7 Numerical groundwater model

7.1 Mining period

The BTM Complex's cumulative 3D numerical groundwater flow model (AGE, 2020) was used to assess the impact of MOD 8. This model has seen continuous refinements and updates over more than a ten year period, with the current iteration using the industry standard modelling code MODFLOW-USG. The AGE (2020) model has been subject to multiple phases of review by NRAR and the water division of DPIE.

The objective of the modelling was to identify the magnitude of potential impacts from MOD 8 on surrounding groundwater systems and water dependent assets, including an assessment of cumulative impacts. A detailed description of the model development is provided in Appendix A.

The model domain covers an area of approximately 39 km from north to south and 25 km from east to west, centred on BCM and encompassing Maules Creek Mine to the north and Tarrawonga Mine to the south (Figure 7.1). The model domain was discretised into 339,855 total model cells with a maximum of 18,920 cells in any one layer. The model cells varied in size and geometry to best represent different environmental and mining features throughout the model domain. The features around which the model grid was refined include the:

- open cut mines – 50 m x 100 m orthogonal grid;
- areas surrounding open cut mines - Voronoi grid with up to 120 m between cell centres;
- streams and alluvial flood plains - Voronoi grid with up to 220 m between cell centres;
- adjacent to active extraction bores - Voronoi grid with approximately 175 m diameter;
- adjacent to inferred Conomos Fault - Voronoi grid with approximately 450 m x 350 m cells; and
- remainder of model domain - Voronoi grid with up to 800 m between cell centres.

The model has 34 layers representing the major hydrostratigraphic units, including the alluvium, weathered zone, interburden, major coal seams, and underlying basement volcanics. The model cells within each layer were active and each cell was assigned to a single hydrostratigraphic unit.

The mine plan for the approved mining scenario (base case) received minor updates to reflect further information provided on the approved progression of mining. The base case mine plan was amended to create a new model scenario, representing MOD 8 as provided by BCOPL (Appendix A). Under MOD 8, BCM will be the final mine to cease operations in December 2039, while Maules Creek Mine is the last to finish mining in December 2036 under the base case. The model keeps all mining voids in the BTM Complex open (i.e. no spoil emplacement) until December 2039, which is a conservative approach for predictions of inflow and causes drawdown to propagate further than if backfilled with spoil. Mining-induced dewatering was represented in the model by drain boundary conditions, in which the drains were set at the floor of the deepest coal seam approved for mining to effectively dewater the open cut mining areas. Private abstraction from irrigation bores was represented in the model using the MODFLOW well package, with private abstraction data provided by the water division of DPIE.

The groundwater model was calibrated to a pre-mining steady state water level dataset and then to transient water level records (2006 to 2019) as well as mine inflow datasets. The calibration was achieved by adjusting groundwater system parameters and stresses to produce the best match between the observed and simulated water levels and mine inflows (history matching). Manual testing, automated parameterisation software (PEST) (Doherty, 2010), and pilot points were used to guide the model towards a set of hydraulic parameters and recharge rates that provided the best calibration.

The match between the observed and simulated water levels was determined by calculating the Scaled Root Mean Square (SRMS) statistic. The SRMS was 4.41%, which is below the commonly accepted upper limit of 10%. The mine inflow was also compared and shown to provide a reasonable match at each of the mines in the BTM Complex (Appendix A).

Following calibration, the model was used to estimate potential changes in groundwater pressure (drawdown) for the various groundwater systems, as well as the volume of groundwater directly and indirectly intercepted by BCM. The impacts from MOD 8 were determined by calculating the difference between two model simulations, with the first model representing the base case and the second including MOD 8.

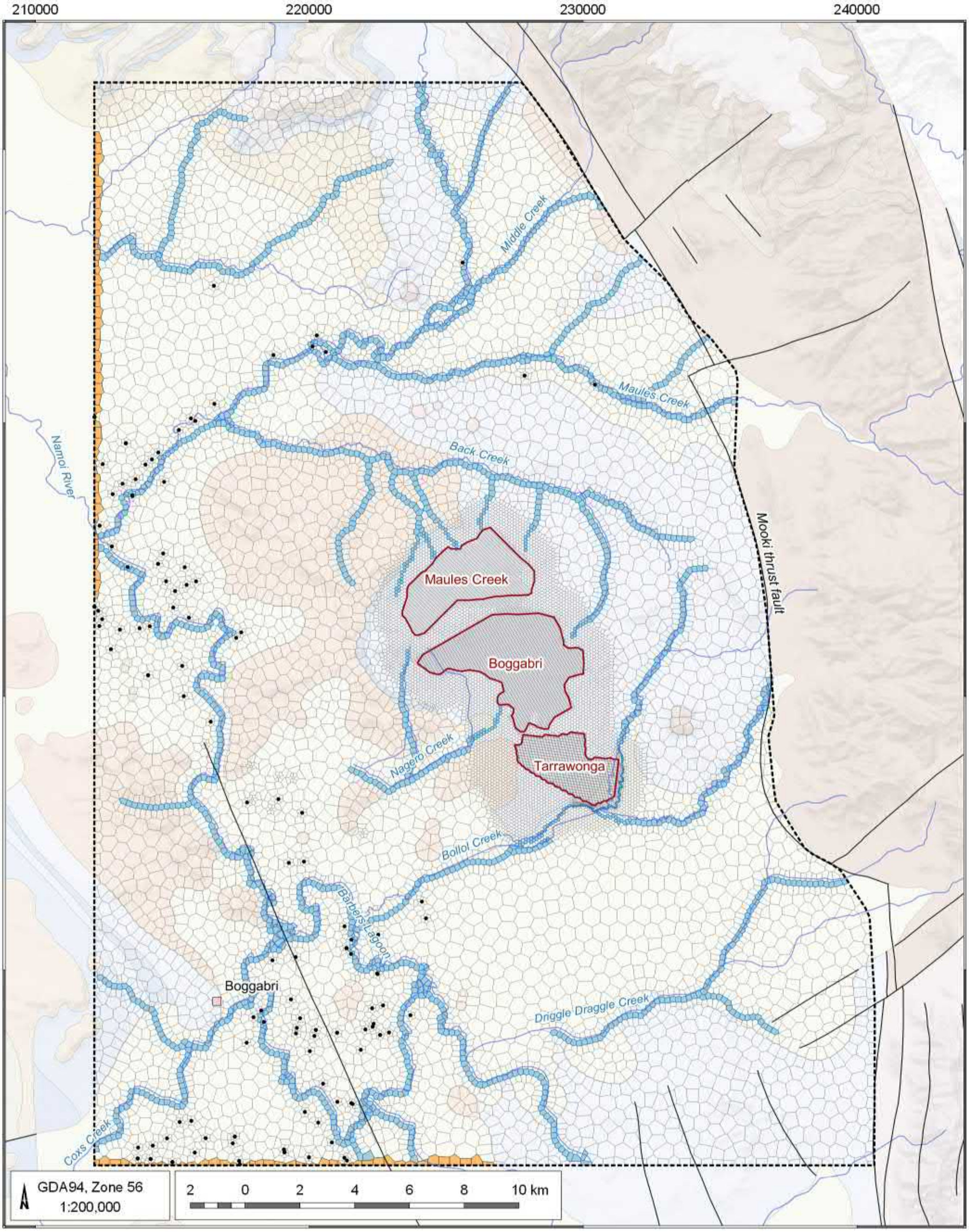
7.2 Recovery simulations

Residual impacts to the groundwater system after mine closure were assessed for a period of 1,000 years by continuing the simulations under long-term average climatic drivers. Spoil was represented in each of the mining areas immediately after mining, with the emplaced material existing between the base of mining and the adopted final landform. The final landform adopted for BCM was specific to MOD 8, while the voids for Maules Creek Mine and Tarrawonga Mine were respectively sourced from the original approval and Tarrawonga's MOD7 application, which was approved in February 2021.

A sensitivity analysis was undertaken to determine how changes to the model parameters influenced the equilibrium water level and time to equilibrium. Two alternate sensitivity 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. Justification for the base case parameters and results of the sensitivity analysis are detailed in Section 8.2.2.

7.3 Peer review

The AGE (2020) model represents the most current version of a cumulative model that has been subject to multiple phases of review over the last decade. Iterative review by NSW Government technical experts spans more than a decade, with an independent peer review of the AGE (2018) model completed by Dr Noel Merrick (HydroSimulations, 2018). This GIA and the application of the BTM complex model to MOD 8 was peer reviewed by Associate Professor Claire Côte of the University of Queensland and is provided as a separate appendix to the Modification Report.



LEGEND

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

AGE

DATE 14/07/2021

FIGURE No: **7.1**

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\07.01_G1850W_Model domain and mesh.qgs

8 Predictions and impact assessment

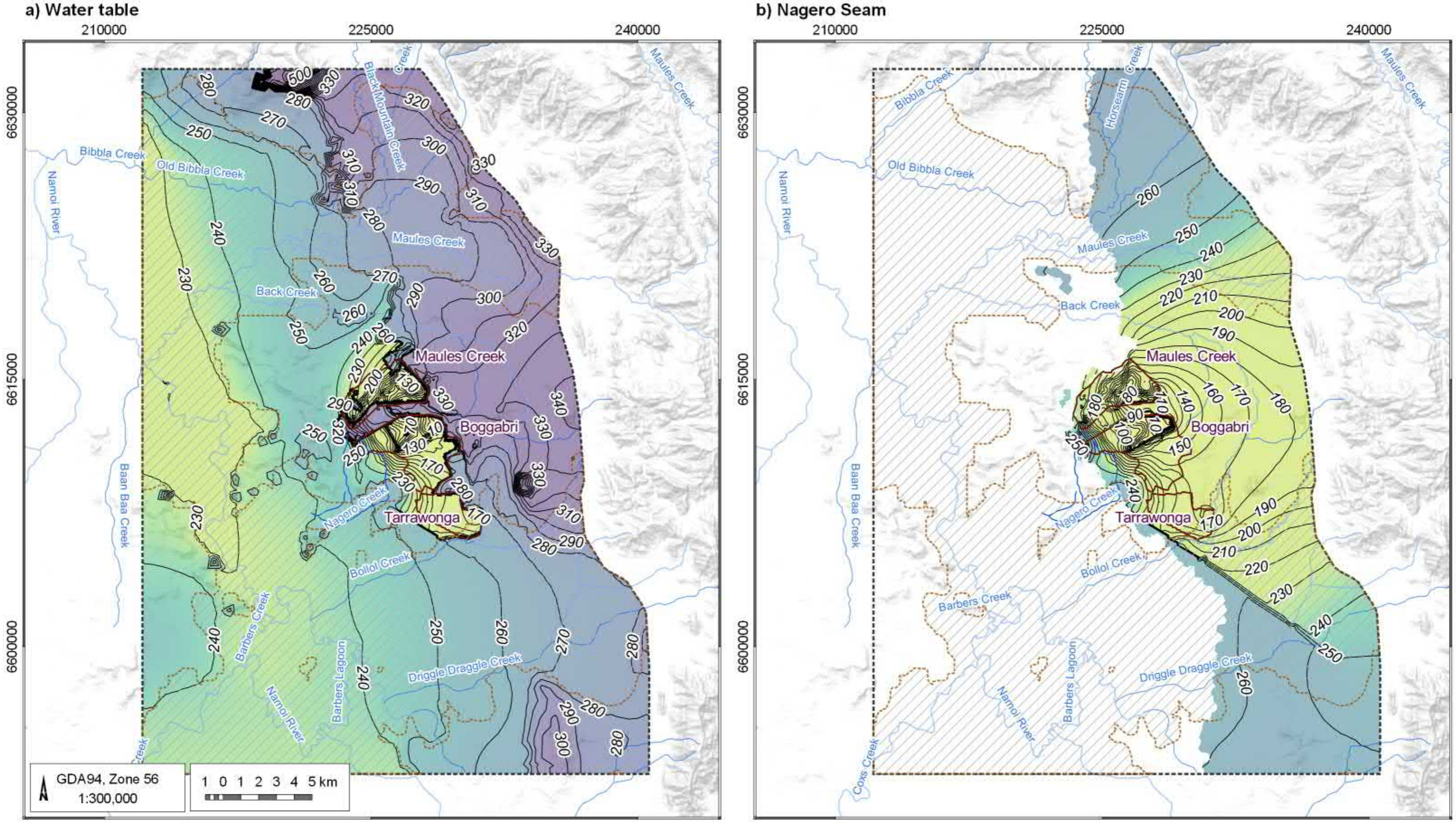
This section describes the numerical model predictions and impacts of MOD 8 during both the operational period and post closure. Results of the cumulative MOD 8 simulation, which includes approved mining at all three of the BTM Complex mines in addition to MOD 8 activities, are presented throughout this section. MOD 8 incremental impacts, i.e. the difference between cumulative simulations with and without MOD 8, are presented with respect to drawdown/depressurisation (Section 8.1.3), potential private bore impacts (Section 8.1.6), and potential GDE impacts (Section 8.1.6.2). These incremental differences are the impacts that are directly attributable to MOD 8.

8.1 Mining period

8.1.1 Heads and flow direction

Outside the mined areas, the end of mining water table (Figure 8.1a) is generally consistent with the current conditions (Section 6.5), with the dominant groundwater flow direction to the west in the direction of the Namoi River. Flow direction is influenced by topography, which is evident in down gradient flow through the Maules Creek and the Bollol Creek flood plains. The influence of mining can clearly be seen within and adjacent to the BTM Complex, where lowered groundwater levels result in a localised hydraulic gradient towards each of the mines.

Within the Nagero Seam, which is the deepest coal seam proposed to be mined by all three members of the BTM Complex, the simulated potentiometric surface (Figure 8.1b) depicts a much greater extent of influence around the mining areas. Where both alluvium and the Nagero Seam are present, groundwater levels generally indicate a downwards vertical gradient from the alluvium to the coal measures, which is consistent with observations discussed in Section 6.5.2.



LEGEND
- Model extent
- Modelled alluvial extent
- Extent of mining
- Contour line
- Drainage

Head (mAHD)
-50
200
250
300
550

Boggabri MOD8 (G1850W)

AGE

MOD8 piezometric surface – end of mining

DATE
14/07/2021

FIGURE No:
8.1

Source: LiDAR DEM, © Department Finance, Services and Innovation.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\08.01_G1850W_MOD8 piezometric surface – end of mining.qgs

8.1.2 Mine inflow

Groundwater inflow rates for each mine were simulated for approved mining and MOD 8, with BCM specific comparisons shown on Figure 8.2. Comparisons for the entire BTM Complex are presented in Appendix D. At BCM, the predicted annual inflows are equal for both simulations until 2020, after which differences can be attributed to modelled differences in the mining progressions (Appendix A).

The influence of MOD 8 increasing inflow is most apparent after 2025, which is the year that mining first steps down to the Templemore Seam. BCM’s inflow is at its highest levels between 2025 and 2030 where the deepest sections of the Templemore Seam are mined in a south-southeast to north-northwest direction, towards the northeast corner of the mining area. Inflow rates then decrease as the already depressurised Templemore Seam continues to be mined at a higher elevation until the end of 2036, with only the Merriown Seam being mined from 2037 until the end of 2039. The maximum annual inflow for BCM is 537 ML/year in 2021 for approved mining and 712 ML/year in 2027 for MOD 8.

At a cumulative scale, MOD 8 generally leads to an increase in total inflow across the three mines within the BTM Complex, although peak inflows are comparable (Appendix D). There is a maximum cumulative annual inflow for approved mining of 1,866 ML/year in 2024 and a maximum cumulative annual inflow for MOD 8 of 1,928 ML/year in 2027. MOD 8 leads to a decrease in the rate of inflow at the Maules Creek and Tarrawonga mines, with maximum reductions of 93 ML/year and 23 ML/year, respectively.

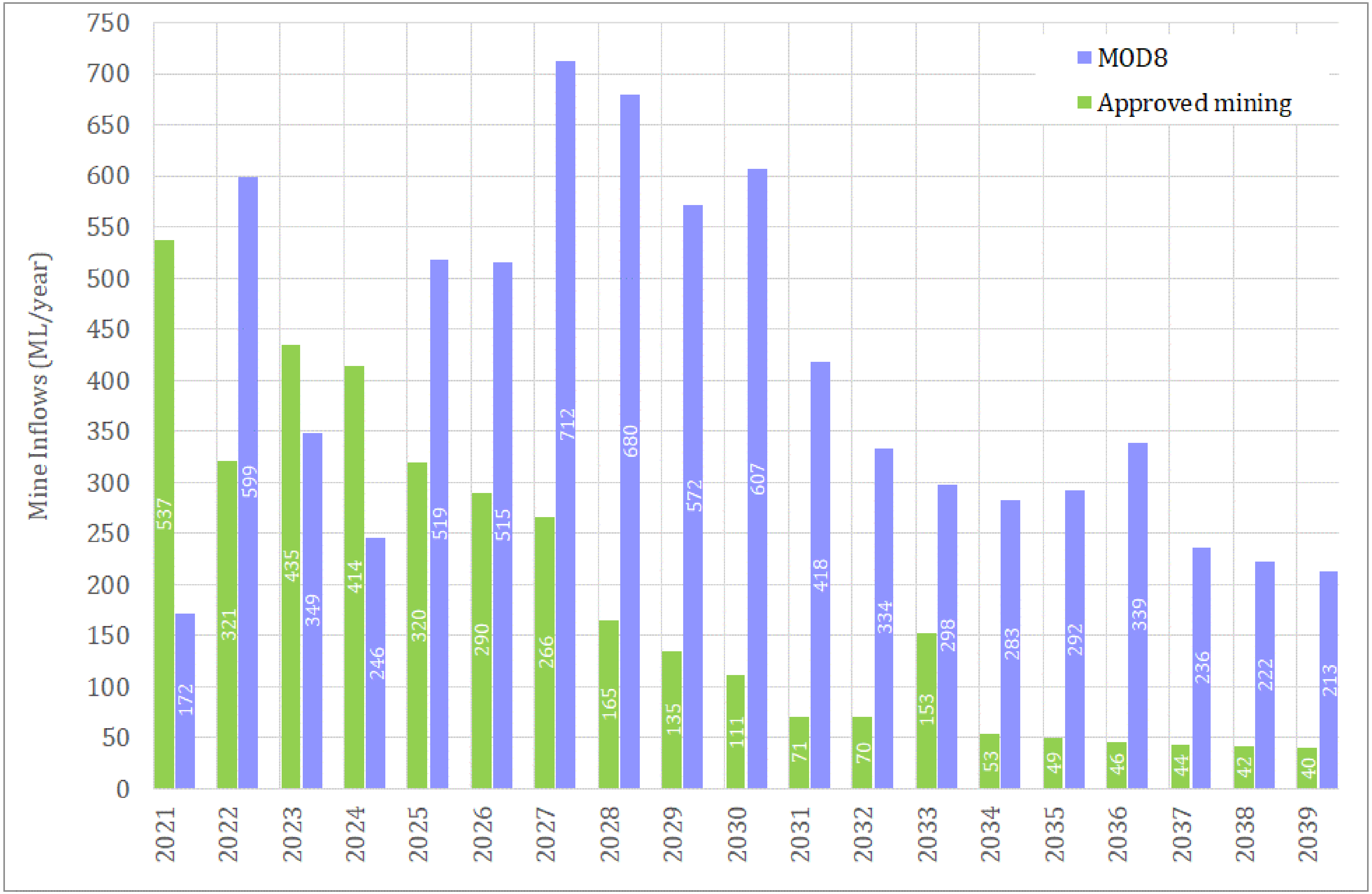


Figure 8.2 Simulated inflows at BCM – approved mining vs MOD 8

8.1.3 Drawdown and depressurisation

8.1.3.1 Cumulative impact

End of mining drawdown predictions within the alluvium, Merriown Seam, Templemore Seam, and the Boggabri Volcanics are shown on Figure 8.3 through to Figure 8.6. For each model layer, two sets of drawdown predictions are provided to illustrate cumulative impacts. These include the:

- left (a) window - cumulative drawdown from all approved and proposed mining in the BTM Complex, which shows the absolute impact that is predicted to occur if MOD 8 is approved;
- right (b) window - cumulative drawdown from all approved mining (excludes MOD 8), which shows the absolute drawdown for already approved activities;

The cumulative drawdown that is predicted within the alluvium is generally less than 2 m for both the approved mining and MOD 8 simulations, with most of the drawdown occurring in the zone 4 alluvium to the south of BCM (Figure 8.3). The predicted drawdown exceeds 2 m in a small portion of the alluvial tongue that is directly southwest of BCM on BCOPL owned land, where a maximum drawdown of approximately 5 m is predicted. Drawdown in excess of 2 m is also observed in the southeast corner of Tarrawonga Mine where the alluvium is mined through.

