WAMBO COAL PTY LIMITED

SOUTH BATES EXTENSION MODIFICATION

ENVIRONMENTAL ASSESSMENT

APPENDIX B

Groundwater Assessment

South Bates Extension Modification

Groundwater Assessment

FOR

Wambo Coal Pty Limited

BY

NPM Technical Pty Ltd
trading as
HydroSimulations

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1 INTRODUCTION

The Wambo Coal Mine (Wambo) is an existing open cut and underground mining operation situated approximately 15 kilometres (km) west of Singleton, near the village of Warkworth, within the Hunter Valley of New South Wales (NSW) (**Figure 1**).

Wambo is owned and operated by Wambo Coal Pty Limited (WCPL), a subsidiary of Peabody Energy Australia Pty Limited.

This report has been prepared for WCPL to provide a groundwater assessment for the planned modification of underground coal mining at the South Bates Underground Mine (the Modification). The South Bates Underground Mine was approved for extraction in three longwall panels in the Whybrow Seam (Longwalls 11 to 13; approved 4 February 2004) and three longwall panels in the Wambo Seam (Longwalls 14 to 16; approved 10 November 2015). WCPL plans to seek approval for a Modification (MOD 17) application for the existing Development Consent (DA 305-7-2003). The proposed Modification involves the extension of mining in the Whybrow Seam to the north-west of the approved longwalls at South Bates Underground, by the addition of nine more longwalls (Longwalls 17 to 25, known as South Bates Extension) (**Figure 2**). The Modification also involves changes to the timing of the approved South Wambo Underground Mine.

1.1 MINING AT WAMBO

A range of open cut and underground mine operations has been conducted at Wambo since mining operations commenced in 1969. Mining under Development Consent DA 305-7-2003 commenced in 2004 and currently both open cut and underground operations are conducted. The approved run of mine (ROM) coal production rate is up to 14.7 million tonnes per annum (Mtpa) and product coal is transported from Wambo by rail. **Table 1** summarises the seams in which mining is currently approved, and those in which the Modification is proposed (see **Figure 7** for the relative stratigraphic position of the seams).

Table 1 Summary of Mined Coal Seams at Wambo

SEAM	APPROVED MINING ACTIVITY	PROPOSED MODIFICATION
Whybrow Coal Seam	Homestead UG[1], Homestead/Wollemi UG[2], South Bates UG[4], Open Cut Pits[4]	South Bates UG[5]
Redbank Creek Coal Seam	Open Cut Pits[4]	
Wambo Coal Seam	North Wambo UG[3], South Bates UG[4], Open Cut Pits[4]	
Whynot Coal Seam	Open Cut Pits[4]	
Woodlands Hill Coal Seam	South Wambo UG[5]	South Wambo UG[5]
Arrowfield Coal Seam	South Wambo UG[5]	South Wambo UG[5]

1. Completed 1999
2. Completed 2002
3. Completed January 2016
4. Ongoing
5. Yet to commence

Previous open cut mining at Wambo has targeted four coal seams:

- Whybrow coal seam;
- Redbank Creek coal seam;
- Wambo coal seam; and
- Whynot coal seam.

WCPL currently operates three open cut pits at Wambo:

- Bates / Bates South;
- Montrose; and
- Homestead.

There has been a series of underground mine areas during the life of Wambo. Longwall extraction has recently finished at the North Wambo Underground Mine (**Figure 2**). Originally the approval for this mine was for eight longwall panels within the Wambo Seam (Longwalls 1 to 8). North Wambo Underground Longwalls 9 and 10 and Longwall 10A were approved under earlier Modifications (DA 305-7-2003 MOD 13 in 2013; DA 305-7-2003 MOD 14 in 2015). Development commenced at the South Bates Underground Mine in late 2014 for the commencement of longwall extraction from the Whybrow Seam from February 2016. In 2015, approval was obtained to mine also the Wambo Seam at the South Bates Underground Mine (DA 305-7-2003 MOD 15).

Historically, underground mining at Wambo has involved recovery from the Wambo and Whybrow Seams. The Wambo Seam was mined in the North Wambo Underground Mine from 2005 to early 2016. The Whybrow Seam was mined at the Homestead underground mine between 1979 and 1999, and at the Homestead / Wollemi underground mine between 1997 and 2002.

Approval has been granted also for the South Wambo Underground Mine which targets the deeper Woodlands Hill and Arrowfield Seams, respectively. No mining in any seams has commenced to date at South Wambo Underground.

WCPL undertook dewatering of existing (historical) workings in the Whybrow Seam in advance of active mining at the North Wambo Underground Mine (in the deeper Wambo Seam) as a safety measure to mitigate inflow risk. Those Whybrow workings were originally mined in the 1960s through to the 1990s, and since active mining stopped, WCPL has occasionally used them for water storage.

WCPL also undertook dewatering of the Wambo No 1 Workings via two bores (Wambore and Wambore 3). This occurred from August 2012 when extraction of Longwall 6 commenced and finished in early 2016.

1.2 NEIGHBOURING MINING OPERATIONS

Historically there has been, and there continues to be, a substantial amount of coal mining in the area surrounding Wambo. This is carried out by a number of companies with development occurring across several coal seams. Coal has been extracted by means of both underground (longwall) and open cut mining methods. Coal mines adjacent to Wambo include (**Figure 2**):

- United Collieries (operated by Glencore) to the north and east of Wambo;

- Mt Thorley Warkworth (operated by Rio Tinto) to the south-east; and
- a number of open cut and underground mines to the north and east within the Hunter Valley Operations (HVO) (also Rio Tinto).

The adjacent United Collieries mined the lower Arrowfield Seam until 2010 (United Underground Mine) directly beneath portions of the North Wambo Underground Mine.

1.3 PROPOSED MODIFICATION – LONGWALLS 17 TO 25 (WHYBROW SEAM)

The main activities associated with the development of this Modification would include:

- Development of nine additional longwall panels (Longwalls 17 to 25) in the Whybrow Seam to the north-west of the three approved Whybrow Seam longwalls at South Bates Underground.
- Change in timing of mining at South Wambo Underground in the Woodlands Hill and Arrowfield Seams. Mining in the Woodlands Hill Seam would occur from 2023 to 2032 (currently approved for 2019 to 2029). Mining in the Arrowfield Seam would occur from 2030 to 2039 (currently approved for 2023 to 2032).

1.4 SCOPE OF WORK

The key tasks for this assessment are:

- Collation of existing data from WCPL including:
  - review of existing groundwater monitoring and assessment reports;
  - review of existing WCPL groundwater monitoring data;
  - review of existing mine water management records; and
  - collation of additional data if required.
- Characterisation of the existing groundwater system.
- Preparation of a Groundwater Assessment report for inclusion in the Environmental Assessment that addresses the groundwater-related Secretary's Environmental Assessment Requirements and includes the following:
  - Assessment of impacts on groundwater pressures and groundwater quality (including cumulative impacts associated with other existing and approved mines in the area) including consideration of the *NSW Aquifer Interference Policy*.
  - Assessment of post-mining groundwater impacts (including recovery run).
  - Assessment of baseflow impacts on Wollombi Brook, North Wambo Creek (including the constructed diversion), Wambo Creek and Stony Creek.
  - Discussion of potential for cracking to alluvium associated with North Wambo Creek.
  - Comparison of the predicted groundwater impacts for the Modification against predictions for the approved layout.
  - Identification of any groundwater licensing requirements under the *Water Act 1912* and/or *Water Management Act 2000*.

Regarding the need for cumulative impact assessment, WCPL's single active and three other approved underground mines have been assessed in this project:

- North Wambo Underground (recently completed);
- South Bates (Whybrow Seam) Underground (longwall extraction commenced);
- South Bates (Wambo Seam) Underground (development commenced);
- South Wambo Underground (as approved, and as modified); as well as
- the neighbouring mines listed in Section 1.2.

This assessment has been prepared in consideration of the following groundwater-related technical policies and guidelines:

- NSW Aquifer Interference Policy (NSW Office of Water [NOW], now Department of Primary Industries [DPI] Water);
- National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia (Agriculture and Resource Management Council of Australia and Australian and New Zealand Environment and Conservation Council [ARMCANZ/ANZECC]);
- NSW State Groundwater Policy Framework Document (NSW Department of Land and Water Conservation [DLWC]);
- NSW State Groundwater Quality Protection Policy (DLWC);
- NSW State Groundwater Quantity Management Policy (DLWC) Draft;
- NSW Groundwater Dependent Ecosystem Policy (DLWC);
- Murray-Darling Basin Groundwater Quality. Sampling Guidelines. Technical Report No 3 (Murray-Darling Basin Commission [MDBC]);
- MDBC Groundwater Flow Modelling Guideline (2001);
- Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012);
- Draft Guidelines for the Assessment & Management of Groundwater Contamination (NSW Department of Environment and Climate Change [DECC]); and
- Information Guidelines for the Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals.

1.5 REGULATORY FRAMEWORK

Based on the location of the mine and the geology at the site (Section 2.3), the Groundwater Management Areas (GMA) and Water Sharing Plans (WSP) relevant to Wambo are as follows:

- Alluvial aquifers in the vicinity of Wambo are managed as the Lower Wollombi Brook Alluvial Water Source, within the *WSP for the Hunter Unregulated and Alluvial Water Sources 2009*. The alluvium along Wollombi Brook and a small portion of alluvium on Wambo Creek are classified as a 'Highly Productive' groundwater source by DPI Water; the remaining alluvial aquifers are classified as 'Less Productive'.

- The Permian and Triassic hard-rock units are managed as the Sydney Basin - North Coast Groundwater Source within the *WSP for the North Coast Fractured and Porous Rock Groundwater Sources*. This WSP was commenced on 1 July 2016. This is classified as a 'Less Productive' groundwater source by DPI Water.

1.6 SUMMARY OF GROUNDWATER LICENSING AT WAMBO

WCPL currently holds water licences (under the *Water Management Act 2000*) for a number of bores and wells located across the mine site. Details of the current groundwater licences for WCPL are given in **Table 2**.

Table 2 WCPL Existing Water Licence Details (Aquifer Access Licences Only)

LICENCE NUMBER	EXTRACTION LIMIT	EXPIRY	PURPOSE	CONVERTED TO WAL NUMBER
Hunter Unregulated and Alluvial Water Sources (Lower Wollombi Brook Water Source)				
WAL 23897	70 ML/a	Perpetuity	Well No. 2	WAL 23897
North Coast Fractured and Porous Rock Groundwater Sources				
20BL132753	243 ML/a	29/07/2018	Old Well No. 1	WAL 39738 (243 shares)
20BL167738	57 ML/a	11/09/2015	Dewatering Bore	DPI Water to confirm status
20BL168643	40 ML/a	7/08/2018	Dewatering Bore	WAL 39735 (40 shares)
20BL168017	750 ML/a (20PT910929)	21/05/2017	Dewatering (Bore No. 2)	DPI Water to confirm status
20BL172061		22/03/2014	Dewatering (Bore No.2a)	DPI Water to confirm status
20BL173040		21/05/2017	Dewatering Bore	DPI Water to confirm status
20BL172156	98 ML/a	3/05/2019	Dewatering	DPI Water to confirm status
20BL166910	450 ML/a (20PT910607)	21/05/2017	Dewatering (Bore No. 1)	WAL 39803 (450 shares)
20BL173032		30/11/2016	Dewatering Bore	-
20BL173033		30/11/2016	Dewatering Bore	-
20BL173034		30/11/2016	Dewatering Bore	-
20BL173035		30/11/2016	Dewatering Bore	-
20BL173844	9 ML/a	04/09/2019	Dewatering Bore	DPI Water to confirm status

ML/a = megalitres per annum.
WAL = Water Access Licence.

This constitutes total entitlement, for all Wambo mine operations, of 70 ML/a from the Lower Wollombi Brook Water Source and 1,647 ML/a from the Porous Rock Water Source.

2 HYDROGEOLOGICAL SETTING

2.1 CLIMATE

The nearest Commonwealth Bureau of Meteorology (BoM) climate stations are located at Jerrys Plains Post Office (station 061086 - closed in April 2015), about 6 km to the north-west of Wambo and at Bulga (South Wambo) (station 061191), located approximately 3 km to the south. Rainfall records, collected between 1884 and 2015 from Jerrys Plains Post Office and from 1959 from Bulga, show a long-term average rainfall of 644.5 millimetres per annum (mm/a) and 666.8 mm/a respectively (**Table 3**).

Average monthly rain records (**Table 3**) show the highest mean rainfall occurring during the summer months and lower rainfall in winter months.

Table 3 Average Monthly Rainfall (mm) at BoM Stations in the Region

STATION NAME	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	SUM
Jerrys Plains Post Office	77.1	73.1	59.7	44.0	40.7	48.1	43.4	36.1	41.7	51.9	61.9	67.5	644.5
Bulga (South Wambo)	89.1	85.5	63.5	47.5	41.7	45.0	31.3	35.0	39.5	53.7	63.4	73.6	666.8

Source: BoM (November 2016).

Residual Mass Curve (RMC) plots using rainfall data from the Jerrys Plains Post Office and Bulga (South Wambo) since 2003 are shown in **Figure 3**. An increasing trend on the RMC plot shows above long-term average rainfall conditions, and a decreasing trend on the RMC plot shows below average rainfall conditions. These increasing and decreasing rainfall trends of excess and deficit can also often be observed as corresponding rises and falls of watertable/potentiometric surface in the underlying groundwater system modified by mining influence. Below average rainfall conditions were observed from late 2005 to mid-2007. Conditions have been wetter than average since mid-2007, with notable wet periods in mid-2007, January 2009, early 2012, December 2012 to January 2013 and December 2015 to January 2016. Below average rainfall conditions were recorded at Bulga towards the end of 2016.

The actual evapotranspiration (ET) in the district is about 680 mm/a according to BoM (2012)[1]. The definition for actual ET is: "... the ET that actually takes place, under the condition of existing water supply, from an area so large that the effects of any upwind boundary transitions are negligible and local variations are integrated to an areal average. For example, this represents the ET which would occur over a large area of land under existing (mean) rainfall conditions."

2.2 TOPOGRAPHY AND DRAINAGE

Wambo is located in the Upper Hunter Valley region where landforms are characterised by gently sloping floodplains associated with the Hunter River and the undulating foothills, ridges and escarpments of the Mount Royal Range and Great Dividing Range.

[1] Site-specific values for evapotranspiration were not used in this assessment due to the scale of the area modelled. This regional actual evapotranspiration value is suitable for the purposes of this assessment by setting a maximum rate in the numerical model.

An overview map of the regional topography is shown in **Figure 4**. Elevations in the vicinity of Wambo range from approximately 60 m Australian Height Datum (mAHD) at Wollombi Brook to approximately 650 mAHD within the Wollemi National Park to the west of Wambo (WCPL, 2003).

Wambo is situated adjacent to the Wollombi Brook, south-west of its confluence with the Hunter River (**Figure 1**). Wollombi Brook drains an area of approximately 1,950 square kilometres (km^2) and joins the Hunter River some 5 km north-east of Wambo. The Wollombi Brook sub-catchment is bound by the Myall Range to the south-east, Doyles Range to the west, the Hunter Range to the south-west and Broken Back Range to the north-east (Hunter Catchment Management Trust, 2002).

The majority of lands within WCPL mining tenements drain via Wambo, Stony, North Wambo and Redbank Creeks to Wollombi Brook, while Waterfall Creek drains directly to the Hunter River (**Figure 2**). These watercourses are generally characterised by ephemeral and semi-perennial flow regimes (Gilbert and Associates, 2003).

Figure 5 shows the local topography over the Wambo Mine site.

There is a single High Priority Groundwater Dependent Ecosystem near to Wambo. Parnell Spring, which likely flows from the Triassic-age Narrabeen Formation and feeds Milbrodale Creek, is located about 11 km south-southwest of the South Bates Extension footprint. This feature is therefore located outside of the active model domain (Section 3.3).

2.3 GEOLOGY

Wambo is situated within the Hunter Coalfield subdivision of the Sydney Basin, which forms the southern part of the Sydney-Gunnedah-Bowen Basin. The stratigraphy in the Wambo area comprises the Triassic Narrabeen Group, Permian coal measures and more recent (Quaternary) alluvial sediments associated with major drainage pathways.

Folding, faulting and igneous intrusions have affected the Permian strata after deposition. Geology within the model domain is shown in **Figure 6**. The study area extends beyond the subcrop trace of the deepest coal seam that is likely to be mined in the future. A discussion of the model domain is included in Section 3.3.

The stratigraphy of the Wambo area and targeted coal seams at Wambo are presented in **Figure 7**. The target Whybrow Seam for South Bates Extension lies within the Mount Leonard Formation of the Jerrys Plains Subgroup of the Wittingham Coal Measures.

2.3.1 ALLUVIUM AND REGOLITH

The alluvium within the Hunter Valley region and more locally is associated with fluvial depositional sequences. The alluvium along the main drainage channels has sediments of up to 10 m to 20 m of unconsolidated materials including gravels, sands, silts and clays depending upon location (Mackie, 2009). The Quaternary alluvial deposits unconformably overlie Triassic and Permian erosion surfaces.

The alluvium typically has a coarse cobble-gravel basal section up to several metres thick that overlies bedrock. The basal section is in turn overlain by silty gravels and sands with frequent inter-bedded silt and clay zones. This in turn is generally overlain by finer grained sandy clays and silts up to land surface. Alluvium is generally less than 15 m thick within the Wambo area.

An investigation undertaken in 1999 indicated that the alluvium of Wambo Creek is 4 m to 7 m deep and consists of clayey to sandy, brown silt with areas of localised fine to medium grained sand (HLA-Envirosciences, 1999). There are also indications that the more permeable zones in the alluvium of Wambo Creek are discontinuous, probably due to bedrock highs (HLA-Envirosciences, 1999).

A geophysical survey of the alluvium in the upper reaches of North Wambo Creek was undertaken by GHD (2007) to estimate the thickness and extent of the North Wambo Creek alluvium adjacent to the Wambo open cut. The investigation used bore logs, seismic refraction and electromagnetic geophysics and found the thickness of alluvium to range up to 19 m, with the upper half sandy and the lower half clayey.

A transient electromagnetic (TEM) survey (Groundwater Imaging, 2012) was also carried out to investigate the extent and thickness of alluvium along the lower reaches of Wambo Creek and North Wambo Creek. The extent of alluvium interpreted from the TEM study is typically of a narrower alluvial body along both the lower reaches of Wambo and North Wambo Creeks than is illustrated in the publicly available mapping (e.g. Glen and Beckett, 1993).

The alluvium within floodplains associated with the main creeks merges gradationally at the margins with colluvium and unconsolidated weathered bedrock material (regolith) of limited thickness.

Tertiary sand dune deposits defined by slightly elevated mounds to the east of Wollombi Brook have also been reported (Mackie, 2009).

2.3.2 TRIASSIC NARRABEEN GROUP

The Triassic Narrabeen Group forms the prominent escarpment on elevated areas to the south-west of Wambo and unconformably overlies the Permian coal measures. The Narrabeen Group is present in the south-western part of the Wambo mining lease area.

2.3.3 PERMIAN COAL MEASURES

The coal measures are contained within the Permian strata which comprise numerous coal seams and associated splits. These are separated by interburden layers comprising interbedded sandstones and laminated mudstones and siltstones. The Permian strata containing the Newcastle and the Wittingham Coal Measures dip gently to the south-west and subcrop in the Wambo area. The Newcastle Coal Measures subcrop to the south of North Wambo Creek and the Wittingham Coal Measures subcrop in the north-east of the Wambo mining lease area along a northwest–southeast strike.

The Permian coal measures generally dip at approximately three degrees to the south-west with structure complicated by some local variations in seam dip and direction, although seams generally have consistent thicknesses and interburden intervals. There are two major fault structures within the Wambo area (**Figure 6**): the Redmanvale Fault and Hunter Valley Cross Fault (Department of Mineral Resources, 1993).

2.4 GROUNDWATER USAGE

There are 197 registered bores belonging to Wambo and other groundwater users within 5 km of Wambo, as listed in **Attachment H**. Boreholes registered on the ‘Pinneena’ (v10.1) database in proximity to Wambo are shown in **Figure 8**. There are 49 bores registered for irrigation, domestic and/or stock use, and 20 bores of unknown use, as shown in **Table 4**. There are 117 monitoring/test/industrial bores and 11 mine use/dewatering bores which are not considered further in this assessment.

Table 4 Registered Bores within 5 km of Wambo

Work No.	Licence	Easting	Northing	FINAL DEPTH (m) *	USE
GW060750	20BL132130	314309.8	6394923	24.4	Domestic
GW066606	-	311207.2	6390674	2.5	Domestic
GW078577	20WA208559	309968.7	6389973	10	Domestic
GW032632	20BL025579	303253	6402568	33.5	Domestic
GW064382	10BL157687	303908	6394477	60	Domestic
GW078477	20BL167575	304018	6398990	102.5	Domestic
GW045122	20BL105223	309572	6402567	12.2	Domestic
GW045123	20BL105224	309154	6402621	12.2	Domestic
GW056696	20BL123304	313297	6401651	10.5	Domestic
GW060780	20BL132167	305926	6399385	25.5	Domestic
GW078332	20BL166324	303704	6401464	42.68	Domestic
GW078722	20BL167495	304737	6402674	15	Domestic
GW078770	20BL167426	318094	6398098	10	Domestic
GW017462	20BL008224	315339.2	6391460		Farming
GW038579	-	309737.7	6393882	20.9	Farming
GW078574	20BL167170	309174.3	6390605	12	Farming
GW078575	20BL167171	309504.8	6389687	12	Farming
GW078576	20BL167172	309763.7	6389784	7	Farming
GW060365	-	311690.8	6392686	6.6	Irrigation
GW060366	-	311195.9	6392646	5.2	Irrigation
GW065117	-	311153.9	6390735	6	Irrigation
GW037998	-	311589.4	6392530	10.9	Irrigation
GW037999	-	311481.6	6392713	13.7	Irrigation
GW038000	-	311457.3	6392620	9.4	Irrigation
GW047240	20CA209896	316826.7	6397095	12.7	Irrigation
GW017648	20BL009859	307397	6400276	12.8	Irrigation
GW021773	20BL014201	309532	6401950	12.5	Irrigation
GW022685	20BL015155	309073	6401387	14.6	Irrigation
GW027120	20BL020353	309521	6401149	13.4	Irrigation
GW027121	20BL016019	309561	6401797	15.8	Irrigation
GW037734	20BL031436	309616	6401644	13.4	Irrigation
GW049187	20BL108626	303025	6403550	10	Irrigation
GW053123	20BL118095	309609	6402013	13.1	Irrigation
GW053173	20BL118414	309098	6401449	14.8	Irrigation
GW053292	20BL119690	317670	6398097	10	Irrigation
GW053690	20BL119580	308429	6402268	11.3	Irrigation
GW053709	20BL119757	304370	6402898	12.2	Irrigation
GW057775	20BL120623	309122	6401542	13.4	Irrigation
GW017644	20BL009861	306708	6399431	11.6	Irrigation
GW042364		316764	6397649	13.3	Irrigation

Work No.	Licence	Easting	Northing	FINAL DEPTH (m) *	USE
GW042993	20BL104637 and 20BL121565	309721	6403001	8.8	Irrigation
GW053708	20BL117803	304231	6403327	13.4	Irrigation
GW053931	20BL120263	312626	6402625	10.4	Irrigation
GW053932	20BL120968	312637	6402070	7.3	Irrigation
GW065014	20BL166572	305777	6400368	14.5	Irrigation
GW200802	20BL151941	318025	6396083	11.9	Irrigation
GW005327	20BL009540	314682.9	6394498	10.4	Stock
GW017801	20BL009818	304320	6397443	42.7	Stock
GW202134	20BL170596	318272	6403565	8.86	Stock
GW079060	-	314595.5	6394852	14.6	Unknown
GW080951	-	314619	6394878	3.1	Unknown
GW080952	-	314643	6394905	1.6	Unknown
GW043225	-	303653	6398949	22.5	Unknown
GW017647	20BL009858	307326	6399905	9.1	Unknown
GW018045	20BL010054	302941	6398556	27.4	Unknown
GW018046	20BL010053	303013	6398866	18.3	Unknown
GW018370	20BL010484	317573	6399112	11.9	Unknown
GW018464	20BL010603	317783	6400471	13	Unknown
GW018549	20BL012095	313134	6401987	9.1	Unknown
GW017646	20BL009860	306937	6399774	11	Unknown
GW017798	20BL009821	307290	6399042	12.2	Unknown
GW017799	20BL009820	306598	6398412	12.2	Unknown
GW017800	20BL009819	304413	6398000	27.4	Unknown
GW018047	20BL010041	302620	6398920	36.3	Unknown
GW018371	20BL010483	317683	6398775	12.2	Unknown
GW029155	20BL022682	305403	6402148	10.1	Unknown
GW200682	20BL171905	310511	6403229	30.4	Unknown
GW018434	20BL010847	311134	6401457	11	Unknown
GW059178	20BL128781	303887	6403536	13.9	Unknown

* Depth as listed in Pinneena database.

m = metres.

During the advance of the North Wambo Underground Mine in the Wambo Seam, WCPL undertook dewatering of existing (historical) workings in the overlying Whybrow Seam as a safety measure to mitigate inflow risk. The extracted volumes ranged from an annual average rate of 1.3 megalitres per day (ML/d) in 2011 to 3.2 ML/d in 2009. From 2008 to 2015 the overall average extraction was 2.1 ML/d. In contrast, the mine inflows due to Wambo Seam extraction averaged 0.35 ML/d during 2012 and 2013, and subsequently declined to 0.2 ML/d in 2014 and 0.1 ML/d in 2015.

WCPL also undertook dewatering of the Wambo No 1 Workings via two bores (Wambore and Wambore 3). The pumping rates averaged 0.72, 0.40 and 0.23 ML/d in 2012, 2013 and 2014 respectively.

2.5 GROUNDWATER MONITORING

Groundwater monitoring at Wambo is undertaken in accordance with the approved Groundwater Monitoring Program (GWMP) (WCPL, 2015a). The objectives of the GWMP are to establish baseline groundwater quality and water level data and to implement a programme of data collection that provides a basis for assessing potential impacts of mining activities on the groundwater resources of the area.

The details of monitoring bores in the network (current and previous) are summarised in **Table 5**. The locations of the bores are shown in **Figure 5.** The current monitoring network is shown in **Figure 9**. Hydrographs for selected monitoring bore sites (**Table 5**) are presented in **Attachments A, B and C**.

Table 5 Groundwater Monitoring Sites

<table>
<tr><th>Monitoring Site</th><th>Lithology</th><th>Start Date</th><th>Frequency</th></tr>
<tr><td>P1, P3, P11, P16, P20</td><td rowspan="2">Alluvium</td><td rowspan="2">from December 2005</td><td>Bi-monthly</td></tr>
<tr><td>P5, P6 (no longer active)</td><td>Removed due to open cut operation 2014</td></tr>
<tr><td>P106, P109, P114, P116</td><td>Alluvium</td><td>from July 2003</td><td>Bi-monthly</td></tr>
<tr><td>P202, P203 (also known as P206)</td><td>Shallow Permian Overburden</td><td>from July 2003</td><td>Bi-monthly</td></tr>
<tr><td>P301, P315</td><td>Alluvium, Shallow Permian Overburden</td><td>from March 2004</td><td>Bi-monthly</td></tr>
<tr><td>GW02, GW08, GW09, GW11</td><td>Alluvium</td><td>from July 2005</td><td>Bi-monthly</td></tr>
<tr><td>GW12, GW13, GW14, GW15, GW16, GW17, GW21, GW22</td><td rowspan="2">Alluvium, Shallow Permian Overburden</td><td rowspan="2">from December 2009</td><td>Bi-monthly</td></tr>
<tr><td>GW18, GW19</td><td>Removed from program</td></tr>
<tr><td>MG08</td><td>Alluvium to Wambo Seam</td><td>from December 2012</td><td>Continuous</td></tr>
<tr><td>MG09</td><td>Regolith to Wambo Seam</td><td>from December 2012</td><td>Continuous</td></tr>
<tr><td>BH2, BH2A, BH4C, WAMBO-03</td><td>Whybrow Seam, Wambo Seam</td><td></td><td>Continuous</td></tr>
<tr><td>BH1G, BH1F, WAMBORE SOUTH</td><td>Whybrow Seam, Wambo Seam</td><td></td><td>Monthly</td></tr>
<tr><td>N2, N3, N5</td><td>Permian Overburden to Wambo Seam</td><td>from August 2015</td><td>Continuous</td></tr>
<tr><td>P12, P13, P15, P18*</td><td>Alluvium</td><td>from December 2005</td><td>Bi-monthly</td></tr>
<tr><td>P33, P34, P35*</td><td>Alluvium, Permian Overburden, Whybrow Seam, Redbank Seam, Wambo Seam</td><td>from January 2010; May 2011; January 2005</td><td>Continuous</td></tr>
<tr><td>P311</td><td>Shallow Permian Overburden</td><td>from January 2010; May 2011; January 2005</td><td>Continuous</td></tr>
</table>

* Part of the United Collieries network.

Consistent with the GWMP, groundwater quality sampling has been undertaken by WCPL in accordance with AS/NZS 5667.11:1998 – *Guidance on Sampling of Ground Waters*. Samples are measured in the field for acidity (pH), electrical conductivity (EC) and temperature (T).

In the latest approved GWMP (WCPL, 2015a), 14 alluvial locations have nominated groundwater trigger levels as listed in **Table 6**.

Table 6 Shallow Bores Water Level Trigger Values

Bore	Depth to Groundwater (mBTOC)[1]		Level (m AHD)[2]	
	Minimum (10th percentile)	Maximum (90th percentile)	Minimum (10th percentile)	Maximum (90th percentile)
P106	6.6	10.7	55.5	51.4
P109	4.6	6.7	58.9	56.8
P114	5.4	7.6	57.0	54.8
P116	4.8	7.3	55.2	52.7
P202	7.8	9.6	53.5	51.7
P203 (also known as P206)	16.1	21.6	45.0	39.5
P315	4.4	9.1	91.3	86.6
GW02	5.8	8.5	73.6	70.9
GW11	4.0	6.5	72.4	69.9
GW12	9.9	12.9	77.4	74.4
GW13	4.8	5.4	57.8	57.2
GW15	10.4	11.1	52.0	51.3
P16	7.1	7.8	51.1	50.4
P20	7.1	8.2	51.0	49.9

1. mBTOC = metres below top of casing
2. m AHD = metres Australian Height Datum

2.6 BASELINE GROUNDWATER LEVEL DATA

A network of monitoring bores and piezometers has been established. These include monitoring bores in the alluvial aquifers associated with the principal drainage streams, and more recently multi-level vibrating wire piezometers (VWPs) have been installed within the Permian groundwater system. **Figure 9** shows the locations of groundwater monitoring bores within the Wambo area and surrounds.

The GWMP includes bi-monthly readings of depth to water, EC, pH and temperature and continuous groundwater pressure readings from multi-level VWPs.

2.6.1 SPATIAL GROUNDWATER LEVELS

Natural groundwater levels are influenced by rainfall recharge, topography, geology and surface water elevations. Typically, groundwater tends to mound beneath hills and then discharge to alluvium associated with creeks and rivers at lower elevation. During short events of high surface flow, streams tend to lose surface water to the underlying groundwater system but, during recession, the groundwater system tends to discharge groundwater slowly back into the stream from alluvial storage. Regional groundwater flows from elevated to lower lying terrain.

Interpolated groundwater level contours in the alluvium for December 2015 are shown on **Figure 10**. Groundwater elevations within the alluvium decrease in a downstream direction from the centre of the study area in a north-easterly direction to the junction of Wollombi Brook with the Hunter River. Hydraulic gradients are similar and uniform along North Wambo Creek, Wambo Creek and Stony Creek, but are much flatter along Wollombi Brook. The alluvium adjacent to the South Bates Extension footprint has been disconnected from the regional alluvial system due to the removal of alluvium downstream of the longwalls by the approved open cut mining operations (and associated construction of the North Wambo Creek Diversion).

Figure 10 shows a groundwater level depression in the alluvium at the confluence of Wollombi Brook and Wambo Creek, with estimated maximum drawdown in the order of 5 m since commencement of mining. This is in an area below which Longwalls 8 and 9 were mined at the Homestead Mine in 1999. An assessment of the impacts of Homestead Mine Longwall 9 extraction on surface water and groundwater has shown that groundwater levels in the vicinity of the panels were lowered following progression of the longwall panel (HLA-Envirosciences, 1999).

2.6.2 TEMPORAL GROUNDWATER LEVELS IN ALLUVIUM

The shallow monitoring bores nearest the South Bates Extension footprint (locations shown in **Figure 5**) are:

- GW16 – over Longwall 24 of the proposed South Bates Extension.
- GW17 – over Longwall 23 of the proposed South Bates Extension.

Although GW17 has been ascribed to alluvium in previous reports, it is now considered that it represents weathered rock beneath alluvium given its high salinity and only 2 m of alluvium recorded in its bore log.

As mining impacts on the alluvium at the location of monitoring bores GW08 and GW09 have been the subject of recent investigation, the following section also presents the most recently obtained data at these locations, which are about 4 km to the south-east of the South Bates Extension footprint (**Figure 5**):

- GW08 – 300m north-east of North Wambo Longwall 10.
- GW09 – 500m north-east of North Wambo Longwall 9.

Figure 11 shows groundwater level hydrographs at GW16 and GW17 compared with the Rainfall Residual Mass Curve (RMC) until August 2016, as well as an annual moving average groundwater level, and the commencement dates of North Wambo Underground and South Bates Underground longwall panels. The moving average assists with identification of correlation between groundwater level and rainfall trends.

