Appendix I

Groundwater study

Appendix I — Groundwater study

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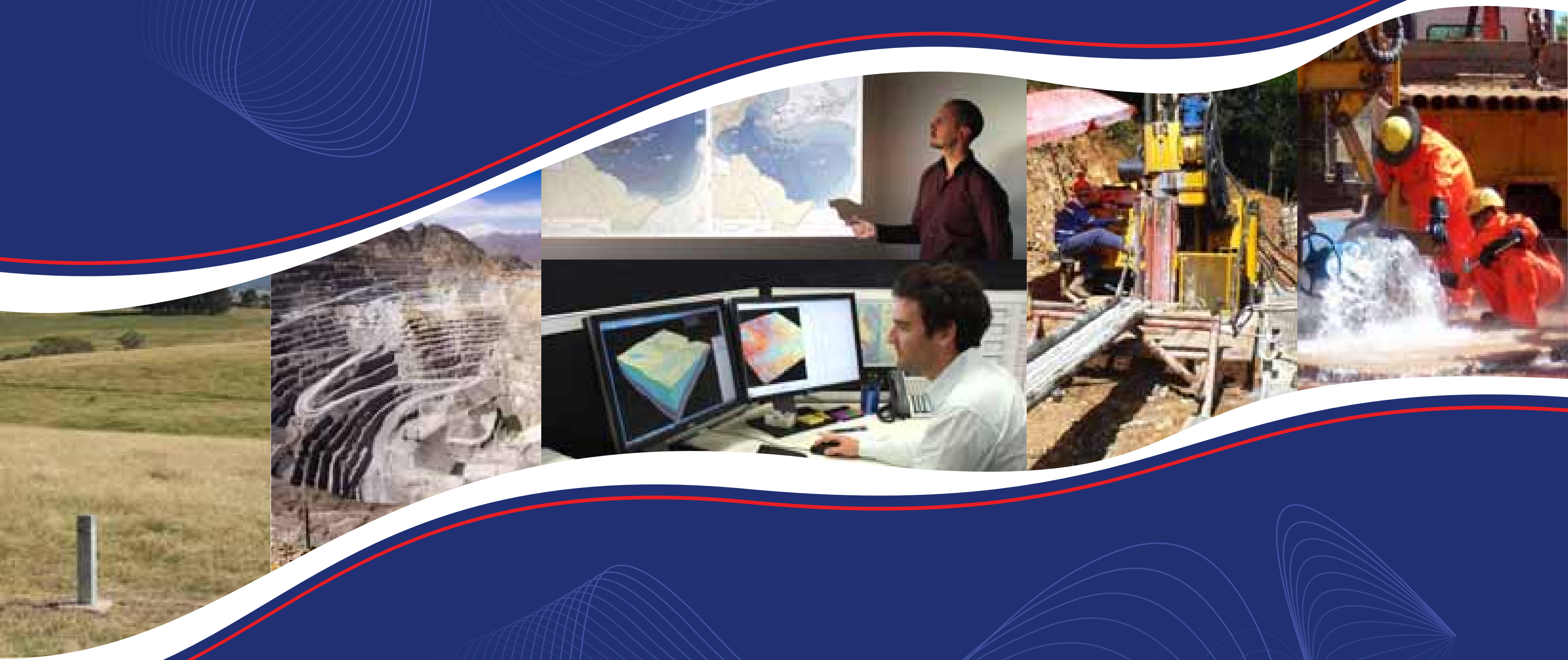

Report on

MOUNT THORLEY OPERATIONS 2014 GROUNDWATER ASSESSMENT

Prepared for

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REPORT ON

MOUNT THORLEY OPERATIONS 2014 GROUNDWATER ASSESSMENT

1 INTRODUCTION

Mount Thorley Operations (MTO) is an open cut coal mine approximately 10.5 kilometres (km) south-west of Singleton in the Hunter Valley, NSW. The mine is operated by Coal & Allied on behalf of Mount Thorley Joint Venture (MTJV). The site currently operates under Development Consent No. DA 34/95 (the development consent) issued by the then Minister for Planning on 22 June 1996 under Part 4 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act).

Immediately to the north is Warkworth Mine. Since 2004, the two mines have integrated at an operational level and are known as Mount Thorley Warkworth (MTW), with a single management team responsible for all the operations. Equipment, personnel, water, rejects and coal preparation are all shared between the mines. The MTW operations involve an existing operation of approximately 1,300 persons, which includes full-time personnel and a small number of short-term contractors. Ownership of the two mines remains separate.

Mining activities approved under DA 34/95 have mostly been completed with the exception of Loders Pit and Abbey Green North Pit (AGN) with rehabilitation well-progressed on the east of the site. Run-of-mine (ROM) coal from MTO is transported to either the MTO or Warkworth Mine coal preparation plant (CPP) for processing. Extraction of coal from other pits has been completed and overburden emplacement is ongoing. Product coal from the CPPs is transported via conveyor to the Mount Thorley Coal Loader (MTCL). Coal loaded onto trains at the MTCL is transported to the Port of Newcastle for export.

The MTO 2014 (the proposal) seeks an approval under Part 4, Division 4.1 of the EP&A Act to complete mining and rehabilitation activities within the current limits of approval.

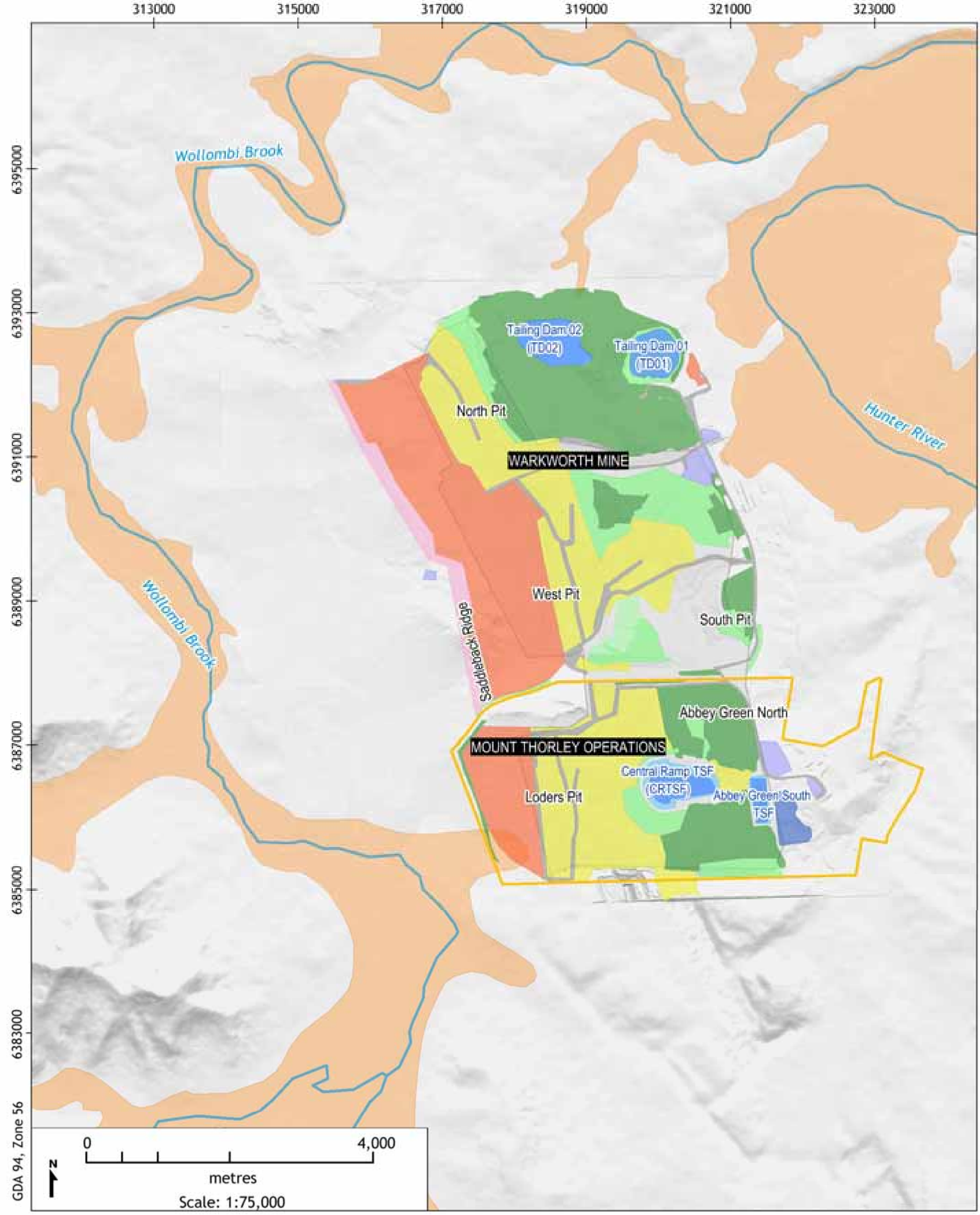
1.1. Project Description

MTO has approval to mine until 22 June 2017 under its development consent. The proposal seeks a 21 year development consent period from the date of any approval. If approval is granted in 2015, operations at MTO are forecast to continue to the end of 2035, an 18 year extension over the current approval. The proposal seeks a continuation of all aspects of MTO as it presently operates and extends or alters them, including:

- mining in Loders Pit and AGN Pit. Mining in Loders Pit is expected to be completed in approximately 2020. Mining in AGN Pit is yet to commence; however, it is anticipated to take approximately two years and be completed before 2022;

- transfer of overburden between MTO and Warkworth Mine to assist in rehabilitation and development of the final landform;
- maintain existing extraction rate of 10 million tonnes per year (Mtpa) of ROM coal; and
- maintain and upgrade to the integrated MTW water management system (WMS), including:
    - upgrade to the approved discharge point and rate of discharge into Loders Creek from 100 Ml/d to 300 Ml/d via the Hunter River Salinity Trading Scheme (HRSTS);
    - ability to transfer and accept mine water from neighbouring operations (ie Bulga Coal Complex, Wambo Mine, Warkworth Mine and Hunter Valley Operations); and
    - increase in the storage capacity of the southern out-of-pit (SOOP) dam from 1.6 giga litres (GL) to 2.2 GL;
- maintain and upgrade to the integrated MTW tailings management:
    - including use of the northern part of Loders Pit as a TSF after completion of mining; and
    - Wall lift to Centre Ramp Tailings Storage Facility to approximately RL 150;
- upgrade to the MTO CPP to facilitate an increase in maximum throughput to 18 Mtpa with the ability to receive this coal from Warkworth Mine;
- acknowledge all approved interactions with Bulga Coal Complex (see Section 1.4.1); and
- continuation of coal transfer between Warkworth Mine and MTO and transportation of coal via the MTCL to Port of Newcastle.

All activities, including coal extraction will be within disturbance areas approved under the existing development consent. The proposal is shown in Figure 1.1 to Figure 1.3.



LEGEND:

- Proposed MTO development consent boundary
- Watercourse
- Quaternary alluvium (100k)

Indicative 2017 mine plan

- Pre-strip clearing
- Mining
- Emplacement
- Stockpile
- Indicative haul roads
- Rehabilitation to final landform
- Rehabilitation
- Temporary rehabilitation
- Out-of-pit water storage
- Tailings storage facility

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Indicative Year 3 mine plan

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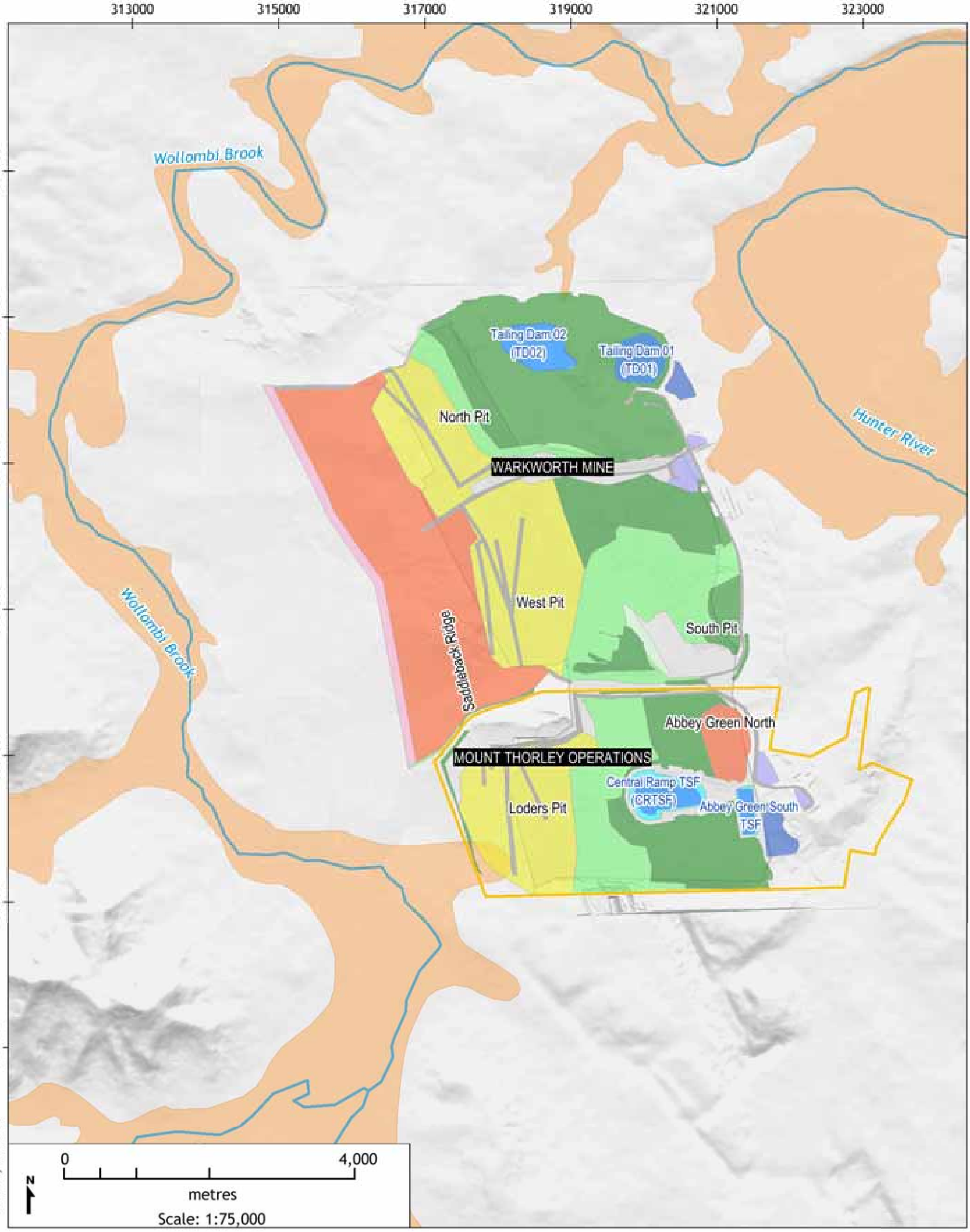
FIGURE No: **1.1**



LEGEND:

- Proposed MTO development consent boundary
- Watercourse
- Quaternary alluvium (100k)

Indicative 2023 mine plan

- Pre-strip clearing
- Mining
- Emplacement
- Stockpile
- Indicative haul roads
- Rehabilitation to final landform
- Rehabilitation
- Temporary rehabilitation
- Out-of-pit water storage
- Tailings storage facility

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Indicative Year 9 mine plan

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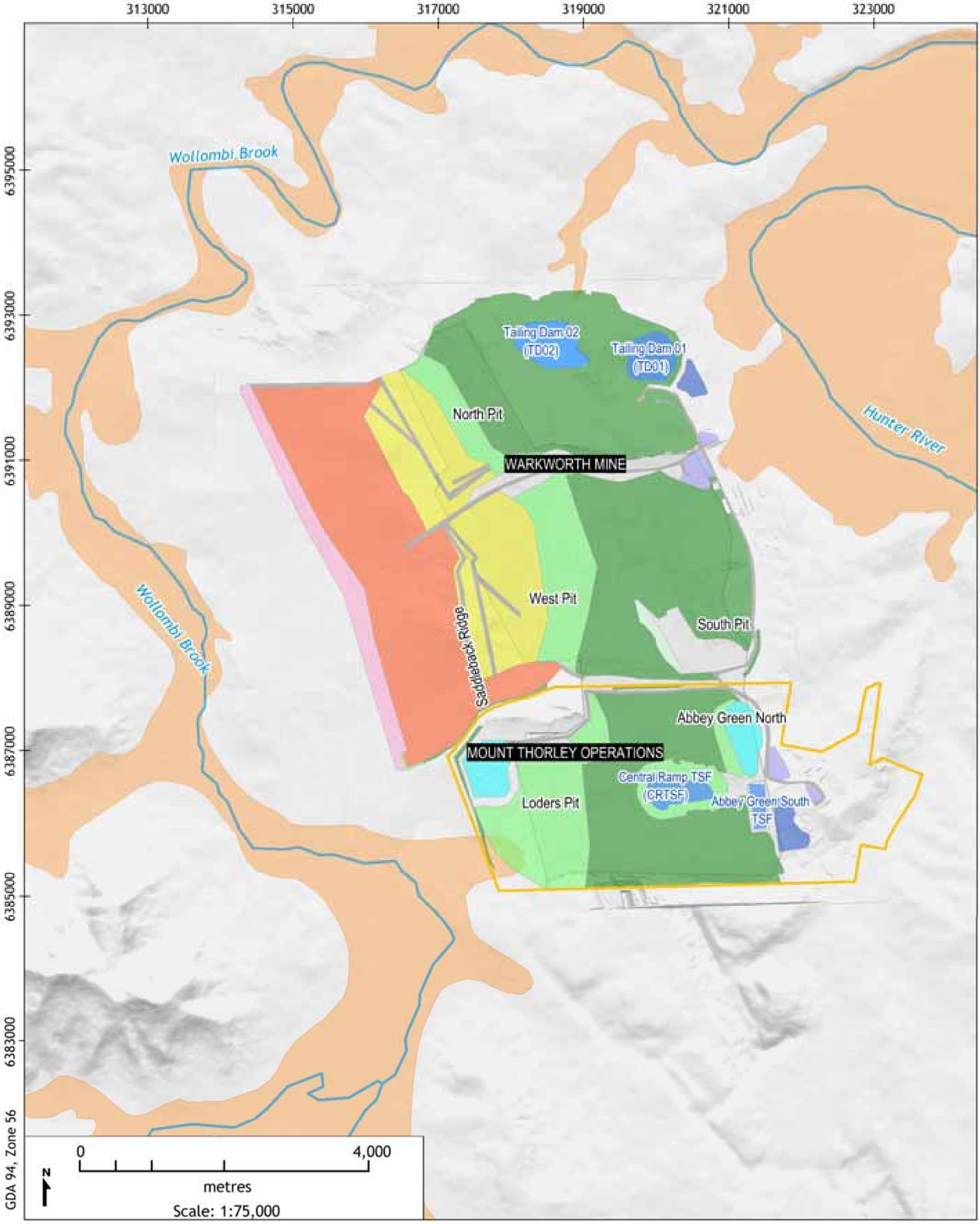
FIGURE No: 1.2



LEGEND:

- Proposed MTO development consent boundary
- Watercourse
- Quaternary alluvium (100k)

Indicative 2028 mine plan

- Pre-strip clearing
- Mining
- Emplacement
- Stockpile
- Indicative haul roads
- Rehabilitation to final landform
- Rehabilitation
- Temporary rehabilitation
- Out-of-pit water storage
- Tailings storage facility

Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

Indicative Year 14 mine plan

DATE: 14/5/2014

FIGURE No: **1.3**

2 OBJECTIVES AND SCOPE OF WORK

The objective of the groundwater study was to assess the impact of the proposal on the groundwater regime, and also comply with the requirements of the NSW and Federal governments that include:

- the NSW Aquifer Interference Policy (AIP);
- Water licensing requirements under the *Water Act 1912; and*
- *Water Management Act 2000 including the Water Sharing Plan for the Hunter Unregulated and Alluviual Water Sources.*

The legislative requirements are discussed further in Section 6. Requirements under the EPBC Act are not necessary for this proposal, as they have already be met for the existing MTW mine plan.

The scope of work to address requirements included:

- describing the existing environment;
- simulating the existing hydrogeological regime with a numerical groundwater model; and
- assessing the impact of the proposal on the groundwater environment, using the model including:
  - Groundwater take due to mine inflow from the Permian Coal Measures (*Water Act 1912);*
  - Groundwater take from the Wollombi Brook and Hunter River alluvial aquifers (*Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources);*
  - Changes to groundwater levels and salinity in private landholder bores (AIP);
  - Changes of more than 1% increase in groundwater salinity (AIP); and
- develop measures to mitigate and monitor potential impacts.

As required under section 78A of the EP&A Act, this EIS has been prepared in accordance with the DGRs and matters raised during stakeholder engagement; however, it also addresses matters raised in the L&E Court judgement. It is noted that the technical study, was progressed on the basis of contemporary DGRs for open cut mining projects in the Hunter Valley, DGRs issued for the Warkworth Extension 2010 and contemporary government policies. Prior to finalisation, the EIS, inclusive of technical studies, was considered against the proposal specific DGRs.

3 SURROUNDING MINES AND CURRENTLY APPROVED MTW OPERATIONS

The groundwater regime in the study area is influenced by historical and current mining operations at Warkworth and other surrounding mines. The latter comprise Wambo to the west, South Lemington in the north and north-west and Bulga in the south. Figure 3.1 shows the locality of the mining operations in the vicinity of MTW.

Because the groundwater regime has already been disturbed this report assesses the existing cumulative impacts from the historical and approved mining activities and the net impact of the proposal.

Mining at MTO and Warkworth Mines (MTW) commenced in the early 1980s with mining progressing west (down-dip) from sub-cropping coal seams of the Jerrys Plains Sub-Group. Most Warkworth sub-pits have been mined down to the Mt Arthur Seam with the exception of the North Pit which extracts to the shallower Warkworth Seam. The MTO pits are mined down to the shallower Woodlands Hill Seam. Mining at Warkworth is approved to continue until 2021, and at MTO until 2017.

Directly south of MTO is the Bulga Coal Complex, which comprises open cut and underground mines. Open cut mining commenced west of Broke Road in the early 1990s extending to the Whybrow Seam and down to the deeper Woodlands Hill Seam since 1999. The Saxonvale Colliery was developed south of Broke Road in in the early 1980s with mining targeting the Vaux Seam in the 1990s. Longwall mining of the Whybrow and Blakefield Seams under the open cut pits was approved to commence from 2010.

The former South Lemington Mine, which is part of Hunter Valley Operations (HVO) South, is located to the north of Warkworth Mine. South Lemington Underground was a bord-and-pillar operation that mined the Bowfield Seam and ceased operating in the early 1990s. The underground footprint underlies Wollombi Brook. The South Lemington Open Pit is part of the HVO South approval and is currently used as a dam to store and transfer water between Coal & Allied's MTO and HVO.

The Wambo Mine is located to the north-west of MTW. It includes both open cut and underground longwall operations. Mining commenced at Wambo in the late 1960s to early 1970s. Open cut operations have extended down to the Whynot Seam. Currently approved underground mining at Wambo includes longwall panels in the Whybrow, Wambo, Arrowfield and Bowfield Seams.

Table 3.1 summarises the coal seams mined at MTW, Bulga Coal Complex and Wambo.

Table 3.1:SUMMARY OF MINING OPERATIONS

Stratigraphic Column			Coal Seam	Bulga Coal Complex						Wambo Mine						MTW					Lemington Underground
				Bulga Pit OC	Whybrow Pit OC	Saxonvale/ Vaux Pit OC	Beltana No1 Mine UG	Blakefield North UG	Blakefield South UG	Wambo OC	Arrowfield UG	Bowfield UG	North Wambo UG	Whybrow UG	United Collieries UG	Homestead/Wollemi UG	North Pit	South Pit	West Pit	Loders /Mount Thorley Pit	Abbey Green North	
Regolith/ alluvium																						
Wittingham Coal Measures	Jerrys Plains Subgroup	*Mt Leonard*	Whybrow	x	x	x	x		x	x				x		x	x		x	x		
		Althorpe Fm		(tuff)																		
		Malabar Fm.	Redbank Creek							x							x		x	x		
			Wambo	x						x			x				x		x	x		
			Whynot							x							x		x	x		
			Blakefield	x				x	x								x		x	x		
		Mt. Ogilvie Fm.	Glen Munro	x				o	o								x		x	x		
			Woodlands Hill	x				o	o						x		x		x	x		
		Milbrodale Fm.		(tuff)																		
		Mt. Thorley Fm.	Arrowfield								x				x		x		x			
			Bowfield									x					x	x	x		x	
			Warkworth														x	x	x		x	
		Fairford Fm.		(tuff)																		
		Burnamwood Fm.	Mt. Arthur															x	x		x	x
			Piercefield																			
			Vaux														o	o	o	o		
			Broonie																			
			Bayswater														o	o	o			

Note:

x — Currently approved or historically mined

LEGEND:

- NOW stream gauge station
- Major watercourse
- Proposed MTO development consent boundary

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Local Context

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FIGURE No: **3.1**

4 CLIMATE AND SURFACE WATER

4.1. Climate

The climate in the vicinity of MTO is mostly temperate and is characterised by hot summers with regular thunderstorms and mild dry winters. Table 4.1 summarises the average monthly temperature, rainfall and evaporation rates for the area. This table shows that rainfall recorded at MTW (since 2012) has generally been below the long-term average (1889-2013) for Jerrys Plains, and that evaporation exceeds rainfall on a monthly basis. The average annual rainfall at MTW is 591 mm, with February being the wettest month.

Table 4.1: CLIMATE AVERAGES JERRYS PLAINS (STATION 061086) and MTW

Statistic	Source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Mean max temp (ºC)	SILO[1]	31	30	28	25	21	18	17	19	23	26	29	31	25
Mean evaporation (mm)	SILO	211	166	148	108	75	55	64	87	117	156	181	213	1579
Mean rainfall (mm)	SILO	77	73	61	44	41	49	42	36	42	53	63	67	648
Warkworth Mine mean rainfall	MTW[2]	78	151	87	25	13	48	21	10	26	9	79	26	591
Evaporation minus MTW rainfall	**-**	**133**	**16**	**61**	**83**	**62**	**7**	**43**	**77**	**90**	**147**	**102**	**187**	**989**

1. SILO Patched Point Data (PPD) from Department of Science, Information Technology, Innovation and the Arts (DSITIA) for Jerrys Plains Station. The PPD includes daily climate readings from the Bureau of Meteorology (BoM) as well as interpolated data where readings are not available. The SILO dataset includes long-term daily rainfall, temperature and evaporation readings from 1889 to present.
2. Rainfall recorded by Warkworth Mine from 2012.

Monthly rainfall records were used to calculate the Cumulative Rainfall Departure (CRD – also known as rainfall residual mass) for the Jerrys Plains Station. Figure 4.1 shows the calculated CRD.

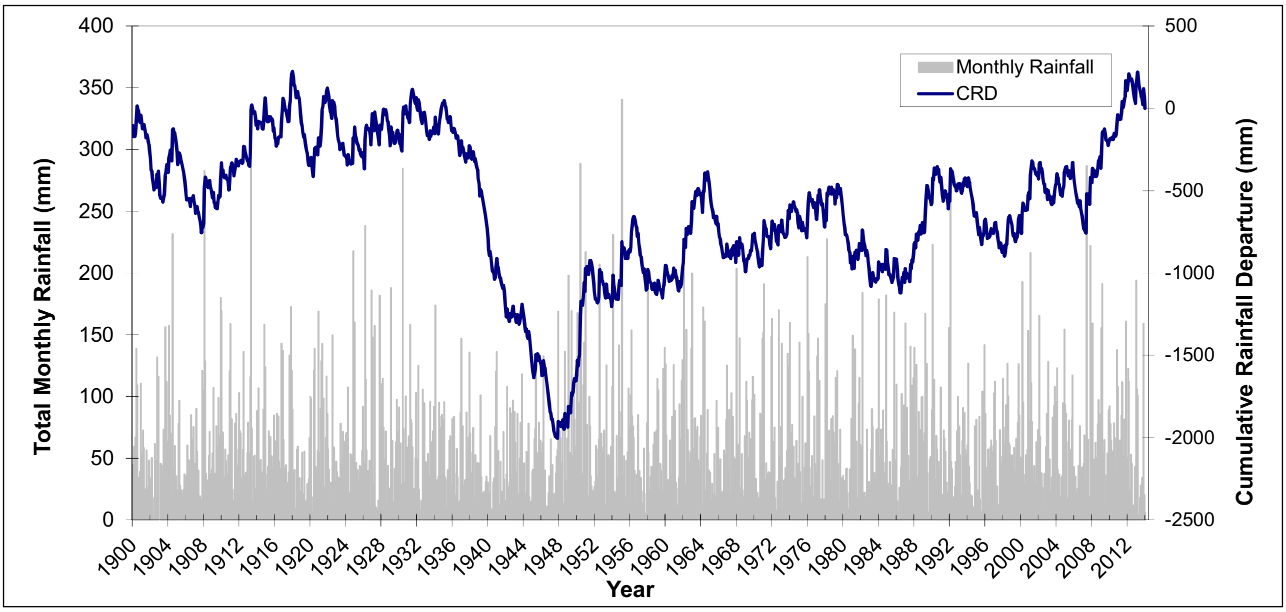


Figure 4.1: Cumulative Rainfall Departure – Jerrys Plains

The CRD shows trends in rainfall relative to the long term average and provides a historical record of relatively wet periods and droughts. A rising trend in slope in the CRD plot indicates periods of above average rainfall, whilst a declining slope indicates periods when rainfall is below average.

The CRD in Figure 4.1 indicates that the district experienced above average rainfall between 2007 and 2012, followed by a general decline in rainfall to the present day.

4.2. Surface Water

The main watercourse in the study area is Wollombi Brook, which is located to the west of MTO. The ephemeral Wollombi Brook is a tributary of the Hunter River and flows in a north to north-easterly direction past Warkworth Mine. The NSW Office of Water (NOW) collects real time stream flow data via the Hunter Integrated Telemetry System (HITS). Figure 3.1 shows the two NOW gauging stations on Wollombi Brook in close proximity to MTW, which are:

- Station 210004 (Wollombi Brook at Warkworth) north of Warkworth Mine (47.8 mRL at zero gauge and 48.4 mRL cease to flow); and
- Station 210028 (Wollombi Brook at Bulga) west of MTO (56.50 mRL at zero gauge and 57.4 mRL cease to flow).

Data on the HITS database indicates Wollombi Brook at Bulga (Station 210028), the closest gauging station west of MTW, flows at a median rate of around 41 ML/day. The median flow rate between April and December 2013 is approximately 8.4 ML/day due to below average rainfall.

Figure 4.2 shows stream flow levels recorded at the two stations, compared against daily rainfall and evaporation from 2010 to present.

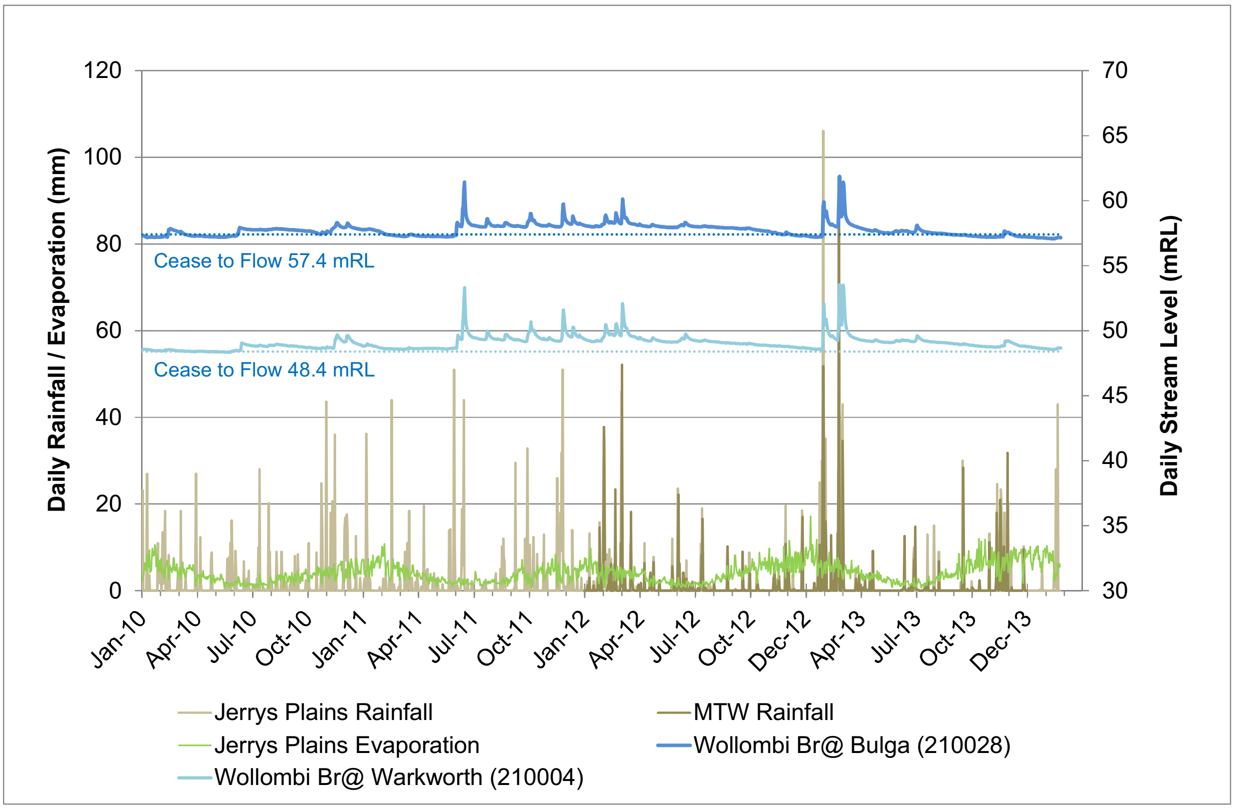


Figure 4.2: Wollombi Brook stream levels and climatic conditions

The graph shows that daily evaporation generally exceeds daily rainfall, and that peaks in stream flow in Wollombi Brook are in response to peak rainfall events. Between peak rainfall events the stream flow shows a steady recession. The graph also shows that stream flow has been maintained in the Wollombi Brook (at Warkworth Station) since 2010, but not at the Bulga Station. In early 2010, and prior to that date, the full record shows that the Wollombi Brook at both Bulga and Warkworth have had extended periods of no flow. In addition, flow volumes were higher downstream of the mine site (Warkworth) than upstream (Bulga). This indicates that there is surface and/or groundwater input to Wollombi Brook between these stations.

5 HYDROGEOLOGICAL REGIME

5.1. Groundwater Occurrence

Figure 5.1 shows the outcropping geology units and aquifer systems in the region. The geologic strata at MTW can be categorised into the following hydrogeological units:

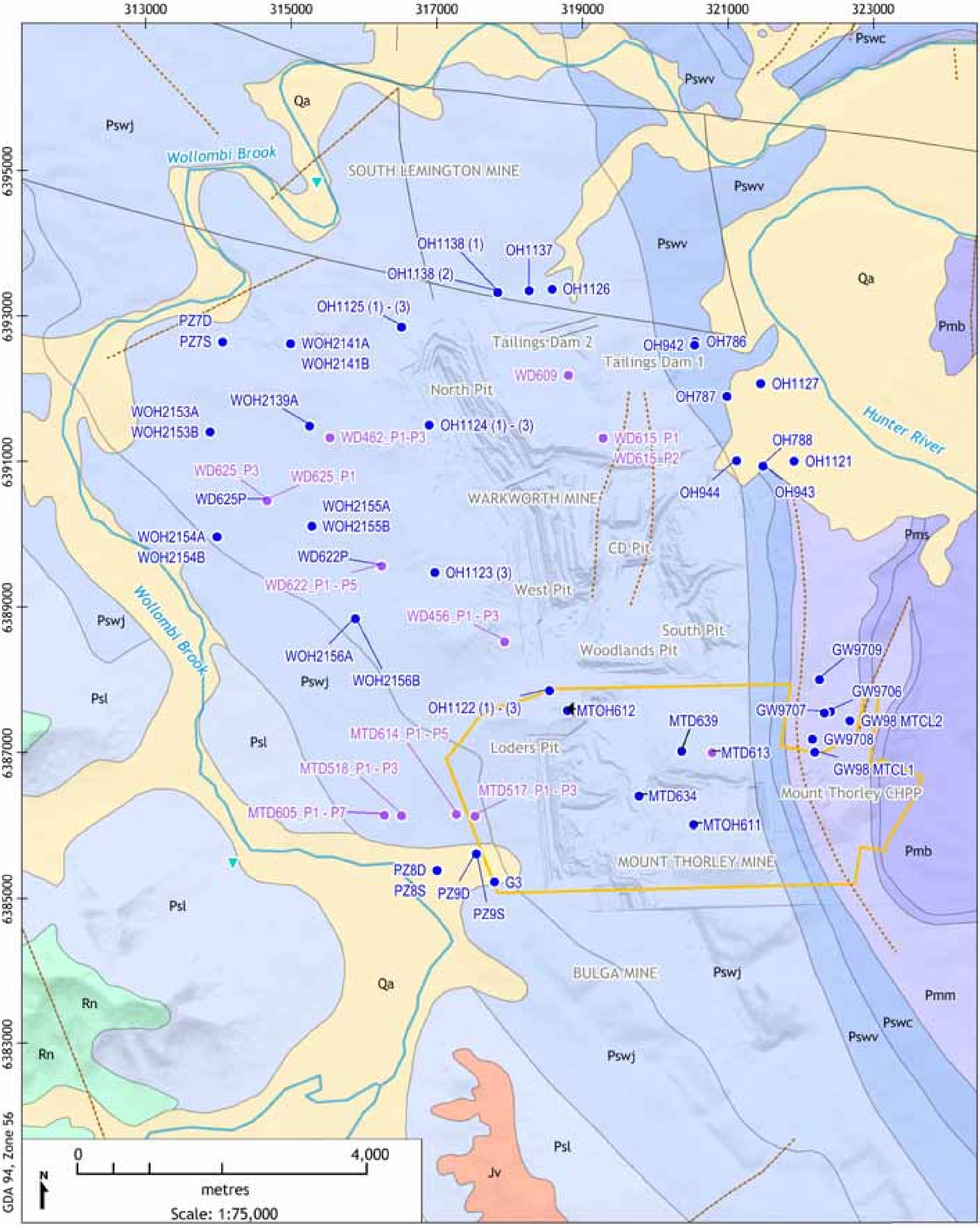
- alluvium along Wollombi Brook and the Hunter River that can form a productive aquifer system, although salinity can limit use of the water;
- aeolian sands associated with the Warkworth Sands Woodland to the north-west of Warkworth Pit that forms a thin perched groundwater system of limited extent;
- shallow weathered bedrock (regolith) near ground surface that is mainly present in the more elevated mining areas and is largely dry;
- hydrogeologically “tight” and very low yielding sandstone, siltstone and conglomerate that comprise the majority of the Permian interburden / overburden and is considered an aquitard; and
- low to moderately permeable coal seams that range in thickness from 1 m to 6 m and are the prime water bearing strata within the Permian sequence.

The Wollombi Brook alluvial aquifer and associated flood plain is largely restricted to the main channel of Wollombi Brook and only extends a short distance up the associated tributaries. Whilst Figure 5.1 shows the alluvium extending into the MTO mining area, this is based on 1:100,000 scale mapping, and work within the approved mining area shows the Loders Pit will not intersect alluvium. The alluvium is typically less than 20 m thick, with many of the private bores intersecting between 10 m and 15 m of sediment.

Groundwater entitlements for the Lower Wollombi Brook Water Source total 5,071 ML/year with approximately 55% used for irrigation and approximately 44% used for industrial purposes. This entitlement is distributed across 38 groundwater licences (DWE, 2009). This distribution is considered current, with an updated search of the NSW Government 2013 version of PINEENA groundwater database showing no new bores within the study area since 2010.

The Wollombi Brook alluvium to the west of MTW, and the Hunter River alluvium to the east of MTW can support higher yielding irrigation bores in some areas and could be considered a ‘highly productive aquifer’ according to the Aquifer Interference Policy (AIP) criteria.

Aeolian sands overlie the Permian coal measures to the north-west of the Warkworth Mine (extent shown in Figure 5.3). The sands ability to store and slowly release water supports woodland known as the Warkworth Sands Woodland. The fine grained sands are approximately 3 m thick and overlie a low permeability base of residual clay associated with the underlying strata. The low permeability clays reduce vertical flow of groundwater and result in the formation of a thin perched water table at the base of the sand mass. Cumberland Ecology (2014) noted species indicative of a persistent water table can be found in dune swales suggesting some groundwater permanence. The Warkworth Sands aquifer is considered to be perched above, and not directly connect to the regional water table.



LEGEND:

Monitoring Bores
- Standpipe
- VWP
- NOW Stream Gauge Station
- Fault
- Fold
- Watercourse
- Proposed MTO development consent boundary

Hunter Coalfields 100k Geology
- Qa - Quaternary Alluvium
- Jv - Jurassic Volcanics
- Rn - Hawkesbury Sandstone, Narrabeen G.
- Psl - Wollombi Coal Measures
- Pswj - Denman Fmt, Jerrys Plains Subgroup
- Pswv - Archerfield Ss., Vane Subgroup
- Pswc - Saltwater Creek Formation
- Pmm - Mulbring Siltstone
- Pms - Muree Sandstone
- Pmb - Braxton Formation

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Geology and Monitoring Bores

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FIGURE No: **5.1**

The Permian deposits occur as a regular layered westerly dipping sedimentary sequence. Coal seams currently mined at MTW include the Redbank Creek, Wambo, Whynot, Blakefield, Glen Munro, Woodlands Hill, Arrowfield, Bowfield, Warkworth and Mt Arthur Seams (Figure 5.2). Currently approved mining at MTO targets seams down to the Woodlands Hill. These seams vary in thickness from 0.3 m to more than 6 m. Groundwater usage from the Permian strata is limited by the generally brackish to saline nature of the groundwater and the low and variable yields.

Figure 5.3 shows an east to west schematic cross-section from the Hunter River through MTO and west to Wollombi Brook. The coal seams outcrop west of the Hunter river and dip steeply along the Mt Thorley Monocline that is located close to the outcrop area. The dip of the seams becomes more gentle within the mining area. The section shows the coal seams are more than 200 metres below the ground surface to the west where the alluvial sediments associated with Wollombi Brook occur.

The prime users of groundwater from the Permian strata are the underground mines in the area. MTW does not report any significant seepage into the pits due to a combination of low permeability formations, and because the evaporation rate generally exceeds the rate of seepage from the mine face. The hydrostratigraphic units of the Permian coal measures typically yield less than 5 L/s, and are therefore classified as 'less productive aquifers' according to the criteria set out in the Aquifer Interference Policy (AIP).

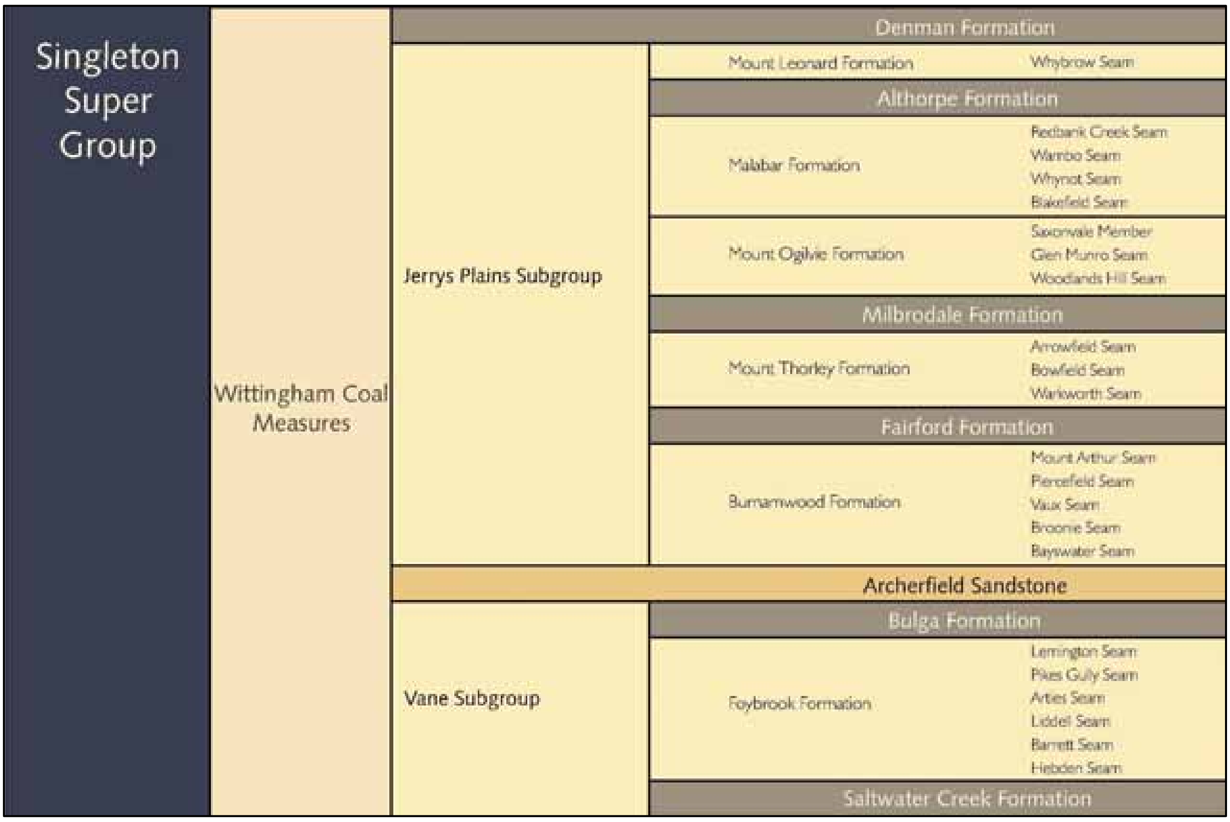
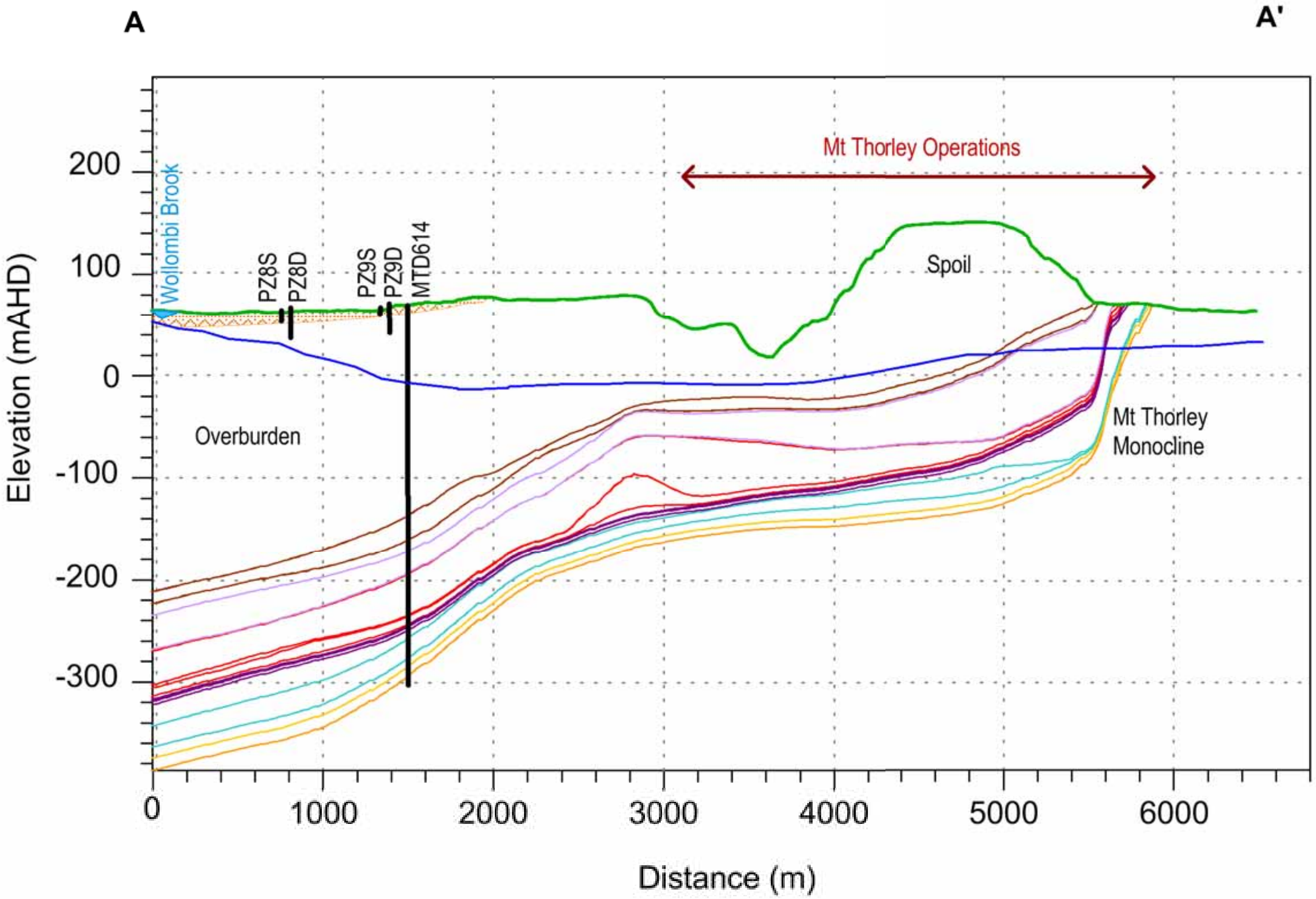
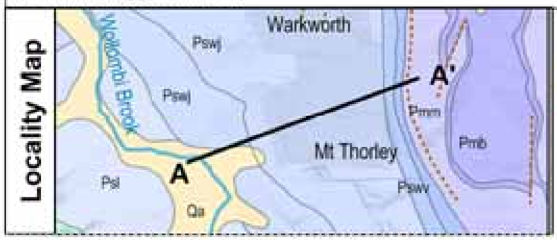


Figure 5.2: Stratigraphic column



(Vertical Exaggeration 1:6)



LEGEND:

- Inferred Permian Potentiometric Surface
- Alluvium
- Surface topography
- Arrowfield Seams
- Bowfield Seams
- Warkworth Seams
- Mt Arthur Seams
- Piercefield Seams
- Vaux Seams

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Hydrogeological Cross-Section
Mt Thorley (A-A')

DATE:
14/5/2014

FIGURE No:
5.3

5.2. Groundwater Monitoring

Water levels are routinely measured in a network of monitoring bores at MTW. Figure 5.4 shows the location of monitoring bores relative to an aerial photograph. The monitoring network comprises standpipe style PVC monitoring bores, and vibrating wire piezometers (VWPs). Temporal groundwater level data has been gathered via manual dipping of bores and via data loggers since 2003. Some sites have both monitoring bores and VWPs, which allows the study of hydraulic gradients between the alluvium and the Permian sequence, and also within the layered Permian strata and spoil.

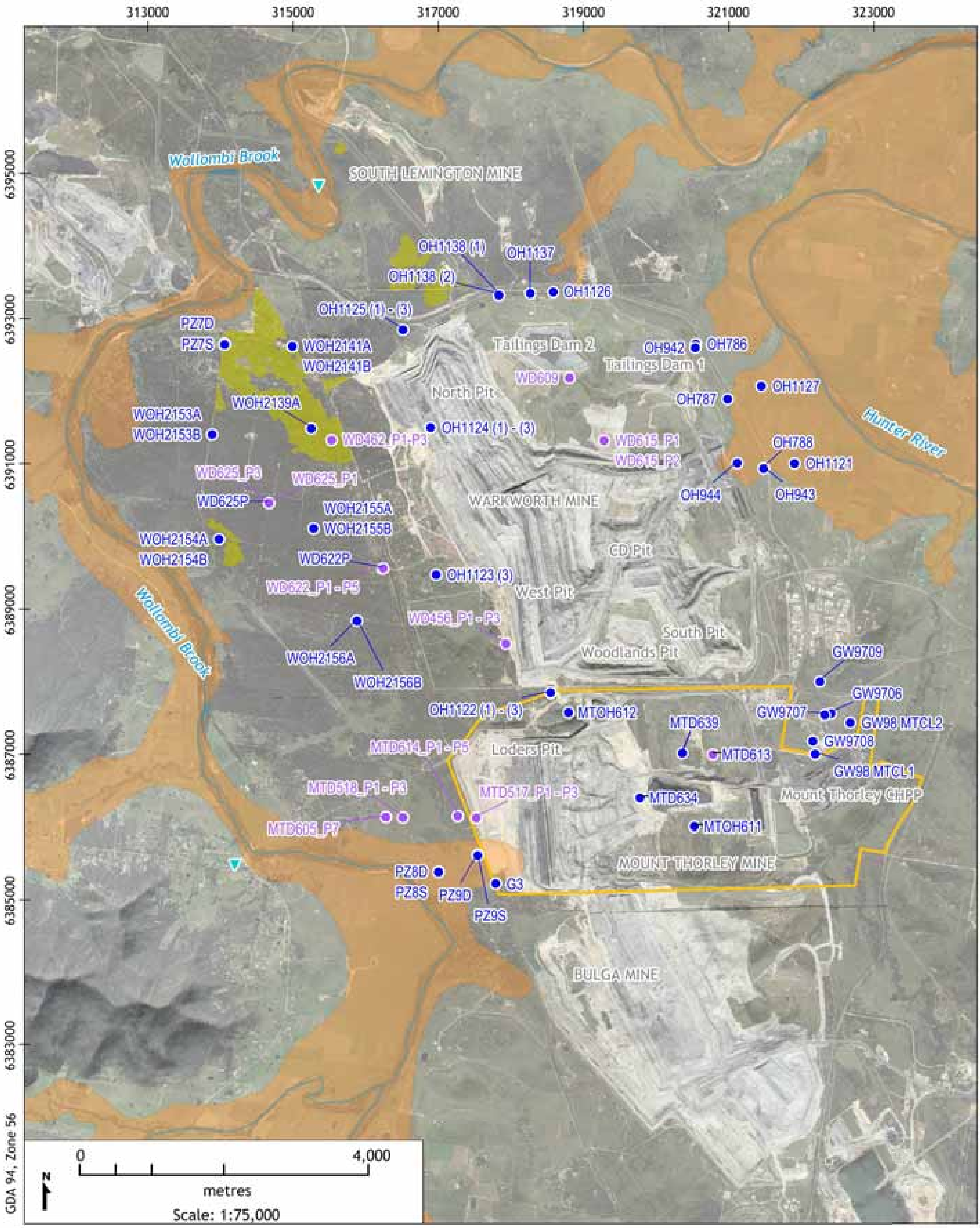
Monitoring bore construction details and recent groundwater levels are detailed under Appendix A.