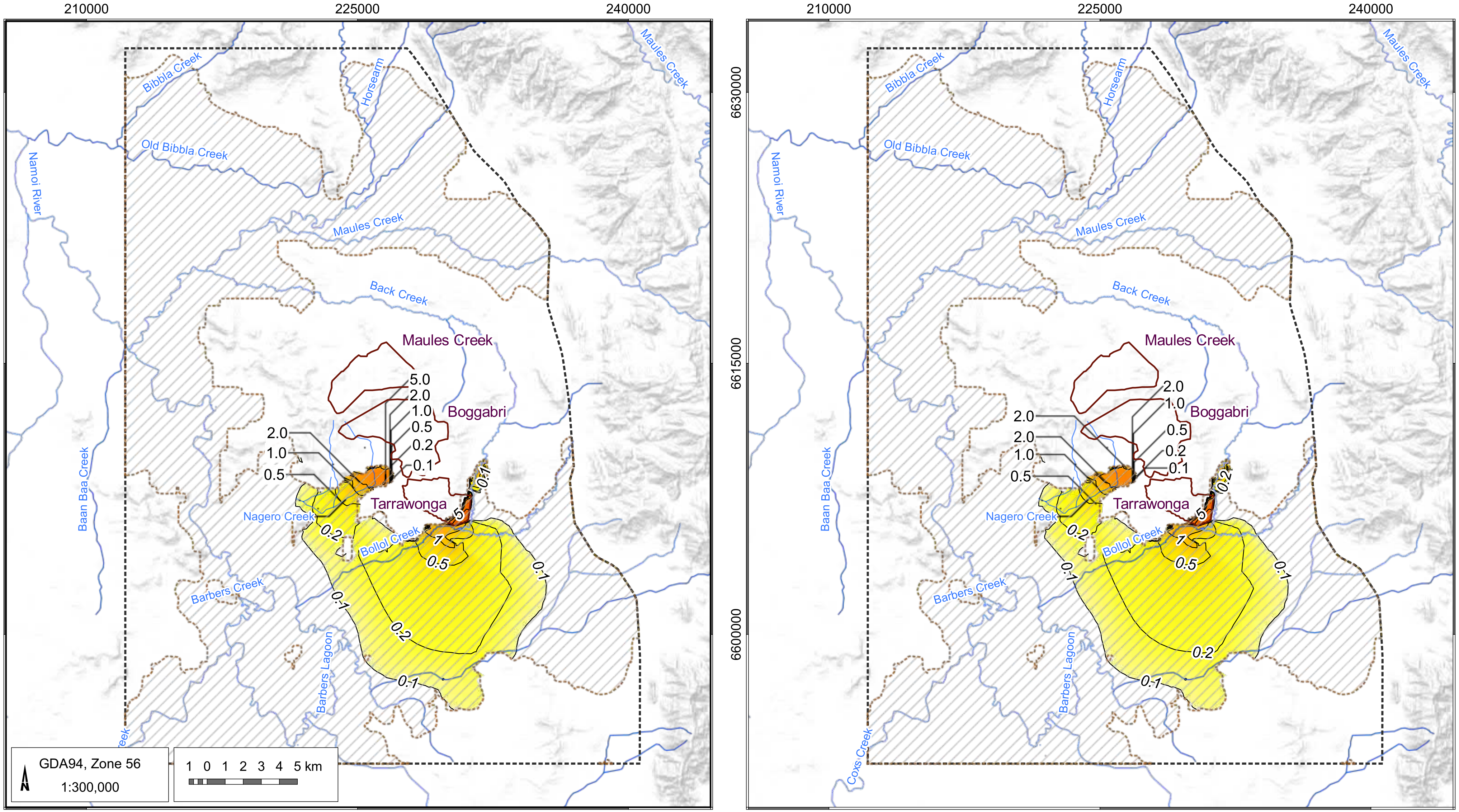
The existing and observed zone of drawdown within each of the coal seams (see Section 6.5) is predicted to expand as mining continues, and reaches the model boundaries by 2039 for both the MOD 8 and approved mining cumulative simulations (Figure 8.4 and Figure 8.5). The extent of drawdown is considered a conservative overestimate, as widespread propagation to the east has not been observed in any coal seams through monitoring to date (e.g. see REG07 and REG09 in Section 6.5.3). The MOD 8 cumulative drawdown predicted for both the Merriown Seam and the Templemore Seam is most significant within the mined footprint, with respective maximums of approximately 110 m and 300 m generally corresponding with the depth of the coal seams.

Drawdown of the Boggabri Volcanics is predicted by both the MOD 8 and approved mining cumulative simulations (Figure 8.9).

The influence of the Conomos Fault is evident in the shape of the predicted drawdown within the coal seams and the Boggabri Volcanics. The figures show how the representation of the fault as a barrier to groundwater flow results in less drawdown occurring to the south. When interpreting the predicted drawdown, it is important to note that other faults are known to exist within the area but are not represented in the numerical model. It is expected that depressurisation and drawdown within the coal seams will not propagate beyond the faults that offset and terminate the coal seams against lower permeability interburden. This is potentially already evident in the lack of drawdown observed in monitoring bores located to the east of BCM (e.g. see REG07 and REG09 in Section 6.5.3).

a) Cumulative drawdown - MOD8

b) Cumulative drawdown - approved mining



LEGEND

- Model extent
- Modelled alluvial extent
- Extent of mining
- Contour line
- Drainage

Drawdown (m): 0, 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50

Boggabri MOD8 (G1850W)

AGE

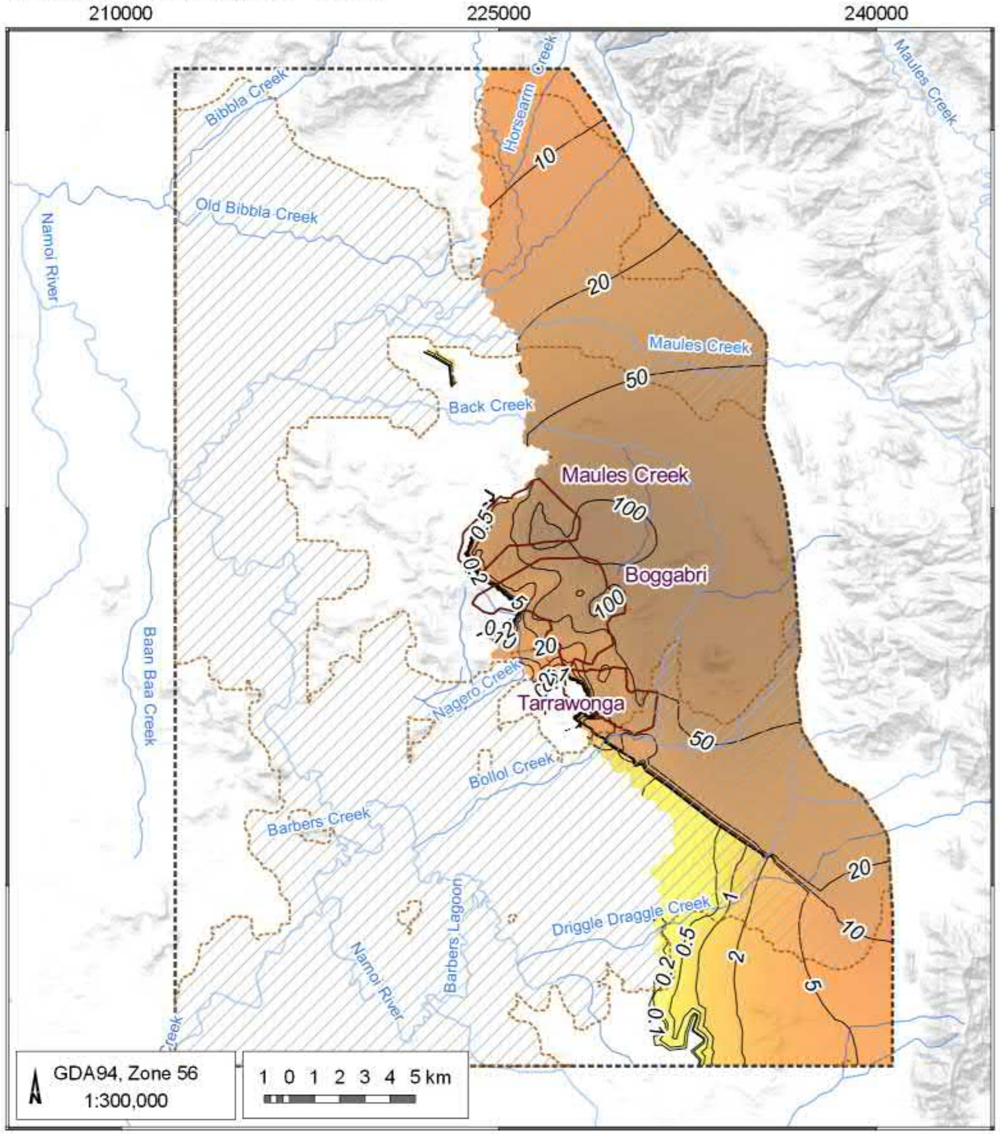
Predicted end of mining drawdown in alluvium – cumulative impacts

DATE 14/07/2021

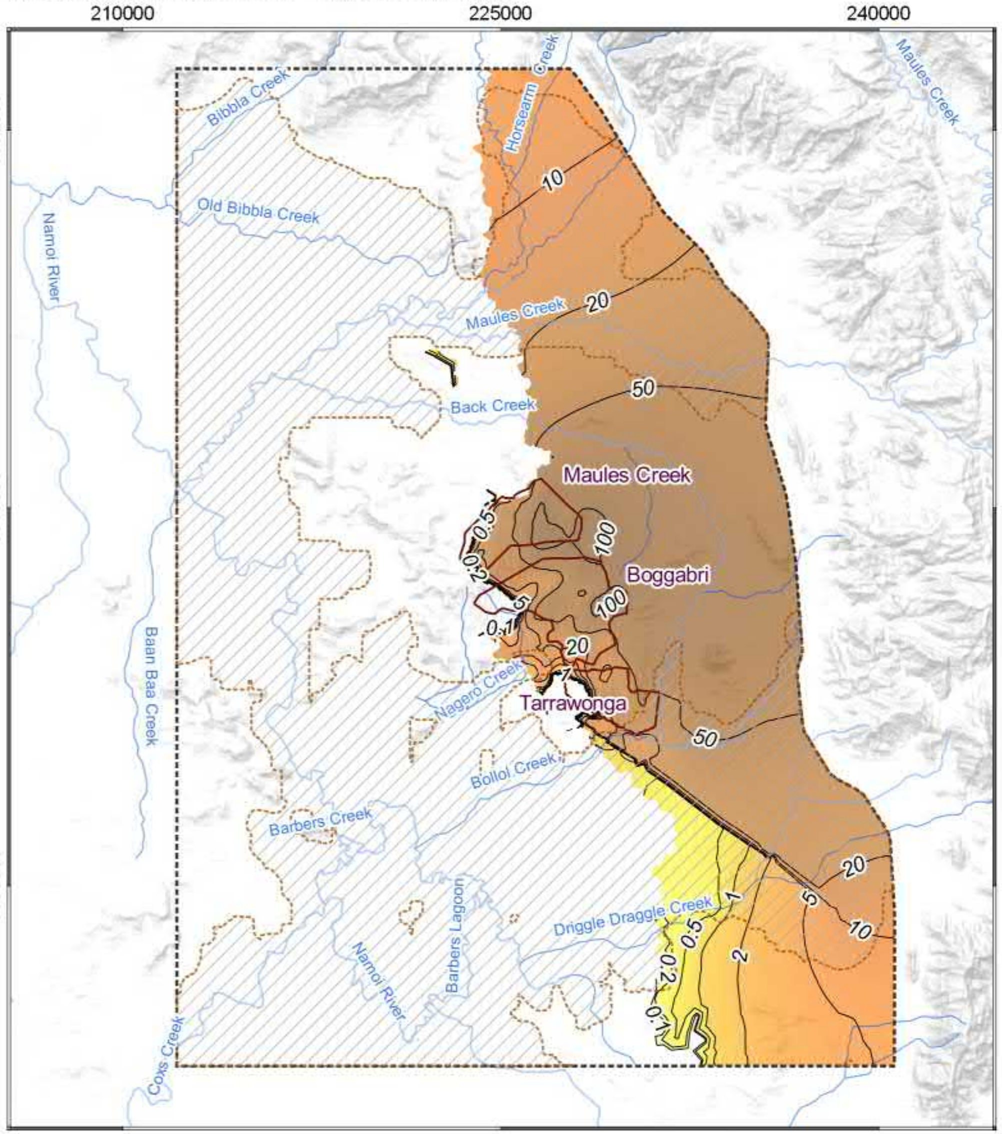
FIGURE No: **8.3**

Source: LiDAR DEM, © Department Finance, Services and Innovation.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\08.03_G1850W_Predicted end of mining drawdown in alluvium – cumulative impacts.qgs

a) Cumulative drawdown - MOD8



b) Cumulative drawdown - approved mining



LEGEND

- Model extent
- Modelled alluvial extent
- Extent of mining
- Contour line
- Drainage

Drawdown (m)

0, 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100, 200, 500

Boggabri MOD8 (G1850W)

AGE

Predicted end of mining drawdown in Merriown Seam – cumulative impacts

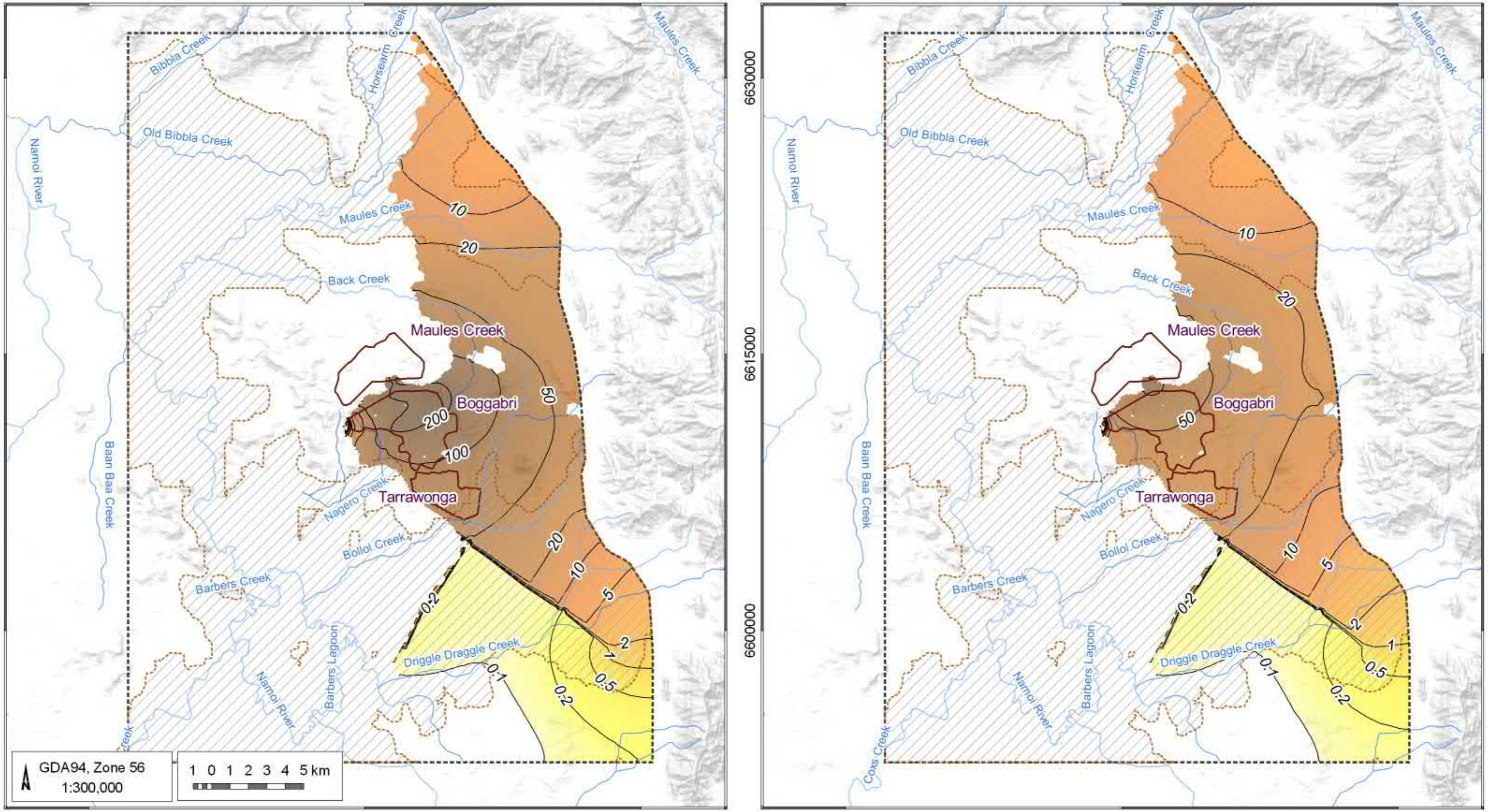
DATE
14/07/2021

FIGURE No:
8.4

Source: LiDAR DEM, © Department Finance, Services and Innovation.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\08.04_G1850W_Predicted end of mining drawdown in Merriown Seam – cumulative impacts.qgs

a) Cumulative drawdown - MOD8

b) Cumulative drawdown - approved mining



LEGEND

- Model extent
- Modelled alluvial extent
- Extent of mining
- Contour line
- Drainage

Drawdown (m)

0	10
0.1	20
0.2	50
0.5	100
1	200
2	500
5	

Boggabri MOD8 (G1850W)

