Appendix A

Numerical model development

A1 Overview

The numerical groundwater model used in the preparation of this report was based on the BTM Complex numerical model, in which the Maules Creek, Boggabri and Tarrawonga coal mines are simulated concurrently to assess their cumulative impact.

Each of the mines within the BTM Complex is approved under Section 75J of the NSW *Environmental Planning & Assessment Act 1979*. The respective approvals include conditions to:

- prevent, minimise and offset adverse environmental impacts;
- set standards and performance measures for acceptable environmental performance;
- require regular monitoring and reporting; and
- provide for the ongoing environmental management of the project.

The Project Approval documents set out conditions for all aspects of the project, i.e. noise, blasting, air quality, biodiversity, heritage, water. Schedule 3 within the Project Approval outlines Environmental Performance Conditions including those that relate to groundwater. Each of the BTM Complex mines are required to prepare:

> *'a Groundwater Management Plan, which includes …a program to validate the groundwater model for the project, including an independent review of the model every 3 years, and comparison of monitoring results with modelled predictions.'*

With respect to the prescribed three yearly model validation/updates, the AGE (2020) model was first submitted in 2018. Due to comments received from NRAR and the water division of DPIE, the BTM Complex commissioned updates to both the conceptual and numerical models. The result of these updates is presented in the AGE (2020) model update report, and the associated numerical model has been adopted and amended, where appropriate, for this MOD 8 impact assessment.

At present, following consultation with NRAR and the water division of DPIE, the AGE (2020) model update report is undergoing some minor amendments. These updates largely relate to further clarification on model boundaries, model parameterisation, and the manner in which surface water-groundwater interactions are modelled.

A2 Model objectives

Predictive numerical modelling was undertaken to assess the impact of MOD 8 on the groundwater regime. The main objective was to assess risks to the groundwater regime using a groundwater model to systematically investigate the causal pathways for potential impacts on groundwater resources and groundwater dependent assets. The numerical modelling was completed in a manner to allow for an assessment of both cumulative impacts, as well as incremental impacts that are specific to MOD 8. Predictive outputs from the basecase model (the 'best' calibrated model) have been provided and discussed within the main report.

A successful model provides predictions of future impacts that are useful for all stakeholders. This does not mean that the model can perfectly represent past and future changes within the groundwater regime, but simply that it is a useful assessment tool. Accurately matching historical water levels and water flows does not necessarily mean a model can predict future behaviour of a groundwater system.

A3 Model construction and development

A3.1 Model code

The model was developed using the MODFLOW-USG (MFUSG) modelling package, which is consistent with the approach adopted in the AGE (2018) model. MFUSG is considered superior to previous versions of MODFLOW as it allows the use of an unstructured model mesh (from triangles to n-sided polygons), meaning that the model grid can be designed to fit environmental features such as rivers, water bodies and excavations etc. MFUSG is numerically stable and does not require continuous layers; meaning it can simulate geological units that pinch out or subcrop, such as coal seams. Flow transfer processes between layers that are not directly connected such as bedrock and alluvium can therefore be more accurately represented and simulated.

The amount of water level monitoring data available for the BTM Complex now means that trial and error selection of model properties is not an efficient method to calibrate the model. The typically faster run times associated with MFUSG mean that the code is well-suited to automated calibration. In addition, MFUSG is not restricted by licence agreements, allowing numerous iterations of the model to be run simultaneously. This can reduce the total time taken for model calibration, and uncertainty analysis where required.

The model was created using Fortran code and a MFUSG edition of the Groundwater Data Utilities by Watermark Numerical Computing. The model mesh was updated using Algomesh (HydroAlgorithmics, 2014).

A3.2 Model design

A3.2.1 Extent and boundaries

The model domain was centred on the approved mining activities in the BTM Complex. The model covers the main sensitive receptors, being alluvial management zones to the north, west and south of the complex. The eastern extent of the model is constrained by the Mooki Thrust System, which represents the extent of the Maules Creek sub-basin, and a change in hydrogeological regime to an area less sensitive to environmental impact from the BTM Complex. The model domain is approximately 30 km wide and 40 km long, with the Mooki Thrust System defining the eastern edge of the model, as shown in Figure A 3.1.

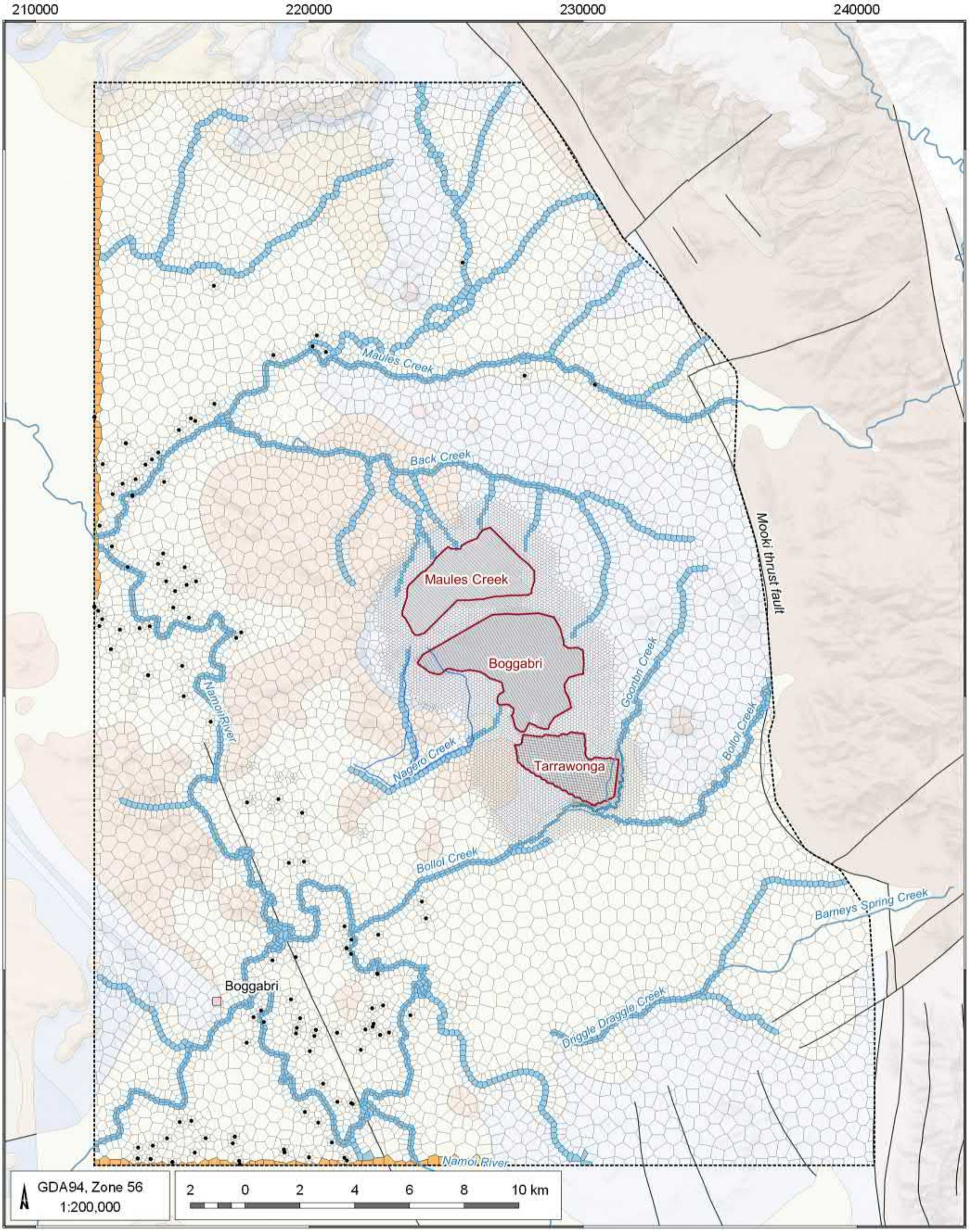
Boundary conditions are consistent with conceptual hydrogeological understandings of the area, with groundwater flow in/out of the model largely occurring through the alluvium, and the Mooki Thrust system representing a change in hydrogeological regime. Adopted boundary conditions are:

- a ‘no flow’ boundary along the Mooki Thrust System (eastern model extent);
- General Head Boundaries (GHB) in alluvial layers along the southern and western boundaries of the model (Figure A 3.2) where alluvial groundwater enters and leaves the model respectively; and
- ‘no-flow’ boundaries along the remainder of the northern, western and southern boundaries.

A3.2.1.1 Consideration of other mining activities

Mining operations that were not incorporated into this project's numerical model and the rationale for not including these operations are detailed below.

- Modification 7 for the Tarrawonga Mine (adjacent to BCM) – The approval for this modification was granted in February 2021, which postdates the numerical modelling and reporting completed for MOD 8. The groundwater assessment for the Tarrawonga modification (HydroSimulations, 2019) indicates that a reduction in the extent of the open cut reduces the impact of the operation to surrounding groundwater systems. As such, the modelling completed as part of this assessment can be considered a conservative prediction of cumulative impacts.
- The Vickery Mine (14 km south of BCM) – Groundwater modelling that was completed as part of the EIS for Vickery Mine Extension SSD (HydroSimulations, 2018b) predicts that the maximum water table drawdown will largely be limited to the area of Permian outcrop adjacent to the operation. As such, when considered in addition to the BTM Complex mines, any further cumulative impacts to alluvial aquifers are unlikely.
- The Narrabri Mine (27 km west-northwest of BCM) – Mining as part of this operation takes place in Mullaley Sub-basin, which is separated by the Boggabri Ridge from Maules Creek Sub-basin that is mined by the BTM Complex. The Boggabri Ridge is comprised of the Boggabri Volcanics, which are known to be of very low permeability/impermeable, and cumulative impacts within each of the respective coal measures is therefore unlikely. Additionally, neither the BTM Complex or the Narrabri mine are modelled to have any significant or extensive drawdown in the Namoi alluvium (AGE 2020; AGE, 2020b).



LEGEND

- Populated place
- Abstraction bore
- Major drainage
- Extent of mining
- Model extent
- Constant head cell
- River cell
- Mesh

Gunnedah Coalfield rock unit (1:100k)

- Qx - Quaternary Sediments
- Tv - Tertiary Volcanics
- Pmx - Maules Creek and Goonbri formations
- Plf - Leard Formation
- Pbr - Boggabri Volcanics
- Cbc - Currabubula Formation
- Crc - Rocky Creek Conglomerate
- Fault

Boggabri MOD8 (G1850W)

Model domain

AGE

DATE 14/07/2021

FIGURE No: **A 3.1**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\A 03.01_G1850W_Model domain.qgs

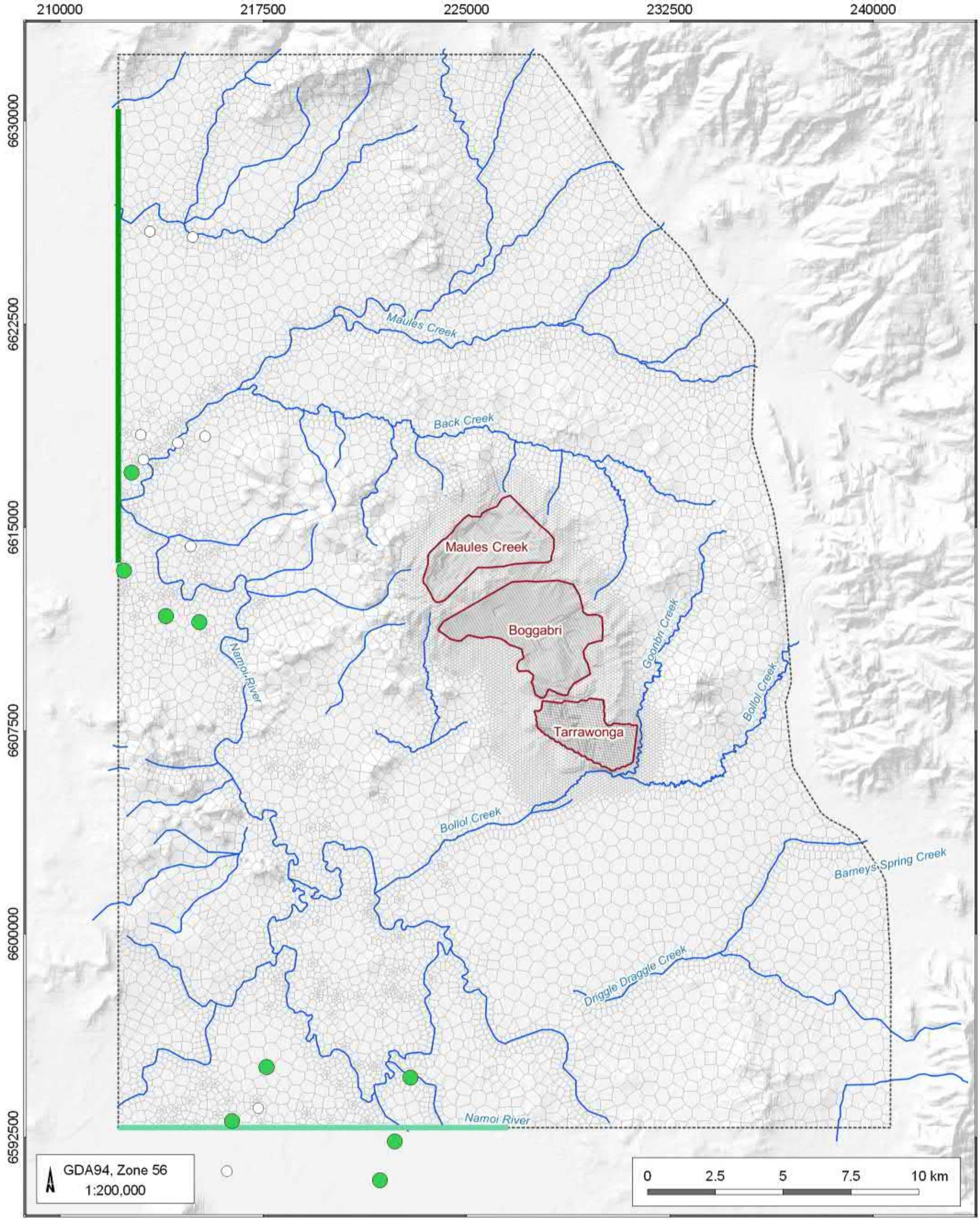
A3.2.2 General head boundaries

Groundwater levels at the general head boundaries (GHBs) were determined based on the average groundwater levels measured in monitoring bores in proximity to the model boundary. The GHBs were setup in the numerical groundwater model to represent alluvial groundwater entering and leaving the model. The GHB zones are displayed in Figure A 3.2. The GHB cells were only represented in model layers 1 and 2 to represent flow in the Quaternary alluvium.

An analysis of observed groundwater levels in the vicinity of each GHB zone was performed with the objective of establishing the input levels for the numerical simulation. The existing government bores are displayed in Figure A 3.2, and their levels are presented in Figure A 3.3 to Figure A 3.6.

Figure A 3.3 includes all the levels available in the vicinity of the Western GHB since 2005 (the numerical simulation starts in 2006). High variability across the levels from different monitoring bores can be observed, with some relatively high levels caused possibly by locally perched groundwater, and some lower levels where pumping abstraction is evident. Both of those effects have a masking effect over the less disturbed groundwater level of the general alluvial system; and were therefore filtered out in Figure A 3.4. Figure A 3.4 displays the levels that better represent the less disturbed alluvial groundwater system. The levels displayed in Figure A 3.4 are relatively well grouped and oscillate together, suggesting they do not represent localised perched systems; they also display less pumping effects compared to the previous figure. The groundwater level in the bores displayed in Figure A 3.4 oscillates around 225 mAHD, and therefore this value was used in the setup of the Western GHB in the numerical groundwater model.

Figure A 3.5 includes all the levels available in its vicinity since 2005. High variability across the levels from different monitoring bores can be observed, with a few relatively high levels again possibly caused by locally perched groundwater, and some lower levels where pumping abstraction is again evident. Again, these effects were filtered out in Figure A 3.6 to determine the level to adopt in the numerical model. The groundwater level in the bores displayed in Figure A 3.6 oscillates around 235 mAHD, and therefore this value was used in the setup of the Southern GHB in the numerical groundwater model.



LEGEND

Monitoring bores used in model

- no
- yes

GHB zones

- south
- west

- Drainage
- Model extent
- Mesh
- Extent of mining

Boggabri MOD8 (G1850W)

GHB and monitoring locations in their vicinity

AGE

DATE 14/07/2021

FIGURE No: **A 3.2**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\A 03.02_G1850W_GHB and monitoring locations in their vicinity.qgs

