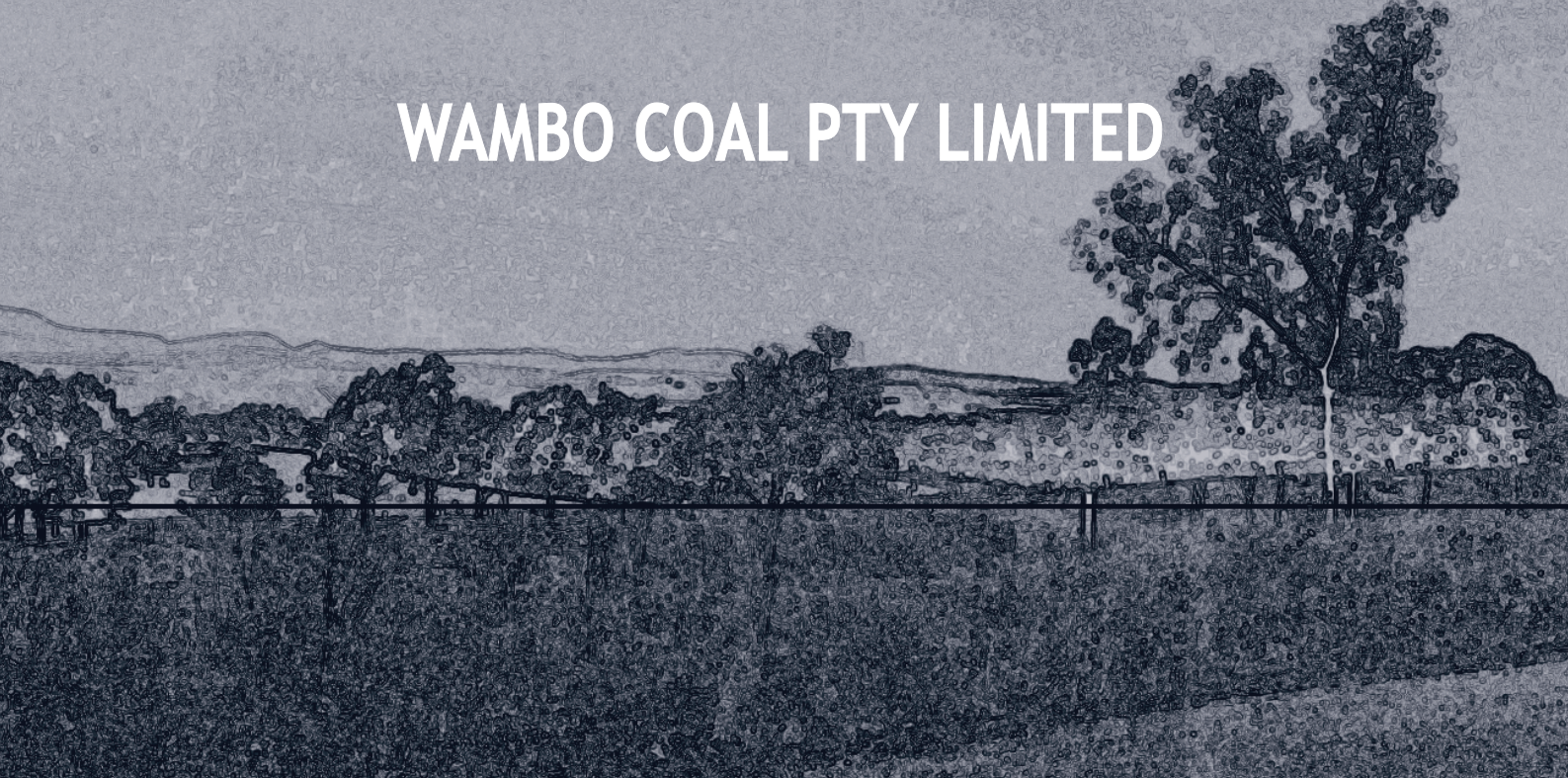




WAMBO COAL PTY LIMITED

SOUTH WAMBO
UNDERGROUND MINE MODIFICATION
ENVIRONMENTAL ASSESSMENT

APPENDIX B
Groundwater Assessment



South Wambo Underground Mine Modification

Groundwater Assessment

FOR

Wambo Coal Pty Limited

BY

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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 Wambo Underground Mine (the Modification). The South Wambo Underground Mine was approved for extraction in longwall panels in the Arrowfield and Bowfield Seams. WCPL plans to seek approval for a Modification application for the existing Development Consent (DA 305-7-2003) for the proposed extension/relocation of the approved longwall panels. Additionally, it is proposed to mine the Woodlands Hill Seam in this area instead of the Bowfield Seam. The Modification (MOD 12) would not involve changes to any aspects of the approved North Wambo Underground Mine or South Bates 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	
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
Arrowfield Coal Seam	South Wambo UG ⁵	South Wambo UG ⁵
Bowfield Coal Seam	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 Arrowfield and Bowfield Seams, respectively. This Modification proposes to shift the mining from the Bowfield Seam into the higher Woodlands Hill Seam, as discussed in Section 1.3. No mining in any seams has commenced to date at South Wambo.

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 Colliery (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 Colliery mined the lower Arrowfield Seam until 2010 (United Underground Mine) directly beneath portions of the North Wambo Underground Mine and the longwalls proposed in the Woodlands Hill Seam as part of this Modification.

1.3 PROPOSED MODIFICATION – ARROWFIELD AND BOWFIELD MINES

No longwall mining has commenced at South Wambo and the proposed Modification is intended to replace the existing underground mine plan in its entirety. The main activities associated with the development of this Modification (MOD 12) would involve changes to the previously approved South Wambo Underground Mine plan to include:

- changing and extending the approved longwall layout in the Arrowfield Seam (including the addition of areas not previously approved for mining);
- mining of the Woodlands Hill Seam with a new extended layout in the Woodlands Hill Seam compared to that previously proposed for the Bowfield Seam;
- extending the approved mine life by seven years (from 2025 to and including 2032);
- increasing the approved run-of-mine underground production rate from 7.5 million tonnes per annum to 9.75 million tonnes per annum; and
- ancillary changes to gas drainage, surface facilities and mine access infrastructure.

The Modification also includes extending the approved life of the open cut operation up to and including 2020, consistent with the approved Mining Operations Plan. There are no changes to the approved open cut mining methods, open cut extent, open cut maximum ROM coal production rates, open cut mine fleet or waste rock management practices. Therefore, no changes in the open cut operation have been modelled as part of this Groundwater Assessment.

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:
 - Calibration of the groundwater model with latest groundwater monitoring data.
 - 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 Wollombi Brook, North Wambo Creek, Wambo Creek and Stony Creek.
 - Comparison of the predicted groundwater impacts for the Modification against the predictions in the *Wambo Development Project Environmental Impact Statement, North Wambo Underground Mine Modification Environmental Assessment, North Wambo Underground Mine Longwall 10A Modification Environmental Assessment and South Bates (Wambo Seam) Underground Mine Modification Environmental Assessment*.
 - 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 (development commenced with longwall extraction to commence in February 2016);
- 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 *Hunter Unregulated and Alluvial Water Sources WSP 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 will be managed as the Sydney Basin - North Coast Groundwater Source within the *WSP for the North Coast Fractured and Porous Rock Groundwater Sources*. This WSP is in Draft form on exhibition from 8 February 2016 until 20 March 2016. Until then the Porous Rock groundwater source is being managed under the *Water Act 1912*. 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 Act 1912* and *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

LICENCE NUMBER	EXTRACTION LIMIT	EXPIRY	PURPOSE
Licences under the <i>Water Management Act 2000</i>			
WAL 23897*	70 ML/a	Perpetuity	Well No. 2
Licences under the <i>Water Act 1912</i>			
20BL167738	57 ML/a	11/09/2015^	Dewatering Bore
20BL168643	40 ML/a	7/08/2018	Dewatering Bore
20BL168017	750 ML/a (20PT910929)	21/05/2017	Dewatering (Bore No. 2)
20BL172061		22/03/2014^	Dewatering (Bore No. 2a)
20BL173040		21/05/2017	Dewatering Bore
20BL172156	98 ML/a	3/05/2019	Dewatering Excavation

LICENCE NUMBER	EXTRACTION LIMIT	EXPIRY	PURPOSE
20BL166910	450 ML/a (20PT910607)	21/05/2017	Dewatering (Bore No. 1)
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	4/09/2019	Dewatering Bore
20BL132753	243 ML/a	29/07/2018	Old Well No. 1

ML/a = megalitres per annum.

*Assigned to the Lower Wollombi Brook Water Source.

^ Renewal lodged.

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 665.0 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	86.8	63.9	48.2	42.2	44.1	31.1	35.2	38.7	54.0	63.4	72.7	665.0

Source: BoM (November 2015).

Information on long-term rainfall trends is provided by the Residual Mass Curve (RMC) (**Figure 3**). This curve is generated by adding the residuals and plotting the results successively over time between actual monthly rainfall and long-term average rainfall for each month. The procedure is essentially a low-pass filter operation which suppresses the natural spikes in rainfall and enhances the long-term trends.

Given the usually slow response of groundwater levels to rainfall inputs, the RMC can be expected to correlate well with groundwater hydrographs over the long term. The groundwater levels recorded during periods of rising RMC tend to rise during rainfall recharge excess, while those recorded during periods of declining RMC tend to decline during periods of rainfall recharge deficit.

RMC plots using rainfall data from the Jerrys Plains Post Office and Bulga (South Wambo) since 2003 are shown in **Figure 3**. These plots suggest that current mining operations have experienced fluctuating weather conditions, with pronounced dry conditions 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 and December 2012 to January 2013.

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."

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.

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.

Elevations in the vicinity of Wambo range from approximately 60 m Australian Height Datum (AHD) at Wollombi Brook to approximately 650 m AHD within the Wollemi National Park to the west of Wambo (WCPL, 2003).

An overview map of the regional topography is shown in **Figure 4**.

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 (km²) 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 higher resolution ground topography over the Wambo area. These levels were extracted from the WCPL geological model on a 20 m grid.

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 9 km south-southwest of the Modification longwall panels. 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 (note that the coal seam 'subcrop' lines marked on **Figure 6** delineate the north-eastern edge of the seams – i.e. the seams are absent to the north-east of the respective subcrop lines). A discussion of the model domain is in Section 3.3.

The stratigraphy of the Wambo area and targeted coal seams at Wambo are presented in **Figure 7**. The target Woodlands Hill and Arrowfield Seams lie within the Mount Ogilvie Formation and Mount Thorley Formation, respectively, 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 near the confluence of North Wambo Creek and Wollombi Brook was undertaken by GHD in 2007 to assess the thickness of the North Wambo Creek alluvium. The survey area was located above underground workings of the old Homestead Underground Mine. The investigation used bore logs and electromagnetic geophysics and found the thickness of alluvium to range from about 7 m to 19 m across the survey area.

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 (South) Wambo 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 (South) 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 78 registered bores belonging to Wambo and other groundwater users within 5 km of Wambo, as listed in **Table 4**. Boreholes registered on the 'Pinneena' (v10.1) database in proximity to Wambo are shown in **Figure 8**. Of these, 48 are monitoring/test bores within the WCPL tenement boundaries, 10 mine use/dewatering bores, and 4 bores of unknown use. The remaining 16 bores are registered for irrigation, domestic and/or stock use.

Table 4: Registered Bores within 5 km of Wambo

WORK NO.	LICENCE	EASTING	NORTHING	FINAL DEPTH (m) *	USE
GW017462	20BL008224	315339.2	6391460.3		Farming
GW060327	-	314180.8	6393441.5	9.8	Mining
GW060328	-	314205.2	6393534.3	10.0	Mining
GW060329	-	311903.5	6392474.4	6.4	Mining
GW060330	-	311726.7	6392163.0	6.2	Mining
GW060363	20BL132753	311697.8	6392316.5	6.3	Mining
GW060364	-	311636.3	6392808.3	5.1	Mining
GW060365	-	311690.8	6392686.1	6.6	Irrigation
GW060366	-	311195.9	6392645.9	5.2	Irrigation
GW060750	20BL132130	314309.8	6394922.8	24.4	Domestic
GW043673	-	311486.3	6392466.6	9.4	Test
GW043674	-	311302.6	6392524.7	8.2	Test
GW043675	-	311432.9	6392527.2	8.5	Test
GW065117	-	311153.9	6390734.8	6.0	Irrigation
GW066606	-	311207.2	6390674.2	2.5	Domestic
GW037184	-	309685.0	6393911.3	21.0	Test
GW038579	-	309737.7	6393881.5	20.9	Farming
GW005327	20BL009540	314682.9	6394498.4	10.4	Stock
GW037998	-	311589.4	6392530.1	10.9	Irrigation
GW037999	-	311481.6	6392713.0	13.7	Irrigation
GW038000	-	311457.3	6392620.1	9.4	Irrigation
GW079780	-	309588.9	6393931.5		Monitoring
GW078574	20BL167170	309174.3	6390604.7	12.0	Farming
GW078575	20BL167171	309504.8	6389686.6	12.0	Farming
GW078577	20WA208559	309968.7	6389972.8	10.0	Domestic
GW080502	20BL168017	308897.0	6390159.8	250.0	Mining
GW080514	20BL168881	310973.0	6394353.4	55.0	Monitoring
GW080515	20BL168882	313418.0	6394794.3	8.1	Monitoring
GW080516	20BL168883	312898.8	6394953.7	15.0	Test

WORK NO.	LICENCE	EASTING	NORTHING	FINAL DEPTH (m) *	USE
GW080517	20BL168884	313572.7	6394741.6	15.0	Monitoring
GW080519	20BL168885	313622.4	6394161.1	10.5	Test
GW079060	-	314595.5	6394851.7	14.6	Unknown
GW047240	20CA209896	316826.7	6397095.2	12.7	Irrigation
GW078576	20BL167172	309763.7	6389784.0	7.0	Farming
GW079059	20BL153300	314595.5	6394851.7		Monitoring
GW060326	-	314104.3	6393347.6	9.8	Mining
GW043676	-	311479.9	6392805.4	10.6	Test
GW080518	20BL168885	313585.8	6394232.3	10.8	Monitoring
GW080951	-	314619.0	6394877.5	3.1	Unknown
GW080952	-	314643.0	6394904.5	1.6	Unknown
GW078055	-	310104.9	6390489.7	198.5	Test
GW080963	20BL170103	315994.0	6397209.5	84.0	Monitoring
GW200615	20BL168886	313434.0	6394246.0	11.5	Monitoring
GW200616	20BL168886	313473.4	6394445.8	8.5	Monitoring
GW200617	20BL168888	309987.4	6393973.8	9.0	Monitoring
GW200618	20BL168888	310100.4	6393819.8	11.5	Monitoring
GW200619	20BL168888	310182.4	6393655.8	11.5	Monitoring
GW200620	20BL168888	310489.4	6394096.8	49.0	Monitoring
GW200621	20BL168887	312857.0	6395909.0	37.0	Monitoring
GW200622	20BL168887	312901.0	6395806.0	30.0	Monitoring
GW200623	20BL168887	312982.1	6395319.1	31.0	Monitoring
GW200624	20BL168939	310165.9	6392650.1	260.0	Mining
GW200625	20BL168940	310901.0	6393375.0	270.0	Mining
GW200634	20BL168999	311470.0	6391252.0	20.0	Monitoring
GW200635	20BL168999	311659.0	6391236.0	20.0	Monitoring
GW200636	20BL168999	311749.0	6391078.0	20.0	Monitoring
GW200637	20BL168999	311662.0	6391094.0	15.0	Monitoring
GW200638	20BL168999	311452.0	6391103.0	20.0	Monitoring
GW200639	20BL168999	311455.0	6390889.0	20.0	Monitoring
GW200640	20BL168999	311638.0	6390920.0	50.0	Monitoring
GW200641	20BL168999	311761.0	6390921.0	20.0	Monitoring
GW200642	20BL168999	311696.0	6390688.0	20.0	Monitoring
GW200643	20BL168999	311454.0	6390685.0	15.0	Monitoring
GW200361	20BL170638	311832.9	6392209.0		Test
GW030740	-	316641	6398365	16.3	Monitoring
GW030732	-	316678	6397633	16	Monitoring
GW030733	-	316661	6397642	15.9	Monitoring
GW043225	-	303653	6398949	22.5	Unknown
GW200833^	20BL172255	311340	6389530	54	Monitoring
GW200834^	20BL172257	313695	6389546	15	Monitoring
GW200827^	20BL172237	312505	6391469	9	Monitoring

WORK NO.	LICENCE	EASTING	NORTHING	FINAL DEPTH (m) *	USE
GW200830^	20BL172240	313335	6392745	16.8	Monitoring
GW080513^	20BL168880	312345	6394818	10	Test
GW200942^	20BL167947	312325	6395750	37	Test
GW200943^	20BL167947	312332	6395760	30	Test
GW200828^	20BL172237	310061	6393206	11.5	Monitoring
GW200829^	20BL172237	308641	6393376	36	Monitoring
GW200835^	20BL172256	308424	6394517	11	Monitoring

* Depth as listed in Pinneena database.

^Monitoring/test bore not considered further in this assessment.

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 2013 the overall average extraction has been 2.0 ML/d. In contrast, the mine inflows due to Wambo Seam extraction have averaged 0.35 ML/d (2012-2013).

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 are summarised in **Table 5**.

Table 5: Groundwater Monitoring Sites

MONITORING SITE	LITHOLOGY	START DATE	FREQUENCY
P1, P3, P11, P16, P20	Alluvium	from December 2005	Bi-monthly
P5, P6 (no longer active)			Removed due to open cut operation 2014
P106, P109, P114, P116	Alluvium	from July 2003	Bi-monthly
P202, P203 (also known as P206)	Shallow Permian Overburden	from July 2003	Bi-monthly
P301, P315	Alluvium, Shallow Permian Overburden	from March 2004	Bi-monthly
GW02, GW08, GW09, GW11	Alluvium	from July 2005	Bi-monthly
GW12, GW13, GW14, GW15, GW16, GW17, GW21, GW22	Alluvium, Shallow Permian Overburden	from December 2009	Bi-monthly

MONITORING SITE	LITHOLOGY	START DATE	FREQUENCY
GW18, GW19			Removed from program
MG08	Alluvium to Wambo Seam	from December 2012	Continuous
MG09	Regolith to Wambo Seam	from December 2012	Continuous
BH2, BH2A, BH4C, WAMBO-03	Whybrow Seam, Wambo Seam		Continuous
BH1G, BH1E, WAMBORE SOUTH	Whybrow Seam, Wambo Seam		Monthly
N2, N3, N5	Permian Overburden to Wambo Seam	from August 2015	Continuous
P12, P13, P15, P17, P18*	Alluvium	from December 2005	Bi-monthly
P33, P34, P35*	Alluvium, Permian Overburden, Whybrow Seam, Redbank Seam, Wambo Seam	from January 2010; May 2011; January 2005	Continuous
P311	Shallow Permian Overburden	from January 2010; May 2011; January 2005	Continuous

* Part of the United Colliery 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).

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

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 (mBTC) ¹	
	Minimum (10 th percentile)	Maximum (90 th percentile)
P106	6.6	10.7
P109	4.6	6.7
P114	5.4	7.6
P116	4.8	7.3
P202	7.8	9.6
P203 (also known as P206)	16.1	21.6

Bore	Depth to Groundwater (mBTC) ¹	
	Minimum (10 th percentile)	Maximum (90 th percentile)
P315	4.4	9.1
GW02	5.8	8.5
GW11	4.0	6.5
GW12	9.9	12.9
GW13	4.8	5.4
GW15	10.4	11.1
P16	7.1	7.8
P20	7.1	8.2

1. mBTC = metres below top of casing

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.

Groundwater elevations within the alluvium decrease in a downstream direction from the centre of the current study area in a north-east direction to the junction with the Hunter River. Reduced water levels in the alluvium for April 2007 are shown on **Figure 10**. This time was chosen as a reference period as it preceded commencement of longwall extraction at the North Wambo Underground Mine and was just prior to a significant recharge event which occurred in June 2007. The groundwater levels provide evidence of groundwater conditions at the end of a long recession period prior to 2007 of consistent below average rainfall.

Figure 10 shows groundwater level depression in the alluvium at two locations due to longwall mining. This includes groundwater level depression at the confluence of Wollombi Brook and Wambo Creek, with estimated maximum drawdown in the order of 5 m (marked as 'A' on the figure). 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). **Figure 10** also shows a groundwater level depression in the alluvium overlying North Wambo Underground Mine Longwalls 1 and 2, in the vicinity of former monitoring bores P5 and P6, with a maximum depression in the order of 4 m (marked as 'B' on the figure).

2.6.2 TEMPORAL GROUNDWATER LEVELS IN ALLUVIUM

The alluvial monitoring bores nearest the South Wambo Underground Mine are (locations given respective of North Wambo Underground longwalls):

- P5 - over North Wambo Longwall 1 (destroyed by open cut progression - no longer monitored);
- P6 - over North Wambo Longwall 2 (destroyed by open cut progression - no longer monitored);
- GW08 – 300m north-east of North Wambo Longwall 10;
- GW09 – 500m north-east of North Wambo Longwall 9;
- P114 – over North Wambo Longwall 10A; and
- P116 – 100 m south-east of North Wambo Longwall 10A.

Figure 11 displays fluctuating groundwater level hydrographs at P5 and P6 until 2014 as well as approximate yearly moving average using 11 data points and also the commencement dates for each longwall panel (LW1 to LW10a). Bores P5 and P6 data collection stopped after they were decommissioned due to the approach of the open cut excavation. Smoothing using averages allows easier recognition of the often good correlation between the groundwater hydrographs and the rainfall residual mass curve (RMC) since 2005.

The data on **Figure 11** 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. This response is consistent with the potential impacts described in the Wambo Development Project Environmental Impact Statement (WCPL, 2003) and the Wambo Seam Underground Mine Modification Statement of Environmental Effects (WCPL, 2005). 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.

For the period of the record to June 2012², the depth to water exceeded 9.6 m at P5 and 7.7 m at P6 for 90% of the time. Drawdown from mid-2012 to late 2013 was about 2.5 m at P5 and 3.5 m at P6 (based on the smoothed data on **Figure 11**).

Figure 12 displays fluctuating and smoothed groundwater level hydrographs at GW08 and GW09, as well as the RMC and the commencement dates for each longwall panel (LW1 to LW10a). 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 increases from 2012, coincident with the commencement of dewatering of the Wambo Seam in the old workings adjacent to North Wambo Longwall 8b. The groundwater levels in these bores show a limited response to rainfall, with declining groundwater levels unable to be arrested by rainfall recharge.

The data on **Figure 13** show that the groundwater levels at P114 and P116 have responded to rainfall events with moderate amplitude (1-3 m). Both hydrographs show mild correlation with the RMC for the entire period of record, although P114 continued to decline through the higher rainfall in mid-2015 after the commencement of Longwall 10. Nearby bores P106 and P109, which are closer to Wollombi Brook, show identical trends but higher amplitude responses to wet periods or creek flows (**Figure 13**). Drawdowns from mid-2012 to early 2015 have been about 1-2 m at P114 and P116.

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**).

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.

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 14** and **Figure B2**), and a mild mining effect is likely at GW21 adjacent to North Wambo Longwall 1 (**Figure 15** and **Figure B4**). 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**. They include hydrographs in the Whybrow Seam, Redbank Seam, Wambo Seam and Alluvium.

² Open cut mining affects the P5 and P6 water levels after this time.

Bore MG08 (**Figure C2**) is a multi-piezometer grouted bore that hosts seven VWP installed at depths of 9 m (alluvium) to 101 m (Wambo Seam). Bore MG09 is a multi-level piezometer grouted bore that hosts eight VWPs installed at depths of 9 m (regolith) to 192 m (Wambo Seam).

The responses at MG08 (between Longwall 7 and Longwall 8) and MG09 (between Longwall 9 and Longwall 10) show clear mining effects at depth.

The MG09 bore (located between Longwall 9 and Longwall 10) has a complex pressure pattern (see **Figure C3**). Prior to 2014, the lowest potentiometric head (5-15 mAHd) was recorded in the Whybrow Seam, as MG09 is located above earlier Whybrow Seam workings which were being actively dewatered as the Wambo Seam longwalls progressed. The pressure heads in the Whybrow Seam ranged from about 50 m to about 35 m from December 2012 to late 2013, with a sudden decline of about 5 m in late June 2013, due either to active dewatering by WCPL or the passage of Longwall 7 past MG09 (600 m away). In contrast, the Wambo Seam was not depressurised significantly with the passing of Longwall 7. However, the pressure head in the Wambo Seam reduced rapidly by over 150 m in April 2014 with the passing of Longwall 8. The Whybrow Seam also experienced rapid depressurisation of approximately 15 m due to the mining of Longwall 8. Data are unavailable beyond June 2014 to show the impacts of mining Longwalls 9 and 10.

2.7 GROUNDWATER CHEMISTRY

Several previous studies carried out in this area document 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 [$\mu\text{S}/\text{cm}$] to 22,000 $\mu\text{S}/\text{cm}$). The highest salinities are reported from the surficial groundwater, i.e. the colluvium and weathered Permian.

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 16**. The alluvial groundwater salinity decreased from 3,000-4,000 $\mu\text{S}/\text{cm}$ at a time coincidental with the commencement of Longwall 1 to less than 1,000 $\mu\text{S}/\text{cm}$ by the end of 2011. For the full period of record, the groundwater EC has been less than 1,000 $\mu\text{S}/\text{cm}$ 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 11** and **Figure 16**).

The salinity of GW08 has remained fairly constant at an EC of around 1,800 $\mu\text{S/cm}$, while GW09 has shown a lower salinity over time similar to P5 and P6, with salinity measurements decreasing from 1,800 $\mu\text{S/cm}$ to an average of about 500 $\mu\text{S/cm}$ since the end of 2011 (**Figure 17**).

Piezometer P114 shows an increasing salinity trend with time. For the first five years of records the salinity is about 700 $\mu\text{S/cm}$, with a sudden increase at the end of 2011/start of 2012 to almost 7,000 $\mu\text{S/cm}$ decreasing to 3,000 $\mu\text{S/cm}$ by mid-2012, and then gradually rising again to over 7,000 $\mu\text{S/cm}$ by mid-2014 (**Figure 18**). Current monitoring indicates salinity fluctuating around 6,000 $\mu\text{S/cm}$. Conversely, P166 shows almost the opposite trend, with initial levels of about 6,500 $\mu\text{S/cm}$ decreasing to below 1,000 $\mu\text{S/cm}$ by mid-2008 maintained for 70% of the time.

Interburden salinities are also quite variable in magnitude and over time. Bores P301 and P311, sited adjacent to Stony Creek, initially had EC values of 7,000-9,000 $\mu\text{S/cm}$ (**Figure 19**). The salinity at P301 decreased rapidly to about 2,000 $\mu\text{S/cm}$ when the RMC started to rise (i.e. rainfall increased) in 2007, fluctuated between 500 $\mu\text{S/cm}$ and 4,000 $\mu\text{S/cm}$ until 2012, with a gradual increase to about 6,000 $\mu\text{S/cm}$.

Although 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 $\mu\text{S/cm}$) (**Figure 20**). This contrasts with Bore GW22 in the South Wambo Underground Mine area, which has had stable EC values close to 7,000 $\mu\text{S/cm}$.

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

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 21** for a typical west-east cross-section. The cross-section A-A' passes through the proposed longwalls in Area 2 of the modified South Wambo Underground mine layout 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 21** 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 and the southern part of Wollombi Brook, and downward leakage was likely to occur along North Wambo Creek and the northern part of Wollombi Brook. Mining is expected to reduce the natural upflow and accentuate the natural 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 joints and fractures spaces decrease and become less frequent.

The laminated fabric of the interbedded sandstone/siltstone/mudstone strata suggests that vertical hydraulic conductivities are significantly lower than horizontal hydraulic conductivities. Due to the laminar nature of the coal measures, groundwater flow generally occurs within or along the boundaries between stratigraphic layers.

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 coal seams are generally more brittle and therefore more densely fractured than the overburden and interburden strata, which causes the higher hydraulic conductivity. Within the coal seams, groundwater flows predominantly through cleat fractures, although there is some evidence of structure-related fracturing and this may play an important role in groundwater flow paths.

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. 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.

As there is an annual rainfall deficit and the hydraulic conductivity of underlying rock is low, recharge rates to the coal measures are 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, 2014b), and again for the South Bates (Wambo Seam) Underground Mine Modification (MOD 15) (HydroSimulations, 2015). As MOD 15 has since been approved, the HydroSimulations (2015) MOD 15 model was used as a starting base for this project.

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.

3.2 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 has elected to re-build the most recent model (as used for the MOD 15 Assessment in July 2015) using the new MODFLOW-USG program code (Panday et al., 2013) and also a version 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). 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 minor recalibration of the model was required during the conversion.

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 km². Sixteen 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 22**.

The two versions of MODFLOW-USG provide the option for a completely unstructured grid, however the existing 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 0.6m 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 results in a revised cell count of 1,668,792 (15% reduction in the cell count) for the USG model.

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: 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 7** is a summary of previous work (Mackie, 2009) and of core laboratory measurements undertaken by WCPL.

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 7**. 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 7: 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}

UNIT	THICKNESS (m)	CORE TESTING RESULTS [^]		K (m/day) [#]
		Kx (m/day)	Kz (m/day)	
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}
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}

[^] 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 in order to reflect values close to the lowest (limiting) hydraulic conductivity of the lumped units, resulting in enhanced vertical anisotropy within 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.

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 $5 \times 10^{-6} \text{ m}^{-1}$ to $5 \times 10^{-5} \text{ m}^{-1}$, 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 22**.

3.5.1 WATERCOURSES

All major waterbodies are represented using the MODFLOW-USG River (RIV) package, as shown in **Figure 23**. 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 Richards Equation for unsaturated flow, to maintain consistency with previous MODFLOW-SURFACT modelling³. The unsaturated zone parameters were applied uniformly across all layers, as per **Table 8**. No variations in parameter values or distributions were considered so as to maintain consistency with previous versions of the Wambo groundwater model.

Table 8: Unsaturated Zone Parameterisation

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

3.5.3 WAMBO MINE WORKINGS

The underground longwall extraction and open cut mining, and bore dewatering, 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.

³ Attempts to use Upstream Weighting without Richards Equation were unsuccessful

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 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 rainfall recharge equal to 100% of average rainfall (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 Colliery.

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 Wambo Underground (Arrowfield/Bowfield Seams for Approved Scenario and Woodlands Hill/Arrowfield Seams for Modification Scenario) (Wambo Coal Mine);
- Lemington Open Cut;
- Lemington Underground;
- Riverview;
- Cheshunt;
- United Open Cut(s);
- 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 9** 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 24**. 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 9: 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
		United Open Cut	Whynot	7	1989	1992
		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
		Wambo Open Cut	Whynot	7	2012	2022
	Underground	Ridge Underground	Whybrow	3	1976	1983
		Homestead and Wollemi Underground	Whybrow	3	1979	2002
		South Bates (Whybrow Seam) Underground	Whybrow	3	2015	2017
		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 [^]	2029 [^]
		South Wambo (Arrowfield) Underground	Arrowfield	11	2019*-2023 [^]	2026*-2032 [^]
		South Wambo (Bowfield) Underground	Bowfield	13	2021*	2028*

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 Colliery	Open Cut	United Open Cut	Whynot	7	1989	1992
	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 15.

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 previous approach used to simulate the vertical extent of subsurface fracturing, adopted in Heritage Computing (2012) and retained by HydroSimulations (2014b and 2015) was based on a conservative ratio (A/W) of 0.67 for fractured zone height (A) to panel width (W). This determines the maximum height of subsidence fracturing that has direct connection with the goaf. This version of the model implements the recently released Ditton and Merrick (2014) subsurface fracture height prediction model.

HydroSimulations (2014b) undertook a detailed comparison of predicted fracture zone heights using the previously used A/W ratio and the more rigorous formulas of Ditton and Merrick (2014). The review examined the subsurface fracture heights resulting from longwall mining occurring in the Wambo Seam as part of the North Wambo Underground mine that undermined the previously extracted Homestead-Wollemi mine, the approved (but not yet extracted) Arrowfield Underground Mine, and the United Underground Mine longwalls, located in the Arrowfield Seam. The prediction model confirmed that the simple A/W ratio was conservative for both single-seam and multi-seam mining. As such, the ratio method was retained in HydroSimulations (2014b) to simulate the extent of the fractured zone.

The expansion of mining to include the extraction of longwall panels in the Bowfield Seam and Arrowfield Seam (Approved Scenario) or the Arrowfield Seam and Woodlands Hill Seam (Modification Scenario) will create areas that are undermined by up to four seams. This increase in the number of mined seams is likely to increase the extent of the subsidence controlled A-Zone fracture height. For this assessment, HydroSimulations provides a re-evaluation of the simple 0.67 A/W approach using the formulas and method described in Ditton and Merrick (2014).

Ditton Model Estimates

Ditton and Merrick (2014) have released a new subsurface fracture height prediction model for longwall mines in NSW Coalfields. The new model 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. Formulas are offered for the two conceptual models:

- Geometry Model, which depends on W, H and T; and
- Geology Model, which depends on W, H, T and t' (where t' is the effective thickness⁴ of the bridging stratum where the A Zone height occurs).

The formulas for fractured zone height (A) for single-seam mining are:

- Geometry Model: $A = 2.215 W'^{0.357} H^{0.271} T^{0.372} \pm (0.10 - 0.16) W'$
- Geology Model: $A = 1.52 W'^{0.4} H^{0.535} T^{0.464} t'^{-0.4} \pm (0.10 - 0.15) W'$

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

The 95th percentile (maximum) A-heights are estimated by adding aW' to A, where a varies from 0.10 for supercritical panels to 0.16 (geometry model) or 0.15 (geology model) for subcritical panels. The models have been validated to measured Australian case-studies (including West Wallsend, Mandalong, Springvale, Able, 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). The two instances of observed fractured zone heights at Wambo are detailed in **Table 10**. Note that the single-seam A/W ratios are less than 0.4.

For multi-seam mining, the mining height (T) in the above formulas is replaced by an effective mining height (T') for the upper mined seam that accounts for the additional subsidence caused by mining other seams.

⁴ Typically 15-20 m in the Hunter Coalfield.

Table 10: Observed Fractured Zone Heights at Wambo

MINE (LW)	MINED SEAM	COVER DEPTH	PANEL WIDTH	MINING HEIGHT	MEASURED A-ZONE HORIZON*	A/W	EFFECTIVE BEAM THICKNESS
		H (m)	W (m)	T (m)	A (m)		t' (m)
Homestead (LW9)	Whybrow	80	200	3.30	70	0.35	15
North Wambo (LWs 1-6)	Wambo LWs under-mining Whybrow LW goaf	160-340	263	2.65	60 - 90	0.23-0.34	15 - 30

Source: Ditton Geotechnical Services Pty Ltd, 2014, pers. comm. * height above mined seam

HydroSimulations 2016 Revision

In this revision of the A-Zone subsurface fracture height, the Ditton model estimates and A/W ratio were calculated for each model cell affected by longwall mining (cell-by-cell). This allows a more refined spatial resolution than the previously used method, and serves to highlight the effects that topography (influencing cover depth, H), geology (influencing Effective Stratum Thickness, t') and panel criticality (based on W/H ratio), have on the A-Zone fracture height.

Massive units in the local geology, such as conglomerate, sandstone and igneous rock, may span the fractured strata and limit the progression of continuous fracturing above the mine workings. The minimum thickness of strata required to span the A-Zone for Australian coal fields is provided in **Table 11**. The cell-by-cell calculations in this revision allowed for the adoption of a progressive change in Effective Stratum Thickness based on cover depth for conditions existing in the Hunter Valley (**Table 12**). As seen in **Table 12**, the Effective Stratum Thickness (15-30m) can increase the calculated height of fracture by up to 30% in normal conditions and 50% in adverse conditions (for t'=10m), detail that is lost when averages for cover depth along an entire longwall panel are taken, and provides more conservative estimates for the height of fracture at shallower cover depths.

Table 11: Minimum Effective Stratum Thickness Based on Subsidence Data for Normal and Adverse Rock Mass Conditions in Australian Coalfields

COVER DEPTH (H) (m)	MINIMUM EFFECTIVE THICKNESS (t'min) (m)					
	NORMAL*					ADVERSE**
	Southern	Western	Newcastle/Greta	Tomago/Hunter Valley/Narrabri	Bowen Basin	All Coalfields
>450	40	-	30	30	30	15
350-450	40	40	20	20	20	15
250-350	20	20	20	20	20	10
150-250	20	20	20	15	15	10
<150	20	15	20	15	15	10

Source: Ditton Geotechnical Services Pty Ltd, 2014, pers. comm.

*Normal conditions refer to rock mass behaviour that is unlikely to be adversely affected by geological structure or atypical rock mass conditions (e.g. deep weathering or lack of low hydraulic conductivity units in the B-zone)

**Adverse conditions are those likely to be affected by geological structure or atypical rock mass conditions (see definition above).

Table 12: Impact of Effective Stratum Thickness on A-Zone Fracture Height

Woodlands Hill UG (Longwall 1)	Average Cover Depth over Longwall (m)	Panel Width (m)	Extraction Height (m)	Conditions	Spanning Beam Thickness (m)	A-Zone Height (m)	A Zone 95% Confidence Height (m)
	190	255	3	Normal	30	99	130
					20	116	147
					15	130	161
				Adverse	10	153	184

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' was used to give the fracture height with 95% confidence and provide a conservative estimate. Where the mining of two or more seams 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. For the two layers above the coal seam Sy 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 the coal seam where active mining has occurred. The hydrostratigraphic unit (HSU) zonation in the Groundwater Vistas 6 software has been used to delineate the fractured 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 (pre-mining) hydraulic conductivity patterns and permanent fracture zones. 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 fully fractured. Fracturing to the surface is not anticipated above the southern longwall area (Area 3) of the Modification mine plan.

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 2029;
- Prediction Scenario B: from 2015 to end of the Modification mining in 2032; and
- transient recovery simulation to equilibrium conditions over 200 years for the Modification Scenario.

3.8 MODEL CALIBRATION

The existing model as reported by HydroSimulations (2015) has been re-calibrated as part of the conversion to MODFLOW-USG. The aim of the transient calibration was to achieve a history match to the reported observed groundwater drawdown/depressurisation during the period January 2003 to December 2014 (stress periods 1 to 30), which included the effects of North Wambo Underground Mine Longwalls 1 to 10, dewatering of the old Wambo workings and Whybrow Seam as the North Wambo longwall panels were mined, the start of the Wambo Open Cut pit, as well as varying recharge conditions in response to actual rainfall.

Mt Thorley Warkworth, HVO and United Colliery open cut and underground operations were included in the calibration period.

Figure 25 shows that model stress period durations are initially set to yearly, decreasing to quarterly, and then monthly during the calibration period. This allowed the mine plan progression to be simulated in detail, including heading development and panel extraction.

The storage parameters used in the calibrated groundwater model are presented in **Table 13**. The final calibrated hydraulic conductivities for the stratigraphic column layers and for the constrained and fractured zones are summarised in **Table 14** to **Table 16** for the various mines. The host values are consistent with field measurements (**Table 7**).

Table 13: Calibrated Storage Parameters

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

Table 14: Calibrated Hydraulic Conductivities [m/day] for North Wambo, United and Homestead Mines

LAYER	LITHOLOGY	ZONE	HOST KX	HOST KZ	NORTH WAMBO UNDERGROUND FRACTURE ZONE KZ	UNITED UNDERGROUND WESTERN FRACTURE ZONE KZ	UNITED UNDERGROUND EASTERN FRACTURE ZONE KZ	HOMESTEAD FRACTURE ZONE KZ
1	Alluvium	1	10	1	5 x Kz host	NA	5 x Kz host	5 x Kz host
1	Colluvium/Regolith	17	5.0E-1	1.0E-2	5 x Kz host	NA	5 x Kz host	5 x Kz host
2	Triassic Sandstone, Whybrow Seam overburden	2	1.0E-3	1.0E-5	2.5E-5	NA	2.1E-5	1.0E-4
3	Whybrow Seam	3	2.5E-3	5.0E-5	5.5E-5	NA	5.3E-5	10
4	Whybrow Seam – Wambo Seam interburden	4	1.0E-4	5.0E-6	7.5E-5	1.4E-5	5.0E-5	3 x Kz host
5	Wambo Seam	5	2.5E-3	1.5E-5	10	1.7E-5	5.8E-5	NA
6	Wambo Seam – Whynot Seam interburden	6	1.0E-4	3.0E-6	3 x Kz host	1.9E-5	5.9E-5	NA
7	Whynot Seam	7	4.4E-3	1.4E-5	NA	4.0E-5	6.1E-5	NA
8	Whynot Seam – Woodlands Hill Seam interburden	8	1.0E-4	1.5E-6	NA	5.0E-5	7.8E-5	NA
9	Woodlands Hill Seam	9	1.2E-3	1.3E-5	NA	8.0E-5	8.0E-5	NA
10	Woodlands Hill Seam - Arrowfield Seam interburden	10	1.0E-4	1.1E-6	NA	8.0E-5	8.0E-5	NA
11	Arrowfield Seam	11	5.1E-3	1.1E-5	NA	10	10	NA
12	Arrowfield Seam – Bowfield Seam interburden	12	1.0E-4	1.0E-6	NA	3 x Kz host	3 x Kz host	NA
13	Bowfield Seam	13	5.0E-3	1.0E-5	NA	NA	NA	NA

LAYER	LITHOLOGY	ZONE	HOST KX	HOST KZ	NORTH WAMBO UNDERGROUND FRACTURE ZONE KZ	UNITED UNDERGROUND WESTERN FRACTURE ZONE KZ	UNITED UNDERGROUND EASTERN FRACTURE ZONE KZ	HOMESTEAD FRACTURE ZONE KZ
14	Bowfield Seam - Warkworth Seam interburden	14	1.0E-4	1.0E-6	NA	NA	NA	NA
15	Warkworth Seam	15	1.0E-3	9.7E-6	NA	NA	NA	NA
16	Basal Layer	16	1.0E-4	6.2E-7	NA	NA	NA	NA

Note 1: For each fractured layer $K_x = 2 \times K_x \text{ host}$.

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

Table 15: Adopted Hydraulic Conductivities [m/day] for South Wambo Woodlands Hill, Arrowfield and Bowfield Seam Mining

LAYER	LITHOLOGY	HOST ZONE	HOST KX	HOST KZ	WOODLANDS HILL (LAYER 9) UNDERGROUND FRACTURE ZONE KZ	ARROWFIELD (LAYER 11) UNDERGROUND FRACTURE ZONE KZ	BOWFIELD (LAYER 13) UNDERGROUND FRACTURE ZONE KZ
1	Alluvium	1	10	1	NA	NA	NA
1	Colluvium/Regolith	17	5.0E-1	1.0E-2	1.77E-2 (Areas 1 and 3 only)	NA	NA
2	Triassic Sandstone, Whybrow Seam overburden	2	1.0E-3	1.0E-5	1.76E-5 (Areas 1 and 3 only)	NA	NA
3	Whybrow Seam	3	2.5E-3	5.0E-5	5.30E-5 (Areas 1 and 3 only)	NA	NA
4	Whybrow Seam – Wambo Seam interburden	4	1.0E-4	5.0E-6	5.70E-5 (Areas 1 and 3 only)	5.3E-5	NA
5	Wambo Seam	5	2.5E-3	1.5E-5	6.00E-5 (Areas 1 and 3 only)	1.4E-5	NA
6	Wambo Seam – Whynot Seam interburden	6	1.0E-4	3.0E-6	7.00E-5	1.7E-5	NA
7	Whynot Seam	7	4.4E-3	1.4E-5	8.00E-5	4.0E-5	NA
8	Whynot Seam – Woodlands Hill Seam interburden	8	1.0E-4	1.5E-6	1.00E-4	5.1E-5	NA
9	Woodlands Hill Seam	9	1.2E-3	1.3E-5	10	8.0E-5	NA
10	Woodlands Hill Seam - Arrowfield Seam interburden	10	1.0E-4	1.1E-6	3 x Kz host	8.0E-5	8.0E-5
11	Arrowfield Seam	11	5.1E-3	1.1E-5	NA	10	10
12	Arrowfield Seam – Bowfield Seam interburden	12	1.0E-4	1.0E-6	NA	3 x Kz host	1.0E-4
13	Bowfield Seam	13	5.0E-3	1.0E-5	NA	NA	10

LAYER	LITHOLOGY	HOST ZONE	HOST KX	HOST KZ	WOODLANDS HILL (LAYER 9) UNDERGROUND FRACTURE ZONE KZ	ARROWFIELD (LAYER 11) UNDERGROUND FRACTURE ZONE KZ	BOWFIELD (LAYER 13) UNDERGROUND FRACTURE ZONE KZ
14	Bowfield Seam - Warkworth Seam interburden	14	1.0E-4	1.0E-6	NA	NA	3 x Kz host
15	Warkworth Seam	15	1.0E-3	9.7E-6	NA	NA	NA
16	Basal Layer	16	1.0E-4	6.2E-7	NA	NA	NA

Notes: For each fractured layer $K_x = 2 \times K_{x \text{ host}}$.

Table 16: Adopted Hydraulic Conductivities [m/day] for South Bates Whybrow Seam and Wambo Seam Mining

LAYER	LITHOLOGY	HOST 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	2.5E-2	NA
2	Triassic Sandstone, Whybrow Seam overburden	2	1.0E-3	1.0E-5	2.5E-5	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

LAYER	LITHOLOGY	HOST ZONE	HOST KX	HOST KZ	WHYBROW (LAYER 3) UNDERGROUND FRACTURE ZONE KZ	WAMBO (LAYER 5) UNDERGROUND FRACTURE ZONE KZ
15	Warkworth Seam	15	1.0E-3	9.7E-6	NA	NA
16	Basal Layer	16	1.0E-4	6.2E-7	NA	NA

Notes: For each fractured layer $K_x = 2 \times K_x \text{ host}$.

A total of 13,056 individual target points located at 86 groundwater monitoring sites (including 21 multi-level piezometer locations) have been used to calibrate the model. Targets have been weighted according to reliability of data⁵, with a weighted absolute Root Mean Square (RMS) value of 8.8 m and a Scaled RMS (SRMS) value of 3.9 % which is well below the target SRMS (10%) suggested in the MDBC flow model guidelines (MDBC, 2001). The 2012 Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012) regard SRMS as a useful descriptor of goodness of fit when the only objective is to fit historical measurements of heads, but is less useful when automated calibration methods are used. **Figure 26** and **Figure 27** show the modelled vs observed heads and error distribution (respectively). In the Whybrow overburden, performance is poor at P301 and GW12 (**Figure 26**), both of which are at the western end of North Wambo Underground longwall panels; the model gives more drawdown from mining than has been observed. In the Wambo Seam, performance is good at early and late times at MG09 (**Figure 26**), but deteriorates at mid-times because the simulated drawdown occurs about three months earlier than has been observed; the hydrograph match is very good (**Attachment G**).

Most of the calibration targets are within the upper model layers (alluvium/colluvium, overburden and Whynot and Wambo Seams). There are fewer target data for layers deeper than the Wambo Seam, and they fall mostly within the coal measures interburden layers. **Table 17** shows the number of targets for each model layer and the average residual of all targets within each layer over the calibration period.

Table 17: Average Residual by Model Layer

Layer	Lithology	Number of Targets	Average Residual [^] (m)
1	Alluvium/Colluvium/Regolith	1623	-1.2
2	Triassic Sandstone, Whybrow Seam overburden	3111	-4.1
3	Whybrow Seam	1821	7.4
4	Whybrow Seam – Wambo Seam interburden	11780	0.5
5	Wambo Seam	1778	-13.1
6	Wambo Seam – Whynot Seam interburden	4	-3.1
7	Whynot Seam	9	-18.9
8	Whynot Seam – Woodlands Hill Seam interburden	2240	-0.5
9	Woodlands Hill Seam	4	-15.2
10	Woodlands Hill Seam - Arrowfield Seam interburden	445	-24.2
11	Arrowfield Seam	2	-5.4
12	Arrowfield Seam – Bowfield Seam interburden	216	-23.3
13	Bowfield Seam	2	-17.3
14	Bowfield Seam - Warkworth Seam interburden	0	NA
15	Warkworth Seam	2	26.5
16	Basal Layer	19	-4.8

[^] Defined as Observed minus Modelled; positive means underestimation by the model; negative means overestimation by the model

⁵ Full weight applied to 20% of data; half weight to 64%; 16% removed.