Both GW16 and GW17 show strong correlation with the RMC until mid-2012, after which a pronounced decline in water levels occurred despite fairly average conditions. This is attributed to the northwards progression of nearby Wambo open cut mining. Since mid-2012 groundwater levels have increased in response to large rainfall events (March 2013, January-March 2015, January 2016), but the long decline in groundwater level from May 2013 to March 2015 is due to open cut mining. With sustained wetter conditions, groundwater levels recover to normal levels, as occurred during 2015. Strong declines in groundwater level during 2016 are likely due to the commencement of underground mining at South Bates Underground and the encroaching open cut, as water levels dropped despite wetter conditions.

Figure 12 displays fluctuating and smoothed groundwater level hydrographs at GW08 and GW09, as well as the RMC and the commencement dates for North Wambo Underground and South Bates Underground longwall panels. Groundwater levels in both GW08 and GW09 have declined since the commencement of measurement (2005), due to the combined effects of approaching North Wambo Underground mining of the Wambo Seam, the approaching Wambo open cut, and perhaps the approaching United mining far below in the Arrowfield Seam which finished in 2012. The rate of decline increased from 2012, coincident with the commencement of dewatering of the Wambo Seam in the old workings adjacent to North Wambo Longwall 8b (with these old workings directly below GW08 and GW09). The groundwater levels in these bores show a limited response to rainfall, with declining groundwater levels unable to be arrested by rainfall recharge. Groundwater levels continued to decline until December 2014, after which there was a gap in observation until April 2016. Following a single observation in April 2016, GW09 has gone dry. Groundwater levels at GW08 showed a minor increase from December 2014 to April 2016, probably due to a large rainfall event in March 2016, and has subsequently shown a mildly declining groundwater level.

Attachment A shows alluvial groundwater hydrographs from the monitoring network grouped into eight clusters by location (**Figure A1**). The hydrographs are presented with a rainfall RMC of long term rainfall data from the Bulga (South Wambo) BoM site in order to evaluate the response of alluvium to rainfall patterns.

Groundwater levels generally correlate well with rainfall trends, showing responses to recharge events and associated recession during periods between major recharge episodes. Additional influence is seen from Wollombi Brook and Wambo Creek on some bores close to the creeks, which tends to override rainfall response. Mining effects are evident in clusters A, B, C and H (**Figure A1**).

The data on **Figure A2** show that the groundwater levels at P5 and P6 have responded rapidly and with relatively high amplitude (2-4 m) to rainfall events. Both hydrographs show a decline in groundwater level during the passage of Longwall 1 and Longwall 2 (late 2008 into 2009), when rainfall was close to average conditions. Following this decline the bores recovered during higher rainfall conditions. The groundwater level decline is indicative of a temporary effect on the groundwater system, due to local sub-surface mining.

Following the decline, groundwater levels recovered during 2011 into 2012 during a period of above average rainfall, but then declined by about 3m. This decline and deviation from the RMC is unlikely to be due to extraction of Longwall 5 at that time (as the bores are 900 m and 650 m respectively away from Longwall 5). The decline is very likely due to the influence of the open cut mining approaching from the north-west. However, at that time the alluvium still remained sufficiently saturated. These bores may provide an indication of the response that may be expected due to the proposed undermining of the upper reaches of North Wambo Creek by the South Bates Extension.

2.6.3 GROUNDWATER LEVELS IN PERMIAN COAL MEASURES

Extensive historical open cut and underground mining in the district has generated a regional zone of depressurisation within the Permian coal sequences.

Figure 13 shows groundwater levels at GW21 and GW22, as well as the RMC and the commencement dates for North Wambo Underground and South Bates Underground longwall panels. A mild mining effect is likely at GW21, located between North Wambo Underground Longwall 1 and South Bates Underground Longwall 13. Mining at South Bates Underground appears to have had no effect, suggestive of the mitigating effect of the fault (unnamed fault shown in **Figure 6**) between GW21 and South Bates Underground. Groundwater levels at GW22 (at 5 km south-east of GW21) fluctuate in response to the RMC, and do not show a mining effect. The decline in groundwater level of approximately 1 m in August 2016 is likely to be a response to Whybrow Seam dewatering towards the end of North Wambo underground mining, given that GW22 overlies old Homestead workings.

Attachment B shows interburden groundwater hydrographs from the monitoring network grouped into three clusters by location (**Figure B1**). The hydrographs are compared with the RMC rainfall trend. Mining effect is evident at P301 (situated over North Wambo Longwall 6) from the commencement of North Wambo Longwall 3 (**Figure B2**). The other sites respond to weather variations.

Drawdowns due to longwall mining are in the order of 6 m at P301 and about 0.5 m at GW21.

Attachment C shows VWP groundwater hydrographs from the monitoring network at locations shown in **Figure C1**, including hydrographs in the Whybrow Seam, Redbank Creek Seam, Wambo Seam and alluvium/regolith.

Bore N5 (**Figure C9**) is multi-piezometer grouted bore with four VWPs installed at depths of 30 m (N5-4), 73 m (N5-3), 89.5 m (N5-2) and 133 m (N5-1) that have been recording since July 2015, and is located above Longwall 23 of the proposed South Bates Extension. Since stabilising in October 2015, groundwater level in the lower sensors has declined by approximately 10 m. This is likely due to the proximity of the Wambo open cut.

2.7 GROUNDWATER CHEMISTRY

Several previous studies carried out in this area have documented the salinity of groundwater sampled from the Wambo mining site and surrounding sediments and strata. An assessment undertaken in 2002 showed that the groundwater quality in the vicinity of North Wambo Creek was variable with total dissolved solids (TDS) concentrations ranging from 710 milligrams per litre (mg/L) to 2,690 mg/L (Coffey Geosciences, 2002). The study concluded that groundwater in the alluvium is recharged from multiple sources with variable water quality.

Assessments of groundwater quality can be useful in understanding the conceptual hydrogeology. For example, groundwater salinity tends to be low in areas of high recharge or connectivity with surface waters, and higher in zones where there is discharge of Permian groundwater, particularly where evapotranspiration is present.

The salinity of groundwater recently sampled from within the Wambo mining site and surrounding mining leases is variable, with TDS ranging from 314 mg/L to 15,000 mg/L (approximately 500 microSiemens per centimetre [µS/cm] to 22,000 µS/cm). The highest salinities are reported from the surficial groundwater, i.e. the colluvium and weathered Permian.

Although spatially very close (~250 m), there is a large difference in salinity between GW16 and GW17 **(Figure 14**). Since the beginning of observation in 2010, GW16 shows groundwater EC of consistently less than 1,000 µS/cm, while GW17 EC is approximately 5,000 µS/cm. While both bores have been classified as 'alluvial', analysis of the driller logs (**Table 7**) indicates that GW16 is likely screened in alluvium while GW17 is likely screened in Permian overburden.

Table 7 Geological Logs for GW16 and GW17

Code	Elevation (mAHD)	From Depth (mbgl)	To Depth (mbgl)	Lithology Code	Description
GW200831 (GW16)	113.05	0.00	1.80	TPSL	Topsoil
		1.80	2.80	SDCY	Sandy clay
		2.80	6.90	SDCY	Sandy clay, gravel bands
		6.90	12.00	SDSN	Sandstone, orange
GW200832 (GW17)	110.51	0.00	0.10	TPSL	Topsoil
		0.10	0.90	SILT	Silt, sandy
		0.90	1.80	CLAY	Clay/sand
		1.80	2.20	SDSN	Sandstone, grey
		2.20	5.00	SDSN	Sandstone/conglomerate
		5.00	5.50	SDSN	Sandstone, grey
		5.50	6.00	SDSN	Sandstone/ironstone
		6.00	14.00	SDSN	Sandstone, orange

mbgl = metres below ground level.

The salinity of GW08 has remained fairly constant at an EC of around 1,800 µS/cm, while GW09 has shown a lower salinity over time, with salinity measurements decreasing from 1,800 µS/cm to an average of about 500 µS/cm since the end of 2011 (**Figure 15**).

Although interburden monitoring bore GW21, adjacent to North Wambo Underground Longwall 1, is usually dry and has not been sampled frequently, available samples suggest very high groundwater salinity (about 16,000 µS/cm) (**Figure 16**). This contrasts with bore GW22 in the South Wambo Underground area, which has had stable EC values close to 7,000 µS/cm.

The EC time-series for bores in the monitoring network are displayed in **Attachment A** (alluvium) and **Attachment B** (interburden).

Until bores P5 and P6 were decommissioned, groundwaters monitored from these bores exhibited a progressive reduction in salinity over time, as illustrated by the EC responses in **Figure A10**. The alluvial groundwater salinity decreased from 3,000-4,000 µS/cm at a time coincidental with the commencement of Longwall 1 to less than 1,000 µS/cm by the end of 2011. For the full period of record, the groundwater EC has been less than 1,000 µS/cm at P5 for about 15% of the time and at P6 for about 40% of the time.

The EC trends suggest replenishment by good quality water beyond what occurred pre-mining. The mechanism could be either increased rainfall recharge or reduced upflow of more saline groundwater into the alluvium in response to mining, or both. The mechanism of increased rainfall recharge is consistent with the period of above average rainfall indicated by the RMC (**Figure A10**).

2.8 CONCEPTUAL MODEL

The hydrogeological regime of the Wambo area and surrounds comprises two main groundwater systems:

- Quaternary alluvial groundwater within channel fill deposits associated with Wollombi Brook, North Wambo Creek, Wambo Creek and Stony Creek; and
- underlying Permian strata of low hydraulic conductivity and hence very low yielding to almost dry sandstone and siltstone. The coal seams which are the prime water-bearing strata within the Permian coal measures have low to moderate hydraulic conductivity, as do the Triassic strata, part of the Narrabeen Group, that are present south-west of the North Wambo Underground Mine, and also occur beneath some parts of the alluvium.

A conceptual summary of the regional flow patterns has been derived from monitoring bore groundwater levels for the alluvium and for the Permian hard rock groundwater system, and for the nearby Triassic strata, as shown in **Figure 17** for a typical west-east cross-section. The cross-section A-A' passes through the southern tip of the approved South Bates Underground longwalls as indicated in **Figure 2**. This conceptual figure would represent the groundwater flow system during and post mining.

2.8.1 ALLUVIAL GROUNDWATER SYSTEM

Groundwater flow patterns within the alluvium reflect topographic levels and the containment of alluvium within the principal drainage pathways. Evidence from groundwater monitoring hydrographs (**Attachment A**) within the alluvium indicates that the alluvial groundwater is responsive to rainfall recharge. In places, alluvial groundwater is likely to be contributing to baseflow of the perennial surface water features (see inset in **Figure 17** where North Wambo Creek is typically a gaining stream while Wollombi Brook is typically a losing stream).

In some areas, upward or lateral flow may occur from the Permian and Triassic rock to alluvium. Before any mining occurred in the district, upflow to alluvium was likely to be dominant along Wambo Creek, Stony Creek, North Wambo Creek and the southern part of Wollombi Brook, and downward leakage was likely to have occurred along the northern part of Wollombi Brook. Mining is expected to reduce the natural higher salinity upflow and increase the natural lower salinity downflow.

2.8.2 PERMIAN GROUNDWATER SYSTEM

Prior to the commencement of mining operations in the region, the potentiometric surface within the Wambo area most probably reflected the topography, with higher groundwater levels in areas distant from the major drainages and lower levels in areas adjacent to the alluvial flats. Potentiometric head within the Permian strata is likely to have been above ground level (artesian) in some places due to the general lack of vertical connectivity resulting in higher hydraulic pressures existing within the confined layers. Historical and ongoing open cut and underground mining within the Wambo area and adjoining mining operations has now created significant groundwater sinks. This has generated a regional zone of depressurisation within the Permian coal measures.

The Permian groundwater system within the Wambo area is continuous through the major geological formations. The various sedimentary rocks at Wambo have low hydraulic conductivities due to their fine-grained nature, the predominance of cemented lithic sandstones and the common occurrence of a clayey matrix in the sandstones and conglomerates. The increased hydraulic conductivity of the groundwater system is related to the joint spacing and aperture width. Hydraulic conductivity of the rock units generally decreases with depth of burial as the joint and fracture openings tend to close and become less frequent.

The hydraulic conductivity of the coal measures is generally low, with rock mass hydraulic conductivities more than two orders of magnitude lower than the unconsolidated alluvial sediments. Within the coal measures, the most permeable horizons are the coal seams, which commonly have hydraulic conductivity one to three orders of magnitude higher than the siltstones, shales and sandstone units. The laminated fabric of the interbedded sandstone/siltstone/mudstone strata suggests that vertical hydraulic conductivities are significantly lower than horizontal hydraulic conductivities.

The influence of fault structures on groundwater flow, such as the Redmanvale Fault, is not known with certainty. However, it is likely that the structures would act as barriers to local groundwater flow rather than conduits, as evidenced by the lack of response at GW21 to South Bates Underground mining to date. Consideration of faults in model development is discussed further in Section 3.4.

2.8.3 RECHARGE AND DISCHARGE MECHANISMS

As alluvium occupies a relatively small area, the main recharge mechanism is infiltration of rainfall through the weathered regolith layer, and from there into the underlying rock mass where favourable hydraulic conductivity is exposed in subcrop areas.

During a period of rainfall deficit and because hydraulic conductivity of underlying rock is low, recharge rates to the coal measures are also low. Significant groundwater recharge will tend to occur only following major prolonged rainfall events, or during the late autumn/early winter period when some longer term ground saturation and recharge is feasible.

The high clay content, and hence long storage/residence times, in the weathered soils that occur above the Permian subcrop areas causes recharge to be particularly low in those areas. Actual vertical percolation of recharge through rock layers is very limited and most recharge is likely to occur at subcrop after which the recharge water will move along relatively more permeable strata, parallel to bedding. The higher hydraulic conductivity of the alluvial areas and runoff concentration within drainage channels means that recharge will also tend to be higher in those areas.

Surface water associated with the principal drainage features will tend to be connected with the associated alluvium, and groundwater within the alluvium will discharge to the stream channels in some areas. However, connectivity with the underlying Permian is thought to be very limited due to the low vertical hydraulic conductivity of the underlying strata.

Groundwater flow paths in the vicinity of creeks are likely to be complex. Creeks may ‘lose’ or ‘gain’ groundwater from alluvium in some areas depending on the relative level of groundwater in the alluvium compared with the creeks, although under most conditions the streams are gaining, and act as discharges for both alluvial groundwater and hard rock groundwater. Connectivity with the regional hard rock groundwater is very low.

Groundwater may discharge to watercourses and much of this discharge occurs due to shallow ‘interflow’ (i.e. movement of perched groundwater through regolith layers or alluvium after rainfall recharge has occurred). The discharge rates from the deeper, hard rock groundwater system to some surface water features is limited due to the low vertical hydraulic conductivity of the Permian strata.

3 GROUNDWATER SIMULATION MODEL

3.1 EXISTING GROUNDWATER MODELS

Several groundwater models have been constructed within this area to simulate the stresses on the groundwater environment from mining activities. A summary of the extent and use of the previous models is provided below.

3.1.1 WAMBO MODELS

A groundwater impact assessment was prepared for WCPL by Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) in 2003. Two numerical groundwater models were developed to assess groundwater inflows to open cut mine workings and underground mines. The first model encompassed the alluvium and the Whybrow, Redbank Creek, Wambo and Whynot Seams, whilst the second modelled the deeper Arrowfield and Bowfield Seams while excluding the geological sequence above.

A groundwater impact assessment of the proposed North Wambo Underground Mine Modification was prepared for WCPL by Heritage Computing in 2012. The numerical groundwater model was developed to assess the two additional longwall panels in the Wambo Seam adjacent to the existing North Wambo Underground Mine (Longwalls 9 and 10). This model was subsequently adapted for the North Wambo Underground Mine Longwall 10A Modification (HydroSimulations, 2014), and again for the South Bates (Wambo Seam) Underground Mine Modification (MOD 15) (HydroSimulations, 2015). A further update of this model was carried out for the South Wambo Underground Mine Modification (MOD12) (HydroSimulations, 2016).

The HydroSimulations (2016) MOD 12 model was used as a starting base for this project. However, it was necessary to add two more layers at the base of the HydroSimulations model in order to simulate extraction from the Vaux Seam by the United Wambo Open Cut Coal Mine Project (discussed in Section 3.1.4). The HydroSimulations model already includes the Warkworth Seam as a separate layer, this being the deepest seam to be mined in the western part of the Joint Venture. This requires deeper open cut mining in the HydroSimulations model than has been done in the past.

3.1.2 MT THORLEY WARKWORTH MODEL

The Mt Thorley Warkworth model developed by AGE in 2010 was produced as part of the Warkworth Extension Groundwater Impact Assessment. This model has recently been updated (AGE, 2014), and some of the information from the more recent study has been used here.

Predictive numerical modelling was undertaken to assess the impacts on the groundwater regime, to estimate groundwater seepage to the open cut pits over the mine life and to predict the zone of influence of dewatering and the level and rate of drawdown at specific locations.

The model domain was surrounded by “no-flow” boundaries. The Redmanvale Fault Zone under the Wollemi National Park defined the western boundary; the Hunter River Cross Fault defined the northern boundary; and to the south a no-flow boundary was placed at a location assessed as being beyond the influence of the Mt Thorley Warkworth Mine. The base of the Bayswater Seam formed the base of the model.

3.1.3 HUNTER VALLEY OPERATIONS MODEL

Groundwater models were prepared for HVO by Environmental Resources Management Australia in 2008. As the area associated with mining operations at the HVO site is extensive, the models were separated into two areas. The model domains in the two separate areas include the vicinity of the South Lemington Pits, and the area near the Cheshunt and Riverview Pits.

The Bowfield Seam, which is proposed to be the deepest coal seam excavated in the South Lemington area, generally outcrops before it reaches the alluvial deposits around the Hunter River. In addition, mining of the coal seams down to, and including, the Bowfield Seam in the Cheshunt and Riverview areas creates a no-flow boundary for groundwater from the north. This creates a geological divide between the investigation area in the north and the investigation area in the south, and the Cheshunt Pit.

3.1.4 UNITED WAMBO OPEN CUT COAL MINE PROJECT MODEL

A groundwater model has been prepared for the submission of an Environmental Impact Statement for the Open Cut Joint Venture between Glencore and Peabody (AGE, 2016). While the AGE (2016) model was declared as fit for purpose, it should be noted that the primary purpose was assessment of open cut mining effects. The AGE (2016) model has implemented underground mining only coarsely, and the model cells do not align well with longwall panels. The reason for this is that the Voronoi mesh design has to be the same for all model layers. Given the focus on open cut mining in the AGE (2016) model, the cell shapes have been designed to follow open cut scheduling.

The AGE (2016) model does not include the rigorous height of fracturing calculations that are in the HydroSimulations model.

The AGE (2016) model is broader and deeper than the HydroSimulations model, in order to bring in distant mines. As these mines are too far away to interfere with Wambo workings, they are not included in the latest HydroSimulations model.

The AGE (2016) model includes a more refined progression of open cut extraction and therefore remains the more appropriate model for estimation of open cut inflows.

3.2 SOFTWARE CONVERSION

Previous versions of the Wambo models created by HydroSimulations were run using MODFLOW-SURFACT v4 (HydroGeoLogic). MODFLOW-SURFACT has been considered the industry standard for modelling coal mines due to its capability to simulate both saturated and unsaturated flow conditions, allowing appropriate handling of dry cells that commonly cause difficulty in mining models and desaturation below the watertable. MODFLOW-SURFACT additionally allows variable hydraulic properties with time (due to subsidence related fracturing and placement of backfill) using the Time-Varying Material Properties (TMP) package.

However, due to the high complexity in the model associated with the numerous mining operations, as well as the need to have thin dummy layers at the eastern edge of the model where the coal seam layers have been eroded away, HydroSimulations re-built the most recent model (as used for the MOD 12 Assessment in March 2016) using the new MODFLOW-USG program code (Panday *et al.*, 2013) and also a version called MODFLOW-USG Beta, both of which use a different underlying numerical scheme: control volume finite difference (CVFD), rather than traditional MODFLOW's finite difference (FD) scheme. The two MODFLOW-USG versions have been found to typically yield extremely low mass balance errors (close to 0.0%). They also allow discontinuous layers (pinch outs), removing the need for dummy layers, reducing the cell count and increasing the conceptual correctness of the model. While the currently publicly available MODFLOW-USG is a saturated model able to handle unconfined conditions, the MODFLOW-USG Beta version used in this study is able to simulate variably saturated flow conditions (similar to SURFACT) and can handle desaturation and re-saturation of multiple hydrogeological layers. When run using the USG-Beta version through Groundwater Vistas, the program is also able to simulate changing hydraulic properties with time using the Time-Variant-Materials (TVM) package developed by HydroAlgorithmics Pty Ltd.

HydroSimulations has undertaken extensive research to compare results from MODFLOW-SURFACT and MODFLOW-USG models (Merrick and Merrick, 2015; Merrick *et al*., 2016). It has been found that the results for simulated groundwater heads, drawdown and inflows are very similar between these codes both spatially and temporally. There is however a difference in the way MODFLOW-USG calculates vertical conductance as well as the way in which the enhanced hydraulic conductivity of the fracture zone above the longwalls is represented; therefore, some recalibration of the model was required during the conversion, as reported in HydroSimulations (2016). For the present study, only minor recalibration was done in the vicinity of bore P114 over Longwall 10A.

3.3 MODEL LAYERS AND GEOMETRY

The model extends 19 km from west to east (Eastings 299800-318800) and 16 km from south to north (Northings 6387600-6403600), covering an area of approximately 300 km^2. Eighteen model layers represent the stratigraphic section indicated in **Figure 7**. The model domain is discretised into 50 m by 50 m cells using 320 rows and 380 columns. The extent of the groundwater model domain is shown in **Figure 18**.

The two versions of MODFLOW-USG provide the option for a completely unstructured grid, however the previous rectilinear structured grid was retained for the model for this Modification to minimise the changes from previous modelling and reporting. Due to the requirement of standard versions of MODFLOW to have fully extensive layers, the eastern edge of the original model contained several thin (dummy) layers to represent coal seam erosion. This gave the original MODFLOW-SURFACT model 1,945,600 cells. During the conversion to MODFLOW-USG, cells that had a thickness of less than 0.6 m were removed from the model, such that in the new model the two layers on either side of the original thin (dummy) layer are now directly connected. This resulted in a revised cell count of 1,668,792 (15% reduction in the cell count) for the USG model. However, after addition of two extra layers at depth, the cell count is now 1,911,992.

Digital elevation surface data for the Wambo area were provided by WCPL. This was spliced with a regional topographic grid with 10 m contoured Digital Elevation Model (DEM) with a 50 m grid spacing sourced from Geoscience Australia.

Based on the conceptual hydrogeology described in Section 2, the following layers are defined in the model:

- Layer 1: Alluvium and regolith.
- Layer 2: Overburden and coal seams above the Whybrow Seam.
- Layer 3: Whybrow Seam.
- Layer 4: Whybrow Seam–Wambo Seam interburden.
- Layer 5: Wambo Seam.
- Layer 6: Wambo Seam–Whynot Seam interburden.
- Layer 7: Whynot Seam.
- Layer 8: Whynot Seam –Woodlands Hill Seam interburden.
- Layer 9: Woodlands Hill Seam.
- Layer 10: Woodlands Hill Seam–Arrowfield Seam interburden.
- Layer 11: Arrowfield Seam.
- Layer 12: Arrowfield Seam–Bowfield Seam interburden.
- Layer 13: Bowfield Seam.
- Layer 14: Bowfield Seam–Warkworth Seam interburden.
- Layer 15: Warkworth Seam.
- Layer 16: Warkworth Seam-Vaux Seam interburden.
- Layer 17: Vaux Seam.
- Layer 18: Basal units.

The model domain has been designed to be large enough to prevent boundary influence on internal model drawdown/depressurisation associated with mining at Wambo. The model extends beyond the subcrop trace of the deepest coal seam that is likely to be mined in the future.

The model domain and boundaries have been selected to incorporate any potential receptors (i.e. surface water bodies) that could be adversely affected by mining.

3.4 HYDRAULIC PROPERTIES

The coal measures are split into multiple model layers in recognition of the vertical hydraulic gradient through the stratigraphic column and the need to represent the various target coal seams as separate model layers.

Previous studies and investigations within the region have provided the basis for initial hydraulic property parameters used within the modelling component of this project for the coal seams and interburden. **Table 8** is a summary of previous work (Mackie, 2009) and of core laboratory measurements undertaken by WCPL. Hydraulic conductivity data collected for United Wambo Open Cut are presented in AGE (2016).

Core samples from interburden horizons were selected from core maintained at Wambo for laboratory testing of vertical (K_z) and horizontal (K_x) hydraulic conductivity. Intervals sampled included:

- Whybrow overburden;
- Whybrow – Redbank Creek Seam interburden;
- Redbank Creek – Wambo Seam interburden;
- Wambo – Whynot Seam interburden; and
- Whynot – Blakefield Seam interburden.

Compiled results are included in **Table 8**. Laboratory core testing provides a means of assessing the hydraulic conductivity of materials at an intergranular scale where porous media flow is the primary mechanism of groundwater flow. It does not account for secondary mechanisms of flow (fracturing/joints) which tend to dominate the movement of groundwater within the rock mass at shallower depths, and therefore this estimate is typically the lowest tenable hydraulic conductivity and is most representative of strata where fracturing and jointing are absent or disconnected.

Table 8 Summary of Hydraulic Properties from Field Testing

UNIT	THICKNESS (m)	CORE TESTING RESULTS^		K (m/day)#
		Kx (m/day)	Kz (m/day)	
Whybrow Overburden Sandstone/Siltstone	50	3.3×10^{-05}	4.0×10^{-06}	1.0×10^{-04}
Whybrow Seam	5	-*	-*	2.5×10^{-02}
Whybrow - Redbank interburden (Sandstone/Siltstone)	20	1.0×10^{-05}	3.2×10^{-06}	1.0×10^{-04}
Redbank Creek Seam	5	-*	-*	2.5×10^{-02}
Redbank - Wambo interburden (Sandstone/Siltstone)	15	3.0×10^{-06}	2.4×10^{-05}	1.0×10^{-04}
Wambo Seam	5	-*	-*	2.5×10^{-02}
Wambo - Whynot interburden (Sandstone/Siltstone)	20	3.2×10^{-06}	2.8×10^{-06}	1.0×10^{-04}
Whynot Seam	5	-*	-*	4.4×10^{-02}
Whynot - Blakefield interburden (Sandstone/Siltstone)	20	2.8×10^{-06}	1.3×10^{-06}	1.0×10^{-04}
Blakefield Seam	4	-*	-*	1.0×10^{-02}
Blakefield - Glen Munro interburden (Sandstone/Siltstone)	20	-*	-*	1.0×10^{-04}
Glen Munro Seam	5	-*	-*	6.5×10^{-02}
Glen Munro - Woodlands Hill interburden (Sandstone/Siltstone)	23	-*	-*	1.0×10^{-02}
Woodlands Hill Seam	4	-*	-*	1.2×10^{-02}

UNIT	THICKNESS (m)	CORE TESTING RESULTS^		K (m/day)#
		Kx (m/day)	Kz (m/day)	
Woodlands Hill - Arrowfield interburden (Sandstone/Siltstone)	25	-*	-*	1.0×10^{-04}
Arrowfield Seam	0	-*	-*	5.1×10^{-02}
Arrowfield - Bowfield interburden (Sandstone/Siltstone)	25	-*	-*	1.0×10^{-04}
Bowfield Seam	6	-*	-*	5.0×10^{-02}
Bowfield - Warkworth interburden (Sandstone/Siltstone)	5	-*	-*	1.0×10^{-04}
Warkworth Seam	2	-*	-*	1.0×10^{-02}
Warkworth - Mt Arthur interburden (Sandstone/Siltstone)	20	-*	-*	1.0×10^{-06}
Mt. Arthur Seam	10	-*	-*	4.6×10^{-04}
Material below Mt. Arthur Seam	8	-*	-*	1.4×10^{-01}

m/day = metres per day.

^ Results of core testing undertaken for this study. # Source: Mackie (2009).

* Core testing for this unit was not undertaken as part of this study. Core testing for the study focused on the interburden above the Wambo Seam as these units are the thicker units affecting groundwater flow vertically between the coal seams. Coal cores are too friable for laboratory measurement under stress. The hydraulic properties for the coal seams sourced from Mackie (2009) are considered to provide adequate initial values for the hydraulic parameters. Final hydraulic parameters used in the model were obtained through the calibration process.

The results also show that laboratory tests for interburden materials demonstrate lower hydraulic conductivities in comparison to the results of other methods, and vertical hydraulic conductivity is also typically much less than horizontal hydraulic conductivity. Discrepancies between laboratory tests and field scale tests are expected, as the laboratory scale tests do not contain fractures or fissures. Mackie (2009) identified three ‘types’ of bulk rock mass hydraulic conductivity in the Hunter Coalfield:

- Areas where there are very few fissures, or where fissures are so deeply compressed by hydrostatic loading that they are effectively closed, and bulk rock mass hydraulic conductivity is similar to laboratory values.
- Areas where there are ‘limited’ active joints. The impact this has on hydraulic conductivity depends on the rock type, with hydraulic conductivity for coarse grained or weathered sandstones/conglomerates only increasing by a factor of five, whereas mudstones could increase by up to 100 times the laboratory value.
- Areas that are de-stressed and heavily jointed. Most rock types in this category have similar hydraulic properties, in the range 0.01 to 0.001 metres per day (m/day).

Differences between vertical and horizontal hydraulic conductivity are also well documented, with vertical hydraulic conductivities typically an order of magnitude or so less than horizontal hydraulic conductivity, and in some cases several orders of magnitude lower. This is because fractures and fissures are generally oriented parallel with bedding, and because layers of claystones, mudstones or other low hydraulic conductivity strata tend to cause coherent barriers to flow perpendicular to the bedding. Vertical hydraulic conductivities of layers in a numerical model must be even lower due to the required vertical aggregation of geological layers. The harmonic mean (as opposed to arithmetic mean) is used to determine the bulk vertical hydraulic conductivity that is dominated by the layer of lowest vertical hydraulic conductivity within the stratified layers, yielding vertical anisotropy that is included in the model layers.

The hydraulic conductivity of coal seam layers is generally dependent on the degree of cleating within the coal (which dominates hydraulic conductivity) and the depth of cover, and hence compressive stress on the cleats (Mackie, 2009). Both empirical analysis (Laubach *et al*., 1998) and modelling of cleat fracture hydraulic conductivity (Mackie, 2009) suggest that the hydraulic conductivity of coal seams tends to decrease by around an order of magnitude with each 200 m of additional overburden.

The results of core hydraulic conductivity testing did not show a noticeable decrease in hydraulic conductivity with depth for the coal measure interburden units with horizontal conductivity ranging from 2.8×10^{-6} m/day to 3.3×10^{-5} m/day and vertical hydraulic conductivity from 1.3×10^{-6} m/day to 2.4×10^{-5} m/day. This is probably the result of testing in near-surface areas where mining operations occur. However, decreasing hydraulic conductivity with depth is expected with greater cover depth and/or remoteness from outcrop and the near-surface effects of weathering.

Faults and dykes in the area are not thought to be transmissive and are likely to represent a minor barrier to groundwater flow in most cases. The ‘basic’ igneous nature of the dykes means that they will tend to weather to impermeable clays, and the faults are relatively small, normal features that include a number of sealing clay layers. Larger, continuous dykes and faults are only present within the southern and eastern parts of the study area, which are located away from the environmental receptors and proposed mine development areas.

According to the Principle of Parsimony, the simplest conceptualisation of the geology should be favoured in a model. Implementation of a fault that has no observable hydrological effect would be contrary to this Principle. In the groundwater model, as the geometry of strata in the vicinity of the fault is honoured, there is an implicit assumption of coal seam continuity. This acts conservatively to propagate drawdown effects farther than would occur if the fault causes dislocation of the seam.

Direct testing data are not generally available for specific storage (Ss) of coal seams or interburden. However, good estimates can be made based on Young’s Modulus and porosity. For coal, Ss generally lies in the range 5×10^{-6} m^{-1} to 5×10^{-5} m^{-1}, and interburden could be slightly higher due to higher porosity (Mackie, 2009).

3.5 MODEL STRESSES AND BOUNDARY CONDITIONS

The model domain covers all of the potentially sensitive receptors. All significant creeks and rivers that could be affected by mining activities are fully contained within the model domain and have been represented in the model, as shown in **Figure 18**.

3.5.1 WATERCOURSES

All major waterbodies are represented using the MODFLOW-USG River (RIV) package, as shown in **Figure 19**. Of the water bodies within the model domain, the Hunter River and Wollombi Brook are considered to be the most important. The Hunter River and associated alluvium occupies the northern sector of the model domain. Wollombi Brook occupies a large portion of the eastern model domain. River stage is mostly constant with time in the model, with occasional user-specified increases during times of high flow.

Specific ‘river’ boundary cells within the model representing the Hunter River and Wollombi Brook are set up with stage levels 1 m below the surrounding topography, and a conductance of 50 square metres per day (m^2/day) corresponding to a vertical hydraulic conductivity at the stream bed in the order of 0.05 m/day.

