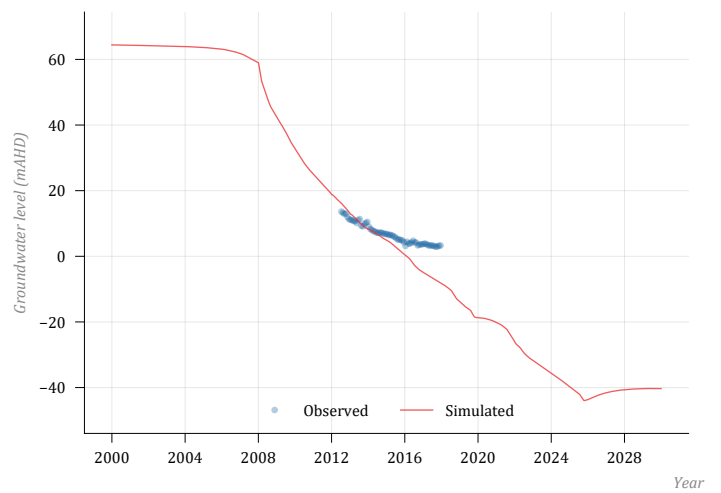
GNP2-BAR



GNP7-BRT

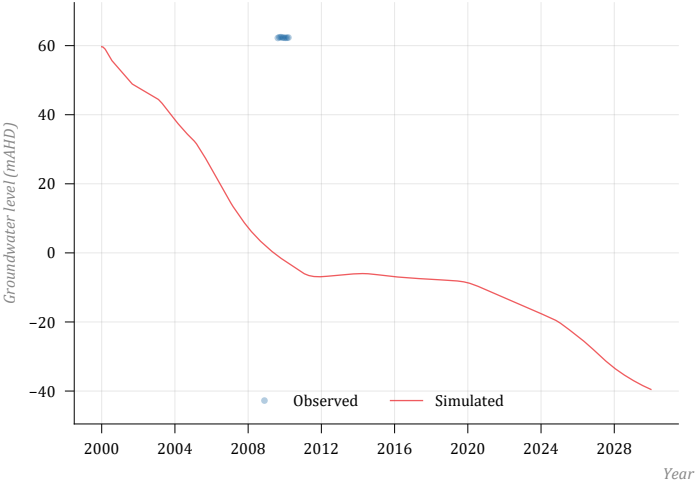


GNP5-BAR



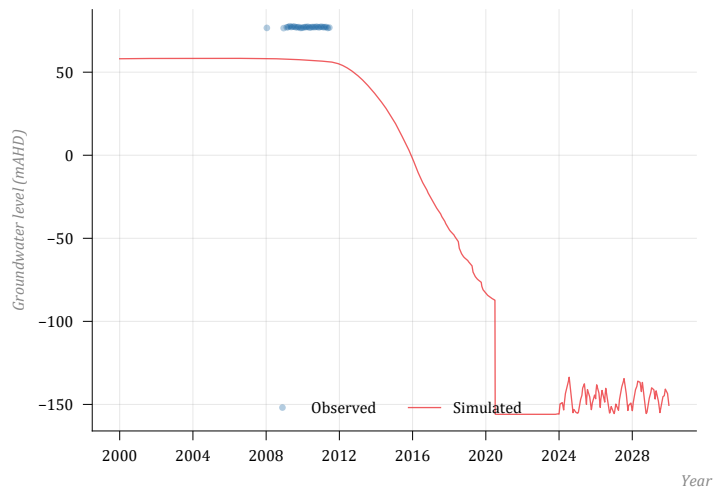
L30_Coal_Barrett_StationCk

GCP27



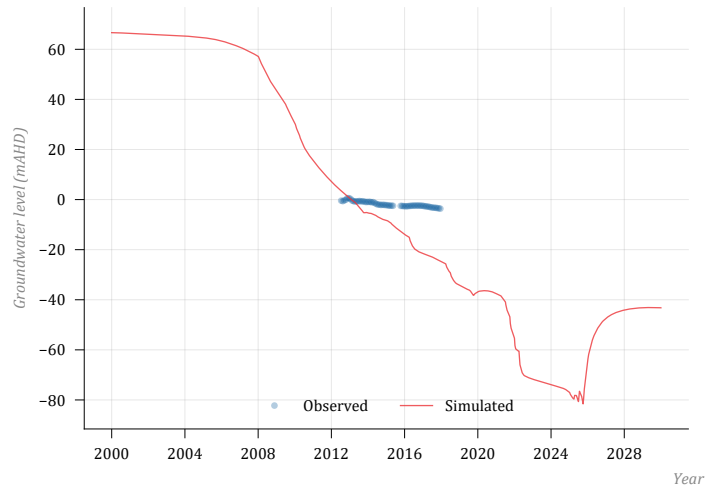
L32_Coal_Hebden_RavMid

CS4545D

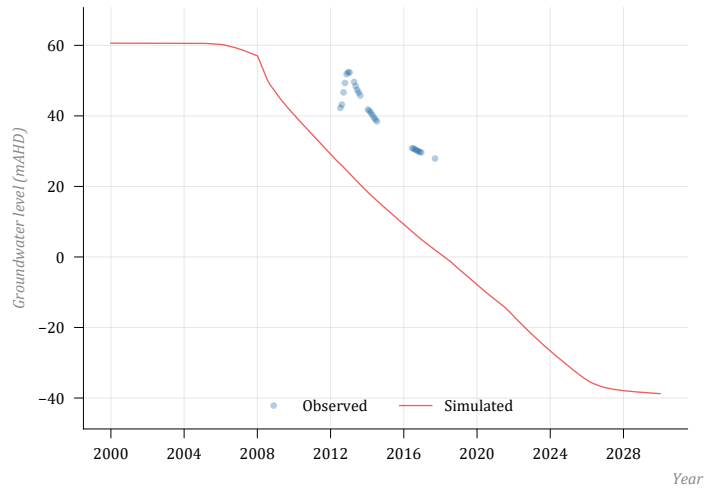


L32_Coal_Hebden_BowmansCk

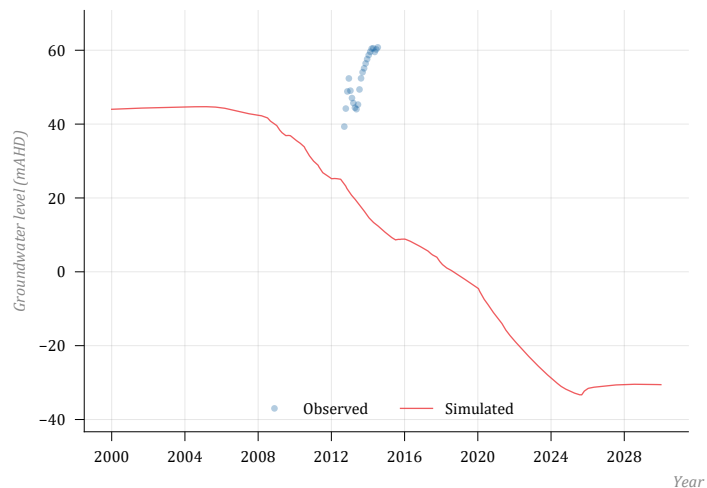
GNP1-HEB



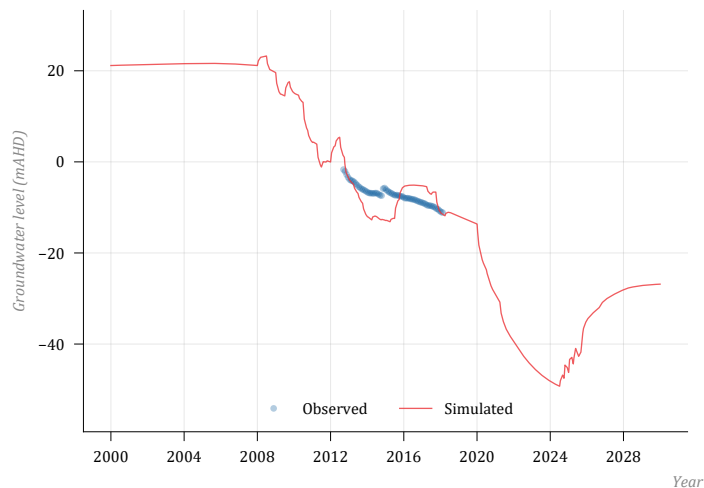
GNP2-HEB



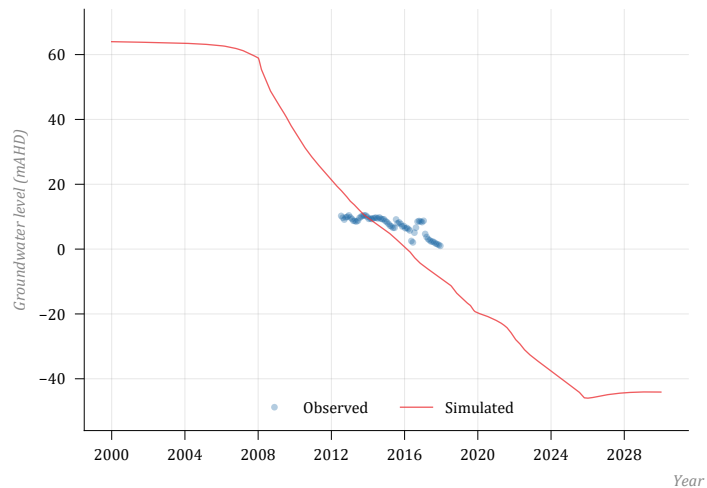
GNP3-HEB



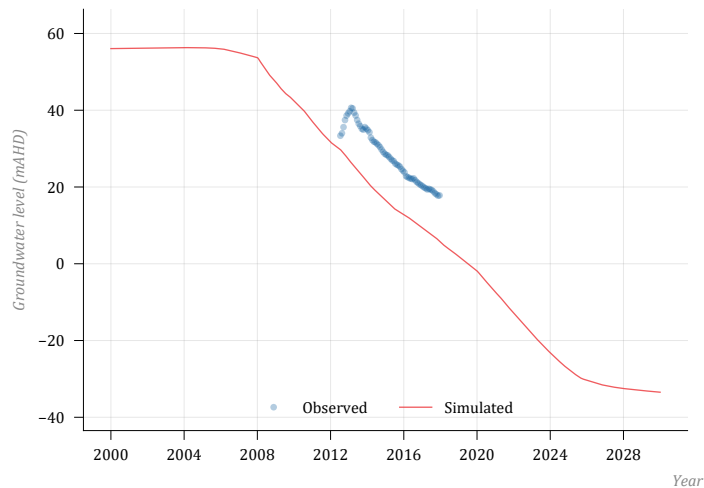
GNP4-HEB



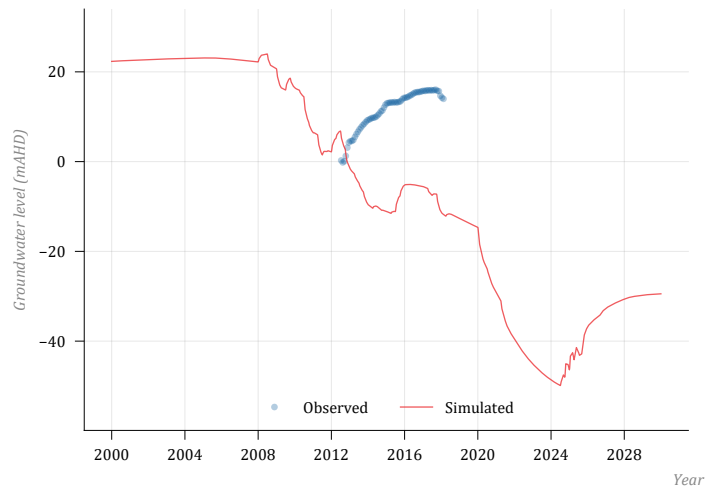
GNP5-HEB



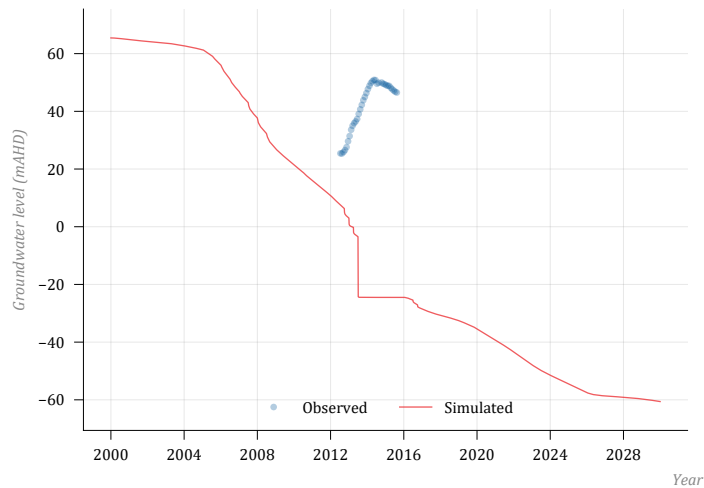
GNP6-HEB



GNP7-HEB

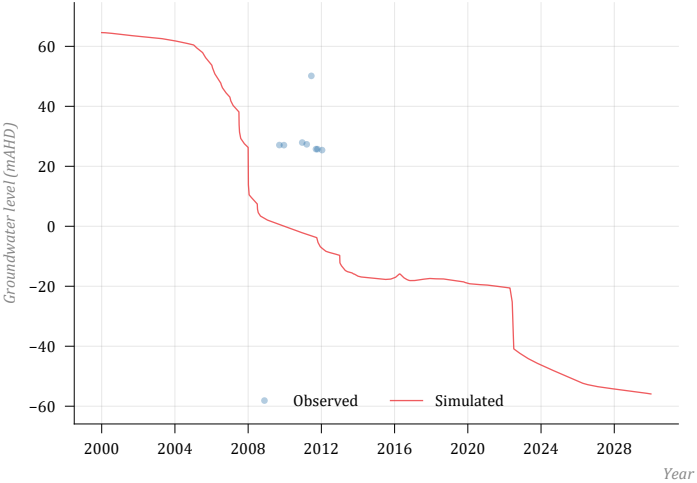


GNP8-HEB



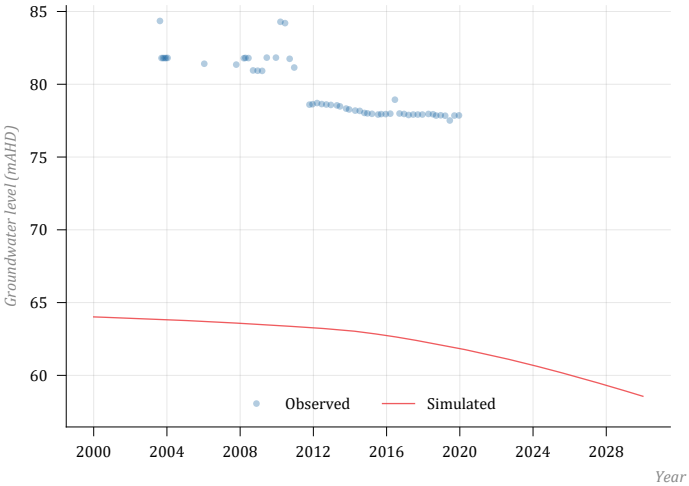
L32_Coal_Hebden_BowmansCk

NPZ14A