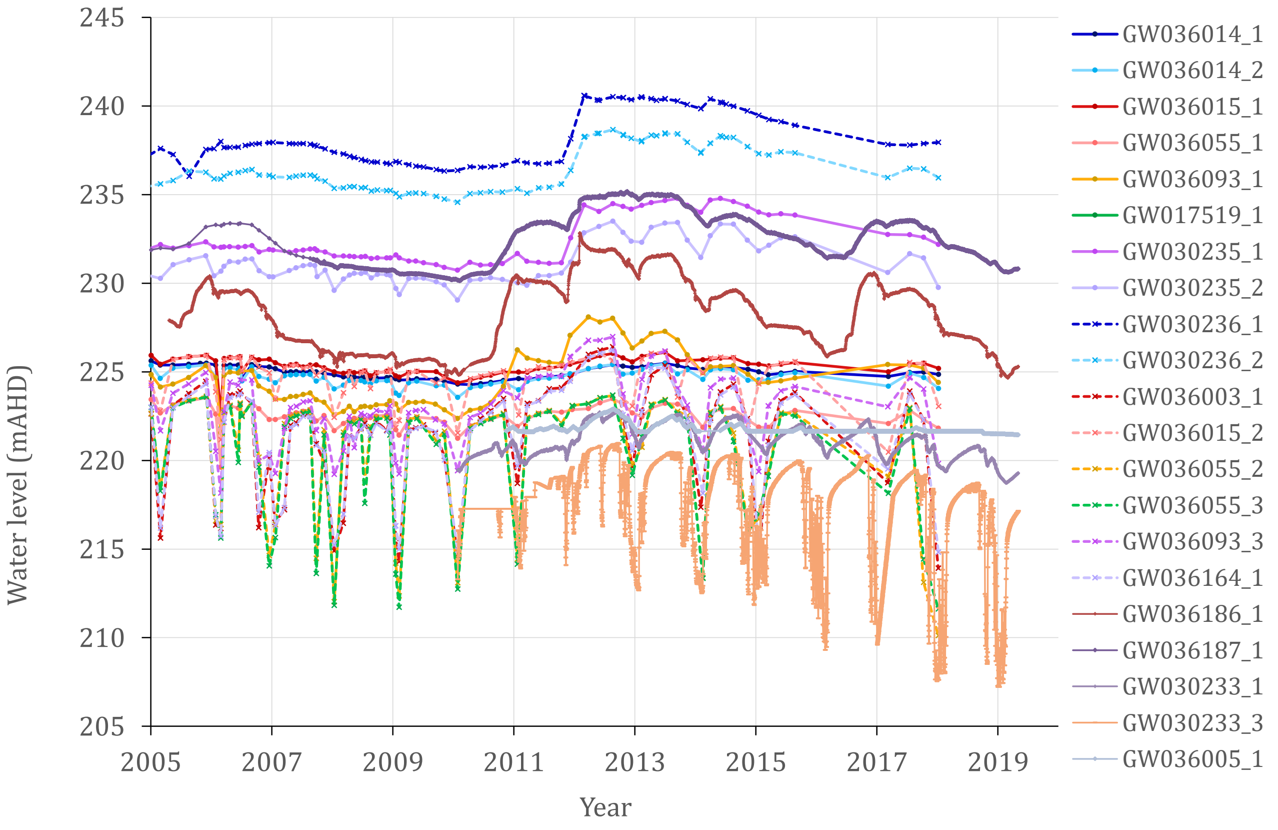


Figure A 3.3 Observed groundwater levels in the vicinity of the Western GHB

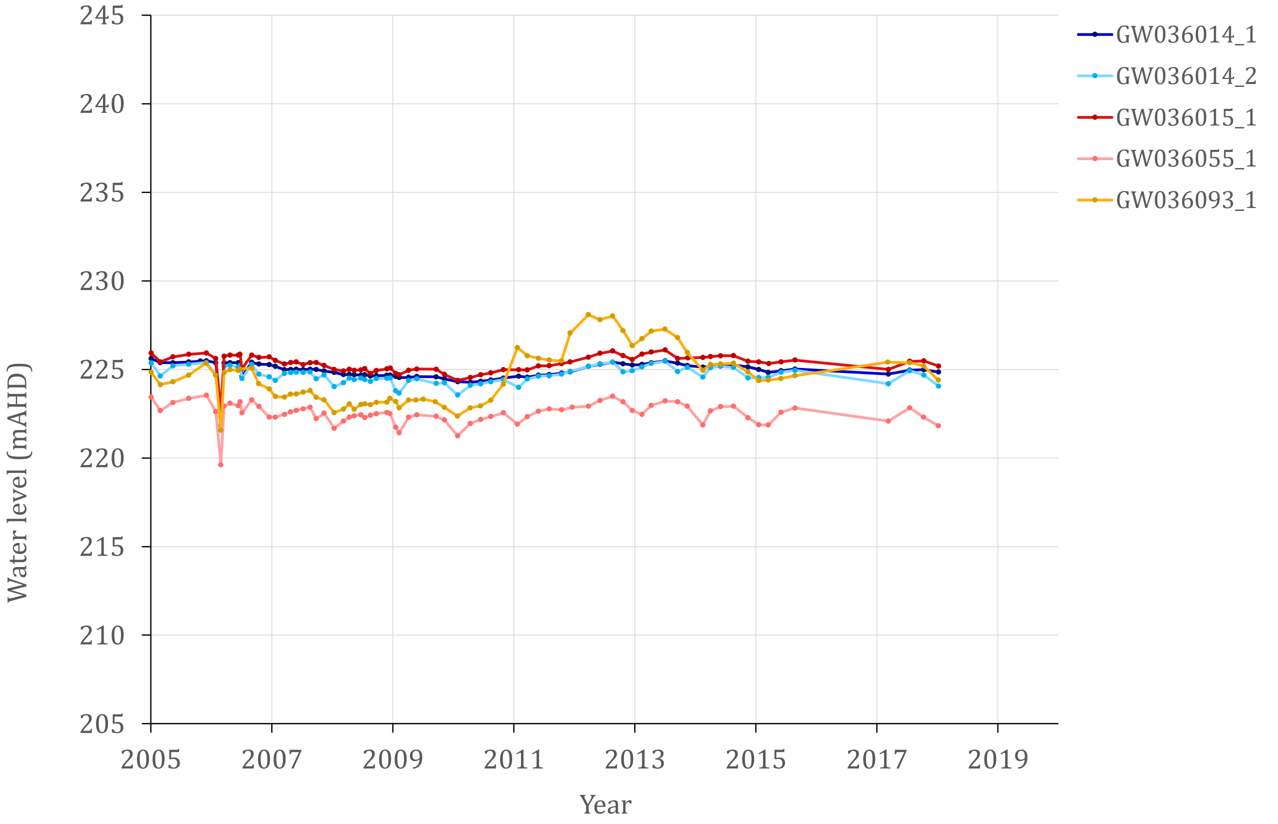


Figure A 3.4 Subset of the observed groundwater levels in the vicinity of the Western GHB

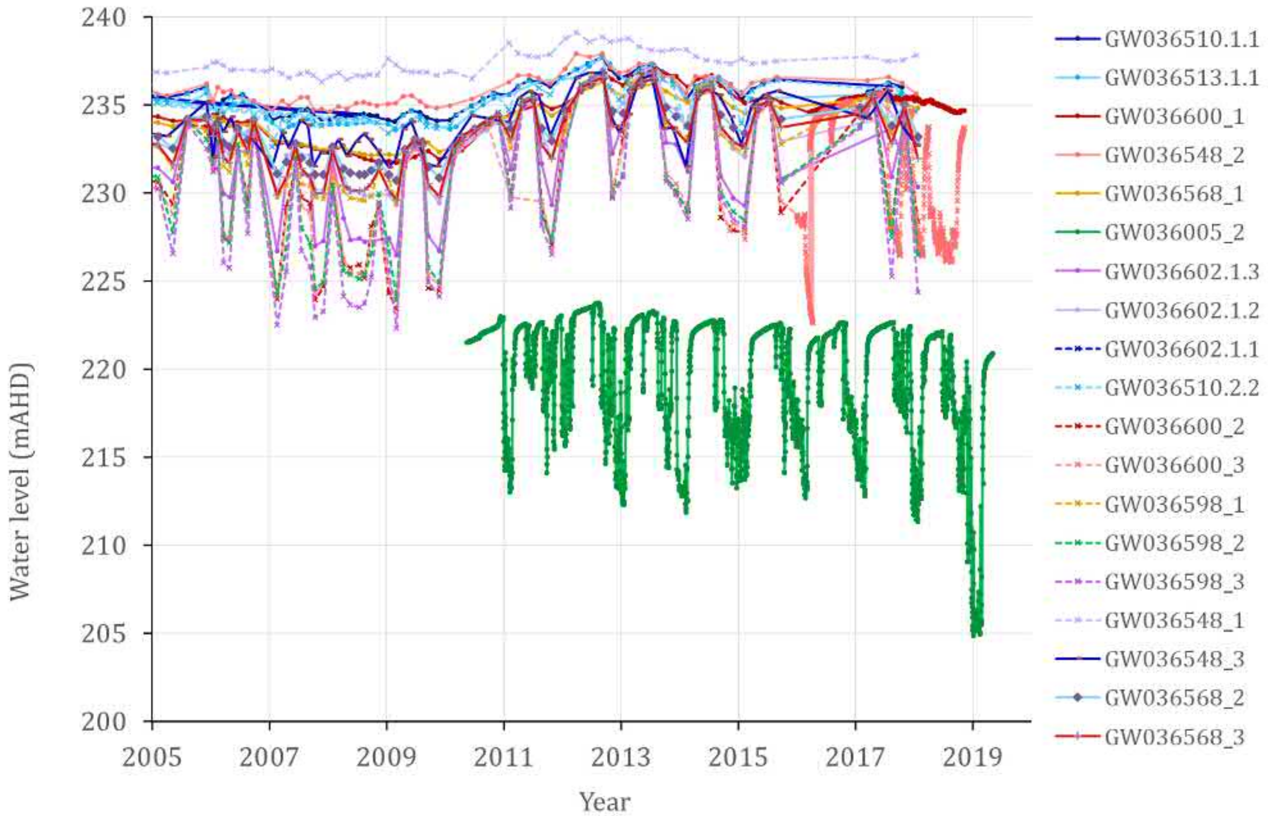


Figure A 3.5 Observed groundwater levels in the vicinity of the Southern GHB

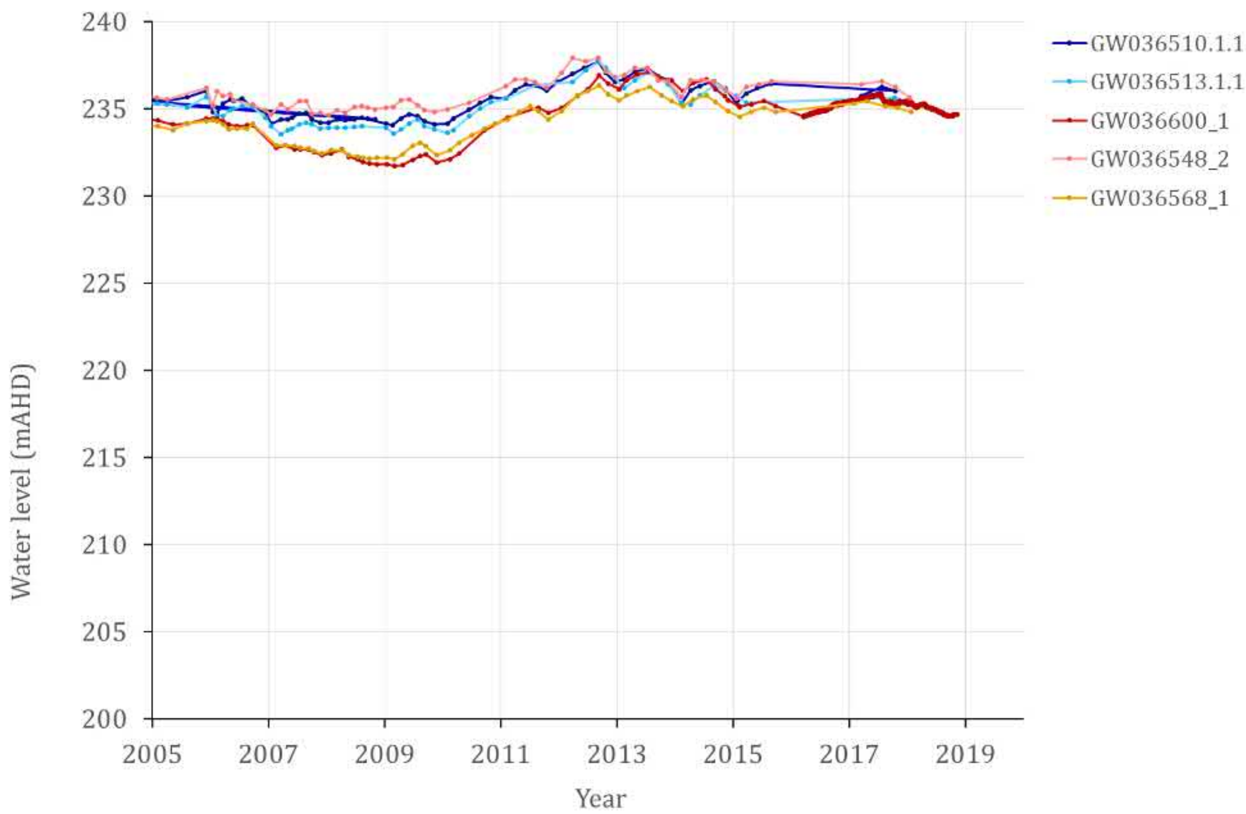


Figure A 3.6 Subset of the observed groundwater levels in the vicinity of the Southern GHB

A3.2.3 Grid

The model grid was comprised of two types of cells, namely rectangular cells aligned with the primary direction of mining for each of BTM mines, and voronoi polygons for the remainder of the model area. The following cell dimensions were adopted:

- mining areas – 100 m x 50 m cells;
- adjacent to major creeks and rivers – 200 m x 200 m voronoi cells;
- buffer zone around mining area (contains most monitoring bores) – 100 m diameter voronoi cells;
- adjacent to active extraction bores – approximately 175 m diameter voronoi cells;
- adjacent to inferred Conomos Fault – approximately 450 m x 350 m voronoi cells; and
- away from areas of interest – approximately 650 m maximum diameter voronoi.

The adopted grid represents a maximum of 18,920 cells per layer, as shown in Figure A 3.1.

A3.2.4 Model layers

The key hydrostratigraphic units identified in the conceptual model are represented in the numerical model by 34 separate model layers (Table A 3.1). Previous versions of the BTM Complex numerical model lumped the 16 known coal seams into 'super seams' that represent multiple coal seams in single layers in the numerical model. This approach has been taken in the past to ensure the run time of the numerical model remained manageable given the computing technology at the time.

The updated version of the BTM Complex model resulted in an increase in the number of model layers from 19 model layers AGE (2018) model to 34, representing a gradual improvement in the representation of the hydrostratigraphic units (Table A 3.1). The purpose of introducing the additional model layers was to improve the ability of the model to represent observed pressure heads in coal seam bores and VWPs.

Table A 3.1 Model layer changes

Model layer		Geological unit
2018 model	2020 model	
1	1	Narrabri Formation (alluvium)
2	2	Gunnedah Formation (alluvium)
3	3	Interburden
4	4	Interburden
5	5	Herndale seam
5	5	Onavale Seam
5	5	Teston Seam
5	5	Thornfield Seam
6	6	Interburden
7	7	Interburden
8	8	Braymont Seam
8	9	Interburden
8	10	Interburden
8	11	Bollol Creek Seam
8	12	Interburden
8	13	Interburden
8	14	Jeralong Seam

Model layer		Geological unit
2018 model	2020 model	
8	15	Interburden
8	16	Interburden
8	17	Merriown Seam
9	18	Interburden
10	19	Interburden
11	20	Velyama Seam
11	20	Nagero Seam
12	21	Interburden
13	22	Interburden
14	23	Upper Northam Seam
14	23	Lower Northam Seam
14	24	Interburden
14	25	Interburden
14	26	Therribri A Seam
14	26	Therribri B Seam
14	27	Interburden
14	28	Interburden
14	29	Flixton Seam
15	-	Interburden
16	-	Interburden
17	29	Tarrawonga Seam
17	30	Interburden
17	31	Interburden
17	32	Templemore Seam
18	33	Interburden
19	34	Volcanics

Updates were also made to the elevation of the selected layers in the numerical model based on new information collected from a range of sources. Table A 3.2 details the geological datasets used to update the elevation of selected model layers.

Table A 3.2 Geological model data sources

Data source	Area of application in numerical model	Changed from AGE (2018)	Note
Geological models from BTM mines [a]	Within each mines footprint	Yes	Surfaces updated including topography, base of weathering, coal seams, interburden and basement volcanics
JB Mining (2010) regional geological model	Entire model extent outside of each mine's disturbance footprint	No unchanged	Only includes coal measures and basement volcanics
CSIRO depth of regolith dataset [b]	Entire model extent outside of each mine's disturbance footprint	Yes	No regolith/weathering applied under areas of alluvium
NSW Government Upper Namoi alluvial groundwater flow model [c]	Used to update base of alluvium	Yes	Alluvial groundwater information provided by NSW Government.
NSW Government 5 m DEM [c]	Entire model extent outside of each mine's disturbance footprint	Yes	2016 acquisition date

Notes: (a) Model surfaces for Boggabri, Tarrawonga and Maules Creek Mines received in May 2019.
(b) https://aclep.csiro.au/aclep/soilandlandscapegrid.
(c) https://elevation.fsdf.org.au.

The model layers for the coal seams in previous iterations of the BTM Complex numerical model were based on a regional geological model prepared by JB Mining (2010) as part of the Maules Creek Mine approval process. The coal seam surfaces in the numerical model were updated in the mining areas using geological models provided by each of the BTM Complex mines. The geological surfaces provided by each mine were combined into a single geological model created using Seequent's Leapfrog Geo software package before being imported into the numerical model.

The NSW government also provided surfaces from an updated numerical groundwater flow model of the Namoi alluvium. The layers from this model were used to update the elevation of the alluvium in the BTM Complex model. The land surface in the model and the depth of regolith was also updated using publicly available datasets as detailed in Table A 3.2.

The updates to the numerical model layers resulted in improved representation of geological layers as well as terrain features including regional drainage lines.

Geological structures

Smaller localised faults, which have been observed in each mine's open cut pit, are conceptualised to have no significant impact on regional flow. These faults are not represented in the numerical model.

The Conomos Fault was identified during the BTM Complex model update through consultation with geologists working at the BTM Complex. As discussed in Section 4.6, the Conomos Fault appears to be a significant geological feature and has an interpreted displacement of 60 m to 90 m immediately to the south of Tarrawonga operations. Given the potential for this fault to cut and offset the continuity of the coal seams to the south of the BTM Complex, it was represented as a barrier to groundwater flow in the updated numerical model. The conductance was allowed to vary between 0% and 100% during calibration (see Section A4.3.3).

The Mooki Thrust System is represented as a no flow barrier as it represents the boundary between the edge of the Maules Creek sub-basin and the non-coal New England fold belt.

As discussed in Section 6.2, detailed mapping and characterisation of regional faults in the model extent is sparse, although available sources generally agree that they are likely present to some degree. As such, the current representation of faulting in the numerical model may be somewhat limited relative to their actual presence. This potential under-representation is typical in numerical groundwater models, although it is an important feature to highlight given the implications it can have on model calibration/predictions. Conceptually, this may be a factor contributing to the conservative predictions of drawdown that are not consistent with observations away from the mining area.

A3.2.5 Timing

To guide the model calibration, an initial steady state calibration to obtain pre-mining conditions was undertaken. This was followed by a transient simulation for the purposes of calibration, where groundwater levels and flows were matched to available measurements. Stress periods remained consistent with AGE (2018), i.e. quarterly stress periods, with the updated transient model consisting of 55 quarterly stress periods running from January 2006 to June 2019.

A3.2.6 Mining progression for the BTM Complex model

Time dependent mining progressions were used to represent approved mining in the model and were established using pit shell surfaces for historical progressions, with 3D staged mine plan surfaces/polygons used for future progressions. Datasets were provided independently by Boggabri, Tarrawonga and Maules Creek mines. A summary of the adopted data is provided below.

Table A 3.3 Mining progression dataset details for BTM Complex model

Mine	Year historical pit shells available to	Year mine plans extend to	Deepest seam intersected by mining	Equivalent layer in groundwater model
Boggabri	2018	2033	Merriown	17
Tarrawonga	2019	2029	Nagero	20
Maules Creek	2019	2036	Templemore	32

The timing and location of mining represented within the numerical model contains an unavoidable element of uncertainty. Middlemis and Peeters (2018) categorise this as ‘scenario uncertainty’. This is because records of historical mining can be difficult to obtain or are necessarily simplified and assumptions on the progress of mining operations, particularly older operations are therefore required. The exact advancement of future mining operations is also uncertain as all mining operations are subject to market conditions that can alter the economics of projects. The historical and future mining represented within the numerical model should therefore be considered a guide rather than highly accurate. Despite these unavoidable limitations, the model is considered to largely have mining represented where it has occurred historically and is approved to occur in the future; it is only the timing and elevation of the mining that has a level of uncertainty.