Other creeks and minor drainage lines are also represented as ‘river’ boundary cells in the model with stage equal to base elevation of the bed layer. This allows groundwater to discharge to the drainage lines as baseflow, but does not allow these watercourses to recharge the underlying groundwater system. Due to narrower creek width, the conductances were set at 25 m^2/day except for a lower value for the North Wambo Creek diversion (0.025 m^2/day) to account for the engineered low hydraulic conductivity clay lining within the diversion. In the steeper terrain the stage level was set at 1.5 m below topography (representing the incised gullies that are known to occur in areas such as Stony Creek), reducing to 0.5 m below topographic ground level in lowland areas.

3.5.2 UNSATURATED ZONE MODELLING

The Beta version of MODFLOW-USG enables similar functionality as MODFLOW-SURFACT with regards to unsaturated zone flow modelling. Van Genuchten and Brooks-Corey parameterisation was used as input into the solution of the Richards Equation for unsaturated flow, to maintain consistency with previous MODFLOW-SURFACT modelling[2]. The unsaturated zone parameters were applied uniformly across all layers, as per **Table 9**. No variations in parameter values or distributions were considered to maintain consistency with previous versions of the Wambo groundwater model. The sensitivity of the adopted parameter values is examined in Section 4.9.3.

Table 9 Unsaturated Zone Parameterisation

PARAMETER	Value	Description
Van Genuchten Alpha (m^{-1})	0.3	Mean Pore Size Parameter
Van Genuchten Beta	2	Pore size distribution exponent
Residual Saturation	0.05	Residual soil water saturation
Brooks-Corey Exponent	2	Brooks-Corey Exponent

[2] Attempts to use Upstream Weighting without Richards Equation were unsuccessful

3.5.3 WAMBO MINE WORKINGS

The underground longwall extraction and open cut mining, and bore dewatering in overlying workings, are simulated in the model as MODFLOW-USG Beta 'Drain' (DRN) cells with the head set to 0.1 m above the floors of the relevant coal seams. These DRN cells were applied wherever workings occur, and were progressed through annual increments in the transient simulation. The set-up involved changing the parameters with time in the goaf and the overlying fractured zone directly after mining of each longwall panel (Section 3.6), whilst simultaneously activating DRN cells along the development headings. The development headings were activated 12 months in advance of the active longwall mining and subsequent subsidence. Although the coal seam void should be dominated by the drain mechanism, the horizontal and vertical hydraulic conductivities were raised to 10 m/day to simulate the highly disturbed nature of materials within the caved zone. A drain conductance value of 1,000 m^2/day was applied during simulation.

The open cut mining areas throughout the model domain form groundwater sinks to levels dictated by excavation depths and by seams which are intersected. These were also represented as DRN cells and effectively form specified head boundaries.

Spoil Emplacement and Final Void

Completed open cut mining areas will be backfilled with waste overburden as the extraction proceeds except the final void cells of the Joint Venture United/Wambo open cut. Backfill was given uniform hydraulic conductivity of 1 m/day, specific yield of 0.2 and rainfall recharge set to 5% of average rainfall (see Section 3.5.5).

The final void was given a higher hydraulic conductivity of 1,000 m/day, specific yield of 1.0 and a storage coefficient of 1.5×10^{-4} (based on a specific storage calculation for pure water). Rainfall recharge equal to 100% of average rainfall was applied to the final void (see Section 3.5.5).

The hydraulic properties were varied with time using the TVM package of MODFLOW-USG Beta.

3.5.4 NEIGHBOURING MINE WORKINGS

The approach of using DRN cells to simulate progression for the Wambo open cut and underground mine plans was applied also for neighbouring mining areas within the model domain, including Mt Thorley Warkworth, HVO and United Collieries.

In all cases, DRN cells were applied to appropriate coal seams being mined, with Drain elevations set to 0.1 m above the base of the mined layer. These DRN cells were applied wherever workings occur, and were progressed through annual increments in a transient model set-up. Implementation is further discussed in Section 4.3.

The mine workings represented in the model include:

- Homestead and Wollemi Underground (Wambo Coal Mine) (completed prior to the steady-state calibration period);
- North Wambo Underground (Wambo Coal Mine);
- South Bates (Whybrow Seam) Underground (Wambo Coal Mine);
- South Bates (Wambo Seam) Underground (Wambo Coal Mine);
- South Bates Extension (Wambo Coal Mine) (Modification Scenario only);

- South Wambo Underground (Woodlands Hill and Arrowfield Seams) (Wambo Coal Mine);
- Lemington Open Cut;
- Lemington Underground;
- Riverview;
- Cheshunt;
- Joint Venture United/Wambo Open Cuts;
- United Underground; and
- Mt Thorley Warkworth.

The development of neighbouring mines within the model was based on information publicly available in the relevant impact assessment documentation. **Table 10** provides a summary of mine workings represented in the model, the starting date of the various mining operations and ancillary information relating to the model build.

3.5.5 RECHARGE AND EVAPOTRANSPIRATION

An overview of the recharge zones used within the model is provided in **Figure 20**. Rainfall recharge was specified as a percentage of historical rainfall at Bulga (South Wambo) for transient calibration, and specified as the same percentage of long-term average rainfall for prediction simulations across two geologically-based zones, with two more zones used to simulate the areas of exposed pits and backfill and the final void during mining and post-mining:

- Zone 1: Alluvium: 1.2 %
- Zone 2: Regolith (Triassic and Permian strata): 0.25 %
- Zone 3: Exposed mining and backfilled areas: 5.0 %
- Zone 4: Wambo Open Cut final void areas: 100 %

The adopted values for rainfall recharge expressed as percentages of long-term average rainfall are similar to those found in steady-state calibration.

The ET package was used in the Wambo model with an extinction depth of 3.0 m and a maximum 365 mm/a ET rate. In the model, ET occurs only in low-lying areas where the water table is close to surface (along river/creek margins). For the Wambo Open Cut final void areas, the extinction depth was set to 1,000 m to ensure that discharge would occur at, or very close to, the potential rate as the water level rises in the void.

Table 10 Summary of Mine Workings in the Model Domain

MINE	TYPE	MINE AREA	COAL SEAM	MODEL LAYER	START	END
Wambo	Open Cut	Bates Open Cut	Whybrow	3	1980	1987
		Ridge Open Cut	Whybrow	3	1986	1988
		Eastern Open Cut	Whybrow	3	1974	1982
		Western Open Cut	Whybrow	3	1974	1983
		Bates North Open Cut	Whybrow	3	1997	1997
		Whynot Open Cut	Whynot	7	1991	1998
		North East Open Cut	Wambo	5	1988	1998
		Hunter Pit	Whynot	7	1969	2011
		Wombat Pit	Whynot	7	1969	2009
		Homestead Pit	Whynot	7	1969	2016
		Bates Pit	Whynot	7	1969	2016
		Bates South Pit	Whynot	7	1969	2016
		Joint Venture Wambo Open Cut	Whynot to Warkworth	7 to 15	2016	2039
	Underground	Ridge Underground	Whybrow	3	1976	1983
		Homestead and Wollemi Underground	Whybrow	3	1979	2002
		South Bates (Whybrow Seam) Underground	Whybrow	3	2015	2017* 2022^
		South Bates (Wambo Seam) Underground	Wambo	5	2017	2018
		Wambo No.1 Underground	Wambo	5	1969	1977
		North Wambo Underground	Wambo	5	2007	2016
		South Wambo (Woodlands Hill) Underground	Woodland Hill	9	2019* 2023^	2029* 2033^
		South Wambo (Arrowfield) Underground	Arrowfield	11	2023* 2030^	2032* 2039^

MINE	TYPE	MINE AREA	COAL SEAM	MODEL LAYER	START	END
Mt Thorley Warkworth	Open Cut	North Pit	Warkworth	13	1981	2031
		West Pit	Mt Arthur	15	1981	2031
		Woodlands Pit	Mt Arthur	15	1981	2031
		South Pit	Mt Arthur	15	1981	2031
		CD Pit	Mt Arthur	15	1981	2031
		Loders Pit	Mt Arthur	15	1981	2017
		Abbey Green	Mt Arthur	15	1981	2017
HVO	Open Cut	North Lemington Open Cut	Bowfield	11	1971	unknown
		South Lemington Pit 1 Open Cut	Bowfield	11	1998	2024
		South Lemington Pit 2 Open Cut	Bowfield	11	2010	2019
		Lemington Underground Mine No.1 &2	Mt Arthur	15	1971	1991
		Riverview Pit Open Cut	Warkworth	13	1991	2019
		Chestnut Pit Open Cut	Mt Arthur	15	2001	2028
United Collieries	Open Cut	United Open Cut	Whynot	7	1989	1992
		Joint Venture United Open Cut	Whynot to Vaux	7 to 17	2021	2039
	Underground	Underground Operations	Arrowfield	11	1992	2010

^ Modification Scenario Only * Approved Scenario Only

Note: The Approved Scenario mine life and progression for South Wambo Underground is consistent with the mine life and progression modelled for MOD 12.

3.6 FRACTURED ZONE IMPLEMENTATION

3.6.1 BACKGROUND

Conceptually, there are a number of physical hydrogeological effects that are expected to occur throughout the life of the underground mining which need to be represented using specific modelling approaches. This includes the simulation of changes to the hydraulic properties of overburden material caused by the caving and subsidence above longwall panels.

It is generally accepted that under most conditions there will be a sequence of zones of strata deformation consisting of the caved zone, the fractured zone (a lower zone of connective-cracking and an upper zone of disconnected-cracking), the constrained zone and the surface zone.

High hydraulic conductivity is expected in the caved zone where there is direct connectivity with the mined goaf. In the lower part of the fractured zone, the collapsed rocks would have a substantially higher vertical hydraulic conductivity than the undisturbed host rocks. In the disconnected-cracking fractured zone, the vertical hydraulic conductivity would not be significantly higher than under natural conditions. Depending on the width of the longwall panels and the depth of mining, and the presence of low hydraulic conductivity lithologies, some increase in horizontal hydraulic conductivity can be expected in the constrained zone. Near-surface fracturing can also occur due to horizontal tension at the edges of a subsidence trough in the surface zone.

3.6.2 MODEL SIMULATION

The fractured zone was simulated with horizontal hydraulic conductivity enhanced by a factor of two (2), and with vertical hydraulic conductivity enhanced according to a log-linear monotonic (ramp) function. The function varied the vertical hydraulic conductivity field within the deformation zone overlying coal extraction areas and weighted the hydraulic conductivity changes on layer thickness. Limits for the variability were governed by predicted fracture height and assigned upper and lower bounds on hydraulic conductivity. Assigned fractured zone properties are presented in Section 3.8.

The approach used to determine subsurface fracture heights is consistent with the approach described in the HydroSimulations (2016) MOD 12 model. In locations where mining in one seam occurs, the Ditton and Merrick (2014) Geology Method was used to calculate the fractured A-zone height. The addition of aW’ (defined below) was used to give the fracture height with 95% confidence and provide a conservative estimate.

The Ditton and Merrick (2014) Geology Method includes the key fracture height driving parameters of panel width (W), cover depth (H), mining height (T) and local geology factors to estimate the A and B zone horizons above a given longwall panel. The A zone corresponds with the connective-cracking part of the fractured zone, while the B Zone corresponds with the disconnected-cracking part of the fractured zone which is equivalent to the lower dilated part of the constrained zone. The Geology Model depends on W, H, T and t' (where t' is the effective thickness of the strata where the A Zone height occurs). The formula for fractured zone height (A) for single-seam mining is:

- Geology Model: $A = 1.52\, W'^{0.4}\, H^{0.535}\, T^{0.464}\, t'^{-0.4} \;\; +/- \; (0.1 - 0.15)\, W'$

where W' is the minimum of the panel width (W) and the critical panel width (1.4H).

The 95th percentile (maximum) A-heights (A95) are estimated by adding aW' to A, where *a* varies from 0.1 for supercritical panels to 0.15 (geology model) for subcritical panels. The models have been validated to measured Australian case-studies (including West Wallsend, Mandalong, Springvale, Abel, Ashton, Austar, Berrima, Metropolitan and Wollemi/North Wambo Underground Mines) with a broad range of mining geometries and geological conditions included. The database also includes three cases in which connective cracking reached the surface (South Bulga, Homestead and Invincible Collieries).

A summary of the key fracture height driving parameters of panel width (W), cover depth (H) and mining height (T) is provided in **Table 11**. The effective seam thickness for the overburden (t') is taken as 20 m, the minimum (most conservative) of the calibrated range in the Western Coalfield. The mean A-Zone (A) and 95th percentile A-zone (A95) heights according to the Ditton Geology Model are also listed in **Table 11** for the mining height planned for the Modification.

To account for the variable cover depth, the longwall panels have been split into segments for the fracture height calculations. The segments (as referenced in **Table 11**) are shown in **Figure D2**. Fracturing to the land surface is assumed when the A95 fracture height comes within 15 m of land surface, the maximum anticipated depth of shallow cracking.

The connected A95 fracture height and associated surface cracking zone is shown in two representative cross-sections near the South Bates Extension (**Figure 22** and **Figure 23**). The location of these cross-sections is shown in **Figure 21**.

Table 11 Ditton Geology Model A-Zone Heights (m) for South Bates Modification

Longwall Segment	Panel Width [W (m)]	Cover Depth [H (m)]	Modification Mining Height [T (m)]	Fracture Zone Height [A (m)]	95th Percentile Fracture Zone Height [A95 (m)]	Average Depth to A95 Fracture Zone (m)
17	250	65-338	3	48-176	57-212	66
18	250	62-342	3	46-177	55-214	67
19	250	56-328	2.8	41-167	49-204	66
20	250	51-336	2.8	37-170	44-207	68
21	250	48-300	2.8	35-160	42-195	57
22_1	250	46-57	3	35-43	41-51	5
22_2	250	57-69	3	43-51	51-61	7
22_3	250	66-83	3	49-61	58-73	9
22_4	250	75-101	2.8	54-71	64-85	13
22_5	250	89-119	2.8	63-83	76-99	16
22_6	250	119-136	2.8	83-94	99-113	21
22_7	250	136-152	2.8	94-104	113-125	25
22_8	250	148-170	2.8	101-115	122-139	28
22_9	250	163-223	2.8	111-136	134-166	43
22_10	250	221-316	2.8	136-164	153-200	99
23_1	250	60-77	3	45-57	53-68	8
23_2	250	63-72	3	47-53	56-63	8
23_3	250	68-81	3	51-60	60-71	9
23_4	250	74-87	3	55-64	65-76	10

Longwall Segment	Panel Width [W (m)]	Cover Depth [H (m)]	Modification Mining Height [T (m)]	Fracture Zone Height [A (m)]	95th Percentile Fracture Zone Height [A95 (m)]	Average Depth to A95 Fracture Zone (m)
23_5	250	81-102	2.8	58-72	69-86	14
23_6	250	101-124	2.8	71-86	86-104	18
23_7	250	124-137	2.8	86-95	103-114	22
23_8	250	137-157	2.8	95-108	114-130	26
23_9	250	160-224	2.8	109-136	132-167	43
23_10	250	213-316	2.8	133-164	150-200	97
24_1	250	61-85	3	46-62	54-74	9
24_2	250	64-82	3	48-60	57-72	9
24_3	250	70-87	3	52-64	62-76	10
24_4	250	81-91	3	59-67	71-79	11
24_5	250	97-106	2.8	68-74	82-89	16
24_6	250	105-116	2.8	74-81	88-97	18
24_7	250	107-128	2.8	75-89	90-107	19
24_8	250	124-144	2.8	86-99	103-119	23
24_9	250	140-164	2.8	96-112	116-135	27
24_10	250	158-223	2.8	108-136	130-166	42
25_1	250	84-91	3	62-66	73-79	11
25_2	250	92-112	3	67-81	80-96	14
25_3	250	82-102	3	60-74	72-88	12
25_4	250	91-116	3	67-83	79-99	14
25_5	250	95-110	3	69-79	83-95	14
25_6	250	108-130	2.8	75-90	90-108	20
25_7	250	106-134	2.8	74-92	89-111	20
25_8	250	105-129	2.8	74-89	89-107	19
25_9	250	118-138	2.8	82-95	99-115	21
25_10	250	138-167	2.8	95-114	114-137	27

Note: Cells highlighted in green indicate longwall segments that fracture to the land surface (A95 fracture height is within 15 m of land surface).

Where the mining of two or more seams has occurred, the goaf of a previously mined seam may be reactivated by the additional subsidence and increase the extent of fracturing above the upper mined seam. For calculating the height of fracture for multi-seam conditions in the mining area at Wambo, the mined height (T) was replaced with an effective mined height (T') for input to the Geology Model formula, based on the additional subsidence caused by the mining of nearby seams as per Ditton (2014 pers. comm.).

Storage properties (specific yield Sy) were also increased in the mined coal seam layer to 15% for the longwalls and 25% for bord and pillar areas. The previously mined bord and pillar areas in the Whybrow Seam are shown in **Figure 2** (represented by a purple outline). For deep coal seams, the Sy for the two layers above the coal seam was increased to 4% in areas overlying the longwall panels. For bord and pillar operations, Sy was increased to 4% in one layer only above a deep coal seam where active mining has occurred. The hydrostratigraphic unit (HSU) zonation in the Groundwater Vistas 6 software has been used to delineate the fracture zones and to attribute these in time consistent with mine progression. Groundwater Vistas then writes the TVM package for use with MODFLOW-USG.

Cross-section slices along a number of transects are provided in **Attachment D**. The locations of the east-west and north-south lines are shown in **Figure D1**. In each diagram, the upper figure shows host hydraulic conductivity patterns and permanent fracture zones (pre-mining at 2003). The lower figure shows fractured zones that grow dynamically as the simulation of mining progresses in the model. These figures show that the extent of adopted fracturing in the groundwater model is conservative, as fracturing is often to land surface, and where multi-seam mining is simulated the interburden between coal seams is taken to be fully fractured.

Figure D1 and **Figure 21** show the extent of simulated fracturing to the surface above Modification Longwalls 17 to 25 based on where the A95 level comes within 15 m of land surface. Fracturing to the surface has been simulated above the northern 40-50% of Longwalls 17 to 25.

There is likely to be surficial cracking of the alluvium associated with North Wambo Creek above Longwalls 23 to 25. However, this is likely to be a temporary effect as the tensile cracks would open and close as the subsidence wave passes. Cracks that remain open are likely to be at least partially infilled by sediments washed into the cracks. Continuous cracking from the void to the alluvium may occur along approximately 1 km of the North Wambo Creek where it traverses the northern ends of Longwalls 23 to 25 (**Figure 21**). There is expected to be some transfer of higher quality creek water through the cracks into the underlying regolith and fracture zone. While the volumes would be small, there should be some beneficial effect on the water quality in the regolith which is known to be saline at bore GW17. The extent of migration of perturbed salinity water through fractured material would be limited by barriers of host material above each coal pillar.

3.7 MODEL VARIANTS

The steady-state model of pre-mining conditions has been adopted for the provision of initial heads for transient simulation. A single transient simulation model has been designed for:

- calibration from 2003 to 2014;
- Prediction Scenario A: from 2015 to end of the Approved mining in 2032 (Approved Scenario);
- Prediction Scenario B: from 2015 to end of the Modification mining in 2039 (Modification Scenario); and
- transient recovery simulation towards equilibrium conditions over 200 years for the Modification Scenario.

Further discussion on model scenarios is provided in Section 4.2.1.

3.8 MODEL CALIBRATION

The existing model was recalibrated recently, up to August 2015, during the MOD 12 assessment (HydroSimulations, 2016). As this model calibration was accepted, no further calibration was carried out as part of this Modification. Interrogation of the model was conducted into the performance of the model at bore P114 and to confirm the addition of two model layers at depth (to allow consistency with the Joint Venture operation) would have no effect on calibration performance.

The storage parameters used in the calibrated groundwater model are presented in **Table 12**. The calibrated hydraulic conductivities for the stratigraphic column, including the two additional model layers, are summarised in **Table 13.** The host values are consistent with field measurements (**Table 8**). **Table 13** also shows the fracture zone vertical hydraulic conductivities associated with Whybrow Seam and Wambo Seam underground mining at South Bates Underground. The extent of simulated fracturing to the surface at South Bates Underground is shown in **Figure D1**. Fracture zone hydraulic conductivities associated with North Wambo, United, Homestead and South Wambo underground mines are reported in HydroSimulations (2016).

Table 12 Calibrated Storage Parameters

Geological Unit	Storage Coefficient (S)	Specific Yield (Sy)
Alluvium	N/A	0.1
Colluvium	5E-4	0.01
Permian interburden and underburden	1E-4	1E-3
Permian coal seams	5E-4	5E-3

Table 13 Calibrated Hydraulic Conductivities [m/day] for South Bates Underground

LAYER	LITHOLOGY	ZONE	HOST KX	HOST KZ	WHYBROW (LAYER 3) UNDERGROUND FRACTURE ZONE KZ	WAMBO (LAYER 5) UNDERGROUND FRACTURE ZONE KZ
1	Alluvium	1	10	1	NA	NA#
1	Colluvium/Regolith	17	5.0E-1	1.0E-2	5.0E-2, 3.0E-2^	NA#
2	Triassic Sandstone, Whybrow Seam overburden	2	1.0E-3	1.0E-5	2.5E-5, 1.1E-4^	NA#
3	Whybrow Seam	3	2.5E-3	5.0E-5	10	NA#
4	Whybrow Seam – Wambo Seam interburden	4	1.0E-4	5.0E-6	3 x Kz host	1.5E-5
5	Wambo Seam	5	2.5E-3	1.5E-5	NA	10
6	Wambo Seam – Whynot Seam interburden	6	1.0E-4	3.0E-6	NA	3 x Kz host
7	Whynot Seam	7	4.4E-3	1.4E-5	NA	NA
8	Whynot Seam – Woodlands Hill Seam interburden	8	1.0E-4	1.5E-6	NA	NA
9	Woodlands Hill Seam	9	1.2E-3	1.3E-5	NA	NA
10	Woodlands Hill Seam - Arrowfield Seam interburden	10	1.0E-4	1.1E-6	NA	NA
11	Arrowfield Seam	11	5.1E-3	1.1E-5	NA	NA
12	Arrowfield Seam – Bowfield Seam interburden	12	1.0E-4	1.0E-6	NA	NA
13	Bowfield Seam	13	5.0E-3	1.0E-5	NA	NA
14	Bowfield Seam - Warkworth Seam interburden	14	1.0E-4	1.0E-6	NA	NA
15	Warkworth Seam	15	1.0E-3	9.7E-6	NA	NA
16	Warkworth Seam – Vaux Seam interburden	14	1.0E-4	1.0E-6	NA	NA
17	Vaux Seam	15	1.0E-3	9.7E-6	NA	NA
18	Basal Layer	16	1.0E-4	6.2E-7	NA	NA

Note 1: For each fractured layer Kx = 2 x Kx host.

Note 2: Although A-zone heights were varied cell-by-cell, laterally uniform enhanced hydraulic conductivities were retained in fracture zone layers.

Note 3: NA# means that the adopted conductivities are consistent with the fracture zone conductivities associated with the overlying seam.

Note 4: ^ applies to South Bates Extension where fractured to land surface.

The model was interrogated near bore P114 over Longwall 10A, given that the previous model appeared to be underestimating the decline in groundwater levels that has been observed at the monitoring bore. As monitoring bore P114 is located outside the revised extent of alluvium, based on the TEM survey by Groundwater Imaging (2012), the drawdown experienced there is not representative of the drawdown that might occur elsewhere in the alluvium.

The calibration hydrograph for P114 is shown in **Figure 24**. The difference between modelled and observed drawdown was found to be due to the inability of the model to represent layering at a fine vertical scale, and the fact that P114 was drilled into the upper part of model layer 2. When the simulated layer 1 and layer 2 heads are weighted according to the partial penetration of the bore into layer 2, a good calibration is achieved. Based on the above and the model response and performance elsewhere, there is no need to change any of the previously adopted hydraulic conductivities.

The model calibration statistics were checked following the addition of two model layers, and remained consistent with those reported in the calibrated MOD 12 assessment (HydroSimulations, 2016).

The mass balance averaged over the calibration period was also checked (**Table 14**) following the addition of two model layers, and remained consistent with the MOD12 assessment. The average water balance for the transient calibration period across the entire model area shows total inflow (recharge) to the groundwater system is approximately 12 ML/d, comprising rainfall recharge (21%), leakage from streams to groundwater (29%), and inflow from the general head boundary on the western margins (5%). The largest proportion of model outflows are the mine inflows (37%), followed by evapotranspiration (35%) and baseflow to rivers and streams (12%). Approximately 1% of the total outflows is due to both wells and regional boundaries. There is a net loss in storage of approximately 3.8 ML/d (32% of through-flow) over the calibration period.

Table 14 Transient Model Mass Balance

	Inflow (ML/d)	Inflow (%)	Outflow (ML/d)	Outflow (%)
Storage	5.28	45.1	1.53	13.1
General Head Boundaries (Regional Boundary)	0.56	4.8	0.13	1.1
Wells	0	0	0.11	0.96
Drains (Mine Inflow)	0	0	4.36	37.3
Rivers	3.37	28.9	1.43	12.3
Evapotranspiration	0	0	4.13	35.3
Recharge	2.48	21.1	0	0
Total	11.69	100	11.69	100

4 SCENARIO ANALYSIS

4.1 MODIFIED MINING SCHEDULE

A summary of the mining schedules that have been assumed in the groundwater model is provided in **Figure 25**. This table outlines the stress period setup for transient simulation for historical, prediction and recovery model runs. The target prediction period extends from stress period 31 (January 2015) to stress period 56 (December 2040). However, the predictive model was initiated from stress period 1 (January 2003) to ensure the drawn-down groundwater levels from the mining throughout the calibration period were included through to the target predictive period so that the full duration of WCPL's approved mines was covered in one simulation.

The timing of longwall mining in the Approved Scenario at South Bates Underground is from stress period 32 to 33 (January 2016 to December 2017) in the Whybrow Seam, and from stress period 33 to 34 (January 2017 to December 2018) in the Wambo Seam. At South Wambo Underground the timing of longwall mining is from stress period 35 to 45 (January 2019 to December 2029) in the Woodlands Hill Seam, and from stress period 39 to 48 (January 2023 to December 2032) in the Arrowfield Seam.

The timing of longwall mining in the Modification Scenario at South Bates Underground is stress period 32 to 33 (January 2016 to December 2017) in the approved Whybrow Seam, from stress period 33 to 34 (January 2017 to December 2018) in the approved Wambo Seam and from stress period 34 to 38 (January 2018 to December 2022) in the Modification longwall panels. At South Wambo Underground the timing of longwall mining is from stress period 39 to 49 (January 2023 to December 2033) in the Woodlands Hill Seam, and from stress period 46 to 55 (January 2030 to December 2039) in the Arrowfield Seam.

For both Approved and Modification scenarios, longwall mining is preceded by separate sequencing of development headings.

4.2 MODELLING APPROACH

4.2.1 MODIFICATION-SPECIFIC EFFECTS

The potential effects, in particular groundwater drawdown and depressurisation, of the Modification have been assessed by comparing model outputs for the Approved mine plan in the Whybrow, Wambo, Woodlands Hill and Arrowfield Seams with the Modification mine plan for the Whybrow, Wambo, Woodlands Hill and Arrowfield Seams. The effects of neighbouring mines and other influences such as rainfall recharge are the same in both models so that the incremental effects of the Modification can be identified uniquely.

Two model scenarios have been run to analyse the effects of the Modification:

Scenario A (Approved Scenario)	The Approved Mine Plan (for South Bates Underground Mine in the Whybrow and Wambo Seams, South Wambo Underground Mine in the Woodlands Hill and Arrowfield Seams, and all other mines).
Scenario B (Modification Scenario)	The proposed South Bates Underground Mine Modification (in the Whybrow Seam) and the change in South Wambo Underground Mine timing(in the Woodlands Hill and Arrowfield Seams). All other mines modelled as per Scenario A.

4.2.2 CUMULATIVE EFFECTS

Figure 25 specifies the timing assumptions for the neighbouring open cut and underground mines that have been included in the model. As all external mines have remained active for Scenarios A and B, cumulative drawdown and depressurisation are embedded in the results presented for Scenarios A and B. The differential drawdowns/depressurisations between this pair of scenarios are, therefore, inclusive of cumulative effects.

As the neighbouring mines have contributed to extensive depressurisation of the Permian coal measures in the vicinity of Wambo, a theoretical simulation that did not include external mines would not be valid because of the existing mine perturbation of the potentiometric surface.

4.3 MODEL IMPLEMENTATION

As noted previously, the underground mining and dewatering activity are simulated in the model using MODFLOW Drain (DRN) cells, with Drain heads set to 0.1 m above the floor of the coal seams. These DRN cells were applied wherever workings occur, and were progressed through time increments coincident with the stress period durations.

For all underground mines, the model setup involved activating MODFLOW DRN cells along development headings in advance of the active mining. Active mining and the consequent subsidence were simulated by activating Drains throughout the relevant longwall panels whilst simultaneously changing the parameters with time in the goaf and overlying fractured zones (and the underlying deformed 'floor strata').

Bore dewatering in the Whybrow Seam, which is operated in order to support safe mining in the underlying Wambo Seam in the North Wambo Underground mine, has been set up as MODFLOW DRN cells in the areas where the footprint of the old Wollemi/Homestead Underground mines (Whybrow Seam – layer 3) overlaps with the footprint of the active North Wambo Underground mine (Wambo Seam – layer 5). DRN cells in layer 3 are activated only for those cells overlying the scheduled Wambo Seam longwall panel, then turned off when that longwall panel is finished (see **Figure 25**). Bore dewatering has also been set up as MODFLOW DRN cells in the Wambo Seam to support safe mining in the underlying South Wambo Underground mine. DRN cells have been activated in the Wambo Seam (layer 5) for those cells overlying the scheduled longwall panels in the Woodlands Hill and Arrowfield Seams. Due to the high hydraulic conductivity of the old seam goaves, the dewatering DRN cells result in the desaturation of the target layer where it overlies the longwall panels.

Dewatering of the Wambo No. 1 Workings adjacent to Longwall 8b was accomplished by specified pumping rates (from Layer 5) at two bores, using the MODFLOW WEL utility.

For the Open Cut Joint Venture, including the Wambo open cut pits (e.g. Bates/South Bates, Homestead and Montrose Pits) and the United open cut pits, DRN elevations are set to 0.1 m above the basal Warkworth Seam and Vaux Seam respectively, and at floor level for the overlying coal seams. DRN cells are kept active for differing periods, representing the historical and proposed pit progression. After an area had been fully mined, the DRN cells are deactivated in the following stress period and the TVM utility was used to assign new properties to the emplaced spoil. The exception is in the areas that are to remain as the final void. In those areas the DRN cells were deactivated at the end of mining, and the layers then are assigned high hydraulic conductivity and high storage properties (see Section 3.5.3) to represent the final void.

4.4 WATER BALANCE

The modelled duration of the Approved Scenario in the Whybrow Seam at South Bates Underground Mine is from January 2016 to December 2017, corresponding to model stress periods 32 to 33 (**Figure 25**). The duration of the Modification Scenario in the Whybow Seam is from January 2016 (stress period 32) to December 2022 (stress period 38). The average water balance for these durations of mining for the two scenarios across the entire model area (for all active mines) is summarised in **Table 15**. The average water balance reports the inflows, outflows and change in storage over the entire model domain.

Table 15 Average Simulated Water Balance at the End of South Bates Underground Mine

COMPONENT	SCENARIO A APPROVED		SCENARIO B MODIFICATION	
	Inflow (ML/d)	**Outflow** (ML/d)	**Inflow** (ML/d)	**Outflow** (ML/d)
Drains (Mine inflow)	-	5.97	-	5.56
Recharge (direct rainfall)	2.41	-	2.40	-
Evapotranspiration (ET)	-	4.08	-	4.08
River (Leakage / Baseflow)	3.45	1.15	3.45	1.13
Regional GW flow (GHB)	0.56	0.13	0.56	0.13
Storage	7.73	2.82	8.93	4.44
Total	**14.15**	**14.15**	**15.34**	**15.34**
Storage & Mass Balance	4.91 loss		4.49 loss	

Note: Scenarios A and B are averaged over 2 years and 7 years, respectively.

The results for the predictive scenarios are almost identical for most components of the water balance. The Modification Scenario has 0.41 ML/d less total mine inflow. As the Joint Venture/Wambo open cuts are still mining during the Modification period, the difference in the mine inflows is due to the Modification and the open cuts. Overall, the net baseflow to all streams is about 0.1 percent lower with the Modification. The difference between the mine inflow rates is complicated by the different averaging periods (2 and 7 years, respectively) but it is clear that the difference is a result of water taken from underground storage.

Discussion of predicted inflows is provided in Section 4.8.

The total inflow (recharge) to the groundwater system (including storage changes) is approximately 14 and 15 ML/d for the Approved and Modification Scenarios respectively, dominated by rainfall recharge (17% and 16%), and leakage from streams into the groundwater (24% and 23%). Groundwater discharge is dominated by evapotranspiration (29% and 27%) and mine inflow (42% and 36%), with approximately 8% and 7% of recharge reporting as stream baseflow.

4.5 PREDICTED GROUNDWATER LEVELS

Predicted groundwater levels at the end of mining operations for the two scenarios are shown in **Figure 26** to **Figure 31**. These figures show groundwater levels in the target Whybrow, Woodlands Hill and Arrowfield Seams in model layers 3, 9 and 11 (respectively).

Figure 26 (Approved Scenario) and **Figure 27** (Modification Scenario) show predicted groundwater levels in the Whybrow Seam (Layer 3) at the end of mining at South Bates Underground. Predicted water levels are substantially more depressed within the Whybrow Seam for the Modification Scenario compared to the Approved Scenario. This is because mining occurs more extensively (over nine additional longwalls) in the Whybrow Seam in the Modification Scenario than in the Approved Scenario.