A selection of calibration hydrographs is presented in **Figure 28** to **Figure 37**. The remainder are shown in **Attachments E, F and G**.

Monitoring bores GW08 and GW09, situated in the alluvium north-east of North Wambo Longwall 10 are calibrated for the most part within ± 2 m of observed values. The overall trend in water levels is well represented by the model, with good capture of the sudden decline in 2012, believed to be due primarily to active dewatering of the goaf in the old Wambo workings adjacent to Longwall 8b. However, there was difficulty achieving the magnitude of observed drawdowns in the order of 3 m; a modelled drawdown of 1-1.5 m at these locations was achieved.

Monitoring locations P5 and P6 were located in the alluvium over North Wambo Longwalls 1 and 2, and near to the Wambo open cut pit prior to being destroyed in 2014. Calibration within ± 2 m has been achieved (with a few point exceptions), with modelled values more or less representing an average declining trend-line in response to the approaching open pit. However, the cyclic trends reflecting rainfall recharge are not closely duplicated by the model, primarily due to conditions being averaged over stress periods (quarterly to annual).

P114 and P116 are located in the alluvium over and adjacent to North Wambo Longwall 10A. Model results are calibrated within ± 2 m for P114 and ± 5 m for P116. However, as with the other alluvial monitoring locations, the fluctuations in water level due to rainfall recharge events (and possibly stream interaction) are not well replicated by the model due to the relatively coarse time scale necessarily adopted in regional groundwater models.

Monitoring bore P3 is screened in the Whynot-Woodlands Hill Seams interburden near Wollombi Brook. The model represents well the declining water levels likely to be associated with mining at the United Colliery.

Bore P202 is screened in the overburden above the Whybrow Seam to the east of North Wambo Underground Mine near the junction of Wollombi Brook with Wambo Creek. Observed data show a gradual rise in level since the start of monitoring, in good agreement with the RMC curve. Model levels remain constant at this location over the duration of the calibration period because the bore is positioned within a RIV cell, as a consequence of the minimum 50 m cell size.

Bores P301 and P311 are also screened in the overburden above the Whybrow Seam and are located at the south-west edge of the North Wambo Underground mine. Model results at the locations are over-estimating the drawdown due to mining effects; therefore, modelled effects are likely to be conservative as a result.

The overall mass balance at the end of the calibration period was excellent, with 0.0% error, and less than 0.1% error recorded for each individual time step. 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/day, comprising rainfall recharge (22%), leakage from streams to groundwater (28%), 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 (34%) 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 3.6 ML/day (30% of through-flow) over the calibration period. The average mass balance for the calibration period is presented in **Table 18**.

Table 18: Transient Model Mass Balance

	Inflow (ML/day)	Inflow (%)	Outflow (ML/day)	Outflow (%)
Storage	5.50	45.4	1.82	15.1
General Head Boundaries (Regional Boundary)	0.56	4.6	0.13	1.1
Wells	0	0	0.11	0.93
Drains (Mine Inflow)	0	0	4.49	37.0
Rivers	3.37	27.8	1.43	11.8
Evapotranspiration	0	0	4.13	34.1
Recharge	2.69	22.2	0	0
Total	12.12	100	12.12	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 49 (December 2033). However, the predictive model was initiated from stress period 1 (January 2009) 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 Wambo Underground is during stress period 35 to 42 (January 2019 to December 2026) in the Arrowfield Seam, and during stress period 37 to 44 (January 2021 to December 2028) in the Bowfield Seam.

The Modification Scenario occurs during stress period 39 to 48 (January 2022 to December 2032) in the Arrowfield Seam, and stress period 35 to 45 (January 2019 to December 2029) in the Woodlands Hill Seam.

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 Arrowfield and Bowfield Seams with the Modification mine plan for the Arrowfield and Woodlands Hill 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 and effects of the Modification:

Scenario A (Approved Scenario)	The Approved Mine Plan (for South Wambo Underground Mine in the Arrowfield and Bowfield Seams, and all other mines).
Scenario B (Modification Scenario)	The proposed South Wambo Underground Mine Modification (mining of the Bowfield Seam shifted to the Woodlands Hill Seam and mine life extended for both 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**). Due to the high hydraulic conductivity of the old Whybrow Seam goaves, the Whybrow Seam DRN cells result in the desaturation of the Whybrow Seam (layer 3) where it overlies the North Wambo 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 Wambo open cut pits (e.g. Bates/South Bates, Homestead and Montrose Pits), DRN elevations are set to 0.1 m above the Whynot Seam. DRN cells are kept active for differing periods, representing the historical and proposed pit progression. After an area had been fully mined (i.e. extraction down to the Whynot Seam), 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 3.5.5) to represent the final void.

4.4 WATER BALANCE

The modelled duration of the Approved Scenario in the Arrowfield and Bowfield Seams at South Wambo Underground Mine is during January 2019 to December 2028, corresponding to model stress periods 35 to 44 (**Figure 25**). The Arrowfield Seam and Bowfield Seam model 'drains' are kept active for another year to the end of stress period 45 to capture the effects of delayed fracturing. The duration of the Modification Scenario in the Arrowfield and Woodlands Hill Seams is from January 2019 (stress period 35) to March 2032 (stress period 48). Again, the drains are kept active for another year to the end of stress period 49 to capture the effects of delayed fracturing.

The average water balance for the duration of mining for the two scenarios across the entire model area (for all active mines) is summarised in **Table 19**. The average water balance reports the inflows, outflows and change in storage over the entire model domain.

Table 19: Average Simulated Water Balance at the End of South Wambo Underground Mine

COMPONENT	SCENARIO A APPROVED		SCENARIO B MODIFICATION	
	Inflow (ML/d)	Outflow (ML/d)	Inflow (ML/d)	Outflow (ML/d)
Drains (Mine inflow)	-	4.52	-	4.49
Recharge (direct rainfall)	5.54	-	5.65	-
Evapotranspiration (ET)	-	5.37	-	5.42
River (Leakage / Baseflow)	3.44	1.17	3.43	1.17
Regional GW flow (GHB)	0.56	0.13	0.56	0.13
Storage	6.10	4.45	5.44	3.87
Total	15.64	15.64	15.07	15.07
Storage & Mass Balance	1.65 loss		1.57 loss	

Note: Scenarios A and B are averaged over 11 years and 15 years, respectively. Due to extra open cut infill over the longer period, with higher specified rainfall recharge, the average recharge is greater for Scenario B than for Scenario A.

The results for the predictive scenarios are almost identical. The Modification Scenario has 0.03 ML/day less total mine inflow despite recharge being higher by 0.11 ML/day (due to additional recharge through open cut emplacements over the longer period of the prediction scenario for the Modification). As other mines are unchanged for the two scenarios, the difference is the incremental effect of the Modification. The decrease in total mine inflows (i.e. at Wambo and neighbouring mines) is less than 1 percent. Overall, the net leakage from all streams is about 0.3 percent lower with the Modification.

Discussion of predicted inflows is provided in Section 4.7.

For both the Approved Scenario and the Modification Scenario, the total inflow (recharge) to the groundwater system is approximately 15 ML/day, dominated by rainfall recharge (37%), and leakage from streams into the groundwater (23%). Groundwater discharge is dominated by evapotranspiration (36%) and mine inflow (30%), with approximately 8% 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 38** to **Figure 43**. These figures show groundwater levels in the target Woodlands Hill, Arrowfield and Bowfield Seams in model layers 9, 11 and 13 (respectively).

Figure 38 and **Figure 39** show predicted groundwater levels in the Woodlands Hill Seam (Layer 9) at the end of mining at South Wambo Underground Mine for the two scenarios:

- Scenario A (Approved Mine Plan) in **Figure 38**; and
- Scenario B (Modification) in **Figure 39**.

Predicted water levels are substantially more depressed within the Woodlands Hill Seam for the Modification Scenario (**Figure 39**) compared to the Approved Scenario (**Figure 38**). This is because mining occurs directly within the Woodlands Hill Seam as part of the Modification Scenario, but not in the Approved Scenario.

Figure 40 and **Figure 41** show predicted groundwater levels in the Arrowfield Seam (Layer 11) at the end of mining at the South Wambo Underground Mine for the predictive scenarios. The distribution of groundwater levels reflects the different shapes of the Approved and proposed Modification mine plans, with the depressurised area associated with mining stretched southwards by the Modification. The groundwater levels are similar for the two scenarios.

Water levels in the Bowfield Seam are substantially lower in the Approved Scenario compared to the Modification Scenario, as mining no longer occurs in the layer as part of the Modification (**Figure 42** and **Figure 43**). However, water levels for the Modification Scenario still show some depressurisation due to the mining of the Arrowfield Seam above.

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

4.6 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 the commencement of the prediction period in January 2010 (midway through Longwall 2 of the North Wambo Underground mine) until the end of the predictive simulation in December 2033. The predicted changes can be inferred from **Figure 44** to **Figure 47** where comparisons are made for the two scenarios. In each case, no perceptible difference in baseflow between the two scenarios is evident. The maximum difference for any stream is less than 4.2 kL/day (for Wambo Creek).

Wollombi Brook (**Figure 44**) and Stony Creek (**Figure 47**) both behave consistently as losing streams overall. Wambo Creek (**Figure 46**) is a net gaining stream while the gains and losses of different reaches along North Wambo Creek (**Figure 45**) appear to balance out.

The model results indicate that the Modification has no discernible influence on stream baseflow or stream leakage, beyond the effects of approved mining, for Wollombi Brook, North Wambo Creek and Stony Creek. There is a simulated minor decrease in baseflow (slight negative effect) at Wambo Creek towards the end of mine life due to the Modification in the order of 3 kL/day.

4.7 PREDICTED MINE INFLOW

The predicted groundwater inflows to the South Wambo Underground Mine are shown in **Figure 48** for the two scenarios. Total inflows from both seams for the Approved and Modification Scenarios are shown in **Figure 49**.

For the Approved Scenario, the simulated inflows to the Arrowfield Seam workings are predicted to increase to a peak of about 1.4 ML/day at the end of 2022, and 2.2 ML/day for the Bowfield Seam at the end of 2026. The peak combined inflow is 3.2 ML/day.

For the Modification Scenario, the peak inflows for the Arrowfield Seam are slightly higher at 1.7 ML/day at the end of 2030, and 2.2 ML/day in the Woodlands Hill Seam at 2020. The peak combined inflow is expected to be about 3.5 ML/day.

The increase in peak inflow due to the Modification is expected to be about 0.3 ML/day, while on average inflows are expected to increase from 2.0 ML/day to 2.3 ML/day, over the duration of mining, due to the Modification.

4.8 FRACTURE ZONE SENSITIVITY ANALYSES

In addition to the calibrated models simulating fracture heights calculated using the Ditton and Merrick (2014) method, model runs for both the Modification and Approved Scenarios have been carried out with no fracture zone (no TVM package) to define the magnitude of influence of the fracture zone. The mine activities remained active using the DRN package for that model simulation.

Results of the sensitivity run for the Approved Scenario are shown in **Figure 50** and **Figure 51** for the Arrowfield and Bowfield Seams respectively. Peak inflows to the Arrowfield Seam decrease by 50% to 0.7 ML/day (0.7 ML/day reduction) without the inclusion of fracturing above longwalls. This decrease is most notable toward the middle of the mining period in the Arrowfield Seam, coinciding with mining of the western (W) longwalls. Peak inflows to the Bowfield Seam decrease by up to 0.55 ML/day over time to 1.65 ML/day without the TVM package active, with the largest difference in inflows seen towards the end of mining, again coinciding with the western longwalls.

For the Modification Scenario, peak inflows to the Arrowfield Seam decrease by 60% to 0.7 ML/day (1.0 ML/day reduction) without the inclusion of fracturing above longwalls. Peak inflows to the Woodlands Hill Seam decrease by 1.6 ML/day to 0.55 ML/day over time without the TVM package active.

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 and Wambo Creeks, 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 Wambo Underground Mine would cause depressurisation of the Permian strata. The upper Permian coal measures within the mine footprint are predicted to be essentially desaturated due to mining at North Wambo Underground, United Underground and South Bates Underground. Additional depressurisation would occur due to the approved mining at South Wambo Underground Mine (targeting the Arrowfield and Bowfield Seams). Due to the change from mining the Bowfield Seam to mining the Woodlands Hill Seam, it follows there would be more drawdown in the Woodlands Hill Seam due to the Modification and less than previously predicted in the Bowfield Seam, as discussed below.

Outside the mine footprint, the main effect from the approved South Wambo Underground Mine 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. Groundwater levels in the Woodlands Hill Seam, Arrowfield Seam and Bowfield Seam following completion of mining activities at the South Wambo Underground Mine for the Approved Scenario and the Modification Scenario are shown in **Figure 38** to **Figure 43**.

The cumulative effects of the South Wambo Underground Mine (incorporating the Modification) and all other approved mines active during 2007⁶-2033 (stress period 7 to stress period 49) are presented as drawdowns in **Figure 52** to **Figure 56** for the alluvium / regolith (Layer 1), Whybrow Seam overburden (Layer 2), Woodlands Hill Seam (Layer 9), Arrowfield Seam (Layer 11) and Bowfield Seam (Layer 13).

The comparisons between Scenario A (Approved Mine Plan) and Scenario B (Modification) allow calculation of the incremental changes due to the Modification. **Figure 57** to **Figure 61** show respectively the component of drawdown/depressurisation due to the Modification Scenario for the alluvium / regolith (Layer 1), Whybrow Seam overburden (Layer 2), Woodlands Hill Seam (Layer 9), Arrowfield Seam (Layer 11) and Bowfield Seam (Layer 13) compared to the Approved Scenario. 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 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. The incremental drawdown due to the Modification, as shown on **Figure 57**, is less than 0.2 m and occurs over the central region of the South Wambo Underground Mine operations adjacent to both North Wambo Creek and Wambo Creek.

⁶ At the commencement of the North Wambo Underground Mine (Longwall 1).

In the Whybrow Seam overburden, mining is expected to generate drawdowns of up to 60 m over the South Wambo Underground Mine footprint (**Figure 53**) of which up to 20 m is attributable to the Modification, that is the longwall mining of the southern Woodlands Hill Seam (**Figure 58**). A minor net reduction (up to 5 m) in drawdown due to the Modification is expected to the west of the mine due to the changed layout of the Arrowfield Seam longwalls.

For mining in the Woodlands Hill Seam at South Wambo Underground Mine, drawdowns to more than 200 m are expected over a broad area, in line with the downdip cover depth (**Figure 54**). Most of the drawdown is due to excavation of the Woodlands Hill Seam in the Modification (**Figure 59**), but some is due to mining the deeper Arrowfield Seam.

In the Arrowfield Seam, cumulative drawdowns are expected to reach more than 200 m over a broad area (**Figure 55**). The Modification shows negligible difference in most areas of the Arrowfield Seam except in the locations of the longwall extensions, where there is more than 100m additional drawdown (**Figure 60**).

Cumulative drawdown in the Bowfield Seam is expected to be no more than 100 m for the Approved Scenario (**Figure 56**) over the South Wambo Underground Mine area. Due to the removal of Bowfield Seam mining under the Modification, drawdown associated with mining this seam has been mostly negated. Therefore, groundwater levels in the Bowfield Seam are predicted to be more than 200 m *higher* under the Modification Scenario, over a broad area (**Figure 61**).

5.4 PREDICTED GROUNDWATER INFLOWS

For the Modification Scenario, the combined inflows to the Arrowfield Seam and Woodlands Hill Seam workings at South Wambo Underground Mine are expected to peak at about 3.5 ML/day at the completion of mining the Woodlands Hill Seam. The peak annual inflow volume predicted for the Modification is approximately 1,293 ML/a. This rate is about 0.3 ML/day (112 ML/a) higher than the peak expected for Approved Scenario, which would occur 4-5 years earlier.

The predicted groundwater inflows to the South Wambo Underground Mine are shown in **Figure 48** for the two scenarios. For the Modification, the separate peaks are expected to be about 1.7 ML/day (621 ML/a) in the Arrowfield Seam and about 2.2 ML/day (797 ML/a) in the Woodlands Hill Seam.

5.5 GROUNDWATER LICENSING

For the conservatively mapped extent of alluvium⁷ shown in **Figure 24**, 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 Wambo Underground Mine. It is not possible to isolate the effect on alluvial flows of South Wambo Underground Mine operations alone, as all mines would contribute to such flows.

⁷ A narrower extent based on Transient Electromagnetic mapping is shown in Figure 62.

For the duration of the South Wambo Underground Mine from 2018 to 2033 (stress period 34 to stress period 49), there is predicted to be a net average loss of alluvial groundwater to the underlying rock of 47-53 kL/day for the two scenarios. The difference between the two scenarios averages 4 kL/day with a maximum of 24 kL/day, with the Modification having more effect than the Approved Scenario.

The predicted annual groundwater volumes required to be licensed for the underground operations over the life of the South Wambo Underground Mine for the Approved and Modified Scenarios are summarised in **Table 20** for both alluvial and porous/fractured rock groundwater sources from the commencement to the completion of the South Wambo Underground Mine. During this time, some residual inflow is expected into the South Bates Underground Mine before it is decommissioned.

Table 20: Groundwater Licensing Summary for Duration of South Wambo Underground

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. 26 Max. 28	Av. 31 Max. 36
Water Act 1912 ^{^^}	Porous Rock – South Wambo	Av. 740	Av. 852
		Max. 1,180	Max. 1,293
	Porous Rock – South Bates	Av. 76	Av. 103
		Max. 125	Max. 179
	Porous Rock – total	Max. 1,180	Max. 1,293

[^] For the duration of South Wambo Underground Mine from January 2018 to December 2033.

^{^^} Porous Rock is the Sydney Basin - North Coast Groundwater Source, as defined in the *Draft WSP for the North Coast Fractured and Porous Rock Groundwater Sources*, on exhibition until 20 March 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 20** for all approved underground mine plans and the Modification for the duration of the South Wambo Underground Mine.

5.6 POTENTIAL DRAWDOWN INTERFERENCE IN REGISTERED PRODUCTION BORES

Figure 62 shows the locations of registered alluvial 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 63** shows those registered bores interpreted as drawing groundwater from the Permian strata in relation to 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. Many (59) registered bores are predicted to have greater than 2 m drawdown (**Attachment K**). However, most (55) 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, four have modelled drawdowns greater than 2 m (calculated by subtracting simulated water levels at the end of South Wambo Underground Mine from 2007 water levels). Of these four, three of the bores were previously affected due to the approved and completed North Wambo Underground Mine and have recovering water levels during the Modification. One bore has cumulative drawdown exceeding 2 m under the Approved and Modification Scenarios. The Modification causes no additional bores to be affected.

Table 21 presents a summary of private bores for which the predicted cumulative drawdown is greater than 2 m. Three of the 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 21: Predicted Drawdown Effects at Registered Bores

Work No. (bore)	Licence	Owner Type	Use	Bore Depth (m)	Aquifer	Predicted drawdown [m]			
						Modification Increment [‡]		Cumulative	
GW078577	20WA208559	Private	Irrigation	10	Alluvium	0.1		2.2	
GW078574*	20BL167170	Private	Irrigation	12	Regolith or Permian	-0.5 [#]	-13.4 [#]	1.3	43.4
GW078575*	20BL167171	Private	Irrigation	12	Regolith or Permian	-0.3 [#]	-13 [#]	0.5	23.1
GW078576*	20BL167172	Private	Irrigation	7	Regolith or Permian	-0.4 [#]	-14.4 [#]	1.1	26

[‡] Modification Increment is the difference in groundwater level between the start of mining at the South Wambo Underground Mine (Modification layout) (Stress Period 35) and the end of mining at the South Wambo Underground Mine (Modification layout) (Stress Period 49).

[#] Negative drawdown indicates recovery from drawdown as a result of the North Wambo Underground drawdown during the South Wambo Underground Mine period.

* 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 Wambo open cut mine (by modifying the modelled hydraulic properties to represent spoil). The Hunter Valley Operations South and Warkworth mines remained active during this simulation.

Figure 64 to Figure 68 present the predicted water levels at the end of the modelled 200-year recovery period (i.e. in 2230). There are no discernible signs of residual drawdown in the alluvium and regolith (**Figure 64**). There are small residual drawdowns (up to about 15 m) predicted in the Whybrow Seam overburden (**Figure 65**), in the Woodlands Hill Seam (**Figure 66**), the Arrowfield Seam (**Figure 67**), and the Bowfield Seam (**Figure 68**). In all layers the regional pattern of flow is toward the local watercourses (alluvium) or to the north-east toward the Hunter River.

Figure 69 displays representative hydrographs for the recovery period for five bores located close to the South Wambo Underground Mine workings:

- Bore GW09 situated above Woodlands Hill Seam LW06, and 400m north of Arrowfield Seam LW02E in Layer 1 (in alluvium);
- Bore P116 situated above Woodlands Hill Seam LW09, and Arrowfield Seam LW04E in Layer 1 (in alluvium);
- Bore GW22 situated above Woodlands Hill Seam LW17, and Arrowfield Seam pillar between LW15E and LW16E in Layer 2 (overburden);
- Bore P3 situated 500m north-east of Woodlands Hill Seam LW01 near Wollombi Brook in Layer 8 (Whynot–Woodlands Hill Seam interburden); and
- hypothetical BORE1 situated above Woodlands Hill Seam LW09 in Layer 9 (Woodlands Hill Seam, NWU_BORE1); and above Arrowfield Seam LW02E in Layer 11 (Arrowfield Seam, EAF_BORE1).

Bore locations are shown on **Figure 9** with the exception of hypothetical BORE1 whose location is indicated in an inset diagram in **Figure 69e**. Hydrographs show both 2007 pre-Wambo mining water levels, which are considered “initial” levels (although they include the influence of some historical mining), and pre-South Wambo Underground mining levels at 2017 to show the relative effect of mining at North Wambo Underground.

The alluvial bore GW09 shows that water levels have been lowered by North Wambo Underground mining by approximately 1.4 m prior to mining at South Wambo Underground. An additional drawdown of 0.3 m occurs due to the Modification. Water levels are predicted to have fully recovered above pre- North Wambo Underground levels within 50 years.

The alluvial bore P116 has a minor drawdown from initial water levels of approximately 0.5 m at the end of the Modification, of which over 0.4 m occurred prior to mining at South Wambo Underground. Water levels are shown to recover to within 0.1 m of the initial water levels within 200 years.

Overburden bore GW22 recovers from drawdowns in the order of 36 m (largely due to mining at North Wambo Underground) to with 2m of initial water levels within 200 years.

Interburden bore P3 situated above the Woodlands Hill Seam has a drawdown of 26 m at the end of the Modification. Almost 25 m of this drawdown occurred prior to mining at South Wambo Underground. Water levels are predicted to recover several metres above the initial water levels, reflecting the initial water levels already being depressurised by other mining in the area.

The hypothetical BORE1 shows rapid recovery of Woodlands Hill Seam water levels from a drawdown in the order of 100 m to a water level that is about 15 m below initial conditions at 200 years post-mining. Fifty percent recovery is achieved after about 20 years. The recovery is very similar in the Arrowfield Seam, with final water levels approximately 20m below initial levels.

This proposed Modification could not be considered to have a significant effect on the quality of groundwater or surface water around Wambo. The modelling shows no potential for increased flux of more saline water, due to the Modification, from the Permian strata to the alluvium for a period of at least 100 years, and only minor zones of enhanced upflow to alluvium after 200 years along the central part of North Wambo Creek and along Stony Creek near its confluence with Wambo Creek. The groundwater levels across the footprint of the South Wambo Underground Mine are expected to settle at about 15 m below initial conditions due to permanent changes in hydraulic conductivity and storage where subsidence would occur.

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 22 to **Table 24** 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 22: Highly Productive Alluvial Aquifer – Minimal Impact Considerations

Aquifer	Unnamed Upriver Alluvium in WSP in the Lower Wollombi Brook Water Source (part of the <i>Hunter Unregulated and Alluvial Water Sources 2009</i>)	
Type	Alluvial Aquifer	
Category	Highly 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 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. A cumulative drawdown of more than 2 m is predicted at one privately owned water supply work in the mapped ‘highly productive’ alluvial aquifer on Wambo Creek. The Modification would result in additional drawdown at this bore of approximately 0.1 m. 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 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.		Level 2 A cumulative drawdown of more than 2 m is predicted at one privately owned water supply work in the mapped ‘highly productive’ alluvial aquifer on Wambo Creek. The Modification would result in additional drawdown at this bore of approximately 0.1 m. 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.

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.

Table 23: Less Productive Alluvial Aquifer – Minimal Impact Considerations

Aquifer	Alluvium outside the boundary of the 'Highly Productive' <i>Hunter Alluvial Water Source</i>	
Type	Alluvium	
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.		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.
<u>Water pressure</u> 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.
<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. 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.

Table 24: Less Productive Porous Rock Aquifer – Minimal Impact Considerations

Aquifer	Sydney Sandstone Central Coast (to be included within the <i>Draft North Coast Fractured and Porous Rock Groundwater Sources WSP</i>)	
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 There is currently no Water Sharing Plan relevant to this porous rock aquifer. 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 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.

6 CONCLUSIONS

The assessment for this Modification (MOD 12) considers the following changes to the South Wambo Underground Mine:

- changing and extending the approved longwall layout in the Arrowfield Seam (including the addition of areas not previously approved for mining);
- mining of the Woodlands Hill Seam instead of the Bowfield Seam and changing and extending the longwall layout;
- extending the approved mine life by seven years (from 2025 to 2032);
- increasing the approved run-of-mine underground production rate from 7.5 million tonnes per annum to 9.75 million tonnes per annum; and
- ancillary changes to gas drainage, surface facilities and mine access infrastructure.

This Groundwater Assessment for the Modification has been conducted with reference to the work done for three earlier modifications: Heritage Computing (2012) for North Wambo Underground Longwalls 9 and 10; HydroSimulations (2014b) for North Wambo Underground Longwall 10A; and HydroSimulations (2015) for South Bates 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 Bates Underground Mine reporting (HydroSimulations, 2015), but was converted to MODFLOW-USG Beta for improved mass balance when simulating longwall mining, as well as faster run-times. The existing rectilinear grid structure of the previous model was retained to enable direct comparison of results. The model was then re-calibrated using the latest data whilst ensuring consistency with previously reported model results.

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:

- The Modification Scenario has a predicted peak mine inflow (during mining of the Woodlands Hill Seam and the Arrowfield Seam) of about 3.5 ML/day (1,293 ML/a).
- The peak annual inflow volume predicted for the Modification is approximately 0.3 ML/day (112 ML/a) higher than the peak simulated for South Wambo Underground Mine for the Approved Scenario, and the peak inflow would occur about four years later.
- The upper Permian coal measures within the mine footprint are predicted to be essentially dewatered due to approved mining at North Wambo Underground, United Underground Mine and South Bates Underground. Additional depressurisation would occur due to the approved mining at South Wambo Underground Mine (targeting the Arrowfield and Bowfield Seams). Due to the change from mining the Bowfield Seam to mining the Woodlands Hill Seam, there would be more drawdown in the Woodlands Hill Seam due to the Modification and less in the Bowfield Seam. Drawdown in the Permian strata would extend to the north-west and south due to the extension of the mine plan, however this is not considered significant from a regional perspective.

- The Modification would cause negligible additional drawdown in a small portion of the alluvium adjacent to North Wambo Creek and South Wambo Creek compared with the Approved Scenario (in the order of 0.2 m). There would be no discernible additional drawdown along the highly productive Wollombi Brook alluvium.
- There would be no additional private groundwater users in the alluvium affected as a result of the Modification. One private bore screened in the alluvium (GW078577) has a predicted drawdown of 2.1 m for the Approved Scenario, and 2.2 m for the Modification Scenario.
- Limited information is available on three other privately-owned bores in the vicinity of Wambo. Depending on extraction depth, these bores may experience more than 2 m cumulative drawdown. However, these drawdowns are due to the cumulative effects of all mining in the Wambo district, and are not directly a result of the Modification. No privately owned registered bores are expected to be additionally affected by drawdown caused by the Modification.
- The maximum net loss of groundwater from the alluvium (within the Wambo leases area) to underlying rock strata for the South Wambo Underground Mine and all other approved mines is expected to increase from 28 ML/a to 36 ML/a due to the Modification over the period of mining at the South Wambo Underground Mine. This amount is within the existing alluvial aquifer water licence volume held by WCPL under the WSP.
- The Modification would have no discernible or negligible effect on stream baseflow or natural river leakage for Wollombi Brook, North Wambo Creek, Wambo Creek or Stony Creek stream systems, beyond the effects of approved mining. The predominant gaining/losing natures of the streams would not be altered.
- This proposed Modification could not be considered to have a significant effect on the quality of groundwater or surface water around Wambo. The modelling shows no potential for increased flux of more saline water, due to the Modification, from the Permian strata to the alluvium for the full recovery simulation of 200 years. The groundwater levels across the footprint of the South Wambo Underground Mine are expected to settle at about 15 m below initial conditions.

No additional groundwater 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.

It is recommended that the approved GWMP is augmented following approval to include the installation of additional groundwater monitoring sites above the southern longwall area.

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 relinquishment of an equivalent portion of water access licences as a direct offset for potential groundwater inflows into the underground.

7 BIBLIOGRAPHY

- AGE [Australasian Groundwater and Environmental Consultants Pty Ltd], 2003, *Wambo Development Project Groundwater Impact Assessment*. Report prepared for Wambo Coal Pty Ltd. April 2003.
- AGE [Australasian Groundwater and Environmental Consultants Pty Ltd], 2010, *Warkworth Mine Extension Groundwater Impact Assessment*. Report prepared for Warkworth Mining Pty Ltd, April 2010.
- AGE [Australasian Groundwater and Environmental Consultants Pty Ltd], 2014, *Warkworth Continuation 2014 Groundwater Assessment*. Report prepared for EMGAMM and Warkworth Mining Pty Ltd, May 2014. Available at:
<https://majorprojects.affinitylive.com/public/58ec858f4e1ee0d44ad2dfbee414f60f/20.%20Warkworth%20Continuation%20Project%20EIS%20-%20Appendix%20K%20Groundwater.pdf>
- ANZECC [Australian and New Zealand Environment and Conservation Council], 2000, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*.
- Barnett, B, Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A. and Boronkay, A., 2012, *Australian Groundwater Modelling Guidelines*. Waterlines report 82, National Water Commission, Canberra.
- BoM [Bureau of Meteorology], 2015, *Climate Data Online*. Available at:
<http://www.bom.gov.au/climate/averages>
- Coal and Allied Operations Pty Ltd, 2007, *Hunter Valley Operations Annual Environmental Management Report* January - December 2006.
- Coffey Geosciences Pty Ltd, 2002, *United Colliery Hydrogeological Assessment – United Colliery Mine Extension*, Warkworth NSW. 24 April 2002.
- Department of Environment, Climate Change and Water, 2010, *NSW Climate Impact Profile – The Impacts of Climate Change on the Biophysical Environment of New South Wales*.
- Department of Mineral Resources, 1993, *Hunter Coalfield Regional Geology* 1:100,000 Sheet.
- Ditton, S. and Merrick, N, 2014, A New Subsurface Fracture Height Prediction Model for Longwall Mines in the NSW Coalfields. Geological Society of Australia, 2014 Australian Earth Sciences Convention (AESC), Sustainable Australia. Abstract No 03EGE-03 of the 22nd Australian Geological Convention, Newcastle City Hall and Civic Theatre, Newcastle, New South Wales. July 7 - 10. Page 136.
- Environmental Resource Management Australia, 2008, *HVO South Coal Project*, Groundwater Assessment Report.
- ESI [Environmental Simulations Inc.], 2011, *Guide to Using Groundwater Vistas*. Reinholds, Pennsylvania, USA.
- Forster, I. and Enever, J., 1992, *Hydrogeological Response of Overburden Strata to Underground Mining - Central Coast New South Wales*. Office of Energy Report OOE 92/105. ISBN 0 7305 6964 0. Volume 1: 78p + 26 figs.
- GHD Pty Ltd, 2007, Report for *Lower Section, North Wambo Creek Geophysical Survey*.
- Gilbert and Associates, 2003, *Wambo Development Project Surface Water Assessment*.

- Glen R.A. and Beckett J., 1993, *Hunter Coalfield Regional Geology 1:100 000*, 2nd edition. Geological Survey of New South Wales, Sydney.
- Groundwater Imaging, 2012, *A Transient Electromagnetic Investigation of the Extent of the Wollombi Brook Alluvium at the Wambo Coal Mine Site*.
- Harbaugh. A. W., Banta E. R., Hill M. C., and McDonald M. G., 2000, *MODFLOW-2000 - The USGS Modular Groundwater Flow Model – User Guide to Modulization Concepts and the Groundwater Flow Process*: U. S. Geological Survey Open-File Report 00-0092.
- Heritage Computing, 2012, *North Wambo Underground Mine Modification Groundwater Assessment* . Report for WCPL. Doc HC2012/13, August 2012.
- HLA-Envirosciences Pty Ltd, 1999, *Effect of Longwall Panel 9 Mining on Surface and Groundwater* – Homestead Underground Mine Warkworth NSW.
- Hunt, R. J., Walker, J. F. and Doherty, J., 2008, *Using GSFLOW to simulate climate change in a northern temperate climate*. In: Poeter, Hill, & Zheng, MODFLOW and More 2008: Ground Water and Public Policy - Conference Proceedings, Golden Colorado, 109-113.
- Hunter Catchment Management Trust, 2002, *Integrated Catchment Management Plan for the Hunter Catchment 2002*.
- HydroGeoLogic Inc., MODFLOW SURFACT Software (Version 4), Herdon, Virginia, USA.
- HydroSimulations, 2014a, *Wambo Coal Open Cut Water Licence – Groundwater Assessment*. Report for WCPL. Doc HC2014/19, August 2014.
- HydroSimulations, 2014b, *North Wambo Underground Mine Longwall 10A Modification – Groundwater Assessment*. Report for WCPL. Doc HC2014/20, September 2014.
- HydroSimulations, 2015, *South Bates (Wambo Seam) Underground Mine Modification – Groundwater Assessment*. Report for WCPL. Doc HC2015/026, July 2015.
- Karacan, C., Ruiz, F.A., Cote, M., Phipps, S. 2011, *Coal Mine Methane: a review of capture and utilization practices with benefits to mining safety and greenhouse gas reduction*. International Journal of Coal Geology, 86 (2011) 121-156.
<http://www.epa.gov/cmop/docs/cmm-paper-2011.pdf>
- Laubach S.E., R.A. Marrett, J.E. Olsen and A.R. Scott, 1998, *Characteristics and origins of coal cleat: A review*. Int. Journal of Coal Geology Vol. 35, p 175-207.
- Mackie, C.D., 2009, *Hydrogeological Characterisation of Coal Measures and Overview of Impacts of Coal Mining on Groundwater Systems in the Upper Hunter Valley of NSW*. PhD Thesis submitted to Faculty of Science, University of Technology, Sydney N.S.W. Australia.
- Mackie Environmental Research, 2002, *Extension of Warkworth Coal Mine: Assessment of Environmental Impacts, Surface and Groundwater Management Studies*. Aug. 2002.
- McDonald, M. G. and Harbaugh, A. W., 1988, *MODFLOW: A modular three-dimensional finite-difference ground-water flow model*. U.S.G.S., Scientific Publications Co., Washington.

- MDBC (Murray Darling Basin Commission), 2001, *Groundwater Flow Modelling Guideline*. Prepared by Aquaterra Pty Ltd, November 2000, Project No. 125, Final guideline issued January 2001.
- Meaney, K. 1997, Investigation of the potential for pre-drainage of the lower seams at Appin Colliery utilising hydraulic fracturing. ACARP project C5036. CSIRO, Australia.
- Merrick, N. P. and Merrick, D. P., 2015, Does MODFLOW-USG / AlgoMesh give the same results as MODFLOW-SURFACT? Keynote Presentation, Australian Groundwater Conference, 3-5 November 2015. National Centre for Groundwater Research and Training, AGC2015 Abstracts Booklet, p83.
- MSEC (Mine Subsidence Engineering Consultants), 2016, *South Wambo Underground Mine Modification Subsidence Assessment - Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Modification Application for the Proposed Longwalls in the Woodlands Hill and Arrowfield Seams*. Report No. MSEC 799. Report prepared for Wambo Coal Pty Ltd, July 2015.
- NSW Department of Planning, 2008, *Impacts of Potential Underground Coal Mining in the Wyong Local Government Area: Strategic Review*. ISBN 978 0 7347 5900 9, July 2008, 99p.
- NSW Government, 2012, *NSW Aquifer Interference Policy* – NSW Government policy for the licensing and assessment of aquifer interference activities. Office of Water, NSW Department of Primary Industries, September 2012.
- Panday, S., Langevin, C.D., Niswonger, R.G., Ibaraki, M., and Hughes, J.D., 2013. *MODFLOW-USG version 1: An unstructured grid version of MODFLOW for simulating groundwater flow and tightly coupled processes using a control volume finite-difference formulation*. U.S. Geological Survey Techniques and Methods. Book 6.
- Pittock, B, 2003, *Climate Change – An Australian Guide to the Science and Potential Impacts*. Australian Greenhouse Office.
- SCT Operations Pty Ltd (SCT), 2008, ACARP Project C13013: *Aquifer Inflow Prediction above Longwall Panels*. Report to the Australian Coal Association Program, September 2008.
- United Collieries Pty Ltd, 2006, *Annual Environmental Management Report* January - December 2006.
- United Collieries Pty Ltd, 2007, *Annual Environmental Management Report* January - December 2007.
- United Collieries Pty Ltd, 2008, *Annual Environmental Management Report* January - December 2008.
- United Collieries Pty Ltd, 2009, *Annual Environmental Management Report* January - December 2009.
- Wambo Coal Pty Limited, 2003, *Wambo Development Project Environmental Impact Statement*.
- Wambo Coal Pty Limited, 2005, *Wambo Seam Underground Mine Modification Statement of Environmental Effects*.

Wambo Coal Pty Limited, 2008, *Annual Environmental Management Report* — July 2007 to June 2008.

Wambo Coal Pty Limited, 2009, *Annual Environmental Management Report* — July 2008 to June 2009.

Wambo Coal Pty Limited, 2010, *Annual Environmental Management Report* — July 2009 to June 2010.

Wambo Coal Pty Limited, 2011, *Annual Environmental Management Report* — July 2010 to June 2011.

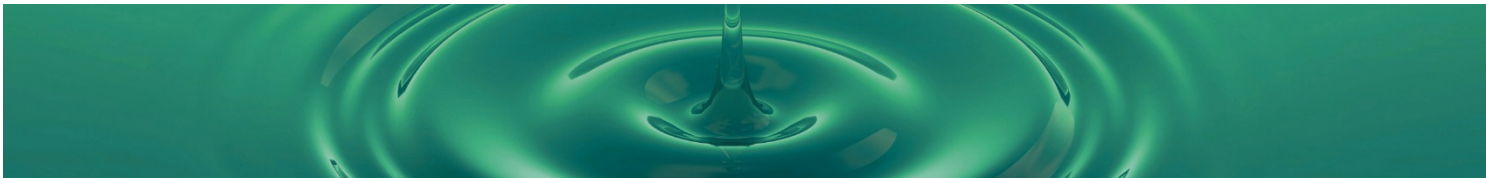
Wambo Coal Pty Limited, 2012, *Annual Environmental Management Report* — July 2011 to June 2012.

Wambo Coal Pty Limited, 2014, *Annual Environmental Management Report* — 2013.

Wambo Coal Pty Limited, 2015a, *Wambo Coal Groundwater Monitoring Program*. Document WA-ENV_MNP-509.1, Revision No. 10, October 2015.

Wambo Coal Pty Limited, 2015b, *Wambo Coal Surface and Groundwater Response Plan*. Document EMP017, Revision No. 9, October 2015.

Wambo Coal Pty Limited, 2015c, *North Wambo Creek Subsidence Response Strategy*. Document NWCSRS-R4, Revision No. 4, March 2015.



FIGURES

FIGURES 1 TO 69

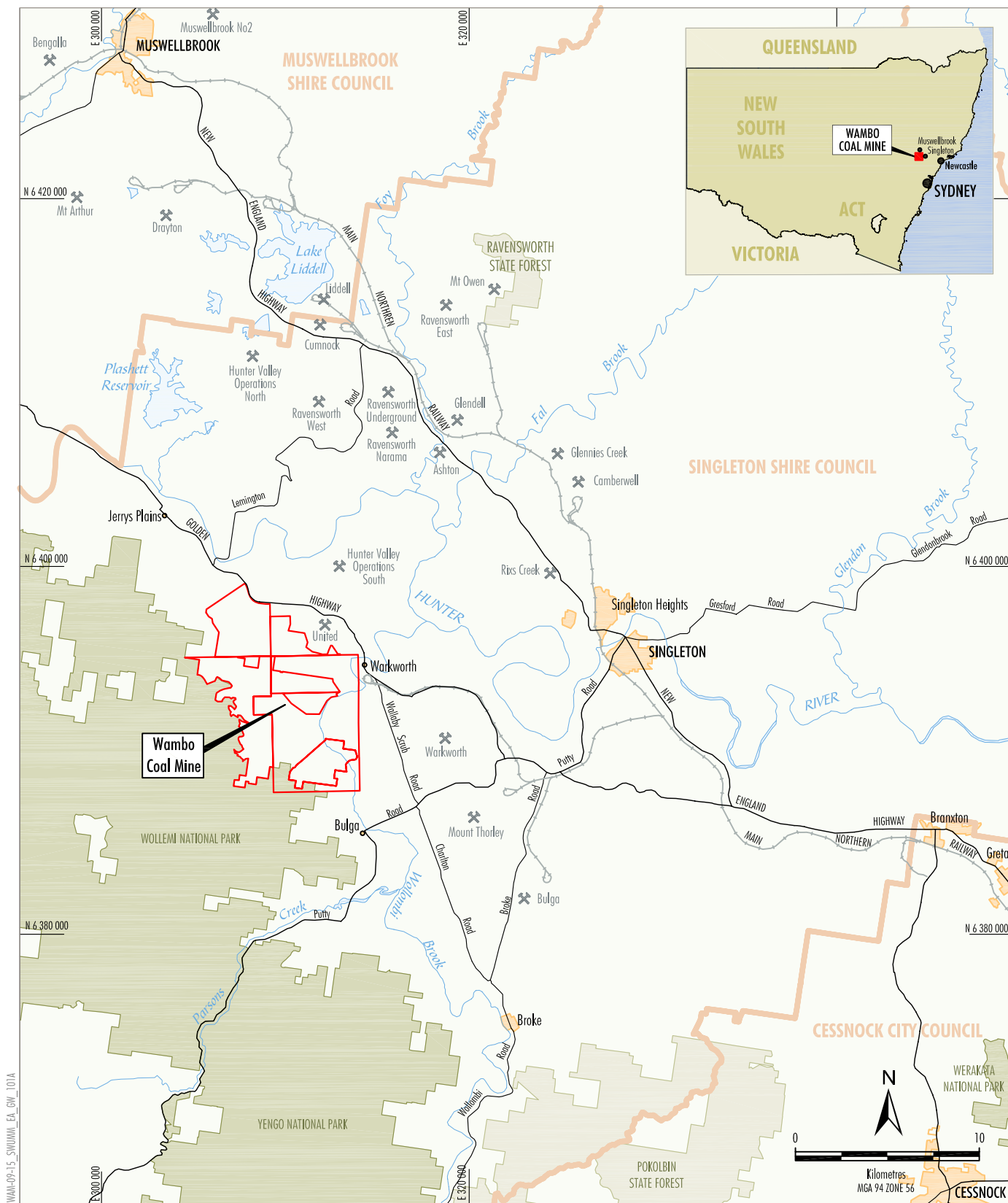
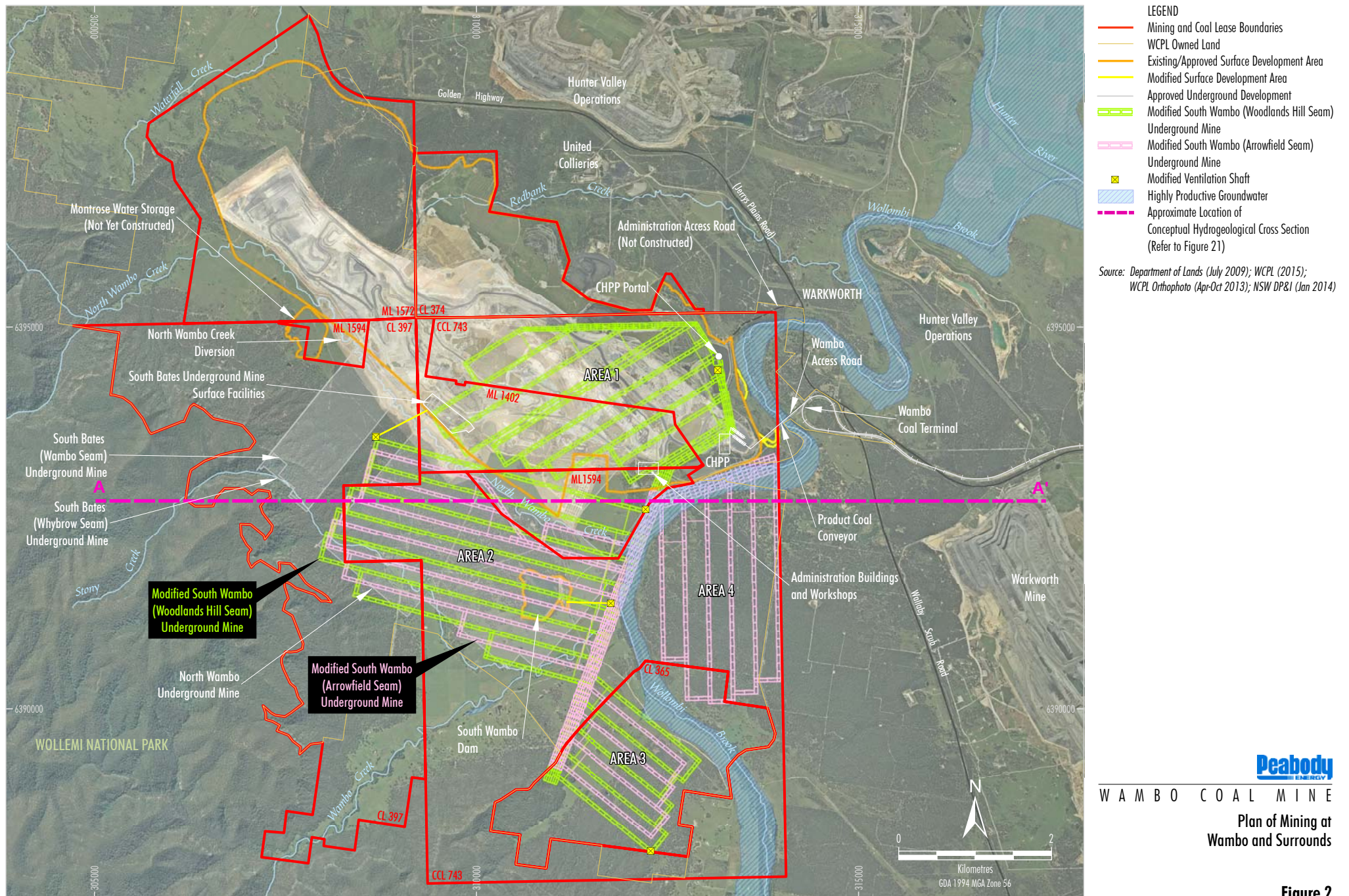


