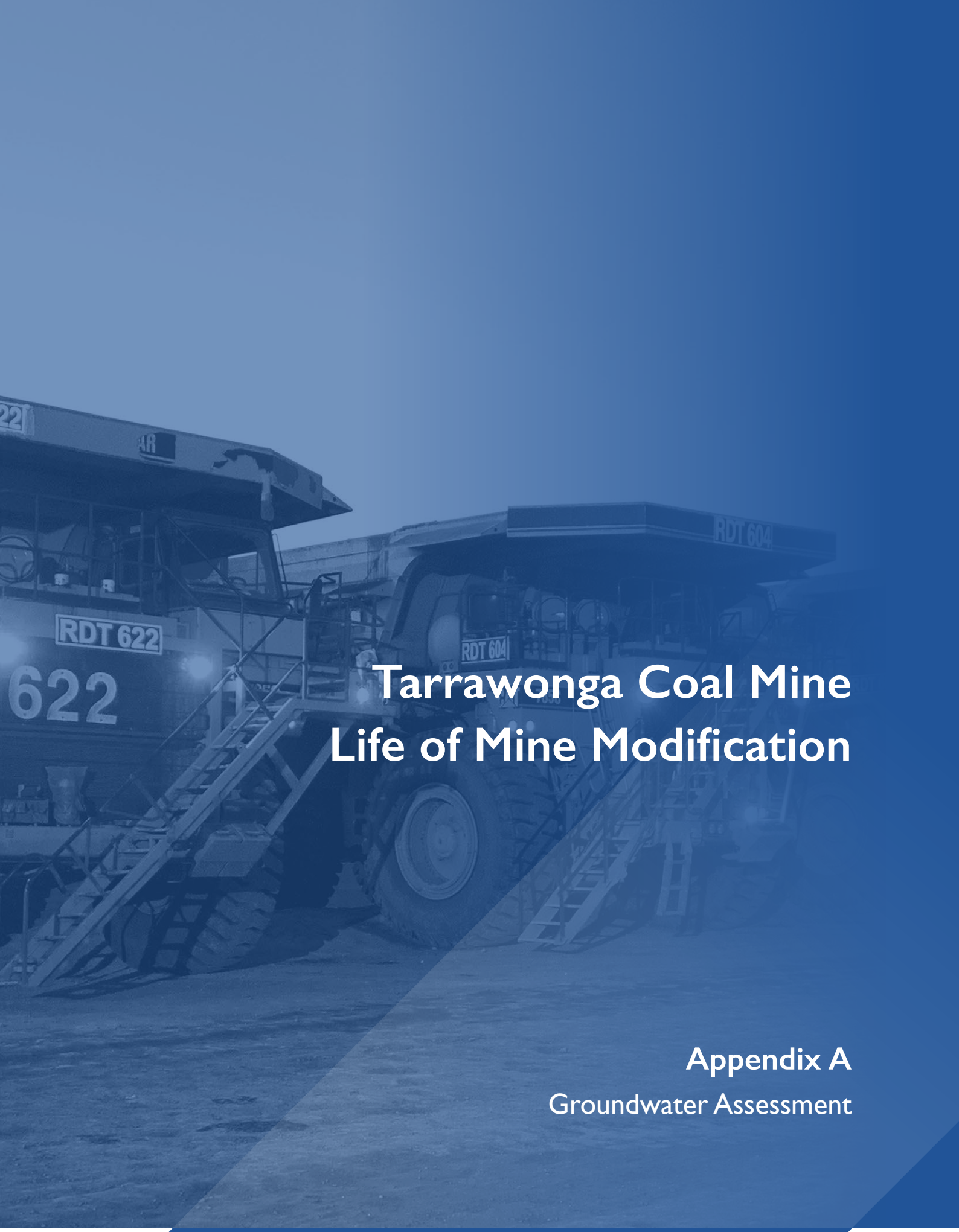


Tarrawonga Coal Mine
Life of Mine Modification

Appendix A

Groundwater Assessment

WHITEHAVEN COAL

TARRAWONGA COAL MINE LIFE OF MINE MODIFICATION: GROUNDWATER ASSESSMENT

IN SUPPORT OF A MODIFICATION REPORT

FOR

Whitehaven Coal Limited

BY

I. Epari, T. Liu and Dr N.P. Merrick

SLR Consulting Australia Pty Ltd

HydroSimulations

Project number: WHI2015

Report: HS2019-19

Date: 30 September 2019

DOCUMENT REGISTER

Revision	Description	Date	Comments
V1.0	First Draft	2 August 2019	First draft for client review.
V2.0	Revised draft	28 August 2019	Updated Draft for client review
V3.0	Inclusion of Uncertainty Analysis	30 September 2019	Final report

File:
h:\projects-slr\660-srvwol\660-wol\665.whi15 tarrawonga gw model assessment\04 reports\01_gw assessment\665.whi15.r01-v3.0_whitehaven tarrawonga groundwater assessment.docx

TABLE OF CONTENTS

1 Introduction ... 1
1.1 Modification description ... 1
1.1.1 Approved operations ... 1
1.1.2 Proposed Mine Development Modification ... 2
1.2 Objectives and scope of work ... 3

2 Regulatory framework ... 4
2.1 Commonwealth Environment Protection and Biodiversity Conservation Act 1999 ... 4
2.2 Water Act 1912 ... 4
2.3 Water Management Act 2000 ... 4
2.4 Water Sharing Plans ... 5
2.5 Aquifer Interference Policy ... 6
2.6 Groundwater quality protection ... 6
2.7 Groundwater quantity management ... 7
2.8 Water licensing ... 7

3 Environmental setting ... 9
3.1 Climate ... 9
3.1.1 Rainfall ... 9
3.1.2 Evaporation ... 11
3.2 Topography and drainage ... 12
3.3 Land use ... 13

4 Geological setting ... 14
4.1 Regional geology ... 14
4.2 Stratigraphy and lithology ... 14
4.2.1 Alluvium ... 14
4.2.2 Coal measures ... 15
4.2.3 Volcanics ... 16
4.3 Structural geology ... 16

5 Hydrogeology ... 17
5.1 Groundwater monitoring network ... 17
5.1.1 'MW' and 'TA' series ... 17
5.1.2 'IBC' series ... 17
5.1.3 'BCS' series ... 17
5.1.4 'RB' series ... 17
5.1.5 'REG' and 'BCM' series ... 17
5.1.6 'GW' bores ... 17
5.2 Groundwater distribution and flow ... 18
5.2.1 Alluvium ... 18
5.2.2 Coal measures ... 18
5.3 Hydraulic properties ... 19
5.4 Groundwater quality ... 20
5.4.1 Major ions ... 20
5.4.2 Salinity ... 21
5.4.3 Water values ... 23
5.5 Groundwater use ... 24
5.5.1 Registered bores ... 24
5.5.2 Groundwater dependent ecosystems ... 24
5.6 Conceptual model ... 25

6 Numerical groundwater model design ... 27
6.1 Modelling software and confidence level ... 27
6.2 Model extent ... 28
6.3 Model stresses and boundary conditions ... 29
6.3.1 Boundary conditions ... 29
6.3.2 Model stresses ... 29

6.4 Calibration ... 29
6.4.1 Calibration data set ... 29
6.4.2 Initial calibration ... 30
6.4.3 Transient calibration ... 31
6.4.4 Resulting model parameters ... 33

7 Scenario Analyis Predictive Runs ... 37
7.1 Mine schedule ... 37
7.1.1 Mining schedules ... 37
7.1.2 Changed model parameters for the spoil ... 38
7.2 Water balance ... 38
7.3 Predicted pit inflow ... 38
7.4 Post-mining equilibrium ... 39
7.4.1 Stage – Inflow curve ... 39
7.4.2 Transient recovery ... 40

8 Impact Assessment ... 42
8.1 Impacts on groundwater ... 42
8.1.1 Difference between Approved case and Modification ... 42
8.1.2 Maximum drawdown caused by Modification ... 43
8.1.3 Groundwater quality ... 44
8.1.4 Potential Impacts on groundwater users ... 44
8.1.5 Upper Namoi (Zone 4) Alluvium ... 45
8.1.6 Murray-Darling Basin Porous Rock (Gunnedah Basin) ... 45
8.2 Impacts on surface water ... 45
8.2.1 Baseflow changes ... 45
8.2.2 Water quality ... 45
8.3 Minimal impact considerations ... 46

9 Model uncertainty and sensitivity ... 49
9.1 Uncertainty analysis ... 49
9.2 Sensitivity analysis ... 50
9.3 Summary ... 51

10 Recommendations ... 52
10.1 Mitigation and management ... 52
10.1.1 Groundwater users ... 52
10.1.2 Groundwater Inflows and Water licensing ... 52
10.2 On-going monitoring ... 52

References ... 55

Figures ... 57

Attachment A – Groundwater Monitoring Network ... 102

Attachment B – Groundwater Quality Summary Table ... 109

Attachment C – Model Stress Periods ... 117

Attachment D – Calibration Hydrographs ... 118

Attachment E – Predictive Hydrographs ... 119

Attachment F – Recovery Hydrographs ... 120

Attachment G – Uncertainty and Sensitivity Analysis ... 121

Attachment H – Residual Maps (Calibration) ... 122

Attachment I – Calibrated Hydraulic Conductivities ... 123

Attachment J – SLR, 2019: Alluvial Boundary Assessment, Tarrawonga Coal Mine ... 124

LIST OF TABLES

Table 1 NSW Aquifer Interference Policy – Salinity and Aquifer Yield Criteria 6
Table 2 TCPL groundwater licences 8
Table 3 Monthly rainfall data for SILO PD and Meteorological Stations near the Modification 10
Table 4 Evaporation data for Meteorological stations close to the Modification 12
Table 5 Indicative Hydraulic Properties of Stratigraphic Units 20
Table 6 Quality guidelines for groundwater resources in NSW (MDBC, 2005) 21
Table 7 Electrical conductivity at monitoring sites 22
Table 8 Groundwater model details 27
Table 9 Groundwater model classification table 28
Table 10 Steady state calibration statistics 30
Table 11 Steady state water balance 31
Table 12 Transient calibration statistics 32
Table 13 Transient water balance (average 2006-2018) 33
Table 14 Calibrated hydraulic properties 34
Table 15 Calibrated recharge values 36
Table 16 Water balance comparison between the Approved case and the Modification 38
Table 17 Mine inflow into the Tarrawonga Coal Mine 39
Table 18 Pit lake stage versus groundwater inflow (Steady State) 40
Table 19 Pit inflows (ML/day) during recovery period (Modification) 41
Table 20 Predicted water level differences in July 2030 for selected bores in the alluvium ... 43
Table 21 Predicted water level impacts in July 2030 for selected bores in the alluvium 44
Table 22 Summary of Aquifer Interference Policy Assessment – Upper Namoi (Zone 4) 47
Table 23 Summary of Aquifer Interference Policy Assessment – Murray-Darling Basin Porous Rock (Gunnedah Basin) 48
Table 24 Probability of exceedance of peak mine inflow, baseflow impacts and the number of drawdown-affected bores 50
Table 25 Parameter values for sensitivity runs 50
Table 26 Peak mine inflows for sensitivity runs 51
Table 27 Groundwater monitoring points and sampling frequency 54

FIGURES

Figure 1 Project location, topography and environmental monitoring stations 58
Figure 2 Approved General Arrangement 59
Figure 3 Indicative Modification General Arrangement 60
Figure 4 Water Sharing Plan for the NSW Murray Darling Porous Rock Groundwater Sources 61
Figure 5 Regional Water Sharing Plans 62
Figure 6 Average Monthly Rainfall at selected stations 63
Figure 7 Long-term rainfall and cumulative rainfall deficit 63
Figure 8 Average Monthly Pan Evaporation 64
Figure 9 Groundwater dependent ecosystems and surface water catchments 65
Figure 10 Regional Geology Overview 66
Figure 11 Regional Geology Cross Sections 67
Figure 12 Regional Geology Legend 68
Figure 13 Local Geology 69
Figure 14 Local Groundwater Network for Modelling 70
Figure 15 Local Stratigraphy 71
Figure 16 Conceptual groundwater models 72
Figure 17 Regional groundwater Bore Inventory (2011) 73
Figure 18 Representative Water table contours in the alluvium (2018) 74
Figure 19 Groundwater Hydrographs for Alluvial Bores 75
Figure 20 Groundwater Hydrographs for Bores screened in Coal, Interburden and Volcanics 75

Figure 21 Multi-Level Groundwater Hydrographs for Bore TA-60C 76
Figure 22 Multi-Level Groundwater Hydrographs for Bore TA-65..... 76
Figure 23 Piper plot 77
Figure 24 Median Electrical Conductivity 78
Figure 25 Timeseries of EC for bores screened in the Alluvium 79
Figure 26 Timeseries of EC for bores screened in the Interburden and Volcanics..... 79
Figure 27 Model Grid 80
Figure 28 Model layers 81
Figure 29 Model cross sections..... 82
Figure 30 Model boundary conditions 83
Figure 31 Total pumping rate in the groundwater model 84
Figure 32 Calibrated recharge rates (m/day) 85
Figure 33 Pilot point distribution in Layer 1 86
Figure 34 Scatterplot for the steady state calibration 87
Figure 35 Scatterplot for the transient calibration..... 88
Figure 36 Pit Inflows during the calibration period 89
Figure 37 Stream Leakage at Goonbri Creek and Bollol Creek during the calibration period 89
Figure 38 Regional Mine Progression Plan 90
Figure 39 Tarrawonga mining plan (Approved case and Modification)..... 91
Figure 40 Mine inflows for the prediction period (Modification) 92
Figure 41 Mine inflows comparison between Approved case and Modification..... 92
Figure 42 Water level in Final Void during recovery..... 93
Figure 43 Recovered Water Level and Direction after 100 years 94
Figure 44 Difference in Water table between Approved case and Modification..... 95
Figure 45 Difference in water levels in the lowest Coal Seam between Approved case and Modification 96
Figure 46 Maximum drawdown of the water table (Modification) 97
Figure 47 Maximum drawdown in the lowest Coal Seam (Modification)..... 98
Figure 48 Stream Leakage at Goonbri Creek and Bollol Creek during the predictive period . 99
Figure 49 Change in Stream Leakage at Goonbri Creek for Approved Case and Modification compared with Null run..... 99
Figure 50 Pit inflows (Sensitivity analysis) 100
Figure 51 Suggested additional monitoring network 101

1 INTRODUCTION

The Tarrawonga Coal Mine is located approximately 42 kilometres (km) north-northwest of Gunnedah in New South Wales (NSW) (**Figure 1**). The Tarrawonga Coal Mine is owned and operated by Tarrawonga Coal Pty Limited (TCPL), a wholly owned subsidiary of Whitehaven Coal Limited (Whitehaven).

The Tarrawonga Coal Mine is an open cut coal mine which has been in operation since 2006. Run-of-mine (ROM) coal is crushed and screened on-site, and the sized ROM coal is loaded onto on-highway trucks for transport via the Approved ROM Coal Transport Route to the Whitehaven Coal Handling Preparation Plant (CHPP).

Mining operations at the Tarrawonga Coal Mine are conducted in accordance with Project Approval (PA) 11_0047, as modified.

TCPL proposes a modification of its PA 11_0047. The Tarrawonga Coal Mine Life of Mine Modification (the Modification) would be sought under section 4.55(2) of the NSW *Environmental Planning and Assessment Act, 1979* (EP&A Act).

The Tarrawonga Coal Mine operates within the Leard Forest Mining Precinct as part of the Boggabri-Tarrawonga-Maules Creek (BTM) Complex. It also lies to the north of the proposed Vickery Extension Project and north-west of the operating Rocglen Coal Mine (however the Rocglen Coal Mine is transitioning into closure in 2019). The approximate extent of the Tarrawonga Coal Mine Life of Mine Modification (the Modification) development lies within Mining Lease (ML) 1579, ML1693, ML1685 and ML1749 (**Figure 1**).

In summary, TCPL plans to seek approval for an increase in the rate of coal production, from 3 to 3.5 million tonnes per annum (Mtpa), and a reduction in the open cut extent by curtailing the Tarrawonga Coal Mine's eastward progression (**Section 1.1.2**).

HydroSimulations (now SLR Consulting Australia Pty Ltd [SLR]) has prepared this Groundwater Assessment, which forms part of a Modification Report for the Modification, to accompany a Development Application made for the Modification in accordance with Part 4 of the EP&A Act.

1.1 Modification description

1.1.1 Approved operations

The main activities approved under the Environmental Assessment (EA) in 2011 included (refer to **Figure 2** for an overview of the approved activities):

- continued development of mining operations in the Maules Creek Formation to facilitate a Tarrawonga Coal Mine ROM coal production rate of up to 3 Mtpa, including open cut extensions:
  - to the east within ML 1579 and ML1693; and
  - to the north within CL 368 which adjoins ML 1579;
- ongoing exploration activities within existing exploration tenements;
- construction and use of a services corridor (including haul road link) directly from the Tarrawonga Coal Mine open cut mining operation to the upgraded Boggabri Coal Mine Infrastructure Facilities;

- use of upgraded Boggabri Coal Mine Infrastructure Facilities for the handling and processing of Tarrawonga Coal Mine coal and the loading of Tarrawonga Coal Mine product coal to trains for transport on the Boggabri Coal Mine private rail spur to the Werris Creek Mungindi Railway;
- construction and use of a new mine facilities area including relocation of existing mine facilities infrastructure and service facilities;
- use of an existing on-site mobile crusher for coal crushing and screening of up to 150,000 tonnes (t) of domestic specification coal per annum for direct collection by customers at the mine site;
- use an existing on-site mobile crusher to produce up to approximately 90,000 cubic metres (m^3) of gravel materials per annum for direct collection by customers at the mine site;
- progressive backfilling of the mine void behind the advancing open cut mining operation with waste rock and minor quantities of coarse reject material;
- continued and expanded placement of waste rock in the Northern Emplacement (including integration with the Boggabri Coal Mine emplacement) and Southern Emplacement, as mining develops;
- progressive development of new haul roads and internal roads, as mining develops;
- realignment of sections of Goonbri Road and construction of new intersections;
- construction of an engineered low permeability barrier to the east and south-east of the open cut to reduce the potential for local drainage of alluvial groundwater into the open cut;
- removal of a section of Goonbri Creek within the Tarrawonga Coal Mine open cut and the establishment of a permanent Goonbri Creek alignment and associated flood bund to the east and south-east of the open cut;
- progressive development of sediment basins and storage dams, pumps, pipelines and other water management equipment and structures;
- continued development of soil stockpiles, laydown areas and gravel/borrow areas;
- ongoing monitoring and rehabilitation; and
- other associated minor infrastructure, plant, equipment and activities.

In the 2011 EA (TCPL, 2011), the proposed mine life of the Tarrawonga Coal Mine was anticipated to be 17 years, commencing 1 January 2013 and finishing 31 December 2029.

1.1.2 Proposed Mine Development Modification

As already noted, TCPL plans to seek approval for an increase in the rate of coal production, from 3 to 3.5 Mtpa, and a reduction in the open cut extent by curtailing the mine's eastward progression.

The main activities involved with the Modification include (refer to **Figure 3** for an overview of the proposed changes):

- ROM coal production rate increase from 3.0 to 3.5 Mtpa;
- Increase to ROM coal transported along the Northern Section of the Approved ROM Coal Transport Route from 3.0 to 3.5 Mtpa;
- Reduction of the extent of the open cut to avoid mining:
  - the Namoi Alluvium; and
  - Goonbri Creek
- Revision of the post-mining landform and land use;

- Relocation of the ROM coal stockpile and associated infrastructure;
- Construction of a new site access road and intersection to allow haulage of ROM coal along a section of Goonbri Road; and
- Construction and use of a water transfer pipeline between the Tarrawonga Coal Mine and the proposed Vickery Extension Project (which is the subject of a separate Development Application for State Significant Development [SSD] 7480).

1.2 Objectives and scope of work

Approval for the Modification would be sought under section 4.55(2) of the EP&A Act, on the basis that the Modification would be 'substantially the same' as the approved Tarrawonga Coal Mine.

The NSW Department of Planning and Environment (DP&E) (now Department of Planning, Industry and Environment [DPIE]) issued assessment requirements for the proposed modification on 18 December 2018.

The DP&E confirmed that the proposed activities can be characterised as a modification to the existing approval and can be assessed and determined under section 4.55(2) of the EP&A Act. Under the EP&A Act, the Environmental Planning and Assessment Regulation 2000 (Schedule 1) requires that a development application must provide a Modification Report. The DP&E accepted TCPL's Modification Report content (see below) and noted that formal Secretary's Environmental Assessment Requirements (SEARs) would not be issued for the Modification.

In relation to the Modification Report, an assessment of the potential impacts on the quantity and quality of the region's groundwater resources (particularly the Upper Namoi Alluvium), including a revised groundwater model was included in TCPL's proposed scope. This groundwater assessment report has been prepared consistent with this scope.

The report outlines the regulatory framework (**Section 2**) and the environmental and geological settings (**Sections 3** and **4**, respectively). **Section 5** describes the hydrogeology and includes updates from the data collected since the 2011 EA. **Section 6** outlines the update of the numerical groundwater model. **Sections 7** and **8** present the model predictions and impact assessment, respectively. **Section 9** describes the uncertainty analysis. The mitigation and management measures, as well as the updated groundwater monitoring program, are presented in **Section 10**.

2 REGULATORY FRAMEWORK

This section provides a summary of the Australian and NSW groundwater-related legislation, policies, licences and guidelines relevant to the Modification.

2.1 Commonwealth Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is administered by the Department of the Environment (DoE). 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, impacts on groundwater resources were included, and are known as the 'water trigger'.

PA 11_0047 was granted on 22 January 2013 under section 75J of the EP&A Act and in accordance with the Significant impact guidelines (DoE, 2013), the approved operations are not considered an action to which the 'water trigger' applies.

The water trigger does not apply to actions already approved under the EPBC Act. However, if an approved project has a substantial change to how it is conducted or an extension, the new matter of national environmental significance may apply if it is likely to have a significant impact on a water resource.

The Modification involves a reduction in the disturbance footprint, to remain outside of the extent of the alluvium. Consequently, for the Modification, when compared to the Approved mine plan, there are no additional significant impacts on groundwater resources or users, and therefore is not considered an action to which the 'water trigger' applies. Irrespective of this, the groundwater assessment has been conducted in consideration of the IESC guidelines. This includes consideration of the recently released information guidelines on uncertainty analysis, with uncertainty analysis results presented in **Section 9**.

2.2 Water Act 1912

The *Water Act 1912* regulates water sources including rivers, lakes and groundwater aquifers across the State. It also manages the trade of water licences and allocations. The *Water Management Act 2000* is progressively replacing the *Water Act 1912* in NSW. The *Water Management Act 2000* has replaced the *Water Act 1912* for the alluvial water sources and surface water regime.

2.3 Water Management Act 2000

The *Water Management Act 2000* provides for the "protection, conservation and ecologically sustainable development of the water sources of the State". The *Water Management Act 2000* provides clear 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 authorises 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 – which authorises the holder to conduct activities that affect an aquifer such as activities that intersect groundwater, other than water supply bores and may be issued for up to 10 years.

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

2.4 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.

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

The Modification coal resource is located within the Maules Creek sub-basin of the Early Permian Bellata Group, which lies within the Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2012 (**Figure 4**). The Tarrawonga Coal Mine targets coal seams in the Maules Creek Formation within the 'Gunnedah - Oxley Basin Murray Darling Basin (MDB) (Other)' Management Zone defined in the WSP for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2012.

The Tarrawonga Coal Mine is located outside, and approximately 5 km west, of the New England Fold Belt Murray Darling Basin – Namoi Management Zone boundary defined by the *Water Sharing Plan for the NSW Murray-Darling Basin Fractured Rock Groundwater Sources 2011* (**Figure 5**). This plan is not considered relevant in this context, as it is understood that the Mooki Thrust, which forms the border between the Porous Rock WSP and Fractured Rock WSP, is inhibiting flow and hence the extent of the potential drawdown into the Fractured Rock Resource (refer to **Section 4.3**).

The Modification area is covered by three Water Sharing Plans related to the Namoi River Alluvium (WSPs, refer to **Figure 5**):

- *Water Sharing Plan for the Namoi Unregulated and Alluvial Water Sources 2012*;
- *Water Sharing Plan for the Upper Namoi and Lower Namoi Regulated River Water Sources 2016*; and
- *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2019*.

The WSP for the Namoi Unregulated and Alluvial Water Sources includes rules for protecting the environment, water extractions, managing license holders' water accounts and water trading in the plan area. Nagero, Bollol and Goonbri creeks flow into the Namoi River, which is administered under the WSP for the Upper and Lower Namoi Regulated River (Lower Namoi water source). Licenses are required for surface water accessed by the TCPL, excluding their 'harvestable right'. Licenses are obtained through acquisition from existing license holders.

A draft Water Sharing Plan for the Namoi Alluvial Groundwater Sources 2019 was exhibited from 11 June 2019 to 20 July 2019. The draft Water Sharing Plan for the Namoi Alluvial Groundwater Sources 2019 would replace the Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2019, the Water Sharing Plan for Namoi Unregulated and Alluvial Water Sources 2012 and the Water Sharing Plan for the Peel Valley Regulated, Unregulated, Alluvial and Fractured Rock Water Sources 2010, following its commencement.

2.5 Aquifer Interference Policy

The NSW Aquifer Interference Policy (AIP) (Department of Industry – Water, 2012) is designed to provide a framework for the assessment of impacts of the taking of water under a proposed development, such as the Modification. The AIP divides groundwater sources into "highly productive" and "less productive" categories based on salinity and aquifer yield as shown in **Table 1**. **Section 5.4** discusses the observed groundwater quality (baseline and more recent observations). The values presented in **Table 1** will set the observations into context.

The AIP also specifies minimal impact considerations for both "highly productive" and "less productive" aquifers; these comprise thresholds for water table and groundwater pressure drawdown, and changes in groundwater and surface water quality. Different minimal impact considerations are specified for "highly productive" and "less productive" groundwater for:

- water supply works;
- listed groundwater dependent ecosystems (GDEs); and
- culturally significant sites.

A summary of the AIP minimal impact considerations is included as part of the Modification potential impacts assessment (**Section 8** of this report).

Table 1 NSW Aquifer Interference Policy – Salinity and Aquifer Yield Criteria

Criteria		Salinity (Total Dissolved Solids [TDS])	
		Less than 1,500 mg/L	More than 1,500 mg/L
Aquifer Yield	More than 5 L/s	Highly Productive	Less Productive
	Less than 5 L/s	Less Productive	

Note: mg/L = milligrams per litre
L/s = litres per second

2.6 Groundwater quality protection

The NSW State Groundwater Quality Protection Policy (Department of Land and Water Conservation [DLWC], 1998) states that the objectives of the policy will be achieved by applying the following management principles:

1. All groundwater systems should be managed such that their most sensitive identified beneficial use (or environmental value) is maintained.
2. Town water supplies should be afforded special protection against contamination.
3. Groundwater pollution should be prevented so that future remediation is not required.

4. For new developments, the scale and scope of work required to demonstrate adequate groundwater protection shall be commensurate with the risk the development poses to a groundwater system and the value of the groundwater resource.

5. A groundwater pumper shall bear the responsibility for environmental damage or degradation caused by using groundwaters that are incompatible with soil, vegetation or receiving waters.

6. GDEs will be afforded protection.

7. Groundwater quality protection should be integrated with the management of groundwater quantity.

8. The cumulative impacts of developments on groundwater quality should be recognised by all those who manage, use, or impact on the resource.

9. Where possible and practical, environmentally degraded areas should be rehabilitated, and their ecosystem support functions restored.

These principles have been considered as part of the groundwater assessment and are discussed within the impact assessment (**Section 8**) and monitoring and mitigation measures (**Section 10**).

2.7 Groundwater quantity management

The NSW State Groundwater Quantity Management Policy (DLWC, 2002) states that the objectives of the policy are to:

- achieve the efficient, equitable and sustainable use of the State's groundwater;
- prevent, halt and reverse degradation of the State's groundwater and their dependent ecosystems;
- provide opportunities for development which generate the most cultural, social and economic benefits to the community, region, state and nation, within the context of environmental sustainability; and
- involve the community in the management of groundwater resources.

These principles have been considered as part of the groundwater assessment and are discussed within the impact assessment (**Section 8**) and monitoring and mitigation measures (**Section 10**).

2.8 Water licensing

The *Water Sharing Plan* for the NSW Murray-Darling Basin Porous Rock Groundwater Sources commenced in January 2012. TCPL currently holds 300 megalitres (ML) of volumetric licence allocation in the Gunnedah - Oxley Basin MDB Groundwater Source. The allocation was approved under licences WAL29548 (50 ML) and WAL31084 (250 ML).

These groundwater licences currently allow TCPL to extract up to a total of 300 ML per year from groundwater sources with **Table 2** showing a summary of the licence numbers and water sources.

The existing operations at the Tarrawonga Coal Mine are located outside of the Upper Namoi Zone 4, Namoi Valley (Keepit Dam to Gins Leap) Groundwater Source defined by the Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2019. Licences under the *Water Management Act 2000* are required to be held by TCPL if mining has a far-field effect of drawing down more water from the alluvium to the underlying strata than would occur naturally.

Groundwater monitoring boreholes owned by Whitehaven are also licensed under the existing Bore Licences (e.g. 90BL253276, 90BL253278, 90BL253841, 90BL253279, 90BL253280, 90BL254255, 90BL254254, 90BL254253, 90BL254220, 90BL102564, 90WA809087, 90BL116929, 90BL255930), which set out conditions of use for the monitoring bores. These monitoring bore licences are purely held by Whitehaven and not third parties.

Heritage Computing (2011) determined, through groundwater modelling, that the licensing requirement for the Gunnedah - Oxley Basin MDB Groundwater Source would be a maximum of 252 megalitres per annum (ML/a) in Years 1 to 11 of the Tarrawonga Coal Mine (to the end of 2023[1]) if the TCPL were acting alone, without the cumulative effect of the Boggabri Coal Mine. **Section 8.1.6** will present an update on these numbers for the proposed modification calculated with the updated groundwater model presented in **Section 6**.

Table 2 TCPL groundwater licences

WAL No	Water Sharing Plan	Water Source	Annual Amount (ML)
WAL29548	NSW Murray Darling Basin Porous Rock Groundwater Sources	Gunnedah - Oxley Basin MDB Groundwater Source	50
WAL31084*	NSW Murray Darling Basin Porous Rock Groundwater Sources	Gunnedah - Oxley Basin MDB Groundwater Source	250
Total			**300**

* Licence for the removal of groundwater from open excavations such as the mine pit.

[1] Note, Year 11 of the Tarrawonga Coal Project Groundwater Assessment (Heritage Computing, 2011) corresponds to Calendar Year 2023.

3 ENVIRONMENTAL SETTING

3.1 Climate

The Commonwealth Bureau of Meteorology (BoM) data has been obtained and used to evaluate the climatic conditions in the Modification area and surrounds. Data was obtained directly from the BoM website and through the Scientific Information for Landowners (SILO) database (State of Queensland, 2018), developed by the BoM and the Queensland Government and currently hosted by the Queensland Department of Environment and Science (DES).

The SILO Point Data request produces a continuous daily time series of data at either recording stations or grid points across Australia:

- Station locations - observational records supplemented by interpolated estimates when observed data are missing.
- Grid point data - interpolated estimates. The data are taken from our gridded datasets and are available at any pixel on a 0.05° × 0.05° grid over the land area of Australia (including some islands).

3.1.1 Rainfall

Climate data was collected from the SILO gridded point database for location Latitude 30.6° S and Longitude 150.15° (refer to **Figure 1**), which is consistent with the datapoint location used for the initial project approval. BoM weather stations within 50 km of SILO PD, with at least 50 years of continuous data are also shown on **Figure 1**.

From the list of BoM station sites within 50 km of SILO PD, those with more than 100 years of at least 95% complete daily rainfall data were selected. Station information for these sites is presented in **Table 3**.

Boggabri (Retreat) is the closest BoM station to the Modification, being about 12 km southeast of ML 1579. Data from Boggabri (Retreat) was utilised for the surface water runoff analysis by Advisian (2018). Boggabri (Post Office) and Boggabri (Kanownda) are also within about 15 km of ML 1579, while Turrawan (Wallah) is about 30 km northeast.

All sites have very similar annual rainfall and monthly rainfall patterns, with average annual rainfalls of 582, 590, 582 and 592 millimetres (mm), respectively (over at least 100 years up to June 2018, **Table 3**).

Figure 6 displays the rainfall data from **Table 3**, showing the similarity between the stations, the dominance of late spring and summer rainfall, and an almost 2:1 relationship between summer and winter rainfall.

Table 3 Monthly rainfall data for SILO PD and Meteorological Stations near the Modification

BoM ID	-	55076	55007	55044	55058
Station name	SILO PD	Boggabri (Kanownda)	Boggabri (Post Office)	Boggabri (Retreat)	Turrawan (Wallah)
Easting[1]	226,738	232,434	217,051	239,171	206,030
Northing[1]	6,611,265	6,621,161	6,599,297	6,599,991	6,627,977
Elevation[2]	337	320	245	302	223
Start	01-01-1889	01-01-1900	01-01-1889	01-01-1900	01-01-1911
End	30-06-2018				
January	78.0	76.8	72.2	71.8	80.8
February	62.4	60.5	62.0	61.1	59.9
March	48.2	47.8	46.6	43.1	44.4
April	34.7	34.1	34.9	34.5	33.3
May	41.4	37.3	41.6	38.3	40.6
June	45.6	41.8	43.5	44.3	44.3
July	42.1	39.0	40.8	41.6	40.5
August	37.4	34.7	37.3	37.0	35.7
September	39.5	36.0	38.2	39.8	37.2
October	49.6	50.4	50.0	50.1	51.2
November	59.5	59.9	59.1	59.0	59.4
December	62.4	63.9	63.3	61.4	65.0
Annual Total	600.7	582	590	582	592

Notes

[1] MGA 94, zone 56,
[2] m AHD = metres Australian Height Datum

A plot of the cumulative difference from the mean (CDM) for time series data allows an examination of trends in the data. The CDM rises in times when the data is continuously higher than the mean and falls when the data is less than the mean.

Figure 7 presents a monthly rainfall and monthly rainfall CDM plot for the SILO PD and Boggabri (Retreat) sites for the period 1900 to 2018. The figure shows a declining trend in rainfall from about 1910 to 1946, followed by an increasing trend until 1977, and then a series of shorter fluctuations until 2010, when increasing rainfall persists until 2012 and is followed by a decline until mid-2016. From 2016 until mid-2018 there is some fluctuation, but no discernible trend. The number of fluctuations in the CDM (short droughts or periods of persistent high rainfall) is an indicator of the variability in rainfall patterns in Australia. The disparity between the CDM plots indicates the spatial variability in the rainfall amounts over approximately 17 km distance between the sites, while the temporal patterns are identical.

For consistency with the earlier model (Heritage Computing, 2011), site SILO PD was used for climatic data for the model (State of Queensland, 2018). Being influenced by all nearby observed data, the point data embraces the spatial variability of the rainfall data. This data set will be used to provide rainfall values and temporal patterns for the model.

3.1.2 Evaporation

The BoM website includes records of evaporation from some of its sites. The data (pan evaporation) consists of the amount of water which evaporates from an open pan each day, measured using a 'class A evaporation pan'. The data is considered indicative of the water evaporating from bare ground or from open water.

The BoM stations with class A pan evaporation data closest to the Modification area are at Gunnedah (Resource Centre, station 55024), Keepit Dam (station 55276) and Boggabri (Retreat, station 55044). Most of the evaporation sites (including 55024 and 55276) have class A pan data from 1970, with data synthesized prior to 1970. At other sites (including 55044), pan evaporation is synthesised. Evaporation data for these sites (including 55044) is presented in **Table 4**, with their locations shown on **Figure 1**.

Figure 8 presents a plot of the data from **Table 4**, showing that the monthly values are virtually identical for all sites with a clear dominance of summer evaporation, being about four times the winter minimum. Average potential (pan) evaporation at the Boggabri Retreat BoM station (55044) is 1,852 mm per year (from commencement of data collection to 30 June 2018).

While pan evaporation reflects evaporation from open water, evaporation from land surfaces covered by vegetation is better estimated by evapotranspiration (ET). The areal actual ET in the district is about 600 mm per year (BoM, 2019), which is only one-third of the pan evaporation measured by the stations.

Table 4 Evaporation data for Meteorological stations close to the Modification

BoM ID	55024	55276	55044
Station name	Gunnedah Resource Centre	Keepit Dam	Boggabri (Retreat)
Easting[1]	239278	260319	239278
Northing[1]	6564301	6580694	6599991
Elevation[2]	307	304	302
Start	01-01-1970[3]	01-01-1973	01-01-1900[4]
End	30-06-2018		
January	251	252	253
February	206	205	205
March	194	187	189
April	136	129	130
May	89	84	84
June	60	57	58
July	65	64	63
August	93	92	91
September	130	131	130
October	180	181	180
November	211	214	214
December	253	252	255
Annual Average Total	**1868**	**1848**	**1852**

Notes

[1] MGA 94, zone 56, m
[2] m AHD
[3] As noted above, although station 55024 opened in 1889, pan evaporation data collection began in 1970
[4] Synthesised data

3.2 Topography and drainage

The Tarrawonga Coal Mine (ML 1579) is located within the Namoi River catchment, at the foothills of the Willowtree Range on the southern border of the Leard State Forest, approximately 12 km east of the Namoi River (**Figure 1**). Goonbri Mountain lies approximately 4 km north-east of ML 1579, and in conjunction with the Willowtree Range forms the main topographic features in the north and east.

Surface elevations in the region vary from approximately 260m AHD on the floodplains of Bollol Creek up to approximately 540 m AHD at the peak of Goonbri Mountain.

The main surface water body in the region is the Namoi River, which flows from the Keepit Dam southeast of the Modification in a westerly direction towards Gunnedah and then in a northwesterly direction through Boggabri. The associated flow gauges are presented in **Figure 1**.

The main local drainage systems associated with the Modification area are Nagero Creek, Goonbri Creek and Bollol Creek (**Figure 9**). As the creeks descend onto the expansive alluvial flats west of the Modification area, they transition into relatively poorly defined drainage paths which become expansive ponded overland flow areas during and following heavy rainfall. Where creeks cease to have permanent surface water, it is likely that sub-surface flow continues beneath the drainage lines. The overland flow moves slowly down-gradient (west and south-west) toward the Namoi River itself (Heritage Computing, 2011).

3.3 Land use

Whitehaven owns most of the land associated with the Tarrawonga Coal Mine and a significant portion of the adjacent lands. The other land owners are Boggabri Coal Operations Pty Ltd and NSW State Forestry.

Agricultural areas are in the southern areas of ML 1579 and ML1693. No agricultural areas are currently located in ML1685. Areas near the Modification site that are not currently used for agriculture include the existing/approved Tarrawonga Coal Mine, the Boggabri Coal Mine, the Leard State Forest and remnant vegetated areas. Whitehaven-owned land in the vicinity of the Tarrawonga Coal Mine is referred to as the buffer area, approximately 4,000 hectares (ha) of land that is typically used for agriculture, to the south and southeast of ML1579 and ML1693 (Resource Strategies, 2011).

Agricultural activities in the Narrabri and Gunnedah Local Government Areas (LGAs) are dominated by livestock and crop (summer and winter crops) production (Australian Bureau of Agricultural and Resource Economics and Sciences [ABARE], 2006).

The Tarrawonga Coal Mine, the Boggabri Coal Mine and the Maules Creek Coal Mine are the three existing mining operations in the immediate area, they are referred to as the BTM Complex (**Figure 10**). In summary:

- Boggabri Coal Mine: On CL368, mining commenced in 2005, open cut mine, approved to extract up to 8.6 Mtpa ROM coal until 2033.
- Tarrawonga Coal Mine: On ML1579, mining commenced in 2006, open cut mine, approved to extract up to 3 Mtpa ROM coal until 2030.
- Maules Creek Coal Mine: On CL375, mining commenced in 2015, approved to extract up to 13 Mtpa ROM coal until 2034.

Other operating mines in the region include the Narrabri Coal Mine (north-west) and the Rocglen Coal Mine (south-east). The Rocglen Coal Mine is transitioning into closure in 2019. Another project in the region is the Vickery Extension Project to the south (**Figure 10**), which is proposing an extension of the approved Vickery Coal Project to operate for 25 years into the future.

4 GEOLOGICAL SETTING

4.1 Regional geology

The Tarrawonga Coal Mine is located in the Gunnedah Basin, in the NSW Gunnedah Coalfield, which contains sedimentary rocks, including coal measures of Permian and Triassic age (**Figure 10**). Cross-sections showing the structural geology of the Gunnedah Basin near the Modification area are shown in **Figure 11** and **Figure** 12.

Regionally, there are two coal-bearing sequences in the Gunnedah Basin, namely:

- Early Permian Bellata Group (comprising the Maules Creek sub-basin and Mullaley sub-basin, separated by the Boggabri Ridge); and
- Late Permian Black Jack Group.

The Tarrawonga Coal Mine coal resource is located within the Maules Creek sub-basin of the Early Permian Bellata Group. The target coal seams within the Maules Creek sub-basin are contained within the Maules Creek Formation. They subcrop on low hills to the west of the Modification area and dip towards the east. Below the Maules Creek Formation are the Goonbri and Leard Formations, which are basal units of the Gunnedah Basin sedimentary sequence and unconformably overlie the Boggabri Volcanics. The Boggabri Volcanics act as a low permeability basement unconformably underlying the coal measures and surficial sediments.

The broad valley and outflow plain areas in the lower slopes and downstream comprise predominantly low lying undifferentiated alluvial sediments (**Figure 13**). The Quaternary sediments comprise the (upper) Narrabri Formation and the (lower) Gunnedah Formation of the upper Namoi Valley. Minor undifferentiated volcanic and igneous rocks of younger age are located in isolated outcrops in the area.

Discussion on each of the main stratigraphic units is included in **Section 4.2** and further detail on the structural geology in the region is included in **Section 4.3**.

4.2 Stratigraphy and lithology

The main stratigraphic units associated with the Modification include the alluvium and coal measures, and the underlying volcanics. Discussion on each of the units is included below.

4.2.1 Alluvium

The Tarrawonga Coal Mine is bordered by alluvial sediments that are associated with the Bollol Creek, Goonbri Creek and Nagero Creek surface drainages (**Figure 13**). These sediments are part of the Upper Namoi Alluvium and their groundwaters lie within the Namoi Valley (Keepit Dam to Gins Leap) Groundwater Source, also known as the Upper Namoi Zone 4 water source. Zone 4 is defined as ‘highly productive’ under the NSW AIP (Department of Industry - Water, 2012) although in reality, yields and water quality can vary considerably. The Bollol Creek, Goonbri Creek and Nagero Creek embayments have alluvial thicknesses in the order of 30 m maximum (McNeilage, 2006). On the floodplain between Bollol Creek and Driggle Draggle Creek further south, the alluvium is generally 40 m to 70 m thick.

Alluvial sediments of the Upper Namoi are usually subdivided into two formations, although they are not always distinguishable. The uppermost Narrabri Formation consists predominantly of clays with minor sand and gravel beds. Underlying the Narrabri Formation is the Gunnedah Formation, which consists predominantly of gravel and sand with minor clay beds. This is the productive aquifer used for irrigation to the west of the Tarrawonga Coal Mine site. The higher-elevation alluvial tongues along Nagero Creek, Goonbri Creek and Bollol Creek are not as productive, have poorer water quality, and are suited for stock and domestic use.

More broadly, the Upper Namoi Alluvium can reach maximum thicknesses of 170 m associated with the Namoi River. Separately, the Narrabri Formation has a maximum thickness of 70 m and the Gunnedah Formation peaks at 115 m (McNeilage, 2006).

To better define the geometry and properties of the Goonbri Creek alluvium to the immediate east of the Modification area, TCPL drilled a transect of nine shallow boreholes (TAWB14-22). The bore transects revealed alluvial thickness from 3 m to 38 m with a median thickness of 26 m. Bore locations for the bores TAWB 17-21 are shown in **Figure 14**.

SLR undertook a study to define the alluvial boundary of Goonbri Creek (SLR, 2019, refer to **Attachment J**). The key objective of this study was to map the Alluvial Soils boundary by classifying and determining the extent of Alluvial Soil within the Study Area. A qualitative field survey along 11 defined transects was undertaken to confirm the alluvial boundary. Transects were located approximately 250 m apart along the alluvial boundary. Soil cores and small investigative pits were used along transect lines to determine soil type and assess the soil material and development in order to determine alluvial or non-alluvial status. The 2015 test work was augmented by additional test work in 2018. **Figure 13** displays the estimated delineation of Goonbri Creek Alluvial Soils. This delineation was relevant to determine the extent of mining for the Modification.

4.2.2 Coal measures

The Modification intersects the Maules Creek Formation, which forms a regular layered easterly dipping sedimentary sequence that gradually thickens to the east to over 800 m at the Mooki Thrust Fault. The Maules Creek Formation consists predominantly of conglomerate and sandstone, with minor siltstone, claystone and intercalated coal seams. **Figure 15** presents the indicative stratigraphy of the Modification area including the target coal seams within the open cut extent, as follows (Minarco-Mineconsult, 2011):

- Braymont;
- Bollol Creek;
- Jeralong;
- Jeralong Lower;
- Merriown;
- Merriown Lower;
- Velyama; and
- Nagero.

Individual coal seams range up to approximately 4.5 m thick, and average 1.5 m. They onlap the Boggabri Ridge to the west of the Modification area and thicken towards the east.

Below the Maules Creek Formation are the Goonbri and Leard Formations, which are basal units of the Gunnedah Basin sedimentary sequence (refer to **Figure 15**) and unconformably overlie the Boggabri Volcanics, which are discussed in the next section.

4.2.3 Volcanics

The Boggabri Volcanics comprise of mainly rhyolite flows and pyroclastics, with minor sediments, basalts and andesite lavas (Tadros, 1995). The formation acts as a low permeability basement to the sedimentary units. The volcanics crop out to the west of the Modification, separating the Namoi Alluvium from the smaller local alluvial aquifers related to the Goonbri Creek and Bollol Creek. A schematic of the conceptual groundwater model including the volcanics is shown in **Figure 16**.

4.3 Structural geology

There are two major fault structures in the region, namely:

- Boggabri Thrust (to the west of the Modification); and
- Mooki Thrust (to the east of the Modification).

The Boggabri Thrust is a north-west/south-east trending formation which begins approximately 12 km west of the Tarrawonga Coal Mine and continues to the south-east aligned with the Namoi River (**Figure 10** to **Figure 12**).

The Mooki Thrust is a generally north-south trending formation which lies between the Rocky Creek Formation in the east and the Maules Creek Formation in the west (**Figure 10** to **Figure 12**). The Mooki Thrust generally delineates the boundary between the 'Gunnedah-Oxley Basin – Namoi' and 'New England Fold Belt MDB – Namoi' Management Zones defined in the Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011 and the Water Sharing Plan for the NSW Murray-Darling Basin Fractured Rock Groundwater Sources 2011, respectively (refer to **Section 2.4** and **Figure 5**).

There are many minor faults with east-west and north-south alignments, especially between the Tarrawonga and Vickery Coal Mines (**Figure 10**). As the target coal seams for the Tarrawonga Coal Mine are truncated either by faulting or erosion, they do not persist to the south or to the east of the Modification area. Coal seam extents are illustrated in Coxhead (2009).

5 HYDROGEOLOGY

5.1 Groundwater monitoring network

Each of the mines within the BTM Complex have a network of baseline monitoring bores around the mining area to detect local impacts on groundwater levels. In addition to this there is a network installed further from the mining areas, within the wider region, designed to detect any cumulative impacts from the BTM Complex.

The Whitehaven groundwater monitoring locations associated with Boggabri, Tarrawonga and Maules Creek Coal Mines, and the DPI Water monitoring locations used in this assessment are listed in **Attachment A** with their location and depth and shown in **Figure 17** and **Figure 14**. The sections below describe the various campaigns undertaken to install the monitoring bores (AGE, 2018).

5.1.1 'MW' and 'TA' series

The 'MW' series of bores was installed at the Tarrawonga Coal Mine in 2006 as part of baseline investigations prior to mining. The 'TA' series comprises vibrating wire piezometers (VWPs) at two locations. TA-60C and TA-65C observe water pressure at four and eight vertical locations, respectively. TA-60C was decommissioned in March 2019.

5.1.2 'IBC' series

Prior to the commencement of the Boggabri Coal Mine, Parsons Brinkerhoff (2005) undertook a baseline groundwater assessment that included installation of monitoring bores, permeability testing and groundwater modelling of the first six years of the mine life. This Modification included the installation of the 'IBC' series of bores around the mining area that comprised seven bores targeting coal seams and the volcanic basement.

5.1.3 'BCS' series

The 'BCS' series of bores along Bollol Creek to the east of the mining area was installed by Tarrawonga Coal Mine. Whilst the installation date is not known, water level records are available for these bores from 2007. These bores are relatively shallow and less than 50 m in depth, targeting shallow alluvium or rock.

5.1.4 'RB' series

The 'RB' series of bores were designed to replace the original Maules Creek network. They were installed between October 2013 and February 2014. The 'RB' series comprises three groundwater monitoring bores and five nested VWPs.

5.1.5 'REG' and 'BCM' series

The 'REG' series comprises twelve groundwater monitoring bores and six nested VWPs designed to detect cumulative impacts from the BTM Complex. Of these bores, BCM1, BCM3 and REG10A were installed along Back Creek to assess the potential for shallow groundwater and the presence of a GDE.

5.1.6 'GW' bores

DPI Water maintains a network of monitoring bores within the Namoi Valley alluvium that surrounds the BTM Complex. The purpose of these bores is to monitor groundwater levels and quality within the Narrabri and Gunnedah Formations.

The DPI Water Groundwater Works Database contains information on groundwater works (e.g. their location, drillers logs, geologist logs, purpose of use, etc.), and water level and groundwater yield data for regional monitoring and production bores. In many cases, the regional monitoring bores provide continuous, long-term groundwater level and quality data, particularly in the Upper Namoi Alluvium. The database information for the Modification mining area and the broader surrounds covered by the regional numerical groundwater model have been used in the numerical modelling and impact assessment where relevant. The network is presented in **Figure 17**.

5.2 Groundwater distribution and flow

5.2.1 Alluvium

Natural groundwater levels are sustained by rainfall infiltration and are controlled by ground surface topography, geology and surface water elevations. Typically, local groundwater would mound beneath hills and would discharge to incised creeks and rivers. During short events of high surface flow, streams would lose water to the host aquifer, but during recession, the aquifer would discharge water slowly back into the stream from bank storage and also discharge from more remote zones due to rainfall infiltration. Groundwater flows from elevated to lower-lying terrain (i.e. downhill).

Local groundwater tends to mound beneath hills, with ultimate discharge to local drainages and loss by ET through geological outcrops and vegetation where the water table is near the ground surface (generally 2 to 3 m below ground level). However, given the typical depth to water (5 to 10 m to the south-east of the Tarrawonga Coal Mine, [Heritage Computing, 2011]), ET is an unlikely occurrence in the vicinity of the mine and adjacent alluvium.

Heritage Computing (2011) displayed the baseline water level contours and depth to groundwater on a data set taken in or around January 2010. The contours indicate that the alluvium is saturated. The groundwater flow direction was towards the west and south-west. The hydraulic gradient flattens appreciably to the south-west between the Tarrawonga Coal Mine and the Namoi River due to the higher permeability of alluvial sediments.

For this report, the groundwater contours for the alluvial bores have been interpolated from data in June 2018. The resulting flow direction is comparable to the previous assessment, with the alluvial waters moving in a westerly direction. The contours are presented in **Figure** 18.

Figure 19 shows the hydrographs for selected alluvial bores from the start of baseline monitoring in 2006 and have been updated with continual groundwater monitoring data since the 2011 report up to June 2018.

Most of the bores shown in **Figure 19** show little variation in the water levels as a response to rainfall. The water level in Bore GW044997 shows the best correlation with the cumulative departure from mean rainfall, i.e. the water level is increasing in wet periods and decreasing in drier periods. Bore MW6 shows increasing water levels over the entire observation period, however the increase does not correlate with the rainfall deficit curve.

5.2.2 Coal measures

Figure 19 and **Figure 20** show the hydrographs for selected alluvial bores and bores screened in the coal measures and volcanics respectively. These figures are displaying the groundwater levels from the start of the baseline monitoring in 2006 and have been updated with continual groundwater monitoring data since the 2011 report up to June 2018.

Figure 20 shows the long-term groundwater level data in five bores, however, only three have a full record from 2006 to 2018, as the others have been mined through and have been lost. MW1 (interburden) and MW3 (volcanics) show a flat and increasing trend, respectively. MW7, also screened in the interburden, shows a response to the mine dewatering with water levels decreasing by 30 m over time, which is an additional 15 m since the 2011 report.

TCPL have installed VWPs in two locations (refer to **Figure 14**), both recording water pressure in the coal measures at different depths. The responses at TA-60C and TA-65C are displayed in **Figure 21** and **Figure 22**, respectively.

At the site closest to current mining (TA-60C; **Figure 21**), the groundwater levels were stable up until 2012. At that time, a steady decline in head with time in the lower two piezometers (Velyama Seam and Velyama-Nagero Interburden) can be seen. The decline also shows in the upper two piezometers (Merriown-Velyama interburden), however to a lesser extent.

At TA-65C there is a slight reduction in head with time in the upper piezometers which might be associated with far-field mining effects. Groundwater heads generally decrease with depth at each site but there are some reversals in gradient. In 2011, all data points laid reasonably close to the hydrostatic pressure line, no significant mining effects had yet been recorded. However, in 2018, the dewatering of the coal seams is apparent and some of the depressurisation effect is visible in the interburden. The Jeralong overburden, which is the shallowest location and closest to the alluvium, does not show any drawdown effects over time.

TA-60C and TA-65C record the groundwater pressure changes in the coal measures (**Figure 21** and **Figure 22)**. The closest two bores in the alluvium are MW5 and GW44997 with a distance of around 1,500 m to TA-60C and TA-65C. These two alluvial bores show some variation potentially attributed to response to rainfall (refer to **Figure 19**). They do not show a drawdown trend, which indicates that the alluvium and the coal measures are not connected, and no impacts can be seen in the alluvium from the mining operations to date.

5.3 Hydraulic properties

Heritage Computing (2011) summarised the results of various studies with regards to the hydraulic conductivity. A table listing a range of values for various stratigraphic units can be found in **Table 5**. These have been determined from slug/pumping tests, core measurements and model calibration conducted by previous studies including AGE (2010), RCA Australia (2005, 2007); and Douglas Partners (2010). Many field tests have found a high hydraulic conductivity for coal in the order of 0.5 m/day. The hydraulic property data collected and reviewed as part of this assessment provides a firm basis for the development of the numerical groundwater model.

The permeability values in **Table 5** are also based on results of the groundwater investigation program undertaken by RPS Aquaterra at the Tarrawonga Coal Mine:

- Core test work (33 samples from three drill holes [TA-60C, TA-63C, TA-65C]);
- Pumping tests (TAWB14 and TAWB16); and
- Slug tests (TA60C at two depths targeting the Merriown-Nagero interburden).

Table 5 Indicative Hydraulic Properties of Stratigraphic Units

Unit		Horizontal hydraulic conductivity Kx (m/day)	Vertical hydraulic conductivity Kz (m/day)
Alluvium		5.0×10^{-1}* - 10	5.0×10^{-1}
Regolith		1.0×10^{-2} – 1.0×10^{-1}	1.0×10^{-3} – 1.0×10^{-2}
Maules Creek Formation	Overburden (above Jeralong Seam)	6.1×10^{-6} - 6.8×10^{-4}	1.1×10^{-5} - 1.4×10^{-5}
	Braymont/Jeralong Seams	1.0×10^{-2} – 6.8×10^{-1}	-
	Interburden (Jeralong to Merriown/Velyama Seams)	7.2×10^{-7} - 8.1×10^{-4}	2.4×10^{-7} - 1.9×10^{-4}
	Merriown/Velyama Seams	5.0×10^{-3} – 6.8×10^{-1}	-
	Interburden (Velyama to Nagero Seam)	6.3×10^{-7} - 1.0×10^{-4}	3.6×10^{-7} - 4.4×10^{-5}
	Nagero Seam	2.5×10^{-2}	2.5×10^{-3}
	Interburden (Nagero to Lower Northam Seams)	8.2×10^{-7} - 3.2×10^{-4}	1.8×10^{-7} - 2.2×10^{-4}
	Northam to Templemore Seams	1.6×10^{-2} to 5.1×10^{-1}	1.6×10^{-3}
	Underburden (below Lower Northam Seam)	1.6×10^{-5}- 1.6×10^{-3}	7.7×10^{-5} - 1.6×10^{-4}
Boggabri Volcanics		1×10^{-4}	1×10^{-5}

Source: After: RPS Aquaterra (2011); AGE (2010); RCA Australia (2005, 2007); Douglas Partners (2010).

* The NOW groundwater model for the Upper Namoi Groundwater Source assumed 0.5 - 1 m/day for alluvium adjacent to Tarrawonga Coal Mine, values of up to 10 m/day were derived from field studies

5.4 Groundwater quality

5.4.1 Major ions

As with water level data, extensive baseline water quality analyses were conducted for the previous groundwater assessment (Heritage Computing, 2011). Key findings were:

- Alluvial bores showed (sodium [Na] and potassium [K]) and (chlorine [Cl] and bicarbonate [HCO_3]) as the dominant Ions, with Ionic ratios showing only mild variability across the site.
- Similar concentrations occurred in hard rock bores, with the same (Na+K) and (Cl/HCO_3) dominance, and ionic ratios uniform across the site.
- The lowest normalised concentrations are observed in the coal sample, which has a strong NaCl type and lower sulphate [SO_4] content.

Piper plots are useful for showing multiple samples and trends in major ions. The Piper plot allows comparisons of water types from a large number of samples. Like all trilinear plots, it does not portray absolute ion concentrations. The main purpose of Piper plots is to show clustering of samples.

Figure 23 shows the Piper plot for the water quality in different formations (alluvium, Interburden, Coal Seams and Volcanics). It is apparent that the composition of the alluvial groundwater quality is varying across the regions, as the sample points are not plotting close together. The samples of the groundwater in the coal on the other hand, are plotting close together, which indicates a similar ionic composition.

5.4.2 Salinity

The AIP distinguishes highly productive and less productive aquifers based on yield and salinity (also refer to **Table 1** in **Section 2.5**). The threshold for the highly productive aquifers in terms of salinity is a TDS of 1,500mg/L. This equates to an EC of approximately 2,350 micro siemens per centimetre (µS/cm), based on a conversion factor of 0.64 between TDS and EC.

Table 6 shows water quality guidelines produced by the Murray Darling Basin Commission (MDBC) (MDBC, 2005). Potable water is classified up to 800 µS/cm and marginal potable water is classified between 800 µS/cm and 2,350 µS/cm.

Table 6 Quality guidelines for groundwater resources in NSW (MDBC, 2005)

Beneficial Use	Salinity, EC (µS/cm)	Description
Potable	Up to 800	Suitable for all drinking water and uses
Marginal Potable	800-2,350	At the upper level, this water is at the limit of potable water, but is suitable for the watering of livestock, irrigation and other general uses
Irrigation	2,350-7,800	At the upper level, the water requires shandying for use as irrigation water, or to be suitable for selective irrigation and watering of livestock
Saline	7,800-22,000	Generally unsuitable for most uses. It may be suitable for a diminishing range of salt-tolerant livestock up to about 10,500 µS/cm and some industrial uses
Highly Saline	>22,000	Suitable for coarse industrial processes up to about 31,000 µS/cm

Table 7 summarises the EC statistics for laboratory samples analysed from the Tarrawonga Coal Mine and Boggabri Coal Mine monitoring networks. In bold are values that included the information collected since the last report (i.e. 2011-2018). **Figure 24** shows the median values on a map based on lithology.

The median values are about 1,000 µS/cm in coal, about 2,000 µS/cm in alluvium and volcanics, and about 2,500 µS/cm in coal measures interburden.

The EC values for coal range from 530 µS/cm to 2,760 µS/cm, increasing in the down dip direction. The lower end of EC recordings is unusually low for groundwater in coal seams. As these lower values tend to occur close to subcrop limits, this suggests that the inherent salinity in the coal seams is diluted by rainfall recharge. Near the Modification, the typical EC of groundwater in coal is more than 2,000 µS/cm.

The EC values for most groundwaters are at the limit of potable use but are suitable for livestock, irrigation and other general uses (**Table 6**). The waters classify as highly productive in terms of salinity within the AIP framework (**Table 1**). Note that the classification of highly productive also relates to yield. This is further discussed in **Section 5.5.1**.

Timeseries of the observed EC in alluvial bores are shown in **Figure 25**. Bores MW2, Reg7a, GW052266 and GW031856 show steady EC concentrations over the entire observation period. MW4, M5 and MW6 however show more variability. Both MW4 and MW6 show a sudden decrease of EC (2010 and 2013, respectively), and EC has since been slowly increasing in those bores. A large recharge event occurred in 2011 (refer to the rainfall deficit in **Figure 7**), which could explain the reduction in EC due to dilution.

Timeseries of the observed EC for bores in the interburden and volcanics are shown in **Figure 26**. The EC in Bore MW1 (interburden) showed an early spike and has since been stable at a high level (around 3,000 µS/cm). MW7 has a short record up to 2013 with an EC between 2,000 and 3,000 µS/cm during that period. No new data was available to assess the impact of the mining since 2013 as the bore has been reported as dry.

Bore MW3 has stable EC values of approximately 1,800 to 2,000 µS/cm between 2010 and 2019. Since then only one record is available, which is very low at only 600 µS/cm. Future monitoring will show if that was an outlier.

Table 7 Electrical conductivity at monitoring sites

BORE	MEDIAN [µS/cm]	MEAN [µS/cm]	STANDARD DEVIATION [µS/cm]	LITHOLOGY
MW2	**594**	**647**	**186**	Alluvium
GW031856	**1106**	**1088**	**80**	Alluvium
GW052266	**752**	**811**	**192**	Alluvium
MW6	**1660**	**1381**	**635**	Alluvium
GW044997	**2380**	**2645**	**1363**	Alluvium
MW5	**1980**	**2259**	**1233**	Alluvium
MW4	**4225**	**4155**	**740**	Alluvium
IBC2104	530	532	67	Coal
IBC2103	645	653	142	Coal
IBC2102	745	779	188	Coal
IBC2105	780	770	111	Coal
IBC2138	930	913	57	Coal
BC2181	980	917	110	Coal
GW002129	1210	1147	127	Coal
BC2193	1820	1837	29	Coal

BORE	MEDIAN [µS/cm]	MEAN [µS/cm]	STANDARD DEVIATION [µS/cm]	LITHOLOGY
IBC2114	2060	2044	133	Coal
TAWB14	2240	2263	96	Coal (Goonbri Ck.)
IBC2115	2280	2241	163	Coal
IBC2139	2760	2692	205	Coal
MW7	**2310**	**2381**	**274**	Coal Measures
MW1	**3220**	**3354**	**488**	Coal Measures
GW002501	4500	3938	1709	Coal Measures
MW8	2260	2370	208	Conglomerate
MW3	**1730**	**1592**	**477**	Volcanics
IBC2110	1705	1642	184	Volcanics
GW020432	2115	2115	120	Volcanics
IBC2111	2120	2089	132	Volcanics
GW3115	3640	3543	195	Volcanics
Templemore A	**1156**	**1166**	**227**	Uncertain
Templemore B	**1487**	**1517**	**116**	Uncertain

Note: values **in bold** indicate that the record was updated with new data (2011-2018)

5.4.3 Water values

Groundwater quality data available for the Modification area and surrounds has been compared to the government Default Guideline Values (DGV) for aquatic ecosystems and primary industries, as well as the Australian and New Zealand Environment and Conservation Council (ANZECC) (2000) guidelines for drinking water, short term and long- term irrigation and specific guideline values for livestock watering (beef cattle). All available water quality results provided by TCPL are presented in **Attachment B**.

This section discusses the parameters where the average or median in a group of bores (by formation and location) exceeds the guideline values. Note that exceedances are not discussed if the maximum reading exceeds the guidelines, however the average or median are below. The following observations can be made:

- Average **aluminium** concentrations exceed the DGV value (which is the same as the ANZECC freshwater guidelines), however, they are well below the stockwater and irrigation guidelines.

- Average **iron** concentrations exceed the DGV guidelines in all formations of the Tarrawonga Coal Mine network. The average and median differ for most of the formation, which indicates that single outliers are skewing the results. Iron staining in the bores can be a likely cause of the elevated concentrations.
- One very high record of **molybdenum** is skewing the average; however, the median is below the guideline values.

5.5 Groundwater use

5.5.1 Registered bores

The previous groundwater assessment (Heritage Computing, 2011) identified 635 registered bores within the regional numerical groundwater model area. Most of the registered bores are located within the Upper Namoi Alluvium (refer to **Figure 17**). In consultation with local landholders, Whitehaven also conducted a bore census in March 2011 of privately owned bores/wells near the Modification.

Groundwater abstraction from the Narrabri Formation and the Gunnedah Formation, respectively, for bores registered for irrigation purposes, is concentrated close to the Namoi River corridor, in particular the paleochannel of the Gunnedah Formation to the west and north-west of the Modification. The nearest active Gunnedah Formation production bore is located on the western side of the Namoi River, approximately 2 km south-west of the Modification mining area.

The volume of water withdrawn annually from the 122 production bores in the model area varied from 11,300 ML in the 2009-2010 water year to about 28,800 ML in the 2006-2007 water year with an average of about 21,200 ML from 2006 to 2010.

Heritage Computing (2011) concluded that the impact on the water level in each privately owned bore is expected to be negligible and would not materially affect the existing or potential future beneficial use of groundwater.

The draft Water Management Plan (TCPL, 2018) noted that:

> *'Of 121 registered bores within 5 km of the TCPL, 67 are on land owned by Whitehaven or BCPL. There are no private bores within the 2 m drawdown zone of influence drawing water from alluvium. One bore in the Leard State Forest (GW967859[2]) that would draw water from porous rock is expected to have a maximum drawdown of about 8 m due to the TCPL alone and about 20 m cumulative impact from all three mines. If this bore is in use, a make-good arrangement is warranted.'*

The NSW groundwater database export showed that the aquifer yields are below 1 L/s in the vicinity of the mine. This would classify the local alluvium as less productive in the AIP framework (refer to **Table 1**). Bores with higher yields (i.e. larger than 5 L/s) are located towards Namoi River and would indicate that the Namoi River alluvium should be classified as highly productive (from a yield perspective).

5.5.2 Groundwater dependent ecosystems

The *NSW State Groundwater Dependent Ecosystems Policy* (DLWC, 2002) describes the five broad types of groundwater systems in NSW, each with associated dependent ecosystems as follows:

[2] This bore, also known as IBC2113, is now destroyed (AGE, 2018)

- Deep Alluvial Groundwater Systems – occurring under floodplains of major rivers west of the Great Dividing Range (e.g. Namoi, Macquarie, Lachlan, Murrumbidgee and Murray alluvium).
- Shallow Alluvial Groundwater Systems – coastal rivers and higher reaches west of the Great Dividing Range (e.g. Hunter, Peel and Cudgegong Alluvium, and beds and lateral bars of the lower Macleay, Bellinger and Nambucca Rivers).
- Fractured Rock Groundwater Systems – outcropping and sub-cropping rocks containing a mixture of fractures, joints, bedding planes and faults that contain and transmit small and occasionally large amounts of groundwater (e.g. Alstonville Basalt, Molong Limestone and the Young Granite).
- Coastal Sand Bed Groundwater Systems – significant sand beds along the coast of NSW (e.g. Botany and Tomago sand beds).

  Sedimentary Rock Groundwater Systems – sedimentary rock aquifers including sandstone, shale and coal (e.g. Great Artesian Basin, Sydney Basin and Clarence Moreton Basin).

The Tarrawonga Coal Mine coal resource is located within the Maules Creek sub-basin of the Early Permian Bellata Group (refer **Section 4.1**), which is within the sedimentary rock groundwater systems of the Gunnedah Basin. These sedimentary rock groundwater systems lie within the boundary defined in the Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011 (as described in **Section 2.4** and shown in **Figure 4**). There are no high priority GDEs as identified in the Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011 in the Modification area (**Figure 9**).

Groundwater resources in the south-east and to the south of the Modification area are associated with the deep alluvial groundwater systems of the Namoi alluvium (i.e. Upper Namoi Zone 4 Groundwater Source – refer **Section 2.4**). There are no high priority GDEs identified in the Upper Namoi (NSW Office of Water, 2010).

The NSW State Groundwater Dependent Ecosystems Policy (DLWC, 2002) recognises the four Australian GDE types (Hatton and Evans, 1998) that can be found in NSW, namely:

- terrestrial vegetation;
- base flows in streams;
- aquifer and cave ecosystems; and
- wetlands.

The GDEs which are known or likely to occur within the Modification area as well as the potential impacts of the Modification on GDEs are described in the Surface Water Assessment (Appendix B of the Tarrawonga Coal Project EA [Gilbert & Associates 2011b]) and Flora Assessment (Appendix F of the Tarrawonga Coal Project EA [FloraSearch, 2011]).

5.6 Conceptual model

A conceptual model of the groundwater regime has been developed in Heritage Computing (2011), based on the review of existing environmental, geological and hydrogeological data. This assessment reviewed the newly available data as described in **Sections 3** to **Section 5**, and found no major changes to the conceptual understanding of the site specific and regional groundwater conditions.

Based on the above, and consistent with the relevant water sharing plans, the data supports two groundwater systems:

- Porous Rock groundwater system - including the coal measures of the Maules Creek Formation; and
- Alluvial groundwater system – associated with the low-lying floodplains of the Upper Namoi.

The conceptual groundwater models before mining and toward the end of mining (both for the Approved Case and the Modification) are displayed in **Figure 16**.

Recharge to the groundwater systems occurs from rainfall and runoff infiltration, lateral groundwater flow and some leakage from surface water sources (e.g. Namoi River). Groundwater levels are controlled by topography, geology and surface water levels in local drainages and sustained by rainfall infiltration. In addition, ET is unlikely or minor in the vicinity of the mine and adjacent alluvium given the typical depth of water (**Section 5.2.1**). During mining, the potentiometric heads in the porous rock groundwater system will be reduced in the vicinity of the mine, but the water table will tend to rise beneath emplacement mounds.

Figure 16 shows two detailed sections for the Approved case and the proposed Modification. For the Approved case (lower left figure), a low permeability barrier that would minimise leakage between the Goonbri Creek alluvium and the mine void was planned. The second detailed section in **Figure 16** (lower right) shows the proposed Modification, where the low permeability barrier is removed. However, as mining will now not progress into the alluvium, the direct connection from the alluvium to the open cut pit is inhibited by the Maules Creek Formation that will be left in place. The performance of the in-situ rock (Modification) has been compared to the performance of the permeability barrier (Approved Case) in **Section 8**. Groundwater sourced from the coal measures and the emplacement will report to the open cut pit in both cases.

6 NUMERICAL GROUNDWATER MODEL DESIGN

6.1 Modelling software and confidence level

Numerical modelling was conducted using MODFLOW-USG Beta. Details of the model setup are listed in **Table 8**.

Table 8 Groundwater model details

Model aspect	Set-up	Details/key settings
Model code	MODFLOW-USG Beta	(Panday *et al.,* 2013)
GUI	Groundwater Vistas, Version 6.84	Environmental Simulations Inc.
Model area & units		Length = metres, Time = days
Grid	Rectangular; regular	1.23 million cells; 50 m to 500 m
Layers and layer types	12 Layers	All layers unconfined (Type 3)
Unsaturated flow	Upstream weighting	Unsaturated zone properties: Alpha = 0.3 Beta = 2 Resid-Sat = 0.05 B-Corey = 2
Vertical conductance	Vertical K	LPF with NOVFC and CONSTANTCV
Solver	SMS	XMD, HCLOSE = 0.001 m
Run modes	Initial calibration Transient calibration Prediction	See **Section 6.4** See **Section 7**
Calibration data	Heads (piezometers; VWP)	See **Sections 6.4.2** and **6.4.3**
Boundary conditions	RCH	Aquifer recharge
	RIV	Rivers, ephemeral streams
	DRN	Mine drainage
	GHB	Boundary flow
	WEL	Pumping bores
	TVM	Temporal variation in aquifer conditions (mining, waste rock emplacement)

Groundwater modelling has been conducted in accordance with the Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012). The 2012 guide has replaced the 'model complexity classification' of the previous guideline by a 'model confidence level. **Table 9** (based on Table 2-1, Barnett et al. 2012) summarises the classification criteria and shows a scoring system allowing model classification. The Modification model may be classified as Class 2 to Class 3 (effectively 'medium to high confidence'), which is an appropriate level for this context.

Table 9 Groundwater model classification table

Class	Data		Calibration		Prediction		Indicators		TOTAL
1	Not much		Not Possible		Timeframe>>calibration		Timeframe>10x		1
	Sparse		Large error statistics		Long stress periods		Stresses>5x		
	No metered usage	x	Inadequate data spread		Transient prediction but steady state calibration		Mass balance>1% (or single 5%)		
	Remote climate data		Targets incompatible with model purpose		Bad verification		Properties<>Field		
							Bad discretisation		
							No review		
2	Some	x	Partial performance		Timeframe>calibration	x	Timeframe=3-10x	x	10
	Poor coverage		Long-term trends wrong		Long stress periods	x	Stresses=2-5x	x	
	Some usage info		Short time record		New stresses not in calibration	x	Mass balance<1%		
	Baseflow estimates		Weak seasonal replication	x	Poor verification		Properties<>Field measurements	x	
			No use of targets compatible with model purpose				Some key coarse discretisation	x	
							Reviewed by hydrogeologist	x	
3	Lots		Good performance stats	x	Timeframe~calibration		Timeframe<3x		7
	Good aquifer geometry	x	Long-term trends replicated		Similar stress periods		Stresses<2x		
	Good usage info		Seasonal fluctuations OK		Similar stresses to those in calibration		Mass balance<0.5%	x	
	Local climate info	x	Present day data targets	x	Steady state prediction consistent with steady state calibration		Properties ~Field measurements		
	K measurements	x	Head and flux targets		Good verification		Some key coarse discretisation		
	Hi –res DEM	x					Reviewed by modeller		

6.2 Model extent

HydroSimulations used the existing groundwater model that focuses on the Tarrawonga Coal Mine component of the BTM Complex, including Boggabri and Maules Creek Coal Mines. This model was developed in 2011 using MODFLOW-SURFACT (v4) software with a structured grid and with inclusion of terminating faults between Tarrawonga and Vickery Coal Mines. For this assessment, the model was converted from MODFLOW-SURFACT to MODFLOW-USG, which reduces the runtimes of the model while keeping the original structure of the model.

The model domain was discretised into 1.23 million cells arranged into 12 layers, comprising 374 rows and 274 columns. The dimensions of the model cells vary from 50 m at mine sites to 500 m towards the model edges. Refer to **Figure 27** for an overview of the model grid.

Three separate model layers are defined for the following groups of target coal seams:

- Braymont Seam to Jeralong Seam;
- Merriown Seam to Velyama Seam; and
- Nagero Upper Seam.

The layers are schematically depicted in **Figure 28**. Representative model cross-sections are displayed in **Figure 29** for Easting 228425 (model column 110) and Northing 6606725 (model row 165), through the center of the Tarrawonga Coal Mine in north-south and east-west direction respectively. As designated coal seams are not continuous everywhere due to faulting and erosion, in the model these layers are given interburden properties where appropriate.

6.3 Model stresses and boundary conditions

6.3.1 Boundary conditions

Figure 30 displays the boundary conditions for Layer 1 (alluvium). The model boundary conditions remained consistent with the 2011 model, with the following two changes:

- The River Boundary at Maules Creek was changed from a constant to a variable river stage as more data has become available since the last model (Gauging Station 419051 *Maules Creek at Avoca East*).
- The Eastern General Head Boundary (GHB) was replaced by a now flow boundary. Hence, there is only a GHB in the Western part of the model, which is only applied to two alluvial layers (Layers 1 and 2).

6.3.2 Model stresses

The mining progression in the model was updated to reflect actual mining to 30 June 2018, and future mining for the Boggabri, Tarrawonga and Maules Creek Coal Mines.

Further, active pumping wells, not related to mining, have been included in the model. Refer to **Section 5.5.1** for a description of the bore users. In line with the previous model, these wells have been included as follows (and presented in **Figure 31**):

- From 2006 to 2010, historical pumping from the alluvial aquifer has been included in agreement with the stresses imposed in the NOW regional model for the Upper Namoi.
- After 2010, the pumping that occurred in 2010 has been assumed to continue at a constant rate. This is consistent with the 2011 groundwater model (Heritage Computing, 2011).

6.4 Calibration

6.4.1 Calibration data set

The current monitoring network was described in **Section 5.1**. For the calibration of the model, the 2011 model included 89 water level monitoring sites, 54 of which are used in the current model (highlighted in **Attachment A**). The current model includes 122 water level monitoring sites, which includes additional sites added as part of monitoring of the BTM Complex (**Attachment A**). Some sites are known to have been destroyed since the 2011 model (for example IBC114), for those the historical data set was used for calibration.

6.4.2 Initial calibration

The model parameters were first calibrated for the pre-mining conditions in steady state. The parameters adjusted to match the historic observations before 2006 were the horizontal and vertical hydraulic conductivity and the recharge. The calibration was undertaken with the software package PEST (Doherty, 2018).

The recharge was calibrated using a zonal approach (refer to **Figure 32**). The hydraulic conductivities were calibrated using a pilot point approach. The pilot points were selected by triangulation around the observation. The remainder of the model was filled in with a grid of pilot points. **Figure 33** presents the pilot point distribution for Layer 1 for illustration. The pilot points are not at the same location for each layer, because the observations are in different locations. However, all layers have the same spacing for the gridded location of pilot points.

Calibration statistics

The calibration scatter plot for the initial steady state calibration is presented in **Figure 34** and the calibration statistics and water balance are listed in **Table 10** and **Table 11** respectively. The Scaled Root Mean Square (SRMS) is 7.6%, which is an acceptable level for the confidence level of the model.

Table 10 Steady state calibration statistics

Calibration statistics	Value
Root Mean Square (RMS) (m)	9.42 m
SRMS (%)	7.6%
Average residual (m)	7.31 m

Water balance

The steady state water balance is presented in **Table 11**. The three inflows into the model domain are river leakage (42%), regional flow (32%) and recharge from rainfall (26%). The outflow comprises of wells, expression into surface water, ET and outflow to head dependent boundaries (regional flow). Of these, the wells account for the majority (95%) of the groundwater outflows.

Table 11 Steady state water balance

Calibration statistics	Inflow (ML/day)	Outflow (ML/day)
Pumping wells	0	166.4
Drain (mine dewatering)	0	0
River leakage	72.9	5.6
ET	0	2.0
Regional Flow	55.2	0.3
Rainfall recharge	46.2	0
Total	**174.3**	**174.3**
Total In-Out	0.0	
Mass Balance error	<0.1%	

ML/day = megalitres per day.

6.4.3 Transient calibration

The calibrated water levels from the steady state calibration (refer to **Section 6.4.2**) were used as initial conditions for the transient calibration.

The transient calibration was undertaken for the time period between 1 January 2006 and 30 June 2018. Refer to **Attachment C** for a list of the stress periods for the transient model. The stress periods are monthly between 2006 and 2011, then quarterly between 2012 and 2018, and annually for the predictive mining timeframe (2018-2035). During the transient calibration, the following parameters were adjusted to match the observed groundwater levels:

- Kh (Pilot point)
- Kv (Pilot point)
- Ss (zonal)
- Sy (zonal)
- Recharge (zonal)

Specific storage, specific yield and the recharge were calibrated using a zonal approach. Refer to **Figure 32** for a display of the recharge zones.

The horizontal and vertical hydraulic conductivities were calibrated using pilot points. The pilot points were selected by triangulation around the observation. The remainder of the model was filled in with a grid of pilot points. **Figure 33** presents the pilot point distribution for Layer 1 for illustrations. The pilot points are not at the same location for each layer, because the observations are in different locations. However, all layers have the same spacing for the gridded location of pilot points.

Calibration statistics

The calibration statistics are presented in **Figure 35** (scatter plot) and in **Table 12** below. The SRMS of the transient calibration was 7.1%, which is an acceptable level for the confidence level of the model.

The scatter plot (observed versus modelled water levels, **Figure 35**) shows that the Tarrawonga Coal Mine bores, DPIE - Water bores and Maules Creek bores are well-calibrated. The Boggabri bores scatter further from the 45° line, however, there is no bias visible. This means the model overestimated the water level in some bores and underestimates them in others. The VWPs at Tarrawonga show mixed results. At the shallower depths (overburden), the model is able to reproduce the observed water levels well. At other depths, however, the calibration fit is not as good, and the model is overestimating the water levels. This could be due to the model vertical discretisation, which cannot reproduce the level of detail that the VWPs provide (point measurement).

The resulting hydrographs (observed and modelled water levels versus time) are presented for each bore in **Attachment D**. It is apparent that the level of calibration differs from bore to bore. Some bores have a better absolute fit, others can replicate the trends better.

Table 12 Transient calibration statistics

Calibration statistics	Value
RMS	11.06 m
SRMS	7.1%
Average residual	7.31 m

In addition to the time dependent results, **Attachment H** shows the average residuals for the transient calibration on a map for each layer. In the Alluvium (Layer 1 and 2), the calibrated model generally underestimates the water levels. Around Tarrawonga Coal mine, Templemore A and BCS7 are standing out with large residuals. The screened intervals in Templemore A and B are not known, and the large residual might be to fact that the bore is not attributed to the Alluvium only.

The coal seams are represented in Layers 4, 6, 8 and 10. The residuals for bores within the coal seams are high in the surrounding mine areas, with modelled groundwater levels generally lower than observed. This may relate to difference between actual mine progression at surrounding operations and what was captured within the model.

For Layer 3, 5, 7, 9 and 11, there are less observations, as those layers represent the overburden, interburden and underburden (aquitard). The two VWPs TA-60 and TA-65 have sensors across the coal and interburden stratigraphy. Results for VWP's TA60 and TA65 show reasonable replication of groundwater trends for most sensors. The model also shows a close match to observed groundwater levels within variable sequences (TA60-109, TA60-118, TA65-47, TA65-56, TA65-97). Where the trends show poorer match this likely relates to the vertical discretisation of the numerical groundwater model compared to the discrete intervals monitored at the VWP's.

Water balance

The average water balance for the transient calibration period is presented in **Table 13.** As shown in the table, the inflows and outflows are smaller than in the steady state phase, which is mainly due to a lower recharge and infiltration from rivers, and the wells also use considerably less water from the groundwater resource. The main model inflow with 40% is sourced from rivers, followed by regional flow and recharge.

Table 13 Transient water balance (average 2006-2018)

Calibration statistics	Inflow (ML/day)	Outflow (ML/day)
Storage	19.8	78.4
Pumping wells	0	50.3
Drains (mine dewatering)	0	1.0
River leakage	60.1	10.7
ET	0	1.7
Regional flow	31.4	0.2
Rainfall Recharge	31.1	0
Total	**142.4**	**142.4**
Total In-Out	0	
Mass balance error	<0.1%	

The term storage in **Table 13** refers to changes in the groundwater level. Inflow from storage into the groundwater system means that the water levels are decreasing. Outflow from the groundwater system into storage means that the groundwater levels are increasing. During the calibration period, there is more outflow that inflow for the storage term, which is likely attributed to the reduction in pumping over that time frame. During steady state, the wells were pumping at 166 ML/day, whereas during the calibration period this value was reduced to 50 ML/day. The water levels in the alluvium recover and hence water accounted as outflow (storage).

The mine inflows for the calibration periods are presented in **Figure 36**. The groundwater inflow into the Tarrawonga Coal Mine between 2006 and 2018 is 0.12 ML/day to 0.24 ML/day, with an average of 0.16 ML/day. Boggabri Coal Mine has an average modelled groundwater inflow of 0.5 ML/day. Rocglen Coal Mine had three years with inflows of over 0.3 ML/day (2011-13) and has since decreased to zero. Maules Creek Coal Mine inflows are starting in 2014 (very limited) and are approximately 0.1 ML/day for the last three years. The BTM Complex combined mine inflows are currently at 1 ML/day.

The stream leakages from Goonbri Creek and Bollol Creek during the calibration period are shown in **Figure 37**. The stream leakages appear to be steady during this period, with Bollol Creek infiltrating approximately 1.9 ML/day and Goonbri Creek approximately 0.9 ML/day into the alluvium.

6.4.4 Resulting model parameters

Table 14 lists the calibrated hydraulic properties of the model in comparison with the calibrated values from the 2011 model. The 2011 model used a zonal approach for calibrating the horizontal and vertical hydraulic conductivities. In this model, a pilot point approach was chosen. To compare the 2011 with the current model, the minimum and maximum values at a pilot point in each of the previous zone were listed. The previous calibrated value falls between the minimum and maximum of the newly calibrated values.

Table 14 Calibrated hydraulic properties

Layer	Zone Number	Lithology	Kh(1) (2011)	Min Kh (1) (2019)	Max Kh(1) (2019)	Kv (1) (2011)	Min Kv (1) (2019)	Max Kv (1) (2019)	Ss (2) (2011)	Ss (2) (2019)	Sy (3) (2011)	Sy (3) (2019)
1	1	Alluvium	5.00E+00	1.32E+00	1.42E+01	1.00E-02	3.01E-03	4.05E-02	1.00E-03	1.00E-04	2.00E-01	2.00E-01
	13	Maules Creek Formation	1.00E-01	4.30E-02	1.91E-01	9.00E-03	3.60E-03	2.03E-02	5.00E-04	1.00E-04	1.00E-02	1.00E-02
	14	Regolith/Weathered Permian	1.00E-01	6.63E-02	1.39E-01	9.00E-03	4.22E-03	1.42E-02	5.00E-04	1.00E-04	1.00E-02	1.00E-02
	16	Boggabri Volcanics	5.00E-03	2.04E-03	5.39E-03	5.00E-04	1.60E-04	6.39E-04	5.00E-04	1.00E-05	1.00E-02	1.00E-02
2	2	Alluvium	8.00E+00	2.07E-01	5.24E+01	5.00E-02	7.91E-04	4.24E-01	1.00E-03	1.00E-04	2.00E-01	2.00E-01
	13	Maules Creek Formation	1.00E-01	4.30E-02	1.91E-01	9.00E-03	3.60E-03	2.03E-02	5.00E-04	1.00E-04	1.00E-02	1.00E-02
	14	Regolith/Weathered Permian	1.00E-01	6.63E-02	1.39E-01	9.00E-03	4.22E-03	1.42E-02	5.00E-04	1.00E-04	1.00E-02	1.00E-02
	16	Boggabri Volcanics	5.00E-03	2.04E-03	5.39E-03	5.00E-04	1.60E-04	6.39E-04	5.00E-04	1.00E-05	1.00E-02	1.00E-02
3	3	Overburden	3.42E-04	9.22E-05	6.56E-04	1.23E-05	2.40E-06	1.90E-04	1.00E-05	1.00E-06	1.00E-04	1.00E-04
4	4	Braymont Seam to Jeralong Seam	4.00E-01	4.21E-02	2.25E+00	1.00E-02	1.51E-03	9.19E-02	1.00E-04	1.00E-05	5.00E-03	5.00E-03
	12	Volcanics	5.00E-03	1.68E-04	4.84E-02	5.00E-04	1.72E-05	7.32E-03	1.00E-04	1.00E-06	1.00E-03	1.00E-03
	15	Boggabri Volcanics	5.00E-03	2.37E-03	4.96E-02	5.00E-04	2.55E-04	8.36E-03	1.00E-04	1.00E-05	1.00E-03	1.00E-03
5	5	Interburden	2.46E-04	1.02E-04	1.74E-03	1.33E-06	1.93E-07	3.06E-05	1.00E-05	1.00E-06	1.00E-04	1.00E-04
6	6	Merriown Seam to Velyama Seam	4.00E-01	3.71E-02	5.17E+00	1.00E-02	1.10E-03	1.52E-01	1.00E-04	1.00E-05	5.00E-03	5.00E-03
	15	Boggabri Volcanics	5.00E-03	2.37E-03	4.96E-02	5.00E-04	2.55E-04	8.36E-03	1.00E-04	1.00E-05	1.00E-03	1.00E-03

Layer	Zone Number	Lithology	Kh[1] (2011)	Min Kh [1] (2019)	Max Kh[1] (2019)	Kv [1] (2011)	Min Kv [1] (2019)	Max Kv [1] (2019)	Ss [2] (2011)	Ss [2] (2019)	Sy [3] (2011)	Sy [3] (2019)
7	7	Interburden	3.99E-05	1.63E-05	6.15E-05	1.09E-06	3.14E-07	4.18E-06	1.00E-05	1.00E-06	1.00E-04	1.00E-04
8	8	Nagero Upper Seam	3.00E-01	5.06E-03	1.91E+00	1.00E-02	2.67E-04	6.32E-02	1.00E-04	1.00E-05	5.00E-03	5.00E-03
	15	Boggabri Volcanics	5.00E-03	2.37E-03	4.96E-02	5.00E-04	2.55E-04	8.36E-03	1.00E-04	1.00E-05	1.00E-03	1.00E-03
9	9	Interburden	3.05E-05	9.74E-06	4.81E-04	8.27E-07	1.66E-07	1.69E-05	1.00E-05	1.00E-06	1.00E-04	1.00E-04
10	10	Northam Seam to Templemore Seam	3.00E-01	8.24E-02	7.40E+00	1.00E-02	3.25E-03	4.07E-01	1.00E-04	1.00E-05	5.00E-03	5.00E-03
11	11	Underburden	1.61E-05	8.37E-06	2.70E-05	3.60E-06	1.42E-06	7.86E-06	1.00E-05	1.00E-06	1.00E-04	1.00E-04
12	12	Volcanics (basement)	5.00E-03	1.68E-04	4.84E-02	5.00E-04	1.72E-05	7.32E-03	1.00E-04	1.00E-06	1.00E-03	1.00E-03

Notes:
[1] the unit for all hydraulic conductivities (kh horizontal and kv vertical) is m/day.
[2] The unit for the specific storage (Ss) is m^{-1}.
[3] the specific yield (Sy) is dimensionless.

Attachment I show the spatial distribution of the calibrated hydraulic conductivities for each layer. White areas indicate that the layer is not present at the location. Due to the volcanics outcropping in to the west of the site, this area is blank for multiple layers.

Special consideration was given the specific storage value. A recent paper (Rau *et al*, 2018) set an upper and lower limit for the specific storage based on calculations. According to the paper, specific storage values would fall into a range of 2.3×10^{-7} m^{-1} to 1.3×10^{-5} m^{-1}. The previous model had calibrated specific storage values beyond this new upper bound. The new calibration has now been undertaken with the range presented above as a limitation for the PEST calibration.

Table 15 lists the resulting calibrated groundwater recharge values, expressed as a percentage of the average rainfall for both the previous model and the newly calibrated model. The results are similar between the two models. The alluvium, Upper Permian and Triassic Outcrop and the Rock-Alluvium contact zone showed a slight increase of 10-30%. The Maules Creek Formation and Boggabri Volcanics showed a decrease by 65% compared to the previous model.

Table 15 Calibrated recharge values

Geology	Recharge (% of rainfall) 2011 Model	Recharge (% of rainfall) 2019 Model
Alluvium	1.20%	1.30%
Maules Creek Formation	0.10%	0.04%
Upper Permian and Triassic outcrop	0.10%	0.12%
Boggabri Volcanics	0.50%	0.20%
Rock-alluvium contacts	10%	11%

7 SCENARIO ANALYIS PREDICTIVE RUNS

The previous model (Heritage Computing, 2011) has been updated as described in **Section 6.** To be able to compare the impacts for the approved case with the impacts for the Modification, both of those scenarios have been included in the predictive runs from July 2018 onwards. The assessed scenarios are:

- Approved Case
- Modification
- NULL run (no future Tarrawonga mining)

All three scenarios are identical during the calibration period between 1 January 2006 and 30 June 2018, reflecting the observed mining to date. After this date the scenarios differ as follows:

- The Approved Case is modelled with mining entering the alluvium, and subsequent Goonbri Creek re-alignment and low permeability barrier.
- The Modification run reflects the reduced mining footprint as proposed under this Modification. The Goonbri Creek re-alignment and low permeability barrier are not required as the mining will not enter the alluvium.
- The Null run comprises of no future Tarrawonga Mining, hence the other mines in the areas would still be active as scheduled. The Null run will be used to assess the impacts for the Modification compared to the scenario where mining would completely stop at the Tarrawonga Coal Mine.

7.1 Mine schedule

7.1.1 Mining schedules

Using the hydraulic and storage properties resulting from the transient calibration, the model was run in transient mode from July 2018 to June 2035 in annual steps. The Modification is simulated to commence in 2018 and finish in 2030. An additional five years were required to take the Maules Creek Coal Mine and the Boggabri Coal Mine to completion. The Rocglen Coal Mine was activated from 2006 to 2016, consistent with the previous model (Heritage Computing, 2011), i.e. no update in mine plan was implemented.

The progression of mining in the model was applied consistent with observed mining activities up to June 2018. Future mining was applied with the information provided for the Boggabri Coal Mine and Maules Creek Coal Mine. The regional mining plan is shown in **Figure 38**, covering the three mines in the BTM Complex and the Rocglen Coal Mine to the south.

The Vickery Coal Project and Vickery Extension Project were not considered in the model. As discussed in **Section 4.3**, there are many minor faults with east-west and north-south alignments, especially between the Tarrawonga and Vickery Coal Mines. As the target coal seams for the Tarrawonga Coal Mine are truncated either by faulting or erosion, they do not persist to the south or to the east of the Modification area and the omission of the Vickery Coal Project and Vickery Extension Project is deemed acceptable.

In **Figure 39** the mining progression for the Tarrawonga Coal Mine is shown for the Approved case and Modification. The Approved case was planned to mine the Upper Namoi alluvium and the natural alignment of Goonbri Creek, which triggered the construction of the low permeability barrier and Goonbri Creek re-alignment. The proposed Modification does not reach the Goonbri Creek alluvium and hence the low permeability barrier and creek re- alignment are not required.

7.1.2 Changed model parameters for the spoil

The hydraulic conductivity for the spoil was assumed to be 1 m/day. The only time-varying stress in the prediction model is mining. Rainfall was applied at constant long-term average rates; constant average river levels were assumed; and the pumping that occurred in 2010 was assumed to continue at a constant rate.

Rainfall recharge was deactivated in cells where mining was currently active, for a period of five years, as mine waste rock would require roughly this length of time to wet up through the unsaturated zone. After five years, 5% recharge is applied to mine waste rock, which is around five times greater than the recharge to the alluvium (refer to **Table 15**).

7.2 Water balance

The water balance for the predictive stress periods of the model (July 2018 - June 2035) is presented in **Table 16** for both the Approved case and the Modification. The values represent the average flow rates over that time period. Most of the components show the same results for the Approved case and the Modification. The small differences are in the drains representing the mine inflow (0.7 ML/day less mine inflow for the modification) and a marginally smaller recharge, which is compensated with a smaller release from storage in the Modification run.

Table 16 Water balance comparison between the Approved case and the Modification

Component	Approved case (revised) ML/day	Modification ML/day
Inflows		
Storage	4.3	3.8
River Leakage	47.1	47.1
Regional Inflow	15.1	15.1
Rainfall Recharge	32.3	32.1
Total Inflow	**98.8**	**98.2**
Mass balance error	0.6%	
Outflows		
Storage	37.4	37.4
Pumping wells	42.6	42.6
Drains (Mine dewatering)	1.9	1.2
River Leakage	14.2	14.2
ET	1.9	1.9
Regional outflow	0.9	0.9
Total Outflow	**98.8**	**98.1**
Mass balance error	0.7%	

7.3 Predicted pit inflow

The predicted mine inflows for all four modelled mines are shown in **Figure 40**, which also displays the cumulative inflow of the three mines of the BTM Complex.

In the BTM Complex, the Boggabri Coal Mine shows the highest modelled mine pit inflows. Maules Creek Coal Mine inflows are significantly lower than predicted in the 2011 model; this can be explained with a major change in mining progression (later start and shallower mining). The mining inflow for the Tarrawonga Coal Mine is approximately 0.2 ML/day over the entire period for the modification, increasing to 0.27 ML/day at the later stages of mining.

Table 17 lists the annual average inflows into the Tarrawonga Coal Mine for the approved case and the modification. The inflows for the approved case are larger for all years. Before the mining encroaches into the alluvium (Financial Year 2023/24) in the Approved case, the values are comparable between the two scenarios. However, the inflows for the Modification are significantly lower than for the Approved case, as the Modification does not mine the Upper Namoi alluvium. The indirect take, or the water losses from the alluvium into lower strata, was calculated to be approximately 0.002 ML/day, and is therefore considered negligible.

Figure 41 graphically represents the data from **Table 17**, with a three-year moving average applied.

Table 17 Mine inflow into the Tarrawonga Coal Mine

Financial Year	Approved case ML/day	Modification ML/day
2018/19	0.22	0.16
2019/20	0.22	0.16
2020/21	0.22	0.16
2021/22	0.23	0.17
2022/23	0.23	0.17
2023/24	1.48	0.17
2024/25	0.29	0.20
2025/26	1.57	0.22
2026/27	0.81	0.25
2027/28	1.20	0.25
2028/29	1.65	0.25
2029/30	1.32	0.27

7.4 Post-mining equilibrium

7.4.1 Stage – Inflow curve

Estimates of groundwater inflow by pit water level, which are required as inputs to the water balance model, were provided by conducting a steady-state groundwater recovery simulation with the void treated as highly permeable water bearing material (K = 1,000 m/day; Sy = 0.99). The evapotranspiration package in MODFLOW was used to represent open water evaporation. The spoil hydrogeological parameters were applied as described in **Section 7.1.2**. As discussed in that section, the transient predictive model has a five-year delay in the recharge to the spoil to consider the re-wetting of the spoil after the mining progresses further. In a steady state model, the higher spoil recharge will be active instantaneously. The steady state model stage/inflow results for each pit level reflect the inflow into the pit for each pit level if that level would be constant over a long period of time. This also implicates that the spoil would be re-saturated and contributing to these inflows in addition to the inflows from the coal measures.

The results of the post-mining estimates of groundwater inflows are presented in **Table 18**. The result, a stage versus groundwater inflow curve, was provided to the surface water consultants (Hydro Engineering & Consulting Pty Ltd [HEC]) conducting the water balance modelling, who then calculated a transient recovery curve for the pit level over time. The void level recovery curve was then used in the groundwater model as a constant head boundary to calculate the long-term transient groundwater level recovery (**Section 7.4.2**).

Table 18 Pit lake stage versus groundwater inflow (Steady State)

Recovered Water level (m AHD)	Inflow into Tarrawonga final void (ML/day)
170	0.90
180	0.90
190	0.90
200	0.90
210	0.88
220	0.87
230	0.84
240	0.80
250	0.73
260	0.62
270	0.45

7.4.2 Transient recovery

The transient groundwater level recovery curve (HEC, 2019) was used to set up the transient recovery run. The stress period set up is presented in **Attachment C**. The first 100 years are divided into five periods of 20 years length, followed by four periods of 100 years length. The recovery was calculated over 500 years.

Figure 42 shows water levels in the pit lake that were used to simulate the recovery. **Attachment F** shows the resulting hydrographs in the observation bores for the recovery period (2035 - 2250). Bores in the interburden and coal show a large drawdown and recovery, whereas the alluvial bores present mostly steady water levels (i.e. no impacts).

Figure 43 presents the water table after 100 years of recovery (year 2135) along with some flow lines to indicate flow directions. The water table does not change significantly after that time (refer to **Attachment F**), hence the figure for the 500 years is not provided. The figure shows that the final void will be a sink, as it is the lowest point in the water table locally. The arrows indicating the flow directions all point towards the final void.

Table 19 lists the predicted inflows into the mining void for the 500 years of the modelled recovery period. The calculated inflow into the void starts at 0.74 ML/day (270 ML/year) and decreases to 0.62 - 0.64 ML/day (230 ML/year) once fully recovered. **Table 19** also provides a breakdown of inflow sources by formation (alluvium, spoil, coal seams and other areas).

Mining pit inflows are predicted as being greater during the recovery period than during mining. This is due to greater inflows from the spoil in the recovery model. In the predictive model, in each mined out area, the recharge to spoil was zero for the first five years, and then the spoil recharge of 5% was applied. This was adopted to reflect the slower recovery time within recently emplaced spoil (refer to **Section 7.1.2**). In the transient recovery model, the stress periods are longer (20 – 100 years) and hence the spoil has time to recover and contributes to higher inflows into the pit. The results in **Table 19** show that the total inflow to the pit is larger than during mining, however, the largest portion is from the spoil, which acts as a conduit for the enhanced recharge.

Table 19 Pit inflows (ML/day) during recovery period (Modification)

Years after recovery started (calendar year)	Total inflow into Tarrawonga final void	From Alluvium	From Tarrawonga Spoil	From coal seams	From other areas [1]
20 (2055)	0.74	0	0.59	0.14	0.003
40 (2075)	0.74	0	0.62	0.12	0.003
60 (2095)	0.74	0	0.62	0.12	0.003
80 (2115)	0.70	0	0.60	0.10	0.003
100 (2135)	0.66	0	0.57	0.09	0.002
200 (2235)	0.69	0	0.59	0.09	0.002
300 (2335)	0.67	0	0.58	0.09	0.002
400 (2335)	0.62	0	0.54	0.08	0.002
500 (2435)	0.64	0	0.56	0.08	0.002

[1]"Other areas" consist of: Regolith, Overburden, Interburden, Volcanics

8 IMPACT ASSESSMENT

8.1 Impacts on groundwater

This section discusses potential impacts on the groundwater environment with respect to:

- The differential impact between the Approved case and the Modification.
- The maximum cumulative impact of the Modification, as a difference from the Null run (no mining after 2018 at the Tarrawonga Coal Mine).

8.1.1 Difference between Approved case and Modification

Figure 44 and **Figure 45** show the difference in water levels between the Approved case and the Modification, i.e. the minimum water level in each model cell during the entire runtime is compared between the two runs. This indicates that the minimum for the Modification might not occur in the same time step as the minimum for the Approved case. A positive drawdown indicates additional drawdown from the Modification; a negative drawdown indicates less drawdown from the Modification.

Figure 44 shows the difference in the water table. Water table in this instance refers to groundwater encountered in the first model layer that is not dry, i.e. the uppermost saturated layer. Some layers are also not present at the surface (for example where the Boggabri Volcanics outcrop). The figure shows only negative differences between -100 m and -2 m, indicating a reduction in drawdown for the Modification of 2 m -100 m. The two areas of difference are in ML1693 along Goonbri Creek and at the eastern boundary of ML1685. Mining does not progress as far east in both cases for the Modification as it was planned in the Approved case resulting in a reduction in drawdown.

Figure 45 shows the differential drawdown in the lowest coal seam (Nagero Seam, Layer 8) between Approved case and Modification. The Modification results in up to 20 m less drawdown in this layer, specifically in the eastern parts of ML1693, because the Modification will not advance as far east as the Approved case. The change in drawdown on the edge of ML1685 can be explained with the different mining schedules between the Approved case and the Modification.

As there is negligible difference in drawdown between the Approved case and the Modification in the alluvium, no drawdown maps were produced. *In lieu*, the results for selected alluvial bores are listed in **Table 20** for comparison. Note that a negative difference indicates less drawdown. For the bore locations refer to **Figure 14**. The differences in water levels between Approved case and Modification are small, which indicates a similar performance of the low permeability barrier for the Approved Case and the in-situ rock, between the open cut and Upper Namoi Alluvium, for the Modification. GW044997 shows the largest difference in water levels of -1.2 m, which equates to a reduction in drawdown of 1.2 m, i.e. the in-situ rock (Modification) has less impact compared to the low permeability barrier (Approved case). In other bores, there is no change in drawdown or a reduction of up to 0.3 m.

In summary, mining within 200 m of the Upper Namoi Alluvium can occur without the requirement for a low permeability barrier.

Table 20 Predicted water level differences in July 2030 for selected bores in the alluvium

Bore	Location	Approved case (WL, m AHD)	Modification (WL, m AHD)	Difference (m)
GW044997	ML 1693 southern border, Goonbri Creek	267.18	268.39	-1.20
MW2	Southeastern border of ML1579	259.10	259.43	-0.33
MW4	1 km south of ML1579	252.89	252.99	-0.10
MW6	North-west border of ML1755	245.99	245.99	0.00
BCS6	Bollol Creek, upstream of BCS7	290.93	290.93	0.00
BCS7	ML1693 southeastern corner Bollol Creek	270.16	270.40	-0.24
GW31856	1 km south of ML1579	254.61	254.70	-0.09

Note: WL = water level

A full set of hydrographs for the predictive period is shown in **Attachment E**. Most of the predicted hydrographs plot identically for the Approved case and the Modification, indicating there is no significant difference in impacts from the Modification compared to the already approved impacts. Where the hydrographs differ, the Modification has a lower impact.

Notable bores with reduced impact due to the modification are GW044997, BCS7 and MW2, all located in the alluvium (also refer to **Table 20**). The BCS-series bores (with the exception of BCS7) further upstream in the Bollol Creek alluvium are showing identical water level results for both Approved case and Modification, meaning there are no changes to the approved impacts.

8.1.2 Maximum drawdown caused by Modification

Figure 46 shows the maximum calculated drawdown in the lowest coal seam (Nagero Seam) of the Modification compared to the Null run (i.e. maximum impact of the Modification). The maximum drawdown of around 65 m is located in the mining areas to be mined in 2019-2027 (ML 1693, east of Goonbri Creek).

Figure 47 shows the maximum calculated drawdown of the water level caused by the Modification. Compared to the no mining scenario, the groundwater levels in the coal seams will be up to 50 m lower. The cone of depression is extending across Goonbri Creek, however this occurs in the coal seam only and the alluvium is not impacted, as discussed in the following section.

As there is negligible difference in drawdown in the alluvium between the Null run (no Tarrawonga mining after June 2018) and the Modification, a drawdown map was not produced. *In lieu*, the results for selected alluvial bores are listed in **Table 21** for comparison. For the bore locations refer to **Figure 14**. The differences in water levels are small. Note that a positive difference indicates additional water level impact. Bores BCS7 and GW044997 show the biggest difference between the Null run and the Modification. It can be concluded that the Modification have minor impacts on the alluvial bores.

Table 21 Predicted water level impacts in July 2030 for selected bores in the alluvium

Bore	Location	NULL Run (WL, m AHD)	Modification (WL, m AHD)	Difference (m)
GW044997	ML 1693 southern border, Goonbri Creek	268.48	268.39	0.09
MW2	Southeastern border of ML1579	259.45	259.43	0.02
MW4	1 km south of ML1579	253.00	252.99	0.01
MW6	North-west border of ML1755	245.99	245.99	0.00
BCS6	Bollol Creek, upstream from BCS7	290.93	290.93	0.00
BCS7	ML1693 southeastern corner Bollol Creek	270.46	270.4	0.06
GW31856	1 km south of ML1579	254.71	254.7	0.01

Note: WL = water level

8.1.3 Groundwater quality

The quality of the inflows will be a mixture of the qualities of the waters in source lithologies, primarily coal measures. These waters have similar ionic signatures with median EC ("salinity") values of approximately 1,000 µS/cm in coal and about 2,500 µS/cm in coal measures interburden, and 2,000 µS/cm in the alluvium (**Table 7**).

Given higher rainfall infiltration rates through mine waste rock, it is possible that the inflow waters could be freshened by lateral flow from mine waste rock to the void. Over time, the salinity in the final void will increase through evaporative concentration. As long as the void remains a groundwater sink, there will be no deleterious effect on the beneficial uses of any groundwater sources. Most waters are currently at the limit of potable use but are suitable for livestock, irrigation and other general uses.

The post-mining groundwater level pattern in **Figure 43** shows that the final void would act as a permanent groundwater sink. The final water level in the void is expected to be approximately 260 m AHD, which is approximately 15 m lower than current levels in the alluvium.

8.1.4 Potential Impacts on groundwater users

The maximum regional drawdowns are expected within model Layer 8 (Upper Nagero seam). **Figure 47** shows the maximum drawdown caused by the Tarrawonga Coal Mine alone for model Layer 8 during the predictive period.

Drawdowns are naturally limited to the west by outcropping coal measures and volcanics and to the east by the Mooki Thrust. However, they propagate to the north towards Maules Creek and are less than 1 m at the northern model boundary. Drawdown to the south of the Tarrawonga Coal Mine reduces sharply to less than 1 m beneath the alluvium associated with Bollol Creek, due to the faulting and erosion of the Upper Nagero Seam.

There are 121 registered bores located within approximately 5 km of the Modification (**Figure 17**). As reported in Heritage Computing 2011, a bore within the Leard State Forest (GW967859, also known as IBC2113) extracted water from the porous rock source when it was in use. However, this bore has now been destroyed (AGE, 2018) during the advancing of mining at Boggabri.

All other privately owned bores are sited in alluvium and it can be expected that they will draw water preferentially from alluvium. In all cases, the maximum drawdown at these sites is predicted to be no more than 1 m, which is well within the natural fluctuation in water levels.

The impact on the water level in each privately owned bore is expected to be negligible.

8.1.5 Upper Namoi (Zone 4) Alluvium

The Approved case entailed mining into the alluvium. Heritage Computing (2011) has reported on the potential water take during the time where mining in the alluvium was occurring (2024-2029). Heritage Computing (2011) assessed two losses:

- Loss from excavation of the alluvium and subsequent reduction in recharge
- Loss from alluvium into the lower formations via vertical leakage

As the Modification is not encroaching into the alluvium, only the second point is considered here. The comparison of the fluxes from the alluvium (Layer 1 and 2) into the connecting lower formations (Layer 3 and 4) resulted in a difference of 0.08 ML/year over the entire model domain. This negligible number is the additional loss from the alluvium into the lower formations by the Modification compared to the Null run.

8.1.6 Murray-Darling Basin Porous Rock (Gunnedah Basin)

The pit inflows from the Murray-Darling Basin Porous Rock Formation during mining are presented in **Table 17.** It is apparent that the inflows for the Modification are reduced compared to the predictive inflows for the Approved case. The implications for Water licensing are discussed in **Section 10.1.2**.

8.2 Impacts on surface water

8.2.1 Baseflow changes

This section presents the potential impacts on surface water, namely the predicted baseflow changes in Bollol Creek and Goonbri Creek. **Figure 48** presents the simulated infiltration from Goonbri Creek (a) and Bollol Creek (b) into the groundwater. A positive number indicates infiltration from the surface water into the groundwater. The stream leakage is approximately 1 ML/day for Goonbri Creek and 1.9 ML/day for Bollol Creek.

Bollol Creek does not show any changes in leakage between scenarios (i.e. consistent infiltration for Approved Case, Modification and Null run).

Infiltration from Goonbri Creek increases by 50 cubic metres per day (m^3/day) (+5%) when comparing the no mining scenario to the Modification case, and an additional 50 m^3/day (a total of 10% when compared to the Null run) to the Approved case. This indicates that the Modification has a reduced impact on streamflow, relative to the Approved case. This is further illustrated in **Figure 49**, where the changes in infiltration are shown as a percentage in comparison with the no mining run. The spike in year 2025 in the Approved case is a result of the previously planned creek re-alignment.

8.2.2 Water quality

There are not expected to be any significant changes in the quality of groundwater as a consequence of the Modification, other than possible freshening over the mine footprint due to higher rainfall infiltration rates through mine waste rock.

As described in **Section 8.1.3**, no significant groundwater quality impact is expected from groundwater interactions with the final void water. Therefore, it is unlikely the water quality of any surface water body would be impacted via final void water migration through groundwater. Maintenance of the void as a groundwater sink will ensure that groundwater flows towards the void rather than from the void towards surface water receptors.

8.3 Minimal impact considerations

This section provides discussion of potential impacts from the Modification[3] in terms of the AIP minimal impact considerations for the following two WSP:

- Upper Namoi (Zone 4) Alluvium
- Murray-Darling Basin Porous Rock (Gunnedah Basin)

Based on the findings of the groundwater modelling and assessment, the Modification meets the Level 1 minimal impact consideration classification of the AIP for 'highly productive' groundwater associated with the Upper Namoi Zone 4 Alluvium.

The Murray Darling Basin Porous Rock (Gunnedah Basin) is classified as 'less productive'.

These water sources are assessed against the AIP minimal impact considerations in **Table 22** and **Table 23** respectively.

[3] As discussed in **Section 8.1.1**, the predicted impact from the Modification compared to the Approved Case is reduced. Hence, this minimal impact assessment is conservative, because the impact by the Modification compared to the Null Run was assessed.

Table 22 Summary of Aquifer Interference Policy Assessment – Upper Namoi (Zone 4)

Aquifer	Alluvial Water Source: Upper Namoi Zone 4
Category	Highly Productive Groundwater Source

Level 1 Minimal Impact Consideration	Assessment
Water Table 1. Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: a) high priority groundwater dependent ecosystem; or b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. *OR* A maximum of a 2 m water table decline cumulatively at any water supply work.	There are no high priority groundwater dependent ecosystems identified and scheduled at the commencement of this Plan. There are no listed high priority culturally significant sites in the Water Sharing Plan. No water supply work within the Upper Namoi Alluvial Water Source (Zone 4) would incur more than 2 m drawdown due to the Modification. **The Modification meets the Level 1 minimal impact consideration classification.**
Water Pressure 1. A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work.	This criterion is not applicable as only unconfined conditions are present in the alluvial water source, therefore, only the above water table consideration is relevant. **The Modification meets the Level 1 minimal impact consideration classification.**
Water Quality 1. a) Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity; and b) No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. Redesign of a highly connected surface water source that is defined as a "reliable water supply" is not an appropriate mitigation measure to meet considerations 1.(a) and 1.(b) above. c) No mining activity to be below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three-dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply". d) Not more than 10% cumulatively of the three-dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200m laterally from the top of high bank and 100m vertically beneath a highly connected surface water source that is defined as a "reliable water supply".	There would be no change to beneficial use categories of the alluvial water source as a result of the Modification or any predicted increase in the salinity of the Namoi River. No mining activity within the specified proximities to the alluvial water source is proposed. No excavation of the highly productive alluvial sediments associated with the Upper Namoi River (Zone 4) is proposed. **The Modification meets Level 1 minimal impact consideration classification.**

Table 23 Summary of Aquifer Interference Policy Assessment – Murray-Darling Basin Porous Rock (Gunnedah Basin)

Aquifer	Murray-Darling Basin Porous Rock (Gunnedah Basin)
Category	Less Productive Groundwater Source

Level 1 Minimal Impact Consideration	Assessment
Water Table 1. Less than or equal to 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: a) high priority groundwater dependent ecosystem; or b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m decline cumulatively at any water supply work. 2. If more than 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: a) high priority groundwater dependent ecosystem; or b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan then appropriate studies (including the hydrogeology, ecological condition and cultural function) will need to demonstrate to the Minister's satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or culturally significant site. If more than 2 m decline cumulatively at any water supply work then make good provisions should apply.	There are no high priority groundwater dependent ecosystems listed in the Water Sharing Plan for Murray Darling Basin Porous Rock Groundwater Sources (Gunnedah) within 20 km of the Tarrawonga Coal Mine. The nearest high priority groundwater dependent ecosystem listed in the Water Sharing Plan to the Modification area is Tigheys Spring located approximately 68 km to the southwest of the Tarrawonga Coal Mine. There are no listed high priority culturally significant sites in the Water Sharing Plan for Murray Darling Basin Porous Rock Groundwater Sources (Gunnedah) Groundwater modelling for the Modification predicts that drawdowns at all privately-owned bores would be less than 2 m **The Modification meets the Level 1 minimal impact consideration classification.**
Water Pressure 1. A cumulative pressure head decline of not more than a 2 m decline, at any water supply work. 2. If the predicted pressure head decline is greater than requirement 1. above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long-term viability of the affected water supply works unless make good provisions apply.	Groundwater modelling for the Modification predicts that drawdowns at all privately-owned bores would be less than 2 m. **The Modification meets the Level 1 minimal impact consideration classification.**
Water Quality 1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.	There would be no change to beneficial use categories of the Permian hard rock groundwater sources as a result of the Modification. **The Modification meets the Level 1 minimal impact consideration classification.**

9 MODEL UNCERTAINTY AND SENSITIVITY

Groundwater modelling has been conducted in accordance with the Australian Groundwater Modelling Guidelines (Barnett *et al*. 2012), the MDBC Groundwater Flow Modelling Guideline (MDBC 2001) and the IESC Explanatory Note for Uncertainty Analysis (IESC 2018).

Section 8 showed that the Modification has a reduced impact compared to the Approved Case, and is therefore considered low risk. While low risk, some limitations in the model parameterisation was identified through the calibration process. Therefore, uncertainty and sensitivity of model predictions to changes in the parameters was conducted.

For the Modification, two analyses have been carried out:

- a Markov Chain Monte Carlo Uncertainty Analysis (**Section 9.1**); and
- a Sensitivity Analysis (**Section 9.2**).

