APPENDIX 12

Groundwater Impact Assessment

Australasian Groundwater and
Environmental Consultants Pty Ltd

Report on

Mangoola Coal Continued Operations Groundwater Impact Assessment

Prepared for
Umwelt Environmental and Social Consultants

Project No. G1839F May 2019
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Table of contents

Page No.

Table of contents (continued)

Page No.

Table of contents (continued)

Page No.

List of figures

Table of contents (continued)

Page No.

Table of contents
(continued)

Page No.

Table of contents (continued)

Page No.

List of tables

List of appendices

Report on

Mangoola Coal Continued Operations Groundwater Impact Assessment

1 Introduction

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) has been engaged by Umwelt Environmental and Social Consultants (Umwelt) on behalf of Mangoola Coal Operations Pty Limited (Mangoola) to complete a groundwater impact assessment for the Mangoola Coal Continued Operations Project (MCCO Project). The purpose of the assessment is to form part of an Environmental Impact Statement being prepared by Umwelt to accompany an application for development consent under Divisions 4.1 and 4.7 of Part 4 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) for the MCCO Project.

1.1 Project overview

Mangoola Coal Mine is an open cut coal mine located approximately 20 kilometres (km) west of Muswellbrook and 10 km north of Denman in the Upper Hunter Valley of NSW (refer Figure 1.1). Mangoola has operated the Mangoola Coal Mine in accordance with Project Approval (PA) 06_0014 since mining commenced at the site in September 2010.

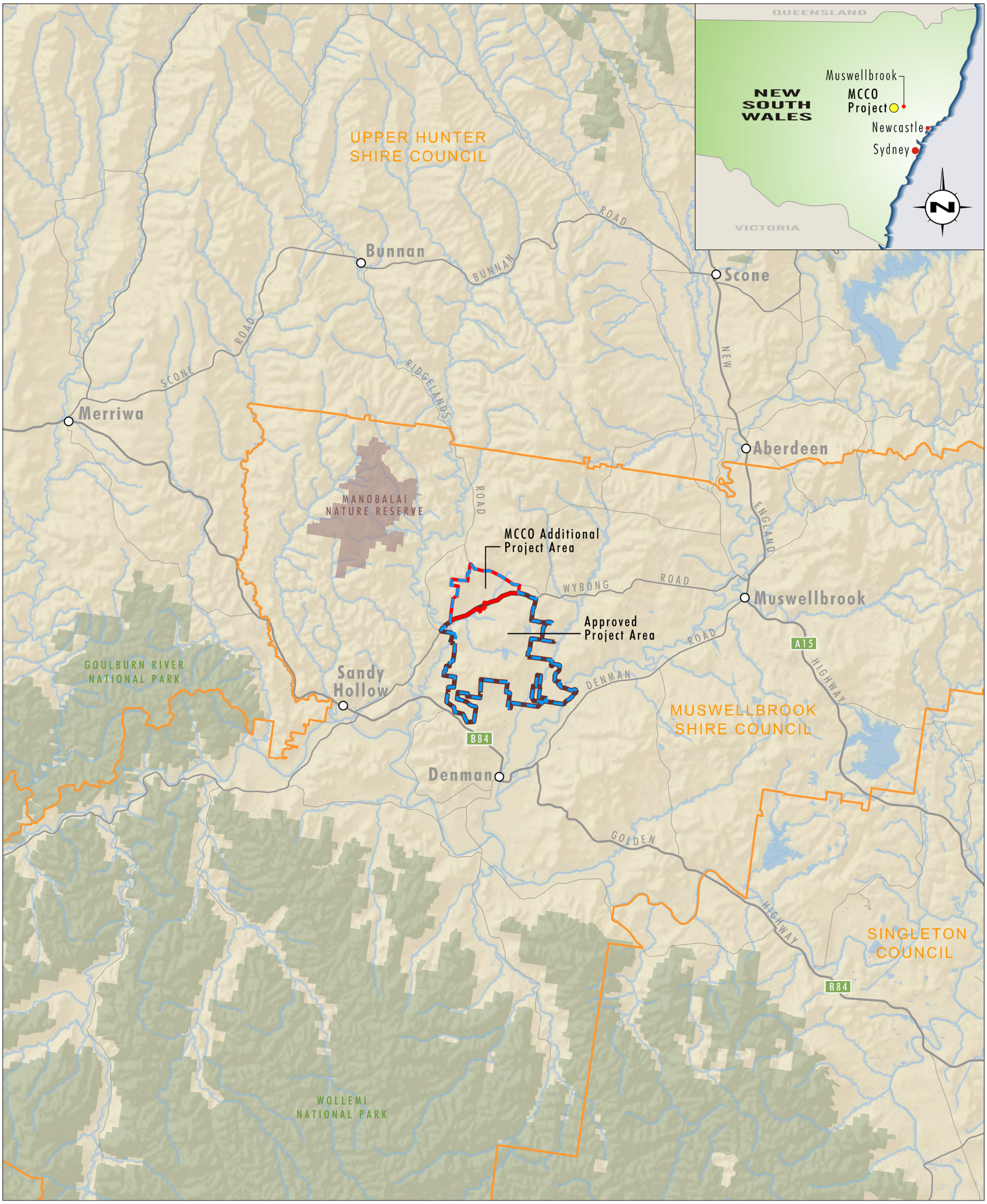
The MCCO Project will allow for the continuation of mining at Mangoola Coal Mine into a new mining area to the immediate north of the existing operations. The MCCO Project will extend the life of the existing operation providing for ongoing employment opportunities for the Mangoola workforce. The MCCO Project Area includes the existing approved Project Area for Mangoola Coal Mine and the MCCO Additional Project Area as shown on Figure 1.1.

Figure 1.2 illustrates the key features of the MCCO Project. The MCCO Project generally comprises:

- Open cut mining at up to the same rate as that currently approved (13.5 Million tonnes per annum (Mtpa) of run of mine (ROM) coal) using truck and excavator mining methods.
- Continued operations within the existing Mangoola Coal Mine.
- Mining operations in a new mining area located north of the existing Mangoola Coal Mine and Wybong Road, south of Ridgelands Road and east of the 500 kV Electricity Transmission Line (ETL).
- Construction of a haul road overpass over Big Flat Creek and Wybong Road to provide access from the existing mine to the proposed MCCO Proposed Additional Mining Area.
- Establishment of an out-of-pit overburden emplacement area.
- Distribution of overburden between the proposed Additional Mining Area and the existing mine in order to optimise the final landform design of the integrated operation.
- Realignment of a portion of Wybong Post Office Road.
- The use of all existing or approved infrastructure and equipment for the Mangoola Coal Mine with some minor additions to the existing mobile equipment fleet.

- Construction of a water management system to manage sediment laden water runoff, divert clean water catchment, provide flood protection from Big Flat Creek and provide for reticulation of mine water. The water management system will be connected to that of the existing mine.
- Continued ability to discharge excess water in accordance with the Hunter River Salinity Trading Scheme (HRSTS)
- Establishment of a final landform in line with current design standards at Mangoola Coal Mine including use of natural landform design principles consistent with the existing site.
- Rehabilitation of the MCCO Proposed Additional Mining Area using the same revegetation techniques as at the existing mine.
- A likely construction workforce of approximately 145 persons. No change to the existing approved operational workforce.
- Continued use of the mine access for the existing operational mine and access to/from Wybong Road, Wybong Post Office Road and Ridgelands Road to the MCCO Project Area for construction, emergency services, environmental monitoring and property maintenance.

umwelt



Data Source: Glencore (2018), LPI (2016)

0 5 10 20km
1:400 000

Legend
- MCCO Project Area
- Approved Project Area
- MCCO Additional Project Area
- Local Government Area

FIGURE 1.1

Regional Locality Plan

File Name (A4): R16/4004_189.dgn
20181004 14.01

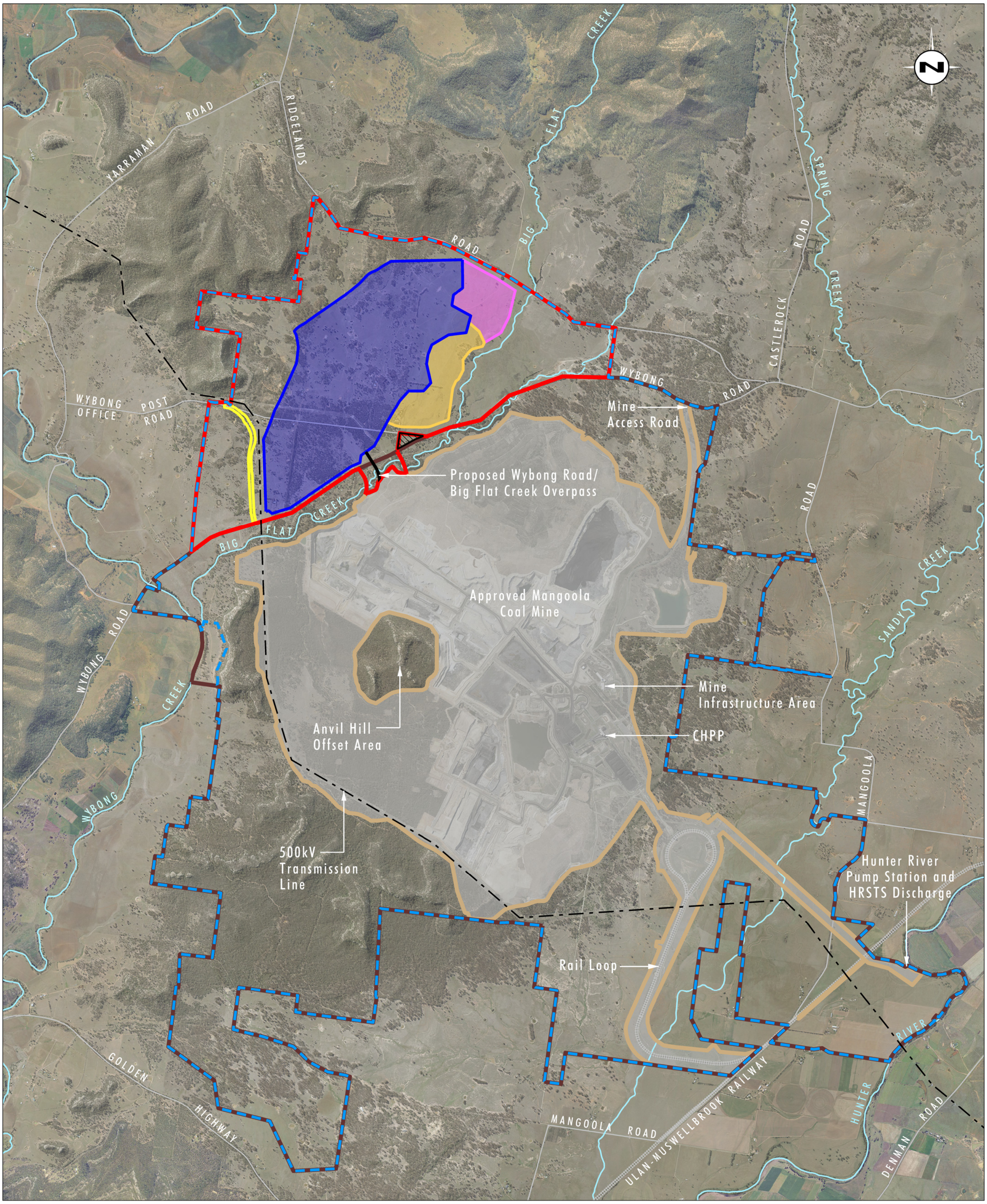


Image Source: Glencore (April 2018)
Data Source: Glencore (2019)

0 1.0 2.0 3.0km

Legend

- MCCO Project Area
- Approved Project Area
- Approved Mangoola Coal Mine Disturbance Area
- MCCO Additional Project Area
- Proposed Additional Mining Area
- Proposed Emplacement Area
- Proposed Topsoil Stockpile Area
- Wybong Post Office Road Realignment
- Crown Land (TSR) Excluded from MCCO Project Area

FIGURE 1.2

Key Features of the Mangoola Coal Continued Operations Project

File Name (A4): 4004_343.dgn
20190328 11.19

1.2 Objectives and scope of work

The objective of the groundwater impact assessment was to assess the impact of the MCCO Project on the groundwater regime, and the requirements of NSW and Federal Government legislation and policies. This included the Secretary's Environmental Assessment Requirements (SEARs) provided by the Department of Planning and Environment (DPE).

The groundwater impact assessment comprised two parts, a description of the existing hydrogeological environment, and an assessment of the impacts of mining the MCCO Project on that environment.

The groundwater impact assessment included:

- review of existing background data and previous hydrogeological investigations;
- updating the existing groundwater model for the approved operations in accordance with the National Groundwater Modelling Guidelines (National Water Commission, 2012) and relevant State and Federal government guidelines;
- using modelling to assess impacts resulting from the MCCO Project on:
    - regional groundwater levels in aquifers and aquitards during and post mining;
    - rates of baseflow to surface waters;
    - groundwater quality during and post mining; and
    - water sharing plans.
- assessment of the potential for impacts upon water dependent assets via causal pathways including:
    - potential groundwater dependant ecosystems (GDE); and
    - third party water users (i.e. private bores).
- comparison of predicted impacts against the requirements of the NSW Aquifer Interference Policy (2012); and
- assessment of risks to groundwater systems and consideration of appropriate mitigation, management and monitoring measures.

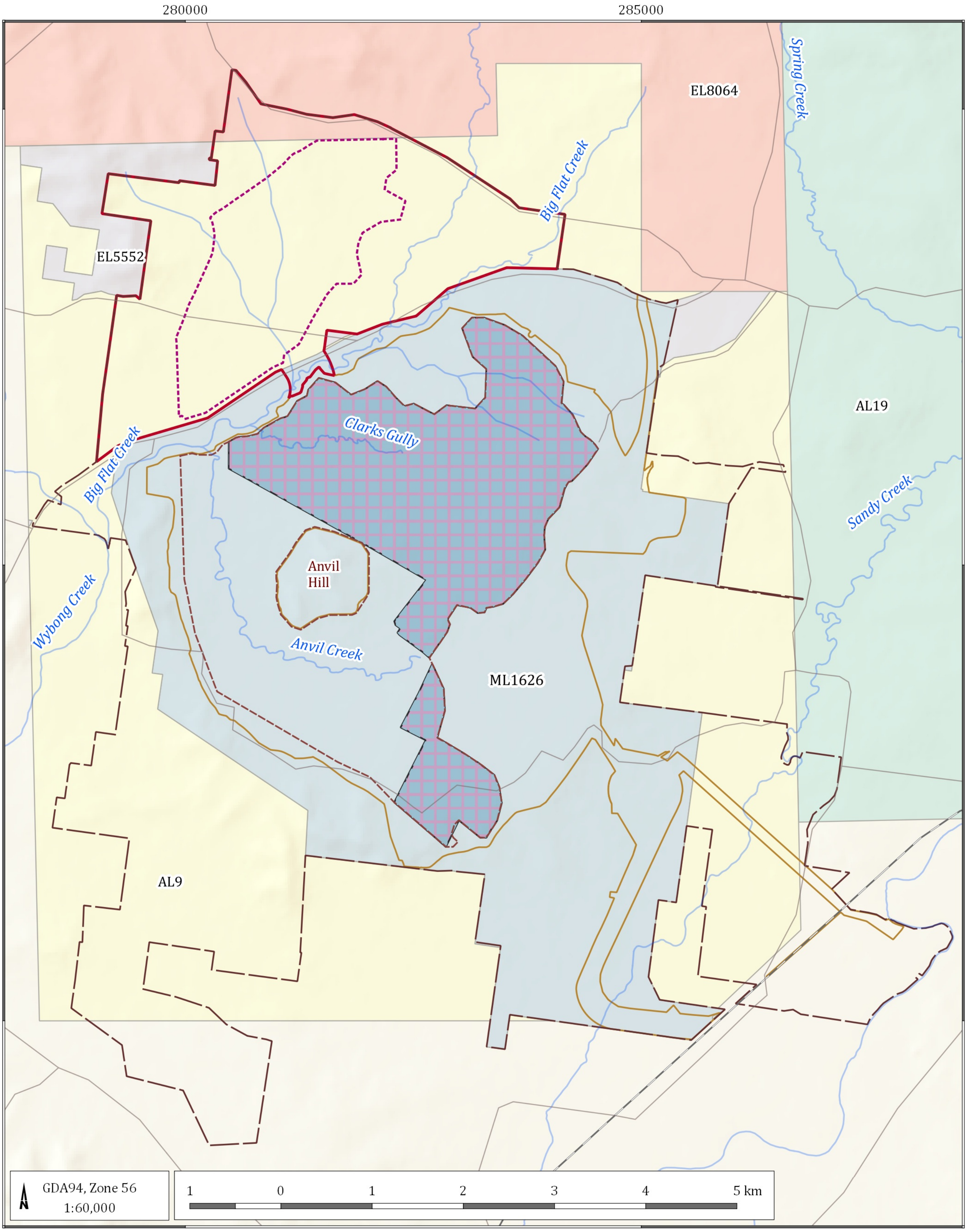
1.3 Mining operations

1.3.1 Approved Mangoola Coal Mine operations

The then Minister for Planning granted Project Approval (PA) 06_0014 for Mangoola Coal Mine in June 2007. To date there have been eight modifications to PA 06_0014. The current approval conditions allow for up to 13.5 (Million tonnes per annum (Mtpa) of run of mine (ROM) coal to be extracted using open-cut truck and shovel operations from Mining Lease (ML) 1626.

Existing operations at Mangoola Coal Mine target coal from the Great Northern, Fassifern and Upper Pilot A/B seams of the Newcastle Coal Measures. Mining started in the north-east of the Approved Mangoola Coal Mine Disturbance Area and has progressed to the south-west around Anvil Hill, which will remain unmined in the centre of the Mangoola Coal Mine. Figure 1.3 shows the mining completed to the end of 2017, and the extent of the approved Mangoola Coal Mine disturbance area. There are no changes being sought to the mining already approved at the Mangoola Coal Mine. Mining will continue as previously documented, with the approved mining included in this document for historical context and future cumulative impact assessment purposes.

Mackie Environmental Research (MER) (2006) assessed the potential impacts of the Mangoola Coal Mine on nearby water resources. The assessment indicated that mining would result in a zone of depressurisation occurring around the open cut mining area, with the extent of the predicted 2 m coal seam drawdown extending about 2 km to the west of the current operations. Post mining water level recovery was predicted to be slow, with two pit lakes predicted to form long term groundwater sinks in two final voids that remained within the mainly backfilled mining footprint. Approval to modify the final landform to a single void was granted in 2012 as part of Mangoola Mine – Modification 4, which concluded that regional impacts would be similar to the impacts assessed in 2006 (MER, 2010).



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Extent of mining - 2017
- Road
- Rail
- Drainage

Adjacent mining lease

- AL19 - West Musellbrook project area
- AL9 - Mangoola project area
- EL5552 - Mangoola exploration lease
- EL8064 - Ridgelands project area
- ML1626 - Mangoola lease area

Mangoola EIS (G1839F)

Mangoola mining operations and adjacent mining leases

AGE

DATE 10/04/2019

FIGURE No: **1.3**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
G:\Projects\G1839F.Mangoola EIS\3_GIS\Workspaces\011_GIA\01.03_G1839F_Mangoola mining operations and adjacent mining leases.qgs

1.3.2 Proposed MCCO Additional Project Area

Mining within the MCCO Additional Project Area is proposed from a portion of Assessment Lease (AL) 9. The additional mining would target coal from the same coal measures and coal seams as the approved Mangoola Coal Mine. Mining would effectively be a continuation of the approved mine and will utilise the existing infrastructure and processing facilities. Mining is proposed to follow the dip of the coal seams moving from southeast to northwest over a period of approximately eight years. The outline of the proposed mining area is shown on Figure 1.3.

1.3.3 Adjacent mining operations

Apart from the approved mining at Mangoola Coal Mine, there are currently no other active mines within 10 km of the MCCO Proposed Additional Mining Area. The nearest active mines are Bengalla, Mt Pleasant, and Mt Arthur Coal, which are approximately located some 12 km to the east. Each of these mines extract from the Wittingham Coal Measures, which underlie the Newcastle Coal Measures being targeted within the MCCO Project Area. The distance to other mines and the fact that the surrounding mines are not extracting from the same geological sequence means cumulative impacts are not considered likely.

Potential future mining activities around the MCCO Project include the West Muswellbrook open cut mine in AL19 to the north east of the MCCO Project Area, the footprint of which could come within 4 km of the Mangoola Coal Mine site boundary (subject to the granting of development consent) (Short, 2014). The seams proposed to be mined at West Muswellbrook are stratigraphically deeper than those mined at the Mangoola Coal Mine. The groundwater impact assessment for the West Muswellbrook gateway application (AGE, 2014) indicated that the West Muswellbrook mine would also be hydraulically separated from the Mangoola Coal Mine by the Mt Ogilvie Fault. The Mt Ogilvie fault is a significant structural feature that offsets the coal seams against lower permeability interburden, forming a barrier to the expansion of drawdown beyond the fault. This is predicted to limit the potential for the groundwater impacts of the two mines to overlap.

An exploration lease (EL8064), held by Ridgelands Coal, lies immediately to the north of the MCCO Proposed Additional Mining Area. Ridgelands Coal is in an earlier phase of exploration and has not proposed a project at this time (Ridgelands Coal, 2019). Ridgelands Coal is also not included in the Catalogue of Potential Resource Developments developed for the Hunter Region Bioregional Assessment (Hodgkinson et at, 2015, website updated January 2018). As shown on Figure 1.3 the northern boundary of the MCCO Project Area extends into EL8064, however the coal mining component of the MCCO Project remains within the AL9 lease boundary. This proximity means that groundwater impacts from the MCCO Project are highly likely to extend into EL8064. If a future Ridgelands mine was proposed adjacent to the MCCO Project there is the possibility the two mines would generate overlapping zones of drawdown and therefore a cumulative impact. This cannot be quantified at this time as there are no proposed mine plans for Ridgelands Coal available in the public domain and any potential cumulative impacts would be highly speculative. Should any future project be proposed for Ridgelands Coal then they would need to consider cumulative impacts with the MCCO Project at that time.

1.4 Report structure

This report is structured as follows:

- Section 1 – Introduction: provides an overview of the MCCO Project and the assessment scope.
- Section 2 – Regulatory framework: describes the regulatory framework relating to groundwater.
- Section 3 – Environmental setting: describes the environmental setting of the MCCO Project including the climate, terrain, land uses and other environmental features.
- Section 4 – Geological setting: describes the regional geology and local stratigraphy.
- Section 5 – Hydrogeology: describes the existing local groundwater regime within the MCCO Project Area and surrounds.
- Section 6 – Numerical groundwater model: describes the application of modelling to assess the impacts associated with the MCCO Project.
- Section 7 – Impact Assessment: describes the predicted impacts of the MCCO Project on the groundwater regime and water dependent assets, and the associated uncertainty.
- Section 8 – Groundwater Monitoring and Management Plan: describes the proposed measures for mitigation, management and monitoring of the groundwater regime and potential impacts.

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

Appendix B compares the impacts predicted for the MCCO Project with State and Federal Government policy and comments on compliance.

Appendix C details the monitoring bore network at Mangoola.

Appendix D provides water quality analysis for the monitoring bores.

Appendix E contains the peer review documents.

2 Regulatory framework

The groundwater impact assessment was undertaken in accordance with the SEARs (re-issued on 15 February 2019 to replace a previous version of the SEARs issued in August 2017) and supporting agency comments. A summary of the SEARs relevant to this report, and the Section in which they are addressed, is provided in Appendix B.

The MCCO Project has also considered the requirements of the following legislation, policies and guidelines relevant for groundwater:

- NSW Government:
  - *Water Management Act 2000* and the associated Water Sharing Plans;
  - Groundwater Quality Protection Policy (1998);
  - Groundwater Dependent Ecosystems Policy (2002);
  - Groundwater Quantity Management Policy (Policy Advisory Note No. 8);
  - Aquifer Interference Policy (AIP)(2012);
  - Strategic Regional Landuse Policy (SRLU Policy)(2012); and
  - Strategic Regional Landuse Plan – Upper Hunter (2012).
- Commonwealth Government:
  - *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) guidelines including:
    - Significant impact guidelines (DoE, 2013).
    - Independent Expert Scientific Committee (IESC) information guidelines for coal seam gas (CSG) and large coal mining development proposals (IESC, 2018).
    - IESC draft Explanatory Note on Uncertainty Analysis in Groundwater Modelling (Middlemis & Peeters, 2018)[1].

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

2.1 Water Management Act 2000

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

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

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[1] The IESC Explanatory Note was finalised in December 2018, however the draft document is referred to throughout this report as the MCCO Project GIA study had already been completed.

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

The Environmental Planning and Assessment Act - Sect 4.41 (previously section 89j 1(a)) notes that a new State Significant Development authorised by a development consent does not require a water use approval, a water management work approval or an activity approval, but does require an aquifer interference approval under the Water Management Act (NSW Legislation, 2018). The AIP establishes and objectively defines minimal impact considerations as they relate to water-dependent assets and as the basis for providing advice to the assessment and/or determining authority (refer Section 3.2.1 and Table 1 within the AIP).

2.2 Water sharing plans

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

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

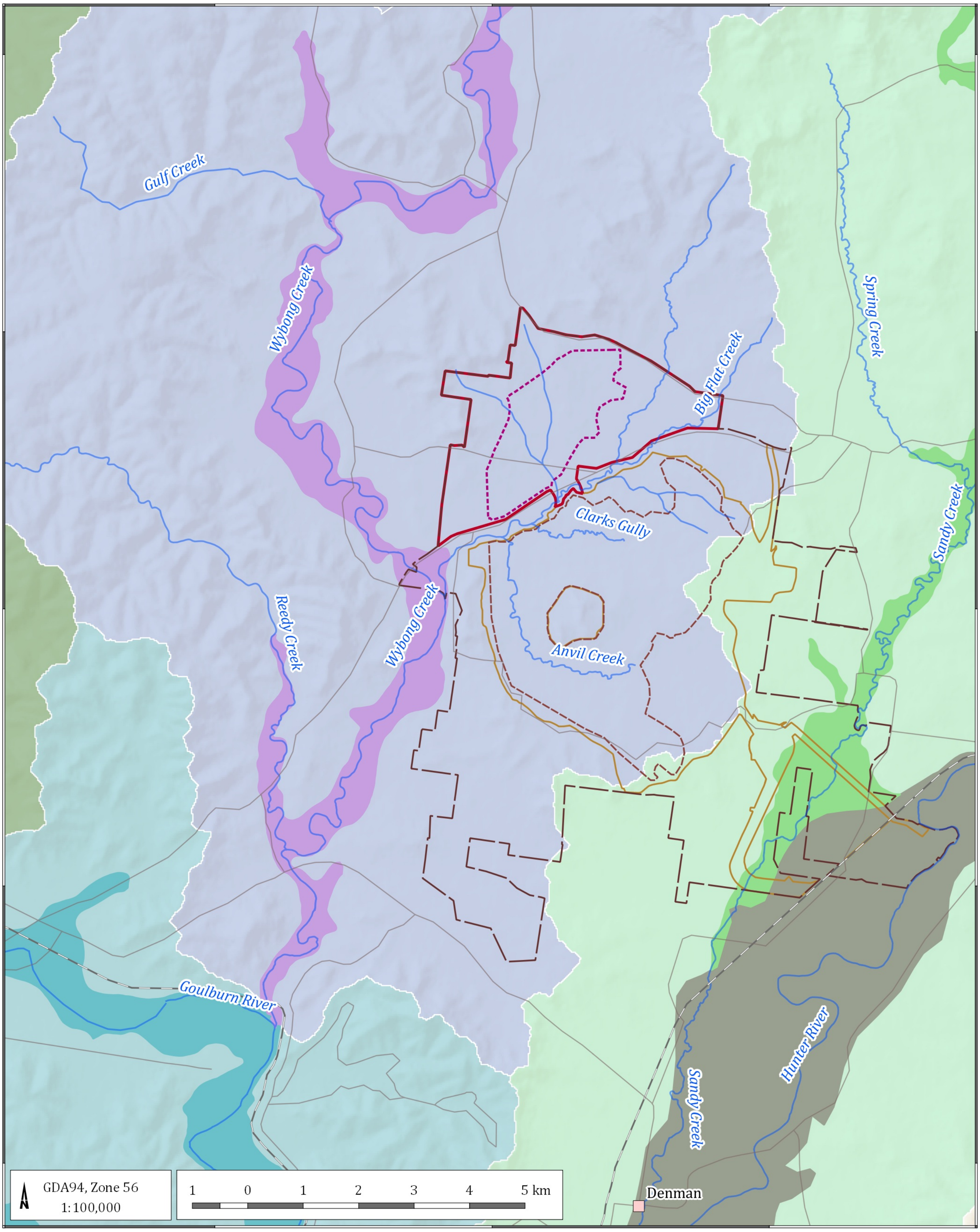
Two WSP's apply to the aquifers and surface waters affected by the MCCO Project. These are:

- the Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources (commenced 1 July 2016); and
- Hunter Unregulated and Alluvial Water Sources Water Sharing Plan 2009 (the current version dated 1 July 2016 includes the Wybong Management Zone 29).

The North Coast Fractured and Porous Rock WSP commenced on 1st July 2016 and establishes the management regime relevant for groundwater in the WSP area. The WSP area is divided into 13 water sources with the MCCO Project located within the Sydney Basin - North Coast Groundwater Source. The plan regulates groundwater occurring within the Triassic and Permian bedrock in the MCCO Project Area, but excludes groundwater within unconsolidated alluvial sediments. In the 2018/2019 financial year a total of 64673.5 share components were allocated for aquifer licensing in the Sydney-Basin – North Coast Groundwater Source (Water NSW, 2018).

The Hunter Unregulated and Alluvial WSP includes the unregulated rivers and creeks within the Hunter River catchment, the highly connected alluvial groundwater (above the tidal limit), and the tidal pool areas. In total, there are 39 water sources covered by the Hunter Unregulated WSP and nine of these are further sub-divided into management zones. The MCCO Additional Project Area is located within the Wybong Creek Water Source. In the 2018/2019 financial year a total of 2443 share components were allocated for aquifer licensing in the Wybong Creek Water Source, and 8088.5 share components were allocated for take from the unregulated rivers (Water NSW, 2018).

Figure 2.1 shows the Hunter Unregulated and Alluvial WSP water sources and management zones occurring around the area of the MCCO Project. The entire area shown on the figure is underlain by the Sydney Basin – North Coast Groundwater Source. If approved the MCCO Project will continue to comply with the applicable rules developed for each WSP and water source, except where exemptions for SSD apply.



LEGEND

- Populated place
- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Road
- Rail
- Drainage

Water Sources

- Halls Creek Water Source
- Lower Goulburn River Water Source
- Muswellbrook Water Source
- Wybong Creek Water Source

Alluvial Groundwater management zone

- Upstream Glennies Creek Management Zone of the Hunter Regulated River Alluvial Water Source
- Unnamed Upriver Alluvium in WSP in the Lower Goulburn River Water Source
- Unnamed Upriver Alluvium in WSP in the Muswellbrook Water Source
- Wybong Management Zone

Mangoola EIS (G1839F)

Hunter Unregulated Water Sharing Plan Water Sources and Management areas

AGE

DATE 26/02/2019

FIGURE No: **2.1**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
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2.3 State groundwater policy

2.3.1 Aquifer Interference Policy

Proponents of aquifer interference activities are required to provide predictions of the volume of water to be taken from a water source(s) as a result of the activity. These predictions need to occur prior to Project approval (predictions are provided within Section 7.1.1). After approval and during operations, these volumes need to be measured and reported in an annual returns or environmental management reports. The water user must hold sufficient share component and water allocation to account for the take of water from the relevant water source when the take occurs (provided within Section 7.1.4).

The AIP states that a water licence is required for the aquifer interference activity regardless of whether water is taken directly for consumptive use or incidentally. In the case of the mining and the MCCO Project the take of water occurs incidentally during the mining process. This incidental take of groundwater can induce flow from adjacent groundwater sources or connected surface water, which constitutes take of water under the AIP. In all cases, separate access licences are required to account for the take from all individual water sources (refer Section 7.1.4 for predicted takes).

The AIP also describes minimal impact considerations for aquifer interference activities which are a series of acceptable thresholds for water level and quality changes. The minimal impact consideration thresholds depend upon whether the water source is highly productive or less productive and whether the water source is alluvial or porous/fractured rock in nature.

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

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

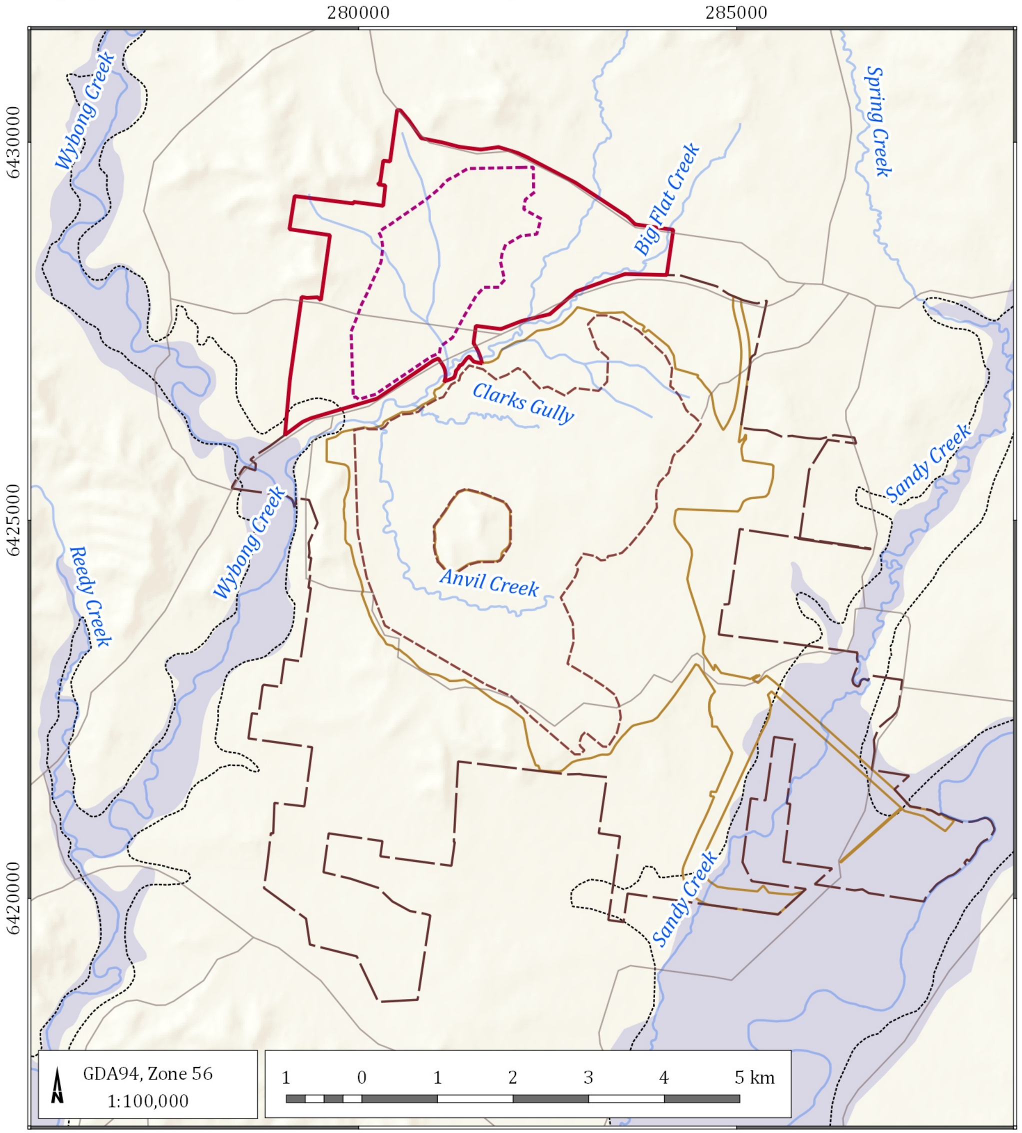
Highly productive groundwater sources are further grouped by geology into alluvial, coastal sands, porous rock, and fractured rock. "Less productive" groundwater sources are all other aquifers that do not satisfy the "highly productive" criteria for yield and water quality.

The AIP requires that impacts on highly and less productive water sources need to be assessed and accounted for. CLWD has produced a map of groundwater productivity across NSW, which shows areas classified as either highly or less productive. The CLWD groundwater productivity map has been produced based on regional scale geological maps. Figure 2.2 shows the CLWD groundwater productivity map, which indicates the alluvium along Wybong Creek and Sandy Creek has been classified as highly productive. Both of these highly productive groundwater areas are located outside of the MCCO Additional Project Area. The extent and characteristics of the Quaternary alluvium is further discussed in Section 4.2.1. Section 5.1.2 provides further information on the properties of the alluvial aquifers.

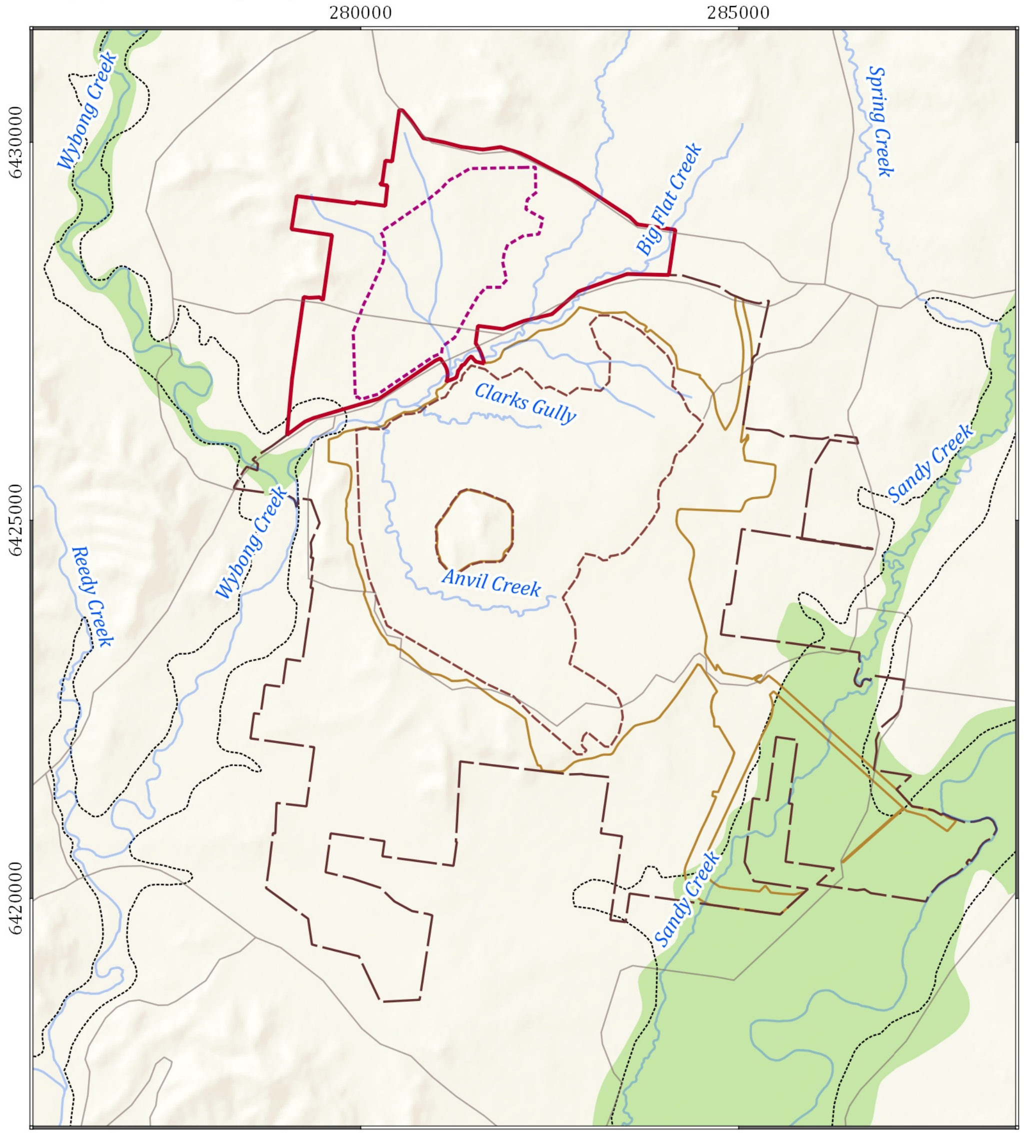
The Permian coal measures (porous and fractured rock) are categorised as "less productive" (DPI-Water, 2012).

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

Highly Productive groundwater (DPI Water)



Biophysical Strategic Agricultural Land



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Approved Mangoola Coal Mine Disturbance Area
- Highly Productive groundwater (DPI Water)
- Biophysical Strategic Agricultural Land
- Alluvium
- Drainage

AGE

Mangoola EIS (G1839F)

Highly Productive groundwater (DPI Water) and Biophysical Strategic Agricultural Land

DATE
10/04/2019

FIGURE No:
2.2

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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2.3.2 NSW Strategic Regional Land Use Policy

The NSW Strategic Regional Land Use Policy applies to the Hunter Valley in which the MCCO Project resides. Biophysical Strategic Agricultural Land (BSAL) is land with high quality soil and water resources capable of sustaining high levels of productivity. BSAL is mapped along parts of the Hunter River, the Sandy Creek, and the Wybong Creek upstream of the Big Flat Creek confluence on regional mapping (Figure 2.2). There is no BSAL mapped within the MCCO Additional Project Area and the absence of BSAL has been confirmed through the Site Verification Certificate issued for the Project by DPE.

2.4 Water licensing

Mangoola hold four water licences to extract groundwater as a result of mining at Mangoola Coal Mine. The combined allocations for each aquifer type are:

- hardrock – up to 700 ML/annum groundwater from the porous rock aquifers including the Permian Newcastle Coal Measures and Triassic Narrabeen Group sandstones; and
- alluvium – up to 254 ML/annum groundwater from the alluvial aquifer associated with Wybong Creek.

Mangoola has estimated the volume of groundwater pumped from the currently approved Mangoola Coal Mine as described in Section 5.2.3. For the calendar year of 2017 it was estimated that mining intercepted a total of approximately 79 ML from the hardrock aquifer.

2.5 Commonwealth Environment Protection and Biodiversity Conservation Act 1999

The EPBC Act is administered by the Department of the Environment and Energy (DoEE). The EPBC Act is designed to protect national environmental assets, known as Matters of National Environmental Significance (MNES). Under the 2013 amendment to the EPBC Act (the water trigger), significant impacts on water resources associated within coal mining and/or coal seam gas (CSG) developments were included.

The IESC is a statutory body under the EPBC Act that provides scientific advice to the Commonwealth Environment Minister and relevant state ministers. Guidelines have been developed in order to assist the IESC in reviewing CSG or large coal mining development proposals that are likely to have significant impacts on water resources (IESC, 2018). Appendix B includes a table summarising the requirements of the IESC information guidelines and a link to the section where the information is provided within this report.

In January 2018 the IESC released a draft guidance note entitled 'Explanatory Note on Uncertainty Analysis in Groundwater Modelling' (Middlemis & Peeters, 2018) to support the information guidelines and complement the Australian Groundwater Modelling Guidelines. The draft explanatory note provides draft guidance on predictive uncertainty analysis during the groundwater modelling process. The guideline notes that numerous complexities and uncertainties inherent in conceptualising and modelling groundwater systems means that, when considered in a risk management context, a single calibrated model is insufficient to fully predict the range of potential impacts and their likelihood. A robust uncertainty analysis is therefore important for regulatory decision-making to ensure management options and approaches are appropriate to the level of risk and its likelihood for any particular impact. Uncertainty analysis also provides insight into the main sources of uncertainty, and how much the uncertainty in model outcomes is reduced by the available observations/data. A summary of how this report addresses the draft IESC methodology for completing uncertainty analysis is provided in Appendix B. The guidelines recommend that proponents engage with the Commonwealth government during the assessment process. Glencore and their environmental management consultants engaged with the Department of the Environment and Energy throughout the early phases of the MCCO Project with meetings held in Canberra on:

- 8 December 2017; and
- 3 October 2018.

Consultation with the Department of the Environment and Energy will be ongoing throughout the assessment of the MCCO Project.

3 Environmental setting

3.1 Location

Mangoola Coal Mine is located in the Hunter Coalfields of the Sydney Basin and is entirely within the Muswellbrook Local Government area. The mine is approximately 20 km west of Muswellbrook and 10 km north of Denman. The MCCO Additional Project Area lies immediately to the north of the currently approved Mangoola Coal mining area.

3.2 Climate

The climate in the Mangoola area is temperate, and is characterised by hot summers with intermittent thunderstorms and mild dry winters. Climate information was obtained from the Scientific Information for Land Owners (SILO) database of historical climate records for Australia (DSITI, 2017). This service interpolates rainfall and evaporation records from available stations to a selected point. The location selected for the SILO data drill resides at longitude 150.70^{0}, latitude -32.25^{0}, and elevation 220 mAHD. Interpolated climatic information was obtained for the period between January 1900 and September 2018. A summary of average monthly rainfall and evaporation totals from 1900 to 2017 is shown in Table 3.1.

SILO data is based on observational records provided by the Bureau of Meteorology (BoM), with data gaps addressed through data processing in order to provide a spatially and temporally complete climate dataset. The dataset indicates the long term average annual rainfall is 591 mm/year, with December and January being the wettest months (65 mm and 73 mm). The two on-site rainfall stations have shorter records but similar averages to the SILO dataset.

The annual evaporation is 1,617 mm/year and exceeds mean rainfall throughout each month of the year. The differences are smallest in the winter, with the potential evaporation in June being close to the average rainfall.

Table 3.1 Summary of climatic averages 1900-2017 (mm/month)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual (mm/yr)
SILO rainfall (mm)	73.0	62.5	55.5	41.4	37.3	42.6	37.6	34.5	37.8	47.7	56.2	65.1	591
SILO evaporation (mm)	220.3	175.9	157.0	110.7	73.2	52.3	60.4	85.4	116.5	157.6	185.9	222.0	1617

The climatic data indicates that groundwater recharge is unlikely to be high due to the high evaporation rates at the site relative to rainfall. Recharge rates depend on a range of factors including soil type, geology, topography, vegetation and dominant land use. Despite the high average evaporation rates recharge will occur sporadically when rainfall activity promotes saturation of the soil profile and evaporation is insufficient to remove the soil moisture. During these periods there is potential for deep drainage of water to underlying groundwater systems. MER (2006) estimated long term steady state rainfall recharge varies from zero to no more than 2% of annual rainfall based on previous studies in the Upper Hunter region.

Figure 3.1 shows the cumulative rainfall departure (CRD) calculated using the SILO rainfall data.

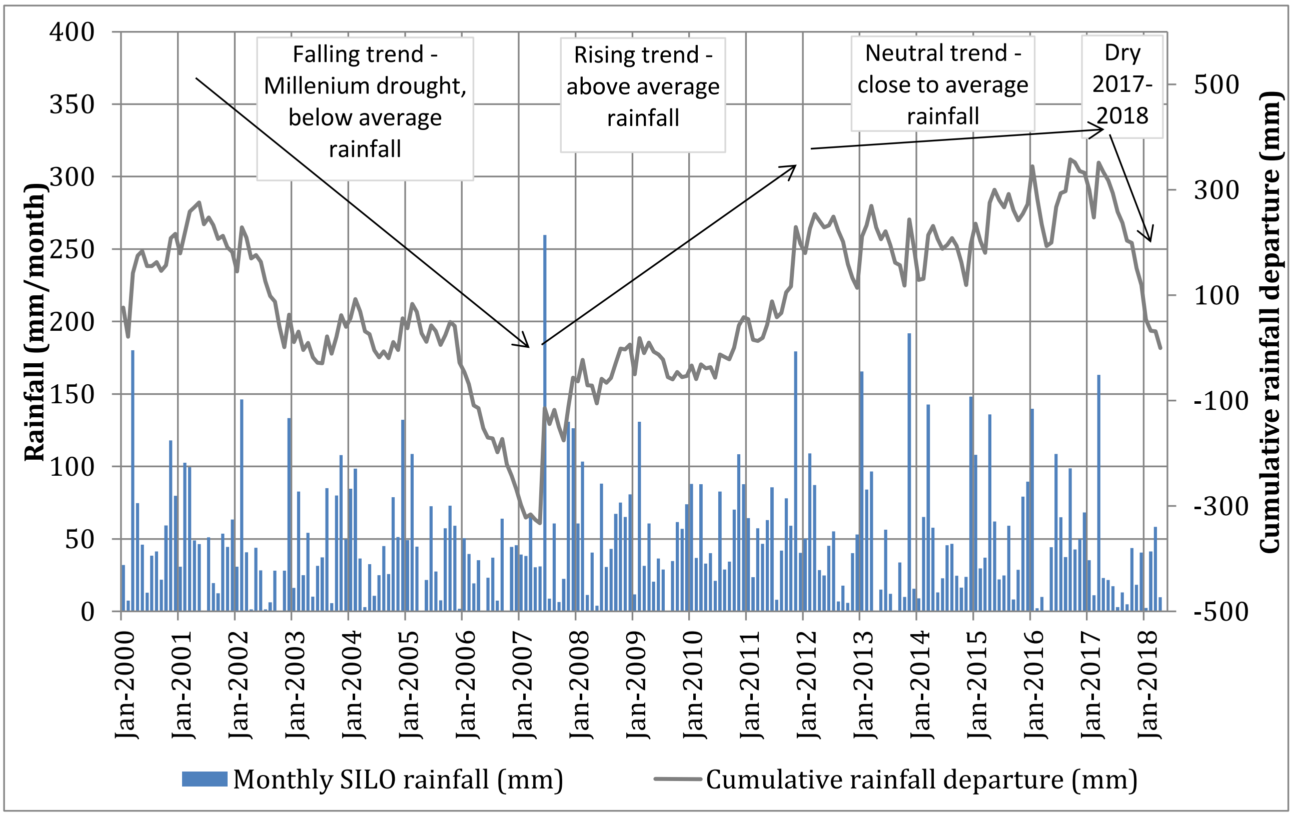


Figure 3.1 Cumulative Rainfall Departure and monthly rainfall (SILO)

The CRD represents visually the deviation of monthly rainfall from long term average rainfall. A rising trend indicates a period of above average rainfall whilst a falling trend is due to below average rainfall. Figure 3.1 shows these periods with four climatically distinct periods evident:

- 2000 – 2007 during the Millennium drought where rainfall was commonly below average;
- 2007 – 2012 when rainfall was commonly above average;
- 2012 – 2017 when rainfall generally remained closer to historical averages, with a slight rising trend; and
- 2017 – 2018 when rainfall was consistently well below averages.

Of note is the below average rainfall recorded at Mangoola Coal Mine from early 2017. Monthly rainfall has been well below long term averages since in March 2017 resulting in the steep decline shown in Figure 3.1. The rainfall recorded between April 2017 and September 2018 is less than half of the long term averages rainfall for the same period. The area is currently (February 2019) classified as being in 'drought' (NSW DPI, 2019), having previously (September 2018) been classified as being in 'intense drought' (NSW DPI, 2018).

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

3.3 Terrain and drainage

The Mangoola area comprises a mix of gently sloping creek/river valleys divided by steep outcropping hills and escarpments (Figure 3.2). The lowest topographic regions in the Mangoola area lie along the creeks, the main ones being:

- Wybong Creek;
- Big Flat Creek;
- Anvil Creek; and
- Sandy Creek.

Wybong Creek is perennial[2] and flows in a north-south alignment about 1.5 km southwest of the MCCO Proposed Additional Mining Area. The Wybong Creek has created notable alluvial flats along its present course. The current creek channel is incised into the alluvium in the vicinity of the mine by approximately 10 m to 12 m, as shown in Figure 3.4. The alluvium associated with Wybong Creek has historically been used as a groundwater source. Wybong Creek joins the Goulburn River approximately 12 km downstream of the confluence with Big Flat Creek. The Goulburn River joins the Hunter River about 17 km further downstream.

Big Flat Creek runs from north-east to south-west along the northern edge of the Mangoola Coal Mine and joins the Wybong Creek approximately 1 km west of the approved Mangoola Coal Disturbance Boundary. Big Flat Creek is ephemeral in nature with little or no flow during dry periods. The Wybong Creek alluvium extends for a short distance up Big Flat Creek before transitioning to highly weathered conglomerate and shallow colluvium. Big Flat Creek falls gently from approximately 170 mAHD at the north-eastern edge of the mine to 130 mAHD at the confluence with Wybong Creek, a distance of just over 6 km. Big Flat Creek branches in two approximately 5 km upstream of the Wybong Creek confluence, with the northern arm turning northeast to run parallel to the MCCO Proposed Additional Mining Area.

LIDAR topographic data is available along Big Flat Creek adjacent to Mangoola Coal Mine. This shows that although the creek is the lowest point in the topographic surface, the degree to which it is incised into the surrounding landscape varies along its length. As a general rule the creek becomes more incised the closer it gets to Wybong Creek. Topographic profiles along and across Big Flat Creek near to the mine were drawn at the locations shown on Figure 3.3, with the results shown on Figure 3.4. At the top of the creek, close to the rehabilitated areas of the Mangoola mine, the creek is incised by approximately 1 m to 2 m into the wider floodplain. The shallow channel depth means that the creek will only intercept groundwater when the water table is very close to surface. Closer to the confluence with Anvil Creek the base of the creek is approximately 4 m to 6 m below the surrounding ground surface, and once the creek turns south on the Wybong Creek alluvium it is incised to a similar depth as the Wybong Creek (~12 m).

Figure 3.4 shows a change in the gradient of Big Flat Creek that occurs close to the confluence of the mined out Clarks Gully. Above Clarks Gully the creek falls at a gradient of approximately 0.6% (1:180), below the confluence gradient reduces to 0.3% (1:320). The small scale variations in creek elevation plotted for the section along the length of the creek are due to the section line not aligning with every small meander in the creek bed.

[2] Flowing at all times except during extreme drought conditions.

Anvil Creek lies within the approved Mangoola Coal Mining area and joins Big Flat Creek from the south approximately 1.7 km upstream of the confluence with Wybong Creek. Anvil Creek is also ephemeral, with its headwaters reaching approximately 170 mAHD, falling to 140 mAHD at the confluence with Big Flat Creek. Anvil Creek is approved to be mined through as the approved Mangoola Coal Mine pit progresses, followed by a re-instatement of the drainage line prior to project closure.

Sandy Creek is a perennial stream situated approximately 2 km to 3 km east of the approved Mangoola Coal Mine. Sandy Creek flows in a north-east to south-west direction and discharges into the Hunter River approximately 9 km south of the Mangoola Coal Mine mining area.

Surface elevations in the approved mining areas at Mangoola Coal mine lie between approximately 220 mAHD and 140 mAHD. Anvil Hill lies within the mine lease area and rises to approximately 288 mAHD but will not be mined.

There are no steep topographic changes within the MCCO Proposed Additional Mining Area although several hills similar in elevation to Anvil Hill exist to the north and northwest. Within the MCCO Proposed Additional Mining Area the ground surface falls gently from about 188 mAHD in the north to 145 mAHD in the south.

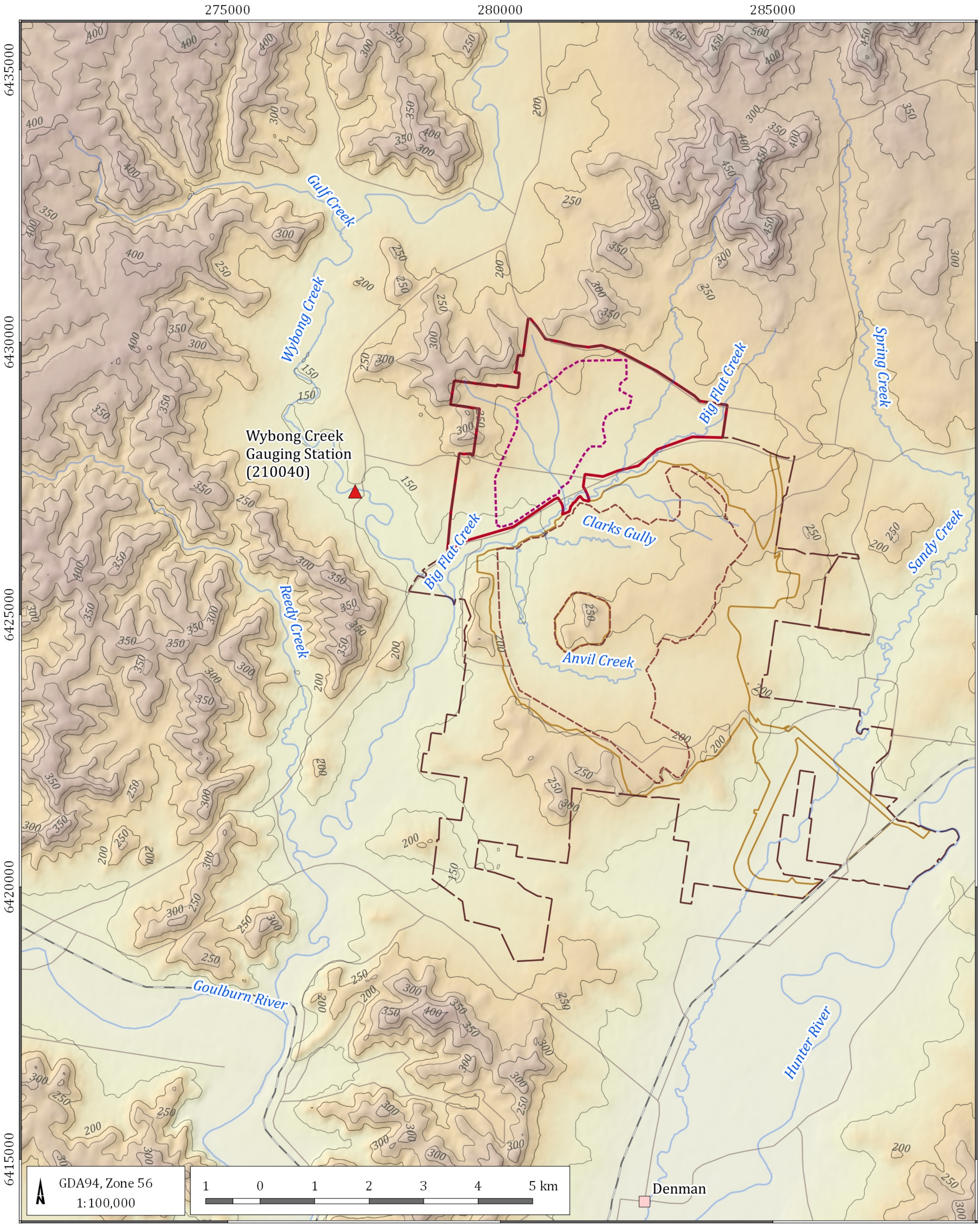
Water NSW monitor flow within the Wybong Creek at Wybong (station 210040), approximately 2.75 km west of the MCCO Proposed Additional Mining Area as shown on Figure 3.2. Water is recorded as flowing in the Wybong Creek at all times since January 2000, with the exception of two periods: the end of the Millennium Drought in 2007, when flows appear to have ceased for approximately six months, and the current drought where flows have been very low since November 2017 (Figure 3.5).

Seasonal responses in flow are apparent between 2008 and 2016 when more typical rainfall occurred. Peaks in flow are coincident with high rainfall events. Flows recorded in late 2017 were lower than the same periods in recent years, most likely due to the lower than average annual rainfall recorded during 2017. The flows from the gauging station in Wybong Creek were analysed to assess the contribution of rainfall runoff to total flow. The baseflow component of Wybong Creek at the Wybong gauging station has been estimated by Hydro Engineering and Consulting Pty Ltd (HEC) (2019) to be approximately 27% of total recorded flows. Baseflow appears to vary seasonally from approximately 1 ML/d during annual lows to 10 ML to 30 ML/d at annual highs.

Electrical conductivity (EC) of the Wybong Creek surface waters are also measured at the Wybong gauging station. EC has a strong inverse correlation to flow rates (Figure 3.5), with the EC increasing as surface water flows fall and a higher percentage of the creek flow becomes groundwater baseflow. The high (~7,000 µS/cm) EC recorded during 2007, when flow ceased, is likely due to evapo-concentration of water that is ponded in the creek bed rather than a sudden influx of higher salinity groundwater to the creek.

Mangoola Coal installed a streamflow gauging station on Big Flat Creek in late 2010. A review of the station by HEC (2019) has concluded that the streamflow data from the gauge is of limited accuracy and is therefore not suitable for use in analysing flows in Big Flat Creek for the MCCO Project assessment. By using a nearby gauging station with similar catchment characteristics as a reference HEC have established that Big Flat Creek is likely to have zero flow on ~28% of days, a median daily flow of 0.036 ML/d, and a low baseflow index.

The EC of Big Flat Creek is highly variable both spatially and temporally. Upstream of Mangoola Coal the EC varies from over 30,000 µS/cm to < 200 µS/cm. Downstream of Mangoola Coal the EC varies from ~15,000 µS/cm to ~300 µS/cm. The variability of the temporal water quality of the creek, from fresh through to saline, most likely reflects the amount of rainfall runoff within the creek at the time of sampling. The spatial variability likely indicates the contributions of lower EC tributaries to the total flow in the creek.



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Road
- Rail
- Drainage
- Water NSW river gauging station
- Populated place

Elevation (mAHD)

- 0
- 100
- 200
- 300
- 400
- 500
- Elevation contour (100 m interval)

Mangoola EIS (G1839F)

Terrain and drainage

AGE

DATE 26/02/2019

FIGURE No: **3.2**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
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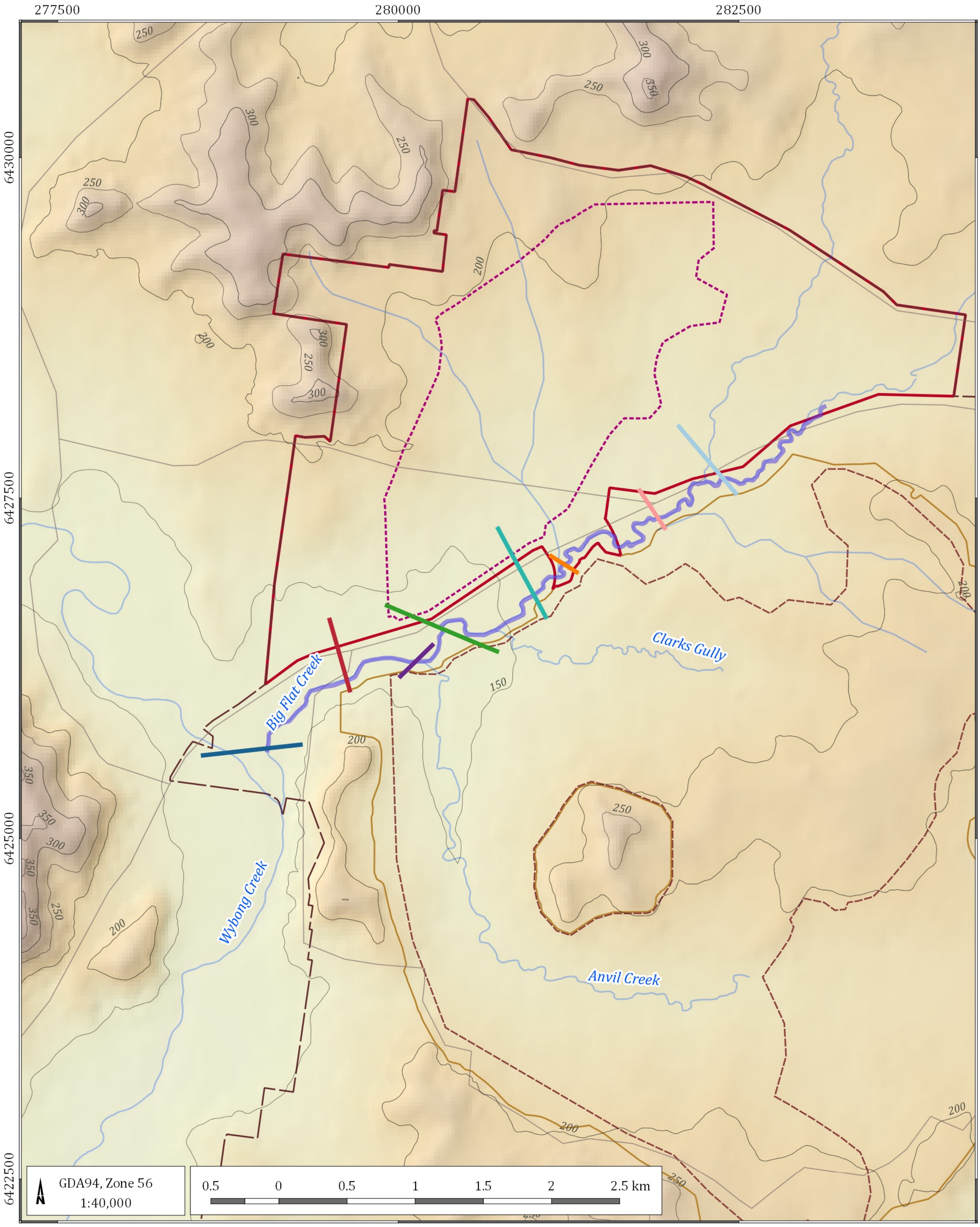

LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Road
- Rail
- Drainage

Big Flat Creek section lines

- Section 1
- Section 2
- Section 3
- Section 4
- Section 5
- Section 6
- Section 7
- Section 8
- Section 9

Elevation (mAHD)

- 0
- 100
- 200
- 300
- 400
- 500
- Elevation contour (100 m interval)

Mangoola EIS (G1839F)

Big Flat Creek Section Lines Location

AGE

DATE 26/02/2019

FIGURE No: **3.3**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
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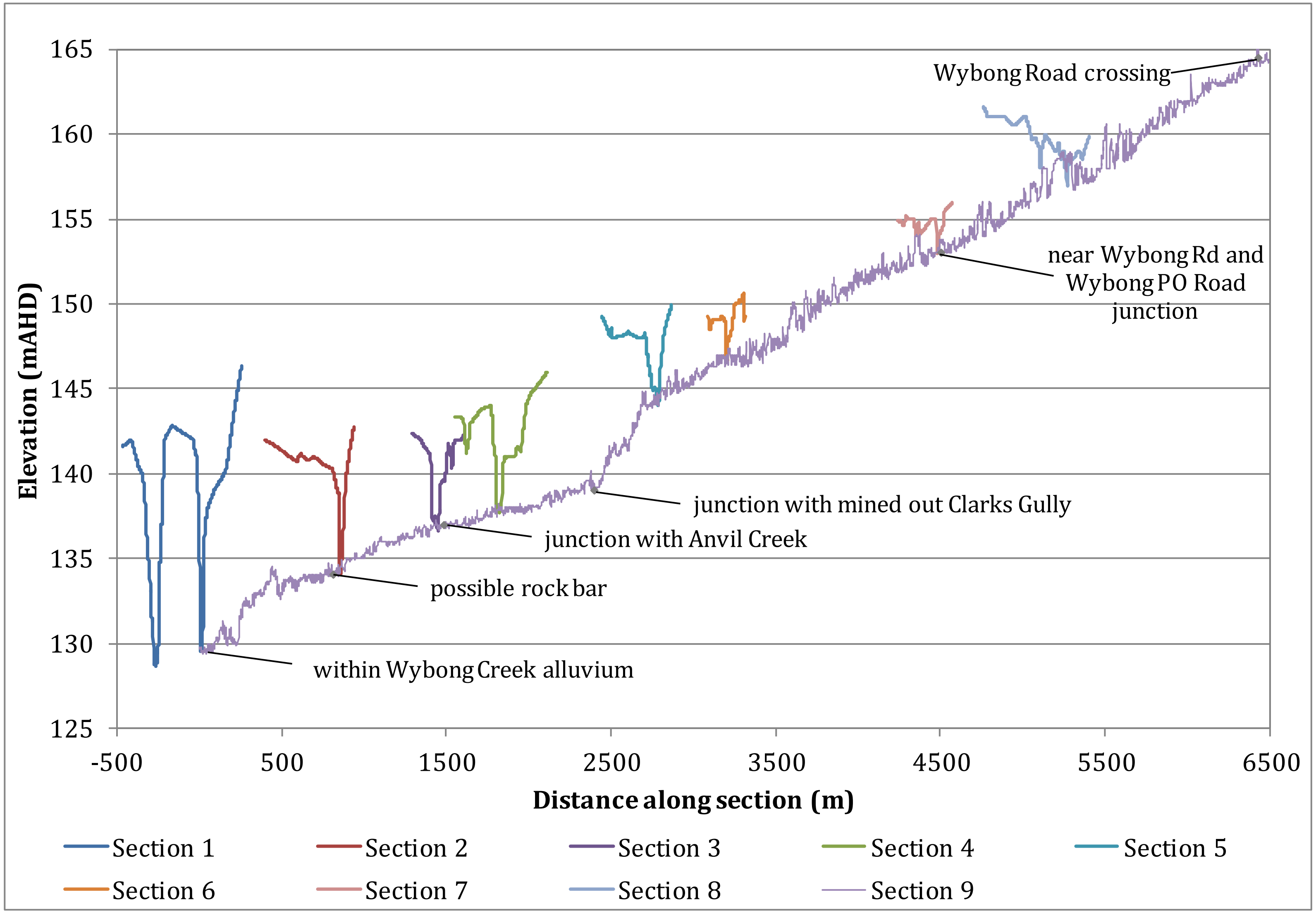


Figure 3.4 Cross sections along and through Big Flat Creek (section locations on Figure 3.3)

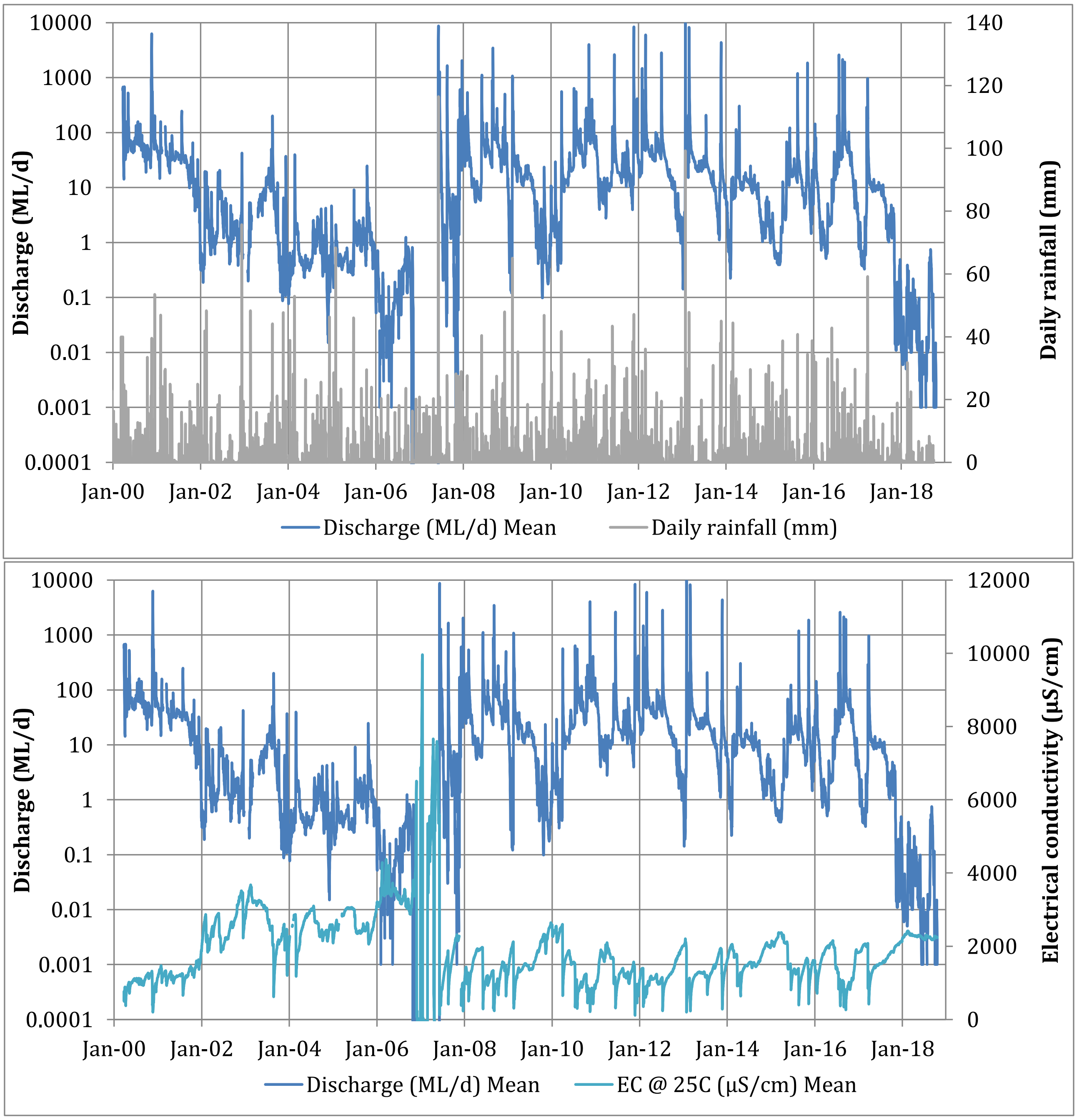
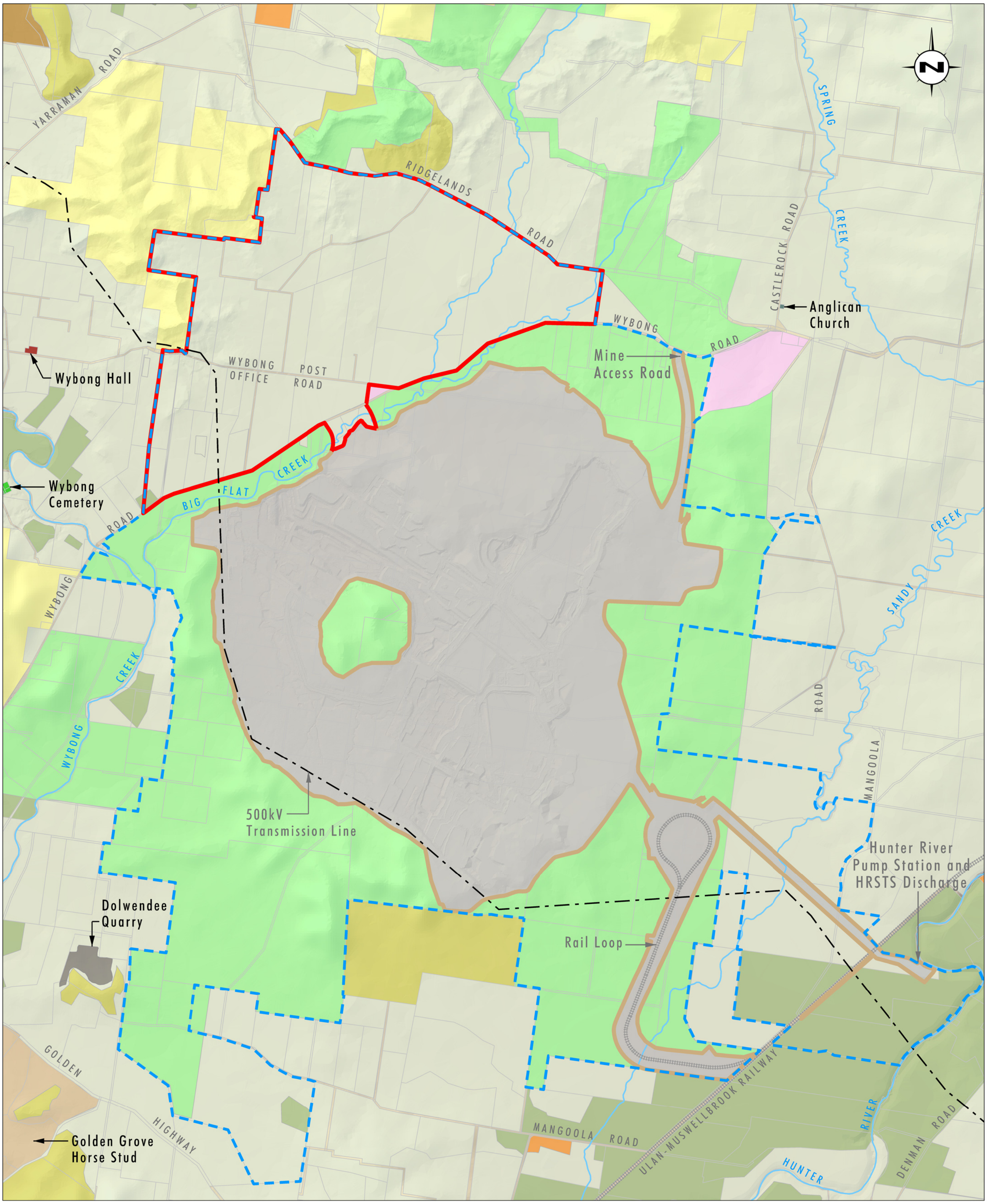


Figure 3.5 Discharge and electrical conductivity at Wybong Creek DPI station

3.4 Land use

Land use in and surrounding the MCCO Project Area is dominated by mining and offset areas associated with the approved Mangoola Coal Mine, cattle grazing, and cropping, with the steeper hills remaining as densely vegetated residual native vegetation. Cropping, including irrigation enterprises and viticulture, is primarily located along the more productive soils associated with the Wybong Creek and Hunter River alluvial flats (Figure 3.6). Away from the alluvium there are also a number of small olive groves. A large parcel of residual native woodland lies within Crown land immediately adjacent to the western boundary of the MCCO Additional Project Area. There are no large population centres, instead there are isolated rural residences scattered throughout the area.

umwelt



Data Source: Glencore (2019), OEH (2013)

0 1.0 2.0 3.0km

Legend

- MCCO Project Area
- Approved Mangoola Coal Mine Disturbance Area
- MCCO Additional Project Area
- Existing Mangoola Offsets

Land Use:

- Church
- Woodland Area
- Cemetery
- Crown Land
- Grazing
- Horse Stud
- Olive Plantation
- Travelling Stock Route (Crown Land)
- Vineyard
- Wybong Hall
- Mixed, Grazing and Irrigation / Cropping / Improved Land
- Quarry

FIGURE 3.6

Land Use

File Name (A4): R13/4004_179.dgn
20190412 14.56

4 Geological setting

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

- publicly available geological maps (Hunter Coalfields map sheets) and reports;
- layers from the Mangoola Coal Mine geology model;
- hydrogeological reports and data prepared for Mangoola Coal Mine; and
- hydrogeological data held on the DPI-Water groundwater database (Pinneena) (DPI-Water, 2015).

The information provided was used to develop a 3D numerical groundwater model for the MCCO Project. Appendix A describes the approach to the groundwater modelling in detail.

4.1 Regional geology

The MCCO Project is located along the western outcrop of the Permian coal measures as shown on the 1:100,000 scale Hunter Coalfield Regional Geology Map (Glen & Beckett, 1993) (Figure 4.1). The regional geology comprises Permian Newcastle Coal Measures overlain by younger, Triassic Narrabeen Group sandstones and conglomerates. The Triassic units form rocky hills and ridges in the area including Anvil Hill, which occurs in the centre of the Mangoola Coal Mine site.

The target coal resources for both the approved Mangoola Coal Mine and MCCO Proposed Additional Mining Area occur within the Newcastle Coal Measures; and include the Great Northern, Fassifern and Upper Pilot seams. The Wallarah seam has varying thickness and will be targeted where it is economically viable within the mining footprints. The coal measures subcrop within the eastern parts of the mining area and dip gently to the west. The coal measures were deposited in an upper deltaic to a progressively drier terrestrial environment that has resulted in an overburden stratigraphy in the Mangoola area comprising well cemented conglomerates and conglomeritic sandstones of Permian and Triassic age (MER, 2006).

The Wittingham Coal Measures conformably underlie the Newcastle Coal Measures and subcrop to the east of the site. Seams within these coal measures are targeted by the nearby coal mines including Bengalla, Mount Pleasant, and Mt Arthur.

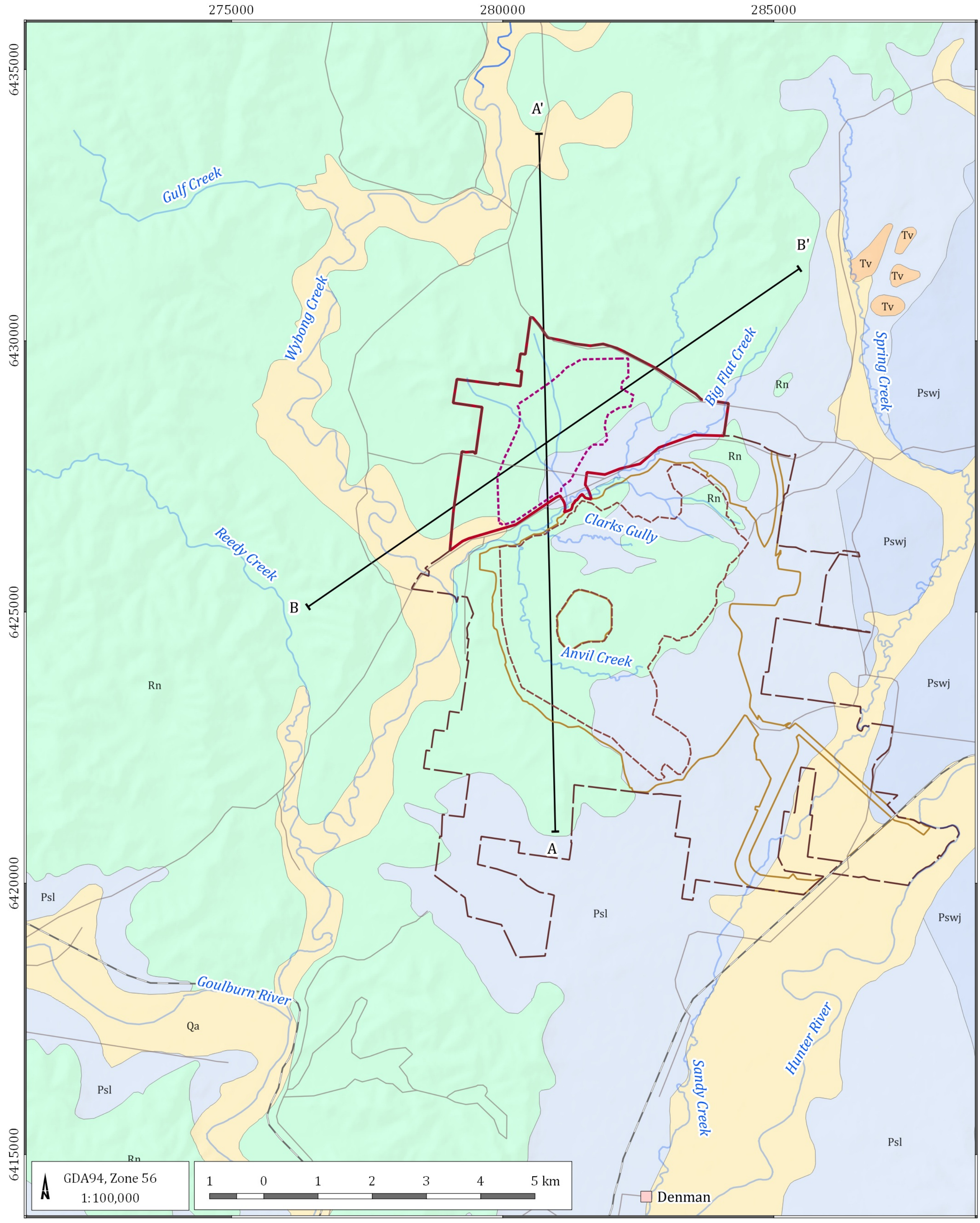
Table 4.1 provides a detailed summary of the regional geology and relevant stratigraphic units within the MCCO Project Area and surrounds. Figure 4.2 and Figure 4.3 provide conceptual geological cross-sections showing the occurrence of key stratigraphic units across the MCCO Project Area.

Table 4.1 Summary of geological units

Age	Stratigraphic unit				Symbol	Description *
Quaternary	Quaternary sediments – alluvium				Qa	Silt, sand, gravel
Tertiary and Jurassic	Basalt				Tv or Jv	Flows, sills and dykes
Triassic	Hawkesbury Sandstone				Rn	Massive bedded, cross bedded and horizontally bedded quartz sandstone and minor siltstone
	Narrabeen Group	Terrigal Formation				Interbedded fine to medium-grained sandstone and siltstone, minor claystone.
		Clifton Subgroup	Patonga Claystone			Sandstone, interbedded sandstone and siltstone, claystone
			Tuggerah Formation			
			Widden Brook Conglomerate			Conglomerate and sandstone
Permian	Singleton Supergroup	Newcastle (Wollombi) Coal Measures	Moon Island Beach Subgroup	Vales Point seam	Psl	Conglomerate, tuff, siltstone, claystone, black coal
				Wallarah seam [1]		
				Great Northern seam		
			Awaba Tuff			Tuff, tuffaceous sandstone, tuffaceous siltstone, claystone, chert, usually contains abundant mica in basal 0.2-0.4 m
			Boolaroo Subgroup	**Fassifern seam**		Sandstone, conglomerate, tuff, black coal
				Upper Pilot seam		
				Mt Hutton Tuff		
				Lower Pilot seam		
				Hartley Hill seam		
			Warners Bay Tuff			Tuff, tuffaceous sandstone, tuffaceous siltstone, claystone, chert

Age	Stratigraphic unit				Symbol	Description *
			Adamstown Subgroup	Australasian seam		Conglomerate, tuff, sandstone, siltstone, claystone, black coal
				Stockrington Tuff		
				Montrose seam		
				Wave Hill seam		
				Edgeworth Tuff		
				Fern Valley seam		
				Victoria Tunnel seam		
			Nobbys Tuff			Tuff, tuffaceous sandstone, tuffaceous siltstone, claystone, chert
			Lambton Subgroup	Nobbys seam		Sandstone, siltstone, claystone, coal and tuffaceous sandstone
				Dudley seam		
				Yard seam		
				Borehole seam		
			Watts Sandstone	Waratah Sandstone		A medium-grained sandstone, well sorted in the middle
		Wittingham Coal Measures	Denman Formation		Pswj	Dark grey striped sandstone-siltstone laminite with abundant burrows
			Jerrys Plains Subgroup			Numerous coal seams; claystone, tuff, siltstone, sandstone, conglomerate

Notes: * *Descriptions predominantly from the Australian Stratigraphic Units Database (Geoscience Australia, 2017).*
*Seams highlighted in **bold** are the MCCO Project target coal seams.*
[1] The Wallarah Seam is only extracted opportunistically where present.



LEGEND

- Populated place
- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mining Area
- Approved Mangoola Coal Mine Disturbance Area
- Proposed Additional Mining Area
- Road
- Rail
- Drainage

Surface geology

(Hunter Coalfield Regional 1:100k Geology map)

- Qa - Quaternary Alluvium
- Tv - Tertiary Basalt
- Rn - Triassic Narrabeen Group
- Psl - Permian Newcastle Coal Measures
- Pswj - Permian Denman Fmt, Jerrys Plains Subgroup
- Cross section lines

Mangoola EIS (G1839F)

Surface geology

DATE 26/02/2019

FIGURE No: **4.1**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
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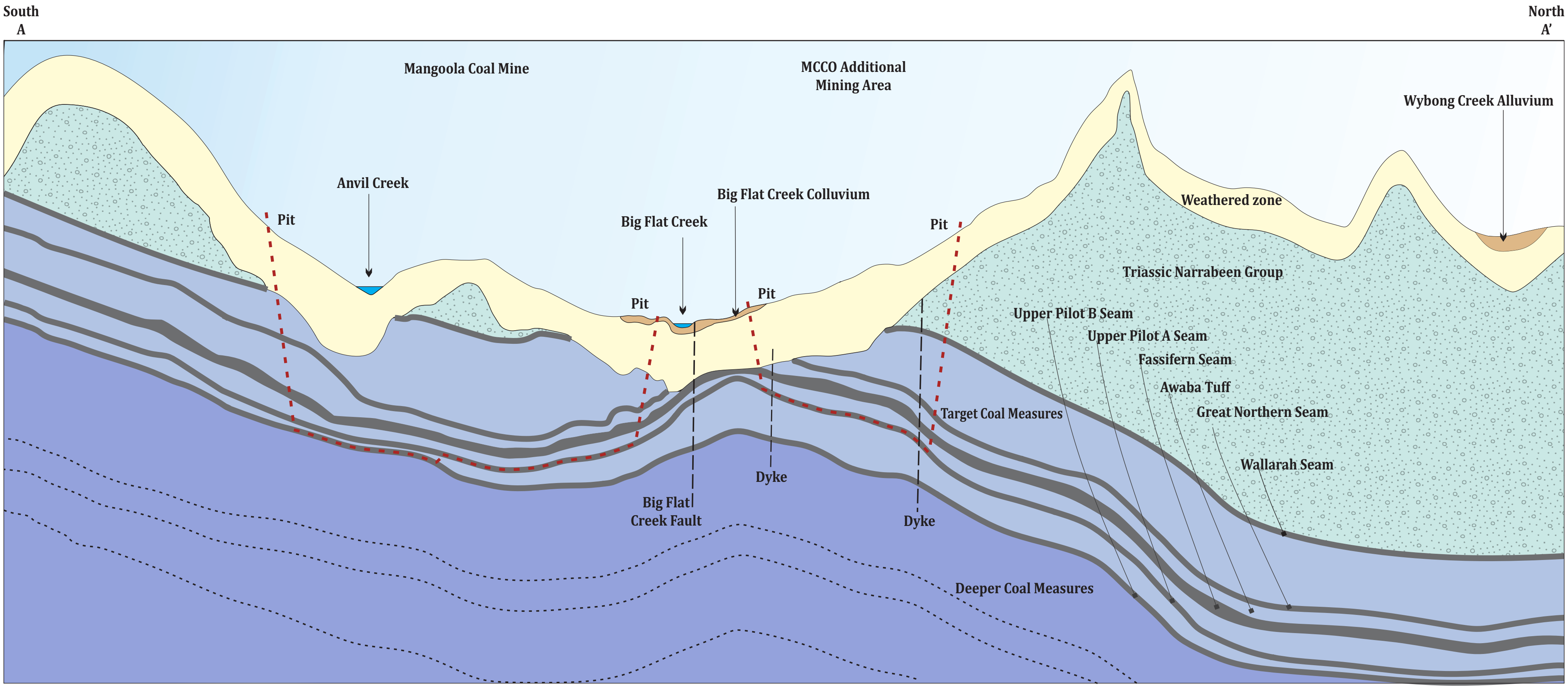
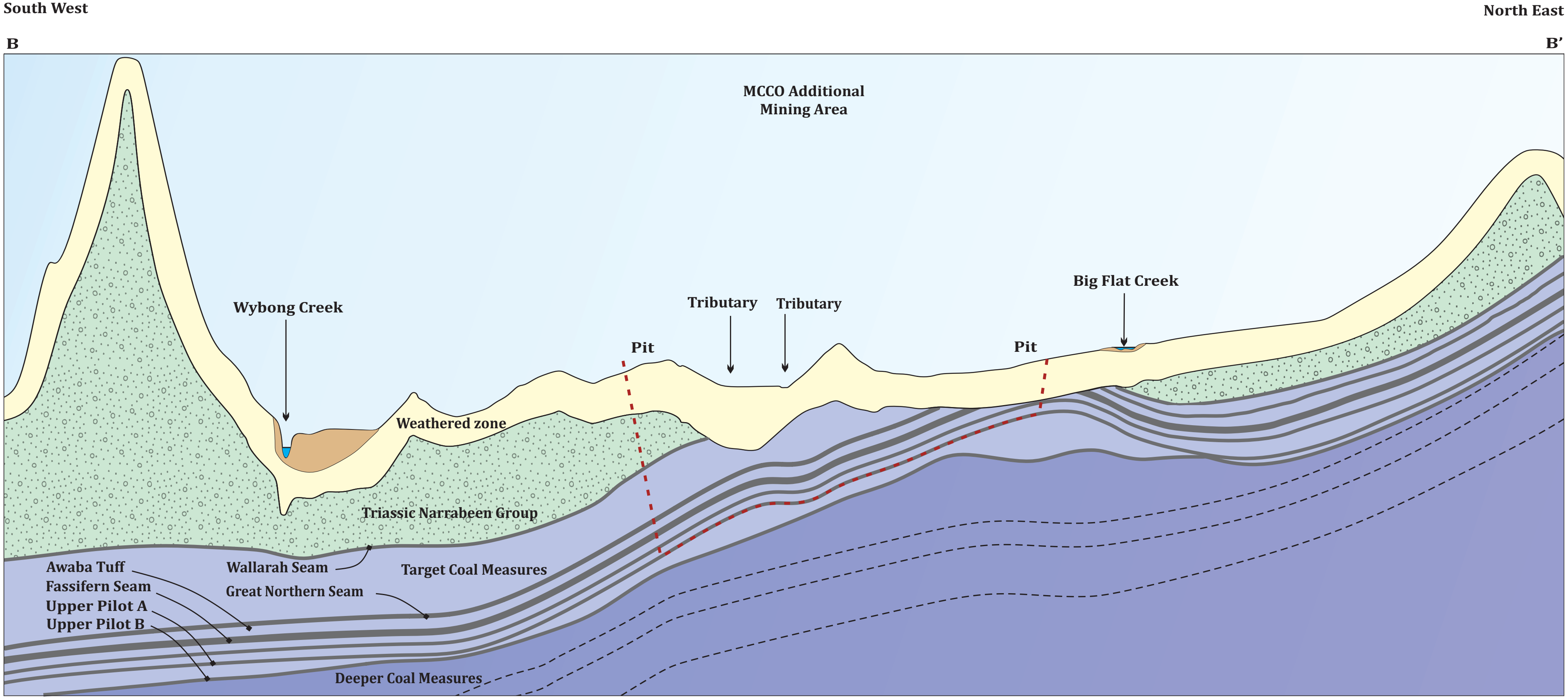


Conceptual interpretation
Not drawn to scale

Conceptualised north – south geological cross section

Figure 4.2

Mangoola GIS (G1839F)



Conceptual interpretation
Not drawn to scale

Conceptualised south-west – north-east geological cross section

Figure 4.3

Mangoola GIA (G1839F)

4.2 Local geology

The following stratigraphic units occur within, or in close proximity to, the MCCO Project Area (from youngest to oldest):

- Quaternary alluvium and colluvium;
- Triassic sandstones and conglomerates; and
- Newcastle Coal Measures.

Each of the main stratigraphic units is discussed in further detail below in order of increasing depth from ground surface/geologic age.

4.2.1 Quaternary alluvium and colluvium

There is no highly productive Quaternary alluvium[3] (Qa) mapped within the MCCO Proposed Additional Project Area, although there are areas present in the larger MCCO Project Area. The closest mapped Quaternary alluvium is located along the Wybong Creek to the west of the MCCO Project. Quaternary alluvium also occurs along Sandy Creek to the southeast of the approved Mangoola Coal Mine.

Big Flat Creek, which flows between the Mangoola Coal Mine and MCCO Proposed Additional Mining Area, drains a much smaller area than the Wybong Creek, and with the exception of approximately the last kilometre before its confluence with Wybong Creek an alluvial unit has not developed. Instead the flat lying areas immediately surrounding Big Flat Creek are infilled with a shallow thickness of colluvium[4] overlying highly weathered Triassic conglomerates. As the colluvium and weathered conglomerate are derived from the underlying bedrock conglomerate they present in returned drilling samples as a mixture of sands, clays and rounded pebbles similar in appearance to an alluvial sequence. The initial monitoring bores drilled and installed for the Mangoola Coal Mine therefore interpreted and reported an 'alluvial' thickness of over 20 m underlying sections of Big Flat Creek (MER, 2006).

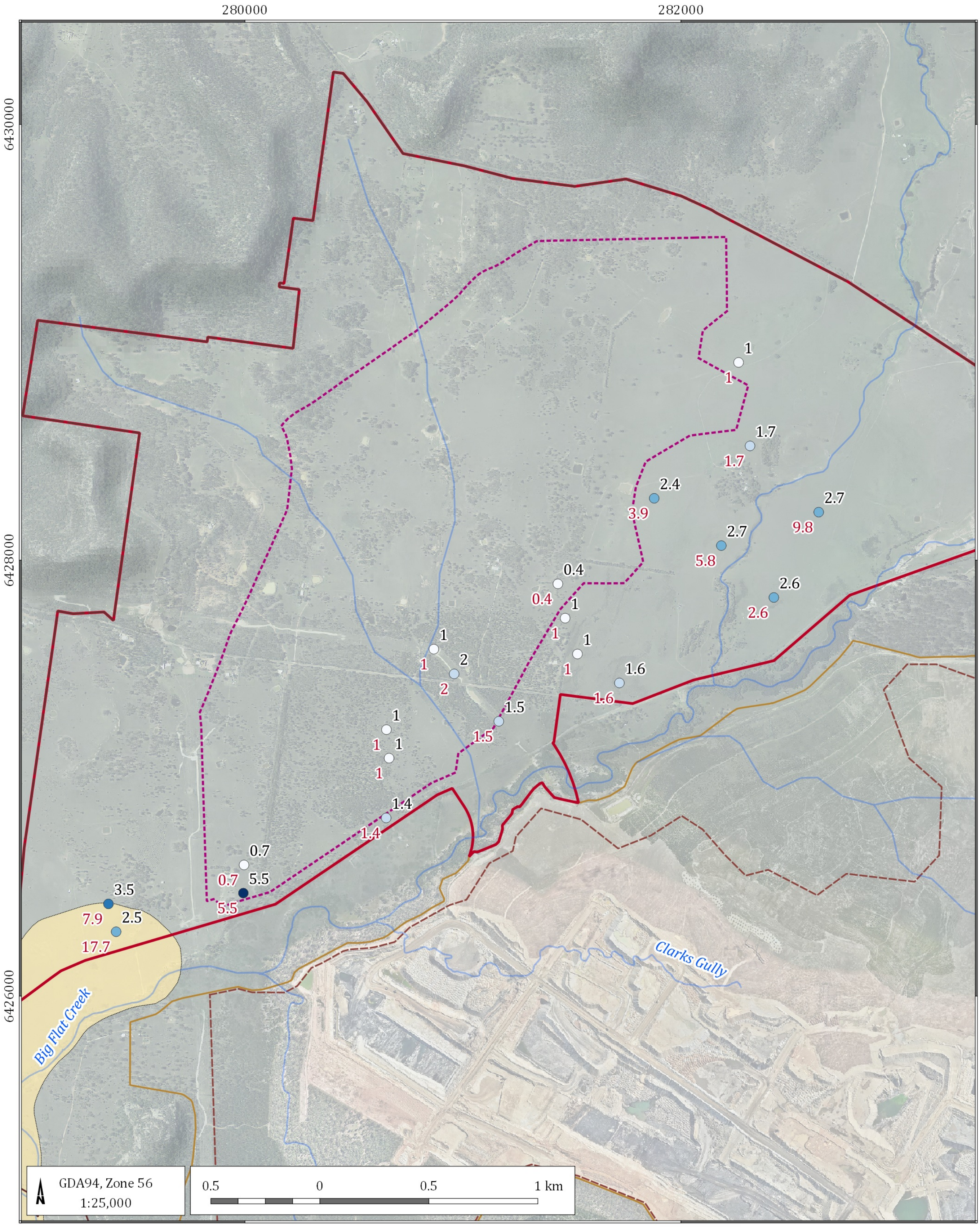
The extent and thickness of the colluvium has been revised through additional field campaigns, including twenty shallow exploratory bores located along transects extending away from the creek which were drilled in late 2017. The exploratory bores indicated that the extent of the colluvium is smaller than previously interpreted. Away from the creek the colluvium transitions to a thin covering (usually <1.5 m) of topsoil and regolith[5] immediately overlying highly weathered bedrock. The thickest depths of colluvium were identified in bores closest to the creek, where depths of 2.5 m to 3.5 m were estimated in the upstream reaches. The colluvium is potentially slightly thicker immediately underlying Big Flat Creek and to the west of the mining areas, where it transitions to an alluvial plain close to Wybong Creek. The colluvium is not defined as a separate unit on the geological maps for the area. The colluvial thicknesses mapped in the shallow bores are shown on Figure 4.4.

[3] sediments deposited by streams or floods in a valley.

[4] material which accumulates at the foot of slopes.

[5] unconsolidated solid material covering the bedrock.

The transition from Big Flat Creek colluvium to Wybong Creek alluvium occurs along Big Flat Creek downstream of the Mangoola mining areas. There is no clear boundary between the two materials and the transition is likely gradational. Downstream of the mining areas the creek bed becomes more incised, in places eroding down to conglomerate bedrock. Figure 4.5 and Figure 4.6 show photographs of the creek bed and exposed strata. The shallow strata exposed on each side of the creek are notably different. To the south (left bank looking downstream) the banks rise to a high elevation bedrock outcrop, orange in colour, and appearing to be primarily derived from weathering of the conglomerate bedrock. To the north (right bank looking downstream) the shallow materials form a flatter 'floodplain' with much darker organic rich soils as shown in Figure 4.5 and Figure 4.6. The darker soils transition back to more orange weathered materials once the topographic gradient increases.



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Alluvium
- Drainage

Interpolated base of colluvium (mbgl)

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5.5

Black labels - Interpolated base
Red labels - Deepest possible base
(base unclear during logging)

Mangoola EIS (G1839F)

Colluvial thickness in test bores

AGE

DATE
26/02/2019

FIGURE No:
4.4

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
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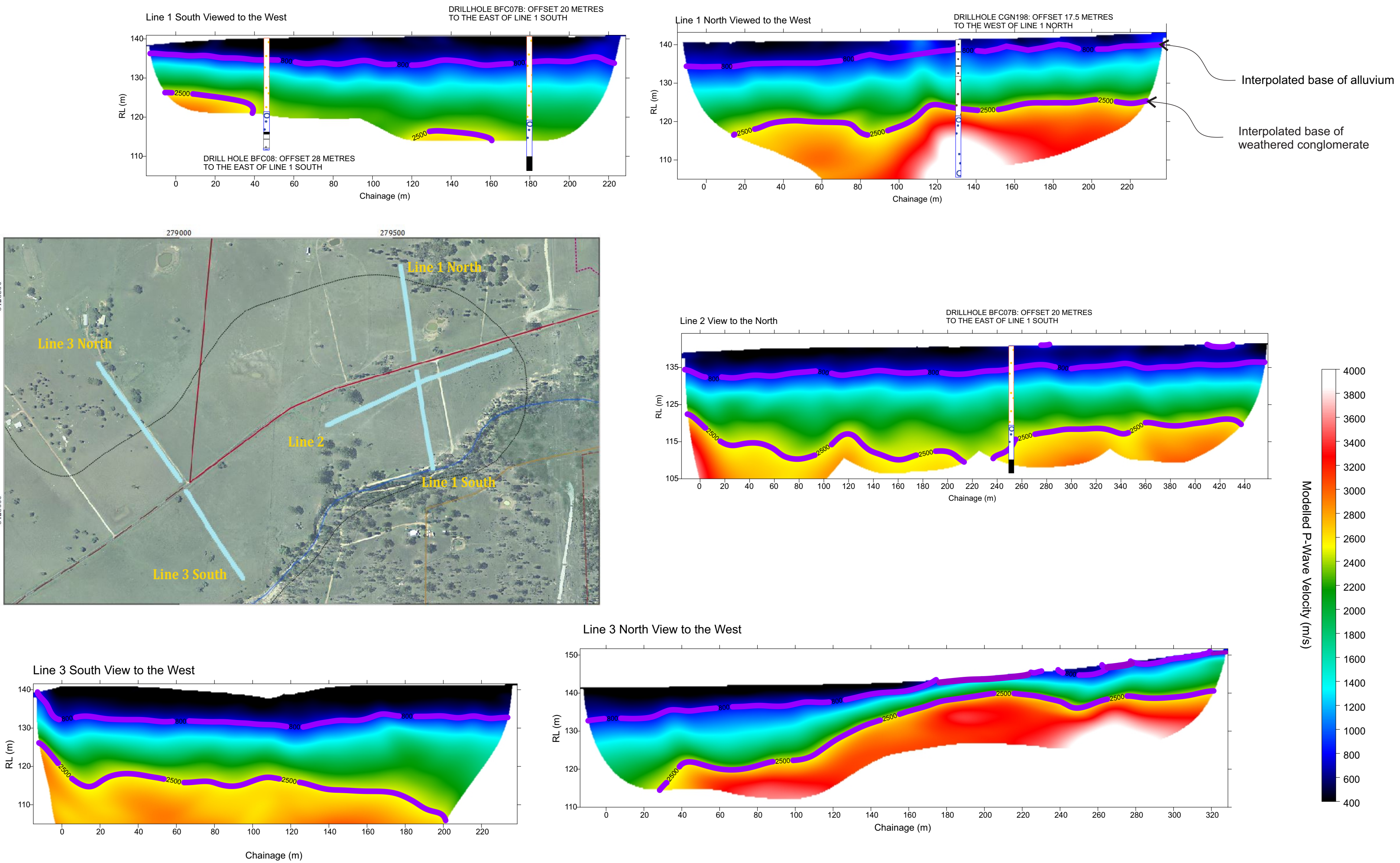
Figure 4.5 Big Flat Creek main rock bar

Figure 4.6 Highly incised Big Flat Creek in lower reaches

A geophysical seismic refraction survey was conducted in September 2018 (GBG, 2018) to assist with identifying the base of the alluvium and the depth of the weathered bedrock materials in the downstream reaches of Big Flat Creek. This was required to determine whether the shallow bedrock exposed in the base of the creek continued northwards at shallow depth, as this would potentially limit the hydraulic connectivity between the mining areas and the Wybong Creek alluvium. The survey was able to interpret both the approximate base of the alluvium and the approximate depth of the weathered bedrock zone. The locations of the seismic lines and interpreted depths are shown on Figure 4.7.

The seismic survey indicated the alluvium is relatively shallow with a maximum thickness of about 9 m. The alluvium appears to thin to the north as it approaches the break of slope. The depth of alluvium interpreted from the seismic survey was similar to alluvial thicknesses measured in exploration and monitoring bores. The thickest alluvium was coincident with the central areas of flatter ground observed from LIDAR and on the ground.



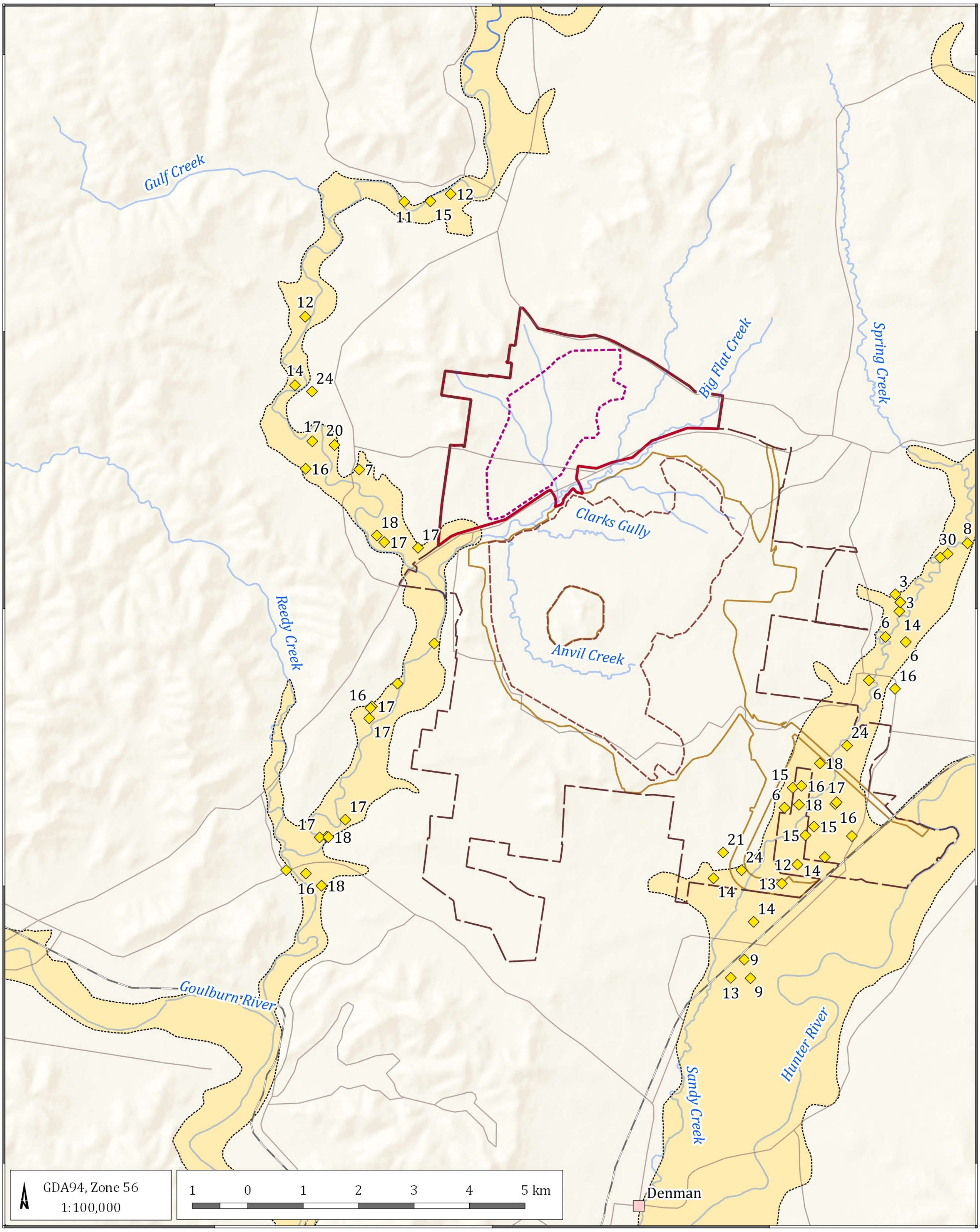
Seismic refraction survey results (after GBG, 2018)

Figure 4.7

Mangoola EIS (G1839F)

The Wybong Creek alluvium is described in drilling logs from registered water bores as comprising a mixture of loam, gravels, sand and clays. The public records indicate the water bores within the alluvium were often completed at approximately 15 m to 18 m depth, with alluvium occurring throughout the depth of the bore. It is unclear if all bores reached the base of the alluvium or were terminated once sufficient water resources had been reached. It is also possible that the basal 'alluvium' is weathered conglomerate bedrock, as observed along Big Flat Creek. Bores that did penetrate the bedrock reached the base of the alluvium at approximately 20 m to 23 m depth.

Records from water bores drilled within the Sandy Creek alluvium indicate similar alluvial depths to those along the Wybong Creek, but appear to contain more gravel within the alluvium. Figure 4.8 shows the depth of each water bore installed within Quaternary alluvium. There are a small number of alluvial bores that appear to be located outside of the mapped and interpreted extent of alluvium. It is expected this occurs when the location of older bores has not been accurately surveyed.



LEGEND

- G1839F_Populated_place
- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mining Area
- Approved Mangoola Coal Mine Disturbance Area
- Proposed Additional Mining Area
- Alluvium
- Road
- Rail
- Drainage
- Registered bores reviewed - bore depth, assumed approx. base of alluvium mbgl

Mangoola EIS (G1839F)

Quaternary alluvium bore depths

DATE 26/02/2019

FIGURE No: **4.8**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
G:\Projects\G1839F.Mangoola EIS\3_GIS\Workspaces\011_GIA\04.08_G1839F_Quaternary alluvium bore depths.qgs

4.2.2 Triassic Narrabeen group

Triassic Narrabeen Group conglomerates and conglomeritic sandstones cover much of the MCCO Project Area and thicken to the northwest with the dip of the coal seams. In the approved Mangoola Coal Mine area there is only a thin cover of Triassic conglomerate occurring, except for Anvil Hill which forms an isolated remnant outcrop. The Triassic units pinch out along a northeast to southwest trending alignment that runs through the approved Mangoola Coal Mine extraction area. However, the Permian interburden also contains sandstone and conglomerates that extend throughout the Mangoola Coal Mine and MCCO Proposed Additional Mining Area.

The conglomerates comprise both angular and rounded pebbles from 5 mm to more than 20 mm diameter, and occasionally distinctly sandy phases (as coarse to fine grained sandstones). Pebbles are commonly volcanic in origin, while the matrix is typically a well cemented fine grained sandstone or siltstone. Conglomerate core samples are variably jointed and fractured. Laboratory tests indicate a moderate to high strength rock with low matrix permeability.

The conglomerate along Big Flat Creek typically weathers to a friable sandy clay material with rounded pebbles which has historically been interpreted as a thick alluvial sequence. As discussed in the previous section, more recently the shallow material within the creek bed and across the valley floor has been reclassified as colluvium based on further investigations. The depth of significant weathering varies across the site, with bore logs indicating it is typically 20 m to 25 m below ground level. Figure 4.9 shows the conglomerates overlying the Great Northern coal seam, and the transition from a brown colour which indicates weathering to pale grey indicative of fresh rock. The thickness of the conglomerates in this photo is greater than average, at about 30 m to 40 m. There is also a seepage zone present near the base of the weathered materials. Further to the north-west of the Mangoola Coal Mine the thickness of the conglomerates is over 140 m (Figure 4.10). Figure 4.11 to Figure 4.13 show competent bedrock units exposed at shallow depth at several locations along the Big Flat Creek and tributary creeks.

The seismic survey completed across the lower reaches of Big Flat Creek also interpreted the base of the weathered zone. As discussed in Section 4.2.1 it was unclear whether the exposed conglomerate rock within the creek bed continued at shallow depth across the stream valley as a rock bar, or continued to deepen between the outcrops to the north and south. The survey suggests that the depth to fresh rock deepens to approximately 15 mbgl to 20 mbgl to the north of Big Flat Creek, and there is not a continuous shallow fresh rock bar in the areas surveyed (Figure 4.7). A shallow fresh rock bar could have potentially restricted the movement of impacts into the Wybong Creek alluvium as it would be expected to be a lower permeability than the weathered material and alluvium. The survey does indicate that in the vicinity of Line 3 the width of the deep weathered zone is primarily restricted to south of Wybong Road, and the weathered zone thins to the north as the survey line starts to rise towards the small ridgeline with exposed conglomerate adjacent to the farm buildings shown on Figure 4.7.

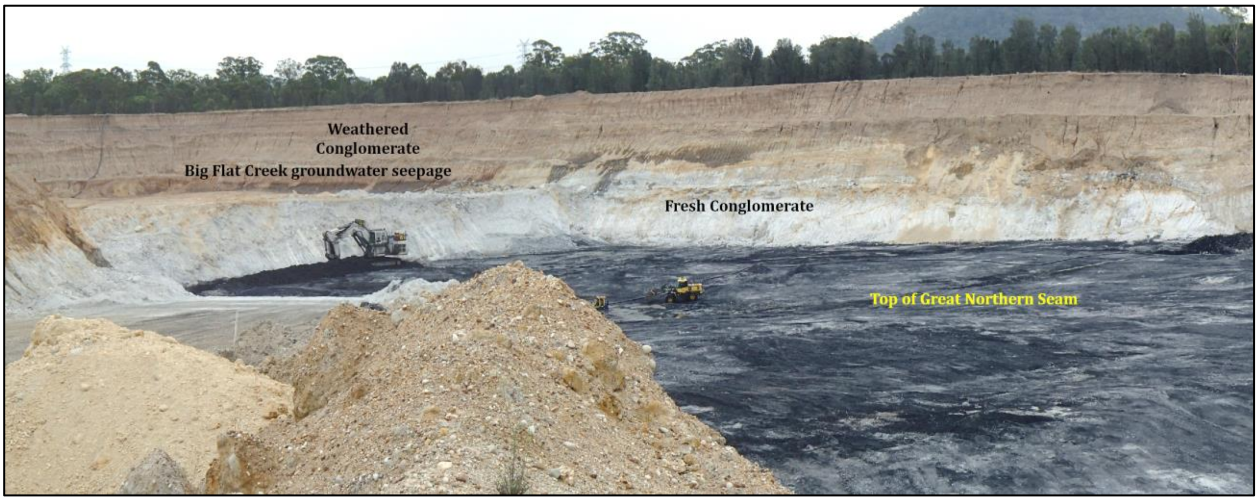


Figure 4.9 Mangoola Coal Mine Main Pit looking towards Big Flat Creek (source: Mangoola Coal, August 2016)

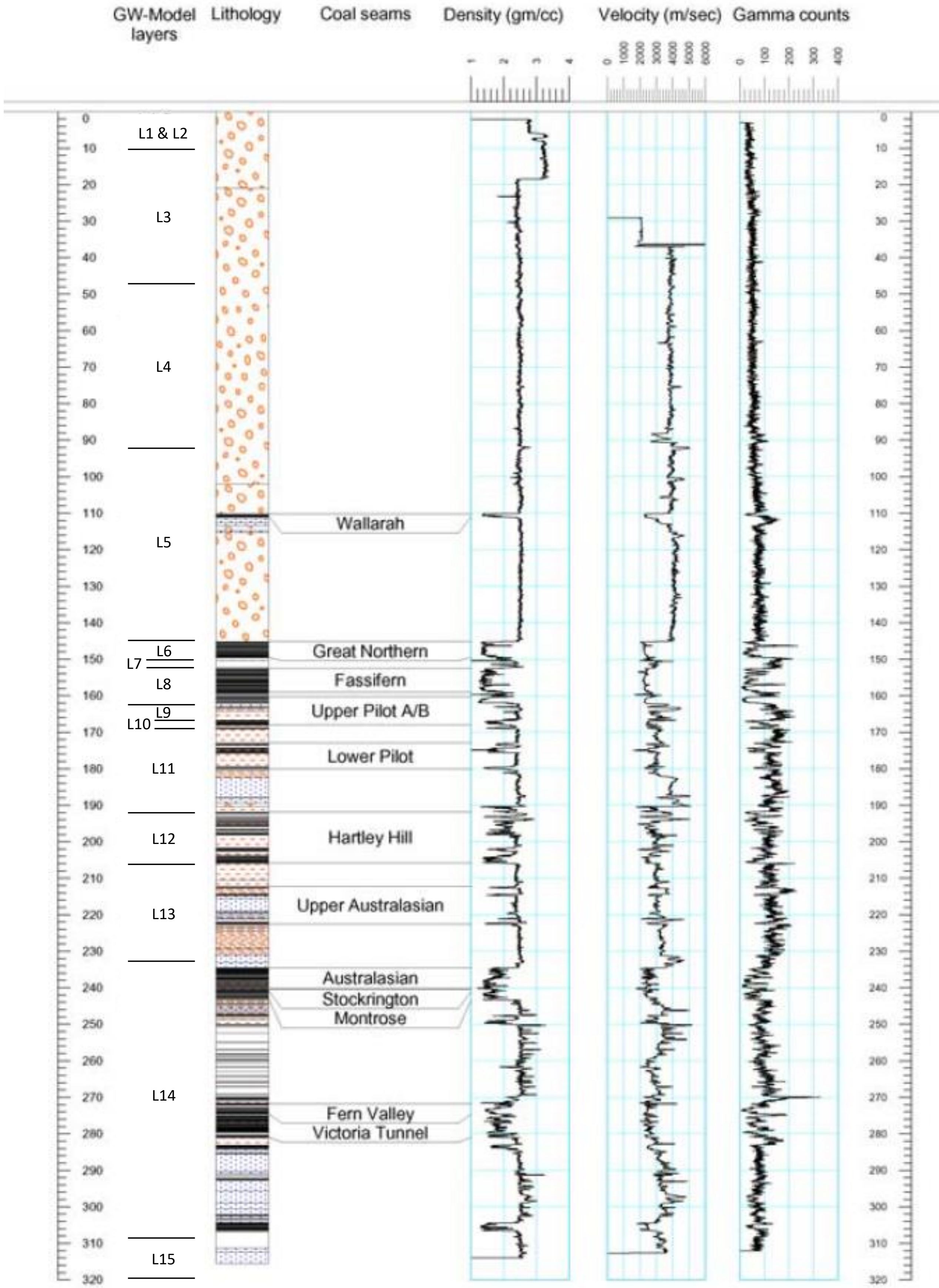


Figure 4.10 Stratigraphic sequence northwest of Mangoola Coal Mine (adapted from MER, 2015)

Figure 4.11 Shallow bedrock exposed in paddock within the MCCO Additional Project area (approx. coordinates 282635, 6428568)

Figure 4.12 Shallow bedrock exposed in Big Flat Creek near Wybong Road (approx. coordinates 283085, 6428088)

Figure 4.13 Shallow bedrock exposed in Big Flat Creek (approx. coordinates 279573, 6426145)

4.2.3 Newcastle coal measures

The late Permian Newcastle coal measures (previously Wollombi coal measures) underlie the Triassic strata. Within the Mangoola Coal Mine and MCCO Proposed Additional Mining Area the target coal seams are as follows (adapted from MER, 2015):

- ***Wallarah seam*** – typically dull with frequent bright bands and less than 2 m thick where present within the MCCO Project Area. Overlain and underlain by relatively impermeable conglomerates of moderate to high strength.
- ***Great Northern seam*** – mostly dull with little cleating, jointing is evident in pit exposures. Approximately 3 m thick across the MCCO Proposed Additional Mining Area but thins in the south of the Mangoola Coal Mine mining area. The Great Northern seam is separated from the underlying Fassifern seam by the relatively impermeable Awaba Tuff as shown in Figure 4.14.

- ***Fassifern seam*** – several plies totalling approximately 6 m coal thickness. The uppermost plies are comprised of high ash dull coal with occasional bright bands and little or no cleating, the middle and lower plies are lower in ash and remain mostly dull. The Fassifern seams are separated from the underlying Pilot seams by a sequence of interbedded carbonaceaous mudstones and tuffaceous claystone-siltstone bands usually about 1 m to 2 m thick.
- ***Upper Pilot seams*** – Upper Pilot A/B seams are high ash, dull coal in the upper sections grading down to a low ash slightly brighter coal, all seams are weakly cleated. The Upper Pilot seams are separated from the Lower Pilot seams by tuffs up to several metres thick.

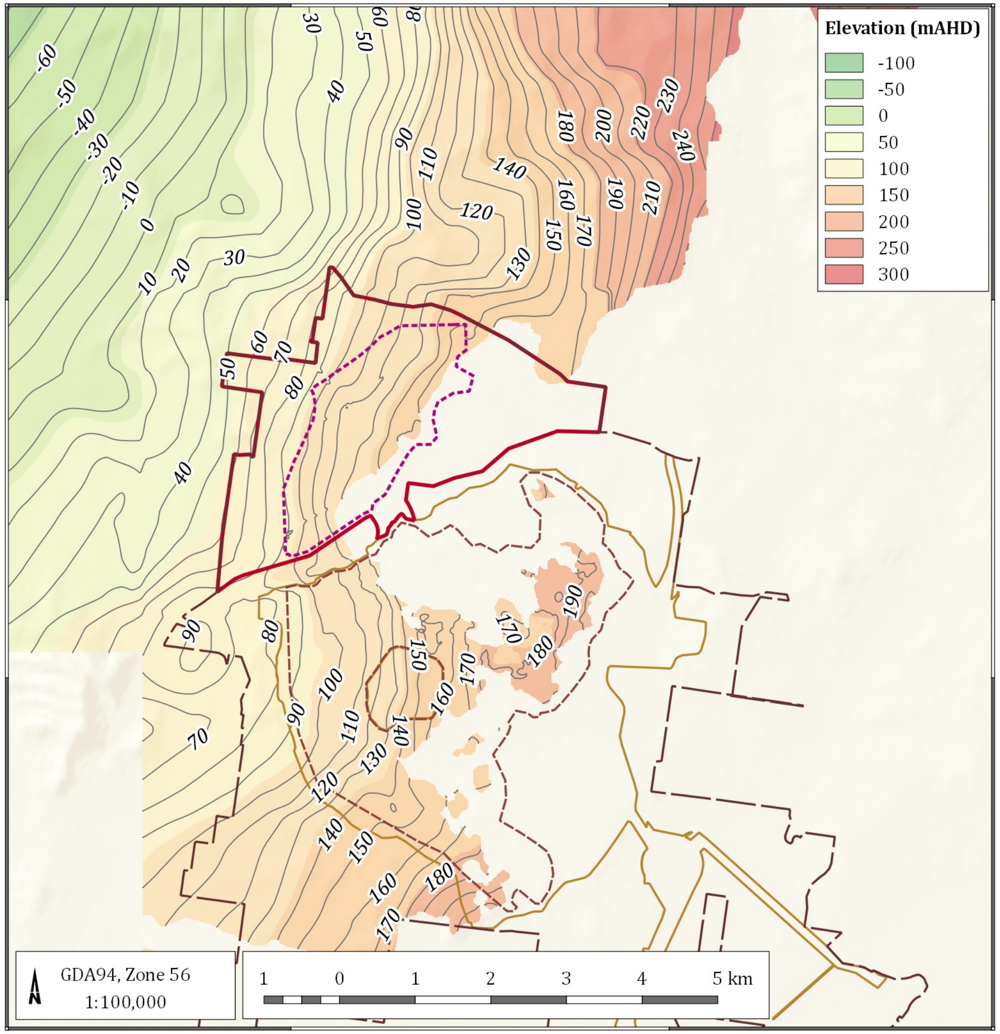
In addition there are several deeper seams which have been identified but are not target seams for the MCCO Project:

- ***Hartley Hill seam group*** – mainly dull coal with numerous bright bands, approximately 12 m thick with numerous tuffaceous layers.
- ***Australasian seam group*** – mainly dull seams with minor bright bands, many seams separated by carbonaceous siltstones and sandstones.
- ***Stockrington, Montrose*** – mostly dull with minor bright bands. Immediately below the lower Australasian seam resulting in about a 10 m total thickness of coal bearing strata.
- ***Wave Hill, Fern Valley, and Victoria Tunnel seams.***

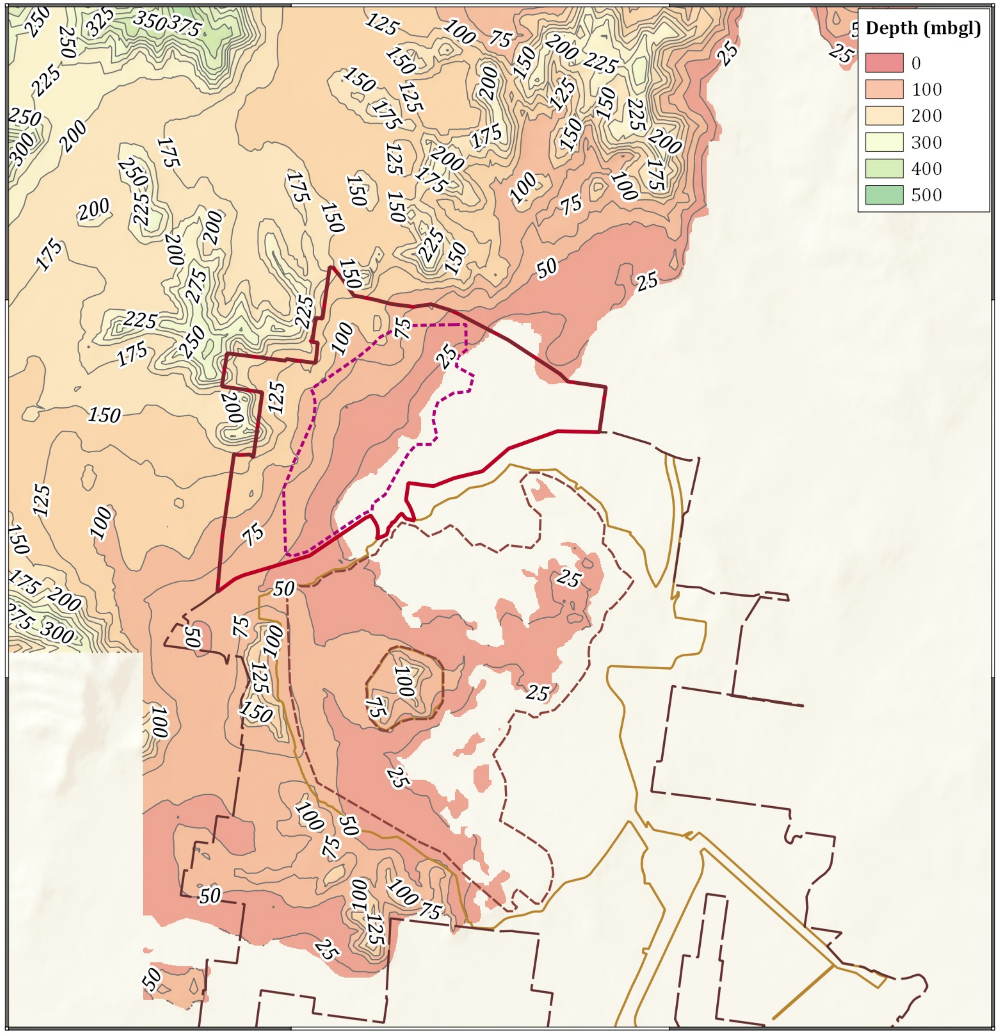
The structure, distribution and depth to the Great Northern seam and Upper Pilot A seam are presented in Figure 4.15 and Figure 4.16 respectively. Both seams subcrop within the MCCO Proposed Additional Mining Area and dip shallowly to the north-west.