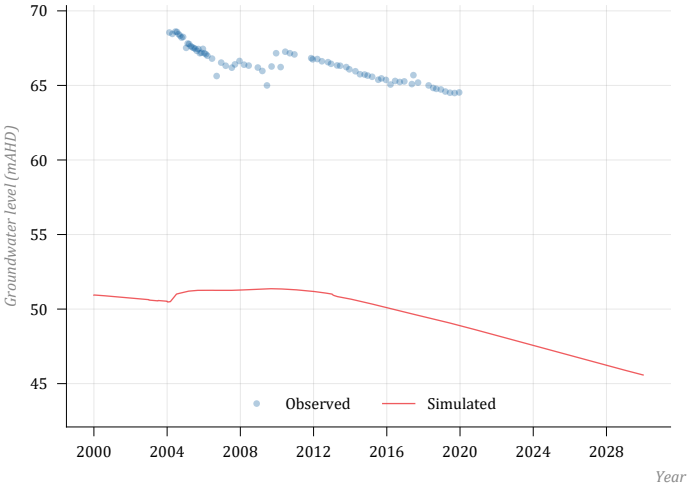


Spoil_HVOnorth

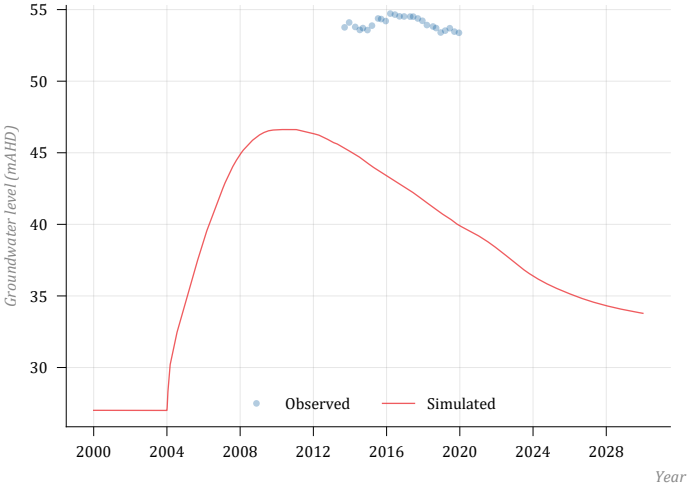
DM1



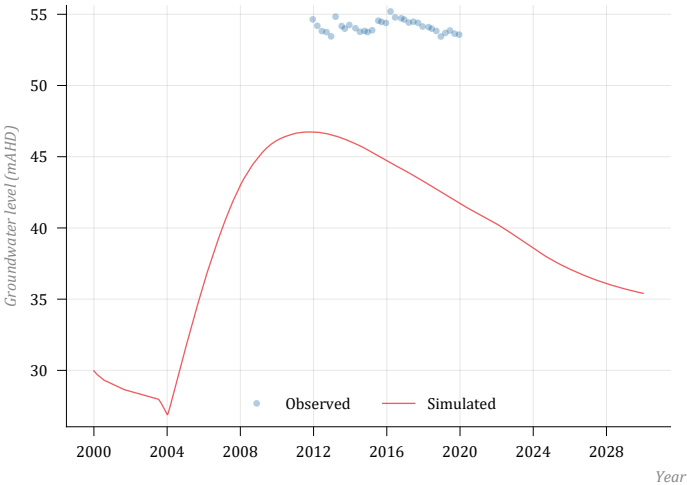
DM3



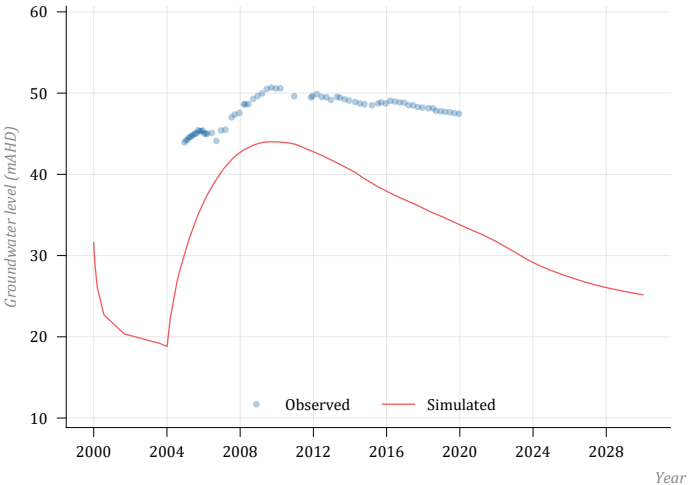
GW_115



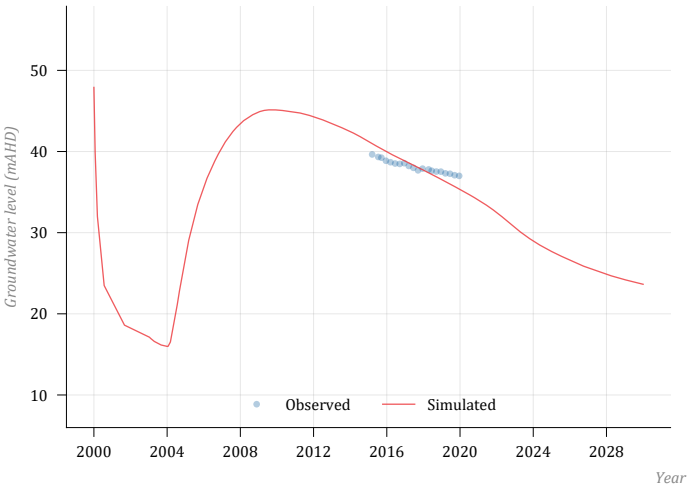
4119P



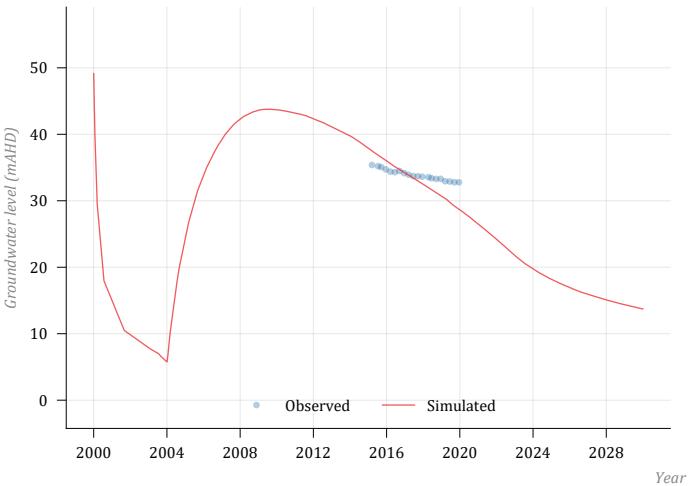
DM4



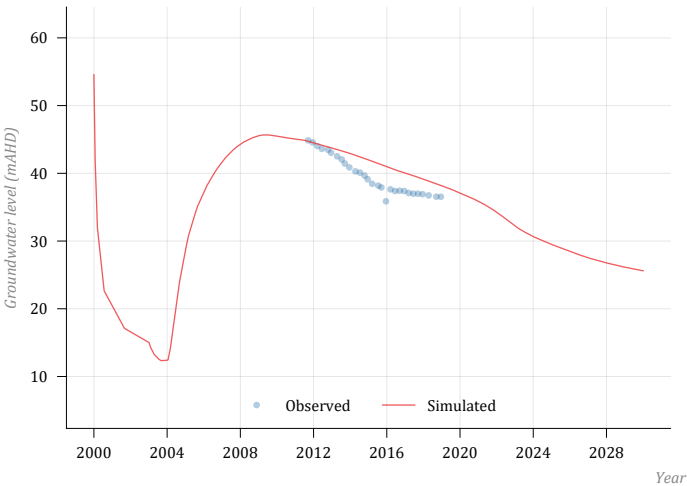
MB14HV004



MB14HV003

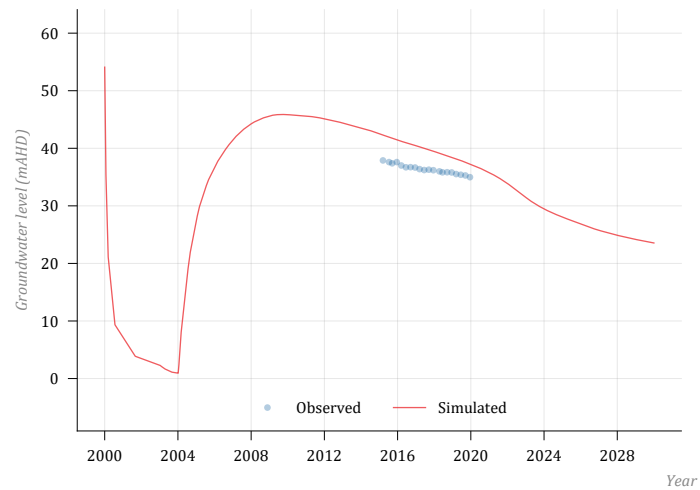


4113P

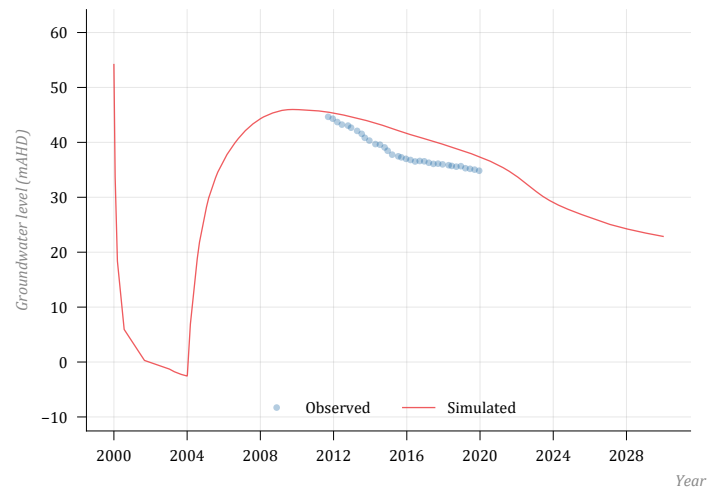


Spoil_HVOnorth

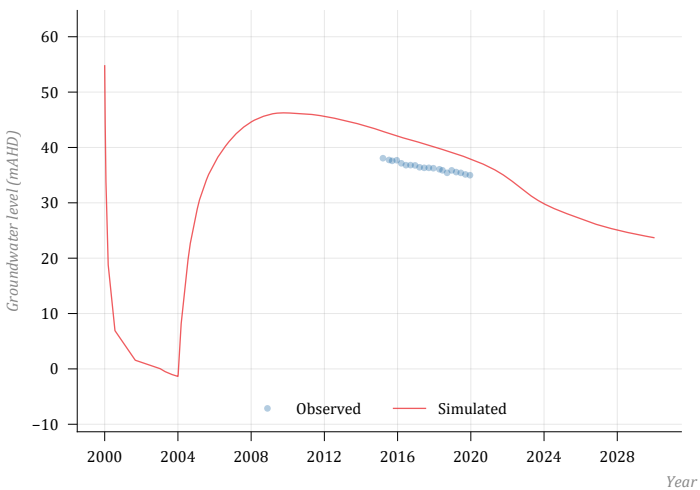
MB14HV005



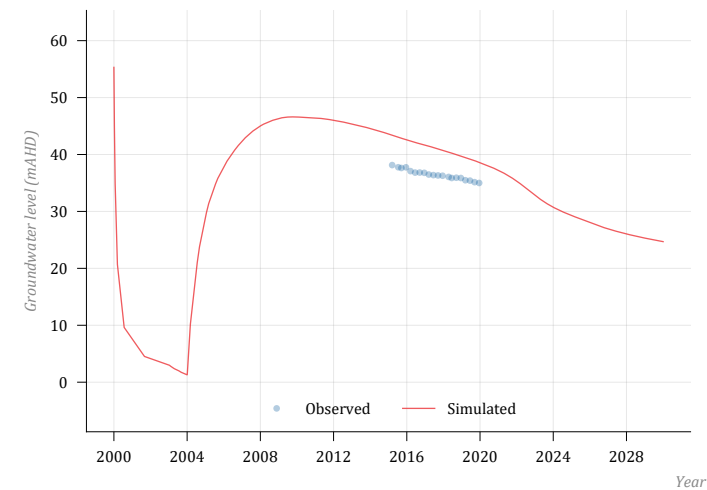
4117P



MB14HV001

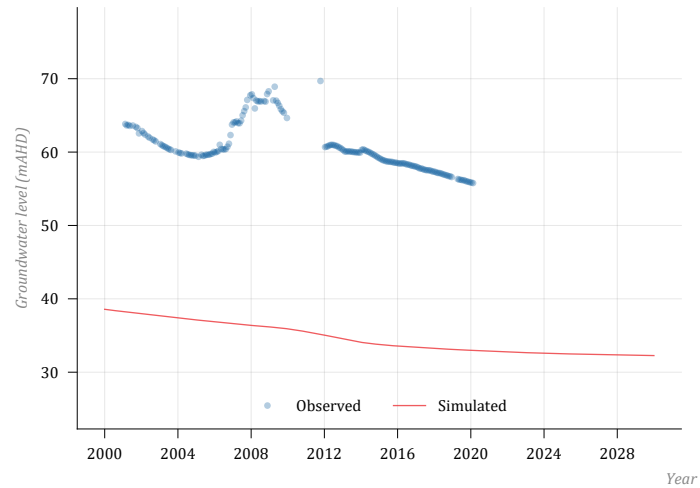


MB14HV002

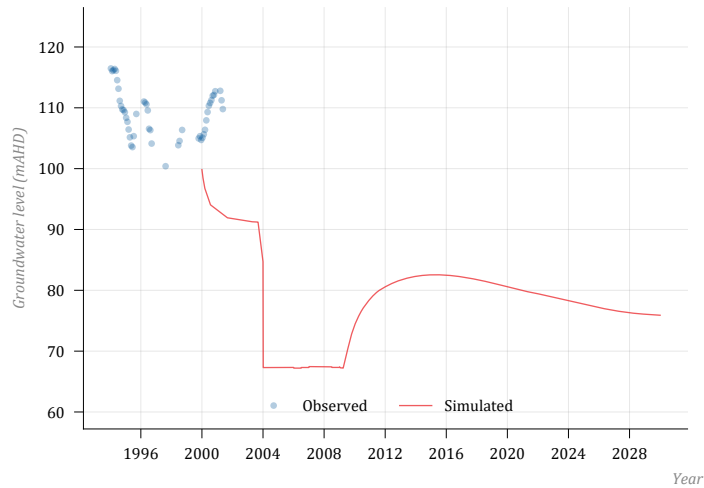


Liddell_UG

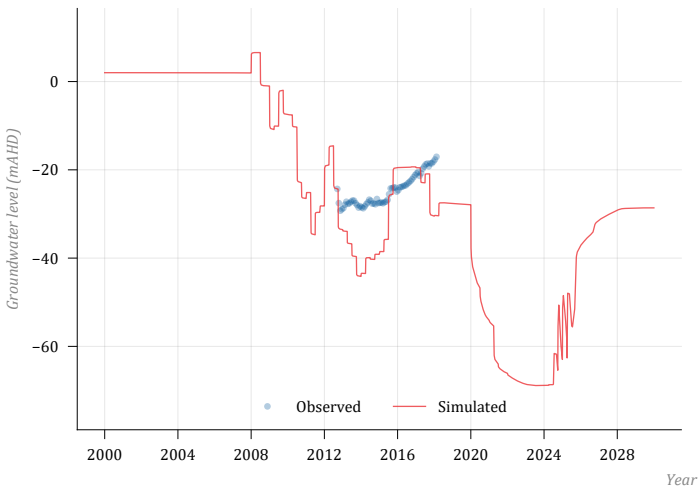
COFFEYDAMB



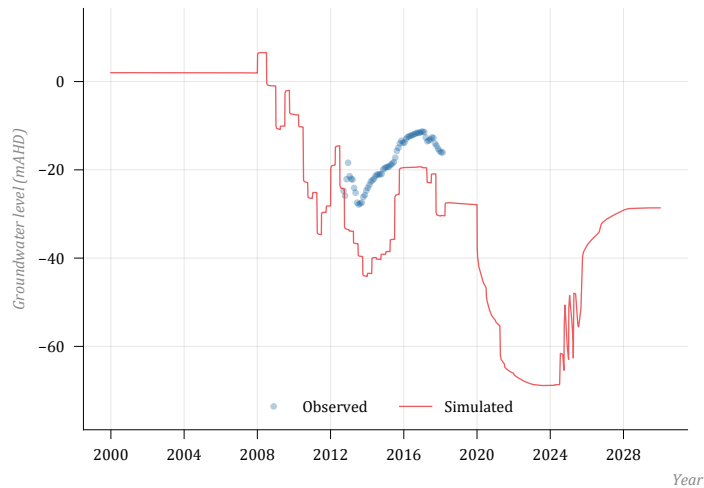
DUR2



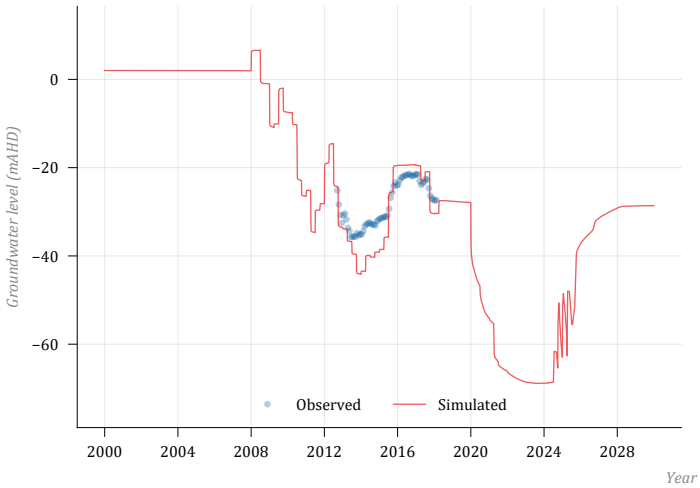