5.3. Groundwater Levels

Monitoring from the network of bores surrounding the MTW open cut pits show mining is depressurising the coal seams to the west of the active face, resulting in declining water levels. Monitoring shows the water levels within the alluvium to date are unaffected by mining. Figure 5.5 shows the drawdown in the potentiometric surface within the Permian sequence in late 2013. The cumulative impact of mining is made evident by the flow of groundwater towards the active mine area. This outlines the importance of simulating the existing effects of mining at MTW and regionally appropriately in this study, to compare effects from this proposal.

Figure 5.5 includes an inset with estimated groundwater levels within the Loders Pit mine spoil. There is limited water level data for the spoils, and therefore data from geophysical logging (Neutron Log) of exploration holes were used to estimate the zone of saturation. The interpreted water levels indicate the spoils are saturated at the base and drain across the historical pit floor towards the open void in the west.

Figure 5.5 highlights the changes to the groundwater regime induced by mining. Prior to mining groundwater levels would have been expected to have been a subtle reflection of the topography, with gradients towards the west and Wollombi Brook. To the west of the MTO high-wall a series of nested monitoring bores and VWPs are present, which monitor both the multi-layered Permian strata and the Wollombi Brook alluvium. The monitoring network shows depressurisation is most significant in the Permian strata in close proximity to the active high-wall and decreases with distance to the west. The cumulative impacts of historical mining are addressed further throughout this report.



LEGEND:

Monitoring Bores

- Standpipe
- VWP
- NOW stream gauge station
- Alluvium (100k)
- Warkworth Sands Woodland
- Major watercourse
- Proposed MTO development consent boundary

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Air Photograph & Monitoring Bores

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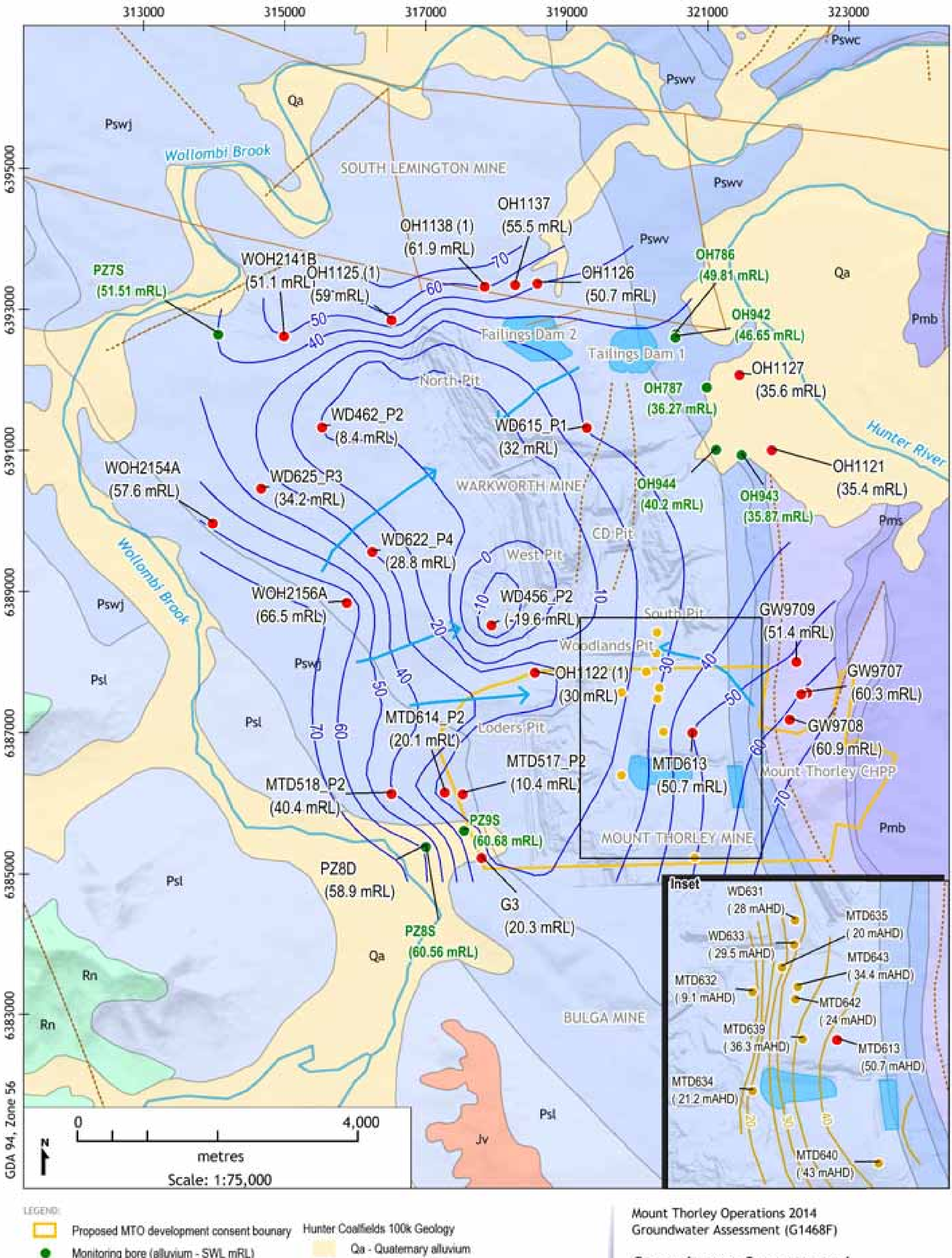
FIGURE No:
5.4



LEGEND:

- Proposed MTO development consent bounary
- Monitoring bore (alluvium - SWL mRL)
- Monitoring bore (Permian - SWL mRL)
- Monitoring/Exploration hole (spoil - SWL mRL)
- 10m Inferred Permian Groundwater Contour (RL - Sep/Oct 2013)
- Inferred groundwater flow direction
- 5m inferred spoil groundwater contours (mRL)
- Tailings storage facility
- Fault
- Fold

Hunter Coalfields 100k Geology

- Qa - Quaternary alluvium
- Jv - Jurassic Volcanics
- Rn - Hawkesbury Sandstone, Narrabeen G.
- Psl - Wollombi Coal Measures
- Pswj - Denman Fmt, Jerrys Plains Subgroup
- Pswv - Archerfield Ss., Vane Subgroup
- Pswc - Saltwater Creek Formation
- Pmm - Mulbring Siltstone
- Pms - Muree Sandstone
- Pmb - Braxton Formation

Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

Groundwater Contours and Groundwater Flow Directions

DATE: 14/5/2014

FIGURE No: 5.5

The multi-level VWPs at site MTD517 monitor the Wambo Seam (P3), Woodlands Hill Seam (P2) and the Mt Arthur Seam (P1) directly west of the current Loders Pit at MTO. Site G3 monitors Wambo Seam to the south-west of Loders Pit. Piezometric levels for these sites are shown in Figure 5.6. The Woodlands Hills Seam is the base of open cut operations in the Loders Pit and Bulga Coal Complex, with the Warkworth pits mined to the lower Mt Arthur Seam. The downward trend in each of the three VWPs and the monitoring bore indicates depressurisation of the coal seams due to mining.

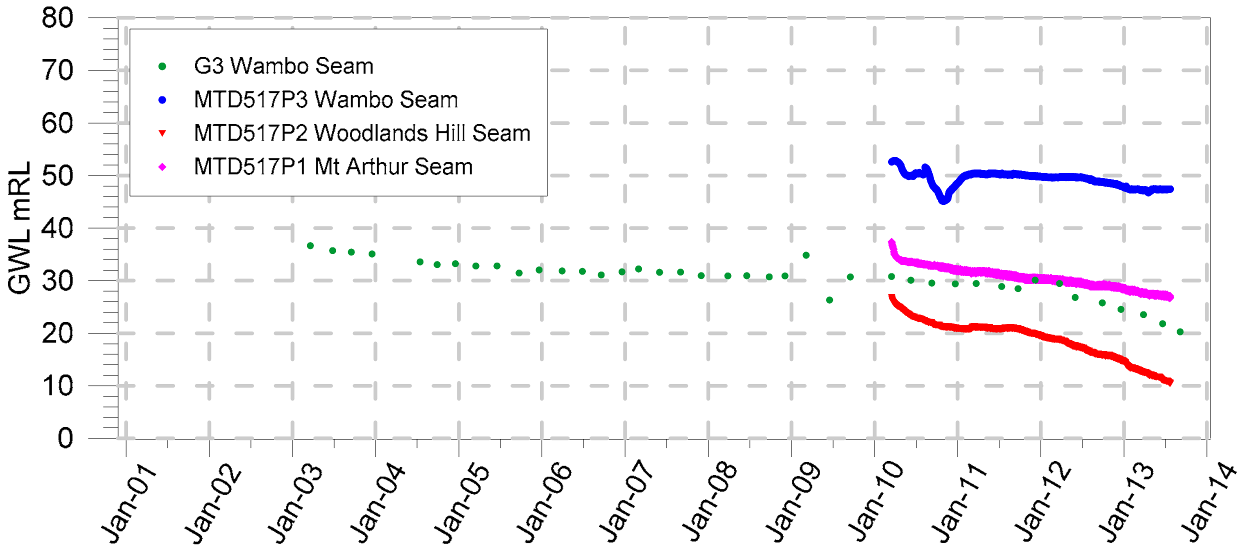


Figure 5.6: Groundwater levels within the Permian coal seams directly west of MTO

Other nested monitoring bores and VWPs within the Permian sequence located west of the proposal show similar downwards dewatering trends. The dewatering effects of mining reduce with distance westwards from the mined area. The low permeability of the Permian strata means the zone of depressurisation remains in relatively close proximity to the mining areas.

Figure 5.7 shows groundwater level data for nested monitoring bores within the Wollombi Alluvium (PZ9S) and underlying Permian overburden (PZ9D) west of MTO that were constructed in 2009.

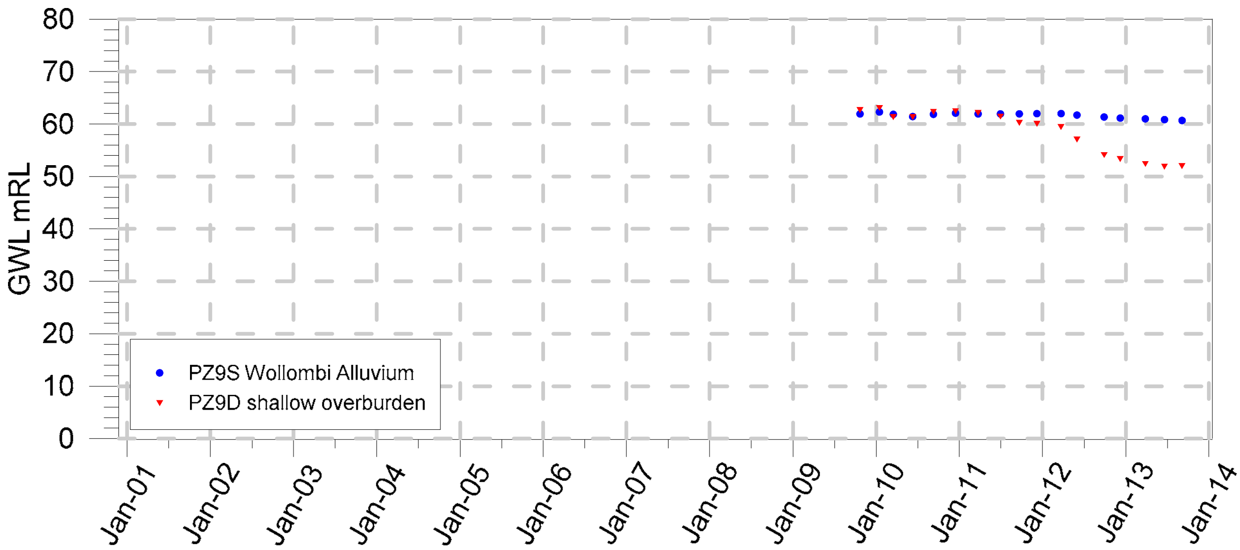


Figure 5.7: Groundwater levels within Wollombi Brook alluvium and overburden west of Loders Pit

The alluvial bore PZ9S shows relatively stable conditions with no impact of mine dewatering evident. The deeper bore PZ9D within overburden does show that drawdown associated with currently approved mining has increased the downward gradient within the overburden, resulting in a decline in groundwater levels. This drawdown in overburden was previously predicted under current approvals for MTO (Mackie Environmental Research, 2002).

Monitoring shows groundwater levels to the east of MTO are unaffected by depressurisation of the coal measures. The sub-crop of coal seams, and exposure of underlying low permeability sediments at surface between MTO and the Hunter River alluvium, prevents drawdown with the coal measures reaching the alluvium. Water levels in all the alluvial monitoring locations east of MTO recorded stable water levels fluctuating only in response to climatic conditions.

In summary, a long history of previous mining at MTO and Bulga Complex to the south have led to localised dewatering of the Permian strata down-dip (west) of the mine site. No drawdown to date has been detected in the Wollombi Brook alluvium. Drawdown to the east in the Hunter River is constrained by sub-crop of geological formations impeding depressurisation in an easterly direction.

5.4. Groundwater Gradients

Figure 5.5 shows the groundwater contours and generalised[1] flow directions of the Permian groundwater, which generally flow towards the active mine area.

Alluvial groundwater contours could not be interpolated due to the limited number of bores within these sediments. The alluvial groundwater levels however indicate a relatively flat groundwater gradient from the edge of the alluvium towards the main watercourse (i.e. Wollombi Brook and Hunter River). In addition, groundwater levels between the alluvium and Permian units appear to be similar beyond a certain distance away from mining activity. Also, alluvial groundwater levels are notably higher in elevation compared to Permian levels closer to the mine (e.g. PZ9S and G3). As discussed in Section 5.3, these results indicate that the current influence of mining on the potentiometric surface is localised in the Permian strata, with no detectable drawdown in the alluvium.

A number of nested monitoring bores and multi-level VWPs surrounding MTO permit the analysis of vertical hydraulic gradients between coal seams being mined and in some cases the underlying unmined coal seams.

West of the Loders Pit most of these sites show a downward gradient to the Woodlands Hill seam which is the base of current open cut operations. Downward gradients comprised of up to 40 m in head difference are noted. Heads from coal seams below the Woodlands Hill Seam tend to show upward gradients, inferring that unmined lower coal seams have not been depressurised extensively from current mining. The majority of the measured vertical hydraulic gradients are presumed to be caused from mining activities, although with no pre-mining data this cannot be confirmed.

5.5. Strata Permeability And Storage

Permeability has been investigated in several site specific studies at MTW and the neighbouring Bulga mine. AGC (1984) and Amoco Australia (1995a and 1995b) are two studies with permeability measurements for coal seams at the site. These studies and one by Mackie (2009) refer to a reduction of coal seam permeability with depth.

[1] The groundwater levels presented in this image are combined for the Permian sequence, where there was more than one coal seam monitored at a given location the lowest value was used to generate the groundwater level surface. Hence this surface presents the 2013 generalised hydraulic gradient in the Permian.

In addition, as documented by AGE (2010), a monitoring bore drill program was undertaken to construct monitoring bores at three sites in the Wollombi Brook alluvial plain. At each site separate monitoring bores were constructed in the alluvial sediments (PZ7S, PZ8S and PZ9S) and underlying coal measures and overburden (PZ7D, PZ8D and PZ9D). As a part of the investigation permeability tests were conducted, with the results summarised in Table 5.1.

Table 5.1: FALLING HEAD TEST RESULTS

Bore ID	Strata	Hydraulic Conductivity	
		m/sec	m/day
PZ7S	Alluvium	3.4×10^{-6}	0.3
PZ8S		1.9×10^{-5}	1.6
PZ9S		2.8×10^{-6}	0.2
PZ7D	Bedrock	1.2×10^{-6}	0.1
PZ8D		-	-
PZ9D		1.1×10^{-6}	0.1

The results show that the hydraulic conductivity within the alluvium is highly heterogeneous, due to the depositional environment. The hydraulic conductivity measured in the Permian stratigraphy was anomalously high, and may have been due to the shallow nature of these boreholes and weathering in the Permian strata.

In addition to the AGE (2010) field investigation, a recent field investigation by Golder (2013) near the study area has provided a number of new results from borehole hydraulic (packer) testing.

Figure 5.8 presents the available data for Permian coal seam hydraulic conductivity versus depth from previous groundwater assessments mentioned in this section.

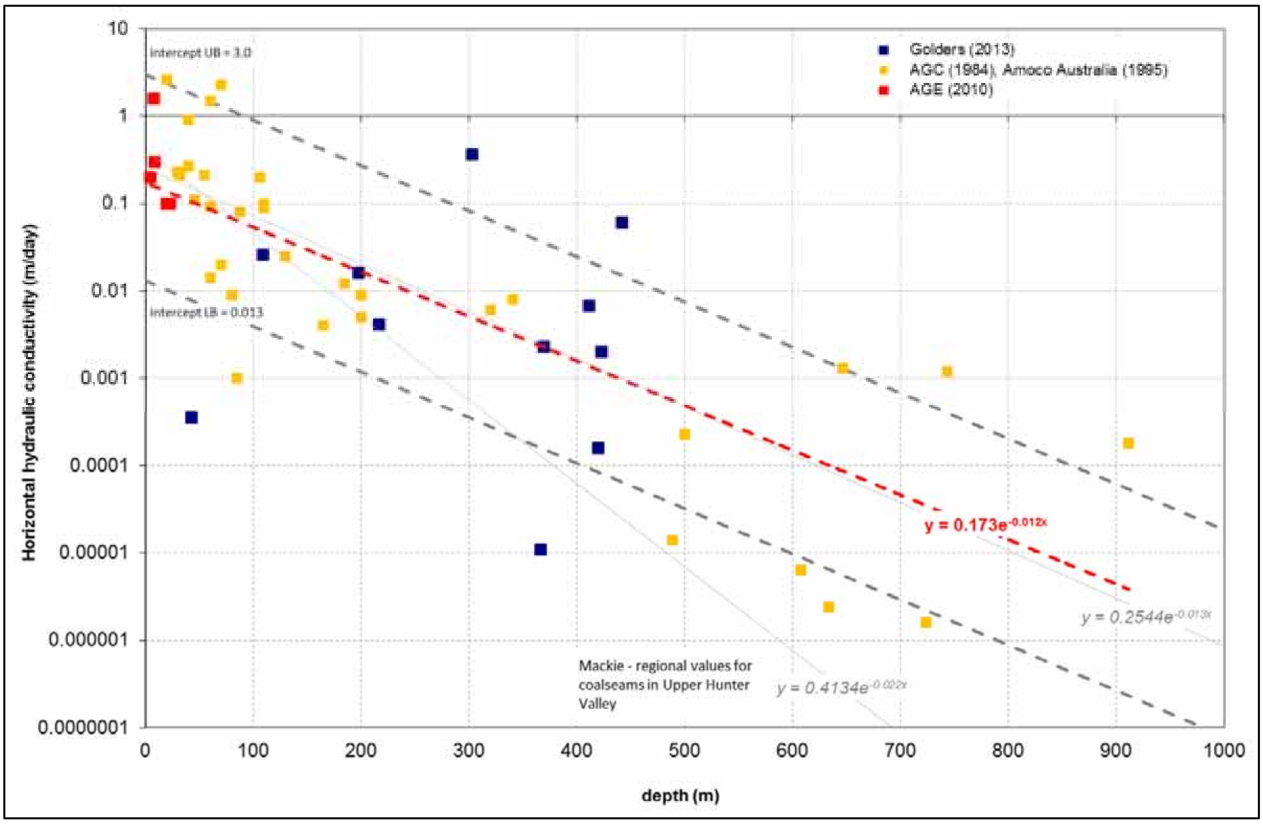


Figure 5.8: Change of hydraulic conductivity with depth in coal seams

Figure 5.8, shows a correlation between depth and declining hydraulic conductivity. The red dotted line shows the best fit through this data, and is similar to that presented by AGE (2010).

Data for hydraulic conductivity of the interburden and overburden is limited. The horizontal hydraulic conductivity of interburden is generally considered at least one, and sometimes several orders of magnitude less permeable than the coal seams.

No site specific data is available for storage properties of local stratigraphy. Mackie (2009) estimated specific storage for the Hunter Region using Young's modulus, and results ranged between 1×10^{-4} and 3×10^{-6} (1/m). These results are based on similar stratigraphy to the proposal area, and are therefore considered applicable to this study.

5.6. Recharge

Recharge to the Permian coal measures can occur where coal seams outcrop or sub-crop close to the surface. Recharge to the alluvium occurs via rainfall infiltration through the unsaturated zone, hill slope runoff and leakage from rivers and streams when and where the surface water levels are above the water table in the alluvium.

Experience in similar studies at MTW (AGE 2010) and within the Hunter Valley suggest recharge to the Permian coal measures is low, typically below 1% of annual rainfall. Recharge to alluvium is around 10% of rainfall, however, this varies based on alluvial composition.

5.7. Discharge

5.7.1. Discharge Processes

Natural discharge processes in the system are via groundwater flow into water courses as baseflow when the water table in the adjacent groundwater system is higher than either the stream bed or the water levels in the stream channel. It also includes groundwater inflow into mining zones, disposal and/or evaporation., groundwater use by private landholders and evapotranspiration where the water table is within the root zone of plants and trees.

5.7.2. Baseflow

As detailed in Section 4.2, a review of surface water flows and climatic conditions indicates groundwater may contribute to baseflow in Wollombi Brook. The proportion of groundwater in steam flow would tend to increase during times of low flow. Figure 5.9 below compares Wollombi Brook levels to rainfall and groundwater levels within the associated alluvium (PZ7S, PZ8S and PZ9S) and the underlying Permian stratigraphy (PZ8D and PZ9D).

It can be seen in Figure 5.9 that groundwater trends within the alluvium do not respond to rapid changes in stream levels. Water levels suggest the alluvium discharges to the stream predominantly, rather than the stream recharging the alluvium. A rapid decline in groundwater levels in June 2013 is visible for PZ8D, which is believed to relate to groundwater sampling. The bore was likely purged during the round of sampling, and the low hydraulic conductivity resulted in a slow rate of groundwater level recovery.

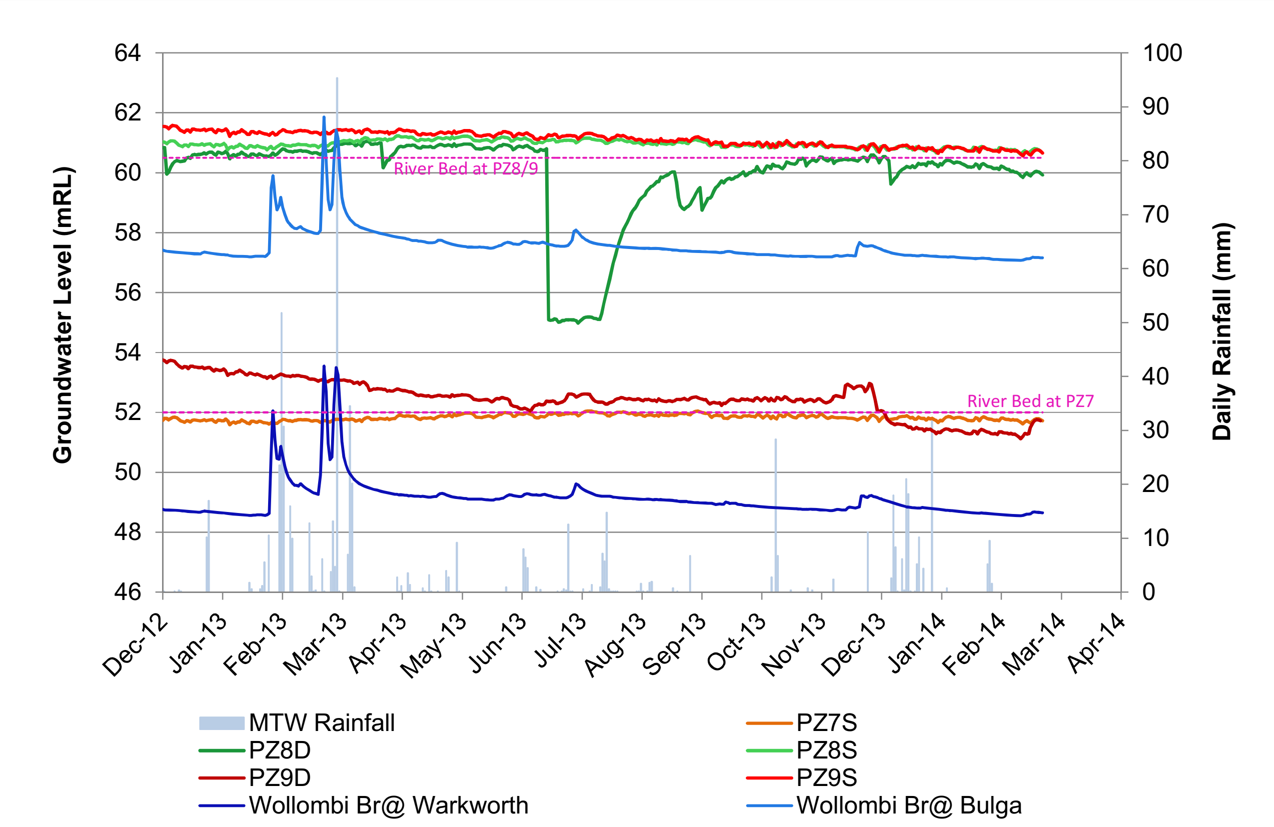


Figure 5.9: Baseflow Assessment for Wollombi Brook

As bores PZ8 and PZ9 (S and D) are located approximately 2.5 km upstream of Station 210028 (Bulga), and bore PZ7S is located over 3 km upstream of Station 210004 (Warkworth), the river bed elevations next to the bore sites were estimated using LIDAR data. Within the PZ8/PZ9 area the river bed level is approximately 60.5 mRL, and within the PZ7 area the river bed level is approximately 52 mRL. Based on these river bed elevations, Wollombi Brook within the PZ8/9 area appears to be a gaining system. However, at the downstream PZ7 site the groundwater levels are close to or slightly below river levels, indicating a slightly losing stream system where the alluvium is potentially recharged by Wollombi Brook. This is supported by water quality results, with brackish water quality within the alluvium at PZ7S, compared to the naturally saline water quality at PZ8S and PZ9S (see Section 5.8).

5.8. Water Quality

Groundwater quality has been measured at MTW since 1993. Appendix B summaries the water quality data and includes the median, 5th percentile and 95th percentile for each bore for the following parameters:

- pH - laboratory data from 1993 to 2002 and field data from 2002 to 2013;
- electrical conductivity (EC) - laboratory data from 1993 to 2002 and field data from 2002 to 2013; and
- major ions (calcium, magnesium, potassium, sulphate, phosphate and sodium).

The results show a degree of variability within and between each stratigraphic unit. The alluvium records from both the Hunter River and Wollombi Brook alluvium show relatively saline water quality, while the underlying Redbank Creek Seam generally records moderately saline groundwater. The deeper coal seams (i.e. Blakefield, Woodlands Hill, Bowfield, Warkworth, Vaux and Bayswater seams) also record saline groundwater. Results for the Wollombi Brook, presented by WRM (2014a), show slightly brackish water quality.

Figure 5.10 shows a Schoeller plot for the alluvium and Permian stratigraphy, based on historic (1993 – 2013) water quality data collected at MTW. Figure 5.10 also shows Wollombi Brook median water quality data (collected by WRM, 2014a) and recent (20/2/2014) spoil water quality data collected by AGE from bore MTO634[2].

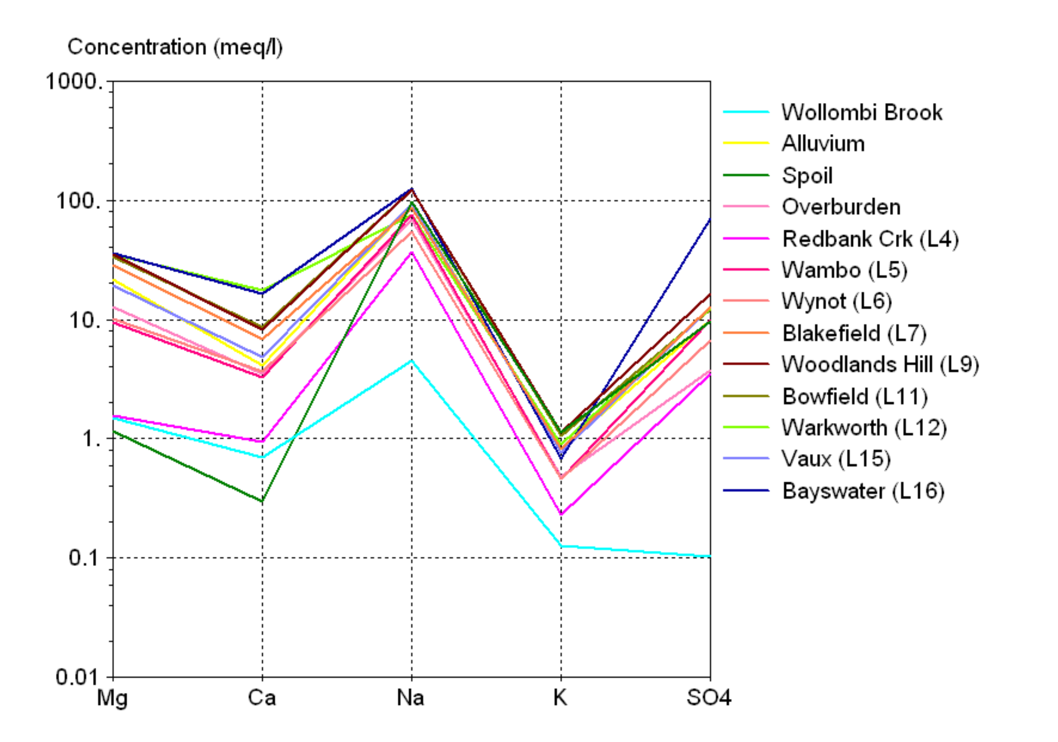


Figure 5.10: Schoeller plot of typical alluvium or seam chemistry

The Schoeller diagram compares chemistry from different samples; similar shaped lines from multiple samples indicate a similarity in origin and vertical displacement of similar lines indicates dilution with fresh water (resulting in downward shift in the line) or concentration/evaporation (resulting in an upward shift).

Figure 5.10 shows that, as expected, the Wollombi Brook has the lowest ion concentrations whilst the deeper Permian coal seams have the highest. The Permian samples have a similar signature indicating similar groundwater provenance. The samples from the spoil show lower concentrations of Mg and Ca compared to the Permian units, indicating potential dilution from rainfall recharge through the more porous spoil material.

5.9. Groundwater Users

AGE (2010) assessed groundwater usage from the groundwater systems by reviewing data held on the NSW Government groundwater database, and by conducting a bore census on private landholdings to the west of the mine. It was also identified during the bore census that bore GW44529 (shown in Figure 5.11) is abandoned, bores GW017462 and GW066590 are located on land owned by MTW, and bore GW080964 is a NOW groundwater monitoring bore.

[2] MTO634 was completed in late 2013 directly downgradient of the CRTSF in MTO, the bore was sampled in early 2014.

During the bore census ten bores were visited to the north of the village of Bulga, locations of the bores are shown in Figure 5.11 and findings are detailed in Table 5.2. The census found that nine of the 10 sites were relatively shallow, at about 14 m or less in depth, indicating that these bores are likely to be constructed in the alluvial sediments. Three bores with a depth greater than 60 m are probably constructed in the underlying bedrock. Comparison of the registered bore details and the bore census findings indicates that two of the registered bores were not identified in the field and may be abandoned or destroyed. Four additional bores were also identified, which are likely not registered.

An updated search of the NSW Government 2013 version of PINEENA groundwater database outlined no new bores within the study area since 2010.

Table 5.2: AGE (2010) LANDHOLDER SURVEY FINDINGS

Registered Number	AGE (2010) census ID	Depth (mbgl)	Easting	Northing	Owner
GW047667	112-W	9.25	313729	6386469	Laurie & Rhonda Caban
GW078782	128-B	12.15	313408	6386512	Laurie & Rhonda Caban
GW078806	140-W	2.84	313439	6386593	Greg Caban
GW065097	177-W	11.85	313073	6386604	Greg Banks
GW078031	248-B	11.65	313298	6387553	Paul Dunn & Susan Irwin
GW078029	89-B	23.62	313446	6386014	Ian & Annette Bartholomew
Not identified in the field survey					
GW066607	-	6.7†	313269‡	6386399‡	-
GW071569	-	14.6†	313169‡	6387568‡	-
No identifiable registration number					
	138-W	11.82	312996	6386427	Greg Banks
-	217-B	100	313234	6387612	George & Honor Lianos
-	217-W	60	313228	6387595	George & Honor Lianos
-	129-W	100	313233	6386442	Damien & Danielle Hanson

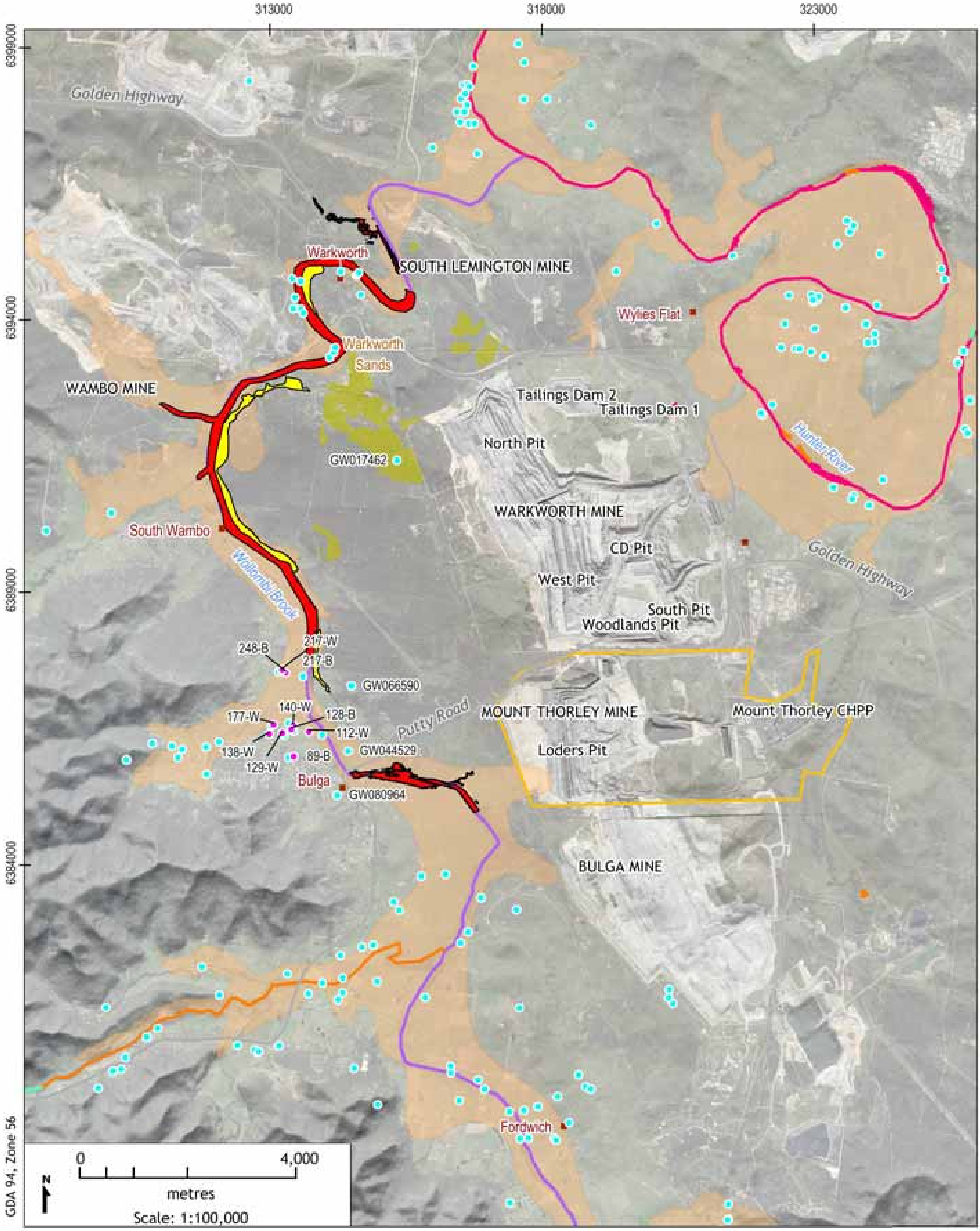
Note: *Coordinates in MGA 94 Zone 56 (field data collected from handheld GPS)*
† Depth from groundwater database (PINEENA)
‡ Coordinates from groundwater database (PINEENA)

5.10. Groundwater Dependent Ecosystems

Aquatic or specifically Groundwater Dependent Ecosystems (GDEs) are defined as *"communities of plants, animals and other organisms whose extent and life processes are dependent on groundwater"*. The Project area has historically been partially cleared of vegetation and used for grazing; however, the southern portion of the Project area remains largely vegetated.

The Federal Government has established the National Atlas of GDEs (GDE Atlas), based on the current knowledge of GDEs across Australia. The atlas shows known GDEs and ecosystems that potentially use groundwater, and is considered the most comprehensive inventory of the location and characteristics of GDEs in Australia. The GDE Atlas (Figure 5.11) shows that are known GDEs identified by previous fieldwork along Wollombi Brook. There are also areas identified as having a moderate to high potential for groundwater interaction.

Cumberland Ecology (2010) identified two potentially groundwater dependent vegetation communities along Wollombi Brook. These were the Hunter Valley River Oak Forest and the River Red Gum Floodplain Woodland which are in a thin riparian zone along Wollombi Brook about 4 km from the mining areas, as shown in Figure 5.11.



LEGEND:

- Proposed MTO development consent boundary
- Private Bore (Pineena 2013)
- Bore Census (AGE 2010)
- Road
- Warkworth Sands Woodland
- Alluvium
- Place Name

GDE Atlas - Surface Expression

- High potential for GW interaction
- Moderate potential for GW interaction
- Low potential for GW interaction
- Identified in previous study: fieldwork

Potential Groundwater Dependent Ecosystems

- Hunter Valley River Oak Forest
- River Red Gum Floodplain Woodland

Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

Groundwater Users and GDEs

DATE: 14/5/2014

FIGURE No: **5.11**

6 POLICY AND LICENSING REQUIREMENTS

Groundwater associated with coal measures is governed under the (NSW) *Water Act 1912* (Water Act), while the NSW *Water Management Act 2000* (WM Act) regulates the use and interference with surface water and alluvial groundwater in the region.

6.1. Water Act 1912

The Water Act governs water licences from water sources including rivers, lakes and groundwater aquifers in NSW. It also manages the trade of water licences and allocations. The Water Act is progressively being replaced by the WM Act, with water sharing plans in place, except for Permian groundwater sources.

6.2. Water Management Act 2000

The objectives of the WM Act include the sustainable and integrated management of the State's water for the benefit of both present and future generations. The WM Act provides clear arrangements for controlling land based activities that affect the quality and quantity of the State's water resources. It provides for three types of approvals:

- *Management works approvals:*
  - water supply work approval;
  - drainable work approval; and
  - flood work approval (Section 90 WM Act)
- *Water use approval – which authorises the use of water at a specified location for a particular purpose, for up to 10 years (Section 89 WM Act);*
- *Activity approvals comprising:*
  - controlled activity approval; and
  - aquifer interference activity approval – which authorises the holder to conduct activities that affect an aquifer such as approval for activities that intersect groundwater, other than water supply bores and may be issued for up to 10 years (Section 91 WM Act).

The proposal relates to an amendment to mine scheduling, and does not include any new disturbance areas. However, this groundwater assessment addresses the potential impact of a more prolonged mine schedule on the groundwater regime.

6.2.1. Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources

The main tool in the WM Act for managing the State's water resources are water sharing plans. These are used to set out the rules for the sharing of water in a particular water source between water users and the environment and rules for the trading of water in a particular water source. The Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources (henceforth referred to as the Water Sharing Plan) commenced on 1 August 2009. The Water Sharing Plan includes the Hunter unregulated rivers and creeks, the highly connected alluvial groundwater above the tidal limit, and tidal pool areas. A licence holder's access to water is managed in the water sharing plan through the long-term average annual extraction limit which sets the total annual extraction rate through daily access rules.

The long term limit is a management tool against which total extraction will be monitored and managed over the 10-year life of the plan. The rules in the plan that determine when licence holders can and cannot pump on a daily basis are more specific. Basic landholder rights do not require a water access licence. However, water access licences are required for mining activities where these activities intercept an unregulated river or connected aquifer water.

6.3. Aquifer Interference Policy

In September 2012 NOW released the AIP, which covers water licensing and assessment processes for aquifer interference activities within NSW. The AIP addresses the 'incidental' take of groundwater from significant developments such as mines, which is not accounted for in the Water Act or WM Act. The AIP ensures that all take of groundwater is accounted for, to ensure Water Sharing Plans function effectively.

The AIP forms the basis for assessment of aquifer interference activities under the EP&A Act. It clarifies the need to hold water licences under the WM Act and Water Act and establishes whether 'minimal impact' occurs. The policy addresses any activity which involves any of the following:

- penetration of an aquifer;
- interference with water in an aquifer;
- obstruction of the flow of water in an aquifer;
- taking of water from an aquifer in the course of carrying out mining or any other activity prescribed by the regulations; and
- disposal of water taken from an aquifer in the course of carrying out mining or any other activity prescribed by the regulations.

The AIP outlines highly productive and less productive groundwater sources, as well as high and minimal impact interference activities. The alluvial aquifers associated with Wollombi Brook and the Hunter River are both potentially highly productive aquifers, while low permeability units and saline groundwater within the Permian coal measures are classed as a less productive groundwater source. Section 7 addresses the key groundwater related requirements of the AIP processes.

7 MODELLING APPROACH

A numerical groundwater flow model was used to assess the potential influences of the proposal on the groundwater regime. The impacts of the proposed mining are described in this section, with the technical details on the modelling included in Appendix C.

In summary, the potential influences were assessed by:

- developing a numerical model using the available information on the hydrogeological regime (refer Section 0);
- calibrating the model using available historical mine stresses at MTW, Bulga and Wambo (1980 to 2013), groundwater levels and stream flows recorded in the area (refer Appendix C);
- assessing the uncertainty and variability in the calibration by running multiple models with randomly generated parameters held within measured and realistic bounds (refer Appendix D);
- simulating the drawdown and water take of the proposed mining from 2015 to the end of 2035;
- assessing the uncertainty and variance in the predictions (refer Appendix D); and
- simulating recovery of the groundwater system after mine decommissioning for an additional 1000 years.

The impacts of the proposal were simulated by running the following two modelling scenarios:

1. The first model included all the mining associated with the proposal, being continued mining of Loders and Abbey Green North Pits, and all other mining activities within the model domain; and
2. The second model included all surrounding mining (Warkworth, Bulga and Wambo mines), but excluded the mining operations associated with the proposal.

The model addresses the requirements of the NSW AIP by estimating the:

- volume of water inflow from the Permian strata and coal seams;
- drawdown induced in the Permian strata and coal seams;
- potential for drawdown and groundwater extracted from alluvial aquifers;
- potential for changes in baseflow to Wollombi Brook and the Hunter River;
- potential drawdown of groundwater levels in surrounding private landholder bores; and
- changes in groundwater salinity.

Recent water level data has been collected from the MTW groundwater monitoring network, as well as from new bores installed since the original model by AGE (2010). This data was utilised to gain a good understanding of the groundwater regime within the proposal area, which is detailed under Section 5. The numerical model has been refined based on this newly collected data, and from peer and independent reviews, creating a robust representation of the local groundwater regime.

As the groundwater regime has been highly modified by mining activities, the model was first used to simulate the approved and historical mining. This then provided the appropriate antecedent conditions prior to the assessment of the current proposal.

Dr Frans Kalf reviewed the modelling work a key stages during the project, and reported on the applicability of the modelling.

7.1. Numerical Model Development

A numerical model using the MODFLOW SURFACT software was developed to assess the impact of the proposed mining on the groundwater regime. The model developed by AGE (2010) formed the basis of the numerical model, but a number of changes were implemented to improve the predictive capability of the model including:

- representing the gradual development and recharge process through the spoil piles;
- adding the existing and proposed tailings storage facilities;
- increasing the number of layers to better represent the coal seams and interburden units; and
- conducting a transient calibration using water level data from the monitoring bore/VWP network.

The 16 layer model simulates the key features in the local groundwater regime including the alluvium associated with Wollombi Brook and the Hunter River, the layered interburden and coal seams of the Permian coal measures, as well as the underlying and unmined Permian coal seams. The active model domain, shown in Figure 7.2, covers an area of approximately 344 km^2 and is approximately 19 km (from west to east) and 24 km (from north to south). The model domain encompasses MTW, as well as the Bulga and Wambo mines. Further details regarding the model construction and design are included in Appendix C.

7.2. Numerical Model Calibration

Appendix C describes the calibration of the model in detail. The appendix provides sufficient information to assess the model performance against the Australian Modelling Guidelines (Barnett *et al* 2012). The model was first calibrated manually by adjusting model parameters and then using software to optimise the calibration. Parameters adjusted during the calibration were intentionally constrained within logical bounds, which in some cases came at the expense of a better statistical fit between model and observed groundwater level data.

The calibrated steady state model simulated as close as possible pre-mining water levels. The water levels generated by this model were then used as the initial conditions for a transient calibration. The transient model simulated the currently approved mining at MTW, Bulga and Wambo for the period 1981 to 2013. The model divided this baseline period into annual stress periods with mines advancing in annual blocks. Recharge to the model was applied as a percentage of annual measured rainfall distributed over zones representing the outcropping alluvium, Permian regolith and emplaced spoil areas. The model represented perennial rivers/streams (using the SURFACT 'River' package) with a constant head set in rivers and ephemeral streams as drains (also using the SURFACT 'River' package).

Appendix C describes in more detail the model set-up, set-up, calibration process and uncertainty analysis. Figure C-11 to Figure C-21 within Appendix C present modelled versus observed water levels for all monitoring bore/VWP sites. Several of the data points presented in these figures were excluded from the calibration process as they appeared in error compared to surrounding data and the conceptualisation. However, for completeness all data supplied by Coal & Allied for the study area has been included in these graphs. Appendix C further discusses the excluded datasets.

7.2.1. Steady State Calibration

The objective of the steady state model calibration was to simulate pre-mining groundwater levels, and to capture natural background conditions for the alluvial aquifer. The groundwater model was calibrated by adjusting aquifer parameters and stresses, within conceptual bounds, to produce the best match between the observed and simulated water levels and fluxes. Figure 7.1 shows the modelled-versus-observed scatter plot for the steady state run.

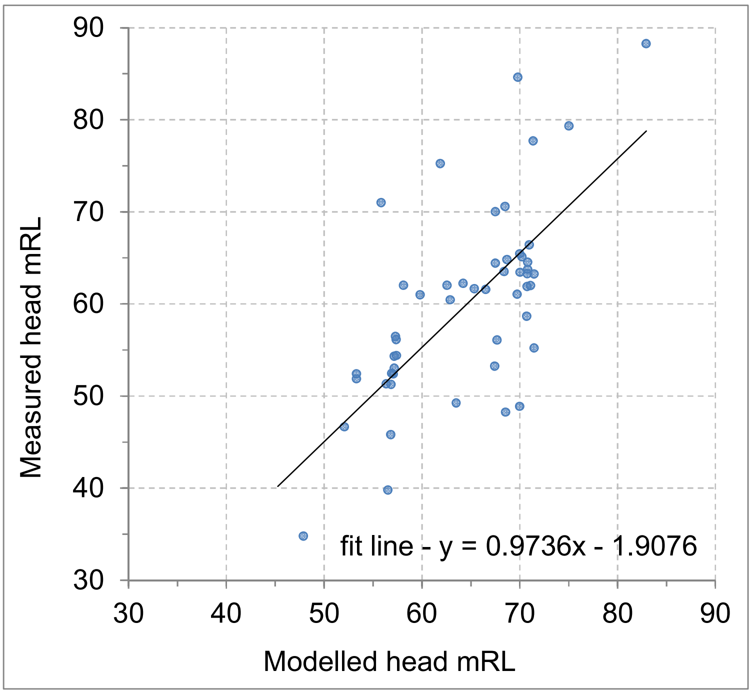


Figure 7.1: Steady state scatter diagram

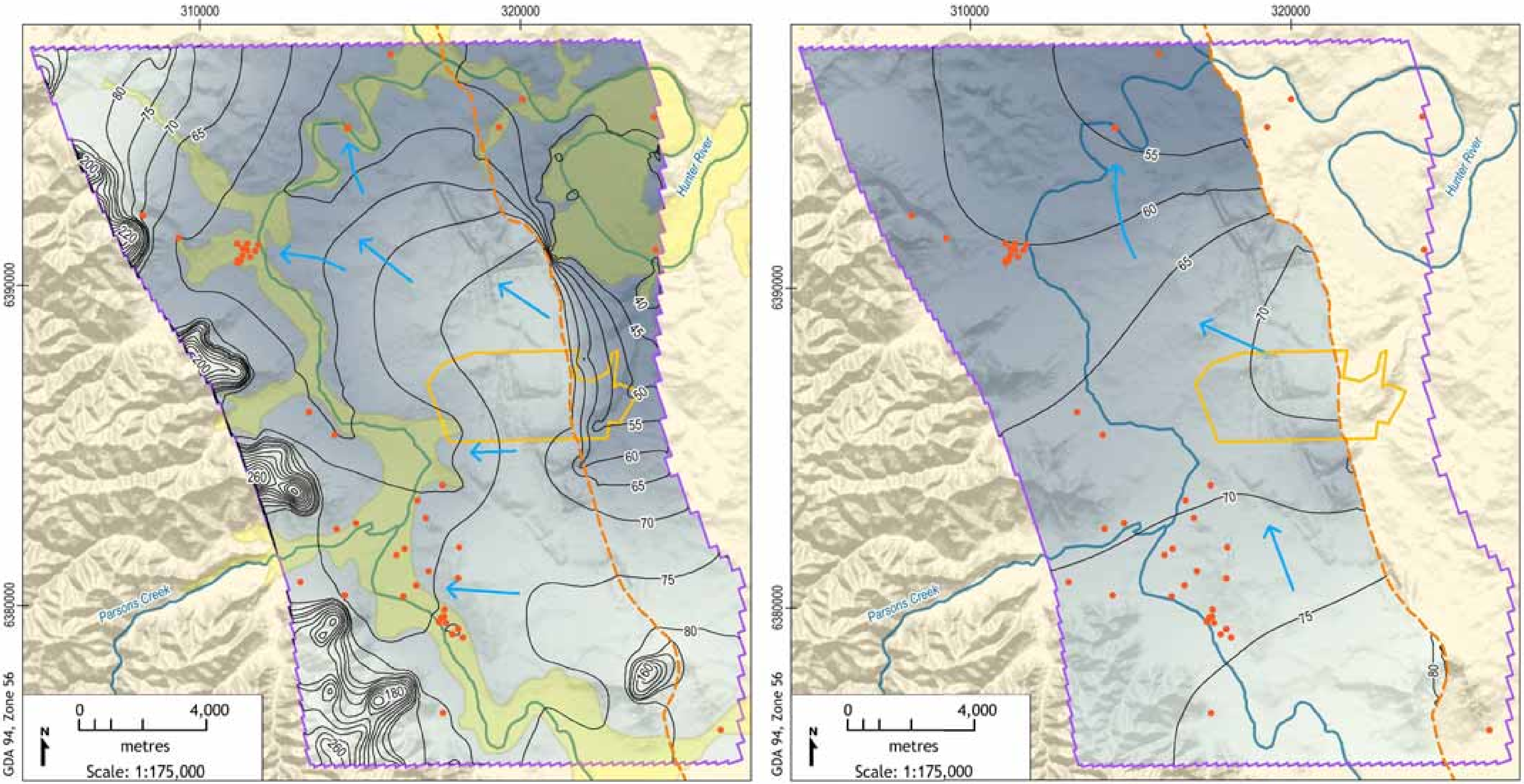
Whilst the measured and simulated water levels do not correlate perfectly, it is important to note the steady state calibration was only used to setup a stable starting water level for the pre-mining period. The suitability of much of the data to adequately represent pre-mining conditions is not known. The calibration process therefore put limited weighting on fitting these points.

Figure 7.2 shows the simulated steady state pre-mining water levels in model Layer 1 and Layer 13. The Layer 1 water levels are a smoothed reflection of topography in the region. A topographic high between MTW and Wollombi Brook is present with water levels reaching 65 mRL. The potentiometric surface within the confined coal sequence shows that groundwater flow is in a generally northerly direction.

The root mean square (RMS) of the steady state model is 9.16 m while the scaled root mean square (SRMS) is 15.7%. This exceeds the 10% suggested by the Australian Modelling Guidelines (Barnett *et al* 2012). However, this steady state calibration is considered adequate given the lack of pre-mining groundwater level data, and an extensive history of mining within the region. The suitability of the model predictions is also further assessed through transient calibration, which provides further measure of the model predictions versus measured groundwater levels.