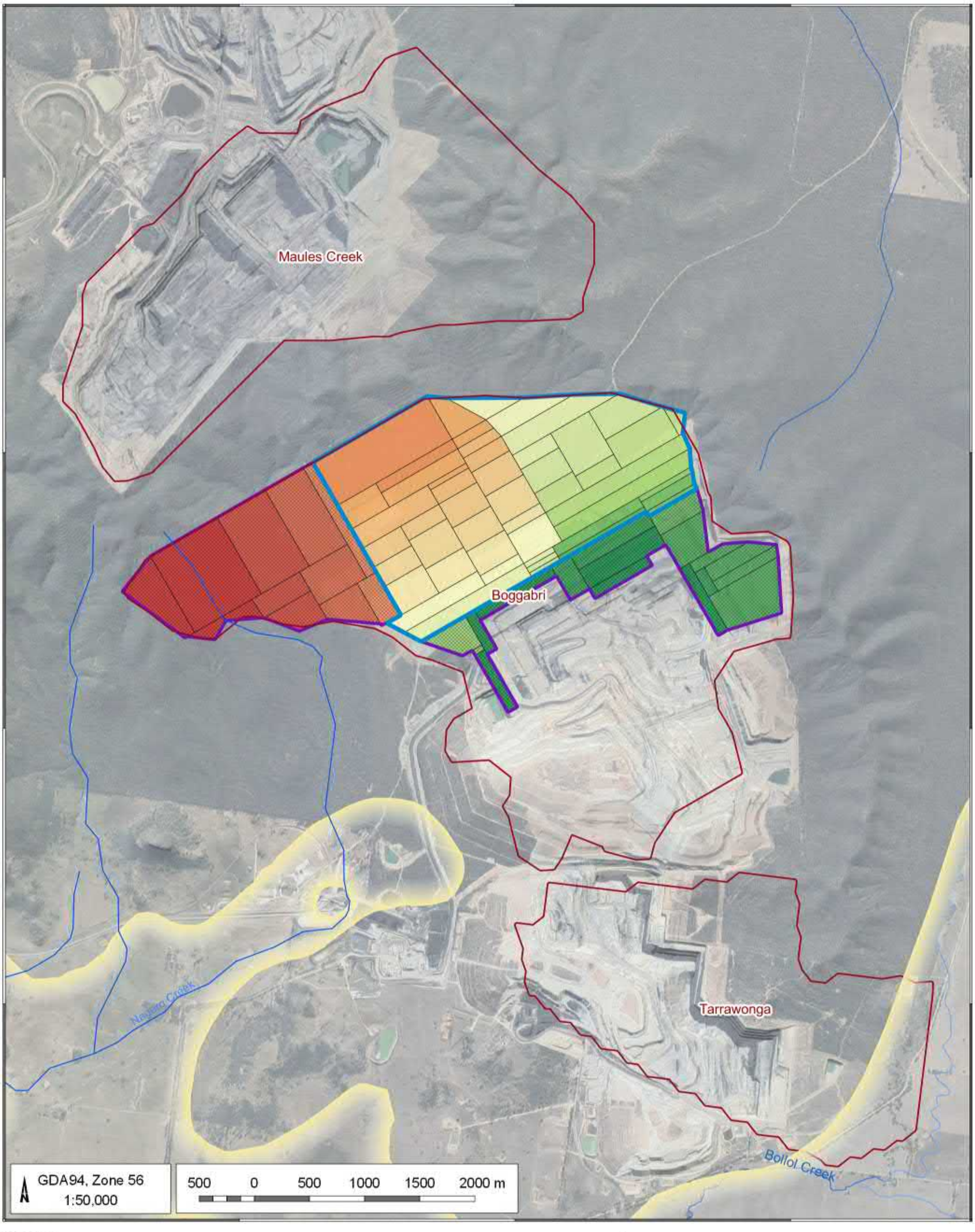
The uncertainty in the location and progression of mining has potential to influence the calibration of the model in areas where water level calibration points are situated in close proximity to mining activities. In areas more distant from mining activities the uncertainties in the historical progression of mining obviously become less influential on the model predictions.

A3.2.7 Mining progression for MOD 8 at BCM

MOD 8 at BCM includes mining of coal to the Templemore seam, with a greater life of mine. Consequently, mining at Boggabri was extended to the end of 2039 (Table A 3.4), while mining at Maules Creek and Tarrawonga mines was unchanged. The mining progression per year can be seen in Figure A 3.7.

Table A 3.4 Mining progression dataset details for MOD 8

Mine	Year historical pit shells available to	Year mine plans extend to	Deepest seam intersected by mining	Equivalent layer in groundwater model
Boggabri	2018	2039	Templemore	32
Tarrawonga	2019	2029	Nagero	20
Maules Creek	2019	2035	Templemore	32



LEGEND

- Drainage
- Extent of mining
- Alluvial boundary zones
- To Layer 17 – Merriown seam
- To Layer 32- Templemore seam

Mine progression (Year)

2020	2030
2021	2031
2022	2032
2023	2033
2024	2034
2025	2035
2026	2036
2027	2037
2028	2038
2029	2039

Boggabri MOD8 (G1850W)

Annual mining progression for Boggabri mine

AGE

DATE 14/07/2021

FIGURE No: **A 3.7**

Source: LiDAR DEM © Department Finance, Services and Innovation, 2016; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\A 03.07_G1850W_Annual mining progression for Boggabri mine.qgs

A3.2.8 Recovery simulations for MOD 8

The post-mining residual impact to the groundwater system was assessed for 1,000 years by continuing the simulation under long-term average climatic drivers. The recovering water table within each void was observed until it reached equilibrium (refer to Section 8.2.2).

The mines were backfilled with spoil emplaced between the base of mine and the proposed final landform, while open void space was simulated between the final landform elevation and the pre-mining topography. Appropriate hydraulic parameters were applied to both spoil and void zones (Table A 3.5).

Recharge to the spoil was taken as the 5.5% of average annual rainfall documented in Mackie (2009), with the 1% alternative chosen as a realistic estimate for Australian forests. Evaporation from the void was taken as the average annual pan evaporation from the Bureau of Meteorology (SILO) database for Boggabri (-30.70º E, 150.05º S). Morton's areal actual evapotranspiration (from SILO at the same location) was chosen to represent evapotranspiration (ET) from the spoil. Morton's areal actual ET takes into account the available moisture based on climatic records and modelling rather than being a measure of potential ET where the soil is well watered. The ET extinction depth was taken as nominal values of 0.5 m representing evaporation from bare soil, and 2 m representing a vegetated surface. The recharge and ET parameters used in the recovery scenarios are documented in Table A 3.6.

A sensitivity analysis was undertaken to determine how changes to the model parameters influenced the equilibrium water level and time to equilibrium. Two alternate recovery scenarios were considered. In the first scenario, the hydraulic conductivity and specific yield of the spoil was reduced an order of magnitude, while in the second the spoil recharge rate was reduced to 1% of the long term average rainfall.

Table A 3.5 Hydraulic properties of spoil and void for recovery scenarios

Strata	Scenario	Hydraulic conductivity (m/day)	Vertical Conductivity (m/day)	Specific yield (%)	Specific Storage (1/m)
Spoil	Base scenario	0.3	0.1	0.1	1.0E-05
	Reduce K/Sy	0.03	0.01	0.01	1.0E-05
	Reduce recharge	0.3	0.1	0.1	1.0E-05
Void	Base scenario Reduce K/Sy Reduce recharge	1000	1000	1	5.0E-06

Table A 3.6 Recharge and evapotranspiration parameters for recovery scenarios

Strata	Scenario	Recharge (mm/year)	Recharge (% of average rainfall)	ET rate (mm/year)	ET extinction depth (m)
Spoil	Base scenario Reduce K/Sy	29.9	5.5	710	2
	Reduce recharge	5.4	1		
Void	Base scenario Reduce K/Sy Reduce recharge	543	100	1903	0.5

A3.3 System stresses

A3.3.1 Recharge

Recharge to the groundwater systems occurs through diffuse infiltration of rainfall through the soil profile and subsequent deep drainage to underlying groundwater systems. A spreadsheet-based soil moisture calculation was used to estimate the timing and magnitude of recharge events used in the model. The simple soil moisture balance provided estimates of when the soil profile was fully saturated following rainfall, and when subsequent deep drainage to the water table occurred.

The MFUSG recharge package (RCH) was used to represent diffuse rainfall recharge to model layer 1. The upstream weighting function with the CONSTANTCV option was selected and therefore flow through the vadose zone was not simulated in the model. Recharge zones were assigned for the Permian coal measures, Boggabri Volcanics, Quaternary alluvium, the break of slope zone occurring at the boundary between the Permian ridge area and the alluvial flood plain and at the Boggabri-Tarrawonga CHPP area, where land-use has altered recharge conditions.

Recharge to the model cells within each zone was adjusted during the pilot point calibration process, with the resulting recharge rates displayed in Figure A 3.8. Recharge to the Permian coal measures and Boggabri Volcanics was negligible at 0 mm to 0.8 mm/year, though recharge was enhanced at the break of slope along the Permian Ridge. Recharge to the alluvium ranged from 20 mm to 30 mm/year and was enhanced along waterways within the alluvial zones (40 mm to 100 mm/year), representing losses from losing streams during flow events.

A3.3.2 Surface drainage

The Namoi River was represented using the stream (STR) package in MFUSG, with a 30 m wide, 2 m thick sloping stream bed incised 1.9 m into the landscape (Figure A 3.9). Flow in the river from outside of the model domain was simulated using quarterly flow observations at the upstream model boundary.

The major ephemeral creeks were represented using the MFUSG river package (RIV). The bed levels for the creeks were based on previous observations over the area, and were set by subtracting the average river depth from the topography. All creek beds were less than or equal to 1.9 m deep based on observations in the region. The river cells in the model were assigned a water level equal to the base elevation, hence they can only simulate the “drainage” of water out of the aquifer where and when the groundwater levels are high enough.

The proposed diverted alignment of Goonbri Creek was represented in the model from the commencement of the calibration period in 2006. The water table within the model was below the base of Goonbri Creek and therefore the calibration was not considered sensitive to the creek location as it does not interact with shallow groundwater.

A3.3.3 Evapotranspiration

A review of the depth to water table was undertaken to determine if evapotranspiration was a significant discharge mechanism for groundwater in the region. The steady state numerical model indicated the depth to the water table is a function of topography, being very deep in the ridge areas and closer to the land surface in the lower lying alluvial plains. In the area where the BTM Complex mines are situated the water table is commonly over 50 m to 100 m below the surface and evapotranspiration therefore does not occur. The alluvial plains also have simulated groundwater levels exceeding 2 m below the land surface and again were considered to have limited evapotranspiration, particularly considering the plains are largely cleared of deep rooted trees and vegetation. For these reasons’ evapotranspiration was not represented in the numerical model.

A3.3.4 Abstraction

Private abstraction from irrigation bores was represented in the model using the MODFLOW well package. Actual abstraction rates for the 2006 to 2019 period were provided by DPIE following stakeholder meetings. This is a significant improvement on the 2018 iteration of the model, which only had access to abstractions recorded in the 2006 to 2010 period. Locations of private abstraction bores, which are active in the model over the period 2006 to 2019 period are shown in Figure A 3.10.

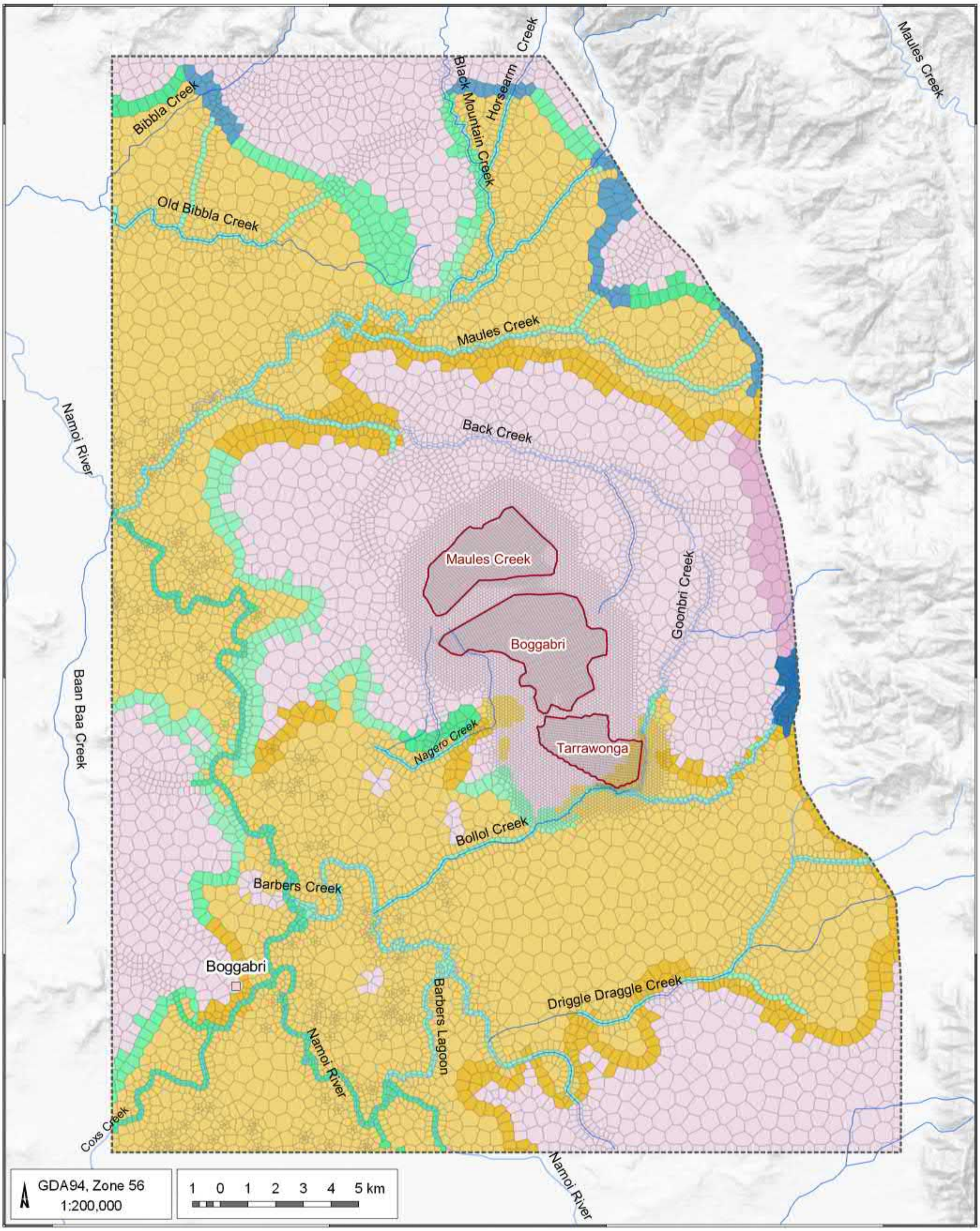
Abstraction data was incorporated into the model at quarterly stress periods. Where meter readings of the provided dataset were less frequent than quarterly, the data was normalised linearly to represent quarterly periods (e.g. an abstraction of 60 ML over three quarters was converted to 20 ML over each quarter). Alternatively, where more than a single reading was taken during the quarter, abstraction data was averaged for that period.

Some differences between new abstraction dataset and the old dataset were noted during processing. In each dataset, total abstraction for the 2006 to 2010 period is approximately equal, although the timing of the extractions does vary. A reason for this could not be determined, but is not considered to have significantly influenced the model predictions.

A3.3.5 Mining

The model represents mining activities using the MODFLOW drain (DRN) package, with the progression of mining over time based on the schedules provided by BTM mines. Drain cells were applied to all intersected model cells, with reference elevations set to the floor of each cell, down to the coal seam targeted for extraction by mining. A nominally high drain conductance of 100 m^2/day was applied to the drain cells to ensure unhindered flow of groundwater into the cell.

Accumulation of spoils was not represented within the model, with the pit shells represented as fully drained for the entire period of approved mining.



LEGEND

- Populated place
- Drainage
- Model mesh
- Model extent
- Extent of mining

Recharge (mm/year)

- 0.0 - 0.8
- 0.8 - 2
- 2 - 20
- 20 - 30
- 30 - 40
- 40 - 60
- 60 - 80
- 80 - 100
- 100 - 200
- 200 - 400

Boggabri MOD8 (G1850W)

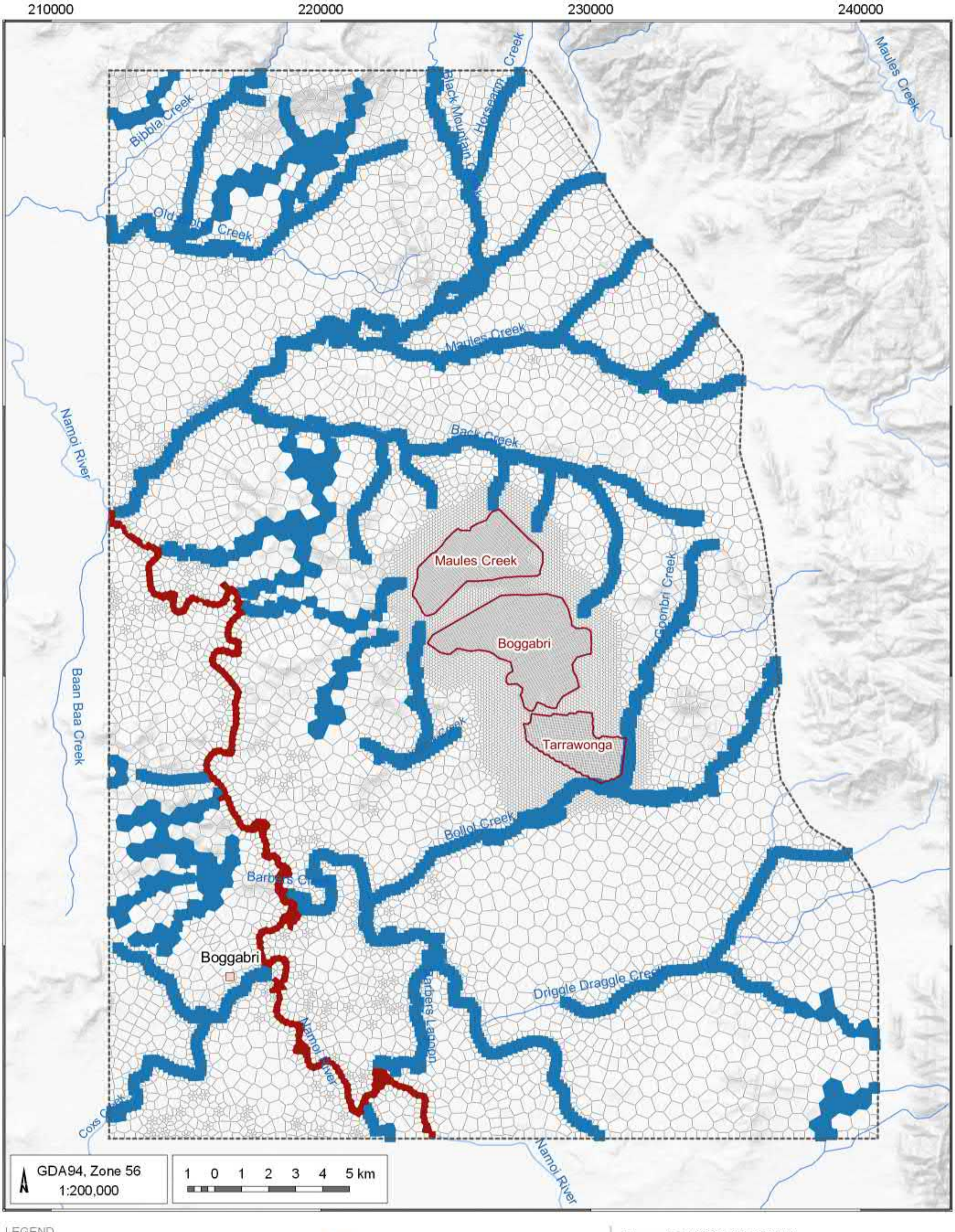
Rainfall recharge zones

AGE

DATE
14/07/2021

FIGURE No:
A 3.8

Source: LiDAR DEM © Department Finance, Services and Innovation, 2016; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\A 03.08_G1850W_Rainfall recharge zones.qgs



LEGEND

- Populated place
- Drainage
- Model extent
- Model mesh
- Extent of mining
- River package
- Stream package

Boggabri MOD8 (G1850W)