The uncertainty analysis was conducted for the predictive model and the recovery model. The sensitivity analysis has been applied to the predictive model (i.e. active mining period), as the target parameter, the pit inflow from the coal seams, is expected to be highest during that time frame.

The outcomes of those two analyses can be used to assess the level of confidence of the predictive model.

9.1 Uncertainty analysis

This section presents a high-level summary of the full Uncertainty Analysis report presented in **Attachment G**, where all the technical details related to the analysis are documented.

This study addresses parameter uncertainty by stochastic modelling using the Monte Carlo method. This method operates by generating numerous alternative sets of input parameters to the deterministic groundwater flow model (realisations), executing the model independently for each realisation, excluding model runs that are exceeding the calibration standards and then aggregating the results for statistical analysis.

Table 24 presents probabilities of exceedance for peak mine inflow, baseflow impact and the number of alluvial bores affected by drawdown of 2 m or more due to mining at the Tarrawonga Coal Mine for the predictive model, covering the active mining and the recovery period.

The results show that:

- The mine inflow estimates vary by ± 20%, which indicates a high confidence level of the inflow predictions.
- The baseflow change estimates vary by ± 50%. Given the small baseflow changes (22 ML/year and 3 ML/year respectively for Goonbri and Bollol Creek, respectively) compared to the predicted baseflow losses (350 ML/year and 700 ML/year respectively for Goonbri and Bollol Creek [**Section 8.2.1**]), the changes are minor and the baseflow estimates can be classified as high confidence.

Further to the mine inflows, the uncertainty analysis has also assessed the extent of the 2 m drawdown contour. The figures for this drawdown assessment are presented in **Attachment G**. The estimated 2 m drawdown curves show good confidence in the vicinity of the Tarrawonga Coal Mine. The probability contour lines spread out to the west and north of the BTM Complex, meaning that the drawdown estimate is less certain in those areas. However, overall, the model estimates show good confidence for the drawdown.

Table 24 Probability of exceedance of peak mine inflow, baseflow impacts and the number of drawdown-affected bores

	Very likely (90%)	Likely (67%)	About as likely as not (50%)	Unlikely (33%)	Very unlikely (10%)
Peak mine inflow (Tarrawonga additional mining) (ML/year)	70.7	82.0	88.0	93.9	104.5
Peak baseflow impact (Goonbri Creek) (ML/year)	11.0	18.5	22.0	25.2	33.6
Peak baseflow impact (Bollol Creek) (ML/year)	1.6	2.4	3.0	3.4	4.6
Number of alluvial bores affected by 2m+ drawdown	0	0	0	0	1

9.2 Sensitivity analysis

The sensitivity analysis is a deterministic method to assess the impact of an input parameter on the model output. As the previously calibrated parameters were assessed by the uncertainty analysis, the sensitivity analysis focused on the spoil characteristics, namely the spoil hydraulic conductivity and recharge to the spoil and their impact on the mine inflow during the mining period. A total of four scenarios were assessed (refer to **Table 25**):

- ± 1 order of magnitude change in horizontal and vertical hydraulic conductivity (Kh and Kz) for the spoil; and
- ± 50% change in the assumed rainfall recharge rate to the spoil.

Table 25 Parameter values for sensitivity runs

Bore	Kh = Kz (m/day)	Recharge (% average annual rainfall)
Sensitivity run 1	0.1	**5%**
Sensitivity run 2	10	**5%**
Sensitivity run 3	**1**	2.5%
Sensitivity run 4	**1**	7.5%

Note: bold values indicate the values used in the predictive model

The results for the mine inflows for the four sensitivity runs compared with the Modification scenario are presented in **Figure 50**. The tabulated peak inflows are listed in **Table 26**.

Table 26 Peak mine inflows for sensitivity runs

Run	Peak Inflow (ML/year)	% change
Modification	**98.1**	
Sensitivity run 1	96.2	-4%
Sensitivity run 2	104.6	+4%
Sensitivity run 3	85.7	-14%
Sensitivity run 4	108.7	+9%

The peak mine inflows for the increased hydraulic conductivity and increased recharge result in slightly increased mine inflows of approximately 4% to 9% respectively. The reduced recharge result in a decrease in inflow of approximately 14%. A reduction in spoil conductivity resulted in lower peak mining inflows (-4%) until 2020. Overall, the spoil parameters have no significant impact on the mine inflows during the active mining period. The maximum estimated mine inflow increased from approximately 98 ML/year to 109 ML/year. During the predictive period, the modelled pit inflows are largely derived from the coal measures due to the five year delay in recovery of groundwater levels in the spoil (refer to **Section 7.1.2**).

9.3 Summary

The uncertainty and sensitivity analysis showed that the predictive model to assess the mining impacts is fit for purpose and the conclusions drawn in this study have a good level of confidence.

10 RECOMMENDATIONS

The report has shown that the Modification will have a reduction in impact on the groundwater and associated surface water compared with the Approved case. This section discusses mitigation and management strategies and proposed monitoring.

10.1 Mitigation and management

10.1.1 Groundwater users

The numerical modelling indicates that the drawdown effects on alluvial groundwater users in the vicinity of the Tarrawonga Coal Mine are not likely to be significant (that is, less than 1 m) and would not materially affect the existing or potential future beneficial use of groundwater (refer to **Section 8.1.4**). Further, this impact of the Modification up to 10 cm less compared to the Approved case.

Notwithstanding the above, it is recommended that the comprehensive groundwater monitoring program (**Section 10.2**) currently in use be continued to monitor the groundwater effects of the Modification (including triggers for investigation) and to enable contingency measures to be implemented in the event that agreed trigger levels are breached. Additional bores are suggested to monitor the potential impacts close to Goonbri Creek.

In the event that a complaint is received in relation to depressurisation of a privately-owned bore by local groundwater users, the relevant data set should be reviewed by TCPL as part of a preliminary evaluation to determine if further investigation, notification and mitigation is required.

10.1.2 Groundwater Inflows and Water licensing

Table 2 lists the current water licences held by TCPL for the Murray-Darling Porous Rock Water Sharing Plan, which consists of:

- WAL29548 (50 ML/year)
- WAL31084 (250 ML/year, including takes from open void mining)

The predicted inflows during the life of mine ranged from 58 ML/year - 99 ML/year (refer to **Table 17**) for the Modification (assumed to be from porous rock only). During the recovery period, the total inflows into the pit increase to 270 ML/year and later decrease to 226 ML/year (refer to **Table 19**). However, 80% of that inflow will incur through the backfilled spoil. The contribution from the coal seams or interburden attributed to the Murray-Darling Porous Rock Water Sharing Plan is 30 ML/year - 52 ML/year, and hence well below the current licence.

Peak licensing requirements would reduce as a result of the Modification compared to the approved Tarrawonga Coal Project.

10.2 On-going monitoring

The current groundwater monitoring program at Tarrawonga Coal Mine (TCPL, 2019) should be continued as presented in **Table 27**, which lists monitoring locations, sampling parameters and monitoring frequencies.

It is recommended that the existing Tarrawonga Coal Mine groundwater monitoring network be augmented as mining progresses to the east, as presented in **Figure 51.** The proposed additional piezometers to the east of the pit should be installed prior to 2022 in order to obtain baseline data before mining moves closer to those locations. The network of piezometers should be focused on (**Figure 51**):

- monitoring of groundwater levels and water quality in the alluvial groundwater system on the western side of Goonbri Creek (two bores suggested);
- monitoring of groundwater levels and water quality in the alluvial groundwater system on the eastern side of the Goonbri Creek to validate the predicted negligible impacts or trigger appropriate responses (one bore suggested);
- monitoring of groundwater pressures in the Porous Rock groundwater system/coal measures and to validate the predicted depressurisation effects to the east (existing VWP TA65 is considered adequate for this scope and will not be mined out, hence no additional bores suggested in the Porous Rock); and
- monitoring of groundwater levels and water quality in the mine waste rock emplacement behind the advancing pit to provide information on the recharge rates and mine waste rock spoil permeabilities and to validate modelling assumptions and predictions (two bores are suggested in the existing backfilled areas).

The final location of piezometers should include consideration of site characteristics, their location relevant to the mine plan and access. The frequency is recommended as quarterly for water levels and six-monthly for water quality (in line with monitoring schedule for existing bores, refer to **Table 27**). It is recommended to initially increase sampling frequency of water quality to quarterly for gathering baseline data for 2 years after installation.

The full suite for the six-monthly sampling will include:

- physio-chemical indicators – pH, electrical conductivity, TDS;
- major ions – calcium, fluoride, magnesium, potassium, sodium, chloride, sulphate;
- total alkalinity as $CaCO_3$, HCO_3, CO_3; and
- dissolved and total metals – aluminium, arsenic, barium, boron, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, strontium, silver, vanadium and zinc.

Monitoring of the mine inflows into the pit should be continued as stipulated in the Tarrawonga Coal Mine Water Management Plan and reported in the Annual Reviews.

Table 27 Groundwater monitoring points and sampling frequency

Site ID	Registered Bore No. & Licence No.	Frequency SWL, EC, pH	Frequency Representative Metals and Ions	Purpose
MW1	GW967848 90BL253276	Quarterly	Six-monthly	To determine existing status and any impacts
MW2	GW967849 90BL253278	Quarterly	Six-monthly	
MW3	GW967860 90BL253841	Quarterly	Six-monthly	
MW4	GW967850 90BL253279	Quarterly	Six-monthly	
MW5	GW967851 90BL253280	Quarterly	Six-monthly	
Templemore A	NA	Quarterly	Six-monthly	
Templemore B	NA	Quarterly	Six-monthly	
GW031856	GW031856 90WA809087	Quarterly	Six-monthly	
GW052266	GW052266 90BL116929	Quarterly	Six-monthly	
TA65	NA 90BL255930	Continuous	Nil	VWP to observe drawdown in coal seams and interburden
Proposed Bore Spoil 1		Quarterly	Six-monthly	Observe recovery in Mine Waste Rock
Proposed Bore Spoil 2		Quarterly	Six-monthly	Observe recovery in Mine Waste Rock
Proposed Bore Alluvium 1		Quarterly	Six-monthly	Observe status and any impacts in the alluvium
Proposed Bore Alluvium 2		Quarterly	Six-monthly	Observe status and any impacts in the alluvium
Proposed Bore Alluvium 3		Quarterly	Six-monthly	Observe status and any impacts in the alluvium

REFERENCES

Advisian (2018) Vickery Extension Project Surface Water Assessment. Prepared for Whitehaven Coal Limited.

Australian and New Zealand Environment and Conservation Council (ANZECC) (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality.

Australian Bureau of Agricultural and Resource Economics and Sciences (2006) Performance of Farms in the North West Slopes and Plains of New South Wales.

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) (2010) Continuation of Boggabri Coal Mine Groundwater Assessment. Report prepared for Boggabri Coal Pty Limited.

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) (2018). Report on Boggabri, Tarrawonga, Maules Creek Complex Numerical Model Update. Prepared for Boggabri Coal Operations Pty Ltd, Project No. G1850A August 2018.

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.

Bureau of Meteorology, 2019: Bureau of Meteorology (BoM) (2019) Climate Data Online (Evaporation Maps). Website: http://www.bom.gov.au/jsp/ncc/climate_averages/evapotranspiration/index.jsp, Date Accessed: May 2019.

Coxhead, C. (2009) Coal Resource Report for the Tarrawonga Open Cut Coal Mine and Adjacent Exploration Area, Gunnedah Coalfield, NSW, Australia. Report prepared for Whitehaven Coal Limited.

Department of Land and Water Conservation (DLWC) (1998) NSW State Groundwater Quality Protection Policy.

Department of Land and Water Conservation (DLWC) (2002) NSW State Groundwater Dependent Ecosystems Policy.

Department of Industry - Water (2012) Aquifer Interference Policy. September 2012.

Department of the Environment (DoE) (2013) Significant impact guidelines 1.3: Coal seam gas and large coal mining developments— impacts on water resources.

Doherty, J. (2018). PEST: Model-Independent Parameter Estimation User Manual Part I: PEST. SENSAN and Global Optimisers (7th ed.): Watermark Numerical Computing, Brisbane, Queensland, Australia.

Douglas Partners (2010) Report on Hydrogeological Assessment for Rocglen Coal Mine Extension Project. Report prepared for Whitehaven Coal Limited.

Hatton, T. and Evans, R. (1998) Dependence of Ecosystems on Groundwater and Its Significance to Australia. LWRDC Occasional Paper No 12/98.

Heritage Computing Pty Ltd (2011) A Hydrogeological Assessment in Support of the Tarrawonga Coal Project Environmental Assessment. Report HC2011/11 prepared for Tarrawonga Coal Pty Ltd.

Hydro Engineering and Consulting (2019): Tarrawonga Coal Mine Life of Mine Modification Surface Water Assessment and Site Water Balance. Report prepared for Whitehaven Coal Limited.

McNeilage, C. (2006) Upper Namoi Groundwater Flow Model: Model Development and Calibration. NSW Department of Natural Resources, draft report.

Minarco-Mineconsult (2011) Tarrawonga Open Cut Coal Mine 2011 Life of Mine Plan.

Murray Darling Basin Commission (MDBC) (2005). National Land and Water Resources Audit.

NSW Office of Water (2010) Upper Namoi Groundwater Sources: Resource Condition Assessment Report – 2010.

Panday, S., Langevin, C.D., Niswonger, R.G., Ibaraki, Motomu, and Hughes, J.D. (2013) MODFLOW–USG version 1: An unstructured grid version of MODFLOW for simulating groundwater flow and tightly coupled processes using a control volume finite-difference formulation: U.S. Geological Survey Techniques and Methods, book 6, chap. A45.

Parsons Brinkerhoff (2005), 'Boggabri Coal Project – Groundwater Assessment, December 2005', for Idemitsu Boggabri Coal Pty Ltd.

Rau, G. C., Acworth, R. I., Halloran, L. J. S., Timms, W. A., & Cuthbert, M. O. (2018). Quantifying compressible groundwater storage by combining cross-hole seismic surveys and head response to atmospheric tides. Journal of Geophysical Research: Earth Surface, 123, 1910– 1930. https://doi.org/10.1029/2018JF004660.

RCA Australia (2005) Groundwater Assessment of the Proposed East Boggabri Coal Mine.

RCA Australia (2007) Groundwater Monitoring Report, Tarrawonga Coal Mine.

Resource Strategies (RS) 2011. Tarrawonga Coal Project Agricultural Resources and Productivity Assessment. October 2011, Project No. WHC-10-04 Document No. 00414552.doc.

RPS Aquaterra (2011) Tarrawonga Groundwater Field Investigation Program.

SLR Consulting (SLR) 2019. Alluvial Boundary Assessment, Tarrawonga Coal Mine. Report Number 634.10042, July 2019.

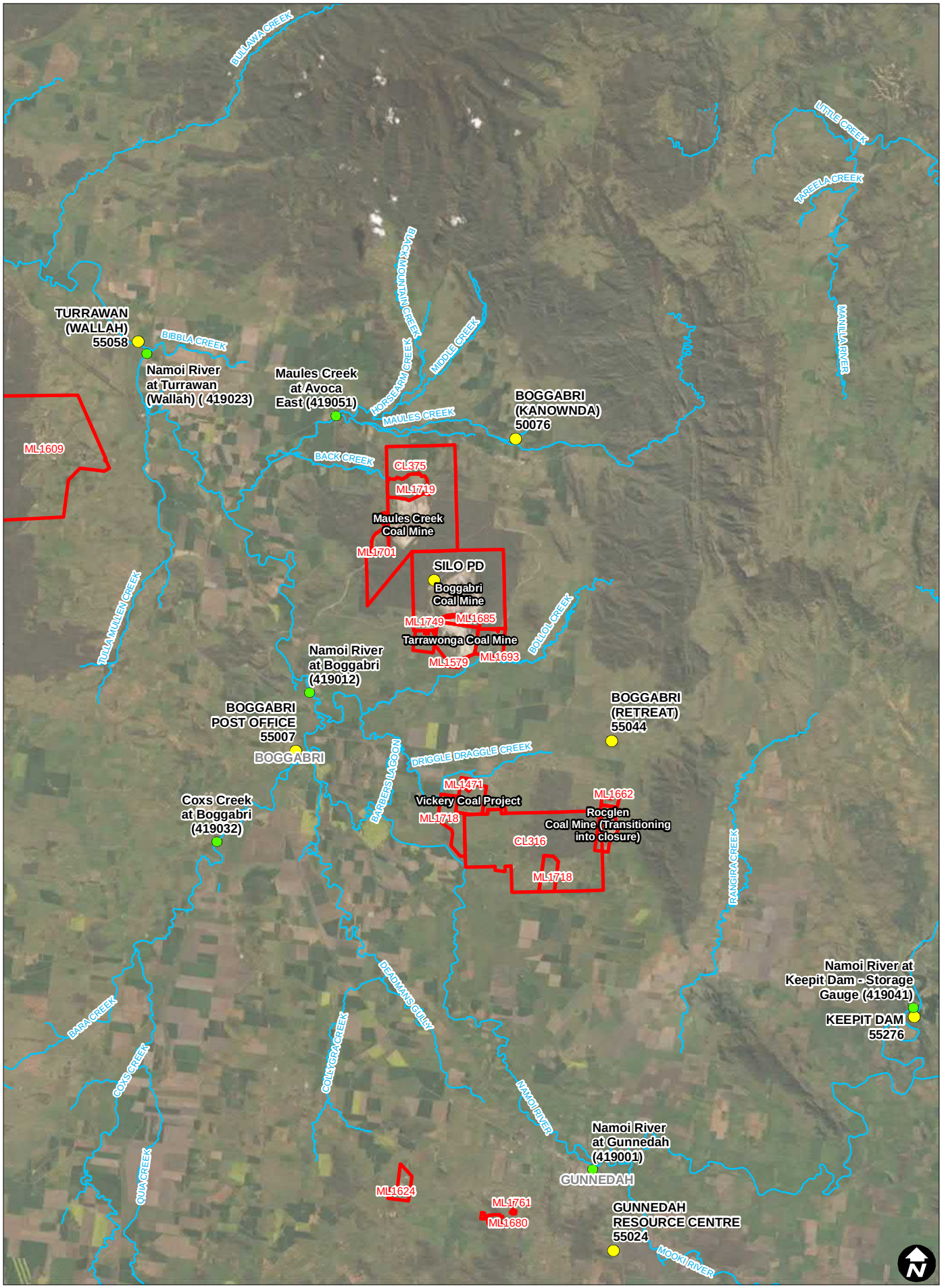
State of Queensland, 2018. SILO (Scientific Information for Land Owners) database of Australian climate data. © The State of Queensland 2018, https://silo.longpaddock.qld.gov.au/.

Tadros N Z (1995), Structure and Tectonics of the Gunnedah Basin, NSW: implications for stratigraphy, sedimentation and coal resources, with emphasis on the Upper Black Jack group. PhD thesis, Department of Geology, University of Wollongong, 1995. http://ro.uow.edu.au/theses/840

Tarrawonga Coal Pty Limited (2018) Tarrawonga Water Management Plan.

Tarrawonga Coal Pty Limited (2019), Tarrawonga Coal Mine, Annual Review 2018.

FIGURES



Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

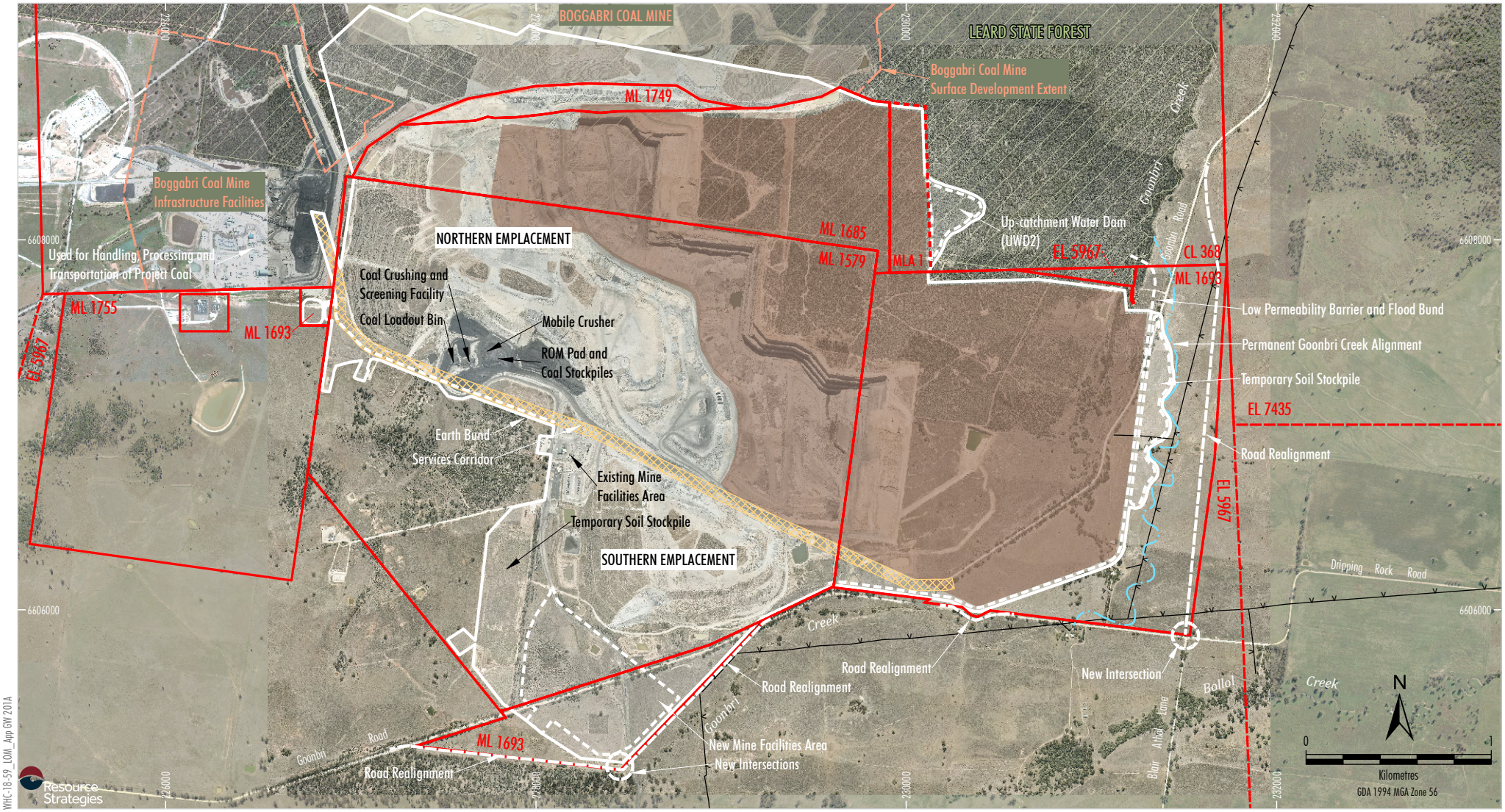
HYDRO SIMULATIONS

LEGEND

- Surface Water Gauging Stations
- Climate Stations
- Watercourses
- Mining Leases

Project location, topography and climate stations

FIGURE 1



LEGEND

- Mining Lease Boundary (ML & CL)
- Mining Lease Application Boundary (MLA 1)
- Exploration Licence (EL)
- 11kV Electricity Transmission Line
- 11kV Electricity Transmission Line Realignment
- Leard State Forest
- Approximate Extent of Approved Surface Development
- Approximate Extent of Approved Open Cut

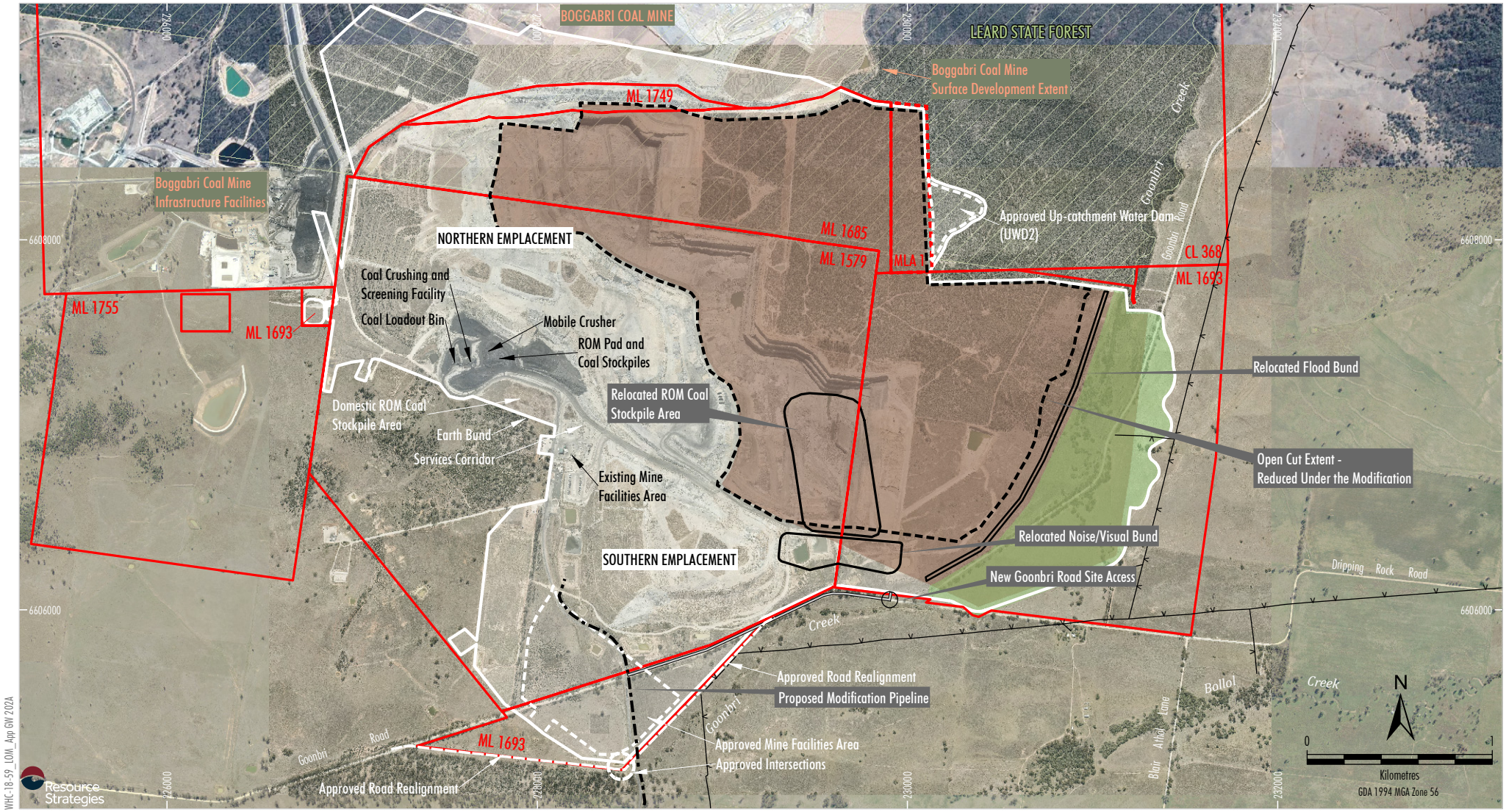
Source: © State of New South Wales and Department of Planning and Environment (2017); © Department Finance, Services & Innovation (2017); Whitehaven Coal (2017); Orthophoto: Whitehaven Coal (2018)

WHITEHAVEN COAL

TARRAWONGA COAL MINE

Approved General Arrangement

Figure 2



LEGEND

- Mining Lease Boundary (ML & CL)
- Mining Lease Application Boundary (MLA 1)
- 11kV Electricity Transmission Line
- 11kV Electricity Transmission Line Realignment
- Leard State Forest
- Approximate Extent of Approved Surface Development
- Approximate Extent of Approved Open Cut
- Modification Open Cut Extent
- Approved Surface Development Area - No Longer Proposed
- Modification ROM Coal Transport Route Along Goonbri Road
- Indicative Location of Modification Pipeline

Source: © State of New South Wales and Department of Planning and Environment (2017); © Department Finance, Services & Innovation (2017); Whitehaven Coal (2018); Orthophoto: Whitehaven Coal (2018); Google (2018)

WHITEHAVEN COAL

TARRAWONGA COAL MINE

Indicative Modification General Arrangement

Figure 3

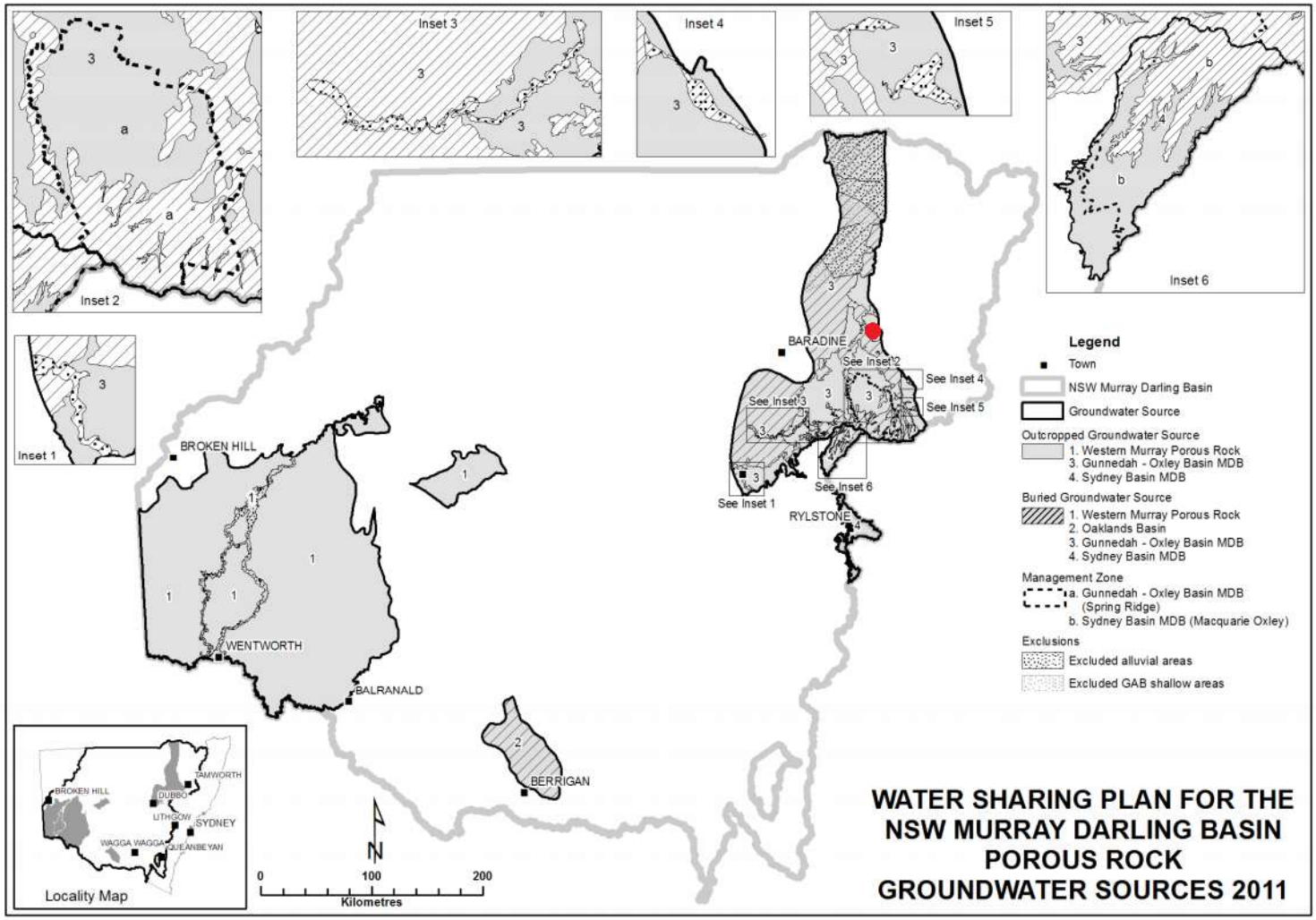


Figure 4 Water Sharing Plan for the NSW Murray Darling Porous Rock Groundwater Sources

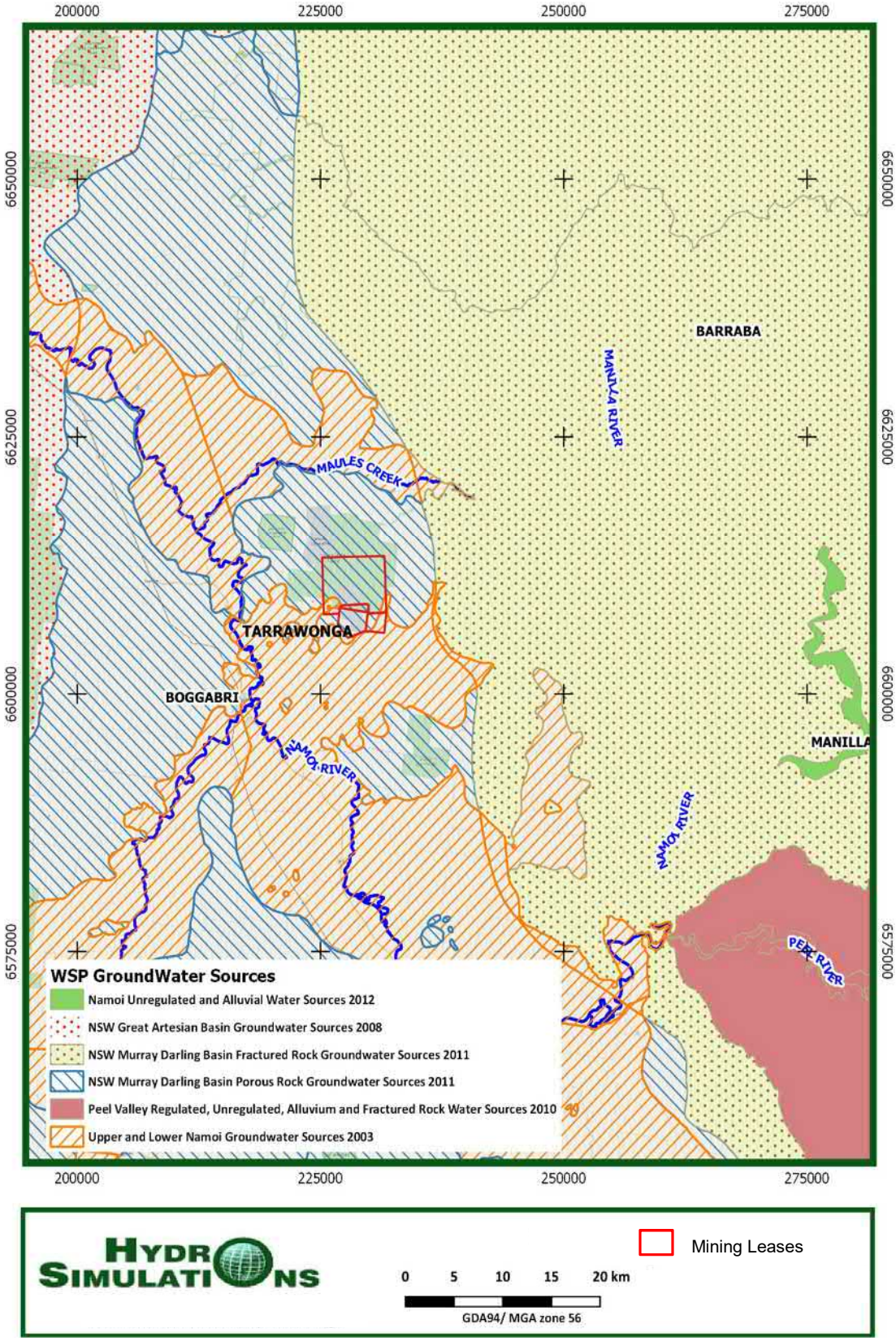


Figure 5 Regional Water Sharing Plans

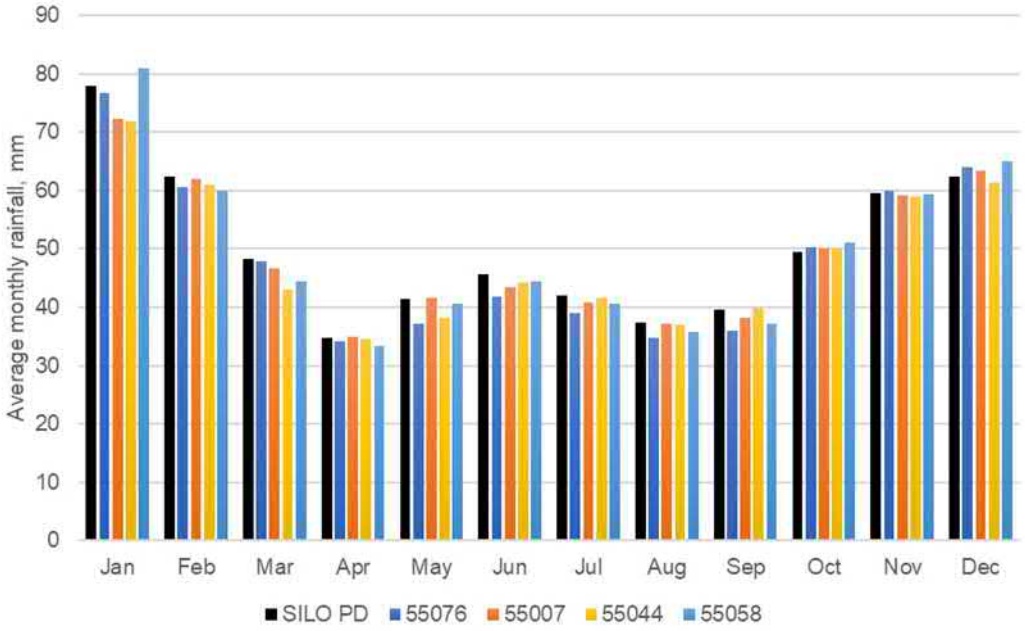


Figure 6 Average Monthly Rainfall at selected stations

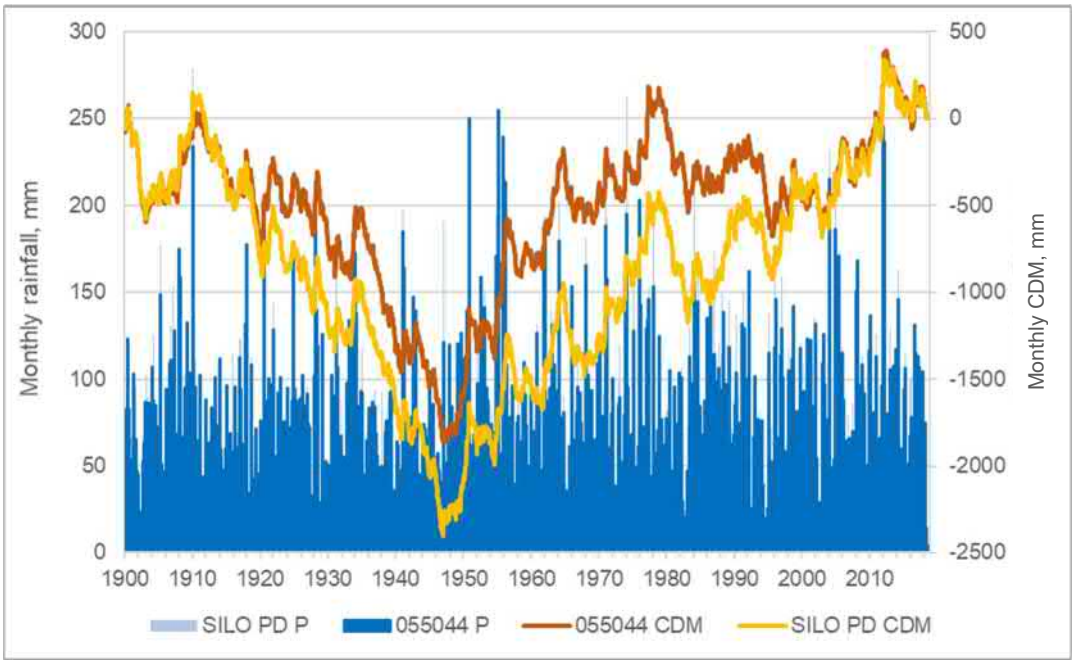


Figure 7 Long-term rainfall and cumulative rainfall deficit

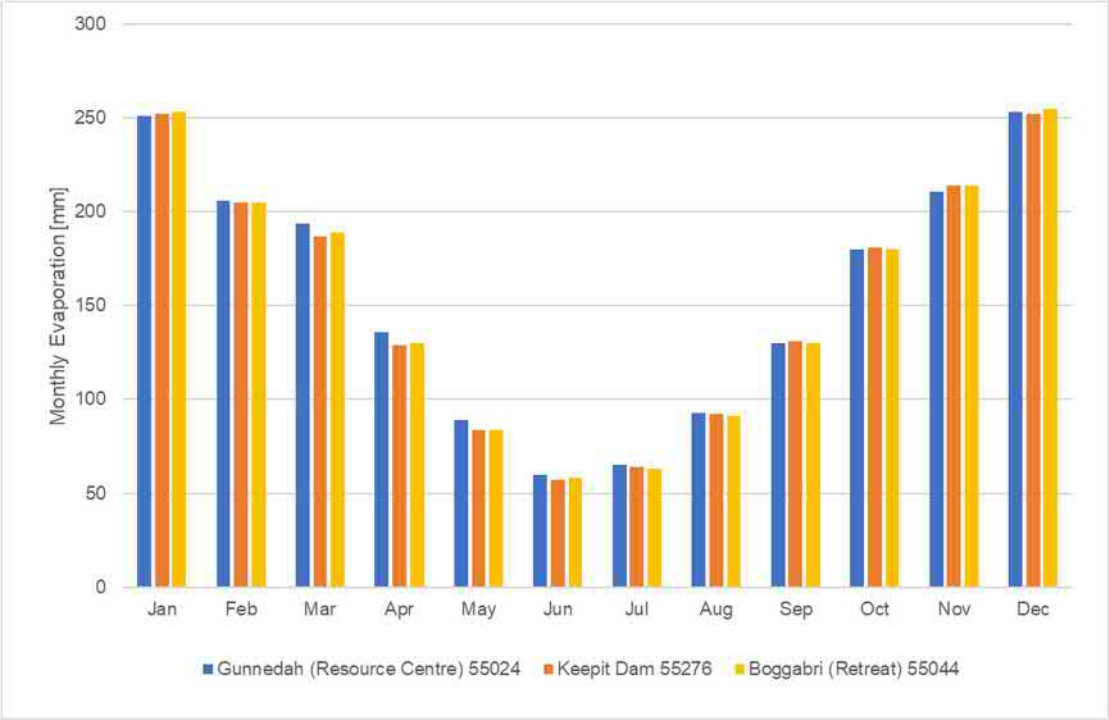
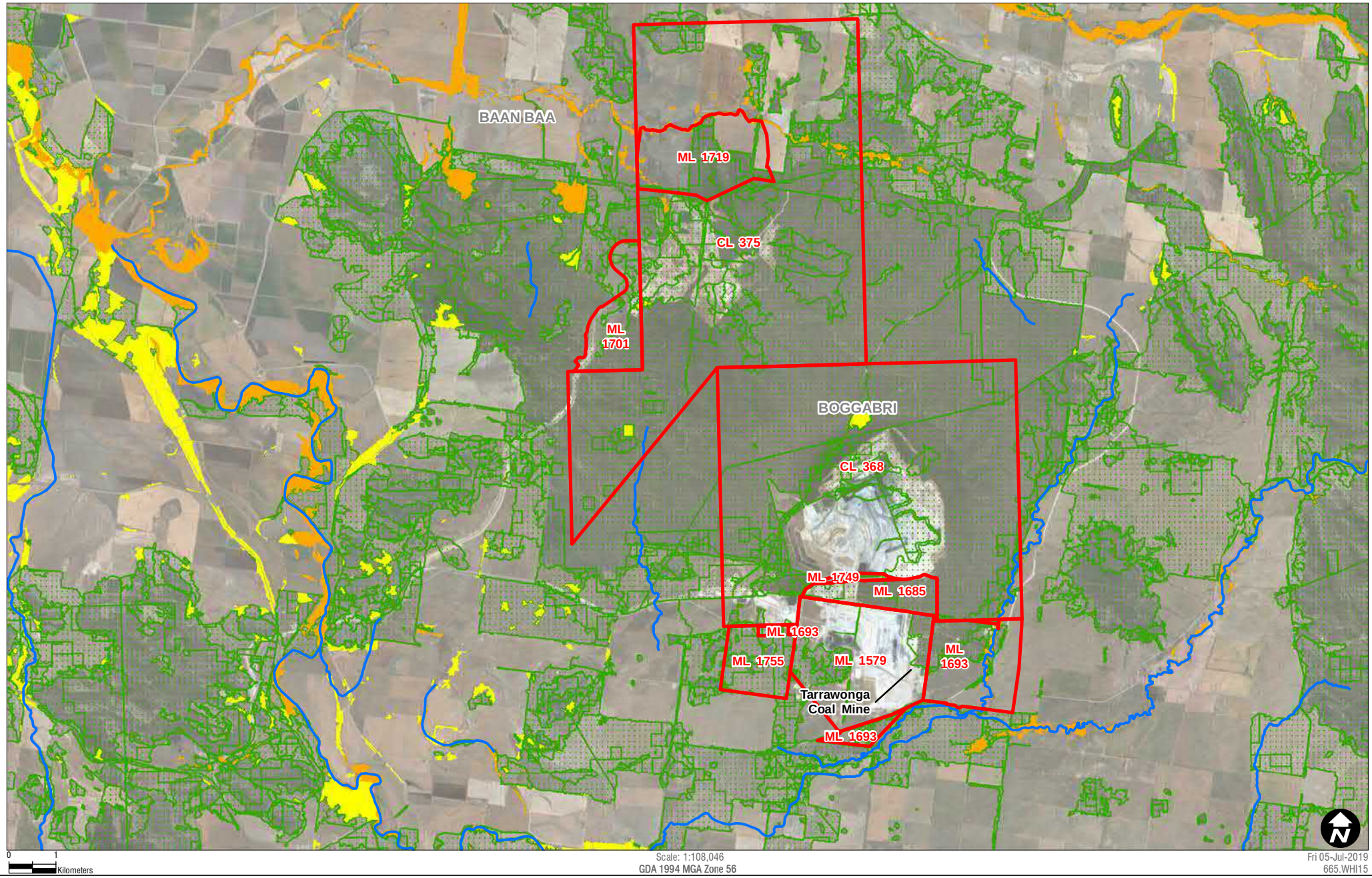


Figure 8 Average Monthly Pan Evaporation



Scale: 1:108,046
GDA 1994 MGA Zone 56

Fri 05-Jul-2019
665.WHI15

LEGEND

Mining Leases
Waterways

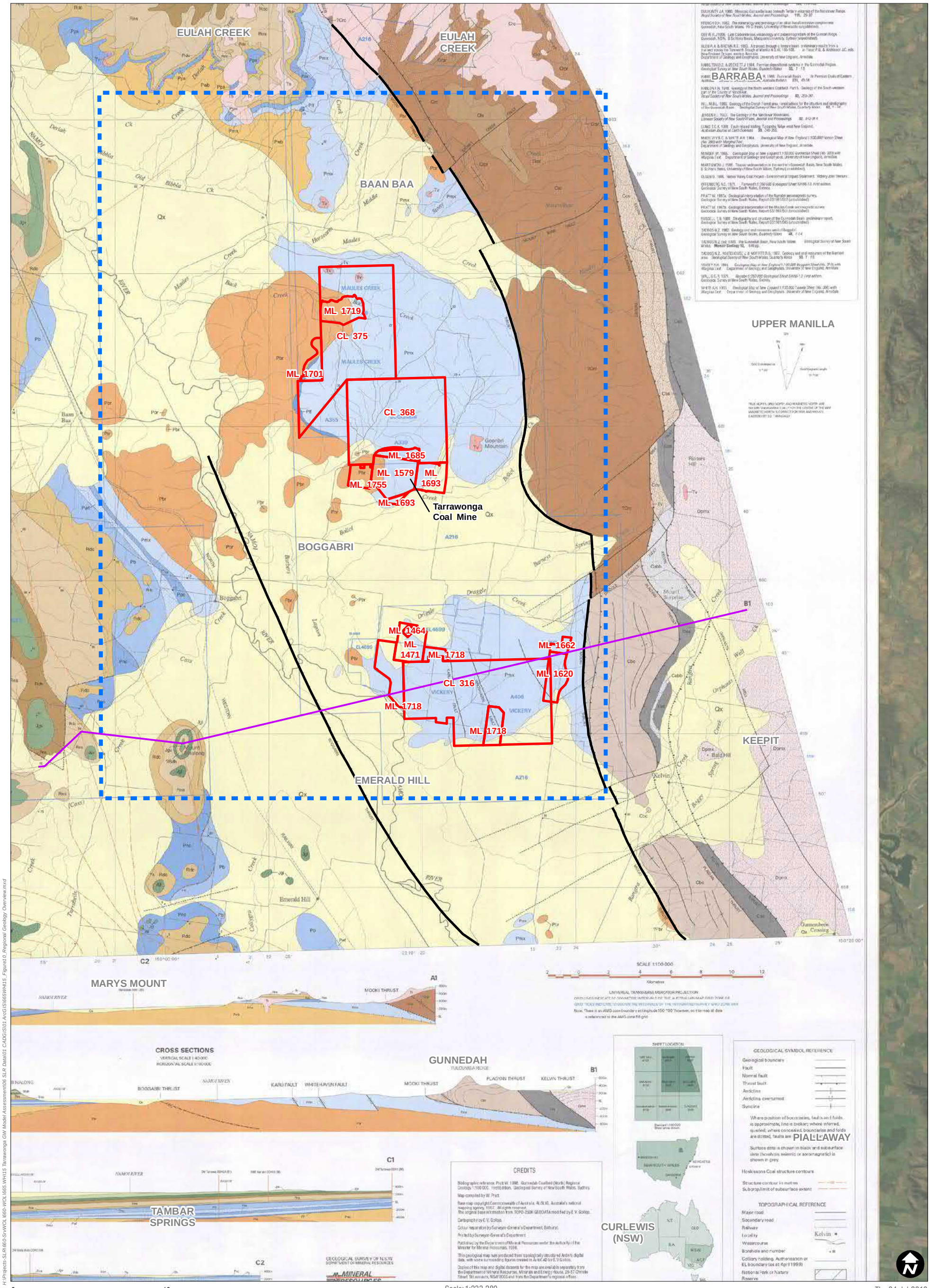
Potential GDE

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

HYDRO SIMULATIONS

Groundwater dependent ecosystems and surface water catchments

FIGURE 9



LEGEND

- Mining Leases
- Model Extent
- Cross Section
- Faults

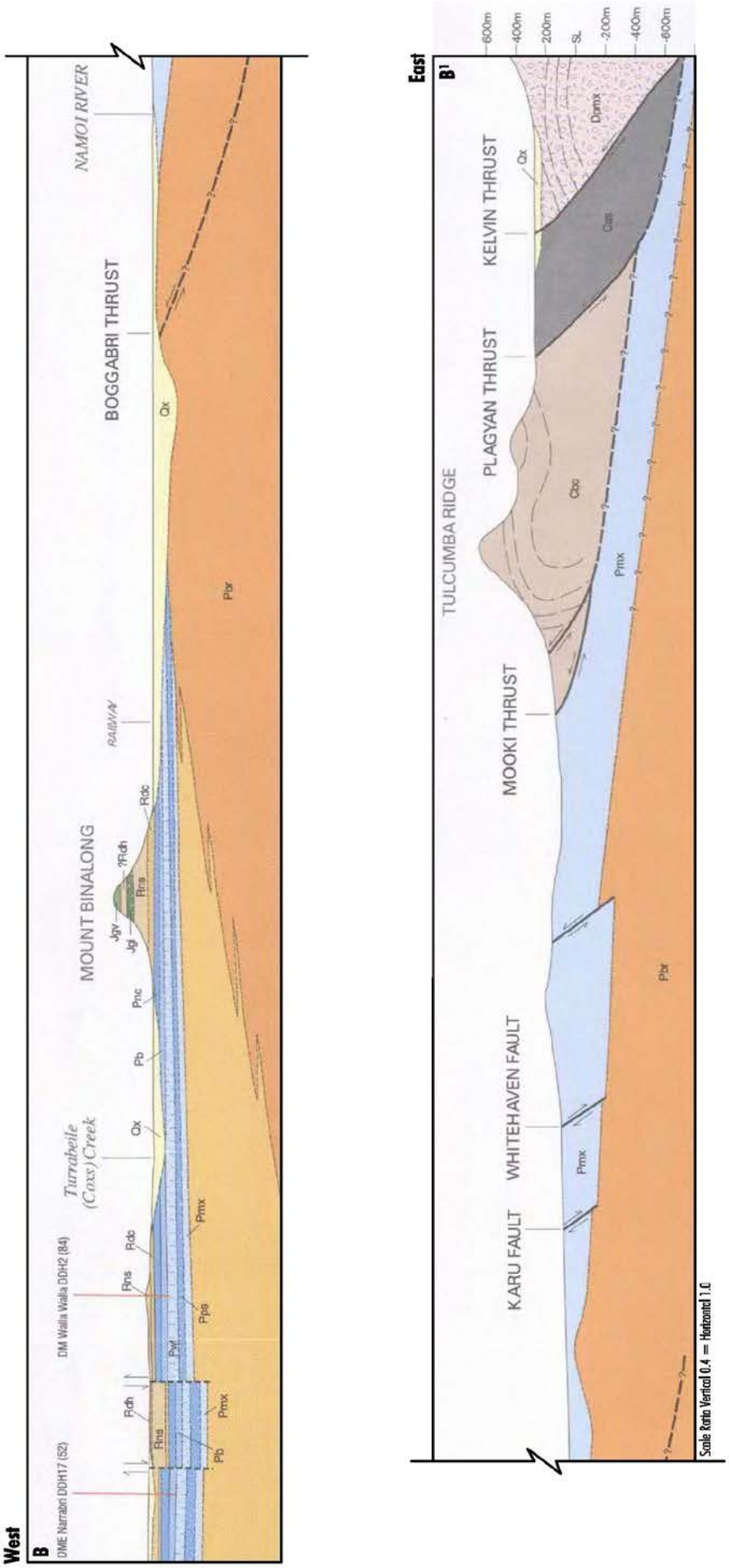
HYDRO SIMULATIONS

Regional Geology Overview

Source: Department of Primary Industries - Gunnedah Coalfield North 100k (2011)

FIGURE 10

H:\Projects-SLR\660-SnWOL\660-WOL\665.WHI15 Tarrawonga GW Model Assessment\06 SLR Data\01 CADGIS\01 ArcGIS\665WHI15_Figure10_Regional Geology Overview.mxd



31-May-2019
665.WHI15

HYDRO SIMULATIONS

Regional Geology Cross Sections

FIGURE 11

\\au.sir.local\Corporate\Projects-SLR\660-SrvWOL\660-WOL665 WHI15 Tarawonga GW Model Assessment\06 SLR Data\01 CAD\GIS\01 ArcGIS\665WHI15_Figure11_Regional Geology Cross Sections.mxd

REFERENCE

Era		Period		Stratigraphy: Group		Stratigraphy: Formation	Symbol	Lithology
CAINOZOIC		QUATERNARY				undifferentiated sediments	Qx	Undifferentiated alluvial deposits; includes Holocene alluvial channels and overbank deposits of sand silt and clay. Generally does not include residual and veneer colluvial deposits
CAINOZOIC		TERTIARY				undifferentiated sediments	Ts	Sand, sandstone, pebble sandstone, pebble to cobble gravels, and tuffs
CAINOZOIC		TERTIARY				Nandewar Volcanic Complex	Tn	Basalt, dolerite, teschenite, nephelinite or trachyte sills, dykes, plugs and flows
CAINOZOIC		TERTIARY				undifferentiated volcanics	Tv	Basalt, dolerite, teschenite, nephelinite or trachyte sills, dykes, plugs and flows
MESOZOIC	Surat Basin Units	JURASSIC				Orallo Formation	Jpo	Fine to coarse grained labile to sub-labile clayey sandstone with interbedded siltstone and mudstone
MESOZOIC	Surat Basin Units	JURASSIC				Pilliga Sandstone	Jps	Quartz pebble and quartzose sandstone with minor lithic sandstone and siltstone
MESOZOIC	Surat Basin Units	JURASSIC				Purlawaugh Formation	Jpx	Thin bedded lithic labile sandstone interbedded with siltstone and mudstone
MESOZOIC	Surat Basin Units	JURASSIC				Glenrowan Intrusives	Jgi	Sills and dykes of alkali dolerite and micro-syenodolerite
MESOZOIC	Surat Basin Units	JURASSIC				Garrawilla Volcanics	Jgv	Vesicular and non-vesicular, alkali olivine basalt, alkali basalt, hawaiite, mugearite, soda trachyte and interbedded pyroclastics
PALAEOZOIC	Gunnedah Basin Units	TRIASSIC	MIDDLE			Deriah Formation	Rdh	Fine to medium grained lithic sandstone rich in volcanic fragments with common mudstone clasts overlain by off-white lithic sandstone and dark grey mudstone
PALAEOZOIC	Gunnedah Basin Units	TRIASSIC	MIDDLE			Napperby Formation	Rns	Coarsening-up sequences of dark-grey siltstone/sandstone laminite overlain by parallel bedded or low-angle crossbedded quartzose sandstone
PALAEOZOIC	Gunnedah Basin Units	TRIASSIC	EARLY			Digby Formation	Rdc	Poorly sorted volcanic-lithic pebble orthoconglomerate overlain by massive, parallel or cross bedded coarse to fine grained quartz-lithic and then quartzose sandstone
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Black Jack Group	Nea Subgroup	Trinkey Formation	Pnc	Claystone, siltstone and fine grained sandstone intercalated with tuff, carbonaceous claystones and tuffaceous stony coal seams
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Black Jack Group	Nea Subgroup	Wallala Formation	Pnc	Fining up sequence of dominant lithic conglomerate, sandstone, siltstone, claystone and coal with minor tuff and tuffaceous sediments
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Black Jack Group	Coogal Subgroup	Clare Sandstone	Pnc	Medium bedded, cross stratified medium to coarse grained quartzose sandstone. Quartzose conglomerate locally developed
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Black Jack Group	Coogal Subgroup	Benalabri Formation	Pnc	Interbedded claystone, siltstone and fine grained quartzose sandstone and coal
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Black Jack Group	Coogal Subgroup	Hoskissons Coal	Pnc	Coal with subordinate layers of fine grained sandstone, carbonaceous siltstone and claystone, and tuff
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Black Jack Group	Brothers Subgroup	Brigalow Formation	Pnc	Fining-up sequence of medium grained quartzose sandstone and siltstone
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Black Jack Group	Brothers Subgroup	Arkarula Formation	Pnc	Fining-up sequence of fine-medium lithic sandstone and siltstone with worm burrows
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Black Jack Group	Brothers Subgroup	Pamboola Formation	Pb	Lithic sandstone, siltstone, claystone, conglomerate and intercalated coals in generally coarsening-up and sporadic fining-up sequences
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Millie Group		Watermark Formation	Pwf	Fining-up sequence of intensely bioturbated silty sandstone to sandstone/claystone laminite with marine fossils overlain by finely laminated siltstone/claystone with little bioturbation, then by coarsening-up sequences of strongly bioturbated silty to sandy laminite
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Millie Group		Porcupine Formation	Ppa	Basal conglomerate passing upward into bioturbated silty sandstone and minor siltstone with dropped pebbles
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	EARLY	Bellata Group		Maules Creek Formation	Pmx	Basal carbonaceous claystone, pelletoidal clay sandstone, passing into fining-up cycles of sandstone, siltstone and coal. Conglomerate dominant towards top
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	EARLY	Bellata Group		Goonbri Formation	*	Carbonaceous siltstone and thin coal grading upwards to fine to medium sandstone
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	EARLY	Bellata Group		Leard Formation	Plf	Buff coloured flint (pelletoidal) claystone, conglomerate, sandstone and siltstone
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	EARLY	Bellata Group		Werrie Basalt	Pwb	Basaltic lavas with intervening palaeosols and local thin coals
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	EARLY	Bellata Group		Boggabri Volcanics	Pbr	Rhyolitic to dacitic lavas and ashflow tuffs with interbedded shale. Rare trachyte and andesite
PALAEOZOIC	New England Orogen Units	CARBONIFEROUS	LATE			Currabubula Formation	Cbc	Paraconglomerate, orthoconglomerate, crossbedded feldspathic and lithic sandstone, siltstone, mudstone and minor limestone. Felsic ashflow and airfall tuff, rhyolitic to andesitic crystal and vitric tuff
PALAEOZOIC	New England Orogen Units	CARBONIFEROUS	LATE			Lark Hill Formation	Cls	Feldspathic arenite, litharenite, subordinate orthoconglomerate and paraconglomerate, siltstone, rhyodacite, and dacitic ashflow and airflow tuff
PALAEOZOIC	New England Orogen Units	CARBONIFEROUS	LATE			Rocky Creek	Crc	Orthoconglomerate, minor feldspathic arenite and litharenite, siltstone and intermediate ashflow tuff
PALAEOZOIC	New England Orogen Units	CARBONIFEROUS	LATE			Plagyan Rhyodacite Tuff Member	Crpt	Multiple beds of rhyolitic to andesitic crystal and vitric tuff
PALAEOZOIC	New England Orogen Units	CARBONIFEROUS	LATE			Conglomerate	Ccs	Crossbedded feldspathic and lithic sandstones, subordinate conglomerate, shale, rhyodacitic and dacitic airfall tuffs
PALAEOZOIC	New England Orogen Units	CARBONIFEROUS	LATE			Clifden Formation		
PALAEOZOIC	New England Orogen Units	CARBONIFEROUS	EARLY			Caroda Formation: Barneys Spring Andesite Member	Cabb	Porphyritic andesite
PALAEOZOIC	New England Orogen Units	CARBONIFEROUS	EARLY			Caroda Formation	Cas	Crossbedded sandstone, minor lenticular oolitic limestone and magnetite sandstone, succeeded by coarse fluvial litharenite, conglomerate, shale, thin coal
PALAEOZOIC	New England Orogen Units	DEVONIAN	LATE	Parry Group		Mostyn Vale Formation	Dpmx	Pebbly lithic wacke, diamictite, lithic wacke, orthoconglomerate, olistostromal volcanic breccia, rhyodacitic to basaltic lavas, tuffs, agglomerates, rare limestones

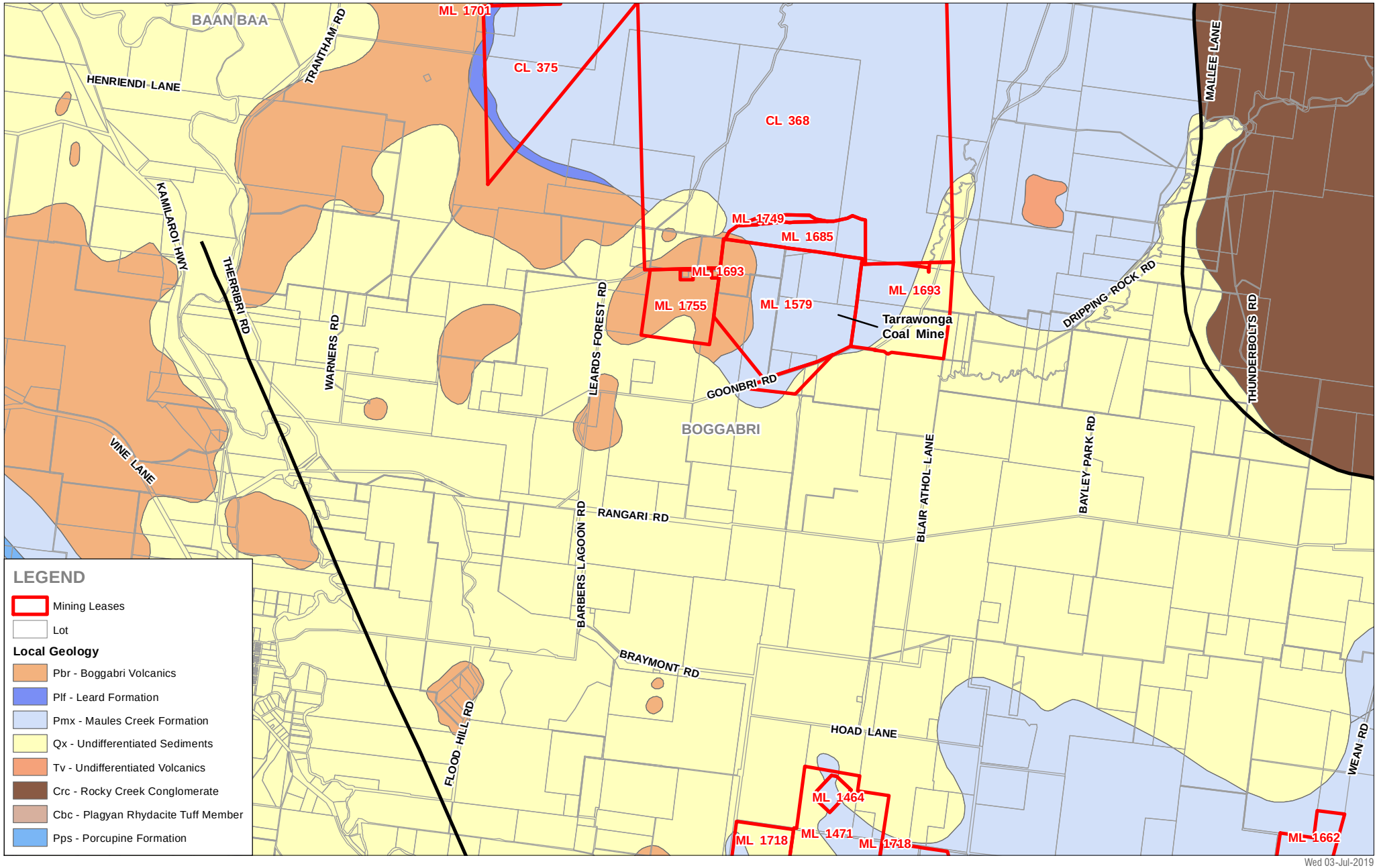
* Known only from borehole data

31-May-2019
665.WHI15

Regional Geology Legend

FIGURE 12

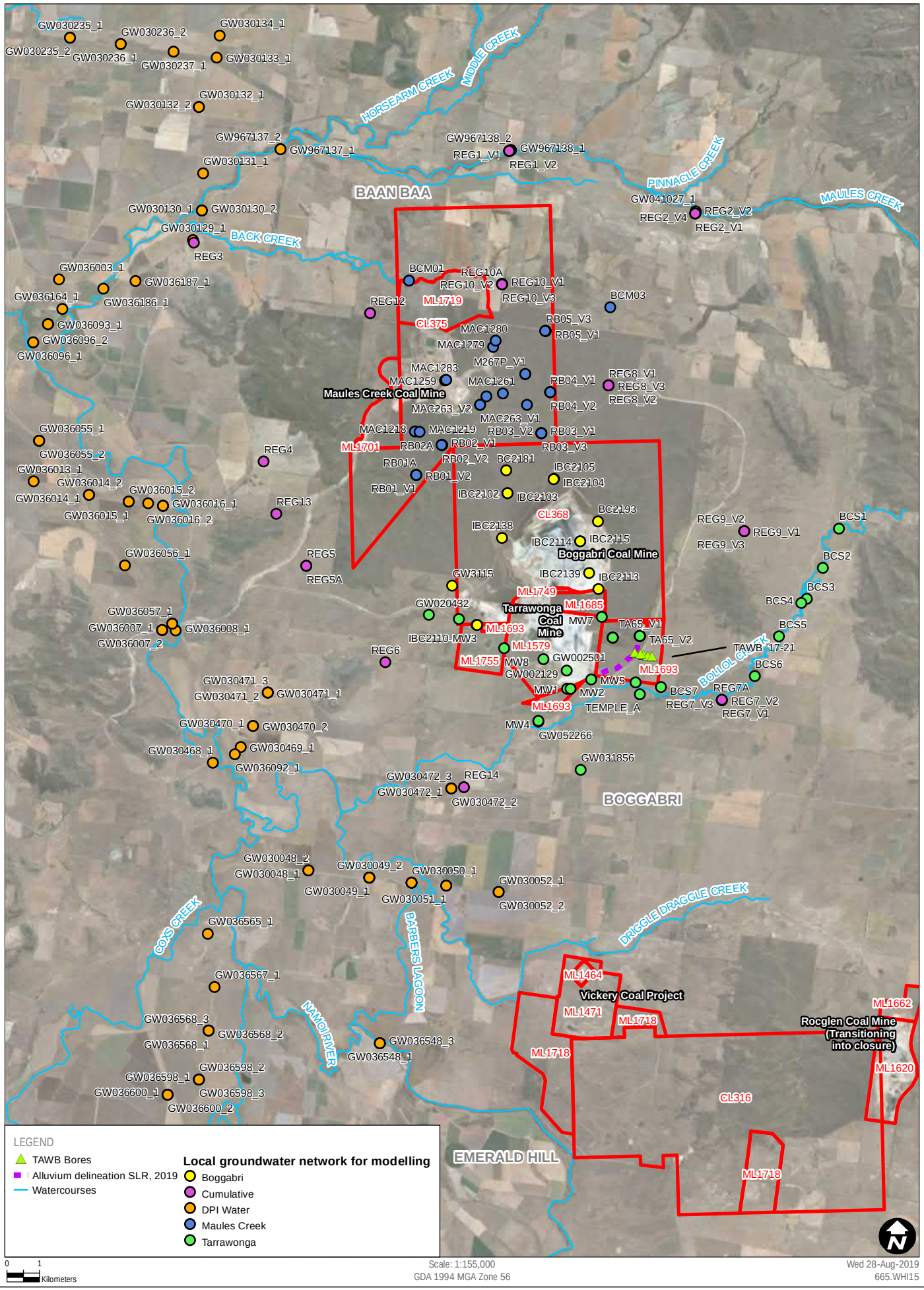
\\au.sir.local\Corporate\Projects-SLR\660-SnWOL\660-WOL665 WHI15 Tarawonga GW Model Assessment\06 SLR Data\01 CADGIS\01 ArcGIS\665WHI15_Figure12_Regional Geology Legend.mxd



HYDRO SIMULATIONS

Local Geology

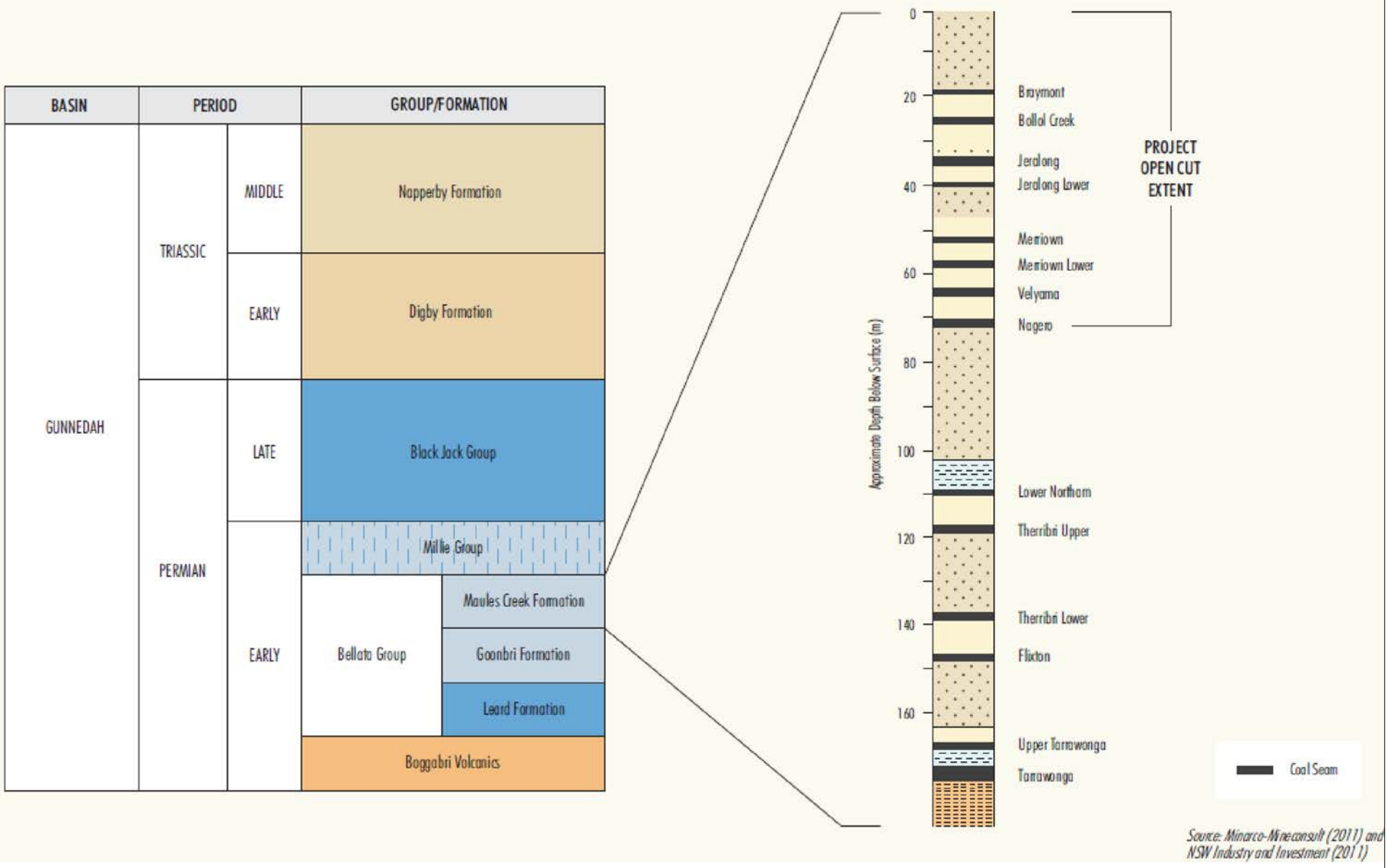
FIGURE 13



Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Local groundwater network for modelling

FIGURE 14



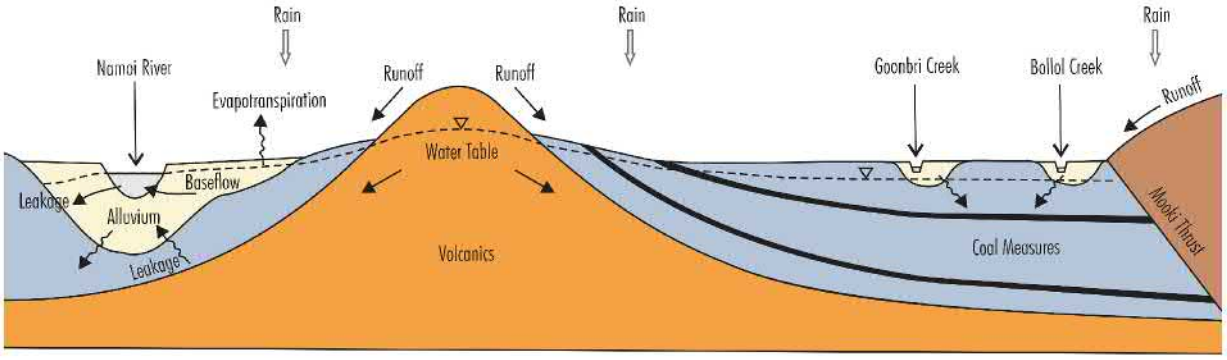
\\au.slr.local\Corporate\Projects-SLR\660-SrvWOL\660-WOL\665.WHI15 Tarrawonga GW Model Assessment\06 SLR Data\01 CADGIS\01 ArcGIS\665WHI15_Figure15_Local Stratigraphy.mxd

Wed 03-Jul-2019
620.WHI15

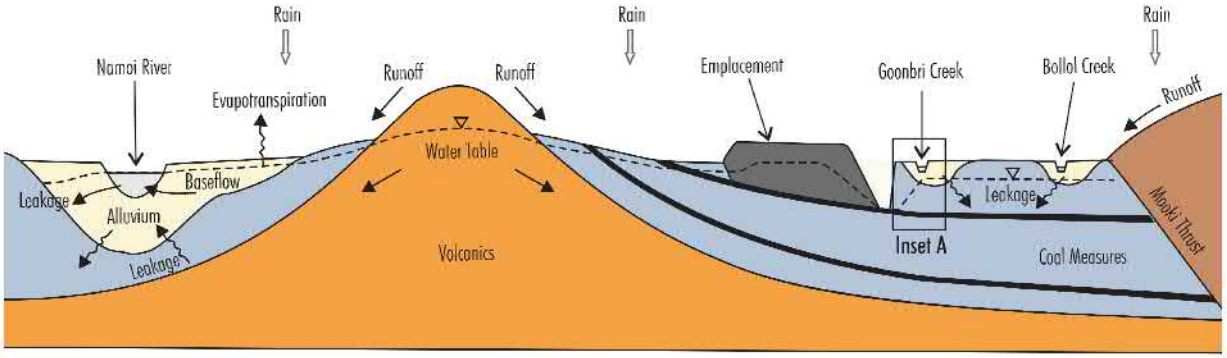
HYDRO SIMULATIONS

Local Stratigraphy

FIGURE 15



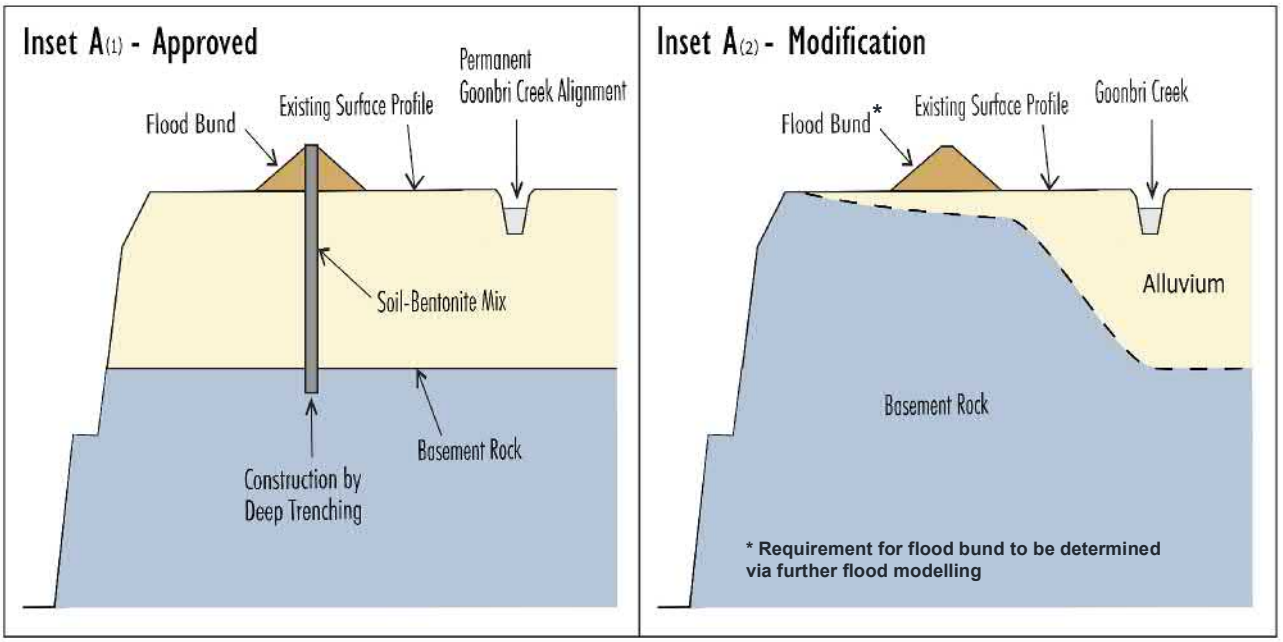
Conceptual Model Prior to Mining



LEGEND

- Alluvium - Undifferentiated Sediments
- Maules Creek Formation
- Boggabri Volcanics
- Rocky Creek Conglomerate

Conceptual Model Towards the End of Mining
(Approved Scenario Shown)



H:\Projects-SLR\660-SydWOL\660-WOL\665 WHI 5 Tarrawonga GW Model Assessment\06 SLR Data\01 CADD\S01 ArcGIS\665WHI15_Figure16_Conceptual groundwater models.mxd

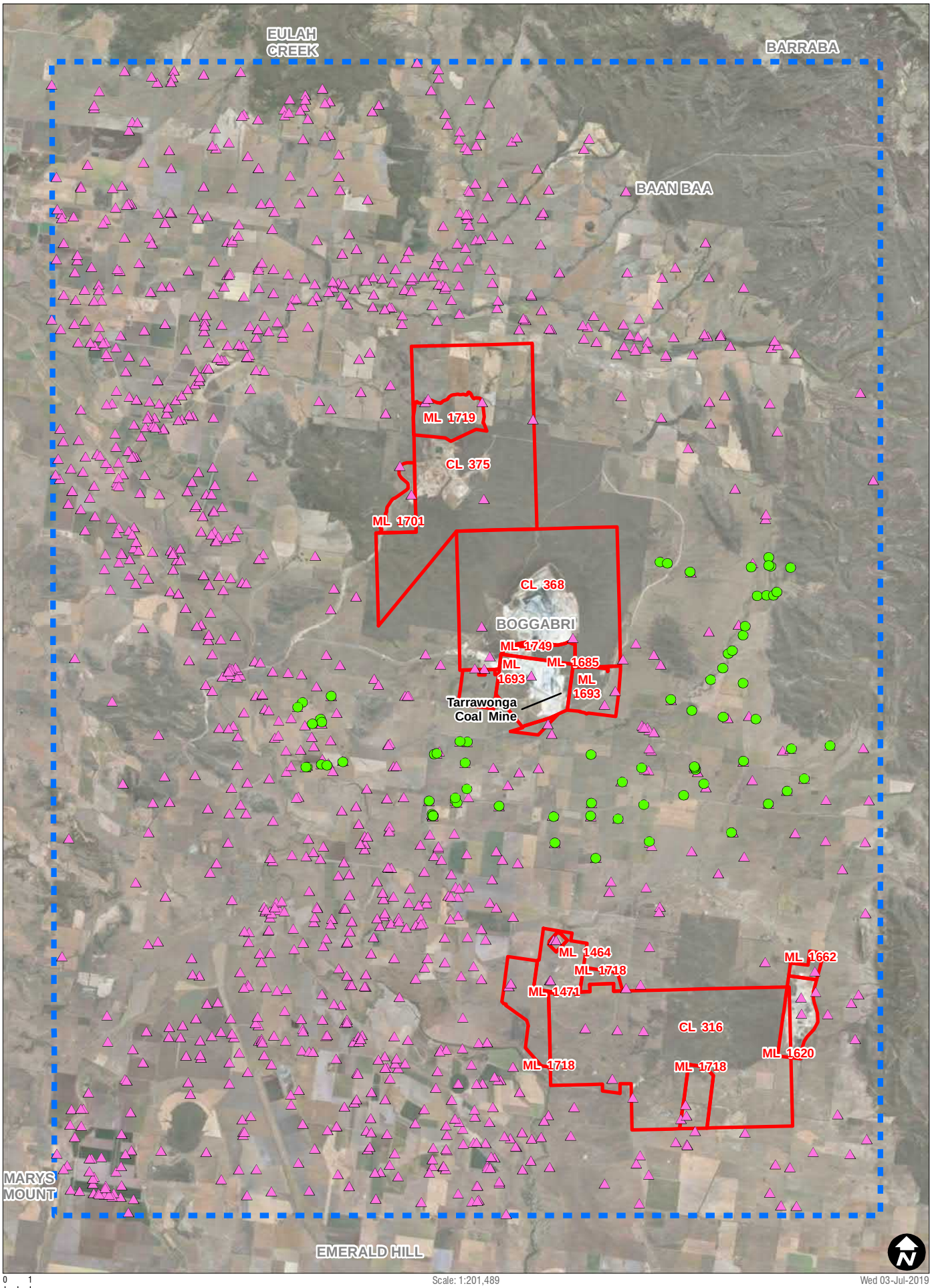
Thu 26-Sep-2019
665.WHI15

Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Conceptual groundwater models

HYDRO SIMULATIONS

FIGURE 16



0 1 Kilometers

Scale: 1:201,489
GDA 1994 MGA Zone 56

Wed 03-Jul-2019
665.WHI15

\\au.sir.local\Corporate\Projects-SLR\660-Sry\WOL\665.WHI15 Tarrawonga GW Model Assessment\06 SLR Data\01 CAD\GIS\01 ArcGIS\665WHI15_Figure17_Regional groundwater bore data base (2011).mxd

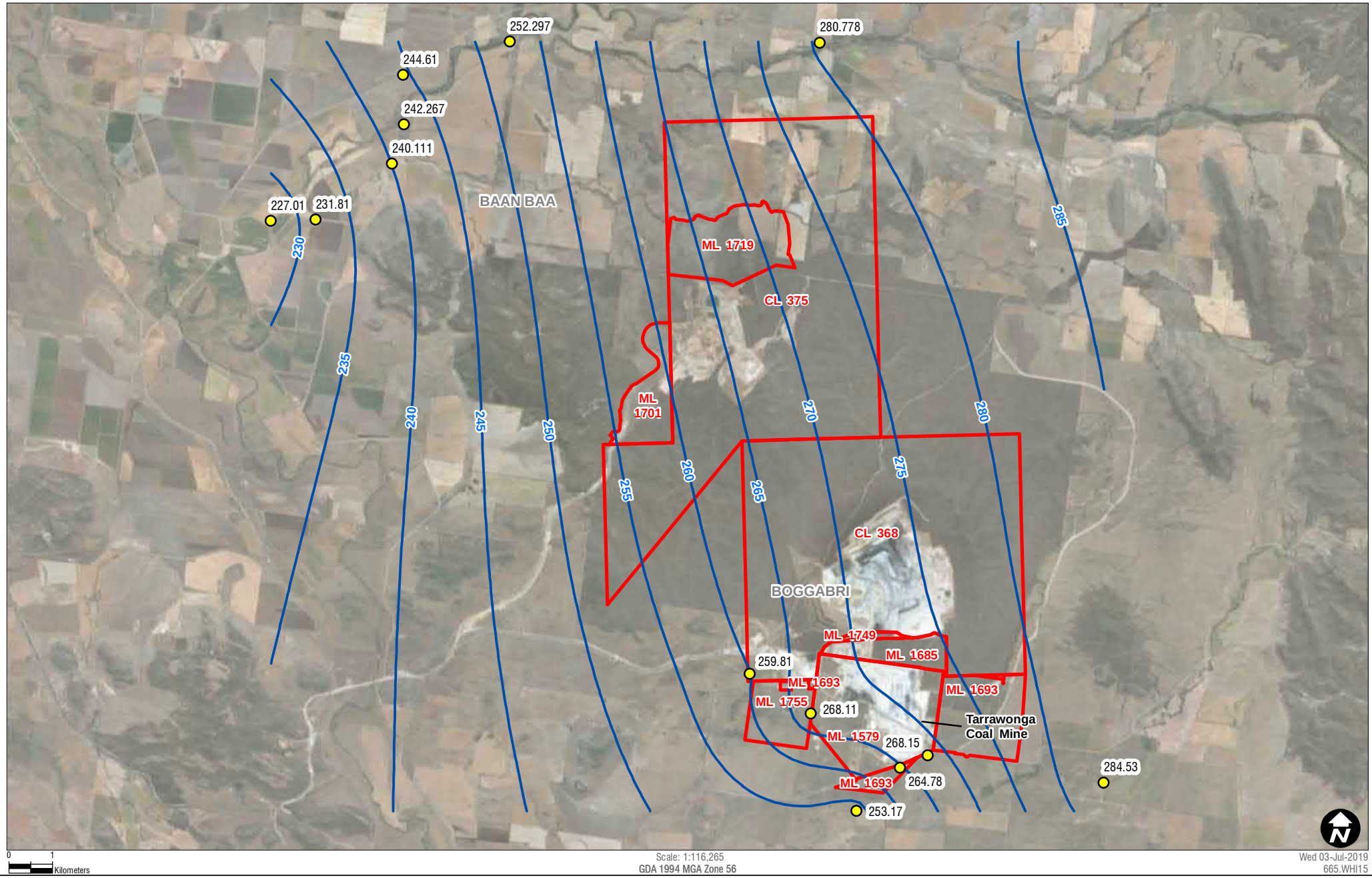
HYDRO SIMULATIONS

LEGEND

- Mining Leases
- New South Wales Groundwater data base
- 2011 Bore census
- Model Extent

Regional groundwater bore data base (2011)

FIGURE 17



LEGEND

- Mining Leases
- Groundwater Monitoring Bore (m ahd)
- Groundwater Elevation (mAHD)

HYDRO SIMULATIONS

Representative Watertable contours in the Alluvium (2018)

FIGURE 18

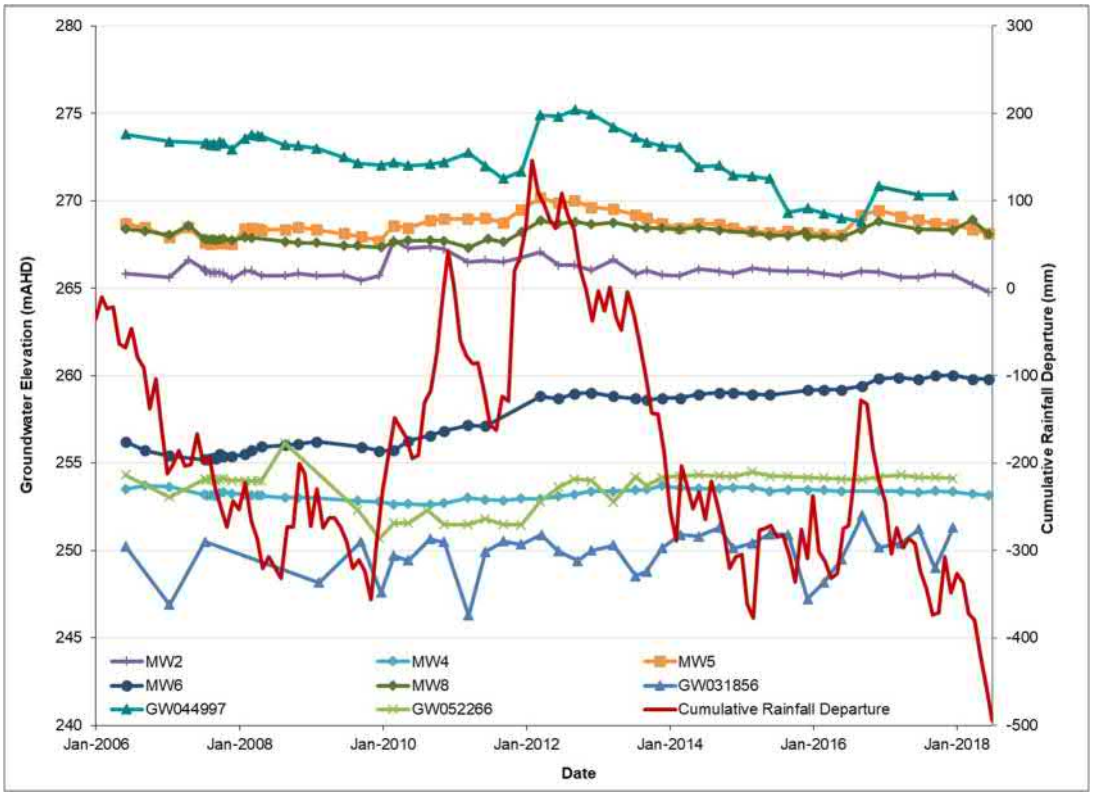


Figure 19 Groundwater Hydrographs for Alluvial Bores

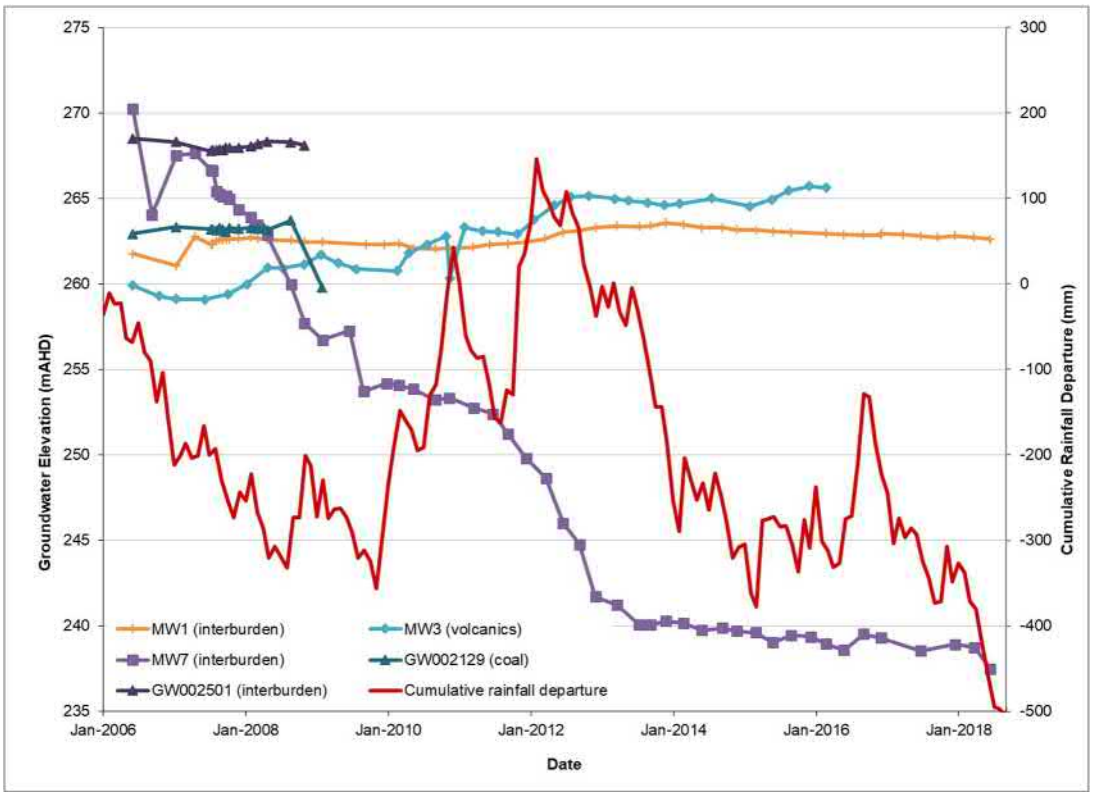


Figure 20 Groundwater Hydrographs for Bores screened in Coal, Interburden and Volcanics

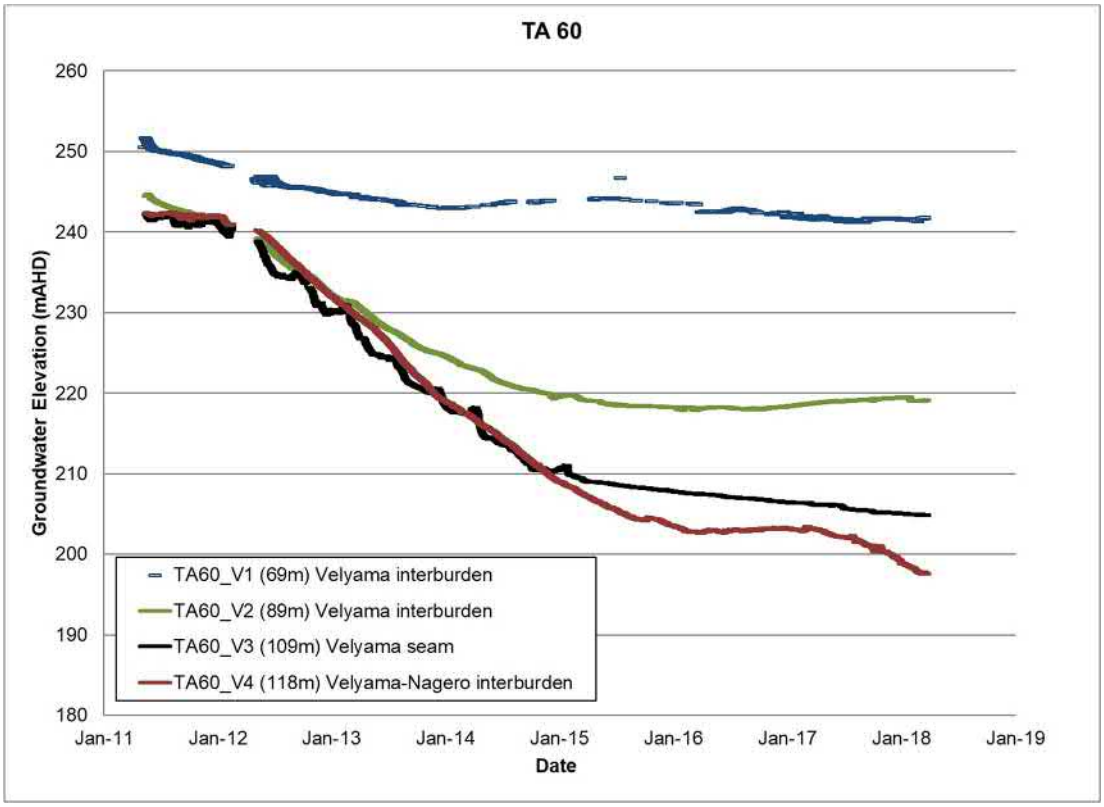


Figure 21 Multi-Level Groundwater Hydrographs for Bore TA-60C

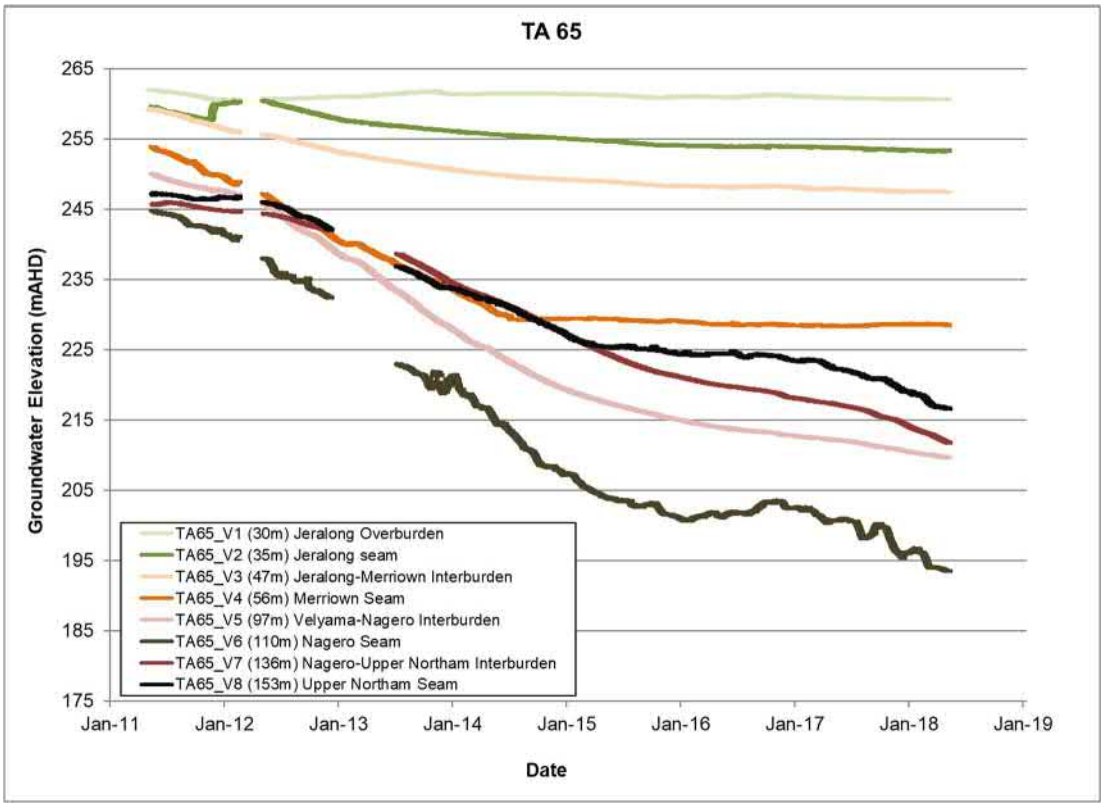


Figure 22 Multi-Level Groundwater Hydrographs for Bore TA-65

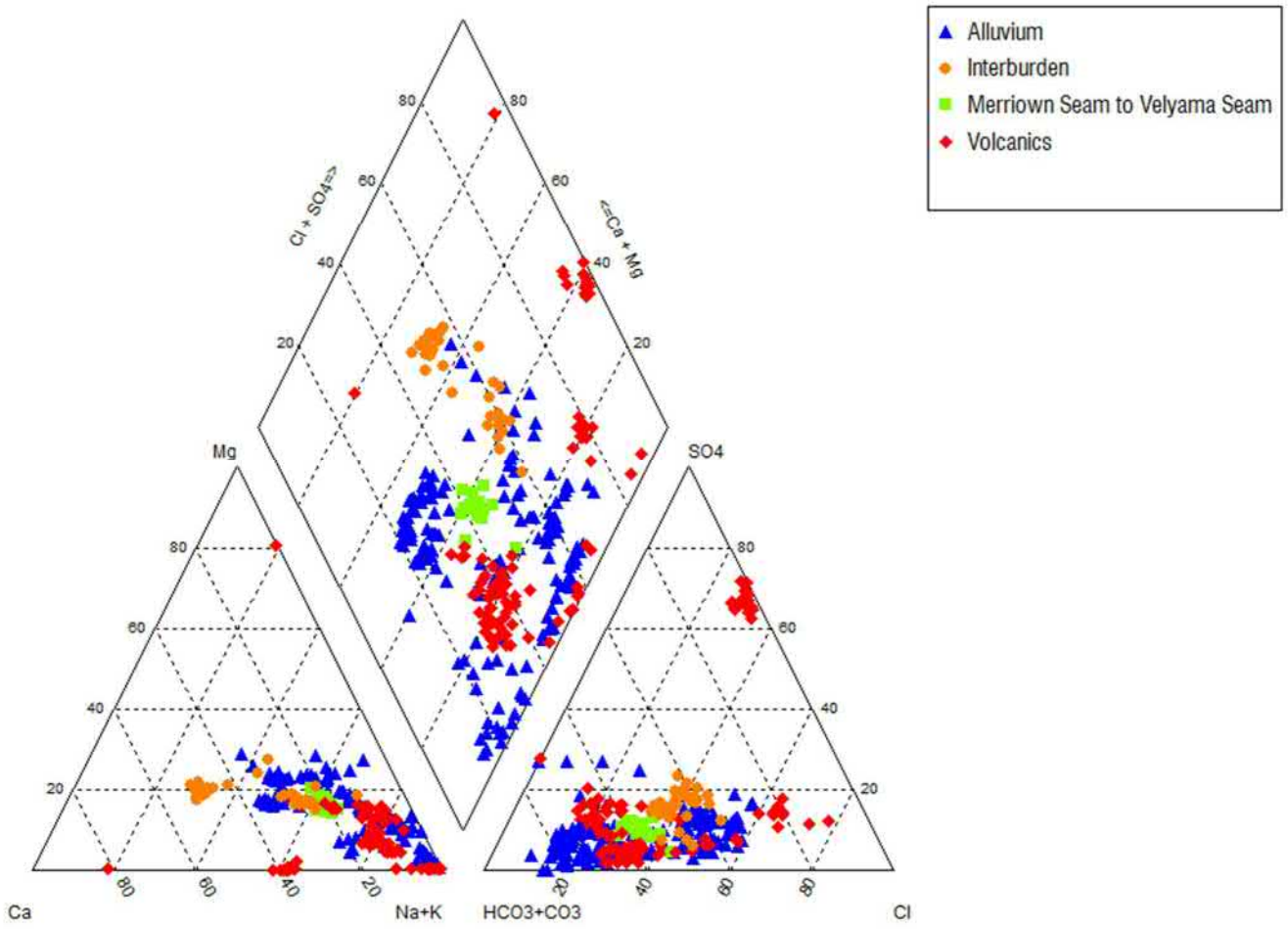
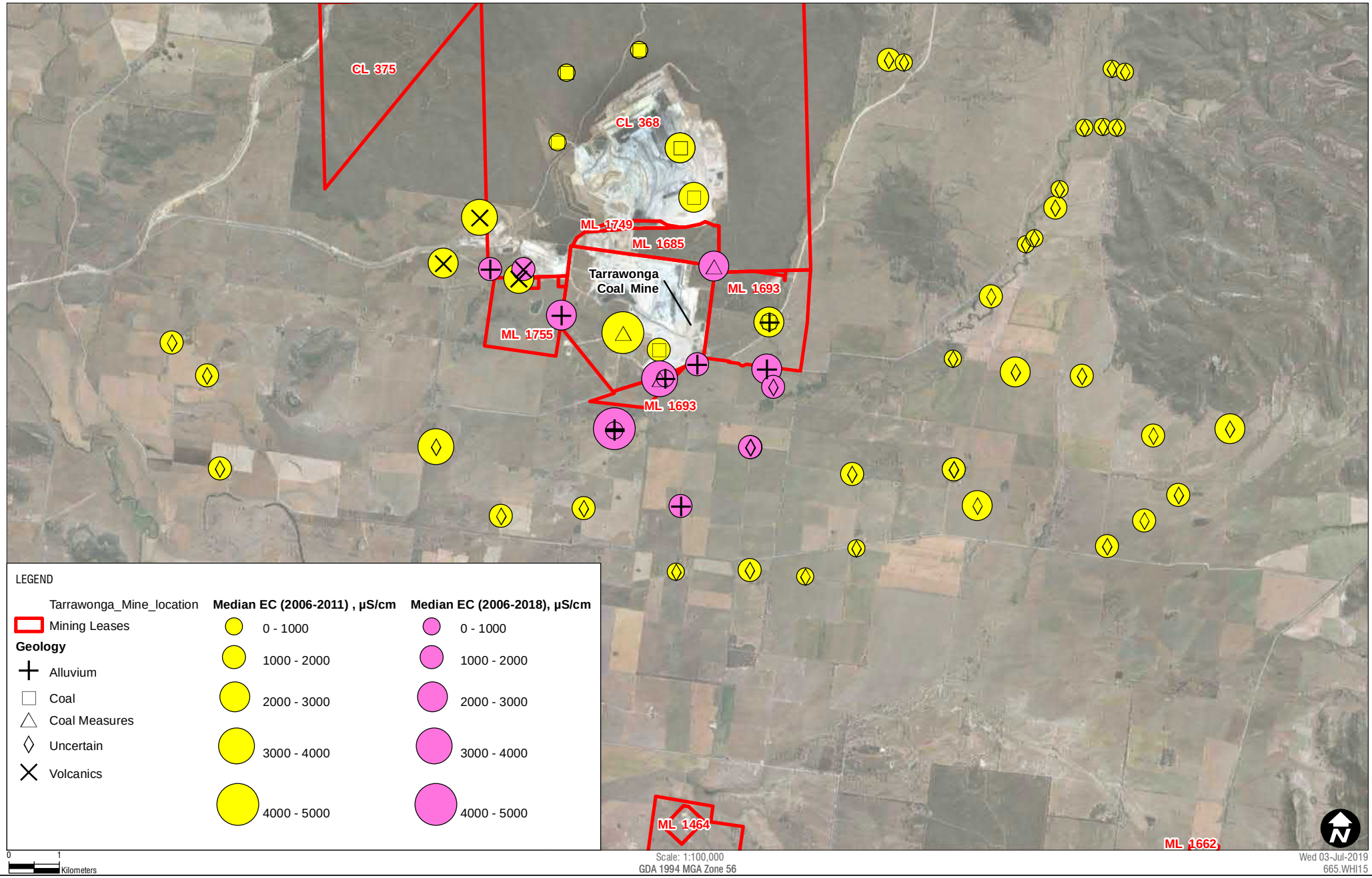


Figure 23 Piper plot



HYDRO SIMULATIONS

Median Electrical Conductivity

FIGURE 24

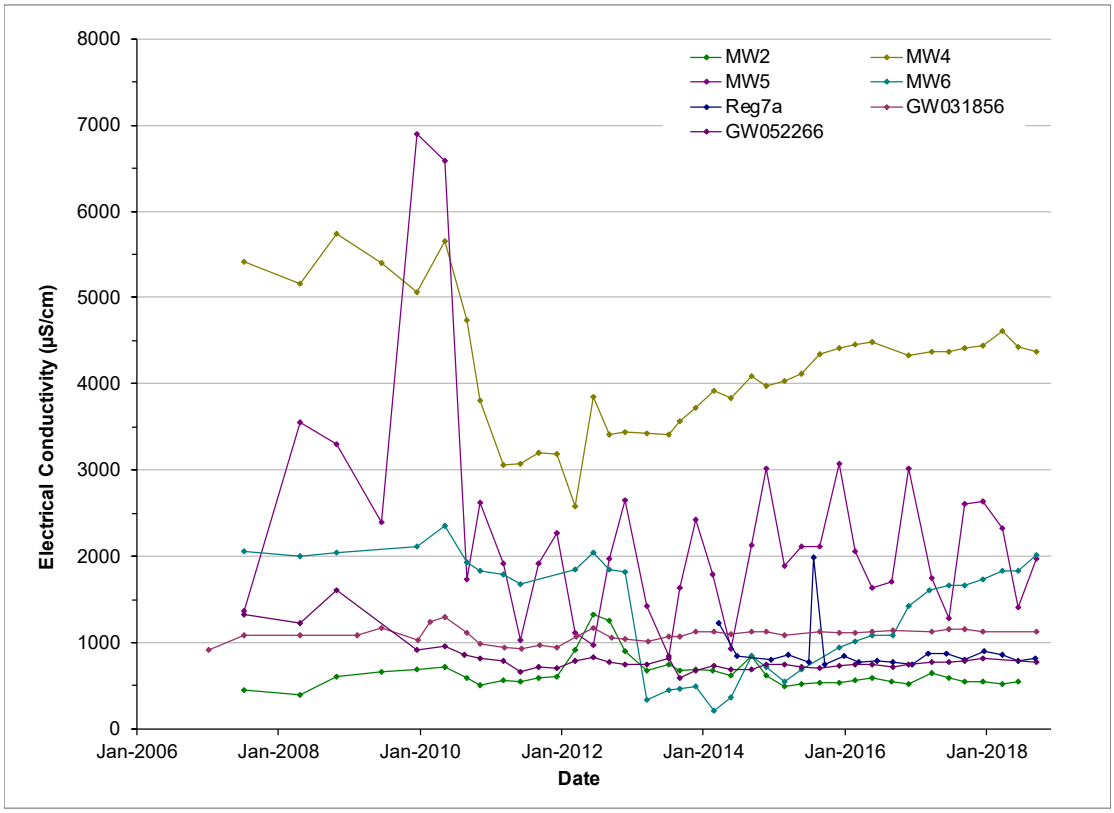


Figure 25 Timeseries of EC for bores screened in the Alluvium

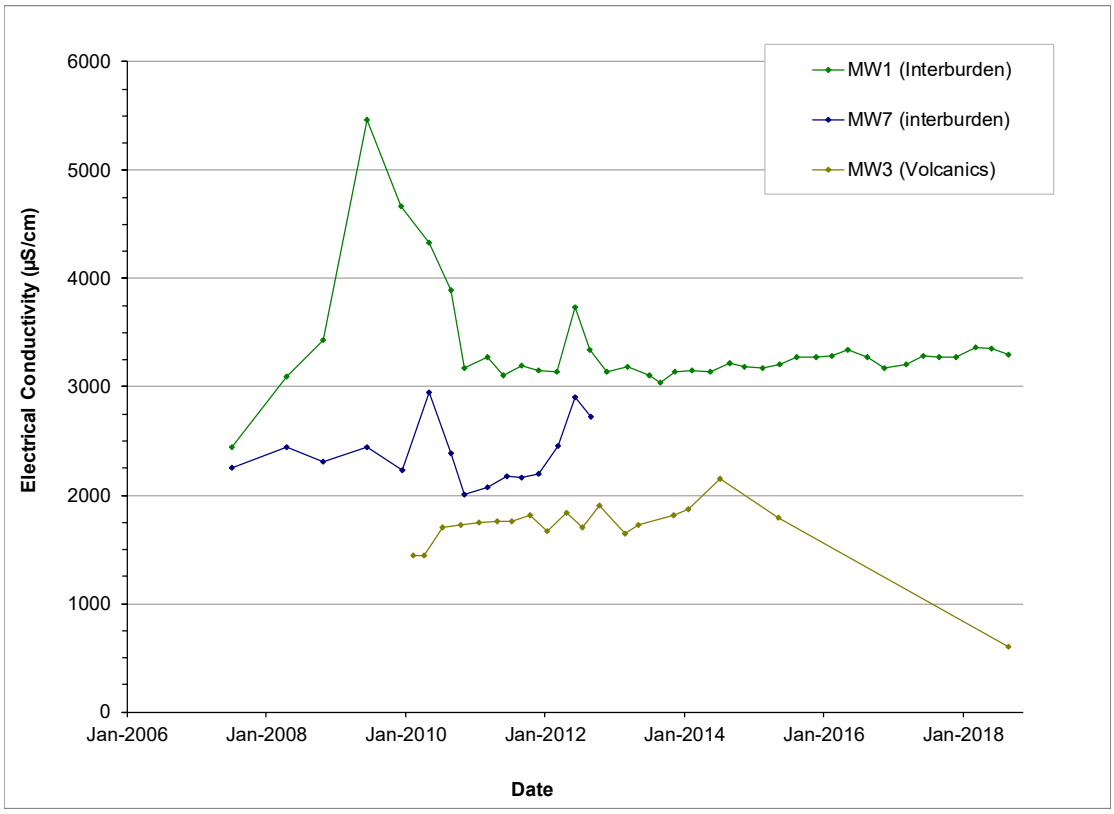
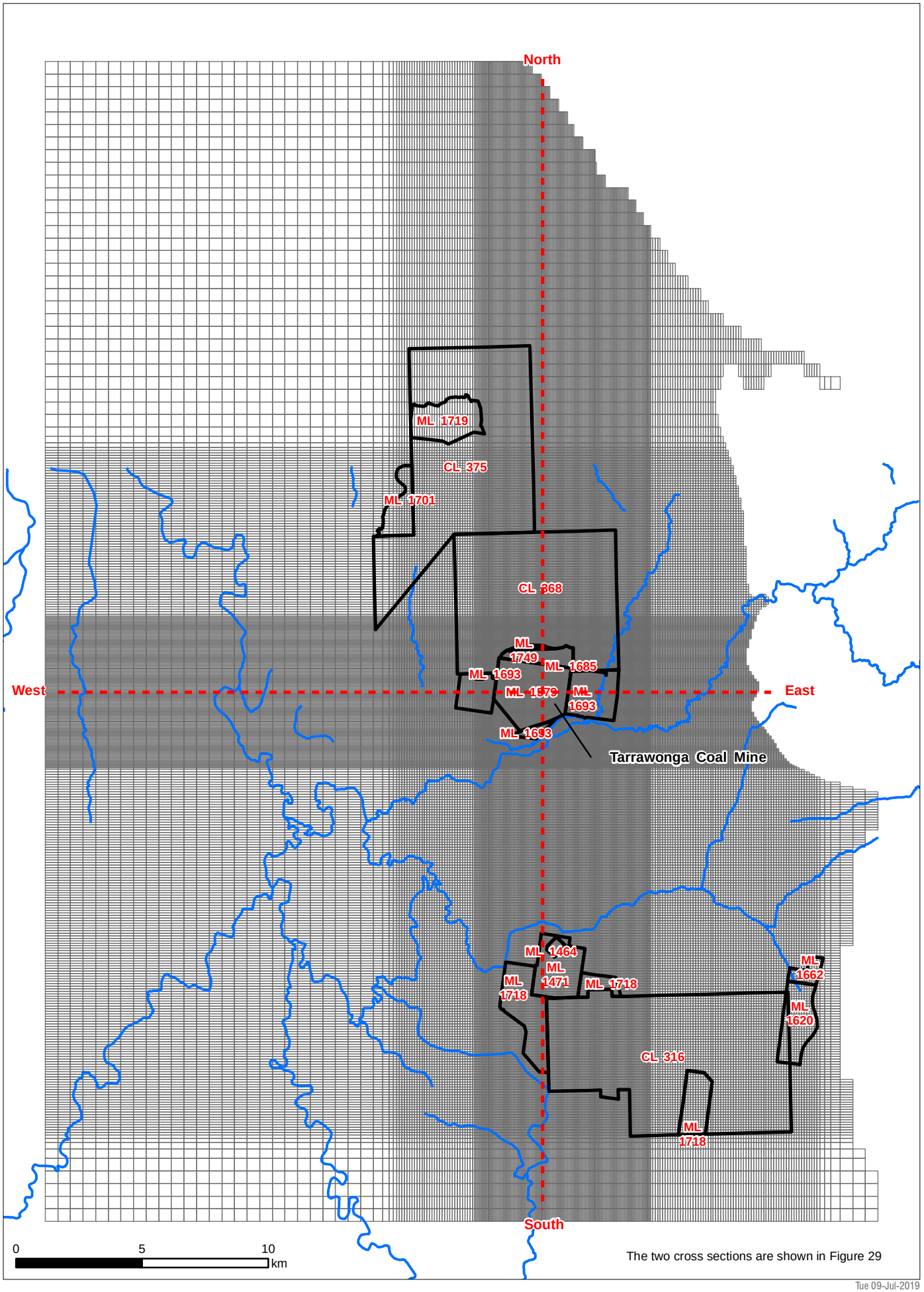


Figure 26 Timeseries of EC for bores screened in the Interburden and Volcanics



The two cross sections are shown in Figure 29

H:\Projects-SLR\660-Sn\WOL\660-WOL\665.WHI15 Tarrawonga GW Model Assessment\06 SLR Data\01 CADD\S01 ArcGIS\665WHI15_Figure27_Model grid.mxd

Tue 09-Jul-2019
665.WHI15

HYDRO SIMULATIONS

Model cross sections

FIGURE 27

INDICATIVE THICKNESS (m)	LAYER	LITHOLOGY
30	1	Alluvium or Regolith
70	2	Alluvium or Overburden
15	3	Overburden
20	4	Braymont Seam to Jeralong Seam
10	5	Interburden
15	6	Merriown Seam to Velyama Seam
5	7	Interburden
2	8	Nagero Upper Seam
35	9	Interburden
90	10	Northam Seam to Templemore Seam
70	11	Underburden
50	12	Volcanics

Note: In the model, seam layers are reduced in thickness to the aggregate thickness of contained coal seams. The surplus layer thickness is allocated to the overlaying interburden.