Figure 4.14 Permian coal seams and Awaba Tuff exposed in Mangoola Coal Mine

Structure elevation of Great Northern seam



Depth-below-surface contours of Great Northern seam



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Contour line

Mangoola EIS (G1839F)

AGE

Structure and depth contours of the Great Northern seam

DATE
18/01/2019

FIGURE No:
4.15

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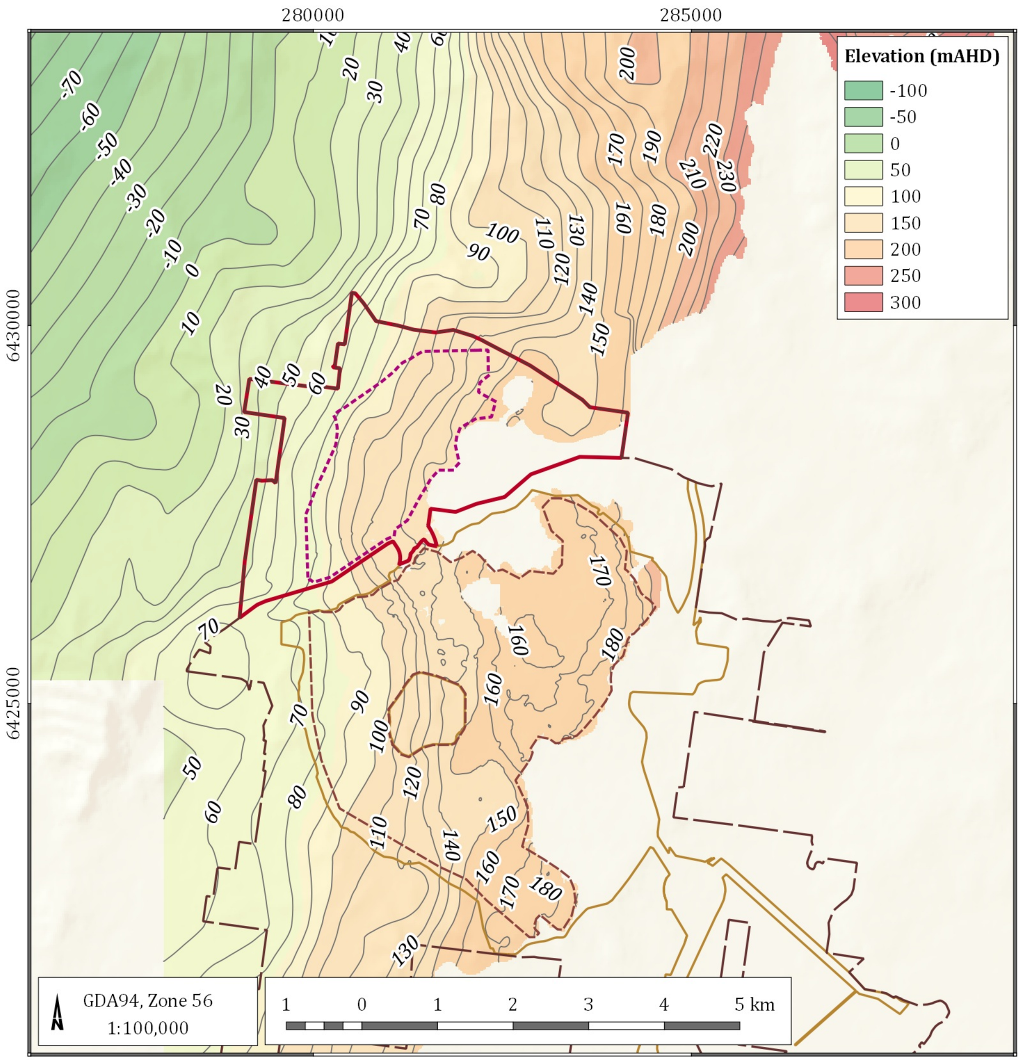
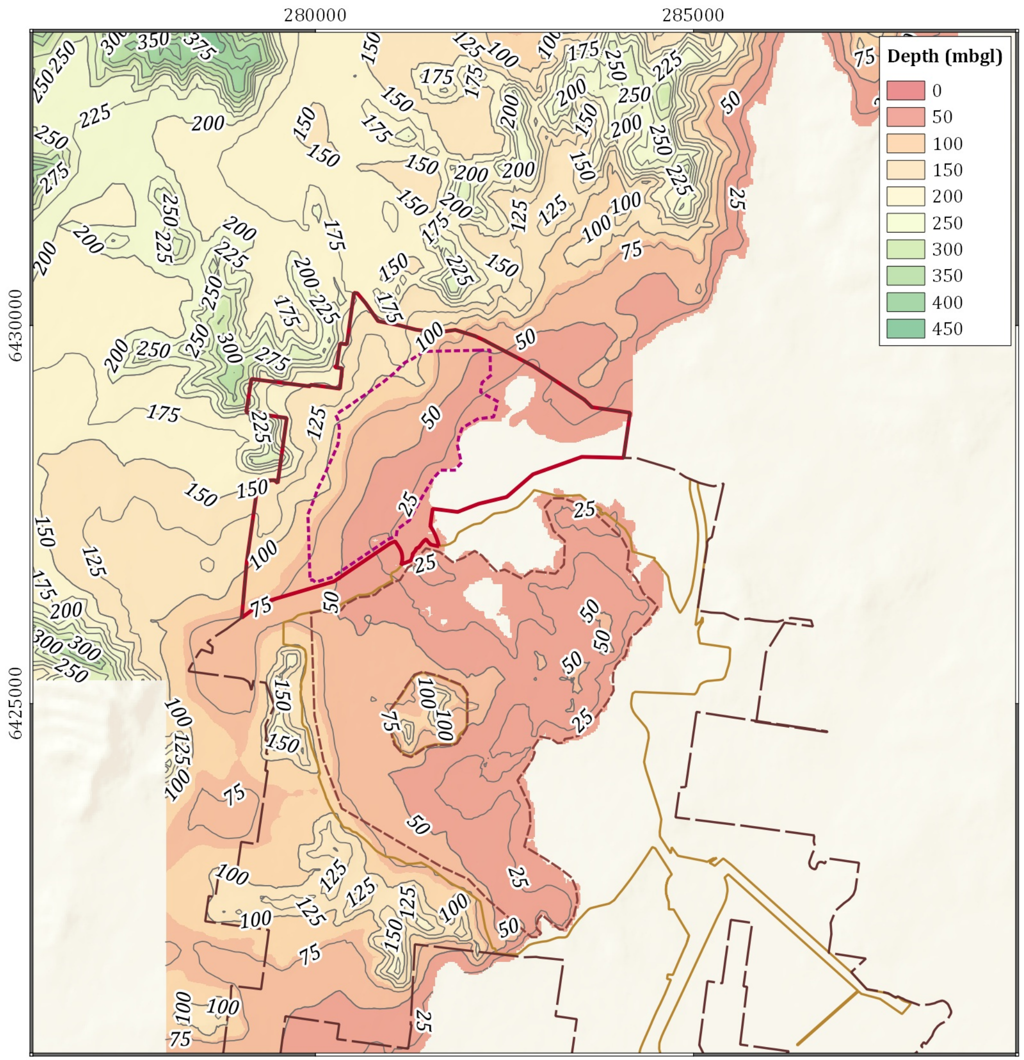
Structure elevation of Upper Pilot seam



Depth-below-surface contours of Upper Pilot seam



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Contour line

Mangoola EIS (G1839F)

Structure and depth contours of the Upper Pilot seam

DATE
18/01/2019

FIGURE No:
4.16

4.3 Geological structure

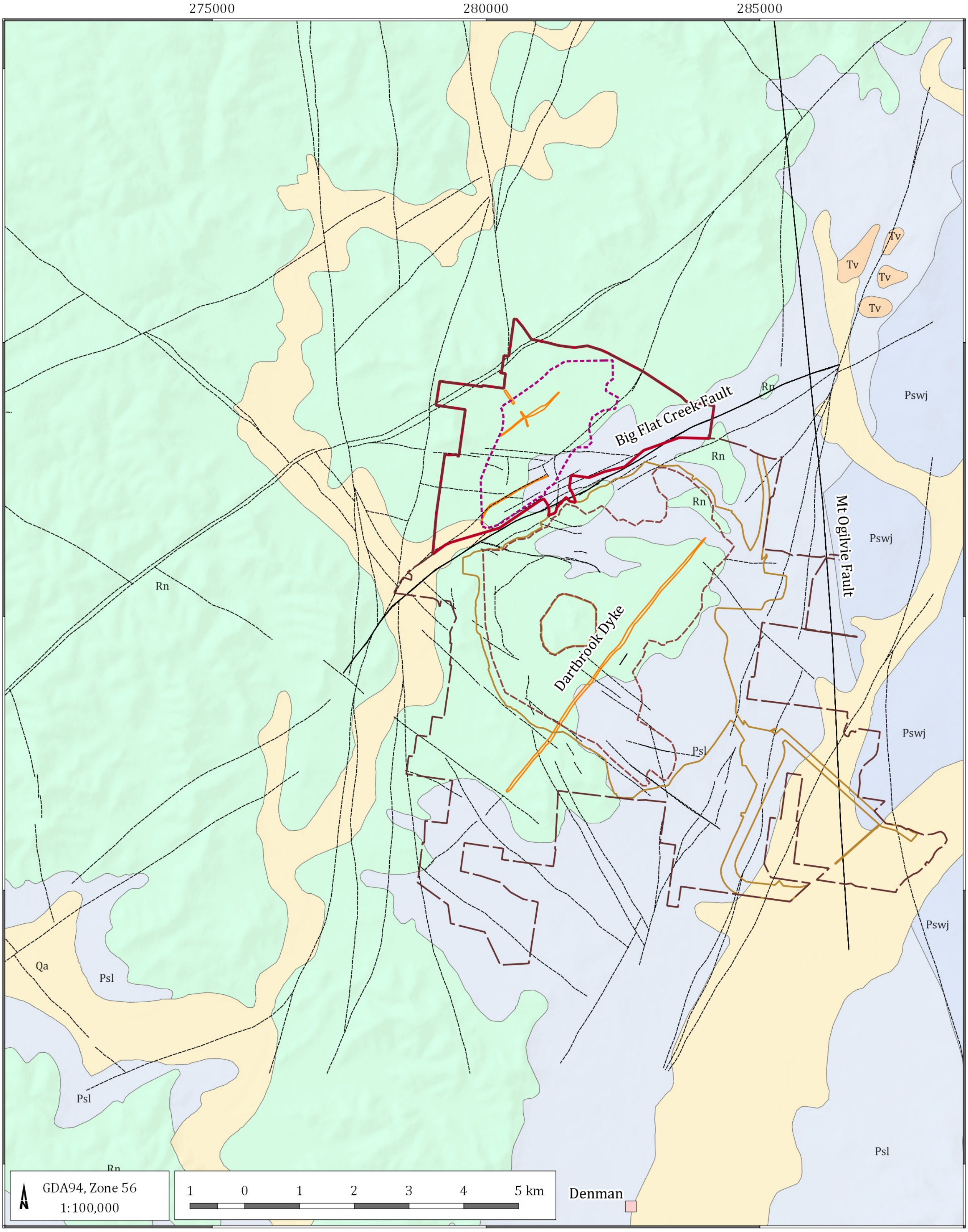
The Permian coal measures are stratified (layered) sequences that have undergone deformation resulting in strata dipping at an approximate 3.5% gradient to the northwest.

The 1:100,000 Hunter Coalfield Geological Map shows no major faults running through the MCCO Proposed Additional Mining Area. The main structural feature identified is the Mt Ogilvie thrust fault (and sub-faults), which is orientated north-south and located approximately 2 km to the east of the MCCO Additional Project Area boundary. The main fault upthrows the Permian Coal Measures strata to the east by approximately 125 m in the vicinity of the Mangoola Coal Mine.

In addition, Mangoola has mapped several additional faults around the MCCO Proposed Additional Mining Area (Figure 4.17). The faults lie in two main orientations; either northeast trending, or northwest trending. It has been suggested (MER, 2006) that these faults may have influenced the locations of both the Big Flat Creek and Wybong Creek by enhancing the depth of weathering along the fault zones. An example of a minor fault intercepted within the pit is shown in Figure 4.18.

There are also a small number of volcanic dykes identified within the Mangoola area. The dykes are oriented along similar alignments as the faults, principally trending northeast. The most extensively mapped dyke is located within the Mangoola Coal mining area (the Dartbrook Dyke) and has a width of 3 m to 6 m. Fracturing of the dyke visible within the Mangoola Coal open cut pit (Figure 4.19) suggests that it is not a barrier to groundwater flow.

Igneous sills and volcanic tuffs are also interbedded within the coal measures.



LEGEND

- Populated place
- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mining Area
- Approved Mangoola Coal Mine Disturbance Area
- Proposed Additional Mining Area

Surface geology

(Hunter Coalfield Regional 1:100k Geology Map)

- Qa - Quaternary Alluvium
- Tv - Tertiary Basalt
- Rn - Hawkesbury Sandstone, Narrabeen G.
- Psl - Wollombi Coal Measures
- Pswj - Denman Fmt, Jerrys Plains Subgroup
- Fault
- Dyke

Mangoola EIS (G1839F)

Structural geology

DATE 02/11/2018

FIGURE No: **4.17**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
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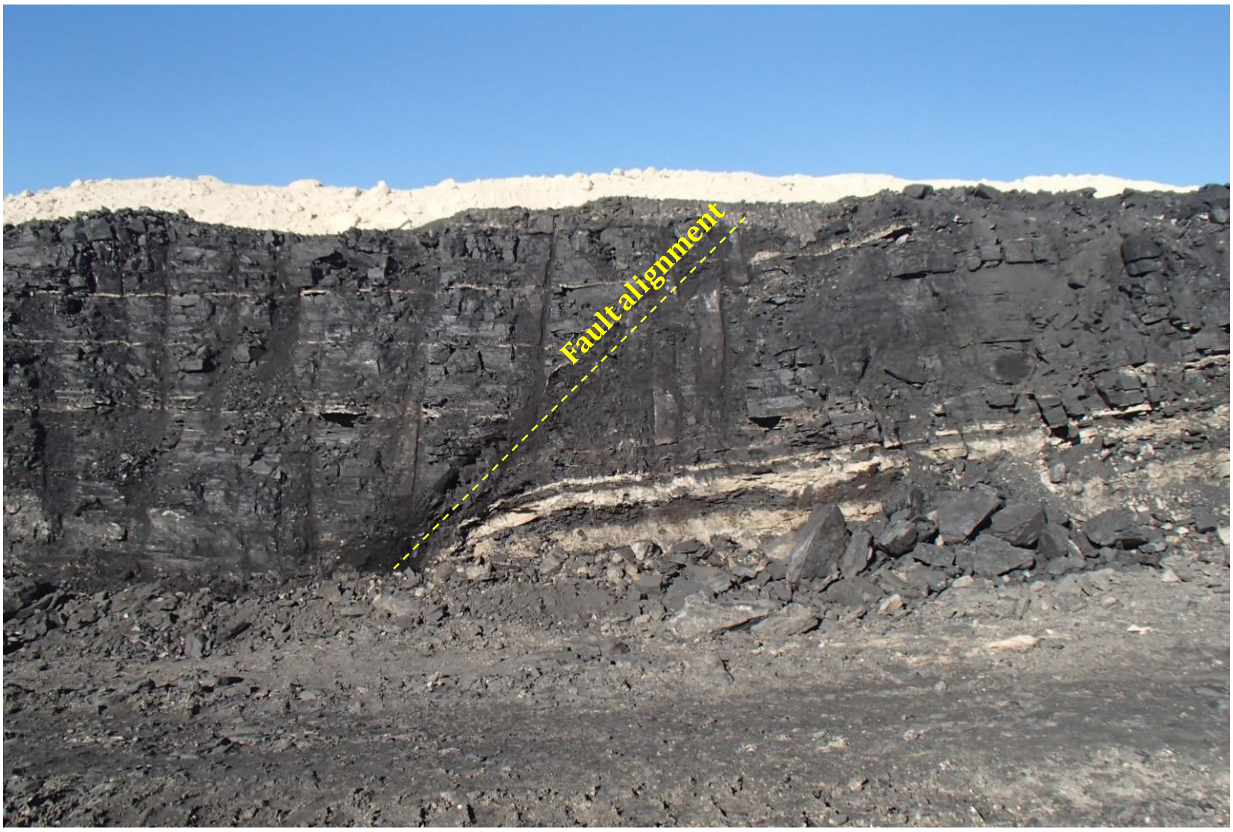


Figure 4.18 Chester's Fault from Main Pit East parallel to the Dartbook Dyke on the Western side (source: Mangoola Coal)

Figure 4.19 Dartbrook Dyke in the Fassifern Seam, Main Pit East (source: Mangoola Coal)

5 Hydrogeology

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

- Quaternary colluvium – occurring as a relatively thin and often unsaturated capping forming a patchy ephemeral aquifer aligned along Big Flat Creek and other tributary drainages;
- Quaternary alluvium – forms a relatively extensive alluvial aquifer system within the flood plains of Wybong Creek and Sandy Creek; and
- Permian and Triassic bedrock sediments that can be divided into:
  - thin, generally dry and variably permeable weathered rock (regolith);
  - highly weathered water bearing rock along Big Flat Creek;
  - non coal interburden such as conglomerates and sandstones that forms aquitards; and
  - low to moderately permeable coal seams that act as the most transmissive strata within the coal measures sequence.

The sections below describe the hydrogeological properties of each hydrostratigraphic units.

5.1 Colluvial and alluvial groundwater systems

5.1.1 Colluvial groundwater

A thin layer of colluvial sediment occurs adjacent to Big Flat Creek and overlies weathered Triassic and Permian bedrock. Away from the creek the colluvium thins and transitions to regolith overlying highly weathered bedrock. The regolith typically lies above the groundwater table and any water present will occur after notable rainfall events rather than an interception of the regional groundwater table.

The Big Flat Creek colluvium has been mapped as up to 3.5 m thick in shallow exploratory bores, but is potentially thicker in areas immediately surrounding the main Big Flat Creek drainage line. The materials forming the colluvium range from sand and gravel sized particles to silts and clays. Areas or lenses that are more clay rich will restrict the passage of water through the colluvial material.

There are a number of shallow monitoring bores in the weathered zone underlying the colluvium that intersect permanent groundwater. It would appear that prior to mining the colluvium close to the creek is likely to have been intersected by the local groundwater table and been partially saturated, especially during wetter periods. Water level monitoring within shallow bores adjacent to the mine have fallen over time as the Mangoola Coal Mine has progressed, and the colluvium is likely to have drained in some areas. It is unlikely the colluvium will re-saturate whilst the mine remains active.

Water quality monitoring along Big Flat Creek indicates that it becomes highly saline when it receives groundwater as baseflow. As this water needs to pass through the colluvium to enter the stream it is therefore likely that the colluvium will also contain saline water if it is saturated. This suggests that any vegetation along Big Flat Creek will be primarily supported by soil moisture and seepage of surface water rather than underlying groundwater.

The hydraulic connection between the colluvium, Big Flat Creek and the underlying Permian materials is discussed in Section 5.2.

5.1.2 Alluvial groundwater

There are no highly productive alluvial groundwater units mapped within the MCCO Proposed Additional Mining Area. The closest highly productive alluvium is associated with Wybong Creek and located approximately 1 km to the west of the MCCO Proposed Additional Mining Area.

The Wybong Creek alluvium has historically been utilised as a water source. Many of the private bores within the alluvium close to the Mangoola Coal Mine were installed in the 1970's and have now been abandoned, converted from their original use, or become inactive. A monitoring bore (GW080434) was also installed by the NSW government within the alluvium in 2003. The bore is located 300 m from the currently flowing channel and is equipped with a logger which records daily water levels as shown in Figure 5.1. With the exception of a period during 2005 and 2006, towards the end of the Millenium Drought, water levels in the bore show a high degree of variability on a short timescale that correlates strongly with changes in level measured in the Wybong Creek. This indicates that the alluvial material is highly permeable and directly connected to the creek. There are no other detailed time series records for the water levels in the Wybong Creek alluvium close to the MCCO Project area.

There are measurements of groundwater level following construction in registered bores close to the MCCO Project Area. The water level in these bores were noted as being between about 12 mbgl and 14 mbgl when completed. The records are mainly from the 1970's, but more recent water level measurements from GW080434 indicate similar water levels. The water level in GW080434 was measured at 14.1 mbgl (129.3 mAHD) in late November 2017.

The Wybong Creek is highly incised into the alluvium. A comparison of the alluvial groundwater levels with the level of the creek bed from a LIDAR survey indicates that groundwater levels are at a similar elevation to the surface water in the creek. This indicates the creek intersects the regional water table and alluvial groundwater potentially contributes to the creek baseflow. Figure 5.2 shows Wybong Creek at the Wybong Creek Bridge on Wybong Road west of the MCCO Project.

Historical records from testing of water bores within the alluvium in both Wybong Creek and Sandy Creek alluvium indicate bore yields range from relatively low (~0.1 L/s) to high (~25 L/s). Figure 5.3 shows the locations of bores where yield and salinity were measured following installation of the bore. Whilst there are no estimates of hydraulic conductivity or aquifer storage within the alluvium the variability of the yields in the water bores suggests the permeability and thickness of the alluvium varies across the floodplain.

Salinity measurements where available are generally within the 'fresh' to 'brackish' salinity ranges (TDS <1,500 mg/L) or 'moderate' salinity of between 1,500 mg/L to 7,000 mg/L.

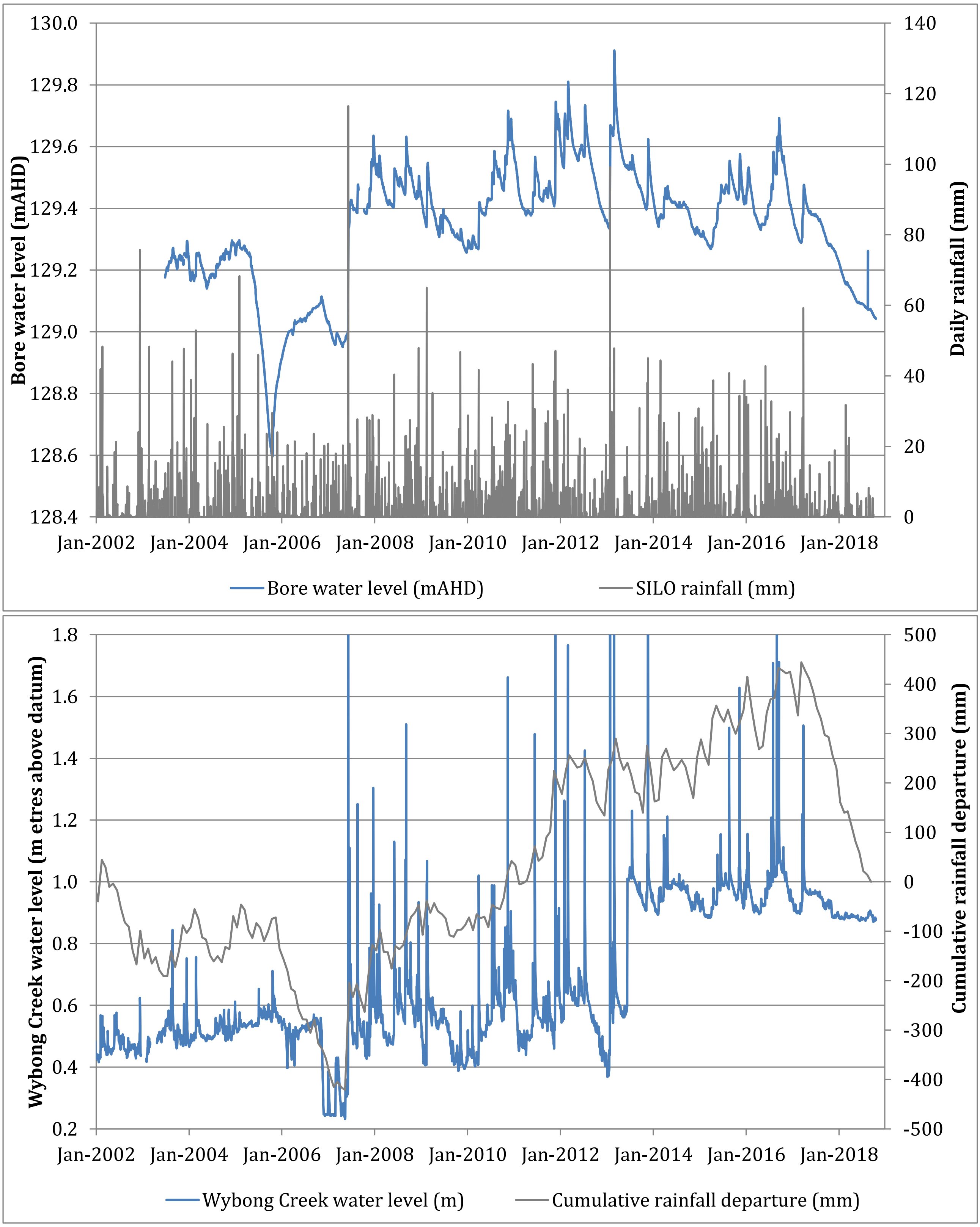
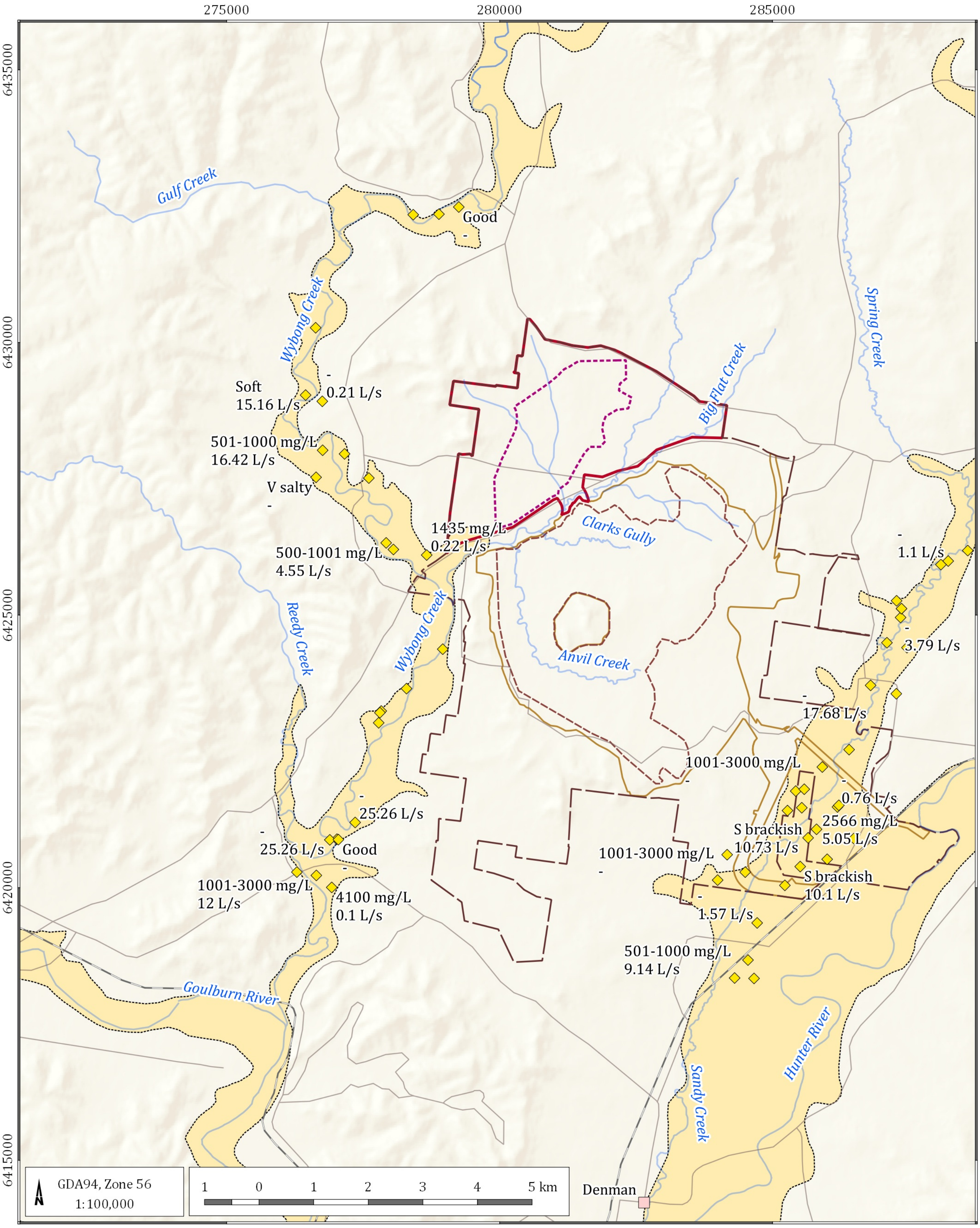


Figure 5.1 Water level hydrograph - bore GW080434

Figure 5.2 Wybong Creek highly incised into alluvium at Wybong Road bridge



LEGEND

- G1839F_Populated_place
- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mining Area
- Approved Mangoola Coal Mine Disturbance Area
- Proposed Additional Mining Area
- Alluvium
- Road
- Rail
- Drainage

- Registered bores reviewed
  :Salinity (mg/l)
  :Yield (L/s)

Mangoola EIS (G1839F)

Quaternary alluvium salinity and bore yields

AGE

DATE 26/02/2019

FIGURE No: **5.3**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
G:\Projects\G1839F.Mangoola EIS\3_GIS\Workspaces\011_GIA\05.03_G1839F_Quaternary alluvium salinity and bore yields.qgs

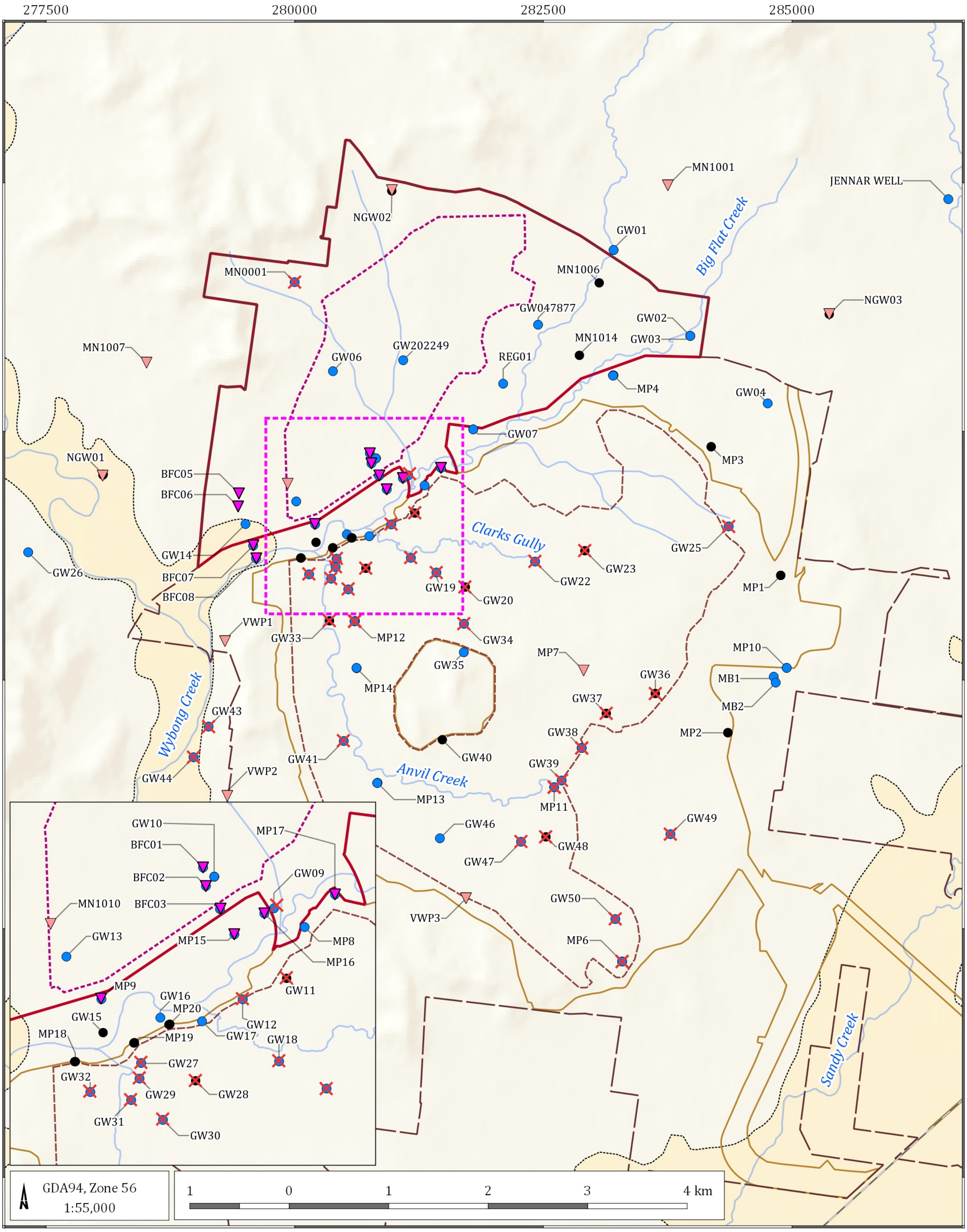
5.2 Permian and Triassic groundwater systems

5.2.1 Monitoring network

Mangoola monitors groundwater levels within the bedrock strata using a combination of open PVC cased monitoring bores and vibrating wire piezometer pressure sensors (VWPs). There are approximately 122 active monitoring bores and VWPs in the current groundwater monitoring program. A total of 37 monitoring sites have been abandoned or destroyed since the start of the program[6], primarily due to the progression of mining or access restrictions placed by private landholders. The number of sites being monitored each month changes in response to expansion of the mining footprint and weather conditions which can affect access routes to monitoring bore sites. Construction details of all monitoring sites are contained within Appendix C. Figure 5.4 shows the locations of the monitoring bores and VWPs within the site monitoring network. There are several combinations of monitoring installations at Mangoola Coal Mine including:

- single open PVC bores;
- pairs or triplets of open PVC bores completed in separate boreholes at different depths;
- pairs comprising a shallow open PVC bore with a single deeper VWP sensor read manually;
- single VWP sensor read manually;
- multiple VWP sensor array with high frequency data loggers; and
- multiple VWP sensor array with high frequency data loggers, combined with a shallow open PVC bore.

[6] as of February 2019.



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Alluvium
- Drainage

Monitoring locations

- Monitoring bore
- Monitoring bore with logger
- VWP single site
- VWP multi site
- Destroyed or no longer monitored

Mangoola EIS (G1839F)

Mangoola Coal monitoring bore locations

AGE

DATE 26/02/2019

FIGURE No: **5.4**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
G:\Projects\G1839F.Mangoola EIS\3_GIS\Workspaces\011_GIA\05.04_G1839F_Mangoola Coal monitoring bore locations.qgs

5.2.2 Water levels and fluctuations

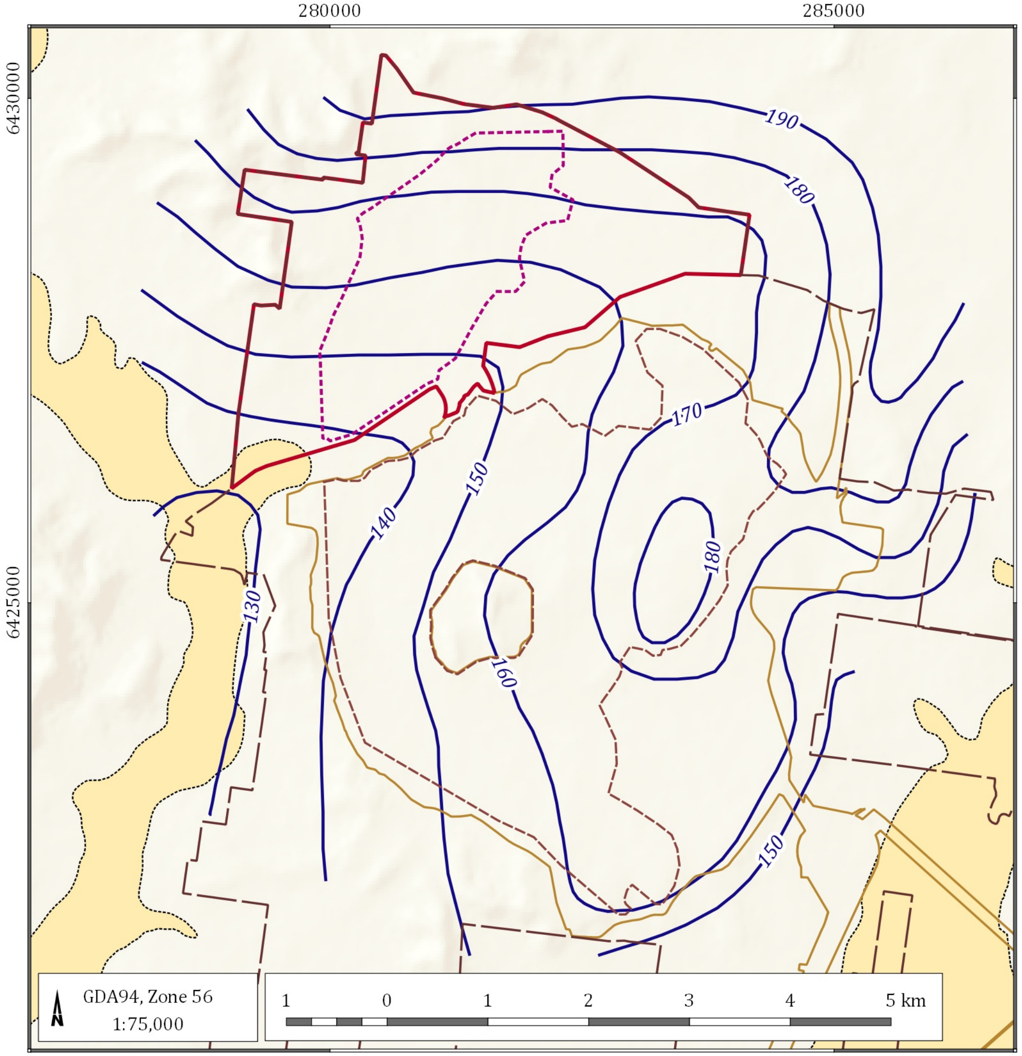
Groundwater level trends measured within the monitoring network are described in the sections below. The discussions are grouped into three key topics – shallow water levels that allow water table contouring, VWP strings showing vertical trends, and water level changes observed adjacent to Big Flat Creek.

5.2.2.1 Shallow groundwater levels

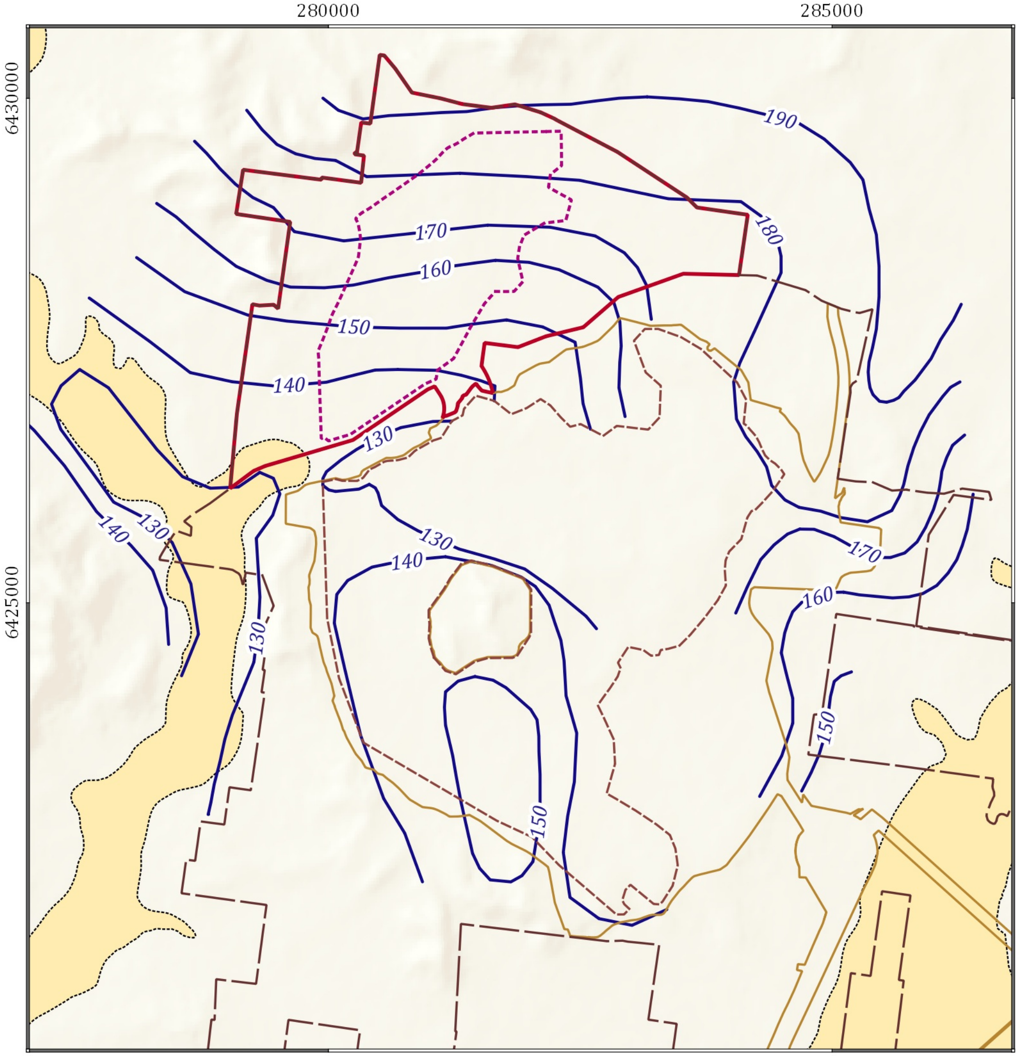
Mining at the Mangoola Coal Mine is open cut and was above the regional water table between 2010 and 2014. There are no high yielding groundwater supply bores in the area, and consequently there were minimal anthropogenic influences on nearby groundwater levels. However, baseline groundwater levels in several monitoring bores at the site did show a slow decline in water level. This was attributed by MER (2013) to slow vertical leakage through unsealed exploration bores. Over time the mine has followed the coal seams down dip, and during 2014 was deep enough to intercept the regional groundwater table. Depressurisation of the nearby groundwater units as groundwater enters the mining void has been occurring since that time, as predicted in the groundwater assessment completed as part of the Anvil Hill Project (now known as the Mangoola Coal Mine) EIS (MER, 2006).

Interpolated groundwater levels in shallow monitoring bores installed across the MCCO Project Area prior to mining (2006) and during active mining of the approved Mangoola Coal Mine (September 2017) are shown on Figure 5.5. The MCCO Additional Project Area is shown on the figure for context only. The figure indicates groundwater levels have reduced close to the Mangoola Coal Mine along Big Flat Creek but there has been little change elsewhere. Whilst the response of shallow groundwater levels to mining is relatively localised the water pressures measured within the deeper coal measures have recorded a greater response, which is described in the section below.

Pre mining - 2006 (after MER)



Recent mining (Sept 2017)



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Alluvium
- Interpolated shallow water level contour (mAHD)

Note: MCCO Additional Project Area shown for context only

Mangoola EIS (G1839F)

AGE

Interpolated shallow water level contours - pre mining and 2017

DATE
18/01/2019

FIGURE No:
5.5

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

Arrays of bores and VWPs are present at a number of locations around the current Mangoola Coal Mine and MCCO Proposed Additional Mining Area and provide information on groundwater pressures within the deeper Triassic and Permian strata. Locations of the sites are shown on Figure 5.4. The figure labels each site but not each individual sensor.

Three VWP sites (VW1, VW2, VW3) were installed between the Mangoola Coal Mine and Wybong Creek in 2012, each comprising an array of five sensors within each borehole. These sensors provide useful information on the magnitude of depressurisation and extent of drawdown. The water pressures recorded at each site are plotted over time in Figure 5.6 to Figure 5.8.

The VW1 and VW2 arrays are located to the west of the Mangoola Coal Mine and were approximately 1.5 km and 2.5 km from the active mining face in late 2017. The sites have historically recorded a higher potentiometric surface elevation in the deeper sensors than recorded by the shallower sensors indicative of confined conditions within the coal measures. The monitoring data shows declining pressures in the individual sensors since 2015. The greatest pressure change is observed within the Upper Pilot A seam in VW1, where pressures have fallen by 37 m since late 2015. As this is one of the target seams in the Mangoola Coal Mine this is not unexpected, and notable mining related drawdown was predicted to occur by MER (2006, 2013). Falling trends have been observed in three of the other sensors, all starting at the same approximate time in late 2015. Whilst rainfall has been low over this period the timing and magnitude of the pressure reduction indicates it is due to depressurisation resulting from mining.

The sensor installed across the Great Northern seam at the VW1 site has recorded a response that is commonly observed when pumps have active and inactive cycles, resulting in a ‘sawtooth’ shaped cycle of drawdown and recovery. The drawdown is relatively rapid with the recovery in groundwater pressures occurring slowly over a period of months. The source of the observed response is unknown but unlikely to be mining related. The sudden fall and long recovery time suggest a very low permeability material around this sensor.

The Upper Pilot A seam within VW2 also shows a stepped drawdown response during 2016 that could be related to an increasing mining influence. The other sensors within the bore also show a gradual fall in water level over the same period. The gradual change suggests that although there is a hydraulic connection it is not high enough to generate an instantaneous response. It is likely that the sensors are showing a subdued response to the pressure changes occurring at the depth of the Upper Pilot seam.

A more stable trend in groundwater pressures has been recorded from the array of VWP sensors installed within VW3. The VW3 site was located approximately 750 m west of the southern Mangoola Coal Mining Area in late 2017, and is located at a higher elevation than the other VW sites. At VW3 the vertical pressures indicate a downwards hydraulic gradient through the geological layers. This has not changed in response to mining activities. A sawtooth pumping trend is also evident within the Lower Pilot seam during 2012 and 2013 but ceased after that time.

VWP sensor pressure readings cannot be checked for accuracy once installed and it is possible that the sensors have become less accurate over time.

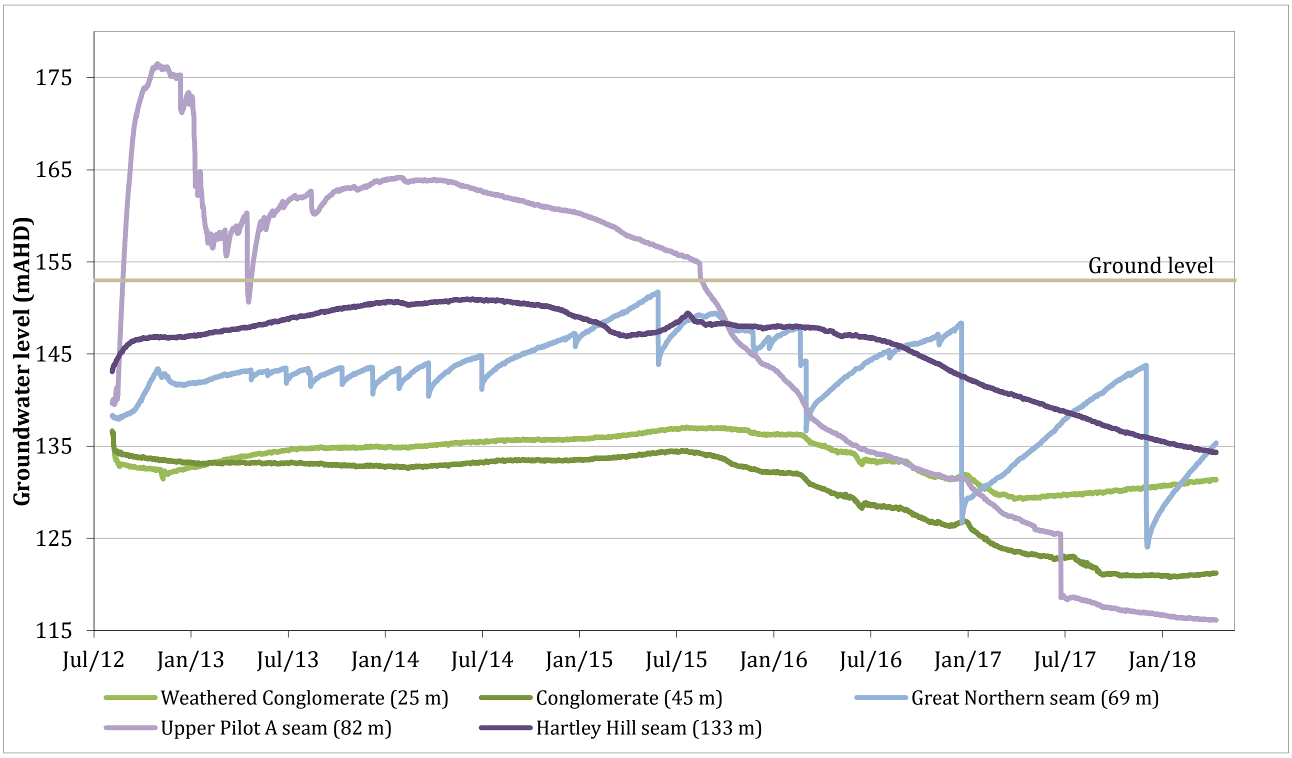


Figure 5.6 Hydrographs – VW1 VWPs

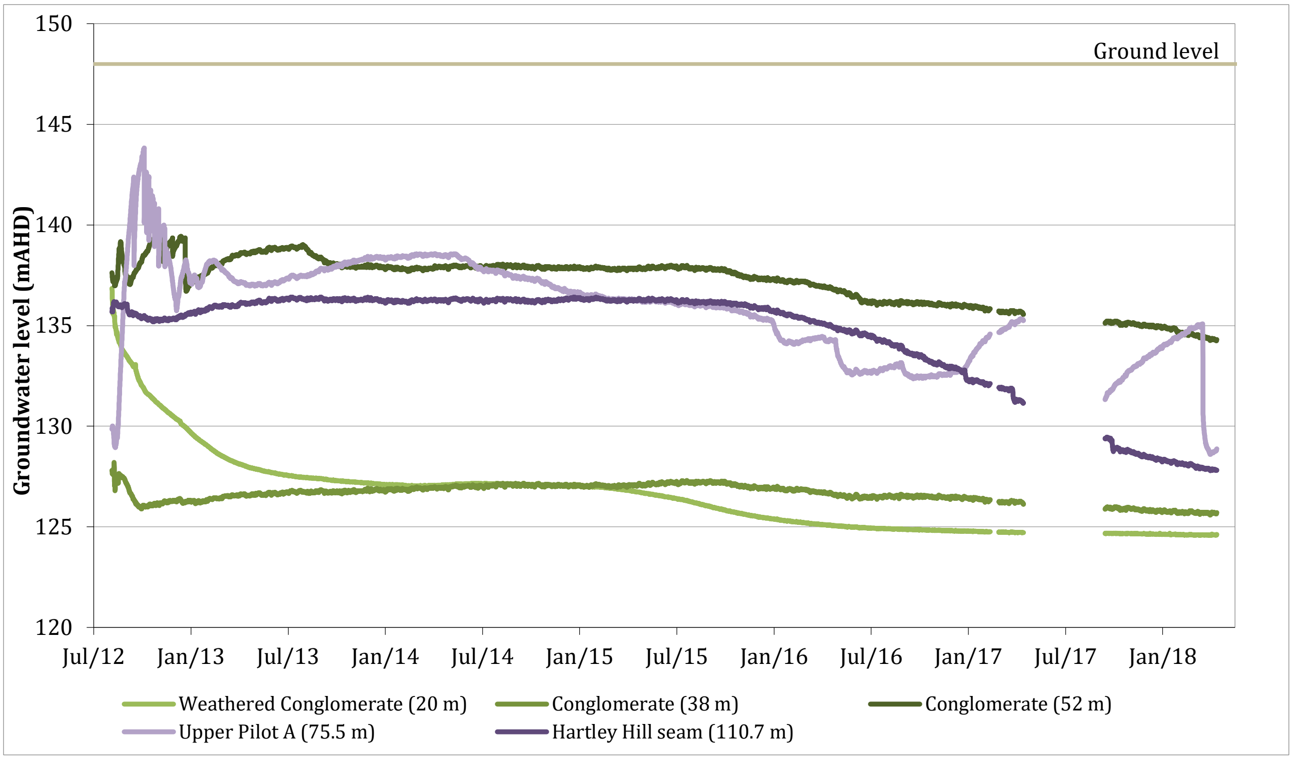


Figure 5.7 Hydrographs – VW2 VWPs

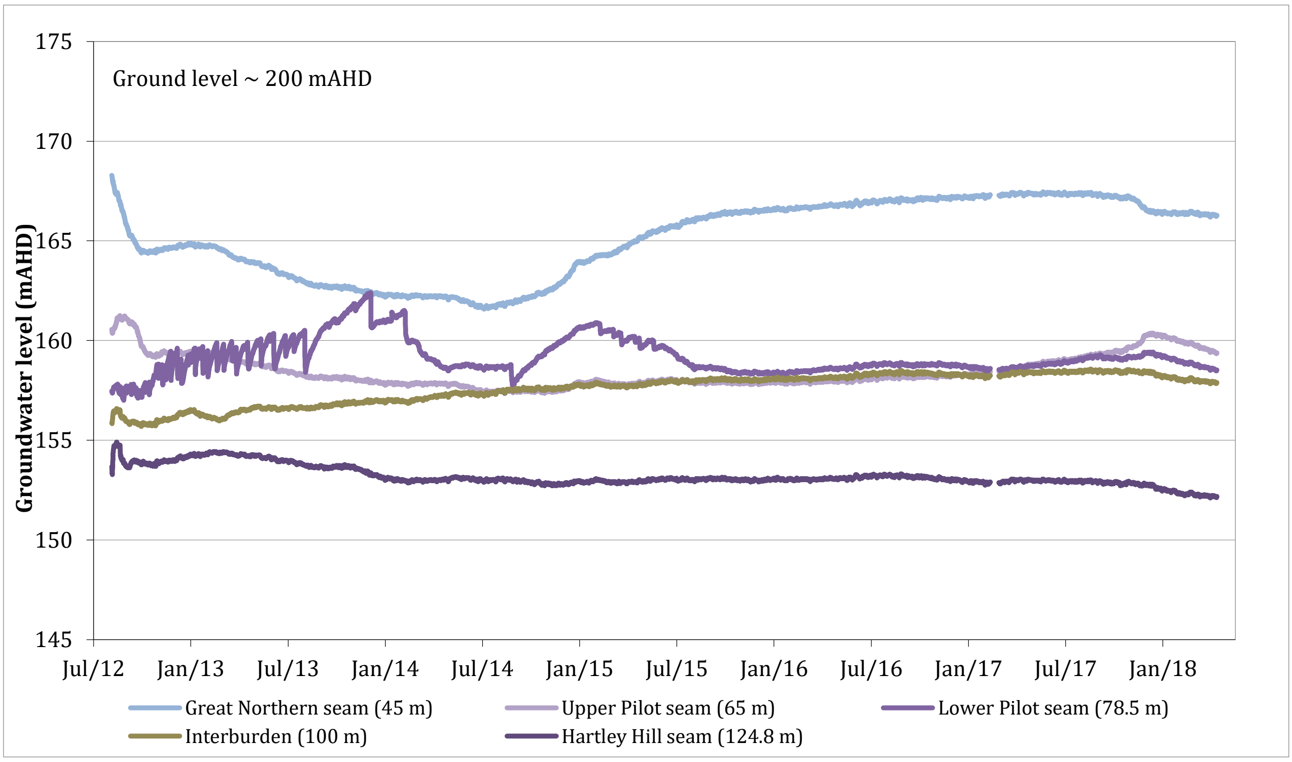


Figure 5.8 Hydrographs – VW3 VWPs

Additional VWP arrays (MN1001, MN1007, MN1010, NGW01, NGW02, NGW03) were installed around the MCCO Proposed Additional Mining Area in 2015. Figure 5.9 and Figure 5.10 show water levels in selected VWP arrays at different locations around the MCCO Project.

Site MN1007 is located to the west of the MCCO Additional Project Area and has five sensors. At the end of 2017 the site was approximately 2.7 km northwest of the active mining at Mangoola Coal Mine. There is no consistent vertical gradient at the site, although the overburden sensors have a higher head than those in the Great Northern and Australasian seams which would indicate an overall downward gradient in approximately the upper 180 m. There is then a significantly higher head in the deepest sensor which is installed within the Fern Valley seam (245 m), suggesting that a confined artesian system exists at depth. Water pressures in both the Great Northern seam and Australasian seam sensors have been falling slowly since late 2015 (approx. 10 m to 15 m fall). In contrast the overburden sensors have shown stable water levels over the same period, indicating that although there is apparent depressurisation in the coal seams there is a low vertical transmission to the shallower layers. The Great Northern Seam is being targeted in the approved Mangoola Coal Mine and the depressurisation is potentially a response to approved mining.

Monitoring within the VWPs indicate relatively stable groundwater levels to the north-east of the MCCO Proposed Additional Mining Area. At NGW03, 2 km to the east of the Mangoola Coal Mine, all five monitoring points show little variation in level since installation. There is a vertically downwards gradient, with the shallower sites recording notably higher water levels than the deeper sensors. Sensor arrays at MN1001, 2.3 km to the northeast of Mangoola Coal Mine, and NGW02, close to the northern boundary of the MCCO Additional Project Area, show similar stable trends and vertically downwards hydraulic gradients.

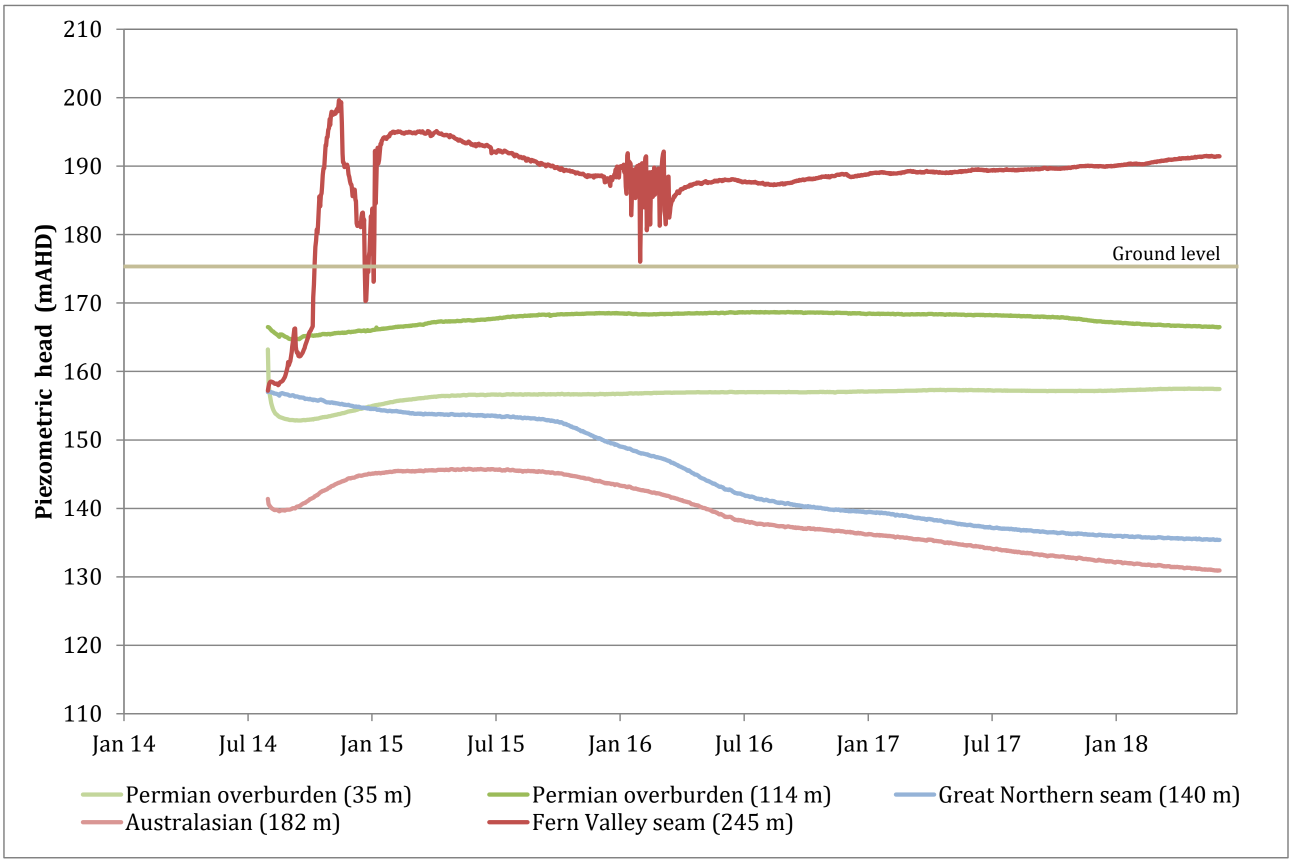


Figure 5.9 Hydrographs – MN1007 VWPs

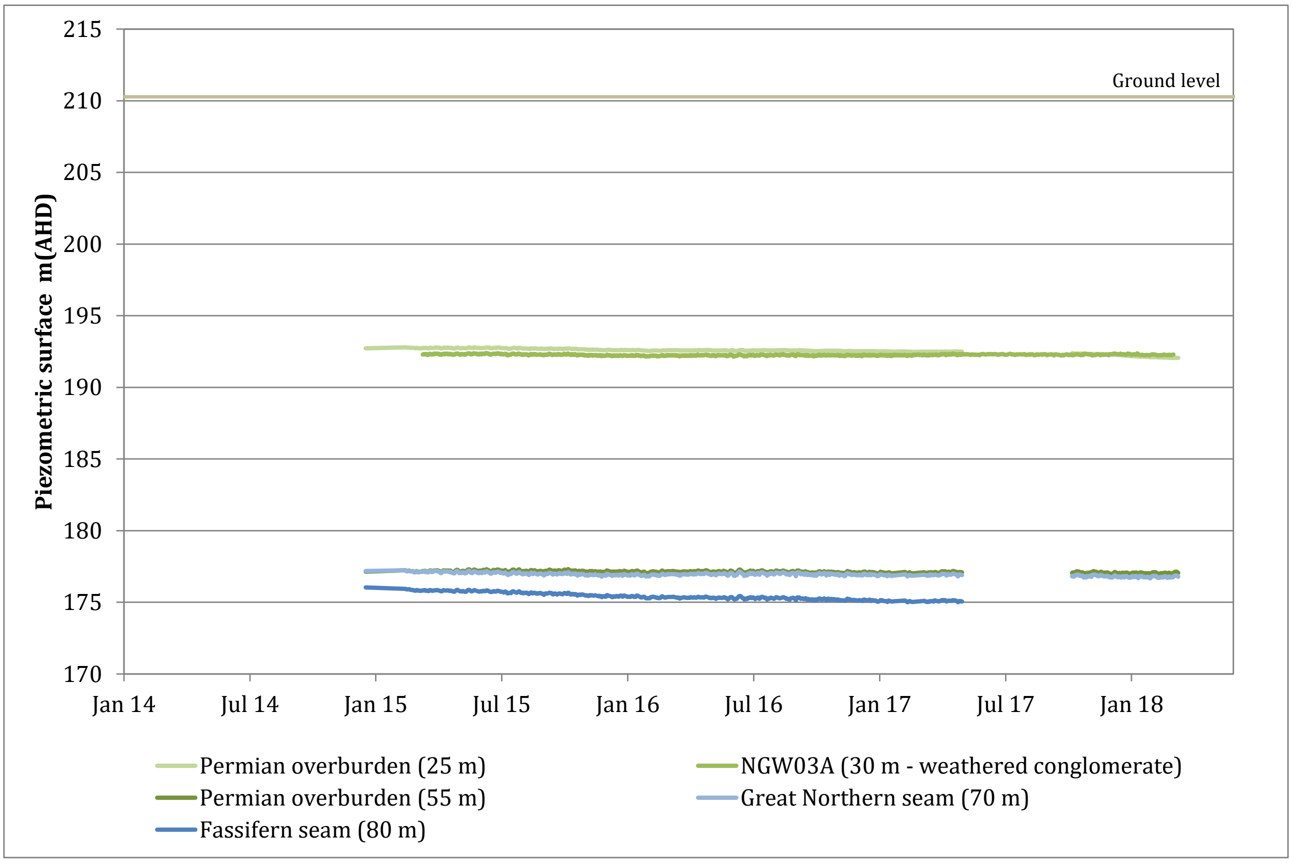


Figure 5.10 Hydrographs – NGW03 VWPs and open standpipe

5.2.2.3 Big Flat Creek monitoring

There are a large number of monitoring bores completed at different depths within the weathered and fresh rock strata along Big Flat Creek. The bore hydrographs provide information on changes in the groundwater system as mining has progressed. The water levels also provide information on the historical and current interactions between Big Flat Creek and underlying groundwater resources.

Groundwater level information for bores along lines crossing Big Flat Creek were compiled to examine the groundwater and surface water interactions indicated by the monitoring datasets. The locations of each cross section line across Big Flat Creek is shown on Figure 3.2. Figure 5.11 to Figure 5.15 show the recorded groundwater levels since the start of mining along each cross section compared with the ground surface, creek bed and bore casing depth.

The figures show that the highest recorded groundwater levels in the shallower bores along Big Flat Creek were close to or above the level of the base of Big Flat Creek at most locations plotted. This indicates that under pre-mining conditions groundwater would have discharged into the creek in wet years. As mining has progressed groundwater levels in the shallow bores have fallen, and groundwater levels now appear consistently below the bed of Big Flat Creek. This means there is currently no groundwater flowing into the creek. Given the brackish to saline nature of the groundwater within the bedrock, this has the potential to reduce the salt load within the creek. Some shallow interflow from within the soil profile that is not connected to the regional water table may still be moving to the creek, although the lack of perennial flow indicates it is not significant.

At paired shallow and deep sites, the early data groundwater heads in the deeper bores were noticeably higher than those recorded in the shallower site over the same period. This indicates confined conditions and an upwards hydraulic gradient. Between 2014 and present day, groundwater levels have been falling as mining has progressed. Groundwater levels in the deeper bores are most significantly affected, but shallower bores have also reduced in level by several metres. The pre-mining upwards hydraulic gradient has either significantly reduced or has reversed to a downwards gradient. The artesian conditions observed at some of the sites are now lower than ground surface in a large number of the deeper bores. The water levels have fallen below the base of the PVC casing in several of the bores meaning they can no longer be monitored.

Depressurisation of the geological strata close to the Mangoola Coal Mine was predicted in previous groundwater models completed for mine (MER, 2006 and MER, 2013). The observed patterns of drawdowns in the Mangoola monitoring network are generally in accordance with these predictions. An exact match would not be expected due to the heterogeneous nature of the subsurface compared to the simulated geological units within the groundwater models.

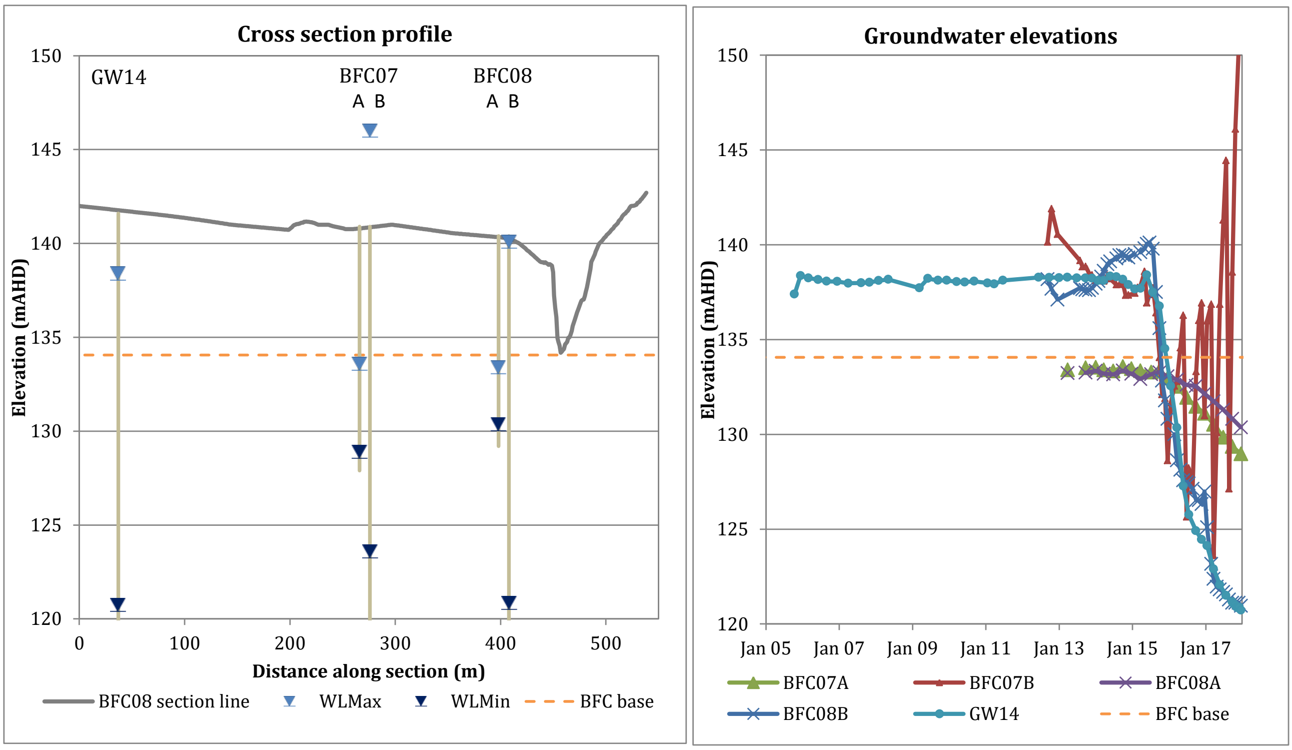


Figure 5.11 Big Flat Creek cross-section 2 – through BFC08

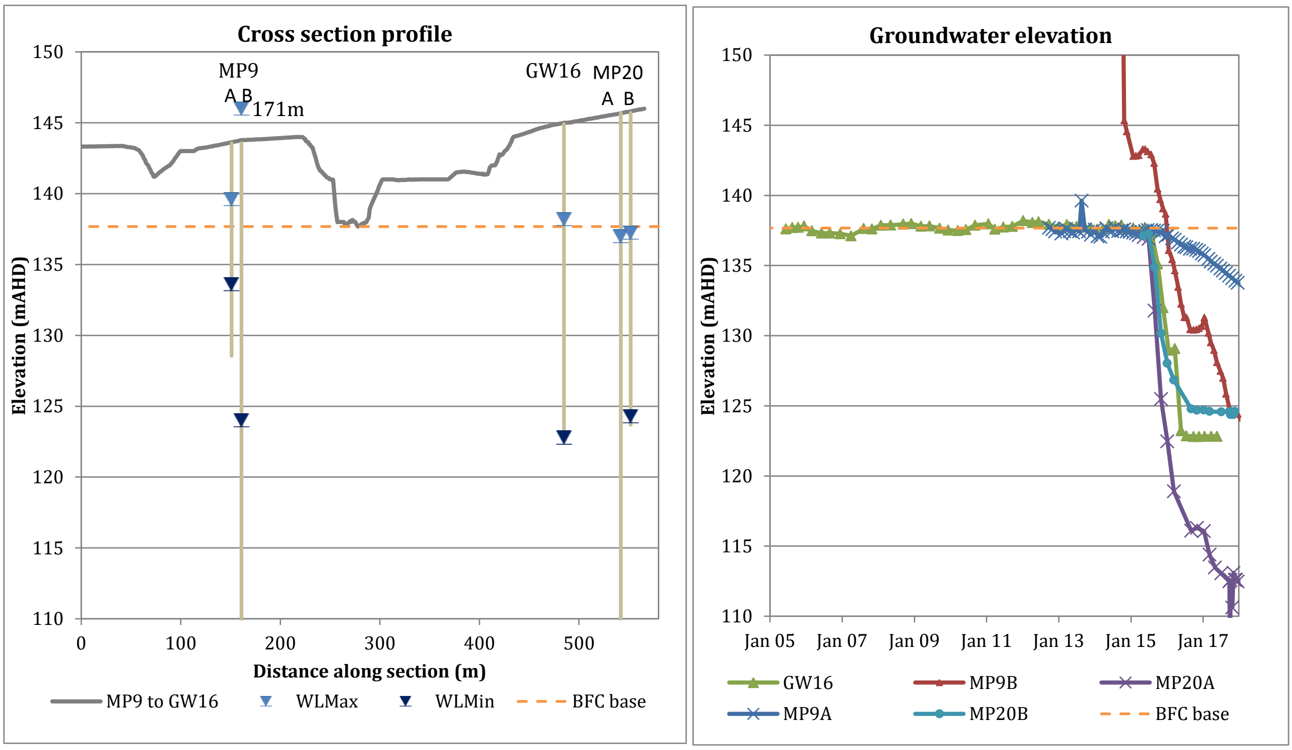


Figure 5.12 Big Flat Creek cross-section 4 – through GW16

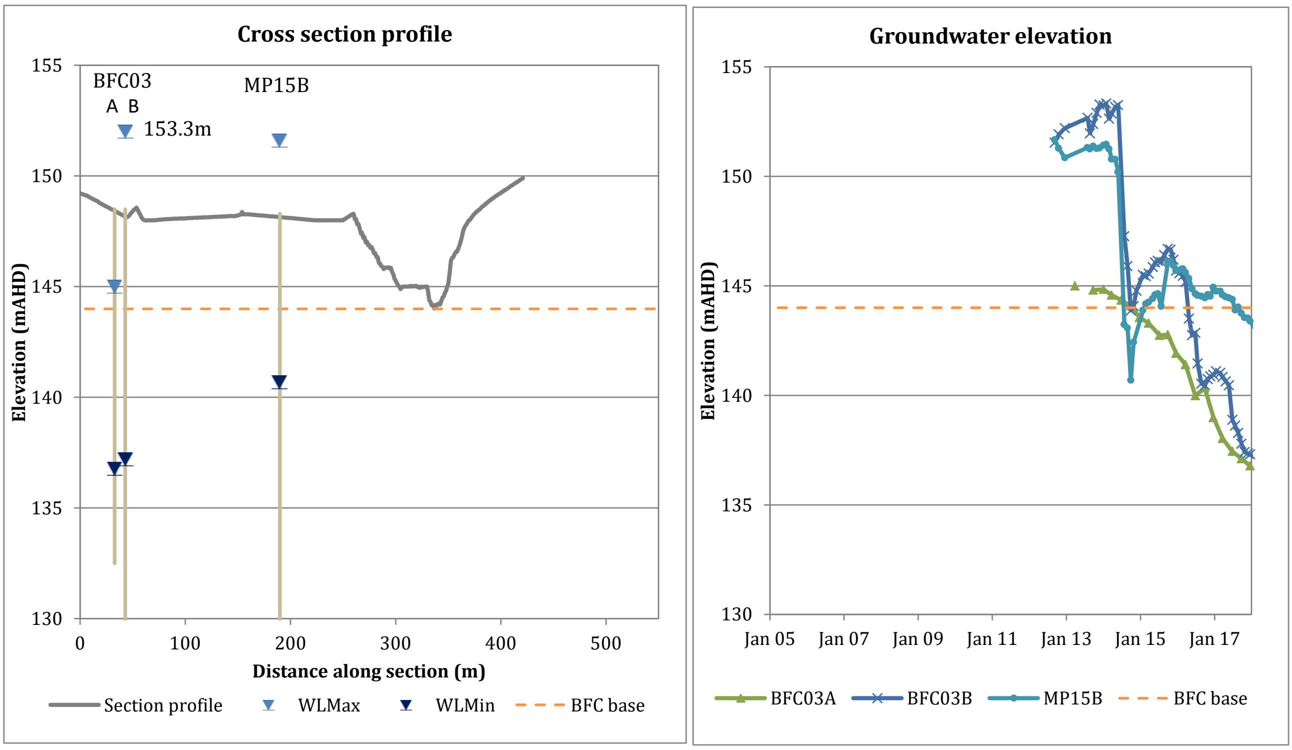


Figure 5.13 Big Flat Creek cross-section 5 – through BFC03

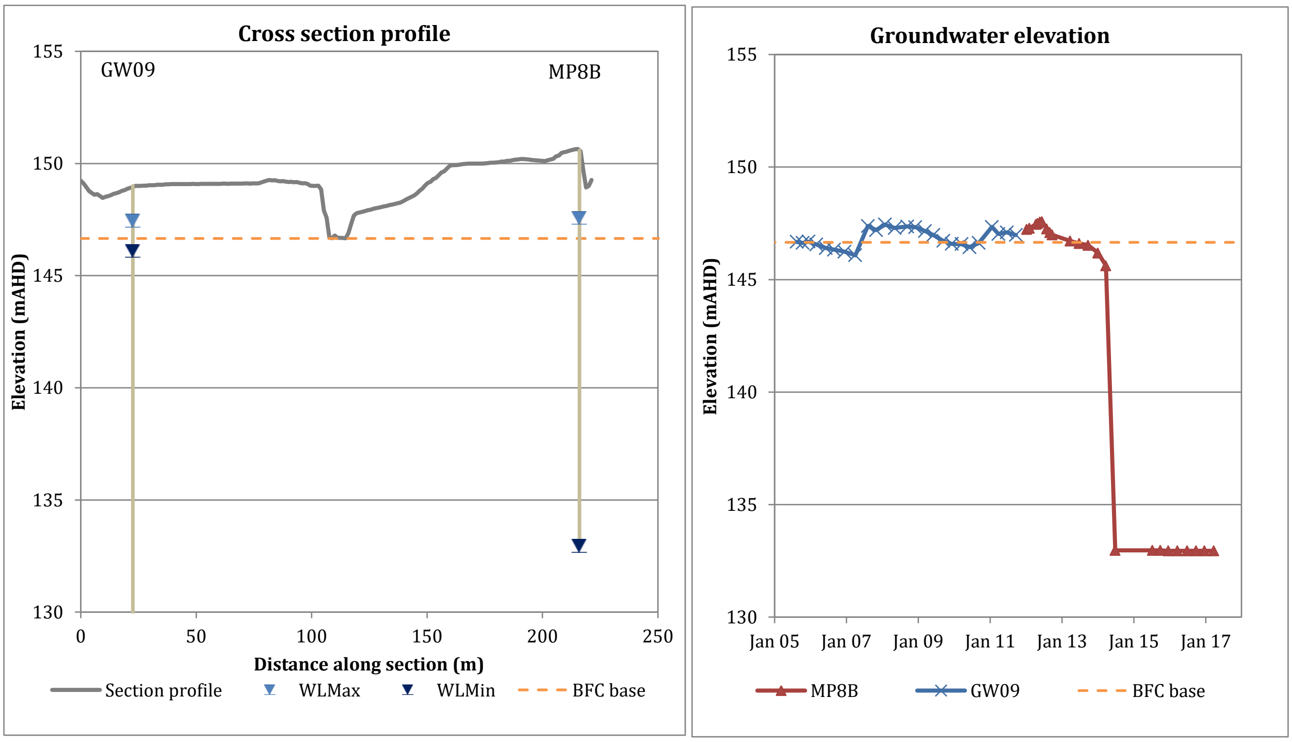


Figure 5.14 Big Flat Creek cross-section 6 – through GW09

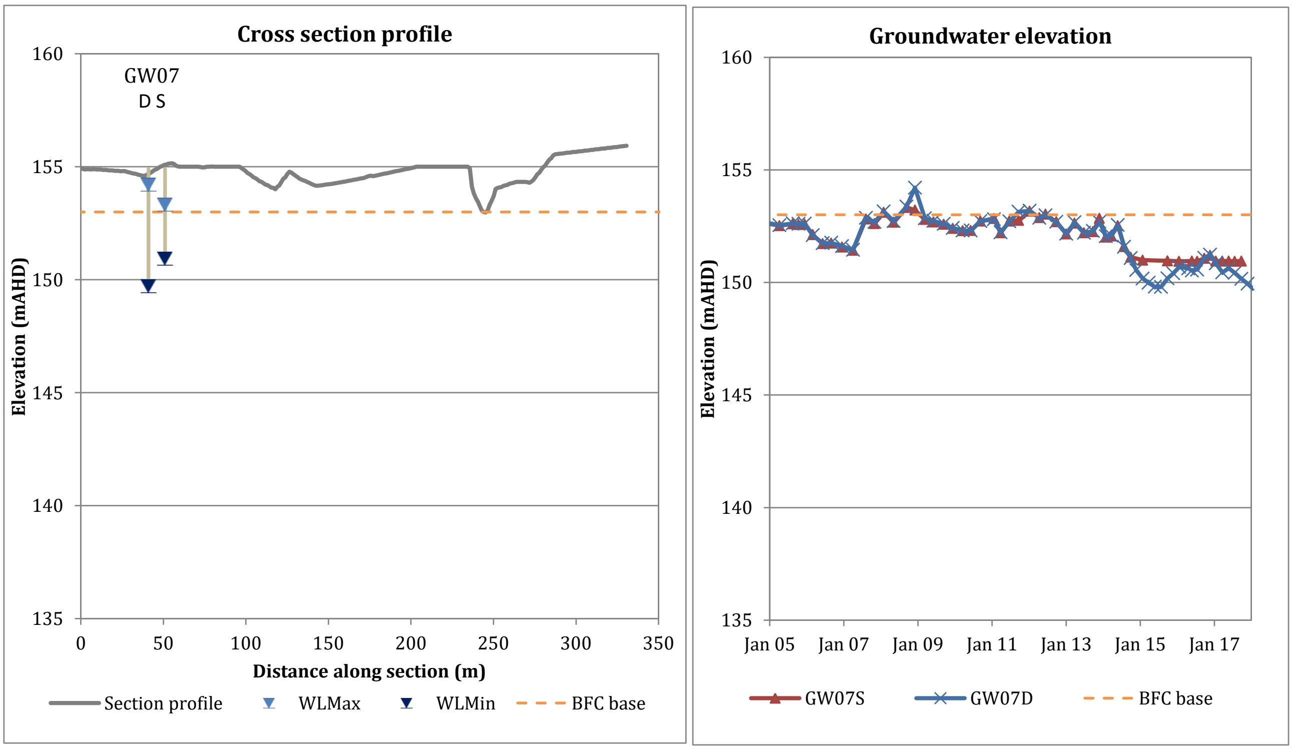


Figure 5.15 Big Flat Creek cross-section 7 – through GW07

5.2.3 Mangoola Coal Mine pit inflows

In the early years of mining, between 2010 and 2014, the Mangoola Coal Mine operations were shallow and above the water table. As the mine moved westerly down dip the mining areas have intersected the water table and groundwater seepage into the mining areas has occurred. Direct measurement of groundwater inflows at the existing approved operation has been difficult because volumes of groundwater seepage are generally low compared to the total volumes pumped. Groundwater inflow has historically been estimated through back calculation using a site wide water balance, which included rainfall runoff and seepage through spoil in addition to groundwater inflows to the pit. During periods of reduced rainfall, the total volumes pumped decrease and the groundwater inflows can be estimated with a higher degree of certainty. This is discussed further below.

The groundwater component of pit inflows is observable as damp seepage lines and small trickles from shallow weathered materials along the highwall, particularly near the confluence of Anvil Creek and Big Flat Creek, and is also likely to occur as vertical inflow from the underlying coal seams and interburden units in areas where fracturing and confined groundwater pressures promote upwelling.

Figure 5.16 shows an aerial view of the standing water and seeps in the vicinity of the mined highwall during October 2017. The Main Pit Sediment Dam, which is used to store water pumped from the pit, is shown in the top right of the figure above the highwall. Large areas of the highwall are visibly dry, with areas of seepage typically evident as darker lines horizontal lines within the mined face. The photograph highlights the challenge associated with directly measuring seepage of groundwater into the mining areas because a proportion evaporates before reaching the floor of the mining area where it can be collected and pumped. Evaporation will also occur from the in-pit sumps before the water is pumped to an out of pit dam.

Figure 5.17 shows a seepage line emerging from the base of a target coal seam in the highwall in July 2018. The seepage is located close to the Main Pit Sediment Dam, and if this dam is leaking then this could also be contributing to the seepages observed.

Figure 5.16 Standing water and seeps – October 2017 (Source: Mangoola Coal)

Figure 5.17 Seepage line – July 2018

The Mangoola mining area is progressively being backfilled with spoil as mining progresses. Rainfall that infiltrates the spoils flows to the base of the backfilled pit and then moves down into the active mining area. Seepage pumped from the active mining areas is commonly from both groundwater flowing in from the geological strata and also from seepage of rainfall through the spoils.

Water balance models have been used at Mangoola Coal Mine to determine the source of water entering the active mining areas. These models aim to separate the volume of water pumped from the pits into its components of rainfall runoff and from groundwater seepage - which is a combination of groundwater from the mine face and spoil seepage. Numerical groundwater flow models have also been used to estimate the volume of groundwater entering the mining areas.

Table 5.1 presents the estimated volumes of 'groundwater + spoil water' intercepted by mining as determined from the site water balance for the Mangoola Coal Mine annual reviews (GSS, 2012; SLR, 2014, 2015, 2016). Estimates of groundwater inflow from numerical models (MER, 2006 and MER, 2013) are also shown. The estimated pumped volumes of groundwater + spoil have increased as mining has progressed.

The inflows estimated by the numerical models do not include spoil seepage and therefore represent groundwater only. The table shows that the groundwater inflow estimates from the numerical models were reduced when the model was updated with additional site data in 2013.

The seepage from rainfall infiltrating through the spoils is not considered groundwater and is typically excluded from estimates of groundwater interception for licensing purposes. In March 2017 Mangoola installed a flow meter along the mining highwall to measure the volume of water pumped from the operating face to improve future water balance and numerical models. As discussed in Section 3.2 rainfall since this time has been well below average, and therefore data collected since this time is dominated by groundwater within the pumped flows rather rainfall runoff and spoil seepage.

Table 5.2 summarises the results of a more recent water balance and includes flow records from the new water meter. Figure 5.18 shows the estimated volume of groundwater and spoil seepage graphically.

Table 5.1 Estimated annual review 'groundwater' inflows to Mangoola Coal mine

Year	Water balance method		Numerical model method	
	Annual total ML/year	Average daily (ML/day)	2006 Model (ML/day)	2013 Model (ML/day)
2012	2	0.005	~0.9	~0.15
2013	2	0.005	~1.1	~0.25
2014	200	0.55	~1.3	~0.35
2015	450	1.23	~1.5	~0.45

Table 5.2 Estimated pit inflows from Engeny water balance

Dates	Rainfall (mm/ quarter)	Water balance inflow estimates (ML/day#)			Highwall flow meter
		Spoil + groundwater	Spoil seepage	Groundwater inflows	
Quarter 1 (Jul-Sept 2016)	197.0	3.0	0.4*	2.7*	-
Quarter 2 (Oct-Dec 2016)	155.2	1.1	0.3	0.8	-
Quarter 3 (Jan-Mar 2017)	197.6	2.1	2.0	0.1	-
Quarter 4 (Apr-Jun 2017)	46.4	2.5	2.2	0.3	0.33 ML/day
Quarter 1 (Jul-Sept 2017)	24.6	1.5	1.4	0.2	0.15 ML/day
Quarter 2 (Oct-Dec 2017)	83.2	0.8	0.5	0.3	negligible pumped
Quarter 3 (Jan-Mar 2018)	85.2	0.7	0.5	0.2	not reliable for Q3
Quarter 4 (Apr-Jun 2018)	53.8	1.0	0.8	0.2	no data

Notes: # *Converted from ML/quarter assuming a steady flow each day.*

* *Estimates inconsistent with other quarters. Potentially anomalous estimates, e.g. due to drawdown of overfull in-pit sumps.*

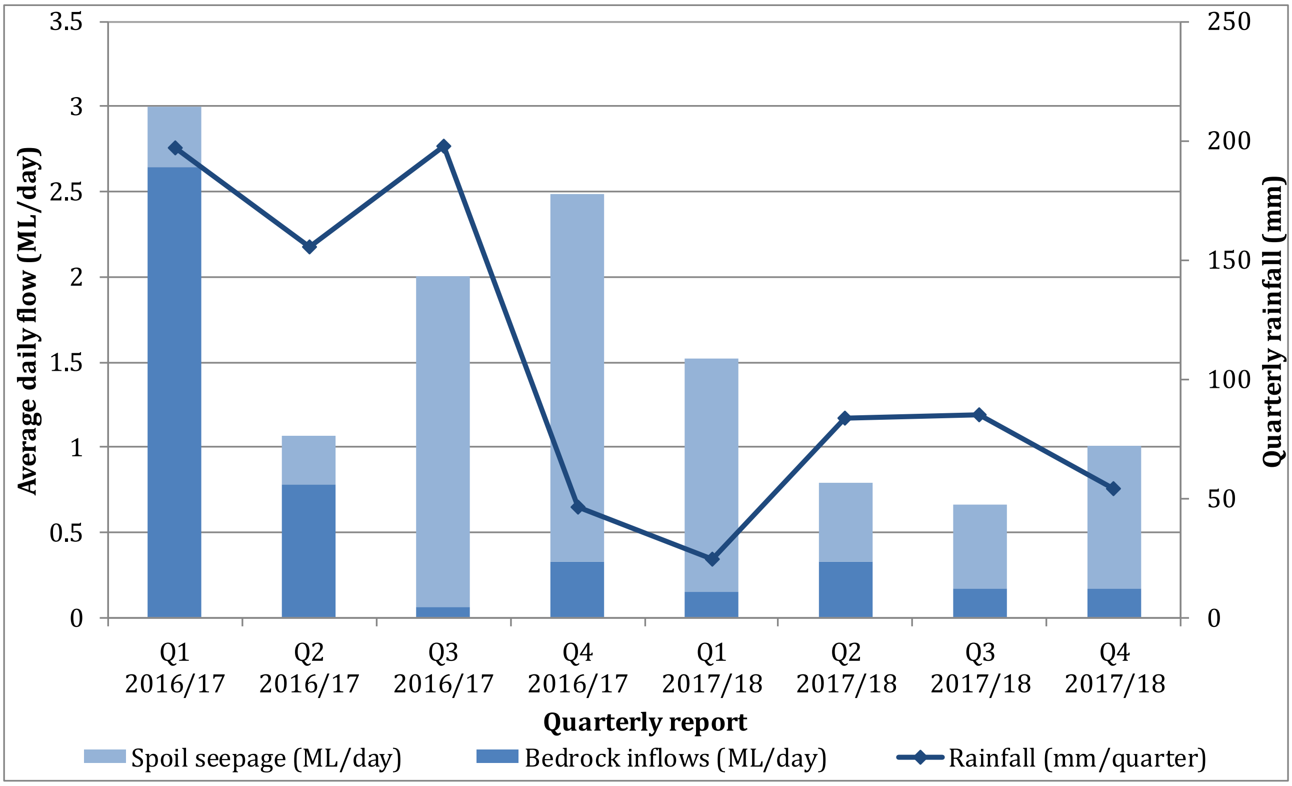


Figure 5.18 Estimated groundwater and spoil water volumes

The above table and graph indicate that the water pumped from the active mining areas is likely to be dominated by seepage from the spoils, with a lesser component of seepage from the active mine face. Groundwater inflows estimated from the highwall flow meter are available for three quarters during 2017 and are no higher than 0.3 ML/day. This represents an estimate of the pumpable fraction of groundwater. As discussed previously not all groundwater intercepted by mining is pumped as it is removed by evaporation, or remains bound to coal and spoils. Whilst this volume is hard to estimate it is a function of a number of factors including; the area of the open coalface, pit orientation, groundwater levels, pit wall permeability and sump levels. At Mangoola during 2018 the evaporative losses are not expected to exceed the volume of water freely pumped. With estimated inflow rates for 2018 this would remain within the groundwater license allocations held by Mangoola.

Also of note in Figure 5.18 is the lag time of approximately six months between the sharp declining rainfall and the reduction in spoil seepage flows. This indicates that drainage of water throughs the spoils is a slow process.

5.2.4 Hydraulic parameters

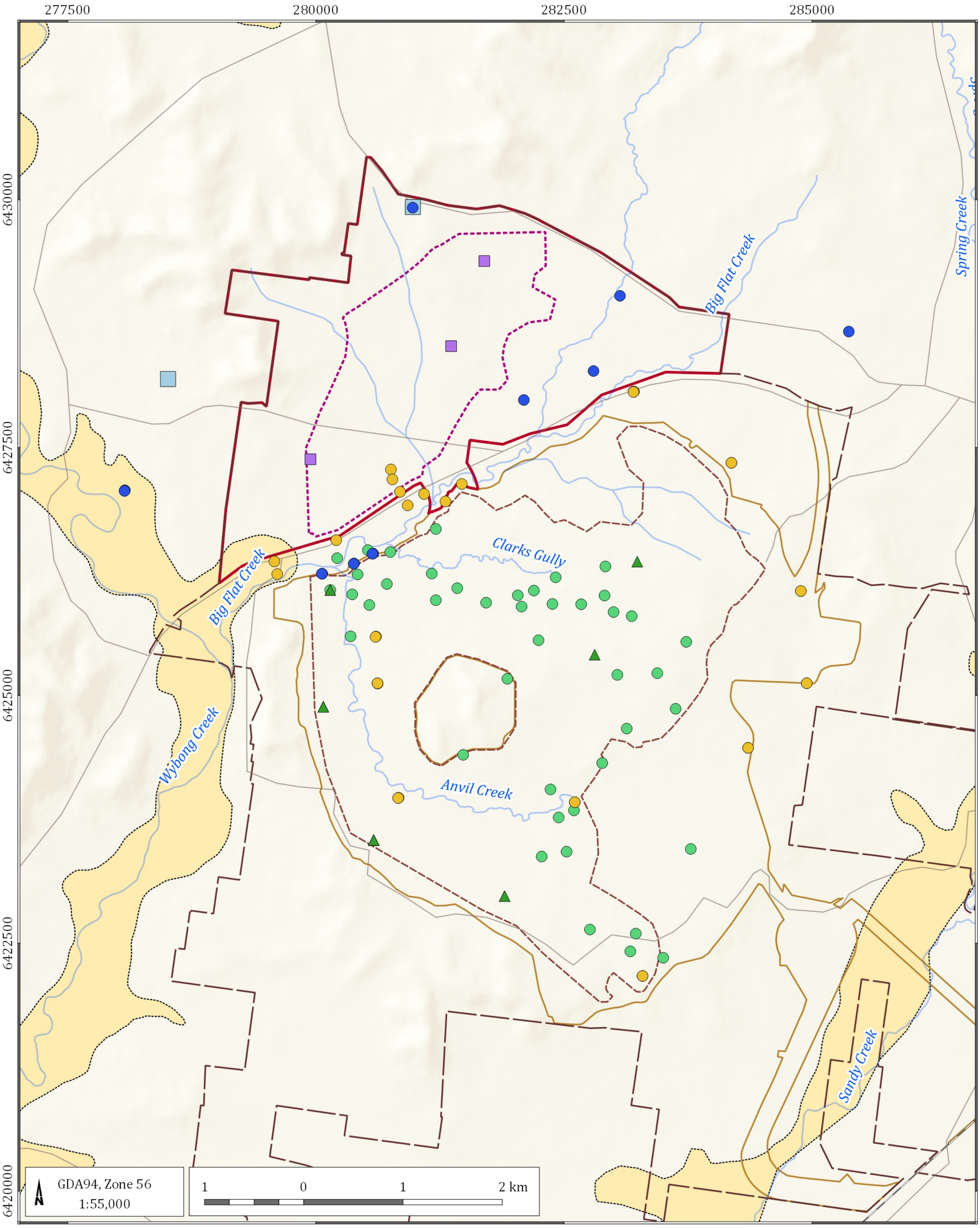
A number of campaigns to measure the hydraulic conductivity of the key hydrostratigraphic units have occurred at the Mangoola Coal Mine over time. The campaigns have utilised a range of methods to measure hydraulic conductivity including variable head (slug) testing on open exploration holes and completed monitoring bores, packer testing of geologic zones isolated within boreholes and laboratory testing of core samples. The spatial distribution of the testing programmes is shown in Figure 5.19. The permeability testing datasets are summarised in Table 5.3.

Additional testing to measure hydraulic conductivity within the MCCO Additional Project Area was conducted as part of the current study. The testing was conducted using single and double packers within exploration bores and also by laboratory testing of interburden core samples. As noted previously there has been some reclassification of shallow strata from 'alluvium' to weathered conglomerate since the earlier reports were issued. Any bore close to the mine that was originally assigned as 'alluvium' has therefore been renamed as weathered conglomerate in the summary information below.

The spatial distribution of the testing programmes indicates that initial hydraulic testing in 2006 was concentrated within the active Mangoola coal mining area (Figure 5.19). Testing was primarily focussed on the weathered conglomerate, undifferentiated coal measures, and Fassifern Seam. Infill permeability testing was conducted in 2013 on undifferentiated coal measures, weathered conglomerate, and the Fassifern Seam. Hydraulic tests in 2015 also included alluvium, weathered conglomerate, coal seams (Upper Pilot, Fassifern and Hartley Hill) and interburden. The ranges in values obtained during each testing campaign are plotted in Figure 5.20. Summary tables of the ranges in results are also provided in Table 5.4 to Table 5.7.

Table 5.3 Sources of permeability testing datasets

Report	Type of testing	Number of samples
MER 2008 - Table C1	Variable head (slug) testing on open exploration holes and completed monitoring bores	44 samples (25 – open hole; 19 – completed monitoring bores)
MER 2008 - Table C2	Interburden core testing	13 samples from 6 holes
MER 2013 - Table C1	Additional variable head (slug) testing on completed monitoring bores	33 samples
MER 2015 - Table C2	Variable head (slug) tests (from EMM, 2015)	14 samples
MER 2015 – Table C3	Packer testing (after GES, 2014)	19 tests from 2 bores - dual and single packers
This report	Packer testing of coal seams and interburden, plus core testing of interburden samples (2017-2018)	9 packer tests from 3 bores, 21 core tests (horizontal and vertical) from 3 holes



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Alluvium
- Road
- Rail
- Drainage
- Variable head testing 2006
- Variable head testing 2013
- Variable head testing 2015
- Core testing 2006
- Packer testing 2015
- Packer and core testing 2017

Mangoola EIS (G1839F)

Permeability testing locations

AGE

DATE 26/02/2019

FIGURE No: **5.19**

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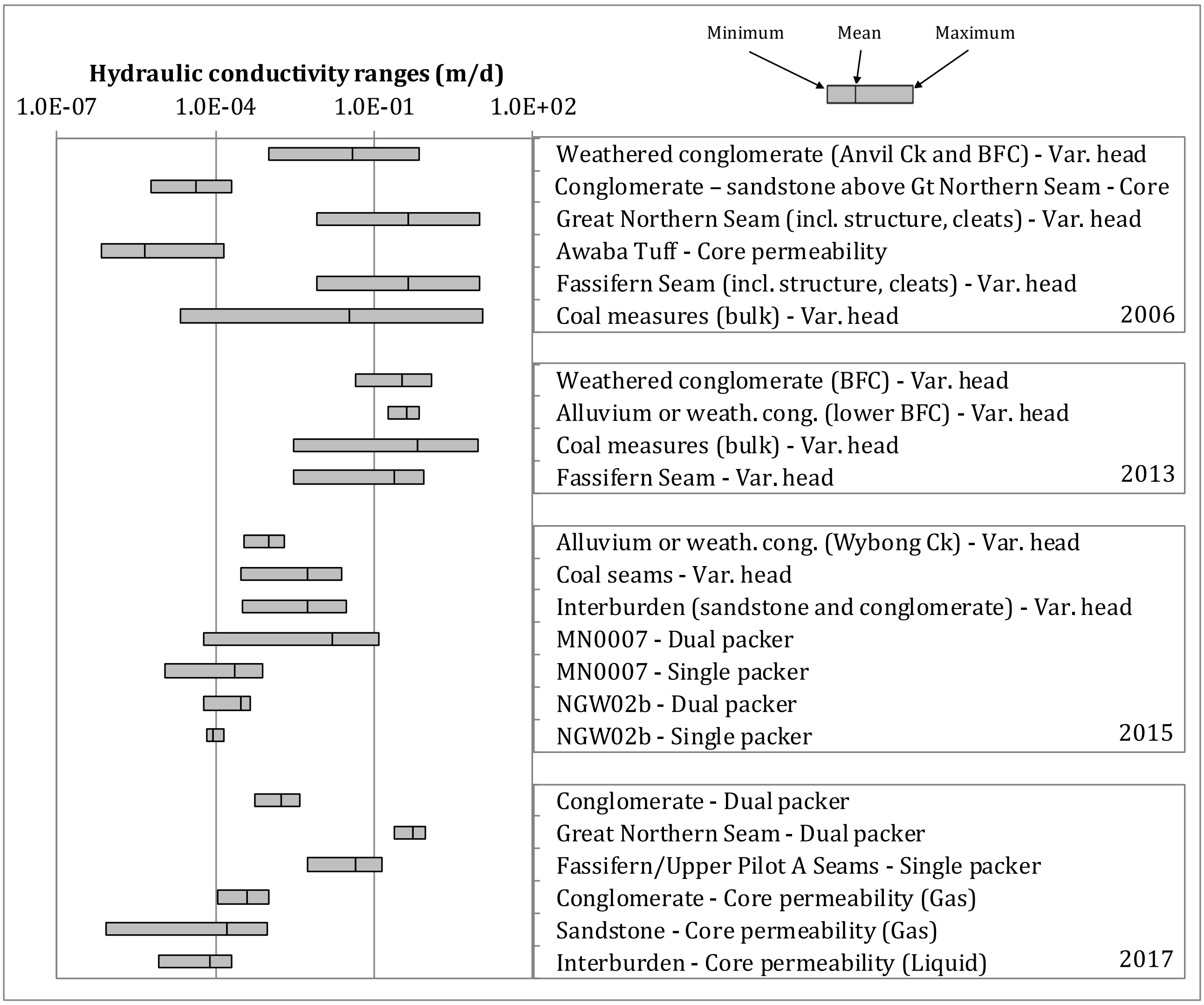


Figure 5.20 Hydraulic conductivity ranges for each field campaign

Table 5.4 Hydraulic conductivity values from 2006 field testing (MER, 2006)

Lithology	Method	K range (m/day)	K mean (m/day)
Weathered conglomerate (Anvil Creek and Big Flat Creek) - reclassified in 2015 from 'alluvium'	Variable head	1.00×10^{-3} – 6.53×10^{-1}	3.69×10^{-2}
Conglomerate – sandstone above Great Northern Seam	Core	6.08×10^{-6} – 1.55×10^{-4}	3.67×10^{-5}
Great Northern Seam (incl. structure, cleats)	Variable head	8.50×10^{-3} – $9.47 \times 10^{+0}$	$<4.44 \times 10^{-1}$
Awaba Tuff	Core	6.97×10^{-7} – 1.38×10^{-4}	4.06×10^{-6}
Fassifern Seam (incl. structure, cleats)	Variable head	8.50×10^{-3} – $9.47 \times 10^{+0}$	$<4.44 \times 10^{-1}$
Coal measures (bulk)	Variable head	2.20×10^{-5} – $1.11 \times 10^{+1}$	3.33×10^{-2}

Table 5.5 Variable head testing 2013 (MER, 2013)

Lithology	Method	K range (m/day)	K mean (m/day)
Weathered conglomerate (Big Flat Creek) – reclassified in 2015 from 'alluvium'	Variable head	4.40×10^{-2} – 8.45×10^{-1}	2.79×10^{-1}
Alluvium or weathered conglomerate (lower Big Flat Creek)	Variable head	1.90×10^{-1} – 2.76×10^{-1}	2.33×10^{-1}
Coal measures (bulk)	Variable head	$<3.10 \times 10^{-3}$ – $8.76 \times 10^{+0}$	$<6.46 \times 10^{-1}$
Fassifern Seam	Variable head	$<<3.10 \times 10^{-3}$ – 6.49×10^{-1}	$<2.33 \times 10^{-1}$

Table 5.6 Variable head testing 2015 (MER, 2015)

Lithology	Method	K range (m/day)	K mean (m/day)
Alluvium or weathered conglomerate (Wybong Creek)	Variable head	3.40×10^{-4} – 9.80×10^{-4}	6.60×10^{-4}
Coal seams	Variable head	3.00×10^{-4} – 1.80×10^{-2}	5.30×10^{-3}
Interburden (sandstone and conglomerate)	Variable head	3.30×10^{-4} – 2.50×10^{-2}	5.23×10^{-3}

Table 5.7 Packer testing 2015 (MER, 2015)

Bore	Method	K range (m/day)	K mean (m/day)
MN0007	Dual packer testing; 7 x ~4 m intervals	6.10×10^{-5} – 1.10×10^{-1}	1.65×10^{-2}
MN0007	Single packer testing; 6 x various longer intervals	1.10×10^{-5} – 5.60×10^{-4}	2.18×10^{-4}
NGW02b	Dual packer testing; 2 x ~4 m intervals	6.20×10^{-5} – 1.70×10^{-4}	2.32×10^{-4}
NGW02b	Single packer testing; 4 x various longer intervals	6.70×10^{-5} – 5.60×10^{-5}	2.42×10^{-5}

Table 5.8 Hydraulic testing 2017-2018

Geology	Method	Number of tests	K range (m/day)	K mean (m/day)
Conglomerate	Dual packer	3	5.44×10^{-4} – 2.10×10^{-3}	1.21×10^{-3}
Great Northern seam	Dual packer	3	2.48×10^{-1} – 3.89×10^{-1}	3.00×10^{-1}
Fassifern seam and interburden	Single packer	3	5.50×10^{-3} – 9.60×10^{-2}	3.87×10^{-2}
Conglomerate	Gas permeability – core plugs	9	1.08×10^{-4} – 6.40×10^{-4}	2.91×10^{-4}
Sandstone	Gas permeability – core plugs	11	8.31×10^{-7} – 7.81×10^{-4}	1.65×10^{-4}
Awaba Tuff	Gas permeability – core plugs	n/a	Core too friable to drill suitable plugs for testing	
Interburden (conglomerate and sandstone)	Liquid permeability – core plugs	3	$<8.31 \times 10^{-6}$ – 1.25×10^{-4}	6.93×10^{-5}

AGE supervised hydraulic testing of additional locations within the MCCO Proposed Additional Mining Area in 2017-2018. Three exploration holes were selected for in-situ packer testing, with core samples also submitted for laboratory permeability testing. The packer tests comprised three separate tests in each hole. A single packer was used to measure hydraulic conductivity across the interval from the Awaba Tuff to the base of the borehole. A dual packer was then used to seal around and test the Great Northern seam and a portion of the unweathered conglomerate. The results of the packer testing (Figure 5.20 and Table 5.8) identified the Great Northern seam as the most permeable interval tested in each hole, with the conglomerate being the least permeable. In some cases no inflow to the conglomerate occurred when pumping water into the packer zone at the lowest pressure step selected. To ensure a good packer seal against the formation the intervals chosen for the conglomerate testing were those that were minimally fractured. Therefore the testing provides a lower permeability estimate for the conglomerate as it excludes significant fracture permeability.

Laboratory testing for porosity, grain density, gas permeability, and liquid permeability was also completed in 2018 on interburden core samples from the same bores in which packer tests were performed. Core testing was completed on plugs of competent unfractured rock, and therefore provides lower bound estimates of permeability for each unit. There was no notable difference in permeability between the three different holes. Results from horizontal and vertical plugs were also similar, indicating that at a plug scale there is little difference in horizontal and vertical permeability. Samples of sandstone showed a larger range in permeability results, and a lower average permeability than conglomerate plugs. Three of the more permeable plugs were also tested for liquid permeability, although only two tests were successful due to swelling clays in one of the samples tested. The two successful liquid permeability tests returned permeability values that were approximately 25% of the gas permeability value obtained for the same sample. The ranges in permeability results for the 2018 core testing are summarised in Figure 5.20 and Table 5.8.

There is a large range in the calculated hydraulic conductivity values for each geological unit, and also between different units. The lowest values were estimated from core testing of the conglomerate and sandstones and Awaba tuff in 2006. Core samples are completed on unfractured materials, so the measured conductivity would be expected to be lower than in the field where fracture networks are present.

The lowest hydraulic conductivity values returned from variable head and packer testing are similar to the higher values returned from the core tests. This likely reflects field testing of zones with a low fracture density. The total range in values estimated from the field testing is around six orders of magnitude, from 10 m/d to 1 x 10^{-5} m/d. The shallow weathered materials are of a similar or lower hydraulic conductivity to the underlying coal measures. A comparison of the locations of groundwater inflows to the mining void with changes in water level in nearby bores indicates that although the weathered materials do not have a high transmissivity they may have a relatively high storage capacity compared to the deeper fresh rock.

Measurements of hydraulic conductivity within Permian coal seams are available for many of the coal mines within the Hunter Valley region and in the wider Sydney Basin. Hydraulic conductivity has been measured using a variety of methods, including packer testing, lab core permeability testing, air lift pumping tests and slug tests. Mackie (2009) compiled much of this data in a single report, and developed a relationship showing likely hydraulic conductivity values for different coal types and different depths (Figure 5.21). The potential range in hydraulic conductivity for the different coal types (bright and dull) is approximately four orders of magnitude. There is a general decline in the hydraulic conductivity with depth below the surface due to the closure of the fractures with increasing stratigraphic pressure and possible infilling due to mineral precipitates. As the coal seams being extracted at Mangoola Coal Mine are relatively shallow there will be limited changes in hydraulic conductivity with depth within the seams being mined.

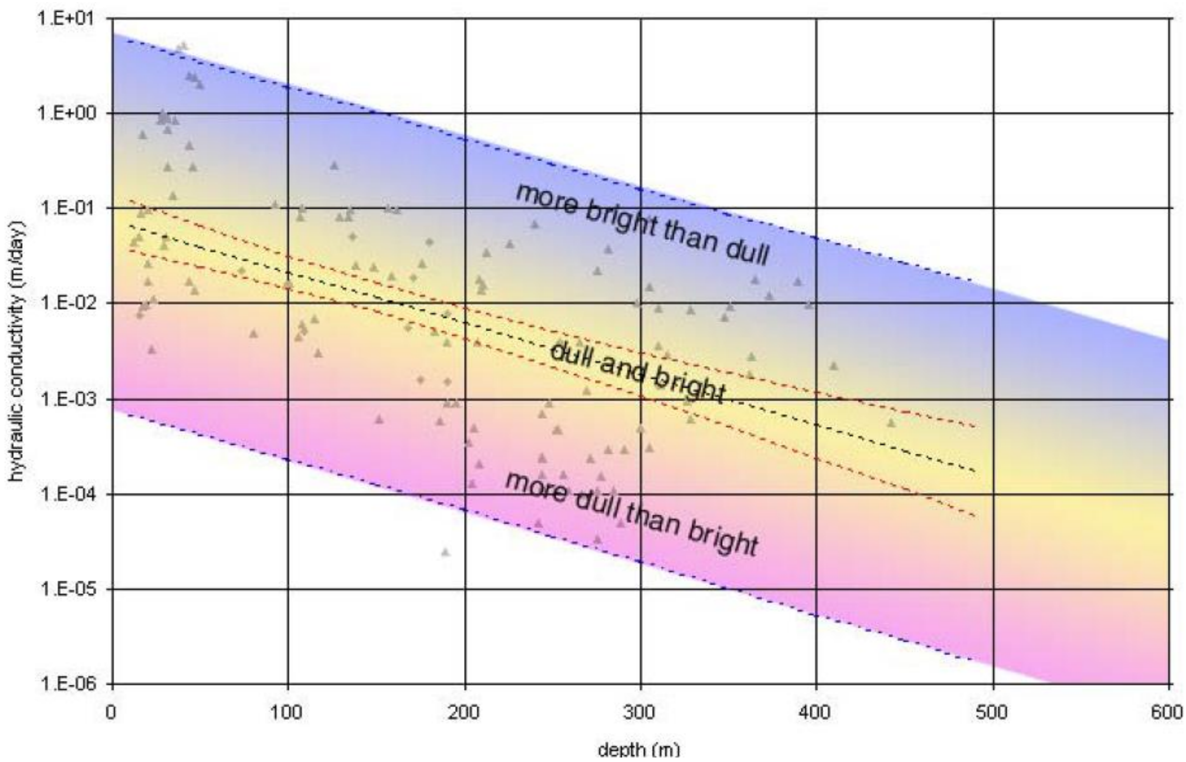


Figure 5.21 Simplified relationship between coal seam conductivity and depth (Mackie, 2009)

5.2.5 Specific storage estimates

Specific storage is a measure of the volume of water stored and released within confined aquifers. Estimates of specific storage are traditionally obtained in the field through analysis of water level changes in an observation bore reacting to abstraction at a nearby pumping bore. This type of test is commonly not possible within coal measures that can only transmit limited volumes of groundwater to bores for pumping.

Literature values of specific storage for coal generally lie between 5×10^{-6} m^{-1} to 5×10^{-5} m^{-1}. Interburden is generally slightly higher than this due to the greater porosity (Mackie, 2009)

In the absence of on-site pumping tests specific storage can also be estimated from knowledge of the porosity and compressibility of the rock material. These parameters are determined through laboratory testing of core for Unconfined Compressive Strength (UCS), Young's Modulus and Poisson's Ratio.

Six core samples of interburden from within the MCCO Proposed Additional Mining Area; three sandstone and three conglomerate, were tested to allow specific storage to be estimated. The samples returned specific storage values of between 1.43×10^{-6} m^{-1} and 8.61×10^{-6} m^{-1}. These are within the physically possible ranges for the rock mass (shaded area on Figure 5.22), but are at the lower end of the ranges expected based on the literature review.

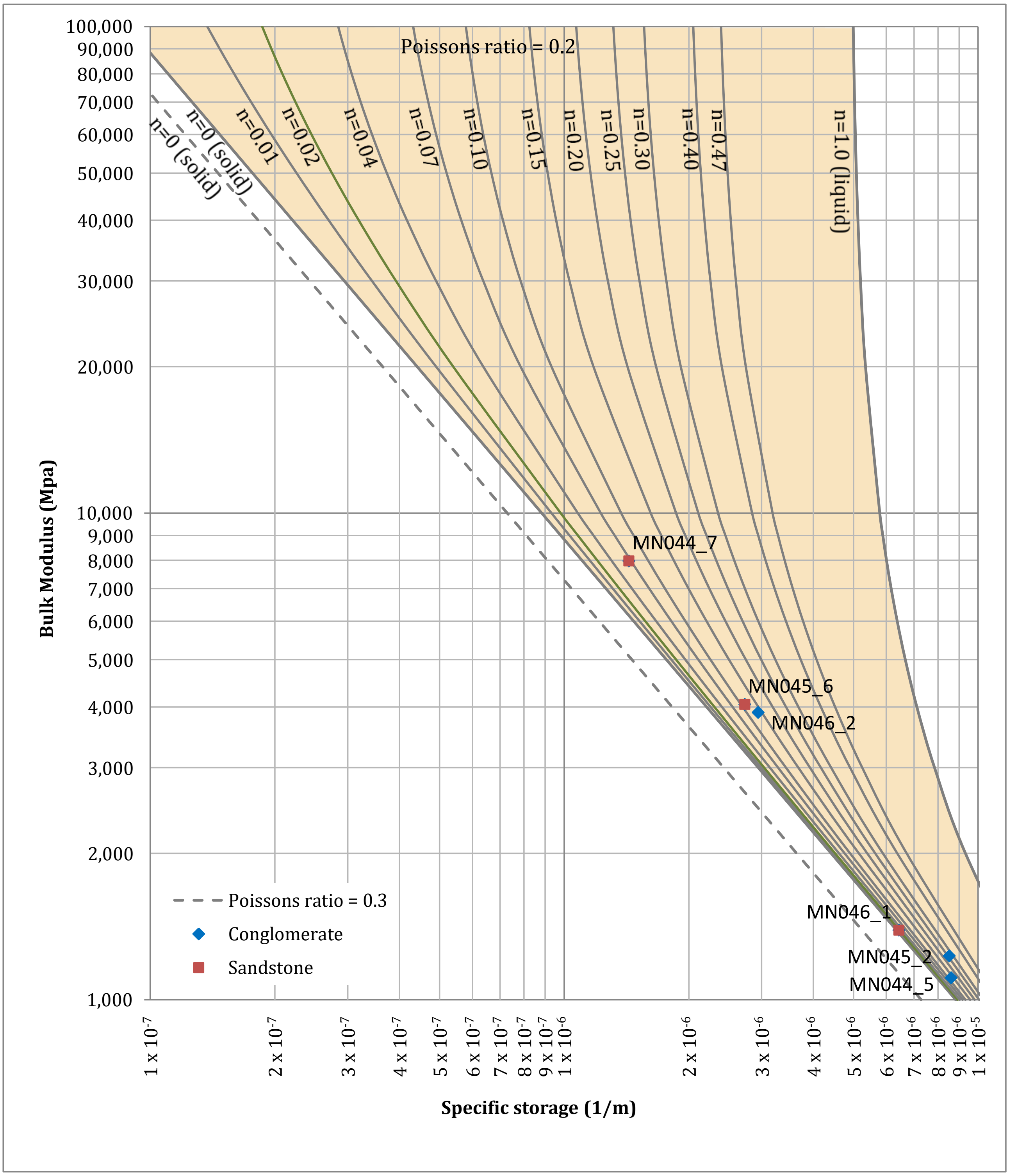


Figure 5.22 Estimated on-site specific storage values

5.3 Groundwater quality and beneficial use

5.3.1 Salinity

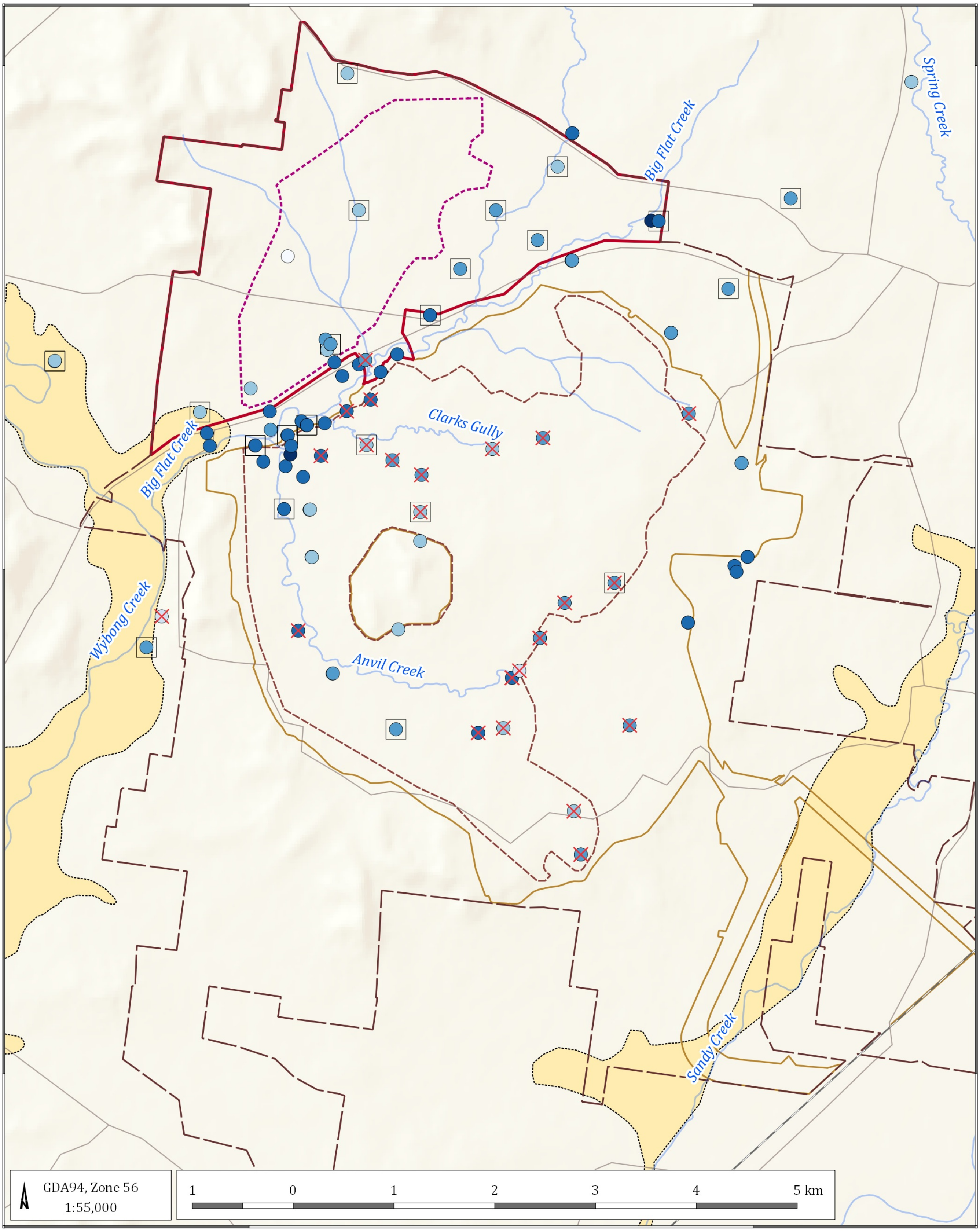
This section describes the water quality and beneficial use of groundwater within the Permian and Triassic groundwater systems. Salinity is the key constraint to groundwater use, and can be classified on a scale ranging from fresh to extremely saline according to concentrations of total dissolved solid (TDS). FAO (2013) provide categories for salinity based on TDS concentrations as summarised in Table 5.9 below.

Table 5.9 Salinity classifications

Category	TDS	Number of Mangoola monitoring bores within this range
Fresh water	<500 mg/L	1
Brackish (slightly saline)	500 to 1,500 mg/L	2
Moderately saline	1,500 to 7,000 mg/L	21
Saline	7,000 to 15,000 mg/L	37
Highly saline	15,000 to 35,000 mg/L	38
Brine	>35,000 mg/L	2

Approximately 60 bores across the Mangoola site are currently sampled bi-monthly or quarterly for pH and electrical conductivity (EC), and historically there have been approximately 100 bores with EC values recorded. EC can be converted to an approximate TDS value by multiplying EC (in µS/cm) by 0.67. The EC values recorded for each bore can vary considerably between readings. Obviously atypical readings were identified and excluded from further analysis. The timescale of other, more stepped, variations may indicate differences in sampling methodology between sample rounds, a poor bore construction, or an error in reading the conductivity meter.

Average TDS values for each bore have been calculated and are displayed on Figure 5.23. There is one monitoring bore that can be classified as fresh water and two more sites which are brackish, with the majority classified as moderately saline to brine as shown in Table 5.9.



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mining Area
- Approved Mangoola Coal Mine Disturbance Area
- Proposed Additional Mining Area
- Alluvium
- Road
- Rail
- Drainage

Average TDS (mg/L)

- Fresh: 0 - 500
- Brackish: 500 - 1,500
- Moderately saline: 1,500 - 7,000
- Saline: 7,000 - 15,000
- Highly saline: 15,000 - 35,000
- Brine: >35,000
- No longer monitored
- Bore sampled for extended site

Mangoola EIS (G1839F)

Average TDS concentrations

AGE

DATE
26/02/2019

FIGURE No:
5.23

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
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Despite the short term variations, the majority of sites have relatively stable longer term EC concentrations over time. The exceptions are bores located close to the active mine along Big Flat Creek, where changes in water levels/water pressure in the Permian strata have drawn in more saline water to the bores (Figure 5.24). The approved Mangoola Coal Mine EIS groundwater assessment (MER, 2006) did not include any discussions on the potential water quality changes in this area during mining. Bores further from the creek e.g. GW46 have continued to return stable EC values. The occurrence of the salinity is considered due to evapo-concentration of rainfall recharge and flow from the underlying Permian into the conglomerates.

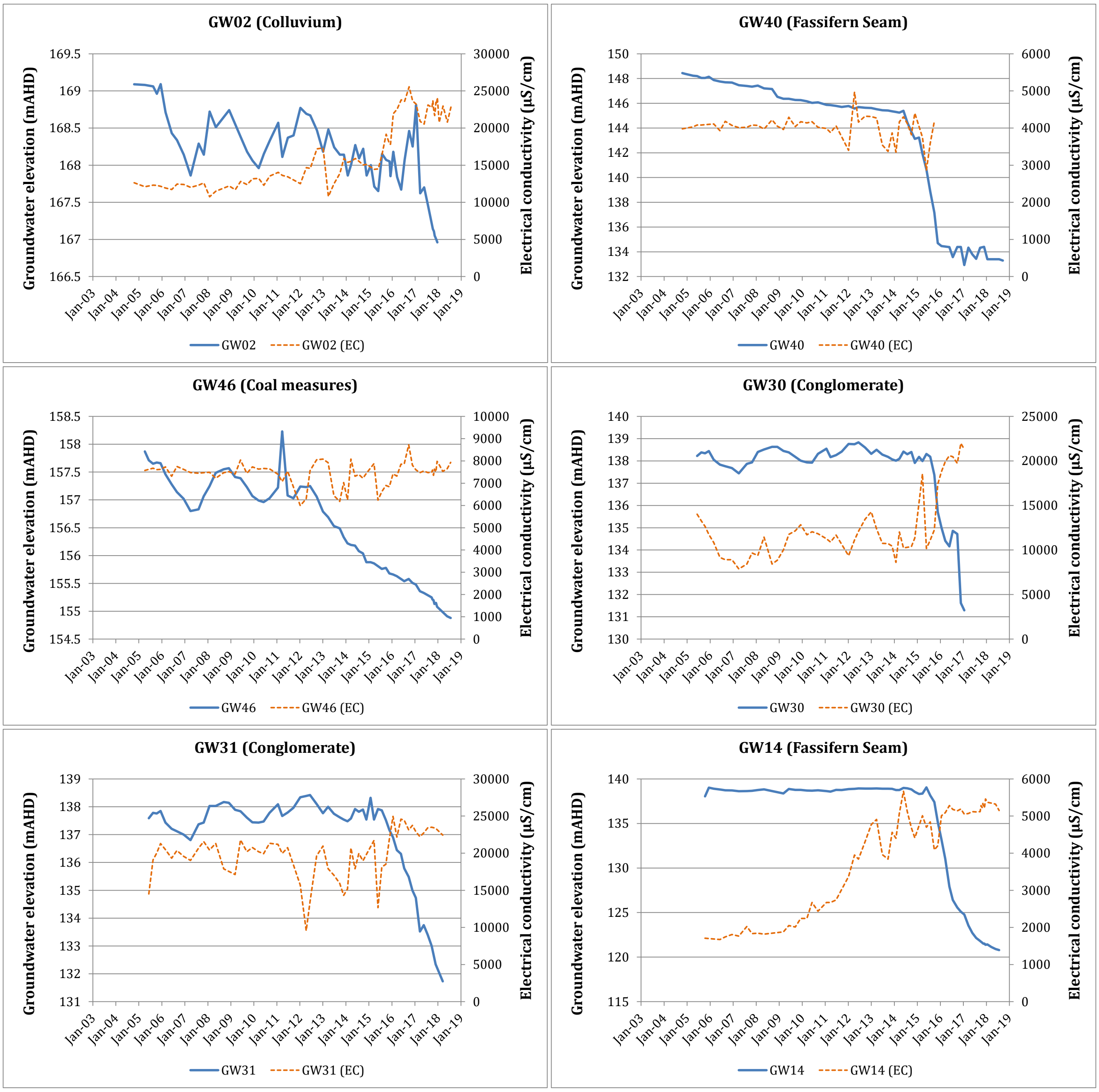


Figure 5.24 Groundwater levels vs EC in selected bores

5.3.2 Chemistry and beneficial use

A number of sites are also sampled for a more detailed water quality suite. Groundwater samples have been taken annually at selected monitoring bores since 2010. Additional sites and parameters were added for three sample rounds in late 2017 to gather more comprehensive baseline data for the MCCO Project. The extended suite included testing for total and dissolved metals, hydrocarbons and nutrients. The sites with detailed water quality samples taken are summarised in Table 5.10 and shown on Figure 5.23. Discussions of the samples collected in 2017 are provided below.