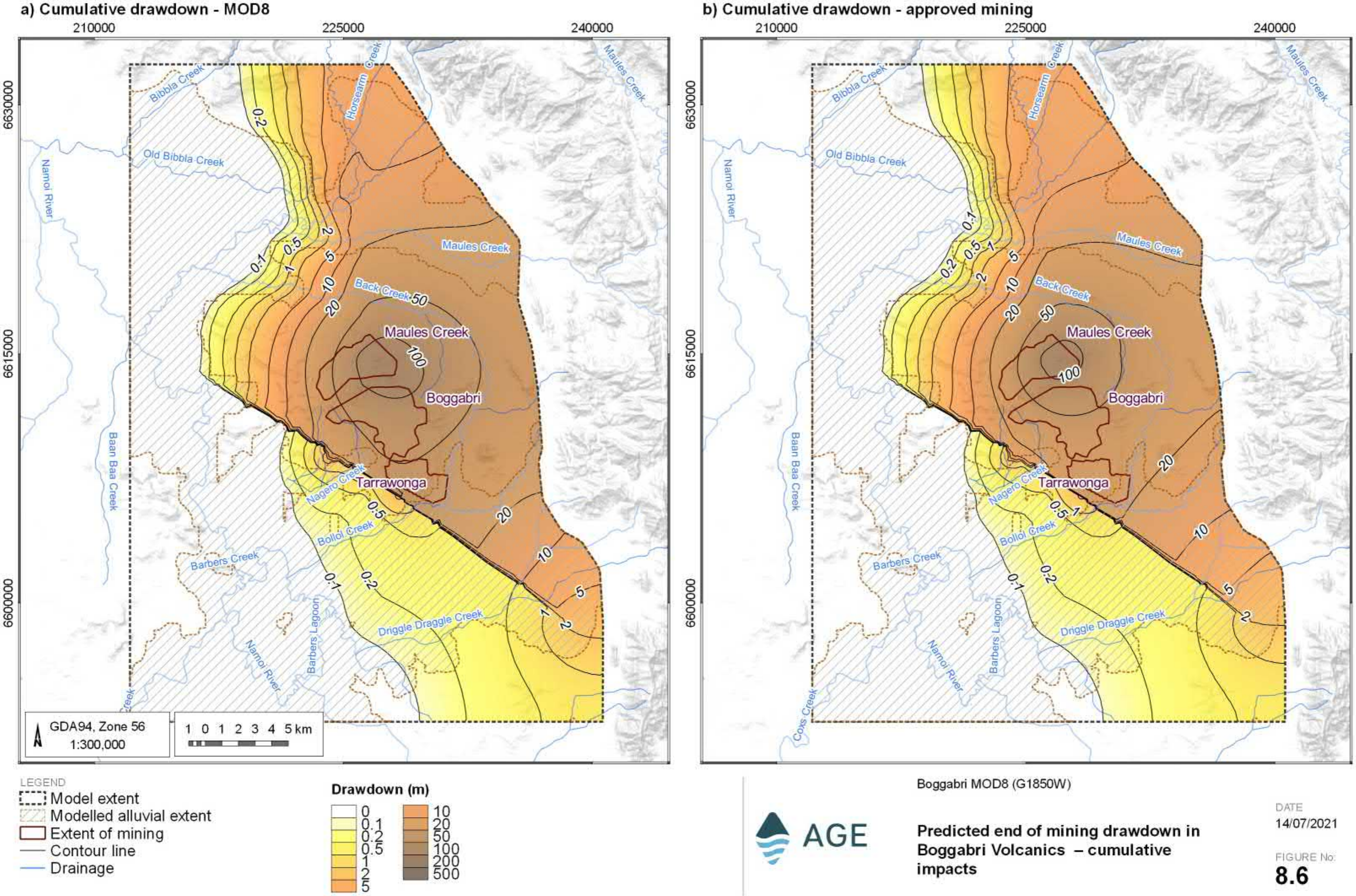
AGE

Predicted end of mining drawdown in Templemore Seam – cumulative impacts

DATE
14/07/2021

FIGURE No:
8.5

Source: LiDAR DEM, © Department Finance, Services and Innovation.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\08.05_G1850W_Predicted end of mining drawdown in Templemore Seam – cumulative impacts.qgs



Boggabri MOD8 (G1850W)

AGE

Predicted end of mining drawdown in Boggabri Volcanics – cumulative impacts

DATE
14/07/2021

FIGURE No:
8.6

Source: LiDAR DEM, © Department Finance, Services and Innovation.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\08.06_G1850W_Predicted end of mining drawdown in Boggabri Volcanics – cumulative impacts.qgs

8.1.3.2 BCM specific impact

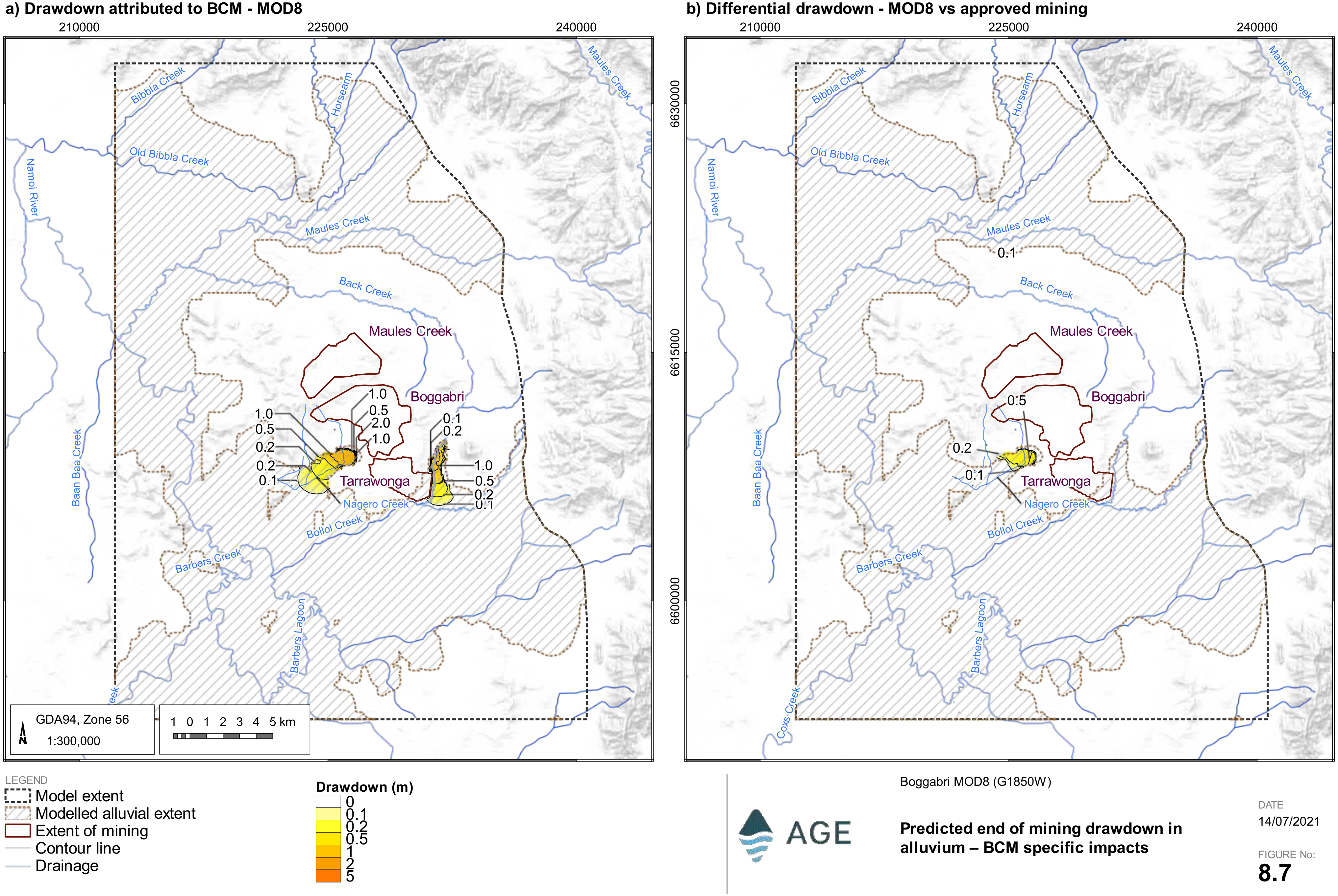
End of mining drawdown predictions within the alluvium, Merriown Seam, Templemore Seam, and the Boggabri Volcanics are shown on Figure 8.7 through to Figure 8.10. For each model layer, two sets of drawdown predictions are provided to illustrate impacts that can be attributed to mining activities at BCM. These include the:

- left (a) window - component of drawdown from all approved and proposed mining that is specific to BCM, which was created by comparing water levels predicted by models including and excluding BCM; and
- right (b) window - component of drawdown that is attributed to MOD 8 only (excludes already approved drawdown), which was created by comparing cumulative simulations with and without MOD 8 (i.e. mining with MOD 8 minus approved cumulative mining).

Alluvial drawdown that can be directly attributed to MOD 8 (Figure 8.7b) is only predicted to occur in a small portion of the alluvial tongue that is directly southwest of BCM on BCOPL owned land, reaching a maximum of approximately 0.8 m. This is consistent with the conceptualisation of MOD 8 impacts (Section 6.10.1), where alluvial impacts were inferred to be minimal.

MOD 8 is predicted to increase the drawdown in all coal seams, with the most pronounced increase occurring within the Templemore Seam (Figure 8.9b). This is expected as MOD 8 would be the first mining activity to significantly extract from this seam. Conversely, coal seams down to the Tarrawonga Seam, which have already been mined to date, or are already approved for mining within the complex, are predicted to be less impacted as a result of MOD 8 (as seen in the Merriown Seam, Figure 8.8b).

Within the Boggabri Volcanics, predictions indicate that MOD 8 would generate up to 50 m of additional drawdown within the centre of the BTM Complex, with additional drawdown that exceeds 10 m generally limited to the Permian outcrop where mining takes place (Figure 8.10b).



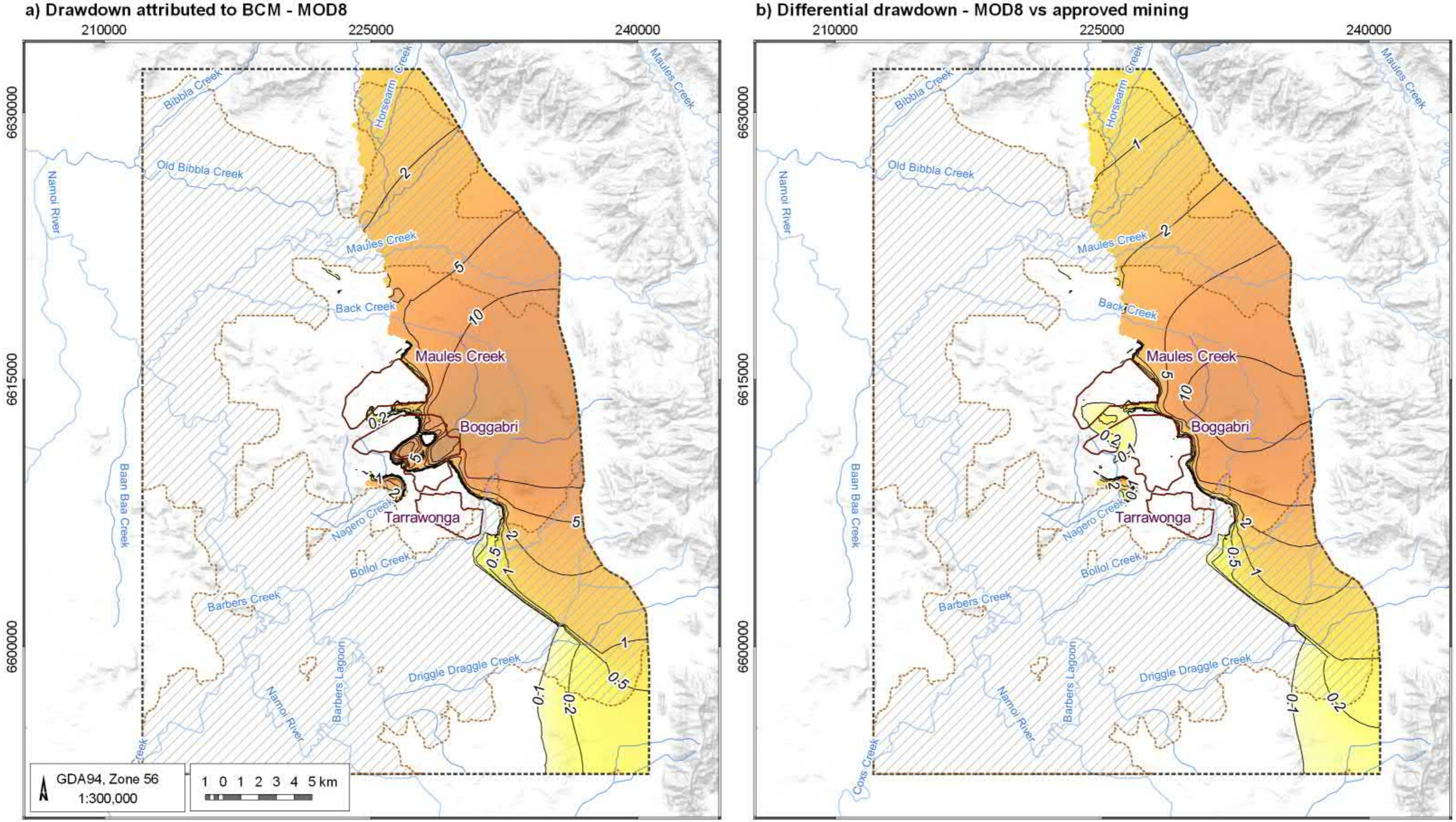
Boggabri MOD8 (G1850W)

AGE

Predicted end of mining drawdown in alluvium – BCM specific impacts

DATE 14/07/2021

FIGURE No: **8.7**



LEGEND

- Model extent
- Modelled alluvial extent
- Extent of mining
- Contour line
- Drainage

Drawdown (m)

0, 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100, 200, 500

Boggabri MOD8 (G1850W)

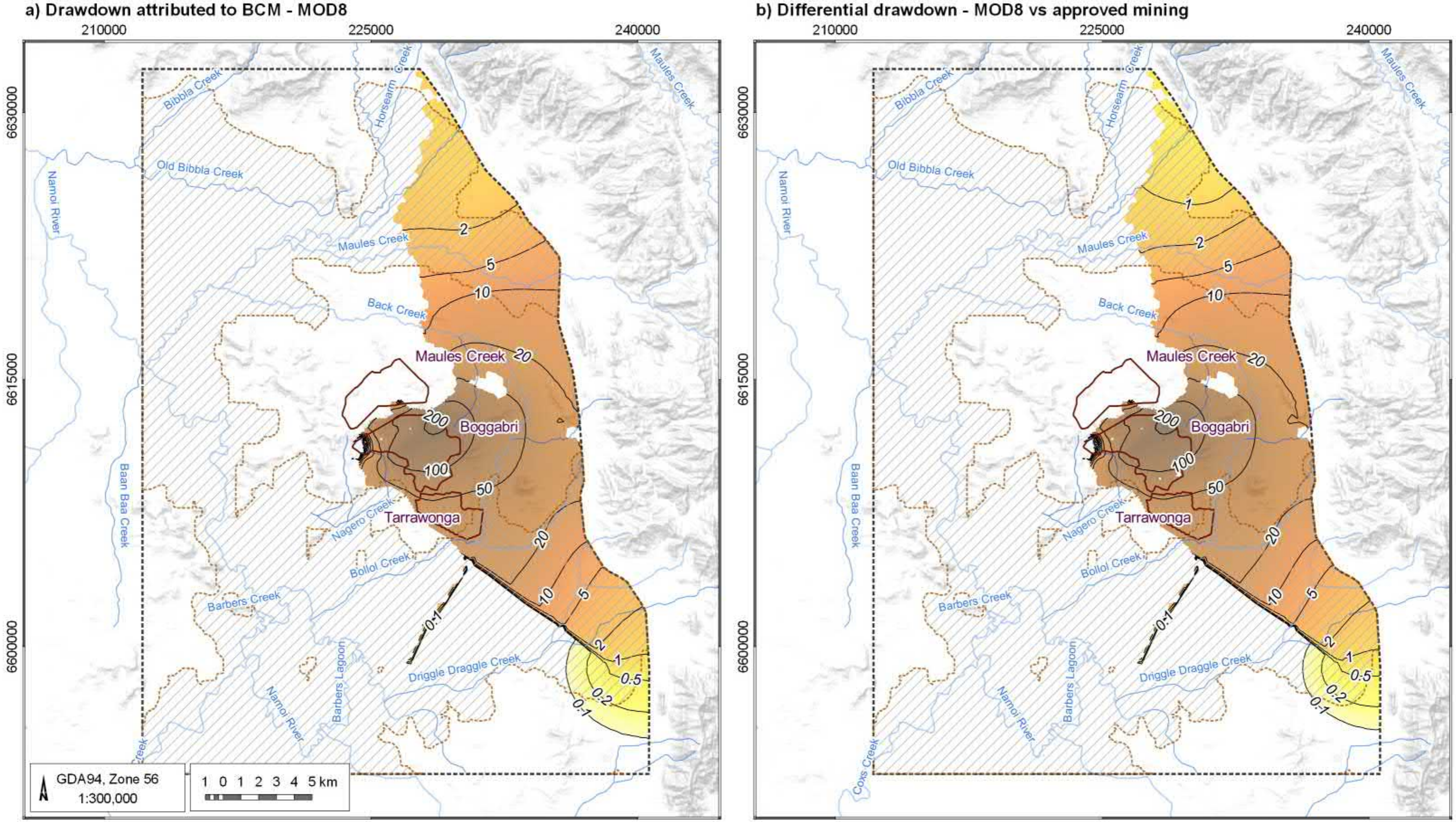
AGE

Predicted end of mining drawdown in Merriown Seam – BCM specific impacts

DATE
14/07/2021

FIGURE No:
8.8

Source: LiDAR DEM, © Department Finance, Services and Innovation.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\08.08_G1850W_Predicted end of mining drawdown in Merriown Seam – BCM specific impacts.qgs



LEGEND
- Model extent
- Modelled alluvial extent
- Extent of mining
- Contour line
- Drainage

Drawdown (m)

0, 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100, 200, 500

Boggabri MOD8 (G1850W)

AGE

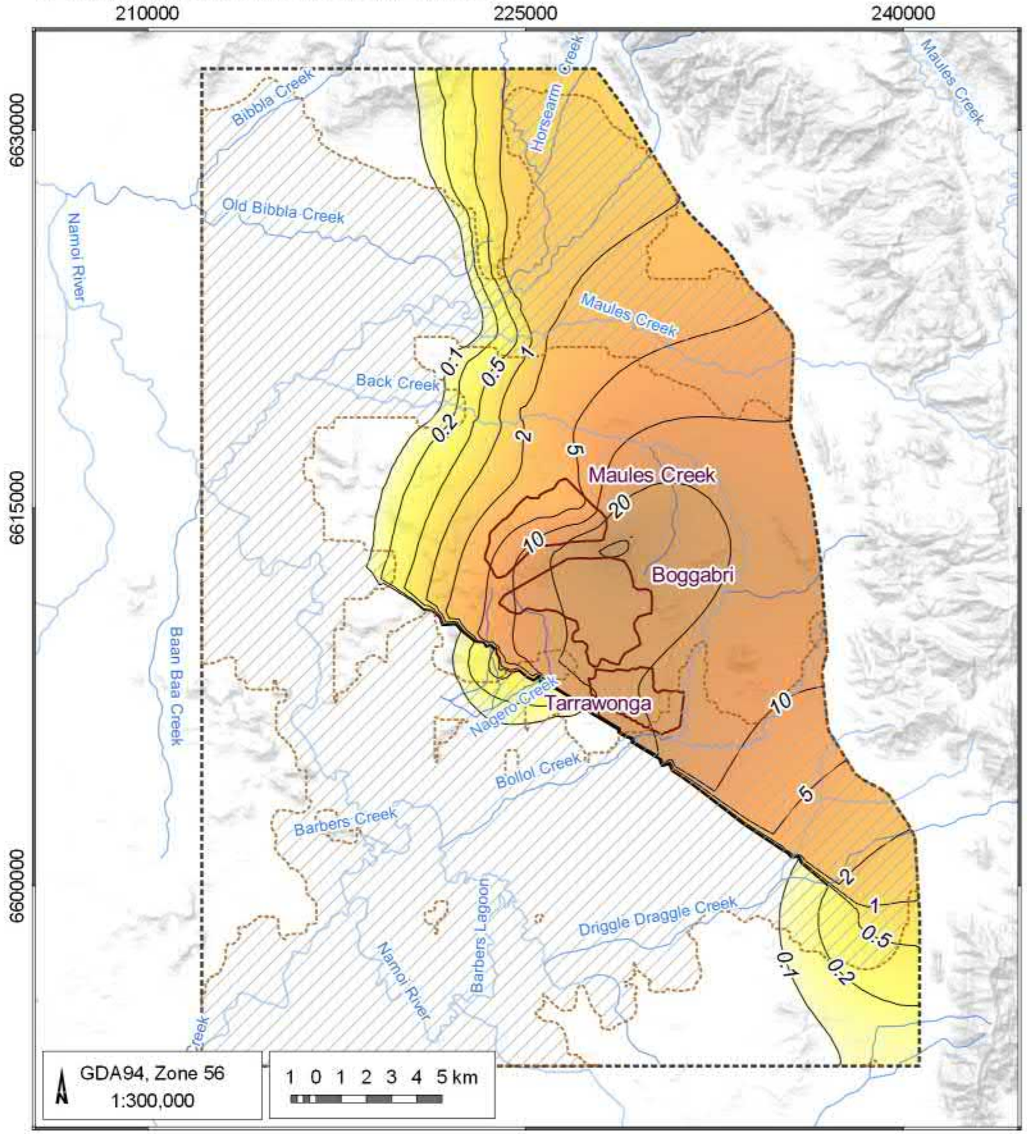
Predicted end of mining drawdown in Templemore Seam – BCM specific impacts