GNP4-ART



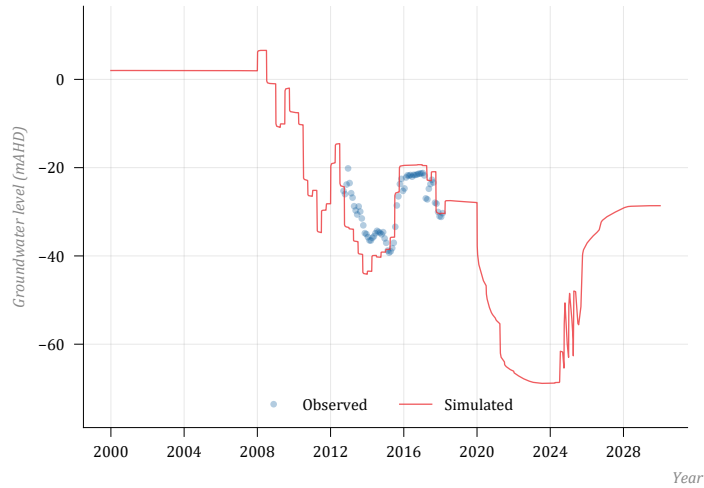
GNP4-LLD



GNP4-MLD



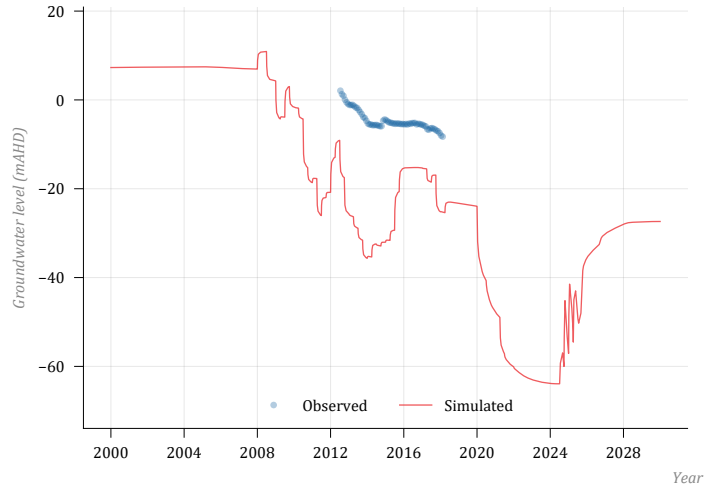
GNP4-ULD



GNP7-ART

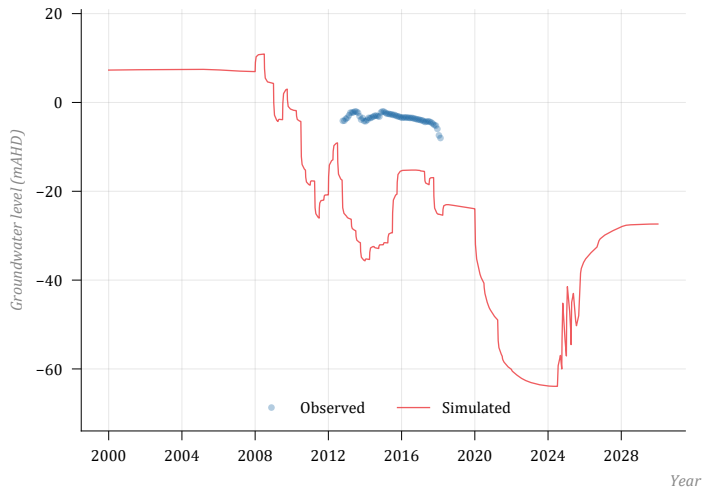


GNP7-LLD

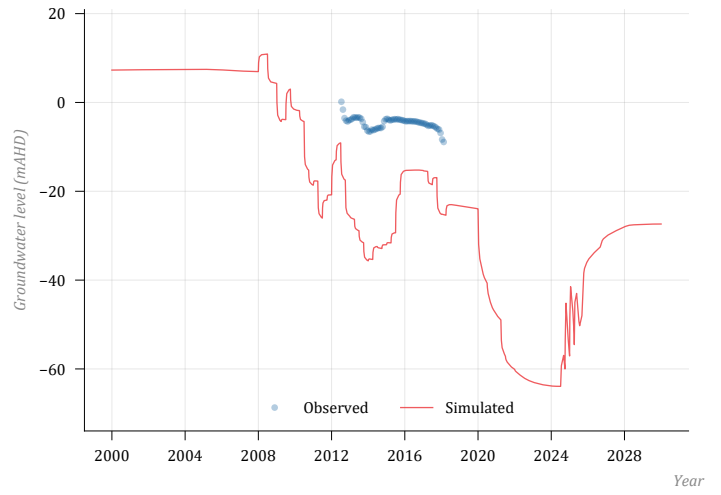


Liddell_UG

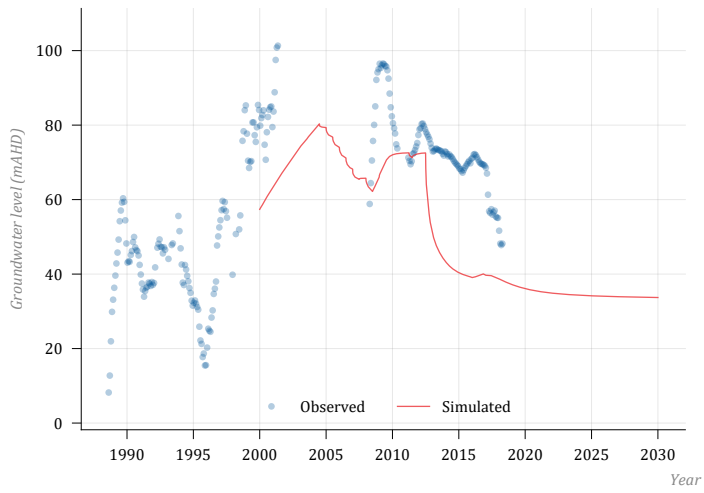
GNP7-MLD



GNP7-ULD



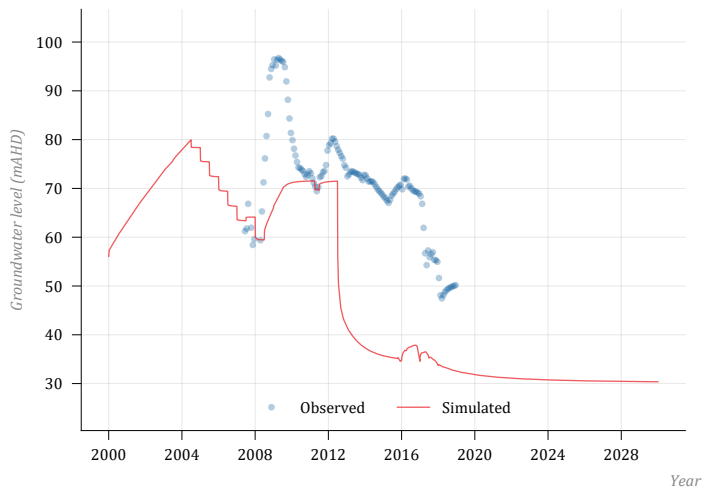
HAZ_3



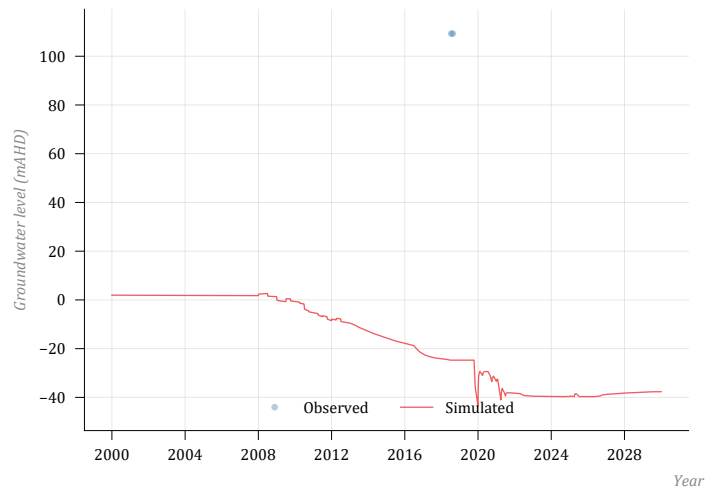
HAZ_4



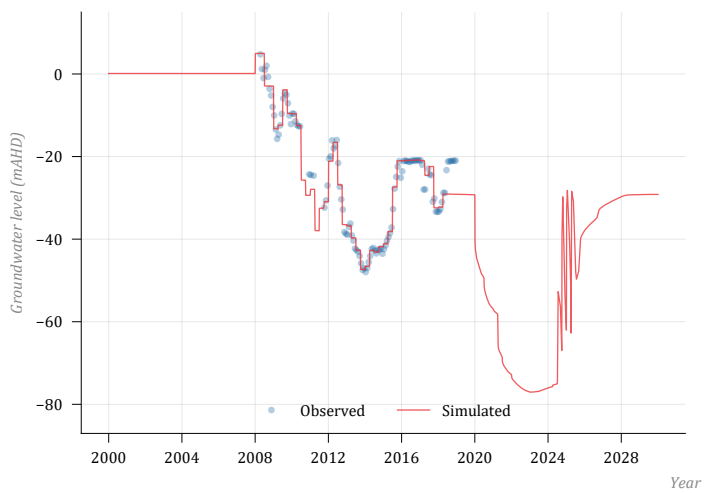
HAZ_6



LC1



M49

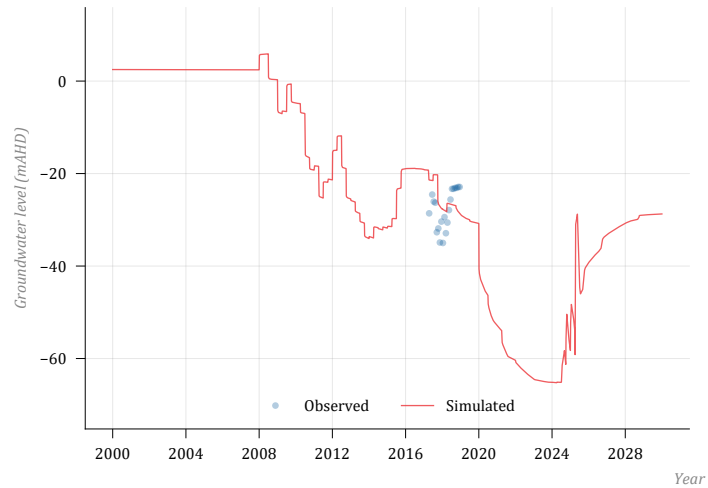


MLD_1



Liddell_UG

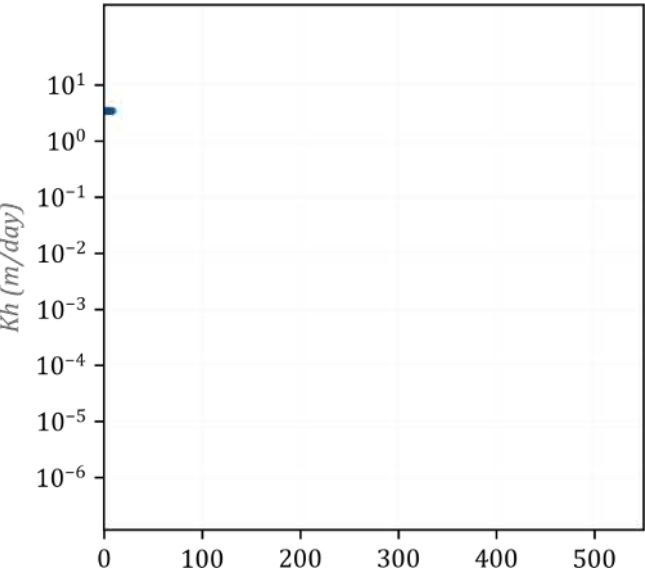
MT_OWEN



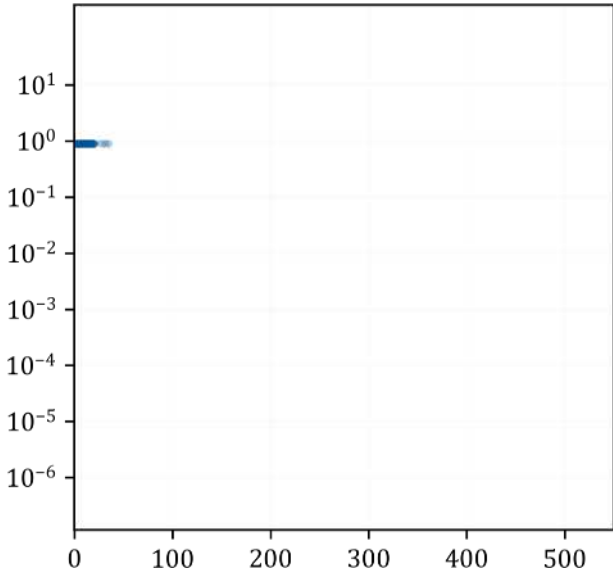
Appendix D 2

Graphs of ‘Kh vs. depth’ for different layers and model zones

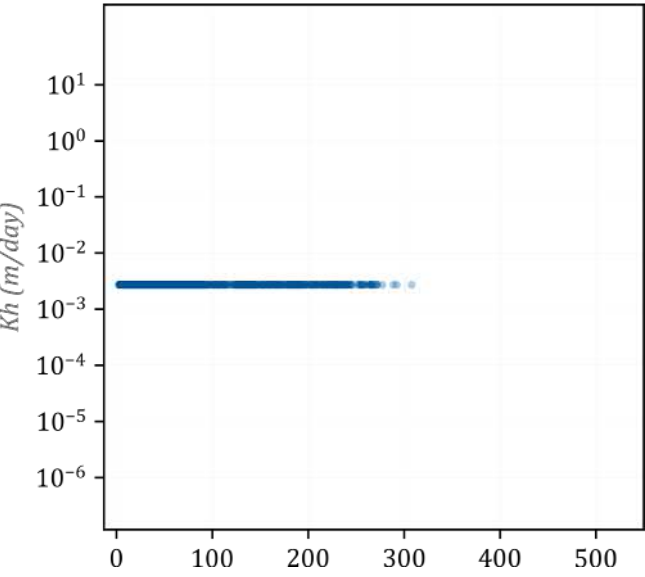
Geo Zone 1: - Shallow alluvium - low productivity zone



