9.0 NUMERICAL GROUNDWATER MODEL

9.1 Modelling Objectives and Summary

The numerical model for the Project Boundary has been designed to answer the key study objectives, including:

- Change in groundwater flow to and from the Hunter River alluvium;
- Drawdowns in the potentiometric level due to mining;
- Effects on local registered bores and GDEs;
- Predictions of seepage inflows to the pit void; and
- Recovery in lake water level in the final Project void.

The Bengalla groundwater model has had a progressive development incorporating information from pre-existing models for the site and adjacent mines over many years. The most recent model (AGE 2007) modelled groundwater levels from the start of mining in 1999 until 2017 and was designed to predict the impact of the Wantana Extension

For the purposes of modelling, a 21-year mine plan commencing 1 January 2014 was added to the model, along with a revised timing schedule. Modifications were also made to the implementation and timing of MAC to the south, including its currently proposed extension, and a revised timing for MTP to the north.

Current monitored water level data post 2007 and a survey of river levels adjacent to Bengalla was used to update the steady state[5] model calibration. The number of elements in the model mesh were reduced to reduce the model run time and allow limited transient model recalibration over the AGE (2007) study.

9.2 Model Software

The finite-element simulation package FEFLOW (Diersch, 2005) simulated the impact of the Project, including the currently approved Bengalla operations and mining activities of neighbouring mines on the groundwater regime. FEFLOW is a high-end groundwater flow modelling package, capable of simulating two and three-dimensional, density-coupled groundwater flow, mass and heat transport in saturated and unsaturated media. Since its creation in 1979, FEFLOW has been continuously improved. The FEFLOW source code is written in ANSI C/C++ and contains more than 1,300,000 lines. FEFLOW is used worldwide as a high-end groundwater modelling tool at universities, research institutes, government offices and consulting engineering companies. It has been previously applied successfully on several projects for mine development in the Upper Hunter Valley.

9.3 Model Settings

The model was developed using both steady state and transient modes using the free and movable model setting. In this mode, the top slice is adjusted automatically to the elevation of the groundwater table. All other slices are distributed along the top and bottom of the saturated model layers, preserving the original material distribution. This so-called Best-Adaptation-to-Stratigraphic-Data (BASD) technique is also useful if applying drainage boundary conditions for Project

[5] Steady state simulation was used to generate a starting condition to the transient simulation.

dewatering. The node, on which such a boundary condition is set, automatically moves to the corresponding elevation in the model. Running FEFLOW in this mode negates modelling instabilities associated with the simulation on the unsaturated zone.

The model was run using the PCG solver with automated time stepping (for transient runs) with a convergence criteria set at 1×10^{-3}.

9.4 Model Geometry and Model Extents

The north western and northern model boundaries are defined by Western Sandy Creek and Northern Sandy Creek with the southern boundary defined by Saddlers Creek. These ephemeral creeks were used as arbitrary model limits, rather than hydraulic boundaries. They were selected at a suitable distance from Bengalla so that hydraulic stresses associated with scenarios would not impact them. The south-western border was set along the Mount Ogilvie Fault, which with a horizontal displacement of 200 m is assumed to be a barrier to groundwater flow in the coal seams. The eastern boundary of the model is formed by the outcrop of the low permeability Saltwater Creek Formation and the Hunter River.

Initial model testing and steady state calibration used the same finite element mesh (FEM) as developed by AGE (2007). The mesh density varied laterally with the highest discretisation at Bengalla (~30m cell size). The model mesh could be considered finely discretised and contains 436,912 elements. Figure 9.1 below shows the three-dimensional model mesh. Figure 9.2 shows the model mesh in plan view.

The AGE (2007) transient model ran very slowly and was not amenable to automated PEST type calibration. The slow run times were primarily due to the large number of finite elements used, especially at locations simulating indicated faults and dykes. A secondary factor for the slow run-time was the hydraulic conductivity contrasts at the faults and dykes, which can cause oscillation (discussed further in Section 10.0). To accommodate transient model calibration a simplified mesh was created; this mesh had 64,640 elements or around 14% of the model elements used for the steady state calibration (Figure 9.2). Section 10.0 discusses the model meshes further.

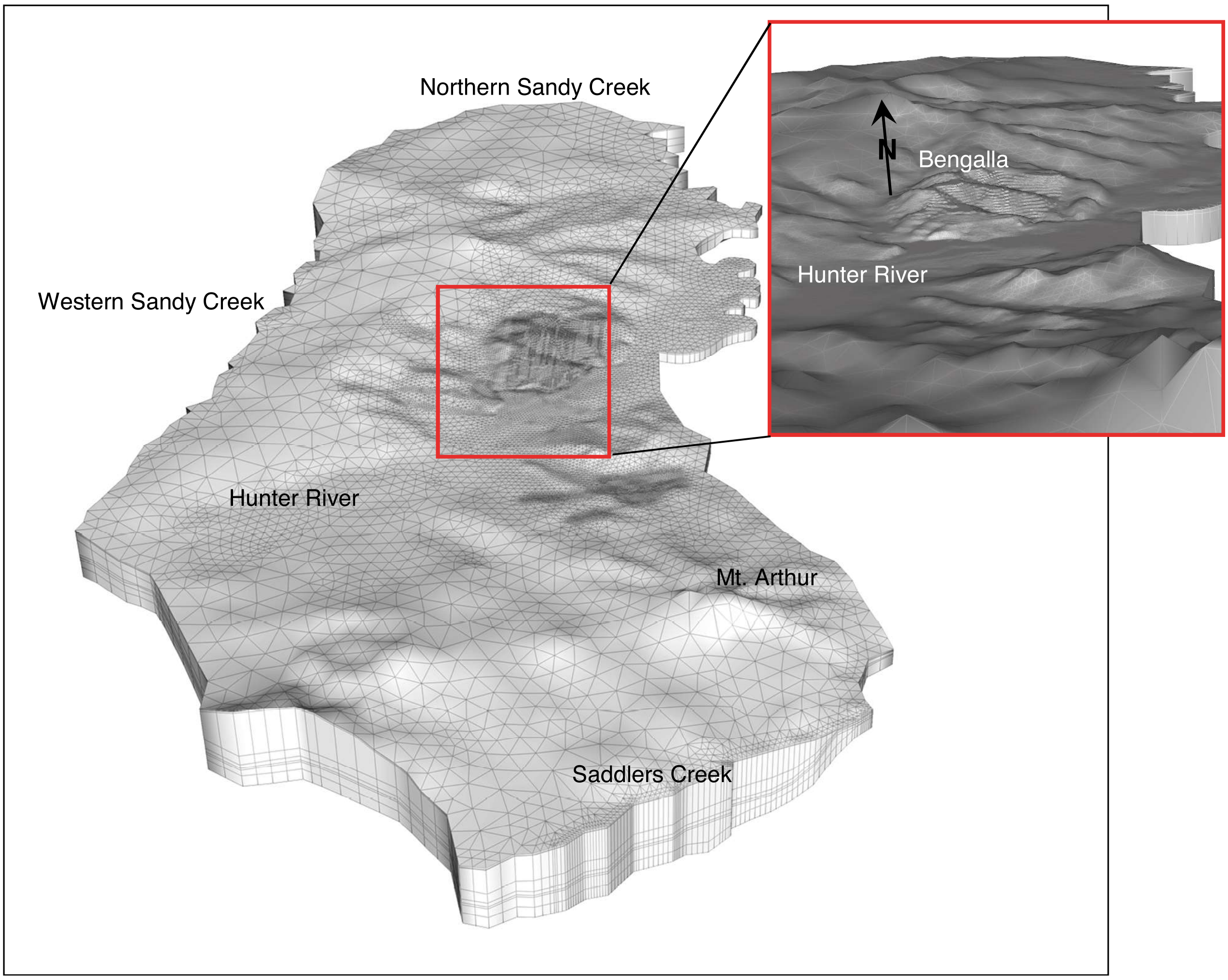
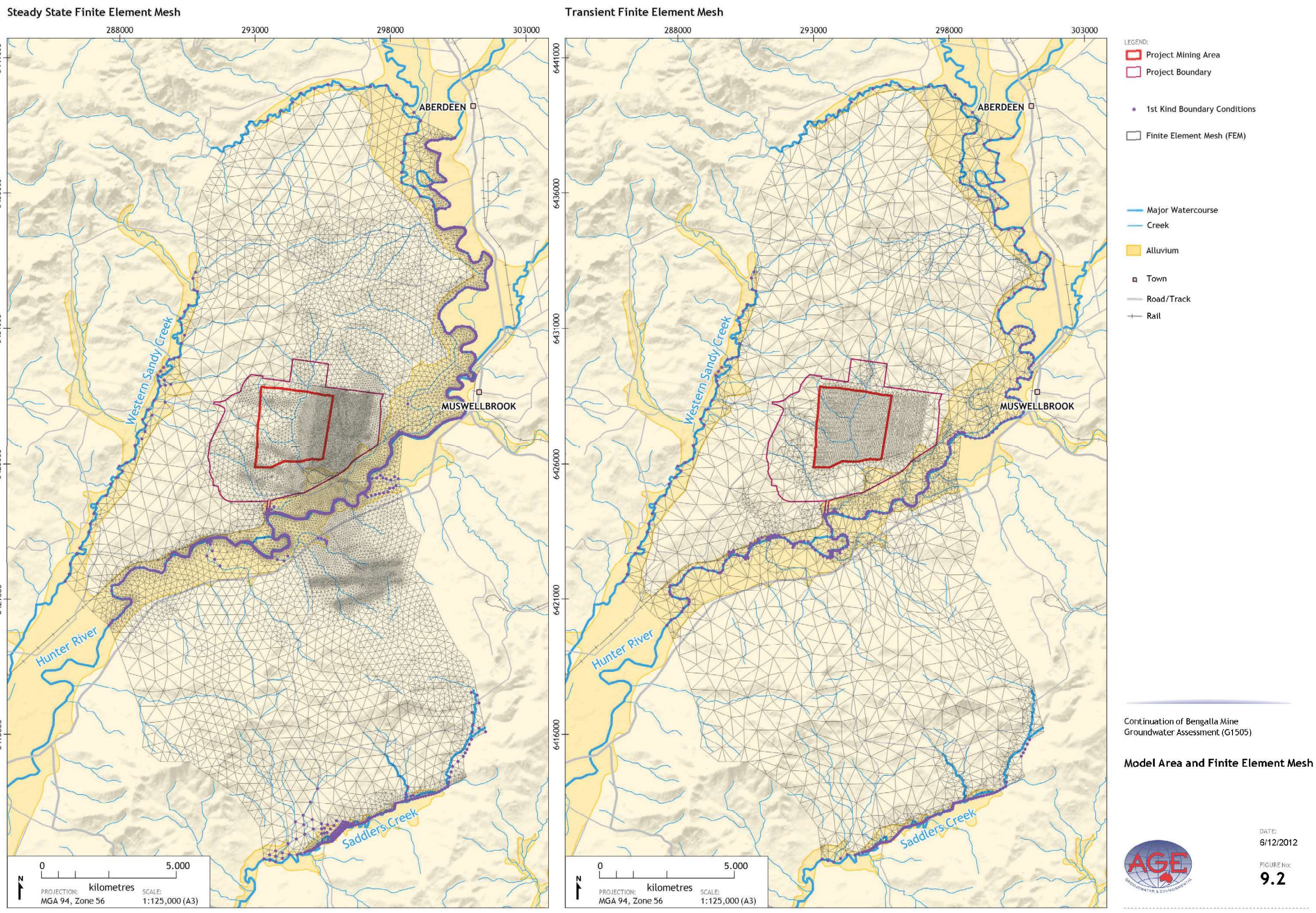


Figure 9.1: Three Dimensional Model Geometry


Steady State Finite Element Mesh
Transient Finite Element Mesh
288000
293000
298000
303000
6441000
6436000
6431300
6426000
6421000
6416000
ABERDEEN
MUSWELLBROOK
Western Sandy Creek
Hunter River
Saddlers Creek
0
5.000
kilometres
PROJECTION:
MGA 94, Zone 56
SCALE:
1:125,000 (A3)
N
LEGEND:
Project Mining Area
Project Boundary
1st Kind Boundary Conditions
Finite Element Mesh (FEM)
Major Watercourse
Creek
Alluvium
Town
Road/Track
Rail
Continuation of Bengalla Mine
Groundwater Assessment (G1505)
Model Area and Finite Element Mesh
DATE:
6/12/2012
FIGURE No:
9.2

9.5 Model Boundary Conditions

The model boundaries conditions were set to be consistent with the conceptual model. The Hunter River to the south and east of Bengalla was simulated as a fixed hydraulic head boundary (1st kind Dirichlet boundary condition) on model slice 1. This boundary condition allowed for the infiltration of surface water into the groundwater system or drainage of the groundwater system, depending on the hydraulic gradient between the river and the surrounding model layers. This type of boundary condition does not use any type of bed conductance term (transfer rate in FEFLOW), rather the hydraulic conductivity of the model layer defines the rate of water movement during each time step.

Figure 9.2 shows the location of the 1st kind boundaries representing the Hunter River. The bed level and water level of the Hunter River was updated based on new survey data collected in the vicinity of the Project.

Outside the Hunter River, the secondary creeks within the model domain were assumed to drain the thin associated alluvial deposits. Recharge from these creeks was conceptually not considered a major recharge source. Therefore, drainage boundary conditions were assigned in the model along the major creek beds that did not allow infiltration of surface water into the alluvial deposits. These were implemented using constrained fixed hydraulic head boundaries (1st kind Dirichlet boundary condition) with a constraint only letting water discharge from the boundary condition (drains). No flux out rate constraint was set for this boundary condition, with hydraulic conductivity the only limitation to discharge at each time step.

Figure 9.2 shows the location of the first kind boundaries representing the creeks (including Saddlers Creek). The drainage lines off the Permian hill areas that do not have any significant associated alluvial sequence, including Dry Creek were not represented in the model.

The surface storage dams within the Project Boundary are well above the groundwater surface and are assumed to be hydraulically isolated from the groundwater systems, and were therefore not represented in the model.

The drain elevations for all surface water features were drawn from the AGE (2007) model which were estimated based on available topographic maps, topographic data provided by BMC and a digital elevation model of the area, (Surface Radar Topography Mission (SRTM) data by NASA). The accuracy of the SRTM data is generally within 9m for elevation. The bed level and water level in the Hunter River near the Project Boundary was updated with on-ground survey data collected by the BMC surveyors.

9.6 Layers

The groundwater model consists of eight layers with different hydrostratigraphic properties as discussed below. Table 10 lists the layers and provides a short description of their conceptualisation and function. Figure 9.3 provides an overview of the layer geometry and Figure 9.4 shows long-sections through the model domain visualising the hydraulic conductivity distribution and model geometry. Figure 9.5 to Figure 9.7 shows the structure contours for Layers 3, 4 and 5 in the model.

The layer data is considered accurate within the existing and proposed mining areas as extensive drilling and mapping has been undertaken to measure coal reserves. Outside the proposed mining area, the drilling is more sparse and the accuracy of the available data decreases. This is a typical constraint in groundwater models.

Table 10: SUMMARY OF GROUNDWATER MODEL LAYERS	
Model Layer	**Description**
1	Alluvium along the Hunter River, colluvial/alluvial deposits along the creeks and the weathered bedrock directly beneath the ground surface.
2	Overburden between the base of top layer and the top of the Warkworth seam.
3	Warkworth coal seams and the interburden down to top of Mount Arthur coal seam.
4	Coal measures from Mount Arthur seam down to Vaux seam.
5 and 6	Coal measures down to the Edderton seam, that is the lowest coal seam to be mined by the Project.
7	Coal measures down to the Ramrod Creek seam, that is, the lowest seam mined by MAC south of the Hunter River.
8	Low permeability Saltwater Creek Formation, base of model.

An additional layer was introduced to subdivide Layer 5 into Layers 5 and 6, since the southern part of the model was transferred from a model that had a further division at the Bayswater seam.

AGE (2007) included all known faults and dykes into the model as special structural features. As discussed previously, the faults and dykes were removed in the model recalibration. This is discussed further in Section 10.0.

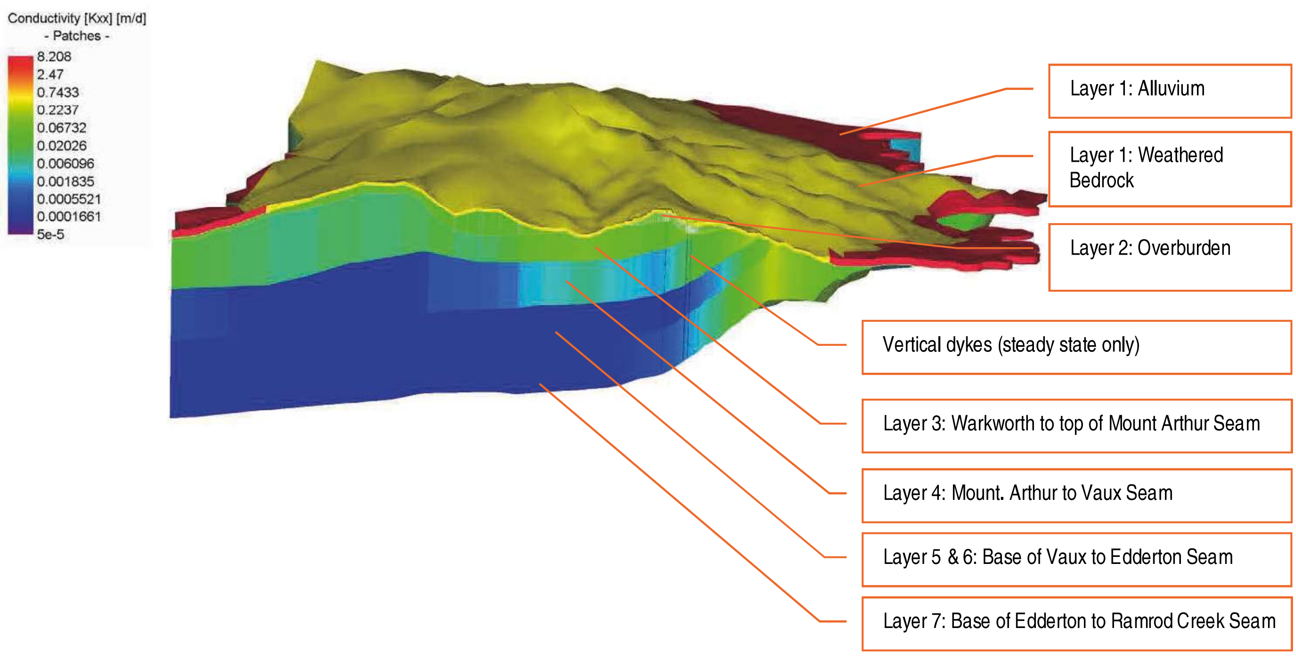
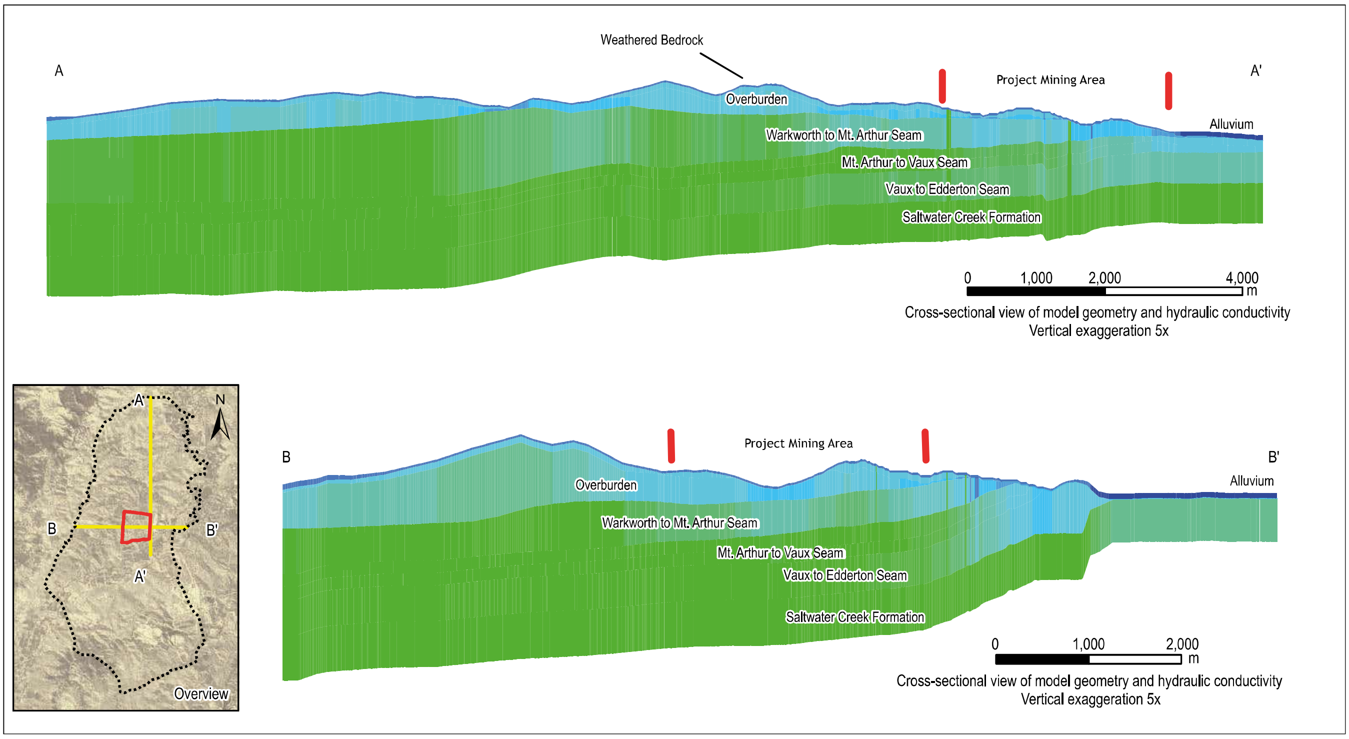


Figure 9.3: 3D Model Geometry (Layer 8 omitted)

The chosen layers represent the main geological units that control groundwater flow, and the segregation of the aquifer units is considered appropriate to meet the model objectives.



LEGEND:

Hydraulic conductivity (m/day)

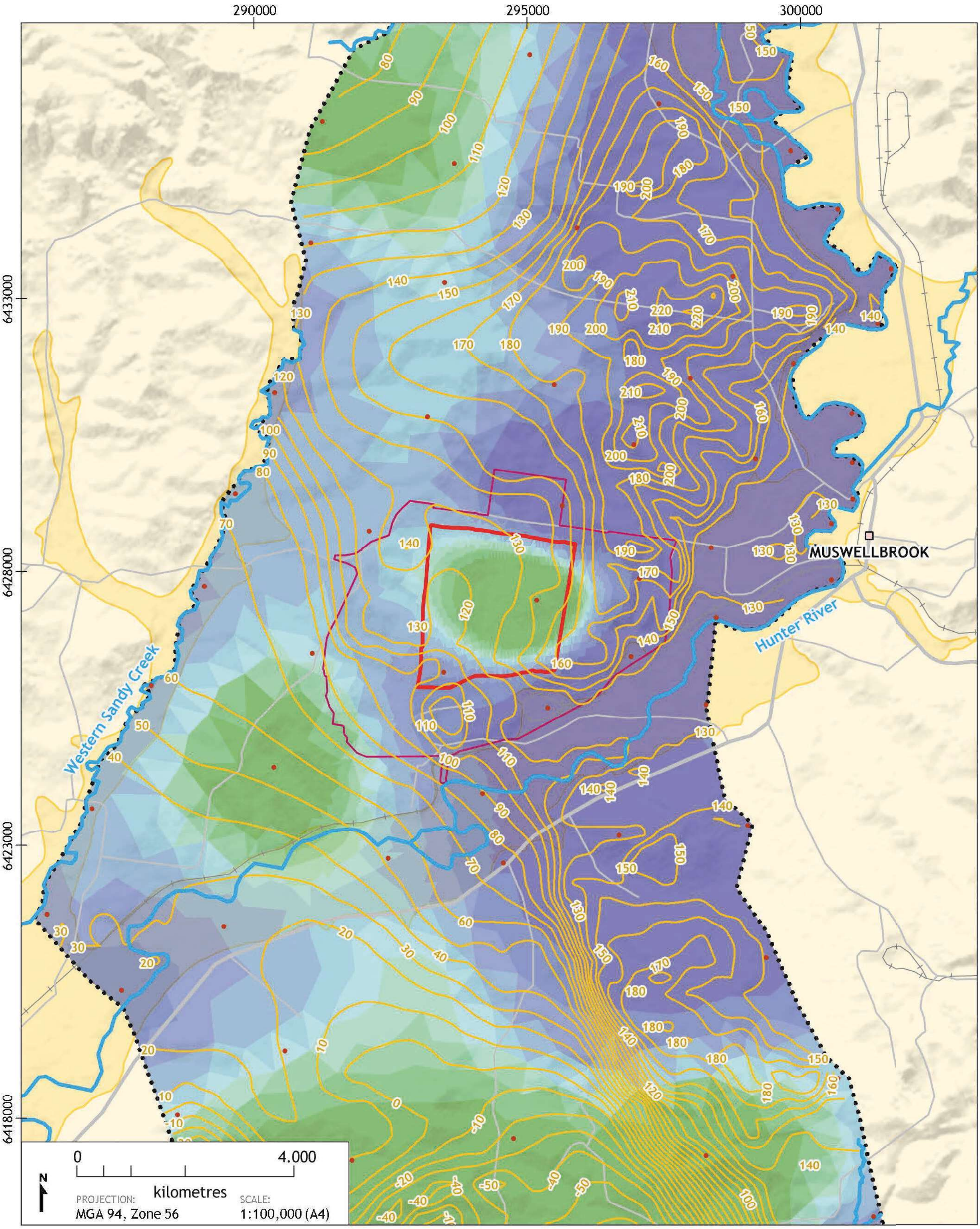
< 0.0002	- 0.001	- 0.05	Cross section
- 0.0005	- 0.002	- 0.1	Project Mining Area
- 0.001	- 0.005	- 0.2	Model limit
- 0.002	- 0.01	- 1	
- 0.005	- 0.02		

Continuation of Bengalla Mine
Groundwater Assessment (G1505)

Long Sections - Hydraulic Conductivity

DATE:
6/12/2012

FIGURE No:
9.4



LEGEND:

Horizontal Hydraulic Conductivity m/d

- 0.048 to 0.617
- 0.021 to 0.048
- 0.013 to 0.021
- 0.008 to 0.013
- 0.006 to 0.008
- 0.005 to 0.006
- 0.004 to 0.005
- 0.003 to 0.004
- 0.002 to 0.003
- 0 to 0.002

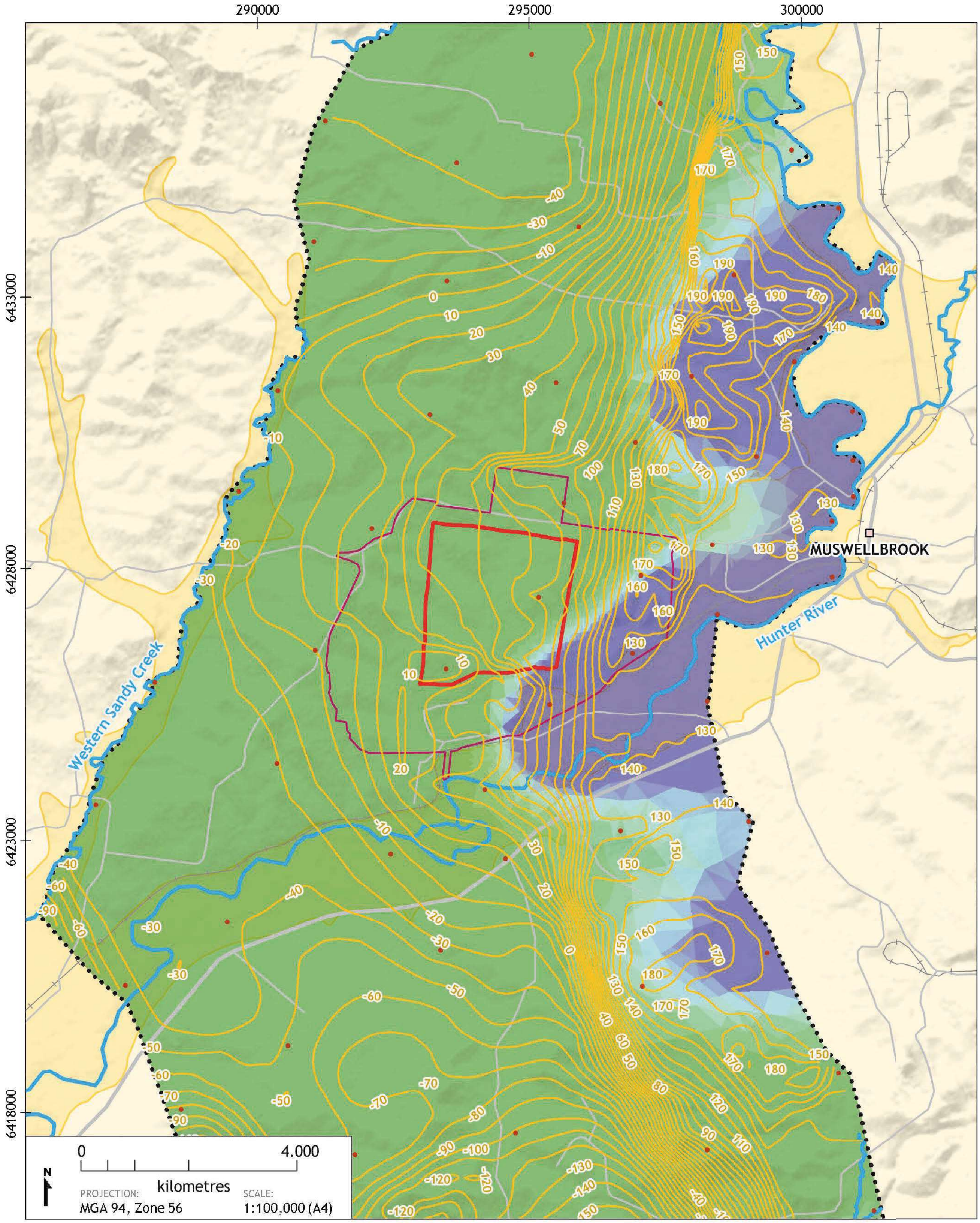
- Project Mining Area
- Project Boundary
- Model Boundary
- Structure Contours (RLm)
- Pilot Points
- Major Watercourse
- Alluvium
- Town
- Road/Track
- Rail

Continuation of Bengalla Mine
Groundwater Assessment (G1505)

Layer 3 - Warkworth Coal Seams and Interburden Floor Elevation and Hydraulic Conductivity