Figure 1



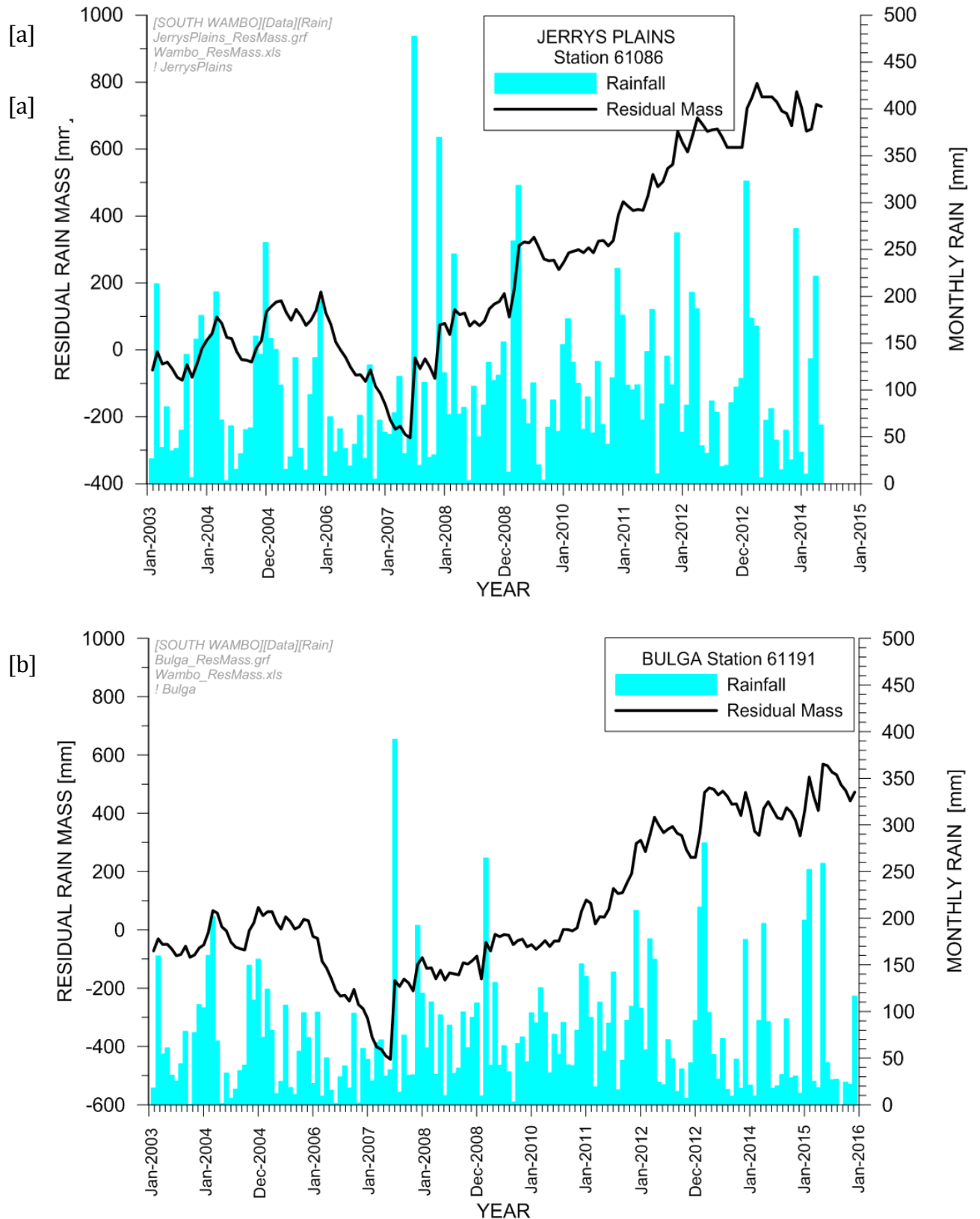
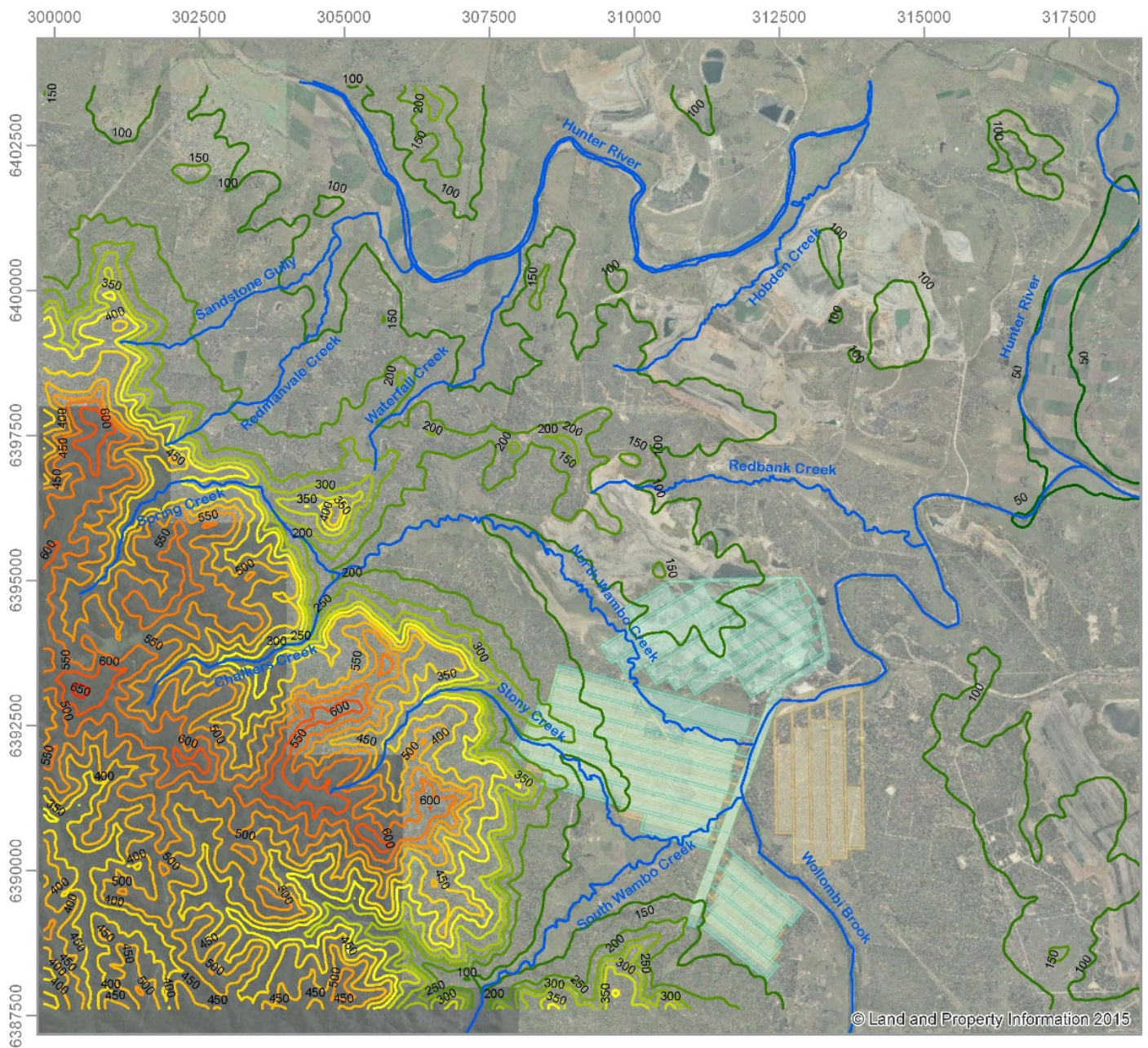


Figure 3: Rainfall Residual Mass Curves for [a] Jerrys Plains Post Office and [b] Bulga (South Wambo)



Elevation (mAHD)



0 0.5 1 2 3 4 km



Scale: 100,000 @ A4
GDA 1994 MGA Zone 56

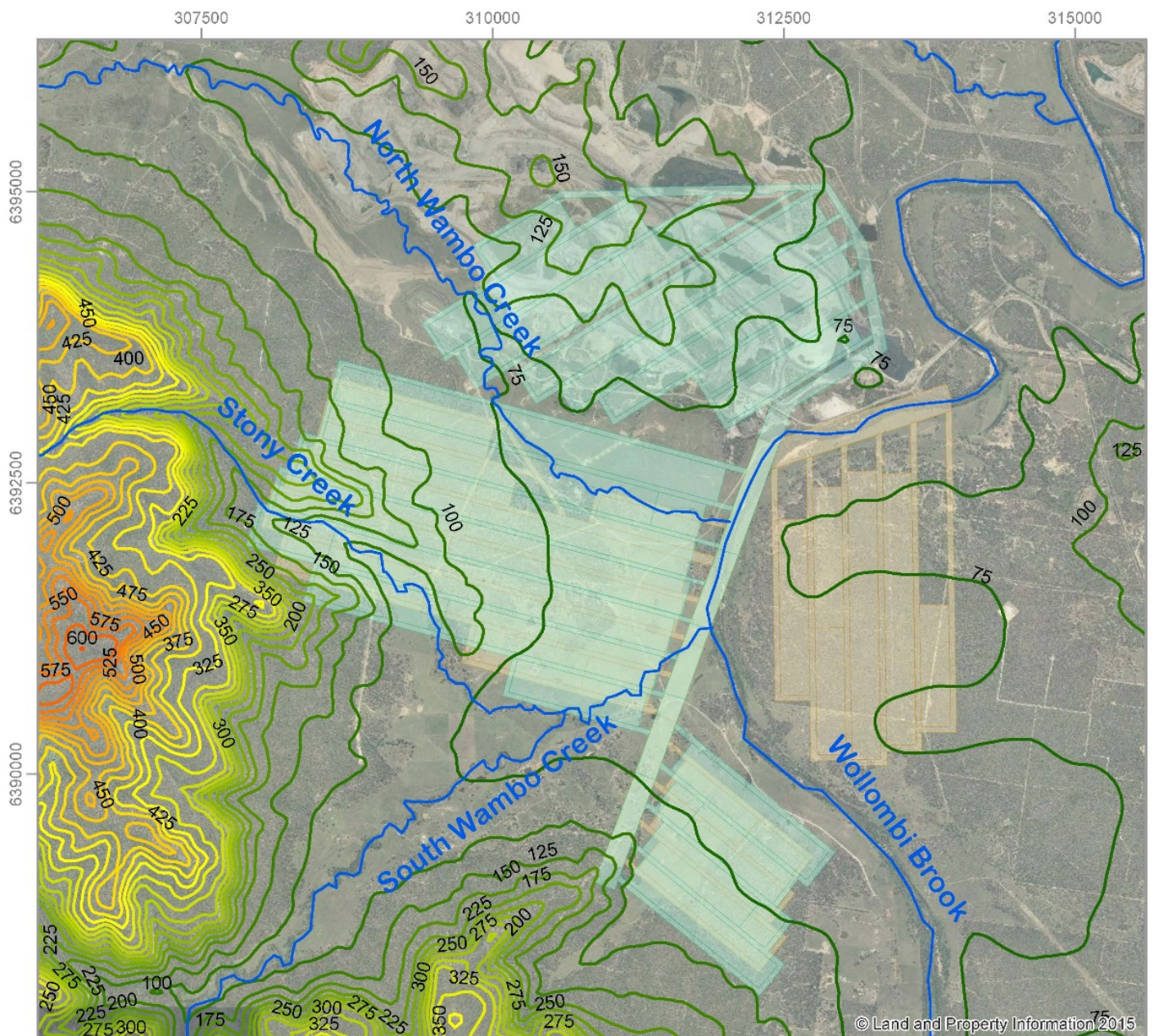
Wambo Coal Pty Ltd
South Wambo Modification

Regional Topography

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HYDR
SIMULATIONS

Figure 4



0 0.5 1 2 3 km

Elevation (mAHD)

50	275	525
75	300	550
100	325	575
125	350	600
150	375	625
175	400	650
200	425	Rivers and Creeks
225	450	Woodlands Hill Seam Layout
250	475	Arrowfield Seam Layout
	500	



Scale: 50,000 @ A4
GDA 1994 MGA Zone 56

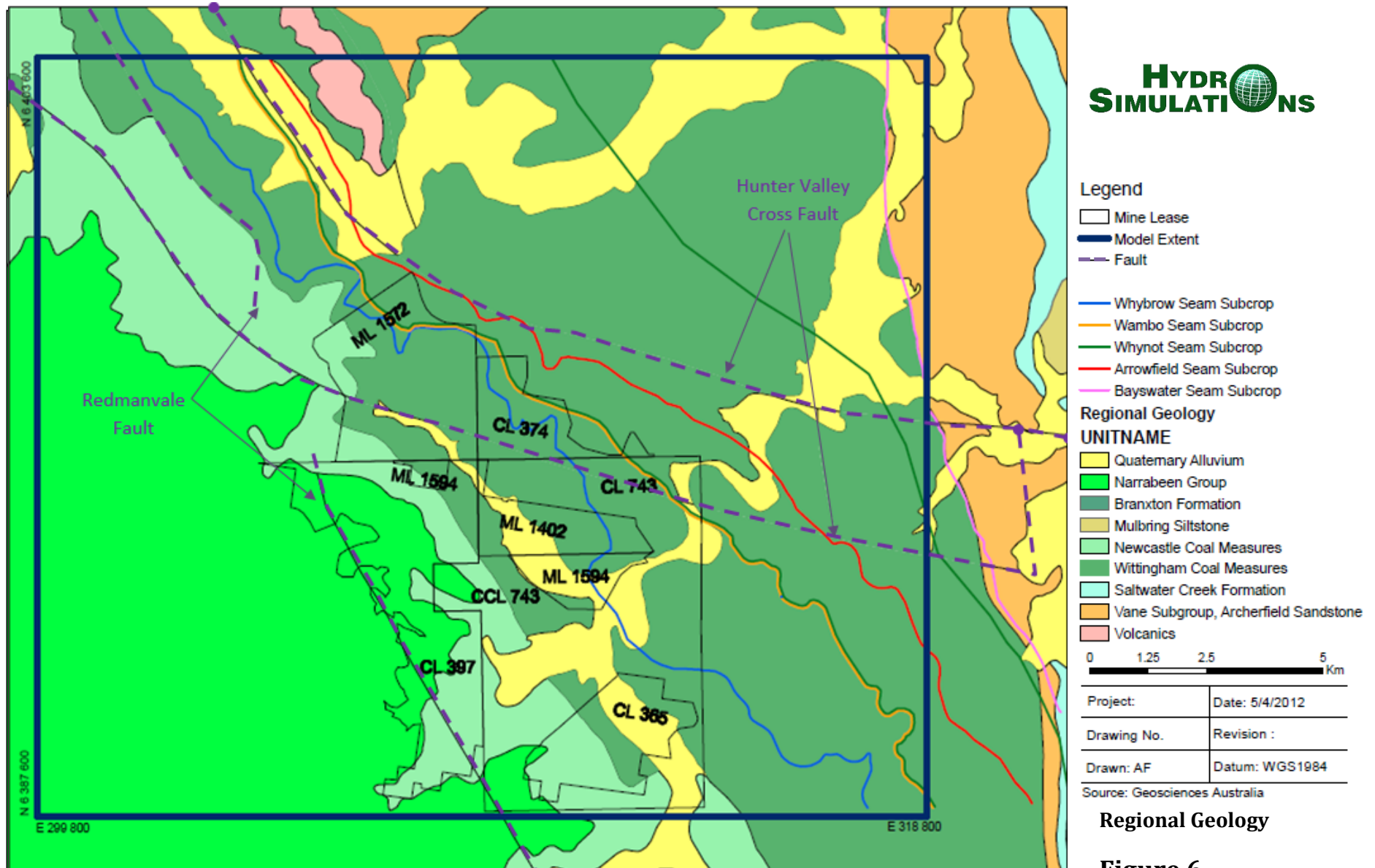
Wambo Coal Pty Ltd
South Wambo Modification

Local Topography

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Rev: A.
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Date: 27/11/2015
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HYDR
SIMULATIONS

Figure 5



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 ⁴	
			Milbrodale Formation		
			Mount Thorley Formation	Arrowfield Seam ²	
				Bowfield Seam ²	
				Warkworth Seam ³	
			Fairford Formation		
			Burnamwood Formation	Mount Arthur Seam	
				Piercefield Seam	
				Vaux Seam	
				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 to be mined by the Wambo Coal Mine where the upper three plies of the Warkworth Seam combine with the two plies of the Bowfield Seam.

⁴ Coal reserves proposed to be mined at Wambo Coal Mine as part of this Modification.

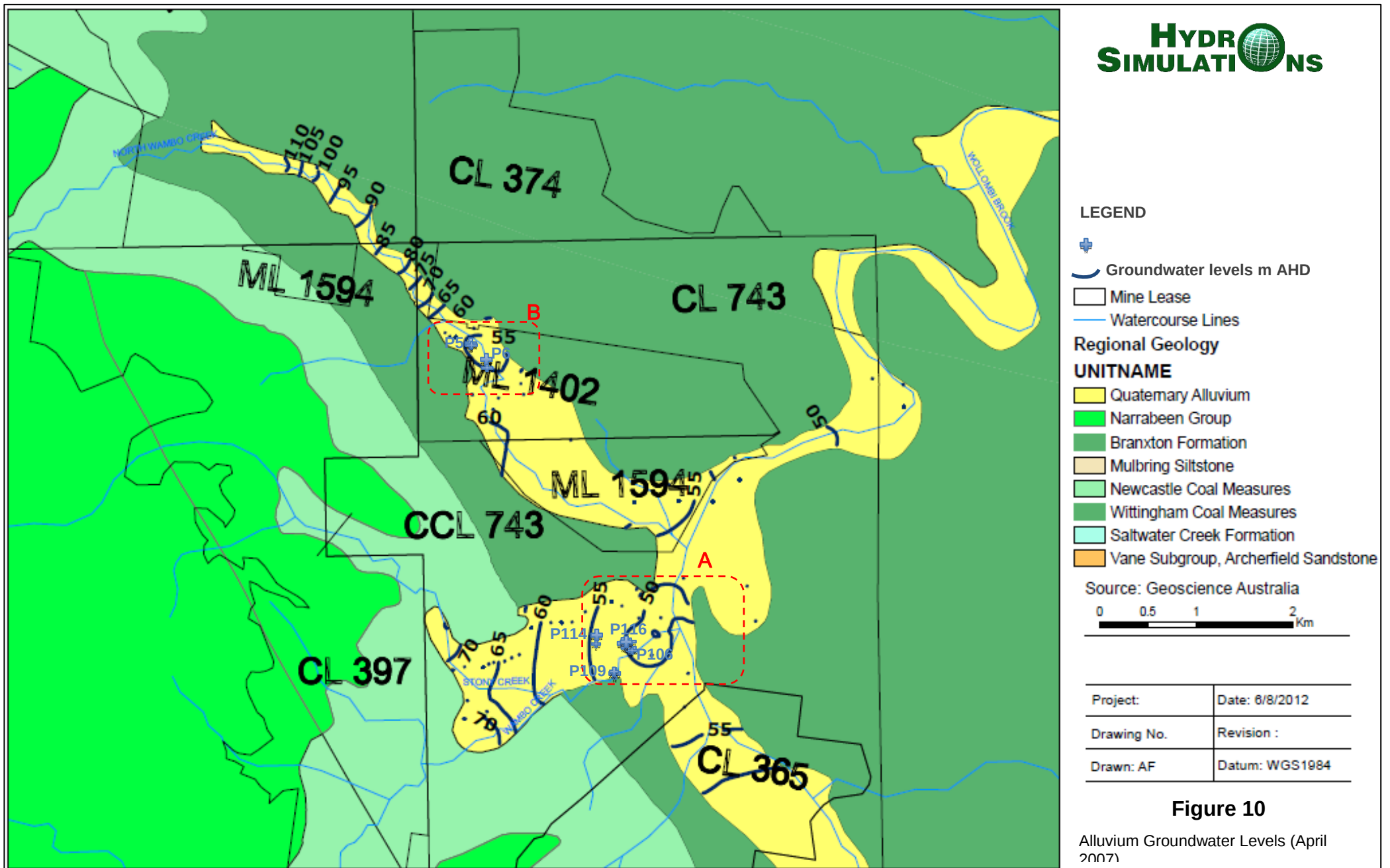
WAM-09-15_SWUMM_EA_GW_0018

After: DMR (1993)



WAMBO COAL MINE
Stratigraphy of the Wambo Area

Figure 7



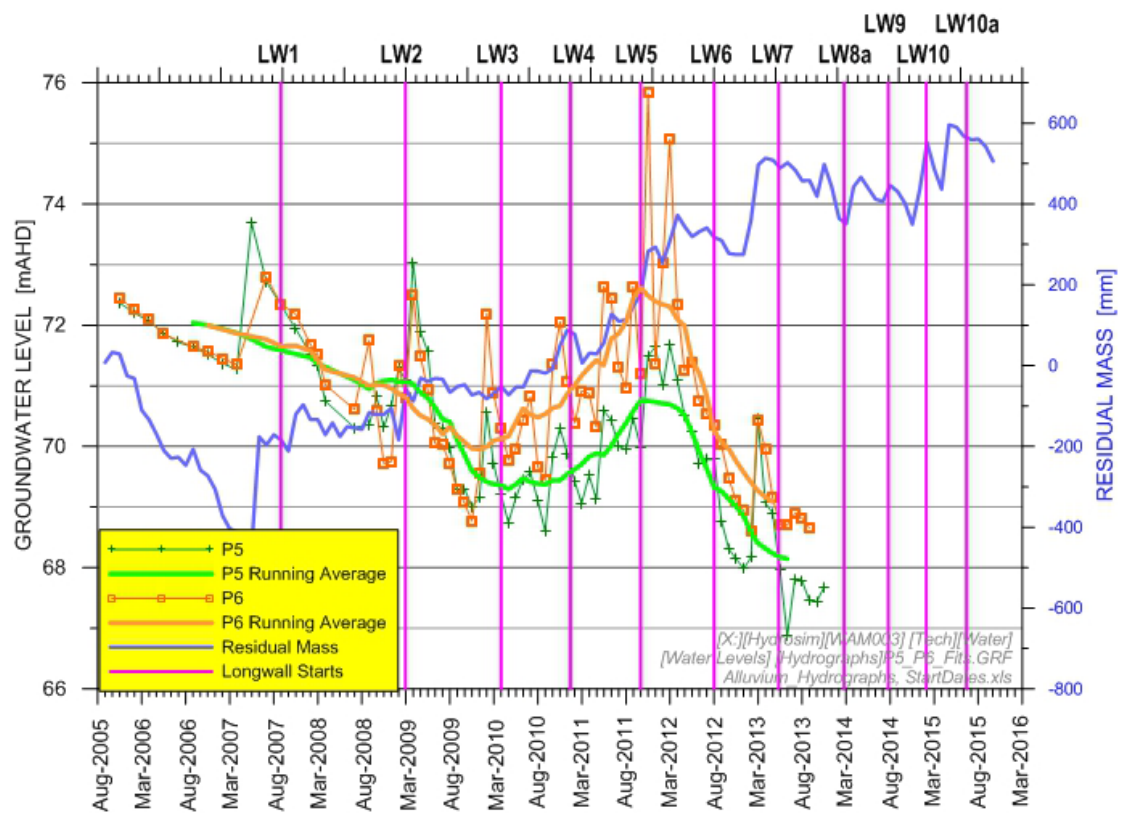


Figure 11: North Wambo Creek Observed and Smoothed Hydrographs at Monitoring Bores P5 and P6

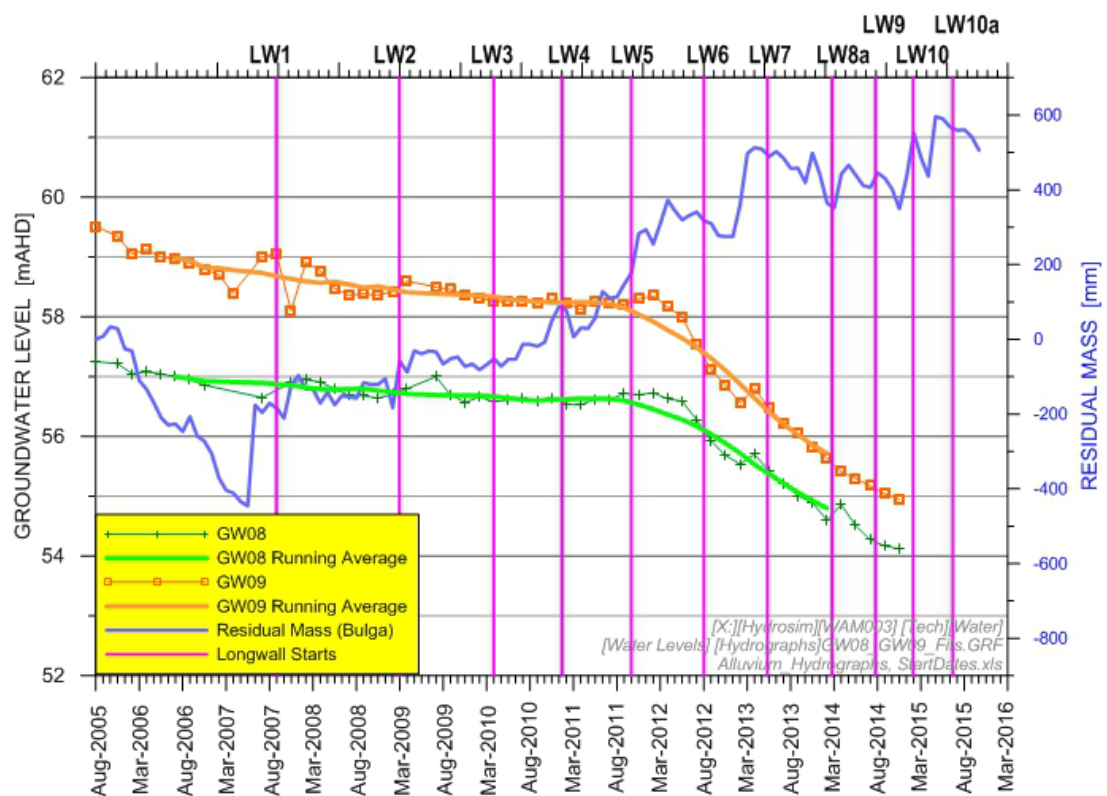


Figure 12: North Wambo Creek Observed and Smoothed Hydrographs at Monitoring Bores GW08 and GW09

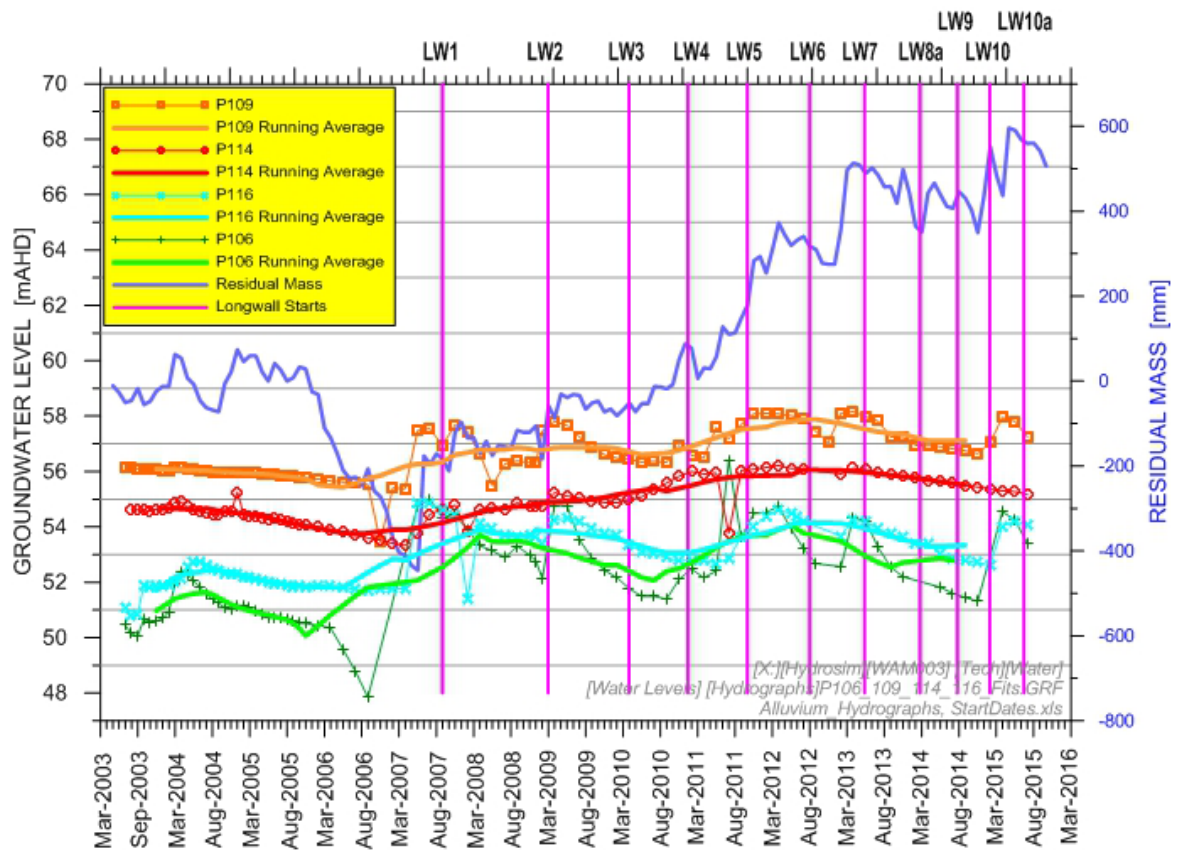


Figure 13: Alluvium Observed and Smoothed Hydrographs at Monitoring Bores P114 and P116

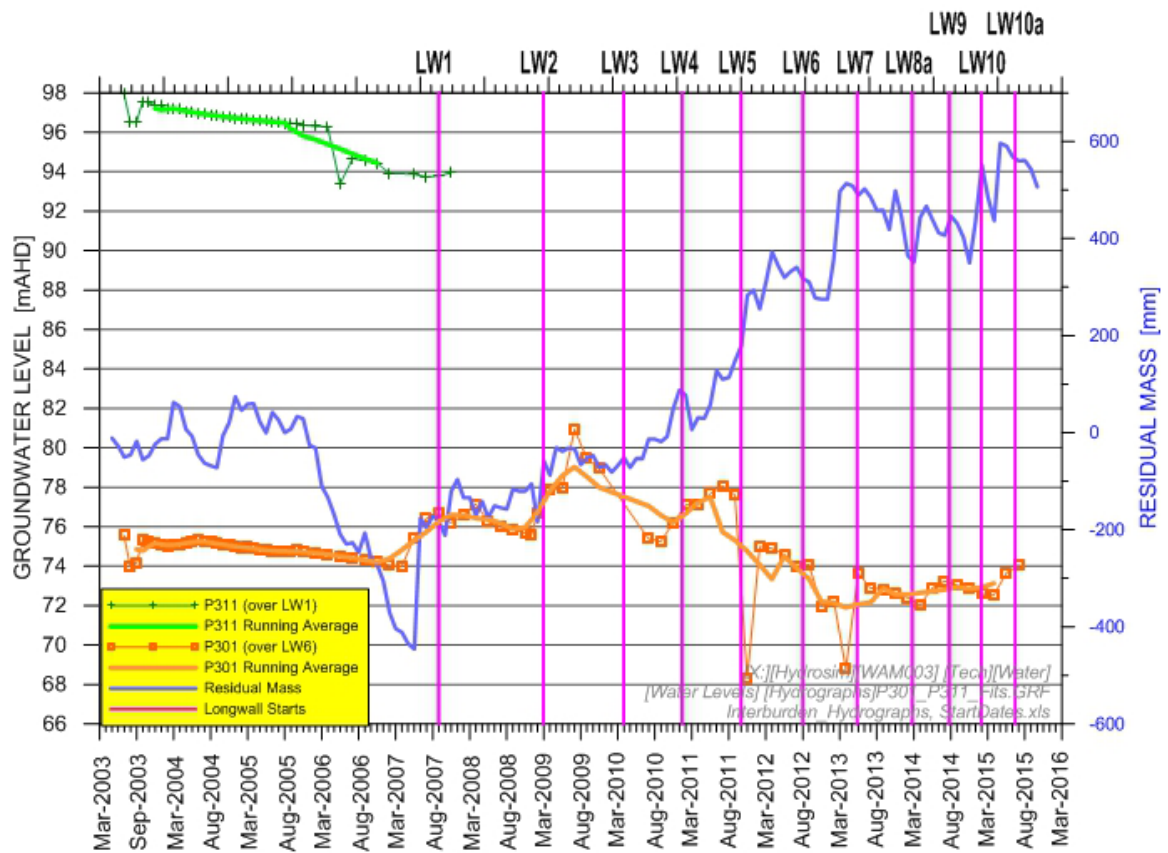


Figure 14: Interburden Observed Hydrograph at Monitoring Bore P301 and P311

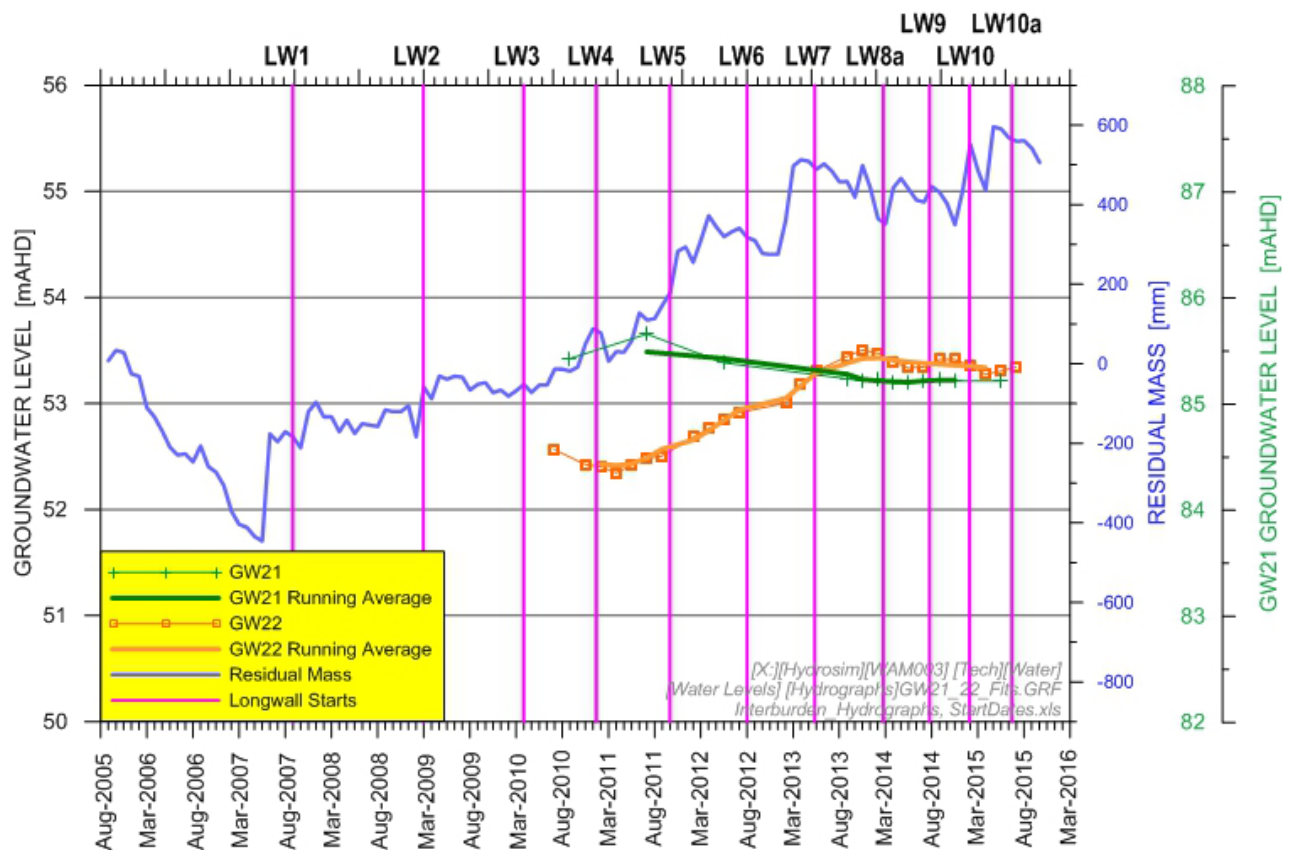


Figure 15: Interburden Observed Hydrograph at Monitoring Bore GW21

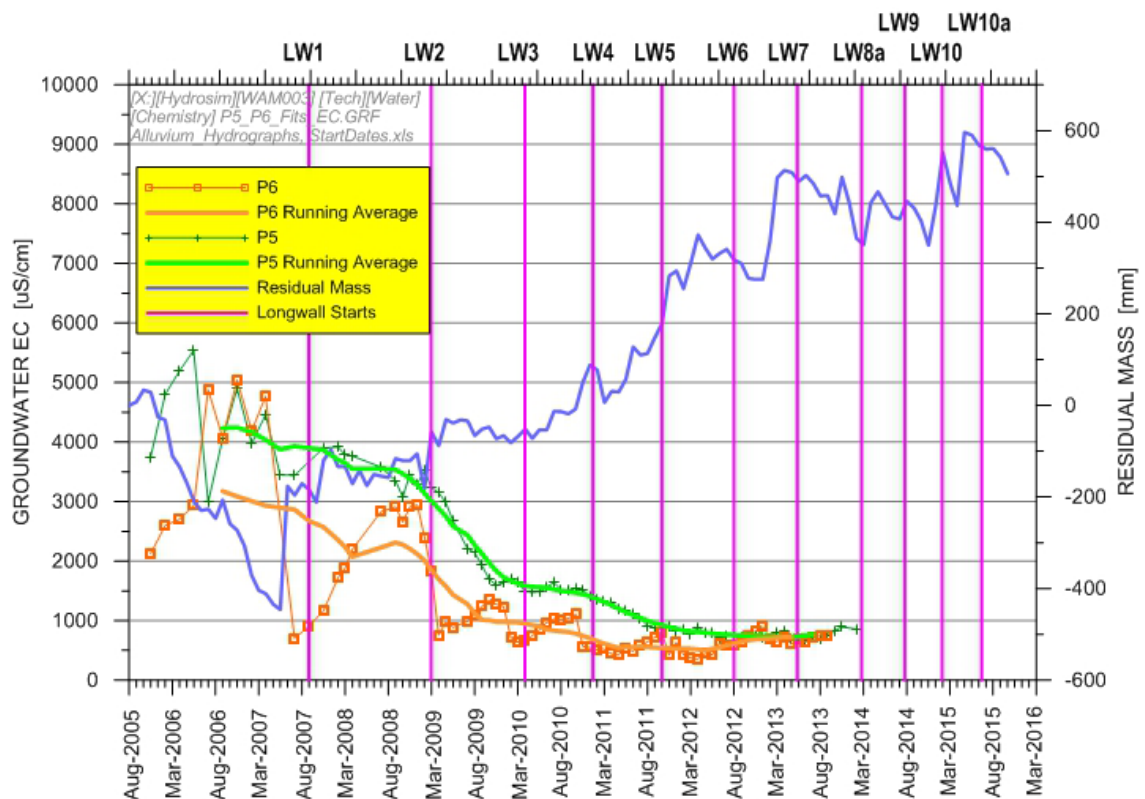


Figure 16: North Wambo Creek Smoothed EC Time-Series at Monitoring Bores P5 and P6

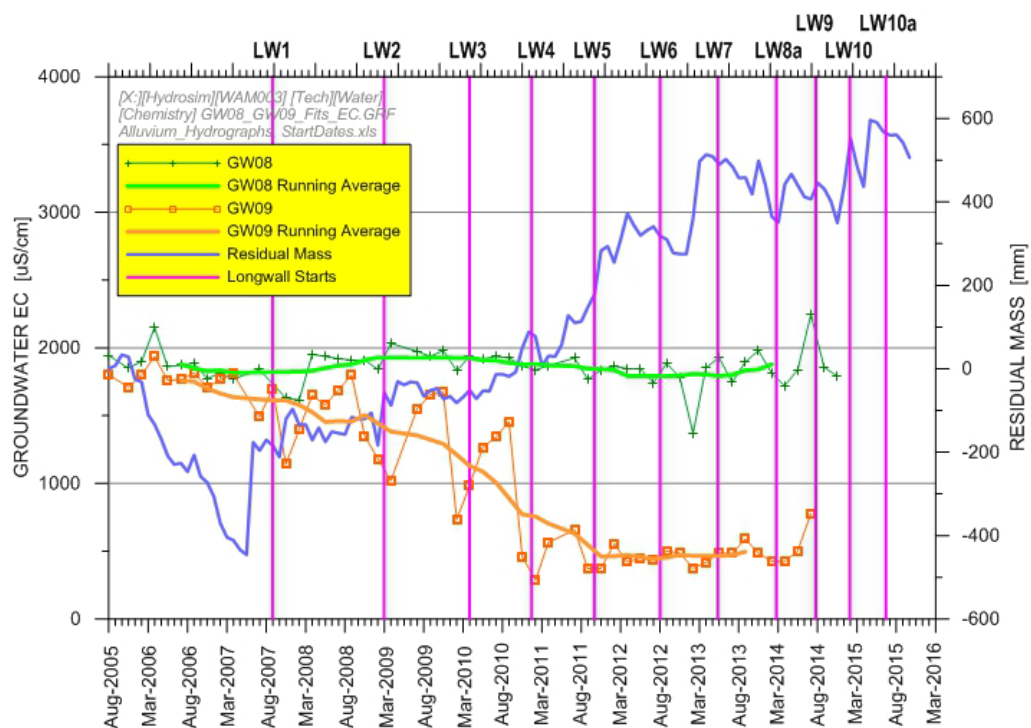


Figure 17: North Wambo Creek Smoothed EC Time-Series at Monitoring Bores GW08 -GW09

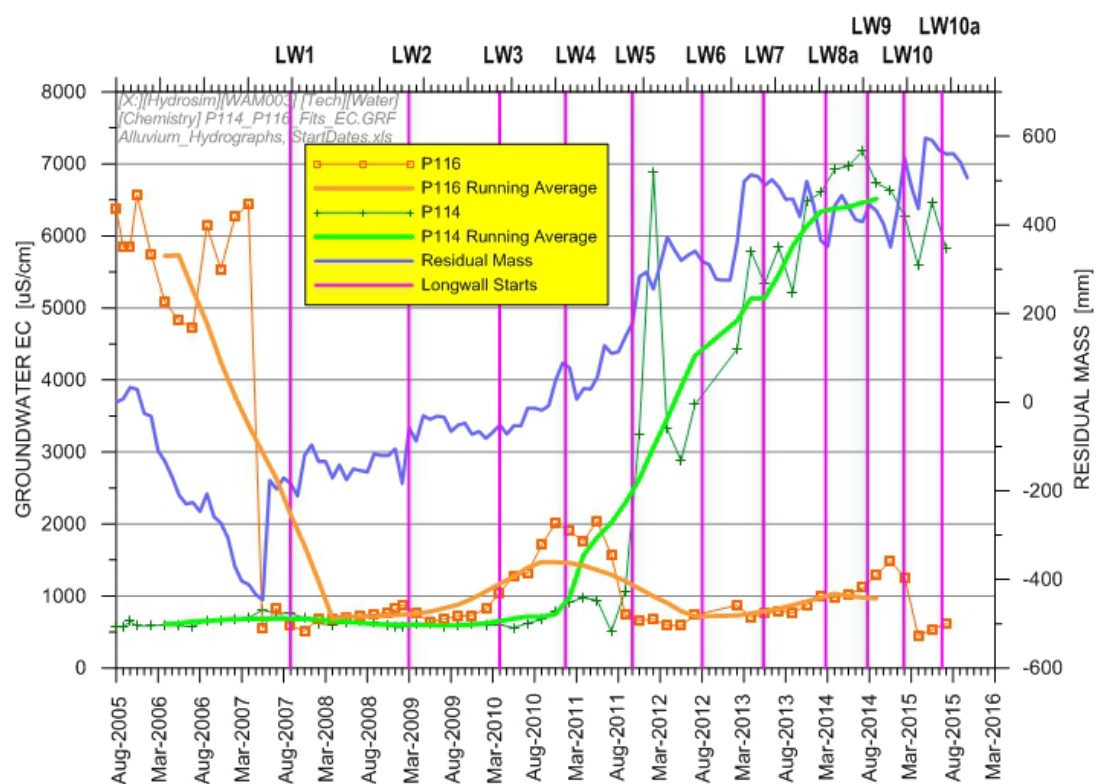


Figure 18: North Wambo Creek Smoothed EC Time-Series at Monitoring Bores P114 and P116