Targeted Coal Seams for the Project

Source: TCPL (2011); Whitehaven Coal Mining Pty Ltd (2011); Idemitsu Boggabri Coal Limited (2011); Aston Resources (2011) and NSW office of Water (2010)

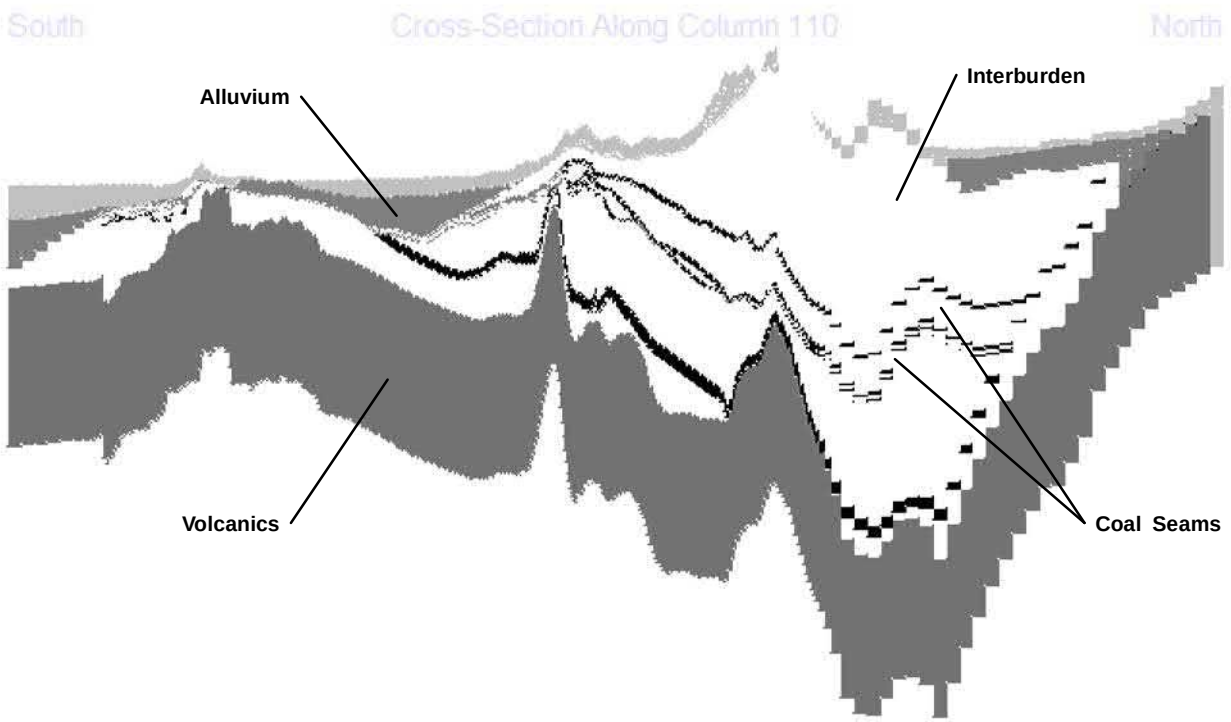
12-Jun-2019
620.WHI15

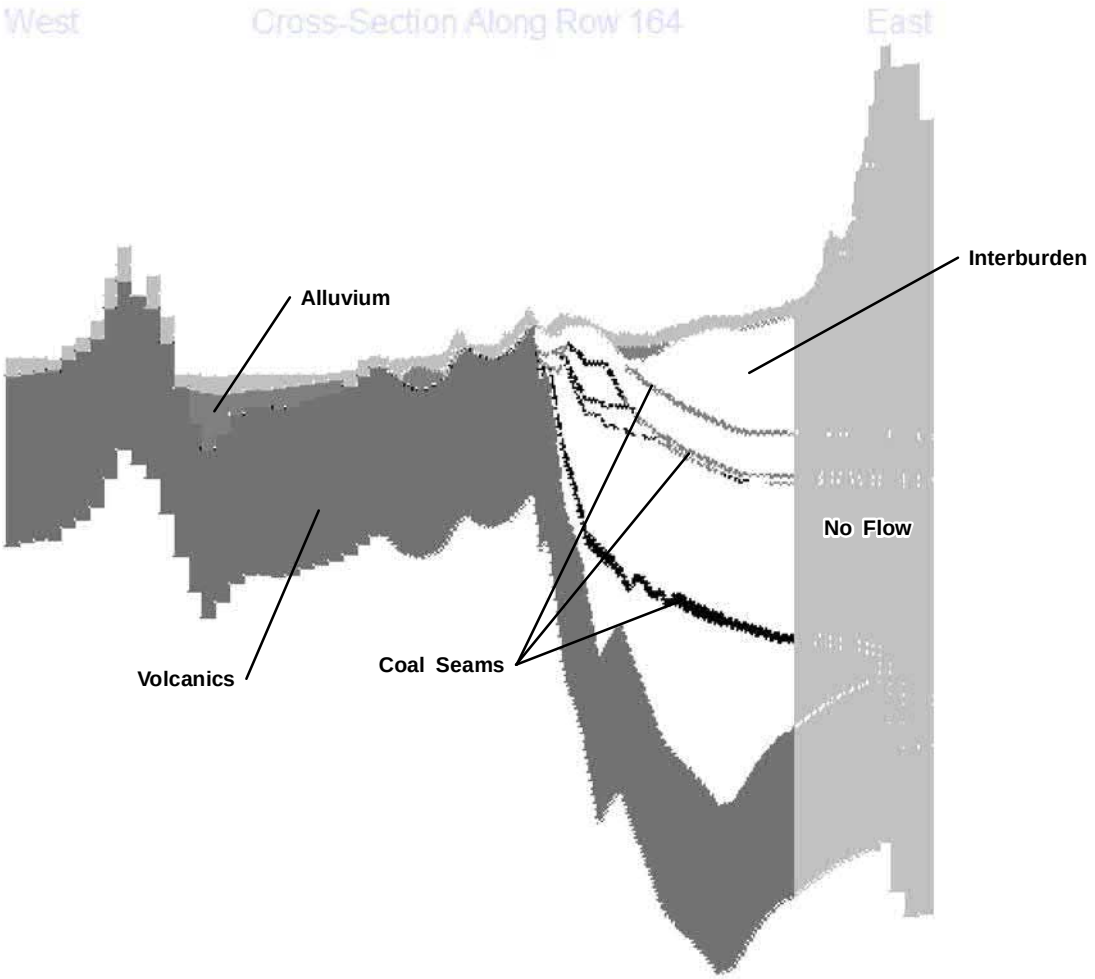
\\au.sf.local\Corporate\Projects-SLR\660-Srv\WOL\660-WOL\665.WHI15 Tarrawonga GW Model Assessment\06 SLR Data\01 CADGIS\01 ArcGIS\665WHI15_Figure28_Model layers.mxd

HYDRO SIMULATIONS

Model layers

FIGURE 28





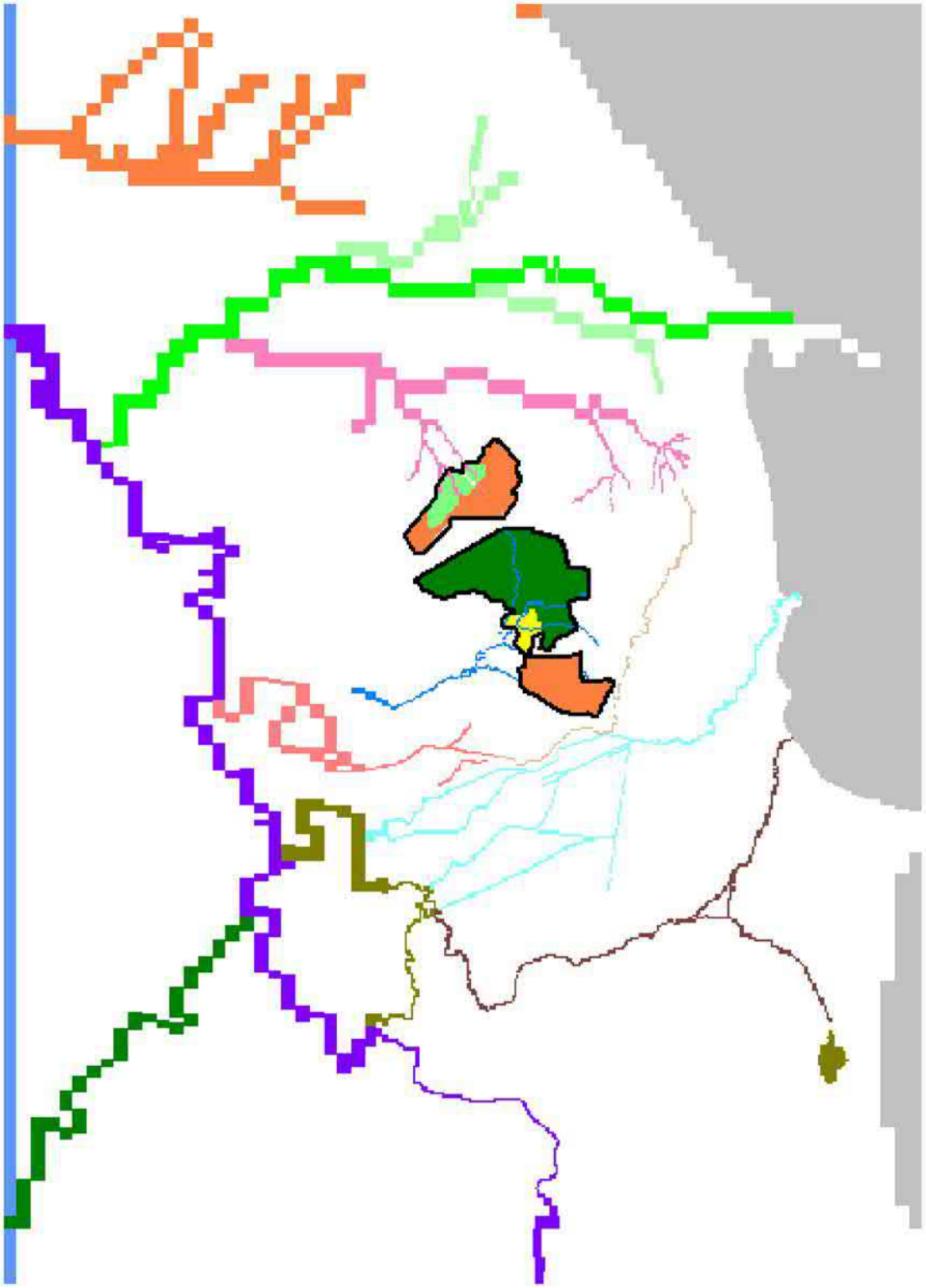
\\au.sir.local\Corporate\Projects-SLR\660-SrvWOL\660-WOL665 WHI15 Tarawonga GW Model Assessment\06 SLR Data\01 CAD\GIS\01 ArcGIS\665WHI15_Figure29_Model cross sections.mxd

Wed 03-Jul-2019
665.WHI15

HYDRO SIMULATIONS

Model cross sections

FIGURE 29



Notes: Rivers and drains are shown in multiple colours

\\au.sir.local\Corporate\Projects-SLR\660-SnWOL\660-WOL665 WHI15 Tarawonga GW Model Assessment\06 SLR Data\01 CAD\GIS\01 ArcGIS\665WHI15_Figure30_Model Boundary conditions.mxd

04-Jun-2019
665.WHI15

HYDRO SIMULATIONS

Model Boundary conditions

FIGURE 30

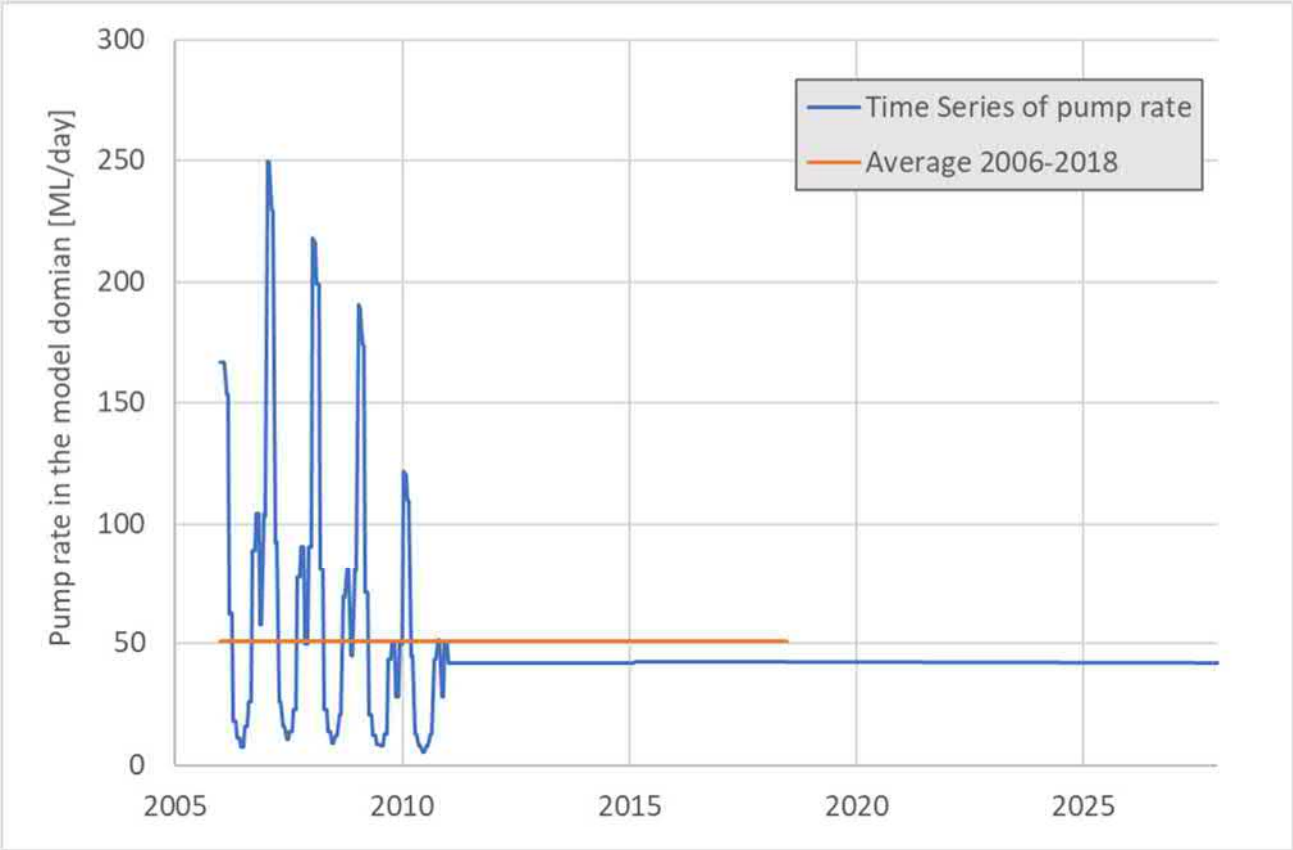
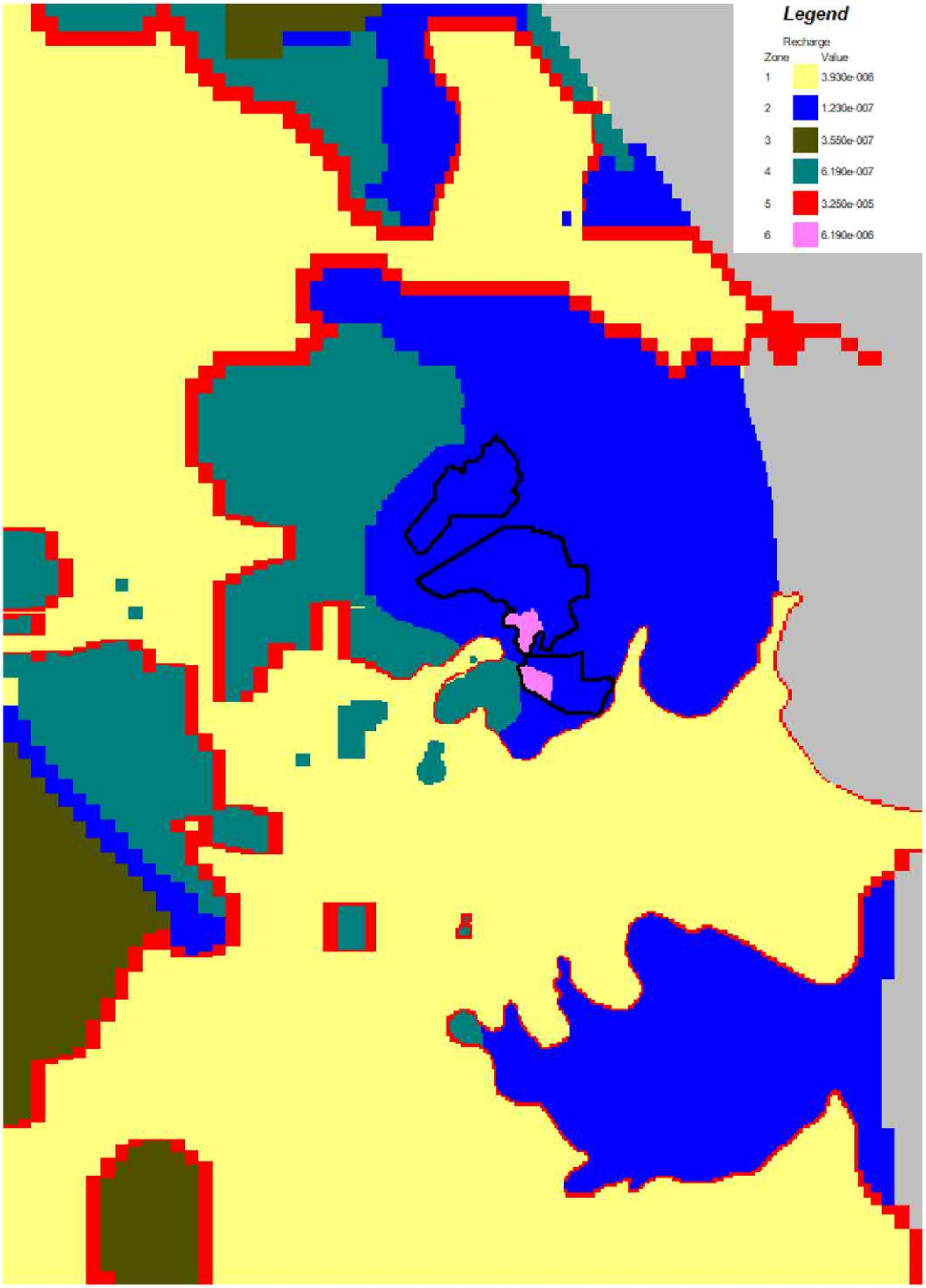


Figure 31 Total pumping rate in the groundwater model



C:\Users\jgoffeau\Desktop\Working\665.WHI15\01.ArcGIS\665WHI15_Figure32_Calibrated Recharge rates.mxd

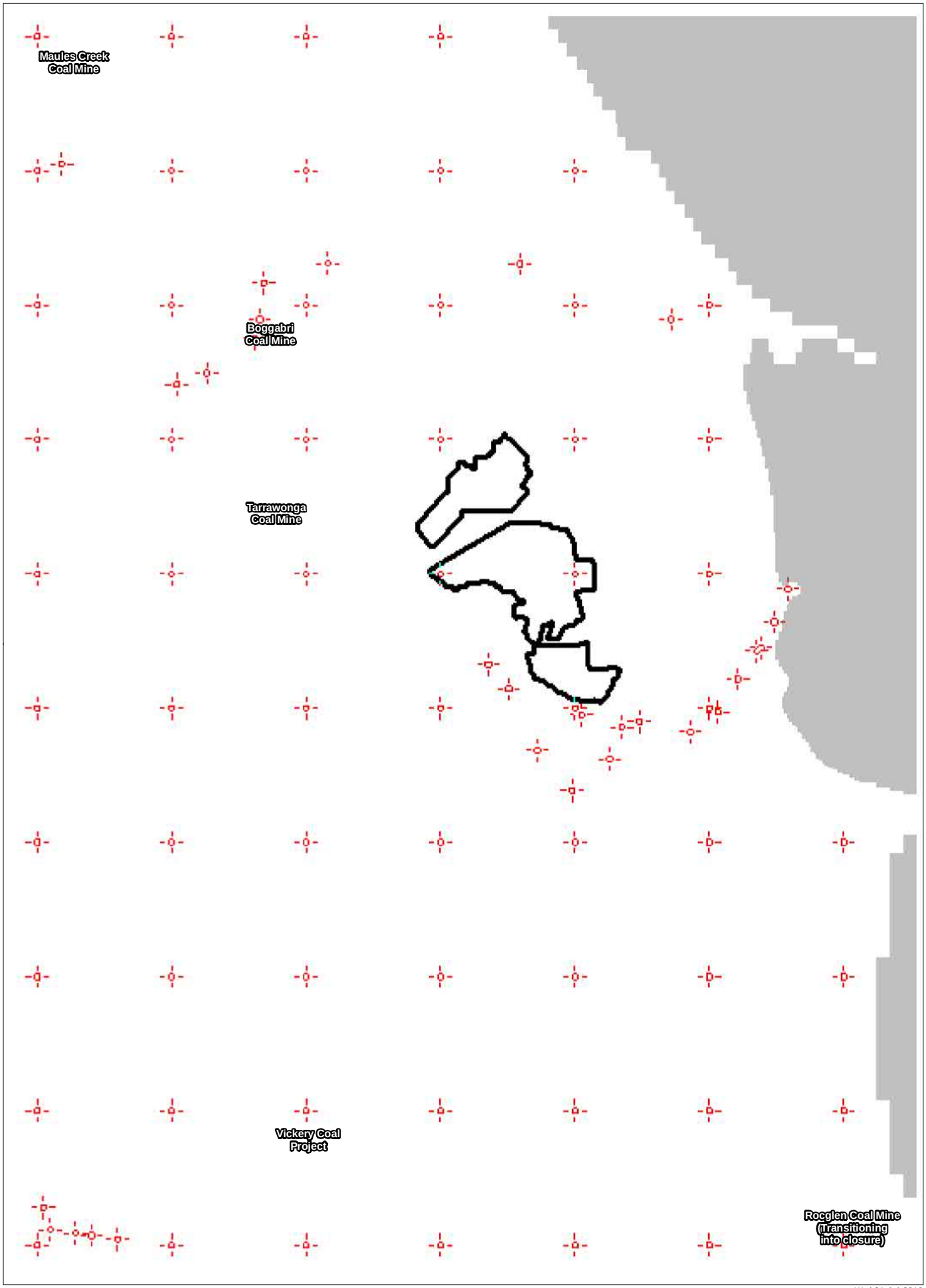
Mon 29-Jul-2019
665.WHI15

Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Calibrated Recharge rates (m/day)

HYDRO SIMULATIONS

FIGURE 32



C:\Users\jgorfeau\Desktop\Working\665.WHI15\01 ArcGIS\665WHI15_Figure33_Pilot points for Layer 1.mxd

Wed 31-Jul-2019
665.WHI15

Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Pilot points for Layer 1

HYDRO SIMULATIONS

FIGURE 33

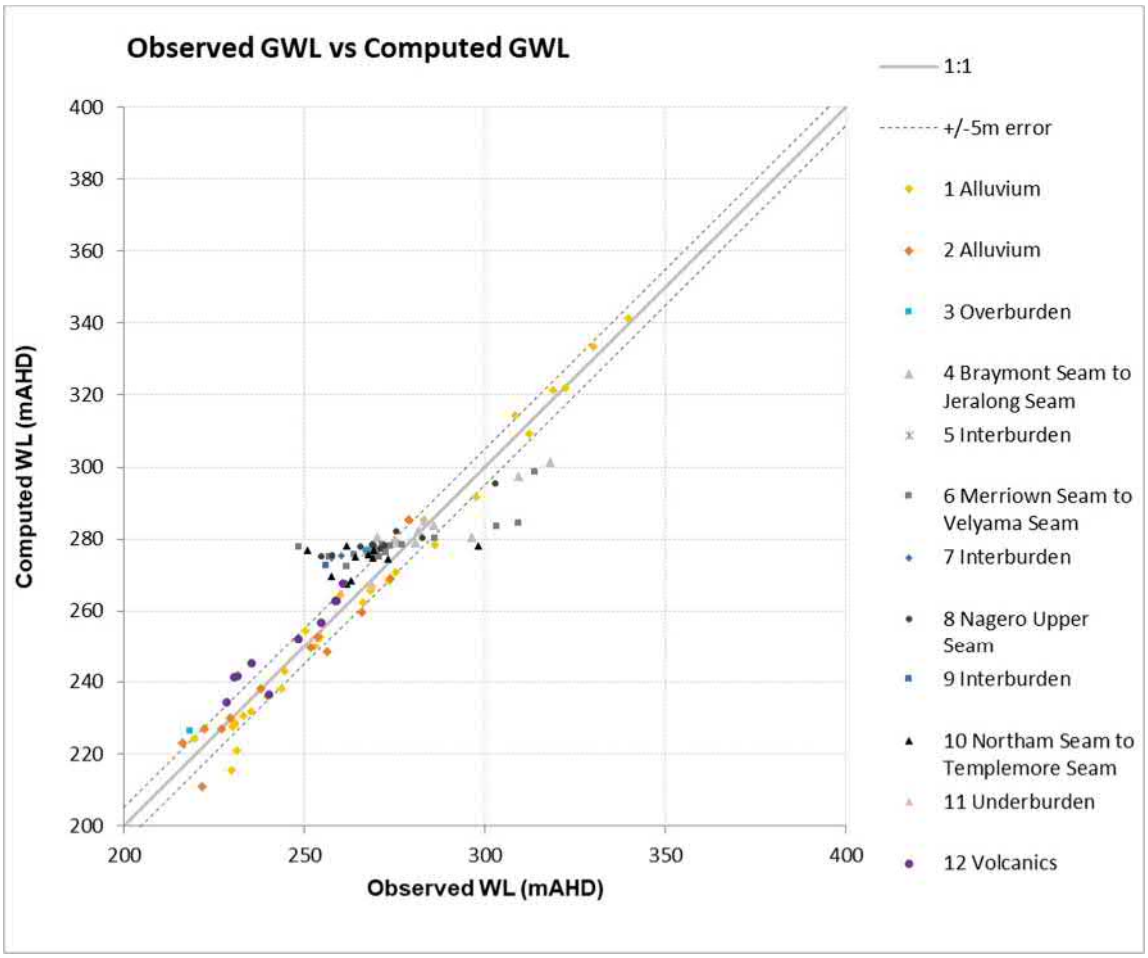


Figure 34 Scatterplot for the steady state calibration

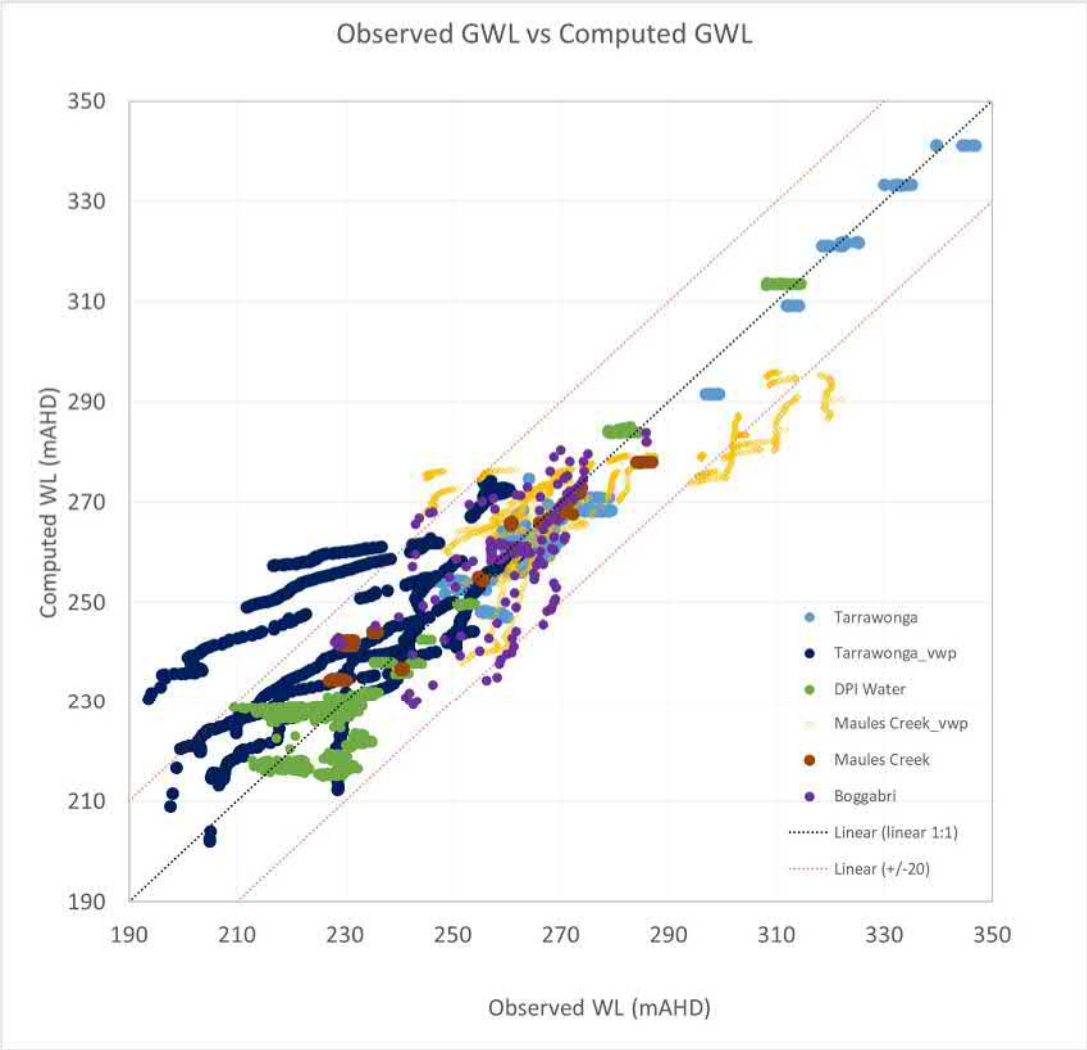


Figure 35 Scatterplot for the transient calibration

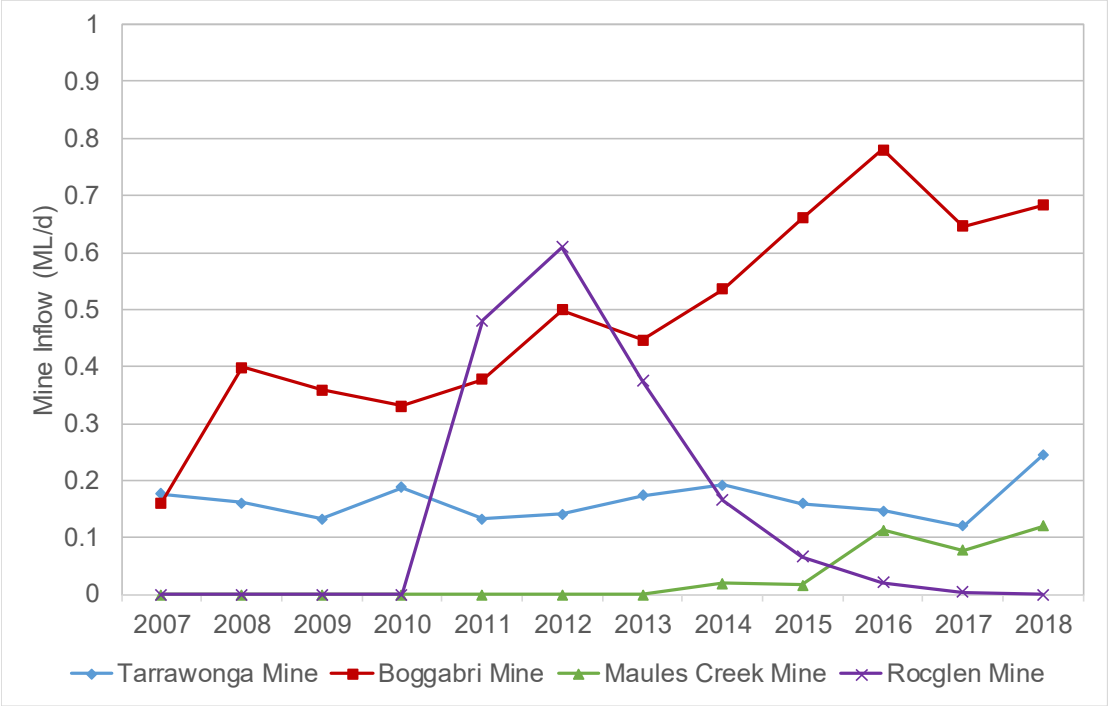


Figure 36 Pit Inflows during the calibration period

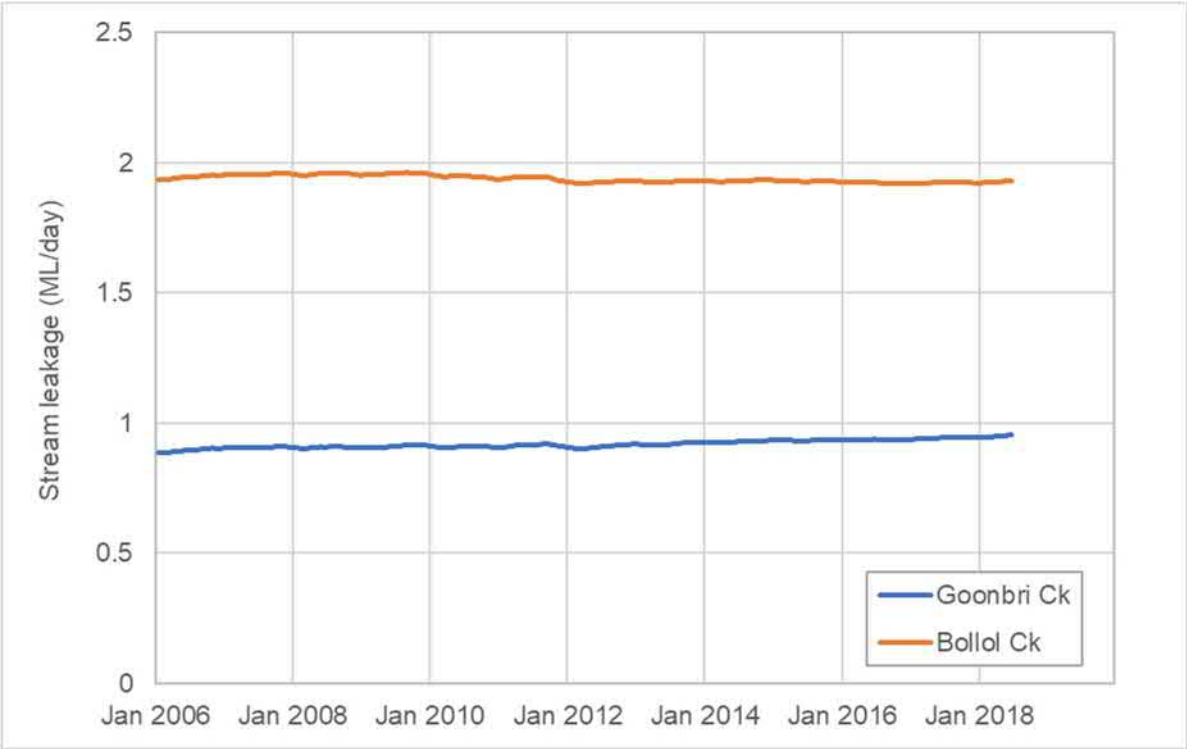
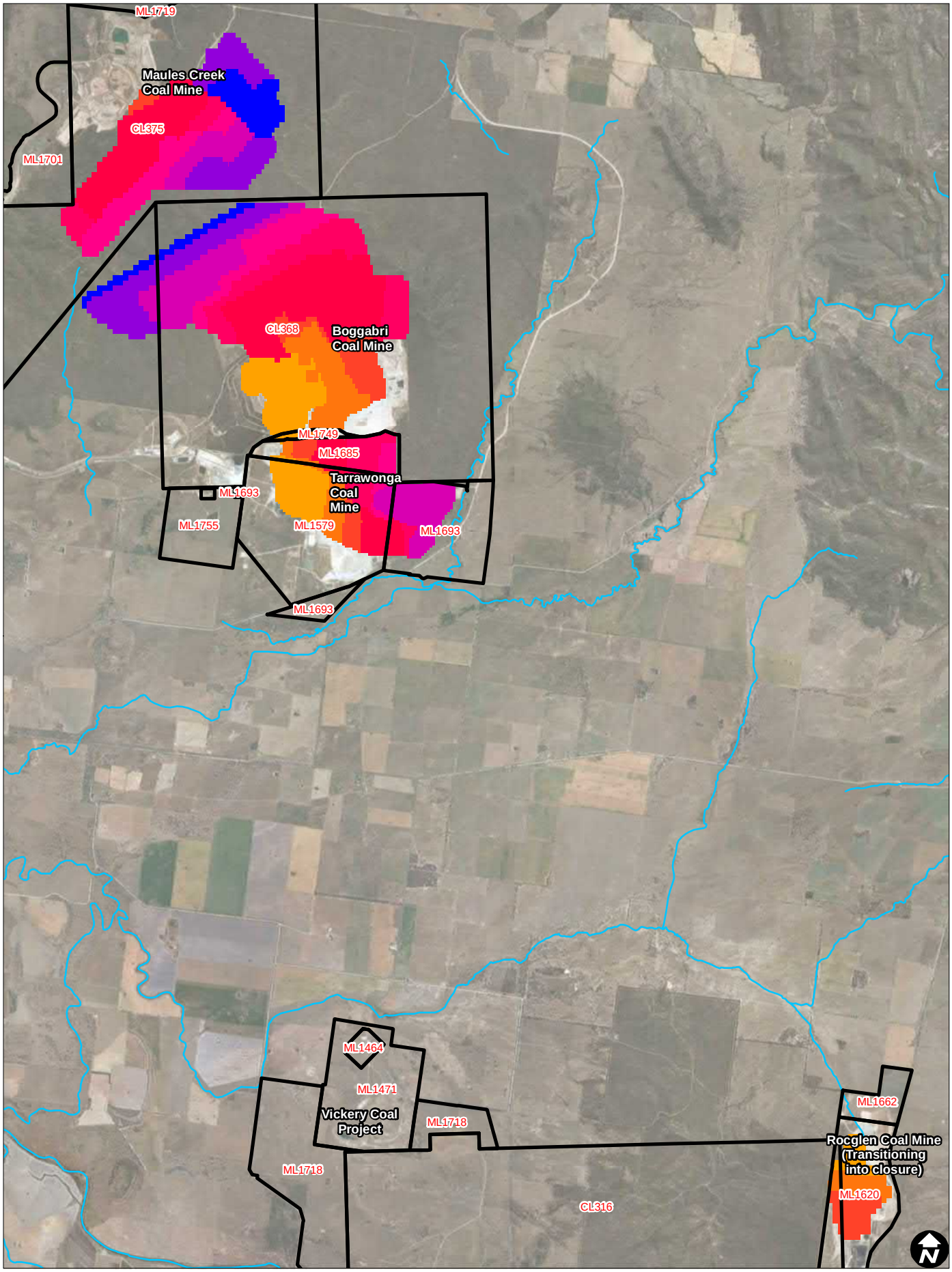


Figure 37 Stream Leakage at Goonbri Creek and Bollol Creek during the calibration period



0 1 Kilometers

Scale: 1:100,000
GDA 1994 MGA Zone 56

Wed 31-Jul-2019
665.WHI15

C:\Users\jgolfeau\Desktop\Working\665.WHI15\01 ArcGIS\665WHI15_Figure38_Regional_mine_progression.mxd

LEGEND

Mining Leases
Watercourses

Progression Years

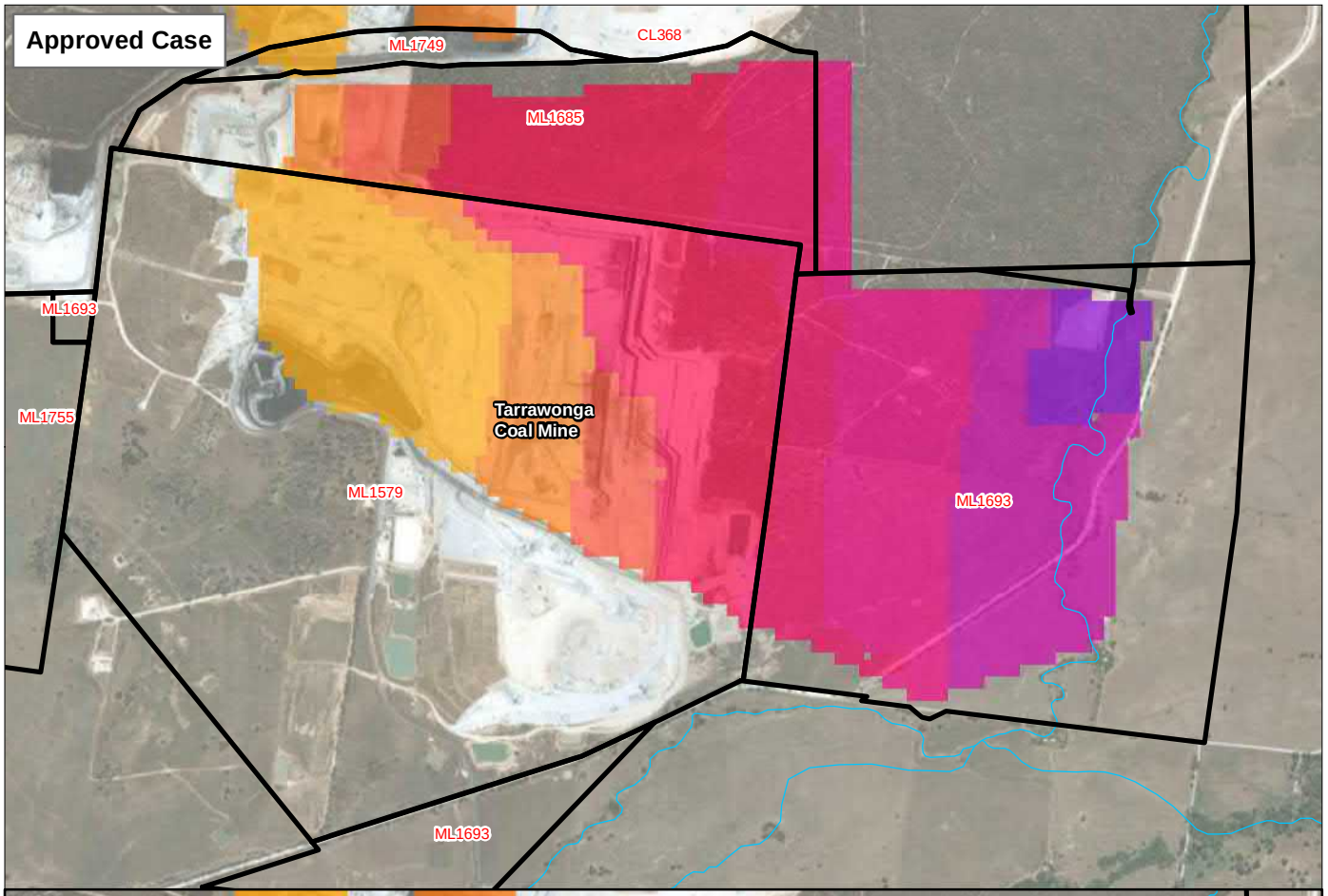
2006-2008
2009-2011
2012-2014
2015-2017
2018-2020
2021-2023
2024-2026
2027-2029
2030-2032
2033-2034

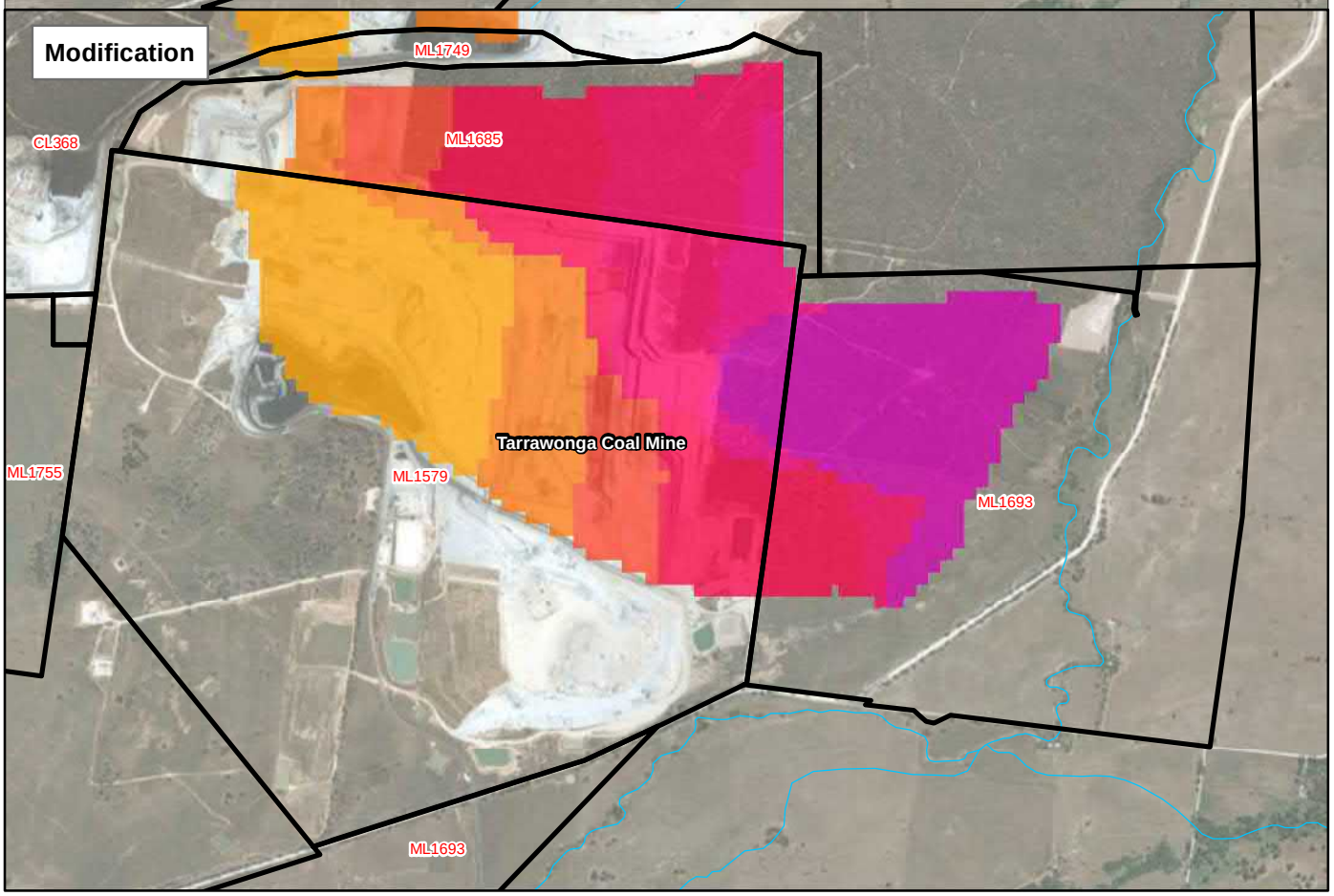
HYDRO SIMULATIONS

Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Regional mine progression plan

FIGURE 38





C:\Users\gofleau\Desktop\Working\665.WHI1501 ArcGIS\665WHI15_Figure39_Tarrawonga_mine_progression.mxd

0 1 Kilometers

Scale: 1:30,000
GDA 1994 MGA Zone 56

Wed 31-Jul-2019
665.WHI15

LEGEND

Mining Leases
Watercourses

Progression Years

2006-2008
2009-2011
2012-2014
2015-2017
2018-2020
2021-2023
2024-2026
2027-2029
2030-2032
2033-2034

HYDRO SIMULATIONS

Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Tarrawonga mine progression plan (approved and modification)

FIGURE 39

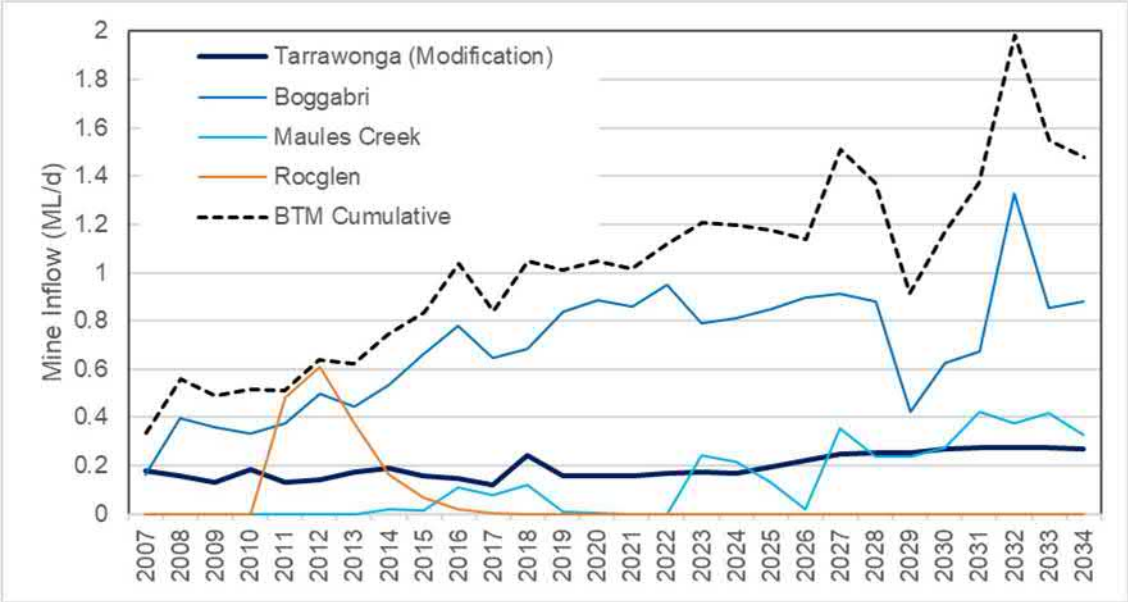


Figure 40 Mine inflows for the prediction period (Modification)

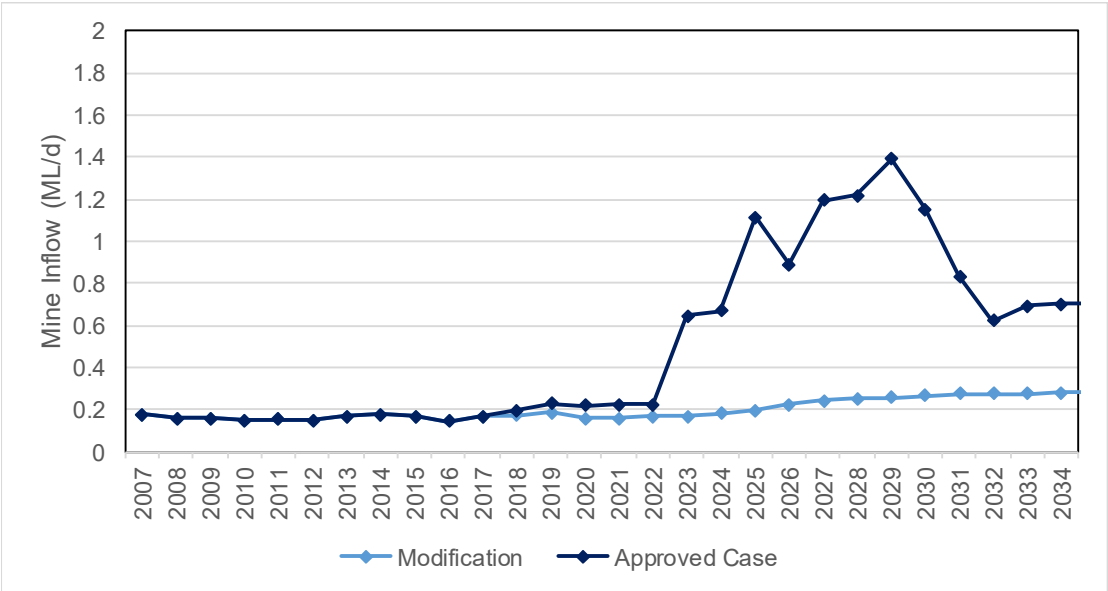


Figure 41 Mine inflows comparison between Approved case and Modification

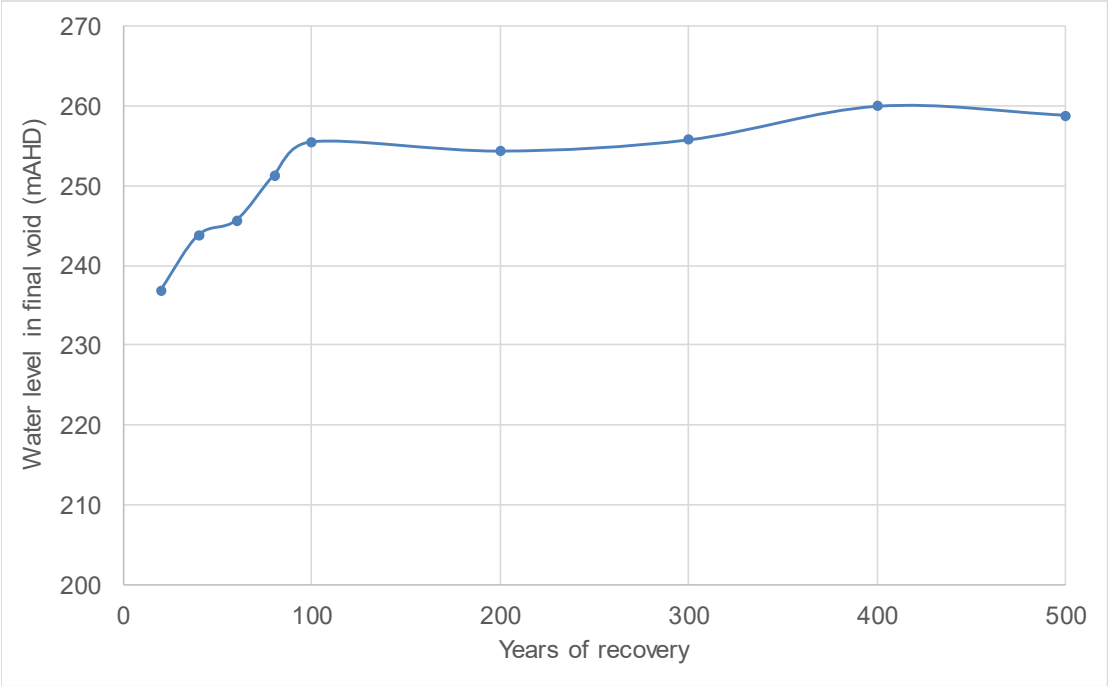
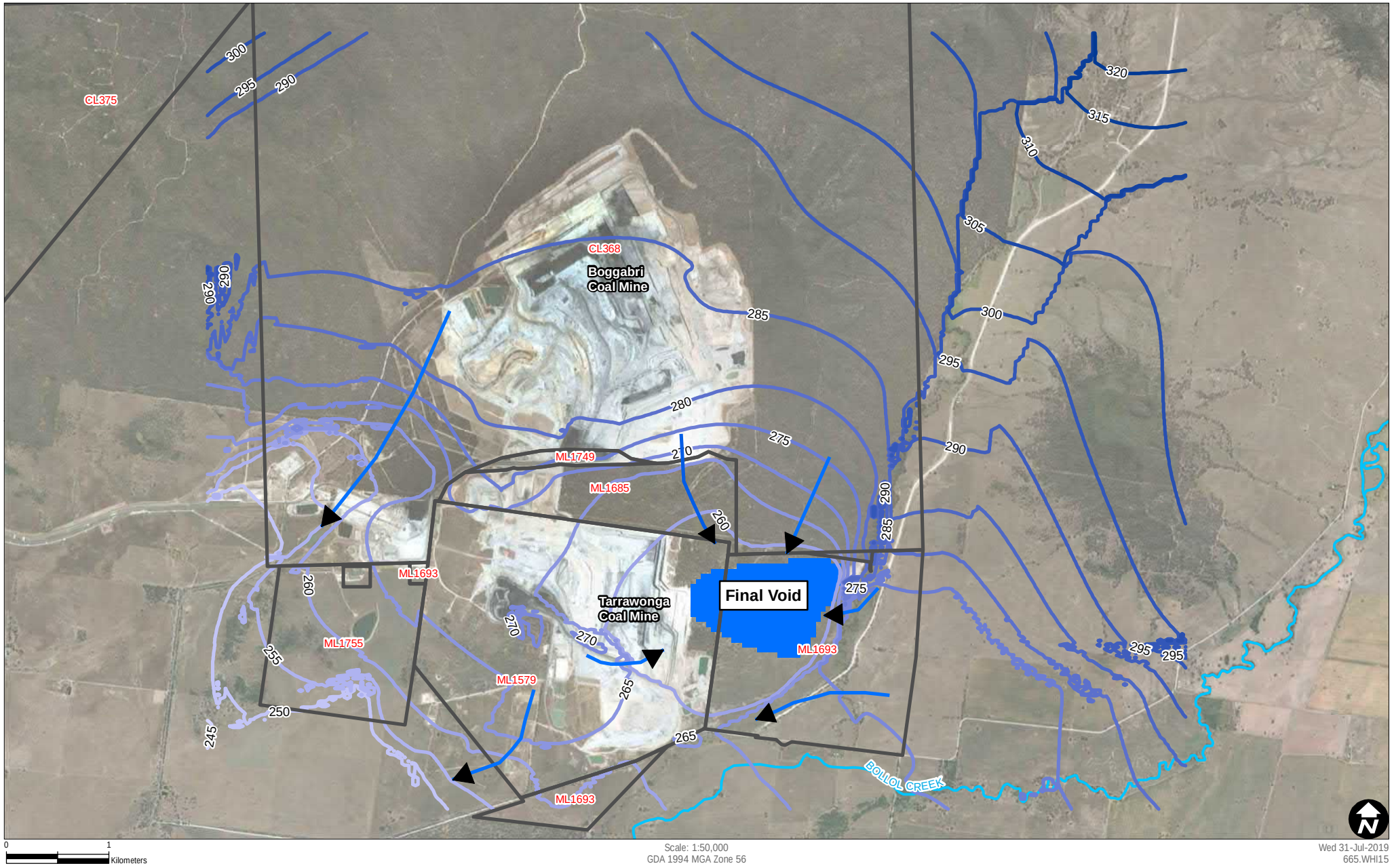


Figure 42 Water level in Final Void during recovery



Scale: 1:50,000
GDA 1994 MGA Zone 56

Wed 31-Jul-2019
665.WHI15

LEGEND

- Final Void
- Watercourses
- Flow direction

Water level

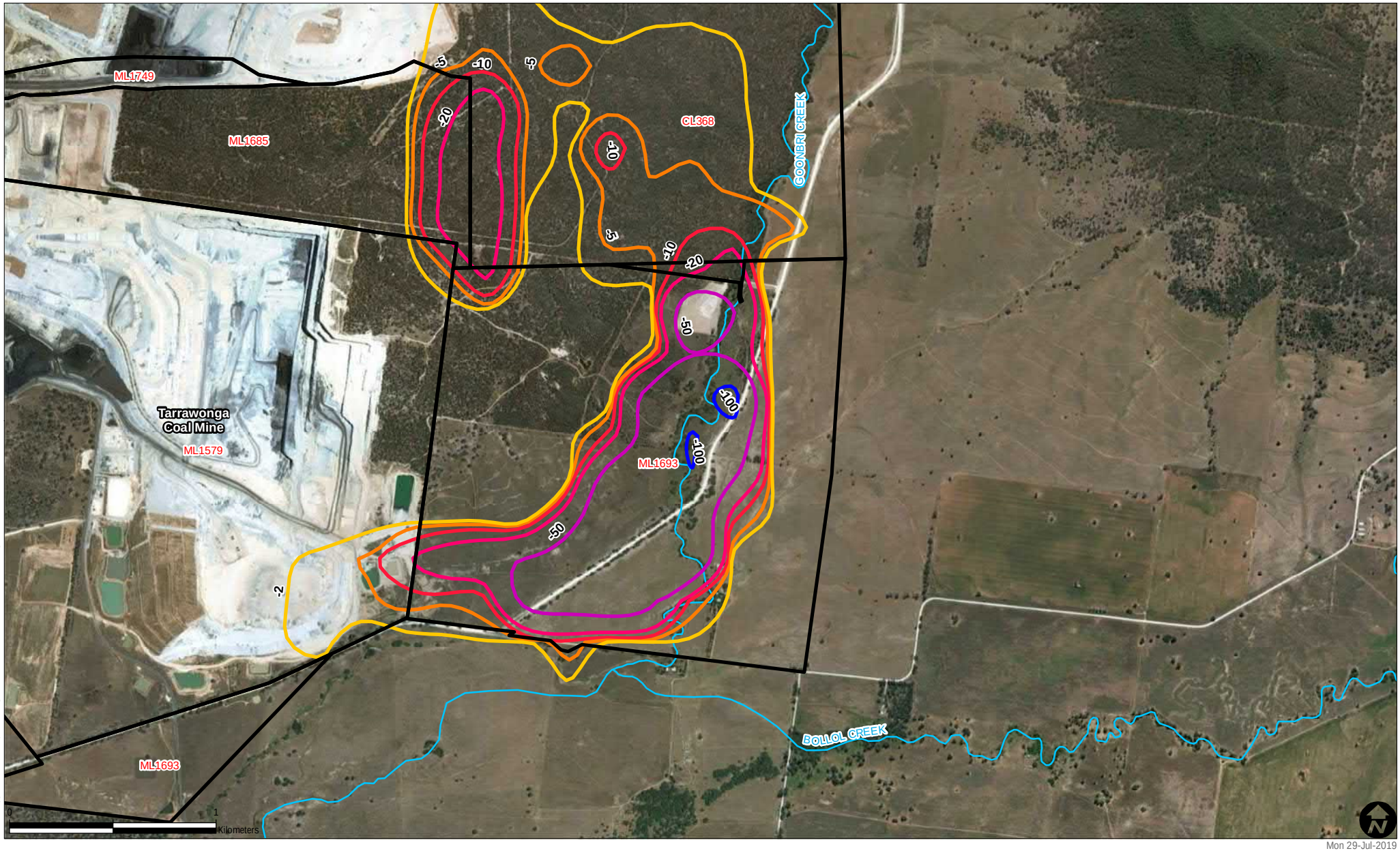
245, 250, 255, 260, 265, 270, 275, 280, 285, 290, 295, 300, 305, 310, 315, 320

HYDRO SIMULATIONS

Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Recovered water levels and flow directions after 100 years

FIGURE 43



LEGEND

Mining Leases

Watercourses

Water Level Difference

-2

-5

-10

-20

-50

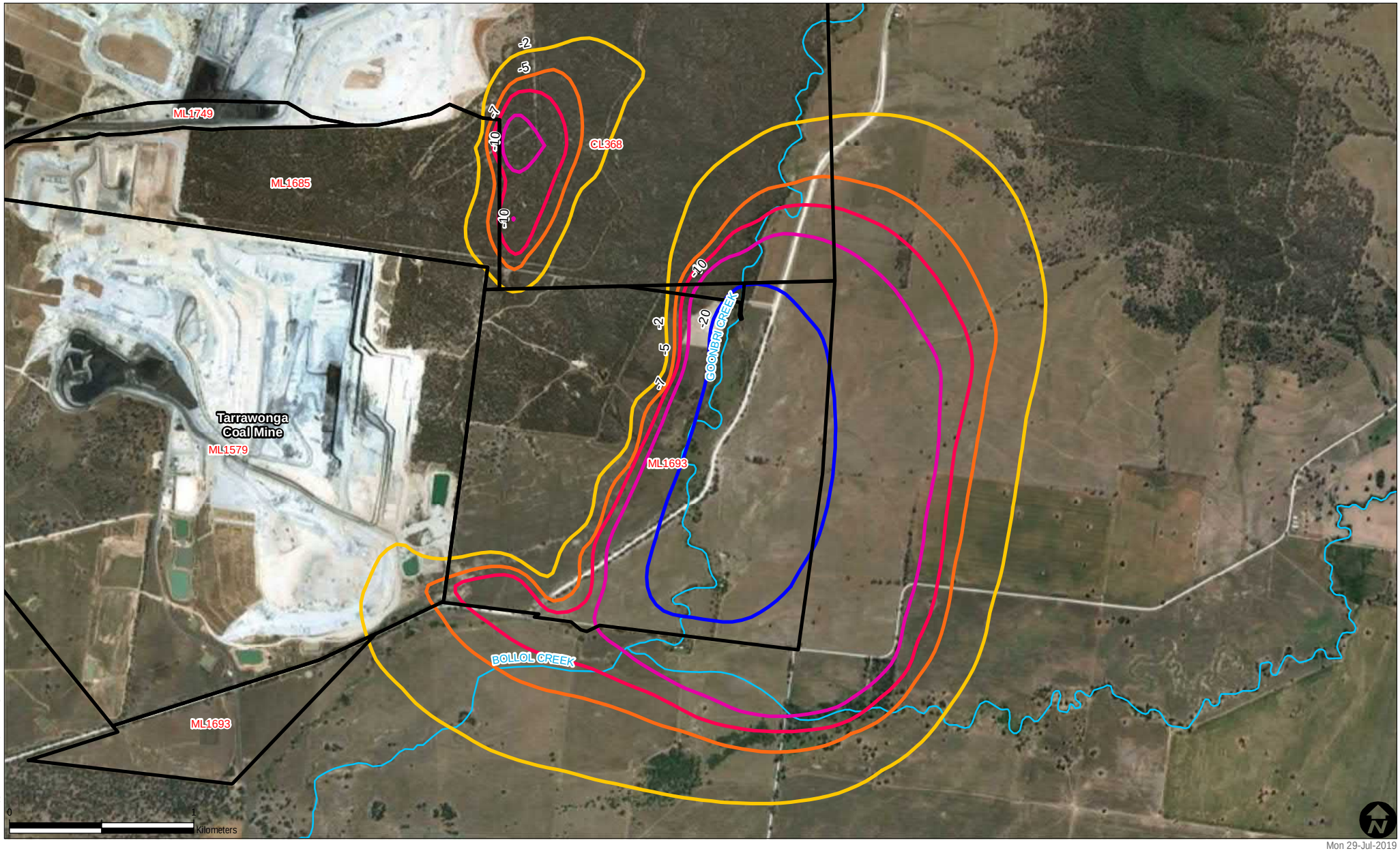
-100

Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Difference in Watertable between Approved case and Modification

A negative difference means that the modification has less impact than the approved case.

FIGURE 44



LEGEND

Mining Leases

Watercourses

Water Level Difference

-2

-5

-7

-10

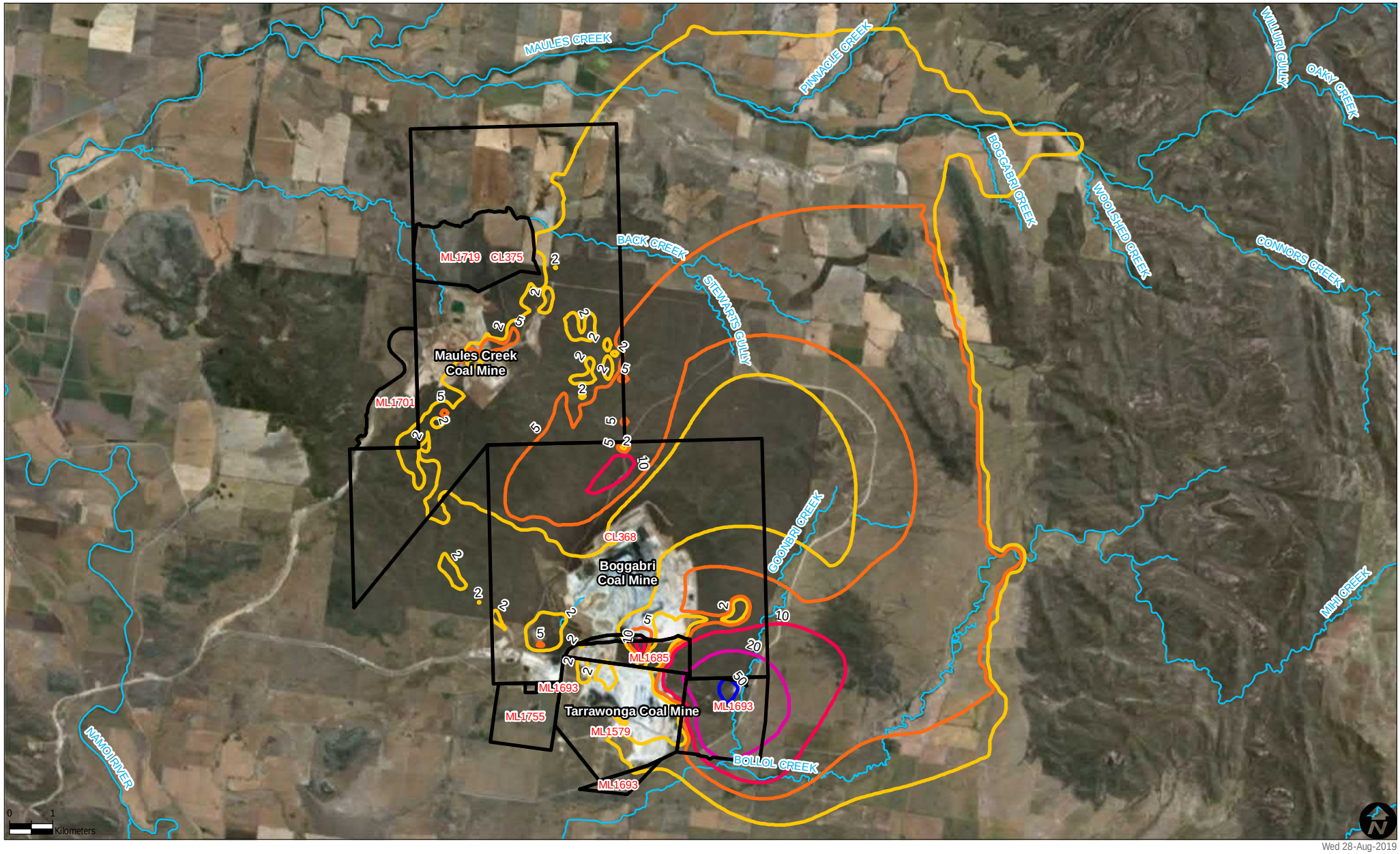
-20

A negative difference means that the modification has less impact than the approved case.

Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Difference in waterlevels in the lowest Coal Seam between Approved case and Modification

FIGURE 45



LEGEND

Mining Leases

Watercourses

Maximum Drawdown

2

5

10

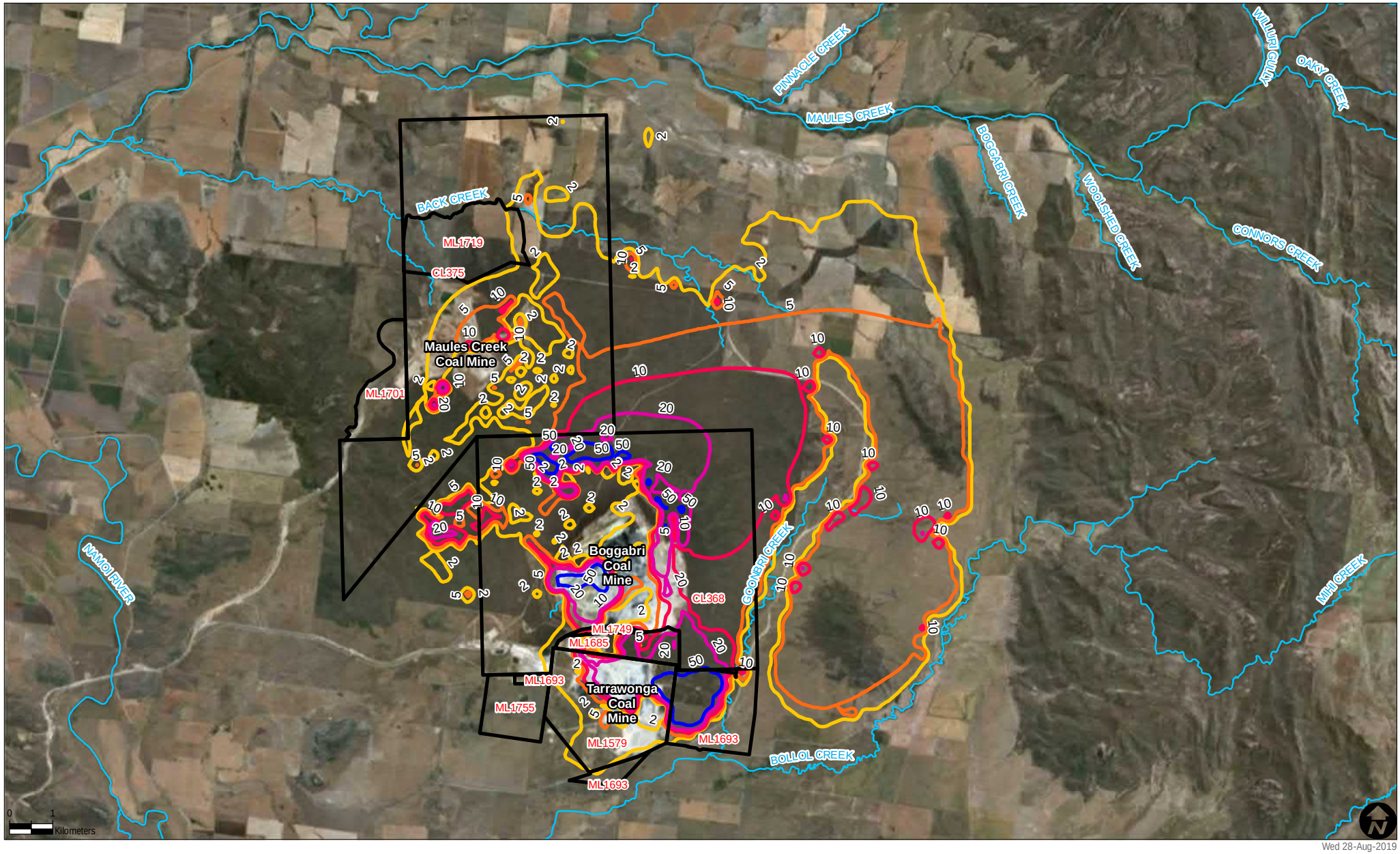
20

50

Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Maximum drawdown in the lowest Coal Seam (Modification)

FIGURE 46



X:\jgoffeau\665.WHI15\01 ArcGIS\665WHI15_Figure47_Max_Drawdown_Watertable.mxd

Wed 28-Aug-2019
665.WHI15

LEGEND

Mining Leases
Watercourses

Maximum Drawdown

2
5
10
20
50

Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Maximum drawdown of the watertable (Modification)

FIGURE 47

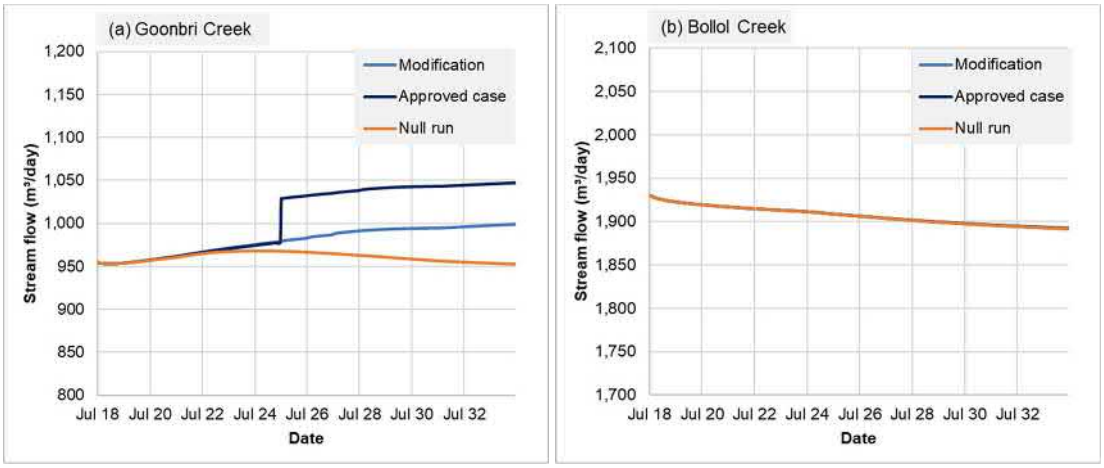


Figure 48 Stream Leakage at Goonbri Creek and Bollol Creek during the predictive period

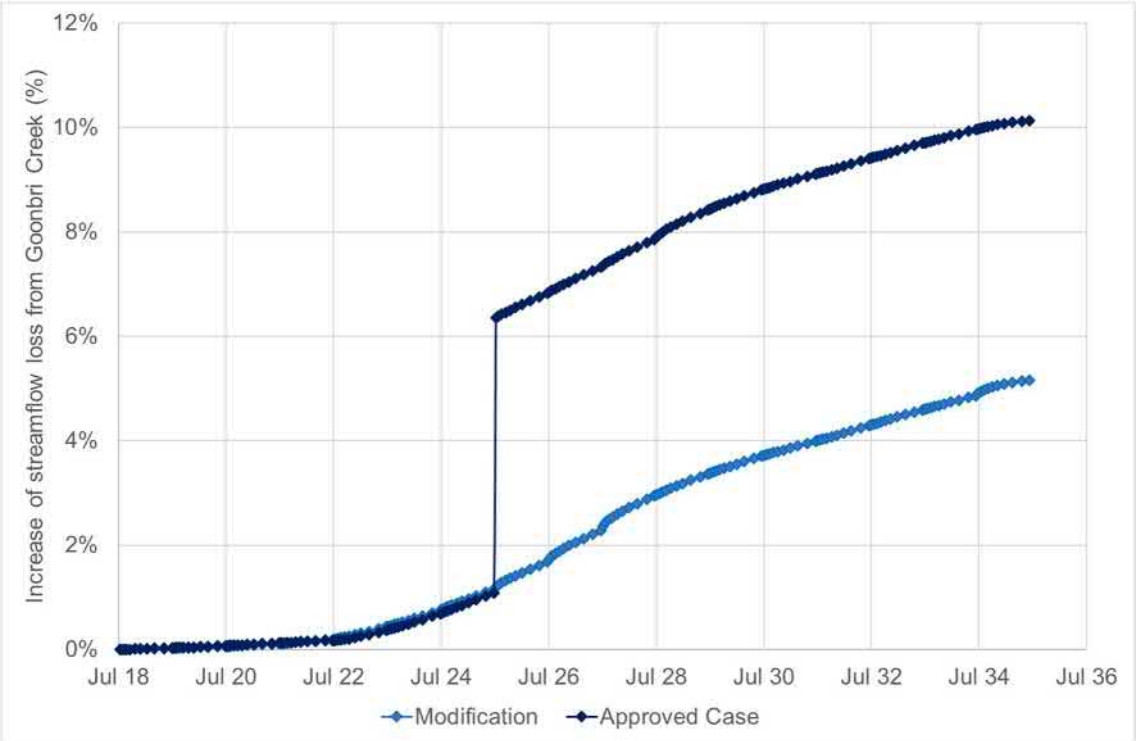


Figure 49 Change in Stream Leakage at Goonbri Creek for Approved Case and Modification compared with Null run

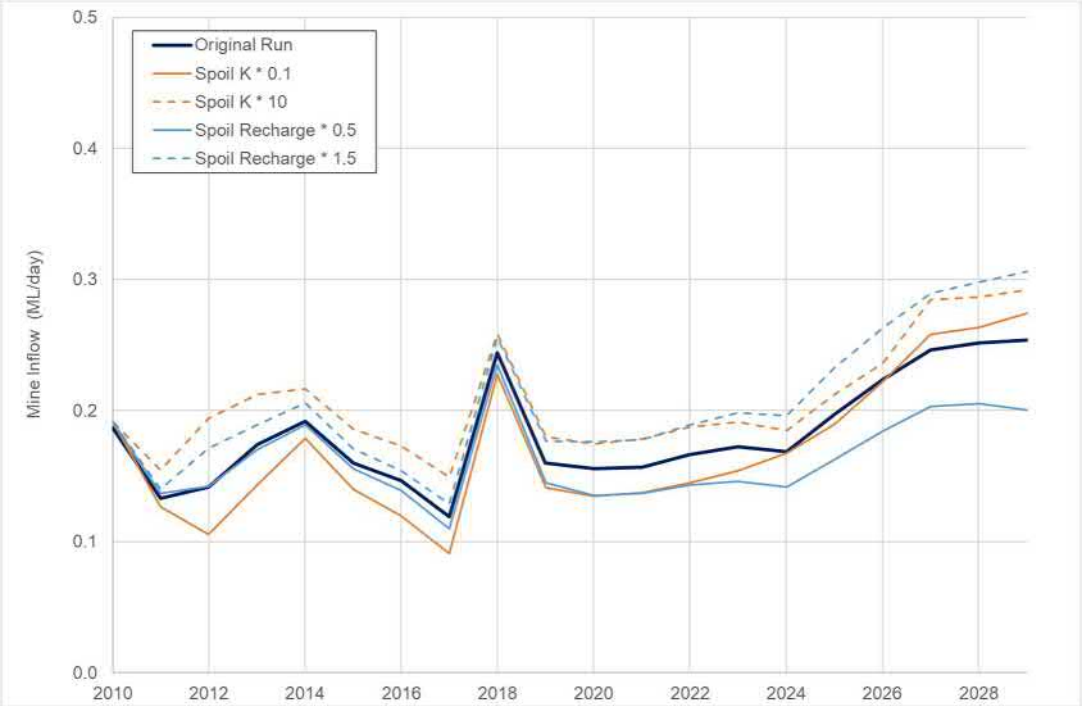
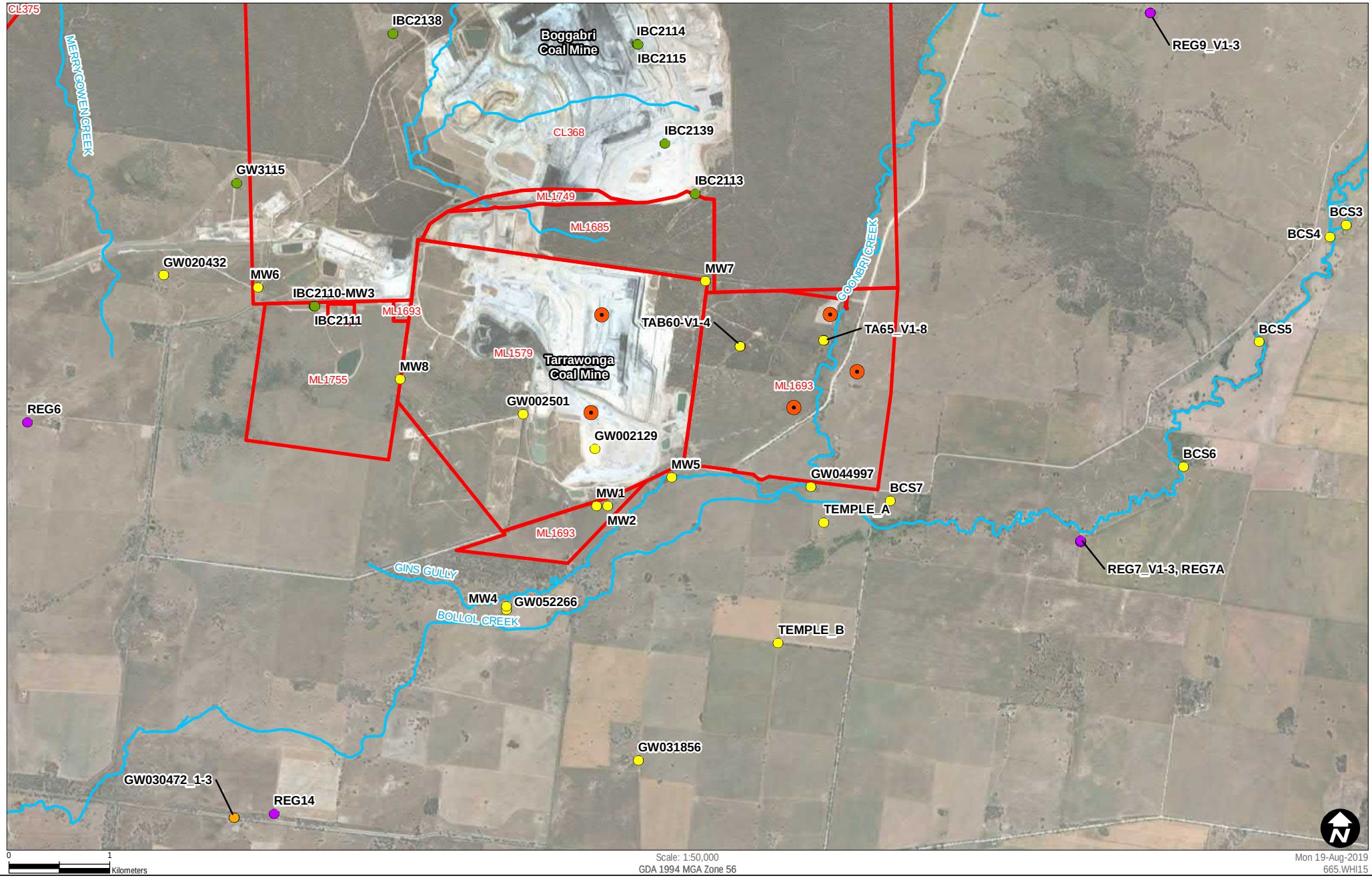


Figure 50 Pit inflows (Sensitivity analysis)



HYDRO SIMULATIONS

LEGEND

- Mining Leases
- Watercourses
- Suggested new monitoring bores

Local groundwater network for modelling

- Boggabri
- Cumulative
- DPI Water
- Tarrawonga

Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Existing and suggested monitoring bores

FIGURE 51

ATTACHMENT A – GROUNDWATER MONITORING NETWORK

Name	Location	Easting MGA94 Z56	Northing MGA94 Z56	Ground level (m AHD)	Target geology
BCM01	Maules Creek	223841	6618371	273.39	Alluvium
BCS1	Tarrawonga	237177	6610679	343	Alluvium
BCS2	Tarrawonga	236682	6609459	331	Alluvium
BCS3	Tarrawonga	236179	6608490	323	Alluvium
BCS4	Tarrawonga	236016	6608368	323	Alluvium
BCS5	Tarrawonga	235314	6607331	314	Alluvium
BCS6	Tarrawonga	234563	6606093	302	Alluvium
BCS7	Tarrawonga	231656	6605754	281.3	Alluvium
GW002129	Tarrawonga	228724	6606271	#NA	Coal Aquifer
GW002501	Tarrawonga	228013	6606613	291.1	Interburden
GW020432	Tarrawonga	224451	6607991	265	Volcanics
GW030129_1	DPI Water	217346	6620008	247.97	Alluvium
GW030130_1	DPI Water	217519.5	6620723	248.45	Alluvium
GW030130_2	DPI Water	217519.5	6620723	248.45	Alluvium
GW030131_01	DPI Water	217666.6	6622081	250.73	Alluvium
GW030233_01	DPI Water	210149.7	6626502	#N/A	#N/A
GW030233_03	DPI Water	210149.7	6626501	#N/A	#N/A
GW031856	Tarrawonga	229157	6603179	#NA	Alluvial
GW036005_02	DPI Water	211530.7	6615780	#N/A	#N/A
GW036186_01	DPI Water	214451.7	6618290	239.07	Alluvium
GW036187_01	DPI Water	215564.3	6618719	261.32	Alluvium

Name	Location	Easting MGA94 Z56	Northing MGA94 Z56	Ground level (m AHD)	Target geology
GW036433_1	DPI Water	209460	6587662	#N/A	#N/A
GW036434_1	DPI Water	209730	6586825	#N/A	#N/A
GW036434_2	DPI Water	209730	6586825	#N/A	#N/A
GW036434_3	DPI Water	209730	6586825	#N/A	#N/A
GW036435_1	DPI Water	210663	6586700	#N/A	#N/A
GW036435_2	DPI Water	210663	6586700	#N/A	#N/A
GW036435_3	DPI Water	210663	6586700	#N/A	#N/A
GW036436_1	DPI Water	211269	6586608	#N/A	#N/A
GW036436_2	DPI Water	211269	6586608	#N/A	#N/A
GW036436_3	DPI Water	211269	6586608	#N/A	#N/A
GW036440_1	DPI Water	212228	6586469	#N/A	#N/A
GW041027_01	DPI Water	232834.2	6620700	#N/A	#N/A
GW044997	DPI Water	230870	6605859	#N/A	Alluvium
GW052266	DPI Water	227848	6604674	#N/A	Alluvium
GW3115	DPI Water	225174	6608903	#N/A	Boggabri Volcanics
GW967137_1	DPI Water	220059.5	6622808	258.79	Alluvium
GW967137_2	DPI Water	220059.5	6622808	258.79	Alluvium
GW967138_1	DPI Water	227209	6622780	288.55	Alluvium
GW967138_2	DPI Water	227209	6622780	288.13	Alluvium
IBC2102	Boggabri	226892	6611771	322	Merriown Coal Seam
IBC2103	Boggabri	226898	6611773	321.8	Jeralong Coal Seam

Name	Location	Easting MGA94 Z56	Northing MGA94 Z56	Ground level (m AHD)	Target geology
IBC2104	Boggabri	228336	6612215	331.1	Braymont Coal Seam
IBC2105	Boggabri	228321	6612212	331.4	Merriown Coal Seam
IBC2110	Boggabri	225939	6607684	272.8	Boggabri Volcanics
IBC2111	Boggabri	225950	6607683	272.7	Boggabri Volcanics
IBC2114	Boggabri	229146	6610283	324.8	Bollol Creek Coal Seam
IBC2115	Boggabri	229155	6610279	325	Merriown Coal Seam
IBC2138	Boggabri	226725	6610387	294.5	Merriown Coal Seam
IBC2139	Boggabri	229421	6609296	319.4	Merriown Coal Seam
MW01	Tarrawonga	228743.4	6605704	269.51	Permian Coal Measures
MW02	Tarrawonga	228850.4	6605703	269.72	Alluvial
MW03	Tarrawonga	226041	6607875	#N/A	Volcanics
MW04	Tarrawonga	227848.3	6604710	262.67	Alluvial
MW05	Tarrawonga	229487.3	6605987	271.32	Alluvial
MW06	Tarrawonga	225385.7	6607866	264.41	Alluvial
MW07	Tarrawonga	229822.2	6607941	344.32	Permian Sediments
MW08	Tarrawonga	226794	6606958	280.93	Permian Sediments
RB01_1	Maules Creek	224058	6612333	#N/A	Braymont
RB01_2	Maules Creek	224058	6612333	#N/A	Merriown
RB01_3	Maules Creek	224058	6612333	#N/A	Flixton
RB02_1	Maules Creek	224860	6613267	#N/A	Braymont

Name	Location	Easting MGA94 Z56	Northing MGA94 Z56	Ground level (m AHD)	Target geology
RB02_2	Maules Creek	224860	6613267	#N/A	Merriown
RB02_3	Maules Creek	224860	6613267	#N/A	Nagero
RB02_4	Maules Creek	224860	6613267	#N/A	Northam
RB03_1	Maules Creek	227947	6613635	#N/A	Braymont
RB03_2	Maules Creek	227947	6613635	#N/A	Merriown
RB03_3	Maules Creek	227947	6613635	#N/A	Nagero
RB03_4	Maules Creek	227947	6613635	#N/A	Templemore
RB04_1	Maules Creek	228213	6614910	#N/A	Braymont
RB04_2	Maules Creek	228213	6614910	#N/A	Merriown
RB04_3	Maules Creek	228213	6614910	#N/A	Nagero
RB04_4	Maules Creek	228213	6614910	#N/A	Lower Northam
RB05_1	Cumulative	228071	6616813	#N/A	Braymont
RB05_2	Cumulative	228071	6616813	#N/A	Jeralong
RB05_3	Cumulative	228071	6616813	#N/A	Nagero
RB05_4	Cumulative	228071	6616813	#N/A	Templemore
RB05a	Maules Creek	228065	6616816	328.1	Merriown
Reg01_1	Cumulative	226946	6622396	#N/A	Jeralong
Reg01_2	Cumulative	226946	6622396	#N/A	Merriown
Reg01_3	Cumulative	226946	6622396	#N/A	Nagero
Reg01_4	Cumulative	226946	6622396	#N/A	Therribri
Reg02_1	Cumulative	232722	6620459	#N/A	Braymont

Name	Location	Easting MGA94 Z56	Northing MGA94 Z56	Ground level (m AHD)	Target geology
Reg02_2	Cumulative	232722	6620459	#N/A	Jeralong
Reg02_3	Cumulative	232722	6620459	#N/A	Merriown
Reg02_4	Cumulative	232722	6620459	#N/A	Therribri
Reg07_1	Cumulative	233543	6605348	#N/A	Braymont
Reg07_2	Cumulative	233543	6605348	#N/A	Merriown
Reg07_3	Cumulative	233543	6605348	#N/A	Nagero
Reg08_1	Cumulative	230030	6615113	#N/A	Braymont
Reg08_2	Cumulative	230030	6615113	#N/A	Merriown
Reg08_3	Cumulative	230030	6615113	#N/A	Nagero
Reg09_1	Cumulative	234233	6610591	#N/A	Braymont
Reg09_2	Cumulative	234233	6610591	#N/A	Merriown
Reg09_3	Cumulative	234233	6610591	#N/A	Nagero
Reg10_1	Cumulative	226723	6618261	#N/A	Braymont
Reg10_2	Cumulative	226723	6618261	#N/A	Merriown
Reg10_3	Cumulative	226723	6618261	#N/A	Nagero
Reg10_4	Cumulative	226723	6618261	#N/A	Upper Northam
Reg12	Cumulative	222632	6617358	285.61	Boggabri Volcanics
Reg13	Cumulative	219713	6611129	277.08	Boggabri Volcanics
Reg14	Cumulative	225547	6602649	250.18	Basement
Reg3	Cumulative	217140	6619454	241.6	Boggabri Volcanics
Reg4	Cumulative	219323	6612763	259.95	Boggabri Volcanics

Name	Location	Easting MGA94 Z56	Northing MGA94 Z56	Ground level (m AHD)	Target geology
Reg5	Cumulative	220649	6609521	252.17	Boggabri Volcanics
Reg5a	Cumulative	220646	6609514	252.03	Alluvium
Reg6	Cumulative	223100	6606534	250.65	Boggabri Volcanics
Reg7a	Cumulative	233545	6605359	291.71	Alluvium
TA60_69	Tarrawonga	230164	6607286	317.46	Velyama Interburden
TA60_89	Tarrawonga	230164	6607286	317.46	Velyama Interburden
TA60_109	Tarrawonga	230164	6607286	317.46	Velyama Seam
TA60_118	Tarrawonga	230164	6607286	317.46	Velyama-Nagero Interburden
TA65_30	Tarrawonga	230997	6607344	287.08	Jeralong Overburden
TA65_35	Tarrawonga	230997	6607344	287.08	Jeralong Seam
TA65_47	Tarrawonga	230997	6607344	287.08	Jeralong-Merriown Interburden
TA65_56	Tarrawonga	230997	6607344	287.08	Merriown Seam
TA65_97	Tarrawonga	230997	6607344	287.08	Velyama-Nagero Interburden
TA65_110	Tarrawonga	230997	6607344	287.08	Nagero Seam
TA65_136	Tarrawonga	230997	6607344	287.08	Nagero-Upper Northam Interburden
TA65_153	Tarrawonga	230997	6607344	287.08	Upper Northam Seam
Templemore A	Tarrawonga	230997	6605537	#N/A	Uncertain
Templemore B	Tarrawonga	230544	6604345	#N/A	Uncertain

ATTACHMENT B – GROUNDWATER QUALITY SUMMARY TABLE

		DEFAULT GUIDELINE VALUES (DGV)	NHMRC DRINKING WATER	ANZECC (2000) FRESH WATER AQUATIC	ANZECC (2000) SHORT-TERM IRRIGATION	ANZECC (2000) LONG-TERM IRRIGATION	ANZECC (2000) STOCK WATER	TA ALLUVIUM	MC ALLUVIUM	TA INTER-BURDEN	MC COAL	TA - VOLCANICS	MC - VOLCANICS	UNCERTAIN (TEMPLEMORE)
PH (FIELD)	Av.	-	6.5 - 8.5[b]	6.5 – 8.5	6.0 - 8.5	6.0 - 8.5	-	7.70	7.32	7.46	7.36	7.70	**8.85**	7.48
	Med.							7.80	7.31	7.50	7.38	7.80	8.06	7.40
	Min.							6.80	6.79	6.70	6.83	6.80	7.05	6.75
	Max.							8.41	7.86	8.32	7.80	8.41	**12.36**	8.01
	Pop.							*34*	*17*	*61*	*19*	*34*	*101*	*67*
EC (FIELD)	Av.	-	-	120 - 300	-	-	-	1790	839	3074	1728	1647	1919	1343
	Med.							1132	814	3170	1741	1740	1939	1400
	Min.							215	742	2010	1533	2	786	810
	Max.							6900	1230	5470	1881	2150	4620	1810
	Pop.							*238*	*18*	*55*	*18*	*18*	*101*	*67*
TDS	Av.	-	600[b]	-	-	-	3,000 - 13,000*	1087	452	1840	964	947	1050	823
	Med.							684	451	1850	966	1010	813	828
	Min.							182	354	1380	761	720	78	500
	Max.							**3630**	606	2320	1100	1190	2760	1200
	Pop.							*85*	*18*	*20*	*18*	*9*	*104*	*28*
CHLORIDE	Av.	-	250[b]	-	-	-	-	**324**	53	**523**	227	197	225	207
	Med.							149	53	**520**	219	127	178	208
	Min.							5	40	0.5	176	103	0.5	103
	Max.							**2230**	84	**2680**	**337**	**397**	**532**	**326**
	Pop.							*148*	*19*	*39*	*19*	*13*	*108*	*36*

		DEFAULT GUIDELINE VALUES (DGV)	NHMRC DRINKING WATER	ANZECC (2000) FRESH WATER AQUATIC	ANZECC (2000) SHORT-TERM IRRIGATION	ANZECC (2000) LONG-TERM IRRIGATION	ANZECC (2000) STOCK WATER	TA ALLUVIUM	MC ALLUVIUM	TA INTER-BURDEN	MC COAL	TA - VOLCANICS	MC - VOLCANICS	UNCERTAIN (TEMPLEMORE)
CALCIUM	Av.	-	-	-	-	-	1,000	53	51	48	73	17	65	100
	Med.							48	52	39	72	17	32	96
	Min.							1	41	5	56	10	0.5	31
	Max.							220	62	196	89	29	286	175
	Pop.							*148*	*19*	*39*	*19*	*14*	*108*	*36*
SODIUM	Av.	-	180[b]	-	-	-	-	**338**	97	**623**	**264**	**370**	**295**	148
	Med.							**192**	97	**614**	**264**	**420**	**258**	150
	Min.							13	79	**298**	**205**	3	70	54
	Max.							**1870**	111	**1710**	**401**	**504**	**497**	**248**
	Pop.							*148*	*19*	*39*	*19*	*14*	*108*	*36*
MAGNESIUM	Av.	-	-	-	-	-	-	38	24	49	35	6	19	32
	Med.							26	24	45	35	5	8	30
	Min.							0.5	20	21	26	4	0.5	20
	Max.							183	30	138	45	10	186	52
	Pop.							*148*	*19*	*39*	*19*	*14*	*108*	*36*
SULPHATE	Av.	-	500[a] / **250[b]**	-	-	-	1,000 – 2,400 (pigs)	90	34	146	86	34	236	109
	Med.							46	35	188	87	33	74	106
	Min.							3.1	20	5	46	0.5	8	49
	Max.							**678**	47	424	112	83	**1340**	181
	Pop.							*144*	*19*	*39*	*19*	*14*	*108*	*34*

		DEFAULT GUIDELINE VALUES (DGV)	NHMRC DRINKING WATER	ANZECC (2000) FRESH WATER AQUATIC	ANZECC (2000) SHORT-TERM IRRIGATION	ANZECC (2000) LONG-TERM IRRIGATION	ANZECC (2000) STOCK WATER	TA ALLUVIUM	MC ALLUVIUM	TA INTER-BURDEN	MC COAL	TA - VOLCANICS	MC - VOLCANICS	UNCERTAIN (TEMPLEMORE)
POTASSIUM	Av.	-	-	-	-	-	-	6	2	20	9	65	20	3
	Med.							4.8	2	22	8	4	6	2
	Min.							0.5	1	7	6	3	0.02	1
	Max.							28	2	43	12	454	159	9
	Pop.							*148*	*19*	*39*	*19*	*14*	*108*	*36*
BICARBONATE	Av.	-	-	-	-	-	-	454	402	781	653	310	382	640
	Med.							415	401	711	639	315	366	715
	Min.							66	360	620	505	189	1	348
	Max.							1110	479	1140	800	426	1113	871
	Pop.							*114*	*19*	*26*	*19*	*36*	*108*	*11*
ALUMINIUM (T) FOR TA (D) FOR MC	Av.	***0.055***	***0.2***[b c]	*0.055*	*20*	*5*	*5*	**1.43**	0.010	**0.23**	0.009	NR	0.016	**0.15**
	Med.							**0.15**	0.005	**0.105**	0.005	NR	0.005	**0.06**
	Min.							0.005	0.0005	0.005	0.005	NR	0.0005	0.005
	Max.							**18.3**	0.06	**1.23**	0.05	NR	0.7	**1.68**
	Pop.							*102*	*19*	*22*	*19*	*0*	*108*	*32*
ARSENIC (T) FOR TA (D) FOR MC	Av.	As (III) 0.024; As (V) 0.013	0.01[a]	As (III) 0.024 As (V) 0.013	2	0.1	0.5	0.004	0.006	0.001	0.001	0.001	0.003	0.003
	Med.							0.002	0.006	0.001	0.0005	0.00075	0.001	0.003
	Min.							0.0001	0.003	0.0005	0.0005	0.0005	0.0002	0.002
	Max.							0.066	0.009	0.006	0.002	0.003	0.068	0.004
	Pop.							*148*	*19*	*39*	*19*	*14*	*108*	*36*

		DEFAULT GUIDELINE VALUES (DGV)	NHMRC DRINKING WATER	ANZECC (2000) FRESH WATER AQUATIC	ANZECC (2000) SHORT-TERM IRRIGATION	ANZECC (2000) LONG-TERM IRRIGATION	ANZECC (2000) STOCK WATER	TA ALLUVIUM	MC ALLUVIUM	TA INTER-BURDEN	MC COAL	TA - VOLCANICS	MC - VOLCANICS	UNCERTAIN (TEMPLEMORE)
BARIUM (T)	Av.	-	2[a]	-	-	-	-	0.139	NR	0.098	NR	NR	NR	0.089
	Med.							0.085	NR	0.068	NR	NR	NR	0.074
	Min.							0.006	NR	0.047	NR	NR	NR	0.025
	Max.							1.840	NR	0.227	NR	NR	NR	0.266
	Pop.							*86*	*0*	*20*	*0*	*0*	*0*	*28*
BERYLLIUM (T)	Av.	0.00013 (low reliability	0.06[a]	-	0.5	0.1	-	0.012	NR	0.001	NR	NR	NR	0.013
	Med.							0.001	NR	0.001	NR	NR	NR	0.001
	Min.							0.001	NR	0.001	NR	NR	NR	0.001
	Max.							0.182	NR	0.001	NR	NR	NR	**0.119**
	Pop.							*86*	*0*	*20*	*0*	*0*	*0*	*28*
BORON (T)	Av.	0.37	4[a]	0.37	refer to guideline	0.5	7 (cattle)	0.0288	NR	0.0294	NR	NR	NR	0.0189
	Med.							0.0250	NR	0.0250	NR	NR	NR	0.0250
	Min.							0.0005	NR	0.0250	NR	NR	NR	0.0005
	Max.							0.1400	NR	0.0600	NR	NR	NR	0.0250
	Pop.							*49*	*0*	*8*	*0*	*0*	*0*	*16*
CADMIUM (T)	Av.	0.0002	0.002[a]	0.0002	0.05	0.01	0.01	0.00018	0.00005	0.00007	0.00005	0.00005	0.00019	0.00006
	Med.							0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005
	Min.							0.00003	0.00005	0.00003	0.00005	0.00005	0.00005	0.00005
	Max.							**0.00900**	0.00005	**0.00040**	0.00005	0.00010	**0.01500**	0.00020
	Pop.							*114*	*19*	*30*	*19*	*12*	*108*	*28*

		DEFAULT GUIDELINE VALUES (DGV)	NHMRC DRINKING WATER	ANZECC (2000) FRESH WATER AQUATIC	ANZECC (2000) SHORT-TERM IRRIGATION	ANZECC (2000) LONG-TERM IRRIGATION	ANZECC (2000) STOCK WATER	TA ALLUVIUM	MC ALLUVIUM	TA INTER-BURDEN	MC COAL	TA - VOLCANICS	MC - VOLCANICS	UNCERTAIN (TEMPLEMORE)
CHROMIUM (T)	Av.	Cr (III) - 0.0033 (low reliability); Cr (VI) 0.0004	0.05[a]	CrIII – ID Cr(VI) 0.001	1	0.1	1	0.0046	0.001	0.0044	0.001	0.002	0.008	0.0005
	Med.							0.002	0.0005	0.0025	0.0005	0.00075	0.0005	0.0005
	Min.							0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
	Max.							**0.11**	0.002	0.023	0.0005	0.008	**0.116**	0.001
	Pop.							*141*	*12*	*36*	*11*	*12*	*66*	*36*
COBALT (T)	Av.	0.0028 (low reliability)	-	-	0.1	0.05	1	0.0033	NR	0.0054	NR	0.0005	NR	0.0005
	Med.							0.0005	NR	0.0005	NR	0.0005	NR	0.0005
	Min.							0.0005	NR	0.0005	NR	0.0005	NR	0.0005
	Max.							0.058	NR	0.094	NR	0.0005	NR	0.001
	Pop.							*86*	*0*	*21*	*0*	*1*	*0*	*28*
COPPER (T) FOR TA (D) FOR MC	Av.	0.0014	2[a] / 1[b]	0.0014	5	0.2	1 (cattle)	0.0299	0.002	0.0529	0.001	0.0035	0.002	0.0252
	Med.							0.0095	0.001	0.032	0.0005	0.001	0.0005	0.015
	Min.							0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
	Max.							**0.324**	0.008	**0.487**	0.002	0.028	0.023	**0.142**
	Pop.							*140*	*19*	*35*	*19*	*13*	*108*	*36*
IRON (T)	Av.	0.3 (ID - interim indicative working level)	0.3[b]	-	10	0.2	-	**4.192**	NR	**0.869**	NR	**0.113**	NR	**0.340**
	Med.							**0.695**	NR	**0.480**	NR	0.025	NR	0.110
	Min.							0.025	NR	0.025	NR	0.003	NR	0.025
	Max.							**88.300**	NR	**3.810**	NR	**0.490**	NR	**2.560**
	Pop.							*114*	*0*	*26*	*0*	*11*	*0*	*35*

		DEFAULT GUIDELINE VALUES (DGV)	NHMRC DRINKING WATER	ANZECC (2000) FRESH WATER AQUATIC	ANZECC (2000) SHORT-TERM IRRIGATION	ANZECC (2000) LONG-TERM IRRIGATION	ANZECC (2000) STOCK WATER	TA ALLUVIUM	MC ALLUVIUM	TA INTER-BURDEN	MC COAL	TA - VOLCANICS	MC - VOLCANICS	UNCERTAIN (TEMPLEMORE)
LEAD (T) FOR TA (D) FOR MC	Av.	0.0034	0.01[a]	0.0034	5	2	0.1	0.0149	0.001	0.0338	0.001	0.0005	0.004	0.0017
	Med.							0.002	0.0005	0.0055	0.0005	0.0005	0.0005	0.0005
	Min.							0.0002	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
	Max.							0.44	0.0005	0.37	0.0005	0.0005	0.381	0.012
	Pop.							*139*	*19*	*36*	*19*	*13*	*108*	*36*
MANGANESE (T)	Av.	0.19	0.5[a] / **0.1**[b]	1.9	10	0.2	-	0.200	0.883	0.131	0.073	NR	0.141	0.285
	Med.							0.061	0.711	0.076	0.071	NR	0.0975	0.016
	Min.							0.0005	0.005	0.016	0.054	NR	0.0005	0.003
	Max.							1.82	**2.53**	0.708	0.099	NR	1.11	**3.31**
	Pop.							*114*	*19*	*26*	*19*	*0*	*108*	*36*
MERCURY (T)	Av.	0.0006	-	0.0006	0.002	0.002	0.002	0.00008	NR	0.00005	NR	NR	NR	0.00005
	Med.							0.00005	NR	0.00005	NR	NR	NR	0.00005
	Min.							0.00005	NR	0.000005	NR	NR	NR	0.00005
	Max.							0.001	NR	0.0002	NR	NR	NR	0.0001
	Pop.							*141*	*0*	*35*	*0*	*0*	*0*	*36*
MOLYBDENUM (T) FOR TA (D) FOR MC	Av.	0.034 (low reliability)	0.05[a]	-	0.05	0.01	0.15	NR	0.001	NR	0.005	NR	**8.950**	NR
	Med.							NR	0.00075	NR	0.004	NR	**0.012**	NR
	Min.							NR	0.0005	NR	0.003	NR	0.002	NR
	Max.							NR	0.003	NR	0.01	NR	**420**	NR
	Pop.							*0*	*8*	*0*	*10*	*0*	*47*	*0*

		DEFAULT GUIDELINE VALUES (DGV)	NHMRC DRINKING WATER	ANZECC (2000) FRESH WATER AQUATIC	ANZECC (2000) SHORT-TERM IRRIGATION	ANZECC (2000) LONG-TERM IRRIGATION	ANZECC (2000) STOCK WATER	TA ALLUVIUM	MC ALLUVIUM	TA INTER-BURDEN	MC COAL	TA - VOLCANICS	MC - VOLCANICS	UNCERTAIN (TEMPLEMORE)
NICKEL (T) FOR TA (D) FOR MC	Av.	0.011	0.02[a]	0.011	2	0.2	1	0.0096	0.002	0.012	0.013	0.0045	0.003	0.0016
	Med.							0.004	0.002	0.009	0.006	0.003	0.002	0.0005
	Min.							0.0005	0.0005	0.004	0.003	0.002	0.0005	0.0005
	Max.							0.16	0.011	0.038	0.079	0.013	0.02	0.006
	Pop.							*141*	*19*	*36*	*19*	*13*	*108*	*36*
SELENIUM (T)	Av.	Total - 0.011; Sel (IV) - ID	0.01[a]	Total – 0.011 SelIV - ID	0.05	0.02	0.02	0.005	NR	0.005	NR	NR	NR	0.005
	Med.							0.005	NR	0.005	NR	NR	NR	0.005
	Min.							0.0005	NR	0.005	NR	NR	NR	0.005
	Max.							0.005	NR	0.005	NR	NR	NR	0.005
	Pop.							*49*	*0*	*9*	*0*	*0*	*0*	*16*
ZINC (T)	Av.	0.008	3[b]	0.008	2	2	20	0.192	0.030	0.104	0.038	0.069	0.022	0.075
	Med.							0.087	0.028	0.085	0.024	0.0155	0.011	0.046
	Min.							0.0025	0.0025	0.007	0.007	0.005	0.0025	0.019
	Max.							**2.29**	0.076	0.624	0.122	0.584	0.226	0.279
	Pop.							*142*	*19*	*35*	*19*	*12*	*108*	*36*

Note: This is a summary of the water quality data sampled by third parties and provided by TCPL. The data did not undergo a QA/QC check by SLR.