DATE: 6/12/2012

FIGURE No: **9.5**



LEGEND:

Horizonal Hydraulic Conductivity m/d

- 0.09 to 1.07
- 0.08 to 0.09
- 0.07 to 0.08
- 0.06 to 0.07
- 0.05 to 0.06
- 0.04 to 0.05
- 0.03 to 0.04
- 0.02 to 0.03
- 0.01 to 0.02
- 0 to 0.01

- Project Mining Area
- Project Boundary
- Model Boundary
- Structure Contours (RLm)
- Pilot Points
- Major Watercourse
- Alluvium

- Town
- Road/Track
- Rail

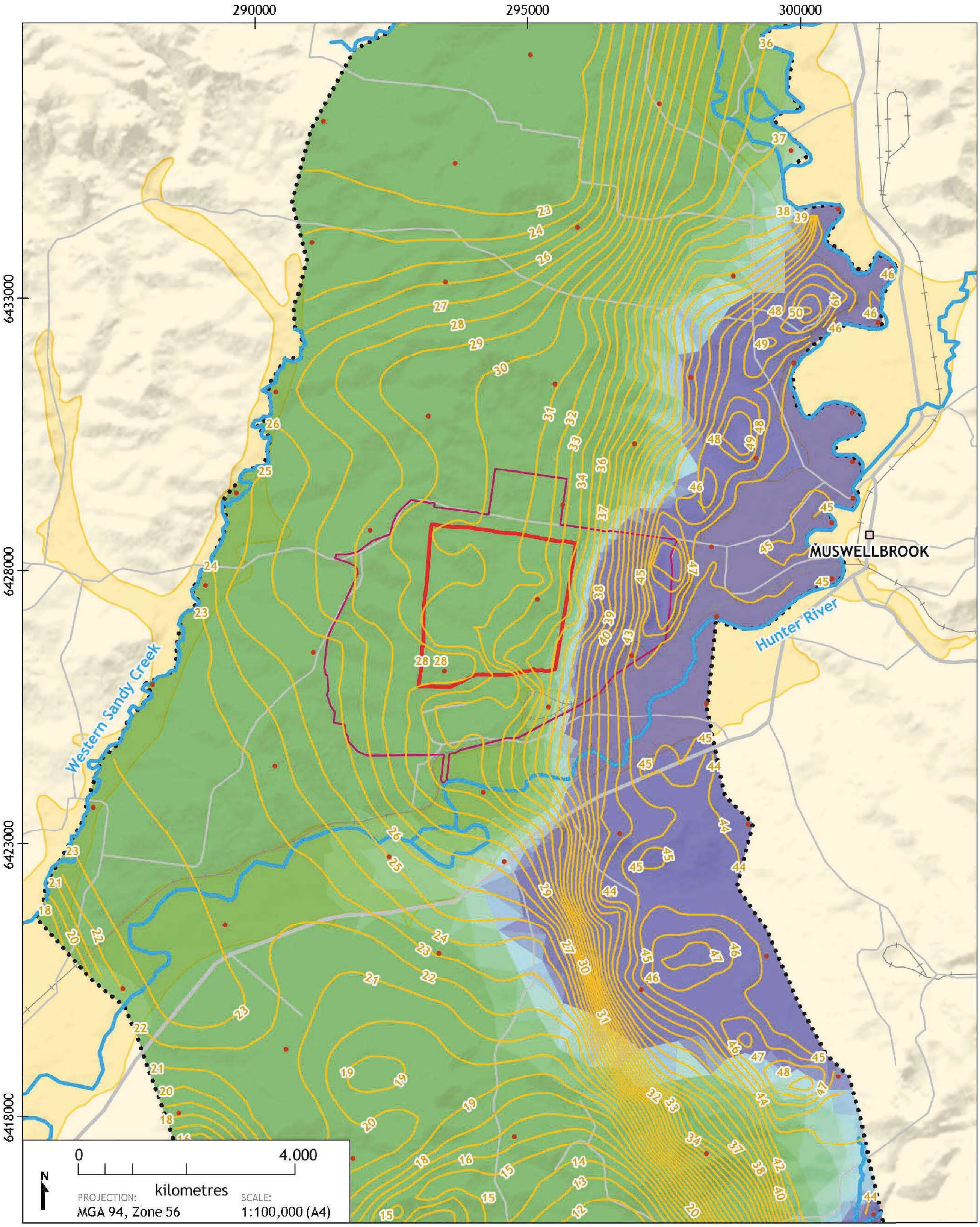
Continuation of Bengalla Mine
Groundwater Assessment (G1505)

Layer 4 - Coal measures from Mount Arthur Seam to Vaux Seam Floor Elevation and Hydraulic Conductivity

AGE GROUNDWATER & ENVIRONMENTAL

DATE: 6/12/2012

FIGURE No: **9.6**



LEGEND:

Horizonal Hydraulic Conductivity m/d

- 0.009 to 0.278
- 0.008 to 0.009
- 0.007 to 0.008
- 0.006 to 0.007
- 0.005 to 0.006
- 0.004 to 0.005
- 0.003 to 0.004
- 0.002 to 0.003
- 0.001 to 0.002
- 0 to 0.001

- Project Mining Area
- Project Boundary
- Model Boundary
- Structure Contours (RLm)
- Pilot Points
- Major Watercourse
- Alluvium
- Town
- Road/Track
- Rail

Continuation of Bengalla Mine Groundwater Assessment (G1505)

Layer 5 - Coal Measures Down to the Edderton Seam - Floor Elevation and Hydraulic Conductivity

DATE: 6/12/2012

FIGURE No: **9.7**

9.7 Recharge and Evapotranspiration

Rainfall sourced recharge was the only external input to the model domain, apart from any localised recharge to the alluvium from the Hunter River. As the dense natural drainage network in the area indicates, most of the rainfall runs off as surface flow with little infiltration. The highest infiltration (recharge) is expected to occur over the permeable alluvium of the Hunter River. AGE (2007) assumed that the recharge over these alluvium areas was 12% of the average annual rainfall, which equates to 76mm/year. Recharge to the remaining areas was assumed to be as follows:

- Permian, 1 to 6 mm/year or less than 1% of the annual average rainfall; and
- Subcrop areas of coal seams, up 12 mm/year or 2% of the annual average rainfall.

These values sourced from the previous AGE (2007) modelling were used as initial values to the steady state and transient calibration in this study. As discussed further in Section 10.0, recharge was allowed to vary within realistic bounds during calibration with results generally less than those in the previous study.

Evapotranspiration was not simulated in the model and is therefore accounted for in the net recharge applied in the model.

9.8 Model Hydraulic Parameters

The hydraulic parameters used in the numerical model calibration were based on the data presented in the model conceptualisation described above. The calibrated parameters from the AGE (2007) model were used as starting values during recalibration of the model. Horizontal/vertical hydraulic conductivity and specific yield/specific storage were adjusted during calibration.

Layer settings for the model were free and moveable for Layer 1, and un-specified for all remaining layers, except the basal layer which was fixed. Using these layer settings FEFLOW implements specific storage using the free and movable surface setting when the water table is above the top of any layers. Specific yield is used for the upper most layer, representing the water table strata. Hydraulic parameter results are discussed in detail in Section 10.0.

AGE (2007) included all known faults and dykes into the model as lower permeability zones to flow, but as discussed previously, these were removed in the model recalibration. This is considered a conservative assumption that allows groundwater to flow more readily within the model.

10.0 MODEL CALIBRATION

Anderson & Woessner (1992)[6] describe the process of calibrating a model as *"a demonstration that the model is capable of producing field measured heads and flows which are the calibration values. Calibration is accomplished by finding a set of parameters, boundary conditions and stresses that produce simulated heads and fluxes that match field measured values within an acceptable range of error"*.

The initial objective of model calibration was to test the plausibility of the conceptual model described above and to reproduce the estimated pseudo steady state[7] groundwater system existing in the surroundings of and within the Project Boundary before the start of mining at Bengalla. The AGE (2007) model was manually calibrated in steady state mode against 22 water level observations in the northern portion of the model, with a reasonable fit to the data (SRMS of 5.07%).

The first task undertaken was to verify the performance of the AGE (2007) model using water level observation data collected since this time. Predicted water levels were compared to new water level records. The verification processes indicated that improvements to the calibration of the model could be achieved.

The AGE (2007) model was recalibrated using new groundwater monitoring data and bore elevation surveys. The water level measurements for some bores dated back to 1999 providing up to 13 years of transient data for calibration of the model. The objective of the recalibration was to improve the pre-mining steady state "fit" and also the through a calibration, the transient predictive capability of the model. Due to the availability of previous model parameterisation, it was decided to use PEST (Doherty 2004) to improve the steady state and transient model calibration.

The 2007 transient model ran very slowly and whilst adequate for manual calibration, it is not amenable to an automated PEST calibration, where numerous model runs are required. The slow run times of the AGE (2007) model were primarily due to the large number of finite elements used, especially at locations simulating indicated faults and dykes. A secondary factor for the slow run-time was the high permeability contrasts at the faults and dykes, which can cause numerical instability. It was therefore decided to re-grid the model with fewer elements and not to specifically simulate the faults and dykes. The absence of the faults and dykes allows groundwater flow to be unimpeded in the model, a conservative assumption that allows the predicted zone of depressurisation to grow to a greater extent.

Note that the calibration process described below focuses on the area north of the Hunter River. AGE (2007) previously calibrated the model area south of the Hunter River during modelling projects for MAC.

10.1 Calibration Targets

The AGE (2007) steady-state model was re-calibrated with PEST using 21 pre-mining groundwater levels. Additional water level data that had not been previously used was incorporated in the steady state PEST calibration for a total of 54 water level observation points. Table 11 shows these bores, the model slice they are in and whether they were a calibration target

[6] Anderson & Woessner, (1992), *"Applied Groundwater Modeling, Simulation of Flow and Advective Transport"*.

[7] Pseudo steady state refers to the fact the local environment is not in true steady state prior to mining at Bengalla, due to cumulative effects of historical mining. But it provides suitable starting head values for the transient simulations.

during the AGE (2007) study. Some of the water level data was observed after mining commenced but is sufficiently distant from Bengalla to be unaffected and representative of pre-mining steady state conditions. The data was weighted based on data confidence, such that a value of 1 was equal to 100% confidence in the accuracy of the observation. Figure 10.2 shows the location of the bores.

Table 11: STEADY STATE CALIBRATED GROUNDWATER MONITORING BORES

Bore ID	Easting (m)	Northing (m)	Date Water Level	Water Level Elevation Median (mAHD)	Model Slice	Weight	Used in Steady State Calibration in AGE (2007) Calibration
18298	294376	6423529	1/05/1999	123.59	1	1	
19116	296085	6425592	1/05/1999	127.8	1	1	
42927	298851	6428600	1/08/1999	134.44	1	0.8	
47277	299166	6428630	1/08/1999	133.43	1	0.8	
1039AC09	295595	6428184	4/02/1992	175.4	1	1	yes
3500C500	295280	6431032	21/01/2004	203.94	1	0.8	yes
BG1	296656	6426003	1/05/1999	127.02	1	0.3	yes
BG3	294731	6424413	1/05/1999	126.13	1	0.8	yes
BG5	298609	6427874	1/05/1999	132.95	1	0.8	yes
GW1	298345	6414995		161.59	1	0.3	
GW12	297407	6422121		147.8	1	0.3	
GW16	294083	6422888		122.69	1	0.3	
GW17	294903	6423723		124.49	1	0.3	
GW21	296070	6424639		127.18	1	1	
GW24	297321	6425072		129.59	1	0.3	
GW6	293714	6418739		206.77	1	0.3	
GW7	295541	6419693		173.68	1	0.3	
46737	291862	6427170	1/05/1999	186.16	3	0.3	
64092	297707	6428807	1/08/1999	142.96	3	0.3	
1013AE04	296730	6427313	5/02/1992	143.3	3	0.3	yes
1020AD02	297284	6427626	6/02/1992	144.7	3	0.8	yes
1056AE06	296088	6427237	30/01/1992	131.6	3	0.3	
1063AD02	297128	6427437	17/02/1992	143.6	3	0.8	yes
7000D000	298771	6431587	11/07/2003	163.84	3	0.8	yes
A10	295418	6428839	1/05/1999	187.13	3	0.3	
A5	296744	6428675	1/05/1999	150.04	3	0.3	
BG45	291559	6424708	1/11/1999	153.47	3	0.3	
E12	294850	6427586	1/05/1999	151.76	3	0.1	
GW10	299999	6418624		218.58	3	0.8	
GW20	297251	6423530		143.21	3	0.3	
GW22	296871	6424148		139.39	3	0.5	
GW23	297870	6424684		139.45	3	0.8	

Table 11: STEADY STATE CALIBRATED GROUNDWATER MONITORING BORES							
Bore ID	**Easting (m)**	**Northing (m)**	**Date Water Level**	**Water Level Elevation Median (mAHD)**	**Model Slice**	**Weight**	**Used in Steady State Calibration in AGE (2007) Calibration**
GW4	296913	6414953		175.48	3	1	
GW5	296666	6414213		171.62	3	0.8	
37774	298593	6429188	1/08/1999	133.73	5	1	yes
42701	298587	6428631	1/08/1999	132.27	5	0.7	yes
53007	298727	6428855	1/02/2000	135.5	5	0.7	yes
1031AF08	295668	6427089	5/02/1992	144.1	5	0.7	yes
1059AE08	295585	6427288	5/02/1992	159.9	5	0.7	
7500F000	299193	6433616	7/04/2003	156.57	5	0.7	yes
GW13	295906	6421080		161.6	5	0.7	
GW15	295367	6422083		140.61	5	0.7	
GW19	295849	6423622		137.29	5	0.7	
GW8	296943	6419569		182.22	5	0.7	
GW9	298153	6419872		182.67	5	0.7	
1010IA16	293547	6426320	5/02/1992	142.5415836	6	0.7	yes
11953	298193	6428692	1/08/1999	135.5	7	0.7	yes
28510	298650	6429104	1/08/1999	130.92	7	0.7	yes
1024AH04	296564	6426284	4/02/1992	131.4	7	0.7	yes
1074AG06	295982	6426529	5/02/1992	131.4	7	0.7	
5500D000	297271	6431566	18/08/2004	161.85	7	0.7	
I7	295712	6426002	1/08/2000	125.915	7	0.7	yes
MPBH3	299826	6430951	7/04/2003	142.21	7	0.7	yes
1005AB18	293414	6428811	5/02/1992	172.8	8	0.7	yes

Table 12 lists the transient groundwater monitoring bores used to calibrate the model using PEST. A total of 21 hydrograph records in the general vicinity of Bengalla were used with data dating back to 1999, (Appendix 1 and Figure 10.2).

Table 12: TRANSIENT GROUNDWATER MONITORING BORES			
Bore ID	**Easting (m)**	**Northing (m)**	**Model Slice**
G19116	295981	6425401	1
BG5	298505	6427683	1
G28510	298545	6428914	7
G37774	298488	6428998	5
G42701	298482	6428441	5
G53007	298622	6428665	5
I7	295607	6425812	7

Table 12: TRANSIENT GROUNDWATER MONITORING BORES			
Bore ID	Easting (m)	Northing (m)	Model Slice
G64092	297603	6428616	3
A10	295314	6428648	3
BG45	291455	6424517	3
E12	294746	6427398	3
A5	296681	6428672	3
WAN1_A	296520	6426099	6
WAN1_B	296520	6426099	7
WAN2_A	296214	6425821	5
WAN2_B	296218	6425824	6
WAN2_C	296218	6425824	7
WAN4_B	295442	6425691	8
WAN5_B	296020	6425360	8
WAN6_B	296553	6425634	8
WAN7_B	296857	6426255	8

10.2 Calibration Method

Model calibration of both steady state and transient models was undertaken using the model - independent parameter estimation code PEST (Doherty, 2004). User intervention was carried out during the automated calibration by periodically stopping the PEST run and analysis of the interim results. This often resulted in modification to the model, sometimes followed by further manual testing, then subsequent and complete (uninterrupted) PEST calibration.

Initial heads and parameterisation from the steady state calibration were used as starting conditions for the transient calibration. Steady state and transient calibration was carried out using PEST in regularisation mode, with pilot points and Truncated Singular Value Decomposition assist (SVDA) (Doherty, 2004). Tikhonov regularisation and SVDA were used in PEST to constrain the parameter estimation problem to deal with non-uniqueness of the solution.

Pilot points (72) were set for in each layer to adjust horizontal/vertical hydraulic conductivity and recharge (1225 adjustable parameters in all). The transient model calibration included adjusting a single uniform zone per layer for specific yield and specific storage (no pilot points). The transient calibration involved fixing a number of parameters to reduce the total adjustable parameters to 290. Figure 9.5 to Figure 9.7 show the distribution of the pilot points in and around the Project.

10.3 Calibration Results

Table 13 summarises the final calibrated steady model parameters. Figure 9.5 to Figure 9.7 show horizontal hydraulic conductivity distribution in the Permian Coal Measures for the key model layers (Layers 3, 4 and 5).

Table 13: SUMMARY OF GROUNDWATER MODEL PARAMETERS			
Model Layer	**Layer Name**	**Feature/Parameter**	**Value**
1	Colluvium / alluvium and weathered zone	top	Interpolated from topographic data
		base	Weathered zone 5 m thick, Hunter River alluvium 10 m thick
		horizontal hydraulic conductivity (Kh) vertical hydraulic conductivity (Kv)	8.6 m/day to 3.0 x 10^{1}m/d Alluvium, 3.5 x 10^{-3} m/day to 5.3 x 10^{-3} m/day colluvium and weathered zone. 6.0 x 10^{-1} m/day to 3.5 m/d Alluvium, 1.6 x 10^{-3} m/day to 5.2 x 10^{-3} m/day colluvium and weathered zone.
		storativity	2.4% alluvium, 2.1% elsewhere
		storage coefficient	1 x 10^{-4} m^{-1}
		recharge	Alluvium 1mm/year to 17.5mm/year (0.3% to 3% of average annual rainfall), remaining area 0.02 mm/year to 1.3 mm/year (0.002% to 0.2% of average annual rainfall)
2	Overburden	top	Base of Layer 1
		base	Top of Warkworth Seam
		horizontal hydraulic conductivity (K) vertical hydraulic conductivity (K)	2.0 x 10^{-4} m/day to 3.5 x 10^{-1} m/day 2.0 x 10^{-5} m/day to 1.7 x 10^{-2} m/day
		storativity	0.10%
		storage coefficient	6 x 10^{-5} m^{-1}
3	Warkworth Seam to Mount Arthur Seam	top	Top of Warkworth Seam
		base	Top of Mount Arthur Seam
		horizontal hydraulic conductivity (K) vertical hydraulic conductivity (K)	1.5 x 10^{-4} m/day to 6.1 x 10^{-1} m/day 3.0 x 10^{-5} m/day to 8.6 x 10^{-3} m/day
		storativity	0.003%
		storage coefficient	3.8 x 10^{-5} m^{-1}
4	Mount Arthur Seam to Vaux Seam	top	Top of Mount Arthur Seam
		base	Base of Vaux Seam
		horizontal hydraulic conductivity (K) vertical hydraulic conductivity (K)	7.2 x 10^{-6} m/day to 1.0 m/day 2.8 x 10^{-6} m/day to 8.6 x 10^{-3} m/day
		storativity	0.07%
		storage coefficient	1.8 x 10^{-5} m^{-1}
5	Vaux Seam to Edderton Seam	top	Base of Vaux Seam
		base	Base of Edderton Seam
		horizontal hydraulic conductivity (K) vertical hydraulic conductivity (K)	3.9 x 10^{-5} m/day to 2.8 x 10^{-1} m/day 2.8 x 10^{-6} m/day to 8.6 x 10^{-3} m/day
		storativity	0.5%
		storage coefficient	1.2 x 10^{-5} m^{-1}
6	Vaux Seam to Edderton Seam	top	Base of Vaux Seam
		base	Base of Edderton Seam
		horizontal hydraulic conductivity (K) vertical hydraulic conductivity (K)	2.9 x 10^{-5} m/day to 4.75 x 10^{-1} m/day 4.2 x 10^{-6} m/day to 8.6 x 10^{-3} m/day
		storativity	0.5%
		storage coefficient	1.8 x 10^{-5} m^{-1}
7	Edderton Seam to Ramrod Creek Seam	top	Base of Edderton Seam
		base	Base of Ramrod Creek Seam
		horizontal hydraulic conductivity (K) vertical hydraulic conductivity (K)	5.0 x 10^{-5} m/day to 1.9 x 10^{-1} m/day 3.8 x 10^{-6} m/day to 8.6 x 10^{-3} m/day

Table 13: SUMMARY OF GROUNDWATER MODEL PARAMETERS			
Model Layer	**Layer Name**	**Feature/Parameter**	**Value**
		storativity	0.20%
		storage coefficient	1.8 x 10^{-5} m^{-1}
8	Saltwater Creek Formation	top	Base of Ramrod Creek Seam
		base	100 m below Ramrod Creek Seam
		horizontal hydraulic conductivity (K) vertical hydraulic conductivity (K)	3.1 x 10^{-7} m/day to 1.0 x 10^{-3} m/day 3.5 x 10^{-8} m/day to 8.6 x 10^{-3} m/day
		storativity	0.01%
		storage coefficient	1.9 x 10^{-5} m^{-1}

The error between the modelled and observed (measured) water levels is known as the root mean square (RMS) and is an objective method to evaluate the model calibration. The RMS is expressed as follows:

$$RMS = \sqrt{\frac{1}{n}\sum(h_0 - h_m)^2}$$

where: n = number of measurements (22)
h_o = observed water level
h_m = modelled water level

RMS is considered to be the best measure of error, if errors are normally distributed.

Scaled root mean squared (SRMS) is the RMS divided by the range of measured heads and expressed as a percentage.

10.3.1 Steady State Results

Table 14 presents a summary of the calibration statistics for the steady state model.

Table 14: STATISTICAL SUMMARY OF CALIBRATION – STEADY-STATE		
Calibration Statistics	**North of Hunter River**	**Full Model**
Number of data (n)	39	54
Sum of data weights	23	33.5
Root mean square (RMS) (m)	2.53	3.65
Scaled root mean square (SRMS) (%)	3.12	4.49
Average residual (m)	1.30	0.91
Absolute average residual (m)	2.39	3.28

The resulting SRMS value for the northern portion of the model was 3.1%, which is considered to be a good fit given the limited water level observations and the fact the data was not a snap shot at a single time period.

Table 15 presents the differences between the median measured groundwater levels and the groundwater levels simulated by the calibrated steady-state model. Figure 10.1 shows the data in a scatter plot. Figure 10.2 shows the steady state potentiometric level contours. The contours compare well against the observed contours shown in Figure 7.26.

Based on the above it is considered that an acceptable calibration of the steady state model was accomplished as the simulated heads match field measured values within an acceptable range.

Table 15: OBSERVED AND MODELLED GROUNDWATER LEVELS

Bore ID	Slice	Observed Heads RL(m)	Modelled Head RL(m)	Residual	Bore ID	Slice	Observed Heads RL(m)	Modelled Head RL(m)	Residual
18298	1	123.6	124.8	-1.3	E12	3	151.8	153.7	-1.9
19116	1	127.8	129.2	-1.4	GW10	3	218.6	218.5	0.1
42927	1	134.4	135.3	-0.9	GW20	3	143.2	145.5	-2.3
47277	1	133.4	135.2	-1.8	GW22	3	139.4	137.9	1.5
1039AC09	1	175.4	173.9	1.5	GW23	3	139.5	134.0	5.4
3500C500	1	203.9	206.7	-2.8	GW4	3	175.5	178.8	-3.3
BG1	1	127.0	130.5	-3.5	GW5	3	171.6	179.7	-8.1
BG3	1	126.1	126.6	-0.5	37774	5	133.7	138.7	-5.0
BG5	1	133.0	133.7	-0.8	42701	5	132.3	135.6	-3.3
GW1	1	161.6	167.4	-5.8	53007	5	135.5	135.8	-0.3
GW12	1	147.8	151.1	-3.3	1031AF08	5	144.1	140.7	3.4
GW16	1	122.7	122.7	0.0	1059AE08	5	159.9	143.8	16.1
GW17	1	124.5	126.3	-1.8	7500F000	5	156.6	160.4	-3.9
GW21	1	127.2	128.0	-0.8	GW13	5	161.6	159.0	2.6
GW24	1	129.6	130.2	-0.6	GW15	5	140.6	143.0	-2.4
GW6	1	206.8	204.9	1.8	GW19	5	137.3	132.0	5.3
GW7	1	173.7	169.9	3.8	GW8	5	182.2	179.5	2.7
46737	3	186.2	162.9	23.3	GW9	5	182.7	186.7	-4.0
64092	3	143.0	142.5	0.4	1010IA16	6	142.5	142.1	0.4
1013AE04	3	143.3	144.0	-0.7	11953	7	135.5	137.3	-1.8
1020AD02	3	144.7	144.4	0.3	28510	7	130.9	138.2	-7.3
1056AE06	3	131.6	142.9	-11.3	1024AH04	7	131.4	132.6	-1.2
1063AD02	3	143.6	144.4	-0.8	1074AG06	7	131.4	134.5	-3.1
7000D000	3	163.8	161.4	2.4	5500D000	7	161.9	167.8	-6.0
A10	3	187.1	188.3	-1.2	I7	7	125.9	130.9	-5.0
A5	3	150.0	155.3	-5.2	MPBH3	7	142.2	142.1	0.2
BG45	3	153.5	153.3	0.1	1005AB18	8	172.8	179.7	-6.9

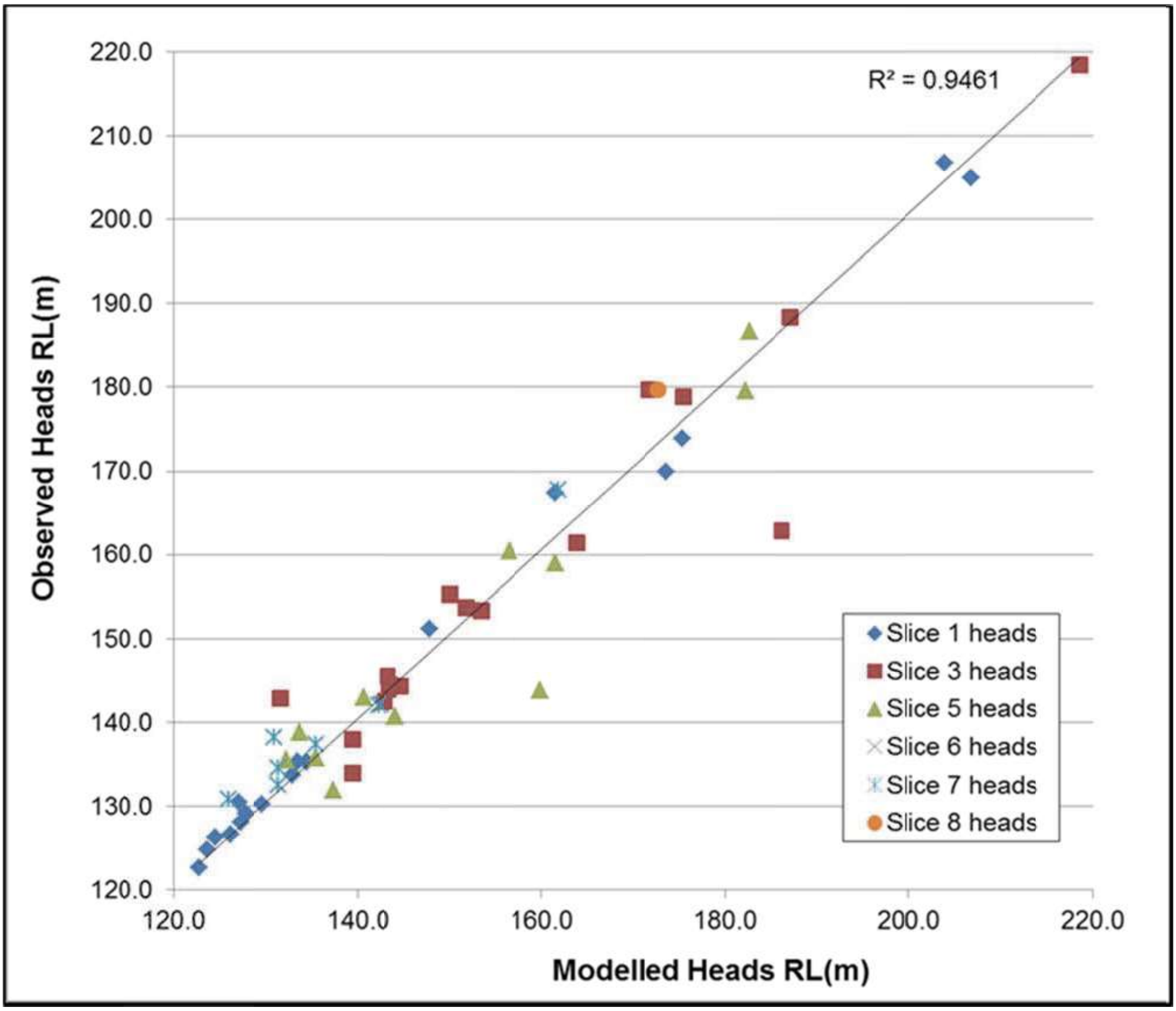
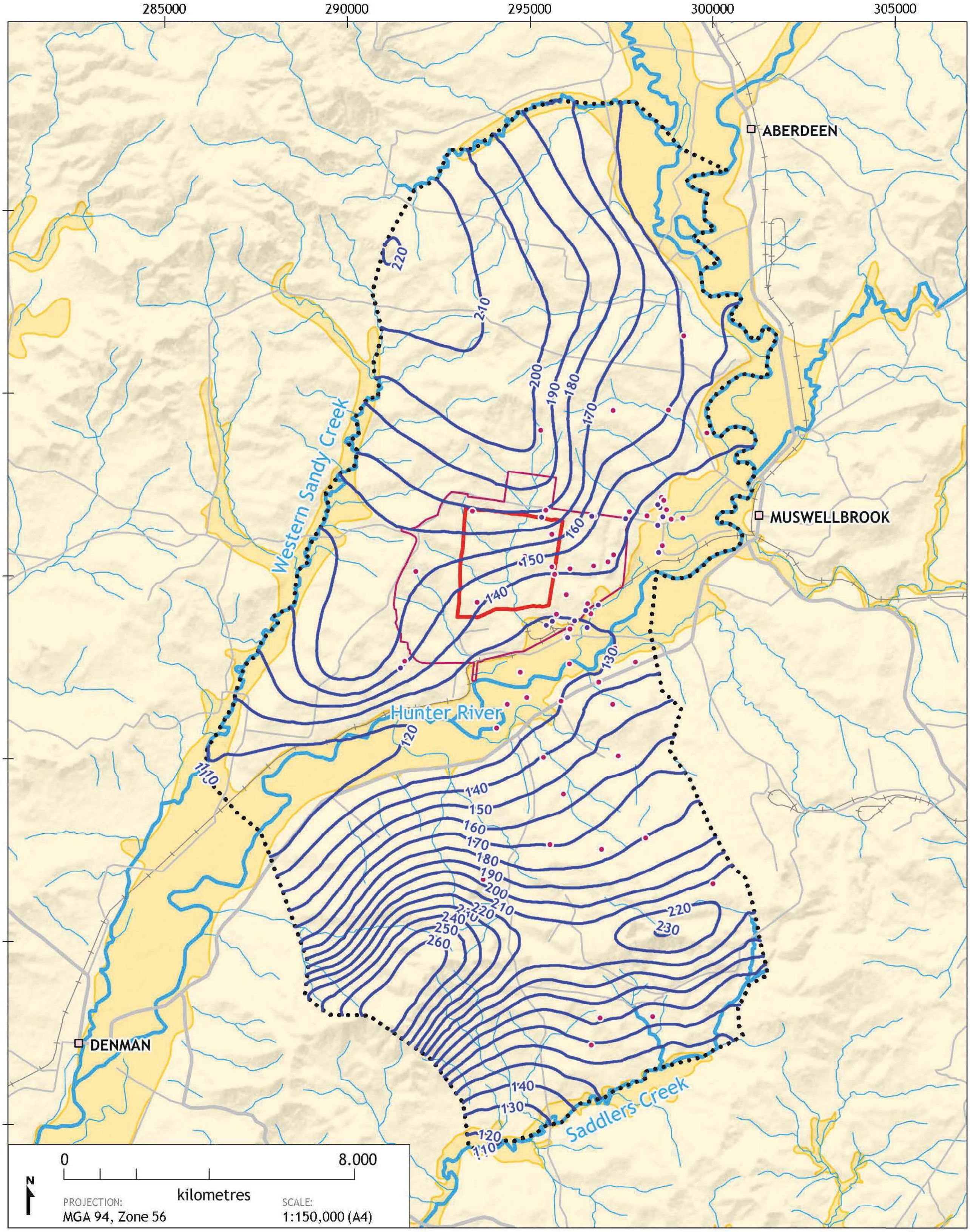


Figure 10.1: Steady state observed vs modelled scatter plot

10.4 Model Budget

Table 16 provides the components of the water budget from the steady state model. The mass balance error, which is expressed as percent discrepancy and is the difference between calculated inflows and outflows to the model at the completion of the steady calibration was 5%. This value is larger than ideal and at the maximum number that is considered acceptable by Barnett et al., (2012).