Figure 28 (Approved Scenario) and **Figure 29** (Modification Scenario) show predicted groundwater levels in the Woodlands Hill Seam (Layer 9) at the end of mining at the South Wambo Underground. Predicted water levels are more depressed within the Woodlands Hill Seam for the Modification Scenario compared to the Approved Scenario at the location of the Wambo Open Cut. This is because the United/Wambo Open Cut has progressed further during the Modification Scenario due to the change in timing at South Wambo Underground. There no discernible difference in the groundwater levels in the Woodlands Hill Seam at the location of the South Wambo Underground at the end of the Approved and Modification Scenarios.

Figure 30 (Approved Scenario) and **Figure 31** (Modification Scenario) show predicted groundwater levels in the Arrowfield Seam (Layer 11) at the end of mining at the South Wambo Underground. Predicted water levels are more depressed within the Arrowfield Seam for the Modification Scenario compared to the Approved Scenario at the location of the Wambo Open Cut. This is because the United/Wambo Open Cut has progressed further during the Modification Scenario due to the change in timing at South Wambo Underground. There is no discernible difference in the groundwater levels in the Arrowfield Seam at the location of the South Wambo Underground at the end of the Approved and Modification Scenarios.

More detailed discussion about the predicted changes in groundwater conditions is provided in Section 5.3.

4.6 PREDICTED PRESSURE HEADS

Predicted pressure heads[3] are presented along three cross sections at the end of South Bates Extension mining:

- Easting 307275 - **Figure 32** and **Figure 33**.
- Northing 6395875 - **Figure 34** and **Figure 35**.
- Northing 6394375 - **Figure 36** and **Figure 37**.

It should be noted that the vertical detail in the figures is interpolated between sparse values for pressure head, as there is but one value for each of the 18 layers in the model. This can lead to contouring artefacts for thick layers, especially model layer 2 (above the Whybrow Seam) in this model. Lateral detail is more reliable as pressure heads are reported by the model at 50 m intervals.

The south-north cross section along Easting 307275 passes through the eastern longwalls of the South Bates Extension and the south-west corner of the South Bates longwalls (**Figure 32**). Zero and near-zero pressure heads are evident above the Whybrow Seam where it has

[3] Defined relative to layer floor level.

been mined, with the lowest pressure heads in the fracture zone where it reaches land surface[4]. Low pressure heads are also evident in the currently active open cut (**Figure 33**).

The west-east cross section along Northing 6395875 passes through the northern part of the South Bates Extension longwalls where fracturing to land surface is expected for most of the panels (**Figure 34**). Again, zero and near-zero pressure heads are reported above the mined Whybrow Seam (subject to interpolation by automatic contouring). Low pressure heads are also evident in the currently active Wambo open cut (**Figure 35**).

The west-east cross section along Northing 6394375 passes through the southern part of the South Bates Extension longwalls where fracturing to land surface is not expected and through the northern part of the South Bates longwalls where fracturing to land surface is expected (**Figure 36**). The region of zero and near-zero pressure heads above the mined Whybrow Seam is not as extensive as on the other cross sections. This section also passes through areas of longwall mining at North Wambo Underground and South Wambo Underground, as well as Wambo open cut mining down to the Warkworth Seam. A complicated pattern of low pressure heads results from the various interacting mining activities (**Figure 37**). Some positive pressure head (20 m maximum) is reported above the Wambo Seam mined 13 years earlier at the North Wambo Underground (**Figure 37**).

4.7 PREDICTED BASEFLOW CAPTURE

Predicted changes in baseflow and natural stream leakage have been assessed for Wollombi Brook, North Wambo Creek, Wambo Creek and Stony Creek from January 2010 until the end of the predictive simulation in December 2040. The predicted changes can be inferred from **Figure 38** to **Figure 41** where comparisons are made for the two scenarios.

Wollombi Brook (**Figure 38**) and Stony Creek (**Figure 41**) both behave consistently as losing streams overall. There is a very minor decrease in stream leakage of about 0.02 ML/d from the Approved Scenario to the Modification scenario for Wollombi Brook. There is no discernible change in stream leakage from Stony Creek between the two scenarios.

North Wambo Creek (**Figure 39**) and Wambo Creek (**Figure 40**) are gaining streams overall. At North Wambo Creek, there is a slight reduction in baseflow (maximum 0.014 ML/d) due to the Modification Scenario compared to the Approved Scenario. This occurs as the northern South Bates Extension longwalls approach and pass beneath the upper reaches of North Wambo Creek. Slight recovery is evident in the 2030s. At Wambo Creek, there is a slight increase in baseflow (maximum 0.003 ML/d) due to the Modification Scenario compared to the Approved Scenario.

4.8 PREDICTED MINE INFLOW

The predicted groundwater inflows to the South Bates Underground are shown in **Figure 42** for the two scenarios. The predicted groundwater inflows to the South Wambo Underground are shown in **Figure 43** for the two scenarios. The predicted groundwater inflows to the Joint Venture United/Wambo Open Cut Mines are shown in **Figure 44** for the two scenarios.

For the Approved Scenario, the inflows to the South Bates Underground workings are predicted to peak at about 0.9 ML/d at the end of 2018. For the Modification Scenario, the inflows are predicted to increase to a maximum of about 1.0 ML/d at the end of 2018.

[4] The pressure heads in the fracture zone are likely to be lower in reality than produced by automatic contouring with sparse data.

For the Approved Scenario, the inflows to the South Wambo Underground workings are predicted to peak at about 3.1 ML/d at the end of 2030. For the Modification Scenario, the predicted peak inflow is slightly lower with a maximum of about 2.9 ML/d at the end of 2037.

There is no discernible difference in the simulated maximum inflows to the Joint Venture United/Wambo Open Cuts for the Approved and Modification scenarios. The AGE (2016) model includes a more refined progression of open cut extraction and therefore should be used for licensing purposes for the open cut operations.

4.9 SENSITIVITY ANALYSIS

4.9.1 NORTH WAMBO CREEK ALLUVIUM

A sensitivity analysis has been conducted on the extent of alluvial material along the upper reaches of North Wambo Creek. Alluvial material has been extended in the sensitivity run based on the interpreted geophysics conducted by GHD (2007) (i.e. hydraulic conductivities, storage parameters and recharge rates for regolith have been modified to match the calibrated properties for alluvium).

The predicted baseflow for North Wambo Creek for the Modification Scenario with and without the alluvial extension is shown in **Figure 39**. The baseflow to North Wambo Creek is initially lower for the Modification scenario with the alluvial extension compared to without. There is 0.002 ML/d less baseflow reduction and 0.001 ML/d less recovery related to underground mining at South Bates Underground with the alluvial extension compared to without.

There is no significant change to the mine inflows as a result of the sensitivity analysis. Nor is there any significant change to vertical alluvial loss.

4.9.2 FRACTURE HEIGHT NEAR NORTH WAMBO CREEK

A sensitivity analysis has been conducted on the height of fracturing near North Wambo Creek. Two model runs were carried out:

- Fracturing to the surface as shown in **Figure D1.** Fracturing to the surface was simulated above the northern 40-50% of Longwalls 17 to 25.
- Fracturing to model layer 2 only in the vicinity of bore GW16 (towards the northern end of Longwalls 22 to 25).

The predicted groundwater levels at monitoring bore GW16 for the two fracture height scenarios are shown in **Figure 45.** There is less than 1 m difference between the water level at GW16 in layer 1 due to the difference in fracture height. Groundwater levels at GW17 in layer 2 do not show any difference in water levels between the two scenarios.

4.9.3 UNSATURATED ZONE PARAMETERS

A sensitivity analysis has been conducted on the unsaturated zone parameters used in the model. Two additional model runs were carried out using the following parameters to represent conditions for clay and sand endpoints (Bouwer, 1978):

- Bouwer Clay parameters: alpha (0.35 m^{-1}), beta (4), Brooks-Corey n (3.7)
- Bouwer Sand parameters: alpha (1.7 m^{-1}), beta (7), Brooks-Corey n (3.3)

The Brooks-Corey n value is calculated as:

$$n = 1 + \frac{2}{1 - \frac{1}{beta}}$$

Use of these parameters resulted in prohibitive run times whilst also applying time varying storage changes in backfilled open cut areas and within the goaf and fracture zone of the longwall panels. The sensitivity analysis model runs on unsaturated zone parameters were therefore set up without any time varying storage change. The Modification Scenario was also run without time varying storage change to allow comparison with the unsaturated zone parameters sensitivity runs.

The predicted mine inflows for the Modification Scenario, the Modification Scenario without storage changes, the Bouwer Clay unsaturated zone parameters (without storage changes) and the Bouwer Sand unsaturated zone parameters (without storage changes) are shown in **Figure 46**. This shows that the Modification Scenario is conservative as it predicts the highest inflows (peak inflow of 1.0 ML/d). The Modification Scenario without storage changes predicts lower peak inflows of 0.55 ML/d, the Bouwer Clay unsaturated zone parameters (without storage changes) predicts peak inflows of 0.49 ML/d and the Bouwer Sand unsaturated zone parameters (without storage changes) predicts peak inflows of 0.44 ML/d.

Additional leakage from Wollombi Brook during South Bates mining (peak at 0.35 ML/d) is highest for the Bouwer Sand unsaturated zone parameters run **(Figure 47)** but is almost same as the reported base case**.** Baseflow reduction to Wambo Creek during South Bates mining (peak at 0.034 ML/d) is highest for the Bouwer Sand unsaturated zone parameters run (**Figure 47**) and is about 30% higher than for the reported base case (peak at 0.023 ML/d). Additional leakage from Stony Creek is lowest for the Bouwer Sand unsaturated zone parameters, being about 15% less than for the base case. There is no change in baseflow reduction to North Wambo Creek for the different unsaturated zone parameters sensitivity runs (**Figure 47**).

Predicted groundwater levels at monitoring bores GW16 and GW17 for the unsaturated zone sensitivity analysis are shown in **Figure 48** and **Figure 49** respectively. This again shows that the Modification Scenario is conservative as it predicts the greatest drawdown at GW16 due to South Bates Mining (**Figure 48**).

4.9.4 EVAPOTRANSPIRATION

The ET package was used in the Wambo model with an extinction depth of 3.0 m and a maximum 365 mm/a ET rate. In the model, ET occurs only in low-lying areas where the water table is close to surface (along river/creek margins). The simulated depth to the water table prior to South Bates mining and after South Bates mining is shown in **Figure 50** and **Figure 51** respectively. There is a very small area of shallow water table (less than 3.0 m) near South Bates over which evapotranspiration will occur in the model. The numerical model results will there before be insensitive to varying the ET rate or the ET extinction depth.

5 POTENTIAL EFFECTS

5.1 POTENTIAL EFFECTS ON GROUNDWATER

The main effect of the underground mining upon the groundwater regime comes from changes in bulk rock mass hydraulic conductivity caused by the fracturing associated with longwall subsidence, and the pumping out of groundwater that enters the mine as a consequence. This caving, and associated extraction of groundwater, have a number of effects on the hydrogeological system during mining operations that have been evaluated as part of the impact assessment. These can be summarised as follows:

- inflow of groundwater to the underground mine and the management of that mine water;
- drawdown of groundwater levels and depressurisation of groundwater during operational mining, both within the Permian hard rock strata and the alluvium associated with North Wambo and Wambo Creeks, Wollombi Brook, Stony Creek and the Hunter River; and
- effects on baseflow and leakage to and from North Wambo, Wambo and Stony Creeks and Wollombi Brook during operational mining.

5.2 GROUNDWATER LEVELS AND FLOWS PRIOR TO PROPOSED MINE DEVELOPMENT

The pre-mining hydrogeological environment has been described within Section 2 of this report. Key features that are relevant to the impact assessment include:

- The general flow direction within the Permian strata is to the east and north-east, flowing from elevated areas on the western side of the study area / model domain, through to the older Permian strata (the Wittingham Coal Measures) to the east.
- Due to the general lack of vertical hydraulic connectivity, potentiometric head in the Permian strata is likely to have been higher than the alluvium groundwater levels, and therefore above ground level in some low-lying areas. Groundwater discharge from deeper, hard rock to alluvial flats would have been limited due to the low vertical hydraulic conductivity of the Permian strata, but it is known that over long periods of time (millennia) salinity can build up along the edges of these sediments. During and post mining these salinity accessions have been and would be arrested as a result of mine drawdown propagation.
- It is inferred that North Wambo Creek, Wambo Creek, Stony Creek, Wollombi Brook and the Hunter River are both gaining and losing streams depending on the stream stage. Some reductions in baseflow to these streams, or increased leakage from these streams, are likely due to the changes in hydrogeological regime as a result of past mining in this area. Groundwater flow paths in the vicinity of these watercourses can therefore vary.

5.3 POTENTIAL EFFECTS ON GROUNDWATER LEVELS

The approved South Bates Underground would cause depressurisation of the Permian strata. Due to the proposed mining of an additional nine longwall panels in the Whybrow Seam, it follows that there would be more drawdown in the Whybrow Seam and overlying strata due to the Modification, as discussed below.

Outside the mine footprint, the main effect from the approved South Bates Underground on hydraulic pressures within Permian strata would occur to the immediate south and west. Depressurisation to the north and east would be minimal due to the influence of neighbouring open cut and underground mines.

The influence on groundwater levels due to the Modification would be localised essentially within the mine footprint as discussed in Section 4.5.

The cumulative maximum drawdown for the Modification Scenario from stress period 32 to 56 is shown in **Figure 52** to **Figure 57** for the alluvium/regolith (Layer 1), Whybrow Seam overburden (Layer 2), Whybrow Seam (Layer 3), Wambo Seam (Layer 5), Woodlands Hill Seam (Layer 9) and the Arrowfield Seam (Layer 11).

The difference in maximum drawdown between the Approved Scenario and the Modified Scenario from stress period 32 to 56 is shown in **Figure 58** to **Figure 63** for alluvium/regolith (Layer 1), Whybrow Seam overburden (Layer 2), Whybrow Seam (Layer 3), Wambo Seam (Layer 5), Woodlands Hill Seam (Layer 9) and the Arrowfield Seam (Layer 11). As the incremental drawdown was calculated as Approved Scenario *minus* Modification Scenario groundwater level elevations, this definition means that a *negative* value is a reduction in predicted drawdown (that is, a benefit), whereas a *positive* value is an increase in predicted drawdown (that is, a disadvantage).

Cumulative maximum drawdown of about 2 m due to approved mining in alluvium and regolith (**Figure 52**) would occur from the commencement of the North Wambo Underground Mine to the completion of the South Wambo Underground Mine. This drawdown would lie over the central area of the mine along the central axis of the North Wambo Creek alluvium. This is partially due to fracturing to land surface but also due to adjacent open cut mining. Negligible drawdown is anticipated at the south-western end of the mine layout in the vicinity of Stony Creek. There is no predicted change in the maximum drawdown between the Approved and Modification scenarios in the alluvium/regolith, as shown in **Figure 58**.

In the Whybrow Seam overburden, mining is expected to generate cumulative maximum drawdowns of up to 55 m over the South Bates Extension footprint (**Figure 53**) all of which is attributable to the Modification, that is the longwall mining of the Whybrow Seam (**Figure 59**). A minor net reduction (up to 5 m) in drawdown due to the Modification is expected in the south due to the changed timing of the South Wambo Underground Mine.

In the Whybrow Seam, mining is expected to generate cumulative maximum drawdowns of up to 200 m over the South Bates Extension footprint, and also over the Wambo Open Cut footprint (**Figure 54**). Comparison of the predicted difference between the maximum drawdown for the Approved and Modification Scenarios (**Figure 60**) shows that only the drawdown over the South Bates Underground footprint is attributable to the Modification in the Whybrow Seam. The same drawdown at the Wambo Open cut is predicted in both scenarios. A net reduction (up to 20 m) in drawdown due to the Modification is expected in the south due to the changed timing of the South Wambo Underground Mine.

In the Wambo Seam, mining is expected to generate cumulative maximum drawdowns of up to 300 m over the South Bates Underground Mine footprint (**Figure 55**). This drawdown is predicted to be the same for the Approved and Modification Scenarios (**Figure 61**). Additional maximum drawdown of up to 55 m is predicted over the South Bates Extension footprint due to the Modification.

For mining in the Woodlands Hill Seam at South Wambo Underground Mine, cumulative maximum drawdowns to more than 200 m are expected over a broad area, in line with the downdip cover depth (**Figure 56**). The cumulative maximum drawdowns predicted in the Modification Scenario are up to 70 m less than the Approved Scenario (**Figure 62**) due to the changed timing of the South Wambo Underground Mine.

In the Arrowfield Seam, cumulative maximum drawdowns are expected to reach up to 450 m over a broad area (**Figure 57**). The cumulative maximum drawdowns predicted in the Modification Scenario are again up to 50 m less that the Approved Scenario (**Figure 63**) due to the changed timing of the South Wambo Underground Mine.

5.4 PREDICTED GROUNDWATER INFLOWS

For the Modification Scenario, the combined inflows to the Whybrow Seam and Wambo Seam workings at South Bates Underground Mine are predicted to peak at about 1.0 ML/d at the completion of mining the Wambo Seam at Longwall 16 (**Figure 42**). The peak annual inflow volume predicted for the Modification is approximately 376 ML/a. This rate is about 0.17 ML/d (60 ML/a) higher that the peak expected for the Approved Scenario (about 0.9 ML/d).

For the Modification Scenario, the inflows to the South Wambo Underground Mine are predicted to peak at about 2.9 ML/d (1,072 ML/a), which is about 0.15 ML/d (53 ML/a) less than the Approved Scenario (**Figure 43**).

5.5 GROUNDWATER LICENSING

For the mapped extent of alluvium shown in **Figure 6**, the model outputs have been assessed to determine the effect on the groundwater flow between the alluvium and the underlying rock for that part of the mapped alluvium within Wambo mine leases, excluding alluvium along North Wambo Creek excavated by open cut operations. Estimates of vertical flow are compared during the time period of both Approved and Modification Scenarios at the South Bates Underground Mine. It is not possible to isolate the effect on alluvial flows of South Bates Underground Mine operations alone, as all mines would contribute to such flows.

The predicted annual groundwater volumes required to be licensed for the underground operations over the life of the South Bates Underground and South Wambo Underground Mines for the Approved and Modified Scenarios are summarised in **Table 16** for both alluvial and porous/fractured rock groundwater sources from the commencement to the completion of each mine. For the duration of the South Bates Underground Mine from 2016 to 2023 (stress period 32 to stress period 39), there is predicted to be a net average loss of alluvial groundwater to the underlying rock of 57 ML/a for the two scenarios with a maximum of 69 ML/a. The maximum take from the hard rock water source is estimated to be 1,072 ML/a, a slight reduction on the take that has been approved (1,125 ML/a).

Table 16 Groundwater Licensing Summary

Water Sharing Plan	Management Zone/ Groundwater Source	Predicted Annual Inflow Volumes requiring Licensing (ML/a)	
		Approved Mine Plan	Modification
Hunter Unregulated and Alluvial Water Sources Water Sharing Plan 2009	**Lower Wollombi Brook Water Source**	Av. 57 Max. 69	Av. 57 Max. 69
North Coast Fractured and Porous Rock Groundwater Sources ^^	**Porous Rock – South Wambo***	Av. 753 Max. 1,125	Av. 707 Max. 1,072
	Porous Rock – South Bates^	Av. 181 Max. 316	Av. 212 Max. 376
	Porous Rock – total	**Max. 1,125**	**Max. 1,072**

* For the duration of South Wambo Underground Mine.

^ For the duration of South Bates Underground Mine.

^^ Porous Rock is the Sydney Basin - North Coast Groundwater Source, as defined in the *WSP for the North Coast Fractured and Porous Rock Groundwater Sources*, released 1 July 2016.

As stated in Section 1.6, WCPL currently has licensed entitlements of 70 ML/a for the Lower Wollombi Brook Water Source and 1,647 ML/a for groundwater derived from the Porous Rock source. The current groundwater licences are therefore sufficient to cover the predicted water extraction shown in **Table 16** for all approved underground mine plans and the Modification for the South Bates Underground Mine. The take from the Lower Wollombi Brook Water Source is higher than reported in HydroSimulations (2015) due primarily to the proximity of the United open cut to Wollombi Brook.

5.6 POTENTIAL DRAWDOWN INTERFERENCE IN REGISTERED PRODUCTION BORES

Figure 64 shows the locations of registered private bores and mine bores in the vicinity of Wambo, in relation to the predicted incremental drawdown in the alluvium and regolith (model layer 1). **Figure 65** shows the predicted incremental drawdown in model layer 2 (Triassic Sandstone and Permian overburden). As the *Aquifer Interference Policy* minimal harm criterion refers to cumulative impact, affected bores are considered in the following section.

Due to the cumulative effects of all mining in the Wambo district, some drawdowns greater than 2 m are to be expected. There are a number of registered bores that are predicted to have a maximum cumulative drawdown greater than 2 m (**Attachment H**). However, most of these bores are either owned by WCPL or have a listed use for mining or monitoring, and therefore the *Aquifer Interference Policy* minimal harm criterion is not relevant. Bore attributes were derived from the NSW Pinneena bore database (v4.1 and v10.1).

Of the bores listed for private use, no bores have drawdown in excess of 2 m due to the Modification. However, there are three bores listed for private use that have modelled drawdowns greater than 2 m when the cumulative effect of all mines is taken into account.

Table 17 presents a summary of private bores for which the predicted cumulative drawdown is greater than 2 m since the commencement of South Bates Underground mining at Longwall 11. These three bores are not able to be definitively assigned to a model layer due to lack of lithology logs and screen information; therefore, drawdown is calculated for both Layer 1 (regolith) and Layer 2 (Permian). If the bores are in fact screened in the regolith, none of the three bores exceeds the 2 m drawdown criterion.

Table 17 Predicted Drawdown Effects at Registered Bores

Work No. (bore)	Licence	Owner Type	Use	Bore Depth (m)	Aquifer	Predicted drawdown [m]			
						Modification Increment‡		Cumulative	
GW078574*	20BL167170	Private	Irrigation	12	Regolith or Permian	<1	<1	<1	18
GW078575*	20BL167171	Private	Irrigation	12	Regolith or Permian	<1	<1	<1	32
GW078576*	20BL167172	Private	Irrigation	7	Regolith or Permian	<1	<1	<1	37

‡ Modification Increment is the difference in groundwater level between the start of mining at the South Bates Underground Mine (Modification layout) (Stress Period 32) and the end of mining at the South Bates Underground Mine (Modification layout) (Stress Period 39).

* Orange cell indicates layer 1 (regolith) drawdown, green cell is layer 2 (Permian) drawdown.

5.7 RECOVERY OF GROUNDWATER LEVELS

A recovery simulation has been run in transient mode for 200 years after completion of mining activities at all Wambo approved mines, including the Modification. For the recovery simulation all underground mine operations (modelled as DRN cells) were deactivated and spoil emplacement was simulated at the United/Wambo open cut mine (by modifying the modelled hydraulic properties to represent spoil).

Figure 66 to **Figure 71** present the predicted water levels at the end of the modelled 200-year recovery period (i.e. in 2241). There are no discernible signs of residual drawdown in the alluvium and regolith as indicated in the map of watertable levels (**Figure 66**). Residual drawdowns are predicted in the Whybrow Seam overburden (**Figure 67**), the Whybrow Seam (**Figure 68**), the Wambo Seam (**Figure 69**), the Woodlands Hill Seam (**Figure 70**) and the Arrowfield Seam (**Figure 71**). In all layers the regional pattern of flow is toward the local watercourses (alluvium) or to the north-east toward the Hunter River.

Figure 72 displays representative hydrographs for the recovery period for four bores located close to the South Bates Underground Mine workings, and **Figure 73** shows hydrographs ford four hypothetical bores located in the Joint Venture United/Wambo final voids:

a) Bore GW16 situated at South Bates Underground Longwall 24 in Layer 1 (alluvium).
b) Bore GW17 situated at South Bates Underground Longwall 23 in Layer 2 (Whybrow Seam Overburden).
c) Bore N5-3 situated at South Bates Underground Longwall 23 in Layer 3 (Whybrow Seam).
d) Bore N5-1 situated at South Bates Underground Longwall 23 in Layer 5 (Wambo Seam).
e) Hypothetical bore HYPO-W within Joint Venture Wambo Open Cut final void in Layer 7 (Whynot Seam).
f) Hypothetical bore HYPO_W4 within Joint Venture Wambo Open Cut spoil area.
g) Hypothetical bore HYPO_U within Joint Venture United Open Cut final void in Layer 17 (Vaux Seam).
h) Hypothetical bore HYPO_U4 within Joint Venture United Open Cut spoil area.

Bore locations are shown on **Figure 72** and **Figure 73.** Hydrographs also show pre-South Bates Underground mining and pre-Joint Venture United/Wambo Open Cut mining levels at 2015, which includes the influence of some historical mining.

Field measurements at GW16 show some degree of saturation in the alluvium despite drawdown caused by adjacent open cut mining. The alluvium in the model however is unsaturated prior to South Bates Underground mining and remains so during the prediction and recovery period of 200 years.

Groundwater levels at bore GW17 increase by about 10 m during the recovery period, but remain about 10 m below the pre-South Bates Underground mining groundwater level at the end of the recovery period.

Groundwater levels at bores N5-3 and N5-1 increase by about 25 m and 15 m respectively during the recovery period. Groundwater levels in both bores remain below the pre-South Bates Underground mining level at the end of the recovery period.

Recovery hydrographs for HYPO_W, HYPO_W4, HYPO_U and HYPO_U2, at the Joint Venture Wambo and United open cut final voids and spoil areas, show that groundwater levels have recovered by approximately 50 m by the end of the recovery period. Groundwater levels remain below pre-mining levels.

This proposed Modification could not be considered to have a significant effect on the quality of groundwater or surface water around Wambo. Previous modelling has shown no potential for increased flux of more saline water from the Permian strata to the alluvium for a period of at least 100 years.

5.8 CLIMATE CHANGE AND GROUNDWATER

The effects of climate change on groundwater are projected to be negative in some places on earth, but positive in other places. Overall predicted changes remain controversial with respect to magnitude and timing.

The NSW Climate Impact Profile – The Impacts of Climate Change on the Biophysical Environment of New South Wales (Department of Environment, Climate Change and Water, 2010) indicates changes to the climate of the Hunter Region may include:

- increase in maximum and minimum temperatures;
- increase in summer rainfall;
- increase in evaporation; and
- increase in the intensity of flood producing rainfall events.

Annual rainfall is expected to change by -10 to +5% by 2030 (Pittock, 2003) in parts of south-eastern Australia. In addition, annual average temperatures are projected to increase by 0.4 to 2.0 degrees Celsius (°C) (relative to 1990) at that time.

In consideration of the above, there are potential cumulative effects to the groundwater system associated with the Modification and climate change. However, as the Modification is not predicted to have significant effects beyond the effects of approved mining, no additional groundwater effects associated with the Modification would be expected when considered cumulatively with potential effects associated with climate change.

5.9 ASSESSMENT AGAINST THE MINIMAL IMPACT CONSIDERATIONS

The NSW *Aquifer Interference Policy* (NSW Government, 2012) establishes minimal impact considerations for highly productive and less productive groundwater. **Figure 2** shows the DPI Water mapping of highly productive groundwater in the vicinity of Wambo, which indicates that an area of highly productive alluvial aquifer exists along Wollombi Brook and a small portion on Wambo Creek (but not into the other tributary channels).

It follows that the remaining alluvial and porous rock groundwater system in the vicinity of the Wambo mine are less productive.

Table 18 to **Table 20** provide an assessment of the Modification against the minimal impact considerations in the *Aquifer Interference Policy* and include consideration of cumulative impacts where appropriate.

Table 18 Highly Productive Alluvial Aquifer – Minimal Impact Considerations

Aquifer	Unnamed Upriver Alluvium* in the Lower Wollombi Brook Water Source (part of the *Hunter Unregulated and Alluvial Water Sources 2009*)
Type	Alluvial Aquifer
Category	Highly Productive
Level 1 Minimal Impact Consideration	**Assessment**
Water Table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.	**Within Level 1** The only High Priority Groundwater Dependent Ecosystem near Wambo is Parnell Spring. Parnell Spring likely flows from the Triassic-age Narrabeen Formation and is located 9 km south-southwest of the Modification longwall panels (Section 2.2). Wambo mining would result in negligible drawdown at Parnell Spring. There are no High Priority Culturally Significant Sites listed in the Hunter Unregulated and Alluvial Water Sources Water Sharing Plan. Wambo mining would not result in cumulative drawdown of more than 2 m at any privately owned water supply work in a 'highly productive' alluvial aquifer over the duration of South Bates Underground mining.
Water pressure A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work.	**Within Level 1** Wambo mining would not result in cumulative drawdown of more than 40% of the pressure head at any privately owned water supply work in a 'highly productive' alluvial aquifer.
Water quality Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity. No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. No mining activity to be below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply". Not more than 10% cumulatively of the three dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200 m laterally from the top of high bank and 100 m vertically beneath a highly connected surface water source that is defined as a "reliable water supply".	**Within Level 1** There are no simulated risks of reduced beneficial uses of the highly productive alluvium as a result of the Modification (Section 5.7). The Modification would have no discernible effect on stream baseflow or natural river leakage for Wollombi Brook, beyond the effects of approved mining. Therefore the Modification would have negligible effect on the long-term salinity of Wollombi Brook. Wollombi Brook is a "reliable water supply" associated with Highly Productive groundwater. The Modification will not extract alluvial material associated with the Highly Productive alluvial groundwater system.

* Online shapefile name

Table 19 Less Productive Alluvial Aquifer – Minimal Impact Considerations

Aquifer	Alluvium outside the boundary of the 'Highly Productive' *Hunter Alluvial Water Source* (part of the *Hunter Unregulated and Alluvial Water Sources 2009*)
Type	Alluvium
Category	Less Productive

Level 1 Minimal Impact Consideration	Assessment
Water Table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.	**Within Level 1** The only high priority groundwater dependent ecosystem near Wambo is Parnell Spring. Parnell Spring likely flows from the Triassic-age Narrabeen Formation and is located 9 km south-southwest of the Modification longwall panels (Section 2.2). Wambo mining would result in negligible drawdown at Parnell Spring. There are no high priority culturally significant sites listed in the Hunter Unregulated and Alluvial Water Sources Water Sharing Plan. Wambo mining would not result in cumulative drawdown of more than 2 m at any privately owned water supply work in a 'less productive' alluvial aquifer over the duration of South Bates Underground mining.
Water pressure A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work.	**Within Level 1** Wambo mining would not result in cumulative drawdown of more than 40% of the pressure head at any privately owned water supply work in a 'less productive' alluvial aquifer.
Water quality Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity. No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. No mining activity to be below the natural ground surface within 200 m laterally from the top of high bank or 100 m vertically beneath (or the three dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply".	**Within Level 1** There are no simulated risks of reduced beneficial uses of the alluvium as a result of the Modification (Section 5.7). The Modification would have no discernible or negligible effect on stream baseflow or natural river leakage for Wambo Creek, North Wambo Creek, or Stony Creek stream systems, beyond the effects of approved mining. It is anticipated that the Modification would not increase the long-term salinity of North Wambo Creek, Stony Creek or Wambo Creek. Extraction would not occur within the three dimensional extent of the alluvial water source associated with North Wambo Creek. There are no bores along the North Wambo Creek alluvium for irrigation, domestic or stock use.

Table 20 Less Productive Porous Rock Aquifer – Minimal Impact Considerations

Aquifer	Sydney Sandstone Central Coast* (part of the *North Coast Fractured and Porous Rock Groundwater Sources* WSP)
Type	Porous Rock Aquifer
Category	Less Productive

Level 1 Minimal Impact Consideration	Assessment
<u>Water Table</u> Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.	**Level 2** A cumulative drawdown of more than 2 m is predicted at one privately owned water supply work in the porous rock water source. The Modification would result in additional drawdown at this bore of approximately 1.4 m. Limited information is available on three privately owned bores in the vicinity of Wambo. Depending on the depth from which these bores pump, these bores may experience more than 2 m cumulative drawdown (not attributable to the Modification). WCPL would continue to implement the Surface and Groundwater Response Plan (WCPL, 2015b) in the event a complaint is received in relation to loss of groundwater supply.
<u>Water pressure</u> A cumulative pressure head decline of not more than a 2 m decline, at any water supply work.	**Level 2** A cumulative drawdown of more than 2 m is predicted at one privately owned water supply work in the porous rock water source. The Modification would result in additional drawdown at this bore of approximately 1.4 m. Limited information is available on three privately owned bores in the vicinity of Wambo. Depending on the extraction depth, these bores may experience more than 2 m cumulative drawdown (not attributable to the Modification). WCPL would continue to implement the Surface and Groundwater Response Plan (WCPL, 2015b) in the event a complaint is received in relation to loss of groundwater supply.
<u>Water quality</u> Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.	**Within Level 1** There is not expected to be a migration of groundwater away from the Wambo areas in the Permian system either during mining or following completion of mining activities. On this basis, Wambo would not lower the beneficial use category of the groundwater within the Permian system.

* http://www.legislation.nsw.gov.au/#/view/regulation/2016/375

6 CONCLUSIONS

The assessment for this Modification (MOD17) considers the following changes to the South Bates Underground Mine:

- Development of nine additional longwall panels (Longwalls 17 to 25) in the Whybrow Seam to the north-west of the three approved Whybrow Seam longwalls at South Bates Underground.

- Change in timing of mining at South Wambo Underground in the Woodlands Hill and Arrowfield Seams. Mining in the Woodlands Hill Seam would occur from 2023 to 2032 (currently approved for 2019 to 2029). Mining in the Arrowfield Seam would occur from 2030 to 2039 (currently approved for 2023 to 2032).