ATTACHMENT C – MODEL STRESS PERIODS

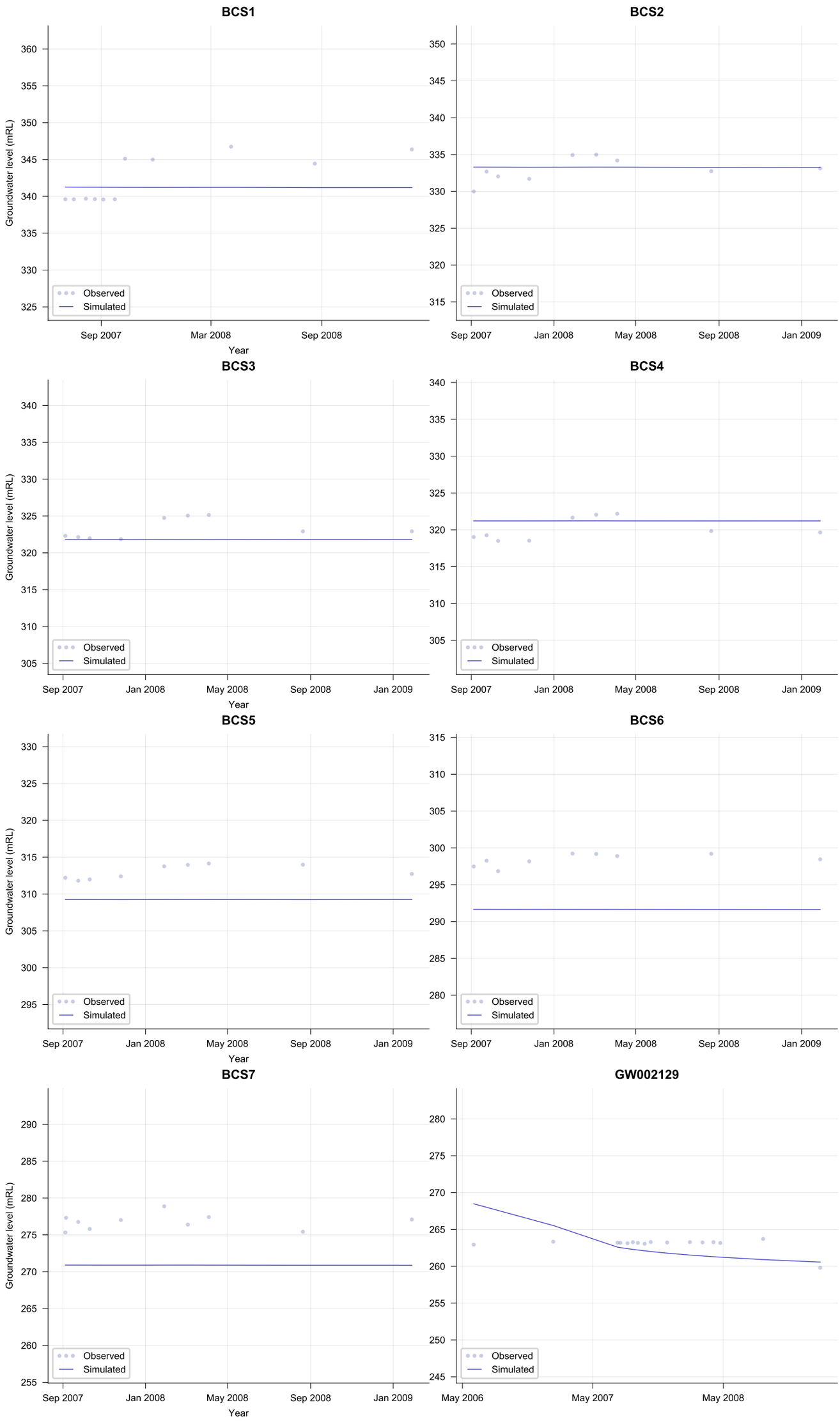
Model Purpose	Model Type	Stress Period	Start Date	End Date	Period Length	Tarrawonga Pit Layers 1-8	Boggabri Pit Layers 1-6	Maules Creek Pit Layers 1-4	Rocglen Pit Layers 1-10
CALIBRATION	Transient	1	01/01/2006	31/01/2006	Monthly				
	Transient	2	01/02/2006	28/02/2006	Monthly				
	Transient	3	01/03/2006	31/03/2006	Monthly				
	Transient	4	01/04/2006	30/04/2006	Monthly				
	Transient	5	01/05/2006	31/05/2006	Monthly				
	Transient	6	01/06/2006	30/06/2006	Monthly				
	Transient	7	01/07/2006	31/07/2006	Monthly				
	Transient	8	01/08/2006	31/08/2006	Monthly				
	Transient	9	01/09/2006	30/09/2006	Monthly	Open Cut	Open Cut		
	Transient	10	01/10/2006	31/10/2006	Monthly				
	Transient	11	01/11/2006	30/11/2006	Monthly				
	Transient	12	01/12/2006	31/12/2006	Monthly				
	Transient	13	01/01/2007	31/01/2007	Monthly				
	Transient	14	01/02/2007	28/02/2007	Monthly				
	Transient	15	01/03/2007	31/03/2007	Monthly				
	Transient	16	01/04/2007	30/04/2007	Monthly				
	Transient	17	01/05/2007	31/05/2007	Monthly				
	Transient	18	01/06/2007	30/06/2007	Monthly				
	Transient	19	01/07/2007	31/07/2007	Monthly				
	Transient	20	01/08/2007	31/08/2007	Monthly				
	Transient	21	01/09/2007	30/09/2007	Monthly				
	Transient	22	01/10/2007	31/10/2007	Monthly				
	Transient	23	01/11/2007	30/11/2007	Monthly				
	Transient	24	01/12/2007	31/12/2007	Monthly				
	Transient	25	01/01/2008	31/01/2008	Monthly				
	Transient	26	01/02/2008	29/02/2008	Monthly				
	Transient	27	01/03/2008	31/03/2008	Monthly				
	Transient	28	01/04/2008	30/04/2008	Monthly				
	Transient	29	01/05/2008	31/05/2008	Monthly				
	Transient	30	01/06/2008	30/06/2008	Monthly				
	Transient	31	01/07/2008	31/07/2008	Monthly				
	Transient	32	01/08/2008	31/08/2008	Monthly				
	Transient	33	01/09/2008	30/09/2008	Monthly				
	Transient	34	01/10/2008	31/10/2008	Monthly				
	Transient	35	01/11/2008	30/11/2008	Monthly				
	Transient	36	01/12/2008	31/12/2008	Monthly				
	Transient	37	01/01/2009	31/01/2009	Monthly				
	Transient	38	01/02/2009	28/02/2009	Monthly				
	Transient	39	01/03/2009	31/03/2009	Monthly				
	Transient	40	01/04/2009	30/04/2009	Monthly				
	Transient	41	01/05/2009	31/05/2009	Monthly				
	Transient	42	01/06/2009	30/06/2009	Monthly				
	Transient	43	01/07/2009	31/07/2009	Monthly				
	Transient	44	01/08/2009	31/08/2009	Monthly				
	Transient	45	01/09/2009	30/09/2009	Monthly				
	Transient	46	01/10/2009	31/10/2009	Monthly				
	Transient	47	01/11/2009	30/11/2009	Monthly				
	Transient	48	01/12/2009	31/12/2009	Monthly				
	Transient	49	01/01/2010	31/01/2010	Monthly				
	Transient	50	01/02/2010	28/02/2010	Monthly				
	Transient	51	01/03/2010	31/03/2010	Monthly				
	Transient	52	01/04/2010	30/04/2010	Monthly				
	Transient	53	01/05/2010	31/05/2010	Monthly				
	Transient	54	01/06/2010	30/06/2010	Monthly				
	Transient	55	01/07/2010	31/07/2010	Monthly				
	Transient	56	01/08/2010	31/08/2010	Monthly				
	Transient	57	01/09/2010	30/09/2010	Monthly				
	Transient	58	01/10/2010	31/10/2010	Monthly				
	Transient	59	01/11/2010	30/11/2010	Monthly				

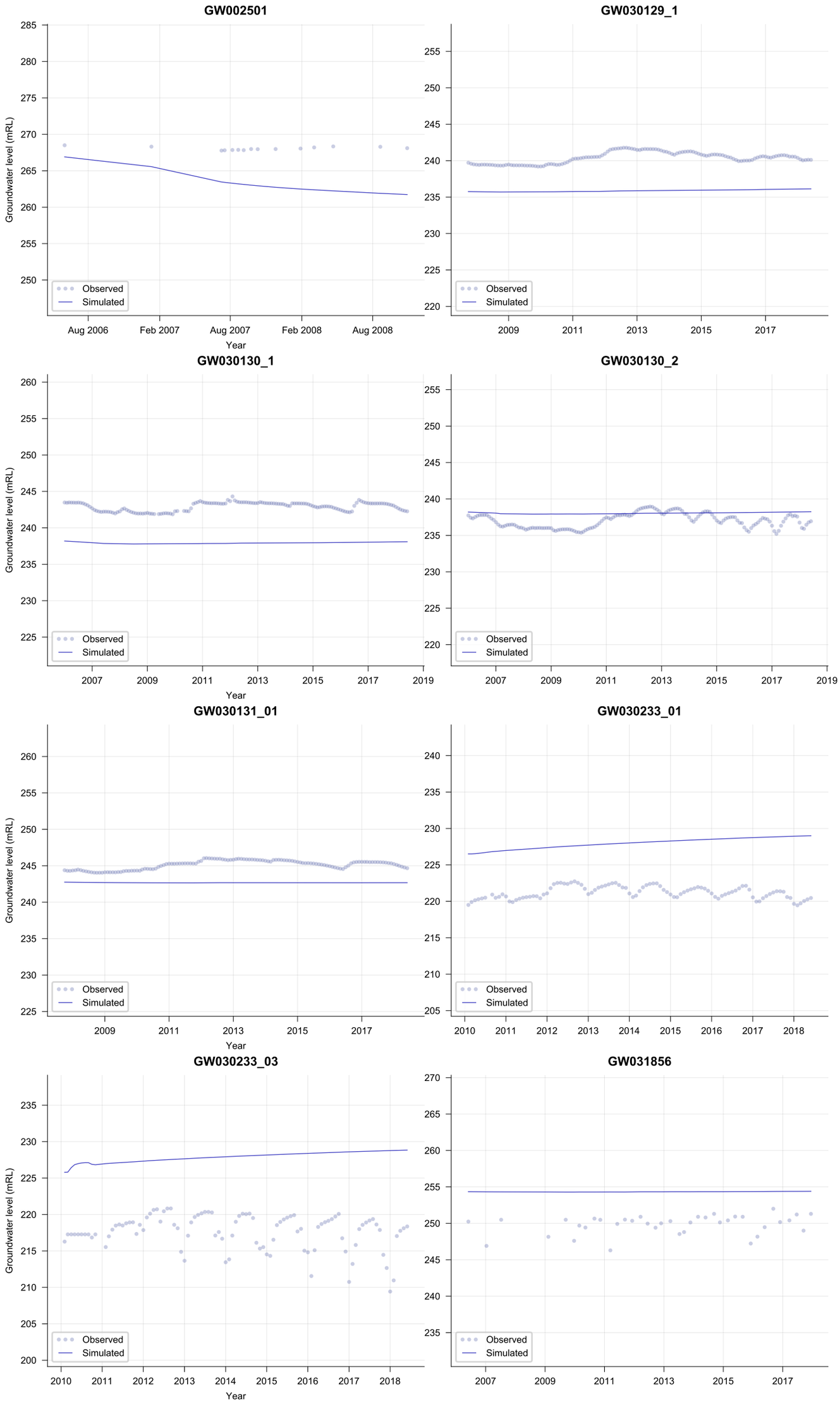
Model Purpose	Model Type	Stress Period	Start Date	End Date	Period Length	Tarrawonga Pit Layers 1-8	Boggabri Pit Layers 1-6	Maules Creek Pit Layers 1-4	Rocglen Pit Layers 1-10
CALIBRATION	Transient	60	01/12/2010	31/12/2010	Monthly				
	Transient	61	01/01/2011	31/03/2011	Quarterly	Open Cut and Backfilled	Open Cut and Backfilled		Open Cut and Backfilled
	Transient	62	01/04/2011	30/06/2011	Quarterly				
	Transient	63	01/07/2011	30/09/2011	Quarterly				
	Transient	64	01/10/2011	31/12/2011	Quarterly				
	Transient	65	01/01/2012	31/03/2012	Quarterly				
	Transient	66	01/04/2012	30/06/2012	Quarterly				
	Transient	67	01/07/2012	30/09/2012	Quarterly				
	Transient	68	01/10/2012	31/12/2012	Quarterly				
	Transient	69	01/01/2013	31/03/2013	Quarterly				
	Transient	70	01/04/2013	30/06/2013	Quarterly				
	Transient	71	01/07/2013	30/09/2013	Quarterly				
	Transient	72	01/10/2013	31/12/2013	Quarterly				
	Transient	73	01/01/2014	31/03/2014	Quarterly			Open Cut and Backfilled	
	Transient	74	01/04/2014	30/06/2014	Quarterly				
	Transient	75	01/07/2014	30/09/2014	Quarterly				
	Transient	76	01/10/2014	31/12/2014	Quarterly				
	Transient	77	01/01/2015	31/03/2015	Quarterly				
	Transient	78	01/04/2015	30/06/2015	Quarterly				
	Transient	79	01/07/2015	30/09/2015	Quarterly				
	Transient	80	01/10/2015	31/12/2015	Quarterly				
	Transient	81	01/01/2016	31/03/2016	Quarterly				
	Transient	82	01/04/2016	30/06/2016	Quarterly				
	Transient	83	01/07/2016	30/09/2016	Quarterly				
	Transient	84	01/10/2016	31/12/2016	Quarterly				
	Transient	85	01/01/2017	31/03/2017	Quarterly				Backfilled
	Transient	86	01/04/2017	30/06/2017	Quarterly				
	Transient	87	01/07/2017	30/09/2017	Quarterly				
	Transient	88	01/10/2017	31/12/2017	Quarterly				
	Transient	89	01/01/2018	31/03/2018	Quarterly				
	Transient	90	01/04/2018	30/06/2018	Quarterly				
PREDICTION	Transient	91	01/07/2018	30/06/2019	Yearly	Open Cut and Backfilled	Open Cut and Backfilled	Open Cut and Backfilled	Backfilled
	Transient	92	01/07/2019	30/06/2020	Yearly				
	Transient	93	01/07/2020	30/06/2021	Yearly				
	Transient	94	01/07/2021	30/06/2022	Yearly				
	Transient	95	01/07/2022	30/06/2023	Yearly				
	Transient	96	01/07/2023	30/06/2024	Yearly				
	Transient	97	01/07/2024	30/06/2025	Yearly				
	Transient	98	01/07/2025	30/06/2026	Yearly				
	Transient	99	01/07/2026	30/06/2027	Yearly				
	Transient	100	01/07/2027	30/06/2028	Yearly				
	Transient	101	01/07/2028	30/06/2029	Yearly	Backfilled and Open Void			
	Transient	102	01/07/2029	30/06/2030	Yearly				
	Transient	103	01/07/2030	30/06/2031	Yearly				
	Transient	104	01/07/2031	30/06/2032	Yearly				
	Transient	105	01/07/2032	30/06/2033	Yearly				
	Transient	106	01/07/2033	30/06/2034	Yearly				
	Transient	107	01/07/2034	30/06/2035	Yearly		Backfilled		
RECOVERY	Transient	1	01/07/2035	30/06/2055	20 Years	Backfilled and Open Void	Backfilled	Backfilled	Backfilled
	Transient	2	01/07/2055	30/06/2075	20 Years				
	Transient	3	01/07/2075	30/06/2095	20 Years				
	Transient	4	01/07/2095	30/06/2115	20 Years				
	Transient	5	01/07/2115	30/06/2135	20 Years				
	Transient	6	01/07/2135	30/06/2235	100 years				
	Transient	7	01/07/2235	30/06/2335	100 years				
	Transient	8	01/07/2335	30/06/2435	100 years				
	Transient	9	01/07/2435	30/06/2535	100 years				

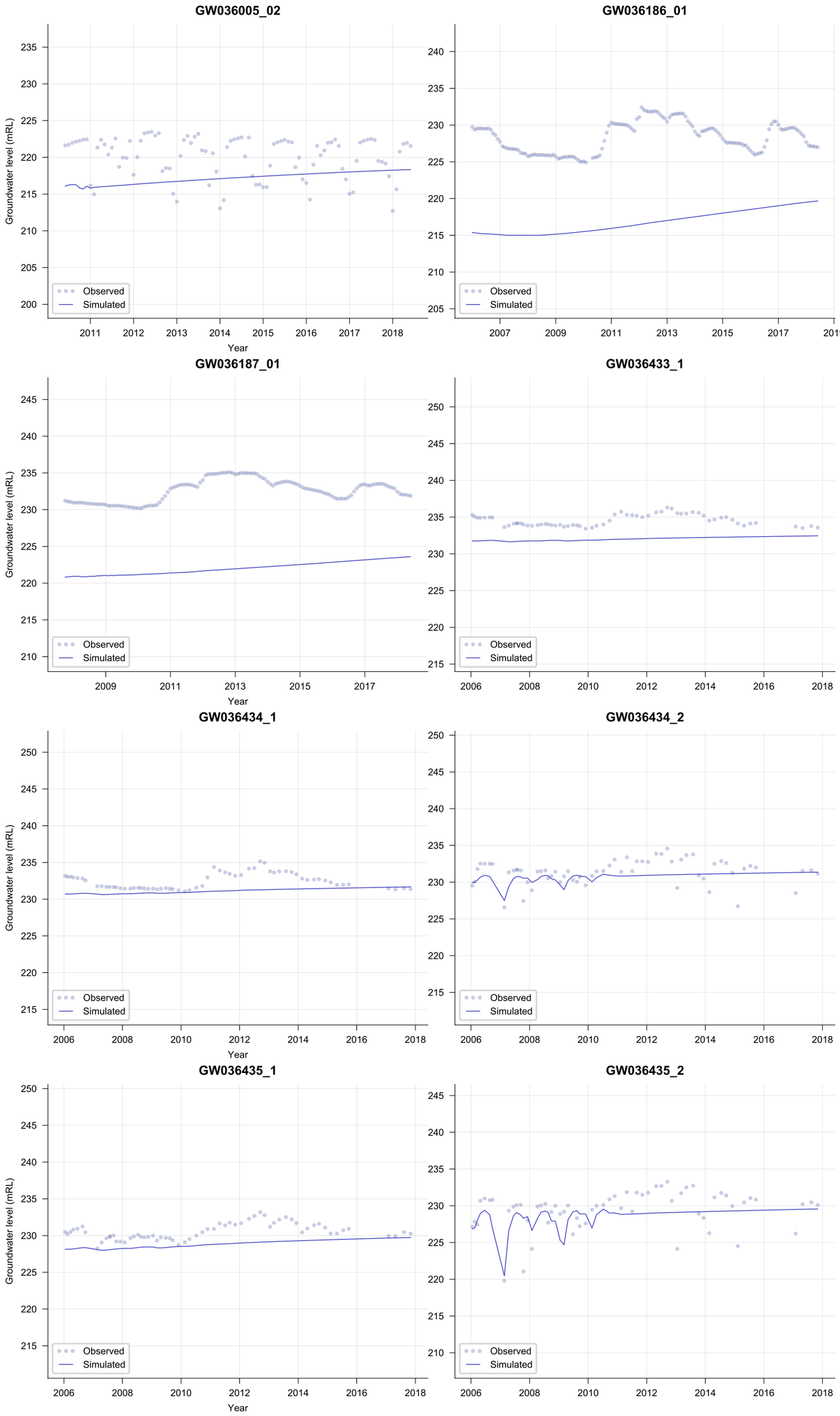
ATTACHMENT D – CALIBRATION HYDROGRAPHS

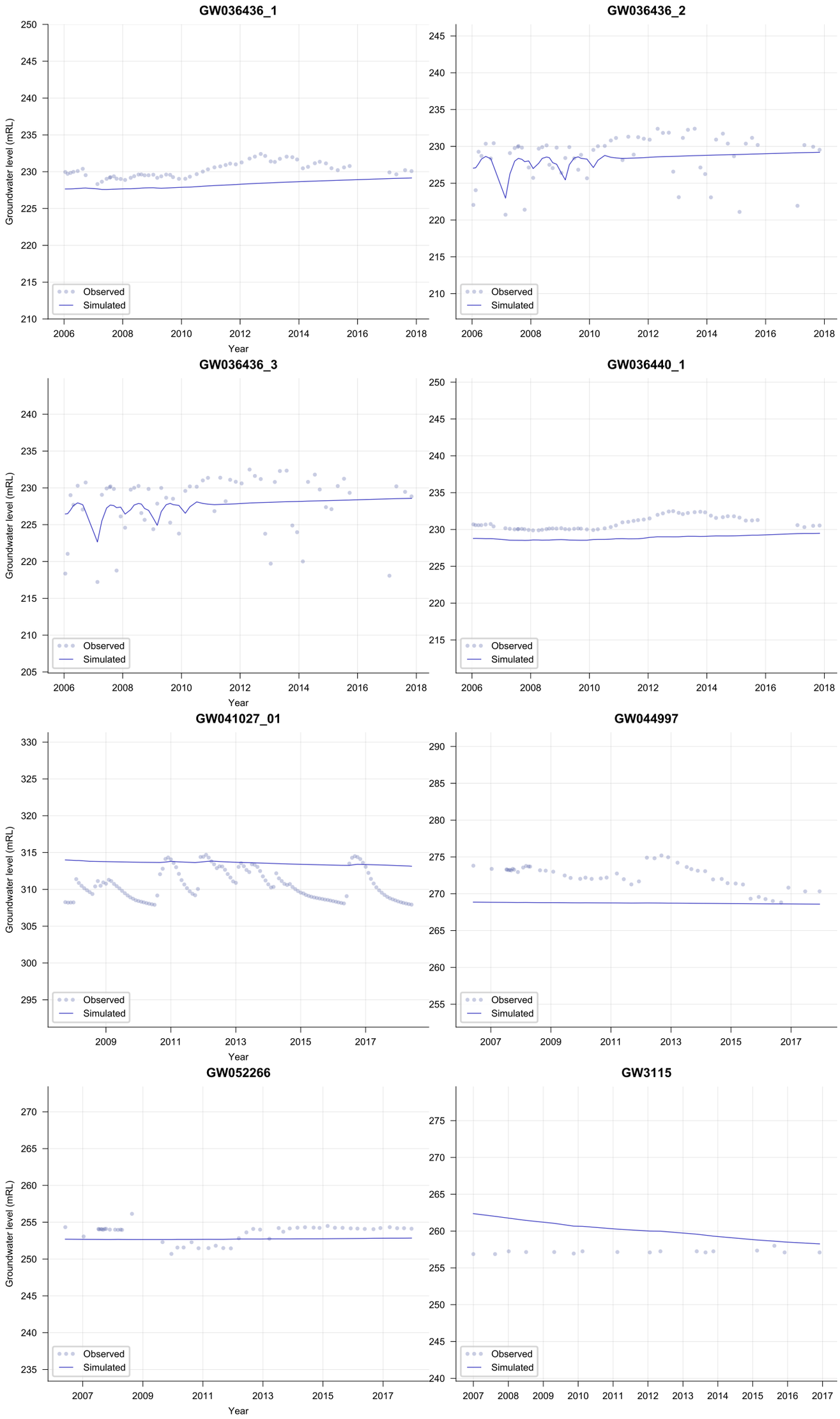
ATTACHMENT D

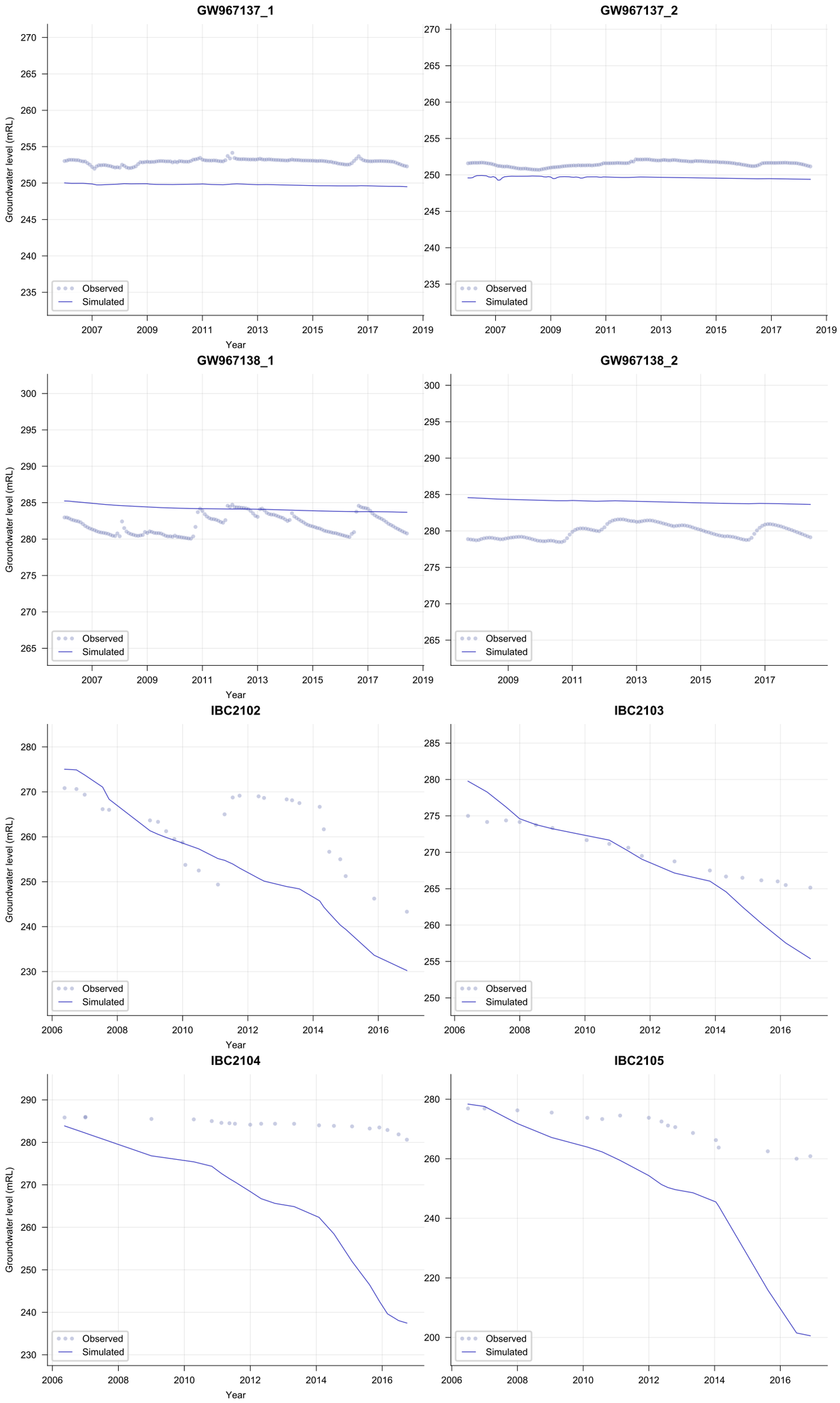
Calibration Hydrographs

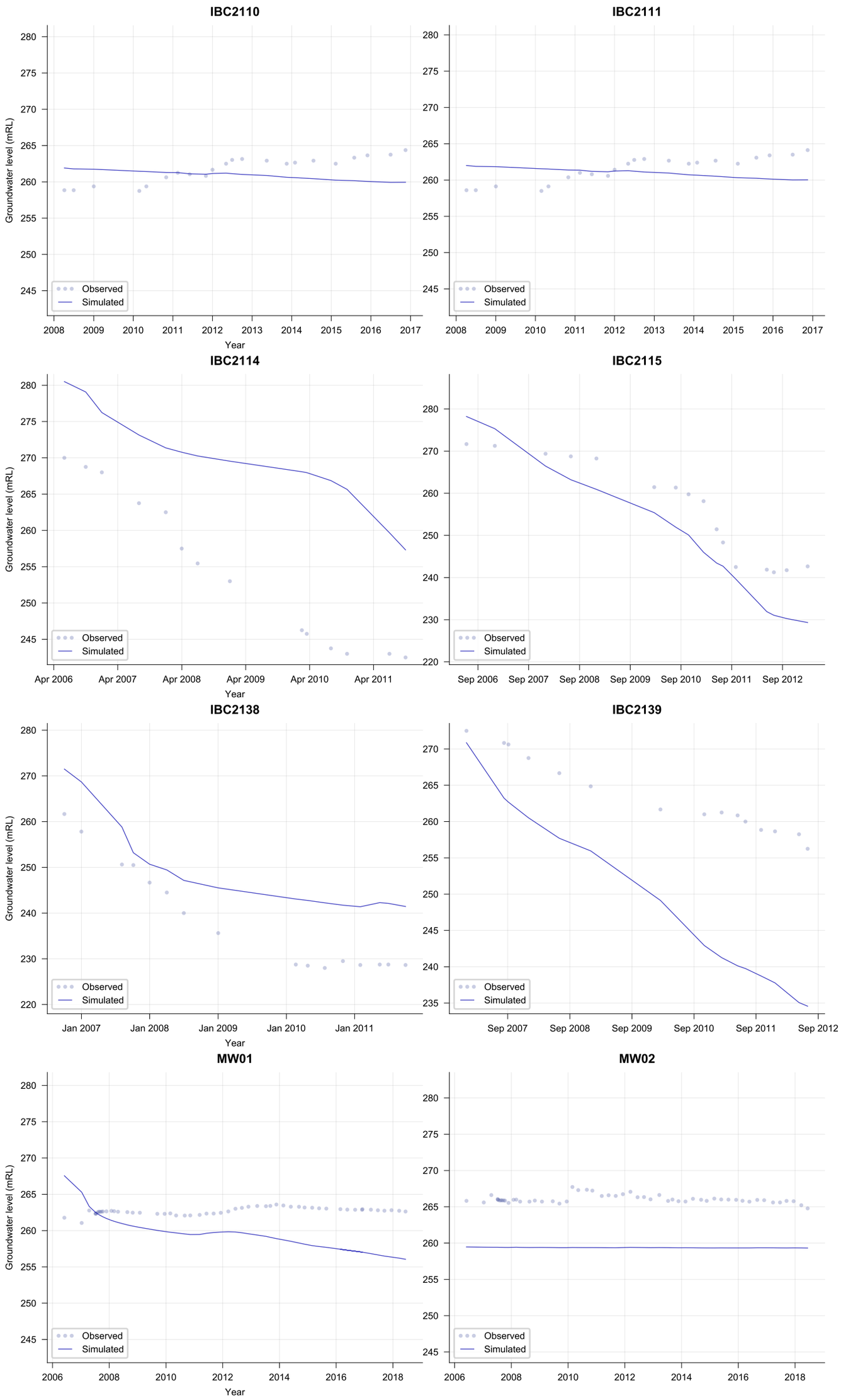


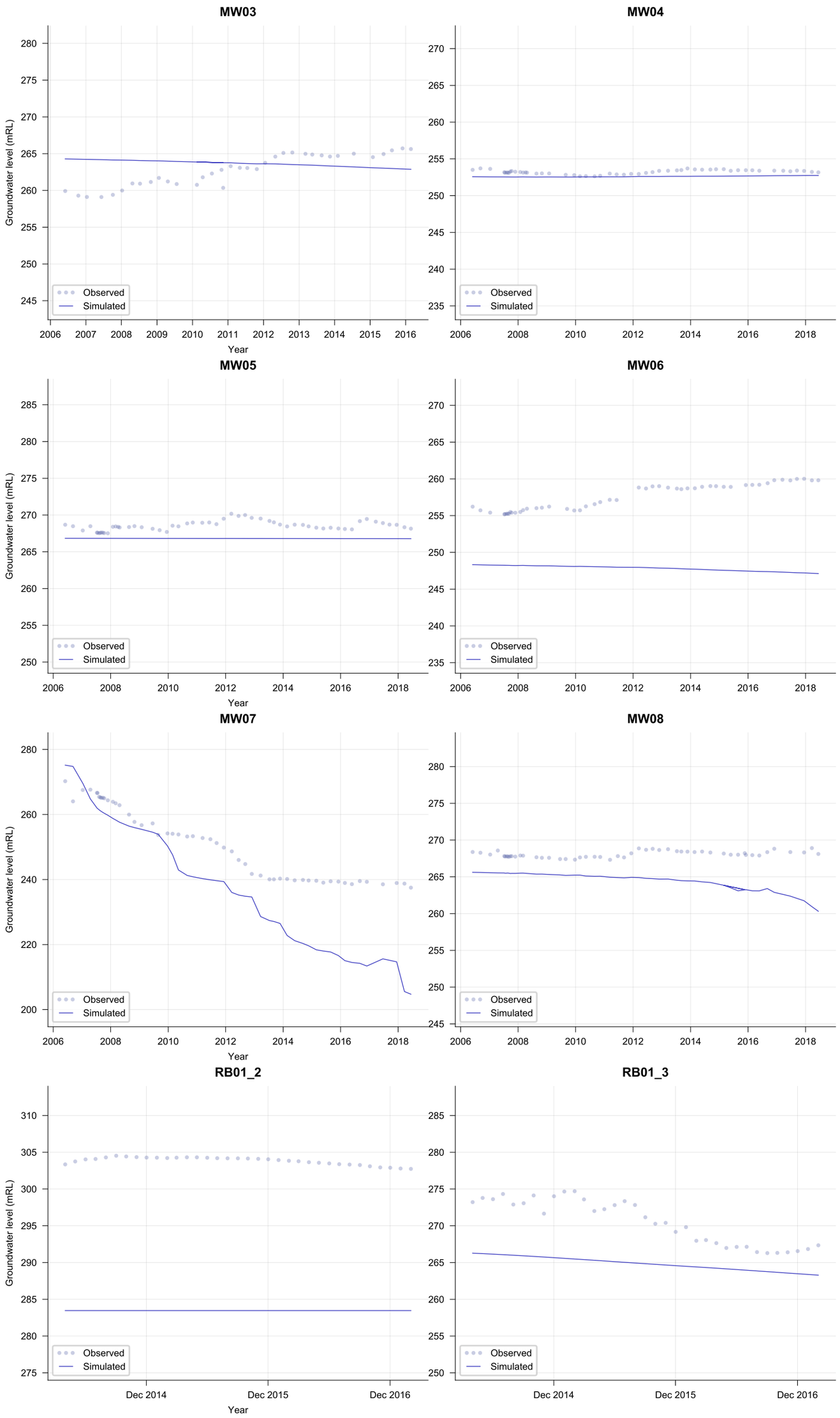

GW002501
GW030129_1
GW030130_1
GW030130_2
GW030131_01
GW030233_01
GW030233_03
GW031856
Groundwater level (mRL)
Year
Observed
Simulated
Aug 2006
Feb 2007
Aug 2007
Feb 2008
Aug 2008

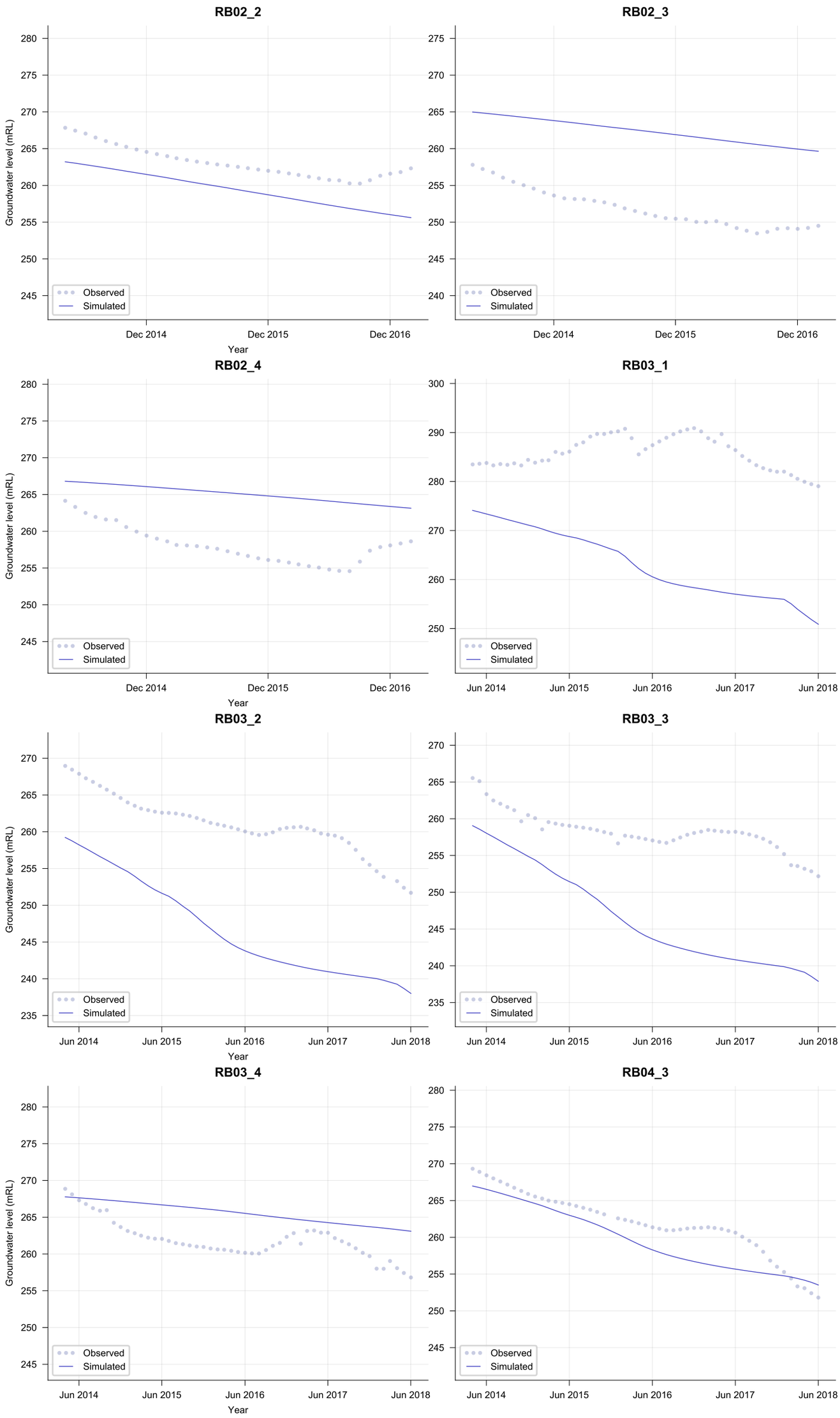

GW036005_02
GW036186_01
GW036187_01
GW036433_1
GW036434_1
GW036434_2
GW036435_1
GW036435_2
Groundwater level (mRL)
Year
Observed
Simulated

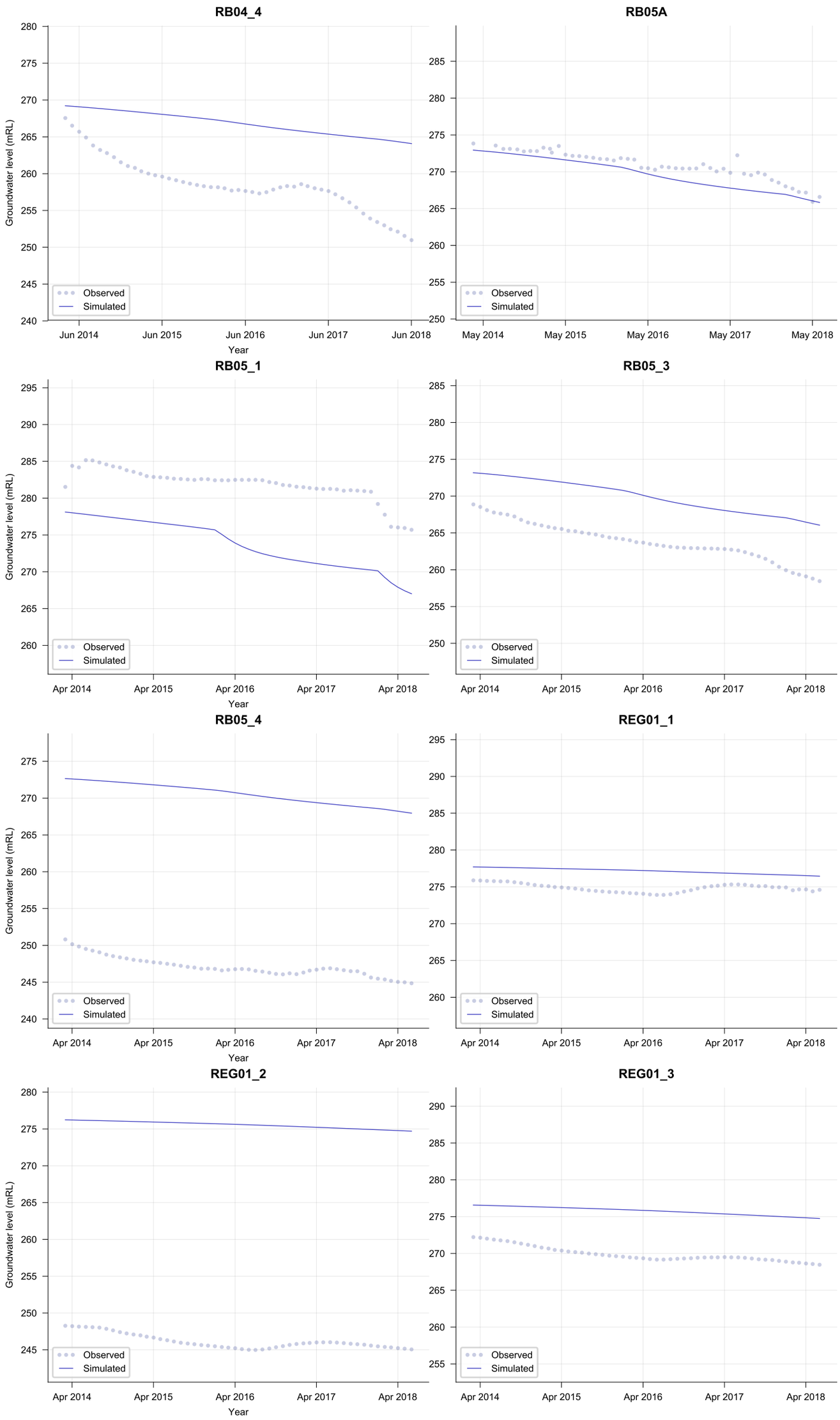

GW036436_1
GW036436_2
GW036436_3
GW036440_1
GW041027_01
GW044997
GW052266
GW3115
Groundwater level (mRL)
Year
Observed
Simulated

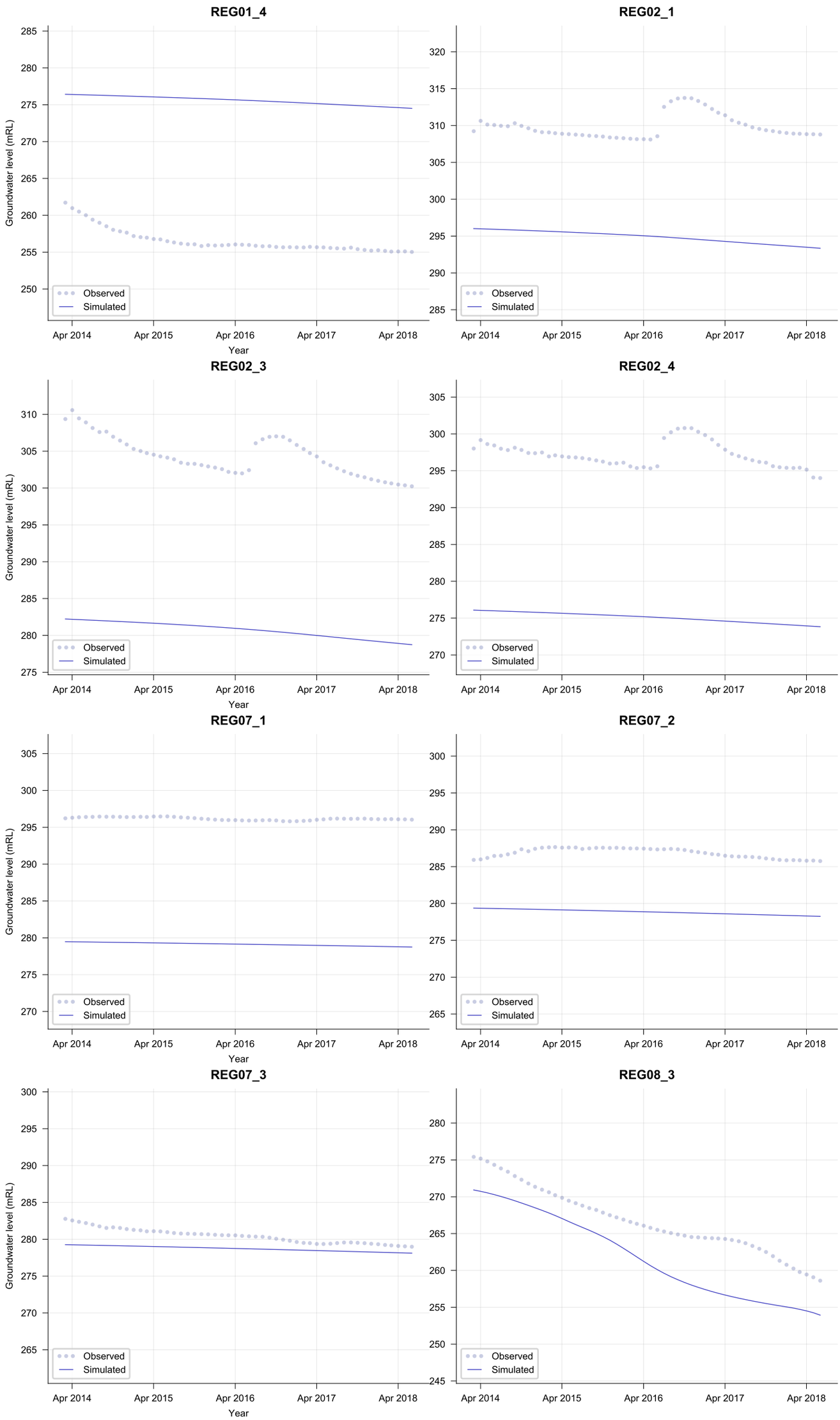

GW967137_1
GW967137_2
GW967138_1
GW967138_2
IBC2102
IBC2103
IBC2104
IBC2105
Groundwater level (mRL)
Year
Observed
Simulated

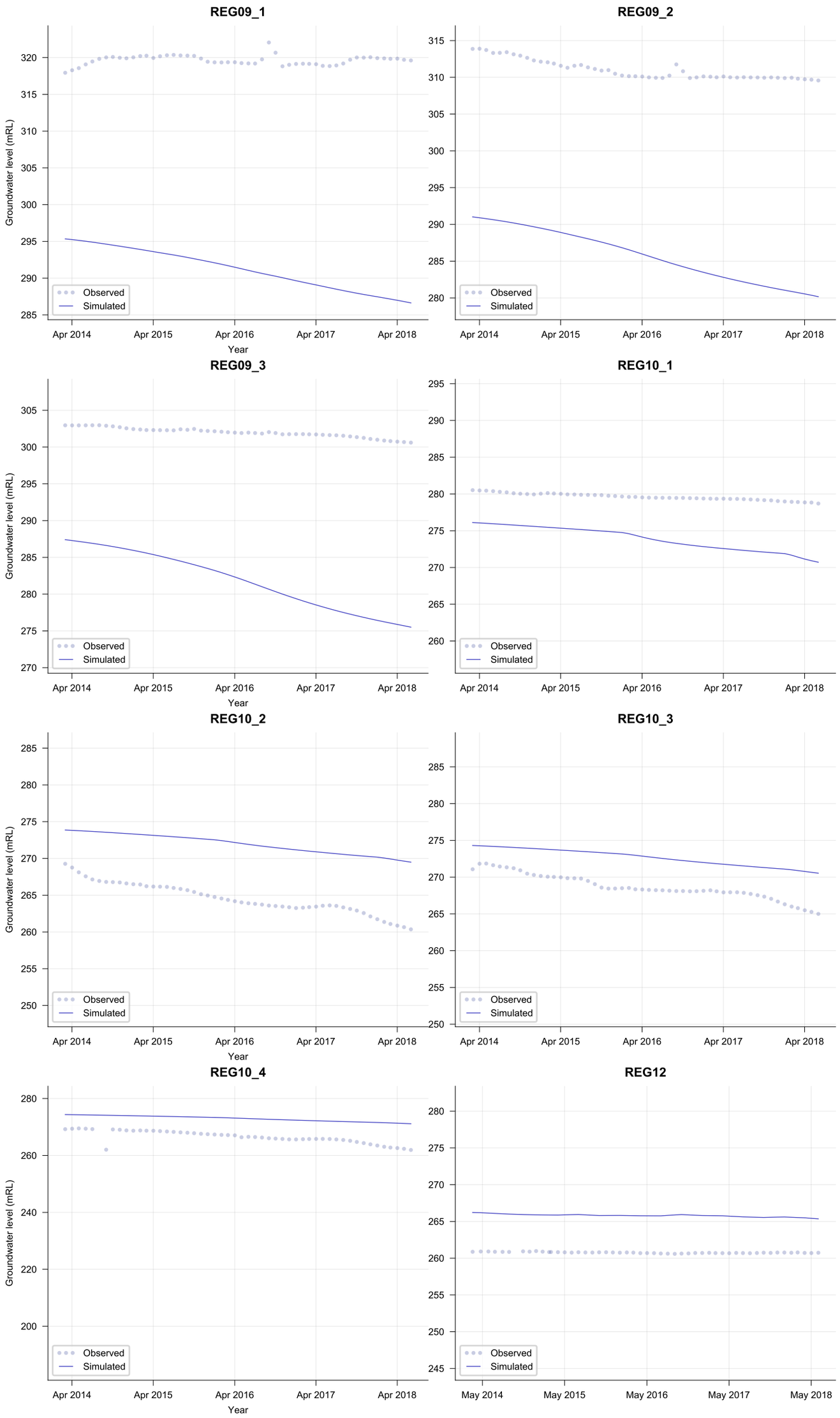

IBC2110
IBC2111
IBC2114
IBC2115
IBC2138
IBC2139
MW01
MW02
Groundwater level (mRL)
Year
Observed
Simulated

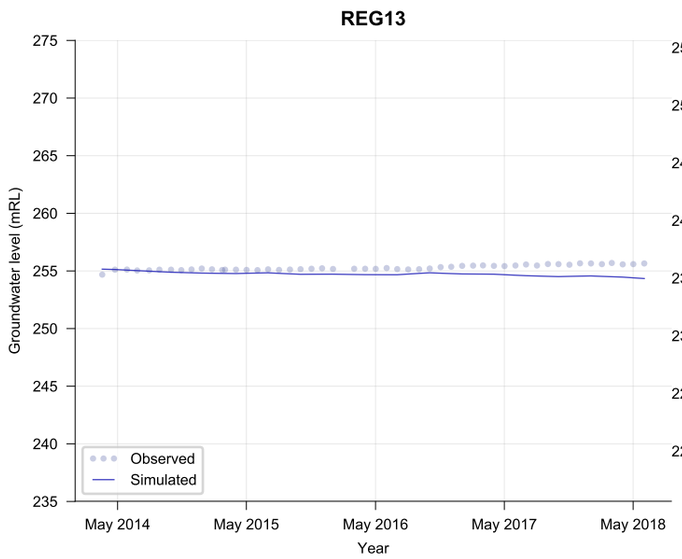

MW03
MW04
MW05
MW06
MW07
MW08
RB01_2
RB01_3
Groundwater level (mRL)
Year
Observed
Simulated

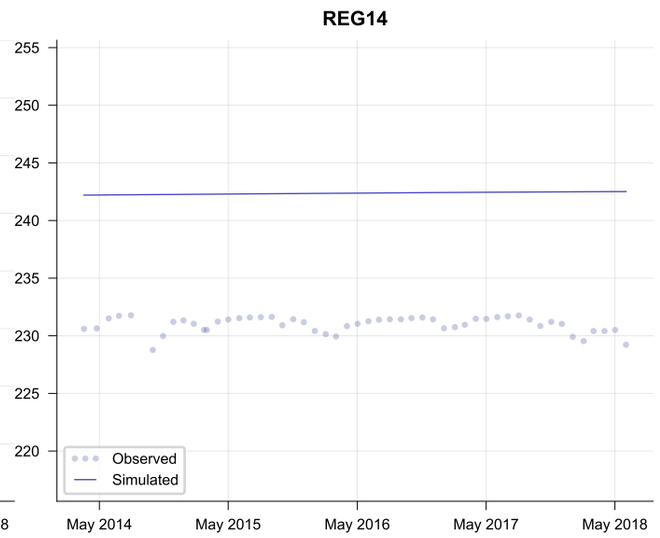

RB02_2
RB02_3
RB02_4
RB03_1
RB03_2
RB03_3
RB03_4
RB04_3
Groundwater level (mRL)
Year
Observed
Simulated
Dec 2014
Dec 2015
Dec 2016
Jun 2014
Jun 2015
Jun 2016
Jun 2017
Jun 2018

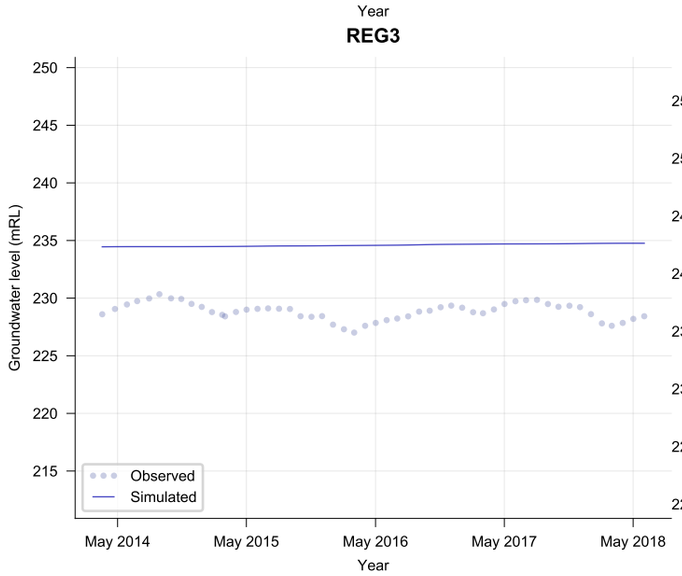

RB04_4
RB05A
RB05_1
RB05_3
RB05_4
REG01_1
REG01_2
REG01_3
Groundwater level (mRL)
Year
Observed
Simulated
Jun 2014
Jun 2015
Jun 2016
Jun 2017
Jun 2018
May 2014
May 2015
May 2016
May 2017
May 2018
Apr 2014
Apr 2015
Apr 2016
Apr 2017
Apr 2018

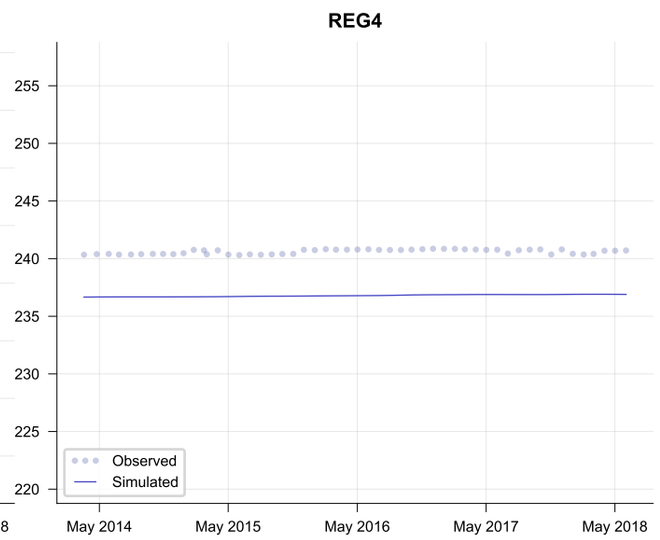

REG01_4
REG02_1
REG02_3
REG02_4
REG07_1
REG07_2
REG07_3
REG08_3
Groundwater level (mRL)
Year
Observed
Simulated
Apr 2014
Apr 2015
Apr 2016
Apr 2017
Apr 2018

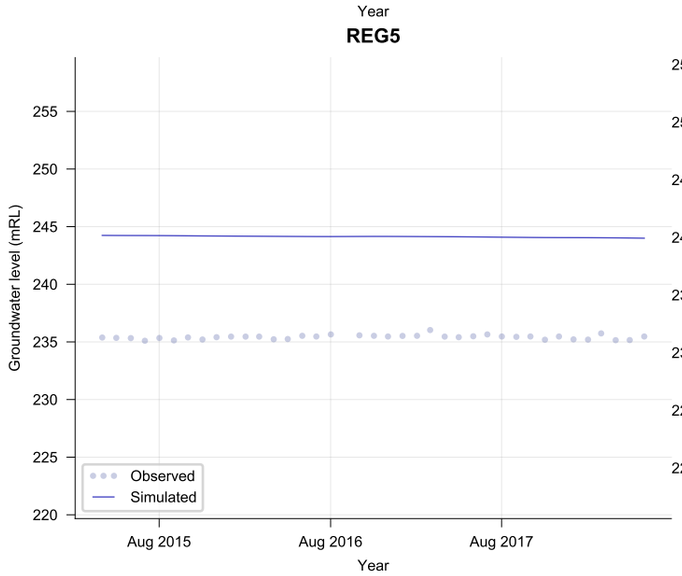

REG09_1
REG09_2
REG09_3
REG10_1
REG10_2
REG10_3
REG10_4
REG12
Groundwater level (mRL)
Year
Observed
Simulated
Apr 2014
Apr 2015
Apr 2016
Apr 2017
Apr 2018
May 2014
May 2015
May 2016
May 2017
May 2018

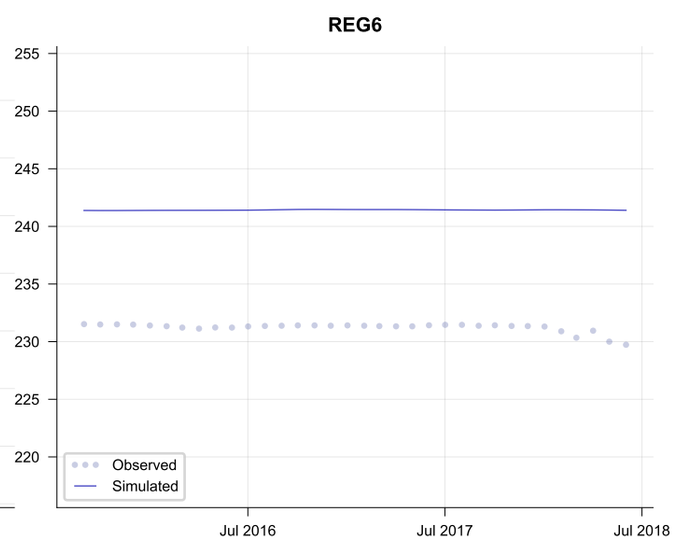

REG13
Groundwater level (mRL)
275
270
265
260
255
250
245
240
235
Observed
Simulated
May 2014
May 2015
May 2016
May 2017
May 2018
Year

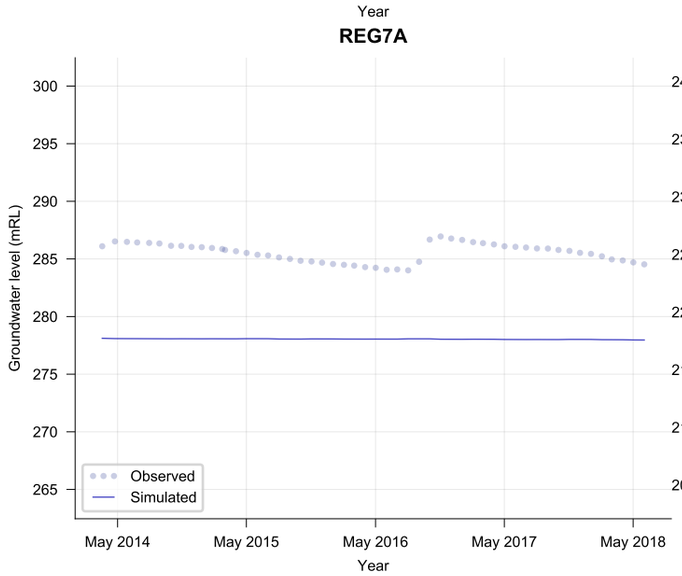

REG14
255
250
245
240
235
230
225
220
Observed
Simulated
May 2014
May 2015
May 2016
May 2017
May 2018

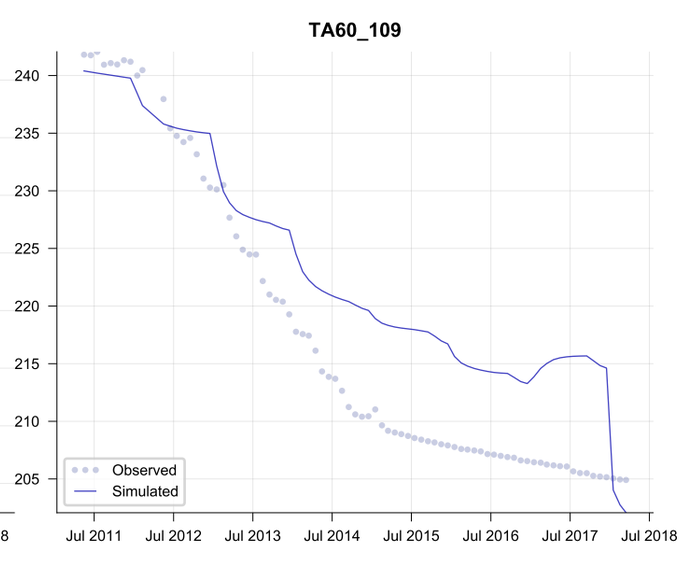

REG3
Groundwater level (mRL)
250
245
240
235
230
225
220
215
Observed
Simulated
May 2014
May 2015
May 2016
May 2017
May 2018
Year

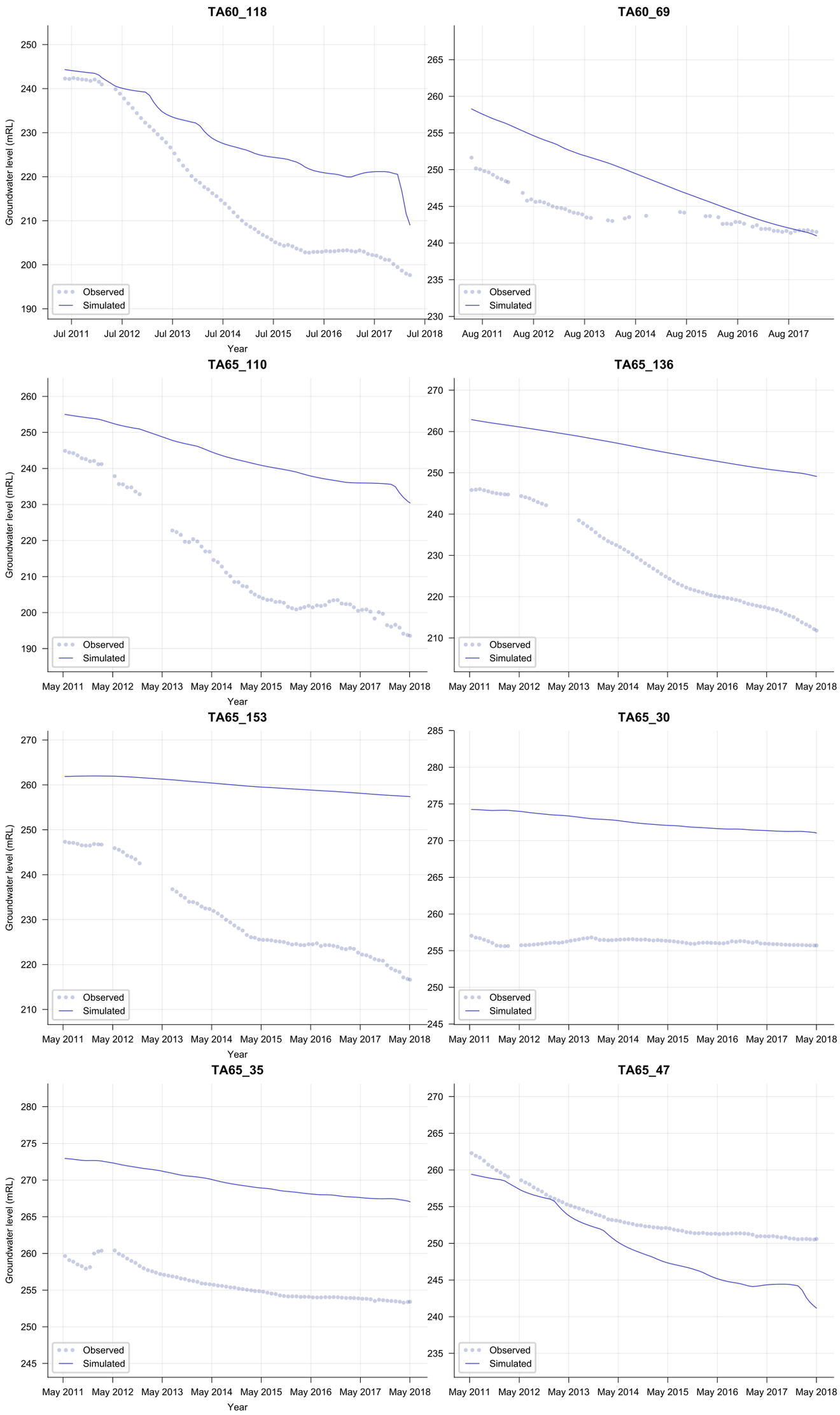

REG4
255
250
245
240
235
230
225
220
Observed
Simulated
May 2014
May 2015
May 2016
May 2017
May 2018

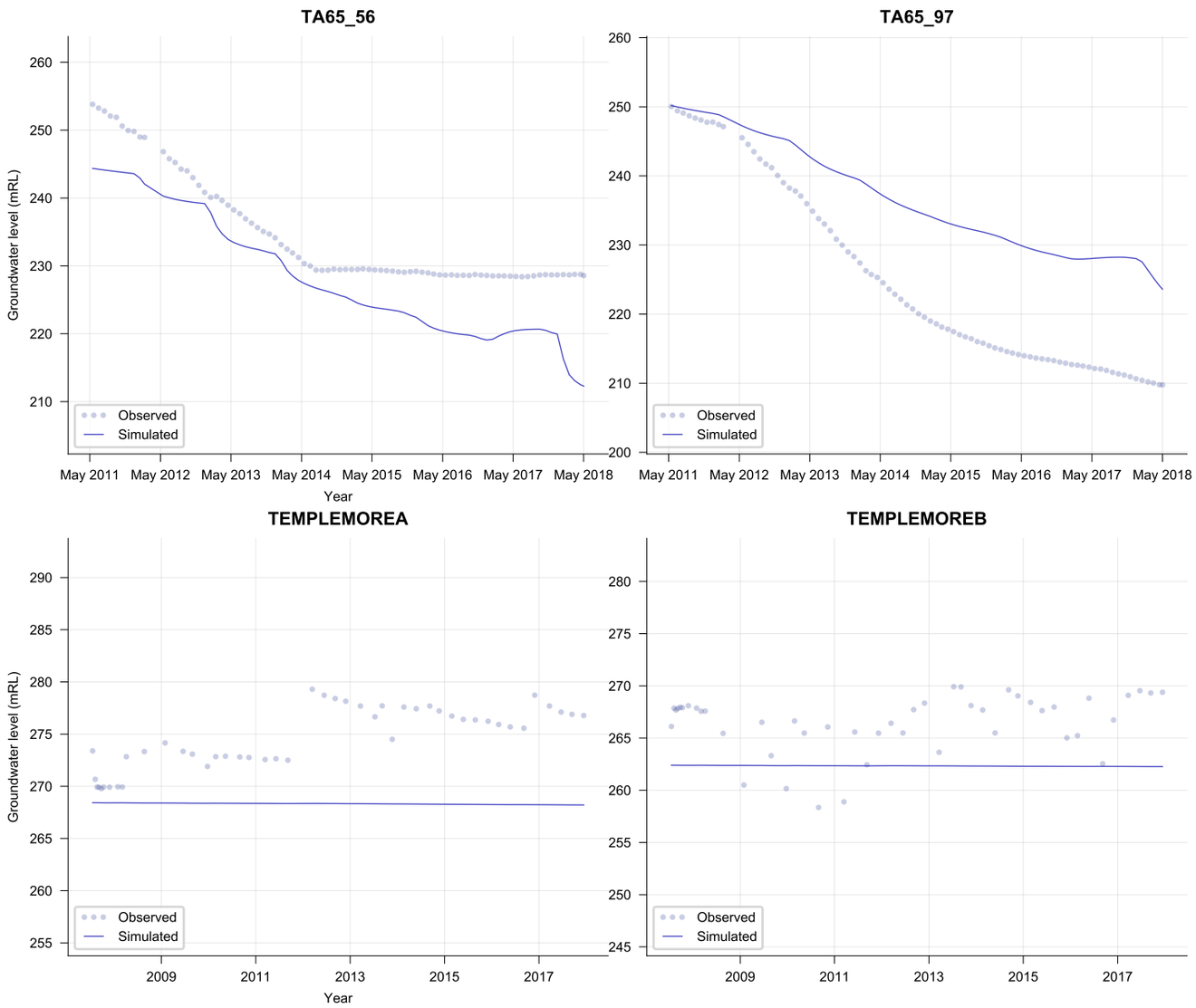

REG5
Groundwater level (mRL)
255
250
245
240
235
230
225
220
Observed
Simulated
Aug 2015
Aug 2016
Aug 2017
Year


REG6
255
250
245
240
235
230
225
220
Observed
Simulated
Jul 2016
Jul 2017
Jul 2018

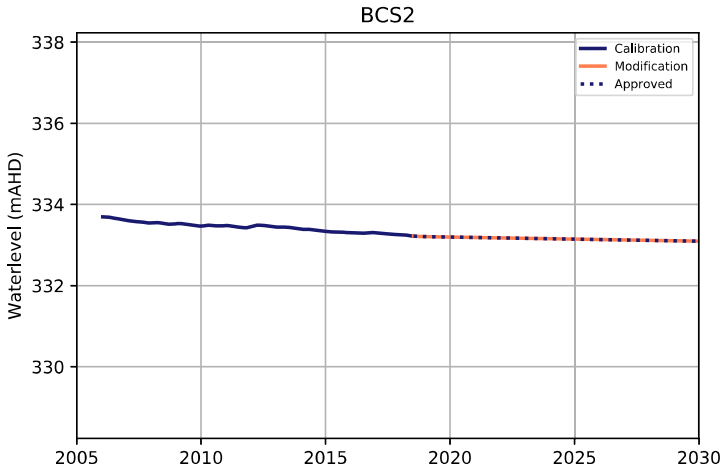

REG7A
Groundwater level (mRL)
300
295
290
285
280
275
270
265
Observed
Simulated
May 2014
May 2015
May 2016
May 2017
May 2018
Year

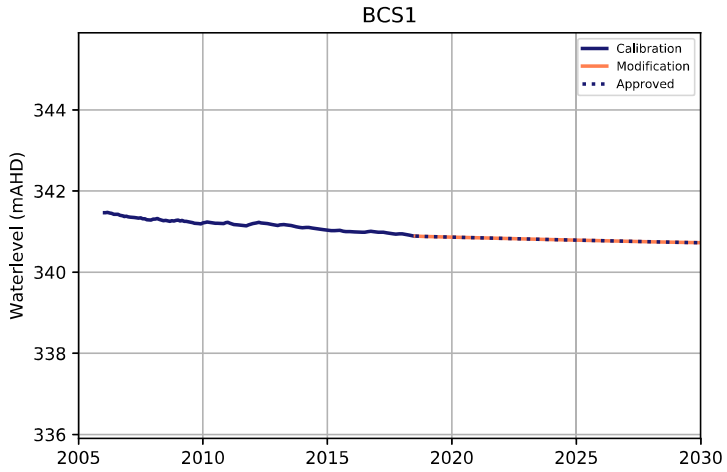

TA60_109
240
235
230
225
220
215
210
205
Observed
Simulated
Jul 2011
Jul 2012
Jul 2013
Jul 2014
Jul 2015
Jul 2016
Jul 2017
Jul 2018

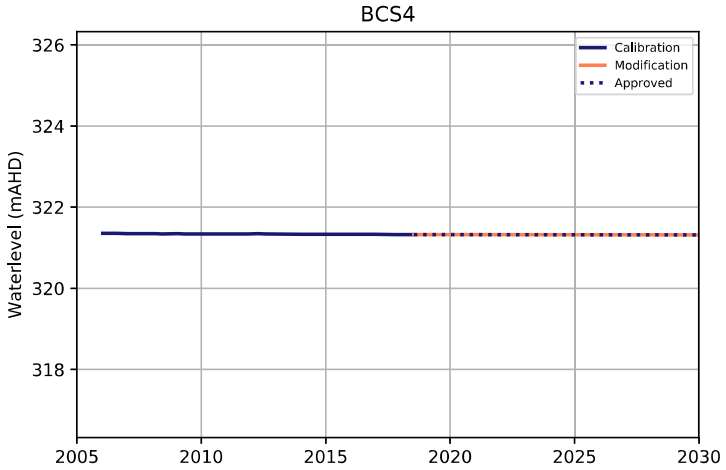

TA60_118
TA60_69
TA65_110
TA65_136
TA65_153
TA65_30
TA65_35
TA65_47
Groundwater level (mRL)
Year
Observed
Simulated
Jul 2011
Jul 2012
Jul 2013
Jul 2014
Jul 2015
Jul 2016
Jul 2017
Jul 2018
Aug 2011
Aug 2012
Aug 2013
Aug 2014
Aug 2015
Aug 2016
Aug 2017
May 2011
May 2012
May 2013
May 2014
May 2015
May 2016
May 2017
May 2018

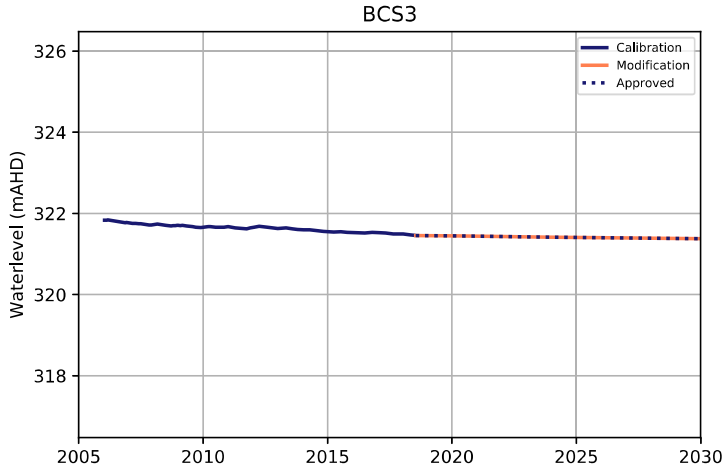

TA65_56
TA65_97
TEMPLEMOREA
TEMPLEMOREB
Groundwater level (mRL)
Year
Observed
Simulated
May 2011
May 2012
May 2013
May 2014
May 2015
May 2016
May 2017
May 2018
2009
2011
2013
2015
2017

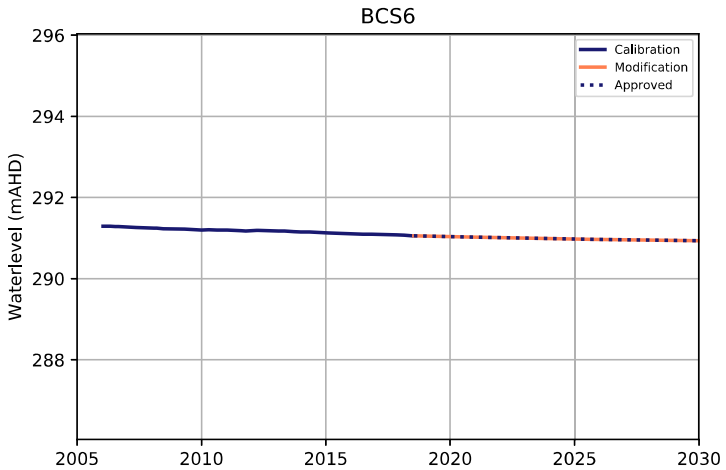
ATTACHMENT E – PREDICTIVE HYDROGRAPHS

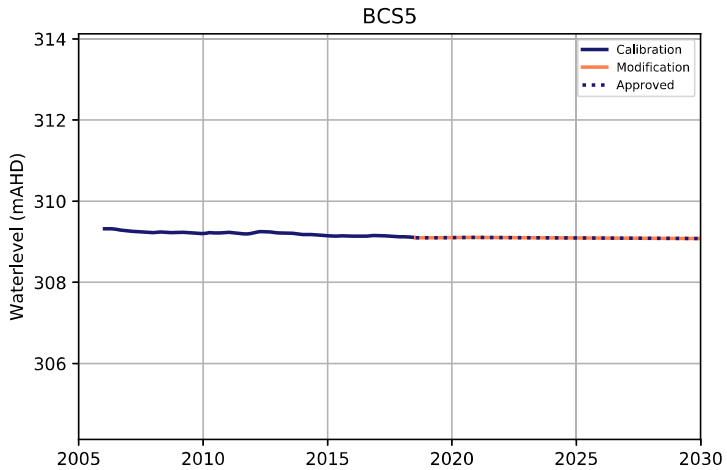

BCS2
Waterlevel (mAHD)
Calibration
Modification
Approved

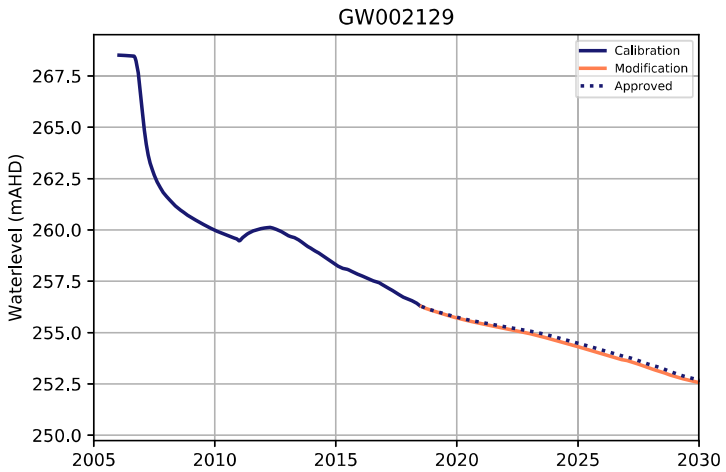

BCS1
Waterlevel (mAHD)
Calibration
Modification
Approved

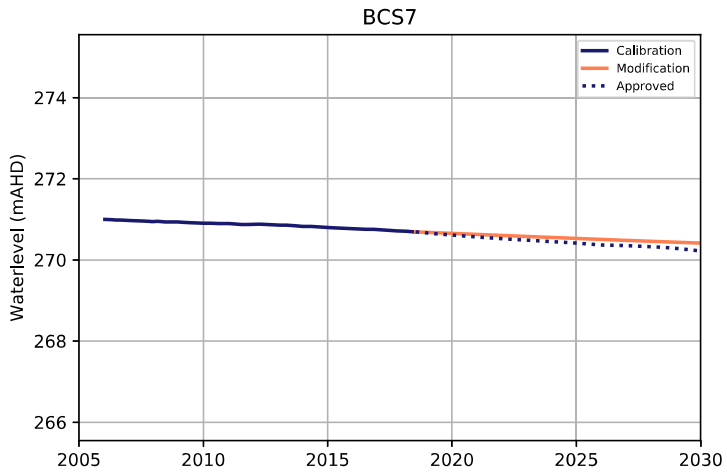

BCS4
Waterlevel (mAHD)
Calibration
Modification
Approved

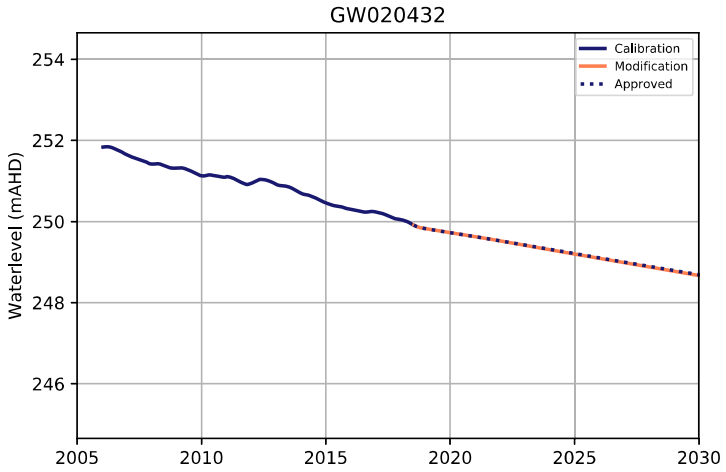

BCS3
Waterlevel (mAHD)
Calibration
Modification
Approved

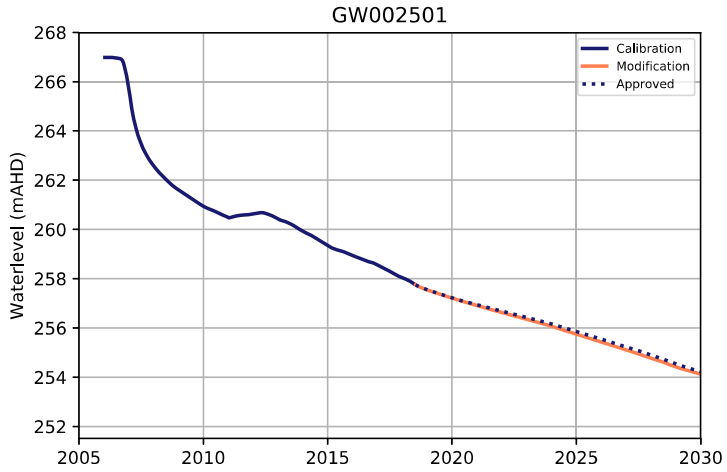

BCS6
Waterlevel (mAHD)
Calibration
Modification
Approved

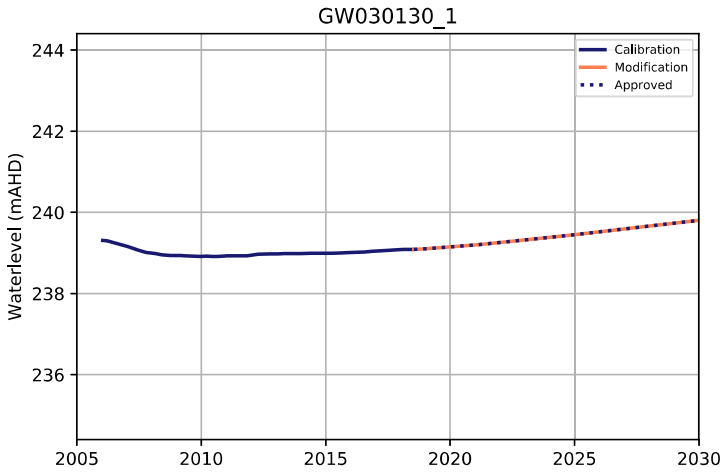

BCS5
Waterlevel (mAHD)
Calibration
Modification
Approved

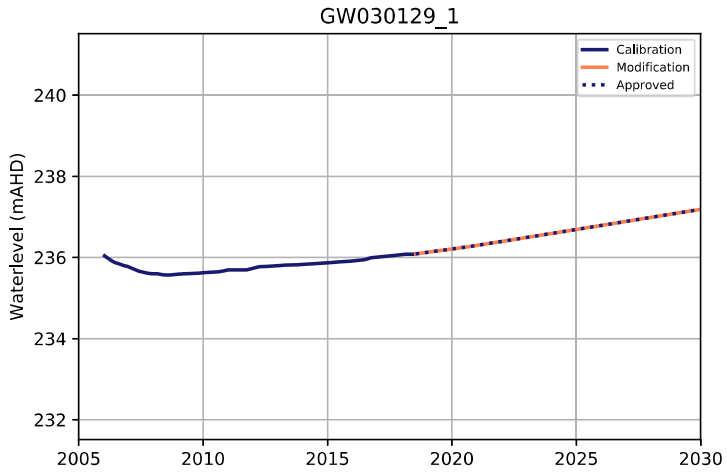

GW002129
Waterlevel (mAHD)
Calibration
Modification
Approved

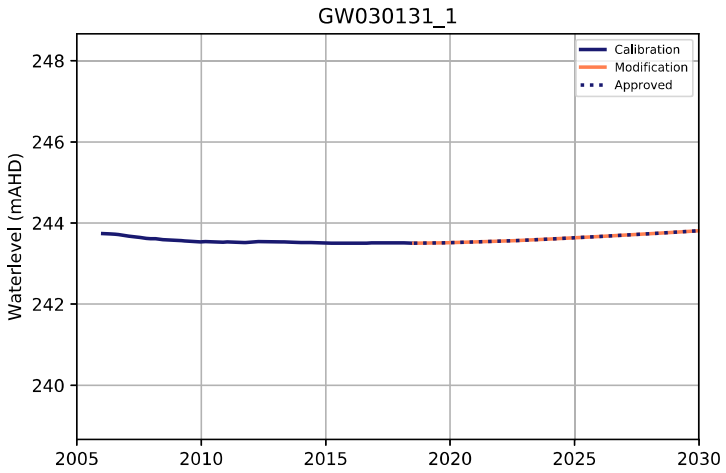

BCS7
Waterlevel (mAHD)
Calibration
Modification
Approved

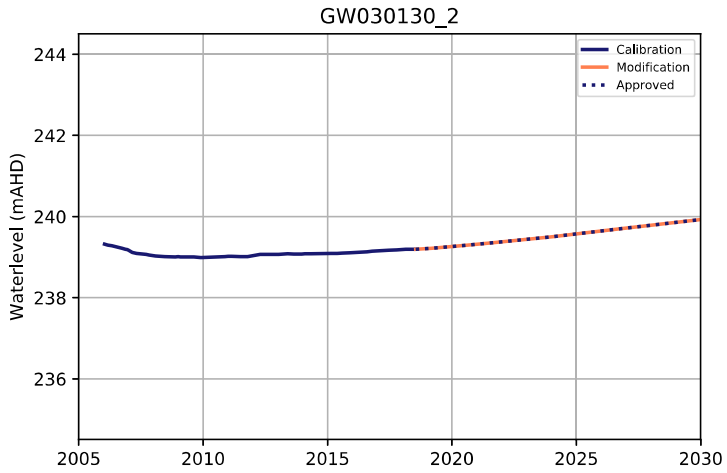

GW020432
Waterlevel (mAHD)
Calibration
Modification
Approved

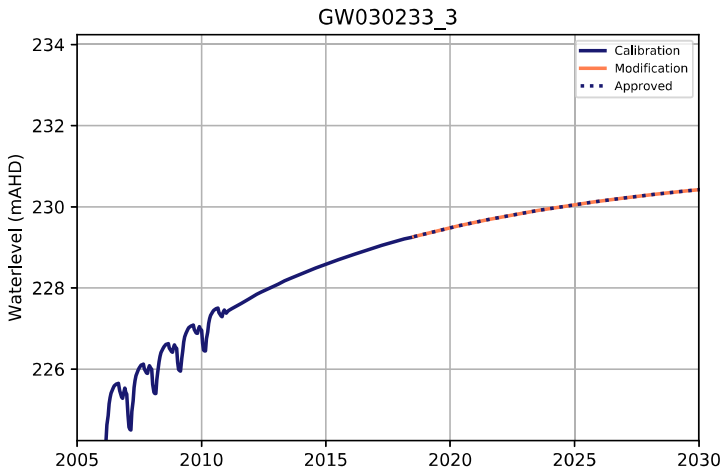

GW002501
Waterlevel (mAHD)
Calibration
Modification
Approved

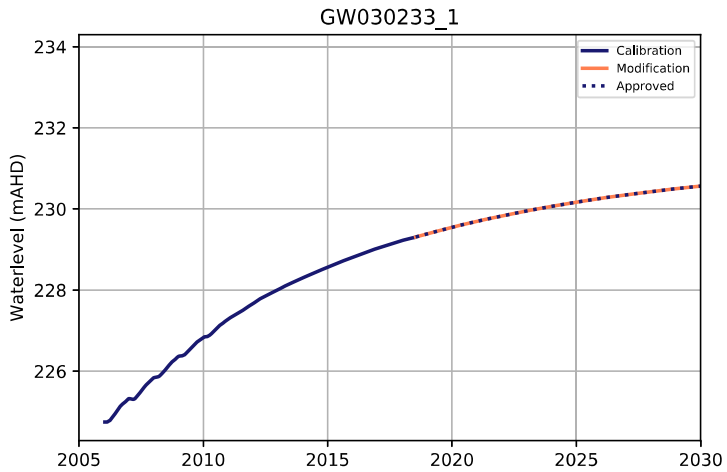

GW030130_1
Waterlevel (mAHD)
Calibration
Modification
Approved

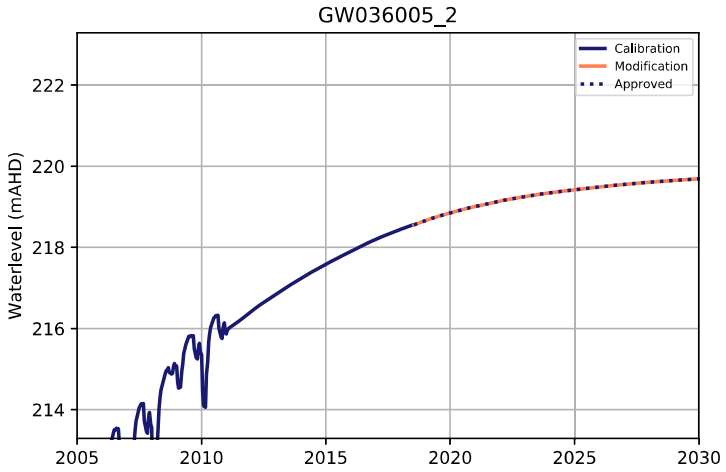

GW030129_1
Waterlevel (mAHD)
Calibration
Modification
Approved

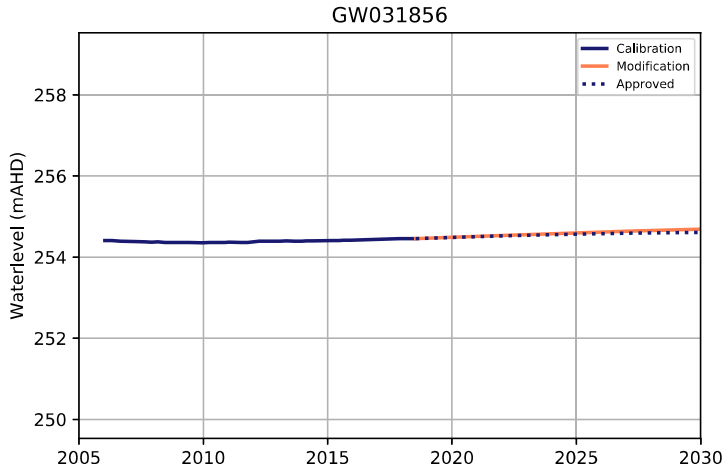

GW030131_1
Waterlevel (mAHD)
Calibration
Modification
Approved

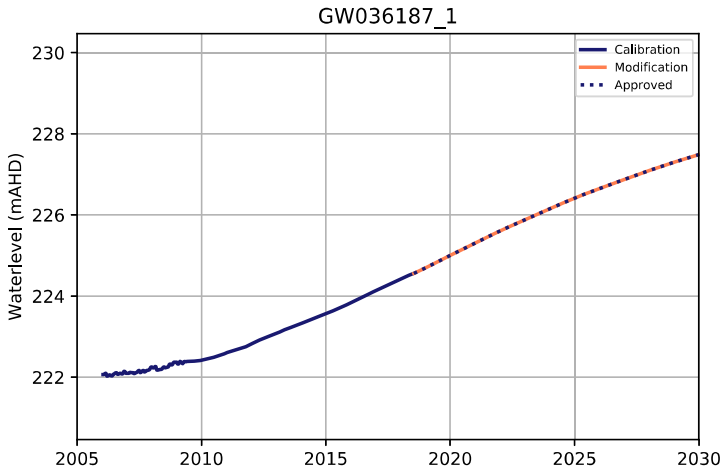

GW030130_2
Waterlevel (mAHD)
Calibration
Modification
Approved

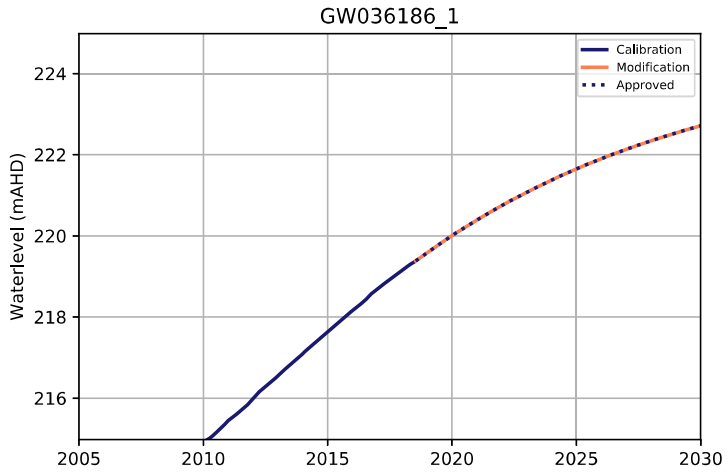

GW030233_3
Waterlevel (mAHD)
Calibration
Modification
Approved

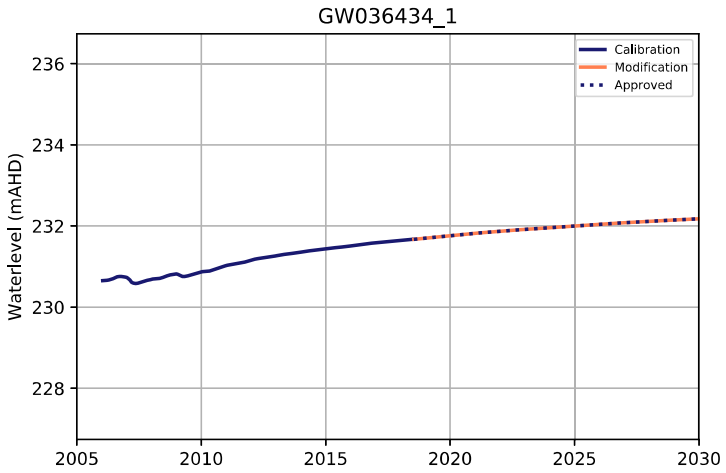

GW030233_1
Waterlevel (mAHD)
Calibration
Modification
Approved

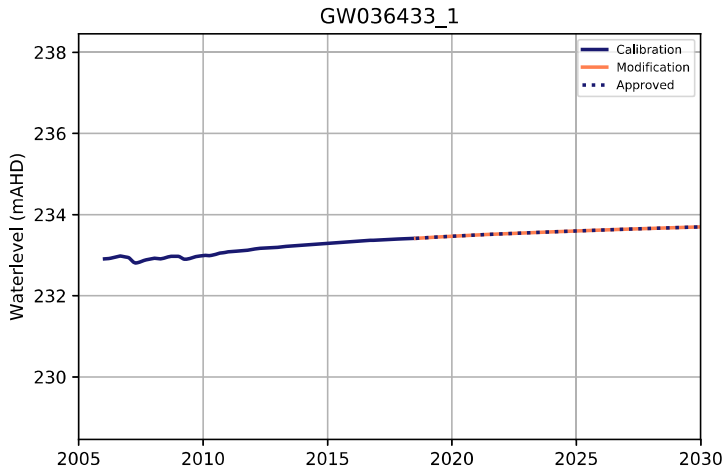

GW036005_2
Calibration
Modification
Approved
Waterlevel (mAHD)
214
216
218
220
222
2005
2010
2015
2020
2025
2030

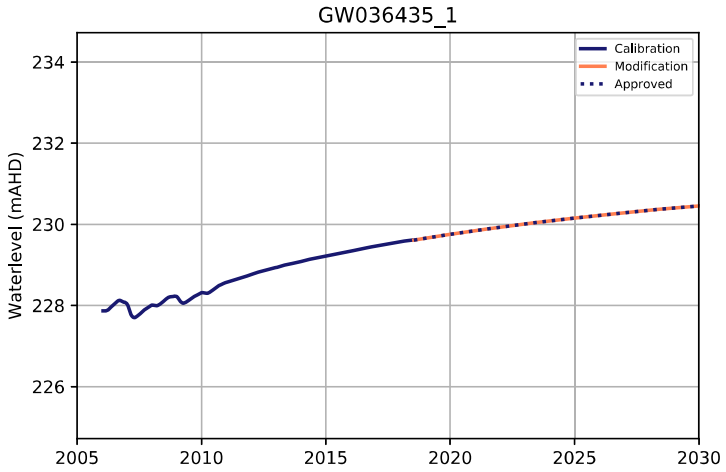

GW031856
Calibration
Modification
Approved
Waterlevel (mAHD)
250
252
254
256
258
2005
2010
2015
2020
2025
2030

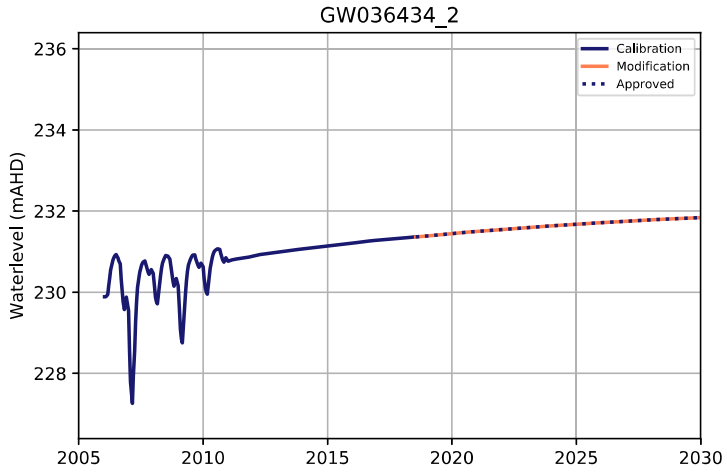

GW036187_1
Calibration
Modification
Approved
Waterlevel (mAHD)
222
224
226
228
230
2005
2010
2015
2020
2025
2030

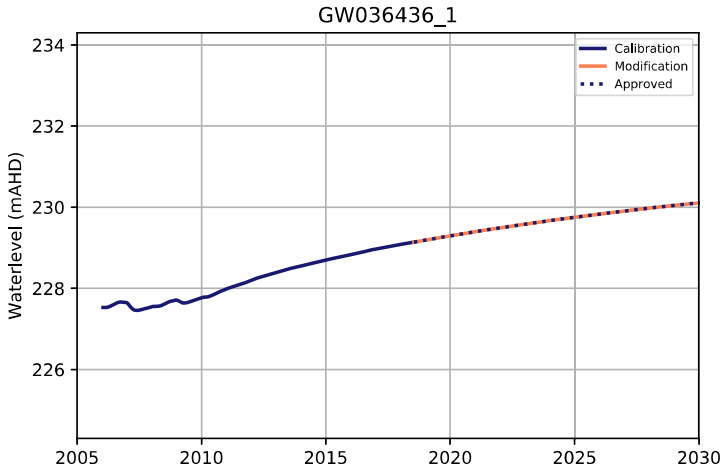

GW036186_1
Calibration
Modification
Approved
Waterlevel (mAHD)
216
218
220
222
224
2005
2010
2015
2020
2025
2030

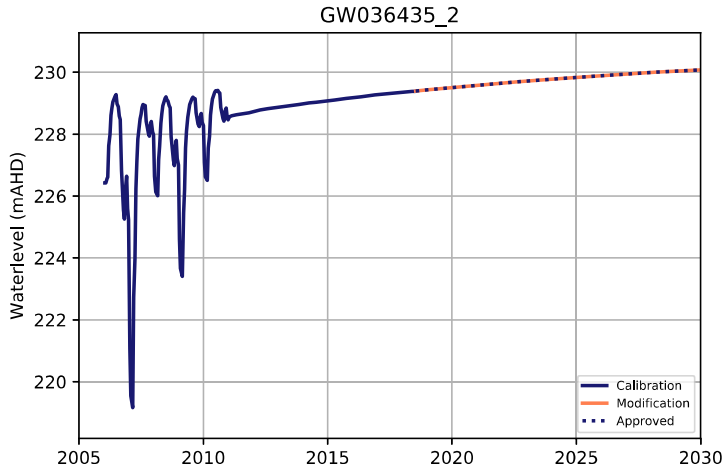

GW036434_1
Calibration
Modification
Approved
Waterlevel (mAHD)
228
230
232
234
236
2005
2010
2015
2020
2025
2030

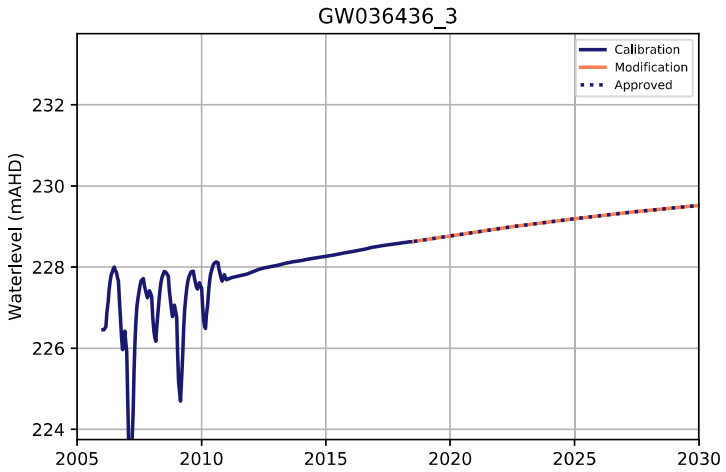

GW036433_1
Calibration
Modification
Approved
Waterlevel (mAHD)
230
232
234
236
238
2005
2010
2015
2020
2025
2030

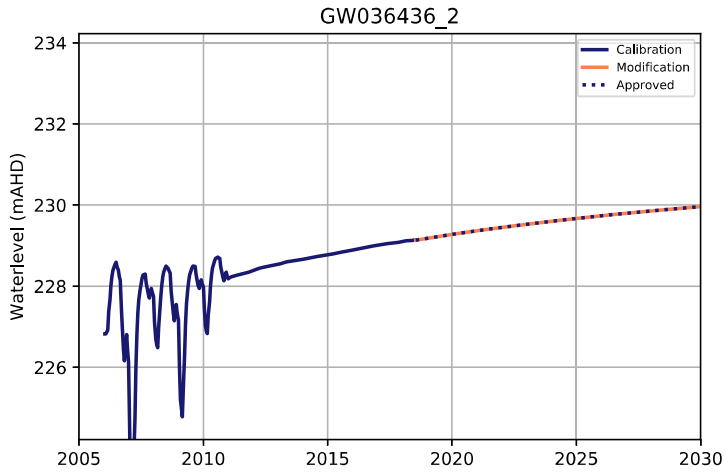

GW036435_1
Calibration
Modification
Approved
Waterlevel (mAHD)
226
228
230
232
234
2005
2010
2015
2020
2025
2030

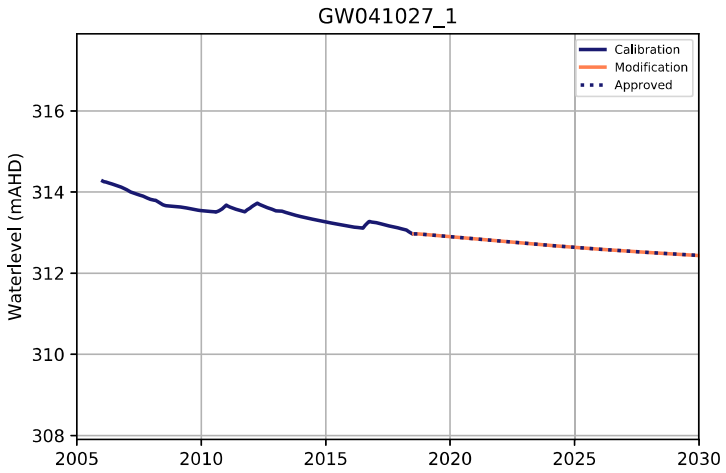

GW036434_2
Calibration
Modification
Approved
Waterlevel (mAHD)
228
230
232
234
236
2005
2010
2015
2020
2025
2030

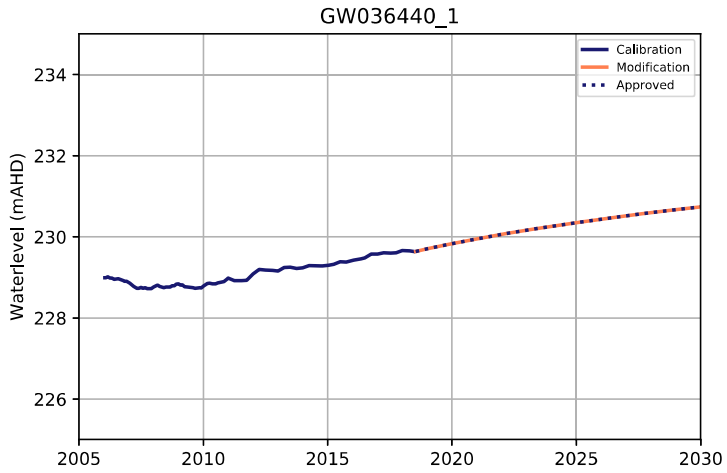

GW036436_1
Waterlevel (mAHD)
234
232
230
228
226
2005
2010
2015
2020
2025
2030
Calibration
Modification
Approved

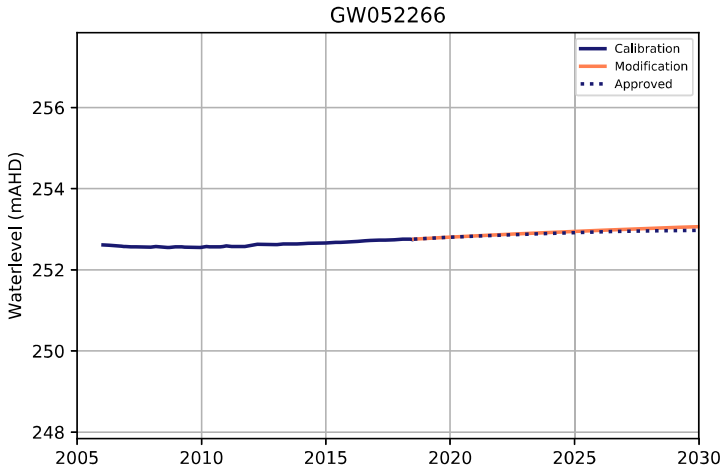

GW036435_2
Waterlevel (mAHD)
230
228
226
224
222
220
2005
2010
2015
2020
2025
2030
Calibration
Modification
Approved

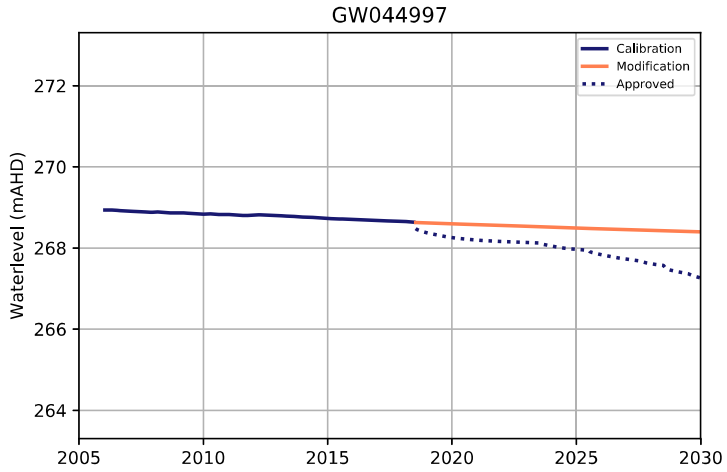

GW036436_3
Waterlevel (mAHD)
232
230
228
226
224
2005
2010
2015
2020
2025
2030
Calibration
Modification
Approved

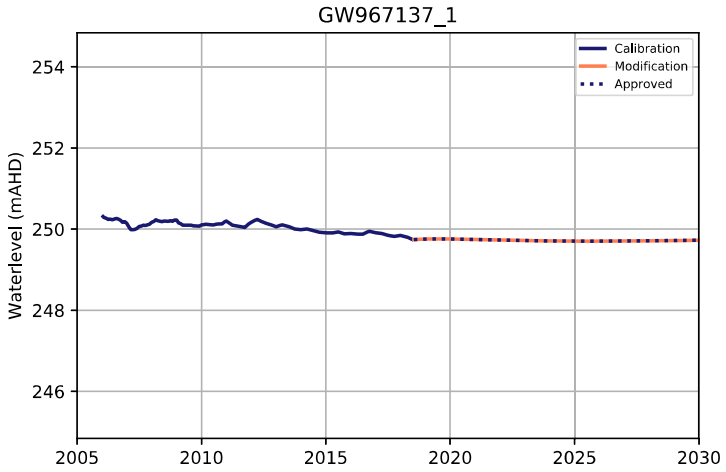

GW036436_2
Waterlevel (mAHD)
234
232
230
228
226
2005
2010
2015
2020
2025
2030
Calibration
Modification
Approved

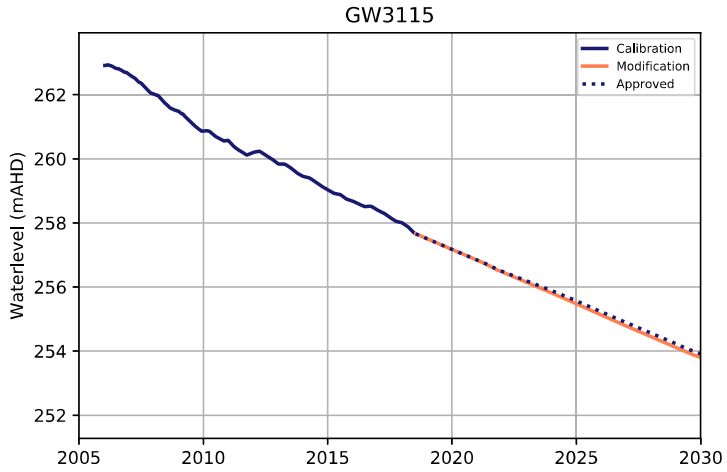

GW041027_1
Waterlevel (mAHD)
316
314
312
310
308
2005
2010
2015
2020
2025
2030
Calibration
Modification
Approved

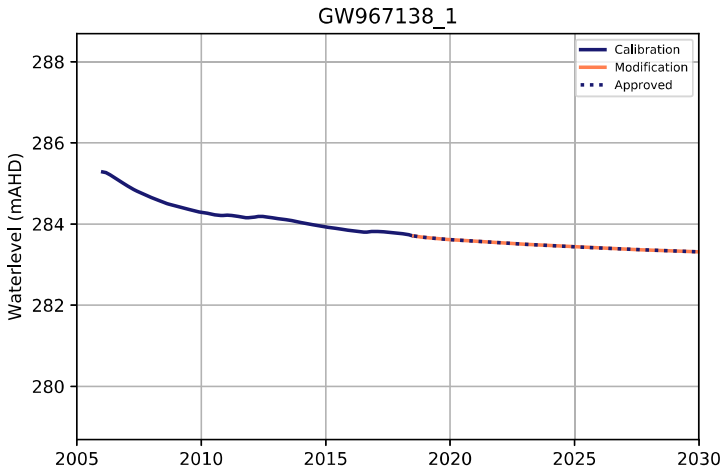

GW036440_1
Waterlevel (mAHD)
234
232
230
228
226
2005
2010
2015
2020
2025
2030
Calibration
Modification
Approved

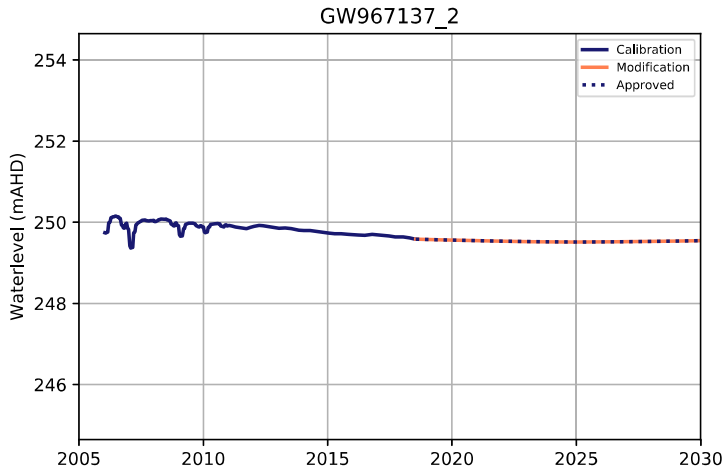

GW052266
Waterlevel (mAHD)
256
254
252
250
248
2005
2010
2015
2020
2025
2030
Calibration
Modification
Approved

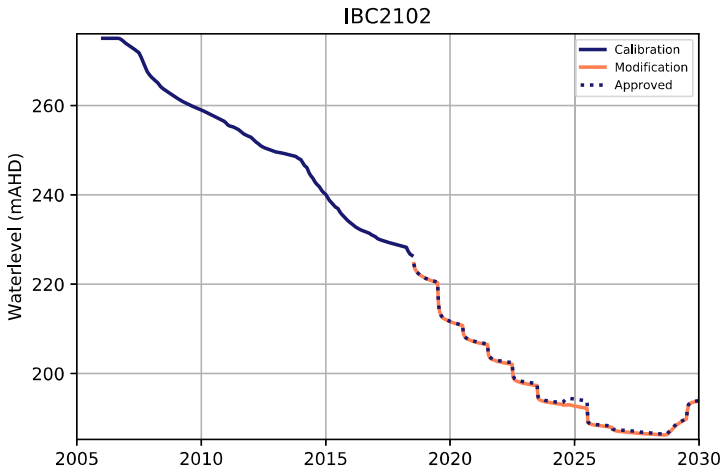

GW044997
Waterlevel (mAHD)
272
270
268
266
264
2005
2010
2015
2020
2025
2030
Calibration
Modification
Approved

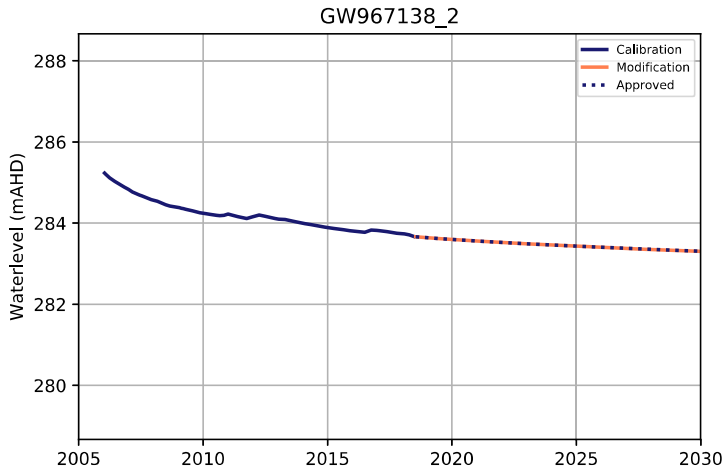

GW967137_1
Calibration
Modification
Approved
Waterlevel (mAHD)
254
252
250
248
246
2005
2010
2015
2020
2025
2030

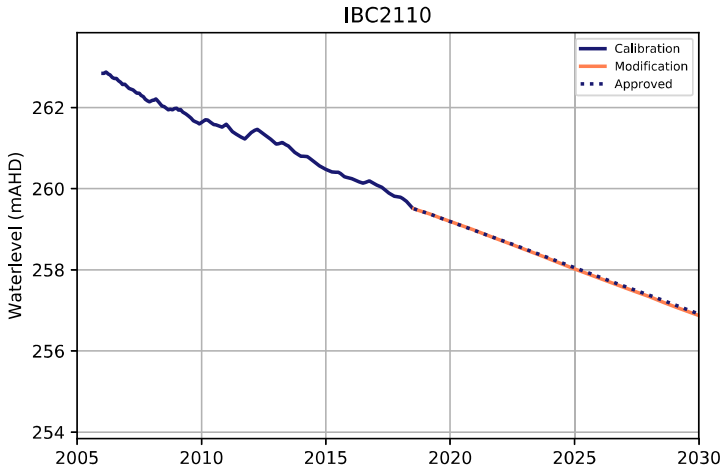

GW3115
Calibration
Modification
Approved
Waterlevel (mAHD)
262
260
258
256
254
252
2005
2010
2015
2020
2025
2030

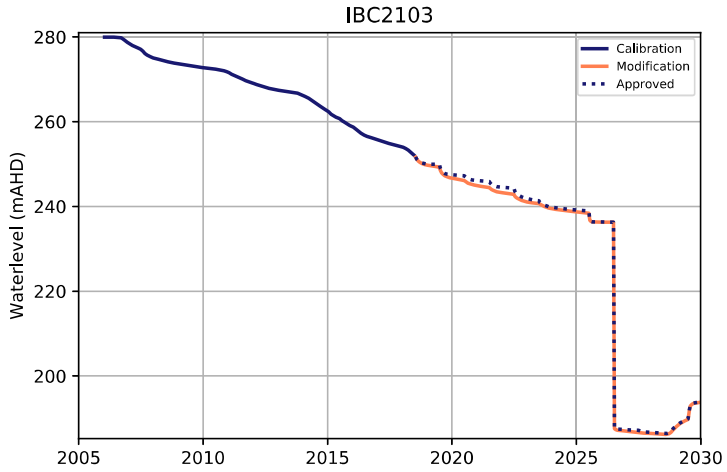

GW967138_1
Calibration
Modification
Approved
Waterlevel (mAHD)
288
286
284
282
280
2005
2010
2015
2020
2025
2030

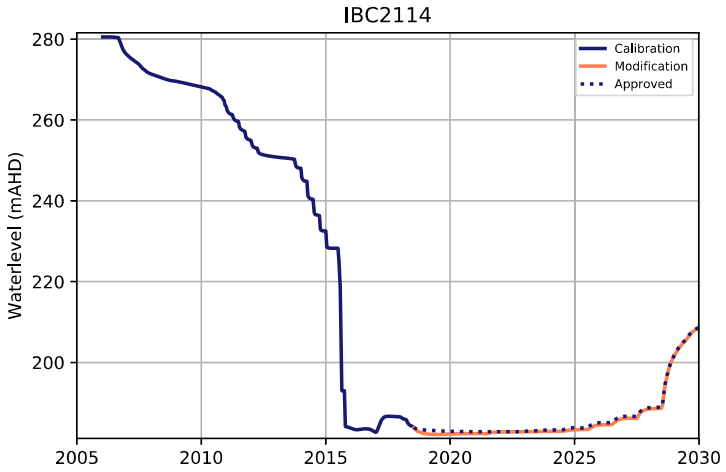

GW967137_2
Calibration
Modification
Approved
Waterlevel (mAHD)
254
252
250
248
246
2005
2010
2015
2020
2025
2030

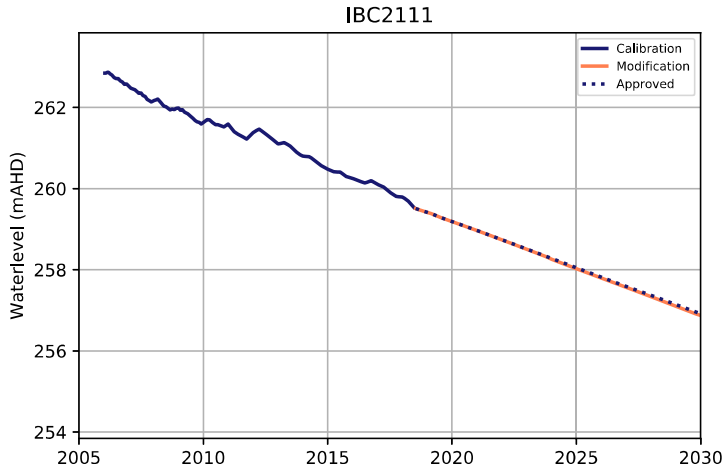

IBC2102
Calibration
Modification
Approved
Waterlevel (mAHD)
260
240
220
200
2005
2010
2015
2020
2025
2030