Table 16: MODEL STEADY STATE WATER BUDGET	
Recharge / Discharge Source	**Flow Rate (ML/day)**
Discharge to creeks and Hunter River	-9.65
Infiltration from Hunter River	4.75
Groundwater recharge by rainfall	3.91
Difference between inflow and outflow from the model domain (ml/day)	-0.99
Percent Discrepancy (%)	**5**



LEGEND:
- Project Mining Area
- Project Boundary
- Model Boundary
- Steady State Potentiometric Level Contour (RLm)
- Transient Calibration Bores
- Steady State Calibrated Bores
- Major Watercourse
- Creek
- Alluvium
- Town
- Road/Track
- Rail

Continuation of Bengalla Mine
Groundwater Assessment (G1505)

Contoured Simulated Pre-Mining Potentiometric Levels

DATE: 6/12/2012

FIGURE No: 10.2

10.4.1 Transient Results

Appendix 1 presents the observed and simulated heads for the 22 observation bores used in the transient calibration. The transient model calibration modestly improved the residual between the observed and modelled heads compared to the steady state calibration. Table 17 presents the statistics for the transient calibration divided amongst each model layer as shown in Table 14.

Table 17: TRANSIENT MODEL CALIBRATION STATISTICS

Layer	Layer 1	Layer 3	Layer 5	Layer 6	Layer 7	Layer 8
number of bores	2	5	4	2	4	4
number of residuals	8	23	12	6	13	12
mean value (m)	-0.57	0.87	-1.96	-8.55	-14.12	-0.79
maximum residual (m)	0.33	9.50	-1.41	-3.71	-4.15	0.53
minimum residual (m)	-1.29	-5.70	-2.62	-14.18	-34.97	-2.86
standard variance (m^2)	0.65	9.84	4.01	94.11	299.20	1.69
RMS (m)	0.81	3.14	2.00	9.70	17.30	1.30

Layers 1, 3, 5 and 8 in the transient calibration are well calibrated. The poorer calibration in Layers 6 and 7 is likely due to aquitards between coal seam layers, which are not fully simulated. The water levels in nested piezometer sets WAN1 and WAN2 show that hydraulic gradients are not completely replicated, with the model under-predicting the drawdown in the deeper layers (Appendix 1).

10.5 Model Calibration Summary

The steady state recalibration successfully improved the residual between pre-mining observed versus modelled heads. The transient calibration also successfully matched modelled drawdown associated with mining activities during the calibration period (1999 to 2012). The 5% imbalance in the water budget in steady state calibration was not ideal, although considering the fit with potentiometric level data, the model is considered suitably calibrated for the Project objectives.

11.0 PREDICTIVE SIMULATIONS

11.1 Modelling Strategy

The response of the groundwater system to the Project was assessed by running the model for a period of 21 years. Figure 8.1 shows the Project mine plan used to develop the predictive model described in this section of the report. Simulated steady state heads were used as initial conditions, during the predictive simulation.

The Project progression of mining was modelled in detail. The cumulative impact of MAC and MTP was simulated based on the available data in the public domain. MTP was assumed to commence in 2008 based on the approved mine plans. The MAC underground mine was also included in the model although this has also not commenced. The cumulative impacts predicted by the model are therefore considered conservative and worst case.

A post closure Project void recovery model was developed and run for a period of 1,000 years to access the pit lake fill rate and final groundwater level should BMC cease mining under this approval.

11.1.1 Model Setup

The predictive model changed the system stresses (equivalent of a timestep in MODFLOW) on the completion of each mining strip, which was approximately six monthly. Timesteps were adaptive and set with a maximum of ten days. The PCG solver was applied.

The recharge rate applied to the model was constant through the predictive scenarios, but based on the distributed field determined from the pilot point calibration. This was considered acceptable as climatic variances were expected to have negligible impact on the predictions.

11.1.2 Simulation of Project Pit Dewatering

The active open cut areas for the Project were simulated using constrained Cauchy type boundary conditions. Cauchy type boundary conditions consist of a reference hydraulic head and a corresponding transfer rate. The higher the transfer rate, the better the hydraulic connection between the reference hydraulic head and the groundwater system. This transfer rate varies in time. For all time stages where an area of the pit is not being mined, the transfer rate is set at zero, which prevents any activity of the associated boundary condition. Once mining commences, the transfer rate is set to the maximum value by switching the associated boundary condition on. The constrained reference hydraulic head conditions only remove water from the model domain, by drainage, if the hydraulic head at a node is above a nominated water level. The nominated water levels were specified as the elevations of the pit floor. Constraint conditions guarantee that water can only be extracted. These boundary conditions were specified over the entire area of the pit and once the pit excavation reaches the natural groundwater table, drainage starts automatically. The transfer rate was set suitably high to allow full drainage of the mining areas. Once the pit was backfilled and the surface elevation rose above the level of the groundwater table, the drainage nodes within the pit footprint were de-activated. As discussed above, the predictive model changed the system stresses when each mining strip was completed, which was approximately six monthly.

The model did not simulate the placement of spoil during the mining (Years 1 to 21) and the associated change in hydraulic conductivity, storage and recharge rates. This is considered a conservative assumption as the placement of the spoil allows for some additional recharge and recovery of surrounding aquifers during mining. The model simulated the spoil after closure of the mine by changing the hydraulic properties and recharge rate within the backfilled pit footprint.

11.2 Simulated Drawdown

Figure 11.1 to Figure 11.5 show the hydraulic heads and predicted zone of depressurisation for Project Years 1, 4, 8, 15 and 21. It is important to note these figures present the cumulative zone of depressurisation associated with the Project and the adjacent MAC and MTP projects.

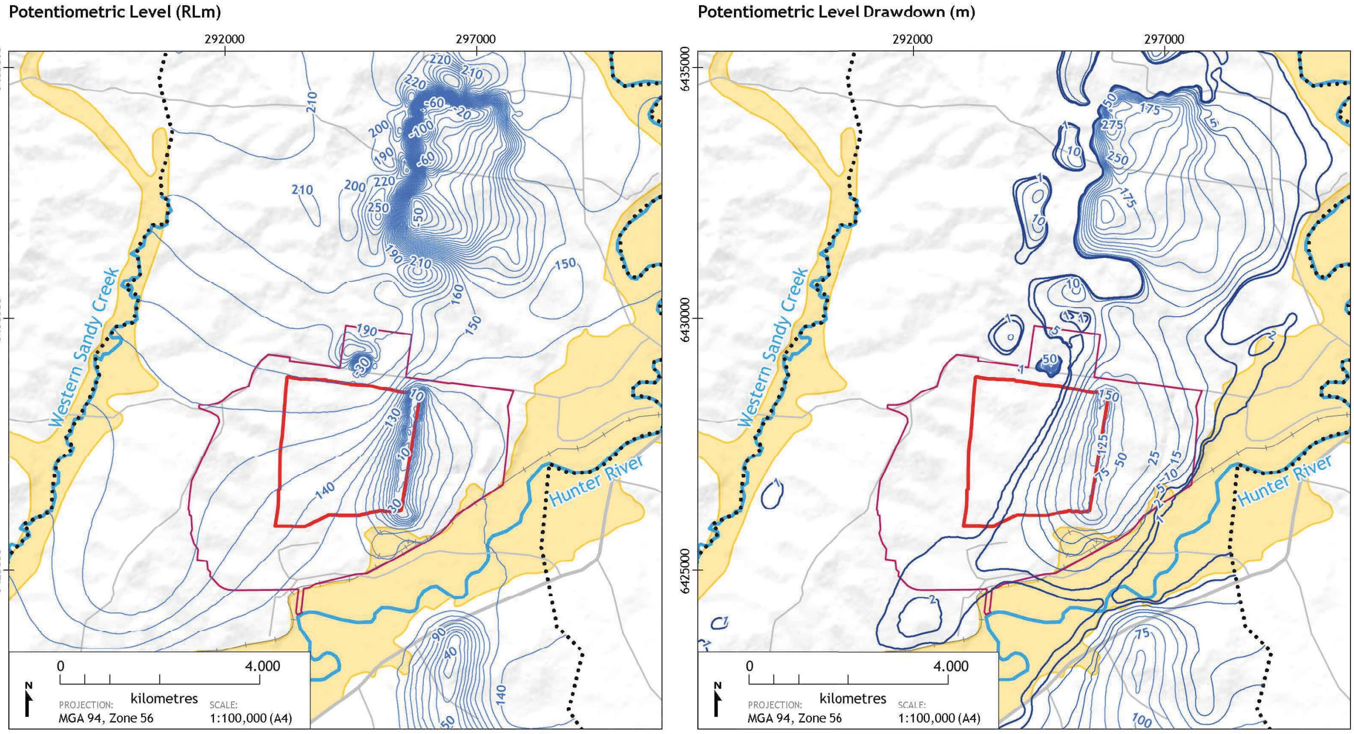
Figure 11.1 shows Year 1 drawdown when mining occurs relatively close to the Hunter River alluvium. The 1 m and 2 m drawdown contours extend below the Hunter River alluvium and combine beneath the Hunter River due to drawdown associated with MAC pit to the south. The cumulative effect from Mount Pleasant Project operations to the north is also clearly visible.

Figure 11.2 (Year 4) shows a slightly reduced dewatering effect below the Hunter River alluvium associated with the Project (to the south). Drawdown does not connect beneath the Hunter River, which was evident in Year 1 drawdown, although still extends within the Hunter River alluvium.

The cumulative impact of Mount Pleasant Project mine operations to the north is still clearly visible. Figure 11.3 (Year 8) shows as mining progresses to the west within the Project Boundary, the 1 m and 2 m drawdown in the Hunter River alluvium to the south decreases in area, compared to Year 1 and Year 4 mine years. The cumulative impact of Mount Pleasant Project mine operations can be seen to the north with drawdown impacting on the northern and eastern extent of the Project Boundary.

Figure 11.4 (Year 15) shows continual reduction in drawdown in the Hunter River alluvium to the south of the Project, while to the north the cumulative effect of the MTP projects can been seen to impact within the north-east corner of the Project Boundary.

Figure 11.5 (Year 21) shows heads and drawdown with active mining to the western extent of the Project. Drawdowns to the east and north-eastern corner of the Project area at this time are more likely associated with the cumulative effects of the MTP project rather than Bengalla.



LEGEND:

Project Mining Area
Project Boundary
Model Boundary
Potentiometric Level Contour (RLm)
Major Watercourse
Alluvium
Town
Road/Track
Rail

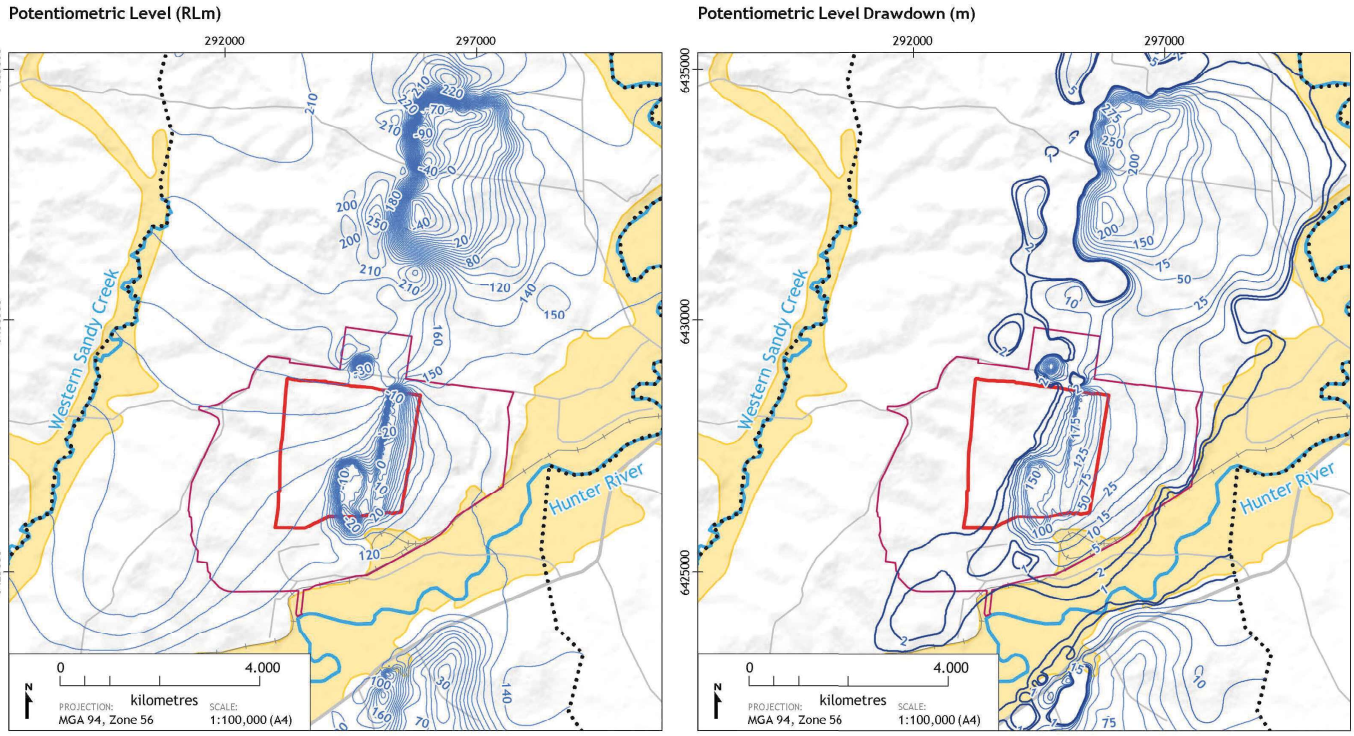
Potentiometric Level Drawdown Contour (m)
1, 2, 5, 10, 15, 25, 50, 75, 100, 125, 150, 175, 200, 225, 250, 275

Continuation of Bengalla Mine
Groundwater Assessment (G1505)

Simulated Potentiometric Level Drawdown During Project Operation - Year 1

DATE: 6/12/2012

FIGURE No: **11.1**



LEGEND:

- Project Mining Area
- Project Boundary
- Model Boundary
- Potentiometric Level Contour (RLm)
- Major Watercourse
- Alluvium
- Town
- Road/Track
- Rail

Potentiometric Level Drawdown Contour (m)

1	50	200
2	75	225
5	100	250
10	125	275
15	150	
25	175	

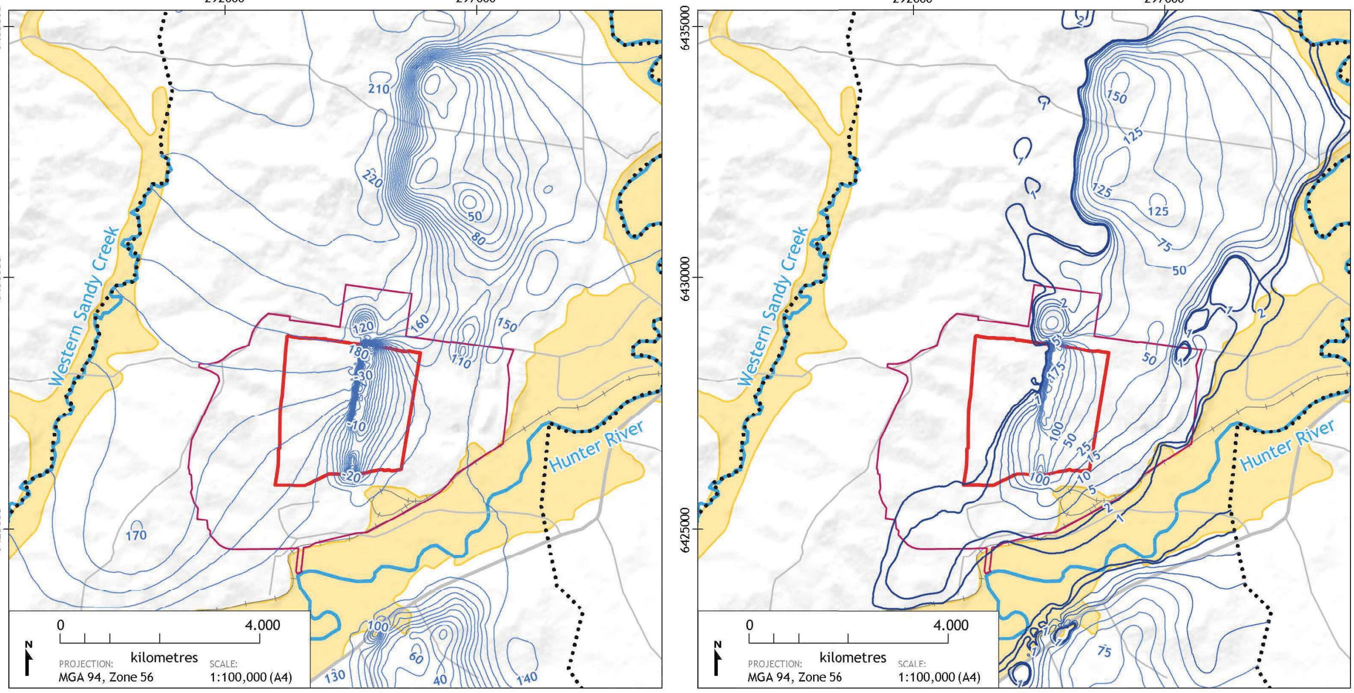
Continuation of Bengalla Mine
Groundwater Assessment (G1505)

Simulated Potentiometric Level Drawdown During Project Operation - Year 4

DATE:
6/12/2012

FIGURE No:
11.2

Potentiometric Level (RLm) | Potentiometric Level Drawdown (m)



LEGEND:

- Project Mining Area
- Project Boundary
- Model Boundary
- Potentiometric Level Contour (RLm)
- Major Watercourse
- Alluvium
- Town
- Road/Track
- Rail

Potentiometric Level Drawdown Contour (m)

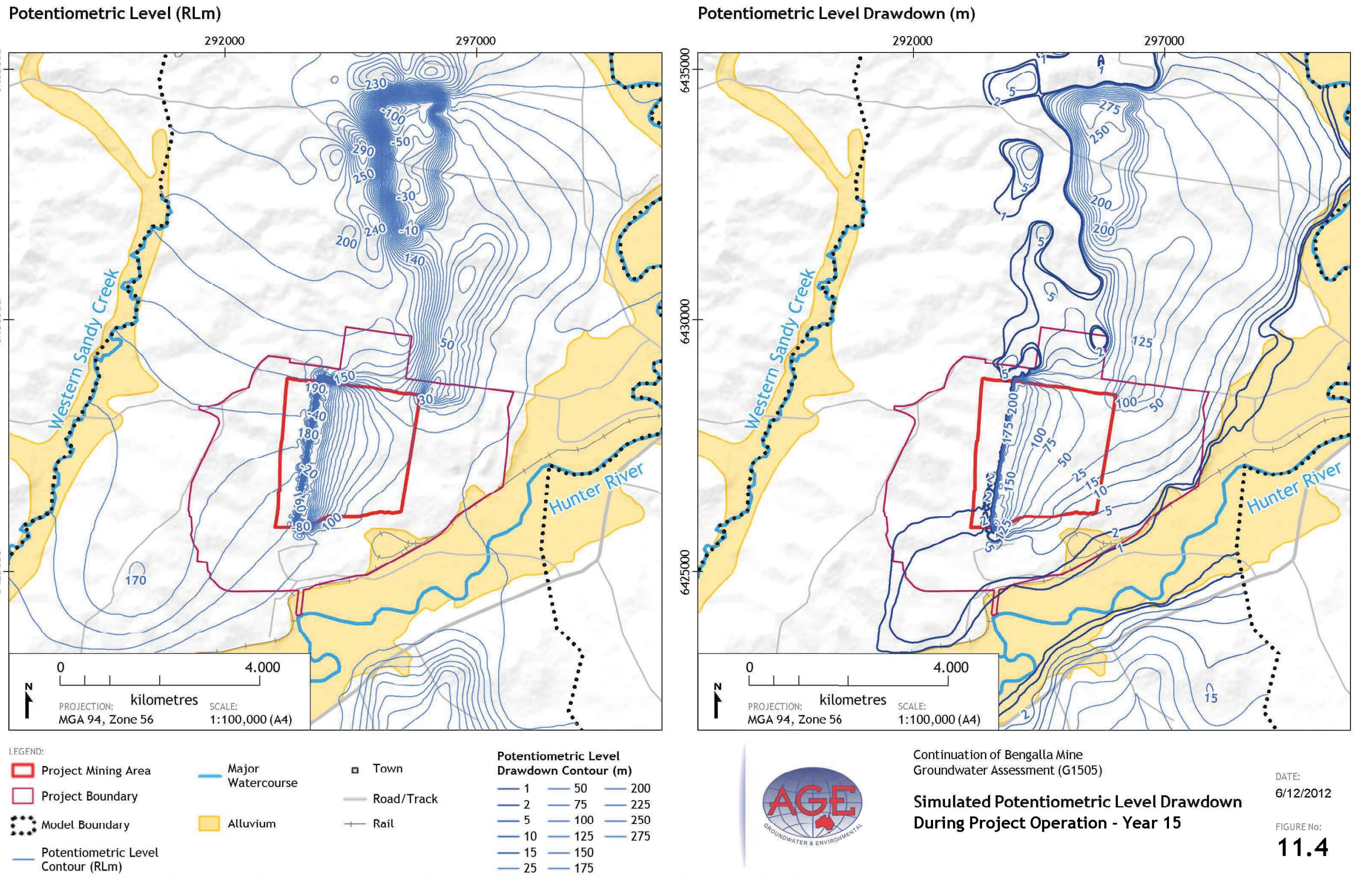
1, 2, 5, 10, 15, 25, 50, 75, 100, 125, 150, 175, 200

Continuation of Bengalla Mine
Groundwater Assessment (G1505)

Simulated Potentiometric Level Drawdown During Project Operation - Year 8

DATE: 6/12/2012

FIGURE No: **11.3**

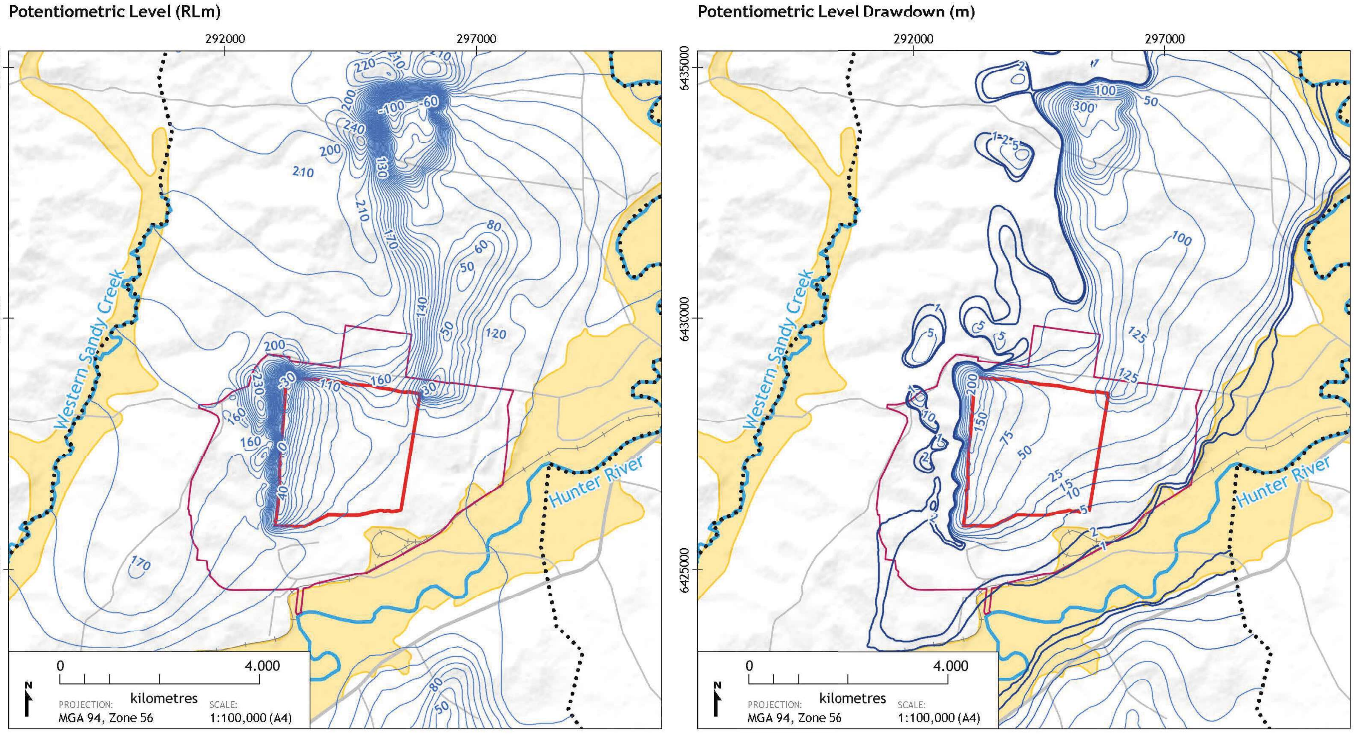


Continuation of Bengalla Mine
Groundwater Assessment (G1505)

Simulated Potentiometric Level Drawdown During Project Operation - Year 15

DATE: 6/12/2012

FIGURE No: **11.4**



LEGEND:

- Project Mining Area
- Project Boundary
- Model Boundary
- Potentiometric Level Contour (RLm)
- Major Watercourse
- Alluvium
- Town
- Road/Track
- Rail

Potentiometric Level Drawdown Contour (m)

1	50	200
2	75	225
5	100	250
10	125	275
15	150	300
25	175	

Continuation of Bengalla Mine
Groundwater Assessment (G1505)

Simulated Potentiometric Level Drawdown During Project Operation - Year 21

DATE:
6/12/2012

FIGURE No:
11.5

11.3 Project Pit Seepage

Figure 11.6 shows the simulated seepage rate of groundwater to the open cut pits.

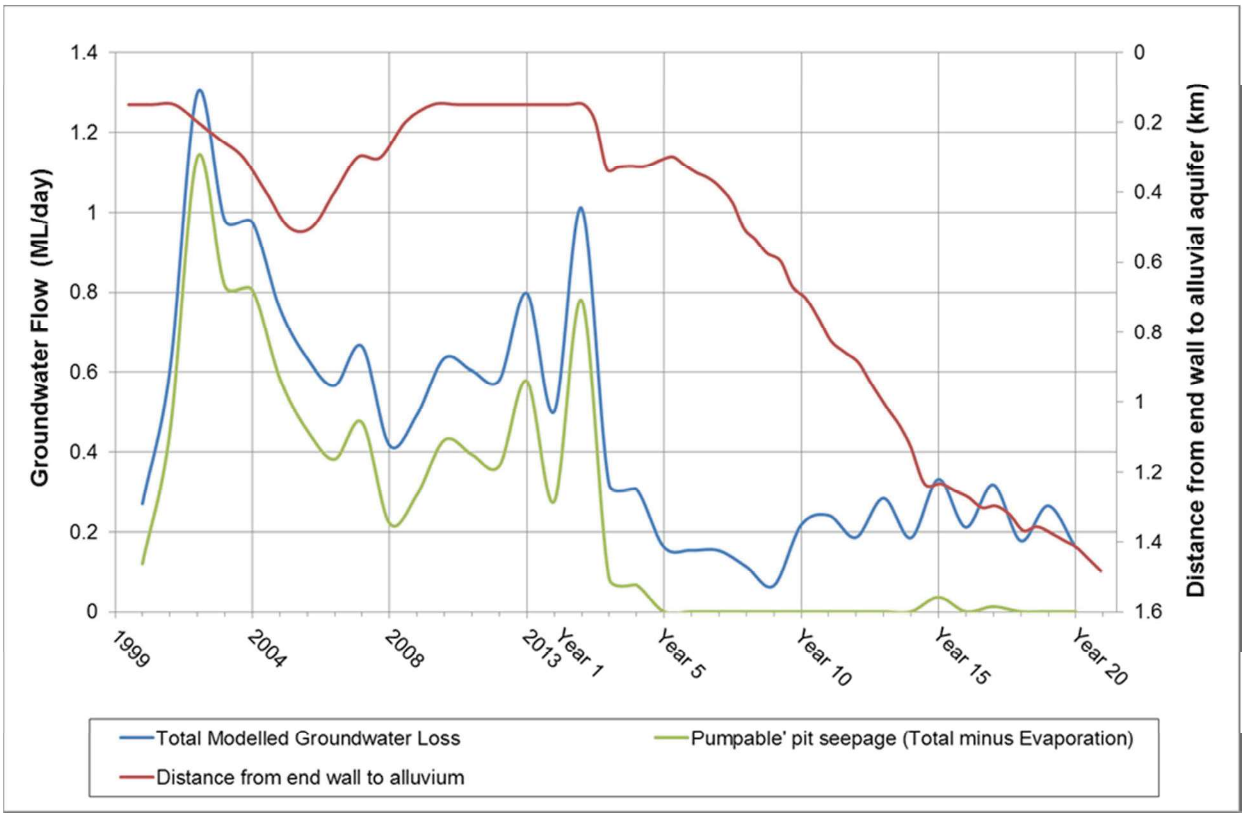


Figure 11.6: Simulated Seepage Rate to Project Open Cut

Evaporative loss of groundwater in the pit seepage was estimated assuming an average evaporation rate of 0.3 ML/day across the coal seam face exposed in the highwall. This was subtracted from the total simulated inflow presented in Figure 11.6 to estimate the volume of groundwater that will require pumping. It should be noted, that due to pool and management of water within the pit, not all of this water may be pumped from the pit.