Table 5.10 Extended suite water quality monitoring sites

Site ID	Base of screen (mbgl)	Screened lithology	2010	2011	2012	2013	2014	2015	2016	2017 x 3	Total samples per bore
GW02	6.7	Coal measures/Permian interburden	-	y	y	y	y	y	y	y	9
GW04	25	Coal measures/Permian interburden	-	y	y	y	y	y	y	y	9
GW07-D	5	Regolith	y	y	y	y	y	-	-	-	5
GW07-S	3	Regolith	-	-	-	-	-	y	y	-	2
GW14	85.3	Fassifern seam and overburden	-	y	y	y	y	y	y	y	9
GW18	40	Fassifern seam and overburden	y	y	y	y	y	-	-	-	5
GW33	20.8	Conglomerate	-	y	y	y	y	y	y	y	9
GW34	51	Fassifern seam and overburden	-	y	y	y	y	-	-	-	4
GW36	36	Fassifern seam and overburden	y	y	-	-	-	-	-	-	2
GW44	58	Conglomerate*	y	-	-	-	-	-	-	-	1
GW46	32.5	Weathered conglomerate*	y	y	y	y	y	y	y	y	10
MN0011 (REG1)	65	Hartley Hill seam	-	-	-	-	-	y	y	y	5
MN1014	53	Hartley Hill seam*	-	-	-	-	-	y	y	y	5
MP18A	78	Fassifern seam	-	-	-	-	-	y	y	y	5
MP18B	16	Conglomerate	-	-	-	-	-	y	y	y	5
MP19A	72	Fassifern seam and Upper Pilot A seam	-	-	-	-	-	y	y	y	5
MP19B	20	Conglomerate	-	-	-	-	-	y	y	-	2
MP20A	66	Fassifern seam and Upper Pilot A seam	-	-	-	-	-	y	y	y	5
MP20B	22	Conglomerate	-	-	-	-	-	y	y	-	2
NGW01B	27	Weathered conglomerate	-	-	-	-	-	y	y	y	5

Site ID	Base of screen (mbgl)	Screened lithology	2010	2011	2012	2013	2014	2015	2016	2017 x 3	Total samples per bore
NGW01C	17	Conglomerate	-	-	-	-	-	y	y	y	5
NGW02B	42	Conglomerate	-	-	-	-	-	y	y	y	5
NGW03A	30	Weathered conglomerate	-	-	-	-	-	y	y	y	5
MN1006	53	Upper Pilot seam	-	-	-	-	-	-	-	y	3
GW10-A2	12	Weathered conglomerate	-	-	-	-	-	-	-	y	3
GW10-P1	24	Conglomerate	-	-	-	-	-	-	-	y	3
GW10-P2	31	Coal measures	-	-	-	-	-	-	-	y	3
GW047877	30.6	Coal measures	-	-	-	-	-	-	-	y	3
GW202249	74.5	Coal measures	-	-	-	-	-	-	-	y	3
Total per year	-	-	5	9	8	8	8	18	18	21	-

Note: * *Estimated lithology.*

Water quality results for samples analysed in September 2017 are provided as tables in Appendix D. The results were compared against ANZECC guideline values for aquatic ecosystems, irrigation, stock, and potable consumption. The tables highlight the parameters exceeded for each of the guideline user groups. Additional sample rounds were taken during October and November 2017, but most results were similar and only the September monitoring results are presented.

The tables show salinity is the main constraint to beneficial use of groundwater in the mining area and surrounds with all bedrock geological units having a water quality that is often unsuitable for aquatic ecosystems, irrigation, or potable consumption. The results also indicate that several metals are present in concentrations above guideline thresholds. The exceptions are bores GW10-A2 and GW10-P2 which have a suitable salinity for potable consumption but which exceed guideline values for a number of metals including aluminium, iron, and lead. Natural variability in the concentrations of dissolved solutes and the beneficial use is common in groundwater systems with relatively low permeability.

A higher number of bores have a suitable salinity for stock watering (assuming that the water is used for watering beef cattle rather than dairy cattle). However, in the September sampling round there are occasional exceedances for different metals in several bores. In most cases the metals exceedances are not consistent across multiple sample rounds. It is therefore possible that beef cattle would be productive if watered from the lower salinity bores.

Testing was completed for BTEX, Total Petroleum Hydrocarbons, and Total Recoverable Hydrocarbons using the silica gel clean up analysis method during the September and October 2017 sampling rounds. All tests returned concentrations that were below the laboratory limit of reporting in both sampling rounds. Consequently, these parameters were removed from ongoing sampling as the baseline value had been established.

For the nutrient parameters there were exceedances to triggers for ammonia for both aquatic ecosystems, and potable consumption. Nitrite concentrations also triggered for aquatic ecosystems; and total nitrogen and total phosphorous triggered for long term irrigation. There were no nutrient exceedances for stock watering.

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

The two ex-landholder bores (GW047877, GW202249) approved for stock and domestic use and sampled by Mangoola Coal from September 2017, did not record any exceedances of stock watering guidelines, but would have been unsuitable for potable use in an undiluted state.

Figure 5.25 contains a Piper diagram showing the distribution of major ions in samples from September, October, and November 2017. The uppermost diamond is scaled to the TDS, with the larger symbols indicating more saline samples. The three samples from each location generally plot in clusters, indicting little variation in water quality between samples. The majority of samples are dominated by sodium and chloride ions, with magnesium and bicarbonate also being notable components. Four of the bores with high magnesium are located around the MCCO Proposed Additional Mining Area, this may indicate that the water chemistry in this area of the site is being influenced more by the composition of the host rock rather than evaporative concentration.

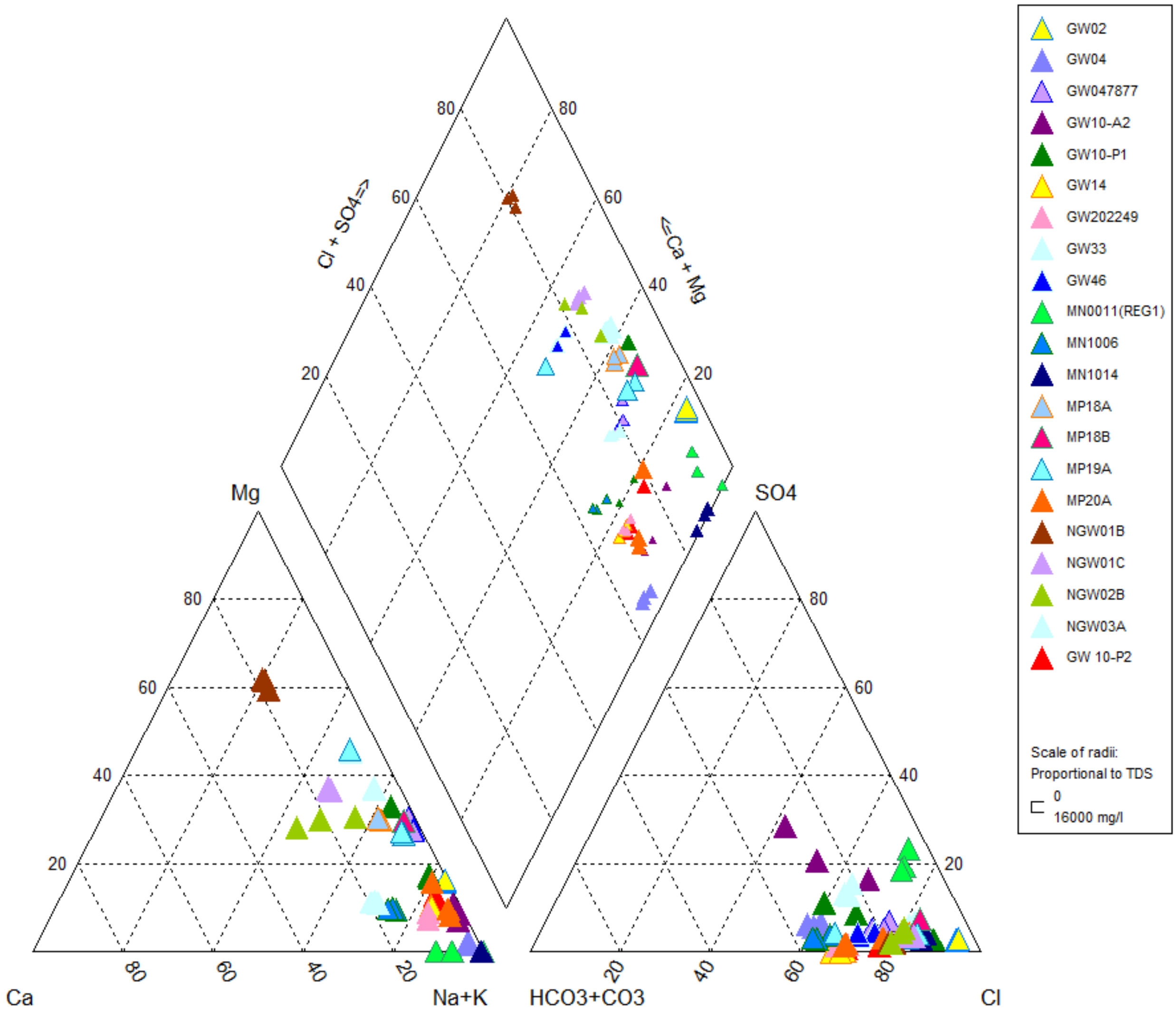


Figure 5.25 Piper plot for 2017 water samples

5.4 Groundwater dependent assets

The IESC Information Guidelines require the identification of water-dependent assets with potential to be impacted by coal seam gas and large coal mines. Information on potentially groundwater dependent assets from a number of different sources is summarised below.

5.4.1 Bioregional Assessment - Hunter subregion water dependent assets

In the context of Bioregional Assessments water-dependent assets are defined as *'an asset potentially impacted by changes in groundwater and/or surface water due to coal or coal seam gas development. Some ecological assets solely depend on rainfall and will not be considered as water dependent if evidence does not support a linkage to groundwater or surface water'* (Macfarlane *et al.,* 2016). Assets can be classified for economic, ecological, or sociocultural.

In the Hunter sub-region ecological water dependent assets are classified into three subgroups:

- 'Surface water feature' – 205 assets;
- 'Groundwater feature (subsurface)' – 24 assets; and
- 'Vegetation' – 1,422 assets, of which;
    - Groundwater-dependent ecosystems – 587 assets; and
    - Habitat (potential species distribution) – 835 assets.

The Wybong Creek alluvium and the Hunter River alluvium are noted as alluvial aquifer assets within the 'Groundwater feature (subsurface)' subgroup (refer Figure 5.26). The alluvium along Sandy Creek, and the colluvium along Big Flat Creek, are not differentiated from the bedrock groundwater units in terms of the asset groupings. There are no groundwater springs identified close to the MCCO Project.

Assets within the 'Vegetation' subgroup and classified as 'Groundwater-dependent ecosystems' assets are shown on Figure 5.27. The closest assets to the MCCO Project are riverine forests located along the Wybong Creek and Hunter River, but not Big Flat Creek or Sandy Creek. Small areas of rainforests are also identified to the west of Wybong Creek within the higher elevation areas, and in more isolated patches to the north of the MCCO Project.

Economic water dependent assets represent water access licenses, basic water rights, water source areas, water supply infrastructure, and regulated rivers. Within the Hunter subregion there are 108 surface water economic assets and 141 groundwater economic assets. The assets identified represent groups of smaller elements, e.g. in the Hunter region the 141 groundwater assets account for 5,463 individual elements as shown on Figure 5.28. The map identifies a number of potential groundwater elements with basic water rights (stock and domestic) or water access rights in the vicinity of the MCCO Project. Bores that are classified as exploratory or monitoring bores and which do not have associated water access rights are not included in the asset register (Macfarlane *et al*, 2016). Registered water bores within the vicinity of the MCCO Project are discussed further in Section 5.4.2.

There were 307 sociocultural water dependent assets identified within the Hunter subregion. These were judged to be water dependent based on their proximity to other surface water or groundwater features. The assets can be classified as:

- Cultural:
    - Heritage site – 275 assets; and
    - Indigenous site – 9 sites.
- Social:
    - Recreational – 23 sites.

There are no maps within the bioregional assessment showing the locations of the sociocultural water dependent assets within the Hunter subregion (Macfarlane *et al*, 2016).

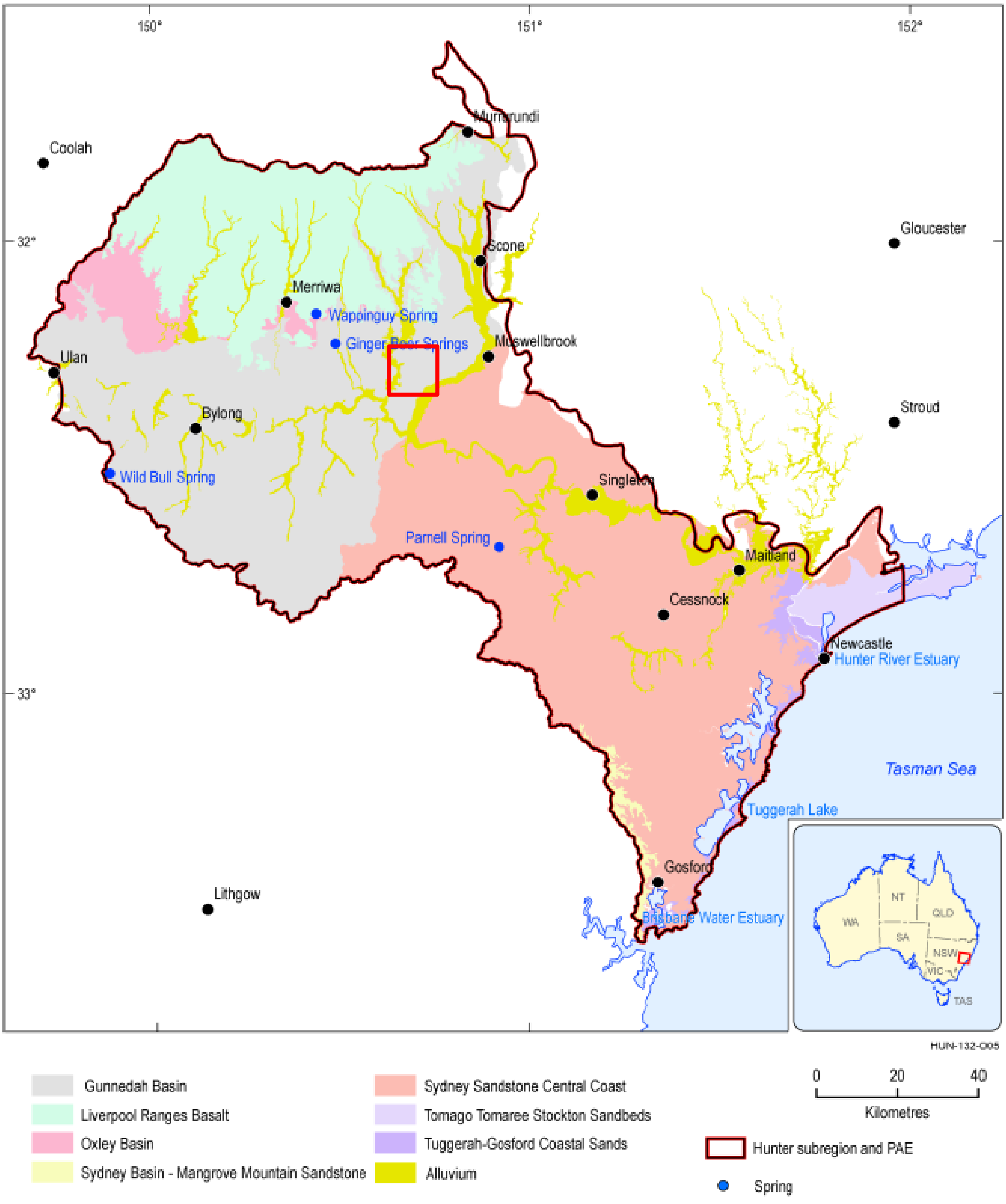


Figure 6 Location of selected assets in the 'Aquifer, geological feature, alluvium or stratum' asset class of the Hunter subregion

Data: Australian Government Department of the Environment (Dataset 3)

Figure 5.26 Bioregional assessment – Hydrogeological assets (Macfarlane *et al.*, 2016)

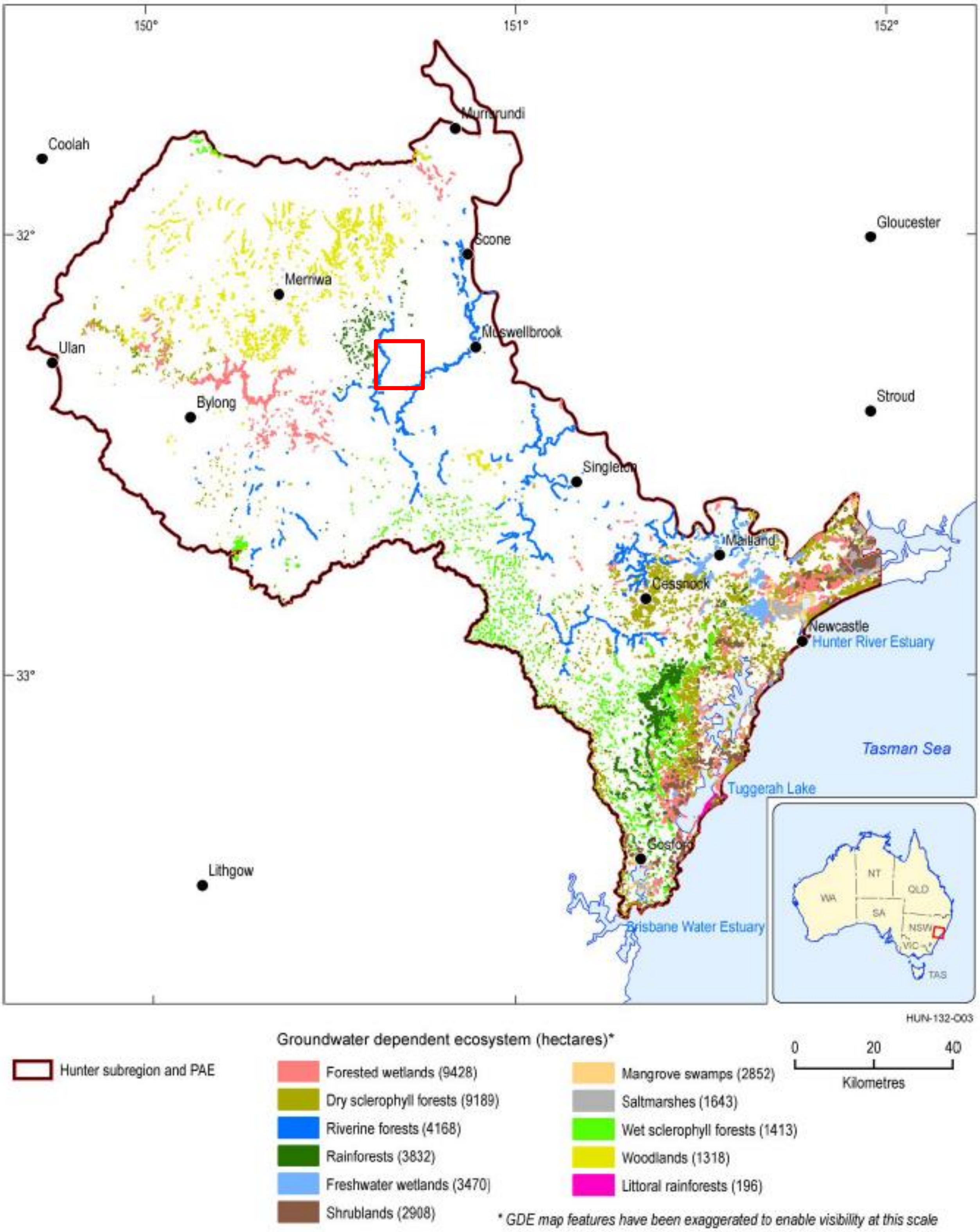


Figure 7 Location of assets in the 'Vegetation' subgroup in the 'Groundwater-dependent ecosystems' asset class of the Hunter subregion

Vegetation types are grouped according to vegetation formation (Keith 2006). Note that within this classification the formation 'Forested wetlands' includes Eastern riverine forests.
Data: NSW Department of Primary Industries (Office of Water) (Dataset 2)

Figure 5.27 Bioregional assessment – Ecological groundwater-dependent ecosystem assets (Macfarlane *et al.*, 2016)

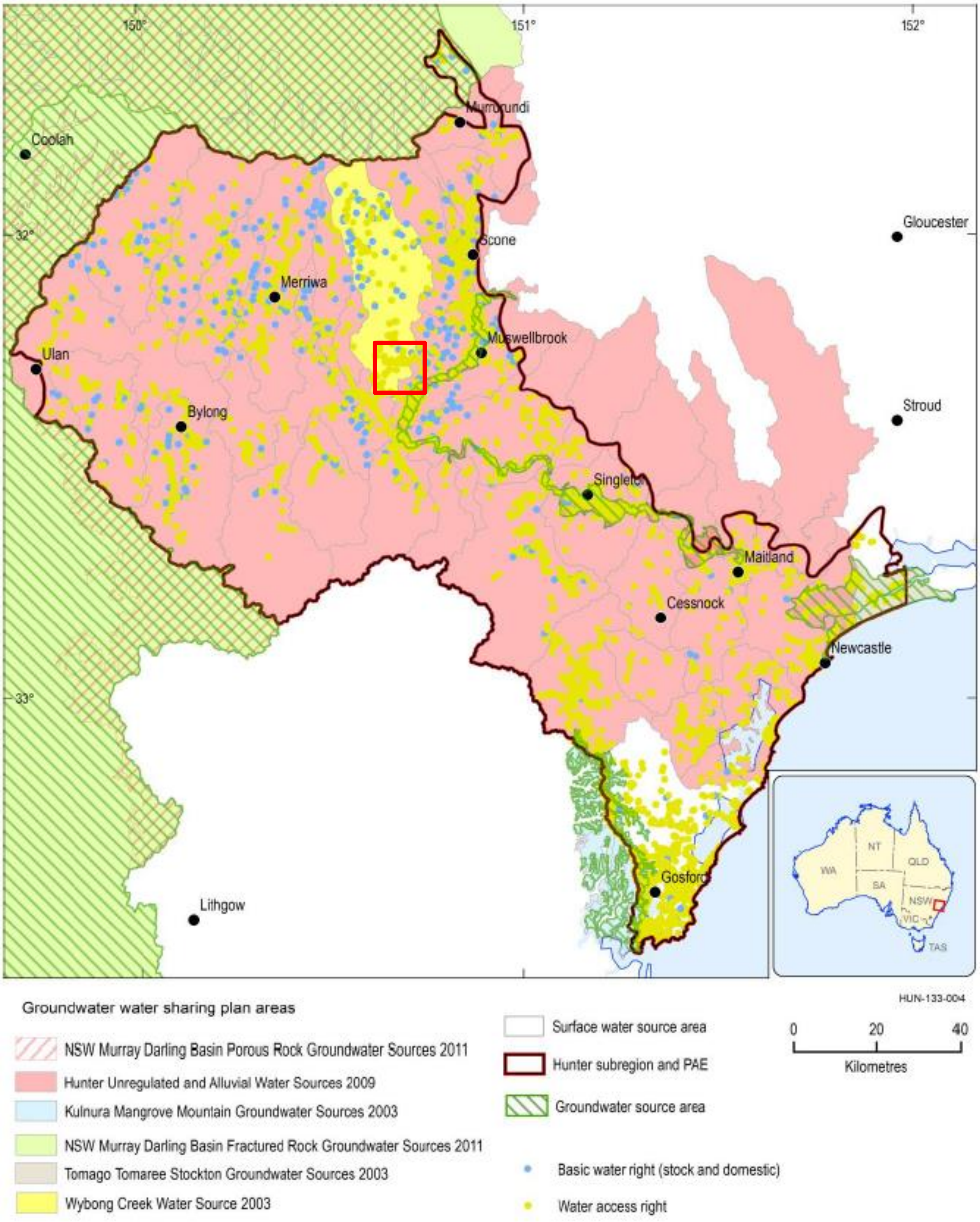


Figure 10 Location of groundwater elements within the preliminary assessment extent (PAE) of the Hunter subregion

Data: NSW Department of Primary Industries, NSW Office of Water (Dataset 2), NSW Office of Water (Dataset 4)

Figure 5.28 Bioregional assessment – Economic groundwater-dependent assets (Macfarlane *et al.*, 2016)

5.4.2 Private water users

A search of the NSW state government groundwater bore database (Pinneena) was conducted to identify the locations of any registered water bores in proximity to the MCCO Project on privately owned land parcels. In addition, a landholder census identified three bores that were not currently present on the registered bore database. The exact locations of the additional bores are uncertain and indicative locations have used based on the limited data provided to date. The results of both searches are shown on Figure 5.29. Nominal buffer zones of 2 km and 3 km have been used to identify those bores closest to the MCCO Proposed Additional Mining Area. The figure shows that there are two bores on private land within a 2 km radius of the MCCO Proposed Additional Mining Area footprint, and an additional six bores within 3 km. The registered bore details are summarised in Table 5.11.

Table 5.11 Registered bores on private lands within 3 km of the MCCO Project

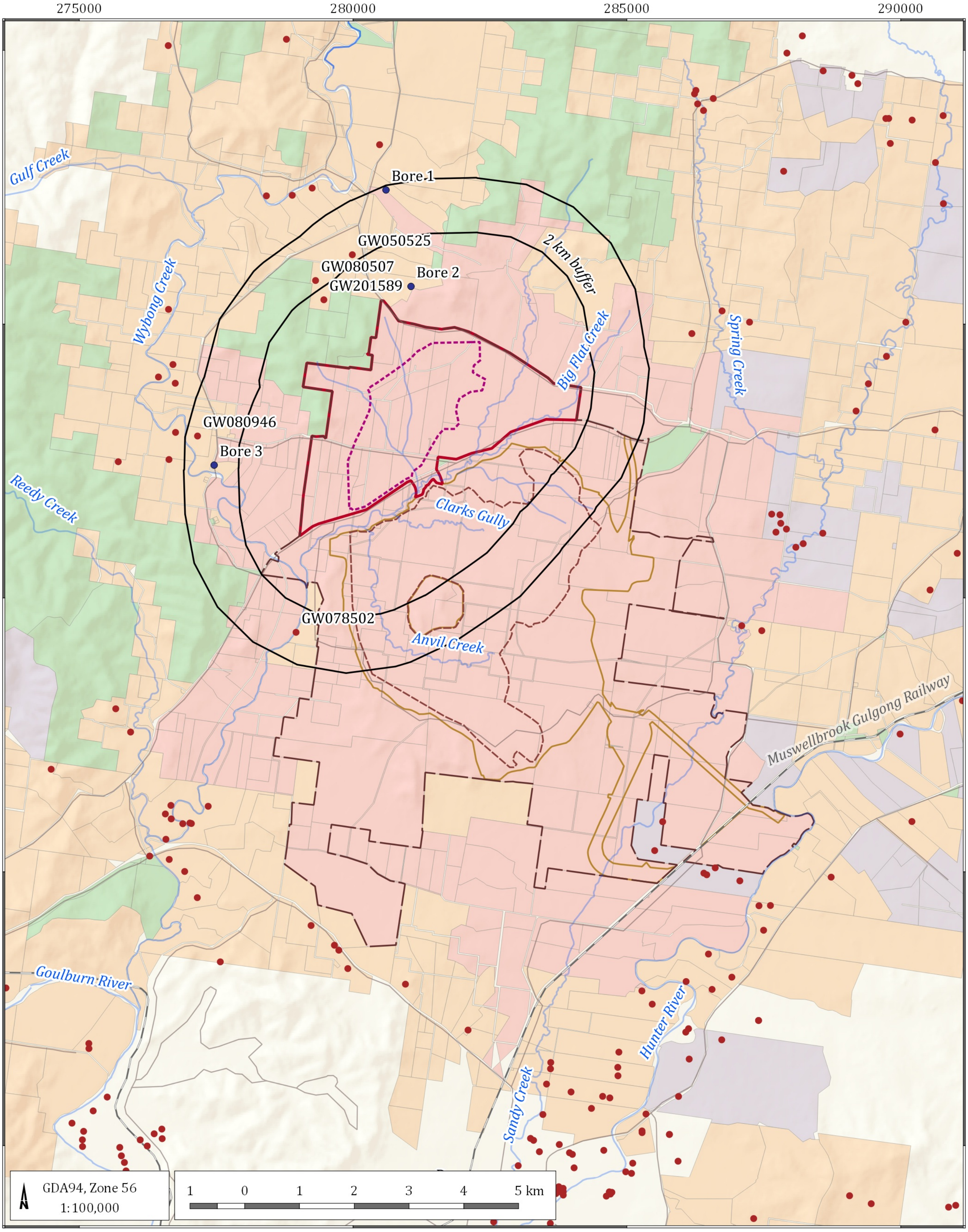
Bore ID	Purpose	Date	Depth (m)	Geological strata	Casing type and diam. (mm)	SWL (mbgl)	Yield (L/s)
GW201589	Stock, domestic	2011	84.0	Shale, blue	PVC Class 9, 150 mm. slots 36-42 mbgl and 60-66 mbgl	10.0	0.5
GW050525	Backfilled. Insufficient yield.#	1978	106.7	Sandstone	N/A	N/A	N/A
GW080507	Stock, domestic	2003	Not recorded	-	-	-	-
GW080946	Farmers bore converted to DIPNR monitoring bore	2005	Unclear: 19.5 m or 30 m	-	PVC Class 9, 100 mm	11.95 (2011)	-
GW078502	Stock, Domestic	-	58*	Coal measures*	-	-	-

***Note**: * Information taken from previous reports not Groundwater Works reports. # - Information from landholder.*

The table indicates that three of the registered bores are authorised for stock and domestic use, one has been backfilled, and one has been converted to a government monitoring bore. Three of the bores have incomplete information in the database. Bore GW080946 is noted as being 19.5 m total depth but cased to 30 m depth, it is unclear which record is an error as the water levels are only ~12 mbgl.

Bore GW078502 is believed to be approximately 58 m deep, although exact construction details are unknown. It is possible that the bore is screened above the coal seams, which would reduce any potential drawdown impacts from mining. The property on which this bore is located already has voluntary acquisition rights afforded by the current Mangoola Coal Mine project approval (Property ID 83).

Bore 1 and Bore 2 of the landholder census are believed to be relatively new and details have not yet been uploaded to the registered bore database. Bore 3 is understood to be an older bore that is only used for lawn watering. 'Form A' details containing the bore construction information have been requested but have yet to be received.



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mining Area
- Approved Mangoola Coal Mine Disturbance Area
- Proposed Additional Mining Area
- Road
- Rail
- Drainage
- Nominal MCCO pit buffer zone
- Private registered bores
- Other landholder bore

Land ownership

- Crown Land
- Mangoola Coal Operations Pty Limited
- Other Mine Owned
- Private Landholder

Mangoola EIS (G1839F)

Nearby groundwater bores on privately owned land

AGE

DATE 06/04/2019

FIGURE No: **5.29**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
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5.4.3 Localised groundwater dependent ecosystem surveys

The Bioregional Assessment water dependent assets mapping was developed using regional scale datasets. Therefore, more localised assessments of potential GDEs in the vicinity of the MCCO Project were also completed (Umwelt, 2019). Draft IESC guidelines 'Consultation on Assessing Groundwater-Dependent Ecosystems: IESC Information Guidelines Explanatory Note' (Draft Explanatory Note) (Doody, Hancock and Pritchard, 2018) were utilised as part of the localised assessment. The draft guidelines state that vegetation located in areas with shallow groundwater (less than 10 m from surface) are most likely to be GDEs as they can often quite easily reach and extract groundwater. Areas around the mine where pre-mining groundwater levels were modelled to be within 10 m of ground surface were therefore used as a starting point for mapping of the vegetation communities.

Sixteen plant community types were identified within the zones of potential shallow groundwater (Umwelt, 2019). Vegetation in three of the community types was considered to have a moderate potential for being dependent on groundwater, one community was considered to have a high potential, and the remaining 12 communities were considered to have a low potential.

The three communities with moderate GDE potential were identified as riparian and floodplain communities:

- HU812/PCT1598 – Forest Red Gum Grassy Open Forest on Floodplains of the Lower Hunter;
- HU821/PCT1607 – Blakely's Red Gum – Narrow-leaved Ironbark – Rough-barked Apple shrubby woodland of the upper Hunter; and
- HU945/PCT1731 – Swamp Oak – Weeping Grass Grassy Riparian Forest of the Hunter Valley.

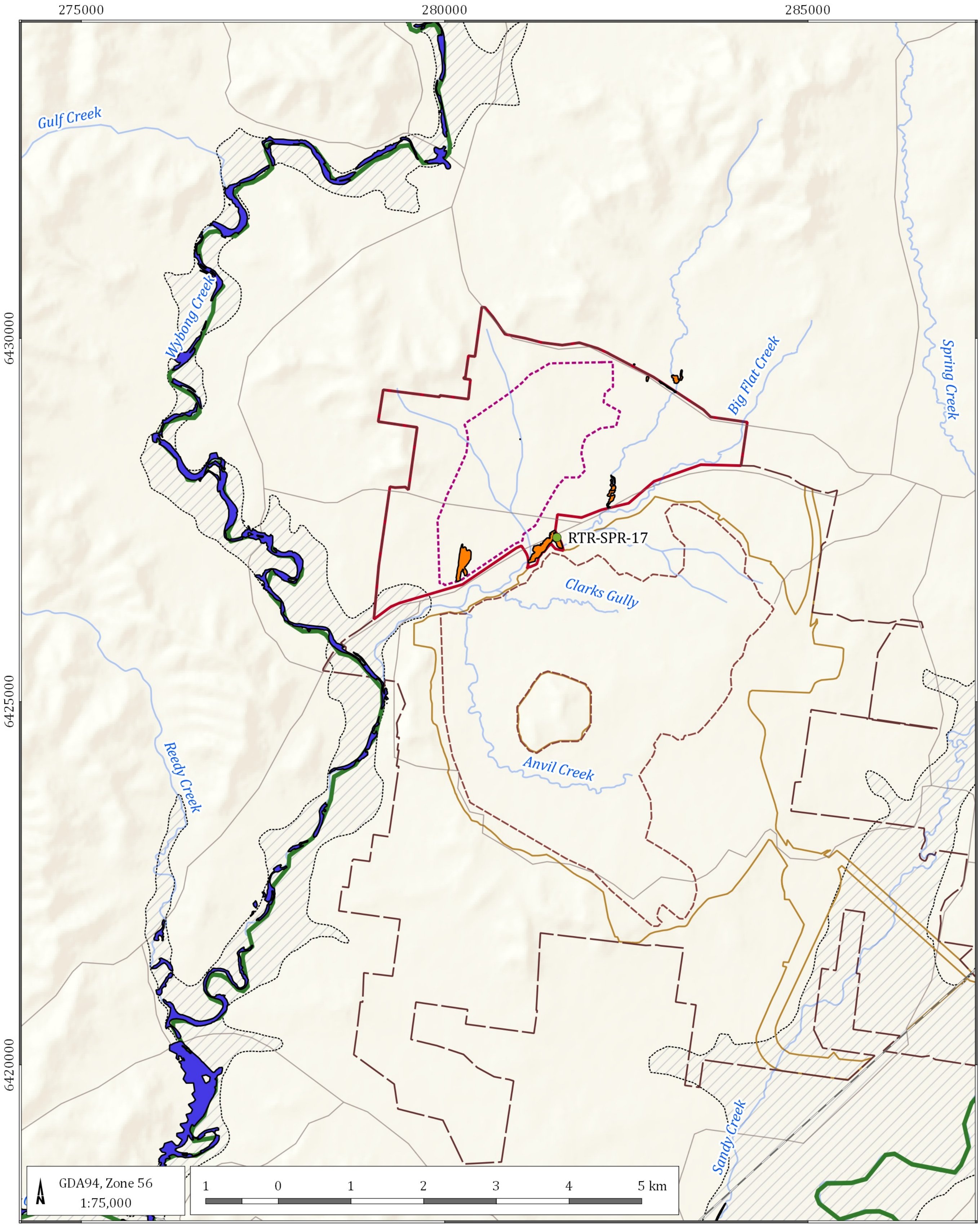
The community with the highest GDE potential occurs within the Wybong Creek alluvium:

- HU928/PCT1714 – *Eucalyptus camaldulensis*/*Casuarina cunninghamiana* grassy riparian woodland of the Hunter Valley.

The National Atlas of Groundwater Dependent Ecosystems (BOM, 2017) also identifies the Wybong Creek and Hunter River as having a moderate potential for being a 'river' type of aquatic GDE.

All areas where the localised surveys have identified moderate or high potential for supporting GDEs are shown in Figure 5.30.

Mangoola Coal Mine undertake annual ecosystem monitoring for one potential GDE location along Big Flat Creek (RTR-SPR-17). The site, a 20 m x 50 m plot, is coincident with an area also identified as having moderate potential to support GDEs during the plant community mapping (Figure 5.30). The purpose of the annual mapping is to identify if there are any observable negative impacts on the flora that can be attributed to groundwater depressurisation caused by mining. The 2017 ecological monitoring report for the site (Umwelt, 2018) notes that although the vegetation may have been partially groundwater dependent until mid-2014, when the water table was drawn down below the root zone, floristic monitoring in 2017 did not observe any dieback that was likely to be associated with de-watering or lack of access to groundwater as a result of mining. The report also comments that the site appeared to be in a good state of health, and that additional floristic monitoring along other sections of Big Flat Creek did not identify areas of unexplained dieback likely to be associated with changes to groundwater.



LEGEND

- G1839F_Populated_place
- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mining Area
- Approved Mangoola Coal Mine Disturbance Area
- Proposed Additional Mining Area
- Alluvium
- Road
- Rail
- Drainage

High or medium potential for GDEs

- High potential - plant community
- Moderate potential - plant community
- Moderate potential - GDE Atlas aquatic
- Mangoola Coal GDE monitoring site

Mangoola EIS (G1839F)

Potential areas with moderate or high potential to support groundwater dependent ecosystems

AGE

DATE 26/02/2019

FIGURE No: **5.30**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
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5.4.4 Stygofauna

Stygofauna are small specialised subterranean aquatic invertebrates that are found in aquifers across Australia and the rest of the world. Stygofauna are predominantly found in aquifers with large (mm or greater) pore spaces, especially alluvial aquifers, and less frequently fractured rock aquifers (Hose *et al.*, 2015). Stygofauna have occasionally been recorded in coal seam aquifers, especially those which are hydraulically connected to a shallow alluvial aquifer.

The majority of stygofauna are found in locations where food supply and oxygen are more plentiful. The optimal conditions for stygofauna have been identified as:

- alluvial systems with large pore spaces;
- water levels within 20 metres of ground surface;
- electrical conductivity of less than 5,000 µS/cm (TDS ~3,350 mg/L); and
- pH of approximately 6.5 to 7.5.

There is the potential for mining activities to impact on stygofauna habitats if they are present in the aquifer units near to the mines. Physically the most likely locations for stygofauna to be present in the vicinity of the mine are within the Wybong Creek alluvium and the immediately adjacent strata.

Eleven of the Mangoola Coal monitoring bores were sampled for stygofauna by Eco Logical Australia in October 2017 following relevant Commonwealth and NSW Government guidelines. No stygofauna taxa were recorded in any of the bores sampled (Eco Logical, 2019). Although no stygofauna were identified in the Wybong Creek alluvium it was considered to have the greatest potential to be a stygofauna habitat, whereas the hardrock and colluvial units within the MCCO Additional Project Area were considered to be unlikely stygofauna habitats (Eco Logical, 2019).

5.5 Conceptual model

Conceptual models are abstractions or simplifications of reality. During development of conceptual models, the essence of how the key system components operate and interact is distilled. This section describes the processes that control and influence the storage and movement of groundwater in the hydrogeological systems occurring in vicinity to the MCCO Project and the broader Mangoola region.

Groundwater recharge to the Permian strata occurs via rainfall to the ground surface infiltrating into the formations through the soil cover and weathered profile. The coal seams also occur as subcrops in localised zones across the Mangoola Coal mining footprint. The alluvial and colluvial sediments are also expected to be recharged by seepage through the creek beds when these are flowing. Groundwater-surface water interactions are expected to be more significant within the Wybong Creek and Sandy Creek alluvium than along the smaller Big Flat Creek where there is no significant alluvial sediment present. The Big Flat Creek colluvium is largely unsaturated as it occurs as a surficial capping of limited thickness, and more recently is also subject to drainage due to the approved operations at the adjacent Mangoola Coal Mine.

The alluvial sediments occurring in the flood plain along Wybong Creek and Sandy Creek can be up to approximately 20 m in thickness. Yields in areas of the alluvium are over 25 L/s, which suggests a high permeability and transmissivity in these areas. This is not consistent across the alluvial units, with some sites having yields of less than 0.5 L/s. There are also areas of brackish to moderate salinity observed within several of the alluvial bores. The salt concentration is due to either upward flow of Permian groundwater through the Triassic strata and into the Quaternary alluvium, and/or evaporative concentration of rainfall recharge. The Wybong Creek and Sandy Creek alluvium appear to have been historically exploited on a small scale for groundwater extraction. The available data indicates these systems would likely meet NSW government criteria to be classified as a "highly productive" groundwater source, which requires TDS concentrations less than 1,500 mg/L and water supply works that can yield water at a rate greater than 5 L/s.

The Bioregional Assessment for the Hunter Valley subregion identifies two landscape classes that could potentially support groundwater dependent ecosystems in the vicinity of the MCCO Project; forested wetlands along the Wybong Creek, and rainforest within the higher ground to the west of Wybong Creek. The depth to groundwater within the Wybong Creek alluvium suggests that the forested wetland communities would only occur within the gullies associated with the currently active incised Wybong Creek channel. A more localised assessment of potential GDEs in the vicinity of the MCCO Project identified small areas along Big Flat Creek with a moderate potential to support GDEs. No areas with a moderate or high potential to support GDEs were identified along Sandy Creek.

The Permian coal measures and Triassic sandstones and conglomerates form less productive groundwater systems, when compared to the shallow alluvial systems, with the coal seams and shallow weathered conglomerates being the most permeable lithology within the bedrock sequences. The unfractured conglomerates, and tuffs within the coal measures retard groundwater flow in a vertical direction. The coal seams occur in a basin structure and any associated groundwater becomes confined by the lower permeability interburden as the seams dip towards the north-west and deepen. There is minimal recorded abstraction of groundwater from the bedrock strata for stock, domestic and other agricultural uses, primarily due to low yields and the high salinity limiting beneficial uses.

Groundwater flows from areas of high head (pressure plus elevation) to low head via the most permeable and transmissive pathways. Although there are few data points within the alluvial systems the flow direction will be a reflection of the topography, with alluvial groundwater flowing ‘downstream’ towards the Hunter River. The groundwater levels within the Permian are influenced by topography and more recently the progression of mining activities at Mangoola Coal Mine. The lower salinity recorded for the Wybong Creek alluvium suggests that the contribution of Permian groundwater to the Quaternary alluvium is limited. Therefore the high baseflow component of flow in Wybong Creek likely represents the release of groundwater stored within the alluvium in the upgradient catchment.

Depressurisation of the Permian strata below the Big Flat Creek colluvium adjacent to the Mangoola Coal Mine is evident in the hydrographs from the Mangoola Coal Mine monitoring bore network. The hydrographs indicate a significant reduction in pressure head in the deeper confined units, and a smaller reduction in the shallow sites. This has led to a long term disconnection of Big Flat Creek from the underlying groundwater system. However, prior to mining commencing groundwater levels would only have reached the level of the creek bed in wet years. The drawdown responses observed in the monitoring bores are generally similar to those predicted in the approved Mangoola Coal Mine EIS groundwater assessment (MER, 2006), although the observed responses show some localised variability that cannot be represented by numerical modelling that assumes more uniform hydraulic properties.

The Mt Ogilvie fault is located to the east of the MCCO Project, and offsets the Permian strata by approximately 125 m. On a local scale it is conceptualised as forming a barrier to flow by truncating any permeable units. However, at a formation scale the units on each side of the fault are both Permian Coal Measures and will be hydrogeologically similar. The target coal measures for the MCCO Project are not present at the fault and there are likely to be no significant influences to predicted Project impacts as a result of the fault being present. Minor faulting also occurs throughout the MCCO Proposed Additional Mining Area. Whilst there is the potential for faults to transmit groundwater this has not been established and is expected to be relatively limited, given the limited cross sectional areas of the fault zones and the potential for the fault gouge sediment to retard groundwater flow.

On a local scale, moderately saline groundwater has historically flowed towards Big Flat Creek within the weathered conglomerate, and a deeper (highly saline) confined groundwater flow system associated with the coal seams has flowed towards the north-west. This is shown conceptually in Figure 5.31 and Figure 5.32. Figure 5.31 shows moderately saline groundwater flow pre-mining within the weathered conglomerate, and a deeper (highly saline) confined groundwater flow system associated with the coal seams. During this time groundwater flow is down topographic gradient, with flow lines converging under Big Flat Creek (Figure 5.31).

During mining at the Mangoola Coal Mine, the groundwater flows for each groundwater system have been intersected and interrupted, as mining has removed the weathered to fresh conglomerate, interburden, and target coal seams. This results in localised groundwater flow towards and into the Mangoola Coal Mine, and localised drawdown of groundwater levels around the perimeter of the Mangoola Coal Mine. Localised drawdown of groundwater levels occurs proximal to the perimeter of the Mangoola Coal Mine. These altered conditions are shown conceptually in Figure 5.32.

During the pre-mining and mining phases, there will be periods of surface water flow within the Big Flat Creek flow channel from rainfall events. The high salinity of the underlying groundwater suggests the seepage rates are low.

If the MCCO Proposed Additional Mining Area were to be extracted then this would affect the groundwater system in a similar way. The exception being that the groundwater regime underlying Big Flat Creek between the two mining areas will already be affected by mining at Mangoola Coal Mine.

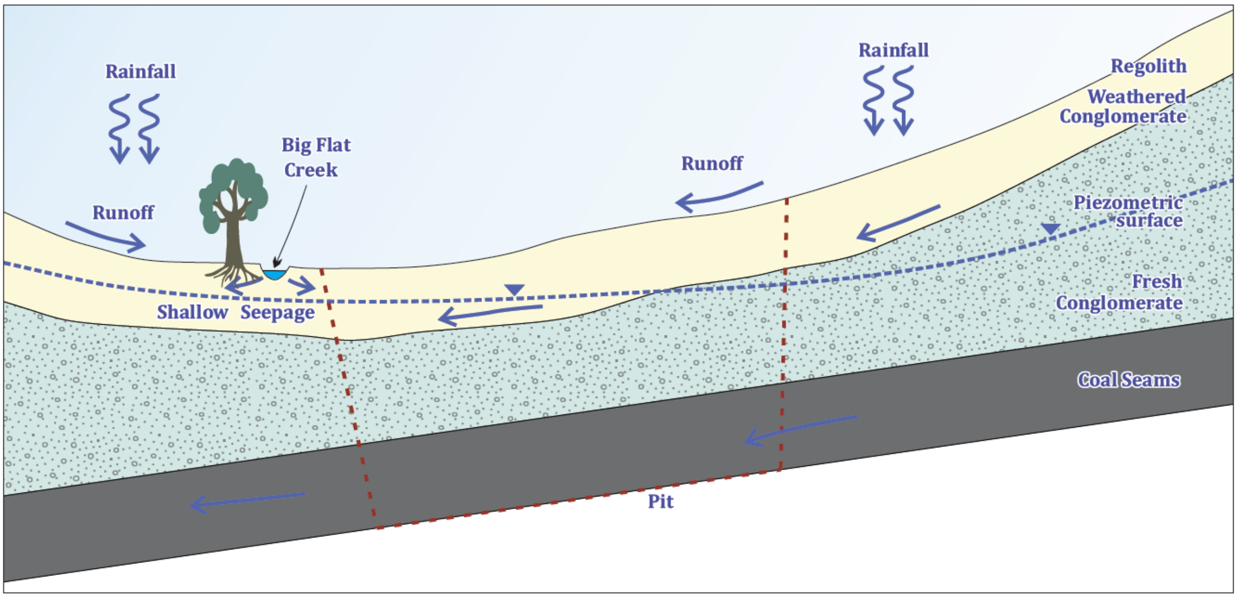


Figure 5.31 Conceptual hydrogeological model – pre mining

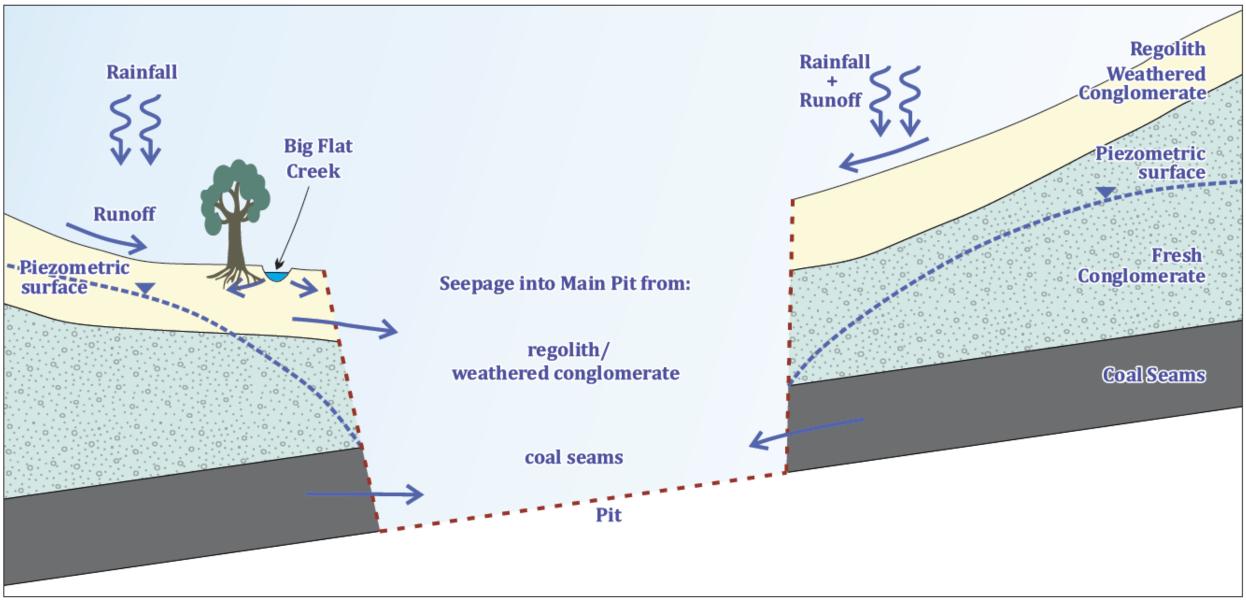


Figure 5.32 Conceptual hydrogeological model – during mining

5.6 Potential impact causal pathways

For the purposes of Bioregional Assessments causal pathways are defined as *'the logical chains of events – either planned or unplanned – that link coal resource development and potential impacts on water resources and water dependent assets'* (Dawes et al, 2018). Water dependent assets can be impacted by changes to quantity, quality or timing of surface water or groundwater or both. Water dependent assets in the vicinity of the MCCO Project were identified in Section 5.4.

The identification of causal pathways between the proposed development and the water-dependent assets is an important part of the impact assessment process. Causal pathways are initiated by an activity associated with the coal resource development. In the case of the MCCO Project this is the mining of coal from within the MCCO Proposed Additional Mining Area. Mining at the existing Mangoola Coal Mine is already approved, and it is the incremental increase in potential impacts that requires assessment. It is also important to note surrounding areas and water-dependent assets that are unlikely to be impacted by the proposed development.

There are four main causal pathway groups associated with coal mining, although there is commonly overlap or linkage between them:

- 'subsurface depressurisation and dewatering';
- 'subsurface physical flow paths';
- 'surface water drainage'; and
- 'operational water management'.

This report focusses on those causal groups primarily related to groundwater, that is 'subsurface depressurisation and dewatering', and 'subsurface physical flow paths'. 'Surface water drainage' is also briefly discussed in relation to groundwater-surface water interactions.

The ‘subsurface depressurisation and dewatering’ group of causal pathways occurs when coal mines intentionally dewater the subsurface so that open-cut mining operations can occur safely. The pre-existing hydraulic gradients are disrupted, usually causing changes to groundwater levels and pressures, and occasionally altering groundwater quality. Pumping from conventional bores extracting groundwater to support mining activities is also part of this causal group. However, the scale of these effects is typically less than those associated with open cut mine dewatering. Groundwater extraction for open cut mine development can unintentionally affect non-target strata in situations where direct hydraulic connections exist. The connections could be diffuse, such as connections between adjacent geological layers, or more focussed via structures such as faults.

The ‘subsurface physical flow paths’ causal pathway group involves activities that physically modify the rock mass, creating new pathways that water may flow along. During open cut mining the enhanced pathways may occur via flow along unsealed exploration bores or incorrectly installed monitoring bores. Long term the replacement of pre-mining bedrock by spoil or a final void lake would alter the physical properties of the subsurface compared to pre-mining conditions.

Example causal pathway diagrams for open cut coal mining developments are presented in Henderson et al. (2016). The groundwater components that are potentially relevant to mining at Mangoola are summarised in Table 5.12. The table outlines the most likely pathways, impact causes, impact modes and activities to generate the impacts. The potential hydrological effects on the groundwater system are noted in the final column. Those components that are most likely to produce the greatest changes to the groundwater system, or which have been identified as occurring within the MCCO Project Area are highlighted bold.

Many of the smaller scale issues can be managed by following current best practices to reduce the likelihood of them occurring e.g. those activities caused by equipment failure or poor component design.

The potential activities that are most likely to produce impacts over a large area relate to the inevitable effects of open cut mining below the groundwater table, and backfilling of the resulting mining void with spoil.

Potential disruption to rivers has also been included as a high potential causal pathway, due to the proximity of Big Flat Creek to both the Mangoola Coal Mine and MCCO Proposed Additional Mining Area. However, there would be minimal impacts expected to the Wybong Creek or Sandy Creek.

There is some evidence that there has historically been a small amount of depressurisation of deeper coal measures close to the Mangoola Coal Mine as a result of vertical movement along unsealed exploration bores (MER, 2006).

The most likely potential causal pathways identified should be considered when designing the numerical groundwater model to ensure that they are suitably represented.

Table 5.12 Causal pathways with a groundwater component

Pathway	Cause	Mode and activity	Hydrological effect
Aquifer outcrop areas – deep soil drainage	Coal characteristics	Fire in stockpiles, fire in the pit from excavation or blasting, fire in stockpiles	Quality
	Incomplete rehabilitation	Negligence during post-closure mine decontamination	Quality
	Consolidation of loose backfill	**Compaction or settlement of backfill over time**	**Direction**
	Diverting site drain line	Changes to natural surface drainage through diverting creeks or for rainfall and runoff diversion Disruption of natural surface drainage via dam construction, site preparation, topsoil and spoil preparation Disruption of natural surface drainage by excavation of the pit	Quality, Direction, Volume/ quantity
	Inevitable, deliberate	**Deliberate pit wall dewatering** **Leaching of spoil dumps or coal stockpiles** **Runoff changes via topsoil excavation and storage**	**Quality,** **Flow (reduction),** **Pressure,** **Volume/ quantity,**
	Poor handling/management	Excessive runoff during closure from water management structures	Quality
Aquifer outcrop areas – SW-GW interactions	Human error, accident	Equipment (pipe) failure leading to containment failure for dewatering water, waste streams, mine dewatering, treatment, re-use, disposal Substantial spillage from on-site mine equipment or on-site coal transport Treatment plant failure during mine water treatment, re-use, disposal	Quality
	Containment failure, leaching, flooding	Groundwater or surface water contamination from drill cutting disposal Increased inflow from natural events during dewatering, treatment, reuse and disposal processes Overflow and/or loss of containment of surface water Treatment plant failure during mine water treatment, re-use, disposal Leaching of tailings water decant dam	Quality

Pathway	Cause	Mode and activity	Hydrological effect
	Physical disruption of river boundary or channel	Linking aquifers via preferential drainage if mine expansion too close to river/lake	Flow (reduction), Pressure, Volume/ quantity
Aquifers – Groundwater conditions	Drilling control issues	Pressure imbalance and localised water table changes	Quality, Level
	Incomplete grouting	**Incomplete/compromised cementing leading to linking of aquifers within groundwater bores**	**Quality,** **Composition**
	Poor design, construction	Bore leakage between aquifers following abandonment Linking aquifers in groundwater supply bores with long screens	Quality, Composition
Aquifers – Groundwater conditions post mining	**Inevitable, deliberate**	**Artificial point of recharge, enhanced aquifer interconnectivity, groundwater source/sink – post closure water filling the pit** **Leaching from in-pit backfill/spoil dump** Groundwater extraction from groundwater supply bores	**Quality,** **Direction,** **Pressure,** **Volume/ quantity** Pressure

Note*:** ***Bold *highlighting indicates those causes and activities that are likely to cause the greatest changes at Mangoola.*

6 Numerical groundwater model

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

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

6.1 Overview of groundwater modelling

A 3D numerical groundwater flow model was developed for the MCCO Project using MODFLOW-USG. The objective was to accurately represent the potential impacts from the MCCO Project on the groundwater system and the identified water dependent assets. A detailed description of the modelling logic is provided in Appendix A.

The model represents the key geological units as 15 layers, extending up to approximately 17 km from east to west, and 17.3 km from north to south. It comprises up to 14,931 cells per layer, making it spatially a large model (Figure 6.1).

The numerical model developed for the MCCO Project was based upon existing models that were developed for the Mangoola Coal Mine by Mackie Environmental Research (2006, 2013). AGE has based the 2018 MODFLOW-USG model on the previous models to, as far as possible, create consistency with previous work. Key updates to the model in 2018 included:

- converting model to MODFLOW USG; including expanding the model boundary, development of a new model mesh, and revised layer extents and thicknesses (based on updated Glencore geological model);
- updating water level monitoring dataset;
- updating recharge dataset;
- adding pilot points to represent the heterogeneity present within hydrogeological layers;
- updating the thickness and extent of the Quaternary alluvium based on revised topographic mapping and CSIRO datasets;
- updating progression of approved and proposed open cut mining at Mangoola Coal Mine;
- recalibrating the model hydraulic parameters to improve the match between simulated and measured water level records and mine inflows at Mangoola Coal Mine;
- adding the MCCO Proposed Additional Mining Area; and
- predicting impacts on the groundwater regime.

The model was used to identify the influence of the MCCO Project on the groundwater regime by comparing the impacts generated by the approved and proposed Mangoola mines (Mangoola Coal and MCCO Proposed Additional Mining Area) vs the approved Mangoola Coal Mine only. The relatively isolated location of the MCCO Project area within the Hunter Valley means that cumulative groundwater impacts with other Hunter Valley mines were considered highly unlikely and therefore did not require representation within the numerical model.

The model was calibrated using historical groundwater levels from monitoring bores. The volume of groundwater estimated as being pumped from Mangoola Coal Mine was also used to guide the calibration of the model. A detailed description of the calibration procedure is provided in Appendix A. The objective of the calibration was to replicate the groundwater levels measured in the monitoring network, and the mine inflows in accordance with the Australian Groundwater Modelling Guidelines (AGMG) (Barnett *et al.* 2012). The transient calibration achieved a 4.9 % scaled root mean square (SRMS) error, which is well within acceptable limits (i.e. 10%), recommended by the AGMG. On a scale of Class 1 to Class 3 (Barnett *et al.* 2012) the model confidence level classification lies between a Class 2 (Impact assessment) and Class 3 (Complex simulator). This indicates that the groundwater model is suitable for predicting groundwater responses to changes in applied stress of hydrological conditions, and the evaluation and management of potential impacts.

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

- Cumulative impacts = Mining occurs from both the approved Mangoola Coal Mine and MCCO Proposed Additional Mining Area.
- MCCO Proposed Additional Mining Area incremental impacts = Cumulative mining predictions minus approved Mangoola Coal Mine only predictions. This shows the incremental impact of mining the proposed MCCO Proposed Additional Mining Area on groundwater resources.

It is important to note that the currently approved operations at Mangoola Coal Mine have been approved based on previously completed groundwater assessments (MER, 2006). As the groundwater model has been updated and refined since this time there are differences in the current and future impacts predicted for the approved Mangoola Coal Mine only mining activities. These differences are not considered material, and at a high level the updated predictions are consistent with those previously predicted. These impacts are described later in Section 7.

The uncertainty of the final model predictions, resulting from initial uncertainty in the assumptions and input parameters, was analysed. The analysis focussed on varying model parameters and design features that have the most influence on model predictions. The model parameters were adjusted to encompass the expected range of uncertainty. Appendix A provides a detailed discussion of the uncertainty analyses. Where possible the uncertainty analysis followed the process recommended in the draft note on uncertainty analysis (Middlemis and Peeters, 2018).

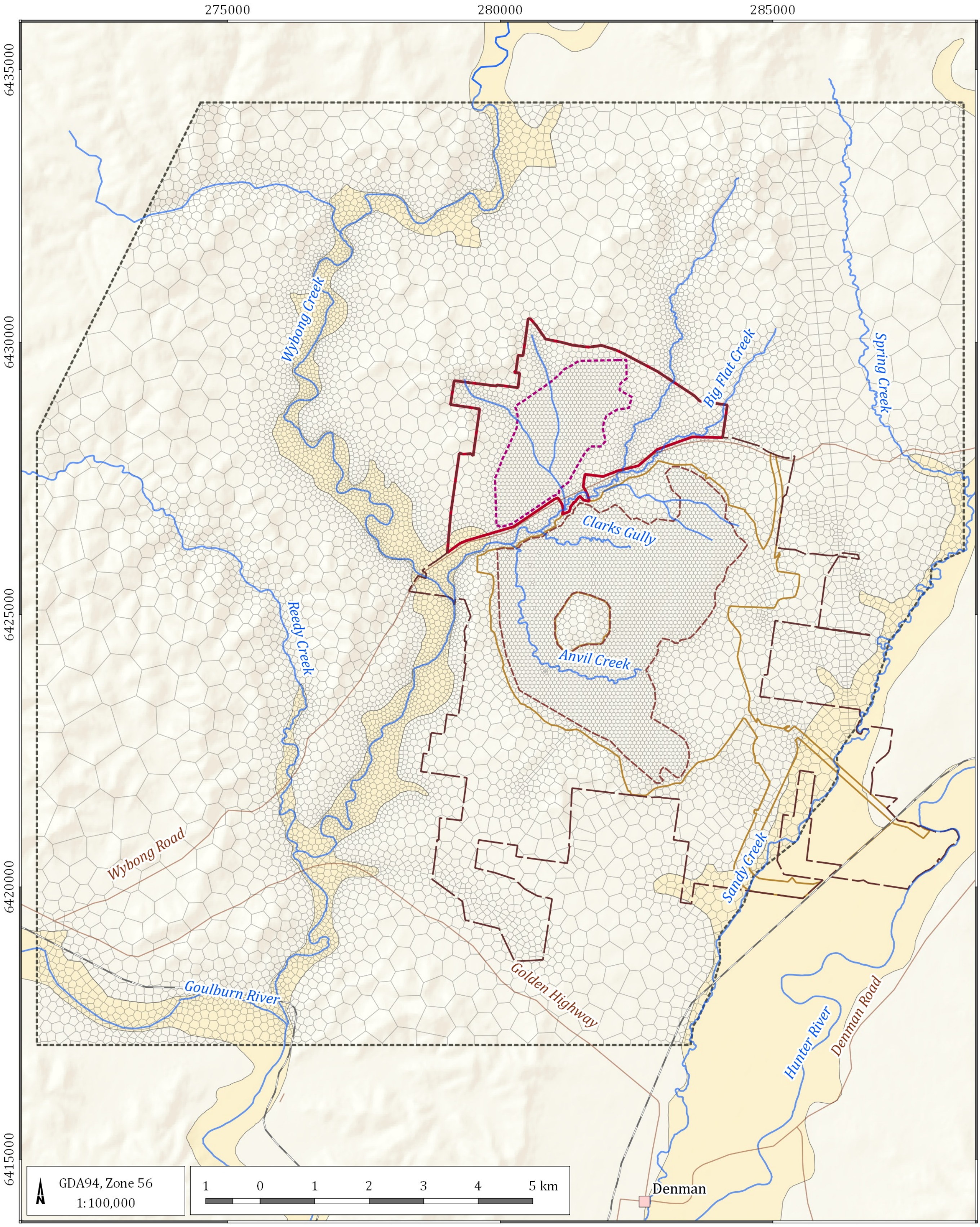
6.2 Peer review

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

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

Dr Merrick also reviewed the modelling to assess if it generally complied with the draft note on uncertainty analysis from the IESC.

The peer review (HydroAlgorithmics, 2019) concluded that the groundwater assessment is best practice and that the model is fit for purpose. It further concluded that the assessment is based on data analysis, conceptualisation and groundwater modelling that has been conducted to a very high standard (HydroAlgorithmics, 2019). The peer review documents are included as Appendix E.



LEGEND

- Populated place
- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Numerical model boundary
- Model mesh
- Alluvium
- Road
- Rail
- Drainage

Mangoola EIS (G1839F)

Model extent and mesh

AGE

DATE 26/02/2019

FIGURE No: **6.1**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
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7 Model predictions and impact assessment

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

- groundwater directly intercepted by mining from the Triassic and Permian coal measures within the Mangoola Coal and MCCO Proposed Additional Mining area (Section 7.1.1);
- drawdown in groundwater levels in the Quaternary alluvium and Permian coal measures as a result of the MCCO Project (Section 7.1.2);
- change in alluvial and baseflow availability (Section 7.1.3);
- water licensing requirements (Section 7.1.4);
- impact on private bores (Section 7.1.5); and
- drawdown impact to potential GDEs (Section 7.1.6).

Post closure impacts are discussed in Section 7.2.

7.1 Groundwater modelling predictions

7.1.1 Groundwater inflows to mining areas

For the purposes of this assessment the groundwater model assumes that mining commences in the MCCO Additional Mining Area in 2022. This timing may change depending on the timing of the project determination. Figure 7.1 shows the predicted direct take of groundwater from the Permian coal measures by the approved Mangoola Coal Mine and the Mangoola Coal Proposed Additional Mining Area. The figure also shows the predicted take from Mangoola Coal Mine if the MCCO Proposed Additional Mining Area were not developed. There is no notable change in inflows predicted at Mangoola Coal in the two different scenarios. The maximum cumulative predicted annual groundwater take of 280 ML/year is significantly less than the 700 ML/year porous rock water licence allocations currently held by Mangoola.

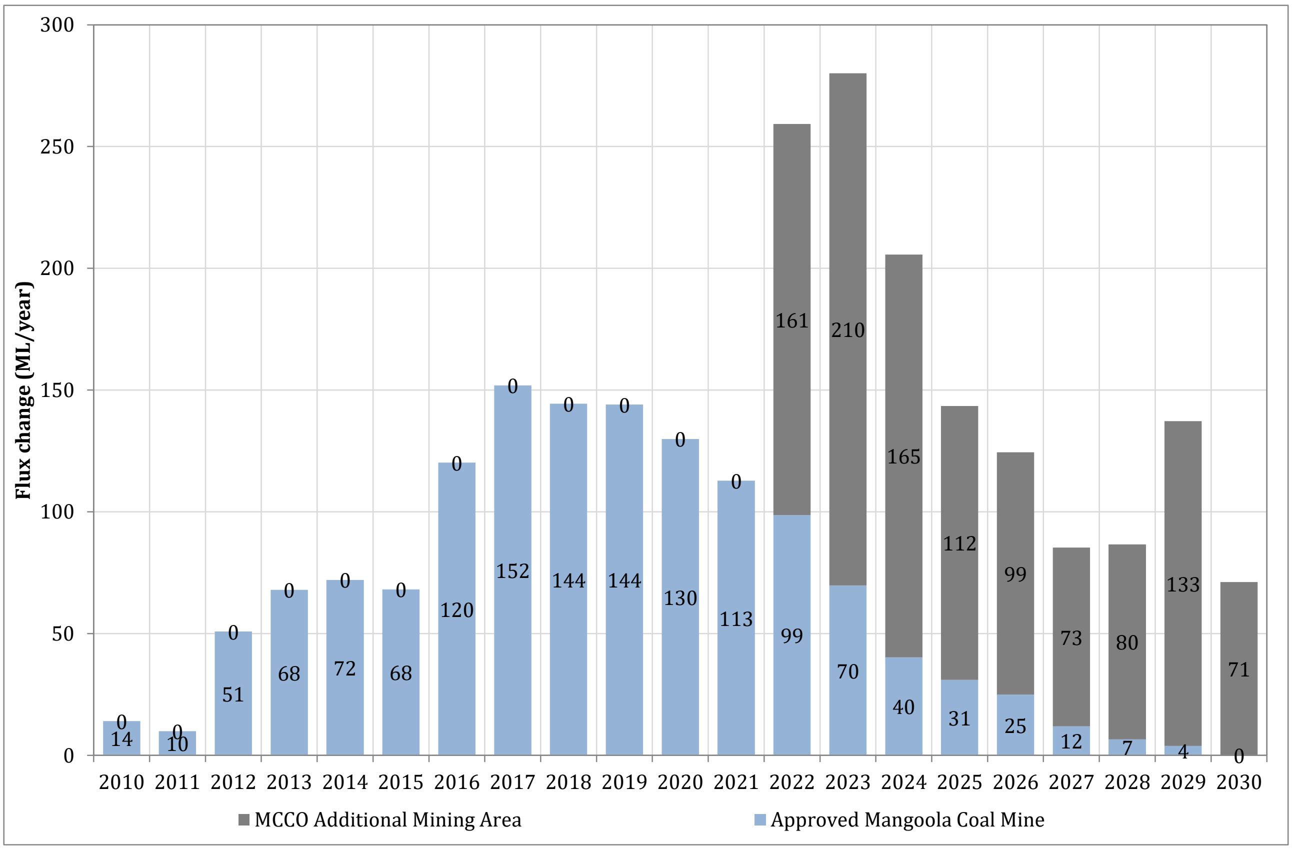


Figure 7.1 Predicted direct take of groundwater by the approved and proposed mines

7.1.2 Drawdown due to mining operations

Predictions of maximum groundwater drawdown during mining have been completed using the numerical groundwater model described in Section 6. This model is termed the 'basecase' model as it represents the most favourable calibration and is the model around which all later uncertainty analysis is conducted. The predicted drawdown contours are a composite of the maximum values predicted at each cell at any time over the operational period of mining. The actual duration and timing of the maximum drawdown within each cell varies depending on the proximity of mining.

Drawdown maps are presented for the alluvium and regolith (Layer 1), shallow weathered zone (Layer 2), unweathered conglomerate (layer 5), and Fassifern and Upper Pilot A seams (layer 8) in Figure 7.2 to Figure 7.5. Areas of drawdown within the mining footprints have been greyed out as the surface materials will be completely removed during mining. Each figure is split to show outputs for two different scenarios:

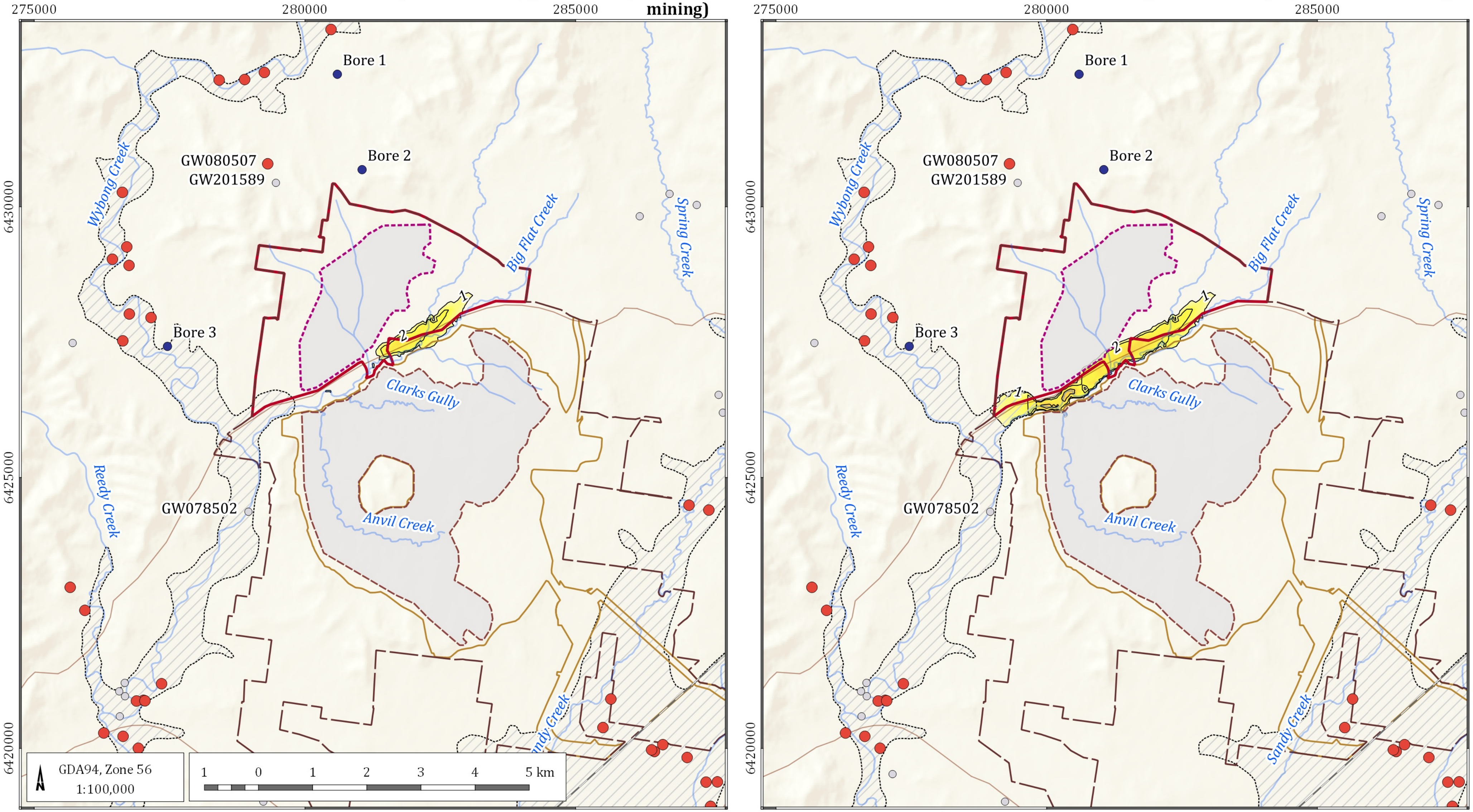
- Maximum cumulative drawdown = Mining occurs from the approved Mangoola Coal Mine and MCCO Proposed Additional Mining Area.
- Maximum MCCO drawdown = Cumulative drawdown minus approved Mangoola Coal Mine only drawdown. This shows the incremental impact of mining the proposed MCCO Proposed Additional Mining Area on groundwater resources.

Model layer 1 represents the shallow strata comprising Wybong Creek alluvium, Sandy Creek alluvium, shallow colluvium along Big Flat Creek, and a thin 2 m thick regolith layer across the remainder of the numerical model area. The preliminary zone of predicted drawdown impacts greater than 1 m within these surface strata is limited to a thin zone along Big Flat Creek that extends slightly into the Wybong Creek alluvium in the cumulative mining scenario. The drawdown primarily occurs as a result of the existing approved mining at Mangoola Coal Mine, with the MCCO Proposed Additional Mining Area extending the predicted zone of drawdown slightly upstream along Big Flat Creek. The limited spatial extent of the shallow drawdown likely reflects the unsaturated nature of the regolith across much of the model area. Once the materials are unsaturated there is no additional drawdown possible within the layer.

Model layer 2 represents the weathered bedrock that underlies the surface strata. This layer is present across the entire model domain. The preliminary zone of predicted drawdown impacts of greater than 1 m shows a similar spatial extent and magnitude to layer 1 in the vicinity of the Wybong Creek alluvium, with the impacts in this area also primarily generated from the approved Mangoola Coal Mine. The predicted layer 2 impacts extend over a larger area upstream of the two mining areas compared to those observed in layer 1. The cumulative drawdown indicates the spatial extent of the predicted drawdown upstream of the MCCO Project is primarily due to mining from the MCCO Proposed Additional Mining Area. Between the two operating areas the magnitude of drawdown is a combination of impacts from both operating areas.

Model layer 5 represents the unweathered conglomerate between the near surface weathered materials and the coal measures. Model layer 8 represents the Fassifern and Upper Pilot A coal seams, which are the lowest seams being mined in the MCCO Proposed Additional Mining Area. The layers subcrop along a northeast-southwest alignment within the mining leases, which restricts potential impacts to those areas north and west of the MCCO Project. Predicted drawdowns during mining are more extensive in the deeper bedrock than the shallow layers, a result that has already been observed through monitoring at Mangoola Coal Mine. Although the cumulative impacts in both model layers extend under the Wybong Creek alluvium, and the unweathered conglomerate being modelled as almost directly underlying a thin alluvial-bedrock transition zone in many areas, the incremental drawdown from the MCCO Proposed Additional Mining under the alluvium is minimal. There are potentially four bores on privately owned land that lie within the predicted areas of over 2 m drawdown at the end of mining. These are discussed further in Section 7.1.5.

Maximum incremental drawdown due to MCCO (in addition to approved Mangoola Coal mining) | **Maximum cumulative drawdown (approved Mangoola Coal and proposed MCCO mining)**



LEGEND

- Populated place
- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Numerical model boundary
- Alluvium
- Mined areas
- Road
- Drainage
- Drawdown contour

Registered bores on privately owned land (including interpreted geology)

- Alluvial bore or shallow soak
- Bedrock bore
- Other landholder bore

Drawdown (m)

- 0
- 1
- 2
- 5
- 10

AGE

Mangoola EIS (G1839F)

Predicted maximum drawdown during mining - model layer 1 (alluvium, colluvium, and regolith)

DATE
06/04/2019

FIGURE No:
7.2

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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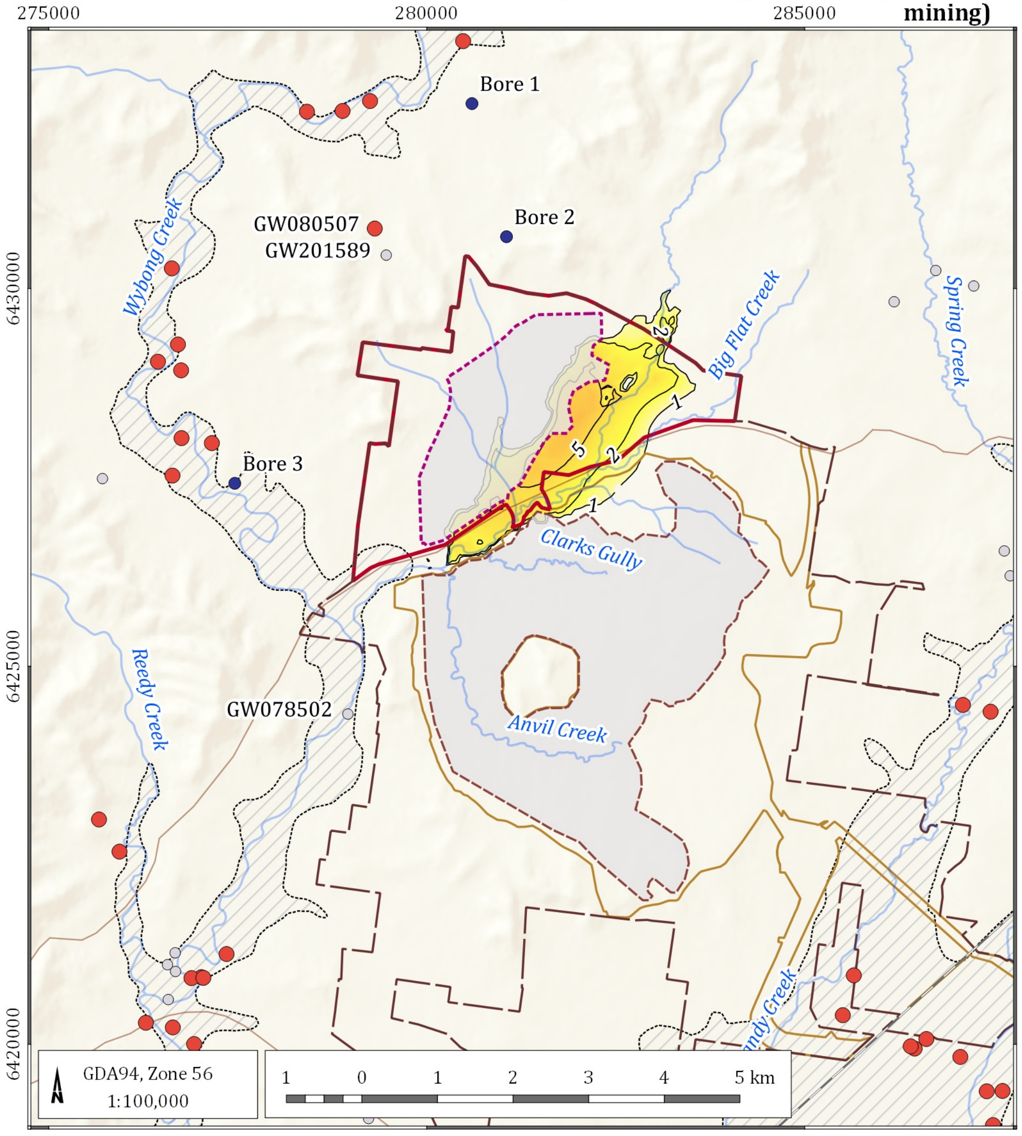
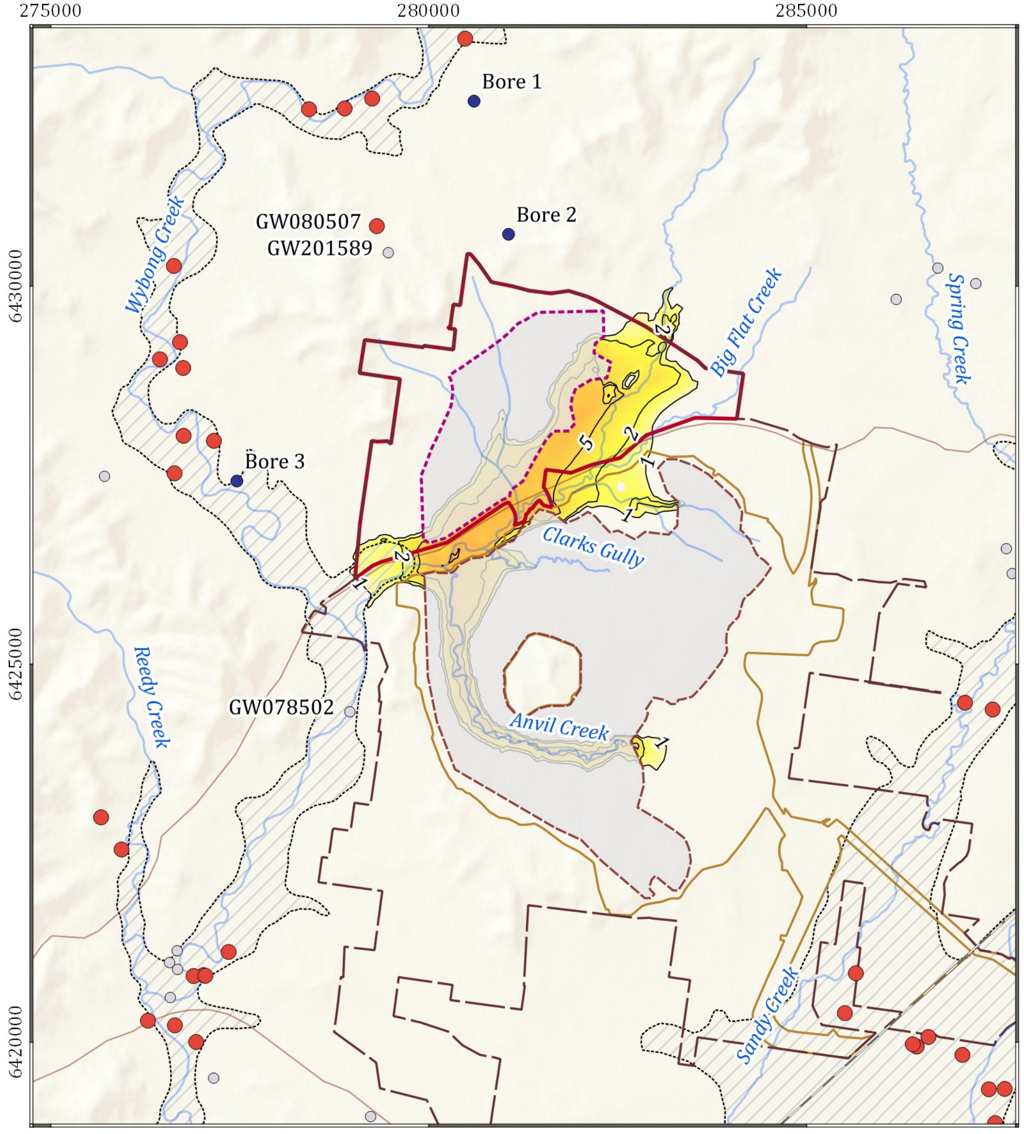
Maximum incremental drawdown due to MCCO (in addition to approved Mangoola Coal mining)



Maximum cumulative drawdown (approved Mangoola Coal and proposed MCCO mining)



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Alluvium
- Mined area
- Road
- Drainage
- Drawdown contour

Registered bores on privately owned land (including interpreted geology)

- Alluvial bore or shallow soak
- Bedrock bore
- Other landholder bore

Drawdown (m)

0	10
1	20
2	50
5	

Mangoola EIS (G1839F)

Predicted maximum drawdown during mining – model layer 2 (shallow weathered bedrock)

DATE
06/04/2019

FIGURE No:
7.3

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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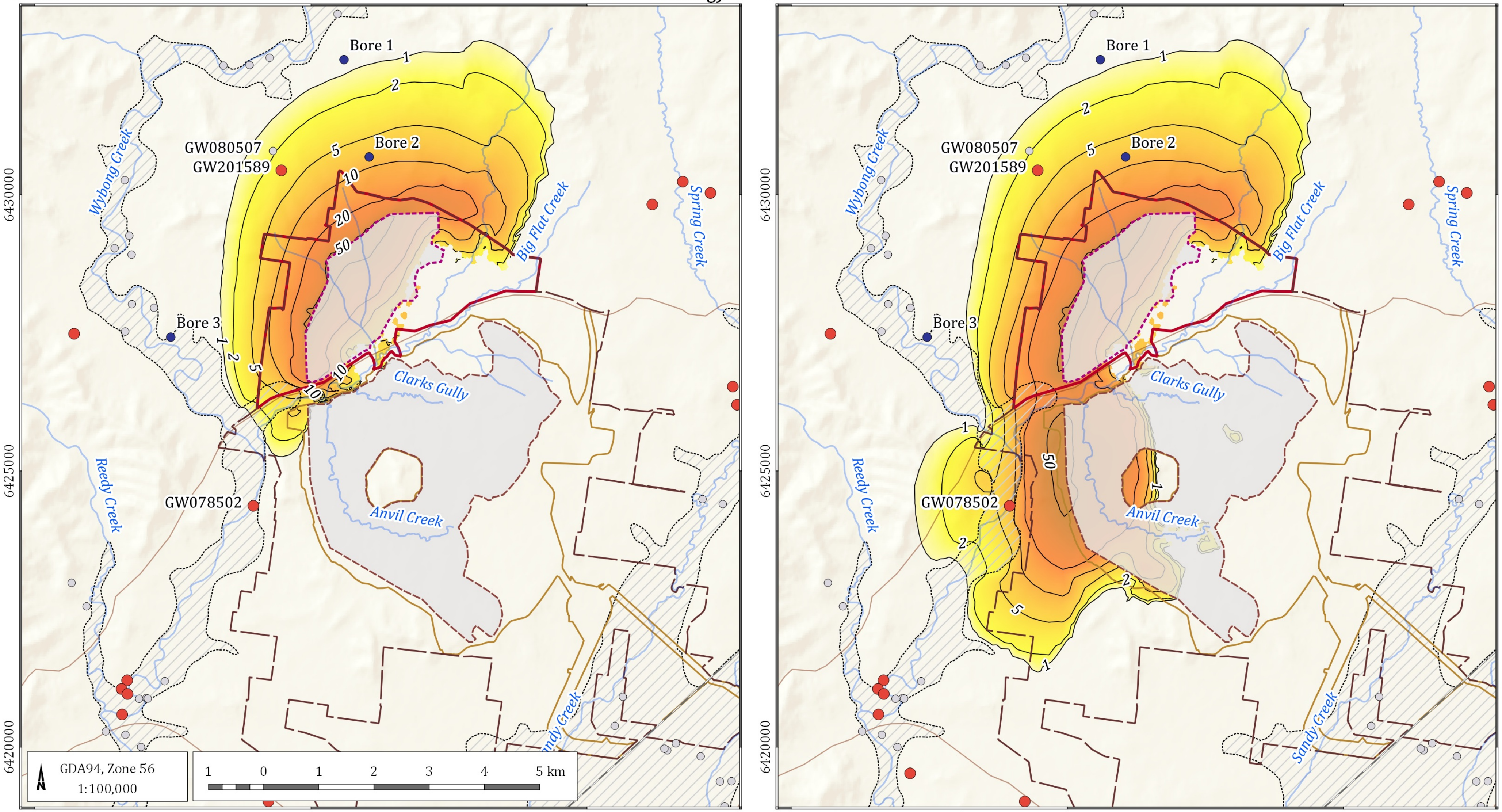
Maximum incremental drawdown due to MCCO (in addition to approved Mangoola Coal mining)

Maximum cumulative drawdown (approved Mangoola Coal and proposed MCCO mining)



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Alluvium
- Mined area
- Road
- Drainage
- Drawdown contour

Registered bores on privately owned land (including interpreted geology)

- Bedrock bore
- Alluvial bore or shallow soak
- Other landholder bore

Drawdown (m)

0, 1, 2, 5, 10, 20, 50

Mangoola EIS (G1839F)

AGE

Predicted maximum drawdown during mining – model layer 5 (unweathered conglomerate)

DATE
06/04/2019

FIGURE No:
7.4

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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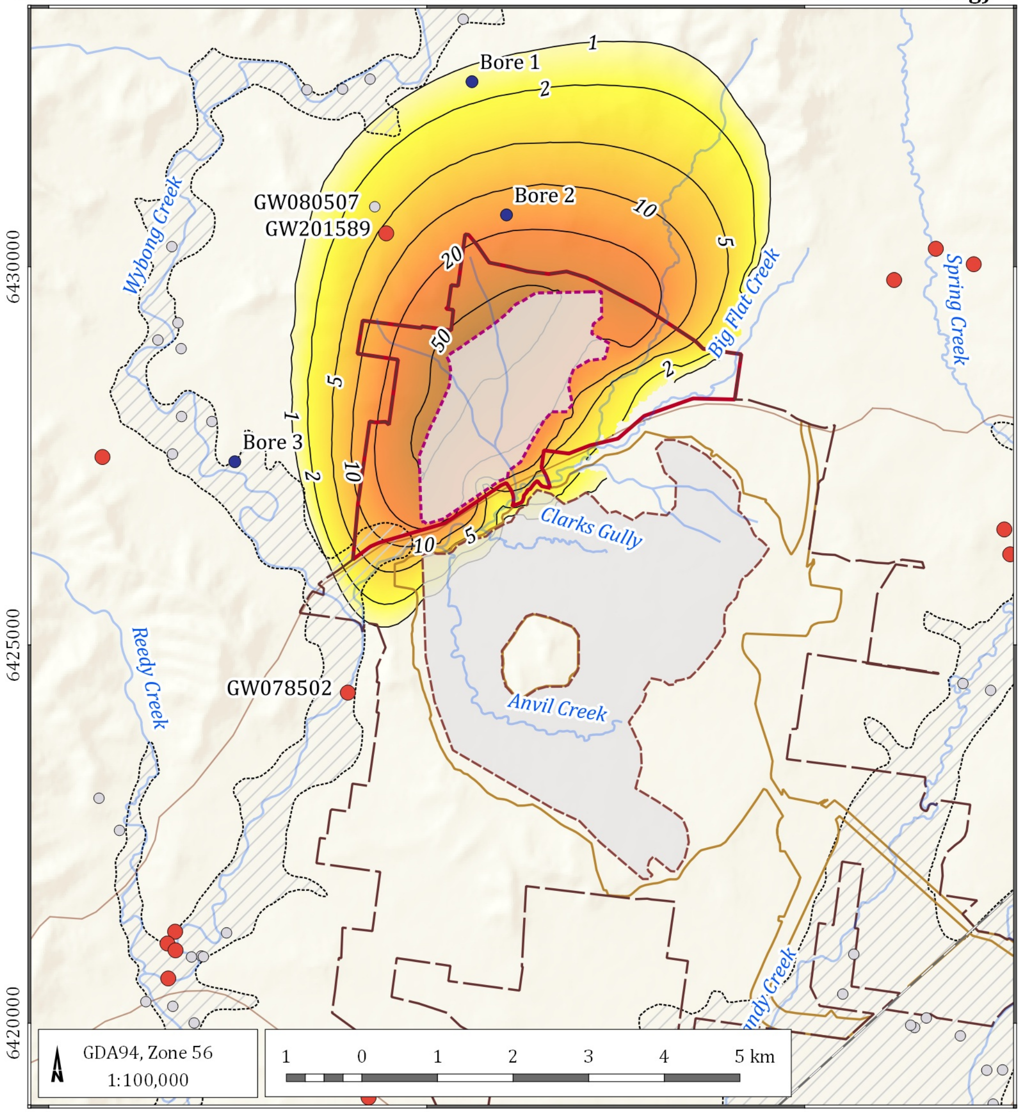
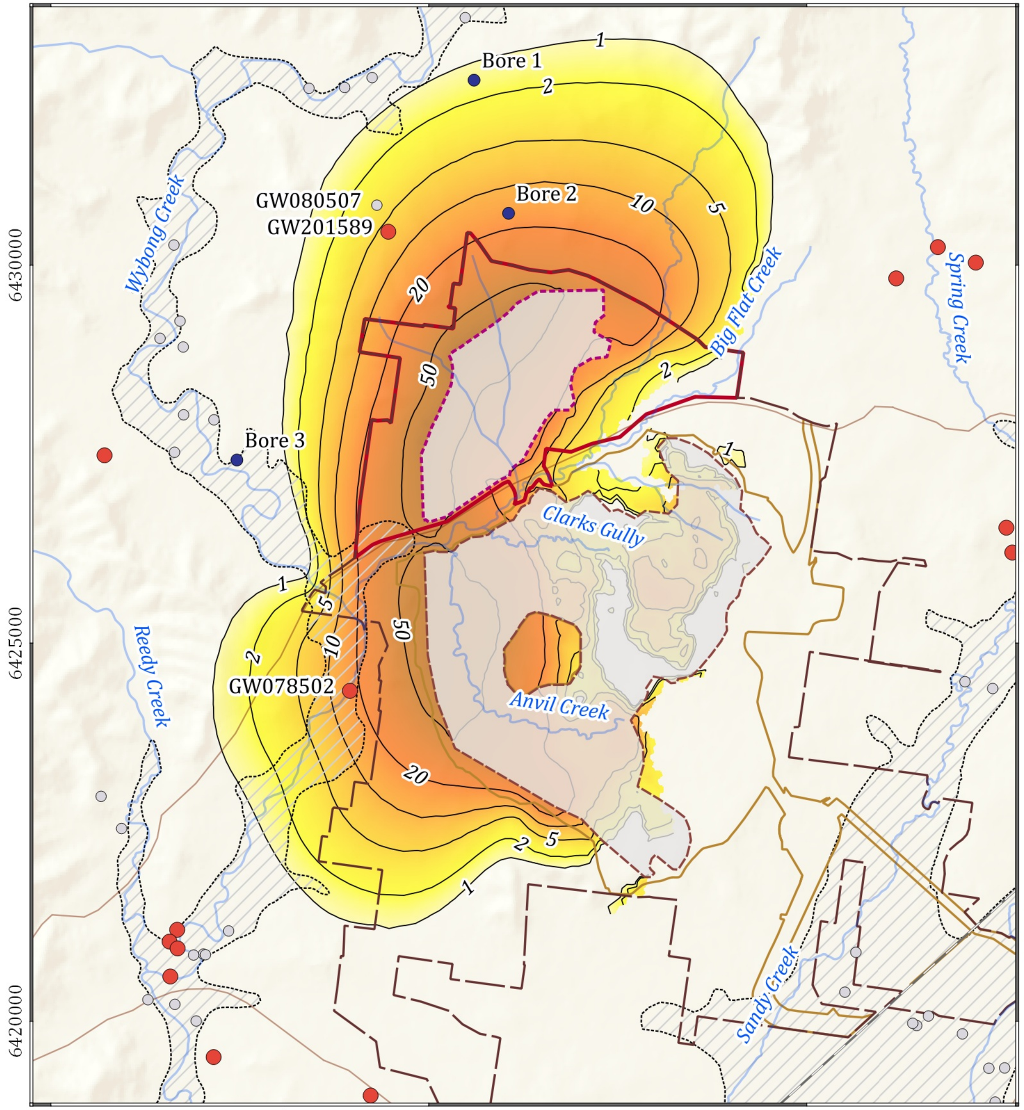
Maximum incremental drawdown due to MCCO (in addition to approved Mangoola Coal mining)



Maximum cumulative drawdown (approved Mangoola Coal and proposed MCCO mining)



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Alluvium
- Mined area
- Road
- Drainage
- Drawdown contour

Registered bores on privately owned land (including interpreted geology)

- Bedrock bore
- Alluvial bore or shallow soak
- Other landholder bore

Drawdown (m)

0, 1, 2, 5, 10, 20, 50

Mangoola EIS (G1839F)

AGE

Predicted maximum drawdown during mining – model layer 8 (Fassifern and Upper Pilot A coal seams)

DATE
06/04/2019

FIGURE No:
7.5

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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7.1.3 Change in alluvial and surface water fluxes

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

Figure 7.6 shows the change in flux predicted by the numerical model within Wybong Creek Alluvium due to the approved Mangoola Coal Mine and MCCO Proposed Additional Mining Area combined. The majority of the total change in flux during active mining (maximum 33 ML/year) can be attributed to the development of the approved Mangoola Coal Mine (maximum 30 ML/year). The incremental change due to mining at the MCCO Proposed Additional Mining Area is a maximum of 3 ML/year. Initially the change in flux compared to pre-mining conditions is almost entirely due to a reduction in groundwater inflow to the alluvium. By the end of mining the change in flux is a combination of a reduction in the groundwater inflow to the alluvium from the bedrock (~62%), and increased loss from the alluvium to bedrock (~38%).

The numerical model did not predict any changes in groundwater flux to the Sandy Creek Alluvium. This is an expected result as drawdown does not extend in this direction.

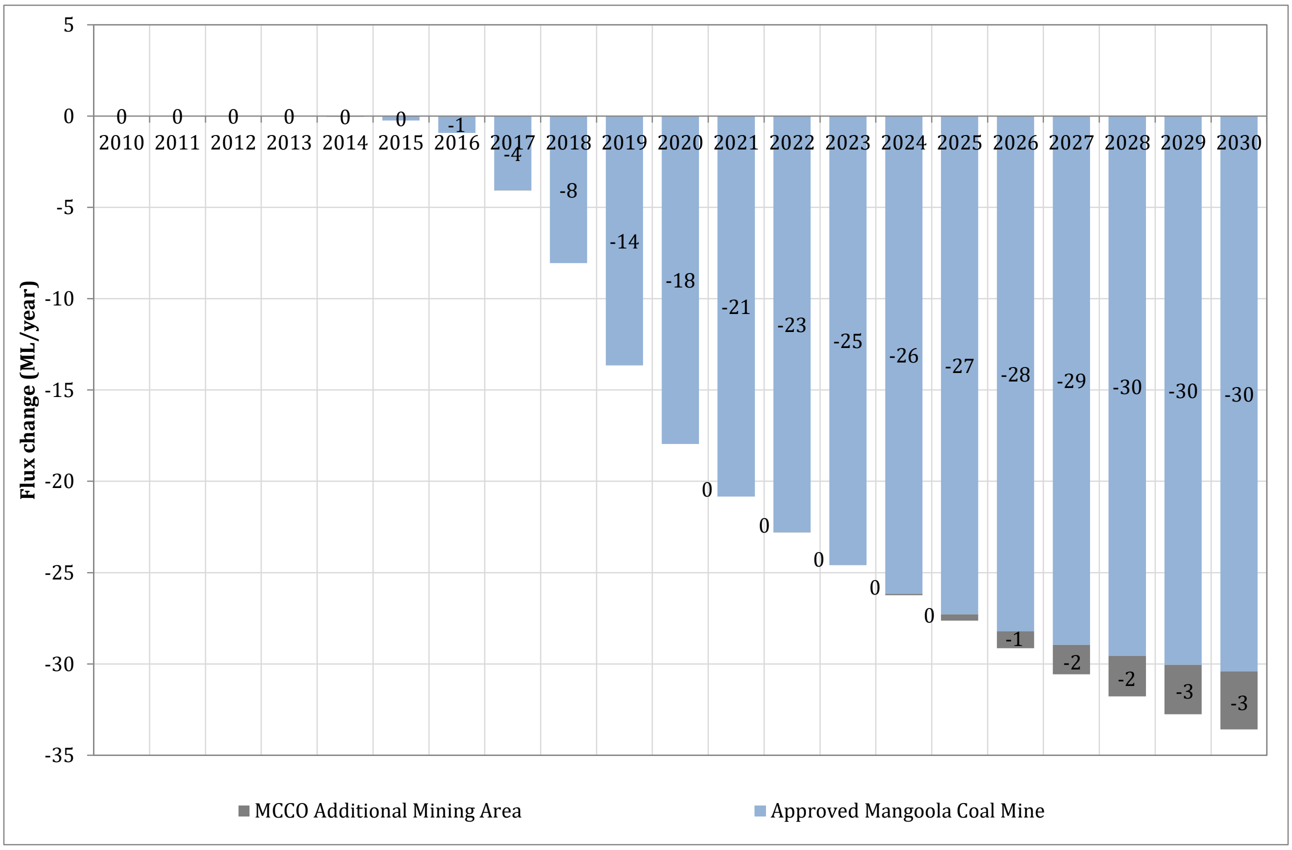


Figure 7.6 Change in flux to Wybong Creek alluvium from approved mining and proposed mining

The reduced groundwater flux from the Permian strata into the overlying Wybong Creek Alluvium also reduces the rate of groundwater discharge into the Wybong Creek as baseflow. Figure 7.7 shows the change in flux to the Wybong Creek alluvium also induces a change in the flow within Wybong Creek of up to 28 ML/year, with the majority of the change once again due to the approved Mangoola Coal Mine (26 ML/year). The gauging station on Wybong Creek (210040) has recorded a mean annual flow of 28,287 ML/year, indicating the predicted change in groundwater baseflow of 28 ML/year is negligible.

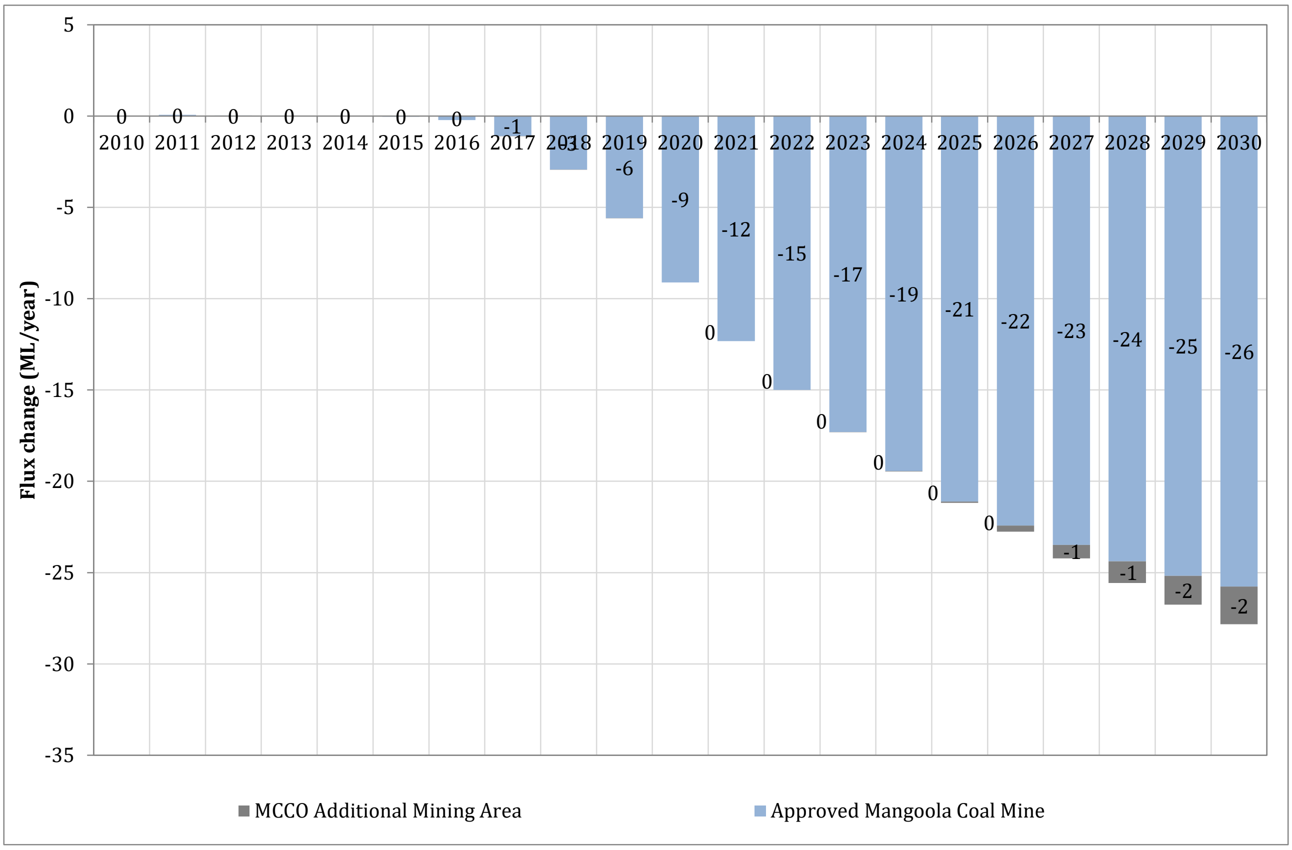


Figure 7.7 Change in flux to Wybong Creek surface water from approved mining and proposed mining

There is no mapped alluvium underlying Big Flat Creek. Any water taken from the shallow strata along Big Flat Creek is therefore grouped into the take from the North Coast Fractured and Porous Rock WSP rather than being allocated to a separate water management licensing unit.

The change in surface water flux in Big Flat Creek has been estimated for the reaches adjacent to the mining areas and is shown in Figure 7.8. Baseflow to the creek is predicted to fall by ~10 ML/year as a result of the approved Mangoola Coal Mine. In the groundwater model this equates to the entire baseflow component of creek flow. Once the bed of the creek becomes disconnected from the groundwater table there are no further baseflow contributions to the creek for the remainder of the approved and proposed mining operations. As the creek is already disconnected from groundwater when the proposed MCCO Proposed Additional Mining Area commences operations there can be no additional impacts on Big Flat Creek baseflow due to the MCCO Proposed Additional Mining Area.

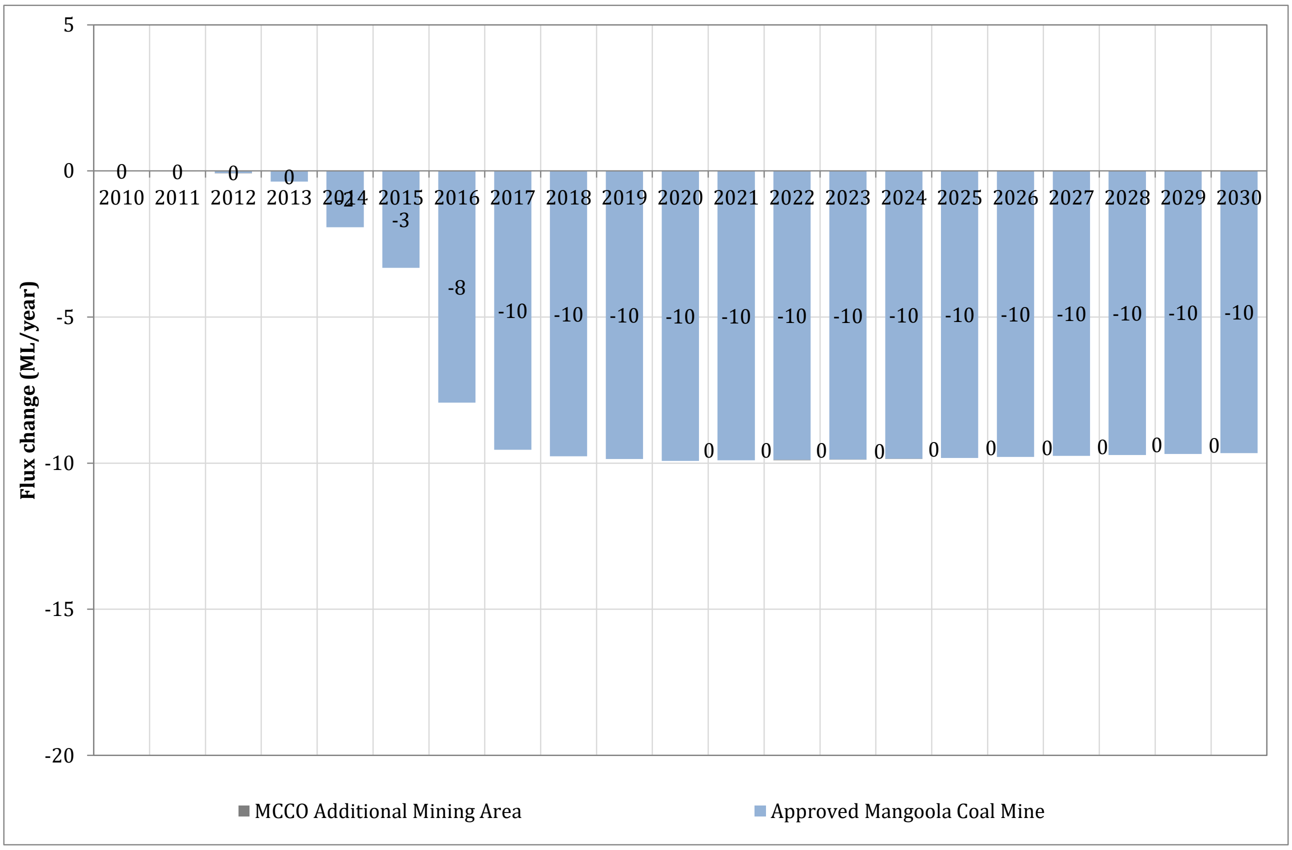


Figure 7.8 Change in flux to Big Flat Creek surface water from approved mining and proposed mining

7.1.4 Water licensing and water sharing plan rules

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

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

- the Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources (commenced 1 July 2016); and
- Hunter Unregulated and Alluvial Water Sources Water Sharing Plan 2009 (the current version dated 1 July 2016 includes the Wybong Management Zone 29).

The predicted annual groundwater volumes required to be licensed to account for the peak water take over the life of mining for the currently approved Mangoola Coal Mine and proposed MCCO Proposed Additional Mining Area are summarised in Table 7.1.

Table 7.1 Groundwater licensing summary – during mining

Water sharing plan	Water source/ management zone	Type	Licenced volume (ML/year)	Peak volume requiring licensing during mining (ML/year)		
				Approved mining	Proposed only	Approved and proposed
North Coast Fractured and Porous Rock WSP	Sydney Basin – North Coast	groundwater	700	152	210	**280***
Hunter Unregulated and Alluvial WSP	Wybong Management Zone (Zone 29)	groundwater	254	4	1	**5**
		surface water	861	26	2	**28**

Note: ** - The predicted 'approved mining' and 'proposed only' peak volumes occur in different years.*

As reported in Section 2.4, Mangoola Coal Mine has a total entitlement of 700 ML/year from the North Coast Fractured and Porous Rock WSP. Mangoola Coal therefore hold sufficient licences to account for the combined 'water take' from this water source of 280 ML/year for the approved and proposed MCCO Project mining.

Mangoola Coal Mine hold an entitlement of 254 ML/year from Wybong Management Zone of the Hunter Unregulated and Alluvial WSP, which will readily account for the indirect 'water take' predicted from the Wybong Creek Alluvium.

When considering the above it is important to note that an adjustment has been made to correct for double accounting of water. Figure 7.9 shows graphically the change in flux induced in the Wybong Creek alluvium and surface water systems due to depressurisation of the Permian bedrock. Where groundwater and surface water are regulated under the same WSP and within the same water source then to prevent double accounting, the change in the baseflow should be subtracted from the alluvial flux change.

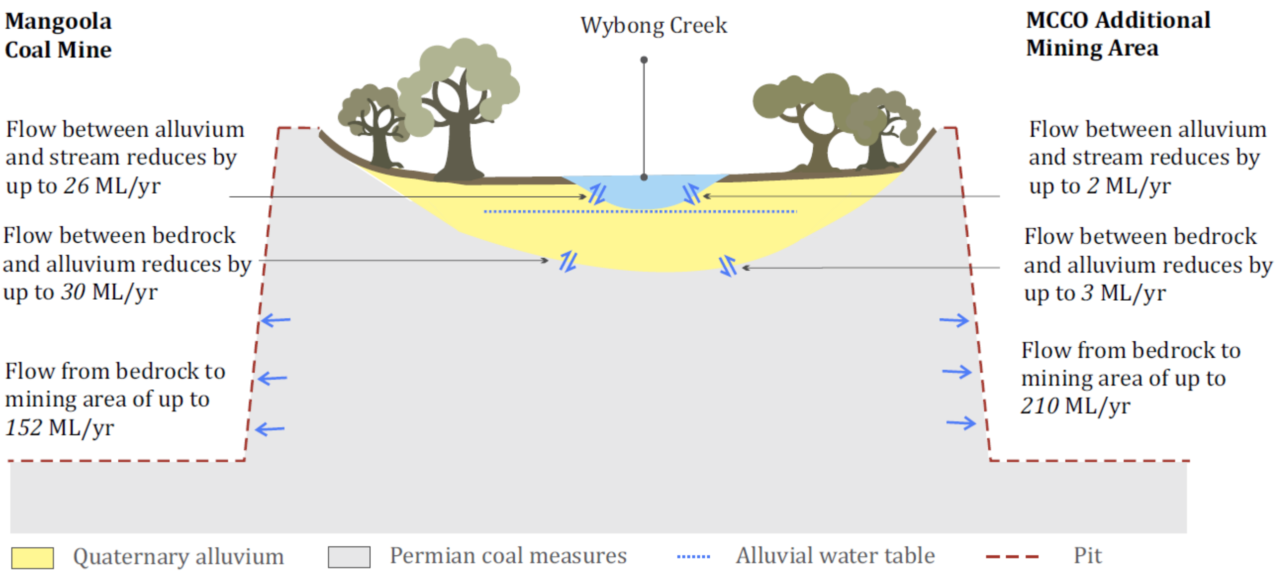


Figure 7.9 Partitioning of water take from Wybong Creek surface water and alluvium for the MCCO Project

The Wybong Creek Water Source has 'cease to pump' rules that require licence holders to cease pumping when there is no visible flow in the creek at nominated locations within the creek (NSW Legislation, 2019). Predicted take from Wybong Creek Water Sources due to the activity occurs only incidentally due to depressurisation of the underlying bedrock, and not from direct extraction. This rule is therefore not applicable to the MCCO Project. In addition the reduction in baseflow predicted is equivalent to less than 1 L/sec and would not be detectable in surface water flow.

7.1.5 Drawdown in private bores

Section 5.4.2 described groundwater usage in private bores in proximity to the MCCO Project. The majority of registered bores within the region are located on land owned by mining companies and are either used for monitoring the impact of mining, or are former water bores/wells no longer in use. Only four bores (three registered and one new bore) were identified as being located on private property and within an area predicted to experience over 2 m drawdown in the fresh conglomerate or Fassifern coal seam in the basecase models (Section 7.1.2). Details of the bores within these zones, and the predicted modelled drawdown at each location, are summarised in Table 7.2.

Three of the bores located in the potential area of >2 m drawdown are located to the north of the MCCO Project. However, when the depths of the bores are reviewed (based on bore construction logs and landholder information) they appear to be screened at depths where less drawdown is predicted, e.g. the model layer containing bore GW201589 is only predicted to be impacted by ~0.3 m, whereas the drawdown in the deeper layers can be up to 5.2 m. To account for uncertainty in the model build and model outputs the maximum drawdowns predicted in the model layers above and below the expected model layer have also been extracted and included in the table. In this scenario the only bore to the north of MCCO Project that could potentially be impacted by more than 2 m is Bore 2 (likely drawdown > 3 m under basecase conditions), the other two sites are predicted to experience drawdown of less than 0.5 m.

Bore 2 is a new bore that was licensed for use in 2018. It is located approximately 1,200 m north of the MCCO Proposed Additional Mining Area. The construction details for the bore have not yet been uploaded to the registered bore database, however, given its location it is very likely to be drawn down by more than 2 m and require mitigation if mining in the proposed MCCO Additional Mining Area were to be approved. Mitigation would likely take the form of 'make good' agreements with the affected landholder.

The fourth bore that is in an area of over 2 m potential drawdown (GW078502) is located to the west of the approved Mangoola Coal Mine and is predicted to primarily be impacted due to mining at the approved Mangoola Coal Mine. Predicted drawdown at the bore is ~7.5 m, although the range could be up to ~14.7 m. This bore already has voluntary acquisition rights afforded by the current Mangoola Coal Mine project approval (Property ID 83).

Table 7.2 Private bore predicted cumulative drawdown

Bore ID	Purpose	Depth (m)	Geological strata	SWL (mbgl) and date	Predicted max drawdown in any model layer (m)	Estimated model layer	Predicted maximum drawdown in this layer (and adjacent layers) (m)	Licence
GW201589	Stock, domestic	84.0	Shale, blue	10.0 (2011)	5.2	3	0.3 (0.5)	20WA211632
GW080507	Stock, domestic	Soak# = shallow?	Not recorded	n/a	4.1	1 or 2	0.0 (0.2)	20BL168908
Bore 2	Stock, domestic	> 20m$	To be confirmed	To be confirmed	16.5$	4+$	3.1 (8.7)$	20WA220001
GW078502	Stock, Domestic	58*	Coal measures*	11.5 (2012)	16.6	5	7.5 (14.7)	20BL167240

Notes: # *Landholder comment, not Groundwater Works report.*

* *Information taken or estimated from previous reports not Groundwater Works reports.*

$ *Indicative drawdown based on approximate location and depth as bore construction details are not yet available.*

7.1.6 Impact on groundwater dependent ecosystems

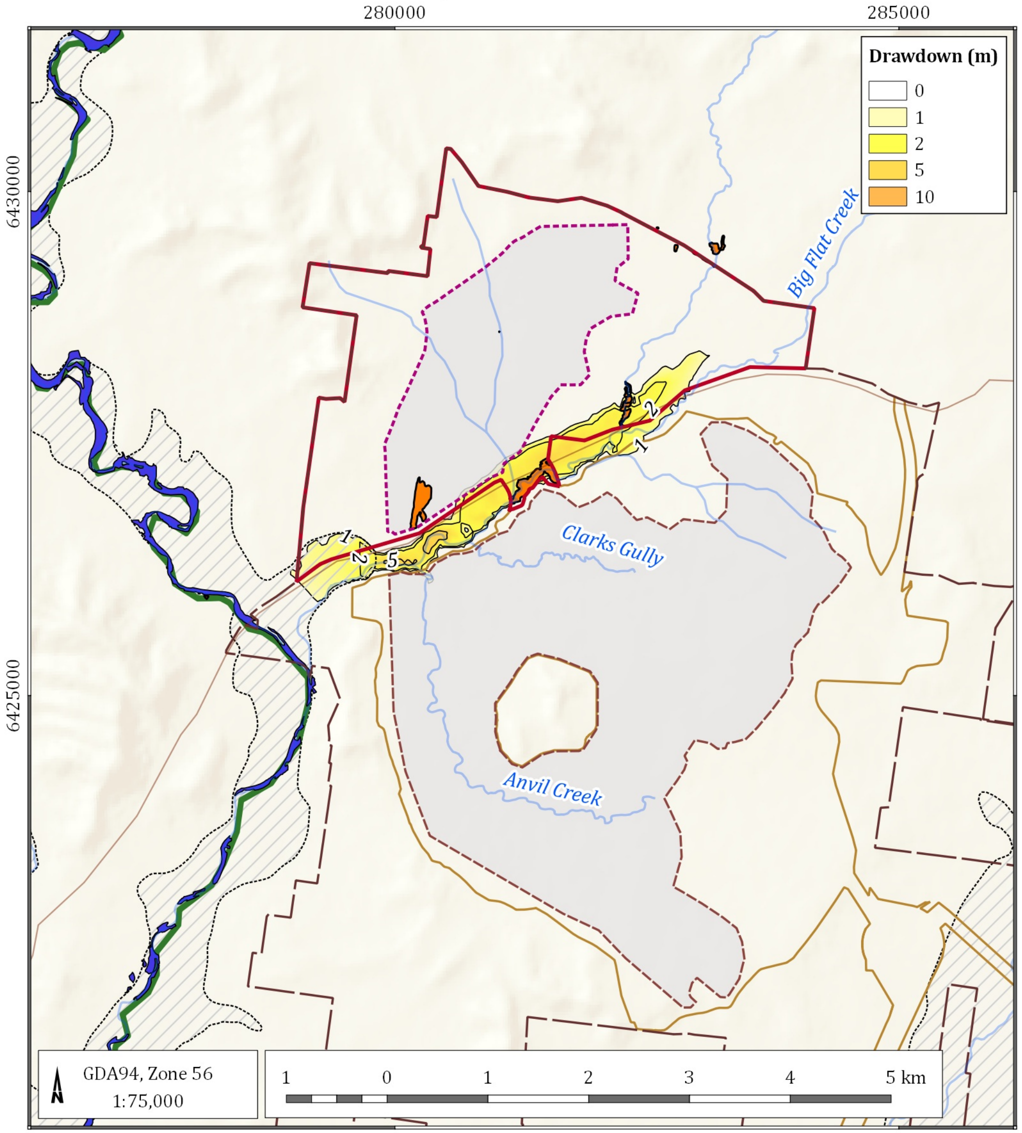
The NSW AIP contains the following Level 1 Minimal Impact Considerations for assessing impacts to GDEs. The considerations are the same for all aquifer types and for both highly productive and less productive water sources. There should be '*less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 m from any high priority groundwater dependent ecosystem'*. High priority GDEs are defined in the relevant Water Sharing Plans. There are no high priority GDEs located in the vicinity of the MCCO Project in either the North Coast Fractured and Porous Rock Groundwater Sources WSP or the Hunter Unregulated and Alluvial Water Sources WSP. The potential GDEs identified in Section 5.4.3 are therefore not classified as high priority GDEs and the AIP considerations do not apply. For completeness, the predicted impacts to the non-WSP potential GDEs have been considered below.

As detailed under Section 5.4.3, areas with moderate or high potential to support GDEs have been identified along Wybong Creek and in small areas within and close to the MCCO Project Area. Figure 7.10 shows the locations of the potential GDEs along with areas where a cumulative drawdown of 1 m or greater is predicted during mining in the shallowest modelled layers. Although the figure shows cumulative drawdown the potential GDEs along Big Flat Creek that would be affected in the cumulative mining scenario are also impacted by more than 1 m when only the MCCO Additional Project Area is considered. Floristic monitoring within one of these sites as part of the approved Mangoola Coal Mine project approval did not identify any negative impacts associated with groundwater drawdown during a 2017 survey (Umwelt, 2018). The potential GDEs within the MCCO proposed Additional Mining Area footprint will be cleared during mining, so long term impacts due to groundwater changes are not applicable for these sites.

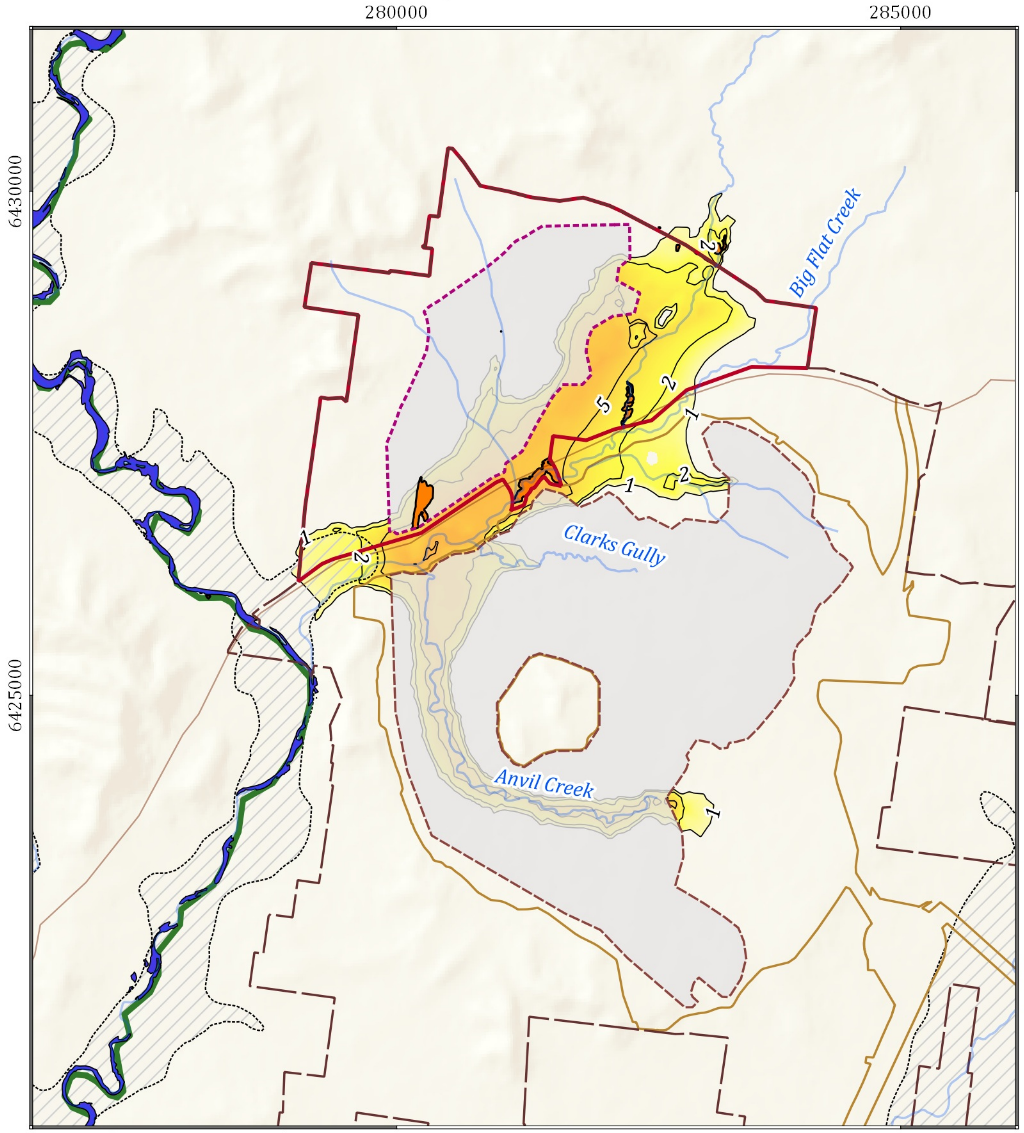
Cumulative drawdown in the vicinity of the potential GDEs along Wybong Creek is predicted to be less than 1 m in the areas with moderate or high potential to support GDEs.