DATE
14/07/2021

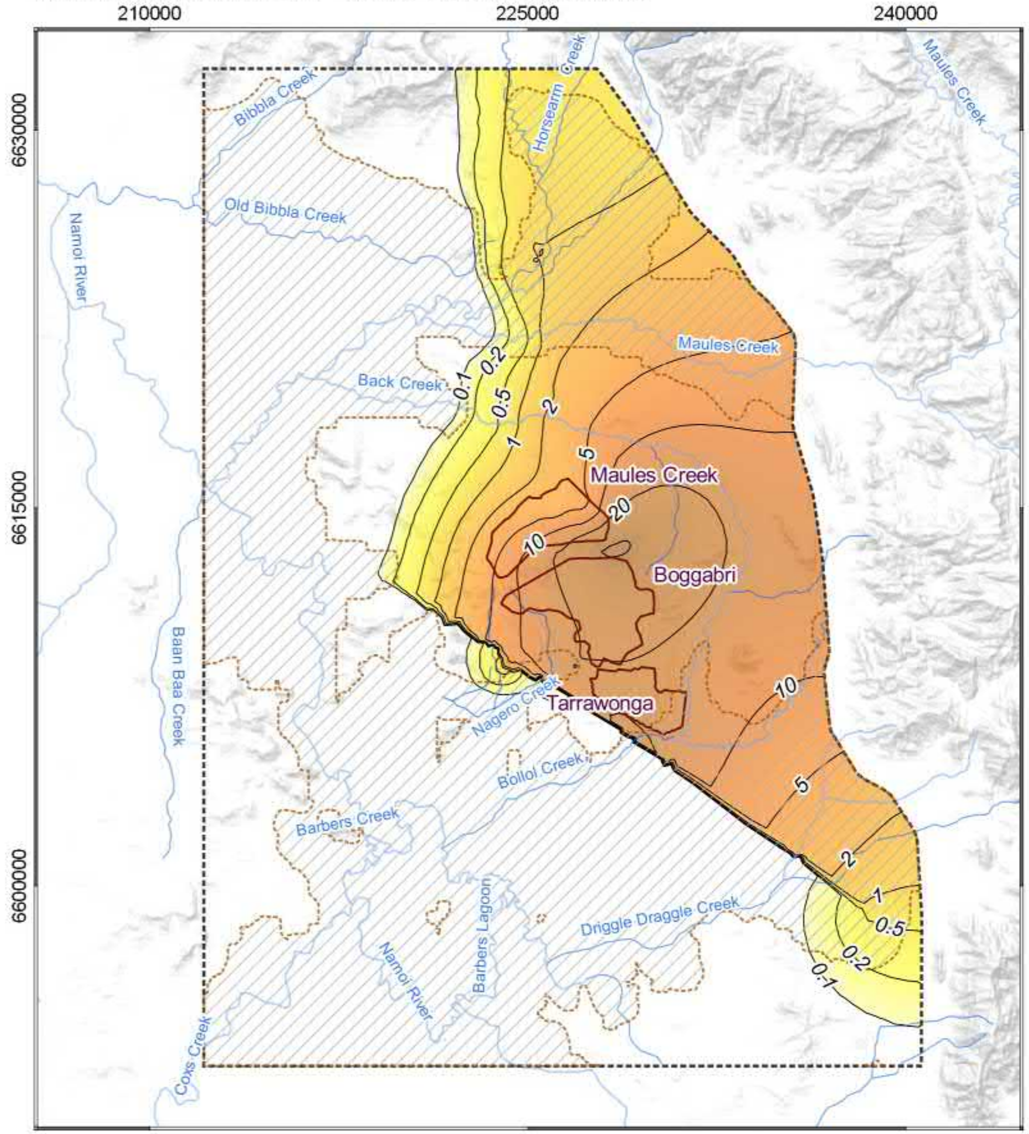
FIGURE No:
8.9

Source: LiDAR DEM, © Department Finance, Services and Innovation.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\08.09_G1850W_Predicted end of mining drawdown in Templemore Seam – BCM specific impacts.qgs

a) Drawdown attributed to BCM - MOD8



b) Differential drawdown - MOD8 vs approved mining



LEGEND
- Model extent
- Modelled alluvial extent
- Extent of mining
- Contour line
- Drainage

Drawdown (m)

0, 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100, 200, 500

AGE

Boggabri MOD8 (G1850W)

Predicted end of mining drawdown in Boggabri Volcanics – BCM specific impacts

DATE
14/07/2021

FIGURE No:
8.10

Source: LiDAR DEM, © Department Finance, Services and Innovation.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\08.10_G1850W_Predicted end of mining drawdown in Boggabri Volcanics – BCM specific impacts.qgs

8.1.4 Groundwater licencing

The *Water Management Act 2000* and AIP require that all groundwater taken, either directly or indirectly, is accounted for via WALs. Mining will not directly intercept alluvial aquifers, although an indirect impact or water take occurs as the Permian strata become depressurised and the volume of groundwater flowing from the coal measures to the alluvium progressively reduces. Groundwater intercepted in the mining area is considered a direct take from the Permian groundwater system.

Indirect alluvial take was estimated using zone budgets from five model scenarios, which included a no mining scenario, a scenario with mining at all three of the sites, and three more scenarios representing mining at a single site only. Zone budgets were defined as per the groundwater management zones detailed in the WSPs for the Upper and Lower Namoi Groundwater Sources, as well as the NSW Murray Darling Basin Porous Rock Groundwater Sources (Figure 2.1). To prevent double accounting, porous rock take was corrected by subtracting indirect alluvial take from the total inflow reporting to each of the mining areas.

A summary of maximum predicted takes and existing entitlements is provided in Table 8.1, with annual BCM specific takes and comparisons between approved mining and MOD 8 presented on Figure 8.11 to Figure 8.13.

Direct take from the porous rock is predicted to peak between 2025 and 2030, when the deepest sections of the Templemore Seam are being mined, as discussed in Section 8.1.2 (Figure 8.11). The indirect take from alluvial zone 4 remains relatively stable after a spike in 2025 (Figure 8.12), while zone 11 take generally increases as BCM continues mining (Figure 8.13). All predicted takes are well below existing BCOPL entitlements (Table 8.1).

Table 8.1 Maximum predicted takes for MOD 8 vs existing entitlements

Water sharing plan	Water Source	Year of maximum take	Maximum predicted annual take (ML)	Existing annual entitlement (ML)
NSW Murray Darling Basin Porous Rock Groundwater Sources	Gunnedah-Oxley Basin porous rock	2027	608	842
Upper and Lower Namoi Groundwater Sources	Zone 4 alluvium	2036	109	1,028
Upper and Lower Namoi Groundwater Sources	Zone 11 alluvium	2036	13	20
Upper and Lower Namoi Groundwater Sources	Zone 5 alluvium	n/a	0	0

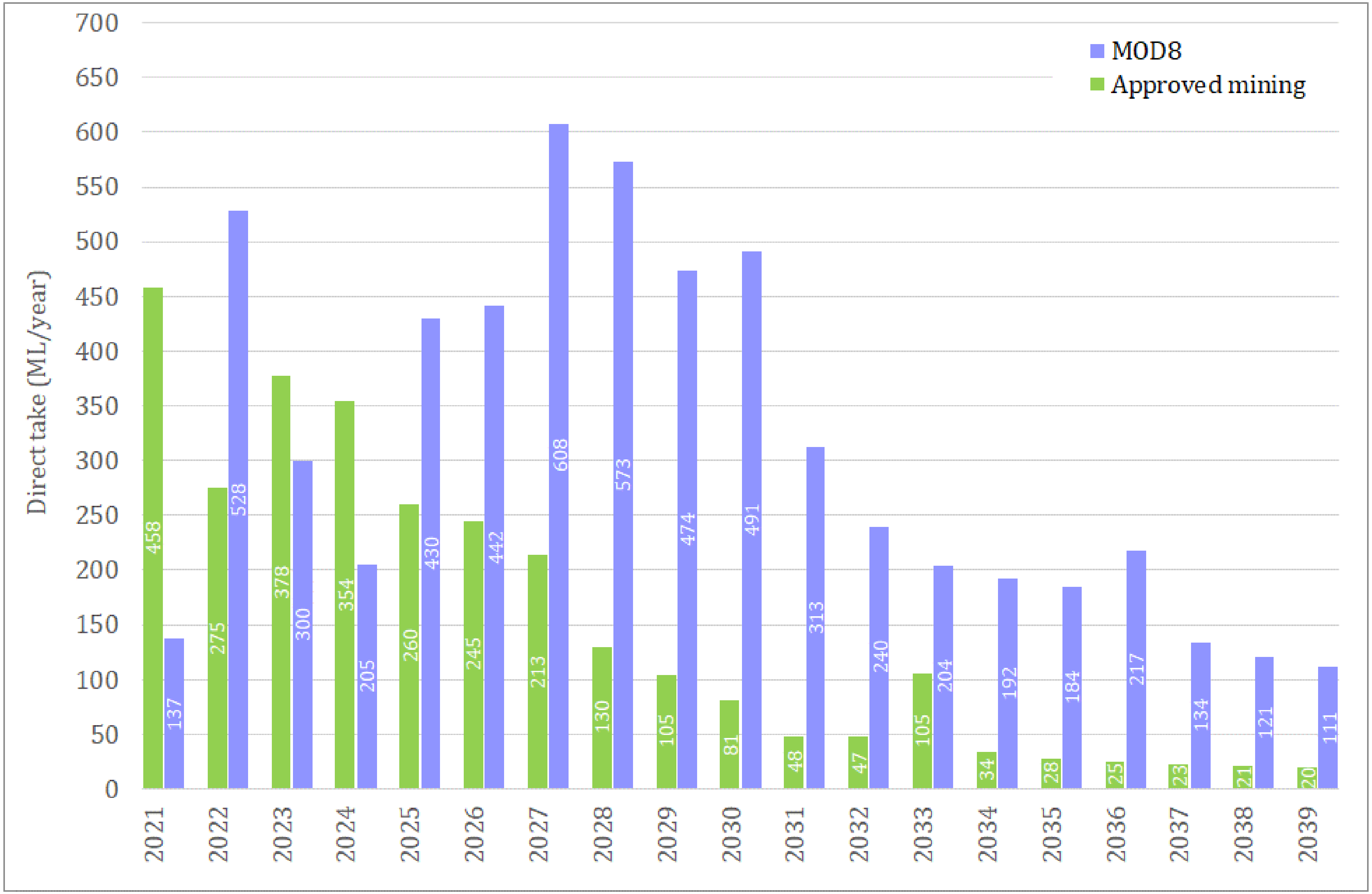


Figure 8.11 Porous rock take – approved mining vs MOD 8

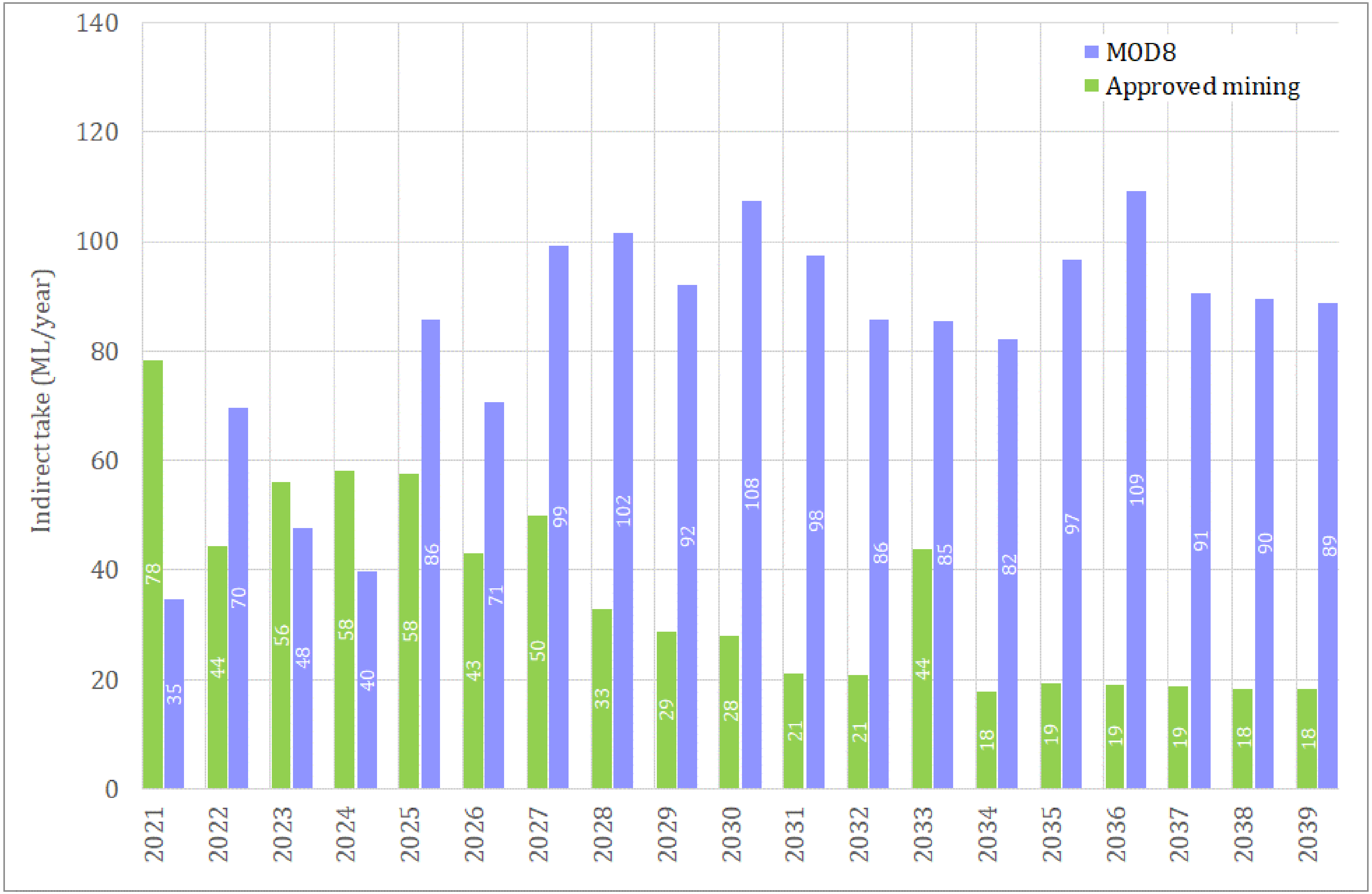


Figure 8.12 Indirect take from zone 4 alluvium – approved mining vs MOD 8

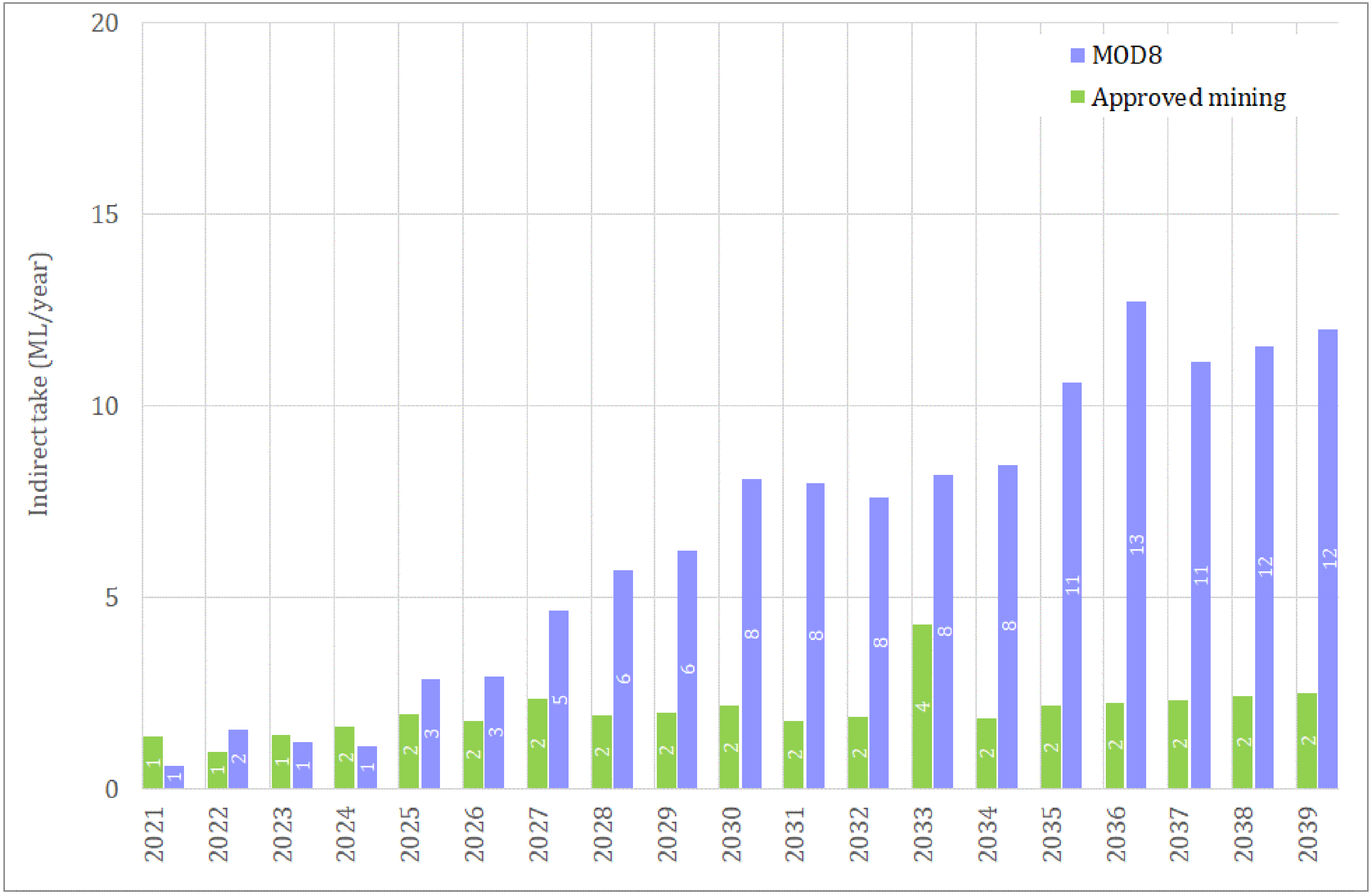


Figure 8.13 Indirect take from zone 11 alluvium – approved mining vs MOD 8

8.1.5 Surface water fluxes

Water budgets indicate that from 2020 onwards, cumulative mining activities including MOD 8 result in a maximum reduction of baseflow to the Namoi River of approximately 7.5 ML/year, with an average loss of approximately 2 ML/year. This loss in baseflow is only of note during periods when the Namoi River is not flowing, although even under these conditions, the volume is still minor. When flowing, WaterNSW records show an average flow rate of 779,883 ML/year over a 108 year monitoring period (station 419012), with predicted cumulative baseflow losses therefore insignificant. Predicted baseflow reductions represent the total loss to all areas of the Namoi River within the model domain and are not representative of baseflow reduction at any single point.