Figure 11.6 shows the simulated rate of inflow to the pit is related to the distance between the end wall of the pit and the Hunter River alluvial aquifer. When mining is close to the alluvium (within 200 m), the hydraulic gradient from the alluvium to the pit is increased and the rate of inflow increases proportionally (0.6 ML/day to 1 ML/day).

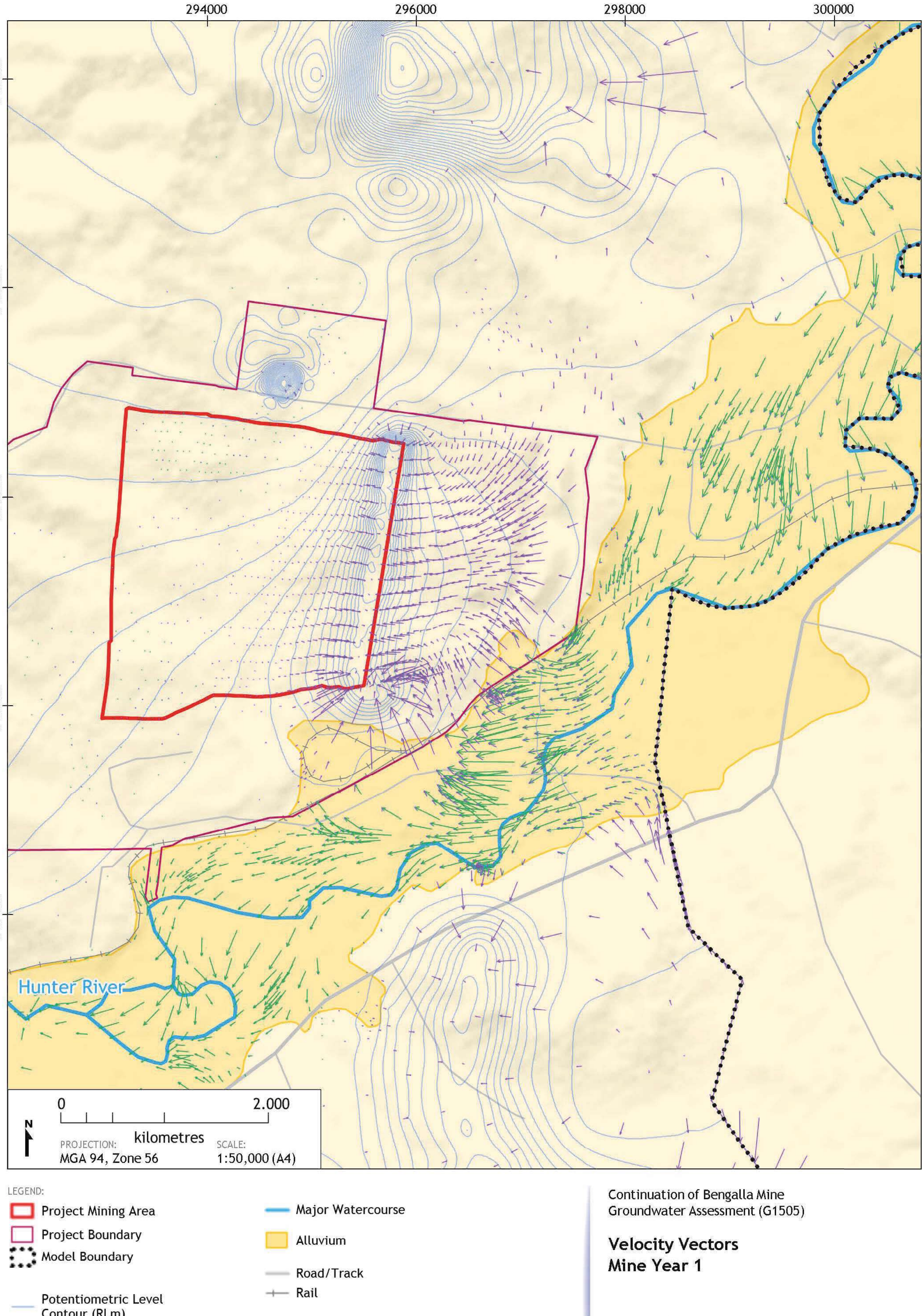
Towards the end of the Project life, the pit moves away from the alluvium (greater than 1 km) and the hydraulic conductivity of the coal seams decreases as the pit becomes deeper, resulting in very low pit inflows (0.2 ML/day) during the last 10 years of mining. Due to the evaporative losses, the last ten years of mining are not expected to experience any observable inflows. This is common in open cut mines in the Hunter Valley, which are remote from zones of alluvium.

There is a correlation between predicted pit inflows and drawdown. Inflows are greatest when drawdowns are largest near the Hunter River alluvium and reduce as the mining moves to the west and the drawdown near the alluvium decreases.

BMC currently has a 125 ML water licence (20BL169798) under the *Water Act 1912* to account for groundwater seepage into the pit. This licence is sufficient to offset the average seepage rate to the open cut pits which is 110 ML/year, but does not cover the peak period when seepage reaches 365 ML/year. BMC will apply to increase water licence 20BL169798 to 365 ML/year to offset the predicted seepage.

11.4 Impact on Alluvial Aquifers and Watercourses

The Hunter River alluvium is likely to be affected by the cumulative mining activities of the Project, the Mount Pleasant Project and MAC. Velocity vector analyses for Year 1 to Year 21 of mining are shown in Figure 11.7 to Figure 11.11. These diagrams show the direction of groundwater flow from the alluvium towards open cut mining operations; a reversal from the pre-mining steady state conditions where vectors flow from Permian formations toward the alluvium (Figure 7.26).

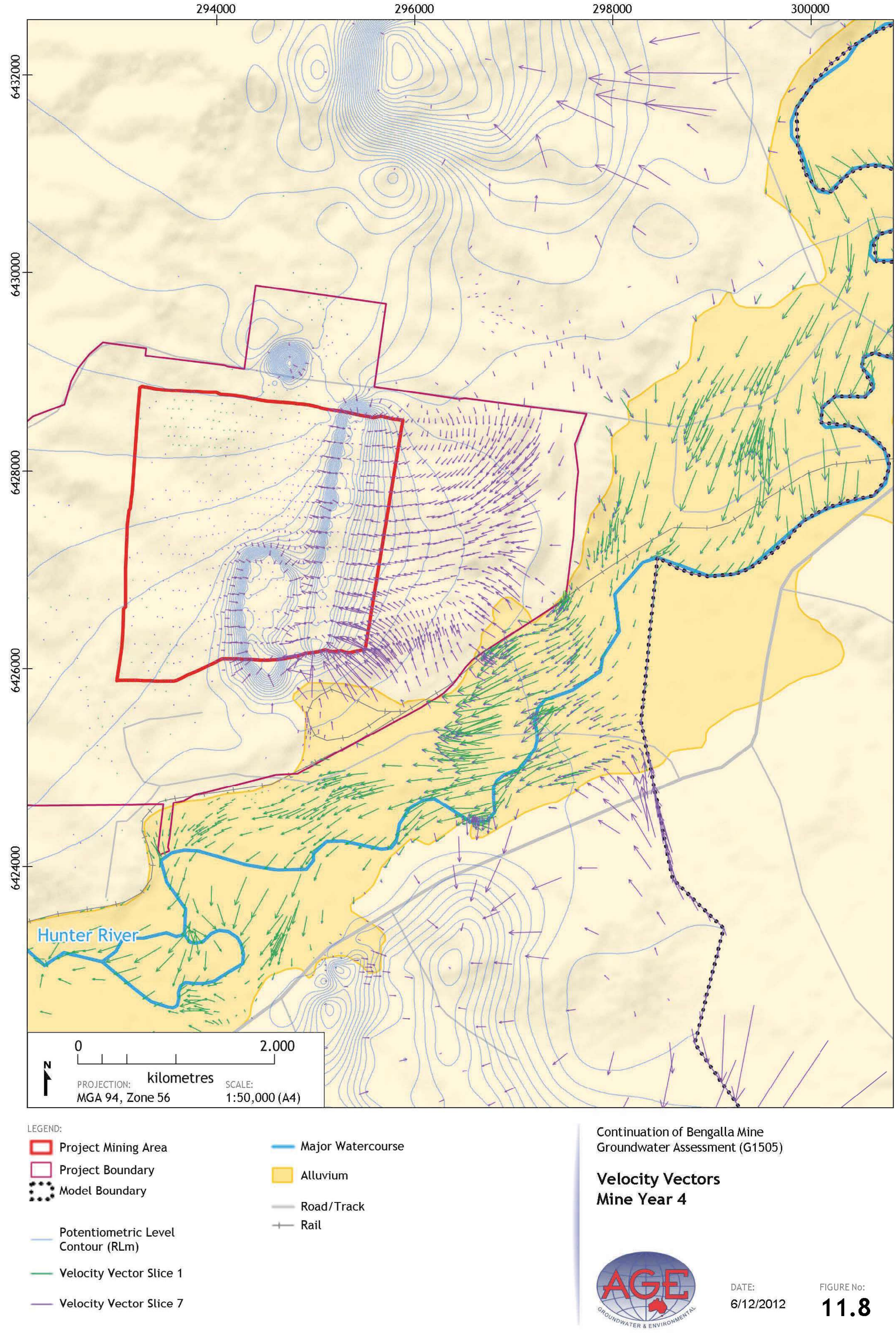


Continuation of Bengalla Mine
Groundwater Assessment (G1505)

Velocity Vectors
Mine Year 1

DATE: 6/12/2012

FIGURE No: **11.7**



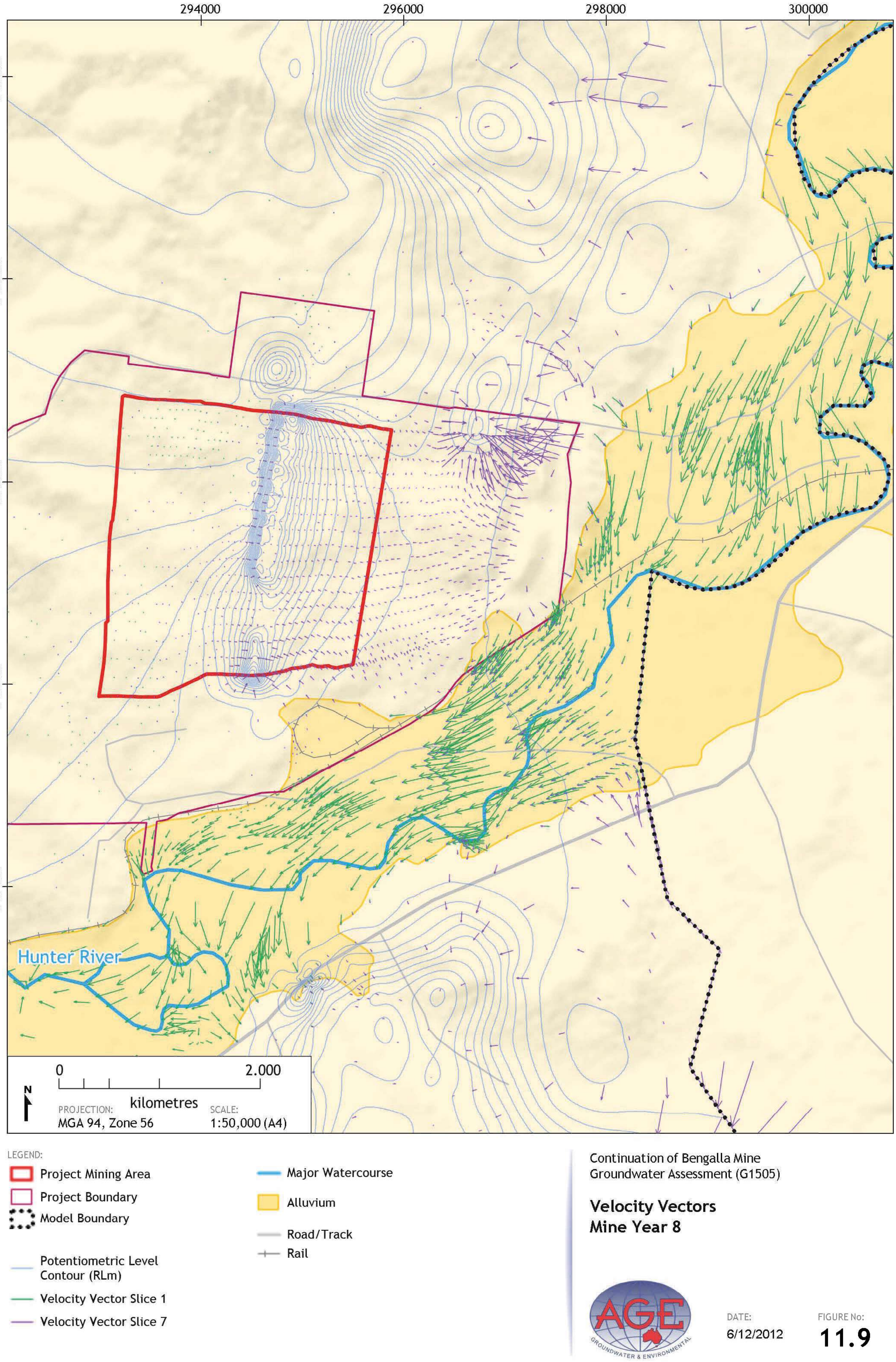
Continuation of Bengalla Mine
Groundwater Assessment (G1505)

Velocity Vectors Mine Year 4

AGE GROUNDWATER & ENVIRONMENTAL

DATE: 6/12/2012

FIGURE No: **11.8**

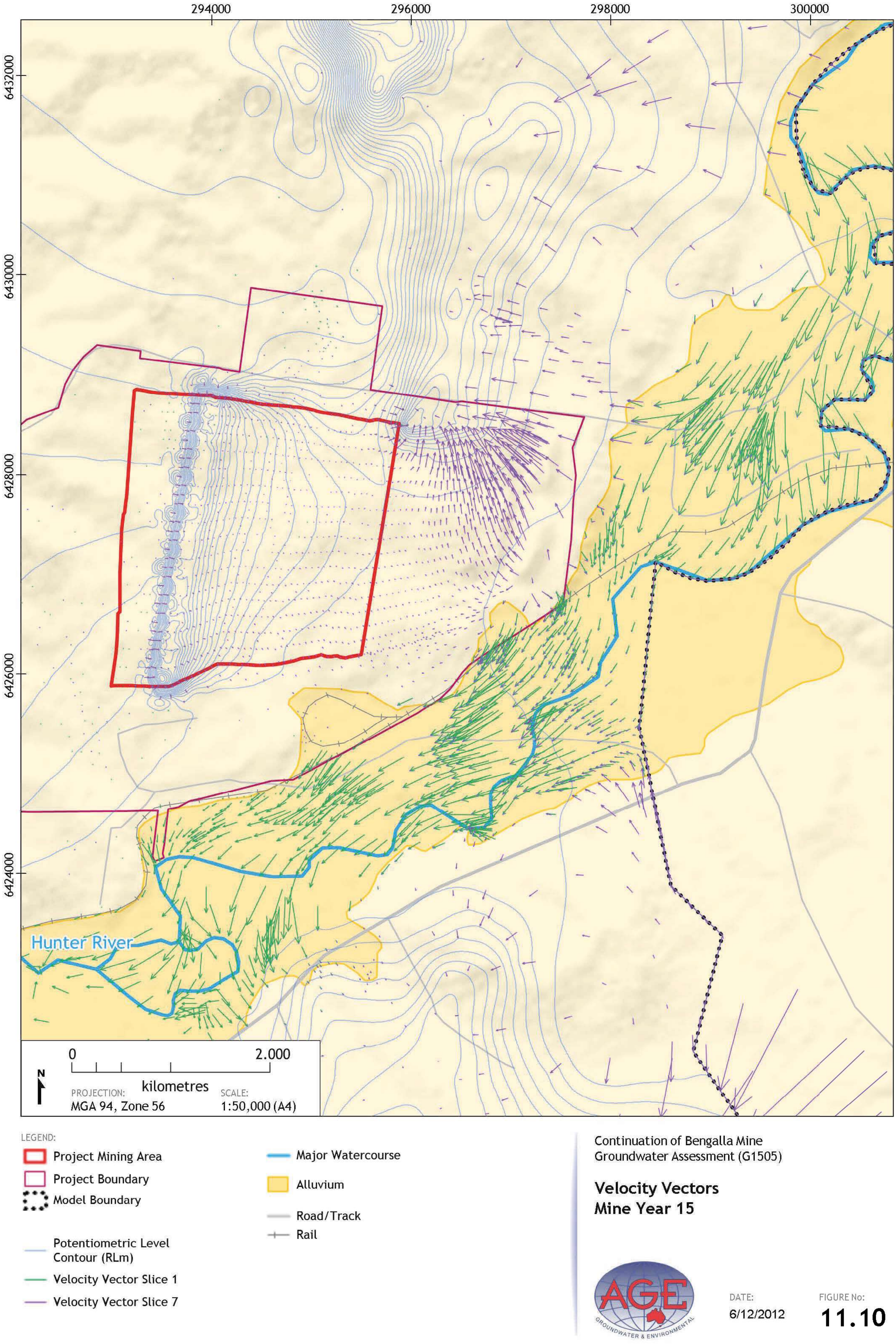


Continuation of Bengalla Mine
Groundwater Assessment (G1505)

Velocity Vectors
Mine Year 8

DATE: 6/12/2012

FIGURE No: **11.9**

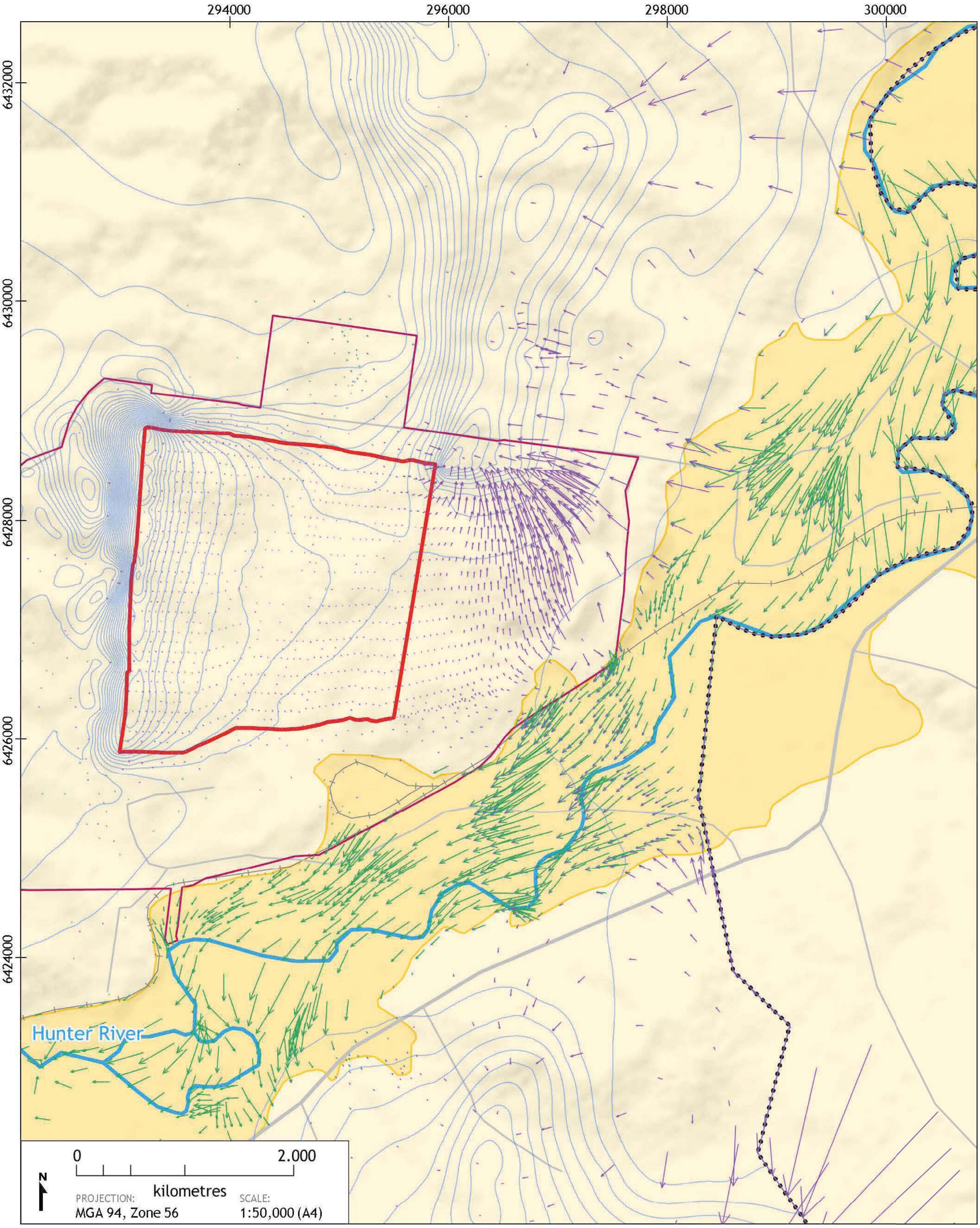


Continuation of Bengalla Mine
Groundwater Assessment (G1505)

Velocity Vectors
Mine Year 15

DATE: 6/12/2012

FIGURE No: **11.10**



LEGEND:

- Project Mining Area
- Project Boundary
- Model Boundary
- Potentiometric Level Contour (RLm)
- Velocity Vector Slice 1
- Velocity Vector Slice 7
- Major Watercourse
- Alluvium
- Road/Track
- Rail

Continuation of Bengalla Mine
Groundwater Assessment (G1505)

Velocity Vectors
Mine Year 21

DATE: 6/12/2012

FIGURE No: **11.11**

Figure 11.12 shows the change in groundwater flow from the Permian to the alluvium attributable to mining.

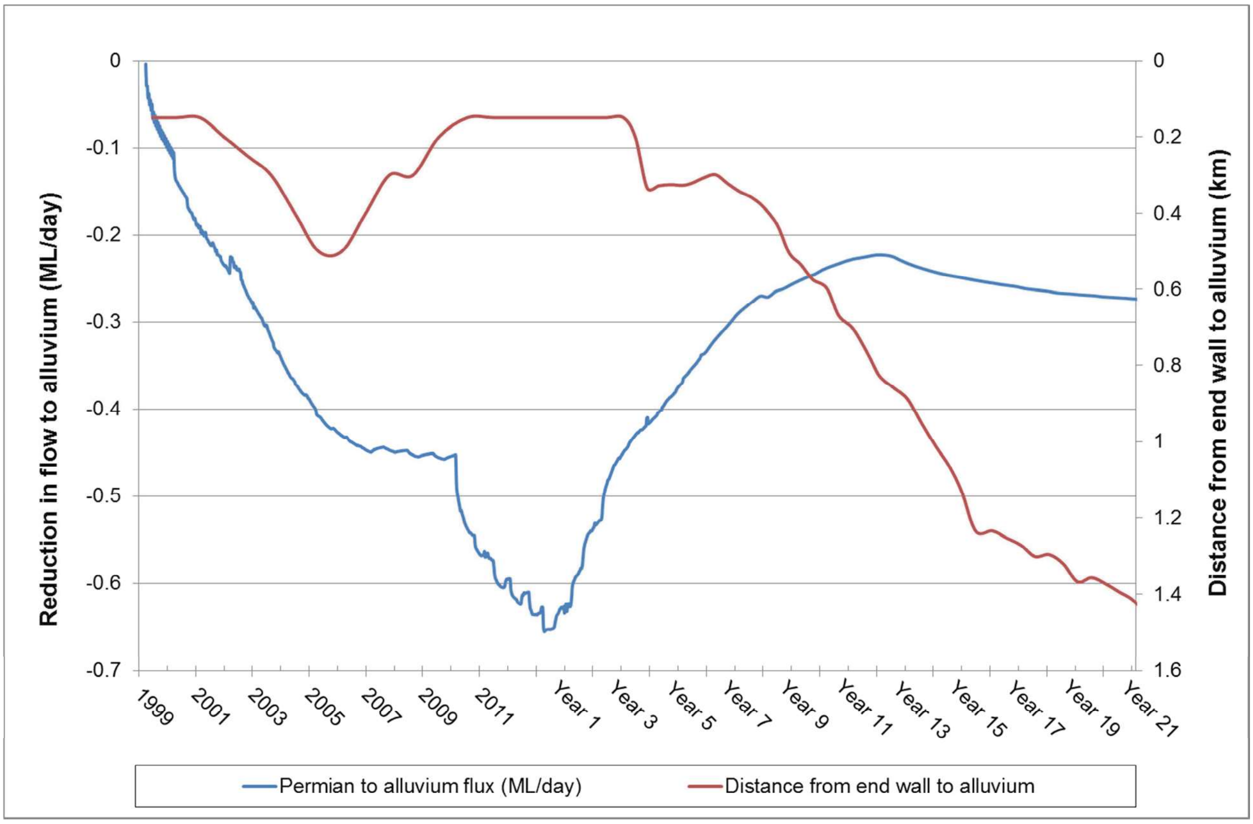


Figure 11.12: Change in groundwater discharge and infiltration rates from Hunter River alluvium

The maximum reduction in leakage to the alluvium occurs in Year 1 of the Project, when mining occurs closest to the alluvium. The flow to the alluvium is reduced by a maximum of 0.63 ML/day at the beginning of Year 1. However, this rate decreases throughout Year 1, resulting in a maximum annual reduction in flow of 220 ML/year. As the Project moves away from the Hunter River alluvium, the leakage from the alluvium decreases to about 0.25 ML/day around Year 10. The loss from the alluvium then stabilises to the end of mining operations at Year 21. The average reduction in flow over the life of the Project is 112 ML/year.

Losses from the alluvium can only be partially attributed to the Project. The MAC operations to the south of the Hunter River are also expected to contribute to this loss. This may be amplified by the MAC pit operation, which is mined to the deeper Ramrod Creek coal seam. The Hunter River in the simulation does appear to buffer effects from the MAC operations, with the dewatering effects of the Project and MAC combining under the Hunter River in Year 1 only.

Bengalla Joint Venturers currently hold a total of 442 units across the following water licences for the Hunter Regulated River Alluvial Water Source (HRRA Water Source) in the upstream Glennies Creek Management Zone:

- WAL 18097 198 units;
- WAL 18061 108 units;
- WAL 18251 60 units;

- WAL 18147 66 units;
- WAL 18069 5 units; and
- WAL 18200 5 units.

The nominated water supply works on licence WAL 18147 will be changed to the mining to account for previous predicted 45 ML per annum take of water from the HRRA Water Source by existing mining operations. A further 175 units for existing water access licences held by the Bengalla Joint Venturers on the HRRA Water Source will progressively be transferred to this licence to account for the total projected maximum annual take of water from this water source of 220 ML/year. These licences will ensure the Project holds sufficient share component and water allocation to account for the take of water from the adjacent water sources at all times, and complies with the requirements of the Aquifer Interference Policy.

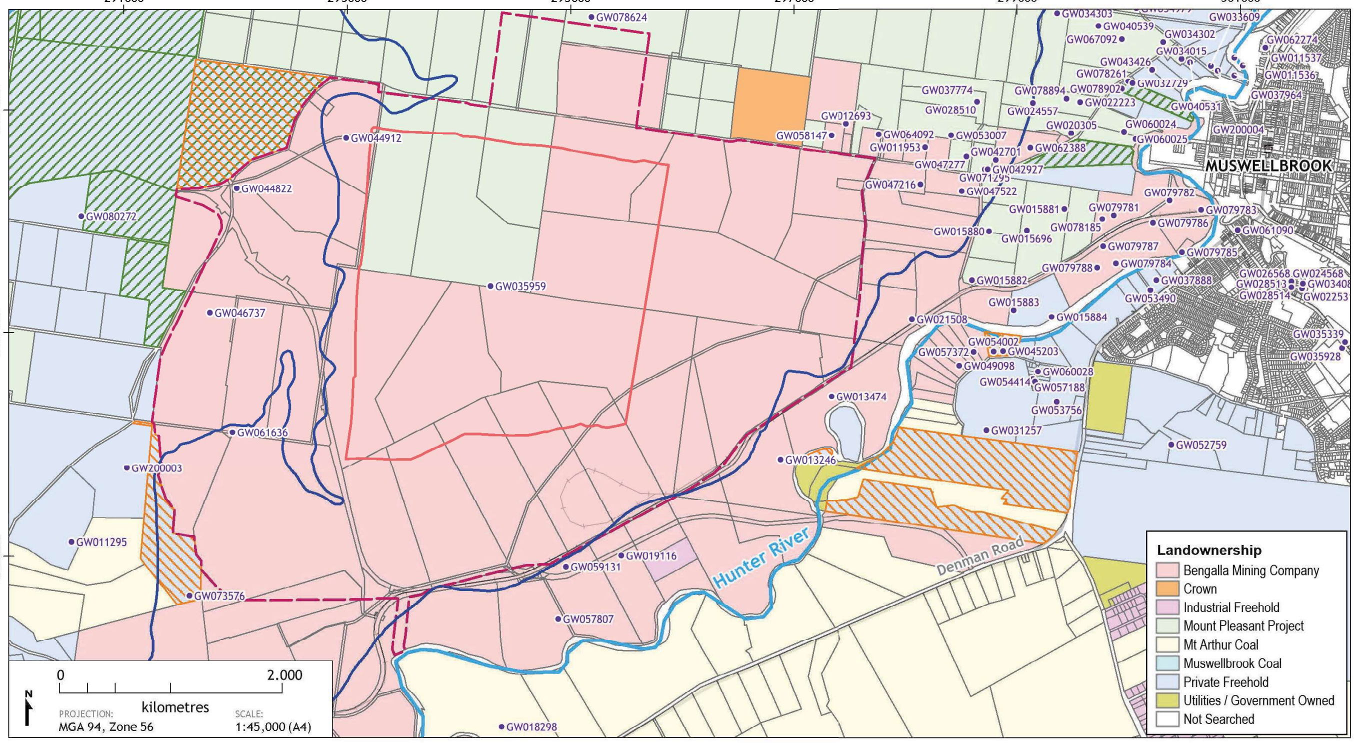
Dry Creek, as the name suggests, is an ephemeral drainage line that does not intersect the groundwater table and therefore does not have any baseflow. The predicted depressurisation of the Permian systems predicted for the Project will therefore not impact upon Dry Creek.