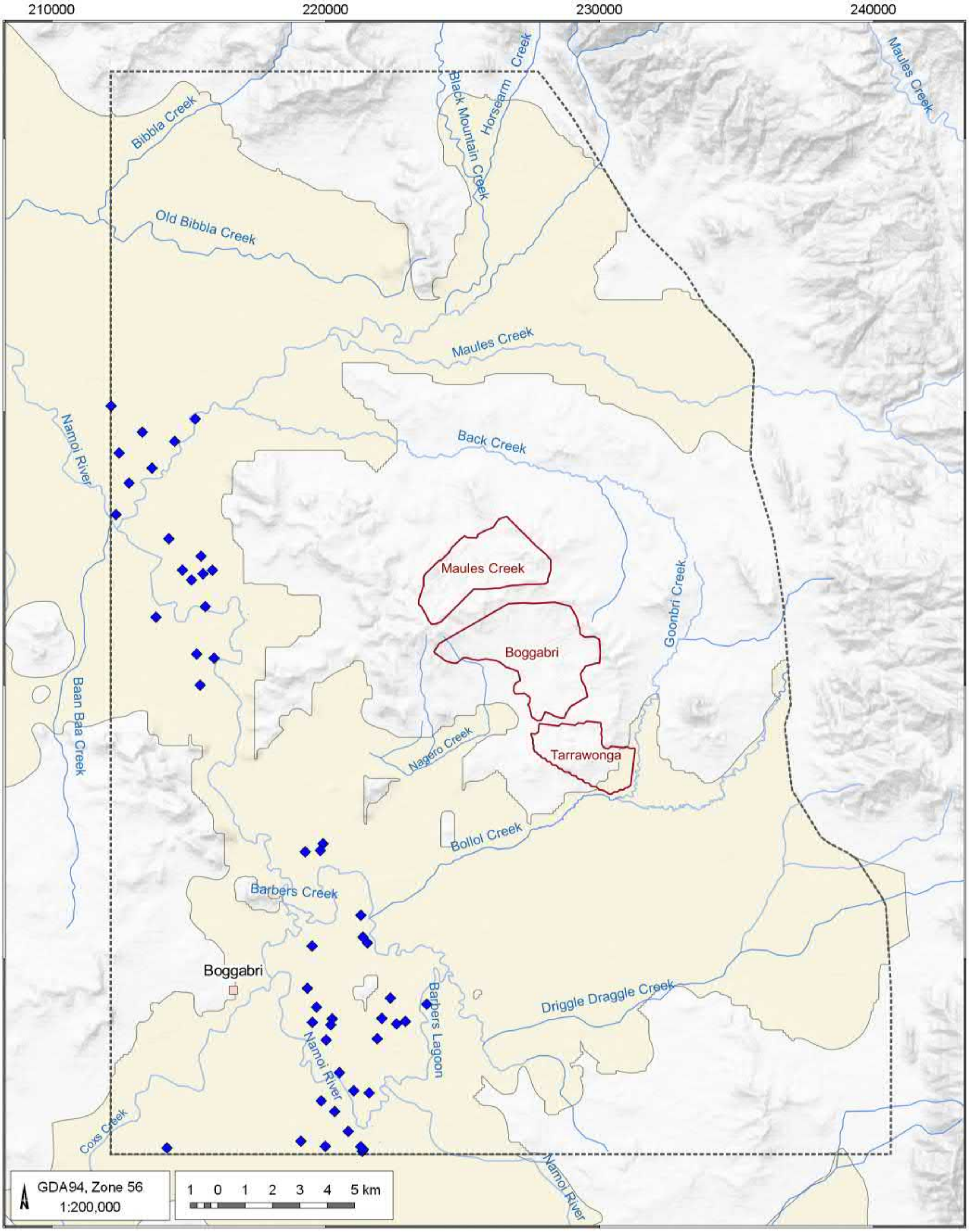
River and surface drainage cells

AGE

DATE 14/07/2021

FIGURE No: **A 3.9**

Source: LiDAR DEM © Department Finance, Services and Innovation, 2016; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\A 03.09_G1850W_River and surface drainage cells.qgs



LEGEND

- Populated place
- Pumping bores
- Drainage
- Model extent
- Modelled alluvium extent
- Extent of mining

Boggabri MOD8 (G1850W)

Pumping bore locations

AGE

DATE 14/07/2021

FIGURE No: **A 3.10**

Source: LiDAR DEM © Department Finance, Services and Innovation, 2016; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\A 03.10_G1850W_Pumping bore locations.qgs

A4 Model calibration

A4.1 Approach and method

The objective of the calibration process was to ensure the model could replicate key aspects of the groundwater regime identified through the review of the conceptual model, and also address comments received from the NSW government review team during the BTM Complex model calibration process. These key aspects of the calibration to be achieved were termed the 'success criteria' and used to guide the calibration process. The success criteria included achieving an improved match with vertical gradients between the Permian and alluvial, valid hydraulic property ranges, measured water level trends due to mining and climate and observed groundwater inflows to mining areas.

The model was calibrated in two stages. Firstly, a steady state model was manually calibrated to reproduce groundwater levels prior to mining occurring at the BTM Complex. The water levels from the steady state model were then used as starting conditions for a transient calibration.

The calibration process involved manual model runs testing the influence of single parameters, as well as automated parameter testing using parameterisation software (Doherty, 2010). The calibration focussed on adjusting the following properties in the model:

- horizontal and vertical hydraulic conductivity;
- percentage of recharge to each recharge zone; and
- storage properties - specific yield and specific storage.

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

A4.2 Calibration targets

A total of 204 monitoring points were used to calibrate the model, comprising:

- 108 monitoring points from the BTM Complex monitoring network, which included bores and VWPs that screen the alluvium and Permian coal measures; and
- 96 NSW Government monitoring bores installed primarily within the Quaternary alluvium.

Middlemis & Peeters (2018) suggest groundwater assessments consider the uncertainty around measurements used during the modelling process. The groundwater levels within the monitoring network are measured manually with electronic water level dippers and the water level converted to an elevation based on surveyed levels at measurement point which is usually the top of bore casing. Modern electronic water level dippers are expected to be accurate to within ±1 cm, and with the measurement point elevation also ±1 m to 10 cm depending on the method of surveying. The measurement of water levels within the monitoring network is therefore considered unlikely to have introduced any significant uncertainty to the model predictions. VWPs in contrast measure pore pressure which is converted to a potentiometric surface based on the elevation of the VWP sensor. The VWPs are sealed with cement grout within the boreholes and therefore cannot be validated, or the data loggers checked for instrument drift.

Therefore, the measurement error for the VWPs is considered higher than monitoring bores and possibly in the range of ±5 m to 10 m. Despite the potential for a larger measurement error in the VWP data, when used with caution it is still considered a useful additional dataset to understand the groundwater regime and guide the calibration of the numerical model where the observed pressure changes are considered conceptually sound.

Figure A 4.1 shows the locations of the observation bores and VWPs that were used in the calibration process. For model calibration purposes the observation bore water level records were weighted as follows:

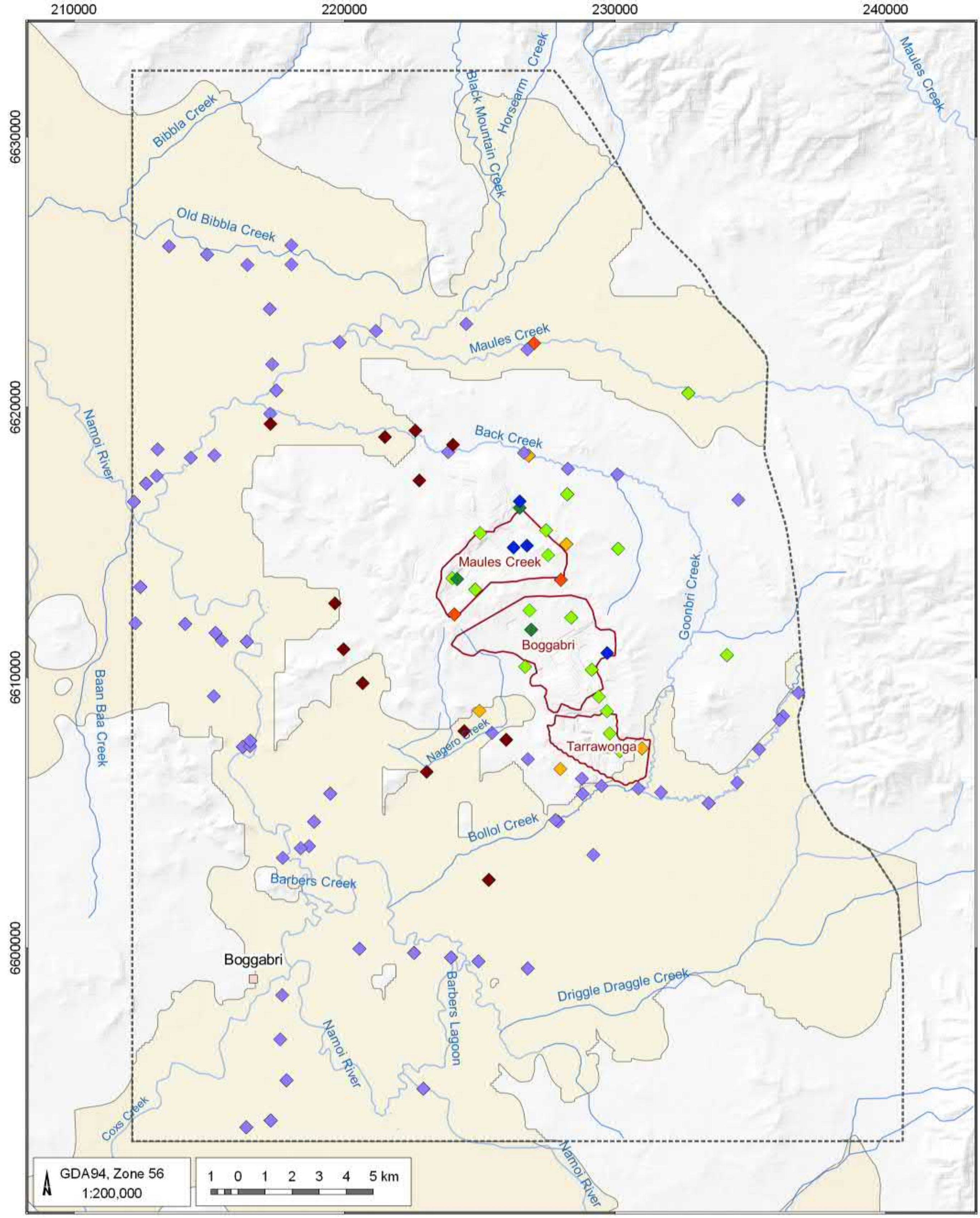
- anomalous results were removed;
- datalogger data was reduced to an appropriate frequency; and
- datapoints for each location were weighted according to the formula:
  weight of datapoint = 1/ √ (number of points for that site).

Using this method, bores with longer records have a lower weighting per datapoint, but a higher overall weighting in the combined dataset. The model was calibrated to the observed water level datasets, with the 'best calibrated' model returning the lowest objective function (phi) value i.e., the lowest statistical difference between the observed and modelled values across the chosen dataset.

The model domain contains a significant network of monitoring bores and water level datasets. The water level responses recorded in the monitoring bores vary depending on a range of factors including geology, location, climatic conditions and mining activities. Water levels recorded in the monitoring bores indicate heterogeneous hydraulic properties and recharge rates. To represent heterogeneity within the model domain and provide a degree of flexibility during the calibration, a series of pilot points were added to each model layer.

The locations of the pilot points in each model layer are shown in Figure A 4.2. The pilot points were situated where it was clear from water level monitoring data or model predictions that heterogeneity in hydraulic properties and/or recharge may be influencing the observations and would be required in the model to provide similar predictions. The pilot points were therefore clustered around the mining areas where the bulk of the available data is located and where the most variability in water levels occurs. For example, pilot points were located in the vicinity of monitoring sites TA60 and TA65, where enhanced permeability was required to match observations, with additional points away from these sites to allow the model the ability to reduce permeability where observations were not suggesting it was enhanced, e.g. at REG07 and REG09.

The pilot points were interpolated across the model domain in each layer of the model using ordinary automatic Kriging through PLPROC (Watermark Numerical Computing, 2015). Horizontal and vertical conductivity were then adjusted, and the absolute values were capped to ensure maximum and minimum values did not exceed appropriate ranges for each units outlined in Section 6.3. Specific storage values are constrained by literature ranges.



LEGEND

- Populated place
- Drainage
- Model extent
- Extent of mining
- Modelled alluvium extent

Model layer

- 1 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- 25 - 30
- 30 - 34

Boggabri MOD8 (G1850W)

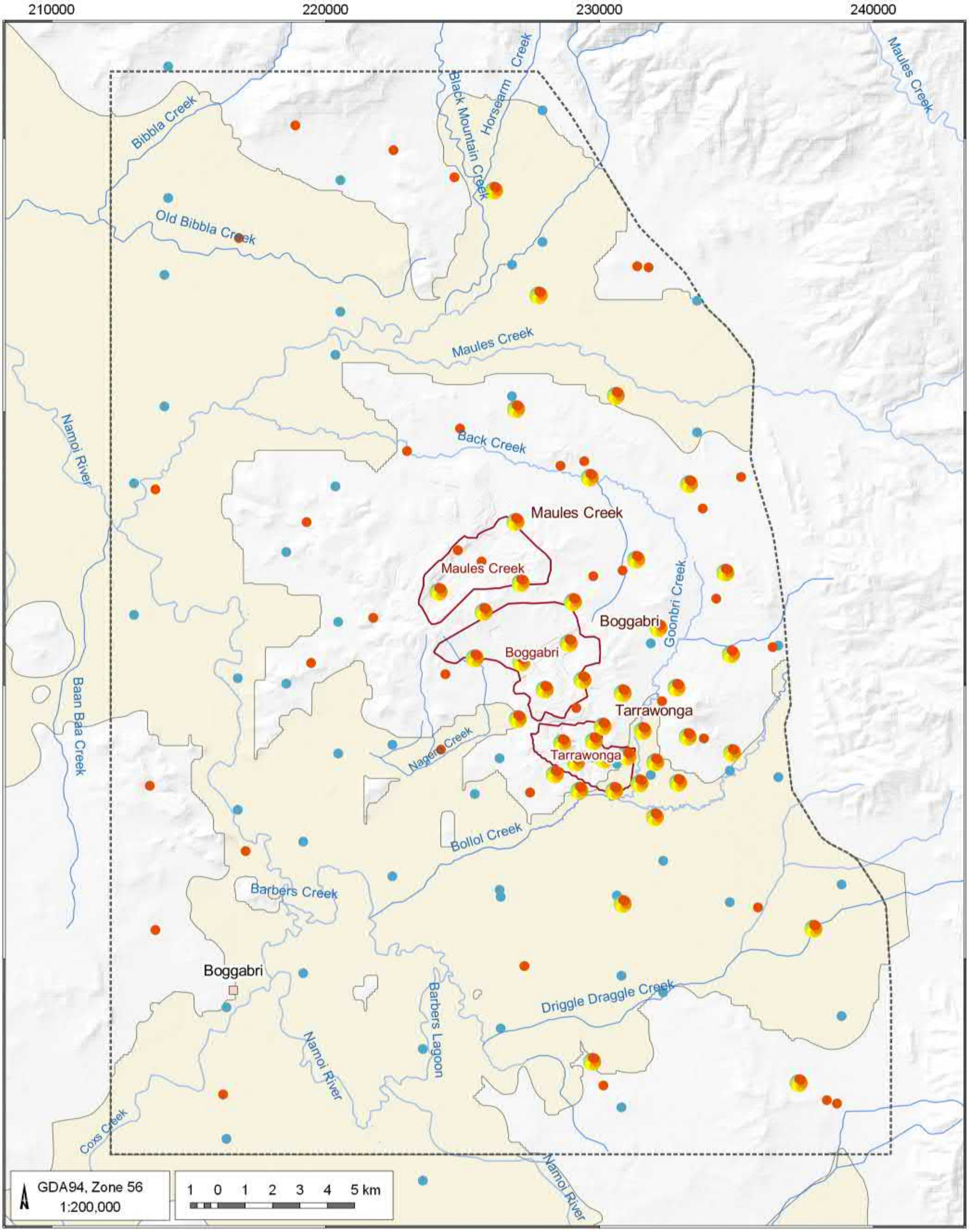
Observation points used for calibration

AGE

DATE
14/07/2021

FIGURE No:
A 4.1

Source: LiDAR DEM © Department Finance, Services and Innovation, 2016; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\A 04.01_G1850W_Observation points used for calibration.qgs



LEGEND

- Populated place
- Drainage
- Model extent
- Extent of mining
- Modelled alluvium extent

Model layer of pilot point

- 1 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- 25 - 30
- 30 - 35

NOTE:
Point dispalcement factor is used for pilot point locations

Boggabri MOD8 (G1850W)

Pilot point locations

AGE

DATE 14/07/2021

FIGURE No: **A 4.2**

Source: LiDAR DEM © Department Finance, Services and Innovation, 2016; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\A 04.02_G1850W_Location of pilot points.qgs

A4.3 Calibration results

A4.3.1 Water level history matching

Figure A 4.3 presents the observed and simulated groundwater levels determined from the calibration in a scattergram.

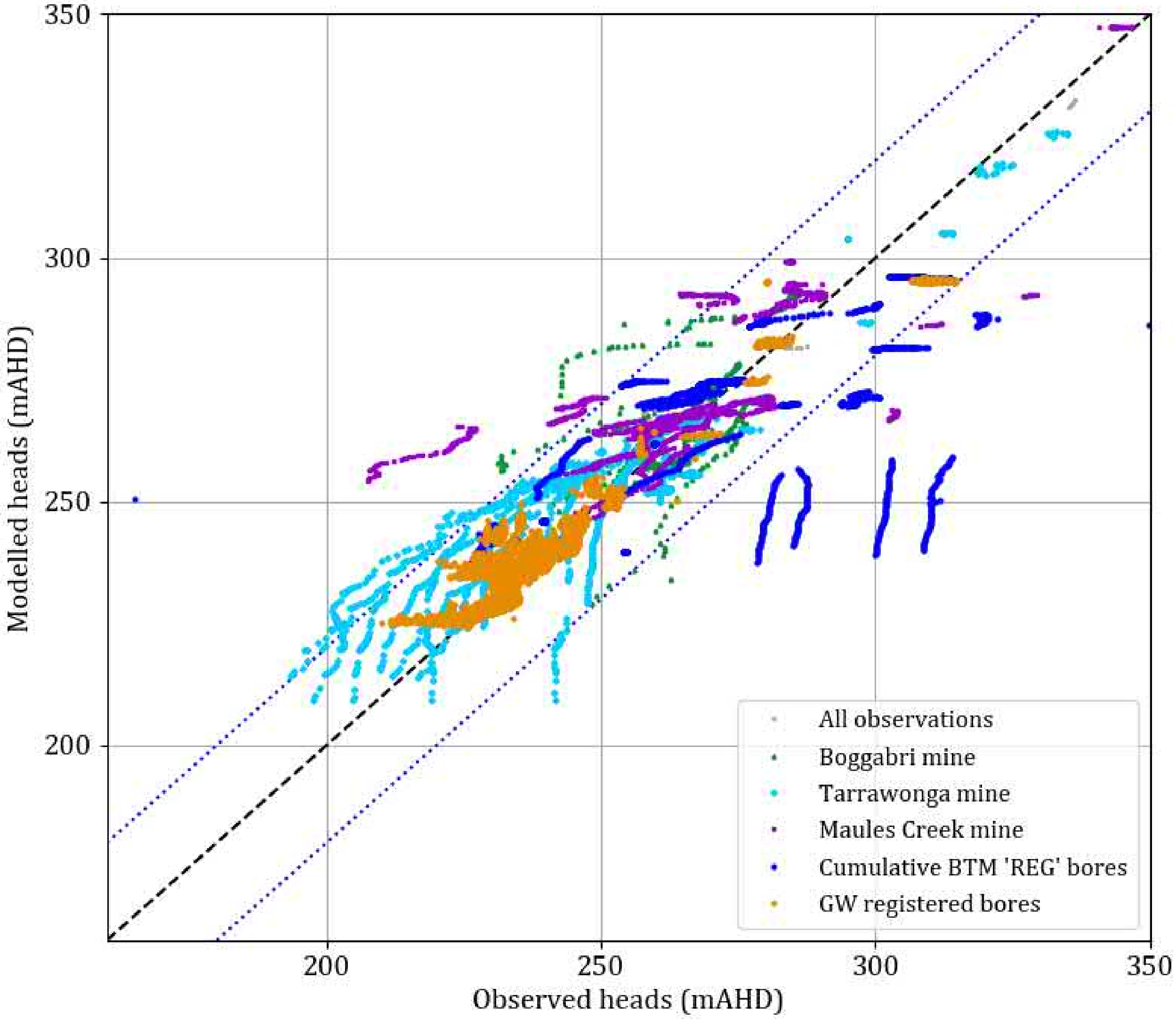


Figure A 4.3 Transient calibration – modelled vs observed groundwater levels

The root mean square (RMS) error calculated for the calibrated model was 16.19 m. The total measured head change across the model domain was 367.06 m, with a scaled root mean square (SRMS) of 4.41%, indicating a good match for the type of system being modelled.