Potential impacts to Nagero Creek, which is adjacent to BCM, were also considered. Simulations indicate that this drainage feature has no contributions from groundwater over the entire calibration/prediction period. This is consistent with the conceptualisation of this drainage feature recharging the underlying water table when flows occur.

8.1.6 Private bores

8.1.6.1 Cumulative impact

As discussed in Section 6.8.1, there are 1,049 registered bores within the numerical model domain. A review of WaterNSW records indicates that these bores are screened within alluvial sediments, Permian overburden/interburden, Permian coal seams, or within the Boggabri Volcanics. To determine if predicted impacts exceed the AIP stipulated maximum water level/water pressure decline of 2 m, registered bore locations were compared to the end of mining drawdown that was predicted for the cumulative mining scenario, including MOD 8. Registered bore locations and the predicted end of mining drawdown within the most productive groundwater systems (alluvium and coal seams) are presented on Figure 8.14.

Within the alluvium, no registered bores are predicted to experience a decline of more than 2 m due to cumulative mining activities, except for two registered bores in the Tarrawonga mining lease (GW017148 and GW970207). These bores will be removed as mining progresses at Tarrawonga, and cumulative drawdown predictions are equal with and without the inclusion of MOD 8. As such, these bores are not considered any further as part of this assessment.

Potential cumulative impacts to bores screened within coal seams were assessed using the predicted drawdown in the Nagero Seam (Figure 8.14b), which is the deepest coal seam to be mined by all members of the BTM Complex. End of mining cumulative drawdown that exceeds 2 m is predicted to occur at 49 registered bores (Table 8.2), noting that of these bores:

- 40 are within the mining area or on land owned by the BTM Complex; and
- 8 are within/adjacent to the Rocglen Coal Mine (in rehabilitation), on mine owned land.

It is unlikely that cumulative impacts of MOD 8 will affect the long term viability of any of these 49 water supply works, nor will make good provisions be required. Thirty-three of these bores are licenced as monitoring bores and the predicted depressurisation will therefore have no impact on their intended purpose. Although the remaining 16 bores are licenced for other purposes (stock and domestic, commercial and industrial, irrigation, and water supply) their licences are largely held by members of the BTM Complex/other mine operators and as such make good works during mining are not required. BCM is unlikely to have any impact on depressurisation post mining, as the final landform will act as a groundwater source (see Section 8.2.1). A single bore (GW002523) may be impacted during mining, although available construction/geological data is limited and its shallow depth of installation (38.4 mbgl) suggests that it is likely installed into overburden material, which would not be depressurised at this location. AGE recommend that an in-field assessment of this bore is undertaken to confirm its existence/suitability for use and to confirm its total depth.

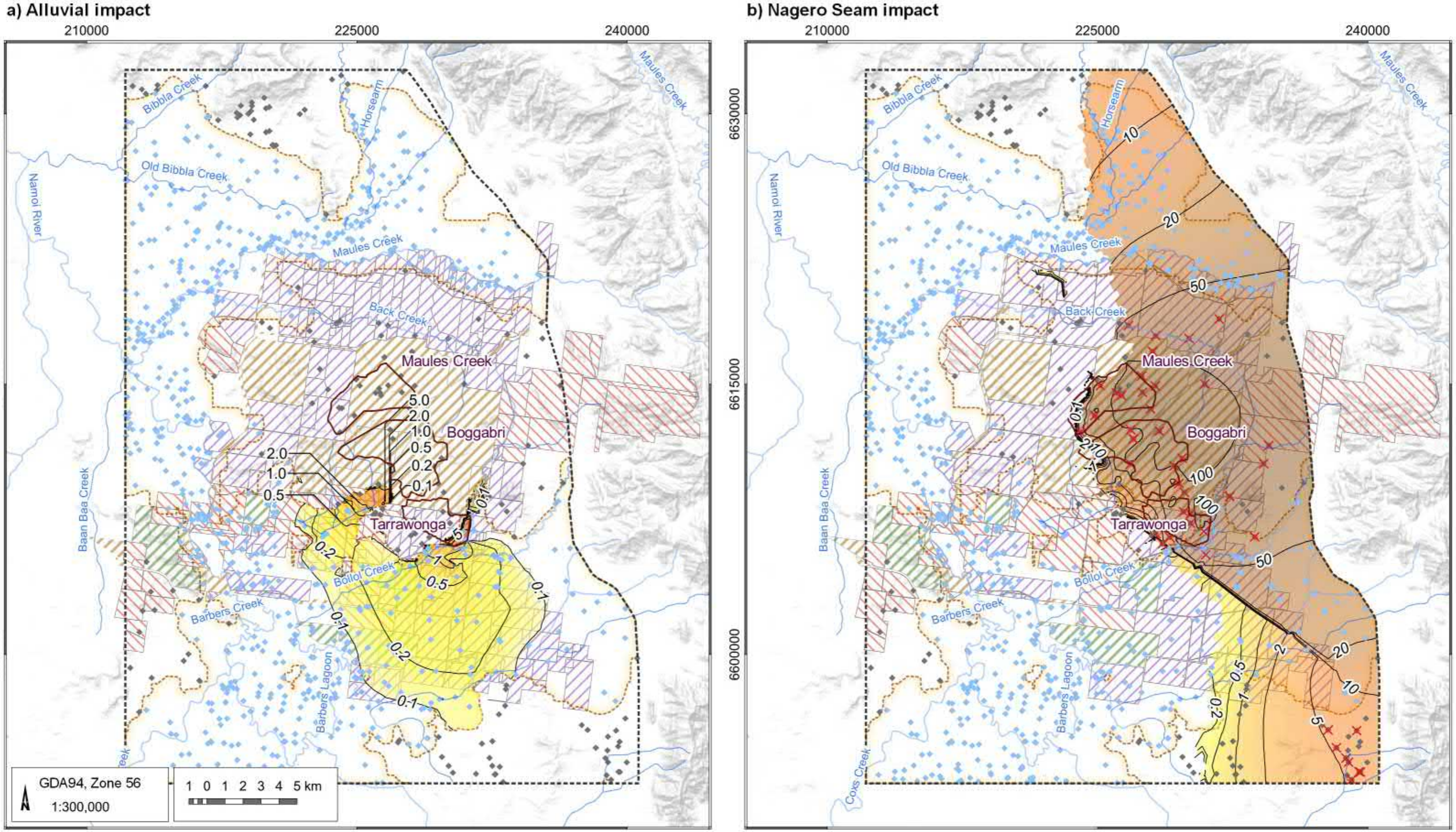
Table 8.2 Permian registered bores with predicted cumulative drawdown exceeding 2 m

Bore ID	Land ownership	Bore depth [a] (mbgl)	Predicted cumulative drawdown – including MOD 8 (m)	Predicted cumulative drawdown – approved mining (m)	Purpose [a]	Comment
GW002523	Private	38.4	64.1	62.0	Stock and Domestic	Installed in 1928, status unknown [a]
GW045621	Mining	10	5.4	5.2	Stock and Domestic	~ 650 m west of Rocglen mining lease
GW050166	Mining	18.3	6.5	6.3	Unknown	Within Rocglen mining lease
GW969666	Mining	96	5.3	5.2	Commercial and Industrial	Adjacent to Rocglen mining lease
GW968990	Mining	110	5.3	5.1	Commercial and Industrial	Within Rocglen mining lease
GW969995	Mining	91	5.3	5.2	Commercial and Industrial	Adjacent to Rocglen mining lease
GW970329	Mining	54	5.2	5.0	Monitoring	Within Rocglen mining lease
GW970326	Mining	78.1	5.2	5.1	Monitoring	Adjacent to Rocglen mining lease
GW016874	Mining	53.9	5.2	5.1	Water Supply	Within Rocglen mining lease
GW970193	BTM Complex	-	28.8	28.8	Commercial and Industrial	Located in TCM pit and therefore likely to be mined out
GW968397	BTM Complex	144	3.4	3.4	Commercial and Industrial	Located within TCM footprint
GW969569	BTM Complex	64	133.6	133.6	Commercial and Industrial	Located within MCM footprint
GW032929	BTM Complex	88.7	90.6	58.7	Irrigation	-
GW969820	BTM Complex	60	94.9	94.9	Monitoring	Located within TCM footprint
GW970710	BTM Complex	342	106.7	90.9	Monitoring	-
GW970680	BTM Complex	189.4	54.5	50.8	Monitoring	Location corresponds with cumulative monitoring point REG10
GW970687	BTM Complex	205	25.9	25.7	Monitoring	Location corresponds with MCCM monitoring point RB01, which has been destroyed [b]
GW970701	BTM Complex	9.75	83.9	75.4	Monitoring	Location corresponds with cumulative monitoring point BCM03
GW970702	BTM Complex	279.1	89.8	79.3	Monitoring	Location corresponds with cumulative monitoring point REG09
GW969817	BTM Complex	119.5	79.3	79.3	Monitoring	Location corresponds with TCM monitoring point TA60, which has been destroyed [b]

Bore ID	Land ownership	Bore depth [a] (mbgl)	Predicted cumulative drawdown – including MOD 8 (m)	Predicted cumulative drawdown – approved mining (m)	Purpose [a]	Comment
GW969481	BTM Complex	105	74.4	74.4	Monitoring	Location corresponds with TCM monitoring point MW7 [b]
GW969935	BTM Complex	421	81.9	81.9	Monitoring	Located within TCM footprint
GW969938	BTM Complex	90	10.4	10.4	Monitoring	Located within TCM footprint
GW001869	BTM Complex	91.4	75.3	69.9	Stock and Domestic	-
GW003496	BTM Complex	50	48.5	64.2	Stock and Domestic	-
GW002506	BTM Complex	297.1	34.7	86.6	Unknown	Located within TCM footprint
GW002129	BTM Complex	42.7	59	34.7	Water Supply	-
GW001852	BTM Complex	49.4	86.4	79.2	Water Supply	-
GW970695	State Forest	391.5	89.9	84.5	Monitoring	Location corresponds with MCCM monitoring points RB05/RB05A [b]
GW970694	State Forest	354	136.2	131.6	Monitoring	Location corresponds with MCCM monitoring point RB04 [b]
GW970696	State Forest	245	89.9	84.5	Monitoring	Location corresponds with MCCM monitoring points RB05/RB05A [b]
GW970692	State Forest	233	94.4	94.3	Monitoring	Location corresponds with MCCM monitoring point RB02, which has been destroyed [b]
GW970693	State Forest	324.4	146.6	141.8	Monitoring	Location corresponds with MCCM monitoring point RB03 [b]
GW970691	State Forest	270	94	93.9	Monitoring	Location corresponds with MCCM monitoring point RB02, which has been destroyed [b]
GW969672	State Forest	231	110.9	110.8	Monitoring	Location corresponds with MCCM monitoring point MAC263, which has been destroyed [b]
GW969682	State Forest	186.2	68.9	68.8	Monitoring	Located in MCCM pit and therefore likely to be mined out
GW969673	State Forest	299	120.3	119.6	Monitoring	Location corresponds with MCCM monitoring point MAC267P, which has been destroyed [b]
GW969674	State Forest	318.2	106.6	106.5	Monitoring	Location corresponds with MCCM monitoring point MAC268P, which has been destroyed [b]

Bore ID	Land ownership	Bore depth [a] (mbgl)	Predicted cumulative drawdown – including MOD 8 (m)	Predicted cumulative drawdown – approved mining (m)	Purpose [a]	Comment
GW969845	State Forest	114	95.3	95.2	Monitoring	Location corresponds with BCM monitoring point IBC2181 [b]
GW969844	State Forest	96.3	113.3	87.6	Monitoring	Location corresponds with BCM monitoring point IBC2193 [b]
GW967855	State Forest	92.79	70.5	70.4	Monitoring	Location likely corresponds with BCM monitoring point IBC2139, which has been destroyed [b]
GW967863	State Forest	160	147.6	103.1	Monitoring	Location likely corresponds with BCM monitoring points IBC2104/ IBC2105 [b]
GW967857	State Forest	111.5	101.1	84.5	Monitoring	Location likely corresponds with BCM monitoring points IBC2114/IBC2115, which have been destroyed [b]
GW967858	State Forest	86	101.1	84.5	Monitoring	Location likely corresponds with BCM monitoring points IBC2114/IBC2115, which have been destroyed [b]
GW967856	State Forest	66.5	84.2	58.4	Monitoring	Location likely corresponds with BCM monitoring point IBC2138, which has been destroyed [b]
GW967859	State Forest	96.8	79.9	79.9	Monitoring	Location likely corresponds with BCM monitoring point IBC2113, which has been destroyed [b]
GW967864	State Forest	91	147.9	103.0	Monitoring	Location likely corresponds with BCM monitoring points IBC2104/ IBC2105 [b]
GW967861	State Forest	59	76.8	76.7	Monitoring	Location likely corresponds with BCM monitoring points IBC2102/IBC2103, which have been destroyed [b]
GW967862	State Forest	85	76.8	76.7	Monitoring	Location likely corresponds with BCM monitoring points IBC2102/IBC2103, which have been destroyed [b]

Notes: (a) data extracted from WaterNSW's realtime data portal;
(b) comparisons with BTM monitoring network taken from AGE (2020);
TCM – Tarrawonga Coal Mine; and
MCCM – Maules Creek Coal Mine.



LEGEND

- Model extent
- Modelled alluvial extent
- Extent of mining
- Contour line
- Drainage
- × Potentially impacted bore

Drawdown (m)

0, 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100, 200, 500

Registered bores

- Alluvial
- Coal measure/volcanics

Land Ownership

- Boggabri Coal
- State Forest/Crown Land
- Whitehaven Coal
- Mining Joint Ownership

AGE

Boggabri MOD8 (G1850W)

Predicted end of mining drawdown and surrounding private bores – alluvium/ Nagero Seam

DATE
14/07/2021

FIGURE No:
8.14

Source: LiDAR DEM, © Department Finance, Services and Innovation.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\08.14_G1850W_Predicted end of mining drawdown and surrounding private bores – alluvium - Nagero Seam.qgs

8.1.6.2 MOD 8 incremental impact

As shown in Section 8.1.3 (Figure 8.7b), incremental alluvial drawdown that is associated with MOD 8 is minimal and is only predicted to occur in a small portion of the alluvial tongue that is directly southwest of BCM. This incremental impact of MOD 8 is not predicted to lead to a decline of more than 2 m in any registered alluvial bore.

The identified impacts for Permian registered bores are predominately associated with approved mining and the specific impacts of MOD 8 are fundamentally equivalent to approved mining (i.e. coal seams impacted in both scenarios). This is shown in Table 8.2, where the predicted cumulative drawdowns, with and without MOD 8, are generally close in value. Additionally, the predicted drawdown for approved mining already exceeds 2 m for all 49 of the registered bores that were considered above.

8.1.7 Groundwater dependent ecosystems

8.1.7.1 Cumulative impact

Relevant WSPs define several high priority GDEs within the model domain. These high priority GDEs are mapped along drainage features, which include the Namoi River, Barber's Lagoon, Maules Creek and its unnamed tributaries, Back Creek, Goonbri Creek, the upper reaches of Bollol Creek, and parts of Driggle Draggle Creek. The location of these potential GDEs and the predicted drawdown of the water table for the MOD 8 cumulative mining scenario is shown on Figure 8.15a for the alluvium, and Figure 8.15b for the coal measures/Boggabri Volcanics. Cumulative drawdown in the water table is predicted to occur beneath several high priority GDEs and includes:

- generally less than 0.5 m of cumulative drawdown in the alluvium that underlies terrestrial GDEs adjacent to small parts of Goonbri Creek, Bollol Creek, and Driggle Draggle Creek;
- up to 40 m of cumulative drawdown in the watertable that underlies terrestrial GDEs adjacent to Back Creek and its upper tributaries; and
- up to 5 m of cumulative drawdown in the watertable that underlies terrestrial GDEs adjacent to the upper reaches of Goonbri Creek.

Assuming seasonal water table fluctuations of 1 m, all of these cumulative impacts exceed the AIP minimal impact threshold of:

> *'Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40m from any: (a) high priority groundwater dependent ecosystem'.*

Several of these potential impact areas have been previously considered as part of environmental assessments (EAs) for the Tarrawonga and Maules Creek mines, as well as the Vickery Extension Project. As discussed in Section 6.8.2, the presence of GDEs adjacent to Back Creek is unlikely given that the identified vegetation is expected to have a root zone extending approximately 2 to 3 mbgl (Cumberland Ecology, 2011), with groundwater monitoring showing that the water table is greater than 10 mbgl. As part of Tarrawonga Mine's EA, FloraSearch (2011) identified the presence of potentially groundwater dependent *Melaleuca bracteate* along the Goonbri and Bollol creeks, which is consistent with BoM (2019) mapping. Potential impacts to this vegetation community were considered as part of the EA, with no significant impacts on the potential GDEs anticipated (Resource Strategies, 2011). BoM (2019) mapping of sedgeland in close proximity to Driggle Draggle Creek is consistent with Eco Logical (2018) surveys to support the Vickery Extension Project. However, this work does note that the surrounding environment is already highly modified from the natural environment due to cattle grazing. WSP (2021) conducted a desktop assessment of this regional high priority GDE mapping and concluded that cumulative impacts are unlikely, although vegetation along Goonbri Creek may have some proportional access to groundwater along some sections of the waterway.

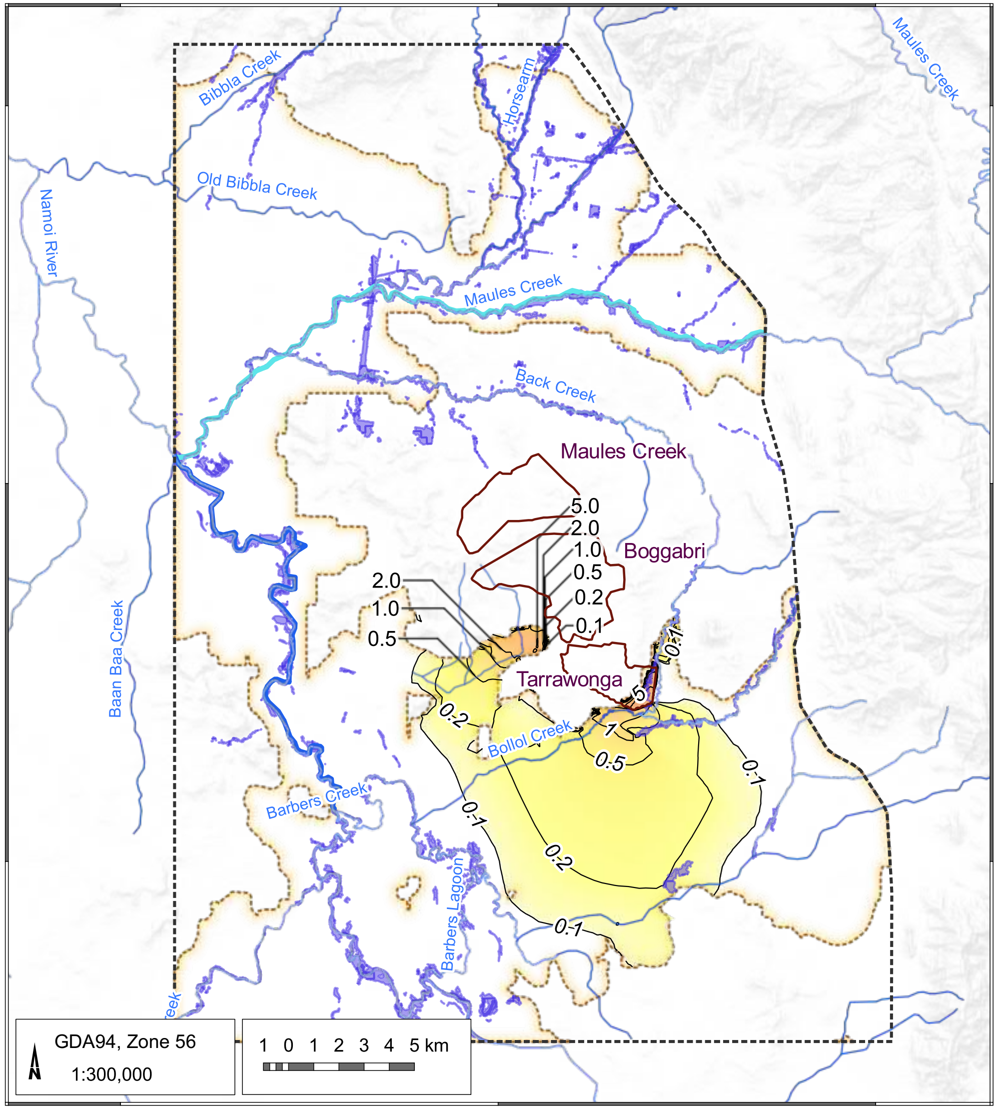
With respect to threatened ecological communities, as nominated under the EPBC Act, drawdown of the alluvial water table that exceeds 0.1 m is predicted to occur near the communities described below (Figure 8.16a).