11.5 Impact on Groundwater Users

The zone of depressurisation in the Permian extends about 0.5 km from the Project highwall at the end of mining in Year 21. The zone of depressurisation extends further to the north and south, but this is due to the cumulative impact of MTP and MAC.

Figure 11.13 shows the predicted zone of depressurisation at Year 21, the registered water bores and the land ownership. There is only one bore on private land, GW 073576, which is within the modelled zone of depressurisation associated with the Project. GW 073576 is located on land that is entitled to be acquired by Mt Arthur Coal and is recorded as being 20m deep with slots from 16 m to 20 m. The drawdown at this point is predicted to be about 2 m.

The minimal impact considerations in the Aquifer Interference Policy require the cumulative water table and pressure head decline to be no more than 2 m at any water supply work. The modelling indicated that the drawdown at all private bores does not exceed the 2 m trigger in the Aquifer Interference Policy.



LEGEND:

- 1m Drawdown Contour Year 21
- Registered Bore Source Pinneena 3.2, September 2010
- Project Mining Area
- Project Boundary
- Property Entitled to Acquisition by Mt Arthur Coal
- Property Entitled to Acquisition by Mt Pleasant Project
- Road
- Rail
- Major Watercourse

Continuation of Bengalla Mine
Groundwater Assessment (G1505)

Groundwater Users, Landownership and Drawdown

DATE:
6/12/2012

FIGURE No:
11.13

11.6 Impact on Groundwater Dependent Ecosystems

The Minimal Impact Considerations in the Aquifer Interference Policy require that *"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; or
(b) high priority culturally significant site;"

The Hunter River Unregulated and Alluvial Water Sources Water Sharing Plan does not define any high priority groundwater dependent ecosystem or high priority culturally significant sites within the Project area or surrounds.

Cumberland Ecology 2013 determined that fragmented occurrences of Hunter Floodplain Red Gum Woodland present along the Hunter River are considered GDEs. The drawdown in the Hunter River alluvium is most extensive during the early years of the Project when the mine remains in close proximity to the alluvial aquifer (refer Figure 11.1). The simulated drawdown is largely less than 1 m at the Hunter River and therefore no impact on the remnant Hunter Floodplain Red Gum Woodland is considered likely. This finding is supported by ongoing monitoring at Bengalla that has not detected any significant decline in groundwater levels adjacent to the Hunter River. The releases of water from the Glenbawn Dam are also expected to maintain groundwater levels in dry periods which would further support riparian GDEs.

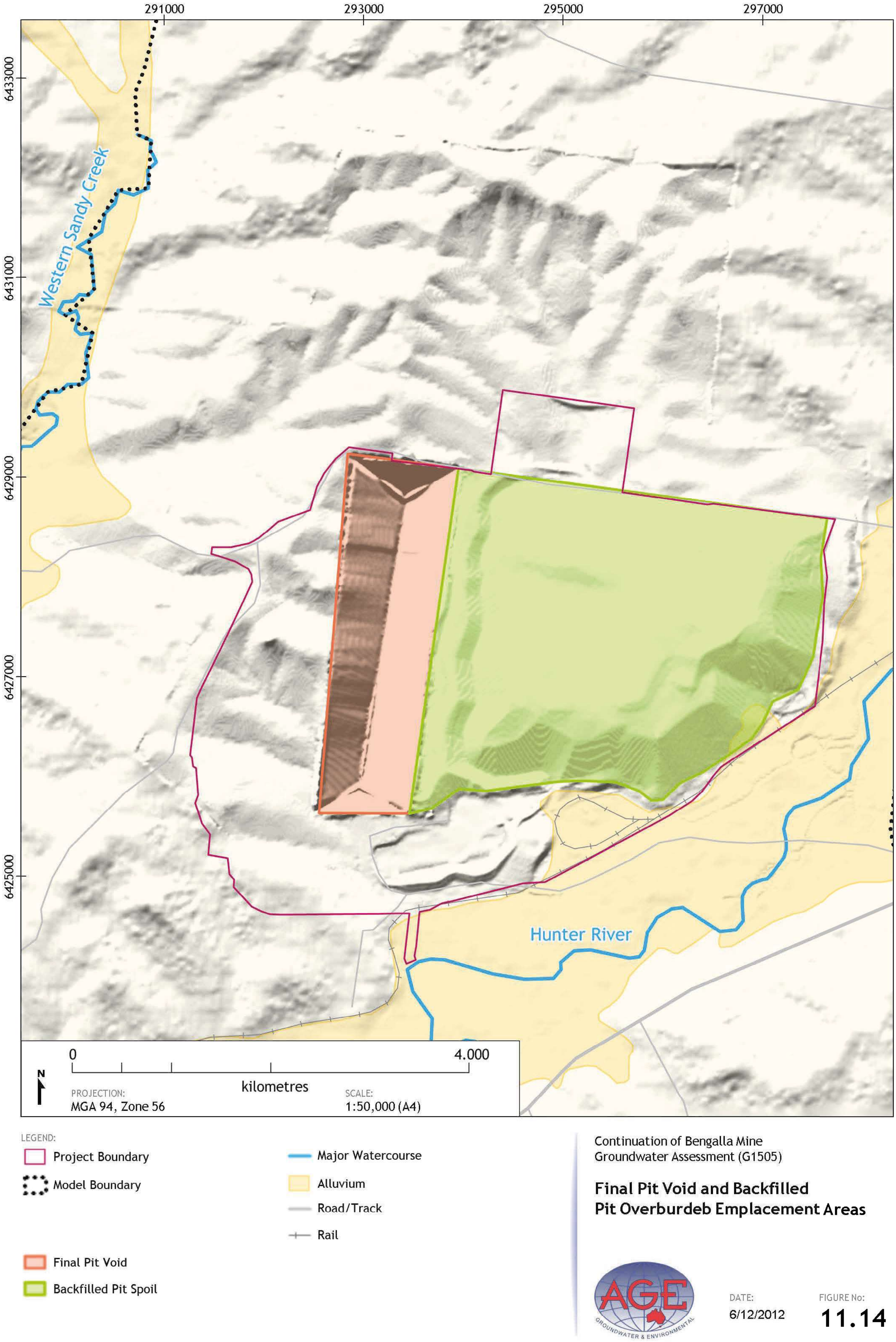
11.7 Groundwater Recovery – Spoil and Final Void

Post mining, dewatering of the pit will cease and a pit lake will form in the final void. Figure 11.14 shows the final void and spoil areas.

The recovery model represented previously mined areas as spoil and simulated the recovery of water levels in the void lake and groundwater system after mine closure. The spoil hydraulic conductivity, storage properties and recharge rates were increased several orders of magnitude over the in-situ Permian sediments. Post mining, seepage will occur directly from exposed Permian sediments, particularly from the western highwall and to a lesser degree through the pit floor into the void. As the regional potentiometric level recovers, water levels will also rise within the spoil, with increased recharge facilitating this process. Groundwater within the spoil will seep to the final void lake.

The volume of the final void shown in Figure 11.14 is 222,000 ML. The recovery model represented the void as a rectangular pit to the base of Layer 6, the base of mining operations. This rectangular pit was orientated around the deepest part of the final void. The use of a rectangular pit will tend to underestimate early void lake levels and overestimate later lake levels. The use of a rectangular pit is considered appropriate for the recovery modelling, as it is the final void lake level and the associated risk of spillage that is more important than the fill rate.

The final void lake was simulated in the model with a hydraulic conductivity in the horizontal and vertical directions of 1000 m/day to ensure no impediment to water movement. Specific yield was also set high at 99% to represent atmospheric conditions. Hydraulic conductivity for spoil in the horizontal and vertical directions was set at 1 m/day, specific yield at 5% and recharge set at 5% of average annual rainfall. Data for spoil parameters was from Mackie (2009).


291000
293000
295000
297000
6433000
6431000
6429000
6427000
6425000
Western Sandy Creek
Hunter River
0
4,000
kilometres
N
PROJECTION:
MGA 94, Zone 56
SCALE:
1:50,000 (A4)
LEGEND:
Project Boundary
Model Boundary
Major Watercourse
Alluvium
Road/Track
Rail
Final Pit Void
Backfilled Pit Spoil
Continuation of Bengalla Mine
Groundwater Assessment (G1505)
Final Pit Void and Backfilled
Pit Overburdeb Emplacement Areas
DATE:
6/12/2012
FIGURE No:
11.14

Annual evaporation exceeds rainfall at Bengalla, indicating a water deficit for any final void lake in the region. Although it is likely that rainfall run-off will occur from a wider site area adding extra water to the lake, hence reducing loss from the lake. Three sensitivity runs were carried out with varying levels of evaporation from the final void lake, these were:

- High evaporation – 474 mm/year loss which is pit lake only incident annual average rainfall minus annual evaporation. This value is consistent with the AGE (2007) modelling;
- Medium evaporation – 237 mm/year loss which assumes some run-off to the lake reducing the net flow out from the lake; and
- Low evaporation – 0 mm/year which assumes a balance between rainfall and run-off and evaporation in the pit lake.

Figure 11.15 shows the final void lake recovery rates and levels over time for the three scenarios.

Figure 11.15 shows rapid recovery over the first 50 years, followed by a slowing in recovery as the hydraulic gradients to the pit reduce. The maximum pit lake level ranges between RL 30 m and RL 37 m after 1000 years for the three evaporation scenarios.

The final void lake level predicted for the Project is lower than the level of RL 60 m estimated by the previous AGE model (2007). The fill rate is also significantly longer. The differences between the two simulations are attributed to the different final void sizes, locations, depths, model hydraulic parameterisation for both the re-calibrated model layers and spoil. It should be noted in Figure 11.15 that levels have not completely recovered during this simulation and may recovery slightly more with a longer run. Nevertheless, both the current recovery predictions and the previous AGE (2007) study both predict that the pit lake will behave as a sink. That is, the final pit lake level is maintained below the pit spill point, regional water table, the groundwater levels of the Hunter River alluvium and the Hunter River.

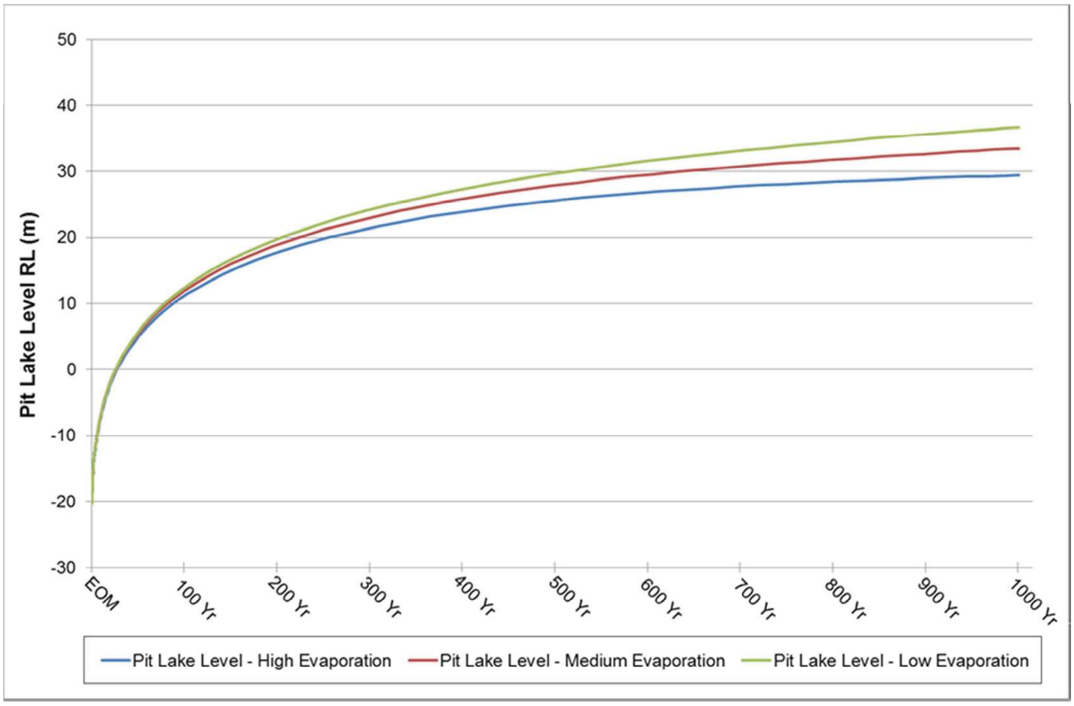


Figure 11.15: Rise of water table in final pit void

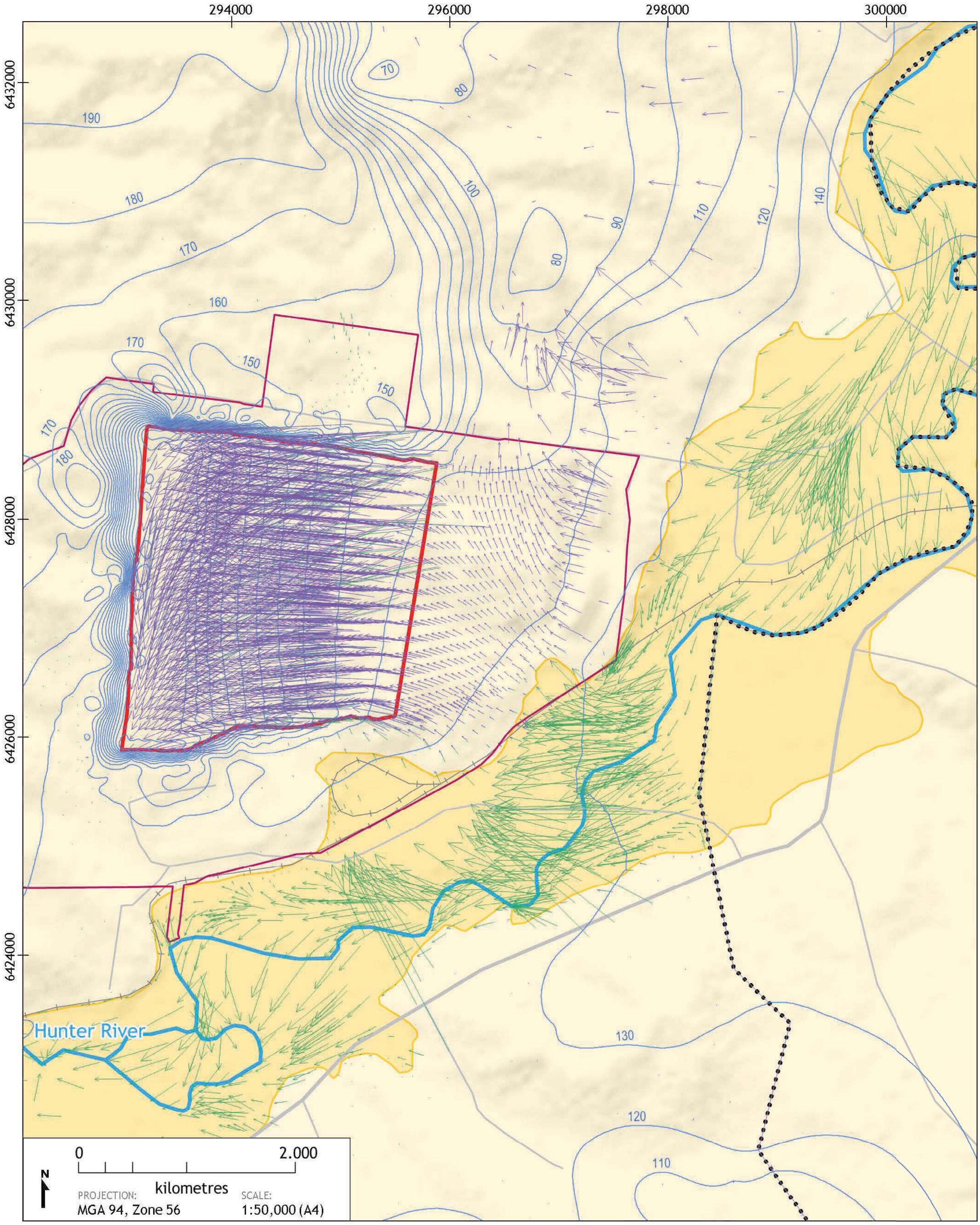
WRM (2013) also assessed the rate of water level recovery in the final void using the OPSIM software. The water balance methodology used by WRM estimated that the long term water level would vary between RL64 m and RL 71 m. The OPSIM model approach has several advantages over using a groundwater model including the ability to use daily rainfall records and better represent the geometry of the final void.

Differences in final void levels between the two methods can be attributed to slight differences in input data sets and the method in which the void is simulated. Particularly the OPSIM model utilises daily rainfall records, which includes storm events, while the FEFLOW model uses average rainfall throughout the recovery period. The evaporative volume of water removed using each technique will be different, with the average rainfall method used in FEFLOW having increased evaporative volumes. Hence, the FEFLOW model used in the groundwater impact assessment has reduced potential inflow to the final void and a lower final void level over the Surface Water Assessment. The correlation between the two methods is thought to be good considering the different methodology.

Both the groundwater model and the OPSIM model indicate that the water level in the final void will stabilise well below the crest of the pit and also the localised regional water table. Therefore spillage of water into the environment will not occur. The final void will act as a sink for groundwater, and this will prevent any poor quality water that develops within the pit from migrating into the surrounding groundwater system.

Post mining the evaporative losses from the pit lake will result in a constant flux of groundwater into the final void. This will result in a permanent zone of depressurisation around the pit final void in the Permian, which will reduce the rate of groundwater flow from the Permian to the Hunter River alluvium. The flux to the alluvium was calculated to be reduced by a maximum of 0.6 ML/day (220 ML/year) at 1000 years. This loss is equal to the rate estimated for the mining phase, and will be accounted for by Water Access Licenses outlined in Section 11.4, that will be surrendered at closure of the mine.

Figure 11.16 shows the modelled hydraulic heads and the groundwater velocity vectors for 100 years post mining, and demonstrates the zone of depressurisation generated by the final void.



LEGEND:

- Project Mining Area
- Project Boundary
- Model Boundary
- Potentiometric Level Contour (RLm)
- Velocity Vector Slice 1
- Velocity Vector Slice 7
- Major Watercourse
- Alluvium
- Road/Track
- Rail

Continuation of Bengalla Mine
Groundwater Assessment (G1505)

Velocity Vectors
Recovery 100 Years

AGE GROUNDWATER & ENVIRONMENTAL

DATE: 6/12/2012

FIGURE No: **11.16**

11.8 Water Quality

RGS Environmental (2013) completed a geochemical impact assessment of overburden and coal reject material for the Project. RGS Environmental (2013) concluded that "*all overburden material, apart from the Archerfield Sandstone (ASS) located above the Wynn seam, has negligible (<0.1%) sulfur content, excess Acid Neutralising Capacity (ANC), and is classified as Non-Acid Forming (NAF).*" As part of the geochemical study, RGS conducted kinetic leaching tests on two composite overburden samples, three composite coal reject samples, and three individual coal reject samples. The overburden samples generated a good quality leachate with a low salinity and an electrical conductivity (EC) between 100 µS/cm and 300 µS/cm. The coal reject material generated a more saline to brackish water quality with EC between about 1000 µS/cm and 5000 µS/cm, and with one sample up to 14,000 µS/cm.

RGS concluded that:

- *"Coal reject contains elevated sulfur content however the only material that is classified as Potentially Acid Forming (PAF) is from the Wynn seam;*
- *The concentration of trace metals and sulfate from most coal rejects will be low. However, Wynn coal reject materials have the potential to generate elevated concentrations of some metals (Al, Cd, Co, Cu, As, Ni, Se and Zn) if exposed to oxidising conditions; and*
- *Current management methods for Wynn coal reject and other coal reject materials at the open cut are sufficient to minimise the risk of any significant impact to the environment."*

It was recommended that the Project *"continues with current management methods for Potentially Acid Forming (PAF) ASS overburden and coal reject materials of deep burial under NAF overburden in the backfilled open cut as described in the Acid Rock Drainage Management Plan (BMC, 2009)".*

The Permian groundwater quality is typically brackish and in the range of 4,000 µS/cm to 8,000 µS/cm. This is similar to the salinity generated by the oxidised coal rejects.

As discussed in Section 11.7, a lake will form in the final void that will act as a sink in the groundwater system. The modelling indicates the water level in the final void will stabilise somewhere between RL 30 m and RL 54 m. This is well below the level of the Hunter River and will prevent flow of brackish to saline water in the final void lake from entering the Hunter River alluvium.

The Minimal Impact Considerations in the Aquifer Interference Policy require that:

a) Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.

b) No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. Redesign of a highly connected surface water source that is defined as a "reliable water supply" is not an appropriate mitigation measure to meet considerations 1.(a) and 1.(b).

c) No mining activity to be below the natural ground surface within 200 m laterally from the top of high bank or 100 m vertically beneath (or the three dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply".

d) Not more than 10% cumulatively of the three dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200 m laterally from the top of high bank and 100 m vertically beneath a highly connected surface water source that is defined as a “reliable water supply”.

BMC regularly monitors groundwater quality in a network of bores installed in the Hunter River alluvium. The bores have generally recorded a stable to falling salinity since the commencement of monitoring, with no widespread impact from the adjacent mining activity that is currently in close proximity to the alluvial aquifer. As the mining activity will be moving away from the Hunter River alluvium during mining, and post mining the void will remain a sink to groundwater, no impact on the beneficial use category of the Hunter River alluvium or the long-term average salinity of the Hunter River is considered likely.

No mining activity will occur within 200m laterally from the top of high bank of the Hunter River, and no alluvial material will be excavated. The Project is therefore considered to comply with Minimal Impact Considerations in the Aquifer Interference Policy.

12.0 SENSITIVITY AND UNCERTAINTY

12.1 Sensitivity Analysis

The purpose of sensitivity analysis is to quantify the uncertainty in the calibrated model caused by uncertainty in the estimated aquifer parameters, stresses, and boundary conditions (Anderson and Woessner 1992). During model calibration using PEST, null space Monte Carlo uncertainty analysis has not been undertaken as comprehensive uncertainty analysis such as this is a resource intensive modelling exercise. Therefore, an uncalibrated sensitivity analysis was carried out on the calibrated transient model to provide insight into the uncertainty in the model predictions. Model parameters for horizontal hydraulic conductivity (Kh), vertical hydraulic conductivity (Kv), specific yield (Sy), specific storage (Ss) and recharge (Rech) were varied by 25% and 50% around the transient calibrated values. A summary of the 16 sensitivity model runs is shown in Table 18.

Table 18: SENSITIVITY ANALYSIS MODEL RUN SETUP AND RESULTS

Run No.	Parameter	Percentage Change	Range Pit Inflows Project ML/day	Range in Flow to (+) and from Hunter Alluvium (-)Project ML/day
0	Calibrated Transient Model	0	0.8 to 1.02	0.08 to - 0.33
1	Kh	-50	0.5 to 0.81	0.4 to -0.23
2	Kh	-25	0.4 to 0.75	0.04 to -0.12
3	Kh	+25	0.08 to 0.93	0.07 to -0.47
4	Kh	+50	0.09 to 0.96	0.07 to -0.53
5	Kv	-50	0.09 to 0.96	0.06 to -0.30
6	Kv	-25	0.04 to 0.86	0.08 to -0.21
7	Kv	+25	0.08 to 0.92	0.05 to -0.44
8	Kv	+50	0.08 to 0.93	0.04 to -0.48
9	Sy & Ss	-50	0.06 to 0.43	0.08 to -0.38
10	Sy & Ss	-25	0.05 to 0.51	0.09 to -0.34
11	Sy & Ss	+25	0.07 to 0.95	0.03 to -0.40
12	Sy & Ss	+50	0.07 to 1.11	0.03 to -0.40
13	Rech	-50	0.07 to 1.11	0.03 to -0.40
14	Rech	-25	0.07 to 0.89	-0.02 to -0.48
15	Rech	+25	0.07 to 0.89	0.07 to -0.37
16	Rech	+50	0.07 to 0.88	0.09 to -0.35

This level of sensitivity analysis is deemed appropriate for this level of study. Results of the analysis have been reported against key modelling study objectives, these being flow to the pit, changes in flow from the Hunter River Alluvium and variations in regional drawdown greater than 1m.

12.1.1 Project Pit Seepage

A summary of the range of pit inflows over the Project Life is shown in Table 18 and the transient values for each 10-day time step are shown in Figure 12.1.

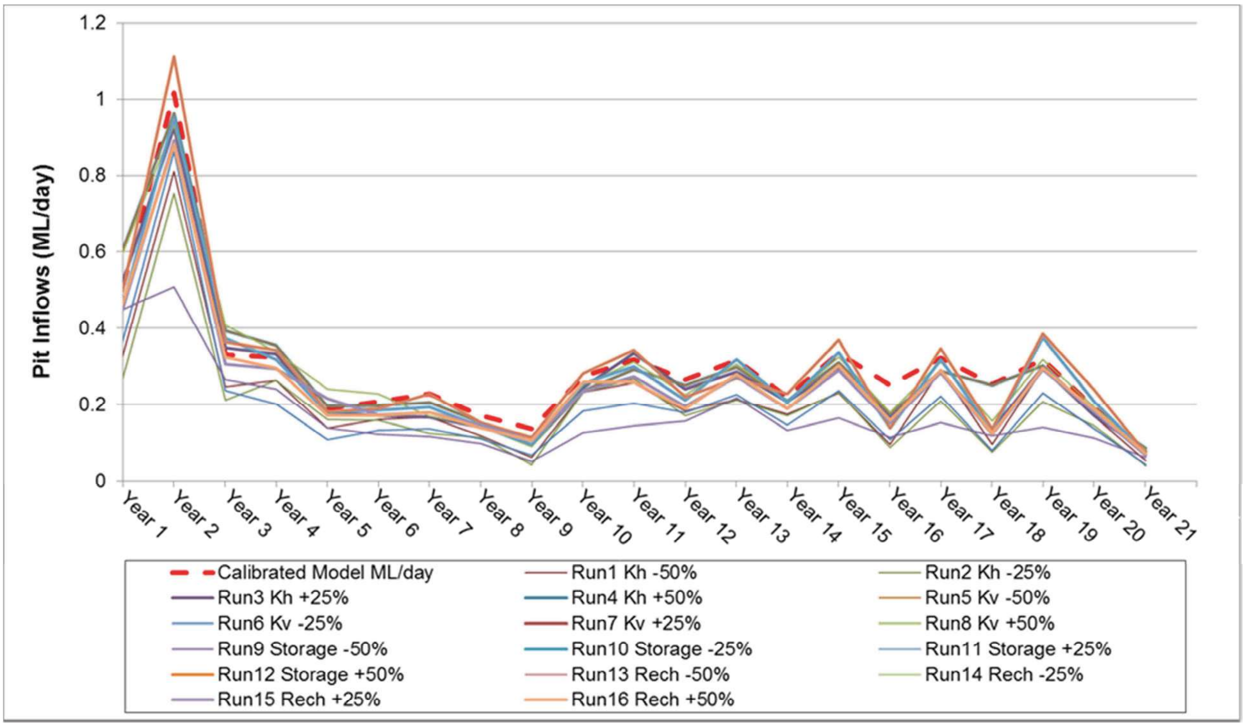


Figure 12.1: Seepage to pit for various sensitivity scenarios

The majority of the sensitivity runs predict lower inflows to the pit, compared to the predictive scenario based on the calibrated model (red dotted line). Only Run 16 (recharge +50%) produced significantly greater pit inflows. The results for the sensitivity runs produced a fairly tight range of results within realistic bounds for an open cut pit in the Hunter Valley.

12.1.2 Groundwater Flow to the Hunter River Alluvium

Groundwater flux to the Hunter River alluvium for the Project life is provided in Table 18 and shown in Figure 12.2. Positive values in the results indicate a groundwater flow direction from the Permian Coal Measures to the alluvium (the pre-mining condition), whereas negative results indicating a reversal of this flow.

As can be seen in Figure 12.2, all results mimic the trend of the calibrated model predictions, that being, a recovery in flow to the alluvium as mining progresses to the west, away from the Hunter River. Sensitivity results indicate a maximum additional flow from the Hunter River of 0.2 ML/day over the prediction based on the calibrated model (red dotted line). As with pit inflows, the results of various runs are constrained to a fairly tight band around the calibrated model.