Impacts to the surface water baseflow in Wybong Creek are predicted to be a maximum of 28 ML/year. When compared to the mean annual flow of 28,287 ML/year at Wybong Creek gauging station 210040 the predicted changes due to mining will likely be indistinguishable in the gauging data.

Maximum cumulative drawdown in layer 1



Maximum cumulative drawdown in layer 2



LEGEND

- Populated place
- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Numerical model boundary
- Alluvium
- Mined areas
- Road
- Drainage
- Drawdown contour

High or medium potential for GDEs

- High potential - plant community
- Moderate potential - plant community
- Moderate potential - GDE Atlas aquatic

AGE

Mangoola EIS (G1839F)

Predicted drawdown in the vicinity of potential GDEs

DATE
26/02/2019

FIGURE No:
7.10

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1839F.Mangoola EIS\3_GIS\Workspaces\011_GIA\07.10_G1839F_Predicted drawdown in the vicinity of potential GDEs.qgs

7.1.7 Groundwater quality during mining operations

The MCCO project is a continuation of the approved Mangoola Coal Mine and will utilise existing infrastructure at the Mangoola Coal Mine for processing coal and storage of rejects associated with coal processing. Therefore, there is no potential for groundwater contamination from new surface infrastructure areas.

The storage of hydrocarbons and chemicals will continue to be managed in accordance with the existing Mangoola Coal Mine management practices, including the use of bunding and immediate clean-up of spills. These procedures are standard practice and a legislated requirement at mine sites to prevent the contamination of the groundwater regime.

Given the limited activities proposed, and the controls that will be adopted, the MCCO Project has very limited potential to give rise to groundwater contamination as a result of hydrocarbon and chemical contamination.

As predicted in the Mangoola Coal Mine EIS groundwater assessment (MER, 2006) several monitoring bores in close proximity to the Mangoola Coal Mine have recorded mining related drawdown in recent years. As water levels have fallen the bores have often become more saline. This likely represents the mixing of water from different depths within the groundwater regime. Although the salinity in the bores has increased there are no nearby groundwater users that are affected by the changes, and any water moving away from the bore will be migrating towards the pit, where it will be captured.

Development of the MCCO Additional Mining Area could result in a similar change in water quality at sites close to the active mine. As with the approved Mangoola Coal Mine any observable changes in quality would likely be restricted to areas close to the active mine where the drawdown impacts are greatest. During mining the pits will act as groundwater sinks, preventing the movement of higher salinity water away from the mining areas.

7.2 Post mining recovery conditions

At the end of mining the majority of the two mining areas will have been backfilled with spoil and recontoured to simulate a more natural landform. A final void will remain in each area at the locations shown on Figure 7.11. The deepest areas of the voids will be similar to the maximum depths mined.

Post mining conditions were also simulated using the numerical model to determine how the changes to the system caused during mining; changes in hydraulic properties, recharge, water levels, affect the groundwater system in the long term. Appendix A (Section A4) provides details of the model set up and the representation of post mining conditions. The sections below describe the post mining predictions of water levels, drawdown, water take, and changes in water quality.

Post mining conditions were simulated using a transient model run over a period of 500 years. Groundwater levels from the end of mining were used as the starting heads after removal of all remaining mine 'drain cells' in the model and switching to the final landform in the backfilled mining areas.

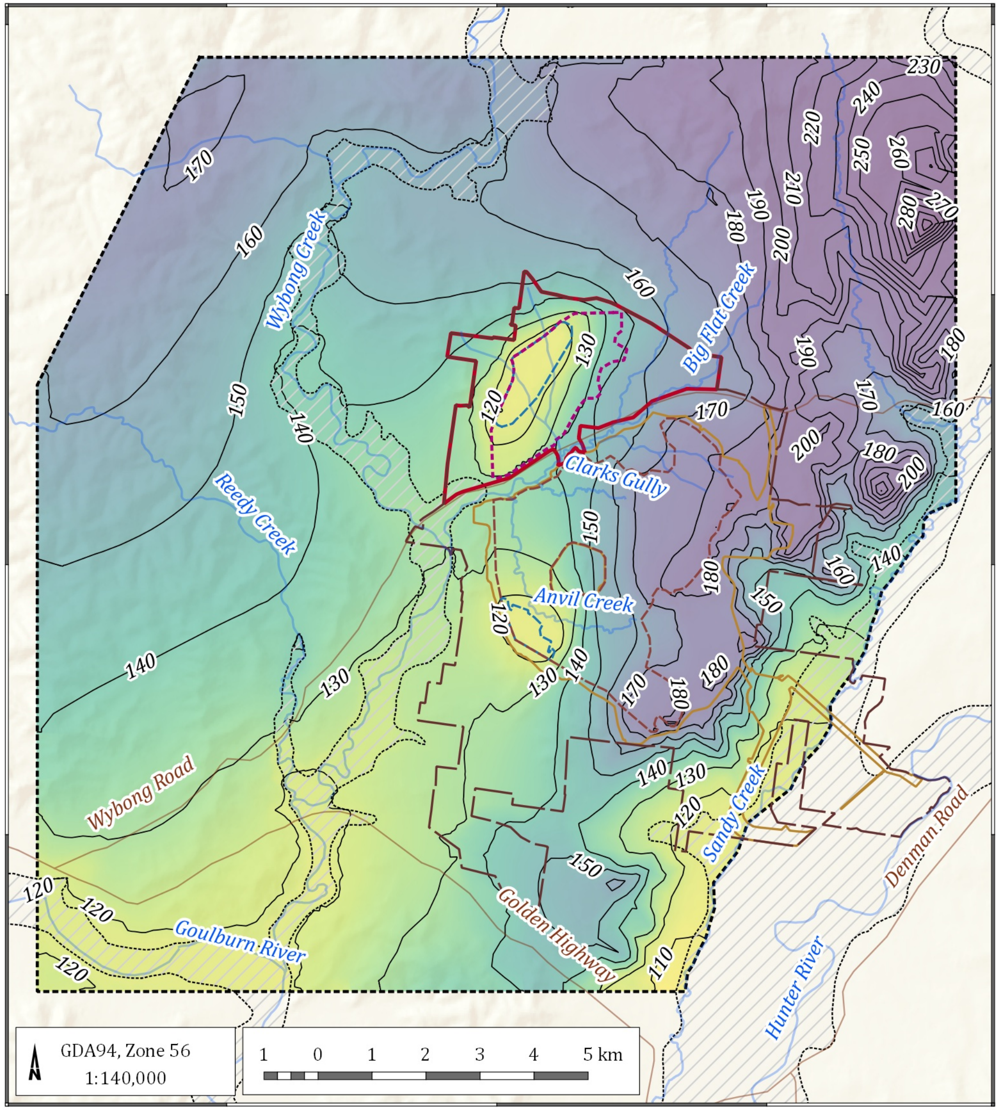
When interpreting the post mining results it is important to note that the long run time reduces the confidence in the forecast of post mining predictions. The post mining predictions should therefore be considered an indicator of potential impacts post mining that can be used to assist in post closure planning for the MCCO Project.

7.2.1 Post closure groundwater recovery

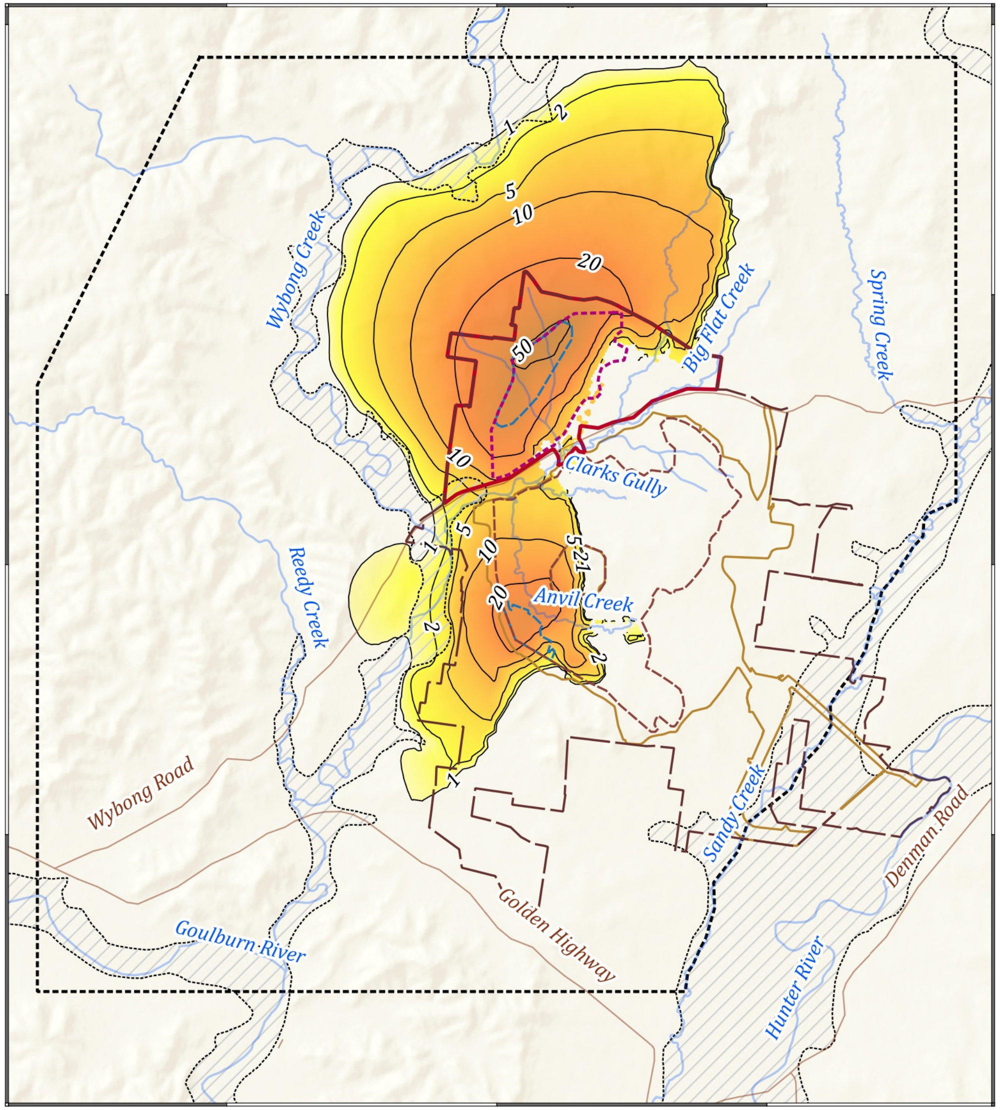
The model results indicate that groundwater levels will gradually recover over time until an equilibrium state is reached. In both mining areas the long term groundwater levels are predicted to equilibrate at a lower level than under pre-mining conditions, with the final voids acting as long term groundwater sinks (Figure 7.11). However, at the Mangoola Coal Mine the groundwater head contours suggest that there is potential for water in backfilled areas away from the final void to migrate into the surrounding bedrock. This will be a slow process due to the low permeability of the bedrock strata.

Predicted flow paths for water originating within the backfilled mining areas were simulated using the groundwater model outputs and the semi-analytical particle tracking software MODPATH (Pollock, 2016). Particles were placed in selected model cells within the backfilled mining areas and an expression of the particle's movement was computed by tracking the particle from one cell to the next over time. The particle tracking (Figure 7.12) indicates that any outwards migration will likely occur in the deeper strata as many areas of the near surface layers remain unsaturated, and that the majority of the water exiting the Mangoola Coal Mine will either be drawn back towards the Mangoola Coal Mine final void or be captured by the MCCO Proposed Additional Mining Area final void. Although the southernmost particles at the Mangoola Coal Mine are not captured they remain in the deeper layer and do not migrate towards the surface.

Post mining equilibrated heads (water table)



Post mining equilibrated drawdown (model layer 5 - unweathered conglomerate)



LEGEND

- Populated place
- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Numerical model boundary
- Alluvium
- Final void locations
- Road
- Drainage

Heads (mAHD)

- 100
- 150
- 200
- 300
- Contour line

Drawdown(m)

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

Mangoola EIS (G1839F)

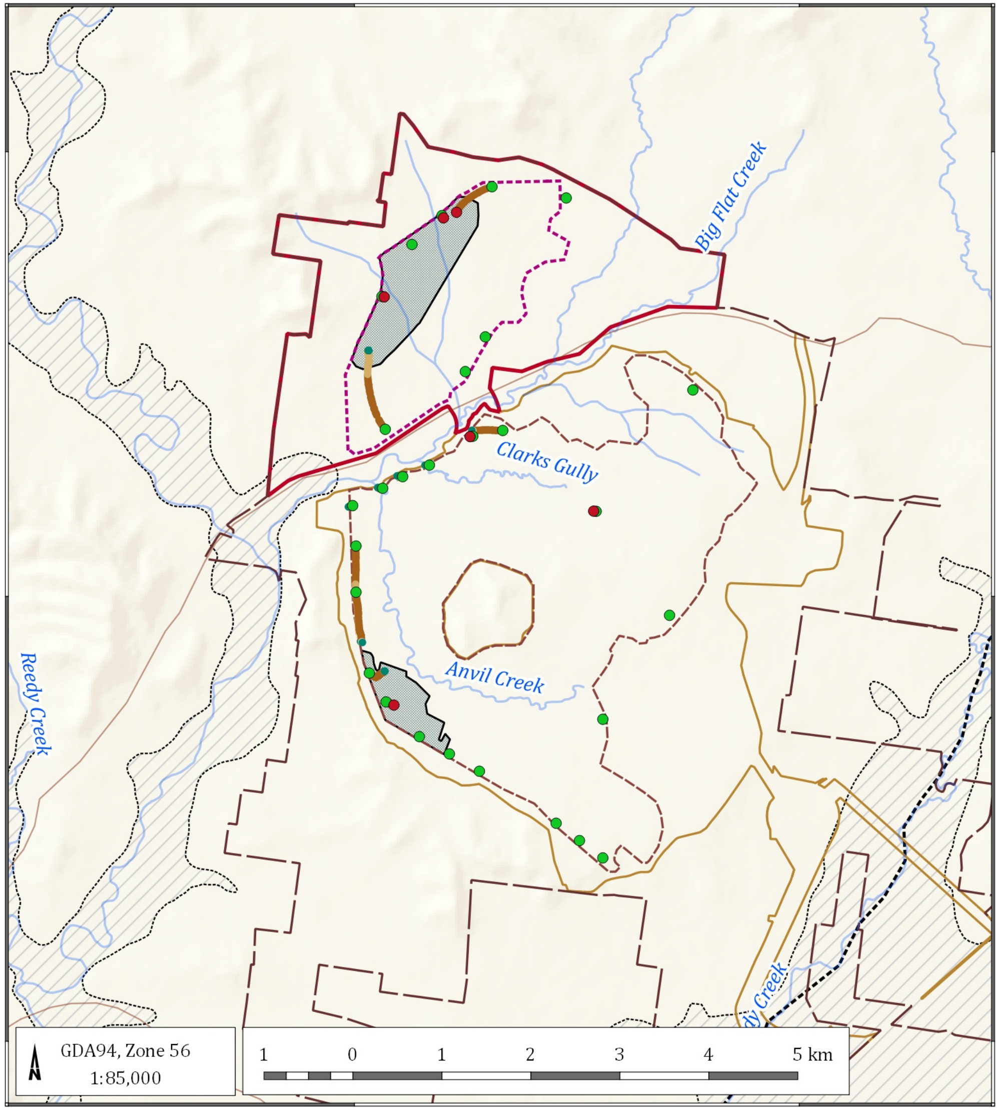
Predicted post mining recovery heads and drawdowns

DATE
26/02/2019

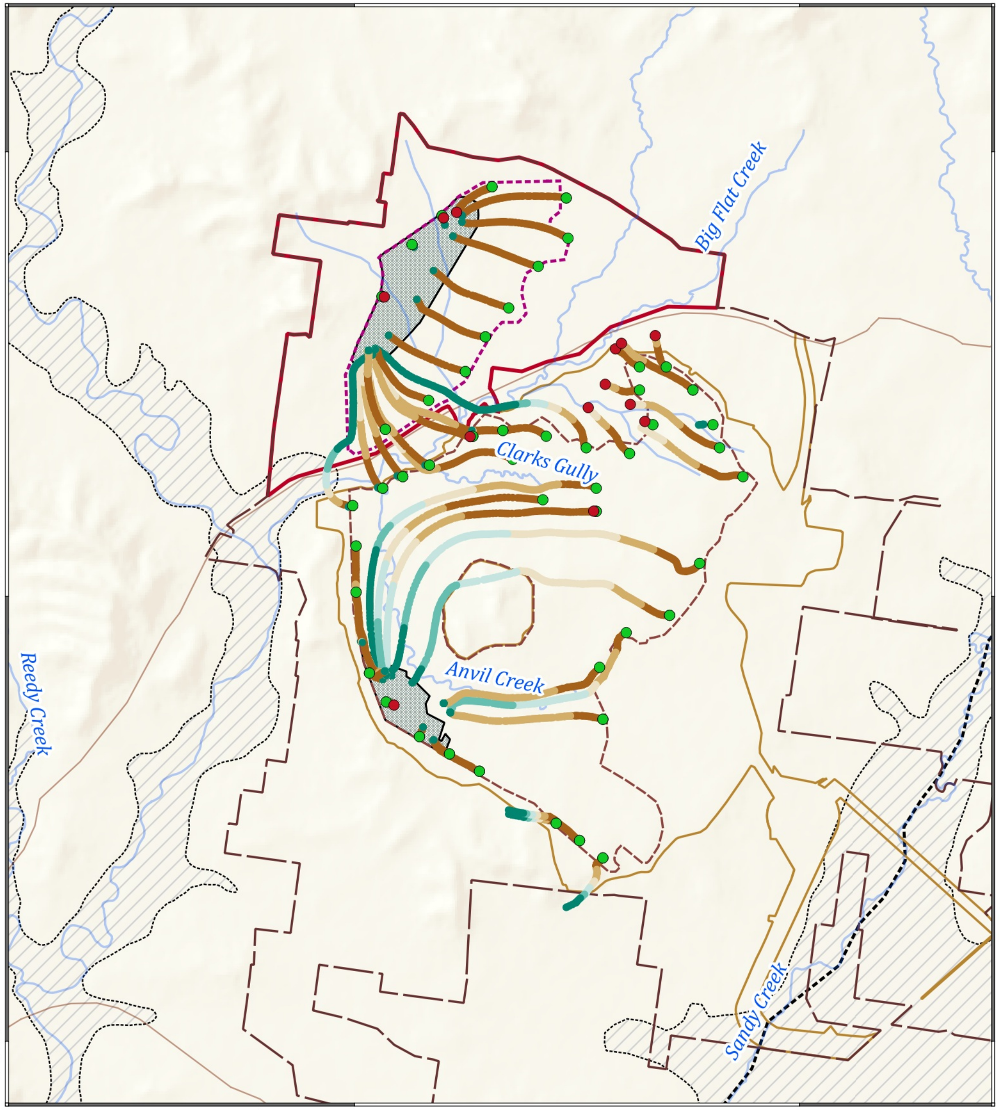
FIGURE No:
7.11

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1839F.Mangoola EIS\3_GIS\Workspaces\011_GIA\07.11_G1839F_Recovery heads and drawdowns.qgs

Particles released in Layer 5 (Spoil/unweathered conglomerate)



Particles released in Layer 8 (Spoil/Fassifern seam)



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Top of final void areas
- Numerical model boundary
- Alluvium
- Road
- Drainage

Particle information

- Starting point
- Termination point (if applicable)

Time elapsed (years)

- 0 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- >500

AGE

Mangoola EIS (G1839F)

Particle tracks for equilibrated recovery model

DATE
26/02/2019

FIGURE No:
7.12

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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7.2.2 Post mining changes in alluvial and surface water fluxes

'Water take' from the groundwater systems will continue post mining due to the residual drawdown created by flow of groundwater to the final voids. Predictions of the long term takes from the alluvial and surface water systems were made using the basecase recovery model as detailed in Appendix A, and are presented in Figure 7.13 to Figure 7.15.

Post mining predicted changes in flux to the Wybong Creek alluvium are shown in Figure 7.13. The predictions indicate that early post mining takes may be slightly greater than those predicted during mining (cumulative maximum 34 ML/year) due to the slow transmission of impacts through the different strata. The majority of the take from Wybong Creek at the start of the recovery period continues to be attributed to the approved Mangoola Coal Mine. As time passes the cumulative water take reduces and the proportion of impact attributed to the MCCO Additional Mining Area increases. Long term take is predicted to be around 23 ML/year, comprising 10 ML/year due to the Mangoola Coal Mine and 13 ML/year from the MCCO Proposed Additional Mining Area. As groundwater recovers the long term flux change becomes primarily a reduction in the groundwater inflow to the alluvium (~88%), rather than increased loss from the alluvium to bedrock (~12%).

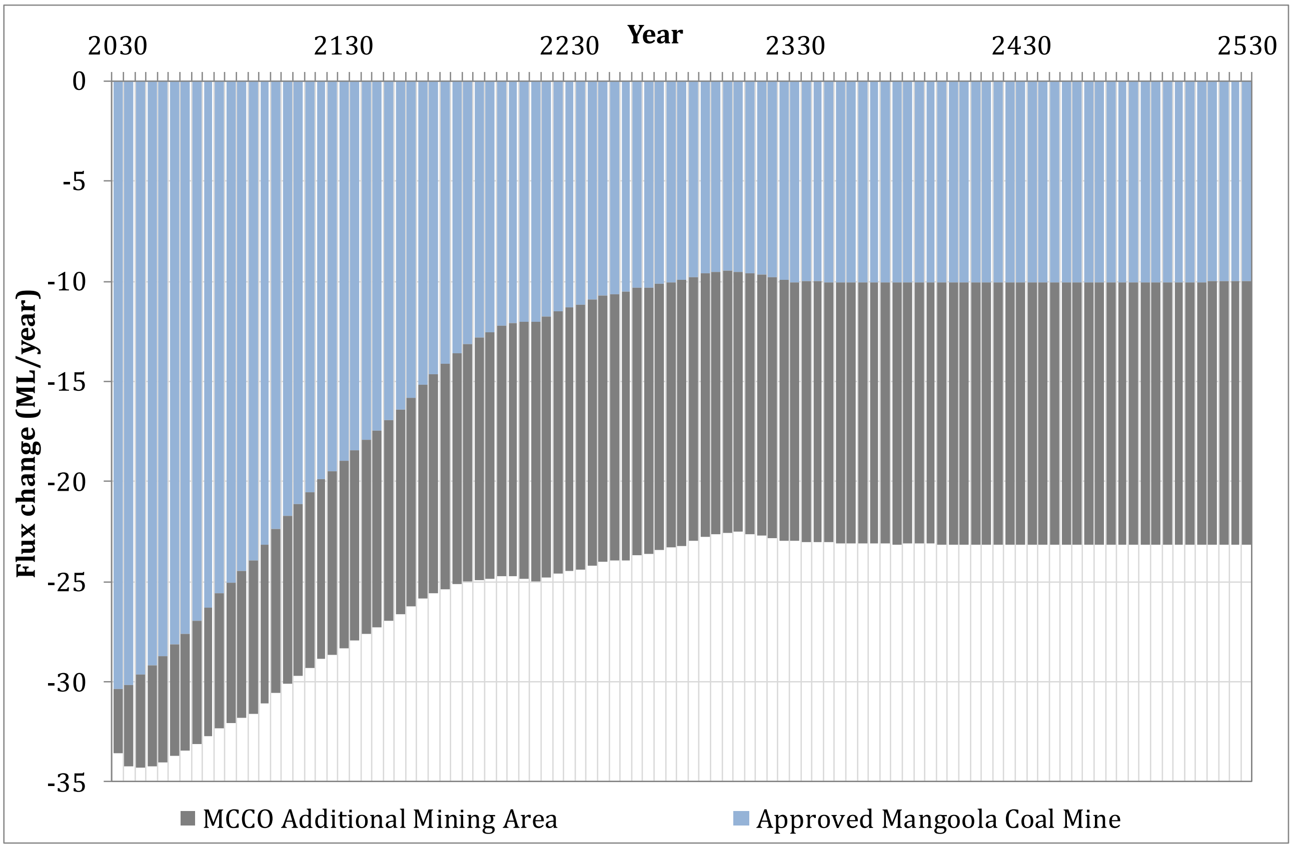


Figure 7.13 Post mining change in flux to Wybong Creek alluvium from approved mining and proposed mining

The predicted take from the Wybong Creek surface water follows a similar pattern to the take from the Wybong Creek alluvium. The cumulative take peaks at ~30 ML/year approximately 10 years after mining ceases within the MCCO Project (Figure 7.14). The predicted take from the Wybong Creek surface water is of a lower total magnitude than from the Wybong Creek alluvium. Long term take is predicted to be around 21 ML/year, comprising 9 ML/year due to the Mangoola Coal Mine and 12 ML/year from the MCCO Proposed Additional Mining Area.

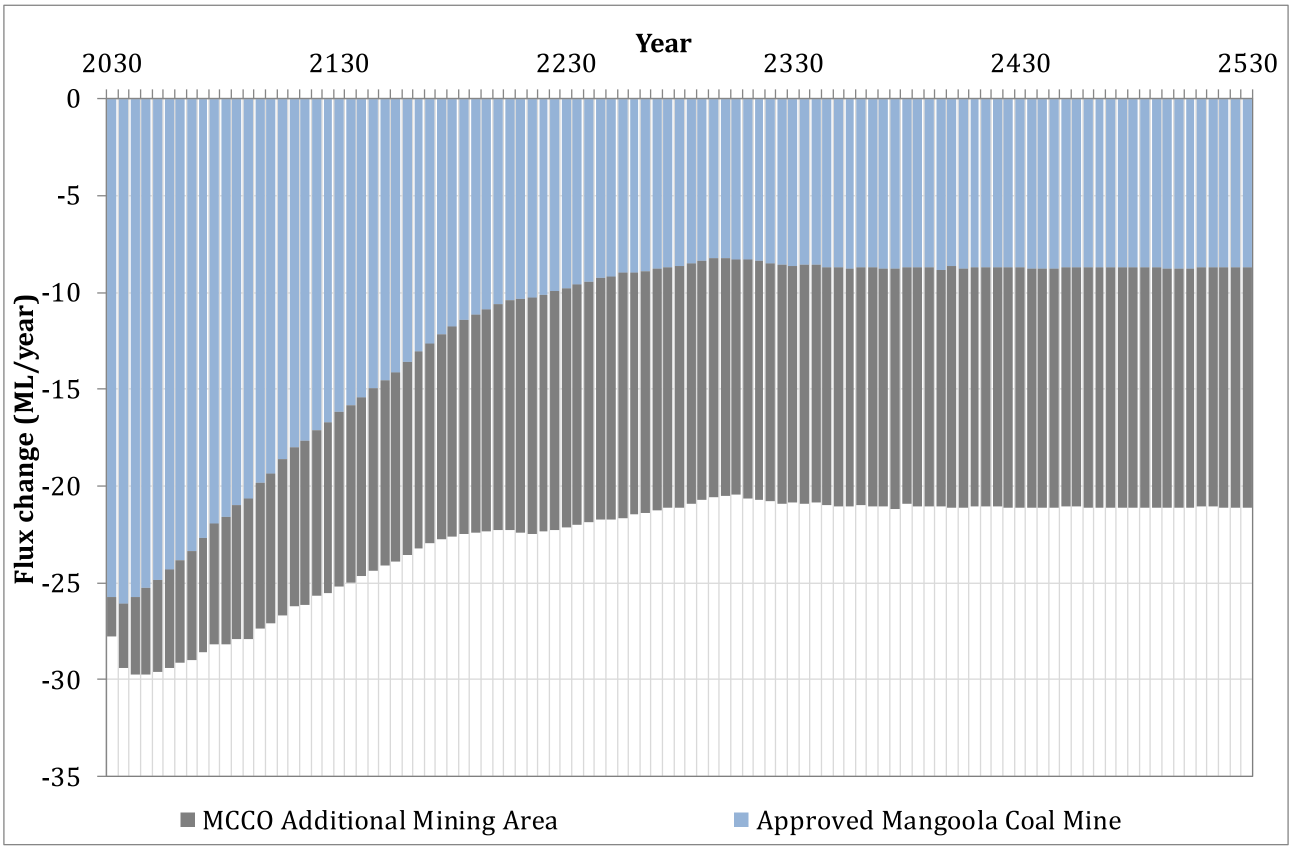


Figure 7.14 Post mining change in flux to Wybong Creek surface water from approved mining and proposed mining

Baseflow to Big Flat Creek is predicted to remain impacted throughout the 500 year recovery period, although there is a slight reduction in water take to approximately 8 ML/year after the first 150 years post mining (Figure 7.15). The long term impact is due to shallow water levels under the creek remaining lower than under pre-mining conditions. The impacts at the start of recovery continue to primarily be attributable to the Mangoola Coal Mine. Over time the proportion of impact attributable to the MCCO Additional Mining Area increases, to approximately 6 ML/year (~75% of total impact) in the long term.

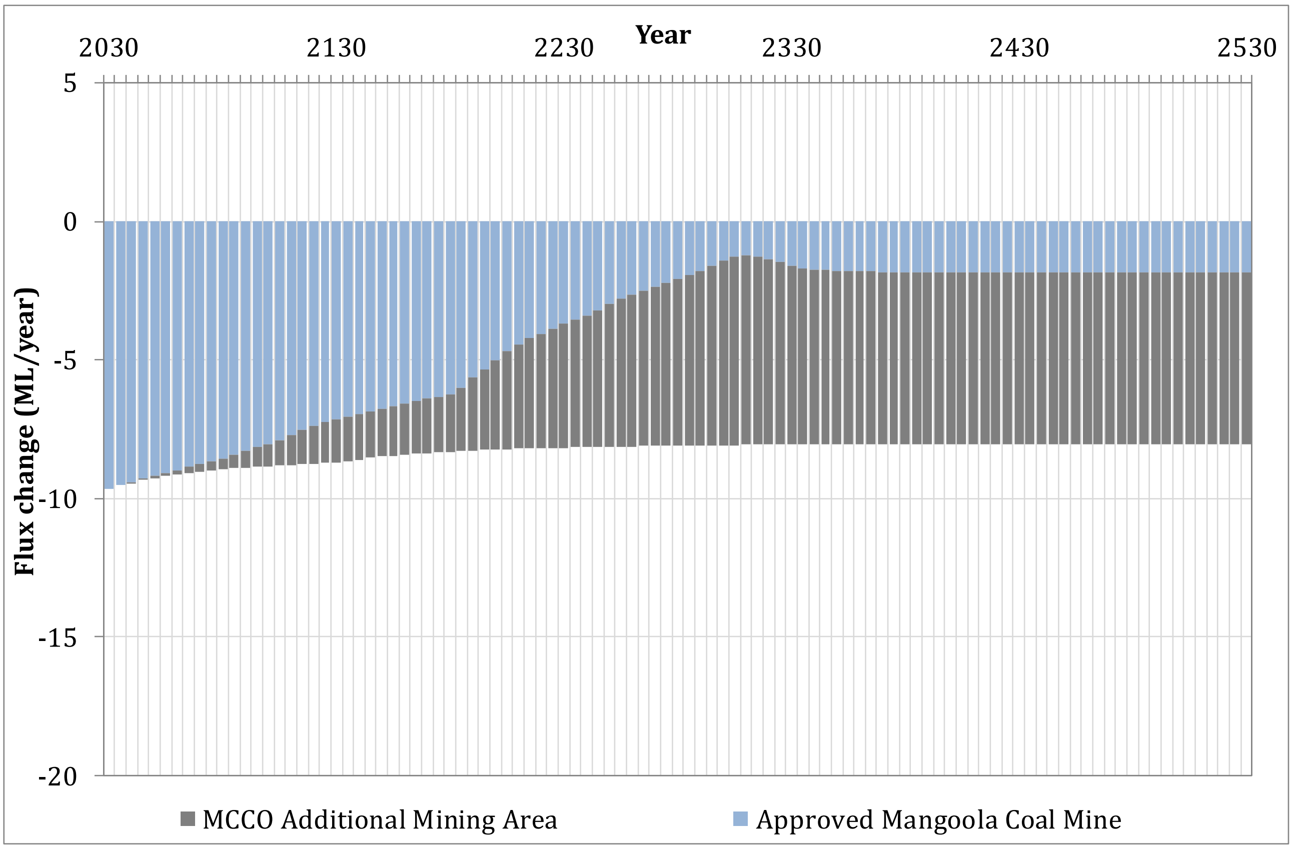


Figure 7.15 Post mining change in flux to Big Flat Creek surface water from approved mining and proposed mining

7.2.3 Groundwater fluxes in backfilled mining areas

Post mining 'water take' from the Permian bedrock to the mining areas will require licensing if there is a net loss of water from the system. Long term fluxes for each of the MCCO Project mining areas are provided in Table 7.3.

Although there are groundwater inflows predicted to both mining areas there is only a predicted net loss to the system from the MCCO Proposed Additional Mining Area. The predicted post mining take is well within the 700 ML/year licensed bedrock take held by Mangoola Coal Operations.

Predictions of long term recovery at the Mangoola Coal Mine suggest that the final void will not capture all water within the backfilled mining area, and there will be an outflow from some areas of the mine. The majority of the outflow is predicted to flow towards the MCCO Proposed Additional Mining Area final void (see Section 7.2.1).

Table 7.3 Post mining Permian bedrock fluxes

Mining Area	Long term inflow	Long term outflow	Long term bedrock flux
Mangoola Coal Mine	47 ML/year	73 ML/year	26 ML/year outflow
MCCO Proposed Additional Mining Area	58 ML/year	1 ML/year	57 ML/year inflow

7.2.4 Post mining water licensing requirements

Maximum and long term takes predicted from each water source are summarised in Table 7.4. Peak takes can occur at different times in each unit so the peak cumulative total may not be a sum of the totals for each individual mining area. It is also important to note that an adjustment has been made to correct for double accounting of water, as discussed in Section 7.1.4 for the water takes during mining.

Long term take from the North Coast Fractured and Porous Rock WSP for the approved Mangoola Coal Mine is negative, indicating a net outflow from the mining area. The net outflow is due to a combination of factors including the large backfilled area within the Mangoola Coal Mine footprint compared to the size of the final void, higher than background recharge over the backfill, and a strong hydraulic gradient towards the final void in the MCCO Additional Mining Area.

Table 7.4 Groundwater licensing summary – post mining peak and long term takes

Water sharing plan	Water source/ management zone	Type	Licenced volume (ML/year)	Peak/long term volume requiring licensing post mining		
				Approved mining	Proposed only	Approved and proposed
North Coast Fractured and Porous Rock WSP	Sydney Basin – North Coast	groundwater	700	20 / -26*	57 / 57	**77 / 31**
Hunter Unregulated and Alluvial WSP	Wybong Management Zone (Zone 29)	groundwater	254	4 / 3	1 / 1	**4 / 2**
		surface water	861	26 / 9	13 / 12	**30 / 21**

Note: ** Due to increased recharge over the backfilled mining area and a net flow of groundwater into the bedrock compared to under pre-mining conditions.*

7.2.5 Groundwater quality changes

As mentioned above the post mining landscape will be contoured to the chosen final landform and groundwater levels will slowly recover. Water quality changes could emerge as a result of mining through the following mechanisms:

- evaporation concentrating salts within the final void lakes;
- rainfall-recharge infiltrating the backfilled spoil and dissolving salts as it passes; and
- long term changes in water level altering flow directions.

Pit lakes are predicted to form within the final voids in each mining area. As the lakes will form groundwater sinks there is the potential for evapoconcentration of any water that flows to them. The likely salinities over time will depend on the concentrations of salts entering the final voids from the spoil and bedrock in addition to the evaporation rates.

Any oxidised zones of sulfidic material occurring within the spoil or on the final void walls has the potential to influence the groundwater quality within the post-mining landscape. Monitoring of the quality of groundwater pumped from the operating Mangoola Coal Mine indicates the water pumped from the mine is currently neutral to slightly alkaline in pH and therefore does not indicate acidification impacts to date. Geochemical testing of the spoil indicates that there is the potential for rainfall-runoff infiltrating through the spoil to remain less saline than the groundwater in the surrounding bedrock. This would improve the overall water quality within the area if the spoil water were to migrate away from the mining footprint.

Water quality is variable within the bedrock units, with notably higher salinity groundwater present underneath Big Flat Creek. Groundwater quality changes are being observed in bores with falling water levels close to the active Mangoola Coal Mine and Big Flat Creek. This is attributed to the Mangoola Coal Mine acting as a groundwater sink, drawing water towards it and altering the pre-mining flow paths. Any groundwater currently entering the pit will be reporting to the in-pit mining sumps for collection and management and is unlikely to be causing environmental harm.

Post mining the majority of the two mining areas will have been backfilled with mine waste/spoil, with the remaining areas forming pit lakes in the final voids. Over time the spoil will re-saturate until water levels equilibrate with the surrounding bedrock groundwater. The final equilibrated water levels are predicted to be altered from pre-mining groundwater conditions, and groundwater is likely to move in different directions to those that were present before the mines were established.

The MCCO Proposed Additional Mining Area will remain a strong groundwater sink, and there will be no significant outflow to bedrock from the mining area. Any water quality changes will therefore remain within the mining footprint. The Mangoola Coal Mine is predicted to form a sink around the final void but may allow water to migrate into the bedrock in areas away from the void. As previously detailed in Section 7.2.1 this will occur slowly and the majority of water that does leave the backfilled mining area is predicted to migrate towards the MCCO Additional Mining Area final void or remain at depth in close proximity to the Mangoola Coal mining footprint. Therefore, although there is the potential for any changes in water quality generated within the mining footprint to migrate outwards into the bedrock it will either be recaptured or remain at depth in strata with naturally high salinity and with no current groundwater users.

The lower equilibrated groundwater heads under Big Flat Creek are predicted to reduce the long term baseflow in the creek by approximately 8 ML/year compared to pre-mining conditions. This could improve the water quality of Big Flat Creek as pre-mining baseflows appear to have been significantly more saline than creek flow generated from rainfall runoff.

7.3 Uncertainty and sensitivity

A complex non-linear uncertainty analysis was undertaken where numerous model parameters were changed at the same time using 207 model realisations. Appendix A presents the results of the uncertainty analyses. The outputs from the uncertainty analysis remain similar to the basecase model, that is:

- Alluvial drawdown of over 2 m remains limited in extent.
- There are no high priority GDEs located within the area that could be impacted.
- Local groundwater users that may be impacted have been identified – there is potentially one additional landholder bore that could be 'about as likely as not' to experience drawdown of over 2 m (Bore 1) if it were screened in the Fassifern coal seam. However, based on the depth of the Fassifern seam at the bore location (~150 mbgl) the bore is more likely to be in the 'unlikely' category if the bore is ~90 m deep, or outside all of the potentially impacted areas if it is shallower than this. This will be confirmed once additional bore construction details are reviewed. All other known sites have an 'unlikely' or 'very unlikely' chance of 2 m drawdown being exceeded.

In addition to the uncertainty analysis a sensitivity analysis on the potential impact of the Mount Ogilvie fault was also completed. The fault was simulated as a lower permeability zone in all layers below the weathered zone. There was no material difference noted in any of the model outputs.

8 Groundwater monitoring and management plan

Mangoola currently operates Mangoola Coal Mine in accordance with a Water Management Plan (WMP) which was prepared in consultation with NSW government agencies and approved in 2018 (Glencore, 2018). The WMP describes the management of environmental and community aspects, impacts and performance relevant to the site's water management system. The existing groundwater monitoring programs will be continued so that the impact of the MCCO Project is monitored and managed. The sections below outline aspects of the current WMP, and recommended updates (should the MCCO Project be approved) to monitor the cumulative impacts of the MCCO Project.

8.1 Mangoola Coal Mine Groundwater Monitoring Plan

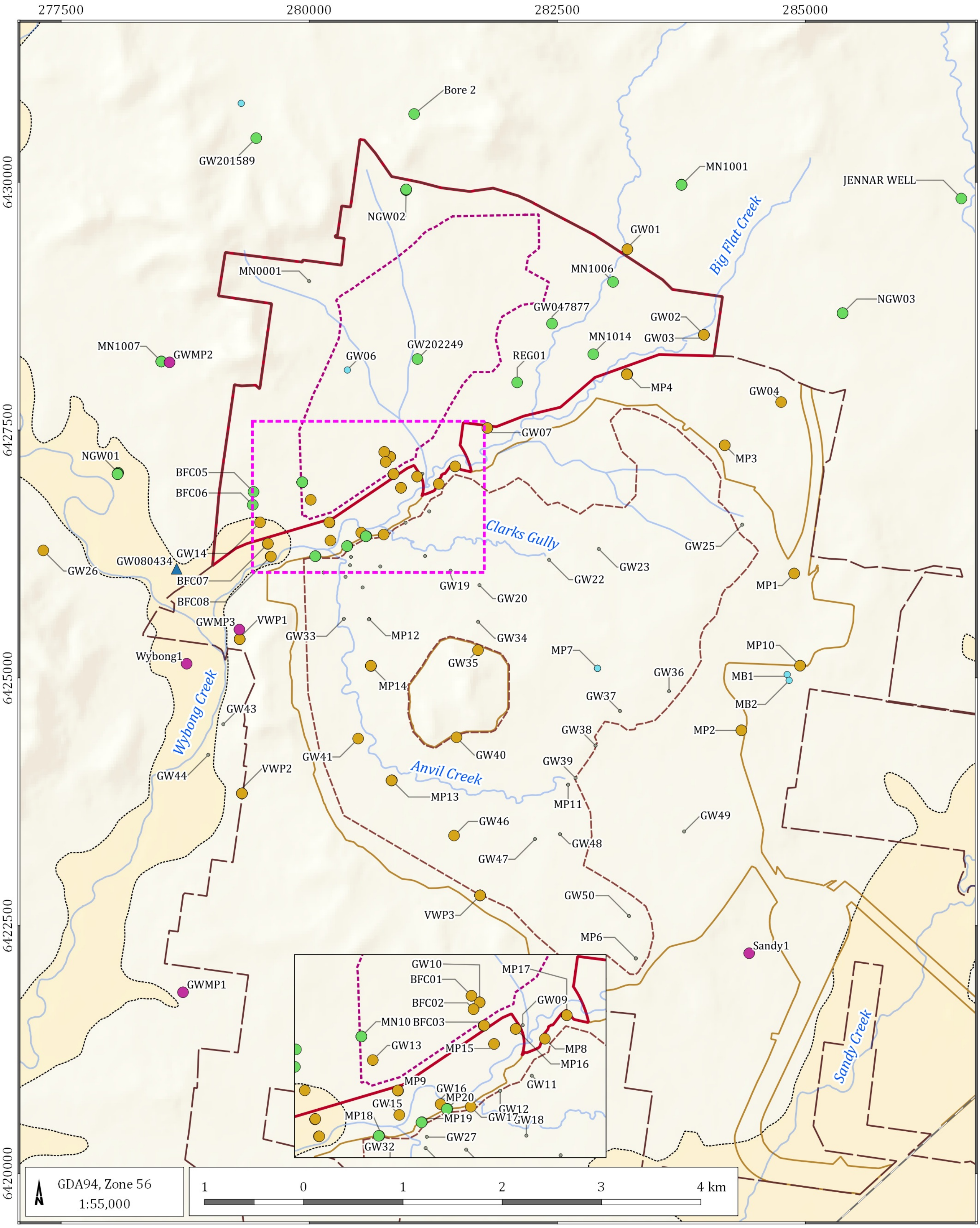
The currently approved Mangoola Coal Groundwater Monitoring Plan (GWMP) (Glencore, 2014) outlines a monitoring program to collect groundwater levels and quality measurements and allow actual impacts to the local groundwater system to be compared against those identified in the environmental assessments. The groundwater monitoring program focusses on collecting information on potential impacts to:

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

The Mangoola Coal GWMP identifies 58 monitoring locations comprising the following sites and monitoring frequencies. It should be noted that several sites have more than one requirement e.g. bimonthly sampling plus annual sampling or continuous monitoring:

- 9 sites – continuous depth to water recordings using VWPs or standpipe dataloggers
- 33 sites – bimonthly depth to water (manual readings), pH and EC;
- 20 sites – quarterly depth to water (manual readings), pH, and EC;
- 8 sites – annual extended water quality suite (major ions, metals; and
- 2 sites – dry when drilled so no monitoring specified.

A large number of the sites were located within the Mangoola Coal Mine footprint and have been mined out as approved mining has progressed. The remaining active bores identified in the Mangoola Coal 2014 GWMP are shown on Figure 8.1. Additional bores have also been installed around the MCCO Project Area since the 2014 GWMP was developed, and the remaining GWMP bores are now a sub-set of the active monitoring network described in Section 5.2.1.



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Alluvium
- Drainage

Proposed MCCO monitoring locations

- 2014 GWMP - active
- 2019 GWMP - active
- 2019 GWMP - new sites
- Non GWMP
- Destroyed
- Government site

Mangoola EIS (G1839F)

Proposed MCCO GWMP monitoring locations

AGE

DATE 06/04/2019

FIGURE No: **8.1**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
G:\Projects\G1839F.Mangoola EIS\3_GIS\Workspaces\011_GIA\08.01_G1839F_Proposed bores.qgs

8.2 Proposed MCCO Groundwater Monitoring Program

As the cumulative groundwater impacts from the MCCO Project are predicted to impact a larger area than for the approved Mangoola Coal Mine the GWMP monitoring network will need to be expanded to ensure that any impacts from the cumulative MCCO Project are identified in a timely manner.

A number of groundwater monitoring sites have already been installed around the proposed MCCO Proposed Additional Mining Area to assess baseline conditions in advance of any potential developments occurring. If the MCCO Project is approved it is proposed that several of these sites are added to the cumulative MCCO GWMP. Based on the data reviewed as part of this document, and predicted impacts from mining the MCCO Additional Mining Area it is also recommended that a number of new monitoring bores are installed to confirm the VWP pressure changes, and monitor for any depressurisation near to the Wybong Creek alluvium and associated GDEs. Completion of the bore census and, if necessary, baseline monitoring of those private bores within the predicted zone of water level drawdown should also be implemented. It is not proposed to include landholder Bore 1 in the GWMP as it is unlikely to be affected by more than 2 m drawdown, however if requested by the landholder the water levels in the bore could be monitored by Mangoola to confirm that there are no impacts occurring. The proposed additions to the Mangoola Coal GWMP and their suggested monitoring requirements are discussed further in the following sections.

The NSW Government has also contacted Mangoola to express interest in the installation of a groundwater monitoring bore on Mangoola owned land close to the existing government monitoring bore (GW080434). The proposed depth and construction details of the proposed bore are unknown at the present time. Although the existing and proposed bore would not form part of the Mangoola monitoring network and GWMP the data would be beneficial as part of site conceptualisation.

8.2.1 Water level monitoring

The monitoring network identified in the 2014 GWMP has evolved over time, with sites being destroyed as mining has progressed. The GWMP sites that remain active are shown on Figure 8.1. It is recommended that the following sites are also added to the water level monitoring locations in the revised GWMP:

- MCCO Additional Mining Area existing monitoring locations;
- additional locations already committed to by Mangoola Coal, to be located in the Wybong Creek alluvium and Sandy Creek alluvium (Wybong1 and Sandy1);
- private bores in the potential areas of impacts (pending results of the bore census and agreement with the landowner); and
- additional bores recommended to clarify changing VWP results (GWMP1, GWMP2, GWMP3).

The proposed locations for the expanded MCCO GWMP network are also shown on Figure 8.1.

Currently groundwater levels are measured in the monitoring bores on a bi-monthly or quarterly basis, in addition to greater than daily readings recorded by the dataloggers in the monitoring bores and VWPs. The current monitoring along with the additional proposed locations are considered sufficient to monitor the predicted impacts of the cumulative MCCO Project in the areas surrounding the MCCO Project. It is proposed that monitoring is continued at the same frequencies as already prescribed in existing bores, and a minimum of bi-monthly at new sites.

Ongoing monitoring will enable natural groundwater level fluctuations (such as responses to rainfall) to be distinguished from potential groundwater level impacts due to depressurisation resulting from approved and proposed mining activities. Ongoing monitoring of groundwater levels will also be used to assess the extent and rate of depressurisation against model predictions.

Yearly reporting of the water level results from the monitoring network will be included in the annual review. As part of the review water levels are compared against predictions of impacts made in the project approval documents, and also location specific water level trigger values. When water levels fall within the approved drawdowns and triggers then there is a low risk of unexpected environmental harm occurring to surrounding groundwater dependent assets. If water level responses are not consistent with predictions then a review is required to determine the cause of the discrepancies. The differences could be from a number of influences such as mining, climate, third party activities etc.

The methodology used to generate water level triggers will be consistent with the methodology in the approved Mangoola Coal GWMP.

The annual review will also identify if any additional monitoring sites are required to better understand any changes being observed, or if optimisation of the existing monitoring sites should be undertaken.

8.2.2 Water quality monitoring

Currently groundwater monitoring is conducted at Mangoola Coal Mine on a bi-monthly basis for field water quality (EC and pH), with selected bores also being monitored on an annual basis for a more comprehensive water quality analysis. The more comprehensive water quality analysis includes the following parameters specified in the GWMP:

- physico-chemical parameters – pH, electrical conductivity, total dissolved solids;
- major ions – calcium, magnesium, sodium, potassium, chloride, sulfate;
- alkalinity – carbonate, bicarbonate; and
- dissolved (or total) metals – aluminium, arsenic, barium, boron, iron, lithium, manganese, rubidium, phosphorous, selenium, silicon, strontium, zinc.

Groundwater quality analysis will continue in order to detect any changes in groundwater quality during mining. The current monitoring bi-monthly frequency for pH and EC monitoring is considered adequate to monitor the larger predicted impacts of the cumulative MCCO Project on groundwater quality. In addition the locations for full annual groundwater quality suites will be adjusted to account for mined out sites and ensure adequate spatial coverage to detect the cumulative mining impacts.

Based on feedback received for other sites it is also proposed to include additional metals analysis within the annual water quality sampling suite. The revised full suite will include:

- physio-chemical indicators – pH, electrical conductivity, total dissolved solids;
- major ions – calcium, fluoride, magnesium, potassium, sodium, chloride, sulfate;
- alkalinity - total alkalinity, carbonate, bicarbonate; and
- dissolved and total metals – aluminium, arsenic, barium, boron, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, strontium, silver, vanadium and zinc.

Yearly reporting of the water quality results will be included in the annual review. Trends in water quality will be compared against defined trigger levels to identify parameters and sites that are varying from baseline conditions. If changing trends are identified in water quality then a review will be completed to identify the cause of the discrepancy. The differences could be from a number of influences, again such as mining, climate, third party activities etc.

The methodology used to generate water quality triggers will be consistent with the methodology in the approved Mangoola Coal GWMP i.e. statistical percentiles for pH and EC, and interim triggers based on ANZECC (2000) recreational water use guideline values for other parameters.

The annual review should also consider if any additional monitoring sites are required to better understand any changes being observed, or if optimisation of the existing monitoring sites, frequency of sampling and analytical suite should be undertaken. The WMP updates will consider the optimal sites for monitoring of groundwater quality during the life of the project.

8.2.3 Mine water seepage monitoring

Regular monitoring of groundwater seepage into the different mining areas (where possible) is a key component in accurately calculating and reporting of licensable groundwater take from surrounding bedrock strata.

The results of this monitoring will be reviewed three monthly. If inflows above the approved predicted volumes are identified then the data will be reviewed to identify the causes.

Groundwater inflows will also be utilised when calibrating and validating any future updates of the numerical groundwater model for the MCCO Project.

As discussed in Section 5.2.3 it is difficult to accurately measure the groundwater seepages entering the mining area as the volumes are relatively small, and total pumped flows are subject to several other uncertainties.

8.2.4 Future model iterations

Every three years, or if significant changes to mining occur, or monitoring results identify a need (e.g. where groundwater extraction from the pit or water level changes are inconsistent with predictions) the validity of the model predictions will be assessed by comparing the extraction volumes and groundwater level data against model predictions. The predictions will be validated against historical monitoring data collected as part of the groundwater monitoring program. It is considered this remains appropriate to track the impacts of the MCCO Project on the groundwater regime.

8.2.5 Data management and reporting

The WMP outlines the data management and reporting requirements for groundwater data. For reporting this includes:

- Publishing bi-monthly groundwater quality monitoring and groundwater level monitoring to the company website as a regular measure of performance.
- All hazards, near misses and incidents are reported to the supervisor of the relevant work area immediately. Mangoola Coal will notify the Secretary and any other relevant agencies as soon as practicable of the incident and provide within seven days a detailed report on the incident. All incidents resulting or having the potential to result in material harm to the environment, as defined by Section 147 of the NSW *Protection of the Environment Operations Act 1997* are managed in accordance with the Mangoola Coal Pollution Incident Response Management Plan.
- The Annual Review is prepared in accordance with Schedule 5, Condition 6 of PA 06_0014.
- Mangoola Coal maintains a centralised location to record details of relevant external stakeholder communications. Complaints are recorded and investigated. Follow up communication with the complainant is undertaken to communicate the outcome of complaint investigations.
- The WMP and supporting plans (including the GWMP) are reviewed and resubmitted to DPE every three years, or earlier if required, for approval by the Secretary. Any changes to the WMP as a result of the review are made in consultation with EPA and DPI Water. The WMP will reflect changes in environmental requirements, technology and operational procedures. Updated versions of the approved WMP are made publicly available on the Mangoola Coal website once approved by the Secretary.

The Annual Review must:

- describe the development that was carried out in the previous calendar year, and the development that is proposed to be carried out over the next year;
- include a comprehensive review of monitoring results and complaints records of the project over the previous calendar year, which includes a comparison of these results against the:
  - relevant statutory requirements, limits or performance measures/criteria;
  - monitoring results of previous years; and
  - relevant predictions in the documents listed in Condition 2 of Schedule 2 of PA 06_0014;
- identify any non-compliance over the last year, and describe what actions were (or are being) taken to ensure compliance;
- identify any trends in monitoring data over the life of the project;
- identify any discrepancies between the predicted and actual impacts of the project;
- analyse the potential cause of any significant discrepancies; and
- describe what measures will be implemented over the next year to improve the environmental performance of the project.

These procedures remain appropriate to report the impacts of the cumulative MCCO Project on the groundwater regime. However, they will be updated to reflect contemporary Development Consent conditions as necessary.

8.2.6 Management and mitigation strategies

The WMP includes a Surface Water and Groundwater Response Plan (SGWRP) containing a Trigger Action Response Plan (TARP) to implement in the case of groundwater monitoring results being detected outside the groundwater trigger value range. The actions to be implemented in the event of three consecutive monitoring results outside of the adopted trigger values for water quality and/or standing water levels, exceedance of extraction licence limits, or landholder complaints are reproduced in Figure 8.2 to Figure 8.4.

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

Impact Assessment Criteria Exceeded for Quality and Standing Water Level

Trigger

Three consecutive monitoring result values outside of the adopted impact assessment criteria for quality and/or standing water level presented in the **GWMP**

Action

Notify the Mangoola Coal ECM
Undertake additional monitoring of the bore
Review results against baseline monitoring for the bore (if available)
Compare against water quality trends and relationships with adjacent bores
Review groundwater model predictions, confirm model assumptions are correct/ reflect what is occurring in the mine. Seek advice from qualified hydrogeologist if required
Review operations and investigate for links to operational activities
Investigate any external influence which may be affecting the results including climatic data
Determine if an incident has occurred as defined under EPL 12894 and / or PA 06_0014

Response

An incident has not occurred and trigger is not a result of mining	An incident is deemed to have occurred
Continue Monitoring and Reporting as per the requirements of the **GWMP**	Assess risk of environmental harm, take all preventative measures to prevent or minimise environmental harm and enact PIRMP if required Provide affected landholders with suitable water supply from the mine water management system Conduct an investigation into the incident Notify as per Schedule 5, Condition 4 of PA 06_0014 and EPL 12894 Condition R2 Submit a detailed report to the EPA, DP&E and Crown Lands and Water Division (within seven days) regarding the incident as per Schedule 5, Condition 4 of PA 06_0014 and EPL 12894 Prioritise actions including any groundwater isolation contingency plans or modification of mining operations based on the risk to the environment and likelihood of a repeat incident Monitor the completion of actions to ensure they have been effective Review and if necessary revise **GWMP** and **SWGWRP** as per Schedule 5, Condition 9 of PA 06_0014

Figure 8.2 TARP for exceedances of water quality or water level

Groundwater extraction exceeding license limits

Trigger

Annual Review Reporting of groundwater intercepted/extracted by mining exceeds approved predicted groundwater make at corresponding stage of mining as outlined as shown in Section 2.3.3 of GWMP.

Action

Notify the Mangoola Coal ECM
Review groundwater model predictions, confirm model assumptions are correct and reflect what is occurring in the mine
Review surface water quality to determine if water quality in pit compared with water quality in Big Flat Creek shows a surface water loss.
Review operations and investigate for links to operational activities
Review Groundwater monitoring network data
Iinvestigate any external influence which may be affecting the results including climatic data
Seek advice from qualified hydrogeologist if required
Seek additional license allocation and make appropriate transfer in consultation with DPI Water
Determine if an incident has occurred (exceedance of license allocation) as defined under EPL 12894 and / or PA 06_0014

Response

An incident has not occurred and trigger is not a result of mining	An incident is deemed to have occurred
Continue Monitoring and Reporting as per the requirements of the **GWMP**	Assess risk of environmental harm, take all preventative measures to prevent or minimise environmental harm and enact PIRMP if required Conduct an investigation into the incident Notify as per Schedule 5, Condition 4 of PA 06_0014 and EPL 12894 Condition R2 Submit a detailed report to the EPA, DP&E and Crown Lands and Water Division (within seven days) regarding the incident as per Schedule 5, Condition 4 of PA 06_0014 and EPL 12894 Prioritise actions including any groundwater isolation contingency plans, modification of operations, temporary license transfers or purchase of more license allocation based on the risk to the environment and likelihood of a repeat incident Monitor the completion of actions to ensure they have been effective Review and if necessary revise **GWMP** and **SWGWRP** as per Schedule 5, Condition 9 of PA 06_0014

Figure 8.3 TARP for exceedances of groundwater extraction licence limits

Groundwater Complaint

Trigger

Complaint received regarding groundwater.

Action

Notify the Mangoola Coal ECM
Undertake additional monitoring of the private bore If required
Review results against baseline monitoring for the bore (if available)
Compare against water quality trends and relationships with adjacent bores
Review groundwater model predictions, confirm model assumptions are correct/ reflect what is occurring in the mine
Review operations and investigate for links to operational activities
Investigate any external influence which may be affecting the results including climatic data
Consult and gain advice from qualified hydrogeologist if required
Determine if an incident has occurred as defined under EPL 12894 and / or PA 06_0014

Response

An incident has not occurred and trigger is not a result of mining	An incident is deemed to have occurred
Continue Monitoring and Reporting as per the requirements of the **GWMP** Respond to complainant as per site Complaints Management Procedure	Assess risk of environmental harm, take all preventative measures to prevent or minimise environmental harm and enact PIRMP if required Provide landholder with suitable water supply from the mine water management system Conduct an investigation into the incident Notify as per Schedule 5, Condition 4 of PA 06_0014 and EPL 12894 Condition R2 Submit a detailed report to the EPA, DP&E and Crown Lands and Water Division (within seven days) regarding the incident as per Schedule 5, Condition 4 of PA 06_0014 and EPL 12894 Prioritise actions based on the risk to the environment and likelihood of a repeat incident Monitor the completion of actions to ensure they have been effective Review and if necessary revise **GWMP** and **SWGWRP** as per Schedule 5, Condition 9 of PA 06_0014

Figure 8.4 TARP for groundwater complaint from landholder with private bore

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Glossary and acronyms

AGE	Australasian Groundwater and Environmental Consultants Pty Ltd
AHD	Australian Height Datum
AIP	Aquifer Interference Policy
ALUM	Australian Land Use Mapping
BSAL	Biophysical Strategic Agricultural Land
CSG	Coal seam gas
CRD	Cumulative Rainfall Departure
EMD	Environmental Monitoring Database
DoEE	Department of the Environment and Energy
DPI	Department of Primary Industries
GDE	Groundwater Dependent Ecosystem
Glencore	Glencore Coal Pty Limited
IESC	Independent Expert Scientific Committee
Mangoola Coal Mine	Existing approved operation
Mangoola Coal Operations Pty Ltd (Mangoola)	The proponent
Mangoola Coal Continued Operations (MCCO) Project	The continuation of mining at Mangoola Coal Mine into a new mining area to the immediate north of the existing operations
MCCO Project Area	Includes the existing approved Project Area for Mangoola Coal Mine and the MCCO Additional Project Area
MCCO Additional Project Area	Encompasses all areas required for the MCCO Project to the immediate north of the existing operations
Approved Project Area	Area pertaining to the approved Mangoola Coal Mine as per PA 06_0014 as modified
MCCO Proposed Additional Mining Area	Mining area footprint associated with the proposed operations within the MCCO Additional Project Area
ML	Megalitres
MNES	Matters of National Environmental Significance
Mtpa	Million tonnes per annum

Glossary and acronyms (continued)

Pinneena	NSW Office of Water supplied database of registered groundwater bores
SILO	SILO is a database of historical climate records for Australia
SRLU Policy	Strategic Regional Landuse Policy
TARP	Trigger Action Response Plan
TDS	Total Dissolved Solids
VWP	Vibrating wire piezometer
WSP	NSW Water Sharing Plan

Appendix A Numerical modelling report

Appendix A

Numerical Modelling Report

Table of contents

Page No

Table of contents (continued)

Page No

List of figures

Table of contents
(continued)

Page No

List of tables

List of Appendices

A1 Introduction

Predictive numerical modelling was undertaken to assess the potential impacts on groundwater dependent assets from the Mangoola Coal Continued Operations (MCCO) Project. The steps taken to complete the assessment were to:

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

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

- geological and topographical maps;
- geological models developed by the proponent;
- results from previous hydrogeological investigations and relevant data from the publicly available datasets; and
- long term monitoring datasets held within the Glencore Environmental Monitoring Database.

The main report details the conceptual understanding of the hydrogeological regime at the MCCO Project. The purpose of this appendix is to describe the model setup, calibration, predictive, recovery, and uncertainty scenarios undertaken with the numerical model.

A2 Model construction and development

A2.1 Numerical model history

Numerical groundwater models used for mining operations inherently require continuous updates to reflect new information and data collected through on-site observations and monitoring. The historical development of the approved Mangoola Coal Mine means there have been several previous groundwater models built. The numerical model created for the MCCO Project was based upon models developed by Mackie Environmental Research (MER) (2006, 2013). This approach was undertaken to ensure consistency with previous work where appropriate.

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

A2.2 Model code

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

- allows use of an unstructured mesh, where cells are refined in the areas of interest to represent hydrogeological and mining features, and larger cells are used where data is limited and 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 subcrop, such as coal seams and alluvium;
- effectively reduces the number of cells with the refinement and pinching options, which allows for faster model run times; and
- better represents flow transfer processes between systems such as bedrock and alluvial groundwater systems through the pinching out of layers.

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

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

A2.3 Model design

A2.3.1 Model grid

The model grid was designed to cover the MCCO Project Area and surrounding areas that may be influenced by mining, with the boundaries set beyond the expected influence of mining activities. The model was extended to the west and south of previous models to ensure this. The model domain is approximately 17 km wide (west to east direction) and 17.3 km long (north to south direction) as shown in Figure A2.1.

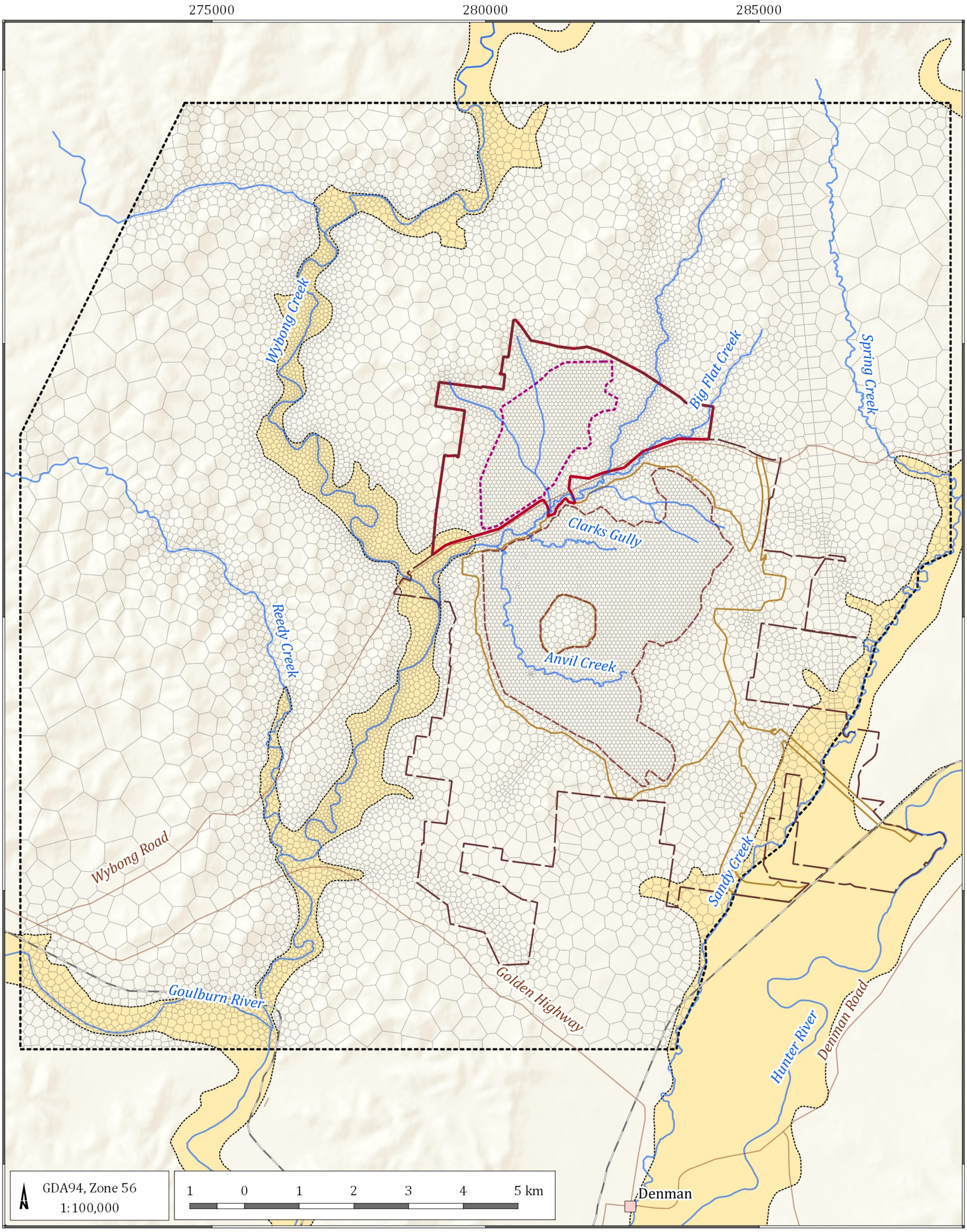
The model boundary is a modified rectangle in shape, with the MCCO Project Area lying slightly to the east of the model centre. As the coal measures subcrop to the east of the Mangoola Coal Mine the predicted impacts have historically been minimal in this direction, and the predicted drawdowns have primarily expanded westwards following the dip of the coal measures.

The south-eastern boundary of the model was aligned with the surface water discharge zone along Sandy Creek.

The model domain was discretised and arranged into 15 layers comprising up to 14,931 cell nodes in each layer with the dimensions of the cells varying according to the features that required representation. Where geological units subcrop or pinch out the corresponding model layers are removed rather than being continued with a minimal thickness. The following Voronoi cell dimensions were adopted:

- open cut areas – 75 m x 75 m cells;
- streams and alluvial flood plains – from 50 m x 50 m to 100 m x 100 m cells;
- major dykes and faults – 120 m x 120 m to 200 m x 200 m cells; and
- up to 700 m cell sizes in more peripheral areas.

Overall, the USG model comprises 184,023 model cells. Compared to the previous SURFACT models this represents a significant decrease in the number of model cells. Coupled with the improved cell communication between Voronoi cells close to dewatered zones, the USG model runs significantly faster than its predecessors.



LEGEND

- Populated place
- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Numerical model boundary
- Alluvium
- Model mesh
- Road
- Rail
- Drainage

Mangoola EIS (G1839F)

Grid layout

AGE

DATE 08/04/2019

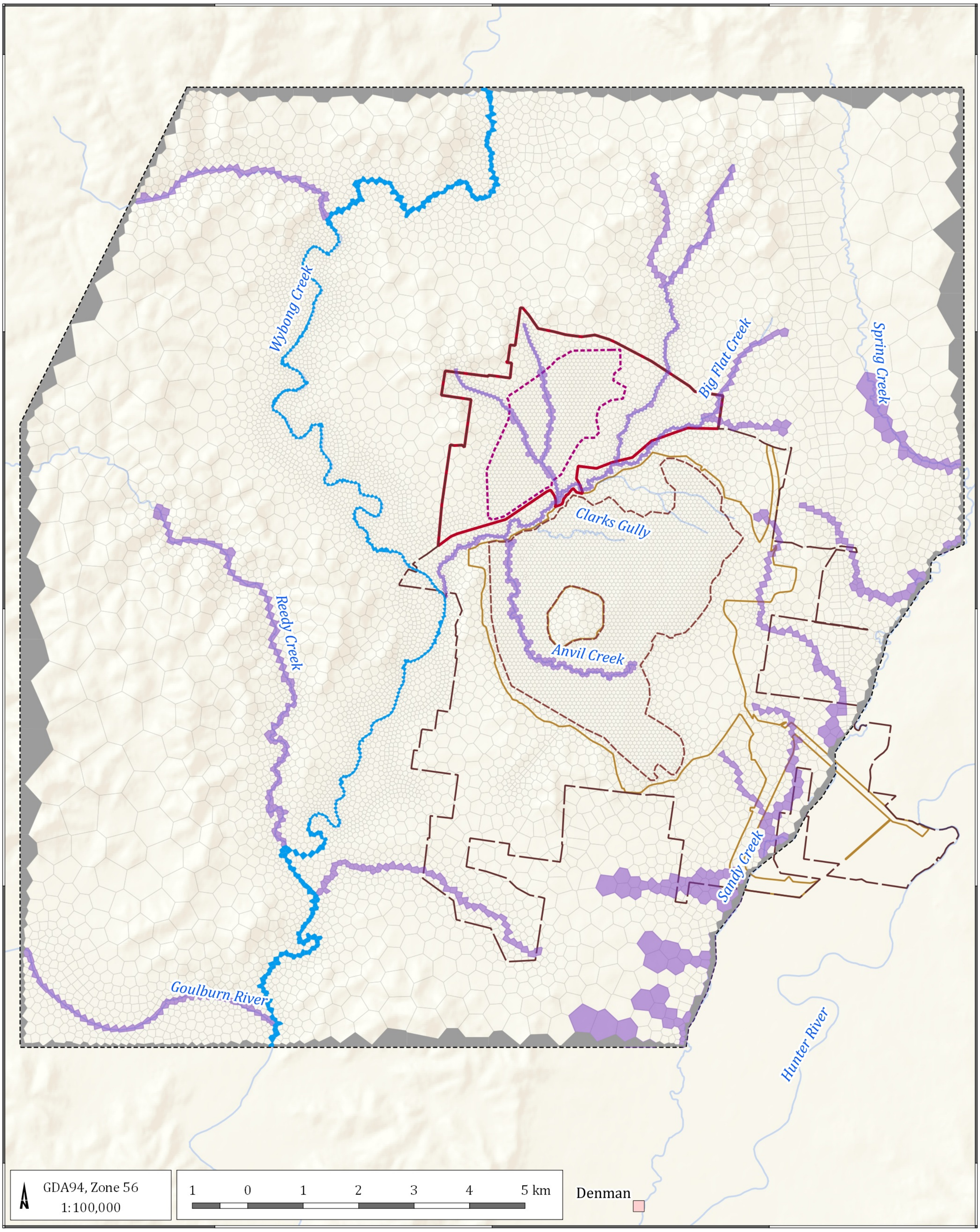
FIGURE No: **A 2.1**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
G:\Projects\G1839F.Mangoola EIS\3_GIS\Workspaces\011_GIA\A-02.01_G1839F_Grid layout.qgs

A2.3.2 Model boundary conditions

Previous versions of the model represented the model boundaries with a 'no flow' boundary condition. Whilst model layers terminate at these boundaries, they are not considered to be groundwater catchment divides where there is 'no-flow'. The 'no flow' boundaries were therefore converted to a general head boundary to allow groundwater to enter or leave the model from the surrounding areas. The general head boundary cells in the model are displayed in Figure A2.2.

Further fluxes into the model domain are in the form of recharge from rainfall. Water can also flow in to or out of the model through baseflow in creeks, which are represented using the river and stream packages. Additional outflows can occur through evapotranspiration across the ground surface. During periods of active mining groundwater is also removed from the system using the drain package to represent open cut mine dewatering. The individual flux packages are detailed further in Section A2.4.



LEGEND

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- Drainage
- General head boundary
- River cells
- Stream cells

Mangoola EIS (G1839F)

General Head Boundary (GHB), stream (STR) and river (RIV) cells

DATE 08/04/2019

FIGURE No: **A 2.2**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
G:\Projects\G1839F.Mangoola EIS\3_GIS\Workspaces\011_GIA\A-02.02_G1839F_General Head Boundary (GHB), stream (STR) and river (RIV) cells.qgs

A2.3.3 Model layers

The model uses 15 layers to represent the key hydro-stratigraphic horizons from the Quaternary alluvium to deeper Permian formations. The layers were based on horizons in available geological models and extrapolated beyond the limit of geological models using available data and experience. The model layering is summarised in Table A2.1.

Table A2.1 Model layers

Layer	Represents
1	Wybong Creek alluvium and Sandy Creek Alluvium, Big Flat Creek colluvium, regolith
2	Moderately weathered conglomerate and unweathered conglomerate
3	Weakly weathered conglomerate and unweathered conglomerate
4	Unweathered conglomerates
5	Unweathered conglomerates
6	Great Northern seam
7	Awaba Tuff
8	Fassifern and Upper Pilot A seam
9	Interburden
10	Upper Pilot B seam
11	Interburden including Lower Pilot seam
12	Hartley Hill seams
13	Interburden including Upper Australasian seam
14	Interburden including Australasian and Montrose seams
15	Nominal interburden

The spatial extent of the Quaternary alluvial sediments along the Wybong Creek and Sandy Creek was redefined based on a 1 m contoured digital terrain model for the area. The alluvial thickness was then assigned based primarily on CSIRO (2015) soil and landscape grid with minor alterations. The resulting alluvial thickness was reviewed against private bore logs to confirm it was an appropriate representation of the alluvial aquifers.

Along Big Flat Creek (BFC) the near-surface colluvial materials surrounding the creek were defined as a separate zone in Layer 1 to allow for flexibility in assigning hydraulic parameters during modelling. The thickness of these materials was adopted from previous model layering. Away from the alluvium and Big Flat Creek, Layer 1 was assigned a thickness of 2 m to represent the thin regolith that overlies the bedrock outside the alignment of the creek.

The CSIRO regolith mapping showed considerably thicker weathering in several areas of the model, including underlying Big Flat Creek. In line with previous modelling the total thickness of the weathered material in Layers 1 and 2 was set to a minimum of 11 m thickness (2 m in Layer 1, and 9 m in Layer 2). Where the CSIRO regolith mapping showed a total thickness of over 11 m the additional depth was assigned to Layer 2. Layer 2 was assigned a minimum thickness of 1 m underneath any alluvial areas, to represent a weathered transition zone between the alluvium and unweathered bedrock units.

A2.3.4 Timing

The numerical groundwater model simulates groundwater flow from 2010 to 2030 as follows:

- last day of 2009 – steady state stress period;
- 2010 – 6 stress periods; 4 x 60 day, 1 x 120 day, 1 x 5 day (as per previous model) (transient here and after); and
- 2011 to 2030 – 80 x quarterly stress periods.

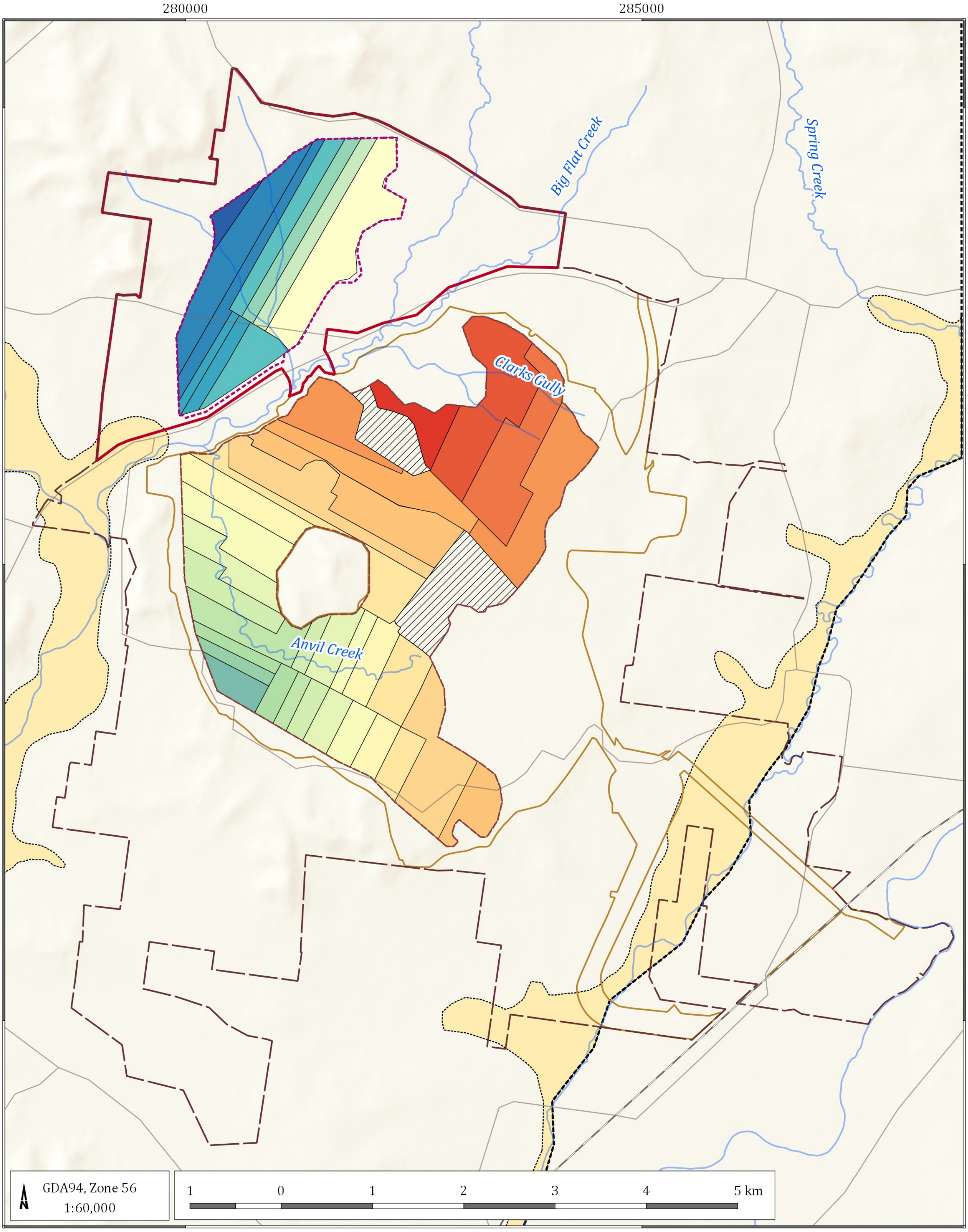
Quarterly stress periods were introduced to the model so that seasonal variability in recharge and stream flows could be represented where data was available for the calibration period (2010 to 2017). The drains representing mining were advanced in quarterly intervals and turned off after a 3 year period. The area was then reclassified as spoil to simulate the mining area being progressively backfilled.

An additional version of the model was developed for simulating recovery after mining ceased at the MCCO Project from January 2031. The recovery model was designed with 5 year stress period for 500 years duration. This allowed for time varying model parameters to be integrated into the recovery simulation. The recovery model is discussed further in Section A4.

A2.3.5 Mining progression

A single combined mining progression was utilised for the MCCO Project Area. Figure A2.3 shows the footprint and progression of the mining annually.

Mining activities associated with Mangoola Coal Mine commenced in 2010, with the mining at the MCCO Additional Mining Area proposed to commence in 2022. The simulation of mining in the model was based on historical mining schedules provided for the Mangoola Coal Mine to 2017, and updated with proposed mining for the Mangoola Coal Mine and MCCO Additional Mining Area according to plans and data provided by Glencore.



LEGEND

- MCCO Project Area
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Mining progression (years)

Pre 2011, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030

Mangoola EIS (G1839F)

Predictive mine progression for Mangoola Coal and MCCO Project

AGE

DATE 02/11/2018

FIGURE No: **A 2.3**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
G:\Projects\G1839F.Mangoola EIS\3_GIS\Workspaces\011_GIA\A-02.03_G1839F_Predictive mine progression for Mangoola Coal and MCCO Project.qgs

A2.4 System stresses

A2.4.1 Recharge

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

The dominant mechanism for recharge to the groundwater system is through diffuse infiltration of rainfall through the soil profile and subsequent deep drainage to underlying groundwater systems. Available data also indicates river leakage can provide recharge to underlying groundwater systems along Wybong Creek. In general, the clayey nature of the regolith, and colluvium along Big Flat Creek, means recharge rates to the groundwater regime will be relatively low across the majority of the model. A spreadsheet based soil moisture budget was used to estimate the timing and magnitude of recharge events. The simple soil moisture balance estimates when the soil profile reaches field capacity, enabling deep drainage to the underlying water table to occur, by looking for a corresponding rise in water levels at shallow groundwater monitoring bores.

Table A2.2 represents the calibrated rate of recharge for each geological unit. Figure A2.4 shows the recharge distribution zones.

Table A2.2 Modelled recharge rates

Zone	Diffuse recharge rate - transient	
	Mean (min-max) mm/year	Mean % of annual rainfall
Quaternary alluvium - Wybong and Sandy Creek	19.1 (0 - 117.9)	3.20%
Triassic/Permian regolith	0.36 (0 - 2.1)	0.06%
Triassic regolith Big Flat Creek	4.4 (0 - 27.1)	0.74%
Triassic/Permian Weathered zone	0.6 (0 - 3.8)	0.10%
Triassic Narrabeen Sandstone	0.29 (0 - 1.79)	0.05%

Recharge for the predictive phase (2018 onwards) adopted constant steady state recharge rates.

A simple SWAT model (Arnold, 2012) covering the model domain catchment area was developed to validate the groundwater recharge rates assumed during the calibration process. Global FAO soil and static land use data were assumed, and weather was applied using interpolated SILO climate data. SWAT calculated that percolation rates to the alluvium of about 108 mm/year and Permian groundwater recharge at a rate of 5.4 mm/year.

Recharge was also estimated using the chloride mass balance method. This estimates rainfall recharge by comparing the concentration of chloride in rainfall and dry deposition with the concentration in the underlying groundwater system. The method assumes the only source of chloride to the system is from evaporated rainfall and dryfall. The groundwater recharge is estimated using the equation (Kellett *et al.*, 2003):

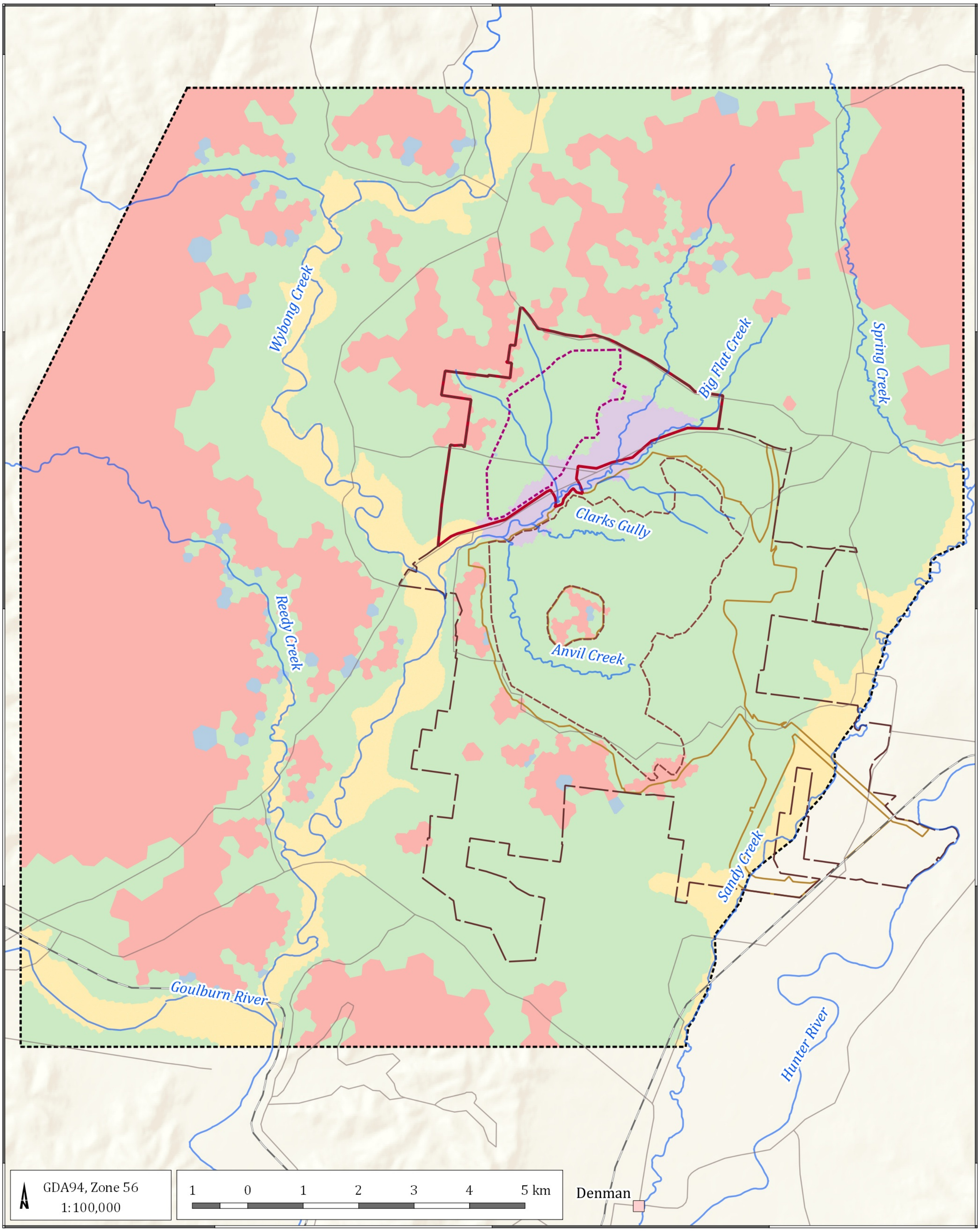
$$R = C_p P_p / C_G$$

Where:

- R = recharge rate (mm/yr) – to be determined;
- C_p = chloride concentration in precipitation and dryfall (mg/L) ~1.45 mg/L;
- P_p = precipitation (mm/yr) ~600 mm/yr; and
- C_G = chloride concentration in groundwater at the water table (mg/L) – variable.

The equation assumes that there is one-dimensional piston flow within the ground and that the only source of chloride to the system is from evaporated rainfall and dryfall. Therefore, the more concentrated the observed chloride concentration in the groundwater the less recharge has entered the system.

The chloride mass balance method generates average recharge rates for bores monitored at Mangoola of between 0.1 mm/year and 75 mm/year, with a median value of approximately 0.5 mm/year. The median value is of the same magnitude as recharge rates estimated by the other methods. The highest recharge rates were calculated for bores GW18 and GW10-P2, which recorded the freshest water quality at the site, and are atypical compared to the majority of sites monitored.



LEGEND

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Recharge rate (m/day)

- Zone 1 - 7x10^(-05)
- Zone 2 - 3x10^(-06)
- Zone 3 - 2x10^(-05)
- Zone 4 - 2x10^(-06)
- Zone 5 - 1x10^(-06)

Mangoola EIS (G1839F)

Recharge zones

DATE 08/04/2019

FIGURE No: **A 2.4**

A2.4.2 Evapotranspiration

Evapotranspiration from shallow water tables was represented with the evapotranspiration package (EVT). Evapotranspiration occurred from the uppermost model cells across the model domain at an areal actual potential evaporation rate (500 mm/year) decreasing linearly to a maximum depth of 2 m below the surface.

The results from the SWAT modelling correlated with the areal potential evaporation datasets, producing an average of 408 mm/year.

A2.4.3 Abstraction

Abstraction from landholder pumping wells is not significant in the vicinity of the Mangoola Coal Mine and was therefore not included in the model simulation. This is consistent with the previous modelling exercises completed for the Mangoola Coal Mine. The discharge that occurs from water bores within the Wybong Creek and Sandy Creek alluvial aquifers is indirectly represented within the baseflow discharge to the creek systems in the model.

A2.4.4 Surface drainage

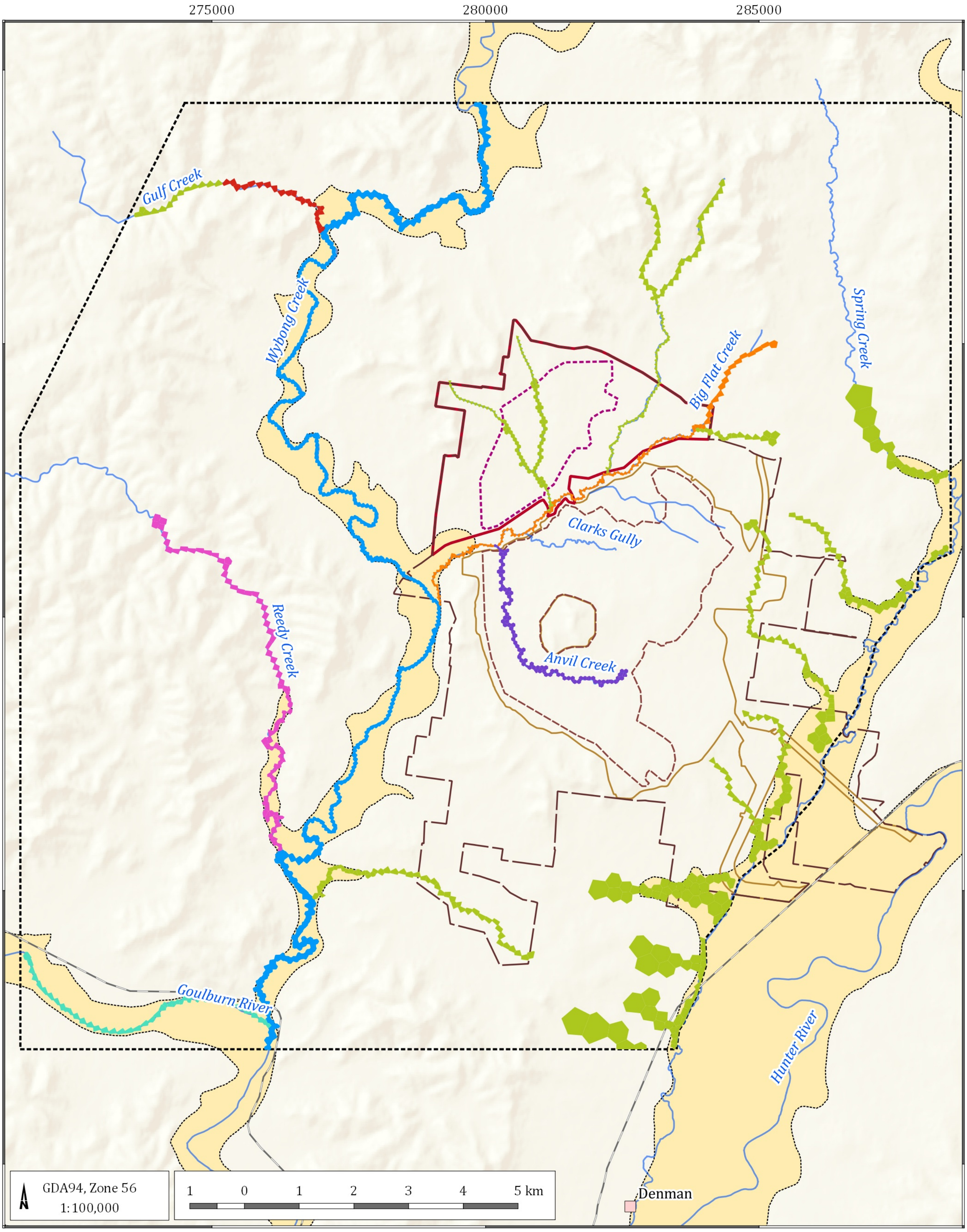
Groundwater interaction with surface drainage was modelled using the stream package (STR) and the river package (RIV) of MODFLOW. The cells assigned to these packages in the model, divided by zones, are displayed on Figure A2.5.

Wybong Creek is a major stream system and was assigned to the stream package. All other drainage systems were simulated using the river package. The STR package requires the level of the river bed and the flux of surface water across the river surface. The river bed conductance was calculated from river width, length, riverbed thickness, and an estimated vertical hydraulic conductivity of the riverbed material. The stage height for rivers and creeks where perennial stream flow occurs (i.e. Wybong Creek) was internally calculated by MODFLOW-USG using an interpolated flow gauging data from the DPI Water stream gauge at Wybong (NSW DPI, 2017). Manning's coefficient values were based on the metric application of firm soil to gravel streambeds, which ranges from 0.025 to 0.035 (USGS, 1989).

Table A2.3 summarises the stream and river cell parameters in the model.

Table A2.3 Modelled stream (STR) and river (RIV) bed parameters

Segment Number	Segment name	Vertical hydraulic conductivity (m/day)	Width (m)	Incised depth (m)	Slope	Bed thickness (m)	Manning's Coefficient
1	Minor Creeks (RIV)	0.1	2	1	---	1.0	---
2	Big Flat Creek (RIV)	0.1	3	1	---	2.0	---
3	Anvil Creek (RIV)	0.1	3	1	---	3.0	---
4	Gulf Creek (RIV)	0.1	3	1	---	4.0	---
5	Reedy Creek (RIV)	0.1	3	1	---	2.0	---
6	Goulburn River (RIV)	0.1	10	1	---	3.0	---
7	Wybong Creek (STR)	0.2	3	1	0.004	1.5	0.03



LEGEND

- Populated place
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River cells

- Segment 1 (minor drainage)
- Segment 2 (Big flat creek)
- Segment 3 (Anvil Creek)
- Segment 4 (Gulf Creek)
- Segment 5 (Reedy Creek)
- Segment 6 (Goulburn River)
- Segment 7 (Wybong Creek)

Mangoola EIS (G1839F)

Stream and river cell segments

AGE

DATE 08/04/2019

FIGURE No: **A 2.5**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
G:\Projects\G1839F.Mangoola EIS\3_GIS\Workspaces\011_GIA\A-02.05_G1839F_Stream and river cell segments.qgs

The water level above the creek bed was set at 0 m for all minor streams and creeks within the model domain. The location of the river cells in the groundwater model were assigned to the highest active layer in the model, which was generally Layer 1 or Layer 2. Where LIDAR topography identified that the creeks were incised through the uppermost model layer, such as along sections of Big Flat Creek, the river cells were assigned in both Layer 1 and Layer 2.

A2.4.5 Mining

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

Within the open-cut mine areas, drain cells were applied to all intersected model cells, at reference elevations set to the floor of each cell down to the target coal seam – Fassifern & Upper Pilot A (Layer 8) or Upper Pilot B (Layer 10). The drains were set up to represent pre-stripping to the base of the conglomerate (base of Layer 5) a year before total depth is reached. Once total depth is reached the drains remain active for 3 years before being turned off and converted to represent the in-pit spoil piles. This way, the model represented the growth of spoil piles for the open-cut by progressively changing the hydraulic properties of mined cells (horizontal hydraulic conductivity (Kh), vertical hydraulic conductivity (Kv), specific yield (Sy) and specific storage (Ss)) behind the active open cut mining area once the drains became inactive.

A3 Model calibration

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

This approach to calibration is recognised in the draft IESC Uncertainty Modelling Guidelines (Middlemis & Peeters, 2018) as being a valid first step in a two-step uncertainty analysis process[1]. As with all models the resulting calibration is non-unique, that is an alternative set of parameters could produce an equally valid calibration, especially where simulations are sensitive to parameter combinations that lie within the calibration null space. The calibration null space refers to the model parameters and parameter combinations that are not informed by the available observed measurements. The second step in the validation process it to quantify the error in simulations made by the history-match model.

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).

A3.1 Calibration targets

A3.1.1 Heads

The steady state and transient model simulated water levels at all available monitoring bores with reliable datasets. A total of 157 monitoring sites were available to calibrate the model, comprising:

- 96 standpipe monitoring bores;
- 54 monitoring points from vibrating wire piezometers; and
- 7 points classed as well, well/spring or 'bore'.

The standpipe bores can be further split into:

- 13 pairs (shallow and deep);
- 4 triplets (shallow, intermediate, deep);
- 1 quad group (4 different depths);
- 9 that are paired with a single deeper VWP sensor; and
- 4 that are grouped with a multiple VWP string.

The number of active monitoring sites has been variable over time as sites are added during drilling campaigns or destroyed as the Mangoola Coal Mine has progressed. As of February 2019 approximately 37 monitoring sites have been abandoned or destroyed. These were primarily located in the Mangoola Coal mining footprint and were removed due to the progression of mining. Data from these sites was used in the calibration until the end of the available record (or the end of the period of calibration if the dataset was longer).

[1] The finalised IESC Uncertainty Modelling Guidelines were issued in mid-December 2018 after the modelling component of the GIA had been completed and the draft of this report had been issued. As the document is a 'guideline', and the draft document itself was issued after the MCCO Project had commenced, AGE have continued to use the draft IESC document as the reference document followed throughout this report.

Figure A3.1 presents the observation bores that were used in the 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; and
- datapoints for each location were weighted according to the formula:

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

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

The model was calibrated to the observed water level datasets, with the 'best calibrated' model returning the lowest objective function (phi) value. Phi is the sum of the squared residuals, where the residuals are the differences between the observed and modelled values.

A3.1.2 Fluxes

Prior to mining commencing at the Mangoola Coal Mine there were no major anthropogenic groundwater stresses in the area, apart from land clearing and private water bores. The principal inputs and outputs to the system were rainfall, evaporation, stream baseflow, and groundwater throughflow.

Groundwater licences to extract water from the Permian bedrock in the area are for low intensity uses only, such as stock and domestic use. A larger number of bores are present within the Wybong Creek alluvium and Sandy Creek alluvium, but these are considered to be far enough away from the mining areas that they will not influence the model outputs. There are no groundwater extraction bores included in the numerical model.

Measurements of Permian groundwater inflows to the Mangoola Coal Mine are uncertain for the reasons discussed in Section 5.2.3 of the main report. Estimated groundwater inflows to the Mangoola Coal Mine, developed from the site water balance throughout the calibration period, are considered to be of moderate to low confidence, and have been used for calibrating on an indicative 'order of magnitude' scale i.e. 10's, 100's, 1000's m^3.

A3.2 Addition of pilot points

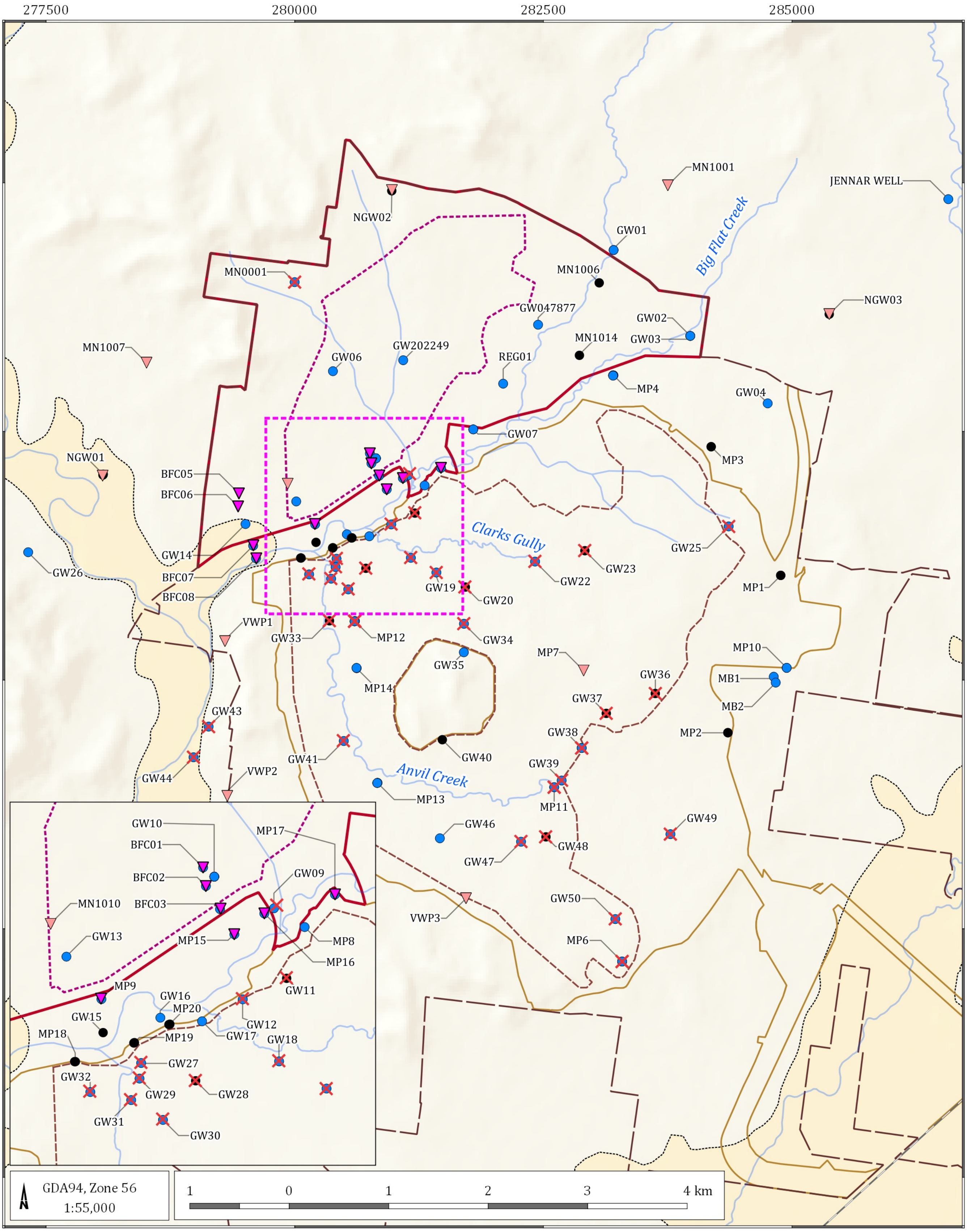
Responses of observation bore water levels to advancing mining suggested that there was a degree of heterogeneity present within several geological layers. This became more apparent during initial model calibration, when not all bores within a layer would calibrate using uniform hydraulic parameters.

To explore the heterogeneity within the model domain and provide a degree of flexibility during the calibration, a series of pilot points were added to each model layer. A greater number of pilot points were added in the key model layers representing the unweathered conglomerate immediately overlying the Great Northern seam, to the Permian interburden immediately underlying the Upper Pilot coal seams. The locations of the pilot points in each model layer are shown in Figure A3.2. The pilot points were interpolated across the model domain in each layer of the model using ordinary automatic Kriging through PLPROG (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 literature ranges for their respective units. Specific storage values are constrained by literature ranges derived from regional studies of similar strata, using the relationship between bulk modulus, Poisson's ratio, and effective porosity, to calculate a physically possible value. Table A3.1 presents the general parameter constraints applied to all layers.

Table A3.1 General parameter constraints

Unit	Min Kh (m/day)	Max Kh (m/day)	Min Kv (m/day)	Max Kv (m/day)	Min Sy (%)	Max Sy (%)	Min_Ss (m^{-1})	Max_Ss (m^{-1})	Max Kh:Kv
Interburden	1.0×10^{-7}	1.0×10^{-2}	1.0×10^{-8}	5.0×10^{-3}	0.1	6	7.0×10^{-7}	1.0×10^{-4}	0.5
Coal	1.0×10^{-7}	1.0×10^{-1}	1.0×10^{-7}	1.0×10^{-1}	0.1	5	2.0×10^{-6}	1.0×10^{-4}	1.0
Sandstone	1.0×10^{-5}	1.0	1.0×10^{-5}	1.0	0.1	20	9.0×10^{-7}	1.0×10^{-4}	1.0

To calibrate the model, the pilot point multipliers were allowed to vary ±2 orders of magnitude from the starting point. The starting point for all multipliers was assumed to be 1.



LEGEND

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- Drainage

Monitoring locations

- Monitoring bore
- Monitoring bore with logger
- VWP single site
- VWP multi site
- Destroyed or no longer monitored

Mangoola EIS (G1839F)

Observation target locations

AGE

DATE 10/04/2019

FIGURE No: **A 3.1**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011
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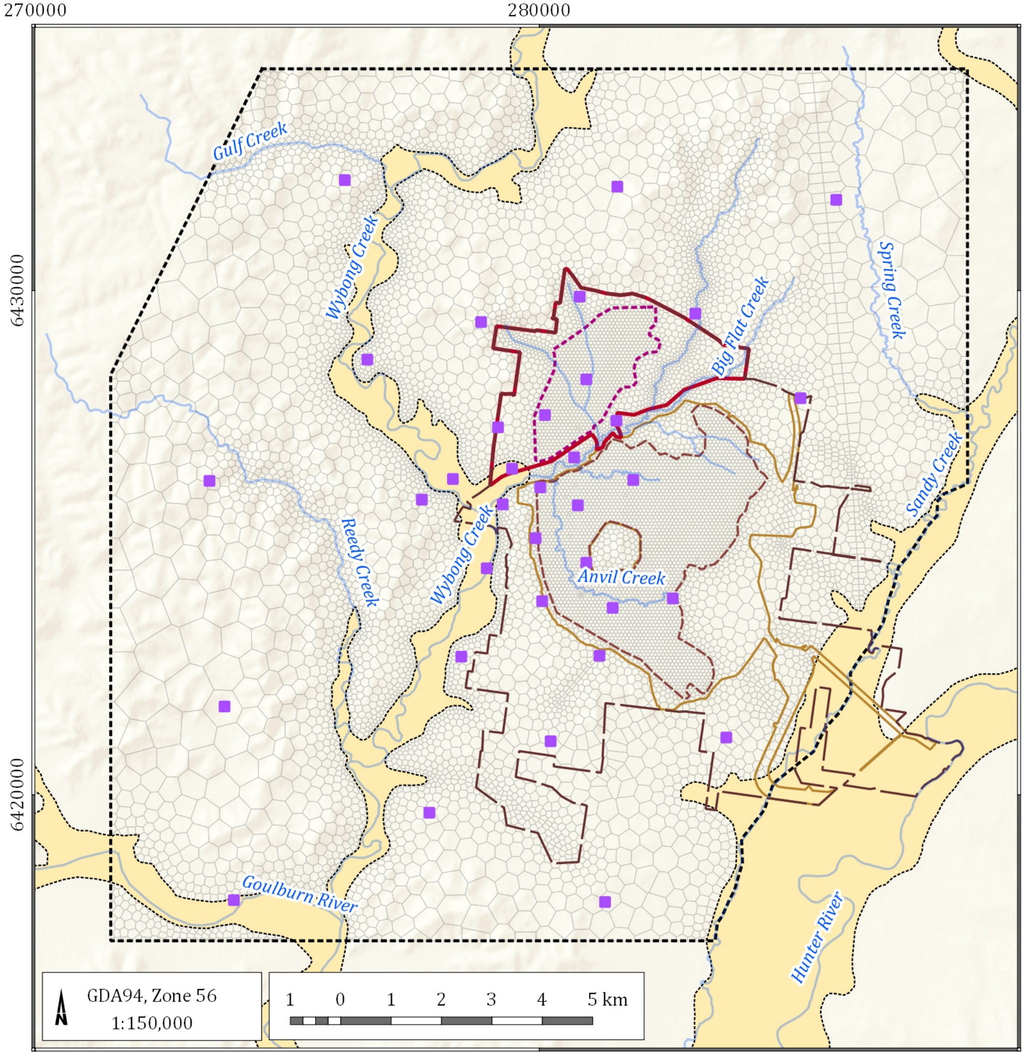
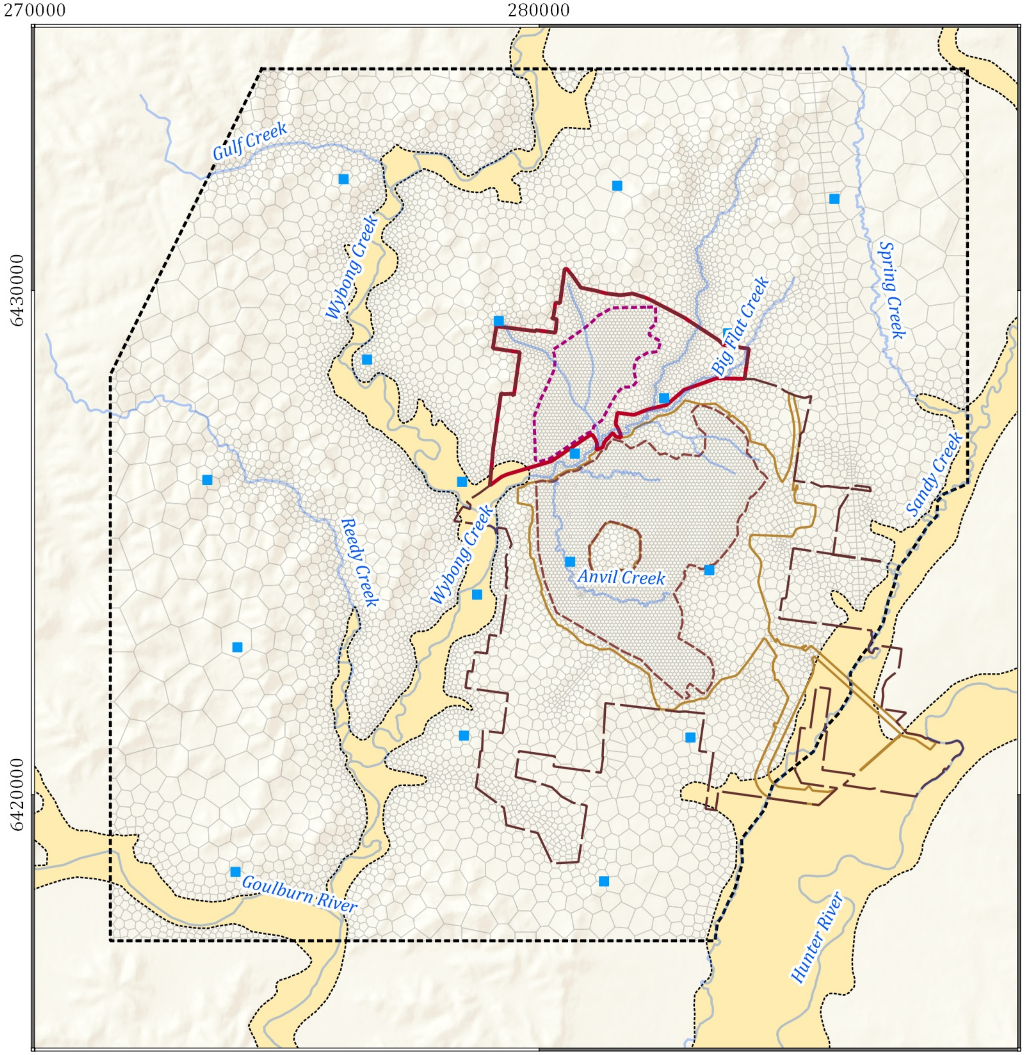
Pilot points utilised in high priority layers



Pilot points utilised in lower priority layers



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- Pilot points utilised in high priority layers
- Pilot points utilised in lower priority layers

Mangoola EIS (G1839F)

AGE

Locations of pilot points

DATE
08/04/2019

FIGURE No:
A 3.2

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1839F.Mangoola EIS\3_GIS\Workspaces\011_GIA\A-03.02_G1939F_Locations of pilot points.qgs

A3.3 Calibration results

Figure A3.3 presents the observed and simulated groundwater levels graphically as a scattergram for the historical transient calibration.

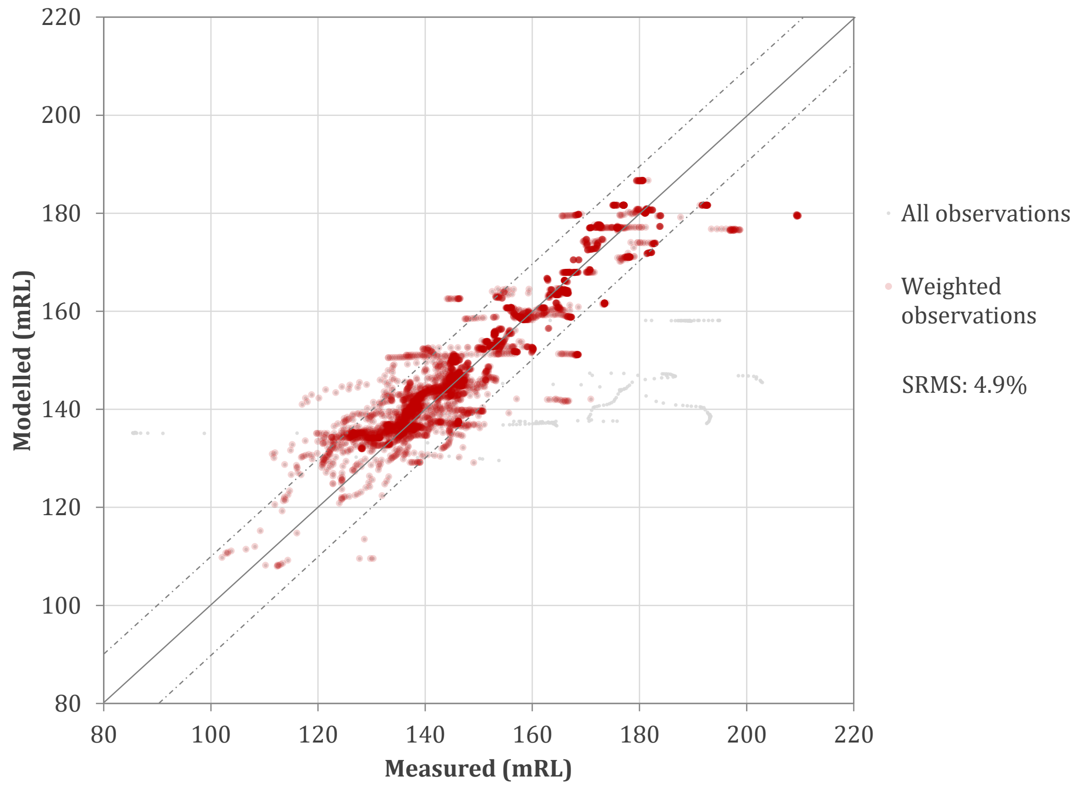


Figure A3.3 Transient calibration – modelled vs observed groundwater levels

The root mean square (RMS) error calculated for the calibrated model was 6.06 m. The total measured head change across the model domain was 124.2 m, with a standardised unweighted RMS (SRMS) of 4.9%. This is approximately half the SRMS target of < 10% suggested in the Australian Modelling Guidelines (Barnett, 2012). Table A3.2 presents the unweighted statistics for the transient calibration model.

Table A3.2 Statistical analysis

Calibration performance measure	Unweighted value
Sum of Residuals (SR) (m)	1983
Mean Sum of Residuals (MSR) (m)	0.37
Scaled Mean Sum of Residuals (SMSR) (%)	0.30
Sum of Squares (SSQ) (m2)	196,620
Mean Sum of Squares (MSSQ) (m2)	36.69
Root Mean Square (RMS) (m)	6.06
Root Mean Fraction Square (RMFS) (%)	0.16
Scaled RMFS (SRMFS) (%)	0.19
Scaled RMS (SRMS) (%)	4.88

Figure A3.4 shows the relationship between the observed water levels and the residuals. It shows that the residuals are almost consistent across the model domain.

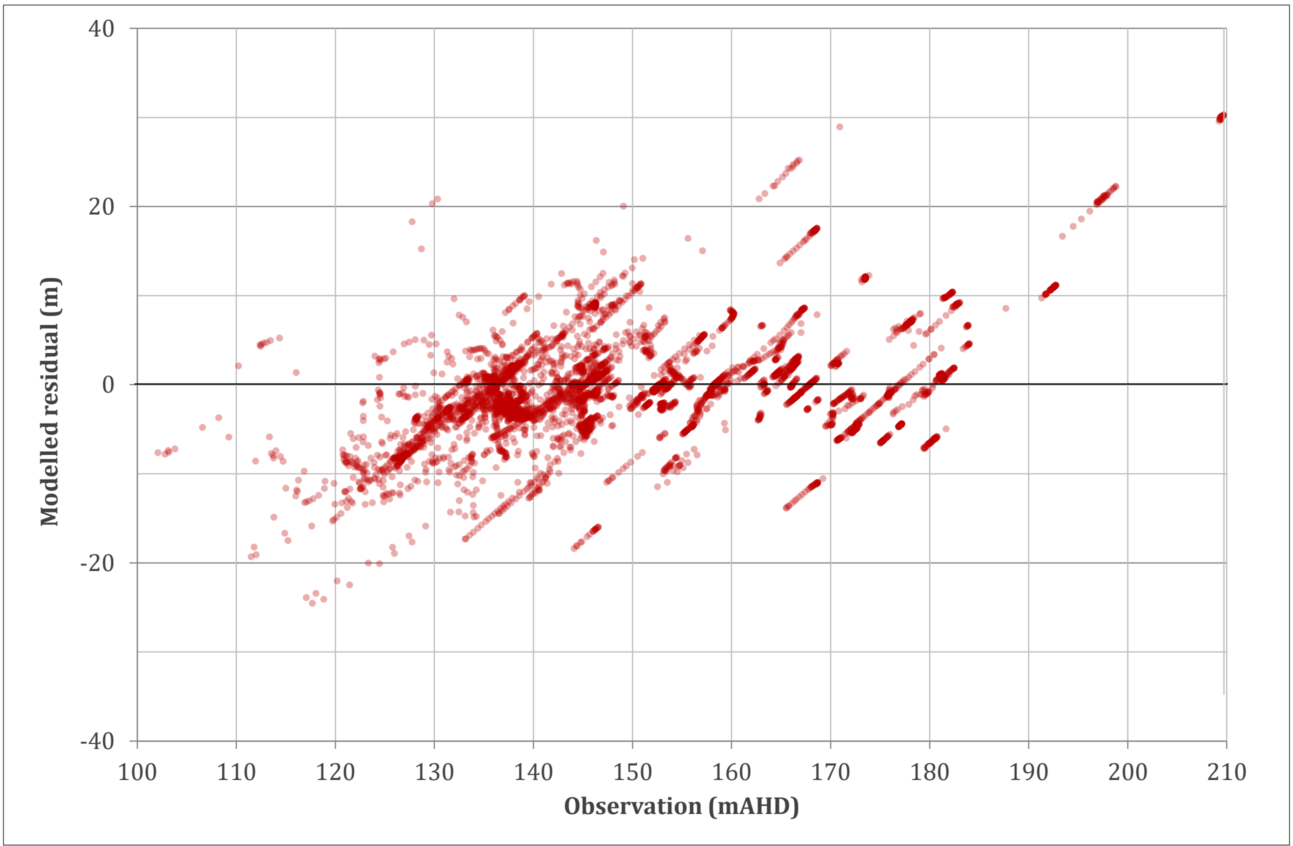


Figure A3.4 Observations versus residuals

Appendix A-1 presents the historic calibration hydrographs, showing the fit between modelled and observed groundwater levels from January 2010 to December 2017.

The model has commonly replicated in a simple way the complex response to the ongoing mining activities at Mangoola Coal Mine over the calibration period. Bores which have recorded stable observed water levels principally show the same response in the model, and bores that have started to draw down are also replicated. In some instances, such as MP13, the timing of the model drawdown does not closely replicate observed water level changes in the groundwater system. This is most likely due to increased heterogeneity in this area of the site that cannot be replicated without more dense pilot points. The resolution of the model layering may also hinder model calibration, particularly within thick models layers, such as Layer 5 unweathered conglomerate, where the permeability may vary vertically within the layer. Groups of standpipe bores completed at different depths indicate that the deeper sections of the conglomerate are responding to depressurisation of the underlying coal seams, whereas water levels in the shallower conglomerate have remained less affected by the applied deep stresses.

However, it is considered the major responses to depressurisation from mining have been replicated adequately to meet the modelling objectives.

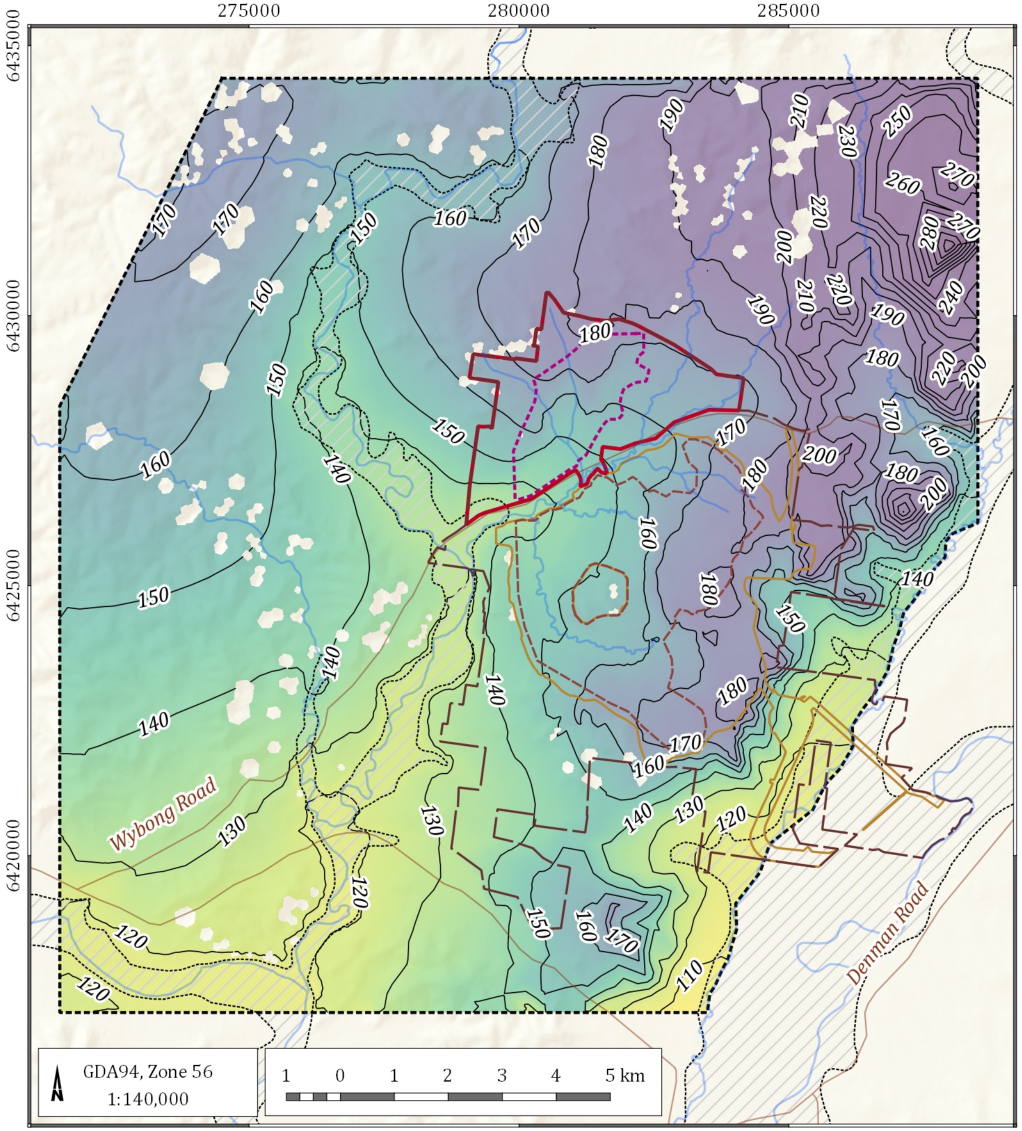
A3.3.1 Calibration heads

The calibrated heads from the pre-mining steady state calibration model are presented for Layer 1 (alluvium and regolith), Layer 5 (unweathered conglomerate) and Layer 8 (Fassifern and Upper Pilot Seams) on the left hand side of Figure A3.5, Figure A3.6, and Figure A3.7 respectively. The figures show groundwater within the Mangoola mining areas generally flowed towards Big Flat Creek and Wybong Creek, and south-east to Sandy Creek, without the presence of active open-cut mining.