- Poplar Box Grassy Woodland on Alluvial Plains - to the southwest of BCM and within the Tarrawonga mining lease; and
- White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland - to the southwest of BCM.

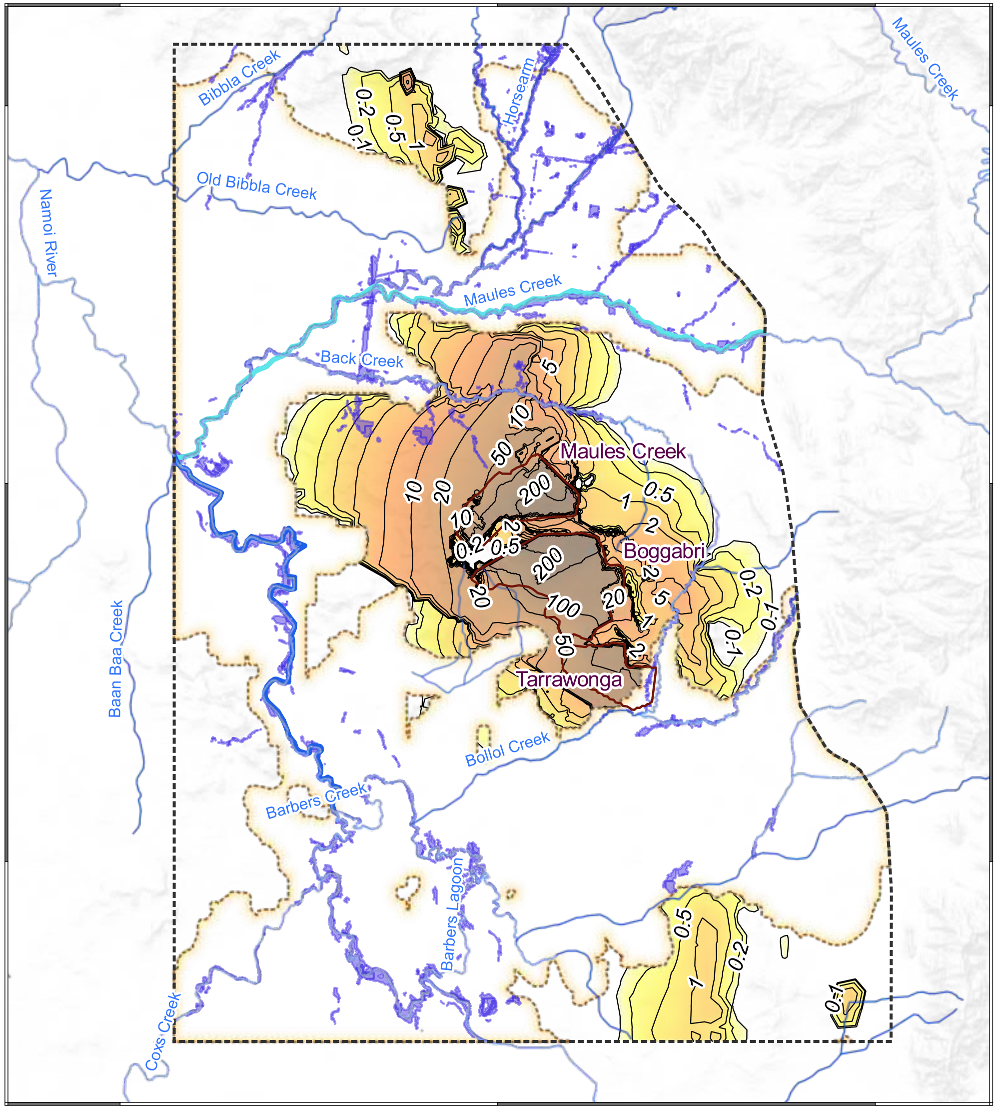
Apart from the Tarrawonga mining lease and the tongue of alluvium adjacent to BCM, the predicted drawdown in the alluvium is generally less than 1 m. As discussed above, GDEs adjacent to Goonbri and Bollol creeks were assessed as part of the Tarrawonga EA, and MOD 8 does not alter the cumulative impacts in this area (Figure 8.7b). As discussed in Section 6.8.2, the WSP (2021) GDE assessment determined that groundwater dependence within the tongue of alluvium is limited to the Poplar Box Woodland communities, which has a proportional dependency on groundwater. WSP (2021) concludes that, within the tongue of alluvium, the risk of the predicted cumulative drawdown impacting the Poplar Box Woodland communities is low.

Drawdown of the water table within the coal measures/volcanics is predicted to be much greater than beneath the alluvium (Figure 8.16b). However, as discussed in Section 6.8.2, the depth to water in these areas of Permian outcrop is generally greater than 20 mbgl, and as such the risk of these communities being solely groundwater dependent is low.

a) Alluvial impact



b) Coal measures/volcanics impact



LEGEND

- Model extent
- Modelled alluvial extent
- Extent of mining
- Contour line
- Drainage

Drawdown (m)

0, 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100, 200, 500

GDEs

- High potential terrestrial GDE from regional studies
- High potential aquatic GDE from national assessment
- Known aquatic GDE from regional studies

AGE

Boggabri MOD8 (G1850W)

Predicted end of mining drawdown and surrounding high priority GDEs

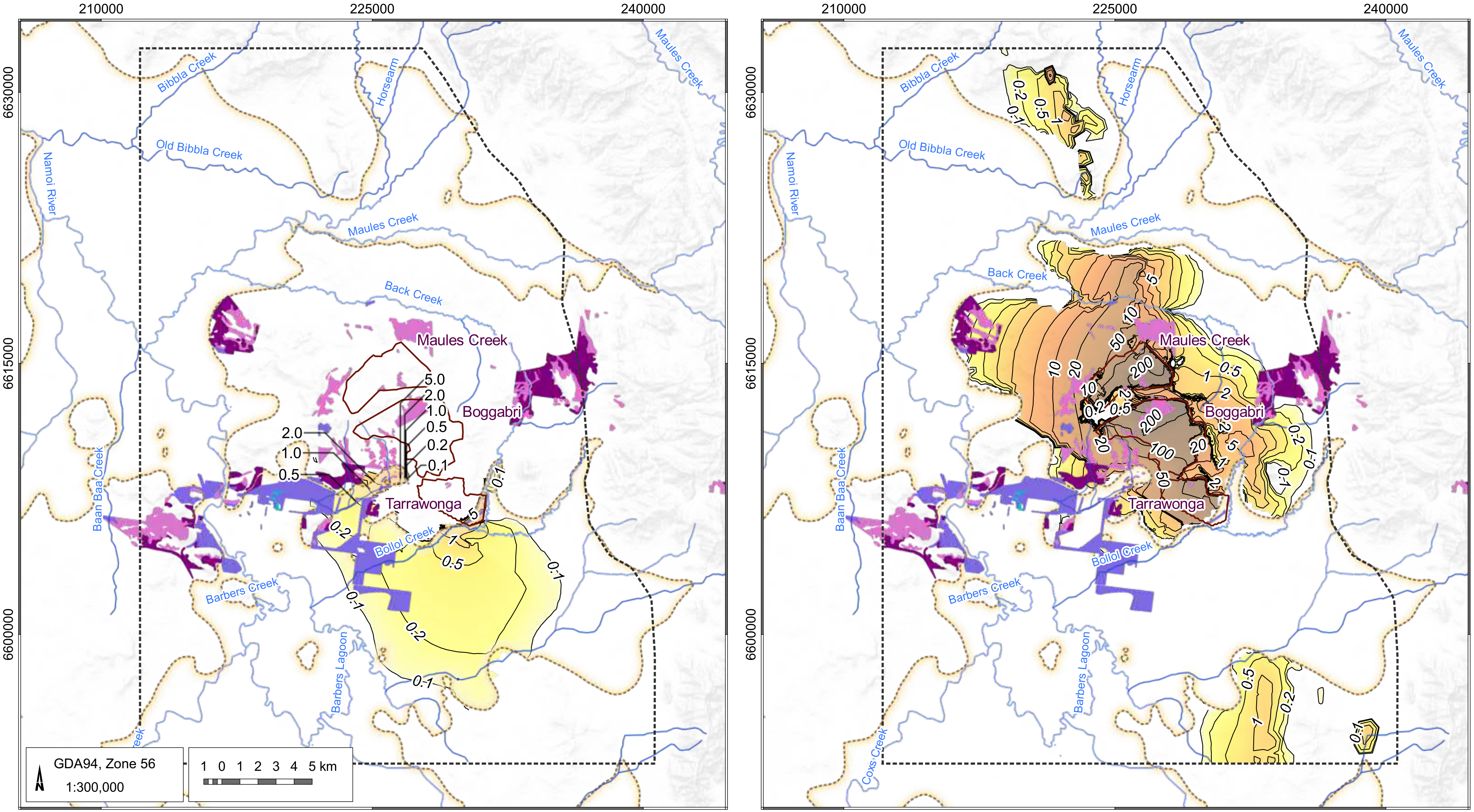
DATE
15/07/2021

FIGURE No:
8.15

Source: LiDAR DEM, © Department Finance, Services and Innovation.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\08.15_G1850W_Predicted end of mining drawdown and surrounding high priority GDEs.qgs

a) Alluvial impact

b) Coal measures/volcanics impact



LEGEND

- Model extent
- Modelled alluvial extent
- Extent of mining
- Contour line
- Drainage

Drawdown (m)

0, 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100, 200, 500

GDEs

- Natural grasslands
- Poplar Box Grassy Woodland
- Box Gum Woodland
- Box Gum Woodland and Derived Native Grassland

AGE

Boggabri MOD8 (G1850W)

Predicted end of mining drawdown and surrounding GDEs - verified field mapping of EPBC ecological communities

DATE
14/07/2021

FIGURE No:
8.16

Source: LiDAR DEM, © Department Finance, Services and Innovation.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\08.16_G1850W_Predicted end of mining drawdown and surrounding GDEs – verified field mapping of EPBC nominated ecological communities.qgs

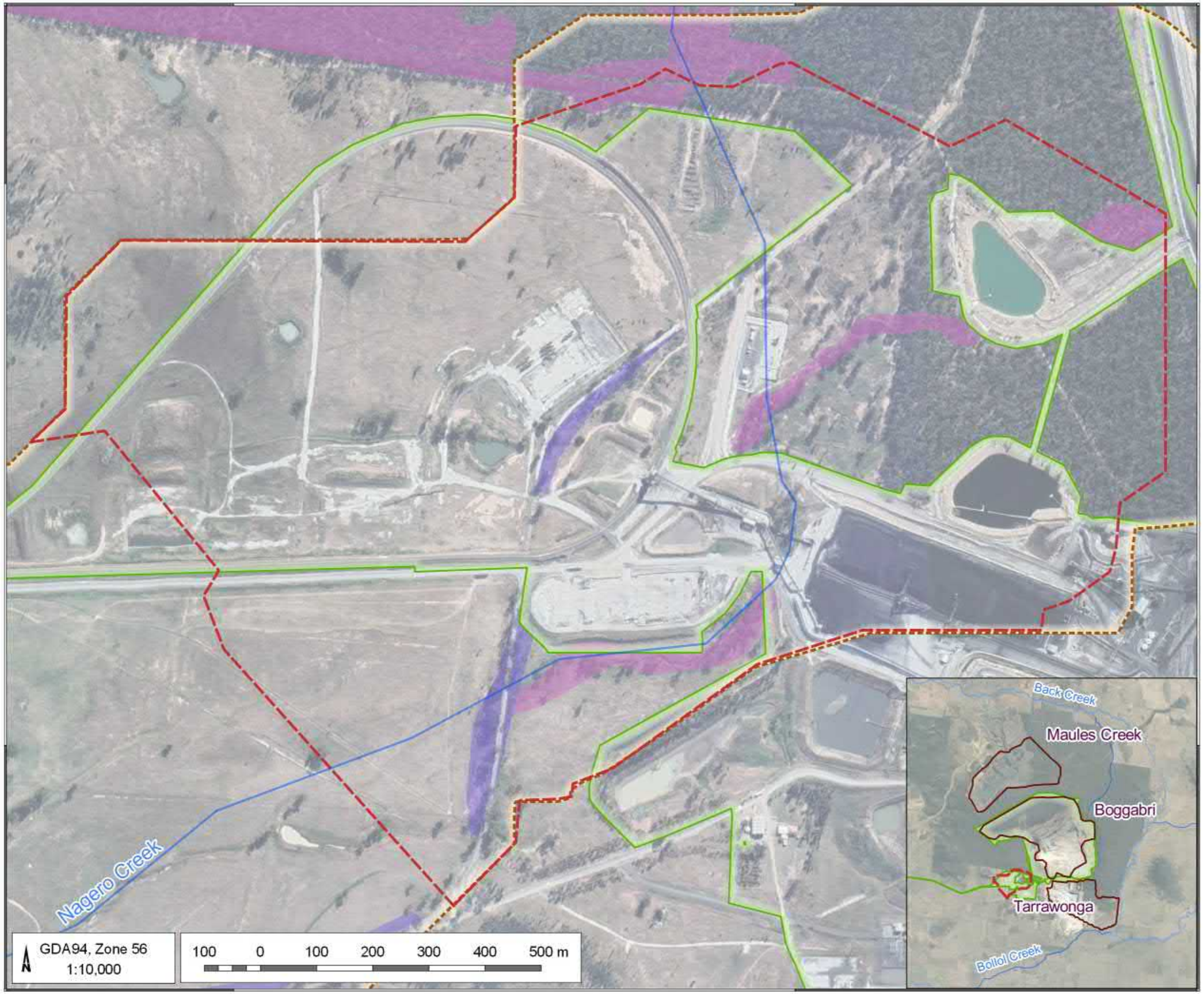
8.1.7.2 MOD 8 incremental impact

As discussed in Section 8.1.3, incremental alluvial drawdown that is associated with MOD 8 is minimal and is only predicted to occur in a small portion of the alluvial tongue that is directly southwest of BCM (Figure 8.7b). Additionally, incremental drawdown of the Permian groundwater system, while present, is considered to be fundamentally equivalent to approved mining, given that approved activities already result in significant drawdown/depressurisation.

To assess potential GDE impacts that are specific to MOD 8, the location of high priority/EPBC nominated GDEs were compared to an approximate incremental impact area. This area was defined by the following criteria:

- where the predicted incremental drawdown of the water table exceeds 0.1 m; and
- where simulations of the current depth to the water table is less than 10 mbgl.

Mapping shows that this impact area is constrained to a small part of the alluvial tongue that is directly southwest of BCM (Figure 8.17). Several small communities of Poplar Box Grassy Woodland on Alluvial Plains/White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland are mapped, but no high priority GDEs are present (as defined within the relevant WSPs). Aerial imagery shows that these ecological communities are in, or adjacent to, the approved infrastructure disturbance boundary. Potential cumulative impacts to these communities have been discussed in Section 8.1.7.1, with WSP (2021) determining that the risk of impacts to the Poplar Box Woodland communities is low.



LEGEND

- Drainage
- Extent of mining
- BCOPL total disturbance area
- Alluvium extent
- Approximate incremental impact area

GDEs (EPBC classification)

Source: WSP mapping

- Poplar Box Grassy Woodland
- Box Gum Woodland

Boggabri MOD8 (G1850W)

GDEs in MOD8 incremental impact area

DATE
14/07/2021

AGE

FIGURE No:
8.17

G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\08.17_G1850W_GDEs in MOD8 incremental impact area.qgs

8.1.8 Groundwater quality

Groundwater flow predictions for MOD 8 indicate that the mining area will act as a groundwater sink during mining, which is consistent with the direction of flow determined for the currently approved mining scenario (AGE, 2010). As per BCM's site water balance (BCOPL, 2017a), inflow that is not lost through evaporation will be treated as mine water, which will be pumped to water storages for reuse onsite.

It is anticipated that if present, the flux of groundwater from spoil to nearby alluvial groundwater systems and connected surface water bodies will be insignificant relative to other sources of recharge. As such, it is inferred that there will be no change in the beneficial use of surrounding groundwater systems and that there will be no increase in salinity to groundwater gaining surface water systems such as the Namoi River.

Geochemical studies (RGS, 2009; RGS, 2020) have also concluded that the potential risk to the quality of groundwater resources from water in contact with mining waste materials at BCM is relatively low. Static and kinetic testing of the overburden, interburden, and potential coal reject material down to the Merriown Seam (RGS, 2009); in addition to testing of the interburden and potential coal reject material down to the Templemore Seam (RGS, 2020), has found that:

- coal reject material is generally non-acid forming, with the exception of the Braymont Seam and potentially the Jeralong Seam, which are potentially acid forming;
- major ion concentrations in leachate from all samples are relatively low, which results in salinity values that are generally equivalent/lower than the averages found in surrounding groundwater systems (see Section 6.6); and
- the concentrations of dissolved trace metals/metalloids in groundwater are likely to be low and below the applied water quality guidelines.

Coal reject material will be strategically managed by deep in-pit burial, which will be covered by inert non-acid forming overburden materials, as described in the approved Mining Operations Plan.

8.2 Recovery simulations

8.2.1 Heads, flow direction and depth to water

The final landform for MOD 8 is designed to be consistent with design considerations utilised within the mine plan for the approved operations under SSD 09_0182. The final landform is designed such that landforms are constructed to drain to the natural environment and the size and depth of the final void is minimised as far as is reasonable and feasible to ensure that the void contains no pit lake, as required by condition 69, Schedule 3 of the Project Approval (SSD 09_0182). On the northern edge of BCM the final landform includes an area where a partially infilled void at 285 mAHD is lower than the surrounding terrain.

Simulated groundwater levels for the base recovery scenario (see Appendix A) successfully equilibrated within the adopted 1,000 year recovery period (see Section 8.2.2). Predictions of the stabilised water table are generally consistent with the findings of the original GIA (AGE, 2010), where stabilised levels do not exceed the final landform elevation and no pit lake is present.