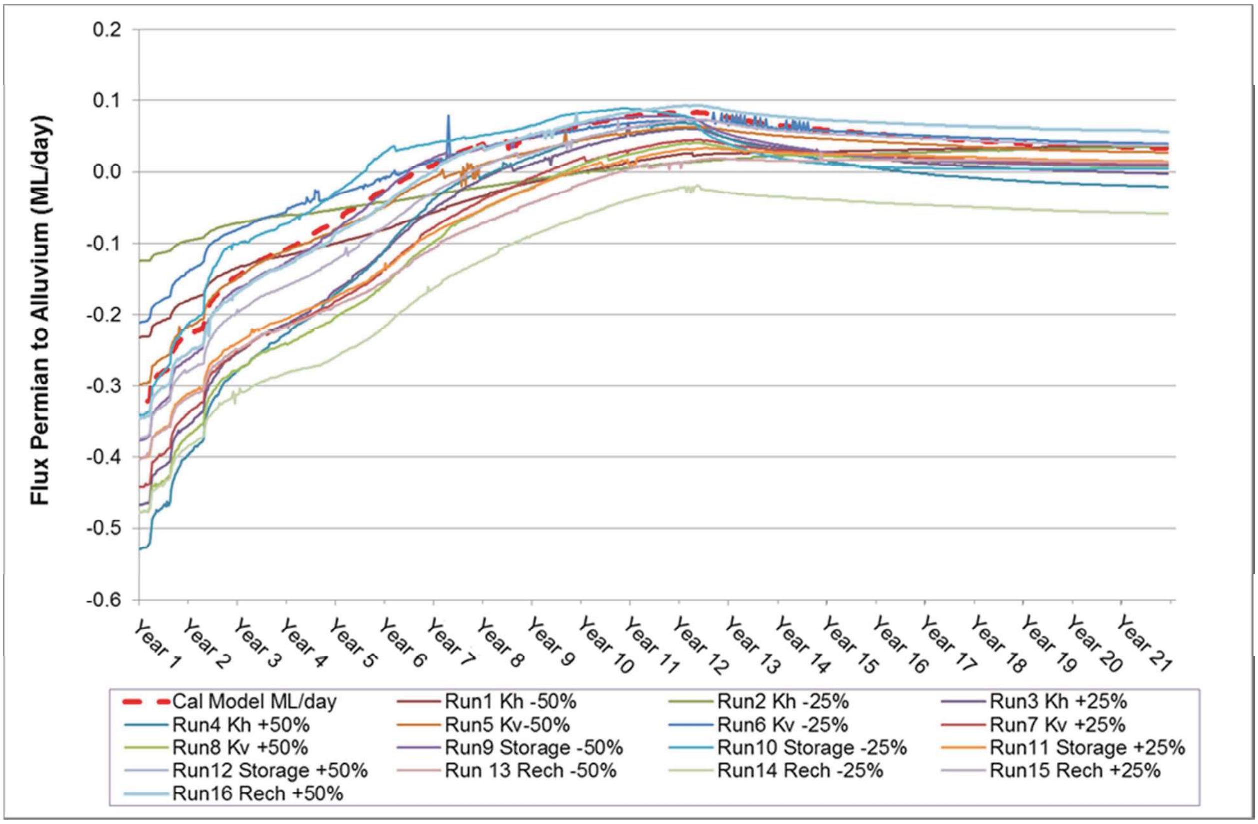
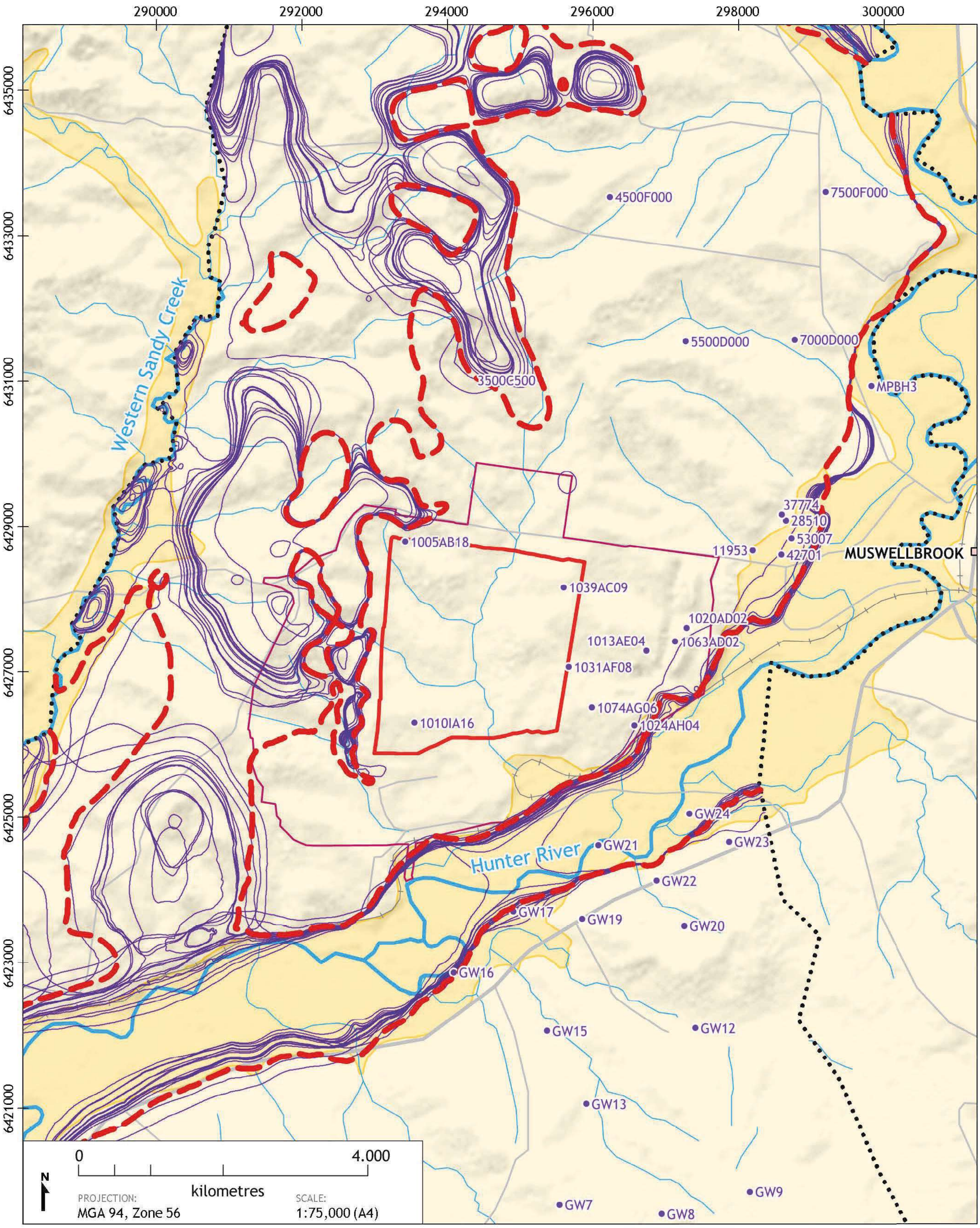


Figure 12.2: Flow to the Hunter River alluvium for various sensitivity scenarios

12.1.3 Drawdowns at the End of Mining

The 1m drawdown contours for the end of mining for each scenario (should further approvals not be granted) are displayed in Figure 12.3. To the south of the Project Boundary, the majority of the contours follow closely to the calibrated model predictive result (red dotted line). Run 6 (Kv -25%) does show some convergence beneath the Hunter River. To the west and north west of the Project Boundary, significant changes can be seen in the extent of drawdown over the calibrated predictive model. These changes are not thought to be attributed to the Project, rather the effects of changes to recharge and aquifer properties causing fluctuations in the unaffected impacted mine area water table.



LEGEND:

- Project Mining Area
- Project Boundary
- Model Boundary
- Groundwater Monitoring Bore for Countouring
- 1m Potentiometric Level Drawdown Calibrated Model
- 1m Potentiometric Level Drawdown Sensitivity Runs
- Major Watercourse
- Creek
- Alluvium
- Town
- Road/Track
- Rail

Continuation of Bengalla Mine
Groundwater Assessment (G1505)

Sensitivity of Potentiometric Level Drawdown at the End of Mining

DATE: 6/12/2012

FIGURE No: **12.3**

12.2 Model Confidence Level Classification

The level of confidence in a model's predictions is critical for decision makers using the information. The level of confidence depends on the:

- Available data;
- Calibration procedures;
- Consistency between calibration and predictive analysis; and
- Level of stresses.

Barnett et al (2012) developed a system to classify the confidence-level for groundwater models. Models are classified as either Class 1, Class 2 or Class 3 in order of increasing confidence. The Project model meets most of the Class 2 criteria, according to the system presented by Barnett et al, (2012). This conclusion was reached based upon:

Data

- Numerous studies have been undertaken to define the proximal/regional aquifer systems and hydraulic parameters; and
- Streamflow and baseflow estimates and several locations have been undertaken to ensure consistency.

Calibration

- Scaled Root Mean Squared error (SRMS) is below prescribed limits;
- Long-term trends replicated in majority of monitoring bores; and
- Recent transient calibration data used.

Key indicators

- Calibration statistics meet agreed targets;
- Model parameters are consistent with conceptualisation; and
- Appropriate computational methods and spatial discretisation used.

Barnett et al (2012) consider a Class 2 confidence level classification to be suitable for predicting groundwater impacts of proposed developments in medium value aquifers and evaluation/ management of medium risk projects.

12.3 Model Limitations

Development, calibration and the results of predictive simulations from any groundwater model are based on available data characterising the groundwater system under investigation. It is not possible to collect all the data characterising the whole groundwater system in detail and therefore various assumptions have to be made during development of the groundwater model. A number of assumptions were made during development of the groundwater model described in this report and these assumptions together with their impact on the simulation results are discussed below.

The planned mining operations associated with MTP and MAC have been implemented in the model to analyse the cumulative impact with the Project. Since detailed mining plans and schedules were not available for these projects, a conservative approach has been chosen, that overestimates rather than underestimates the hydraulic impact of these operations.

The conceptual model assumes that the hydraulic properties of the numerous Permian coal seams present within the Project Boundary can be represented by the eight-layer model. The hydraulic properties of a number of coal seams present within these layers were merged with the properties of the interburden. This simplification may lead to underestimation of the extent of development of the cone of depression. This is because the cone of depression is likely to be more extensive in coal seams that have relatively higher hydraulic conductivity than in the less permeable interburden. However, the drawdowns created in shallower groundwater system will be more constrained due to the much lower hydraulic conductivity of the interburden and overburden and hence this will not result in drawdown extending to any significant degree into the alluvial sediments. The model estimates that drawdown will less than 1m in these sediments.

The model predicts transient mine impacts using time constant conditions representing recharge and river flow. This approach is common place for a model of this complexity with the need to model more complex transient recharge and climatic data beyond the scope and objectives of the model.

13.0 SUMMARY AND CONCLUSIONS

13.1 Project Impacts

The stratigraphic sequence across the site comprises two distinct units, namely a low permeability Permian coal seam sequence with an overburden and interburden consisting of lithic sandstone, interbedded with siltstone, tuffaceous claystone and mudstone. The Permian sediments are unconformably overlain by thin Quaternary alluvial deposits along the alignment of the Hunter River located to the south of the Project. The closest watercourse to the Project is Dry Creek, which as the name suggests, is an ephemeral drainage line that does not intersect the groundwater table and therefore does not have a permanent baseflow.

The Permian Whittingham Coal Measures are not a significant aquifer. While some coal seams may locally show a moderate permeability, the dominant interburden sections are of very low hydraulic conductivity. This is evidenced by the very limited volumes of groundwater that have been experienced in the current open cut pits. The groundwater system has only one significant aquifer system, which are the sand and gravel zones within alluvium along the Hunter River. The Quaternary alluvium is connected to the Hunter River, which appears to act as both a recharge and discharge zone depending on the water levels in the river. The alluvium supports groundwater dependent ecosystems in the form of stygofauna species and river red gums along the Hunter River.

BMC has been gradually expanding a network of bores for monitoring groundwater levels and quality since 1992. BMC now monitors groundwater levels and/or water quality at a total of 45 bore sites installed in either the alluvium or Permian coal measures. The monitoring has recorded cyclic fluctuations in groundwater levels in the alluvial aquifer in response to rainfall, and no regional impact due to mining is evident, although some localised drawdown immediately adjacent to the Wantana extension is possible. Mining has depressurised the coal seams but has created only in a narrow zone of drawdown in the shallow groundwater system locally around the mining area.

BMC is currently mining the Wantana extension area, which is in relatively close proximity to the Hunter River alluvium. The distance from the edge of the alluvium to the pit crest is greater than 150 m. When the Wantana extension is completed, the Project will extend the pit further to the west and progressively further away from the edge of the Hunter River alluvium. At the end of the Project life, the pit will be 1.5 km from the alluvial aquifer.

A numerical groundwater flow model was used to simulate the impact of the Project on the groundwater regime. The model was based on a previous FEFLOW model constructed for the Wantana extension in 2007. The 2007 model was recalibrated to obtain the best match to steady state and transient water level measurements collected from the aquifers. The transient recalibration improved the calibration statistics and importantly provided confidence in the storage properties adopted in the model. After calibration, the modelling assessed the impact of the Project on groundwater levels and the transfer of groundwater between the Permian and the alluvial aquifers. The modelling indicated groundwater losses due to open cut mining will peak early in the Project life at about 1 ML/day, and then slowly reduce over the Project life as the Project moves further away from the alluvial aquifer, and up into more elevated land where the saturated thickness increases. Evaporation of groundwater flowing through the coal seams at the pit face will be significant, and is likely to mean that there will be no notable seepage into the pit that needs pumping in the latter years of the Project life, i.e. the pit will be dry.

The model predicts mining will continue to depressurise and lower groundwater levels in the Permian sequence, but this will not result in drawdown extending a significant degree into the alluvial aquifer system, with model drawdown calculated to be less than 1 m. A sensitivity analysis indicated the river and alluvial aquifer acted as a controlling boundary condition, with the 1m drawdown contour remaining along the edge of the alluvium when model parameters were varied. The limited drawdown predicted means there is only one private groundwater user where the groundwater drawdown is predicted to be 2 m. Stygofauna and groundwater dependent vegetation are also not expected to be impacted significantly by the limited drawdown.

The groundwater study was subject to a third party review which is contained in Appendix B.

13.2 Compliance with NSW Government Policy

Groundwater in NSW is regulated under the *Water Management Act 2000*, *Water Act 1912* and a series of policies on groundwater quantity, quality and dependent ecosystems.

New South Wales Office of Water requires that *"the EA must also detail the extent to which the proposed project is consistent with the water management principles of the aquifer interference activities prescribed in section 5(8) of the Water Management Act 2000".* Section 5(8) of the *Water Management Act 2000* outlines the principals and states *"in relation to aquifer interference activities:*

a) the carrying out of aquifer interference activities must avoid or minimise land degradation, including soil erosion, compaction, geomorphic instability, contamination, acidity, waterlogging, decline of native vegetation or, where appropriate, salinity and, where possible, land must be rehabilitated, and

b) the impacts of the carrying out of aquifer interference activities on other water users must be avoided or minimised."

The impact of the Project on soil erosion, compaction, geomorphic instability, contamination, acidity and decline of native vegetation were assessed separately as follows:

- GSS Environmental (2013) assessed soil erosion and geomorphology;
- Cumberland Ecology (2013) assessed the potential for decline of native vegetation; and
- RGS Environmental (2013) assessed the geochemistry of overburden and coal materials and the generation and management of acidity.

Groundwater salinity, water logging and impacts on other users are discussed in this report. The Project will depressurise and lower groundwater levels in the Permian sequence, but this will not result in drawdown extending a significant distance into the alluvial aquifer with drawdown being less than 1 m. This depressurisation and drawdown means there is no potential for water logging to occur. The limited drawdown predicted means there are no known groundwater users within the region where the groundwater drawdown is predicted to exceed 1 m. Stygofauna and groundwater dependent vegetation are also not expected to be significantly impacted by the limited drawdown.

The NOW DGRs require *"details of the extent to which the proposed development is consistent with The NSW State Groundwater Policy Framework Document (1997), The NSW Groundwater Quality Protection Policy (1998) and the Guidelines for Groundwater Protection in Australia (1995)."*

The NSW Groundwater Quality Protection Policy (1998), states that the objectives of the policy will be achieved by applying the management principles listed below.

- *All groundwater systems should be managed such that their most sensitive identified beneficial use (or environmental value) is maintained.*

- *Town water supplies should be afforded special protection against contamination.*
- *Groundwater pollution should be prevented so that future remediation is not required.*
- *For new developments, the scale and scope of work required to demonstrate adequate groundwater protection shall be commensurate with the risk the development poses to a groundwater system and the value of the groundwater resource.*
- *A groundwater pumper shall bear the responsibility for environmental damage or degradation caused by using groundwaters that are incompatible with soil, vegetation and receiving waters.*
- *Groundwater dependent ecosystems will be afforded protection.*
- *Groundwater quality protection should be integrated with the management of groundwater quality.*
- *The cumulative impacts of developments on groundwater quality should be recognised by all those who manage, use, or impact on the resource.*
- *Where possible and practical, environmentally degraded areas should be rehabilitated and their ecosystem support functions restored.*

It is considered that the Project conforms with the Principles of the Groundwater Quality Protection Policy because:

- The modelling has indicated that the users of the Hunter River alluvial aquifer, including water bores extracting water and groundwater dependent flora and fauna will not be significantly impacted by the Project. The beneficial use of the Hunter River alluvial aquifer will not be degraded by the Project;
- A Water Management Plan is in place, and will be updated to manage the risks to water quality associated with acid generating material;
- The Water Management Plan will outline monitoring and management of groundwater quality; and
- The cumulative impacts of the Project with surrounding approved and proposed mining was assessed.

The NSW State Groundwater Dependent Ecosystems Policy (2002) outlines five management principles that establish a framework by which groundwater is managed in ways that ensure, whenever possible, that ecological processes of dependent ecosystems are maintained or restored. The principles are:

- *GDEs can have important values. Threats should be identified and action taken to protect them;*
- *Groundwater extractions should be managed within the sustainable yield of aquifers;*
- *Priority should be given to GDEs, such that sufficient groundwater is available at all times to meet their needs;*
- *Where scientific knowledge is lacking, the precautionary principle should be applied to protect GDEs; and*
- *Planning, approval and management of developments should aim to minimise adverse effects on groundwater by maintaining natural patterns, not polluting or*

causing changes to groundwater quality and rehabilitating degraded groundwater ecosystems where necessary.

The Project is considered to be aligned with the principles of the NSW State Groundwater Dependent Ecosystems Policy (2002). Only the Hunter River alluvium and areas of Dry Creek hosts GDEs and the predicted impacts are not considered to be above thresholds that will result in a significant impact.

The Aquifer Interference Policy (2012) has the following key requirements:

- A water licence is required for the aquifer interference activity regardless of whether water is taken directly for consumptive use or incidentally. Activities may induce flow from adjacent groundwater sources or connected surface water. Flows induced from other water sources also constitute take of water. In all cases, separate access licences are required to account for the take from all individual water sources.
- Minimal impact considerations require:
  - the cumulative water table and pressure head decline not more than 2m at any water supply work;
  - any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity; and
  - no increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity.

The groundwater water sources affected by the Project are as follows:

(1) Porous Rock (basement rocks as referred to in the Hunter Unregulated and Alluvial Water Sources 2009 Water Sharing Plan) with expected maximum annual pit inflows of 365 ML per annum- regulated under the Water Act 1912; and

(2) Hunter Regulated River Alluvial Water Source with expected maximum annual pit inflows of 220 ML per annum- regulated under the *Water Management Act 2000*.

BMC currently has a 125 ML water licence (20BL169798) under the *Water Act 1912* to account for groundwater seepage into the pit from the Permian “basement rocks”. This licence is sufficient to account for the average current inflow from basement rocks seepage rate to the open cut pits which is 110 ML/year, but BMC will apply to change the conditions of water licence 20BL169798 to progressively increase maximum annual volume to 365 ML/year to offset the predicted seepage when required. There is no current embargo under the *Water Management Act 2000* Bengalla Joint Venturers will transfer the requisite share component (from other water access licences already owned by Bengalla Joint Venture) to its existing water access licence for the Hunter Regulated River Alluvial Water Source to account for take from that water source. These licenses will ensure the Project holds sufficient share component and water allocation to account for the take of water from the adjacent water sources at all times, and complies with the requirements of the Aquifer Interference Policy.

The Project meets the minimal impact considerations as:

- There are no private water bores where the cumulative water table and pressure head decline is more than 2 m; and
- Post mining a lake will form in the final void that will act as a sink in the groundwater system. The modelling indicates the water level in the final void will stabilise somewhere between RL 30 m and RL 54 m. This is well below the level of the Hunter River and will prevent flow of brackish to saline water in the final void lake from entering the Hunter River and associated alluvium. No impact on water quality of the alluvium or Hunter River is therefore expected.

14.0 GROUNDWATER MANAGEMENT AND MONITORING

14.1 Water Management Plan

BMC currently operates under a Water Management Plan that was developed in accordance with the requirements of the most recent approval (Schedule 3, Condition 28 of DA 211/93 (M4)). The Water Management Plan includes a:

- Site Water Balance;
- Drainage Path Diversion Plan;
- Erosion and Sediment Control Plan;
- Surface Water Management Plan;
- Groundwater Management Plan; and
- Surface and Groundwater Response Plan.

The Groundwater Management Plan includes:

a) detailed baseline data on groundwater levels, yield and quality in the region;
b) groundwater impact assessment criteria, including trigger levels for investigating potentially adverse groundwater impacts;
c) measures to minimise potential impacts on groundwater quality from the emplacement of overburden on alluvial lands;
d) a program to monitor and assess:
   i. groundwater inflows to the mining operations;
   ii. impacts on regional and local (including alluvial) groundwater systems;
   iii. impacts on the groundwater supply of potentially affected landowners; and
   iv. impacts on any groundwater dependent ecosystems and riparian vegetation.

The existing Groundwater Management Plan (as a component of the Water Management Plan) will be updated to reflect the impacts predicted for the Project. The revised Groundwater Management Plan will address the:

- Increased zone of depressurisation in the Permian;
- Drawdown in the Hunter River alluvium;
- Groundwater seepages into the open cut pit;
- Health of groundwater dependent ecosystems; and
- Groundwater quality in the voids and aquifers.

The NOW DGRs require *"Details of ongoing monitoring programs for groundwater quality and quantity (minimum monthly data)".* The Groundwater Management Plan will consider the monthly monitoring of groundwater quality; however, it is unlikely to be appropriate due to the naturally slow movement of groundwater within the geological formations in the region. Annual monitoring of groundwater quality is expected to be sufficient to detect any changes in water quality over time.

15.0 REFERENCES

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16.0 GLOSSARY

Alluvium – Sediment (gravel, sand, silt, clay) transported by water (i.e. deposits in a stream channel or floodplain).

Colluvium – Sediment (gravel, sand, silt, clay) transported by gravity (i.e. deposits at the base of a slope).

Cone of Depression – The cone-shaped depression in the groundwater surface caused by groundwater abstraction.

Hydraulic Conductivity – A measure of the rate at which water moves through a soil/rock mass. It is the volume of water that moves within a unit of time under a unit hydraulic gradient through a unit cross-sectional area that is perpendicular to the direction of flow.

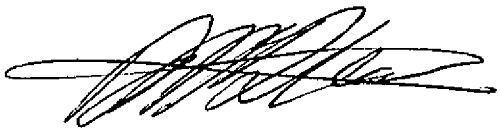
Pumping Test – A test made by pumping a well for a period of time and observing the response/change in hydraulic head in the aquifer.

Slug Test – A test made by the instantaneous addition, or removal, of a known volume of water to or from a well. The subsequent well recovery is measured.

Storativity – The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer, per unit change in head.

Transmissivity – A measure of the rate at which water moves through an aquifer of unit width under a unit hydraulic gradient.

AUSTRALASIAN GROUNDWATER AND ENVIRONMENTAL CONSULTANTS PTY LTD



JAMES TOMLIN
Principal Hydrogeologist / Director

DOUGLAS McALISTER
Principal Hydrogeologist

LIMITATIONS OF REPORT

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) has prepared this report for the use of Hansen Bailey Pty Ltd in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal of 30 June 2011.

The methodology adopted and sources of information used by AGE are outlined in this report. AGE has made no independent verification of this information beyond the agreed scope of works and AGE assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to AGE was false.

This study was undertaken between 20 January 2011 and 30 June 2013 and is based on the conditions encountered and the information available at the time of preparation of the report. AGE disclaims responsibility for any changes that may occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. It may not contain sufficient information for the purposes of other parties or other users. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

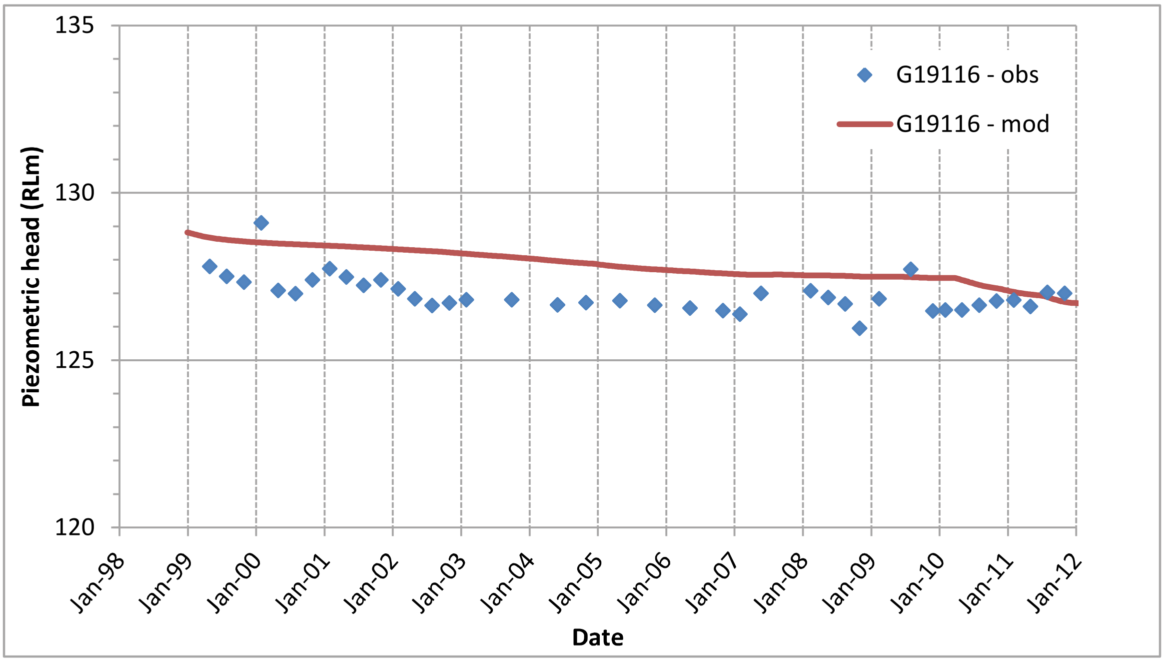
This report contains information obtained by inspection, sampling, testing and other means of investigation. This information is directly relevant only to the points in the ground where they were obtained at the time of the assessment. Where borehole logs are provided they indicate the inferred ground conditions only at the specific locations tested. The precision with which conditions are indicated depends largely on the frequency and method of sampling, and the uniformity of the site, as constrained by the project budget limitations. The behaviour of groundwater is complex. Our conclusions are based upon the analytical data presented in this report and our experience.

Where conditions encountered at the site are subsequently found to differ significantly from those anticipated in this report, AGE must be notified of any such findings and be provided with an opportunity to review the recommendations of this report.

Whilst to the best of our knowledge, information contained in this report is accurate at the date of issue, subsurface conditions, including groundwater levels can change in a limited time. Therefore this document and the information contained herein should only be regarded as valid at the time of the investigation unless otherwise explicitly stated in this report.