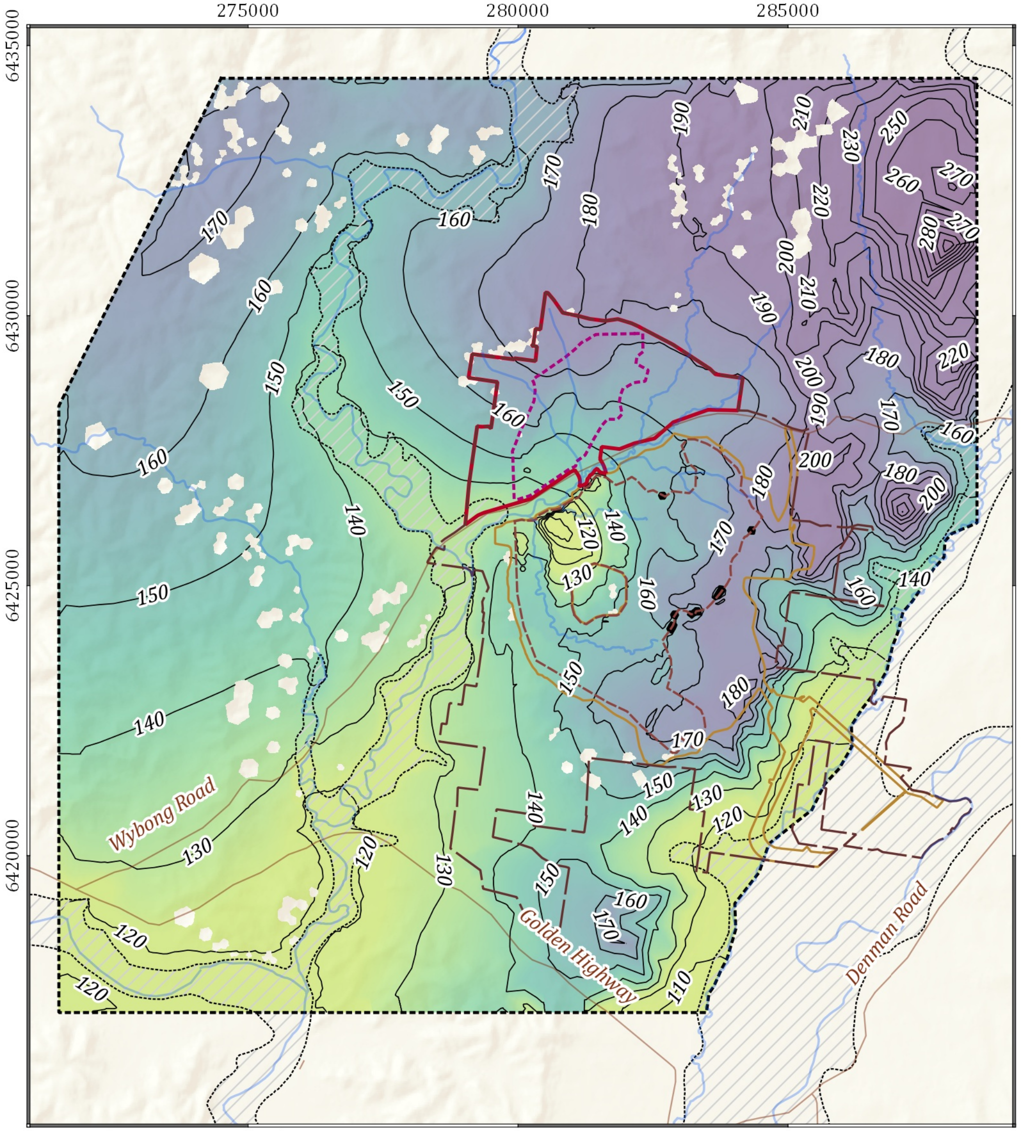
The pre-mining modelled heads are similar to the interpolated pre-mining contours developed by MER (2006). For 2017, when mining drawdown starts to become more apparent in the observed data, the comparison is slightly less good around the main area of active mining. This likely reflects a combination of hand contouring water levels from bores completed in different shallow strata, and a slight delay in the modelled drawdown.

The calibrated heads at the end of the transient calibration model (2017) are presented on the right hand side of Figure A3.5, Figure A3.6, and Figure A3.7. Groundwater levels representing 2017 conditions show the depressurised zones within the potentiometric surface caused by the advancement of mining at Mangoola Coal Mine.

Groundwater levels (Pre-mining)



Groundwater levels (2017)



LEGEND

- Populated place
- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Numerical model boundary
- Alluvium
- Road
- Drainage

Head (mAHD)

100	250
150	300
200	350

Head contour (mAHD)

AGE

Mangoola EIS (G1839F)

Modelled historical groundwater levels – Layer 1 (Alluvium and Regolith)

DATE
08/04/2019

FIGURE No:
A 3.5

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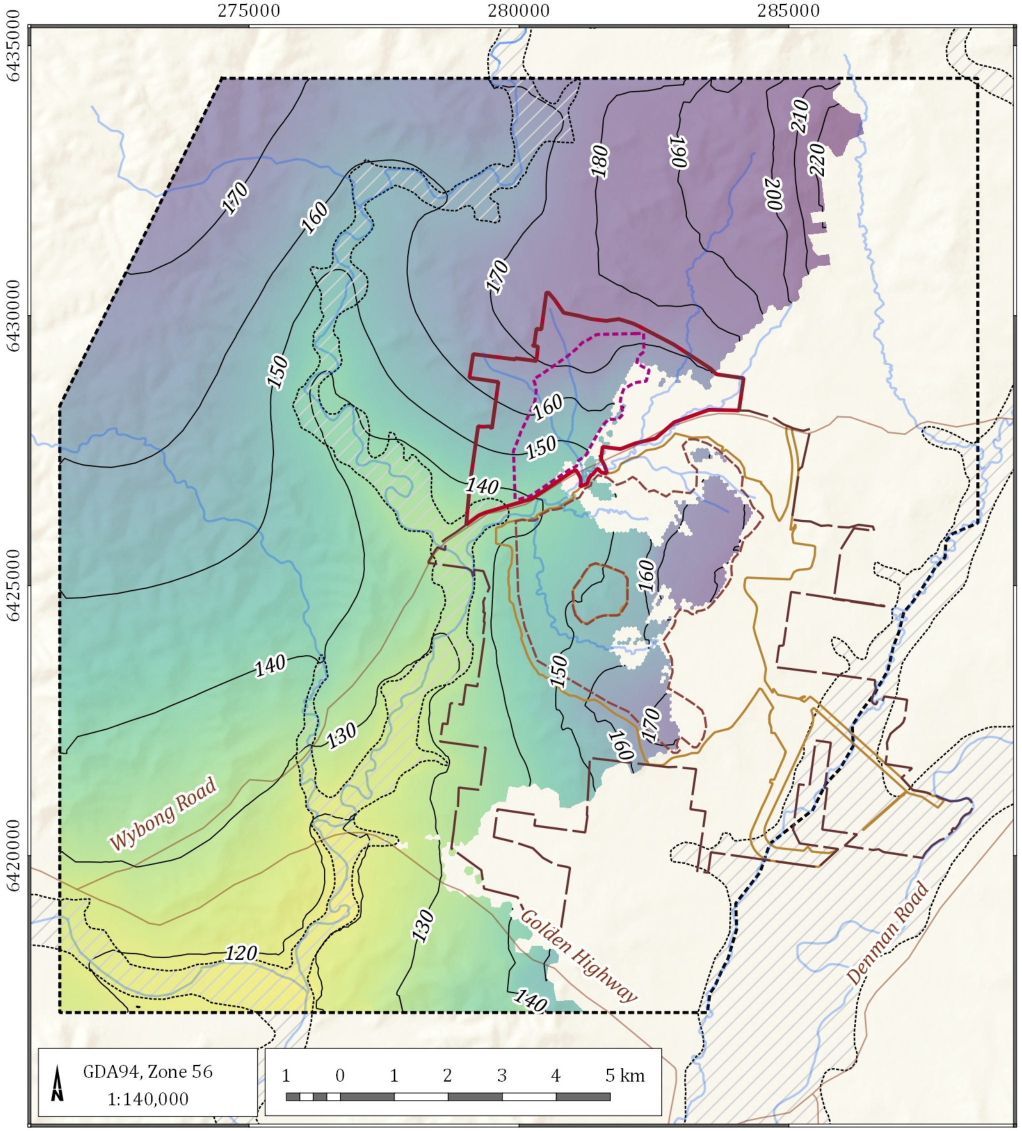
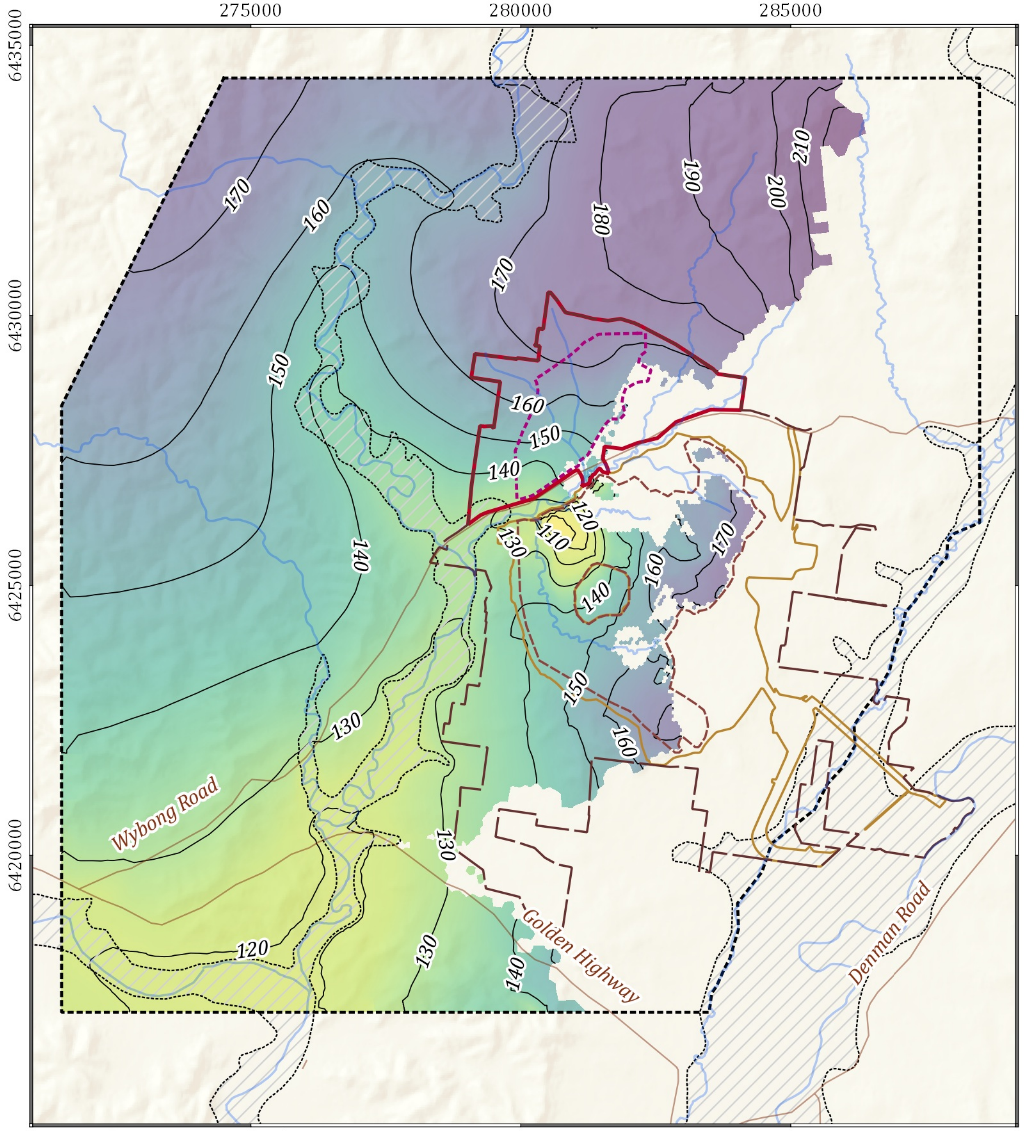
G:\Projects\G1839F.Mangoola EIS\3_GIS\Workspaces\011_GIA\A-03.05 to A-03.07_Modelled historical groundwater levels.qgs

Groundwater levels (Pre-mining)



Groundwater levels (2017)



LEGEND

- Populated place
- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Numerical model boundary
- Alluvium
- Road
- Drainage

Head (mAHD)

100		250	
150		300	
200		350	

Head contour (mAHD)

Mangoola EIS (G1839F)

Modelled historical groundwater levels – Layer 5 (Unweathered conglomerate)

DATE
08/04/2019

FIGURE No:
A 3.6

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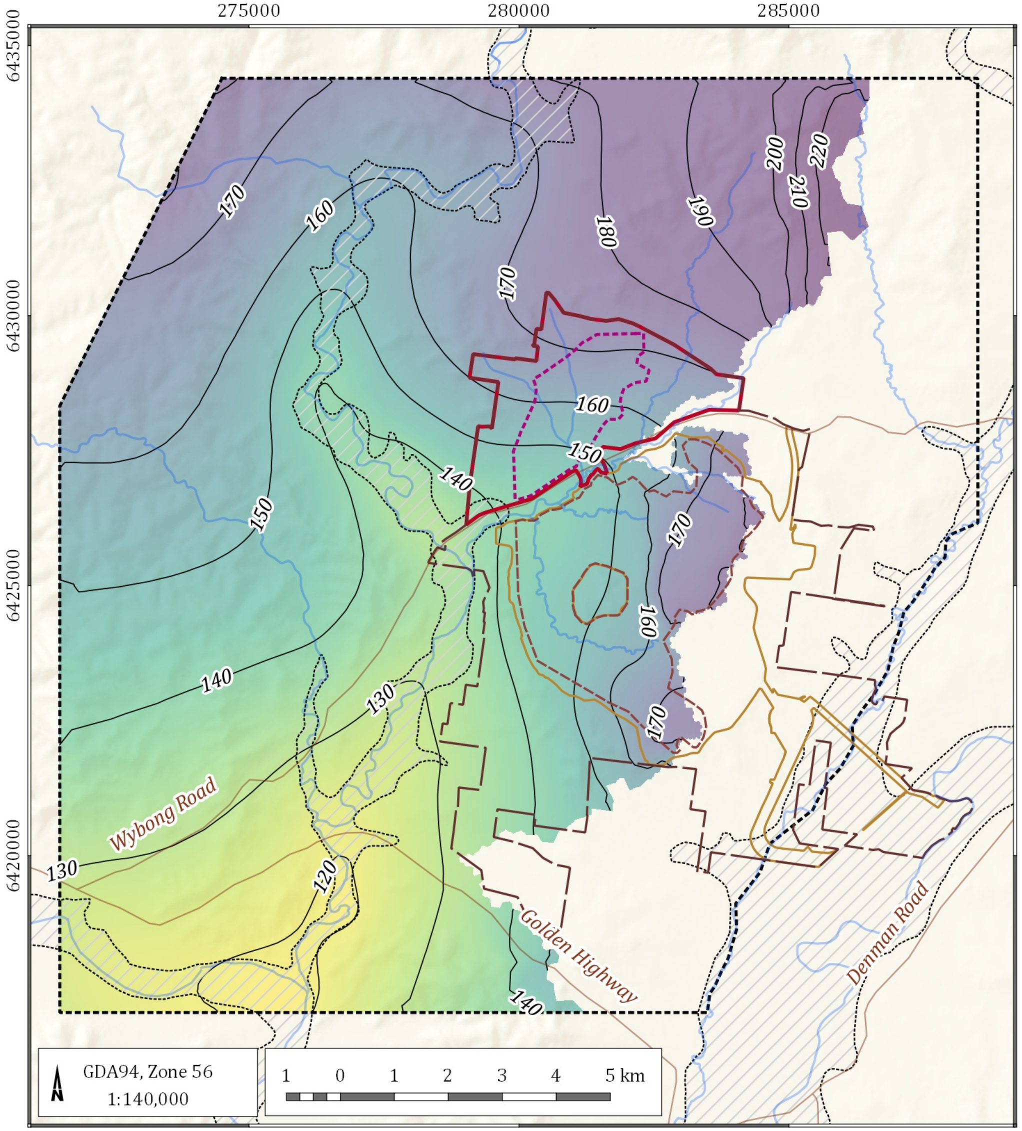
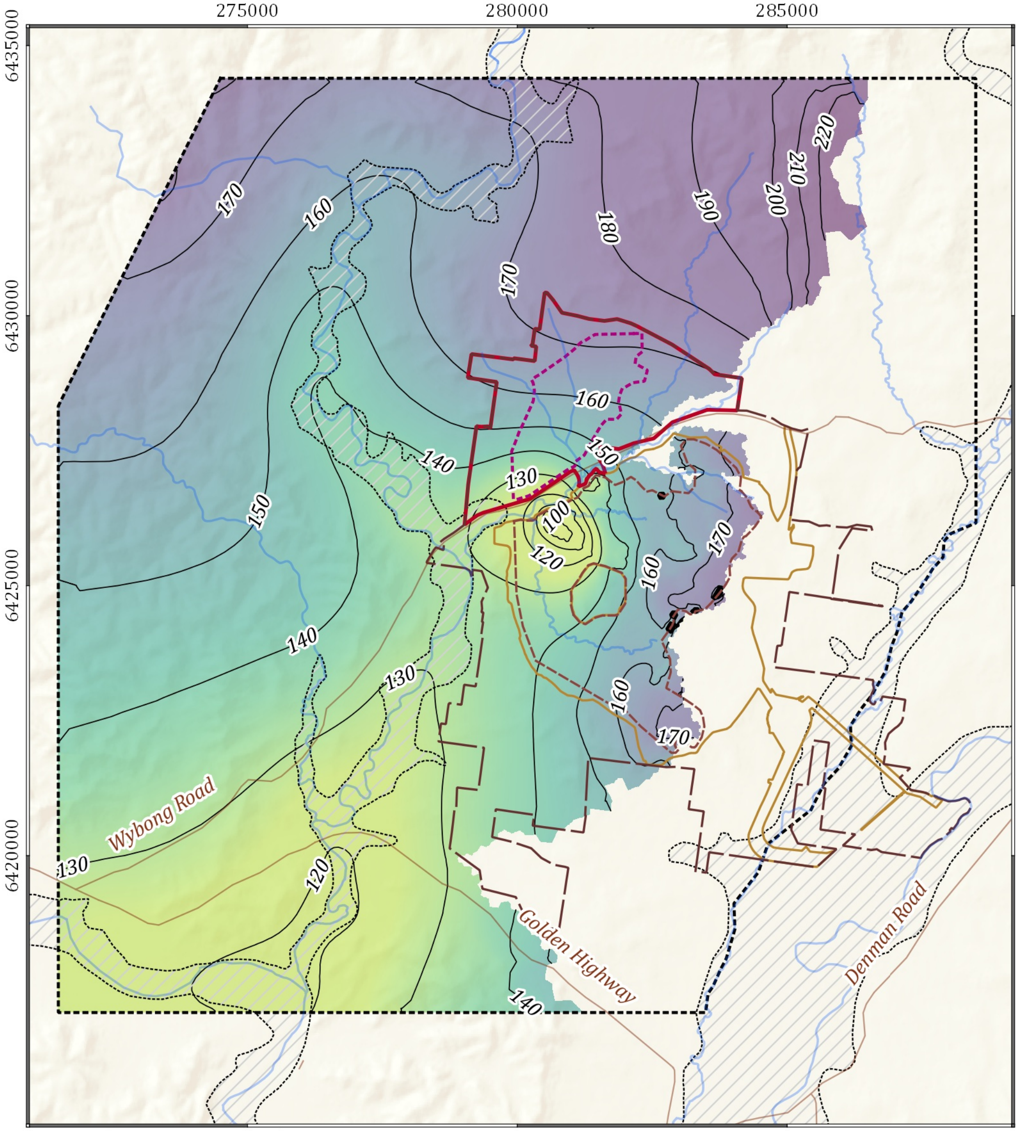
Groundwater levels (Pre-mining)



Groundwater levels (2017)



LEGEND

- Populated place
- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Numerical model boundary
- Alluvium
- Road
- Drainage

Head (mAHD)

100	250
150	300
200	350

Head contour (mAHD)

Mangoola EIS (G1839F)

Modelled historical groundwater levels – Layer 8 (Fassifern and Upper pilot)

DATE
08/04/2019

FIGURE No:
A 3.7

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G:\Projects\G1839F.Mangoola EIS\3_GIS\Workspaces\011_GIA\A-03.05 to A-03.07_Modelled historical groundwater levels.qgs

A3.3.2 Hydraulic parameters

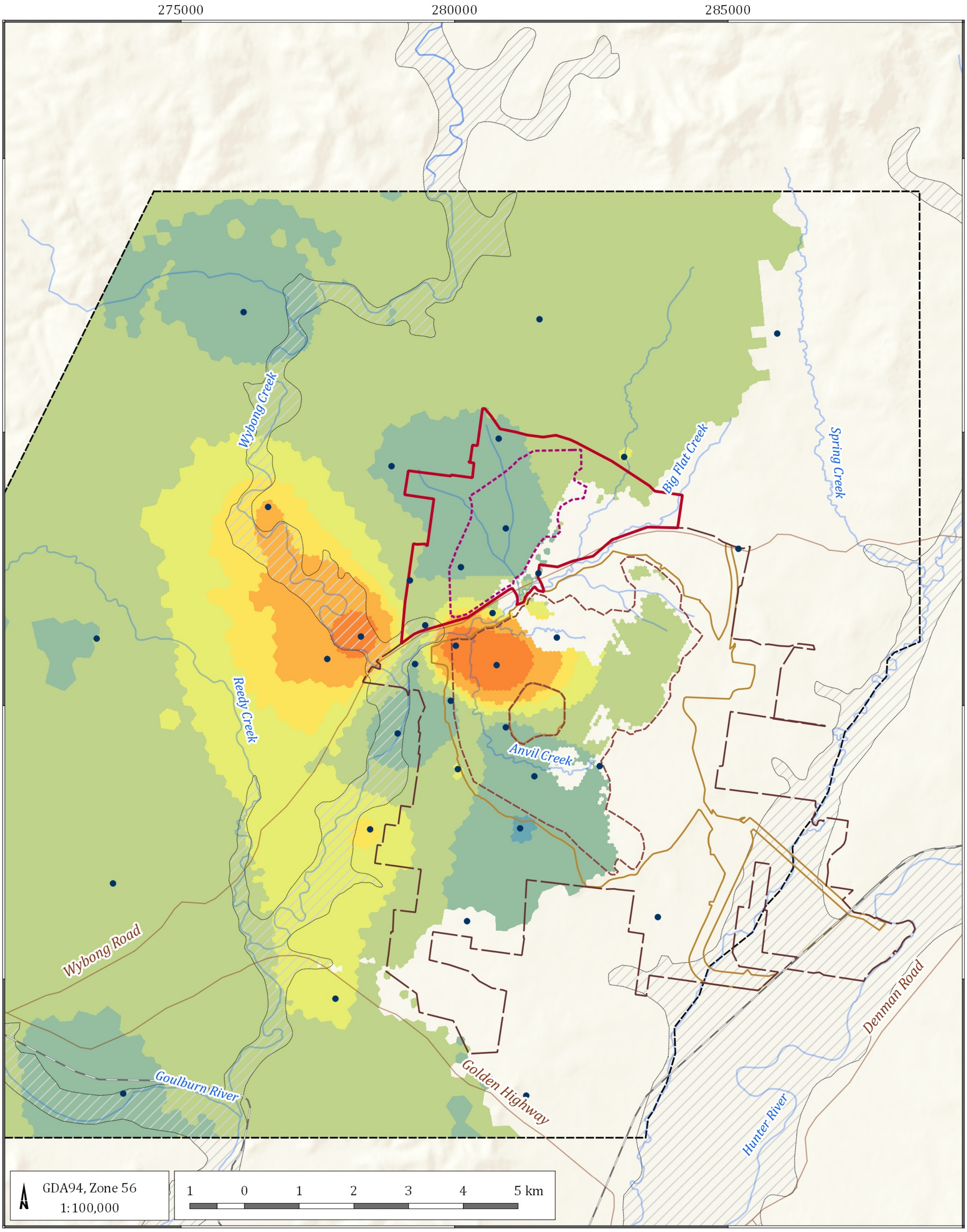
Table A3.3 summarises the calibrated hydraulic conductivity for each of the hydrostratigraphic units within the model domain. The values presented are the basecase value for each layer. These values are adjusted at each of the pilot points using the constraints presented in Table A3.1. An example of how the pilot points adjust the parameter ranges within a model layer are shown in Figure A3.8.

Percentile plots showing the calibrated ranges in hydraulic conductivity are shown in Figure A3.9. The plots use data from a regularised 200 m grid covering the model domain rather than model cell centres. This approach has been used to remove the effect of different cell sizes, which could bias the outputs.

If there were no pilot points the value for each of the layers with a single strata type would plot as horizontal lines. The slight gradients observed for each layer show that although the pilot points do adjust the hydraulic properties within each layer the variations are generally very small. The notable steps in values in layer 1 and layer 2 represent the different stratigraphic zones present within that layer e.g. alluvium and regolith.

Table A3.3 Calibrated base hydraulic conductivity values

Model layer	Lithology	Horizontal hydraulic conductivity Kh (m/day)	Vertical hydraulic conductivity factor (Kv:Kh)
1	Narrabeen sandstone	9.26×10^{-4}	0.6
1	Regolith	5.80×10^{-1}	1.0
1	Wybong + Sandy Creek alluvium	$5.00 \times 10^{+0}$	1.0
1	Big Flat Creek regolith	1.59×10^{-1}	0.05
2	Highly weathered conglomerate	2.45×10^{-1}	0.06
2	Big flat Creek highly weathered zone	2.61×10^{-1}	0.05
3	Unweathered conglomerate	1.84×10^{-3}	0.5
3	Partially weathered conglomerate	1.36×10^{-1}	1.0
4	Unweathered conglomerate	1.73×10^{-3}	0.5
5	Unweathered conglomerate	1.72×10^{-4}	0.19
6	Great Northern seam	2.77×10^{-3}	1.0
7	Awaba Tuff	3.41×10^{-4}	0.12
8	Fassifern + Upper Pilot A seams	2.88×10^{-2}	1.0
9	Interburden	1.04×10^{-3}	0.06
10	Upper Pilot B seam	1.04×10^{-3}	0.06
11	Interburden including Lower Pilot seam	1.04×10^{-3}	0.06
12	Hartley Hill seam	8.53×10^{-4}	0.005
13	Upper Australian	4.67×10^{-4}	0.005
14	Australian + Montrose	6.54×10^{-4}	0.002
15	Interburden	8.13×10^{-5}	0.21



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Model boundary
- Alluvium
- Road
- Drainage
- Pilot points

Hydraulic conductivity (m/day)

- 1E-04
- 2E-04
- 3E-04
- 4E-04
- 5E-04
- 1E-03
- 1E-02

Mangoola EIS (G1839F)

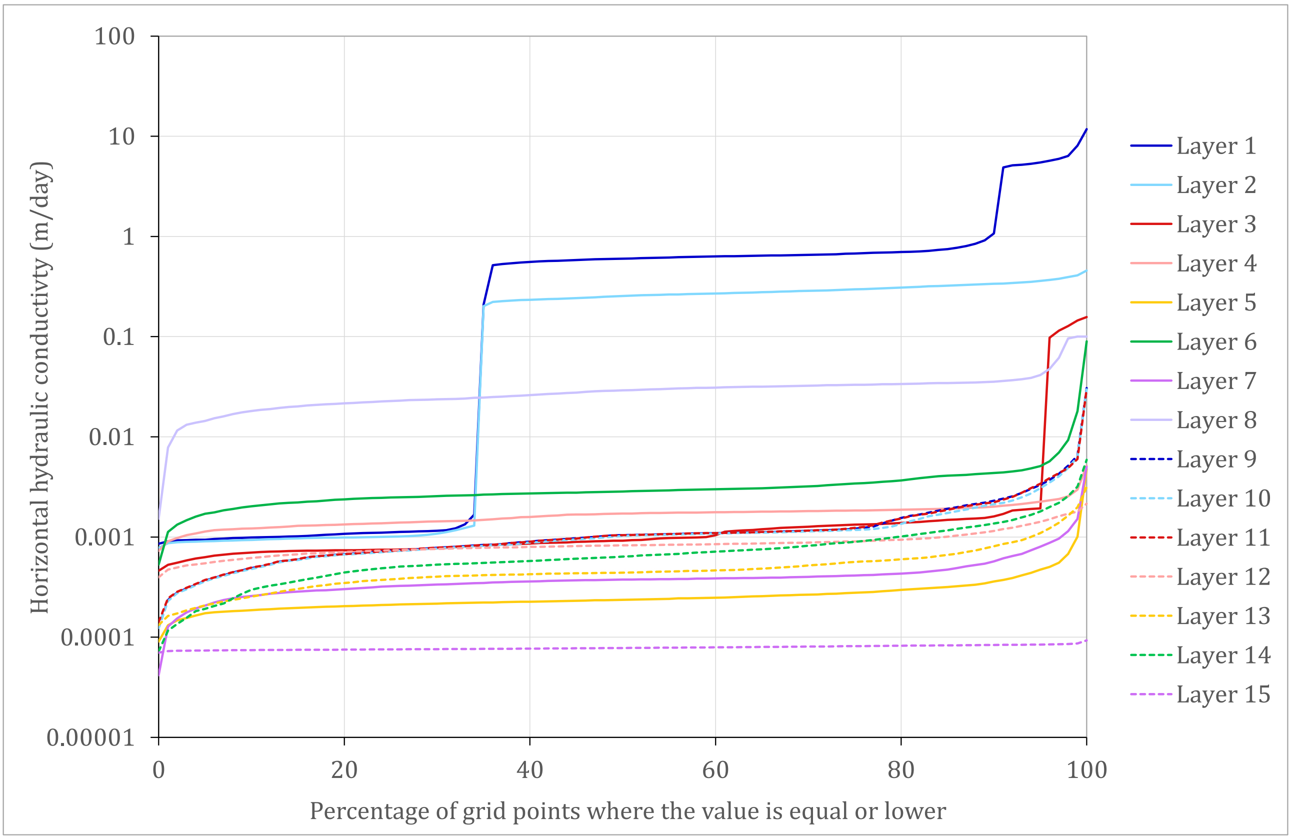
Example of hydraulic conductivity changes generated by Pilot Points - Model layer 5 Kh

AGE

DATE 08/04/2019

FIGURE No: **A 3.8**

G:\Projects\G1839F.Mangoola EIS\3_GIS\Workspaces\011_GIA\A-03.08_G1939F_Example of hydraulic conductivity changes generated by Pilot Points.qgs



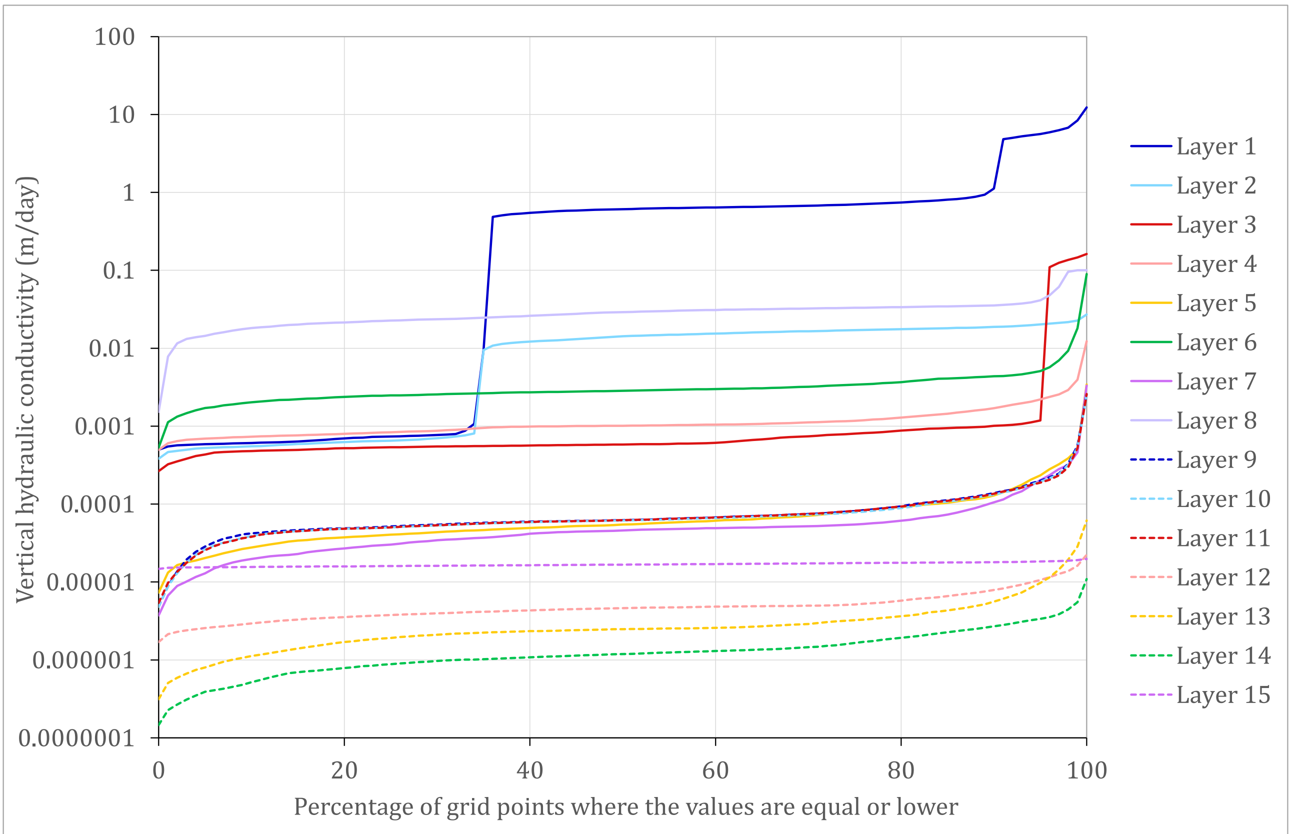


Figure A3.9 Calibrated hydraulic conductivity ranges in each model layer

A3.3.3 Storage properties

Table A3.4 summarises the calibrated values for specific storage and specific yield. The values presented are the basecase value for each layer. These values are adjusted at each of the pilot points using the constraints presented in Table A3.1. Percentile plots showing the calibrated ranges in storage properties are shown in Figure A3.10. The storage plots also use the data from a regularised 200 m grid covering the model domain rather than model cell centres. This approach has been used to remove the effect of different cell sizes, which could bias the outputs. The storage plots show less overall variation in results than for the calibrated hydraulic conductivity parameters. Specific yield is only relevant in the model where the layers become unconfined, so the parameter is not applied to the deeper model layers. Specific storage is only applied where the model layers are confined, and is therefore not relevant to layers that intercept the water table.

Table A3.4 Calibrated base storage values

Model layer	Lithology	Specific yield - Sy (%)	Specific storage – Ss (m-1)
1	Narrabeen sandstone	0.80	1.03×10^{-6}
1	Regolith	2.20	1.06×10^{-5}
1	Wybong + Sandy Creek alluvium	6.00	1.08×10^{-5}
1	Big Flat Creek regolith	2.20	1.08×10^{-5}
2	Highly weathered conglomerate	2.30	1.13×10^{-5}
2	Big flat Creek highly weathered zone	3.70	1.08×10^{-5}
3	Unweathered conglomerate	0.90	1.07×10^{-6}
3	Partially weathered conglomerate	0.90	1.08×10^{-6}
4	Unweathered conglomerate	0.30	1.09×10^{-6}
5	Unweathered conglomerate	0.04	1.06×10^{-6}
6	Great Northern seam	0.90	1.08×10^{-6}
7	Awaba Tuff	0.60	1.05×10^{-6}
8	Fassifern + Upper Pilot A seams	0.80	8.17×10^{-7}
9	Interburden	0.10	1.08×10^{-6}
10	Upper Pilot B seam	0.10	1.08×10^{-6}
11	Interburden including Lower Pilot seam	0.10	1.08×10^{-6}
12	Hartley Hill seam	0.50	8.50×10^{-7}
13	Upper Australian	0.40	7.34×10^{-7}
14	Australian + Montrose	0.70	1.07×10^{-6}
15	Interburden	1.00	1.10×10^{-6}

Direct testing data are not generally available for specific storage (Ss) of coal seams or interburden. However, estimates can be made based on Young's Modulus and porosity. For coal, Ss generally lies in the range 5×10^{-6} m^{-1} to 5×10^{-5} m^{-1}. The calibrated parameters for coal were guided by these bounds, although some flexibility was allowed for improvement of the calibration results. Interburden is generally slightly higher than this due to the greater porosity (Mackie, 2009), however testing of samples of interburden from within the MCCO Additional Mining Area returned specific storage values of between 1.43×10^{-6} m^{-1} and 8.61×10^{-6} m^{-1}, which is within the physically possible literature ranges but at the lower end of those expected.

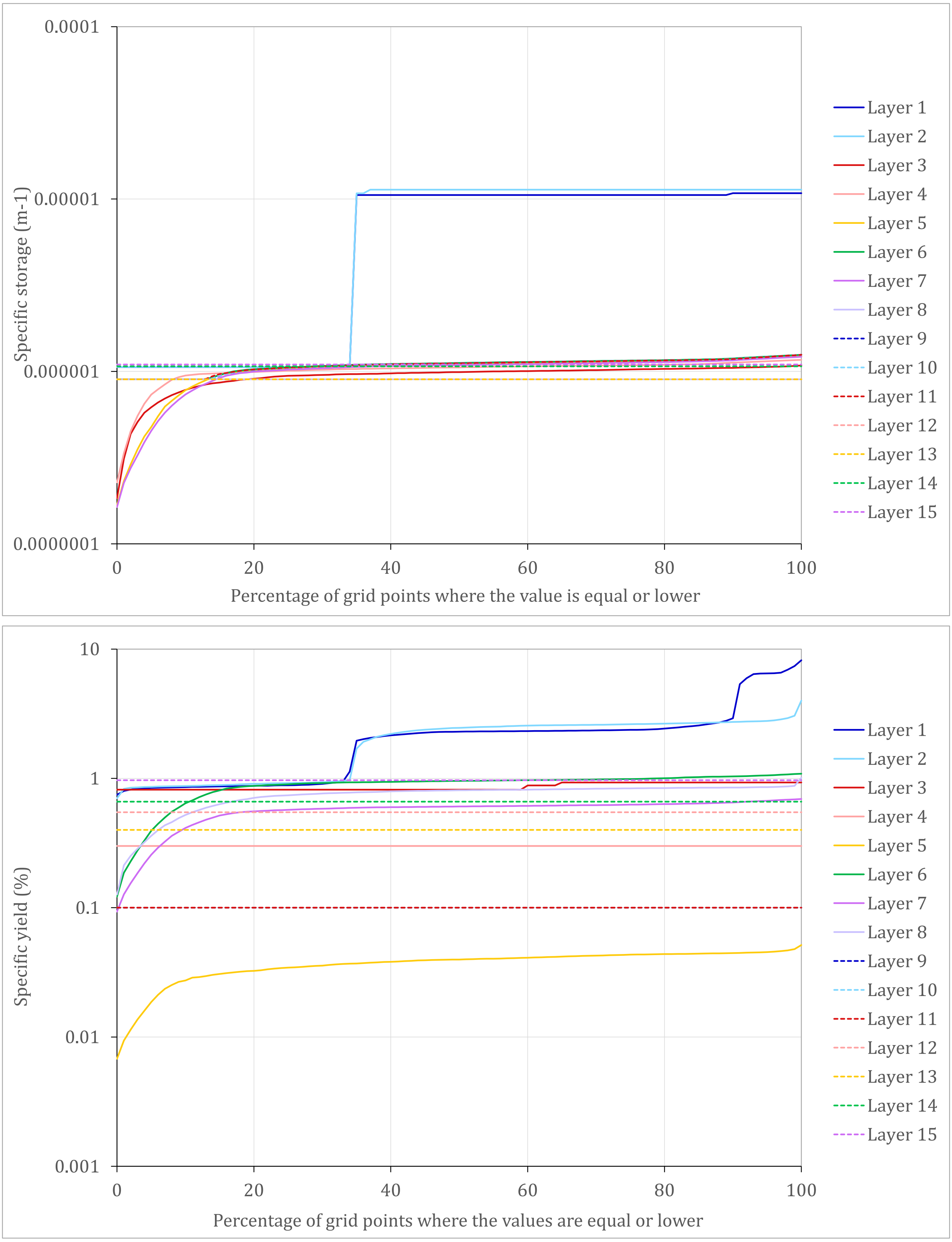


Figure A3.10 Calibrated storage ranges in each model layer

A3.3.4 Water budget

The mass balance error, that is, the difference between calculated model inflows and outflows at the completion of the steady state calibration was 0.00%. The maximum percent discrepancy at any time step in the simulation was also 0.01%. This value indicates that the model is stable and achieves an accurate numerical solution. Table A3.5 shows the water budget for the steady state (pre-mining) model.

Table A3.5 Model budgets – steady state

Parameter	In (ML/day)	Out (ML/day)	In - Out (ML/day)
Rainfall recharge	2.2	-	2.2
River	0.3	0.4	-0.1
Stream	0.8	1.4	-0.6
Evapotranspiration	-	1.6	-1.6
General head boundary	0.6	0.6	0.0
Total	**3.9**	**3.9**	**0.0**

The water budget indicates that recharge to the groundwater system within the model averages 2.2 ML/day, with approximately 0.6 ML/day being discharged via surface drainage, and 1.6 ML/day lost to evapotranspiration in areas where the water table is within 2.0 m of the land surface. Regional through flow from the general head boundary contributes 15% of the total input to the groundwater model.

Table A3.6 shows the average water budget for the transient calibration (2010 to 2017).

Table A3.6 Model budgets – transient calibration

Parameter	In (ML/day)	Out (ML/day)	In - Out (ML/day)
Rainfall recharge	1.6	-	1.6
River	0.4	0.4	0.0
Stream	0.7	1.2	-0.5
Evapotranspiration	-	1.5	-1.5
General head boundary	0.7	0.5	0.2
Drains	-	0.2	-0.2
Storage	1.1	0.8	0.4
Total	**4.5**	**4.5**	**0.0**

The transient water budget indicates that the groundwater system slightly departs from steady state conditions because of expanding mining in the model domain. Recharge (rainfall and river leakage) within the model averages 1.6 ML/day, with approximately 0.5 ML/day being discharged via surface drainage. The differences between the steady state and transient recharge rates are due to different climatic conditions during the transient calibration period (2010 to 2017) when compared to the annual average (steady state). The transient budget also shows that, on average, drains (mining) take out 0.2 ML/day, which is relatively small component of the overall water budget.

A3.3.5 Mine inflow verification

Volumes of water pumped from the in-pit sumps at Mangoola Coal Mine are reported on a quarterly time scale. The water collected in the sumps is a combination of water from rainfall, runoff, groundwater inflow, spoil seepage, and potentially tailings and in-pit dam seepage. Due to the potential uncertainty involved with estimating the groundwater inflow component to the pumped totals in the site water balance there is a moderate to low confidence in the estimated groundwater inflows to the mine. Inflows from the groundwater model have therefore only been verified against the water balance estimates on an indicative 'order of magnitude' scale.

Inflow estimates from the site water balance models were an average of 26 ML/quarter from October 2016 to June 2018. The numerical groundwater model estimated an average of 34 ML/quarter for 2016 and 2017. As these are of a similar magnitude this supports the validity of the numerical groundwater model calibration.

A3.3.6 Parameter Identifiability

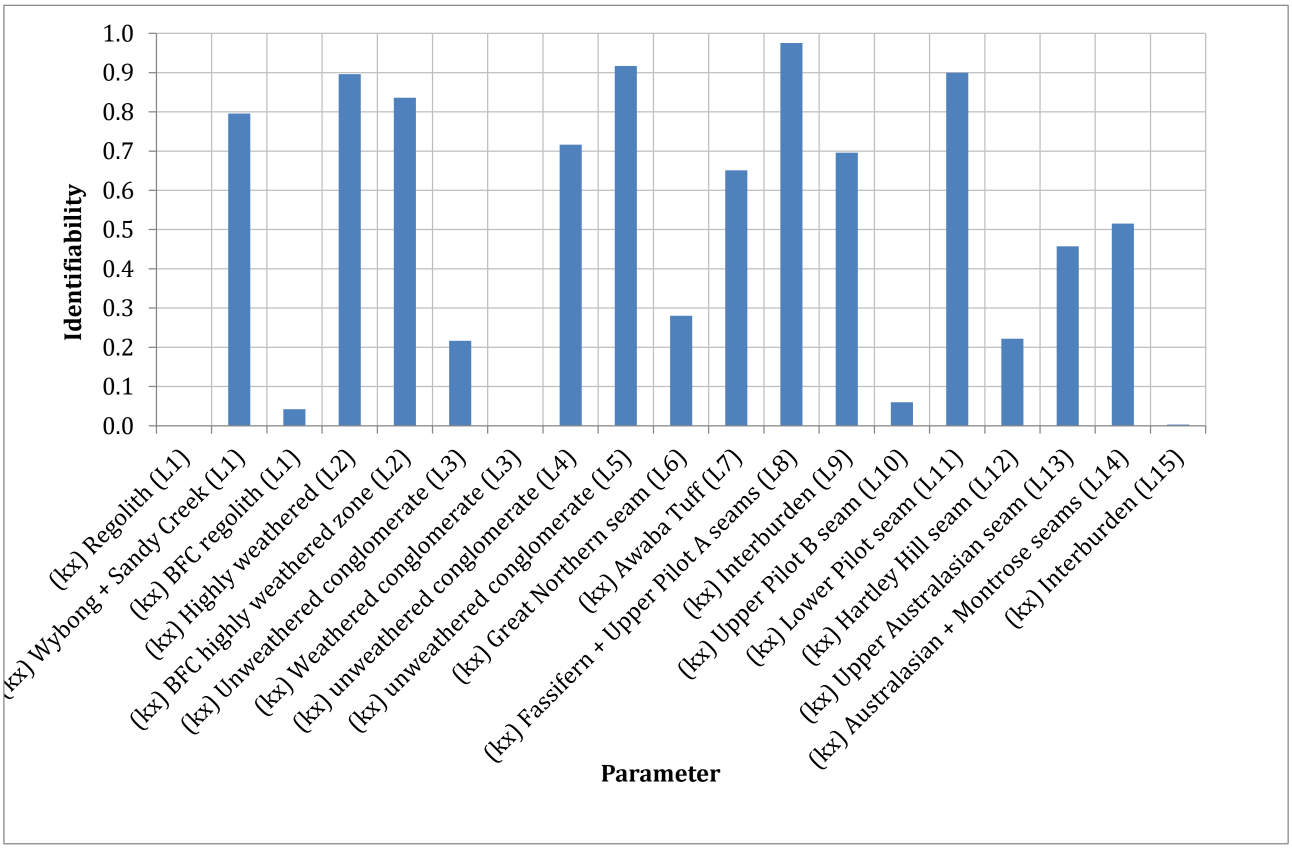
Identifiability can be defined as the capability of the model calibration to constrain parameters used by a model and ultimately reduce the predictive model uncertainty. Identifiability is only a qualitative indicator and should not be over-interpreted. However, it can provide some insight into calibrated model behaviour. In a qualitative sense, parameters with high identifiability can be interpreted as important controls on model performance.

To further investigate this issue the PEST utility GENLINPRED was used to provide an estimate of parameter identifiability. GENLINPRED provides an identifiability value for each parameter ranging between 0 and 1. An identifiability value of one means that the parameter can be well constrained through the calibration process and hence the parameter is highly estimable. In contrast, an identifiability value of zero indicates that the parameter cannot be supported by the calibration datasets and hence its uncertainty does not reduce through the calibration process. Figure A3.11 and Figure A3.12 show the identifiability of groundwater model parameter zones for Kh, Kv, Sy and Ss in respect to the groundwater level observation dataset.

There are eight Kh parameter zones with an identifiability of ~0.7 or higher, meaning that the modelled heads are highly sensitive to parameters within these zones. The identifiability of Kv zones is highest in the deeper layers, although the layers of conglomerate, tuff, and interburden surrounding the target coal seams are also somewhat identifiable.

The results suggest that the least identifiable parameters are storage parameters. This is expected for zones where there has been minimal change in water level or pressure to date, and hence only limited data is available to constrain storage parameters. Specific storage is most identifiable in the unweathered conglomerate and Fassifern and Upper Pilot A seam model layers.

If not managed properly parameters that are highly identifiable can have a narrow posterior distribution when conducting uncertainty analysis. This is most likely to show as artificially high parameter identifiability if the number of pilot points within the layer is too low (under-parameterised model). In this case even a small change in parameter value will make the model calibration worse and the spread in posterior values will be minimal.



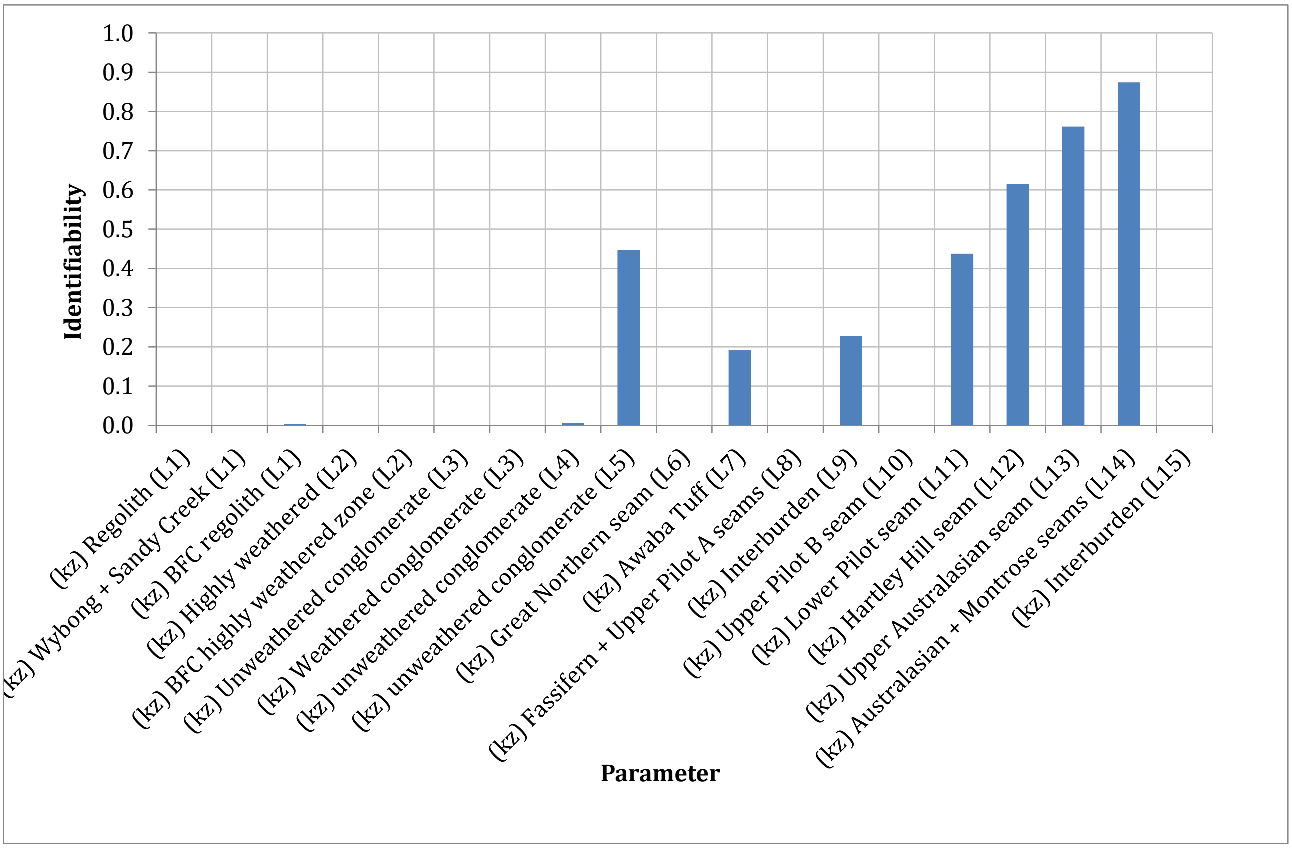


Figure A3.11 Identifiability of hydraulic conductivity parameters

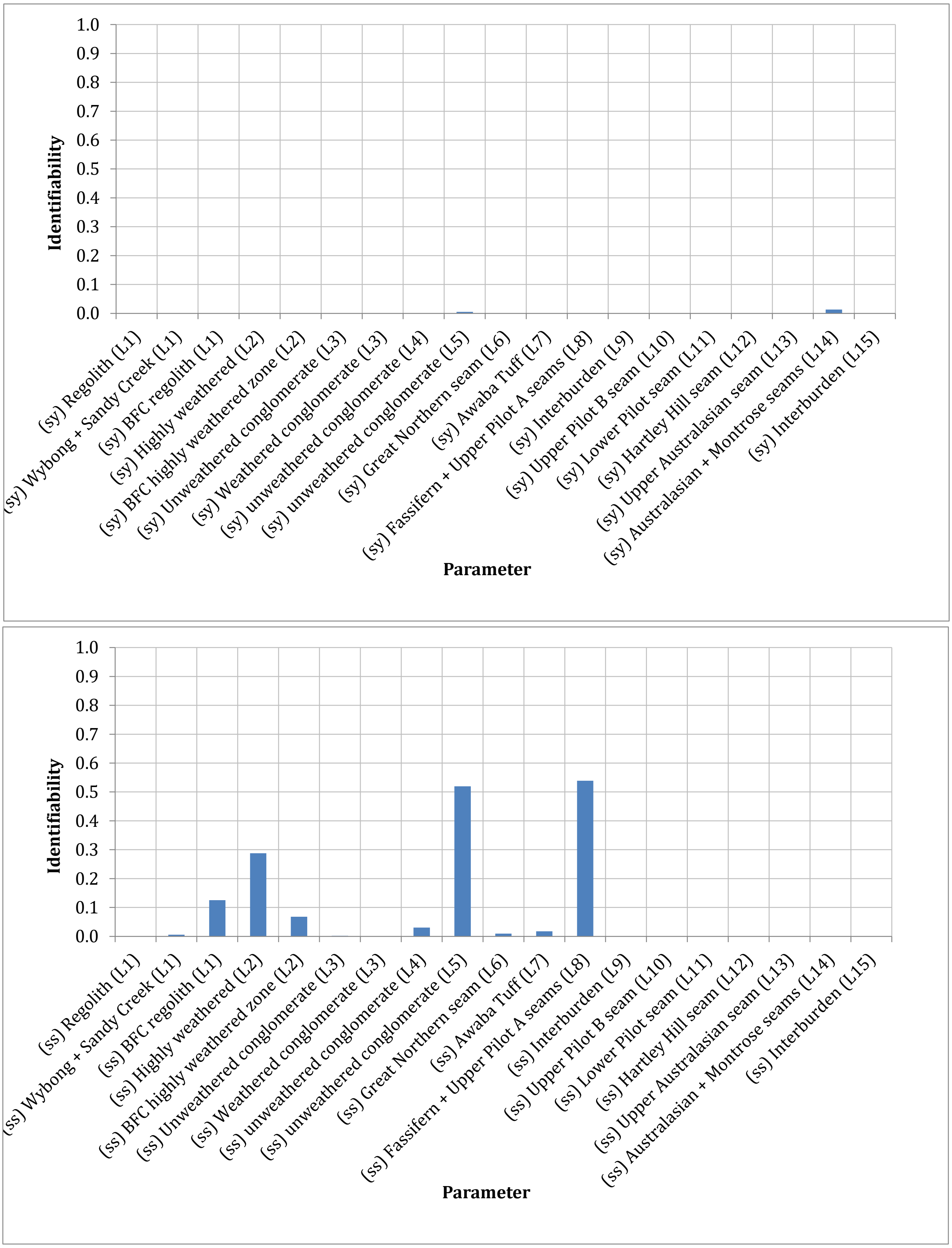


Figure A3.12 Identifiability of storage parameters

A3.3.7 Model confidence level classification

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

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

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

Comparison against the performance indicators for individual model classes are presented in Table A3.7.

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

- 2 out 18 (11%) performance indicators align with a Class 1 model;
- 11 out 22 (50%) performance indicators align with a Class 2 model; and
- 15 out 21 (71%) performance indicators align with a Class 3 model.

The above indicates the groundwater model has been developed to be suitable for predicting groundwater responses to changes in applied stress or hydrological conditions, and the evaluation and management of potential impacts.

Table A3.7 Model classification – model performance indicators

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

A4 Predictive and recovery simulations

A4.1 Predictive simulations

Three models were run for the predictive simulations. These were:

- no mining – the model is run without any mining to provide a baseline output against which the simulations with mining can be compared;
- mining from approved Mangoola Coal Mine only; and
- mining from approved Mangoola Coal Mine plus the proposed MCCO Additional Mining Area.

By comparing the outputs from these three model simulations the cumulative impacts from both mining areas, and the incremental additional impacts from just the proposed MCCO Additional Mining Area can be predicted. Outputs from the predictive models are presented in Section 7.1 of the main report.

A4.2 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 more permeable spoil, and enhanced recharge rates to the spoil to simulate their enhanced recharge capacity. In addition, an evaporative boundary condition was applied over the final landform with the exception of the pit lake areas. Final voids remain in both the Mangoola Coal Mine and MCCO Additional Mining Area. Climatic inputs and outputs to the voids were estimated by HEC.

The recovery simulation was run for 500 years, thus allowing the groundwater levels in the backfilled spoil, final void lake, unmined coal seams, and the overlying water-bearing strata to recover to a long term post mining equilibrium.

Model cells representing backfilled spoil were assigned a higher horizontal (0.3 m/day) and vertical (0.1 m/day) conductivity than the bedrock units, and a porosity (specific yield) of 0.1. There are few reported measurements of hydraulic properties of backfilled mining spoil, therefore these parameters are estimated based on experience. Recharge rates to the spoil were also increased to 2% of average annual rainfall.

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. The climatic inputs and outputs to the final void lakes were estimated by HEC using a water balance model for the final void catchment. The net climatic inputs/outputs were utilised in an iterative approach between AGE and HEC as follows:

- HEC utilise the final landform to generate a preliminary water balance for the voids.
- HEC provide AGE with climatic inputs and outputs to the void pit lake, assuming no spoil inputs/outputs.
- AGE represent the net climatic input/output to the void using a high permeability well in the void.
- AGE run model and provide preliminary groundwater inflows/outflows from the voids to HEC.
- HEC update the water balance model and compare to initial outputs. HEC provide revised climatic inputs/outputs to AGE if required.
- AGE rerun groundwater model with updated void water level datasets.

Outputs from the recovery modelling are presented in Section 7.2 of the main report.

A5 Uncertainty analysis

Groundwater models represent complex environmental systems and processes in a simplified manner. This means that predictions from groundwater models, like so many other environmental models, are inherently uncertain. When considered in a risk management context, a single calibrated model is insufficient to fully predict the range of potential impacts and their likelihood. A robust uncertainty analysis is therefore important for regulatory decision-making to ensure management options and approaches are appropriate to the level of risk and its likelihood for any particular impact.

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 MCCO Project numerical model.

A5.1 Methodology

A Null-space Monte Carlo uncertainty analysis was undertaken to quantify the magnitude of uncertainty in the future impacts predicted by the model. This type of analysis produces probability distributions for predictive impacts by assessing a composite likelihood of an impact occurring through assessing and ranking the predictions from hundreds of models 'realisations'. Each model realisation is informed by the observation dataset by using the relationship between the observations statistics to perturbations of each parameter in the groundwater model.

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

The constrained realisations were tested and the models that failed to converge or could not achieve adequate calibration were rejected, leaving only the output from 207 successful models. Models were considered to have an acceptable calibration if they had less than a 25% increase in the model phi. This output was analysed to provide a statistical distribution of the predictive impacts.

Outputs from the uncertainty modelling were processed in accordance with the risk-based calibrated language proposed in Middlemis & Peeters (2018). The ranges adopted are shown in Table A5.1.

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 A5.1 Calibrated uncertainty modelling language

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

A5.2 Parameter generation

A5.2.1 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 A5.2 to Table A5.7 show the 'prior' range explored during the uncertainty analysis simulation. This represents the 95th confidence interval based 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.

A total of 250 models were generated using a random parameter generator to produce 'realisations' to assess predictive impacts. Although parameters were allowed to vary in all layers for Kh, Kv, Ss, and Sy the layers that showed the highest identifiability (Section A3.3.6) were focussed on.

Table A5.2 Prior homogenous uncertainty range – Kh

Model layer	Lithology	Horizontal hydraulic conductivity - Lower (m/day)	Horizontal hydraulic conductivity - Mean (m/day)	Horizontal hydraulic conductivity - Upper (m/day)
1	Narrabeen sandstone	1.00×10^{-4}	9.83×10^{-4}	1.00×10^{-2}
1	Regolith	9.00×10^{-4}	6.50×10^{-1}	1.00×10^{0}
1	Wybong Creek alluvium	1.00×10^{-3}	6.49×10^{0}	1.00×10^{1}
1	Big Flat Creek colluvium	9.00×10^{-4}	1.67×10^{-1}	1.00×10^{0}
2	Highly weathered conglomerate	9.00×10^{-4}	3.00×10^{-1}	1.00×10^{0}
2	Unweathered conglomerate	9.00×10^{-4}	3.76×10^{-1}	1.00×10^{0}
3	Partially weathered conglomerate	1.00×10^{-5}	1.38×10^{-3}	1.00×10^{-1}
3	Unweathered conglomerate	1.00×10^{-5}	1.17×10^{-1}	2.00×10^{-1}
4	Unweathered conglomerate	1.00×10^{-5}	1.72×10^{-3}	1.00×10^{-1}
5	Unweathered conglomerate	1.00×10^{-5}	3.35×10^{-4}	1.00×10^{-1}
6	Great Northern seam	3.00×10^{-4}	4.62×10^{-3}	1.00×10^{1}
7	Awaba Tuff	1.00×10^{-6}	4.85×10^{-4}	5.00×10^{-3}
8	Fassifern and Upper Pilot A seam	3.00×10^{-4}	3.47×10^{-2}	1.00×10^{1}
9	Interburden	3.00×10^{-4}	1.66×10^{-3}	5.00×10^{0}
10	Upper Pilot B seam	3.00×10^{-4}	1.66×10^{-3}	5.00×10^{0}
11	Interburden including Lower Pilot seam	3.00×10^{-4}	1.66×10^{-3}	5.00×10^{0}
12	Hartley Hill seams	1.00×10^{-4}	9.45×10^{-4}	5.00×10^{-3}
13	Interburden including Upper Australasian seam	1.00×10^{-4}	6.57×10^{-4}	5.00×10^{-3}
14	Interburden including Australasian and Montrose seams	1.00×10^{-4}	8.18×10^{-4}	5.00×10^{-3}
15	Interburden	1.00×10^{-5}	7.88×10^{-5}	1.00×10^{-3}

Table A5.3 Prior range – Kv factor

Model layer	Lithology	Vertical hydraulic conductivity factor - Lower	Vertical hydraulic conductivity factor - Mean	Vertical hydraulic conductivity factor - Upper
1	Narrabeen sandstone	0.061	0.600	1.000
1	Regolith	0.100	1.000	1.000
1	Wybong Creek alluvium	0.100	1.000	1.000
1	Big Flat Creek colluvium	0.006	0.047	0.500
2	Highly weathered conglomerate	0.006	0.055	0.500
2	Unweathered conglomerate	0.006	0.051	0.500
3	Partially weathered conglomerate	0.041	0.500	0.500
3	Unweathered conglomerate	0.100	1.000	1.000
4	Unweathered conglomerate	0.041	0.500	0.500
5	Unweathered conglomerate	0.024	0.189	0.500
6	Great Northern seam	0.100	1.000	1.000
7	Awaba Tuff	0.010	0.124	1.000
8	Fassifern and Upper Pilot A seam	0.100	1.000	1.000
9	Interburden	0.004	0.063	0.500
10	Upper Pilot B seam	0.004	0.063	0.500
11	Interburden including Lower Pilot seam	0.004	0.063	0.500
12	Hartley Hill seams	0.001	0.005	0.500
13	Interburden including Upper Australasian seam	0.001	0.005	0.500
14	Interburden including Australasian and Montrose seams	0.001	0.002	0.500
15	Interburden	0.023	0.209	0.300

Table A5.4 Prior range – Specific yield

Model layer	Lithology	Specific yield - Lower	Specific yield - Mean	Specific yield - Upper
1	Narrabeen sandstone	8.00×10^{-4}	8.17×10^{-3}	8.00×10^{-2}
1	Regolith	2.00×10^{-3}	2.16×10^{-2}	1.00×10^{-1}
1	Wybong Creek alluvium	8.00×10^{-3}	6.05×10^{-2}	2.00×10^{-1}
1	Big Flat Creek colluvium	3.00×10^{-3}	2.22×10^{-2}	5.00×10^{-2}
2	Highly weathered conglomerate	3.00×10^{-3}	2.29×10^{-2}	8.00×10^{-2}
2	Unweathered conglomerate	3.00×10^{-3}	3.65×10^{-2}	8.00×10^{-2}
3	Partially weathered conglomerate	1.00×10^{-3}	9.31×10^{-3}	5.00×10^{-2}
3	Unweathered conglomerate	8.00×10^{-4}	8.82×10^{-3}	5.00×10^{-2}
4	Unweathered conglomerates	5.00×10^{-4}	3.00×10^{-3}	2.00×10^{-2}
5	Unweathered conglomerates	1.00×10^{-4}	4.17×10^{-4}	2.00×10^{-2}
6	Great Northern seam	7.00×10^{-4}	9.07×10^{-3}	2.00×10^{-2}
7	Awaba Tuff	5.00×10^{-4}	5.79×10^{-3}	2.00×10^{-2}
8	Fassifern and Upper Pilot A seam	4.00×10^{-4}	7.81×10^{-3}	2.00×10^{-2}
9	Interburden	1.00×10^{-4}	2.00×10^{-2}	2.00×10^{-2}
10	Upper Pilot B seam	1.00×10^{-4}	2.00×10^{-2}	2.00×10^{-2}
11	Interburden including Lower Pilot seam	1.00×10^{-4}	7.22×10^{-4}	2.00×10^{-2}
12	Hartley Hill seams	5.00×10^{-4}	5.47×10^{-3}	2.00×10^{-2}
13	Interburden including Upper Australasian seam	3.00×10^{-4}	3.99×10^{-3}	2.00×10^{-2}
14	Interburden including Australasian and Montrose seams	6.00×10^{-4}	6.60×10^{-3}	2.00×10^{-2}
15	Interburden	9.00×10^{-4}	9.67×10^{-3}	2.00×10^{-2}

Table A5.5 Prior range – Specific storage

Model layer	Lithology	Specific Storage - Lower (m-1)	Specific Storage - Mean (m-1)	Specific Storage - Upper (m-1)
1	Narrabeen sandstone	9.90×10^{-8}	1.06×10^{-6}	1.00×10^{-5}
1	Regolith	9.98×10^{-7}	1.06×10^{-5}	1.00×10^{-4}
1	Wybong Creek alluvium	9.98×10^{-7}	1.08×10^{-5}	1.00×10^{-4}
1	Big Flat Creek colluvium	1.00×10^{-6}	1.08×10^{-5}	1.00×10^{-4}
2	Highly weathered conglomerate	1.00×10^{-6}	1.13×10^{-5}	1.00×10^{-4}
2	Unweathered conglomerate	1.00×10^{-6}	1.08×10^{-5}	1.50×10^{-5}
3	Partially weathered conglomerate	2.00×10^{-7}	1.07×10^{-6}	1.00×10^{-5}
3	Unweathered conglomerate	2.00×10^{-7}	1.08×10^{-6}	1.00×10^{-5}
4	Unweathered conglomerate	2.00×10^{-7}	1.09×10^{-6}	1.00×10^{-5}
5	Unweathered conglomerate	2.00×10^{-7}	1.06×10^{-6}	1.00×10^{-5}
6	Great Northern seam	2.00×10^{-7}	1.08×10^{-6}	1.00×10^{-5}
7	Awaba Tuff	2.00×10^{-7}	1.05×10^{-6}	1.00×10^{-5}
8	Fassifern and Upper Pilot A seam	2.00×10^{-7}	8.17×10^{-7}	1.00×10^{-5}
9	Interburden	2.00×10^{-7}	1.08×10^{-6}	1.00×10^{-5}
10	Upper Pilot B seam	2.00×10^{-7}	1.08×10^{-6}	1.00×10^{-5}
11	Interburden including Lower Pilot seam	2.00×10^{-7}	1.08×10^{-6}	1.00×10^{-5}
12	Hartley Hill seams	2.00×10^{-7}	8.50×10^{-7}	1.00×10^{-5}
13	Interburden including Upper Australasian seam	2.00×10^{-7}	7.34×10^{-7}	1.00×10^{-5}
14	Interburden including Australasian and Montrose seams	2.00×10^{-7}	1.07×10^{-6}	1.00×10^{-5}
15	Interburden	2.00×10^{-7}	1.10×10^{-6}	1.00×10^{-5}

Table A5.6 Prior range – recharge

Unit	Lithology	Recharge factor - Lower	Recharge factor - Mean	Recharge factor - Upper
1	Narrabeen Sandstone	1.01×10^{-4}	1.35×10^{-3}	5.00×10^{-2}
2	Regolith	1.98×10^{-4}	3.20×10^{-3}	5.00×10^{-2}
3	Wybong and Sandy Creek Alluvium	3.00×10^{-2}	8.87×10^{-2}	0.7
4	BFC regolith	1.02×10^{-2}	2.04×10^{-2}	2.00×10^{-1}
5	Weathered zone	4.00×10^{-4}	2.86×10^{-3}	1.00×10^{-1}

Table A5.7 Prior range – streambed Kv

Unit	Segment	Vertical hydraulic conductivity - Lower (m/d)	Vertical hydraulic conductivity - Mean (m/d)	Vertical hydraulic conductivity - Upper (m/d)
1	Minor drainage	0.10	1.03	10.00
2	Big Flat Creek	0.01	0.10	1.00
3	Anvil Creek	0.01	0.09	1.00
4	Gulf Creek	0.01	0.10	1.00
5	Reedy Creek	0.01	0.10	1.00
6	Goulburn River	0.01	0.11	1.00

Table A5.8 Prior range for pilot point multiplier

Parameter	Lower	Basecase	Upper
Pilot point multiplier	0.001	1-100	100

A5.2.2 Posterior ranges

The posterior range was derived using information from the Jacobian matrix. If parameter ranges were constrained by more than a 50% improvement, the posterior range was restricted to this as a limit.

As pilot points are present in each layer, reviewing the basecase prior and posterior ranges is not sufficient to show the global range in parameter for each layer. Instead the posterior distribution of parameters was analysed using regularised (200 m) cumulative distribution function (CDF) plots with uncertainty ranges added. Example plots are provided as Figure A5.1 and Figure A5.2 for Kh in layer 5 (unweathered conglomerate) and Kh in layer 8 (Fassifern and Upper Pilot A seams). The plots show that the 50th percentile (P50) of the uncertainty analysis outputs is similar to the basecase model, and the basecase model is therefore not an unrealistic scenario.

In layer 8 the highest Kh values in the basecase model reached the upper limit prescribed for coal seams (0.1 m/day – see Section A3.2) at less than 1% of grid points. However, in the most permeable uncertainty models this limit was reached at 20% of the grid points. If this cap were not present the permeability would have increased to unrealistically high values. In contrast the layer 5 uncertainty ranges are not affected by the parameter constraints applied to the interburden layers (maximum 0.01 m/day).

The uncertainty bands for each layer show that Kh varied by approximately 0.5 to 1 order of magnitude across the 207 realisations. This is considered to be a suitable range in conditions to properly simulate uncertainty, but could be expanded if the calibration criteria were allowed to vary by more than 25% of the basecase model phi.

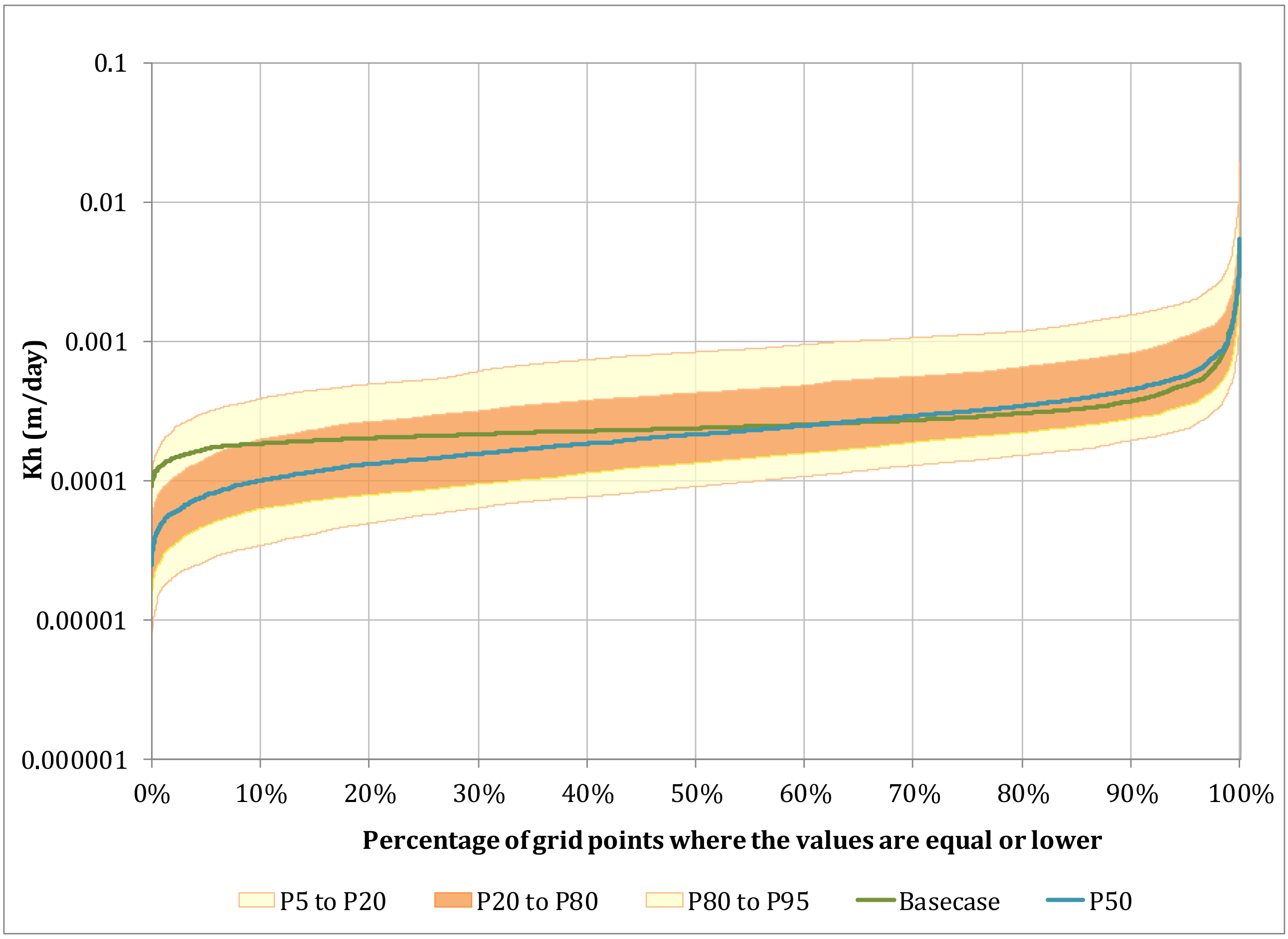


Figure A5.1 Cumulative distribution function plot for Kh layer 5

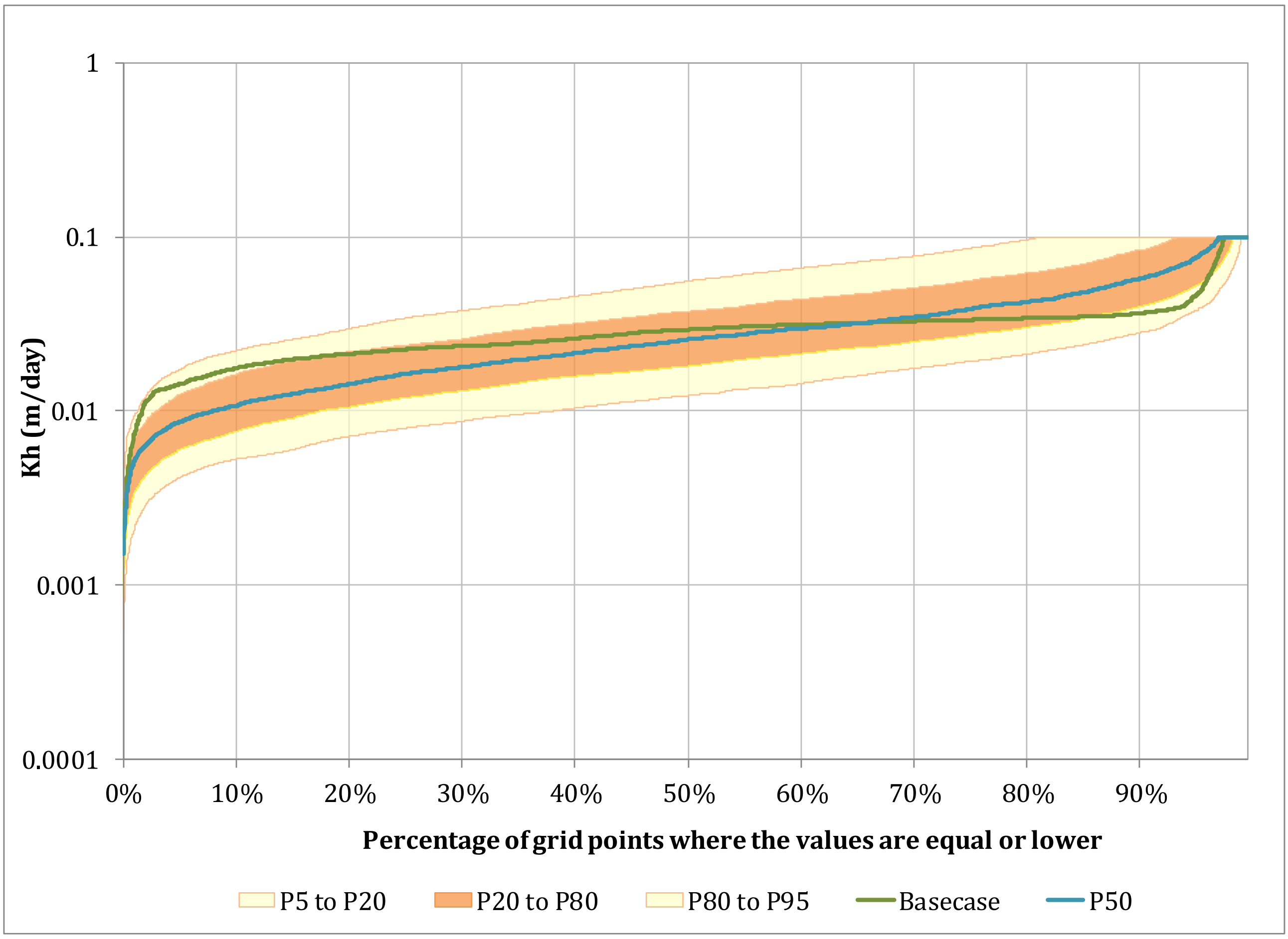


Figure A5.2 Cumulative distribution function plot for Kh layer 8

A5.3 Results

As noted previously, a total of 250 models were generated and set to run. Solver settings were allowed to adjust if model convergence was not achieved with the original criteria. i.e. SMS convergence criteria was initially set to 0.005 m, but relaxed to 0.01 m if the initial model did not converge. If convergence was still not achieved with the relaxed solver settings then the model run was rejected. Of the 250 models run only 7 models did not converge, and 36 models did not produce acceptable calibration statistics, leaving 207 models for the uncertainty calculations.

Figure A5.3 shows the number of model simulations contributing to the uncertainty analysis and the range in the outputs produced. As the number of models contributing to the uncertainty analysis increases the difference in the output ranges reduces, until the addition of further models has little influence on the results. For the MCCO Project the results are similar after 200 models are combined. The number of models contributing to the MCCO Project uncertainty analysis (207) is therefore sufficient to minimise the potential uncertainty in the final results obtained.

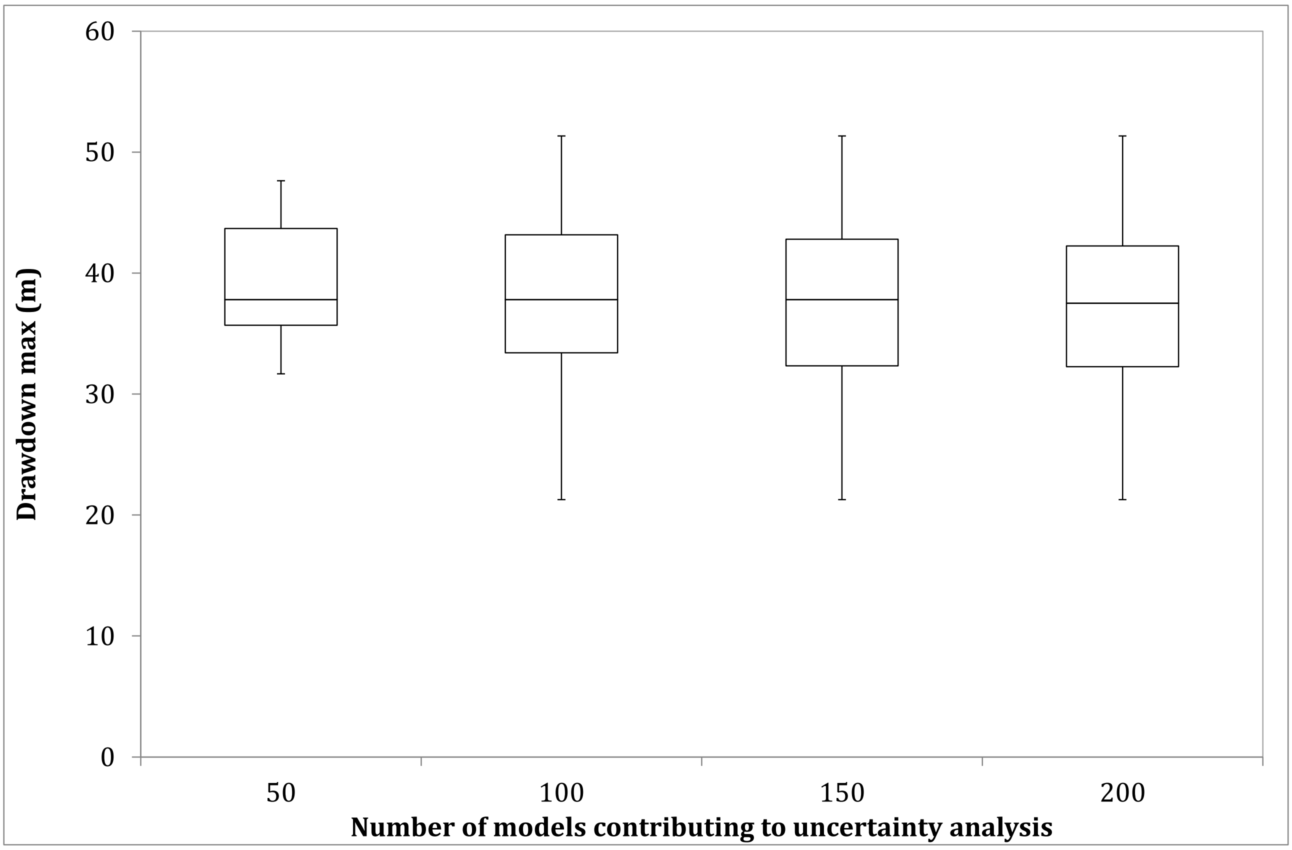


Figure A5.3 Model convergence check plots

A summary of the calibration performance and predictive response to mining is provided in Appendix A-2 The hydrographs show the composite distribution of the heads across all 207 realisations and indicate that the majority of the models are acceptably calibrated.

A5.3.1 Groundwater inflow to the mine

Figure A5.4 presents the uncertainty of groundwater inflow into the Mangoola Coal Mine from 2010 to 2030 as an exceedance probability plot. The uncertainty analysis indicates the peak 'very unlikely' inflows could be over double the peak inflows predicted for the calibrated model. As detailed in Section A5.1 any of the potential inflows within the 'very unlikely' red zone on the plots have less than a 10% chance of occurring. In NSW water licensing and water take is based on the basecase predicted totals.

A model simulation with only the approved Mangoola Coal Mine operational was also completed. The predicted inflow from only the approved Mangoola Coal Mine operating is also shown on the figure. There is no noticeable difference in predicted inflow if only the Mangoola Coal Mine were to be mined. As MCCO is not operational for much of the period of mining at Mangoola Coal Mine this is not unexpected in the years prior to 2022.

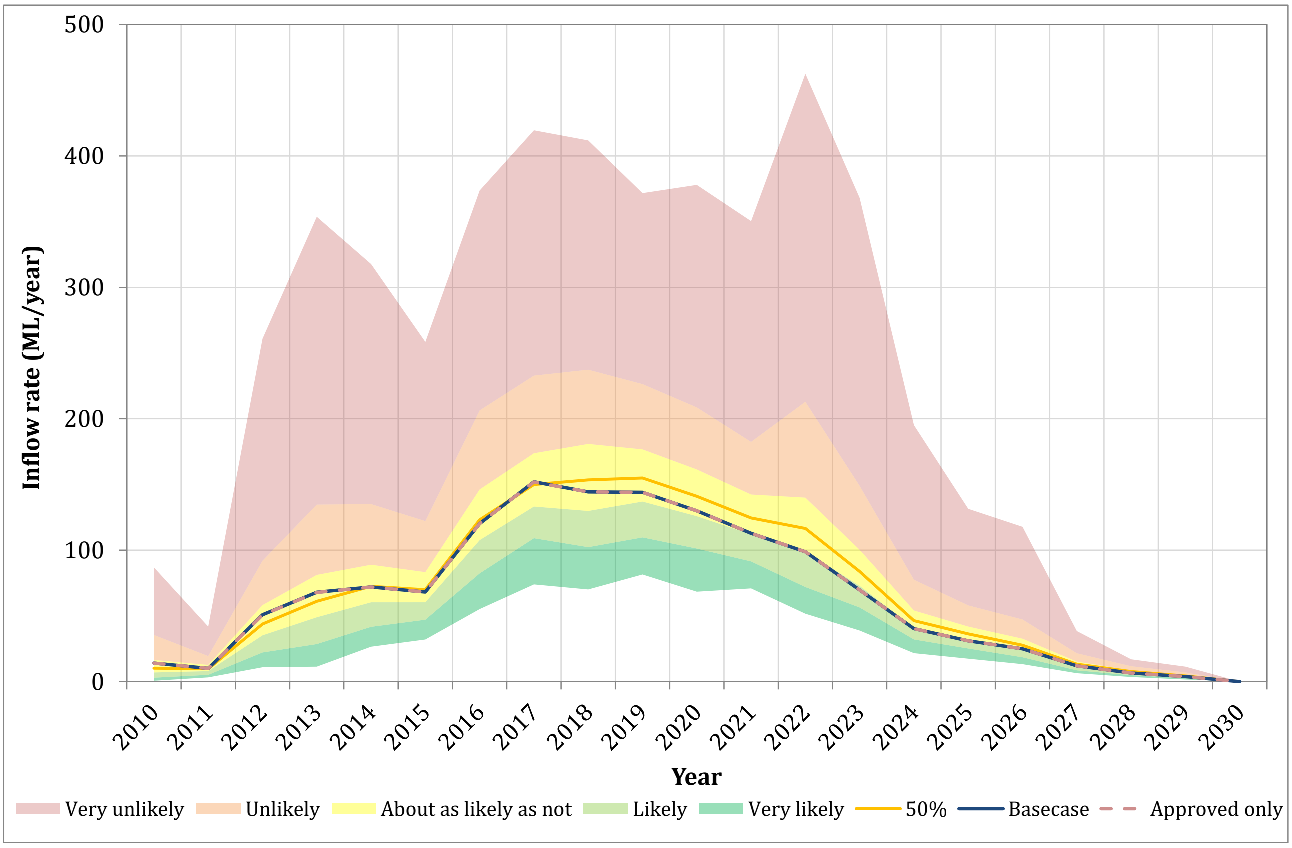


Figure A5.4 Mangoola Coal Mine groundwater inflow exceedance probability

Figure A5.5 shows the uncertainty modelling probability exceedance plot with respect to predicted groundwater inflow to the MCCO Additional Mining Area. It shows that in 'very unlikely' extreme cases the predicted inflows could peak at ~800 ML/year. This early peak is likely a function of a large mining footprint being present within the MCCO Additional Mining Area progression during 2022 and 2023. Table A5.9 presents the potential ranges in groundwater inflow to the MCCO Additional Mining Area each year. Inflows start in 2022, prior to the apparent start year for MCCO in the mine progression, as the model includes pre-stripping to the base of layer 5 during the 12 months prior to total depth being reached.

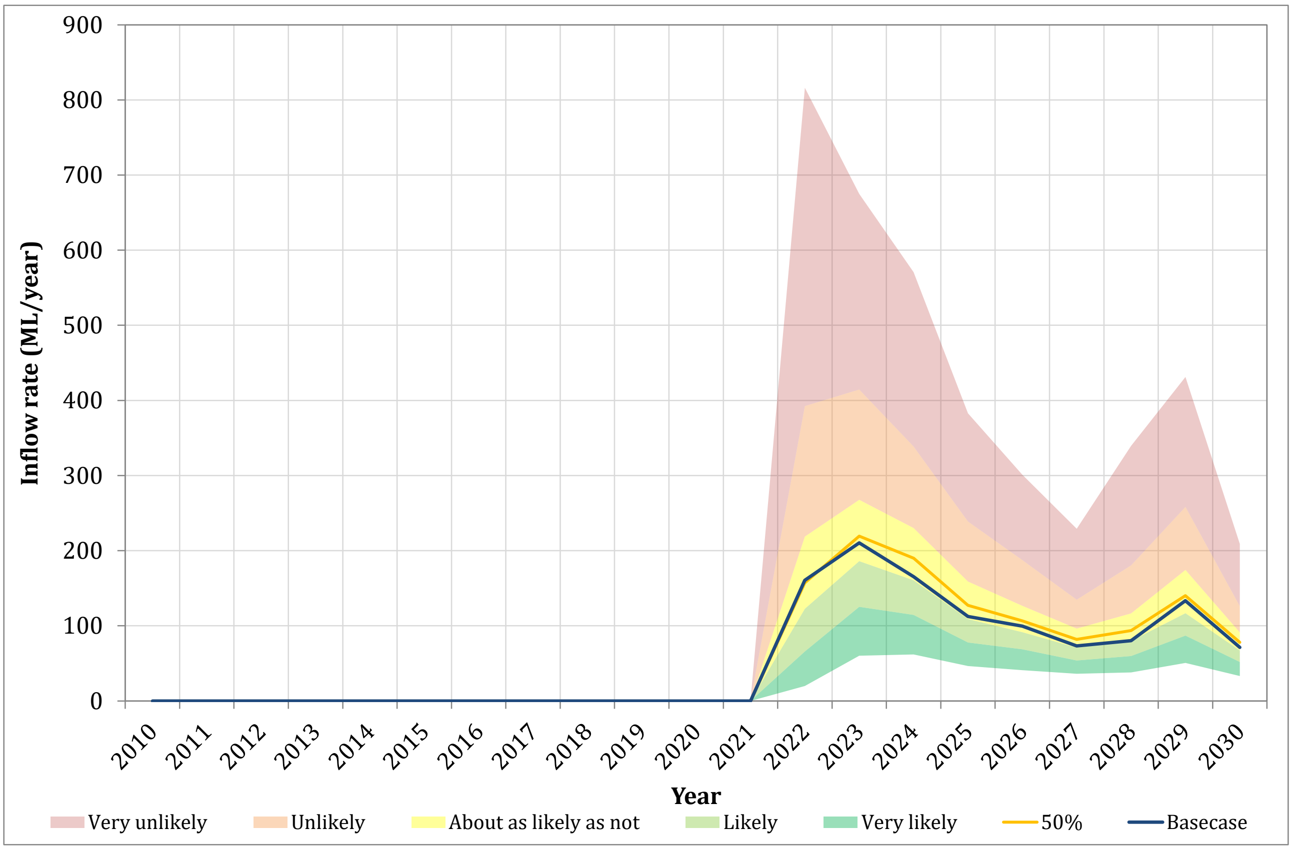


Figure A5.5 MCCO Additional Mining Area groundwater inflow exceedance probability

Table A5.9 Potential range in MCCO Additional Mining Area inflow ('take')

Year	Groundwater inflow (ML/year) (Minimum)	Groundwater inflow (ML/year) (Basecase)	Groundwater inflow (ML/year) (Maximum)
2010	0	0	0
2011	0	0	0
2012	0	0	0
2013	0	0	0
2014	0	0	0
2015	0	0	0
2016	0	0	0
2017	0	0	0
2018	0	0	0
2019	0	0	0
2020	0	0	0
2021	0	0	0
2022	20	161	816
2023	60	210	675
2024	62	165	571

Year	Groundwater inflow (ML/year) (Minimum)	Groundwater inflow (ML/year) (Basecase)	Groundwater inflow (ML/year) (Maximum)
2025	46	112	383
2026	41	99	301
2027	36	73	229
2028	38	80	340
2029	51	133	431
2030	33	71	209
Max	**62**	**210**	**816**

A5.3.2 Alluvial groundwater and surface water 'take'

Figure A5.6 to Figure A5.8 present the uncertainty with respect to the change in flux to the alluvial and surface water systems. The likelihood ranges were developed based on the same basecase cumulative mining model as used for the inflow analysis. i.e. with both Mangoola Coal Mine and MCCO Additional Mining Area actively mining. A separate model run was completed with only the approved Mangoola Coal Mine active, and the flux change from only the approved mining is also shown on the figures.

The models predict that the majority of impacts to the alluvium and surface water systems in the basecase simulations occur from the approved mining at Mangoola Coal Mine. For the Wybong Creek Alluvium the Mangoola Coal Mine accounts for a take of ~30 ML/year, with only a small additional take (~3 ML/year) predicted from mining the MCCO Additional Mining Area. The uncertainty ranges in take from the alluvium indicate that there is predicted to be a small take in all simulations. The maximum 'Very unlikely' peak take during cumulative basecase mining could be up to ~59 ML/year. It is important to note that no adjustments have been made to correct for double accounting of water, and for licensing purposes the change in surface water baseflow should be subtracted from the alluvial flux change. This would reduce the maximum basecase flux change from the alluvium during mining to as low as ~5 ML/year.

The predicted take from the Wybong Creek surface water is less than the take predicted from the Wybong Creek alluvium. In basecase conditions the maximum Wybong Creek surface water take during mining is predicted to reach ~28 ML/year, with 26 ML/year attributed to the approved Mangoola Coal Mine, and only a small additional take of ~2 ML/year due to mining at the MCCO Additional Mining Area. The maximum 'Very unlikely' peak take during cumulative basecase mining could be up to 52 ML/year. The variations in 'Very likely' flow in the early years of the uncertainty ranges for this plot are thought to be a model artefact relating to model simulations that had convergence issues rather than representing a genuine uncertainty range.

The predicted basecase take from Big Flat Creek surface water peaks at ~10 ML/year as this is the maximum basecase component of the creek. Once groundwater levels fall below the base of the creek there can be no further baseflow contributions to streamflow until groundwater levels rise again. The baseflow component of the creek is predicted to reduce to zero as a result of the approved Mangoola Coal Mine. As the creek is already disconnected from groundwater when the proposed MCCO Additional Mining Area commences operations there can be no additional impacts on Big Flat Creek baseflow due to the MCCO Additional Mining Area. The maximum 'Very unlikely' peak take from Big Flat creek surface water during cumulative mining could reach 48 ML/year. This would occur in uncertainty model simulations where there is more pre-mining baseflow in Big Flat Creek. This could occur with combinations of parameter values that result in a higher pre-mining groundwater level.

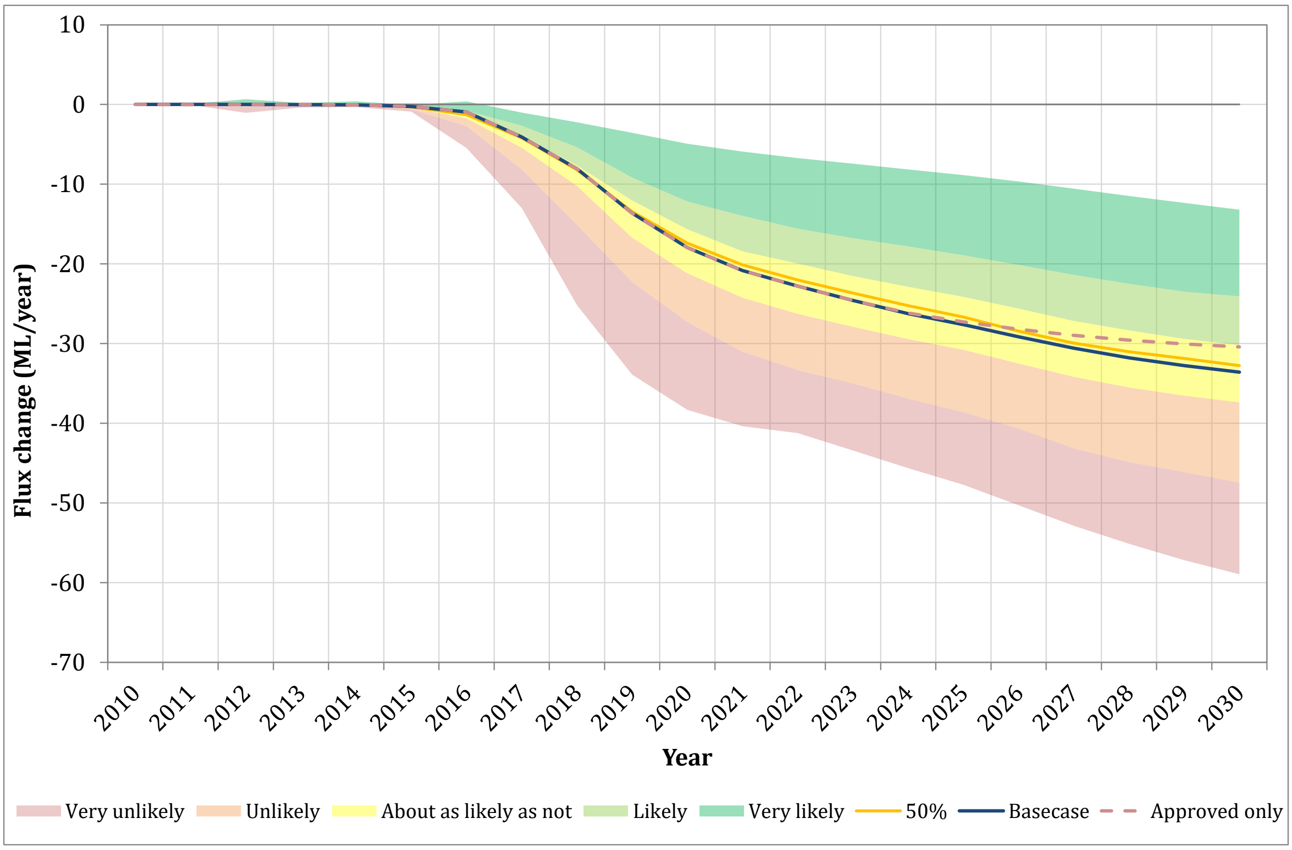


Figure A5.6 Likelihood of Wybong Creek alluvial flux change

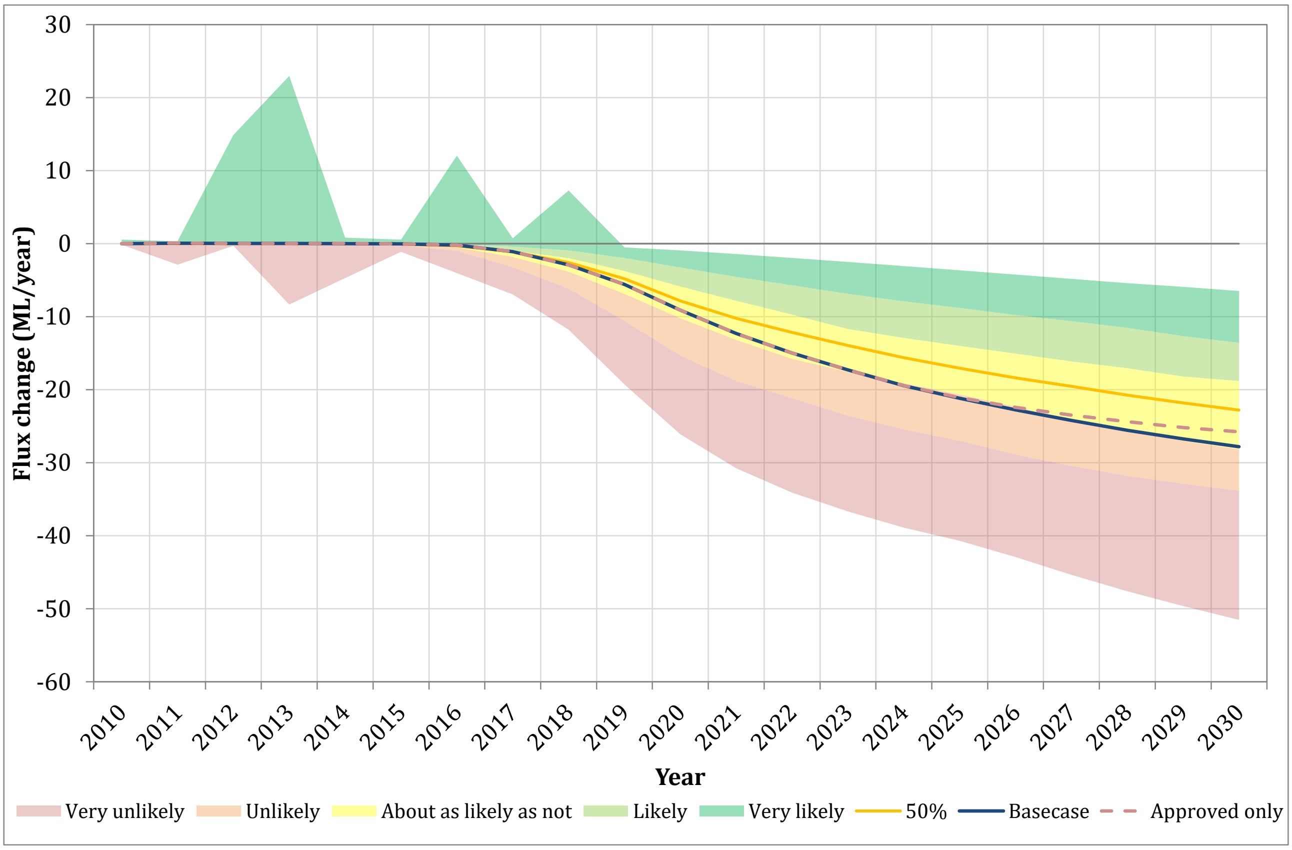


Figure A5.7 Likelihood of Wybong Creek surface water flux change

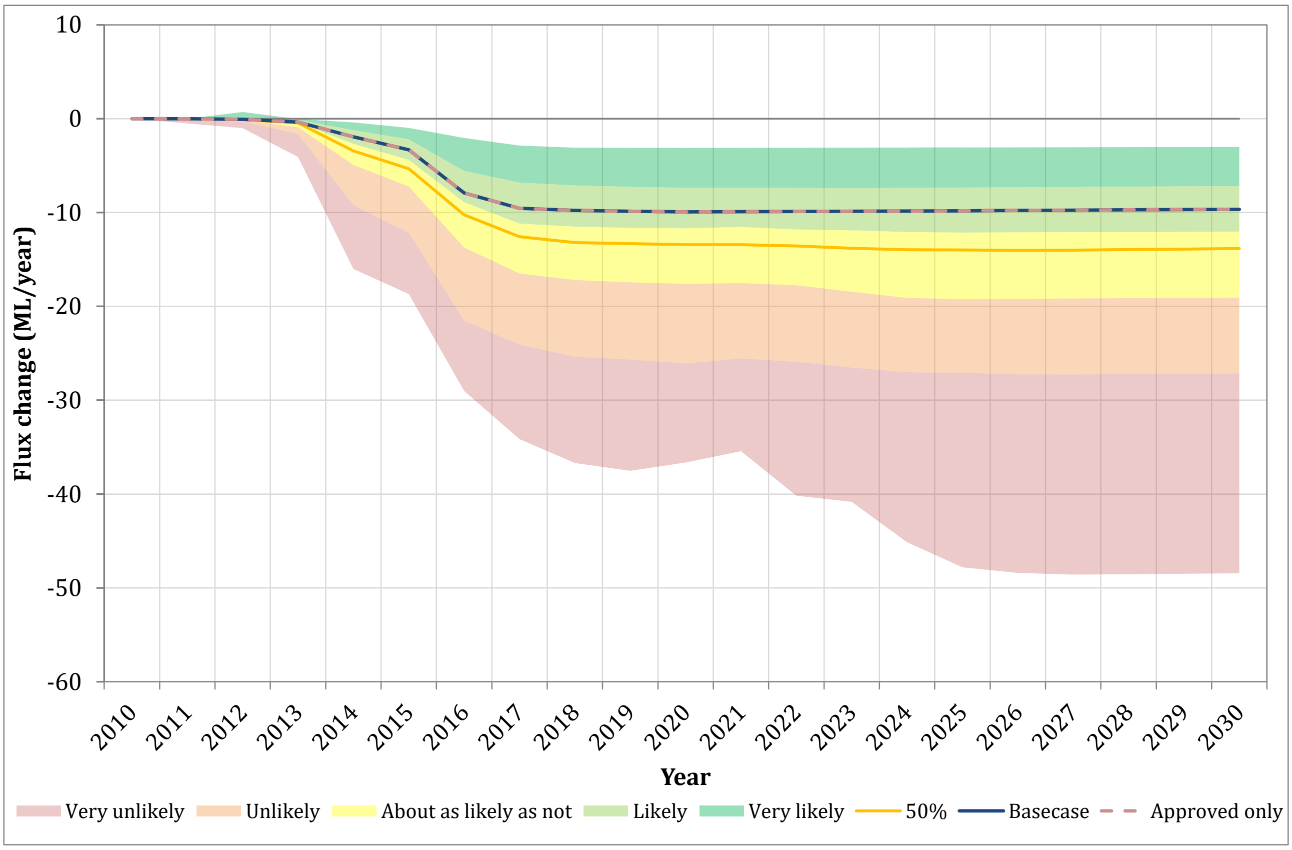


Figure A5.8 Likelihood of Big Flat Creek surface water flux change

A5.3.3 Groundwater drawdown

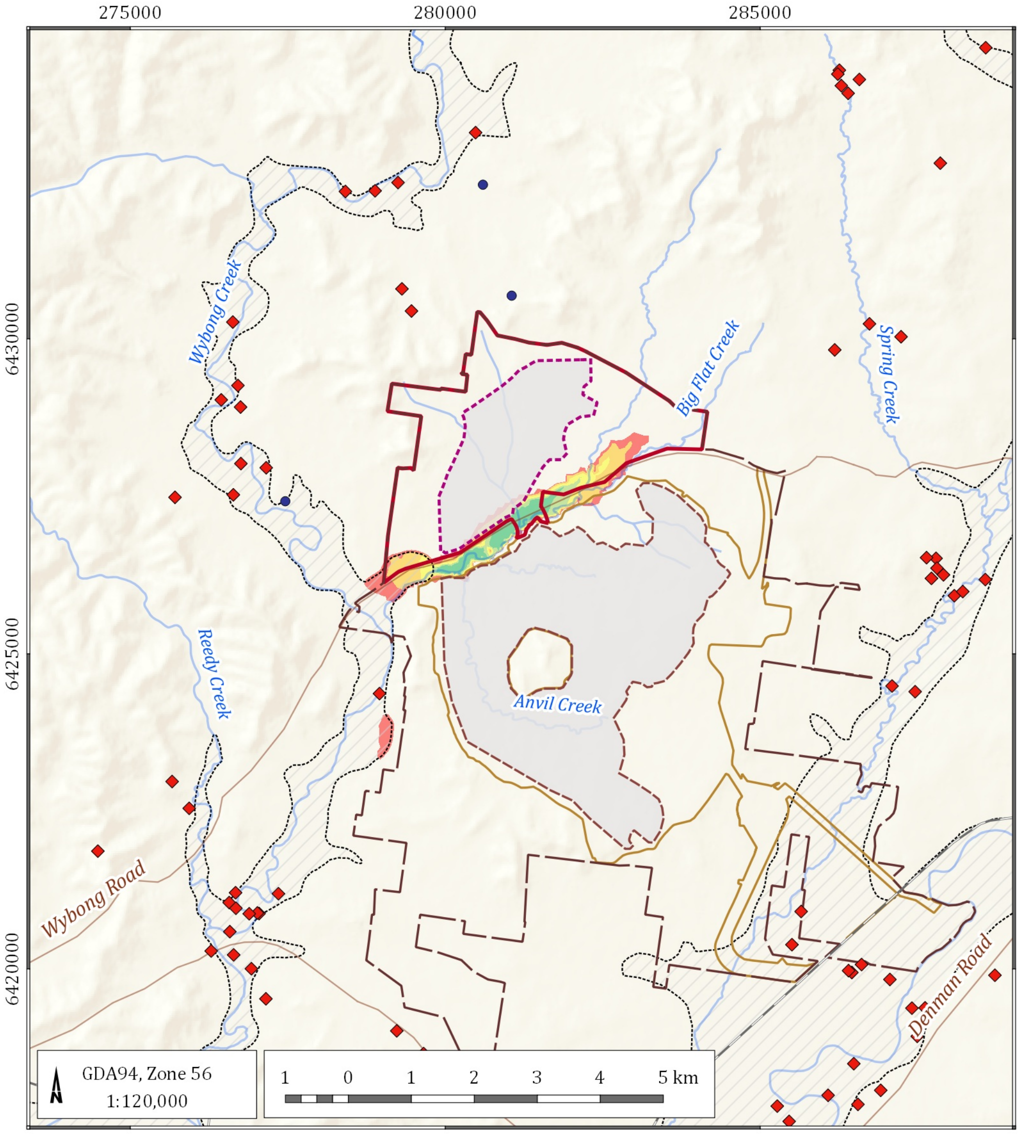
Basecase model drawdown maps are presented for the alluvium and regolith (Layer 1), shallow weathered zone (Layer 2), unweathered conglomerate (Layer 5), and Fassifern and Upper Pilot A seams (Layer 8) in the main report.

To assess the level of uncertainty in the extent of predicted cumulative drawdown from both the approved Mangoola Coal Mine and the MCCO Additional Mining Area being active the likelihood of 2 m drawdown occurring was developed. Figure A5.9 to Figure A5.10 present the uncertainty in maximum groundwater drawdown at any time during mining within alluvium and regolith (Layer 1), shallow weathered zone (Layer 2), unweathered conglomerate (Layer 5), and Fassifern and Upper Pilot A seam (Layer 8). The figures use the calibrated uncertainty language detailed in Section A5.1.

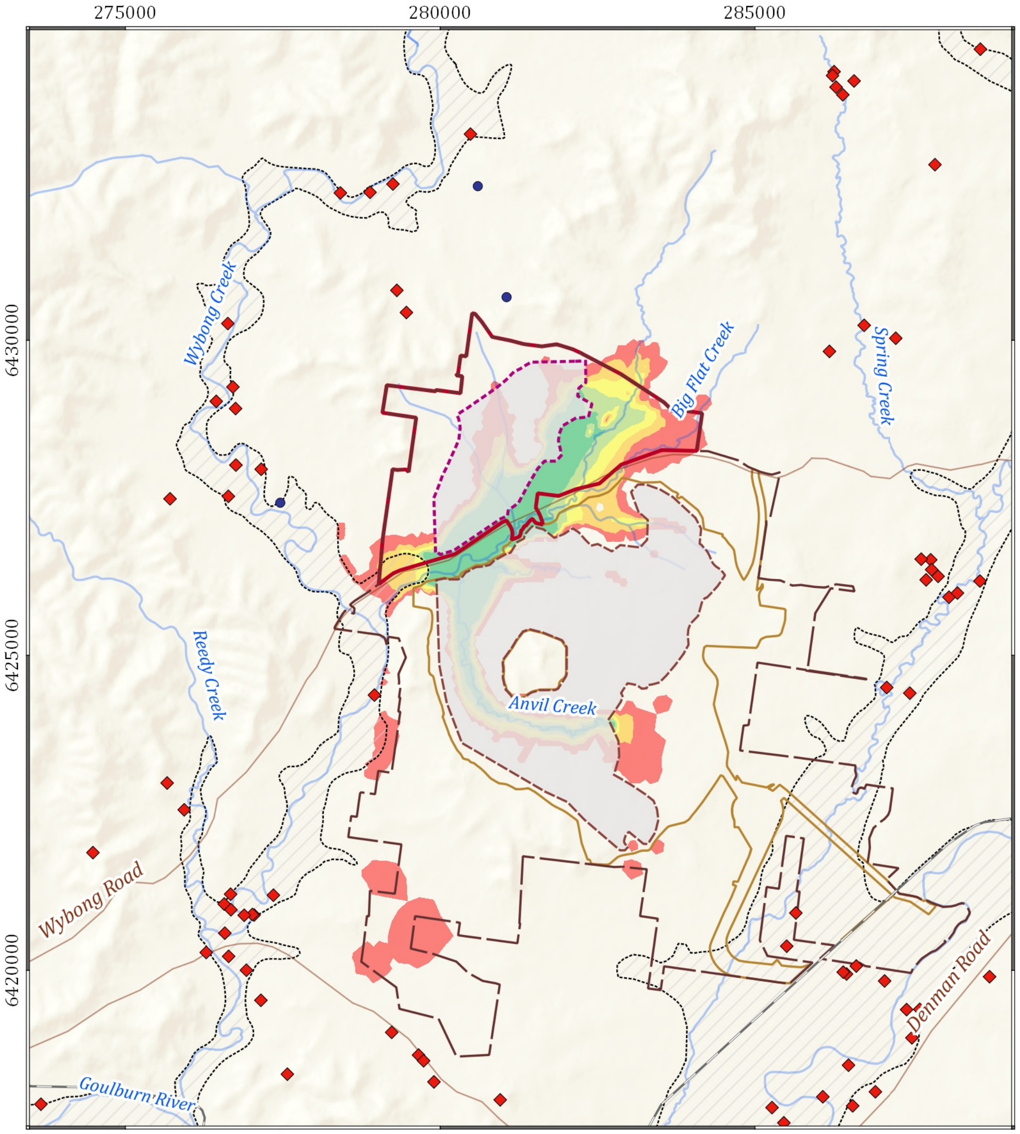
The likelihood plots indicate that for the two shallowest model layers there are only limited areas where drawdowns of over 2 m are within the range 'Very likely' to 'Unlikely'. There are only limited areas of the Wybong Creek alluvium that may by impacted by more than 2 m. The most likely area of Wybong Creek alluvium to be impacted is the small spur along the end of Big Flat Creek. For Layer 2 there are also a number of small areas to the south west of the MCCO Project Area where a drawdown of over 2 m would be 'Very unlikely'.

In the deeper model layers the spatial extents of drawdown are greater and, as expected, radiate out in decreasing likelihood from the active mining areas. Although the deeper layers show a larger area of drawdown this is not transmitted to the shallower layers. In these areas potential impacts will therefore primarily be associated with uses such as private bores that take water from depth.

Likelihood of 2 m drawdown - model layer 1



Likelihood of 2 m drawdown - model layer 2



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Alluvium
- Mined area
- Road
- Drainage
- Registered bores on privately owned land
- Other landholder bore

Exceedance probability (%)

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

Mangoola EIS (G1839F)

AGE

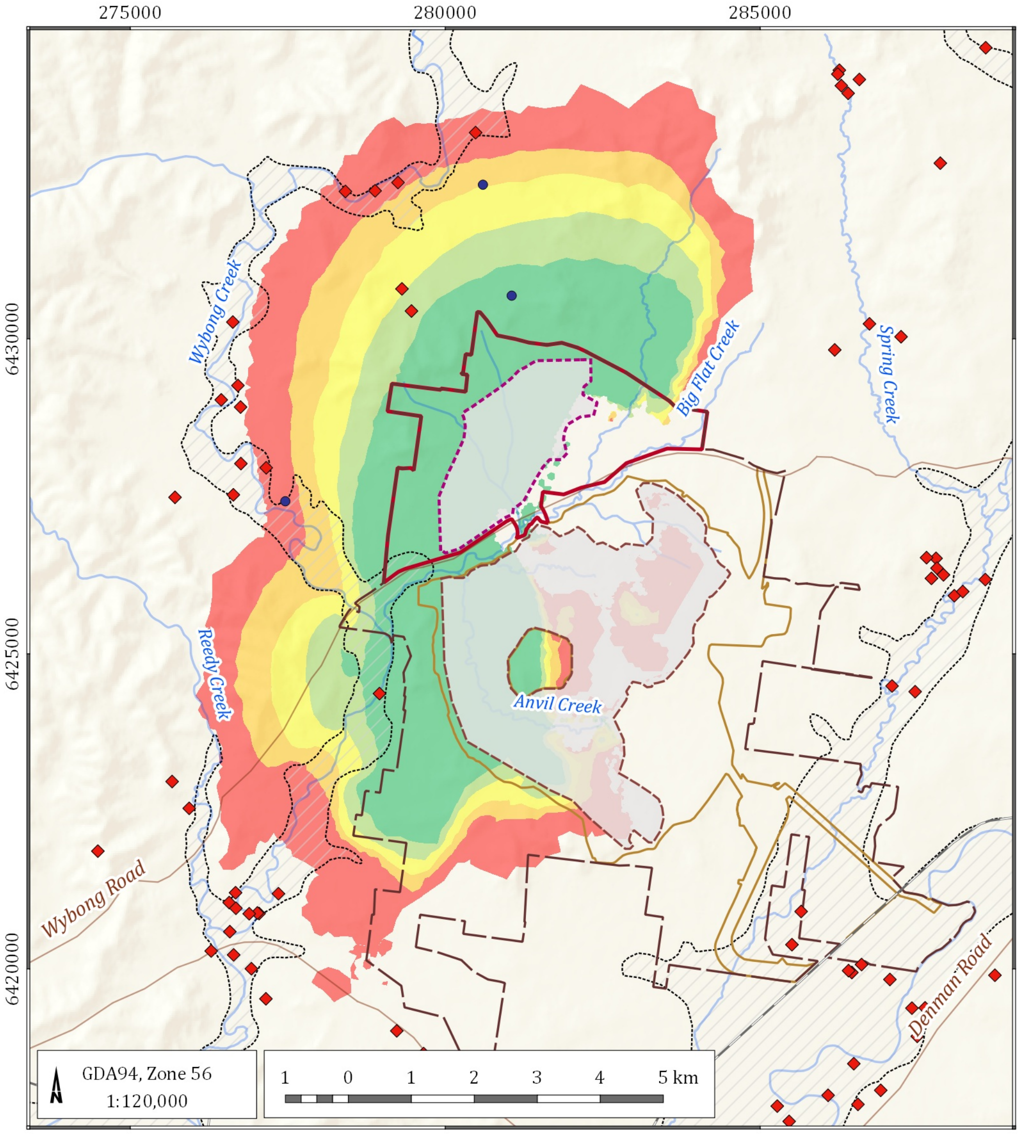
Likelihood of 2 m drawdown in layer 1 and layer 2

DATE
10/04/2019

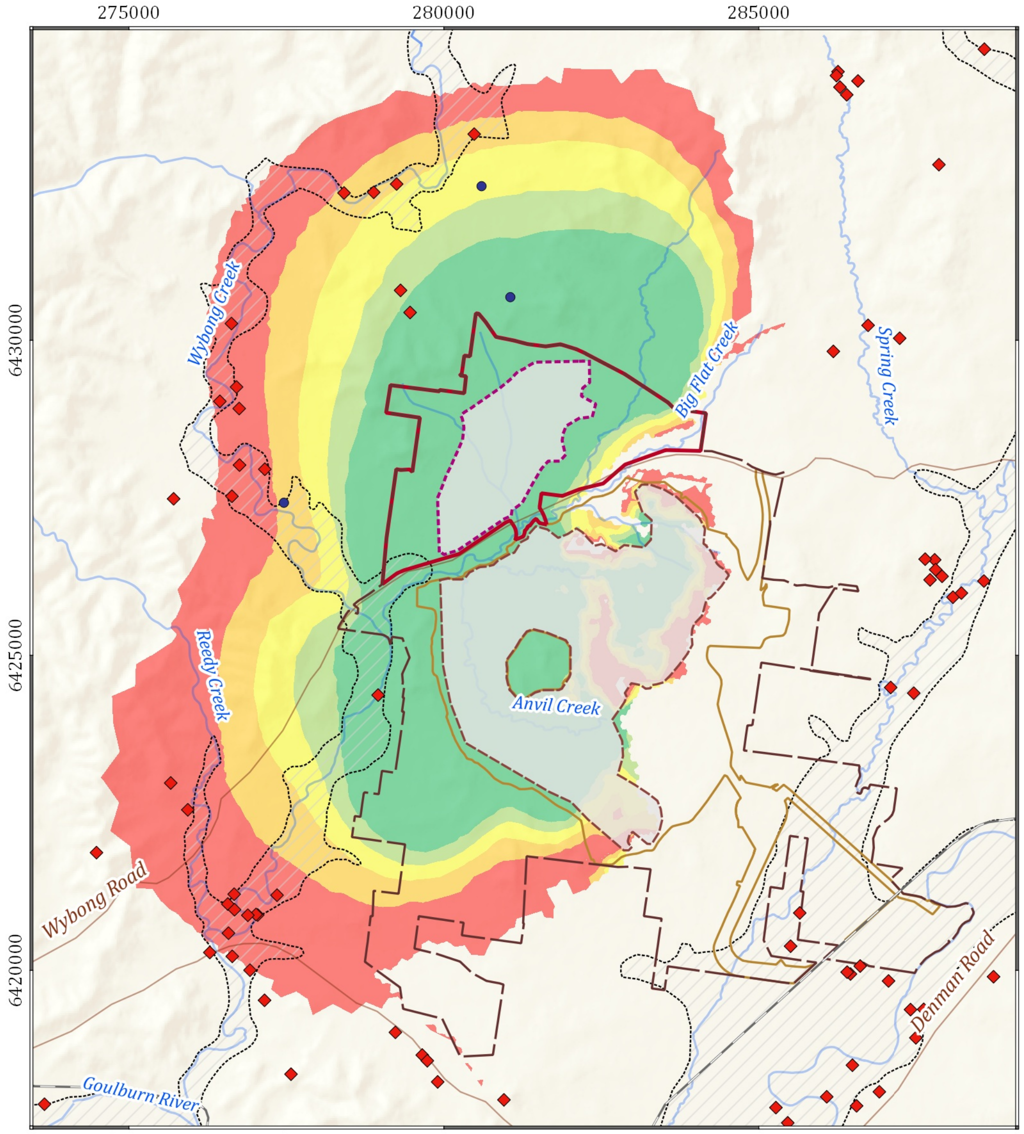
FIGURE No:
A 5.9

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1839F.Mangoola EIS\3_GIS\Workspaces\011_GIA\A-05.09 to A-05.10_Likelihood of 2 m drawdown.qgs

Likelihood of 2 m drawdown - model layer 5



Likelihood of 2 m drawdown - model layer 8



LEGEND

- MCCO Project Area
- MCCO Additional Project area
- Approved Mangoola Coal Mine Disturbance Area
- Approved Mangoola Coal Mining Area
- Proposed Additional Mining Area
- Alluvium
- Mined area
- Road
- Drainage
- Registered bores on privately owned land
- Other landholder bore

Exceedance probability (%)

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

AGE

Mangoola EIS (G1839F)

Likelihood of 2 m drawdown in layer 5 and layer 8

DATE
10/04/2019

FIGURE No:
A 5.10

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1839F.Mangoola EIS\3_GIS\Workspaces\011_GIA\A-05.09 to A-05.10_Likelihood of 2 m drawdown.qgs

A6 Sensitivity Analysis

In addition to the uncertainty analysis a sensitivity analysis on the potential impact of the Mount Ogilvie fault was also completed. The fault was simulated as a low permeability zone in all layers below the weathered zone. The fault zone was given a hydraulic conductivity 1.0 x 10^{-6} m/day and 1.0 x 10^{-8} m/day, or approximately two orders of magnitude and four orders of magnitude lower than the basecase model. There was no material difference noted in any of the model outputs.