This Groundwater Assessment for the Modification has been conducted with reference to the work done for four earlier modifications: Heritage Computing (2012) for North Wambo Underground Longwalls 9 and 10; HydroSimulations (2014) for North Wambo Underground Longwall 10A; HydroSimulations (2015) for South Bates (Wambo Seam) Underground Mine and HydroSimulations (2016) for South Wambo Underground Mine. Data gathered since that time has been analysed (Section 2), most notably groundwater levels (Section 2.6) and groundwater salinities (Section 2.7).

The groundwater modelling carried out for this Modification was based on that used for South Wambo Underground Mine reporting (HydroSimulations, 2016), using MODFLOW-USG Beta.

The incremental effects of the Modification have been considered as changes between the Approved Scenario and the Modification Scenario. Cumulative effects of neighbouring mines have also been considered.

The key findings of this assessment are:

- For the Modification, inflows to South Bates Underground are predicted to peak at a maximum of about 1.0 ML/d at the end of 2018.
- The alluvium adjacent to the South Bates Extension footprint has been disconnected from the regional alluvial system due to the removal of alluvium downstream of the longwalls by the approved open cut mining operations (and associated construction of the North Wambo Creek Diversion).
- The alluvium adjacent to the South Bates Extension footprint has been affected by open cut mining activities, with several metres of drawdown in the alluvium observed to date.
- There are no bores above the South Bates Extension footprint that are used for irrigation, domestic or stock use.
- The Modification would not have a significant impact on water levels in the Permian coal measures from a regional perspective due to the regional zone of depressurisation within the Permian coal measures created by historical and ongoing open cut and underground mining.
- There is expected to be negligible impact on the highly productive alluvium associated with the Wollombi Brook and Hunter River as a result of the Modification.

- The Wambo Coal Mine would not lower the beneficial use category of the groundwater within the Permian aquifers, as there would be no migration of groundwater away from the underground mining areas in the Permian aquifers either during mining or following completion of mining activities.
- The Modification would not result in reduced beneficial uses of the alluvium (from a water quality perspective).
- The change in timing in mining at South Wambo Underground Mine is predicted to slightly decrease the maximum inflows to the South Wambo Mine from the Approved to the Modification Scenario.
- The change in timing in mining at South Wambo Underground Mine is predicted to result in a slight increase in groundwater levels in the Whybrow, Wambo, Woodlands Hill and Arrowfield Seams from the Approved to the Modification Scenario.

No additional groundwater monitoring or impact mitigation measures are proposed for the Modification. Groundwater levels and quality should continue to be monitored at Wambo in accordance with a GWMP approved under the Development Consent.

Consistent with the currently approved *Surface and Groundwater Response Plan* (WCPL, 2015b), in the event that a groundwater quality or level trigger level specified in the GWMP is exceeded, an investigation should be conducted in accordance with the *Surface and Groundwater Response Plan*. Consistent with the *Aquifer Interference Policy* (NSW Government, 2012), management measures that may be implemented as a result of the investigation described above could include a “make good” commitment or relinquishment of an equivalent portion of water access licences as a direct offset for potential groundwater inflows into the underground.

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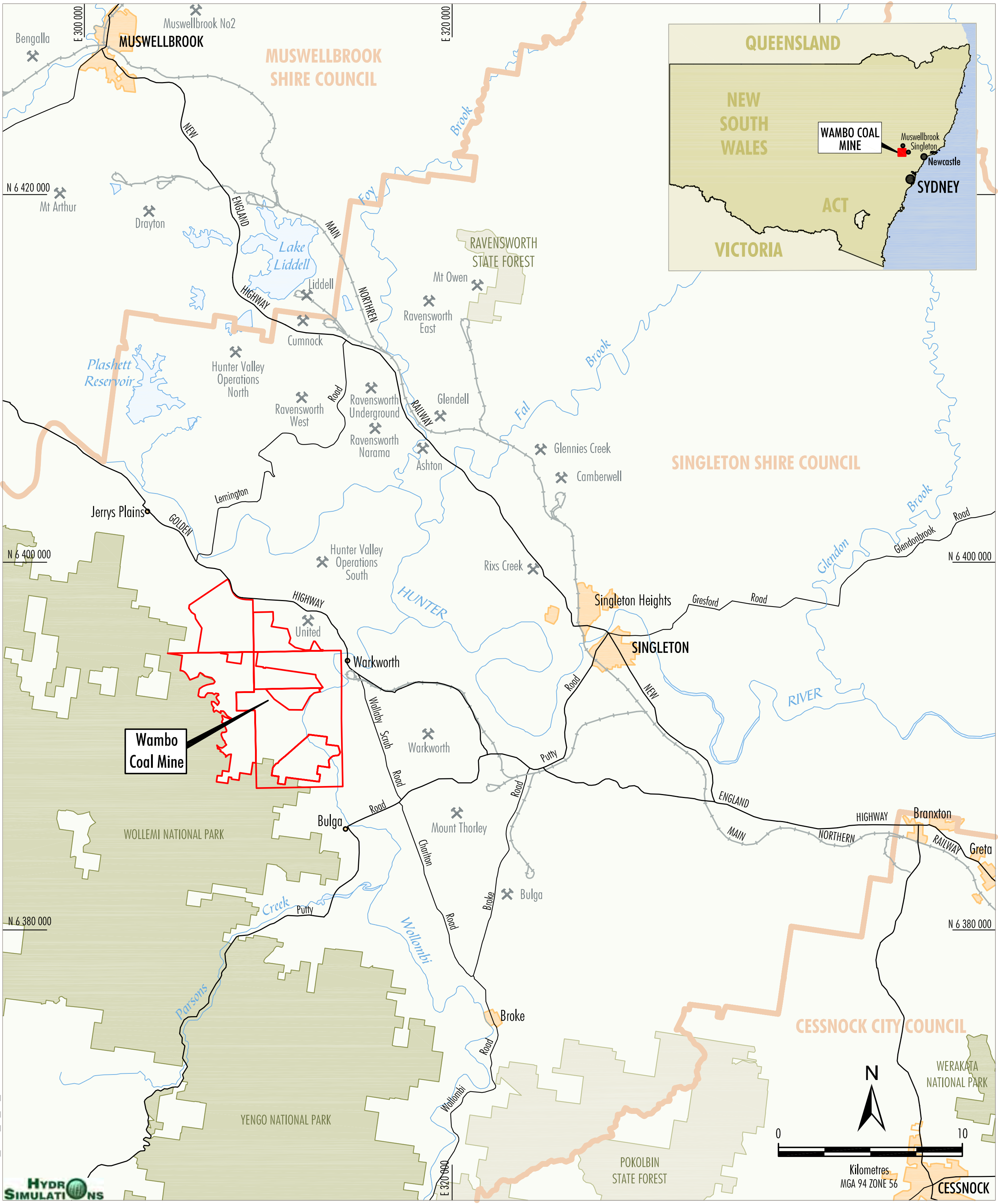
FIGURES



LEGEND

Mining and Coal Lease Boundary

Local Government Boundary

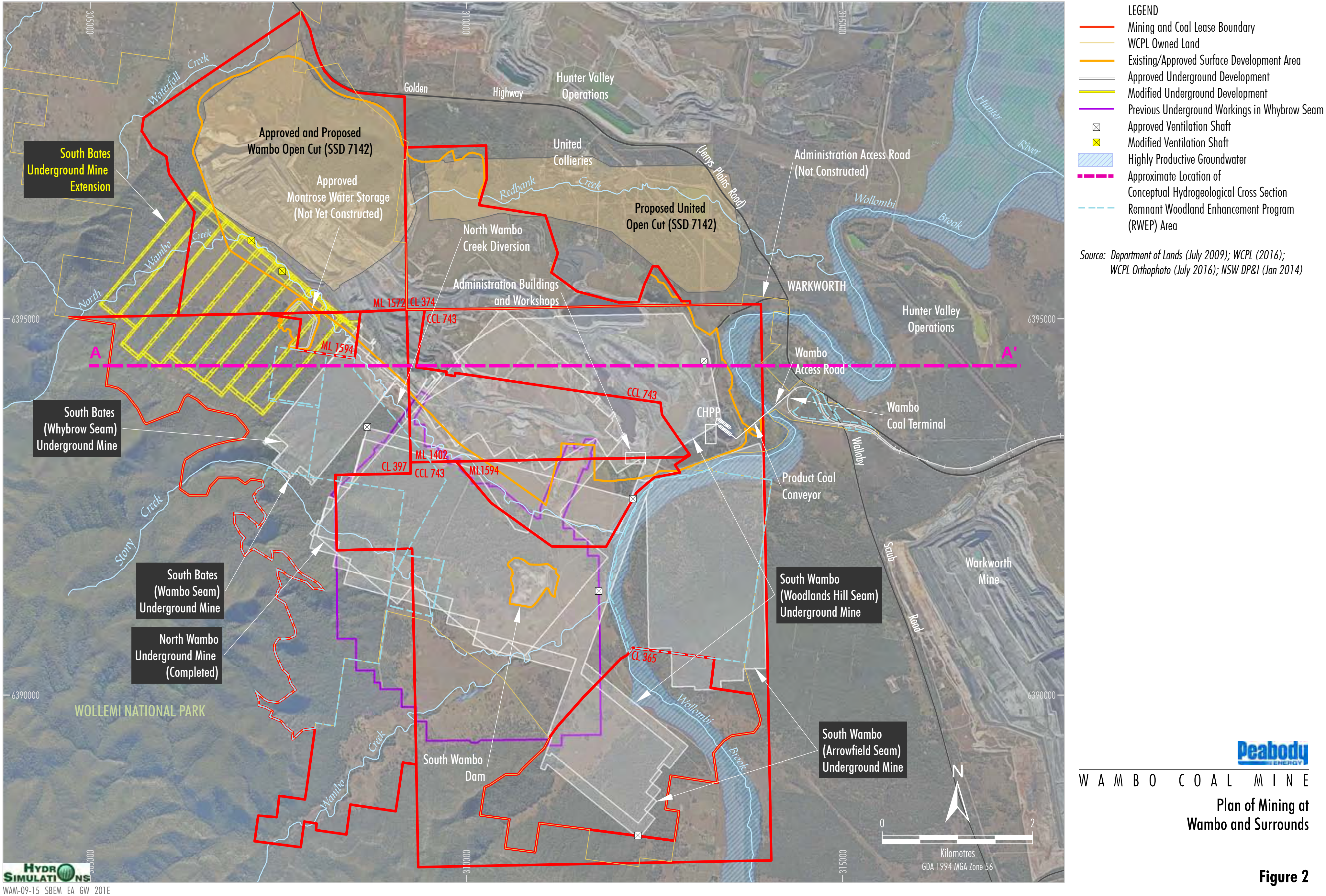
Mining Operation

Source: Geoscience Australia (2009)

WAMBO COAL MINE

Regional Location

Figure 1

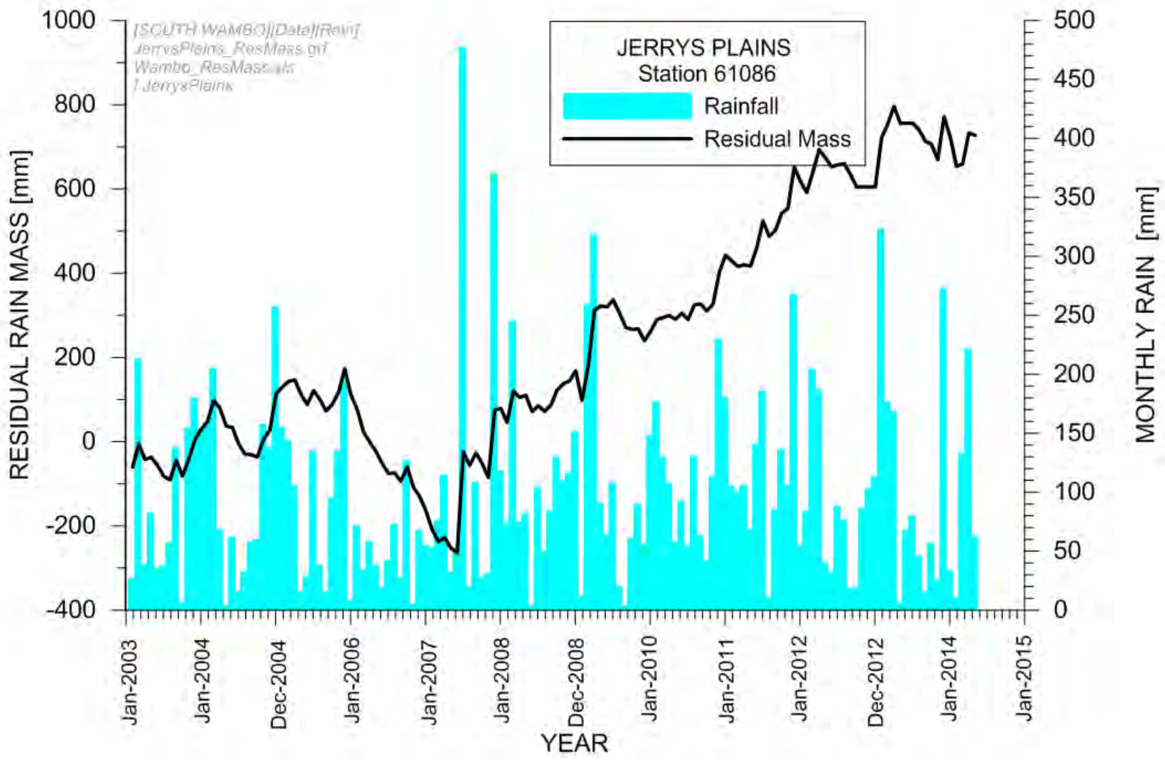


WAMBO COAL MINE

Plan of Mining at Wambo and Surrounds

Figure 2

[a]



[b]

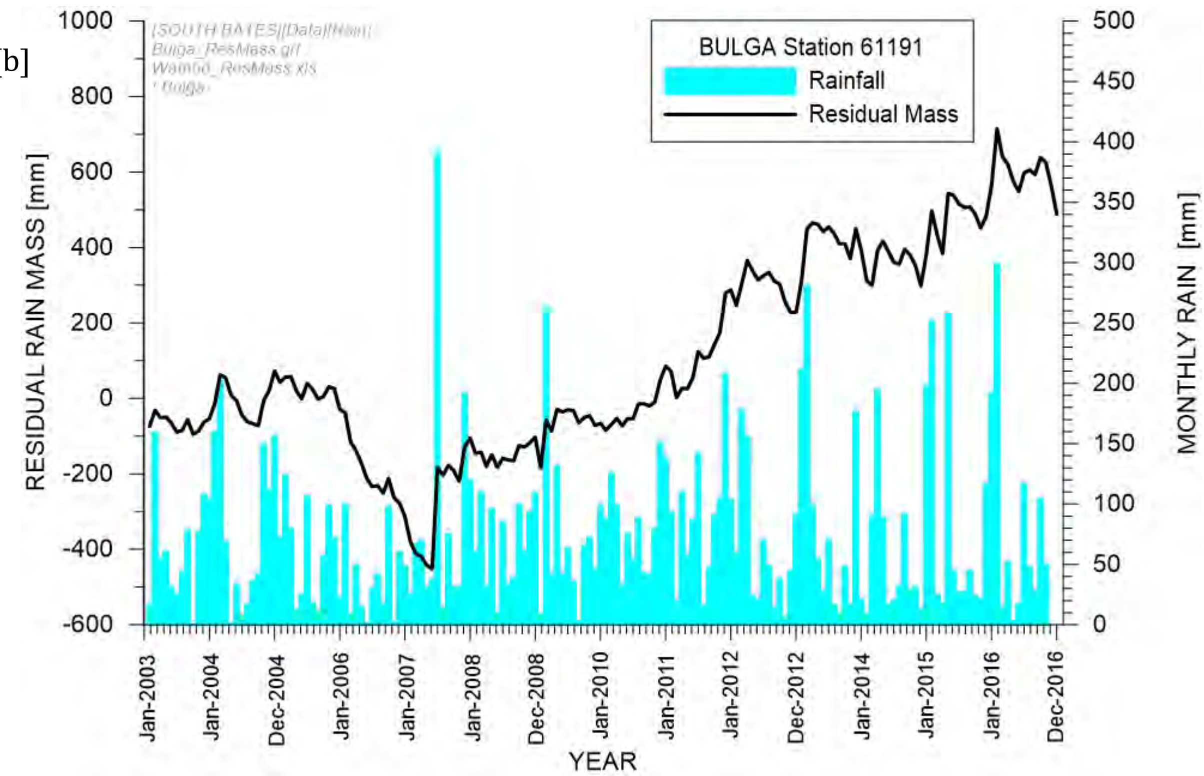


Figure 3 Rainfall Residual Mass Curves for [a] Jerrys Plains Post Office and [b] Bulga (South Wambo)

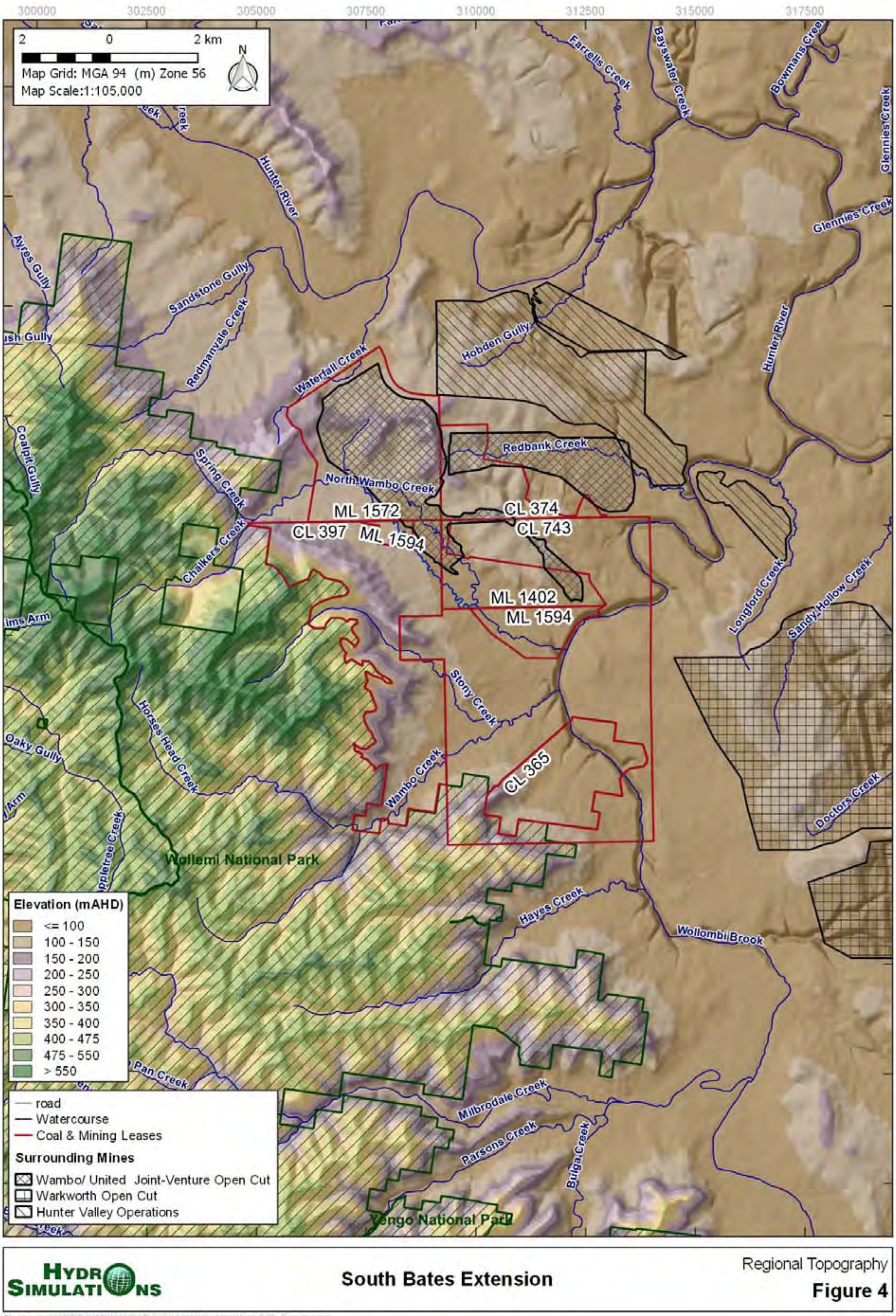


Figure 4 Regional Topography

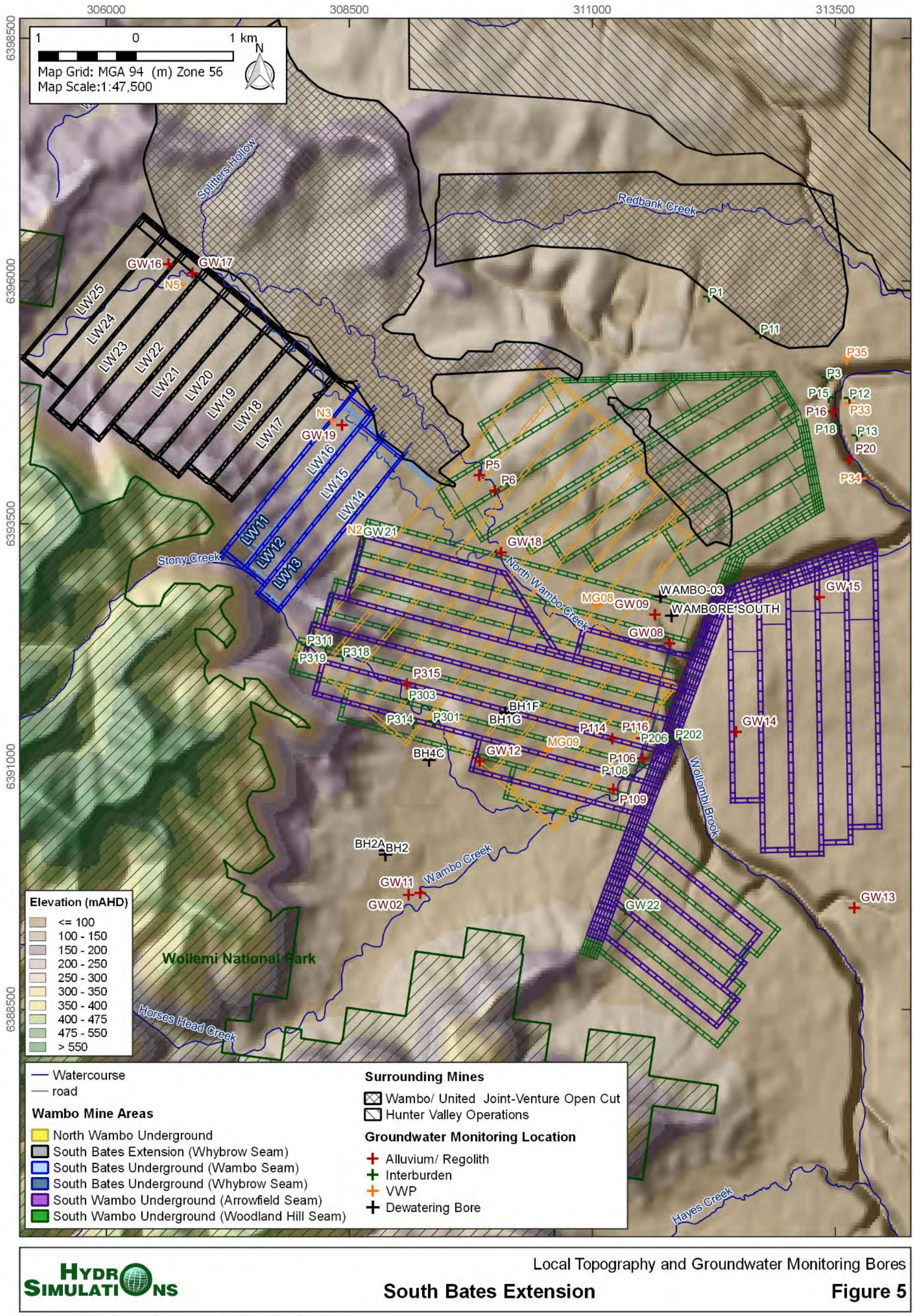


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Figure 5 Local Topography and Groundwater Monitoring Bores

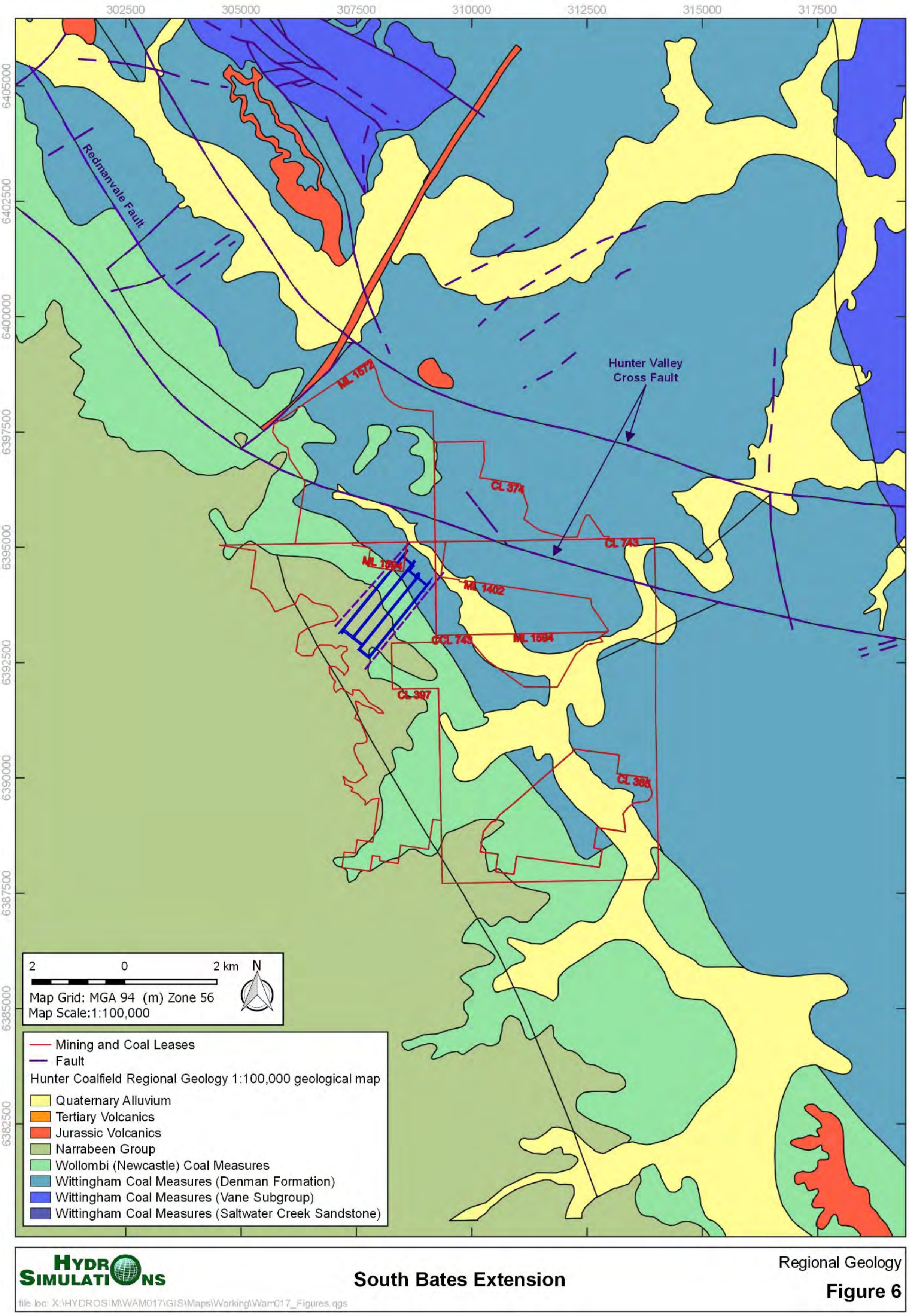


Figure 6 **Regional Geology**

SUPERGROUP	GROUP	SUBGROUP	FORMATION	SEAM
SINGLETON SUPERGROUP	NARRABEEN GROUP	WIDDEN BROOK CONGLOMERATE		
	NEWCASTLE COAL MEASURES [1]	GLEN GALLIC SUBGROUP	Greigs Creek Coal	
			Redmanvale Creek Formation	
			Dights Creek Coal	
		DOYLES CREEK SUBGROUP	Waterfall Gully Formation	
			Pinegrove Formation	
		HORSESHOE CREEK SUBGROUP	Lucernia Coal	
			Strathmore Formation	
			Alcheringa Coal	
			Clifford Formation	
		APPLETREE FLAT SUBGROUP	Charlton Formation	
			Abbey Green Coal	
		WATTS SANDSTONE		
	WITTINGHAM COAL MEASURES	DENMAN FORMATION		
		JERRYS PLAINS SUBGROUP	Mount Leonard Formation	***Whybrow Seam*** [2]
			Althorpe Formation	
			Malabar Formation	***Redbank Creek Seam*** [2]
				Wambo Seam [2]
				Whynot Seam [2]
				Blakefield Seam
			Mount Ogilvie Formation	*Glen Munro Seam*
				Woodlands Hill Seam [2]
			Milbrodale Formation	
			Mount Thorley Formation	***Arrowfield Seam*** [2]
				Bowfield Seam [3]
				Warkworth Seam [3]
			Fairford Formation	
			Burnamwood Formation	*Mount Arthur Seam* [3]
				Piercefield Seam [3]
				Vaux Seam [3]
				Broonie Seam
				Bayswater Seam
		ARCHERFIELD SANDSTONE		
		VANE SUBGROUP	Bulga Formation	
			Foybrook Formation	
			Saltwater Creek Formation	

[1] Previously known as the Wollombi Coal Measures.
[2] Coal reserves currently approved to be mined at the Wambo Coal Mine.
[3] Coal reserves proposed to be mined by the United Wambo Open Cut Coal Mine Project (SSD 7142).