Appendix A

OBSERVED VS PREDICTED GROUNDWATER LEVELS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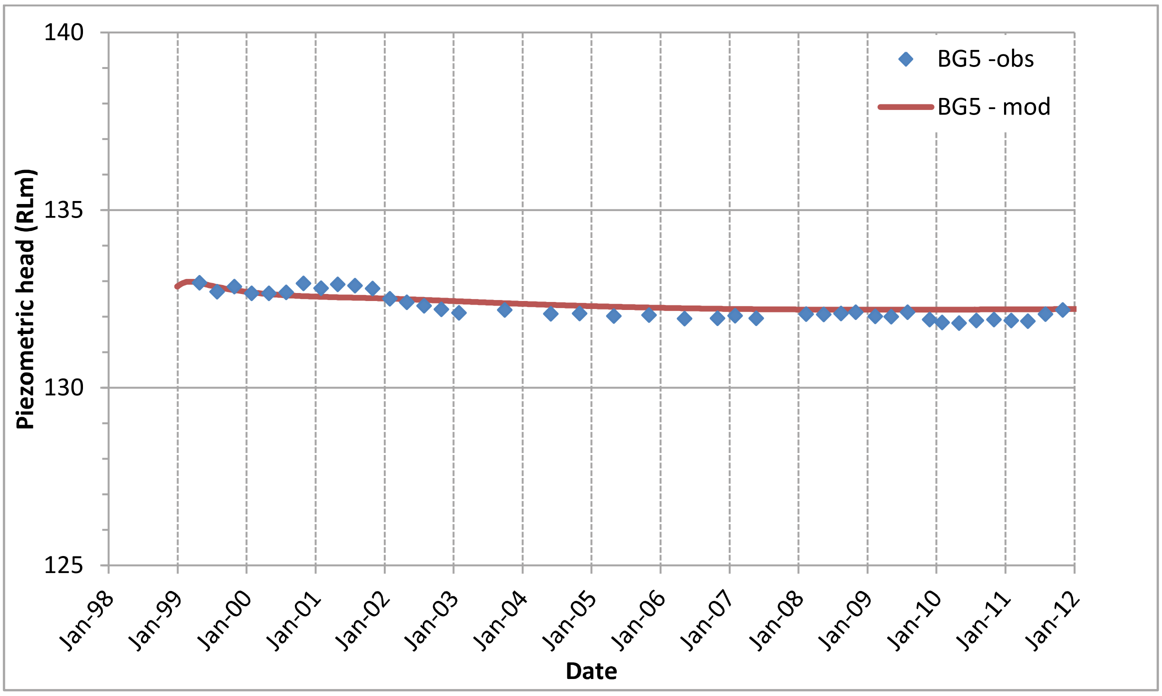
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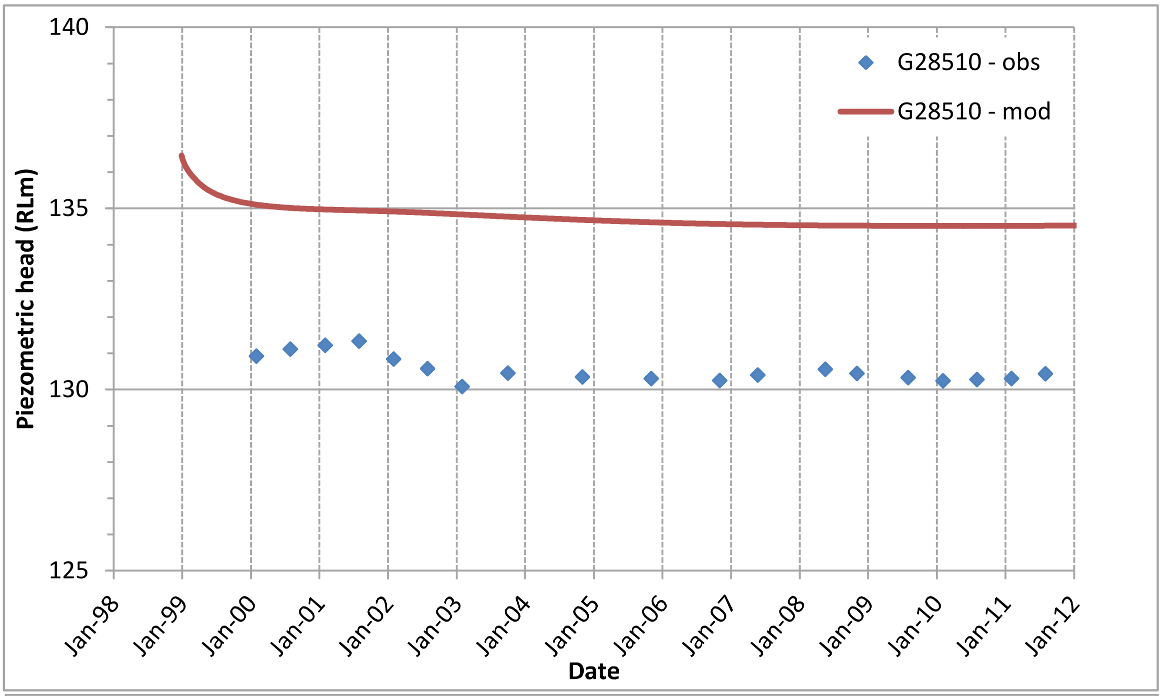
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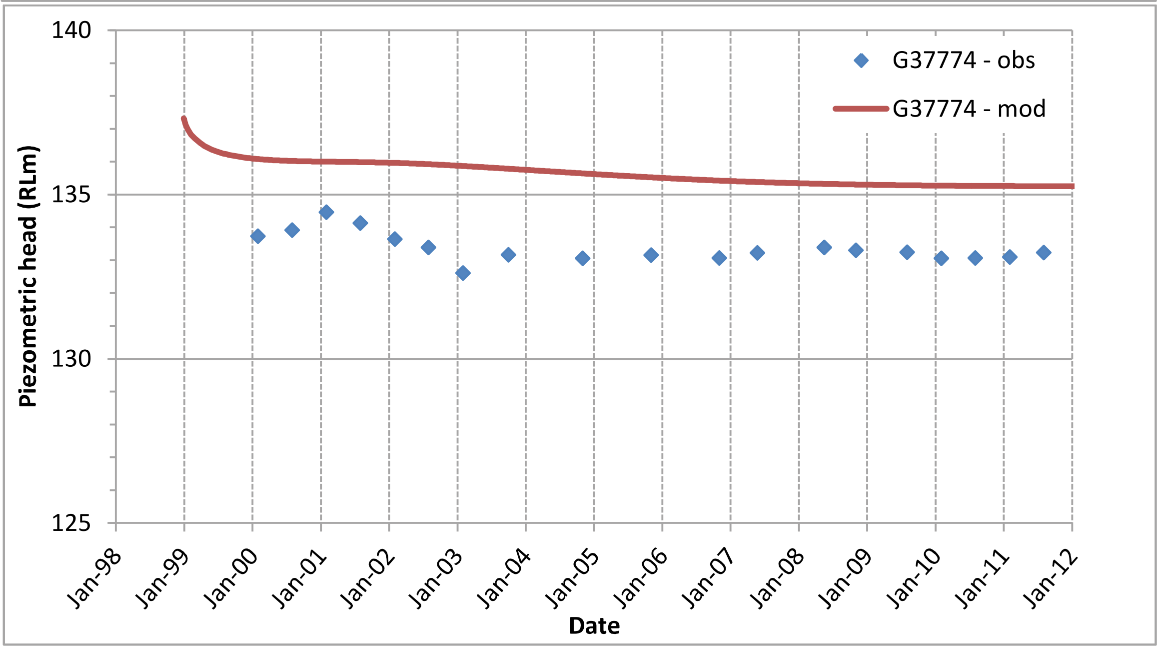
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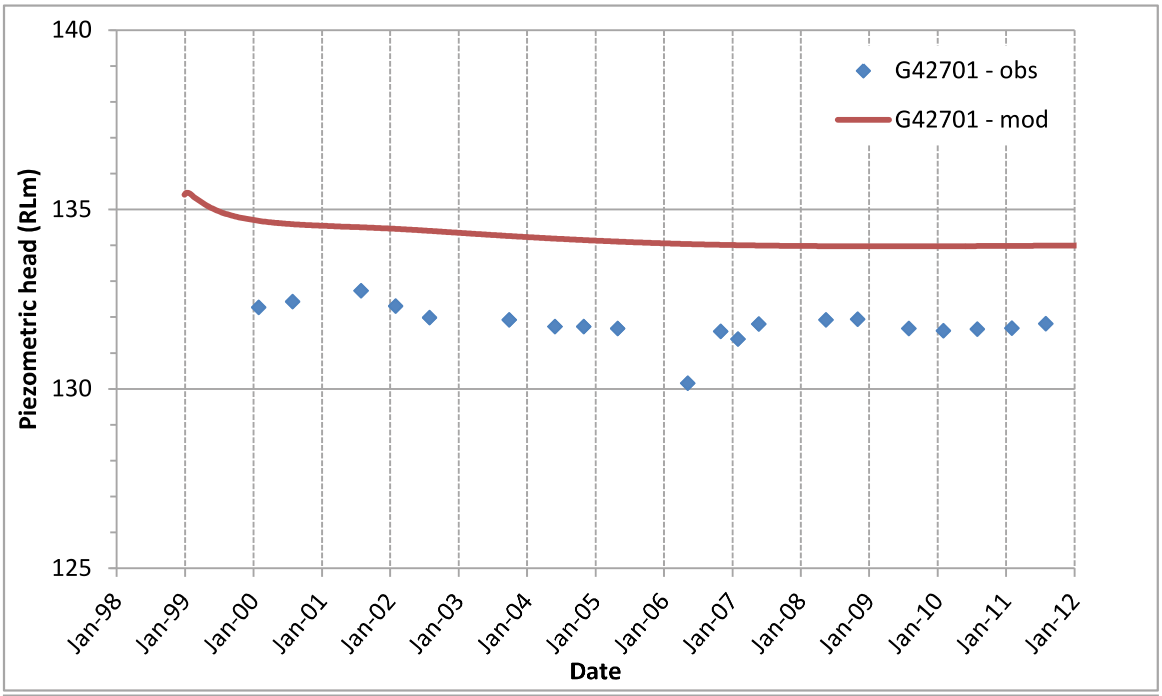
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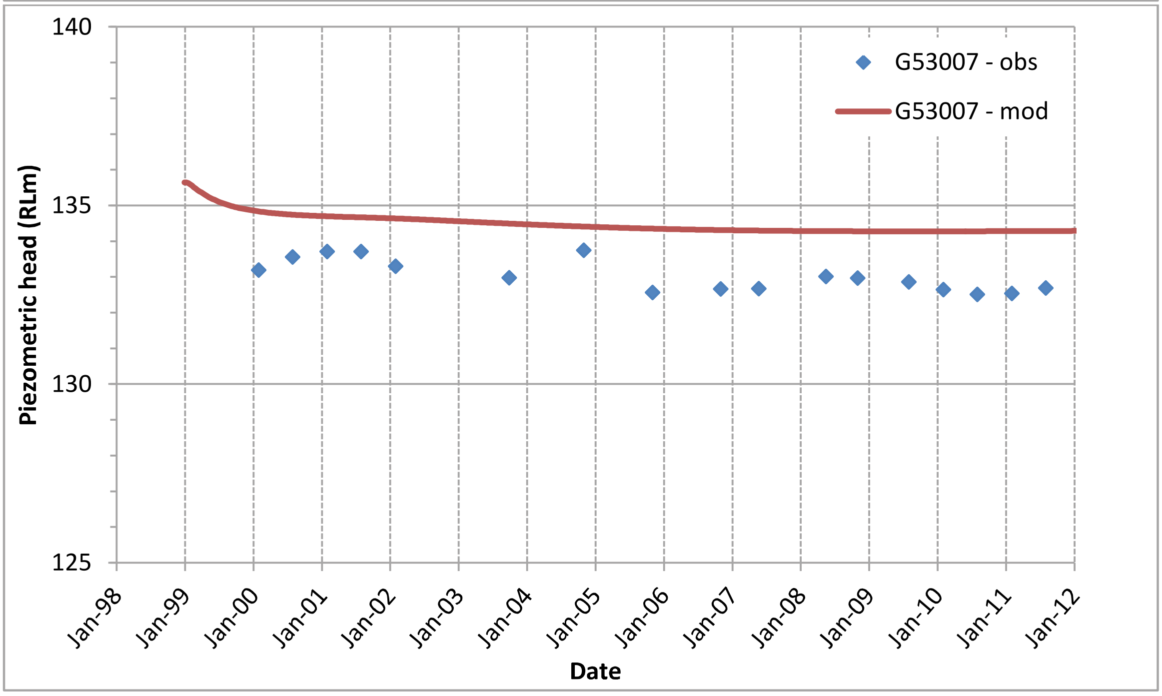
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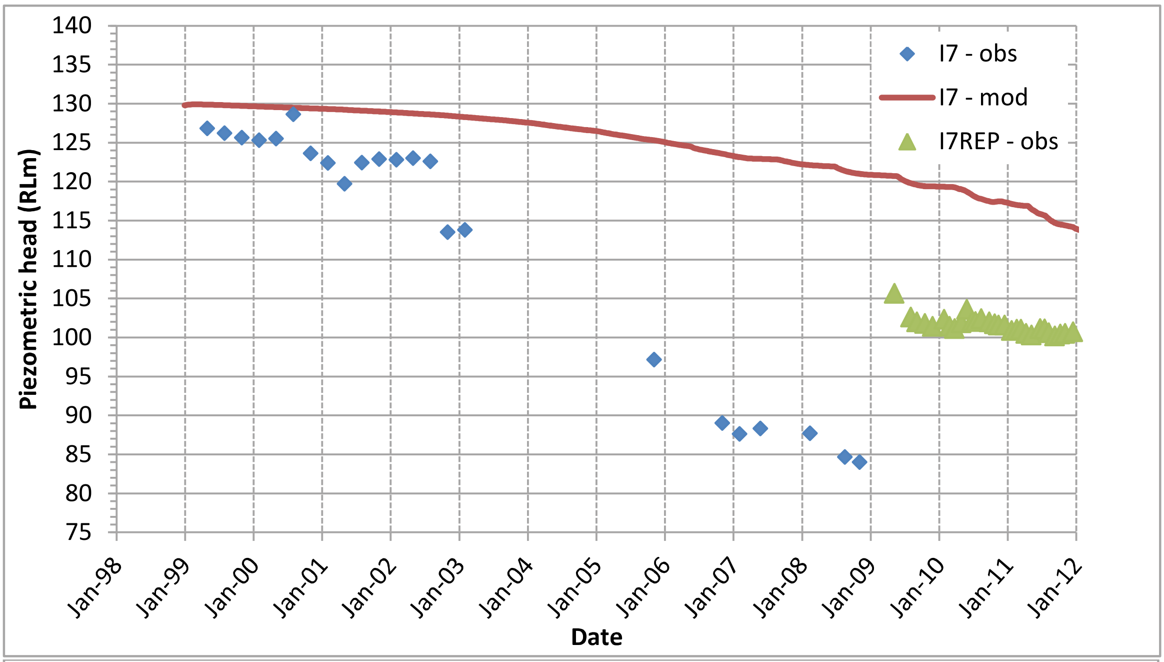
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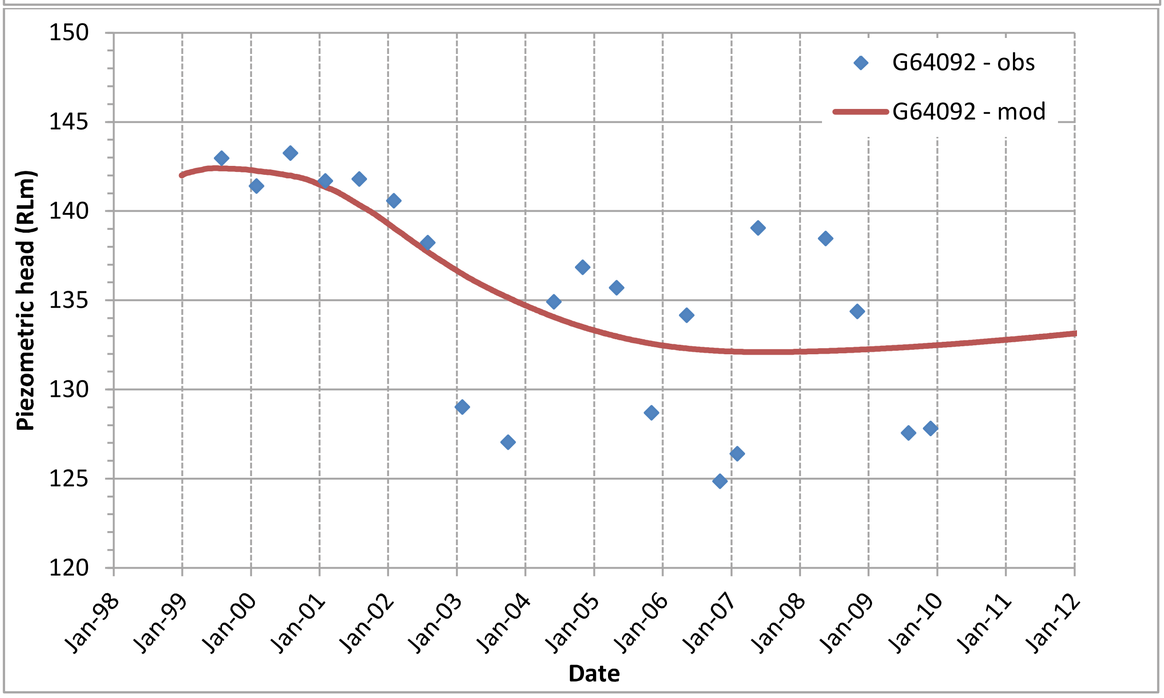
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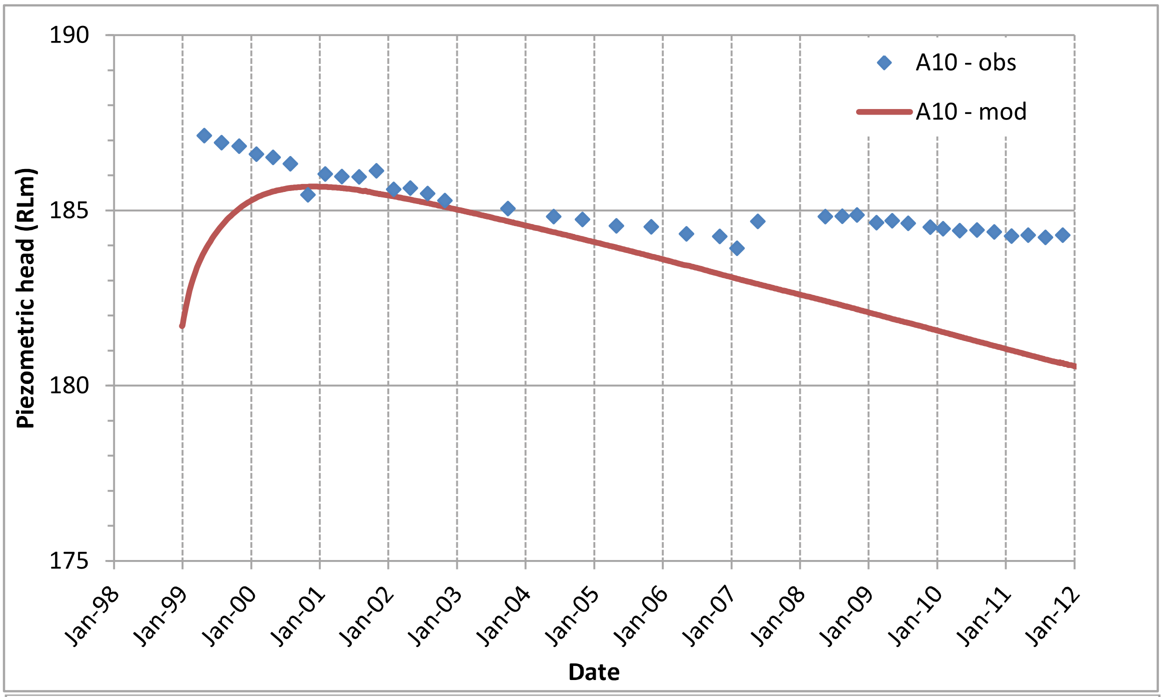
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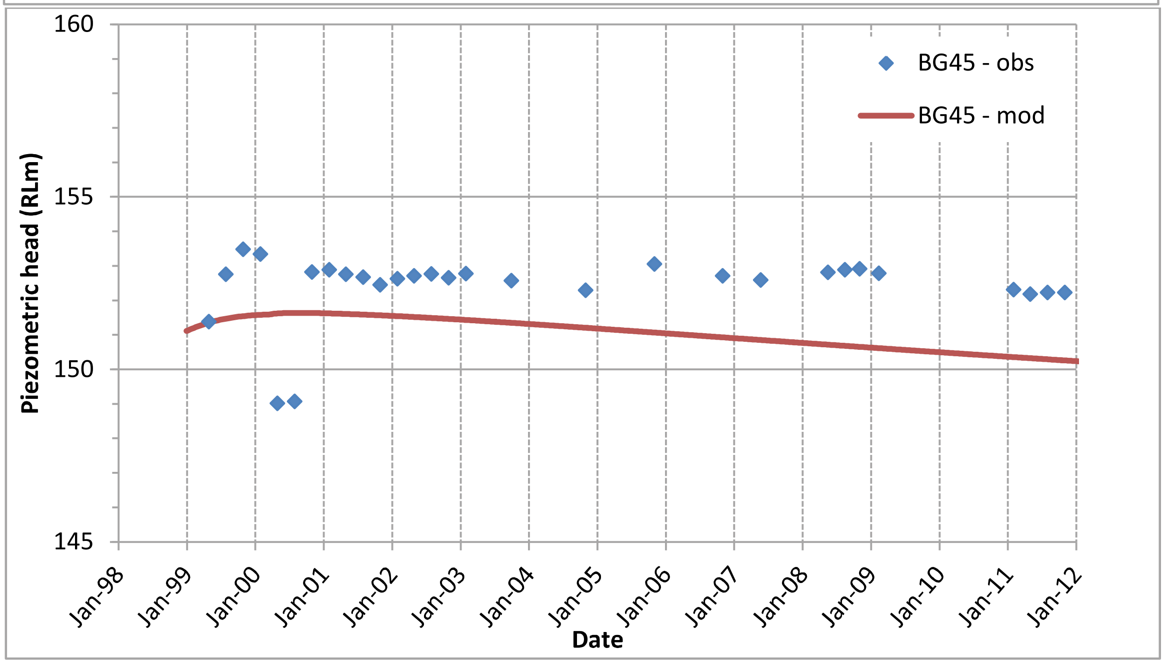
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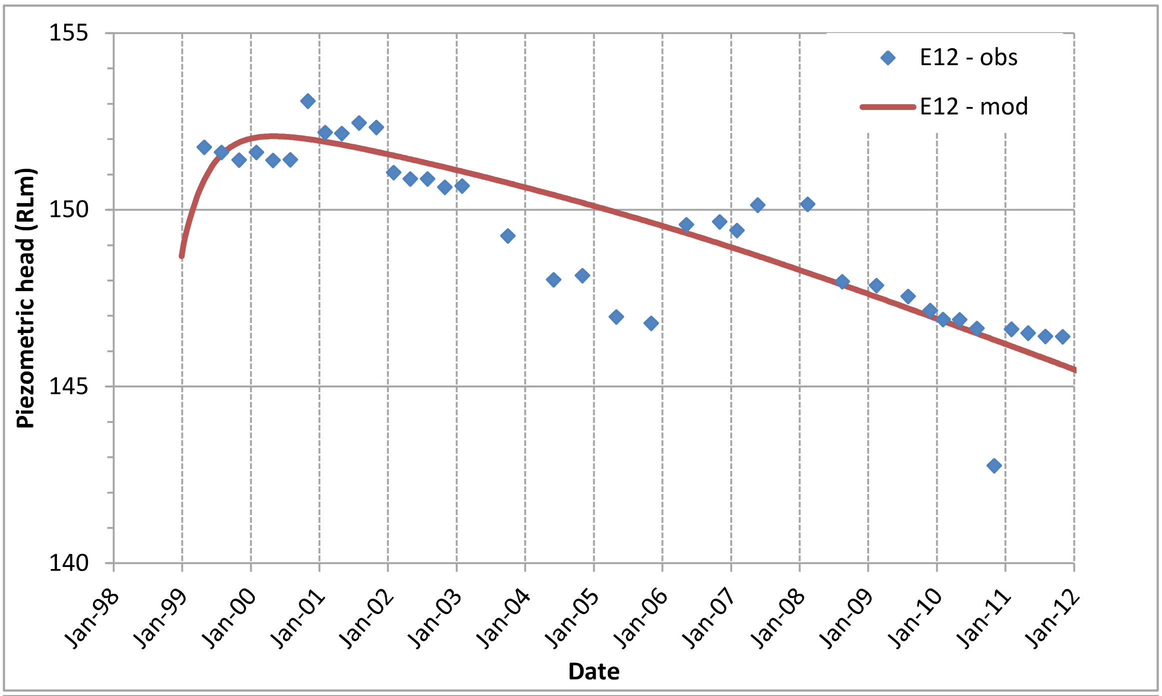
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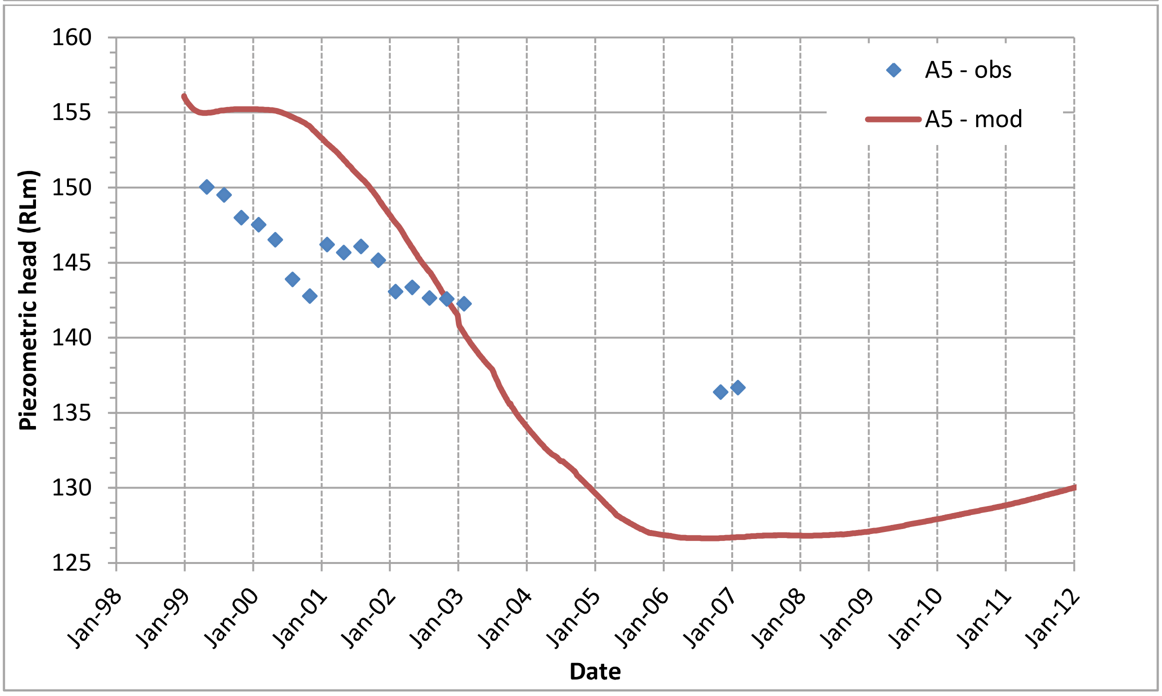
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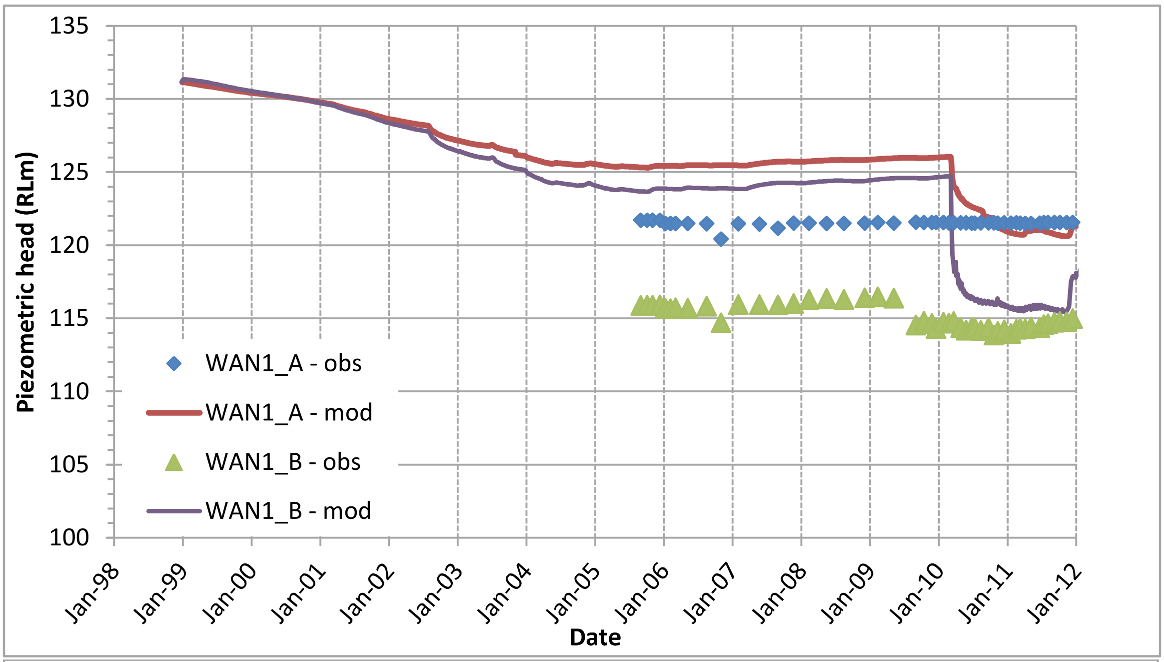
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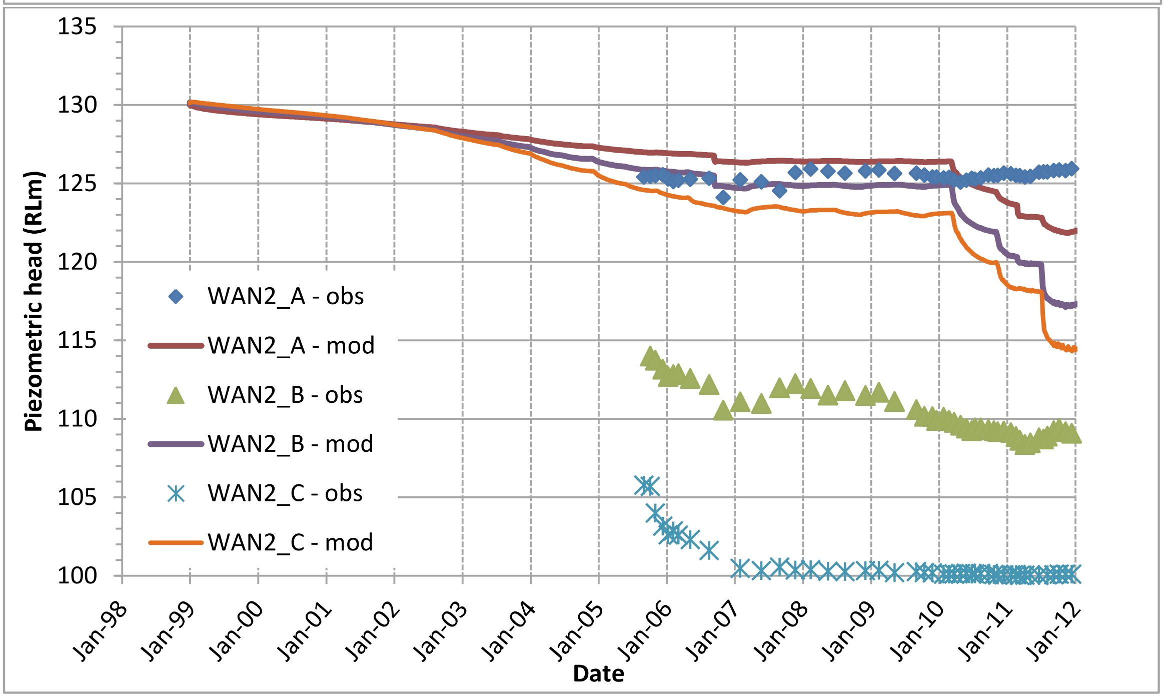
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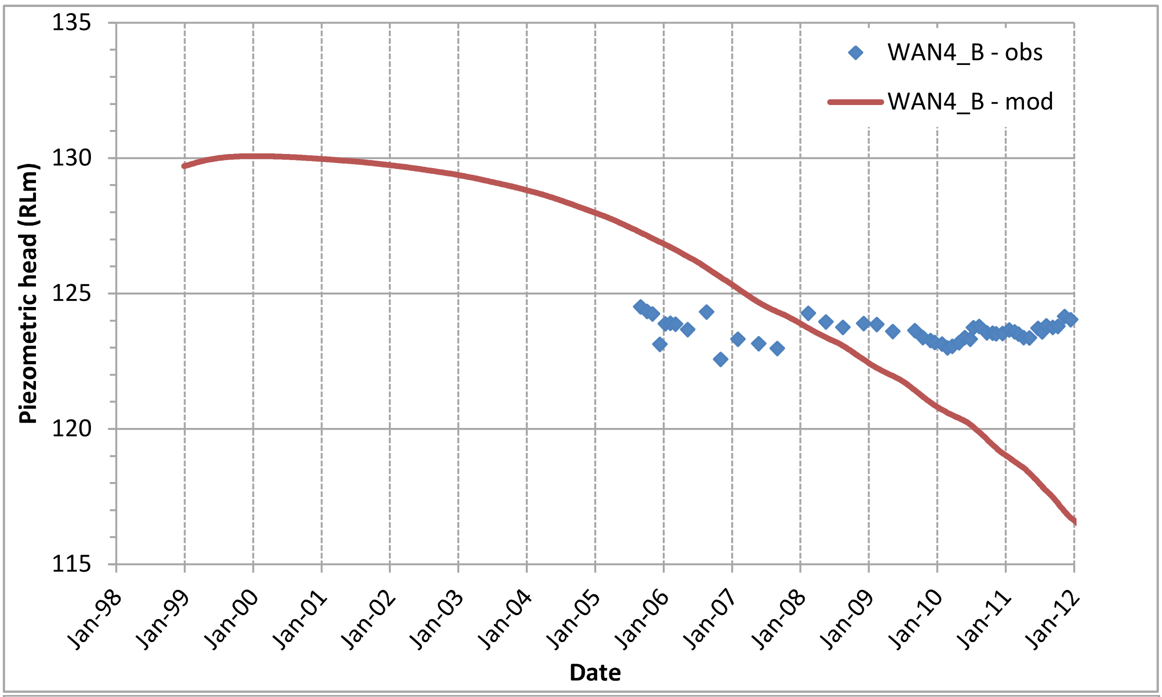
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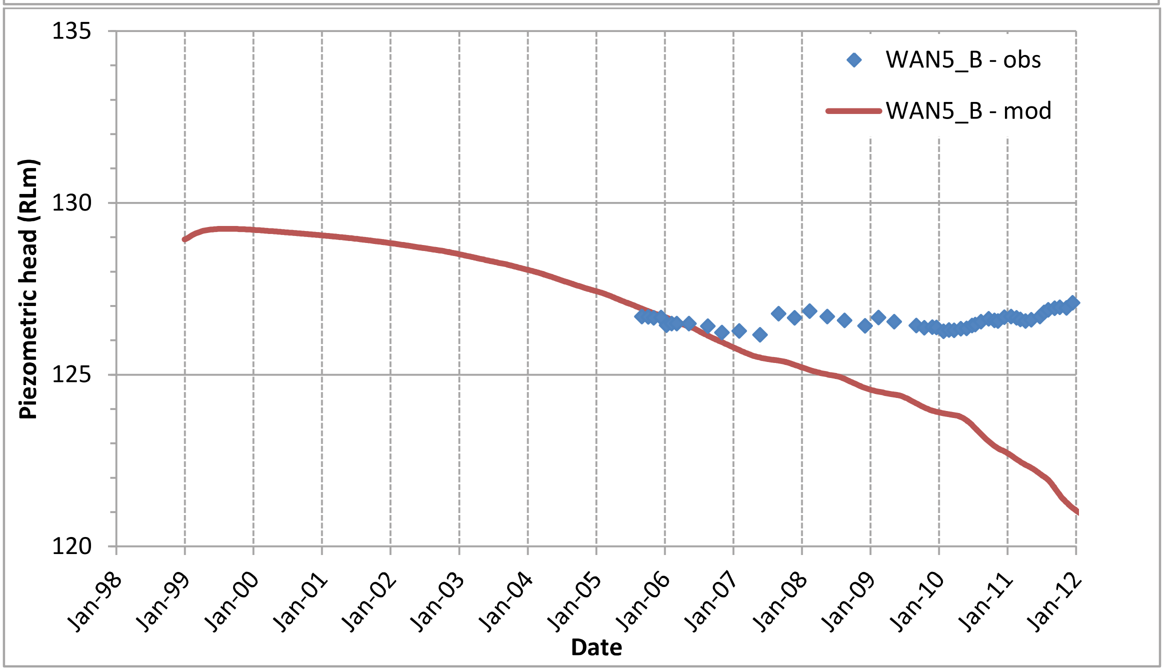
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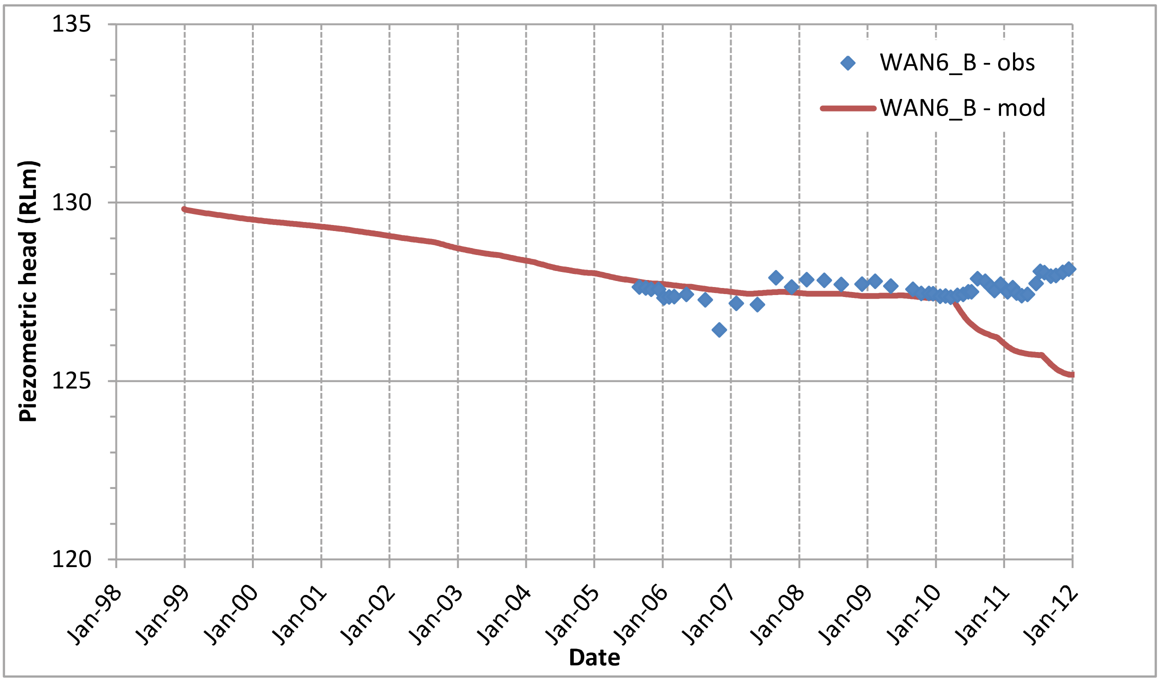
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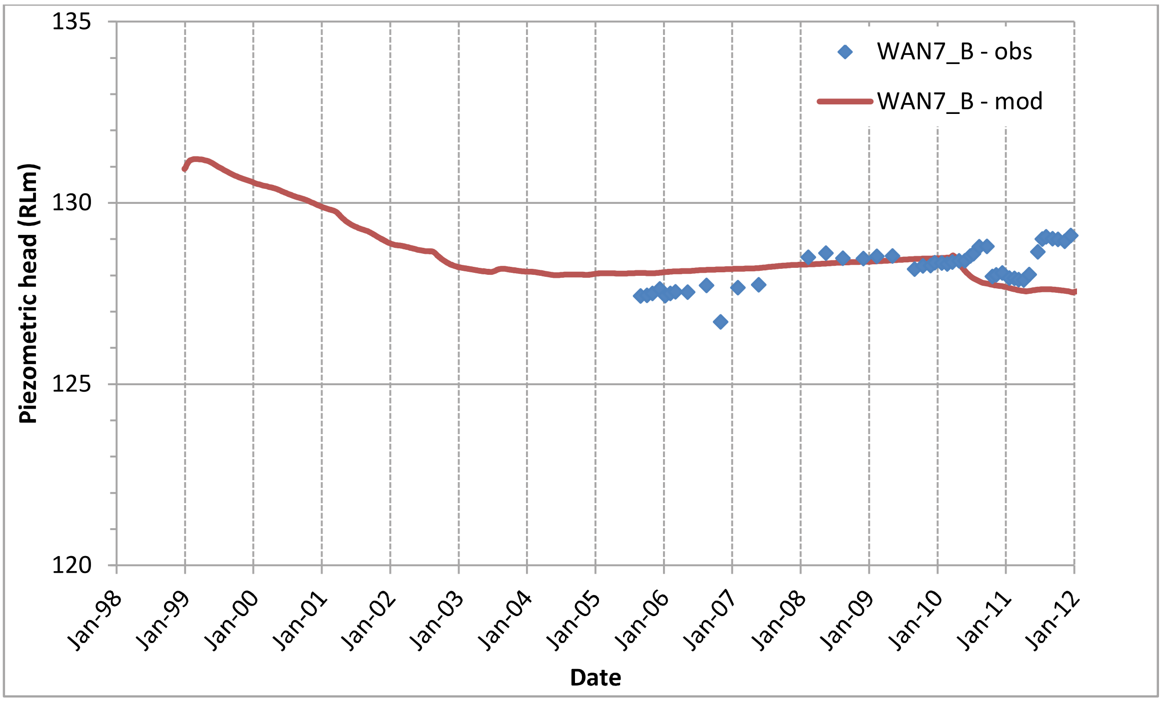
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Appendix B