Where monitoring bores are installed with a nested design adjacent to multilevel VWPs the observed and predicted levels are shown as grouped so the ability of the model to match the absolute levels and vertical gradients within and between layers can be examined. Charts showing the observed and predicted water levels in each monitoring bore or VWP sensor are also shown separately.

The hydrographs contained within Appendix E indicate the model can generally replicate declining pressure trends where these have been observed via VWPs, and some of the head separation that occurs through the Permian strata, particularly in areas adjacent to the BTM mines where the depressurisation enhances the vertical gradients through the Permian strata (e.g. RB05, RB05).

A notable recharge event in mid/late 2016 that is evident in the monitoring data is generally not reproduced at the same scale in many of the monitoring bores installed within the Permian strata around the mines.

REG01 is a multilevel VWP site located adjacent to Maules Creek and NSW government monitoring bores GW 967138. The model simulates the higher groundwater level observed within the alluvial aquifer and a lower pressure within the underlying Permian bedrock that indicates a downgradient from the alluvium to the underlying bedrock.

At REG01, the different pressures observed within the Permian VWP sensors is not well replicated by the model. Conceptually, this may relate to the location of the subcrop for each coal seam which has not been well defined in the area underlying the Maules Creek alluvium. This is a residual uncertainty in the geology that cannot be addressed further with modelling.

The IBC series of monitoring bores that were installed within the footprint of BCM provide a good record of water level responses induced by mining. The model generally simulates the overall water level trends measured in these bores well. The exception is IBC 2102 which rises when the model is predicting a declining trend. This is potentially due to temporary storage of water within the pit, that is not represented within the model.

The model provides an improved match to the VWPs within TA60 and TA65 east of the Tarrawonga Mine, which have recorded declining water levels that could not be matched well by the previous version of the model (AGE, 2018). Pilot points installed within this area of the model allowed a localised higher permeability to occur in this area of the model which enhanced the drainage of groundwater to the mining areas and better matches the magnitude of the predicted drawdown.

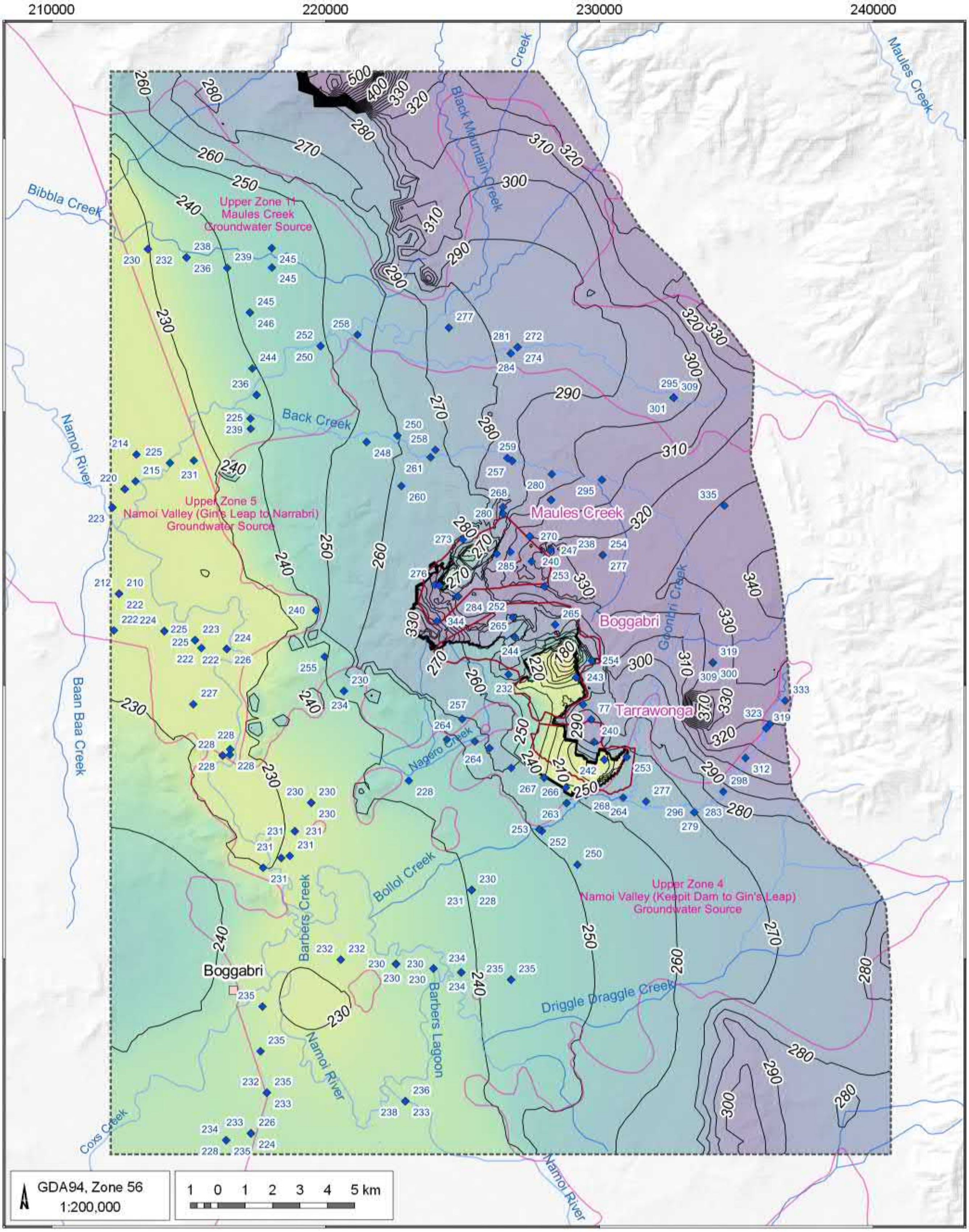
The GW series are largely government monitoring bores installed within the alluvial aquifer to the west of the BTM Complex. The model replicates the absolute levels well within the alluvial aquifer, probably due to the high permeability and storage that promote relatively flat hydraulic gradients and predictable levels. Trends in the GW series of monitoring bores are generally not influenced by mining but driven by climatic conditions and groundwater abstraction from private irrigation bores. Climatic trends are clearly influencing groundwater levels within the model, sometimes more significantly than is observed within the monitoring data.

Overall, the ability of the model to predict groundwater levels is considered to have improved relative to previous versions. Despite this, reproducing all the major trends observed within the monitoring network remains challenging, as all the complexity within the hydrogeological regime cannot be contained within a necessarily simplified model.

A4.3.2 Water table and potentiometric surface

The simulated water table along with measured groundwater levels in monitoring bores during 2019 is shown in Figure A 4.4. The water table shows the dominant east to west flow direction within the model domain which is influenced by the topography and alignment the Maules Creek and Bollol Creek alluvial aquifers. The dominant flow direction turns towards the north at the western boundary of the model following the alignment and flow of the Namoi River. The active mining areas within the BTM Complex area are evident in the water table as areas of locally lowered water levels with inward hydraulic gradients.

Figure A 4.5 shows the simulated potentiometric surface within the Merriown Seam in 2019. The figures show a flatter hydraulic gradient than occurs within the water table and flow directions more strongly influenced by the active mining areas. The Merriown seam potentiometric surface is generally at a lower elevation than the water table, indicating a vertical gradient from the alluvium downwards into the underlying coal measures. This is supported by available monitoring data. Depressurised zones within the potentiometric surface caused by the mining within the BTM Complex footprint is also evident on the figure.



LEGEND

- Populated place
- Observation locations
- Drainage
- Model extent
- Extent of mining
- Alluvial boundary zones

2019 simulated water table (mAHD)

- 150
- 200
- 250
- 300
- 600

Boggabri MOD8 (G1850W)

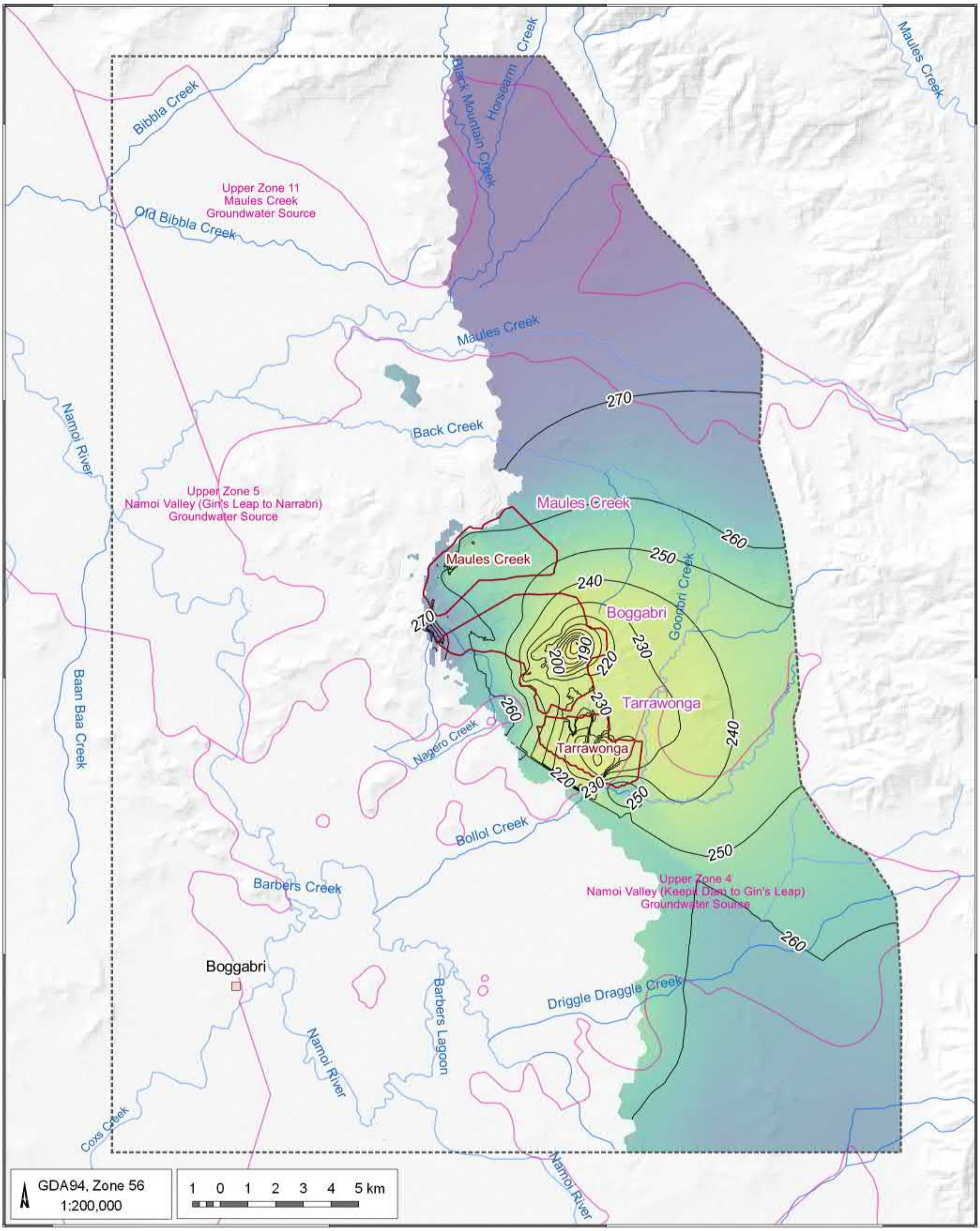
Simulated water table 2019

AGE

DATE 14/07/2021

FIGURE No: **A 4.4**

Source: LiDAR DEM © Department Finance, Services and Innovation, 2016; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\A 04.04_G1850W_Simulated water table 2019.qgs



LEGEND

- Populated place
- Drainage
- Model extent
- Model mesh
- Extent of mining
- Alluvial boundary zones

Contour line

Head (mAHD)

- 150
- 200
- 250
- 300

Boggabri MOD8 (G1850W)

Simulated potentiometric surface – Merriown Seam 2019

AGE

DATE 14/07/2021

FIGURE No: **A 4.5**

Source: LiDAR DEM © Department Finance, Services and Innovation, 2016; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\A 04.05_G1850W_Simulated potentiometric surface- Merriown seam 2019.qgs

A4.3.3 Hydraulic parameters

The hydraulic parameter ranges adopted for each model layer were guided by the field measurements described in Section 6.3. Where data was not present, experience with similar hydrogeological settings was used to guide parameter ranges. The calibration was commenced using uniform values of hydraulic conductivity for the model layers representing the alluvium, regolith, and coal seams, which are relatively the most permeable layers within the hydrogeological regime. A function representing hydraulic conductivity reducing with depth below the surface was used to obtain the starting values for the model layers representing the lower permeability interburden, as was suggested in the available field data/known to occur in the Sydney and Bowen Basins.

The base hydraulic properties are summarised in Table A 4.1 below. These hydraulic properties were the initial values used to setup the model and were then adjusted using pilot points.

Table A 4.1 Calibrated base hydraulic properties used in the numerical groundwater model

Model layer	Lithology	Kh (m/day)			Kv (m/day)	Sy (dec %)	Ss (m^{-1})
		Base value	cap max	cap min			
1	Alluvium - Narrabri Fm	10			Kh x 0.5	0.008	2.3E-7
1	Regolith	0.032			Kh x 0.12	0.004	2.2E-7
2	Alluvium - Gunnedah Fm	4.74			Kh x 0.54	0.25	2.3E-7
3	Interburden	2500 x (depth ^ -2.7)	1.0E-2	1.0E-5	Kh x 0.037	0.00007	1.0E-6
4	Interburden	1500 x (depth ^ -3.7)	1.0E-2	1.0E-5	Kh x 0.02	0.00009	1.0E-6
5	Seam Herndale, Onavale, Teston, Thornfield	0.005			Kh x 0.01	0.05	9.1E-6
6	Interburden	2500 x (depth ^ -3.7)	1.0E-2	1.0E-5	Kh x 0.01	0.0007	1.0E-6
7	Interburden	1500 x (depth ^ -2.7)	1.0E-2	1.0E-5	Kh x 0.03	0.0007	1.0E-6
8	Seam Braymont	0.63			Kh x 0.3	0.05	1.3E-5
9	Interburden	2500 x (depth ^ -3.7)	1.0E-2	1.0E-5	Kh x 0.0009	0.0007	1.0E-6
10	Interburden	2500 x (depth ^ -2.3)	1.0E-2	1.0E-5	Kh x 0.08	0.00007	1.0E-6
11	Seam Bollol Ck	0.13			Kh x 0.08	0.05	9.2E-6
12	Interburden	1500 x (depth ^ -3.7)	1.0E-2	1.0E-5	Kh x 0.1	0.00009	1.0E-6
13	Interburden	1500 x (depth ^ -3.7)	1.0E-2	1.0E-5	Kh x 0.001	0.00009	2.3E-7
14	Seam Jeralong	0.14			Kh x 0.08	0.05	1.0E-5
15	Interburden	1500 x (depth ^ -3)	1.0E-2	1.0E-5	Kh x 0.001	0.00007	1.0E-6
16	Interburden	2500 x (depth ^ -2.3)	1.0E-2	1.0E-5	Kh x 0.0004	0.00007	1.0E-6
17	Seam Merriown	0.29			Kh x 0.55	0.01	3.0E-6
18	Interburden	2500 x (depth ^ -2.3)	1.0E-2	1.0E-5	Kh x 0.0002	0.00009	2.3E-7
19	Interburden	2500 x (depth ^ -2.3)	1.0E-2	1.0E-5	Kh x 0.1	0.00009	3.1E-7

Model layer	Lithology	Kh (m/day)			Kv (m/day)	Sy (dec %)	Ss (m^{-1})
		Base value	cap max	cap min			
20	Seams Velyama, Nagero	0.313			Kh x 0.115	0.01	1.3E-5
21	Interburden	2500 x (depth ^ -2.3)	1.0E-2	1.0E-5	Kh x 0.052	0.00007	2.3E-7
22	Interburden	2500 x (depth ^ -2.3)	1.0E-2	1.0E-5	Kh x 0.1	0.00007	2.3E-7
23	Seams Upper Northam, Lower Northam	0.025			Kh x 0.3	0.01	1.14E-5
24	Interburden	2500 x (depth ^ -2.3)	1.0E-2	1.0E-5	Kh x 0.001	0.00009	2.3E-7
25	Interburden	1500 x (depth ^ -2.3)	1.0E-2	1.0E-5	Kh x 0.05	0.00009	2.3E-7
26	Seams Therribri A, Therribri B	0.086			Kh x 0.024	0.01	8.0E-6
27	Interburden	1502 x (depth ^ -2.3)	1.0E-2	1.0E-5	Kh x 0.013	0.00007	2.3E-7
28	Interburden	2500 x (depth ^ -3.7)	1.0E-2	1.0E-5	Kh x 0.003	0.00009	2.3E-7
29	Seams Flixton, Tarrawonga	0.036			Kh x 0.043	0.01	8.3E-6
30	Interburden	2119 x (depth ^ -3.7)	1.0E-2	1.0E-5	Kh x 0.028	0.00007	2.3E-7
31	Interburden	2016 x (depth ^ -3.7)	1.0E-2	1.0E-5	Kh x 0.003	0.00009	2.3E-7
32	Seam Templemore	0.052			Kh x 0.027	0.01	1.3E-5
33	Interburden	1500 x (depth ^ -3.7)	1.0E-2	1.0E-5	Kh x 0.007	0.00009	5.7E-7
34	Volcanics	0.001			Kh x 0.548	0.00009	2.2E-7

Notes: * depth: For the Kh calculation, depth of the cell in metres from the ground level. For the numerical groundwater model, the depth of a given cell is measured between the cell centre and the top of layer 01 in the vertical column of cells.

After applying the depth-dependence equation to the interburden, the horizontal hydraulic conductivity was capped at a maximum of 1x10-2 m/day and a minimum of 1x10-5 m/day to remain with the expected range indicated by field measurements.