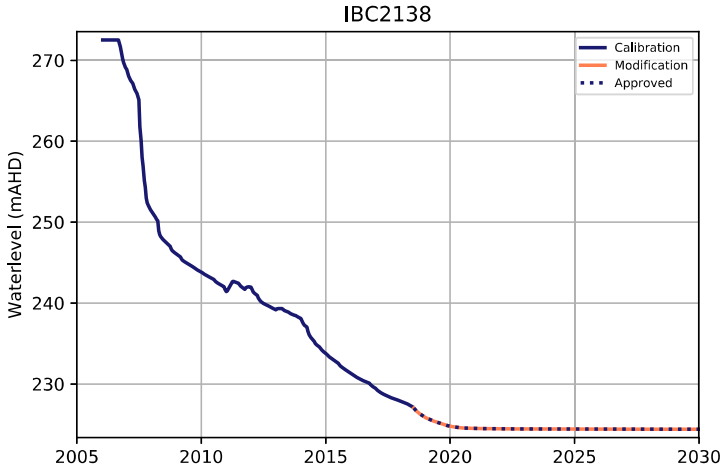

GW967138_2
Calibration
Modification
Approved
Waterlevel (mAHD)
288
286
284
282
280
2005
2010
2015
2020
2025
2030

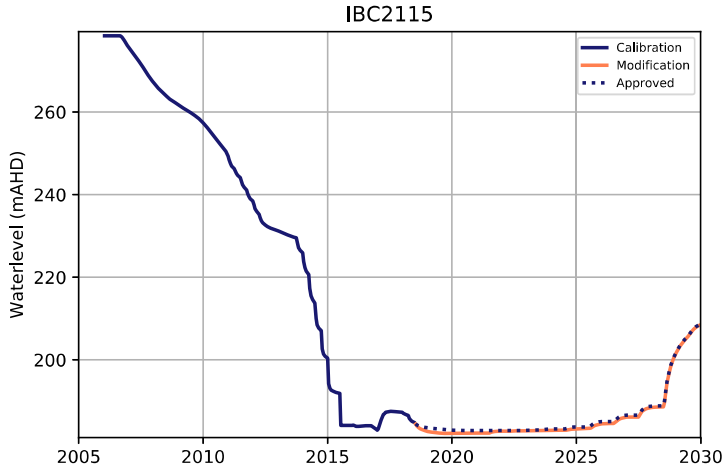

IBC2110
Calibration
Modification
Approved
Waterlevel (mAHD)
262
260
258
256
254
2005
2010
2015
2020
2025
2030

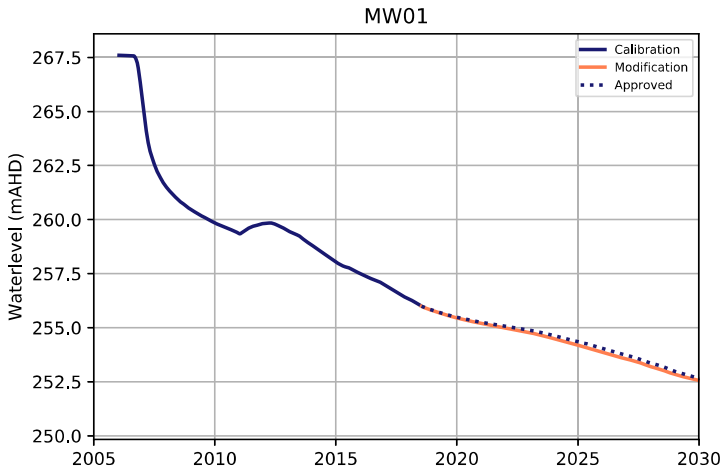

IBC2103
Calibration
Modification
Approved
Waterlevel (mAHD)
280
260
240
220
200
2005
2010
2015
2020
2025
2030

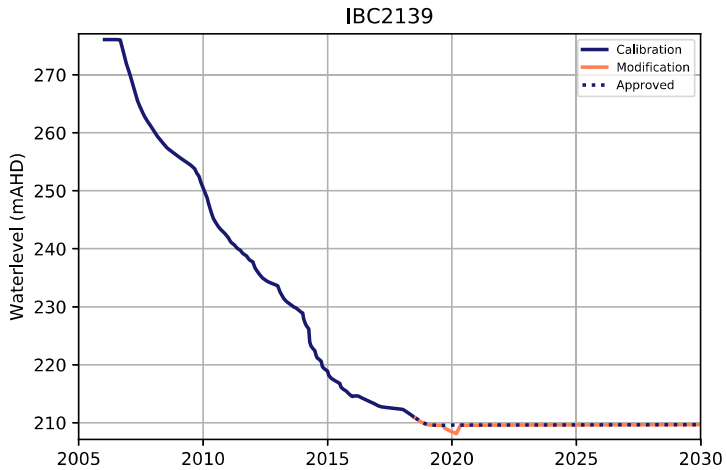

IBC2114
Waterlevel (mAHD)
Calibration
Modification
Approved

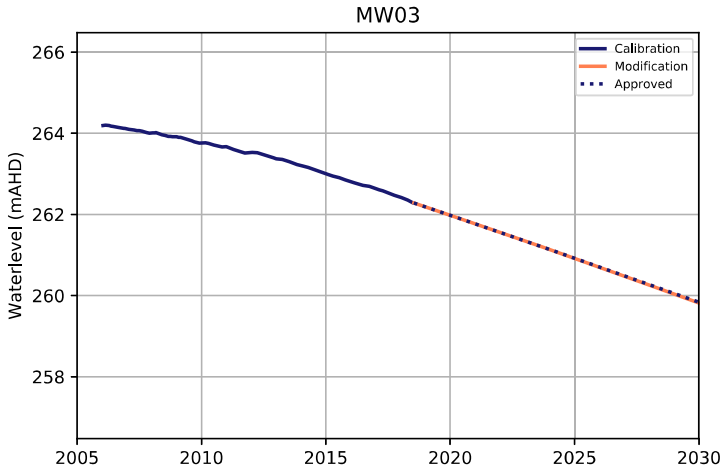

IBC2111
Waterlevel (mAHD)
Calibration
Modification
Approved

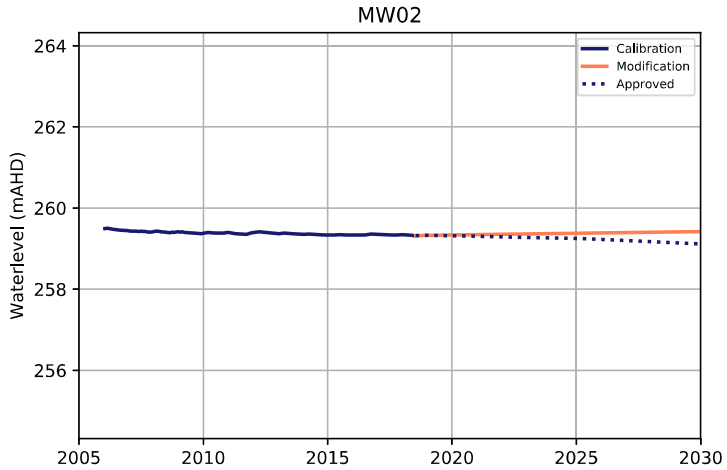

IBC2138
Waterlevel (mAHD)
Calibration
Modification
Approved

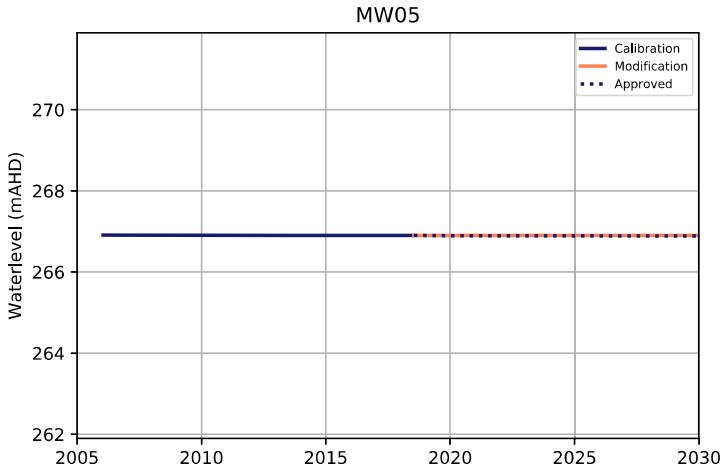

IBC2115
Waterlevel (mAHD)
Calibration
Modification
Approved

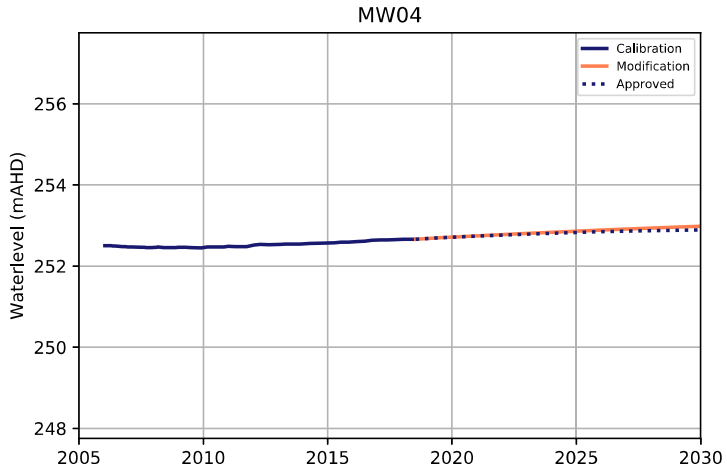

MW01
Waterlevel (mAHD)
Calibration
Modification
Approved

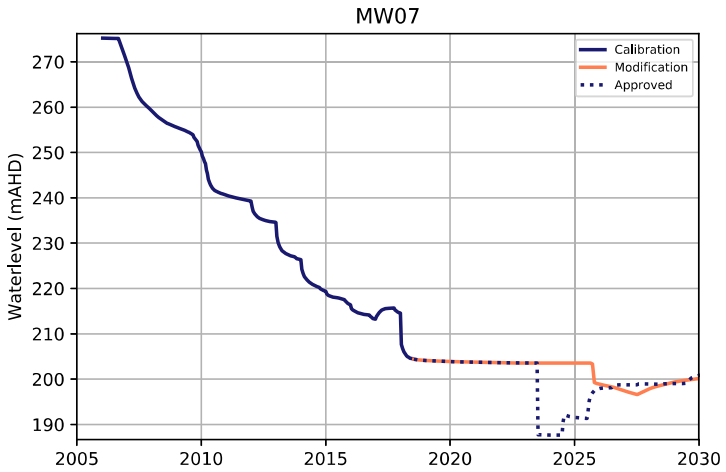

IBC2139
Waterlevel (mAHD)
Calibration
Modification
Approved

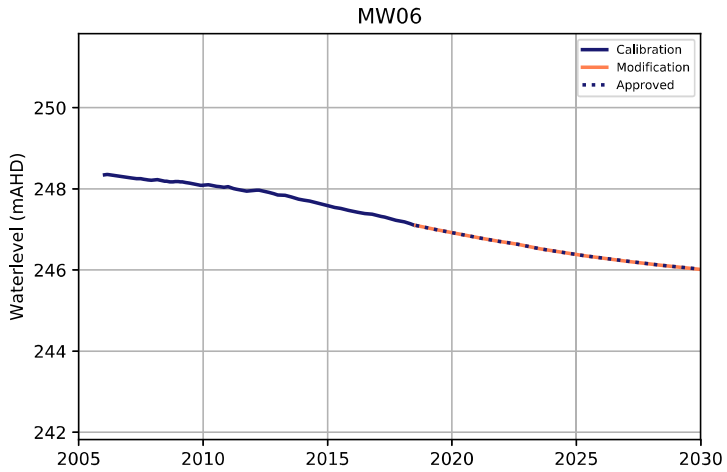

MW03
Waterlevel (mAHD)
Calibration
Modification
Approved

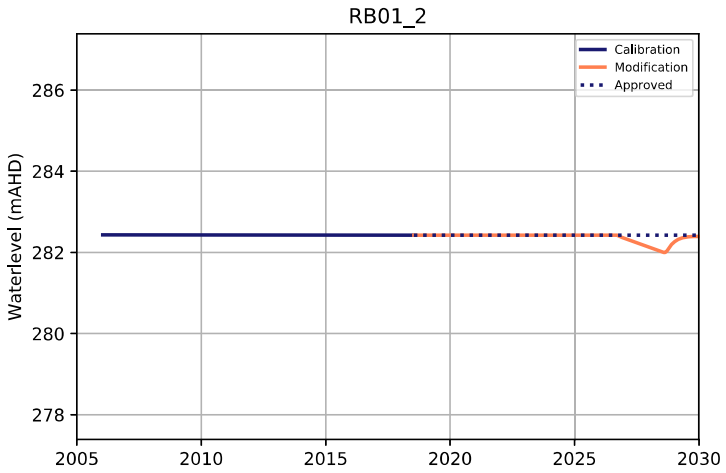

MW02
Waterlevel (mAHD)
Calibration
Modification
Approved

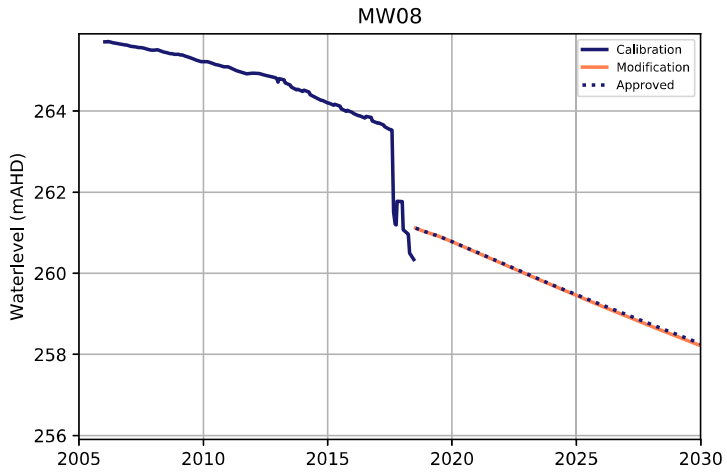

MW05
Calibration
Modification
Approved
Waterlevel (mAHD)
262
264
266
268
270
2005
2010
2015
2020
2025
2030

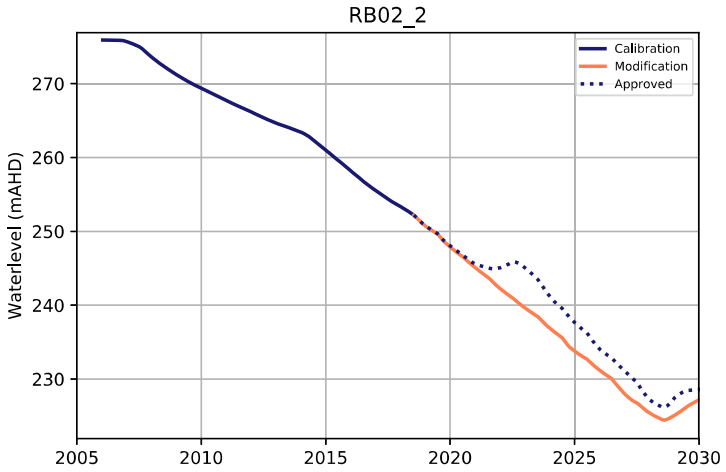

MW04
Calibration
Modification
Approved
Waterlevel (mAHD)
248
250
252
254
256
2005
2010
2015
2020
2025
2030

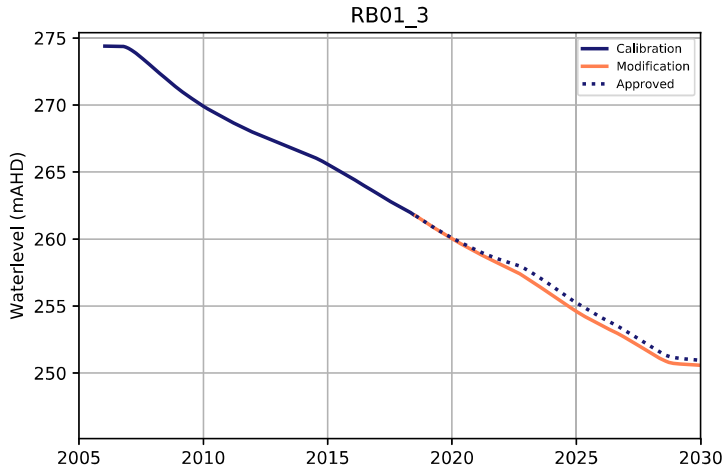

MW07
Calibration
Modification
Approved
Waterlevel (mAHD)
190
200
210
220
230
240
250
260
270
2005
2010
2015
2020
2025
2030

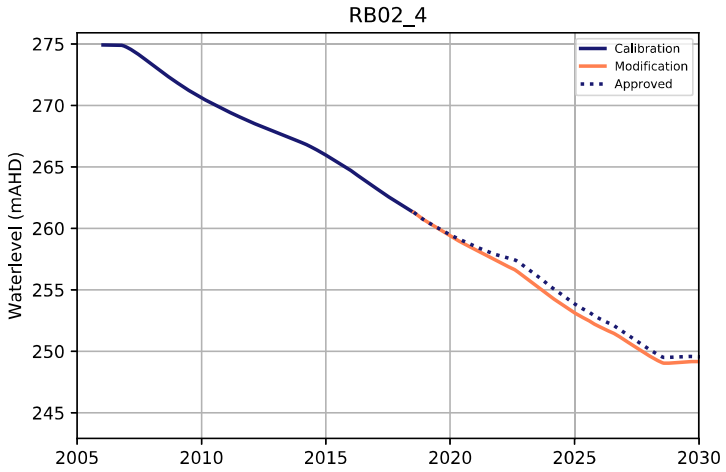

MW06
Calibration
Modification
Approved
Waterlevel (mAHD)
242
244
246
248
250
2005
2010
2015
2020
2025
2030

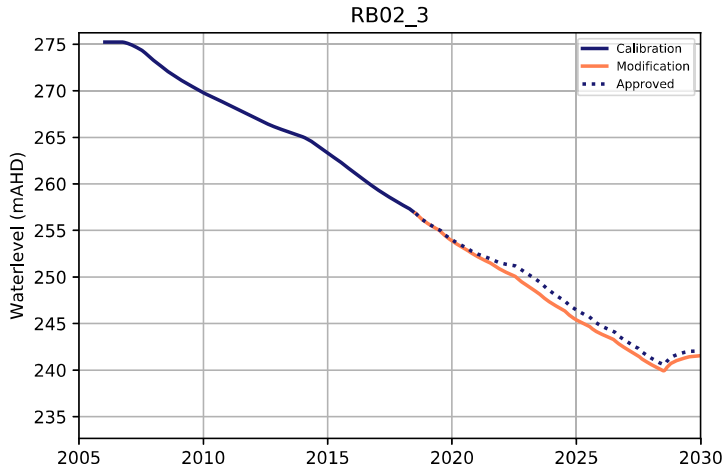

RB01_2
Calibration
Modification
Approved
Waterlevel (mAHD)
278
280
282
284
286
2005
2010
2015
2020
2025
2030

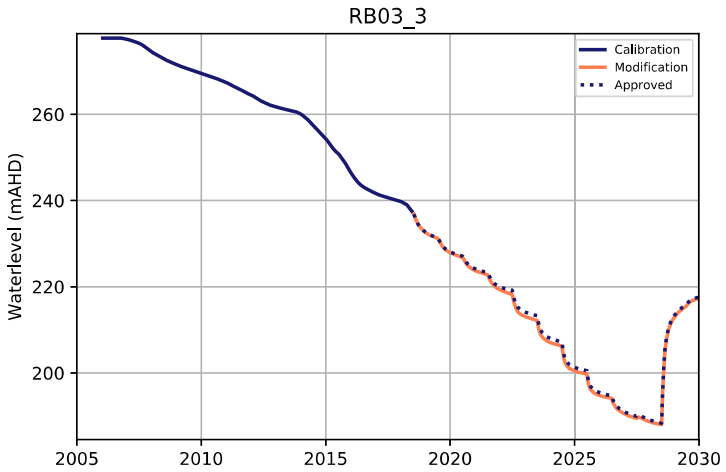

MW08
Calibration
Modification
Approved
Waterlevel (mAHD)
256
258
260
262
264
2005
2010
2015
2020
2025
2030

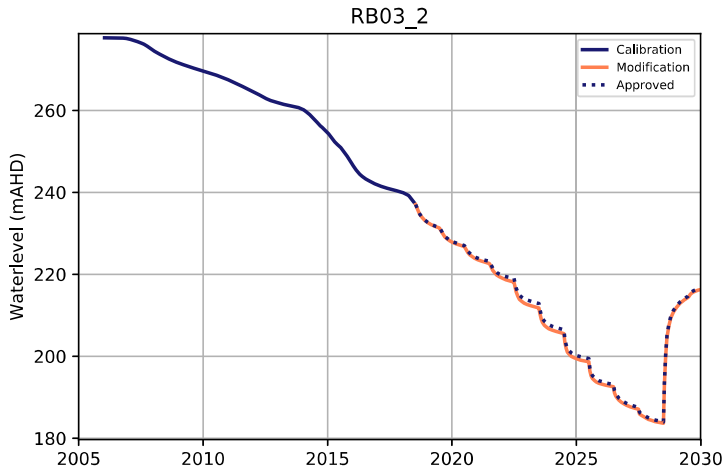

RB02_2
Calibration
Modification
Approved
Waterlevel (mAHD)
230
240
250
260
270
2005
2010
2015
2020
2025
2030

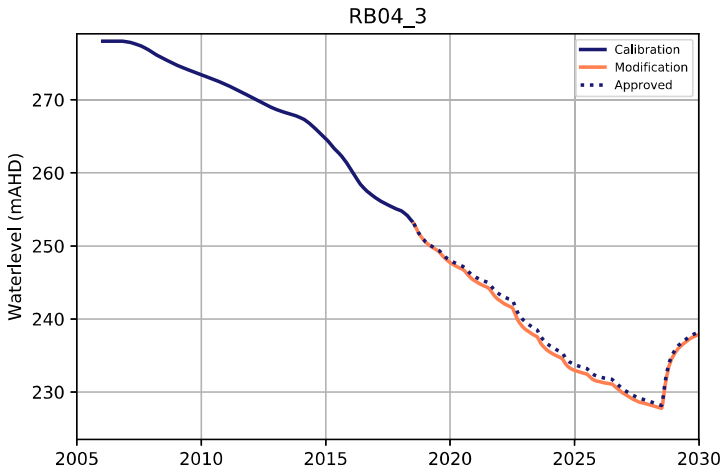

RB01_3
Calibration
Modification
Approved
Waterlevel (mAHD)
250
255
260
265
270
275
2005
2010
2015
2020
2025
2030

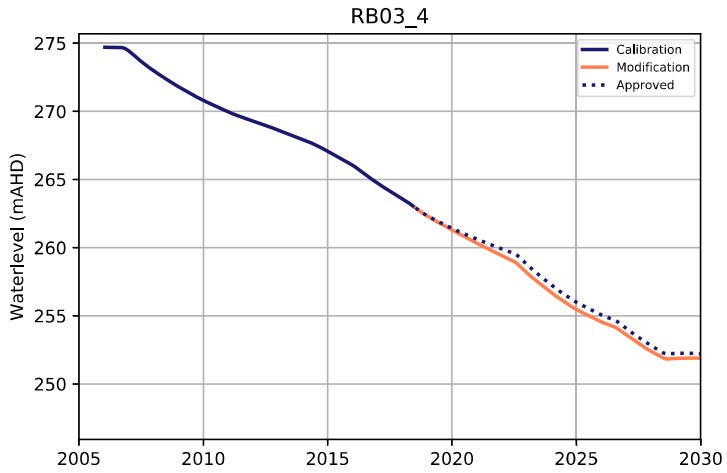

RB02_4
Waterlevel (mAHD)
Calibration
Modification
Approved

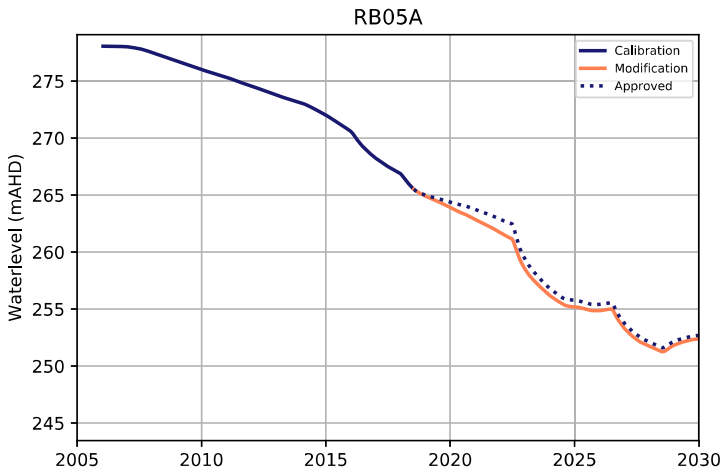

RB02_3
Waterlevel (mAHD)
Calibration
Modification
Approved

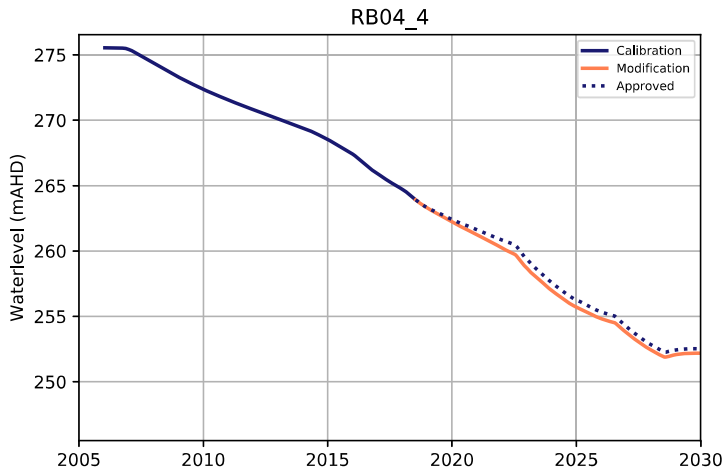

RB03_3
Waterlevel (mAHD)
Calibration
Modification
Approved

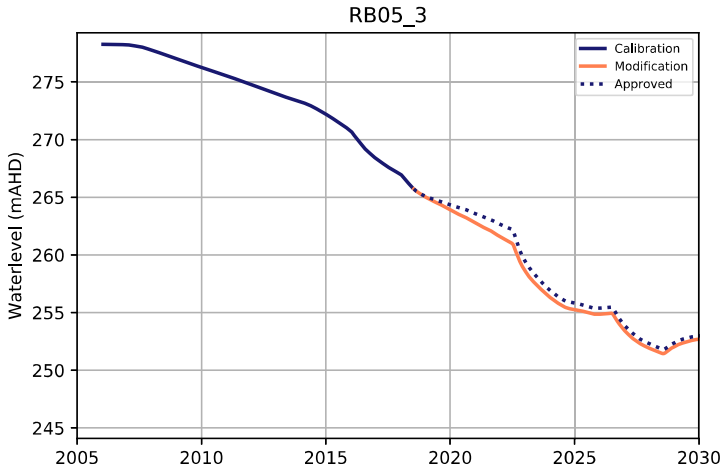

RB03_2
Waterlevel (mAHD)
Calibration
Modification
Approved

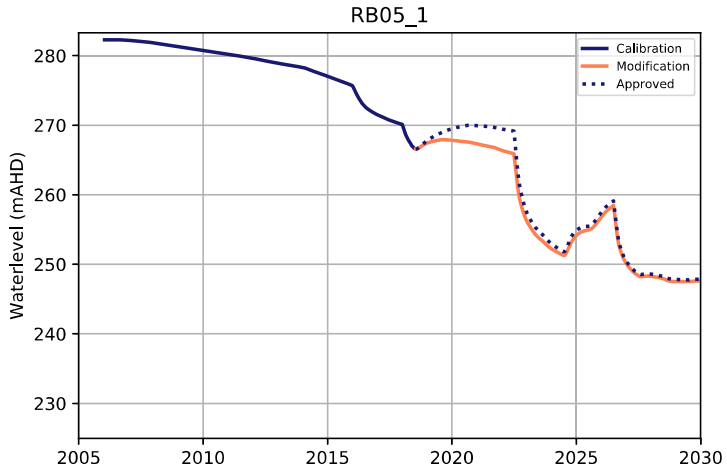

RB04_3
Waterlevel (mAHD)
Calibration
Modification
Approved

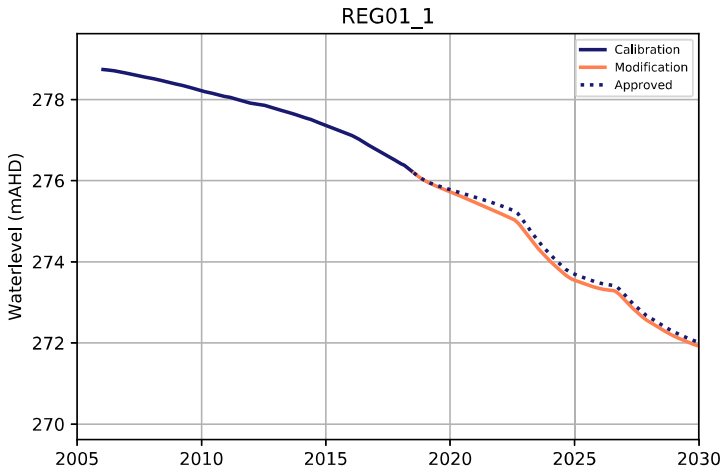

RB03_4
Waterlevel (mAHD)
Calibration
Modification
Approved

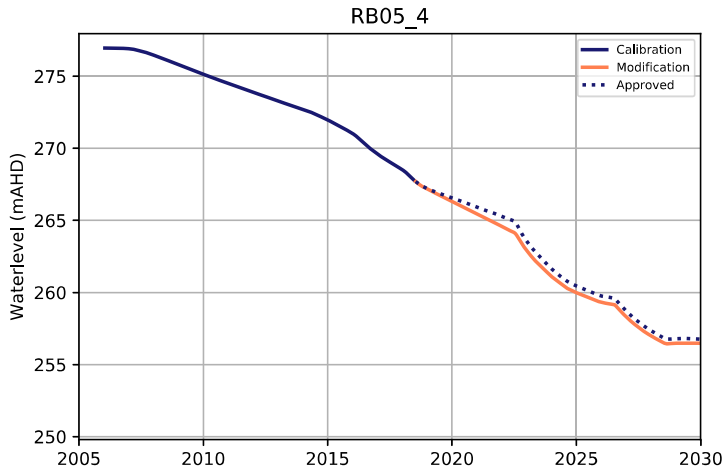

RB05A
Waterlevel (mAHD)
Calibration
Modification
Approved

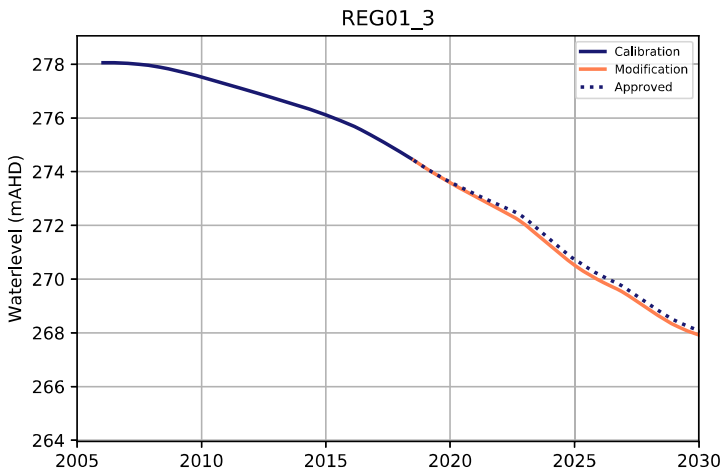

RB04_4
Waterlevel (mAHD)
Calibration
Modification
Approved

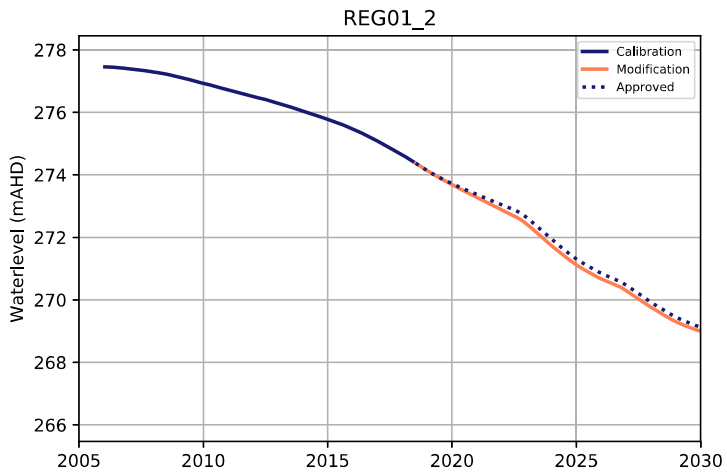

RB05_3
Waterlevel (mAHD)
Calibration
Modification
Approved

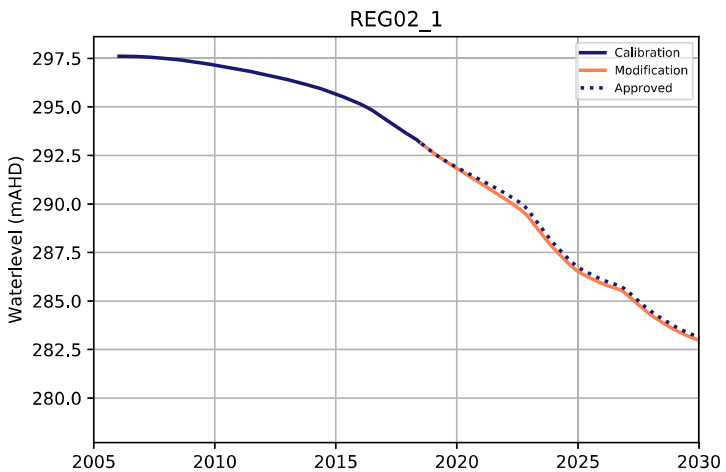

RB05_1
Waterlevel (mAHD)
Calibration
Modification
Approved

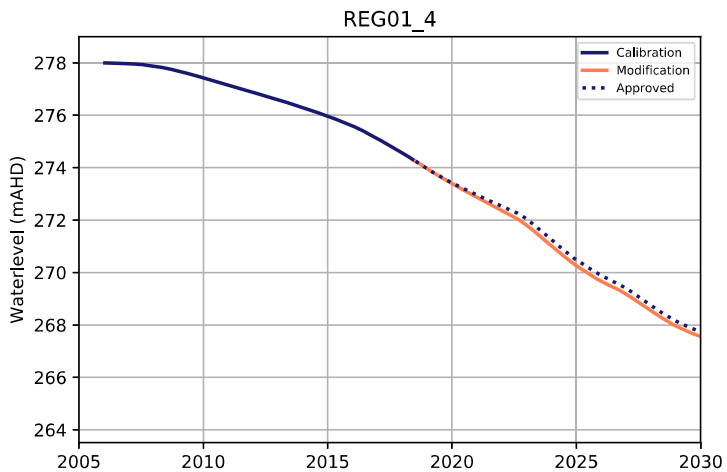

REG01_1
Waterlevel (mAHD)
Calibration
Modification
Approved

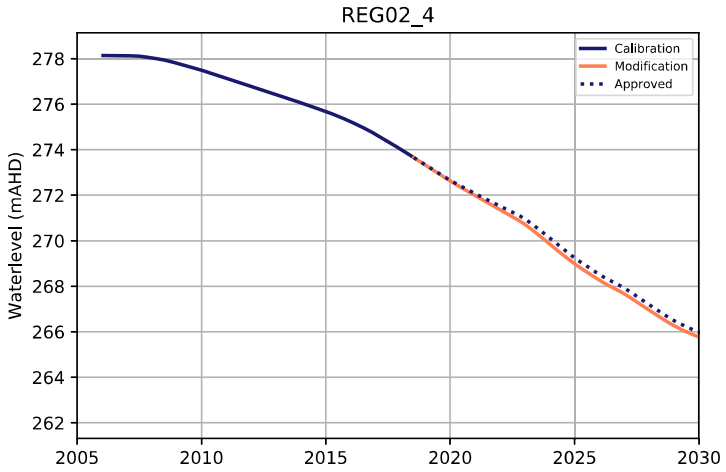

RB05_4
Waterlevel (mAHD)
Calibration
Modification
Approved

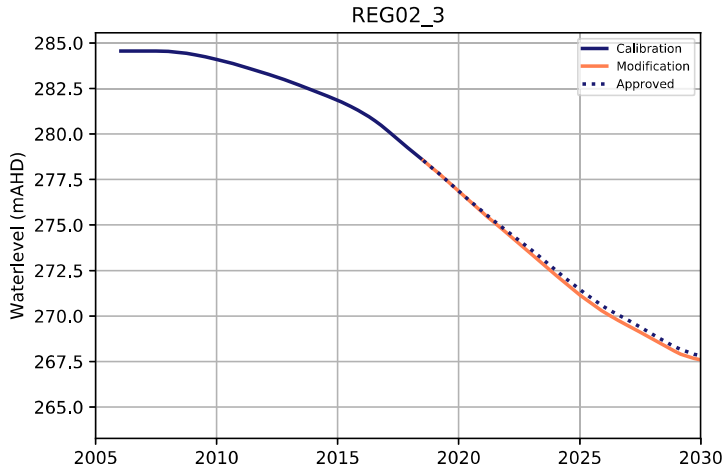

REG01_3
Waterlevel (mAHD)
Calibration
Modification
Approved

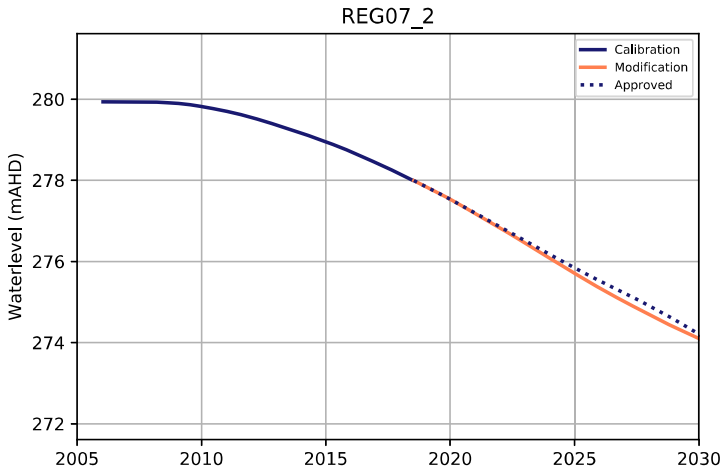

REG01_2
Waterlevel (mAHD)
Calibration
Modification
Approved

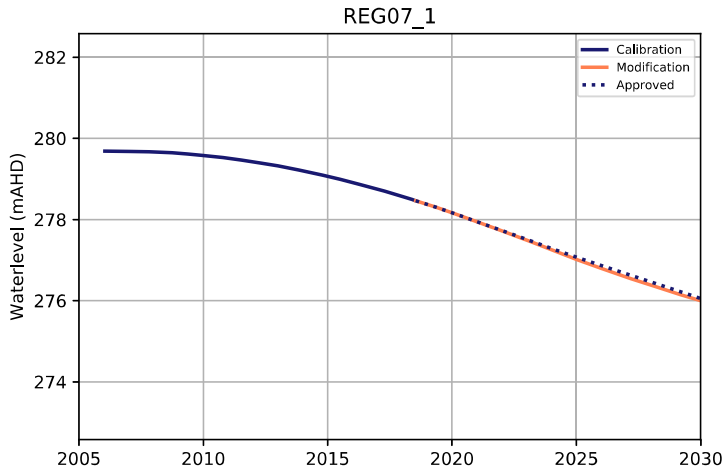

REG02_1
Waterlevel (mAHD)
Calibration
Modification
Approved

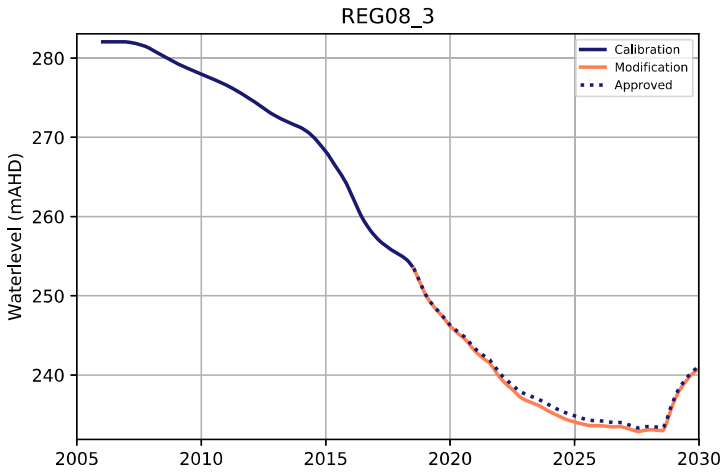

REG01_4
Waterlevel (mAHD)
Calibration
Modification
Approved

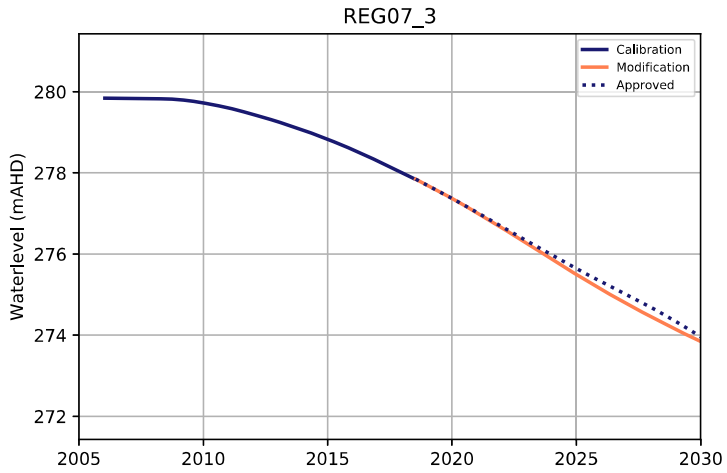

REG02_4
Waterlevel (mAHD)
Calibration
Modification
Approved

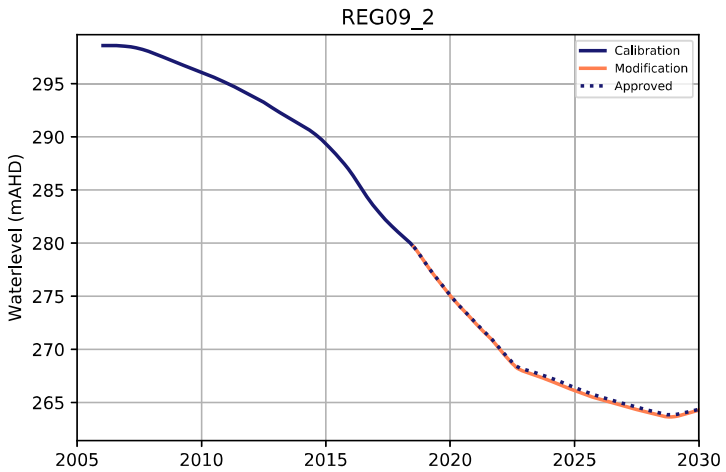

REG02_3
Waterlevel (mAHD)
Calibration
Modification
Approved

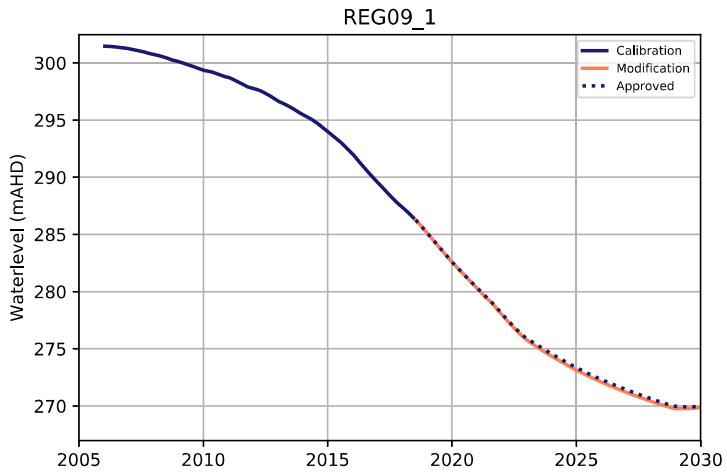

REG07_2
Waterlevel (mAHD)
Calibration
Modification
Approved

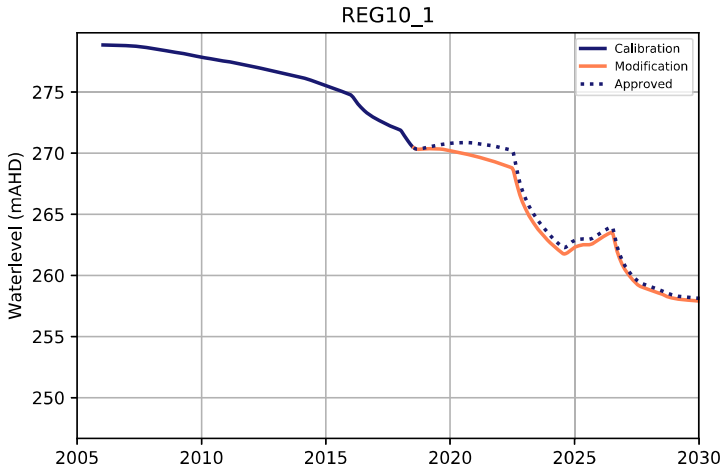

REG07_1
Waterlevel (mAHD)
Calibration
Modification
Approved

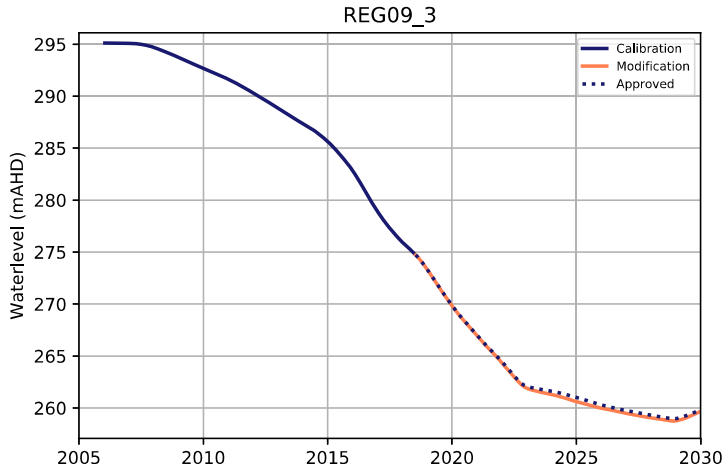

REG08_3
Waterlevel (mAHD)
Calibration
Modification
Approved

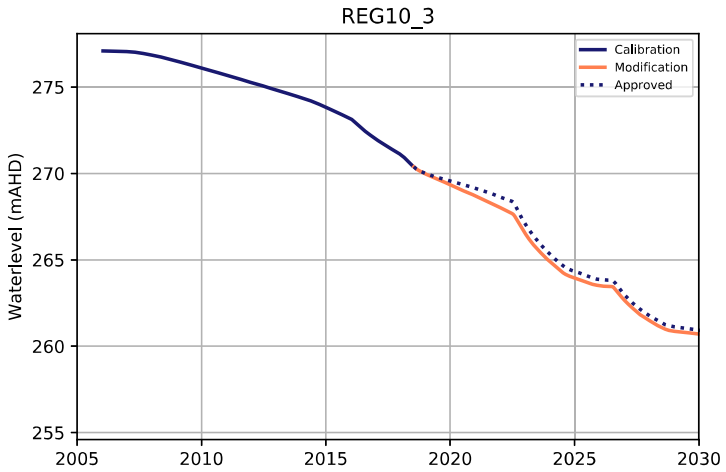

REG07_3
Waterlevel (mAHD)
Calibration
Modification
Approved

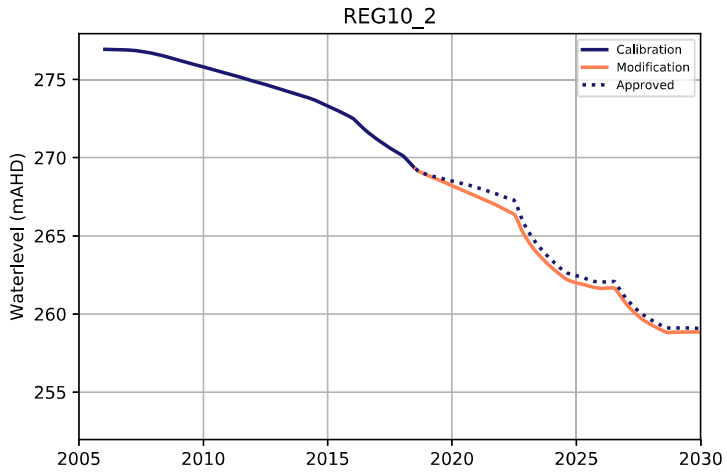

REG09_2
Waterlevel (mAHD)
Calibration
Modification
Approved

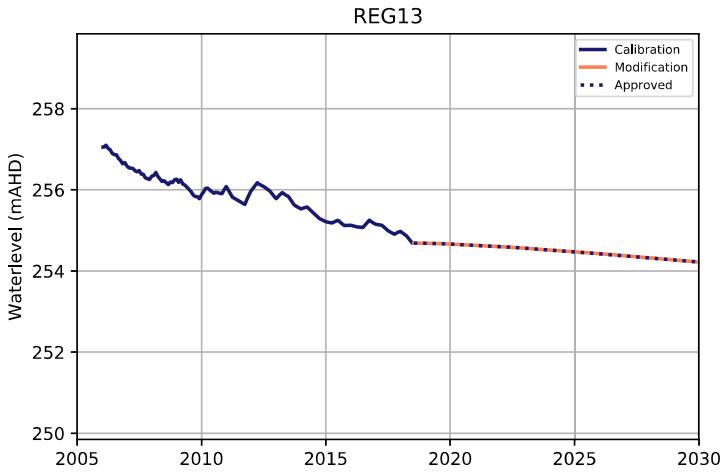

REG09_1
Waterlevel (mAHD)
Calibration
Modification
Approved

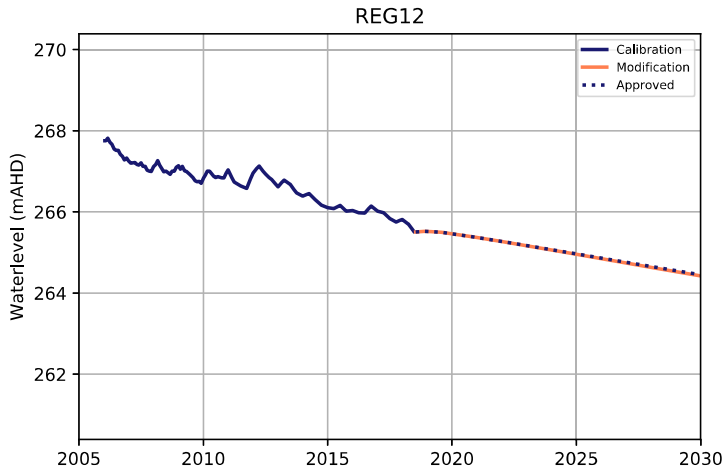

REG10_1
Calibration
Modification
Approved
Waterlevel (mAHD)
275
270
265
260
255
250
2005
2010
2015
2020
2025
2030

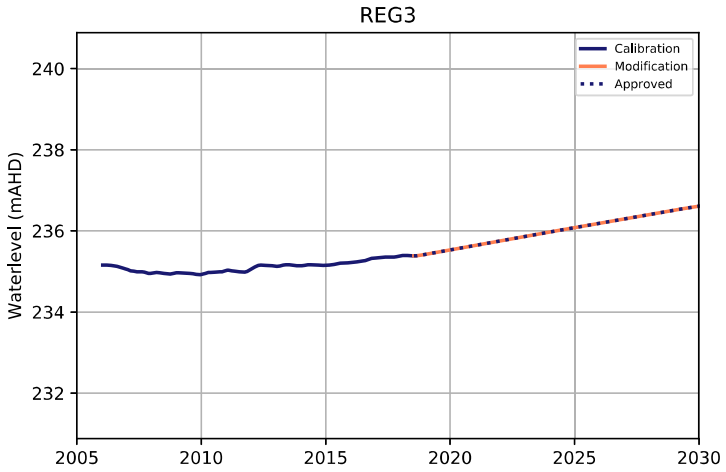

REG09_3
Calibration
Modification
Approved
Waterlevel (mAHD)
295
290
285
280
275
270
265
260
2005
2010
2015
2020
2025
2030

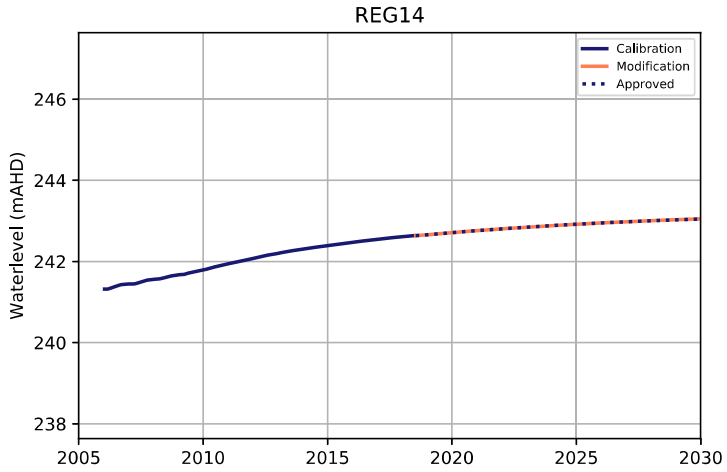

REG10_3
Calibration
Modification
Approved
Waterlevel (mAHD)
275
270
265
260
255
2005
2010
2015
2020
2025
2030

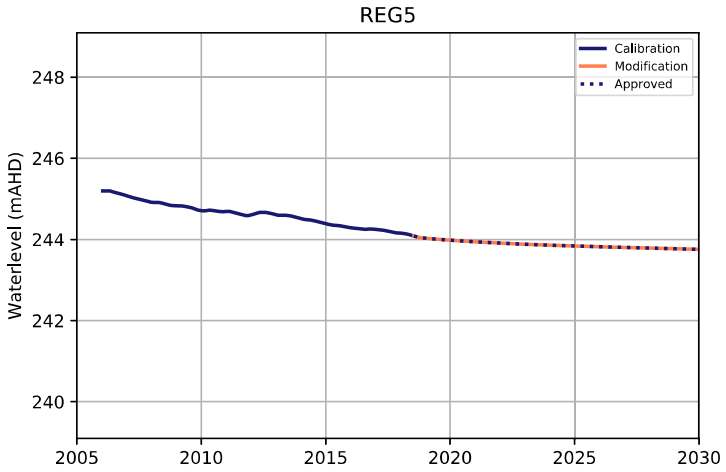

REG10_2
Calibration
Modification
Approved
Waterlevel (mAHD)
275
270
265
260
255
2005
2010
2015
2020
2025
2030

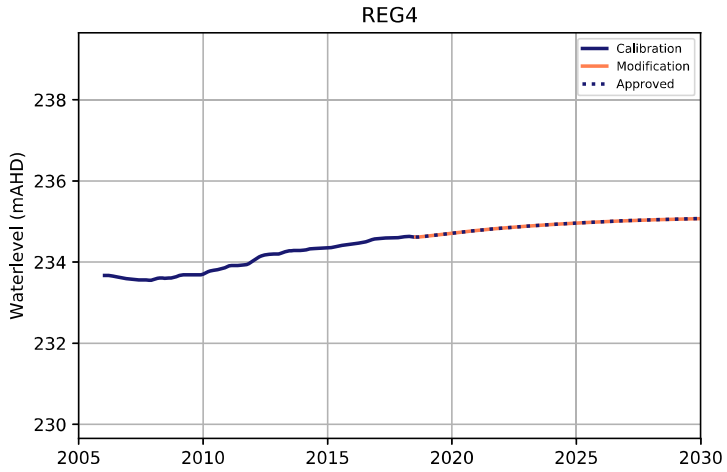

REG13
Calibration
Modification
Approved
Waterlevel (mAHD)
258
256
254
252
250
2005
2010
2015
2020
2025
2030

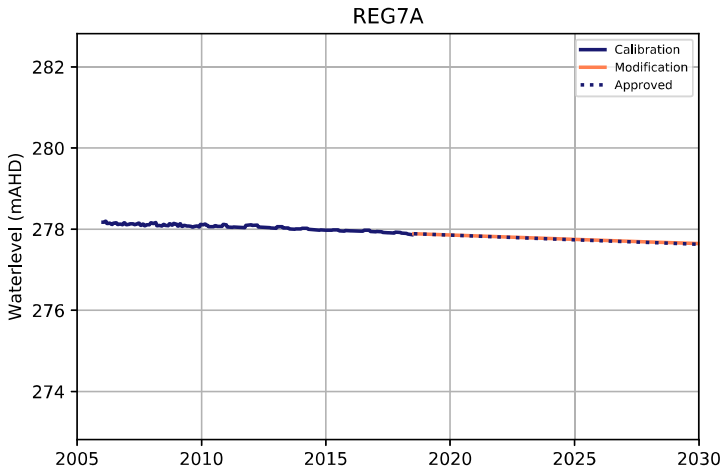

REG12
Calibration
Modification
Approved
Waterlevel (mAHD)
270
268
266
264
262
2005
2010
2015
2020
2025
2030

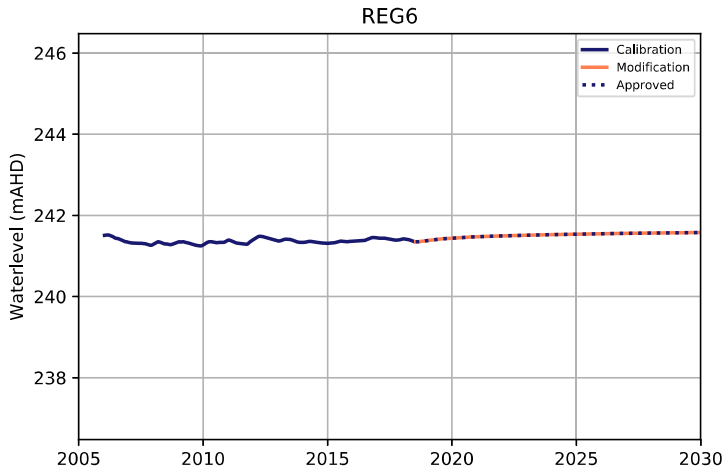

REG3
Calibration
Modification
Approved
Waterlevel (mAHD)
240
238
236
234
232
2005
2010
2015
2020
2025
2030

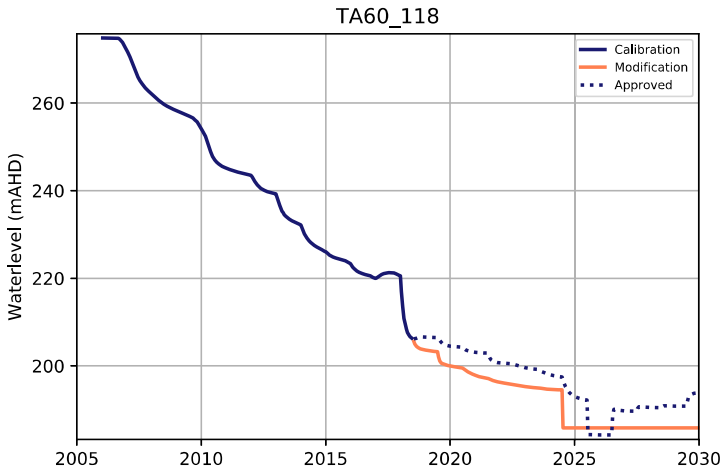

REG14
Calibration
Modification
Approved
Waterlevel (mAHD)
246
244
242
240
238
2005
2010
2015
2020
2025
2030

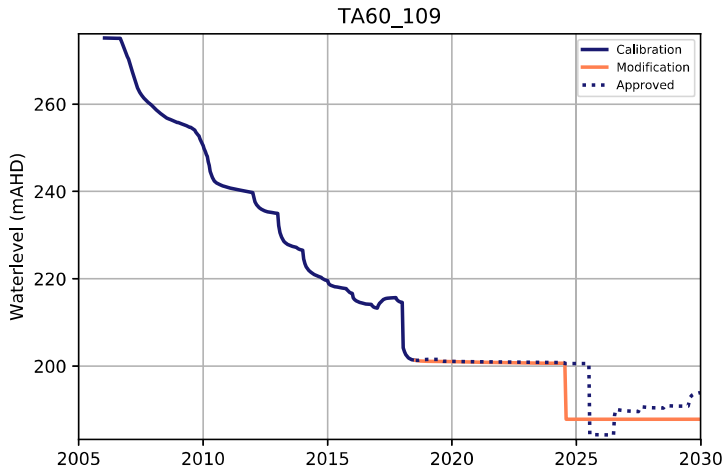

REG5
Calibration
Modification
Approved
Waterlevel (mAHD)
248
246
244
242
240
2005
2010
2015
2020
2025
2030

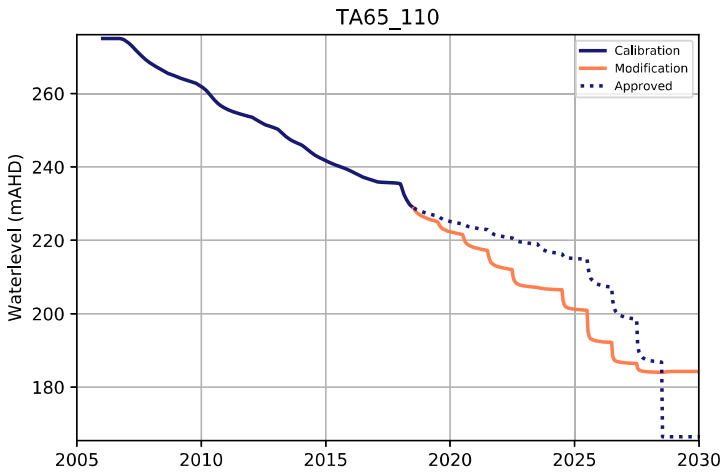

REG4
Calibration
Modification
Approved
Waterlevel (mAHD)
238
236
234
232
230
2005
2010
2015
2020
2025
2030

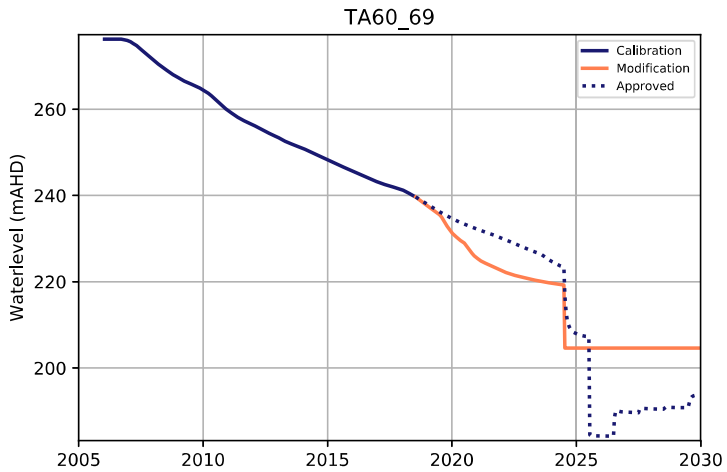

REG7A
Calibration
Modification
Approved
Waterlevel (mAHD)
282
280
278
276
274
2005
2010
2015
2020
2025
2030

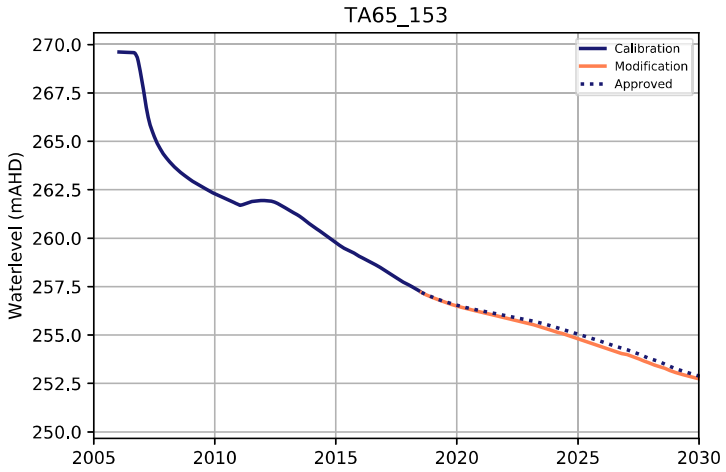

REG6
Calibration
Modification
Approved
Waterlevel (mAHD)
246
244
242
240
238
2005
2010
2015
2020
2025
2030

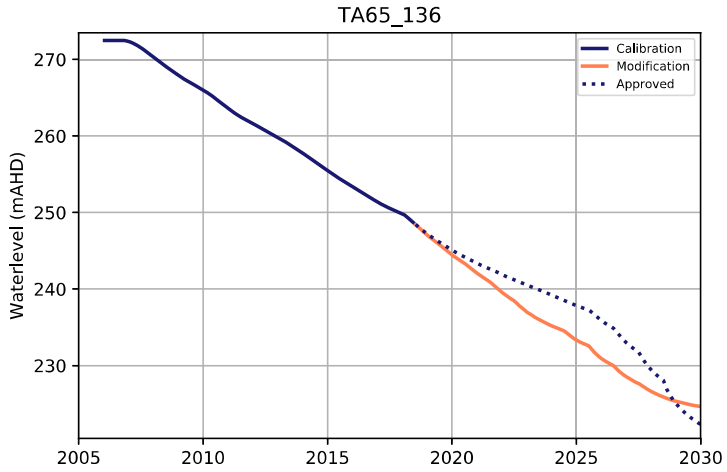

TA60_118
Calibration
Modification
Approved
Waterlevel (mAHD)
260
240
220
200
2005
2010
2015
2020
2025
2030

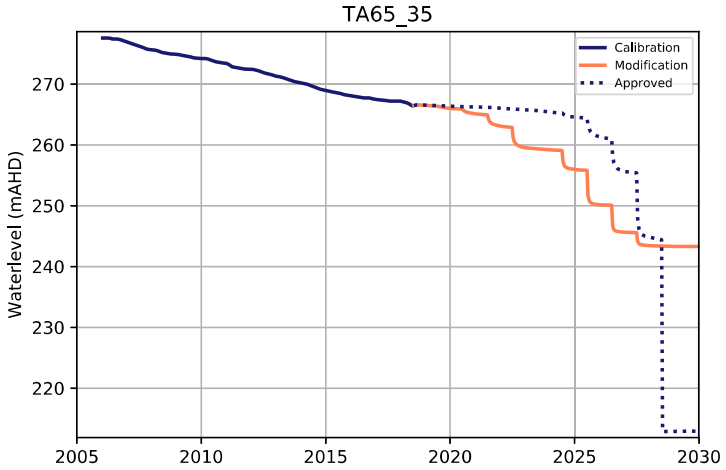

TA60_109
Calibration
Modification
Approved
Waterlevel (mAHD)
260
240
220
200
2005
2010
2015
2020
2025
2030

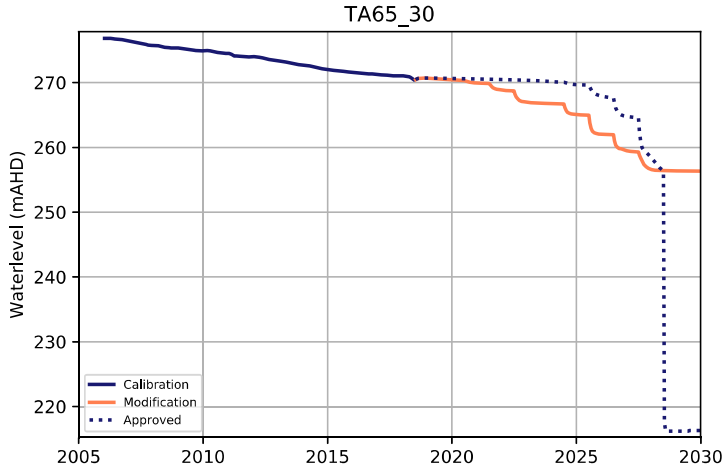

TA65_110
Calibration
Modification
Approved
Waterlevel (mAHD)
260
240
220
200
180
2005
2010
2015
2020
2025
2030

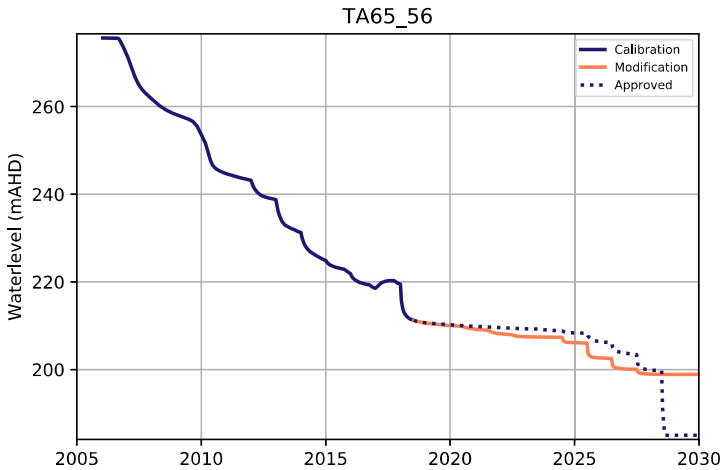

TA60_69
Calibration
Modification
Approved
Waterlevel (mAHD)
260
240
220
200
2005
2010
2015
2020
2025
2030

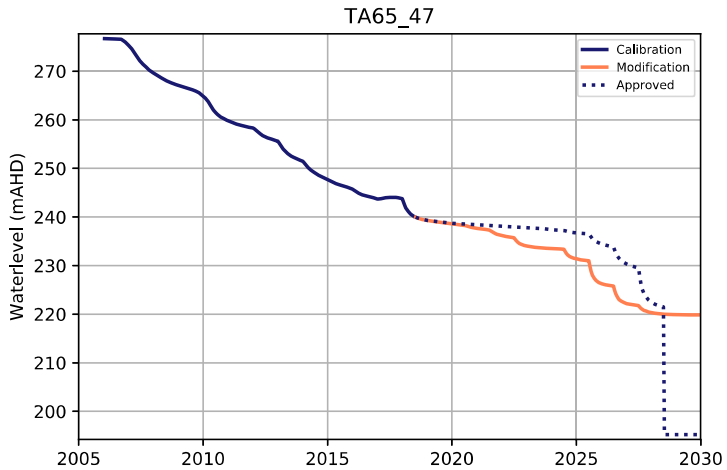

TA65_153
Waterlevel (mAHD)
Calibration
Modification
Approved

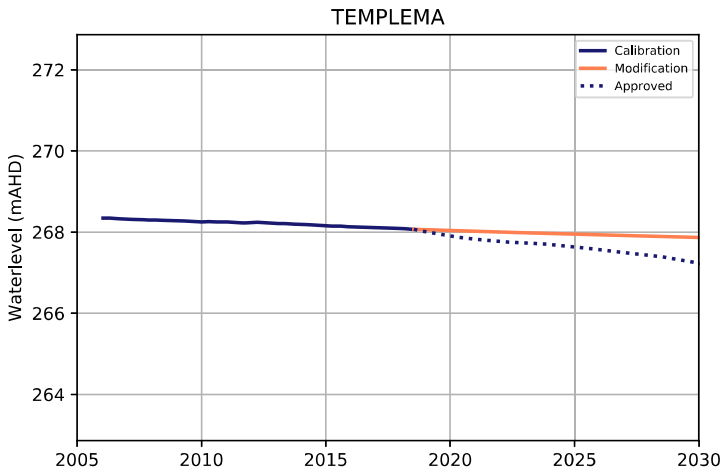

TA65_136
Waterlevel (mAHD)
Calibration
Modification
Approved

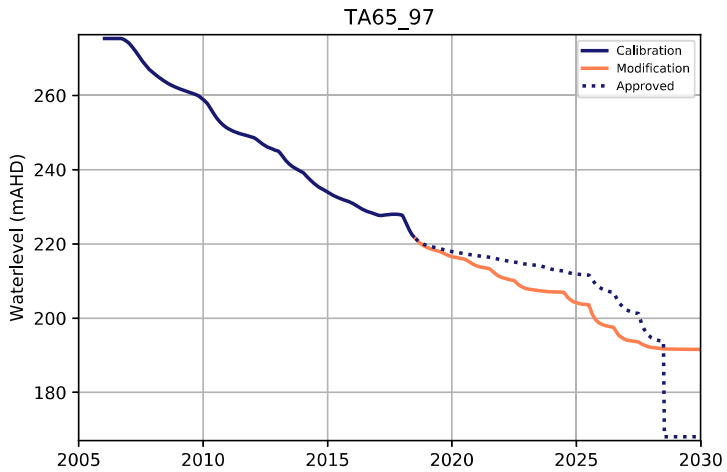

TA65_35
Waterlevel (mAHD)
Calibration
Modification
Approved

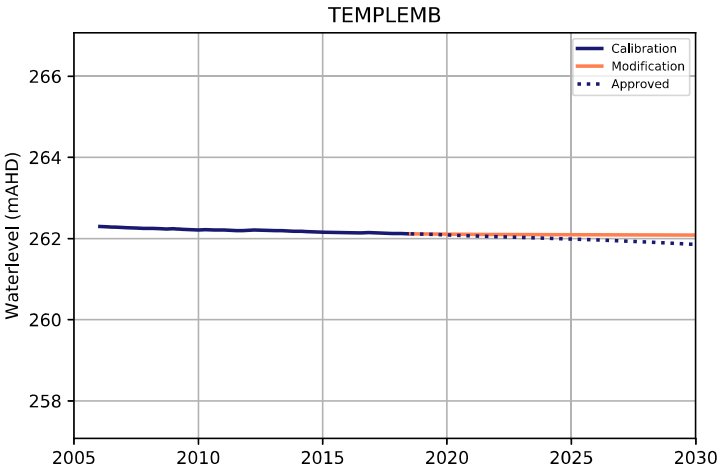

TA65_30
Waterlevel (mAHD)
Calibration
Modification
Approved


TA65_56
Waterlevel (mAHD)
Calibration
Modification
Approved


TA65_47
Waterlevel (mAHD)
Calibration
Modification
Approved


TEMPLEMA
Waterlevel (mAHD)
Calibration
Modification
Approved

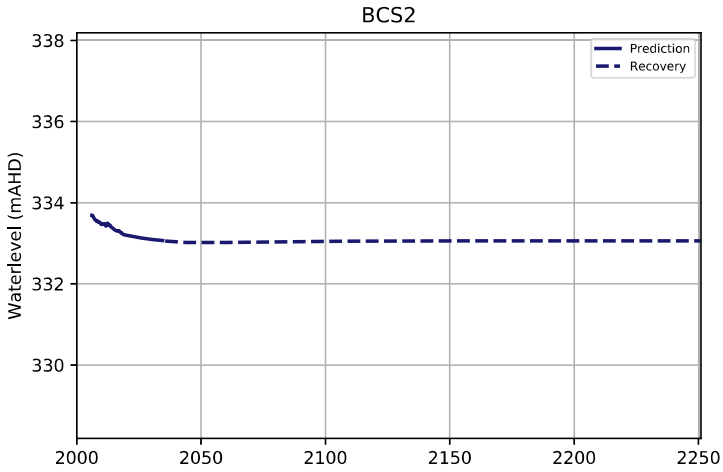

TA65_97
Waterlevel (mAHD)
Calibration
Modification
Approved

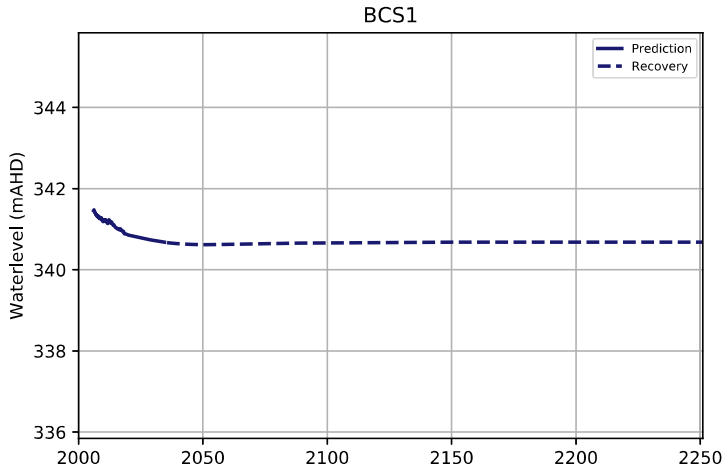

TEMPLEMB
Calibration
Modification
Approved
Waterlevel (mAHD)
266
264
262
260
258
2005
2010
2015
2020
2025
2030

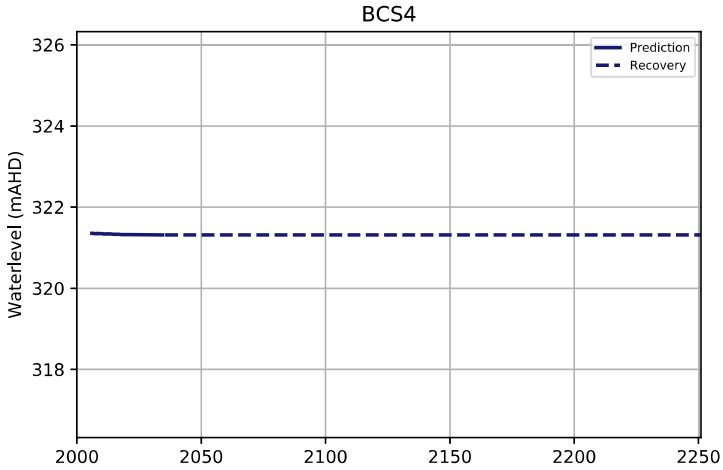
ATTACHMENT F – RECOVERY HYDROGRAPHS

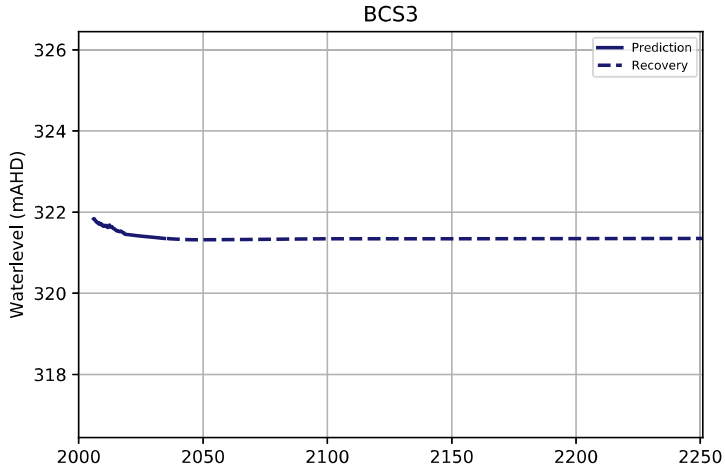
ATTACHMENT F

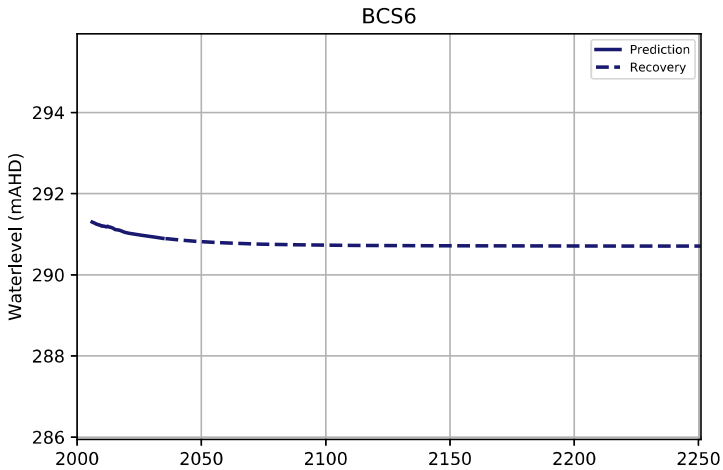
Recovery Hydrographs

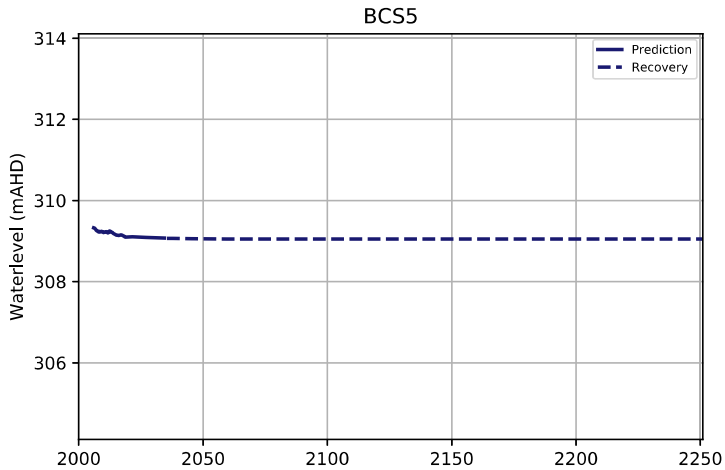


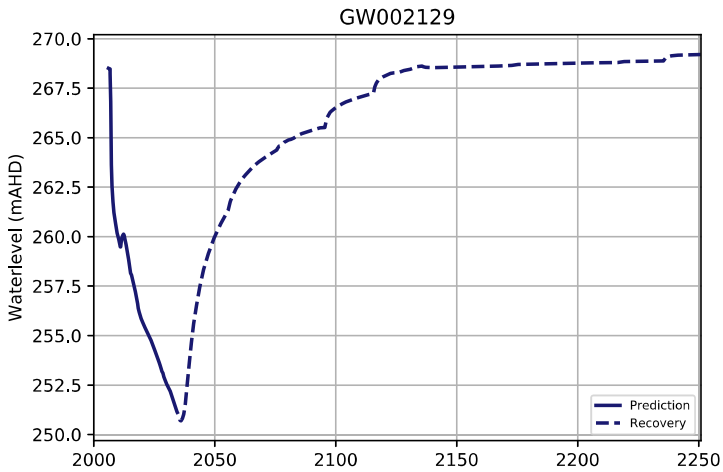


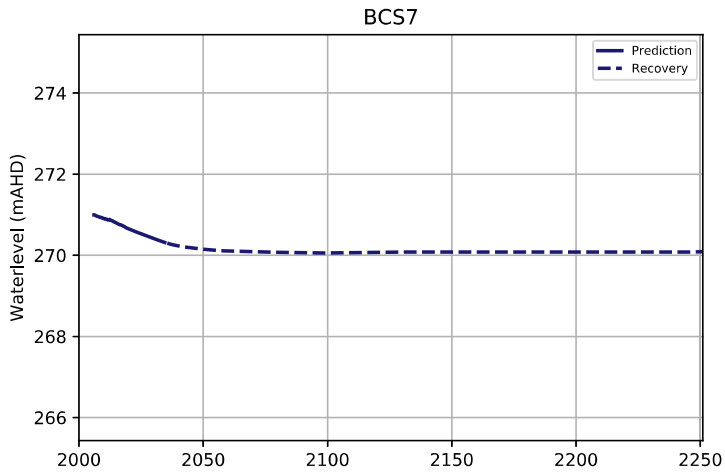


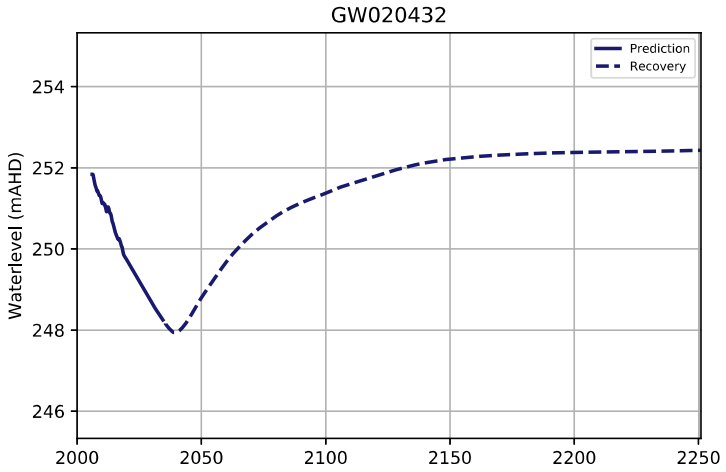


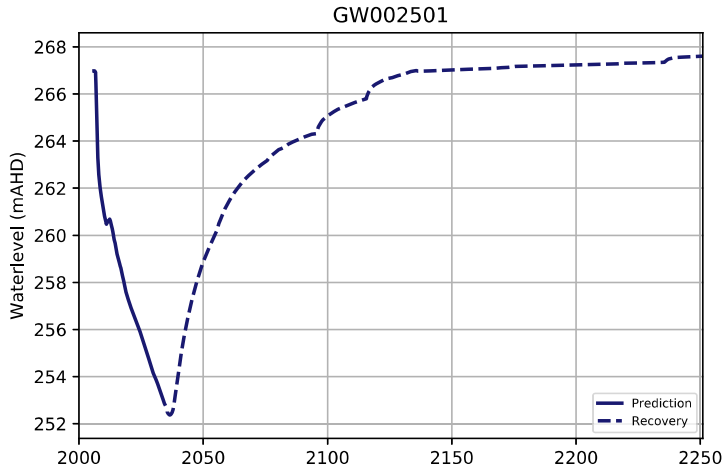


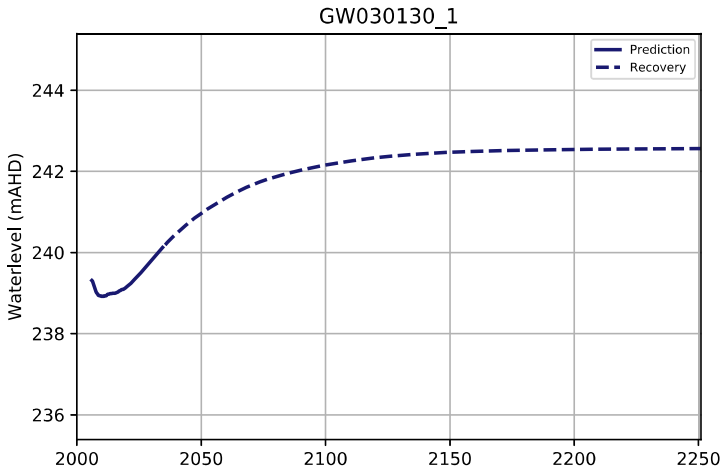


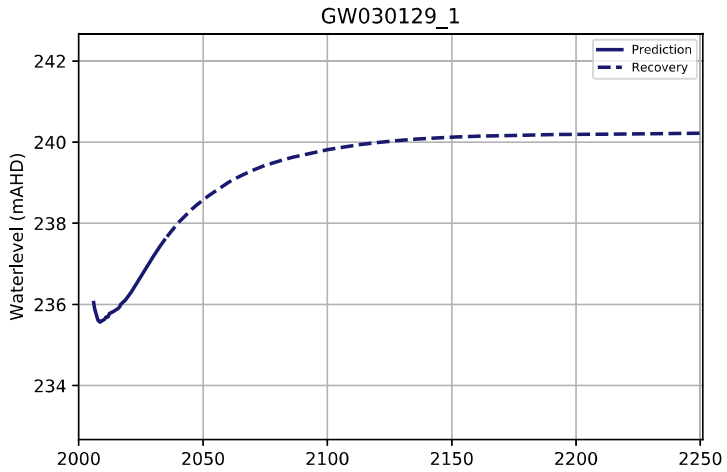


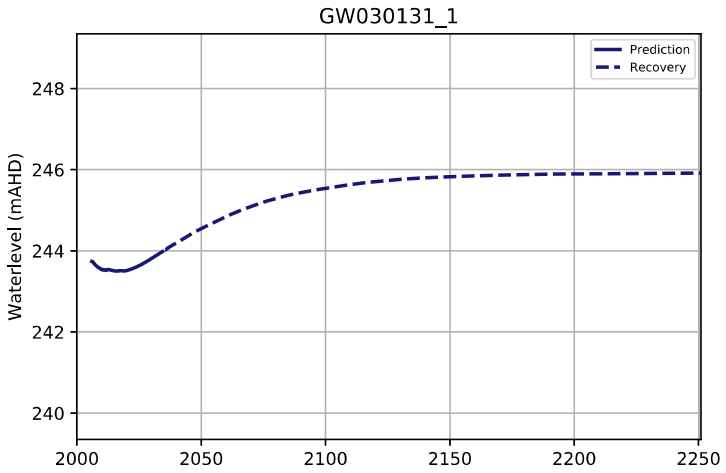


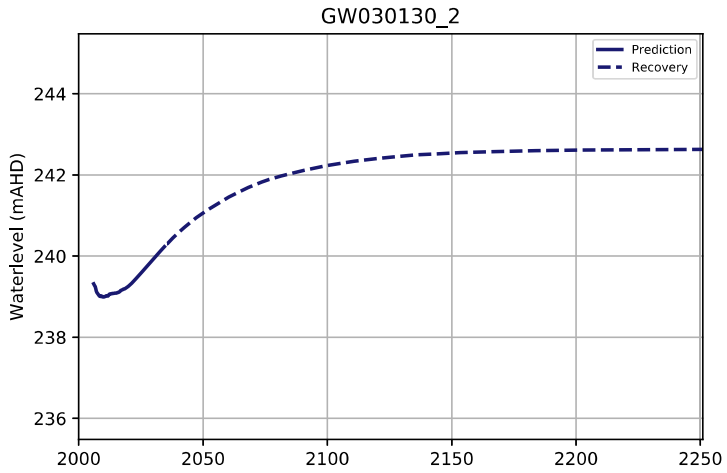

GW020432
Prediction
Recovery
Waterlevel (mAHD)
254
252
250
248
246
2000
2050
2100
2150
2200
2250

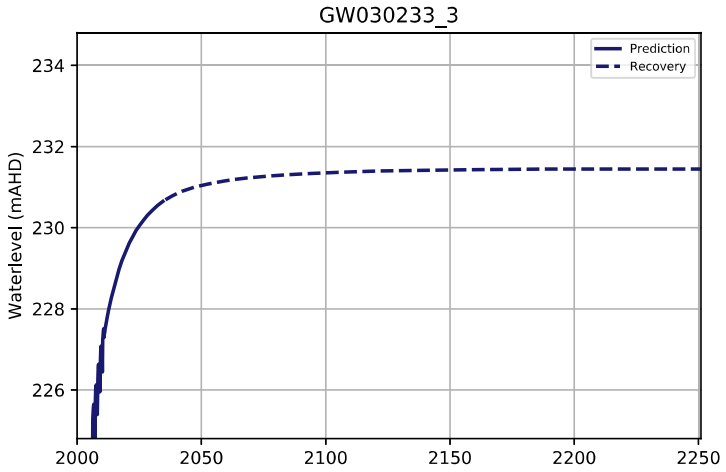

GW002501
Prediction
Recovery
Waterlevel (mAHD)
268
266
264
262
260
258
256
254
252
2000
2050
2100
2150
2200
2250

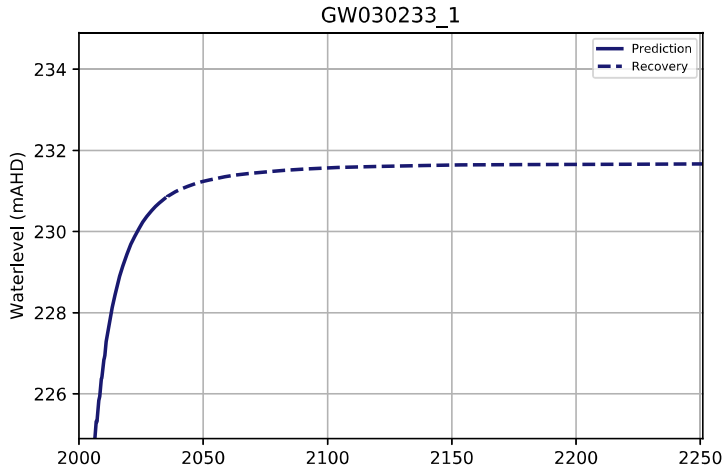

GW030130_1
Prediction
Recovery
Waterlevel (mAHD)
244
242
240
238
236
2000
2050
2100
2150
2200
2250

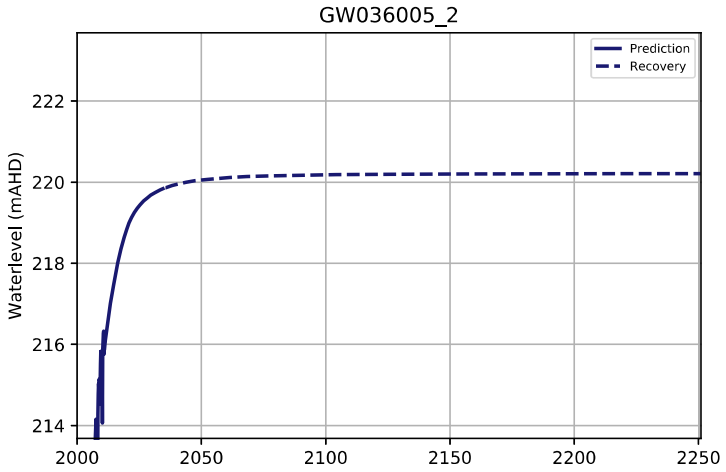

GW030129_1
Prediction
Recovery
Waterlevel (mAHD)
242
240
238
236
234
2000
2050
2100
2150
2200
2250

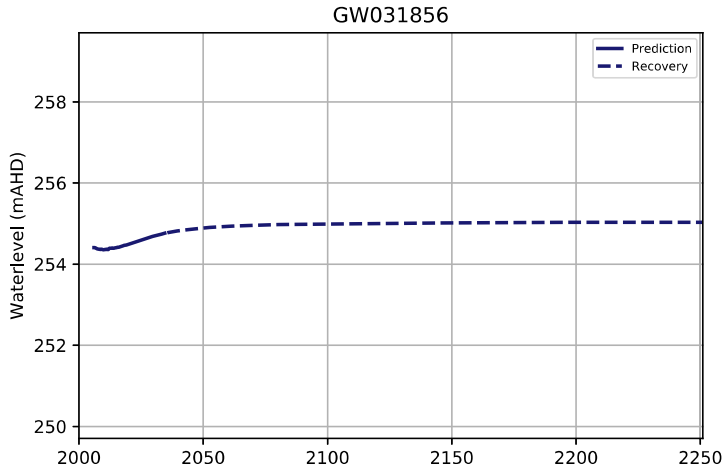

GW030131_1
Prediction
Recovery
Waterlevel (mAHD)
248
246
244
242
240
2000
2050
2100
2150
2200
2250

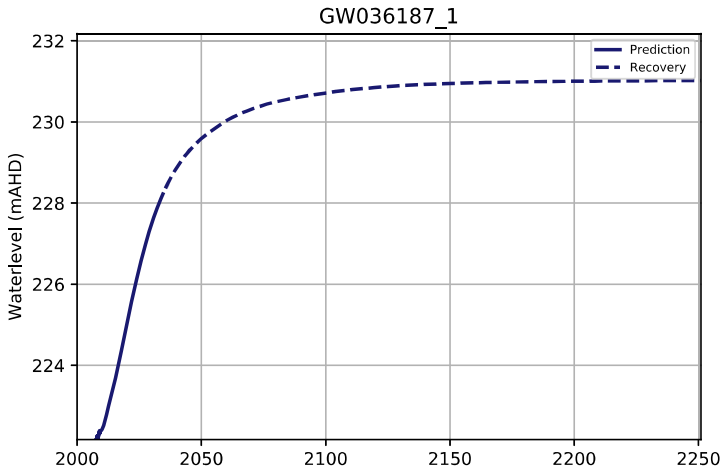

GW030130_2
Prediction
Recovery
Waterlevel (mAHD)
244
242
240
238
236
2000
2050
2100
2150
2200
2250

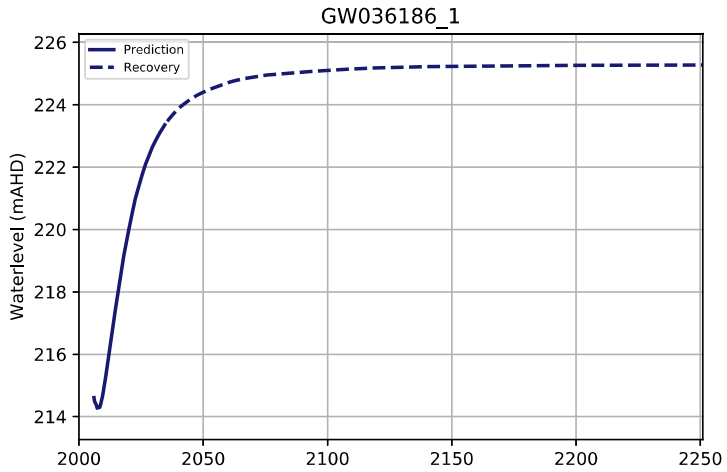

GW030233_3
Prediction
Recovery
Waterlevel (mAHD)
234
232
230
228
226
2000
2050
2100
2150
2200
2250

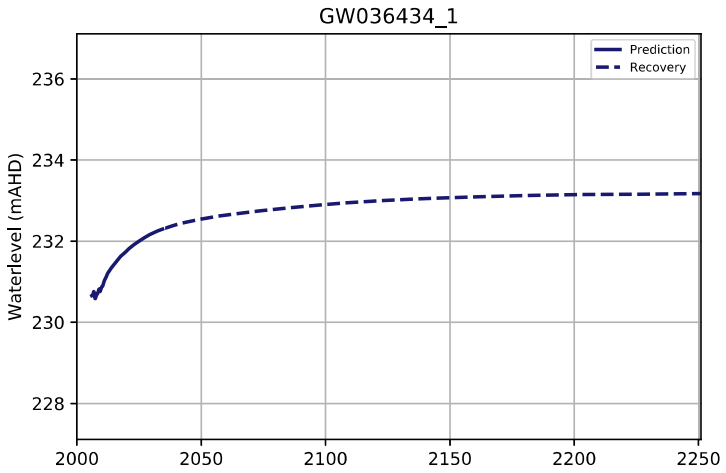

GW030233_1
Prediction
Recovery
Waterlevel (mAHD)
234
232
230
228
226
2000
2050
2100
2150
2200
2250

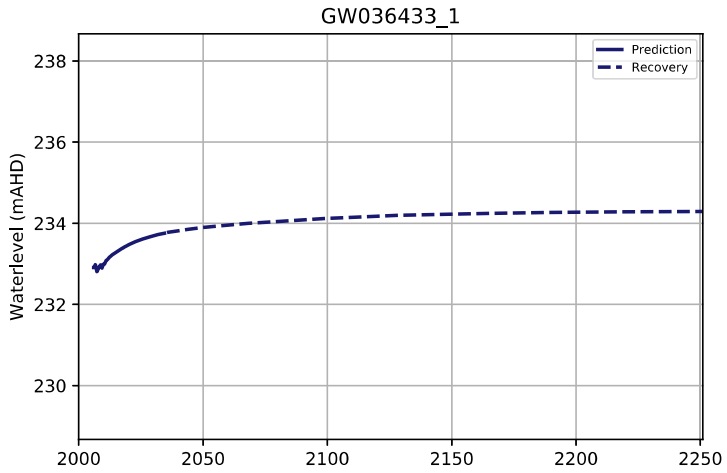

GW036005_2
Prediction
Recovery
Waterlevel (mAHD)
214
216
218
220
222
2000
2050
2100
2150
2200
2250

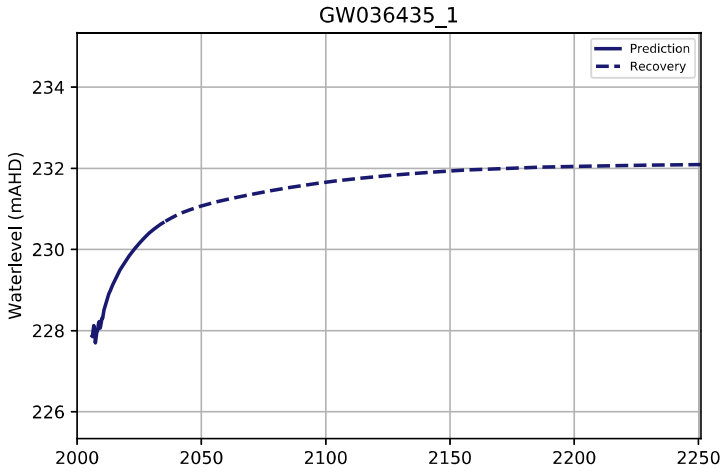

GW031856
Prediction
Recovery
Waterlevel (mAHD)
250
252
254
256
258
2000
2050
2100
2150
2200
2250

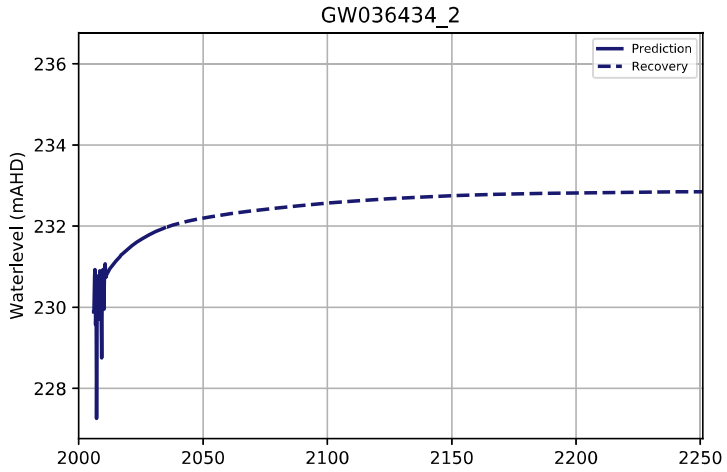

GW036187_1
Prediction
Recovery
Waterlevel (mAHD)
224
226
228
230
232
2000
2050
2100
2150
2200
2250

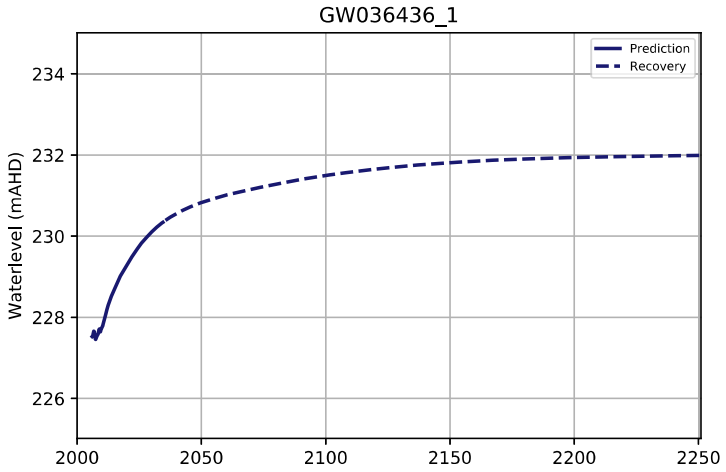

GW036186_1
Prediction
Recovery
Waterlevel (mAHD)
214
216
218
220
222
224
226
2000
2050
2100
2150
2200
2250

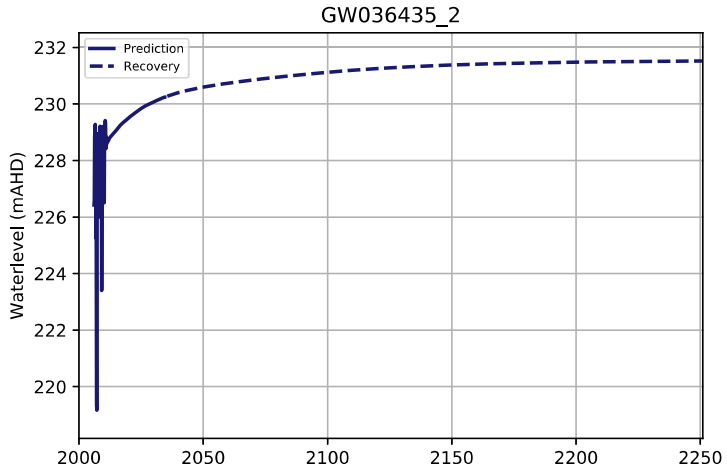

GW036434_1
Prediction
Recovery
Waterlevel (mAHD)
228
230
232
234
236
2000
2050
2100
2150
2200
2250

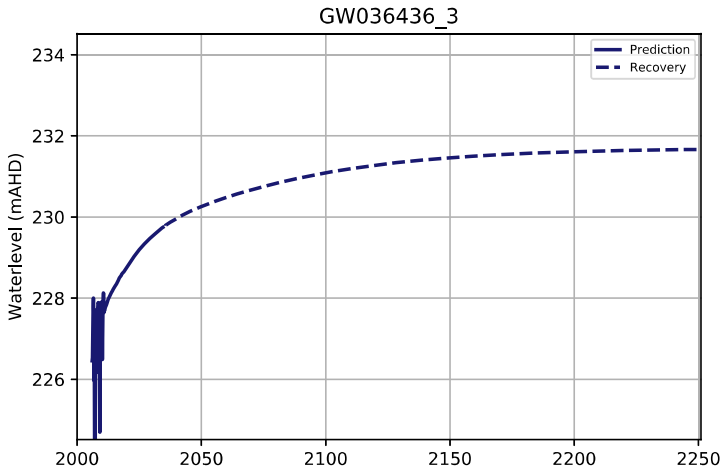

GW036433_1
Prediction
Recovery
Waterlevel (mAHD)
230
232
234
236
238
2000
2050
2100
2150
2200
2250

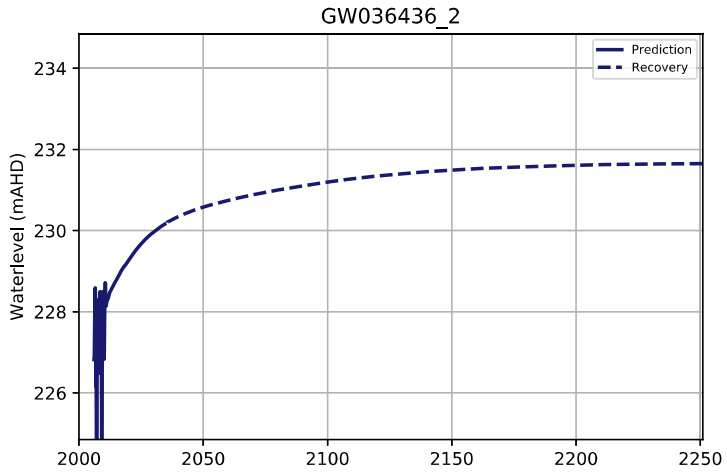

GW036435_1
Prediction
Recovery
Waterlevel (mAHD)
226
228
230
232
234
2000
2050
2100
2150
2200
2250

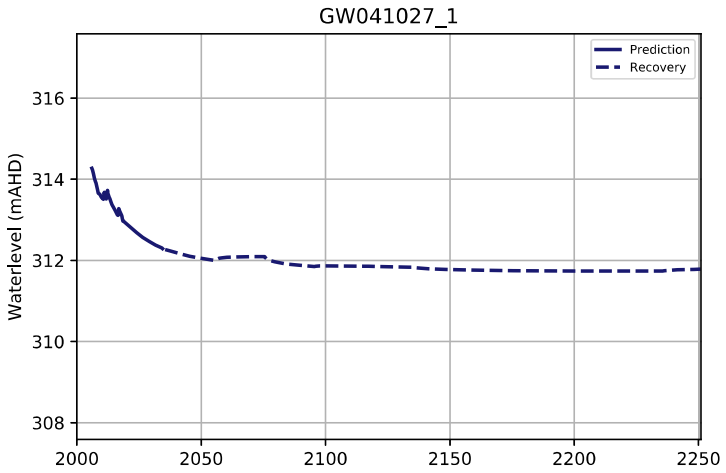

GW036434_2
Prediction
Recovery
Waterlevel (mAHD)
228
230
232
234
236
2000
2050
2100
2150
2200
2250

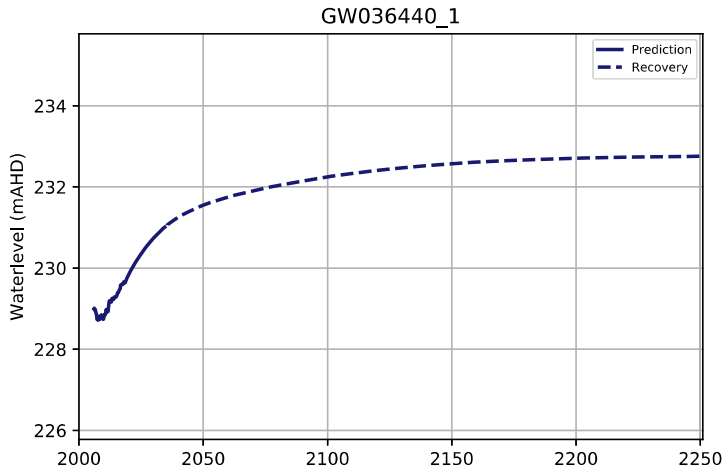

GW036436_1
Prediction
Recovery
Waterlevel (mAHD)
234
232
230
228
226
2000
2050
2100
2150
2200
2250

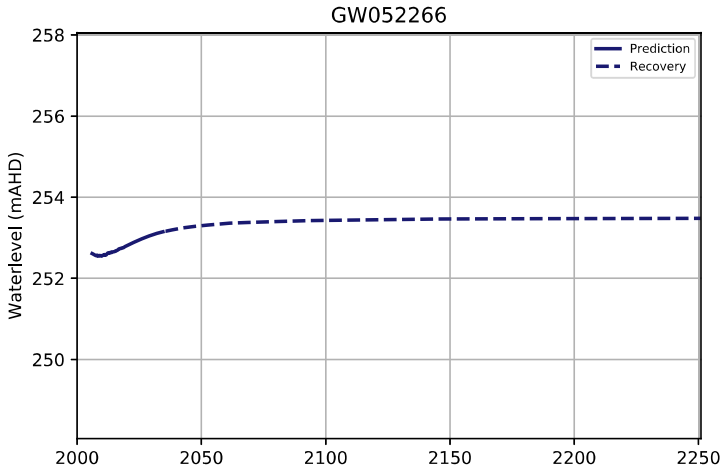

GW036435_2
Prediction
Recovery
Waterlevel (mAHD)
232
230
228
226
224
222
220
2000
2050
2100
2150
2200
2250

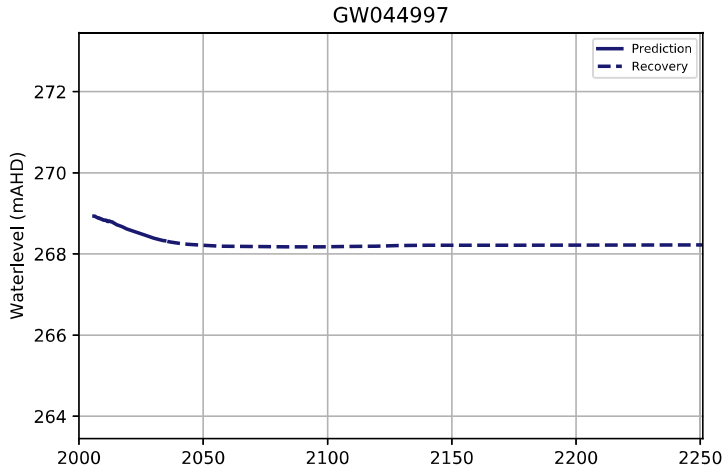

GW036436_3
Prediction
Recovery
Waterlevel (mAHD)
234
232
230
228
226
2000
2050
2100
2150
2200
2250

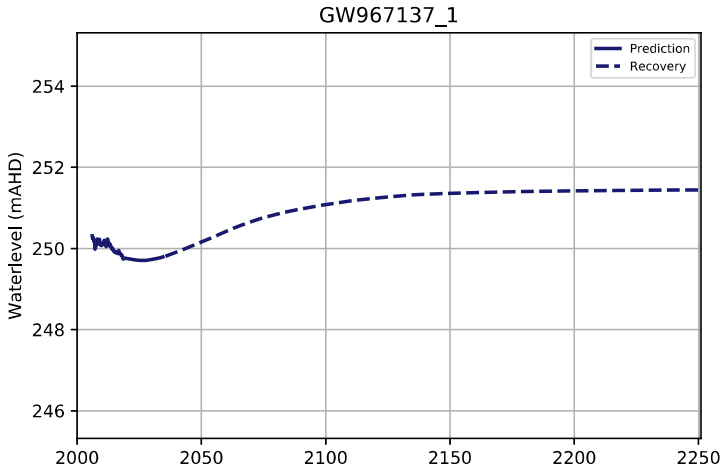

GW036436_2
Prediction
Recovery
Waterlevel (mAHD)
234
232
230
228
226
2000
2050
2100
2150
2200
2250

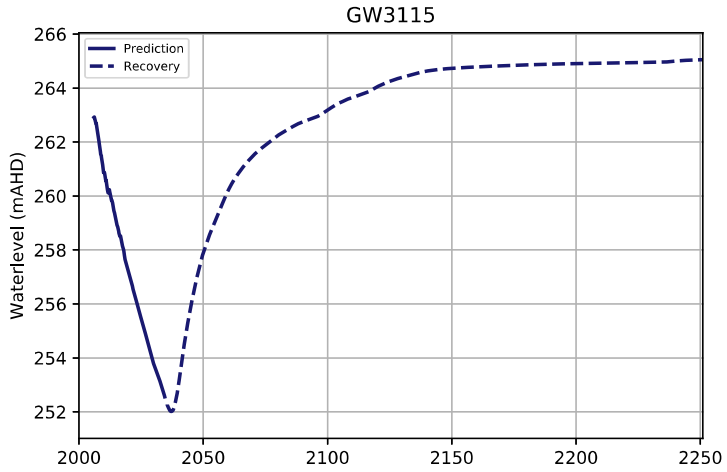

GW041027_1
Prediction
Recovery
Waterlevel (mAHD)
316
314
312
310
308
2000
2050
2100
2150
2200
2250

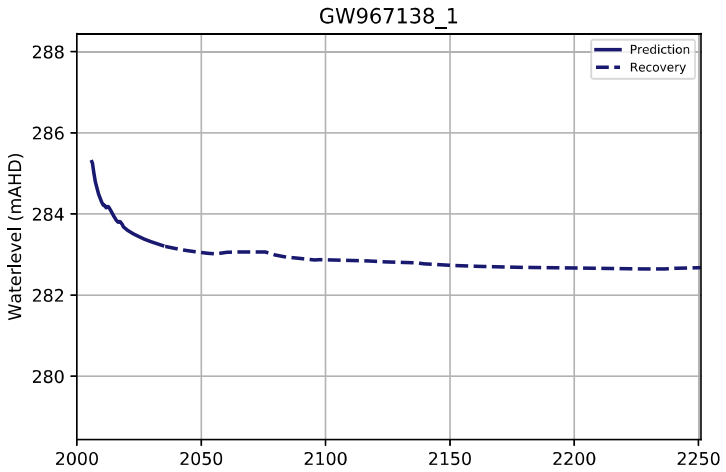

GW036440_1
Prediction
Recovery
Waterlevel (mAHD)
234
232
230
228
226
2000
2050
2100
2150
2200
2250

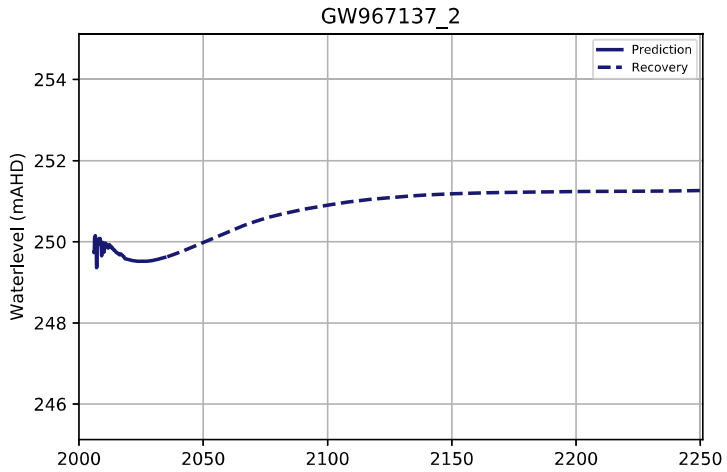

GW052266
Prediction
Recovery
Waterlevel (mAHD)
258
256
254
252
250
2000
2050
2100
2150
2200
2250

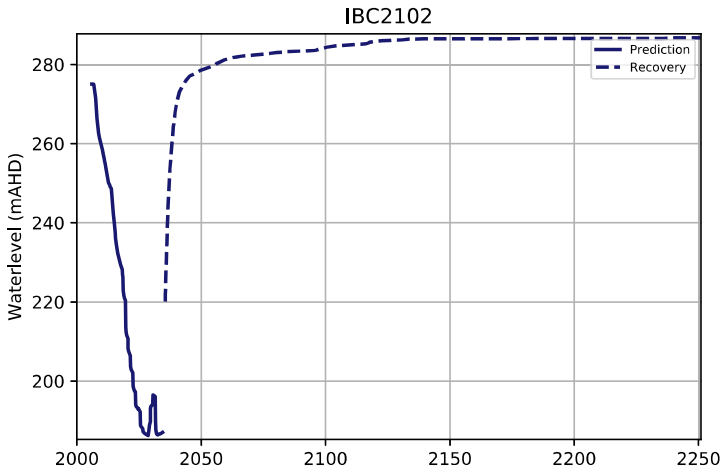

GW044997
Prediction
Recovery
Waterlevel (mAHD)
272
270
268
266
264
2000
2050
2100
2150
2200
2250