Steady State Heads - Layer 1 - Alluvium and Regolith

Steady State Heads - Layer 13 - Mount Arthur Seam



LEGEND:

- Proposed MTO development consent boundary
- Active model boundary
- Quaternary alluvium (100k)
- Subcrop of Jerrys Plains Formation
- Steady state observation bore
- Groundwater level contour
- Inferred groundwater flow direction
- Major watercourse

AGE GROUNDWATER & ENVIRONMENTAL

Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

Steady State Heads
Start of Transient Calibration
Layer 1 and Layer 13

DATE:
14/5/2014

FIGURE No:
7.2

7.2.2. Transient Calibration

The hydraulic heads and strata hydraulic properties from the manual steady state calibration provided the starting values for the transient calibration of the model. The steady state calibration was used to establish pre-mining groundwater conditions (to 1980), while the transient calibration was used to establish current groundwater conditions since mining commenced in 1981 until 2014.

Figure 7.3 shows a modelled versus observed transient scatter plot for the transient calibration. Figure 7.4 shows selected representative modelled versus observed hydrographs. Figure 7.5 shows the simulated groundwater levels in Layer 1 and Layer 13 for 2013 at the end of the transient calibrated model run.

The heads are also the starting point for simulating proposed future mining. The zone of depressurisation generated by mining is evident in both water level surfaces. The modelled versus observed transient hydrographs for all monitoring locations show variable fit, from good matches in key monitoring locations near to and beneath Wollombi Brook alluvium, to some significant over and under-prediction in some nested VWP data locations (see Appendix C).

Statistically the overall SRMS of the calibration of 15.1%,is greater than the upper limit of 10% in the Australian Groundwater Modelling Guidelines (Barnett et al 2012). During initial calibration the SRMS was skewed by the density of data from bores with automatic level recorders. Some bores for example have recorded levels every 15 minutes and this led to over representation of these bores within the statistical analysis. In contrast many other bores have only monthly or greater periods of manual dip data available. Bores with high resolution data were resampled to a weekly average prior to final calibration and reporting of statistics.

The SRMS shows statistically what is evident graphically in the hydrographs in Appendix C, that there are some predictions (particularly from VWPs in the Permian strata) significantly different than observed. In general, however, transient modelled head data reflects the zone of depressurisation that is being generated by the active mining. It should also be noted that roughly as many monitoring data points over-predict as under-predict, suggesting the calibration is in middle ground between under- and over-prediction. Figure 7.6 shows the average residual for each monitoring location with red dots showing where the model is over predicting heads and the blue dots are where the model is under predicting. Generally the model over predicts drawdown close to the current mine areas and under predicts effects further to the west. Critically, predictions are good in Layers 1 to 9 around the key assessment location of Wollombi Brook alluvium. Predictions near these key regional assessment location were considered to be more important than localised predictions near the active pit. Even though the model calibration is above the SRMS criteria stipulated in the Australian model guidelines it is still thought an accurate representation of the aquifer system and fit for purpose as a simulator for predictions in this study.

Appendix C discusses in more detail the simulated and measured groundwater levels. A key limiting factor in the calibration is the lack of information on the historical sequence of mining. This, in effect, inputs a further variable into the model that may prevent significant improvement in the current calibration.

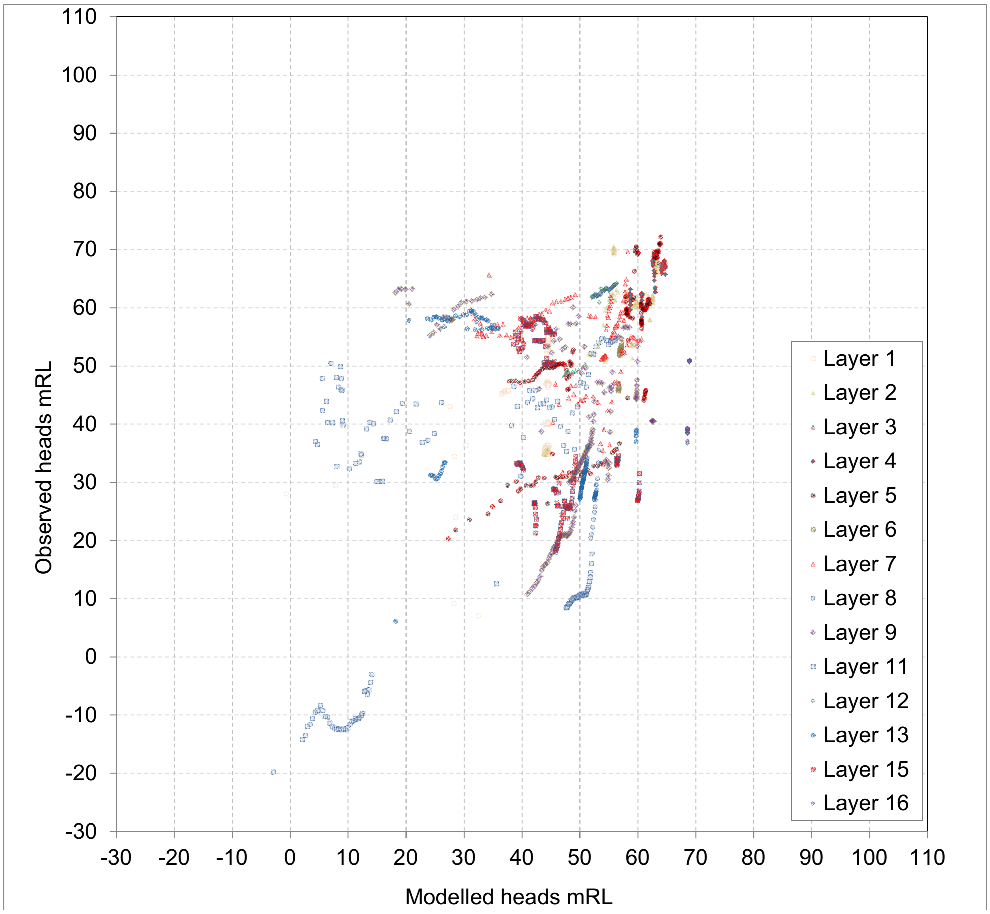


Figure 7.3: Transient scatter plot of modeller versus observed heads

Figure 7.4-A shows example modelled versus observed groundwater heads to the west of the Loders high-wall. The observed data from this site is from a multi-level VWP and shows a significant vertical hydraulic gradient between seams. The observed data in the figure also shows there is higher groundwater pressure in Layer 13 (Mt Arthur Seam) below the base of active mining in Loders Pit, which mines to the base of the Woodlands Hills Seam (Layer 9). The modelled data in Figure 7.4A shows a over-prediction of drawdown in the shallower Layer 5 with an under-prediction of drawdown in Layer 9. Appendix C Figures C-16 and C-17 shows data from other nested monitoring sites west of the Loders pit. Generally there is a under-prediction of drawdowns in deeper coal seams west of the Loders pit compared the monitoring installations west of the Warkworth Mine high-wall to the north.

Figure 7.4-B shows example modelled versus observed groundwater heads from shallow formations to the west of the Loders high-wall. The fit in these shallow alluvium (PZ9S), shallow overburden (PZ9D) and shallow coal seam (G3) is excellent. The fit in data for deeper coal seams monitored close to the Loders Pit high-wall was given less weighting in the calibration compared to these more distal sites close and within Wollombi Brook alluvium. Figure 7.4-B shows the model is predicting effects accurately close to the Wollombi Brook alluvium.

Figure 7.4-C shows example modelled versus observed groundwater heads from bore and geophysics picks of the water table within the Loders pit spoil surrounding CRTSF. See Section 5.3 for further background. The observed data shows groundwater level mounding in the spoil around CRTSF. The observed data was used during calibration to estimate spoil and TSF leakage parameters. The model estimates reasonable fits to water level data within the spoil for the end of the calibration period, no time series groundwater level data within the spoil was available for this study.

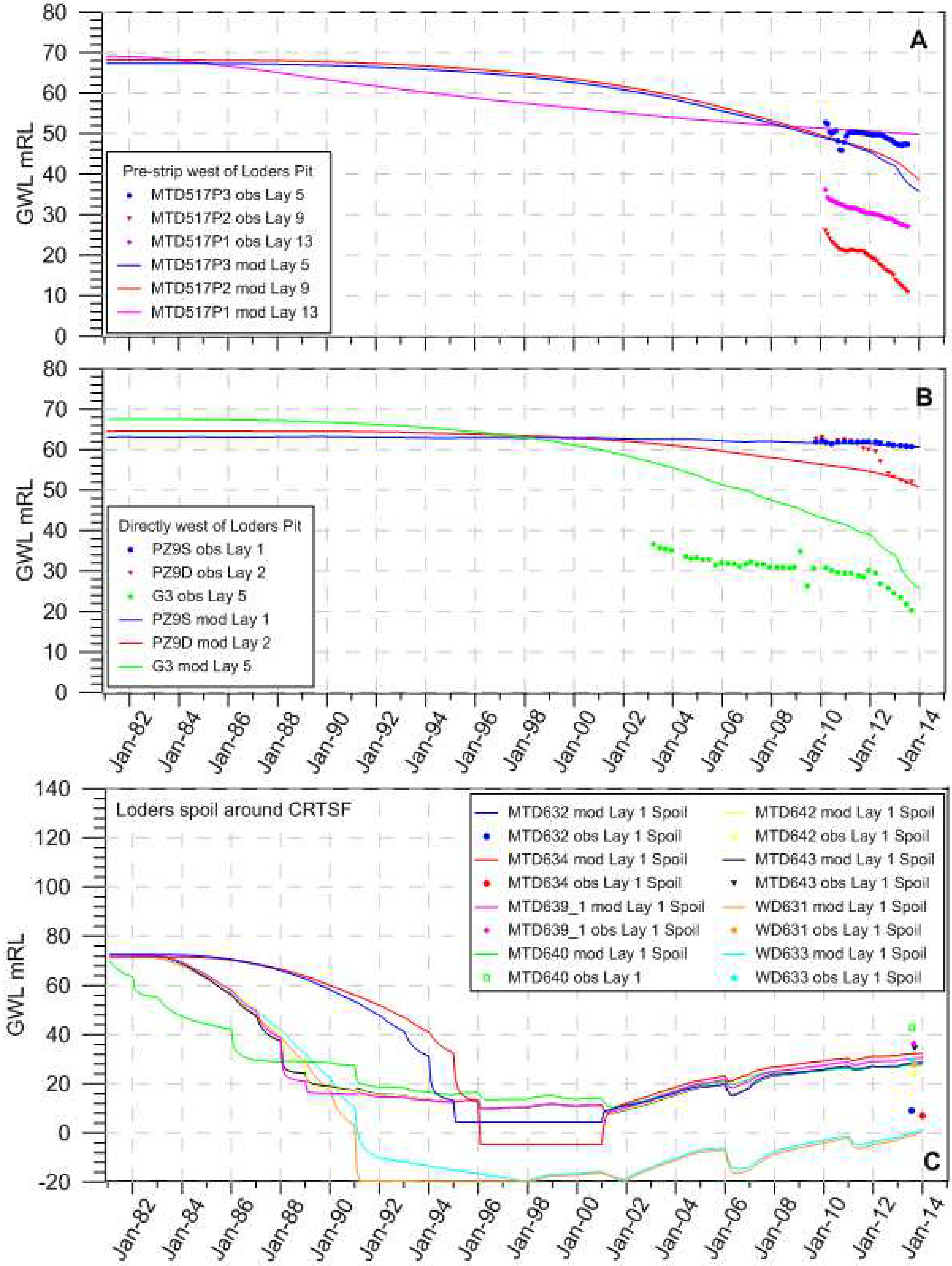
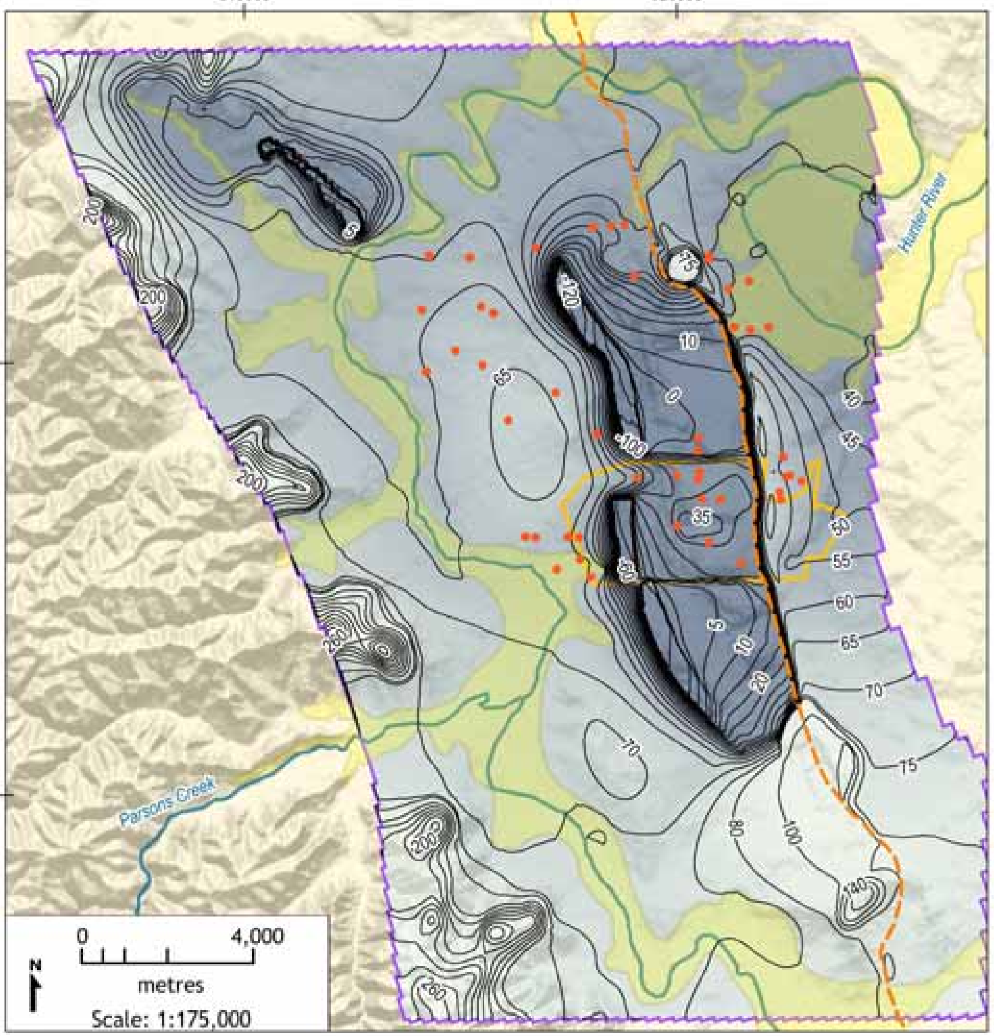
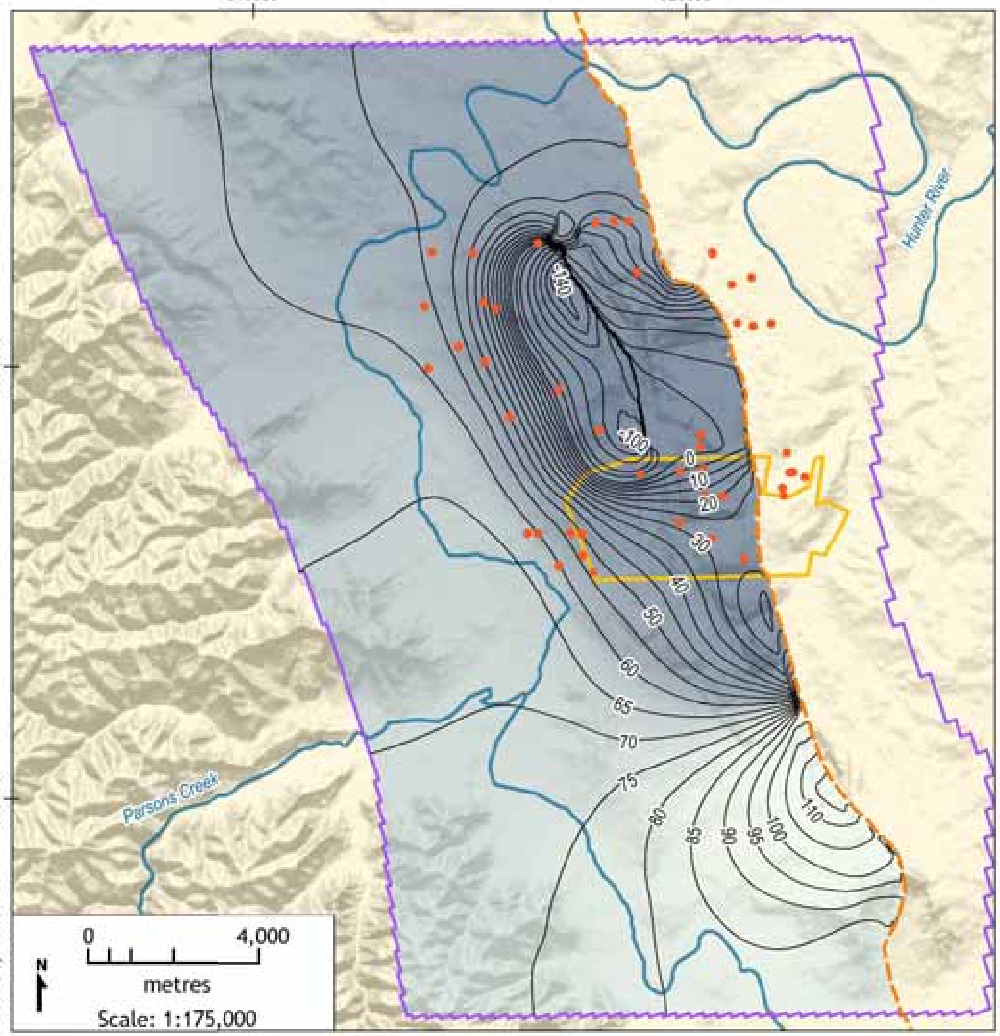


Figure 7.4: Representative transient modelled versus observed hydrographs

Heads - Layer 1 - Alluvium and Regolith



Heads - Layer 13 - Mount Arthur Seam



LEGEND:

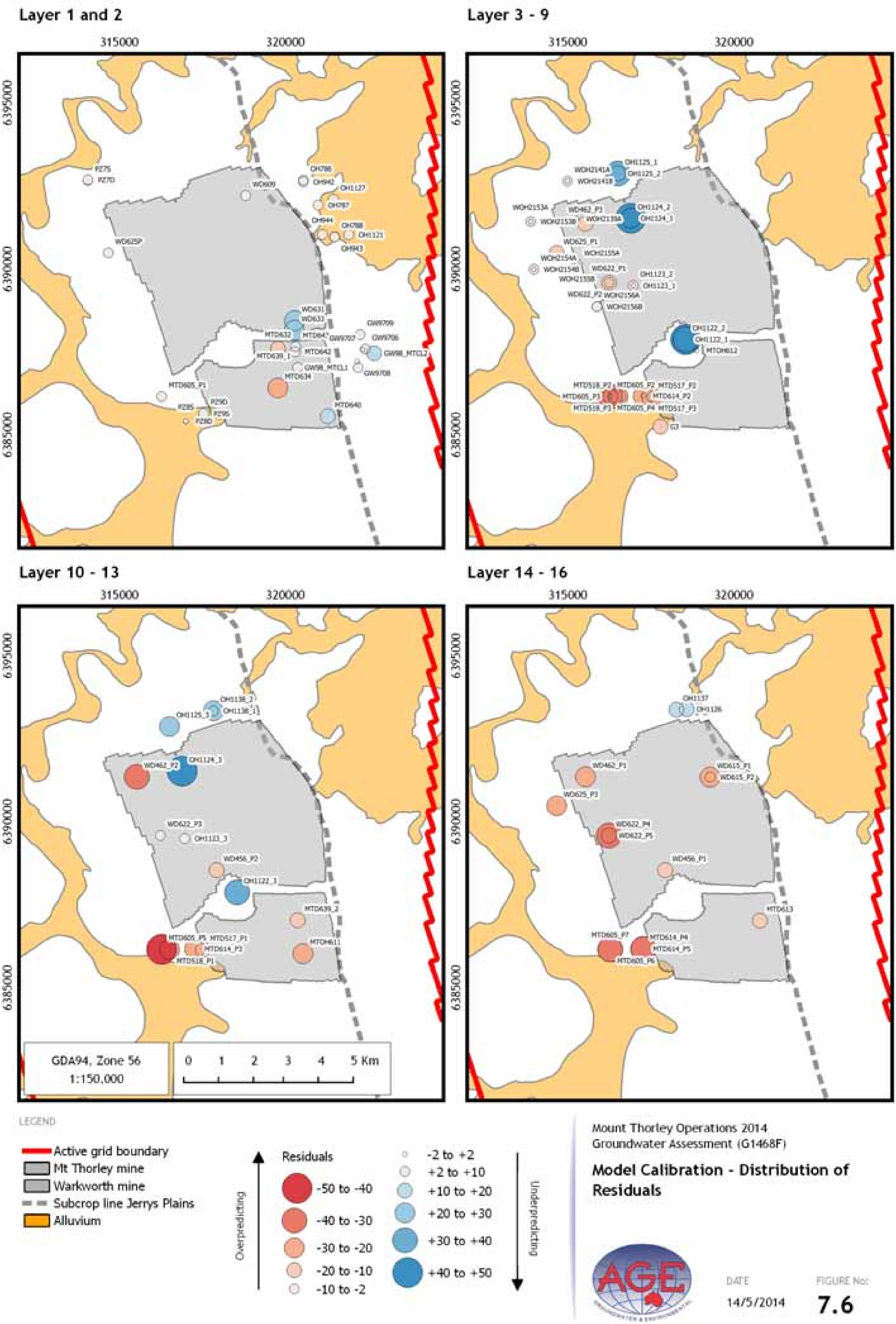
- Proposed MTO development consent boundary
- Active model boundary
- Quaternary alluvium (100k)
- Subcrop of Jerrys Plains Formation
- Transient observation bore
- Groundwater level contour
- Major watercourse

Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

Heads at the End of Calibration Run (Year 2013)

DATE:
14/5/2014

FIGURE No:
7.5



Layer 1 and 2
Layer 3 - 9
Layer 10 - 13
Layer 14 - 16
315000
320000
6395000
6390000
6385000
GDA94, Zone 56
1:150,000
0 1 2 3 4 5 Km
LEGEND
Active grid boundary
Mt Thorley mine
Warkworth mine
Subcrop line Jerrys Plains
Alluvium
Residuals
Overpredicting
Underpredicting
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to -2
-2 to +2
+2 to +10
+10 to +20
+20 to +30
+30 to +40
+40 to +50
Mount Thorley Operations 2014
Groundwater Assessment (G1468F)
Model Calibration - Distribution of Residuals
AGE
DATE
14/5/2014
FIGURE No:
7.6

8 IMPACT ASSESSMENT

The impact of the proposal contribution to the cumulative impact was assessed as the difference between the predictive results for the two model scenarios, as described in Section 7.1. The impacts assessed from the model results include:

- drawdown associated with the proposal;
- magnitude of drawdown on private landholder bores ;
- magnitude of drawdown and water take from the alluvium of Wollombi Brook and Hunter River;
- changes to stream baseflow and salinity;
- negative influence on GDEs;
- inflow rates into the MTO Loders Pit;
- implications for groundwater licensing;
- post mining recovery, including final void water levels; and
- water quality and leachate migration from mine spoil and TSFs.

8.1. Results of the Predictive Model Run

8.1.1. Water Levels and Drawdown

Figure 8.1, Figure 8.2 and Figure 8.3 show simulated water levels and drawdown at the end of proposed mining for:

- Layer 1 - alluvium and shallow regolith;
- Layer 9 - Woodlands Hill coal seam - base of MTO; and
- Layer 13 - Mt. Arthur coal seam - base of Warkworth Mine.

Figure 8.1 shows the extent of the drawdown in the water table associated with the proposal. This represents the component of drawdown attributable to the proposal. 1 m drawdown contour can be seen to extend primarily within the Permian, although directly west of MTO it does enter the margins of the Wollombi Brook alluvium. The drawdown also extends into the Warkworth Mine to the north, and Bulga Mine to the south, which represents the projects portion of the cumulative impacts attributable to mining.

Figure 8.1 shows a groundwater level mound in Layer 1 at the end of mining in the region of the CRTSF and Loders Tailings Storage Facility (TSF). The groundwater model creates hydraulic gradients and groundwater flows towards the north to the Warkworth Mine but also westerly towards Wollombi Brook. The groundwater levels and gradients at the end of mining indicate a flux of groundwater from the MTO to Wollombi Brook alluvium.

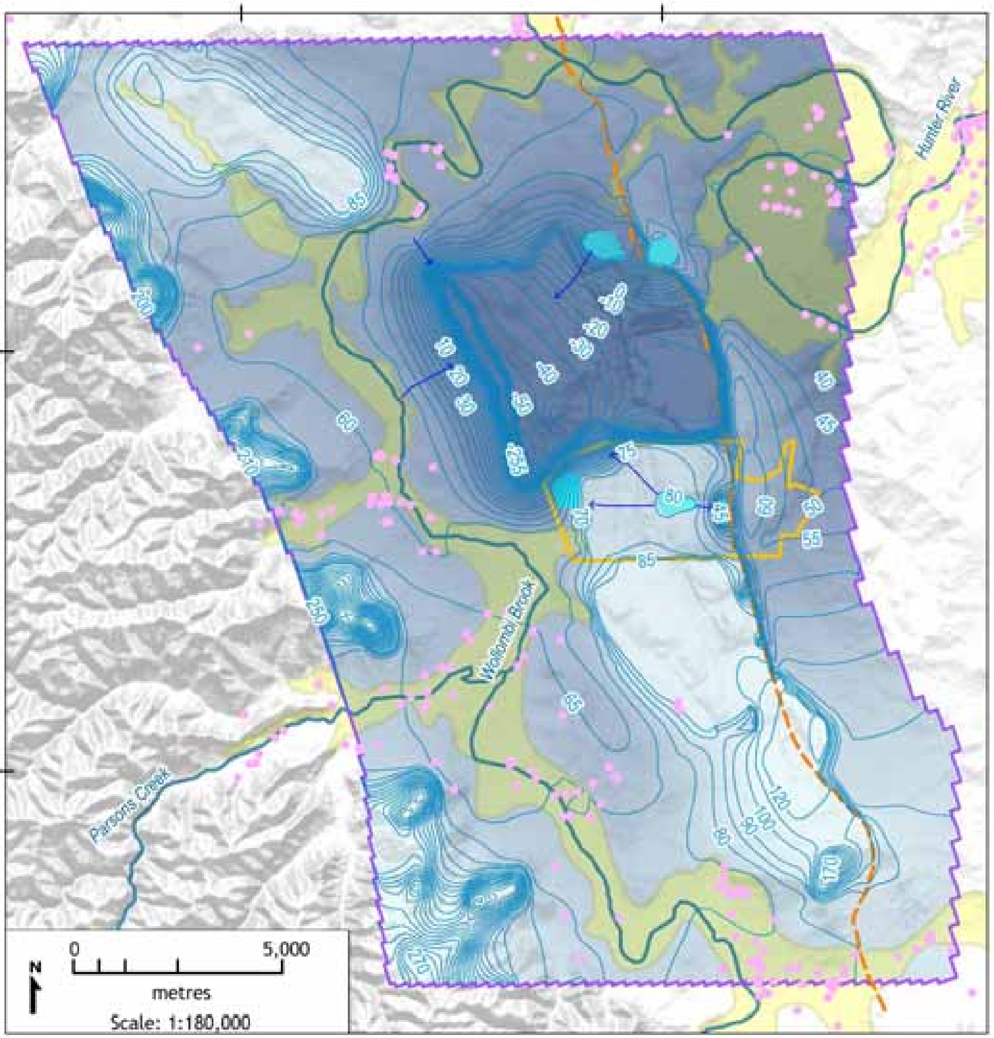
Figure 8.2 shows the drawdown in Layer 9 associated with the proposal representing the Woodlands Hill seam. Figure 8.3 shows the drawdown in Layer 13 associated with The Mt Arthur Seam. The drawdowns in both can be seen to extend west below Wollombi Brook alluvium.

Figure 8.4 shows a schematic cross section west to east at the end of mining (2035) through the Wollombi Brook to CRTSF. The water levels at the end of mining show the small groundwater mound associated with the CRTSF. Figure 8.5 shows a second south west to north east schematic cross section through the proposed Loders TSF.

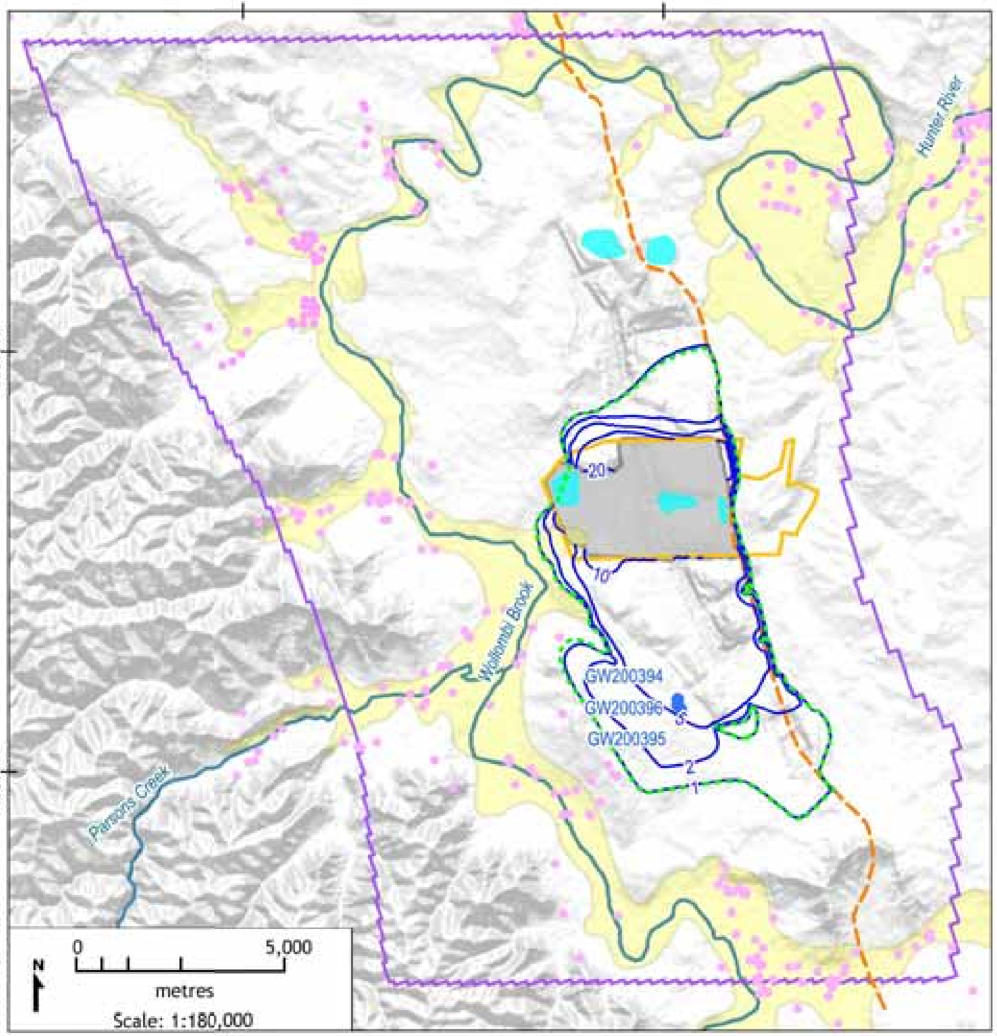
To test if the river boundary conditions used in the simulation buffers and retards the drawdown from moving beyond the simulated rivers a sensitivity model run was completed with no flow[3] set in Wollombi Brook for the 21 year predictive run. Figure 8.1 shows the 1m drawdown contours from this sensitivity simulation are very close to those of the calibrated model. This infers that the calibrated model river simulations do not buffer drawdowns during prediction.

[3] Zero river stage set in river boundaries to simulate the river as a ephemeral stream.

Groundwater Levels - Alluvium/ Regolith (Layer 1) Year 21 (2035)



Change in Groundwater Levels - Alluvium/ Regolith (Layer 1) Year 21 (2035)



LEGEND:

- 5m EOM Groundwater Contours (mAHD)
- Groundwater drawdown contours (m)
- Inferred groundwater flow direction
- 1m drawdown - sensitivity run
- Groundwater users (Pinneena 2013)
- Private groundwater user (predicted drawdown >1m)
- Active model boundary
- Quaternary alluvium (100k)
- Tailings storage facility
- Excavated mine area
- Proposed MTO deveopment consent boundary
- Subcrop of Jerrys Plains Formation
- Major watercourse

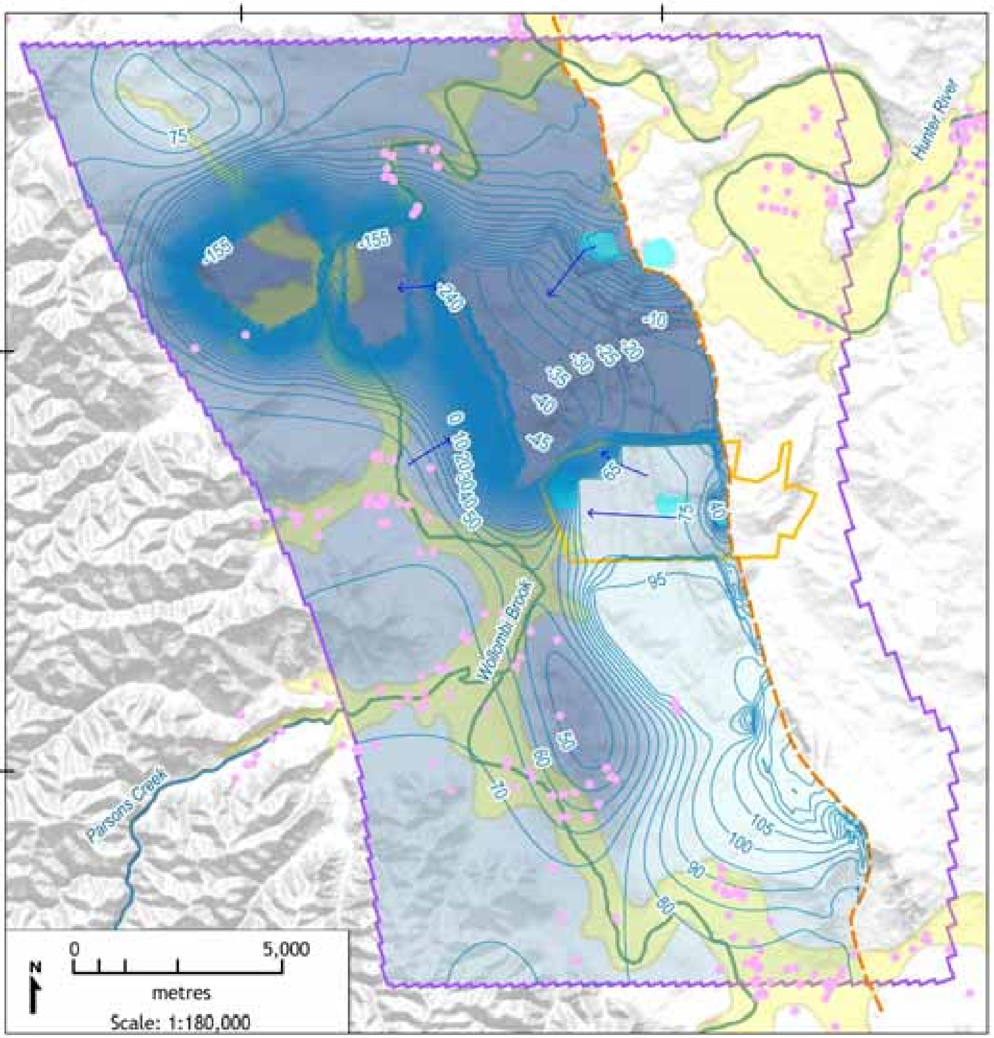
Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

End of Mining Groundwater Levels & Change in Groundwater Levels Layer 1

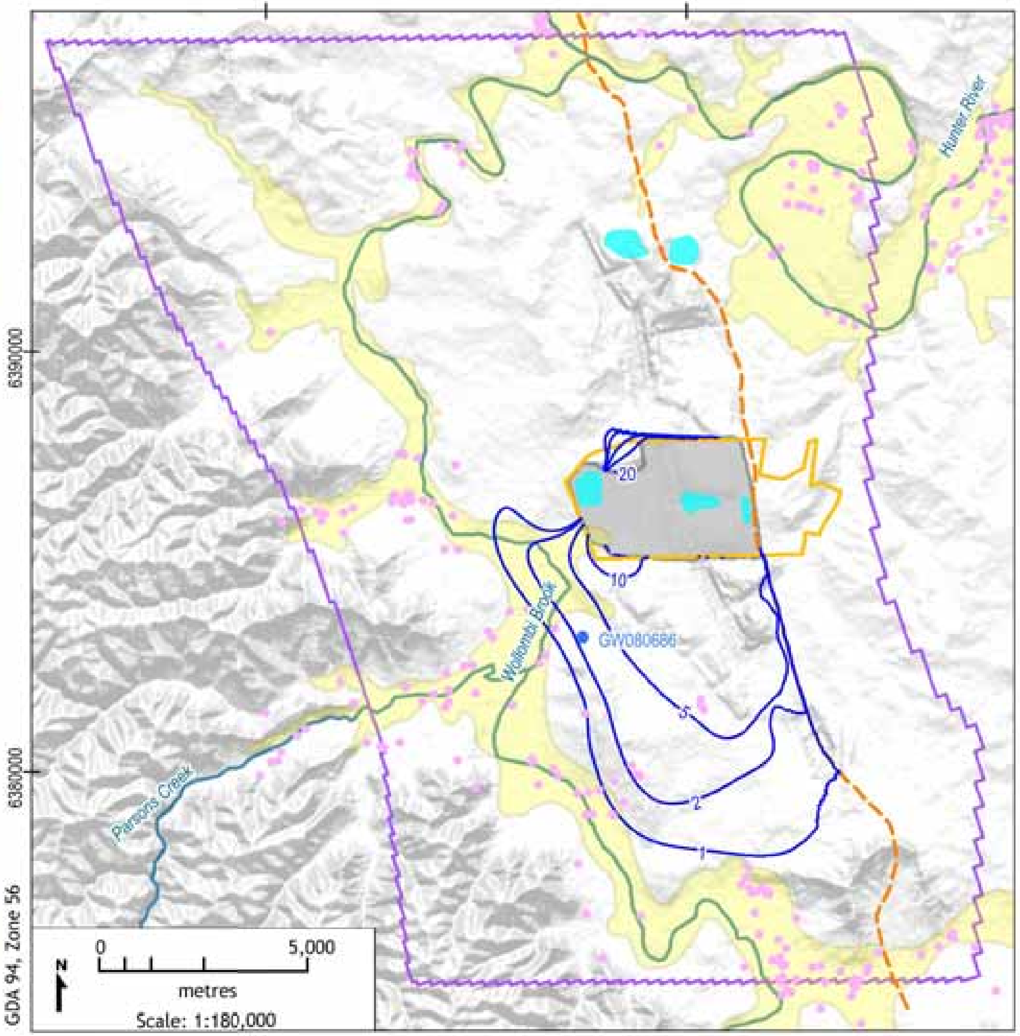
DATE:
14/5/2014

FIGURE No:
8.1

Groundwater Levels - (Layer 9) Year 21 (2035)



Change in Groundwater Levels - (Layer 9) Year 21 (2035)



LEGEND:

- 5m EOM Groundwater Contours (mAHD)
- Groundwater drawdown contours (m)
- Inferred groundwater flow direction
- Groundwater users (Pinneena 2013)
- Private groundwater user (predicted drawdown >1m)
- Proposed MTO deveopment consent boundary
- Active model boundary
- Quaternary alluvium (100k, Layer 1)
- Excavated mine area
- Tailings storage facility
- Major watercourse
- Subcrop of Jerrys Plains Formation

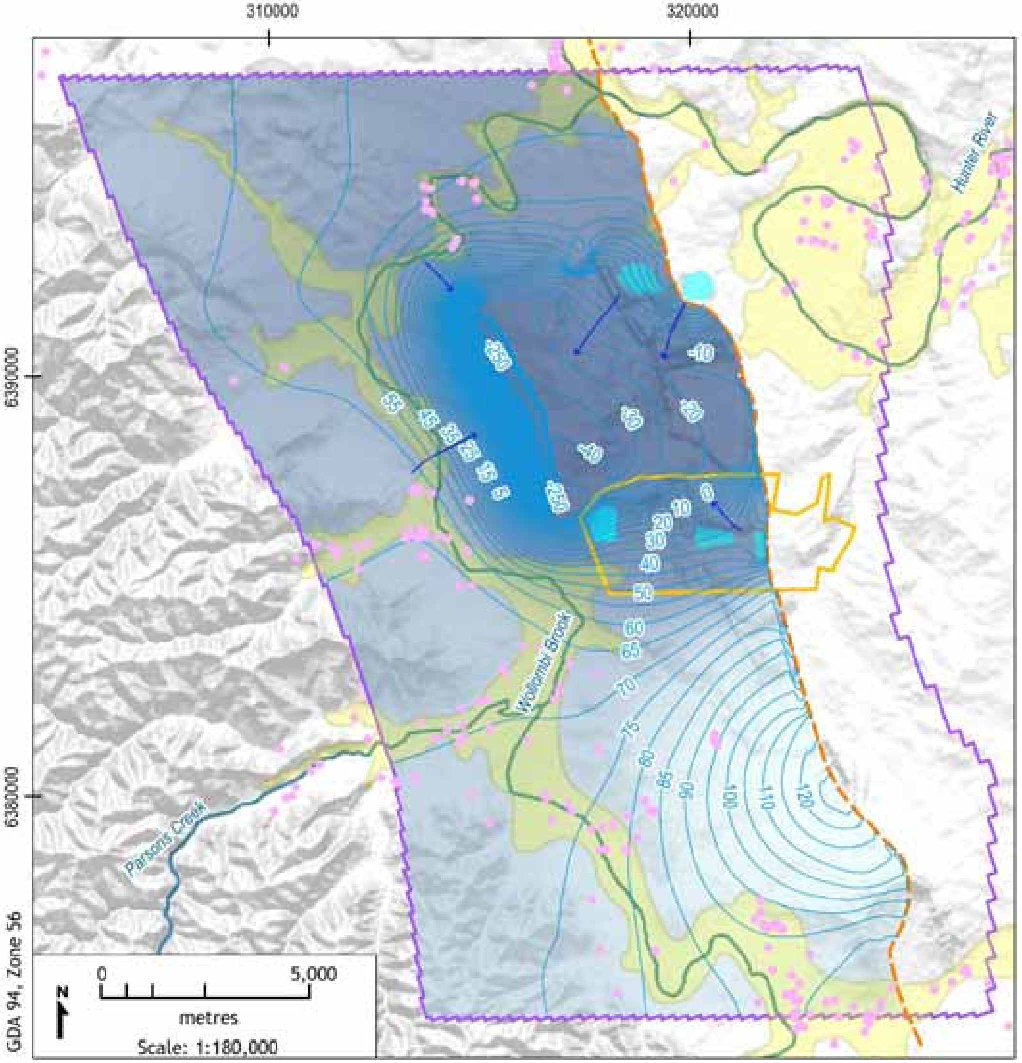
Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

End of Mining Groundwater Levels & Change in Groundwater Levels Layer 9

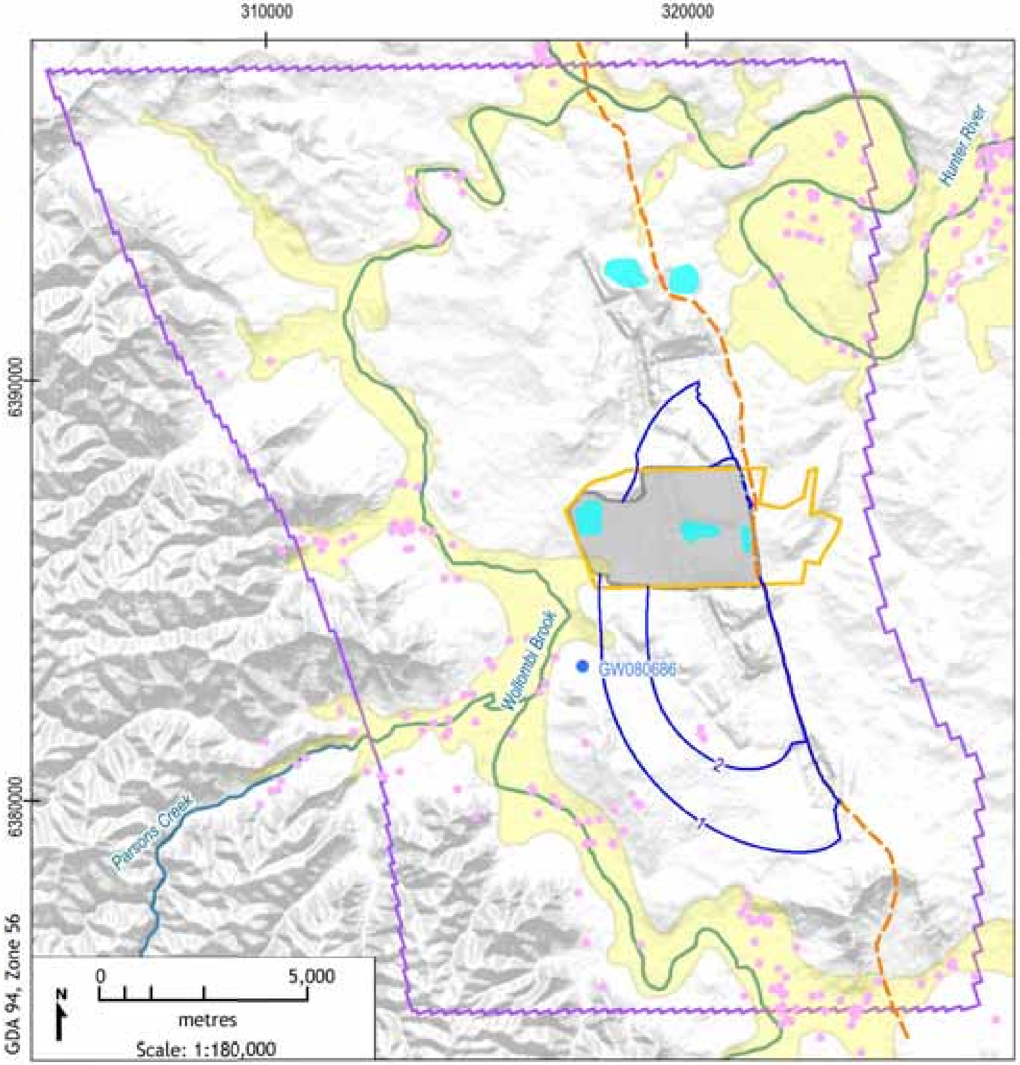
DATE:
14/5/2014

FIGURE No:
8.2

Groundwater Levels - Mt Arthur Seam (Layer 13) Year 21 (2035)



Change in Groundwater Levels - Mt Arthur Seam (Layer 13) Year 21 (2035)



LEGEND:

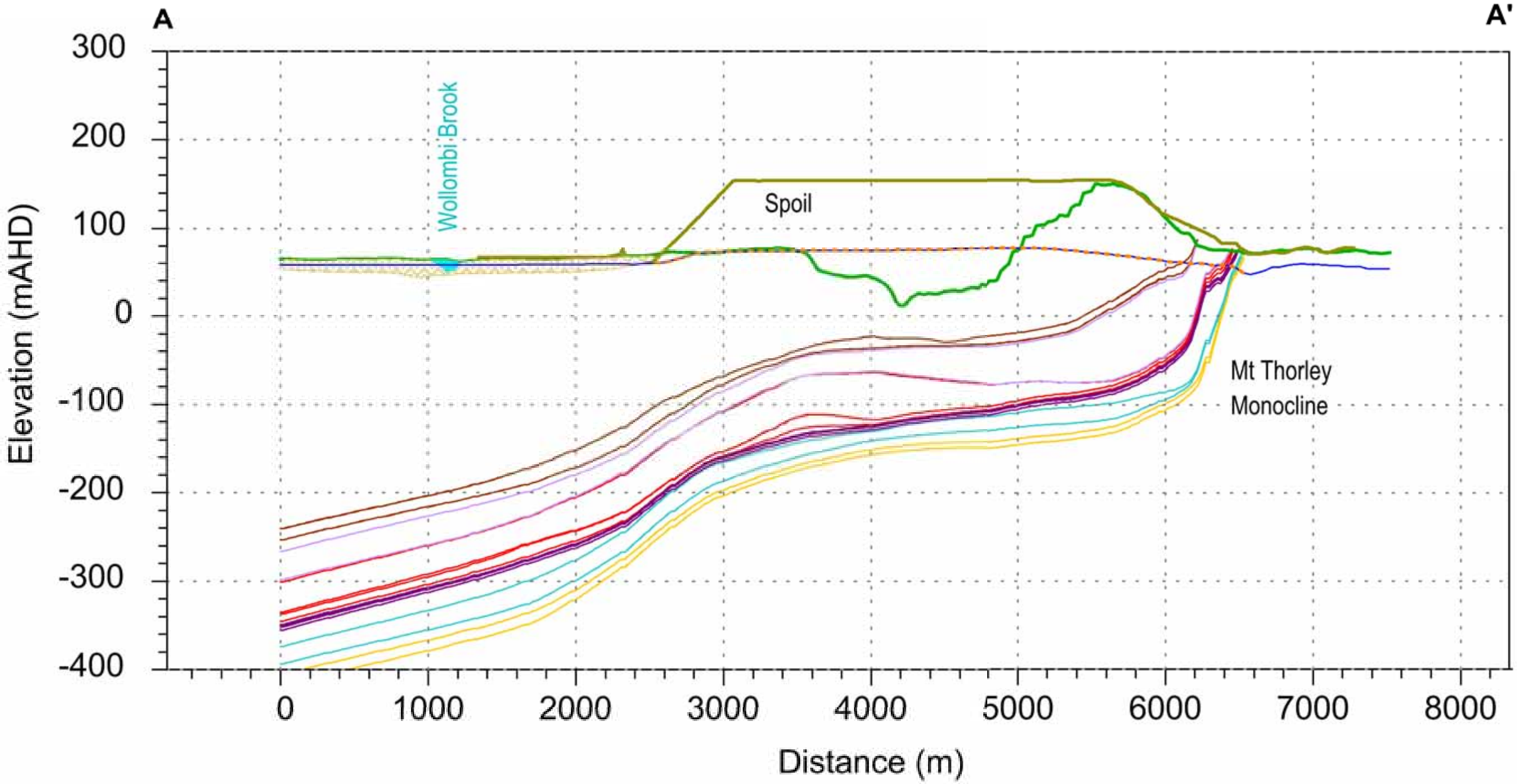
- 5m EOM Groundwater Contours (mAHD)
- Groundwater drawdown contours (m)
- Inferred groundwater flow direction
- Groundwater users (Pinneena 2013)
- Private groundwater user (predicted drawdown >1m)
- Proposed MTO deveopment consent boundary
- Active model boundary
- Quaternary alluvium (100k, Layer 1)
- Excavated mine area
- Tailings storage facility
- Major watercourse
- Subcrop of Jerrys Plains Formation

Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

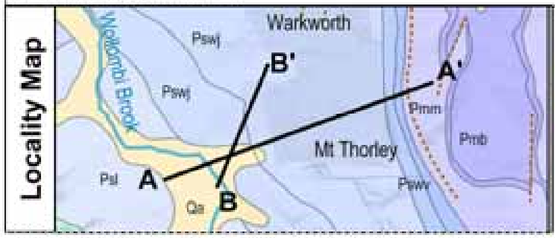
End of Mining Groundwater Levels & Change in Groundwater Levels Layer 13

DATE: 14/5/2014

FIGURE No: **8.3**



(Vertical Exaggeration 1:6)



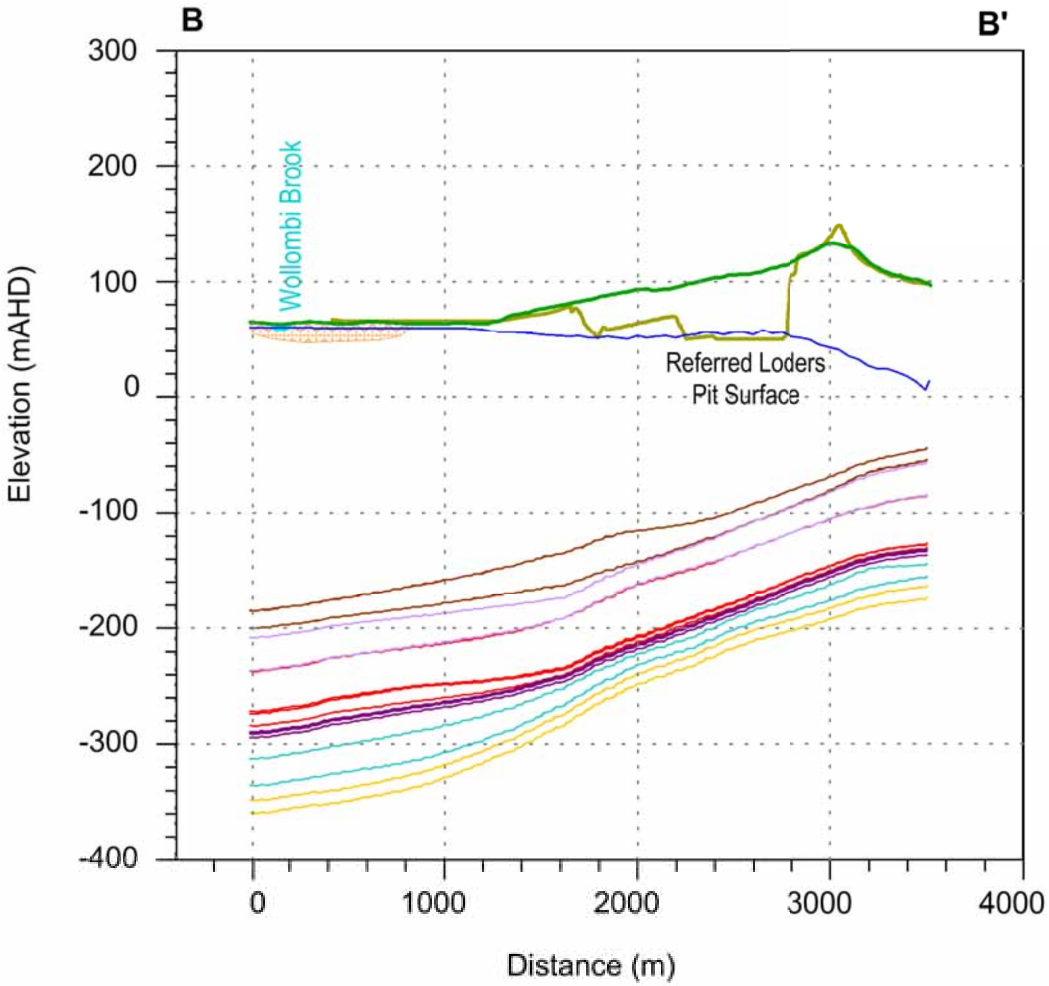
LEGEND:
- Modelled EOM groundwater levels - Layer 1 (mAHD)
- Modelled EOM groundwater mound
- Proposed final landform
- Surface topography
- Arrowfield Seams
- Bowfield Seams
- Alluvium
- Warkworth Seams
- Mt Arthur Seams
- Piercefield Seams
- Vaux Seams

Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

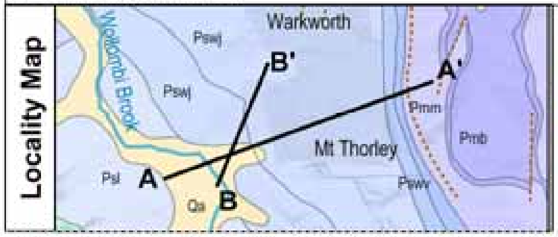
Model End of Mining Groundwater Levels (Layer 1) Mt Thorley Cross-Section (A-A')

DATE: 14/5/2014

FIGURE No: **8.4**



(Vertical Exaggeration 1:6)



LEGEND:
- Modelled EOM groundwater levels - Layer 1 (mRL)
- Alluvium
- Proposed final landform
- Surface topography
- Arrowfield Seams
- Bowfield Seams
- Warkworth Seams
- Mt Arthur Seams
- Piercefield Seams
- Vaux Seams

Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

Model End of Mining Groundwater Levels (Layer 1) Mt Thorley Cross-Section (B-B')

DATE: 14/5/2014

FIGURE No: **8.5**

8.1.2. Impact on Groundwater Users

The AIP stipulates that within highly productive groundwater sources (i.e. alluvial water sources) and less productive sources (i.e. porous and fractured rock) the maximum cumulative drawdown at any water supply bore should not be more than 2 m. Table 8.1 shows the predicted drawdown within the Permian sequence at registered bores where drawdown attributable to the project exceeds 1 m. Table 8.1 also shows the cumulative drawdown at these bores due to all mining projects in the region.