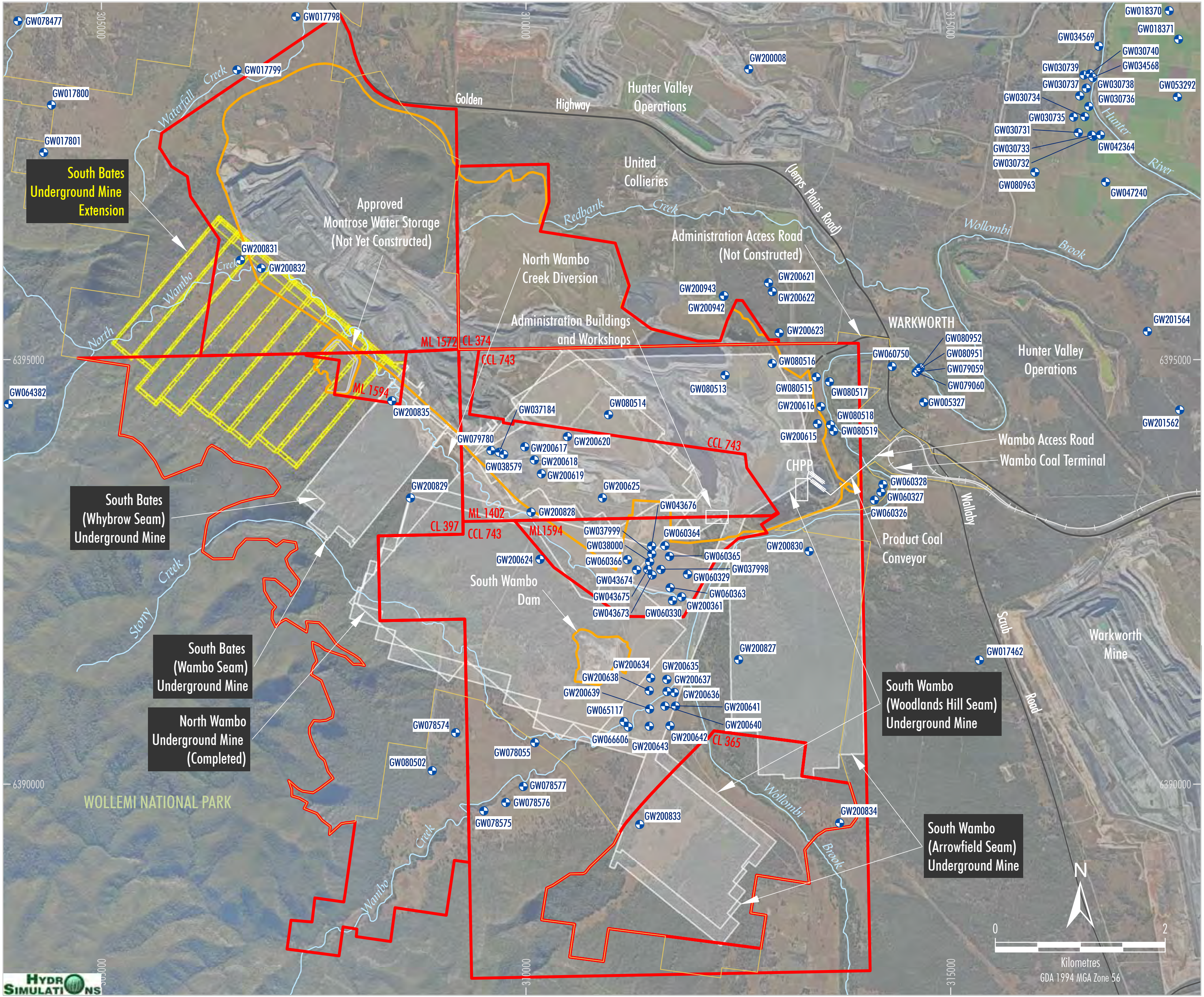
WAM-09-15_SBEM_EA_GW_001A

After: DMR (1993)

WAMBO COAL MINE

Stratigraphy of the Wambo Area

Figure 7



LEGEND

- Mining and Coal Lease Boundary
- WCPL Owned Land
- Existing/Approved Surface Development Area
- Approved Underground Development
- Modified Underground Development
- Registered Bore

Source: Department of Lands (July 2009); WCPL (2016); WCPL Orthophoto (July 2016); DPI Water (2015)

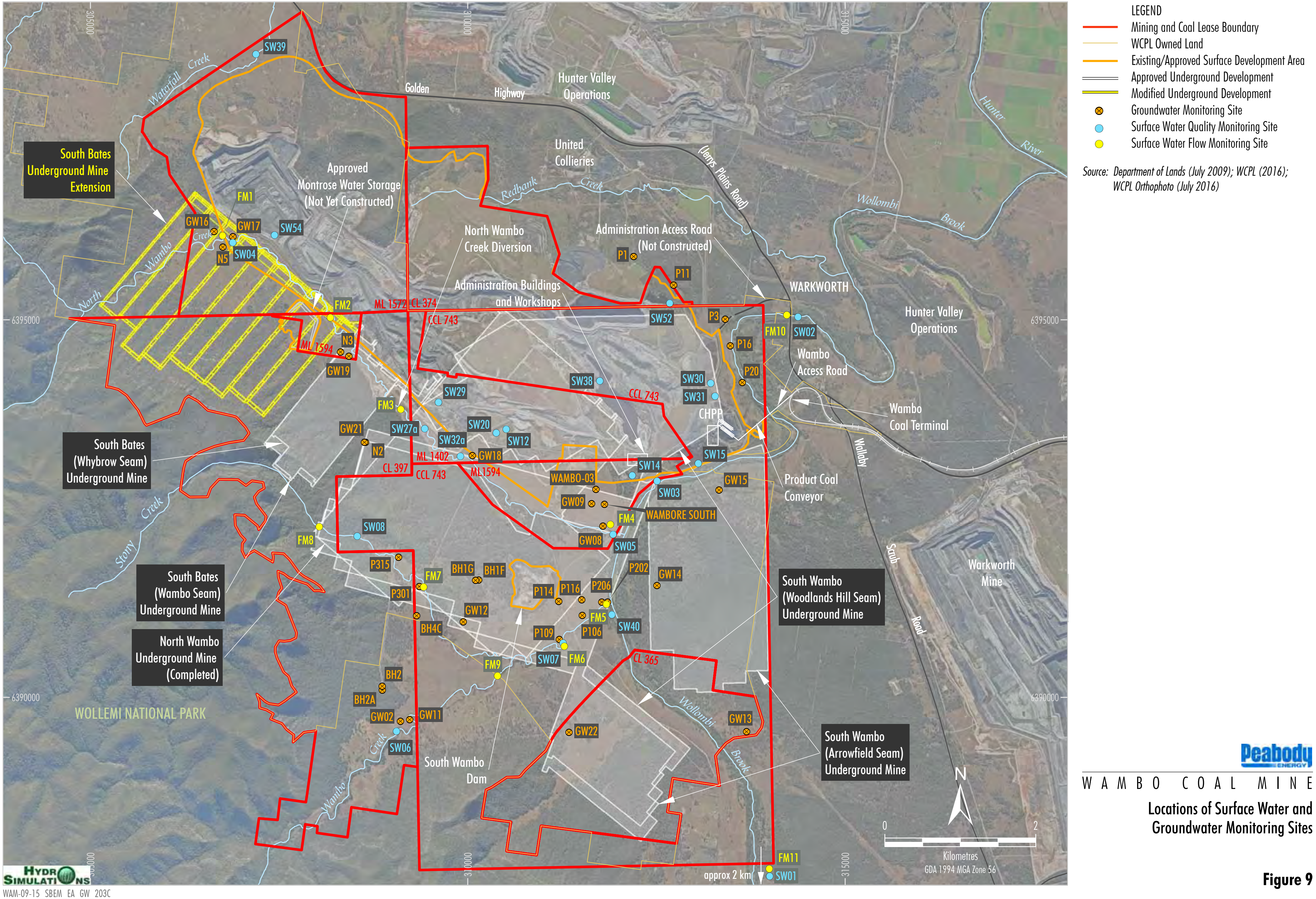
Peabody ENERGY

W A M B O C O A L M I N E

Location of Registered Bores

Figure 8

WAM-09-15_SBEM_EA_GW_202B



WAMBO COAL MINE

Locations of Surface Water and Groundwater Monitoring Sites

Figure 9

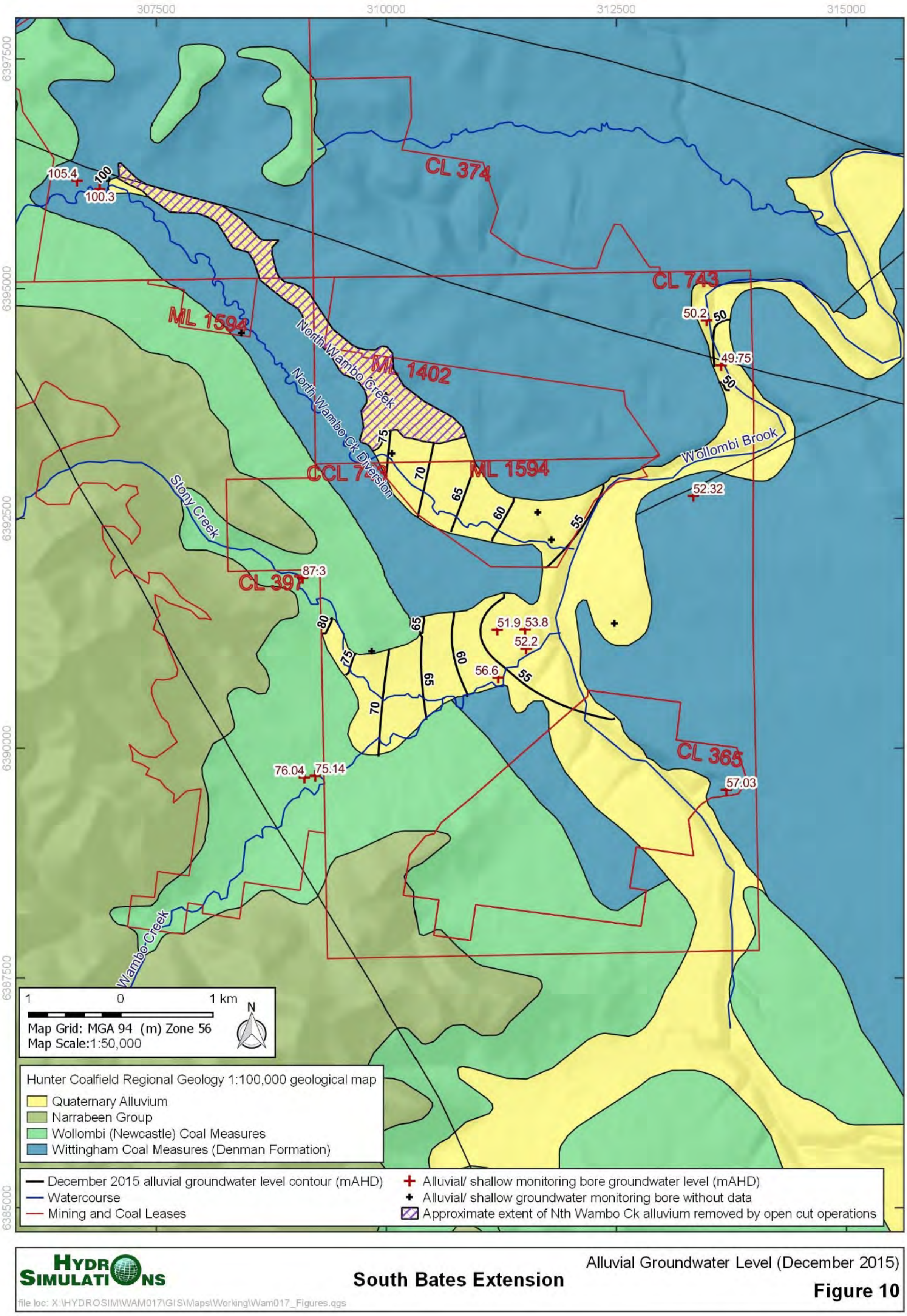


Figure 10 Alluvium Groundwater Levels (December 2015)

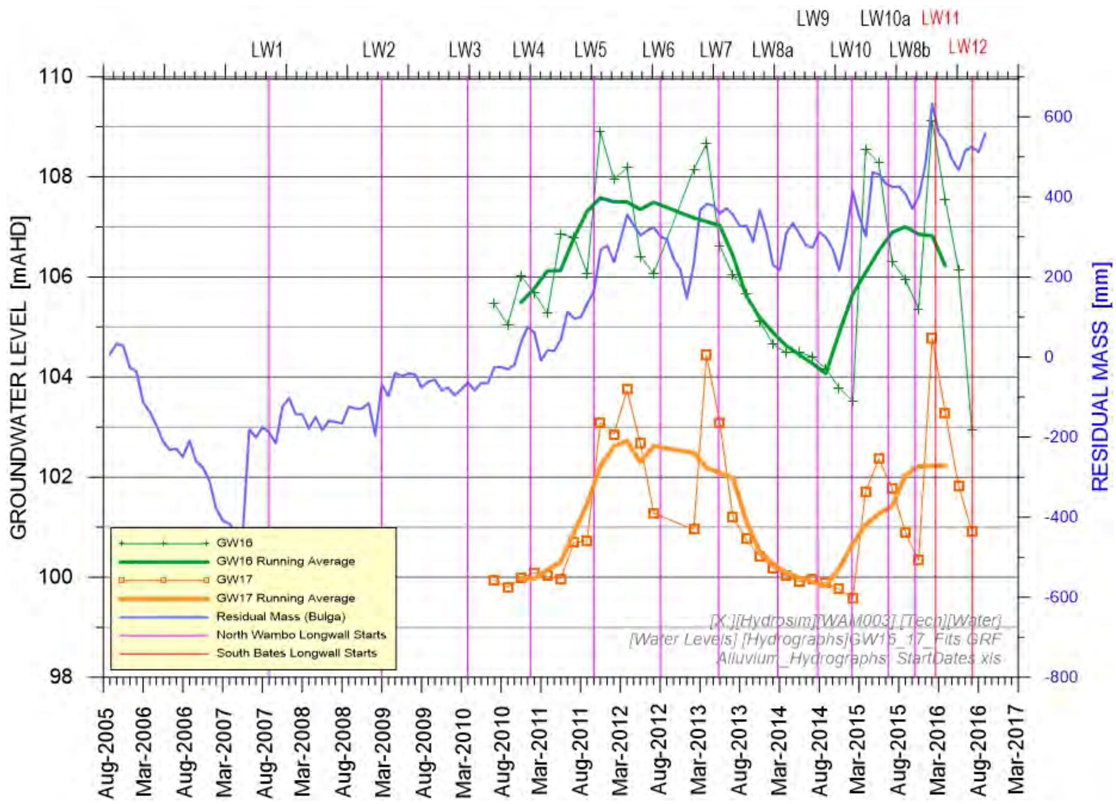


Figure 11 North Wambo Creek Observed and Smoothed Hydrographs at Monitoring Bores GW16 and 17

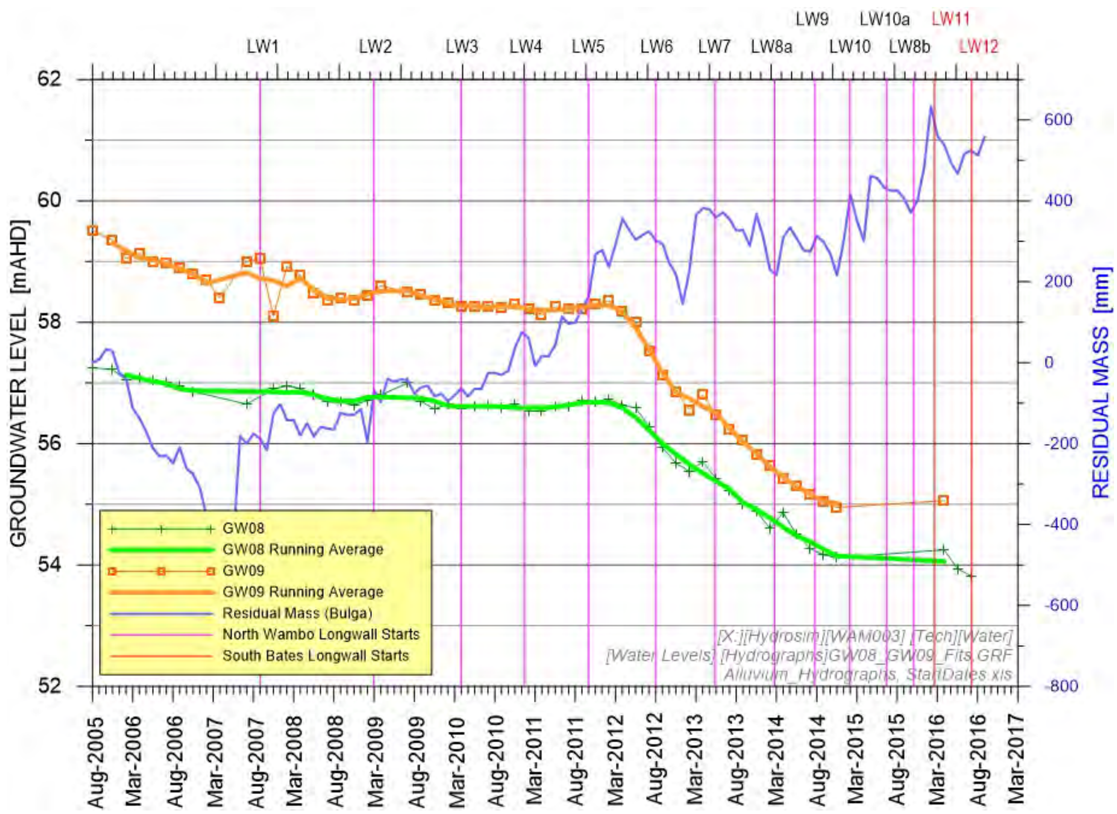


Figure 12 North Wambo Creek Observed and Smoothed Hydrographs at Monitoring Bores GW08 and GW09

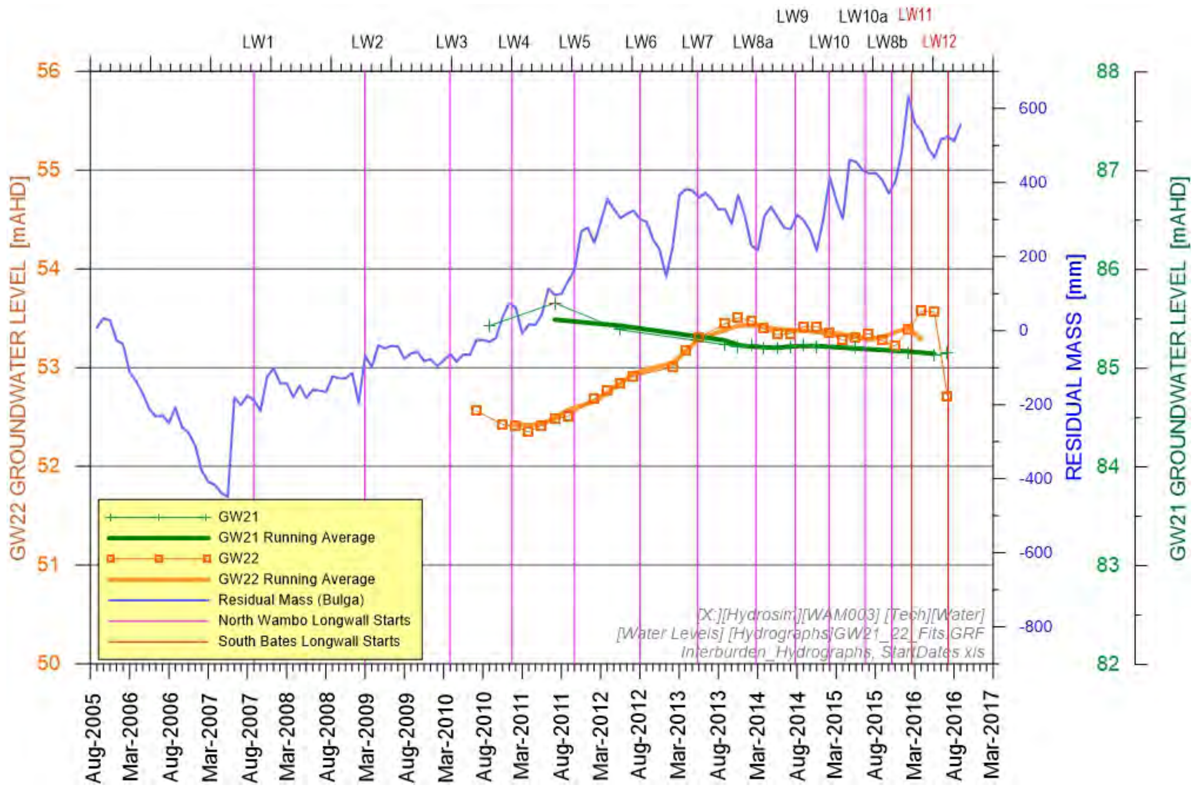


Figure 13 Interburden Observed Hydrograph at Monitoring Bore GW21 and GW22

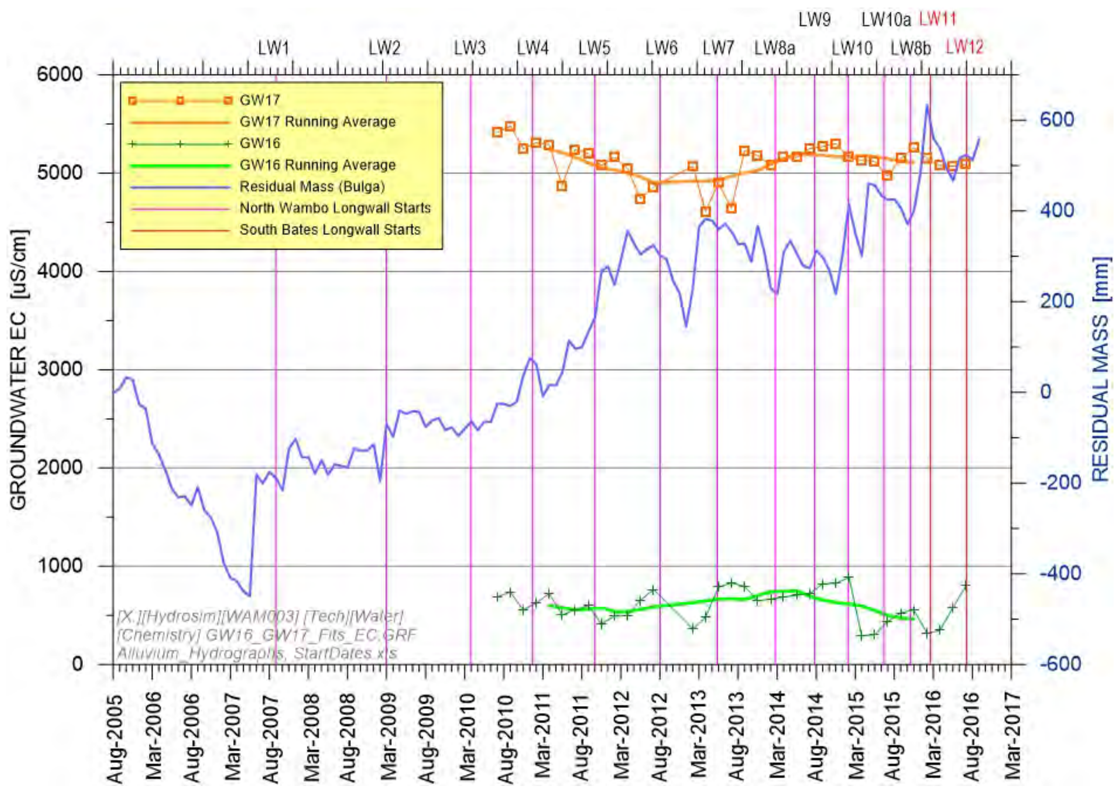


Figure 14 North Wambo Creek Smoothed EC Time-Series at Monitoring Bores GW16 and GW17

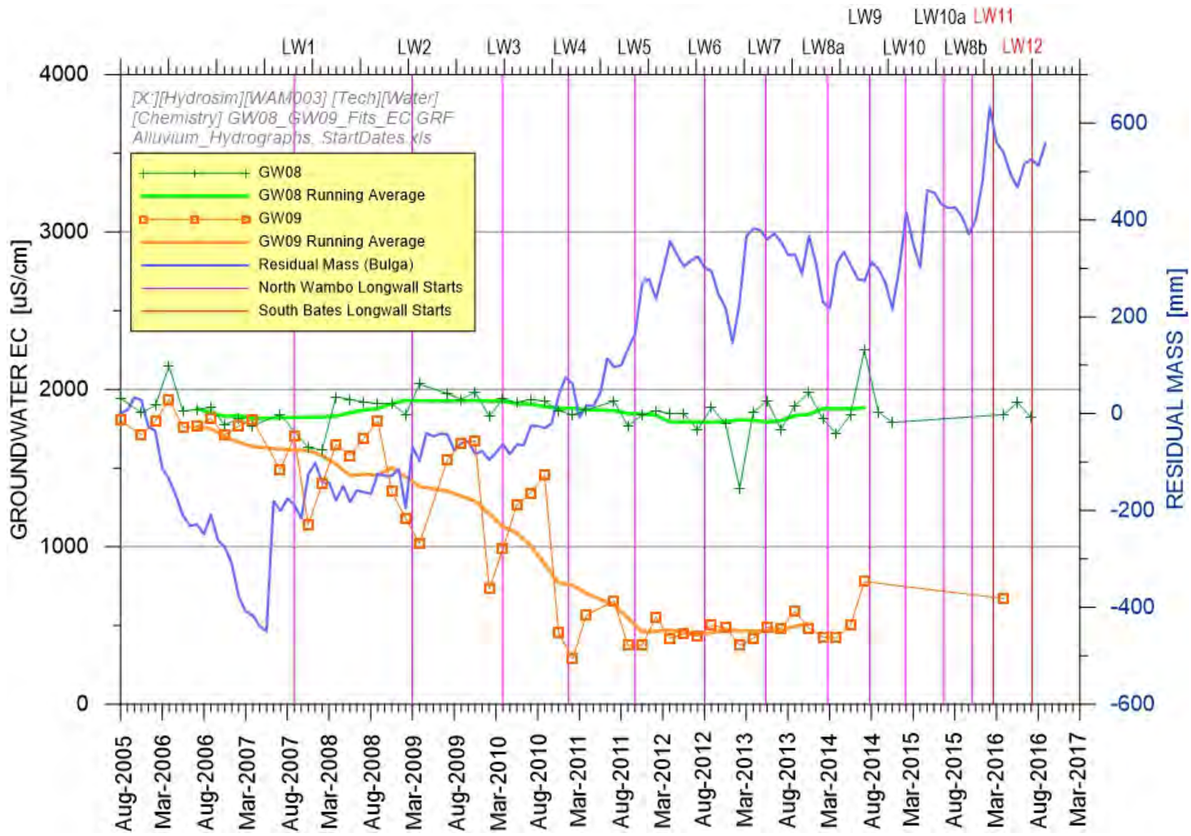


Figure 15 North Wambo Creek Smoothed EC Time-Series at Monitoring Bores GW08 and GW09

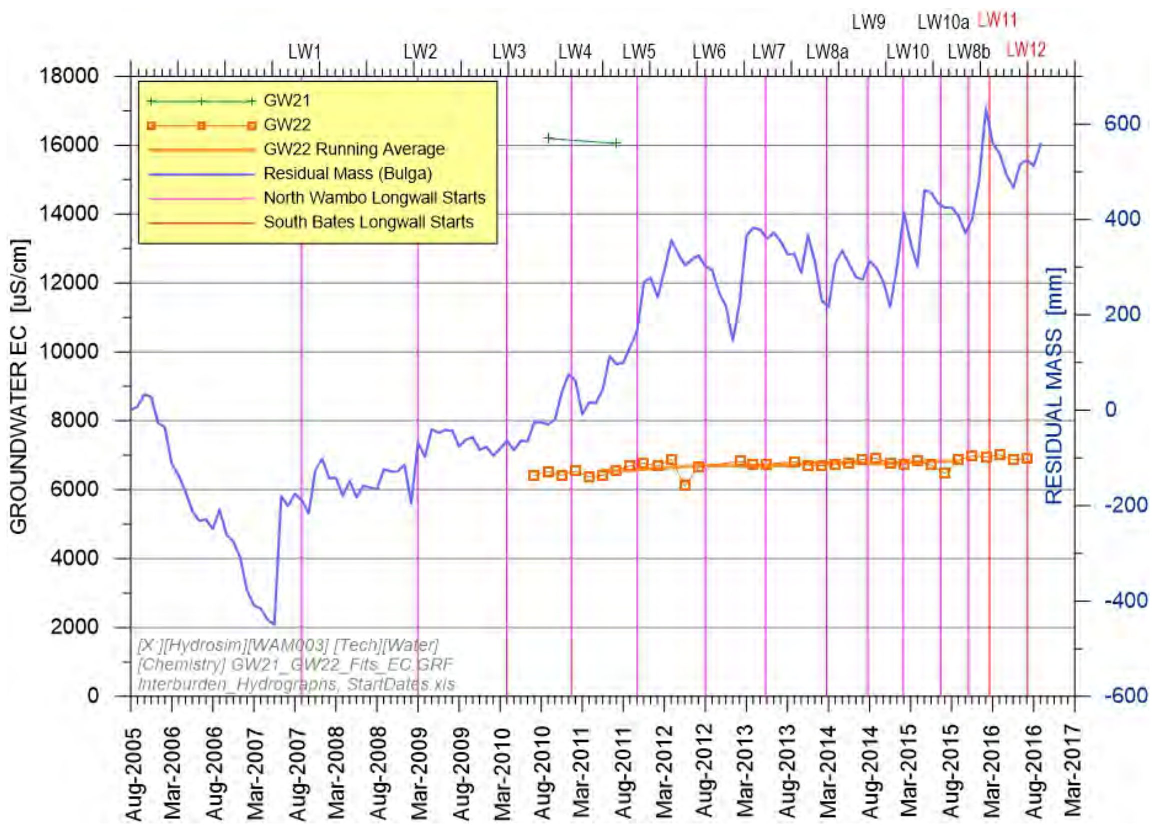


Figure 16 Interburden EC Time-Series at Monitoring Bores GW21 and GW22

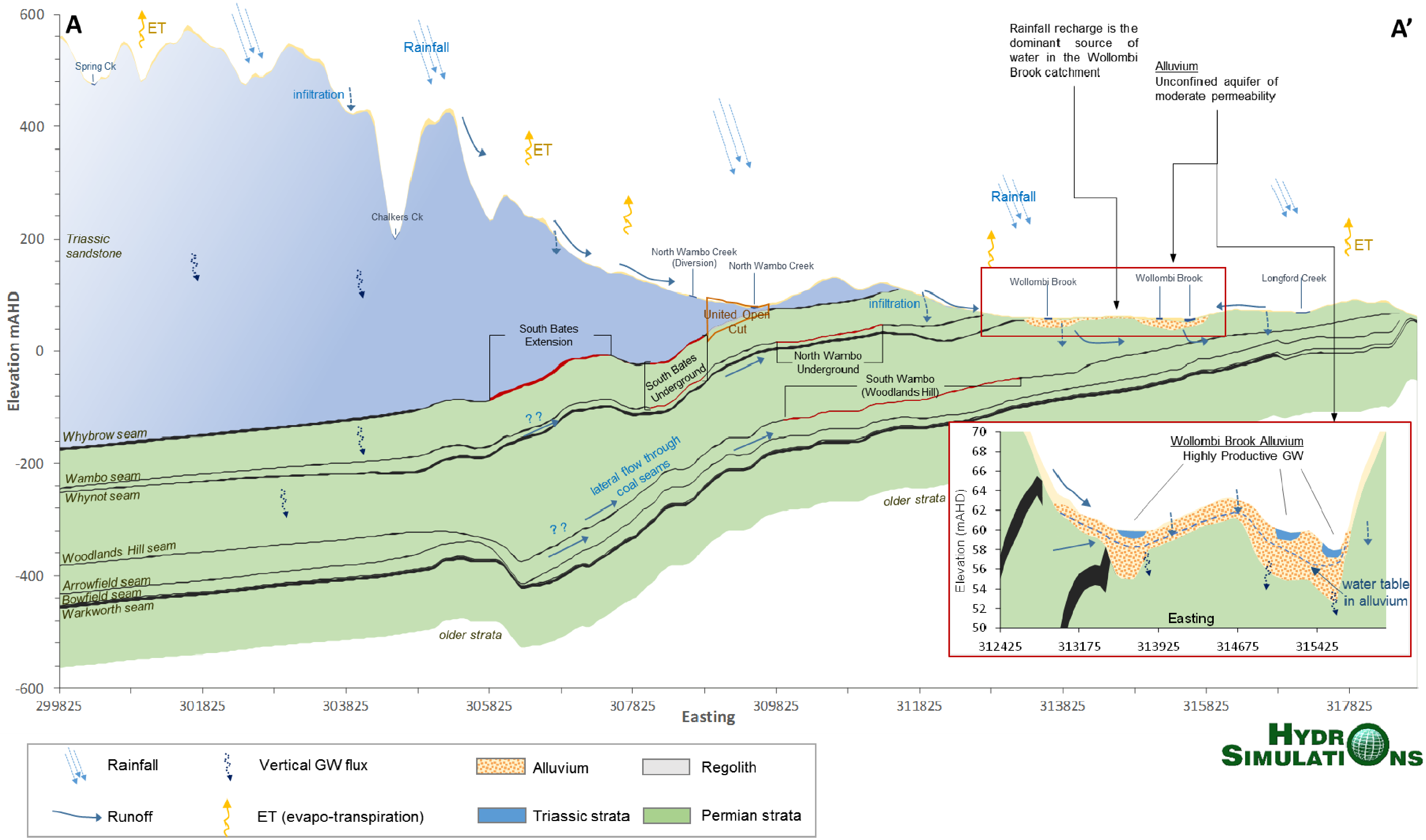


Figure 17 Conceptual Hydrogeological Cross-Section (During and Post Mining)