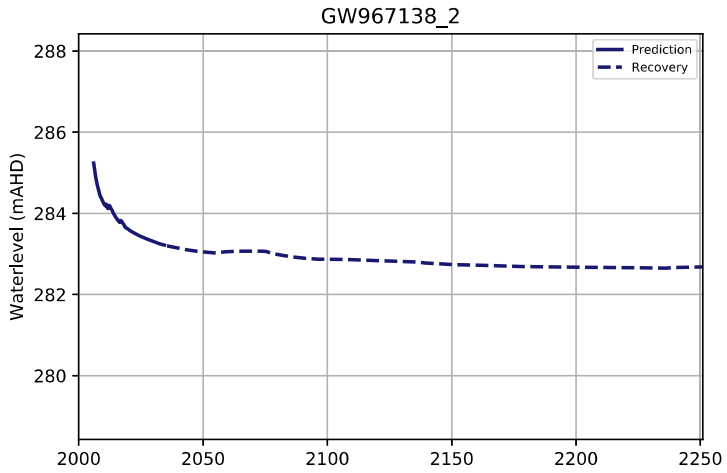

GW967137_1
Prediction
Recovery
Waterlevel (mAHD)
254
252
250
248
246
2000
2050
2100
2150
2200
2250

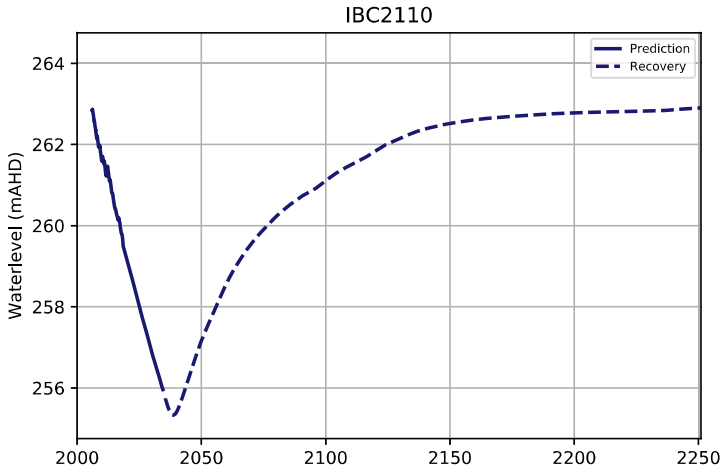

GW3115
Prediction
Recovery
Waterlevel (mAHD)
266
264
262
260
258
256
254
252
2000
2050
2100
2150
2200
2250

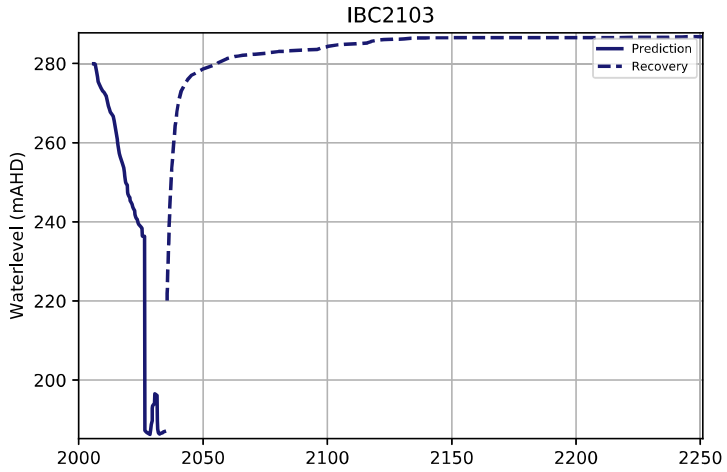

GW967138_1
Prediction
Recovery
Waterlevel (mAHD)
288
286
284
282
280
2000
2050
2100
2150
2200
2250

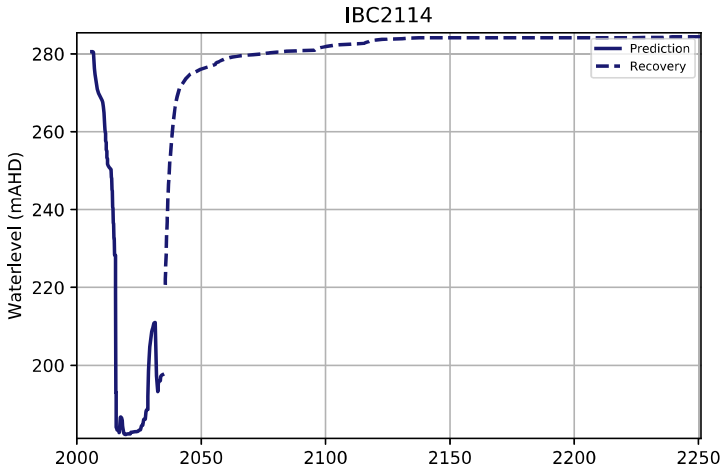

GW967137_2
Prediction
Recovery
Waterlevel (mAHD)
254
252
250
248
246
2000
2050
2100
2150
2200
2250

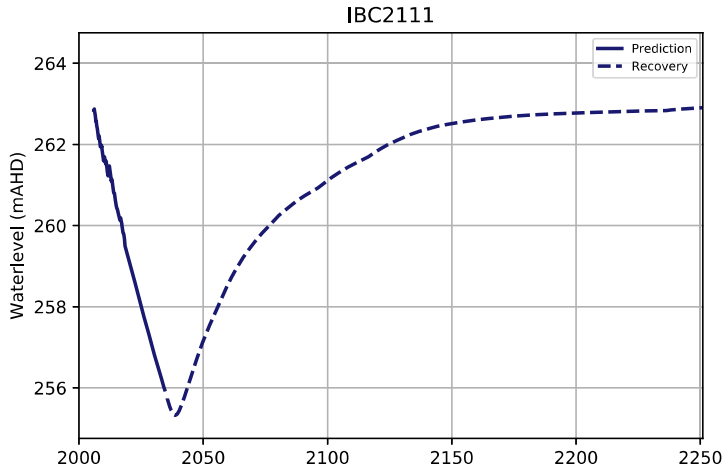

IBC2102
Prediction
Recovery
Waterlevel (mAHD)
280
260
240
220
200
2000
2050
2100
2150
2200
2250

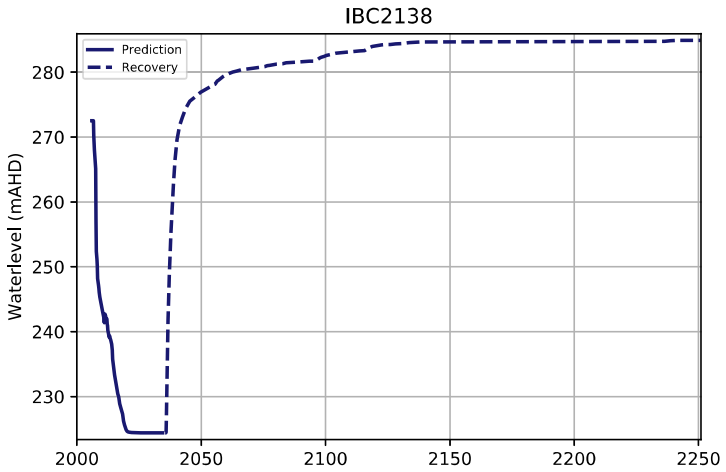

GW967138_2
Prediction
Recovery
Waterlevel (mAHD)
288
286
284
282
280
2000
2050
2100
2150
2200
2250

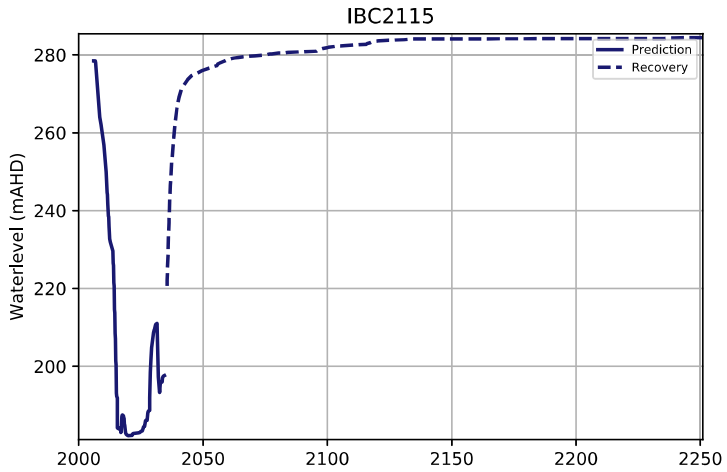

IBC2110
Prediction
Recovery
Waterlevel (mAHD)
264
262
260
258
256
2000
2050
2100
2150
2200
2250

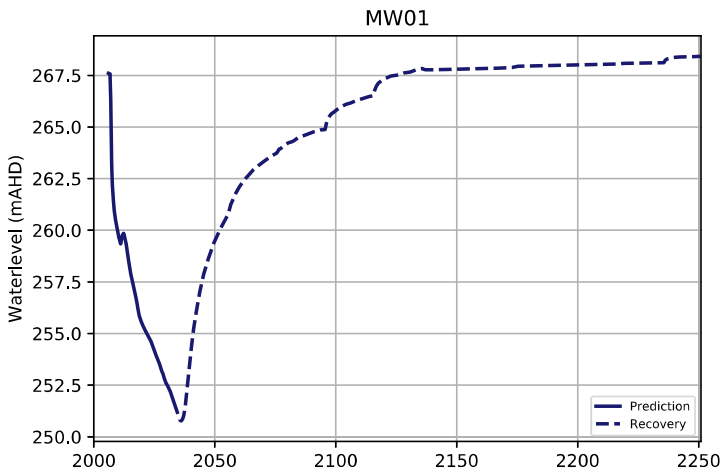

IBC2103
Prediction
Recovery
Waterlevel (mAHD)
280
260
240
220
200
2000
2050
2100
2150
2200
2250

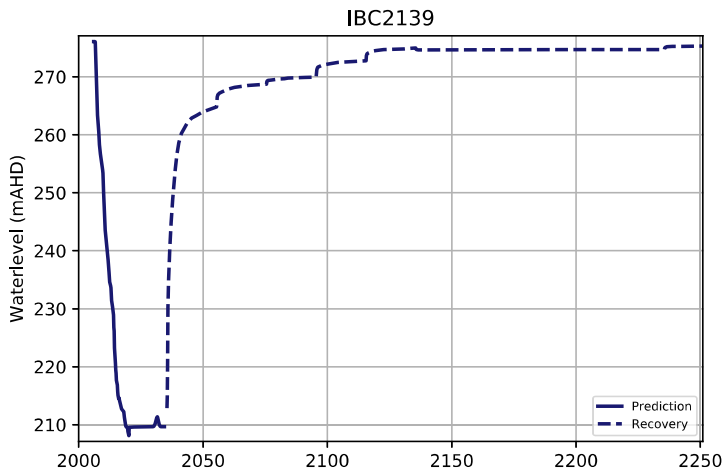

IBC2114
Waterlevel (mAHD)
Prediction
Recovery

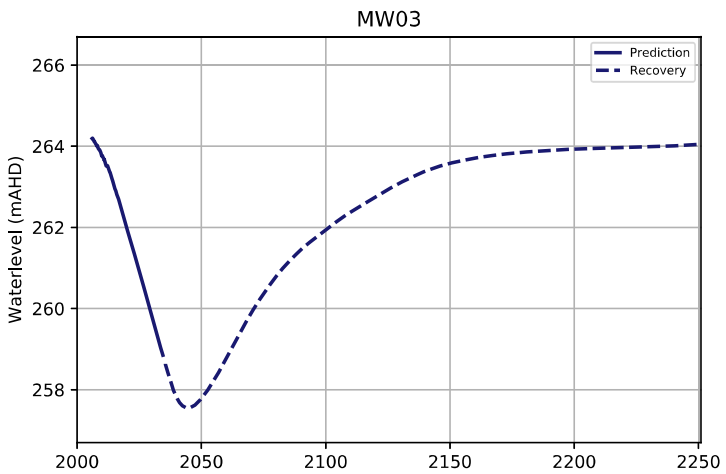

IBC2111
Waterlevel (mAHD)
Prediction
Recovery

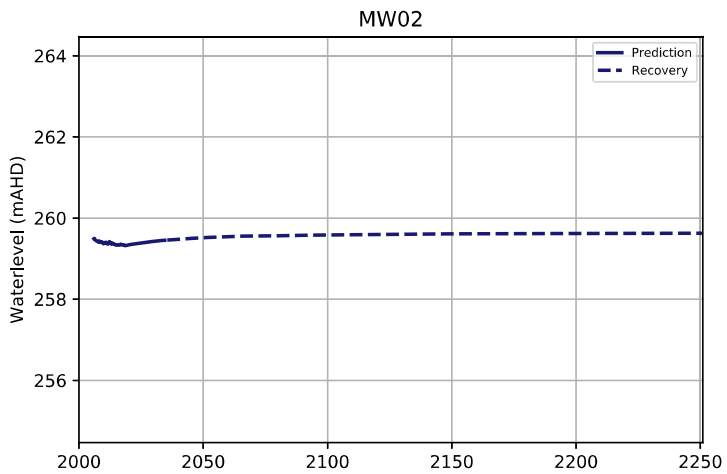

IBC2138
Waterlevel (mAHD)
Prediction
Recovery

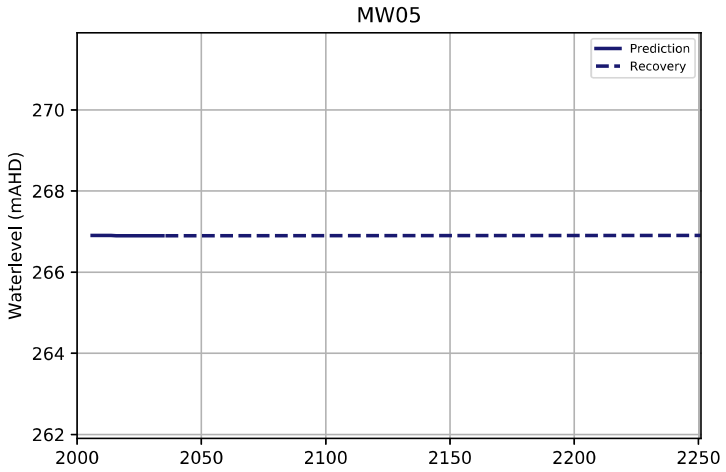

IBC2115
Waterlevel (mAHD)
Prediction
Recovery

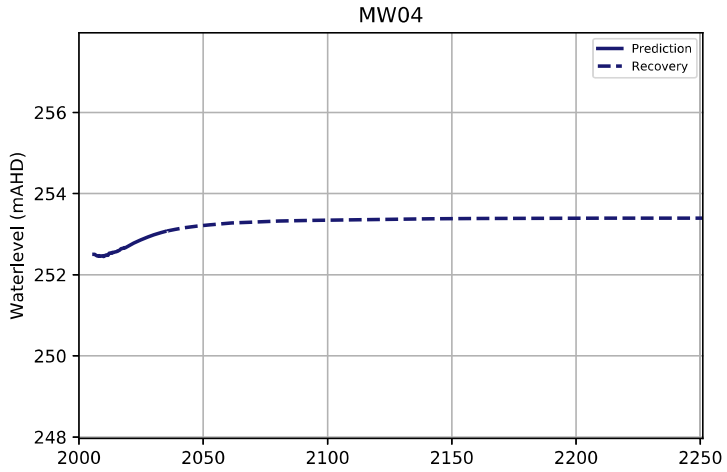

MW01
Waterlevel (mAHD)
Prediction
Recovery

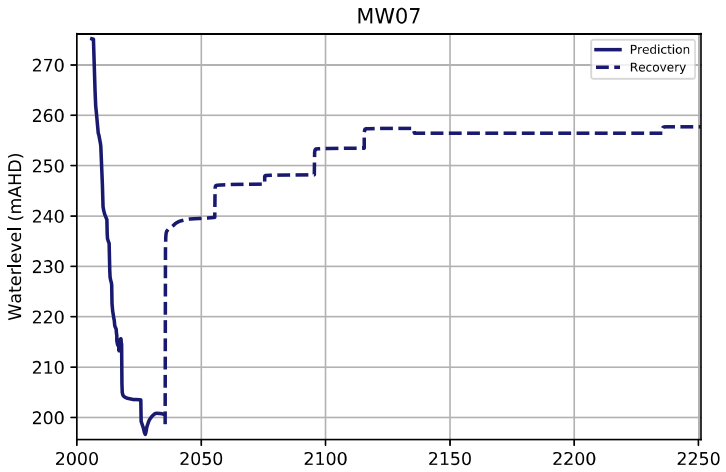

IBC2139
Waterlevel (mAHD)
Prediction
Recovery

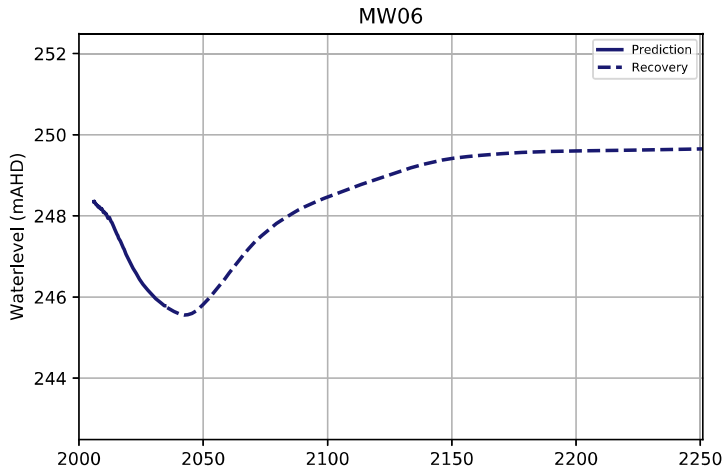

MW03
Waterlevel (mAHD)
Prediction
Recovery

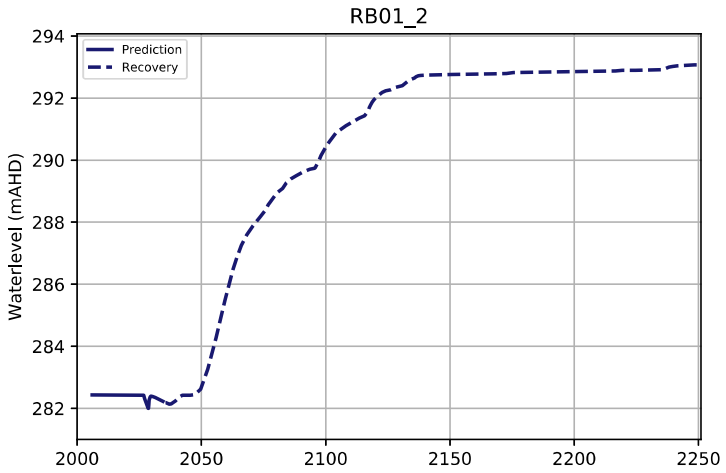

MW02
Waterlevel (mAHD)
Prediction
Recovery

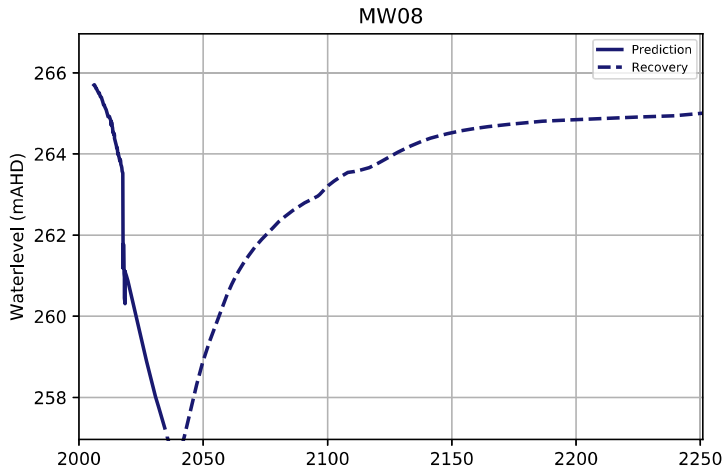

MW05
Prediction
Recovery
Waterlevel (mAHD)
262
264
266
268
270
2000
2050
2100
2150
2200
2250

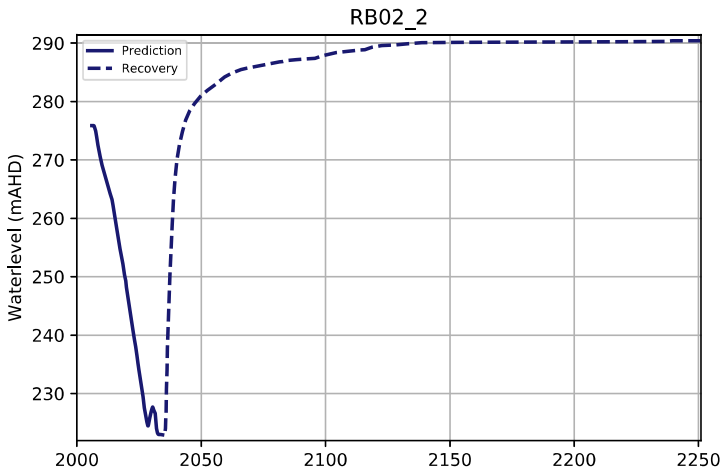

MW04
Prediction
Recovery
Waterlevel (mAHD)
248
250
252
254
256
2000
2050
2100
2150
2200
2250

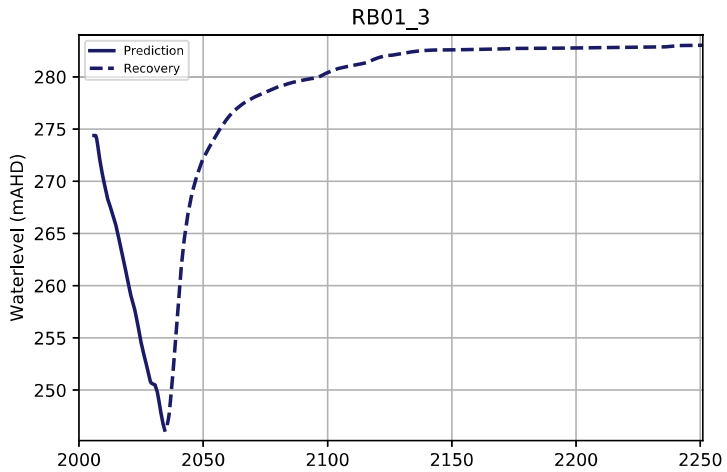

MW07
Prediction
Recovery
Waterlevel (mAHD)
200
210
220
230
240
250
260
270
2000
2050
2100
2150
2200
2250

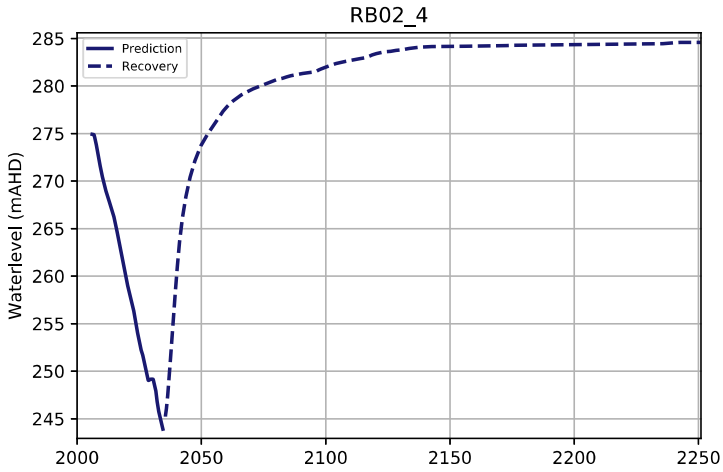

MW06
Prediction
Recovery
Waterlevel (mAHD)
244
246
248
250
252
2000
2050
2100
2150
2200
2250

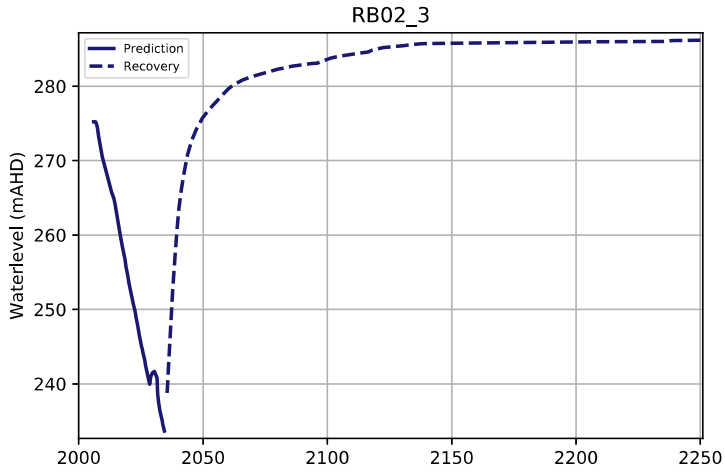

RB01_2
Prediction
Recovery
Waterlevel (mAHD)
282
284
286
288
290
292
294
2000
2050
2100
2150
2200
2250

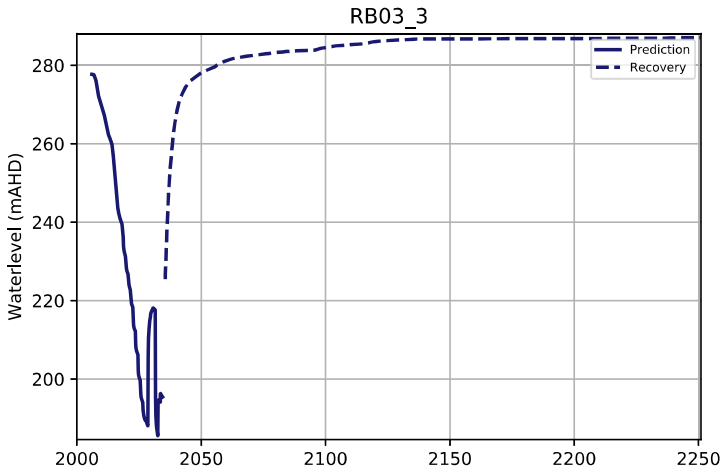

MW08
Prediction
Recovery
Waterlevel (mAHD)
258
260
262
264
266
2000
2050
2100
2150
2200
2250

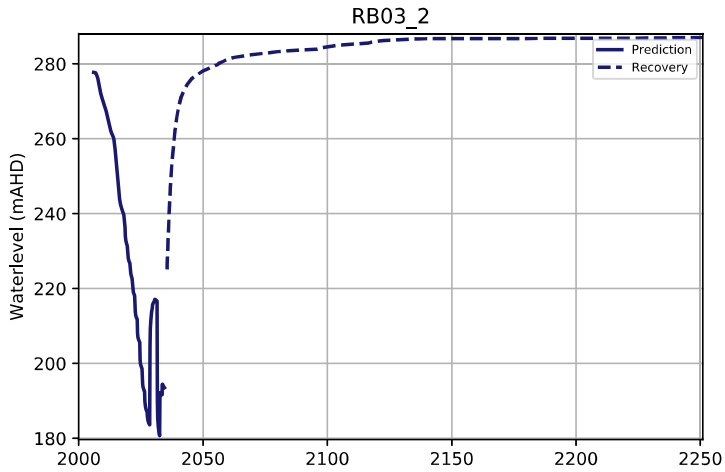

RB02_2
Prediction
Recovery
Waterlevel (mAHD)
230
240
250
260
270
280
290
2000
2050
2100
2150
2200
2250

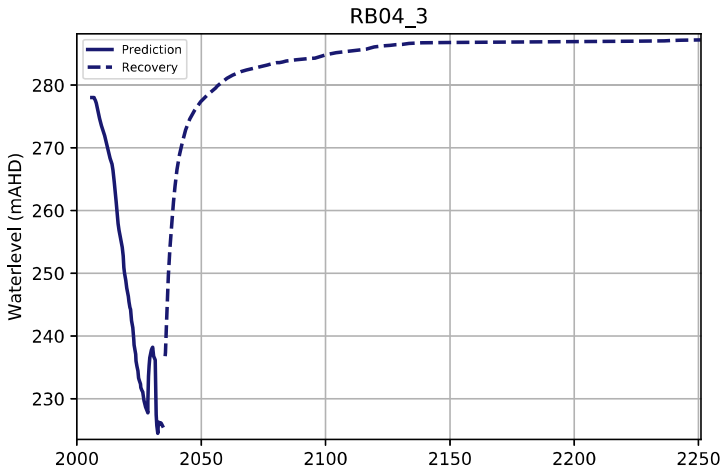

RB01_3
Prediction
Recovery
Waterlevel (mAHD)
250
255
260
265
270
275
280
2000
2050
2100
2150
2200
2250

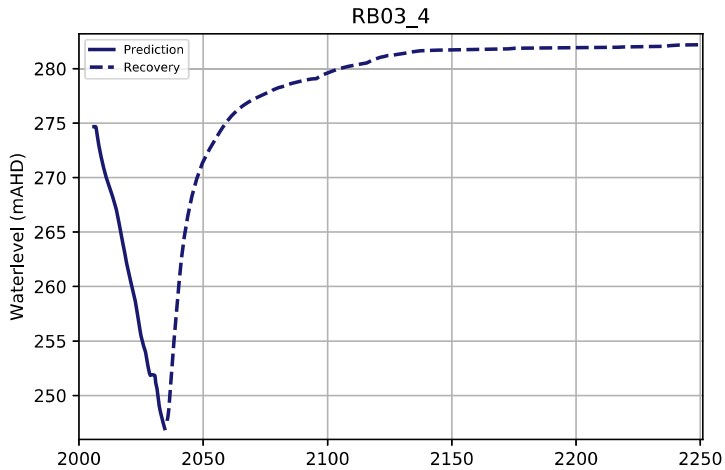

RB02_4
Prediction
Recovery
Waterlevel (mAHD)
285
280
275
270
265
260
255
250
245
2000
2050
2100
2150
2200
2250

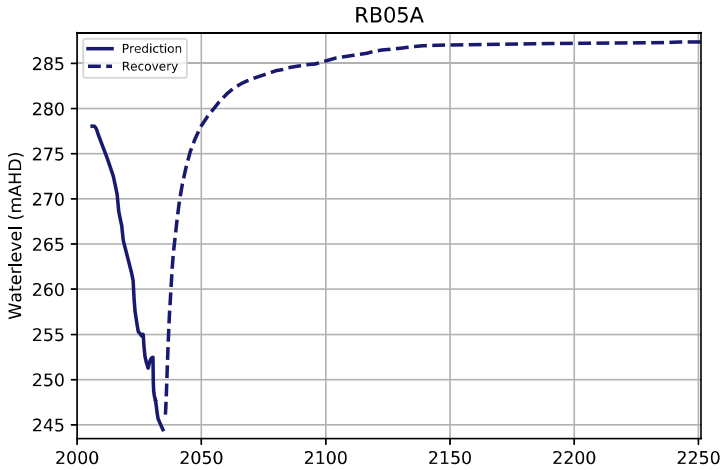

RB02_3
Prediction
Recovery
Waterlevel (mAHD)
280
270
260
250
240
2000
2050
2100
2150
2200
2250

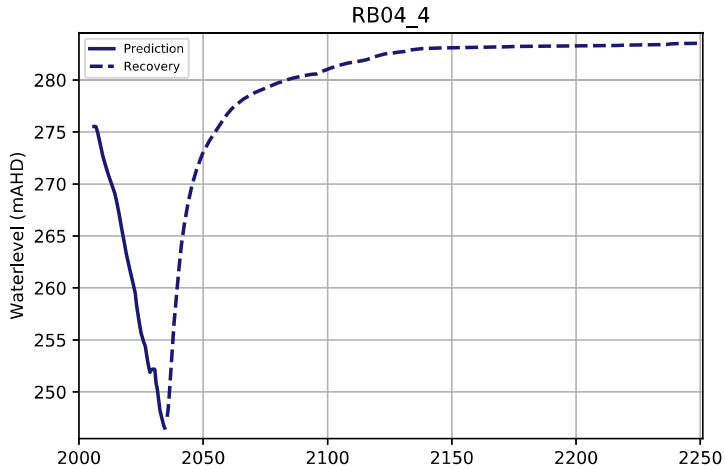

RB03_3
Prediction
Recovery
Waterlevel (mAHD)
280
260
240
220
200
2000
2050
2100
2150
2200
2250

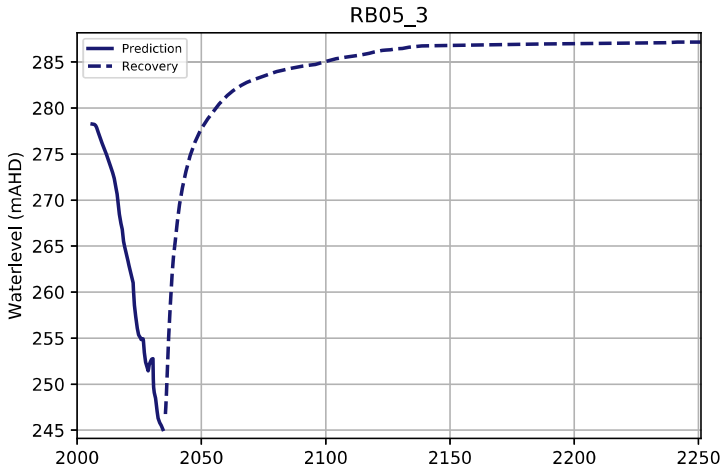

RB03_2
Prediction
Recovery
Waterlevel (mAHD)
280
260
240
220
200
180
2000
2050
2100
2150
2200
2250

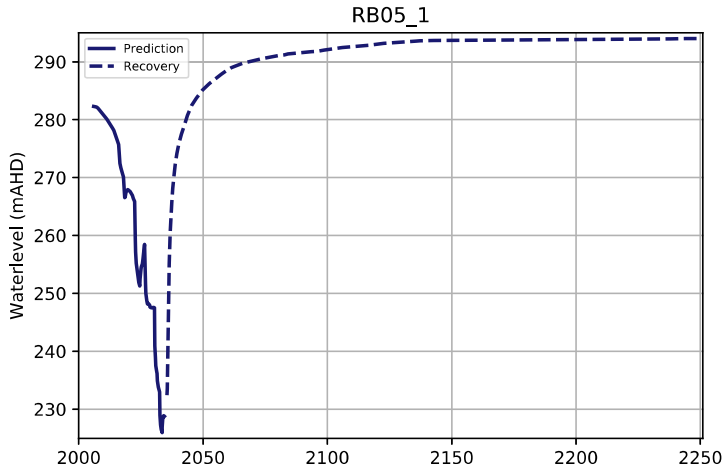

RB04_3
Prediction
Recovery
Waterlevel (mAHD)
280
270
260
250
240
230
2000
2050
2100
2150
2200
2250

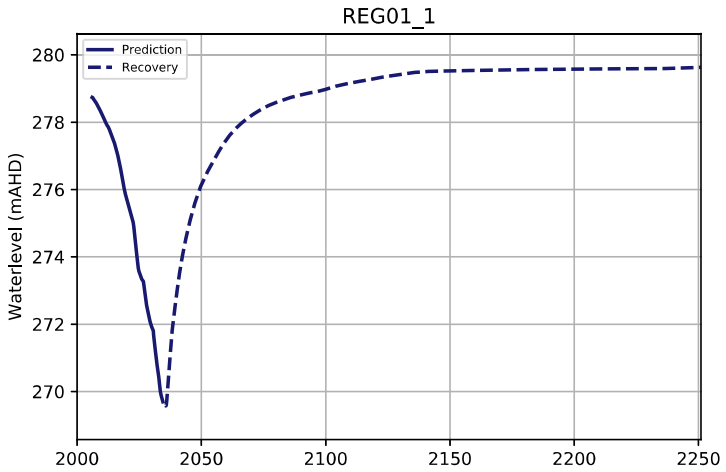

RB03_4
Prediction
Recovery
Waterlevel (mAHD)
280
275
270
265
260
255
250
2000
2050
2100
2150
2200
2250

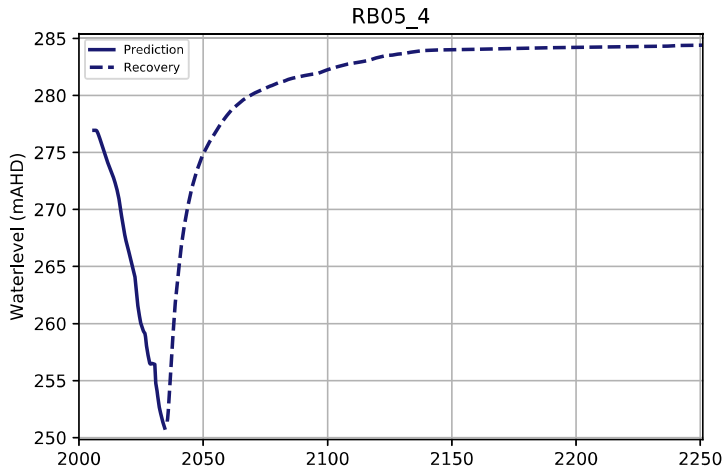

RB05A
Prediction
Recovery
Waterlevel (mAHD)
285
280
275
270
265
260
255
250
245
2000
2050
2100
2150
2200
2250

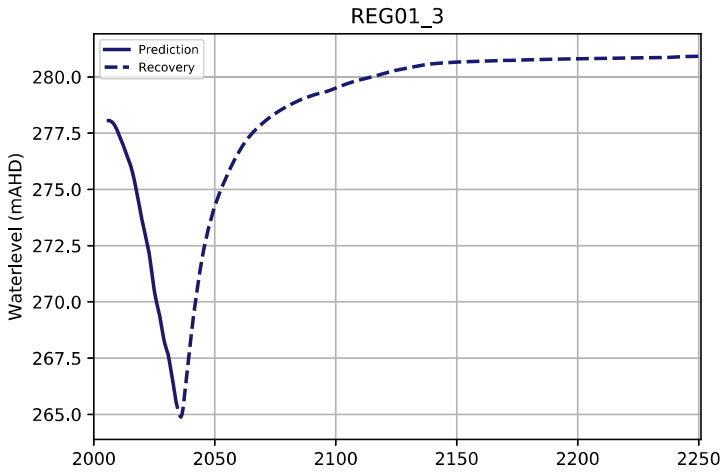

RB04_4
Prediction
Recovery
Waterlevel (mAHD)
280
275
270
265
260
255
250
2000
2050
2100
2150
2200
2250

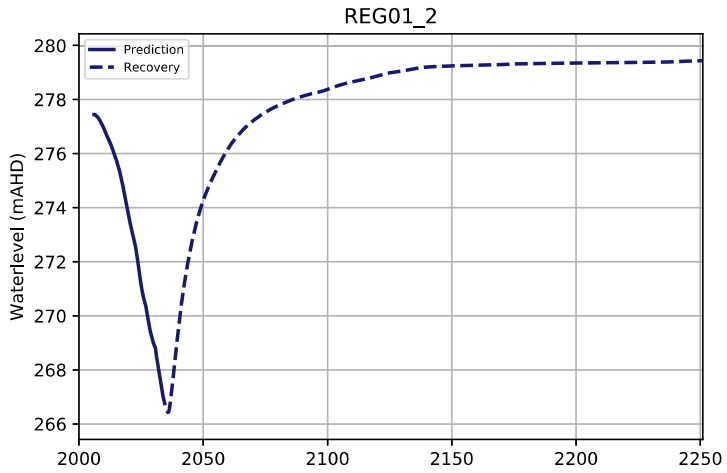

RB05_3
Prediction
Recovery
Waterlevel (mAHD)
285
280
275
270
265
260
255
250
245
2000
2050
2100
2150
2200
2250

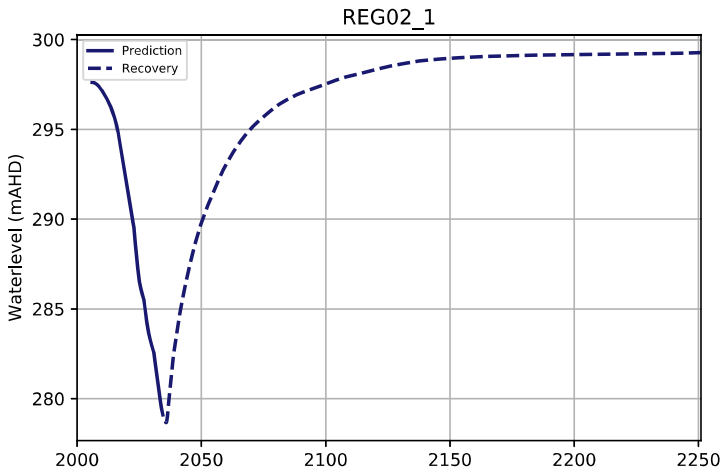

RB05_1
Prediction
Recovery
Waterlevel (mAHD)
290
280
270
260
250
240
230
2000
2050
2100
2150
2200
2250

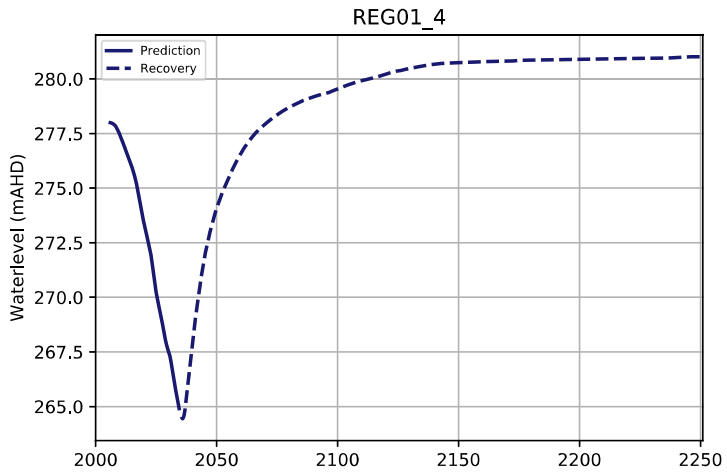

REG01_1
Prediction
Recovery
Waterlevel (mAHD)
280
278
276
274
272
270
2000
2050
2100
2150
2200
2250

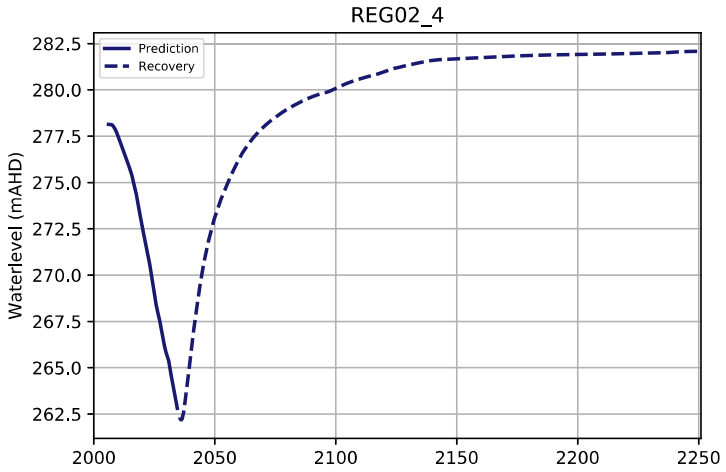

RB05_4
Prediction
Recovery
Waterlevel (mAHD)
285
280
275
270
265
260
255
250
2000
2050
2100
2150
2200
2250

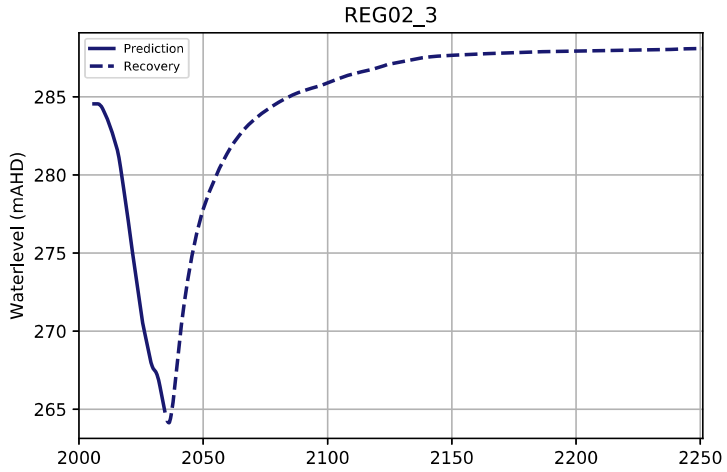

REG01_3
Prediction
Recovery
Waterlevel (mAHD)
280.0
277.5
275.0
272.5
270.0
267.5
265.0
2000
2050
2100
2150
2200
2250

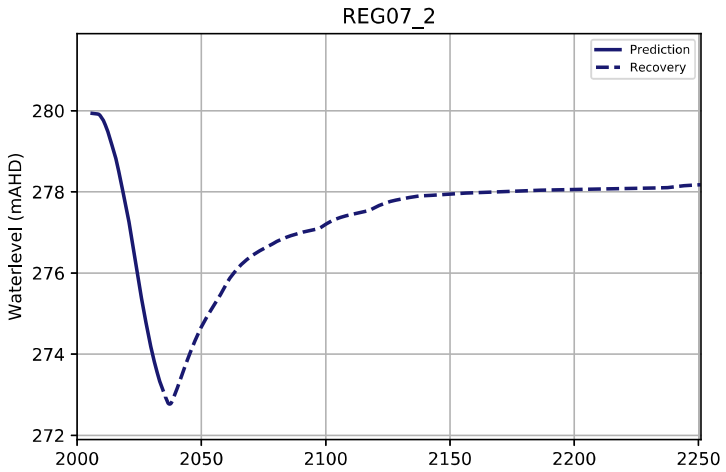

REG01_2
Prediction
Recovery
Waterlevel (mAHD)
280
278
276
274
272
270
268
266
2000
2050
2100
2150
2200
2250

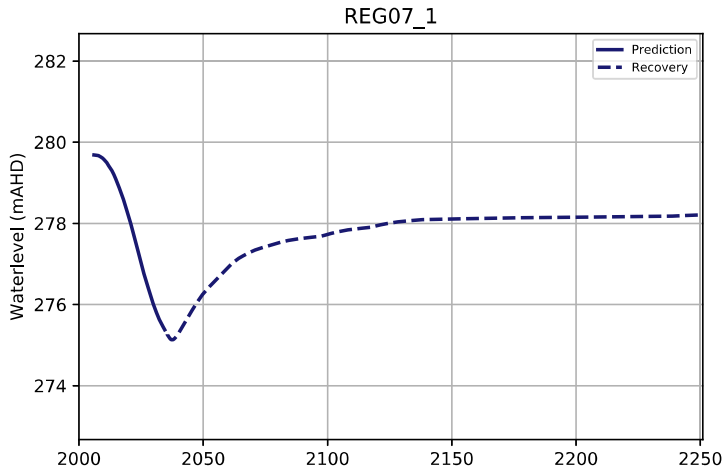

REG02_1
Prediction
Recovery
Waterlevel (mAHD)
300
295
290
285
280
2000
2050
2100
2150
2200
2250

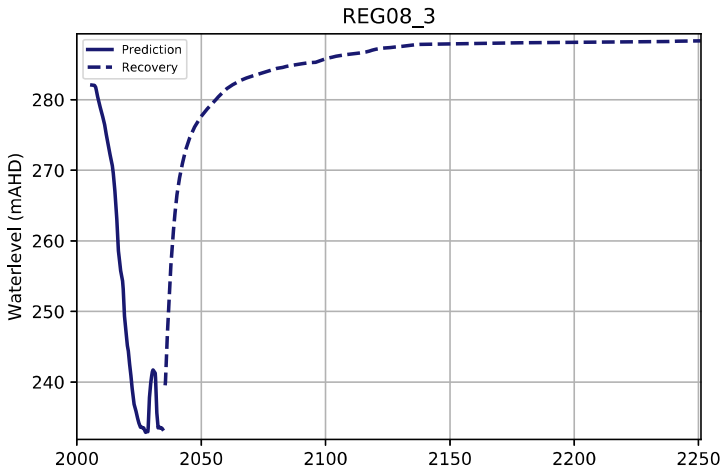

REG01_4
Prediction
Recovery
Waterlevel (mAHD)
280.0
277.5
275.0
272.5
270.0
267.5
265.0
2000
2050
2100
2150
2200
2250

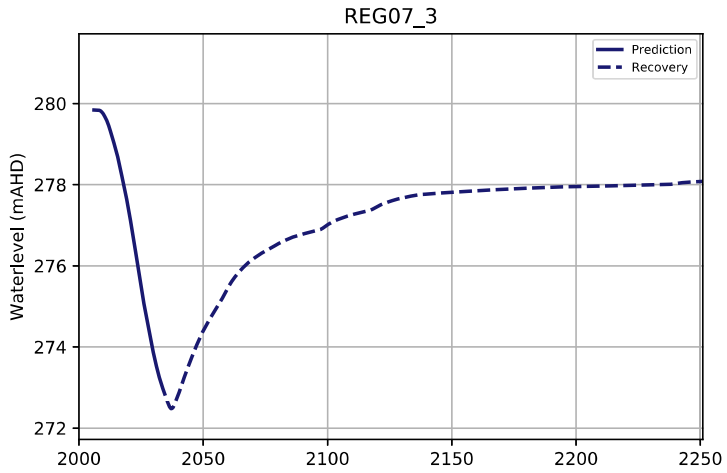

REG02_4
Prediction
Recovery
Waterlevel (mAHD)
282.5
280.0
277.5
275.0
272.5
270.0
267.5
265.0
262.5
2000
2050
2100
2150
2200
2250

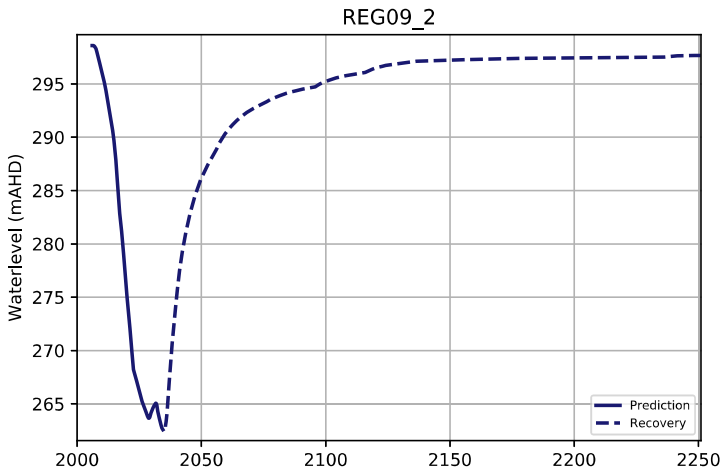

REG02_3
Prediction
Recovery
Waterlevel (mAHD)
285
280
275
270
265
2000
2050
2100
2150
2200
2250

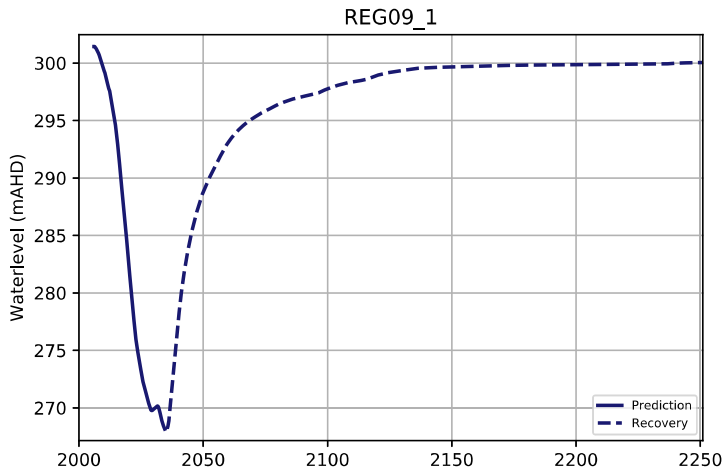

REG07_2
Prediction
Recovery
Waterlevel (mAHD)
280
278
276
274
272
2000
2050
2100
2150
2200
2250

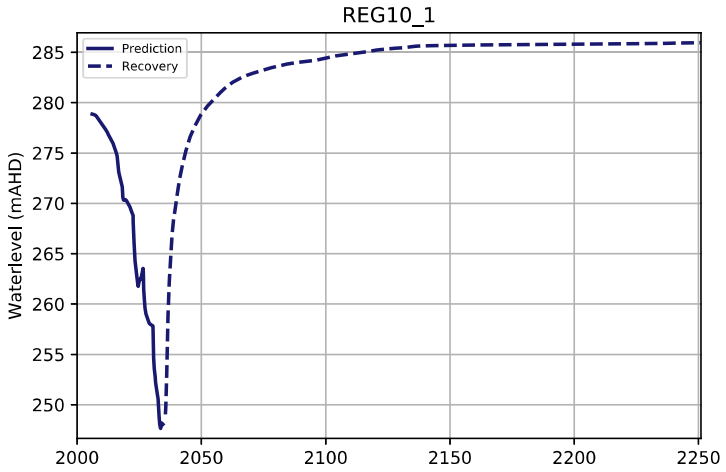

REG07_1
Prediction
Recovery
Waterlevel (mAHD)
282
280
278
276
274
2000
2050
2100
2150
2200
2250

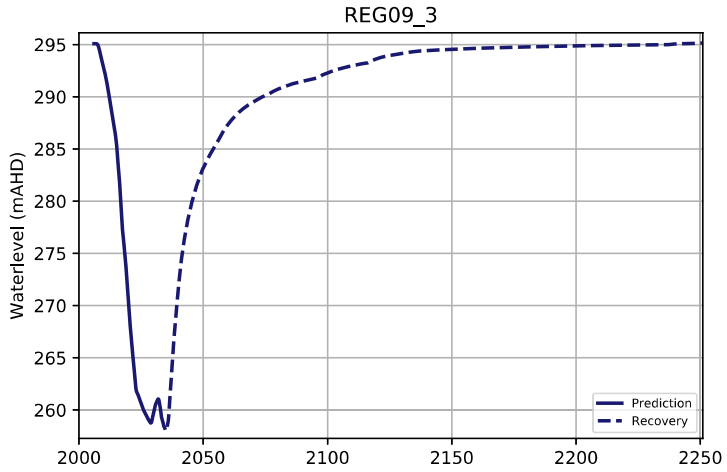

REG08_3
Prediction
Recovery
Waterlevel (mAHD)
280
270
260
250
240
2000
2050
2100
2150
2200
2250

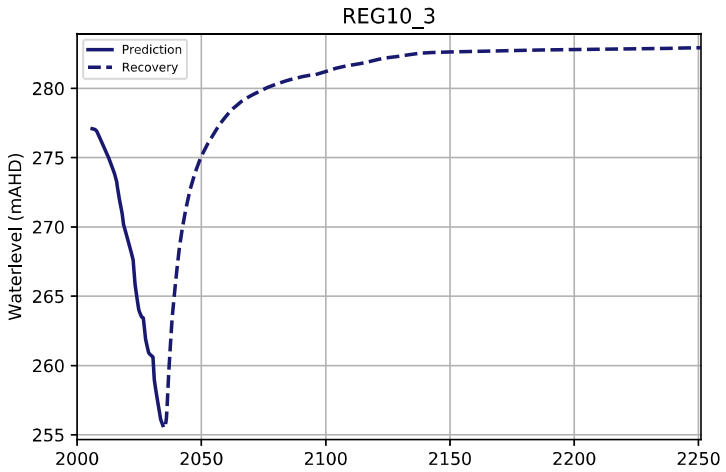

REG07_3
Prediction
Recovery
Waterlevel (mAHD)
280
278
276
274
272
2000
2050
2100
2150
2200
2250

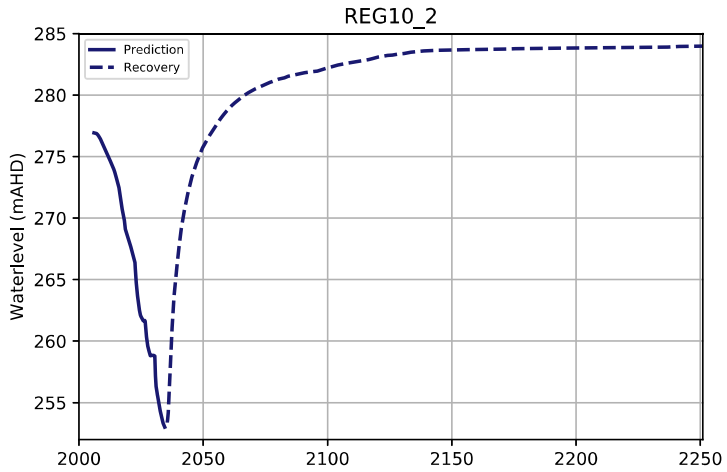

REG09_2
Prediction
Recovery
Waterlevel (mAHD)
295
290
285
280
275
270
265
2000
2050
2100
2150
2200
2250

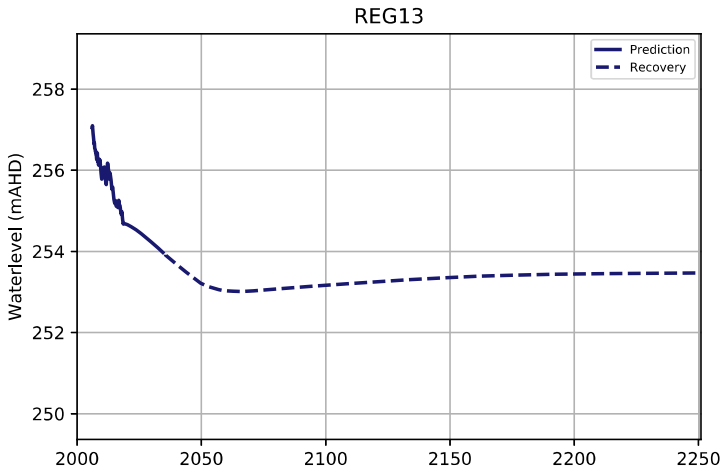

REG09_1
Prediction
Recovery
Waterlevel (mAHD)
300
295
290
285
280
275
270
2000
2050
2100
2150
2200
2250

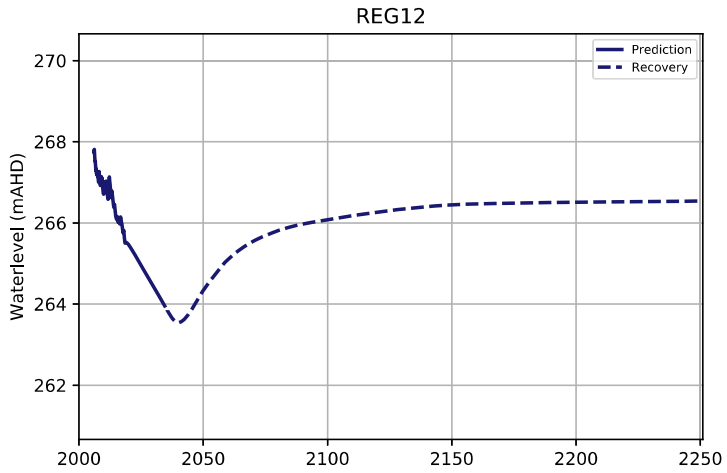

REG10_1
Prediction
Recovery
Waterlevel (mAHD)
285
280
275
270
265
260
255
250
2000
2050
2100
2150
2200
2250

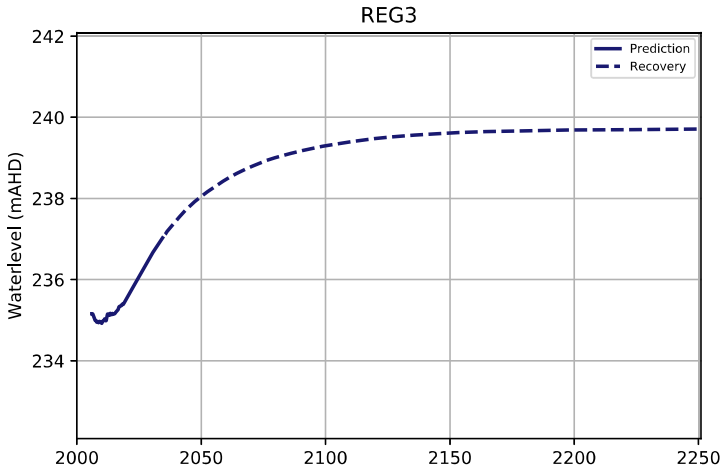

REG09_3
Prediction
Recovery
Waterlevel (mAHD)
295
290
285
280
275
270
265
260
2000
2050
2100
2150
2200
2250

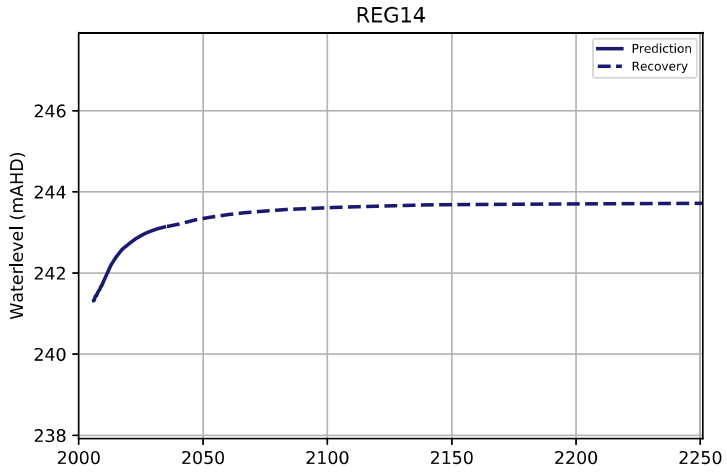

REG10_3
Prediction
Recovery
Waterlevel (mAHD)
280
275
270
265
260
255
2000
2050
2100
2150
2200
2250

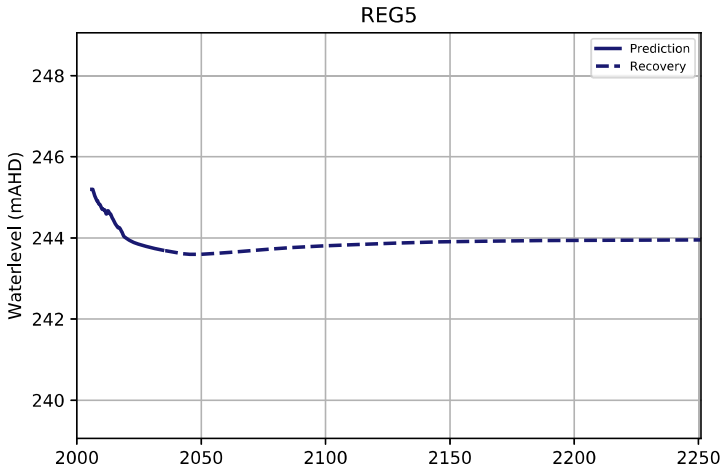

REG10_2
Prediction
Recovery
Waterlevel (mAHD)
285
280
275
270
265
260
255
2000
2050
2100
2150
2200
2250

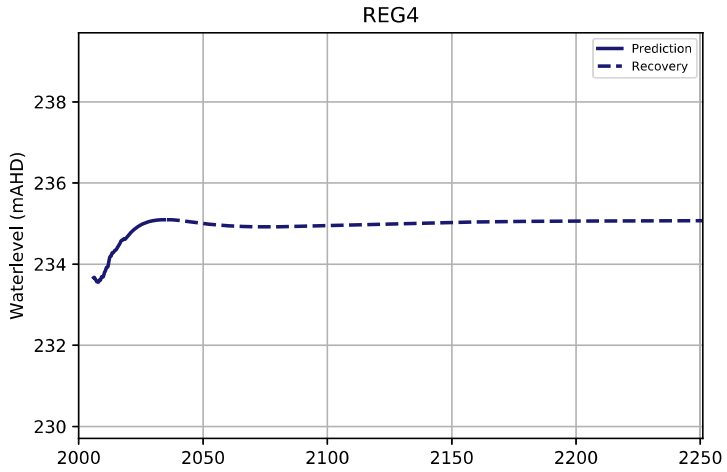

REG13
Prediction
Recovery
Waterlevel (mAHD)
258
256
254
252
250
2000
2050
2100
2150
2200
2250

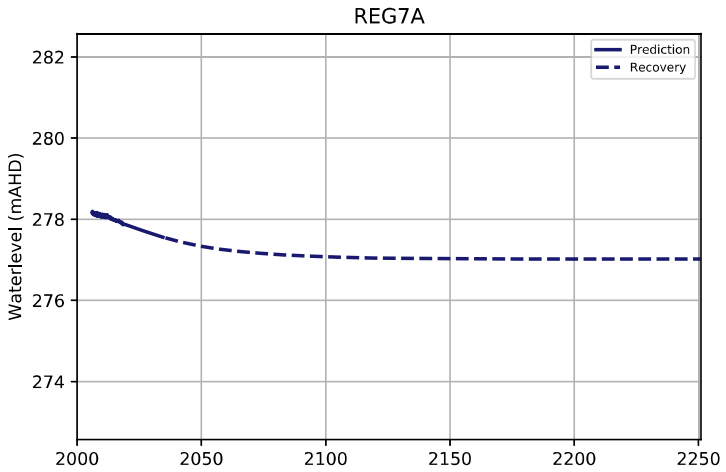

REG12
Prediction
Recovery
Waterlevel (mAHD)
270
268
266
264
262
2000
2050
2100
2150
2200
2250

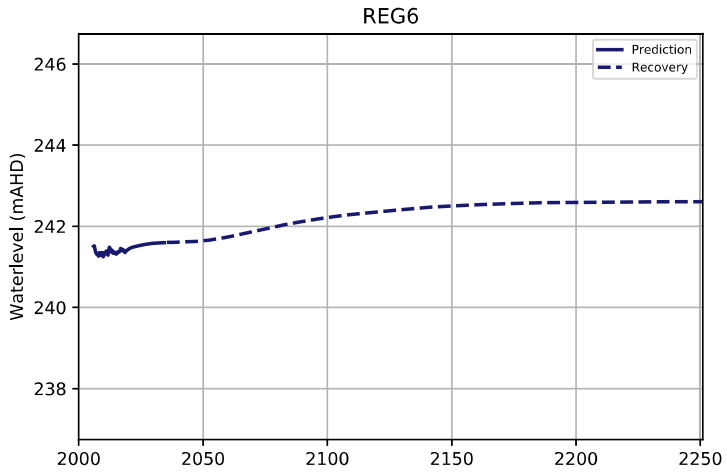

REG3
Prediction
Recovery
Waterlevel (mAHD)
242
240
238
236
234
2000
2050
2100
2150
2200
2250

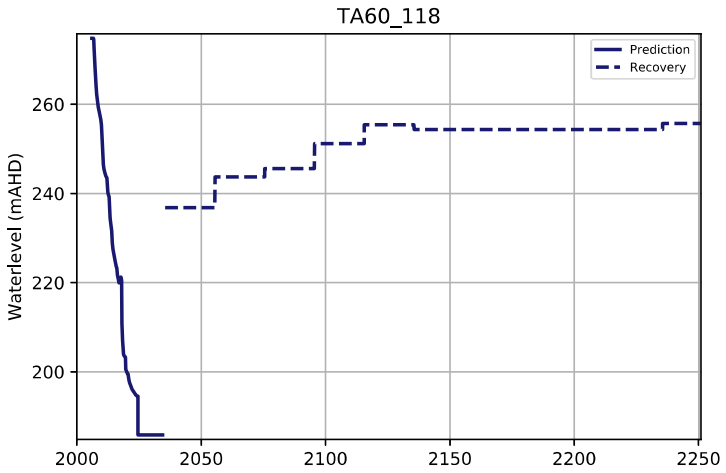

REG14
Prediction
Recovery
Waterlevel (mAHD)
246
244
242
240
238
2000
2050
2100
2150
2200
2250

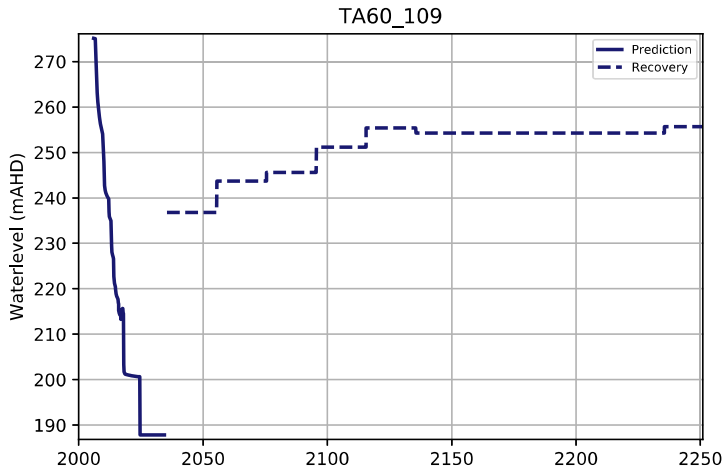

REG5
Prediction
Recovery
Waterlevel (mAHD)
248
246
244
242
240
2000
2050
2100
2150
2200
2250

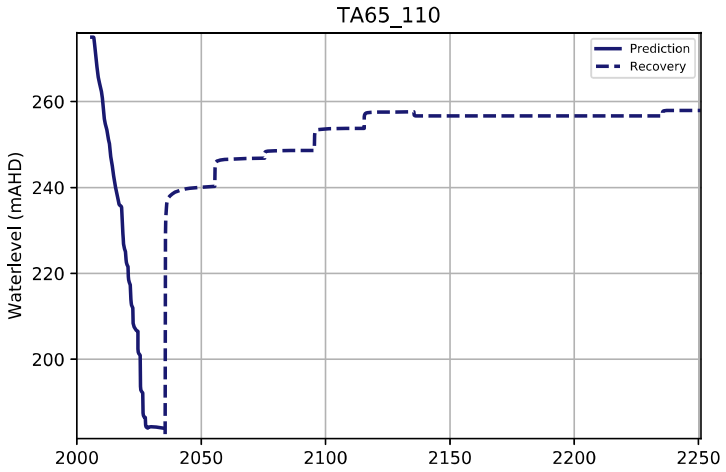

REG4
Prediction
Recovery
Waterlevel (mAHD)
238
236
234
232
230
2000
2050
2100
2150
2200
2250

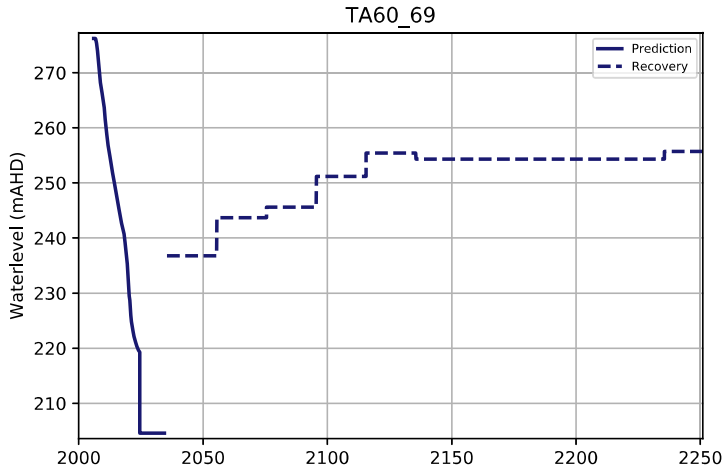

REG7A
Prediction
Recovery
Waterlevel (mAHD)
282
280
278
276
274
2000
2050
2100
2150
2200
2250

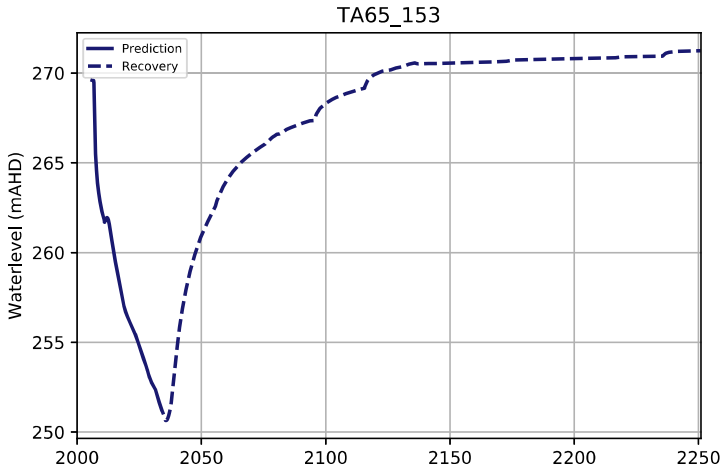

REG6
Prediction
Recovery
Waterlevel (mAHD)
246
244
242
240
238
2000
2050
2100
2150
2200
2250

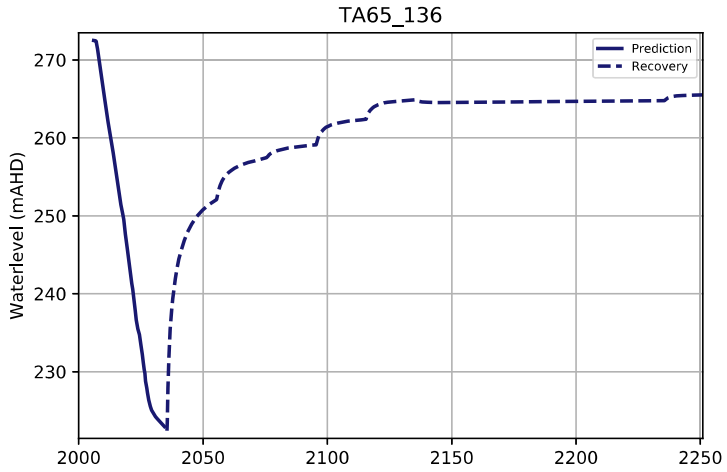

TA60_118
Prediction
Recovery
Waterlevel (mAHD)
260
240
220
200
2000
2050
2100
2150
2200
2250

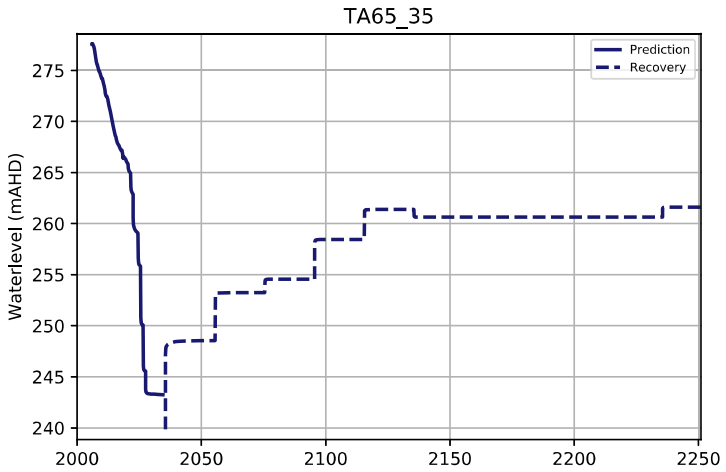

TA60_109
Prediction
Recovery
Waterlevel (mAHD)
270
260
250
240
230
220
210
200
190
2000
2050
2100
2150
2200
2250

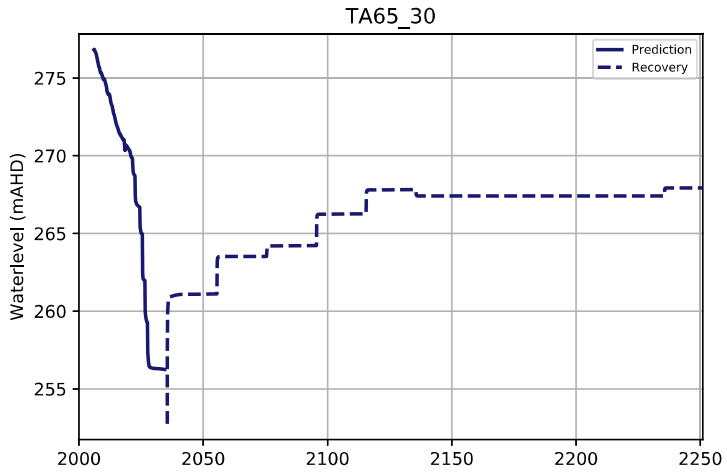

TA65_110
Prediction
Recovery
Waterlevel (mAHD)
260
240
220
200
2000
2050
2100
2150
2200
2250

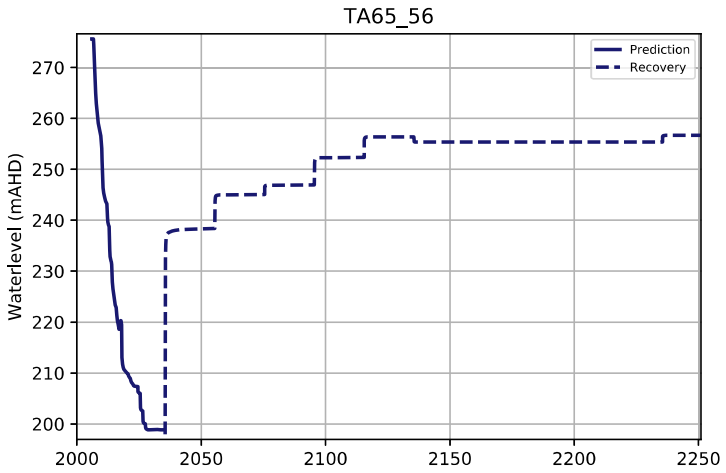

TA60_69
Prediction
Recovery
Waterlevel (mAHD)
270
260
250
240
230
220
210
2000
2050
2100
2150
2200
2250

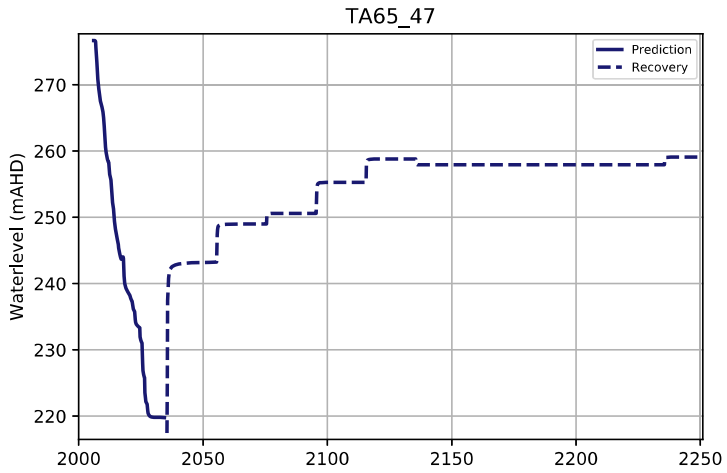

TA65_153
Prediction
Recovery
Waterlevel (mAHD)
270
265
260
255
250
2000
2050
2100
2150
2200
2250

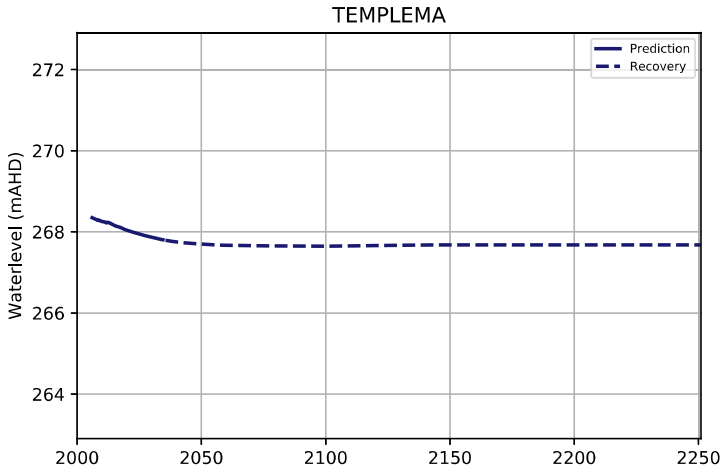

TA65_136
Prediction
Recovery
Waterlevel (mAHD)
270
260
250
240
230
2000
2050
2100
2150
2200
2250

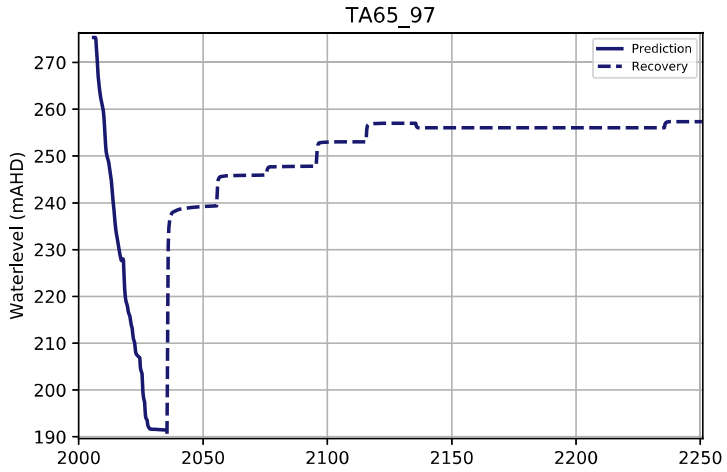

TA65_35
Prediction
Recovery
Waterlevel (mAHD)
275
270
265
260
255
250
245
240
2000
2050
2100
2150
2200
2250

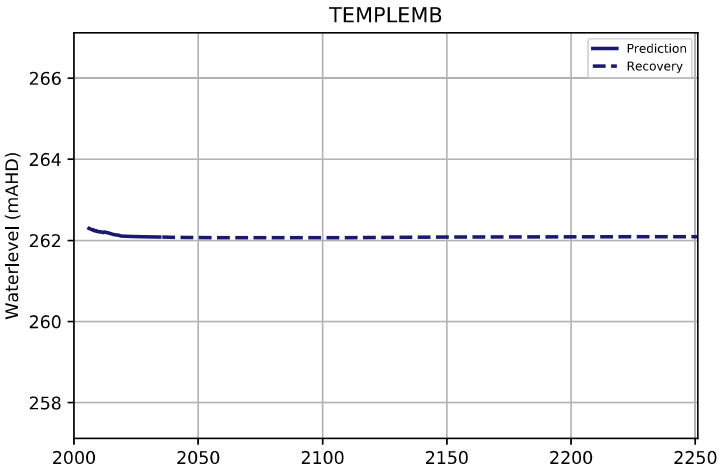

TA65_30
Prediction
Recovery
Waterlevel (mAHD)
275
270
265
260
255
2000
2050
2100
2150
2200
2250


TA65_56
Prediction
Recovery
Waterlevel (mAHD)
270
260
250
240
230
220
210
200
2000
2050
2100
2150
2200
2250


TA65_47
Prediction
Recovery
Waterlevel (mAHD)
270
260
250
240
230
220
2000
2050
2100
2150
2200
2250


TEMPLEMA
Prediction
Recovery
Waterlevel (mAHD)
272
270
268
266
264
2000
2050
2100
2150
2200
2250


TA65_97
Prediction
Recovery
Waterlevel (mAHD)
270
260
250
240
230
220
210
200
190
2000
2050
2100
2150
2200
2250


TEMPLEMB
Prediction
Recovery
Waterlevel (mAHD)
266
264
262
260
258
2000
2050
2100
2150
2200
2250

ATTACHMENT G – UNCERTAINTY AND SENSITIVITY ANALYSIS

Uncertainty Analysis

Methodology

This study addresses parameter uncertainty by stochastic modelling using the *Monte Carlo* method. This method operates by generating numerous alternative sets of input parameters to the deterministic groundwater flow model (realisations), executing the model independently for each realisation, and then aggregating the results for statistical analysis.

A traditional drawback to the Monte Carlo method is that its successful application often necessitates hundreds or thousands of model runs, each of which may take several hours of run time on a modern computer. More complex variants of Monte Carlo exist which aim to explore the parameter space more efficiently than the basic Monte Carlo approach, such as Null Space Monte Carlo (NSMC) (*Doherty, 2015*) and Markov Chain Monte Carlo (MCMC) approaches (e.g. *Vrugt et al., 2009*).

However, recent offerings in the field of cloud computing have greatly increased the availability and accessibility of computing resources, allowing hundreds of model runs to be evaluated simultaneously. Owing to this, we have elected to use the more basic Monte Carlo approach, which places no reliance on a linearisation of the model, allows for each individual model run to be kept relatively simple and with predictable run time (no additional calibration steps), and is free from the problem of autocorrelated samples that may occur with MCMC approaches.

AlgoCompute (*HydroAlgorithmics, 2019*; *Merrick, 2017*) was used as the platform for executing the model runs in parallel; up to 50 realisations were evaluated simultaneously, each being allocated to a single virtual machine in the cloud. The model-independent uncertainty quantification software HGSUQ (*Miller et al., 2018*) was used to generate the Monte Carlo parameter realisations and orchestrate the model runs within the AlgoCompute environment.

Pilot points

To assess the uncertainty in the hydraulic conductivity and storage parameters in the model, a *pilot point* approach was applied. Lateral conductivity (Kx), vertical anisotropy (Kx/Kz), specific storage (Ss), specific yield (Sy), and fractional infiltration ratio (Kx/Rch) values were permitted to vary spatially throughout the model domain, by taking representative values at numerous pilot point locations in each zone of the model.

The locations of the pilot points were distributed approximately equidistantly around the edges of the model domain, and progressively densified closer to the mine to increase the local resolution of the parameterisation therein. This was accomplished by starting with points placed in initially random locations within each zone of the model, and then using the optimisation algorithm for mesh generation in the AlgoMesh software tool (*Merrick and Merrick, 2015*) to distribute the points according to a prescribed distance function.

A set of 500 pilot point locations was duplicated in each layer of the model, with each pilot point assigned the hydraulic parameter zone according to the model cell containing it. In locations where the containing model cells were pinched out, the corresponding pilot points were removed from the set. Figure 1 illustrates the two-dimensional distribution of pilot point locations and shows their hydraulic property zone assignments in layer 1 of the model.

Table 1 lists the number of pilot points used in each zone after pinch-outs were taken into account. In total, 3,548 pilot points were used over the 12 layers of the model.

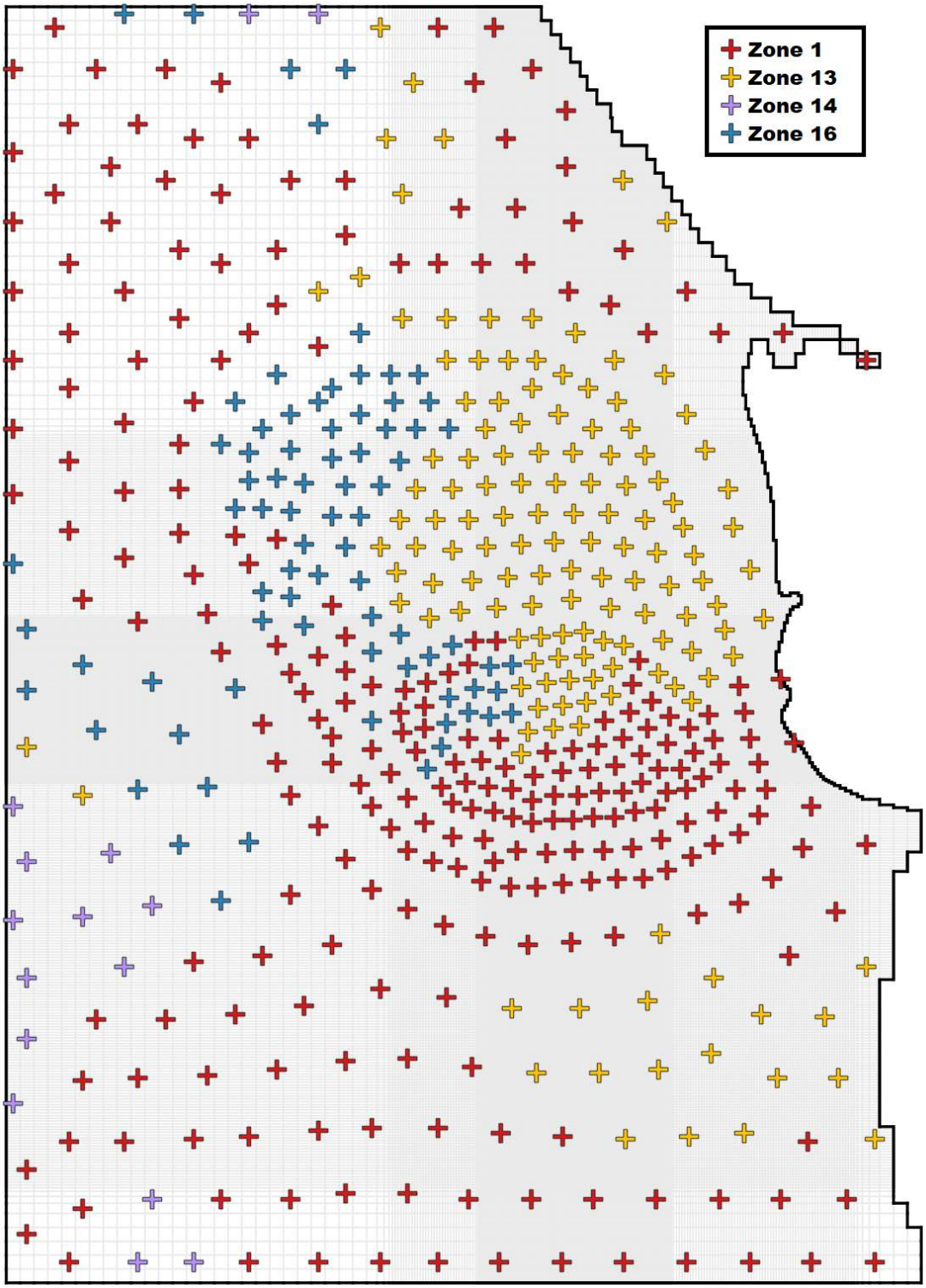


Figure 1: Pilot point locations in layer 1 (zones 1, 13, 14 and 16).

For each realisation generated by the Monte Carlo process, every pilot point was assigned a Kx value, a Kx/Kz ratio, an Ss value, an Sy value, and a Kx/Rch fractional infiltration ratio. Infiltration ratios were

assigned only to layer 1 pilot points. In total, 14,692 parameters were used (= 3,548 pilot points (all layers) * 4 parameters + 500 pilot points (layer 1) * 1 parameter).

Table 1: Number of pilot points within each model hydraulic property zone.

Layer	Zone	Number of Pilot Points
1	1	265
	13	142
	14	15
	16	78
2	2	254
	13	57
	14	4
	16	29
3	3	225
4	4	149
	15	94
5	5	217
	15	1
6	6	143
	15	101
7	7	252
	15	5
8	8	139
	15	124
9	9	248
	15	1
10	10	257
	15	2
11	11	246
12	12	500

Each model cell was assigned Kx, Kx/Kz, Ss, Sy and Kx/Rch through interpolation from surrounding pilot point values by *kriging*. Vertical conductivity (Kz) values were generated by dividing the sampled Kx values by the vertical anisotropy factor Kx/Kz. Recharge rates were generated by dividing the sampled Kx values by the fractional infiltration ratio Kx/Rch, then multiplying by rainfall rate for each simulated stress period.

Kx, Ss and Sy values at each pilot point were sampled from log-normal distributions with a mean of the calibrated base case model value in the corresponding zone. A standard deviation of one half an order of magnitude was used for distributions of Kx/Kz, Ss and Sy (i.e. a standard deviation of 0.5 for $\log_{10}(x)$, where x is one of Kx, Ss, Sy), under the assumption that 95% of values for these properties should lie within one order of magnitude (two standard deviations) of the calibrated value.

Kx/Kz ratios were sampled from log-uniform distributions centred at the calibrated base case model value, with a minimum of the calibrated value divided by 10, and a maximum of the calibrated value multiplied by 10. The minimum of each Kx/Kz distribution was restricted to be no less than 1 to ensure that Kx ≥ Kz.

Kx/Rch ratios were sampled from log-uniform distributions centred at the calibrated base case model value, with a minimum of the calibrated value divided by 5, and a maximum of the calibrated value multiplied by 5.

Run procedure

For each Monte Carlo realisation, the following process was executed on a virtual machine in the cloud, initiated by a HGSUQ "slave" worker process:

1. Convert Kx value, Kx/Kz ratio and Kx/Rch ratio at each pilot point to Kx, Kz and Rch values.
2. Interpolate Kx, Kz, Ss, Sy and Rch values to model cells by kriging with PLPROC (*Doherty, 2016*).
3. Multiply Rch values at each model cell by rainfall rates to obtain recharge rate for each model stress period.
4. Run model under existing approved conditions only, i.e. with proposed mining inactive.
5. Run model with proposed mining active.
6. Aggregate predictive outputs and calibration statistics and return these to the HGSUQ "master" process for amalgamation with other run results.

After running the entire set of Monte Carlo realisations and collecting the results, the result set was culled of poorly-calibrated realisations using a calibration error cut-off of 8.165% SRMS, a 15% margin on the base case model's 7.1% SRMS.

Assumptions of note

The following assumptions should be noted in assessing the information presented in this report.

- The stochastic modelling performed was limited to hydraulic conductivity, specific storage, specific yield and fractional infiltration values.
- Kz values were assumed to correlate to Kx according to a spatially-varying linear ratio.
- Each calibrated realisation was assumed to be equally likely in the analysis of the model outputs, i.e. apart from rejecting particularly poorly-calibrated runs, no weighting was applied to distinguish models based on how well they fit the observed data.

Parameter Distributions

Two sets of parameter distributions are discussed in this section: *prior* and *posterior* distributions. The prior distributions are those from which the Monte Carlo process builds random samples for evaluation. This process produces a finite number of sample sets. Additionally, some of these sample sets are rejected during evaluation due to non-convergence or failing calibration checks. The posterior distributions model the actual property distributions evaluated after sampling and rejection have taken place.

In total, 700 realisations were evaluated as part of the Monte Carlo process. Of these, 262 (37.43%) were accepted, 346 (49.43%) were rejected due to model non-convergence, and 92 (13.14%) were rejected because they exceeded the prescribed calibration error criterion of 8.165% SRMS.

Prior and posterior distributions

Table 2 through Table 6 compare the mean and standard deviation of prior and posterior distributions of Kx, Kx/Kz, Ss, Sy and Kx/Rch parameters, organised by model layer and hydraulic property zone. Substantial differences between the posterior and prior distributions may indicate that part of the prior distribution resulted in poorly-calibrated or non-convergent models.

Note that the prior mean and standard deviation values reported here for Kx, Ss and Sy are themselves an aggregation across all pilot points in each zone. These values were obtained by convolution of a zero-mean normal distribution with standard deviation as used at each pilot point, with the normal

distribution fitting the set of mean values used at all pilot points. This allows a comparison between prior and posterior to be made which accounts for the variance of the mean values among different pilot points as derived from calibrated model values.

For Kx/Kz and Kx/Rch parameters, the minimum and maximum of the (log-)uniform range at each pilot points were recorded, and mean and log standard deviation values are reported for these sets of minima and maxima.

Comparisons of means and standard deviations in the tables suggest very little difference between prior and posterior distributions.

Table 2: Posterior vs prior distributions for Kx (lateral hydraulic conductivity). Note that mean values are taken from log-normal distributions but presented as non-log transformed values.

Layer	Zone	Posterior Mean Kx	Posterior Stdev $Log_{10}(Kx)$	Prior Mean Kx	Prior Stdev $Log_{10}(Kx)$
1	1	4.4E+00	0.53	4.4E+00	0.53
	13	8.3E-02	0.51	8.4E-02	0.51
	14	8.5E-02	0.52	8.7E-02	0.50
	16	3.5E-03	0.51	3.5E-03	0.51
2	2	5.9E+00	0.61	5.9E+00	0.61
	13	9.7E-02	0.50	9.6E-02	0.50
	14	1.1E-01	0.52	1.0E-01	0.51
	16	4.1E-03	0.49	4.1E-03	0.50
3	3	2.5E-04	0.52	2.5E-04	0.52
4	4	2.5E-01	0.55	2.5E-01	0.55
	15	1.0E-02	0.59	1.0E-02	0.59
5	5	2.4E-04	0.56	2.4E-04	0.56
	15	5.1E-03	0.52	5.0E-03	0.50
6	6	2.5E-01	0.61	2.5E-01	0.61
	15	4.9E-03	0.51	4.9E-03	0.51
7	7	3.3E-05	0.51	3.3E-05	0.51
	15	5.0E-03	0.51	5.0E-03	0.50
8	8	1.8E-01	0.62	1.8E-01	0.62
	15	5.6E-03	0.51	5.5E-03	0.51
9	9	3.2E-05	0.54	3.2E-05	0.54
	15	5.2E-03	0.49	5.0E-03	0.50
10	10	2.8E-01	0.56	2.8E-01	0.56
	15	5.3E-03	0.49	5.0E-03	0.50
11	11	1.5E-05	0.50	1.5E-05	0.50
12	12	3.3E-03	0.56	3.3E-03	0.57

Table 3: Posterior vs prior ranges for Kx/Kz (vertical anisotropy ratio). Note that mean values are taken from log-uniform distributions but presented as non-log transformed values.

Layer	Zone	Posterior Mean of Minimum Kx/Kz	Posterior Mean of Maximum Kx/Kz	Posterior Stdev of Minimum Log_{10}(Kx/Kz)	Prior Stdev of Maximum Log_{10}(Kx/Kz)	Prior Mean of Minimum Kx/Kz	Prior Mean of Maximum Kx/Kz	Prior Stdev of Minimum Log_{10}(Kx/Kz)	Prior Stdev of Maximum Log_{10}(Kx/Kz)
1	1	41.6	4017.7	0.102	0.102	40.8	4083.7	0.102	0.102
	13	1.2	111.0	0.075	0.119	1.2	112.8	0.075	0.118
	14	1.2	111.6	0.053	0.066	1.2	113.9	0.055	0.069
	16	1.2	108.1	0.045	0.066	1.1	110.1	0.046	0.067
2	2	14.0	1356.6	0.106	0.106	13.8	1379.9	0.105	0.105
	13	1.1	98.5	0.029	0.051	1.0	100.0	0.026	0.050
	14	1.1	109.4	0.035	0.032	1.1	111.1	0.034	0.034
	16	1.4	133.5	0.008	0.007	1.4	136.6	0.002	0.002
3	3	2.4	225.8	0.182	0.215	2.4	229.8	0.182	0.215
4	4	3.5	340.0	0.137	0.136	3.5	346.4	0.137	0.137
	15	1.0	77.8	0.008	0.062	1.0	79.2	0.004	0.062
5	5	15.5	1494.0	0.186	0.186	15.2	1520.6	0.186	0.186
	15	1.0	98.3	0.000	0.000	1.0	100.0	0.000	0.000
6	6	3.4	326.8	0.104	0.104	3.3	332.3	0.104	0.104
	15	1.0	77.2	0.008	0.085	1.0	78.4	0.005	0.086
7	7	3.0	292.5	0.108	0.108	3.0	297.3	0.108	0.108
	15	1.0	99.0	0.009	0.004	1.0	100.0	0.000	0.000
8	8	2.5	239.0	0.099	0.099	2.4	243.5	0.098	0.098
	15	1.1	92.5	0.037	0.087	1.1	94.1	0.035	0.088
9	9	3.5	336.4	0.147	0.148	3.4	342.5	0.147	0.147
	15	1.0	98.9	0.000	0.000	1.0	100.0	0.000	0.000
10	10	2.6	249.7	0.084	0.082	2.5	254.7	0.083	0.083
	15	1.0	99.3	0.003	0.000	1.0	100.0	0.000	0.000
11	11	1.0	46.7	0.006	0.064	1.0	47.4	0.000	0.064
12	12	1.0	81.2	0.027	0.100	1.0	82.6	0.026	0.100

Table 4: Posterior vs prior distributions for Ss (specific storage). Note that mean values are taken from log-normal distributions but presented as non-log transformed values.

Layer	Zone	Posterior Mean Kx	Posterior Stdev $Log_{10}(Kx)$	Prior Mean Kx	Prior Stdev $Log_{10}(Kx)$
1	1	1.0E-04	0.50	1.0E-04	0.50
	13	1.0E-04	0.50	1.0E-04	0.50
	14	1.0E-04	0.50	1.0E-04	0.50
	16	1.0E-05	0.50	1.0E-05	0.50
2	2	1.0E-04	0.50	1.0E-04	0.50
	13	1.0E-04	0.50	1.0E-04	0.50
	14	1.0E-04	0.51	1.0E-04	0.50
	16	1.0E-05	0.49	1.0E-05	0.50
3	3	1.0E-06	0.50	1.0E-06	0.50
4	4	1.0E-05	0.50	1.0E-05	0.50
	15	9.9E-06	0.50	1.0E-05	0.50
5	5	1.0E-06	0.50	1.0E-06	0.50
	15	1.2E-05	0.48	1.0E-05	0.50
6	6	1.0E-05	0.50	1.0E-05	0.50
	15	9.9E-06	0.50	1.0E-05	0.50
7	7	1.0E-06	0.50	1.0E-06	0.50
	15	1.0E-05	0.50	1.0E-05	0.50
8	8	1.0E-05	0.50	1.0E-05	0.50
	15	9.9E-06	0.50	1.0E-05	0.50
9	9	1.0E-06	0.50	1.0E-06	0.50
	15	9.2E-06	0.47	1.0E-05	0.50
10	10	1.0E-05	0.50	1.0E-05	0.50
	15	9.9E-06	0.49	1.0E-05	0.50
11	11	1.0E-06	0.50	1.0E-06	0.50
12	12	1.0E-06	0.50	1.0E-06	0.50

Table 5: Posterior vs prior distributions for Sy (specific yield). Note that mean values are taken from log-normal distributions but presented as non-log transformed values.

Layer	Zone	Posterior Mean Kx	Posterior Stdev $Log_{10}(Kx)$	Prior Mean Kx	Prior Stdev $Log_{10}(Kx)$
1	1	0.2006	0.50	0.2	0.50
	13	0.01	0.50	0.01	0.50
	14	0.0099	0.49	0.01	0.50
	16	0.0098	0.50	0.01	0.50
2	2	0.2006	0.50	0.2	0.50
	13	0.0101	0.50	0.01	0.50
	14	0.0096	0.50	0.01	0.50
	16	0.0098	0.50	0.01	0.50
3	3	0.0001	0.50	0.0001	0.50
4	4	0.005	0.50	0.005	0.50
	15	0.001	0.50	0.001	0.50
5	5	0.0001	0.50	0.0001	0.50
	15	0.0011	0.50	0.001	0.50
6	6	0.005	0.50	0.005	0.50
	15	0.001	0.50	0.001	0.50
7	7	0.0001	0.50	0.0001	0.50
	15	0.001	0.50	0.001	0.50
8	8	0.005	0.50	0.005	0.50
	15	0.001	0.50	0.001	0.50
9	9	0.0001	0.50	0.0001	0.50
	15	0.0009	0.53	0.001	0.50
10	10	0.005	0.50	0.005	0.50
	15	0.001	0.51	0.001	0.50
11	11	0.0001	0.50	0.0001	0.50
12	12	0.001	0.50	0.001	0.50

Table 6: Posterior vs prior distributions for Kx/Rch (fractional infiltration ratio). Note that mean values are taken from log-uniform distributions but presented as non-log transformed values.

Layer	Zone	Posterior Mean of Minimum Kx/Kz	Posterior Mean of Maximum Kx/Kz	Posterior Stdev of Minimum Log_{10}(Kx/Kz)	Prior Stdev of Maximum Log_{10}(Kx/Kz)	Prior Mean of Minimum Kx/Kz	Prior Mean of Maximum Kx/Kz	Prior Stdev of Minimum Log_{10}(Kx/Kz)	Prior Stdev of Maximum Log_{10}(Kx/Kz)
1	1	56.9	1387.7	0.323	0.323	56.2	1405.5	0.323	0.323
	13	41.5	1012.2	0.105	0.106	41.1	1026.4	0.105	0.105
	14	14.9	363.0	0.068	0.069	14.8	368.9	0.070	0.070
	16	0.4	8.6	0.079	0.079	0.3	8.7	0.079	0.079

Results

Statistics on key predictive outputs were computed from the results of the 262 accepted model runs and are presented in this section. Percentile results were calculated from the Monte Carlo outputs strictly on a conservative "round to higher value" basis, and are represented as "probabilities of exceedance" in five categories: "very likely (90%) - **green**, "likely (67%)" - **light yellow-green**, "about as likely as not (50%)" - **black**, "unlikely (33%)" - **orange**, and "very unlikely (10%)" - **red**.

To clarify, a "very unlikely (10%)" probability of exceedance value of X for a metric should be interpreted to mean "10% of realisations from the set of accepted realisations resulted in a value for this metric larger than X".

Key predictive outputs

Table 7 presents probabilities of exceedance for peak mine inflow, baseflow impact and the number of alluvial bores affected by drawdown of 2m or more. The following bores were considered for assessment in these results: GW031856, GW044997, MW02, MW04, MW06, BCS6 and BCS7.

Note that each row of the table represents a different distribution of the Monte Carlo run results, wherein each percentile result is representative of a different subset of runs. As such, the results from different rows should be taken independently and may not be directly combined. For example, the set of runs for which peak baseflow impact to Bollol Creek was 1.6 ML/year does not necessarily correlate with the set of runs for which peak mine inflow was 70.7 ML/year, despite these values being presented in the same column of the table.

Table 7: Probability of exceedance of peak mine inflow, baseflow impacts and the number of drawdown-affected bores.

	Very likely (90%)	**Likely (67%)**	**About as likely as not (50%)**	**Unlikely (33%)**	**Very unlikely (10%)**
Peak mine inflow (Tarrawonga additional mining) *(ML/year)*	70.7	82.0	88.0	93.9	104.5
Peak baseflow impact (Goonbri Creek) *(ML/year)*	11.0	18.5	22.0	25.2	33.6
Peak baseflow impact (Bollol Creek) *(ML/year)*	1.6	2.4	3.0	3.4	4.6
Number of alluvial bores affected by 2m+ drawdown	0	0	0	0	1

Spatial drawdown: probability of exceedance

Spatial drawdown statistics computed on a cell-by-cell basis are contoured on "probability of exceedance" basis in Figure 2 and Figure 3, for the watertable and layer 8, respectively. The value of each contour represents the probability of drawdown due to additional Tarrawonga mining exceeding 2m inside the area of the contour. Contour lines are presented at 10%, 33%, 50%, 67% and 90% probabilities.

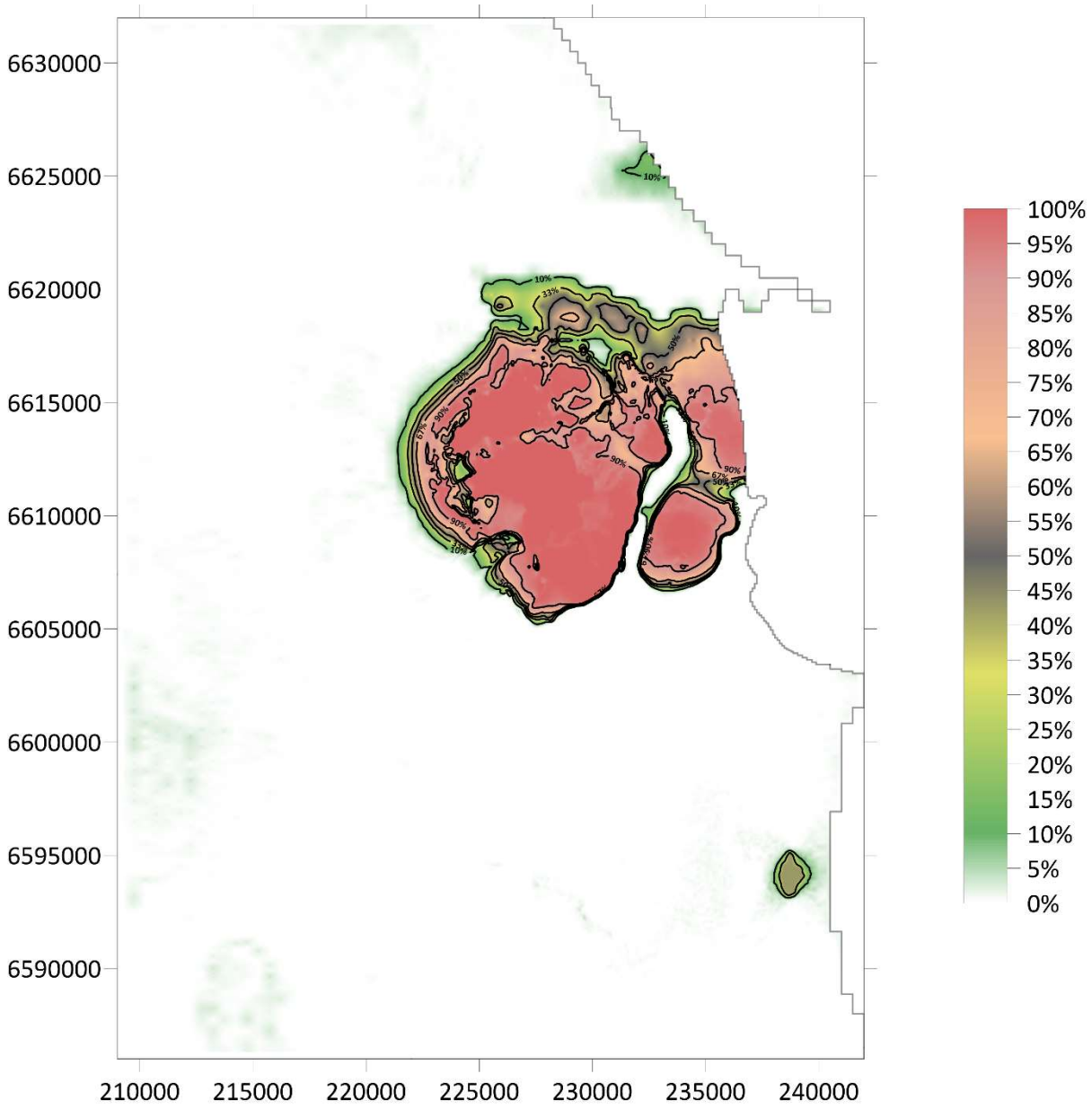


*Figure 2: Probability of exceedance of **2m drawdown** to the **watertable**. Contours are at 10%, 33%, 50%, 67% and 90% probability of exceedance.*

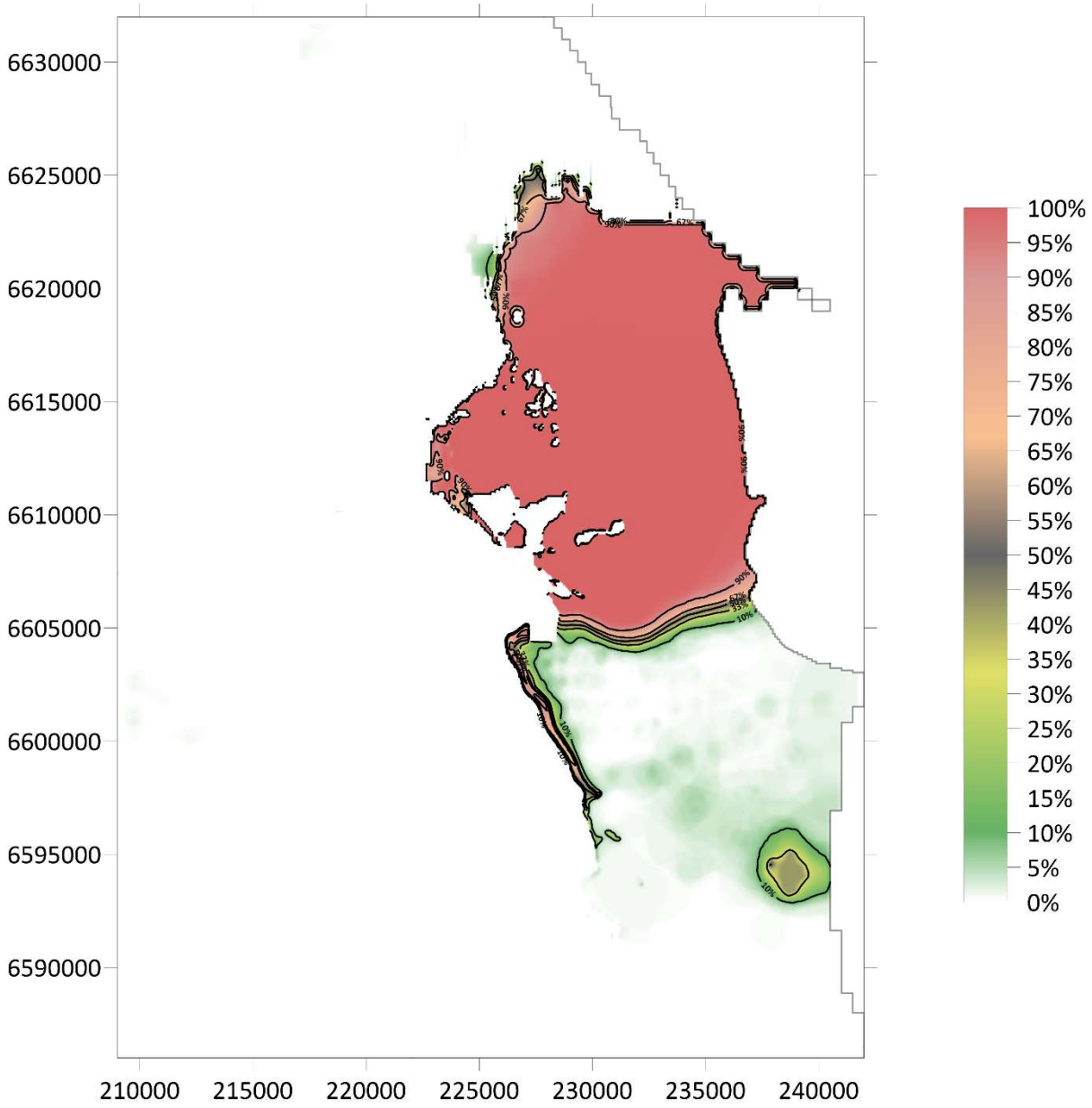


*Figure 3: Probability of exceedance of **2m drawdown** in **layer 8**.*
Contours are at 10%, 33%, 50%, 67% and 90% probability of exceedance.

Spatial drawdown: maximum drawdown at percentiles

Figure 4 through Figure 9 show contours of maximum drawdown over all simulation time at 10th, 50th and 90th percentiles for the watertable and layer 8 due to additional Tarrawonga mining.