Table 8.1: IMPACTS OF THE MINING ACTIVITIES ON GROUNDWATER USERS

Bore ID	Easting	Northing	Depth	Formation	Owner	Drawdown	
						Proposal component	Total cumulative
GW200394	320338	6381740	20	Permian regolith	Bulga Mine	6.5	13.2
GW200396	320329	6381589	5	Permian regolith	Bulga Mine	5.9	9.8
GW200395	320406	6381484	20	Permian regolith	Bulga Mine	5.7	9.3
GW080686	317535	6383210	na	Permian	Bulga Mine	2.5	19.2

The NOW groundwater database shows a total of four water bores as being present in the Permian strata within the predicted zone where depressurisation attributed to the project exceeds 1 m. None of these bores are private bores used for water supply purposes and are owned by Bulga Mine. There are no bores within the alluvium with predicted drawdown impacts.

The modelling predicts water levels at most of the bores will reduce by less than 1 m due to the proposal. The majority of the private bores are screened in the Wollombi Brook alluvium, which experiences less drawdown than the Permian sequence due to the buffering effect of diffuse rainfall recharge and stream bed leakage. The pumping yield of private bores will not be affected by the proposal.

As detailed above, the AIP requires that aquifer interference activities do not induce a decline of more than 2 m in the water table or water pressure at any water supply work, (i.e. a bore or a well) in both highly and less productive groundwater sources. The modelling predicted no drawdown in any private bores within alluvium. Groundwater level declines of over 2 m in Permian units are predicted at four monitoring bores at Bulga Mine (see Table 8.2). However, as there are no predicted impacts on private water supply bores, this condition of the AIP is met.

8.1.3. Impact on Alluvium

In the early years of the calibration model, i.e. the 1980s, the model predicts there is a net upward flow entering the alluvium from the Permian formations across the whole model domain. As mining operations in the region expand over time, the Permian strata depressurises within the zone of influence, will decrease upward flow of groundwater from the Permian to the alluvium. As water quality within the Permian stratigraphy is brackish to saline, a reduction in upward flow will consequently reduce the salinity levels within the alluvium.

Two model runs were used to estimate the change in groundwater flow from the Permian to the alluvial aquifers. The first run was a simulation without mining at MTO, and therefore only included the surrounding mining zones, while the second run included mining under the proposal as well as the surrounding mining zones. The change in flow contribution from the Permian to the alluvial aquifer was then calculated by extracting alluvium zoned cell-by-cell flow data for each stress period from the “mine proposal” and “no mine” scenarios.

Figure 8.6 shows the predicted additional take from Wollombi Brook alluvium and Hunter River alluvium resulting from the proposal. The simulation shows a gradual increase in take from the Wollombi Brook alluvium to a peak calculated take of 532 m^3/day at year 2019 which corresponds to the final year of active mining simulated in Loders Pit. As spoil is placed in Loders Pit after 2019 a reduction in calculated take from the Wollombi alluvium occurs, with the long term rate of 320 m^3/day at year 2035. Take from the Hunter River alluvium is undetectable.

In summary the maximum additional take associated with the proposal from the Wollombi Brook alluvium (at year 2019) is estimated at 195 ML/yr (532m^3/day).

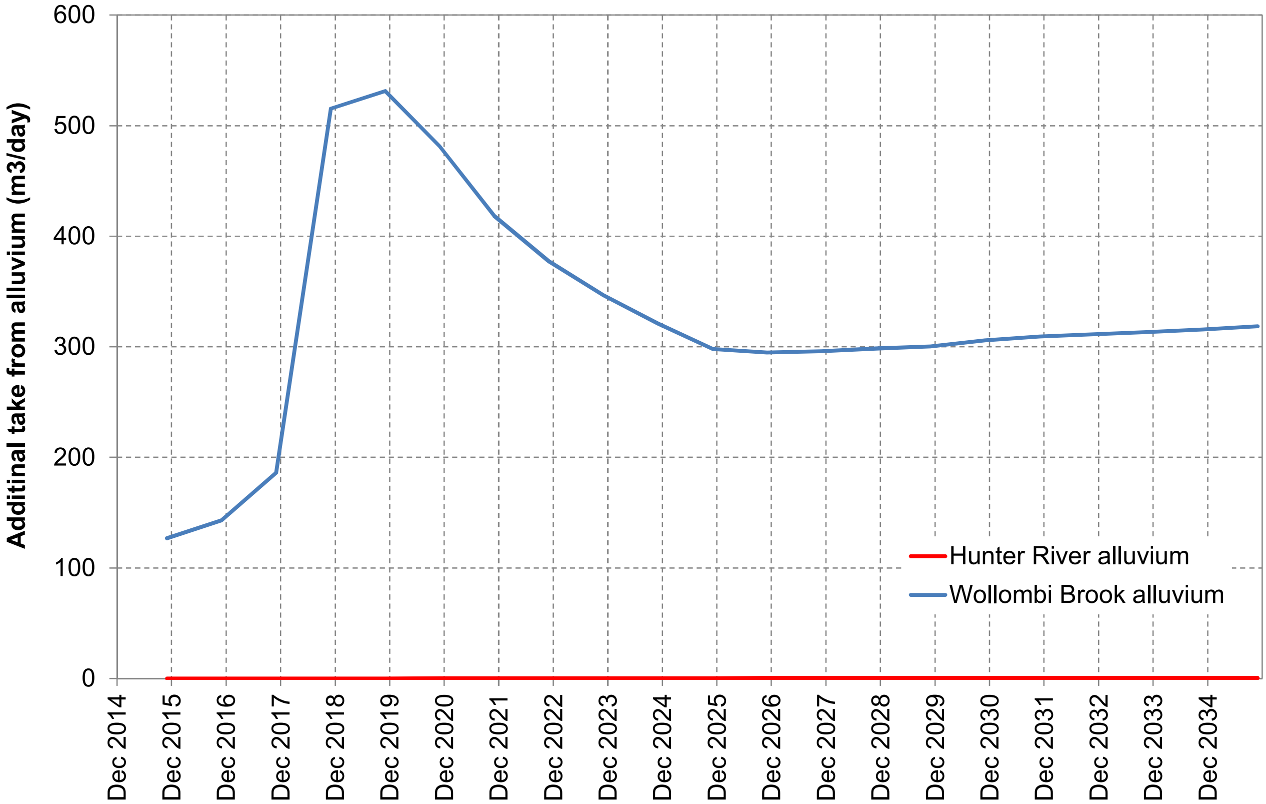


Figure 8.6: Change in groundwater seepage into Wollombi Brook alluvium from the Permian Coal Measures

8.1.4. Impact on Stream Baseflow

In the absence of mining, the river and creek network surrounding MTO is largely a gaining stream from groundwater discharge (baseflow). As mining expands in the region, the Permian strata depressurisation within the zone of influence will decrease upward groundwater flow from the Permian to the alluvium. The result is a slight lowering of groundwater levels in the Wollombi Brook alluvium, reducing the hydraulic gradient between the stream bed and alluvial aquifer and in turn decreasing baseflow.

Figure 8.7 presents the net change in the river/brook baseflows in response to mining. This was determined by subtracting the net river/creek flows in the predictive model from the scenario that removed mining of the proposal.

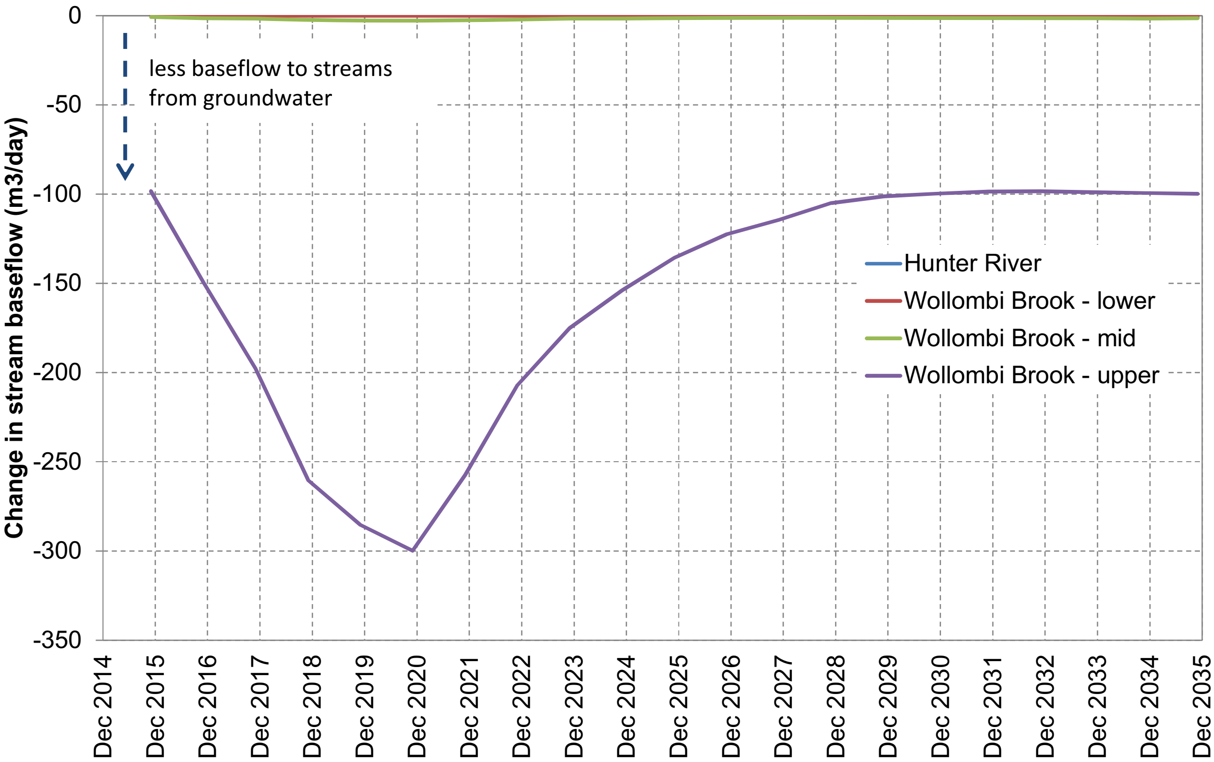


Figure 8.7: Net Change in surface water flow

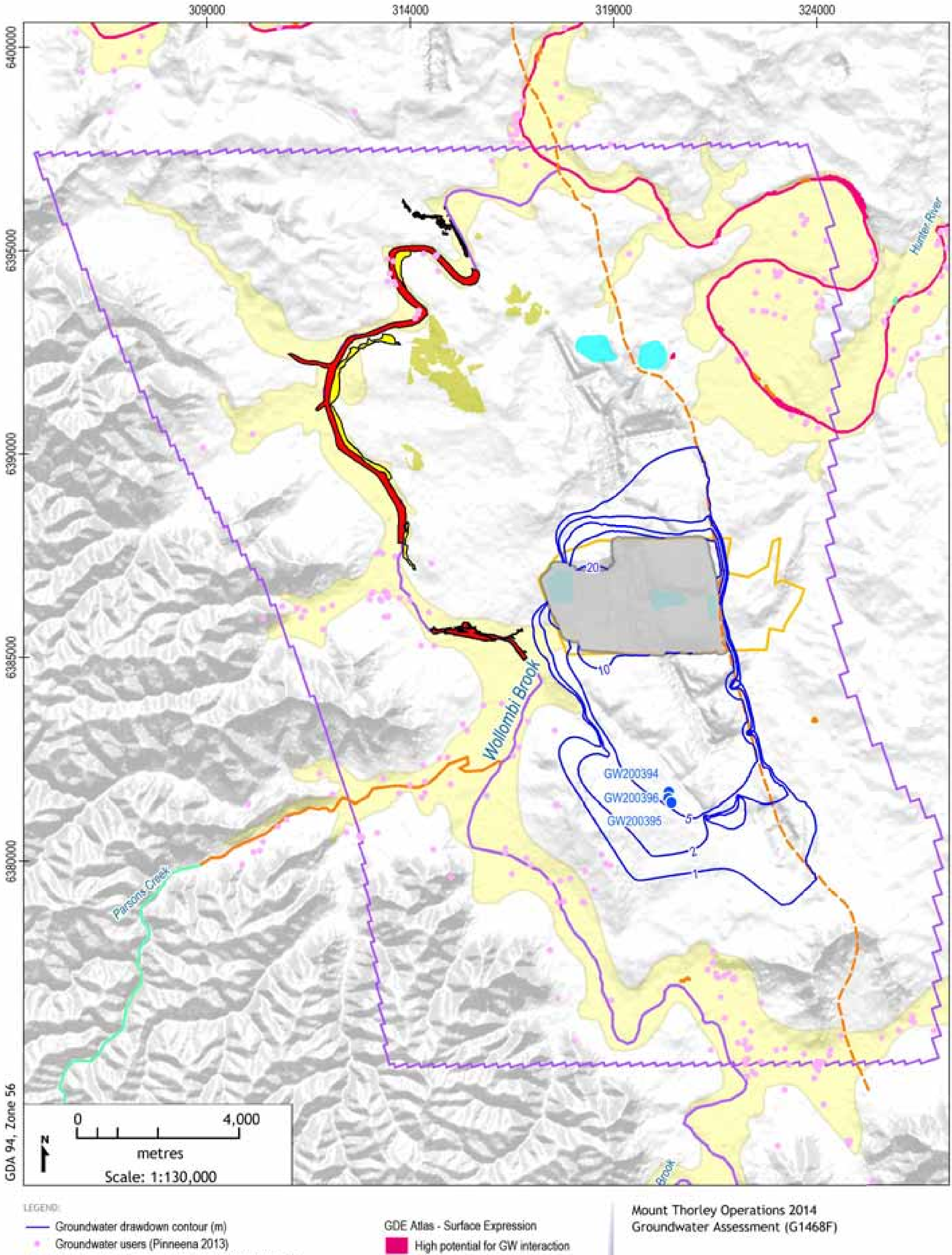
Figure 8.7 shows a reduction in baseflow to the Wollombi Brook for the proposal. The peak reduction in baseflow is in 2020 during the final stages of mining in Loders Pit. The majority of the loss in Wollombi Brook baseflow is in the upper reach above the stream gauge at Bulga (Station 210028), with only negligible loss in the mid reach to the stream gauge north of Warkworth Mine (Station 210004) and the lower reach to the confluence with the Hunter River. Baseflow reduction for Wollombi Brook (all reaches) is at a maximum of 300 m^3/day at 2020. Zero impact on baseflow is calculated for the Hunter River.

It is important to note from a water accounting point of view the reduction in baseflow is accounted for in the calculated reduced groundwater flow from the Permian to the alluvium. Of the calculated 532 m^3/day maximum take from the Wollombi Brook alluvium a maximum 300 m^3/day decrease in baseflow is expected.

8.1.5. Impact on Groundwater Dependent Ecosystems

Cumberland Ecology (2010) identified two potentially groundwater dependent vegetation communities along Wollombi Brook. These were the Hunter Valley River Oak Forest and the River Red Gum Floodplain Woodland which are in a thin riparian zone along Wollombi Brook about 4 km from the mining areas,

Model predictions do not predict a significant change in baseflow to the Wollombi Brook or Hunter River or drawdown within the alluvium. Therefore any riparian ecosystems or subterranean fauna will not be impacted by the proposal.



LEGEND:

- Groundwater drawdown contour (m)
- Groundwater users (Pinneena 2013)
- Private groundwater user (predicted drawdown >1m)
- Proposed MTO deveopment consent boundary
- Tailings storage facility
- Active model boundary
- Excavated mine area
- Quaternary alluvium (100k)
- Subcrop of Jerrys Plains Formation

GDE Atlas - Surface Expression

- High potential for GW interaction
- Moderate potential for GW interaction
- Low potential for GW interaction
- Identified in previous study: fieldwork

Groundwater Dependent Ecosystems

- Hunter Valley River Oak Forest
- River Red Gum Floodplain Woodland
- Warkworth Sands Woodland

Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

GDEs and Predicted Drawdown in the Water Table (Layer 1)

AGE

GROUNDWATER & ENVIRONMENTAL

DATE: 14/5/2014

FIGURE No: **8.8**

8.1.6. Pit Inflows

Figure 8.9 shows simulated inflows to Loders Pit that includes water derived from leakage through spoil combined with dewatering from the Permian coal measures. The split between the two sources is shown on the figure with take from the Permian the highest during the first year of mining (2015) at 1,064 m^3/day. Inflows fall to zero when mining ceases and the pit begins to be backfilled with spoil. The peak water take is 389 ML/year for the first year of the proposal. Post mining the take from the Permian will continue past 2020 at reduced rates.

The inflow from the spoil is initially 2,832 m^3/day in the first year of predicted mining in 2015, increasing to a maximum of 3,721 m^3/day in 2017.

Figure 8.10 shows inflows to the spoil from rainfall infiltration and leakage from Central Ramp TSF (CRTSF), Abbey Green South (AGS) TSF and Loders TSF. This plot shows approximately two thirds of the inflow to spoil is derived from CRTSF leakage.

The presented inflows do not include evaporation at the coal face and retained water bound as moisture in coal and overburden. Not all water simulated inflow will appear at the pit floor during mining. Inflows from spoil have been estimated using annual average rainfall records.

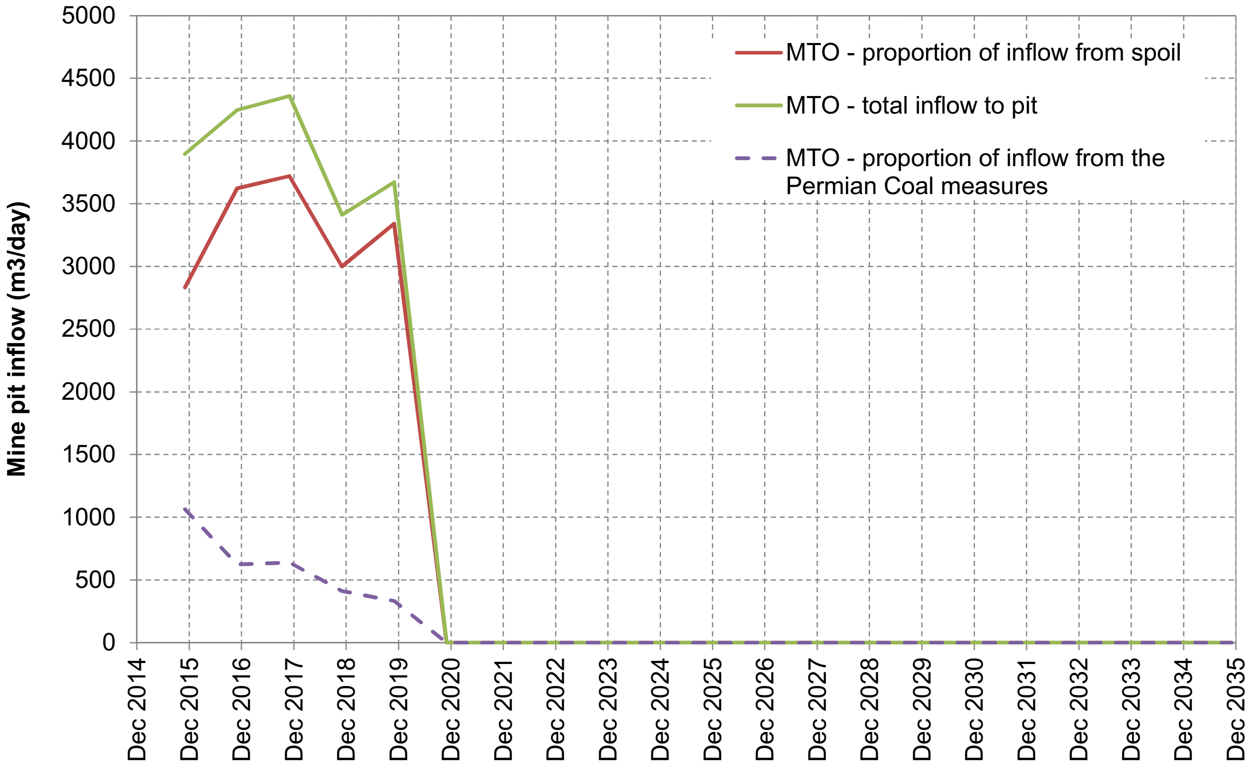


Figure 8.9: Simulated inflows to Loders Pit

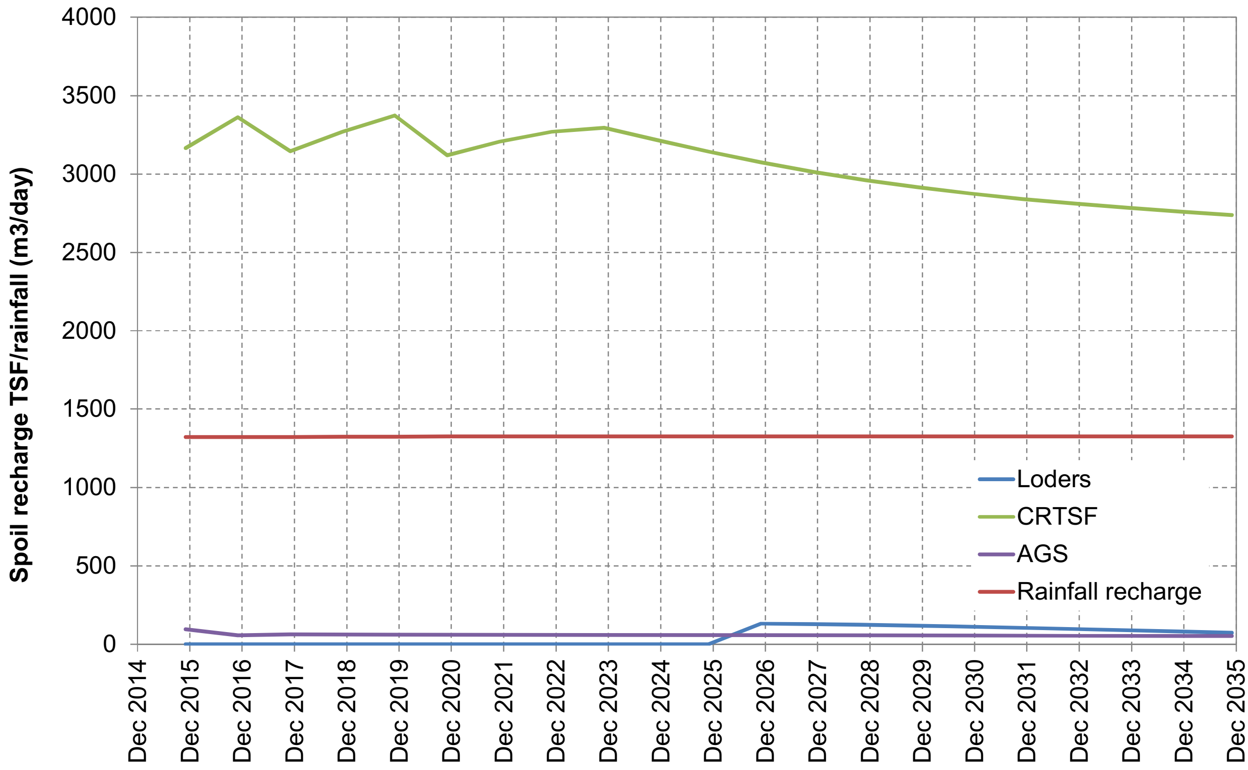


Figure 8.10: Spoil recharge rates from TSFs and rainfall infiltration

8.1.7. Water Quality and Leachate Migration

To protect surface water the AIP requires "no increase of more than 1% per activity in the long term average salinity in a highly connected surface water source at the nearest point to the activity". As discussed in Section 8.1.4, during operations the predicted depressurisation will decrease net baseflow to the Wollombi Brook. Section 8.1.1 discusses that there is head gradient at the end of mining from the Loders Pit spoil towards Wollombi Brook alluvium. It should be noted while in a net bulk sense there is a take from the Wollombi Brook alluvium, there remains an area adjacent to Loders Pit where mounded groundwater may flow from the spoil towards Wollombi Brook and the alluvium.

Loders Pit will be gradually filled with spoil and tailings to a level of 65mRL. A small depression will remain in the north western end of the previous void, about 10 m below the pre-mining ground level. Rainfall will gradually seep through the spoils and a mound of groundwater will develop within the spoil. The more permeable nature of the spoils means the groundwater levels are expected to rise above pre-mining levels, and there will be a net increase in the flow of groundwater from the mining spoils into the Wollombi Brook during and post mining.

Groundwater samples collected from monitoring bores installed within the Wollombi Brook alluvium indicate it is saline, between 15,000 µS/cm to 20,000 µS/cm. The groundwater seepage from the Mount Thorley spoil and void will be controlled by a range of factors including the recharge rate through the spoils and capped tailings, the mineralogy of the spoils / tailings, the flow rate through the spoils evaporative concentration in the remaining open void and prevailing climatic conditions. A salinity balance indicates that the electrical conductivity of the groundwater leaving the mined void and entering the alluvium will be significantly less saline and less than 10,000 µS/cm (WRM 2014). The landform that will remain post mining will therefore not degrade the beneficial use of the alluvial groundwater.

The Aquifer Interference Policy requires proposals do not increase the salinity of baseflow in streams fed by groundwater by more than 1%, which is essentially an undetectable change. The available data indicates that whilst there will be net outflow of groundwater from the final void, the volume will be limited (0.35 ML/day), and the outflowing water will have less salinity than the water that is naturally present within the alluvial system. The impact of the mining on the salinity of the baseflow in the Wollombi Brook will therefore be undetectable, as required by the Aquifer Interference Policy.

8.1.8. Water Licensing

The two key pieces of legislation for the management of water in NSW are the WM Act and the Water Act. Operations at MTW have the potential to interact with water sources that require licensing, namely:

- the Permian groundwater described in Section 5, which is not yet covered by a water sharing plan and is therefore still under the Water Act; and
- the alluvium associated with the Wollombi Brook and Hunter River, which is covered by the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009 (WSPHUAWS).

The Water Sharing Plan for the Hunter Regulated River Water Source 2003 (WSPHRRWS) is not relevant to the proposal as there will be no take from the Hunter River or other Hunter regulated water sources.

Coal & Allied will have sufficient water licenses in place to account for the predicted water takes summarised in Section 9 of this report.

8.1.9. Post Mining Recovery

The recovery model commenced from the end of mining and used the final groundwater levels at 2035 as the starting heads. The 'drains' simulating groundwater inflow into the mining pits were removed at the end of mining in Loders pit in 2020 and TSF leakage was removed from the model in 2035 to simulate capping and enabled groundwater levels to recover.

In order to minimise long-term groundwater impacts, the Proposal includes backfilling of the Loders Pit final void to approximately 10 m below the original pre-mining land surface. Groundwater, surface runoff and rainfall inflows will slowly fill the backfilled void either forming a groundwater table within the backfill or a shallow surface water body in the limited depression. The water level will eventually reach an equilibrium influenced by the balance of seepages from groundwater, surface runoff / infiltration and losses from evaporation.

At the cessation of mining in 2020, there will be a relatively high hydraulic gradient between the open void and the surrounding areas, which will result in relatively high initial seepage rates to backfill. As watertable forms in the backfilled spoil, the gradient decreases and the rate of groundwater inflow to the dewatered area will slow. Eventually, a state of equilibrium will occur where inputs are balanced by outputs and the water level will have stabilised.

The rate of recovery of groundwater levels in the aquifers will be dependent on rainfall, with years of below average rainfall extending the recovery period, and wet years reducing the time for steady state conditions to be reached. Evaporation of ponded water from any final void water body results in a continuous flow of groundwater into the void, in an effect known as evaporative pumping. This results in groundwater levels attaining an equilibrium water level at a lower elevation than the pre-mining water level; this, however, is dependent on the magnitude of catchment inputs.

To calculate the recovery water level in the backfilled Loders void the backfill was simulated using calibrated spoil parameters for recharge, permeability and storage. A thin approximately 10 m thick final depression was introduced to the model above the final backfilled landform in Loders pit to analyse if a shallow pit lake would form in the depression or if a lake would form within the backfill.

The recovery model was run for a period of 1000 years post mining. Rainfall, evaporation and surface run-off to the shallow final void in the Loders pit area were supplied by WRM Consultants as used in their calculations of final void levels (WRM 2014b). Rainfall was a looped record of available data to simulate variable climatic periods. Inflows to the backfilled spoil area/ final void were through the recharge package in MODFLOW. Evapotranspiration was set using the final landform surface using the evapotranspiration package in MODFLOW.

Inflows and any potential outflows results from the simulation were supplied to WRM consultants for calculations of Loders final void water level and salinity. Figure 8.11 shows the groundwater inflows to the backfilled Loders pit area, where this is dominated by inflow from the spoil area around the capped CRTSF. As groundwater in the backfilled Loders pit area rises groundwater outflow occurs both to the north towards Warkworth Mine final void and west towards Wollombi Brook alluvium. Inflow from the Permian Coal Measures is negligible peaking at 2.1 m^3/day (0.8 ML/yr) 16 years after mining ceases dropping to long term rate of 0.5 m^3/day.

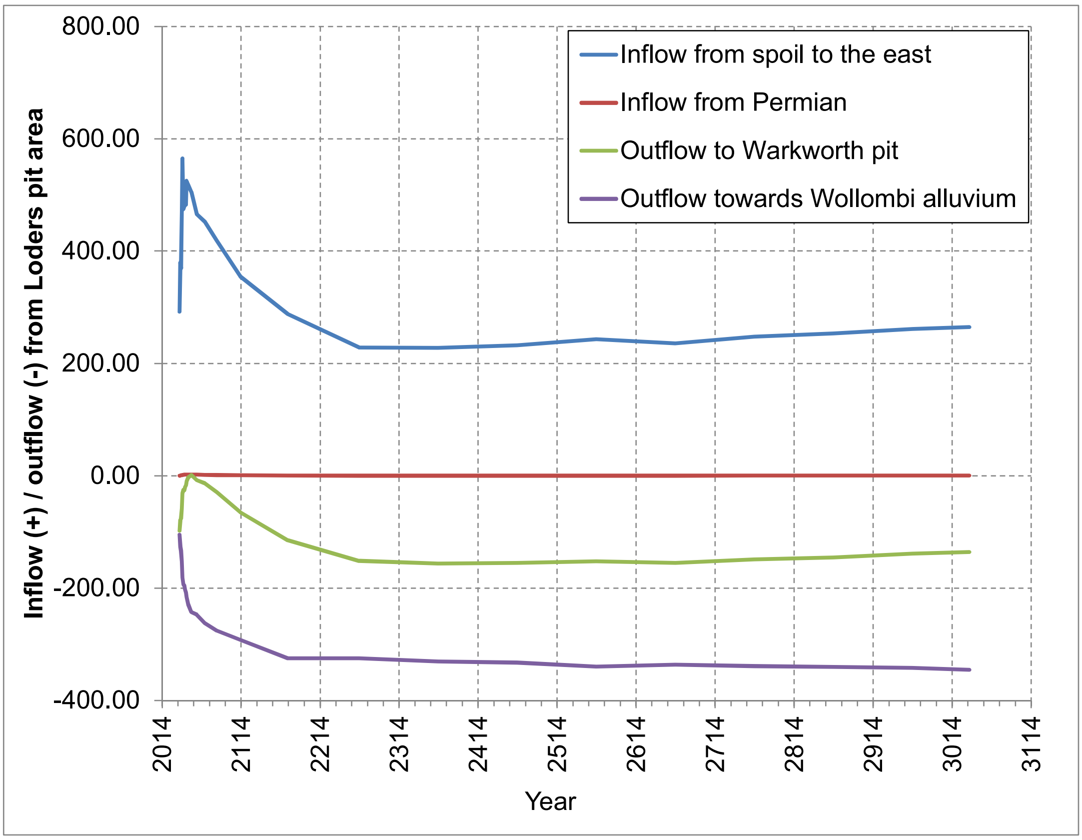
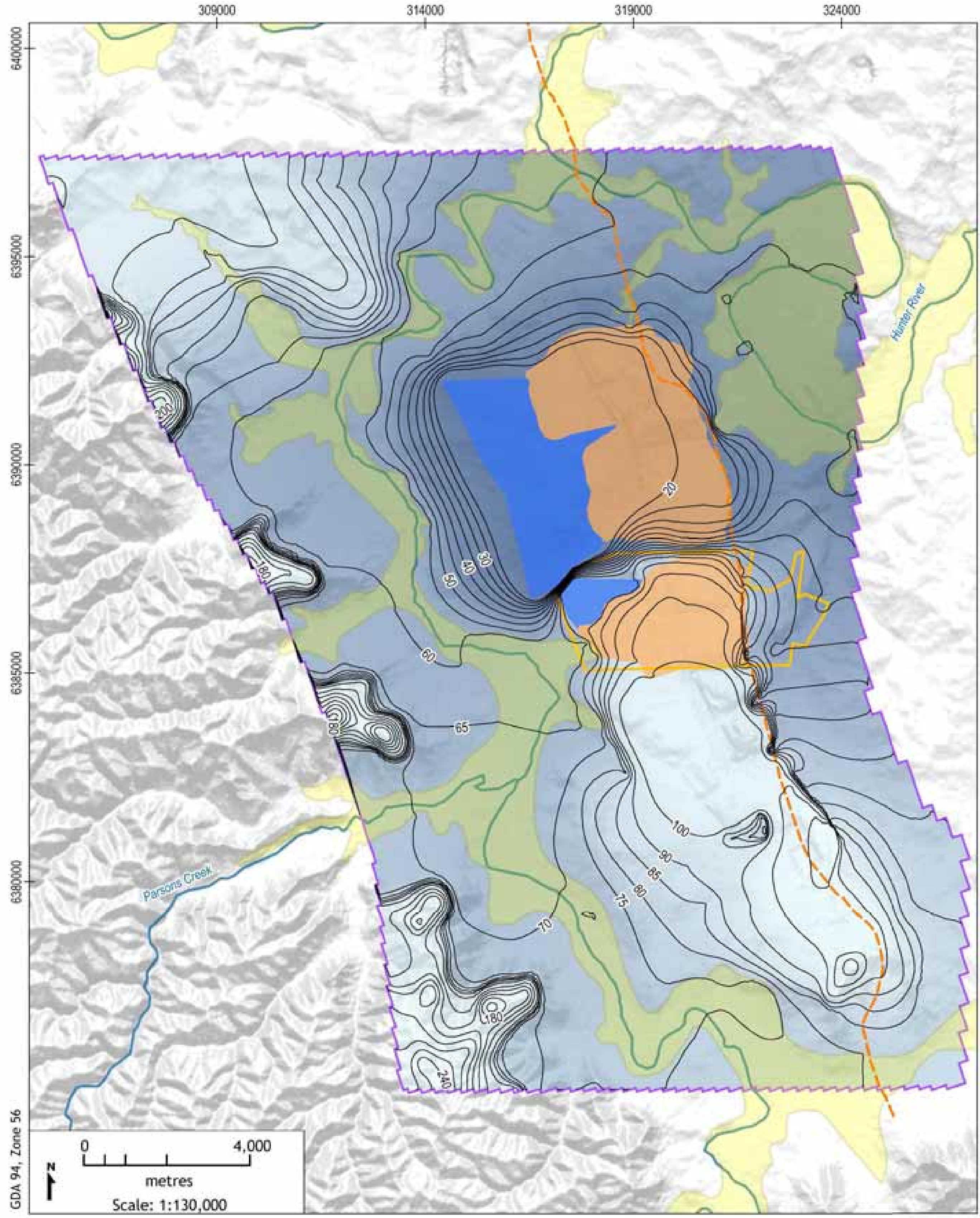


Figure 8.11: Inflows and outflows to the backfilled Loders void (m^3/day)

Groundwater levels within the backfilled Loders pit area recover within about 200 years to the final landform surface, suggesting that a marsh or even shallow pit lake may form in the shallow depression in Loders pit area. Figure 8.12 presents the predicted groundwater levels surrounding the final void post mining. WRM (2014b) using the OPSIM model calculated that intermittent surface water may pond in this area with open water RL between 66 mRL and 60 mRL.

WRM (2014b) also calculated and median EC for the ponded open water of 3000 µS/cm and a 90th percentile value of 8,000 µS/cm. It is possible that mounded groundwater and / or ponded surface water of this EC range will form in the backfilled Loders pit and may migrate at a maximum rate of 345 m^3/day (4 L/s) towards Wollombi Brook alluvium. Both the rate of discharge and salinity are not deemed a threat to salinity increases above 1% in Wollombi Brook alluvium in the long term. Available monitoring data from alluvial monitoring bores west of Loders pit show salinity in excess of 15,000 µS/cm.

Long term post closure take from the Wollombi Brook alluvium due the recovery in groundwater levels reduces at the start of the recovery period from 162 m^3/day to a long term rate of less than 5 m^3/day 200 years after closure. Post closure take from the Wollombi Brook alluvium and the Brook itself peak at 60 ML/yr. Post closure take from the Hunter River and Hunter River Alluvium is negligible (0.3 ML/yr).



LEGEND:

- Proposed MTO development consent boundary
- Active model boundary
- Quaternary alluvium (100k)
- Subcrop of Jerrys Plains Formation
- Groundwater level contour
- Major watercourse
- Modelled pit lake
- Modelled spoil zone

Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

Water Levels in Post Mining Void

DATE: 14/5/2014

FIGURE No: **8.12**

Figure 8.13 shows the long term post closure net flow to alluvium recovers substantially and is less than the peak recorded during mining. The peak take from the alluvium simulated during mining is more than enough to account for long term effects post closure.

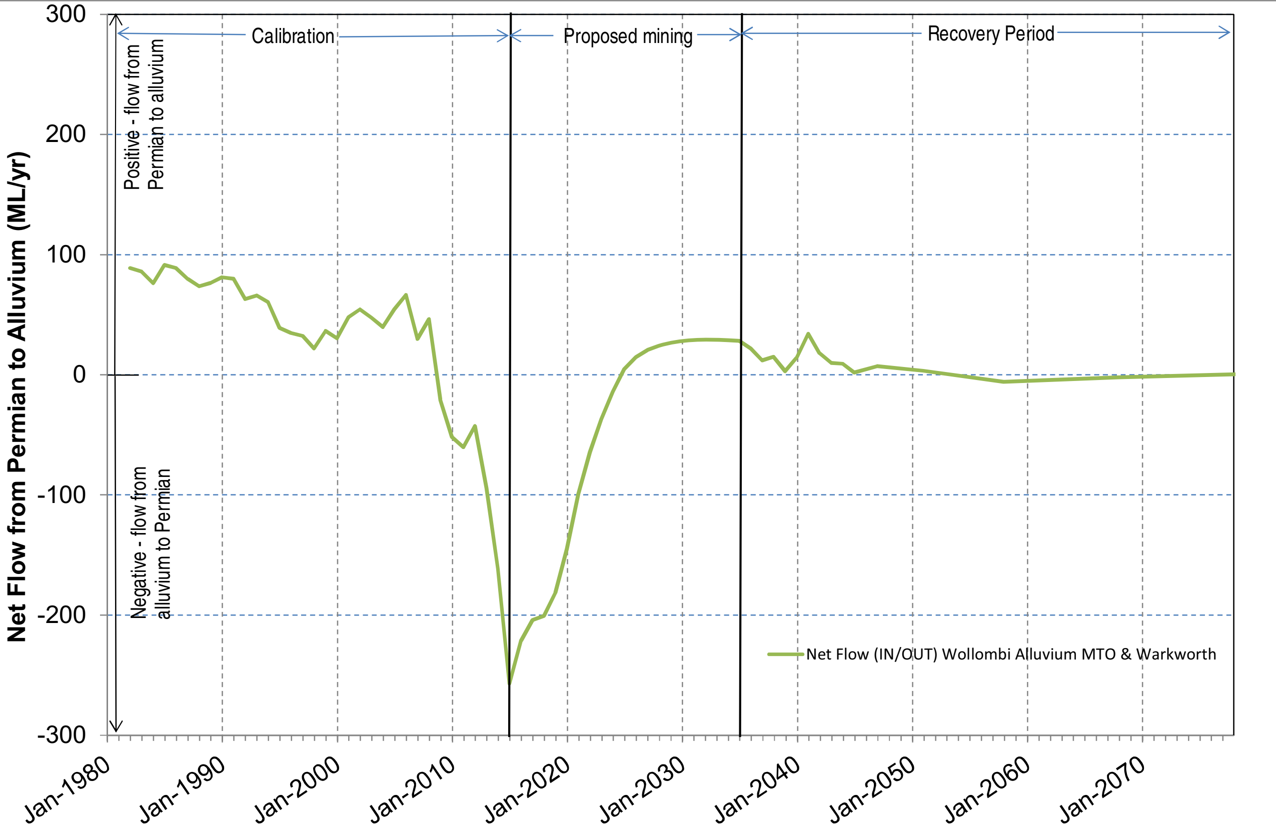


Figure 8.13: Recovery in net flows to Wollombi Alluvium

Due to a recovery in potentiometric levels post mining no additional private bore users will be affected post closure other than those already documented in this report.

8.2. Uncertainty Analysis

8.2.1. Background

This section assesses the uncertainty of the model predictions to natural variability in the calibrated parameters. Analysis of the uncertainty of model outputs is referred to as “uncertainty analysis”. Model calibration does not necessarily result in a unique set of parameter values, especially if the model employs a number of parameters to simulate system complexity. As the model was calibrated to known measurements, a calibration-constrained Monte Carlo analysis was carried out, rather than an unconstrained uncertainly analysis.

The objectives of uncertainty analysis were:

- to describe the numerical approach for quantification of uncertainty for this model; and
- to report the results of applying the methodology to estimate the potential uncertainty associated with the 30-year transient calibration model, and the 20-year development of mining areas.

Detailed reporting of the methodology, implementation, results and recommendations is presented as Appendix D.

Calibration-constrained Monte Carlo method for predictive uncertainty analysis uses many different parameter sets that still match (with certain level of misfit) the measured data. The level of misfit between modelled outcomes and measured field data is in proportion to potential measurement errors within observed data. These errors are represented by ranges defined by parameter bounds obtained by statistical analysis of field data. Two hundred such parameter sets, based on the calibrated mean and range of expected values, were generated. 200 models were rerun and checked against the baseline calibration statistics to ensure the model remained calibrated to observed data. 127 realised models were determined suitable and were therefore used in the calibration and predictive analysis.

It should be noted that the calibrated model used to base the uncertainty analysis on was not the final calibration discussed within this document. Time constraints to maintain the project deliverable meant that uncertainty analysis had to be conducted prior to final model completion. Although the uncertainty analysis was not based on the final model calibration the results of this analysis are still thought of worth in the discussion on the measurement error in the calibration.

All hydraulic parameters explored in the automatic calibration were explored in the analysis, including horizontal hydraulic conductivity, vertical hydraulic conductivity multipliers, specific storage, specific yield, groundwater recharge, and riverbed conductance.

8.2.2. Results

Results from the uncertainty analysis have been discussed in the context of the predicted impacts during mining to put potential errors bars around predictive results. In each case the 95th percentile worst case result from the uncertainty analysis has been discussed.

8.2.2.1. Drawdowns

Figure 8.14 shows the 2 m drawdown (Layer 1 and Layer 9) from the calibrated model against the 95th percentile 2 m drawdown from the uncertainty analysis. The 95th percentile drawdown in Layer 1 extends further west than the calibrated predictive model and extends under the Wollombi Brook river boundary condition. The effects of the river boundary condition were also investigated and discussed earlier within Section 8. The extent of drawdown in Layer 1 for the 95th percentile case are thought to be exaggerated by the way in which the 'mine' and 'no-mine' scenarios were simulated.

The 95th percentile drawdown in Layer 9 can be seen to extend further west and north below Wollombi Brook than the calibrated model. It should be noted that the 95th percentile drawdown in Layer 9 does not extend as far as the predictive model to the south west of Bulga Mine. This is a result of differences in spoil parameter base case model parameterisation between the comparison runs.

8.2.2.2. Groundwater Users

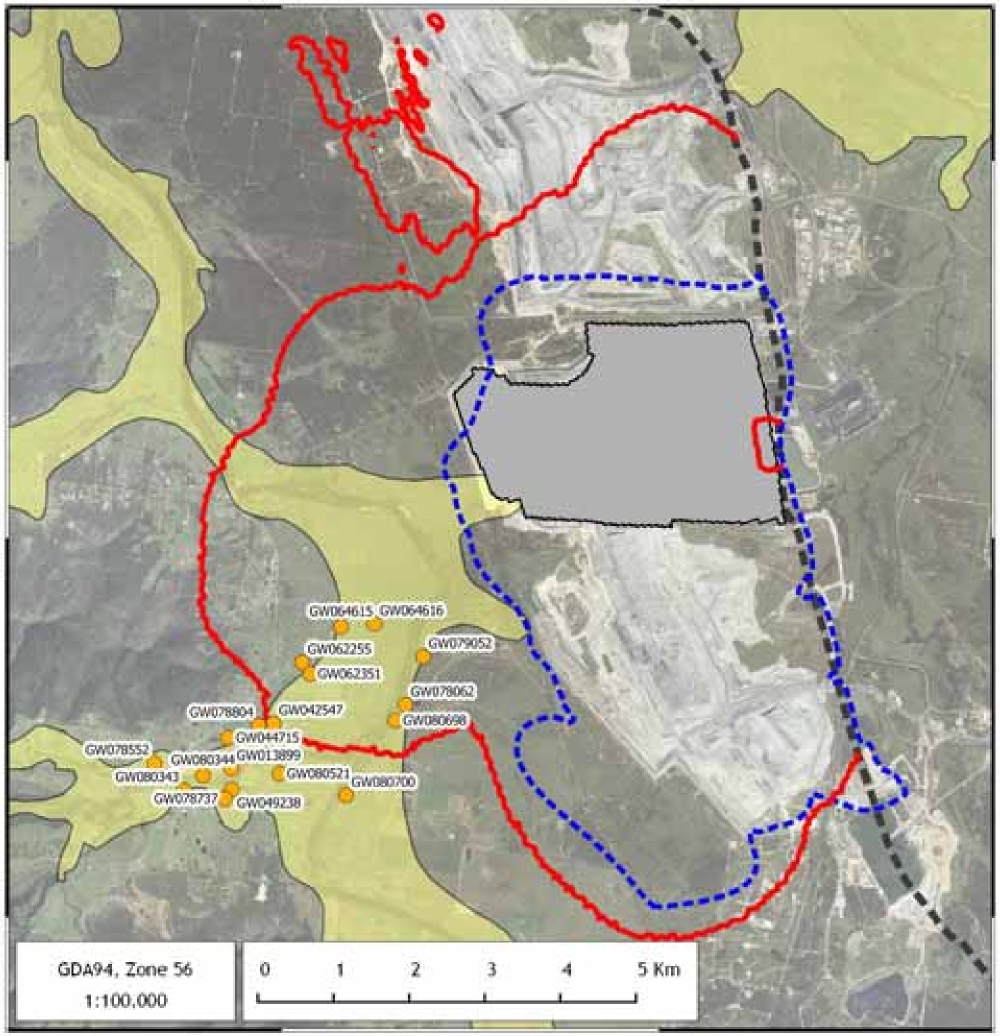
The uncertainty analysis 95th percentile drawdown identified 18 additional bores within Wollombi Brook alluvium or shallow regolith (Layer 1) with >1m drawdown compared to the bores already identified in Section 8. Table 8.2 and Figure 8.14 shows details of the 18 bores. Six appear to be on the east of Wollombi Brook on land owned by Bulga Mine, the rest of the bores appear to be private. The largest worst case 95th percentile drawdown is 3.55m at bore GW062255.

The 95th percentile drawdown in the Permian strata identified no additional private bores would be impacted by the Proposal over those already discussed in Section 8.1.2.

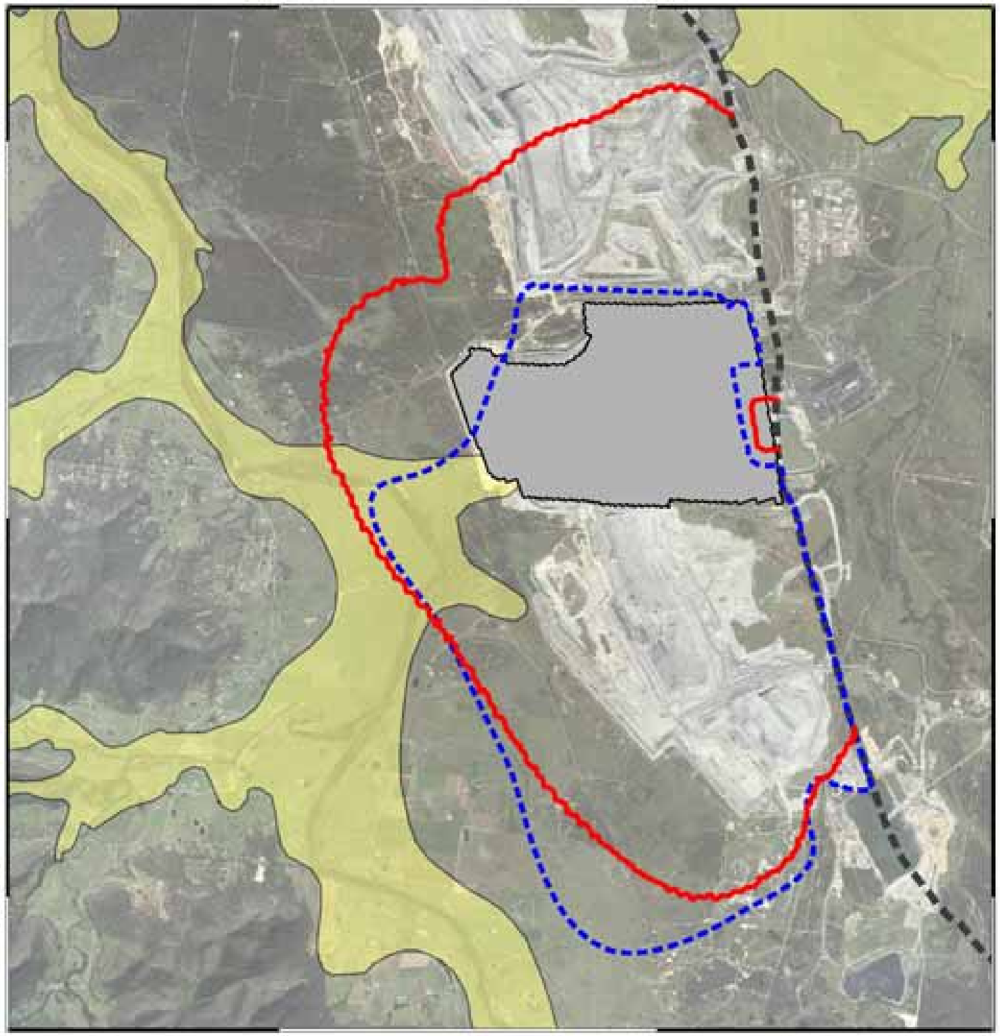
Table 8.2: IMPACTS OF THE MINING ACTIVITIES ON GROUNDWATER USERS

Bore ID	Easting	Northing	Formation	Owner	95th Percentile Drawdown (m)
GW064616	316236	6383867	Alluvium	Bulga Mine owned land	8.76
GW079052	316880	6383433	Alluvium	Bulga Mine owned land	7.38
GW064615	315793	6383828	Alluvium	Bulga Mine owned land	7.32
GW078062	316646	6382796	Alluvium	Bulga Mine owned land	3.8
GW062255	315281	6383356	Alluvium	Private	3.55
GW062351	315388	6383204	Alluvium	Private	3.33
GW080698	316514	6382589	Alluvium	Bulga Mine owned land	3.12
GW042547	314905	6382548	Alluvium	Private	2.06
GW078804	314701	6382520	Alluvium	Private	1.85
GW080521	314977	6381886	Alluvium	Private	1.59
GW013899	314343	6381952	Alluvium	Private	1.45
GW044715	314302	6382362	Alluvium	Private	1.44
GW049238	314348	6381675	Alluvium	Private	1.4
GW078737	314261	6381555	Alluvium	Private	1.34
GW080344	313969	6381859	Alluvium	Private	1.29
GW080700	315862	6381598	Alluvium	Bulga Mine owned land	1.23
GW080343	313719	6381665	Alluvium	Private	1.19
GW078552	313325	6382024	Alluvium	Private	1.14

Layer 1



Layer 9



LEGEND

- Groundwater users - 95th percentile drawdown > 1m
- Calibrated model 2m drawdown
- 95th percentile 2m drawdown
- Mt Thorley mine
- Alluvium
- Subcrop line Jerrys Plains

Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

95th percentile 2m drawdown extent - Layer 1 and Layer 9

DATE
14/5/2014

FIGURE No:
8.14

8.2.2.3. Impact on Alluvium

The predictive model simulation shows a gradual increase in take from the Wollombi Brook alluvium to a peak calculated take of 532 m^3/day (195 ML/yr) at year 2019, which corresponds to the final year of active mining simulated in Loders Pit. The 95th percentile worst case take from the Wollombi Brook Alluvium is 609 m^3/day (222 ML/yr). This is a 15% increase over the calibrated predicative model and shows relatively tight variance in the uncertainty results.