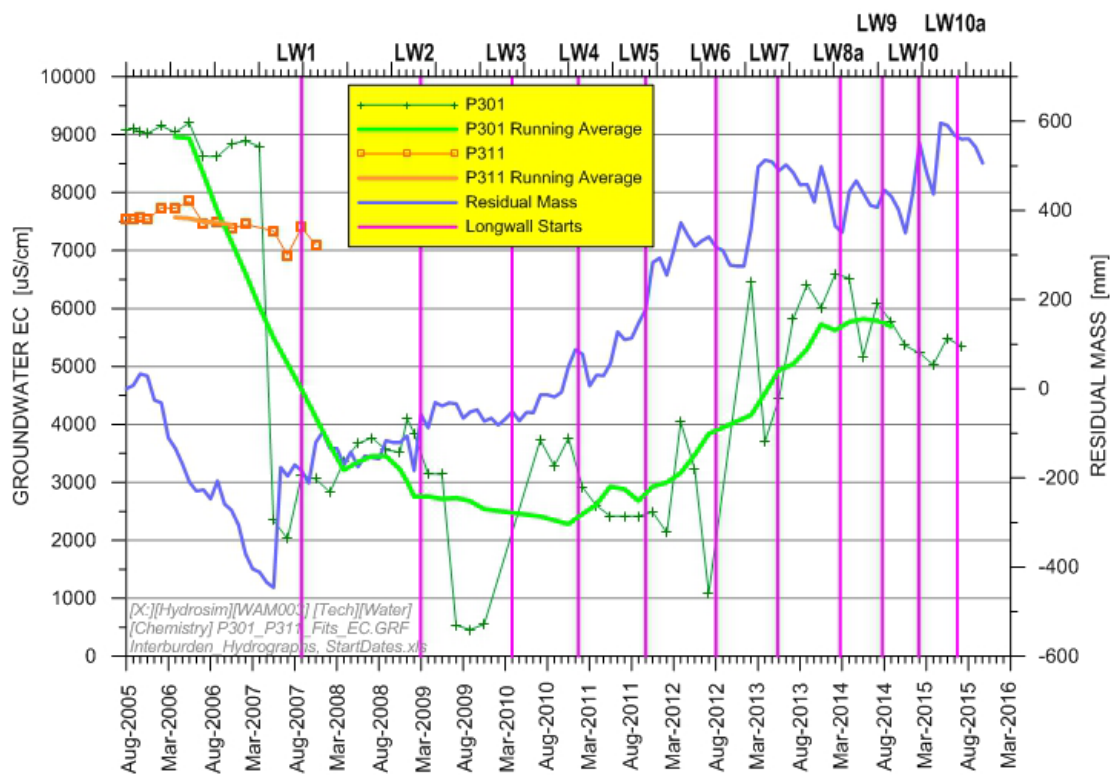


Figure 19: Interburden EC Time-Series at Monitoring Bores P301 and P311

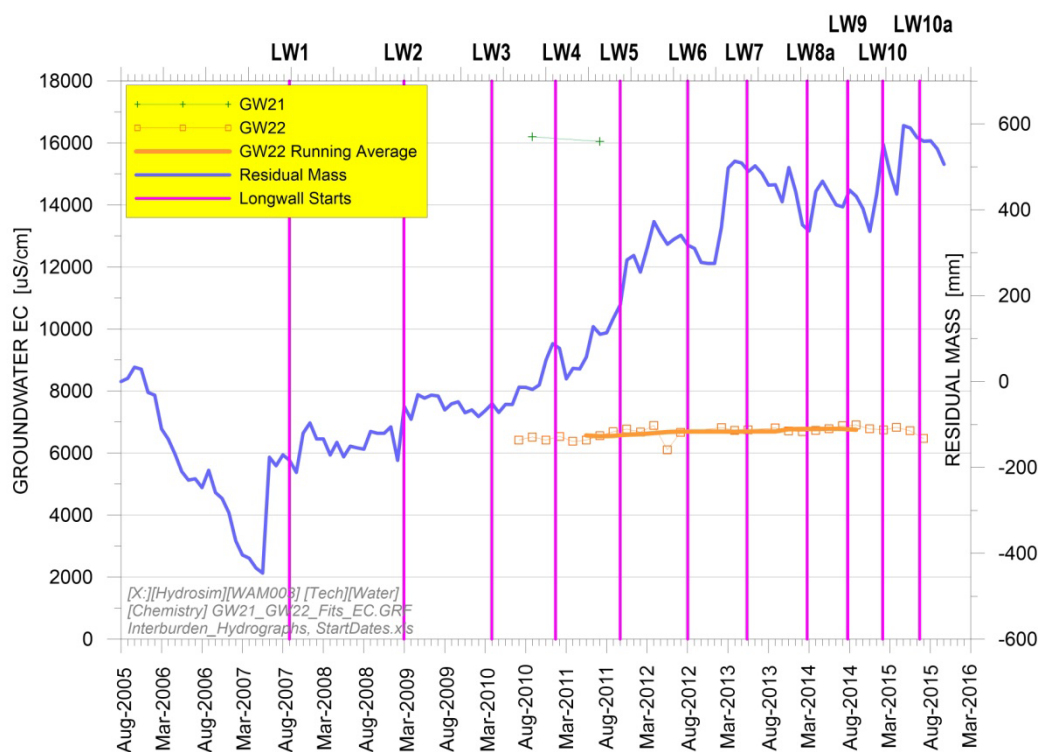


Figure 20: Interburden EC Time-Series at Monitoring Bores GW21 and GW22

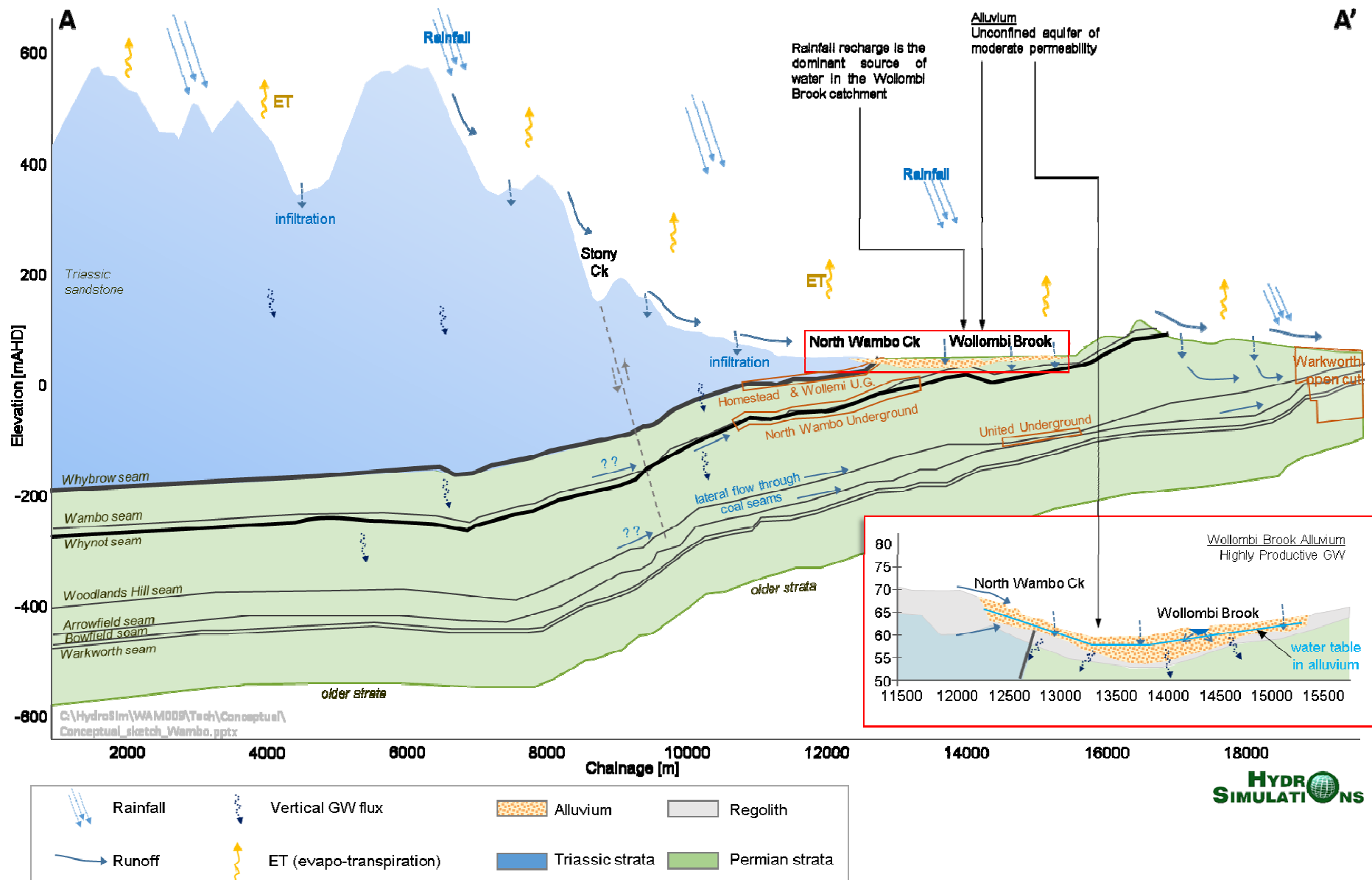
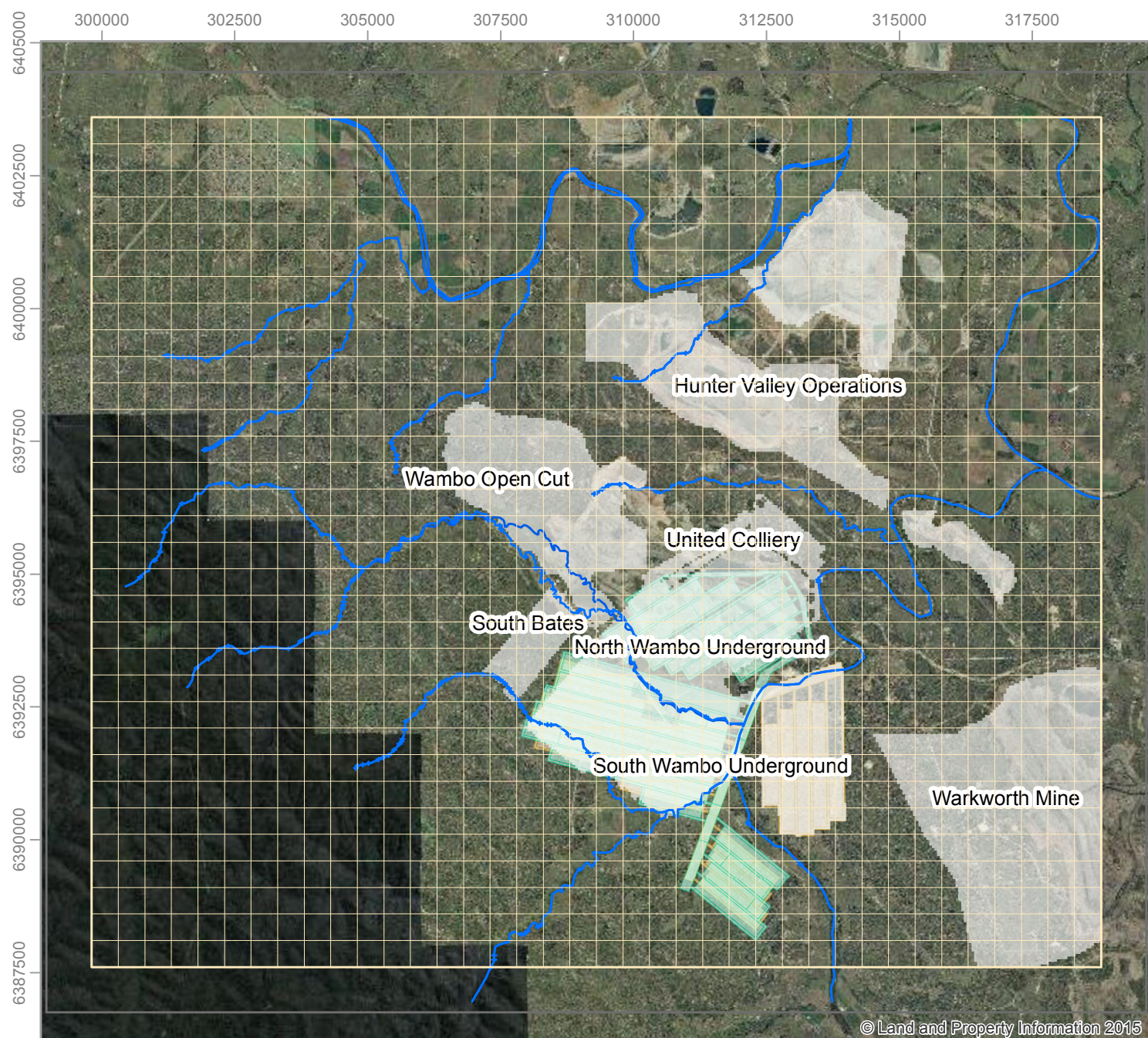


Figure 21: Conceptual Hydrogeological Cross-Section (During and Post Mining)



Model Grid

- 1 square = 100 model cells
- Rivers and Creeks
- Woodlands Hill Layout
- Arrowfield Layout

0 0.5 1 2 3
km



Scale: 0 @ A4
GDA 1994 MGA Zone 56

Wambo Coal Pty Ltd
South Wambo Modification

Model Domain

DrawingNo: WAM003
Rev: A.
Created by: CTurvey
Date: 27/11/2015
X:\HYDROSIM\WAM003\GIS\Maps\Deliverable\Model_Domain.mxd



Figure 22

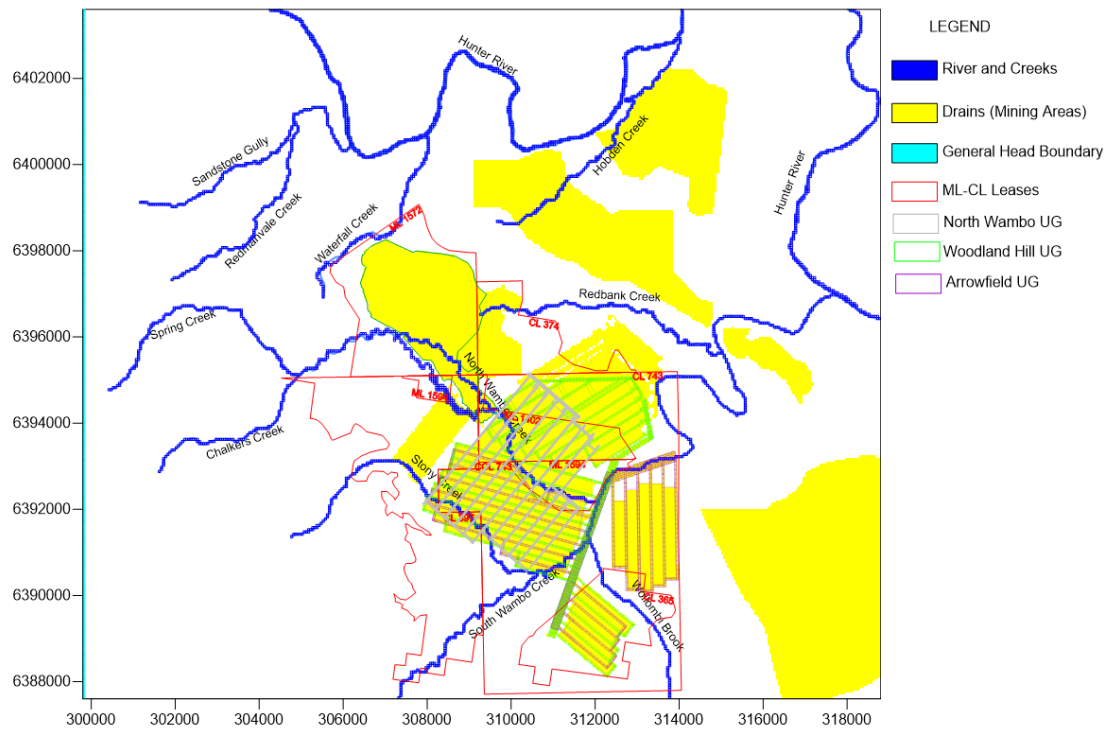


Figure 23: Groundwater Model Boundary Conditions

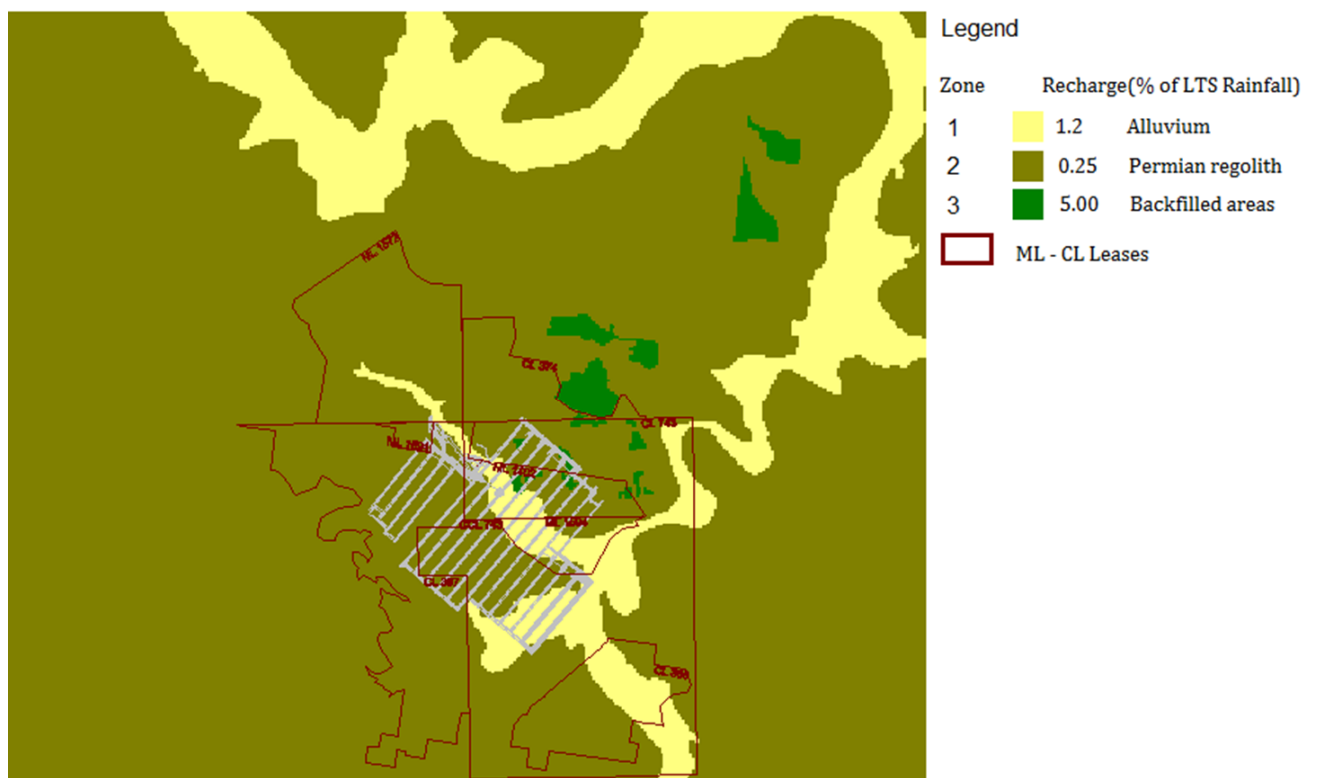


Figure 24: Modelled Recharge Zones

Note: At commencement of prediction period.

StressPeriods_MinePlans_12222015.xlsx						Approved			Modified			Wambo UG			South Bates UG									
Model Purpose	Model Type	Stress Period	Start Date	End Date	Period Length	Arrowfield Seam UG	Bowfield Seam UG	Wambo OC	Woodlands Hill Seam UG	Arrowfield Seam UG	Wambo OC	North Wambo UG	Whybrow Seam Dewatering for N.Wambo Layer 3	Whybrow Seam UG Approved Longwalls UG Layer 3	Wambo Seam UG Modification Longwalls UG Layer5	United	United Bord and Pillar UG Layer 11	Wombat	Homestead	Warkworth	Riverview	Cheshunt	South Lemington	
						Longwalls UG Layer 11	Longwalls UG Layer 13	Open Cut Layers1-7	Longwalls UG Layer 9	Longwalls UG Layer 11	Open Cut Layers1-7	Approved Longwalls UG Layer 5				Longwalls UG Layer 11		OC Pit Layers 1-7	OC Pit Layers 1-7	OC Pit Layers 1-15	OC Pit Layers 1-16	OC Pit Layers 1-16	OC Pit Layers 1-13	
CALIBRATION	Transient	1	1/01/2003	31/12/2003	Yearly											LW1, LW2	Bord and Pillar UG	Open Cut and Backfilled	Open Cut and Backfilled	Open Cut	Open Cut	Open Cut		
	Transient	2	1/01/2004	31/12/2004	Yearly											LW3								
	Transient	3	1/01/2005	31/12/2005	Yearly											LW4								
	Transient	4	1/01/2006	31/12/2006	Yearly											LW5								
	Transient	5	1/01/2007	31/03/2007	Quarterly											LW6								
	Transient	6	1/04/2007	30/06/2007	Quarterly											LW6								
	Transient	7	1/07/2007	30/09/2007	Quarterly											LW6								
	Transient	8	1/10/2007	31/12/2007	Quarterly							LW1				LW6, LW7								
	Transient	9	1/01/2008	31/03/2008	Quarterly							LW1				LW7								
	Transient	10	1/04/2008	30/06/2008	Quarterly							LW1				LW7								
	Transient	11	1/07/2008	30/09/2008	Quarterly							LW1				LW7, LW8								
	Transient	12	1/09/2008	31/12/2008	Quarterly							LW1				LW8								
	Transient	13	1/01/2009	31/01/2009	Monthly							LW1				LW8								
	Transient	14	1/02/2009	28/02/2009	Monthly							LW1				LW8								
	Transient	15	1/03/2009	31/03/2009	Monthly							LW1				LW8								
	Transient	16	1/04/2009	30/04/2009	Monthly							LW1				LW8								
	Transient	17	1/05/2009	31/05/2009	Monthly							LW2	DRN over LW2			LW8								
	Transient	18	1/06/2009	30/06/2009	Monthly							LW2	DRN over LW2			LW8								
	Transient	19	1/07/2009	31/07/2009	Monthly							LW2	DRN over LW2			LW8								
	Transient	20	1/08/2009	31/08/2009	Monthly							LW2	DRN over LW2			LW10								
	Transient	21	1/09/2009	30/09/2009	Monthly							LW2	DRN over LW2			LW10								
	Transient	22	1/10/2009	31/10/2009	Monthly							LW2	DRN over LW2			LW10								
	Transient	23	1/11/2009	30/11/2009	Monthly							LW2	DRN over LW2			LW10								
	Transient	24	1/12/2009	31/12/2009	Monthly							LW2	DRN over LW2			LW10								
	Transient	25	1/01/2010	30/04/2010	120 days							LW2	DRN over LW2			LW10								
	Transient	26	1/05/2010	31/12/2010	245 days							LW3	DRN over LW3			LW11								
	Transient	27	1/01/2011	31/12/2011	Yearly							LW4, LW5	DRN over LW4,5			LW11								
	Transient	28	1/01/2012	31/12/2012	Yearly							LW5, LW6	DRN over LW6			All Longwalls Active								
	Transient	29	1/01/2013	31/12/2013	Yearly			Open Cut and Backfilled				LW6, LW7	DRN over LW7			All Longwalls Inactive								
	Transient	30	1/01/2014	31/12/2014	Yearly							LW7, LW6A, LW9, LW10	DRN over LW8A,9,10			All Longwalls Inactive								
PREDICTION	Transient	31	1/01/2015	31/12/2015	Yearly			Open Cut and Backfilled			Open Cut and Backfilled	LW10, LW10A	DRN over LW8A,9,10				Bord and Pillar UG	Backfilled	Backfilled	Open Cut	Open Cut	Open Cut		
	Transient	32	1/01/2016	31/12/2016	Yearly						Open Cut and Backfilled	LW8B	DRN over LW10A			LW11, LW12								
	Transient	33	1/01/2017	31/12/2017	Yearly							All Longwalls Active				LW13								
	Transient	34	1/01/2018	31/12/2018	Yearly											All Longwalls Active								
	Transient	35	1/01/2019	31/12/2019	Yearly	ELW1			LW1, LW2, LW3							LW14								
	Transient	36	1/01/2020	31/12/2020	Yearly	ELW1, ELW2 & WLW1			LW3, LW4, LW5, LW6							All Longwalls Active								
	Transient	37	1/01/2021	31/12/2021	Yearly	ELW2, ELW3 & WLW1, WLW2	ELW1		LW6, LW7															
	Transient	38	1/01/2022	31/12/2022	Yearly	ELW4, ELW5 & WLW2, WLW3	ELW2, ELW3		LW7, LW8															
	Transient	39	1/01/2023	31/12/2023	Yearly	ELW5 & WLW3, WLW4	ELW3, ELW4		LW9, LW10	LW01E, LW02E														
	Transient	40	1/01/2024	31/12/2024	Yearly	WLW4, WLW5	ELW4, ELW5		LW10, LW11	LW02E, LW03E														
	Transient	41	1/01/2025	31/12/2025	Yearly	WLW6, WLW7	WLW1, WLW4		LW11, LW12, LW16, LW17	LW03E, LW04E	All Longwalls Inactive	All DRNs Inactive												
	Transient	42	1/01/2026	31/12/2026	Yearly	WLW7, WLW8	WLW1, WLW2, WLW4, WLW5	Final Void and Backfilled	LW17, LW18	LW04E, LW05E	Final Void and Backfilled													
	Transient	43	1/01/2027	31/12/2027	Yearly		WLW2, WLW3, WLW5, WLW6, WLW7		LW18, LW19, LW01N	LW05E, LW06E														
	Transient	44	1/01/2028	31/12/2028	Yearly	All Longwalls Active	WLW7, WLW8		LW02N, LW03N	LW06E, LW15E, LW16E, LW17E														
	Transient	45	1/01/2029	31/12/2029	Yearly		All Longwalls Active		LW03N	LW17E, LW01X, LW02X														
	Transient	46	1/01/2030	31/12/2030	Yearly					LW02X, LW03X														
	Transient	47	1/01/2031	31/12/2031	Yearly					LW04X, LW05X														
	Transient	48	1/01/2032	31/12/2032	Yearly	Inactive	Inactive		All Longwalls Active	LW05X														
	Transient	49	1/01/2033	31/12/2033	Yearly							All Longwalls Active												
	RECOVERY	Transient	50	1/01/2033	1/01/2230	197 Years	Inactive	Inactive	Final Void and Backfilled	Inactive	Inactive	Final Void and Backfilled	Inactive	Inactive	Inactive	Inactive							Inactive	Inactive

Figure 25: Mine Evolution and Model Stress Period Definition

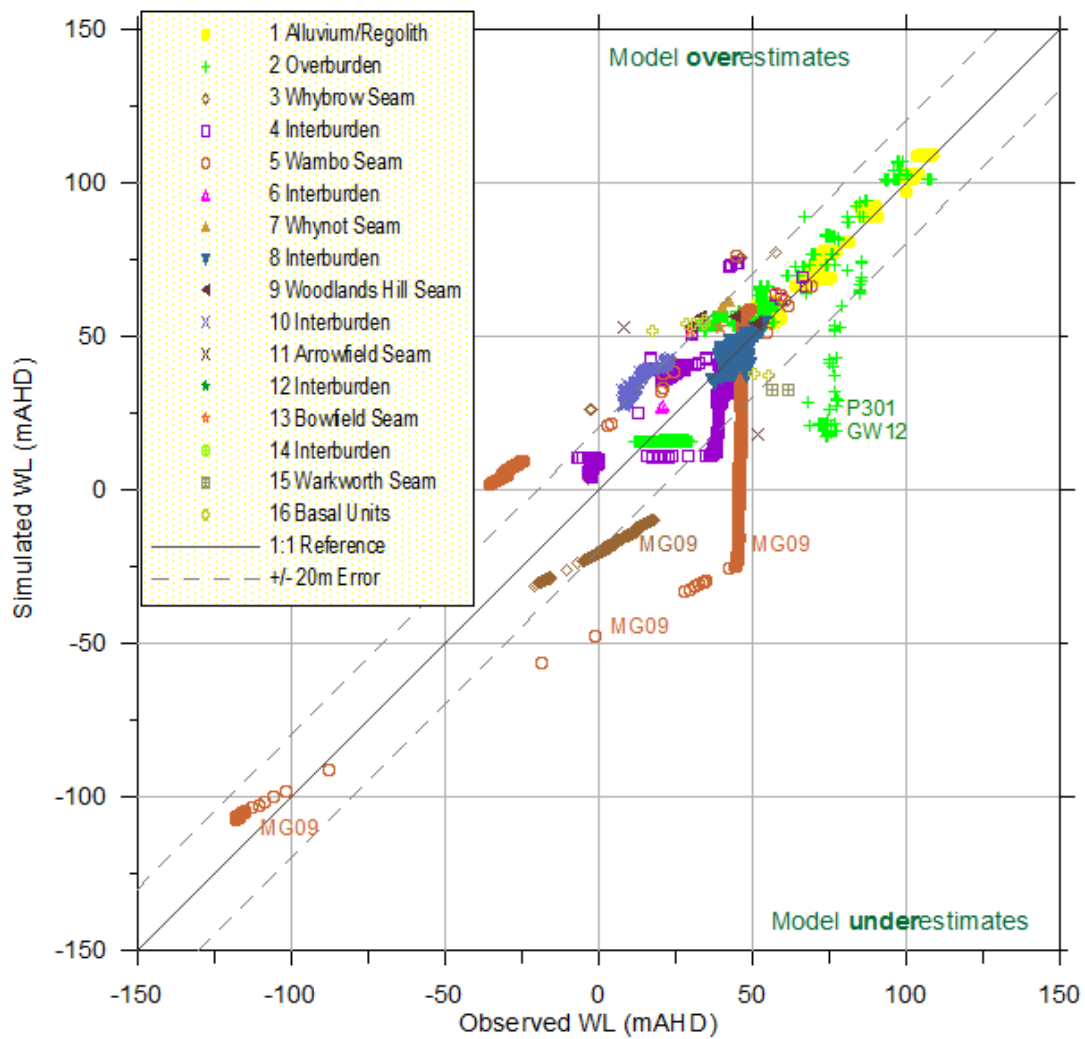


Figure 26: Calibration Scatter Diagram – Simulated vs Observed Water Levels

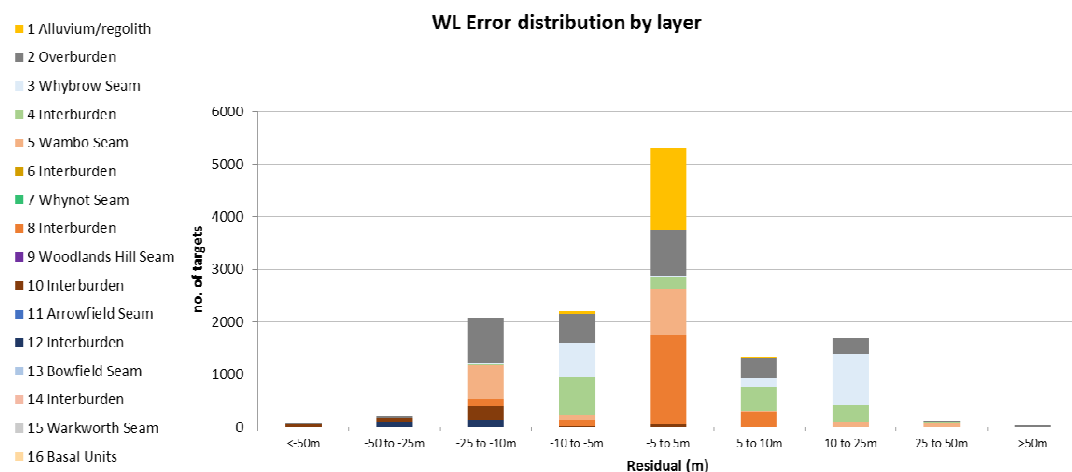


Figure 27: Water Level Error Distribution by Layer

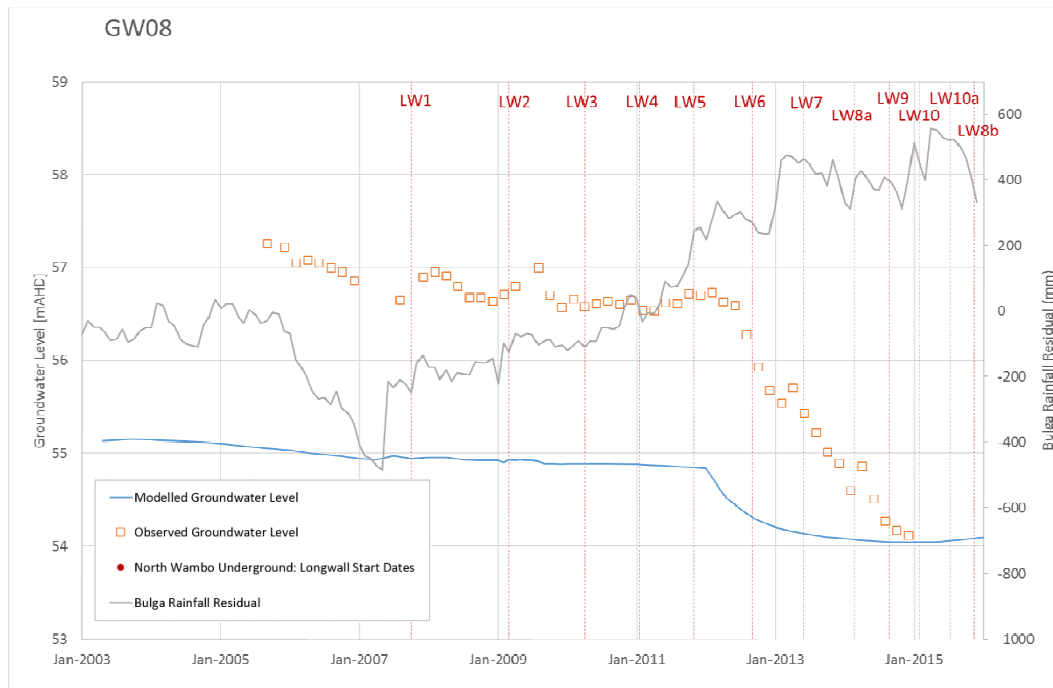


Figure 28: GW08 Calibration Hydrograph – Layer 1 Alluvium

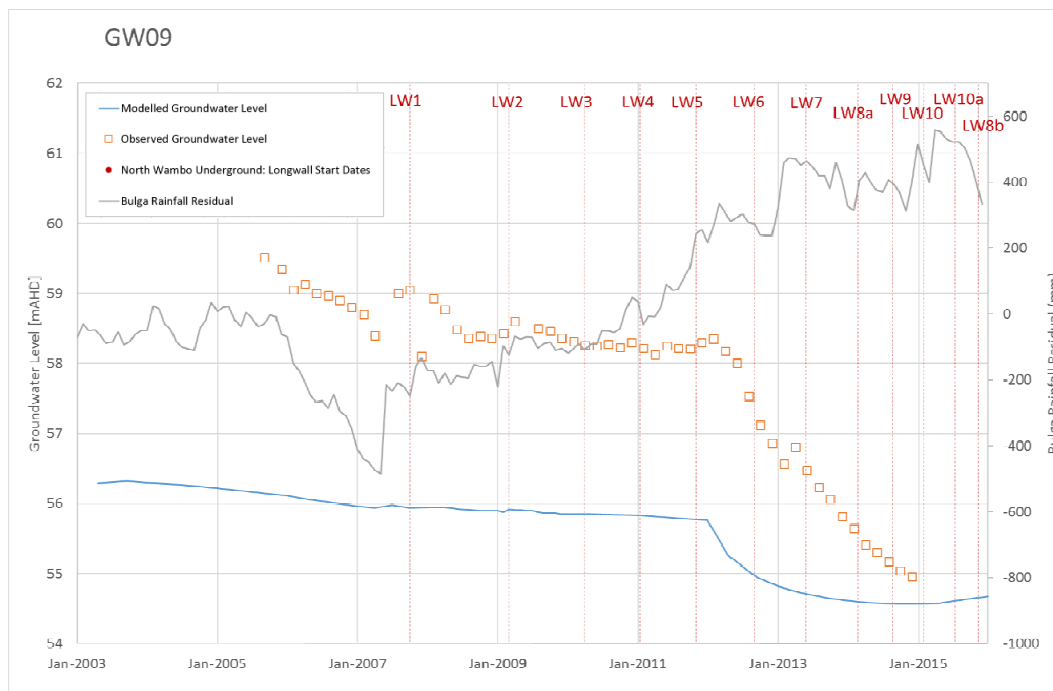


Figure 29: GW09 Calibration Hydrograph – Layer 1 Alluvium

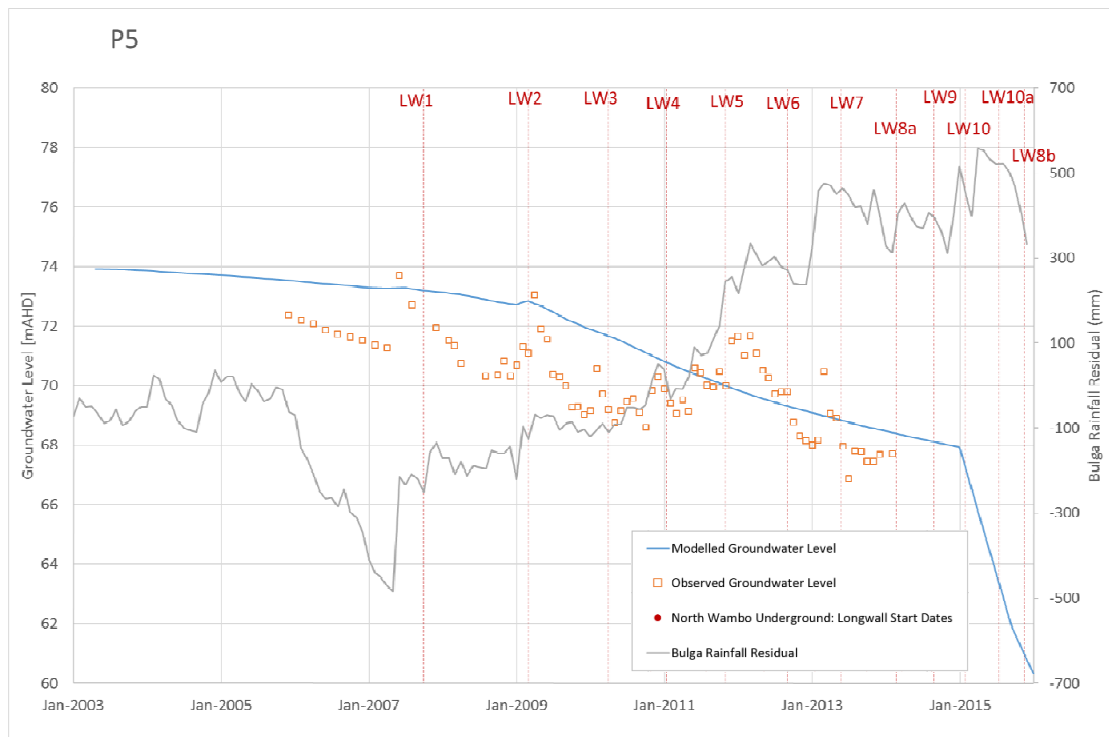


Figure 30: P5 Calibration Hydrograph – Layer 1 Alluvium

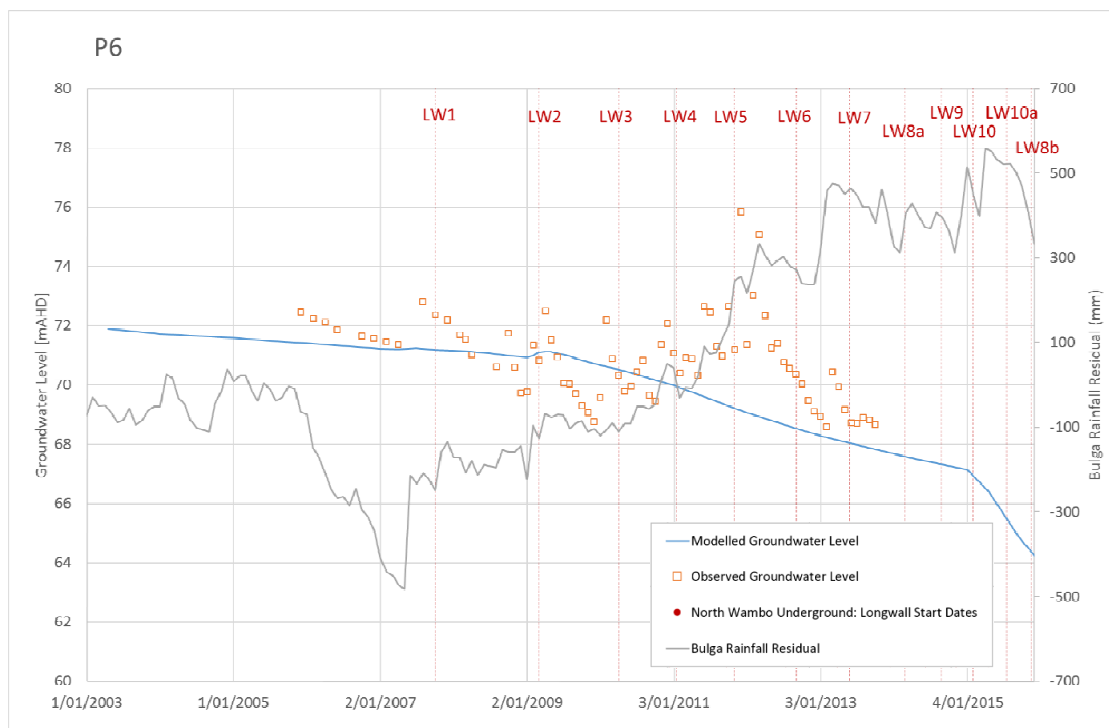


Figure 31: P6 Calibration Hydrograph – Layer 1 Alluvium

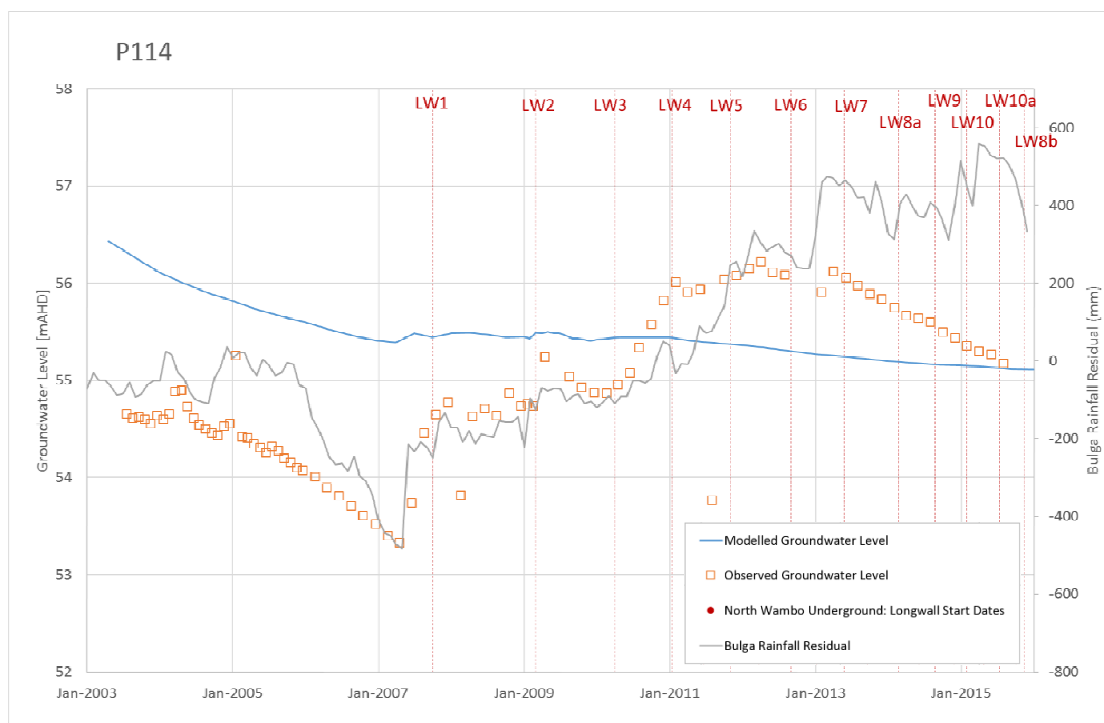


Figure 32: P114 Calibration Hydrograph – Layer 1 Alluvium

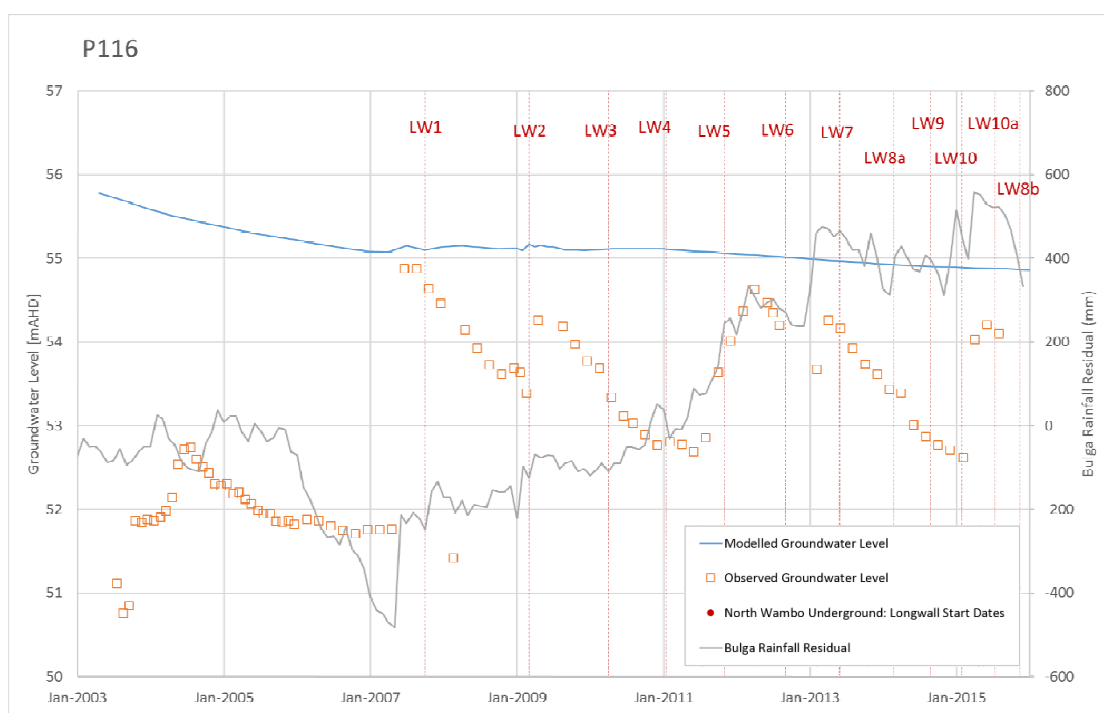


Figure 33: P116 Calibration Hydrograph – Layer 1 Alluvium

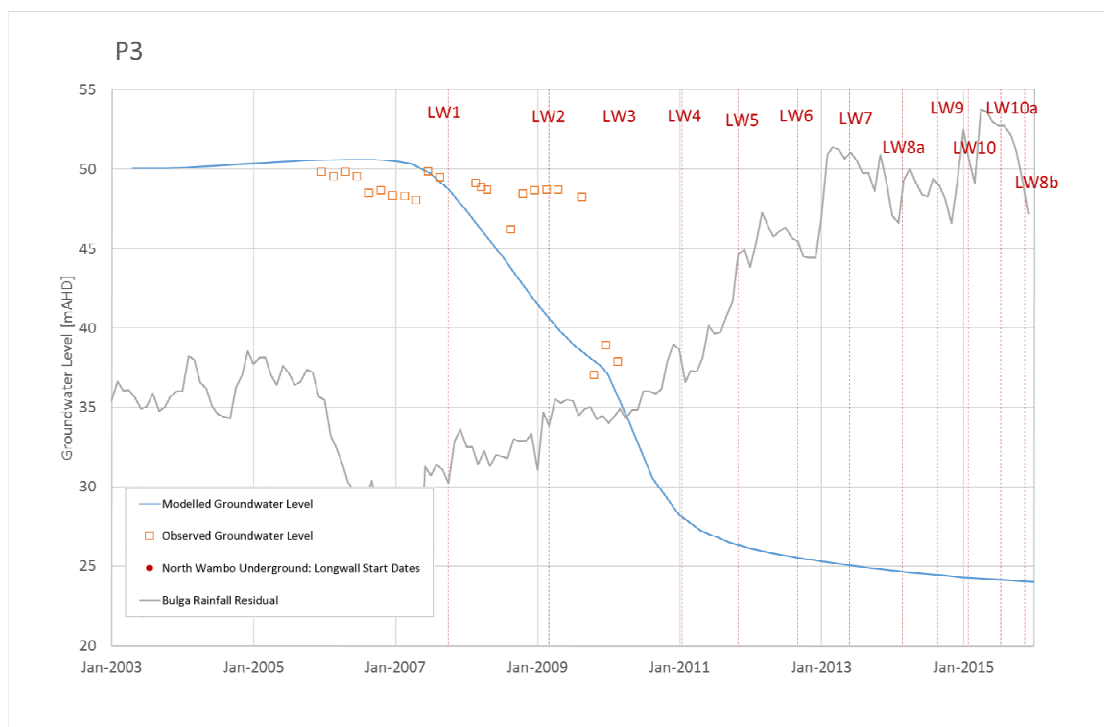


Figure 34: P3 Calibration Hydrograph – Layer 8 Whynot-Woodlands Hill Seam Interburden