THIRD PARTY REVIEW REPORT

KALF AND ASSOCIATES Pty Ltd
Hydrogeological, Numerical Modelling Specialists

BENGALLA MINING COMPANY
CONTINUATION OF BENGALLA COAL MINE

PEER REVIEW OF AGE GROUNDWATER ASSESSMENT

Dr F. Kalf
B.Sc M.App.Sc PhD
19 November 2012

Table of Contents

Background Summary

This report is the Kalf and Associates Pty Ltd (KA) peer review commissioned by Bengalla Mining Company for the Australasian Groundwater and Environmental Consultants Pty Ltd (AGE 2012) Bengalla continuation mining groundwater assessment report.

Bengalla Mining Company propose to continue open cut mining of Permian coal measure strata at their existing site over the next 21 years. The coal measure strata within the mining zone are contained within the western limb of the north-south trending regional Muswellbrook Anticline structure with its crest located some kilometres east of the mine boundary. The coal seam strata that have been mined to date and those that are proposed to be mined dip to the west at about 5 degrees across the mine site.

The Hunter River and associated low-lying alluvial flats are situated immediately east and southeast of the mine site boundary. Topography over the mine site area rises gently in a westerly direction to a ridge along the western mine boundary with corresponding drainage back across the site toward the east and southeast.

Naturally occurring groundwater in the Permian strata to be mined is for the most part of low quality, slightly alkaline with salinity measured over time in the coal seams in the range 1,200 to 4,000 μS/cm (majority > 2000 μS/cm). The overburden and interburden sedimentary strata groundwater salinity is brackish in the range 4,000 to 8,000 μS/cm. Permeability is low to very low and therefore groundwater contained in these strata have limited groundwater potential across and surrounding the proposed mining area.

The Hunter River alluvium with much higher permeability sediments contains much better quality groundwater. The groundwater quality is however known to be affected by upward and lateral inflow from the brackish Permian groundwater bearing rocks and hence the ground water quality deteriorates along the edges and at depth in the alluvium, where there is less flushing action and dilution by the associated river channel seepage during periods of high fresh surface water flow. The tendency of Permian groundwater to well up into the base and migrate into the edges of the River alluvium, occurs as a result of higher groundwater levels established by rainfall recharge along the topographic ridges and down slope region on either side of the River valley catchment.

Modelling of the groundwater system indicates moderate inflow to the open cut mine of between 0.6 to 1 ML/day that has in part already occurred and will be maintained in this range until second year of the mine extension (Year 2) and then rapidly decrease as the elongated north-south pit migrates further westward. Beyond Year 5 the inflow will be on average 0.2 ML/day. Most of this lower inflow will be evaporated from the mine pit. Thus the inflow would not affect the shallow groundwater within the alluvium sediments to any significant extent.

Although measured drawdown is significant in the coal seams the effect on the overlying alluvium is minimal. Predicted short term drawdown will be less than 1m as already verified by bore water level monitoring and would not increase over time. This monitoring shows that the deficit rainfall period ('drought') from about 2000 to 2007 and subsequent excess rainfall has had a much greater influence on watertable variation than mine drawdown. This indicates that rainfall recharge and to some extent river recharge has a strong buffering influence on the relatively small mine drawdown in the alluvium.

There are no private bores where cumulative drawdown will be significant.

Velocity vector analysis indicates that ultimately the strong down-valley groundwater flow within the Hunter River alluvium is not influenced to any significant extent by the proposed continuation of mining at the site. However, presence of the mine pit during operations has already and will continue to divert much of the slow seepage of brackish Permian strata groundwater immediately surrounding and beneath the pit from intruding into the Hunter River alluvial sediments.

The final mine void located some kilometres west of the River will act as a 'sink' and therefore there would be no outflow of water contained in the void into the surrounding strata. Higher permeability of backfill material within the mined out zone compared with the original mined out strata will result in greater flushing action of rainfall and runoff recharge. This in turn will dilute in-situ salinity of backfill material and groundwater and therefore will not create higher salinity groundwater flowing into the void than occurred prior to mining.

Increasing salinity of void water due to evaporation is a natural outcome over time but would be of no consequence, as the system would not allow any such water in the void to migrate into the surrounding strata or alluvium.

KA is in agreement with the key issues presented in the AGE report as summarised above.

Peer Review Assessment

Previous Studies and Reviews

There are a number of coalmines in the region that have been assessed for their influence on the groundwater system. Mackie, Martin and Associates (1993) and AGE (2007, 2010) conducted groundwater studies at Bengalla. The AGE (2007) work included development of a FEFLOW numerical model for the mine. That model is the precursor of the updated model used in the current study. References are provided in the AGE (2012) report.

KA (Dr F. Kalf) was included in an early meeting with AGE to discuss model conceptualisation and other issues. At that meeting it was accepted that the original 2007 FEFLOW finite element model be modified for the project rather than developing a new MODFLOW-SURFACT model.

During September 2012 KA subsequently conducted a preliminary review of the initial AGE hydrogeological and modelling report for the current Bengalla extension project. In that review a range of changes, comments and suggestions were made for report modification. More recently in October additional comments were provided for an updated report. The current review is based on the final report submitted by AGE including comments by NOW.

Hydrogeological and Modelling Description

The hydrogeological description of the region and modelling work described in the AGE report (2012) is detailed and has been completed and presented in a professional manner in my opinion.

The report covers a wide range of topics that include: government legislation and policies; regional setting that includes topography, drainage, geology and structures.

The Hydrogeological Regime section provides a detailed description of previous studies, groundwater monitoring program, the various geological strata, groundwater occurrence; ecosystems; hydraulic properties; recharge; groundwater quality and yields; strata potentiometric levels and recharge and discharge; mining operations and groundwater conceptualisation.

The Numerical Groundwater Model section covers description of modelling objectives; model extents and hydraulic properties; boundary conditions; calibration targets; steady state and transient calibration and predictive simulations including groundwater recovery. The parameter estimation computer code PEST is used for calibration. Model sensitivity for pit seepage and drawdowns are also presented including model limitations.

A final section presents a summary and conclusions, groundwater management and monitoring.

Modelling Guidelines

This review report uses as a basis the new Australian Groundwater Modelling Guidelines (National Water Commission 2012). It should be noted that while this set of guidelines contains relevant procedures and items for the AGE modelling work, it does not specifically cover open cut coal mining *per se*. Where no guidelines are available specific comments are made regarding the adequacy or otherwise of the approach used for modelling the groundwater system at Bengalla mine based on the author's experience, previous reviews or available reported field evidence. The completed Peer Review guideline checklists for this modelling work are presented in Appendix A.

Model Conceptualisation, Design and Simulation Methods

Use is made of the variably saturated computer modelling code FEFLOW and the parameter estimation code (PEST) to calibrate the model. However, according to the report the unsaturated option in FEFLOW has not been used in the current study because of instabilities that can occur using that feature in the computer code. In its stead the moving watertable boundary option is used for simulations.

The model conceptualisation is considered suitable and described in detail in the AGE report. The model is comprised of 8 model layers representing the various rock strata including some 'lumping' of coal seams together with interburden strata into separate single layers in the simulated geological profile.

The boundaries chosen for this model include the Western and Northern Sandy Creek and Saddlers Creek to the south but this is for convenience since these features are not naturally occurring no-flow boundaries. Use of these features as boundaries was criticised initially by this reviewer but it appears that the chosen boundaries are sufficiently distant not to have a major influence on the drawdown distribution. Clearly any influence would conservatively slightly overestimate drawdown in the model if it occurs at all.

Although faults and dykes were initially included the model, the AGE modeller found it necessary to exclude these features (apart from a major southern western Mount Ogilvie barrier fault) as they required considerable numbers of finite elements for simulation and in addition it was found that permeability contrasts so created caused instabilities in model computation. In addition it was found necessary to reduce the overall number of elements for transient simulation in order to allow practical application of the PEST code that requires a large number of iterations. Exclusion of faults/dykes is not considered to be a major impediment to impact assessment. Faults can locally increase or decrease permeability in the same way, as there may be local changes in permeability due to fractures or inclusions within the strata. Research on stochastic simulation of permeability variations has indicated that this does not have a significant overall effect on drawdown distributions but can increase or decrease inflow estimation that can usually be allowed for in the uncertainty estimates.

It is pleasing to see in this report that at least sensible measures were taken to restrict the number of elements in order for the parameter estimation computer code to be applied for the transient runs.

The Hunter River in the region are included and has a high hydraulic connectivity between shallow groundwater and surface water channels as it was set as a constant head boundary in the upper model layer. The other creeks across the site are ephemeral have no important alluvium or baseflow and have been set as drains. Net recharge was applied in the model and therefore evapotranspiration was not used.

Hydraulic parameters used are founded on a vast number of hydraulic parameters accumulated over the last 40 years in the Upper Hunter region. However, initial parameters adopted are those used for the old version of the current model updated using the parameter estimation code.

Calibration

Steady state calibration could not be strictly be applied in the model as the groundwater system has already been subjected to mining influence for a number of years. Therefore the 'steady state' simulation was used to establish a set of starting heads suitable for transient calibration. This is considered to be suitable and permissible. The scatter diagram of model versus measured groundwater levels indicates that the 'steady state' calibration is good enough for the water levels to be used as a starting condition for the transient calibration. The results of the transient calibration are reasonable with a mismatch in the deeper coal bearing layers. It is likely this may be due to some of the 'lumping' of coal and interburden strata used in the current model. Future model updates should examine whether this mismatch can be improved by layer subdivision. However, this change is unlikely to change the current predicted drawdowns in the alluvium.

The water balance derived from the' steady state' model can only be considered to be indicative given it is an approximation under previous existing transient conditions.

Prediction, Sensitivity and Model Constraints

The predictions of shallow groundwater drawdown presented in the report, taking into consideration adjacent mine influence, is considered to be reasonable. There is no mining drawdown influence predicted for any registered bores.

Uncalibrated sensitivity was conducted on strata and sediment hydraulic parameters and recharge. This was to determine the influence on the predicted inflows to the pit and flow to and from the Hunter River alluvium. The analysis indicates little variation in inflow with a maximum difference of 0.2 Ml/day towards the pit from the base case.

Drawdown contours within the alluvium also showed very little variation in extent based on the sensitivity runs.

The modelling results are considered plausible.

The model constraints and limitations are adequately outlined in the report.

Mitigation and Monitoring Plans

The project already operates under an existing water management plan that includes trigger level(s) or criteria according to the AGE report.

Conclusions and Considerations

This peer review has assessed the adequacy of the hydrogeological data and the development of a numerical model for predicting the local and regional effects of open cut mining at the Bengalla site. The hydrogeological description, conceptualisation, model design, simulations and reporting have been conducted in a professional manner and described in detail.

Groundwater in the Permian coal bearing strata currently mined contains brackish groundwater that is slightly alkaline and therefore has limited groundwater potential.

A 'steady state' calibration of water levels has provided a suitable set of starting heads for the transient analysis. Transient calibration overall is reasonable.

Predictions of drawdown within the adjacent alluvium and inflow rates to the pit over time are plausible. Drawdown in the alluvium is minimal and will not significantly influence the strong down-valley groundwater flow. No private bores in the area will be affected.

The final mine void during the mining period and after decommissioning will act as a 'sink' and no void storage water will therefore migrate into the surrounding strata. Hence it will also continue to capture the previous Permian groundwater seepage into alluvium before mining commenced within the boundaries of the mine site.

The model prepared for this project is considered "fit-for-purpose" for assessing the influence of continued mining on the groundwater system at the Bengalla mine site.

References

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) 2012
Continuation of Bengalla Mine Groundwater Impact Assessment. Report prepared for Hansen Bailey Pty Ltd. Project No G1505. October 2012.

Appendix A - Peer Review Checklists

BENGALLA MINING COMPANY
Bengalla Continuation Coal Mine Project

PEER REVIEW
Groundwater Assessment

Peer review checklists

NA - Not Applicable

Question	*Yes/No*
1. Are the model objectives and model confidence level classification clearly stated?	Y
2. Are the objectives satisfied?	Y
3. Is the conceptual model consistent with objectives and confidence level classification?	Y
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Y
5. Does the model design conform to best practice?	Y
6. Is the model calibration satisfactory?	Y
7. Are the calibrated parameter values and estimated fluxes plausible?	Y
8. Do the model predictions conform to best practice?	Y
9. Is the uncertainty associated with the predictions reported?	Y
10. Is the model fit for purpose?	Y

Review questions	*Yes/No*	*Comment*
1. Planning		
1.1 Are the project objectives stated?	Y	
1.2 Are the model objectives stated?	Y	
1.3 Is it clear how the model will contribute to meeting the project objectives?	Y	
1.4 Is a groundwater model the best option to address the project and model objectives?	Y	
1.5 Is the target model confidence-level classification stated and justified?	Y	Class 2 with aspects of Class 3 due to pre-mine site conditions.
1.6 Are the planned limitations and exclusions of the model stated?	Y	
2. Conceptualisation		
2.1 Has a literature review been completed, including examination of prior investigations?	Y	
2.2 Is the aquifer system adequately described?	Y	
2.2.1 hydrostratigraphy including aquifer type (porous, fractured rock ...)	Y	
2.2.2 lateral extent, boundaries and significant internal features such as faults and regional folds	Y	
2.2.3 aquifer geometry including layer elevations and thicknesses	Y	
2.2.4 confined or unconfined flow and the variation of these conditions in space and time?	Y	
2.3 Have data on groundwater stresses been collected and analysed?	Y	
2.3.1 recharge from rainfall, irrigation, floods, lakes	Y	
2.3.2 river or lake stage heights	Y	
2.3.3 groundwater usage (pumping, returns etc)	N	No relevant bores
2.3.4 evapotranspiration	Y	
2.3.5 other?		
2.4 Have groundwater level observations been collected and	Y	

analysed?		
2.4.1 selection of representative bore hydrographs	Y	
2.4.2 comparison of hydrographs	Y	
2.4.3 effect of stresses on hydrographs	Y	
2.4.4 watertable maps/piezometric surfaces?	Y	
2.4.5 If relevant, are density and barometric effects taken into account in the interpretation of groundwater head and flow data?	NA	
2.5 Have flow observations been collected and analysed?	Y	
2.5.1 baseflow in rivers	NA	
2.5.2 discharge in springs	NA	
2.5.3 location of diffuse discharge areas?	Y	
2.6 Is the measurement error or data uncertainty reported?	N	
2.6.1 measurement error for directly measured quantities (e.g. piezometric level, concentration, flows)	N	
2.6.2 spatial variability/heterogeneity of parameters	Y	
2.6.3 interpolation algorithm(s) and uncertainty of gridded data?	N	
2.7 Have consistent data units and geometric datum been used?	Y	
2.8 Is there a clear description of the conceptual model?	Y	
2.8.1 Is there a graphical representation of the conceptual model?	Y	
2.8.2 Is the conceptual model based on all available, relevant data?	Y	
2.9 Is the conceptual model consistent with the model objectives and target model confidence level classification?	Y	
2.9.1 Are the relevant processes identified?	Y	
2.9.2 Is justification provided for omission or simplification of processes?	Y	
2.10 Have alternative conceptual models been investigated?	N	
3. Design and construction		
3.1 Is the design consistent with the conceptual model?	Y	
3.2 Is the choice of numerical method and software appropriate	Y	FEFLOW and PEST
3.2.1 Are the numerical and discretisation methods appropriate?	Y	
3.2.2 Is the software reputable?	Y	
3.2.3 Is the software included in the archive or are references to the software provided?	N	
3.3 Are the spatial domain and discretisation appropriate?	Y	
3.3.1 1D/2D/3D	Y	3D
3.3.2 lateral extent	Y	
3.3.3 layer geometry?	Y	
3.3.4 Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model and target confidence level classification?	Y	
3.3.5 Is the vertical discretisation appropriate? Are aquitards divided in multiple layers to model time lags of propagation of responses in the vertical direction?	Y	Some lumping of coal seams and interburden
3.4 Are the temporal domain and discretisation appropriate?	Y	

3.4.1 steady state or transient	Y	Steady state as starting heads
3.4.2 stress periods	Y	
3.4.3 time steps?	Y	
3.5 Are the boundary conditions plausible and sufficiently unrestrictive?	Y	
3.5.1 Is the implementation of boundary conditions consistent with the conceptual model?	Y	
3.5.2 Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained?	Y	Drawdown distribution
3.5.3 Is the calculation of diffuse recharge consistent with model objectives and confidence level?	Y	
3.5.4 Are lateral boundaries time-invariant?	Y	
3.6 Are the initial conditions appropriate?	Y	Steady State derived.
3.6.1 Are the initial heads based on interpolation or on groundwater modelling?	-	GW modelling steady state
3.6.2 Is the effect of initial conditions on key model outcomes assessed?	N	initial heads are suitable
3.6.3 How is the initial concentration of solutes obtained (when relevant)?	NA	
3.7 Is the numerical solution of the model adequate?	Y	
3.7.1 Solution method/solver	.	Preconditioned Conjugate Gradient (PCG)
3.7.2 Convergence criteria	.	0.001m
3.7.3 Numerical precision	.	Single
4. Calibration and sensitivity		
4.1 Are all available types of observations used for calibration?	Y	
4.1.1 Groundwater head data	Y	
4.1.2 Flux observations	Y	
4.1.3 Other: environmental tracers, gradients, age, temperature, concentrations etc.	N/A	
4.2 Does the calibration methodology conform to best practice?	Y	
4.2.1 Parameterisation	Y	
4.2.2 Objective function	Y	PEST
4.2.3 Identifiability of parameters	Y	
4.2.4 Which methodology is used for model calibration?	.	PEST
4.3 Is sensitivity of key model outcomes assessed against?	Y	
4.3.1 parameters	Y	
4.3.2 boundary conditions	.Y	
4.3.3 initial conditions	.N	
4.3.4 stresses	.Y	recharge
4.4 Have the calibration results been adequately reported?	Y	
4.4.1 Are there graphs showing modelled and observed hydrographs at an appropriate scale?	Y	
4.4.2 Is it clear whether observed or assumed vertical head gradients have been replicated by the model?	Y	limited by "lumping"
4.4.3 Are calibration statistics reported and illustrated in a reasonable manner?	Y	
4.5 Are multiple methods of plotting calibration results used	Y	Lower strata may need

to highlight goodness of fit robustly? Is the model sufficiently calibrated?		subdivision but unlikely to influence shallow alluvial drawdown
4.5.1 spatially	.Y	
4.5.2 temporally	Y	
4.6 Are the calibrated parameters plausible?	Y	
4.7 Are the water volumes and fluxes in the water balance realistic?	Y	
4.8 has the model been verified?	N	Recommended after 2 years mine operation
5. Prediction		
5.1 Are the model predictions designed in a manner that meets the model objectives?	Y	
5.2 Is predictive uncertainty acknowledged and addressed?	Y	By way of comments only
5.3 Are the assumed climatic stresses appropriate?	Y	
5.4 Is a null scenario defined?	.	
5.5 Are the scenarios defined in accordance with the model objectives and confidence level classification?	Y	
5.5.1 Are the pumping stresses similar in magnitude to those of the calibrated model? If not, is there reference to the associated reduction in model confidence?	NA	
5.5.2 Are well losses accounted for when estimating maximum pumping rates per well?	NA	
5.5.3 Is the temporal scale of the predictions commensurate with the calibrated model? If not, is there reference to the associated reduction in model confidence?	N	
5.5.4 Are the assumed stresses and timescale appropriate for the stated objectives?	Y	
5.6 Do the prediction results meet the stated objectives?	Y	
5.7 Are the components of the predicted mass balance realistic?	Y	
5.7.1 Are the pumping rates assigned in the input files equal to the modelled pumping rates?	NA	
5.7.2 Does predicted seepage to or from a river exceed measured or expected river flow?	NA	
5.7.3 Are there any anomalous boundary fluxes due to superposition of head dependent sinks (e.g. evapotranspiration) on head-dependent boundary cells (Type 1 or 3 boundary conditions)?	N	
5.7.4 Is diffuse recharge from rainfall smaller than rainfall?	Y	
5.7.5 Are model storage changes dominated by anomalous head increases in isolated cells that receive recharge?	N	
5.8 Has particle tracking been considered as an alternative to solute transport modelling?	Y	But velocity vector analysis a better alternative
6. Uncertainty		
6.1 Is some qualitative or quantitative measure of uncertainty associated with the prediction reported together with the prediction?	Y	Limitations only
6.2 Is the model with minimum prediction-error variance chosen for each prediction?	N	
6.3 Are the sources of uncertainty discussed?	Y	Where relevant (limitations)
6.3.1 measurement of uncertainty of observations and parameters	N	

BENGALLA MINING COMPANY
Bengalla Continuation Coal Mine Project

PEER REVIEW
Groundwater Assessment

6.3.2 structural or model uncertainty	N	
6.4 Is the approach to estimation of uncertainty described and appropriate?	Y	Sufficient because of previous development
6.5 Are there useful depictions of uncertainty?	Y	
7. Solute transport	NA	Not Applicable
7.1 Has all available data on the solute distributions, sources and transport processes been collected and analysed?		
7.2 Has the appropriate extent of the model domain been delineated and are the adopted solute concentration boundaries defensible?		
7.3 Is the choice of numerical method and software appropriate?		
7.4 Is the grid design and resolution adequate, and has the effect of the discretisation on the model outcomes been systematically evaluated?		
7.5 Is there sufficient basis for the description and parameterisation of the solute transport processes?		
7.6 Are the solver and its parameters appropriate for the problem under consideration?		
7.7 Has the relative importance of advection, dispersion and diffusion been assessed?		
7.8 Has an assessment been made of the need to consider variable density conditions?		
7.9 Is the initial solute concentration distribution sufficiently well-known for transient problems and consistent with the initial conditions for head/pressure?		
7.10 Is the initial solute concentration distribution stable and in equilibrium with the solute boundary conditions and stresses?		
7.11 Is the calibration based on meaningful metrics?		
7.12 Has the effect of spatial and temporal discretisation and solution method taken into account in the sensitivity analysis?		
7.13 Has the effect of flow parameters on solute concentration predictions been evaluated, or have solute concentrations been used to constrain flow parameters?		
7.14 Does the uncertainty analysis consider the effect of solute transport parameter uncertainty, grid design and solver selection/settings?		
7.15 Does the report address the role of geologic heterogeneity on solute concentration distributions?		
8. Surface water–groundwater interaction		
8.1 Is the conceptualisation of surface water–groundwater interaction in accordance with the model objectives?	Y	
8.2 Is the implementation of surface water–groundwater interaction appropriate?	Y	
8.3 Is the groundwater model coupled with a surface water model?	N	
8.3.1 Is the adopted approach appropriate?	Y	
8.3.2 Have appropriate time steps and stress periods been adopted?	Y	
8.3.3 Are the interface fluxes consistent between the groundwater and surface water models?	Y	