8.2.2.4. Groundwater Inflow to Mining Areas

The predictive model simulation showed inflow from the Permian to the Loders open pit peaks at 1,064 m^3/day (389 ML/yr) in 2015. The 95th percentile worst case inflows peak at 2736 m^3/day (999 ML/yr) is also at 2015. This is a 157% increase over the calibrated predicative model and shows the largest variance in the analysed uncertainty results.

9 COMPLIANCE

Assessment of the proposed modification against the NSW AIP is detailed under Section 9.1 to Section 9.3, below.

9.1. Accounting for, or Preventing the Take of Water

Table 9.1: ACCOUNTING FOR OR PREVENTING THE TAKE OF WATER

AIP Requirement		Proponent Response
1	Described the water source (s) the activity will take water from?	Based on the AIP the groundwater system impacted by the proposed modification can be separated into two systems, as follows: • porous and/or fractured consolidated sedimentary rock of the Permian coal measures; and • groundwater within alluvium associated with the Wollombi Brook and Hunter River alluvium. Water quality and yields for the coal measures and Wollombi Brook is considered a less productive aquifer according to the AIP, while the Hunter River alluvium is considered a highly productive aquifer.
2	Predicted the total amount of water that will be taken from each connected groundwater or surface water source on an annual basis as a result of the activity?	Predicted peak annual take from: • Permian coal measures: 389ML/yr • Wollombi Brook alluvium: 194ML/yr • Wollombi Brook (surface water): 110ML/yr (accounted for in the alluvial take) • Hunter River alluvium: none • Hunter River (surface water): none See Section 8 for further details.
3	Predicted the total amount of water that will be taken from each connected groundwater or surface water source after the closure of the activity?	Predicted take from: • Permian coal measures: 0.8ML/yr • Wollombi Brook alluvium: 60ML/yr • Wollombi Brook (surface water): 60ML/yr (accounted for in the alluvial take) • Hunter River alluvium: 0.3ML/yr • Hunter River (surface water): 0.3ML/yr (accounted for in the alluvial take) See Section 8 for further details.
4	Made these predictions in accordance with Section 3.2.3 of the AIP? (page 27)	Based on 3D numerical modelling
5	Described how and in what proportions this take will be assigned to the affected aquifers and connected surface water sources?	Predicted take from: • Permian coal measures: 0.8ML/yr • Wollombi Brook alluvium: 60ML/yr • Wollombi Brook (surface water): 60ML/yr (accounted for in the alluvial take) • Hunter River alluvium: 0.3ML/yr • Hunter River (surface water): 0.3ML/yr (accounted for in the alluvial take) See Section 8 for further details.
6	Described how any licence exemptions might apply?	Not necessary.
7	Described the characteristics of the water requirements?	There are no water requirements; however, additional interception of groundwater due to the proposed modification is predicted.
8	Determined if there are sufficient	Coal & Allied will make sure appropriate water license are in place to account for

Table 9.1: ACCOUNTING FOR OR PREVENTING THE TAKE OF WATER		
AIP Requirement		Proponent Response
	water entitlements and water allocations that are able to be obtained for the activity?	predicted takes. See Section 8.1.8 for further details
9	Considered the rules of the relevant water sharing plan and if it can meet these rules?	Compliant – see Section 8 of report
10	Determined how it will obtain the required water?	Via seepage to the high-wall face, but most will likely evaporate or be removed as moisture in coal and will not enter the site water circuit.
11	Considered the effect that activation of existing entitlement may have on future available water determinations?	
12	Considered actions required both during and post-closure to minimize the risk of inflows to a mine void as a result of flooding?	Flood assessment was undertaken as part of the Warkworth Extension Project. The results indicated that the Project's footprint was above the 1 in 100 year ARI flood event.
13	Developed a strategy to account for any water taken beyond the life of the operation of the project?	Surrender of existing water entitlements that are used to license take of water.
	Will uncertainty in the predicted inflows have a significant impact on the environment or other authorized water users? *Items 14-16 must be addressed if so.*	Risks to groundwater systems are low as the proposal does not entail any modification to the disturbance footprint, and involves resurfacing of the final mine void. Uncertainty analysis, presented in Section 8.2, indicates that the predicted impact on alluvium has a relatively low degree of uncertainty (±15%). However, the predicted inflows from Permian units shows a high degree of uncertainty (±150%)
14	Considered any potential for causing or enhancing hydraulic connections, and quantified the risk?	See Section 8 of report
15	Quantified any other uncertainties in the groundwater or surface water impact modeling conducted for the activity?	Risks to groundwater systems are low as the proposal does not entail any modification to the disturbance footprint, and involves backfilling of the final mine void. Available monitoring data indicates the two existing groundwater models MER (2002) and AGE (2010), and the current model results presented in this report have been relatively conservative. Despite this conservatism the predicted impacts are still negligible and manageable, so the uncertainty in the predictions is not considered to have the potential to impact on the environment or water users.
16	Considered strategies for monitoring actual and reassessing any predicted take of water throughout the life of the project, and how these requirements will be accounted for?	Yes. See Section 10 of report

9.2. Determining Water Predictions in Accordance with AIP (Section 3.2.3)

Table 9.2: DETERMINING WATER PREDICTIONS		
AIP Requirement		Proponent response
1	Addressed the minimum requirements found on page 27 of the AIP for the estimation of water quantities both during and following cessation of the proposed activity?	Based on conservative numerical modelling, see Section 8 and Appendix C of report.

9.3. Other Requirements to be Reported in Accordance with AIP (Section 3.2.3)

Table 9.3: OTHER REQUIREMENTS

	AIP Requirement	Proponent response
1	Establishment of baseline groundwater conditions?	Compliant – see Section 5 of report.
2	A strategy for complying with any water access rules?	Water licences held by or will be purchased by proponent.
3	Potential water level, quality or pressure drawdown impacts on nearby basic landholder rights water users?	No predicted impact of over 2m for water supply bores in alluvium or Permian. Predicted impacts over 2m are restricted to bores located on land owned by adjoining mines. See Section 8.1.2
4	Potential water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources?	No predicted impact of over 2m for water supply bores in alluvium or Permian. Predicted impacts over 2m are restricted to bores located on land owned by adjoining mines. See Section 8.1.2
5	Potential water level, quality or pressure drawdown impacts on groundwater dependent ecosystems?	None predicted - see Section 8.1.5 of report
6	Potential for increased saline or contaminated water inflows to aquifers and highly connected river systems?	None predicted - see Section 8.1.5 of report
7	Potential to cause or enhance hydraulic connection between aquifers?	None predicted - see Section 8 of report
8	Potential for river bank instability, or high-wall instability or failure to occur?	Not assessed, but improbable.
9	Details of the method for disposing of extracted activities (for CSG activities)?	N/A

10 MITIGATION AND MONITORING

10.1. Review of Current Monitoring Programme

Groundwater management is currently undertaken based on the existing MTW groundwater monitoring program, which is included in the Water Management Plan (WMP) (Coal & Allied, 2013). The WMP includes scheduled monitoring of 30 groundwater monitoring bores within and around MTW. Review of the MTW groundwater database indicates that groundwater level data is currently collected at 50 monitoring locations (see Appendix A).

The Groundwater Monitoring Programme (Appendix F of WMP) details that the monitoring bores will be monitored for field parameters of pH, EC and water level on a quarterly basis, and a comprehensive water quality analysis conducted annually.

Review of the MTW groundwater database indicates that the groundwater samples are being collected on an annual basis for all bores.

10.2. Proposed Amendments to Monitoring Programme

The following recommendations are made to update the existing monitoring programme, to assist ongoing assessment and quantification of any potential surface water and groundwater impacts:

- Installation of nested monitoring bores along the Wollombi Brook (PZ10, PZ11, PZ12).

Yearly audits of the performance of the monitoring network should also be included as part of the annual groundwater review, and optimisation of the monitoring sites and frequency should be undertaken where required.

10.3. Mine Water Seepage Monitoring

It is recommended that monitoring of mine water seepage be undertaken, particularly to identify seepage rates and quality. The seepage monitoring program should include:

- recording of the time, location and estimated volume of any unexpected increased groundwater outflow from the high-wall and end-wall;
- measurement of water pumped from the void, preferably using flow meters or other suitable gauging apparatus;
- correlation of rainfall records with mine seepage records so groundwater and surface water can be separated; and
- monitoring of coal moisture content.

10.4. Trigger Values

Trigger values provide a quantifiable measure for identifying adverse changes in groundwater levels and quality. The existing WMP (Coal & Allied, 2013) details that key water quality triggers include pH, EC and Total Suspended Solids (TSS). In the absence of licence or applicable ANZECC (2000) criteria, the 95^{th} percentile of the available data is adopted and compared to monitoring results on a monthly basis. Water quality trigger levels at the 95^{th} / 5^{th} percentile, based on baseline data, is considered adequate to identify mine related impacts, while still accounting for natural and seasonal variations.

As detailed in the WMP A site specific investigation into trigger level exceedance if:

- *"professional judgement determines that the single deviation or a developing trend could result in environmental harm; or*
- *Three consecutive measurements exceed trigger values."*

10.5. Data Management and Reporting

It is recommended that data management and reporting include:

- establishment of trigger levels;
- quarterly review of groundwater levels and field water quality against trigger levels, with site specific investigations initiated, as detailed in Section 10.4;
- annual reporting (including all water level and water quality data); and
- all groundwater data should be stored in a database customised for MTW with suitable QA / QC controls.

10.6. Future Model Iterations

Every three years the validity of the model predictions should be assessed. If these data indicate substantial differences (previously unrecognised information) to those interpreted, these data should be incorporated into the model and revised predictions made and reported.

10.7. Make Good Agreements

According to the AIP, make good agreements are required when a 2 m or greater cumulative decline occurs at any water supply work. As detailed in Section **Error! Reference source not found.**, drawdowns of greater than 2 m are not predicted to occur at any privately owned bores.

11 CONCLUSION

Mount Thorley Operations is an open cut coal mine approximately 10.5 kilometres south-west of Singleton in the Hunter Valley, NSW. Mining commenced in 1981, and much of the coal resource has been removed and the site rehabilitated. The operator of the mine, Coal and Allied seeks to extend the current approval, which expires in 2017, by a further 18 years until 2035. This additional time will allow Coal and Allied time to complete remaining mining of Loders Pit by 2020, and Abbey Green North Pit by 2023. Loders pit will then be backfilled with spoil trucked in from the Warkworth Mine and used to store tailings until 2035.

All available geological and groundwater data was assessed to develop a conceptual understanding of the hydrogeological regime at MTO. As shown in Figure 5.3, the coal measures of the Jerrys Plains Subgroup dip towards the west of the MTO. The multiple coal seams in the Jerrys Plains Sub-group form low to moderately permeable aquifer, confined by very low yielding interburden / overburden. The coal measures sub-crop immediately east of the mine area, along the Mt Thorley Monocline, with the basal Archerfield Sandstone and Bulga Formation of the Vane Subgroup underlying the Hunter River.

Groundwater levels within the Permian stratigraphy are highly influenced by existing mining, flowing towards the active open-cut pits at MTW (see Figure 5.5). The Permian stratigraphy is recharged where it occurs at sub-crop, to the east. However, the saline water quality and high ion concentrations indicate that the Permian groundwater has a low rate of recharge. Groundwater within the Wollombi Brook alluvium appears to be unaffected by current mining, and contains brackish to saline groundwater. Review of stream flow levels and alluvial groundwater levels indicates that the Wollombi Brook west of MTO is a gaining stream (baseflow contributions from Permian), while to the north it is likely a losing stream (downward leakage to Warkworth Sands and Permian stratigraphy).

Review of the NSW groundwater database (PINEENA, 2013) identified that there are numerous private groundwater users along Wollombi Brook, primarily accessing the alluvial groundwater. There are also some private bores intercepting the Permian stratigraphy, however, these are largely located on land owned by mines. There are also GDEs identified from previous studies along the Wollombi Brook (see Figure 5.11).

Results from the numerical groundwater model identified:

- minor impact on the Wollombi Brook alluvium, with:
  - drawdown levels within the Wollombi Brook alluvium is largely predicted to be less than 1 m at the end of mining;
  - predicted reduction in baseflow to the Wollombi Brook (all reaches) at a maximum rate of 300 m^3/day (110 ML/yr) at 2020;
  - predicted maximum additional take from the Wollombi Brook alluvium (at the end of mining) is estimated at 532 m^3/day (194 ML/yr); and
  - as spoil is placed in Loders Pit, after 2019, the predicted take from the Wollombi alluvium decrease to a rate of 320 m^3/day (117 ML/yr);
- no impact on the Hunter River and Hunter River alluvium, with:
  - drawdown in the Hunter River alluvium is less than 1 m;
  - there is no detectable reduction in baseflow to the Hunter River; and
  - there is no detectable take from the Hunter River alluvium;
- minor impact on groundwater users, with:

  - no predicted drawdown in any private water supply bores within alluvium;
  - there are no drawdowns of over 2 m are predicted for private water supply bores within the Permian units; and
  - no predicted impacts on GDEs relating to the Warkworth Sands, as it has a perched groundwater system that is not in direct hydraulic connection with the underlying Permian fractured rock;
- mine pit inflow estimates of:
  - predicted inflow to the proposal from the Permian units is highest during the first year of mining (2015), at a rate of 1,064 m^3/day (389 ML/yr); and
  - predicted inflows from the spoil into the proposal peaks at a maximum of 3,721 m^3/day in 2017;
- predicted groundwater levels within the reshaped (to 10 m depth) final void will slowly recover and reach equilibrium at about 70 mRL to 75 mRL, after approximately 1000 years post mining; and
- salinity balance indicates that the electrical conductivity of the groundwater leaving the mined void and entering the alluvium will be less than 10,000 µS/cm. This is well below recorded salinity levels within the Wollombi Brook alluvium (see Section 5.8); therefore, the final landform will not degrade the beneficial use of the alluvial groundwater.

Ongoing groundwater monitoring will be undertaken as per the existing requirements under the WMP (Coal & Allied, 2013), with additional recommendations to improve the program stipulated under Section 10.

12 REFERENCES

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AUSTRALASIAN GROUNDWATER AND ENVIRONMENTAL CONSULTANTS PTY LTD

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LIMITATIONS OF REPORT

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) has prepared this report for the use of EMGA Mitchell McLennan 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 Proposal dated 11 February 2014, and Change of Scope dated 24 February 2014 and 2 May 2014.

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 2014 and 21 May 2014 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

Monitoring Bore Summary Table

Table A- 1- MONITORING BORE SUMMARY

Bore ID	Alternate ID	Easting	Northing	Type	Collar Elevation mRL	Target Formation Bottom	SWL (mRL)		Model Layer
							Av.	Q4 2013	
OH786	OH786	320542	6392674	Standpipe	55.65	Alluvium	53.9	49.8	1
OH787	OH787	320982	6391921	Standpipe	49.96	Alluvium	36.0	36.3	1
OH788	OH788	321482	6390967	Standpipe	45.38	Alluvium	35.7	35.8	1
OH942	OH942	320536	6392622	Standpipe	55.75	Alluvium	46.9	46.7	1
OH943	OH943	321476	6390963	Standpipe	45.04	Alluvium	35.7	35.9	1
OH944	OH944	321113	6391035	Standpipe	47.88	Alluvium	40.1	40.2	1
OH1121	OH1121 (1?)	321902	6391030	Standpipe	45.64	Vaux Seam	35.1	35.4	15
OH1122 (1)	OH1122 (1)	318545	6387877	Standpipe	101.19	Blakefield Seam	52.7	55.8	7
OH1122 (2)	OH1122 (2)	318545	6387877	Standpipe	101.18	Woodlands Hill Seam*	44.4	-	9
OH1122 (3)	OH1122 (3)	318545	6387877	Standpipe	101.15	Bowfield Seam*	42.4	30.0	11
OH1123 (1)	OH1123 (1)	316967	6389501	Standpipe	99.2	Woodlands Hill Seam	51.8	51.5	9
OH1123 (2)	OH1123 (2)	316967	6389501	Standpipe	99.22	Blakefield Seam	47.6	40.3	7
OH1123 (3)	OH1123 (3)	316967	6389501	Standpipe	99.18	Bowfield Seam	45.4	39.7	11
OH1124 (1)	OH1124 (1)	316893	6391526	Standpipe	88.2	Unknown - no depth info		-	7
OH1124 (2)	OH1124 (2)	316893	6391526	Standpipe	88.2	Unknown - no depth info	41.8	-	9
OH1124 (3)	OH1124 (3)	316893	6391526	Standpipe	88.2	Unknown - no depth info	42.1	-	11
OH1125 (1)	OH1125 (1)	316511	6392875	Standpipe	85.4	Unknown - no depth info	58.0	59.8	7
OH1125 (2)	OH1125 (2)	316511	6392875	Standpipe	85.4	Unknown - no depth info	60.0	-	9
OH1125 (3)	OH1125 (3)	316511	6392875	Standpipe	85.4	Unknown - no depth info	39.8	49.9	11
OH1126	OH1126	318579	6393394	Standpipe	63.7	Vaux Seam*	53.4	50.7	15
OH1127	OH1127(1?)	321444	6392097	Standpipe	51.22	Bayswater Seam*	35.5	35.6	16
OH1137	OH1137	318266	6393377	Standpipe	67.7	Vaux Seam	57.0	55.5	15
OH1138 (1)	OH1138 (1)	317835	6393346	Standpipe	70.72	Warkworth Seam	62.9	61.8	12
OH1138 (2)	OH1138 (2)	317835	6393346	Standpipe	70.72	Warkworth Seam	57.7	56.4	13
GW9706	GW9706	322404	6387589	Standpipe	64.24	Bayswater Seam*	62.1	61.9	16
GW9707	GW9707	322319	6387569	Standpipe	63.93	Bayswater Seam*	60.8	60.3	16
GW9708	GW9708	322158	6387209	Standpipe	73.14	Bayswater Seam*	61.6	60.9	16
GW9709	GW9709	322251	6388026	Standpipe	60.33	Bayswater Seam*	53.6	51.4	16
G3	G3	317786	6385251	Standpipe	73.04	Wambo Seam*	30.5	20.3	5
WOH2141A	PZ6	314989	6392647	Standpipe	91.59	Wynot Seam B-D	0.0	-	6
WOH2141B	PZ6	314989	6392647	Standpipe	91.52	Blakefield Seam - E, F	0.0	51.1	7
WOH2139A	PZ5	315249	6391511	Standpipe	91.71	Blakefield Seam - E, F	0.0	54.5	7
WOH2153A	PZ2	313881	6391429	Standpipe	68.26	Redbank Creek Seam - D, E	0.0	59.8	4
WOH2153B	PZ2	313881	6391429	Standpipe	68.26	Wambo Seam - B, C	0.0	61.9	5
WOH2154A	"PZ1"	313976	6389990	Standpipe	68.89	Redbank Creek Seam - D, E	0.0	57.6	4
WOH2154B	"PZ1"	313976	6389990	Standpipe	68.65	Wambo Seam - B, C	0.0	60.7	5
WOH2155A	PZ4	315278	6390138	Standpipe	74.55	Redbank Creek Seam - D, E	0.0	67.5	4
WOH2155B	PZ4	315278	6390138	Standpipe	74.55	Wambo Seam - B, C	0.0	59.8	5
WOH2156A	PZ3	315874	6388866	Standpipe	80.38	Redbank Ck Seam - D, E	0.0	66.5	4
WOH2156B	PZ3	315874	6388866	Standpipe	80.38	Wambo Seam - B, C	0.0	69.5	5
PZ7D	PZ7D	314057	6392684	Standpipe	58.42	Shallow overburden	51.6	51.8	2

Table A- 1- MONITORING BORE SUMMARY

Bore ID	Alternate ID	Easting	Northing	Type	Collar Elevation mRL	Target Formation Bottom	SWL (mRL)		Model Layer
							Av.	Q4 2013	
PZ7S	PZ7S	314055	6392671	Standpipe	58.44	Alluvium/*Whybrow Seam /OVB	51.3	51.5	1
PZ8D	PZ8D	317001	6385418	Standpipe	65.77	Shallow overburden	60.1	59.0	2
PZ8S	PZ8S	317002	6385411	Standpipe	65.75	Alluvium	60.5	60.6	1
PZ9D	PZ9D	317541	6385652	Standpipe	65.52	Shallow overburden	58.6	52.0	2
PZ9S	PZ9S	317542	6385642	Standpipe	65.43	Alluvium	61.6	60.7	1
GW98 MTCL1	GW98 MTCL1	322188	6387032	Standpipe	77.75	Bayswater Seam*	67.2	66.3	16
GW98 MTCL2	GW98 MTCL2	322669	6387462	Standpipe	79.47	Bayswater Seam*	70.0	69.3	16
WD609	UG_10	318803	6392211	VWP	129.98	Spoil	0.0	45.7	1
WD615_P1	UG_15_VWP1	319281	6391347	VWP	159.96	Piercefeild Seam	0.0	32.0	14
WD615_P2	UG_15_VWP2	319281	6391347	VWP	159.96	Bayswater Seam	0.0	39.2	16
WD625_P1	UG_16_VWP1	314663	6390483	VWP	76.42	Woodlands Hill Seam	0.0	44.3	9
WD625_P3	UG_16_VWP3	314663	6390483	VWP	76.42	Vaux Seam	0.0	34.3	15
WD625P	UG_16	314669	6390487	Standpipe	76.4	Whybrow Seam	0.0	57.9	2
WD622_P1	UG_24_VWP1	316236	6389588	VWP	84.52	Wambo Seam	0.0	58.0	5
WD622_P2	UG_24_VWP2	316236	6389588	VWP	84.52	Woodlands Hill Seam	0.0	33.6	9
WD622_P3	UG_24_VWP3	316236	6389588	VWP	84.52	Mt Arthur Seam	0.0	31.3	13
WD622_P4	UG_24_VWP4	316236	6389588	VWP	84.52	Vaux Seam	0.0	28.8	15
WD622_P5	UG_24_VWP5	316236	6389588	VWP	84.52	Bayswater Seam	0.0	34.6	16
WD622P	UG_24	316229	6389585	Standpipe	84.46	Wambo Seam			5
MTD613	UG_48	320778	6387025	VWP	150.45	Broonie Seam (possible)/Bayswater	50.8	50.7	16
MTD605_P1	UG_49_VWP1	317265	6386174	VWP	77.08	Weathering zone above Whybrow Seam*	54.6	54.0	2
MTD605_P2	UG_49_VWP2	317265	6386174	VWP	77.08	Whybrow Seam*	59.8	56.5	3
MTD605_P3	UG_49_VWP3	317265	6386174	VWP	77.08	Between Wambo and Whynot seams	47.8	47.3	6
MTD605_P4	UG_49_VWP4	317265	6386174	VWP	77.08	Blakefield Seam	30.9	28.2	7
MTD605_P5	UG_49_VWP5	317265	6386174	VWP	77.08	Mt Arthur Seam	13.4	12.1	13
MTD605_P6	UG_49_VWP6	317265	6386174	VWP	77.08	Vaux Seam	33.0	31.0	15
MTD605_P7	UG_49_VWP7	317265	6386174	VWP	77.08	Bayswater Seam	36.4	35.0	16
MTD614_P1	UG_50_VWP1	317265	6386174	VWP	72.43	Whybrow Seam	49.0	48.3	3
MTD614_P2	UG_50_VWP2	317265	6386174	VWP	73.43	Glen Munro Seam	26.5	20.2	8
MTD614_P3	UG_50_VWP3	317265	6386174	VWP	74.43	Mt Arthur Seam	27.9	27.0	13
MTD614_P4	UG_50_VWP4	317265	6386174	VWP	75.43	Vaux Seam	28.0	26.7	15
MTD614_P5	UG_50_VWP5	317265	6386174	VWP	76.43	Bayswater Seam	38.6	39.2	16
WD456_P1	C09_21_P1	317929	6388545	VWP	100.59	Vaux Seam	24.8	-	15
WD456_P2	C09_21_P2	317929	6388545	VWP	100.59	Bowfield Seam	-10.2	52.0	11
WD456_P3	C09_21_P3	317929	6388545	VWP	100.59	Blakefield Seam	82.9	60.7	7
WD462_P1	C09_04_P1	315529	6391358	VWP	101.67	Vaux Seam	25.2	17.8	15
WD462_P2	C09_04_P2	315529	6391358	VWP	101.67	Bowfield Seam	10.7	8.3	11
WD462_P3	C09_04_P3	315529	6391358	VWP	101.67	Woodlands Hill Seam	34.2	29.9	9
MTD517_P1	UG09_21_P1	317521	6386147	VWP	77.27	Mt Arthur Seam	30.6	26.9	13
MTD517_P2	UG09_21_P2	317521	6386147	VWP	77.27	Woodlands Seam	18.7	10.5	9

Table A- 1- MONITORING BORE SUMMARY									
Bore ID	**Alternate ID**	**Easting**	**Northing**	**Type**	**Collar Elevation mRL**	**Target Formation Bottom**	**SWL (mRL)**		**Model Layer**
							Av.	**Q4 2013**	
MTD517_P3	UG09_21_P3	317521	6386147	VWP	77.27	Wambo Seam*	49.2	47.4	5
MTD518_P1	UG09_20_P1	316512	6386156	VWP	79.96	Mt Arthur Seam	38.7	37.0	13
MTD518_P2	UG09_20_P2	316512	6386156	VWP	79.96	Blakefield Seam/Woodlands Hill	40.5	40.5	9
MTD518_P3	UG09_20_P3	316512	6386156	VWP	79.96	Wambo Seam	45.1	44.0	5

Notes: Projection MGA94 Zone 56
* in Target Formation infers a best estimate was made based on available data

Appendix B

HISTORIC WATER QUALITY DATA (1993 – 2013)

APPENDIX B: Historic Water Quality Data (1993 - 2013)

(Project: G1468F)

Bore ID	Alternate ID	Target Formation Bottom	Model Layer	EC (Field)			PH (Field)			Ca (mg/L)			Mg (mg/L)			K (mg/L)			SO_4 (mg/L)			P (mg/L)			Na (mg/L)		
				Median	5%	95%	Median	5%	95%	Median	5%	95%	Median	5%	95%	Median	5%	95%	Median	5%	95%	Median	5%	95%	Median	5%	95%
WRM 2014		**Wollombi Brook**	**1**	764	368	1060	7.4	7.0	8.0	14	12	15	18	16	19	5	4	6	5	2	13	0.02	0.02	0.02	104	102	110
OH786	OH786	Alluvium	1	931	931	21270	7.4	7.4	8.0	70	70	130	22	22	38	11	11	15	18	18	90	1.25	1.25	2.82	89	89	191
OH787	OH787	Alluvium	1	17230	17230	26700	7.6	7.6	8.0	95	95	170	323	323	339	40	40	47	244	244	275	1.46	1.46	2.89	3770	3770	4009
OH788	OH788	Alluvium	1	12590	12590	27800	7.4	7.4	8.0	145	145	181	219	219	296	37	37	60	427	427	537	0.34	0.34	1.03	2040	2040	2636
OH942	OH942	Alluvium	1	13505	13505	26365	6.8	6.8	8.3	120	120	191	651	651	896	40	40	64	863	863	929	0.10	0.10	0.33	4140	4140	5432
OH943	OH943	Alluvium	1	8520	8520	9626	7.5	7.5	8.3	36	36	104	186	186	195	33	33	36	153	153	153	10.55	10.55	12.76	1515	1515	1547
OH944	OH944	Alluvium	1	7710	7710	8847	7.8	7.8	8.9	35	35	51	54	54	55	30	30	31	750	750	794	0.55	0.55	6.15	1650	1650	1740
PZ7S	PZ7S	Alluvium?	1	1563	1563	2152	6.9	6.9	7.6	46	46	66	37	37	60	10	10	10	19	19	21	0.57	0.57	1.19	208	208	219
PZ8S	PZ8S	Alluvium	1	14335	14335	15245	6.7	6.7	7.0	109	109	113	337	337	374	17	17	18	493	493	505	0.08	0.08	0.08	2780	2780	2859
PZ9S	PZ9S	Alluvium	1	15130	15130	16620	6.8	6.8	6.9	95	95	99	554	554	755	71	71	79	821	821	859	0.14	0.14	0.20	2775	2775	2900
PZ7D	PZ7D	Shallow overburden	2	1730	1730	2084	8.0	8.0	8.1	14	14	23	15	15	26	6	6	6	31	31	31	0.03	0.03	0.14	376	376	410
PZ8D	PZ8D	Shallow overburden	2	8295	8295	8815	7.7	7.7	8.0	33	33	41	46	46	60	15	15	16	50	50	56	0.34	0.34	0.48	1945	1945	1960
PZ9D	PZ9D	Shallow overburden	2	9925	9925	10625	7.1	7.1	7.3	167	167	177	344	344	428	33	33	36	407	407	481	0.05	0.05	0.11	1690	1690	1774
WD625P	UG_16	Whybrow	2	12000	12000	12099	7.2	7.2	7.2	67	67	67	212	212	212	21	21	21	241	241	241	0.04	0.04	0.04	2270	2270	2270
WOH2153A	PZ2	Redbank Ck - D, E	4	1848	1848	2010	7.8	7.8	8.1	5	5	9	3	3	3	4	4	5	62	62	76	0.15	0.15	13.82	426	426	485
WOH2154A	"PZ1"	Redbank Ck - D, E	4	4690	4690	4830	7.6	7.6	7.8	6	6	15	5	5	18	9	9	10	118	118	141	0.10	0.10	10.13	1080	1080	1174
WOH2155A	PZ4	Redbank Ck - D, E	4	7040	7040	7301	7.6	7.6	7.7	32	32	48	57	57	94	16	16	21	321	321	875	0.09	0.09	3.17	1470	1470	1928
WOH2156A	PZ3	Redbank Ck - D, E	4	2360	2360	11090	7.3	7.3	7.6	21	21	104	12	12	239	9	9	30	238	238	1142	0.34	0.34	3.56	367	367	3734
G3	G3	Wambo?	5	7275	7275	7673	7.3	7.3	7.8	32	32	37	27	27	29	25	25	29	0	0	0	0.32	0.32	0.89	1660	1660	1767
WD622P	UG_24	Wambo	5	14075	14075	17698	7.2	7.2	7.5	167	167	167	533	533	533	42	42	42	1470	1470	1470	0.03	0.03	0.03	3720	3720	3720
WOH2153B	PZ2	Wambo - B, C	5	1840	1840	1947	7.8	7.8	8.1	5	5	8	5	5	8	4	4	6	57	57	70	0.20	0.20	3.64	466	466	478
WOH2154B	"PZ1"	Wambo - B, C	5	4700	4700	4815	7.6	7.6	7.9	5	5	6	6	6	9	8	8	11	112	112	134	0.16	0.16	3.64	1100	1100	1172
WOH2155B	PZ4	Wambo - B, C	5	6180	6180	7424	7.5	7.5	7.6	44	44	44	44	44	75	14	14	17	344	344	583	0.22	0.22	4.13	1385	1385	1660
WOH2156B	PZ3	Wambo - B, C	5	8375	8375	15859	7.4	7.4	7.9	75	75	107	70	70	263	18	18	37	402	402	1253	0.52	0.52	4.26	1960	1960	3848
WOH2141A	PZ6	Wynot B-D	6	6690	6690	6848	7.5	7.5	7.8	74	74	84	123	123	164	18	18	19	320	320	425	0.11	0.11	3.60	1250	1250	1370
OH1122 (1)	OH1122 (1)	Blakefield Seam	7	12880	12880	14164	7.1	7.1	7.5	93	93	175	259	259	370	37	37	48	457	457	755	0.26	0.26	0.35	2490	2490	2616
OH1123 (2)	OH1123 (2)	Blakefield	7	18250	18250	19602	6.8	6.8	7.4	135	135	201	488	488	562	45	45	52	1260	1260	1474	0.23	0.23	0.29	3858	3858	4090
OH1124 (1)	OH1124 (1)	Unknown	7	16675	16675	17863	6.7	6.7	7.1	260	260	302	586	586	668	56	56	58	885	885	885	1.08	1.08	2.00	1314	1314	2476
OH1125 (1)	OH1125 (1)	Unknown	7	16115	16115	18070	6.7	6.7	7.0	274	274	301	683	683	772	35	35	46	860	860	922	0.23	0.23	2.98	2175	2175	2633
WOH2139A	PZ5	Blakefield - E, F	7	2010	2010	2230	7.2	7.2	7.4	18	18	37	15	15	43	7	7	9	15	15	39	0.26	0.26	3.44	426	426	460
WOH2141B	PZ6	Blakefield - E, F	7	5770	5770	8727	8.6	8.6	10.3	41	41	47	67	67	76	15	15	17	228	228	272	1.45	1.45	4.11	1690	1690	1780
OH1122 (2)	OH1122 (2)	Woodlands Hill	9	13230	13230	14428	6.9	6.9	7.7	100	100	143	267	267	293	37	37	39	695	695	721	6.22	6.22	11.42	2825	2825	2857
OH1123 (1)	OH1123 (1)	Woodlands	9	17550	17550	19318	6.9	6.9	7.3	130	130	213	316	316	468	42	42	52	895	895	1220	0.10	0.10	12.04	3925	3925	4158
OH1124 (2)	OH1124 (2)	Unknown	9	13680	13680	14353	6.9	6.9	7.3	160	160	298	360	360	361	35	35	36	692	692	692	6.58	6.58	12.36	2310	2310	2391
OH1125 (2)	OH1125 (2)	Unknown	9	16150	16150	17130	6.7	6.7	7.6	270	270	320	747	747	816	63	63	87	857	857	890	0.41	0.41	0.58	2145	2145	2366
OH1122 (3)	OH1122 (3)	Bowfield Seam?	11	12090	12090	12899	7.3	7.3	7.8	82	82	97	262	262	338	39	39	48	296	296	385	0.39	0.39	1.02	2460	2460	2582
OH1123 (3)	OH1123 (3)	Bowfield	11	17720	17720	19610	6.9	6.9	7.5	130	130	157	188	188	384	37	37	47	400	400	1047	0.22	0.22	1.33	4035	4035	4386
OH1124 (3)	OH1124 (3)	Unknown	11	13915	13915	15863	6.8	6.8	7.1	190	190	275	491	491	580	54	54	74	830	830	830	0.08	0.08	0.09	2460	2460	2586
OH1125 (3)	OH1125 (3)	Unknown	11	15290	15290	16458	6.7	6.7	7.3	289	289	506	673	673	810	35	35	43	833	833	918	0.08	0.08	12.02	2225	2225	2308
OH1138 (1)	OH1138 (1)	Warkworth Seam	12	13000	13000	15820	6.9	6.9	7.3	324	324	474	470	470	711	42	42	77	418	418	572	0.18	0.18	0.44	1920	1920	2848
OH1138 (2)	OH1138 (2)	Warkworth Seam	12	10750	10750	11791	6.9	6.9	7.1	375	375	462	375	375	429	27	27	32	780	780	934	0.16	0.16	0.32	1570	1570	1628
OH1121	OH1121 (1?)	Vaux	15	7730	7730	8658	7.0	7.0	7.2	99	99	182	117	117	222	15	15	24	180	180	821	0.08	0.08	1.72	1490	1490	1765
OH1126	OH1126	Vaux?	15	7960	7960	8468	7.1	7.1	7.3	78	78	86	195	195	200	32	32	34	867	867	1168	0.16	0.16	0.26	1550	1550	1610
OH1137	OH1137	Vaux	15	15290	15290	17554	7.0	7.0	7.4	110	110	150	396	396	532	42	42	54	808	808	886	0.20	0.20	3.03	3310	3310	3970
GW9706	GW9706	Bayswater Seam?	16	3625	3625	5385	7.3	7.3	7.7	144	144	156	110	110	137	16	16	17	1110	1110	1292	0.02	0.02	0.05	828	828	1130
GW9707	GW9707	Bayswater Seam?	16	16760	16760	20900	7.3	7.3	7.8	315	315	370	635	635	729	23	23	34	4160	4160	5060	0.08	0.08	0.14	4690	4690	4823
GW9708	GW9708	Bayswater Seam?	16	14450	14450	16080	6.9	6.9	7.1	460	460	488	457	457	494	27	27	35	4020	4020	5012	0.05	0.05	0.11	2370	2370	3018
GW9709	GW9709	Bayswater Seam?	16	22900	22900	24700	6.9	6.9	7.3	546	546	616	923	923	959	30	30	42	5500	5500	6168	0.03	0.03	0.09	4975	4975	5123
GW98 MTCL1	GW98 MTCL1	Bayswater?	16	9645	9645	10033	7.2	7.2	7.6	90	90	396	182	182	403	24	24	29	870	870	4223	0.10	0.10	0.32	1935	1935	2253
GW98 MTCL2	GW98 MTCL2	Bayswater?	16	15700	15700	16322	6.9	6.9	7.2	603	603	728	599	599	788	48	48	64	4300	4300	4596	0.12	0.12	0.33	2700	2700	2875
OH1127	OH1127(1?)	Bayswater Seam?	16	11610	11610	12895	6.9	6.9	7.2	134	134	145	145	145	150	22	22	26	5	5	8	0.03	0.03	0.55	2450	2450	2577

Appendix C

NUMERICAL MODEL – DEVELOPMENT & CALIBRATION

1. MODEL DEVELOPMENT AND CALIBRATION

1.1 Model Objectives

A numerical model was developed to assess the impacts of the Proposal on the surrounding groundwater regime. Whilst developing the model, the requirements of the NSW AIP were considered to ensure the model would predict the:

- volume of water produced by dewatering Permian strata and coal seams;
- drawdown induced in the Permian strata and coal seams groundwater system;
- drawdown (or water take) from alluvial aquifers;
- potential for changes in baseflow to Wollombi Brook and the Hunter River;
- potential for drawdown in surrounding private landholder bores; and
- potential for changes in groundwater salinity.

1.2 Previous Models

In 2002 Coal & Allied commissioned Mackie Environmental Research (MER, 2002) to assess the impact of a proposed extension to Warkworth Mine on surface- and groundwater as part of the 2002 Environmental Impact Statement (EIS). That study included the development of a numerical groundwater flow model and recommended that additional monitoring bores be installed to monitor depressurisation and water quality in areas to the west of the proposed extension. Coal & Allied subsequently installed monitoring bores WOH2154A to WOH2141A in 2004 after planning approval was granted in 2003. Groundwater level monitoring in these bores has shown that the predictions of MER (2002) were conservative as the magnitude or the extent of depressurisation has not been as extensive as predicted by the model. The inflows to the open cut pit have also not reached the rates predicted by MER (2002).

In 2010, Coal & Allied proposed to further extend Warkworth Mine (the *Warkworth Extension Project*) about 1 km down-dip (to the west) of the area approved in 2003 and commissioned Australasian Groundwater and Environment (AGE) to assess potentially associated groundwater impacts (AGE, 2010). That study included the development of another numerical model that built upon the work of MER (2002). Both the Commonwealth and NSW Governments approved this project, but a subsequent appeal in the NSW Land and Environment Court overturned the approval based on issues unrelated to groundwater.

Since 2010 Coal & Allied have increased the groundwater monitoring network through the installation of several multi-level vibrating wire piezometers (VWPs) west and down-dip of the active MTW mining areas (Golder, 2013). The data obtained from those VWPs have been included in the calibration of the latest (AGE, 2014 – this report) model, discussed below.

Four new monitoring bores within the Permian coal measures around the Project and within the spoil (Loders Pit) were installed in early 2014. Groundwater level and water quality data from these were included in the 2014 model calibration.

1.3 Model Design and Construction

1.3.1 Conceptual Model and Extent

A conceptual understanding of the groundwater regime developed from field measurements, observations and experience is the basis for the development of any numerical groundwater flow model. Section 5 of this report outlines the conceptual groundwater model for Mount Thorley Warkworth (MTW). This conceptual model is a summary of how the groundwater system is believed to operate based upon the available information and represents the natural system in an idealised and simplified way.

The extent of the numerical model boundaries were selected to be suffiently distant from the currently approved and proposed mining so as to not influence the drawdown predictions. These boundaries are as follows:

- The eastern model boundary was defined along the line of sub-crop of the Jerrys Plain Subgroup. The Jerries Pains Subgroup is the target of current and future mining activities and groundwater level monitoring has indicated that there is very limited hydraulic connection between the mine and the area to the east of this line.

- The western model boundary was defined along the base of the outcropping Hawkesbury Sandstone. This sandstone has not been included in the model as previous work has indicated that groundwater drawdown associated with currently approved and proposed mining would not extend far beyond Wollombi Brook.

- The northern and southern boundaries have been set at a distance to capture cumulative impacts from the adjacent active mines of Wambo and Bulga, and lie well beyond the likely influence of the proposed mining activity being assessed at Warkworth.

1.3.2 Software Used

The MODFLOW SURFACT code (referred to as SURFACT for the remainder of the report) was used to simulate of groundwater flow.

SURFACT is a commercial derivative of the standard MODFLOW code and has some distinct advantages over the standard MODFLOW for simulating mining projects. SURFACT simulates variably saturated conditions. This is beneficial for mining where coal seams can become progressively dewatered which avoids the rewetting of cells that can be problemetic with standard MODFLOW. The SURFACT also includes adaptive time-steps, and robust numerical solver that help to converge the numerical solution.

The MODFLOW pre- and post-processor PMWIN (Chaing and Kinzelbach, 1996) was used to generate some of the input files for the SURFACT model. Where files differ to allow for the additional capabilities of SURFACT, these changes were undertaken through manual editing of the model files.

1.3.3 Time

The model used days as the unit of time. The model represented the progress of mining and recharge with annual stress periods. The stress period duration was set as one year (365.25 days).The model simulated mining in stages representing the progression of the pit floor (using drain cells) and creation of spoil piles (by changing hydraulic properties with time). After every modelling stage, the model paused and the hydraulic heads were extracted to use as the starting conditions for the next stage. The hydraulic properties of the spoils were updated, and the next stage started. The stage duration for the calibrated model was:

- five years for the first six stages from 1981 to 2010;
- four years for stage seven from 2011 to 2014; and
- annual increments of one year length for predictive modelling years 2014 to 2035.

The first seven stages from 1981 to 2013 were used to calibrate the model as groundwater monitoring data was available for this period. Stages eight to 28 from 2014 to 2035 simulated the currently approved and proposed mining to predict future impacts on the groundwater regime.

1.3.4 Model Dimensions, Extent and Layers

The model grid consisted of 98,644 cells per model layer (271 columns, 364 rows, 76,089 active cells per layer, 16 layers). The upper left corner of the grid was set at: x = 304400, y = 6397500 (GDA94, MGA zone 56) and rotated by 18.43°. The cell size varied from a minimum of 30 x 30 m in the mining areas to a maximum of 100 x 225 m outside these zones. Figure C-5 shows the rotated grid and active model domain, as well as the refined grid over MTW.

The main difference between the current and previous models is that the interburden between selected major coal seams was represented with a model layer, whereas in the AGE (2010) model the interburden aquitards were simulated using the vertical conductance term in SURFACT. More coal seams were also added to the updated model to better represent the geology and mining activities in different pits at MTW.

Each of the coal seams within the Jerrys Plains subgroup have numerous plies, typically between 5 and 15, that coalesce and split over the mining area. The complexity of the coal seam structure was simplified for the numerical model by merging several coal seams plys into single model layers. In all instances the total measured thickness of the coal plys was preserved in the model to ensure seam transmissivity remains the same. The model consists of 16 model layers including seven coal seams. Table C- 1 summarises the hydrostratigraphic units represented by each model layer and the seams targeted by each mining operation.

<table>
<tr><th colspan="5">Table C- 1:UPDATED MODEL LAYERING</th></tr>
<tr><th colspan="3">Unit</th><th>Coal Seam</th><th>Model Layer</th></tr>
<tr><td colspan="4">Alluvium/ Regolith</td><td>L1</td></tr>
<tr><td rowspan="16">Wittingham Coal Measures</td><td rowspan="16">Jerrys Plains Subgrp.</td><td rowspan="3">Mt. Leonard</td><td>Overburden</td><td>L2</td></tr>
<tr><td>Whybrow</td><td>L3</td></tr>
<tr><td>Interburden</td><td rowspan="5">L4</td></tr>
<tr><td colspan="2">Althorpe Fmtn.</td></tr>
<tr><td rowspan="8">Malabar Fmtn.</td><td>Interburden</td></tr>
<tr><td>Redbank Crk</td></tr>
<tr><td>Interburden</td></tr>
<tr><td>Wambo</td><td>L5</td></tr>
<tr><td>Interburden</td><td rowspan="3">L6</td></tr>
<tr><td>Whynot</td></tr>
<tr><td>Interburden</td></tr>
<tr><td>Blakefield</td><td>L7</td></tr>
<tr><td rowspan="4">Mt. Ogilvie Fmtn.</td><td>Interburden</td><td rowspan="3">L8</td></tr>
<tr><td>Glen Munro</td></tr>
<tr><td>Interburden</td></tr>
<tr><td>Woodlands Hill</td><td>L9</td></tr>
</table>

Unit	Coal Seam	Model Layer
	Interburden	L10
Milbrodale Fmtn.		
Mt. Thorley Fmtn	*Interburden*	
	Arrowfield	
	Interburden	
	Bowfield	L11
	Interburden	L12
	Warkworth	
	Interburden	
Fairford Fmtn.		
Burnamwood Fmtn.	*Interburden*	
	Mt. Arthur	L13
	Interburden	L14
	Piercefield	
	Interburden	
	Vaux	L15
	Interburden	L16
	Broonie	
	Interburden	
	Bayswater	

Table C- 1:UPDATED MODEL LAYERING

The model layers represent:

- Layer 1:
  - alluvial aquifers associated with Wollombi Brook and the Hunter River - the thickness of the alluvial sediments was based on the available driller's logs;
  - outside the alluvial plain where the Permian strata outcrop, the thickness of Layer 1 was set at 5 m to represent a regolith / soil zone;
- Layer 2 - the overburden above the uppermost coal seams;
- Layer 3 - the Whybrow Seam, with an average thickness of 5.1m;
- Layer 4 - interburden;
- Layer 5 - the Wambo and Redbank Seams, with a combined average thickness of 3.8 m measured from the base of the Wambo Seam;
- Layer 6 - interburden;
- Layer 7 - the Blakefield and Whynot Seams, with a combined average thickness of 5.4 m measured from the base of the Blakefield Seam;
- Layer 8 - interburden;
- Layer 9 - Glen Munro and Woodlands Hill Seams, with a combined average thickness of 6.4 m measured from the base of the Woodlands Hill Seam (base of mining in MTO);
- Layer 10 - interburden including the Milbrodale Formation;
- Layer 11 - the Arrowfield and Bowfield Seams, with a combined average thickness of 5.7 m measured from the base of the Bowfield Seam;
- Layer 12 - interburden including the Fairford Formation;

- Layer 13 - Mt Arthur Seam, with an average thickness of 4.15 m measured from the base of the seam (base of mining in Warkworth Mine);
- Layer 14 - interburden;
- Layer 15 - the Piercefield and Vaux Seams, with a combine average thickness of 4.85 m measured from the base of the Vaux Seam, representing an in coal seam below the Proposal; and
- Layer 16 - interburden and the top of the low permeability Archerfield Sandstone at the base of the Jerrys Plain sub-group.

Figure C- 1 shows a west to east cross section through the model. The thin blue lines show the cells representing the individual coal seams.

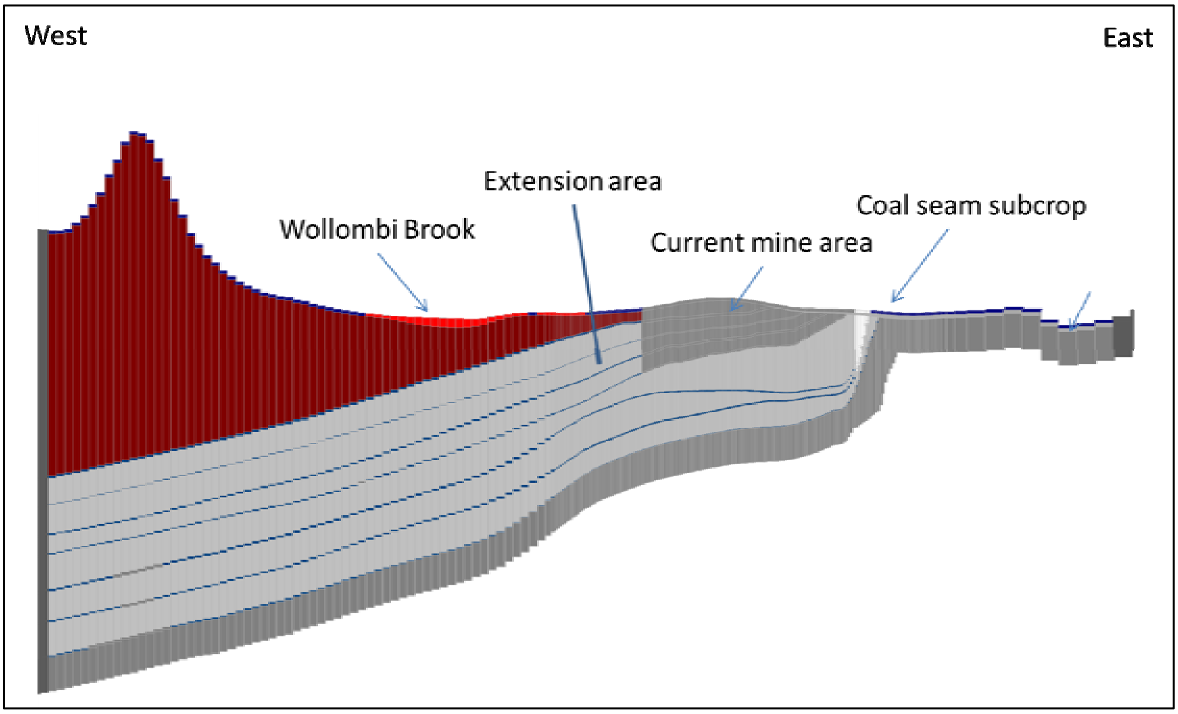
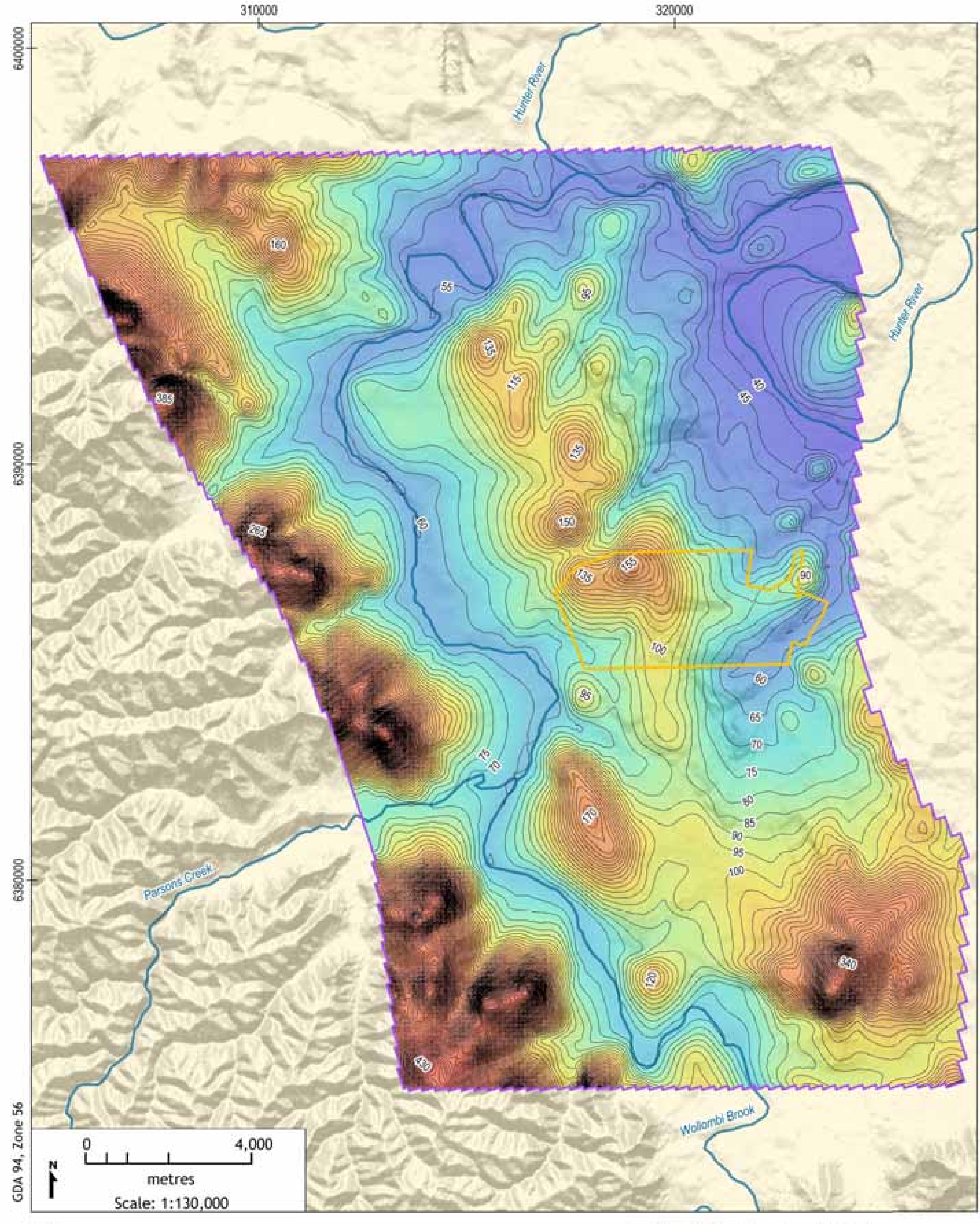


Figure C- 1: West to east cross-section through the model layers

Publicly available nine-second digital elevation data with a 250m x 250m grid spacing were used to represent the ground surface in the model during calibration. These data were chosen as the open cut pits were not evident and therefore the dataset was suitable for the pre-mining calibration. Figure C- 2 shows the top of Layer 1 in the model showing the pre-mining land surface.