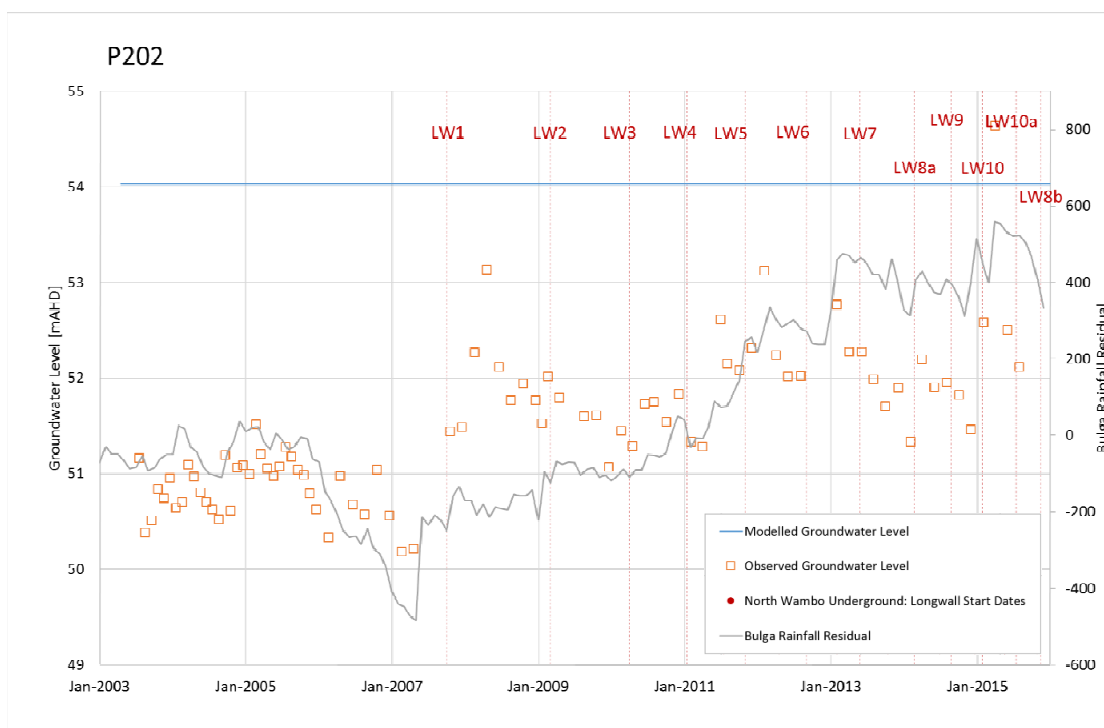


Figure 35: P202 Calibration Hydrograph – Layer 2 Overburden above Whybrow Seam

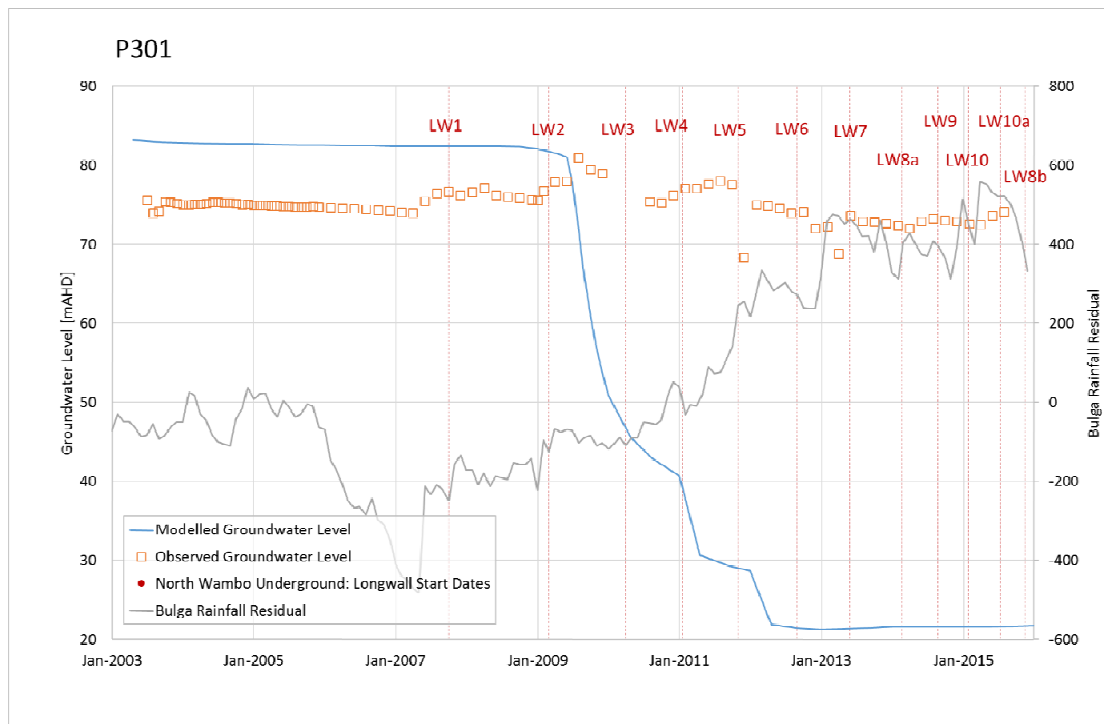


Figure 36: P301 Calibration Hydrograph – Layer 2 Overburden above Whybrow Seam

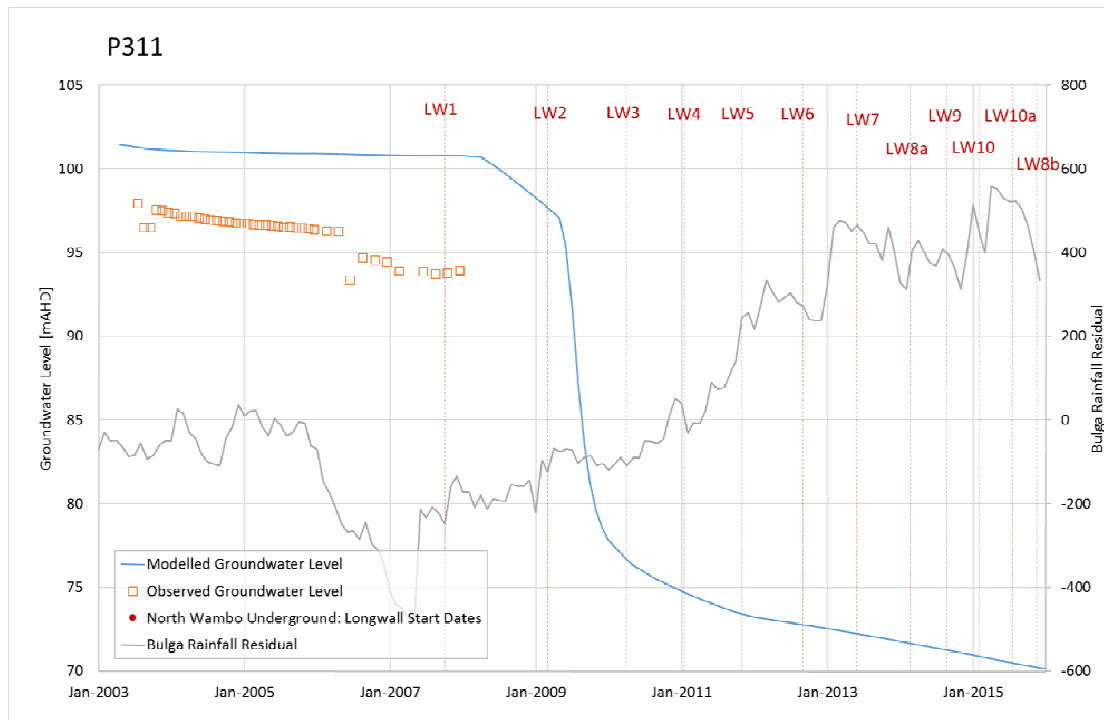


Figure 37: P311 Calibration Hydrograph – Layer 2 Overburden above Whybrow Seam

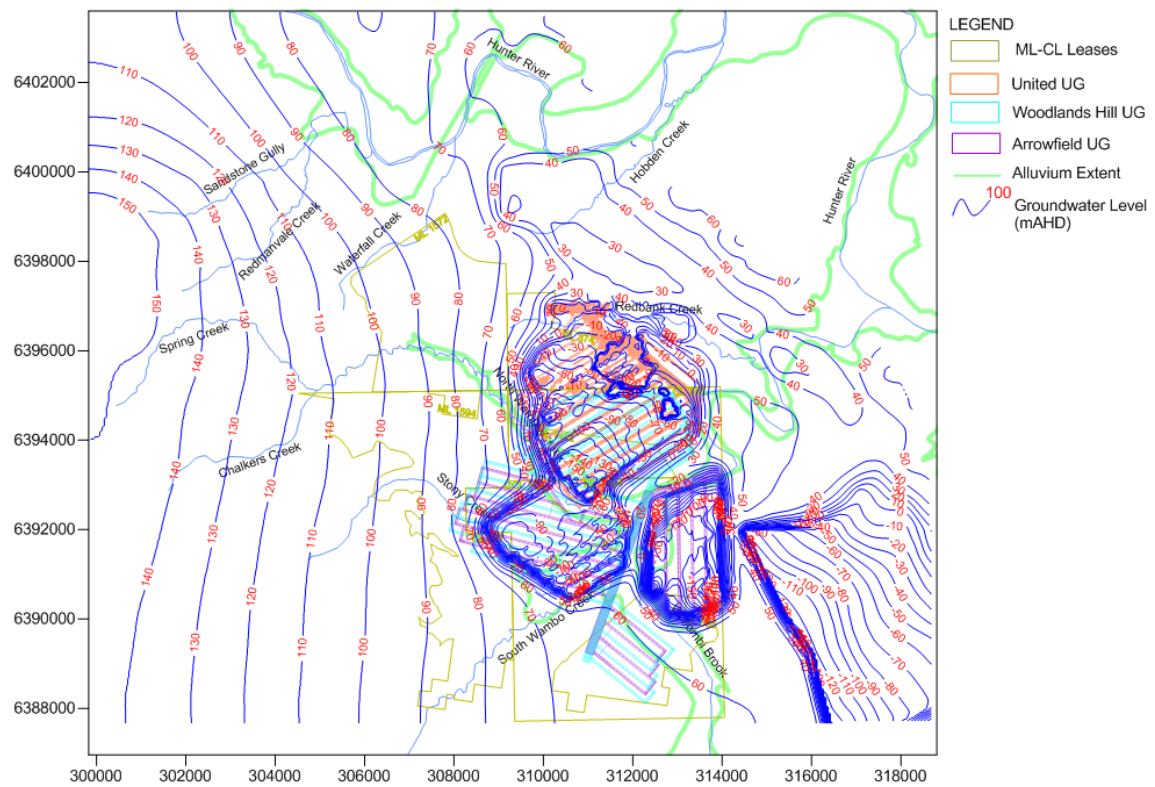


Figure 38: Predicted Groundwater Levels (mAHD) in the Woodlands Hill Seam (Model Layer 9) at the End of South Wambo Mining - Approved Scenario

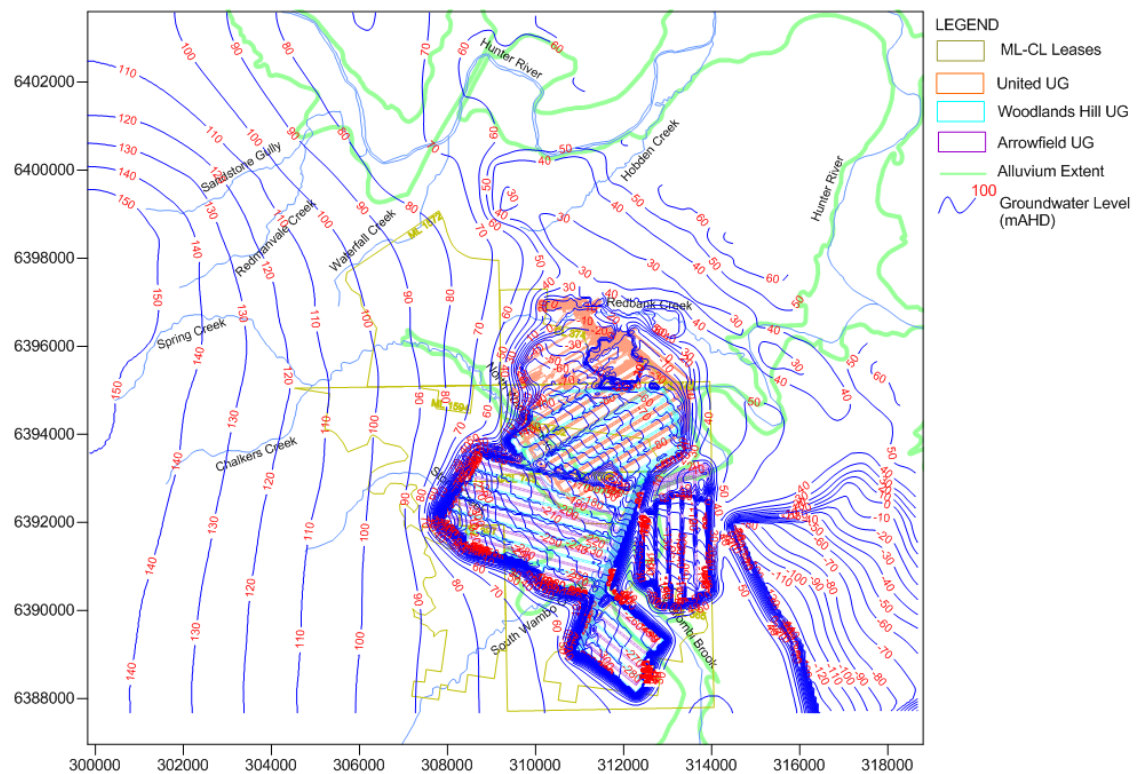


Figure 39: Predicted Groundwater Levels (mAHD) in the Woodlands Hill Seam (Model Layer 9) at the End of South Wambo Mining - Modification Scenario

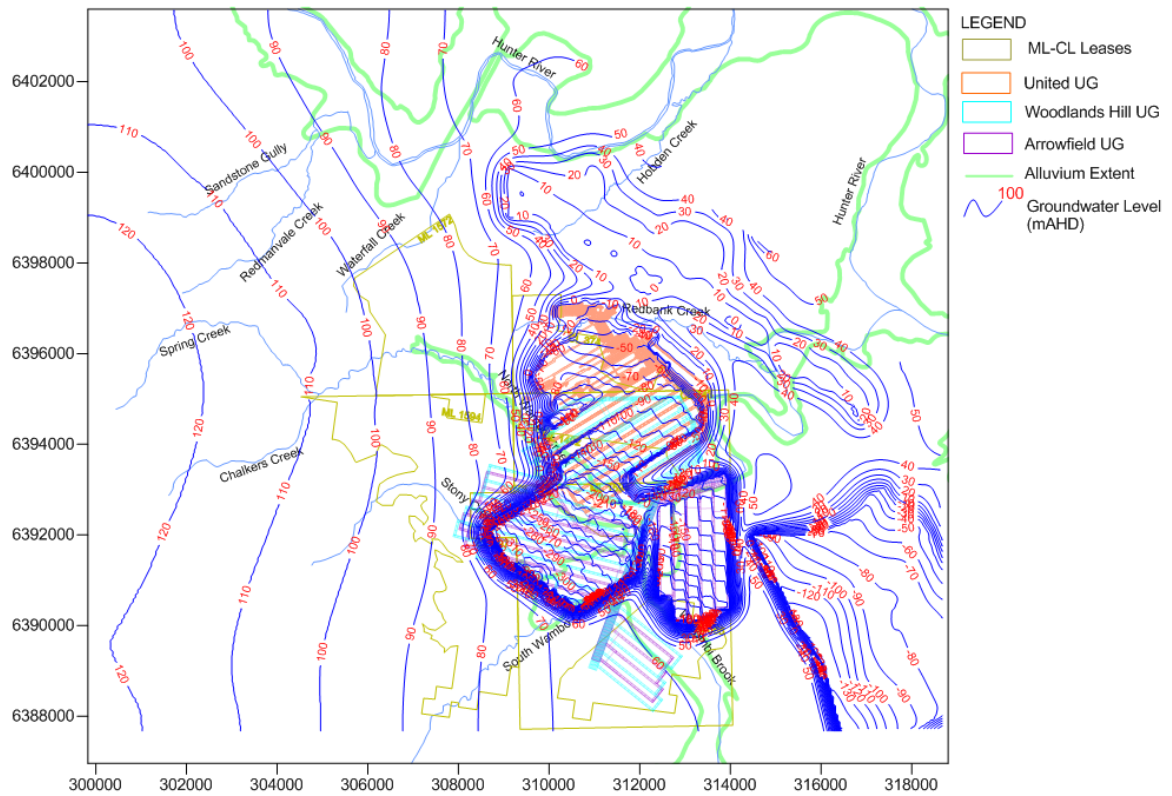


Figure 40: Predicted Groundwater Levels (mAHD) in the Arrowfield Seam (Model Layer 11) at the End of South Wambo Mining – Approved Scenario

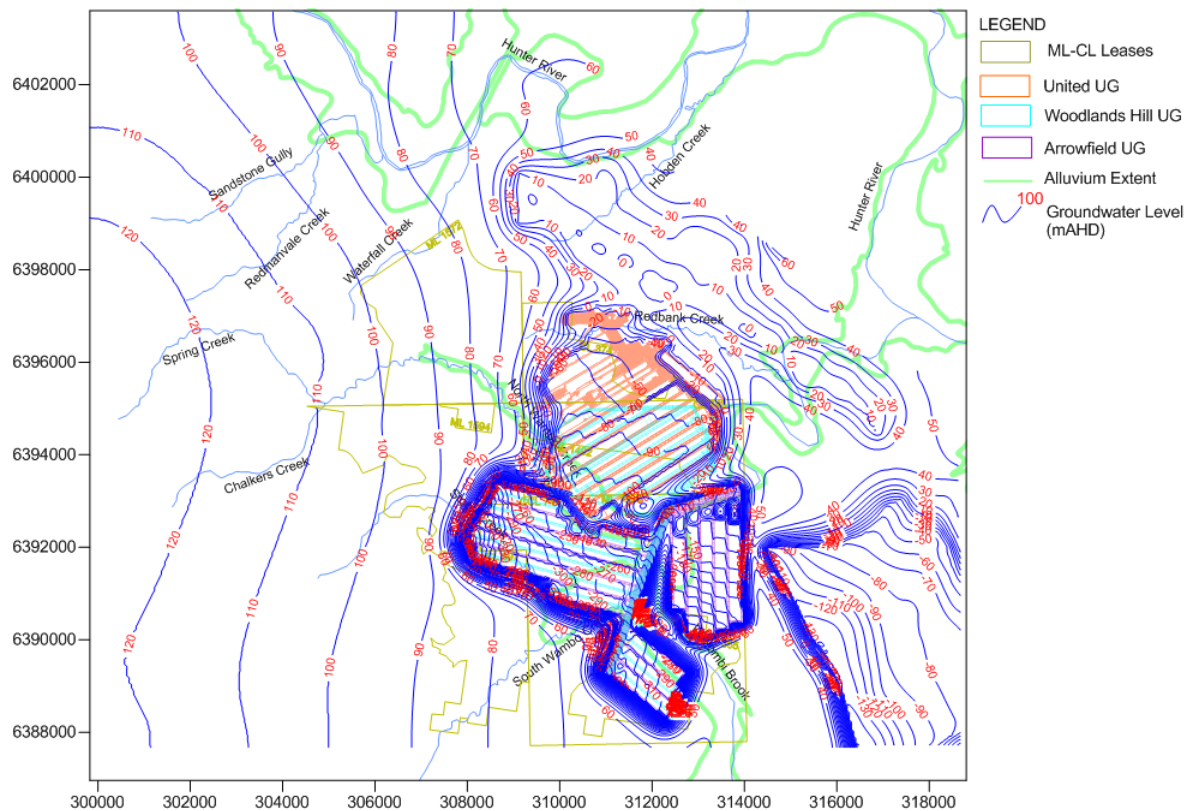


Figure 41: Predicted Groundwater Levels (mAHD) in the Arrowfield Seam (Model Layer 11) at the End of South Wambo Mining – Modification Scenario

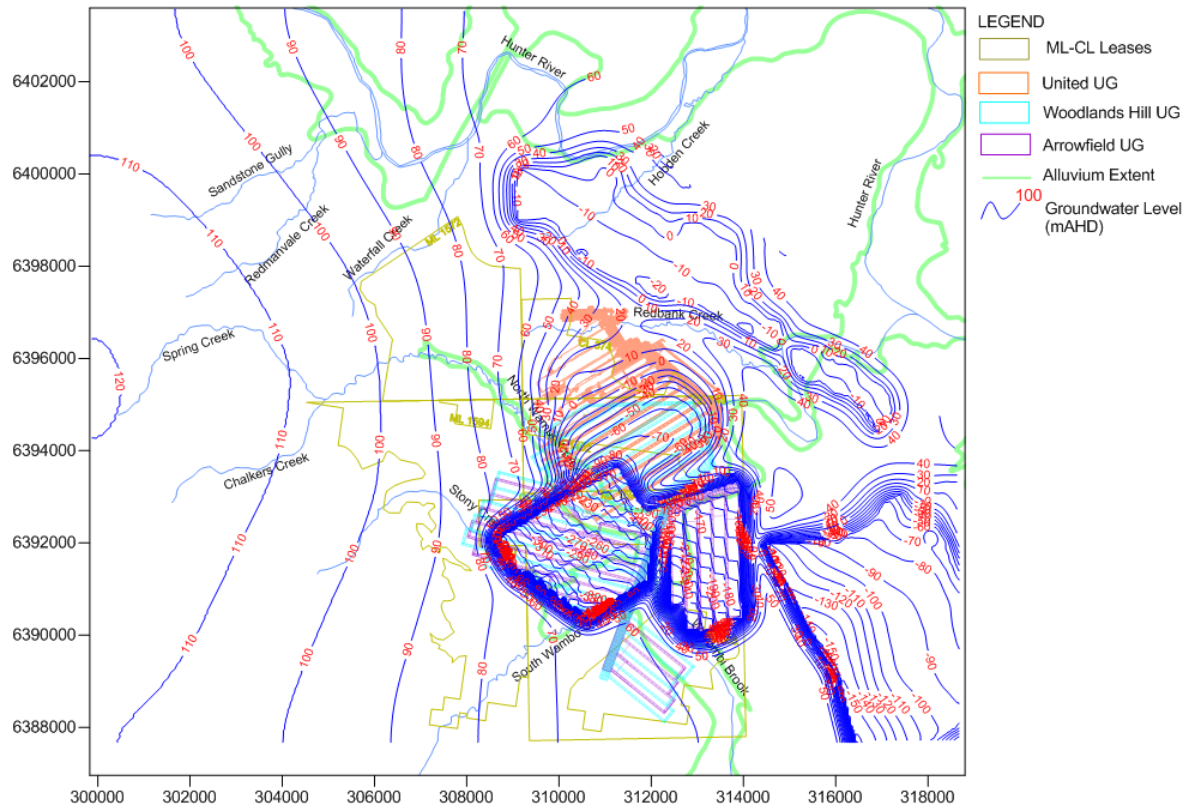


Figure 42: Predicted Groundwater Levels (mAHD) in the Bowfield Seam (Model Layer 13) at the End of South Wambo Mining – Approved Scenario

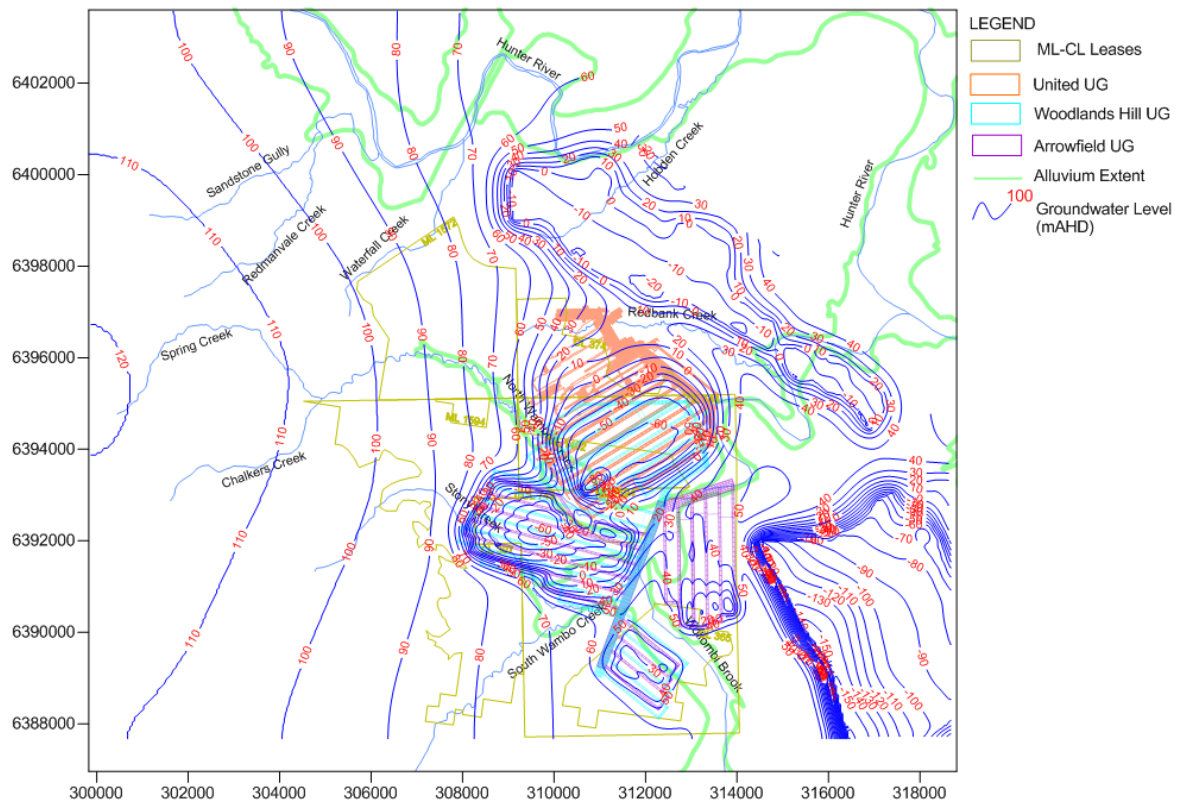


Figure 43: Predicted Groundwater Levels (mAHD) in the Bowfield Seam (Model Layer 13) at the End of South Wambo Mining – Modification Scenario

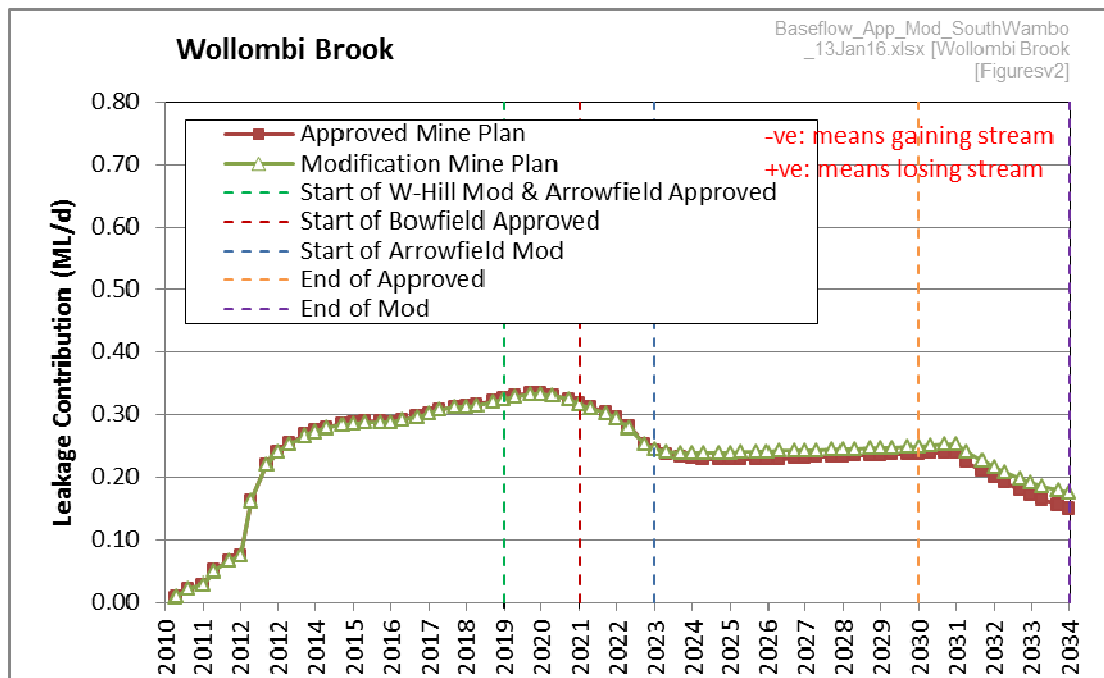


Figure 44: Predicted Groundwater-Surface interaction on Wollombi Brook

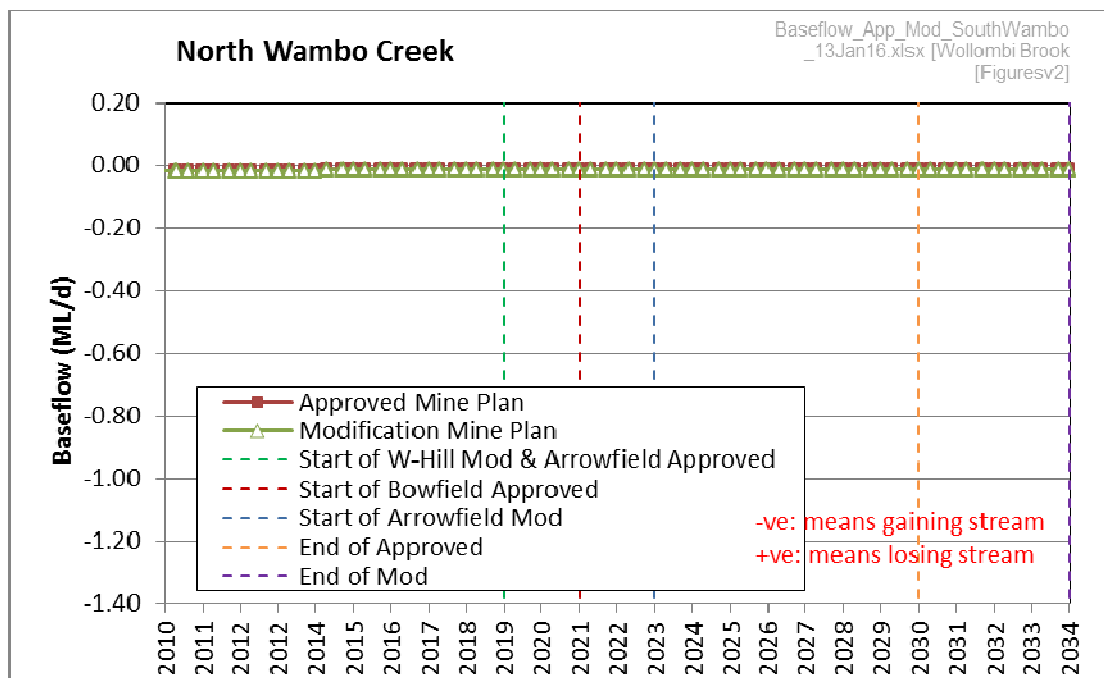


Figure 45: Predicted Groundwater-Surface interaction on North Wambo Creek

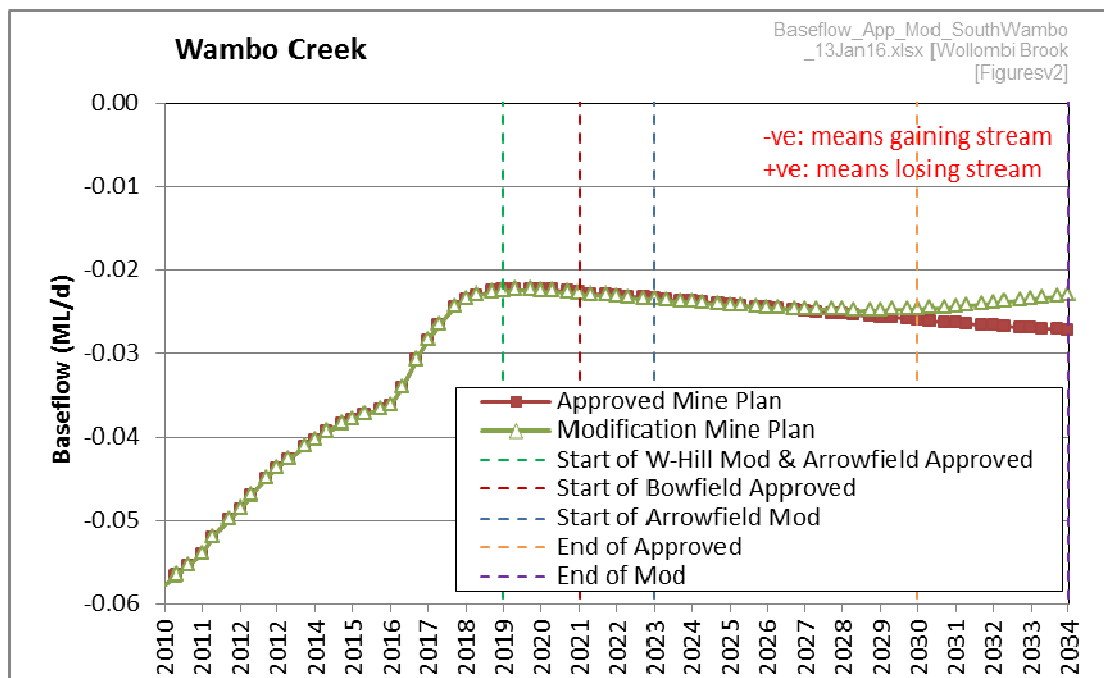


Figure 46: Predicted Groundwater-Surface interaction on Wambo Creek

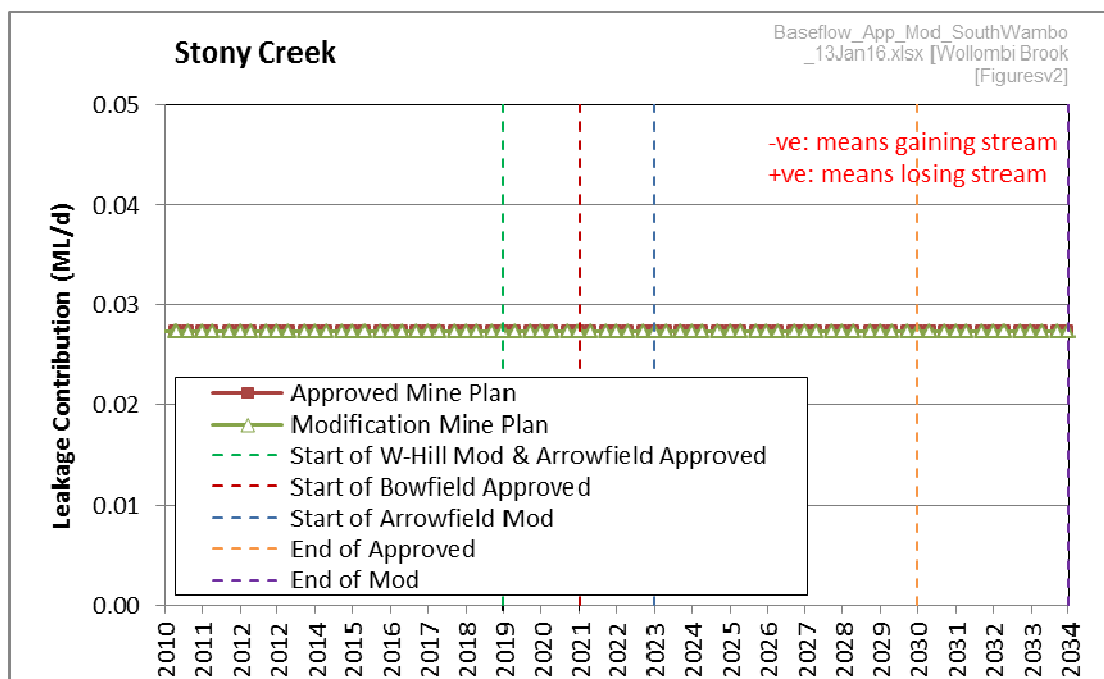


Figure 47: Predicted Groundwater-Surface interaction on Stony Creek

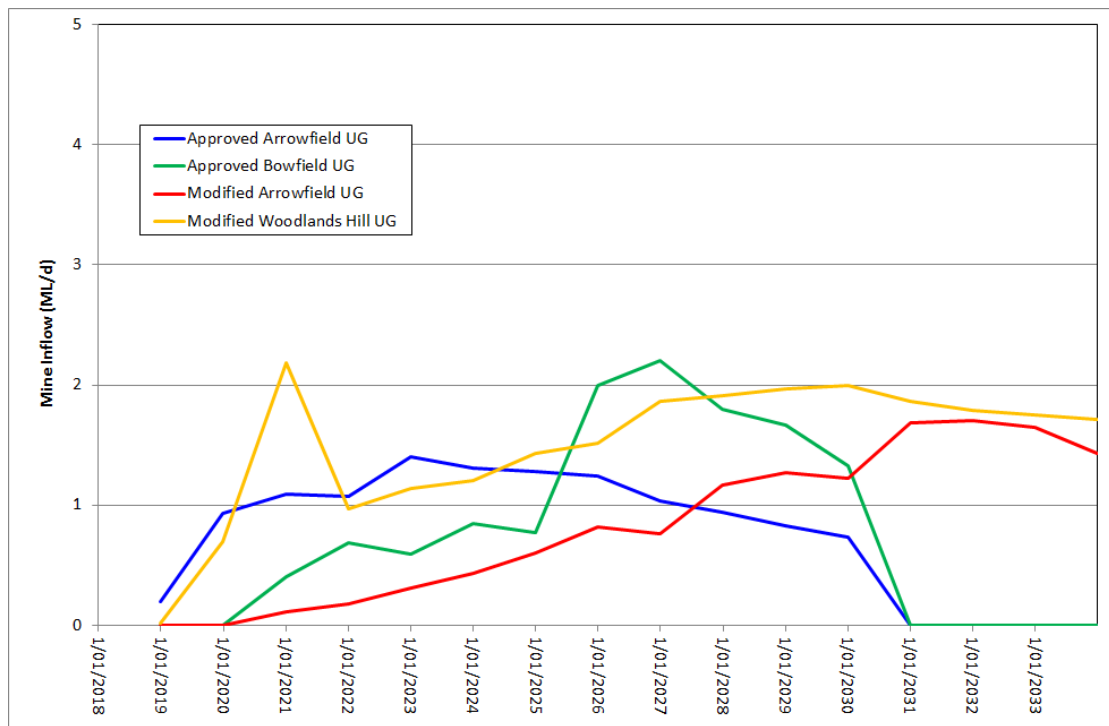


Figure 48: Predicted South Wambo Underground Mine Inflow for Individual Mine Seams

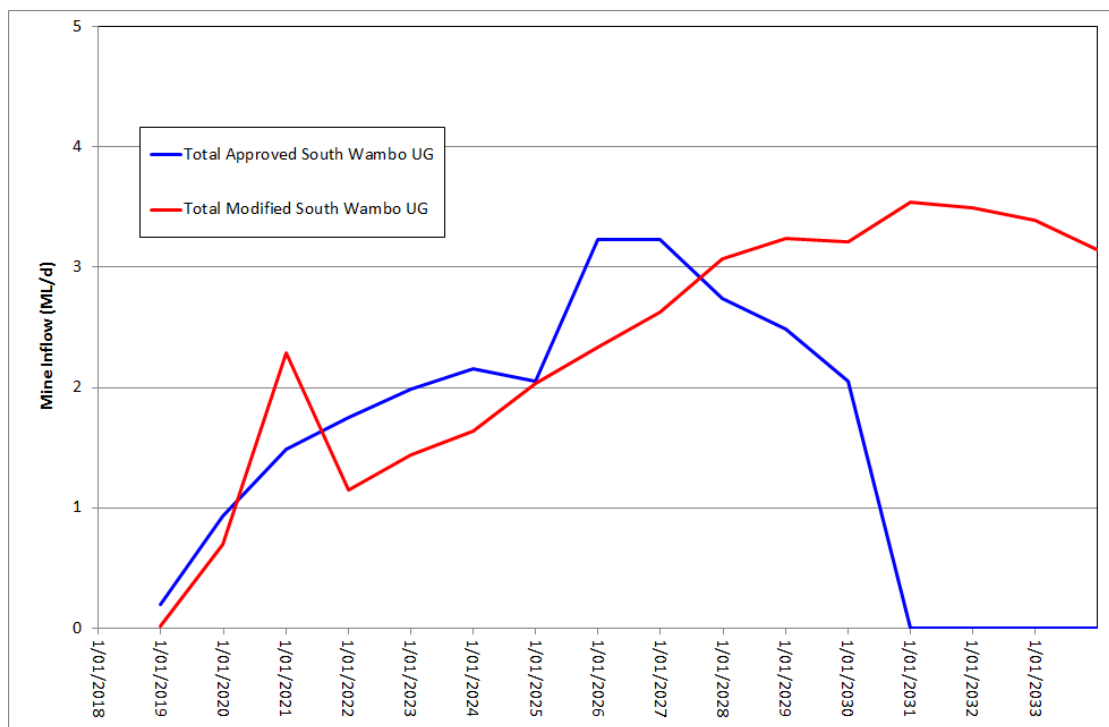


Figure 49: Combined Predicted South Wambo Underground Mine Inflow

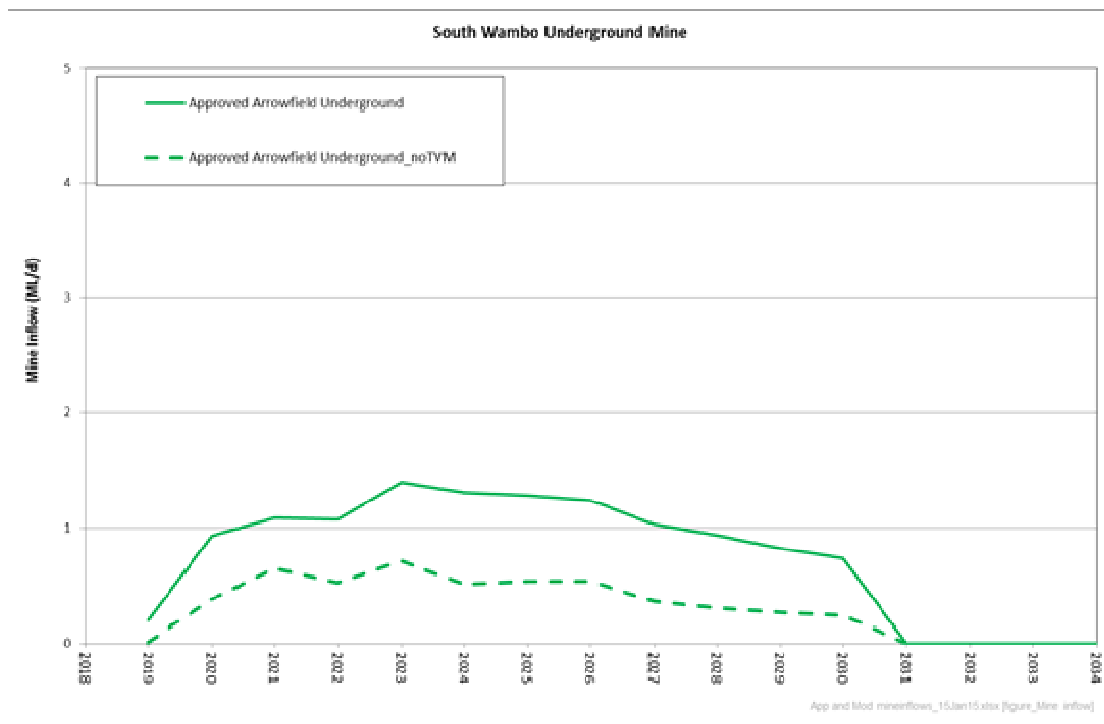


Figure 50: Arrowfield Seam Mine Inflow Sensitivity to Fracture Zone

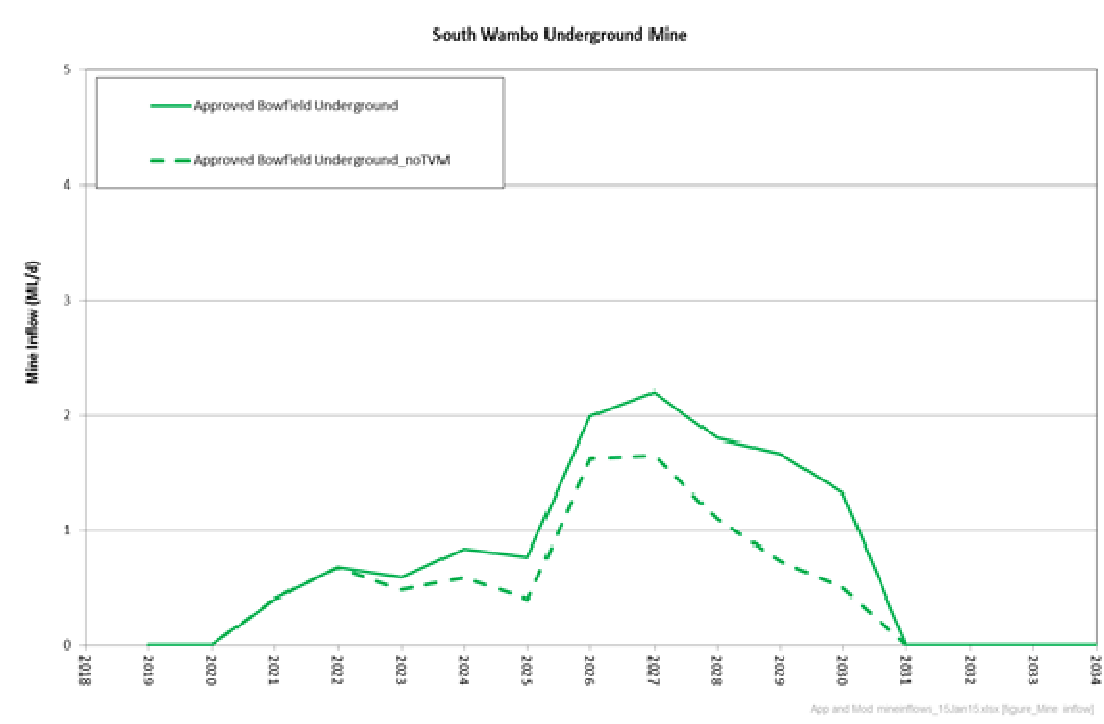


Figure 51: Bowfield Seam Mine Inflow Sensitivity to Fracture Zone

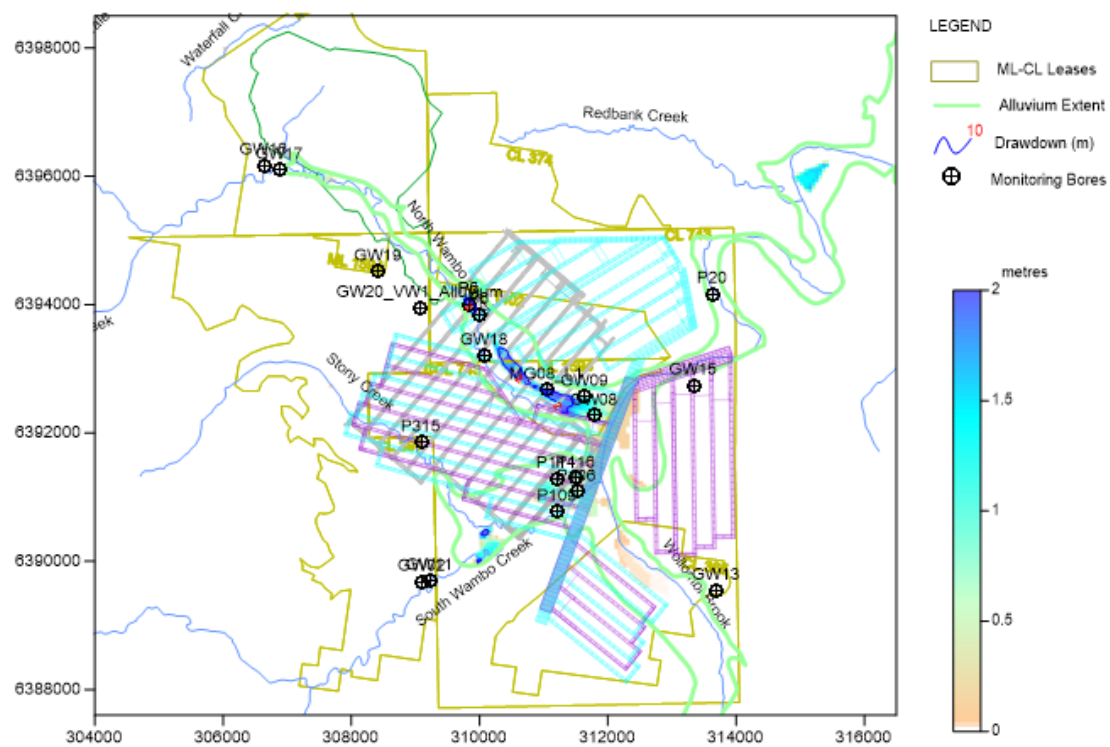


Figure 52: Cumulative Drawdown (m) in Alluvium / Regolith at the End of South Wambo Mining for Modification Scenario

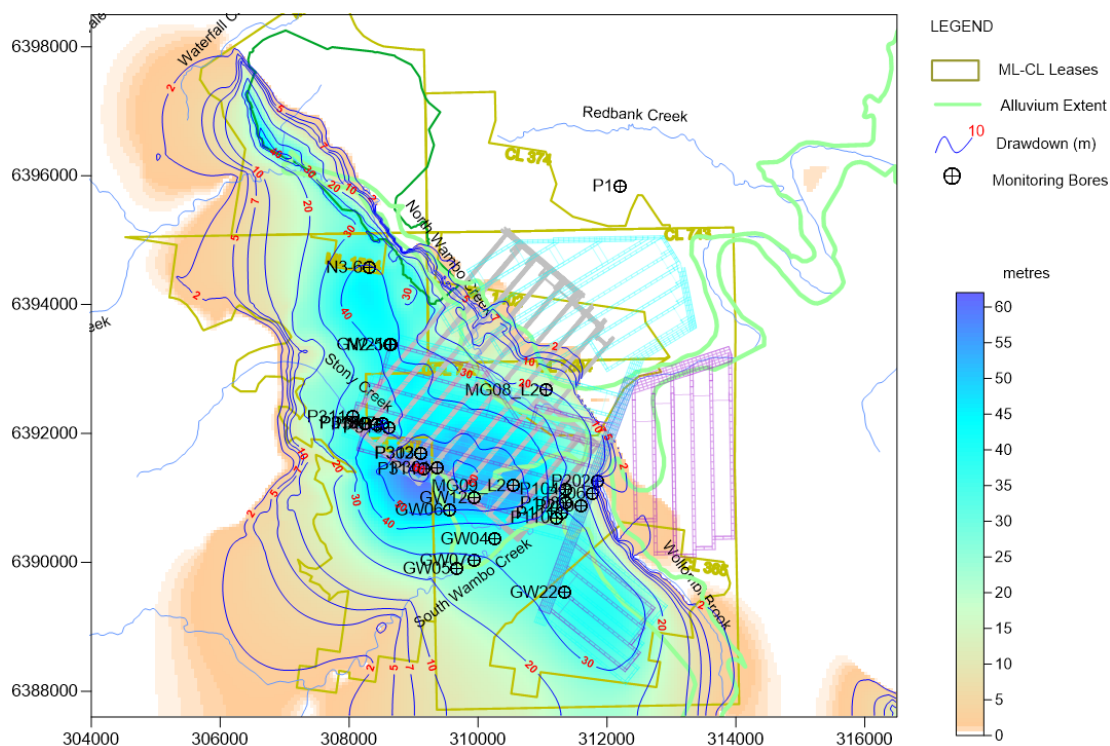


Figure 53: Cumulative Drawdown (m) in Whybrow Seam Overburden at the End of South Wambo Mining for Modification Scenario