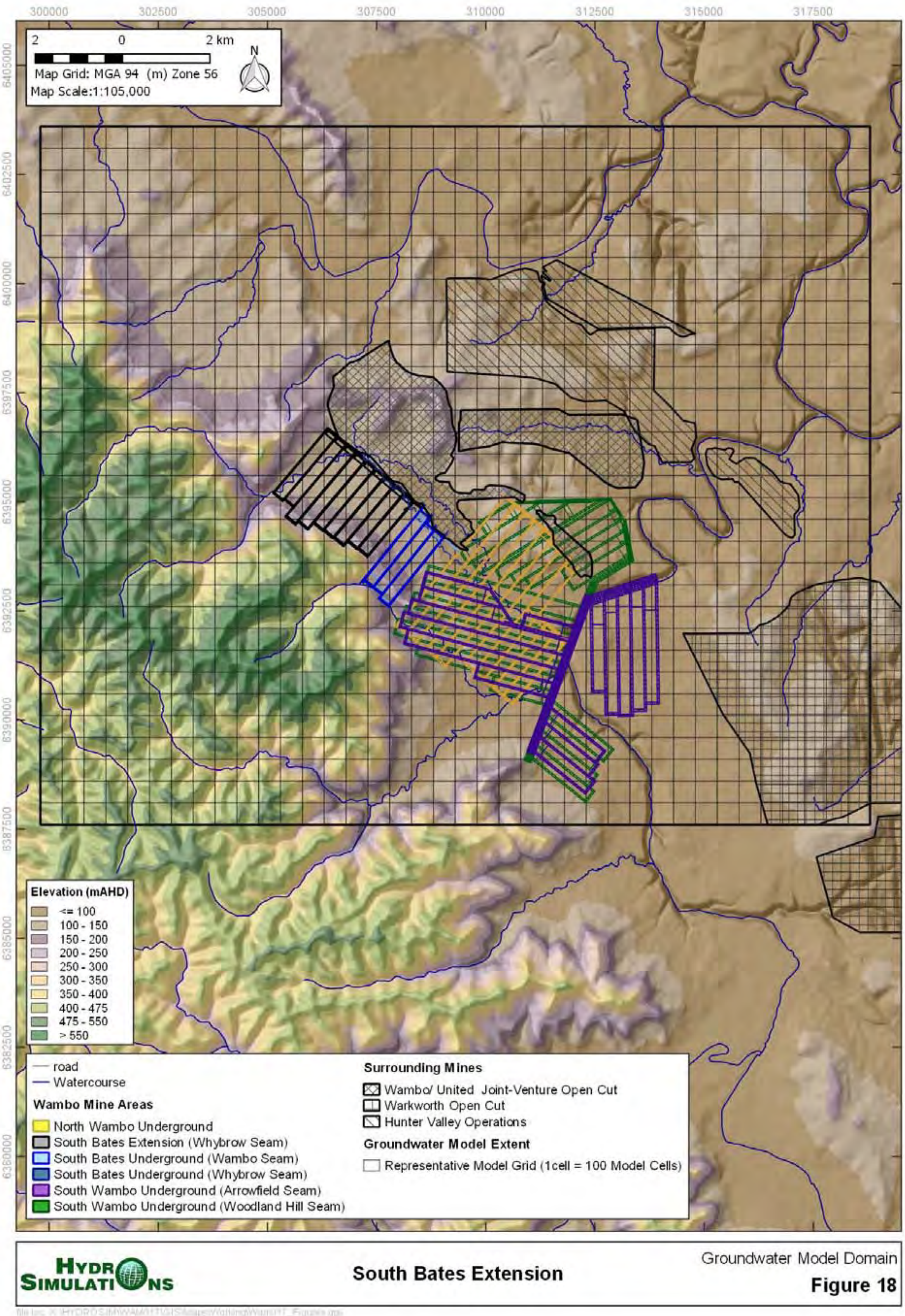


Figure 18 Groundwater Model Domain

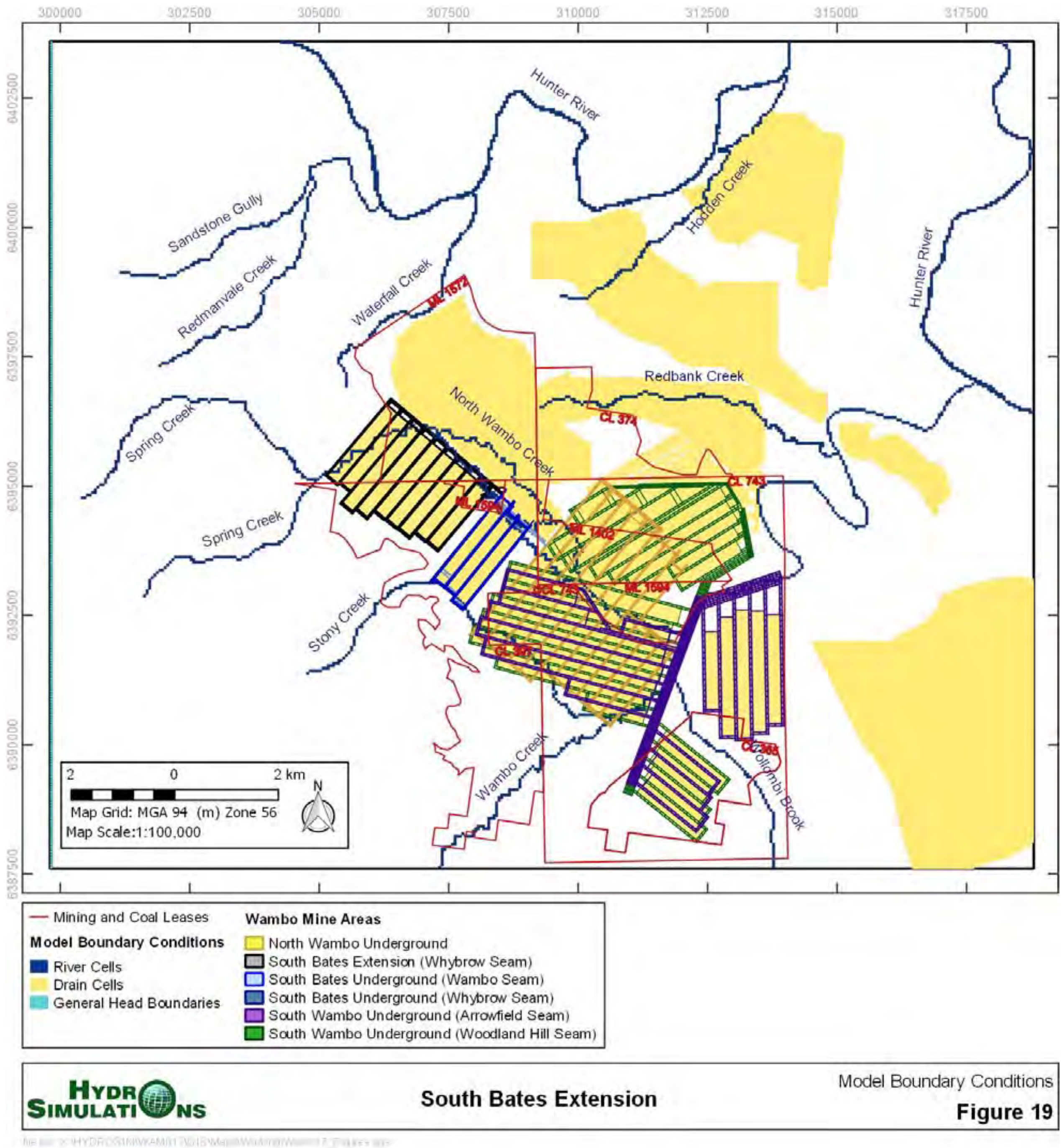


Figure 19 Groundwater Model Boundary Conditions

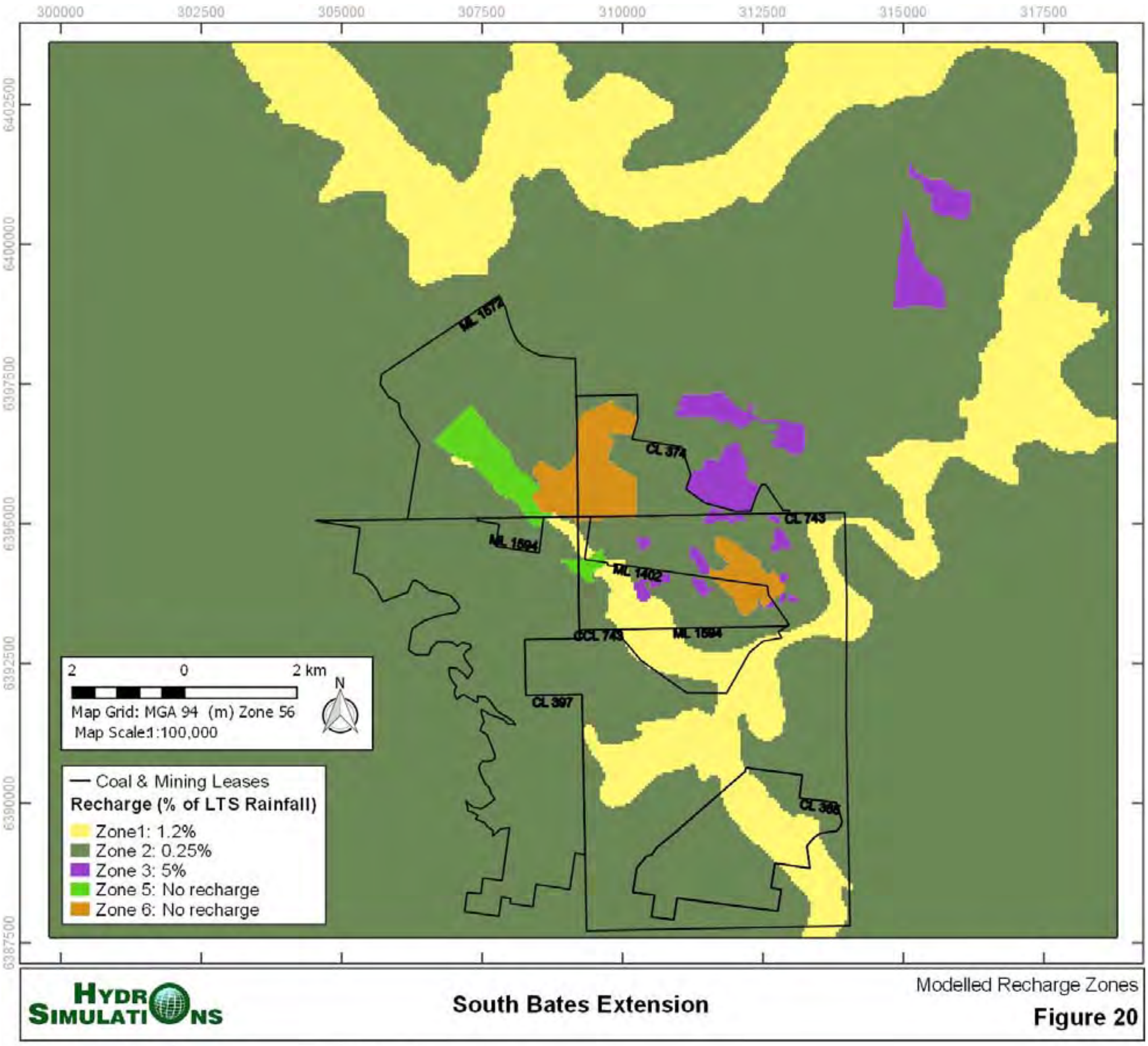


Figure 20 **Modelled Recharge Zones**

Note: At commencement of prediction period.

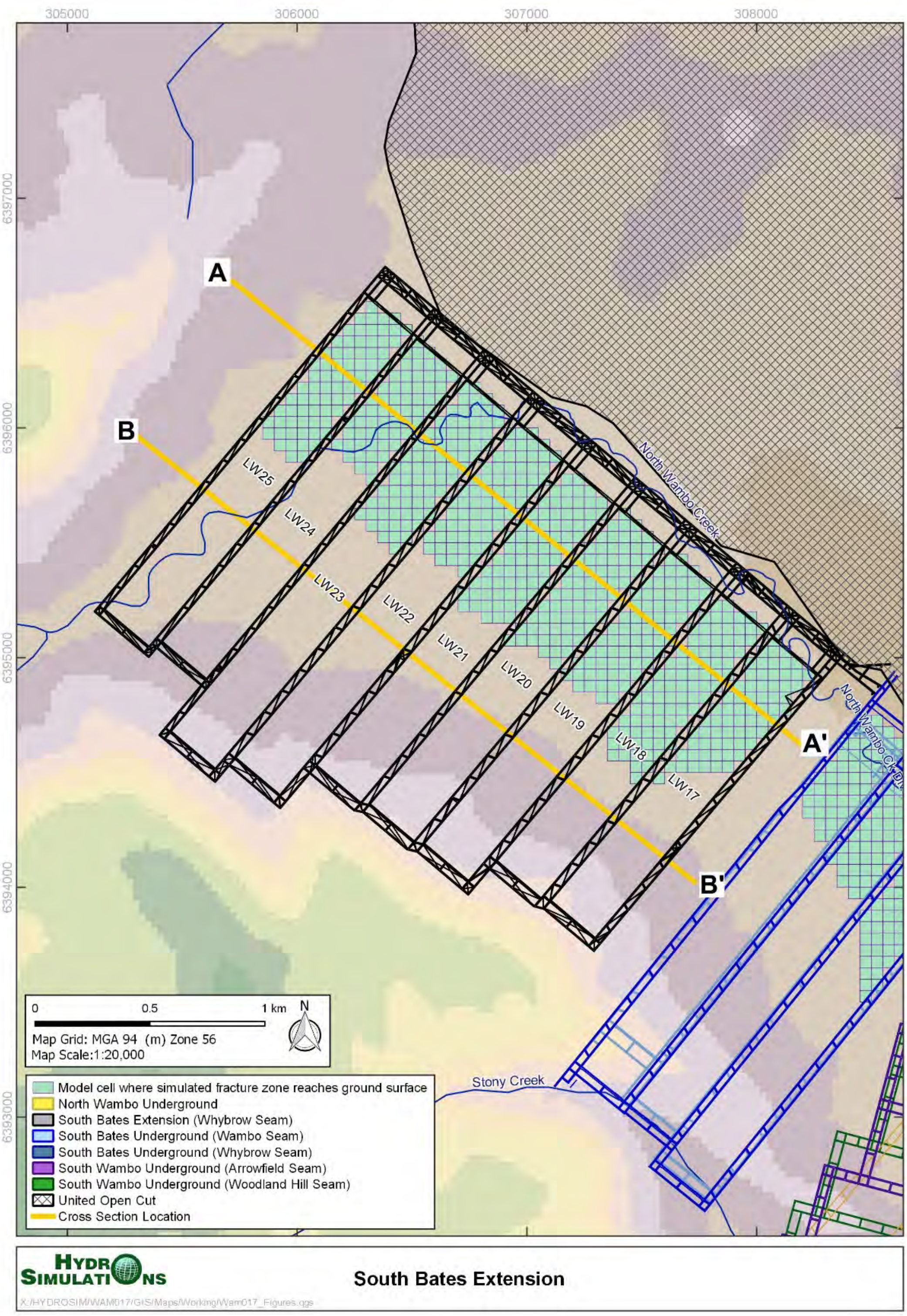


Figure 21 Location of Local Fracture Extent Cross-Sections

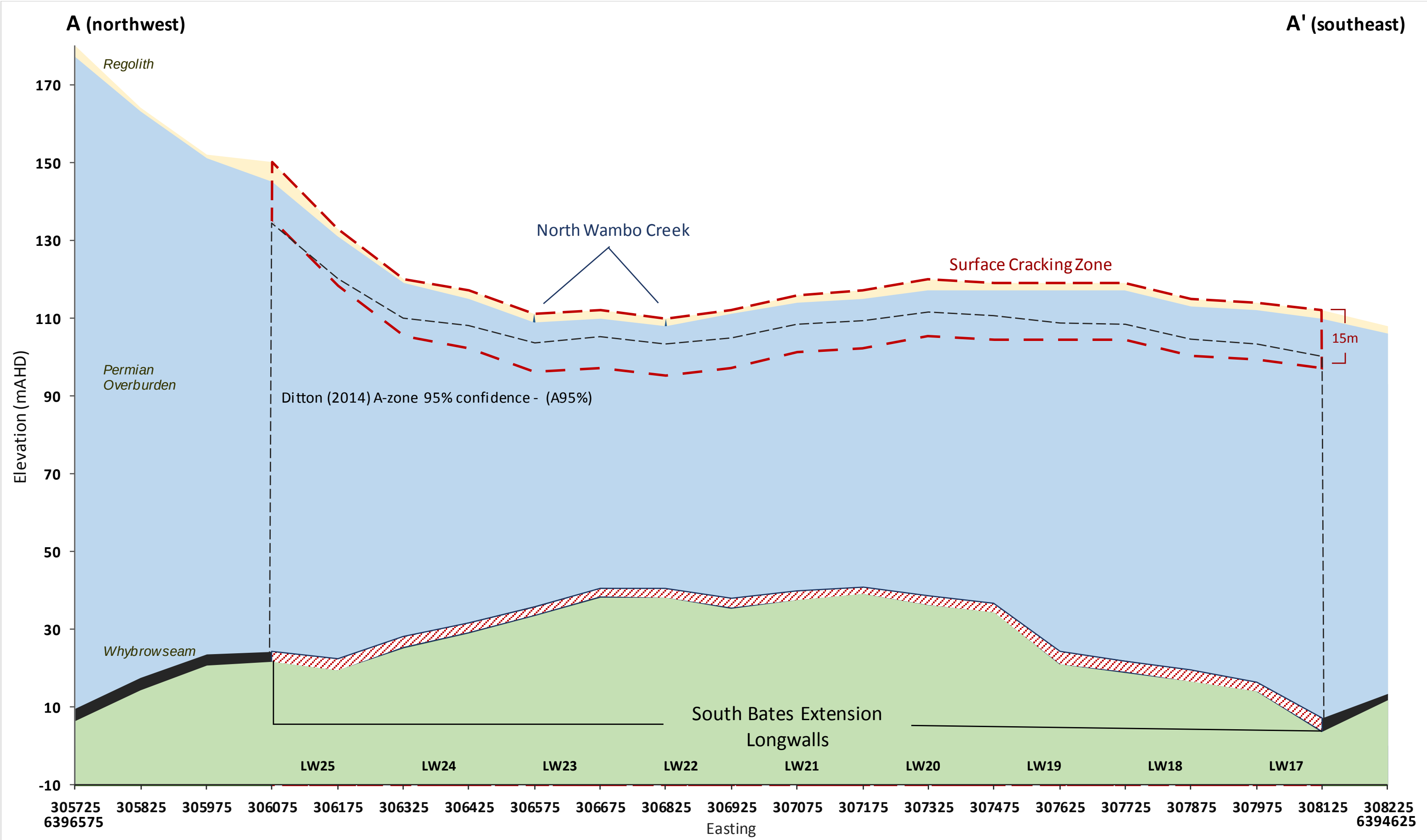


Figure 22 South Bates Extension Fracture Extent Local Cross-Section A-A' (Location Shown on Figure 21)

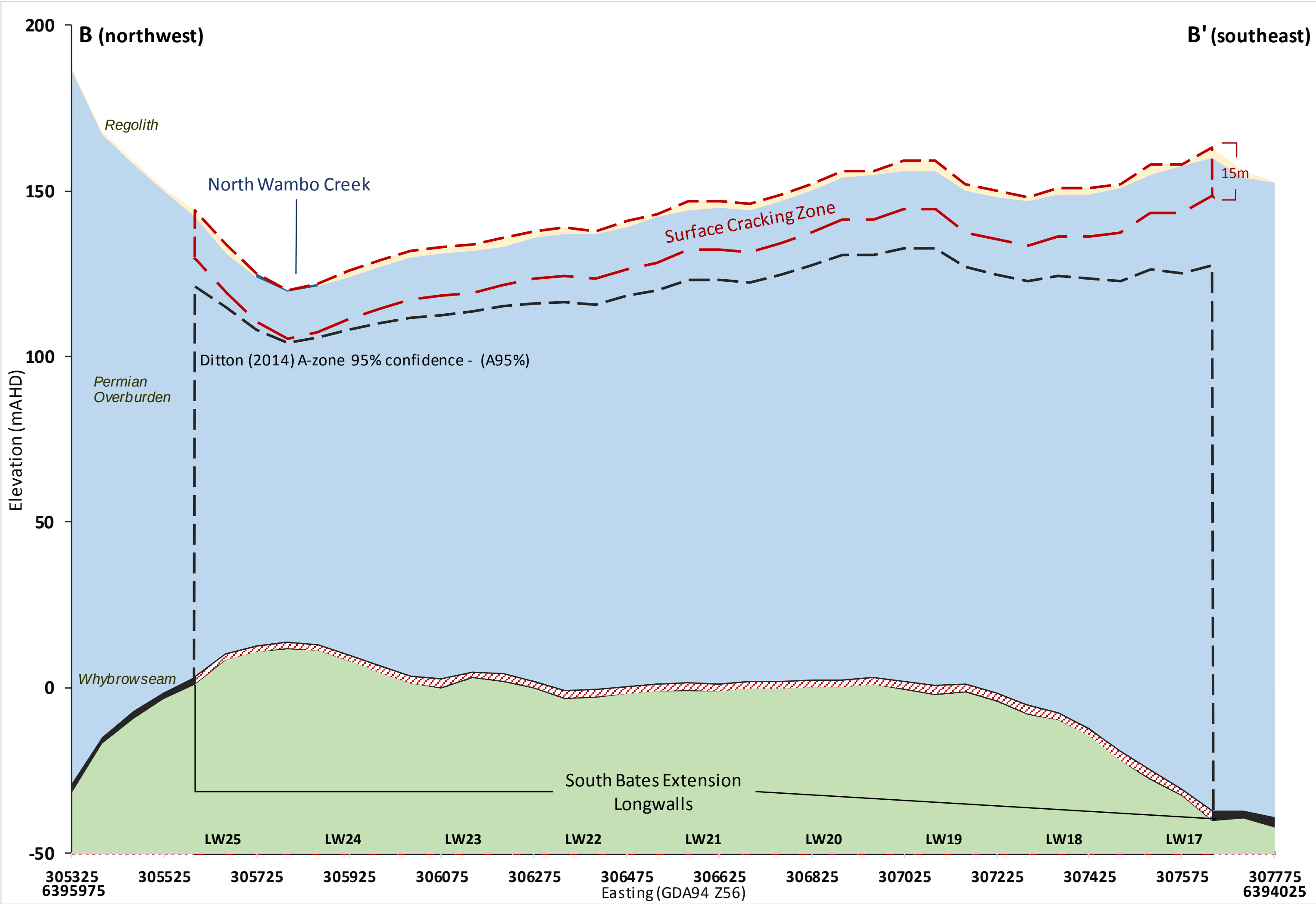


Figure 23 South Bates Extension Fracture Extent Local Cross-Section B-B' (Location Shown on Figure 22)

Figure 24 P114 Calibration Hydrograph

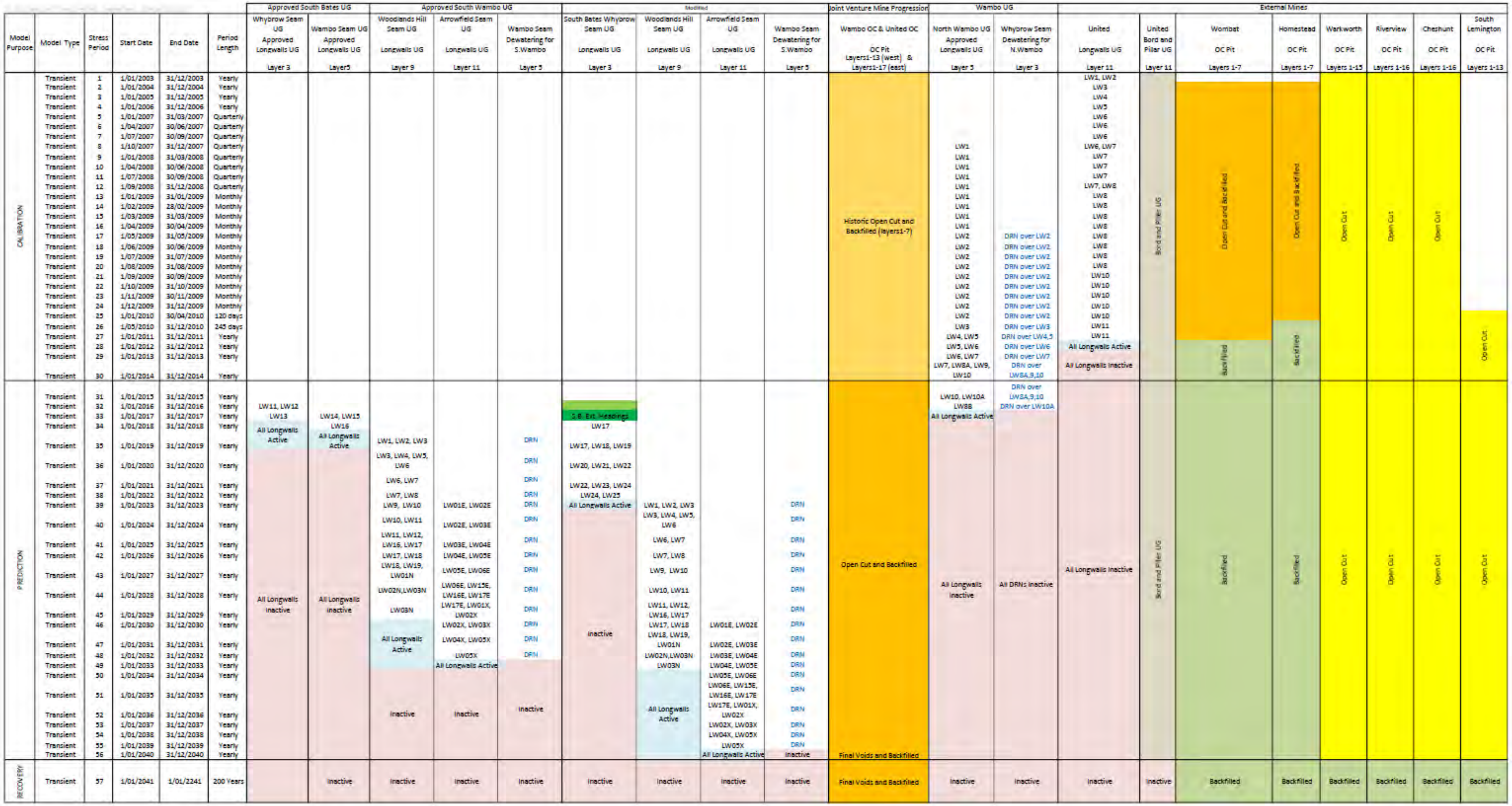


Figure 25 Mine Evolution and Model Stress Period Definition

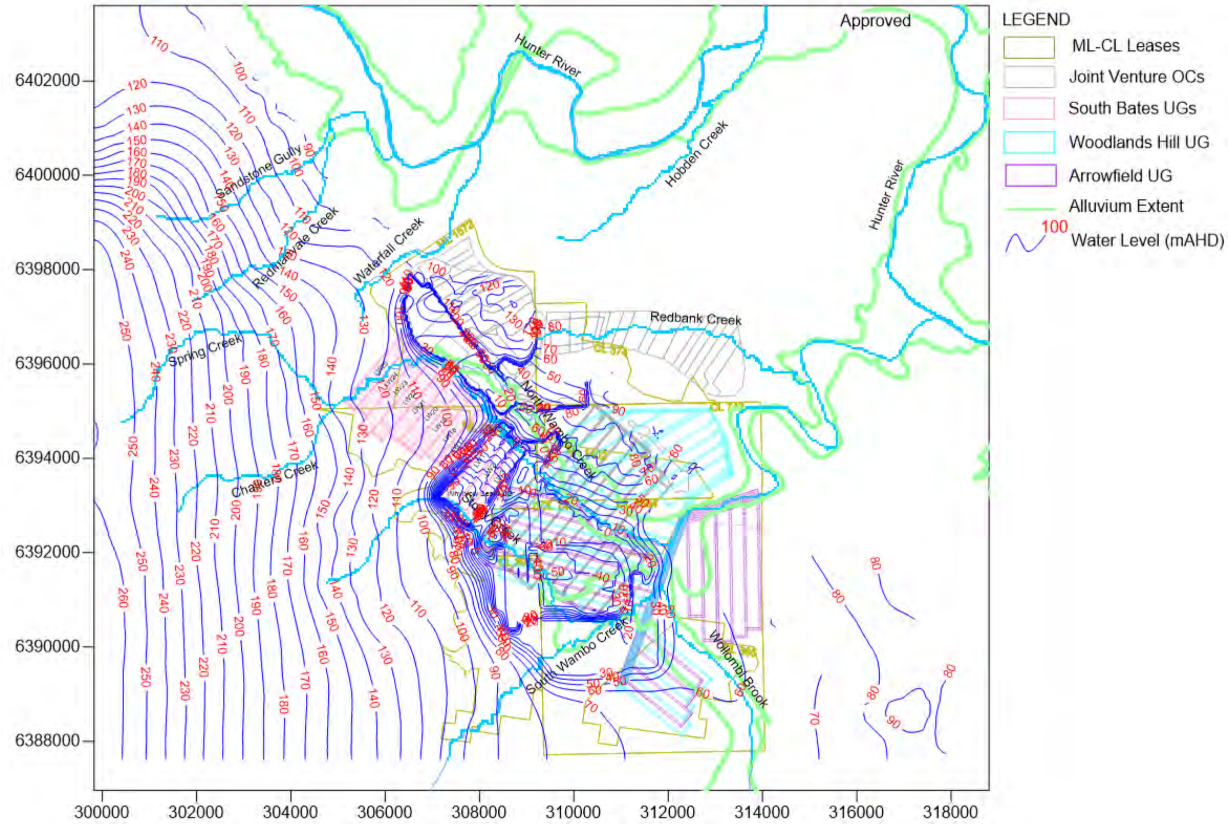


Figure 26 **Predicted Groundwater Levels (mAHD) in the Whybrow Seam (Model Layer 3) at the End of South Bates Mining - Approved Scenario**

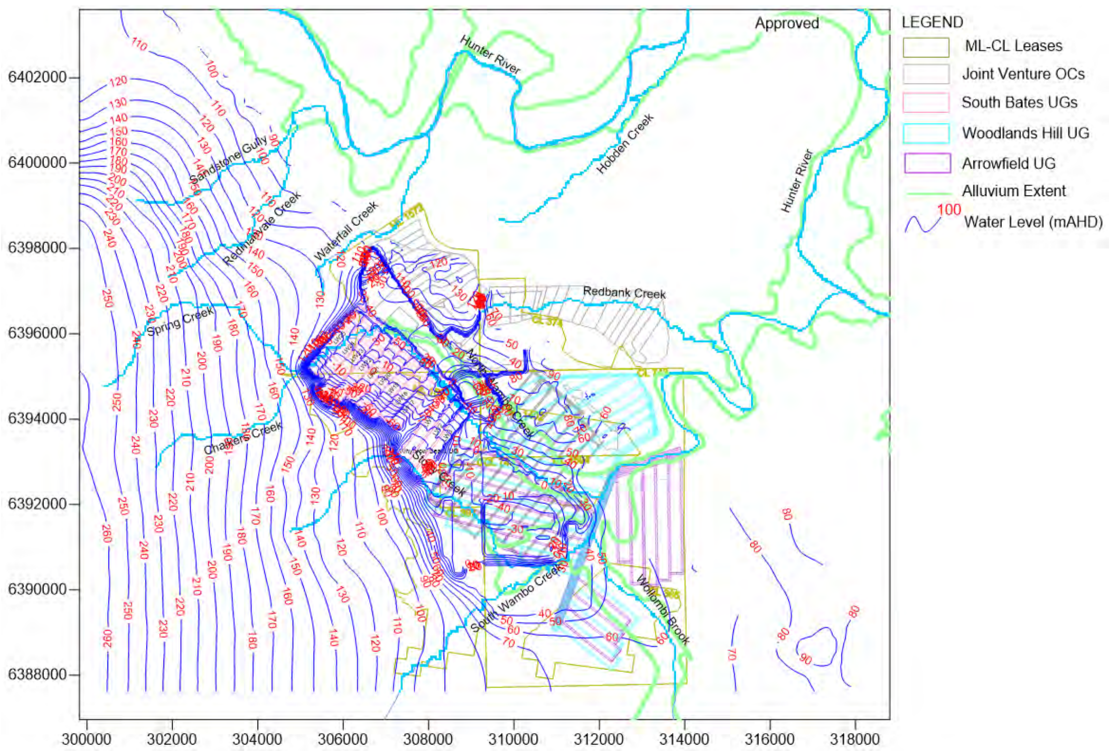


Figure 27 **Predicted Groundwater Levels (mAHD) in the Whybrow Seam (Model Layer 3) at the End of South Bates Mining - Modification Scenario**

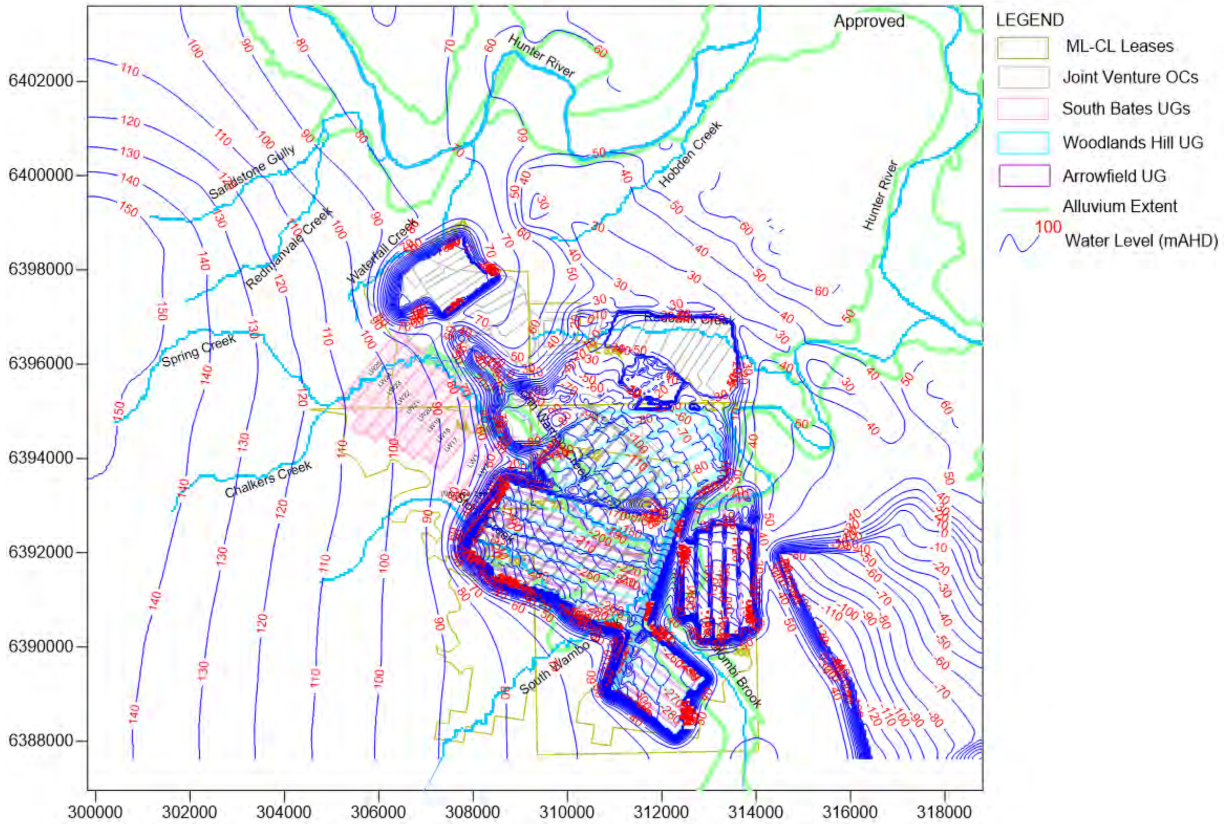


Figure 28 Predicted Groundwater Levels (mAHD) in the Woodlands Hill Seam (Model Layer 9) at the End of South Wambo Mining - Approved Scenario