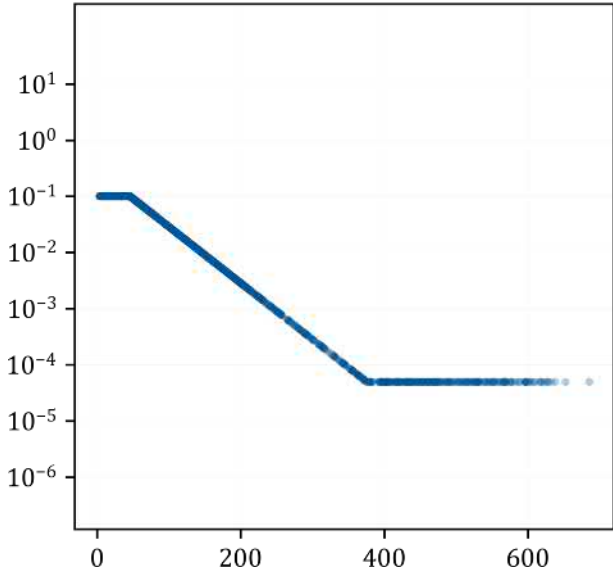
Geo Zone 2: - Deep alluvium - low productivity zone



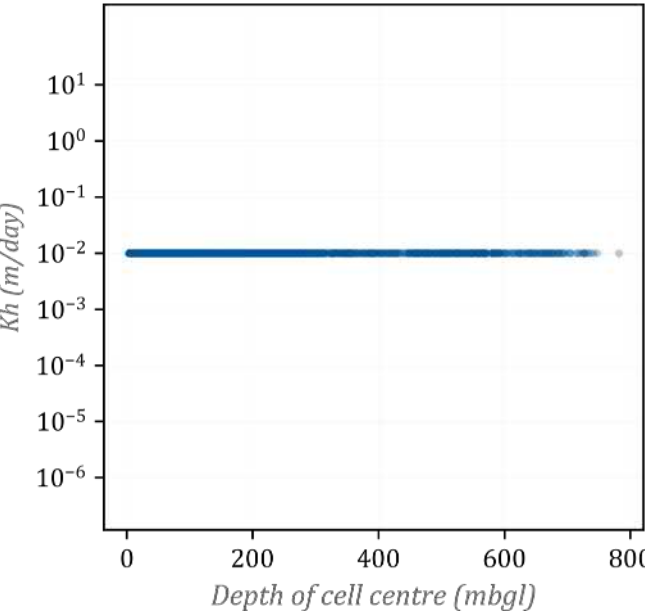
Geo Zone 3: - Overburden



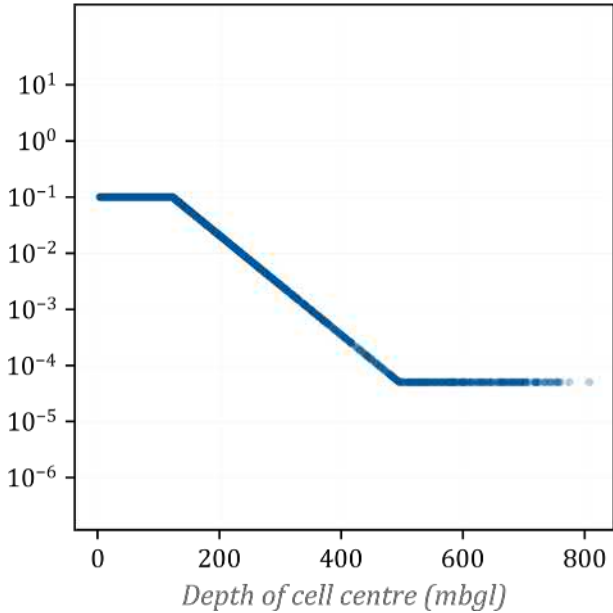
Geo Zone 4: - Newcastle, Whybrow



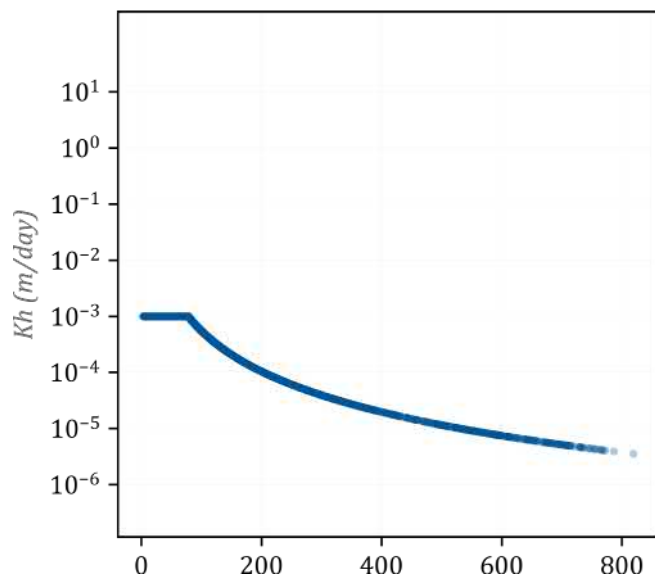
Geo Zone 5: - Interburden



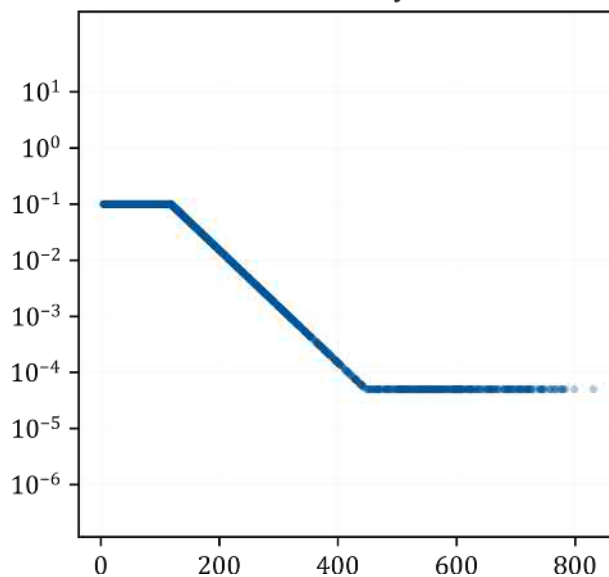
Geo Zone 6: - Wambo



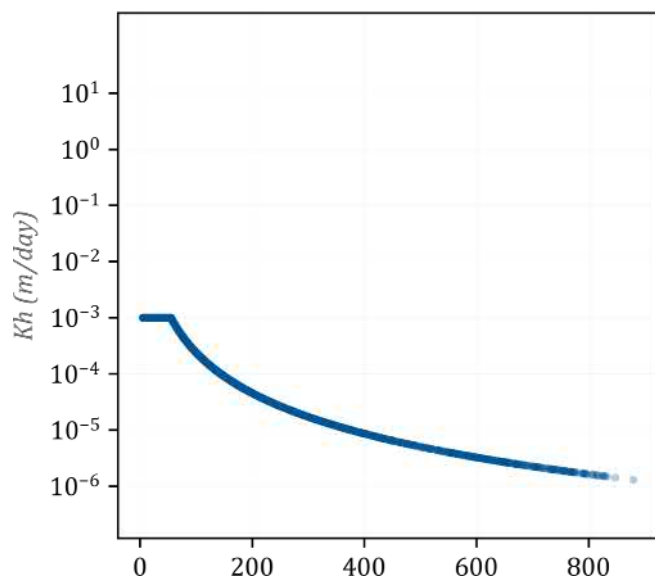
Geo Zone 7: - Interburden



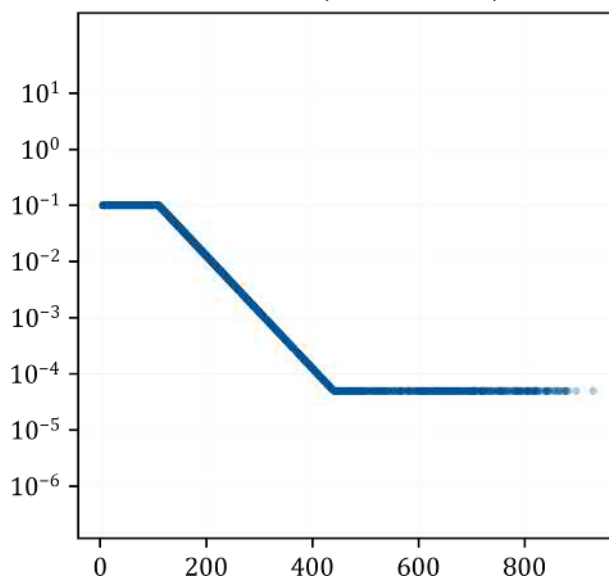
Geo Zone 8: - Whynot seam



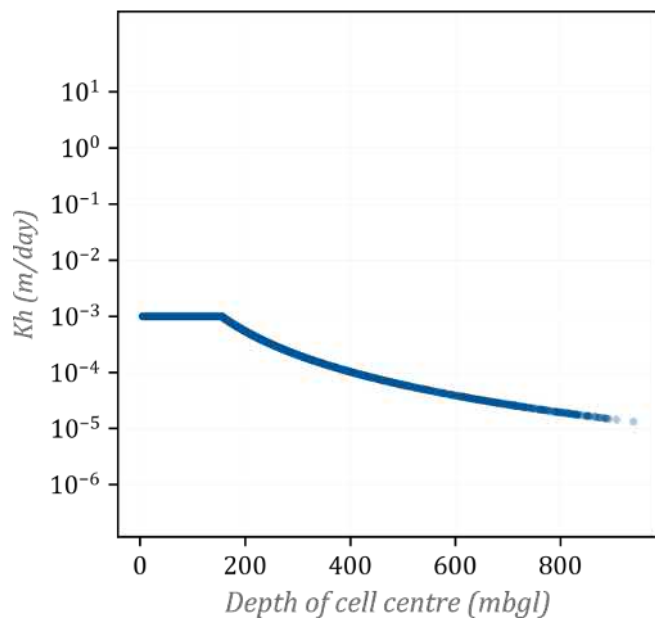
Geo Zone 9: - Interburden



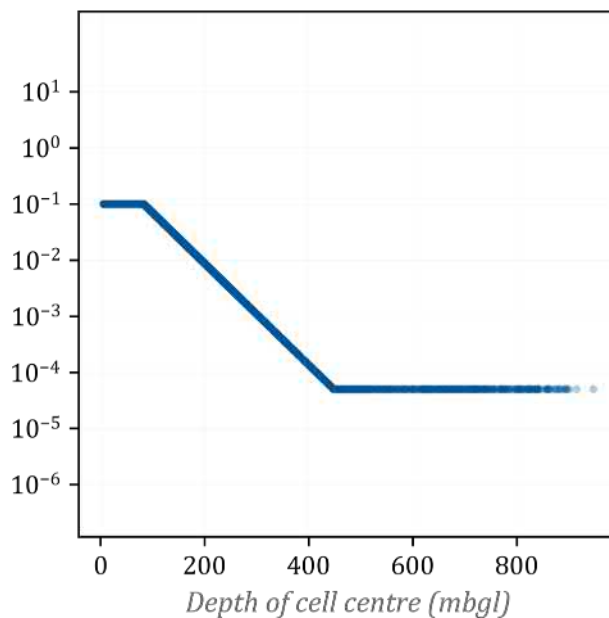
Geo Zone 10: - Blakefield, GlenMunro, WoodlandsHill