The simulated water table shows that groundwater breakthrough in the partially infilled area is constrained by evapotranspiration, with both the final landform level and water table at or near 285 mAHD (Figure 8.18). Recovery simulations are driven by a constant long-term average of recharge that does not capture seasonal fluctuations or significant recharge events. As such, rather than postulating a continued absence of standing water, the partially infilled mining area is expected to form an ephemeral surface water body, where periods of high rainfall and recharge are expected to result in the short-term presence of surface water. This is consistent with Schedule 3, Condition 69 of the current project approval (SSD 09_0182):

> *'Minimise the size and depth of the final void as far as is reasonable and feasible and ensure that the void contains no retained surface water (i.e. no pit lake)'*

Once equilibrated, the Boggabri mining area is predicted to act as a rainfall recharged groundwater source, where it served as a groundwater sink throughout the period of mining. Groundwater level contours shows that groundwater from the BCM spoil largely reports to the void lakes within the adjacent Maules Creek and Tarrawonga mines, with a component also moving to the southwest towards the adjacent alluvial tongue (Figure 8.18 and Figure 8.19). This is more clearly evident in the piezometric surface of the Nagero Seam (Figure 8.19), as opposed to the water table, where perched water and changes in terrain create more complex flow paths.

8.2.2 Recovery duration

Temporal recovery data from the deepest point of each mine's final landform was extracted from the numerical model. Due to uncertainty around the hydraulic properties of site spoil and future climate conditions, recovery predictions were extracted from three unique simulations including the base recovery case, a scenario where the hydraulic conductivity and specific yield of the spoil was reduced, and a scenario with reduced recharge to spoil. More detail on each of these scenarios is provided within Appendix A.

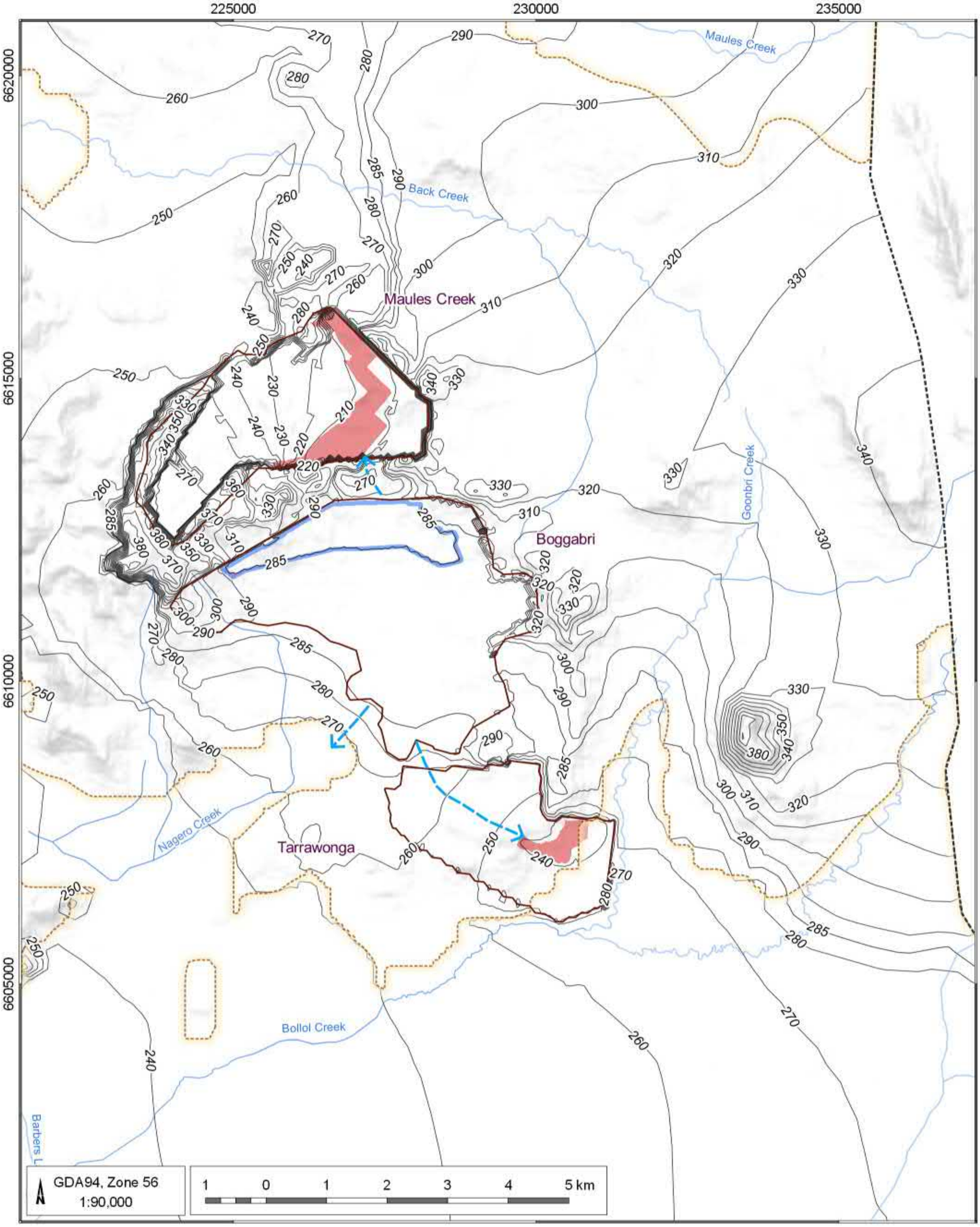
Recovery of the post-mining water table is predicted to reach a new equilibrium within 300 years after mining for all scenarios (Figure 8.20). This is approximately 125 years slower than predictions of the original GIA (AGE, 2010), which is expected given the increased depth of mining proposed by MOD 8 will lead to increased storage within the spoil. Reducing the horizontal (and consequently vertical) hydraulic conductivity and specific yield an order of magnitude decreased the time required for water table recovery, while reducing recharge to the spoil increased recovery time. At BCM, all three scenarios resulted in the water table equilibrating at 285 mAHD due to the controlling influence of evaporation at the surface of the final landform. This finding is consistent with predictions of the original GIA (AGE, 2010), which also determined that the equilibrated post mining water table at BCM will be controlled by evaporation.

Under the base recovery scenario, the water table within the Maules Creek void stabilised at approximately 202 mAHD, compared to a level of 220 mAHD predicted in the GIA for the Maules Creek Mine approval (AGE, 2011). Similarly, the water table within the Tarrawonga void stabilised at approximately 236 mAHD, compared to a level of 260 mAHD predicted in the MOD7 groundwater assessment (HydroSimulations, 2019). It should be noted that recovery modelling for MOD 8 is the first to include final landform designs for all three mines within the BTM Complex and differences between predictions are therefore not considered to be of significance.

8.2.3 Groundwater quality

As discussed in Section 8.2.1, once equilibrated, the BCM mining area is predicted to act as a rainfall recharged groundwater source, where it previously served as a groundwater sink throughout the period of mining. Predictions of recovered groundwater levels (Figure 8.18) indicate that groundwater within the BCM spoil largely reports to the void lakes within the adjacent Maules Creek Mine and Tarrawonga Mine, with a relatively minor volume of seepage potentially entering the adjacent alluvial tongue to the southwest of BCM. Any flux of groundwater from spoil to nearby alluvial groundwater systems and connected surface water bodies is expected to be insignificant relative to other sources of recharge. As such, it is inferred that a long-term change in the beneficial use of surrounding groundwater systems is unlikely, as are any increases in salinity to groundwater gaining surface water systems such as the Namoi River.

Groundwater that does migrate from the BCM mining area is expected to be of relatively good quality, with geochemical studies (RGS, 2009; RGS, 2020) concluding that the potential risk on the quality of groundwater resources from water in contact with mining waste materials is relatively low (see Section 8.1.7.2). No changes in the beneficial use or salinity of surrounding receptors are therefore anticipated.



LEGEND

- Model extent
- Modelled alluvial extent
- Extent of mining
- Contour line
- Drainage
- Flow out of BCM
- BCM partially infilled area
- Contour line (285 mAHD)
- Free standing water

Boggabri MOD8 (G1850W)

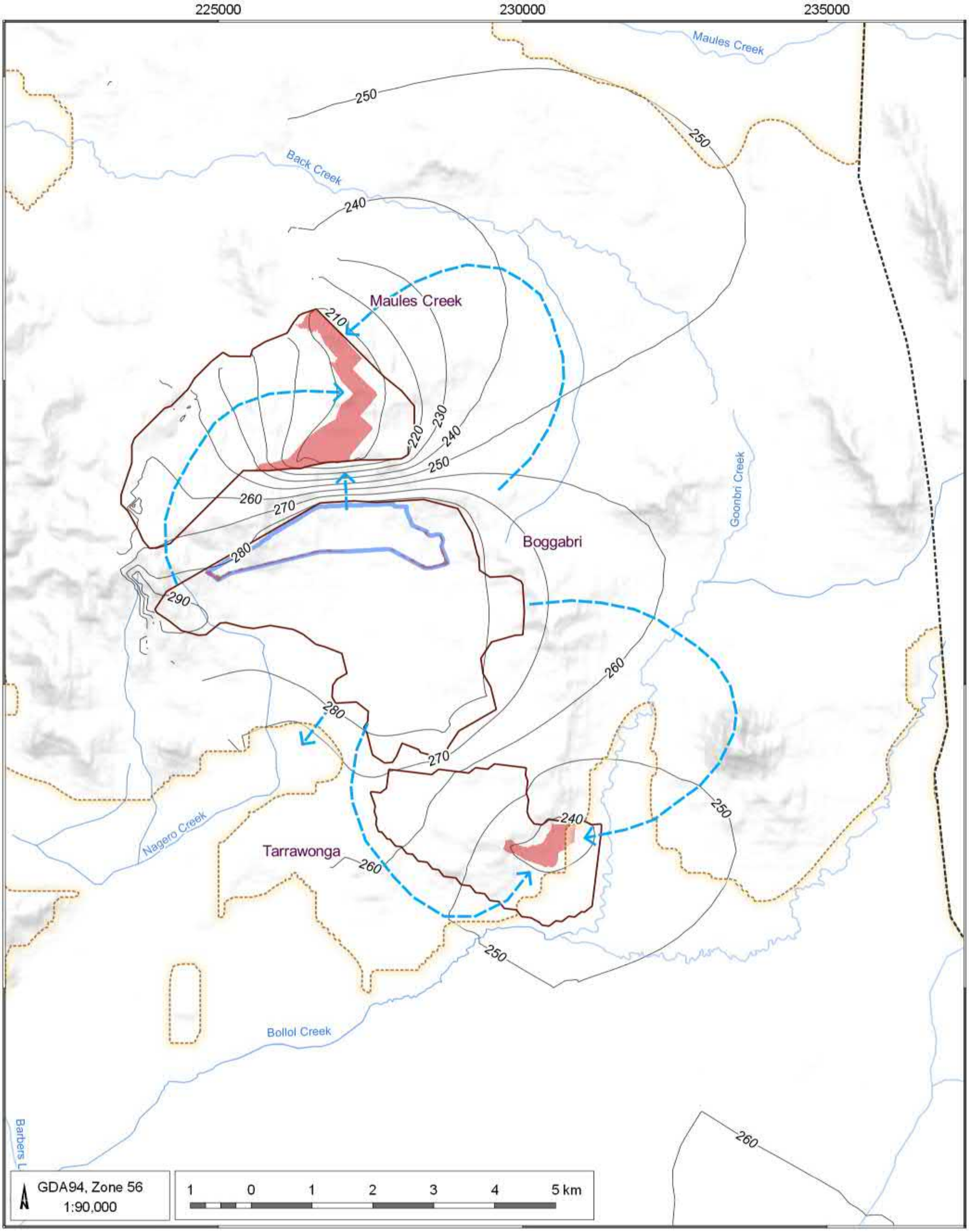
Equilibrated post mining piezometric surface – water table

AGE

DATE 14/07/2021

FIGURE No: **8.18**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\08.18_G1850W_Equilibrated post mining piezometric surface – water table.qgs



LEGEND
Model extent
Modelled alluvial extent
Extent of mining
Contour line
Drainage
Flow out of BCM
BCM partially infilled area
Free standing water

Boggabri MOD8 (G1850W)

Equilibrated post mining piezometric surface – Nagero Seam

AGE

DATE 14/07/2021

FIGURE No: **8.19**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\08.19_G1850W_Equilibrated post mining piezometric surface – Nagero Seam.qgs

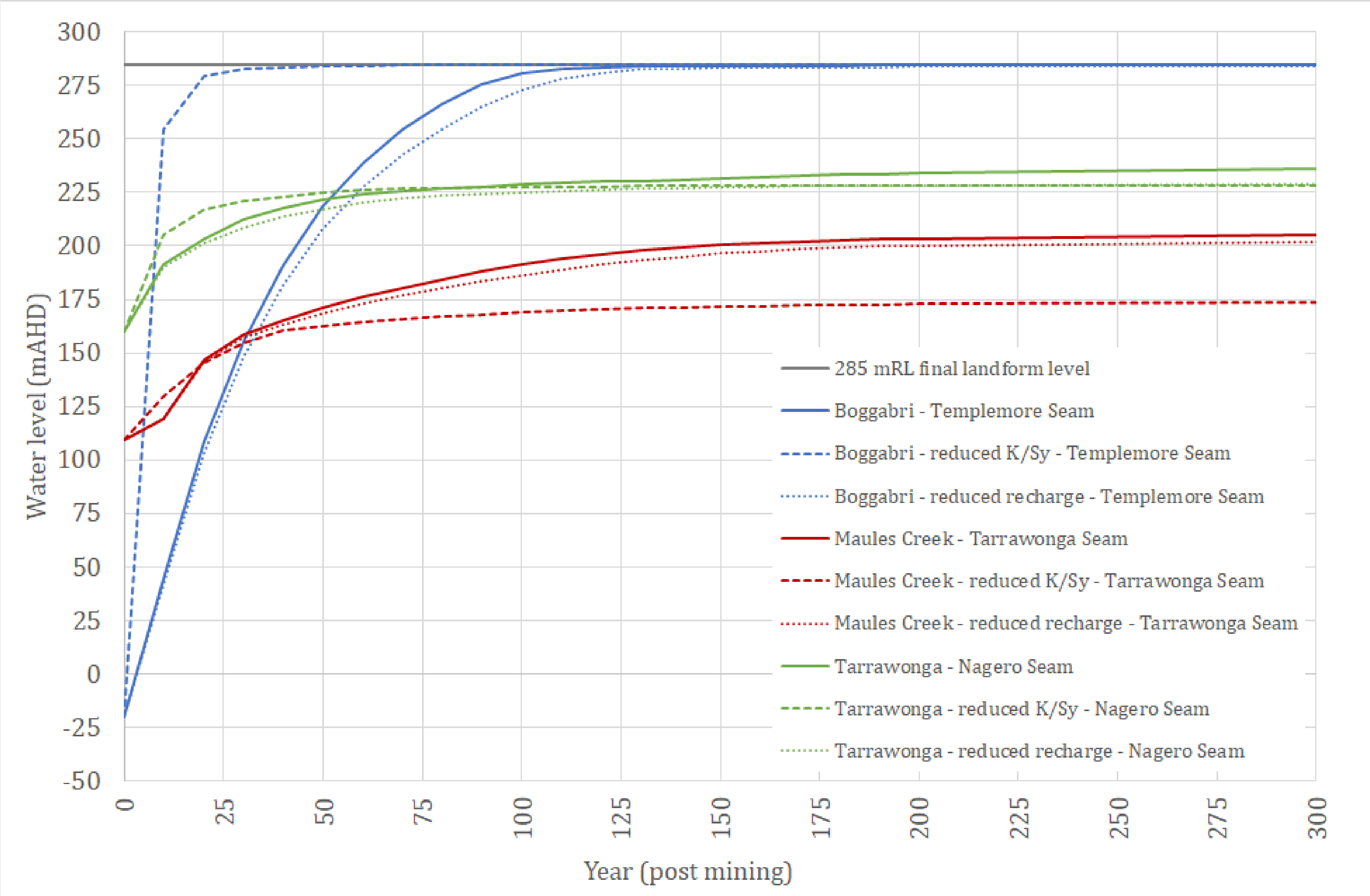


Figure 8.20 Post-mining water table recovery and sensitivity scenarios

8.2.4 MOD 8 implications on groundwater flux from spoil to surrounding environment

The MOD 8 final landform design generally aligns with the approved design, and no changes to the approved rehabilitation objectives are sought. The most significant difference is the greater volume of spoil and depth of emplacement that is associated with an increased depth of mining. There are some minor differences in the surface profile, including a 5 m increase to the maximum height of the overburden emplacement area. With respect to groundwater, key design elements remain consistent between the approved final landform and the MOD 8 final landform, with:

- the surface profile of the final landform remaining above the equilibrated post mining groundwater level (minimum elevation of 285 mAHD in the partially infilled area); and
- the land surface between the BCM extent of mining and the adjacent tongue of alluvium remaining unchanged.

As discussed throughout Section 8.2, recovery simulations indicate that the final landform for MOD 8 will act as a rainfall recharged groundwater source. Groundwater from the BCM spoil is predicted to largely report to the adjacent Maules Creek and Tarrawonga voids, with a smaller component moving to the southwest, towards the adjacent tongue of alluvium.

The potential migration of groundwater from the spoil to the nearby alluvium poses the greatest risk to receptors. However, given that the potential migration pathway is consistent with the approved final landform, equilibrated heads, fluxes, and potential spill points are also consistent. As such, the potential migration of groundwater from BCM spoil to the alluvium is consistent with the current approval and is not specific to MOD 8.

Additionally, geochemical studies indicate that leachate associated with the deeper MOD 8 coal reject material is of equivalent/better quality than the leachate to be generated from approved activities. As such, potential groundwater quality impacts are consistent with the current approval and are not specific to MOD 8. Leachate for both the MOD 8/approved coal reject material are comparable to the natural groundwater quality in adjacent systems.

8.3 Predictive uncertainty analysis

The uncertainty in model predictions that is introduced by model parameters was assessed using a nonlinear uncertainty analysis; where numerous model parameters are changed at the same time. This analysis was completed for the cumulative mining scenario that includes MOD 8. The results of this analysis are presented in Appendix A. In total, 500 alternative parameter sets were randomly generated, 216 of these were not rejected due to disparities with site groundwater level observations.

Uncertainty analysis results for drawdown indicate that the basecase set of predictions, which are presented throughout Section 8, are conservative. Basecase drawdown extents in the more productive alluvium/coal seam aquifers are generally only exceeded by ‘unlikely’ and ‘very unlikely’ realisations of the model. As such, the assessment of impacts that is presented throughout Section 8 is considered appropriate.

An assessment of uncertainty for estimates of inflow to the Boggabri mining area indicates that relative to the peak inflow rate for the basecase (712 ML/year), inflow could be approximately twice as high for the maximum of the ‘very unlikely’ scenario. The maximum of the ‘about as likely as not’ scenario is approximately 1.5 times that of the basecase.

9 Compliance with legislation, policy, and guidelines

9.1 Aquifer interference policy

The numerical groundwater model used to assess MOD 8 is consistent with AIP requirements in that it is appropriately calibrated and validated, it has been developed in a manner consistent with the Australian Groundwater Modelling Guidelines, and it has been independently reviewed.

As discussed throughout Section 8, for both the 'highly productive' Upper Namoi Alluvium, and the 'less productive' Gunnedah-Oxley Basin Porous Rock:

- cumulative impacts generally meet the Level 1 minimal impact considerations; and
- MOD 8 incremental impacts meet all Level 1 minimal impact considerations.

Cumulative water table or water pressure declines of more than 2 m are not predicted at any water supply work within the 'highly productive' Upper Namoi Alluvium Water Sources. Minimal impact considerations are predicted to be exceeded at 49 registered groundwater bores within the 'less productive' Gunnedah-Oxley Basin Porous Rock Water Source. Make good works are unlikely to be required on account of the following.