The calibrated hydraulic properties (horizontal and vertical hydraulic conductivity, specific storage, specific yield) are shown spatially for all layers within Appendix F. Appendix F also includes charts that show the adopted hydraulic conductivity values from the calibration versus depth for each cell in each model layer (blue dots), and the starting values (red line) prior to commencing the PEST calibration process. The calibrated hydraulic conductivity values generally remained within the range of measured values at the completion of calibration.

There is limited direct testing data for estimates of specific storage (Ss) for coal seams/interburden, largely because of the difficulties in assessing this for low permeability formations. Rau et al (2018) provides limits based on poroelastic theory which indicates that specific storage is restricted to the range of 2.3×10^{-7} m^{-1} and 1.3×10^{-5} m^{-1}. The calibrated parameters were restricted to remain within these bounds.

A4.3.4 Water budget

The mass balance error, that is, the difference between calculated model inflows and outflows at the completion of the steady state calibration was 0.03%. The maximum percent discrepancy at any time step in the simulation was also 1.98%. This value indicates that the model is stable and achieves an accurate numerical solution. This maximum error is within acceptable limits for adequate numerical convergence (<2%: Australian Groundwater Modelling Guidelines [Barnett, 2012]).

Table A 4.2 shows the water budget for the steady state (pre-mining) model and the averages from the transient model for the period 2006 to 2019.

Table A 4.2 Calibration stage water budget (ML/day)

Parameter	Steady state model			Transient model average		
	in	out	in - out	in	out	in - out
Storage	0.00	0.00	0.00	36.27	27.22	9.05
Recharge	55.82	0.00	55.82	41.74	0.00	41.74
River	0.00	19.41	-19.41	0.00	16.07	-16.07
Stream	16.87	15.42	1.45	12.33	14.09	-1.76
General head boundary	0.07	31.13	-31.06	0.27	25.18	-24.91
Wells	0.00	6.78	-6.78	0.00	5.81	-5.81
Drains	0.00	0.00	0.00	0.00	2.25	-2.25
Total	**72.76**	**72.74**	**0.02**	**90.61**	**90.62**	**-0.01**

The steady state water budget indicates that recharge to the groundwater system within the model averages 55.82 ML/day, with approximately 17.96 ML/day being discharged via surface drainage. Regional through flow from the general head boundary contributes 0.09% of the total input to the groundwater model.

The transient model water budget departs from steady state conditions because of mining in the model domain. Mine dewatering represented by drain cells indicates regional dewatering intercepts 2.25 ML/day on average, which indirectly reduces stream baseflow, and increases inflows from the general and constant head boundaries. Recharge from rainfall and river leakage increases very slightly within the transient model due to the use of actual climatic data during the transient calibration period from 2006 to 2019.

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

A4.3.5 Mine inflow verification

Figure A 4.6 shows the simulated groundwater inflow to the drain cells representing the BTM Complex open cut mining areas.

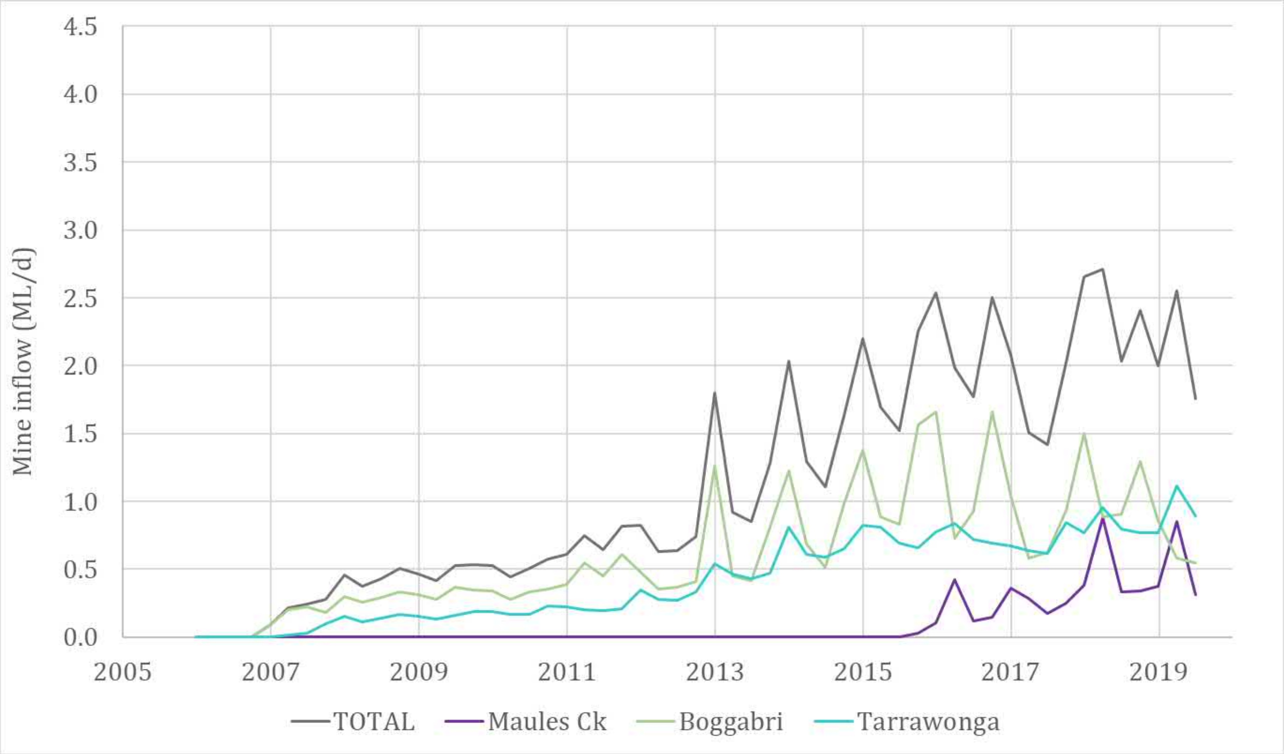


Figure A 4.6 Simulated inflow to mining areas (2006 to 2020)

Groundwater inflows to the open cut mining areas are not large relative to other open cut mining operations in NSW. The most common method to estimate the groundwater inflow is to use a mine site water balance model to compare inputs and outputs and determine if any additional water can be attributed to groundwater inflow. Estimates of groundwater inflow from water balance models were used to guide the calibration process. At Maules Creek the inflow was estimated at 1.58 ML/day for year 2018. At Boggabri, the inflow was estimated at 0.33 ML/day for year 2018 and at Tarrawonga the inflow was estimated at 0.5 ML/day for year 2018. The groundwater model represents groundwater removed by pumping and does not account for water that evaporates from the highwall or is bound as moisture with coal and spoil. In contrast the water balance method only estimates the volume of water that flows into the mine water circuit. Both methods are therefore not directly comparable due to differing underlying assumptions. While estimates are different, the agreement is considered relatively good given the differences in the methodologies.

A5 Uncertainty analysis

A number of potential sources of uncertainty have been highlighted in the preceding sections including uncertainties in model inputs and simplifications that are inherent in any numerical model of complex natural systems. The following sections describe the methodology and results of an uncertainty analysis completed for MOD 8, which was undertaken to assess the sensitivity of key model predictions to inevitable uncertainties in model parameters.

A5.1 Methodology

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

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

A Monte Carlo uncertainty analysis was undertaken (option 3) to quantify the magnitude of uncertainty in the future impacts predicted by the model. This type of analysis produces probability distributions for predictive impacts by assessing a composite likelihood of an impact occurring through assessing and ranking the predictions from hundreds of model 'realisations'. Each model realisation is informed by the observation dataset by using the relationship between the observation statistics to perturbations of each parameter in the groundwater model.

This uncertainty analysis was essentially undertaken as a three-part process. Firstly, a valid range for each parameter (i.e. pre-calibration range) was determined, and then 500 model realisations were created, each with varied parameter values. The constrained realisations were tested and the models that failed to converge or could not achieve adequate calibration were rejected, leaving the output from 216 successful models. Models were considered to have an acceptable calibration if SRMS (heads) ≤10%. The outputs were analysed to provide a statistical distribution of the predictive impacts.

Outputs from the uncertainty modelling were processed in accordance with the risk-based calibrated language proposed in Middlemis & Peeters (2018). The ranges adopted are shown in Table A 5.1.

Table A 5.1 Calibrated uncertainty modelling language

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

A5.2 Parameter generation

A5.2.1 Prior ranges

To undertake this type of analysis it is necessary to firstly assess the response of the calibration statistics to changes in the parameters in the groundwater model using a ‘prior’ or pre-calibration range. Table A 5.2 to Table A 5.9 shows the ‘prior’ range explored during the uncertainty analysis simulations, which was at least as wide as the range used during calibration of the model. In cases where the calibrated parameter value was at either the lower or upper bound used for calibration, then the adopted prior range was either increased or decreased within realistic physical bounds to prevent bias in the analysis. All parameters were assumed to possess a log-normal distribution centred around a mean value, or most probable value.

As mentioned previously, a total of 500 models were generated using a random parameter generator to produce ‘realisations’ to assess predictive impacts.

Table A 5.2 Prior range – horizontal hydraulic conductivity

Model layer	Lithology	Horizontal hydraulic conductivity (m/day)		
		lower	mean	upper
1	Alluvium - Narrabri Fm	0.1	10	12.5
1	Regolith	0.01	0.032	0.1
2	Alluvium - Gunnedah Fm	1	4.75	100
3	Interburden	1500 x (depth ^ -2.7)	2500 x (depth ^ -2.7)	3125 x (depth ^ -2.7)
4	Interburden	1125 x (depth ^ -3.7)	1500 x (depth ^ -3.7)	2500 x (depth ^ -3.7)
5	Seam Herndale, Onavale, Teston, Thornfield	0.0001	0.00505	1
6	Interburden	1500 x (depth ^ -3.7)	2500 x (depth ^ -3.7)	3125 x (depth ^ -3.7)
7	Interburden	1125 x (depth ^ -2.7)	1500 x (depth ^ -2.7)	2500 x (depth ^ -2.7)
8	Seam Braymont	0.0001	0.6327455	1
9	Interburden	1500 x (depth ^ -3.7)	2500 x (depth ^ -3.7)	3125 x (depth ^ -3.7)
10	Interburden	1500 x (depth ^ -2.3)	2499.4 x (depth ^ -2.3)	3125 x (depth ^ -2.3)
11	Seam Bollol Ck	0.0001	0.1320736	1
12	Interburden	1125 x (depth ^ -3.7)	1500 x (depth ^ -3.7)	2500 x (depth ^ -3.7)
13	Interburden	1125 x (depth ^ -3.7)	1500 x (depth ^ -3.7)	2500 x (depth ^ -3.7)
14	Seam Jeralong	0.0001	0.1416955	1
15	Interburden	1125 x (depth ^ -3)	1500 x (depth ^ -3)	2500 x (depth ^ -3)
16	Interburden	1500 x (depth ^ -2.3)	2500 x (depth ^ -2.3)	3125 x (depth ^ -2.3)
17	Seam Merriown	0.0001	0.0287	1
18	Interburden	1500 x (depth ^ -2.3)	2500 x (depth ^ -2.3)	3125 x (depth ^ -2.3)
19	Interburden	1500 x (depth ^ -2.3)	2500 x (depth ^ -2.3)	3125 x (depth ^ -2.3)
20	Seams Velyama, Nagero	0.0001	0.312731	1
21	Interburden	1500 x (depth ^ -2.3)	2500 x (depth ^ -2.3)	3125 x (depth ^ -2.3)
22	Interburden	1500 x (depth ^ -2.3)	2500 x (depth ^ -2.3)	3125 x (depth ^ -2.3)
23	Seams Upper Northam, Lower Northam	0.0001	0.0251	1
24	Interburden	1500 x (depth ^ -2.3)	2500 x (depth ^ -2.3)	3125 x (depth ^ -2.3)

Model layer	Lithology	Horizontal hydraulic conductivity (m/day)		
		lower	mean	upper
25	Interburden	1125 x (depth ^ - 2.3)	1500 x (depth ^ - 2.3)	2500 x (depth ^ - 2.3)
26	Seams Therribri A, Therribri B	0.0001	0.0862	1
27	Interburden	1125 x (depth ^ - 2.3)	1502 x (depth ^ - 2.3)	2500 x (depth ^ - 2.3)
28	Interburden	1500 x (depth ^ - 3.7)	2500 x (depth ^ - 3.7)	3125 x (depth ^ - 3.7)
29	Seams Flixton, Tarrawonga	0.0001	0.0363	1
30	Interburden	1500 x (depth ^ - 3.7)	2118.9 x (depth ^ - 3.7)	3125 x (depth ^ - 3.7)
31	Interburden	1500 x (depth ^ - 3.7)	2016.1 x (depth ^ - 3.7)	3125 x (depth ^ - 3.7)
32	Seam Templemore	0.0001	0.0524	1
33	Interburden	1125 x (depth ^ - 3.7)	1500 x (depth ^ - 3.7)	2500 x (depth ^ - 3.7)
34	Volcanics	0.0001	0.0012	0.0015

Table A 5.3 Prior range – vertical hydraulic conductivity

Model layer	Lithology	Vertical hydraulic conductivity factor (Kz/Kx)		
		lower	mean	upper
1	Alluvium - Narrabri Fm	0.1	0.49	1
1	Regolith	0.075	0.12	0.3
2	Alluvium - Gunnedah Fm	0.1	0.54	1
3	Interburden	0.0001	0.04	0.1
4	Interburden	0.0001	0.02	0.1
5	Seam Herndale, Onavale, Teston, Thornfield	0.0075	0.01	0.3
6	Interburden	0.0001	0.01	0.1
7	Interburden	0.0001	0.03	0.1
8	Seam Braymont	0.01	0.30	0.375
9	Interburden	0.0001	0.001	0.1
10	Interburden	0.0001	0.08	0.125
11	Seam Bollol Ck	0.01	0.08	0.3
12	Interburden	0.0001	0.10	0.125
13	Interburden	0.0001	0.001	0.1
14	Seam Jeralong	0.01	0.08	0.3
15	Interburden	0.0001	0.001	0.1
16	Interburden	0.0001	0.0004	0.1
17	Seam Merriown	0.01	0.05	0.3
18	Interburden	0.0001	0.0002	0.1
19	Interburden	0.0001	0.10	0.125
20	Seams Velyama, Nagero	0.01	0.12	0.3
21	Interburden	0.0001	0.05	0.1
22	Interburden	0.0001	0.10	0.125
23	Seams Upper Northam, Lower Northam	0.01	0.30	0.375
24	Interburden	0.0001	0.001	0.1
25	Interburden	0.0001	0.05	0.1
26	Seams Therribri A, Therribri B	0.01	0.02	0.3
27	Interburden	0.0001	0.01	0.1
28	Interburden	0.0001	0.003	0.1

Model layer	Lithology	Vertical hydraulic conductivity factor (Kz/Kx)		
		lower	mean	upper
29	Seams Flixton, Tarrawonga	0.01	0.04	0.3
30	Interburden	0.0001	0.03	0.1
31	Interburden	0.0001	0.003	0.1
32	Seam Templemore	0.01	0.03	0.3
33	Interburden	0.0001	0.01	0.1
34	Volcanics	0.375	0.55	1

Table A 5.4 Prior range – specific yield

Model layer	Lithology	Specific yield - Sy (dec %)		
		lower	mean	upper
1	Alluvium - Narrabri Fm	0.005	0.008	0.15
1	Regolith	0.001	0.004	0.01
2	Alluvium - Gunnedah Fm	0.02	0.25	0.3125
3	Interburden	0.00001	0.0001	0.01
4	Interburden	0.00001	0.0001	0.01
5	Seam Herndale, Onavale, Teston, Thornfield	0.01	0.05	0.0625
6	Interburden	0.00001	0.00007	0.01
7	Interburden	0.00001	0.00007	0.01
8	Seam Braymont	0.01	0.05	0.0625
9	Interburden	0.00001	0.00007	0.01
10	Interburden	0.00001	0.00007	0.01
11	Seam Bollol Ck	0.01	0.05	0.0625
12	Interburden	0.00001	0.00009	0.01
13	Interburden	0.00001	0.00009	0.01
14	Seam Jeralong	0.01	0.05	0.0625
15	Interburden	0.00001	0.00007	0.01
16	Interburden	0.00001	0.00007	0.01
17	Seam Merriown	0.01	0.0154	0.05
18	Interburden	0.00001	0.00009	0.01
19	Interburden	0.00001	0.00009	0.01
20	Seams Velyama, Nagero	0.0075	0.01	0.05
21	Interburden	0.00001	0.00007	0.01
22	Interburden	0.00001	0.00007	0.01
23	Seams Upper Northam, Lower Northam	0.0075	0.01	0.05
24	Interburden	0.00001	0.00007	0.01
25	Interburden	0.00001	0.00009	0.01
26	Seams Therribri A, Therribri B	0.0075	0.01	0.05
27	Interburden	0.00001	0.00007	0.01
28	Interburden	0.00001	0.00009	0.01
29	Seams Flixton, Tarrawonga	0.0075	0.01	0.05
30	Interburden	0.00001	0.00007	0.01
31	Interburden	0.00001	0.00009	0.01
32	Seam Templemore	0.0075	0.01	0.05
33	Interburden	0.00001	0.00009	0.01
34	Volcanics	0.00001	0.00009	0.001

Table A 5.5 Prior range – specific storage

Model layer	Lithology	Specific storage - Ss (m^{-1})		
		lower	mean	upper
1	Alluvium - Narrabri Fm	1.73E-07	2.30E-07	1.30E-05
1	Regolith	1.65E-07	2.20E-07	1.00E-05
2	Alluvium - Gunnedah Fm	1.73E-07	2.30E-07	1.30E-05
3	Interburden	2.30E-07	1.00E-06	1.30E-05
4	Interburden	2.30E-07	1.00E-06	1.30E-05
5	Seam Herndale, Onavale, Teston, Thornfield	1.00E-06	9.13E-06	1.30E-05
6	Interburden	2.30E-07	1.00E-06	1.30E-05
7	Interburden	2.30E-07	1.00E-06	1.30E-05
8	Seam Braymont	1.00E-06	1.30E-05	1.63E-05
9	Interburden	2.30E-07	1.00E-06	1.30E-05
10	Interburden	2.30E-07	1.00E-06	1.30E-05
11	Seam Bollol Ck	1.00E-06	9.21E-06	1.30E-05
12	Interburden	2.30E-07	1.00E-06	1.30E-05
13	Interburden	1.73E-07	2.30E-07	1.30E-05
14	Seam Jeralong	1.00E-06	1.03E-05	1.30E-05
15	Interburden	2.30E-07	1.00E-06	1.30E-05
16	Interburden	2.30E-07	1.00E-06	1.30E-05
17	Seam Merriown	1.00E-06	3.04E-06	1.30E-05
18	Interburden	1.73E-07	2.30E-07	1.30E-05
19	Interburden	2.30E-07	3.06E-07	1.30E-05
20	Seams Velyama, Nagero	1.00E-06	1.29E-05	1.63E-05
21	Interburden	1.73E-07	2.30E-07	1.00E-06
22	Interburden	1.73E-07	2.30E-07	1.00E-06
23	Seams Upper Northam, Lower Northam	1.00E-06	1.14E-05	1.63E-05
24	Interburden	1.73E-07	2.30E-07	1.00E-06
25	Interburden	1.73E-07	2.30E-07	1.00E-06
26	Seams Therribri A, Therribri B	1.00E-06	8.03E-06	1.30E-05
27	Interburden	1.73E-07	2.30E-07	1.00E-06
28	Interburden	1.73E-07	2.30E-07	1.00E-06
29	Seams Flixton, Tarrawonga	1.00E-06	8.23E-06	1.30E-05
30	Interburden	1.73E-07	2.30E-07	1.00E-06
31	Interburden	1.73E-07	2.30E-07	1.00E-06
32	Seam Templemore	1.00E-06	1.30E-05	1.63E-05
33	Interburden	2.30E-07	5.70E-07	1.00E-06
34	Volcanics	1.65E-07	2.20E-07	1.00E-05