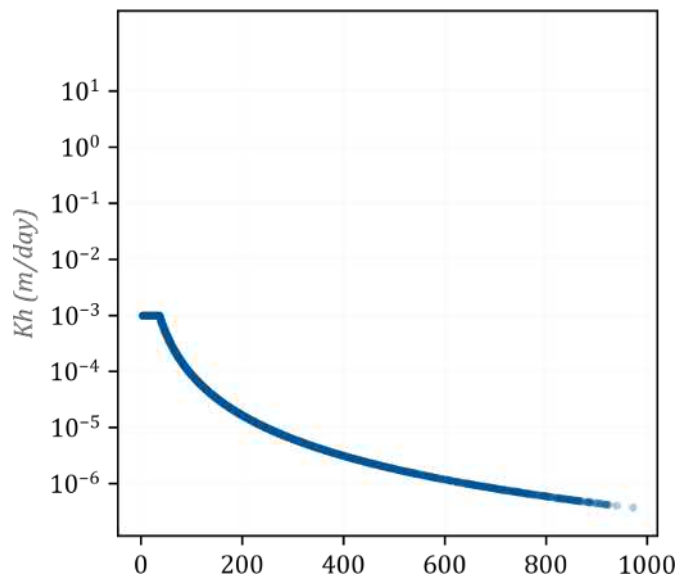
Geo Zone 11: - Interburden



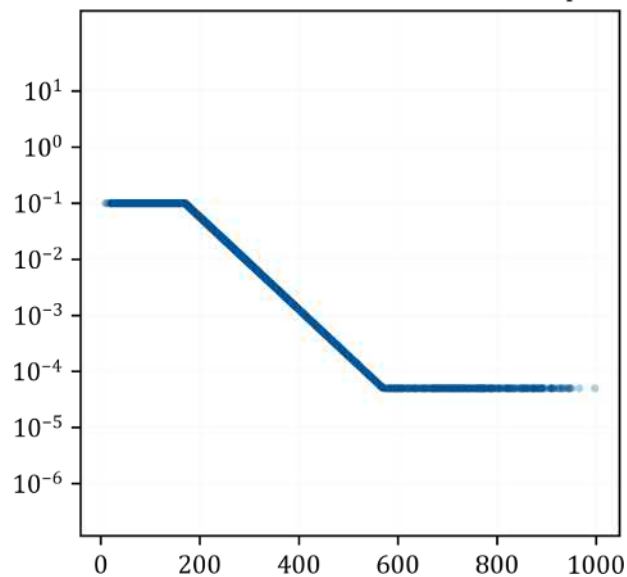
Geo Zone 12: - Arrowfield



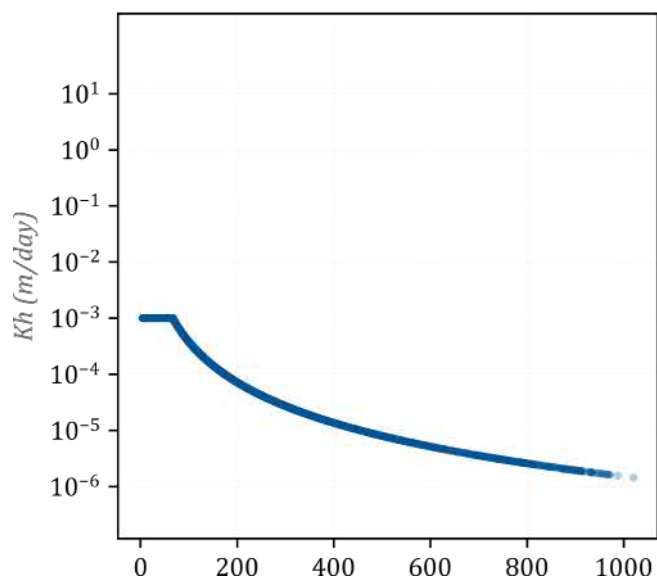
Geo Zone 13: - Interburden



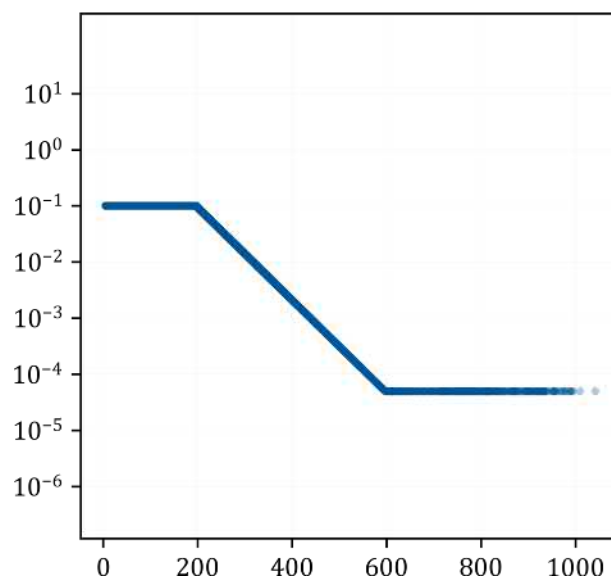
Geo Zone 14: - Bowfield, BowfieldSplit



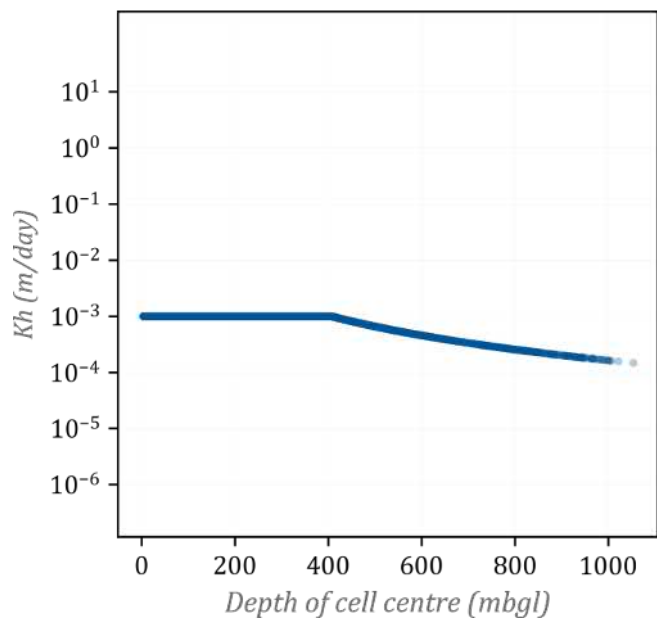
Geo Zone 15: - Interburden



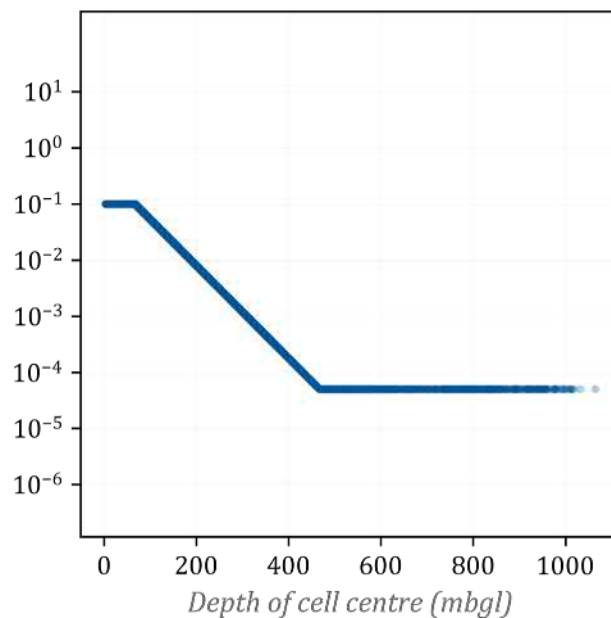
Geo Zone 16: - Warkworth



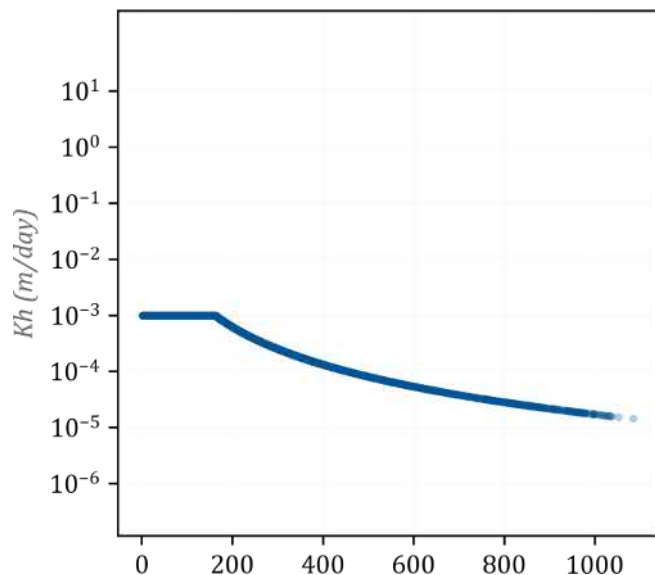
Geo Zone 17: - Interburden



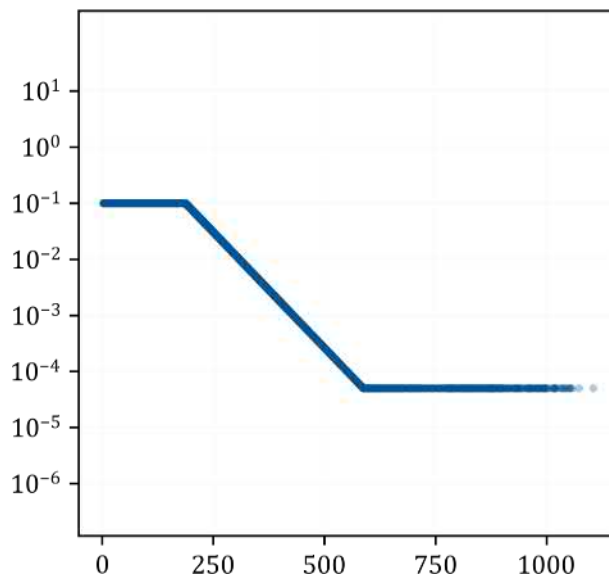
Geo Zone 18: - MtArthur



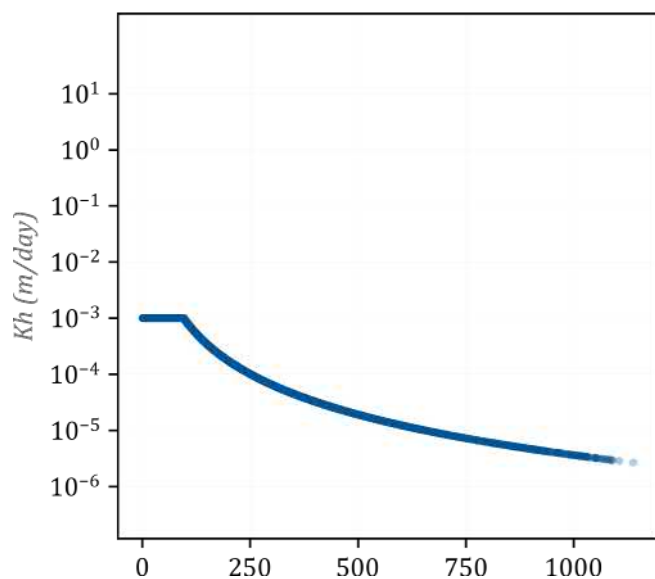
Geo Zone 19: - Interburden



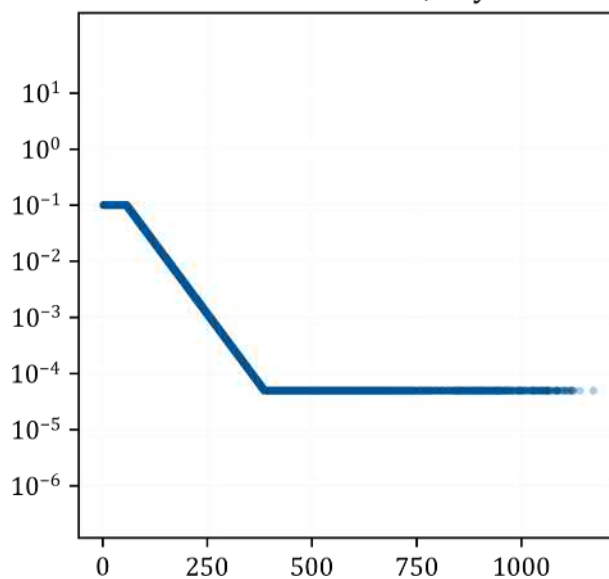
Geo Zone 20: - Piercefield, Vaux



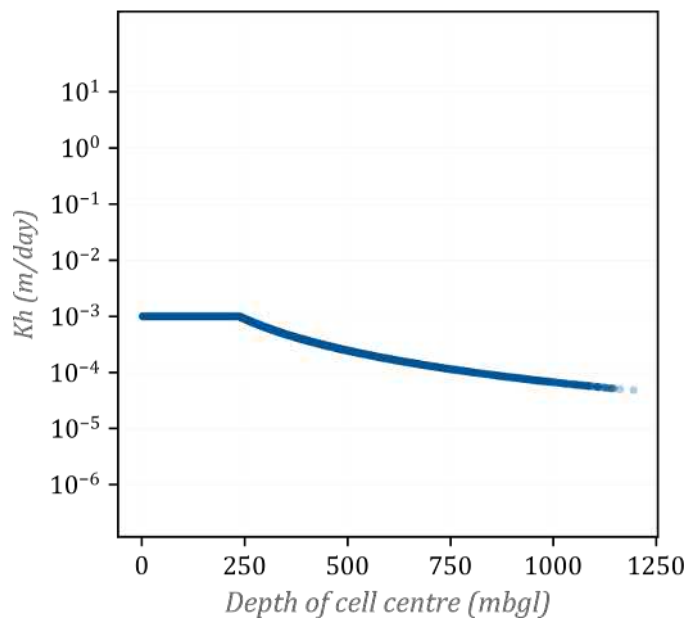
Geo Zone 21: - Interburden



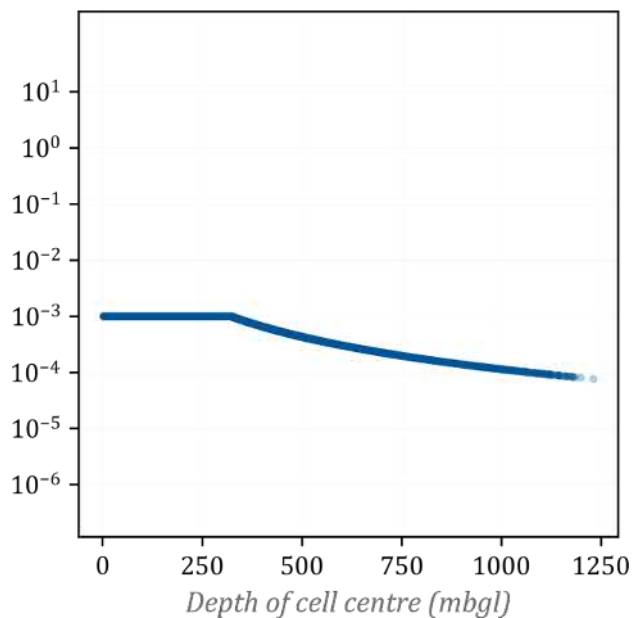
Geo Zone 22: - Broonie, Bayswater



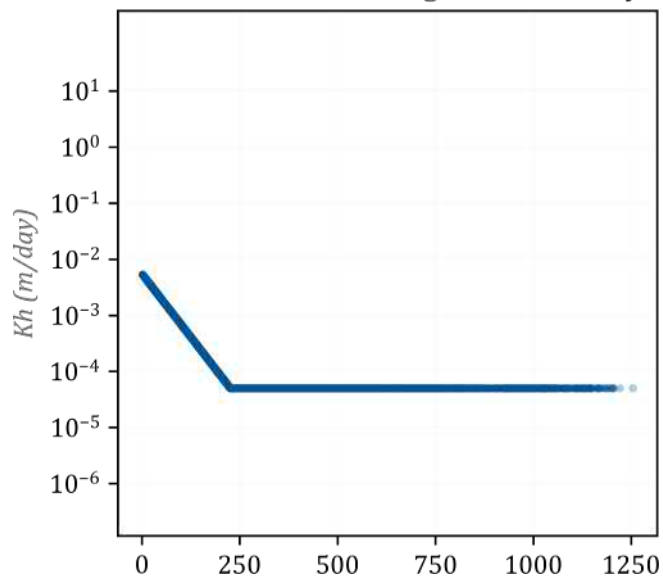
Geo Zone 23: - Interburden



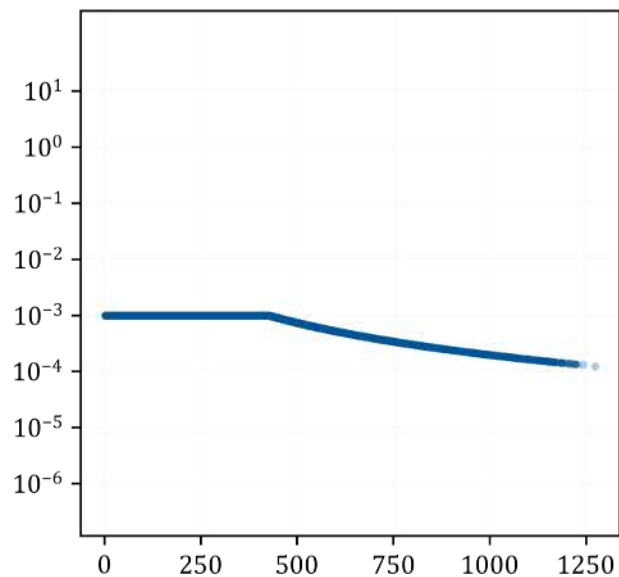