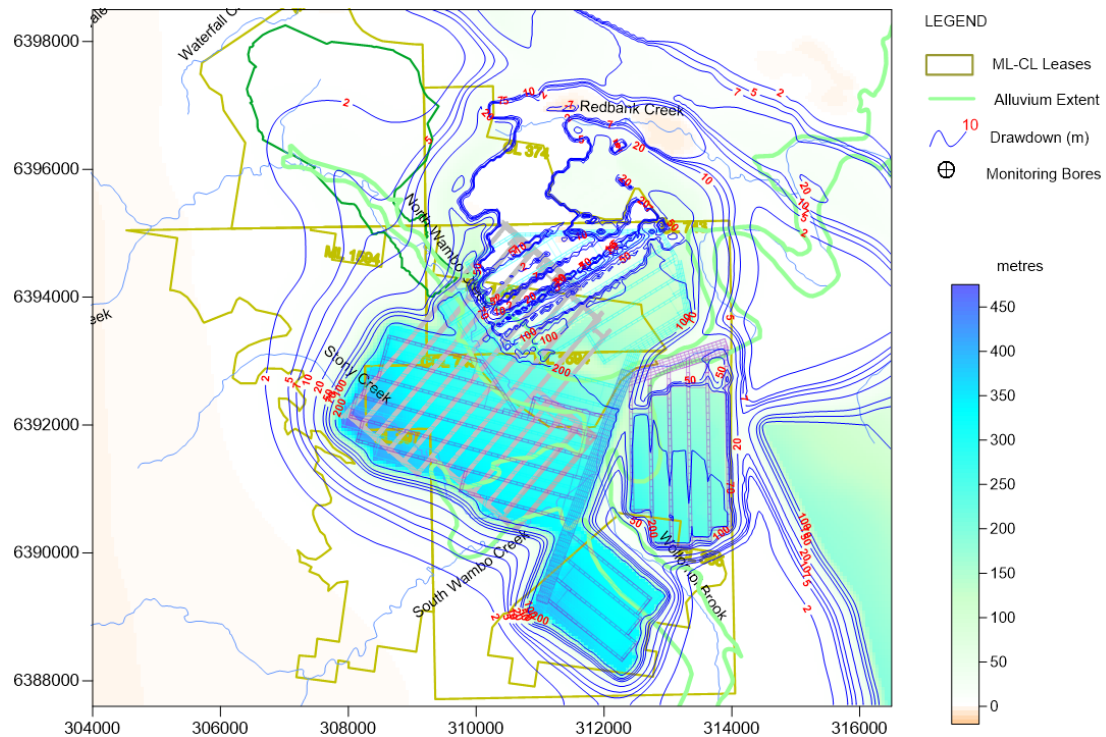


Figure 54: Cumulative Drawdown (m) in Woodlands Hill Seam at the End of South Wambo Mining for Modification Scenario

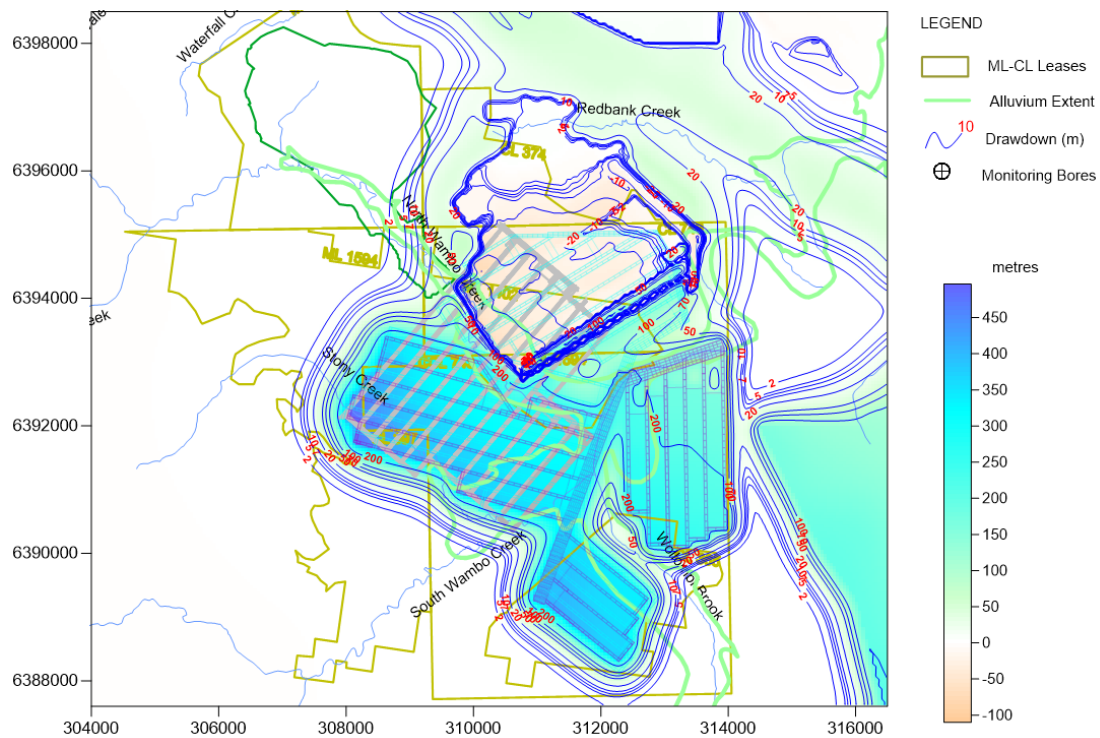
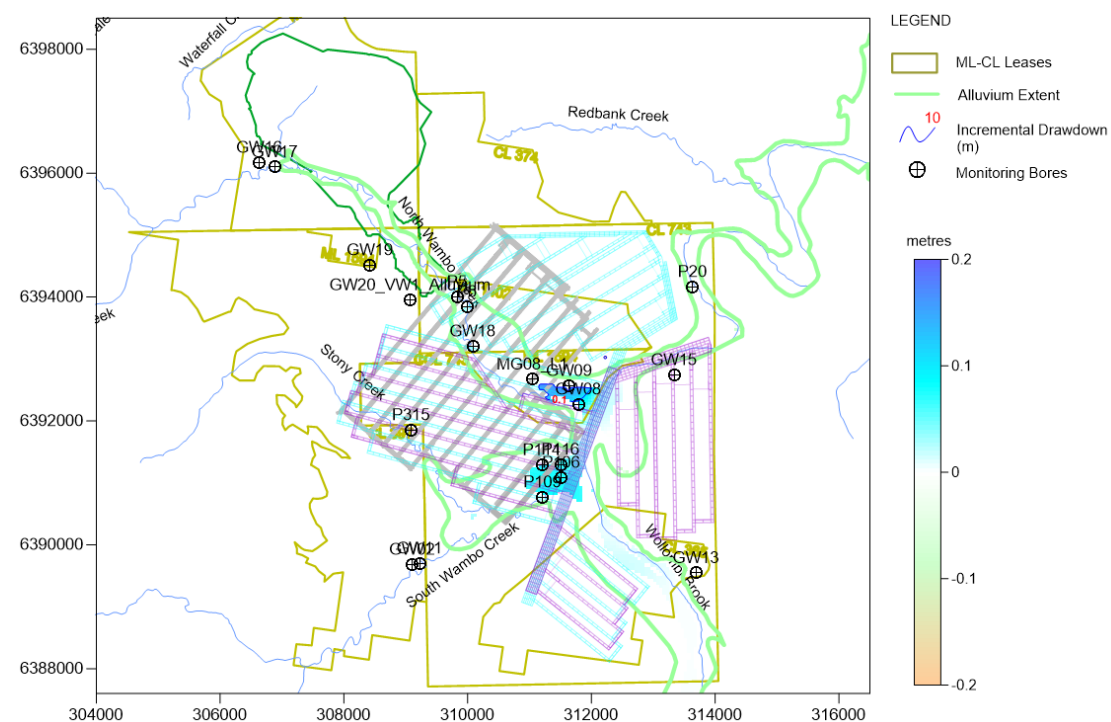
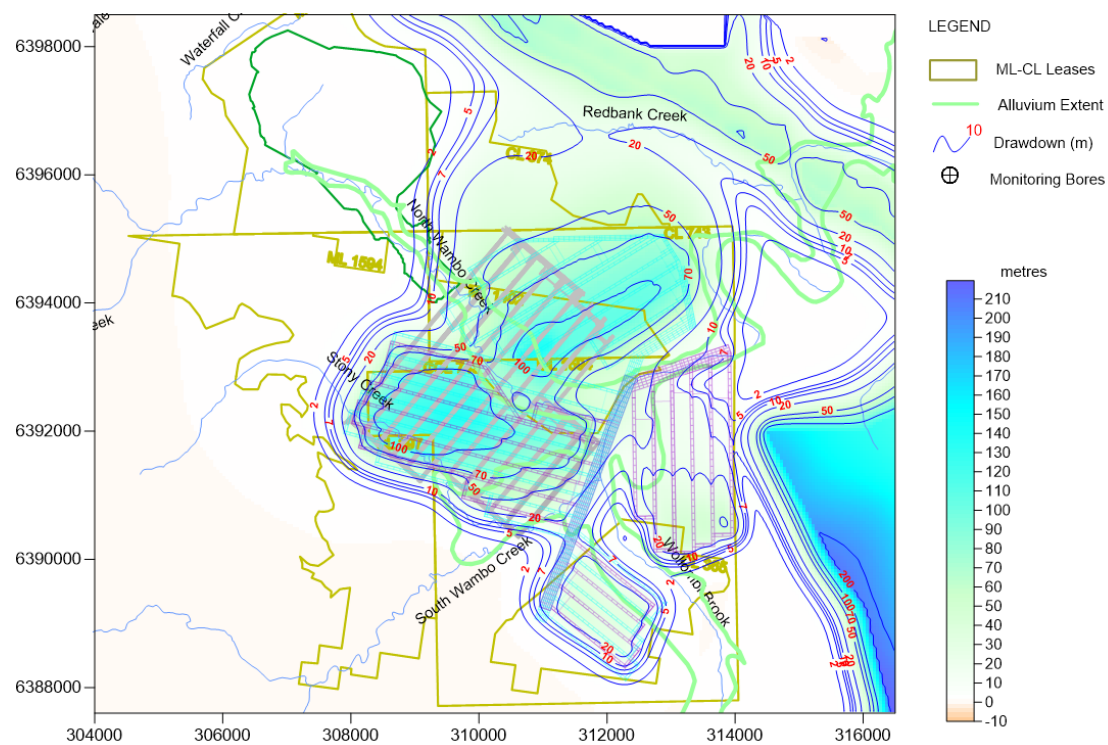


Figure 55: Cumulative Drawdown (m) in Arrowfield Seam at the End of South Wambo Mining for Modification Scenario



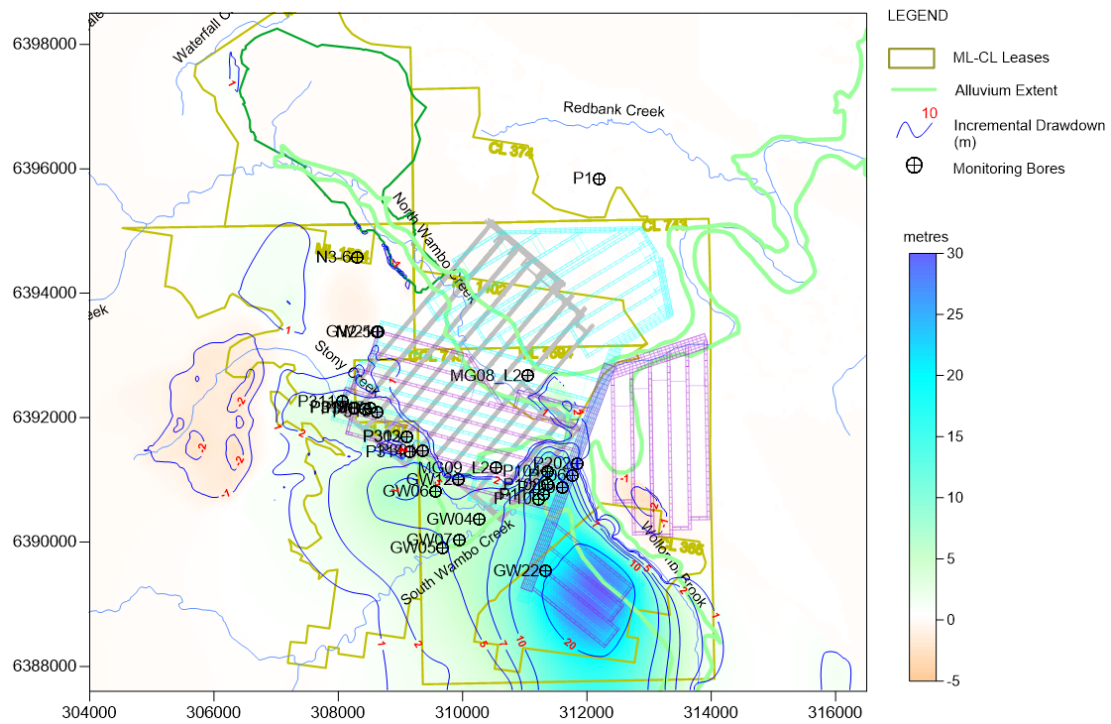


Figure 58: Modification Incremental Drawdown (m) in Whybrow Seam Overburden at the End of Mining

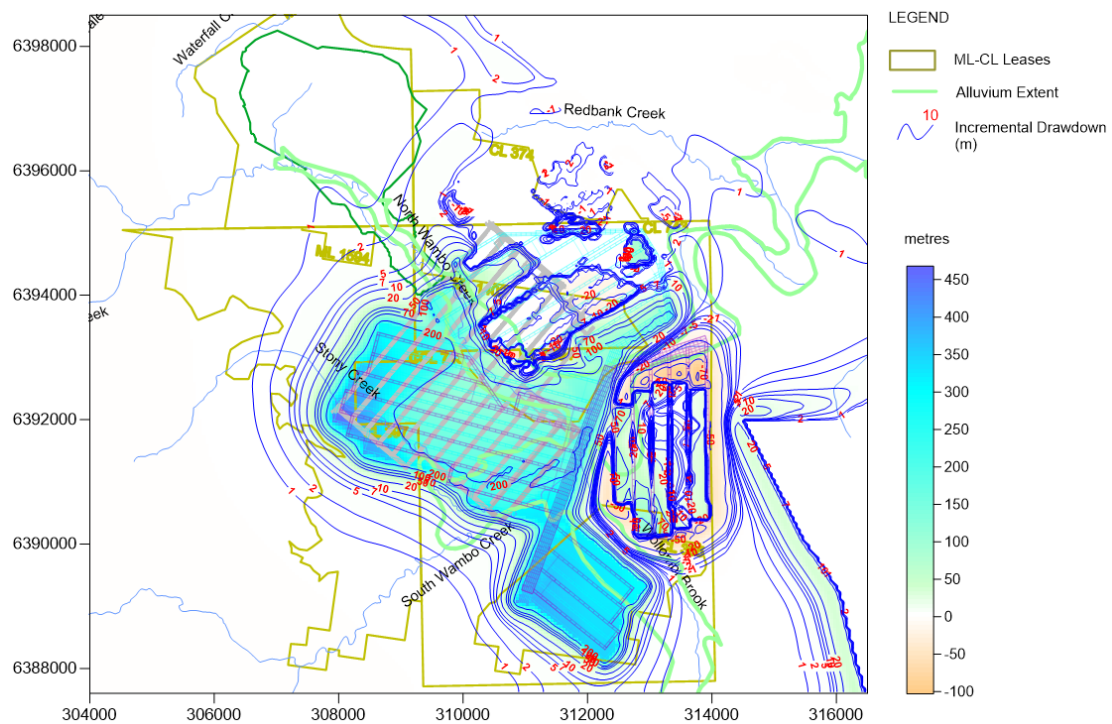


Figure 59: Modification Incremental Drawdown (m) in Woodlands Hill Seam at the End of Mining

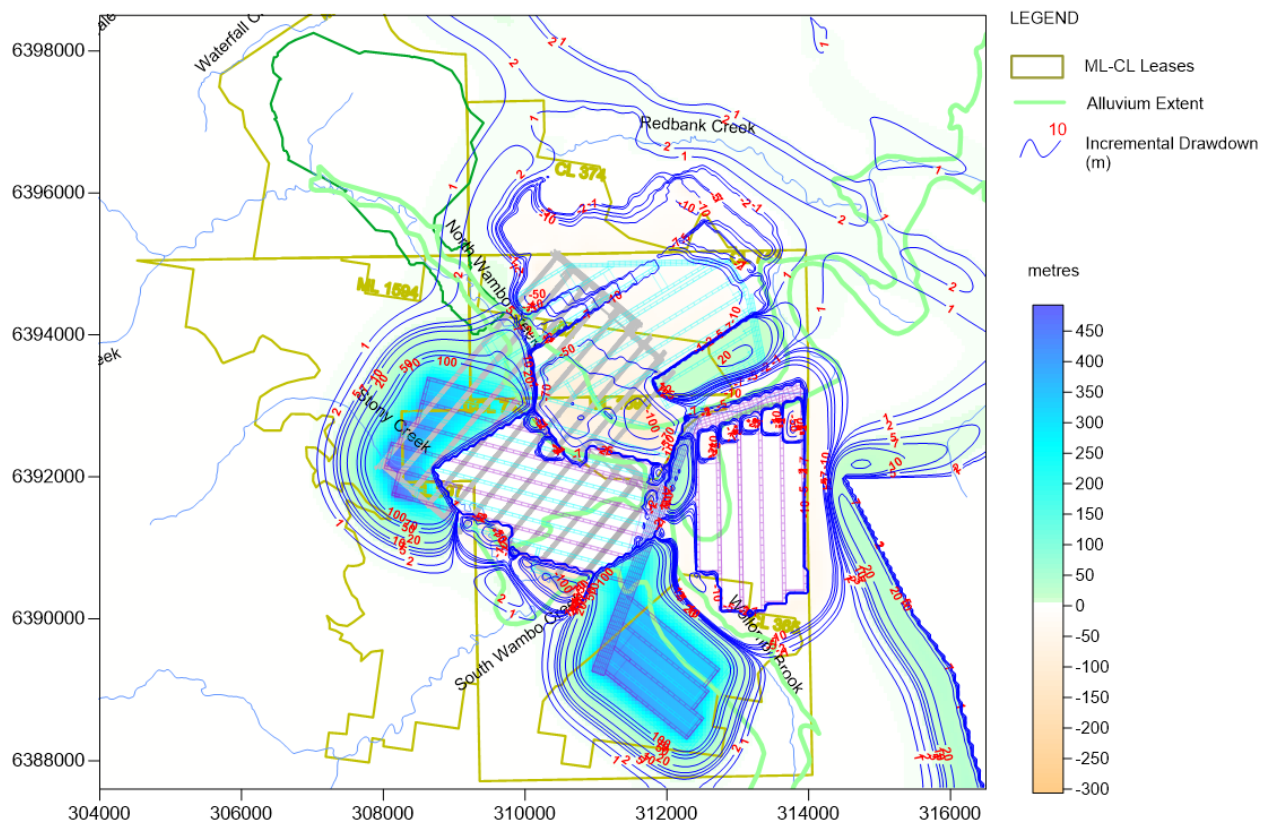


Figure 60: Modification Incremental Drawdown (m) in Arrowfield Seam at the End of Mining

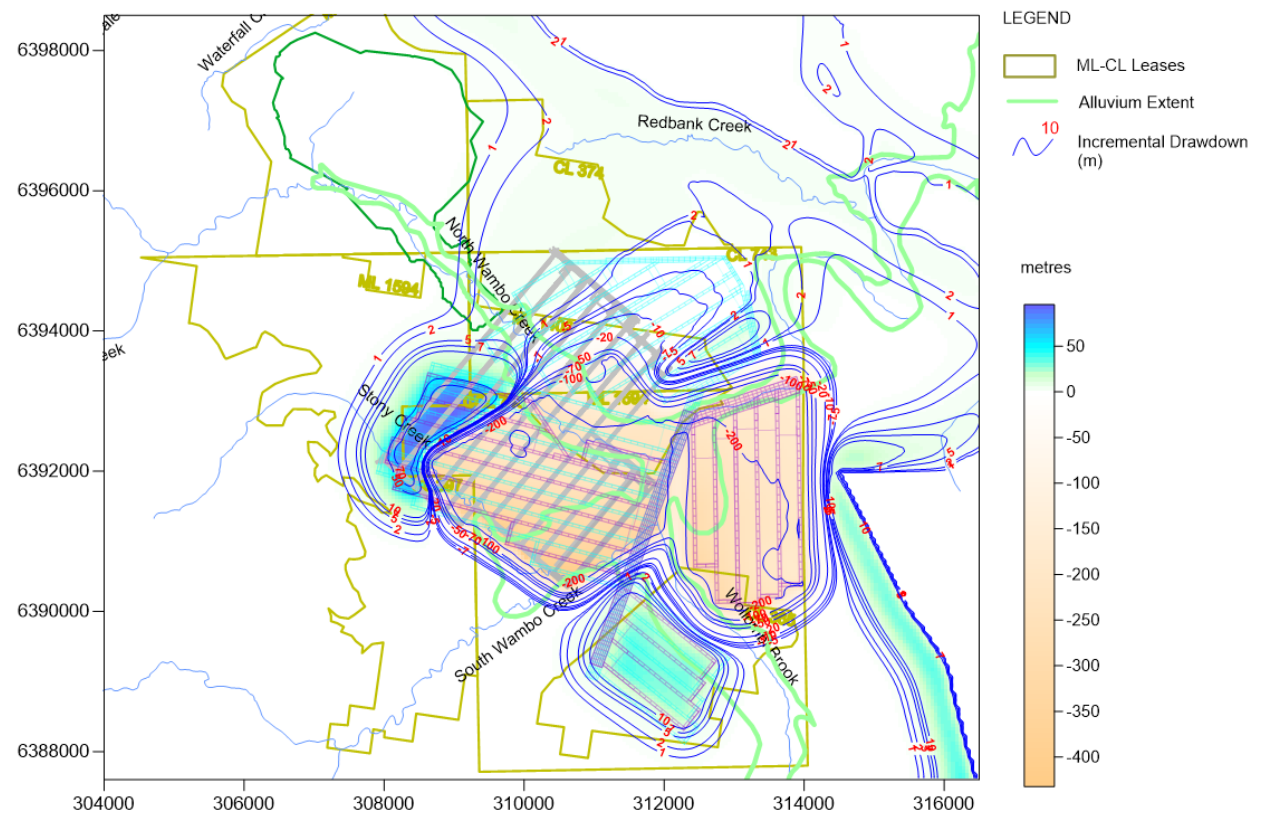


Figure 61: Modification Incremental Drawdown (m) in Bowfield Seam at the End of Mining

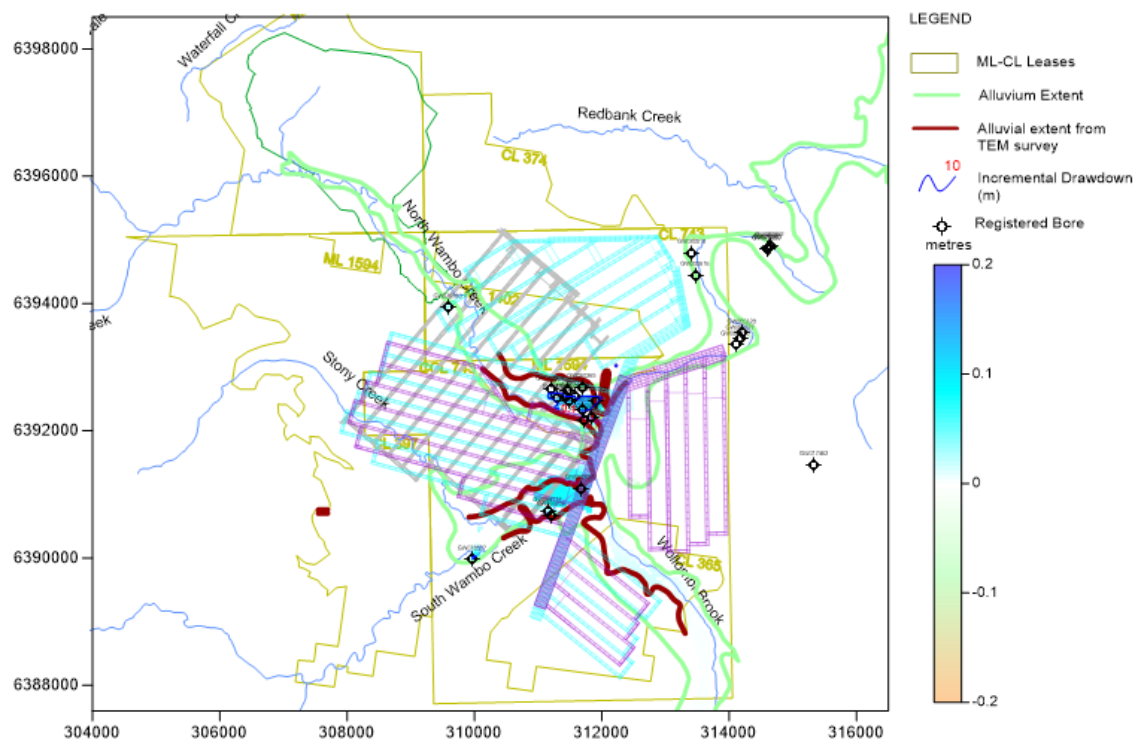


Figure 62: Proximity of Registered Bores to Incremental Drawdown (m) in Alluvium / Regolith due to South Wambo Modification Scenario

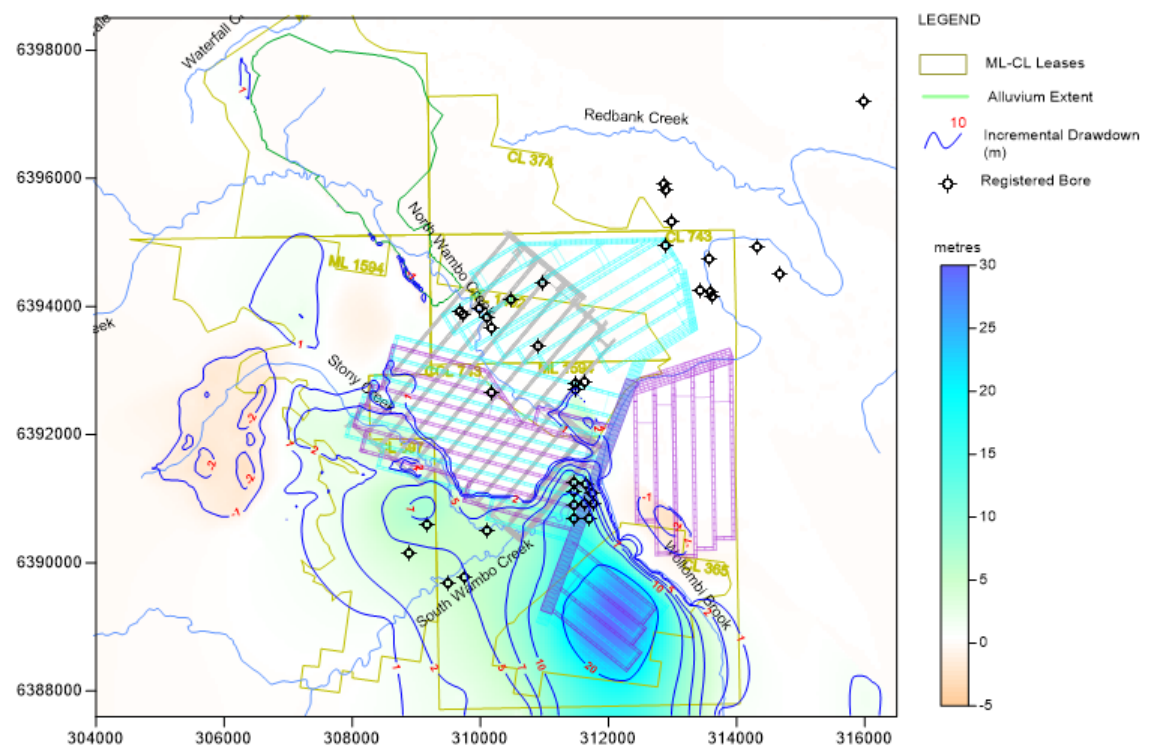


Figure 63: Proximity of Registered Bores to Incremental Drawdown (m) in Triassic Sandstone and Permian Overburden due to South Wambo Modification Scenario

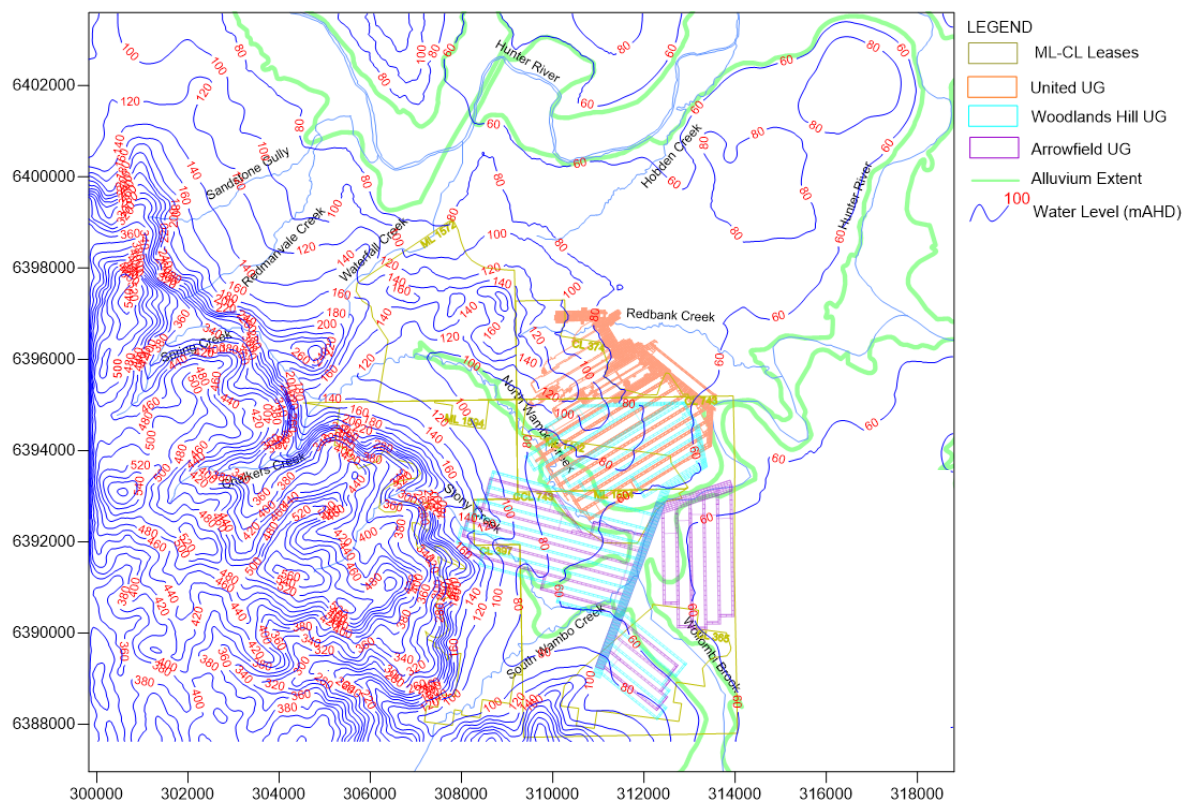


Figure 64: Recovered Groundwater Levels (mAHD) in Alluvium / Regolith (Model Layer 1) after 200 Years

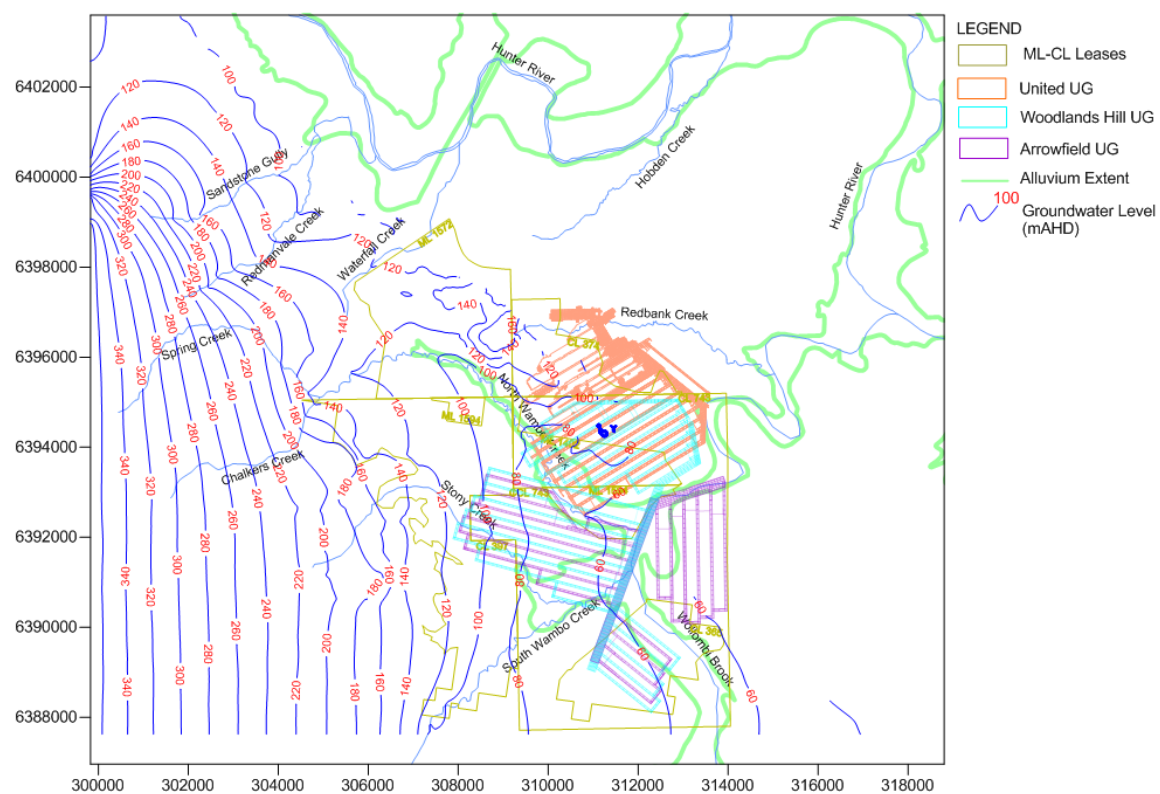


Figure 65: Recovered Groundwater Levels (mAHD) in Whybrow Seam Overburden (Model Layer 2) after 200 Years

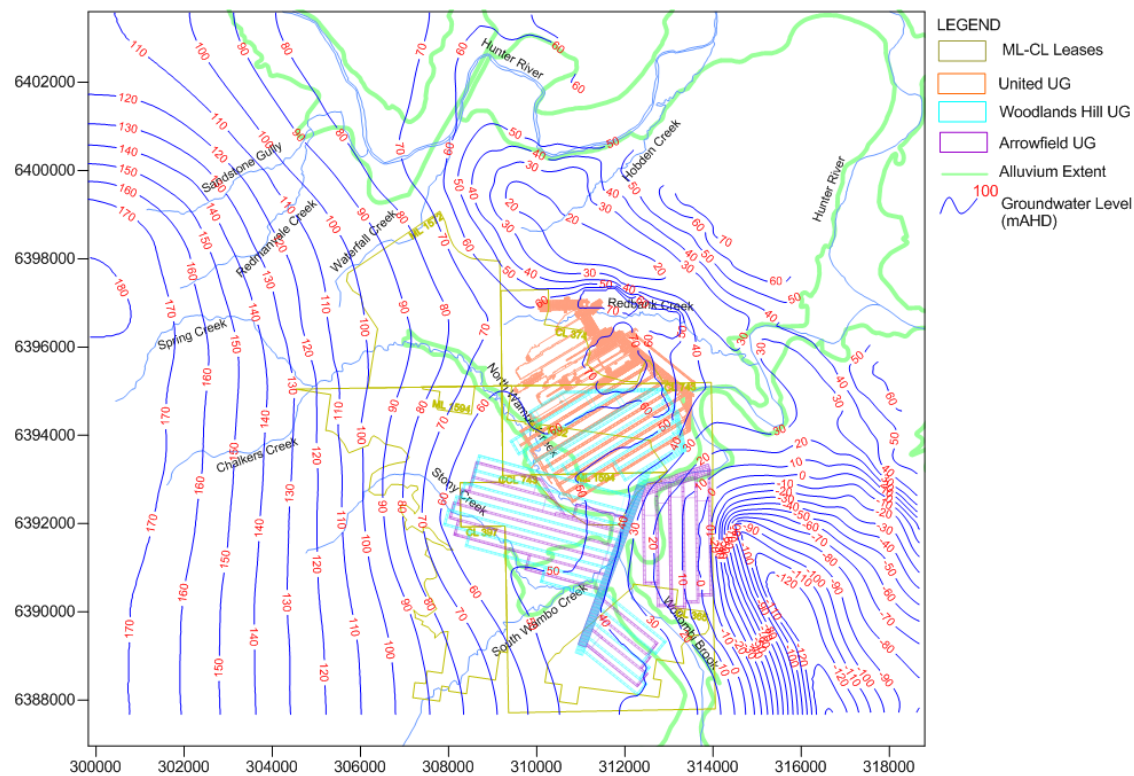


Figure 66: Recovered Groundwater Levels (mAH) in the Woodlands Hill Seam (Model Layer 9) after 200 Years

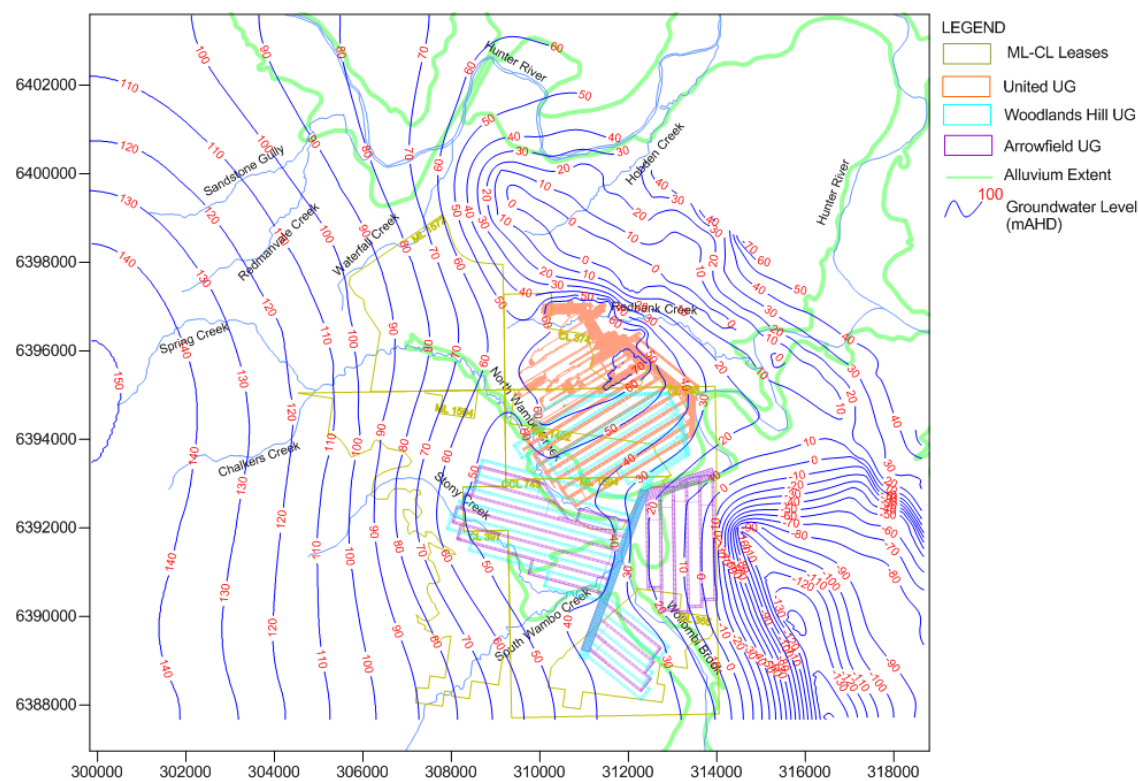


Figure 67: Recovered Groundwater Levels (mAH) in the Arrowfield Seam (Model Layer 11) after 200 Years

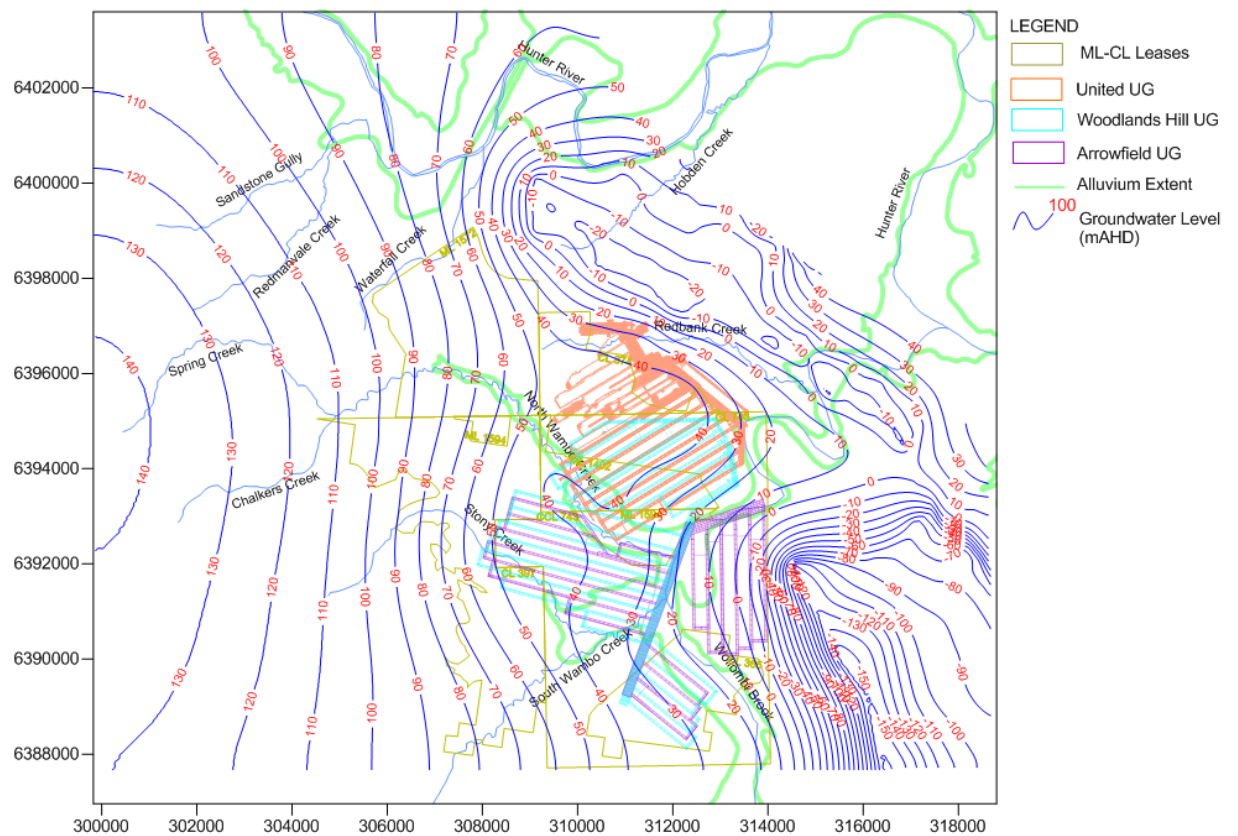


Figure 68: Recovered Groundwater Levels (mAHD) in the Bowfield Seam (Model Layer 13) after 200 Years

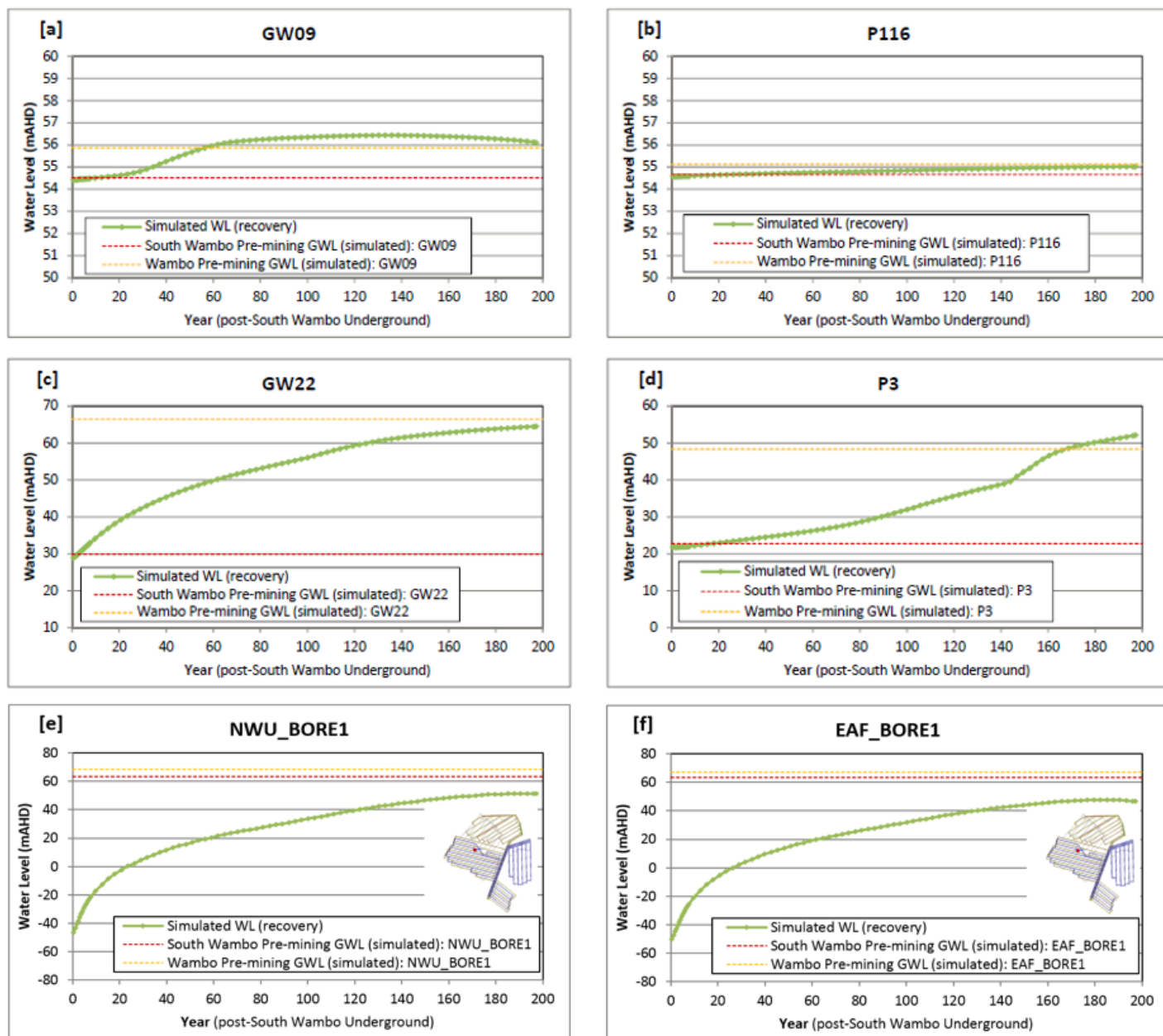


Figure 69: Representative Recovery Hydrographs: [a] GW09 above Woodlands Hill LW6 in Layer 1 (alluvium); [b] P116 above Woodlands Hill LW06 in Layer 1 (alluvium); [c] GW22 above Woodlands Hill LW09 in Layer 1 (alluvium); [d] P3 500m north-east Woodlands Hill LW01 in Layer 8 (Whynot/Woodlands Hill Interburden); [e] NWU_Bore1 within Woodlands Hill LW09 in Layer 9 (Woodlands Hill Seam); and [f] EAF_Bore1 within Arrowfield LW02E in Layer 11 (Arrowfield Seam).