LEGEND:

- Active model boundary
- Contour (5m interval)
- Major watercourse
- Proposed MTO development consent boundary

Elevation (mAHD)
485
300
200
100
90
80
70
60
50
35

Mount Thorley Operations 2014 EIS Project
Groundwater Assessment (G1468F)

Model Topographic Surface

AGE GROUNDWATER & ENVIRONMENTAL

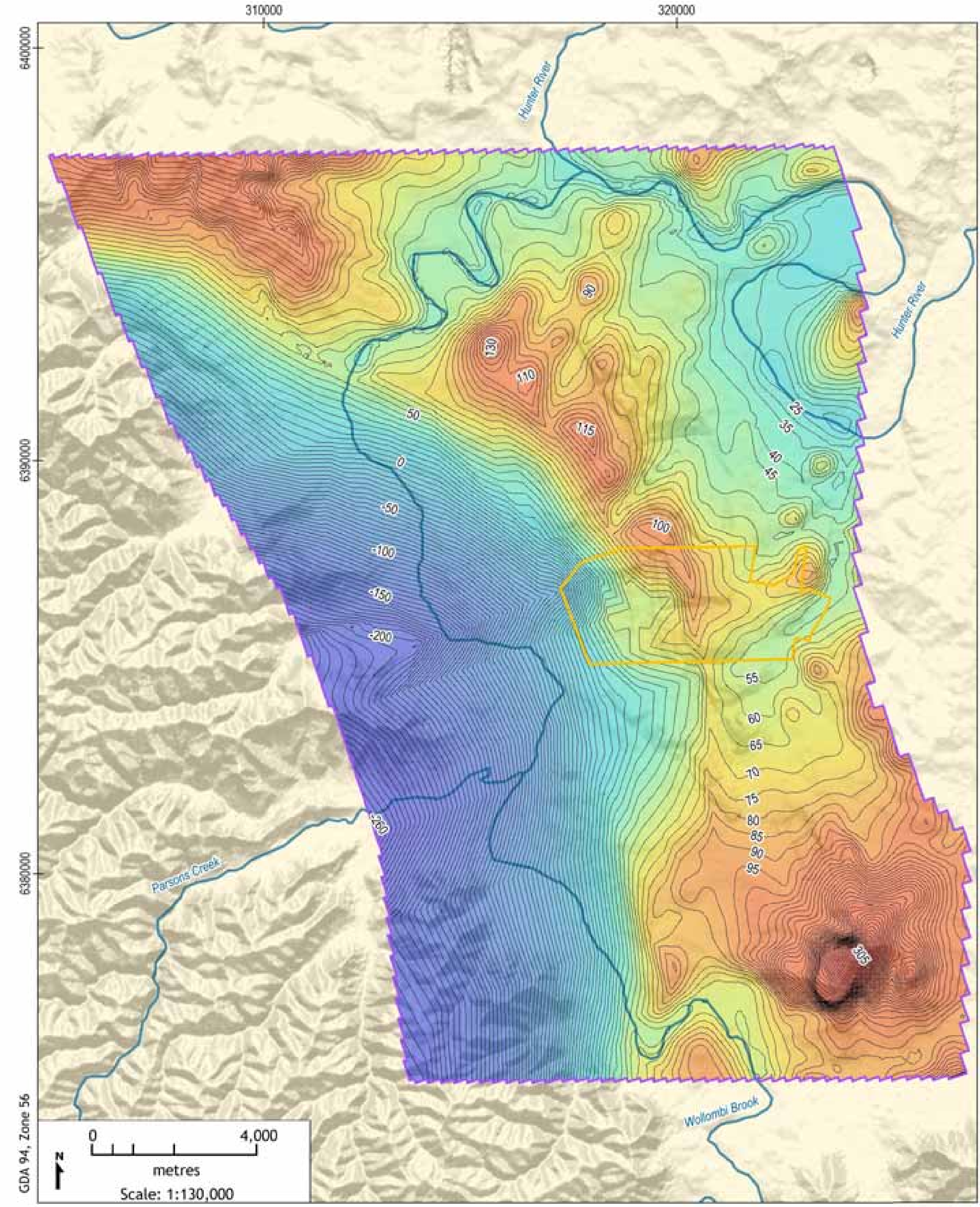
DATE: 3/4/2014

FIGURE No: **C-2**

Within MTW, the structure of the coal seams being mined has been mapped on relatively close drill spacing by the exploration program. As the groundwater model extended outside the mining lease, geologists from MTW mapped the structure of the key coal seams using publicly available data from exploration companies, regional exploration data and the NSW Geological Survey.

In the western section of the model, in the Wollemi National Park area, no data on coal seam structure was available due to a lack of exploration. In this area the coal seams were extended to the west with a constant dip and terminated at the Redmanvale Fault zone, which marks the western boundary of the model. The coal seam structure is considered to be accurate within the mining lease but less certain outside this area due to the limited availability of spatial data.

Figure C- 3 and Figure C- 4 show the base of Layer 3 (Whybrow Seam) and base of Layer 13 (Mt Arthur Seam) to show the westerly dipping structure within the model.



LEGEND:

- Active model boundary
- Contour (5m interval)
- Major watercourse
- Proposed MTO development consent boundary

Elevation (mAHD)

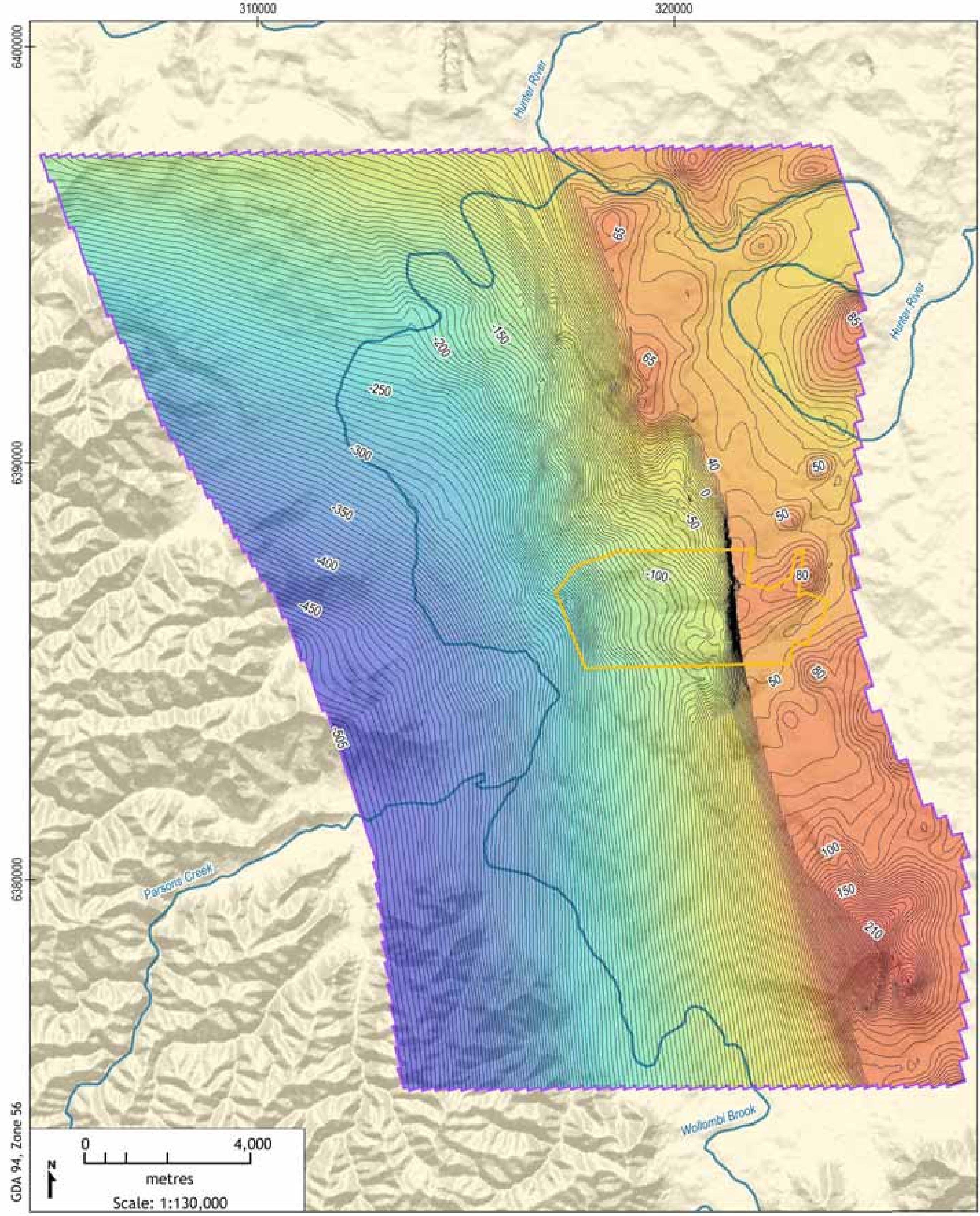
310
200
100
70
60
50
0
-50
-100
-265

Mount Thorley Operations 2014 EIS Project
Groundwater Assessment (G1468F)

Model Layer 3 - Floor Whybrow Seam

DATE: 3/4/2014

FIGURE No: **C-3**



LEGEND:

- Active model boundary
- Contour (5m interval)
- Major watercourse
- Proposed MTO development consent boundary

Elevation (mAHD)

220
100
50
0
-50
-100
-200
-300
-400
-510

Mount Thorley Operations 2014 EIS Project
Groundwater Assessment (G1468F)

Model Layer 13 - Floor
Mount Arthur Seam

AGE

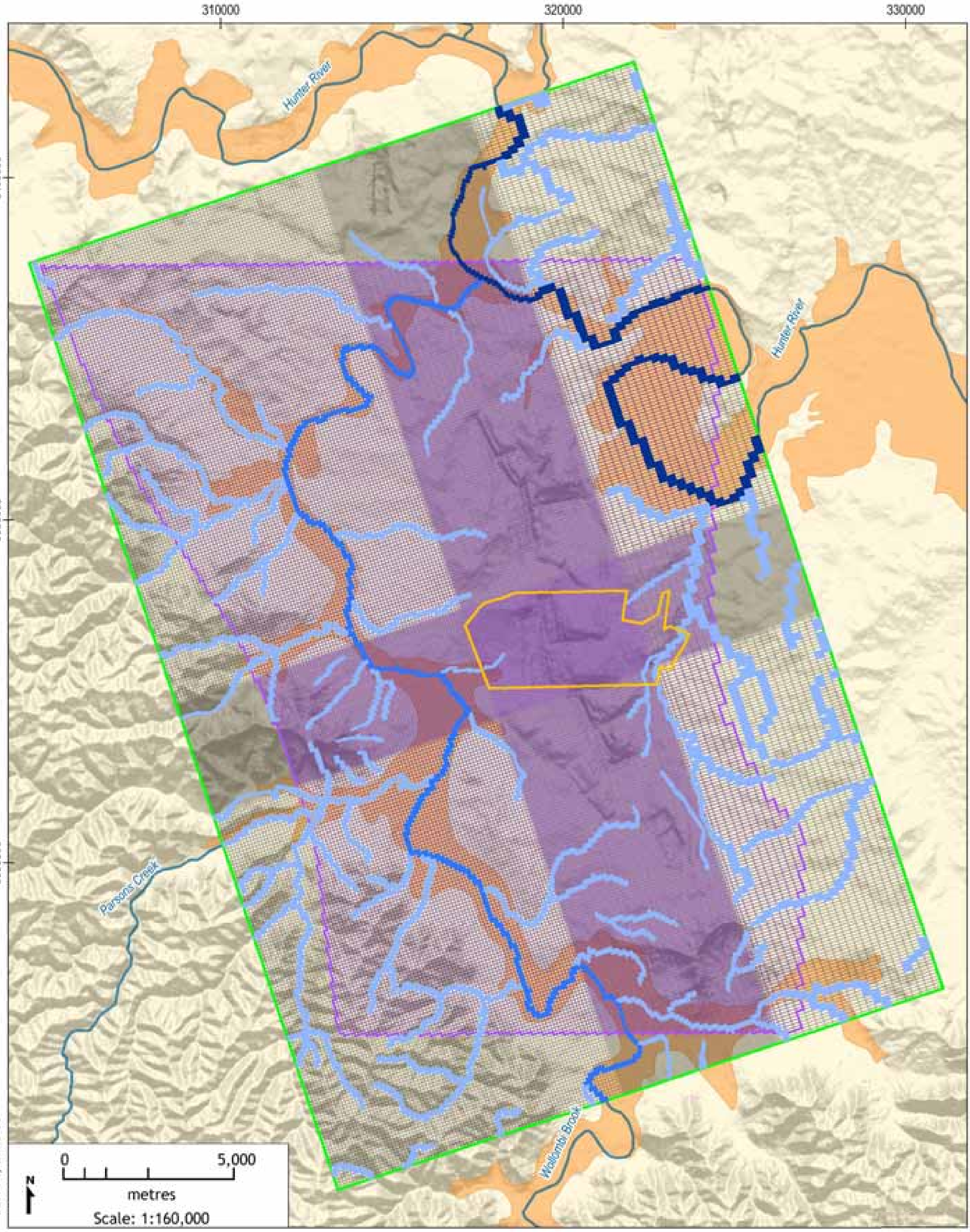
DATE: 3/4/2014

FIGURE No: **C-4**

The model domain is surrounded by “no flow” boundaries as follows:

- the Redmanvale Fault Zone under the Wollemi National Park marks the western boundary;
- the outcrop of the Jerrys Plains subgroup along the Loder Anticline marks the eastern boundary - note the outcrop zone for each seam varies;
- the Hunter River Cross Fault marks the northern boundary;
- an arbitrary distance to the south judged to be beyond the influence of MTW; and
- the base of Layer 16 in the model, which represents the floor of the Bayswater Seam/ top of Archerfield Sandstone.

Figure C- 5 shows the model domain and boundaries.



LEGEND:

Model River Cells

- Hunter River
- Wollombi Brook
- Surface Drainage
- Proposed MTO development consent boundary
- Quaternary alluvium (100k)
- Major watercourse
- Active model boundary
- Active model grid
- Model domain
- Inactive model Grid

Mount Thorley Operations 2014 EIS Project
Groundwater Assessment (G1468F)

Model Domain and River Cells

DATE: 3/4/2014

FIGURE No: **C-5**

1.3.5 Data Exclusions

Prior to the transient calibration, datasets representing the vibrating wire piezometers (VWP) were used to help with the conceptualisation of vertical leakage between different hydrostratigraphic units. Given the model stress period length (one year for the predictive part of the model run), the use of the high density (15 minutes intervals) data for the transient calibration was not practical and did not contribute to the quality of the calibration. The dataset was thus resampled from the 15 minutes intervals to monthly intervals in order to speed up the processing of the modelled results.

During the calibration process, several bores with detrimental influence on the calibration process were identified. These observations were either not relevant to the performance of model in the critical areas, identified as faulty (providing data contradicting to the observation in surrounding areas) or identified as influenced by underground works previously unacounted for in the model. Such observations were removed from the calibration by weighting their contribution towards the objective function to zero.

Bores weighted out of the calibration were: OH1122_1, OH1122_2, OH1122_3, OH1124_1, OH1124_2, OH1124_3, wd615_p2, wd622_p5

1.3.6 Boundary Conditions

1.3.6.1 Rivers and Streams

The SURFACT River package can represent the permanent rivers and ephemeral streams within the active model domain. The river boundary condition was set with a permanent 0.5 m of water in the Hunter River, and 0.1 m in Wollombi Brook to allow for surface – groundwater interconnectivity. The minor surface drainage lines were set as drains and only discharged groundwater from the groundwater systems if groundwater level reached the base of the rivers. Figure C- 5 shows the location of the river cells.

LIDAR elevation data was available for the reach of Wollombi Brook adjacent to MTW. The LIDAR data was used to set the level of the river bed, the coarser SRTM data used where LIDAR coverage was not available. The availability of LIDAR means the bed elevation is accurate along a critical reach of Wollombi Brook (adjacent to the proposed mining).

The vertical hydraulic conductivity of the bed of Wollombi Brook and Hunter River river boundary cells were set as 0.01 m/day and 0.1 m/day respectively. The bed thickness was 2 m for the Hunter River and 1.5 m for the Wollombi Brook. The sensitivity analysis also simulated an extended dry period with no flow in the Wollombi Brook by removing the fixed stream water level.

1.3.6.2 Recharge

Table C-2 shows rainfall data used for the model calibration – sourced from Bulga mine.

Table C- 2: ANNUAL RAINFALL FROM BULGA USED IN MODEL CALIBRATION

Year	Rainfall (mm/year)	Year	Rainfall (mm/year)
1981	810.8	1998	797.4
1982	601	1999	641.6
1983	641.9	2000	777.7

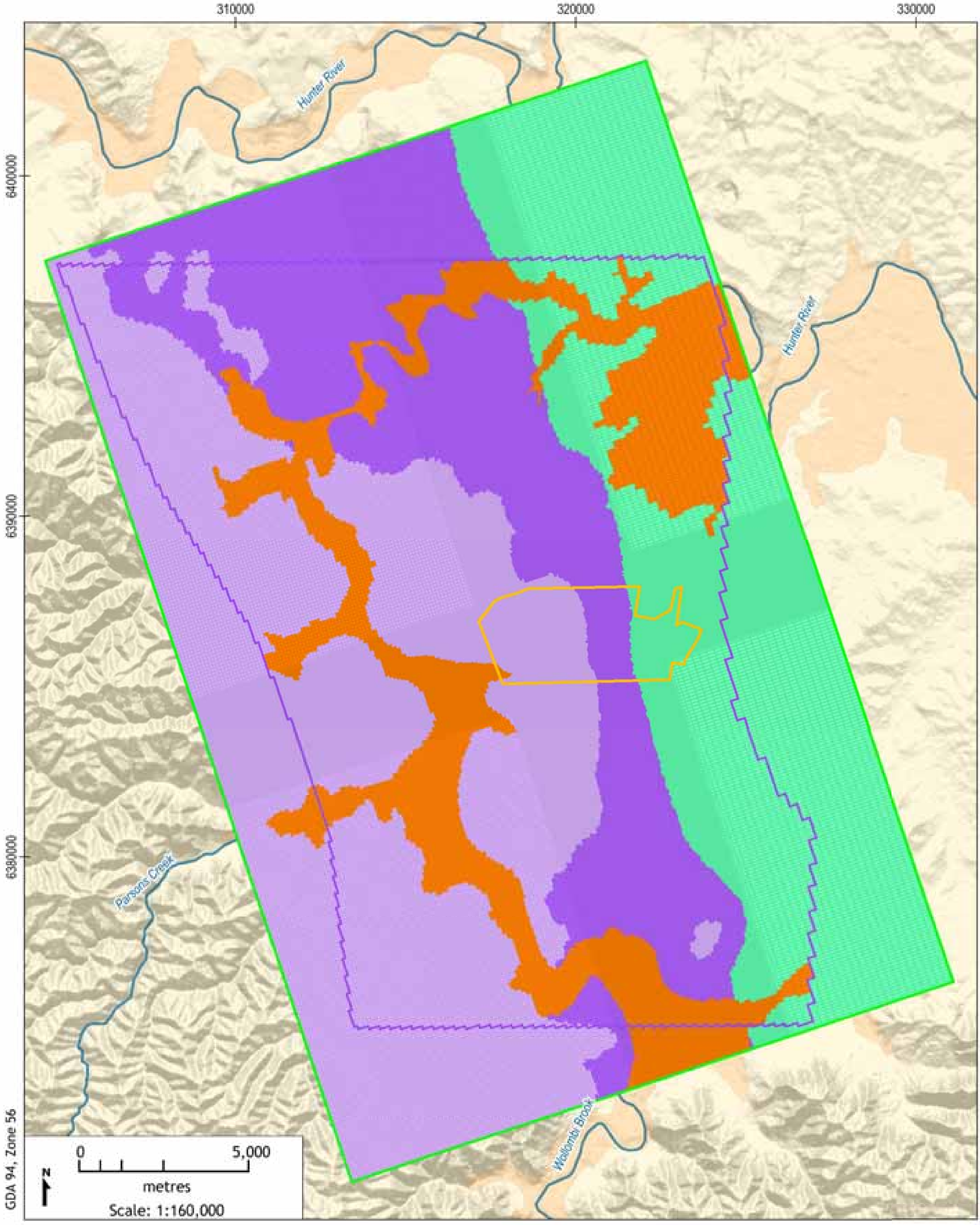
Table C- 2: ANNUAL RAINFALL FROM BULGA USED IN MODEL CALIBRATION			
Year	**Rainfall (mm/year)**	**Year**	**Rainfall (mm/year)**
1984	791	2001	579.98
1985	588	2002	505.7
1986	618.6	2003	615.5
1987	748.8	2004	750.66
1988	867	2005	566.9
1989	860	2006	385.6
1990	742.6	2007	875.3
1991	603.6	2008	659.55
1992	700.6	2009	705.7
1993	540.6	2010	820.3
1994	487.2	2011	871.4
1995	658.6	2012	606.5
1996	619.4	2013	833.9
1997	622.2		

The SURFACT Recharge package applied recharge to the first layer in the model. The rate of recharge to the alluvial aquifer was initially set at 12.5% of rainfall. The recharge rate for the Permian outcrop areas (similar to the rate adopted by MER 2002) was initially set at 0.5 % of rainfall. These values were used as initial starting point to calibrate the model and were the values previously adopted by AGE (2010). The recharge rate (as a proportion of rainfall) was later varied in subsequent transient model calibration runs.

Figure C-6 shows the recharge zones for the alluvium and Permian derived regolith. The model applied recharge over the calibration period as a fixed proportion of annual rainfall recorded at Bulga. Water levels in both the Permian and alluvium recorded with data loggers show a very subdued response to rainfall events. Individual rainfall events therefore did not need to be represented in the model. Table C-3 shows calibrated model recharge values.

As mining progressed, the model increased recharge to the expanding zones of spoil.

Table C-3: CALIBRATED RECHARGE		
Recharge zone		**% of annual rainfall**
Zone 1	alluvium	3.00
Zone 2	regolith	1.50×10^{-1}
Zone 3	Permian outcrops west of Jerrys Plains Subgrp outcrop line	9.27×10^{-2}
Zone 4	Permian outcrops east of Jerrys Plains Subgrp outcrop line	1.00×10^{-7}
Zone 5	spoil	10.32



LEGEND:

Recharge zones:

- Alluvium
- Regolith and Permian overburden
- Permian coalseams outcrop/subcrop
- Archerfield Sandstone (below Bayswater seam)

- Model domain
- Model grid
- Active model boundary
- Proposed MTO development consent boundary
- Quaternary alluvium (100k)
- Major watercourse

Mount Thorley Operations 2014 EIS Project
Groundwater Assessment (G1468F)

Recharge Zones - Layer 1

DATE: 13/5/2014

FIGURE No: C-6

1.3.6.3 Drain Cells, Mining and Spoil

The SURFACT drain package was used to simulate both open-cut and underground mining. A conductance term of 100m/day was applied to all drain cells.

Available mine plans for MTW and publically available mine plans for Bulga and Wambo open-cut and underground mines were used to define the yearly progress of mining for the calibration period from 1980 to 2013. The main body of the report (Section 3) documents the coal seams targeted by each mining operation.

Figure C- 7 shows the simulated progress for mining in all model layers. In each case drain cells were set at the base of the layer that best represented the basal seam being mined in each open pit or longwall.

Within each stage of mining the model increased the amount of the drain cells to simulate the progress of the mine, and at the end of the stage, the hydraulic properties of the mined area changed to represent spoil in the open-cut or the goaf in underground mines.

The lengthy transient calibration period, and the detailed mine progress was implemented to provide the best antecedent conditions possible prior to the proposed mining.

Due to limited availability of historic mine plans each yearly mine strip was simulated by applying drain cells to the base of the seam being mined in each pit or underground operation. This approach may have overestimated the drawdowns during the simulation, and also affected the ability of the model to match observed water levels in some bores during the calibration process.

1.3.6.4 Tailings Storage Facilities

Tailings at MTW are stored in several cells within the spoil heaps and are represented in the model by river cells. The main report Figure 1.1 shows the locations of the tailings storage facilities (TSF). The base of each TSF river cell was set at TSF floor elevation, with the bed thickness increased with time to simulate filling with tailings.

When the TSF were actively being filled the water level within the cells was set at 1 m above the fill elevation. The hydraulic conductivity (k) of the thickening TSF (b) was held constant, resulting in the conductance term (proportional to k/b) reducing as the TSF filled with sediment. This supports field evidence that the TSF have initially high leakage rates which progressively reduce over time as the tailings consolidate and thicken.

All simulated TSFs are located on or within spoil piles and (based on field evidence) contributed to mounded water tables within spoils. The mounding within spoils appears to have contributed to groundwater level recovery in Permian units north of Warkworth mine spoil following mining.

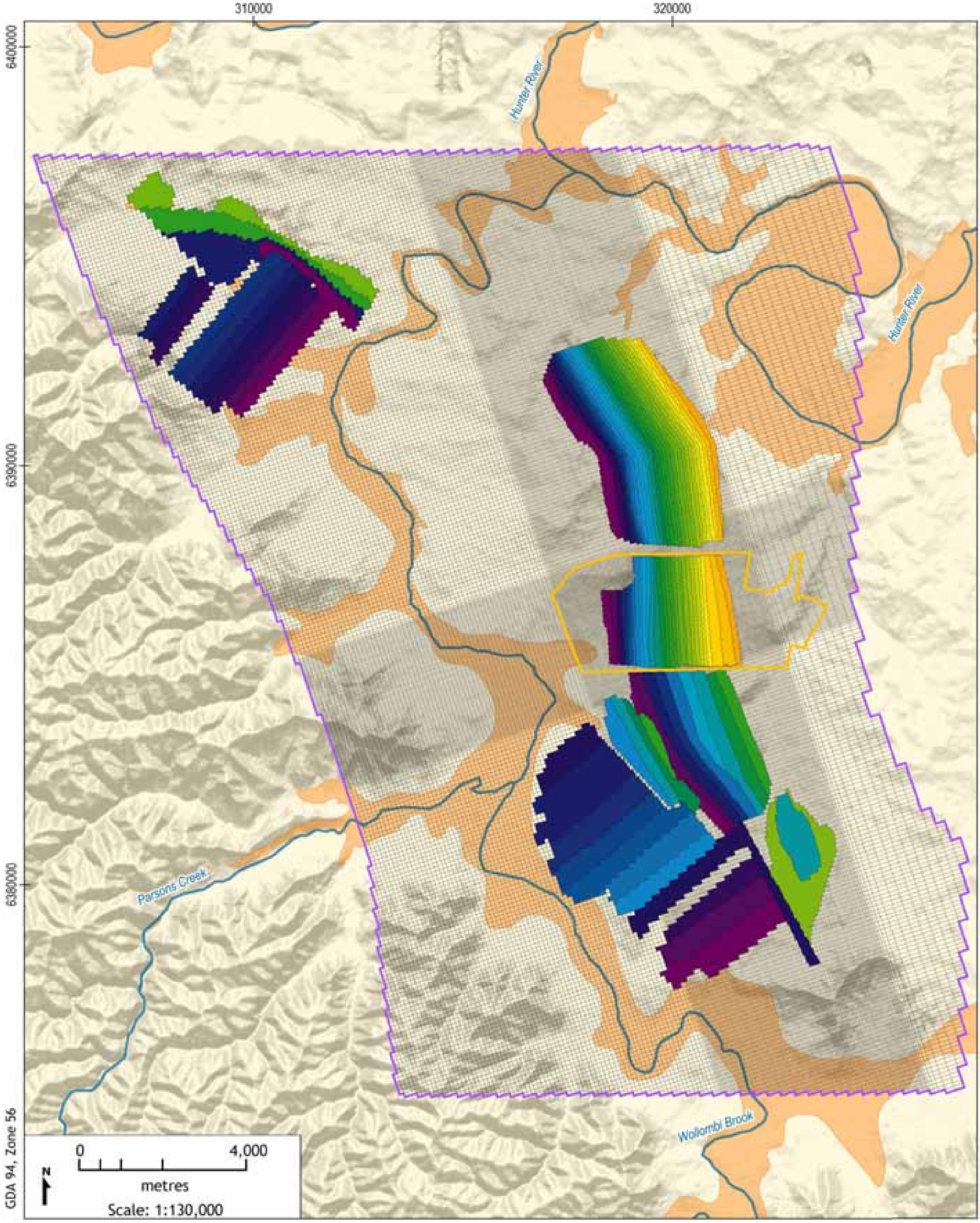
Historical information of TSF fill rates and timing was sourced from ATC (2014a) for Tailings Dam 1 (TD1), ATC (2014b) for Tailings Dam 2 (TD2), ATC (2014c) for the Centre Ramp Tailing Storage Facility (CRTSF) and ATC (2014d) for Abbey Green South (AGS). The smaller mining strip TSF located between Warkworth Pit and Loders pit was not simulated. Table C-4 summarises input data collated for the simulated TSFs, the area of each TSF has also been used to calculated bed conductance through time for each TSF as they fill.

Table C- 4: TSF BED CONDUCTANCE, FILL RATES AND CAPPING SCHEDULES

	Year	Sediment thickness (m)	Head (mRL)	Conductance (m2/day)		Year	Sediment thickness (m)	Head (mRL)	Conductance (m2/day)
	Tailings Dam 1 - TD01					Tailings Dam 2 - TD02			
Tailings Dam 1 - TD01	1984	1	59	37.944	Tailings Dam 2 - TD02	2001	6	121	6.324
	1985	3	61	12.648		2002	7	122	5.421
	1986	5	63	7.589		2003	7	122	5.421
	1987	7	65	5.421		2004	8	123	4.743
	1988	9	67	4.216		2005	8	123	4.743
	1989	11	69	3.449		2006	9	124	4.216
	1990	13	71	2.919		2007	10	125	3.794
	1991	15	73	2.53		2008	12	127	3.162
	1992	17	75	2.232		2009	14	129	2.71
	1993	19	77	1.997		2010	15	130	2.53
	1994	21	79	1.807		2011	15	130	2.53
	1995	23	81	1.65		2012	14.5	129.5	2.617
	1996	23	81	1.65		2013	14.5	129.5	2.617
	1997	23	81	1.65		2014	14.5	129.5	2.617
	1998	23	81	1.65		2015	14.5	129.5	2.617
	1999	23	80.1	1.65		2016	14.5	129.5	2.617
	2000	23	80.1	1.65		2017	14.5	129.5	2.617
	2001	23	80.1	1.65		2018	14.5	129.5	2.617
	2002	23	80.1	1.65		2019	14.5	129.5	2.617
	2003	23	80.1	1.65		2020	14.5	129.5	2.617
	2004	23	80.1	1.65		2021	14.5	129.5	2.617
	2005	23	80.1	1.65		2022	14.5	129.5	2.617
	2006	23	80.1	1.65		2023	14.5	129.5	2.617
	2007	23	80.1	1.65		2024	14.5	129.5	2.617
	2008	23	80.1	1.65		2025	14.5	129.5	2.617
	2009	23	80.1	1.65		2026	14.5	129.5	2.617
	2010	23	80.1	1.65		2027	14.5	129.5	2.617
	2011	23	80.1	1.65		2028	14.5	129.5	2.617
	2012	23	80.1	1.65		2029	14.5	129.5	2.617
	2013	23	80.1	1.65		2030	14.5	128.5	2.617
	2014	23	80.1	1.65		2031	14.5	128.5	2.617
	Abby Green South - AGS					2032	14.5	128.5	2.617
Abby Green South - AGS	2010	20	29	0.045		2033	14.5	128.5	2.617
	2011	20	29	0.045		2034	14.5	128.5	2.617
	2012	24	36	0.038		2035	14.5	128.5	2.617
	2013	50	62	0.018		2036	14.5	128.5	2.617
	2014	50	61	0.018		Central Ramp TSF			
	2015	57	68	0.016	Central Ramp TSF	2001	30	56	0.379
	2016	65	76	0.014		2002	48	74	0.237
	2017	70	81	0.013		2003	64	90	0.178
	2018	70	79	0.013		2004	72	98	0.158
	2019	70	79	0.013		2005	78	104	0.146
	2020	70	79	0.013		2006	78	104	0.146
	2021	70	79	0.013		2007	80	106	0.142

Table C- 4: TSF BED CONDUCTANCE, FILL RATES AND CAPPING SCHEDULES

	Year	Sediment thickness (m)	Head (mRL)	Conductance (m2/day)		Year	Sediment thickness (m)	Head (mRL)	Conductance (m2/day)
	2022	70	79	0.013		2008	84	110	0.136
	2023	70	79	0.013		2009	90	116	0.126
	2024	70	79	0.013		2010	92	118	0.124
	2025	70	79	0.013		2011	98	124	0.116
	2026	70	79	0.013		2012	100	126	0.114
	2027	70	79	0.013		2013	102	128	0.112
	2028	70	79	0.013		2014	106	132	0.107
	2029	70	79	0.013		2015	112	138	0.102
	2030	70	79	0.013		2016	118	144	0.096
	2031	70	79	0.013		2017	122	148	0.093
	2032	70	79	0.013		2018	126	152	0.09
	2033	70	79	0.013		2019	130	156	0.088
	2034	70	79	0.013		2020	135	161	0.084
	2035	70	79	0.013		2021	140	166	0.081
	2036	70	79	0.013		2022	145	171	0.079
	Loders TSF					2023	149	175	0.076
Loders TSF	2020	1	-78	11.383		2024	149	175	0.076
	2021	30	-49	0.379		2025	149	175	0.076
	2022	55	-24	0.207		2026	149	175	0.076
	2023	80	1	0.142		2027	149	175	0.076
	2024	90	11	0.126		2028	149	175	0.076
	2025	100	21	0.114		2029	149	175	0.076
	2026	110	31	0.103		2030	149	175	0.076
	2027	120	41	0.095		2031	149	175	0.076
	2028	130	51	0.088		2032	149	175	0.076
	2029	130	51	0.088		2033	149	175	0.076
	2030	130	51	0.088		2034	149	175	0.076
	2031	130	51	0.088		2035	149	175	0.076
	2032	130	51	0.088		2036	149	175	0.076
	2033	130	51	0.088					
	2034	130	51	0.088					
	2035	130	51	0.088					
	2036	130	51	0.088					



LEGEND:

- Active Model Boundary
- Active Model Grid
- Quaternary Alluvium
- Major Watercourse
- Proposed MTO development consent boundary

Mine Progress

1981	1990	1999	2008
1982	1991	2000	2009
1983	1992	2001	2010
1984	1993	2002	2011
1985	1994	2003	2012
1986	1995	2004	2013
1987	1996	2005	
1988	1997	2006	
1989	1998	2007	

Mount Thorley Operations 2014 EIS Project
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Mine Progress

AGE GROUNDWATER & ENVIRONMENT

DATE: 3/4/2014

FIGURE No: **C-7**

1.4 Model Calibration

Calibration of a groundwater flow model is a process that demonstrates that a model is capable of replicating observed field data. 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.

1.4.1 Calibration Method

The model calibration method was primarily driven by adjusting selected parameters within realistic ranges to match transient groundwater levels. A secondary calibration target was baseflow in Wollombi Brook.

The calibration strategy initially involved manual testing and adjusting parameters to obtain an initial fit against the observation data. The final calibration was completed using PEST to refine the manual calibration. The PEST control file was later used to guide uncertainty analysis.

Matching declining water level trends where these had been measured at monitoring sites was the primary objective of the manual calibration process; whilst obtaining an absolute match was considered secondary. Less weighting was given to bores close to the mine pit face, with groundwater levels at a distance from the mine (towards third-party groundwater users and alluvial aquifers) deemed more important. Parameters were only adjusted within realistic parameter bounds, and were not allowed to move to extremes just to meet statistical objectives.

The steady state model simulated pre-mining conditions and starting heads for the transient model which commenced in 1981. It should be noted that some surrounding mining did commence prior to 1981, with some unknown dewatering effects prior to mining. This historical mining was not simulated in the steady state model, however its impact on groundwater levels is considered to be relatively minor.

A long transient model run from 1981 to 2000 simulated the cumulative impact of mining and served as a suitably long period to represent antecedent conditions prior to the first groundwater levels measurements at MTW in the early 2000’s.

The transient model was calibrated or verified against available transient groundwater level data for the MTW site. A significant data set from multiple locations surrounding the mine was available for this including multi-level monitoring at point locations. Unfortunately no transient groundwater level data was available from the adjoining mines.

1.4.2 Calibration Targets

A selection of groundwater levels measured in monitoring bores and registered water bores were used as the calibration targets for the steady-state model representing approximately pre-mine conditions. Therefore bores which had been potentially affected by mining activities were removed from the calibration process. A total of 60 bores were used to calibrate the steady-state model.

Groundwater levels were collated for monitoring bores at Wambo Mine and Bulga Mine from publicly available AEMR reports. Water levels for registered bores were obtained from NSW Office of Water (NOW), and water levels for the mine monitoring bores were provided by MTW.

All available transient groundwater level data was initially used in the calibration. The main report (Section 5, Figure 5.4) shows the location of bores and VWPs with transient data. Some erroneous outlying data points were given zero weighting during the calibration (see Section 1.3.5). Due to some boreholes only having manual dip data and some bores sites having finely spaced automatic data equal weighting to the calibration was given to each bore site. Following initial calibration a higher weighting was given the three key nested bores in and below the Wollombi Alluvium (PZ7, PZ8 and PZ9).

1.4.3 Calibrated Parameters

Adjustable parameters for all model layers within the calibration process were:

- horizontal hydraulic conductivity (HC);
- vertical hydraulic conductivity (VHC) converted to VCONT in SURFACT;
- specific yield and specific storage;
- river bed vertical conductivity (rivers/streams and TSFs); and
- recharge.

The first model layer was divided into two zones: alluvium and regolith. All other model layers comprised a single zone. The alluvium, interburden and regolith were assigned uniform hydraulic properties for each layer. The hydraulic conductivity of the coal seam layers decreased with depth according to Equation 1 below.

$$HC = HC_0 \times e^{(-0.012*depth)} \quad \text{(Eq. 1)}$$

Where: *HC* is horizontal hydraulic conductivity at specific depth
HC_0 is horizontal hydraulic conductivity at depth of 0 m (surface)
depth is depth of the floor of the coalseam

The Equation 1 was derived from field data presented in the main report. Figure C- 8 shows how hydraulic conductivity was assumed to decrease with depth.

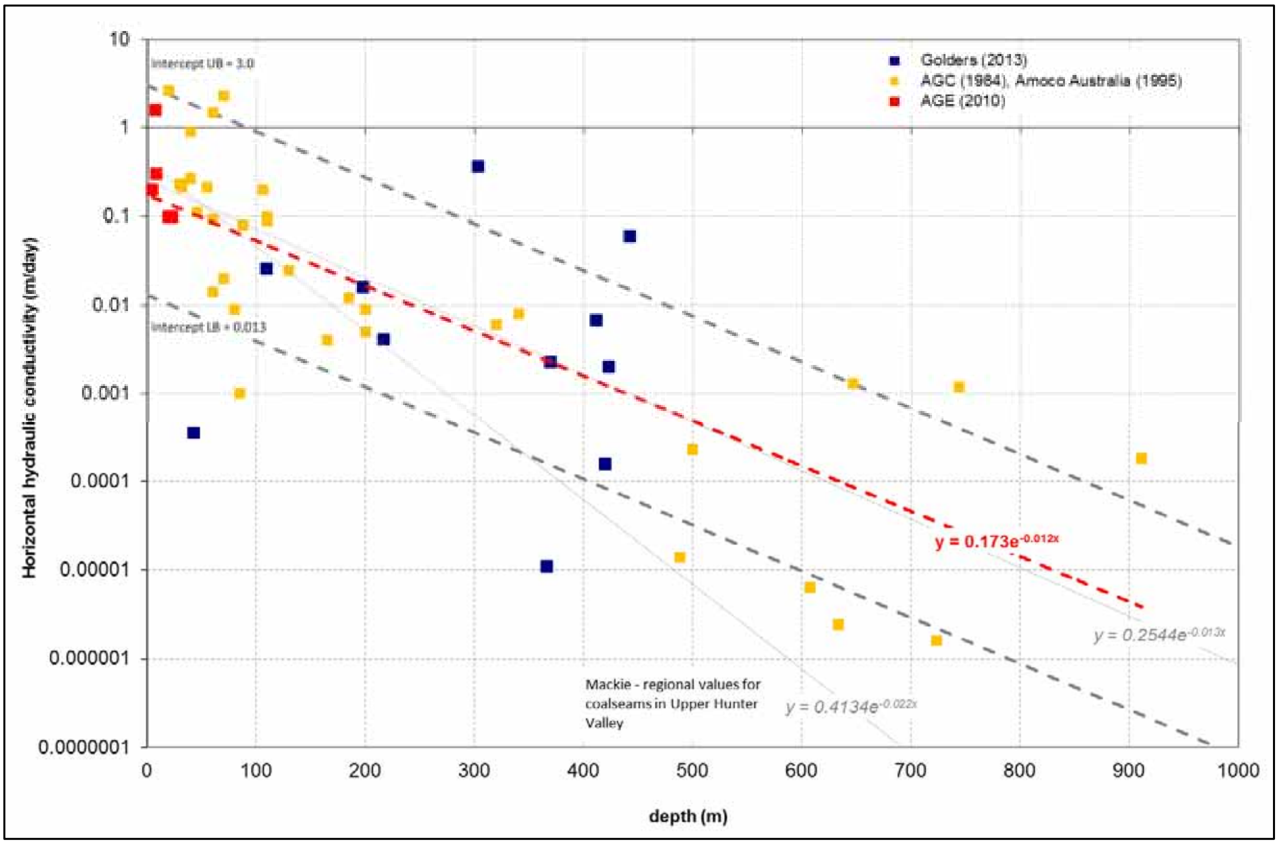


Figure C- 8: Change of hydraulic conductivity with depth – field data

The red fit line shown in this figure was the starting point to the calibration with an upper bound and lower constraints as shown by two grey dotted line in Figure C- 8. The bounds these were set manually within measured data ranges. It is possible setting these tight bounds limited the ability of the model to reproduce some local scale drawdowns processes observed in the monitoring data. However it was considered that keeping parameters within realistic ranges was more important than achieving an absolute fit through measured data points.

Vertical hydraulic conductivity was calculated using the VHC factor (multiplier) using Equation 2. In the case of coal seams VHC (derived from variable HC) is also depth dependant.

$VHC = HC \times VHC_{factor}$ (Eq. 2)

Table C-5summarises the calibrated hydraulic properties.

Table C-5: CALIBRATED HYDRAULIC PROPERTIES					
Model layer		HC, HC0 (m/day)	VHC factor (-)	SS (-)	SY (-)
L01	Regolith	2.37×10^{-01}	1.04×10^{-03}	2.00×10^{-03}	5.00×10^{-03}
L01	Alluvium	$9.44 \times 10^{+00}$	4.01×10^{-04}	2.00×10^{-03}	8.00×10^{-02}
L01 - L02	Permian outcrop	1.00×10^{-05}	1.00×10^{-02}	1.00×10^{-05}	1.00×10^{-04}
L02	Overburden	3.36×10^{-03}	1.00×10^{-02}	1.97×10^{-05}	2.19×10^{-04}
L03	Whybrow Seam	9.38×10^{-02}	9.39×10^{-03}	6.27×10^{-06}	5.50×10^{-03}
L04	Interburden	3.40×10^{-04}	4.22×10^{-03}	6.28×10^{-06}	1.10×10^{-03}
L05	Wambo Seam	3.36×10^{-02}	1.00×10^{-02}	6.30×10^{-06}	5.50×10^{-03}

Table C-5: CALIBRATED HYDRAULIC PROPERTIES					
Model layer		HC, HC0 (m/day)	VHC factor (-)	SS (-)	SY (-)
L06	Interburden	1.76 x10^{-04}	4.66 x10^{-03}	6.30 x10^{-06}	1.10 x10^{-03}
L07	Blakefield Seam	1.30 x10^{-02}	1.00 x10^{-02}	4.00 x10^{-06}	5.50 x10^{-03}
L08	Interburden	3.18 x10^{-04}	4.66 x10^{-03}	4.00 x10^{-06}	1.10 x10^{-03}
L09	Woodlands Hill Seam	2.69 x10^{-02}	6.15 x10^{-03}	5.92 x10^{-06}	5.50 x10^{-03}
L10	Interburden	5.00 x10^{-05}	2.87 x10^{-03}	5.92 x10^{-06}	1.10 x10^{-03}
L11	Bowfield Seam	2.12 x10^{-02}	6.15 x10^{-03}	8.77 x10^{-06}	5.50 x10^{-03}
L12	Interburden	5.00 x10^{-05}	2.87 x10^{-03}	8.77 x10^{-06}	1.10 x10^{-03}
L13	Mt Arthur Seam	1.65 x10^{-01}	4.70 x10^{-03}	4.32 x10^{-06}	5.50 x10^{-03}
L14	Interburden	1.08 x10^{-04}	2.19 x10^{-03}	4.32 x10^{-06}	1.10 x10^{-03}
L15	Vaux Seam	1.68 x10^{-01}	2.35 x10^{-03}	4.00 x10^{-06}	5.50 x10^{-03}
L16	Basement	1.00 x10^{-06}	1.00 x10^{-02}	1.00 x10^{-06}	1.00 x10^{-03}
L01 - L13	spoil - open cut	1.33 x10^{+00}	1.13 x10^{-02}	1.00 x10^{-04}	1.09 x10^{-02}
L03 - L15	spoil - underground	5.00 x10^{-01}	1.00 x10^{-03}	1.00 x10^{-04}	1.00 x10^{-01}

Note: *HC – horizontal hydraulic conductivity, HC0 – horizontal hydraulic conductivity at depth of 0m, SS – specific storage, SY – specific yield.*

Table C-5 also presents the calibrated storage parameters. Optimal calibration occurred with a specific yield (sy) in the alluvium of 5% with 2% for the regolith. Specific yield for open cut spoil was estimated to be 2%.

Figure C- 9 shows the calibrated coal seam hydraulic conductivity values for each coal seam. The graph indicates the calibrated values are towards the lower bound, but still well within the measured data limits.

The model calibrated to a low value of vertical hydraulic conductivity for the interburden, which is considered reasonable given that the interburden sediments effectively confine individual coal seams. Vertical hydraulic conductivity for alluvium was set to a low value to represent vertical conductance between the alluvium and underlying Permian overburden.

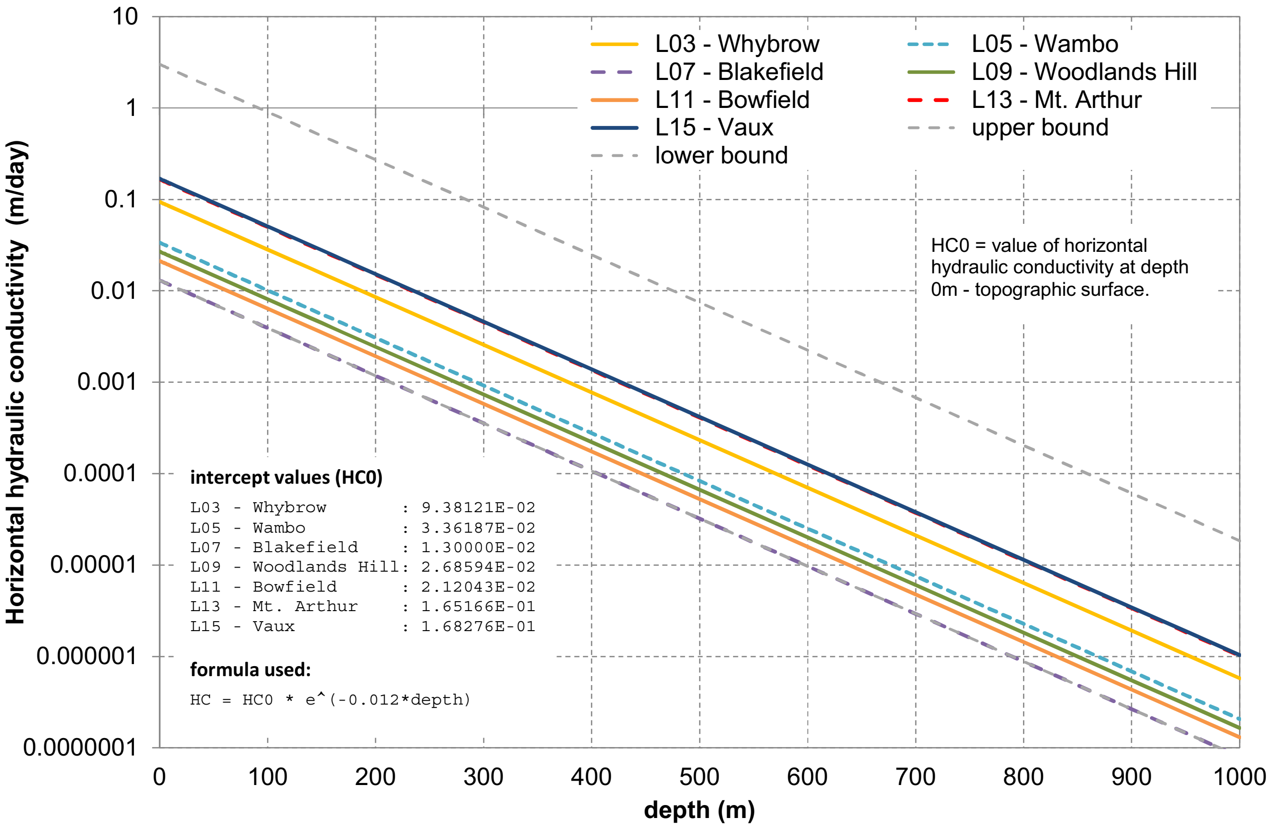


Figure C- 9: Change of hydraulic conductivity with depth – calibrated model data

Optimal calibration was achieved for recharge within expected bounds, with 3% of annual rainfall for the alluvium, 0.15% for the Permian regolith west of the Jerrys Plains subcrop line, 10^{-7}% for the regolith east of Jerrys Plains subcrop line and 10.3% for spoil.

The parameter calibrated for the river boundary condition was the vertical conductivity of the stream bed. As presented in Table C-6 below, the bed vertical conductivity was estimated to be 0.10 m/day for Hunter River, 0.01m/day for Wollombi Brook and 0.10m/day for minor surface drainage.

Table C- 3: CALIBRATED RIVER PARAMETERS

River zone	Bed thickness (m)	Bed vertical conductivity (m/day)	Head (m)
RIV1 - Hunter River	2.00	0.10	1.00
RIV2 - Wollombi Brook	1.50	0.01	1.00
RIV3 - minor surface drainage	1.00	0.10	0.00

1.4.4 Hydraulic Heads

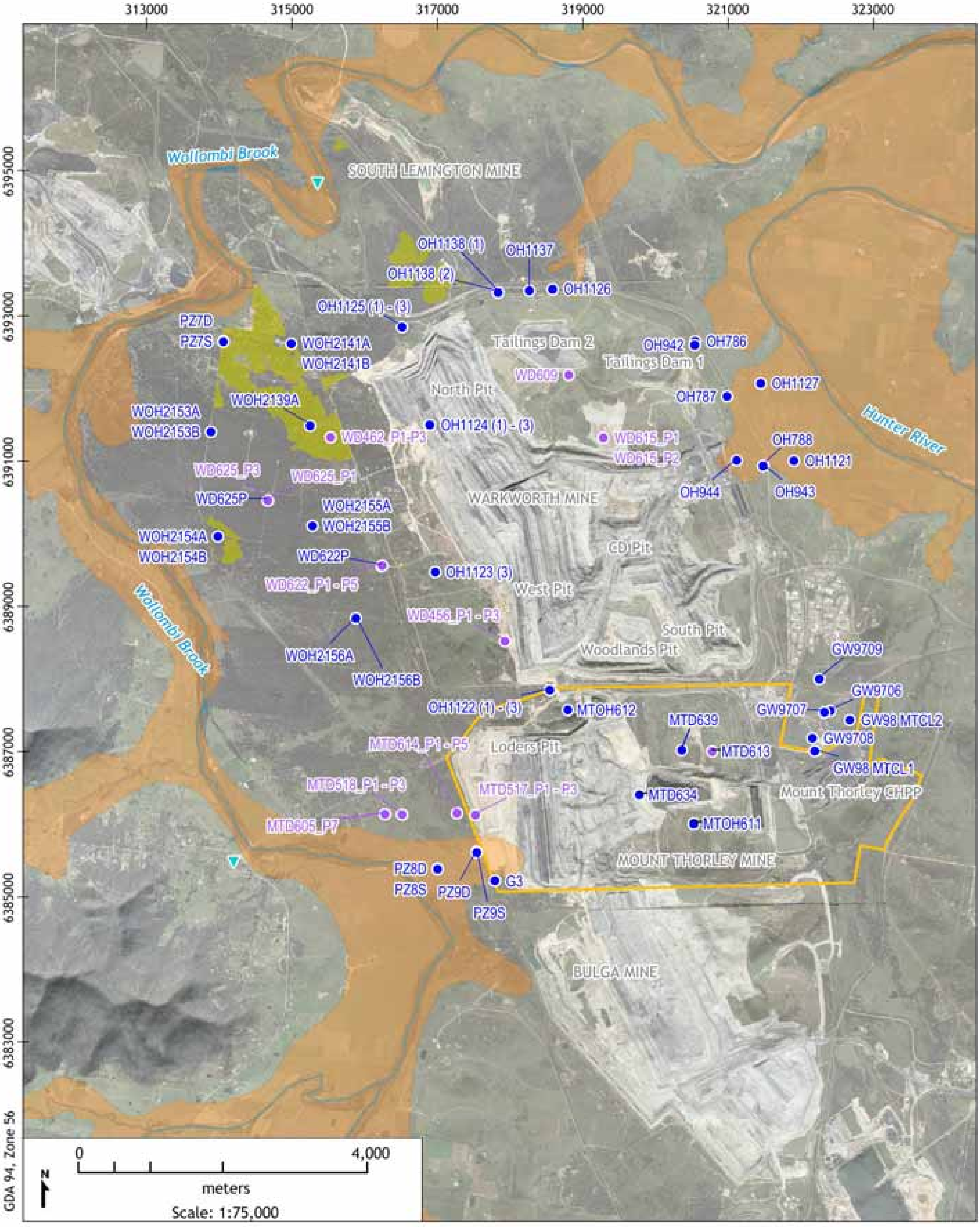
Table C-7 shows the steady state model calibration statistics. As described above this was run to generate the initial heads for the transient model run. Table C-7 shows that the steady state run is above the 10% target (15%) for SRMS lined out in the Australian Groundwater Modelling Guidelines (Barnett *et al* 2012).