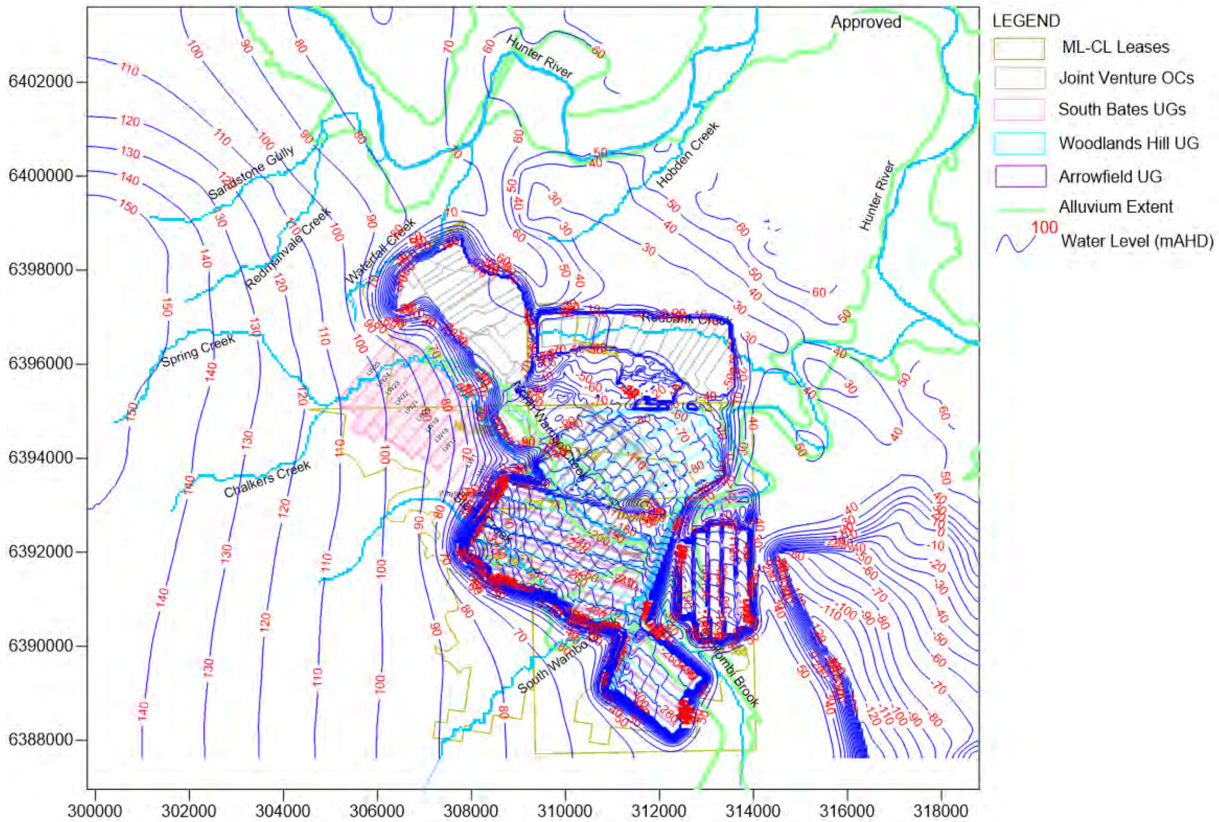


Figure 29 Predicted Groundwater Levels (mAHD) in the Woodlands Hill Seam (Model Layer 9) at the End of South Wambo Mining - Modification Scenario

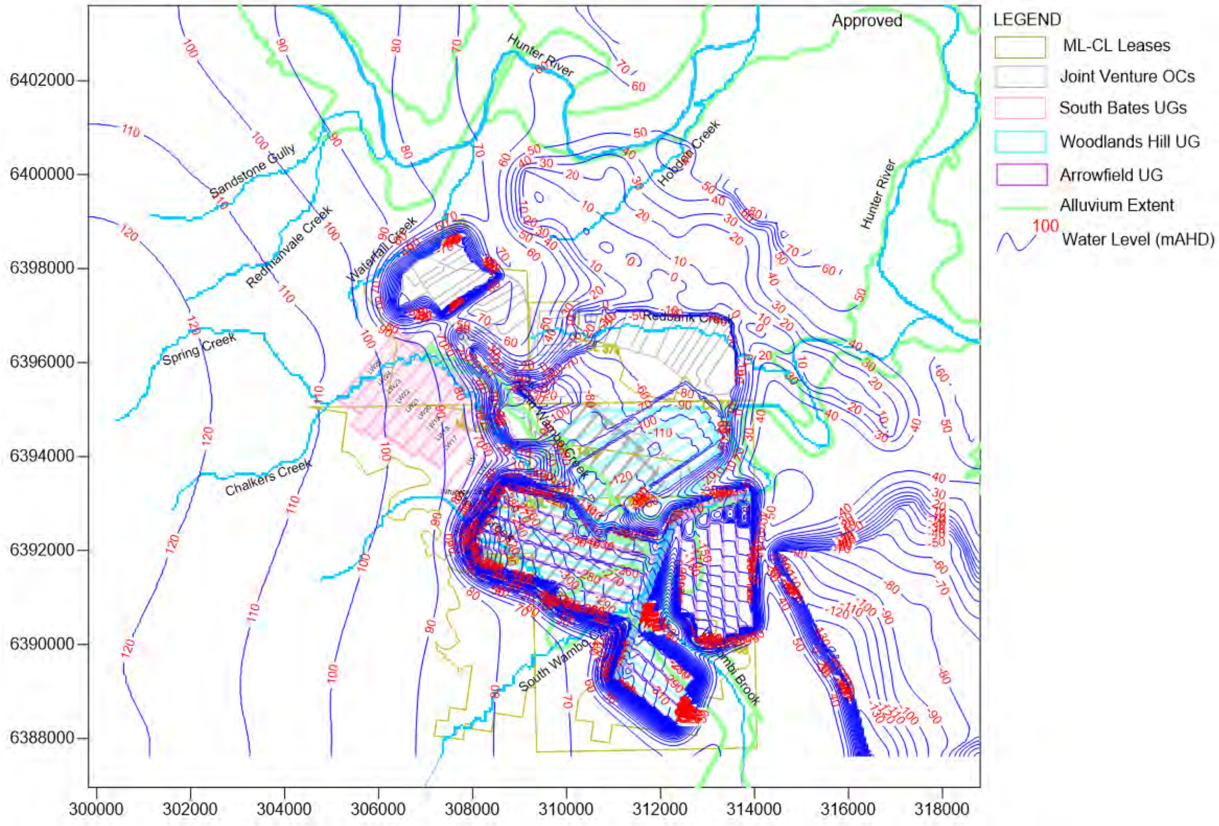


Figure 30 Predicted Groundwater Levels (mAHD) in the Arrowfield Seam (Model Layer 11) at the End of South Wambo Mining – Approved Scenario

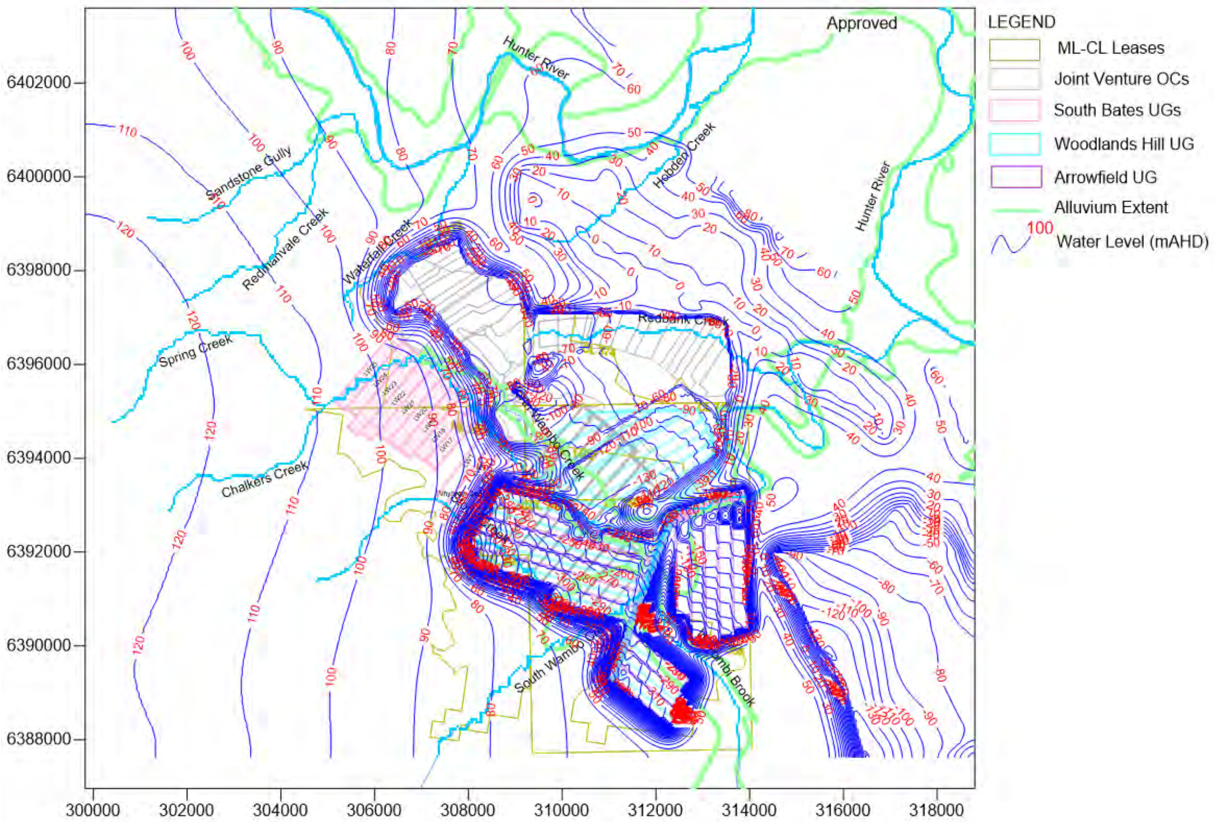


Figure 31 Predicted Groundwater Levels (mAHD) in the Arrowfield Seam (Model Layer 11) at the End of South Wambo Mining – Modification Scenario

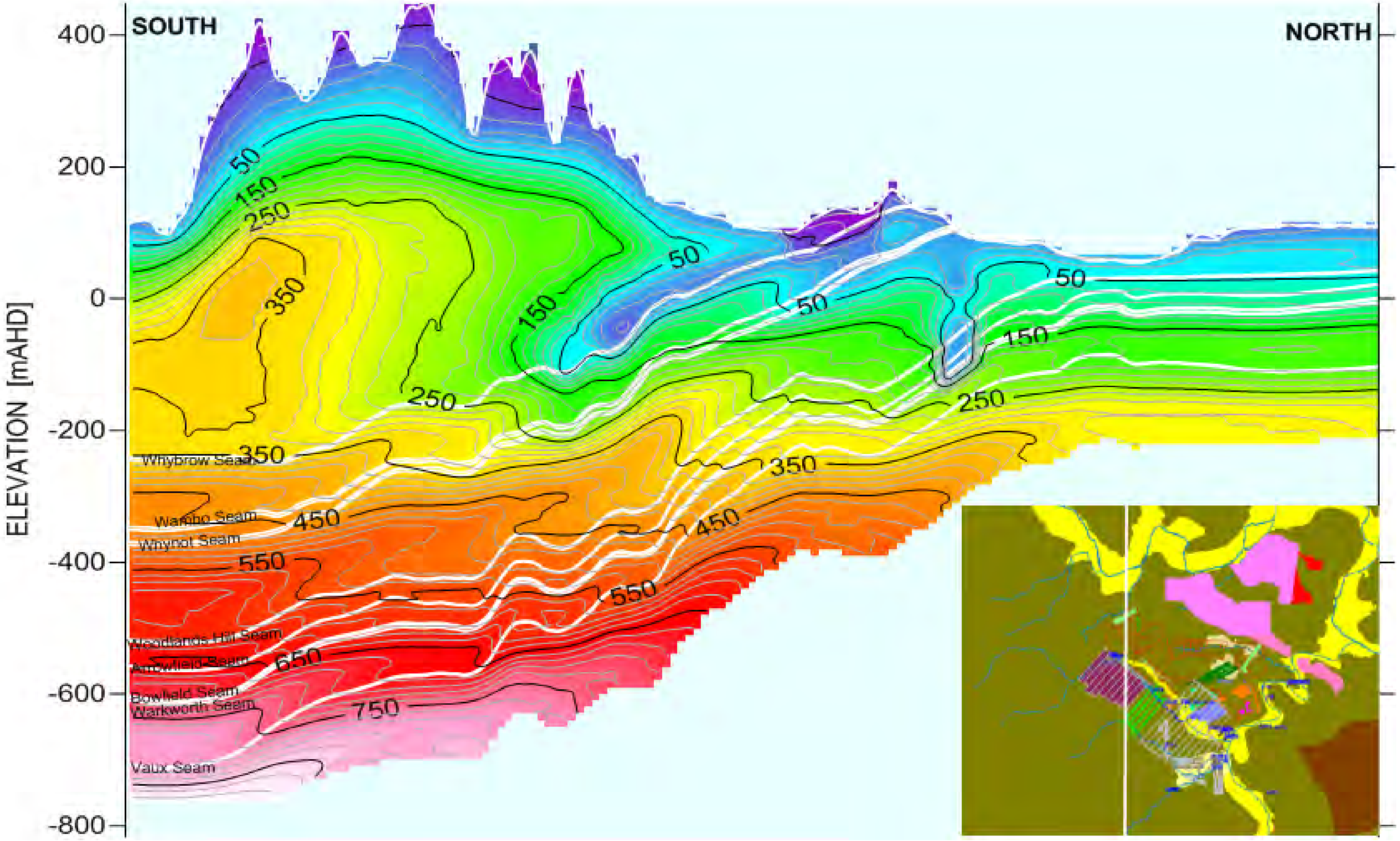


Figure 32 Interpolated Pressure Head (m) Along Easting 307275 (model column 150) at End of South Bates Mining (model stress period 39) (10m x 100m interpolation grid)

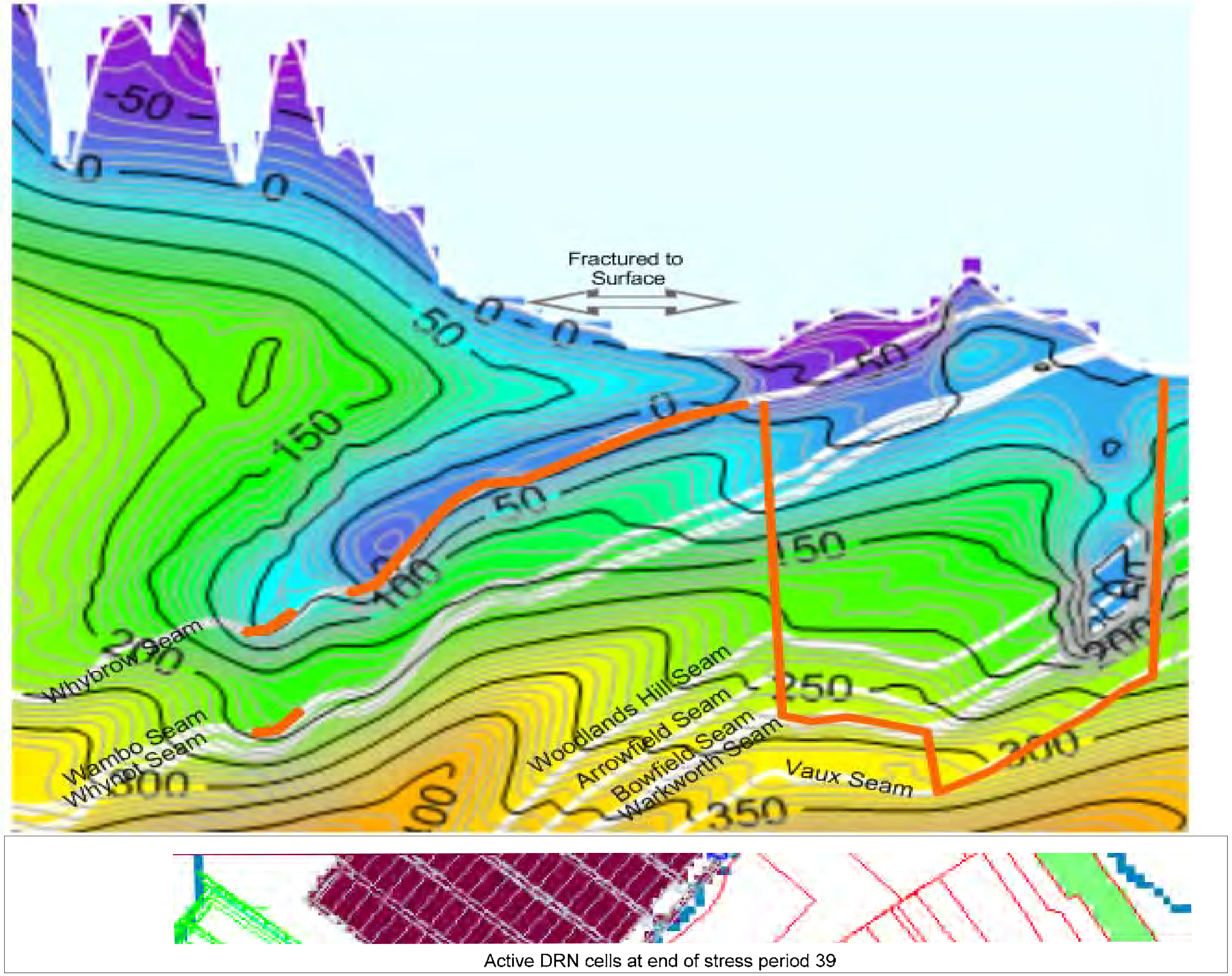


Figure 33 Interpolated Pressure Head (m) Along Easting 307275 (model column 150) Focused on South Bates Mining

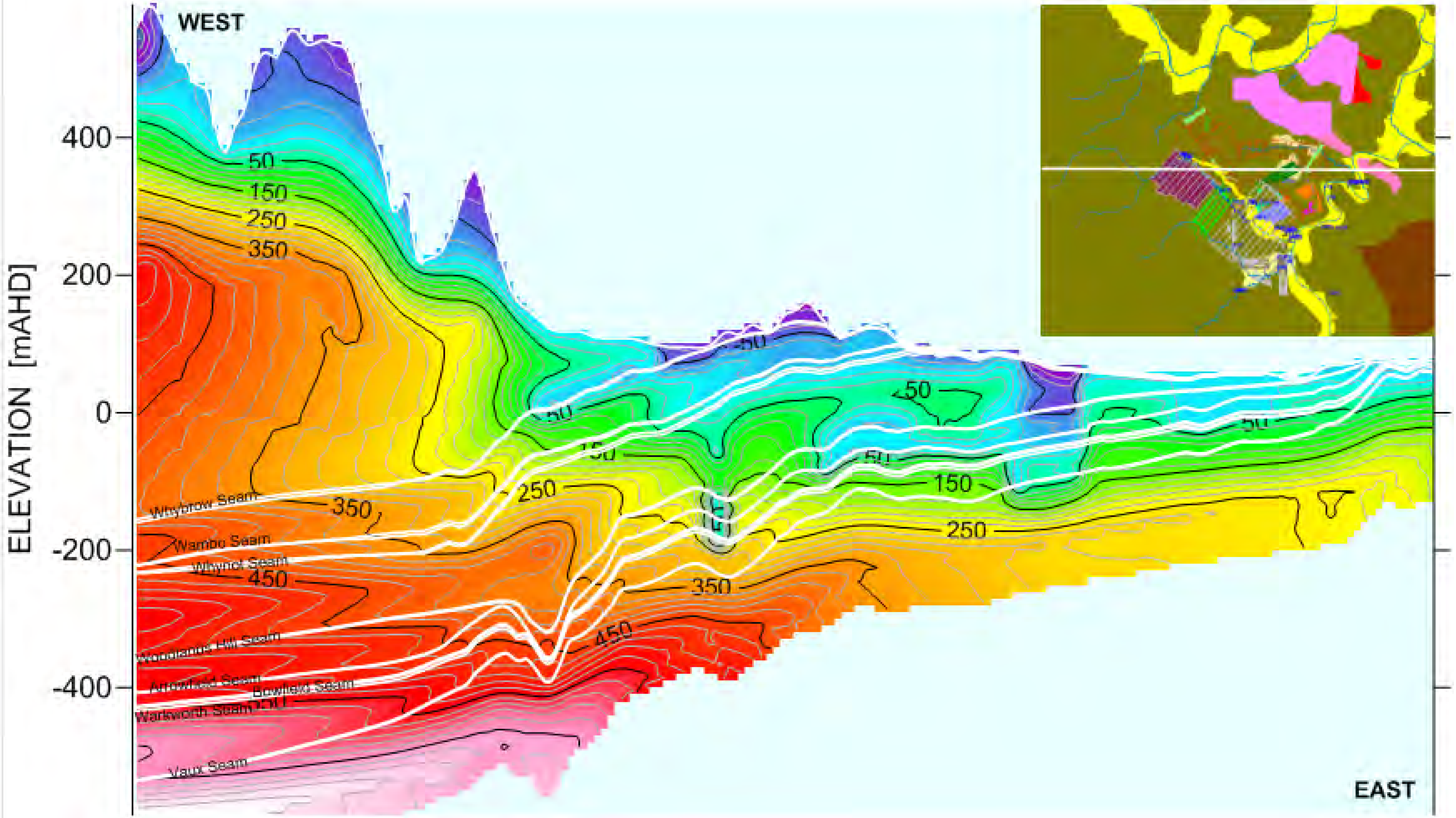


Figure 34 Interpolated Pressure Head (m) along Northing 6395875 (model row 155) at End of South Bates Mining (model stress period 39) (10m x 100m interpolation grid)

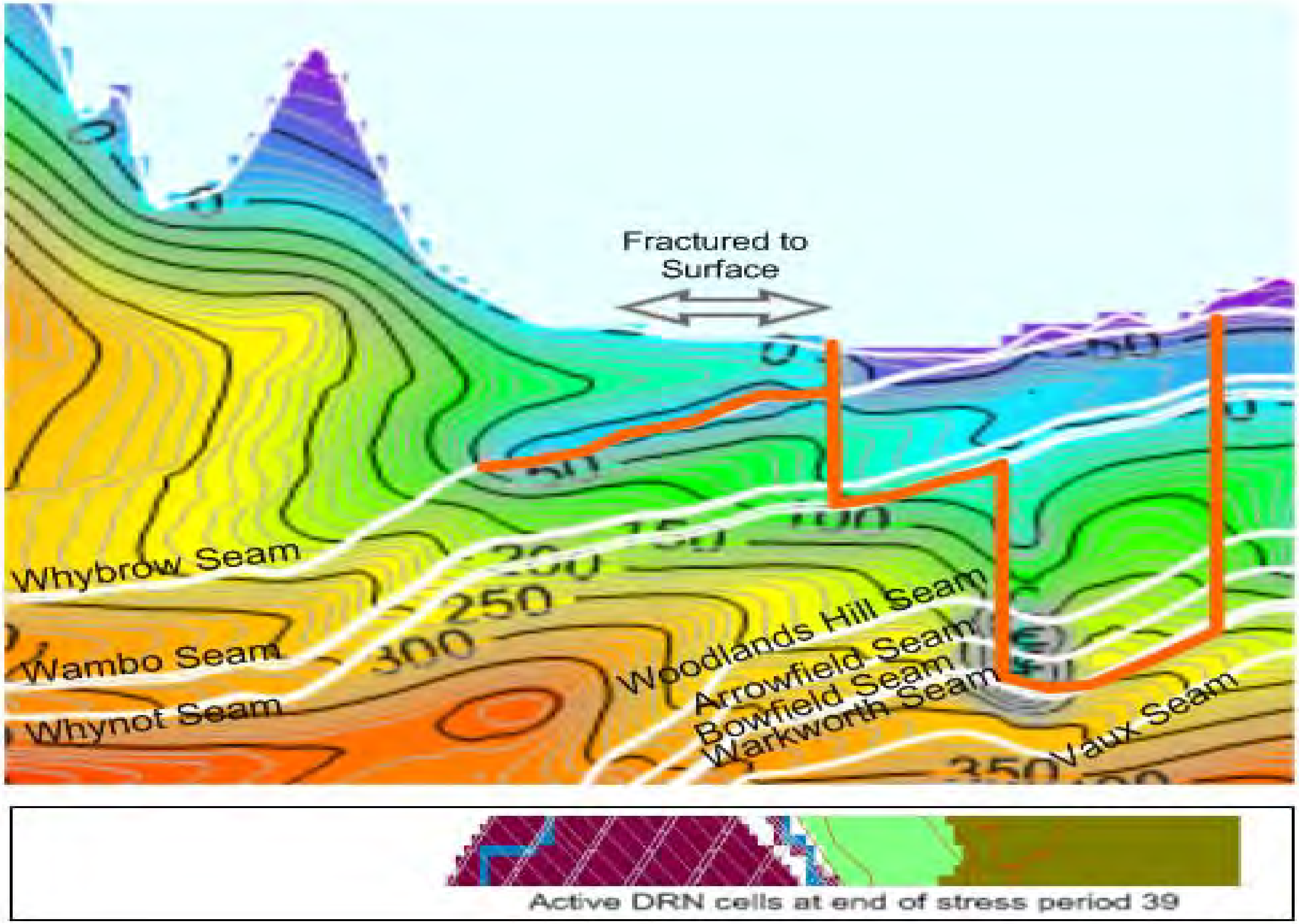


Figure 35 **Interpolated Pressure Head (m) along Northing 6395875 (model row 155) Focused on South Bates Mining**

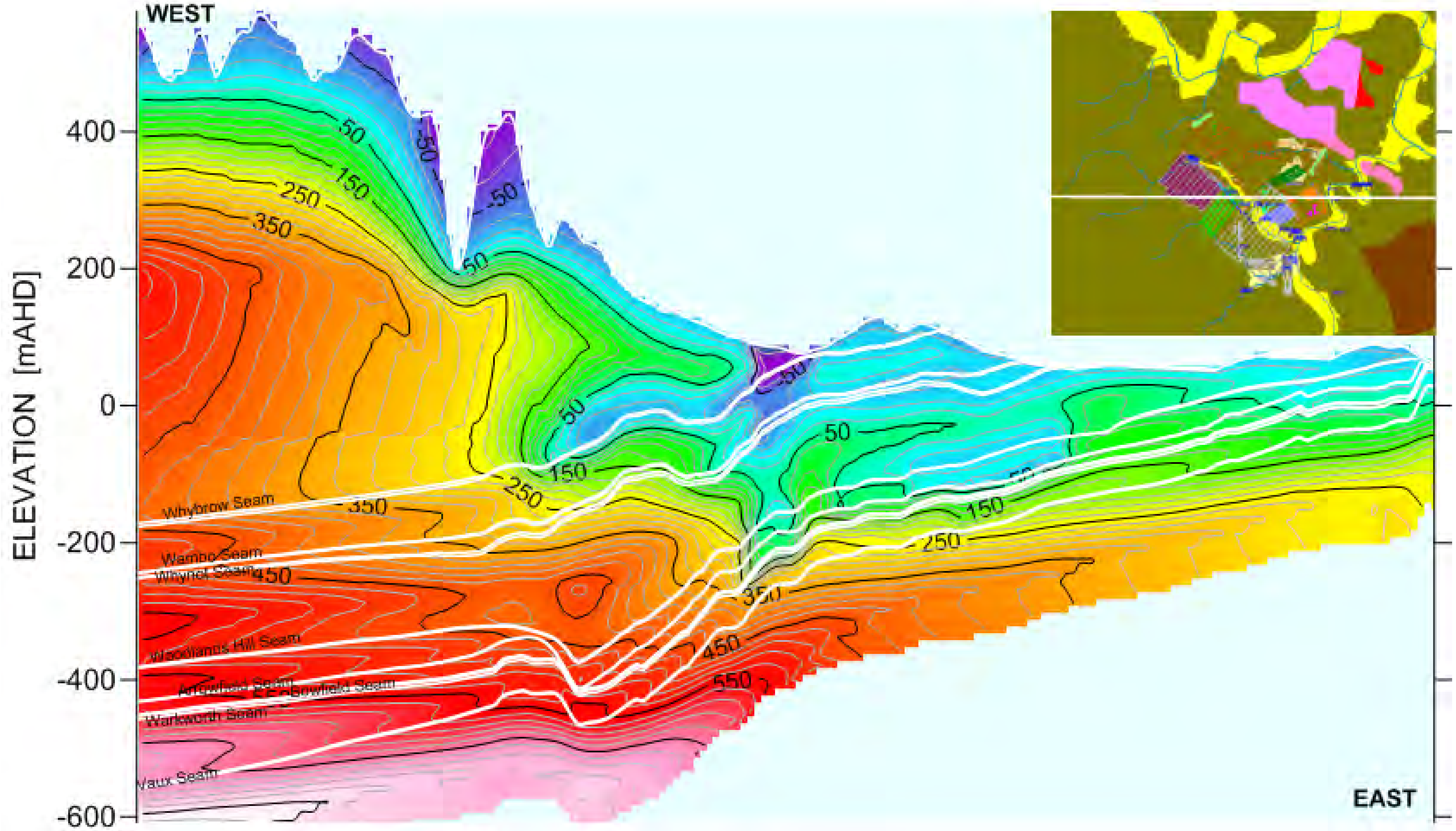


Figure 36 Interpolated Pressure Head (m) along Northing 6394375 (model row 185) at End of South Bates Mining (model stress period 39) (10m x 100m interpolation grid)

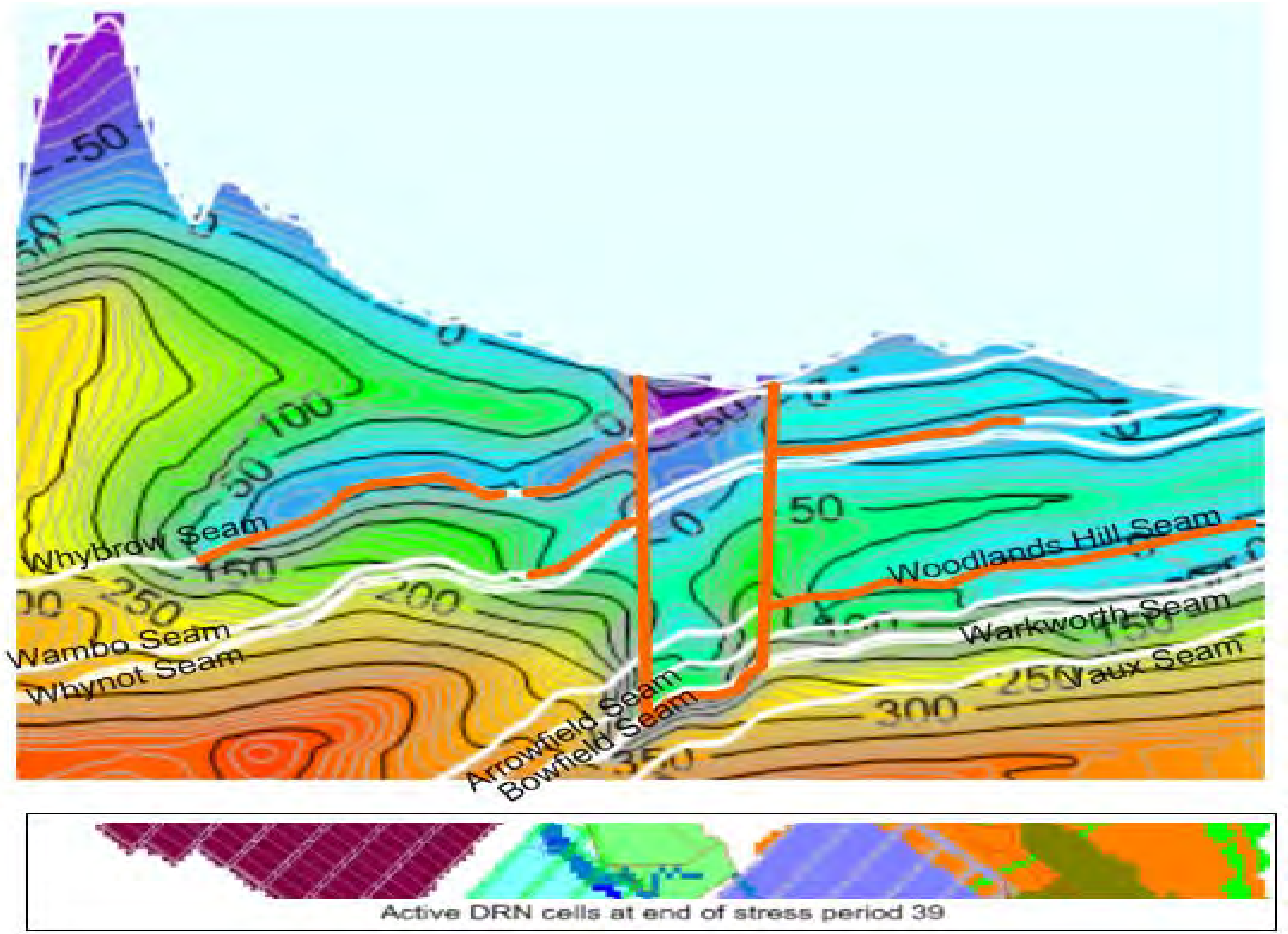


Figure 37 **Interpolated Pressure Head (m) Along Northing 6394375 (model row 185) Focused on South Bates Mining**