Note: "Wambo Pre-mining GWL (simulated)" is the 2007 pre-Wambo mining water levels, which includes the influence of some historical mining.

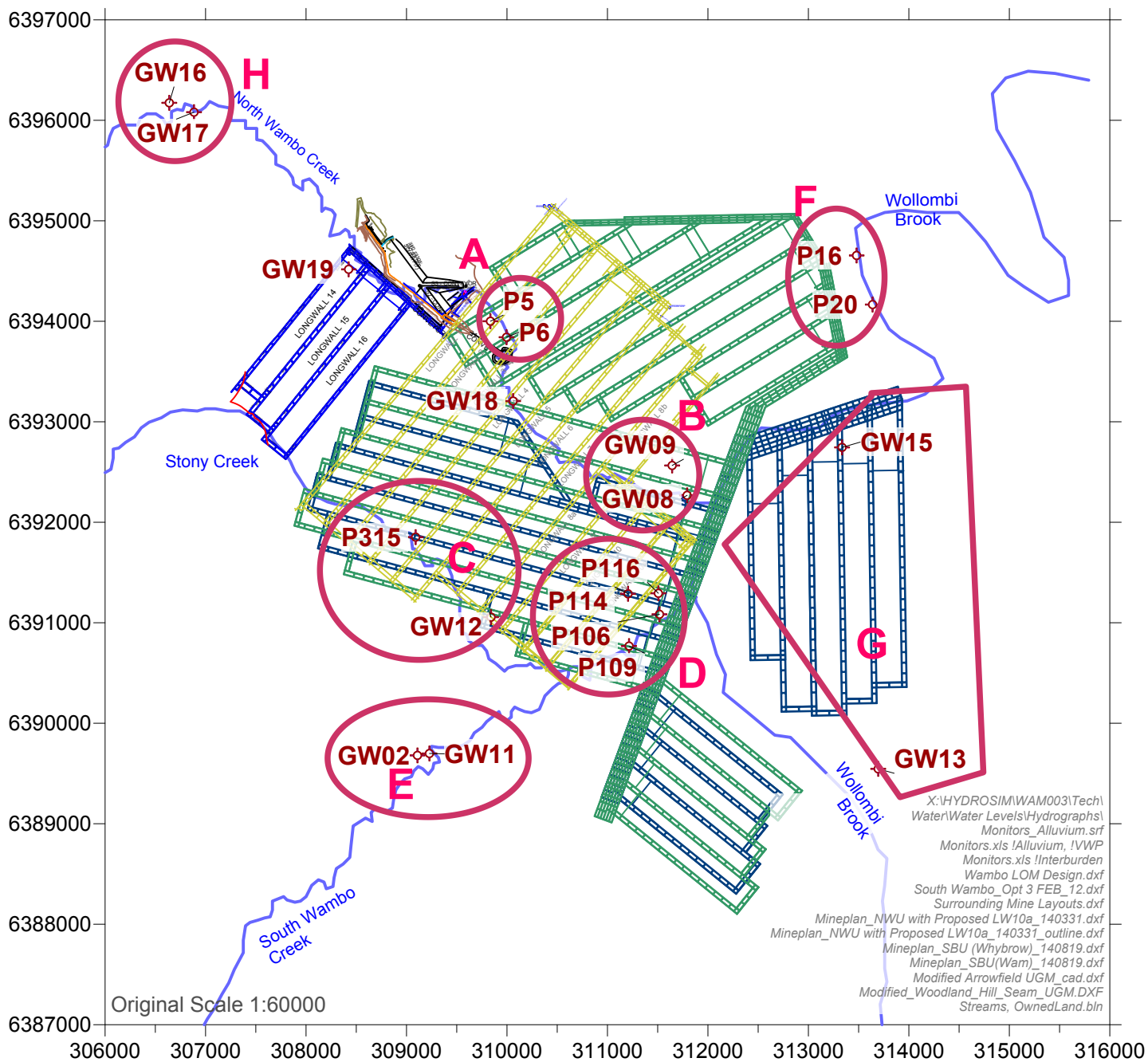


Figure A1. Alluvial Groundwater Monitoring Network and Hydrograph Groups

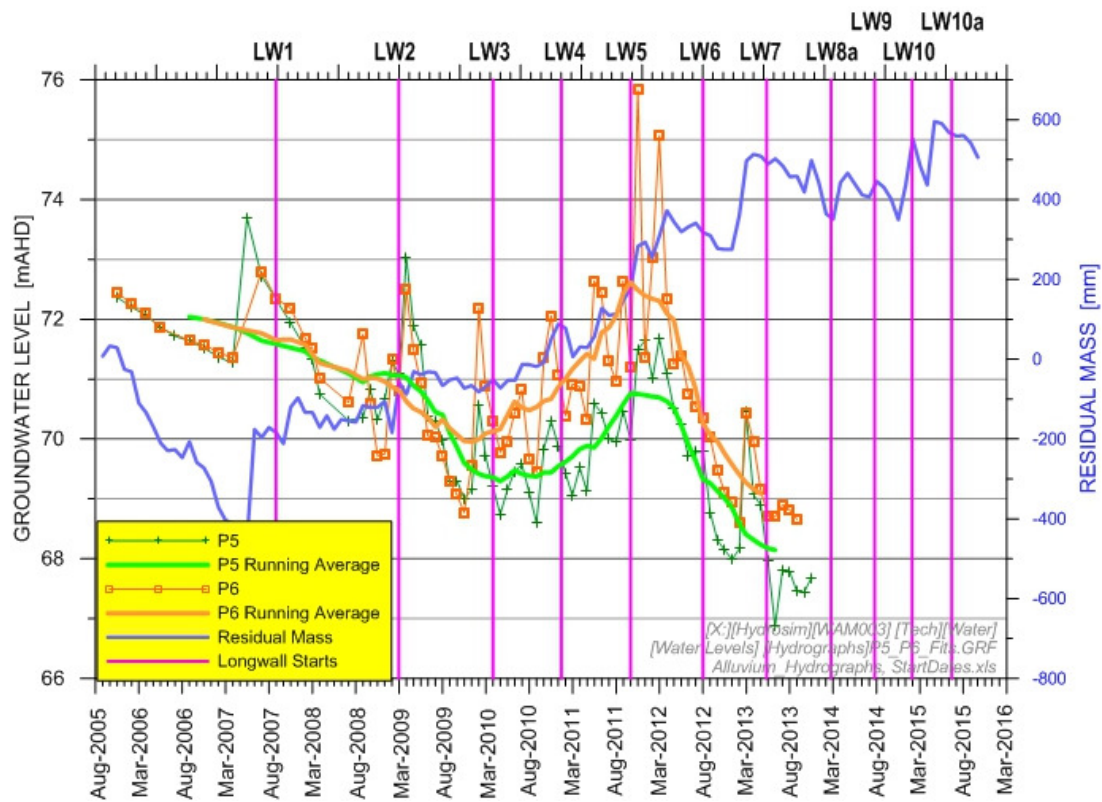


Figure A2. Group A Alluvial Hydrographs

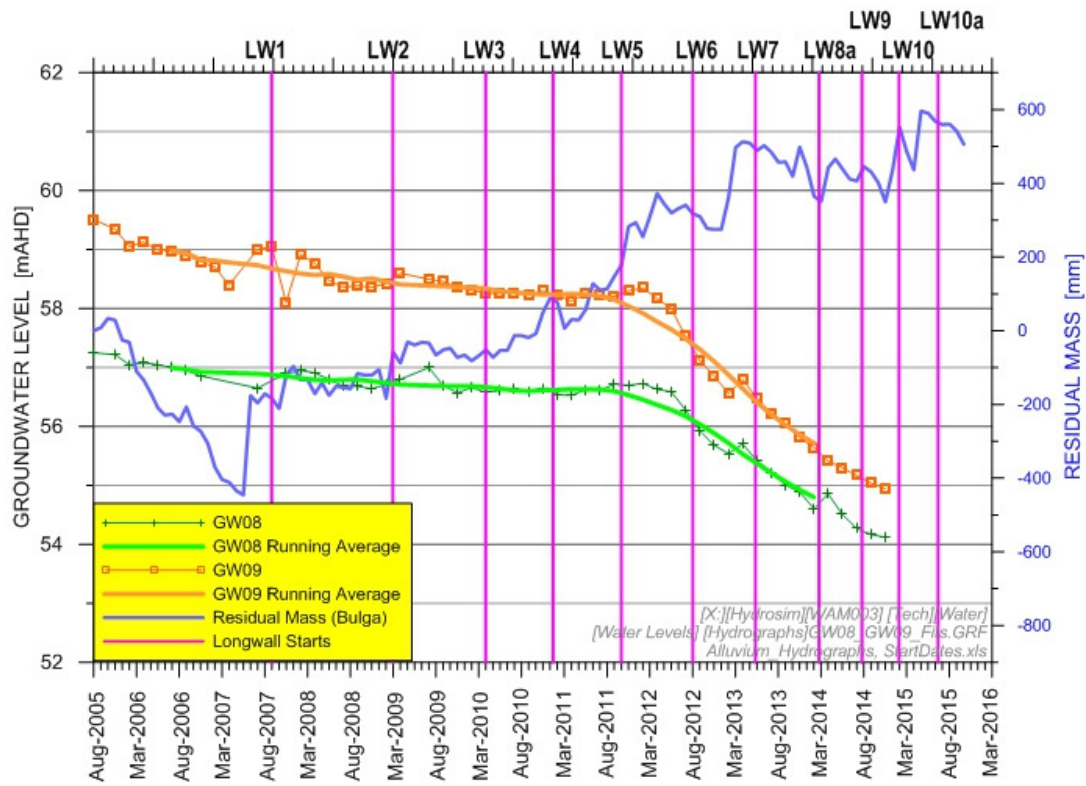


Figure A3. Group B Alluvial Hydrographs

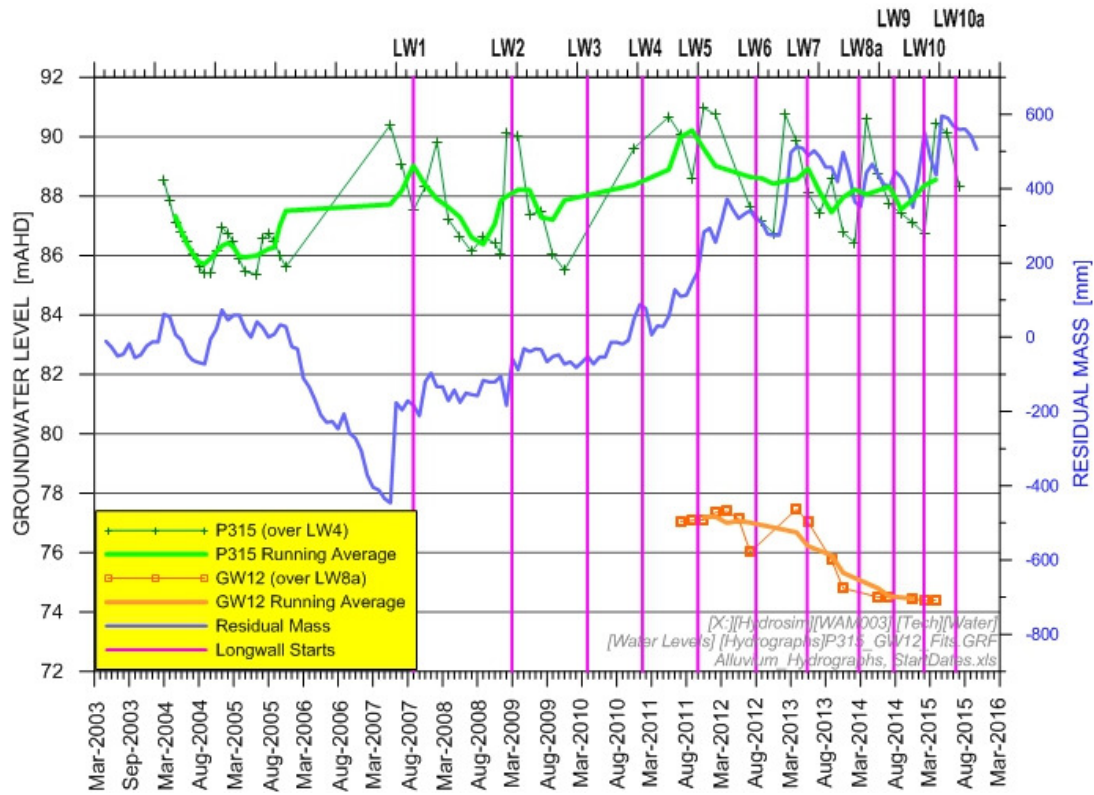


Figure A4. Group C Alluvial Hydrographs

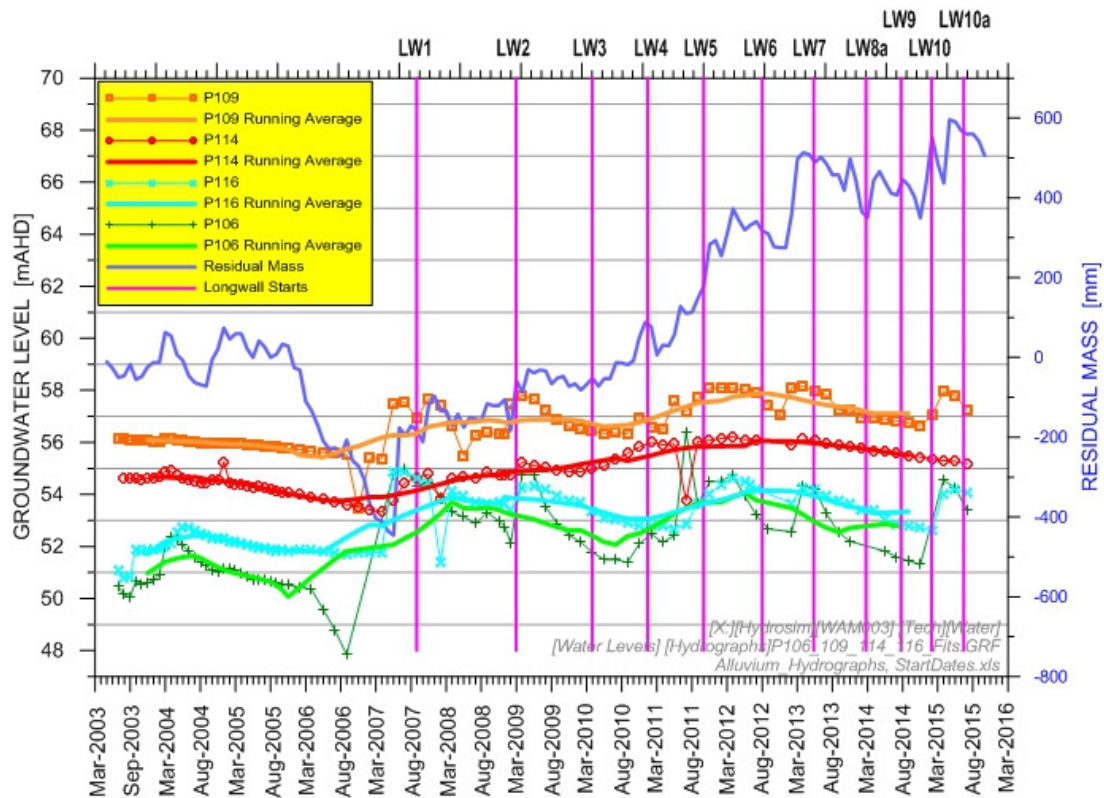


Figure A5. Group D Alluvial Hydrographs

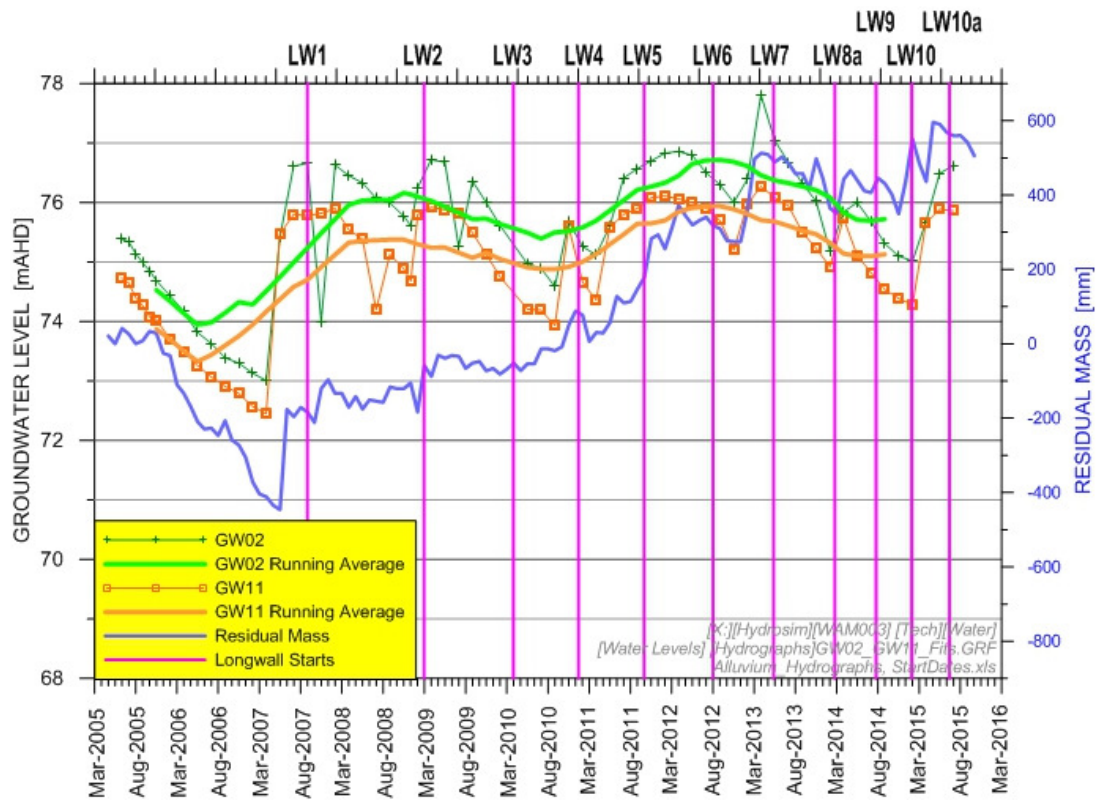


Figure A6. Group E Alluvial Hydrographs

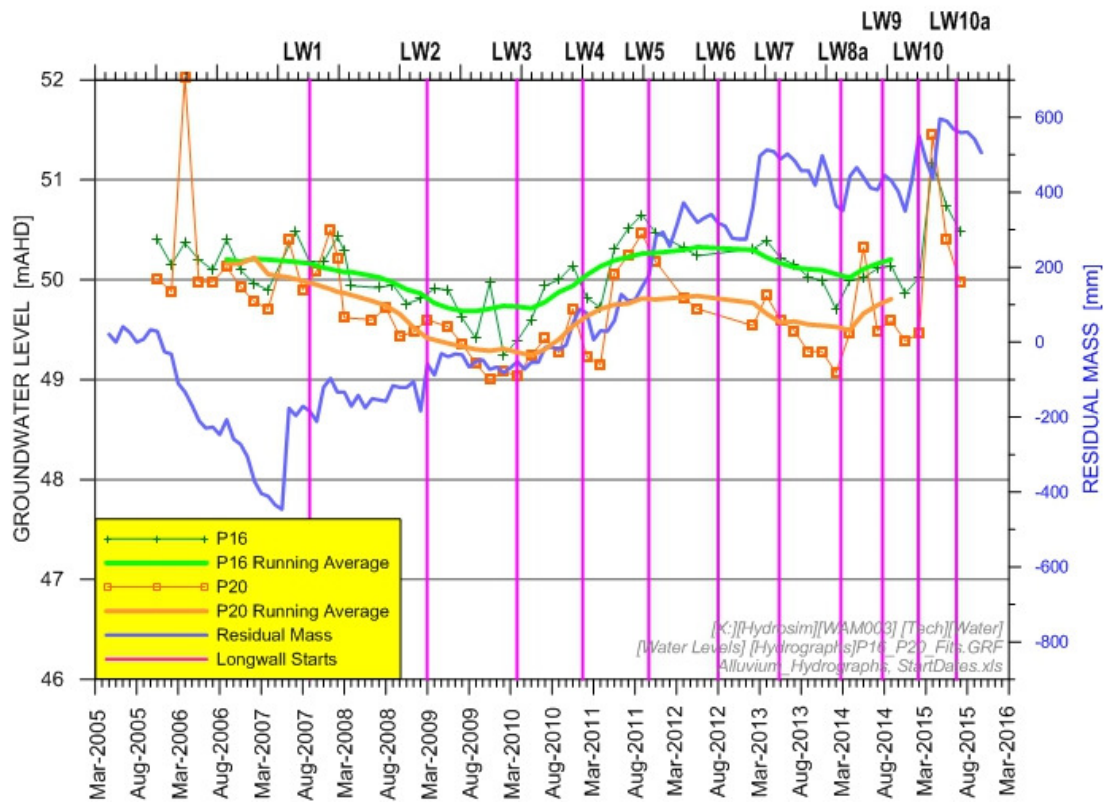


Figure A7. Group F Alluvial Hydrographs

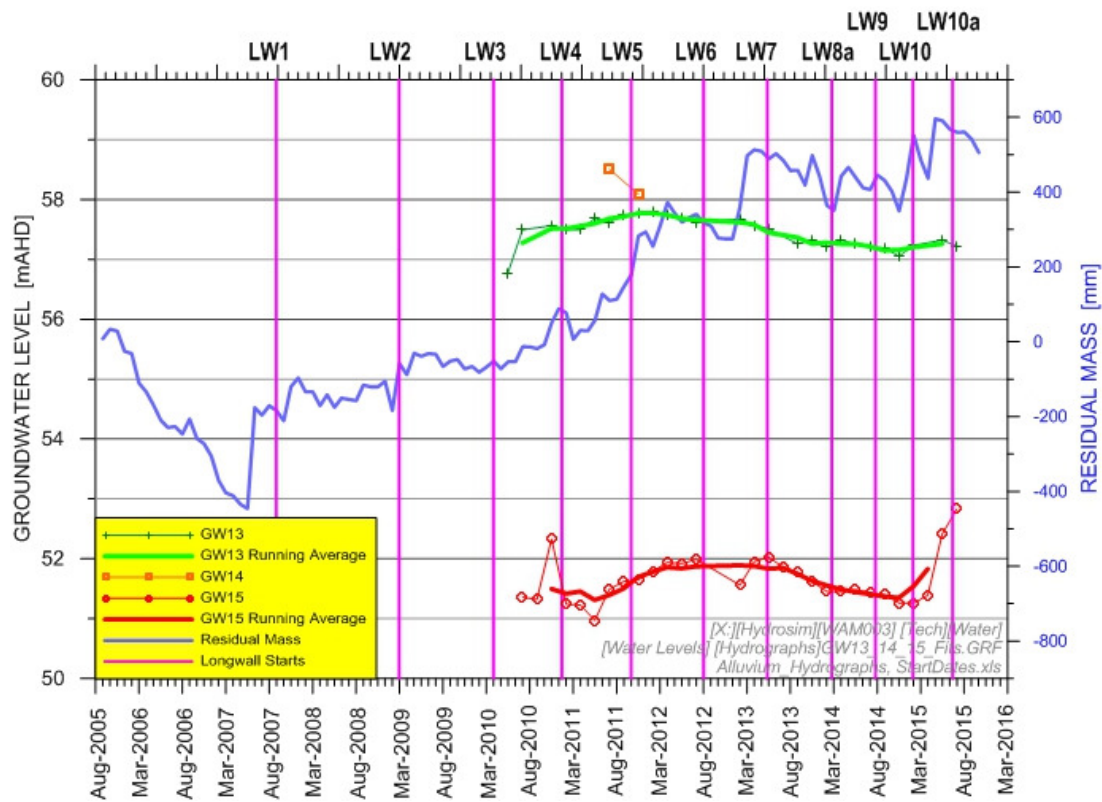


Figure A8. Group G Alluvial Hydrographs

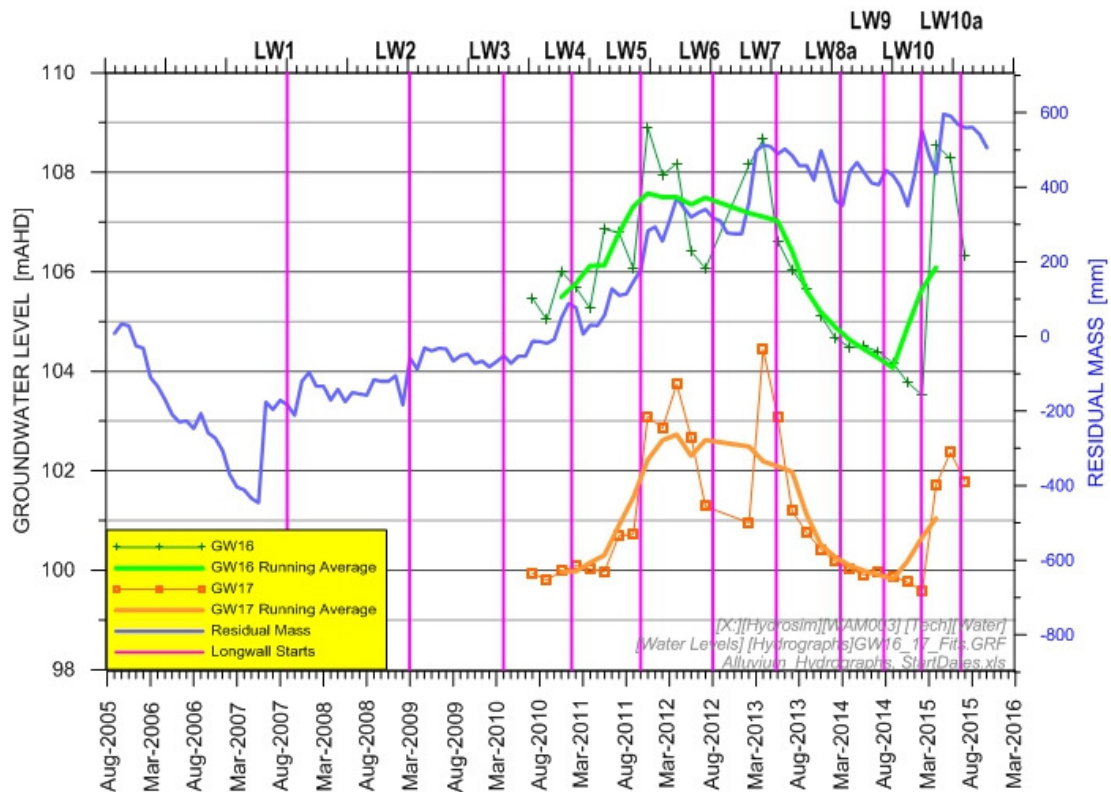


Figure A9. Group H Alluvial Hydrographs

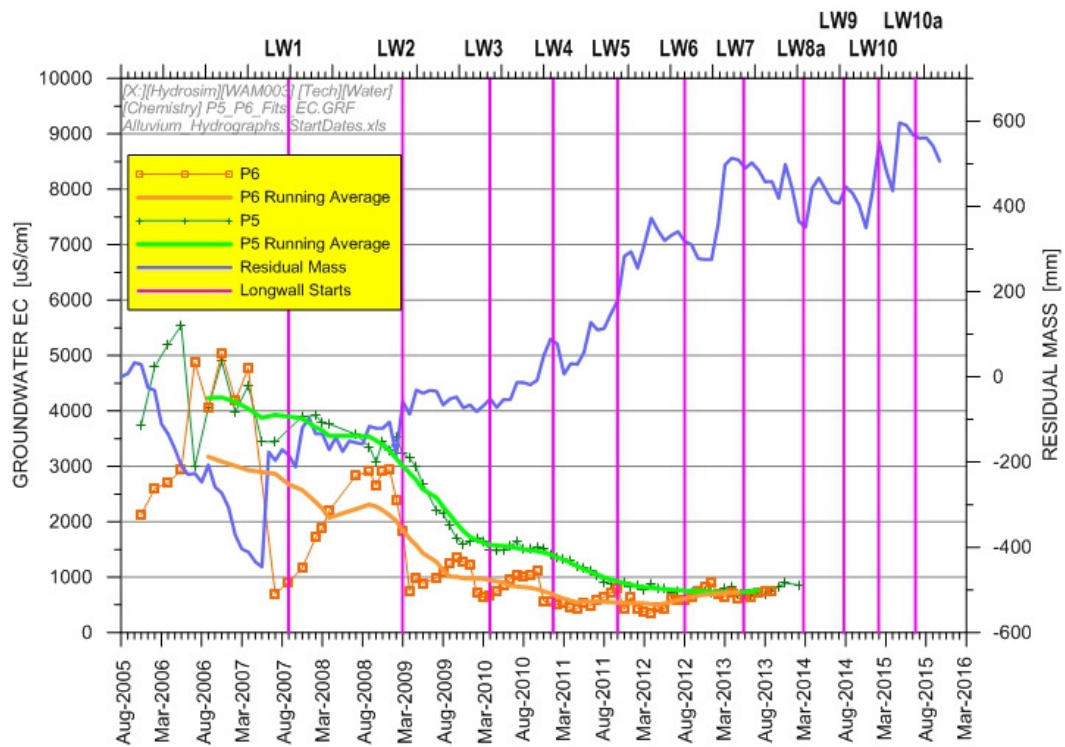


Figure A10. Group A Alluvial EC Time-Series

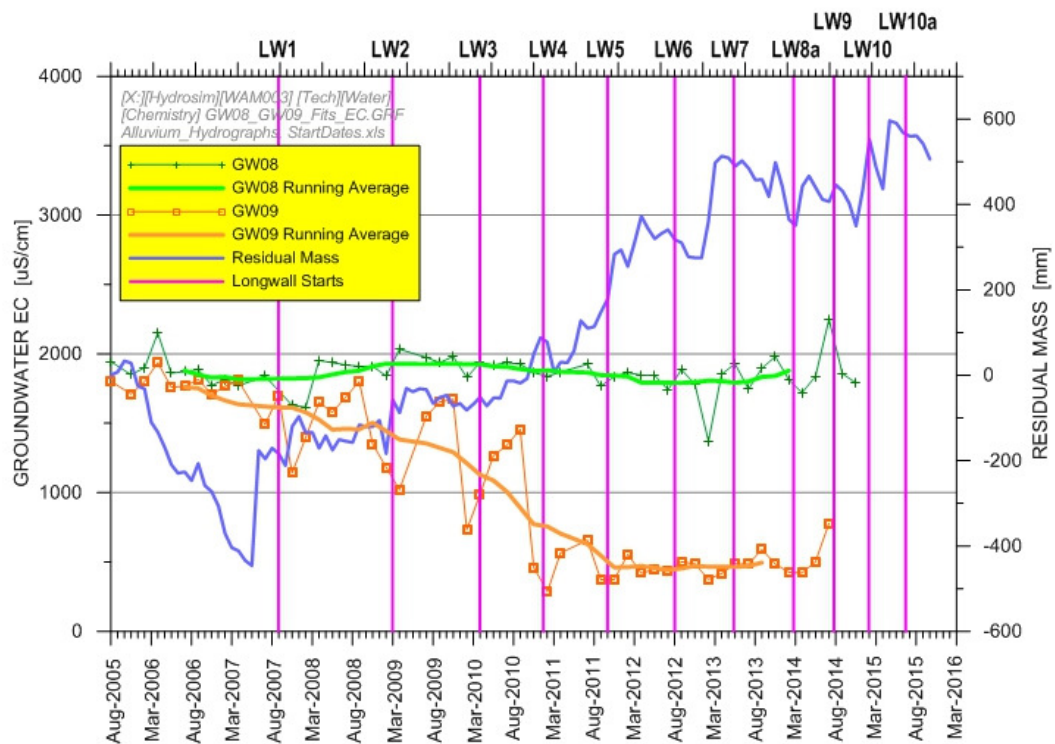


Figure A11. Group B Alluvial EC Time-Series

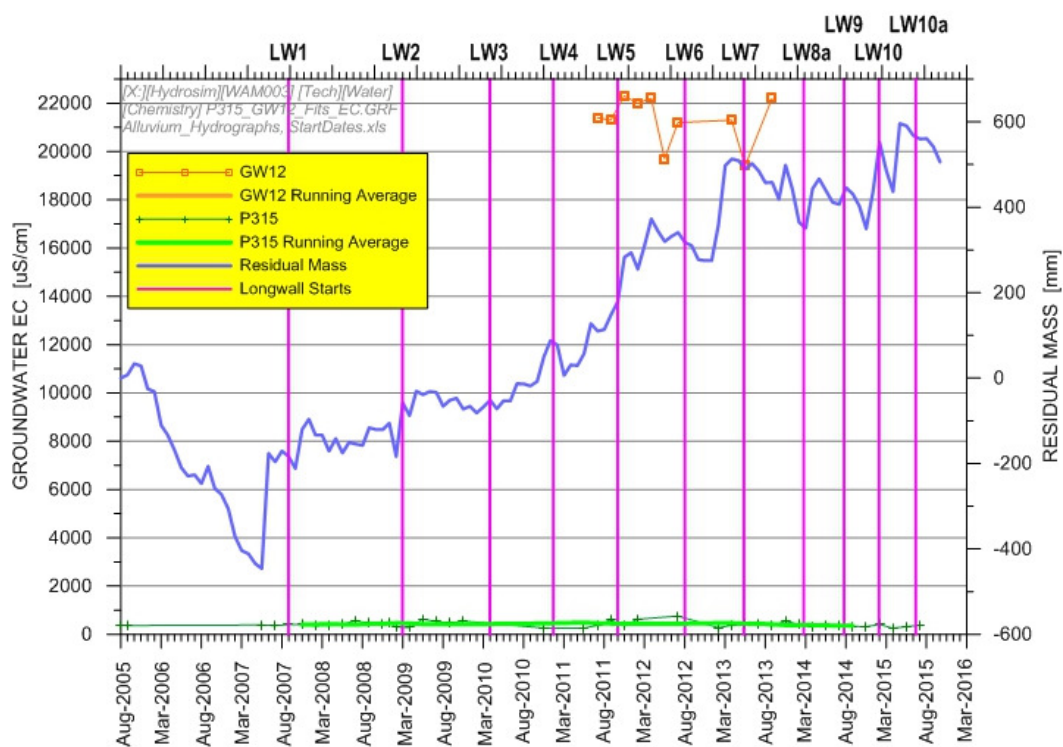


Figure A12. Group C Alluvial EC Time-Series

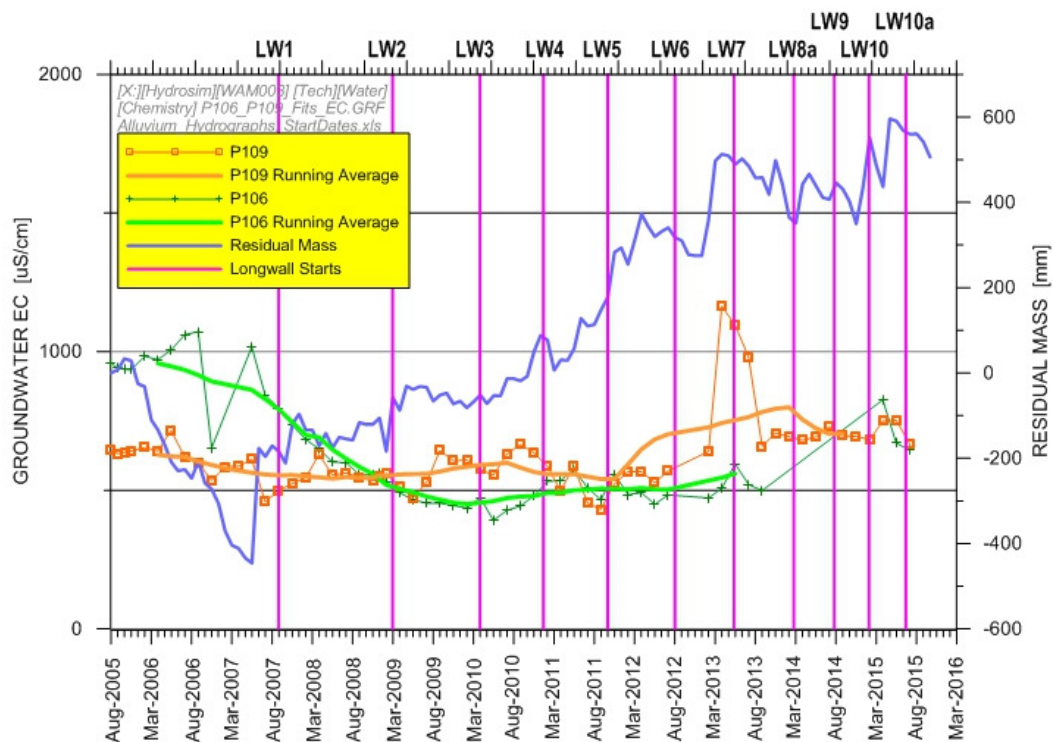


Figure A13a. Group D Alluvial EC Time-Series

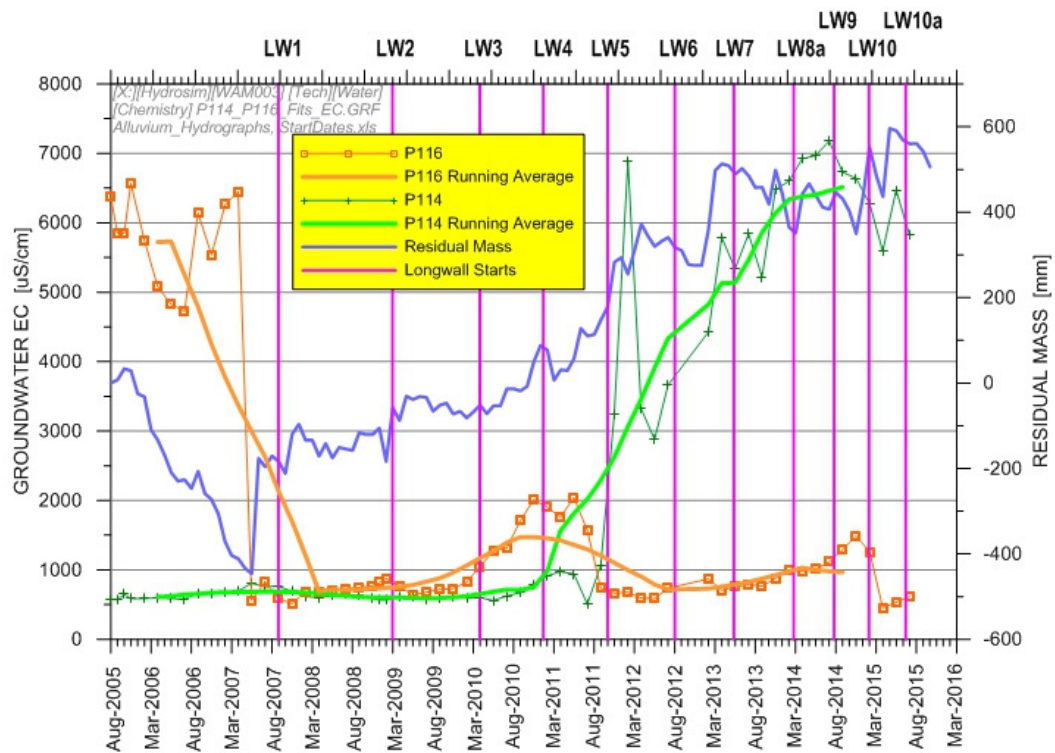


Figure A13b. Group D Alluvial EC Time-Series

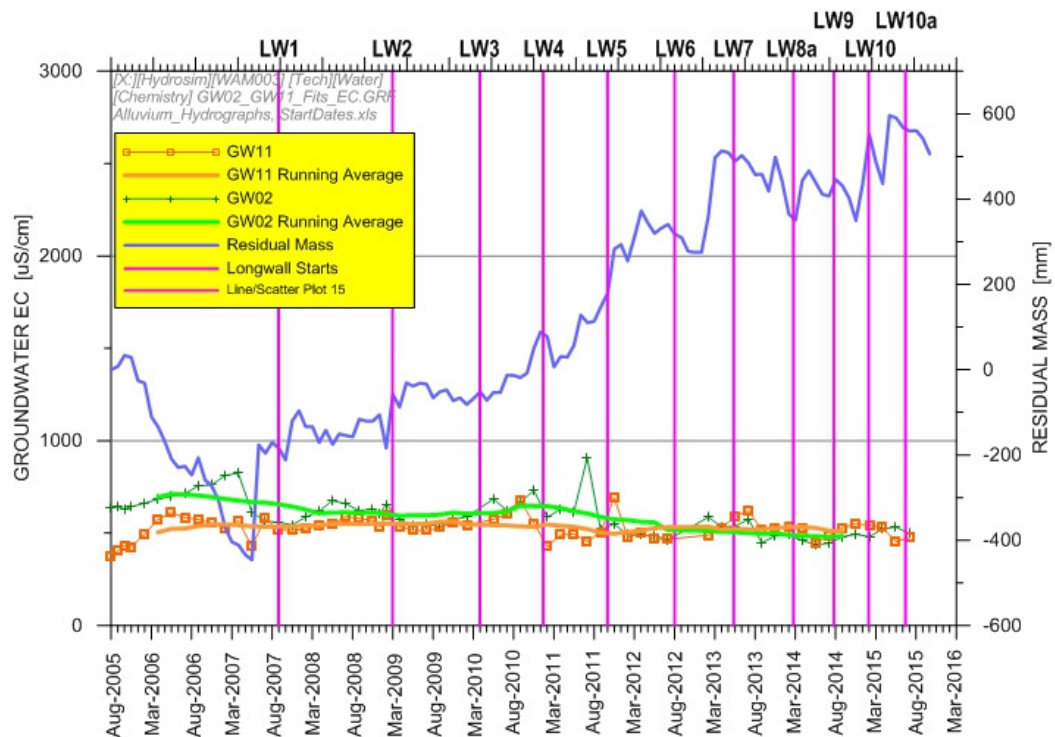


Figure A14. Group E Alluvial EC Time-Series

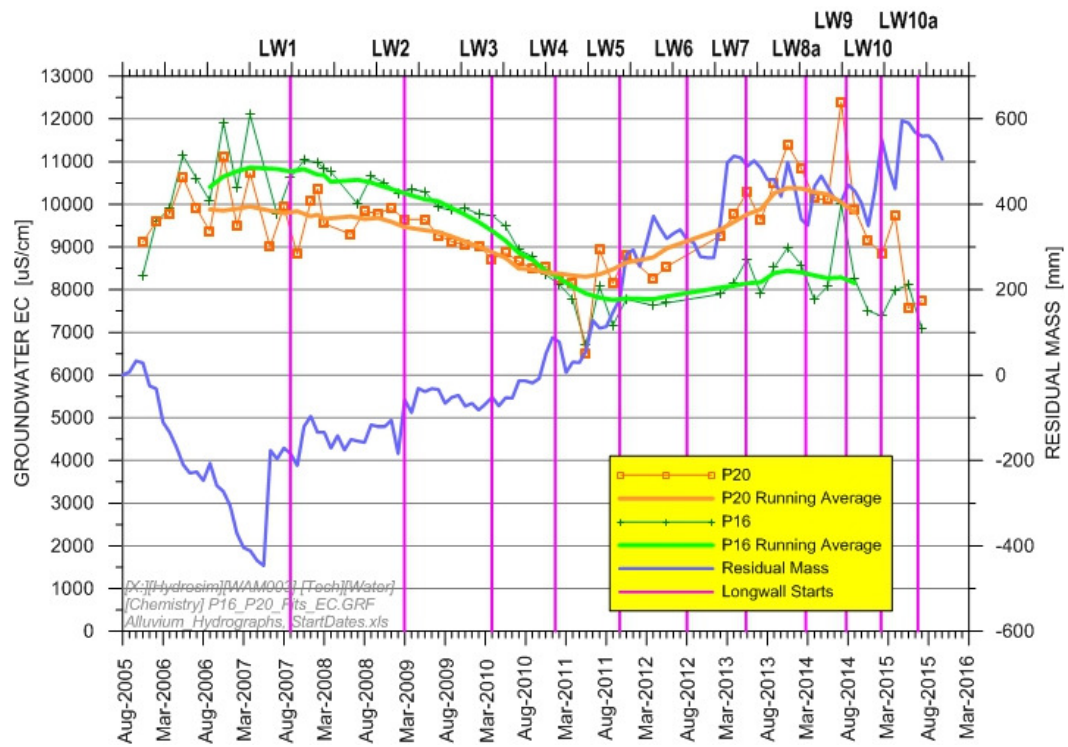


Figure A15. Group F Alluvial EC Time-Series