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Appendix A-1 Calibration Details and Hydrographs

Bore ID	Easting (GDA94z56)	Northing (GDA94z56)	Layer	Count of Residual	Average of Residual	Range in residuals	
						Min of Residual	Max of Residual
BFC01A	280755	6427279	5	20	0.1	-1.4	5.4
BFC01B	280755	6427279	9	54	0.5	-3	2.9
BFC02A	280770	6427179	6	18	-0.3	-1.7	0.7
BFC02B	280770	6427178	9	53	31.8	22.2	38.6
BFC03A	280847	6427054	2	20	-1.9	-6.1	3.5
BFC03B	280850	6427056	9	54	2.5	-2.8	6
BFC05A	279438	6426876	5	51	-0.7	-2	1.2
BFC06A	279430	6426745	5	51	-1.1	-3.9	1.1
BFC07A	279581	6426351	2	20	-0.1	-3.6	7.3
BFC07B	279583	6426354	5	52	2.2	-8.8	23.9
BFC08A	279610	6426224	2	19	-0.2	-2.2	0.5
BFC08B	279613	6426223	5	52	-3	-9.7	4.2
GW01-D	283206	6429324	1	32	6.8	6	7.7
GW01-S	283206	6429324	1	32	6.8	6.2	7.8
GW02	283977	6428460	2	49	0	-1.1	0.7
GW03-D	283977	6428460	2	46	-1.5	-2.3	-0.7
GW03-S	283977	6428460	2	5	-0.9	-1	-0.9
GW04	284755	6427782	11	50	-5.3	-6.4	-4.8
GW047877	282447	6428562	9	5	-0.3	-0.5	-0.1
GW06	280383	6428106	2	41	12.4	11.8	12.8
GW07-D	281794	6427520	1	49	-0.9	-2.7	1.4
GW07-S	281794	6427520	1	39	-0.5	-1.6	0.5
GW09	281139	6427058	1	15	1.2	0.7	1.7
GW10-A1	280816	6427229	1	5	4.8	4.3	5.2
GW10-A2	280816	6427229	2	51	-0.8	-5.8	3.2
GW10-P1	280816	6427229	7	51	-1.7	-7.5	1
GW10-P2	280816	6427229	8	50	-1.3	-3.6	1
GW11	281208	6426679	8	25	0.9	0.3	1.7
GW12	280970	6426565	9	29	0.1	-11.8	2
GW13	280014	6426796	5	49	-0.1	-3.5	7.4
GW14	279504	6426568	9	45	-4.4	-11.5	-0.9

Bore ID	Easting (GDA94z56)	Northing (GDA94z56)	Layer	Count of Residual	Average of Residual	Range in residuals	
						Min of Residual	Max of Residual
GW15	280213	6426384	5	49	-3.6	-10.8	-0.2
GW16	280523	6426465	5	45	-3.5	-10.3	-1.2
GW17	280749	6426446	5	46	-2.9	-10.4	-0.6
GW18	281167	6426229	9	30	-0.5	-5.6	1.4
GW19	281424	6426081	9	32	-2.3	-5.6	-1.4
GW20	281715	6425935	9	32	-5.1	-6.8	-3.8
GW202249	281196	6428217	9	5	6.2	6.1	6.2
GW22	282416	6426191	9	27	-1.5	-2.6	0.9
GW23	282917	6426300	9	13	5.2	4.9	5.3
GW25	284363	6426545	11	1	7.4	7.4	7.4
GW26	277319	6426285	5	43	8.1	6.8	8.4
GW27	280420	6426220	5	49	-0.4	-5.3	21.9
GW28	280715	6426123	5	32	-3.4	-3.9	-2.4
GW29	280411	6426135	2	41	-1.5	-2.7	5.1
GW30	280538	6425911	5	43	-3.4	-5	0.7
GW31	280365	6426019	5	48	-1.5	-3.6	9.2
GW32	280144	6426062	5	48	-2.2	-3.6	3.2
GW33	280349	6425595	5	49	-2.1	-4.2	5.4
GW34	281701	6425565	9	32	-5.2	-6	-4.6
GW35	281700	6425279	9	39	-4.9	-7.5	-2.3
GW36	283625	6424864	9	11	3.6	3.2	3.7
GW37	283132	6424665	9	8	7.8	7.6	7.8
GW38-D	282885	6424316	9	7	-1.9	-2	-1.8
GW38-S	282885	6424316	9	7	-0.9	-1.1	-0.8
GW39	282683	6423989	2	10	2.9	2.8	3.1
GW40	281484	6424400	8	46	-8.8	-15.8	-5
GW41	280492	6424387	5	27	-2.7	-3.1	-2.3
GW43	279133	6424531	2	12	9.2	8.1	10
GW44	278982	6424223	5	16	-4.2	-4.4	-3.9
GW46	281459	6423408	7	51	-1.3	-2.2	-0.7
GW47	282275	6423374	8	38	-5.8	-9.6	0.6

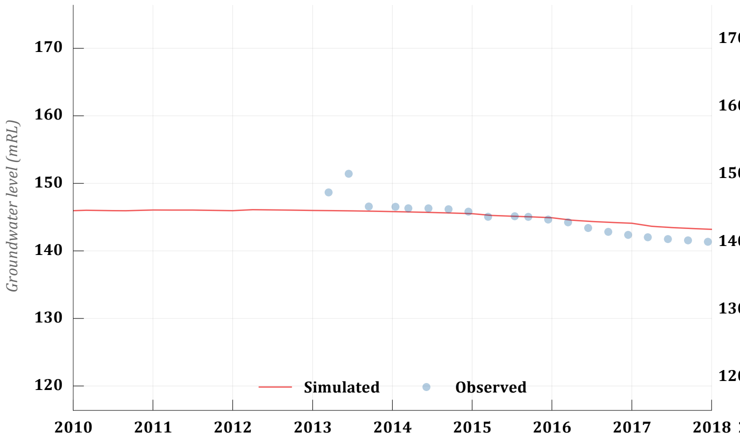
Bore ID	Easting (GDA94z56)	Northing (GDA94z56)	Layer	Count of Residual	Average of Residual	Range in residuals	
						Min of Residual	Max of Residual
GW48	282526	6423423	9	22	-4.2	-10.7	0.1
GW49	283777	6423450	12	6	-3.3	-3.8	-3
GW50	283223	6422596	9	21	-0.5	-1.2	0.9
Jennar WL	286571	6429836	2	49	-6.3	-7.2	-5
MB1	284816	6425033	2	58	-0.3	-3.6	4.1
MB2	284836	6424974	2	59	-0.6	-1.1	3.5
MN1001-1	283751	6429974	8	39	0.4	-0.3	1.2
MN1001-2	283751	6429974	11	39	0.4	-0.2	0.6
MN1001-3	283751	6429974	12	39	-0.8	-1.9	2.8
MN1001-4	283751	6429974	12	39	-2.8	-5	3.5
MN1001-5	283751	6429974	12	39	-6.2	-6.8	-5
MN1006	283061	6428994	9	19	2.1	1.5	3.2
MN1007-1	278509	6428191	3	39	4.3	0.7	5.2
MN1007-2	278509	6428191	5	39	16.3	13.3	17.1
MN1007-3	278509	6428191	5	39	-5.1	-14.9	5.1
MN1007-4	278509	6428191	9	39	-10.9	-17.7	-5.5
MN1007-5	278509	6428191	12	39	29	-0.2	36
MN1010-1	279929	6426973	6	40	-9.4	-13	-7.6
MN1010-2	279929	6426973	10	40	-4	-9.4	-0.4
MN1010-3	279929	6426973	11	40	-6	-9.7	-0.4
MN1010-4	279929	6426973	12	40	6.7	4.7	7.7
MN1010-5	279929	6426973	12	39	-7.2	-13.5	3.3
MN1014	282862	6428265	9	18	-17.1	-18.7	-16.3
MP10-A	284946	6425122	12	28	-5.6	-6.1	-5
MP10-B	284946	6425122	12	28	0.8	0.1	1.2
MP11-A	282608	6423922	9	1	7.2	7.2	7.2
MP11-B	282608	6423922	9	23	4.3	3.2	6.7
MP12-A	280604	6425593	5	25	-2.4	-18.6	1.8
MP12-B	280601	6425590	5	24	-3.2	-4	0.2
MP12-C	280601	6425590	8	25	-2.2	-13.1	1.3
MP13-A	280832	6423966	5	27	-3.7	-6.3	-2.5

Bore ID	Easting (GDA94z56)	Northing (GDA94z56)	Layer	Count of Residual	Average of Residual	Range in residuals	
						Min of Residual	Max of Residual
MP13-B	280829	6423964	9	28	-9.5	-25.4	-3.4
MP13-C	280829	6423964	6	26	-10.1	-26.2	-4.2
MP14-A	280622	6425119	5	28	5.1	-2.6	18.5
MP14-B	280620	6425121	7	26	-4.7	-17	-0.5
MP14-C	280620	6425121	5	27	-4.2	-13	-0.3
MP15B	280924	6426917	9	54	5.4	-5.2	10.3
MP15-B	280924	6426917	2	60	-2.8	-6.4	0.3
MP16A	281087	6427030	9	54	39.5	-3.3	55.1
MP16-B	281087	6427030	2	62	-2.2	-4.4	0.8
MP17-B	281470	6427133	2	27	-0.2	-9.1	3.9
MP17C	281470	6427133	9	53	0.1	-5.4	1.6
MP18-A	280063	6426227	9	19	-9.8	-13.9	-3
MP18-B	280059	6426227	5	17	-2.5	-3.9	-1.4
MP19-A	280383	6426330	9	19	-10.8	-20.3	-2.9
MP19-B	280380	6426328	5	16	-3.3	-8.3	3
MP1-A	284886	6426052	12	28	8.7	8.2	9.1
MP1-B	284886	6426052	11	28	-2.6	-4.7	-1.3
MP20-A	280575	6426430	8	19	-3.4	-13	4.3
MP20-B	280570	6426428	5	15	-4.4	-8.5	-1.4
MP2-A	284355	6424470	12	27	-2.6	-3	-2.3
MP2-B	284355	6424470	11	27	-0.2	-0.5	0.5
MP3-A	284187	6427346	9	27	-5.2	-6.6	-4
MP3-B	284187	6427346	9	27	-2.9	-3.9	-2.1
MP4-A	283205	6428064	11	61	1.7	-0.1	2.6
MP4-B	283200	6428065	10	61	2.7	1.3	3.3
MP4-C	283200	6428061	9	62	1.3	0.9	2.1
MP6-A	283291	6422169	10	15	-4	-4.4	-3.4
MP6-B	283291	6422169	9	15	6.6	5.1	8.3
MP8-B	281305	6426956	8	22	-2	-11.5	0.9
MP9-A	280204	6426566	5	62	-0.3	-2.4	3.6
MP9B	280202	6426568	9	53	7.4	-4.1	28.7

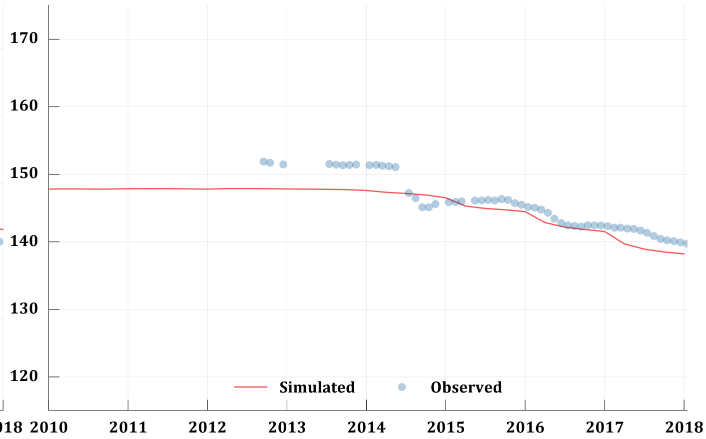
Bore ID	Easting (GDA94z56)	Northing (GDA94z56)	Layer	Count of Residual	Average of Residual	Range in residuals	
						Min of Residual	Max of Residual
NGW01A-1	278067	6427055	6	31	-8.9	-15.3	-4.3
NGW01A-2	278067	6427055	9	31	-43.6	-49.9	-3.7
NGW01A-3	278067	6427055	4	31	-5	-7.9	-3.7
NGW01A-4	278067	6427055	4	30	-7.6	-11.7	-3.2
NGW01A-5	278067	6427055	5	31	0.1	-8.6	5.8
NGW01B	278074	6427069	4	19	-2.7	-2.9	-2.4
NGW01C	278071	6427062	4	19	-2.9	-3.2	-2.6
NGW02A-1	280977	6429927	5	33	20.2	16.2	21.8
NGW02A-2	280977	6429927	6	31	7.9	5.2	8.7
NGW02A-3	280977	6429927	8	33	-1.9	-2.6	-1
NGW02A-4	280977	6429927	4	33	-12.3	-14.4	-11
NGW02B	280975	6429920	4	19	29.5	29.1	29.8
NGW03A	285374	6428679	12	19	10.1	9.4	10.4
NGW03B-1	285374	6428679	12	29	10.7	10.6	10.8
NGW03B-2	285374	6428679	12	29	-4.8	-4.9	-4.7
NGW03B-3	285374	6428679	12	29	-5	-5.1	-4.8
NGW03B-4	285374	6428679	12	29	-6.5	-6.9	-5.9
REG01	282095	6427980	11	17	-8.4	-11.1	-5.6
VW1-1	279298	6425390	11	65	7.1	1	10.6
VW1-2	279298	6425390	9	65	12.4	-13.8	37.7
VW1-3	279298	6425390	7	65	6.8	-5.4	13.8
VW1-4	279298	6425390	5	65	-5.6	-12.4	-2.2
VW1-5	279298	6425390	5	65	-2.3	-5.2	0.4
VW2-1	279321	6423834	10	65	-3.3	-7.9	-1.9
VW2-2	279321	6423834	9	65	-1.8	-6.8	2.2
VW2-3	279321	6423834	7	65	-0.2	-1	0.7
VW2-4	279321	6423834	5	65	-9.1	-10.3	-8.6
VW2-5	279321	6423834	5	18	-7.3	-8.9	-2
VW3-1	281721	6422805	10	65	-4.2	-4.7	-3.7
VW3-2	281721	6422805	9	65	-1.6	-4.2	-0.1
VW3-3	281721	6422805	9	65	0	-2.5	2.3

Bore ID	Easting (GDA94z56)	Northing (GDA94z56)	Layer	Count of Residual	Average of Residual	Range in residuals	
						Min of Residual	Max of Residual
VW3-4	281721	6422805	9	65	-0.8	-1.8	1.5
VW3-5	281721	6422805	7	68	4.9	1.5	7.6

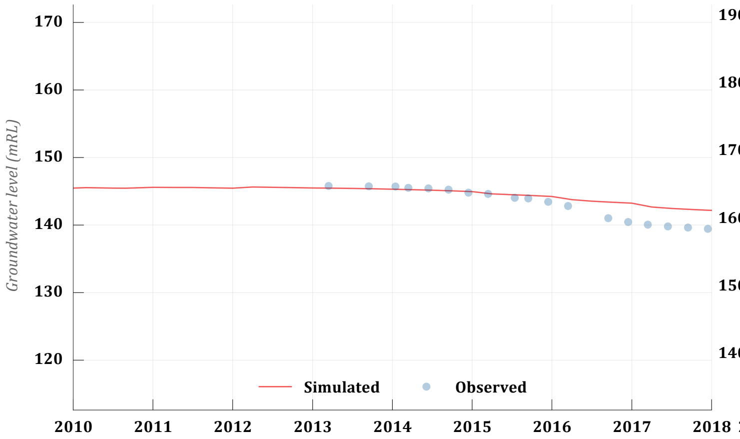
BFC01A



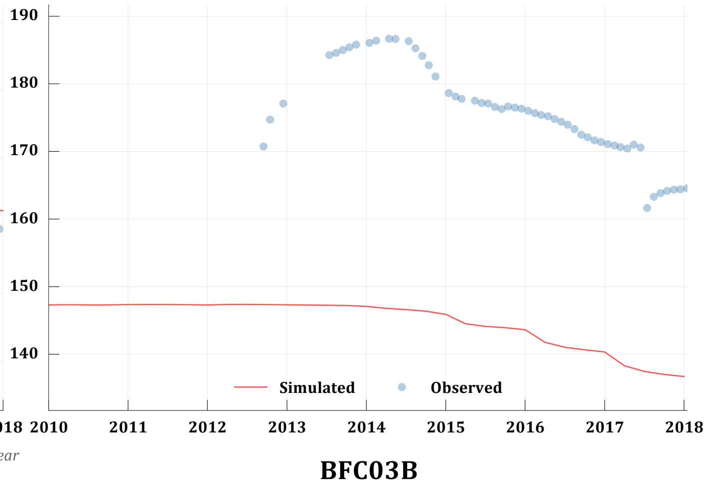
BFC01B



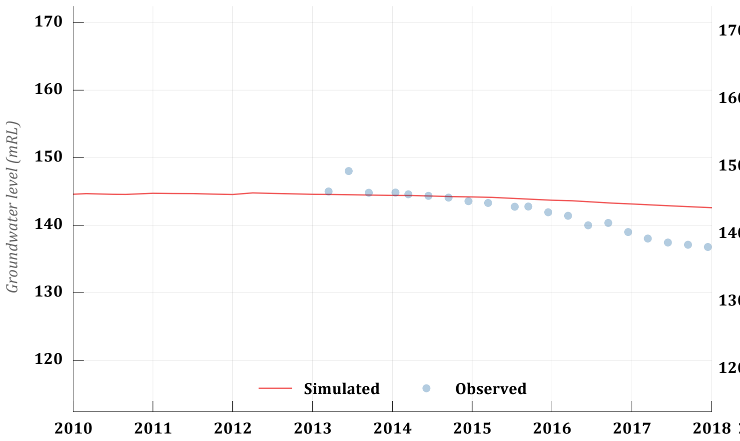
BFC02A



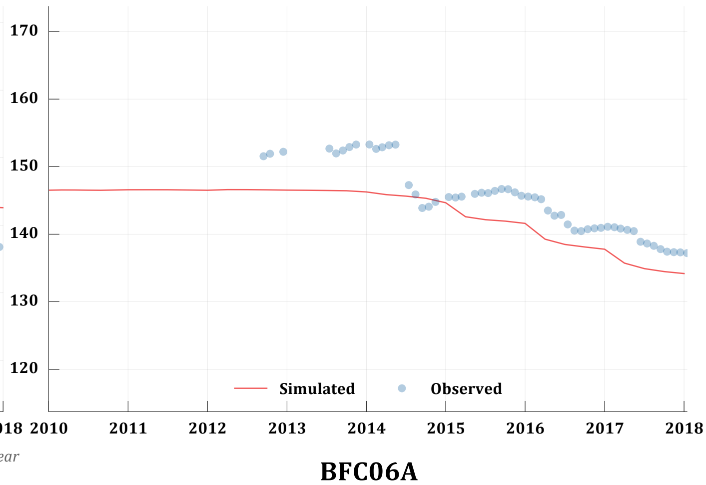
BFC02B



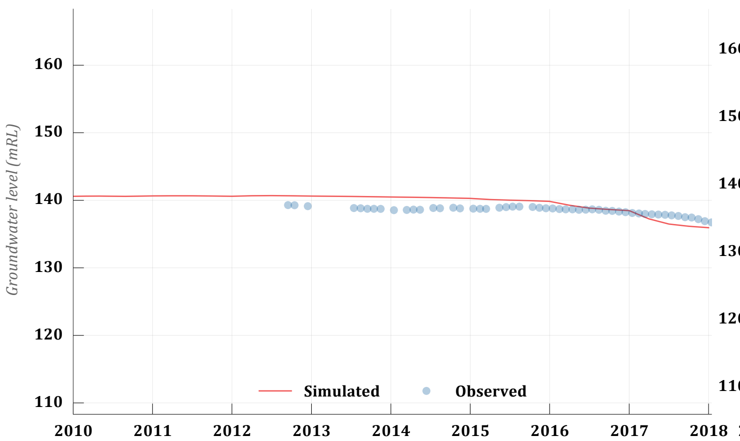
BFC03A



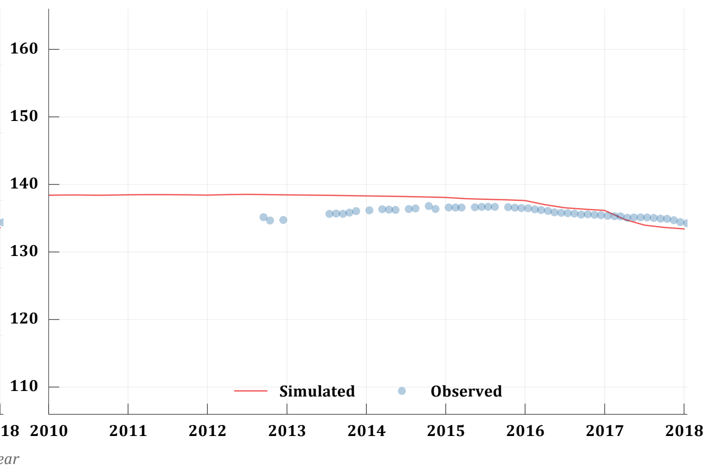
BFC03B

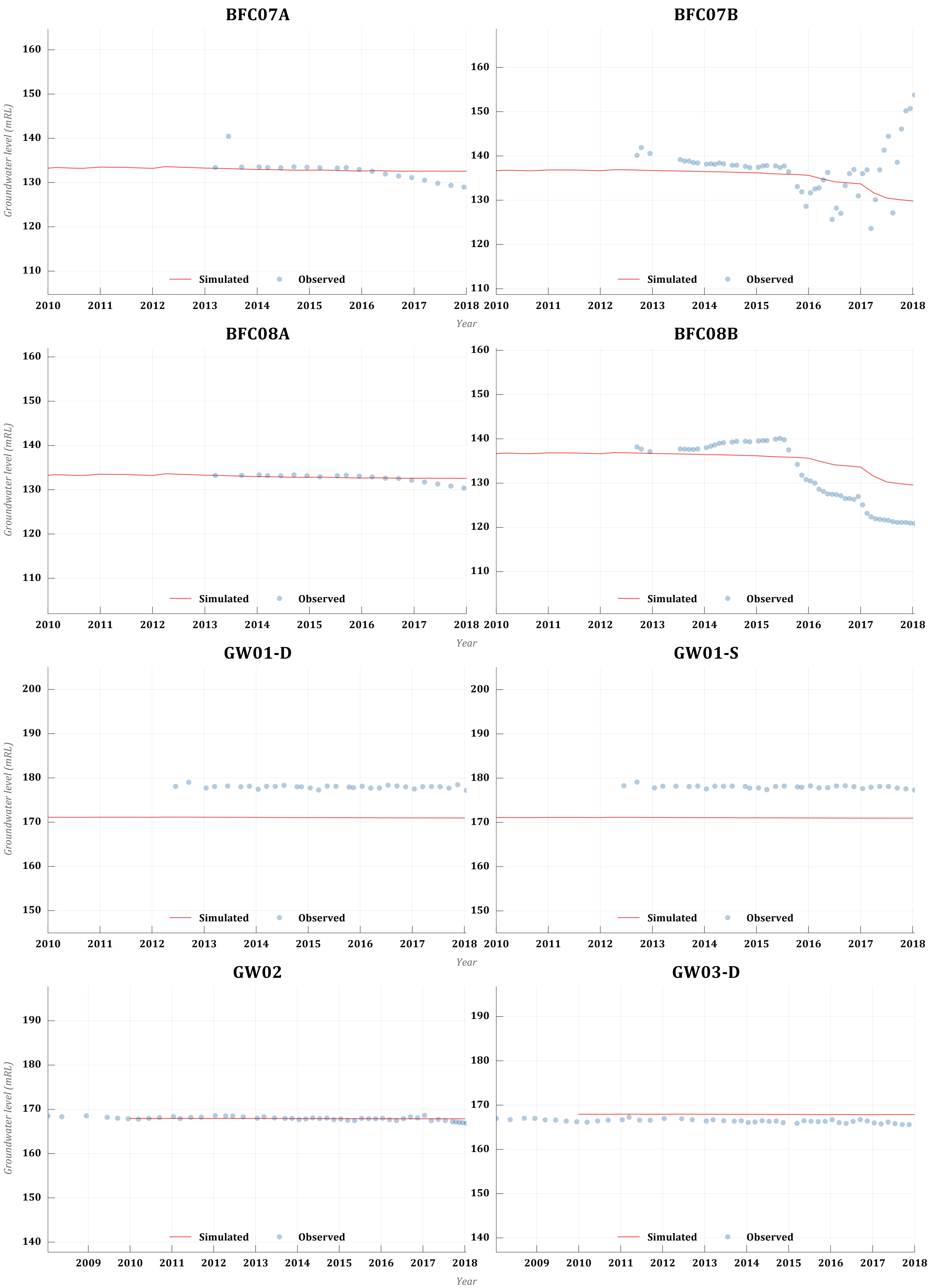


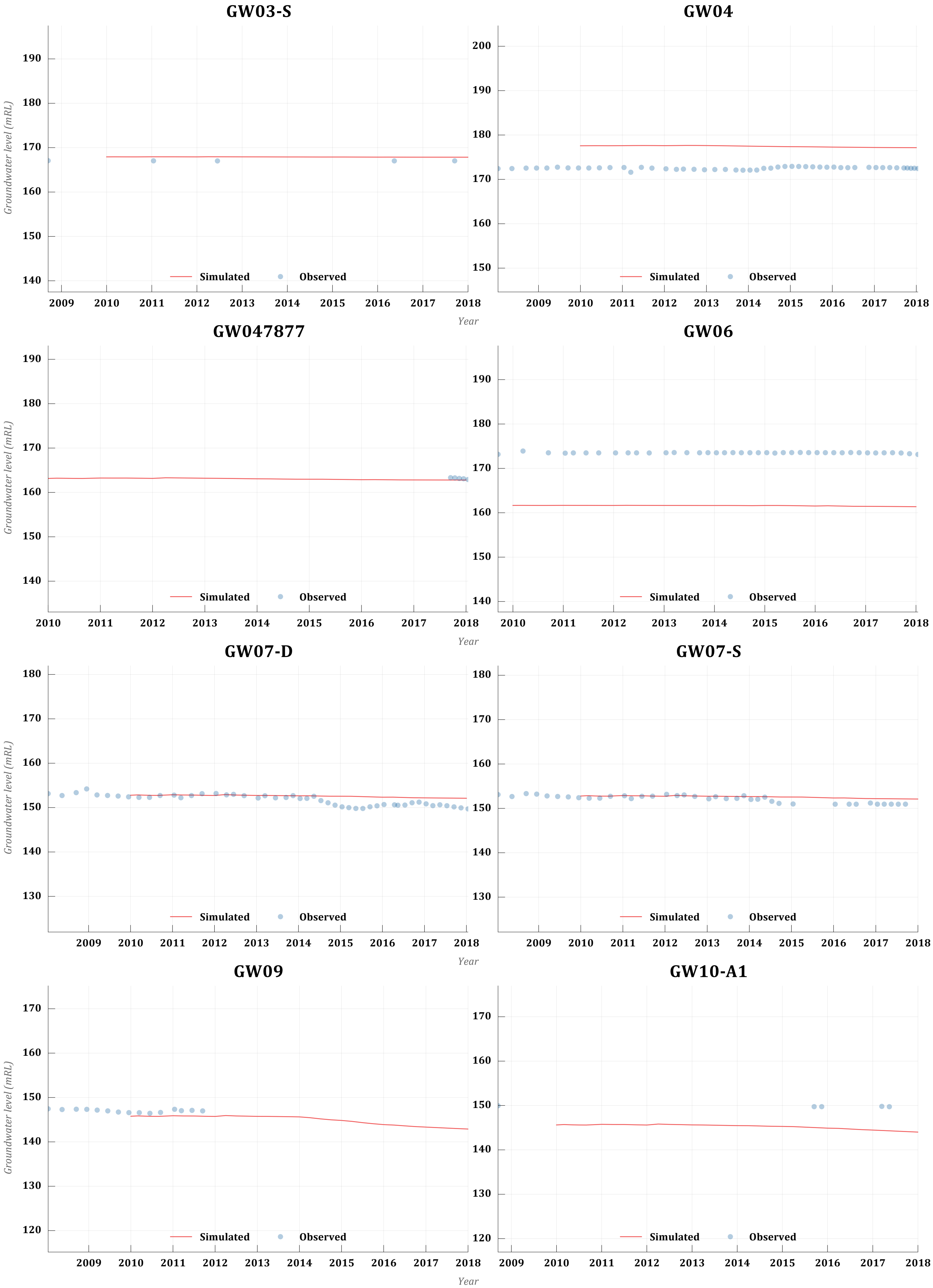
BFC05A

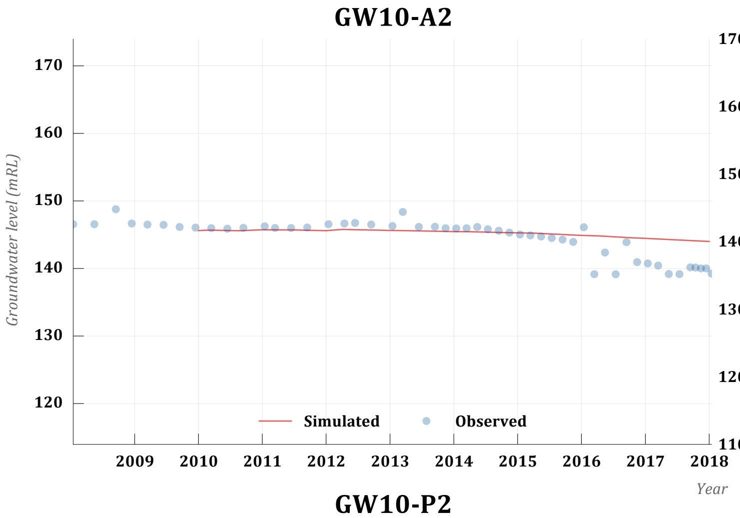


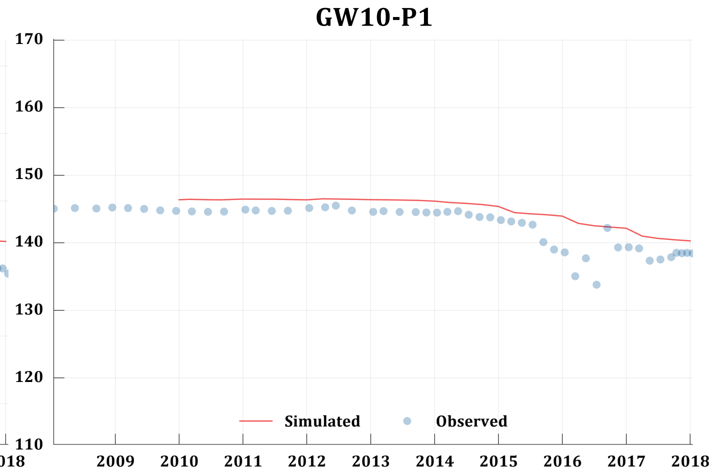
BFC06A

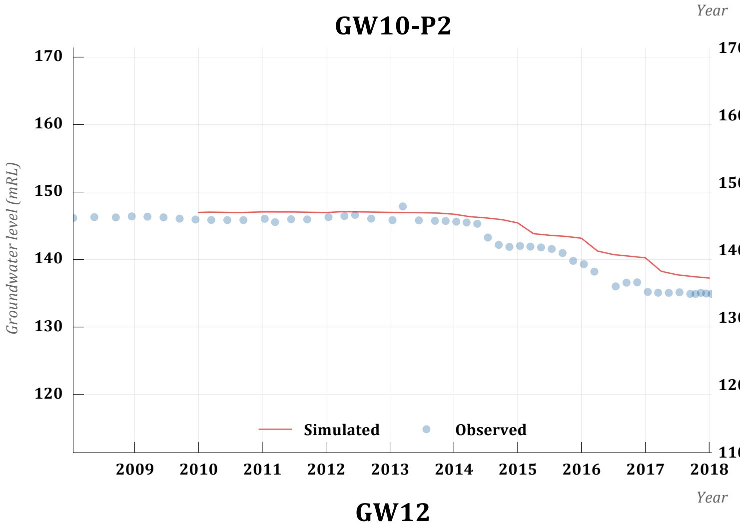


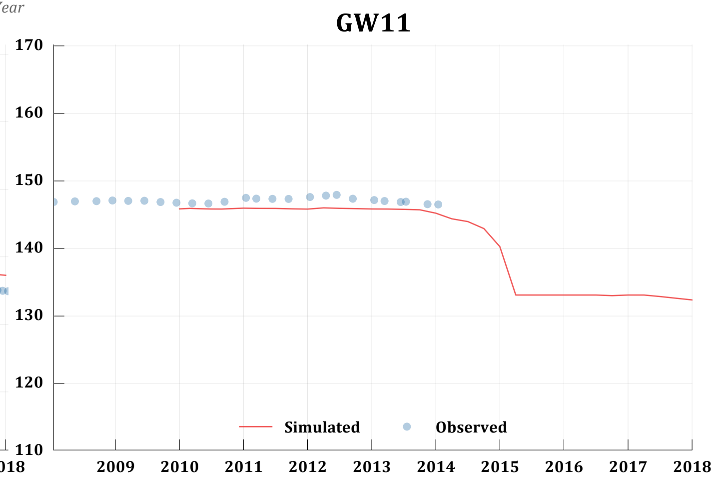

BFC07A
BFC07B
BFC08A
BFC08B
GW01-D
GW01-S
GW02
GW03-D
Groundwater level (mRL)
Year
Simulated
Observed

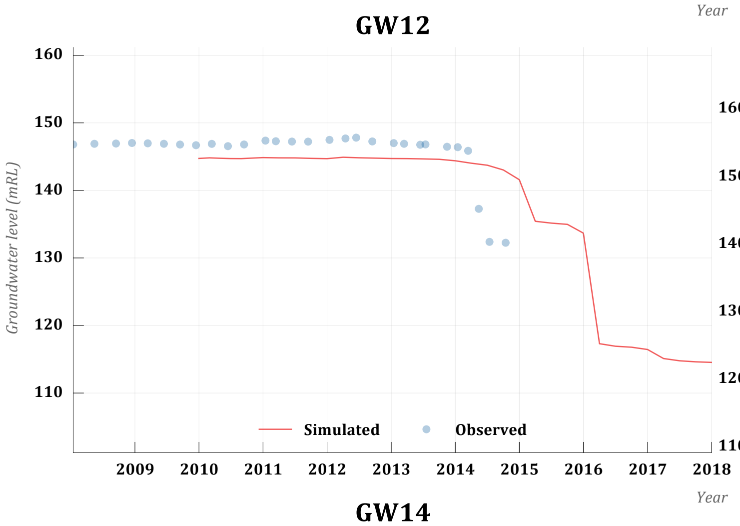

GW03-S
GW04
GW047877
GW06
GW07-D
GW07-S
GW09
GW10-A1
Groundwater level (mRL)
Year
Simulated
Observed
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018

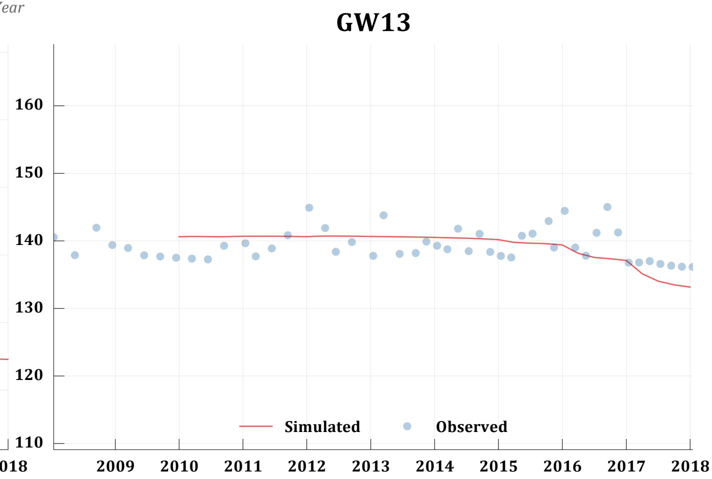

GW10-A2
Groundwater level (mRL)
120
130
140
150
160
170
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Simulated
Observed

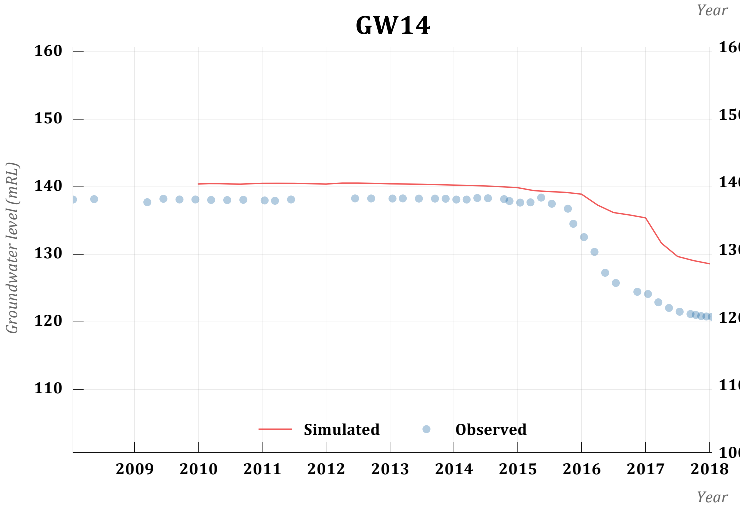

GW10-P1
110
120
130
140
150
160
170
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Simulated
Observed

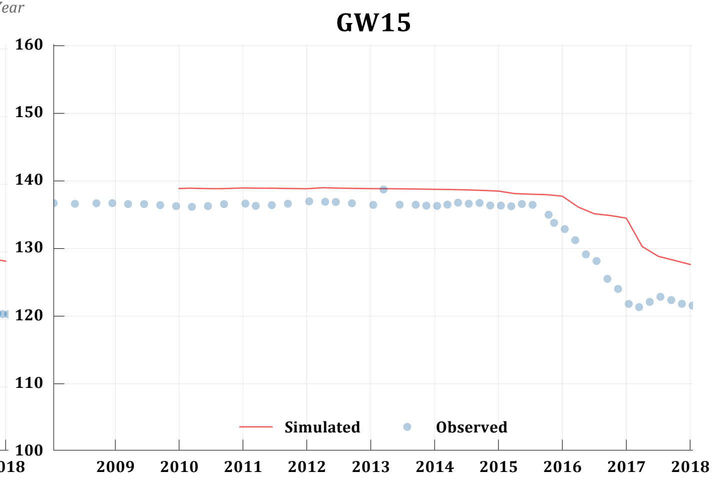

GW10-P2
Groundwater level (mRL)
120
130
140
150
160
170
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Simulated
Observed


GW11
110
120
130
140
150
160
170
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Simulated
Observed

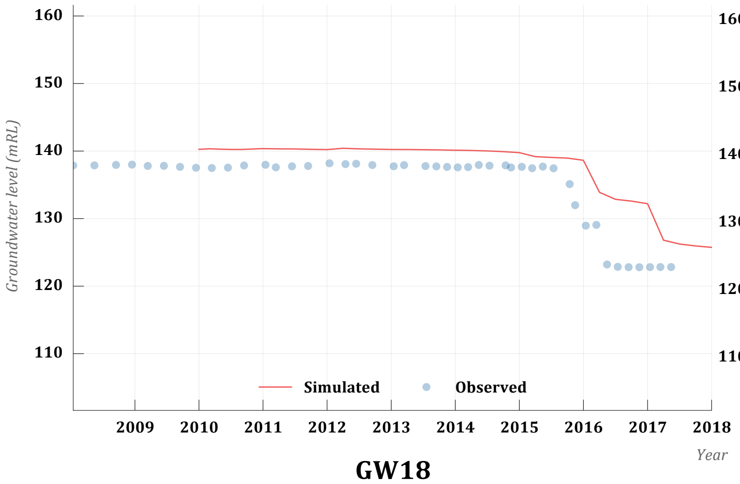

GW12
Groundwater level (mRL)
110
120
130
140
150
160
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Simulated
Observed


GW13
110
120
130
140
150
160
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Simulated
Observed

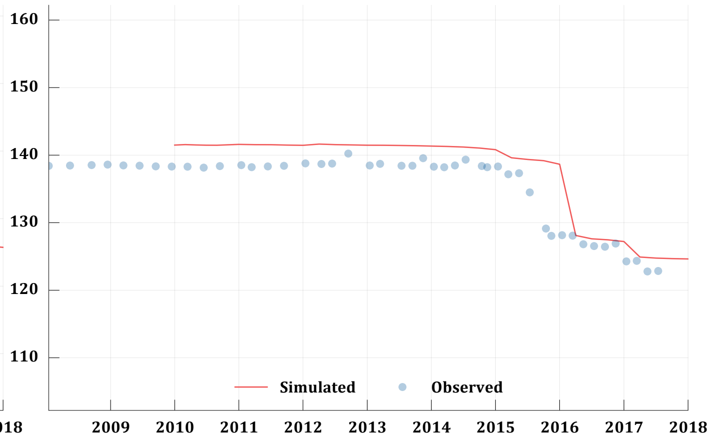

GW14
Groundwater level (mRL)
110
120
130
140
150
160
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year
Simulated
Observed


GW15
100
110
120
130
140
150
160
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Simulated
Observed

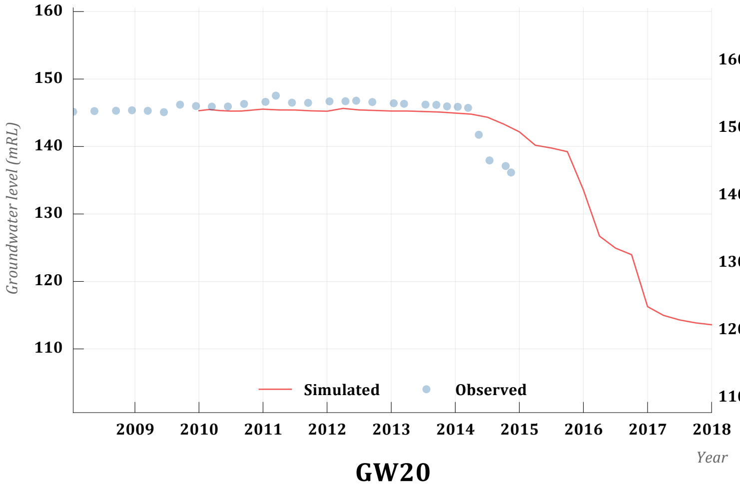
GW16



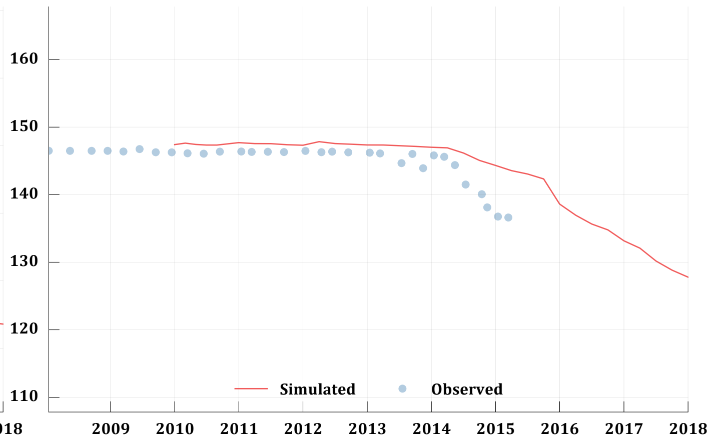
GW17



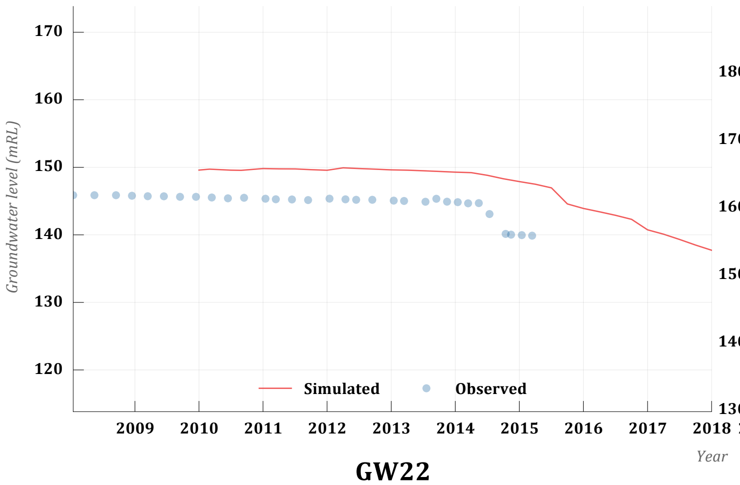
GW18



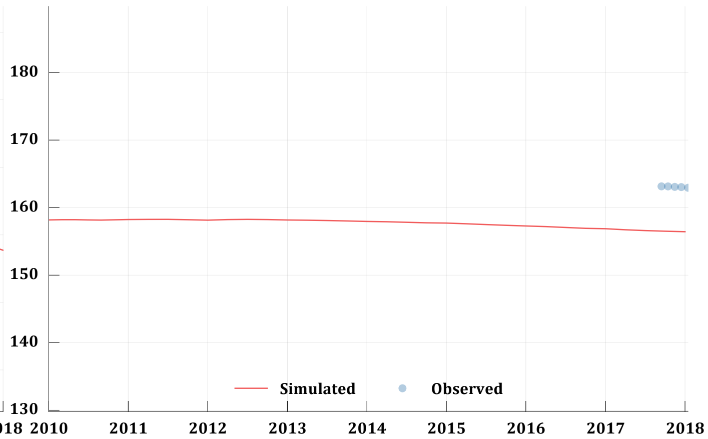
GW19



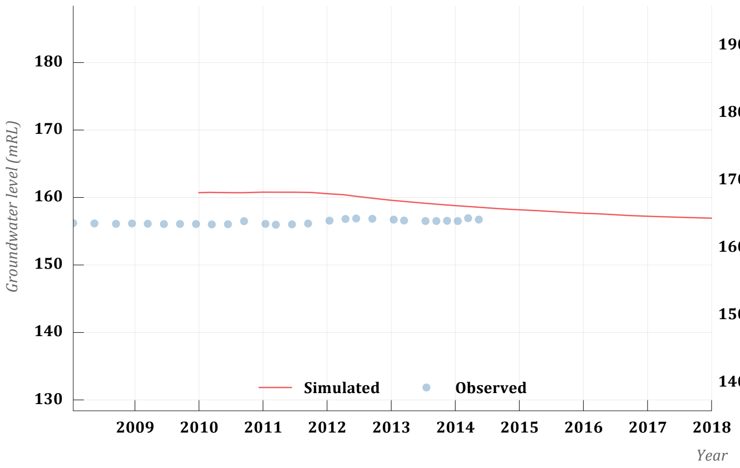
GW20



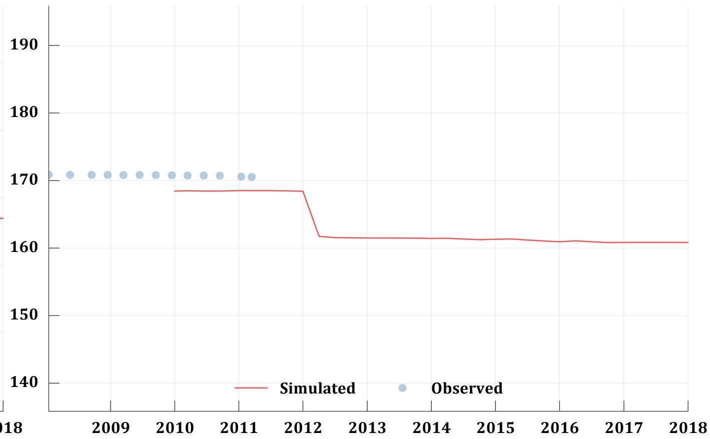
GW202249

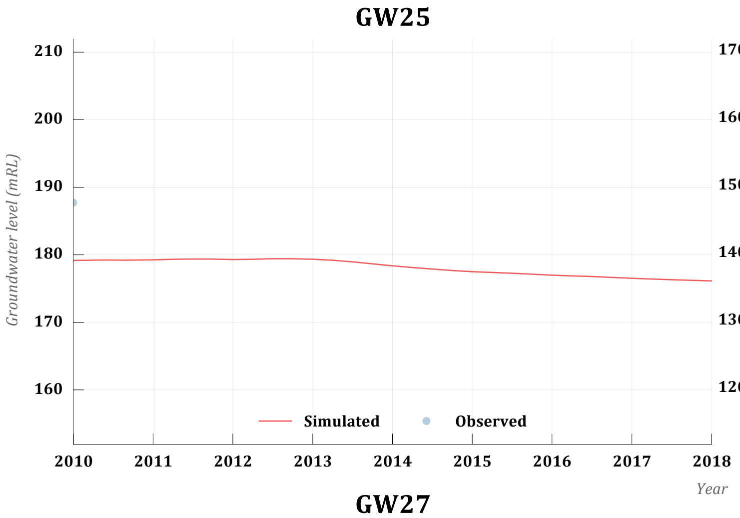


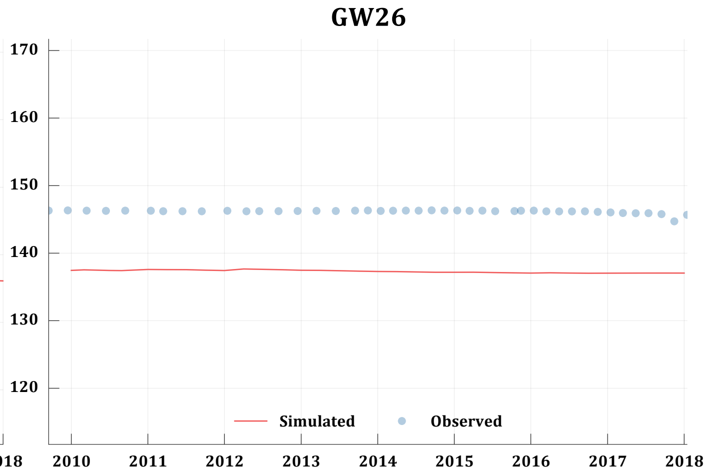
GW22

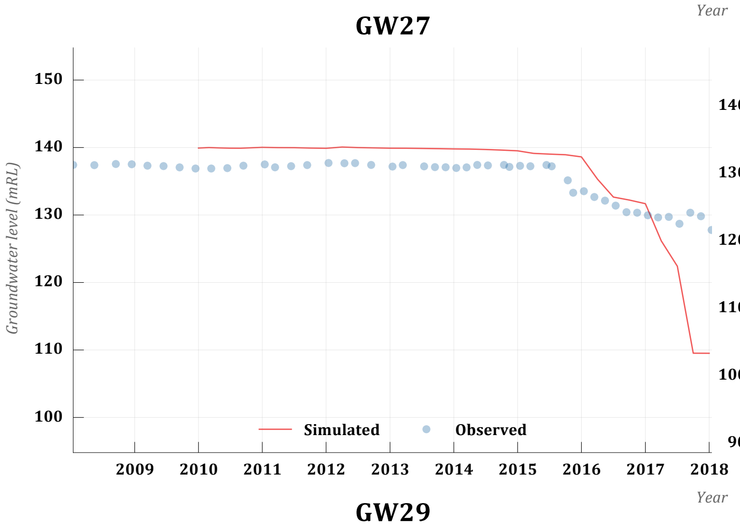


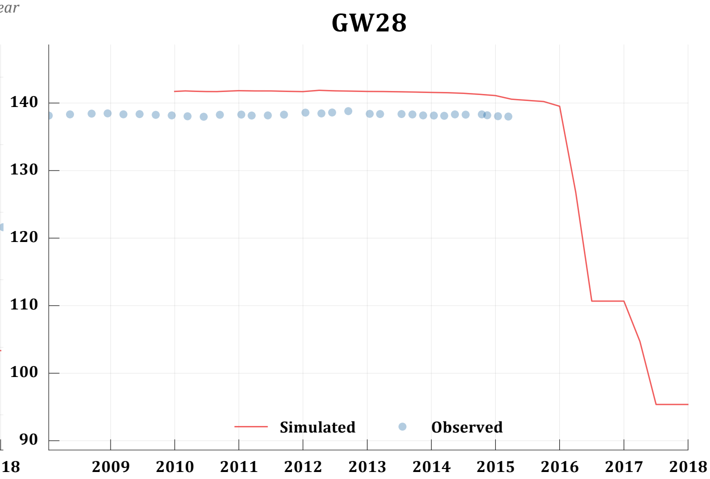
GW23

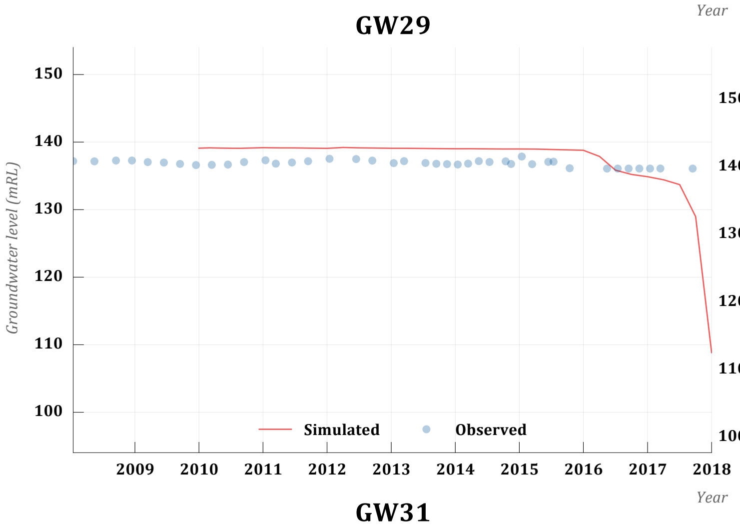


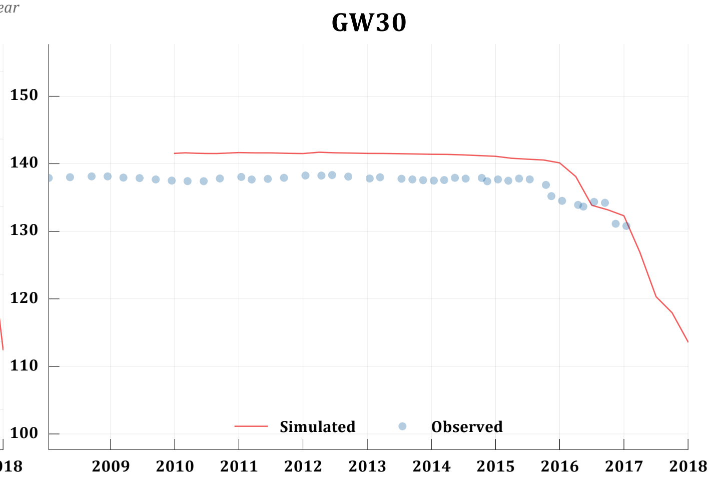

GW25
210
200
190
180
170
160
Groundwater level (mRL)
Simulated
Observed
2010 2011 2012 2013 2014 2015 2016 2017 2018
Year

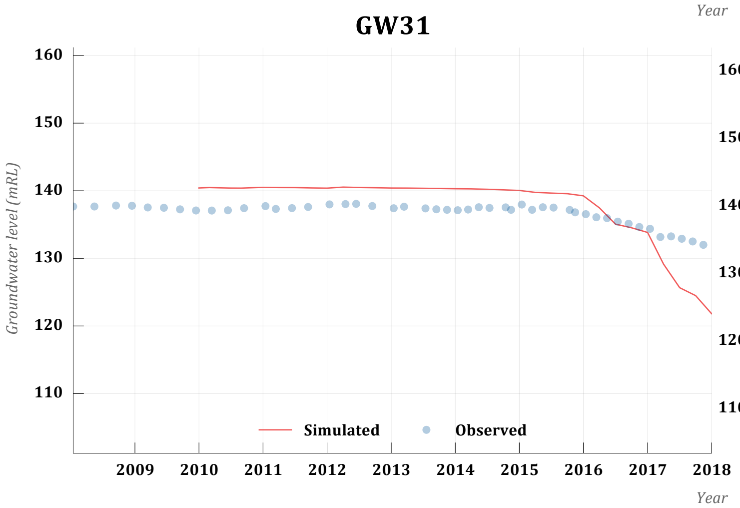

GW26
170
160
150
140
130
120
Simulated
Observed
2010 2011 2012 2013 2014 2015 2016 2017 2018

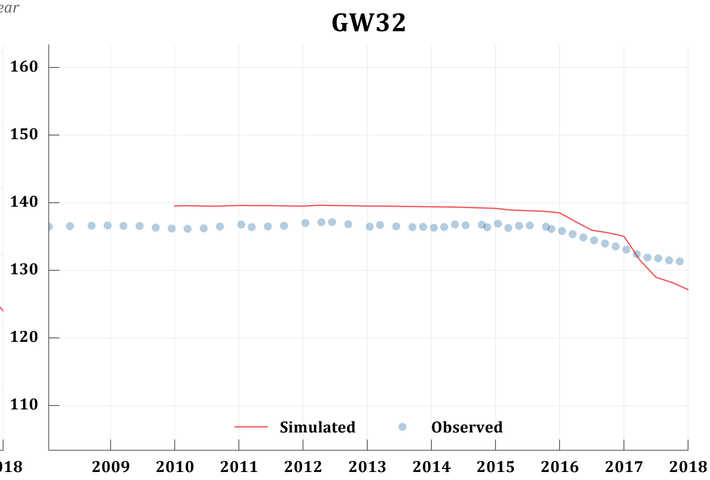

GW27
150
140
130
120
110
100
Groundwater level (mRL)
Simulated
Observed
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year


GW28
140
130
120
110
100
90
Simulated
Observed
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018

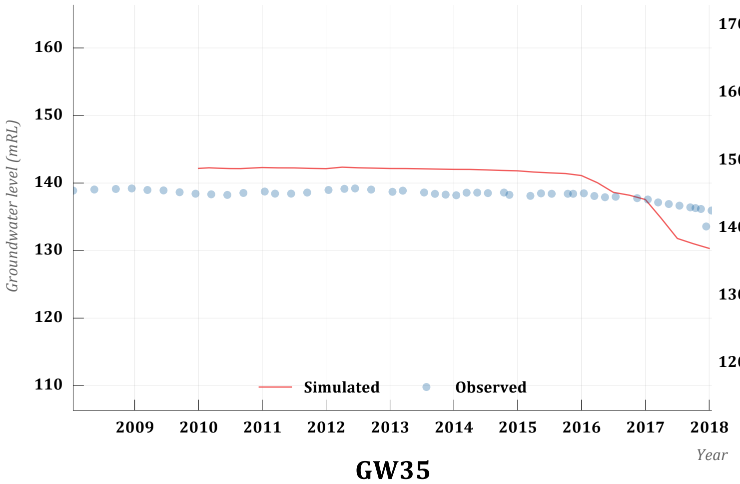

GW29
150
140
130
120
110
100
Groundwater level (mRL)
Simulated
Observed
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year


GW30
150
140
130
120
110
100
Simulated
Observed
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018

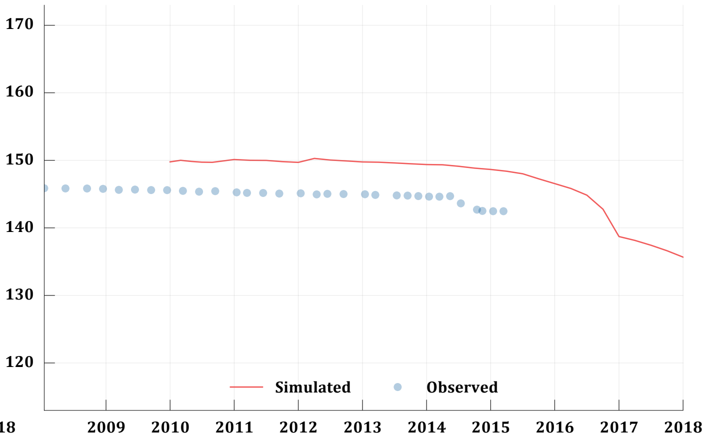

GW31
160
150
140
130
120
110
Groundwater level (mRL)
Simulated
Observed
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year


GW32
160
150
140
130
120
110
Simulated
Observed
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018

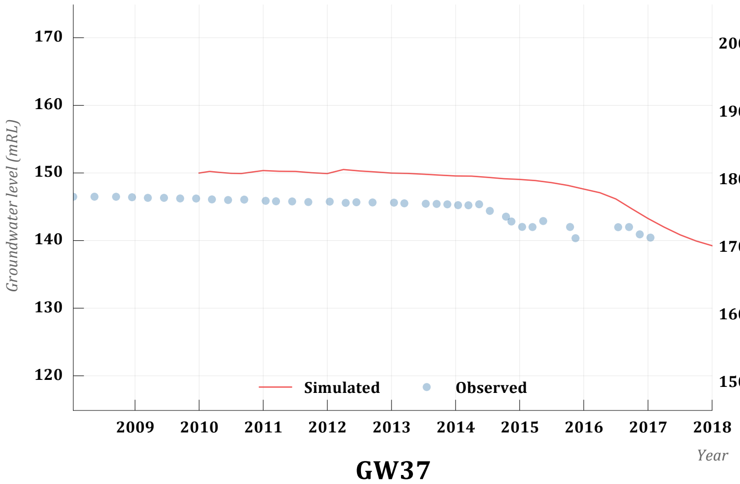
GW33



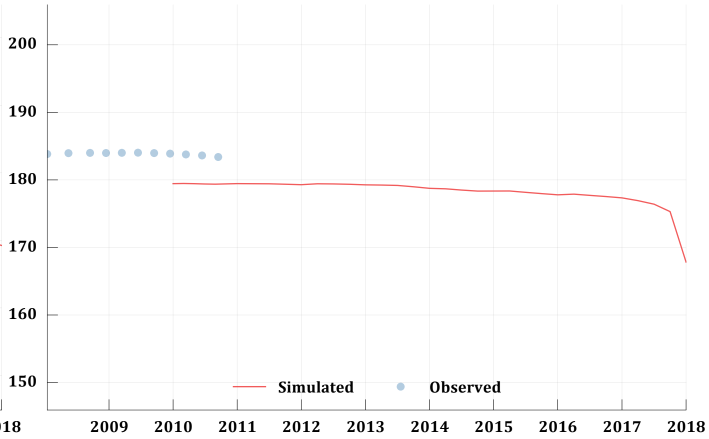
GW34



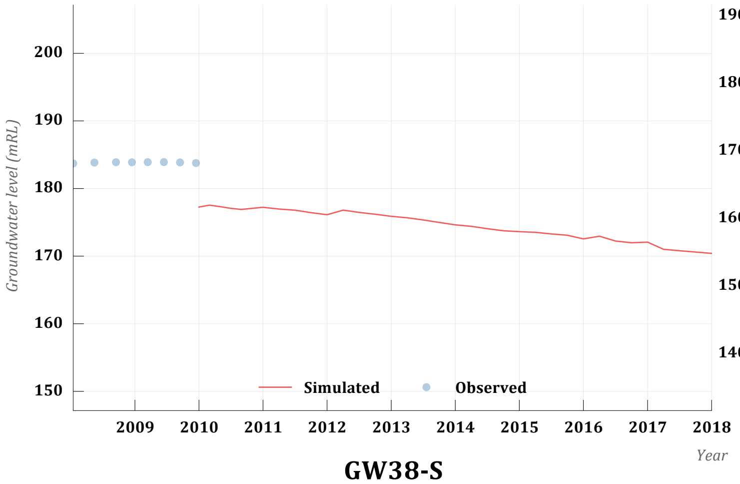
GW35



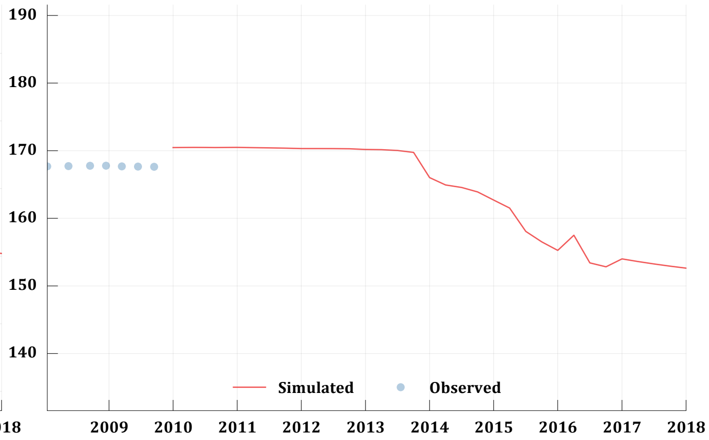
GW36



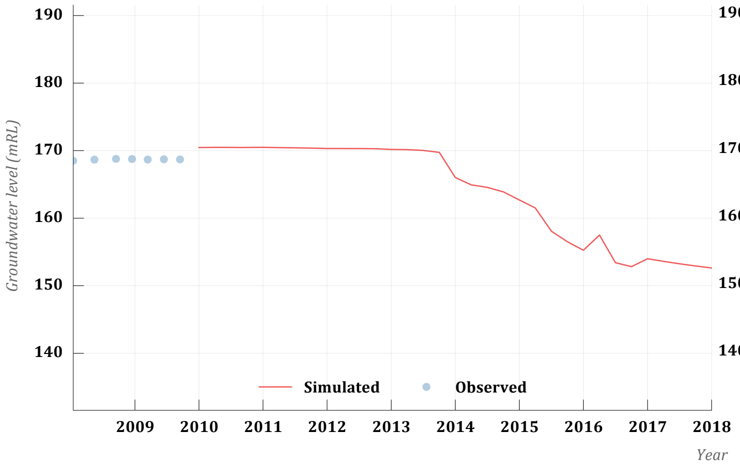
GW37



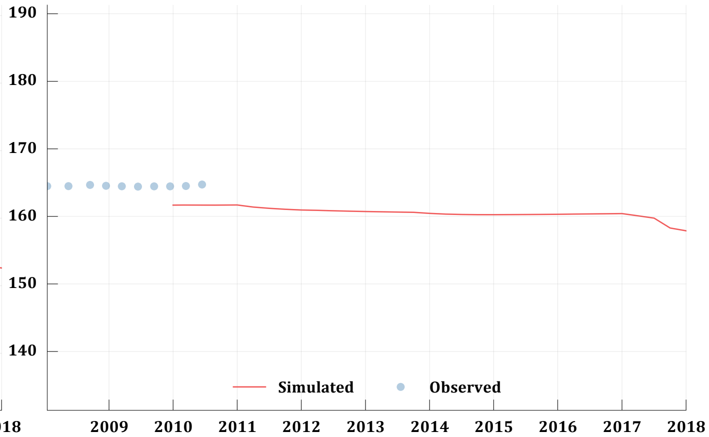
GW38-D



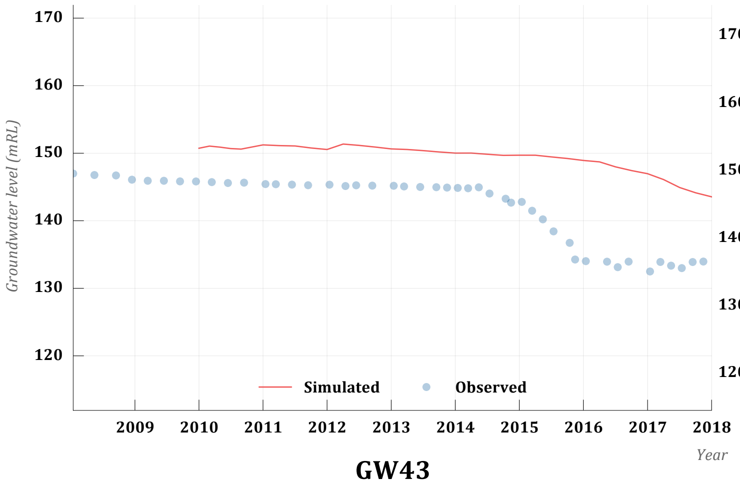
GW38-S



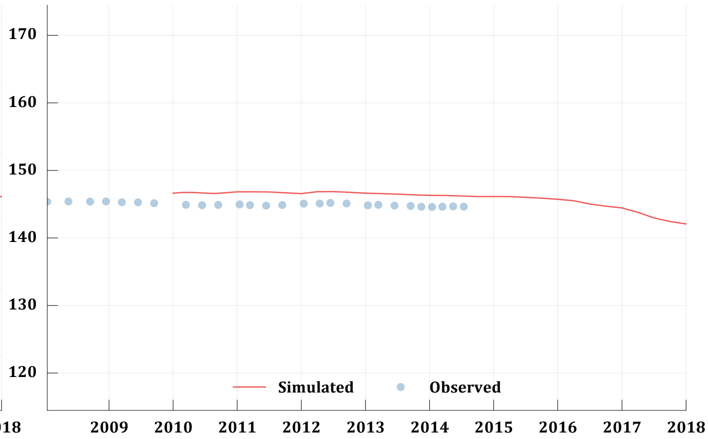
GW39



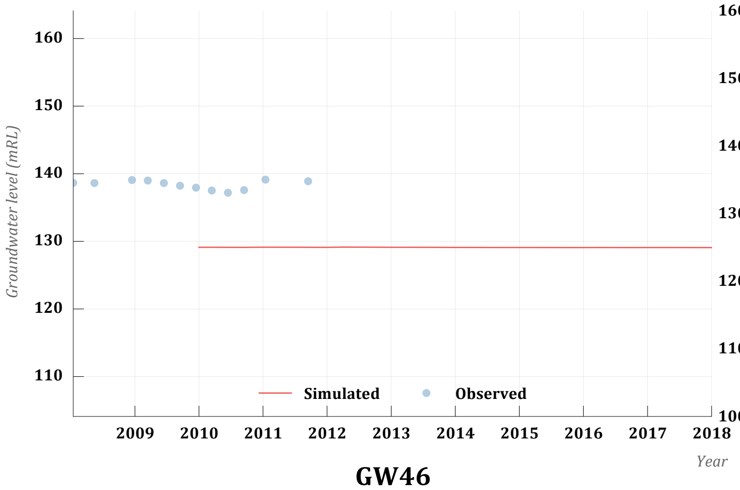
GW40



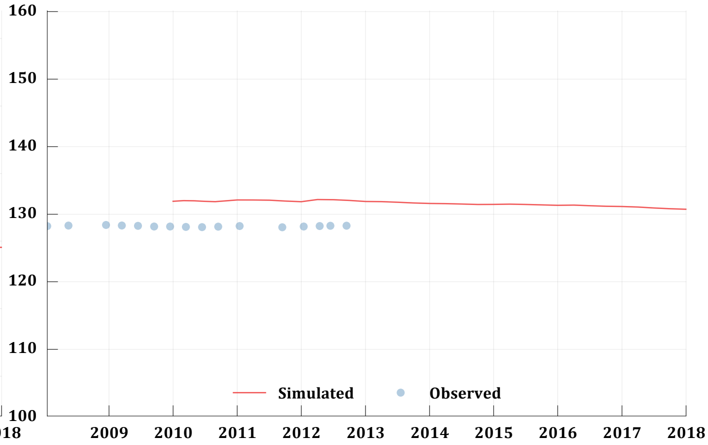
GW41



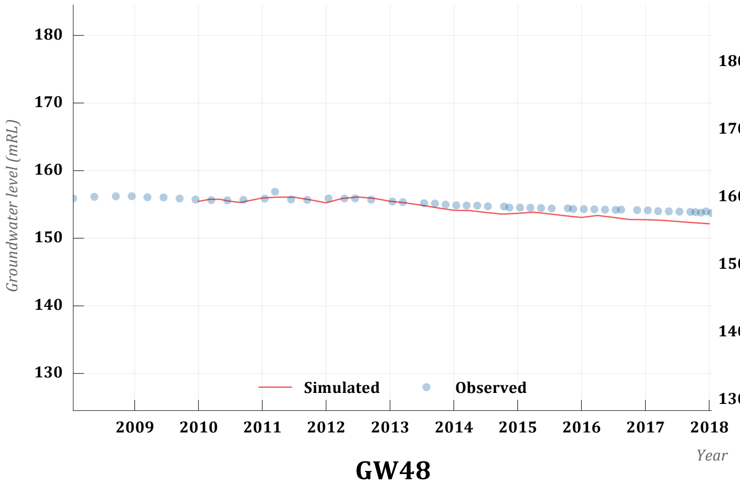
GW43



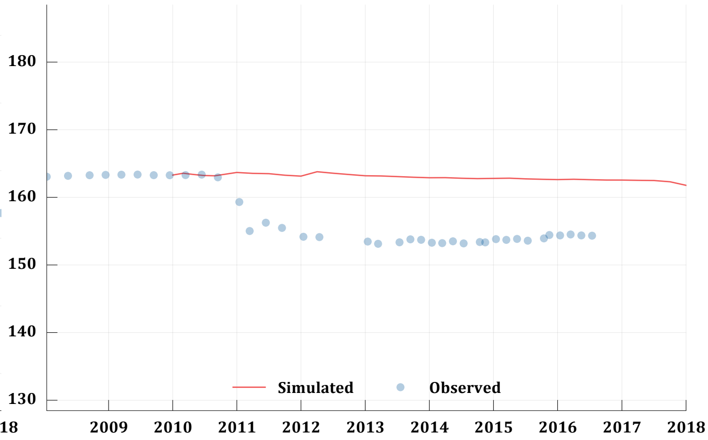
GW44



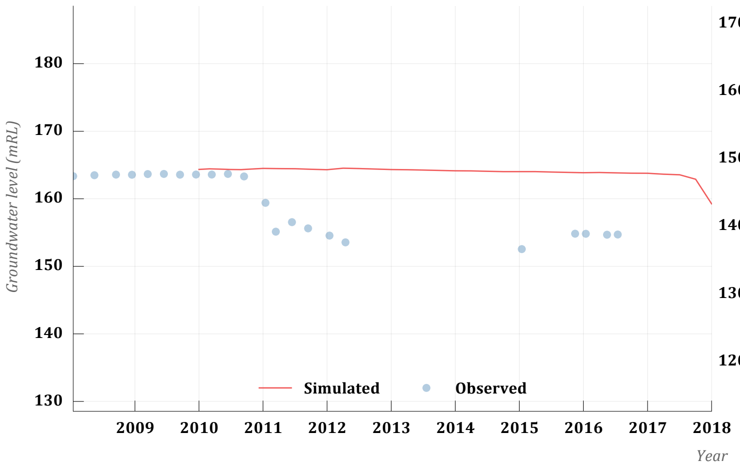
GW46



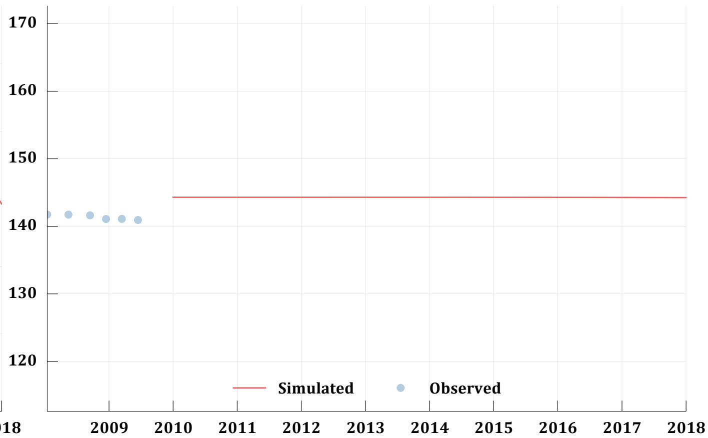
GW47



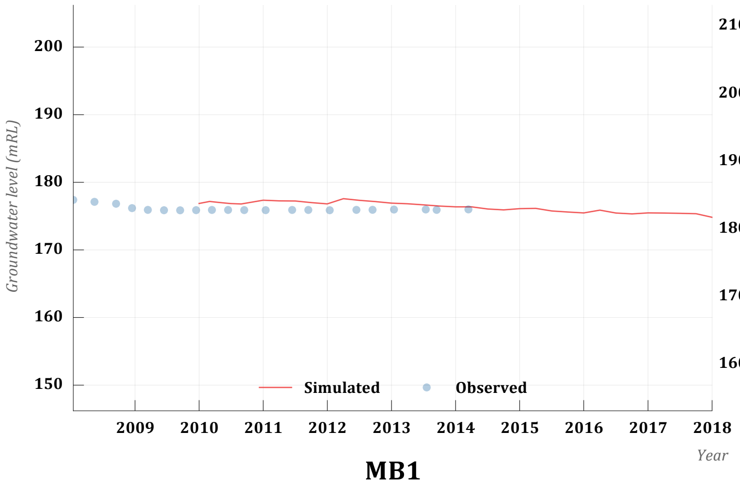
GW48



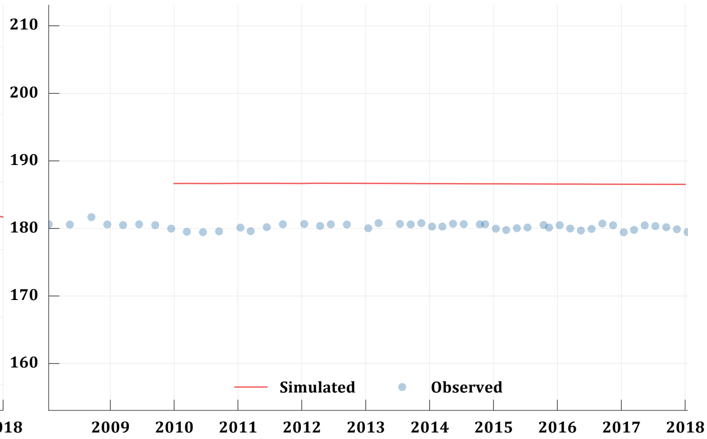
GW49



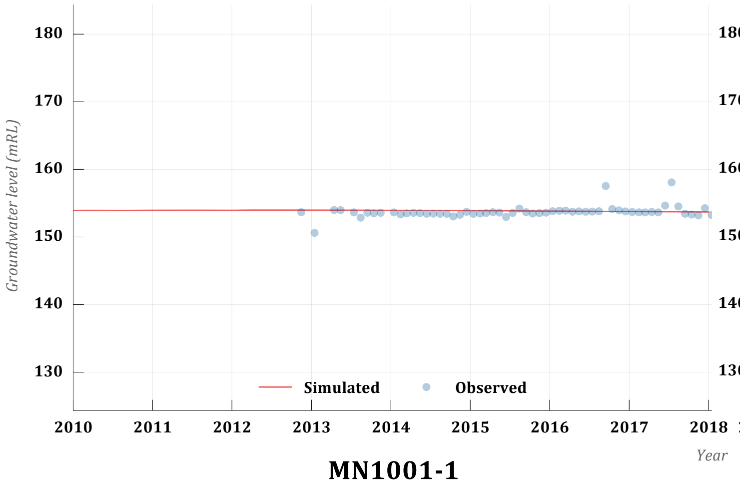
GW50



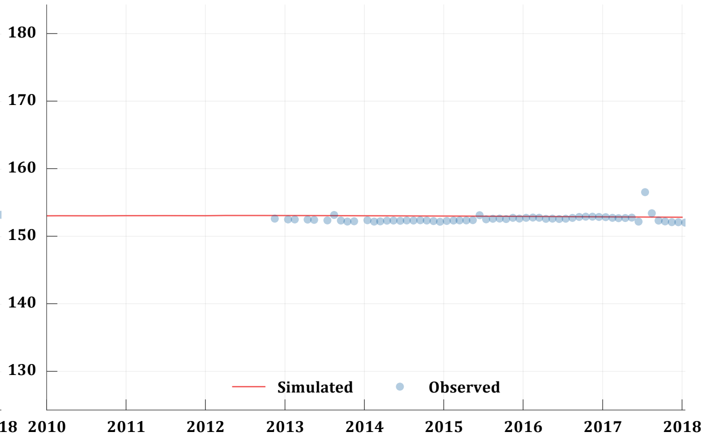
JENNAR_WL



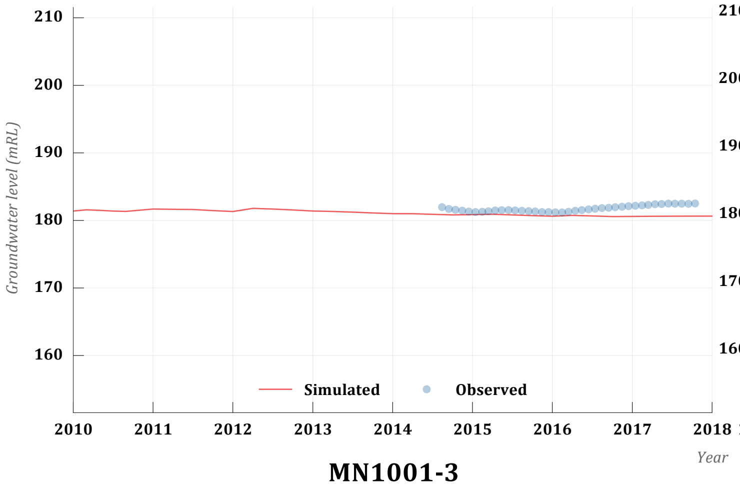
MB1



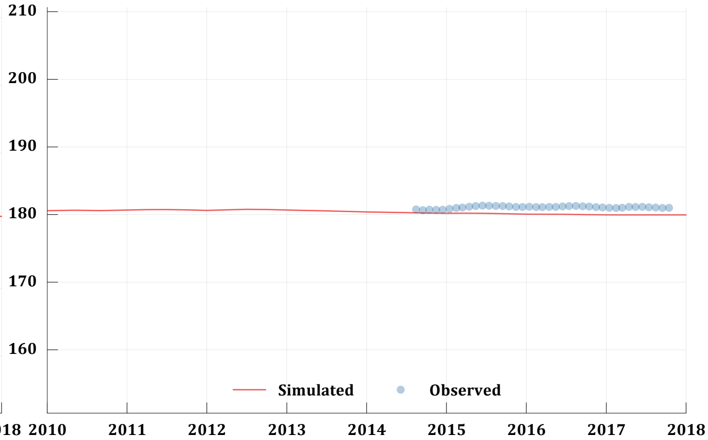
MB2



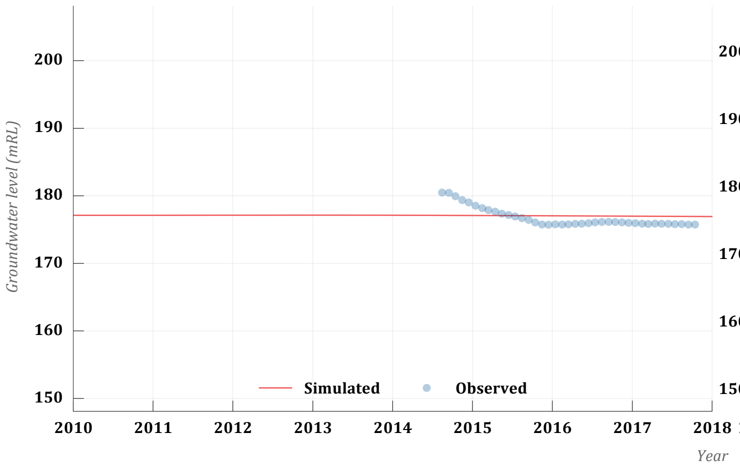
MN1001-1



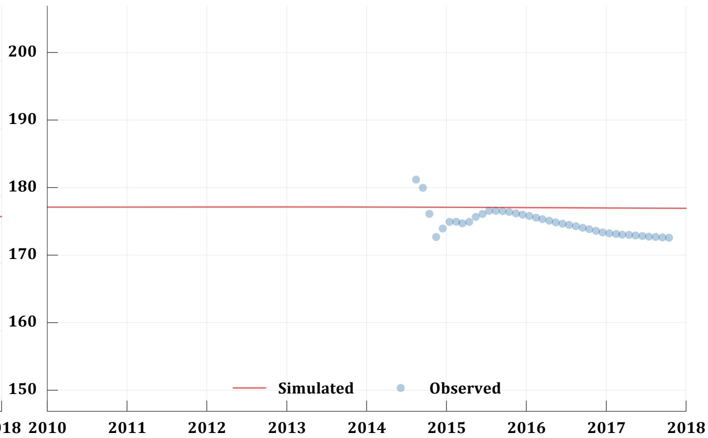
MN1001-2

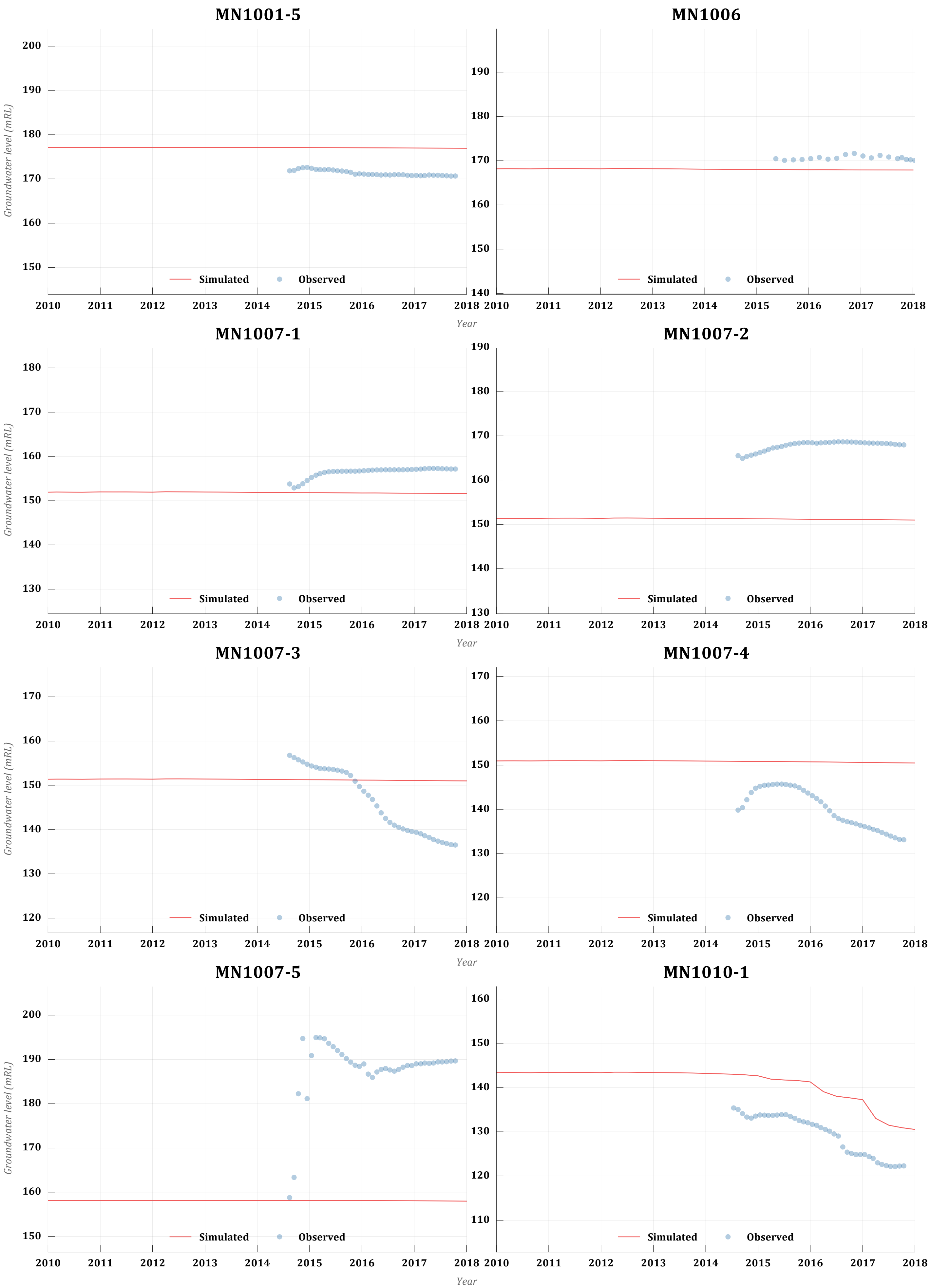


MN1001-3

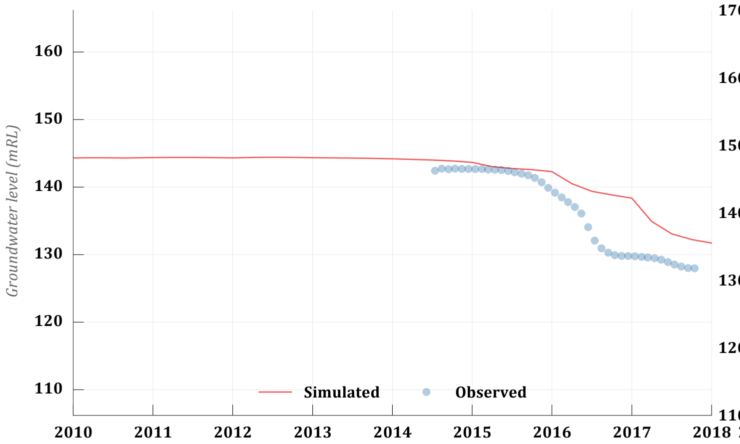


MN1001-4

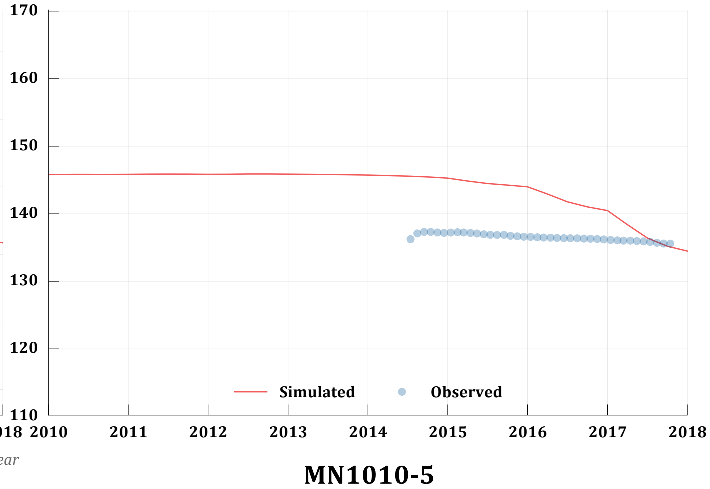



MN1001-5
MN1006
MN1007-1
MN1007-2
MN1007-3
MN1007-4
MN1007-5
MN1010-1
Groundwater level (mRL)
Year
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018

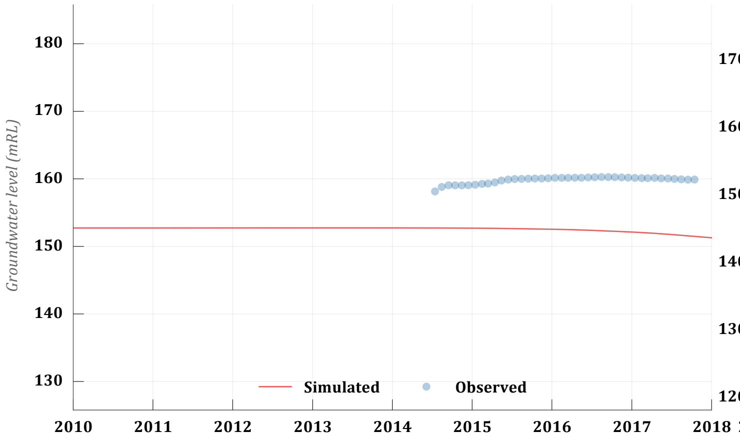
MN1010-2



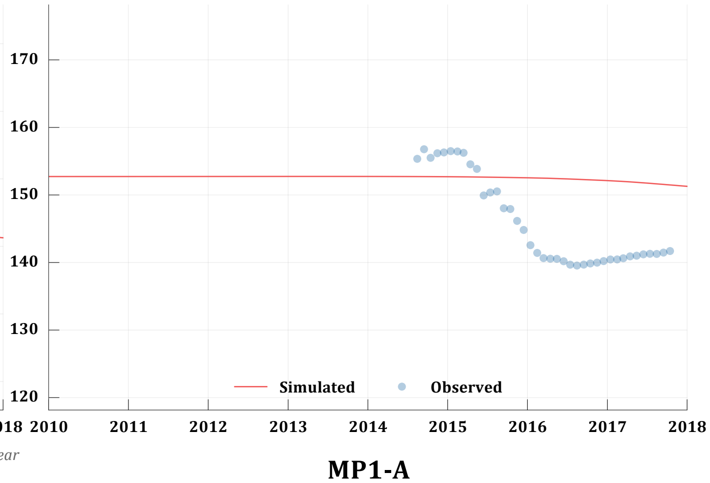
MN1010-3



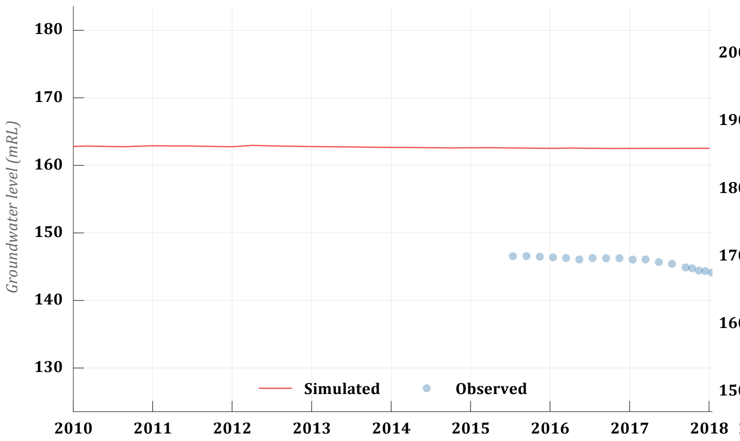
MN1010-4



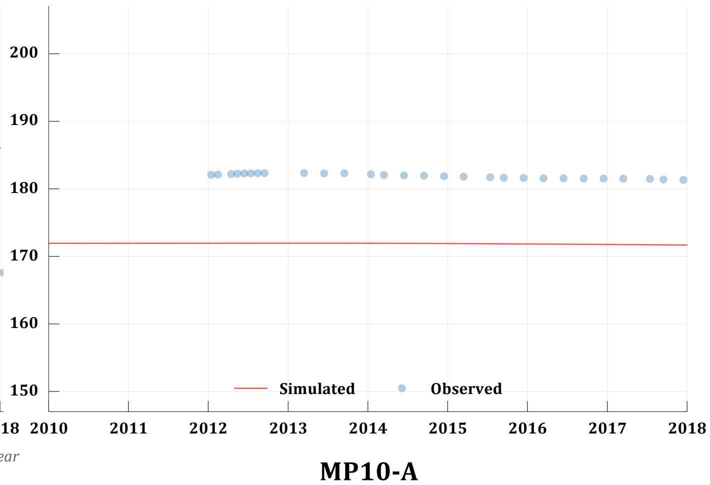
MN1010-5



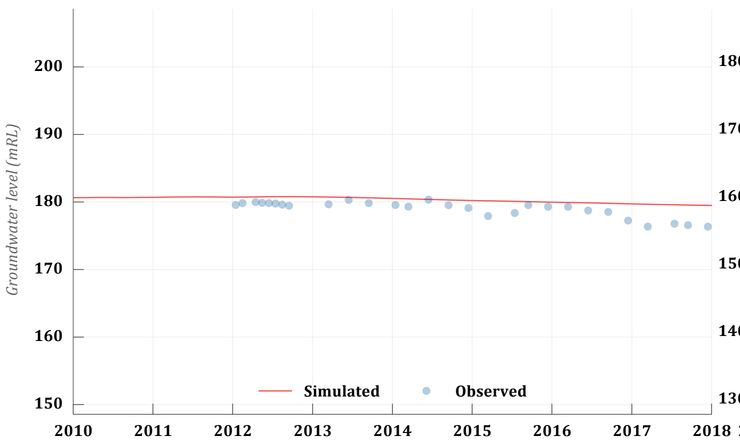
MN1014



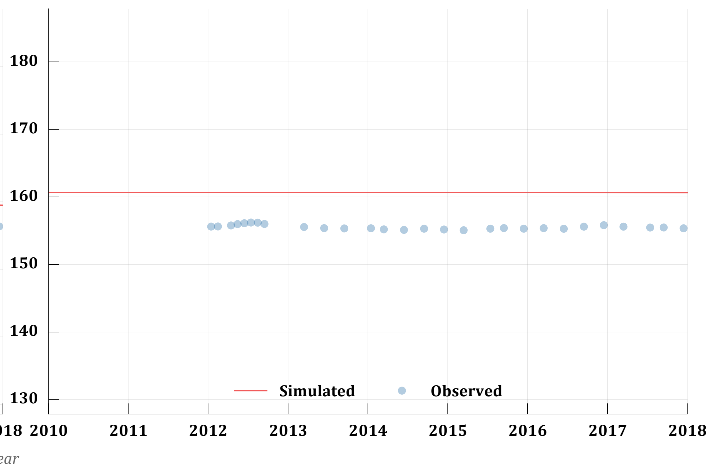
MP1-A



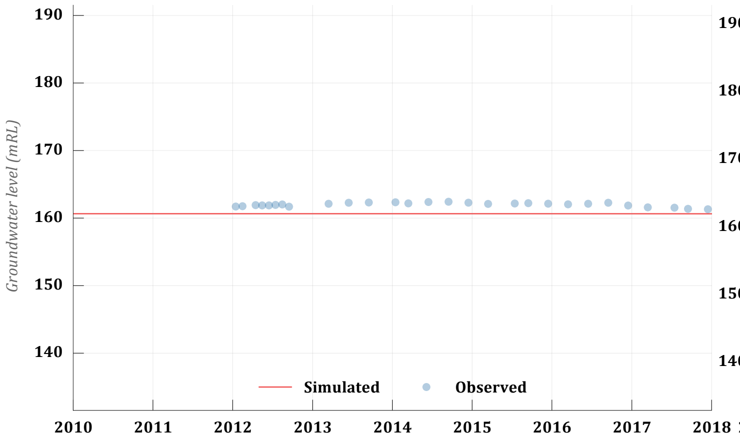
MP1-B



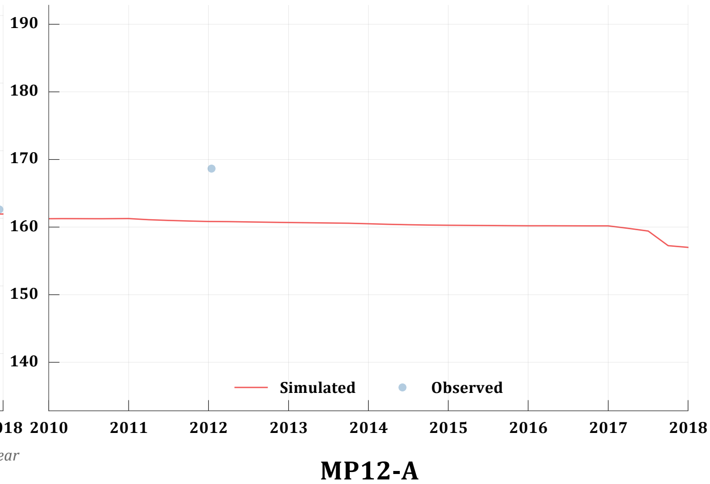
MP10-A



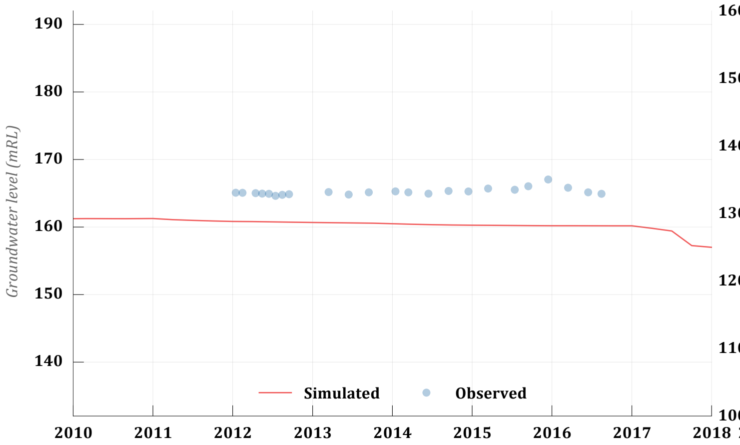
MP10-B



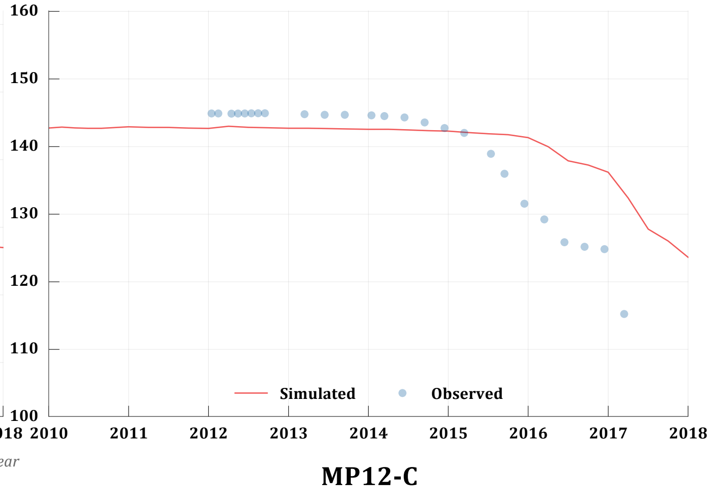
MP11-A



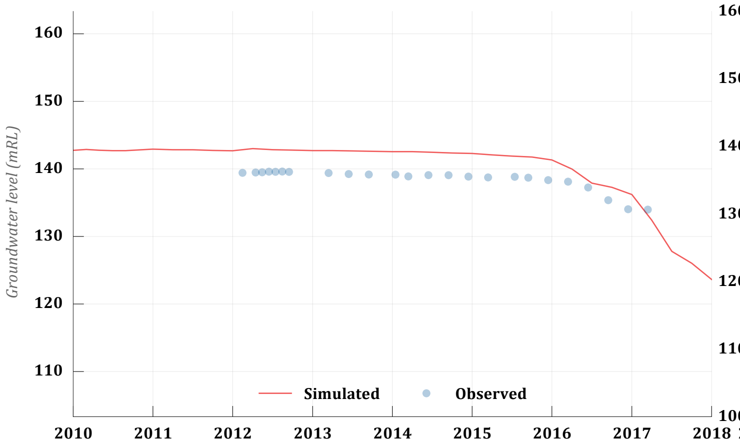
MP11-B



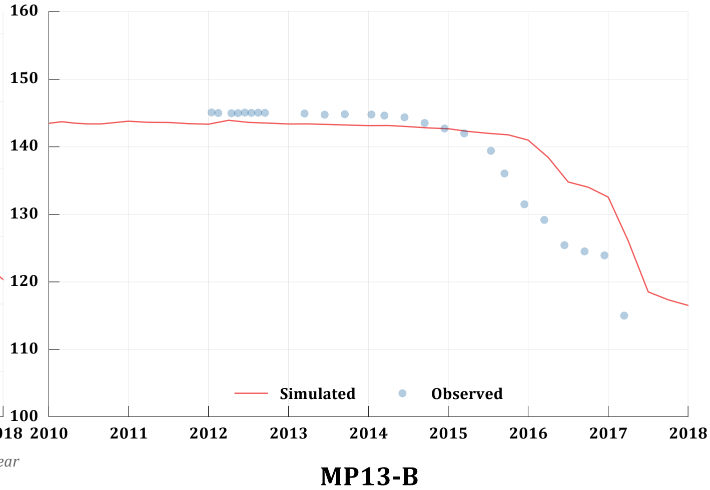
MP12-A



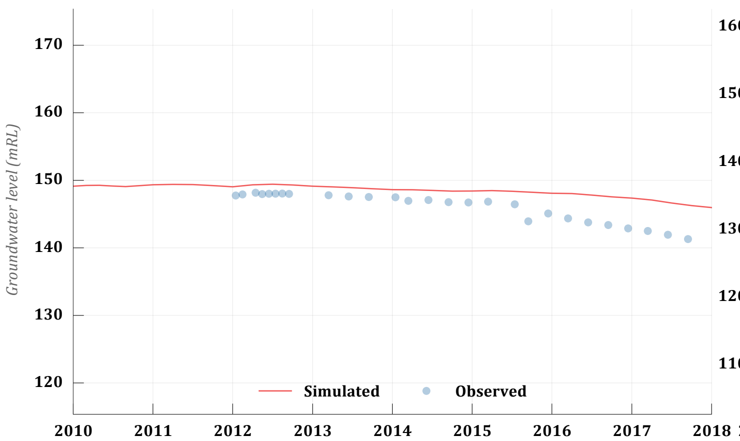
MP12-B



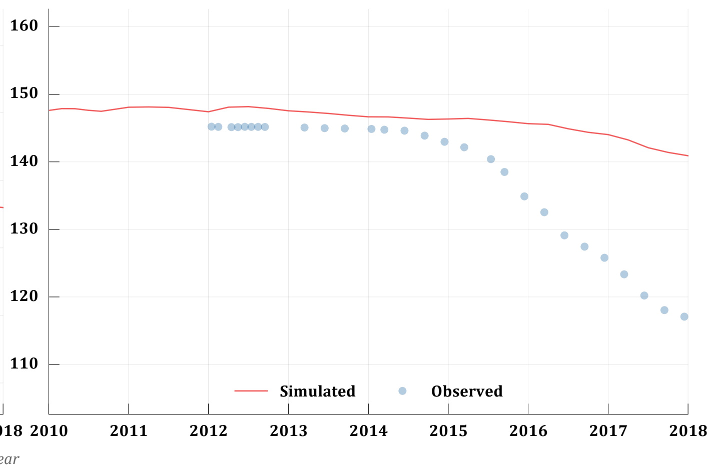
MP12-C



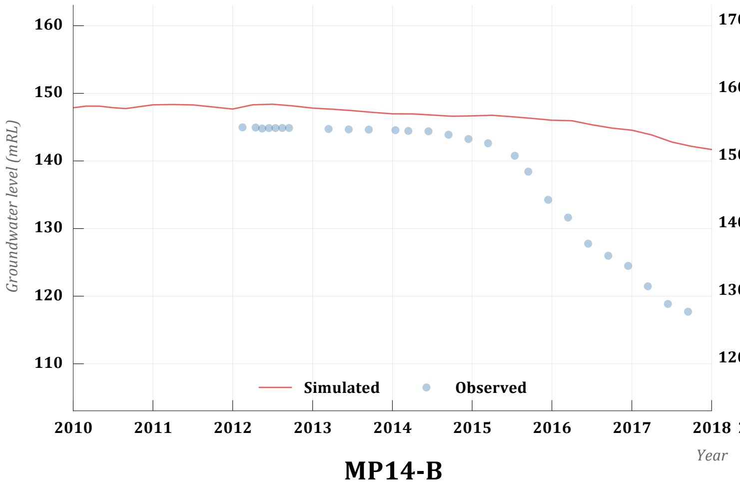
MP13-A



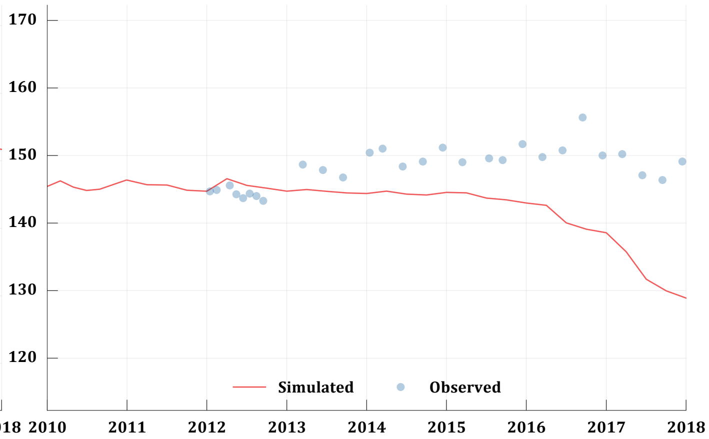
MP13-B



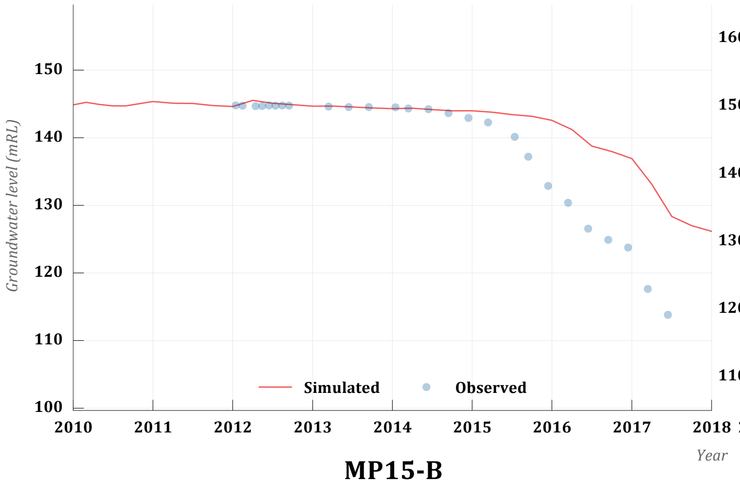
MP13-C



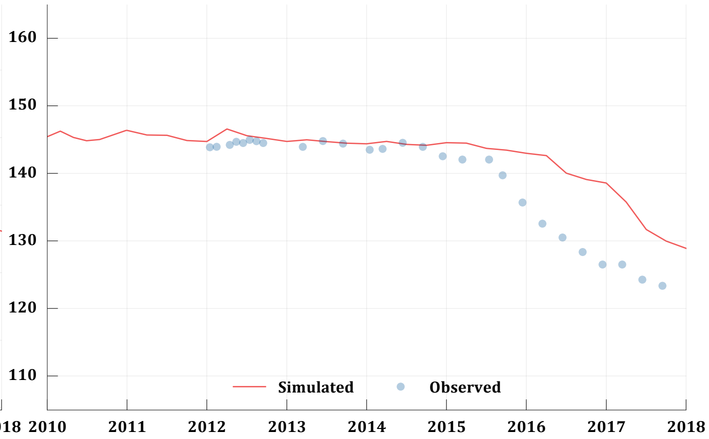
MP14-A



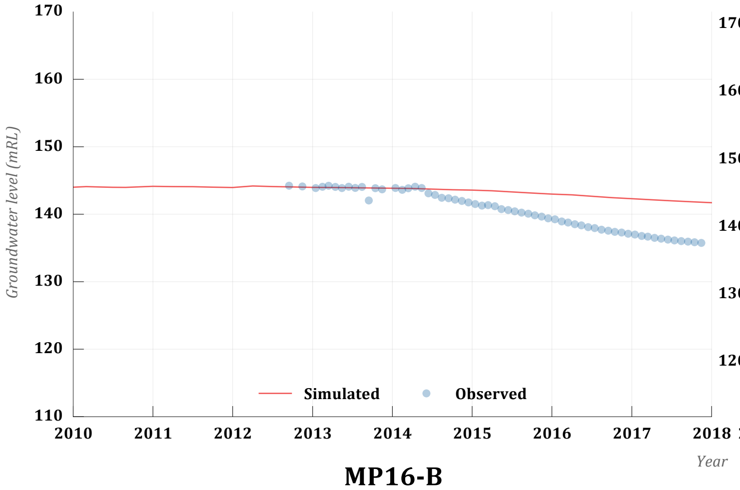
MP14-B



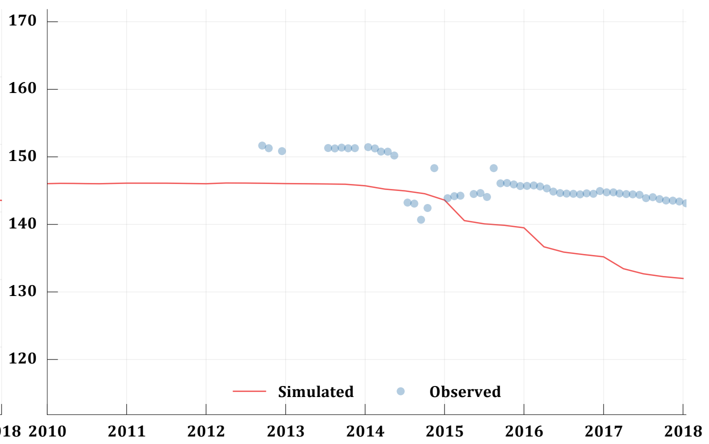
MP14-C



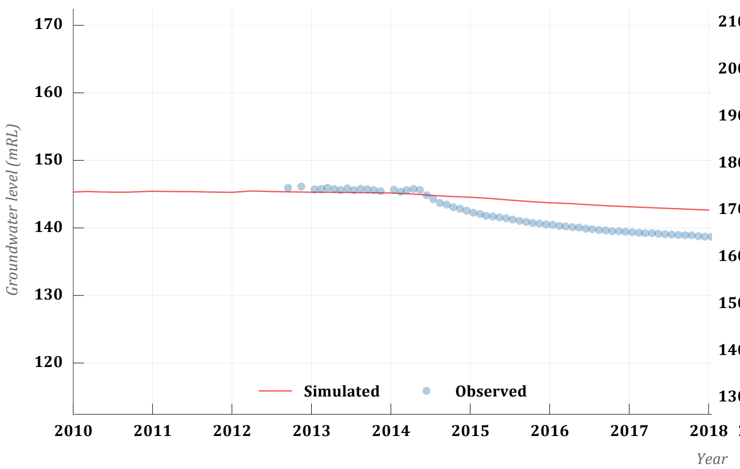
MP15-B



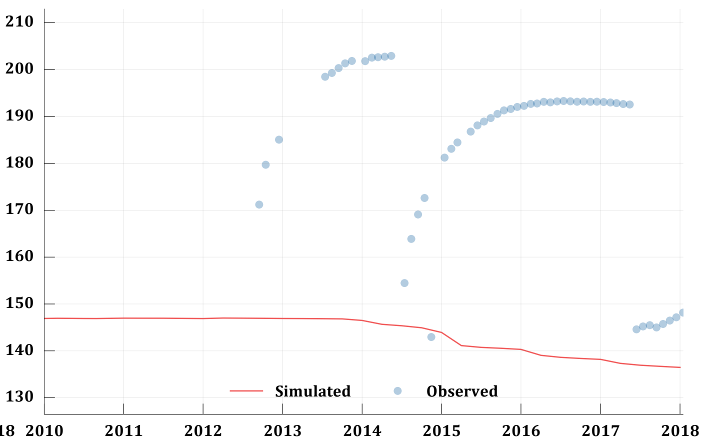
MP15B

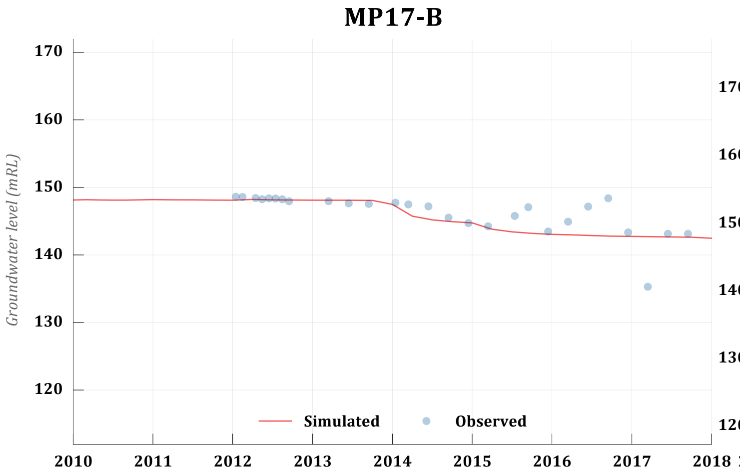


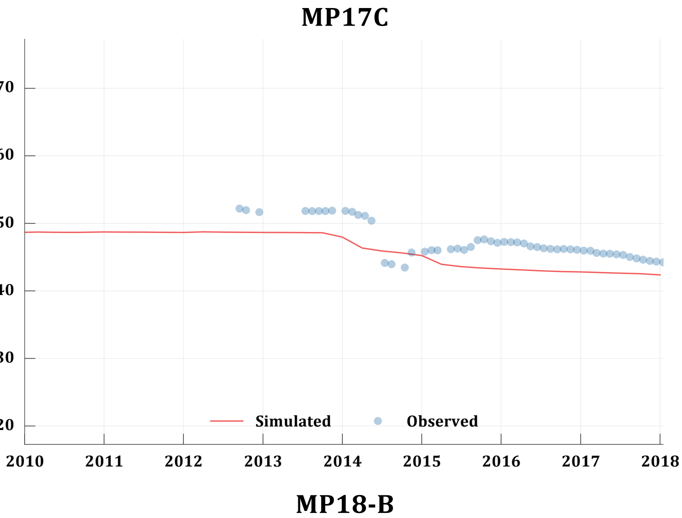
MP16-B

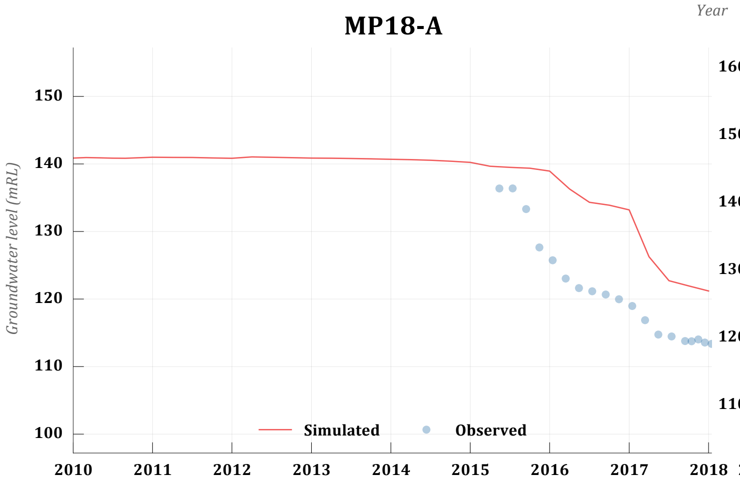


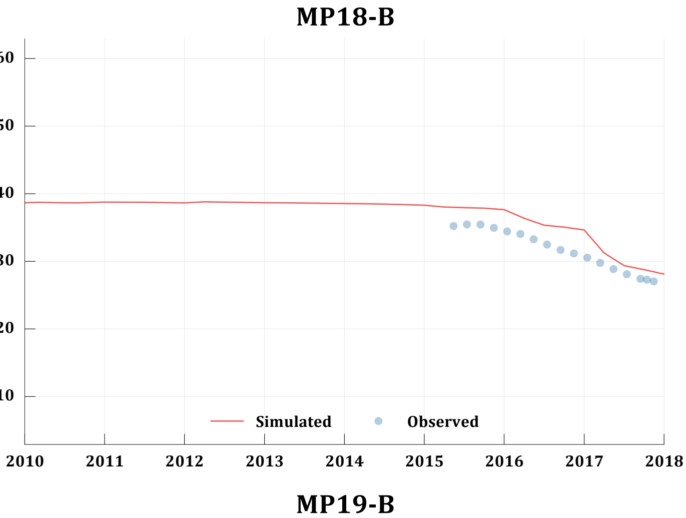
MP16A

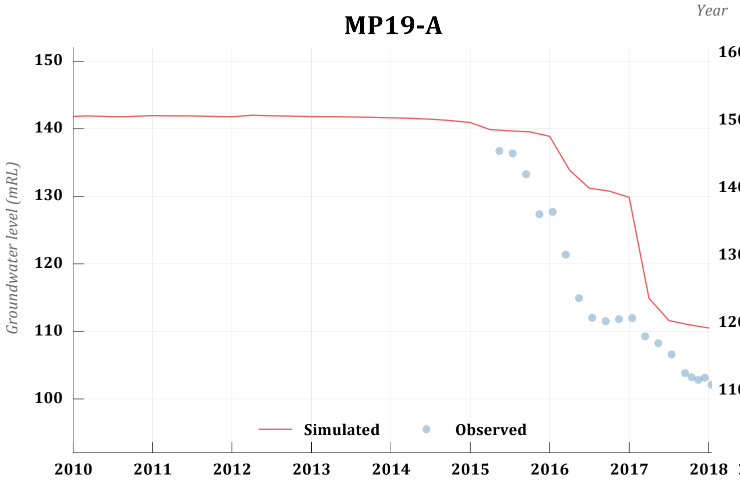


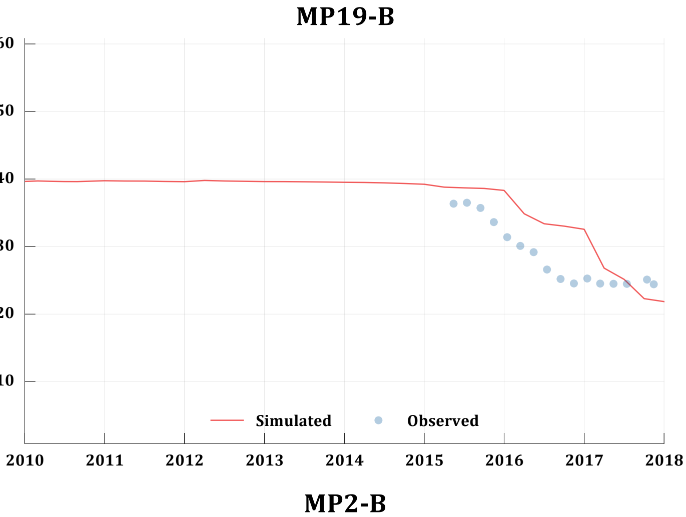

MP17-B
Groundwater level (mRL)
170
160
150
140
130
120
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018

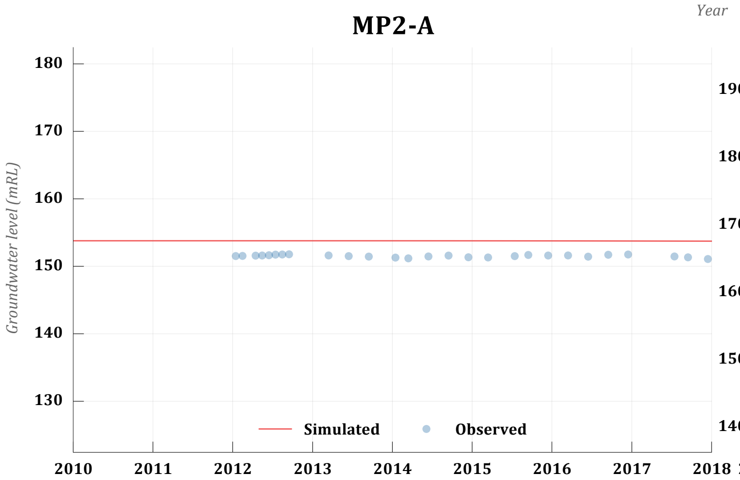

MP17C
170
160
150
140
130
120
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year

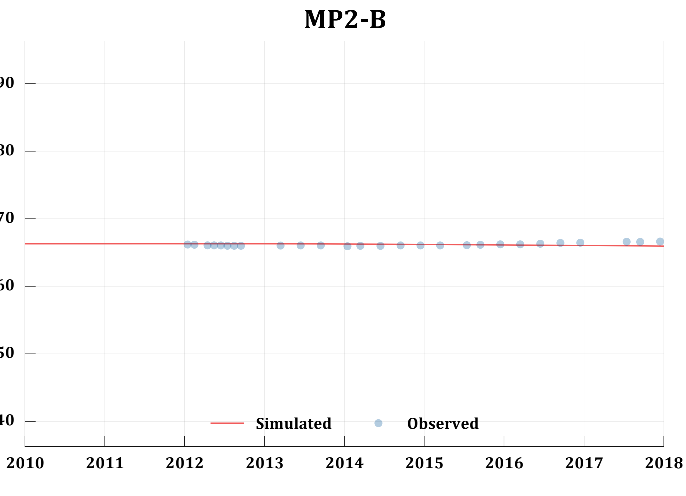

MP18-A
Groundwater level (mRL)
150
140
130
120
110
100
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018

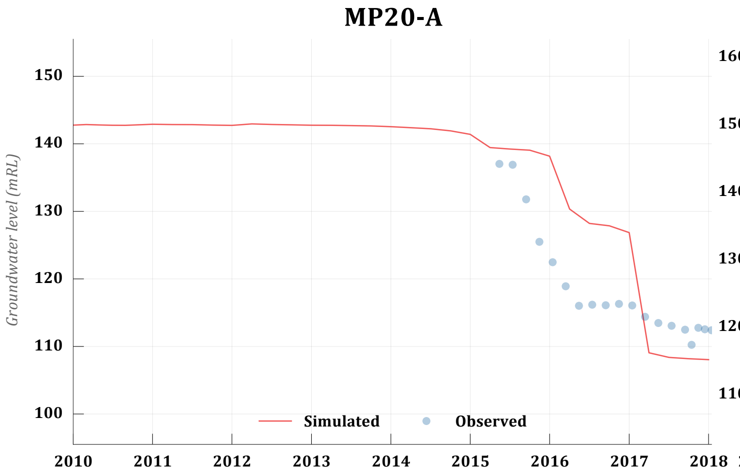

MP18-B
160
150
140
130
120
110
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year

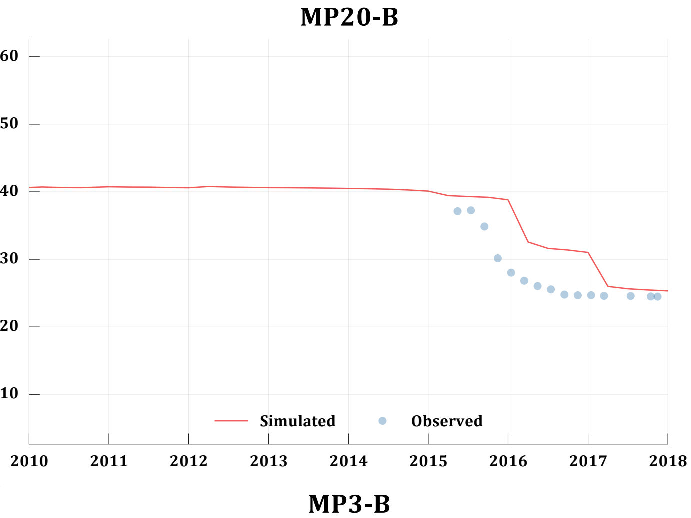

MP19-A
Groundwater level (mRL)
150
140
130
120
110
100
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018

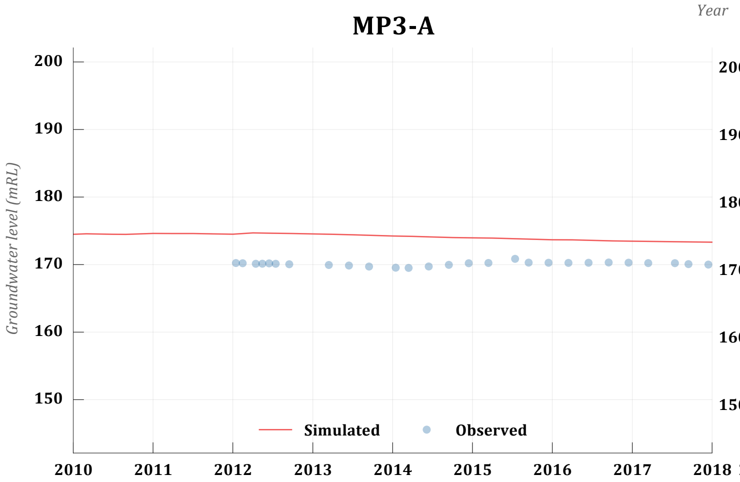

MP19-B
160
150
140
130
120
110
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year

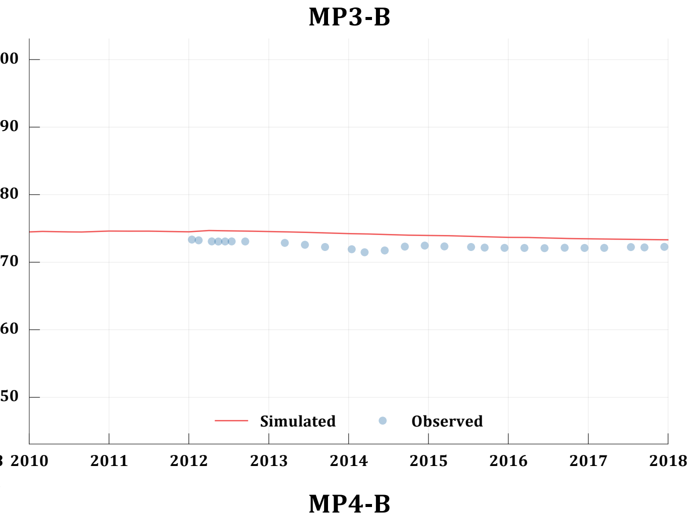

MP2-A
Groundwater level (mRL)
180
170
160
150
140
130
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018

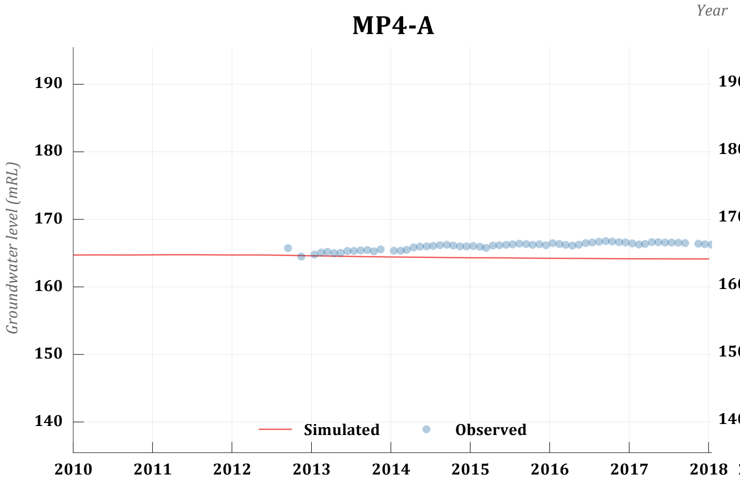

MP2-B
190
180
170
160
150
140
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year

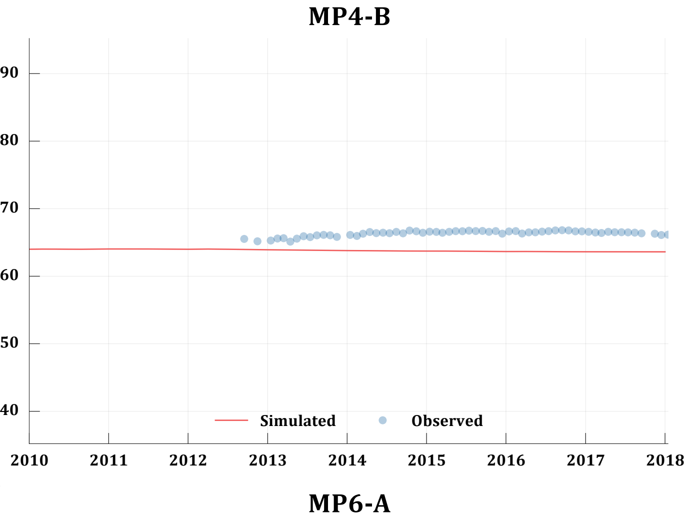

MP20-A
Groundwater level (mRL)
100
110
120
130
140
150
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018

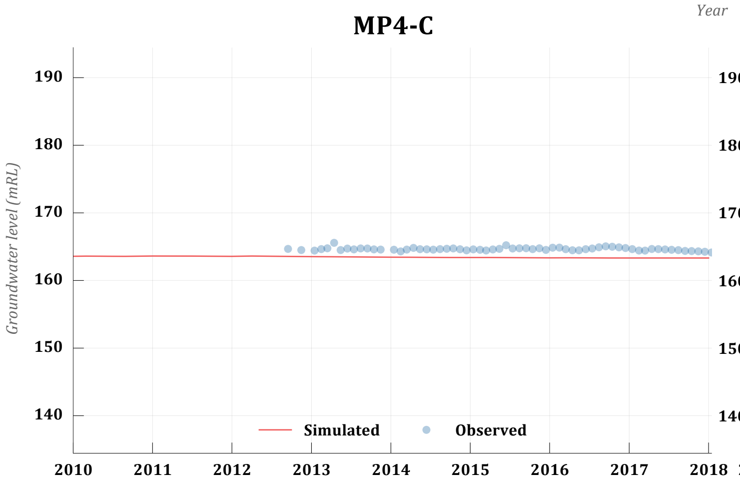

MP20-B
110
120
130
140
150
160
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year