Table C- 4: STEADY STATE CALIBRATION STATISTICS		
Parameter	**Value**	**Unit**
sum of residuals (SR):	354.04	[m]
mean sum of residuals (MSR):	7.53	[m]
scaled mean sum of residuals (SMSR):	12.90	[%]
sum of squares (SSQ):	3941.94	[m^2]
mean sum of squares (MSSQ):	83.87	[m^2]
root mean square (RMS):	9.16	[m]
root mean fraction square (RMFS):	18.70	[m]
scaled RMFS (SRMFS):	18.85	[%]
scaled RMS (SRMS):	15.68	[%]

Statistics for the transient run are presented in Table C-8 and these also show SRMS above the target described within the guidelines. Whilst the transient model has statistics above prescribed limits it is still deemed a suitable simulation of the Proposal. This is because the parameters remain within realistic ranges and the model simulates the groundwater depressurisation trends. Further discussion about calibrated model results are present in the main body of the report in Section 7 with contour plots of steady state heads and heads at the end of the calibration for Layer 1 and Layer 13 also presented.

Table C- 5: TRANSIENT CALIBRATION STATISTICS		
Parameter	**Value**	**Unit**
sum of residuals (SR):	21410.65	[m]
mean sum of residuals (MSR):	12.93	[m]
scaled mean sum of residuals (SMSR):	10.91	[%]
sum of squares (SSQ):	530229.79	[m^2]
mean sum of squares (MSSQ):	320.19	[m^2]
root mean square (RMS):	17.89	[m]
root mean fraction square (RMFS):	82.35	[m]
scaled RMFS (SRMFS):	31.86	[%]
scaled RMS (SRMS):	15.10	[%]

The modelled-versus-observed hydrographs for all bores surrounding MTW are included in Figures C-11 to C-20. Figure C- 10 shows the location of the calibration bores.



LEGEND:

Monitoring Bores

- Standpipe
- VWP
- NOW stream gauge station
- Alluvium (100k)
- Warkworth Sands Woodland
- Major watercourse
- Proposed MTO development consent boundary

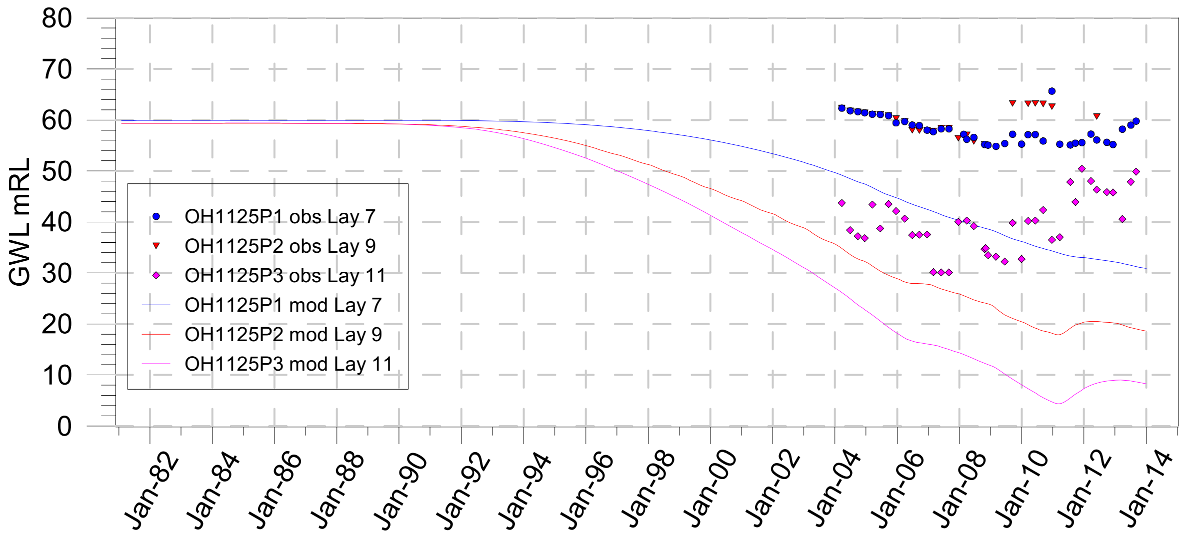
Mount Thorley Operations 2014 EIS Project
Groundwater Assessment (G1468F)

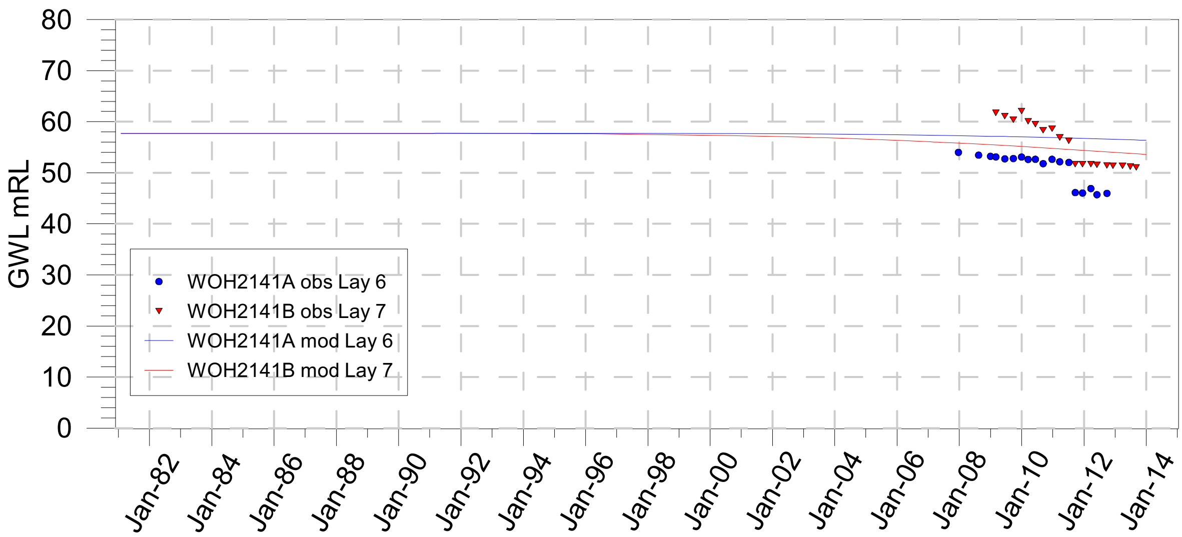
Monitoring Bores

AGE GROUNDWATER & ENVIRONMENTAL

DATE: 9/5/2014

FIGURE No: C-10





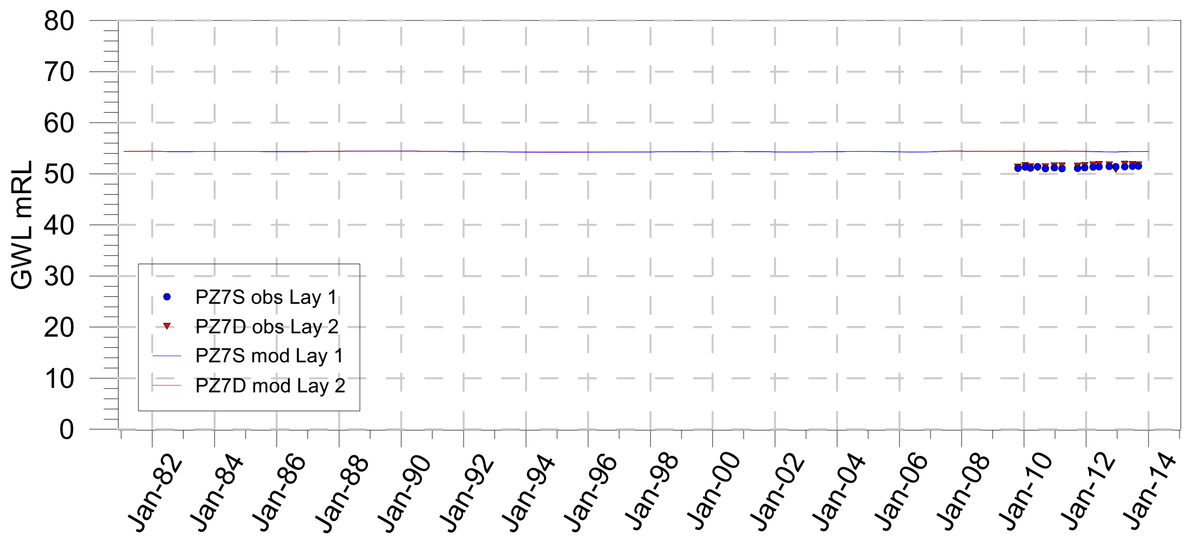
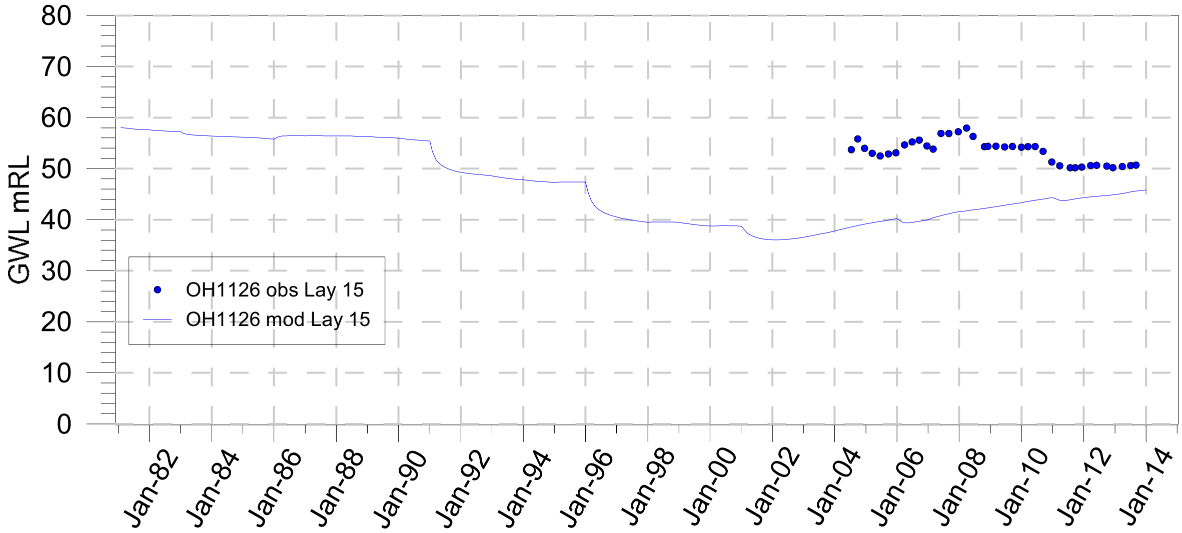
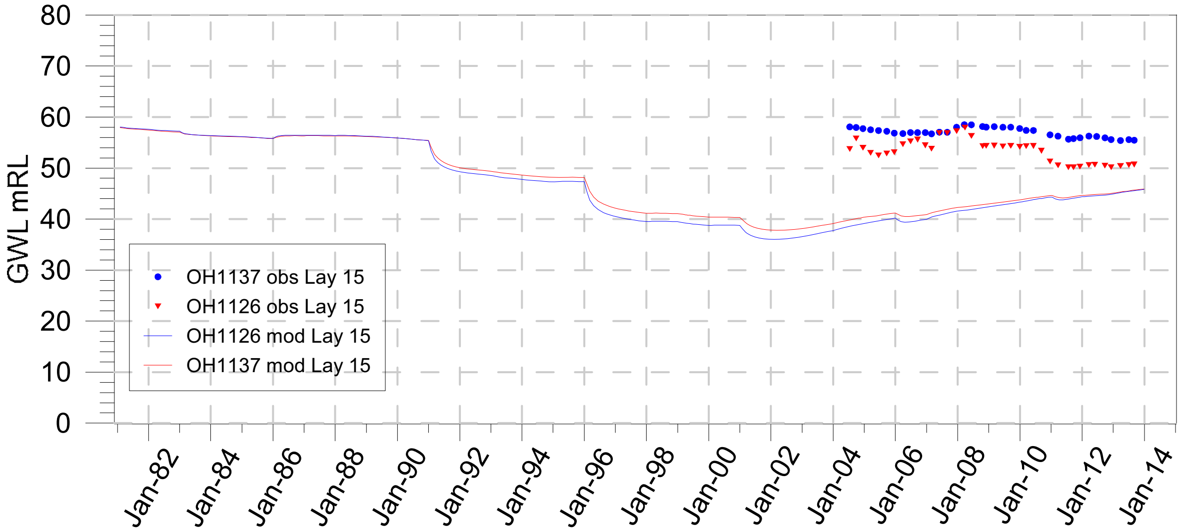


Figure C- 11: Transient modelled versus observed hydrographs





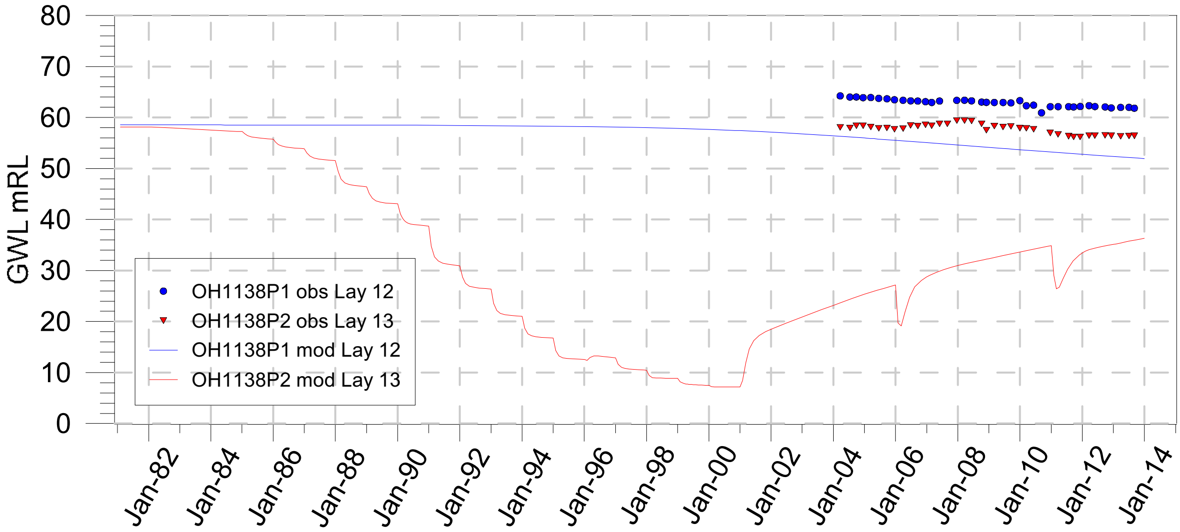


Figure C- 12: Transient modelled versus observed hydrographs

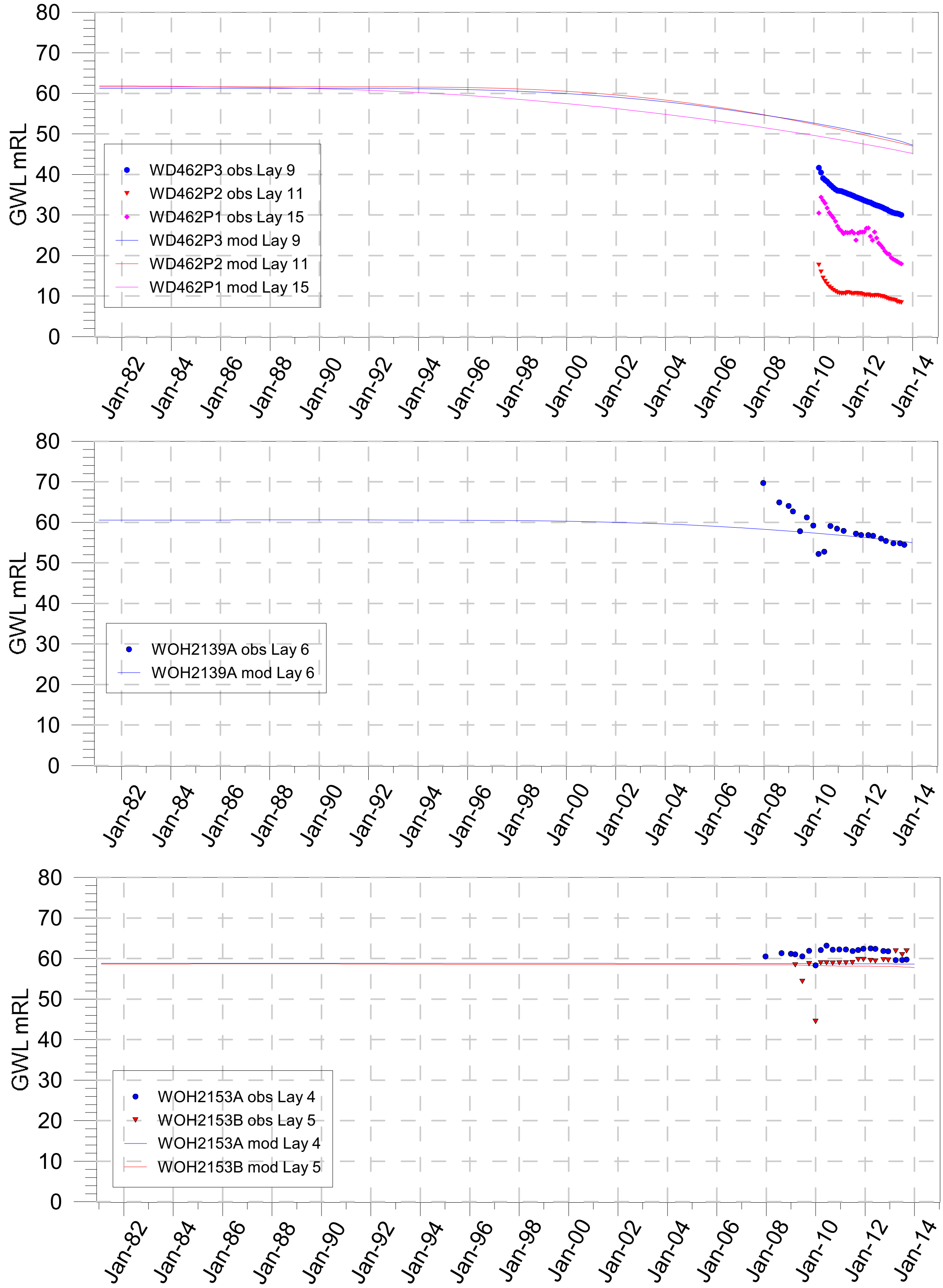


Figure C- 13: Transient modelled versus observed hydrographs

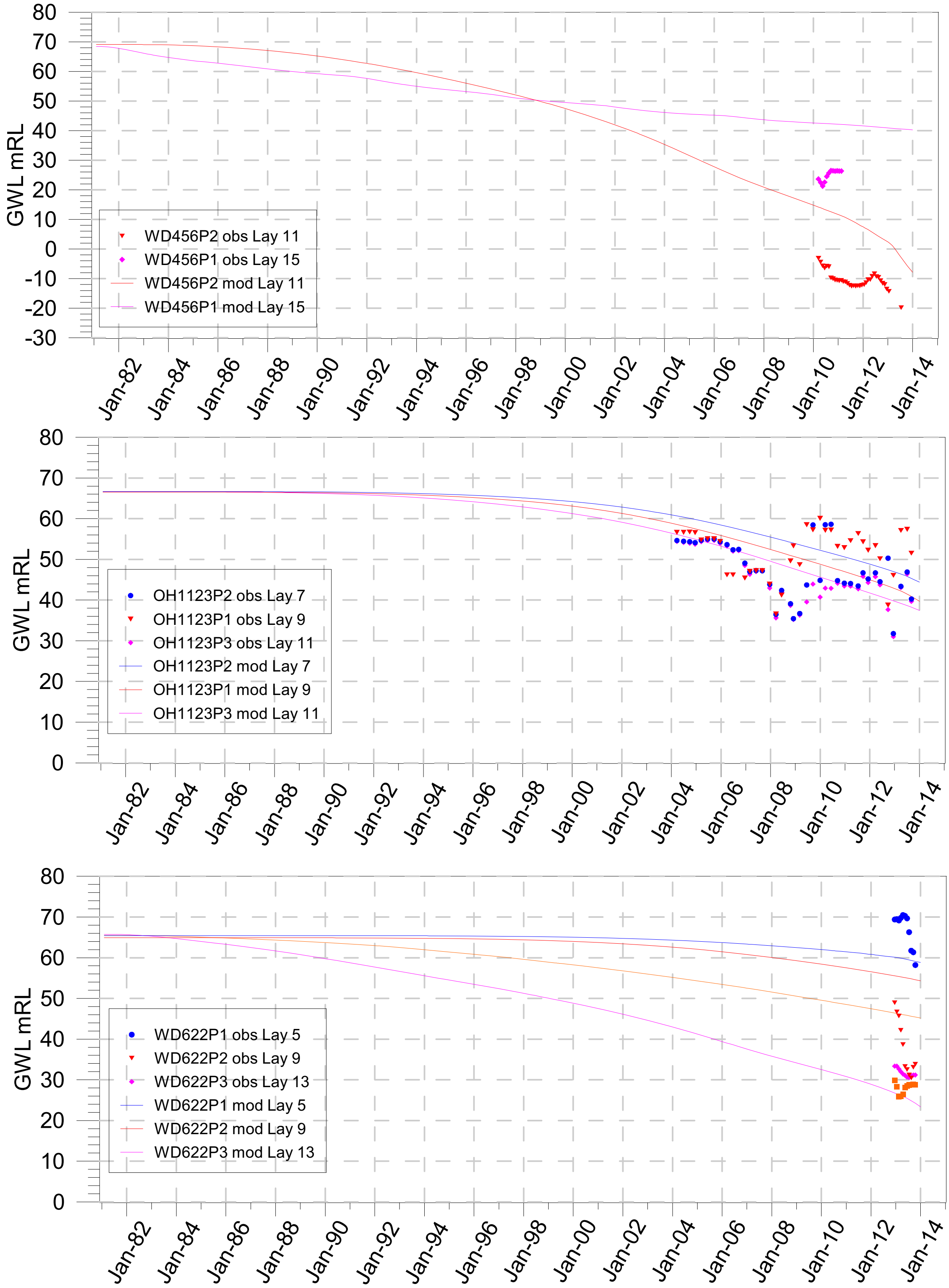
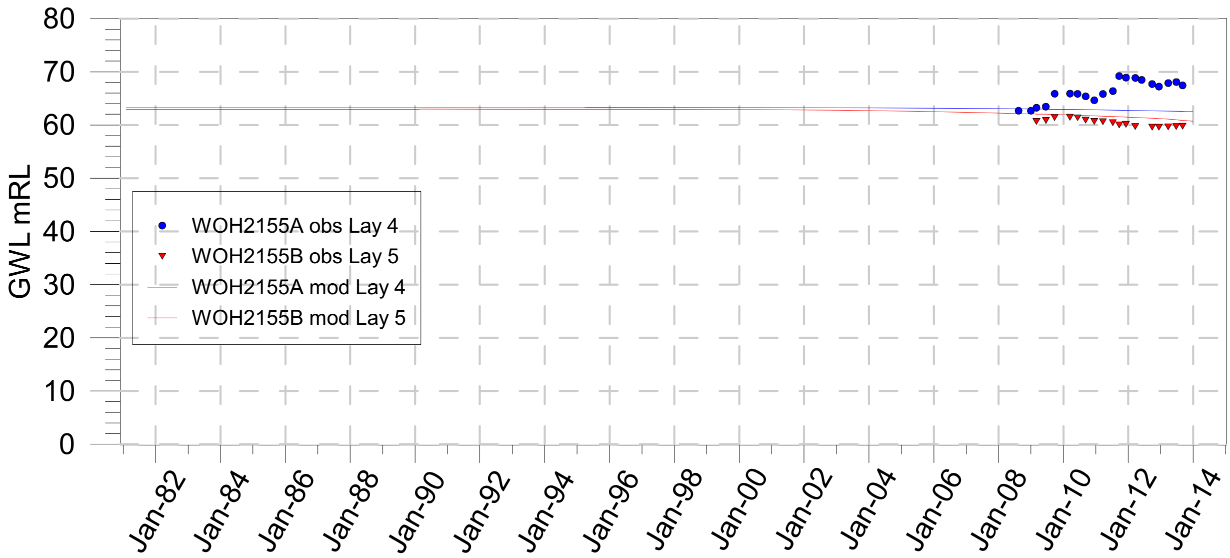
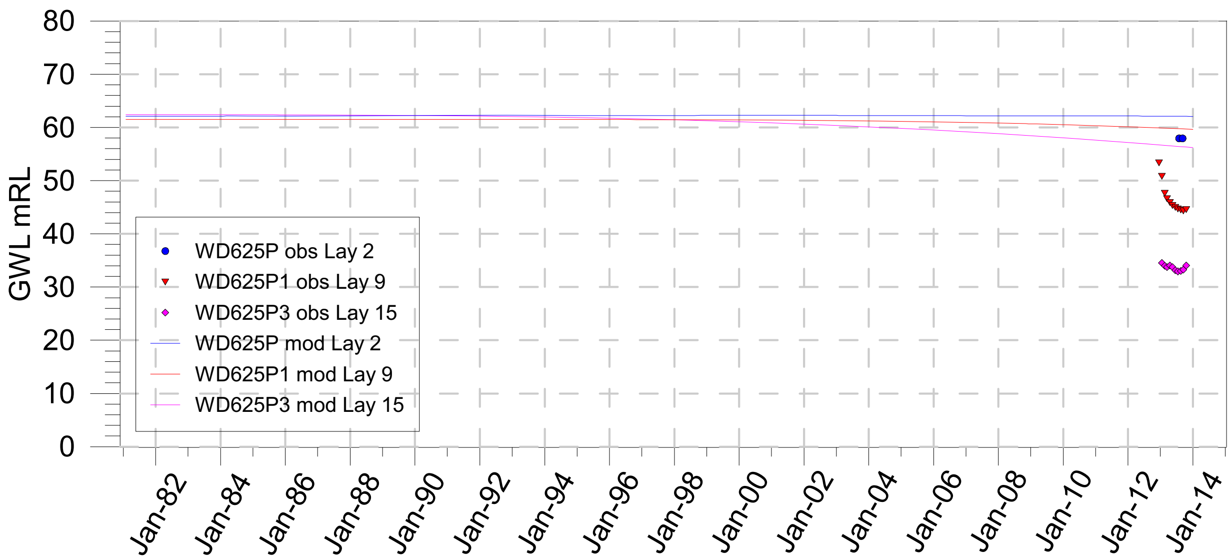


Figure C- 14: Transient modelled versus observed hydrographs





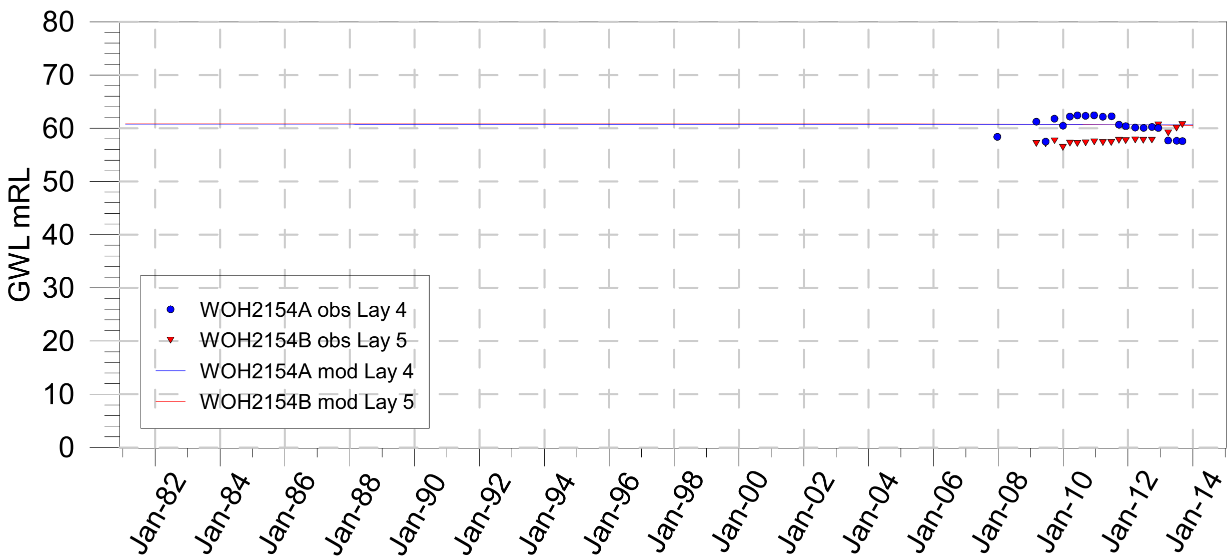
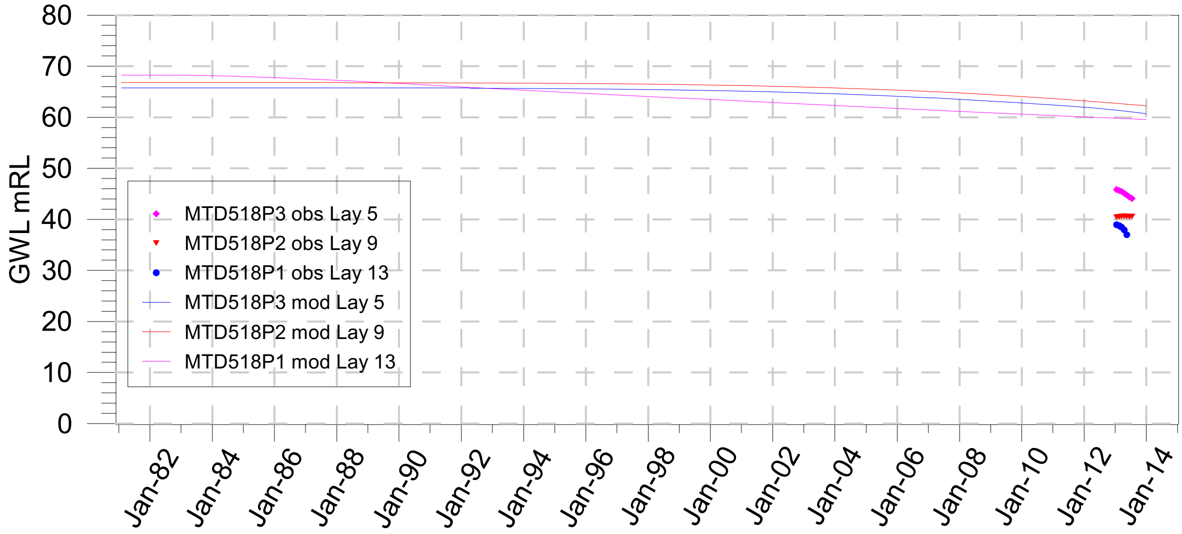


Figure C- 15: Transient modelled versus observed hydrographs



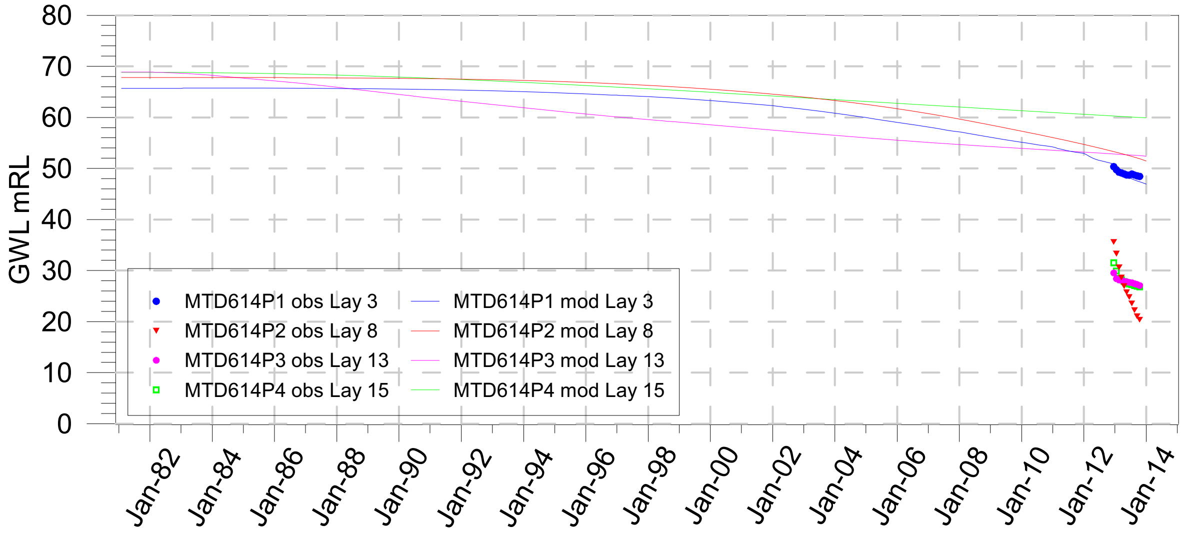


Figure C- 16: Transient modelled versus observed hydrographs

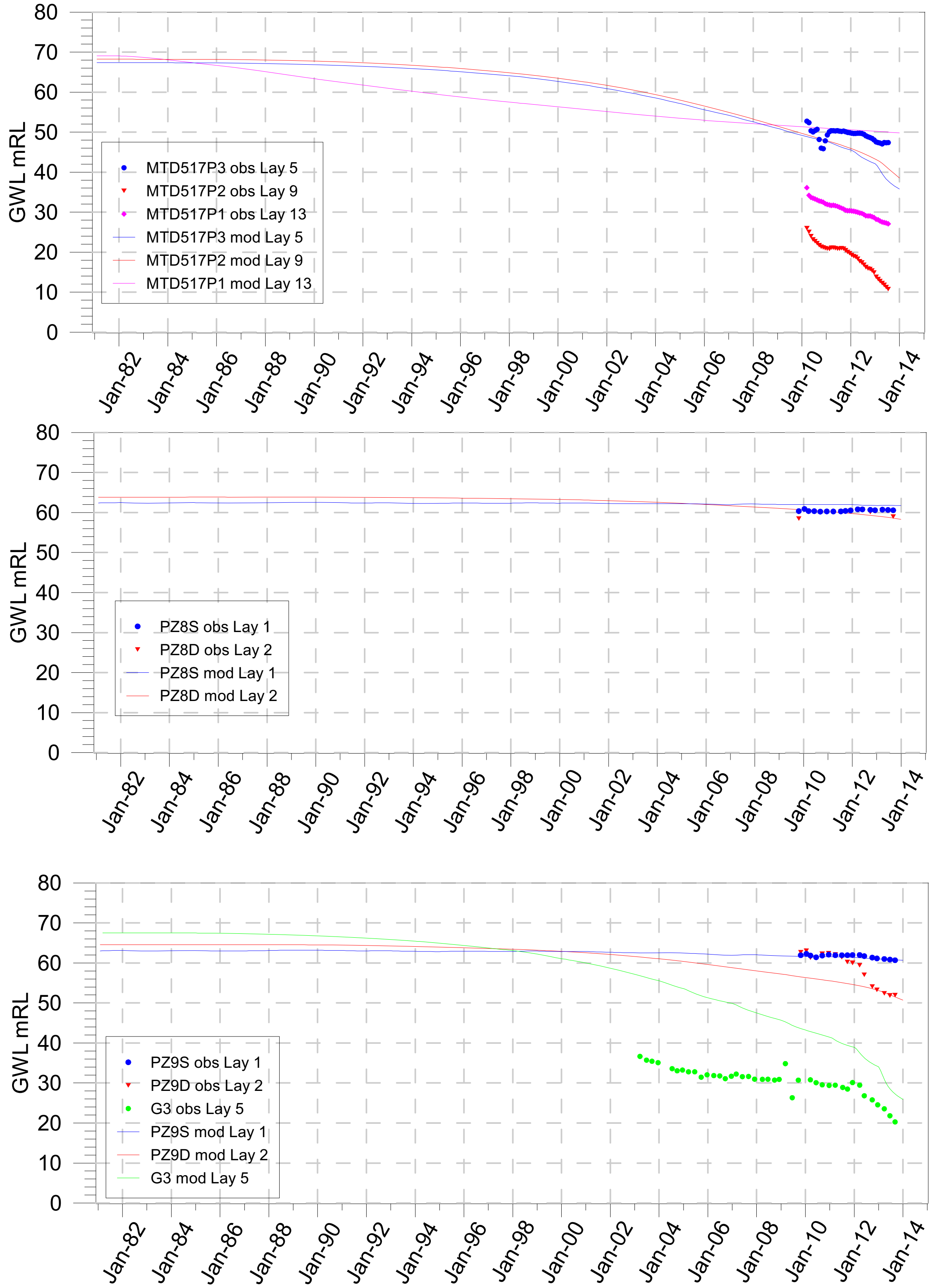


Figure C- 17: Transient modelled versus observed hydrographs

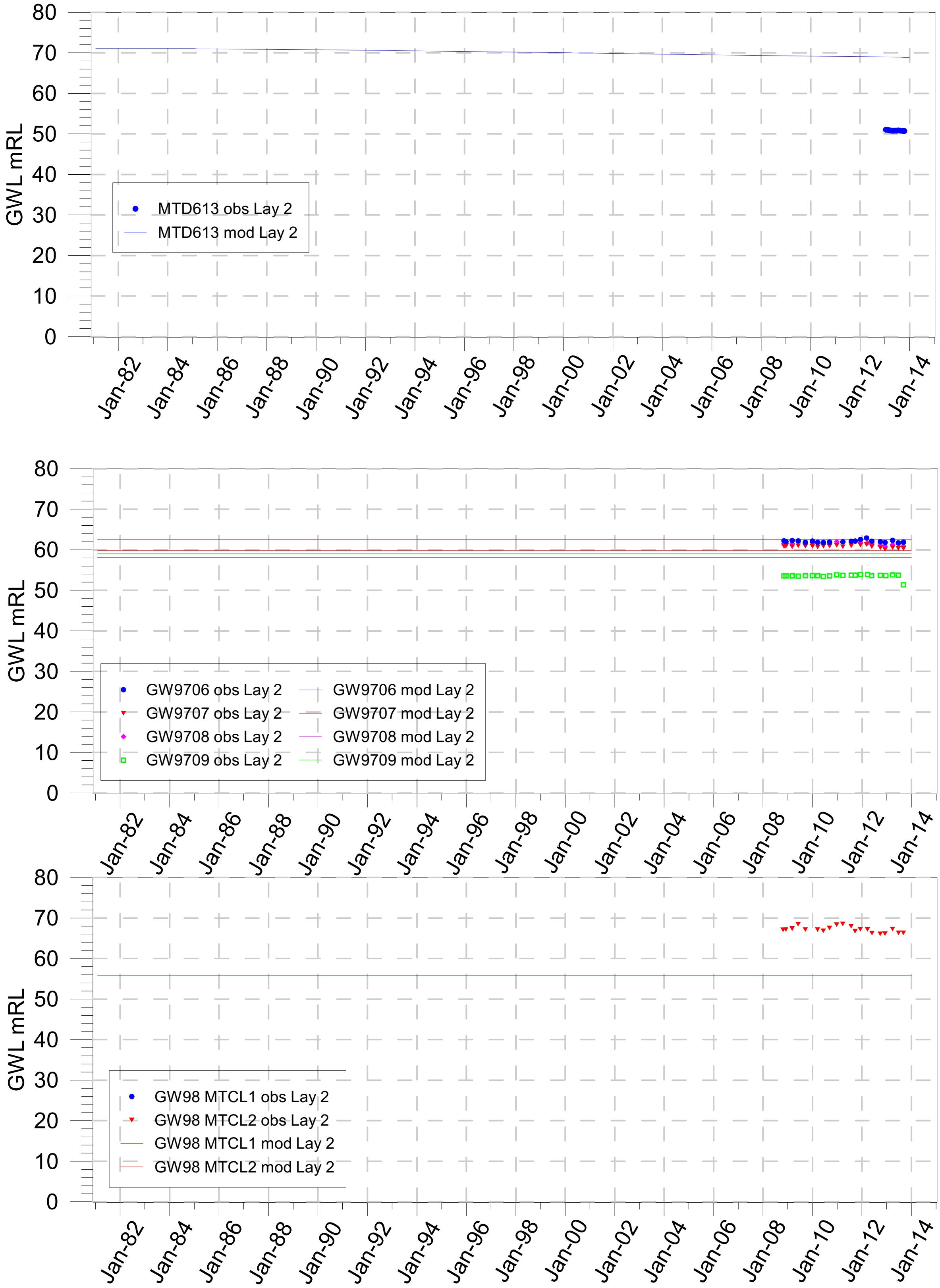


Figure C- 18: Transient modelled versus observed hydrographs

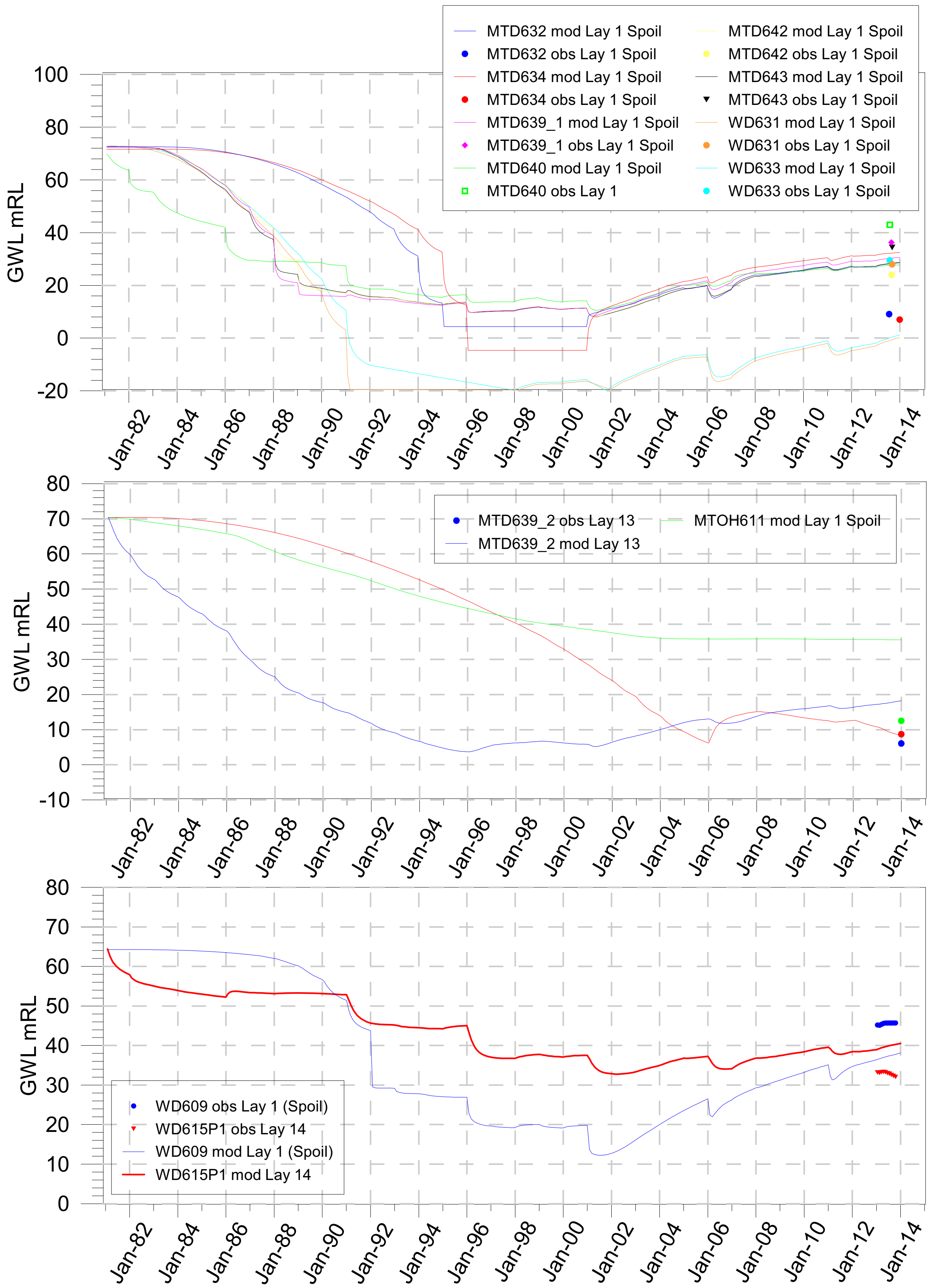


Figure C- 19: Transient modelled versus observed hydrographs

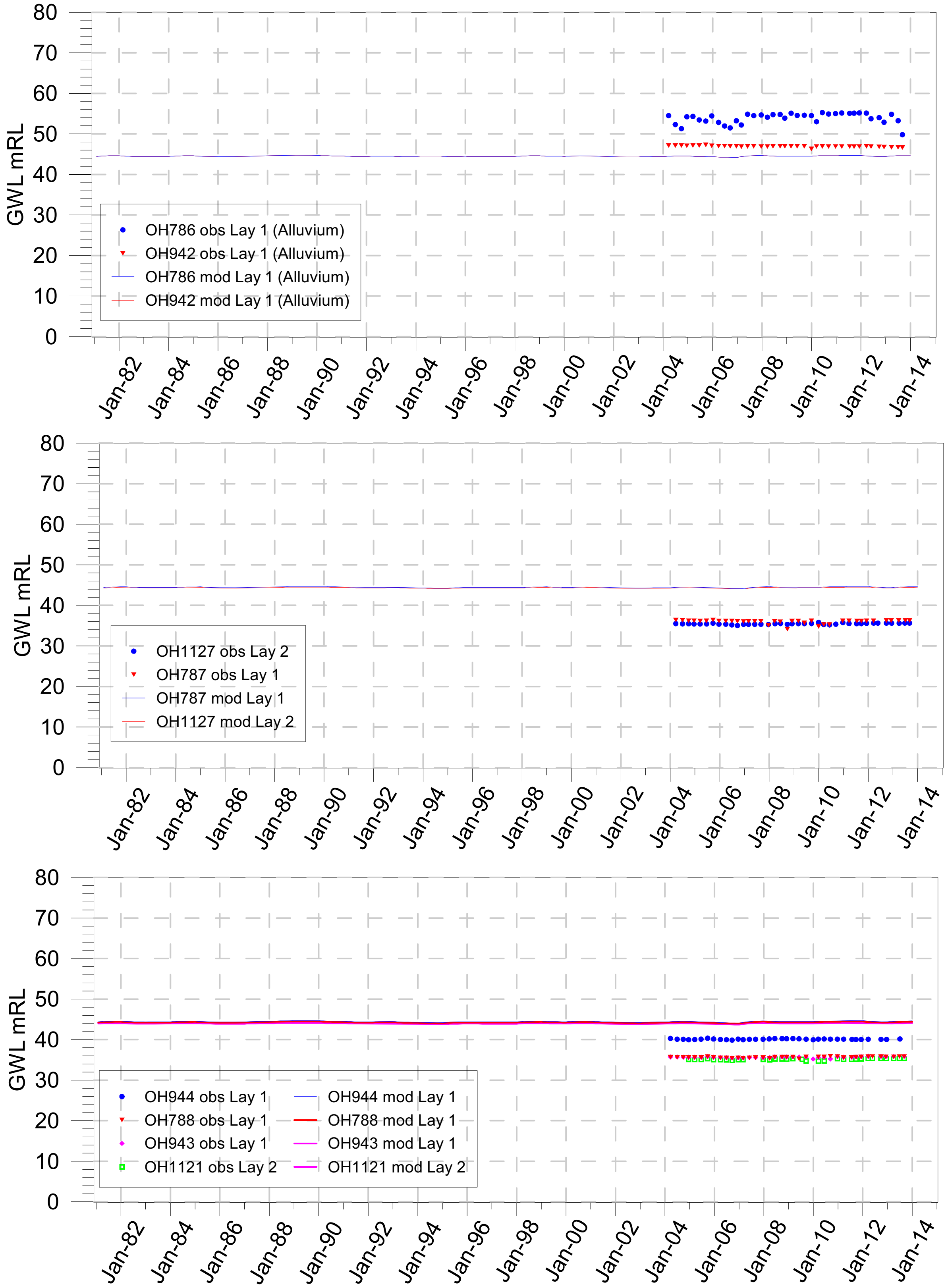


Figure C- 20: Transient modelled versus observed hydrographs

1.5 Calibrated Model Sensitivity Analysis

Following manual calibration, the transient model was calibrated with PEST. Figure C- 21 shows the parameters sensitivities for the first optimisation in the PEST.

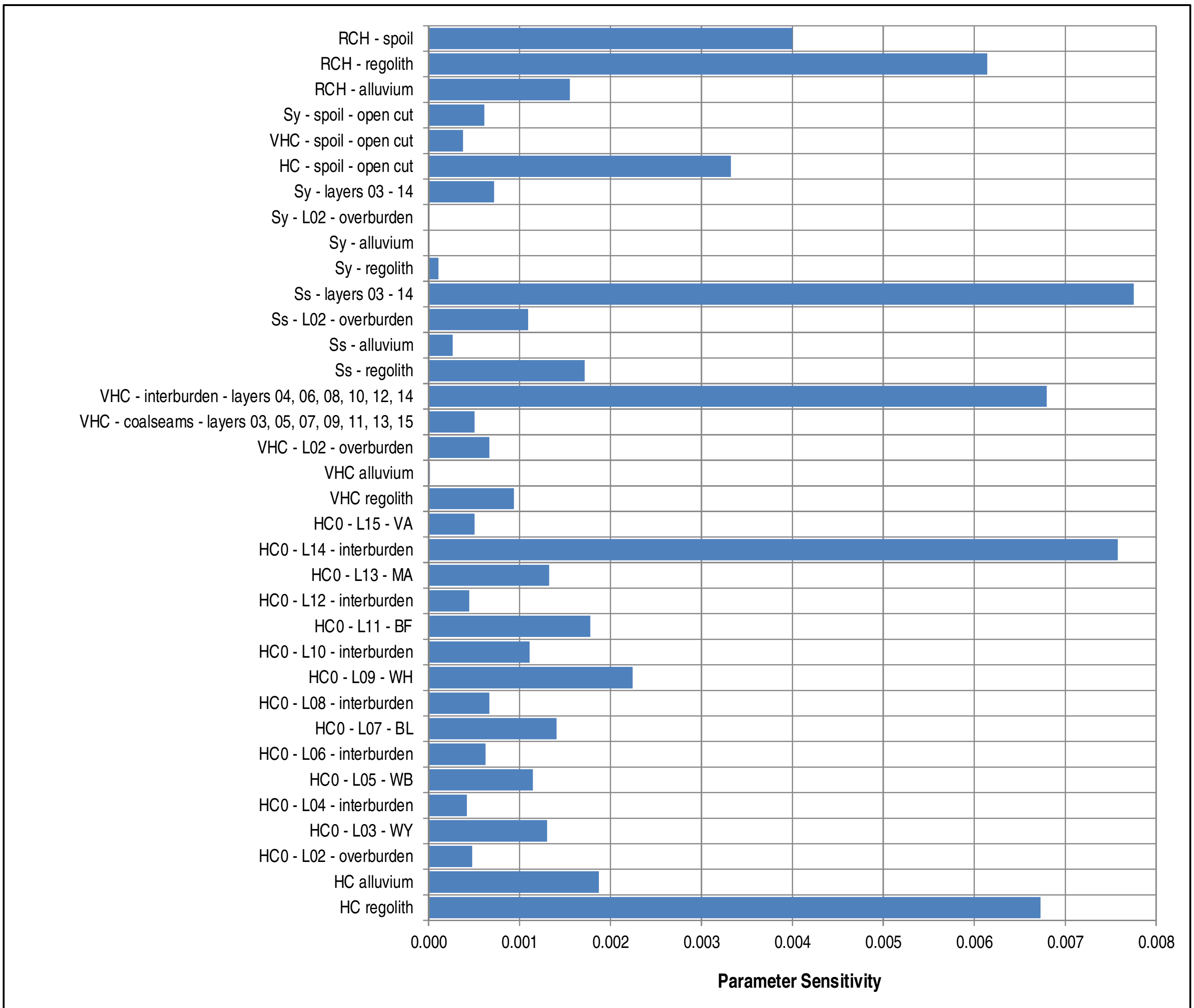


Figure C- 21: Initial automated calibration parameter sensitivities

As some parameters were tied during the initial calibration run they appear with combined sensitivities. Sensitive parameter groups were:

- recharge (RCH) to spoil and regolith (Permian);
- specific storage (ss) in all confined layers;
- horizontal (HCO) and vertical (VHC) hydraulic conductivity in interburden aquitards; and
- horizontal hydraulic conductivity in regolith.