Geo Zone 24: - Interburden



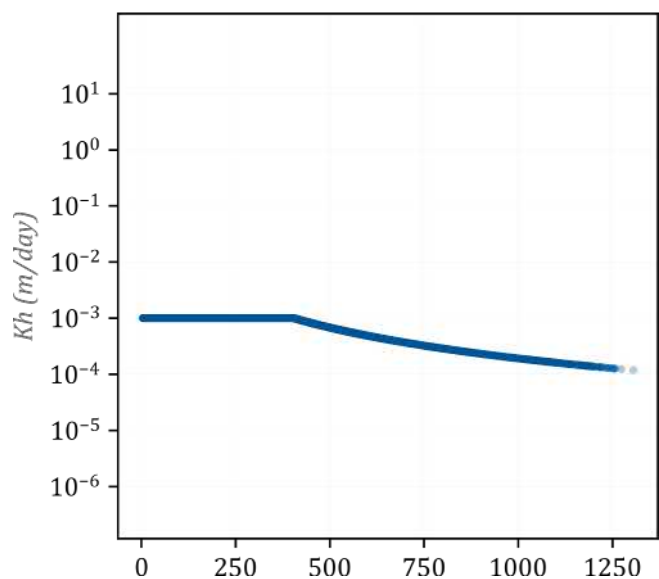
Geo Zone 25: - Lemington, PikesGully



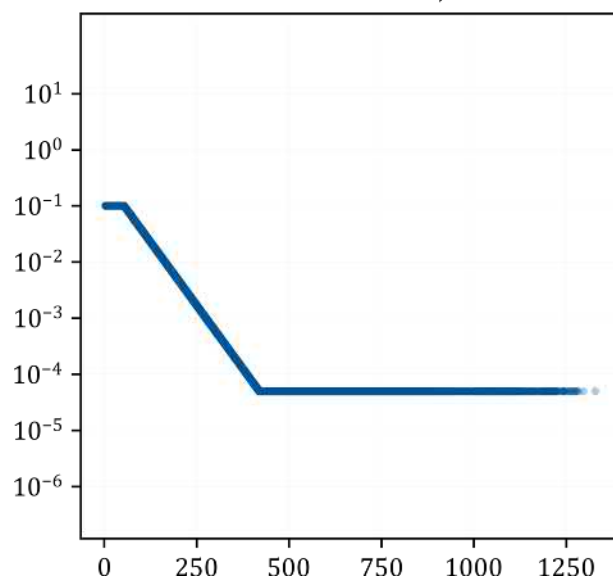
Geo Zone 26: - Interburden



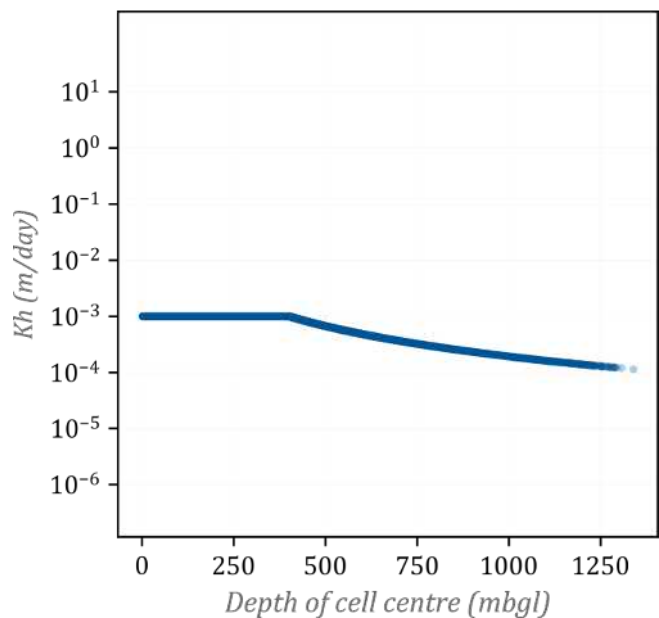
Geo Zone 27: - Interburden



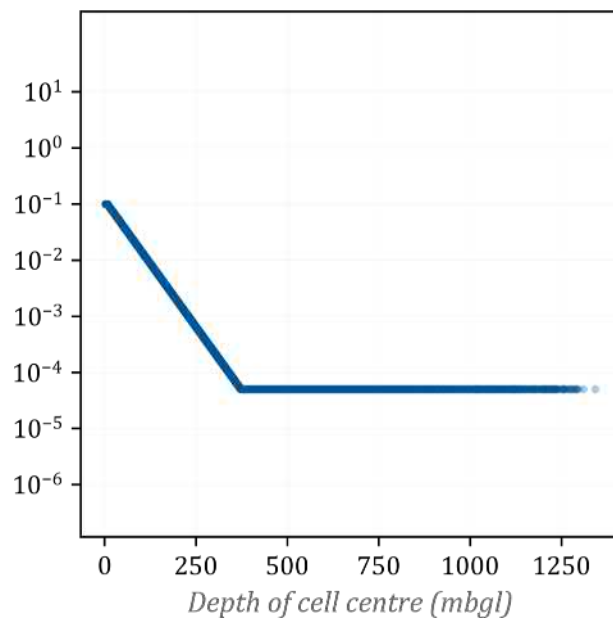
Geo Zone 28: - Arties, Liddell



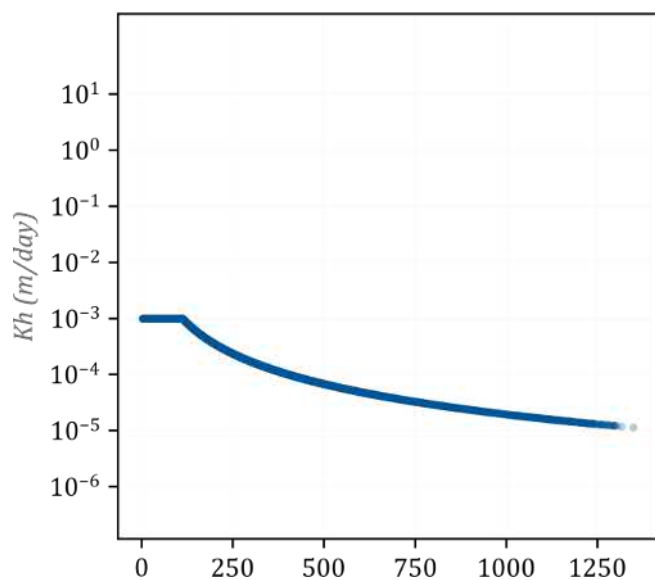
Geo Zone 29: - Interburden



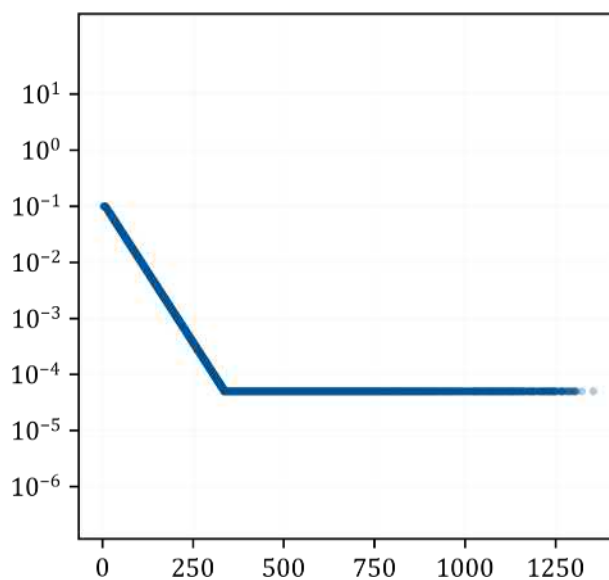
Geo Zone 30: - Barrett



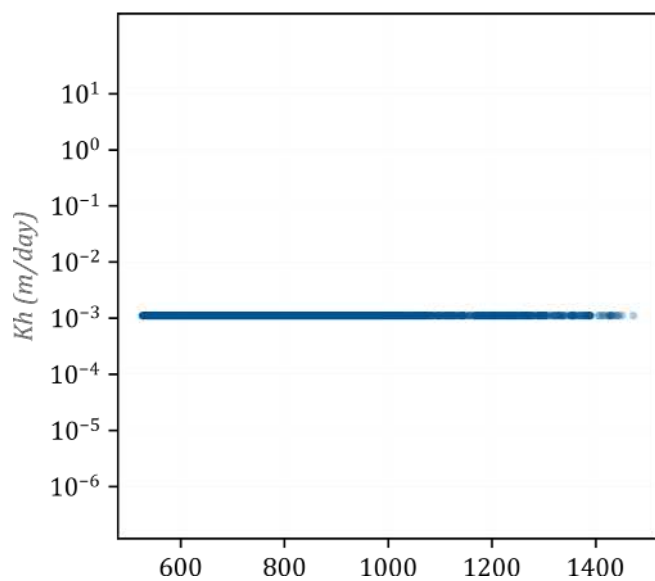
Geo Zone 31: - Interburden



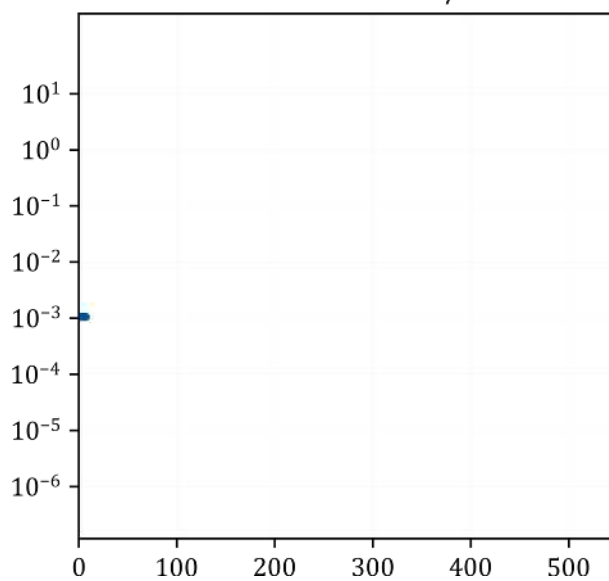
Geo Zone 32: - Hebden



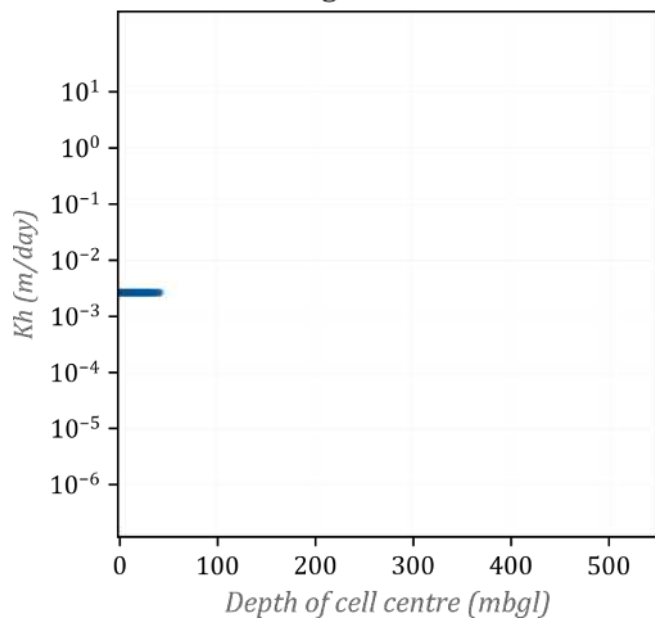
Geo Zone 33: - SaltwaterCkFm



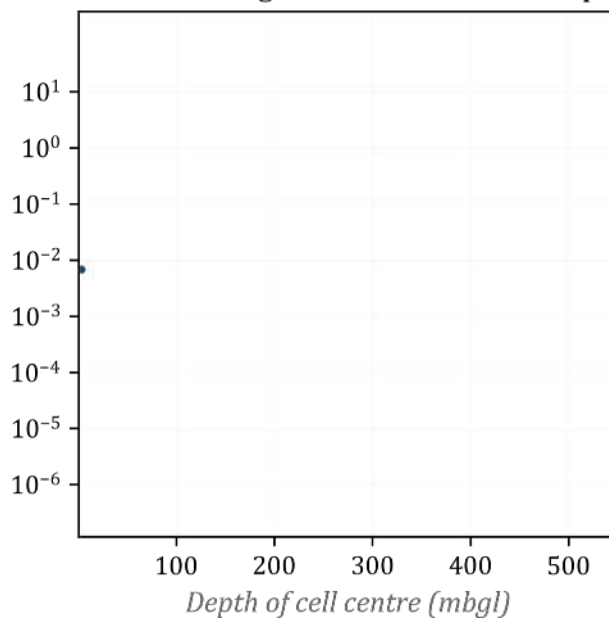
Geo Zone 34: - Water/Lakes



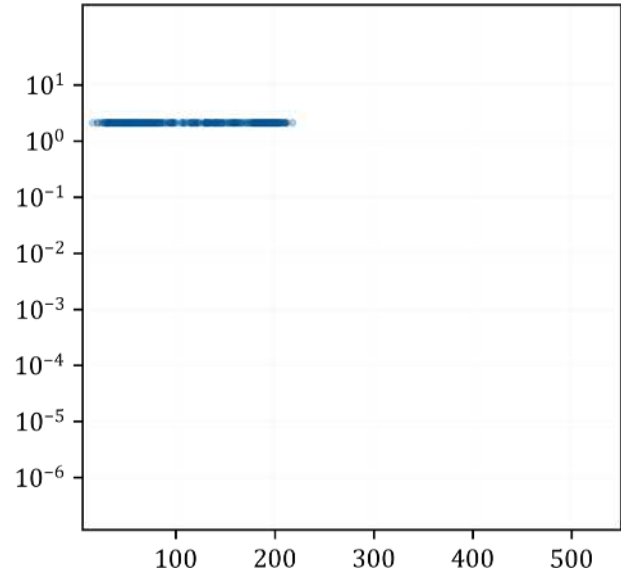
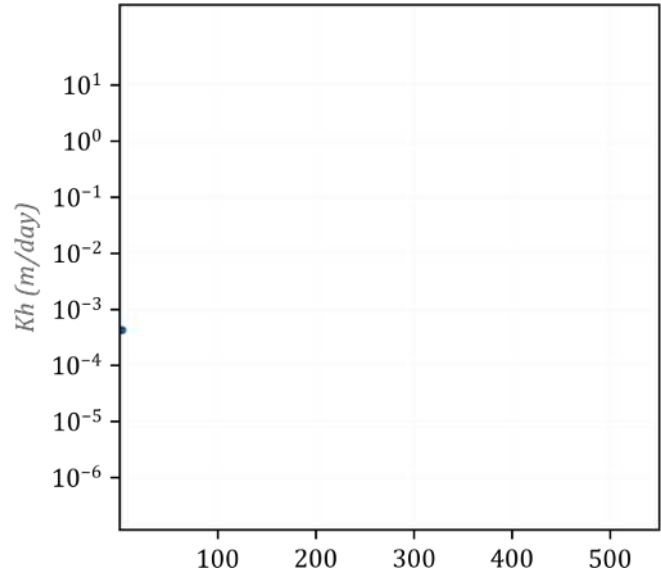
Geo Zone 35: - Regolith - Permian Formation



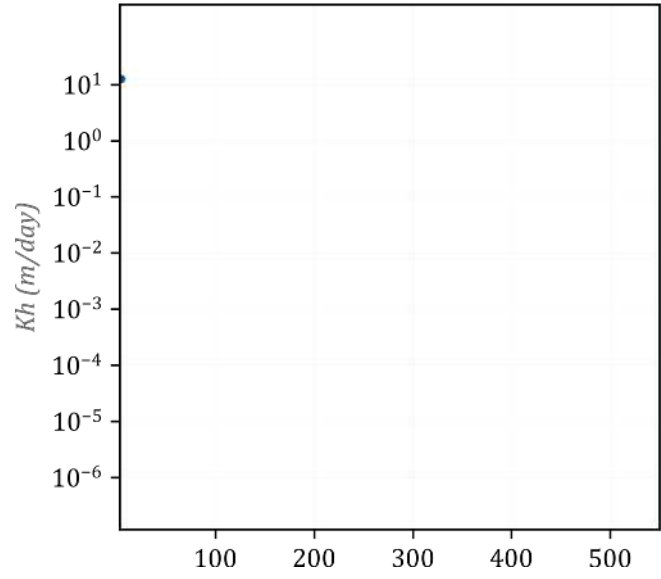
Geo Zone 36: - Regolith - Narrabeen Group (SW)