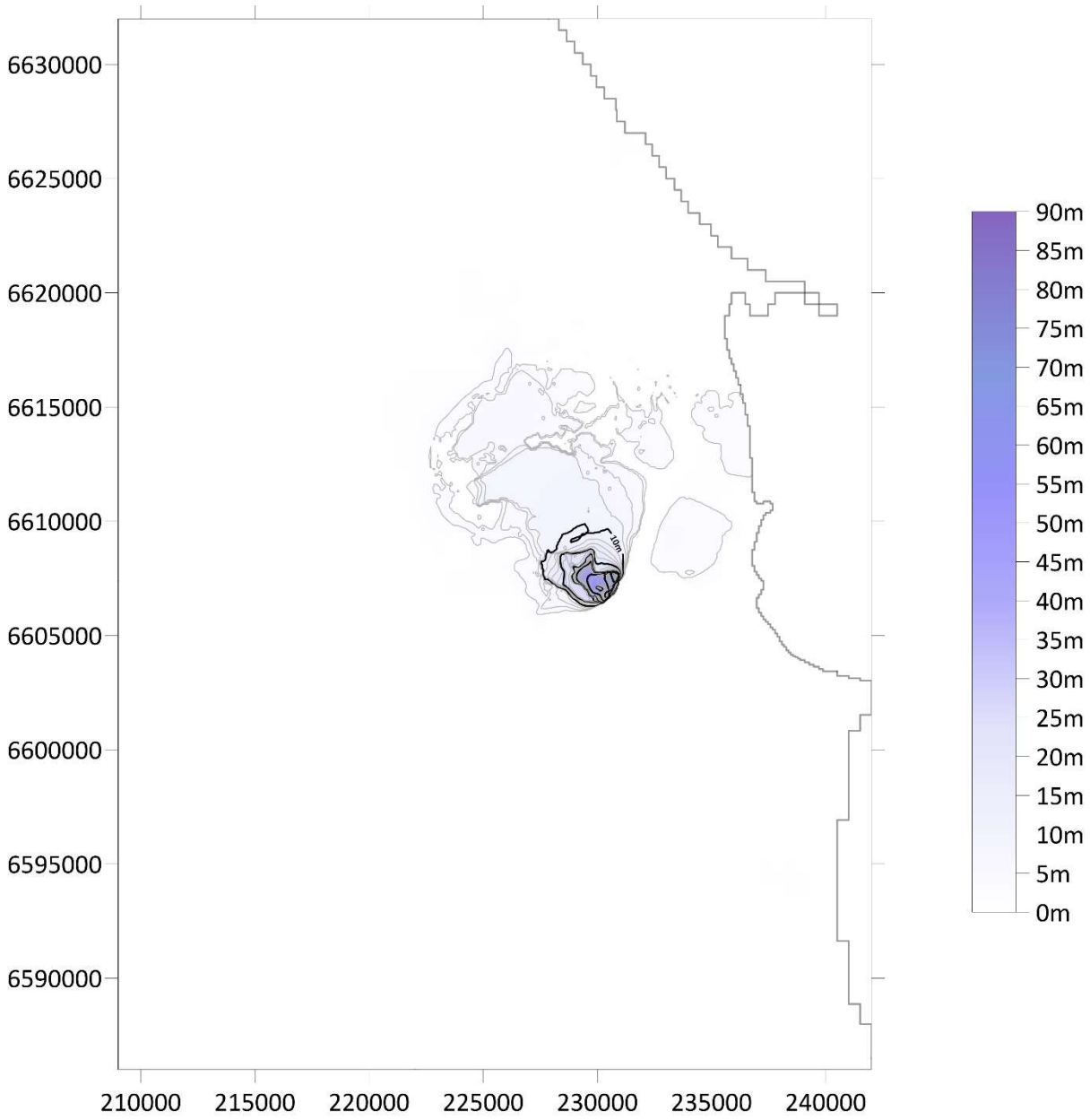


*Figure 4: **10th percentile** maximum drawdown (over all time) to the **watertable**. Light grey contours are at 2m intervals and black contours are at 10m intervals.*

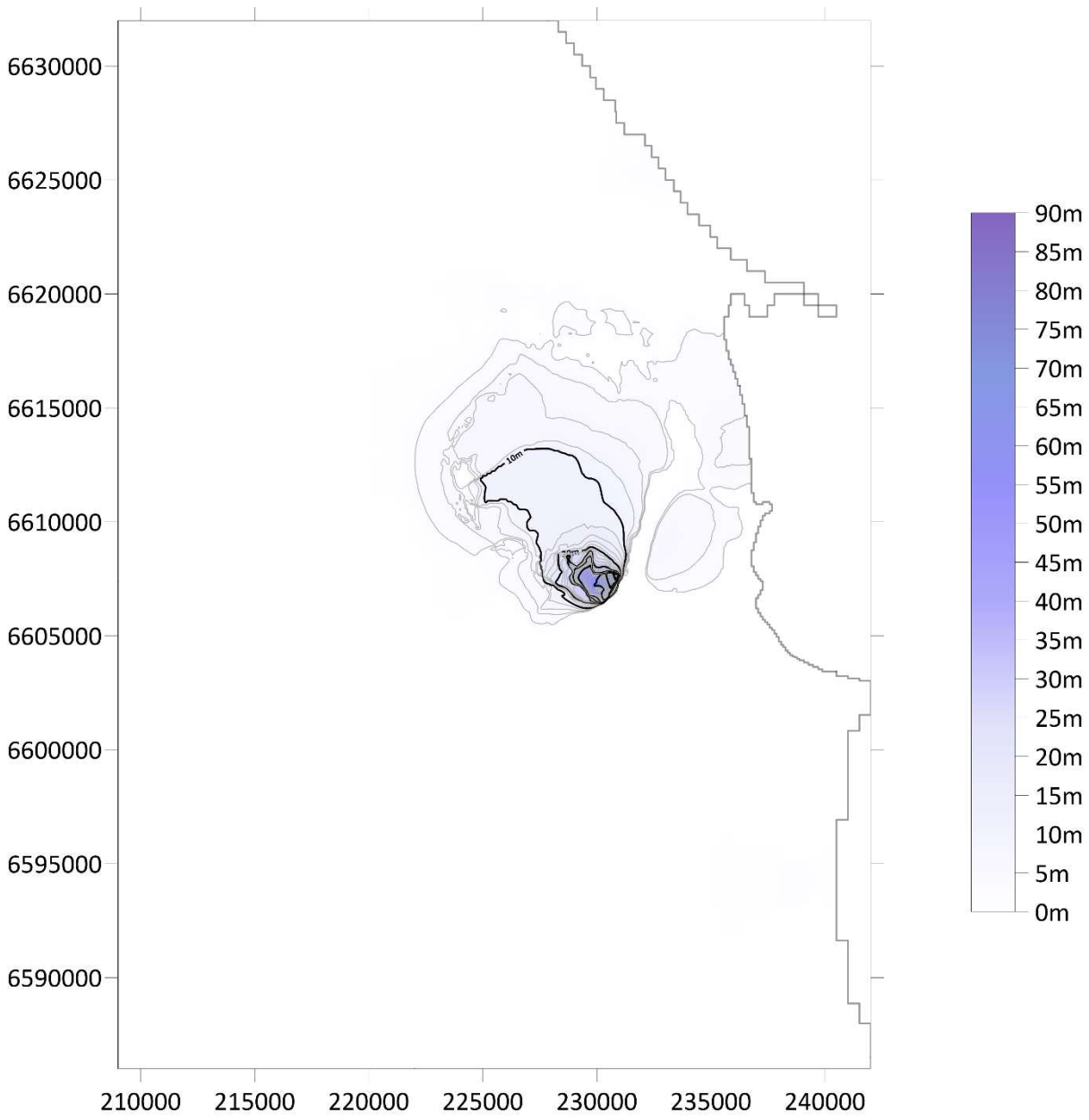


*Figure 5: **50th percentile** maximum drawdown (over all time) to the **watertable**. Light grey contours are at 2m intervals and black contours are at 10m intervals.*

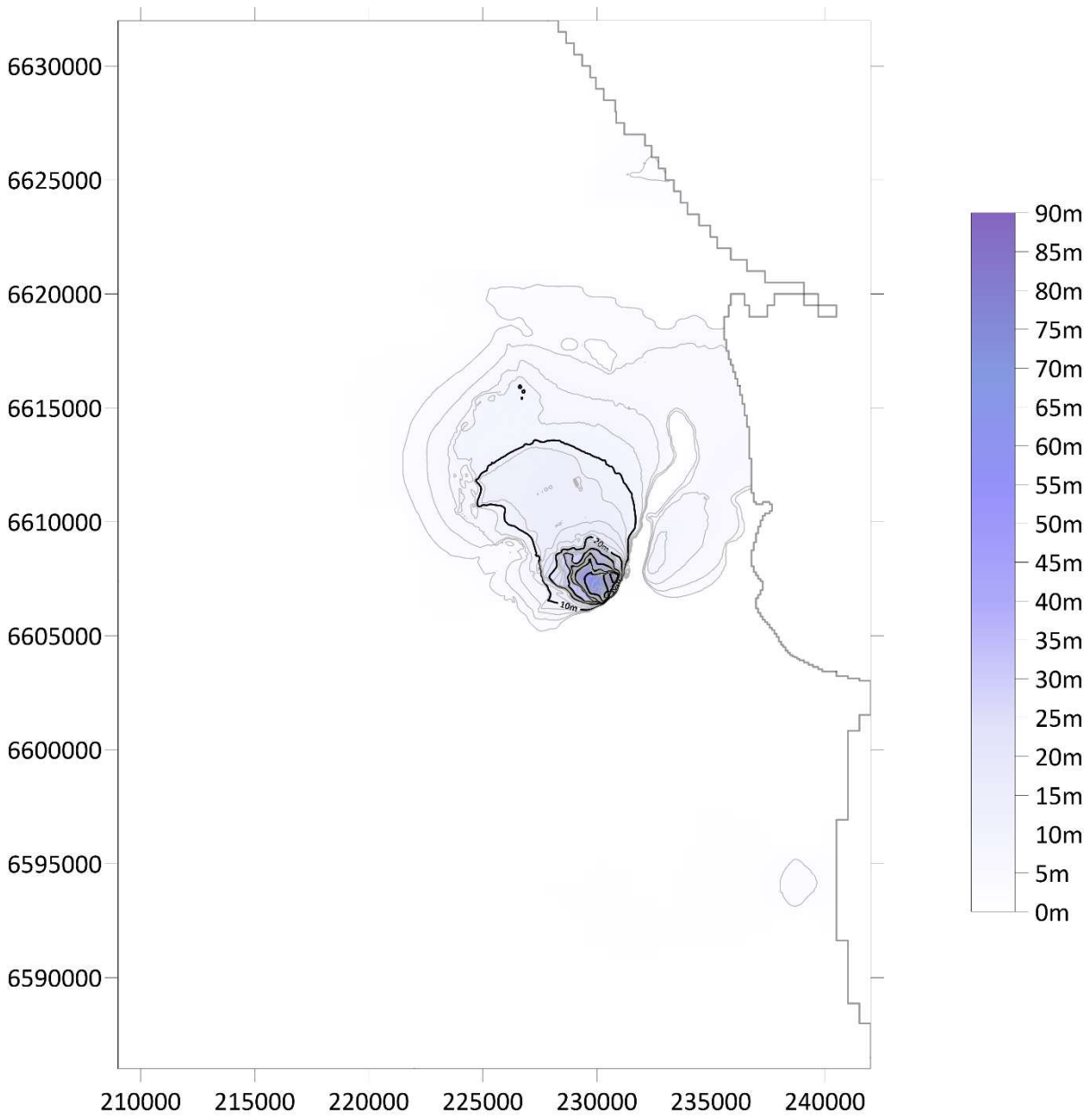


*Figure 6: **90th percentile** maximum drawdown (over all time) to the **watertable**. Light grey contours are at 2m intervals and black contours are at 10m intervals.*

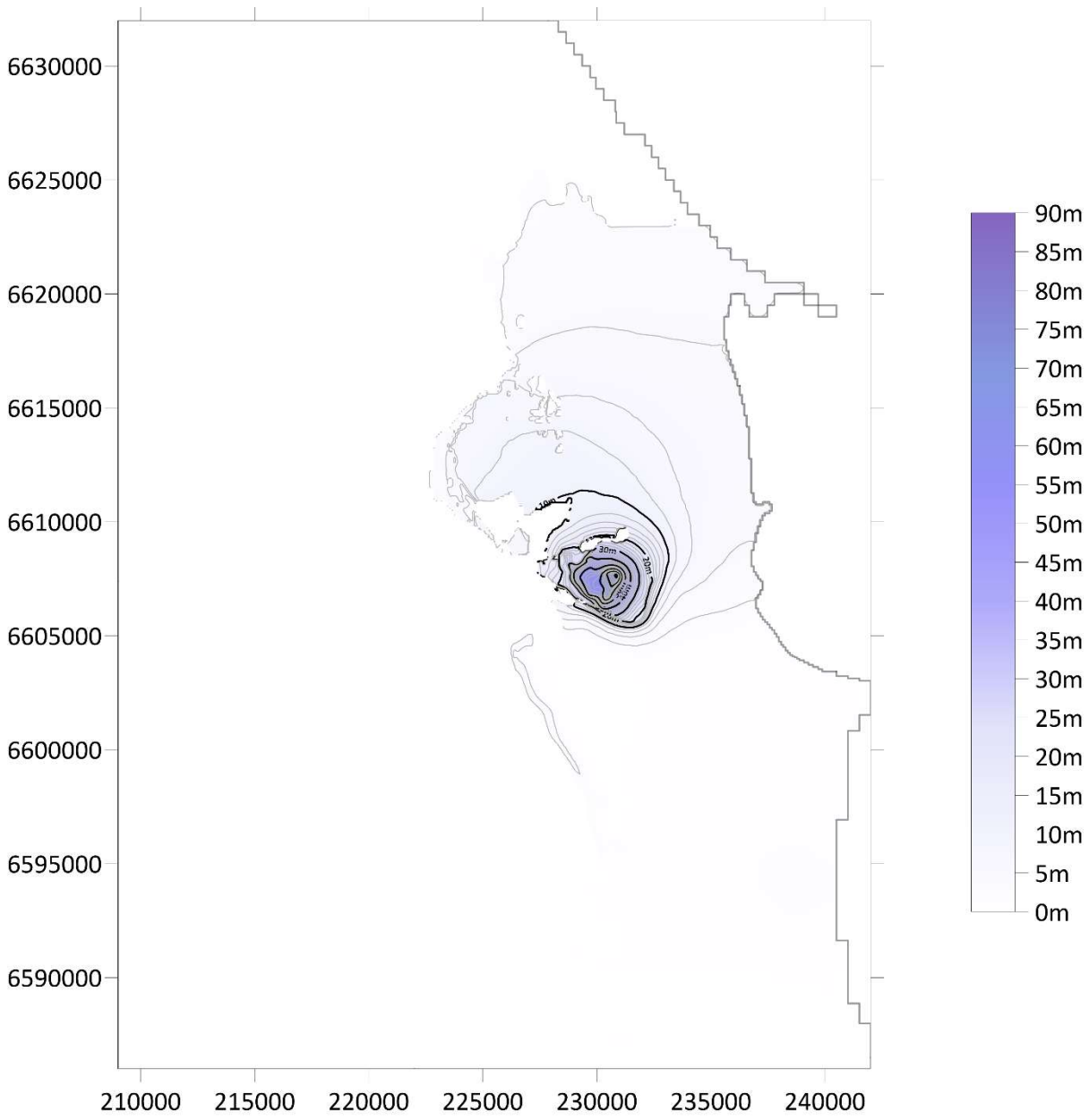


*Figure 7: **10th percentile** maximum drawdown (over all time) in **layer 8**.*
Light grey contours are at 2m intervals and black contours are at 10m intervals.

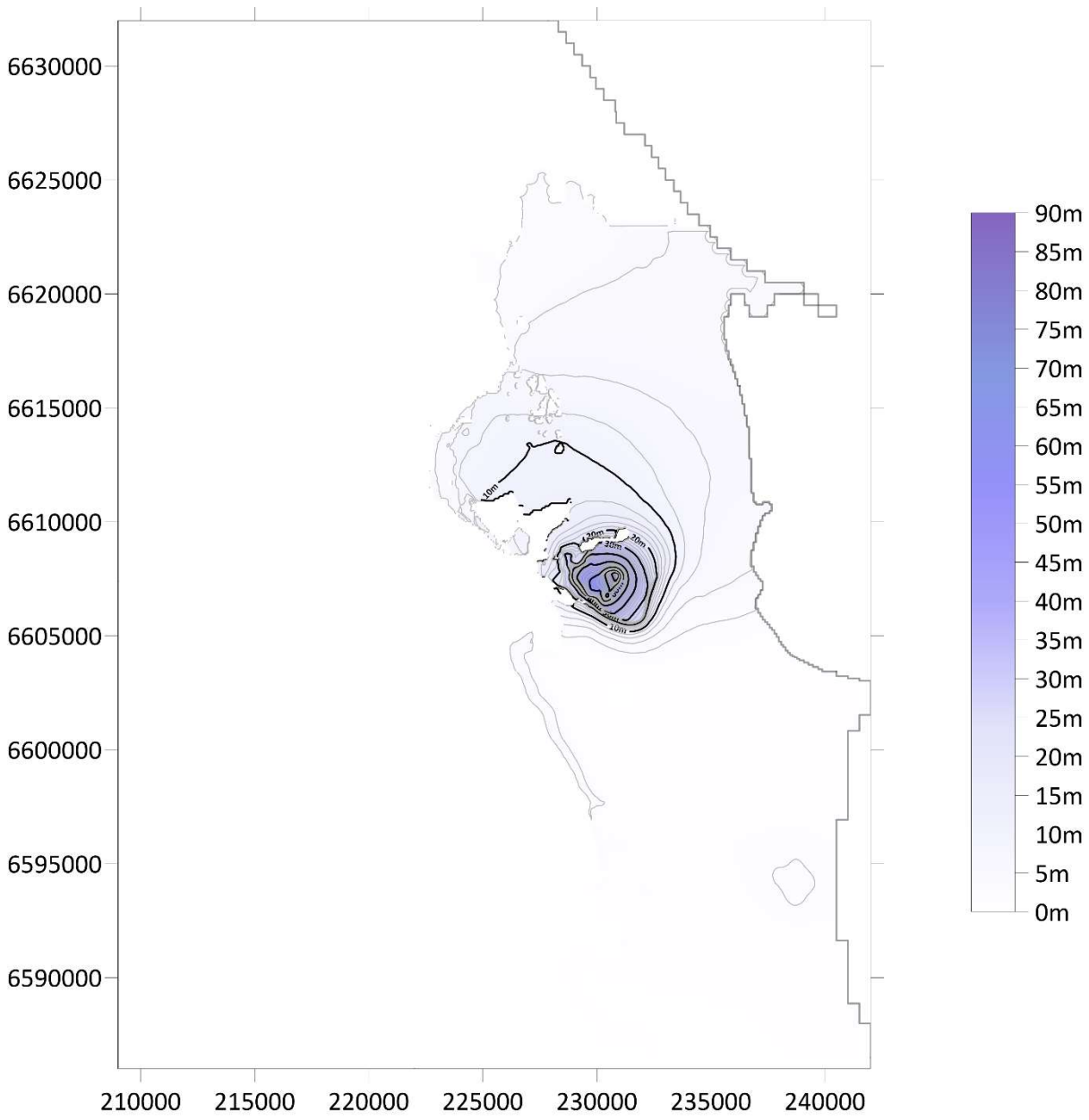


*Figure 8: **50th percentile** maximum drawdown (over all time) in **layer 8**.*
Light grey contours are at 2m intervals and black contours are at 10m intervals.

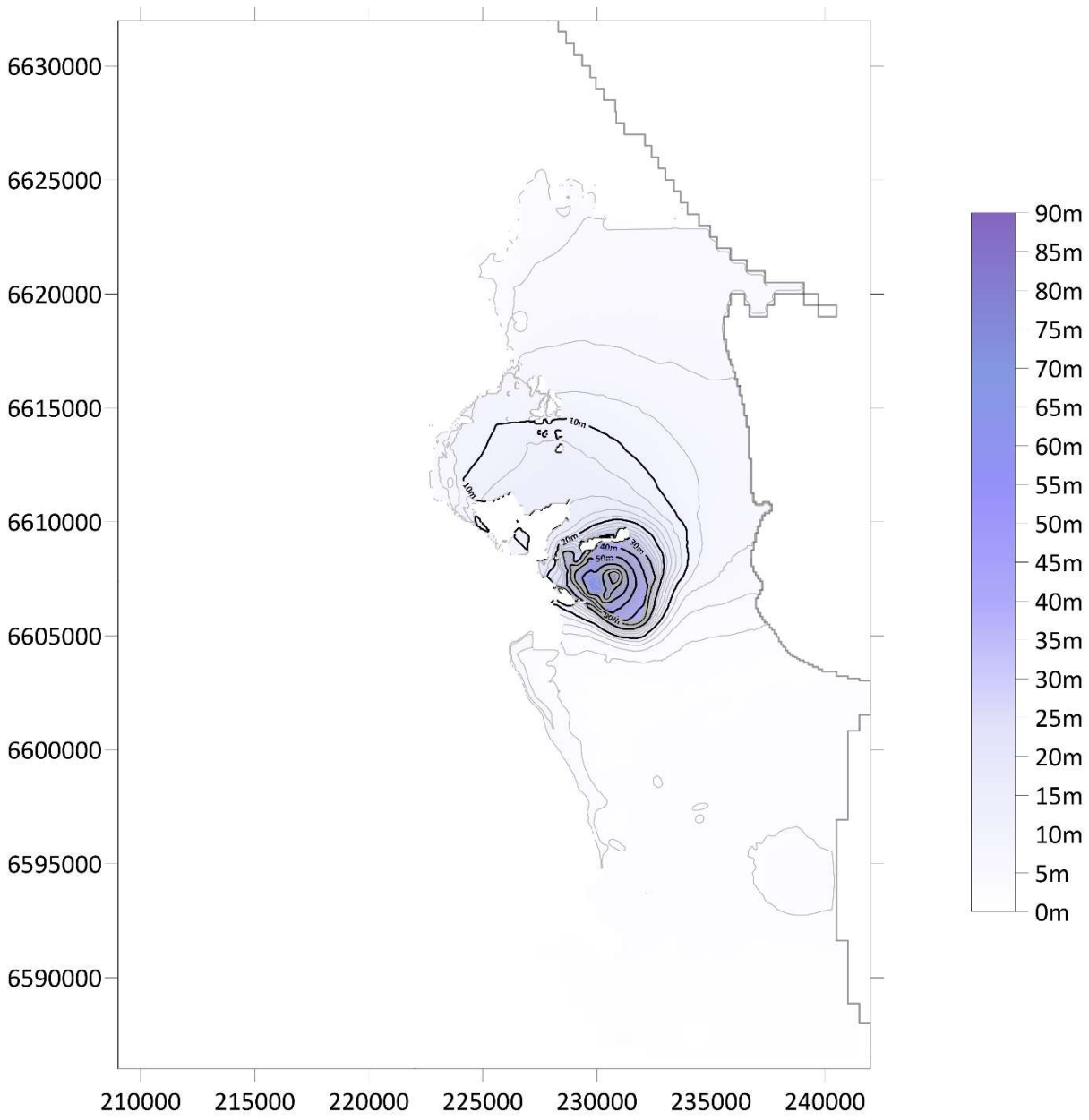


*Figure 9: **90th percentile** maximum drawdown (over all time) in **layer 8**.*
Light grey contours are at 2m intervals and black contours are at 10m intervals.

Monte Carlo convergence

When conducting stochastic modelling such as that performed here, it is important that enough realisations have been evaluated to ensure that the results reported are accurate – that is, that the stochastic process has *converged* to within an acceptable probabilistic margin of error.

To gain confidence that the reported results were sufficiently close to their correct values, 99.7% confidence intervals were computed for the 10%, 33%, 50%, 67% and 90% probabilities of exceedance of key aggregate metrics.

Confidence interval bounds for the $(100 \times p)$ th percentile may be approximated by the formula $p \pm \sqrt{p(1-p)c^2/n}$, where c is the desired confidence in standard deviations of the normal distribution – $c = 3$ for 99.7% confidence – and n is the number of runs (see e.g. *Mood et al., 1974* for derivations of confidence interval bounds). For example, it may be said with 99.7% confidence after 312 successful runs that the true 90th percentile value lies between the 84.9th and 95.1st percentile estimates ($= 100 \times \left(0.9 \pm \sqrt{0.9 \times 0.1 \times 9/312}\right)$).

In this section, charts are presented illustrating the convergence of selected key metrics to illustrate the convergence of the Monte Carlo process. Two types of chart are presented. The first shows the values of the 10th, 33rd, 50th, 67th and 90th percentiles as they evolve with the number of runs evaluated. The second shows the 10th, 50th and 90th percentile values surrounded by their computed 99.7% confidence intervals, also as they evolve with respect to the number of runs evaluated. Note that 33rd and 67th percentile confidence intervals have been omitted from these charts to ease readability; the intervals in these cases were similar or narrower in width than those of the 10th, 50th and 90th percentiles shown.

The colour coding of the convergence charts follows the same categorisation as in the other charts presented: “very likely (90%) - **green**, “likely (67%)” - **light yellow-green**, “about as likely as not (50%)” - **black**, “unlikely (33%)” - **orange**, and “very unlikely (10%)” - **red**. Solid lines in the convergence charts represent the actual sampled percentile values, and dashed lines represent the 99.7% confidence intervals of the percentile corresponding to their colour.

Peak Mine Inflow (Tarrawonga Additional Mining)

Figure 10 and Figure 11 illustrate the change in peak mine inflow rates with respect to the number of Monte Carlo realisations evaluated. The 99.7% confidence intervals indicate that the reported values are within 10.0 ML/year of the true values with high probability.

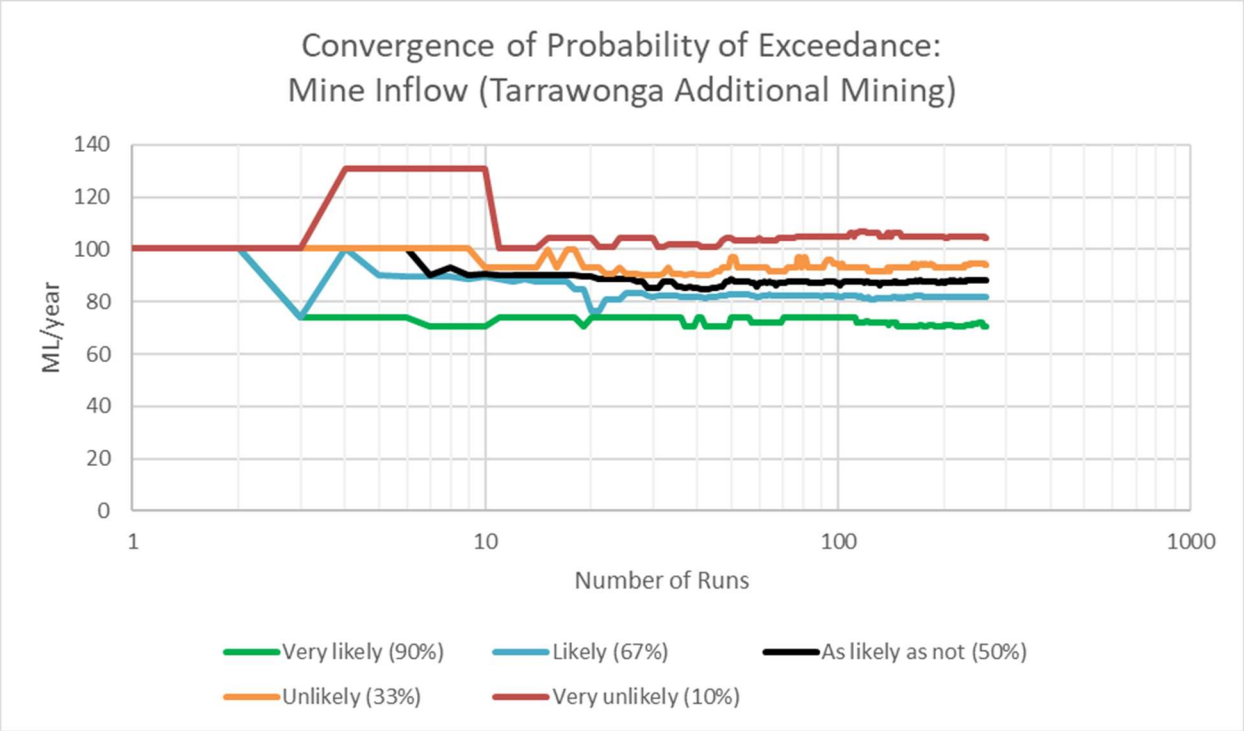


Figure 10: Change in peak mine inflow with number of Monte Carlo runs.

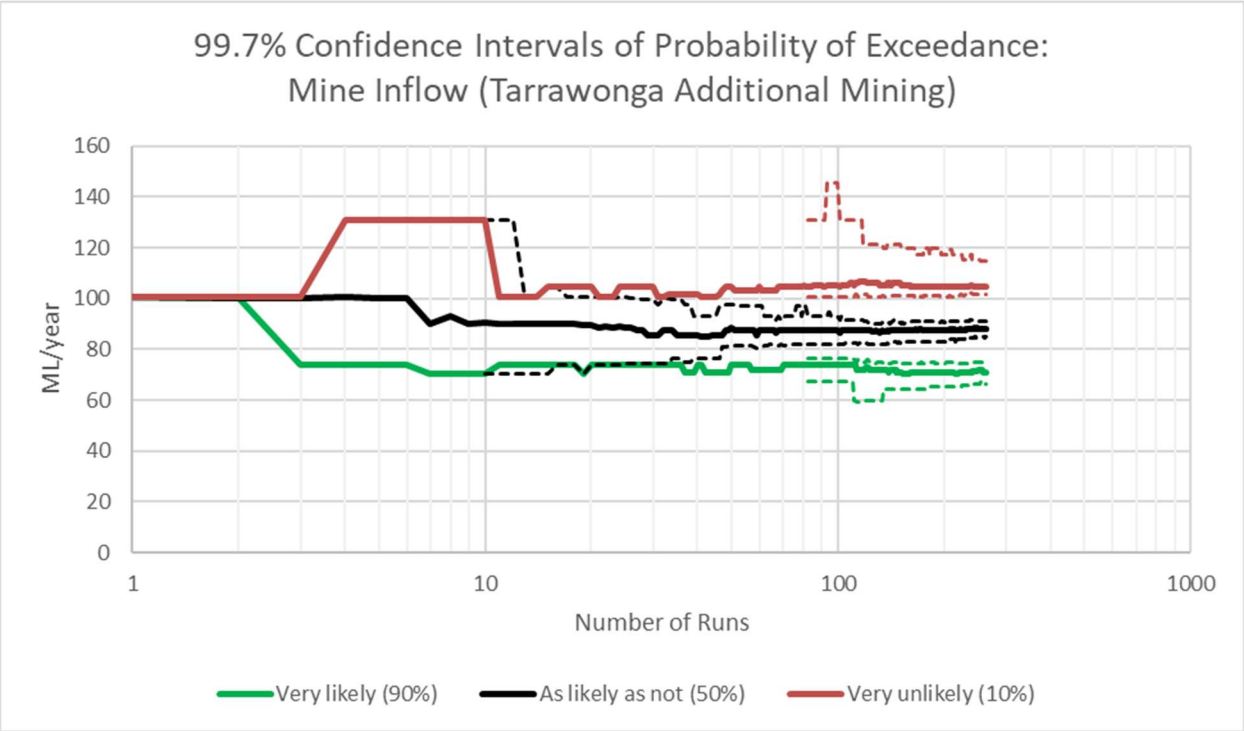


Figure 11: 99.7% confidence intervals for convergence of peak mine inflow.

Peak Baseflow Impact (Goonbri Creek)

Figure 12 and Figure 13 illustrate the change in peak baseflow impacts for Goonbri Creek with respect to the number of Monte Carlo realisations evaluated. The 99.7% confidence intervals indicate that the reported values are within 3.9 ML/year of the true values with high probability.

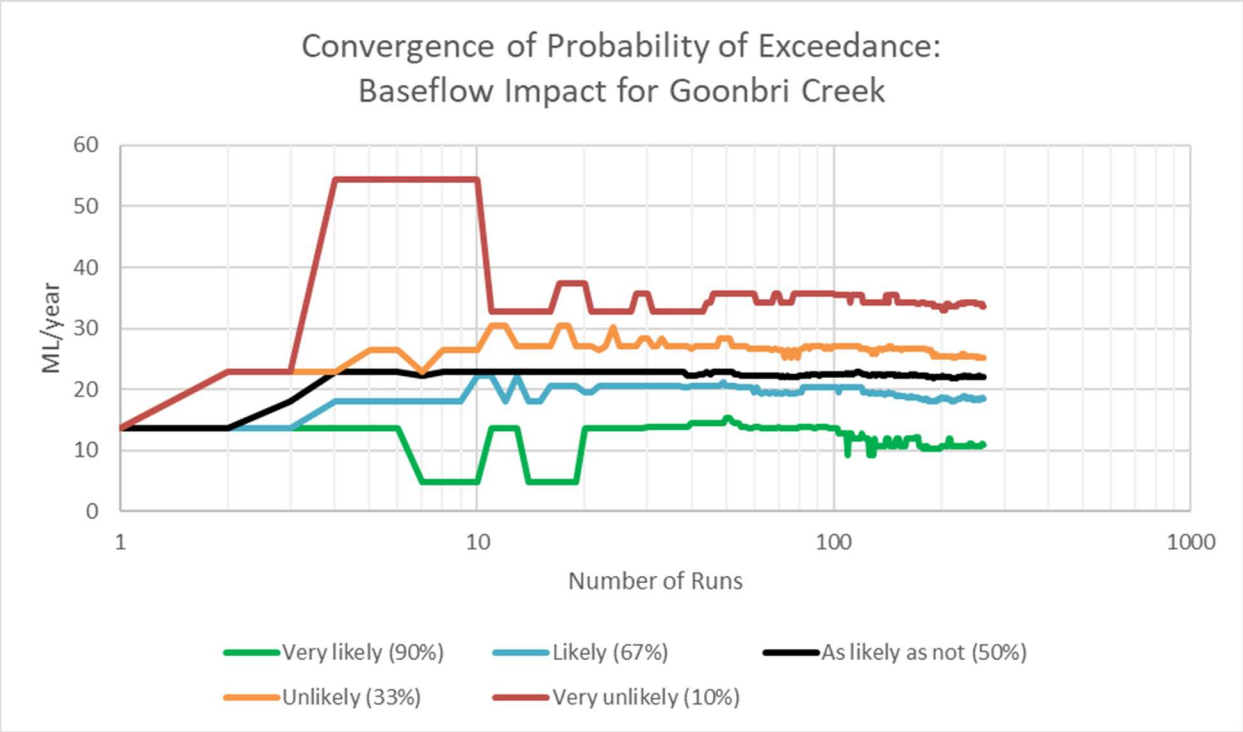


Figure 12: Change in peak baseflow impact for Goonbri Creek with number of Monte Carlo runs.

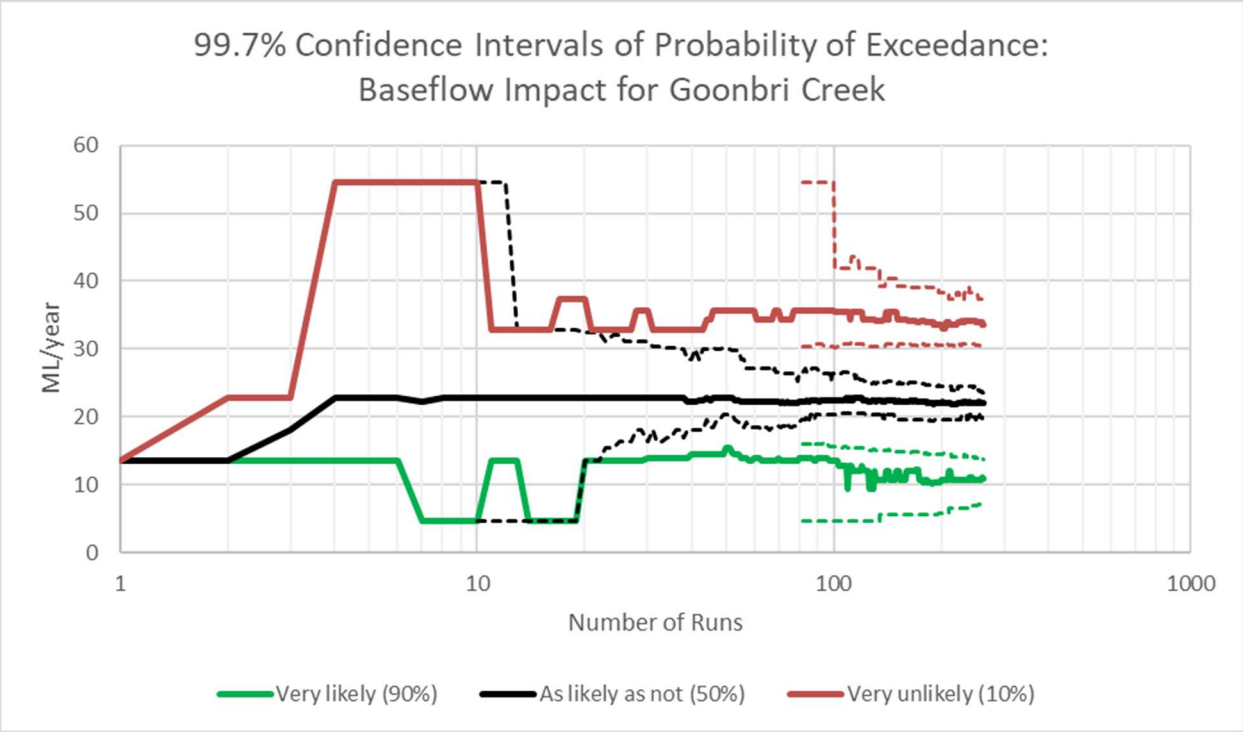


Figure 13: 99.7% confidence intervals for convergence of peak baseflow impact for Goonbri Creek.

Peak Baseflow Impact (Bollol Creek)

Figure 14 and Figure 15 illustrate the change in peak baseflow impacts for Bollol Creek with respect to the number of Monte Carlo realisations evaluated. The 99.7% confidence intervals indicate that the reported values are within 0.6 ML/year of the true values with high probability.

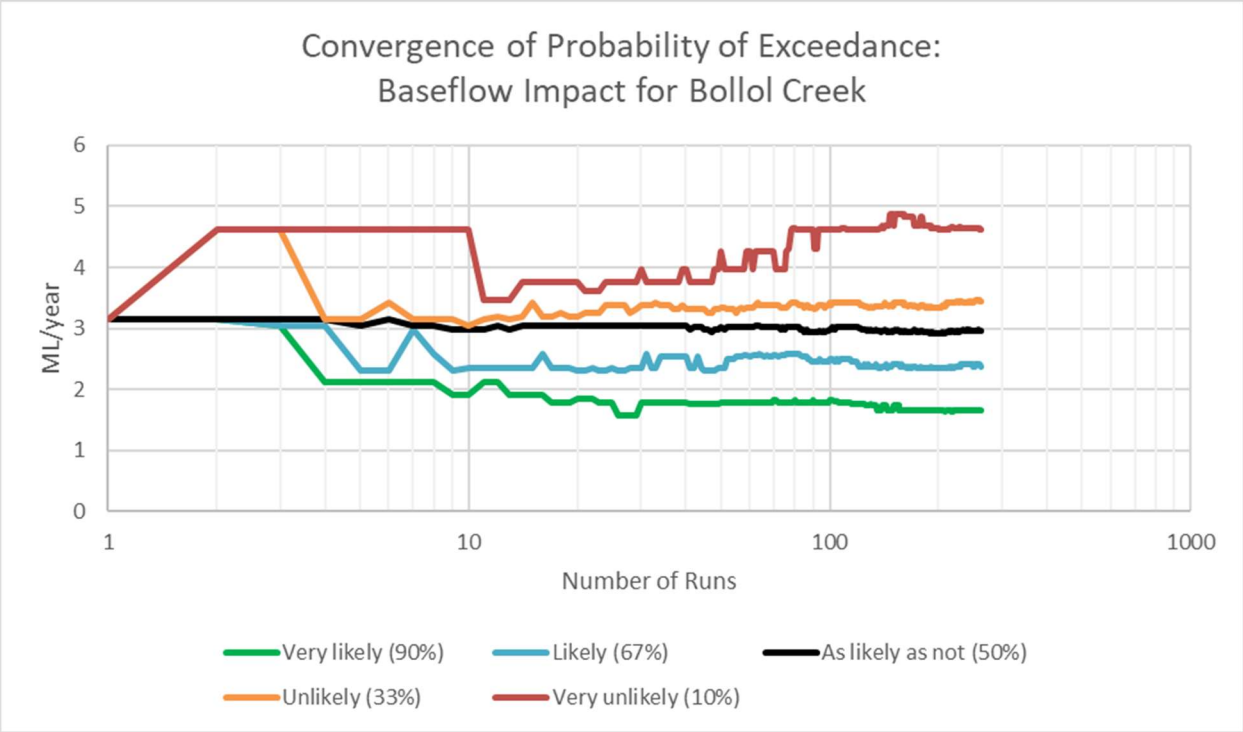


Figure 14: Change in peak baseflow impact for Bollol Creek with number of Monte Carlo runs.

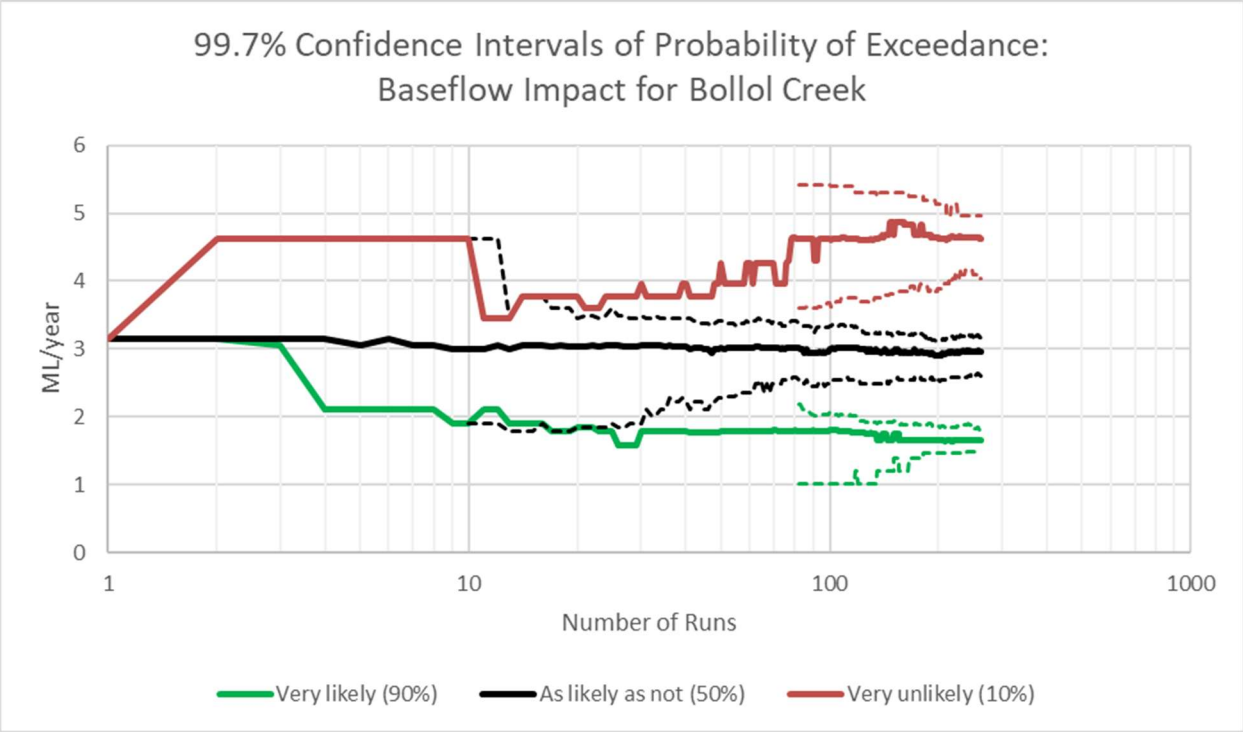


Figure 15: 99.7% confidence intervals for convergence of peak baseflow impact for Bollol Creek.

References

Doherty, J., 2015. *Calibration and Uncertainty Analysis for Complex Environmental Models*. Watermark Numerical Computing, Brisbane, Australia. ISBN: 978-0-9943786-0-6.

Doherty, J., 2016. PLPROC: A parameter list processor. Software manual.

HydroAlgorithmics, 2019. AlgoCompute web site, https://www.algocompute.com/. Accessed 1 August, 2019.

Merrick, D. and Merrick, N., 2015. AlgoMesh: A new software tool for building unstructured grid models. In *Proc. MODFLOW and More*, Golden, Colorado.

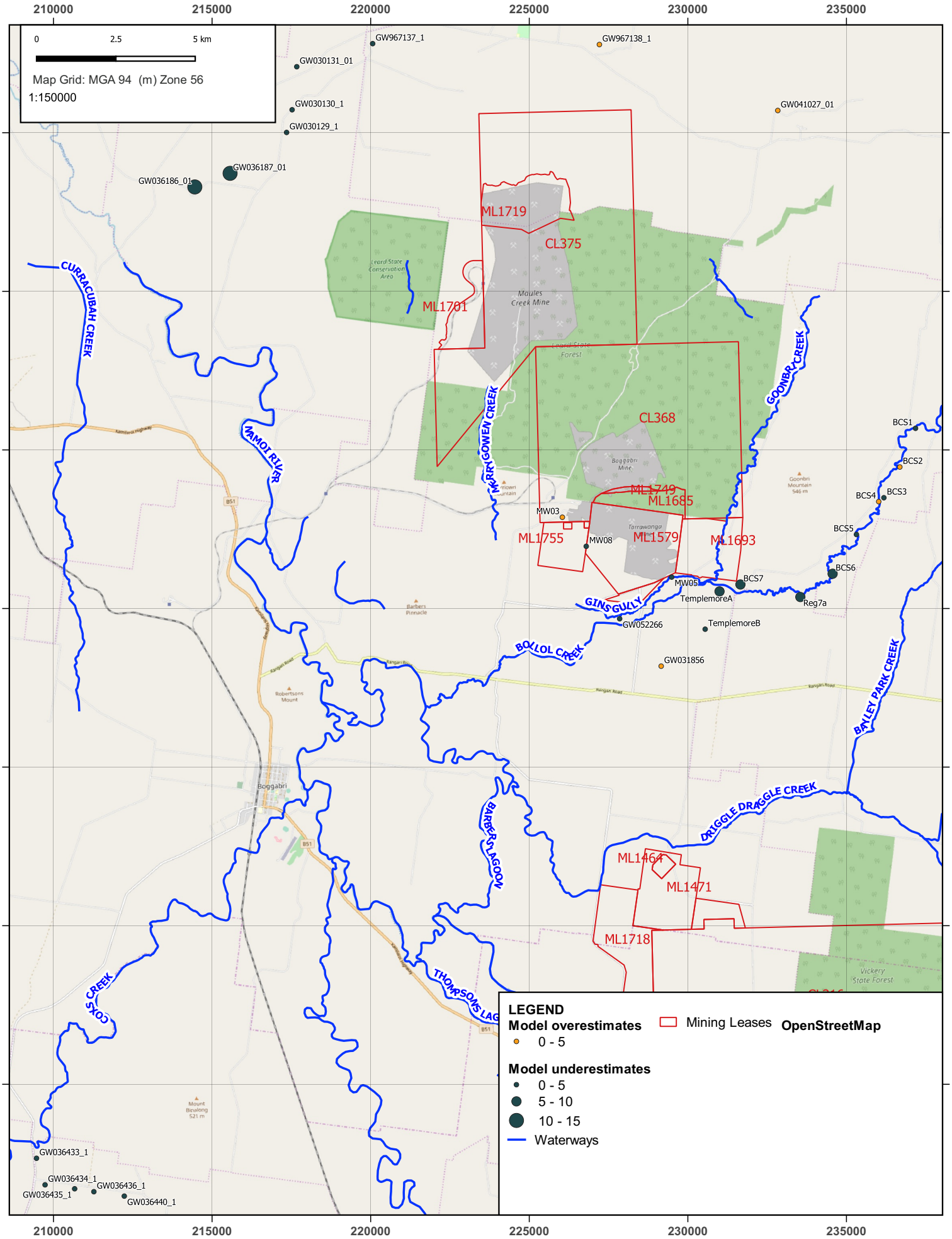
Merrick, D., 2017. AlgoCompute: Large-scale calibration and uncertainty analysis made easy in the cloud. In *Proc. MODFLOW and More*, Golden, Colorado.

Miller, K.L., Berg, S.J., Davison, J.H., Sudicky, E.A., Forsyth, P.A., 2018. Efficient uncertainty quantification in fully-integrated surface and subsurface hydrologic simulations. *Advances in Water Resources*, Volume 111, pp. 381-394.

Mood, A.M., Graybill, F.A., Boes, D.C., 1974. *Introduction to the Theory of Statistics, 3rd Edition*. Mcgraw-Hill, Inc. ISBN: 978-0-07-042864-5.

Vrugt, J.A., ter Braak, C J.F., Diks, C.G.H., Higdon, D., Robinson, B.A., and Hyman, J.M., 2009. Accelerating Markov chain Monte Carlo simulation by differential evolution with self-adaptive randomized subspace sampling. *International Journal of Nonlinear Sciences and Numerical Simulation*, Volume 10, Issue 3, pp. 273-290.

ATTACHMENT H – RESIDUAL MAPS (CALIBRATION)

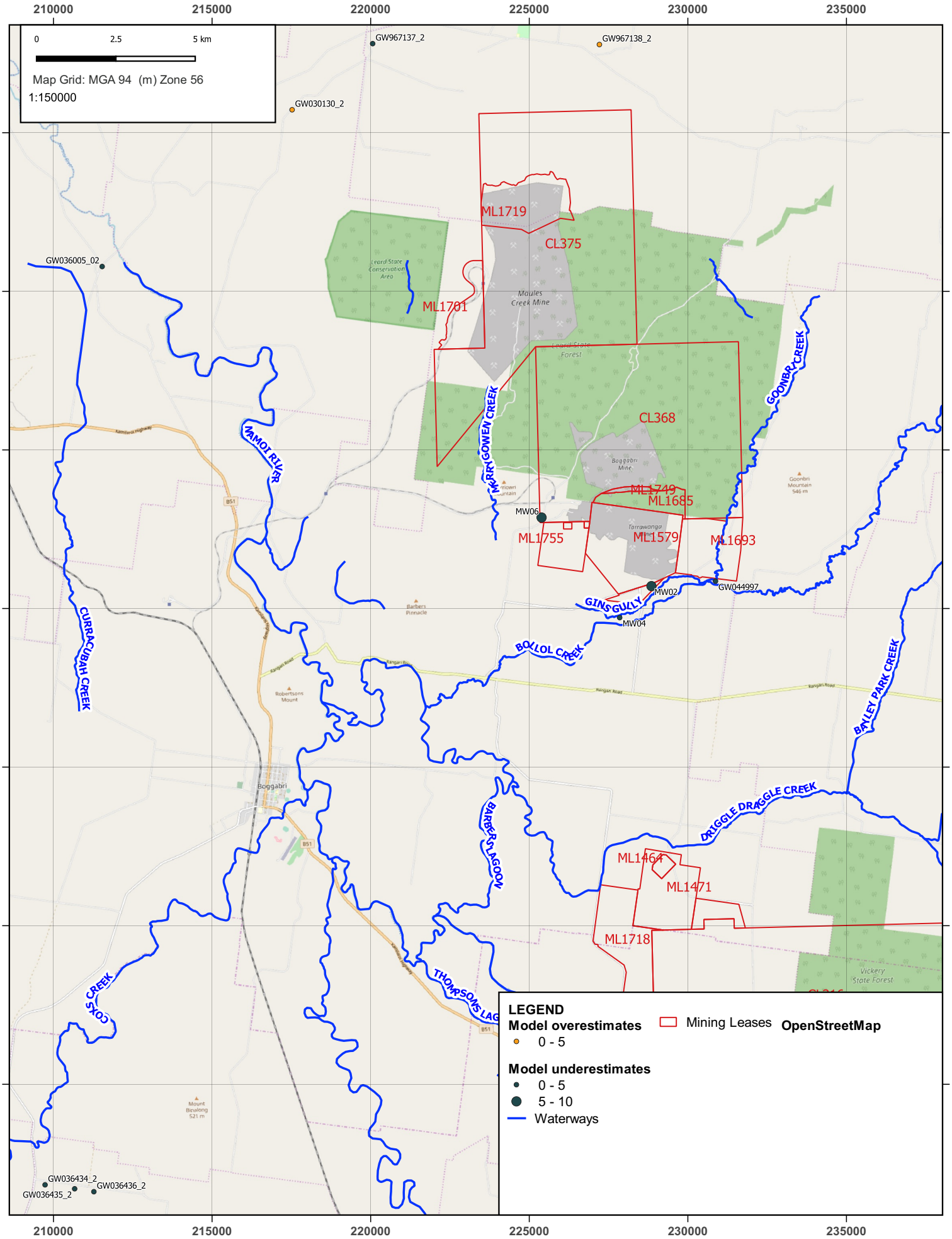


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment H - Average Residual Maps

Layer 1 - Alluvium

HYDRO SIMULATIONS

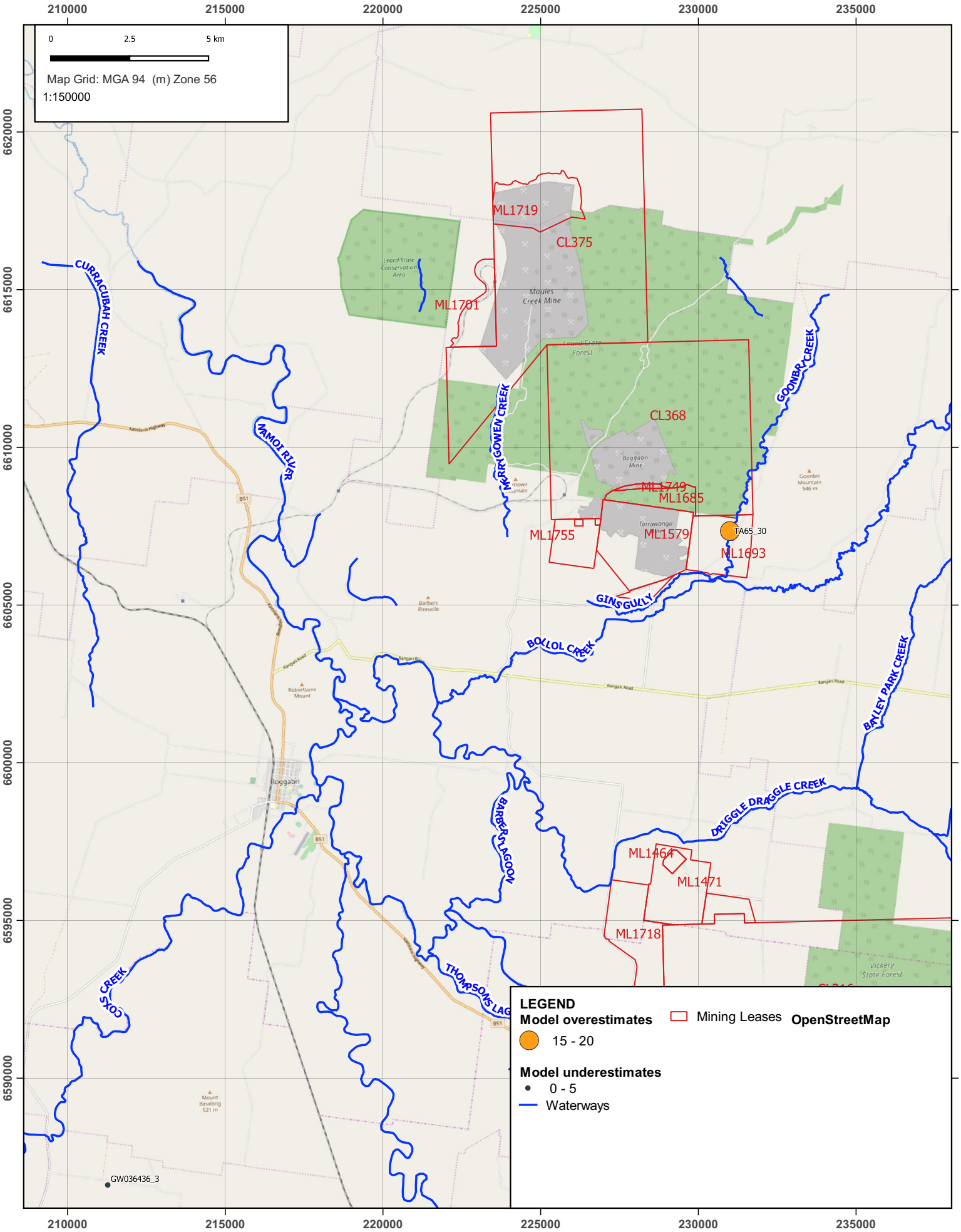


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment H - Average Residual Maps

Layer 2 - Alluvium

HYDRO SIMULATIONS

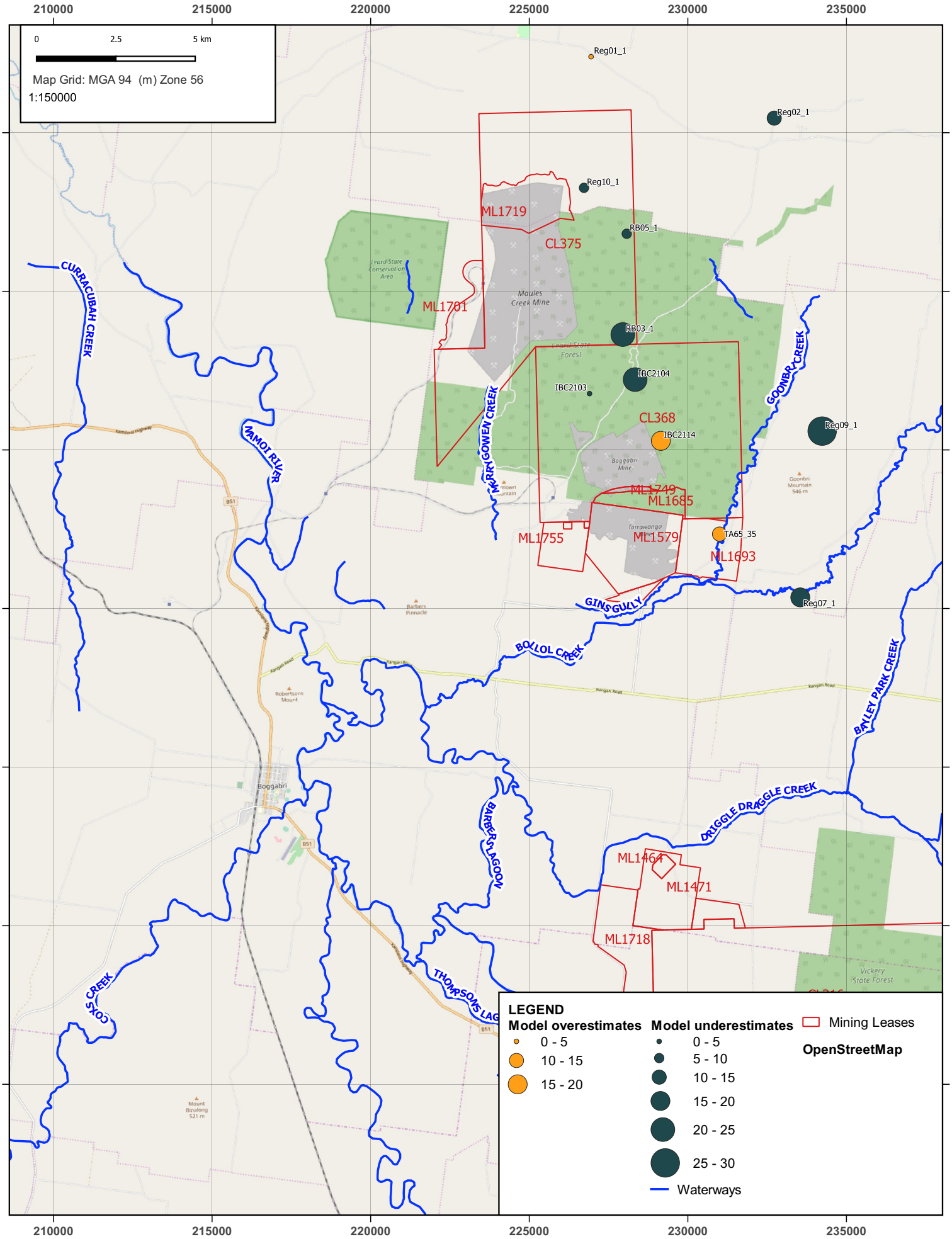


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment H - Average Residual Maps

Layer 3 - Overburden

HYDRO SIMULATIONS

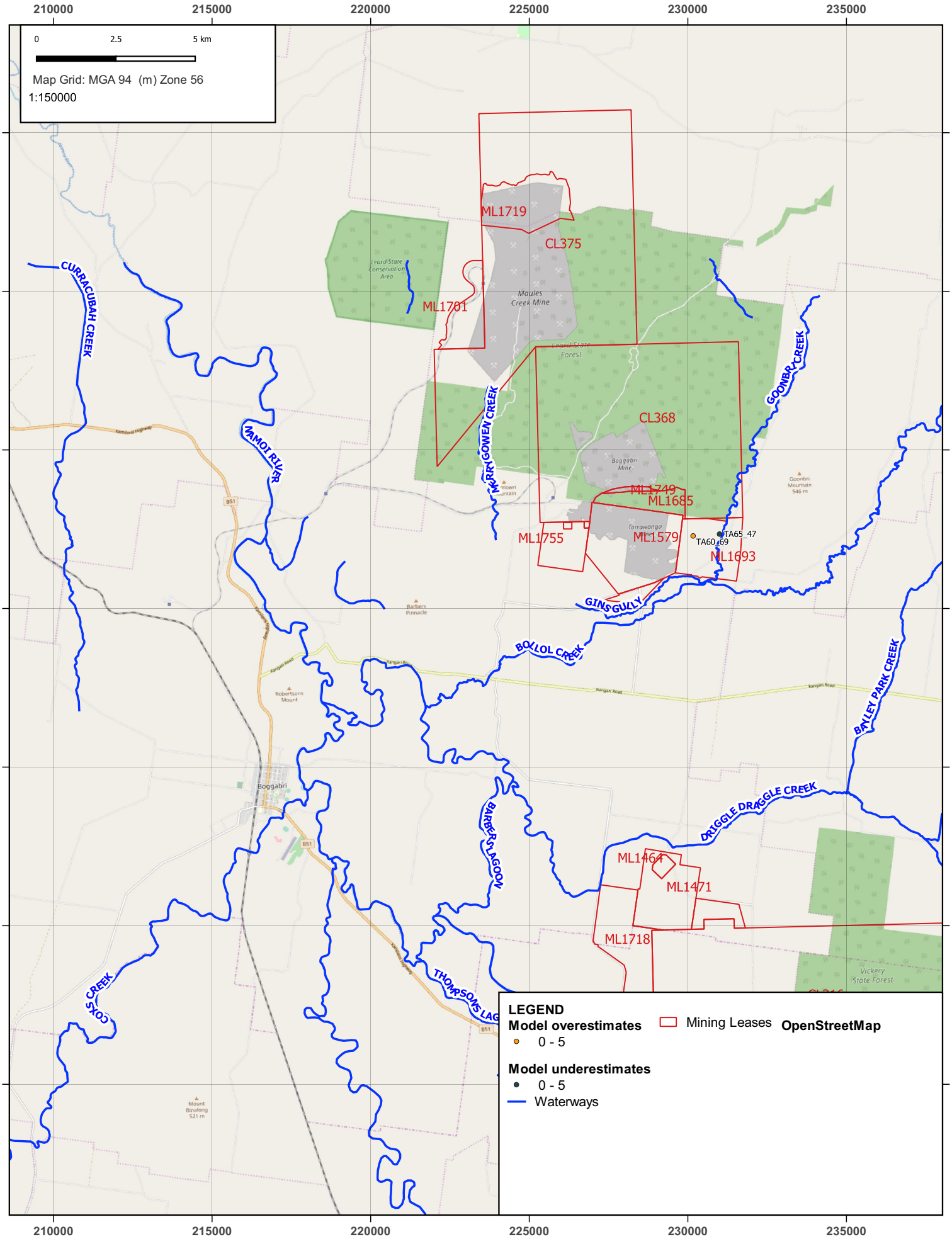


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment H - Average Residual Maps

Layer 4 - Braymont Seam to Jeralong Seam

HYDRO SIMULATIONS

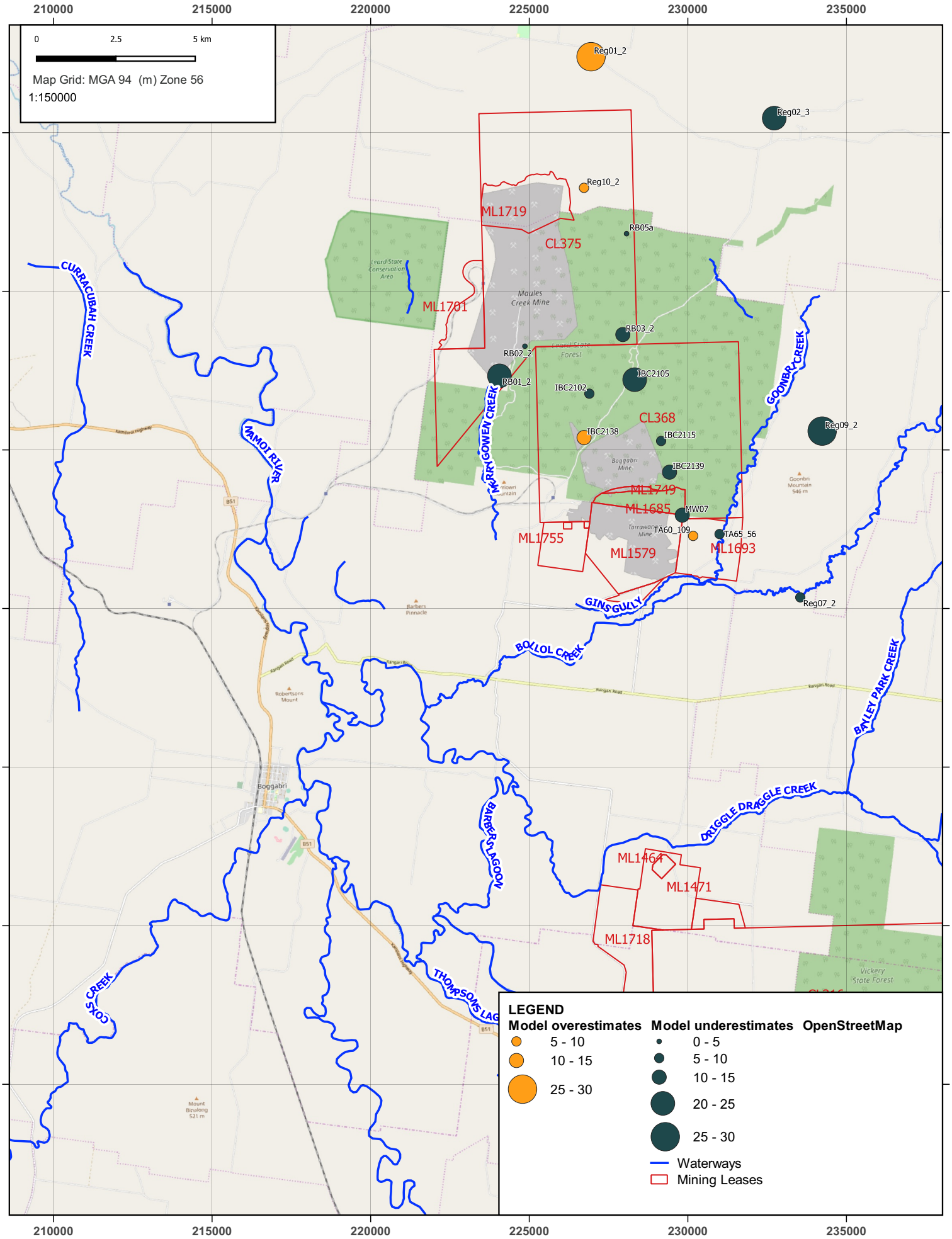


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment H - Average Residual Maps

Layer 5 - Interburden

HYDRO SIMULATIONS

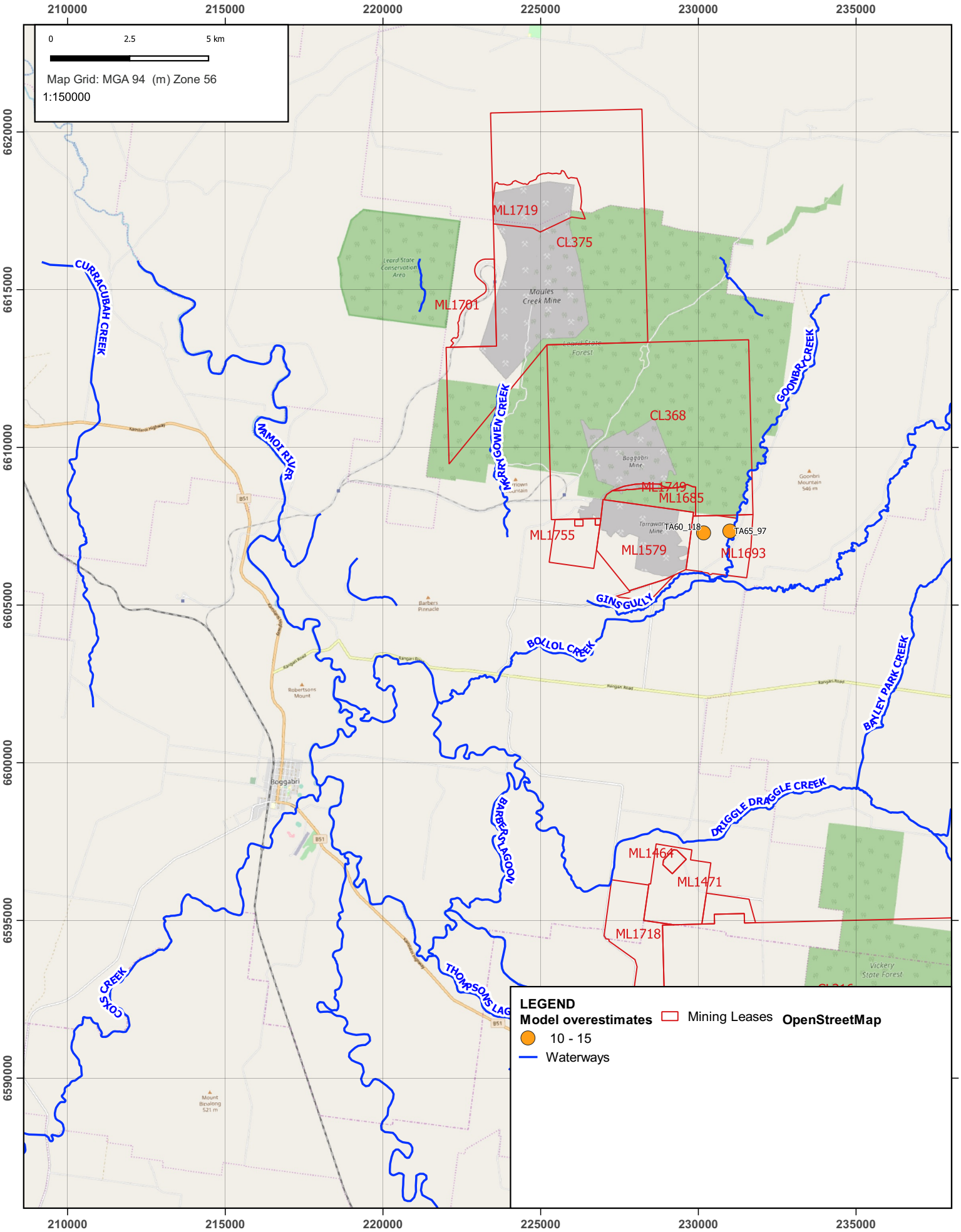


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment H - Average Residual Maps

Layer 6 - Merriown Seam to Velyama Seam

HYDRO SIMULATIONS

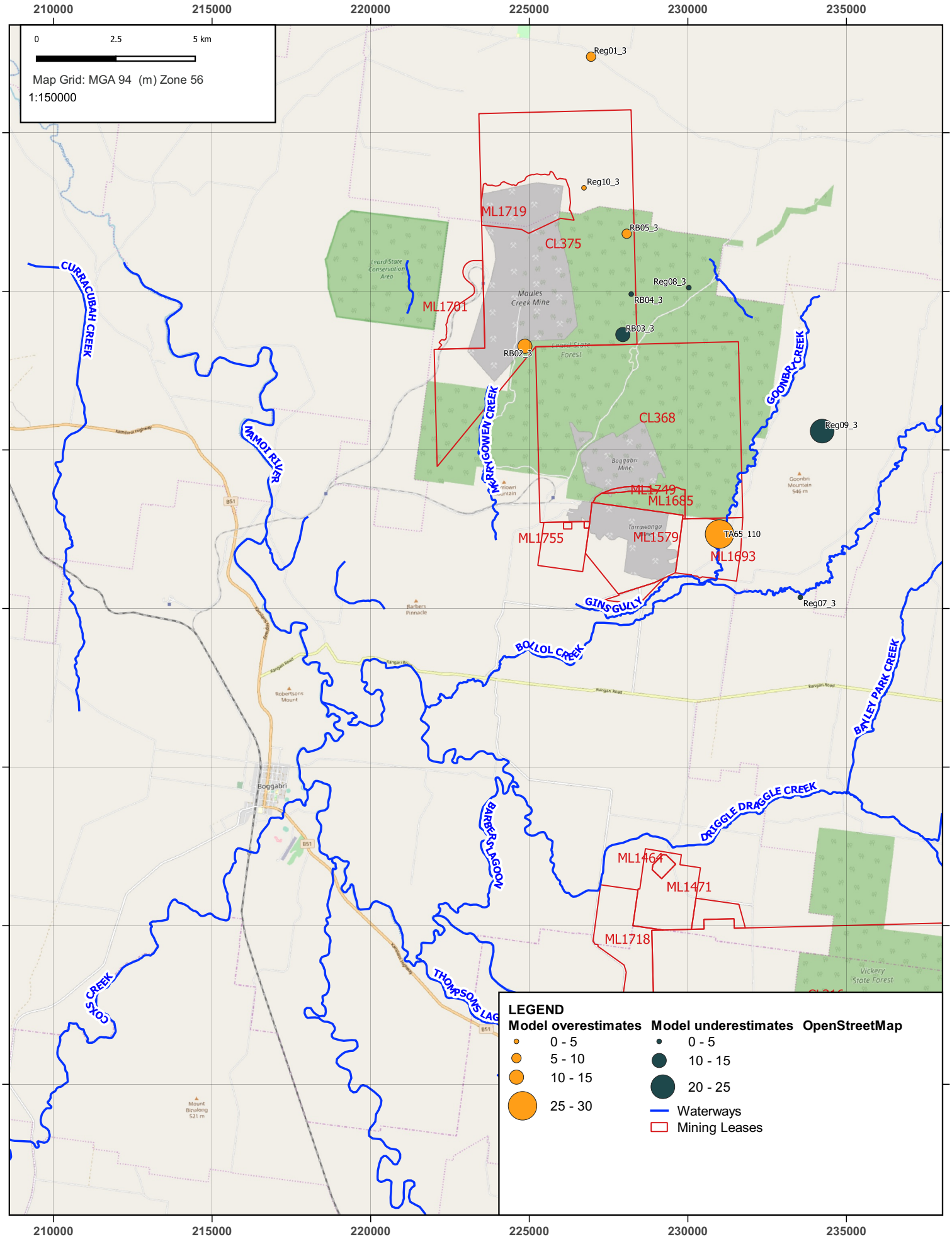


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment H - Average Residual Maps

Layer 7 - Interburden

HYDRO SIMULATIONS

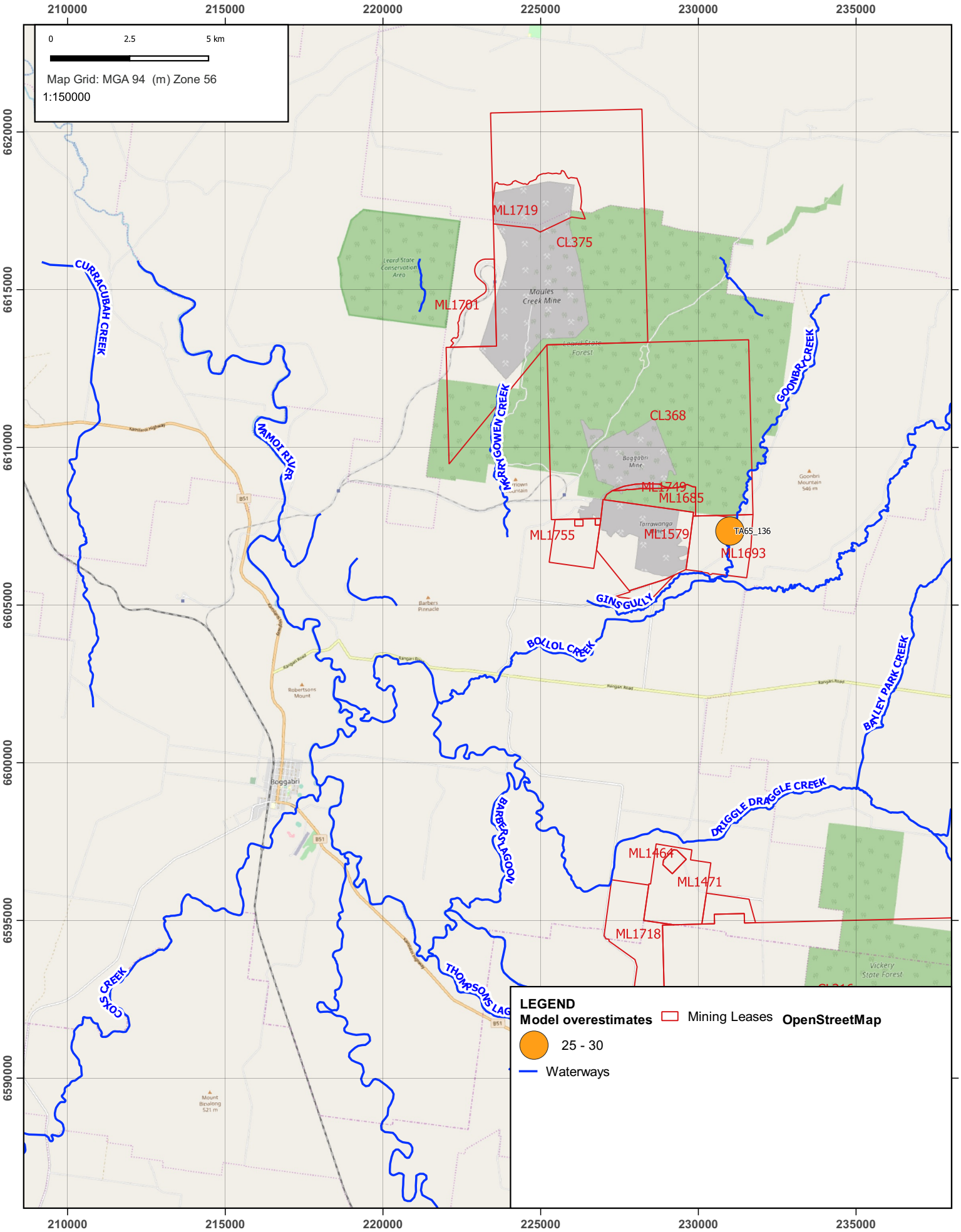


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment H - Average Residual Maps

Layer 8 - Nagero Upper Seam

HYDRO SIMULATIONS

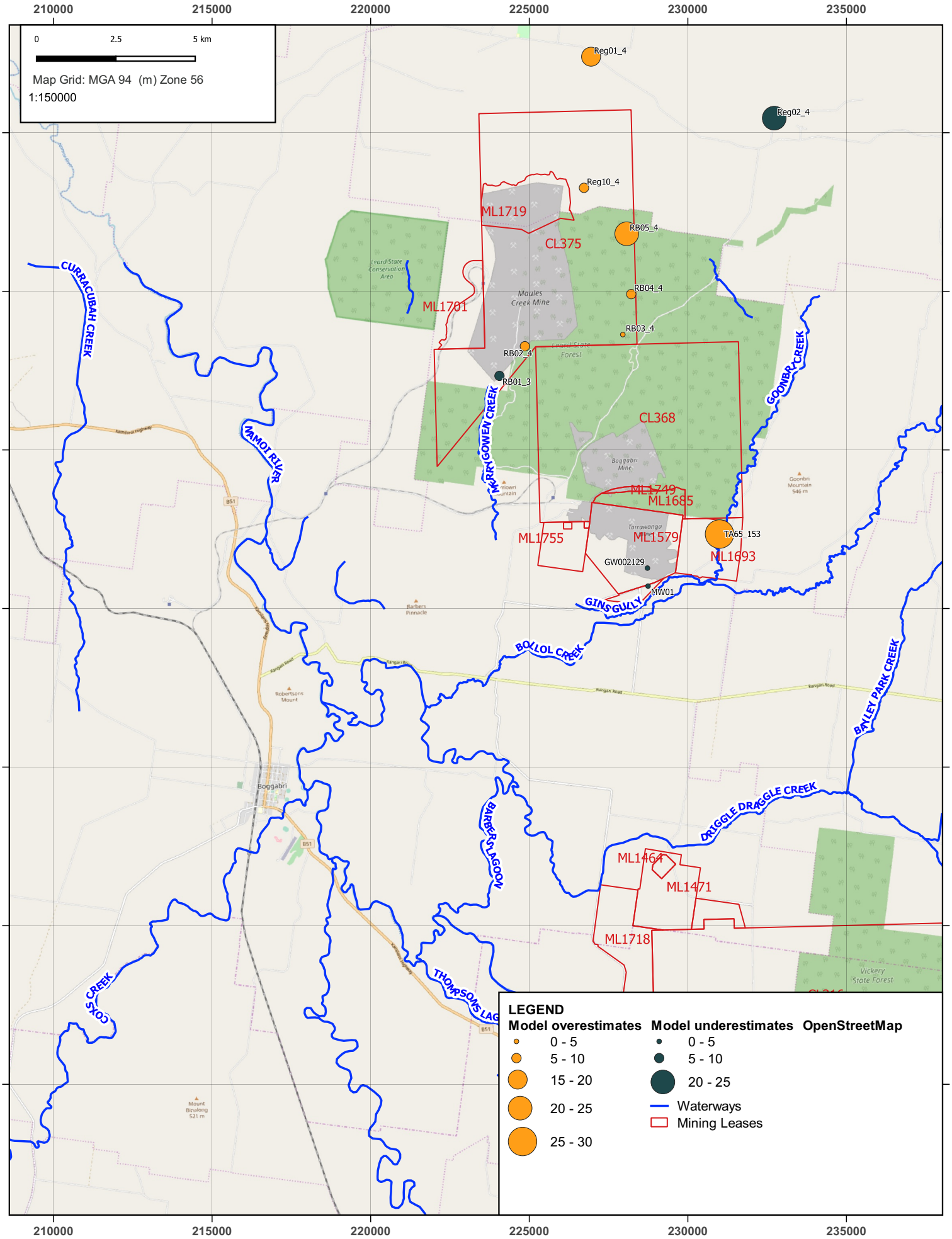


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment H - Average Residual Maps

Layer 9 - Interburden

HYDRO SIMULATIONS

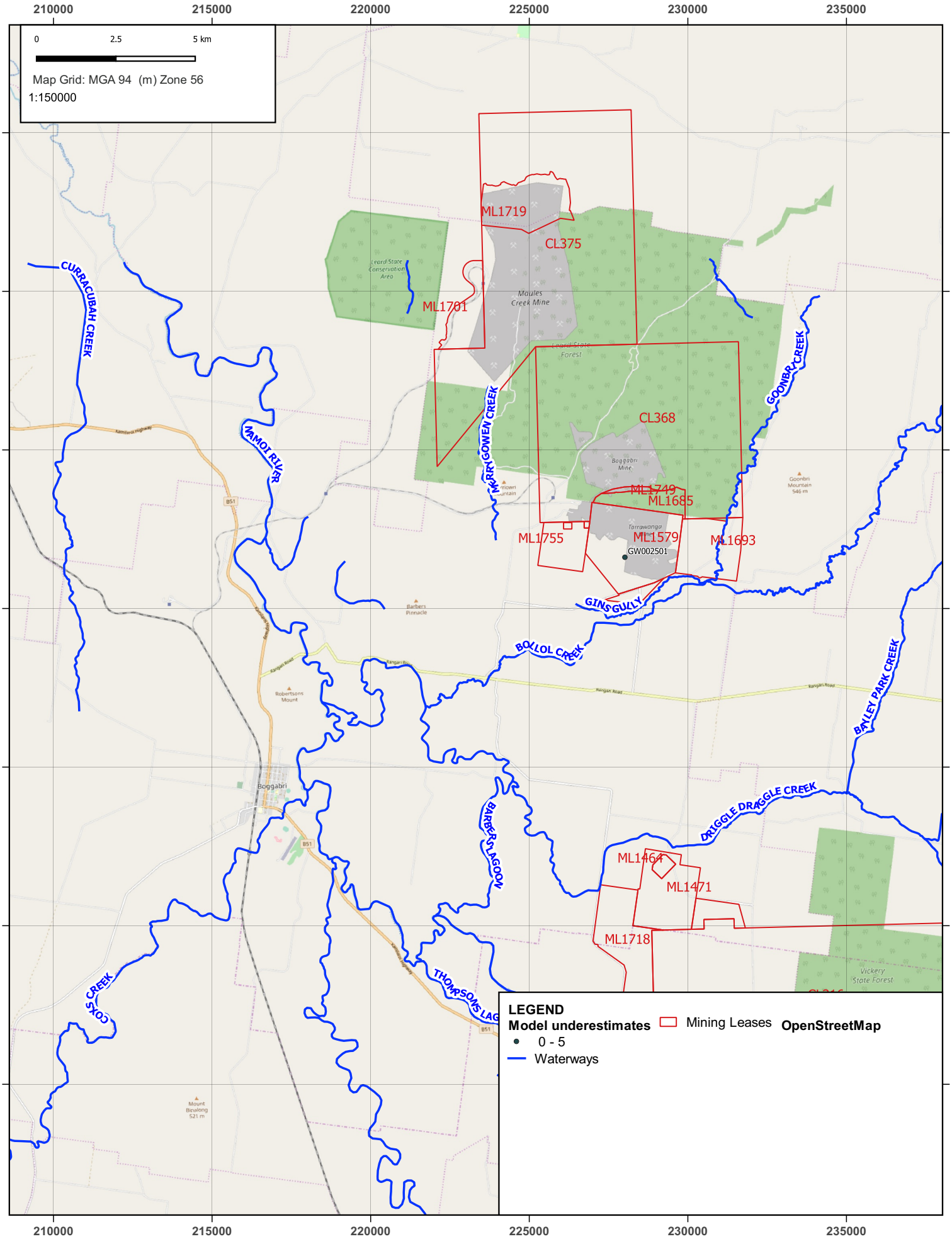


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment H - Average Residual Maps

Layer 10 - Northam Seam to Templemore Seam

HYDRO SIMULATIONS

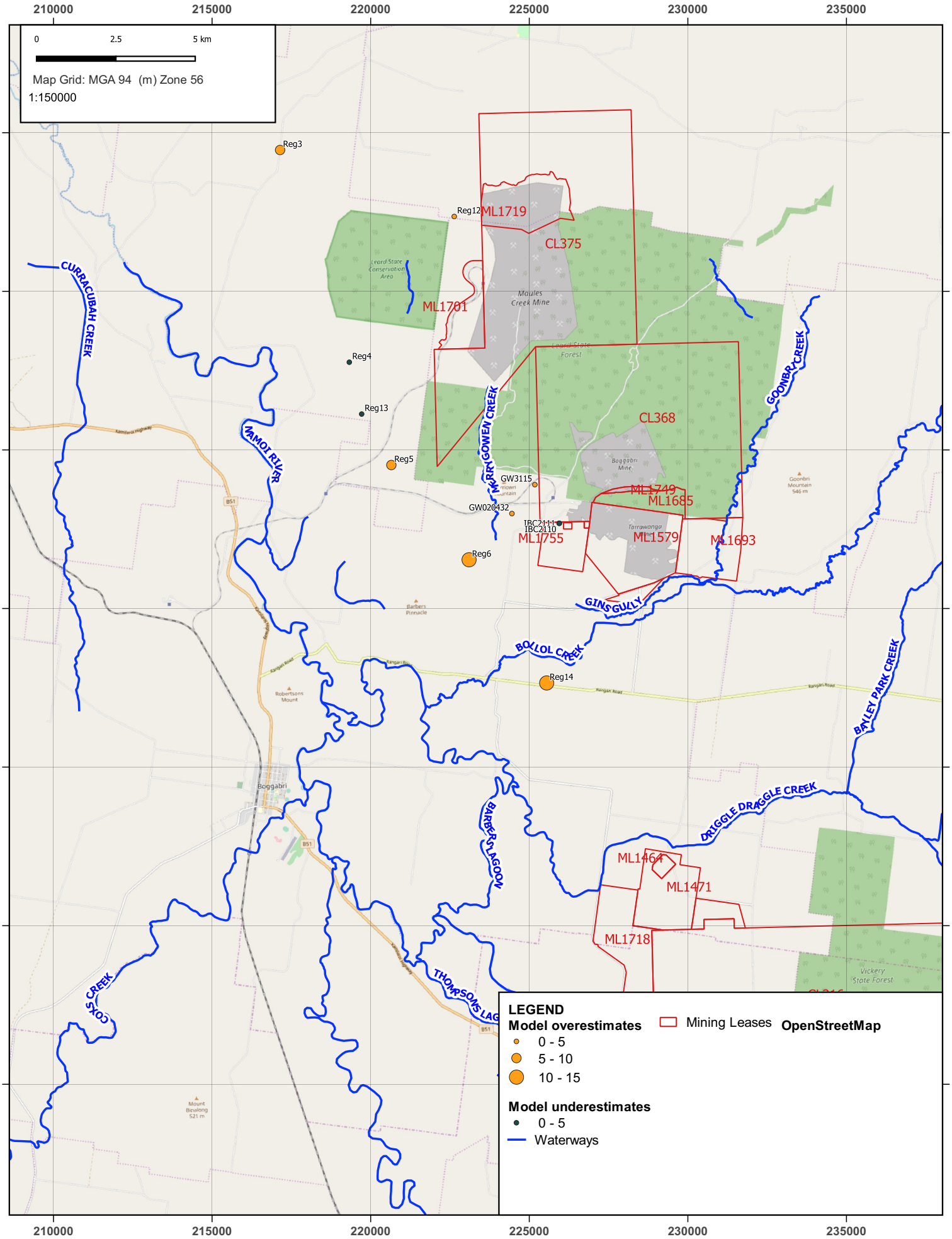


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment H - Average Residual Maps

Layer 11 - Underburden

HYDRO SIMULATIONS



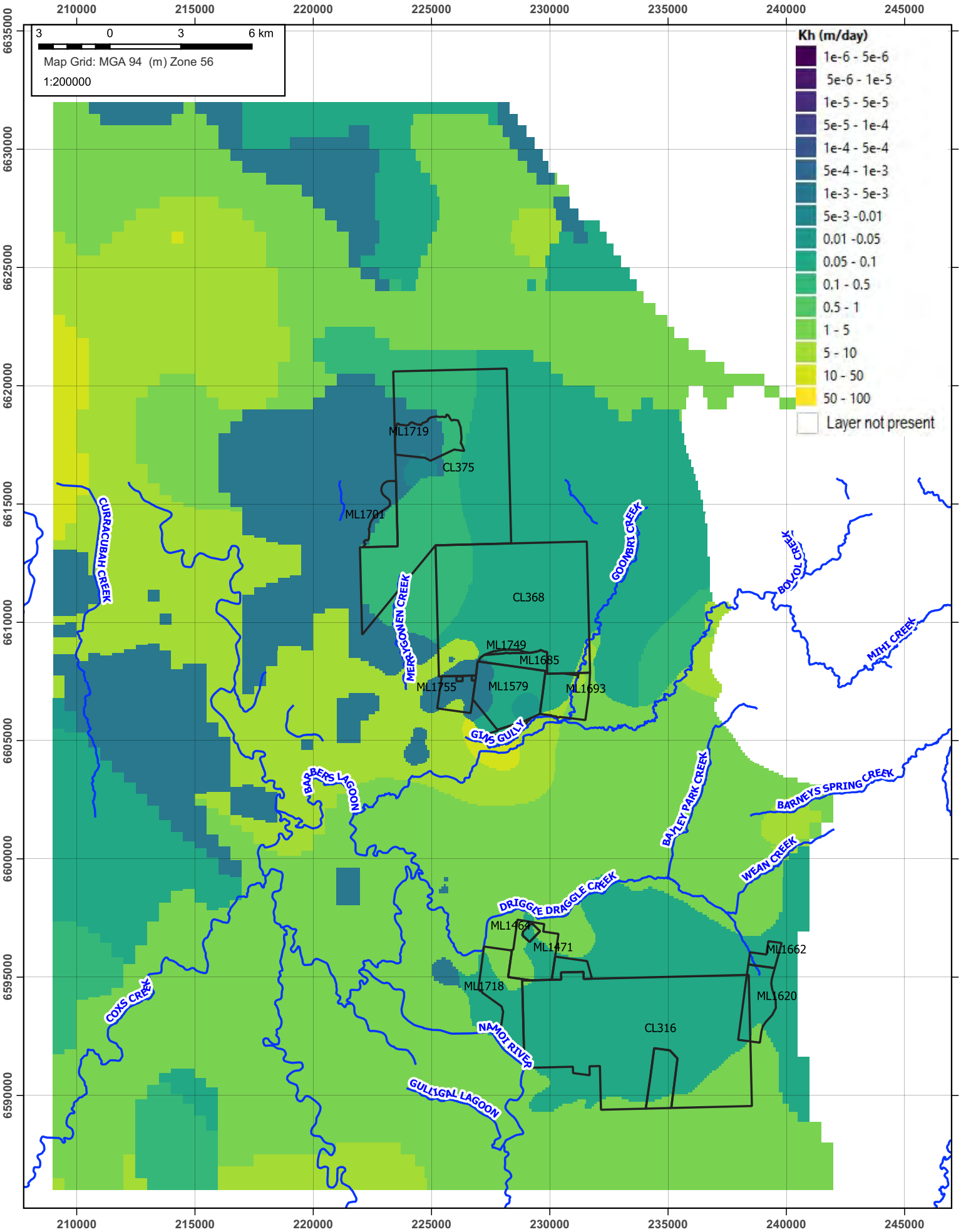
Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment H - Average Residual Maps

Layer 12 - Volcanics

HYDRO SIMULATIONS

ATTACHMENT I – CALIBRATED HYDRAULIC CONDUCTIVITIES

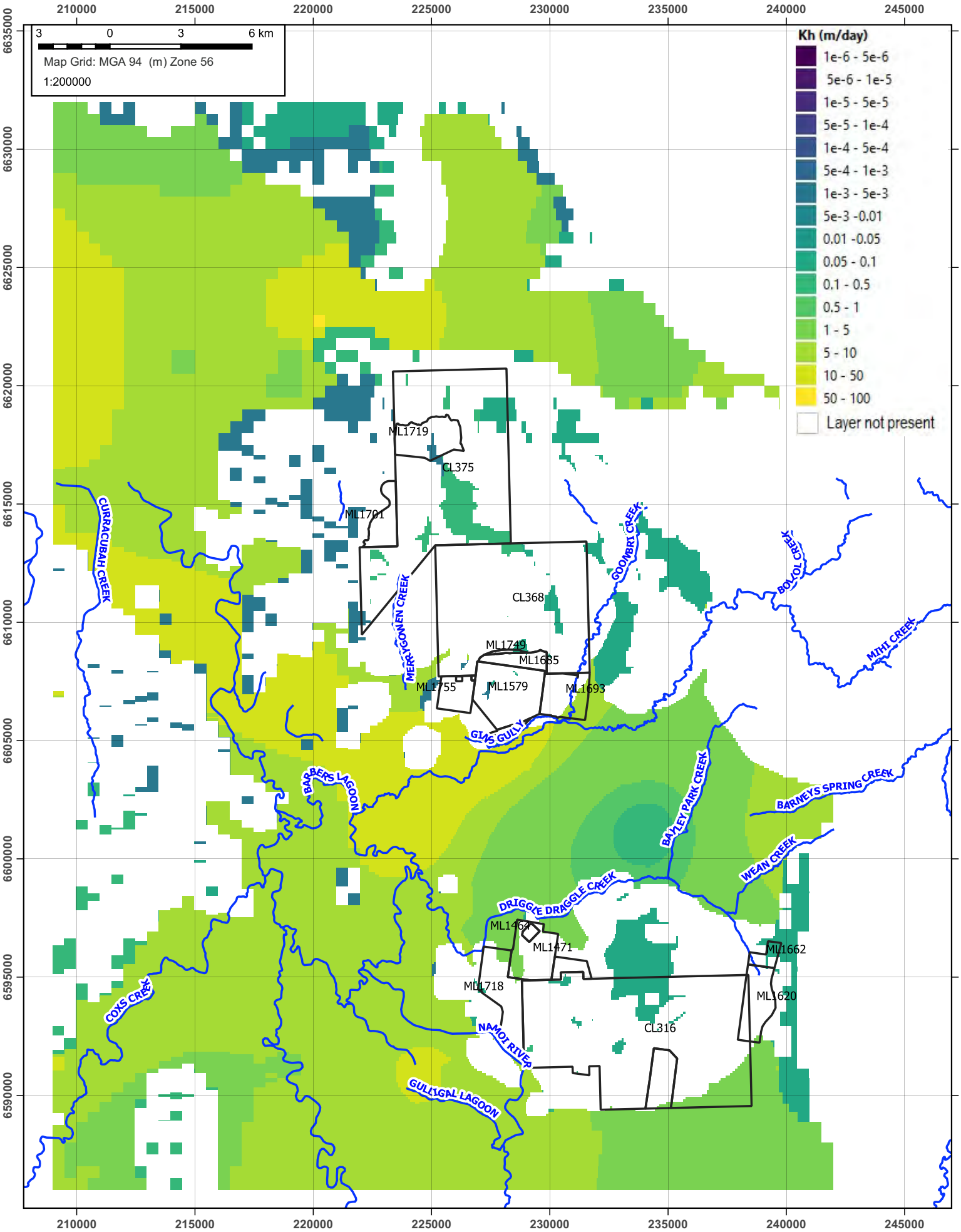


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment I - Horizontal hydraulic conductivity

Layer 1 - Alluvium

C:\Users\iepari\Downloads\WHI 015 Tarrawonga\GIS\location.qgz

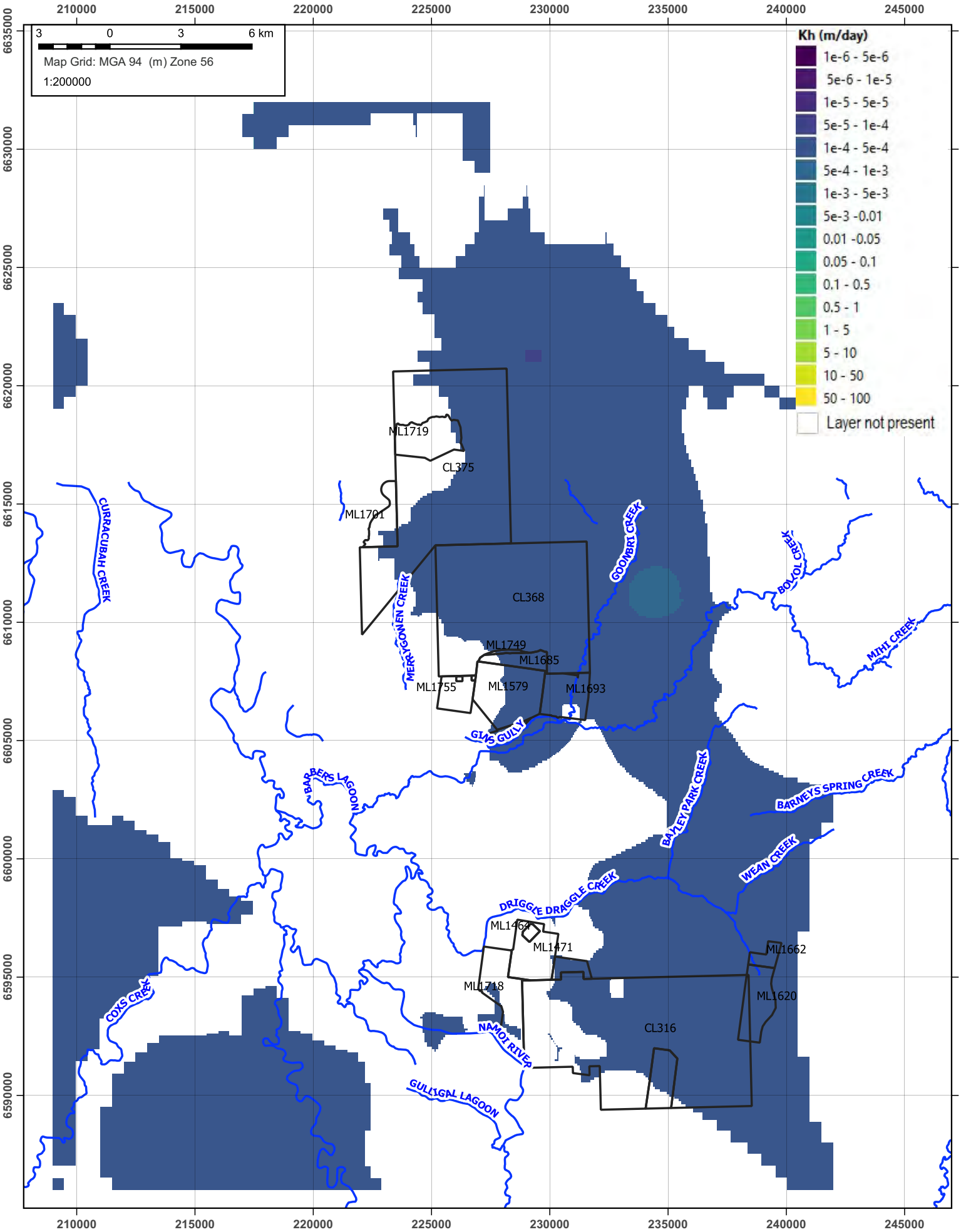


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment I - Horizontal hydraulic conductivity

Layer 2 - Alluvium

C:\Users\iepari\Downloads\WHI 015 Tarrawonga\GIS\location.qgz

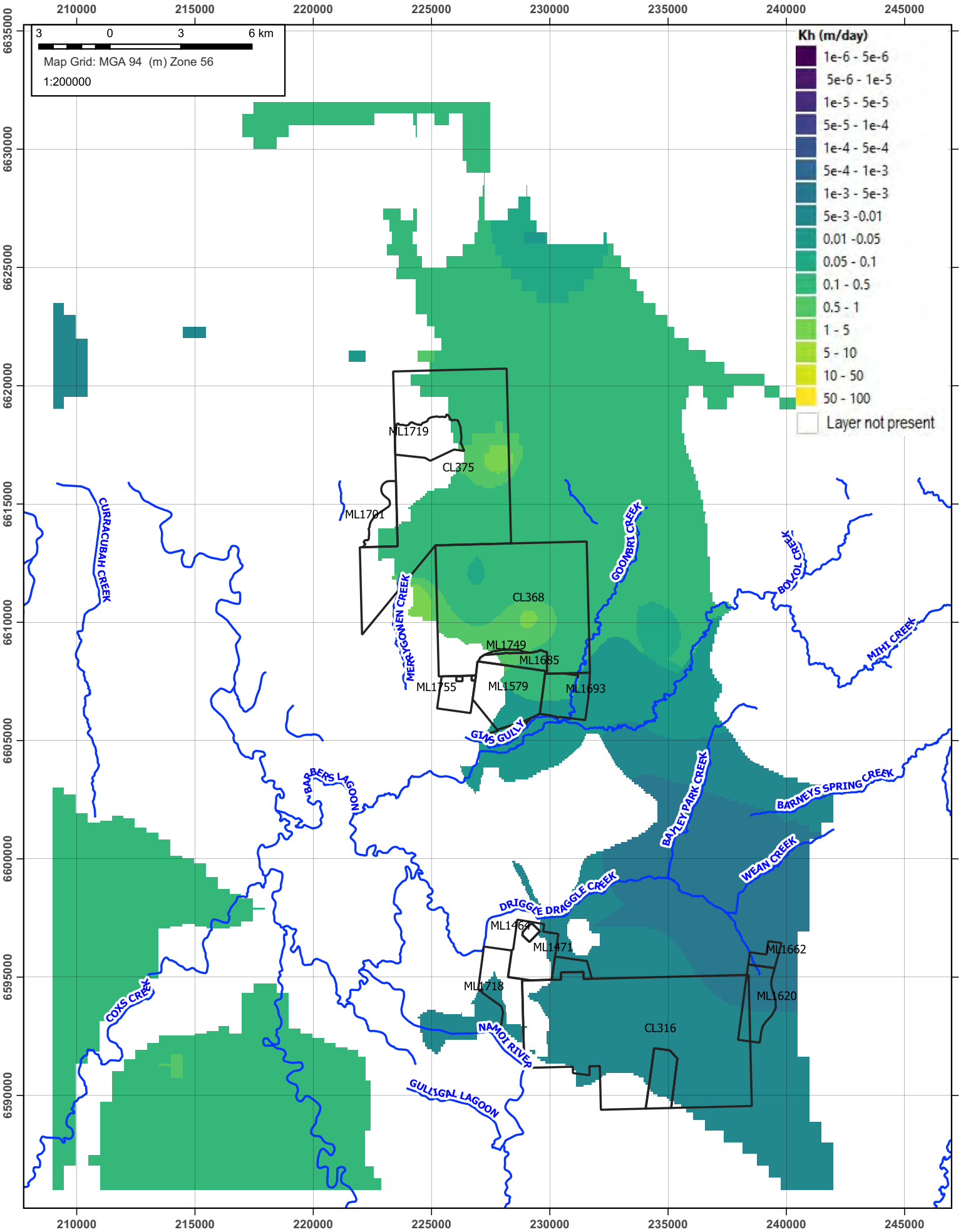


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment I - Horizontal hydraulic conductivity

Layer 3 - Overburden

C:\Users\iepari\Downloads\WHI 015 Tarrawonga\GIS\location.qgz

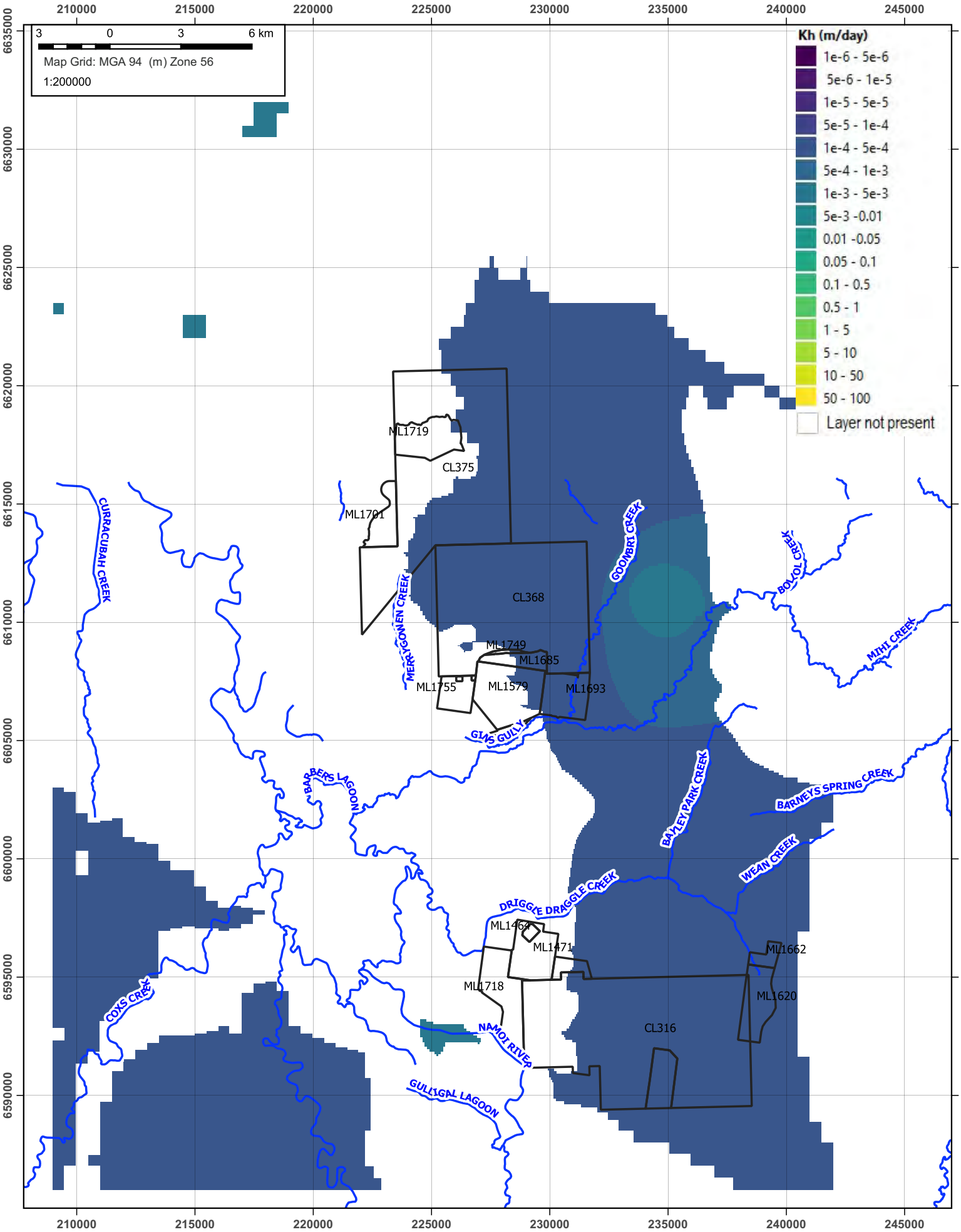


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment I - Horizontal hydraulic conductivity

Layer 4 - Braymont Seam to Jeralong Seam

C:\Users\iepari\Downloads\WHI 015 Tarrawonga\GIS\location.qgz

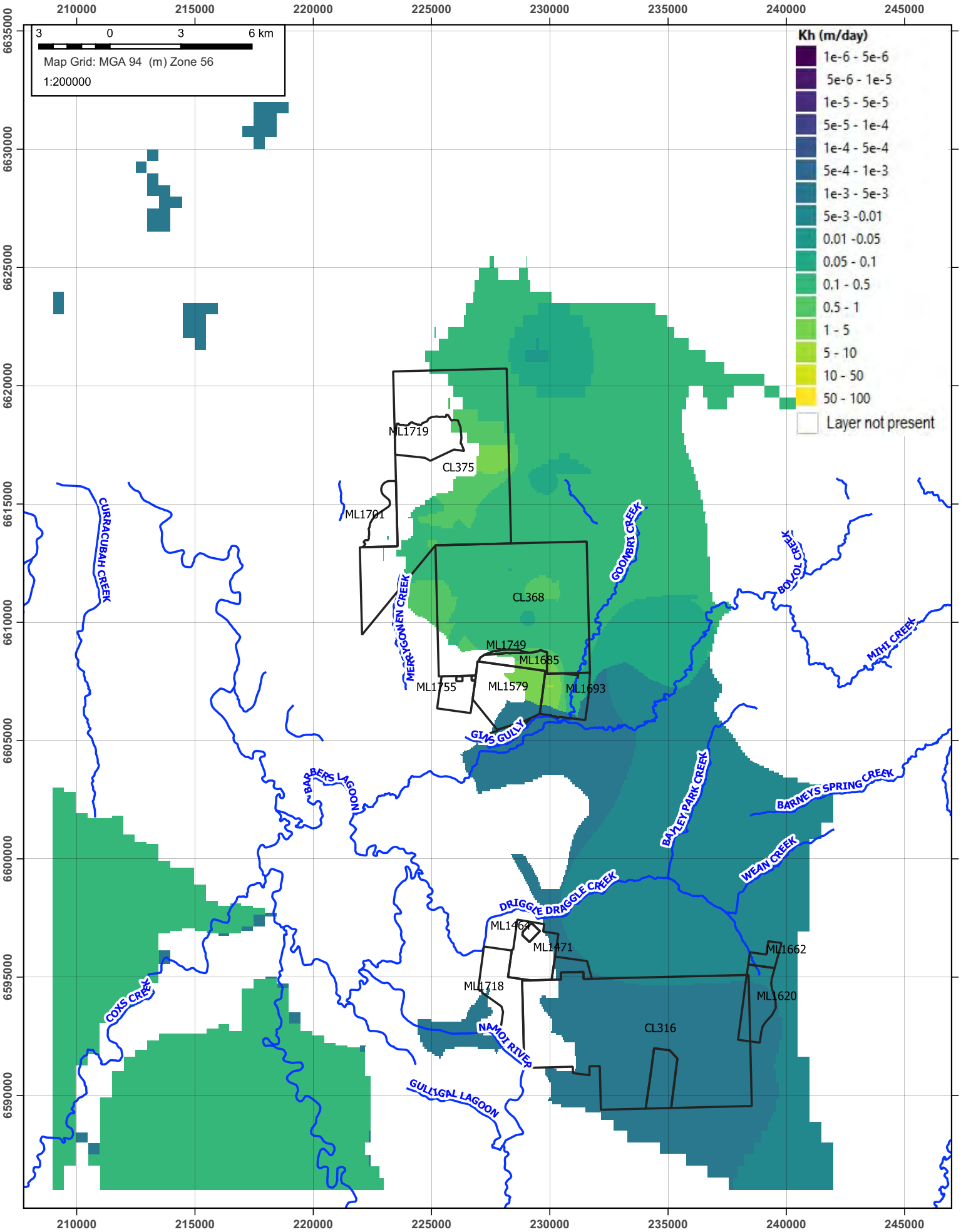


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment I - Horizontal hydraulic conductivity

Layer 5 - Interburden

C:\Users\iepari\Downloads\WHI 015 Tarrawonga\GIS\location.qgz

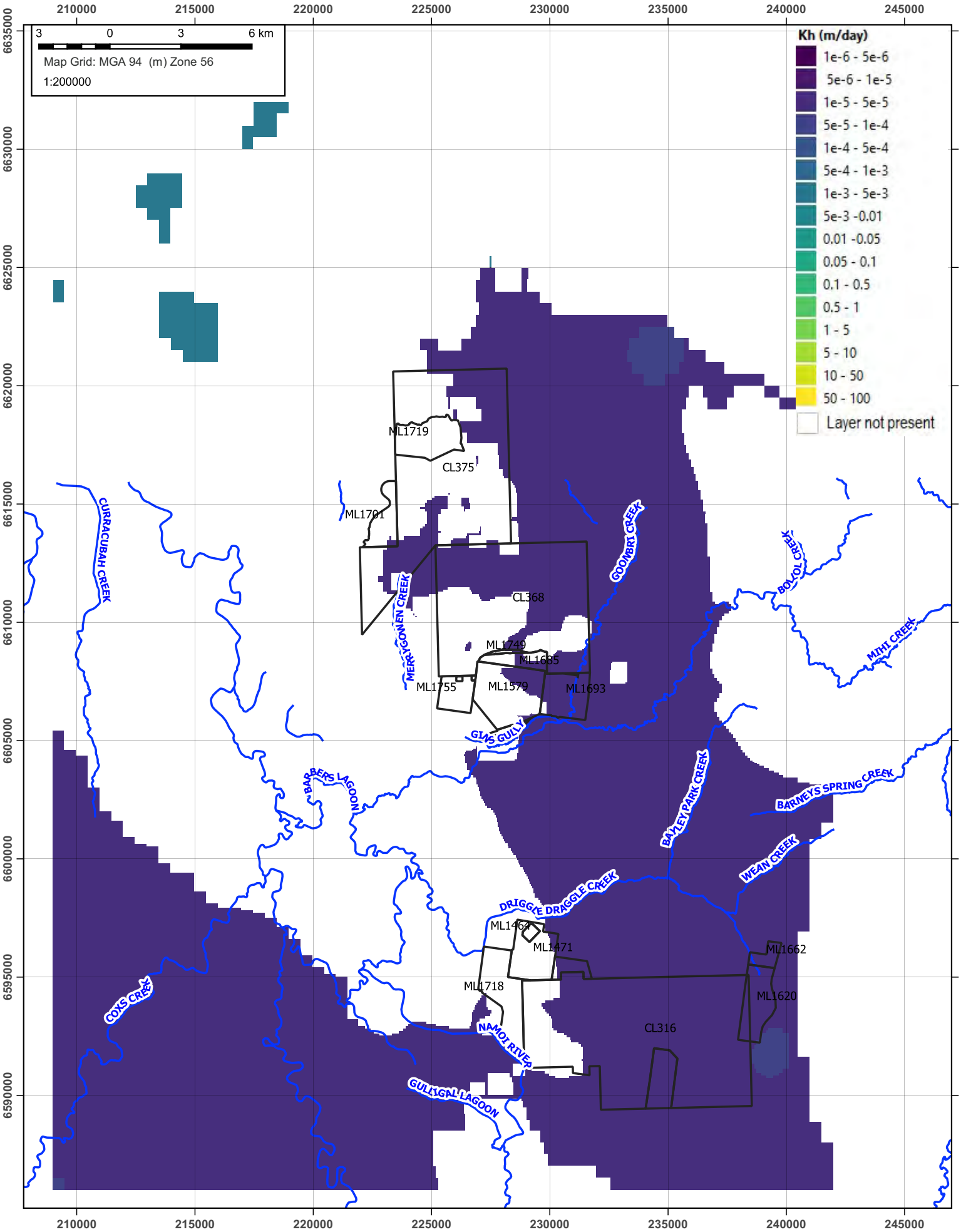


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment I - Horizontal hydraulic conductivity