The remaining parameter groups had lower sensitivity. The sensitivity analysis confirms what was evident from manual calibration that the permeability of interburden aquitards plays an important role confining each coal seam, and producing the hydraulic gradient seen on most nested monitoring sites.

Appendix D

NUMERICAL MODEL – UNCERTAINTY ANALYSIS

1. UNCERTAINTY ANALYSIS

1.1 Introduction

This section assesses the uncertainty of the model predictions to natural variability in the calibrated parameters. Analysis of the uncertainty of model outputs is referred to as "uncertainty analysis". Model calibration does not necessarily result in a unique set of parameter values, especially if the model employs a number of parameters to simulate system complexity. As the model was calibrated to known measurements, a calibration-constrained Monte Carlo analysis was carried out, rather than an unconstrained uncertainly analysis.

Typically, groundwater models employ numerous levels of simplification and assumptions, in order to represent reality. Therefore, a number of issues may arise, including:

(i) adequacy in representing naturally complex processes;

(ii) gaps in our understanding of the hydrogeological system process; and,

(iii) measurement 'noise' in observed aquifer measurements.

A calibration-constrained Monte Carlo analysis was carried out with the following objectives:

- to describe a numerically-tractable approach for quantification of uncertainty for this model; and
- report the results of potential uncertainty associated with calibration and predictive model simulations.

The calibration-constrained Monte Carlo method was used for predictive uncertainty analysis to generate variable model parameter sets. To ensure the model remained calibrated, the results from the models were then compared against observed data, accounting for intrinsic errors associated with observed data (i.e. measurement error).

It should be noted that the calibrated model used to base the uncertainty analysis on was not the final calibration discussed within this document. Time constraints to maintain the project deliverable meant that uncertainty analysis had to be conducted prior to final model completion. Although the uncertainty analysis was not based on the final model calibration the results of this analysis are still thought of worth in the discussion on the measurement error in the calibration.

1.2 Methodology

During the pre-calibration stage, appropriate bounds were established for each parameter set, based on observed data, textbook sources and best knowledge. These bounds could represent, for example, the 95th confidence interval of field hydraulic testing data, or one-magnitude variability in specific storage as suggested from similar hydrostratigraphic units in the region. The groundwater model was manually calibrated using these conceptual bounds as parameter limits then set in the automated calibration software, (e.g. PEST).

Model calibration does not necessarily produce a unique set of parameter values, therefore model predictions can vary with a 'calibrated' parameter set. The analysis of the variability in these predictions is known as a calibration-constrained Monte Carlo approach.

Given large variability in the expected range of hydraulic parameters required to create a groundwater model, it is assumed that the predictive results will be subject to a similar level of uncertainty (although the level of uncertaimty depends on type of prediction).

In this study, predictive uncertainty analysis was applied to the MTW Underground groundwater model, which was calibrated to a measurement dataset. This dataset was selected to best represent the groundwater response to seasonal and mining induced stresses on the system from years 1981 to 2014. These parameter sets were 'realized' using a stochastic random number generator, using an adopted set of parameter statistical properties to best represent the observed and/or estimated range.

The randomised realized fields represent the possible variability of the parameter dataset that leads to variability in model predictions. An acceptable level of 'de-calibration' of the calibration model was sought to ensure a calibration constrained and therefore realistic analysis was honoured.

Randomised parameter sets were generated by allowing random heterogeneity on a cell-by-cell basis, to better represent the type of aquifer variability that exists in the real world (Tonkin and Doherty, 2009). Each spatial parameter field was generated using a cell-by-cell stochastic field generator (e.g. the GSLIB geostatistical suite of Deutsch and Journel, 1998). Cell-by-cell variability of parameters also assumed a log-normal prior probability distribution, with means corresponding to optimised parameter values and a variogram sill (upper bound) corresponding to the assumed parameter variance.

200 realised parameter sets were explored for the calibration model, using bounds to correspond with 95% confidence intervals from the expected calibrated parameter bounds used in PEST. The rejection of these parameter sets was determined by ranking the objective function (i.e. Phi) from the transient calibration simulation for each realisation. Realisations that exceeded the calibrated objective function by more than 200% were rejected from the predictive calibration analysis, which was determined from the spread of the Phi results and subsequent levels of de-calibration. Of the 200 realised parameter sets, 127 fell within the acceptable calibrated objective function. The suite of 127 realisations was used to predict the degree of uncertainty within the model outputs, and computing the statistical probabilities of the results (e.g. groundwater drawdown) from all model runs.

1.3 Application of Uncertainty Analysis

1.3.1 Variable Parameters

All hydraulic parameters explored in the automatic calibration were explored in the analysis, including horizontal hydraulic conductivity, vertical hydraulic conductivity multipliers, specific storage, specific yield, groundwater recharge, and riverbed conductance.

The original calibration process employed layer-wide parameters to represent aquifer hydraulic properties for the undisturbed country rock, spoil and underground longwall areas. Thus, these parameters were replaced with spatially varying fields to replicate cell-by-cell variability across the model domain.

The reduction of hydraulic conductivity with depth below surface was represented using an exponential decline function determined from measurement data (refer Section 5.5 of the main report). To introduce a variability of hydraulic parameters, the obsereved decline of horizontal hydraulic conductivity with depth was honored, however a multiplier array changing the calculated hydraulic conductivity value was applied. The multiplier array adjusted the calculated horizontal hydraulic conductivity of the coal seam by a value of 1 standard derivation of the calibrated parameter interval.

Cell-by cell groundwater recharge rates from diffuse rainfall were also included in the uncertainty analyses, using the random-generated multiplication fields. Realised fields representing daily recharge rates were generated for the regolith and alluvial zones, using bounds utilised in the automated calibration process.

Zonal parameter schemes for vertical riverbed permeability were modified for uncertainty analyses, again using random-generated multiplier field (using statistical bounds of expected riverbed conductance rates). The application of vertical riverbed conductivity was split into three separate zones, namely the Hunter River, Wollombi River and 'other' zones.

1.3.2 Statistical Representation

The covariance matrix C(**k**) represents information on hydraulic properties available from outside of the calibration process, and represents "expert knowledge" in the model parameterisation process. The hydraulic parameters within the C(**k**) matrix were set realistic bounds based on the "expert knowledge". The uncertainty of the predictions made by an uncalibrated model is a function of C(**k**).

Information used to assemble the components of the C(**k**) matrix for random parameter generation is presented in Figure D-1 to Figure D- **7**. All parameters and standard deviations were converted to log values given the relationship between parameter and model output is likely to approach linearity. Note, the exponential variogram range in kilometres applied to realised parameter fields was based on expected structural variances in the model (e.g. 2000 m).

Within Table D-1 to Table D- **7**, the calculation of standard deviation of each parameter was based on the assumption that the parameter has a normal distribution and parameter bounds represent the 95% confidence limit. Variance, or the multiplying range applied to the random number generator, is the square of the standard deviation. The mean represents the calibrated value attained from automated PEST calibration, which best replicates the calibrated parameter set. Section 1.4 presents the spatial distribution of the randomised fields, and their native parameter values across the model domain.

Table D-1: HYDRAULIC CONDUCTIVITY CELL-BY-CELL FIELD GENERATION STATISTICS

Parameter Zone	Parameter Name	Mean (m/day)	Standard Deviation	Variance	"a" of Exponential Variogram
			(log_{10})	(log_{10})	(m)
1	Regolith	4.19E-01	0.37	0.14	2000
2	Interburden 1	3.95E-03	0.42	0.18	2000
3	Whybrow Seam	7.61E-02	0.50	0.25	2000
4	Interburden 2	2.19E-04	0.25	0.06	2000
5	Wambo Seam	2.79E-02	0.50	0.25	2000
6	Interburden 3	1.48E-04	0.25	0.06	2000
7	Blakefield Seam	2.56E-02	0.50	0.25	2000
8	Interburden 4	7.31E-05	0.25	0.06	2000
9	Woodlands Seam	2.60E-02	0.50	0.25	2000
10	Interburden 5	6.97E-05	0.25	0.06	2000
11	Bowfield Seam	2.17E-02	0.50	0.25	2000
12	Interburden 6	5.00E-05	0.25	0.06	2000

Table D-1: HYDRAULIC CONDUCTIVITY CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean (m/day)	Standard Deviation	Variance	"a" of Exponential Variogram
			(log_{10})	(log_{10})	(m)
13	Mt Arthur Seam	7.79E-02	0.50	0.25	2000
14	Interburden 7	1.92E-04	0.25	0.06	2000
15	Vaux Seam	5.00E-02	0.50	0.25	2000
16	Interburden 8	1.00E-06	0.42	0.18	2000
17	Alluvium	1.00E+01	0.08	0.01	2000
18	Spoil	3.54E-01	0.45	0.20	2000
19	Underground	5.00E-01	0.50	0.25	2000

Table D- 2: COAL SEAM CONDUCTANCE MULTIPLIER FOR CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean	Standard Deviation	Variance	"a" of Exponential Variogram
			(log_{10})	(log_{10})	(m)
1	Coal Seam	1.00	0.5	0.25	2000

Table D- 3: VERTICAL CONDUCTIVITY MULTIPIER FOR CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean	Standard Deviation	Variance	"a" of Exponential Variogram
			(log_{10})	(log_{10})	(m)
1	Regolith	6.89E-04	0.58	0.33	2000
2	Interburden 1	1.00E-02	0.33	0.11	2000
3	Whybrow Seam	1.00E-02	0.33	0.11	2000
4	Interburden 2	4.12E-03	0.33	0.11	2000
5	Wambo Seam	1.00E-02	0.33	0.11	2000
6	Interburden 3	4.12E-03	0.33	0.11	2000
7	Blakefield Seam	1.00E-02	0.33	0.11	2000
8	Interburden 4	4.12E-03	0.33	0.11	2000
9	Woodlands Seam	1.00E-02	0.33	0.11	2000
10	Interburden 5	4.12E-03	0.33	0.11	2000
11	Bowfield Seam	1.00E-02	0.33	0.11	2000
12	Interburden 6	4.12E-03	0.33	0.11	2000
13	Mt Arthur Seam	1.00E-02	0.33	0.11	2000
14	Interburden 7	4.12E-03	0.33	0.11	2000
15	Vaux Seam	5.00E-03	0.25	0.06	2000
16	Interburden 8	1.00E-02	0.33	0.11	2000
17	Alluvium	8.35E-04	0.50	0.25	2000
18	Spoil	2.95E-02	0.25	0.06	2000

Table D- 3: VERTICAL CONDUCTIVITY MULTIPIER FOR CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean	Standard Deviation	Variance	"a" of Exponential Variogram
			($\log_{10}$)	($\log_{10}$)	(m)
19	Underground	1.00E-03	0.25	0.06	2000

Table D- 4: SPECIFIC YIELD FOR CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean	Standard Deviation	Variance	"a" of Exponential Variogram
			($\log_{10}$)	($\log_{10}$)	(m)
1	Regolith	2.00E-02	0.15	0.02	2000
2	Interburden 1	1.02E-04	0.50	0.25	2000
3	Whybrow Seam	4.74E-03	0.67	0.46	2000
4	Interburden 2	9.49E-04	0.58	0.33	2000
5	Wambo Seam	4.74E-03	0.67	0.46	2000
6	Interburden 3	9.49E-04	0.58	0.33	2000
7	Blakefield Seam	4.74E-03	0.67	0.46	2000
8	Interburden 4	9.49E-04	0.58	0.33	2000
9	Woodlands Seam	4.74E-03	0.67	0.46	2000
10	Interburden 5	9.49E-04	0.58	0.33	2000
11	Bowfield Seam	4.74E-03	0.67	0.46	2000
12	Interburden 6	9.49E-04	0.58	0.33	2000
13	Mt Arthur Seam	4.74E-03	0.67	0.46	2000
14	Interburden 7	9.49E-04	0.58	0.33	2000
15	Vaux Seam	4.74E-03	0.67	0.46	2000
16	Interburden 8	1.00E-03	0.58	0.33	2000
17	Alluvium	5.00E-02	0.29	0.09	2000
18	Spoil	1.98E-02	0.33	0.11	2000
19	Underground	1.00E-01	1.00	1.00	2000

Table D- 5: SPECIFIC STORAGE FOR CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean (m^{-1})	Standard Deviation	Variance	"a" of Exponential Variogram
			($\log_{10}$)	($\log_{10}$)	(m)
1	Regolith	8.33E-04	0.33	0.11	2000
2	Interburden 1	4.68E-05	0.25	0.06	2000
3	Whybrow Seam	6.28E-06	0.42	0.18	2000
4	Interburden 2	6.28E-06	0.42	0.18	2000
5	Wambo Seam	6.28E-06	0.42	0.18	2000

Table D- 5: SPECIFIC STORAGE FOR CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean (m^{-1})	Standard Deviation	Variance	"a" of Exponential Variogram
			(log_{10})	(log_{10})	(m)
6	Interburden 3	6.28E-06	0.42	0.18	2000
7	Blakefield Seam	6.28E-06	0.42	0.18	2000
8	Interburden 4	6.28E-06	0.42	0.18	2000
9	Woodlands Seam	6.28E-06	0.42	0.18	2000
10	Interburden 5	6.28E-06	0.42	0.18	2000
11	Bowfield Seam	6.28E-06	0.42	0.18	2000
12	Interburden 6	6.28E-06	0.42	0.18	2000
13	Mt Arthur Seam	6.28E-06	0.42	0.18	2000
14	Interburden 7	6.28E-06	0.42	0.18	2000
15	Vaux Seam	6.28E-06	0.42	0.18	2000
16	Interburden 8	1.00E-06	0.42	0.18	2000
17	Alluvium	6.03E-04	0.33	0.11	2000
18	Spoil	1.00E-04	0.42	0.18	2000
19	Underground	1.00E-04	0.50	0.25	2000

Table D- 6: RECHARGE FACTOR FOR CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean	Standard Deviation	Variance	"a" of Exponential Variogram
			(log_{10})	(log_{10})	(m)
1	Regolith	4.23E-03	0.17	0.03	2000
2	Alluvium	3.00E-02	0.13	0.02	2000
3	Spoil	7.45E-02	0.17	0.03	2000

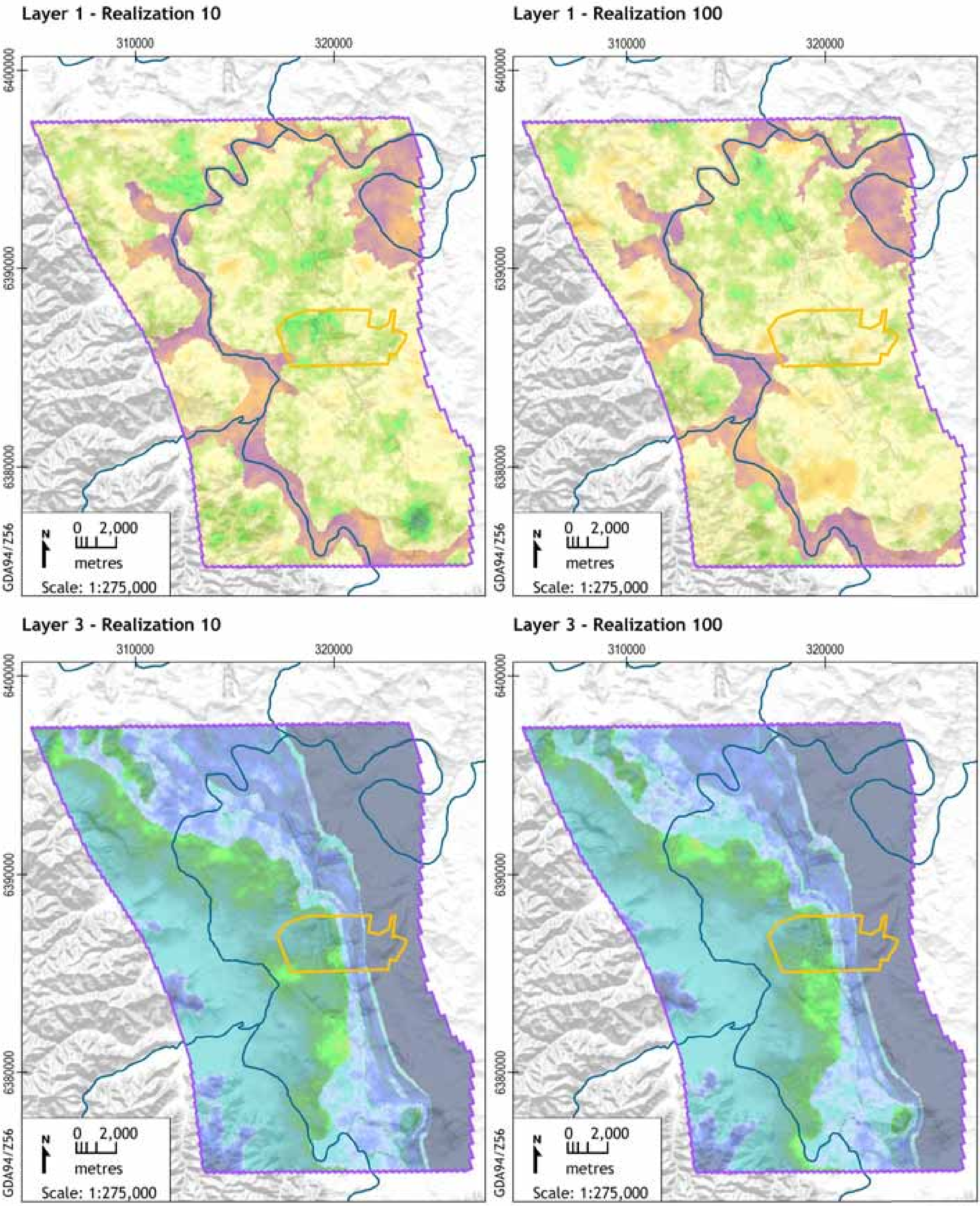
Table D- 7: VERTICAL RIVERBED CONDUCTIVITY FOR CELL-BY-CELL FIELD GENERATION STATISTICS					
Parameter Zone	Parameter Name	Mean (m/day)	Standard Deviation	Variance	"a" of Exponential Variogram
			(log_{10})	(log_{10})	(m)
1	Hunter	1.00E-01	0.58	0.33	2000
2	Wollombi	1.00E-02	0.58	0.33	2000
3	Minor drains	1.00E-01	0.58	0.33	2000

1.4 Application

Two hundred randomised realisations were generated with FIELDGEN using the parameters listed in Section 1.3.2. All 200 realisations were tested using PEST, and the objective function (sum of squared residuals) from each run was examined. The calibrated objective function[1] (Phi) was determined as 399,200 m^2, and a suitable cut off for "de-calibration" was set to be 200% of the calibrated Phi (i.e. 798,400 m^2). 127 realisations meet these criteria, and 73 realisations were rejected from further analysis. Of these 73 realisations, a total of 4 simulations failed to converge, meaning that the combination of varied parameters e.g. high recharge and low hydraulic parameters, caused numerical instability.

Figure D1 to Figure D-6 show a sample of the 127 realisations for the hydraulic conductivity, vertical conductivity, confined aquifer storage coefficient and specific yield for layers 1, 3, 6 and 13.

[1] The initial model calibration Phi used for uncertainty analysis.



LEGEND:

- Proposed MTO development consent boundary
- Active model boundary
- Major watercourse

Hydraulic Conductivity (m/day)

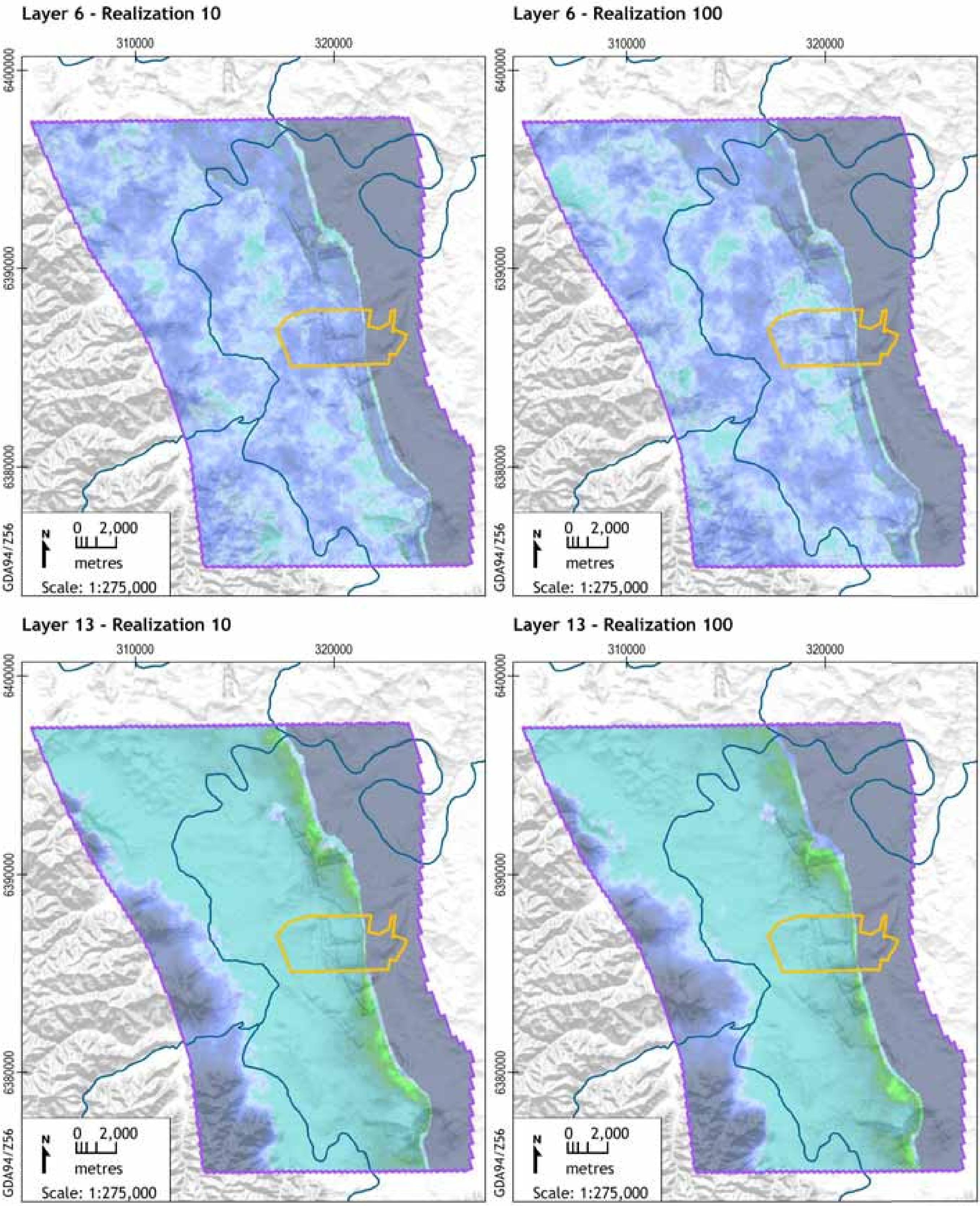
18	0.05
12	0.02
7	0.0003
2	0.0002
0.5	0.0001
0.2	0
0.1	

Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

Uncertainty
Hydraulic conductivity (m/day)

DATE: 3/4/2014

FIGURE No: **D-1**



LEGEND:

- Proposed MTO development consent boundary
- Active model boundary
- Major watercourse

Hydraulic Conductivity (m/day)

18	0.05
12	0.02
7	0.0003
2	0.0002
0.5	0.0001
0.2	0
0.1	

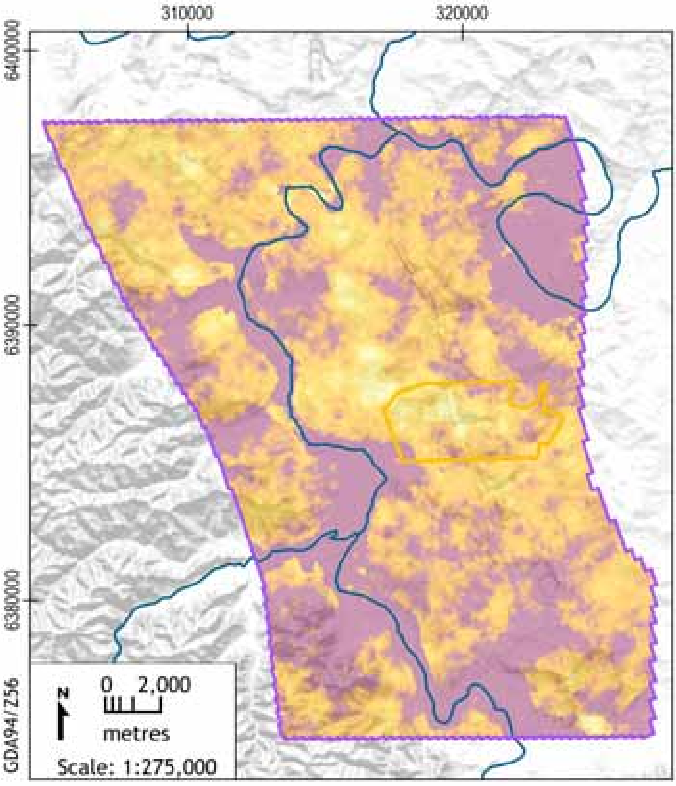
Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

Uncertainty
Hydraulic conductivity (m/day)

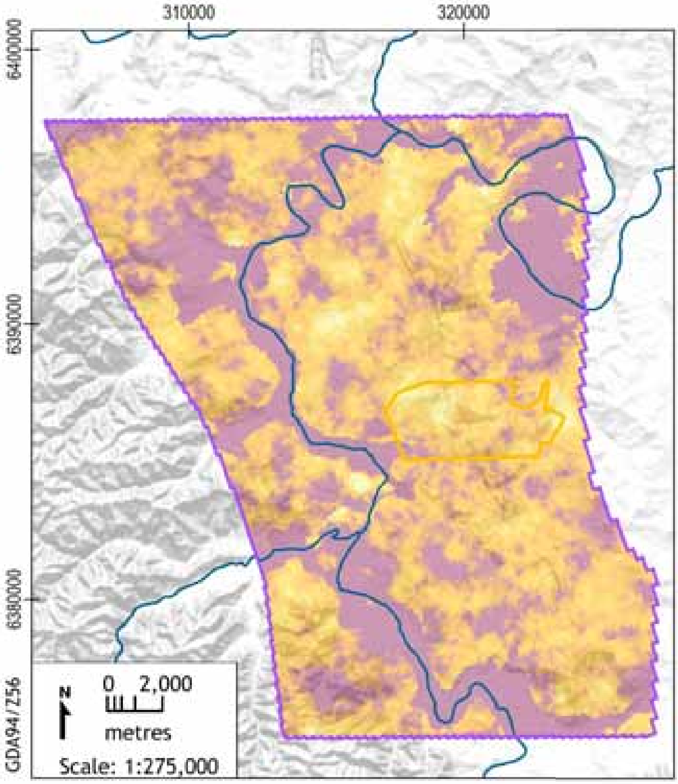
DATE: 3/4/2014

FIGURE No: **D-2**

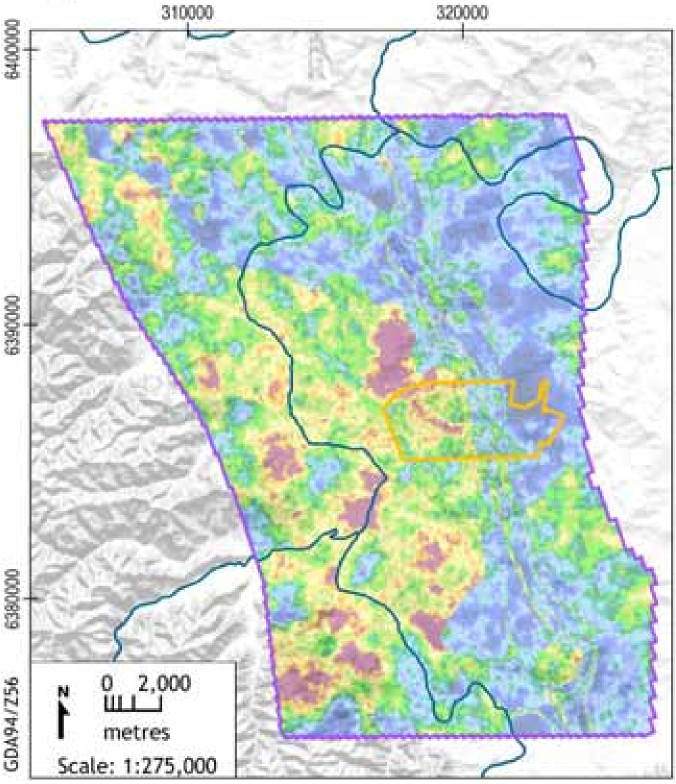
Layer 1 - Realization 110



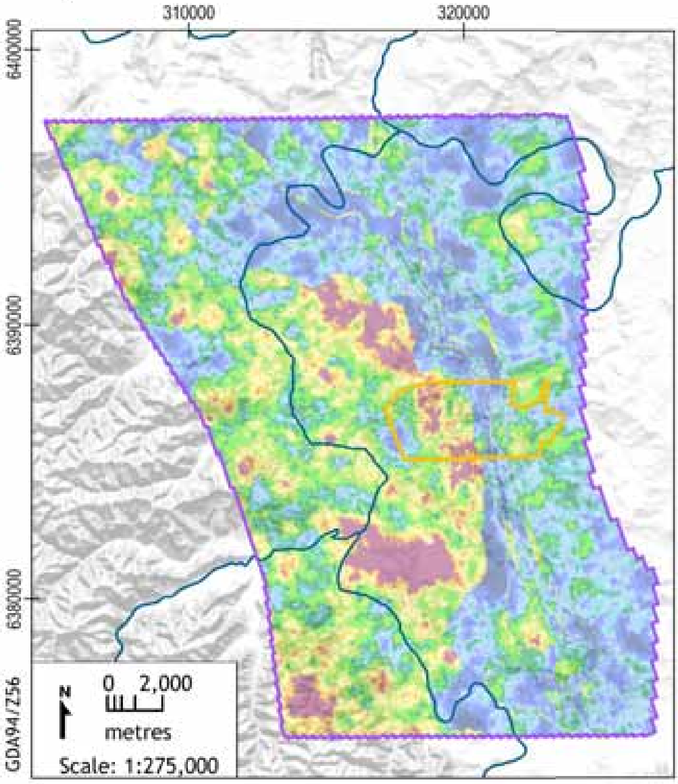
Layer 1 - Realization 168



Layer 3 - Realization 36



Layer 13 - Realization 83



LEGEND:

- Proposed MTO development consent boundary
- Active model boundary
- Major watercourse

Specific Yield

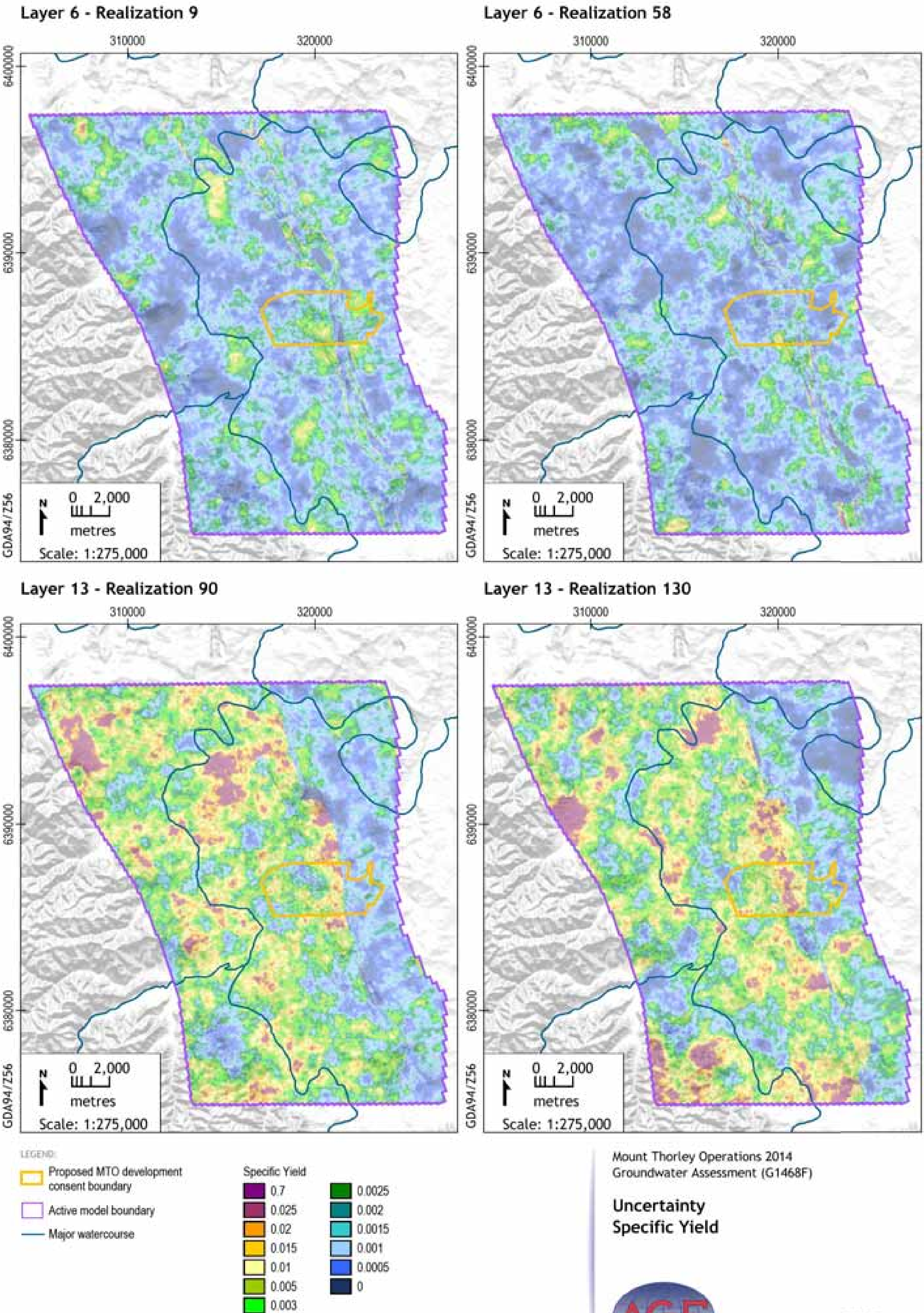
0.7	0.0025
0.025	0.002
0.02	0.0015
0.015	0.001
0.01	0.0005
0.005	0
0.003	

Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

Uncertainty Specific Yield

DATE: 3/4/2014

FIGURE No: **D-3**

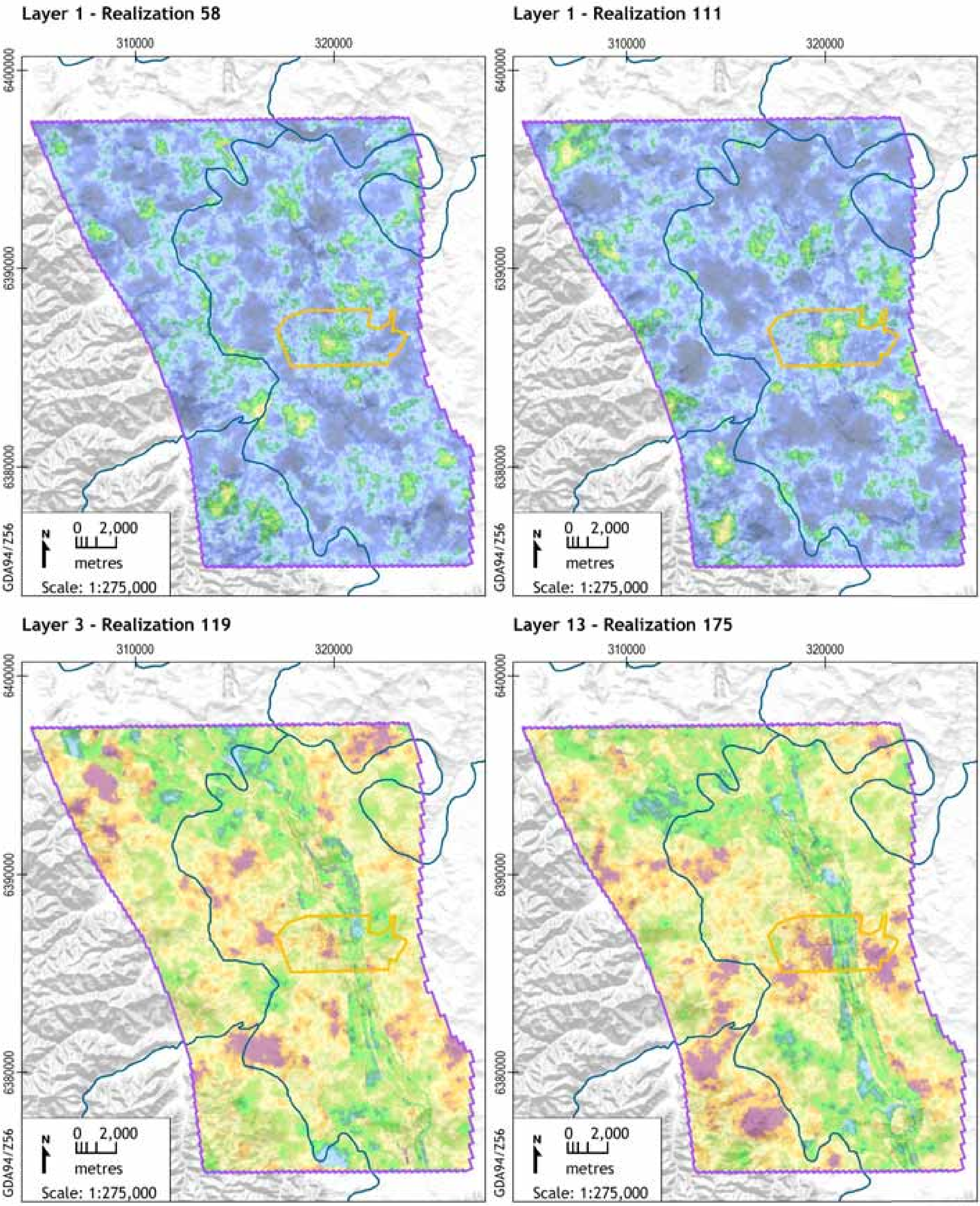


Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

Uncertainty
Specific Yield

DATE: 3/4/2014

FIGURE No: **D-4**



LEGEND:

- Proposed MTO development consent boundary
- Active model boundary
- Major watercourse

Vertical Hydraulic Conductivity Factor

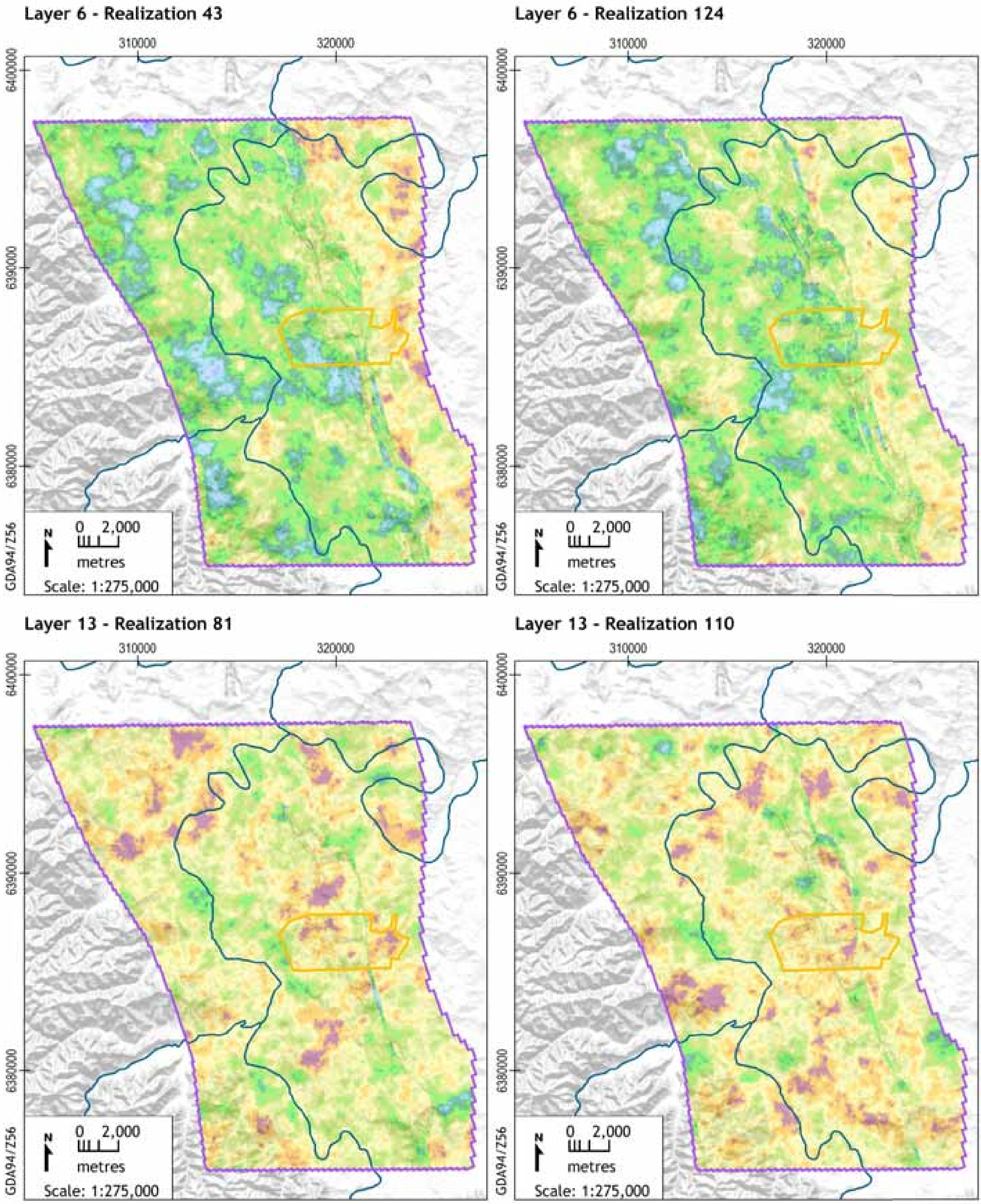
0.1	0.0025
0.025	0.002
0.02	0.0015
0.015	0.001
0.01	0.0005
0.005	0
0.003	

Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

Uncertainty
Vertical Hydraulic Conductivity Factor

DATE: 3/4/2014

FIGURE No: **D-5**



LEGEND:

- Proposed MTO development consent boundary
- Active model boundary
- Major watercourse

Vertical Hydraulic Conductivity Factor

0.1	0.0025
0.025	0.002
0.02	0.0015
0.015	0.001
0.01	0.0005
0.005	0
0.003	

Mount Thorley Operations 2014
Groundwater Assessment (G1468F)

Uncertainty
Vertical Hydraulic Conductivity Factor

DATE: 3/4/2014

FIGURE No: **D-6**

Figure D- 7 shows the results from the calibration uncertainty analysis (Realisations), as well as the calibrated and cutoff levels for the objective function (Phi).

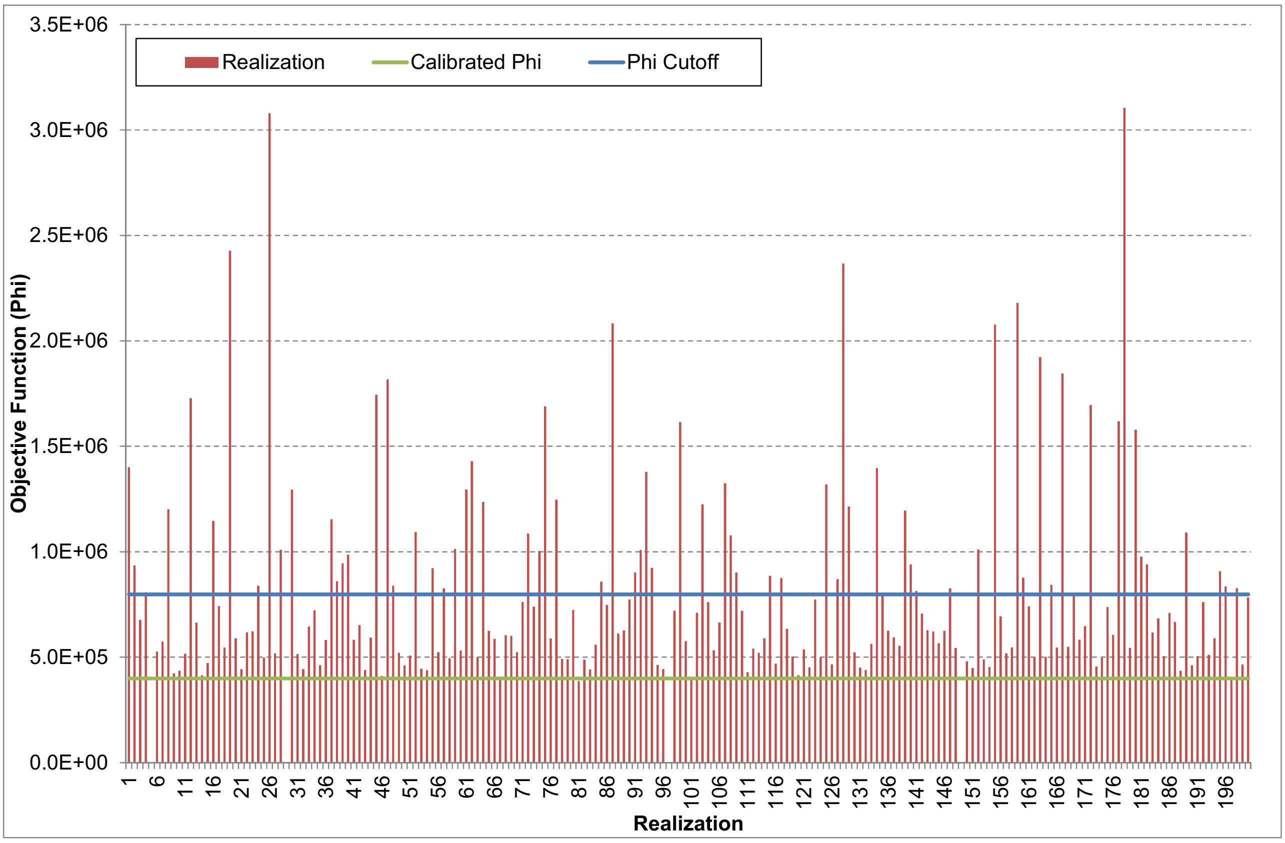


Figure D- 7: Ranking of Objective Function (Phi) from Calibration Runs

Appendix E

EXTERNAL REVIEW REPORT

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23 May 2014

Mt Thorley Operations 2014
KA Final Peer Review of the AGE Groundwater Assessment

Background

The Peer Review presented herein is for the proposed completion of mining at the Mt Thorley mine site Upper Hunter Valley. The mine is seeking approval under Part 4, Division 4.1 of the EP&A Act to complete mining and rehabilitation activities within the current limits of approval.

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) have completed a report (AGE 2014) that describes the groundwater conditions at the site and used numerical model analysis to predict the impact of the proposed mining to completion on the surrounding groundwater system.

The KA peer review was completed in two parts: First a detailed preliminary review report was prepared of requested clarifications and also corrections, and error tabulation. AGE has in turn addressed most of these items in response. This report provides the final peer review documentation of the re-issued updated final AGE (2014) report.

In the following review the National Water Commission modelling guidelines have been taken into consideration.

Review

Overall the AGE (2014) report's hydrogeological description and assessment is comprehensive with suitable numerical modelling procedures applied together with uncertainty analysis. The AGE report provides a detailed description of the model development and calibration in an Appendix C.

The AGE 2014 model is based on previous models developed by MER (2002) and subsequently by AGE (2010) for the Warkworth mine site. The groundwater assessment based on the AGE 2010 work for the Warkworth mine was previously approved by both Commonwealth and NSW governments but overturned by the NSW Land and Environment Court. Since the 2010 work more monitoring bores have been installed that has allowed a much larger data base of groundwater levels to be established.

Hydrogeological Description

The hydrogeology of the site and surrounding area is described in detail and covers groundwater occurrence, monitoring, water levels, gradients, strata permeability and storage, recharge, discharge, water quality, users and ground water dependent ecosystems, policy and licensing requirements.

Conceptual Model

The area has had a long history of mining both on the Mt Thorley mine site and in adjacent mining zones and the geology and hydrogeology are well understood. The conceptual model used as the basis for the numerical model is considered suitable.

Model Software and Extent

The modelling software used for this project by AGE was MODFLOW-SURFACT (MS) which is entirely suitable for this kind of modelling assessment. The model covers an adequate area of 344 km^2 extending about 19 km from west to east and 24 km from north to south.

Model layers and cells

Model layering adopted is considered suitable with sixteen layers used to represent Permian coal bearing hydrogeological units both within the mining zone and below, as well as the overlying alluvial sediments of the drainage streams in the area, in particular Wollombi Brook and also the Hunter River. The layering has provided sufficient vertical resolution in the model and differs from the AGE (2010) model by including interburden as separate layers rather than as vertical conductances. Model cells used were 30m x 30m within the mining zone increasing up to 100m x 225m outside this zone. Higher resolution grid arrays were cantered on the Mt Thorley mining area.

Boundary conditions

Boundary conditions set for the model are suitable. Ephemeral streams were set initially using the ‘river package’ with very low stage but then with zero surface flow over an extended period as part of the uncertainty analysis. Recharge was applied as net recharge..

Model parameters

Initial model parameters were applied based on values used in previous modelling work and then subsequently calibrated using the new 2014 AGE model. Calibration was achieved by initial trial and error and then applying the PEST algorithm.

Calibration

Both steady state calibration using interpolated bore water level measurements and transient analysis calibration was conducted. Steady state calibration was problematic because of the considerable activity within the mining area over many years of operation both within the mine itself and in adjacent mines. Therefore the groundwater levels so obtained can only be considered to be a set of starting heads for the transient analysis.

Examination of the transient analysis scatter diagram indicates very good to poor fit. Statistically the results yielded an overall RMS value of 18% (and sRMS = 15%). This lies outside the range of 5% to 10% suggested in the modelling guidelines. There are some mitigation circumstances however. First is that the mining zones are highly disturbed and are also confounded by the lack of precise knowledge about the historical mining sequences in the region. The scatter diagram outliers also are over represented by having a longer duration of high frequency measurements.

KA in the preliminary review requested AGE to indicate the location of these outlier water levels. AGE has responded with a Figure 7.6. This puts those measurements in perspective. It shows that they relate to the deeper Permian model strata but not to the upper model layers that are more important in assessing any predicted drawdown influence both on the adjacent Wollombi Brook alluvium. That is, the drawdown residuals in layer 1 and 2 for example are relatively smaller and therefore would likely lie within the 5 to 10% suggested limits, but also that they over predict drawdown compared to that measured rather than under-predict.

Overall drawdown distributions depicted in Figure 7.5, that shows the regional extent of potentiometric heads at the end of the calibration period in both the alluvium and regolith and within the Mt Arthur coal seam, are consistent and appear plausible.

Predictions and Potential Impacts

Prediction of potentiometric heads and changes in head in Figures 8.1 to 8.3 also appear consistent and plausible.

Predicted inflows to the Loders pit and the influence to baseflows presented are considered to be plausible. Inflow from the high salinity Permian groundwater during the first year (2015) is 1064 m^3/day decreasing thereafter. Inflow from spoil is much higher at 2832 m3/day in 2015 increasing to a maximum of 3721 m3/day in 2017 decreasing thereafter. These inflows do not include losses due to direct evaporation from the high wall or pit floor.

Baseflow reduction from Wollombi Brook peaks at 300 m^3/day in 2020 with negligible loss to the Hunter River surface water flow. It should be noted that the baseflow reduction is due to the capture of brackish to saline groundwater from the Permian strata that would have otherwise entered Wollombi Brook alluvium and its stream channel.

Modelling indicates only four bores would be affected by the proposal with drawdowns in the Permian strata in the range 2.5 to 6.5m. However, these bores are not privately owned but belong to the Bulga Mine.

The main GDE in the area is the Warkworth Sands Woodland situated north-west of the Warkworth mine. However groundwater in these Sands comprise a perched system with limited hydraulic connection to the main regional watertable and therefore would not be significantly affected by mine drawdown.

The Southern Biodiversity Area (Valley Oak Forest and River Red Gum Woodland) are situated 4km from the proposed mining area in alluvium along the Wollombi eastern bank. These zones will not be influenced by mine drawdown.

There would be no significant increase in salinity created in the alluvium and Wollombi Brook stream flow during mining. On the contrary the reduction in groundwater flow from the Permian strata to the alluvium will be up to 532 m^3/day[1] and therefore correspondingly less brackish to saline groundwater would enter the alluvium and subsequently some as Wollombi baseflow.

Post Mining

Loders pit will be backfilled with spoil and tailings to 65m RL and a small depression 10m below pre-mine groundwater levels will remain that will fill with runoff and groundwater. There is potential of groundwater flow from the spoil post mining toward the Wollombi Brook alluvium due to the expected higher groundwater levels in the spoil than during pre-mining conditions. However, salinity of destination zones are reported to be in the range 15,000 to 20,000 microSeimens/cm with migrating groundwater salinity of about 10,000 microSeimens/cm. Hence there is unlikely to be undesirable degradation of groundwater salinity as a result of spoil groundwater migration.

Conclusion

[1] Of the 532 m^3/day groundwater flow reduction from the Permian to alluvium, 300 m^3/day of this rate is the baseflow component.

The AGE groundwater assessment report is comprehensive and has satisfactorily provided descriptions of the hydrogeological system of the Mt Thorley mine site. The model setup, calibration and predications are also considered to be suitable. Model analyses of the proposed continuation of mining indicate that the impacts will be minimal with respect to drawdown influence and beneficial to surface and groundwater quality. Simulations results are considered reasonable and plausible. Ongoing monitoring of water levels and a model update every 5 years during operations is recommended to compare model predicted with measured drawdown influence.

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