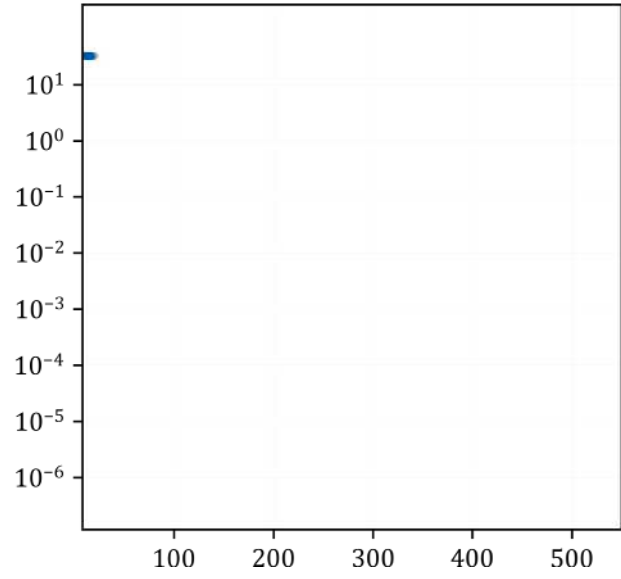
Geo Zone 37: - Regolith - Carboniferous tuff Geo Zone 38: - Cell underground (historical workings, excluding Haz



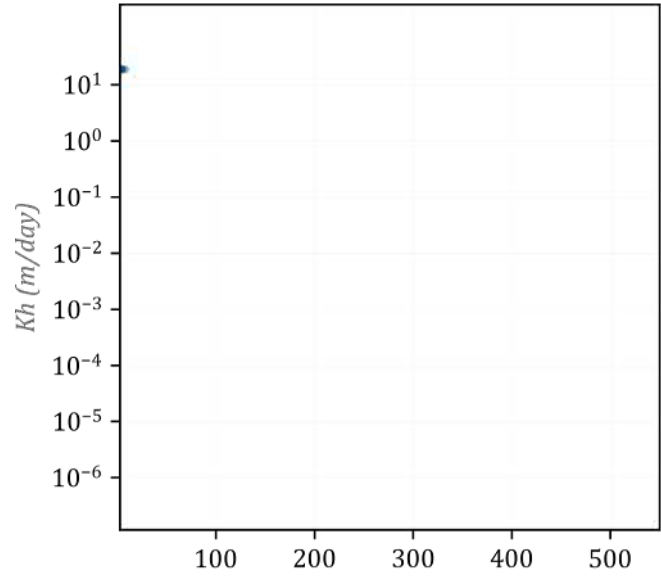
Geo Zone 39: - Shlw alluvium - high_prod - PalaeoCh_W



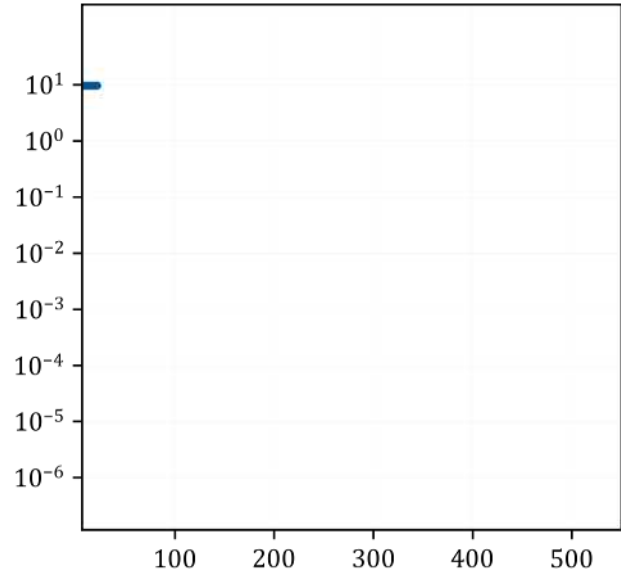
Geo Zone 40: - Deep alluvium - high_prod - PalaeoCh_W



Geo Zone 41: - Shlw alluvium - high_prod - PalaeoCh_E



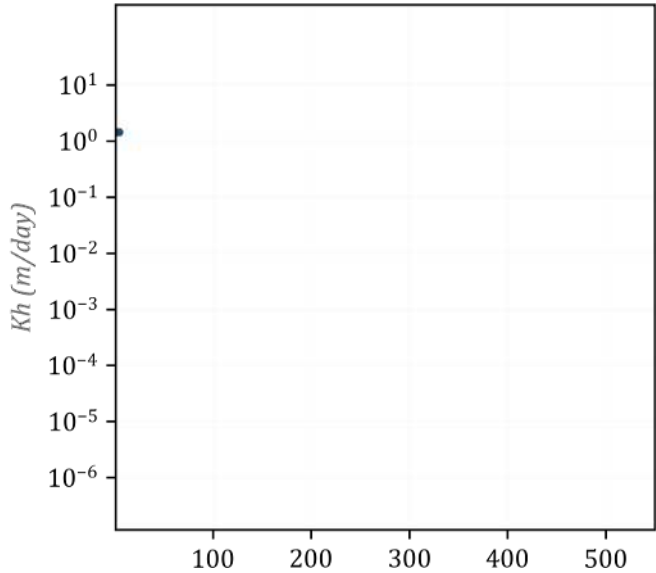
Geo Zone 42: - Deep alluvium - high_prod - PalaeoCh_E



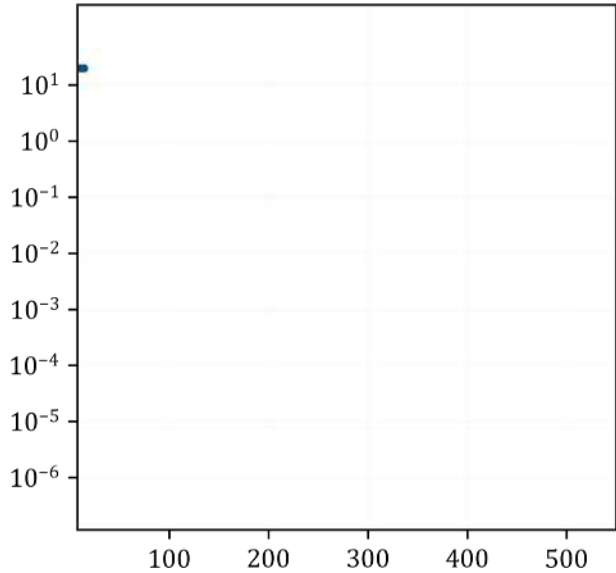
Depth of cell centre (mbgl)

Depth of cell centre (mbgl)

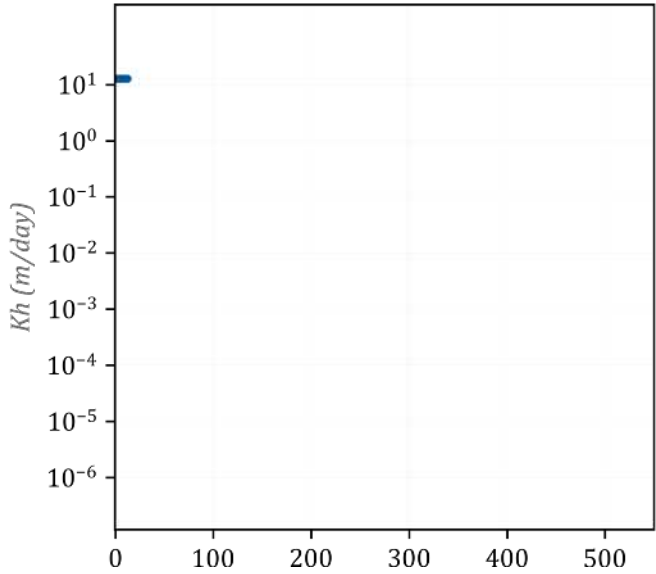
Geo Zone 43: - Shlw alluvium - high_prod - HunterUpstreamFar



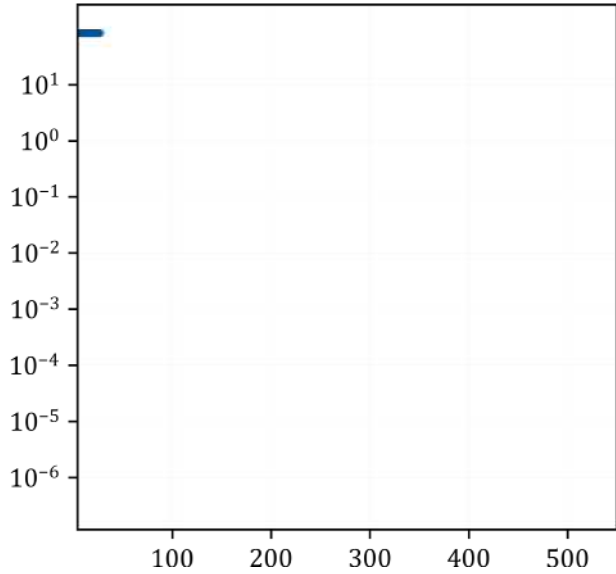
Geo Zone 44: - Deep alluvium - high_prod - HunterUpstreamFar



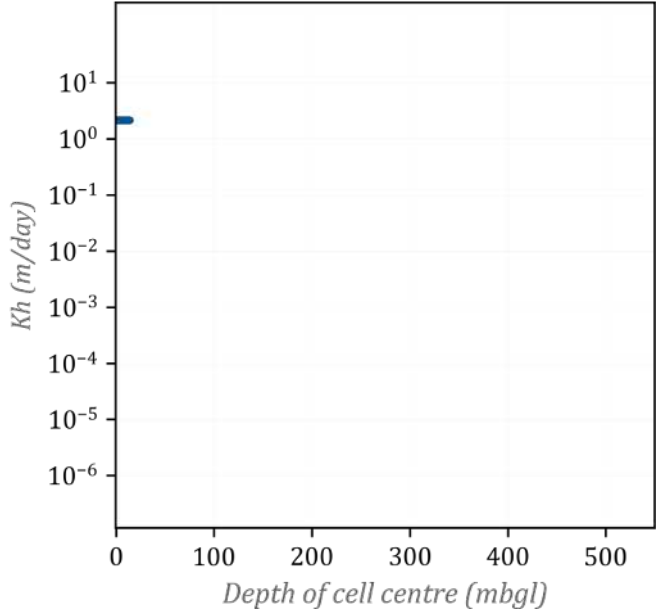
Geo Zone 45: - Shlw alluvium - high_prod - HunterUpstreamNear



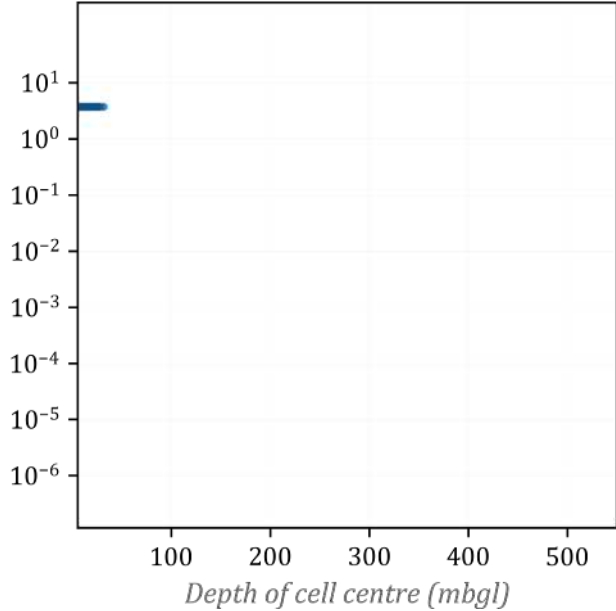
Geo Zone 46: - Deep alluvium - high_prod - HunterUpstreamNear



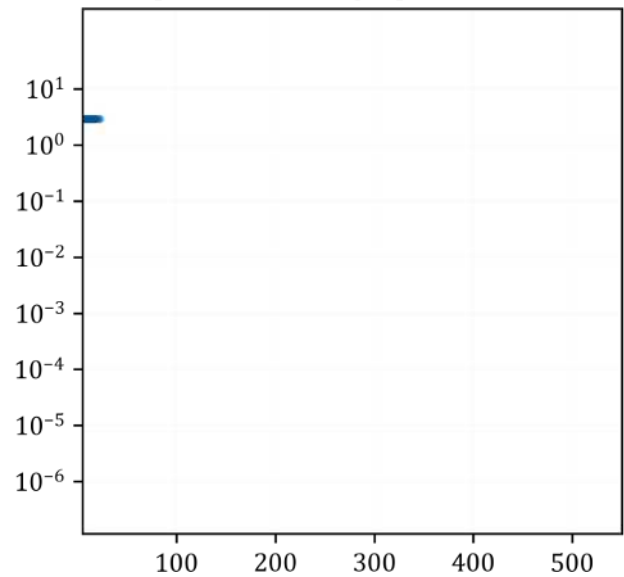
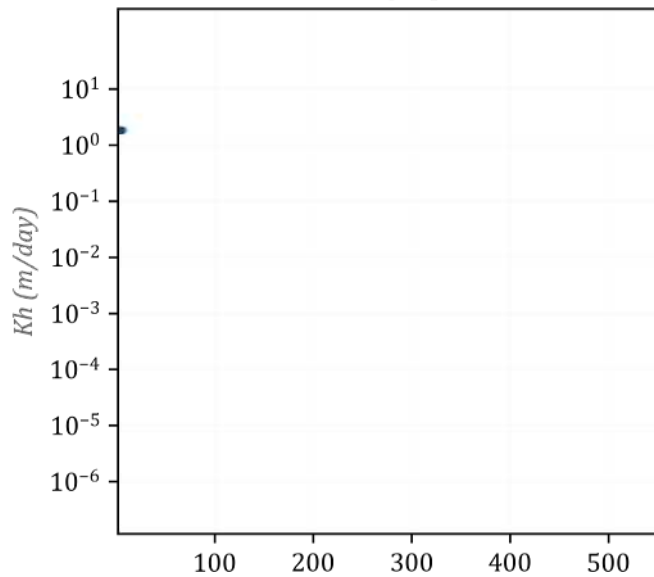
Geo Zone 47: - Shlw alluvium - high_prod - HunterDownstreamNear



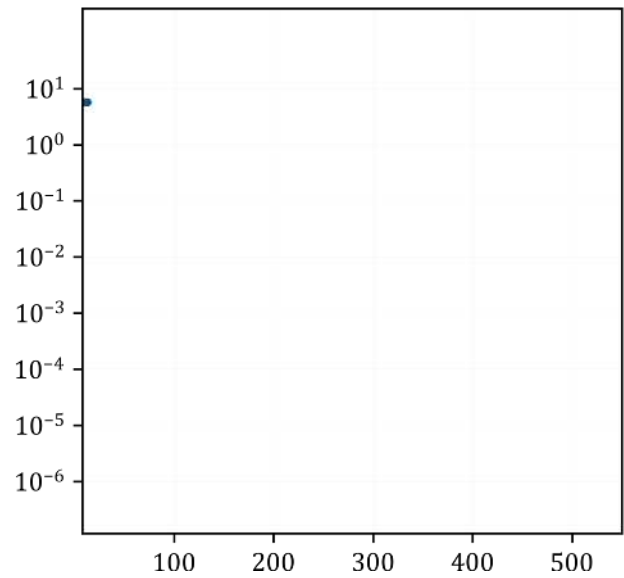
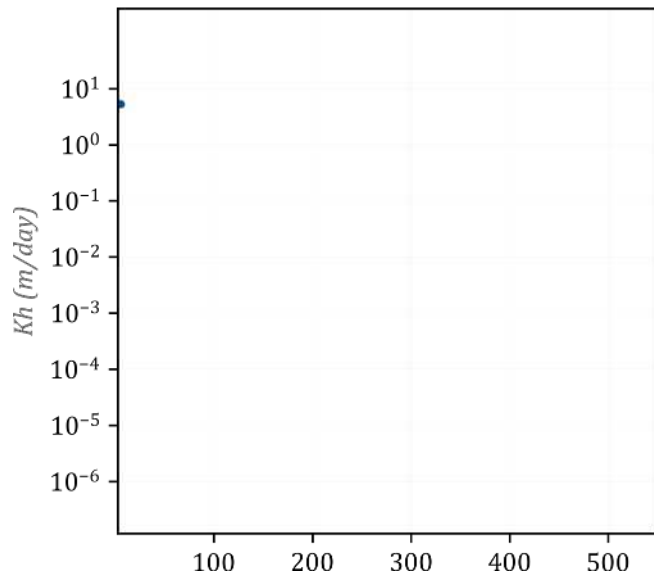
Geo Zone 48: - Deep alluvium - high_prod - HunterDownstreamNear