Table A 5.6 Prior range – recharge rate

Recharge zone	Recharge rate (mm/year)		
	lower	mean	upper
Alluvium	0.38	0.5	1
Alluvium - Bollol Creek upstream	0.5	5	6.25
Regolith - Permian	0.001	0.0139	0.1
Regolith - Volcanics	0.0005	0.0012	0.02
Regolith - Volcanics (lake west of Tarrawonga)	0.001	0.5	3
Permian - east boundary	0.001	0.0191	3

Table A 5.7 Prior range – recharge factor

Area	Recharge factor		
	lower	mean	upper
Break slope north	0.1	0.6214129	1.8
Break slope mid-north	0.075	0.1	1.8
Break slope centre	0.1	0.5045542	1.8
Break slope west	0.1	0.4105722	1.8
Break slope south	0.075	0.1	1.8
Stream alluvium north	1.5	2	10
Stream alluvium mid	2	3.580409	10
Stream alluvium south	1.5	2	10
Stream Permian	0.75	1	3
Stream volcanics	0.75	1	3

Table A 5.8 Prior range – river vertical conductivity

River zone	Description	River vertical conductivity (m/day)		
		lower	mean	upper
1	Barbers Lagoon lower	0.00001	1	100
2	Coxs Creek - area 1	0.00001	1	100
3	Coxs Creek - area 2	0.00001	1	100
4	Namoi River - area 1	0.00001	1	100
5	Namoi River - area 4	0.00001	1	100
6	Namoi River - area 5	0.00001	1	100
7	Namoi River - area 6	0.00001	1	100
8	Bollol Creek lower - area 1	0.00001	1	100
9	Bollol Creek lower - area 2	0.00001	1	100
10	Bollol Creek upper	0.00001	1	100
11	Driggle Draggle Creek	0.00001	1	100
12	Barneys Spring Creek	0.00001	1	100
13	Barbers Lagoon middle	0.00001	1	100
14	Barbers Lagoon upper	0.00001	1	100
15	Namoi River - area 2	0.00001	1	100
16	Namoi River - area 3	0.00001	1	100
17	Nagero Creek - area 1	0.00001	1	100
18	Nagero Creek - area 2	0.00001	1	100
19	Maules Creek lower	0.00001	1	100
20	Maules Creek upper	0.00001	1	100
21	Stony Creek	0.00001	1	100
22	Maules Creek - area 1	0.00001	1	100
23	Back Creek - area 1	0.00001	1	100
24	Back Creek - area 2	0.00001	1	100
25	Back Creek - area 3	0.00001	1	100
26	Back Creek - area 4	0.00001	1	100
27	Back Creek - area 5	0.00001	1	100
28	Back Creek - area 6	0.00001	1	100
29	Horsearm Creek	0.00001	1	100
30	Middle Creek	0.00001	1	100
31	Black Mountain Creek	0.00001	1	100
32	Old Bibbla Creek - area 1	0.00001	1	100

River zone	Description	River vertical conductivity (m/day)		
		lower	mean	upper
33	Old Bibbla Creek - area 2	0.00001	1	100
34	Old Bibbla Creek - area 3	0.00001	1	100
35	Goonbri Creek realignment	0.00001	1	100
36	Goonbri Creek	0.00001	1	100
37	Namoi River - area 7	0.00001	1	100
38	Old Bibbla Creek - area 4	0.00001	1	100
39	Bibbla Creek	0.00001	1	100
40	Deriah Creek	0.00001	1	100
41	Back Creek - area 7	0.00001	1	100
42	Back Creek - area 8	0.00001	1	100
43	Namoi River - area 8	0.00001	1	100
44	Namoi River - area 9	0.00001	1	100
45	Namoi River - area 10	0.00001	1	100
46	NoName - area 1	0.00001	1	100
47	NoName - area 2	0.00001	1	100
48	NoName - area 3	0.00001	1	100
49	NoName - area 4	0.00001	1	100
50	Back Creek - area 9	0.00001	1	100

Table A 5.9 Prior range – stream vertical conductivity

Stream zone	Description	Stream vertical conductivity (m/day)		
		lower	mean	upper
1	Namoi River	0.00001	0.0922	10

A5.2.2 Posterior ranges

A suite of parameter probability distributions were randomly generated using the prior parameter ranges to produce alternative realisations.

As pilot points are present in each layer, reviewing the basecase prior and posterior ranges is not sufficient to show the full distribution in parameters for each layer. Instead, the calibrated parameter distribution was analysed using regularised (200 m) cumulative distribution function (CDF) plots with uncertainty ranges added. This assesses the spatial distribution of parameter values. Example plots are provided in Figure A 5.1 through to Figure A 5.4 for Kx in layer 1 (Narrabri Formation/regolith), Kx in layer 2 (Gunnedah Formation), Kx in layer and 7 (interburden above the Braymont Seam), and Kx in layer 20 (Nagero Seam).

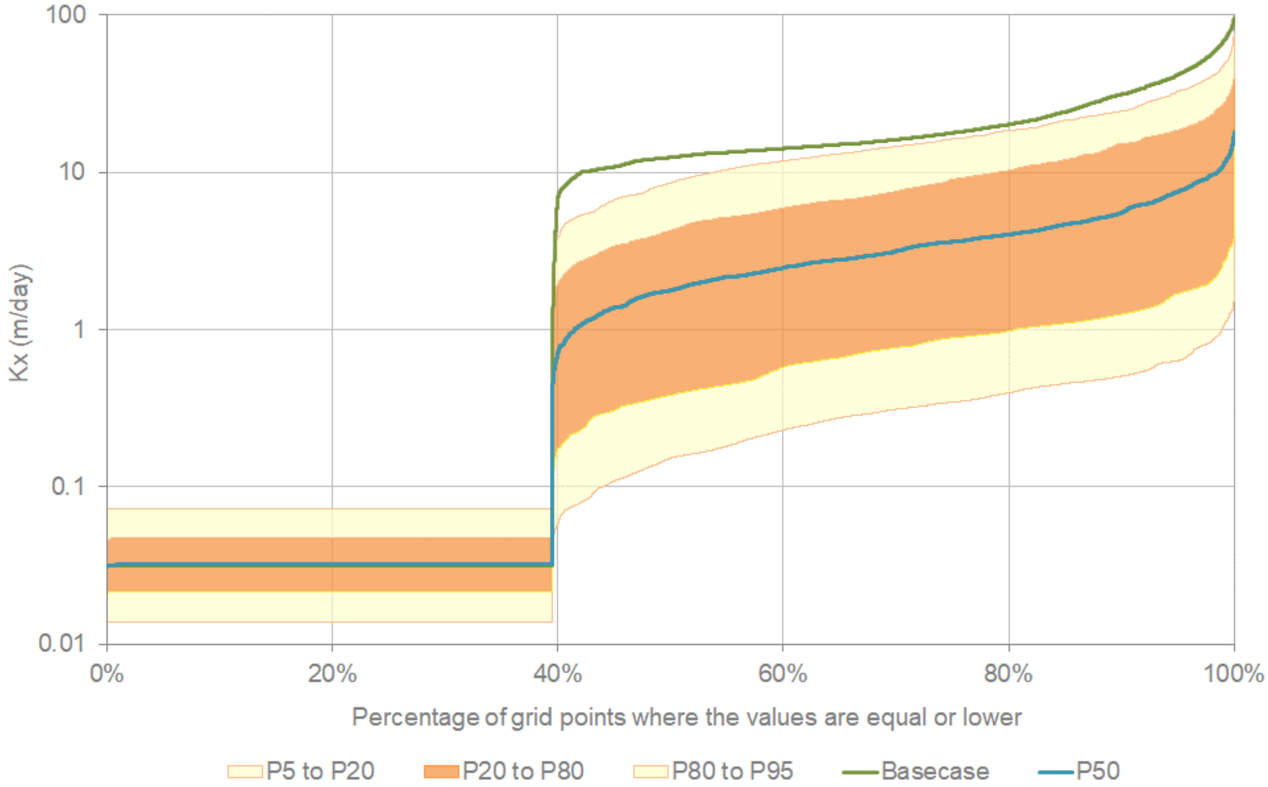


Figure A 5.1 Cumulative distribution function plot for Kx: layer 1 – Narrabri Formation/regolith

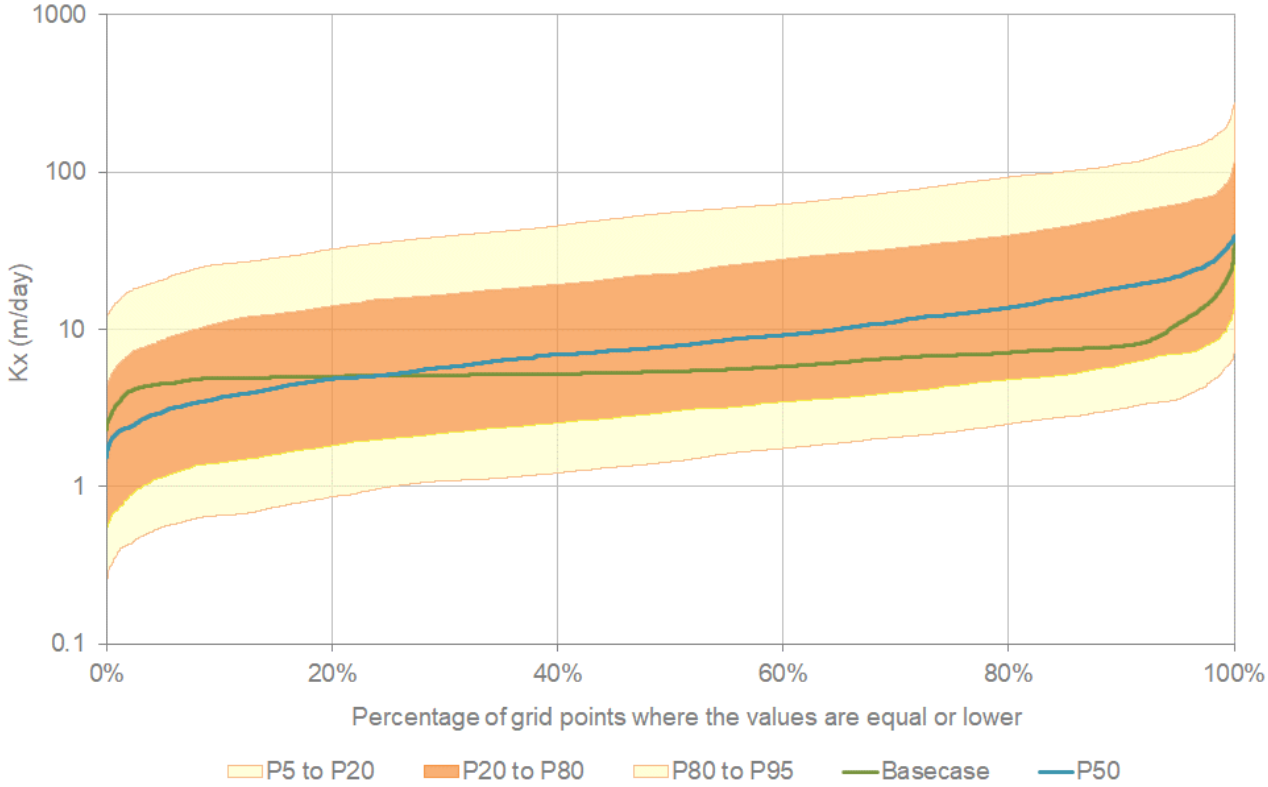


Figure A 5.2 Cumulative distribution function plot for Kx: layer 2 – Gunnedah Formation

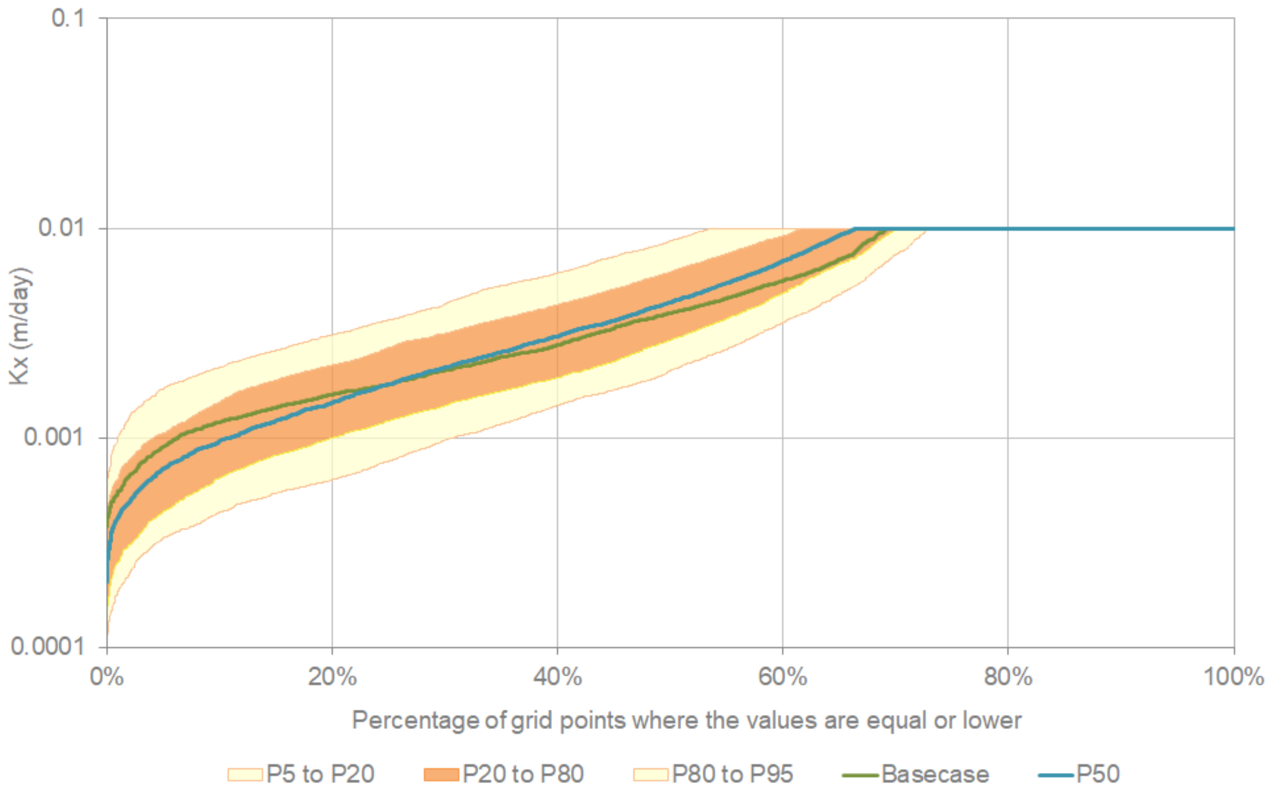


Figure A 5.3 Cumulative distribution function plot for Kx: layer 7 – interburden above Braymont Seam

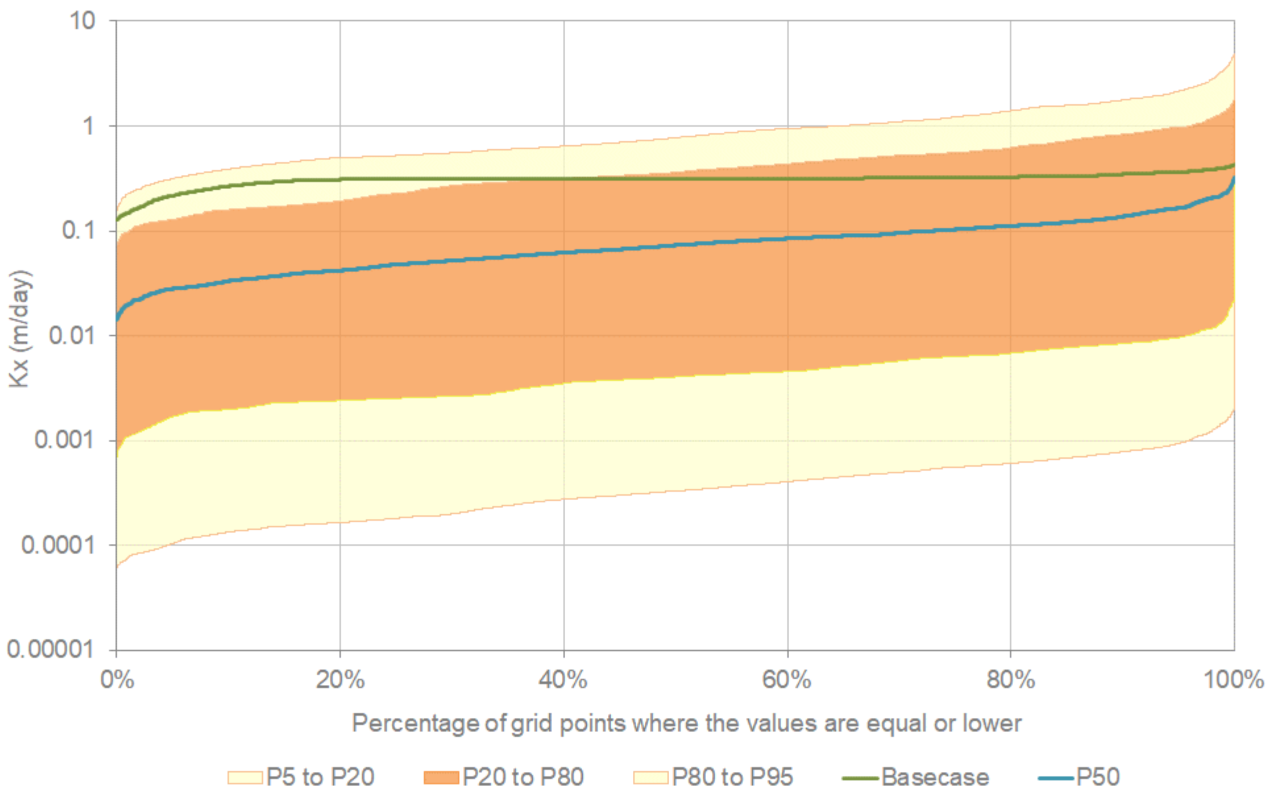


Figure A 5.4 Cumulative distribution function plot for Kx: layer 20 – Nagero Seam

In most cases these plots show that the 50th percentile (P50) parameter values adopted for the uncertainty analysis are similar to the basecase, although in some cases the final calibrated basecase value is towards the upper bound of the range that is considered physically realistic. This is evident in layer 1, where values for the Narrabri Formation (see values for 40% to 100% range) exceed the 95th percentile (P95). This may indicate some convergence issues in this layer for uncertainty realisations where values were around those of the elevated basecase. The basecase values relating to the layer 1 regolith (see values for 0% to 40% range) are equal to the P50.

The uncertainty bands for each of the select layers show that the average Kx of the entire hydrostratigraphic unit varied by approximately:

- 1 order of magnitude in the regolith;
- 1.5 orders of magnitude in the alluvium;
- 0.5 order of magnitude in the interburden; and
- 3 orders of magnitude in the coal seams.