- 33 of these bores are licenced as monitoring bores and the predicted depressurisation will therefore have no impact on their intended purpose.
- Licences for 15 of these bores are held by members of the BTM Complex/other mine operators and as such make good works during mining are not required. Additionally, BCM is not predicted to contribute to depressurisation post mining, instead acting as a source of groundwater.
- The single remaining private bore is likely installed into overburden material, which would not be depressurised during mining. Additionally, predictions for approved mining activities show that this bore is already impacted irrespective of MOD 8.

The cumulative end of mining water table drawdown beneath several high priority GDEs is predicted to exceed the 10% cumulative drawdown threshold. This is predicted to occur beneath terrestrial GDEs adjacent to small parts of Goonbri Creek, Bollol Creek, and Driggle Draggle Creek, as well as Back Creek and its upper tributaries (Section 8.1.6.2). Previous works, which are discussed in Section 8.1.6.2, have demonstrated that these potential GDEs are either unlikely to be present (Back Creek potential GDEs), or that potential impacts have already been taken into consideration as part of the original approval investigations for surrounding mining operations (Goonbri Creek, Bollol Creek, and Driggle Draggle Creek potential GDEs).

The incremental alluvial impact from MOD

8 is negligible and results in no further drawdown beneath these high priority GDEs.

Changes in groundwater quality are not predicted to lower the beneficial use in either of the water sources, nor are any long-term salinity increases expected in connected surface water bodies. Groundwater fluxes during mining and post recovery are inferred to be largely constrained within the BTM Complex, while the groundwater in contact with mining waste materials is expected to be of comparable quality to surrounding systems (Section 8.1.7.2 and Section 8.2.3).

All direct and indirect groundwater takes can be accounted for with WALs held by BCOPL for each water source under the *Water Management Act 2000* (Section 8.1.4).

9.2 Environment Protection and Biodiversity Conservation Act 1999

A referral under the EPBC Act was submitted to the DAWE prior to the completion of this GIA. Within this referral, a conceptualisation of the perceived impacts that are associated with MOD 8 was presented, which was based on previous modelling and observations to date. DAWE determined that MOD 8 would constitute a controlled action on 28 May 2021, stating that:

> *'the proposed action will result in a significant impact to groundwater and surface water quality and hydrological regimes, including potential impacts to groundwater dependent ecosystems and from cumulative impacts associated with existing mines in the area.'*

As per the Significant impact guidelines 1.3 (DoE, 2013):

> *'A significant impact on the hydrological characteristics of a water resource may occur where there are, as a result of the action:*
>
> *a) changes in the water quantity, including the timing of variations in water quantity;*
>
> *b) changes in the integrity of hydrological or hydrogeological connections, including substantial structural damage (e.g. large scale subsidence); and*
>
> *c) changes in the area or extent of a water resource.*
>
> *Where these changes are of sufficient scale or intensity as to significantly reduce the current or future utility of the water resource for third party users, including environmental and other public benefit outcomes.'*

Modelling undertaken for MOD 8 indicates that changes in flow regimes, recharge rates, aquifer pressure/water table level, groundwater-surface water interactions, river-floodplain connectivity, and inter-aquifer activity are not expected to be sufficient scale or intensity as to significantly reduce the quantity or quality of the water resources for third party users or the environment.

The incremental impacts of MOD 8 relative to approved mining, are minimal, while cumulative impacts are fundamentally equivalent to those for already approved mining activities.

As per the Significant impact guidelines and in line with impact considerations that were discussed throughout Section 8, MOD 8 is not likely to have a significant impact on the hydrological characteristics of surrounding water sources.

This assessment was completed with consideration of IESC information guidelines, as well as associated explanatory notes.

10 Groundwater monitoring and management plan

10.1 Existing water management plan

BCM operates in accordance with a Water Management Plan (WMP) (BCOPL, 2017b), which has been prepared in consultation with NSW government agencies, as well as a joint WMP for the BTM Complex (Resource Strategies, 2019). A standalone Groundwater Management Plan (GWMP) (BCOPL, 2017c) falls under the BCM WMP. The WMPs describe the management of environmental and community aspects, in addition to impacts and performance relevant to the sites water management system.

As described in Section 5, BCM operates an existing groundwater monitoring network, with regular monitoring from bores that are installed into the adjacent alluvium, the Boggabri Volcanics, and coal seams down to the Merriown Seam. This monitoring network is supplemented by cumulative monitoring for the BTM Complex, which includes multi-level VWPs and monitoring bores down to the Templemore Seam.

As stipulated in the GWMP, manual groundwater levels and groundwater quality field parameters (EC, pH, and temperature) are collected on a quarterly basis, with laboratory analysis for major ions, dissolved metals, and nutrients occurring bi-annually. Monitoring data is reviewed annually by an independent consultant and findings are provided to DPIE. As part of annual reviews, groundwater level and groundwater quality data is compared to trigger levels, which are respectively based on the 5th percentile of the monitoring record and determined via the control chart method.

The GWMP stipulates that an independent review and validation of the groundwater model for BCM will be carried out every three years, with the aim of validating the model. Additionally, BCOPL reviews the GWMP annually, upon submission of an incident report, under the direction of an audit, and as part of a modification to the project approval (BCOPL, 2017c). If necessary, the GWMP is then updated.

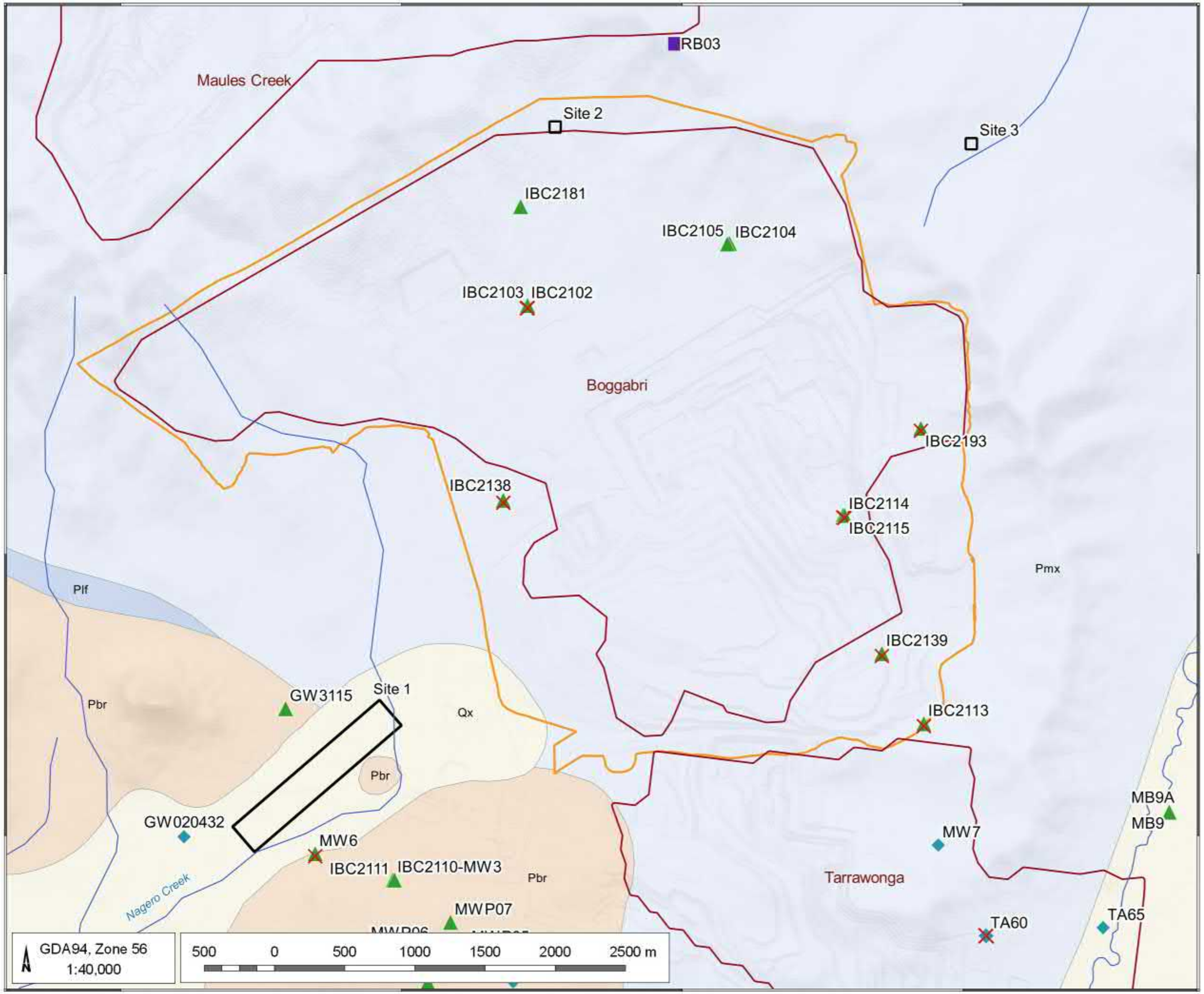
10.2 Additional monitoring/remediation recommendations

The current groundwater monitoring program at BCM should be continued, as should the BTM Complex's cumulative monitoring program. There is no need for remedial action associated with MOD 8 given that specific impacts to groundwater assets are predicted to be minimal relative to approved mining. An in-field assessment of the potentially cumulatively impacted private registered bore (GW002523) is recommended to confirm its existence/suitability for use and to confirm its total depth. It is recommended that the existing monitoring network be supplemented with additional monitoring bores in the tongue of alluvium to the southwest of BCM, as well as a number of deep multi-level monitoring sites, both within the approved disturbance boundary and further to the east of the BCM mining area. Recommendations for potential sites and supporting rationale are provided below in Table 10.1, with locations shown on Figure 10.1.

Table 10.1 Recommended monitoring locations

Location	Design	Priority	Rationale
Site 1: Centre of 'alluvial tongue'	Transect of two or three shallow monitoring bores along centre of alluvial tongue	High	Only existing bore in this area is now not operational being MW6. Important to have monitoring in this area as: (a) groundwater levels are predicted to be impacted by both approved mining and MOD 8; and (b) this area is the most likely pathway should impacts propagate further to the west of BCM.
Site 2: Northern edge of approved mine disturbance boundary	Nested [a] series of monitoring bores in the Templemore, Nagero, and Merriown (optional) seams	Medium	Partially replaces mined out 'IBC' series of bores. Allows for the collection of groundwater level/quality data in the deeper seams that are targeted by MOD 8.
Site 3: Approximately 1 km east of Site 2	Multi-level VWP in the Templemore, Nagero, and Merriown (optional) seams	Medium	BCM specific monitoring of groundwater levels in the deeper seams that are targeted by MOD 8. Records of the expected coal seam depressurisation as mining progresses will improve the calibration of future updates to the numerical groundwater model.

Note: (a) 'nested' locations should be comprised of individual bore constructions within 10 m of one another.



LEGEND

- Drainage
- Extent of mining
- Approved disturbance boundary
- Proposed monitoring sites

Monitoring bore

Group

- Boggabri-Active
- Boggabri-Destroyed
- Maules Creek-Active
- Tarrawonga-Active
- Tarrawonga-Destroyed

Gunnedah Coalfield rock unit (1:100k)

- Qx - Quaternary Sediments
- Pmx - Maules Creek and Goonbri formations
- Plf - Leard Formation
- Pbr - Boggabri Volcanics

Boggabri MOD8 (G1850W)

Recommended monitoring locations

AGE

DATE 14/07/2021

FIGURE No: **10.1**

G:\Projects\G1850W.Boggabri MOD8\3_GIS\Workspaces\002_Deliverable2\10.01_G1850W_Recommended monitoring locations.qgs

11 References

Acworth, Timms, Kelly, McGeeney, Ralph, Larkin and Rau, (2015), "*Late Cenozoic paleovalley fill sequence from the Southern Liverpool Plains, New South Wales – implications for groundwater resource evaluation*". Australian Journal of Earth Sciences 62(6), 657–680.

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE), (2010), *"Continuation of Boggabri Coal Mine - Groundwater Assessment"* prepared for Boggabri Coal Pty Limited. Project No. G1465, October 2010.

Australian Groundwater and Environmental Consultants Pty Ltd, (2011), *"Maules Creek Coal Project – Groundwater Impact Assessment"* prepared for Aston Resources Limited. Project No. G1508, June 2011.

Australian Groundwater and Environmental Consultants Pty Ltd, (2014), "*Maules Creek Coal Project Installation of Monitoring Bore Network and Updating Groundwater Model*" Prepared for Whitehaven Coal Project No. G1508/B, January 2014.

Australian Groundwater and Environmental Consultants Pty Ltd, (2018), "*Boggabri, Tarrawonga, Maules Creek Complex – Numerical Model Update*" Prepared for Boggabri Coal and Whitehaven Coal, Project No. G1850A, August 2018.

Australian Groundwater and Environmental Consultants Pty Ltd, (2020), *"Boggabri, Tarrawonga, Maules Creek Complex - Groundwater Model Update"* prepared for Boggabri, Tarrawonga and Maules Creek mines. Project No. G1850P, version 3.02, December 2020.

Australian Groundwater and Environmental Consultants Pty Ltd, (2020b), *"Groundwater Assessment – Narrabri Mine – Stage 3 Extension Project"* prepared for Narrabri Coal Operations Pty Limited. Project No. G1973, version 6.01, August 2020.

Barnett et al, (2012), "*Australian Groundwater Modelling Guidelines*". Waterlines Report, National Water Commission, Canberra.

Boggabri Coal Operations Pty Ltd (BCOPL), (2017a), *"Site Water Balance, May 2017".* Revision 8.

BCOPL, (2017b), *"Water Management Plan, May 2017".* Revision 6.

BCOPL, (2017c), *"Groundwater Management Plan, May 2017".* Revision 6.

Bureau of Meteorology (BoM), (2019), "*Groundwater Dependent Ecosystems Atlas of Australia*", Accessed: http://www.bom.gov.au/water/groundwater/gde/index.shtml

Commonwealth of Australia, (2018), "*Information guidelines for proponents preparing coal seam gas and large coal mining development proposals*".

Cowan, (1995), "*Scone – Gunnedah Surveys, Maules Creek area, aeromagnetic and radiometric interpretation*". Geological Survey of NSW.

Cumberland Ecology, (2011), "*Maules Creek Coal Project Ecological Impact Assessment*".

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

Doody, Hancock, Pritchard, (2019), "*Information Guidelines explanatory note: Assessing groundwater dependent ecosystems*". Report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy, Commonwealth of Australia 2019.

Doherty, (2010), "*PEST – Model independent parameter estimation user manual: 5th edition*". Watermark Numerical Computing, Corinda, Australia.

Eco Logical, (2018), "*Vickery Extension Project - Aquatic Ecology Assessment*" prepared for Whitehaven Coal Limited.

Fetter, (2001), *"Applied Hydrogeology"*. Fourth edition.

FloraSearch, (2011), "*Tarrawonga Coal Project – Flora Assessment*" prepared for Whitehaven Coal Pty Ltd.

Food and Agricultural Organisation of the United Nations (FAO), (2013), "*The use of saline waters for crop production*". Chapter 2, by J.D. Rhoades, A. Kandiah and A.M. Mashali.

Gates and Ross, (1980), "*Cainozoic alluviation and hydrogeology of the Namoi River basin, NSW*".

Gunn, (2002), "*Interpretation of gravity and magnetic data over the northern Gunnedah Basin, New South Wales*". March 2002.

Herr, Northey, Mitchell, Aryal, Merrin and Slater, (2018), "*Conceptual modelling for the Namoi subregion*". Product 2.3 for the Namoi subregion from the Northern Inland Catchments Bioregional Assessment. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.

Hydroalgorithmics, 2014, "*Algomesh User Guide, Version 1.4*". March 2014.

HydroSimulations, (2018), *"Boggabri-Tarrawonga-Maules Creek Complex - Groundwater Model Review".*

HydroSimulations, (2018b), *"Vickery Extension Project Groundwater Assessment"* prepared for Whitehaven Coal Limited.

HydroSimulations, (2019), *"Tarrawonga Coal Mine Life of Mine Modification: Groundwater Assessment"* prepared for Whitehaven Coal Limited.

Janardhanan, Aryal, Northey, Slatter, Ivkovic, Crosbie, Peña-Arancibia and Bell, (2018), "*Observations analysis, statistical analysis and interpolation for the Namoi subregion*". Product 2.1-2.2 for the Namoi subregion from the Northern Inland Catchments Bioregional Assessment, Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.

JB Mining, (2010), "*Interpolation of regional coal seam surfaces*". Raw data only, no report.

Mackie, (2009), "*Hydrogeological Characterisation of Coal Measures and Overview of Impacts of Coal Mining on Groundwater Systems in The Upper Hunter Valley of NSW*". Faculty of Science, University of Technology, Sydney N.S.W. Australia.

McNeilage, (2006). "*Upper Namoi groundwater flow model*". Published by NSW Department of Natural Resources.

Middlemis and Peeters, (2018), "*Uncertainty analysis—Guidance for groundwater modelling within a risk management framework*". A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy, Commonwealth of Australia 2018.

Parsons Brinkerhoff Australia Pty Ltd, (2015), "*Boggabri Coal Mine – Project Approval Modification Environmental Assessment (MOD 5)*". Document No. 2200545A-ENV-REP-2 RevF, Nov 2016.

Pena-Arancibia, Slatter, Northey and Cassel, (2016), "*Current water accounts and water quality for the Namoi subregion*". Product 1.5 for the Namoi subregion from the Northern Inland Catchments Bioregional Assessment, Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.

Pratt, (1998), "*Gunnedah Coalfield (north) Regional Geology 1:100 000*". 1st Edition, Geological Survey of New South Wales, Sydney.

Rau;Acworth;Halloran, Timms WA;Cuthbert MO, 2018, "Quantifying Compressible Groundwater Storage by Combining Cross-Hole Seismic Surveys and Head Response to Atmospheric Tides", Journal of Geophysical Research: Earth Surface, vol. 123, pp. 1910 - 1930, http://dx.doi.org/10.1029/2018JF004660SKM 2013.

Resource Strategies, (2011), "*Tarrawonga Coal Project*" prepared for Tarrawgona Coal Pty Ltd.

Resource Strategies, (2019), "*Boggabri - Tarrawonga - Maules Creek Complex Water Management Strategy*" prepared for Whitehaven Coal and Boggabri Coal Operations Pty Limited.

RGS, (2009), *"Continuation of Boggabri Coal Mine Geochemical Assessment"* prepared for Hansen Bailey Pty Ltd.

RGS, (2020), *"Geochemical Assessment of Interburden and Potential Coal Reject"* prepared for Hansen Bailey Pty Ltd, on behalf of Boggabri Coal Operations Pty Ltd.

Scientific Information for Land Owners (SILO), "*Database of historical climate records for Australia*". Website accessed at: https://www.longpaddock.qld.gov.au/silo/

Tadros, (1995), "*Structure and tectonics of the Gunnedah Basin, N.S.W: implications for stratigraphy, sedimentation and coal resources, with emphasis on the Upper Black Jack group*". University of Wollongong.

Watermark Numerical Computing, (2015), "*Watermark Numerical Computing, Calibration and Uncertainty Analysis for Complex Environmental Models*".

Whitehouse, (1993), "*Coal resources of the Maules Creek Sub-basin*". The Gunnedah Basin, New South Wales, Geological Survey of New South Wales, Memoir Geology 12, 523-534.

WSP, (2021), "*Modification 8 – Terrestrial Groundwater Dependent Ecosystem Assessment* ". Draft report, revision B.

WSP, (2021b), "*Boggabri Coal Mine - Modification 8 Biodiversity Development Assessment Report*". Revision F.