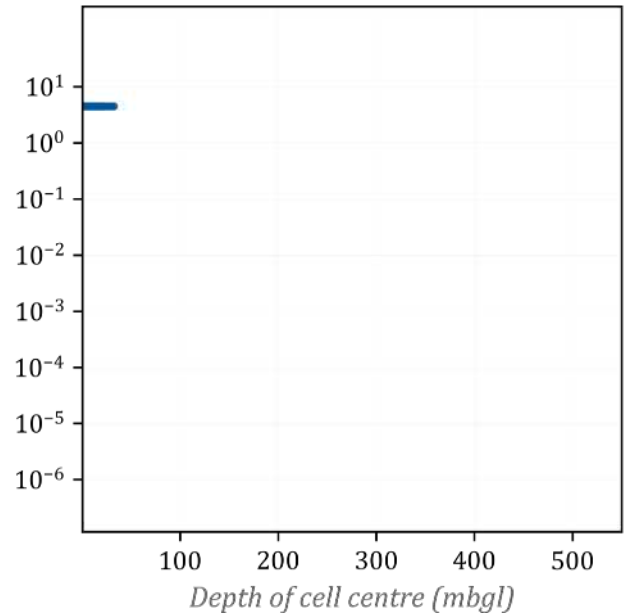
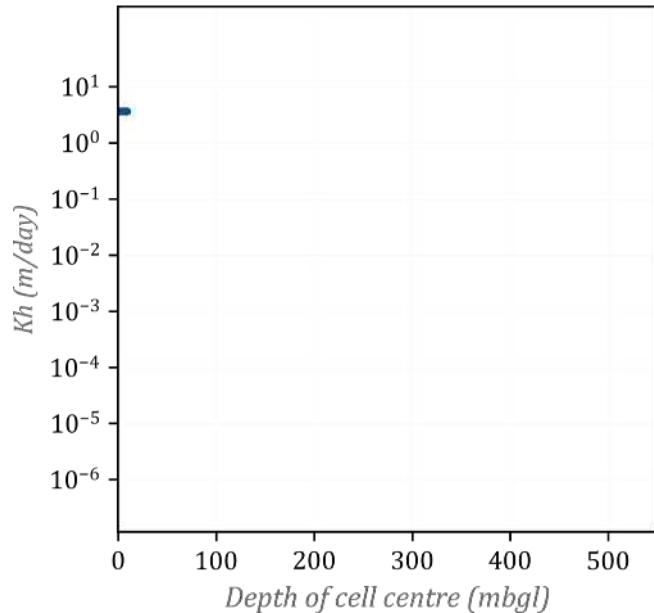
Geo Zone 49: - Shlw alluvium - high_prod - HunterDownstreamFarDeep alluvium - high_prod - HunterDownstreamFar



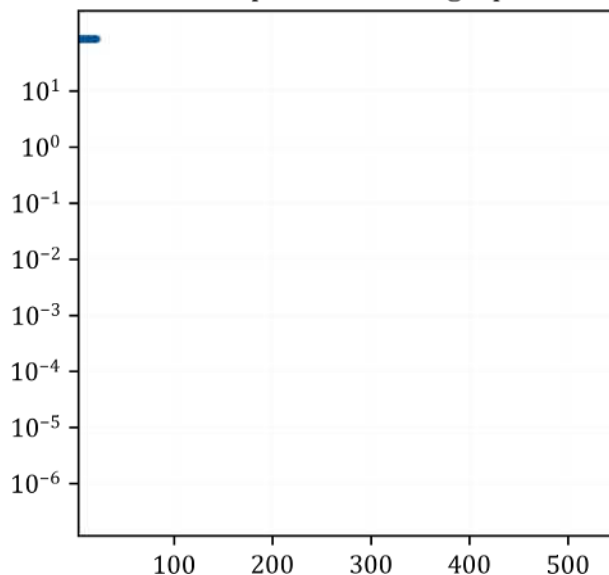
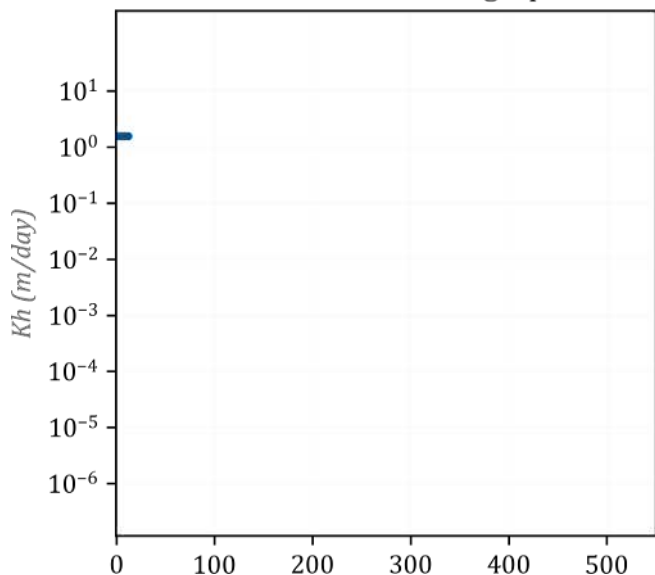
Geo Zone 51: - Shlw alluvium - high_prod - WollombiGeo Zone 52: - Deep alluvium - high_prod - Wollombi



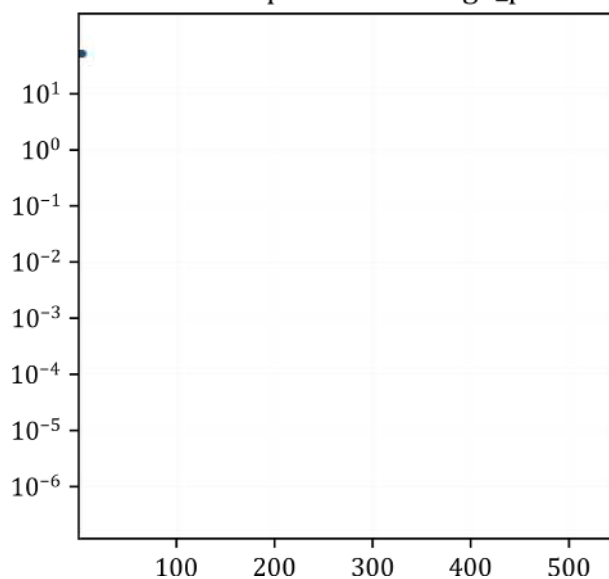
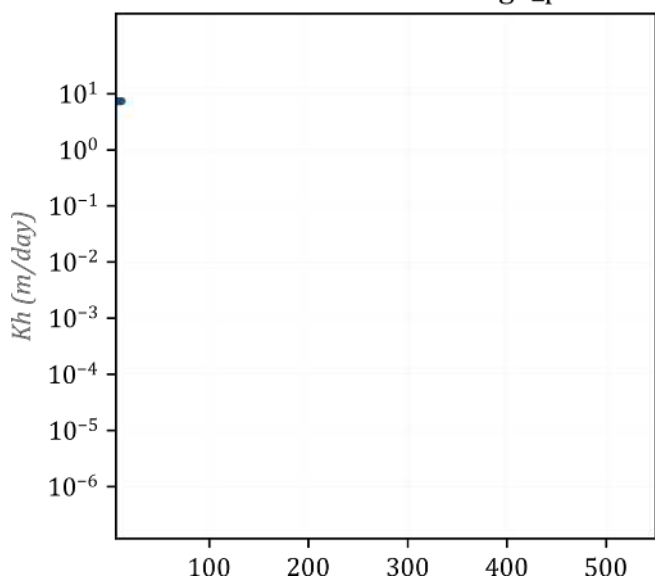
Geo Zone 53: - Shlw alluvium - high_prod - BowmansGeo Zone 54: - Deep alluvium - high_prod - Bowmans



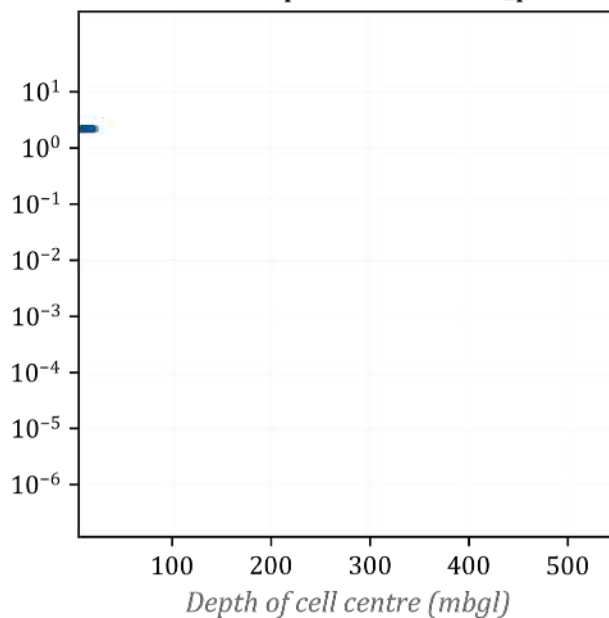
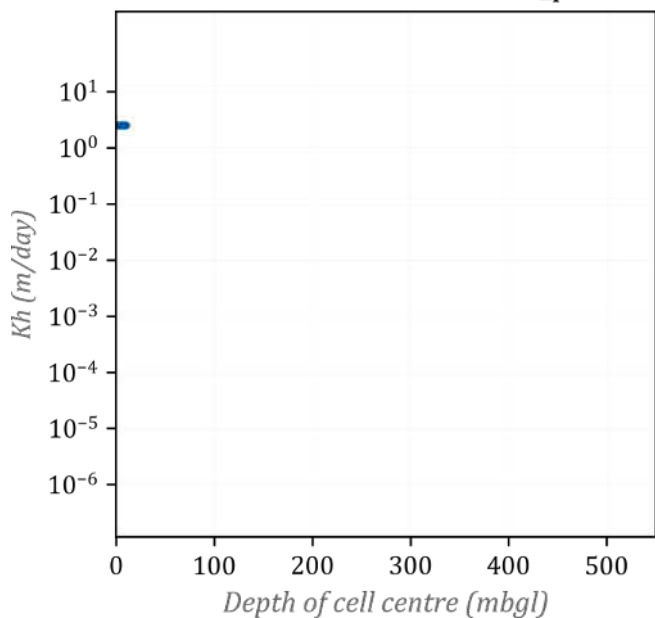
Geo Zone 55: - Shlw alluvium - high_prod - GlenniesGeo Zone 56: - Deep alluvium - high_prod - Glennies



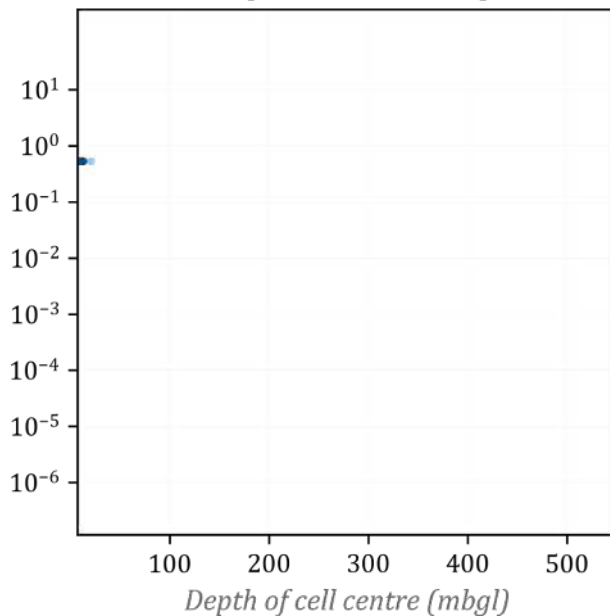
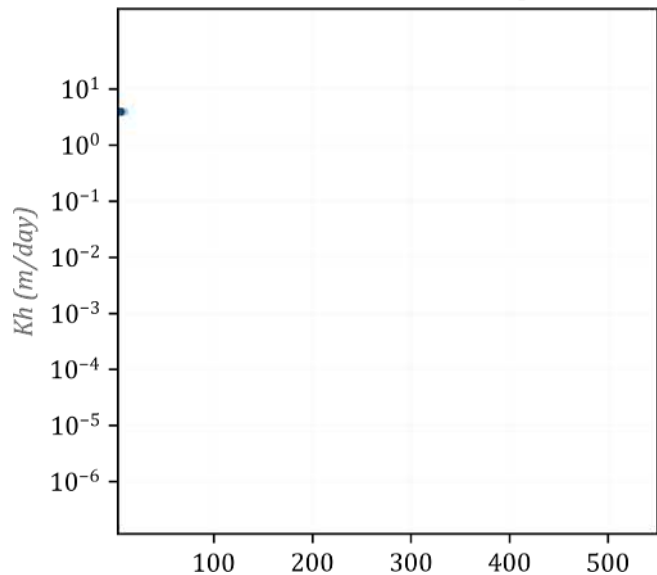
Geo Zone 57: - Shlw alluvium - high_prod - BettysGeo Zone 58: - Deep alluvium - high_prod - Bettys



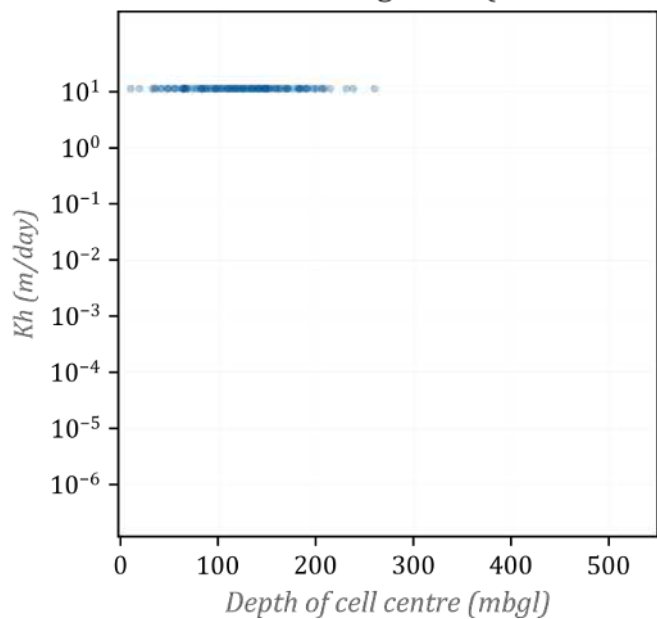
Geo Zone 59: - Shlw alluvium - low_prod - HVOGeo Zone 60: - Deep alluvium - low_prod - HVO



Geo Zone 61: - Shlw alluvium - low_prod - WollombGeo Zone 62: - Deep alluvium - low_prod - Wollombi



Geo Zone 63: - Liddell underground (Hazeldene area only)



Appendix D 3

Violin plots of distributions of posterior parameters used for estimation of model uncertainty