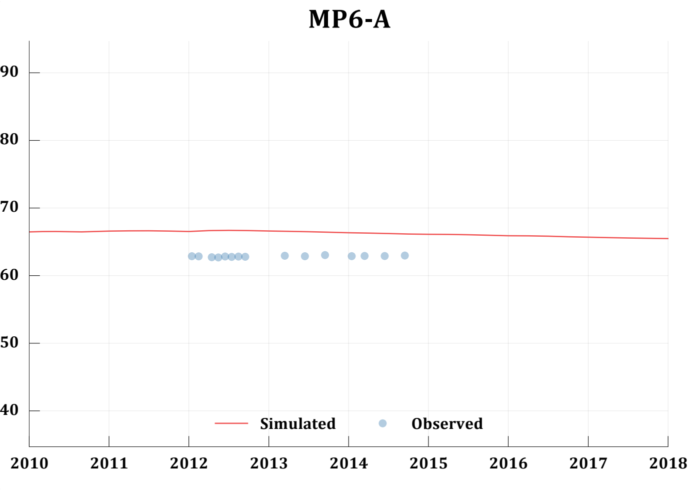

MP3-A
Groundwater level (mRL)
150
160
170
180
190
200
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018

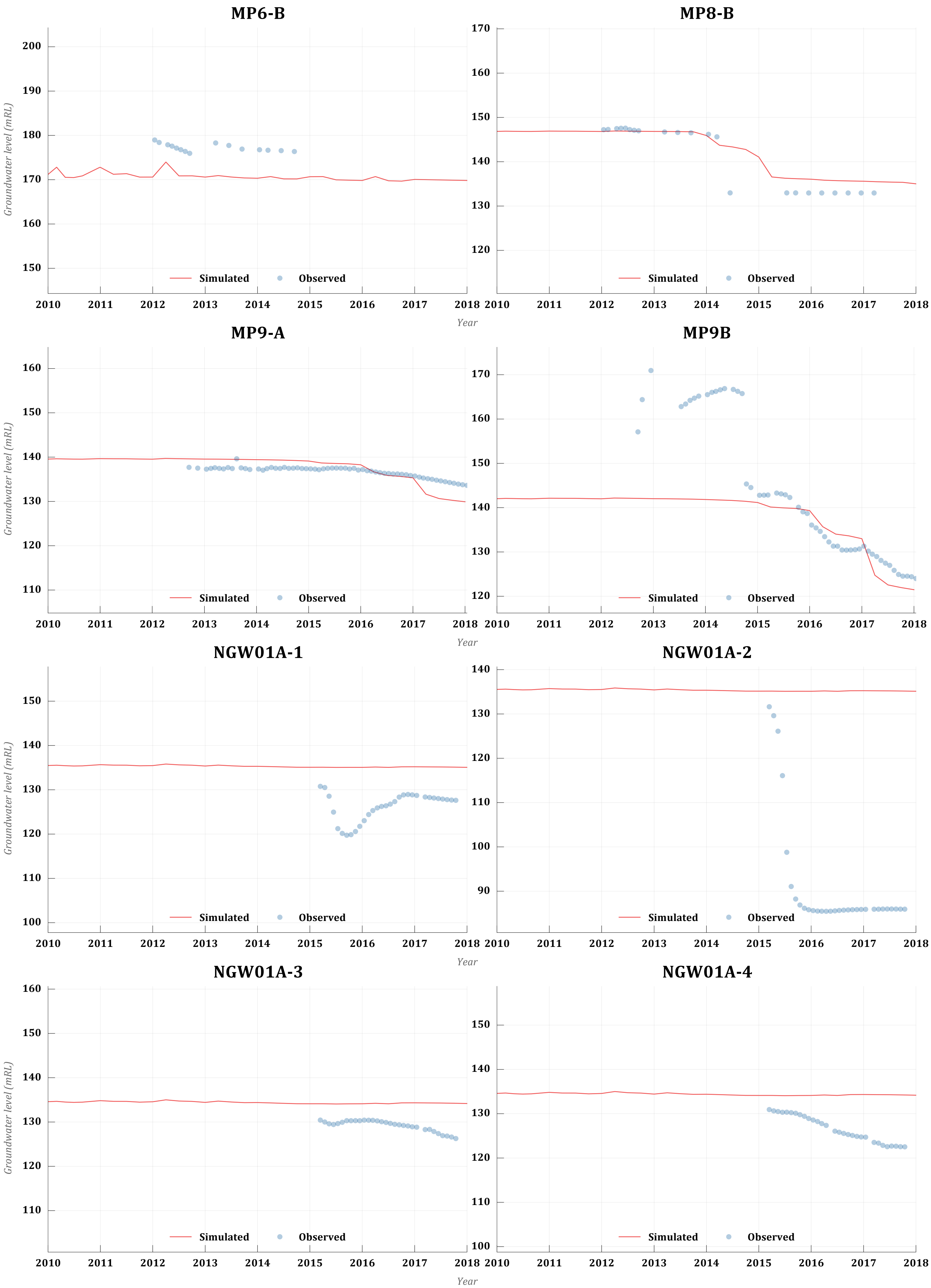

MP3-B
150
160
170
180
190
200
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year


MP4-A
Groundwater level (mRL)
140
150
160
170
180
190
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018

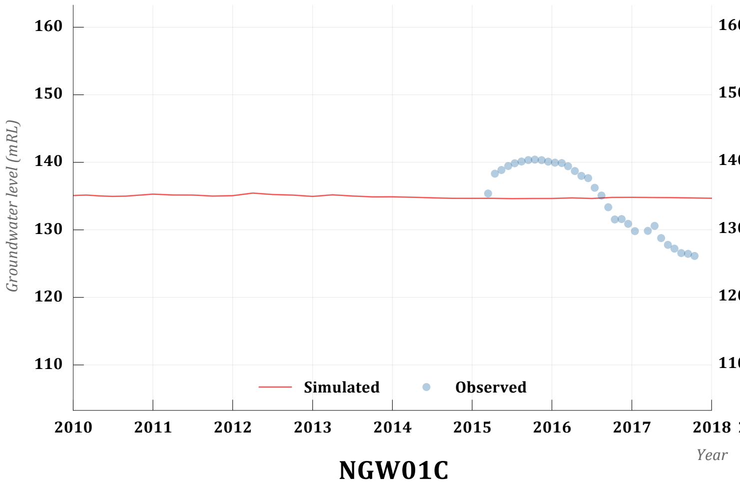

MP4-B
140
150
160
170
180
190
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year


MP4-C
Groundwater level (mRL)
140
150
160
170
180
190
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018

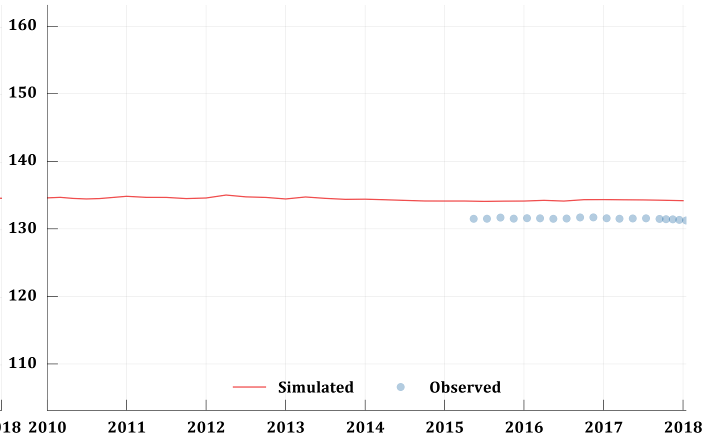

MP6-A
140
150
160
170
180
190
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year


MP6-B
MP8-B
MP9-A
MP9B
NGW01A-1
NGW01A-2
NGW01A-3
NGW01A-4
Groundwater level (mRL)
Year
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018

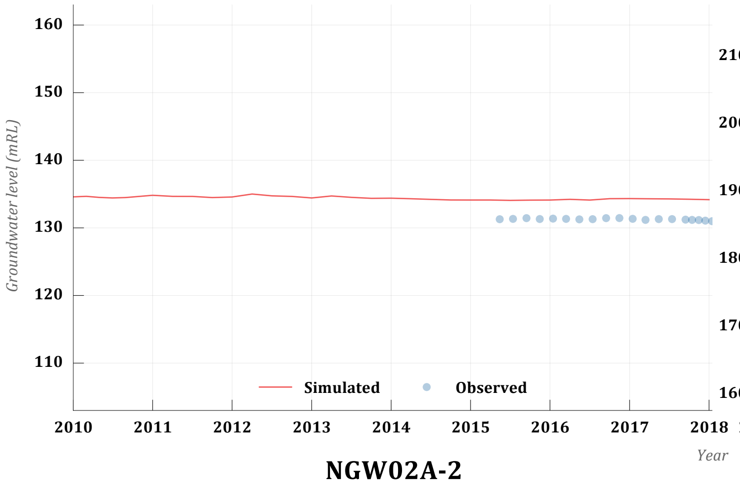
NGW01A-5



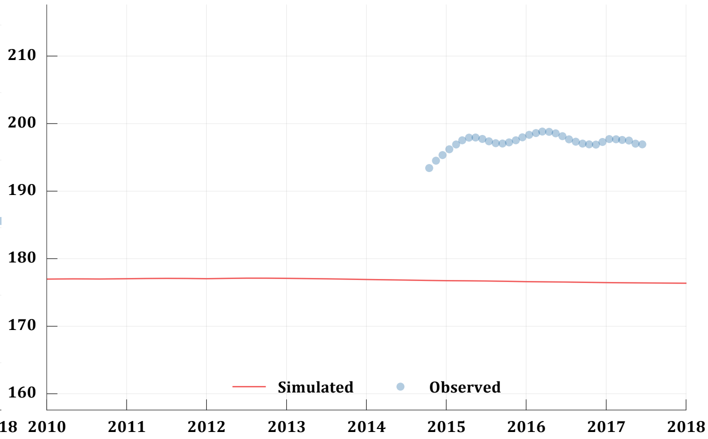
NGW01B



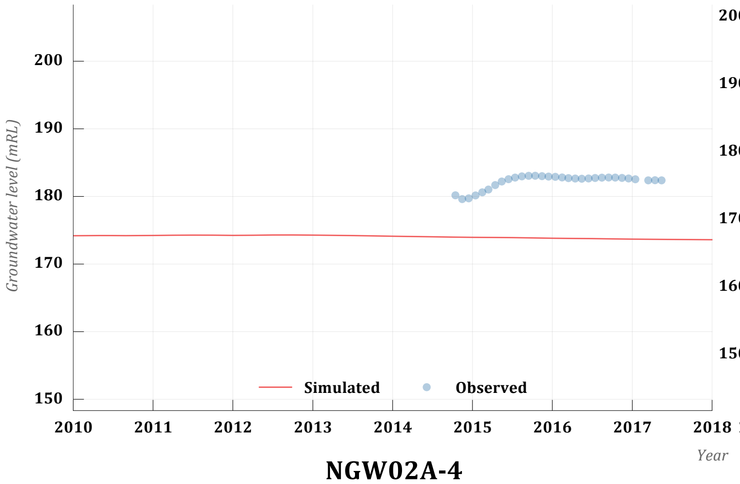
NGW01C



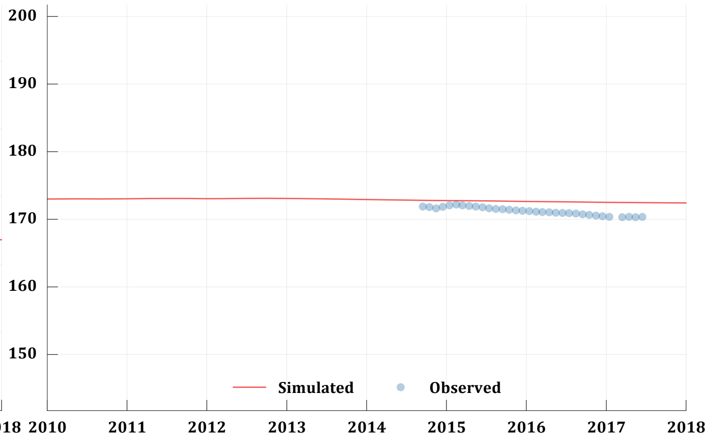
NGW02A-1



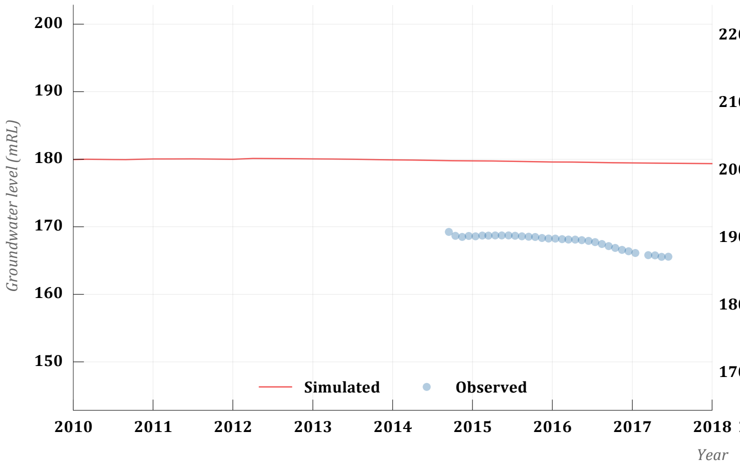
NGW02A-2



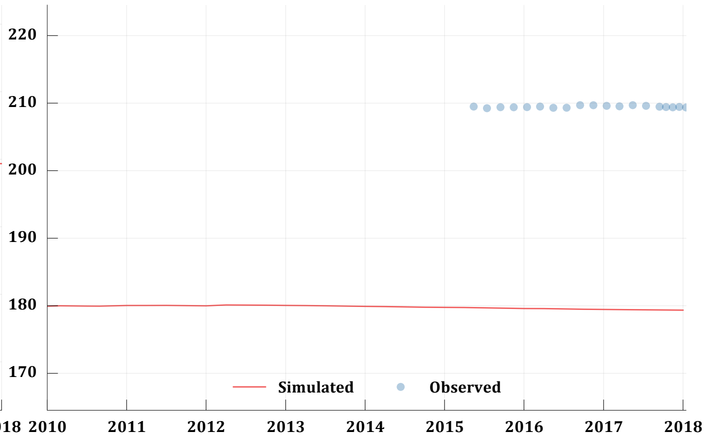
NGW02A-3

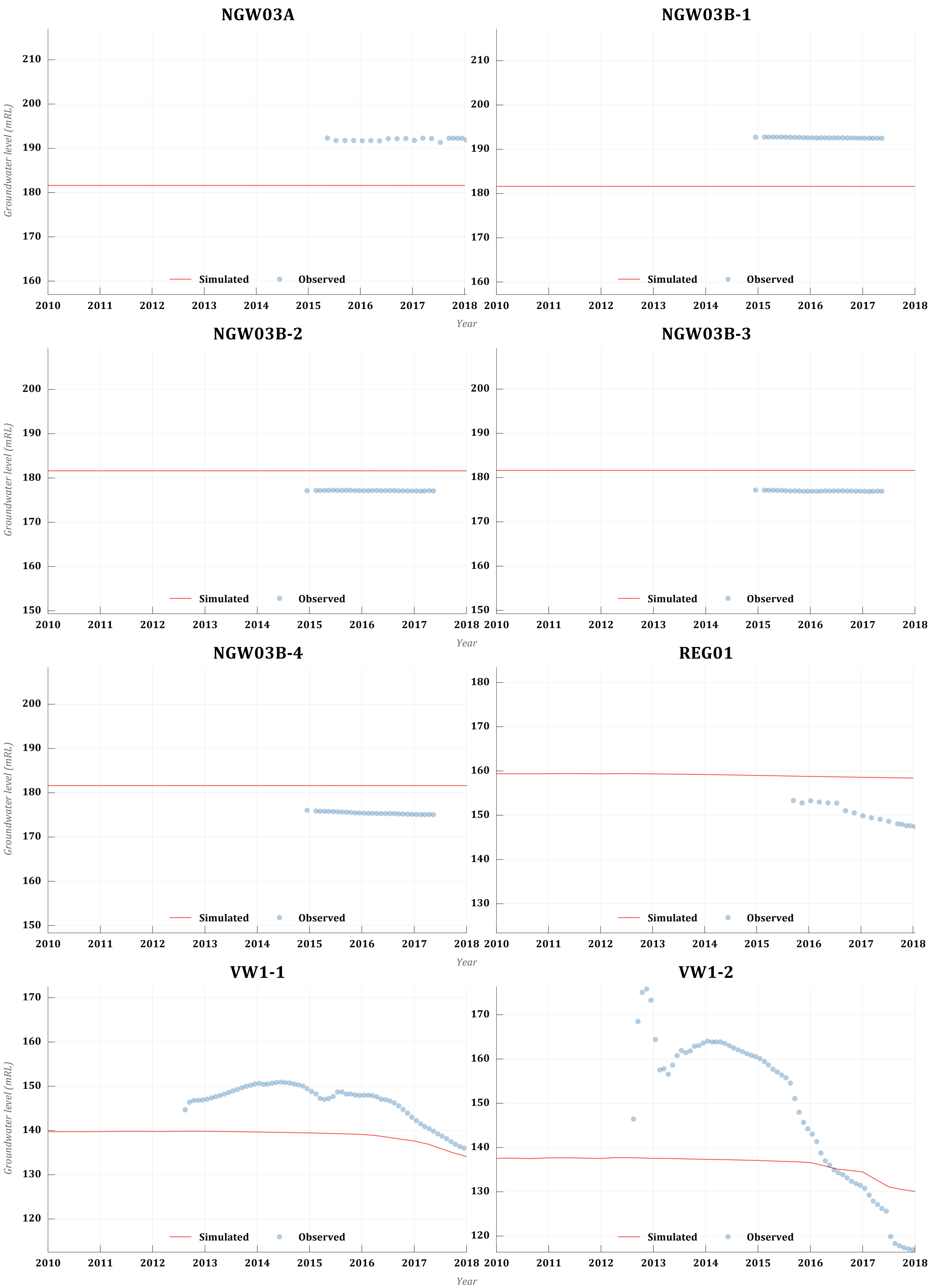


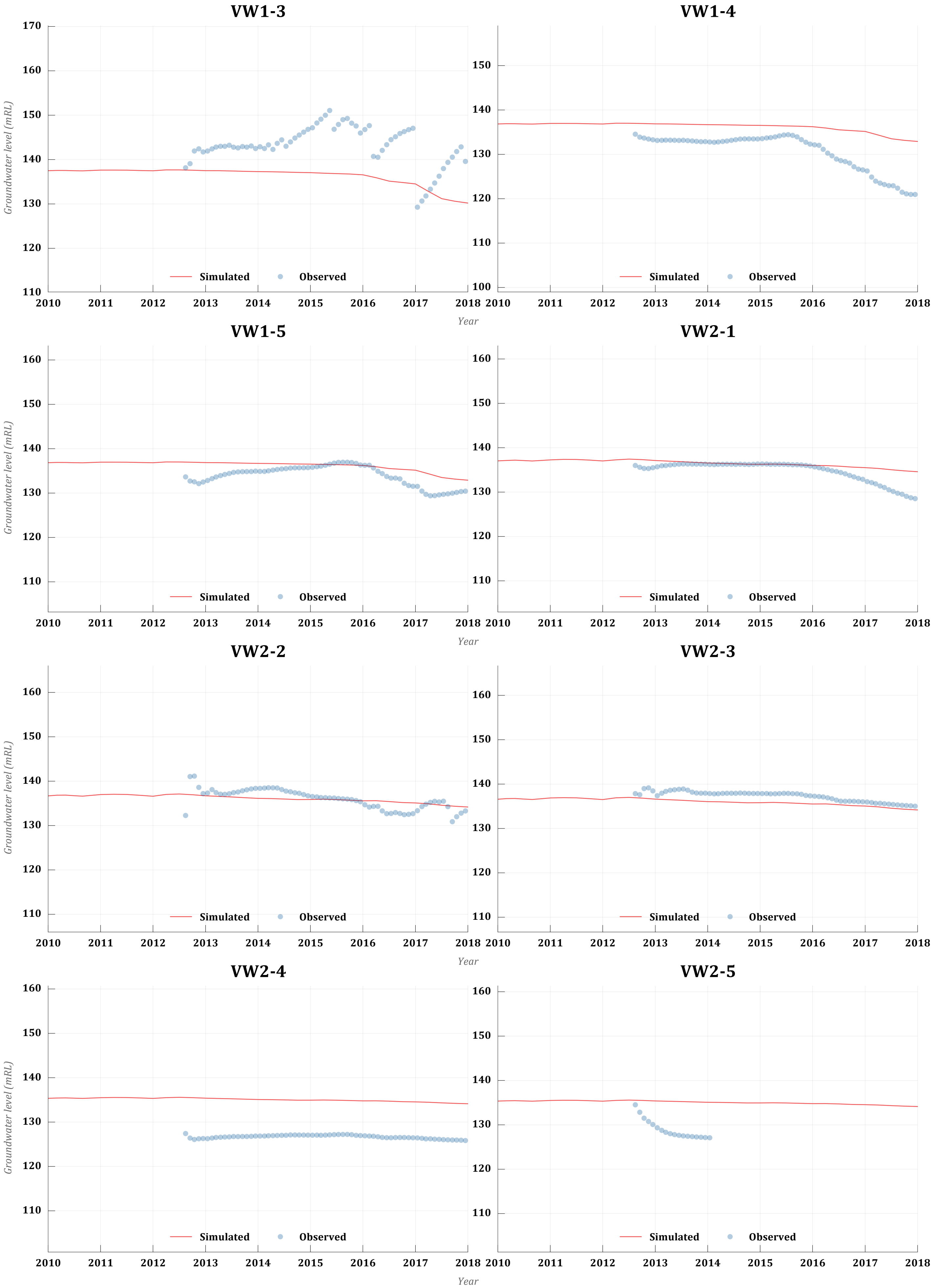
NGW02A-4



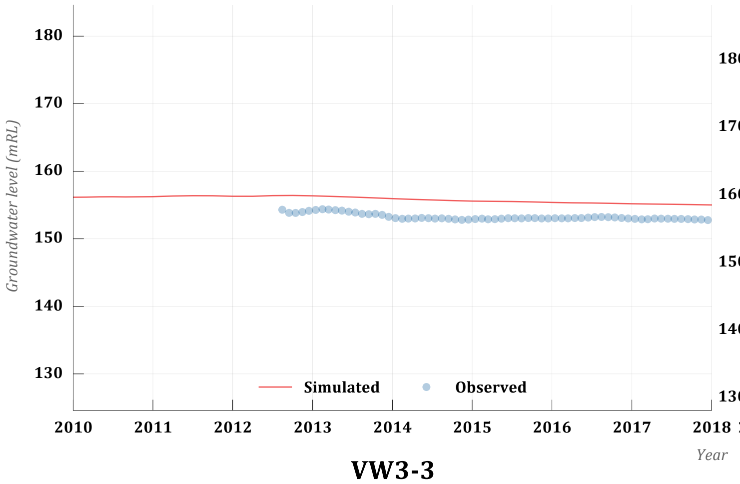
NGW02B



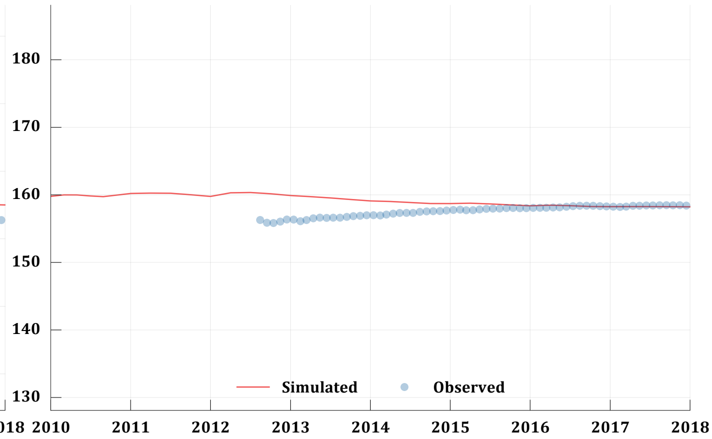

NGW03A
NGW03B-1
NGW03B-2
NGW03B-3
NGW03B-4
REG01
VW1-1
VW1-2
Groundwater level (mRL)
Year
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018


VW1-3
VW1-4
VW1-5
VW2-1
VW2-2
VW2-3
VW2-4
VW2-5
Groundwater level (mRL)
Year
Simulated
Observed
2010
2011
2012
2013
2014
2015
2016
2017
2018
170
160
150
140
130
120
110
100

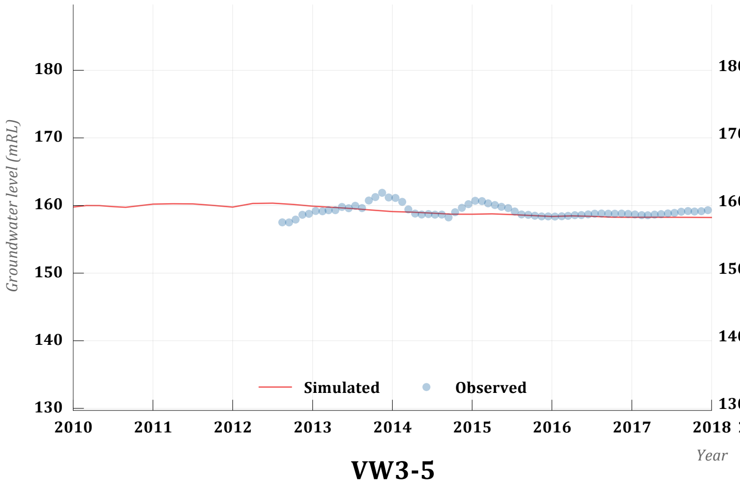
VW3-1



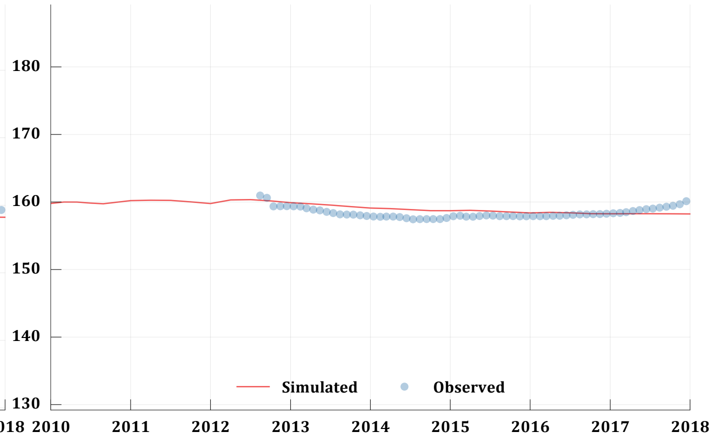
VW3-2



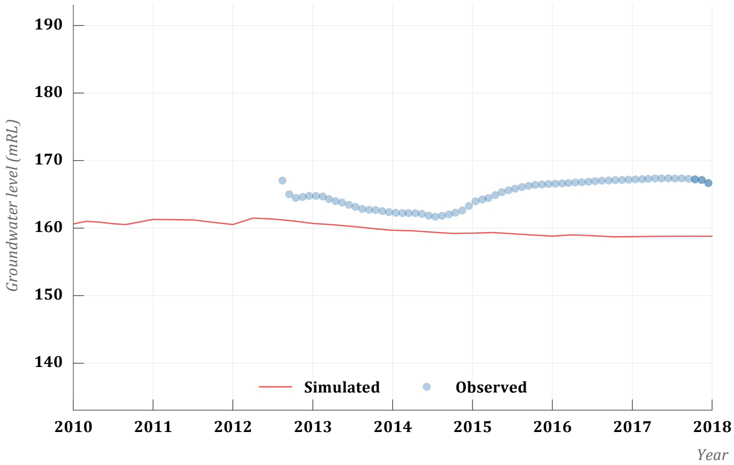
VW3-3



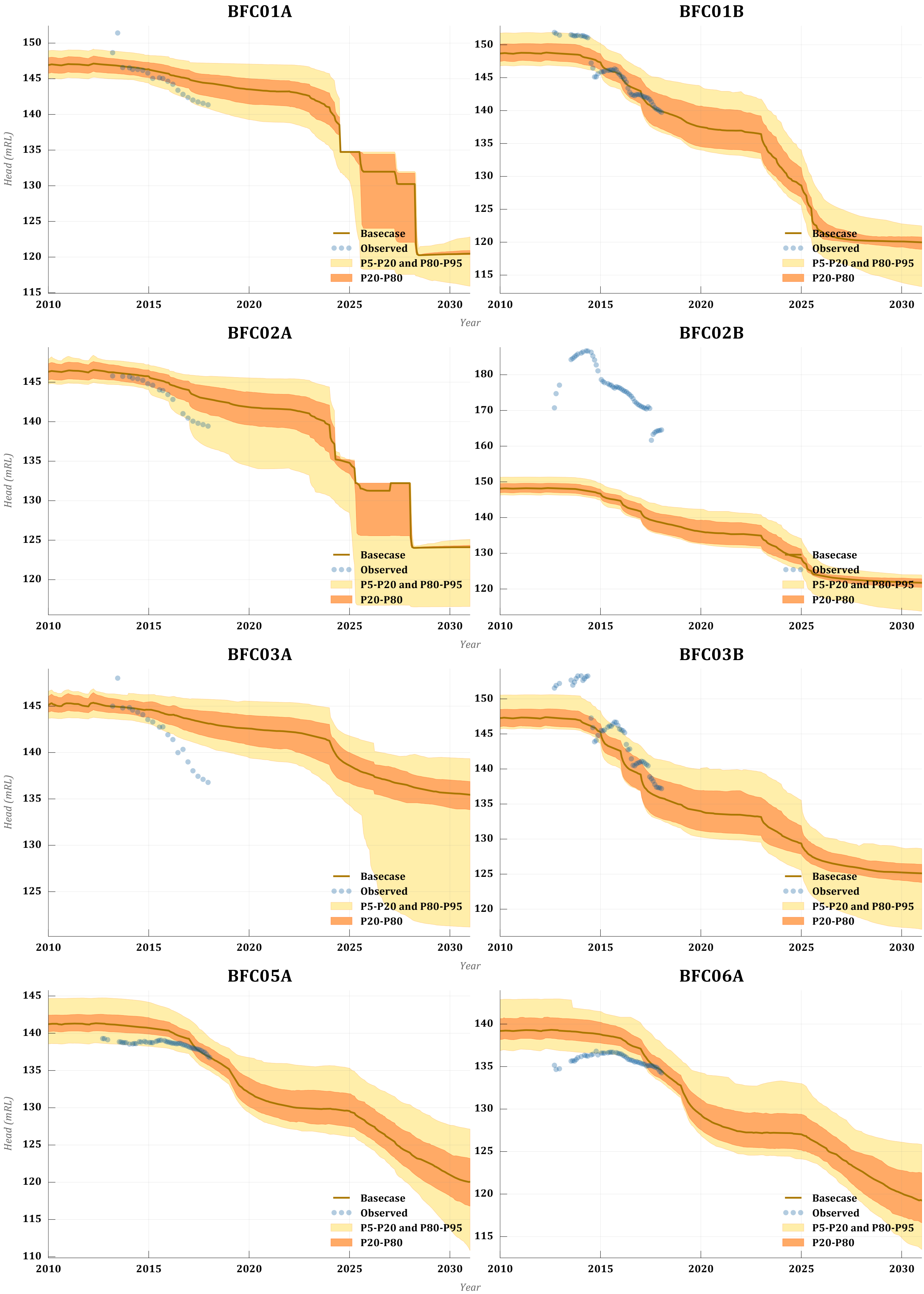
VW3-4

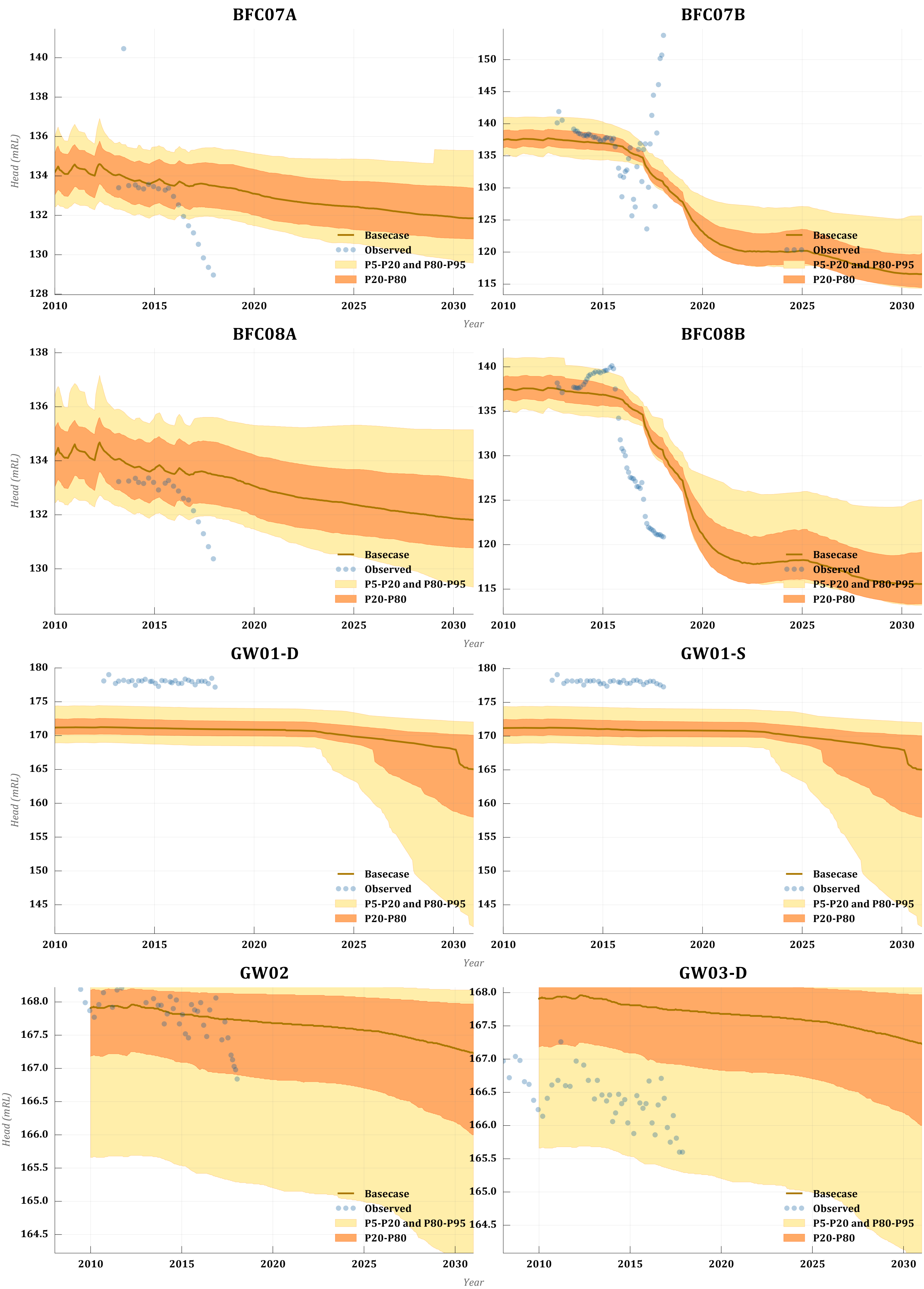


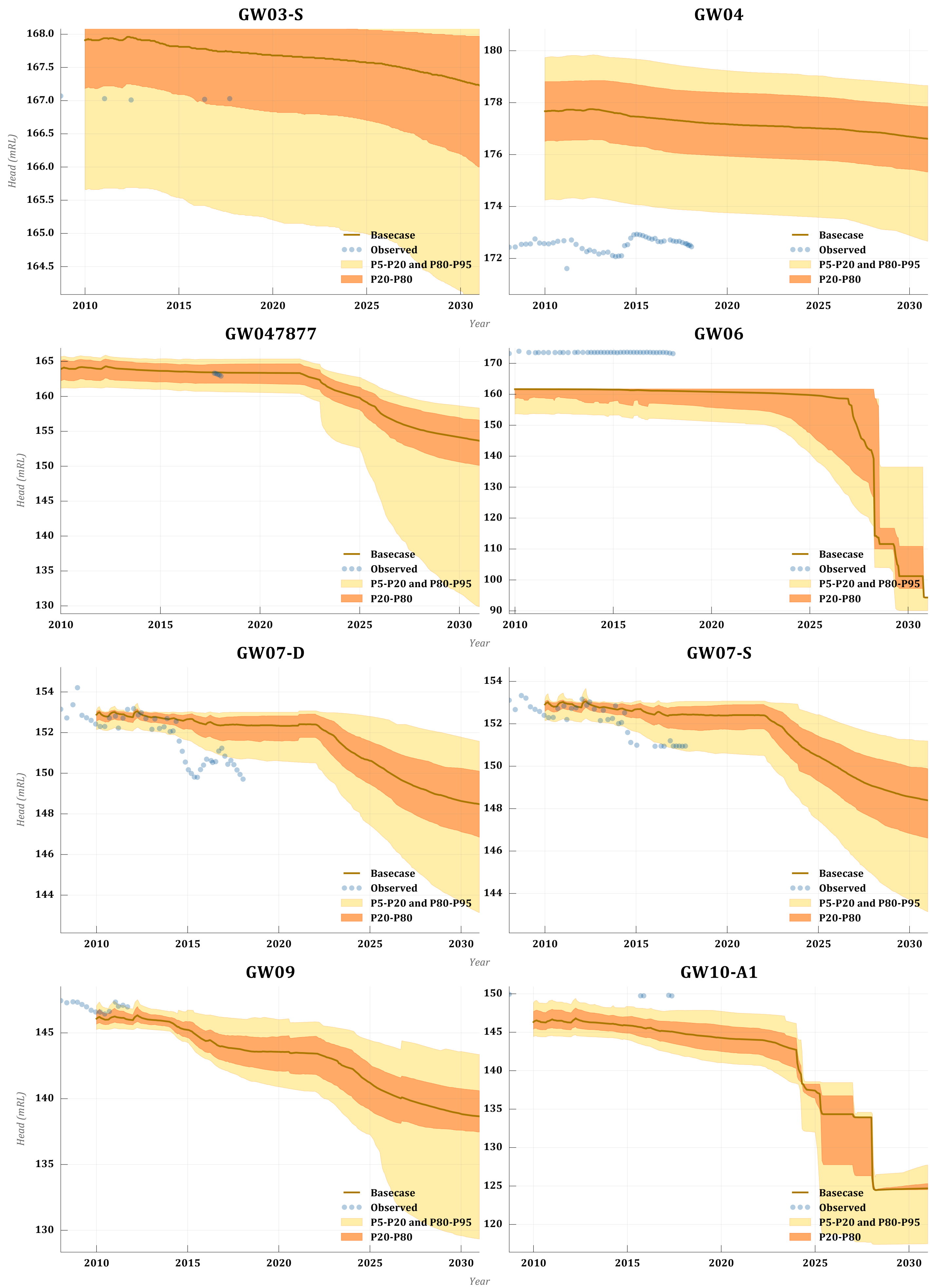
VW3-5

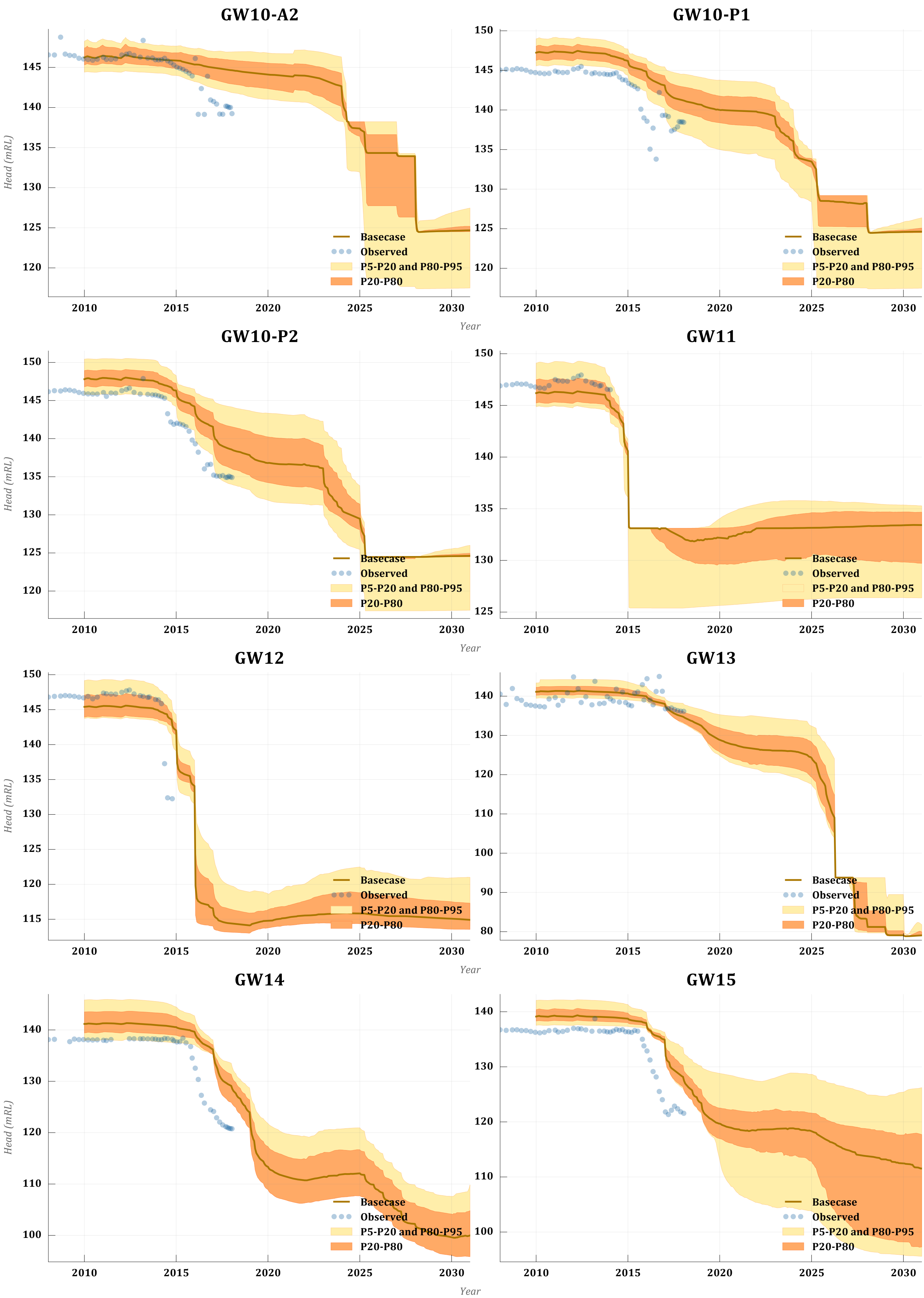


Appendix A-2 Predictive uncertainty hydrographs

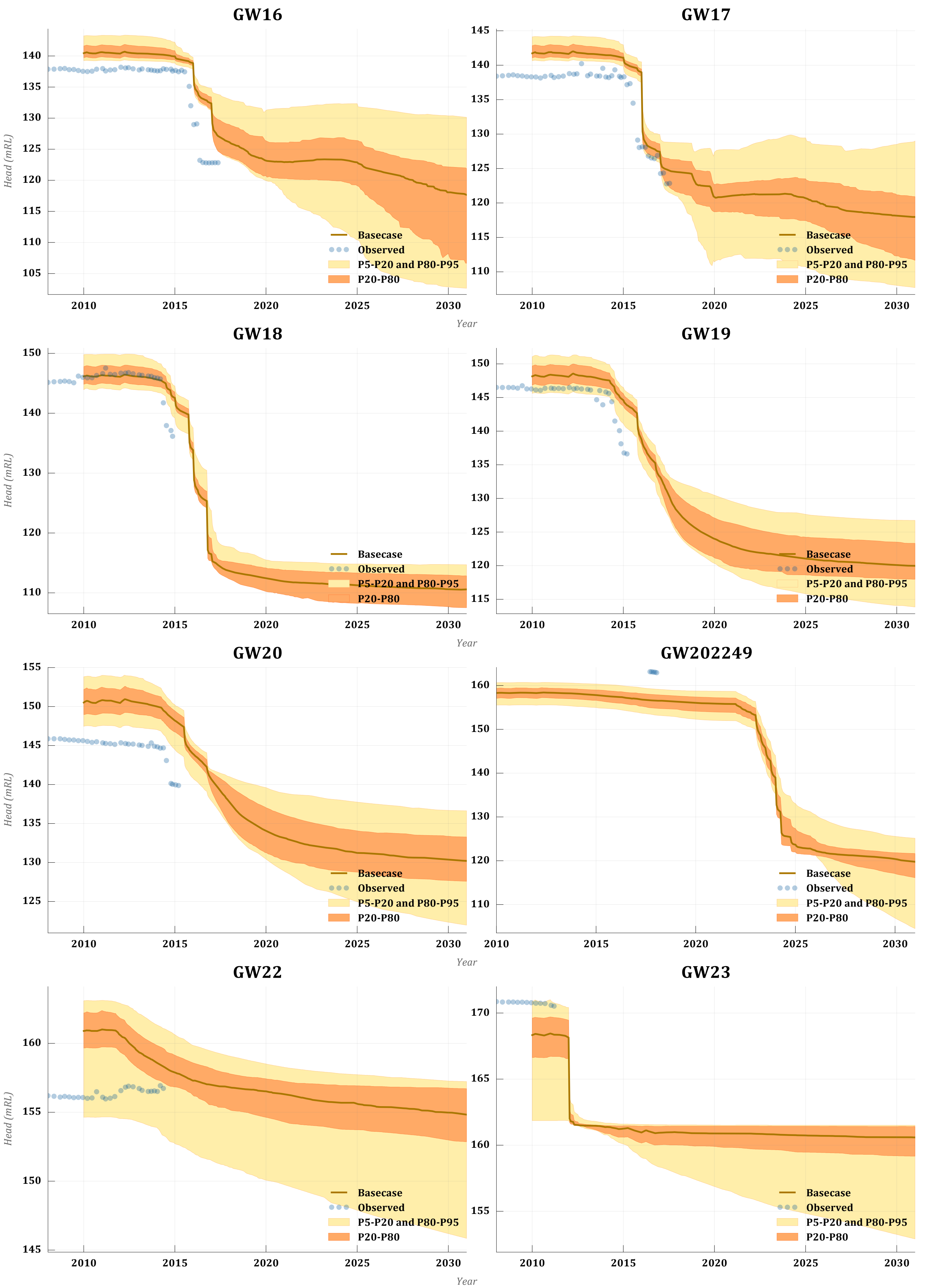

BFC01A
BFC01B
BFC02A
BFC02B
BFC03A
BFC03B
BFC05A
BFC06A
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80

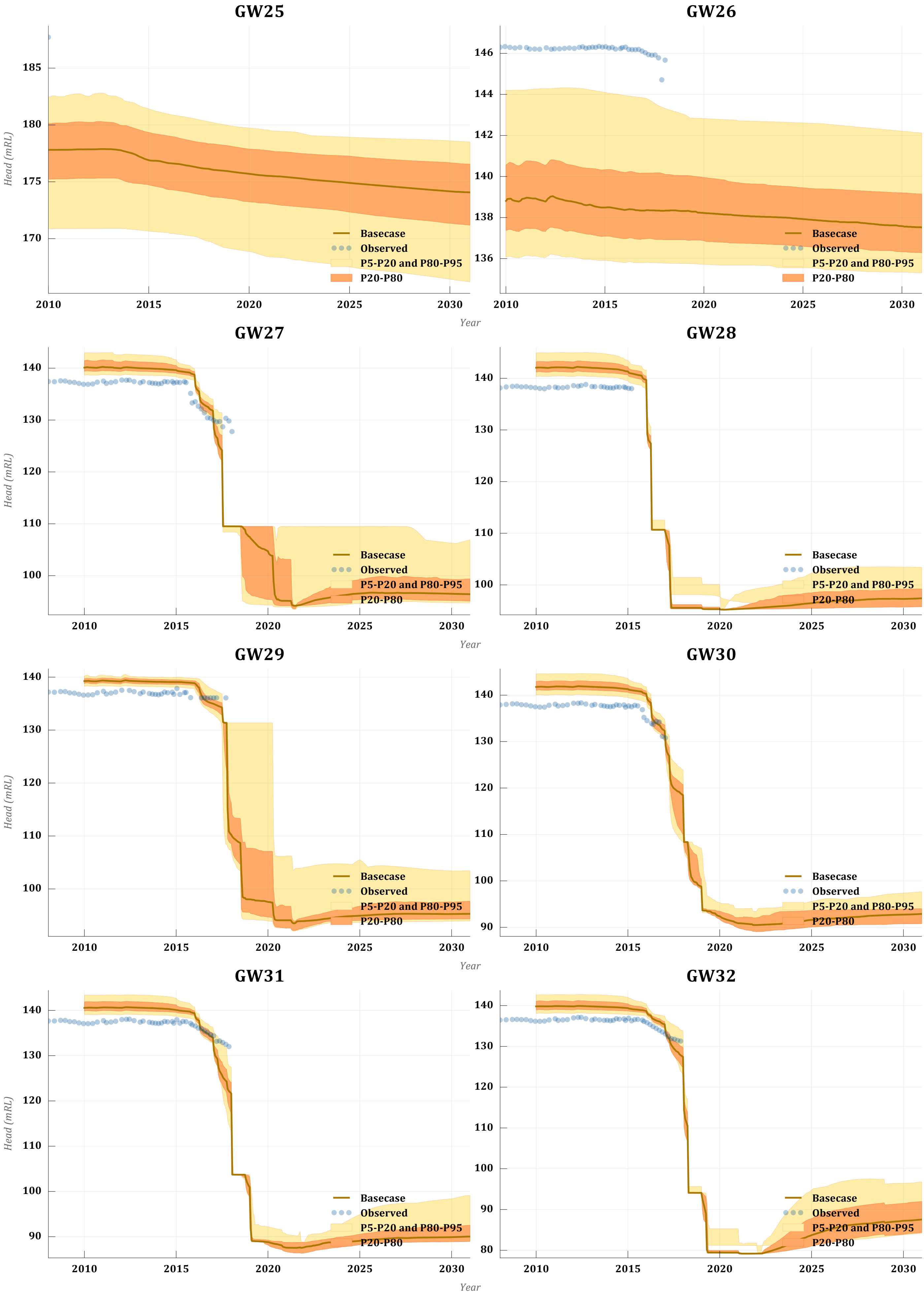

BFC07A
BFC07B
BFC08A
BFC08B
GW01-D
GW01-S
GW02
GW03-D
Head (mRL)
Year
2010
2015
2020
2025
2030
Basecase
Observed
P5-P20 and P80-P95
P20-P80

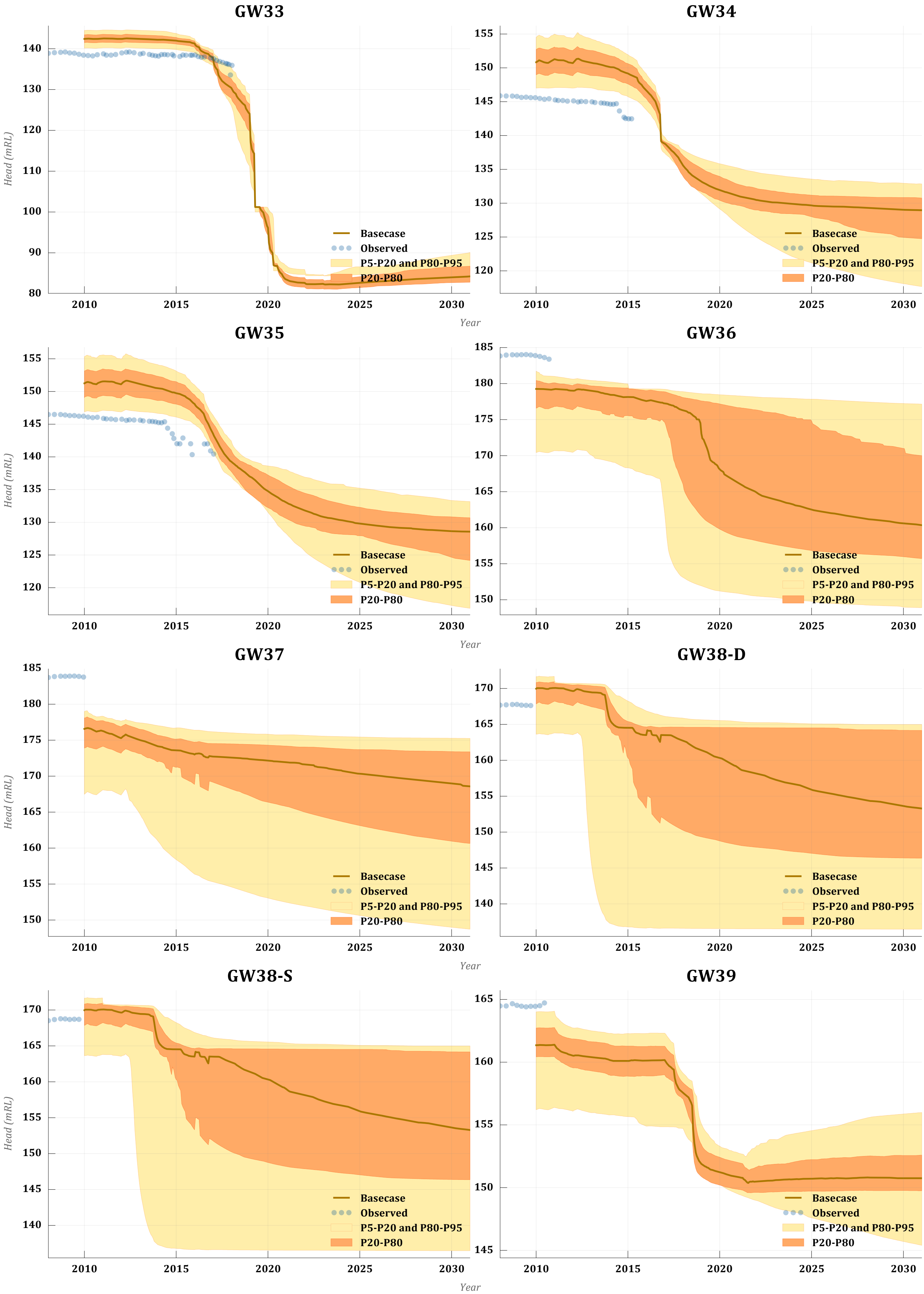

GW03-S
GW04
GW047877
GW06
GW07-D
GW07-S
GW09
GW10-A1
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80

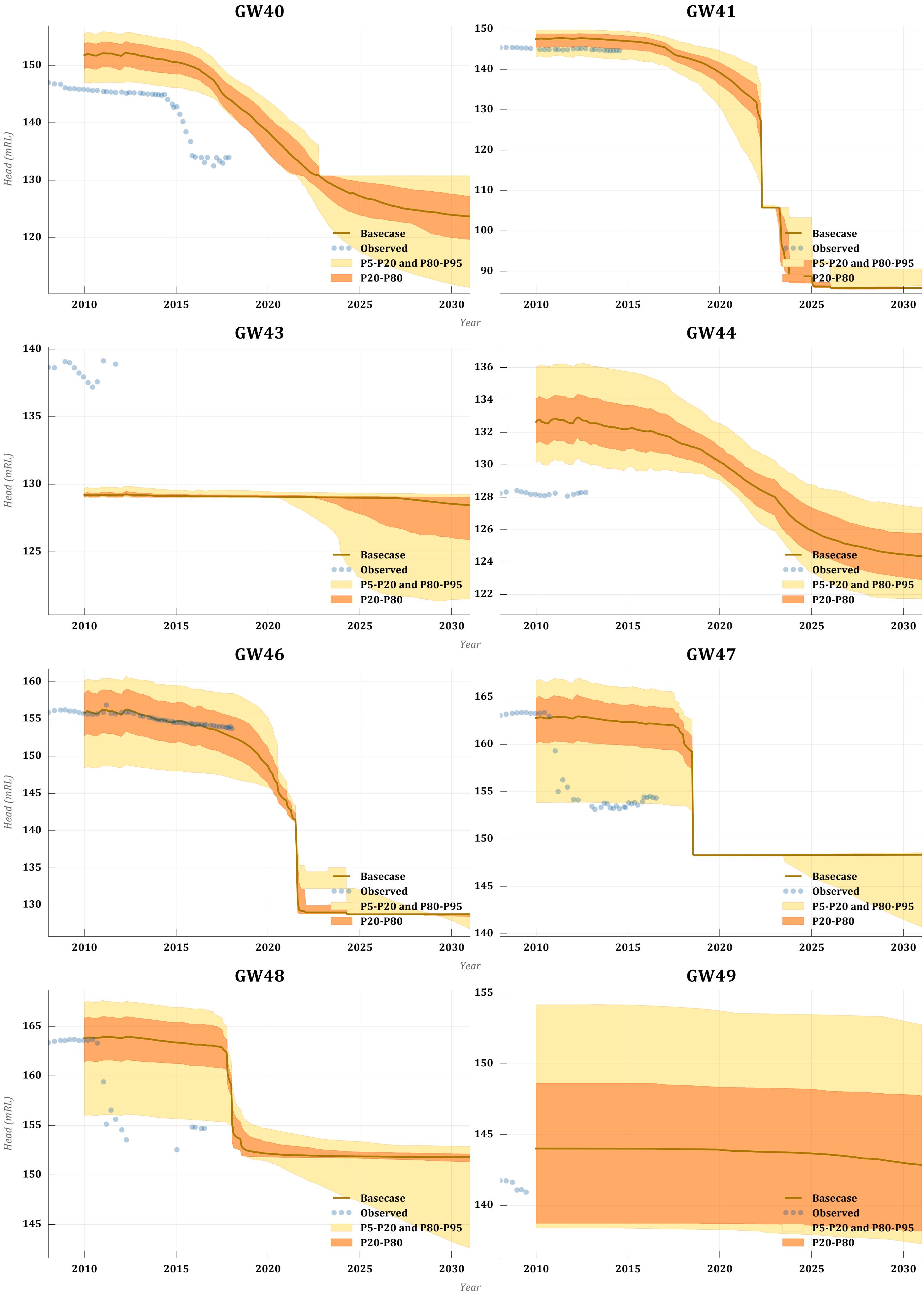


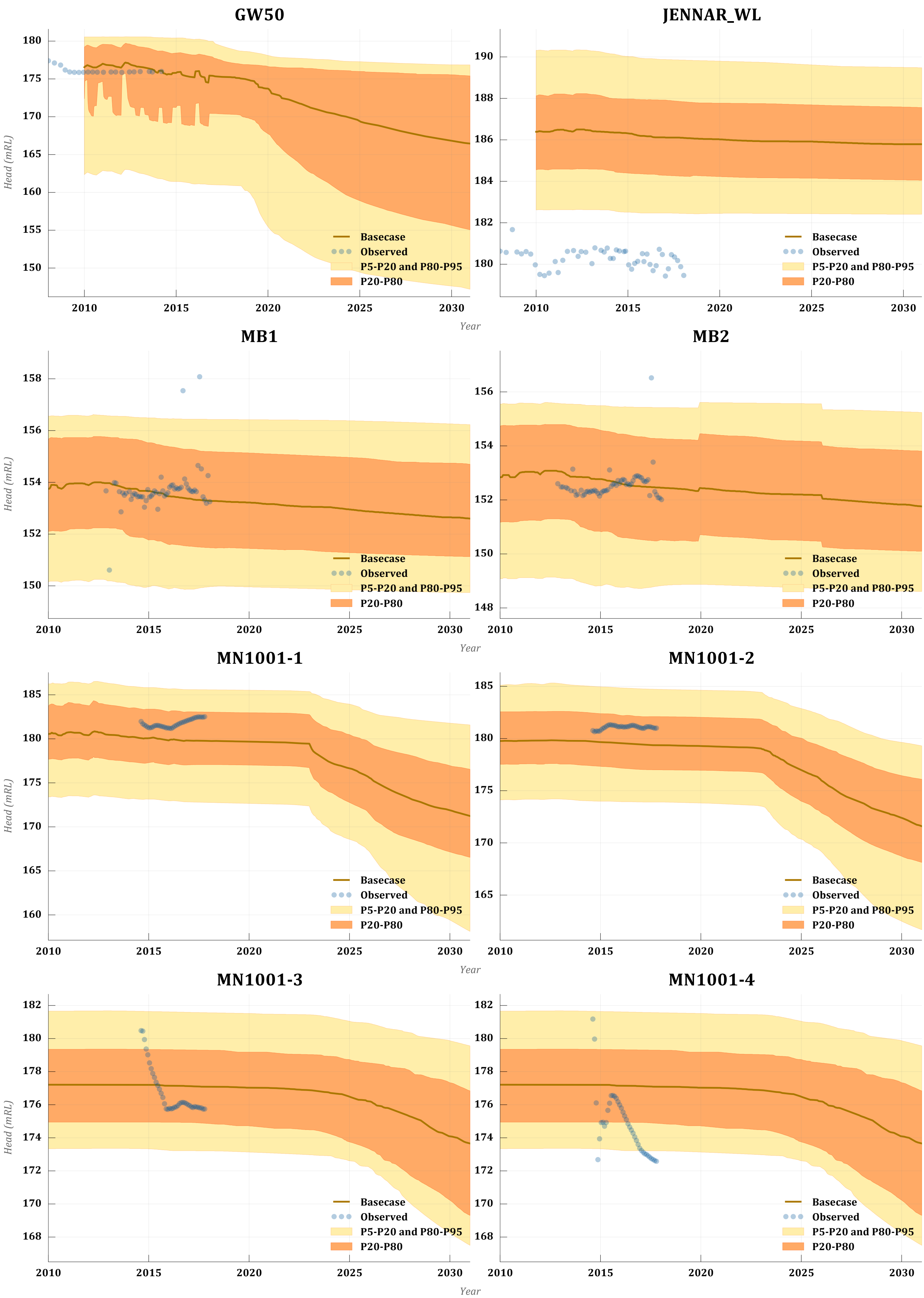
GW10-A2
GW10-P1
GW10-P2
GW11
GW12
GW13
GW14
GW15
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80

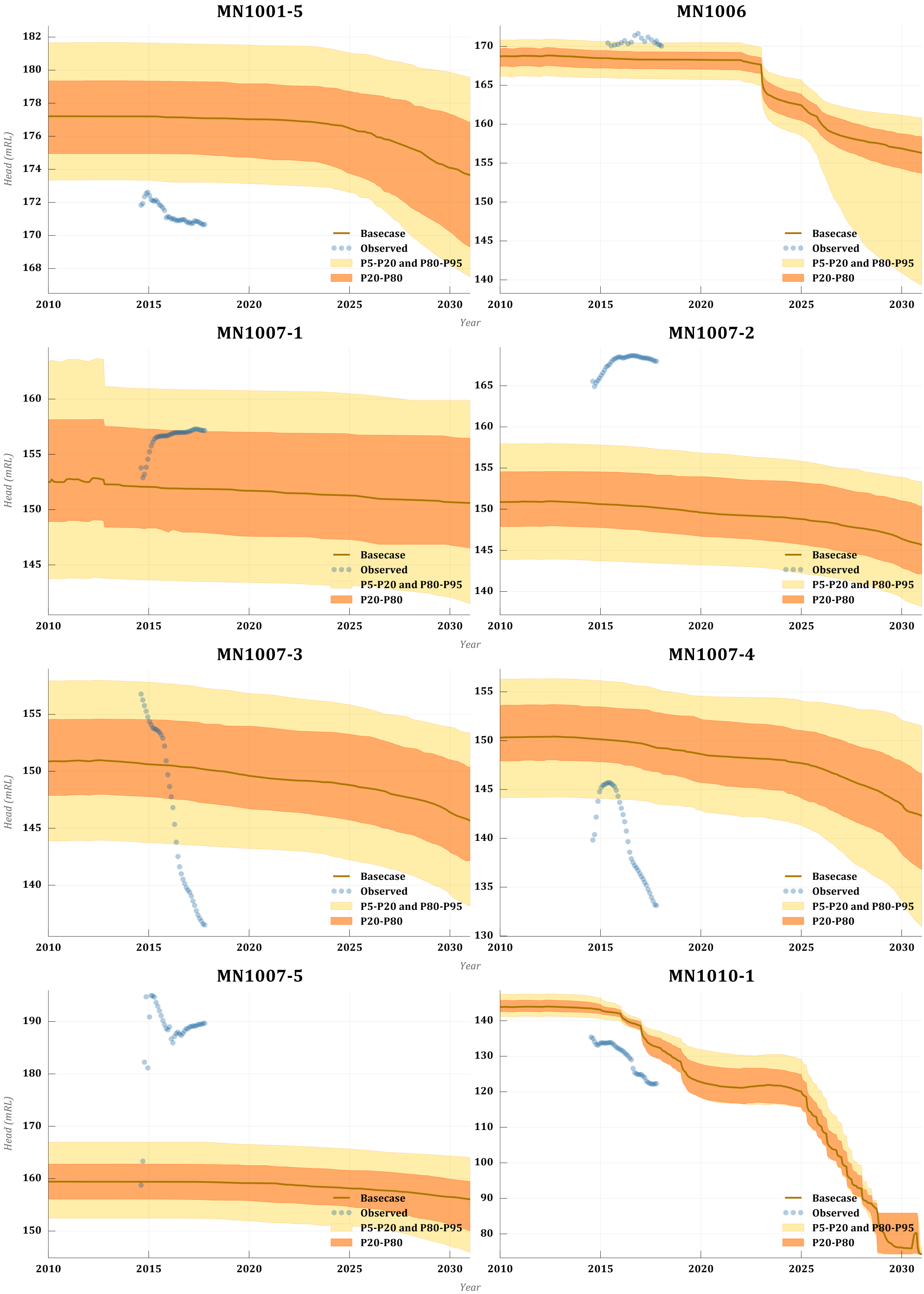

GW16
GW17
GW18
GW19
GW20
GW202249
GW22
GW23
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
2010
2015
2020
2025
2030

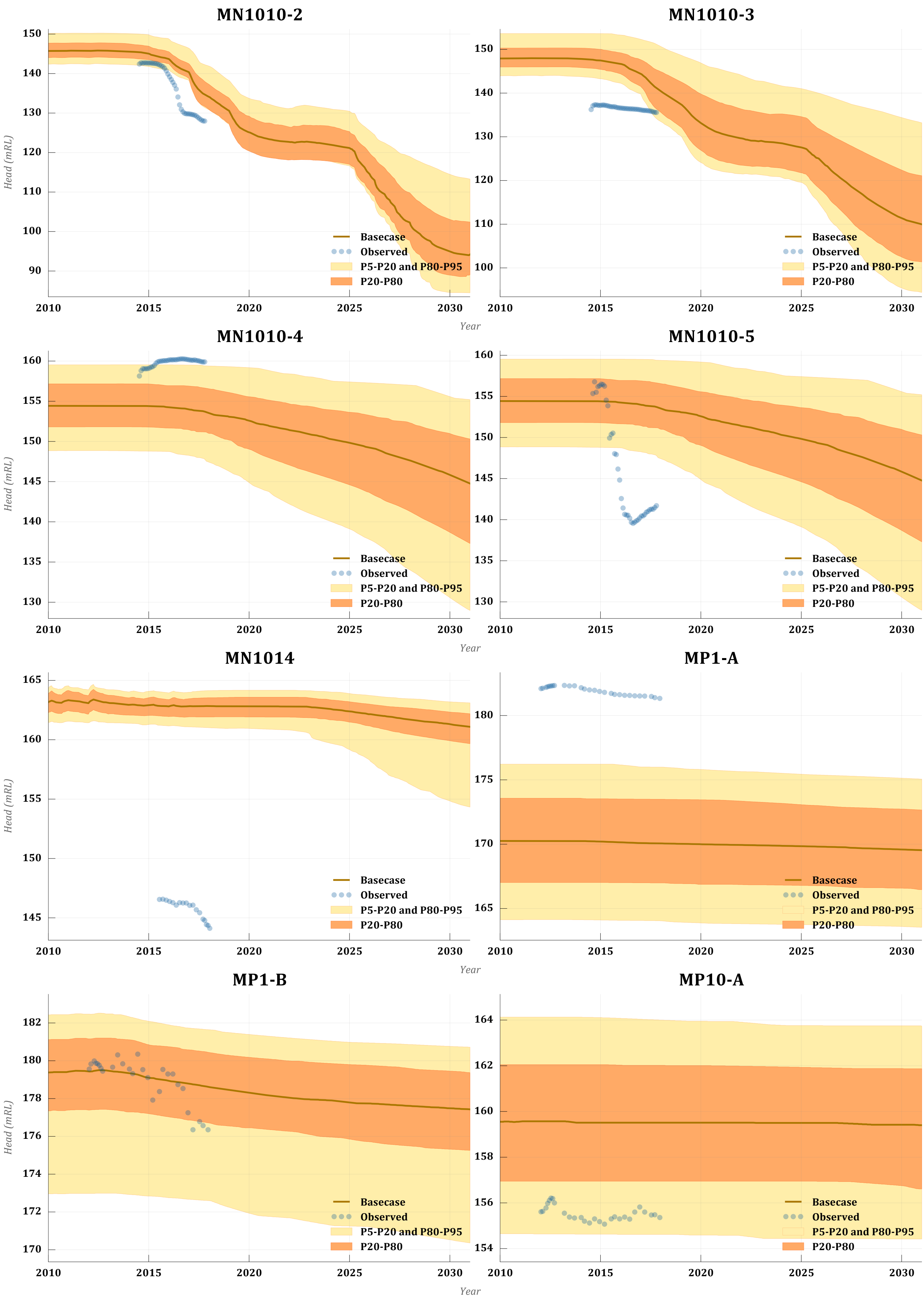

GW25
GW26
GW27
GW28
GW29
GW30
GW31
GW32
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80

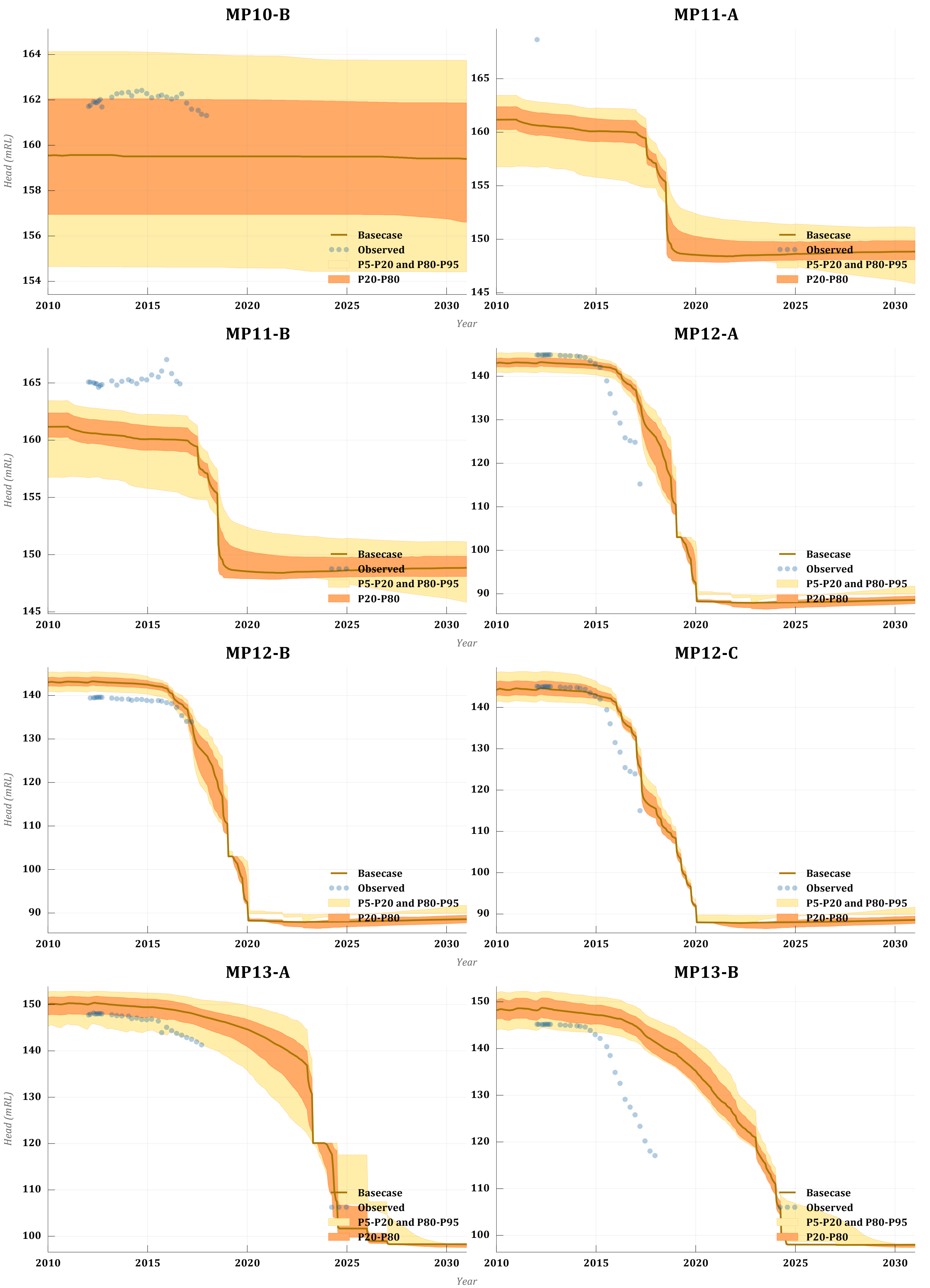

GW33
GW34
GW35
GW36
GW37
GW38-D
GW38-S
GW39
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80

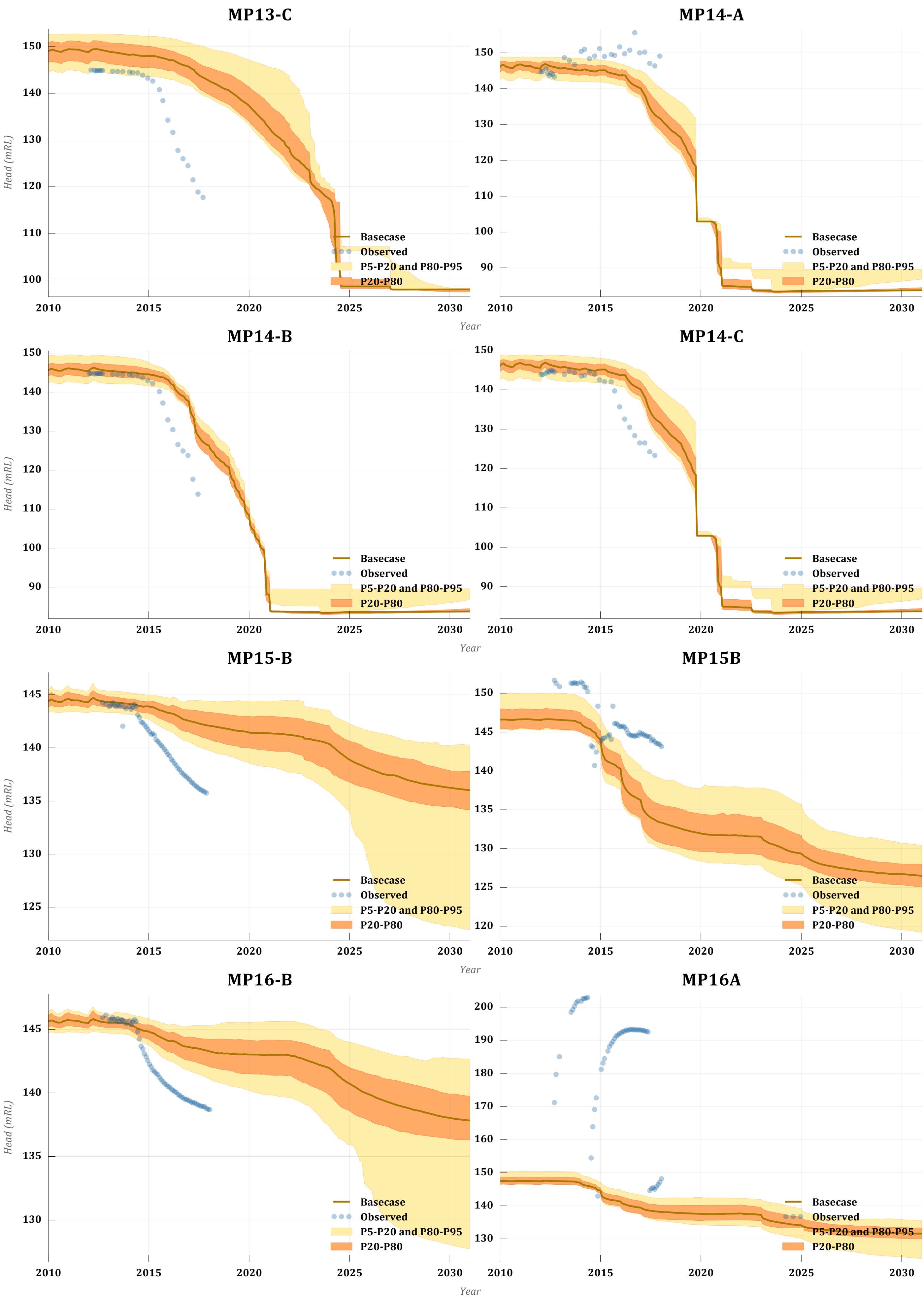

GW40
GW41
GW43
GW44
GW46
GW47
GW48
GW49
Head (mRL)
Year
2010
2015
2020
2025
2030
Basecase
Observed
P5-P20 and P80-P95
P20-P80

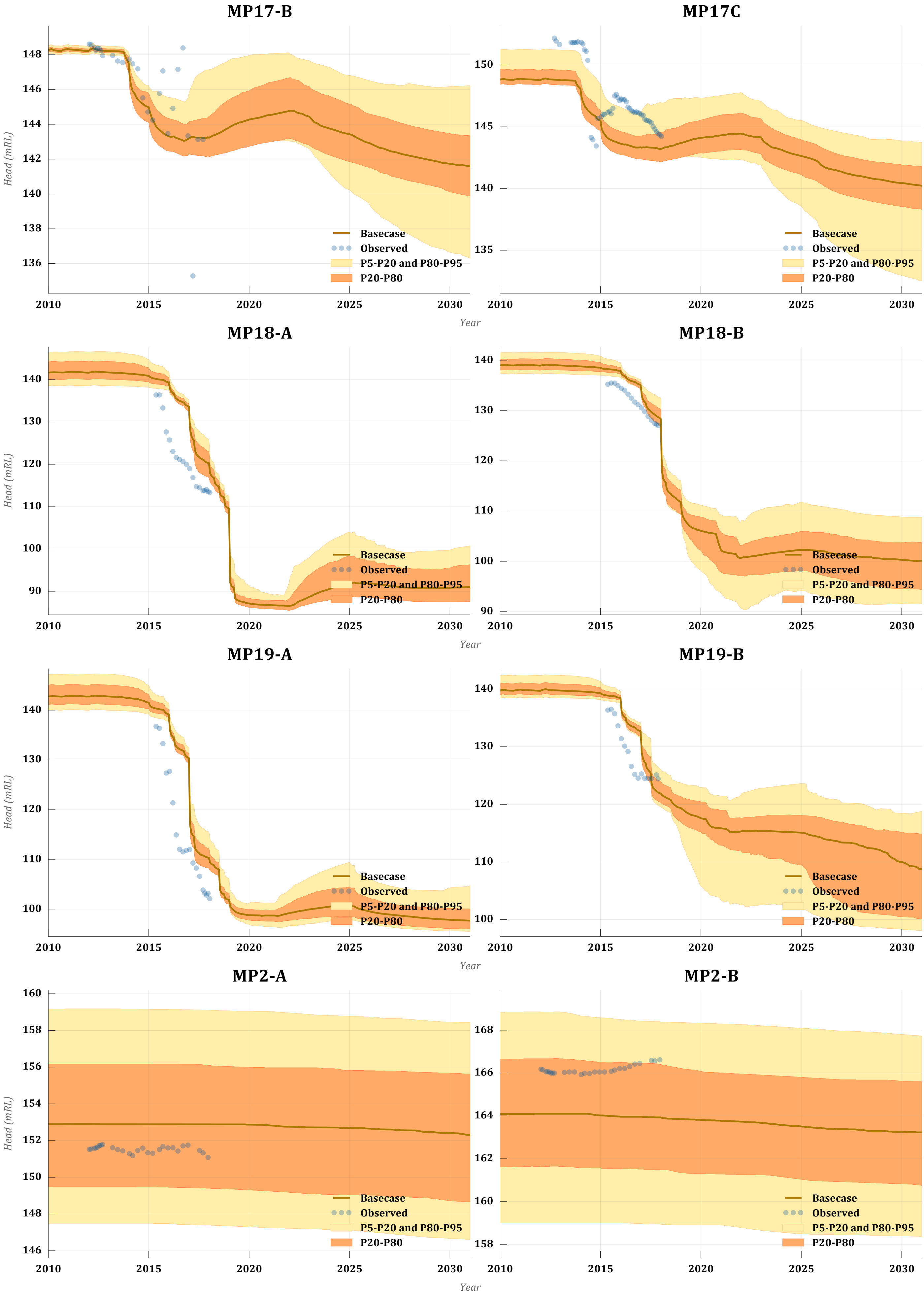

GW50
JENNAR_WL
MB1
MB2
MN1001-1
MN1001-2
MN1001-3
MN1001-4
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80


MN1001-5
MN1006
MN1007-1
MN1007-2
MN1007-3
MN1007-4
MN1007-5
MN1010-1
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
2010
2015
2020
2025
2030


MN1010-2
MN1010-3
MN1010-4
MN1010-5
MN1014
MP1-A
MP1-B
MP10-A
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80
2010
2015
2020
2025
2030


MP10-B
MP11-A
MP11-B
MP12-A
MP12-B
MP12-C
MP13-A
MP13-B
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80


MP13-C
MP14-A
MP14-B
MP14-C
MP15-B
MP15B
MP16-B
MP16A
Head (mRL)
Year
Basecase
Observed
P5-P20 and P80-P95
P20-P80


MP17-B
MP17C
MP18-A
MP18-B
MP19-A
MP19-B
MP2-A
MP2-B
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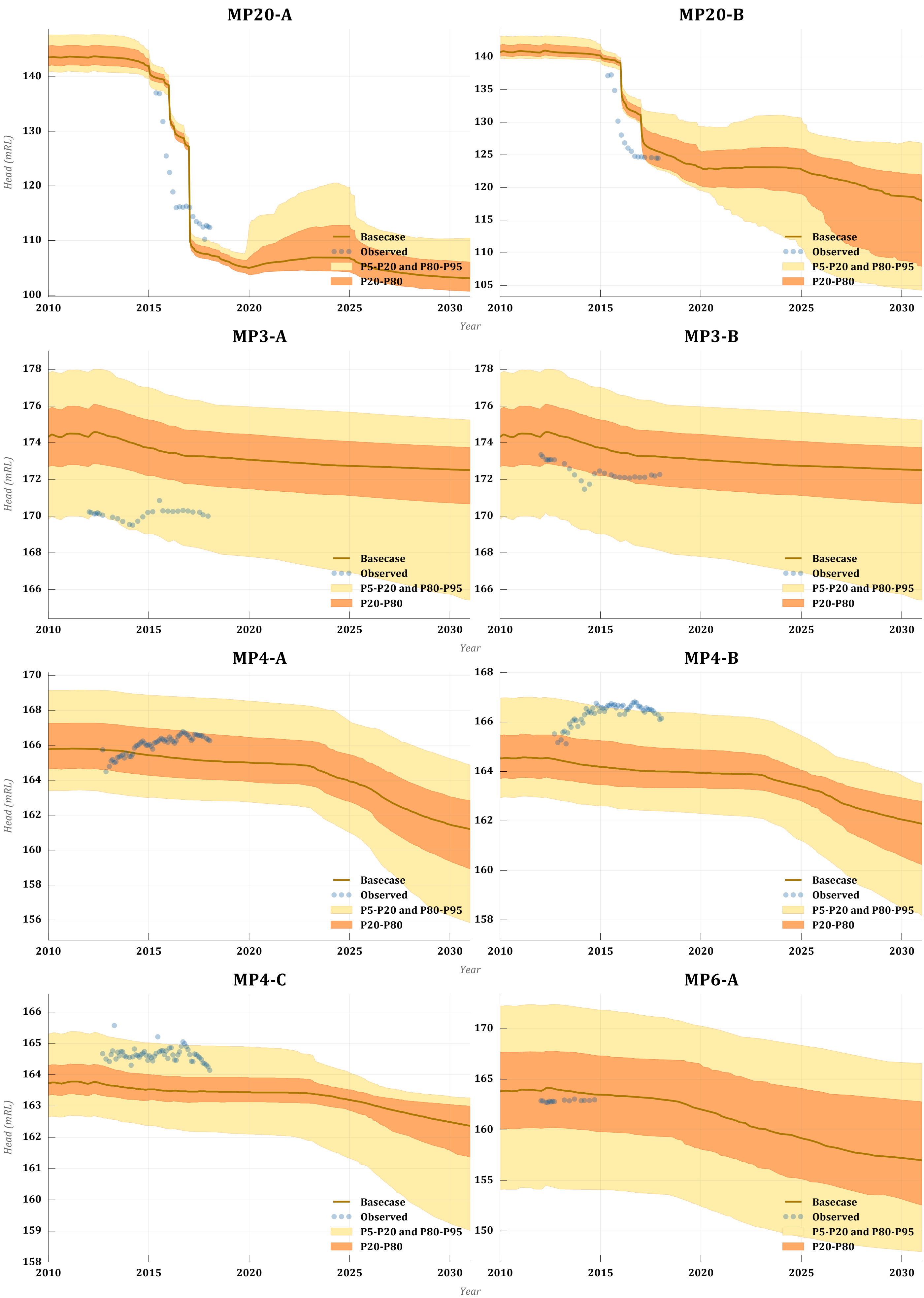
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MP4-B
MP4-C
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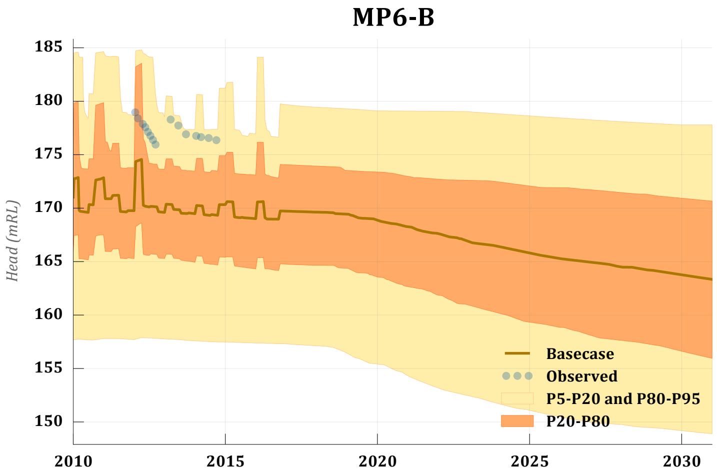
P20-P80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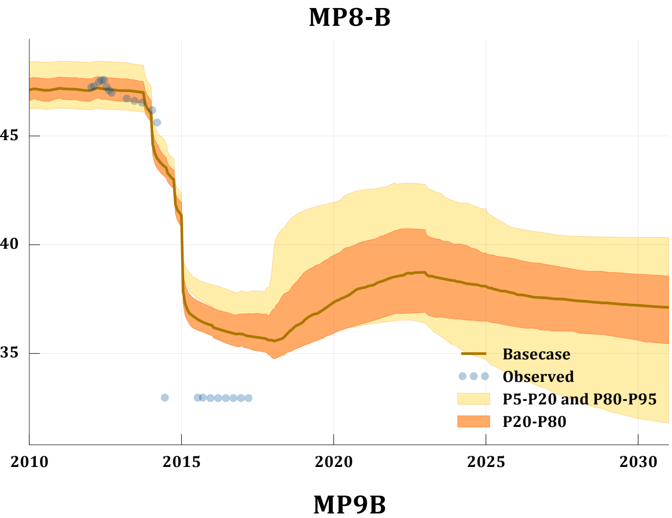
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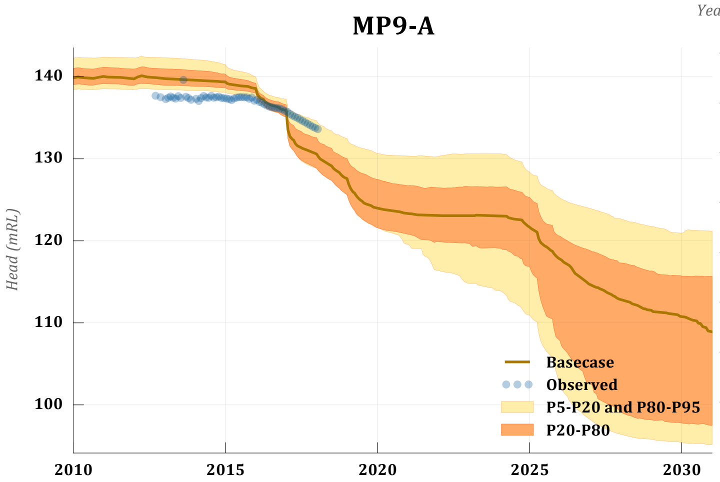
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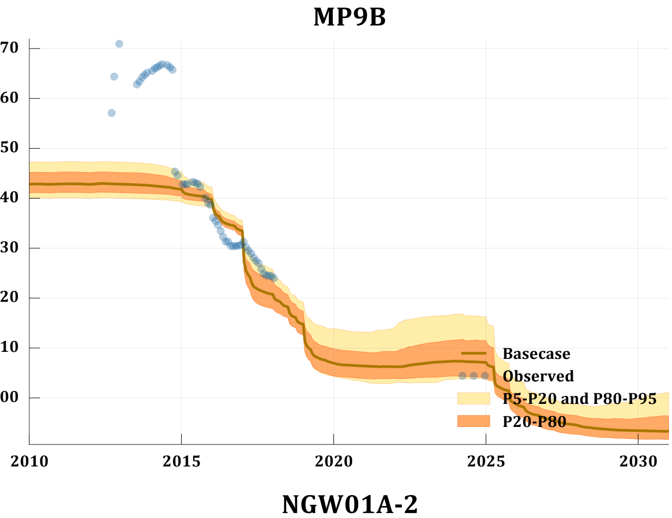
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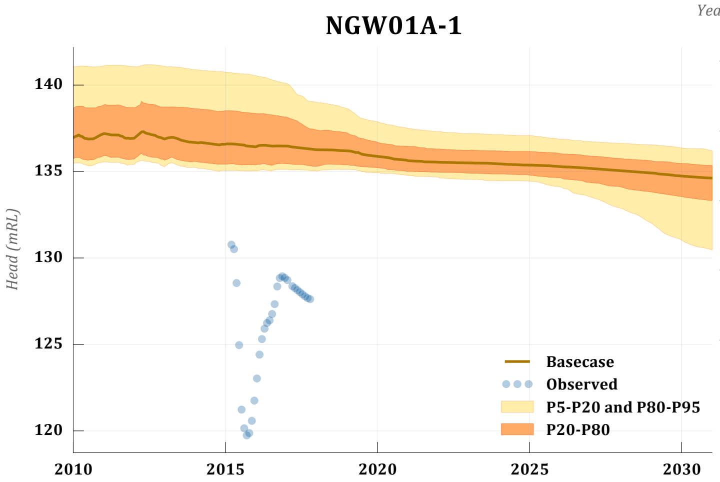
P20-P80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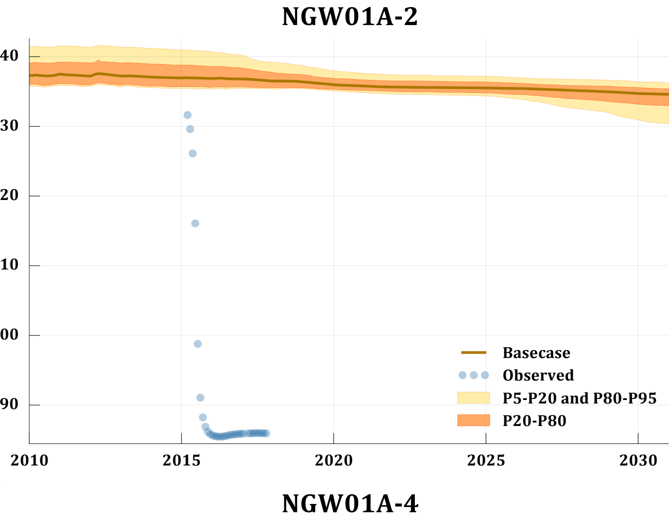
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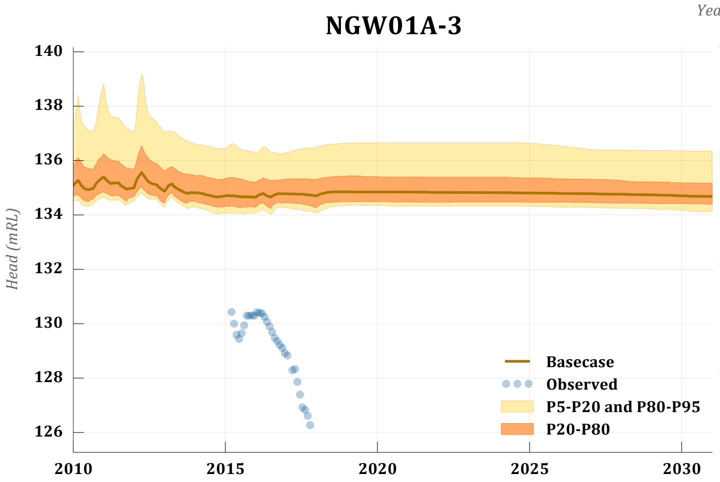
P20-P80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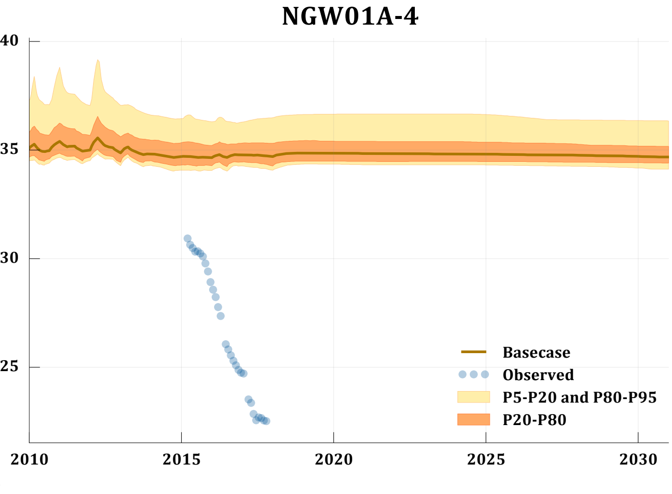
P20-P80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P20-P80

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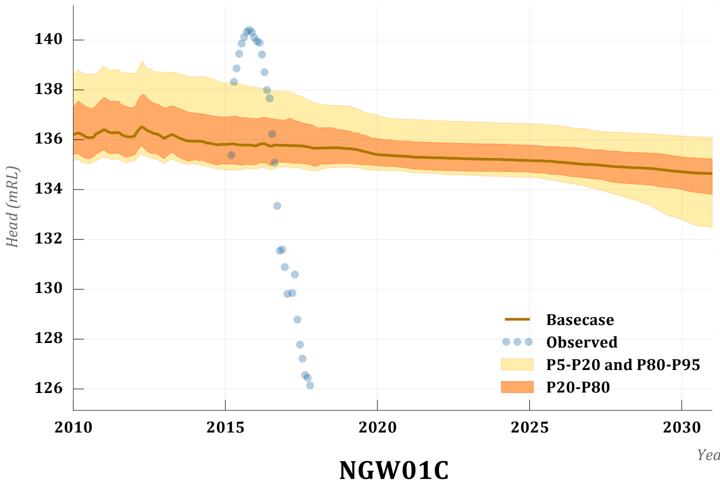

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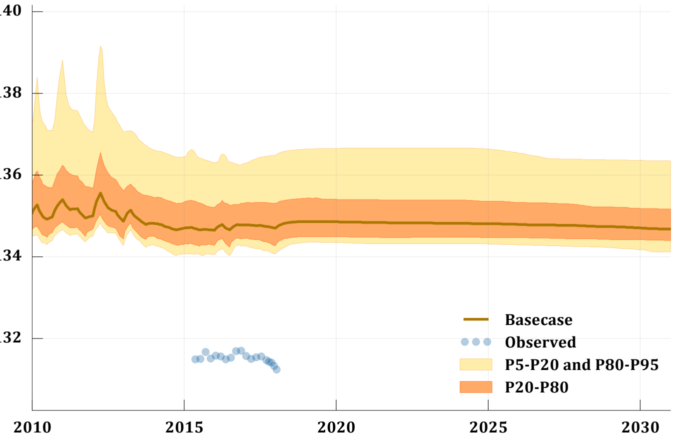

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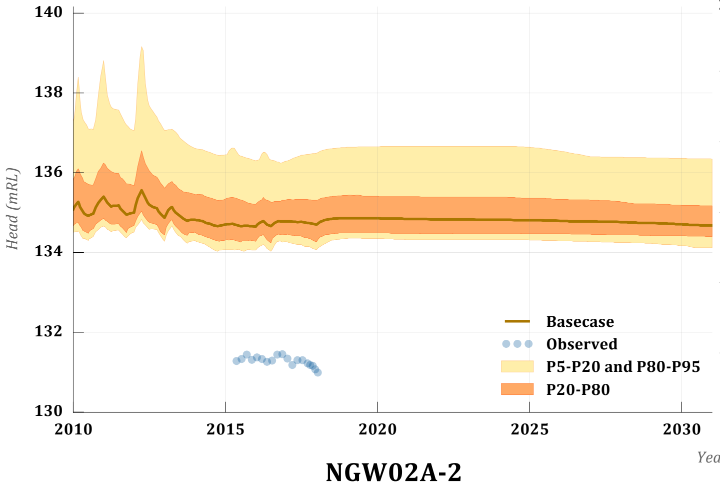

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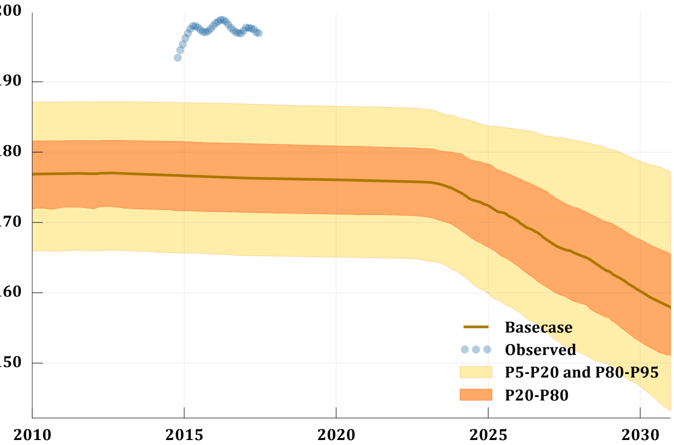

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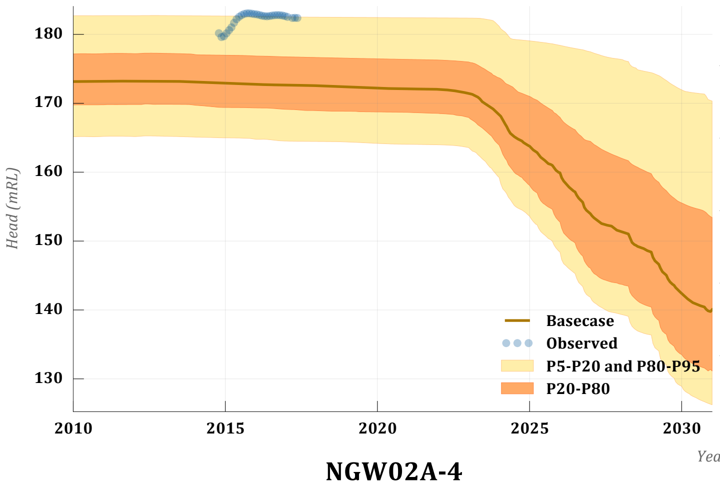

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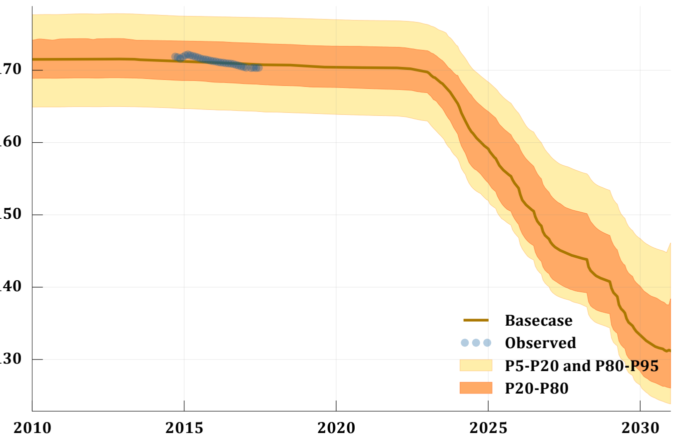

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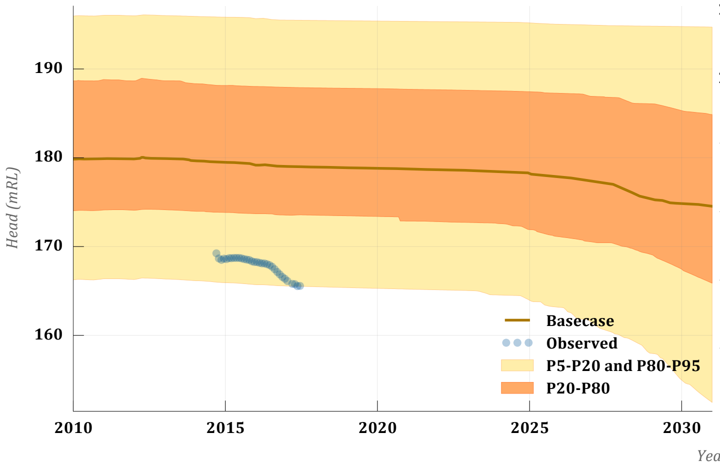

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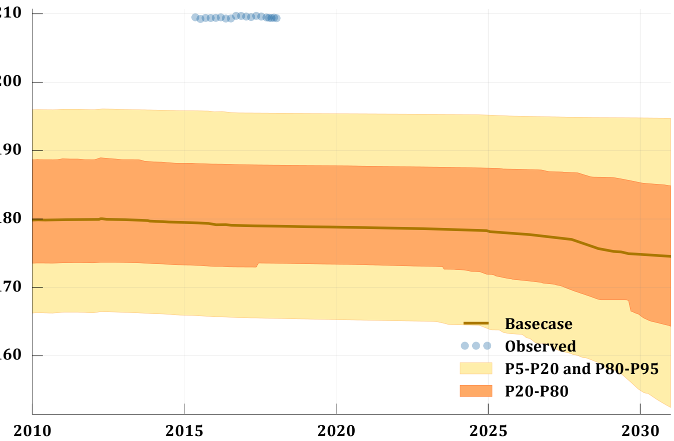

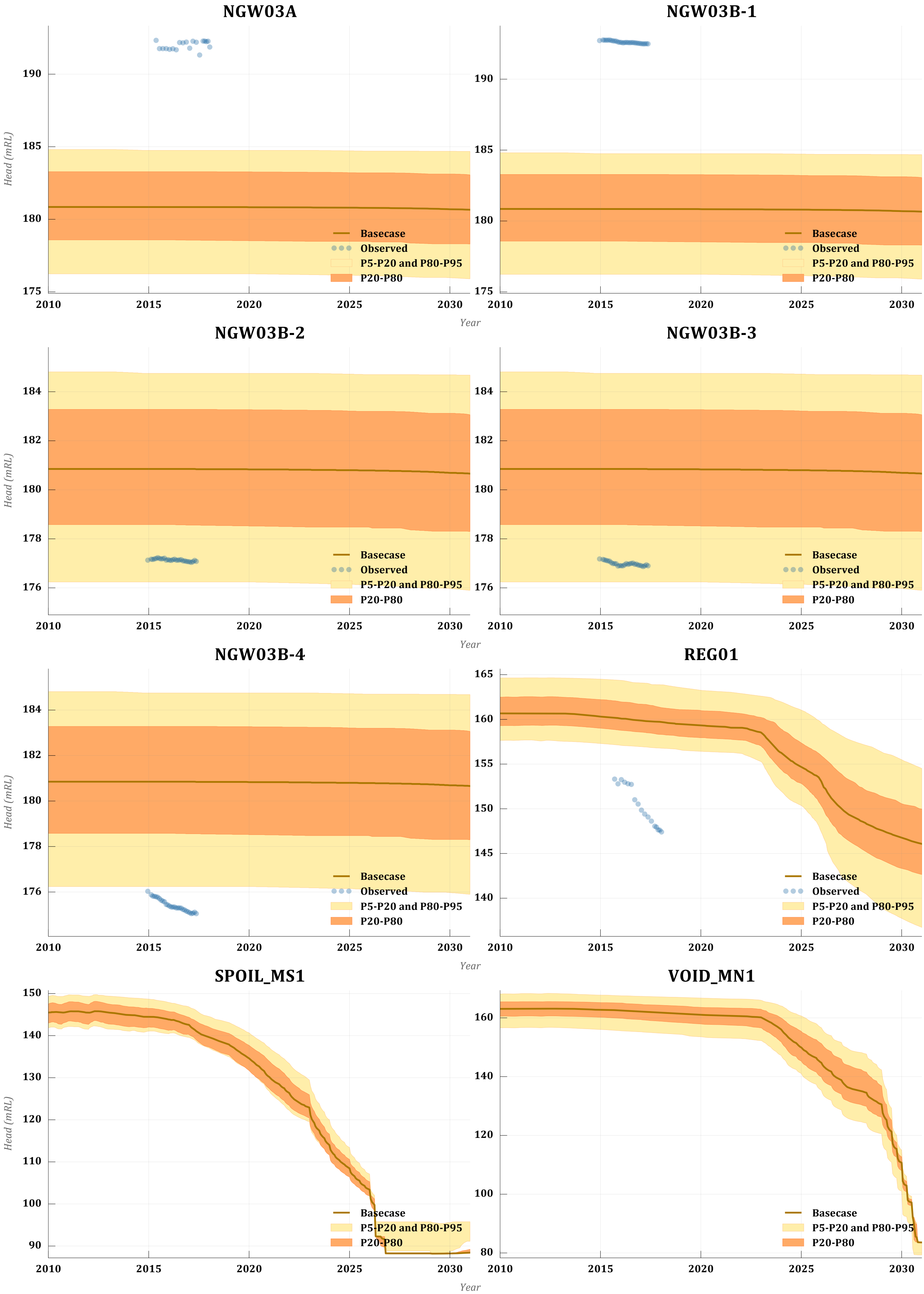

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NGW03B-3
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VOID_MN1
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Year
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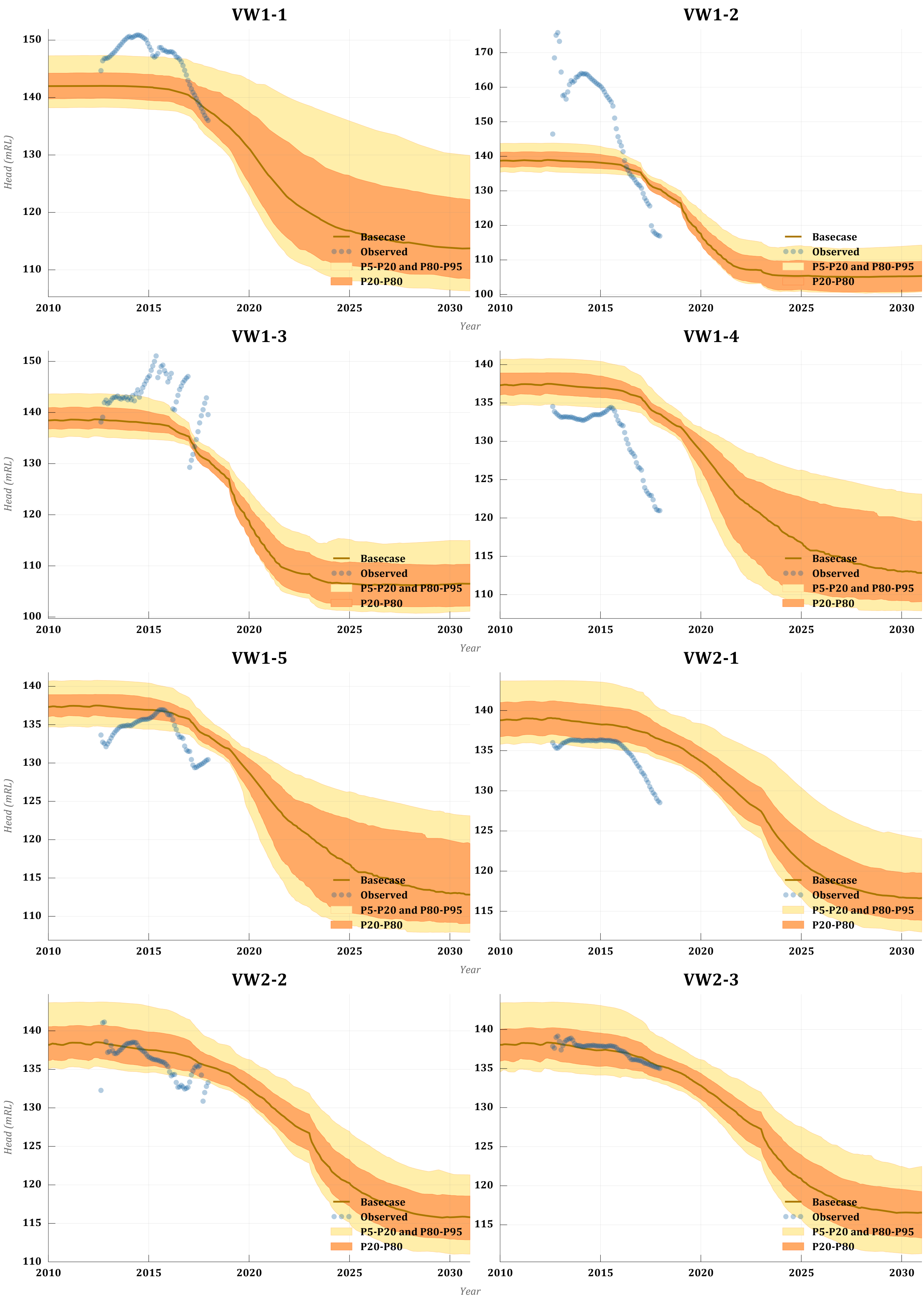
P5-P20 and P80-P95
P20-P80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Year
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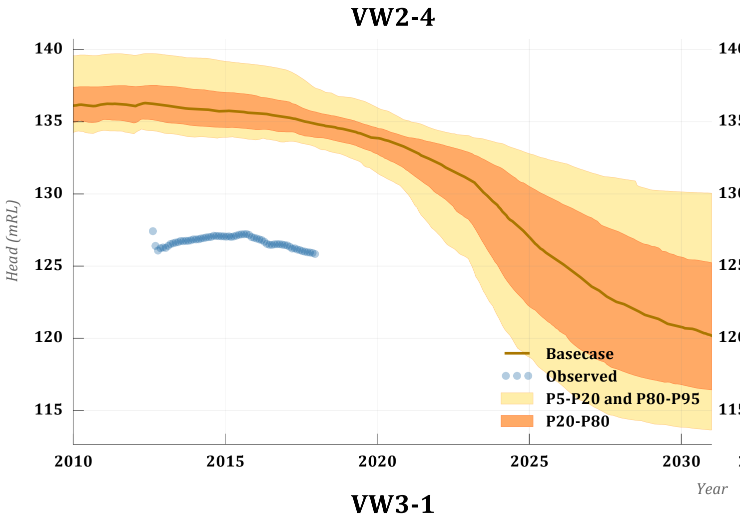
Observed
P5-P20 and P80-P95
P20-P80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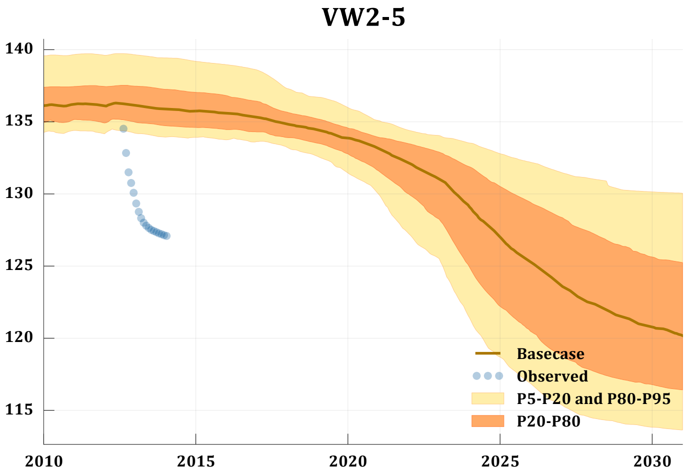
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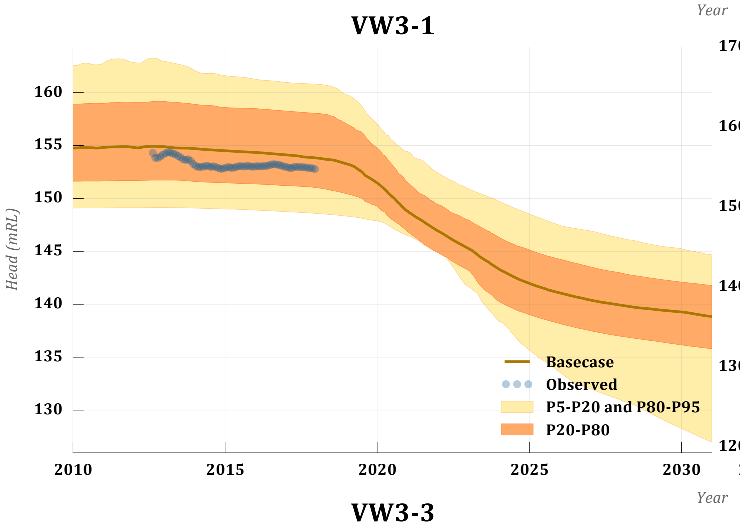
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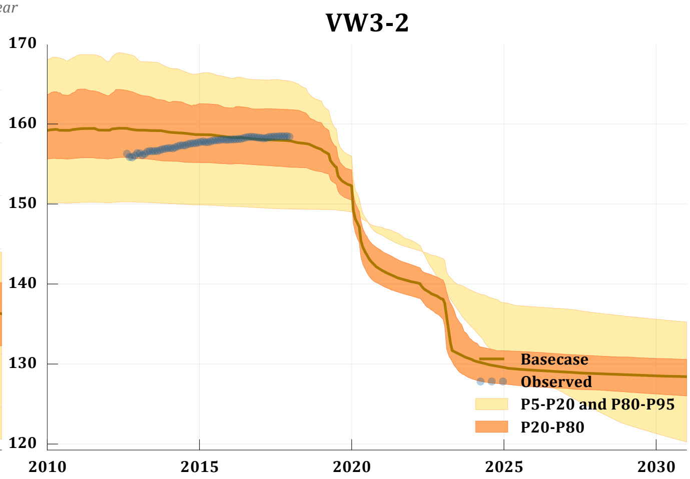
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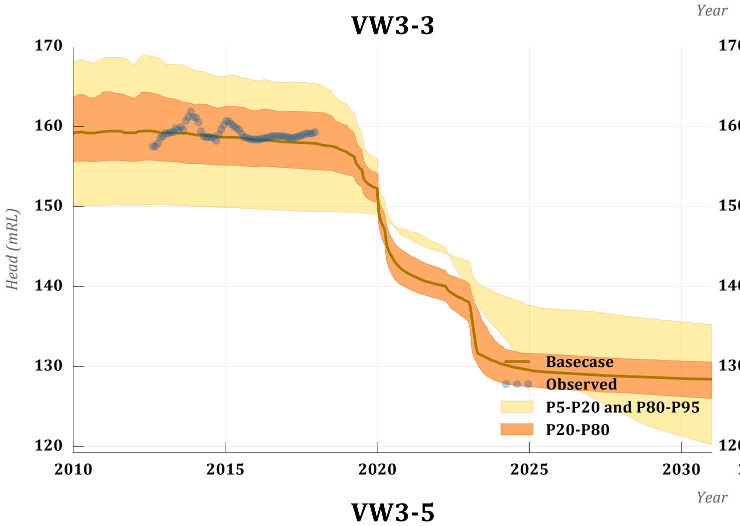
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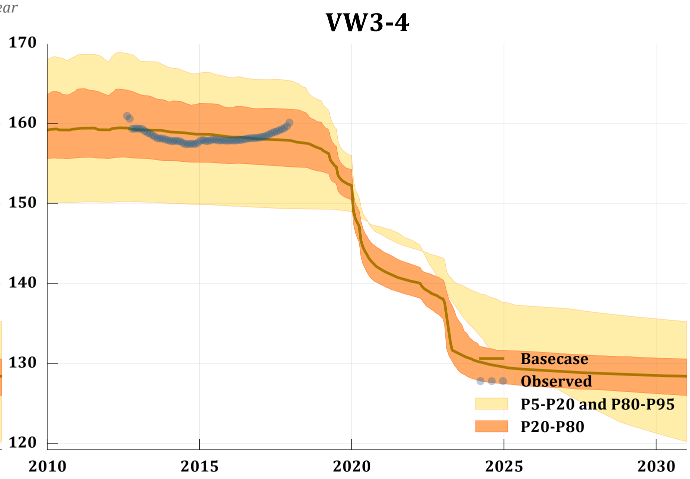
P20-P80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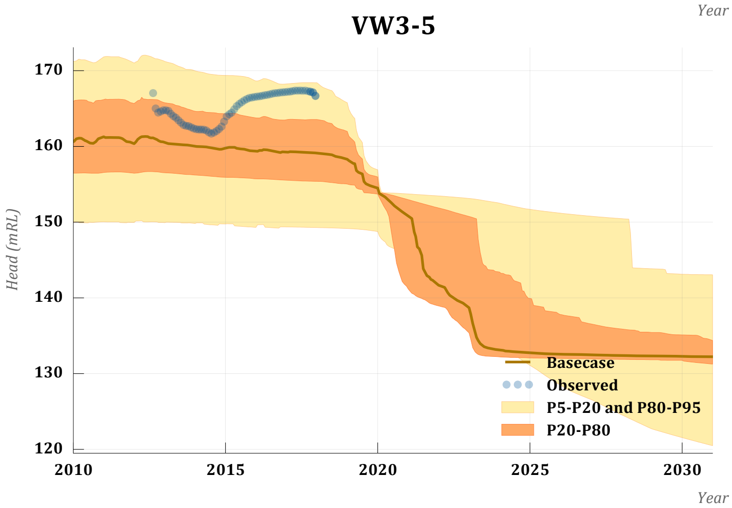
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P20-P80

Appendix B Compliance with government policy

B1 Groundwater monitoring and management plan

B1.1 Aquifer interference policy

This section discusses the ability of the MCCO Project to comply with the AIP. Table B1.1 to Table B1.3 below compare the groundwater impact predictions for the MCCO Project against the requirements under the AIP.

Table B1.1 Accounting for or preventing the take of water

AIP requirement		Proponent response
1	Described the water source (s) the activity will take water from?	Section 2.2 describes the water sharing plans that the MCCO Project will take water from, namely: • Sydney Basin North Coast Fractured and Porous Rock Groundwater Sources Water Sharing Plan; and • Hunter Unregulated and Alluvial Water Sources Water Sharing Plan.
2	Predict the total amount of water that will be taken from each connected groundwater or surface water source on an annual basis as a result of the activity?	Section 7.1.1 and Section 7.1.3 summarise the peak take of groundwater and surface water from each water source due to the approved mining and the additional incremental effect of the proposed MCCO Additional Mining Area.
3	Predicted the total amount of water that will be taken from each connected groundwater or surface water source after the closure of the activity?	Section 7.2 describes post mining impacts.
4	Made these predictions in accordance with Section 3.2.3 of the AIP? (page 27)	Based on 3D numerical modelling.
5	Described how and in what proportions this take will be assigned to the affected aquifers and connected surface water sources?	Table 7.1 summarises the peak take of surface water and groundwater from each water source due to the approved mining and the additional incremental effect of the Proposed MCCO Additional Mining Area.
6	Described how any licence exemptions might apply?	Not necessary.
7	Described the characteristics of the water requirements?	Refer to surface water assessment.
8	Determined if there are sufficient water entitlements and water allocations that are able to be obtained for the activity?	Section 2.4 describes the entitlements held by the proponent and indicates these are sufficient to account for water taken from the potentially affected water sources. In accordance with current development consent requirements, the proponent will ensure all necessary water licences are obtained for the development.

AIP requirement		Proponent response
9	Considered the rules of the relevant water sharing plan and if it can meet these rules?	The 'Cease to Pump' rules for the Wybong Creek require abstraction to cease if no flow is detected at specified locations along the creek. The predicted take of water from the Wybong Creek Water Source due to the activity is an indirect and passive water take that occurs not due to pumping from the water source, but due to depressurisation of the underlying bedrock being mined. This rule has been considered and it is concluded it is not relevant as it is designed for active pumping sites.
10	Determined how it will obtain the required water?	Via seepage to the mine face (refer to Section 7.1.1). Mangoola also hold licences to take water from the regulated sections of the Hunter River.
11	Considered the effect that activation of existing entitlement may have on future available water determinations?	The following share components are available for each of the water sources to be impacted by the approved and proposed activity: • Hunter Unregulated and Alluvial Water Source – 2443 aquifer licence shares; and • Sydney Basin North Coast Water Source – 64673.5 aquifer licence shares. Future available water determinations are a matter for the NSW government. The volume of water taken by the MCCO Project is considered an insignificant component of the existing entitlement of the Sydney Basin North Coast Water Source. The very small predicted indirect water take from the Wybong Creek Water Source has been determined to be undetectable in a catchment context. This component cannot be directly measured, but will be subject to further validation using the groundwater model as mining progresses and additional monitoring bore data is collected.
12	Considered actions required both during and post-closure to minimise the risk of inflows to a mine void as a result of flooding?	Refer to the surface water report (HEC, 2019).
13	Developed a strategy to account for any water taken beyond the life of the operation of the Project?	Allocate existing and future groundwater entitlements as necessary to license the MCCO Project predicted water takes. Refer to the surface water report (HEC, 2019) for surface water strategy.

AIP requirement		Proponent response
	Will uncertainty in the predicted inflows have a significant impact on the environment or other authorised water users? Items 14-16 must be addressed if so.	There is inherent uncertainty in the predictions of groundwater models as the 'water take' predictions are difficult to measure and validate. Despite this fact, groundwater model uncertainty analysis has indicated that potential inflows generated from the 'very likely' to 'unlikely' uncertainty ranges can be accounted for through the currently held water licenses. There are small areas with moderate potential to support terrestrial GDEs along Big Flat Creek within the area of predicted shallow water table drawdown resulting from the proposed MCCO Additional Mining Area. The degree to which the potential GDEs are dependent on groundwater is currently unclear, however they are expected to be largely dependent on surface water flows and rainfall-recharge for their water needs (*pers. comm* Umwelt 2019). There are a number of registered bores located within the 'unlikely' to 'very unlikely' groundwater drawdown zones for the deeper bedrock strata. However, the locations of these bores suggest that they will be shallow and take water from the Wybong Creek Alluvium, which is not predicted to be impacted in these locations. Given this, some uncertainty in the predictions is not expected to have a significant impact on other water users.
14	Considered any potential for causing or enhancing hydraulic connections, and quantified the risk?	Open cut mining is not expected to generate significant changes in hydraulic connections beyond the pit shell.
15	Quantified any other uncertainties in the groundwater or surface water impact modelling conducted for the activity?	An uncertainty analysis has been completed to identify model features and parameters that create changes in the predictions.
16	Considered strategies for monitoring actual and reassessing any predicted take of water throughout the life of the Project, and how these requirements will be accounted for?	Ongoing monitoring and verification of modelling.

Table B1.2 Determining water predictions

AIP requirement		Proponent response
1	Addressed the minimum requirements found on page 27 of the AIP for the estimation of water quantities both during and following cessation of the proposed activity?	Predictions based on modelling made to address the requirements of page 27 of the AIP are provided in Section 7.

Table B1.3 Determining water predictions

AIP requirement		Proponent response
1	Establishment of baseline groundwater conditions?	Refer to Section 5. Water quality and level data has been collected at the MCCO Project area since 2005 for some of the key groundwater units and tested for a selection of water quality analytes. The monitoring network has been adapted over time to ensure that good spatial coverage is maintained.
2	A strategy for complying with any water access rules?	Not applicable as water is taken in an indirect passive manner.
3	Potential water level, quality or pressure drawdown impacts on nearby basic landholder rights water users?	There is one 'stock and domestic' water supply bore identified as being on private property and with the potential of developing over 2 m drawdown due to the proposed MCCO Additional Mining Area. Make good provisions would be applied at the site if the need arose. One additional bore is predicted to be impacted due to cumulative mining impacts. The bore is located on a property that already has voluntary acquisition right afforded by the current Mangoola Coal Mine Project Approval due to noise impacts.
4	Potential water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources?	There is one private water supply bore identified as being on private property and with the potential of developing over 2 m drawdown due to the proposed MCCO Additional Mining Area. Make good provisions would be applied at the site if the need arose. One additional bore is predicted to be impacted due to cumulative mining and already has voluntary acquisition right afforded by the current Mangoola Coal Mine.
5	Potential water level, quality or pressure drawdown impacts on groundwater dependent ecosystems?	There are no high priority GDEs, as defined within WSPs, within the predicted area of drawdown. However, there are small areas of terrestrial vegetation communities located along Big Flat Creek, and in areas with over 1 m predicted drawdown, that have a moderate potential to support terrestrial GDEs. The degree to which the potential GDEs are dependent on groundwater is currently unclear but they are expected to be largely dependent on surface water flows and rainfall-recharge for their water needs (*pers. comm* Umwelt 2019).

AIP requirement		Proponent response
6	Potential for increased saline or contaminated water inflows to aquifers and highly connected river systems?	The final void in the MCCO Additional Mining Area will act as a 'groundwater sink' therefore no saline or contaminated water inflows to aquifers and highly connected river systems will occur. There is the potential for water from the approved Mangoola Coal Mine to migrate away from the backfilled mining area, although most of this water will be recaptured by the MCCO Additional Mining Area final void.
7	Potential to cause or enhance hydraulic connection between aquifers?	Only open cut mining is proposed which is not expected to generate significant changes in hydraulic connection beyond the pit shell.
8	Potential for river bank instability, or high wall instability or failure to occur?	Refer to surface water report (HEC, 2019).
9	Details of the method for disposing of extracted activities (for CSG activities)?	N/A

There are two levels of minimal impact considerations specified in the AIP. If the predicted impacts are less than the Level 1 minimal impact considerations, then these impacts will be considered as acceptable. Where the predicted impacts are greater than the Level 1 minimal impact considerations then the AIP requires additional studies to fully assess these predicted impacts. If this assessment shows that the predicted impacts do not prevent the long-term viability of the relevant water-dependent asset, then the impacts will be considered to be acceptable. The modelling indicates the Level 1 minimal impact consideration thresholds could be exceeded for the proposed MCCO Additional Mining Area in the form of > 2 m drawdown at one private bore.