Layer 6 - Merriown Seam to Velyama Seam

C:\Users\iepari\Downloads\WHI 015 Tarrawonga\GIS\location.qgz

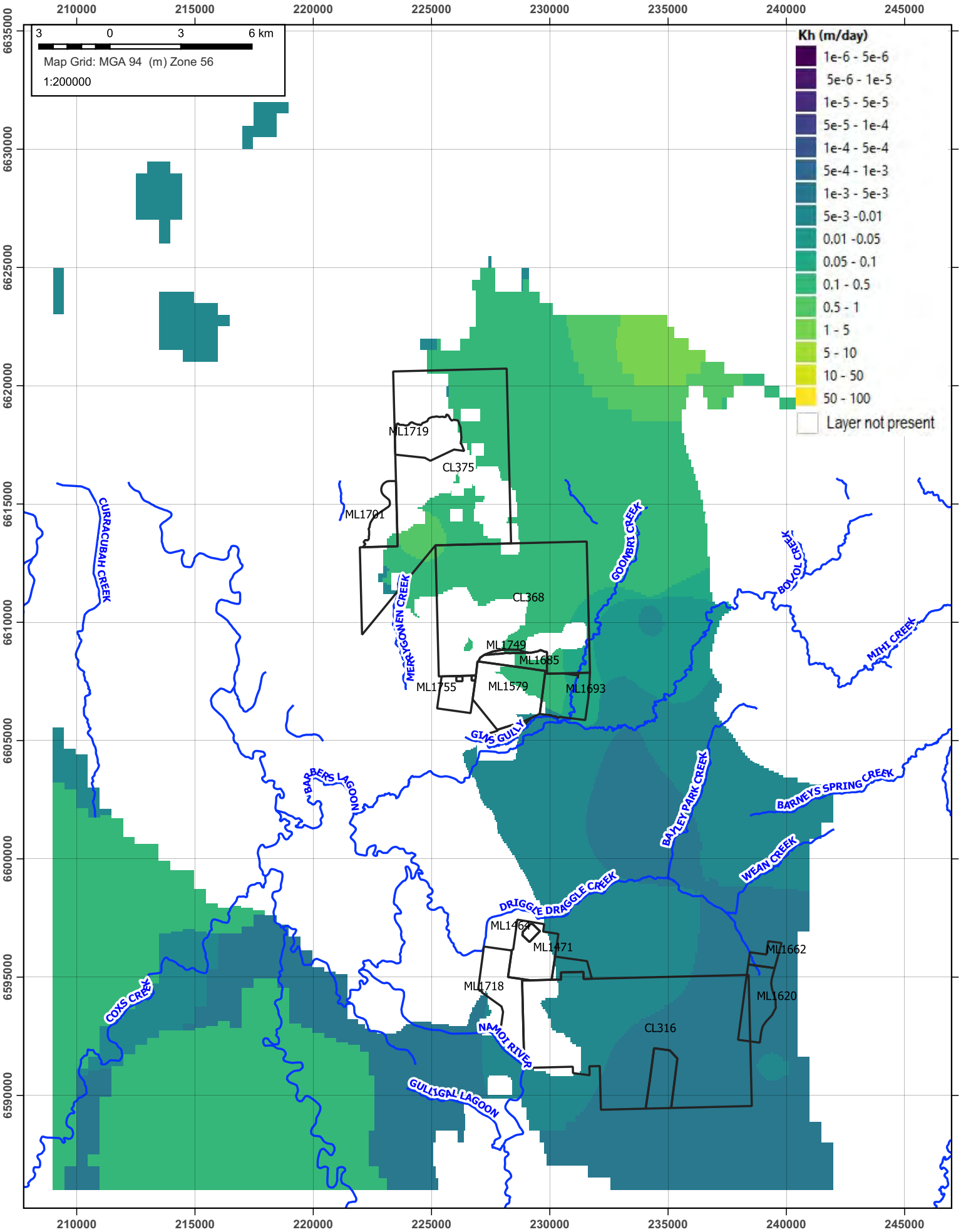


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment I - Horizontal hydraulic conductivity

Layer 7 - Interburden

C:\Users\iepari\Downloads\WHI 015 Tarrawonga\GIS\location.qgz

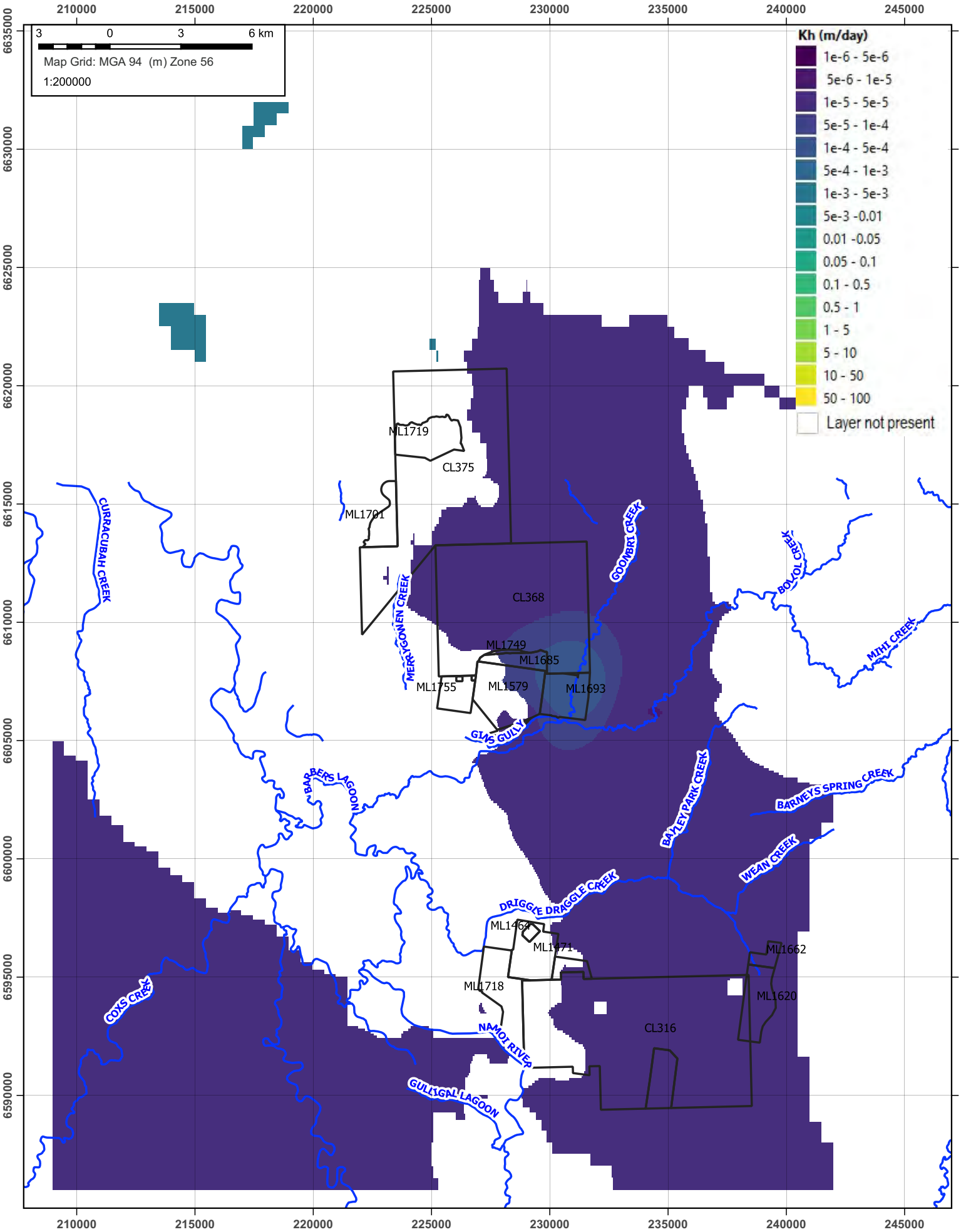


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment I - Horizontal hydraulic conductivity

Layer 8 - Nagero Upper Seam

C:\Users\iepari\Downloads\WHI 015 Tarrawonga\GIS\location.qgz



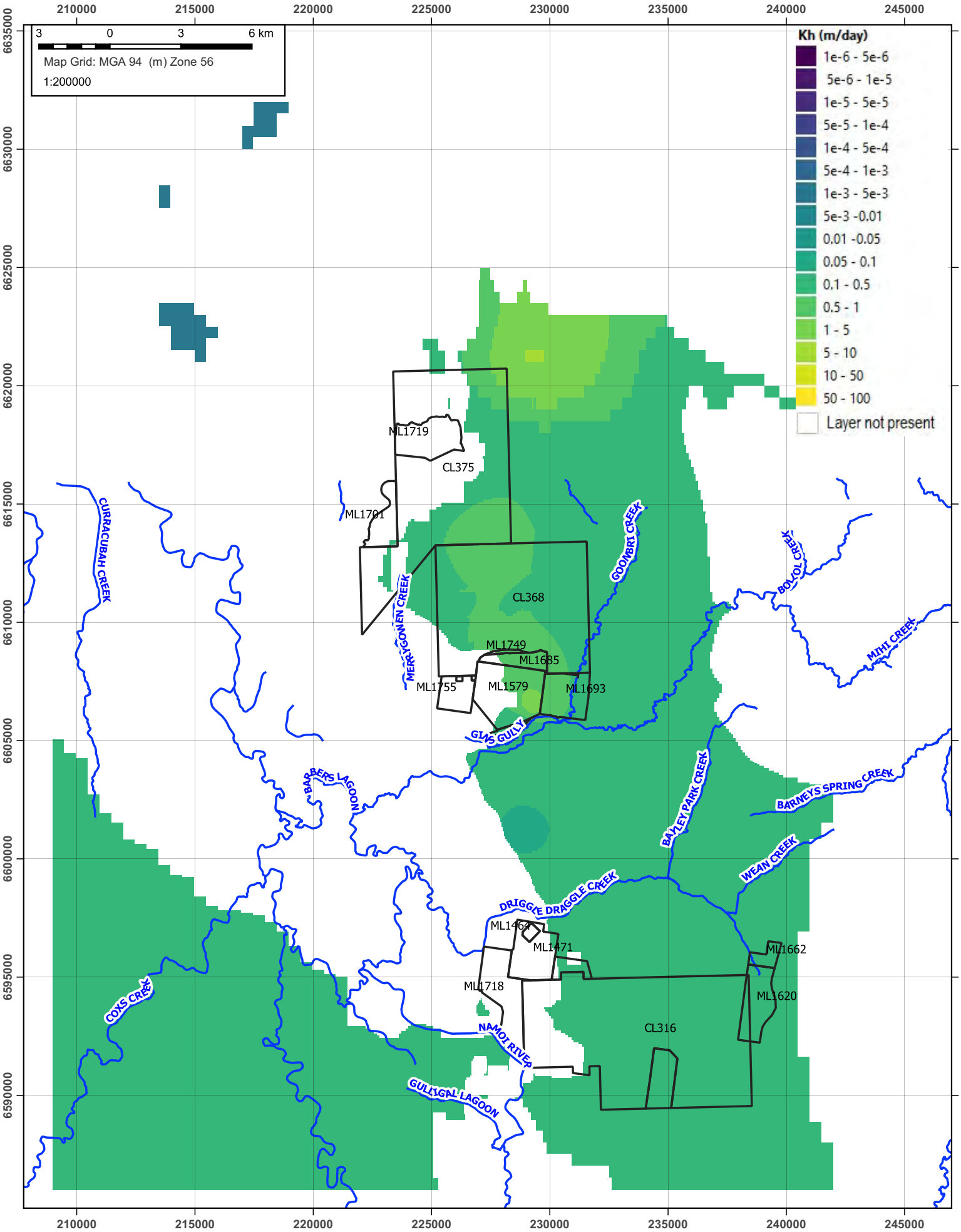
HYDRO SIMULATIONS

Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment I - Horizontal hydraulic conductivity

Layer 9 - Interburden

C:\Users\iepari\Downloads\WHI 015 Tarrawonga\GIS\location.qgz

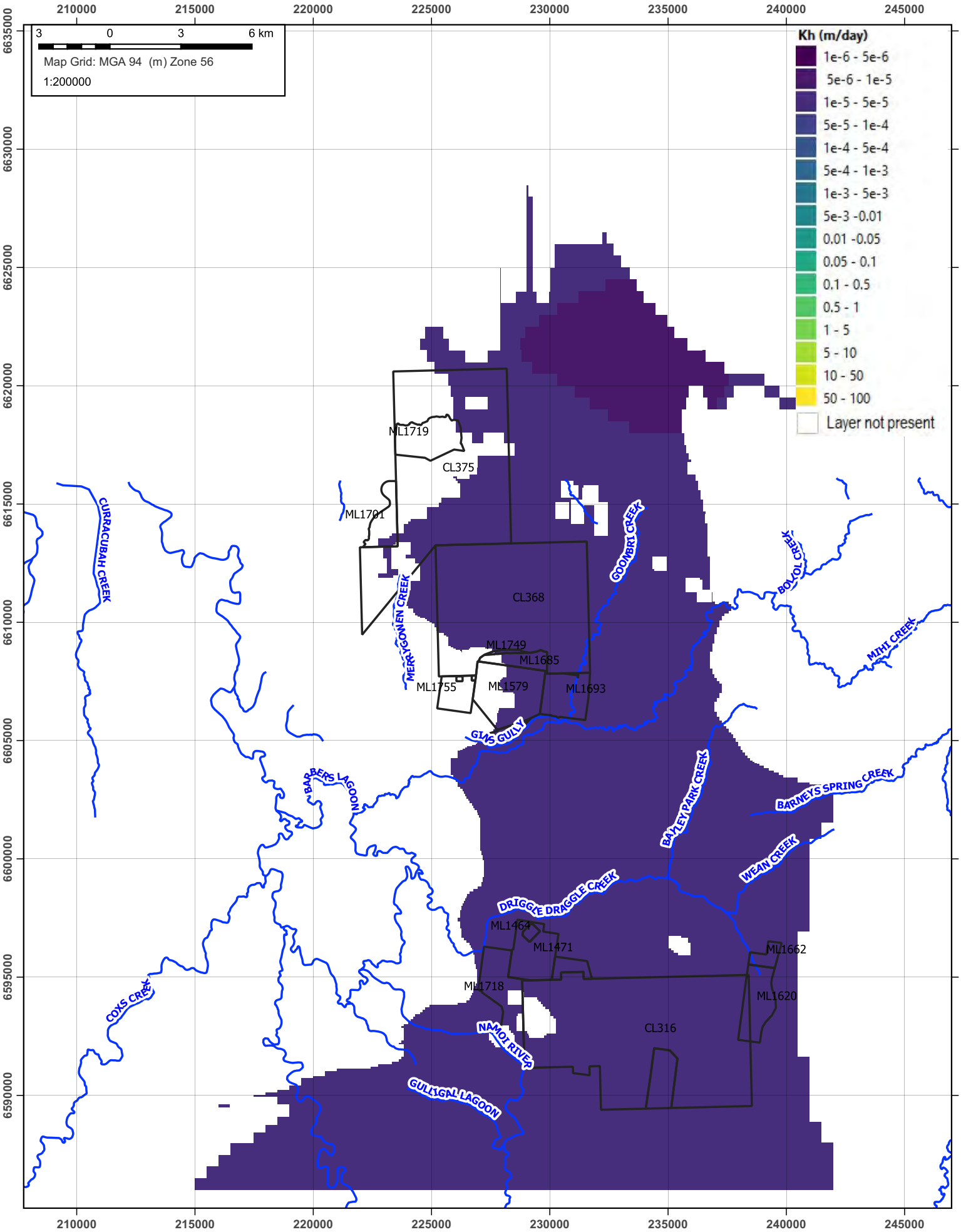


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment I - Horizontal hydraulic conductivity

Layer 10 - Northam Seam to Templemore Seam

C:\Users\iepari\Downloads\WHI 015 Tarrawonga\GIS\location.qgz

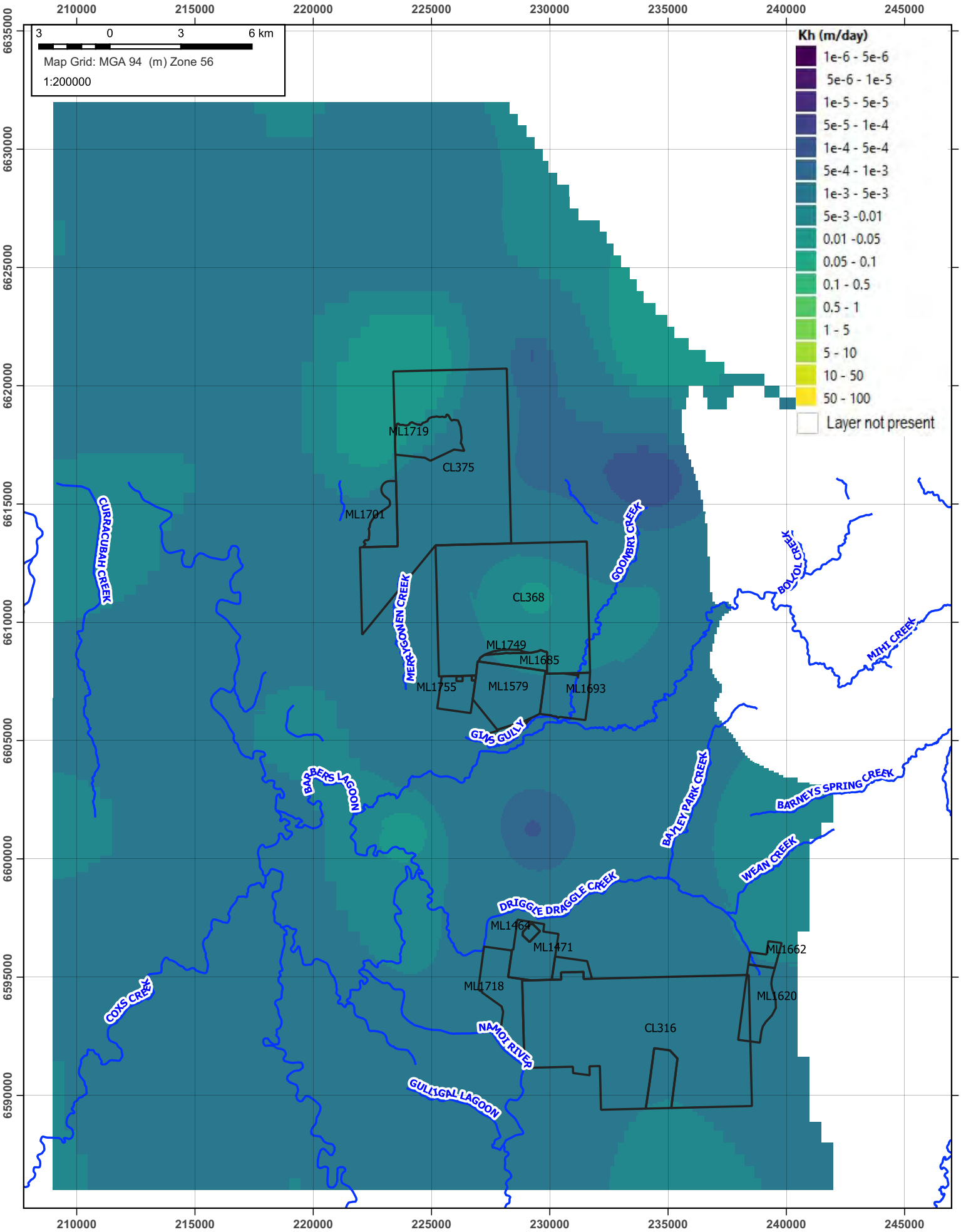


Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment I - Horizontal hydraulic conductivity

Layer 11 - Underburden

C:\Users\iepari\Downloads\WHI 015 Tarrawonga\GIS\location.qgz



HYDRO SIMULATIONS

Tarrawonga Coal Mine Life of Mine Modification - Groundwater Assessment

Attachment I - Horizontal hydraulic conductivity

Layer 12 - Volcanics

C:\Users\iepari\Downloads\WHI 015 Tarrawonga\GIS\location.qgz

ATTACHMENT J – SLR, 2019: ALLUVIAL BOUNDARY ASSESSMENT, TARRAWONGA COAL MINE

global environmental solutions

Alluvial Boundary Assessment

Tarrawonga Coal Mine

Report Number 634.10042

July 2019

Whitehaven Coal Limited

Version: Final

Alluvial Boundary Assessment

Tarrawonga Coal Mine

PREPARED BY:

SLR Consulting Australia Pty Ltd
ABN 29 001 584 612
www.slrconsulting.com

This report has been prepared by SLR Consulting Australia Pty Ltd
with all reasonable skill, care and diligence, and taking account of the
timescale and resources allocated to it by agreement with the Client.
Information reported herein is based on the interpretation of data collected,
which has been accepted in good faith as being accurate and valid.

This report is for the exclusive use of Whitehaven Coal Limited.
No warranties or guarantees are expressed or should be inferred by any third parties.
This report may not be relied upon by other parties without written consent from SLR.

SLR disclaims any responsibility to the Client and others
in respect of any matters outside the agreed scope of the work.

DOCUMENT CONTROL

Reference	Status	Date	Prepared	Checked	Authorised
634.10042	Draft	September 2015	Clayton Richards	Murray Fraser	
634.10042	Final	July 2019	Murray Fraser	Rod Masters	Rod Masters

Table of Contents

1 INTRODUCTION 5

2 ALLUVIAL BOUNDARY DEFINITION METHODOLOGY 5

2.1 Field Survey Type 5

2.2 Survey Observation Types 6

2.3 Methodology 9

3 SOIL SURVEY RESULTS 10

3.1 Alluvial Soil Desktop Assessment 10

3.2 Alluvial Soil Field Assessment 16

3.2.1 Stage 1 16

3.2.2 Stage 2 16

4 DISCUSSION AND CONCLUSION 43

4.1 Alluvial Soil Boundary Discussion 43

4.2 Alluvial Boundary Conclusion 43

5 REFERENCES 45

TABLES

Table 1 Soil Landscape Information 15

FIGURES

Figure 1 Project Locality 7

Figure 2 Study Areas 8

Figure 3 Alluvial Boundary Ground Truthing 17

Figure 4 Alluvial Boundary 44

Table of Contents

PHOTOS

Photo 1	Tarrawonga Study Area 2010	11
Photo 2	Tarrawonga Study Area 2011	11
Photo 3	Tarrawonga Study Area 2013	12
Photo 4	Tarrawonga Study Area 2014	12
Photo 5	Tarrawonga Study Area 2015	13
Photo 6	Tarrawonga Study Area 2017	13
Photo 7	Tarrawonga Study Area 2018	14
Photo 8	Extract from Figure 5 Soil Landscapes Mapping in Tarrawonga Coal Project – Agricultural Resource and Productivity Assessment by McKenzie (2011)	15
Photo 9	Western Alluvial Boundary at start of colluvial slope (southern aspect)	35
Photo 10	Creek line bank defines western alluvial boundary (southern aspect)	36
Photo 11	Exposed colluvial material defines western alluvial boundary (southern aspect)	36
Photo 12	Exposed colluvial material defines western alluvial boundary (southern aspect)	37
Photo 13	Creek line lies adjacent to western alluvial boundary with gradual slope to the west (southern aspect)	37
Photo 14	Alluvial Boundary at start of colluvial slope (western aspect)	38
Photo 15	Alluvial Boundary at start of colluvial slope (northern aspect)	38

APPENDICES

Appendix A	Alluvial Boundary Ground Truthing Figures
Appendix B	Laboratory Certificates of Analysis

1 INTRODUCTION

SLR Consulting (SLR) was commissioned by Tarrawonga Coal Pty Ltd (TCPL) to undertake an Alluvial Soil Boundary Assessment for the Tarrawonga Coal Mine. The Tarrawonga Coal Mine is owned and operated by TCPL, a wholly owned subsidiary of Whitehaven Coal Limited (Whitehaven). The Tarrawonga Coal Mine is located approximately 16 km north-east of Boggabri in New South Wales as shown on **Figure 1**. The Study Area lies to the east of current operations at the Tarrawonga Coal Mine and within Mining Lease 1693.

The key objective of this study was to map the Alluvial Soils boundary by classifying and determining the extent of Alluvial Soil within the Study Area. The assessment was undertaken in two stages. Stage 1 of the project was completed in 2015 and Stage 2 of the project was completed in 2018, extending the Study Area further upstream and downstream of the Stage 1 Study Area.

2 ALLUVIAL BOUNDARY DEFINITION METHODOLOGY

2.1 Field Survey Type

For this assessment, Alluvial Soils are defined as soils derived from alluvial flows from Goonbri Creek and Gins Gully. Generally, alluvial soils are defined as soils formed by recent deposition along rivers and streams, normally characterised by little or no modification of the deposited material by soil forming processes, particularly with respect to soil horizon development (Charman & Murphy, 2007). However, a combination of clays subsoils and cultivated topsoils has resulted in some profile development within alluvial soils. Recent deposition refers to alluvium that has been deposited within the last 5,000 – 10,000 years.

SLR undertook a qualitative field survey along eleven defined transects to confirm the alluvial boundary. Seven transects were taken during the initial Stage 1 assessment with a further four undertaken as part of the Stage 2 assessment. Transects were located approximately 100-250 metres (m) apart along the alluvial boundary mapped in *Appendix I – Agricultural Resources of the Tarrawonga Coal Project EA* (**Figure 1**). Soil cores and small investigative pits were used along transect lines to determine soil type and assess the soil material and development in order to delineate alluvial or non-alluvial status. Mapping observations or check sites were used to confirm the alluvial boundary between transect lines.

2.2 Survey Observation Types

There are three types of observations utilised for this Soil Survey:

- **Detailed Sites**: Field observation sites that allows for the identification of any physiographic factors or vegetation associations that characterise the site and associated map unit, the major pedological and structural features of the soil that are of relevance to classification are recorded.
- **Analysed Sites**: Detailed Sites from which soil samples were collected and sent to a NATA accredited laboratory for chemical and or physical analyses, four sites were analysed during Stage 1: Sites 5, 9, 11 and 12, and a further 5 sites during Stage 2: Upstream Study Area: Sites 15 (A1), 18 (A2) and 17 (C2). Downstream Study Area: Sites 20 (A3) and 19 (C3).
- **Check Sites**: Field observation sites that are examined in sufficient detail to allocate the site to a specific soil type and/or alluvial/non-alluvial map unit. Commonly referred to as mapping observations. These sites were used to track the alluvial boundary between transect lines.

Scale: 1:15,000
GDA 1994 MGA Zone 56

17-Jul-2019
634.10042

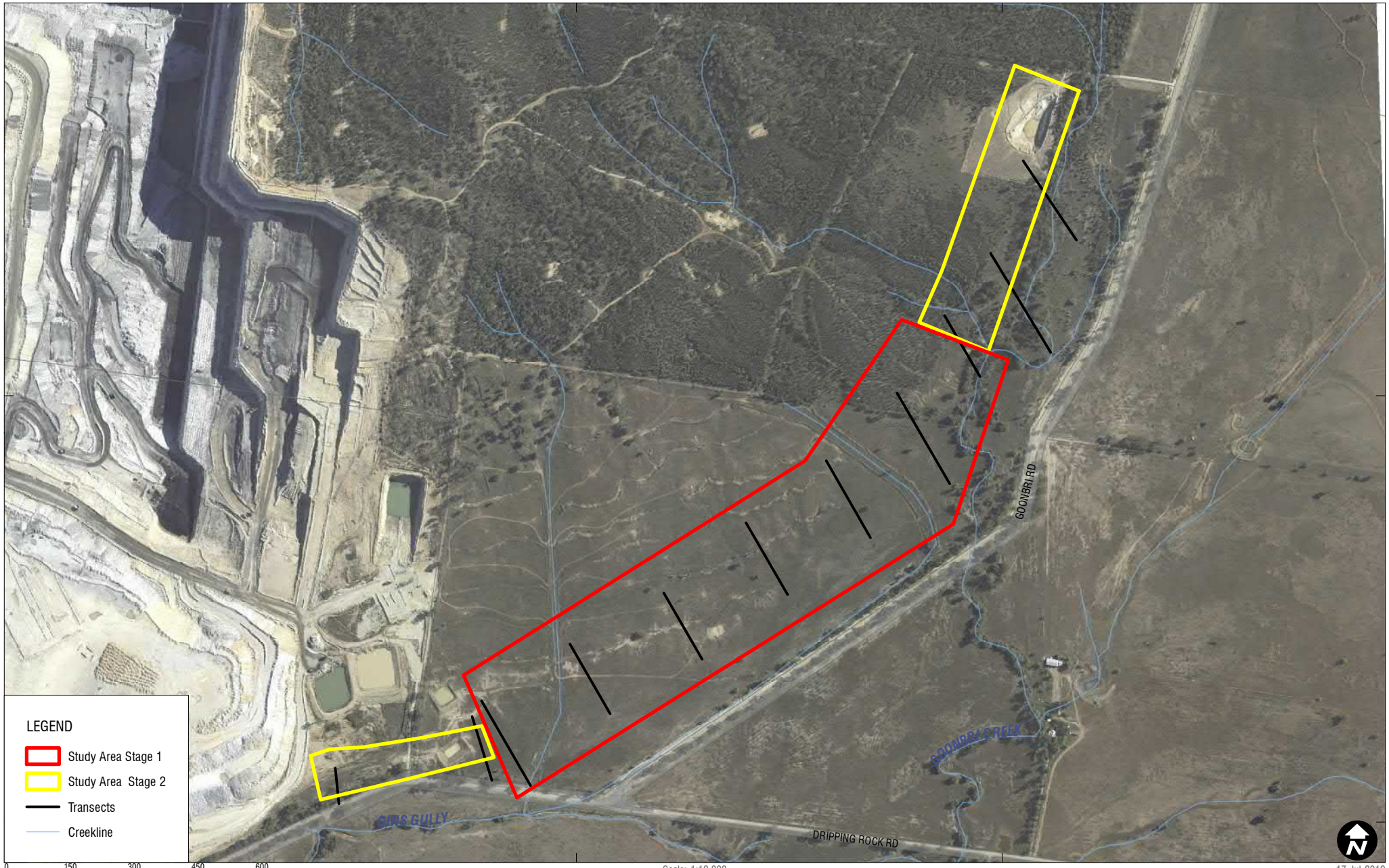
H:\Projects-SLR\610-Srv-SYD\630-NTL\634.10042 - Tarrawonga Alluvial Boundary\Figures\ArcGIS\SLR63410042_001_ProjectLocality_01.mxd

Sheet Size : A4

SLR
www.slrconsultingaustralia.com.au

Project Locality

FIGURE 1



H:\Projects-SLR\610-Srv-SYD\630-NTL\634.10042 - Tarrawonga Alluvial Boundary\Figures\ArcGIS\SLR63410042_002_StudyAreas_01.mxd

Scale: 1:12,000
GDA 1994 MGA Zone 56

17-Jul-2019
634.10042

Sheet Size : A4

SLR
www.slrconsulting.com
PH: 02 4037 3200

Study Areas

FIGURE 2

2.3 Methodology

A desktop study and field survey were undertaken in the Study Area to identify the presence and extent of alluvial soils. This process consisted of the following two stages:

Stage 1: Reference Mapping

An initial alluvial soil map (reference map) was developed using the following resources and techniques:

- Satellite imagery and topographic maps:

Satellite imagery and topographic map interpretation was used as remote sensing tools allowing detailed analysis of the landscape and mapping of features expected to be related to the distribution of alluvial soils within the Study Area. Historical imagery from Google Earth was used to gain an appreciation of vegetation differences over various seasons and periods of wet and dry years.

- Reference information and previous reports:

Source materials were used to obtain correlations between pattern elements and soil properties that may be observable in the field. These materials included cadastral data, prior and current physiographic, geological, vegetation, and water resources studies.

Soil Landscapes of the Boggabri 1:100,000 Sheet (Banks & King, 2004);

This reference delineates the alluvial Driggle Draggle soil landscape from the adjoining residual Tally Ho soil landscape upslope to the North West. The Boggabri soil landscape report essentially defined the boundary of the Alluvial Soil on a broad scale. However further work along the boundary was required to define the boundary at a higher accuracy.

Stage 2: Field Survey

Two field surveys have been undertaken by SLR. The Stage 1 field survey was undertaken in July 2015, and the Stage 2 field survey in December 2018. Background reference information derived from sources as cited above were used to predict the distribution of Alluvial Soils in the field. The characteristics evaluated to generate the correlated sets include vegetation type, landform, topography and geology. Four profiles from the 2015 survey and five profiles from the 2018 survey were selected as representative sites for laboratory analysis; comprising six alluvial sites and three non-alluvial sites.

The specific type of integrated survey undertaken was a ‘transect survey’. Eleven transects were selected. These transects were positioned along the general alluvial boundary derived from the desktop assessment, in areas where proposed mining activities may encroach alluvial soils. Alluvial boundaries can be abrupt or gradual, with catena and toposequences used to aid the description of gradual or sudden variation.

3 SOIL SURVEY RESULTS

3.1 Alluvial Soil Desktop Assessment

The following photos show satellite images of the Study area from 2010 to 2018.

Photo 1 Tarrawonga Study Area 2010

Photo 2 Tarrawonga Study Area 2011

Photo 3 Tarrawonga Study Area 2013

Photo 4 Tarrawonga Study Area 2014

Photo 5 Tarrawonga Study Area 2015

Photo 6 Tarrawonga Study Area 2017

Photo 7 Tarrawonga Study Area 2018

The soil landscapes as mapped by Banks and King (2004) remain unpublished however the below extracts from the *Tarrawonga Coal Project – Agricultural Resource and Productivity Assessment* by McKenzie (2011), show the two soil landscapes relevant to the study area and alluvial boundary assessment.

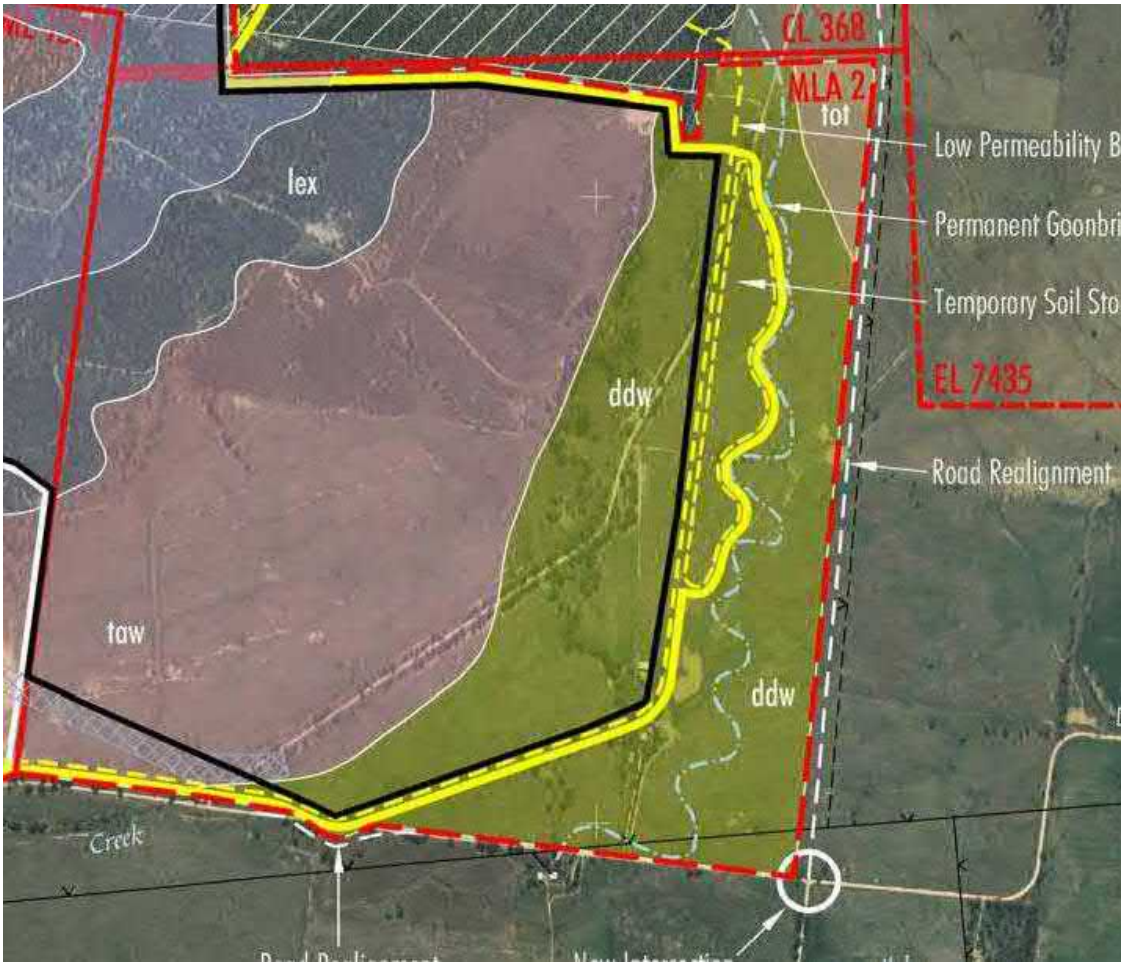


Photo 8 Extract from Figure 5 Soil Landscapes Mapping in Tarrawonga Coal Project – Agricultural Resource and Productivity Assessment by McKenzie (2011)

Table 1 Soil Landscape Information

Soil Landscape Unit	Position in Landscape	Soil Types (Australian Soil Classification)
Driggle Draggle (ddw)	Extensive plains created by ancient alluvial processes which are no longer evident (Stagnant Alluvial).	Soil distribution is complex. Soil types include Grey Chromosols, Brown Sodosols, Grey and Brown Vertosols and Brown Dermosols.
Tally Ho (taw)	Undulating broad hillcrests, and plateaux, on Jurassic basalts and dolerites (Residual).	Very deep Red Ferrosols and Dermosols are dominant. Shallow Leptic Rudosols occur on some of the rocky crests. Red, Brown and Black Vertosols are occasionally present on broad crests and plateaux.

Source: *Table 1. Soil landscape units for the Project site (Banks and King, in press) in Tarrawonga Coal Project – Agricultural Resource and Productivity Assessment* by McKenzie (2011)

3.2 Alluvial Soil Field Assessment

As described in **Section 2.3** this assessment was undertaken in two stages. Detailed alluvial boundary ground truthing figures for the Stage 1 and Stage 2 survey areas are shown in **Appendix A**. The Stage 2 survey area consisted of areas north and south of the Stage 1 survey area.

3.2.1 Stage 1

The Stage 1 field assessment to define the alluvial boundary consisted of seven transects, two detailed sites per transect and 20 mapping observations along the alluvial boundary, as shown in **Figure 3**. Samples from four of the detailed sites were analysed at the NATA accredited Scone Research Centre. The results of the soil field assessment and profile details are following, with laboratory analytes included, as well as reproduced in **Appendix B**.

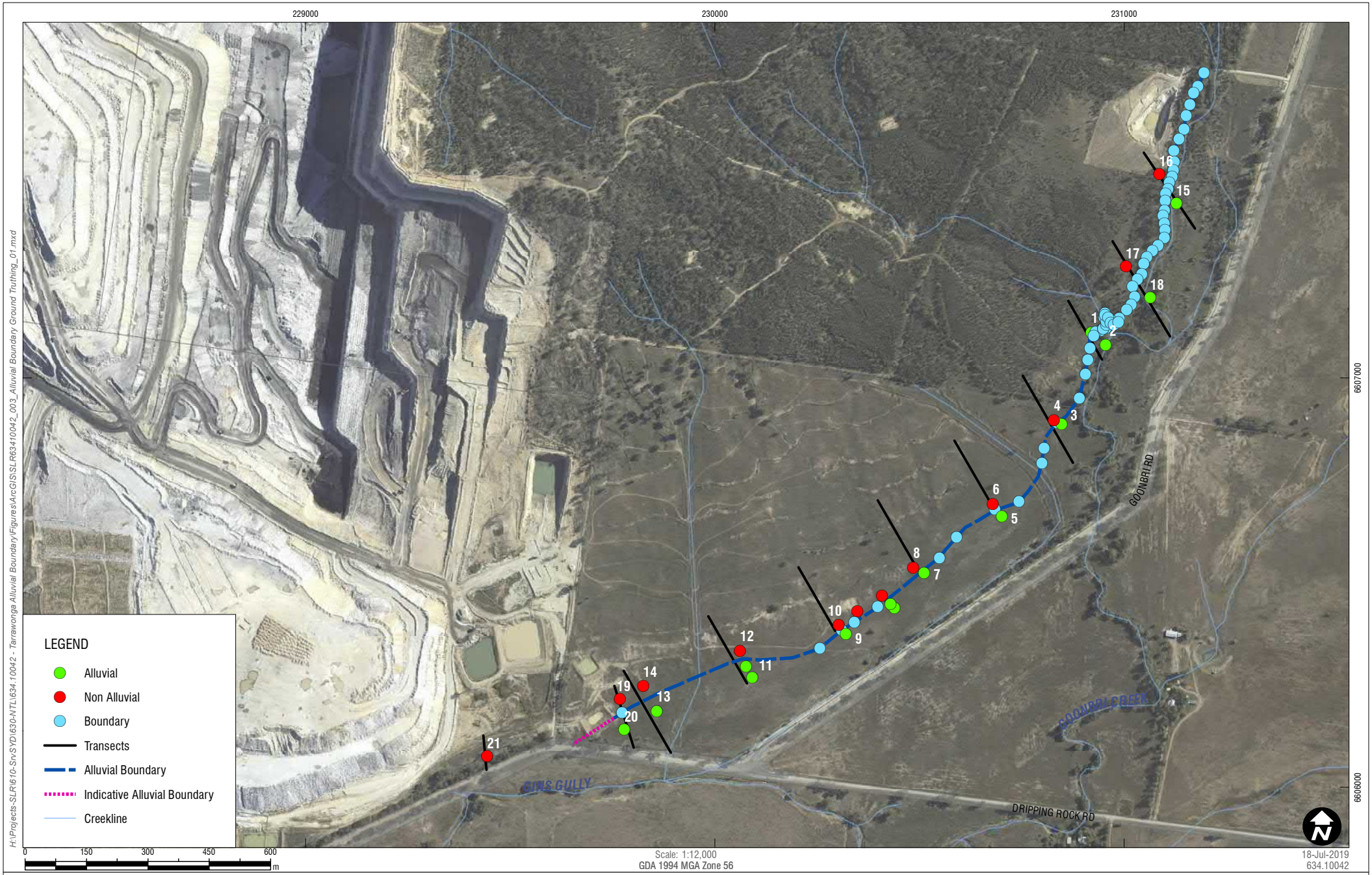
3.2.2 Stage 2

The Stage 2 field assessment to further define the alluvial boundary focussed on two study areas, namely the Northern Section and the Southern Section.

The Northern Section field assessment consisted of an initial walk through, which recorded the alluvial boundary based on landform and geomorphological features. Photos were taken and mapping observation points were recorded along the length of the Northern Section. Soil profile cores were taken and assessed to determine Alluvial (A) and Colluvial (C) materials. The sites for these cores were labelled A1 (15), C1 (16) and A2 (18), C2 (17). Soil samples from these sites were taken and sent for lab analysis to determine soil types and for material characterisation, confirming field assessment results. The location of transects and mapping observation points, along with the alluvial boundary are shown in **Figure 3**.

The Southern Section field assessment consisted of an initial walk through, which recorded the areas of obvious disturbance including public road, site access and internal tracks, man-made drainage channels and water storage dams. Photos were taken and mapping observation points were recorded within the Southern section. Soil profile cores were taken and assessed to determine Alluvial (A) and Colluvial (C) materials. The sites for these cores were labelled A3 (20) and C3 (19). Soil samples from these sites were taken and sent for lab analysis to determine soil types and material characterisation, confirming the field assessment results. A further site C4 (21) was recorded for site information, however this site was severely impacted by man-made activities, and no original alluvial material was evident. The location of transects and mapping observation points for the Southern Section are shown in **Figure 3**.

Samples from five detailed sites were analysed at the NATA accredited EAL Southern Cross University. The results of the soil field assessment and profile details are following, with the laboratory analytes included, as well as reproduced in **Appendix B**.



Sheet Size : A4

SLR

www.slrconsulting.com

PH: 02 4037 3200

Alluvial Boundary Ground Truthing

FIGURE 3

Site 1: Lower Slope - Creek Edge (Alluvial Boundary)

ASC Name	Grey/Brown Sodosol; Eroded
Site No.	1 - Detailed
Eastings; Northings	
Geology	
Microrelief	Nil
Landform Pattern	Lower hillslope
Landform Element	Creek line
Dominant Slope (%)	3.5% (up) 0% (down)
Slope Type	Simple
Surface Coarse Fragments	Gravelly stones
Drainage	Poor
Permeability	Poor
Site Disturbances	Cleared
Current Land Use	Grazing pasture
Surface Condition	Hard Set
Vegetation	Poa tussock, flatweed, burr medic, Paterson's curse, red grass, annual ryegrass, capeweed

Profile	Horizon / Depth (m)	Description
	A 0.00 – 0.00	Layer has been eroded away exposing the subsoil.
	B21 0.00 – 0.25	Light brown gravelly clay, weak structure of <20 mm sub angular blocky peds with a rough-ped fabric and firm consistence. Nil mottling; 40% stone content; nil segregations; gradual and even boundary.
	B22 0.25 – 0.60	Light brown medium clay, moderate structure of 20-50 mm polyhedral peds with a rough-ped fabric and firm consistence. Nil mottling; nil stone content; nil segregations; layer continues.

Site 2: Alluvial

ASC Name	Grey/Brown Sodosol; Deep
Site No.	2 - Check
Eastings; Northings	
Geology	
Microrelief	Nil
Landform Pattern	Alluvial Plain
Landform Element	Plain
Dominant Slope (%)	0-1%
Slope Type	Flat
Surface Coarse Fragments	Nil
Drainage	Moderately well
Permeability	Moderate
Site Disturbances	Cleared
Current Land Use	Grazing pasture
Surface Condition	Soft
Vegetation	Poa tussock, bedstraw, burr medic, Paterson's curse, red grass, annual ryegrass, saffron thistle

Profile	Horizon / Depth (m)	Description
	A1 0.0 – 0.20	Very dark grey sandy loam, moderate structure of <10 mm crumb peds with a rough-ped fabric and moderate consistence. Nil mottling; nil stone content; nil segregations; clear and even boundary.
	B21 0.20 – 0.35	Dark brown medium clay, strong structure of 20-50 mm polyhedral peds with a rough-ped fabric and firm consistence. Nil mottling; nil stone content; nil segregations; gradual and irregular boundary.
	B22 0.35 +	Dark brown gravelly medium clay, strong structure of 20-50 mm angular blocky peds with a smooth-ped fabric and firm consistence. Nil mottling; gravel layer at 0.40 m; layer continues.

Site 3: Alluvial

ASC Name	Grey/Brown Sodosol
Site No.	3 - Detailed
Eastings; Northings	
Geology	
Microrelief	Nil
Landform Pattern	Alluvial Plain
Landform Element	Plain
Dominant Slope (%)	0% (down) 4% (up)
Slope Type	Flat
Surface Coarse Fragments	Nil
Drainage	Poor
Permeability	Moderate
Site Disturbances	Cleared
Current Land Use	Grazing pasture
Surface Condition	Soft
Vegetation	Burr medic, Paterson's curse, saffron thistle, annual ryegrass, capeweed

Profile	Horizon / Depth (m)	Description
	A1 0.0 – 0.20	Brown loam, moderate structure of 5 mm sun angular blocky peds with a rough-ped fabric and weak consistence. Nil mottling; 10% 10 mm conglomerate stone content; nil segregations; gradual and even boundary.
	A2 0.20 – 0.35	Grey sand, apedal single grained and very week consistence. Nil mottling; 40% 10 mm stone content; nil segregations; clear and even boundary.
	B21 0.35 – 0.55	Grey brown silty clay, strong structure of 10-20 mm sub angular blocky peds with a rough-ped fabric and moderate consistence. 10% distinct orange mottling; 50% 10 mm stone content; gradual and even boundary.
	B22 0.55 – 1.00	Brown clay, strong structure of 20-50 mm blocky peds with a smooth-ped fabric and firm consistence. Nil mottling; 20% 5 mm stone content; layer continues.

Site 4: Lower Hillslope (Non-Alluvial)

ASC Name	Clastic Rudosol
Site No.	4
Eastings; Northings	
Geology	
Microrelief	Nil
Landform Pattern	Hillslope
Landform Element	Lower slope
Dominant Slope (%)	0% (down) 5.0% (up)
Slope Type	Waning
Surface Coarse Fragments	2% 60 mm Conglomerate
Drainage	Moderate
Permeability	Moderate
Site Disturbances	Cleared
Current Land Use	Grazing pasture
Surface Condition	Firm
Vegetation	Cobbler's peg, red grass, wiregrass, deadnettle, cotton bush, silver grass, flatweed, burr medic

Profile	Horizon / Depth (m)	Description
	A1 0.0 – 0.15	Brown loam, moderate structure of 5 mm sub angular blocky peds with a rough-ped fabric and weak consistence. Nil mottling; 10% 10-20 mm conglomerate stone content; nil segregations; gradual and even boundary.
	B/C 0.15 – 0.35	Light Brown sandy clay, apedal single grained and very week consistence. Nil mottling; 60% 5 – 25 mm stone content; nil segregations; layer continues

Site 5: Alluvial

ASC Name	Grey Sodosol
Site No.	5
Eastings; Northings	
Geology	
Microrelief	Nil
Landform Pattern	Alluvial Plain
Landform Element	Plain
Dominant Slope (%)	0% (down) 0% (up)
Slope Type	Flat
Surface Coarse Fragments	Nil
Drainage	Poor
Permeability	Moderate to Poor
Site Disturbances	Cleared
Current Land Use	Grazing pasture
Surface Condition	Trampled soft
Vegetation	Annual ryegrass, burr medic, saffron thistle, Paterson's curse, roly poly

Profile	Horizon / Depth (m)	Description
	A1 0.0 – 0.12	Brown silty clay loam, moderate structure of 5-10 mm sub angular blocky peds with a rough-ped fabric and weak consistence. Slightly acidic and non-sodic. Nil mottling; nil stone content; nil segregations; abrupt and even boundary.
	B21 0.12 – 0.60	Dark Grey medium clay, strong structure of 20 mm smooth faced peds and moderate consistence. Strongly alkaline and sodic. Nil mottling; nil stone content; nil segregations; gradual and even boundary.
	B22 0.60 – 0.90	Dark Grey medium clay, strong structure of 20-50 mm rough faced peds and firm consistence. Very strongly alkaline and sodic. Nil mottling; 5% 20 mm stone content; nil segregations; clear and even boundary.
	C 0.90 +	Weathered sandstone.

Site 6: Lower Hillslope (Non-Alluvial)

ASC Name	Clastic Rudosol
Site No.	6
Eastings; Northings	
Geology	
Microrelief	Nil
Landform Pattern	Hillslope
Landform Element	Lower slop[e
Dominant Slope (%)	0% (down) 5% (up)
Slope Type	simple
Surface Coarse Fragments	20% >60 mm Sedimentary
Drainage	Well
Permeability	Moderately well
Site Disturbances	Cleared
Current Land Use	Grazing pasture
Surface Condition	Firm
Vegetation	Red grass, saffron thistle, sliver grass, Paterson's curse, wiregrass, copperburr

Profile	Horizon / Depth (m)	Description
	A1 0.00 – 0.05	Brown loam, moderate structure of 5 mm sub angular blocky peds with a rough-ped fabric and moderate consistence. Nil mottling; 50% 20 mm conglomerate stone content; nil segregations; gradual and even boundary.
	B/C 0.05 – 0.40	Grey gravelly sand, apedal single grained and very week consistence. Nil mottling; 90% 10-50 mm stone content; nil segregations; gradual and even boundary.
	B/C 0.40 +	Light brown gravelly clay, weak structure of 5-10 mm sub angular blocky peds with a rough-ped fabric and moderate consistence. Nil mottling; 90% 10-20 mm stone content; layer continues.

Site 7: Alluvial

ASC Name	Grey/Brown Sodosol
Site No.	7
Eastings; Northings	
Geology	
Microrelief	Nil
Landform Pattern	Alluvial Plain
Landform Element	Plain
Dominant Slope (%)	0%
Slope Type	Flat
Surface Coarse Fragments	Nil
Drainage	Moderate
Permeability	Moderate
Site Disturbances	Cleared
Current Land Use	Grazing pasture
Surface Condition	Soft, trampled
Vegetation	Flatweed, burr medic, Paterson's curse, annual ryegrass, capeweed, red grass, paspalum, mustard weed, saffron thistle

Profile	Horizon / Depth (m)	Description
	A1 0.00 – 0.10	Brown sandy clay loam, moderate structure of 5-10 mm sub angular blocky peds with a rough-ped fabric and moderate consistence. Nil mottling; nil stone content; nil segregations; clear and even boundary.
	B21 0.10 – 0.35	Grey medium clay, strong blocky structure 20 mm, smooth fabric with moderate consistence. Nil mottling; nil stone content; nil segregations; gradual and even boundary.
	B22 0.35 – 0.80	Grey heavy clay, strong structure of 20-50 mm blocky peds with a rough-ped fabric and moderate consistence. Nil mottling; 10% 5 mm stone content; 5% 10 mm $CaCO_3$ nodules; gradual and even boundary.
	B/C 0.80 +	Weathered sandstone.

Site 8: Lower Hillslope (Non-Alluvial)

ASC Name	Clastic Rudosol
Site No.	8
Eastings; Northings	
Geology	
Microrelief	Nil
Landform Pattern	Hillslope
Landform Element	Lower Slope
Dominant Slope (%)	0% (down) 4.5% (up)
Slope Type	Simple
Surface Coarse Fragments	10% >60 mm Conglomerate
Drainage	Moderate
Permeability	Moderately well
Site Disturbances	Cleared
Current Land Use	Grazing pasture
Surface Condition	Soft
Vegetation	Wiregrass, flatweed, burr medic, Paterson's curse, red grass, saffron thistle, silver grass

Profile	Horizon / Depth (m)	Description
	A1 0.0 – 0.15	Brown loam, moderate structure of 5 mm sub angular blocky peds with a rough-ped fabric and weak consistence. Nil mottling; 10% 10 mm conglomerate stone content; nil segregations; gradual and even boundary.
	B/C 0.15 – 0.65	Brown gravelly sandy clay, weak structure and very week consistence. Nil mottling; 90% 10 mm stone content; nil segregations; gradual and even boundary.
	C 0.65 +	Weathered sandstone.

Site 9: Alluvial

ASC Name	Grey/Brown Sodosol
Site No.	9
Eastings; Northings	
Geology	
Microrelief	Nil
Landform Pattern	Alluvial Plain
Landform Element	Plain
Dominant Slope (%)	0%
Slope Type	Flat
Surface Coarse Fragments	Nil
Drainage	Moderate
Permeability	Moderate
Site Disturbances	Cleared
Current Land Use	Grazing pasture
Surface Condition	Soft trampled
Vegetation	Cobbler's peg, flatweed, burr medic, Paterson's curse, annual ryegrass, capeweed, red grass, paspalum, mustard weed, saffron thistle

Profile	Horizon / Depth (m)	Description
	A1 0.00 – 0.15	Brown sandy clay loam, weak structure of 10 mm crumb peds with a rough-ped fabric and weak consistence. Moderately acidic and non-sodic. Nil mottling; nil stone content; nil segregations; clear and even boundary.
	B1 0.15 – 0.30	Dark Grey light clay, strong structure of 20 mm sub angular blocky peds with smooth fabric and firm consistence. Slightly acidic and non-sodic. Nil mottling; nil stone content; nil segregations; gradual and even boundary.
	B2 0.30 – 0.70	Grey heavy clay, strong structure of 20-50 mm sub angular blocky peds with smooth fabric and firm consistence. Moderately alkaline and sodic. Nil mottling; nil stone content; nil segregations; clear and even boundary.
	B/C 0.70 +	Weathered sandstone.

Site 10: Lower Hillslope (Non-Alluvial)

ASC Name	Gravelly Brown Sodosol
Site No.	10
Eastings; Northings	
Geology	
Microrelief	Nil
Landform Pattern	Hillslope
Landform Element	Lower Slope
Dominant Slope (%)	0% (down) 4.0% (up)
Slope Type	Simple
Surface Coarse Fragments	10% >60 mm Conglomerate
Drainage	Moderate
Permeability	Moderately well
Site Disturbances	Cleared
Current Land Use	Grazing pasture
Surface Condition	Soft
Vegetation	Wiregrass, flatweed, burr medic, Paterson's curse, red grass, saffron thistle, silver grass, cobbler's peg, copperburr, cotton bush

Profile	Horizon / Depth (m)	Description
	A1 0.0 – 0.15	Brown loam, moderate structure of 5 mm sub angular blocky peds with a rough-ped fabric and weak consistence. Nil mottling; 10% 10 mm conglomerate stone content; nil segregations; gradual and even boundary.
	B2 0.15 – 0.35	Brown gravelly sandy clay, moderate structure and moderate consistence. Nil mottling; 80% <10 mm stone content; nil segregations; gradual and even boundary.
	B/C 0.35 +	Weathered sandstone / gravelly clay.

Site 11: Alluvial

ASC Name	Brown Sodosol
Site No.	11
Eastings; Northings	
Geology	
Microrelief	Nil
Landform Pattern	Alluvial Plain
Landform Element	Plain
Dominant Slope (%)	0%
Slope Type	Flat
Surface Coarse Fragments	Nil
Drainage	Moderate
Permeability	Moderate
Site Disturbances	Cleared
Current Land Use	Grazing pasture
Surface Condition	Soft and Lumpy
Vegetation	Cobbler's peg, flatweed, burr medic, Paterson's curse, annual ryegrass, red grass, saffron thistle

Profile	Horizon / Depth (m)	Description
	A1 0.0 – 0.10	Brown sandy clay loam, moderate structure of 10 mm sub angular blocky peds with a rough-ped fabric and weak consistence. Slightly acidic and non-sodic. Nil mottling; nil stone content; nil segregations; clear and even boundary.
	B21 0.10 – 0.45	Brown medium clay, strong structure of 20 mm sub angular blocky peds with a rough-ped fabric and moderate consistence. Mildly alkaline and sodic. Nil mottling; nil stone content; nil segregations; gradual and even boundary.
	B22 0.45 – 0.85	Brown medium clay, strong structure of 20-50 mm blocky peds with a rough-ped fabric and moderate consistence. Strongly alkaline and sodic. Nil mottling; nil stone content; nil segregations; gradual and even boundary.
	B/C 0.85 +	Weathered sandstone.

Site 12: Lower Hillslope (Non-Alluvial)

ASC Name	Grey Chromosol
Site No.	12
Eastings; Northings	
Geology	
Microrelief	Nil
Landform Pattern	Hillslope
Landform Element	Lower Slope Broad drainage line from hill
Dominant Slope (%)	2.0% (down) 5.0% (up)
Slope Type	Waning
Surface Coarse Fragments	20% 10-20 mm conglomerate
Drainage	Moderate
Permeability	Moderately poor
Site Disturbances	Cleared
Current Land Use	Grazing pasture
Surface Condition	Soft
Vegetation	Wiregrass, flatweed, burr medic, Paterson's curse, red grass, saffron thistle, silver grass, cobbler's peg

Profile	Horizon / Depth (m)	Description
	A1 0.0 – 0.15	Brown sandy loam, moderate structure of 10 mm sub angular blocky peds with a rough-ped fabric and weak consistence. Nil mottling; nil stone content; nil segregations; clear and even boundary.
	B2 0.15 – 0.70	Grey medium clay, strong structure of 20-50 mm sub angular blocky peds with a rough-ped fabric and moderate consistence. 30% faint orange mottling; nil stone content; nil segregations; gradual and even boundary.
	B/C 0.70 +	Weathered sandstone / gravelly clay.

Site 13: Alluvial

ASC Name	Brown Sodosol
Site No.	13
Eastings; Northings	
Geology	
Microrelief	Nil
Landform Pattern	Alluvial Plain
Landform Element	Plain
Dominant Slope (%)	0%
Slope Type	Flat
Surface Coarse Fragments	Nil
Drainage	Moderately poor
Permeability	Moderate poor
Site Disturbances	Cleared
Current Land Use	Grazing pasture
Surface Condition	Soft lumpy
Vegetation	Cobbler's peg, flatweed, burr medic, Paterson's curse, annual ryegrass, red grass, saffron thistle

Profile	Horizon / Depth (m)	Description
	A1 0.0 – 0.12	Brown sandy clay loam, moderate structure of 10 mm sub angular blocky peds with a rough-ped fabric and weak consistence. Nil mottling; nil stone content; nil segregations; clear and even boundary.
	B21 0.12 – 0.40	Light Brown medium clay, strong structure of 20 mm sub angular blocky peds with a rough-ped fabric and moderate consistence. Nil mottling; nil stone content; gradual and even boundary.
	B22 0.40 – 0.75	Pale brown heavy clay, strong structure of 20-50 mm sub angular blocky peds with a rough-ped fabric and moderate consistence. 30% faint yellow mottling; nil stone content; clear and even boundary.
	B/C 0.75 +	Weathered sandstone / gravelly clay.

Site 14: Lower Hillslope (Non-Alluvial)

ASC Name	Gravelly Grey Chromosol
Site No.	14
Eastings; Northings	
Geology	
Microrelief	Nil
Landform Pattern	Hillslope
Landform Element	Lower Slope
Dominant Slope (%)	1.0% (down) 4.5% (up)
Slope Type	Waning
Surface Coarse Fragments	20% 10-20 mm conglomerate
Drainage	Moderate
Permeability	Moderate
Site Disturbances	Cleared
Current Land Use	Grazing pasture
Surface Condition	Hard setting
Vegetation	Wiregrass, flatweed, burr medic, Paterson's curse, red grass, saffron thistle, silver grass, cobbler's peg, deadnettle, copperburr

Profile	Horizon / Depth (m)	Description
	A1 0.0 – 0.10	Brown sandy loam, moderate structure of 5 mm sub angular blocky peds with a rough-ped fabric and weak consistence. Nil mottling; 10% 10 mm stone content; nil segregations; clear and even boundary.
	B21 0.10 – 0.55	Grey medium clay, strong structure of 20-50 mm sub angular blocky peds with a rough-ped fabric and firm consistence. Nil mottling; 10% 10 mm stone content; nil segregations; gradual and even boundary.
	B22 0.55 – 0.90	Grey heavy clay, strong structure of 20-50 mm sub angular blocky peds with a rough-ped fabric and firm consistence. Nil mottling; 50% 10-20 mm stone content; nil segregations; gradual and even boundary.
	B/C 0.90 +	Weathered sandstone / gravelly clay.

Site 15: Alluvial

ASC Name	Haplic Eutrophic Black Chromosol
Site No.	15 (A1)
Eastings; Northings	231128, 6607427
Geology	Alluvial
Microrelief	Nil
Landform Pattern	Alluvial Plain
Landform Element	Plain
Dominant Slope (%)	0%
Slope Type	Flat
Surface Coarse Fragments	Nil
Drainage	Moderate
Permeability	Moderate
Site Disturbances	Cleared + regrowth
Current Land Use	Grazing pasture
Surface Condition	Firm
Vegetation	Grasses, saffron thistle, dodder, cypress pines, prickly pear.

Profile	Horizon / Depth (m)	Description
	A1 0.00 – 0.20	Black loam, moderate structure of 5-10 mm crumb peds with a rough-ped fabric and weak consistence. Neutral pH, non-sodic, non-saline and moderate CEC. Nil mottling; 5% <5 mm stones; nil segregations; clear and even boundary.
	A2 0.20 – 0.60	Very dark grey to dark brown sandy loam to loam, apedal and weak consistence. Neutral pH, non-sodic, non-saline and low CEC. Nil mottling; 5% <5 mm stones; nil segregations; clear and even boundary.
	B2 0.60 – 1.00	Very dark grey clay loam, strong structure of 10-20 mm polyhedral peds with a rough-ped fabric and firm consistence. Nil mottling; 5% <5 mm stones; nil segregations; layer continues but trends to higher gravel content below 0.90m.

Site 16: Non Alluvial

ASC Name	Clastic Rudosol
Site No.	16 (C1)
Eastings; Northings	231087, 6607498
Geology	Conglomerate
Microrelief	Nil
Landform Pattern	Hillslope
Landform Element	Lower slope
Dominant Slope (%)	2%
Slope Type	Waning
Surface Coarse Fragments	Nil
Drainage	Moderate
Permeability	Moderate
Site Disturbances	Disused quarry
Current Land Use	Unused
Surface Condition	Firm
Vegetation	Ironbark, cypress, grasses

Profile	Horizon / Depth (m)	Description
	A1 0.0 – 0.20	Dark brown loam, weak structure of 5 mm crumb peds with a sandy fabric and weak consistence. Nil mottling; 20% <5 mm stones; nil segregations; gradual and even boundary.
	B21 0.20 – 0.60	Brown sandy loam to sand, apedal with a sandy fabric and weak consistence. Nil mottling; 40% 5-10 mm stones; nil segregations; gradual and even boundary.
	B22 0.60 – 0.90	Strong brown loamy sand, apedal with a sandy fabric and weak consistence. Nil mottling; 40% 5 mm stones; nil segregations; layer continues

Site 17: Non-Alluvial

ASC Name	Clastic Rudosol
Site No.	17 (C2)
Eastings; Northings	231005, 6607273
Geology	Conglomerate
Microrelief	Nil
Landform Pattern	Hillslope
Landform Element	Lower slope
Dominant Slope (%)	2%
Slope Type	Waning
Surface Coarse Fragments	Nil
Drainage	Moderate
Permeability	Moderate
Site Disturbances	Cleared + Regrowth
Current Land Use	Unused
Surface Condition	Firm
Vegetation	Ironbark, cypress, grasses

Profile	Horizon / Depth (m)	Description
	A1 0.0 – 0.20	Dark brown loam, weak structure of 5 mm crumb peds with a sandy fabric and weak consistence. Moderately acidic pH, non-sodic, non-saline and very low CEC. Nil mottling; 20% <5 mm stones; nil segregations; gradual and even boundary.
	B21 0.20 – 0.60	Brown sandy loam to sand, apedal with a sandy fabric and weak consistence. Slightly acidic to neutral pH, non-sodic, non-saline and very low CEC. Nil mottling; 40% 5-10 mm stones; nil segregations; gradual and even boundary.
	B22 0.60 – 0.90	Strong brown loamy sand, apedal with a sandy fabric and weak consistence. Neutral pH, non-sodic, non-saline and very low CEC. Nil mottling; 40% 5 mm stones; nil segregations; layer continues.

Site Photos Distinguishing Northern Alluvial Boundary

The alluvial boundary in the Northern Section of the Stage 2 Study Area was distinguishable by landform and geomorphological features as shown in **Figure 3**. The drainage line had developed against the edge of the colluvial slope and soil landscape boundary. The site photos show evidence for justifying the alluvial boundary mapping, along with site C1 which was an open quarry that allowed a general soil profile to be observed from distance a due to unsafe access.

Photo 9 Western Alluvial Boundary at start of colluvial slope (southern aspect)

Photo 10 Creek line bank defines western alluvial boundary (southern aspect)

Photo 11 Exposed colluvial material defines western alluvial boundary (southern aspect)

Photo 12 Exposed colluvial material defines western alluvial boundary (southern aspect)

Photo 13 Creek line lies adjacent to western alluvial boundary with gradual slope to the west (southern aspect)

Photo 14 Alluvial Boundary at start of colluvial slope (western aspect)

Photo 15 Alluvial Boundary at start of colluvial slope (northern aspect)

Site 18: Alluvial

ASC Name	Haplic Eutrophic Black Dermosol
Site No.	18 (A2)
Eastings; Northings	231065, 6607196
Geology	Alluvial
Microrelief	Nil
Landform Pattern	Alluvial Plain
Landform Element	Plain
Dominant Slope (%)	0%
Slope Type	Flat
Surface Coarse Fragments	Nil
Drainage	Moderate
Permeability	Moderate
Site Disturbances	Cleared + regrowth
Current Land Use	Grazing pasture
Surface Condition	Firm
Vegetation	Grasses, saffron thistle, dodder, cypress pines, prickly pear.

Profile	Horizon / Depth (m)	Description
	A1 0.0 – 0.20	Black sandy clay loam, moderate structure of 5 mm crumb peds with a rough-ped fabric and moderate consistence. Neutral pH, non-sodic, non-saline and moderate CEC Nil mottling; 5% <5 mm stones; nil segregations; gradual and even boundary.
	A2 0.20 – 0.70	Dark brown sandy loam to sandy clay loam, moderate structure of 5 mm crumb peds with a rough-ped fabric and moderate consistence. Neutral to mildly alkaline pH, non-sodic, non-saline and low CEC. Nil mottling; 5% <5 mm stones; nil segregations; gradual and even boundary.
	B2 0.70 – 1.00	Dark brown clay loam, moderate structure of 5 mm crumb peds with a rough-ped fabric and moderate consistence. Mildly alkaline pH, non-sodic, non-saline and moderate CEC. Nil mottling; 5% <5 mm stones; nil segregations; layer continues.

Site 19: Non-Alluvial

ASC Name	Haplic Eutrophic Grey Chromosol
Site No.	19 (C3)
Eastings; Northings	229769, 6606217
Geology	Conglomerate
Microrelief	Nil
Landform Pattern	Hillslope
Landform Element	Lower slope
Dominant Slope (%)	2%
Slope Type	simple
Surface Coarse Fragments	Nil
Drainage	Moderate
Permeability	Moderately
Site Disturbances	Cleared
Current Land Use	Unused
Surface Condition	Firm
Vegetation	Grasses

Profile	Horizon / Depth (m)	Description
	A1 0.00 – 0.10	Dark brown loam, weak structure of 2-5 mm crumb peds with sandy fabric and weak consistence. Slightly acidic pH; non-sodic; non saline; low CEC. Nil mottling; 20% 5-10 mm stones; nil segregations; gradual and even boundary.
	A2 0.10 – 0.20	Greyish brown sandy loam, apedal with sandy fabric. Neutral pH; non-sodic; non saline; low CEC. Nil mottling; 30% 5-10 mm stones; nil segregations; clear and even boundary.
	B21 0.20 – 0.60	Light brownish grey clay loam, strong structure of 10-20 mm polyhedral peds with rough faced fabric and moderate consistence. Neutral pH; non-sodic; non saline; moderate CEC. Nil mottling; 10% 5-10 mm stones; nil segregations; gradual and even boundary.
	B22 0.60 – 0.90	Pale brown medium clay, moderate structure of 20-50 mm polyhedral peds with rough faced fabric and moderate consistence. Mildly alkaline pH; non-sodic; non-saline; moderate CEC. Nil mottling; 5% 5-10 mm stones; nil segregations.

Site 20: Alluvial

ASC Name	Haplic Eutrophic Grey Dermosol
Site No.	20 (A3)
Eastings; Northings	229780, 6606142
Geology	Alluvial
Microrelief	Nil
Landform Pattern	Alluvial Plain
Landform Element	Plain
Dominant Slope (%)	0%
Slope Type	Flat
Surface Coarse Fragments	Nil
Drainage	Moderate
Permeability	Moderate
Site Disturbances	Cleared
Current Land Use	Grazing pasture
Surface Condition	Firm
Vegetation	Grasses, saffron thistle. Paterson's curse

Profile	Horizon / Depth (m)	Description
	A1 0.00 – 0.10	Brown loam, weak structure of 5-10 mm crumb peds with a rough-ped fabric and weak consistence. Neutral pH; non-sodic; non saline; low CEC. Nil mottling; 5% <5 mm stones; nil segregations; gradual and even boundary.
	B21 0.10 – 0.40	Dark Grey heavy clay, strong structure of 20-40 mm rough faced polyhedral peds and moderate consistence. Moderately Alkaline pH; non-sodic; non saline; high CEC. Nil mottling; nil stone content; nil segregations; gradual and even boundary.
	B22 0.40 – 0.80	Very dark grey silty clay, strong structure of 20-40 mm rough faced polyhedral peds and moderate consistence. Strongly Alkaline pH; non-sodic; slightly-saline; high CEC. Nil mottling; nil stone content; nil segregations; gradual and even boundary.
	B23 0.80 +	Brown silty loam, very weak structure to apedal and weak consistence. Strongly Alkaline pH; non-sodic; slightly-saline; high CEC. Nil mottling; nil stone content; nil segregations; layer continues.

Site 21: Non Alluvial (Disturbed Anthroposol)

ASC Name	Anthroposol
Site No.	21 (C4)
Eastings; Northings	229444, 6606076
Geology	Conglomerate
Microrelief	Nil
Landform Pattern	Plain to Hillslope
Landform Element	Plain to Lower Slope
Dominant Slope (%)	1%
Slope Type	Simple
Surface Coarse Fragments	80% Gravel (20% >60 mm)
Drainage	Moderate
Permeability	Moderate
Site Disturbances	Cleared, road, track, contour channel, Dam
Current Land Use	Ancillary mining earthworks
Surface Condition	Disturbed
Vegetation	Grasses and Eucalypt regrowth

Profile	Horizon / Depth (m)	Description
	Surface and Anthroposol disturbances	The soils in this area have been highly disturbed by earthworks and material dumping and spreading associated with road, track, dam and contour bank construction. The subsurface material which has been exposed by these constructions appears to be consistent with the non-alluvial soils assessed within the Stage 1 and Stage 2 Assessments.

4 DISCUSSION AND CONCLUSION

4.1 Alluvial Soil Boundary Discussion

The Stage 1 Alluvial Soil Boundary investigation showed a general transition between soils formed by alluvial deposition, and those formed from other land forming processes, dominated by colluvial processes in this case. The Alluvial Soils were found to be dominated by Grey and Brown Sodosols. Whilst the colluvial soils ranged from Clastic Rudosols to gravelly Chromosols (**Figure 3**). Heavy clay subsoils with higher concentrations of salts such as sodium are commonplace in alluvial soils and drainage depressions and were found where predicted, based on the desktop assessment. Changes in soil type from alluvial to non-alluvial material indicated a significantly reduced degree of alluvial influence away from the source points of the Goonbri Creek. The ground truthing of slope proved to be indicative of the alluvial boundary as the non-alluvial landform exhibited slopes of between 2.5% and 5% which was easily distinguished against the near level to level alluvial plain within 5 to 10 m.

The Alluvial Soil Boundary for the two Study Areas within the Stage 2 Study Area (i.e. the Northern and Southern Sections) showed the following results:

Northern Section: There was a distinct transition between soils formed by alluvial deposition, and those formed from other land forming processes, dominated by colluvial processes in this case. The Alluvial Soils were found to be dominated by Grey and Black Chromosols and Dermosols. Whilst the colluvial soils were found to be Clastic Rudosols. Changes in soil type from alluvial to non-alluvial material indicated a significantly reduced degree of alluvial influence away from the source points of Goonbri Creek. The ground truthing of slope proved to be indicative of the alluvial boundary as the non-alluvial landform exhibited slopes of between 2 to 3% which was easily distinguished against the near level to level alluvial plain within 5 to 10 linear metres. All observation sites for the Northern Section are shown on **Figure 3**.

Southern Section: Much of the Southern Section was significantly disturbed through the construction of a public road, site access and internal tracks, man-made drainage channels and water storage dams. These non-alluvial soils were found to be a gravelly Grey Chromosol and an area of highly disturbed Anthroposols. The Alluvial soil was found to be a Grey Dermosol. An indicative alluvial boundary across these disturbed areas has been provided on **Figure 4**.

An analysis of colluvial material was undertaken to determine the soil type change from alluvial to colluvial. Any material identified as colluvium was excluded from the alluvial boundary.

Vigorous pasture growth of ‘fertility loving’ plants such as Paterson’s curse, burr medic, saffron thistle and annual ryegrass was observed on the higher clay content and wetter alluvial soils, transitioning to less vigorous areas of pasture dominated by wiregrass, silver grass, copperburr and cotton bush on the dryer, lower fertility, colluvial materials. This transitioning can be seen in the landscape photos taken at each site.

4.2 Alluvial Boundary Conclusion

Based on soil characteristics, topography, and observations on vegetation, a boundary between alluvial soils and non-alluvial soils has been confirmed to within 5 to 10 m accuracy as shown on **Figure 4**.

Scale: 1:12,000
GDA 1994 MGA Zone 56

18-Jul-2019
634.10042

H:\Projects-SLR\610-Srv-SYD\630-NTL\634.10042 - Tarrawonga Alluvial Boundary\Figures\ArcGIS\SLR63410042_004_Alluvial Boundary.mxd

Sheet Size : A4

SLR
www.slrconsulting.com
PH: 02 4037 3200

Alluvial Boundary

FIGURE 4

5 REFERENCES

Banks RG, King D (In Press) *Soil Landscapes of the Boggabri 1:100 000 Sheet (Boggabri, Gunnedah, Maules Creek, Carroll)* (DIPNR, Gunnedah; unpublished draft).

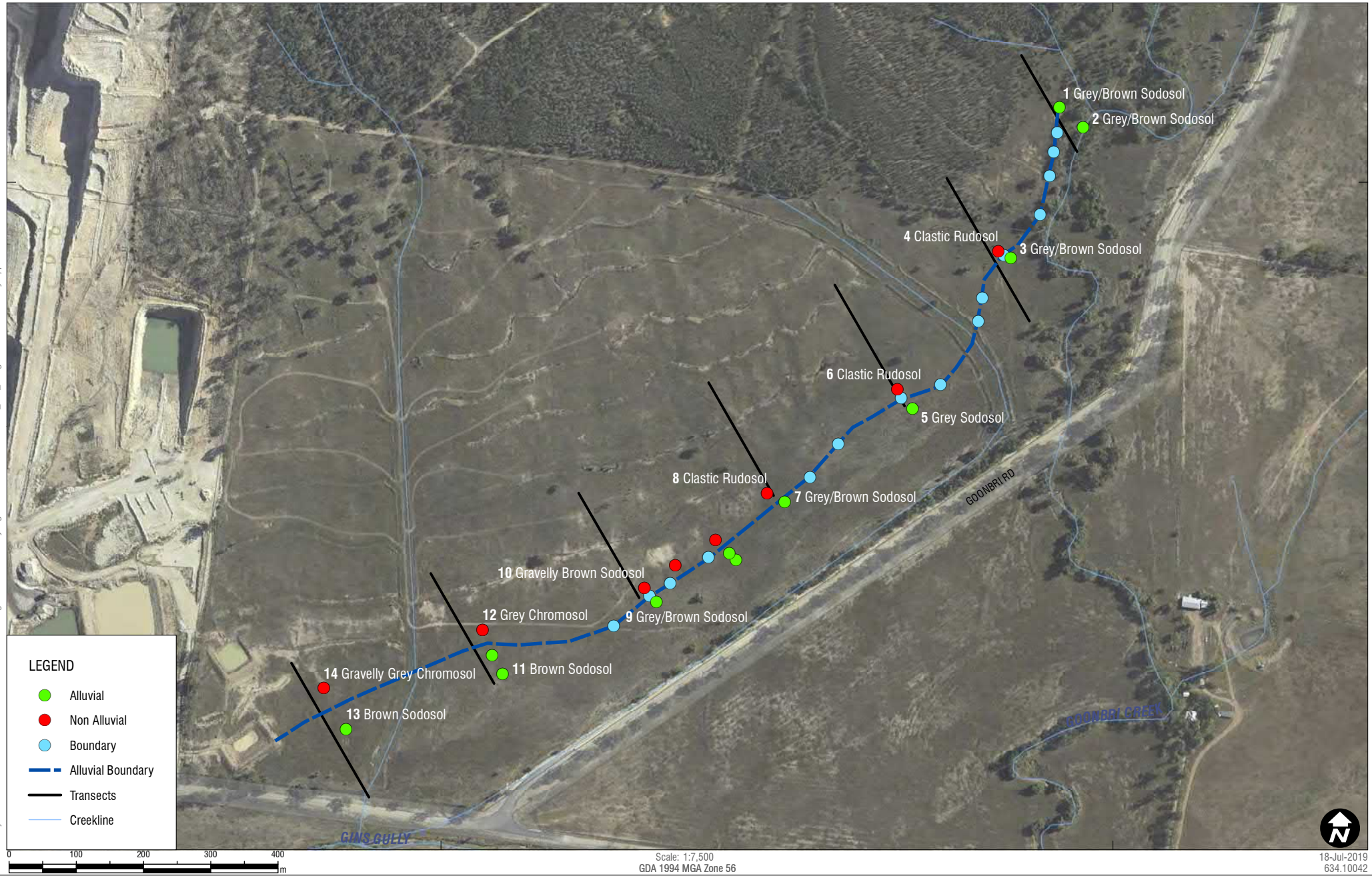
Charman PEV, Murphy BW (2007) *Soils: Their Properties and Management, 3rd Edition.*

McKenzie Soil Management Pty Ltd (2011) *Agricultural Resource Assessment: "Tarrawonga Coal Project", Boggabri NSW.* Prepared for Whitehaven Coal Limited.

NSW Office of Environment and Heritage (2004) *Soil Landscapes of the Blackville 1:100,000 Sheet.* Accessible at: http://data.nsw.gov.au/data/dataset/soil-landscapes-of-the-blackville-1-100000-sheet6cfd7.

APPENDIX A

Alluvial Boundary Ground Truthing Figures



Sheet Size : A4

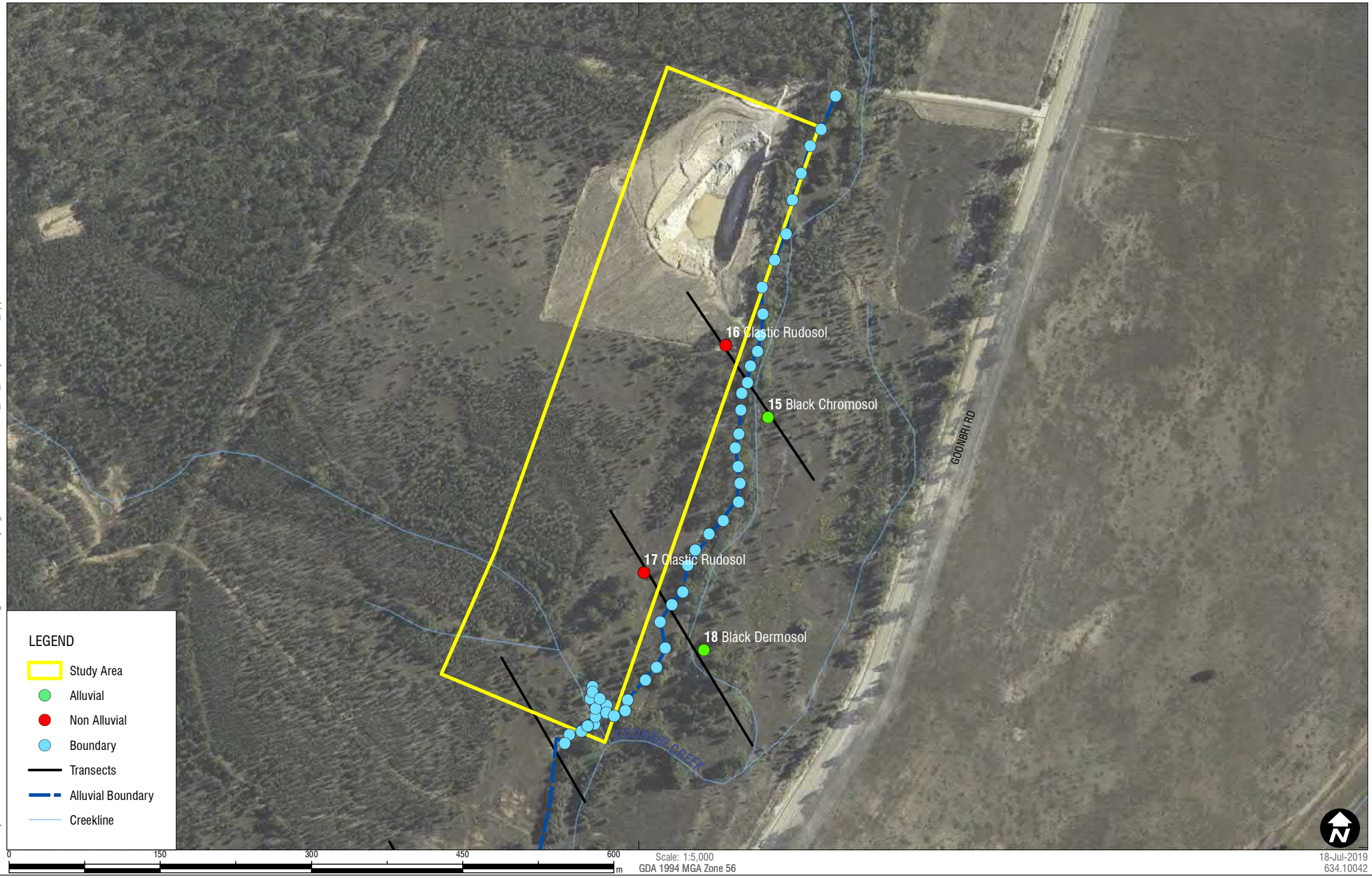
SLR

www.slrconsultingaustralia.com.au

APPENDIX

Stage 1
Alluvial Boundary

FIGURE 1



Sheet Size : A4

SLR

www.slrconsulting.com

PH: 02 4037 3200

APPENDIX

Stage 2
Northern Study Area

FIGURE 2

H:\Projects-SLR\610-Srv-SYD\630-NTL\634.10042 - Tarrawonga Alluvial Boundary\Figures\ArcGIS\SLR63410042_003_StudyArea South_Appendix.mxd

Sheet Size : A4

SLR

www.slrconsulting.com PH: 02 4037 3200

APPENDIX

Stage 2
Southern Study Area

FIGURE 3

APPENDIX B

Laboratory Certificates of Analysis

Department of Primary Industries
Soil Conservation Service

SOIL TEST REPORT

Scone Research Centre

REPORT NO:	SCO15/138R1
REPORT TO:	Murray Fraser SLR Consulting 10 Kings Rd New Lambton NSW 2305
REPORT ON:	Eighteen soil samples Your ref: 634.10042 Tarrawonga Alluvial EIS
PRELIMINARY RESULTS ISSUED:	Not issued
REPORT STATUS:	Final
DATE REPORTED:	12 August 2015
METHODS:	Information on test procedures can be obtained from Scone Research Centre

TESTING CARRIED OUT ON SAMPLE AS RECEIVED
THIS DOCUMENT MAY NOT BE REPRODUCED EXCEPT IN FULL

SR Young
(Laboratory Manager)

Scone Research Centre, PO Box 283 Scone 2337, 709 Gundy Road Scone 2337
Ph: 02 6545 1666, Email: scone.lab@scs.nsw.gov.au

SOIL CONSERVATION SERVICE
Scone Research Centre

Report No: SCO15/138R1
Client Reference: Murray Fraser
SLR Consulting
10 Kings Rd
New Lambton NSW 2305

Lab No	Method	C1A/5	C2A/4	C2B/4	C5A/4 CEC & exchangeable cations (cmol (+)/kg)					
	Sample Id	EC (dS/m)	pH	pH ($CaCl_2$)	CEC	Na	K	Ca	Mg	Al
1	Site 5 0-10	0.04	6.5	5.3	15.8	0.7	1.2	6.6	2.9	<0.5
2	Site 5 20-30	0.04	7.4	6.1	29.3	1.7	0.4	16.6	6.2	nt
3	Site 5 50-60	0.20	8.9	8.1	36.2	3.0	0.2	18.6	7.3	nt
4	Site 5 80-90	0.18	9.1	8.1	28.9	2.5	0.4	19.1	6.3	nt
5	Site 9 0-10	0.02	5.6	4.5	8.4	0.2	0.8	2.7	1.6	<0.5
6	Site 9 20-30	0.02	6.5	5.1	17.5	0.6	0.5	9.2	3.8	<0.5
7	Site 9 50-60	0.03	8.3	6.9	24.6	1.5	0.3	13.2	6.3	nt
8	Site 11 0-10	0.02	6.4	5.1	14.4	0.5	1.1	6.1	3.4	<0.5
9	Site 11 20-30	0.05	7.7	6.4	26.6	2.1	0.2	13.7	7.5	nt
10	Site 11 50-60	0.22	8.7	7.7	32.9	4.2	0.4	16.3	9.5	nt
11	Site 11 80-90	0.43	9.0	8.1	35.0	3.8	0.4	21.0	9.5	nt
12	Site 12 0-10	0.03	6.5	5.7	7.7	0.1	0.9	3.0	1.5	nt
13	Site 12 20-30	0.01	7.0	6.0	20.1	0.3	0.9	9.7	5.5	nt
14	Site 12 50-60	0.04	8.3	7.3	21.8	0.6	0.6	10.3	6.5	nt
15	Site 12 80-90	0.08	8.8	8.0	17.2	0.6	0.5	8.6	5.0	nt
16	Site 15 0-10	0.02	6.4	5.5	8.2	0.1	0.7	4.1	1.3	nt
17	Site 15 20-30	0.01	6.5	5.5	7.5	0.1	0.3	3.6	1.5	nt
18	Site 15 45-55	<0.01	6.5	5.5	6.8	0.1	0.3	2.6	1.4	nt

nt = not tested

Lab No	Method	P7B/2 Particle Size Analysis (%)					Colour	
	Sample Id	clay	silt	f sand	c sand	gravel	Dry	Moist
16	Site 15 0-10	5	12	27	32	24	10YR 5/3	10YR 4/2
17	Site 15 20-30	6	10	24	27	33	10YR 6/2	10YR 4/2
18	Site 15 45-55	5	9	15	28	43	10YR 7/2	10YR 5/4

END OF TEST REPORT

GRAIN SIZE ANALYSIS (hydrometer and sieving techniques)

20 soil samples supplied by SLR Consulting Australia Pty Ltd on 17th December, 2019 - Lab Job No. H7007
Analysis requested by Murray Fraser. **Your Project: Tarrawonga Alluvial 634.10042**
10 Kings Road NEW LAMBTON NSW 2305

SAMPLE ID	Lab Code	MOISTURE CONTENT (% of water in air-dry sample)	TOTAL GRAVEL > 2 mm (% of total oven-dry equivalent)	COARSE SAND 200-2000 µm (0.2-2.0 mm) (% of total oven-dry equivalent)	FINE SAND 20-200 µm (0.02-0.2 mm) (% of total oven-dry equivalent)	SILT 2-20 µm ISSS (% of total oven-dry equivalent)	CLAY < 2 µm (% of total oven-dry equivalent)
A1 0-10	H7007/1	6.8%	0.9%	18.4%	43.9%	15.2%	21.6%
A1 30-40	H7007/2	5.8%	2.7%	32.7%	41.8%	5.2%	17.7%
A1 50-60	H7007/3	5.4%	1.3%	24.0%	48.4%	14.0%	12.3%
A1 70-80	H7007/4	9.0%	3.8%	20.5%	36.9%	9.6%	29.2%
A2 0-10	H7007/5	6.5%	0.5%	16.4%	54.5%	7.8%	20.8%
A2 30-40	H7007/6	6.8%	0.3%	29.3%	43.5%	9.8%	17.1%
A2 50-60	H7007/7	7.7%	0.9%	35.2%	35.6%	6.8%	21.5%
A2 80-90	H7007/8	9.0%	5.2%	20.6%	37.7%	9.6%	26.9%
A3 0-10	H7007/9	3.4%	22.6%	24.0%	30.4%	10.7%	12.3%
A3 30-40	H7007/10	14.4%	1.2%	2.7%	22.0%	19.6%	54.5%
A3 50-60	H7007/11	14.5%	0.7%	2.9%	21.1%	27.8%	47.5%
A3 80-90	H7007/12	14.2%	4.1%	20.6%	20.0%	30.8%	24.6%
C2 0-10	H7007/13	3.6%	20.4%	28.8%	28.1%	13.0%	9.6%
C2 30-40	H7007/14	3.7%	33.8%	27.4%	27.0%	5.0%	6.8%
C2 50-60	H7007/15	3.6%	25.1%	45.6%	22.6%	1.8%	4.9%
C2 70-80	H7007/16	3.4%	33.6%	16.7%	35.3%	8.5%	6.0%
C3 0-10	H7007/17	2.3%	26.3%	20.7%	30.0%	12.3%	10.8%
C3 30-40	H7007/18	5.2%	24.7%	36.2%	21.3%	7.2%	10.5%
C3 50-60	H7007/19	8.1%	20.8%	31.4%	17.6%	8.7%	21.4%
C3 60-70	H7007/20	11.8%	16.7%	3.1%	28.1%	12.8%	39.2%

Note:

1: The Hydrometer Analysis method was used to determine the percentage sand, silt and clay,
modified from SOP meth004 (California Dept of Pesticide Regulation), using method of Gee & Bauder (1986),
in *Methods of Soil Analysis. Part 1* Agron. Monogr. 9 (2nd Ed). Klute, A., American Soc. of Agronomy Inc., Soil Sci. Soc. America Inc., Madison WI: 383-411.

2: All services undertaken by EAL are covered by the EAL Laboratory Services Terms and Conditions.
These Terms and Conditions are available on the EAL website: scu.edu.au/eal, or on request.

checked: .....
Graham Lancaster (Nata signatory)
Laboratory Manager

Southern Cross University
PO Box 157 Lismore NSW 2480
P: +61 2 6620 3678
E: eal@scu.edu.au
www.scu.edu.au/eal
ABN: 41 995 651 524

AGRICULTURAL SOIL ANALYSIS REPORT

20 samples supplied by SLR Consulting Australia Pty Ltd on 17th December, 2018. Lab Job No.H7007

Analysis requested by Murray Fraser. Your Job: Tarrawonga Alluvial

10 Kings Road NEW LAMBTON NSW 2305

			Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
		Sample ID:	A1 0-10	A1 30-40	A1 50-60	A1 70-80	A2 0-10
		Crop:	N/G	N/G	N/G	N/G	N/G
		Client:	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial
Parameter		Method reference	H7007/1	H7007/2	H7007/3	H7007/4	H7007/5
pH		Rayment & Lyons 2011 - 4A1 (1:5 Water)	6.86	6.79	6.60	6.34	6.57
Electrical Conductivity (dS/m)		Rayment & Lyons 2011 - 3A1 (1:5 Water)	0.032	0.016	0.012	0.013	0.037
Exchangeable Calcium	(cmol$_+$/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	8.76	6.35	5.09	9.08	8.44
	(kg/ha)		3931	2850	2283	4074	3788
	(mg/kg)		1755	1272	1019	1819	1691
Exchangeable Magnesium	(cmol$_+$/kg)		2.15	1.51	1.57	4.30	2.26
	(kg/ha)		584	410	428	1170	615
	(mg/kg)		261	183	191	522	274
Exchangeable Potassium	(cmol$_+$/kg)		1.41	0.77	0.42	0.50	0.96
	(kg/ha)		1239	671	372	437	840
	(mg/kg)		553	300	166	195	375
Exchangeable Sodium	(cmol$_+$/kg)		0.16	0.14	0.12	0.33	0.15
	(kg/ha)		80	70	63	172	79
	(mg/kg)		36	31	28	77	35
Exchangeable Aluminium	(cmol$_+$/kg)	**Inhouse S37 (KCl)	<0.01	<0.01	<0.01	0.03	<0.01
	(kg/ha)		<1	2	<1	6	1
	(mg/kg)		<1	<1	<1	3	<1
Exchangeable Hydrogen	(cmol$_+$/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	<0.01	0.06	<0.01
	(kg/ha)		<1	<1	<1	1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol$_+$/kg)		**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol$_+$/kg)	12.48	8.77	7.21	14.30	11.81
Calcium (%)		**Base Saturation Calculations - Cation cmol$_+$/kg / ECEC x 100	70.2	72.4	70.6	63.5	71.4
Magnesium (%)			17.2	17.2	21.8	30.1	19.1
Potassium (%)			11.3	8.7	5.9	3.5	8.1
Sodium - ESP (%)			1.2	1.6	1.7	2.3	1.3
Aluminium (%)			0.0	0.1	0.1	0.2	0.1
Hydrogen			0.0	0.0	0.0	0.4	0.0
Calcium/Magnesium Ratio		**Calculation: Calcium / Magnesium (cmol$_+$/kg)	4.1	4.2	3.2	2.1	3.7
pH		**Rayment & Lyons 2011 - 4B4 ($CaCl_2$)	5.85	5.67	5.43	4.90	5.66
Colour (Munsell Soil Colour Classification) - Hue/Colour		**Inhouse	5YR	5YR	7.5YR	7.5YR	10YR
Colour (Munsell Soil Colour Classification) - Value/Chroma		**Inhouse	2.5/1	3/1	3/2	3/1	3/1
Colour (Munsell Soil Colour Classification) - Mottle Hue, Value/Chroma, Proportion		**Inhouse	N/A	N/A	N/A	N/A	N/A

Southern Cross University
PO Box 157 Lismore NSW 2480
P: +61 2 6620 3678
E: eal@scu.edu.au
www.scu.edu.au/eal
ABN: 41 995 651 524

AGRICULTURAL SOIL ANALYSIS REPORT

20 samples supplied by SLR Consulting Australia Pty Ltd on 17th December, 2018. Lab Job No.H7007

Analysis requested by Murray Fraser. Your Job: Tarrawonga Alluvial

10 Kings Road NEW LAMBTON NSW 2305

		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
	Sample ID:	A1 0-10	A1 30-40	A1 50-60	A1 70-80	A2 0-10
	Crop:	N/G	N/G	N/G	N/G	N/G
	Client:	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial
Parameter	Method reference	H7007/1	H7007/2	H7007/3	H7007/4	H7007/5

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013, Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
10. Conversions for 1 $cmol_+/kg$ = 230 mg/kg Sodium, 390 mg/kg Potassium, 122 mg/kg Magnesium, 200 mg/kg Calcium
11. Conversions to kg/ha = mg/kg x 2.24
12. The chloride calculation of Cl mg/L = EC x 640 is considered an estimate, and most likely an over-estimate
13. ** NATA accreditation does not cover the performance of this service.
14. Analysis conducted between sample arrival date and reporting date.
15. This report is not to be reproduced except in full.
16. All services undertaken by EAL are covered by the EAL Laboratory Services Terms and Conditions. These Terms and Conditions are available on the EAL website: scu.edu.au/eal, or on request.

Quality Checked: Kris Saville
Agricultural Co-Ordinator

Southern Cross University
PO Box 157 Lismore NSW 2480
P: +61 2 6620 3678
E: eal@scu.edu.au
www.scu.edu.au/eal
ABN: 41 995 651 524

AGRICULTURAL SOIL ANALYSIS REPORT

20 samples supplied by SLR Consulting Australia Pty Ltd on 17th December, 2018. Lab Job No.H7007

Analysis requested by Murray Fraser. Your Job: Tarrawonga Alluvial

10 Kings Road NEW LAMBTON NSW 2305

			Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
		Sample ID:	A2 30-40	A2 50-60	A2 80-90	A3 0-10	A3 30-40
		Crop:	N/G	N/G	N/G	N/G	N/G
		Client:	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial
Parameter		Method reference	H7007/6	H7007/7	H7007/8	H7007/9	H7007/10
pH		Rayment & Lyons 2011 - 4A1 (1:5 Water)	7.03	7.39	7.45	6.55	8.20
Electrical Conductivity (dS/m)		Rayment & Lyons 2011 - 3A1 (1:5 Water)	0.018	0.019	0.021	0.040	0.234
Exchangeable Calcium	(cmol$_+$/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	7.33	8.60	9.78	4.29	15.00
	(kg/ha)		3292	3861	4391	1925	6735
	(mg/kg)		1470	1724	1960	859	3007
Exchangeable Magnesium	(cmol$_+$/kg)		1.99	2.74	3.24	1.98	8.25
	(kg/ha)		541	747	882	538	2247
	(mg/kg)		242	333	394	240	1003
Exchangeable Potassium	(cmol$_+$/kg)		0.69	0.54	0.58	1.08	0.67
	(kg/ha)		602	475	508	944	584
	(mg/kg)		269	212	227	421	261
Exchangeable Sodium	(cmol$_+$/kg)		0.13	<0.065	<0.065	0.14	3.10
	(kg/ha)		69	<33	<33	74	1596
	(mg/kg)		31	<15	<15	33	712
Exchangeable Aluminium	(cmol$_+$/kg)	**Inhouse S37 (KCl)	<0.01	<0.01	0.01	<0.01	<0.01
	(kg/ha)		1	<1	2	2	2
	(mg/kg)		<1	<1	1	<1	<1
Exchangeable Hydrogen	(cmol$_+$/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol$_+$/kg)		**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol$_+$/kg)	10.15	11.94	13.61	7.49	27.03
Calcium (%)		**Base Saturation Calculations - Cation cmol$_+$/kg / ECEC x 100	72.3	72.0	71.9	57.2	55.5
Magnesium (%)			19.6	23.0	23.8	26.4	30.5
Potassium (%)			6.8	4.5	4.3	14.4	2.5
Sodium - ESP (%)			1.3	0.5	0.0	1.9	11.5
Aluminium (%)			0.1	0.0	0.1	0.1	0.0
Hydrogen			0.0	0.0	0.0	0.0	0.0
Calcium/Magnesium Ratio		**Calculation: Calcium / Magnesium (cmol$_+$/kg)	3.7	3.1	3.0	2.2	1.8
pH		**Rayment & Lyons 2011 - 4B4 ($CaCl_2$)	5.93	6.29	6.34	5.69	7.13
Colour (Munsell Soil Colour Classification) - Hue/Colour		**Inhouse	7.5YR	7.5YR	7.5YR	7.5YR	7.5YR
Colour (Munsell Soil Colour Classification) - Value/Chroma		**Inhouse	3/2	3/2	3/2	4/2	4/1
Colour (Munsell Soil Colour Classification) - Mottle Hue, Value/Chroma, Proportion		**Inhouse	N/A	N/A	N/A	N/A	N/A

Southern Cross University
PO Box 157 Lismore NSW 2480
P: +61 2 6620 3678
E: eal@scu.edu.au
www.scu.edu.au/eal
ABN: 41 995 651 524

AGRICULTURAL SOIL ANALYSIS REPORT

20 samples supplied by SLR Consulting Australia Pty Ltd on 17th December, 2018. Lab Job No.H7007

Analysis requested by Murray Fraser. Your Job: Tarrawonga Alluvial

10 Kings Road NEW LAMBTON NSW 2305

			Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
		Sample ID:	A2 30-40	A2 50-60	A2 80-90	A3 0-10	A3 30-40
		Crop:	N/G	N/G	N/G	N/G	N/G
		Client:	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial
	Parameter	Method reference	H7007/6	H7007/7	H7007/8	H7007/9	H7007/10
Notes:							

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013,
Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
10. Conversions for 1 $cmol_+/kg$ = 230 mg/kg Sodium, 390 mg/kg Potassium,
122 mg/kg Magnesium, 200 mg/kg Calcium
11. Conversions to kg/ha = mg/kg x 2.24
12. The chloride calculation of Cl mg/L = EC x 640 is considered an estimate, and most likely an over-estimate
13. ** NATA accreditation does not cover the performance of this service.
14. Analysis conducted between sample arrival date and reporting date.
15. This report is not to be reproduced except in full.
16. All services undertaken by EAL are covered by the EAL Laboratory Services Terms and Conditions.
These Terms and Conditions are available on the EAL website: scu.edu.au/eal, or on request.

Quality Checked: Kris Saville
Agricultural Co-Ordinator KS

Southern Cross University
PO Box 157 Lismore NSW 2480
P: +61 2 6620 3678
E: eal@scu.edu.au
www.scu.edu.au/eal
ABN: 41 995 651 524

AGRICULTURAL SOIL ANALYSIS REPORT

20 samples supplied by SLR Consulting Australia Pty Ltd on 17th December, 2018. Lab Job No.H7007

Analysis requested by Murray Fraser. Your Job: Tarrawonga Alluvial

10 Kings Road NEW LAMBTON NSW 2305

			Sample 11	Sample 12	Sample 13	Sample 14	Sample 15
		Sample ID:	A3 50-60	A3 80-90	C2 0-10	C2 30-40	C2 50-60
		Crop:	N/G	N/G	N/G	N/G	N/G
		Client:	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial
Parameter		Method reference	H7007/11	H7007/12	H7007/13	H7007/14	H7007/15
pH		Rayment & Lyons 2011 - 4A1 (1:5 Water)	8.84	8.66	5.92	6.16	7.01
Electrical Conductivity (dS/m)		Rayment & Lyons 2011 - 3A1 (1:5 Water)	0.417	0.362	0.036	0.016	0.017
Exchangeable Calcium	(cmol$_+$/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	18.30	13.33	2.75	1.62	1.18
	(kg/ha)		8216	5982	1234	727	531
	(mg/kg)		3668	2670	551	325	237
Exchangeable Magnesium	(cmol$_+$/kg)		8.68	7.58	0.96	0.75	1.26
	(kg/ha)		2364	2063	260	203	343
	(mg/kg)		1055	921	116	91	153
Exchangeable Potassium	(cmol$_+$/kg)		0.72	0.98	1.01	0.51	0.28
	(kg/ha)		632	856	880	444	242
	(mg/kg)		282	382	393	198	108
Exchangeable Sodium	(cmol$_+$/kg)		3.83	3.51	0.12	0.07	0.14
	(kg/ha)		1973	1809	59	35	74
	(mg/kg)		881	808	26	16	33
Exchangeable Aluminium	(cmol$_+$/kg)	**Inhouse S37 (KCl)	<0.01	<0.01	0.06	0.04	<0.01
	(kg/ha)		1	2	11	9	1
	(mg/kg)		<1	<1	5	4	<1
Exchangeable Hydrogen	(cmol$_+$/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	0.07	0.03	<0.01
	(kg/ha)		<1	<1	2	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol$_+$/kg)		**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol$_+$/kg)	31.54	25.40	4.95	3.02	2.87
Calcium (%)		**Base Saturation Calculations - Cation cmol$_+$/kg / ECEC x 100	58.0	52.5	55.5	53.7	41.2
Magnesium (%)			27.5	29.8	19.3	24.7	43.9
Potassium (%)			2.3	3.8	20.3	16.8	9.6
Sodium - ESP (%)			12.1	13.8	2.3	2.3	5.0
Aluminium (%)			0.0	0.0	1.1	1.5	0.2
Hydrogen			0.0	0.0	1.5	1.1	0.0
Calcium/Magnesium Ratio		**Calculation: Calcium / Magnesium (cmol$_+$/kg)	2.1	1.8	2.9	2.2	0.9
pH		**Rayment & Lyons 2011 - 4B4 ($CaCl_2$)	8.07	7.80	4.91	5.16	6.15
Colour (Munsell Soil Colour Classification) - Hue/Colour		**Inhouse	7.5YR	10YR	10YR	7.5YR	7.5YR
Colour (Munsell Soil Colour Classification) - Value/Chroma		**Inhouse	3/1	4/3	3/3	4/4	5/4
Colour (Munsell Soil Colour Classification) - Mottle Hue, Value/Chroma, Proportion		**Inhouse	N/A	N/A	N/A	N/A	N/A

Southern Cross University
PO Box 157 Lismore NSW 2480
P: +61 2 6620 3678
E: eal@scu.edu.au
www.scu.edu.au/eal
ABN: 41 995 651 524

AGRICULTURAL SOIL ANALYSIS REPORT

20 samples supplied by SLR Consulting Australia Pty Ltd on 17th December, 2018. Lab Job No.H7007

Analysis requested by Murray Fraser. Your Job: Tarrawonga Alluvial

10 Kings Road NEW LAMBTON NSW 2305

			Sample 11	Sample 12	Sample 13	Sample 14	Sample 15
		Sample ID:	A3 50-60	A3 80-90	C2 0-10	C2 30-40	C2 50-60
		Crop:	N/G	N/G	N/G	N/G	N/G
		Client:	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial
	Parameter	Method reference	H7007/11	H7007/12	H7007/13	H7007/14	H7007/15

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013, Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
10. Conversions for 1 $cmol_+$/kg = 230 mg/kg Sodium, 390 mg/kg Potassium, 122 mg/kg Magnesium, 200 mg/kg Calcium
11. Conversions to kg/ha = mg/kg x 2.24
12. The chloride calculation of Cl mg/L = EC x 640 is considered an estimate, and most likely an over-estimate
13. ** NATA accreditation does not cover the performance of this service.
14. Analysis conducted between sample arrival date and reporting date.
15. This report is not to be reproduced except in full.
16. All services undertaken by EAL are covered by the EAL Laboratory Services Terms and Conditions. These Terms and Conditions are available on the EAL website: scu.edu.au/eal, or on request.

Quality Checked: Kris Saville
Agricultural Co-Ordinator KS

Southern Cross University
PO Box 157 Lismore NSW 2480
P: +61 2 6620 3678
E: eal@scu.edu.au
www.scu.edu.au/eal
ABN: 41 995 651 524

AGRICULTURAL SOIL ANALYSIS REPORT

20 samples supplied by SLR Consulting Australia Pty Ltd on 17th December, 2018. Lab Job No.H7007

Analysis requested by Murray Fraser. Your Job: Tarrawonga Alluvial

10 Kings Road NEW LAMBTON NSW 2305

			Sample 16	Sample 17	Sample 18	Sample 19	Sample 20
		Sample ID:	C2 70-80	C3 0-10	C3 30-40	C3 50-60	C3 60-70
		Crop:	N/G	N/G	N/G	N/G	N/G
		Client:	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial
Parameter		Method reference	H7007/16	H7007/17	H7007/18	H7007/19	H7007/20
pH		Rayment & Lyons 2011 - 4A1 (1:5 Water)	7.16	6.49	6.76	7.18	7.71
Electrical Conductivity (dS/m)		Rayment & Lyons 2011 - 3A1 (1:5 Water)	0.009	0.041	0.029	0.084	0.196
Exchangeable Calcium	(cmol$_+$/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	0.84	5.03	3.81	7.24	7.57
	(kg/ha)		378	2259	1709	3251	3400
	(mg/kg)		169	1008	763	1451	1518
Exchangeable Magnesium	(cmol$_+$/kg)		1.80	1.83	2.09	5.96	6.96
	(kg/ha)		489	499	569	1622	1894
	(mg/kg)		218	223	254	724	846
Exchangeable Potassium	(cmol$_+$/kg)		0.33	1.49	0.68	0.55	0.71
	(kg/ha)		287	1308	593	480	620
	(mg/kg)		128	584	265	214	277
Exchangeable Sodium	(cmol$_+$/kg)		0.30	0.20	0.43	1.70	2.48
	(kg/ha)		154	101	223	875	1277
	(mg/kg)		69	45	100	391	570
Exchangeable Aluminium	(cmol$_+$/kg)	**Inhouse S37 (KCl)	<0.01	0.01	0.02	0.02	0.01
	(kg/ha)		1	2	5	4	2
	(mg/kg)		<1	<1	2	2	<1
Exchangeable Hydrogen	(cmol$_+$/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	0.04	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol$_+$/kg)		**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol$_+$/kg)	3.27	8.61	7.03	15.47	17.73
Calcium (%)		**Base Saturation Calculations - Cation cmol$_+$/kg / ECEC x 100	25.7	58.5	54.1	46.8	42.7
Magnesium (%)			54.9	21.3	29.7	38.5	39.2
Potassium (%)			10.0	17.4	9.6	3.5	4.0
Sodium - ESP (%)			9.2	2.3	6.2	11.0	14.0
Aluminium (%)			0.2	0.1	0.3	0.1	0.1
Hydrogen			0.0	0.5	0.0	0.0	0.0
Calcium/Magnesium Ratio		**Calculation: Calcium / Magnesium (cmol$_+$/kg)	0.5	2.7	1.8	1.2	1.1
pH		**Rayment & Lyons 2011 - 4B4 ($CaCl_2$)	6.28	5.75	5.38	5.85	6.66
Colour (Munsell Soil Colour Classification) - Hue/Colour		**Inhouse	7.5YR	7.5YR	10YR	10YR	10YR
Colour (Munsell Soil Colour Classification) - Value/Chroma		**Inhouse	5/6	3/2	5/2	6/2	6/3
Colour (Munsell Soil Colour Classification) - Mottle Hue, Value/Chroma, Proportion		**Inhouse	N/A	N/A	N/A	N/A	N/A

Southern Cross University
PO Box 157 Lismore NSW 2480
P: +61 2 6620 3678
E: eal@scu.edu.au
www.scu.edu.au/eal
ABN: 41 995 651 524

AGRICULTURAL SOIL ANALYSIS REPORT

20 samples supplied by SLR Consulting Australia Pty Ltd on 17th December, 2018. Lab Job No.H7007

Analysis requested by Murray Fraser. Your Job: Tarrawonga Alluvial

10 Kings Road NEW LAMBTON NSW 2305

		Sample 16	Sample 17	Sample 18	Sample 19	Sample 20
	Sample ID:	C2 70-80	C3 0-10	C3 30-40	C3 50-60	C3 60-70
	Crop:	N/G	N/G	N/G	N/G	N/G
	Client:	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial	Tarrawonga Alluvial
Parameter	Method reference	H7007/16	H7007/17	H7007/18	H7007/19	H7007/20

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013, Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
10. Conversions for 1 $cmol_+/kg$ = 230 mg/kg Sodium, 390 mg/kg Potassium, 122 mg/kg Magnesium, 200 mg/kg Calcium
11. Conversions to kg/ha = mg/kg x 2.24
12. The chloride calculation of Cl mg/L = EC x 640 is considered an estimate, and most likely an over-estimate
13. ** NATA accreditation does not cover the performance of this service.
14. Analysis conducted between sample arrival date and reporting date.
15. This report is not to be reproduced except in full.
16. All services undertaken by EAL are covered by the EAL Laboratory Services Terms and Conditions. These Terms and Conditions are available on the EAL website: scu.edu.au/eal, or on request.

Quality Checked: Kris Saville
Agricultural Co-Ordinator KS

Southern Cross University
PO Box 157 Lismore NSW 2480
P: +61 2 6620 3678
E: eal@scu.edu.au
www.scu.edu.au/eal
ABN: 41 995 651 524

AGRICULTURAL SOIL ANALYSIS REPORT

20 samples supplied by SLR Consulting Australia Pty Ltd on 17th December, 2018. Lab Job No.H7007

Analysis requested by Murray Fraser. Your Job: Tarrawonga Alluvial

10 Kings Road NEW LAMBTON NSW 2305

			Sample ID:	Heavy Soil	Medium Soil	Light Soil	Sandy Soil
			Crop:				
			Client:	Clay	Clay Loam	Loam	Loamy Sand
	Parameter		**Method reference**	**Indicative guidelines - refer to Notes 6 and 8**			
	pH		Rayment & Lyons 2011 - 4A1 (1:5 Water)	6.5	6.5	6.3	6.3
	Electrical Conductivity (dS/m)		Rayment & Lyons 2011 - 3A1 (1:5 Water)	0.200	0.150	0.120	0.100
	Exchangeable Calcium	**(cmol$_+$/kg)**	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	15.6	10.8	5.0	1.9
		(kg/ha)		7000	4816	2240	840
		(mg/kg)		3125	2150	1000	375
	Exchangeable Magnesium	**(cmol$_+$/kg)**		2.4	1.7	1.2	0.60
		(kg/ha)		650	448	325	168
		(mg/kg)		290	200	145	75
	Exchangeable Potassium	**(cmol$_+$/kg)**		0.60	0.50	0.40	0.30
		(kg/ha)		526	426	336	224
		(mg/kg)		235	190	150	100
	Exchangeable Sodium	**(cmol$_+$/kg)**		0.3	0.26	0.22	0.11
		(kg/ha)		155	134	113	57
		(mg/kg)		69	60	51	25
	Exchangeable Aluminium	**(cmol$_+$/kg)**	**Inhouse S37 (KCl)	0.6	0.5	0.4	0.2
		(kg/ha)		121	101	73	30
		(mg/kg)		54	45	32	14
	Exchangeable Hydrogen	**(cmol$_+$/kg)**	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	0.6	0.5	0.4	0.2
		(kg/ha)		13	11	8	3
		(mg/kg)		6	5	4	2
	Effective Cation Exchange Capacity (ECEC) (cmol$_+$/kg)		**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol$_+$/kg)	20.1	14.3	7.8	3.3
	Calcium (%)		**Base Saturation Calculations - Cation cmol$_+$/kg / ECEC x 100	77.6	75.7	65.6	57.4
	Magnesium (%)			11.9	11.9	15.7	18.1
	Potassium (%)			3.0	3.5	5.2	9.1
	Sodium - ESP (%)			1.5	1.8	2.9	3.3
	Aluminium (%)			6.0	7.1	10.5	12.1
	Hydrogen						
	Calcium/Magnesium Ratio		**Calculation: Calcium / Magnesium (cmol$_+$/kg)	6.5	6.4	4.2	3.2
	pH		**Rayment & Lyons 2011 - 4B4 ($CaCl_2$)	..			
	Colour (Munsell Soil Colour Classification) - Hue/Colour		**Inhouse	..			
	Colour (Munsell Soil Colour Classification) - Value/Chroma		**Inhouse	..			
	Colour (Munsell Soil Colour Classification) - Mottle Hue, Value/Chroma, Proportion		**Inhouse	..			

Southern Cross University
PO Box 157 Lismore NSW 2480
P: +61 2 6620 3678
E: eal@scu.edu.au
www.scu.edu.au/eal
ABN: 41 995 651 524

AGRICULTURAL SOIL ANALYSIS REPORT

20 samples supplied by SLR Consulting Australia Pty Ltd on 17th December, 2018. Lab Job No.H7007

Analysis requested by Murray Fraser. Your Job: Tarrawonga Alluvial

10 Kings Road NEW LAMBTON NSW 2305

			Heavy Soil	***Medium Soil***	***Light Soil***	***Sandy Soil***
		Sample ID:				
		Crop:				
		Client:	*Clay*	*Clay Loam*	*Loam*	*Loamy Sand*
	Parameter	**Method reference**	**Indicative guidelines - refer to Notes 6 and 8**			
Notes:						

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013,
Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
10. Conversions for 1 $cmol_+/kg$ = 230 mg/kg Sodium, 390 mg/kg Potassium,
122 mg/kg Magnesium, 200 mg/kg Calcium
11. Conversions to kg/ha = mg/kg x 2.24
12. The chloride calculation of Cl mg/L = EC x 640 is considered an estimate, and most likely an over-estimate
13. ** NATA accreditation does not cover the performance of this service.
14. Analysis conducted between sample arrival date and reporting date.
15. This report is not to be reproduced except in full.
16. All services undertaken by EAL are covered by the EAL Laboratory Services Terms and Conditions.
These Terms and Conditions are available on the EAL website: scu.edu.au/eal, or on request.

Quality Checked: Kris Saville
Agricultural Co-Ordinator KS