A5.3 Results

Inflow rates

Uncertainty bands for inflow to the BCM mining area (Figure A 5.5) indicates that the basecase calibration generally falls between the 10th and 33rd percentiles (P10 - P33), with some periods exceeding the P50. It should be noted that realisation success criteria was not linked to inflow observations, given that: (a) inflow observations are uncertain estimates; and (b) drawdown and depressurisation is considered to be the biggest risk to groundwater dependent assets. The predicted peak inflows range from 639 ML/year (1st percentile) to 1,512 ML/year (98th percentile), compared to the predicted inflow for the basecase, which has been shown to peak at 712 ML/year (Section 8.1.2).

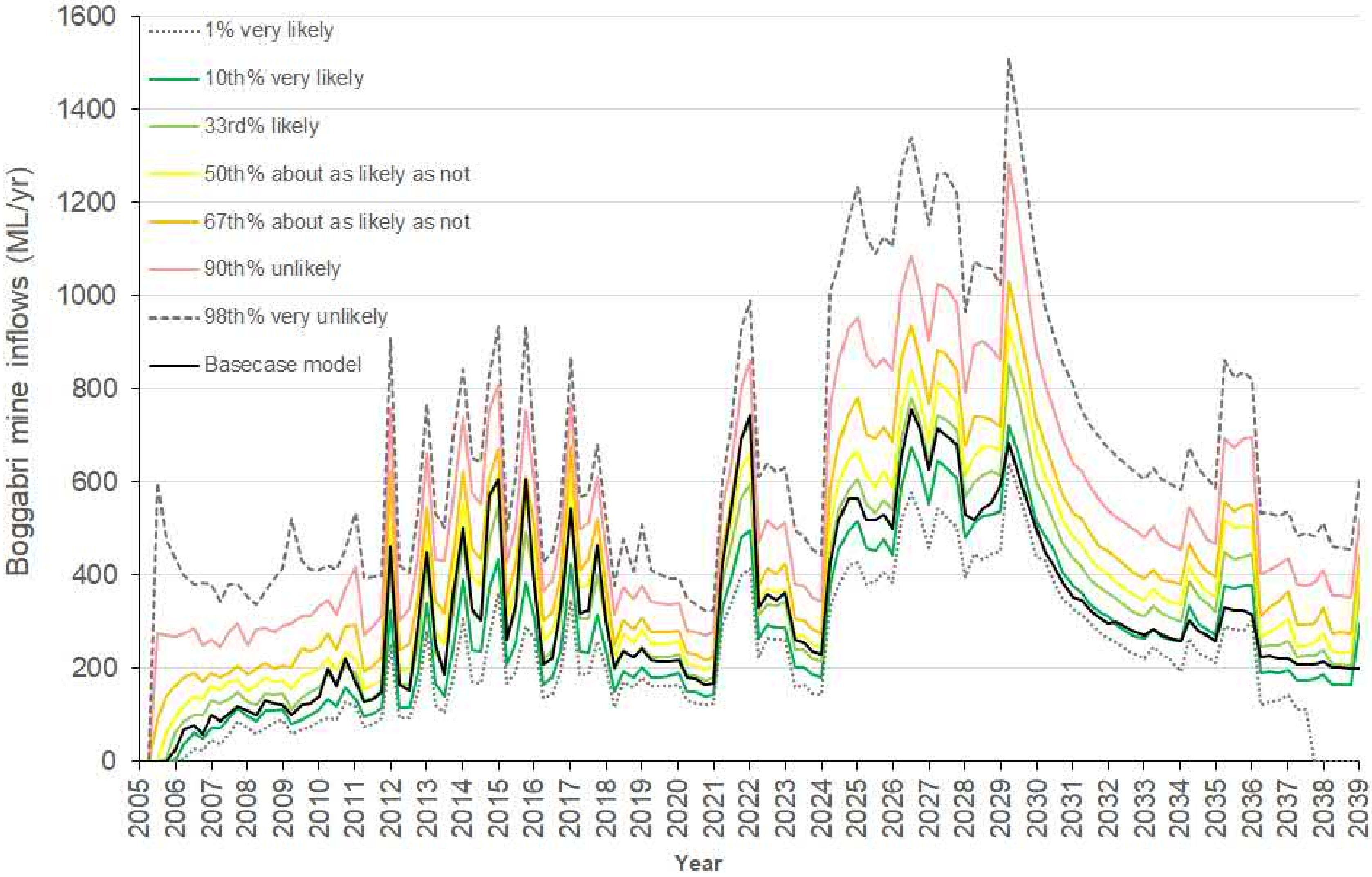


Figure A 5.5 Probability distribution for Boggabri mine inflow rate

A5.3.1 Zone of drawdown

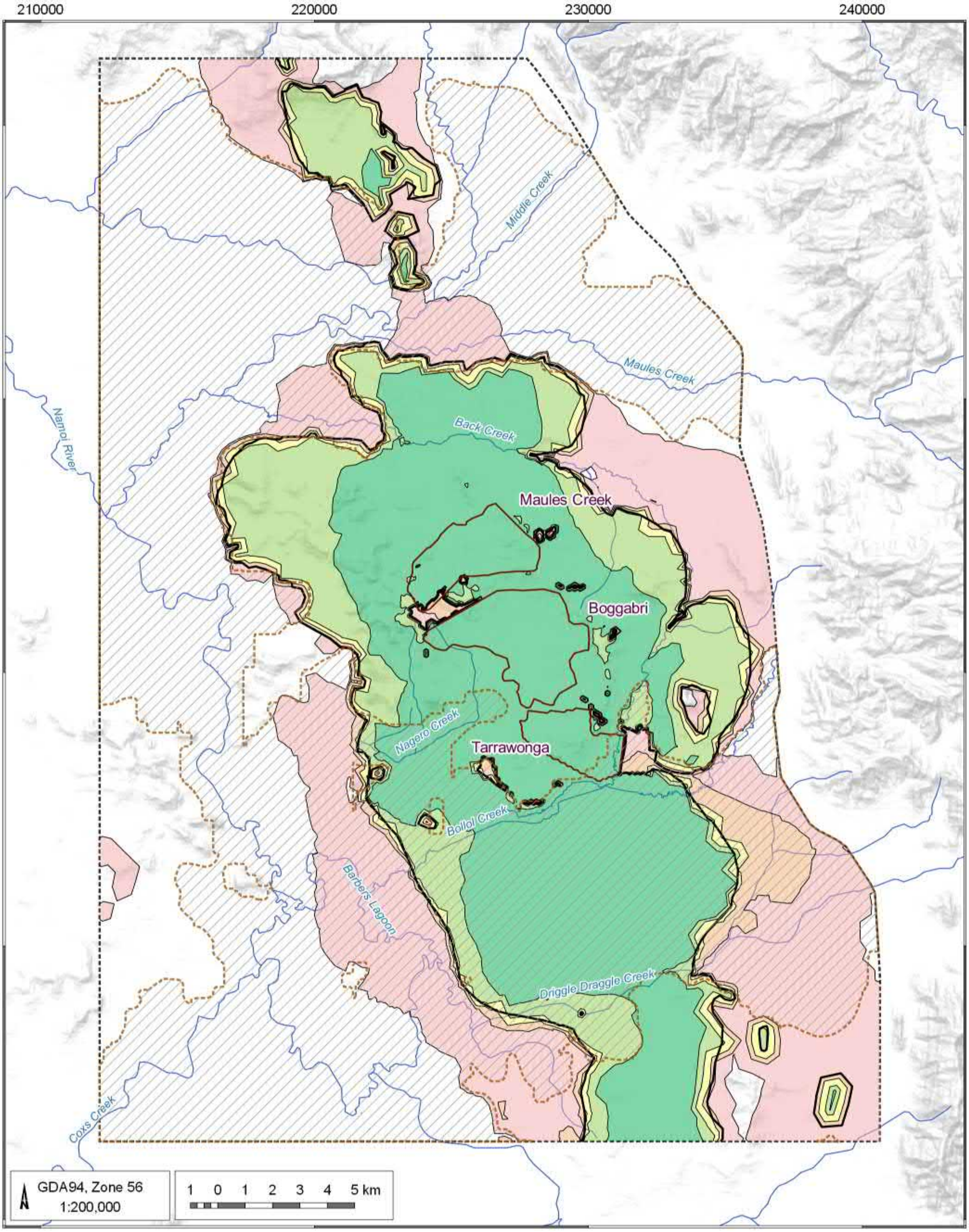
The uncertainty of drawdown at the end of mining was determined using the 216 successful model realisations, with the following scenarios assessed.

- Likelihood for 0.1 m drawdown of the water table (Figure A 5.6) – Used to show drawdown uncertainty and to assess potential GDE impacts as per the AIP minimal impact threshold (assuming a seasonal water table fluctuation of 1 m).
- Likelihood for 2 m drawdown of the water table (Figure A 5.7) – Used to show drawdown uncertainty and to assess potential impacts to shallow private bores, particularly in the alluvium, as per the AIP stipulated maximum water level/water pressure decline of 2 m.
- Likelihood for 2 m drawdown of the Nagero Seam (Figure A 5.8) – Used to show drawdown uncertainty and to assess potential impacts to private bores installed in the coal measures, as per the AIP stipulated maximum water level/water pressure decline of 2 m. Note that the Nagero Seam is the deepest coal seam to be mined by all members of the BTM Complex as part of the cumulative MOD 8 scenario.

For each of these figures, the total number of times a model cell had drawdown greater than the target value was tallied and converted to a probability percentile. The greater the extent of drawdown away from the mines, the less likely it is to occur.

Results show that basecase predictions of drawdown in the water table are conservative, with both the 0.1 m/2 m extent generally falling between 'about as likely as not' and 'unlikely'. Any significant changes to the extent of water table drawdown are limited to the 'very unlikely' scenario. Within the tongue of alluvium immediately to the southwest of BCM, the extent of 2 m drawdown shows that drawdown extends through a greater portion of the tongue as the likelihood reduces. While the uncertainty for the incremental impact of MOD 8 has not been assessed, it is expected that the incremental drawdown of the alluvium in this area (Figure 8.7b) would have a similar response.

Basecase predictions of drawdown in the Nagero Seam are similarly conservative, with the 2 m drawdown extent only being exceeded by the 'unlikely' and 'very unlikely' scenarios. The 'very unlikely' scenario results in coverage of the full layer extent. As discussed throughout the report, drawdown to even the basecase extent is unlikely, given that depressurisation is still yet to be observed at distant monitoring locations to the north, east, and south of the BTM Complex.



LEGEND

- Model extent
- Modelled alluvial extent
- Extent of mining
- Drainage
- Uncertainty drawdown contour
- Basecase drawdown contour (0.1 m)

Likelihood of 0.1 m drawdown

- Very unlikely
- Unlikely
- About as likely as not
- Likely
- Very likely

Boggabri MOD8 (G1850W)

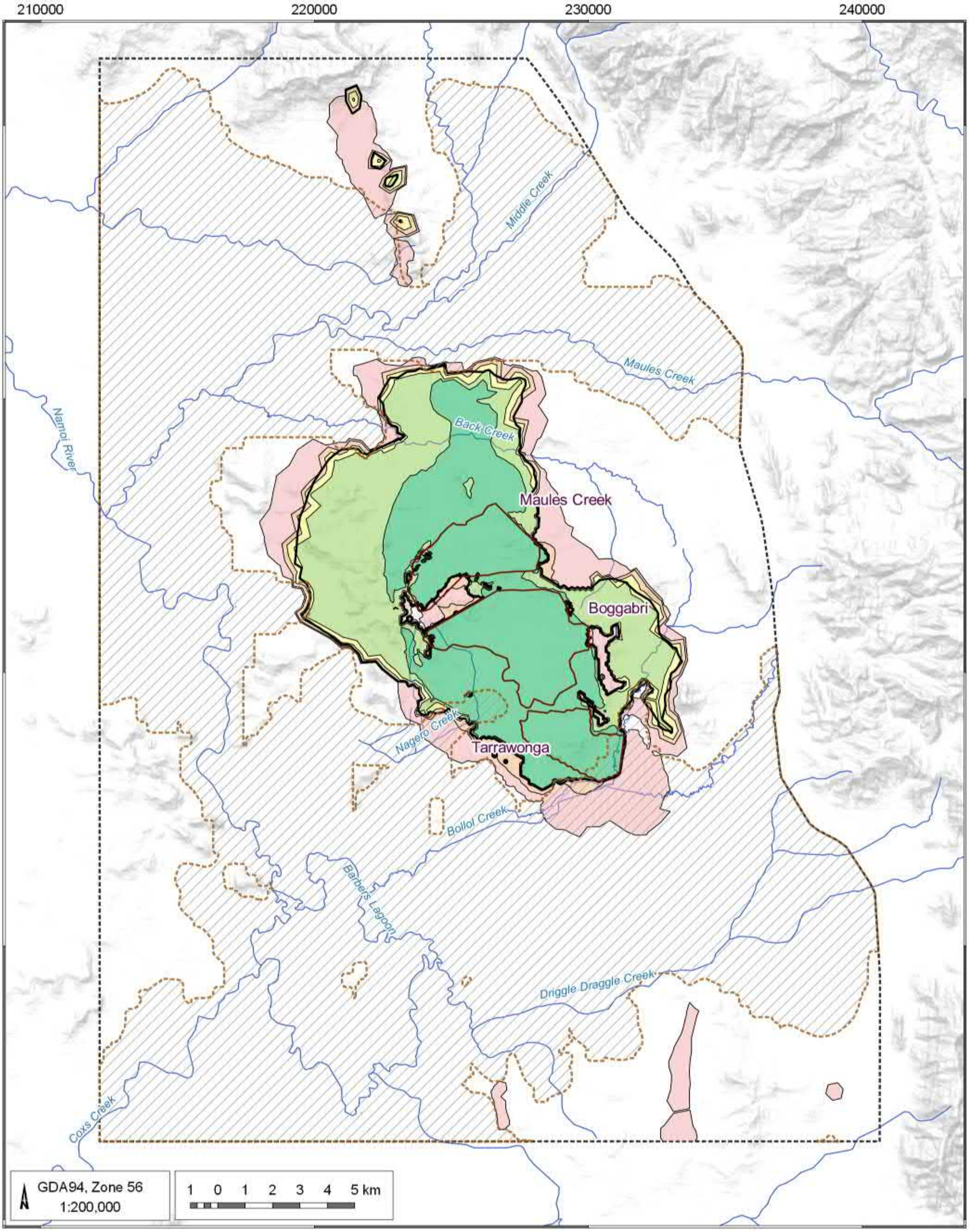
Likelihood of 0.1 m drawdown at end of mining – water table

AGE

DATE 14/07/2021

FIGURE No: **A 5.6**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\A 05.06_G1850W_Likelihood of 0.1 m drawdown at end of mining – water table.qgs



LEGEND

- Model extent
- Modelled alluvial extent
- Extent of mining
- Drainage
- Uncertainty drawdown contour
- Basecase drawdown contour (2 m)

Likelihood of 2 m drawdown

- Very unlikely
- Unlikely
- About as likely as not
- Likely
- Very likely

Boggabri MOD8 (G1850W)

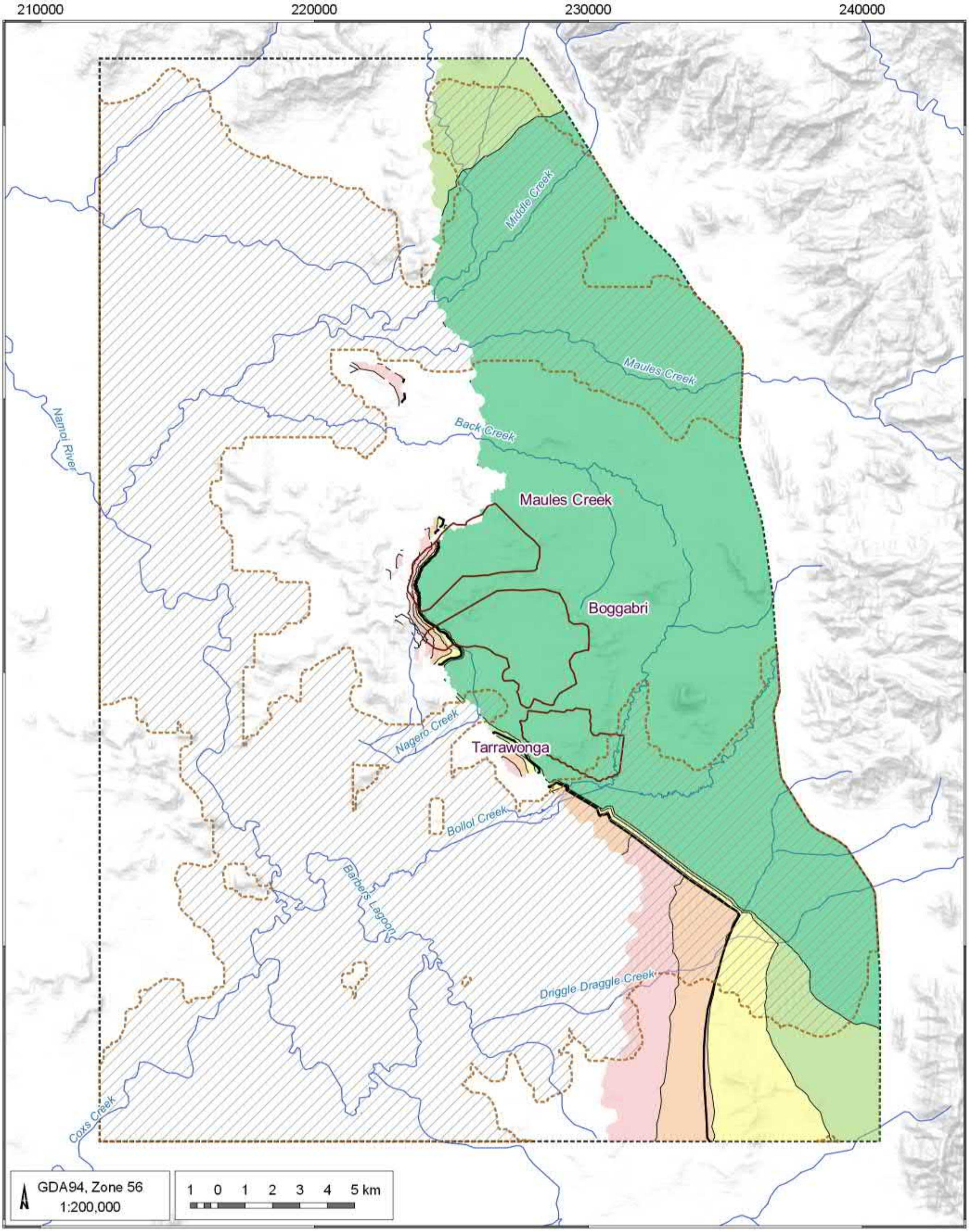
Likelihood of 2 m drawdown at end of mining - water table

AGE

DATE 14/07/2021

FIGURE No: **A 5.7**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\A 05.07_G1850W_Likelihood of 2 m drawdown at end of mining – water table.qgs



LEGEND

- Model extent
- Modelled alluvial extent
- Extent of mining
- Drainage
- Uncertainty drawdown contour
- Basecase drawdown contour (2 m)

Likelihood of 2 m drawdown

- Very unlikely
- Unlikely
- About as likely as not
- Likely
- Very likely

Boggabri MOD8 (G1850W)

Likelihood of 2 m drawdown at end of mining - Nagero Seam (Layer 20)

AGE

DATE 14/07/2021

FIGURE No: **A 5.8**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\A 05.08_G1850W_Likelihood of 2 m drawdown at end of mining – Nagero Seam (Layer 20).qgs