B1.2 Planning Environmental Assessment Requirements (SEARs)

Table B1.4 Key SEARs Issues - Water

Requirement	Comment relating to MCCO Project
A detailed site water balance, including a description of site water demands, water disposal methods (inclusive of volume and frequency of any water discharges), water supply infrastructure and water storage structure.	Refer to surface water report (HEC, 2019).
Identification of any licensing requirements or other approvals under the NSW *Water Act 1912* and/or Water Management Act 2000.	Section 2.1 discusses the requirements of the Water Management Act.
Demonstration that water for the construction and operation of the proposed development can be obtained from an appropriately authorised and reliable supply in accordance with the operating rules of any relevant Water Sharing Plan (WSP) or water source embargo.	Section 7 discusses the potential mining and post mining takes from the proposed development in relation to the relevant WSPs.
An assessment of any likely flooding impacts of the development.	Refer to surface water report (HEC, 2019).
The measures which would be put in place to control sediment runoff and avoid erosion.	Refer to surface water report (HEC, 2019).
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.	Section 7 discusses the likely impacts on groundwater resources. Refer to surface water report (HEC, 2019) for surface water components.
An assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure, and other water users.	Section 7 discusses the likely impacts on aquifers and other groundwater users.
An assessment of the likely impacts of the development on a water resource, in relation to coal seam gas development and large coal mining development under the Environment Protection and Biodiversity Conservation Act 1999 (see Attachment 3).	See Table B1.5 for responses to this requirement.

The following table (Table B1.5) addresses comments in SEARs Attachment 3 that relate to groundwater resources. In particular Assessment Requirement 15, which states that "the EIS must include a detailed assessment of the potential impacts of the proposed action on water resources. The water assessment must be undertaken in accordance with the IESC Information Guidelines: (http://iesc.environment.gov.au/publications/information-guidelines-independent-expertscientific-committee-advice-coal-seam-gas) and provide the information outlined in these guidelines including (… *see items listed in Table B1.5*)". SEARs Attachment 3 provides a high-level overview of the information required. A more detailed comparison with the IESC requirements is provided in Sections B2B2.7 and 0 of this report.

Table B1.5 SEARs Attachment 3 – Commonwealth Department of Environment and Energy assessment requirements.

Assessment Requirement 15	Comment relating to MCCO Project
a) Hydrogeological assessment:	---
i. Provision of hydrogeological conceptualisations.	Section 5.5 presents the site conceptualisation Sections 3, 4, & 5 present the supporting datasets.
ii. Descriptions of geology and hydrogeology.	Sections 4 and 5 present the geological and hydrogeological information.
iii. Predictions of groundwater changes over the life of the proposed project (e.g. using numerical groundwater models).	Section 7.1 presents the predicted groundwater changes over the life of the mine generated using the numerical groundwater model.
iv. Predictions of groundwater recovery beyond the life of the proposed project (e.g. using numerical groundwater models).	Section 7.2 presents the predicted post mining groundwater changes generated using the numerical groundwater model.
v. Reference all of the above to analysis on groundwater quality and quantity data gathered from the existing project.	Refer to Section 7.
b) Surface water assessment:	Refer to surface water report (HEC, 2019).
c) Ecological and ecohydrological assessment:	Refer to ecology report.
d) Cumulative impact assessment:	---
i. Identify all surrounding existing and known future operations that could contribute cumulatively to surface water and groundwater impacts.	Section 1.3.3 discusses surrounding mining operations.
ii. The proposed project area is within the Hunter Subregion of the Northern Sydney Basin Bioregional Assessment (BA) area. While the proposed extension is not within the BA 'additional coal resource developments' pathway, the proponent should consider cumulative impacts with reference to the BA assessment.	Section 1.3.3 discusses the potential for cumulative impacts with surrounding mining operations.
e) Final landform and rehabilitation assessment:	---
i. Provision of a rehabilitation strategy.	
ii. Predictions of final void water quality and quantity.	Refer to surface water assessment (HEC, 2019).
iii. Discussion on re-equilibration of groundwater and eventual discharges to the environment.	Section 7.2 discusses post mining recovery and potential long term impacts.
iv. Comprehensive risk assessment.	Risks are identified in Section 5.6 and Section 7, with a management plan discussed in Section 8. Numerical model uncertainty analysis is presented in Appendix A.

B2 Compliance with Commonwealth government policy

In January 2019, the DoEE determined the MCCO Project (EPBC 2018/8280) was a controlled action under Section 75 of the EPBC Act, with the controlling provisions being:

- listed threatened species and communities; and
- a water resource, in relation to coal seam gas development and large coal mining development.

This section of the report considers the impact of the MCCO Project on groundwater resources, and if these impacts are significant according to the guidelines. The discussion focusses on the incremental impact of the Proposed MCCO Additional Mining Area component of the MCCO Project, not the impact of the approved Mangoola Coal Mine which was considered to not be a controlled action in 2008 (EPBC 2007/3228). Mangoola Coal Mine is discussed as part of the cumulative impacts from mining where relevant.

It is important to note that coal mining will always impact the groundwater regime, as dewatering of the mine workings is essential to extract coal safely. However, we have interpreted the DoEE guidelines to mean that this unavoidable impact is only considered significant where there is a consequence from this impact, i.e. that groundwater users or the environment are affected by changes in the quality or quantity of groundwater.

The guidelines indicate that the MCCO Project must have '*a real or not remote chance or possibility that it will directly or indirectly result in a change to*' the '*hydrology*' or '*water quality*' of the water resource. This change must be of '*sufficient scale or intensity as to reduce the current or future utility of the water resource for third party users'*. Third party users can include '*environmental and other public benefit outcomes, or to create a material risk of such reduction in utility occurring'*. Furthermore, '*whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the water resource which is impacted, and upon the intensity, duration, magnitude and geographic extent of the impacts'*.

B2.1 Water availability to users

There is one known operating private bore within proximity to the approved Mangoola Coal Mine that is predicted to be impacted by more than 2 m drawdown. The property on which this bore is located already has voluntary acquisition rights afforded by the Mangoola Coal Mine Project Approval. There is one additional bore that is likely to be impacted by more than 2 m drawdown as a result of mining at the MCCO Additional Mining Area. If the bore is confirmed to be screened in geological units which may be affected by the proposed MCCO Project then a 'make good' agreement will be arranged with the affected landholder.

B2.2 Water availability to the environment

The numerical modelling indicates the depressurisation due to the Proposed MCCO Additional Mining Area will not significantly reduce the flow of Permian groundwater to the alluvial aquifers during mining. Therefore, during mining there is not predicted to be any drawdown of over 1 m occurring within the alluvial aquifers in proximity to the mine.

There are small areas of non-AIP moderate potential terrestrial GDEs within the area of predicted shallow water table drawdown resulting from the proposed MCCO Additional Mining Area. The extent to which the vegetation communities within these potential GDEs are dependent on groundwater resources has yet to be confirmed. However, they are expected to be largely dependent on surface water flows and rainfall-recharge for their water needs (*pers. comm* Umwelt 2019). Monitoring by Mangoola Coal at RTR-SPR-17, a location within one of the potential GDE areas along Big Flat Creek, has not identified any potential dieback that could be associated with lowering of the shallow water table, despite shallow groundwater levels starting to be affected by dewatering impacts from Mangoola Coal Mine.

B2.3 Water quality

The post mining pit lake water levels are predicted to recover to a new equilibrium level; approximately 55 metres below pre-mining groundwater levels in the proposed MCCO Additional Mining Area final void, and approximately 30 metres below pre-mining groundwater levels in the approved Mangoola Coal Mine final void.

The final void in the proposed MCCO Additional Mining Area will act as a sink in perpetuity with no escape of contained void water. The final void in the approved Mangoola Coal Mine will also act as a long term groundwater sink. However, due to the size and shape of the Mangoola Coal Mine the final void will not capture all water that enters the backfilled mining area. Therefore, in some areas of the backfilled mining area there is potential for water quality changes generated within the mining footprint to migrate into the bedrock. This is predicted to primarily occur within the deeper strata rather than the shallow near surface strata, with much of the water being recaptured by the MCCO Additional Mining Area final void.

B2.4 Cumulative impacts

Cumulative impacts from both the approved Mangoola Coal Mine and the proposed MCCO Additional Mining Area becoming operational are notable within the deeper bedrock strata. Logically the drawdown that is most attributable to the Proposed MCCO Additional Mining Area is adjacent to that mining area. Cumulative drawdown propagates to the north and west of the mine within the deeper bedrock strata, with the zone of influence reducing with distance from the mining areas. Cumulative impacts within the shallower layers are limited to a zone close to Big Flat Creek, and the transition from Big Flat Creek colluvium to Wybong Creek alluvium.

The cumulative impacts suggest the Proposed MCCO Additional Mining Area will only add a small additional 'water take' from alluvial and surface water sources. The predicted cumulative take is within the licensed groundwater entitlements currently held by Mangoola Coal Mine.

Surrounding mines are a sufficient distance away from the MCCO Project that cumulative impacts with other mining operations would be highly unlikely.

B2.5 Avoidance or mitigation measures

The proposed mine plan does not intersect alluvial aquifers. The impacts on the alluvial aquifers are therefore indirect, and occur through the depressurisation of the underlying Permian coal measures. Locating the mining outside the alluvial areas effectively mitigates the impact upon the alluvial aquifer and connected streams. The groundwater seepage to the mining areas cannot be prevented, and must be removed to ensure safe operating conditions within the mining areas. There is potentially one private groundwater user with a bore that could be impacted by more than 2 m drawdown during development of the MCCO Additional Mining Area, and who would therefore require mitigation measures or make good agreements. One additional bore is within the predicted zone of drawdown for the cumulative MCCO Project. The additional bore is located on a property that already has voluntary acquisition rights for the existing Mangoola Coal Mine.

B2.6 Tabulated impacts

Table B2.1 and Table B2.2 summarise the conclusions compared against DoEE guidelines:

Table B2.1 Summary of impacts to the hydrology of the water resource compared to the DoEE guidelines

Is there a substantial change to the hydrology of the water resource for:	Comment relating to MCCO Project
flow volume?	Modelling predicts changes in flows of groundwater from Permian bedrock to the alluvial aquifers (Sections 7.1.3 & 7.2.2). The changes are predicted to be small. There is one bore to the north of the proposed MCCO Additional Mining Area that may experience a fall in water level of over 2 m as a result of the proposed MCCO Additional Mining.
flow timing?	Cumulative impacts to the alluvium and surface water are predicted to gradually increase and peak post mining (~2040-2045) before reducing in the long term as the system re-equilibrates to the changed hydrogeological baseline conditions. (Sections 7.1.3 & 7.2.2).
flow duration and frequency of water flows?	Volumes of baseflow removed are small compared to surface water flows within the Wybong Creek system. Baseflow in Big Flat Creek is predicted to be more significantly impacted by mining, with baseflow in Big Flat Creek reducing to zero in the zone of interest during active mining. During mining the impacts are predicted to primarily occur due to the approved Mangoola Coal Mine. Post mining the absolute impacts will reduce but the impacts related to the MCCO Additional Mining Area will increase. (Sections 7.1.3 & 7.2.2).
recharge rates?	Recharge rates may be altered due to increased recharge through mine spoil heaps – this has been assessed using numerical modelling.
aquifer pressure or pressure relationships between aquifers?	Pressures will reduce in coal measures during the mine life but slowly recover to a new equilibrium pressure/level post mining. (Sections 7.1.2 & 7.2.1).
groundwater table levels?	The water table within the Quaternary alluvium will be largely unaffected, with drawdown of over 1 m only predicted in areas close to the transition from Big Flat Creek colluvium to Wybong Creek alluvium (Section 7.1.2). Water table drawdown will be greater in the weathered zone underlying Big Flat Creek that is located between the two mining areas.
groundwater/surface interactions?	Water table drawdown within the Quaternary alluvium will not produce detectable changes in base flow to or from the interconnected Wybong Creek. Groundwater levels along Big Flat Creek during mining will primarily reduce due to the approved Mangoola Coal Mine, with only a small additional area of drawdown predicted due to the proposed MCCO Additional Mining Area. There are small areas of potential terrestrial GDEs located along Big Flat Creek that could be impacted by a reduced shallow water table (Section 7.1.6), however they are expected to be largely dependent on surface water flows and rainfall-recharge for their water needs (*pers. comm* Umwelt 2019).

Is there a substantial change to the hydrology of the water resource for:	Comment relating to MCCO Project
river/floodplain connectivity?	No impact as no mining proposed in floodplain. There is indirect connectivity through the Permian aquifer to the base of the Quaternary alluvium and river system. The predicted indirect takes from the river and floodplain area are small and unlikely to be detectable (Sections 7.1.3 & 7.2.2).
inter-aquifer connectivity?	No significant changes in connectivity are considered likely outside the pit shells.
coastal processes?	Not applicable.
large scale subsidence?	Only open cut mining is proposed. No large scale subsidence is therefore expected.
other uses?	No.
state water resource plans?	Numerical modelling has been used to assess volumes of groundwater that need to be accounted for with water licences. Proponent holds sufficient water licences for the predicted Permian water and Wybong Creek alluvial water take (Sections 7.1.4 & 7.2.4).
cumulative impact?	Yes – with the approved Mangoola Coal Mine only. This has been assessed using a numerical groundwater model (Appendix A).

Table B2.2 Summary of impacts to the water quality of the water resource compared to the DoEE guidelines

Is there a substantial change in water quality of the water resource:	Comment
create risks to human or animal health or the condition of the natural environment?	No
substantially reduce the amount of water available for human consumptive uses or for other uses dependent on water quality?	No
cause persistent organic chemicals, heavy metals, salt or other potentially harmful substances to accumulate in the environment?	Evaporation will concentrate salt in the final void lakes.
results in worsening of local water quality where local water quality is superior to local or regional water quality objectives (i.e. ANZECC guidelines for Fresh and Marine Water Quality)?	No
salt concentration/generation?	Evaporation will concentrate salt in the final void lakes.
cumulative impact?	Cumulative impacts have been estimated using a numerical model. The cumulative impacts are not predicted to results in a substantial changed in water quality of the surrounding bedrock water resources.
if significant impact on hydrology or water quality above, the likelihood of significant impacts to function and ecosystem integrity are to be assessed. The ecosystem function and integrity of a water resource includes the ecosystem components, processes and benefits/services that characterise the water resource.	No

B2.7 IESC Information Guidelines for Coal Seam Gas and Large Coal Mining Development

The Independent Expert Scientific Committee (IESC) on Coal Seam Gas and Large Coal Mining Development has information guidelines for advice on coal seam gas and large coal mining development proposals (IESC, 2018). The following tables specify where the IESC information requirements for individual proposals have been addressed within this report.

Table B2.3 Description of the proposal

Project Information	Addressed in section
Provide a regional overview of the proposed project area including a description of the geological basin; coal resource; surface water catchments; groundwater systems; water-dependent assets; and past, present and reasonably foreseeable coal mining and CSG developments.	Sections 1,3,4 & 5
Describe the statutory context, including information on the proposal's status within the regulatory assessment process and any applicable water management policies or regulations.	Section 2
Describe the proposal's location, purpose, scale, duration, disturbance area, and the means by which it is likely to have a significant impact on water resources and water-dependent assets.	Sections 1.1 & 5.6
Describe how impacted water resources are currently being regulated under state or Commonwealth law, including whether there are any applicable standard conditions.	Section 2

Table B2.4 Risk Assessment

Project Information	Addressed in section
Identify and assess all potential environmental risks to water resources and water-related assets, and their possible impacts. In selecting a risk assessment approach consideration should be given to the complexity of the project, and the probability and potential consequences of risks.	Sections 5.6, 7, 8 & Appendix A
Assess risks following the implementation of any proposed mitigation and management options to determine if these will reduce risks to an acceptable level based on the identified environmental objectives.	Section 8 & Appendix A
Incorporate causal mechanisms and pathways identified in the risk assessment in conceptual and numerical modelling. Use the results of these models to update the risk assessment.	Section 7 & Appendix A
The risk assessment should include an assessment of: • all potential cumulative impacts which could affect water resources and water-related assets; and, • mitigation and management options which the proponent could implement to reduce these impacts.	Sections 7 & 8

Table B2.5 Groundwater – Context and conceptualisation

Project Information	Addressed in section
Describe and map geology at an appropriate level of horizontal and vertical resolution including: • definition of the geological sequence(s) in the area, with names and descriptions of the formations and accompanying surface geology, cross-sections and any relevant field data. • geological maps appropriately annotated with symbols that denote fault type, throw and the parts of sequences the faults intersect or displace.	Section 4
Define and describe or characterise significant geological structures (e.g. faults, folds, intrusives) and associated fracturing in the area and their influence on groundwater – particularly groundwater flow, discharge or recharge. • Site-specific studies (e.g. geophysical, coring / wireline logging etc.) should give consideration to characterising and detailing the local stress regime and fault structure (e.g. damage zone size, open/closed along fault plane, presence of clay/shale smear, fault jogs or splays). • Discussion on how this fits into the fault's potential influence on regional-scale groundwater conditions should also be included.	Sections 4.3, 5.5 & 7.3
Provide site-specific values for hydraulic parameters (e.g. vertical and horizontal hydraulic conductivity and specific yield or specific storage characteristics including the data from which these parameters were derived) for each relevant hydrogeological unit. In situ observations of these parameters should be sufficient to characterise the heterogeneity of these properties for modelling.	Section 5.2.4 & 5.2.5
Provide time series level and water quality data representative of seasonal and climatic cycles.	Section 5 & Appendix A
Provide data to demonstrate the varying depths to the hydrogeological units and associated standing water levels or potentiometric heads, including direction of groundwater flow, contour maps, and hydrographs. All boreholes used to provide this data should have been surveyed.	Section 5
Provide hydrochemical (e.g. acidity/alkalinity, electrical conductivity, metals, and major ions) and environmental tracer (e.g. stable isotopes of water, tritium, helium, strontium isotopes, etc.) characterisation to identify sources of water, recharge rates, transit times in aquifers, connectivity between geological units and groundwater discharge locations.	Section 5
Describe the likely recharge, discharge and flow pathways for all hydrogeological units likely to be impacted by the proposed development.	Section 5
Assess the frequency (and time lags if any), location, volume and direction of interactions between water resources, including surface water/groundwater connectivity, inter-aquifer connectivity and connectivity with sea water.	Section 5

Table B2.6 Groundwater – Numerical modelling

Project Information	Addressed in section
Provide a detailed description of all analytical and/or numerical models used, and any methods and evidence (e.g. expert opinion, analogue sites) employed in addition to modelling.	Section 6 & Appendix A2
Undertaken groundwater modelling in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al. 2012), including independent peer review.	Appendix A & Section 6.2
Calibrate models with adequate monitoring data, ideally with calibration targets related to model prediction (e.g. use baseflow calibration targets where predicting changes to baseflow).	Appendix A3
Describe each hydrogeological unit as incorporated in the groundwater model, including the thickness, storage and hydraulic characteristics, and linkages between units, if any.	Appendix A
Describe the existing recharge/discharge pathways of the units and the changes that are predicted to occur upon commencement, throughout, and after completion of the proposed project.	Section 7 & Appendix A
Describe the various stages of the proposed project (construction, operation and rehabilitation) and their incorporation into the groundwater model. Provide predictions of water level and/or pressure declines and recovery in each hydrogeological unit for the life of the project and beyond, including surface contour maps for all hydrogeological units.	Section 7 & Appendix A
Identify the volumes of water predicted to be taken annually with an indication of the proportion supplied from each hydrogeological unit.	Section 7
Undertake model verification with past and/or existing site monitoring data.	Appendix A3.3.5
Provide an explanation of the model conceptualisation of the hydrogeological system or systems, including multiple conceptual models if appropriate. Key assumptions and model limitations and any consequences should also be described.	Section 5.5
Consider a variety of boundary conditions across the model domain, including constant head or general head boundaries, river cells and drains, to enable a comparison of groundwater model outputs to seasonal field observations.	Appendix A2
Undertake sensitivity analysis and uncertainty analysis of boundary conditions and hydraulic and storage parameters, and justify the conditions applied in the final groundwater model (see Middlemis and Peeters [in press]).	Section A5
Provide an assessment of the quality of, and risks and uncertainty inherent in, the data used to establish baseline conditions and in modelling, particularly with respect to predicted potential impact scenarios.	Section 5
Undertake an uncertainty analysis of model construction, data, conceptualisation and predictions (see Middlemis and Peeters [in press]).	Appendix A5
Provide a program for review and update of models as more data and information become available, including reporting requirements.	Section 8
Provide information on the magnitude and time for maximum drawdown and post-development drawdown equilibrium to be reached.	Section 7.2

Table B2.7 Groundwater – Impacts on water resources and water dependent assets

Project Information	Addressed in section
Provide an assessment of the potential impacts of the proposal, including how impacts are predicted to change over time and any residual long-term impacts. Consider and describe:	
• any hydrogeological units that will be directly or indirectly dewatered or depressurised, including the extent of impact on hydrological interactions between water resources, surface water/groundwater connectivity, inter-aquifer connectivity and connectivity with sea water.	Section 7
• the effects of dewatering and depressurisation (including lateral effects) on water resources, water-dependent assets, groundwater, flow direction and surface topography, including resultant impacts on the groundwater balance.	Section 7
• the potential impacts on hydraulic and storage properties of hydrogeological units, including changes in storage, potential for physical transmission of water within and between units, and estimates of likelihood of leakage of contaminants through hydrogeological units.	N/A
• the possible fracturing of and other damage to confining layers.	N/A
• for each relevant hydrogeological unit, the proportional increase in groundwater use and impacts as a consequence of the proposed project, including an assessment of any consequential increase in demand for groundwater from towns or other industries resulting from associated population or economic growth due to the proposal.	Section 7 & N/A
Describe the water resources and water-dependent assets that will be directly impacted by mining or CSG operations, including hydrogeological units that will be exposed/partially removed by open cut mining and/or underground mining.	Section 5.4
For each potentially impacted water resource, provide a clear description of the impact to the resource, the resultant impact to any water-dependent assets dependent on the resource, and the consequence or significance of the impact.	Section 7
Describe existing water quality guidelines, environmental flow objectives and other requirements (e.g. water planning rules) for the groundwater basin(s) within which the development proposal is based.	Section 2
Provide an assessment of the cumulative impact of the proposal on groundwater when all developments (past, present and/or reasonably foreseeable) are considered in combination.	Section 7
Describe proposed mitigation and management actions for each significant impact identified, including any proposed mitigation or offset measures for long-term impacts post mining.	Section 8
Provide a description and assessment of the adequacy of proposed measures to prevent/minimise impacts on water resources and water-dependent assets.	Section 8

Table B2.8 Groundwater – Data and monitoring

Project Information	Addressed in section
Provide sufficient data on physical aquifer parameters and hydrogeochemistry to establish pre-development conditions, including fluctuations in groundwater levels at time intervals relevant to aquifer processes.	Section 5 & 8
Develop and describe a robust groundwater monitoring program using dedicated groundwater monitoring wells – including nested arrays where there may be connectivity between hydrogeological units – and targeting specific aquifers, providing an understanding of the groundwater regime, recharge and discharge processes and identifying changes over time.	Section 8
Develop and describe proposed targeted field programs to address key areas of uncertainty, such as the hydraulic connectivity between geological formations, the sources of groundwater sustaining GDEs, the hydraulic properties of significant faults, fracture networks and aquitards in the impacted system, etc., where appropriate.	Section 8
Provide long-term groundwater monitoring data, including a comprehensive assessment of all relevant chemical parameters to inform changes in groundwater quality and detect potential contamination events.	Section 8
Ensure water quality monitoring complies with relevant National Water Quality Management Strategy (NWQMS) guidelines (ANZECC/ARMCANZ 2000) and relevant legislated state protocols (e.g. QLD Government 2013).	Section 8

Table B2.9 Water dependent assets – Context and conceptualisation

Project Information	Addressed in section
Identify water-dependent assets, including: • water-dependent fauna and flora and provide surveys of habitat, flora and fauna (including stygofauna) (see Doody et al. [in press]). • public health, recreation, amenity, Indigenous, tourism or agricultural values for each water resource.	Section 5.4
Identify GDEs in accordance with the method outlined by Eamus *et al*. (2006). Information from the GDE Toolbox (Richardson *et al*. 2011) and GDE Atlas (CoA 2017a) may assist in identification of GDEs (see Doody *et al*. [in press]).	Section 5.4
Describe the conceptualisation and rationale for likely water-dependence, impact pathways, tolerance and resilience of water-dependent assets. Examples of ecological conceptual models can be found in Commonwealth of Australia (2015).	Sections 5.4, 5.6 & ecology report
Estimate the ecological water requirements of identified GDEs and other water-dependent assets (see Doody *et al*. [in press]).	Refer to ecology report
Identify the hydrogeological units on which any identified GDEs are dependent (see Doody *et al*. [in press]).	Section 5 & ecology report
Provide an outline of the water-dependent assets and associated environmental objectives and the modelling approach to assess impacts to the assets.	Section 5.4 & 5.6
Describe the process employed to determine water quality and quantity triggers and impact thresholds for water-dependent assets (e.g. threshold at which a significant impact on an asset may occur).triggers and impact thresholds for water-dependent assets (e.g. threshold at which a significant impact on an asset may occur).	Section 8

Table B2.10 Water dependent assets – Impacts, risk assessment and management of risks

Project Information	Addressed in section
Provide an assessment of direct and indirect impacts on water-dependent assets, including ecological assets such as flora and fauna dependent on surface water and groundwater, springs and other GDEs (see Doody *et al*. [in press]).	Section 7
Describe the potential range of drawdown at each affected bore, and clearly articulate of the scale of impacts to other water users.	Section 7.1.5
Indicate the vulnerability to contamination (e.g. from salt production and salinity) and the likely impacts of contamination on the identified water-dependent assets and ecological processes.	Section 7.2.5
Identify and consider landscape modifications (e.g. voids, on-site earthworks, and roadway and pipeline networks) and their potential effects on surface water flow, erosion and habitat fragmentation of water-dependent species and communities.	Refer to ecology report
Provide estimates of the volume, beneficial uses and impact of operational discharges of water (particularly saline water), including potential emergency discharges due to unusual events, on water-dependent assets and ecological processes.	Refer to surface water assessment and ecology report
Assess the overall level of risk to water-dependent assets through combining probability of occurrence with severity of impact.	Refer to ecology report
Identify the proposed acceptable level of impact for each water-dependent asset based on leading-practice science and site-specific data, and ideally developed in conjunction with stakeholders.	Refer to ecology report
Propose mitigation actions for each identified impact, including a description of the adequacy of the proposed measures and how these will be assessed.	Refer to ecology report

Table B2.11 Water dependent assets – Data and monitoring

Project Information	Addressed in section
Identify an appropriate sampling frequency and spatial coverage of monitoring sites to establish pre-development (baseline) conditions, and test potential responses to impacts of the proposal (see Doody *et al*. [in press]).	Sections 5 & 8
Consider concurrent baseline monitoring from unimpacted control and reference sites to distinguish impacts from background variation in the region (e.g. BACI design, see Doody *et al*. [in press]).	Sections 5 & 8
Develop and describe a monitoring program that	See ecology report

Project Information	Addressed in section
identifies impacts, evaluates the effectiveness of impact prevention or mitigation strategies, measures trends in ecological responses and detects whether ecological responses are within identified thresholds of acceptable change (see Doody *et al*. [in press]).	
Describe the proposed process for regular reporting, review and revisions to the monitoring program.	Section 8
Ensure ecological monitoring complies with relevant state or national monitoring guidelines (e.g. the DSITI guideline for sampling stygofauna [QLD Government 2015]).	See ecology report

Table B2.12 Water and salt balance and water management strategy

Project Information	Addressed in section
Provide a quantitative site water balance model describing the total water supply and demand under a range of rainfall conditions and allocation of water for mining activities (e.g. dust suppression, coal washing etc.), including all sources and uses.	Refer to surface water assessment
Describe the water requirements and on-site water management infrastructure, including modelling to demonstrate adequacy under a range of potential climatic conditions.	Refer to surface water assessment
Provide estimates of the quality and quantity of operational discharges under dry, median and wet conditions, potential emergency discharges due to unusual events and the likely impacts on water-dependent assets.	Refer to surface water assessment
Provide salt balance modelling that includes stores and the movement of salt between stores, and takes into account seasonal and long-term variation.	Refer to surface water assessment

Table B2.13 Cumulative Impacts – Context and conceptualisation

Project Information	Addressed in section
Provide cumulative impact analysis with sufficient geographic and temporal boundaries to include all potentially significant water-related impacts.	Sections 1.3.3, 7 & Appendix A6
Consider all past, present and reasonably foreseeable actions, including development proposals, programs and policies that are likely to impact on the water resources of concern in the cumulative impact analysis. Where a proposed project is located within the area of a bioregional assessment consider the results of the bioregional assessment.	Section 1.3

Table B2.14 Cumulative Impacts – Impacts

Project Information	Addressed in section
Provide an assessment of the condition of affected water resources which includes: • identification of all water resources likely to be cumulatively impacted by the proposed development; • a description of the current condition and quality of water resources and information on condition trends; • identification of ecological characteristics, processes, conditions, trends and values of water resources; • adequate water and salt balances; and, • identification of potential thresholds for each water resource and its likely response to change and capacity to withstand adverse impacts (e.g. altered water quality, drawdown).	Section 7 Section 5 See ecology report Appendix A & surface water assessment Section 7
Assess the cumulative impacts to water resources considering: • the full extent of potential impacts from the proposed project, (including whether there are alternative options for infrastructure and mine configurations which could reduce impacts), and encompassing all linkages, including both direct and indirect links, operating upstream, downstream, vertically and laterally; • all stages of the development, including exploration, operations and post closure / decommissioning; • appropriately robust, repeatable and transparent methods; • the likely spatial magnitude and timeframe over which impacts will occur, and significance of cumulative impacts; and, • opportunities to work with other water users to avoid, minimise or mitigate potential cumulative impacts.	Section 7 & Appendix A5

Table B2.15 Cumulative Impacts – Mitigation, monitoring and management

Project Information	Addressed in section
Identify modifications or alternatives to avoid, minimise or mitigate potential cumulative impacts. Evidence of the likely success of these measures (e.g. case studies) should be provided.	Section 8
Identify measures to detect and monitor cumulative impacts, pre and post development, and assess the success of mitigation strategies.	Section 8
Identify cumulative impact environmental objectives.	Section 8
Describe appropriate reporting mechanisms.	Section 8
Propose adaptive management measures and management responses.	Section 8

Table B2.16 Final landform and voids – coal mines

Project Information	Addressed in section
Identify and consider landscape modifications (e.g. voids, on-site earthworks, and roadway and pipeline networks) and their potential effects on surface water flow, erosion, sedimentation and habitat fragmentation of water-dependent species and communities.	Refer to surface water assessment
Assess the adequacy of modelling, including surface water and groundwater quantity and quality, lake behaviour, timeframes and calibration.	Appendix A5
Provide an evaluation of stability of void slopes where failure during extreme events or over the long term (for example due to aquifer recovery causing geological heave and landform failure) may have implications for water quality.	---
Evaluate mitigating inflows of saline groundwater by planning for partial backfilling of final voids.	Section 7.2
Provide an assessment of the long-term impacts to water resources and water-dependent assets posed by various options for the final landform design, including complete or partial backfilling of mining voids. Assessment of the final landform for which approval is being sought should consider: • groundwater behaviour – sink or lateral flow from void. • water level recovery – rate, depth, and stabilisation point (e.g. timeframe and level in relation to existing groundwater level, surface elevation). • seepage – geochemistry and potential impacts. • long-term water quality, including salinity, pH, metals and toxicity. • measures to prevent migration of void water off-site. For other final landform options considered sufficient detail of potential impacts should be provided to clearly justify the proposed option.	Section 7.2, plus surface water and geochemistry reports
Assess the probability of overtopping of final voids with variable climate extremes, and management mitigations.	Refer to surface water assessment

Table B2.17 Acid-forming materials and other contaminants of concern

Project Information	Addressed in section
Identify the presence and potential exposure of acid-sulphate soils (including oxidation from groundwater drawdown).	N/A
Identify the presence and volume of potentially acid-forming waste rock, fine-grained amorphous sulphide minerals and coal reject/tailings material and exposure pathways.	See geochemistry assessment
Identify other sources of contaminants, such as high metal concentrations in groundwater, leachate generation potential and seepage paths.	See geochemistry assessment
Describe handling and storage plans for acid-forming material (co-disposal, tailings dam, and encapsulation).	See geochemistry assessment
Assess the potential impact to water-dependent assets, taking into account dilution factors, and including solute transport modelling where relevant, representative and statistically valid sampling, and appropriate analytical techniques.	Sections 7.1.7, 7.2.5 & geochemistry assessment
Describe proposed measures to prevent/minimise impacts on water resources, water users and water-dependent ecosystems and species.	Section 8

B2.8 IESC Explanatory Note on Uncertainty Analysis in Groundwater Modelling

The Explanatory Note provides a fatal-flaw checklist for reviewers to assess the uncertainty analysis. The following table has been included to assist the reviewer with identifying the relevant sections in the groundwater report that address the checklist.

Table B2.18 Fatal flaws review checklist for Uncertainty Assessment

Project Information	Addressed in section
Is there evidence of engagement ('without prejudice') between the project proponent and regulatory agencies, invoked from the project outset and at subsequent key stages:	---
• to discuss and agree the project objectives and the modelling objectives?	N/A. Explanatory note not written at the start of the project.
• to discuss and agree the uncertainty analysis methodologies, including the nature and scope of the (minimum requirement) qualitative uncertainty analysis, and the quantitative uncertainty analysis for high risk projects (i.e. most large coal mines and CSG projects)?	N/A. Explanatory note not written at the start of the project.
• to review the reporting on the modelling and uncertainty analyses, which must be presented in a manner that is open, transparent and amenable for scrutiny (and not prone to misinterpretation), and must include agreed justifications for invoking assumptions/criteria applied to implement the methodology?	N/A. Explanatory note not written at the start of the project.
• to understand the implications of the results in terms of environmental decision-making?	N/A. Explanatory note not written at the start of the project.
• to identify whether an independent technical review of the modelling and/or the uncertainty analysis is warranted?	An independent technical reviewer has been associated with the project from the outset.
Is the modelling and uncertainty analysis methodology designed to provide information for decision makers on the effects of uncertainty on the project objectives (echoing the definition of risk in ISO31000:2009), and on the effects of potential bias? Is the adopted complexity-simplicity balance commensurate with the overall risk context and the model purpose of investigating the uncertainty/risk issues (i.e. based on the evidence available of engagement identified in item 1)?	Modelling and uncertainty analysis follows the IESC Guidelines as far as practicable. Appendix A5
Has the uncertainty assessment and modelling methodology been designed and implemented using all the available data, with detailed consideration of the hydrological stressors arising from the development and from natural stressors including climate variability, and with unbiased consideration of water-related asset values and causal pathways for potential impacts (direct, indirect and cumulative)?	Appendix A5
Where history-match conditional calibration is undertaken, has it minimised non-uniqueness and error variance and if not, is a reasoned justification provided? (AGMG recommends fitting model outputs to measured data on heads and	Appendix A3

Project Information	Addressed in section
discharges for a wide range of climate and hydrological stressor conditions, using Pilot Points and regularisation)? Is an acceptable level of model-to-measurement mismatch defined for the conditional calibration?	
Are all simulations consistent with all relevant information/data and if not, is a reasoned justification provided? (AGMG recommends restricting predictions to the same types and magnitudes of variables used for conditional calibration (e.g. heads and fluxes) and to similar hydrological stressor regimes and timeframes).	Section 7 & Appendix A5
Has the model been submitted to stress testing in which a number of extreme parameter combinations (representative of a computationally-intensive automated conditional calibration or stochastic model evaluation) are tested for model convergence?	Appendix A5
Has a parameter sensitivity analysis and/or a parameter identifiability analysis been completed to identify which parameters can be constrained by the available observations and which parameters affect the simulations the most, and are the implications discussed?	Appendix A3
Have all reports been prepared in an open, honest and transparent way that is:	---
1. amenable for independent scrutiny and not prone to misinterpretation	This report & Appendix A
• based on agreed and transparent model objectives	
• tailored to decision-makers' needs (focus on messages relevant to their decisions)	
• presented in plain and clear language (precise, jargon-free, calibrated) and in conjunction with graphics in a manner that reduces cognitive strain	
Do the hydrogeology and modelling reports present a transparent and logical discussion of the following?	---
• project objectives and the model objectives and uncertainty analysis methodologies	Section1.2, 6.1 & Appendix A5
• how the modelling objectives are defined in specific and measurable terms in space and time (e.g. threshold impacts of drawdown at a GDE of more than 2m in X years)	Not required at the time model objectives were set.
• hydrogeological conceptualisations and parameterisations	Section 5, Appendix A3 & Appendix A5
• parameters to include in uncertainty quantification and related probability distributions	Appendix A3 & Appendix A5
• measurement uncertainty of each observation or model to measurement misfit criteria	Not required at the time model objectives were set.
• agreed justifications for invoking model/method assumptions/criteria and how those choices affect	Appendix A

Project Information	Addressed in section
simulations and uncertainties	
• methods, simulations and results discussed using calibrated language and presented in a way that reduces cognitive strain and is not prone to misinterpretation	Section 7 & Appendix A

Appendix C Monitoring bore details

BoreID	Other ref	Easting	Northing	Collar (mAHD)	TOC (mAHD)	Monitored depth? (mbgl)	Type	Status	Lithology 2013 (MER)	Lithology 2015 (MER)	Log geology	Logged screen or sensor depth (mbgl)	Measured bore depth 2017-2018 (mbTOC)	K tested?
BFC01A	BFC1E(A)	280759	6427279	151.8		20	SP	Active	Big Flat Creek alluvium	weathered congl.	Clay and alluvium	14-17	17.48	Yes
BFC01B	BFC1W(B)	280755	6427279	151.889		50.5	VWP	Active		conglomerate	Coal (Upper Pilot B seam) and tuff	50.5		
BFC02A	BFC2E(A)	280774	6427175	150.32		21	SP	Active	Big Flat Creek alluvium	weathered congl.	Alluvium, sandy, brown, weathered	17-20	20.34	Yes
BFC02B	BFC2W(B)	280770	6427178	150.415		45	VWP	Active		conglomerate	Coal (Upper Pilot B seam)	45		
BFC03A	BFC3E(A)	280847	6427053	148.558		16	SP	Active	Big Flat Creek alluvium	weathered congl.	Alluvium, polymictic, weathered, brown, fine to coarse grained	12-15	15.45	Yes
BFC03B	BFC3W(B)	280850	6427056	148.561		51.5	VWP	Active		conglomerate	Carbonaceous siltstone	51.5		
BFC05a		279438	6426876	150.278		49.5	VWP	Active		weathered congl.	Coal (Wallarah seam) immediately below fresh conglomerate	49.5		
BFC06a		279430	6426745	144.97		43.5	VWP	Active		weathered congl.	Coal (Wallarah seam) immediately below fresh conglomerate	43.5		
BFC07a		279581	6426351	140.899		13	SP	Active	Big Flat Creek alluvium	weathered congl.	Not logged, weathered	9.5-12.5	12.92	Yes
BFC07b		279583	6426354	140.853		45	VWP	Active		conglomerate	coal and conglomerate	45		
BFC08a		279610	6426223	140.411		11.2	SP	Active	Big Flat Creek alluvium	weathered congl.	weathered conglomerate	8.2-11.2	11.58	Yes
BFC08b		279613	6426223	140.346		48	VWP	Active		conglomerate	conglomerate	48		
GW01-D	Calm 05 Deep	283207	6429325			2.06	SP	Active		regolith			4.46	
GW01-S	Calm 05 Shallow	283207	6429327			1.93	SP	Active		regolith			5.98	
GW02	BM Bore	284064	6428454	170.86	171.051	6.71	Bore	Active	Alluvium	Permian interburden			6.53	
GW03-D	BM Piezo deep	283989	6428458	170.41	171.339	3.8	SP	Active	Alluvium?	Permian interburden			4.84	
GW03-S	BM Piezo shallow	283989	6428458	170.41	171.319	2.36	SP	Active		Permian interburden			3.37	
GW04	BR Bore (GW023072)	284755	6427782	184.209	185	27.7	Bore	Inactive		Permian interburden	Alluvium, conglomerate, shale, sandstone	2.1-25.0	45.52	
GW06	Roger-Keegan Well (K1W)	280383	6428105		174.17	<5?	Spring/well	Active	Alluvium	regolith				
GW07-D	CALM04 - deep	281796	6427520	154.924	155.744	5.03	SP	Active	Deeper alluvium	regolith			5.97	
GW07-S	CALM04 - shallow	281796	6427520	154.924	155.744	3.03	SP	Active	Shallow alluvium	regolith			3.97	
GW09	Hogan Well (H1W)	281154	6427075		148.86		Well	Not sampled		BFC alluvium?				
GW10-A1	CGN199 A1	280808	6427233	151.119	151.84	0.6	SP	Active	Alluvium	regolith	sand		1.4	
GW10-A2	CGN199 A2	280808	6427233	151.119	151.84	12	SP	Active	Permian coal measures	weathered congl.	clay		12.86	
GW10-P1	CGN199 P1	280808	6427233	151.119	151.84	24	SP	Active	Alluvium	conglomerate	coal (Fassifern 19.6-25) + tuff		24.44	
GW10-P2	CGN199 P2	280808	6427233	151.119	151.84	31	SP	Active	Permian coal measures	Fassifern	siltstone		31.03	
GW11	PAHOH40	281206	6426682	157.27	157.25	30	SP	Destroyed	Great Northern Seam	Fassifern +overburden	mudstone, coal above			Yes
GW12	PAH50	280968	6426568	155.81	156.41	48	SP	Destroyed	Great Northern Seam	Fassifern +overburden	siltstone, coaly shale, sandstone			
GW13	Pitman well (P2W)	280015	6426794			11	Well	Active		weathered congl.				
GW14	CGN198	279512	6426559	141.599	142.25	85.3	SP	Active	Alluvium	Fassifern +overburden	fine sandstone and siltstone (Fassifern 73-80m)		86.44	
GW15	CGN020	280214	6426384	141.899	142.32	24.7	SP	Active	Alluvium	conglomerate	weathered conglomerate ? Core loss			Yes
GW16	CGN053	280520	6426468	144.93	145.37	21.8	SP	Active	Alluvium	conglomerate	conglomerate		22.12	Yes
GW17	CGN156	280750	6426448	147.227	147.73	23.8	SP	Active	Alluvium	conglomerate	conglomerate		24.49	Yes
GW18	PAHOH25	281165	6426232	154.01	154.845	40	SP	Destroyed	Great Northern Seam	Fassifern +overburden	mudstone, coal above			Yes
GW19	PAHOH37	281422	6426081	160.17	160.667	37	SP	Destroyed	Great Northern Seam	Fassifern +overburden	sandstone, coal above			Yes
GW20	PAHOH20	281710	6425936	167.99	168.665	30	SP	Destroyed	Great Northern Seam	Fassifern +overburden	mudstone, coal above			Yes
GW22	PAHOH39	282414	6426193	174.09	175.22	33.5	SP	Destroyed	Great Northern Seam	Fassifern +overburden	mudstone, coal above			Yes
GW23	PAHOH13	282915	6426302	186.56	187.116	35	SP	Destroyed	Great Northern Seam	Fassifern +overburden	mudstone, coal above			Yes
GW25	Anshaw Piezo (CGN144)	284363	6426544	211.54		100.2	SP	Destroyed		coal measures				
GW26	GW078396	277319	6426285	161.49	161.5	103	SP	Active		conglomerate	coal	96-102	>100	
GW27	CGN155	280418	6426223	143.739	144.2	24.7	SP	Destroyed	Alluvium	conglomerate	conglomerate, slightly weathered		25.28	Yes
GW28	CGN148	280713	6426125	146.421	146.76	27.8	SP	Destroyed	Alluvium	conglomerate	sandstone or conglomerate ? Core loss			Yes

BoreID	Other ref	Easting	Northing	Collar (mAHD)	TOC (mAHD)	Monitored depth? (mbgl)	Type	Status	Lithology 2013 (MER)	Lithology 2015 (MER)	Log geology	Logged screen or sensor depth (mbgl)	Measured bore depth 2017-2018 (mbTOC)	K tested?
GW29	CALM02	280409	6426139	143.827	144.597	6.84	SP	Destroyed	Alluvium	regolith			7.74	
GW30	CGN054	280536	6425916	145.305	145.81	26.8	SP	Destroyed	Alluvium	conglomerate	unknown, not on log			Yes
GW31	CGN160	280362	6426021	144.864	145.22	20.8	SP	Destroyed	Alluvium	conglomerate	conglomerate, sandstone		14.86	Yes
GW32	CGN092	280141	6426067	144.118	144.56	14.8	SP	Destroyed	Alluvium	conglomerate	conglomerate, slightly weathered		13.76	Yes
GW33	CGN059	280347	6425597	146.048	146.49	20.8	SP	Destroyed	Alluvium	conglomerate	conglomerate?, above start of log		21.41	Yes
GW34	PAHOH36	281699	6425567	181.96	182.702	51	SP	Destroyed	Great Northern Seam	Fassifern +overburden				
GW35	PAH49	281698	6425279	206.48	206.482	73	SP	Active	Great Northern Seam	Fassifern +overburden	Great Northern seam?			
GW36	PAHOH09	283625	6424864	205.11	205.17	36	SP	Destroyed	Great Northern Seam	Fassifern +overburden				Yes
GW37	CGN169	283131	6424665	197.494	197.6	26.6	SP	Destroyed	Alluvium	conglomerate	tuffite, claystone, coal (Upper Pilot B seam) above			Yes
GW38-D	CGN184 deep	282885	6424316	186.277	186.96	32.3	SP	Destroyed	Permian coal measures	conglomerate	tuffite, core loss (Mount Hutton Tuff)			Yes
GW38-S	CGN184 shallow	282885	6424316	186.277	187.02	22	SP	Destroyed	Regolith	conglomerate	tuffite, core loss			
GW39	CALM01	282682	6423992	167.813	168.573	2.88	SP	Destroyed	Alluvium	regolith				
GW40	CGN033	281481	6424403	181.99	182.431	55.3	SP	Active	Great Northern Seam	Fassifern +overburden	sandstone, thin coal above (Fassifern base 49.6)		49	Yes
GW41	K Bore	280488	6424390	155.1	155.2	<15?	SP	Destroyed	Permian coal measures	Fassifern +overburden				
GW43	R1W	279133	6424531	139.67		<3?	Well (timber)	Not sampled		regolith?				
GW44	GW078502	278981	6424224	139.82	140.02	58	SP	Inactive	Permian coal measures	conglomerate	Wybong Creek alluvium and coal measures			
GW46	HW Bore	281457	6423411	174.31	175.66	32.5	SP	Active	Permian coal measures	Fassifern +overburden			33.87	
GW47	CGN186	282274	6423376	180.345	181.3	32.1	SP	Destroyed	Great Northern Seam	Fassifern +overburden	sandstone, siltstone, coal (Upper Pilot A seam) above to 31.8. FF to 30.8			Yes
GW48	PAHOH01	282522	6423423	180.85	181.59	32	SP	Destroyed	Great Northern Seam	Fassifern +overburden				Yes
GW49	CGN190	283776	6423450	186.325	187.13	99.2	SP	Destroyed	Great Northern Seam	Fassifern +overburden	sandstone and siltstone, no nearby coal			Yes
GW50	CGN191	283222	6422598	202.533	203.53	27	SP	Destroyed	Great Northern Seam	Great Northern	siltstone, sandstone, shale at base. Upper Pilot A seam to 20.8			Yes
GW047877		282446	6428573			30.6	Bore	Active			Coal measures		32.13	
GW202249		281090	6428216			74.5	Bore	Active			Coal measures		77.93	
JENNAR_WL		286571	6429836				Well	Active						
MB1		284816	6425033			7.92	SP	Active					7.92	
MB2		284836	6424974			7.95	SP	Active					7.95	
MN0001		279998	6429001					Destroyed						
MN1001_137	MN0005	283751	6429974	199.48			VWP	Active		MS (Montrose Seam)	coal (Montrose seam 137-137.7)	137		
MN1001_185	MN0005	283751	6429974	199.48			VWP	Active		VT (Victoria Tunnel)	coal (Victoria Tunnel seam 184.2-185.4)	185		
MN1001_210	MN0005	283751	6429974	199.48			VWP	Active		YW (Young Wallsend)	coal (Young Wallsend seam 208.9-210.6)	210		
MN1001_45	MN0005	283751	6429974	199.48			VWP	Active		FF (Fassifern Seam)	coal (Fassifern seam 44.8-45.5)	45		
MN1001_95	MN0005	283751	6429974	199.48			VWP	Active		HH (Hartley Hill seam)	siltstone and sandstone (Hartley Hill seam 84.1-93.6)	95		
MN1006	MN0008	283061	6428994	176.99		53	SP	Active		Upper Pilot A/B seam	siltstone and coal (Upper Pilot A seam)	29-35	34.9	Yes
MN1007_114	MN0004	278509	6428191	175.36			VWP	Active		?	conglomerate	114		
MN1007_140	MN0004	278509	6428191	175.36			VWP	Active		GN (Great Northern Seam)	conglomerate (Great Northern seam 145-150)	140		
MN1007_182	MN0004	278509	6428191	175.36			VWP	Active		AA (Australasian seam)	siltstone (Australasian seam is 235-240)	182		
MN1007_245	MN0004	278509	6428191	175.36			VWP	Active		FV (Fern Valley seam)	Montrose seam (Fern Valley seam is 272-274)	245		
MN1007_35	MN0004	278509	6428191	175.36			VWP	Active		?	conglomerate, unweathered?	35		
MN1010_130	MN0003	279929	6426973	152.64			VWP	Active		HH (Hartley Hill seam)	Hartley Hill seam	130		
MN1010_157	MN0003	279929	6426973	152.64			VWP	Active		AA (Australasian seam)	Siltstone (Australasian seam 153-155)	157		
MN1010_175	MN0003	279929	6426973	152.64			VWP	Active		MS (Montrose Seam)	Sandstone (Montrose seam 181-185)	175		
MN1010_247	MN0003	279929	6426973	152.64			VWP	Active		YW (Young Wallsend)	Young Wallsend seam	247		
MN1010_65	MN0003	279929	6426973	152.64			VWP	Active		GN (Great Northern Seam)	Great Northern seam	65		
MN1014	MN0009	282862	6428265	166.7	151.99	53	SP	Active		Overburden	Hartley Hill seam? Coal on Form A, shale and sandstone on Graphic log	47-53	51.34	Yes

BoreID	Other ref	Easting	Northing	Collar (mAHD)	TOC (mAHD)	Monitored depth? (mbgl)	Type	Status	Lithology 2013 (MER)	Lithology 2015 (MER)	Log geology	Logged screen or sensor depth (mbgl)	Measured bore depth 2017-2018 (mbTOC)	K tested?
MP10a	MP10-1	284946	6425122	172.48		50.37	SP	Active	Coal measures	Fassifern	Quartz lithic grey sandstone	47.4-50.4		Yes
MP10b	MP10-2	284946	6425122	172.48		18.3	SP	Active	Coal measures	conglomerate	Claystone, shale and minor coal	15.3-18.3		Yes
MP11a		282608	6423922	168.98		50	SP	Destroyed	Coal measures	Fassifern	Claystone, siltstone, sandstone	47-50		Yes
MP11b		282608	6423922	168.98		23.4	SP	Destroyed	Coal measures	conglomerate	coal and coaly shale	20.4-23.4		Yes
MP12a		280601	6425590	149.07		40	SP	Destroyed	Coal measures	interburden	Conglomerate	37-40	41.11	Yes
MP12b		280601	6425590	149.07		18.2	SP	Destroyed	Coal measures	conglomerate	Conglomerate	15.2-18.2	16.57	Yes
MP12c		280604	6425593	149.13		60	SP	Destroyed	Coal measures	Fassifern	Coal, shale and siltstone	57.5-60	56.93	
MP13a		280829	6423964	159.27		20	SP	Active	Coal measures	interburden	claystone, shale, conglomerate, weathered	17-20	18	Yes
MP13b	MP13	280832	6423966	159.21		59.25	SP	Active	Coal measures	Fassifern	coal	56.2-59.2	58.56	Yes
MP13c		280829	6423964	159.27		41.11	SP	Active	Fassifern seam	conglomerate	Coal, shale	38.1-41.1	41.6	Yes
MP14a		280620	6425121	159.2		20.66	SP	Active	Fassifern seam	interburden	conglomerate	17.7-20.7	20.84	Yes
MP14b	MP14-1	280622	6425119	159.23		60.66	SP	Active	Coal measures	interburden	coal	57.6-60.6	62.38	Yes
MP14c	MP14-2	280620	6425121	159.2		35.5	SP	Active	Coal measures	conglomerate	conglomerate	32.5-35.5	36.1	Yes
MP15b		280924	6426917	148.33		43.5	VWP	Active		conglomerate?	coal (Upper Pilot B seam 42.9-44.9), tuff	43.5		
MP15-B		280924	6426917	148.33		13	SP	Active	Big Flat Creek alluvium	weathered conglomerate	Alluvium - gravelly, fine to coarse grained, weathered, tuff	9.5-12.5	12.58	Yes
MP16a		281087	6427030	149.39		44.5	VWP	Active		conglomerate	coal (LPM 43.8-45.0), tuff	44.5		
MP16b		281089	6427031	149.49		13	SP	Active	Big Flat Creek alluvium	weathered conglomerate	tuff, weathered	9.8-12.8		Yes
MP17b		281470	6427133	151.57		8.7	SP	Active	Big Flat Creek alluvium	weathered conglomerate	Gravel and sand, conglomerate, weathered?	5.7-8.7		Yes
MP17c		281470	6427133	151.57		41	VWP	Active		Fassifern + UPA	coal (36.3-40), claystone/tuff	41		
MP18a		280063	6426227	142.06		78	SP	Active		Fassifern + UPA	Fassifern	53-59	60.73	Yes
MP18b		280059	6426227	142.05		16	SP	Active		conglomerate	sandstone and conglomerate	11-14	15	Yes
MP19a		280383	6426330	142.77		72	SP	Active		Fassifern + UPA	Fassifern + Upper Pilot A seam	41-47	48.9	Yes
MP19b		280380	6426328	142.57		20	SP	Active		conglomerate	conglomerate	11-17	18.2	Yes
MP1a	MP1-1	284886	6426052	192.73		68.32	SP	Active	Coal measures	Fassifern	Siltstone, sandstone, igneous sill?	65.3-68.3		Yes
MP1b	MP1-2	284886	6426052	192.73		35.92	SP	Active	Coal measures	conglomerate	claystone, tuff, coal	32.9-35.9		Yes
MP20a		280575	6426430	145.74		66	SP	Active		Fassifern + UPA	Fassifern + Upper Pilot A seam	42-48	45.2	Yes
MP20b		280570	6426428	145.71		22	SP	Active		conglomerate	conglomerate	14-20	21.35	Yes
MP2a	MP2-1	284355	6424470	189.9		70	SP	Active	Coal measures	Fassifern	siltstone to fine quartz lithic sandstone	67-70		Yes
MP2b	MP2-2	284355	6424470	189.9		33.35	SP	Active	Coal measures	conglomerate	coal and coaly sediments	30.3-33.3		Yes
MP3a	MP3-1	284187	6427346	198.34		68.85	SP	Active	Coal measures	Fassifern	Fine white quartz lithic sandstone	65.9-68.9		Yes
MP3b	MP3-2	284187	6427346	198.34		34.22	SP	Active	Coal measures	conglomerate	Shale, siltstone, interbedded coal and shale	31.2-34.2		Yes
MP4a		283205	6428064	168.695		73	SP	Active	Coal measures	Fassifern	shale, coal (UNB/UNC), siltstone	67.6-70.6		Yes
MP4b		283200	6428065	168.655		54	SP	Active	Coal measures	interburden	coal (Hartley Hill seam) and tuff interbedded	51-54		Yes
MP4c		283200	6428061	168.641		18	SP	Active	Coal measures	conglomerate	tuff, shale, siltstone	15-18		Yes
MP6a	MP6-1	283291	6422169	215.17		80.15	SP	Destroyed	Coal measures	Fassifern	shale, coal to 73	77.1-80.1		Yes
MP6b	MP6-2	283291	6422169	215.17		40	SP	Destroyed	Coal measures	conglomerate	shale.claystone, coal and shale	37-40		Yes
MP7_17		282904	6425096	203.744			VWP	Active		?	conglomerate	17		
MP7_29		282904	6425096	203.744			VWP	Active		FF (Fassifern Seam)	Fassifern seam	29		
MP7_35		282904	6425096	203.744			VWP	Active		UPA (Upper Pilot A)	Upper Pilot A seam	35		
MP8b		281305	6426956	150.591		17.8	SP	Active	Coal measures	alluvium	coaly shale, bright coal 14-15 and 16-21	14.8-17.8		Yes
MP9a		280204	6426566	143.549		15	SP	Active	Big Flat Creek alluvium	alluvium	sandstone, weathered	11.5-14.5		Yes
MP9b		280202	6426568	143.452		64	VWP	Active		conglomerate	coal (Upper Pilot B seam 63.6-64.8), tuff, shale	64		
NGW01A_112		278067	6427055	146.204			VWP	Active			Great Northern seam	112		
NGW01A_130		278067	6427055	146.204			VWP	Active			Shale and Upper Pilot seam?	130		
NGW01A_33		278067	6427055	146.204			VWP	Active			conglomerate	33		
NGW01A_60		278067	6427055	146.204			VWP	Active			conglomerate	60		
NGW01A_85		278067	6427055	146.204			VWP	Active			conglomerate	85		
NGW-1b		278074	6427069	146.023		27	SP	Active		weathered conglomerate	Gravel + weathered conglomerate	21-27	27.5	Yes

BoreID	Other ref	Easting	Northing	Collar (mAHD)	TOC (mAHD)	Monitored depth? (mbgl)	Type	Status	Lithology 2013 (MER)	Lithology 2015 (MER)	Log geology	Logged screen or sensor depth (mbgl)	Measured bore depth 2017-2018 (mbTOC)	K tested?
NGW-1c		278071	6427062	146.058		17	SP	Active		conglomerate	Gravel	14-17	18.22	Yes
NGW02A_101		280977	6429927	216.4			VWP	Active		?	Coal - Wallarah	101		
NGW02A_117		280977	6429927	216.4			VWP	Active		?	Coal - Great Northern	117		
NGW02A_128		280977	6429927	216.4			VWP	Active		FF (Fassifern Seam)	Coal - Fassifern	128		
NGW02A_48	NGW02A-1	280977	6429927	216.4			VWP	Active		?	Weathered coarse grained sandstone	48		
NGW-2b		280975	6429920	216.323		42	SP	Active		sandstone	weathered + fresh conglomerate	35-41	41.74	Yes
NGW-3a		285374	6428679	210.274		30	SP	Active		weathered conglomerate	white sandstone	21-27	26.96	Yes
NGW03B_25		285370	6428670	210.014			VWP	Active		?	Sandstone	25		
NGW03B_55		285370	6428670	210.014			VWP	Active		?	Siltstone	55		
NGW03B_70		285370	6428670	210.014			VWP	Active		GN (Great Northern)	Coal (FVA - Fern Valley) and siltstone	70		
NGW03B_80		285370	6428670	210.014			VWP	Active		FF (Fassifern Seam)	Coal (VTE - Victoria Tunnel) and siltstone	80		
REG01	MN0011	282095	6427980	160.89			SP	Active		Hartley Hill seam	Coal	59-65	67.34	Yes
VW1-1		279298	6425390	146			VWP	Active		Hartley Hill seam	tuff, shale, Hartley Hill seam underlies	133		
VW1-2		279298	6425390	146			VWP	Active		Upper Pilot A seam	coal (Upper Pilot A seam)	82		
VW1-3		279298	6425390	146			VWP	Active		Great Northern seam	coal (Great Northern seam)	69		
VW1-4		279298	6425390	146			VWP	Active		conglomerate	conglomerate	45		
VW1-5		279298	6425390	146			VWP	Active		weathered conglomerate	conglomerate	25		
VW2-1		279321	6423834	145.08			VWP	Active		Hartley Hill seam		110.7		
VW2-2		279321	6423834	145.08			VWP	Active		Upper Pilot A seam		75.5		
VW2-3		279321	6423834	145.08			VWP	Active		conglomerate		62		
VW2-4		279321	6423834	145.08			VWP	Active		conglomerate		38		
VW2-5		279321	6423834	145.08			VWP	Active		weathered conglomerate		20		
VW3-1		281721	6422805	199.75			VWP	Active		Hartley Hill seam	Siltstone/tuff, coal (Hartley Hill seam?) slightly above to 124 m	124.8		
VW3-2		281721	6422805	199.75			VWP	Active		interburden	sandstone	100		
VW3-3		281721	6422805	199.75			VWP	Active		Lower Pilot seam	coal (Lower Pilot?), carbonaceous shale	78.5		
VW3-4		281721	6422805	199.75			VWP	Active		Upper Pilot seam	coal (Upper Pilot?)	65		
VW3-5		281721	6422805	199.75			VWP	Active		Great Northern seam	coal (Great Northern seam?)	45		

Standpipe/well/bore

Standpipe + logger

Multi VWP

Single VWP

Destroyed/not sampled

Appendix D Water quality tables

G1839F

Groundwater Quality Results

Parameter	Units	LOR#	ANZECC GUIDELINES																					
Sample Location																								
Lab Number			Fresh Water Aquatic (95th)	GW02	GW04	GW14	GW33	GW46	NGW01B	NGW01C	NGW02B	NGW03A	MN1006	MN1014	MN0011 (REG1)	MP18A	MP18B	MP19A	MP20A	GW10-A2	GW10-P1	GW 10-P2	GW047877	GW202249
Date Sampled				25/09/2017	25/09/2017	25/09/2017	27/09/2017	27/09/2017	26/09/2017	26/09/2017	29/09/2017	29/09/2017	29/09/2017	26/09/2017	26/09/2017	27/09/2017	27/09/2017	27/09/2017	27/09/2017	25/09/2017	25/09/2017	25/09/2017	26/09/2017	26/09/2017
Lithology																								
Field Parameters																								
Field pH	pH units		6.5-8.5	8.6	7.2	7.6	6.2	6.4	7.5	7.4	7.7	6.6	7.6	11.9	12.4	6.9	6.9	7.3	7.1	7.2	6.9	7.4		
Field Electrical Conductivity (EC)	µS/cm		120 - 300	22770	7640	5120	15660	7480	4450	7250	4090	5980	3290	7560	6940	12000	21790	14640	13260	487	747	7980		
Depth to Groundwater	m TOC			3.66	11.64	20.44	9.65	20.41	14.59	14.88	6.97	18.03	6.57	7.15	12.9	28.32	14.69	39.46	38.22	11.47	11.5	11.55		
Physical Parameters																								
pH	pH Units	0.1	6.5 - 8.5	8.46	7.81	7.96	7.7	7.54	7.9	7.67	7.84	7.29	8.02	11.4	11.8	7.6	7.7	7.7	7.84	7.31	7.48	7.92	7.81	8.19
Electrical conductivity	µS/cm	1	120 - 300	23300	7660	5120	16300	7470	4290	7360	3970	6080	3410	7330	6040	12500	22800	15200	11800	450	795	8310	5380	2060
Total Dissolved Solids (grav) @180°C	mg/L	1.00		15100	4500	3710	13700	5270	3240	4410	2830	3780	1930	3950	3330	5900	14300	7490	6030	472	420	3660	3320	1090
Hydroxide Alkalinity as $CaCO_3$	mg/L	1.00		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	247	460	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1.00		33	<1	<1	<1	<1	<1	<1	<1	<1	<1	360	145	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1.00		339	1270	729	1020	845	368	522	331	651	589	<1	<1	851	1080	1100	1760	40	96	1160	544	301
Total Alkalinity as $CaCO_3$	mg/L	1.00		372	1270	729	1020	845	368	522	331	651	589	607	605	851	1080	1100	1760	40	96	1160	544	301
Major Ions																								
Sulfate as SO_4 - Turbidimetric	mg/L	1		311	216	1	419	144	38	120	36	350	50	86	315	258	810	152	85	39	36	26	146	14
Chloride	mg/L	1		7220	1490	1140	4750	1690	1110	1850	994	1240	719	1870	912	3620	6570	1700	2910	43	142	1830	1560	475
Calcium	mg/L	1		29	41	72	176	106	152	229	222	222	104	7	65	203	140	119	81	1	5	71	22	36
Magnesium	mg/L	1		452	14	66	654	426	302	317	138	78	37	<1	<1	441	817	489	116	4	15	106	181	19
Sodium	mg/L	1		4330	1560	1020	1870	814	210	757	403	894	522	1260	939	1670	3460	915	2340	77	125	1500	857	393
Potassium	mg/L	1		50	9	17	71	48	9	8	11	29	19	84	75	29	76	56	24	4	6	24	39	10
Total Anions	meq/L	0.01		218	71.9	46.7	163	67.6	39.4	65.1	35.4	55.3	33.1	66.7	44.4	124	224	73.1	119	2.82	6.67	75.3	57.9	19.7
Total Cations	meq/L	0.01		228	71.3	53.8	146	77	41.8	70.6	40.2	57.1	31.4	57.3	46	120	227	87.4	116	3.83	7.07	78.1	54.3	20.7
Ionic Balance	%	0.01		2.4	0.43	7.04	5.61	6.52	2.89	4.08	6.4	1.65	2.58	7.55	1.81	1.92	0.64	8.92	1.29	15.1	2.92	1.82	3.25	2.49
Nutrients																								
Ammonia as N	mg/L	0.01	0.9	0.64	4.27	1.86	0.02	3.34	0.13	<0.01	0.05	3.59	0.02	7.8	1	0.32	0.21	0.07	2.51	<0.01	0.34	2.13	0.08	<0.01
Nitrite as N	mg/L	0.01		0.15	<0.01	<0.01	<0.01	0.09	0.06	<0.01	<0.01	0.07	0.03	<0.01	0.02	<0.01	<0.01	<0.01	0.06	0.02	0.12	0.33	<0.10	<0.01
Nitrate as N	mg/L	0.01	0.7	<0.01	0.06	0.33	0.04	<0.01	0.04	1.17	0.05	<0.01	2.55	0.04	0.01	0.06	0.16	0.43	0.45	12.4	<0.10	<0.01	<0.10	2.08
Nitrite + Nitrate as N	mg/L	0.01		0.03	0.06	0.33	0.04	0.08	0.1	1.17	0.05	0.05	2.58	0.04	0.03	0.06	0.16	0.43	0.51	12.4	0.11	0.04	<0.10	2.08
Total Kjeldahl Nitrogen as N	mg/L	0.1		1.2	4.6	2.2	0.2	3.6	0.3	0.7	1.6	3.7	1	14.2	3.5	0.5	4.5	0.4	3.5	5	1.6	2.9	0.2	0.5
Total Nitrogen as N	mg/L	0.1		1.2	4.7	2.5	0.2	3.7	0.4	1.9	1.6	3.8	3.6	14.2	3.5	0.6	4.7	0.8	4	17.4	1.7	2.9	0.2	2.6
Total Phosphorus as P	mg/L	0.01		0.02	0.62	0.05	0.18	0.32	0.11	0.47	0.1	0.02	0.13	0.56	0.74	0.15	2.3	1.18	0.23	0.93	0.14	0.37	0.02	0.28
Reactive Phosphorus as P	mg/L	0.01		<0.01	0.48	<0.01	0.02	<0.01	0.08	0.09	<0.01	<0.01	0.03	0.6	<0.01	<0.01	0.07	0.02	<0.01	<0.01	0.08	0.16	0.07	0.23
Total Metals																								
Aluminium	mg/L	0.01	0.055	0.05	0.02	0.2	0.35	0.06	1.21	7.66	0.14	0.11	0.78	2.62	0.42	0.22	108	0.42	0.45	69.1	1.14	1.39	0.1	0.69
Antimony	mg/L	0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.003	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic	mg/L	0.001	As (III) 0.024 As (V) 0.013	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	0.001	<0.001	<0.001	<0.001	0.006	<0.001	0.004	*0.026*	*0.015*	0.002	0.004	<0.001	0.001	<0.001	0.002
Barium	mg/L	0.001		0.02	0.237	1.14	0.127	0.292	0.164	0.099	0.422	0.04	0.238	0.037	0.192	0.375	5.24	0.333	1.26	0.098	0.054	0.583	0.066	0.216
Beryllium	mg/L	0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.008	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001
Boron	mg/L	0.05	0.37	<0.05	0.38	0.18	<0.05	0.06	<0.05	<0.05	0.06	0.12	0.12	0.12	0.07	0.08	0.08	0.11	0.48	0.09	0.08	0.26	0.08	0.09
Cadmium	mg/L	0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002
Chromium	mg/L	0.001	CrIII – ID Cr(VI) 0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.008	0.032	<0.001	<0.001	0.002	<0.001	0.003	<0.001	0.215	0.002	0.001	0.131	0.003	0.005	<0.001	<0.001
Cobalt	mg/L	0.001		<0.001	<0.001	<0.001	0.003	<0.001	0.002	0.015	0.004	<0.001	<0.001	<0.001	0.001	<0.001	0.061	<0.001	0.001	0.035	0.004	0.002	<0.001	0.002
Copper	mg/L	0.001	0.0014	<0.001	<0.001	0.006	0.013	<0.001	0.189	0.017	0.02	0.012	0.068	0.038	0.003	0.006	0.374	0.002	0.012	0.08	0.009	0.012	<0.001	0.003
Iron	mg/L	0.05	-	24.6	0.49	0.9	3.16	16.5	1.64	10.5	0.55	2.78	1.06	0.25	0.74	8.58	137	20	3.46	59.1	2.47	2.38	0.15	0.36
Lead	mg/L	0.001	0.0034	<0.001	<0.001	0.003	<0.001	0.001	0.002	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.064	<0.001	0.002	0.027	0.004	0.006	0.006	0.019
Manganese	mg/L	0.001	1.9	0.509	0.076	0.208	0.099	0.505	0.804	0.253	2.05	0.214	0.041	0.01	0.017	0.194	0.358	0.162	0.092	0.316	0.064	0.284	0.032	0.021
Mercury	mg/L	0.0001	0.0006	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Molybdenum	mg/L	0.001	-	<0.001	<0.001	0.001	<0.001	<0.001	0.002	0.001	<0.001	<0.001	0.008	0.12	0.462	0.002	0.001	0.003	<0.001	<0.001	<0.001	0.001	0.002	0.003
Nickel	mg/L	0.001	0.011	<0.001	<0.001	0.002	0.005	<0.001	0.011	0.017	0.036	<0.001	0.009	0.025	0.008	0.001	0.121	<0.001	0.005	0.071	0.009	0.006	0.001	0.024
Selenium	mg/L	0.01	Total – 0.011 SeIIV - ID	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	*0.07*	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
Silver	mg/L	0.001		0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Strontium	mg/L	0.001		2.38	2.94	2.75	6.33	3.05	2.09	3.91	3.9	8.01	6.55	0.321	2.02	5.9	7.75	6.51	6.78	0.147	0.188	5.52	0.942	1.79
Vanadium	mg/L	0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.34	<0.01	<0.01	0.08	<0.01	<0.01	<0.01	<0.01
Zinc	mg/L	0.005	0.008	0.024	0.006	0.098	0.013	0.006	0.024	0.026	0.011	0.028	0.018	0.026	0.022	0.024	0.204	0.007	0.025	0.154	0.096	0.173	0.008	0.108
BTEX																								
Benzene	µg/L	1	900	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	----	<1	<1	<1	<1	<1	<1	<1	<1	<1
Toluene	µg/L	2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
Ethylbenzene	µg/L	2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
meta- & para-Xylene	µg/L	2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
ortho-Xylene	µg/L	2	350	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
Total Xylenes	µg/L	2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
Sum of BTEX	µg/L	1		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	----	<1	<1	<1	<1	<1	<1	<1	<1	<1
Naphthalene	µg/L	5	16	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	----	<5	<5	<5	<5	<5	<5	<5	<5	<5
Total Petroleum Hydrocarbons (Silica gel cleanup)																								
C10 - C14 Fraction (EP071 SG)	µg/L	50		<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
C15 - C28 Fraction (EP071 SG)	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
C29 - C36 Fraction (EP071 SG)	µg/L	50		<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
C10 - C36 Fraction (sum - EP071 SG)	µg/L	50		<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Total Recoverable Hydrocarbons																								
>C10 - C16 Fraction (EP071 SG)	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C16 - C34 Fraction (EP071 SG)	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C34 - C40 Fraction (EP071 SG)	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C10 - C40 Fraction (sum - EP071 SG)	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C10 - C16 Fraction minus Naphthalen	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	----	<100	<100	<100	<100	<100	<100	<100	<100	<100

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

G1839F

Groundwater Quality Results

Parameter	Units	LOR[#]	NHMRC																					
Sample Location																								
Lab Number			**Drinking Water**	GW02	GW04	GW14	GW33	GW46	NGW01B	NGW01C	NGW02B	NGW03A	MN1006	MN1014	MN0011 (REG1)	MP18A	MP18B	MP19A	MP20A	GW10-A2	GW10-P1	GW 10-P2	GW047877	GW202249
Date Sampled				25/09/2017	25/09/2017	25/09/2017	27/09/2017	27/09/2017	26/09/2017	26/09/2017	29/09/2017	29/09/2017	29/09/2017	26/09/2017	26/09/2017	27/09/2017	27/09/2017	27/09/2017	27/09/2017	25/09/2017	25/09/2017	25/09/2017	26/09/2017	26/09/2017
Lithology																								
Field Parameters																								
Field pH	pH units		**6.5-8.5**	8.62	7.18	7.61	6.16	6.38	7.5	7.4	7.67	6.63	7.6	11.94	12.37	6.94	6.91	7.25	7.08	7.2	6.91	7.41		
Field Electrical Conductivity (EC)	µS/cm		-	22770	7640	5120	15660	7480	4450	7250	4090	5980	3290	7560	6940	12000	21790	14640	13260	487	747	7980		
Depth to Groundwater	m TOC		-																					
Physical Parameters																								
pH	pH Units	0.1	**6.5 - 8.5[b]**	8.46	7.81	7.96	7.7	7.54	7.9	7.67	7.84	7.29	8.02	11.4	11.8	7.6	7.7	7.7	7.84	7.31	7.48	7.92	7.81	8.19
Electrical conductivity	µS/cm	1	-	23300	7660	5120	16300	7470	4290	7360	3970	6080	3410	7330	6040	12500	22800	15200	11800	450	795	8310	5380	2060
Total Dissolved Solids (grav) @180°C	mg/L	1.00	**600[b]**	15100	4500	3710	13700	5270	3240	4410	2830	3780	1930	3950	3330	5900	14300	7490	6030	472	420	3660	3320	1090
Hydroxide Alkalinity as $CaCO_3$	mg/L	1.00	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	247	460	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1.00	-	33	<1	<1	<1	<1	<1	<1	<1	<1	<1	360	145	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1.00	-	339	1270	729	1020	845	368	522	331	651	589	<1	<1	851	1080	1100	1760	40	96	1160	544	301
Total Alkalinity as $CaCO_3$	mg/L	1.00	-	372	1270	729	1020	845	368	522	331	651	589	607	605	851	1080	1100	1760	40	96	1160	544	301
Major Ions																								
Sulfate as SO_4 - Turbidimetric	mg/L	1	**500[a] / 250[b]**	311	216	1	419	144	38	120	36	350	50	86	315	258	810	152	85	39	36	26	146	14
Chloride	mg/L	1	**250[b]**	7220	1490	1140	4750	1690	1110	1850	994	1240	719	1870	912	3620	6570	1700	2910	43	142	1830	1560	475
Calcium	mg/L	1	-	29	41	72	176	106	152	229	222	222	104	7	65	203	140	119	81	1	5	71	22	36
Magnesium	mg/L	1	-	452	14	66	654	426	302	317	138	78	37	<1	<1	441	817	489	116	4	15	106	181	19
Sodium	mg/L	1	**180[b]**	4330	1560	1020	1870	814	210	757	403	894	522	1260	939	1670	3460	915	2340	77	125	1500	857	393
Potassium	mg/L	1	-	50	9	17	71	48	9	8	11	29	19	84	75	29	76	56	24	4	6	24	39	10
Total Anions	meq/L	0.01	-	218	71.9	46.7	163	67.6	39.4	65.1	35.4	55.3	33.1	66.7	44.4	124	224	73.1	119	2.82	6.67	75.3	57.9	19.7
Total Cations	meq/L	0.01	-	228	71.3	53.8	146	77	41.8	70.6	40.2	57.1	31.4	57.3	46	120	227	87.4	116	3.83	7.07	78.1	54.3	20.7
Ionic Balance	%	0.01	-	2.4	0.43	7.04	5.61	6.52	2.89	4.08	6.4	1.65	2.58	7.55	1.81	1.92	0.64	8.92	1.29	15.1	2.92	1.82	3.25	2.49
Nutrients																								
Ammonia as N	mg/L	0.01	**0.5[b]**	0.64	4.27	1.86	0.02	3.34	0.13	<0.01	0.05	3.59	0.02	7.8	1	0.32	0.21	0.07	2.51	<0.01	0.34	2.13	0.08	<0.01
Nitrite as N	mg/L	0.01	**3[a]**	0.15	<0.01	<0.01	<0.01	0.09	0.06	<0.01	<0.01	0.07	0.03	<0.01	0.02	<0.01	<0.01	<0.01	0.06	0.02	0.12	0.33	<0.10	<0.01
Nitrate as N	mg/L	0.01	**50[a]**	<0.01	0.06	0.33	0.04	<0.01	0.04	1.17	0.05	<0.01	2.55	0.04	0.01	0.06	0.16	0.43	0.45	12.4	<0.10	<0.01	<0.10	2.08
Nitrite + Nitrate as N	mg/L	0.01	-	0.03	0.06	0.33	0.04	0.08	0.1	1.17	0.05	0.05	2.58	0.04	0.03	0.06	0.16	0.43	0.51	12.4	0.11	0.04	<0.10	2.08
Total Kjeldahl Nitrogen as N	mg/L	0.1	-	1.2	4.6	2.2	0.2	3.6	0.3	0.7	1.6	3.7	1	14.2	3.5	0.5	4.5	0.4	3.5	5	1.6	2.9	0.2	0.5
Total Nitrogen as N	mg/L	0.1	-	1.2	4.7	2.5	0.2	3.7	0.4	1.9	1.6	3.8	3.6	14.2	3.5	0.6	4.7	0.8	4	17.4	1.7	2.9	0.2	2.6
Total Phosphorus as P	mg/L	0.01	-	0.02	0.62	0.05	0.18	0.32	0.11	0.47	0.1	0.02	0.13	0.56	0.74	0.15	2.3	1.18	0.23	0.93	0.14	0.37	0.02	0.28
Reactive Phosphorus as P	mg/L	0.01	-	<0.01	0.48	<0.01	0.02	<0.01	0.08	0.09	<0.01	<0.01	0.03	0.6	<0.01	<0.01	0.07	0.02	<0.01	<0.01	0.08	0.16	0.07	0.23
Total Metals																								
Aluminium	mg/L	0.01	**0.2[b+]**	0.05	0.02	0.2	0.35	0.06	1.21	7.66	0.14	0.11	0.78	2.62	0.42	0.22	108	0.42	0.45	69.1	1.14	1.39	0.1	0.69
Antimony	mg/L	0.001	**0.003[a]**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.003	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic	mg/L	0.001	**0.01[a]**	<0.001	<0.001	<0.001	0.003	<0.001	0.003	0.001	<0.001	<0.001	<0.001	0.006	<0.001	0.004	0.026	0.015	0.002	0.004	<0.001	0.001	<0.001	0.002
Barium	mg/L	0.001	**2[a]**	0.02	0.237	1.14	0.127	0.292	0.164	0.099	0.422	0.04	0.238	0.037	0.192	0.375	5.24	0.333	1.26	0.098	0.054	0.583	0.066	0.216
Beryllium	mg/L	0.001	**0.06[a]**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.008	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001
Boron	mg/L	0.05	**4[a]**	<0.05	0.38	0.18	<0.05	0.06	<0.05	<0.05	0.06	0.12	0.12	0.12	0.07	0.08	0.08	0.11	0.48	0.09	0.08	0.26	0.08	0.09
Cadmium	mg/L	0.0001	**0.002[a]**	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002
Chromium	mg/L	0.001	**0.05[a]**	<0.001	<0.001	0.001	<0.001	<0.001	0.008	0.032	<0.001	<0.001	0.002	<0.001	0.003	<0.001	0.215	0.002	0.001	0.131	0.003	0.005	<0.001	<0.001
Cobalt	mg/L	0.001	-	<0.001	<0.001	<0.001	0.003	<0.001	0.002	0.015	0.004	<0.001	<0.001	<0.001	0.001	<0.001	0.061	<0.001	0.001	0.035	0.004	0.002	<0.001	0.002
Copper	mg/L	0.001	**2[a] / 1[b]**	<0.001	<0.001	0.006	0.013	<0.001	0.189	0.017	0.02	0.012	0.068	0.038	0.003	0.006	0.374	0.002	0.012	0.08	0.009	0.012	<0.001	0.003
Iron	mg/L	0.05	**0.3[b]**	24.6	0.49	0.9	3.16	16.5	1.64	10.5	0.55	2.78	1.06	0.25	0.74	8.58	137	20	3.46	59.1	2.47	2.38	0.15	0.36
Lead	mg/L	0.001	**0.01[a]**	<0.001	<0.001	0.003	<0.001	0.001	0.002	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.064	<0.001	0.002	0.027	0.004	0.006	0.006	0.019
Manganese	mg/L	0.001	**0.5[a] / 0.1[b]**	0.509	0.076	0.208	0.099	0.505	0.804	0.253	2.05	0.214	0.041	0.01	0.017	0.194	0.358	0.162	0.092	0.316	0.064	0.284	0.032	0.021
Mercury	mg/L	0.0001		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Molybdenum	mg/L	0.001	**0.05[a]**	<0.001	<0.001	0.001	<0.001	<0.001	0.002	0.001	<0.001	<0.001	0.008	0.12	0.462	0.002	0.001	0.003	<0.001	<0.001	<0.001	0.001	0.002	0.003
Nickel	mg/L	0.001	**0.02[a]**	<0.001	<0.001	0.002	0.005	<0.001	0.011	0.017	0.036	<0.001	0.009	0.025	0.008	0.001	0.121	<0.001	0.005	0.071	0.009	0.006	0.001	0.024
Selenium	mg/L	0.01	**0.01[a]**	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
Silver	mg/L	0.001	**0.1[a]**	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Strontium	mg/L	0.001	-	2.38	2.94	2.75	6.33	3.05	2.09	3.91	3.9	8.01	6.55	0.321	2.02	5.9	7.75	6.51	6.78	0.147	0.188	5.52	0.942	1.79
Vanadium	mg/L	0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.34	<0.01	<0.01	0.08	<0.01	<0.01	<0.01	<0.01
Zinc	mg/L	0.005	**3[b]**	0.024	0.006	0.098	0.013	0.006	0.024	0.026	0.011	0.028	0.018	0.026	0.022	0.024	0.204	0.007	0.025	0.154	0.096	0.173	0.008	0.108
BTEX																								
Benzene	µg/L	1		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	----	<1	<1	<1	<1	<1	<1	<1	<1	<1
Toluene	µg/L	2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
Ethylbenzene	µg/L	2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
meta- & para-Xylene	µg/L	2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
ortho-Xylene	µg/L	2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
Total Xylenes	µg/L	2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
Sum of BTEX	µg/L	1		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	----	<1	<1	<1	<1	<1	<1	<1	<1	<1
Naphthalene	µg/L	5		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	----	<5	<5	<5	<5	<5	<5	<5	<5	<5
Total Petroleum Hydrocarbons (Silica gel cleanup)																								
C10 - C14 Fraction (EP071 SG)	µg/L	50		<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
C15 - C28 Fraction (EP071 SG)	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
C29 - C36 Fraction (EP071 SG)	µg/L	50		<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
C10 - C36 Fraction (sum - EP071 SG)	µg/L	50		<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Total Recoverable Hydrocarbons																								
>C10 - C16 Fraction (EP071 SG)	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C16 - C34 Fraction (EP071 SG)	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C34 - C40 Fraction (EP071 SG)	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C10 - C40 Fraction (sum - EP071 SG)	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C10 - C16 Fraction minus Naphthalene	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	----	<100	<100	<100	<100	<100	<100	<100	<100	<100

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

G1839F

Groundwater Quality Results

Parameter	Units	LOR[#]	ANZECC GUIDELINES Short term irrigation	ANZECC GUIDELINES Long Term irrigation																					
Sample Location																									
Lab Number					GW02	GW04	GW14	GW33	GW46	NGW01B	NGW01C	NGW02B	NGW03A	MN1006	MN1014	MN0011 (REG1)	MP18A	MP18B	MP19A	MP20A	GW10-A2	GW10-P1	GW 10-P2	GW047877	GW202249
Date Sampled					25/09/2017	25/09/2017	25/09/2017	27/09/2017	27/09/2017	26/09/2017	26/09/2017	29/09/2017	29/09/2017	29/09/2017	26/09/2017	26/09/2017	27/09/2017	27/09/2017	27/09/2017	27/09/2017	25/09/2017	25/09/2017	25/09/2017	26/09/2017	26/09/2017
Lithology																									
Field Parameters																									
Field pH	pH units		6.0 - 8.5	6.0 - 8.5	8.62	7.18	7.61	6.16	6.38	7.5	7.4	7.67	6.63	7.6	11.94	12.37	6.94	6.91	7.25	7.08	7.2	6.91	7.41		
Field Electrical Conductivity (EC)	µS/cm		-		22770	7640	5120	15660	7480	4450	7250	4090	5980	3290	7560	6940	12000	21790	14640	13260	487	747	7980		
Depth to Groundwater	m TOC		-																						
Physical Parameters																									
pH	pH Units	0.1	6.0 - 8.5	6.0 - 8.5	8.46	7.81	7.96	7.7	7.54	7.9	7.67	7.84	7.29	8.02	11.4	11.8	7.6	7.7	7.7	7.84	7.31	7.48	7.92	7.81	8.19
Electrical conductivity	µS/cm	1	-		23300	7660	5120	16300	7470	4290	7360	3970	6080	3410	7330	6040	12500	22800	15200	11800	450	795	8310	5380	2060
Total Dissolved Solids (grav) @180°C	mg/L	1.00	-		15100	4500	3710	13700	5270	3240	4410	2830	3780	1930	3950	3330	5900	14300	7490	6030	472	420	3660	3320	1090
Hydroxide Alkalinity as $CaCO_3$	mg/L	1.00	-		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	247	460	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1.00	-		33	<1	<1	<1	<1	<1	<1	<1	<1	<1	360	145	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1.00	-		339	1270	729	1020	845	368	522	331	651	589	<1	<1	851	1080	1100	1760	40	96	1160	544	301
Total Alkalinity as $CaCO_3$	mg/L	1.00	-		372	1270	729	1020	845	368	522	331	651	589	607	605	851	1080	1100	1760	40	96	1160	544	301
Major Ions																									
Sulfate as SO_4 - Turbidimetric	mg/L	1	-		311	216	1	419	144	38	120	36	350	50	86	315	258	810	152	85	39	36	26	146	14
Chloride	mg/L	1		40	7220	1490	1140	4750	1690	1110	1850	994	1240	719	1870	912	3620	6570	1700	2910	43	142	1830	1560	475
Calcium	mg/L	1	-		29	41	72	176	106	152	229	222	222	104	7	65	203	140	119	81	1	5	71	22	36
Magnesium	mg/L	1	-		452	14	66	654	426	302	317	138	78	37	<1	<1	441	817	489	116	4	15	106	181	19
Sodium	mg/L	1	-		4330	1560	1020	1870	814	210	757	403	894	522	1260	939	1670	3460	915	2340	77	125	1500	857	393
Potassium	mg/L	1	-		50	9	17	71	48	9	8	11	29	19	84	75	29	76	56	24	4	6	24	39	10
Total Anions	meq/L	0.01	-		218	71.9	46.7	163	67.6	39.4	65.1	35.4	55.3	33.1	66.7	44.4	124	224	73.1	119	2.82	6.67	75.3	57.9	19.7
Total Cations	meq/L	0.01	-		228	71.3	53.8	146	77	41.8	70.6	40.2	57.1	31.4	57.3	46	120	227	87.4	116	3.83	7.07	78.1	54.3	20.7
Ionic Balance	%	0.01	-		2.4	0.43	7.04	5.61	6.52	2.89	4.08	6.4	1.65	2.58	7.55	1.81	1.92	0.64	8.92	1.29	15.1	2.92	1.82	3.25	2.49
Nutrients																									
Ammonia as N	mg/L	0.01	-		0.64	4.27	1.86	0.02	3.34	0.13	<0.01	0.05	3.59	0.02	7.8	1	0.32	0.21	0.07	2.51	<0.01	0.34	2.13	0.08	<0.01
Nitrite as N	mg/L	0.01	-		0.15	<0.01	<0.01	<0.01	0.09	0.06	<0.01	<0.01	0.07	0.03	<0.01	0.02	<0.01	<0.01	<0.01	0.06	0.02	0.12	0.33	<0.10	<0.01
Nitrate as N	mg/L	0.01	-		<0.01	0.06	0.33	0.04	<0.01	0.04	1.17	0.05	<0.01	2.55	0.04	0.01	0.06	0.16	0.43	0.45	12.4	<0.10	<0.01	<0.10	2.08
Nitrite + Nitrate as N	mg/L	0.01	-		0.03	0.06	0.33	0.04	0.08	0.1	1.17	0.05	0.05	2.58	0.04	0.03	0.06	0.16	0.43	0.51	12.4	0.11	0.04	<0.10	2.08
Total Kjeldahl Nitrogen as N	mg/L	0.1	-		1.2	4.6	2.2	0.2	3.6	0.3	0.7	1.6	3.7	1	14.2	3.5	0.5	4.5	0.4	3.5	5	1.6	2.9	0.2	0.5
Total Nitrogen as N	mg/L	0.1	25 - 125	5	1.2	4.7	2.5	0.2	3.7	0.4	1.9	1.6	3.8	3.6	14.2	3.5	0.6	4.7	0.8	4	17.4	1.7	2.9	0.2	2.6
Total Phosphorus as P	mg/L	0.01	0.8 - 12	0.05	0.02	0.62	0.05	0.18	0.32	0.11	0.47	0.1	0.02	0.13	0.56	0.74	0.15	2.3	1.18	0.23	0.93	0.14	0.37	0.02	0.28
Reactive Phosphorus as P	mg/L	0.01			<0.01	0.48	<0.01	0.02	<0.01	0.08	0.09	<0.01	<0.01	0.03	0.6	<0.01	<0.01	0.07	0.02	<0.01	<0.01	0.08	0.16	0.07	0.23
Total Metals																									
Aluminium	mg/L	0.01	5		0.05	0.02	0.2	0.35	0.06	1.21	7.66	0.14	0.11	0.78	2.62	0.42	0.22	108	0.42	0.45	69.1	1.14	1.39	0.1	0.69
Antimony	mg/L	0.001	-		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.003	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic	mg/L	0.001	2.0	0.1	<0.001	<0.001	<0.001	0.003	<0.001	0.003	0.001	<0.001	<0.001	<0.001	0.006	<0.001	0.004	0.026	0.015	0.002	0.004	<0.001	0.001	<0.001	0.002
Barium	mg/L	0.001	-		0.02	0.237	1.14	0.127	0.292	0.164	0.099	0.422	0.04	0.238	0.037	0.192	0.375	5.24	0.333	1.26	0.098	0.054	0.583	0.066	0.216
Beryllium	mg/L	0.001	0.5	0.1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.008	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001
Boron	mg/L	0.05	efer to guidelin	0.5	<0.05	0.38	0.18	<0.05	0.06	<0.05	<0.05	0.06	0.12	0.12	0.12	0.07	0.08	0.08	0.11	0.48	0.09	0.08	0.26	0.08	0.09
Cadmium	mg/L	0.0001	0.05	0.01	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002
Chromium	mg/L	0.001	1.0	0.1	<0.001	<0.001	0.001	<0.001	<0.001	0.008	0.032	<0.001	<0.001	0.002	<0.001	0.003	<0.001	0.215	0.002	0.001	0.131	0.003	0.005	<0.001	<0.001
Cobalt	mg/L	0.001	0.10	0.05	<0.001	<0.001	<0.001	0.003	<0.001	0.002	0.015	0.004	<0.001	<0.001	<0.001	0.001	<0.001	0.061	<0.001	0.001	0.035	0.004	0.002	<0.001	0.002
Copper	mg/L	0.001	5.0	0.2	<0.001	<0.001	0.006	0.013	<0.001	0.189	0.017	0.02	0.012	0.068	0.038	0.003	0.006	0.374	0.002	0.012	0.08	0.009	0.012	<0.001	0.003
Iron	mg/L	0.05	10.0	0.2	24.6	0.49	0.9	3.16	16.5	1.64	10.5	0.55	2.78	1.06	0.25	0.74	8.58	137	20	3.46	59.1	2.47	2.38	0.15	0.36
Lead	mg/L	0.001	5.0	2.0	<0.001	<0.001	0.003	<0.001	0.001	0.002	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.064	<0.001	0.002	0.027	0.004	0.006	0.006	0.019
Manganese	mg/L	0.001	10.0	0.2	0.509	0.076	0.208	0.099	0.505	0.804	0.253	2.05	0.214	0.041	0.01	0.017	0.194	0.358	0.162	0.092	0.316	0.064	0.284	0.032	0.021
Mercury	mg/L	0.0001	0.002	0.002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Molybdenum	mg/L	0.001	0.05	0.01	<0.001	<0.001	0.001	<0.001	<0.001	0.002	0.001	<0.001	<0.001	0.008	0.12	0.462	0.002	0.001	0.003	<0.001	<0.001	<0.001	0.001	0.002	0.003
Nickel	mg/L	0.001	2.0	0.2	<0.001	<0.001	0.002	0.005	<0.001	0.011	0.017	0.036	<0.001	0.009	0.025	0.008	0.001	0.121	<0.001	0.005	0.071	0.009	0.006	0.001	0.024
Selenium	mg/L	0.01	0.05	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
Silver	mg/L	0.001		-	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Strontium	mg/L	0.001		-	2.38	2.94	2.75	6.33	3.05	2.09	3.91	3.9	8.01	6.55	0.321	2.02	5.9	7.75	6.51	6.78	0.147	0.188	5.52	0.942	1.79
Vanadium	mg/L	0.01	0.5	0.1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.34	<0.01	<0.01	0.08	<0.01	<0.01	<0.01	<0.01
Zinc	mg/L	0.005	2.0	2.0	0.024	0.006	0.098	0.013	0.006	0.024	0.026	0.011	0.028	0.018	0.026	0.022	0.024	0.204	0.007	0.025	0.154	0.096	0.173	0.008	0.108
BTEX																									
Benzene	µg/L	1			<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	----	<1	<1	<1	<1	<1	<1	<1	<1	<1
Toluene	µg/L	2			<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
Ethylbenzene	µg/L	2			<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
meta- & para-Xylene	µg/L	2			<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
ortho-Xylene	µg/L	2			<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
Total Xylenes	µg/L	2			<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
Sum of BTEX	µg/L	1			<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	----	<1	<1	<1	<1	<1	<1	<1	<1	<1
Naphthalene	µg/L	5			<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	----	<5	<5	<5	<5	<5	<5	<5	<5	<5
Total Petroleum Hydrocarbons (Silica gel cleanup)																									
C10 - C14 Fraction (EP071 SG)	µg/L	50			<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
C15 - C28 Fraction (EP071 SG)	µg/L	100			<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
C29 - C36 Fraction (EP071 SG)	µg/L	50			<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
C10 - C36 Fraction (sum - EP071 SG)	µg/L	50			<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Total Recoverable Hydrocarbons																									
>C10 - C16 Fraction (EP071 SG)	µg/L	100			<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C16 - C34 Fraction (EP071 SG)	µg/L	100			<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C34 - C40 Fraction (EP071 SG)	µg/L	100			<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C10 - C40 Fraction (sum - EP071 SG)	µg/L	100			<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C10 - C16 Fraction minus Naphthalene	µg/L	100			<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	----	<100	<100	<100	<100	<100	<100	<100	<100	<100

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

AGE

G1839F

Groundwater Quality Results

Parameter	Units	LOR#	ANZECC GUIDELINES																					
Sample Location																								
Lab Number			Stock Water	GW02	GW04	GW14	GW33	GW46	NGW01B	NGW01C	NGW02B	NGW03A	MN1006	MN1014	MN0011 (REG1)	MP18A	MP18B	MP19A	MP20A	GW10-A2	GW10-P1	GW 10-P2	GW047877	GW202249
Date Sampled				25/09/2017	25/09/2017	25/09/2017	27/09/2017	27/09/2017	26/09/2017	26/09/2017	29/09/2017	29/09/2017	29/09/2017	26/09/2017	26/09/2017	27/09/2017	27/09/2017	27/09/2017	27/09/2017	25/09/2017	25/09/2017	25/09/2017	26/09/2017	26/09/2017
Lithology																								
Field Parameters																								
Field pH	pH units		-	8.62	7.18	7.61	6.16	6.38	7.5	7.4	7.67	6.63	7.6	11.94	12.37	6.94	6.91	7.25	7.08	7.2	6.91	7.41		
Field Electrical Conductivity (EC)	µS/cm		-	22770	7640	5120	15660	7480	4450	7250	4090	5980	3290	7560	6940	12000	21790	14640	13260	487	747	7980		
Depth to Groundwater	m TOC		-																					
Physical Parameters																								
pH	pH Units	0.1	-	8.46	7.81	7.96	7.7	7.54	7.9	7.67	7.84	7.29	8.02	11.4	11.8	7.6	7.7	7.7	7.84	7.31	7.48	7.92	7.81	8.19
Electrical conductivity	µS/cm	1	-	23300	7660	5120	16300	7470	4290	7360	3970	6080	3410	7330	6040	12500	22800	15200	11800	450	795	8310	5380	2060
Total Dissolved Solids (grav) @180°C	mg/L	1.00	3000 - 13000*	15100	4500	3710	13700	5270	3240	4410	2830	3780	1930	3950	3330	5900	14300	7490	6030	472	420	3660	3320	1090
Hydroxide Alkalinity as $CaCO_3$	mg/L	1.00	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	247	460	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1.00	-	33	<1	<1	<1	<1	<1	<1	<1	<1	<1	360	145	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1.00	-	339	1270	729	1020	845	368	522	331	651	589	<1	<1	851	1080	1100	1760	40	96	1160	544	301
Total Alkalinity as $CaCO_3$	mg/L	1.00	-	372	1270	729	1020	845	368	522	331	651	589	607	605	851	1080	1100	1760	40	96	1160	544	301
Major Ions																								
Sulfate as SO_4 - Turbidimetric	mg/L	1	1000 - 2000	311	216	1	419	144	38	120	36	350	50	86	315	258	810	152	85	39	36	26	146	14
Chloride	mg/L	1	-	7220	1490	1140	4750	1690	1110	1850	994	1240	719	1870	912	3620	6570	1700	2910	43	142	1830	1560	475
Calcium	mg/L	1	1000	29	41	72	176	106	152	229	222	222	104	7	65	203	140	119	81	1	5	71	22	36
Magnesium	mg/L	1	-	452	14	66	654	426	302	317	138	78	37	<1	<1	441	817	489	116	4	15	106	181	19
Sodium	mg/L	1	-	4330	1560	1020	1870	814	210	757	403	894	522	1260	939	1670	3460	915	2340	77	125	1500	857	393
Potassium	mg/L	1	-	50	9	17	71	48	9	8	11	29	19	84	75	29	76	56	24	4	6	24	39	10
Total Anions	meq/L	0.01	-	218	71.9	46.7	163	67.6	39.4	65.1	35.4	55.3	33.1	66.7	44.4	124	224	73.1	119	2.82	6.67	75.3	57.9	19.7
Total Cations	meq/L	0.01	-	228	71.3	53.8	146	77	41.8	70.6	40.2	57.1	31.4	57.3	46	120	227	87.4	116	3.83	7.07	78.1	54.3	20.7
Ionic Balance	%	0.01	-	2.4	0.43	7.04	5.61	6.52	2.89	4.08	6.4	1.65	2.58	7.55	1.81	1.92	0.64	8.92	1.29	15.1	2.92	1.82	3.25	2.49
Nutrients																								
Ammonia as N	mg/L	0.01	-	0.64	4.27	1.86	0.02	3.34	0.13	<0.01	0.05	3.59	0.02	7.8	1	0.32	0.21	0.07	2.51	<0.01	0.34	2.13	0.08	<0.01
Nitrite as N	mg/L	0.01	30	0.15	<0.01	<0.01	<0.01	0.09	0.06	<0.01	<0.01	0.07	0.03	<0.01	0.02	<0.01	<0.01	<0.01	0.06	0.02	0.12	0.33	<0.10	<0.01
Nitrate as N	mg/L	0.01	-	<0.01	0.06	0.33	0.04	<0.01	0.04	1.17	0.05	<0.01	2.55	0.04	0.01	0.06	0.16	0.43	0.45	12.4	<0.10	<0.01	<0.10	2.08
Nitrite + Nitrate as N	mg/L	0.01	400	0.03	0.06	0.33	0.04	0.08	0.1	1.17	0.05	0.05	2.58	0.04	0.03	0.06	0.16	0.43	0.51	12.4	0.11	0.04	<0.10	2.08
Total Kjeldahl Nitrogen as N	mg/L	0.1	-	1.2	4.6	2.2	0.2	3.6	0.3	0.7	1.6	3.7	1	14.2	3.5	0.5	4.5	0.4	3.5	5	1.6	2.9	0.2	0.5
Total Nitrogen as N	mg/L	0.1	-	1.2	4.7	2.5	0.2	3.7	0.4	1.9	1.6	3.8	3.6	14.2	3.5	0.6	4.7	0.8	4	17.4	1.7	2.9	0.2	2.6
Total Phosphorus as P	mg/L	0.01	-	0.02	0.62	0.05	0.18	0.32	0.11	0.47	0.1	0.02	0.13	0.56	0.74	0.15	2.3	1.18	0.23	0.93	0.14	0.37	0.02	0.28
Reactive Phosphorus as P	mg/L	0.01	-	<0.01	0.48	<0.01	0.02	<0.01	0.08	0.09	<0.01	<0.01	0.03	0.6	<0.01	<0.01	0.07	0.02	<0.01	<0.01	0.08	0.16	0.07	0.23
Total Metals																								
Aluminium	mg/L	0.01	5	0.05	0.02	0.2	0.35	0.06	1.21	7.66	0.14	0.11	0.78	2.62	0.42	0.22	108	0.42	0.45	69.1	1.14	1.39	0.1	0.69
Antimony	mg/L	0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.003	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic	mg/L	0.001	0.5	<0.001	<0.001	<0.001	0.003	<0.001	0.003	0.001	<0.001	<0.001	<0.001	0.006	<0.001	0.004	0.026	0.015	0.002	0.004	<0.001	0.001	<0.001	0.002
Barium	mg/L	0.001	-	0.02	0.237	1.14	0.127	0.292	0.164	0.099	0.422	0.04	0.238	0.037	0.192	0.375	5.24	0.333	1.26	0.098	0.054	0.583	0.066	0.216
Beryllium	mg/L	0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.008	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001
Bismuth	mg/L	0.001	-																					
Boron	mg/L	0.05	5.0	<0.05	0.38	0.18	<0.05	0.06	<0.05	<0.05	0.06	0.12	0.12	0.12	0.07	0.08	0.08	0.11	0.48	0.09	0.08	0.26	0.08	0.09
Cadmium	mg/L	0.0001	0.01	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002
Caesium	mg/L	0.001	-																					
Cerium	mg/L	0.001	-																					
Chromium	mg/L	0.001	1.0	<0.001	<0.001	0.001	<0.001	<0.001	0.008	0.032	<0.001	<0.001	0.002	<0.001	0.003	<0.001	0.215	0.002	0.001	0.131	0.003	0.005	<0.001	<0.001
Cobalt	mg/L	0.001	1.0	<0.001	<0.001	<0.001	0.003	<0.001	0.002	0.015	0.004	<0.001	<0.001	<0.001	0.001	<0.001	0.061	<0.001	0.001	0.035	0.004	0.002	<0.001	0.002
Copper	mg/L	0.001	0.5 - 5^	<0.001	<0.001	0.006	0.013	<0.001	0.189	0.017	0.02	0.012	0.068	0.038	0.003	0.006	0.374	0.002	0.012	0.08	0.009	0.012	<0.001	0.003
Iron	mg/L	0.05	-	24.6	0.49	0.9	3.16	16.5	1.64	10.5	0.55	2.78	1.06	0.25	0.74	8.58	137	20	3.46	59.1	2.47	2.38	0.15	0.36
Lead	mg/L	0.001	0.1	<0.001	<0.001	0.003	<0.001	0.001	0.002	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.064	<0.001	0.002	0.027	0.004	0.006	0.006	0.019
Manganese	mg/L	0.001	-	0.509	0.076	0.208	0.099	0.505	0.804	0.253	2.05	0.214	0.041	0.01	0.017	0.194	0.358	0.162	0.092	0.316	0.064	0.284	0.032	0.021
Mercury	mg/L	0.0001	0.002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Molybdenum	mg/L	0.001	0.15	<0.001	<0.001	0.001	<0.001	<0.001	0.002	0.001	<0.001	<0.001	0.008	0.12	0.462	0.002	0.001	0.003	<0.001	<0.001	<0.001	0.001	0.002	0.003
Nickel	mg/L	0.001	1	<0.001	<0.001	0.002	0.005	<0.001	0.011	0.017	0.036	<0.001	0.009	0.025	0.008	0.001	0.121	<0.001	0.005	0.071	0.009	0.006	0.001	0.024
Selenium	mg/L	0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
Silver	mg/L	0.001	-	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Strontium	mg/L	0.001	-	2.38	2.94	2.75	6.33	3.05	2.09	3.91	3.9	8.01	6.55	0.321	2.02	5.9	7.75	6.51	6.78	0.147	0.188	5.52	0.942	1.79
Vanadium	mg/L	0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.34	<0.01	<0.01	0.08	<0.01	<0.01	<0.01	<0.01
Zinc	mg/L	0.005	20	0.024	0.006	0.098	0.013	0.006	0.024	0.026	0.011	0.028	0.018	0.026	0.022	0.024	0.204	0.007	0.025	0.154	0.096	0.173	0.008	0.108
BTEX																								
Benzene	µg/L	1		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	----	<1	<1	<1	<1	<1	<1	<1	<1	<1
Toluene	µg/L	2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
Ethylbenzene	µg/L	2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
meta- & para-Xylene	µg/L	2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
ortho-Xylene	µg/L	2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
Total Xylenes	µg/L	2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	----	<2	<2	<2	<2	<2	<2	<2	<2	<2
Sum of BTEX	µg/L	1		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	----	<1	<1	<1	<1	<1	<1	<1	<1	<1
Naphthalene	µg/L	5		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	----	<5	<5	<5	<5	<5	<5	<5	<5	<5
Total Petroleum Hydrocarbons (Silica gel cleanup)																								
C10 - C14 Fraction (EP071 SG)	µg/L	50		<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
C15 - C28 Fraction (EP071 SG)	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
C29 - C36 Fraction (EP071 SG)	µg/L	50		<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
C10 - C36 Fraction (sum - EP071 SG)	µg/L	50		<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Total Recoverable Hydrocarbons																								
>C10 - C16 Fraction (EP071 SG)	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C16 - C34 Fraction (EP071 SG)	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C34 - C40 Fraction (EP071 SG)	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C10 - C40 Fraction (sum - EP071 SG)	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C10 - C16 Fraction minus Naphthalene	µg/L	100		<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	----	<100	<100	<100	<100	<100	<100	<100	<100	<100

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

Appendix E Peer review documents

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DATE: 15 May 2019

TO: Daniel Sullivan
Principal Environmental Consultant
Umwelt (Australia) Pty Limited
75 York Street
Teralba NSW 2284
Tel: (02) 4950 5322

FROM: Dr Noel Merrick

RE: Mangoola Continued Operations Project –
Groundwater Assessment Peer Review

YOUR REF: 4004/12042017/DS/JM

OUR REF: HA2019/2b

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1. Introduction

This report provides a peer review of the groundwater impact assessment (GIA) and associated modelling for the Mangoola Coal Continued Operations Project (MCCO), located to the west of Muswellbrook NSW. The GIA has been prepared by Australasian Groundwater and Environmental Consultants (AGE) under the project management of Umwelt, for the client Mangoola Coal Pty Ltd, a subsidiary of Glencore Coal Pty Ltd.

The main element of the Project is an extension of existing and approved open cut coal mining into an Additional Area on the north side of Big Flat Creek.

This review has been conducted solely by Dr Noel Merrick as a staged review. He provided interim reviews in January 2018 (on modelling approach and conceptualisation), May 2018 (on calibration) and January 2019 (on predictions).

2. Documentation

The review is based on the following report:

1. AGE, 2019, Mangoola Coal Continued Operations Groundwater Impact Assessment. Report No. G1839F prepared for Mangoola Coal Operations Pty Ltd. Edition v04.01 (26 April 2019), 139p + 4 Appendices.

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

2. AGE, 2019, Numerical Modelling Report, 57p + 2 Appendices.

Document #1 has the following sections:

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

The Appendices are:

A. Numerical modelling report
B. Compliance with government policy
C. Monitoring bore details
D. Water quality tables

Document #2 is structured as follows:

1. Introduction
2. Model construction and development
3. Model calibration
4. Predictive and recovery simulations
5. Uncertainty analysis
6. Sensitivity analysis
7. References.

The Appendices are:

1. Calibration details and hydrographs
2. Predictive uncertainty hydrographs.

3. Review Methodology

There are two accepted guides to the review of groundwater models: (A) the Murray-Darling Basin Commission (**MDBC**) Groundwater Flow Modelling Guideline[1], issued in 2001,and (B) newer guidelines issued by the National Water Commission (**NWC**) in June 2012 (Barnett *et al*., 2012[2]). Both guides also offer techniques for reviewing the non-modelling components of a groundwater assessment. The NWC national guidelines were built upon the original MDBC guide, with substantial consistency in the model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details.

The NWC guide promotes the concept of "model confidence level", which is defined using a number of criteria that relate to data availability, calibration, and prediction scenarios. The NWC guide is almost silent on coal mine modelling and offers no direction on best practice methodology for such applications. There is, however, an expectation of more effort in uncertainty analysis, although the guide is not prescriptive as to which methodology should be adopted.

Guidelines on uncertainty analysis for groundwater models were issued by the Independent Expert Scientific Committee (IESC) on Coal Seam Gas and Large Coal Mining Development in February

[1] MDBC (2001). Groundwater flow modelling guideline. Murray-Darling Basin Commission. URL: www.mdbc.gov.au/nrm/water_management/groundwater/groundwater_guides

[2] Barnett, B, Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A. and Boronkay, A. (2012). *Australian Groundwater Modelling Guidelines*. Waterlines report 82, National Water Commission, Canberra.

2018 in draft form and finalised in December 2018[3].

The groundwater guides include useful checklists for peer review. For this review, the 2-page Model Appraisal checklist[4] in MDBC (2001) has been used for groundwater model review. This checklist has questions on (1) The Report; (2) Data Analysis; (3) Conceptualisation; (4) Model Design; (5) Calibration; (6) Verification; (7) Prediction; (8) Sensitivity Analysis; and (9) Uncertainty Analysis. Non-modelling components of the impact assessments are addressed by the first three sections of the checklist.

It should be recognised that the effort put into a modelling project is very dependent on possible timing and budgetary constraints that are generally not known to a reviewer.

This review has been conducted progressively, with involvement of the peer reviewer at all stages of model development and application. The interaction was conducted through one face-to-face meeting on 24 January 2018 and subsequent phone/email correspondence.

A detailed assessment has been made in terms of the peer review checklists in **Table 1** and **Table 2**. **Table 1** addresses reporting, data analysis, conceptualisation and model design. **Table 2** addresses calibration, verification, prediction, sensitivity analysis and uncertainty analysis. Supplementary comments are offered in the following sections.

4. Report Matters

Previous review comments after conceptualisation, model design, calibration and prediction stages have been addressed satisfactorily.

The GIA report is a high-quality document of about 140 pages length, not counting a number of appendices that contain more detail on numerical modelling, policy compliance, bore details and water quality measurements. It is well structured, well written and the graphics are of high quality. The report serves well as a standalone document, with no undue dependence on earlier work. Document #2 on numerical modelling adds a further 57 pages plus appendices.

A feature of the main report is the inclusion of many informative photographs.

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

The objectives are stated at the outset (Section 1.2). The text of the report sufficiently addresses those objectives but there is no Conclusion section to summarise the findings of the assessment and the meeting of objectives.

There is a detailed exposition of geology, supported by seismic refraction, and an extensive description and defence of hydrogeological conceptualisation informed primarily by cause-and-effect analysis of groundwater hydrograph responses to natural and mining stresses.

An unusual feature is the partitioning of recorded/inferred mine inflow between spoil and host rock, showing spoil as the dominant source.

A mass balance tabulation should have been provided for the prediction simulation.

[3] Middlemis H and Peeters LJM (2018) *Uncertainty analysis—Guidance for groundwater modelling within a risk management framework*. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy, Commonwealth of Australia 2018.

[4] The NWC guidelines include a more detailed checklist but they do not offer the graded assessments of the MDBC checklist, which this reviewer regards as more informative for readers.

5. Data Matters

Much legacy information on hydraulic properties is available from previous on-site field investigations. This has been supplemented by recent packer testing and laboratory measurements on cores. The cores have also been used in the estimation of specific storage, very rarely done.

In Document #1, there are said to be "approximately 122 active monitoring bores and VWPs in the current groundwater monitoring program", with 37 sites abandoned or destroyed since the start of the program. Although full details are provided in Appendix C of Document #1, there is no neat summary of the numbers per lithology and the numbers per bore type (standpipes, nests, VWPs). However, this is provided in Section A3.1.1 of Document #2 for bore type but not lithology.

The groundwater hydrographs have clear signatures that document the groundwater system's response to stresses. A thorough cause-and-effect analysis underpins a valid hydrogeological conceptualisation. The cause-and-effect analysis reveals mining effects at depth but not in alluvium.

Considerable effort has been put into differentiation between colluvium and alluvium along Big Flat Creek, with support from a seismic refraction survey.

As the target coal seams are within the Newcastle Coal Measures, the potential effects of distant neighbouring mines are further lessened by their targeting of seams in the older Wittingham Coal Measures.

A comprehensive description of each local stream and its interaction with groundwater is provided in Document #1.

Private groundwater pumping is recognised as not significant in terms of its stress on the overall groundwater system.

The geology, though complex, is well known. Mapped structural faults are noted as minor, apart from the Mt Ogilvie fault to the north-east. Its effect has been tested through sensitivity analysis.

6. Model Matters

The reviewer concurs with the entire modelling methodology described in Document #2 and recognises it as "state-of-art".

Key features of the modelling approach are:

- MODFLOW-USG plus AlgoMesh software platform for better mass balance and better spatial resolution;
- use of an equivalent pseudo-soil representation of unsaturated zones;
- a novel identifiability procedure to replace sensitivity analysis by perturbation, in which many more model properties can be included, and relative sensitivities are produced as a matter of course; the downside is an absence of reporting on calibration performance (if a sensitive parameter were varied) and on the magnitude of model outputs (if a sensitive parameter were varied); and
- a *monte carlo* style rigorous procedure for uncertainty analysis.

In terms of model confidence level classifications, Document #2 states:

"...the Project model is classified between a Class 2 and Class 3 model."

An IESC-compliant annotated classification table of attributes from the NWC guidelines has been included as Table A3.7. If counts were made of the attributes in each class, the model could be said to be 7% Class 1, 39% Class 2 and 54% Class 3.

The groundwater hydrographs at 157 monitoring sites with good spatial spread serve as the basis for model calibration using PEST software and pilot points. Less reliable pit inflow records were not used as calibration targets, but as *ad hoc* calibration checks. During 2016-2017, simulated inflow was about 0.4 ML/day compared to estimated actual inflow of 0.3 ML/day. This is good agreement.

Calibration target heads have been weighted to counteract bias towards areas of higher data density. No further weighting has been considered (at least not reported) for data quality or reliability.

Calibration performance statistics of 4.9%RMS and 6.1 mRMS are very good for a complex mining precinct. The scattergram (Figure A3.3) is generally linear across a wide range but there is substantial scatter, not unusual at a mining site, especially for VWP datasets. There is some systematic bias evident by the diagonal trends in the residuals diagram (Figure A3.4). Replication of vertical head differences is generally good.

Hydrographic trends are generally replicated for many examples of mining effects, but there are some timing and drawdown inconsistencies. Legitimate reasons are put forward where model performance is poor.

The simulated water table contours in Figure A3.5 of Document #2 should be compared with the observed/interpolated contours in Figure 5.5 of Document #1. The agreement is quite good for pre-mining and fair for 2017.

There are three modelling scenarios:

- Null (no mining).
- Approved mining.
- Approved plus proposed mining (with subsequent recovery).

There is no cumulative scenario due to distance (>10 km) and different coal measures targeted by other mines.

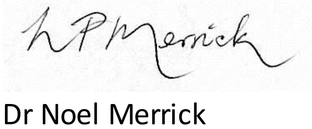
A substantial uncertainty analysis has been undertaken using a null-space *monte carlo* technique, using 207 alternative calibrated realisations out of a trial set of 250 selections. The acceptability criterion is stated as less than a 25% increase in *phi*. Evidence is provided in Figure A5.3 that maximum drawdown has sufficiently converged for the chosen number of realisations. A convergence test is encouraged by the IESC Explanatory Note on Uncertainty Analysis in Groundwater Modelling.

7. Conclusion

The reviewer is of the opinion that the documented groundwater assessment is best practice and concludes that the model is *fit for purpose*, where the purpose is defined broadly by the requirements of NSW and Commonwealth legislation and policies.

All usual “outputs of concern” are presented to give an overall impression of the environmental effects and their uncertainties. The assessment has been based on data analysis, conceptualisation and groundwater modelling that has been conducted to a very high standard.

Yours sincerely



Dr Noel Merrick

Table 1. Model Review (Part A)

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
1.0	THE REPORT								*Main Report & Appendix A*
1.1	Is there a clear statement of project objectives in the modelling report?		Missing	Deficient	Adequate	**Very Good**			Agency requirements: Section 1.2 Doc#1.
1.2	Is the level of model complexity clear or acknowledged?		Missing	No	**Yes**				Mixture of Class 2 (39%) and Class 3 (54%). Table A3.7 is IESC-compliant.
1.3	Is a water or mass balance reported?		Missing	Deficient	**Adequate**	Very Good			Tables A3.5 & A3.6 for steady-state and transient calibration. Prediction table missing – but components provided as graphs.
1.4	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	**Very Good**			
1.5	Are the model results of any practical use?			No	Maybe	**Yes**			
2.0	DATA ANALYSIS								
2.1	Has hydrogeology data been collected and analysed?		Missing	Deficient	Adequate	**Very Good**			Newcastle Coal Measures – younger seams than neighbouring mines. Colluvium along Big Flat Creek; rock bar photo. Alluvium definition (test bores and seismic refraction for base of weathering). Structure and depth contours. Legacy on-site K measurement. 3 packer tests + lab core tests. Calculation of Ss from cores Fig.5.22. 60 water quality points, Piper diagram Fig.5.25.
2.2	Are groundwater contours or flow directions presented??		Missing	Deficient	**Adequate**	Very Good			Water table (Fig.5-5) pre-mining and 2017.
2.3	Have all potential recharge data been collected and analysed? (rainfall, streamflow, irrigation, floods, etc.)		Missing	Deficient	Adequate	**Very Good**			SILO rainfall. Streamflow presented in graphical form for Wybong Creek. CMB rain recharge assessment. SWAT model.

2.4	Have all potential discharge data been collected and analysed? (abstraction, evapotranspiration, drainage, springflow, etc.)		Missing	Deficient	Adequate	**Very Good**			Baseflow to Wybong Creek & Sandy Creek. Creek EC. Private pumping not significant. Actual ET 500 mm/a; 2m extinction. Pit inflow estimates Table 5.1; split between spoil and rock source Fig.5.18. SWAT model.
2.5	Have the recharge and discharge datasets been analysed for their groundwater response?		Missing	Deficient	Adequate	**Very Good**			Detailed descriptions. CRD & creek WL comparison. Evident mining effects at depth but not in alluvium. Analysis of vertical gradient.
2.6	Are groundwater hydrographs used for calibration?			No	Maybe	**Yes**			Hydrographs: 130 sites, standpipes often nested & VWPs. Many mining effects evident. One govt. bore since 2003 (Fig.5.1).
2.7	Have consistent data units and standard geometrical datums been used?			No	**Yes**				
3.0	CONCEPTUALISATION								
3.1	Is the conceptual model consistent with project objectives and the required model complexity?		Unknown	No	Maybe	**Yes**			
3.2	Is there a clear description of the conceptual model?		Missing	Deficient	Adequate	**Very Good**			Extensive description in Section 5.5.
3.3	Is there a graphical representation of the modeller's conceptualisation?		Missing	Deficient	**Adequate**	Very Good			Geology X-Sections Fig.4-2 & 4.3 with mine cutouts but no flow indicators: no major marked faults (cf. Fig.4.17). Big Flat Creek: 8 cross sections (Fig.3.4). Pre-mining and during-mining conceptual model schematics Figs.5.31, 5.32. Reference to causal pathways of Bioregional Assessment: Table 5.12.
3.4	Is the conceptual model unnecessarily simple or unnecessarily complex?			Yes	**No**				
4.0	MODEL DESIGN								*Several prior models by MER.*

4.1	Is the spatial extent of the model appropriate?			No	Maybe	**Yes**			17km x 17km. 15 layers. Max 15k cells/layer (less pinchouts). Total 0.18million cells. Minimum cell size 50m. Maximum cell size 700m. Confined by Sandy Creek to east and south-east. No relevant mines for cumulative impact.
4.2	Are the applied boundary conditions plausible and unrestrictive?		Missing	Deficient	Adequate	**Very Good**			GHB on edges. Justified in Section A2.3.2. RIV & STR internally.
4.3	Is the software appropriate for the objectives of the study?			No	Maybe	**Yes**			MF-USG unstructured + AlgoMesh Voronoi cells. Upstream weighting = pseudo-soil. CONSTANTCV.

Table 2. Model Review (Part B)

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
5.0	CALIBRATION								*Steady-state 2009.* *Transient 2010 - 2017 (8 years).*
5.1	Is there sufficient evidence provided for model calibration?		Missing	Deficient	Adequate	**Very Good**			157 monitoring sites - good spread (x,z). Scattergram; residuals x-y plot; hydrographs.
5.2	Is the model sufficiently calibrated against spatial observations?		Missing	Deficient	**Adequate**	Very Good			Scattergram generally linear across a wide range but substantial scatter. Shallow head contours Fig.A3.5 match observed patterns in Doc#1 Fig.5.5.
5.3	Is the model sufficiently calibrated against temporal observations?		Missing	Deficient	**Adequate**	Very Good			Quarterly stress periods from 2011; 6 periods in 2010 (5-120d). Generally good trend matches for many examples of mining effects. Some timing and drawdown inconsistencies. Systematic diagonal features on residual x-y plot.
5.4	Are calibrated parameter distributions and ranges plausible?		Missing	No	Maybe	**Yes**			Spatial variability using PEST pilot points.
5.5	Does the calibration statistic satisfy agreed performance criteria?		Missing	Deficient	Adequate	**Very Good**			4.9%RMS unweighted, 6.1 mRMS.
5.6	Are there good reasons for not meeting agreed performance criteria?		Missing	Deficient	**Adequate**	Very Good			Timing of mining; heterogeneity; some thick layers (assumed single head); pilot point density.
6.0	VERIFICATION								*Optional for heads subset*
6.1	Is there sufficient evidence provided for model verification?		Missing	Deficient	**Adequate**	Very Good			Mine inflow verification. About 30% higher than estimated inflow of low reliability (0.37 vs 0.28 ML/day).
6.2	Does the reserved dataset include stresses consistent with the prediction scenarios?	**N/A**	Unknown	No	Maybe	Yes			All monitoring data used for calibration.
6.3	Are there good reasons for an unsatisfactory verification?	**N/A**	Missing	Deficient	Adequate	Very Good			
7.0	PREDICTION								*2018-2030 (13 years) + recovery 500 yrs. Extension from 2022.*

7.1	Have multiple scenarios been run for climate variability?		Missing	Deficient	**Adequate**	Very Good			Long-term average during prediction and recovery. Climate variability is accommodated through uncertainty analysis by varying recharge factors.
7.2	Have multiple scenarios been run for operational /management alternatives?		Missing	Deficient	**Adequate**	Very Good			Single mine plan - normal practice.
7.3	Is the time horizon for prediction comparable with the length of the calibration / verification period?		Missing	No	Maybe	**Yes**			Calib:8 yrs, Pred:13yrs. Ratio Pred/Calib = 1.6 (implies high "confidence")
7.4	Are the model predictions plausible?			No	Maybe	**Yes**			Drawdown generally matches observation.
8.0	SENSITIVITY ANALYSIS								*Identifiability approach*
8.1	Is the sensitivity analysis sufficiently intensive for key parameters?		Missing	Deficient	**Adequate**	Very Good			Usual sensitivity analysis on model properties done differently by linear analysis. Sensible findings. Sensitivity to Sy possible only when unconfined; only in Layer 14 (at outcrop?). Also conducted on with/without Mt Ogilvie Fault – no material effect on impact predictions.
8.2	Are sensitivity results used to qualify the reliability of model calibration?	**N/A**	Missing	Deficient	Adequate	Very Good			Not an output of identifiability approach, a better method than conventional sensitivity analysis. The results inherently remain calibrated, as perturbation does not occur.
8.3	Are sensitivity results used to qualify the accuracy of model prediction?		Missing	Deficient	**Adequate**	Very Good			Usual sensitivity analysis outputs done differently by uncertainty analysis.
9.0	UNCERTAINTY ANALYSIS								*IESC-Compliant.*
9.1	If required by the project brief, is uncertainty quantified in any way?		Missing	No	Maybe	**Yes**			Substantial work. 250 realisations (Kx, Kz, Sy, Ss, RCH, RIV conductance). Null-space Monte Carlo. Prior and posterior distributions.
9.2	Are uncertainty results used to qualify the reliability of model calibration?		Missing	Deficient	Adequate	**Very Good**			83% calibrated (207 of 250). Acceptability statistic is 25% higher PHI (sum of squares). Box-whisker evidence provided in Figure A5.3 that max drawdown has converged sufficiently with acceptable runs [new requirement of IESC Explanatory Note].

9.3	Are uncertainty results used to qualify the accuracy of model prediction?		Missing	Deficient	Adequate	Very Good			Uncertain outputs of interest: hydrographs; 2m draw down (x,y); mine inflow (median close to base case); alluvium take; surface w ater take.
	TOTAL SCORE								PERFORMANCE: %

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LB/JST (G1839F_MCCO)
16 May 2019

Attention: John Merrell

Umwelt (Australia) Pty Ltd
75 York Street
TERALBA NSW 2284

via email

Dear John,

RE: Response to Mangoola Continued Operations Project – Groundwater Assessment Peer Review

Umwelt (Australia) and Glencore have requested that AGE respond to clarify one item raised in the peer review[1]

Section 4 of the peer review commented that: "*An unusual feature is the partitioning of the recorded/inferred mine inflow between spoil and host rock, showing spoil as the dominant source*". A water balance model was used to estimate the volume of groundwater reporting to the sumps from the host rock and the volume of water from the spoil emplacements. This work was undertaken to ensure that the project could correctly account for groundwater inflow from the regulated water sources for licensing purposes.

If you have any queries, please do not hesitate to call.

Yours faithfully,

JAMES TOMLIN
Principal Hydrogeologist/Director
Australasian Groundwater and Environmental Consultants Pty Ltd

[1] HydroAlgorithmics, 2019. Mangoola Coal Continued Operations Project – Groundwater Assessment Peer Review. 15 May 2019. Ref: HA2019/2b.