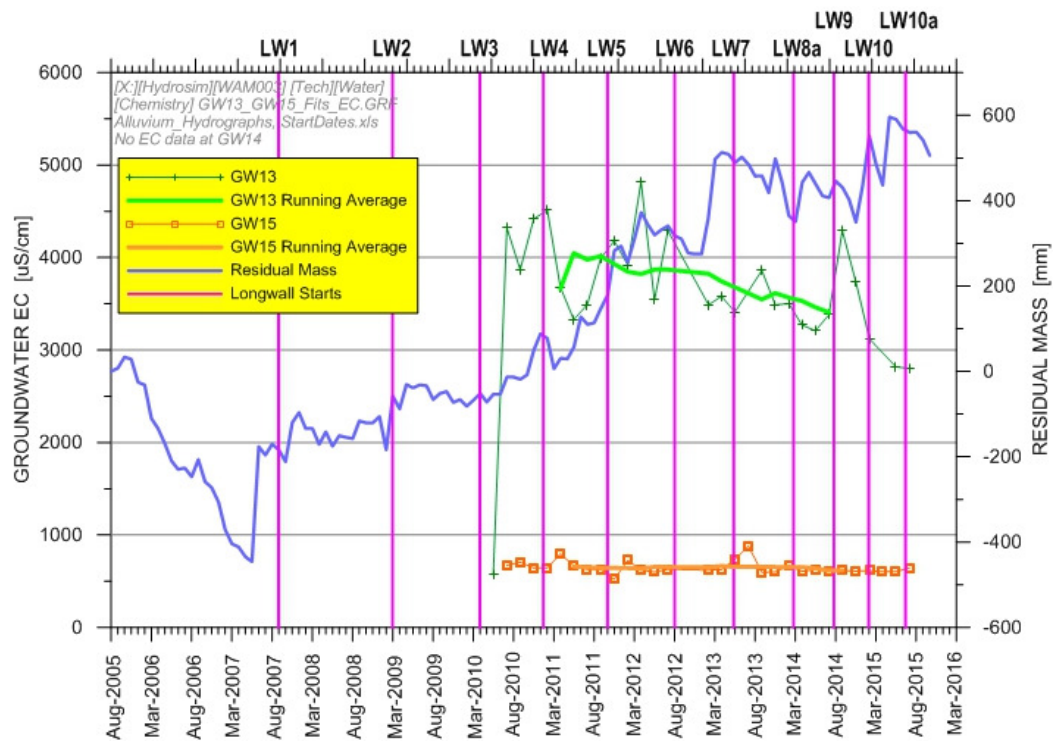


Figure A16. Group G Alluvial EC Time-Series

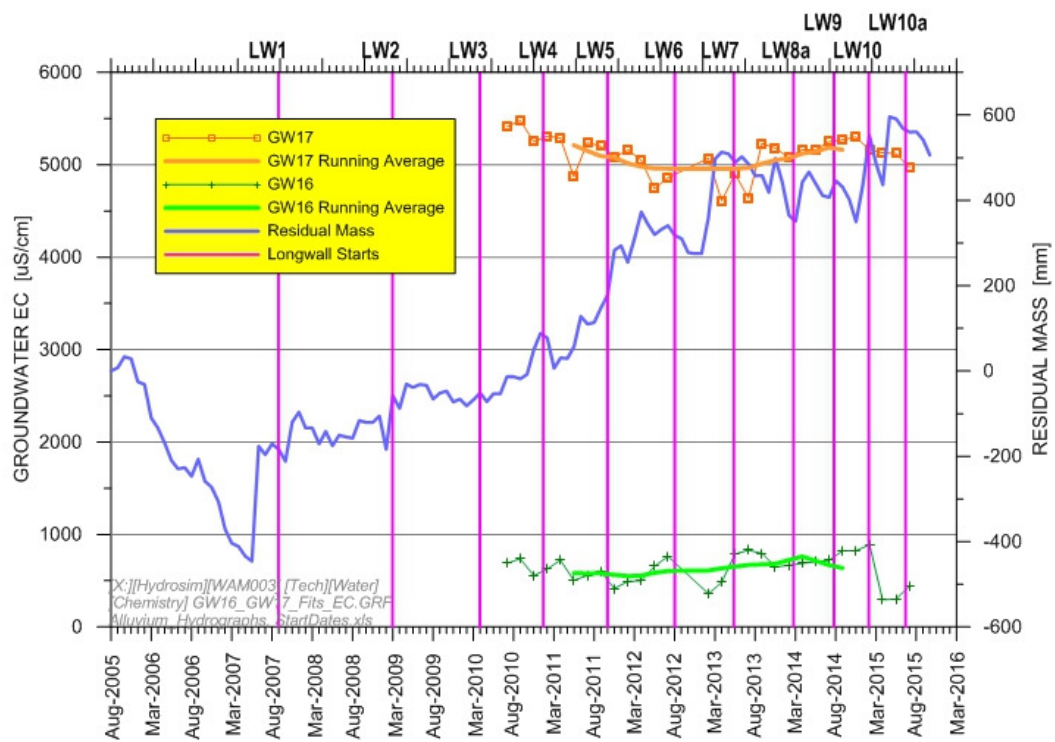


Figure A17. Group H Alluvial EC Time-Series

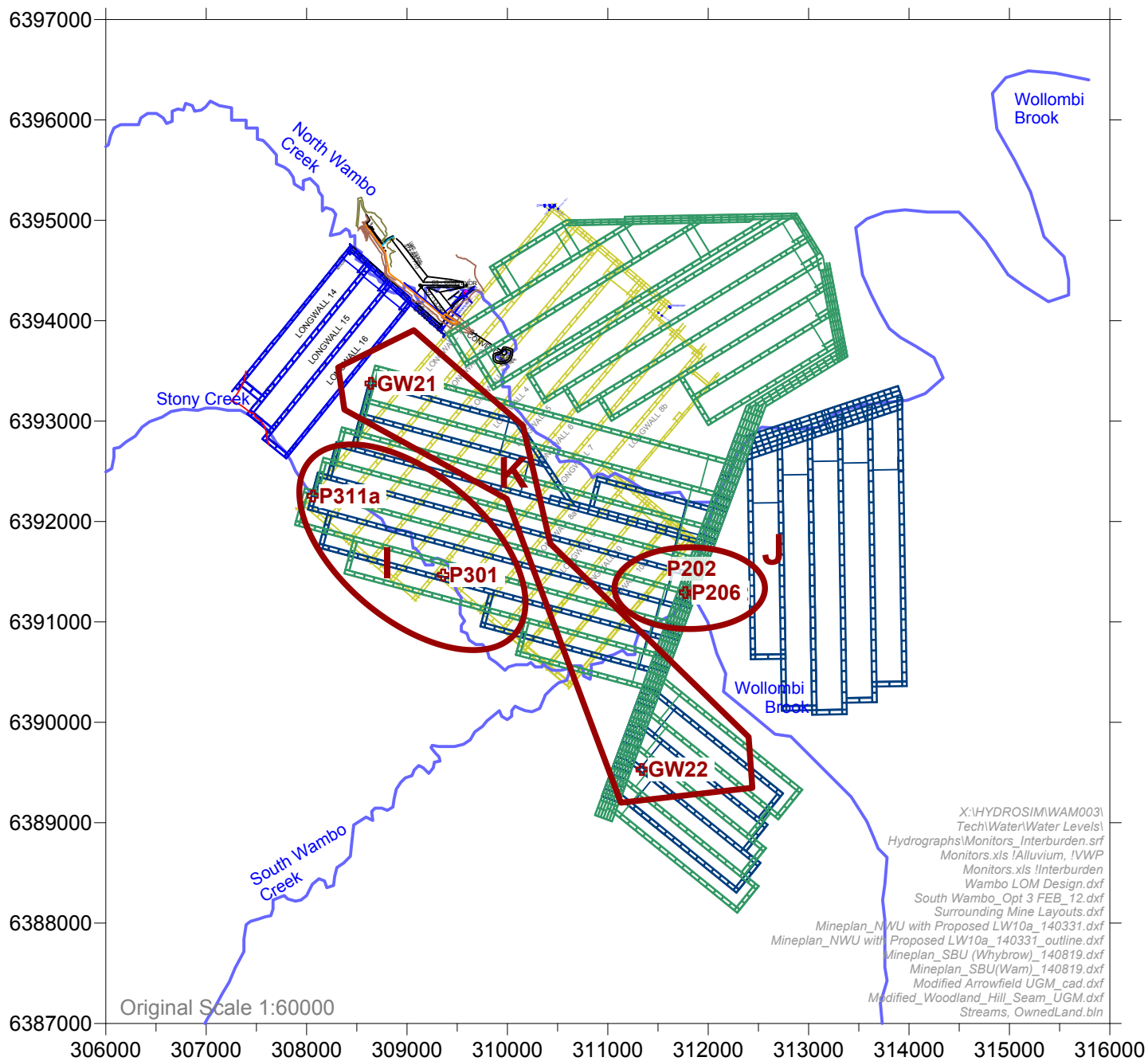


Figure B1. Interburden Groundwater Monitoring Network and Hydrograph Groups

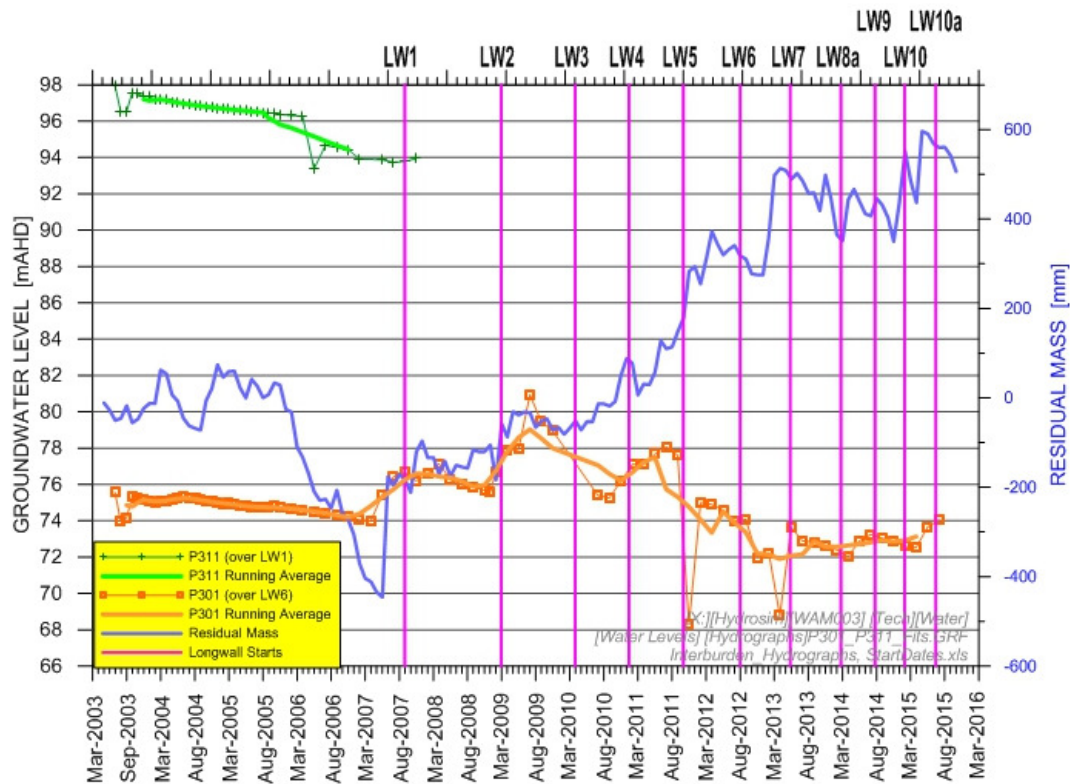


Figure B2. Group I Interburden Hydrographs

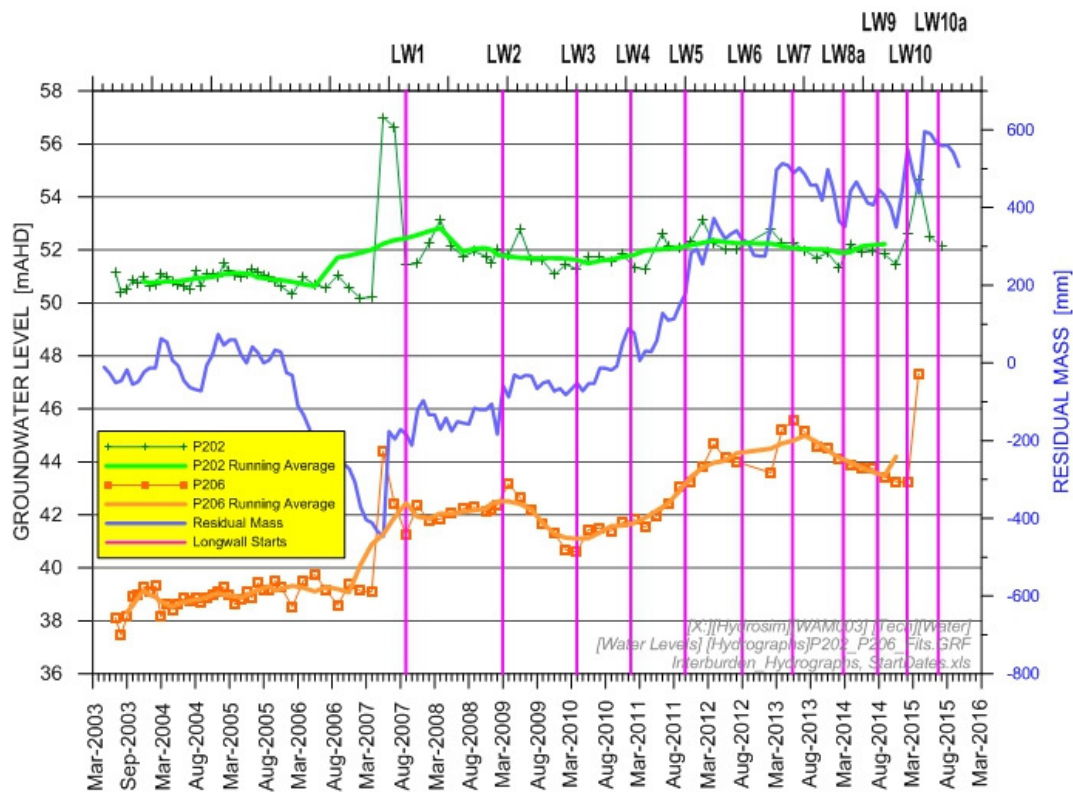


Figure B3. Group J Interburden Hydrographs

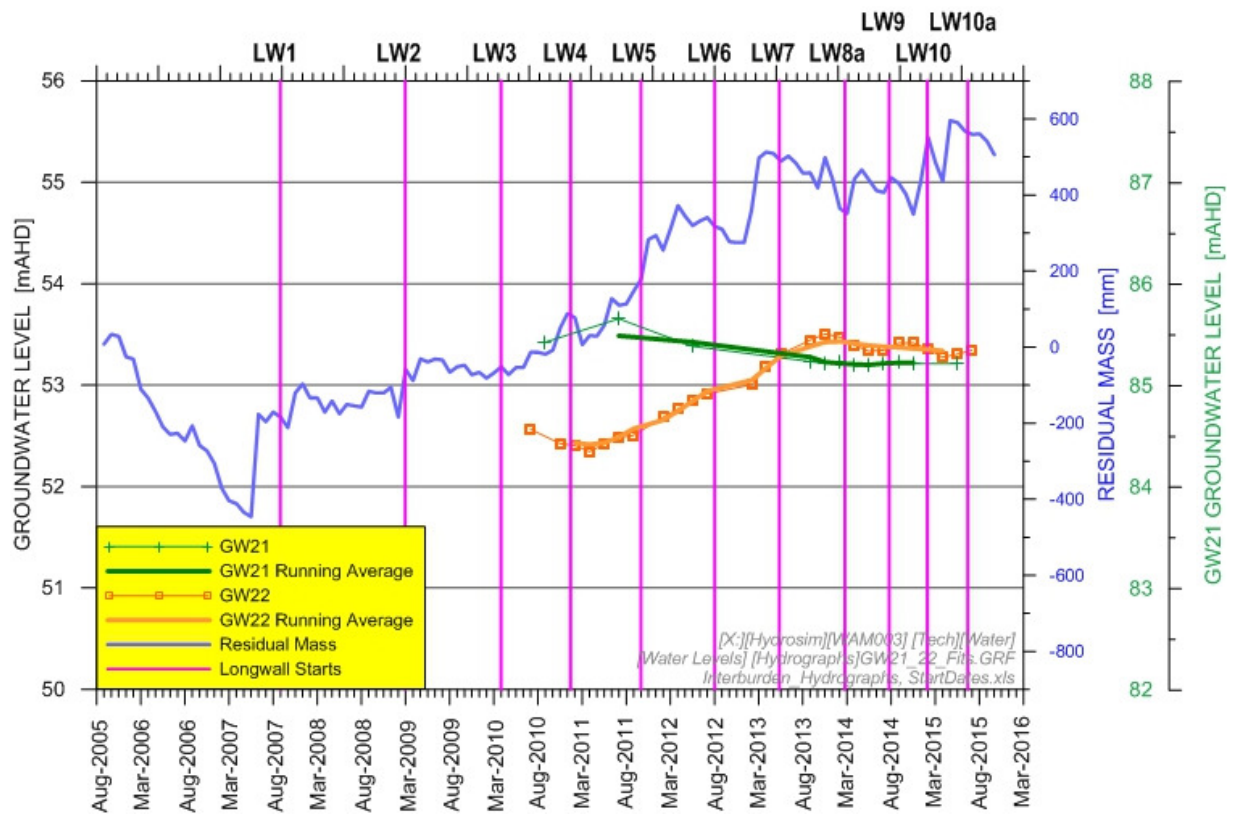


Figure B4. Group K Interburden Hydrographs

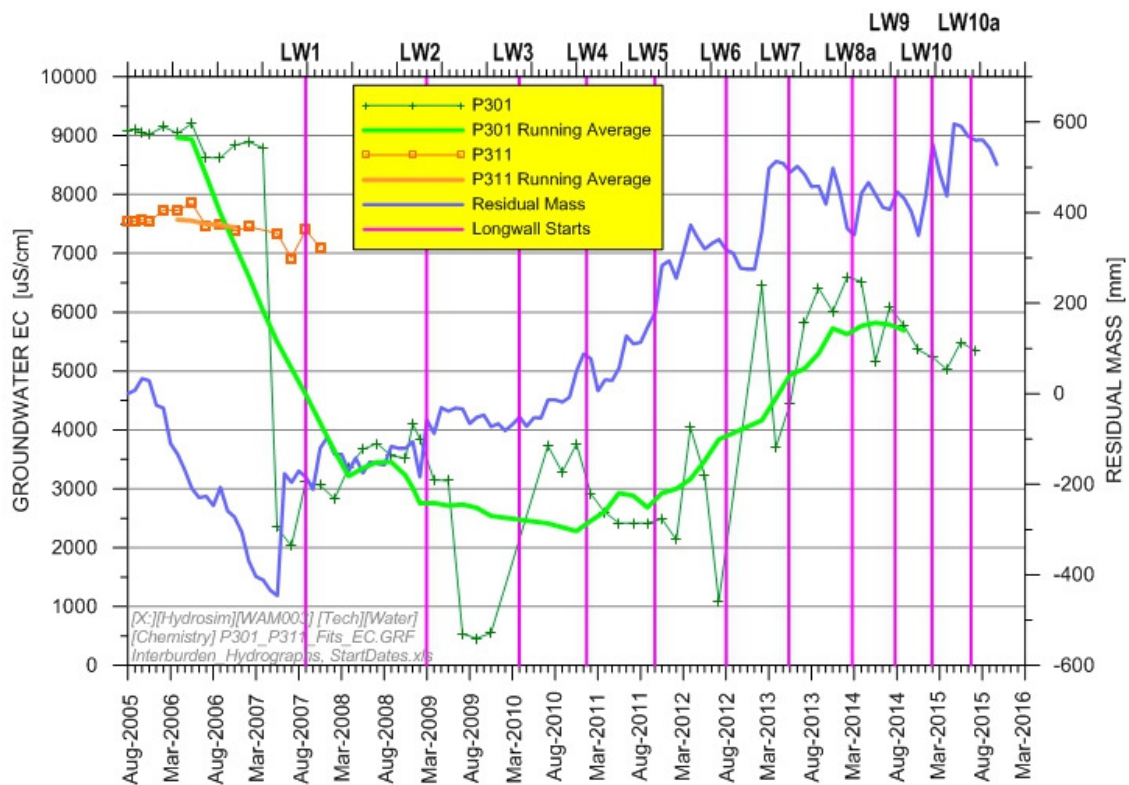


Figure B5. Group I Interburden EC Time-Series

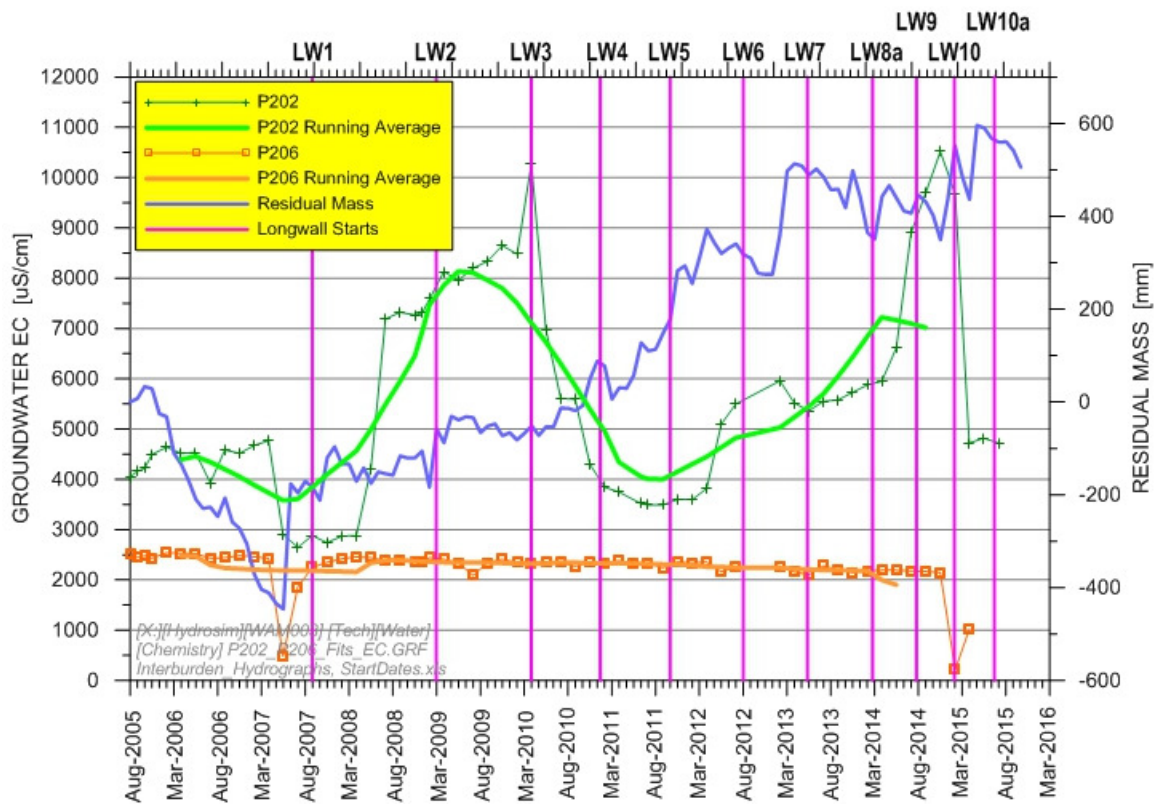


Figure B6. Group J Interburden EC Time-Series

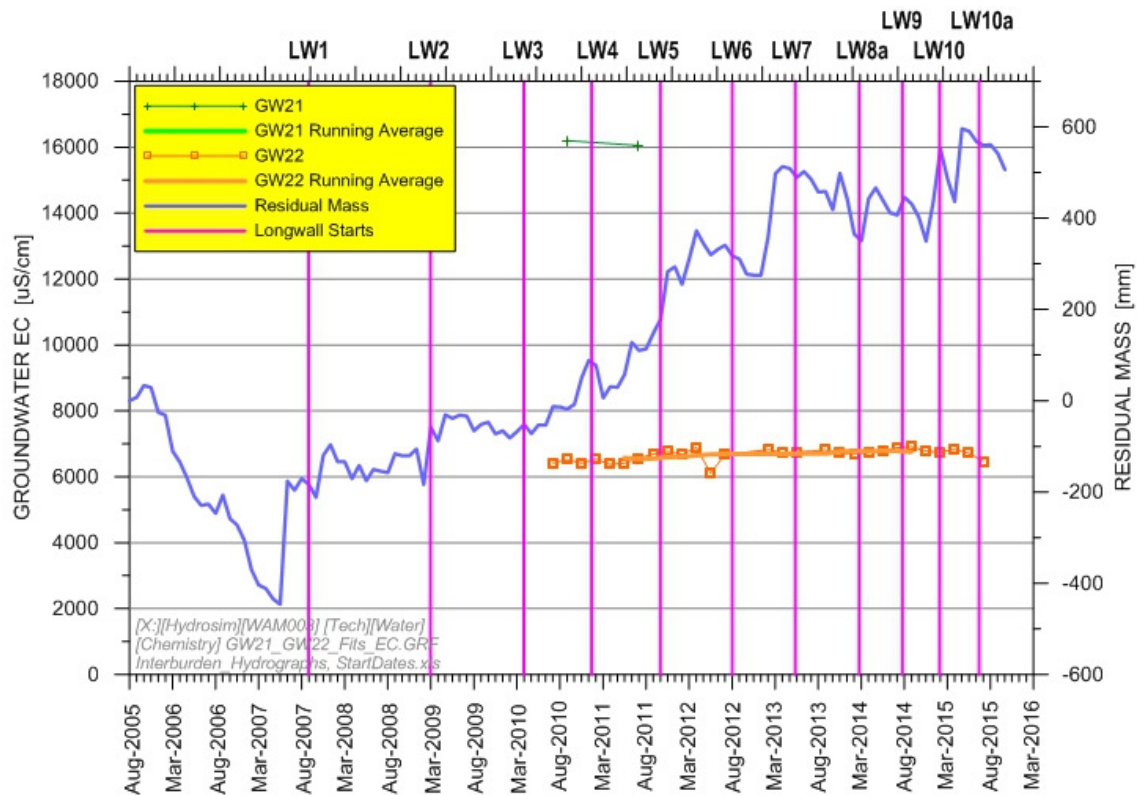


Figure B7. Group K Interburden EC Time-Series

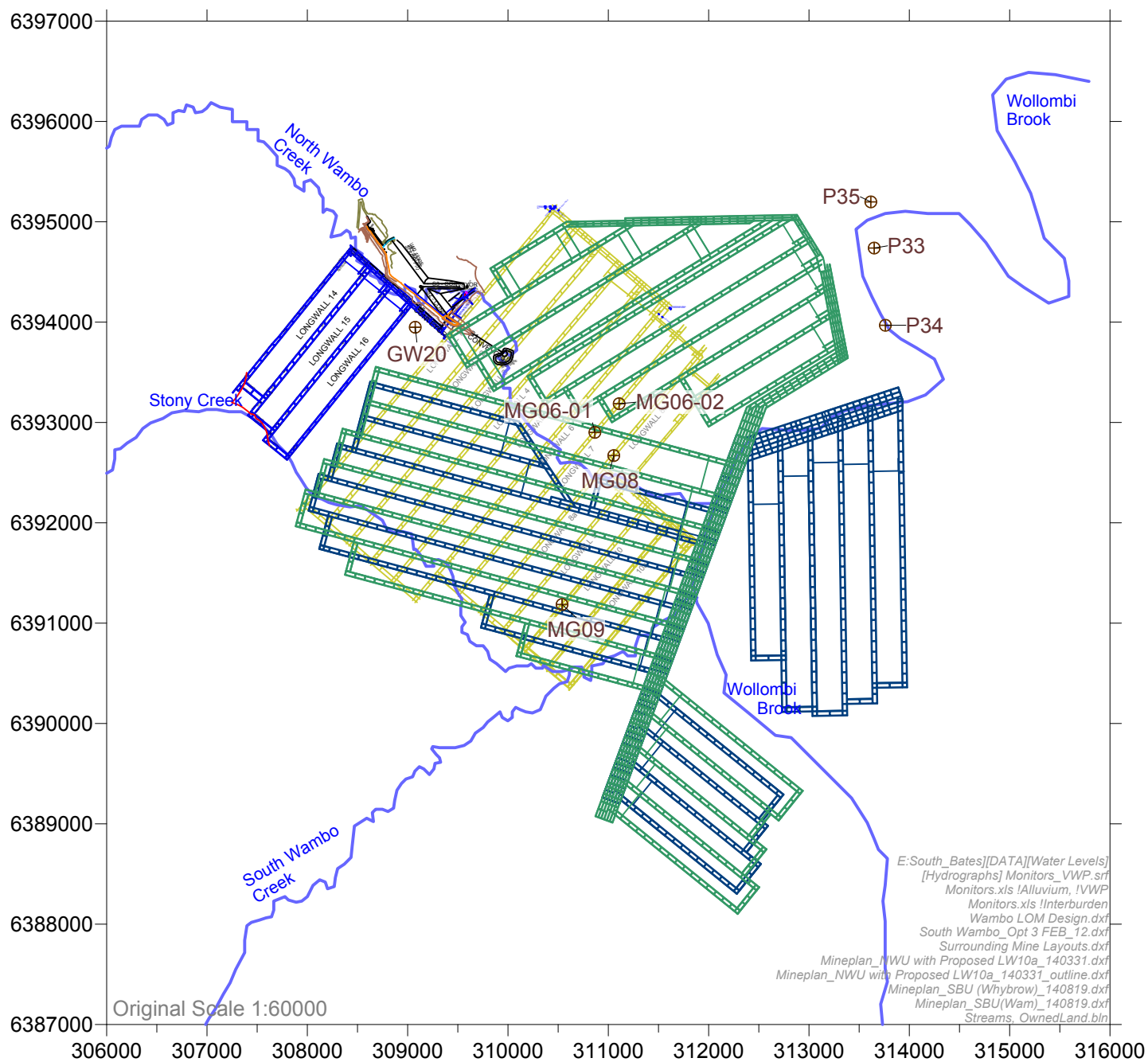


Figure C1. Vibrating Wire Piezometer Monitoring Network

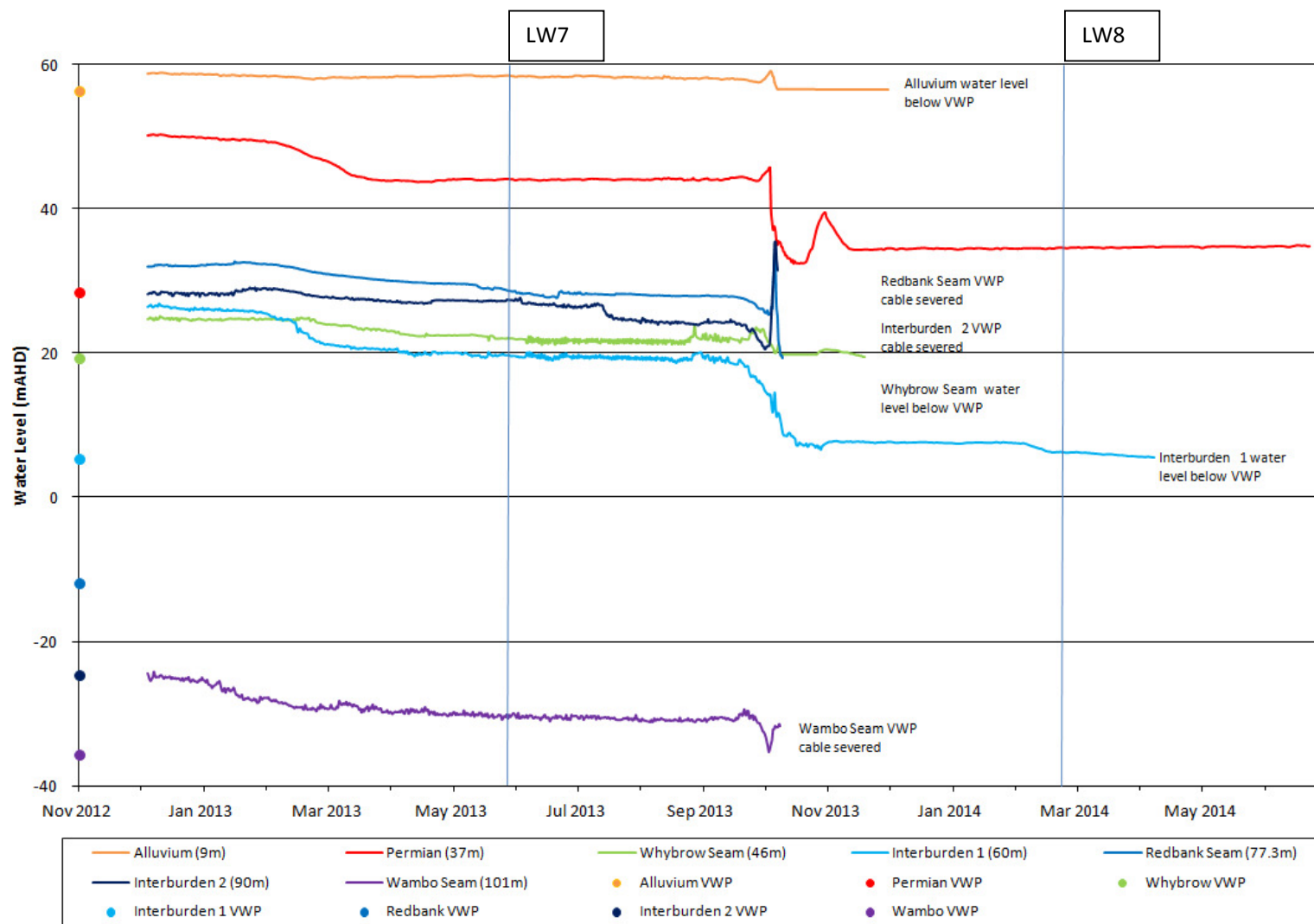


Figure C2. MG08 VWP Hydrographs

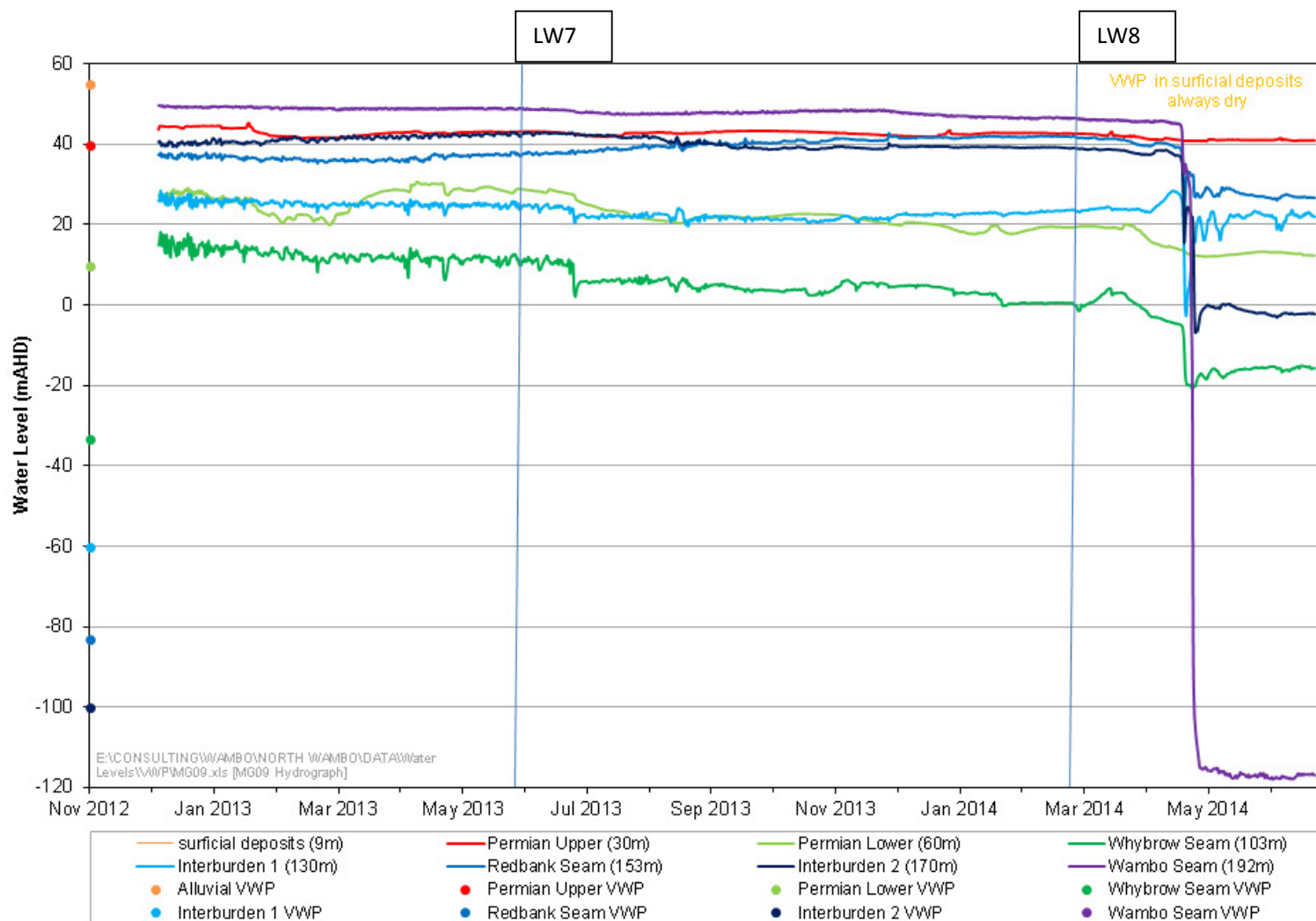


Figure C3. MG09 VWP Hydrographs

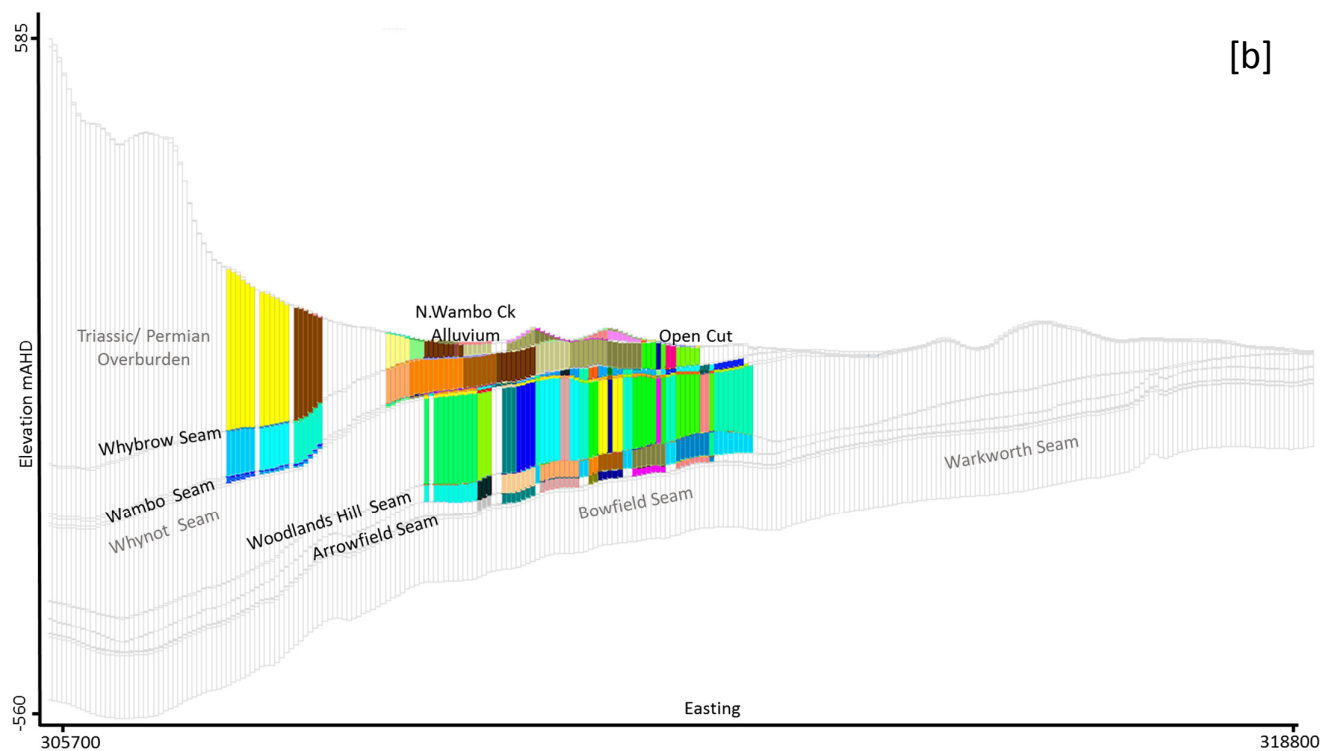
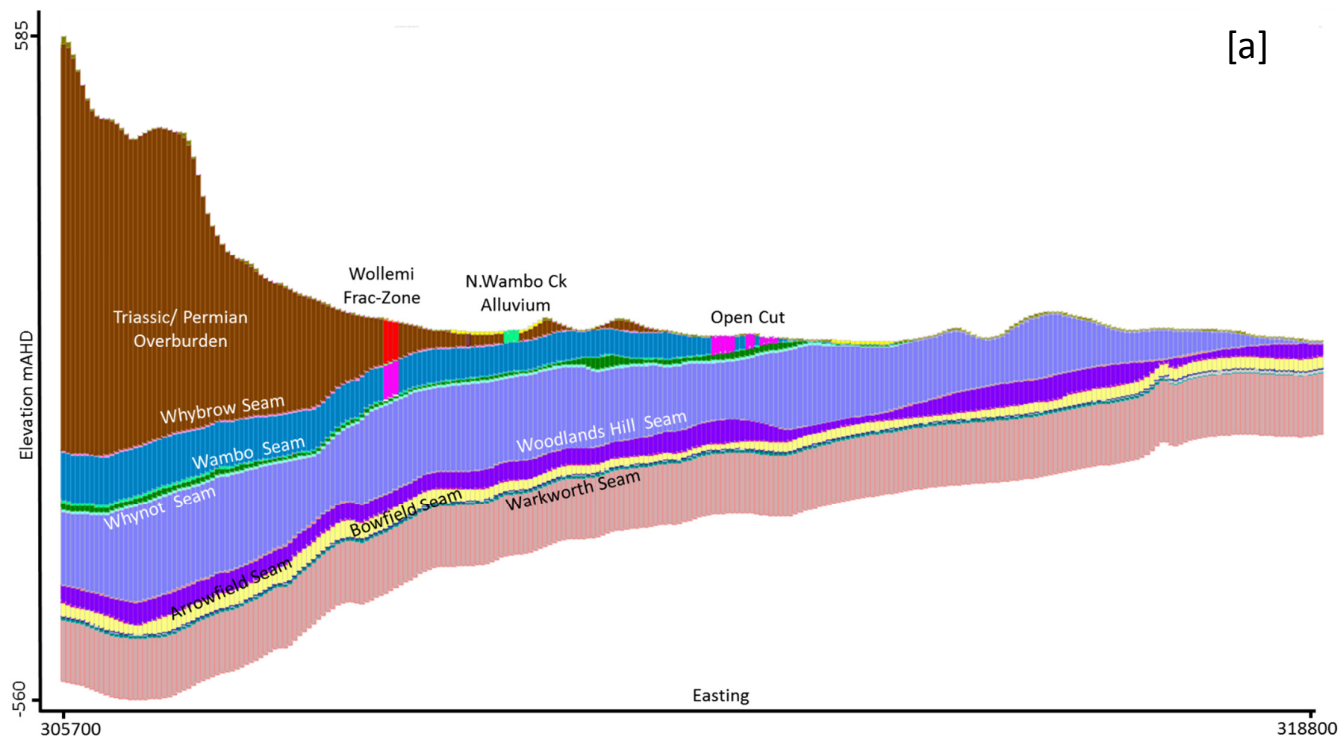


Figure D 2. Modified Scenario Model Row 200: (a) Hydraulic Conductivity Host Zones and Permanent Fracture Zones; (b) Dynamic Fractured Zones

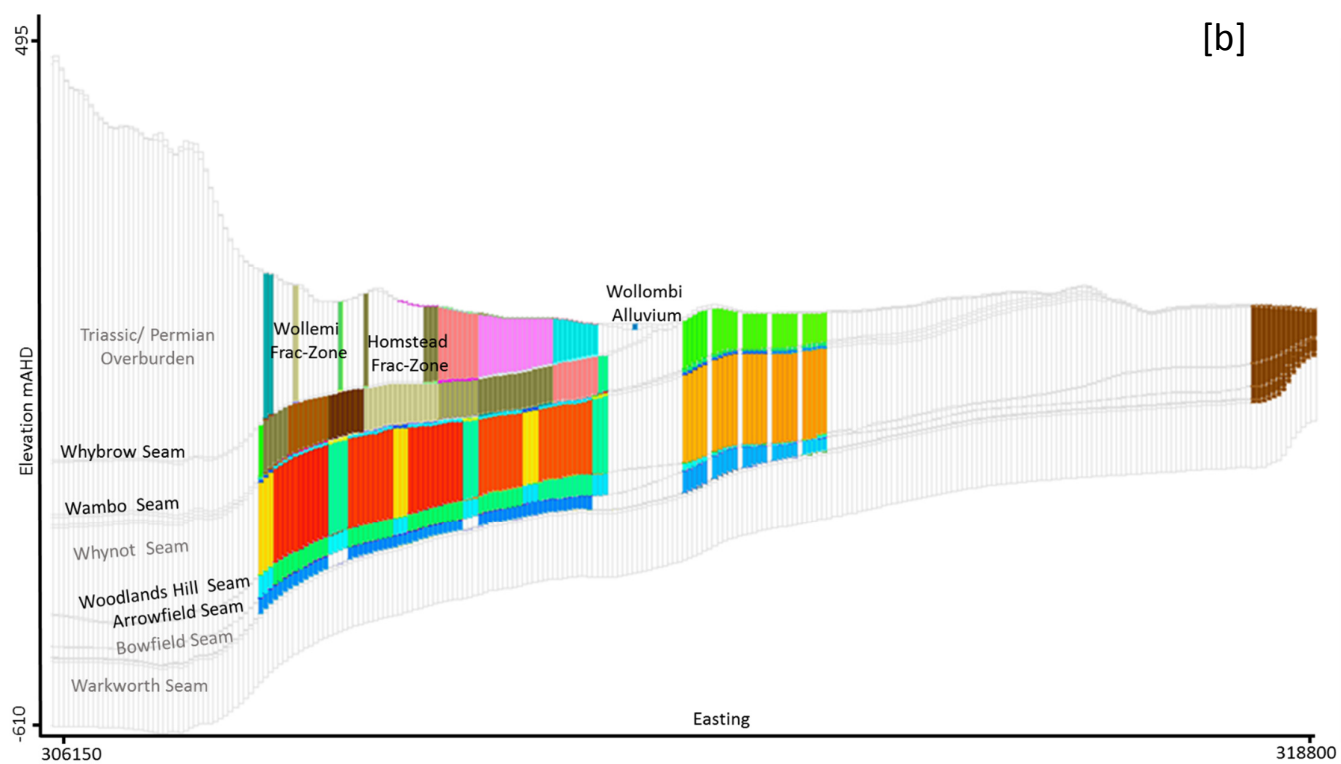
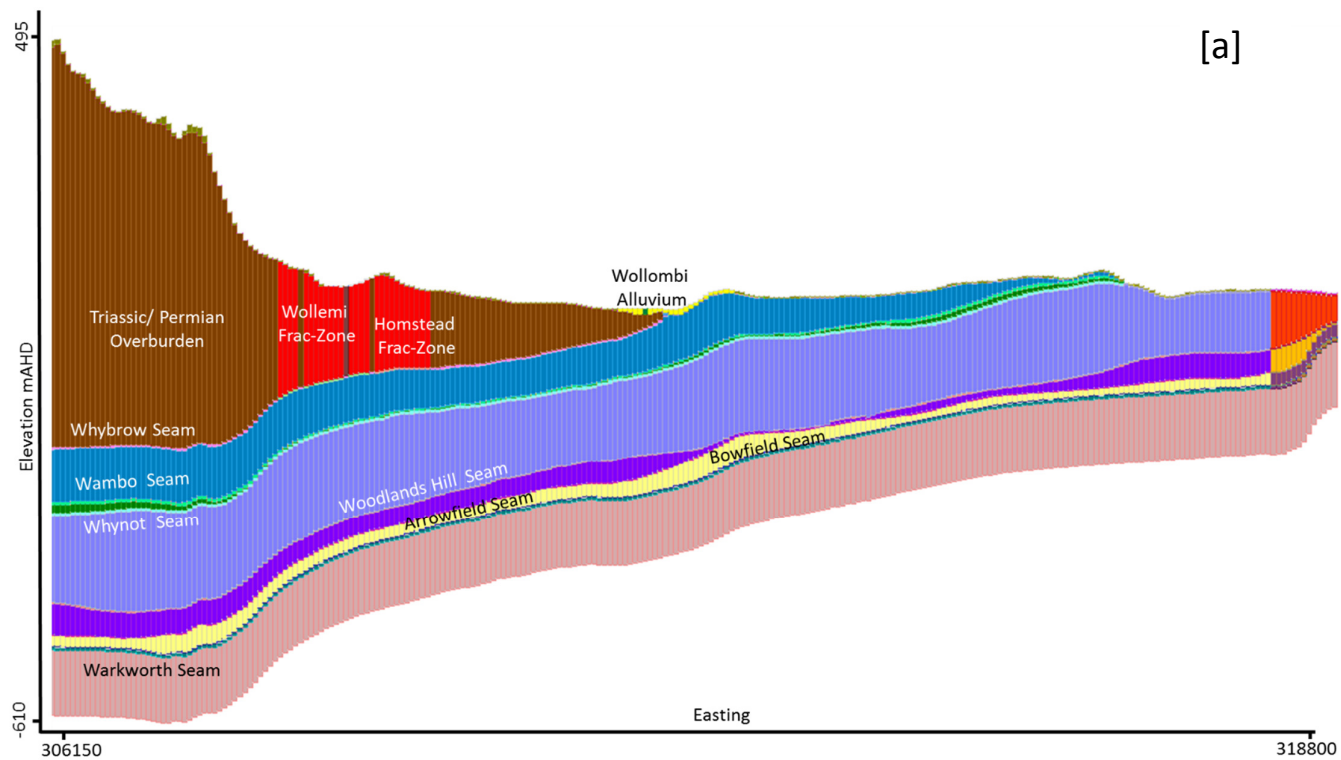


Figure D 3. Modified Scenario Model Row 235: (a) Hydraulic Conductivity Host Zones and Permanent Fracture Zones; (b) Dynamic Fractured Zones

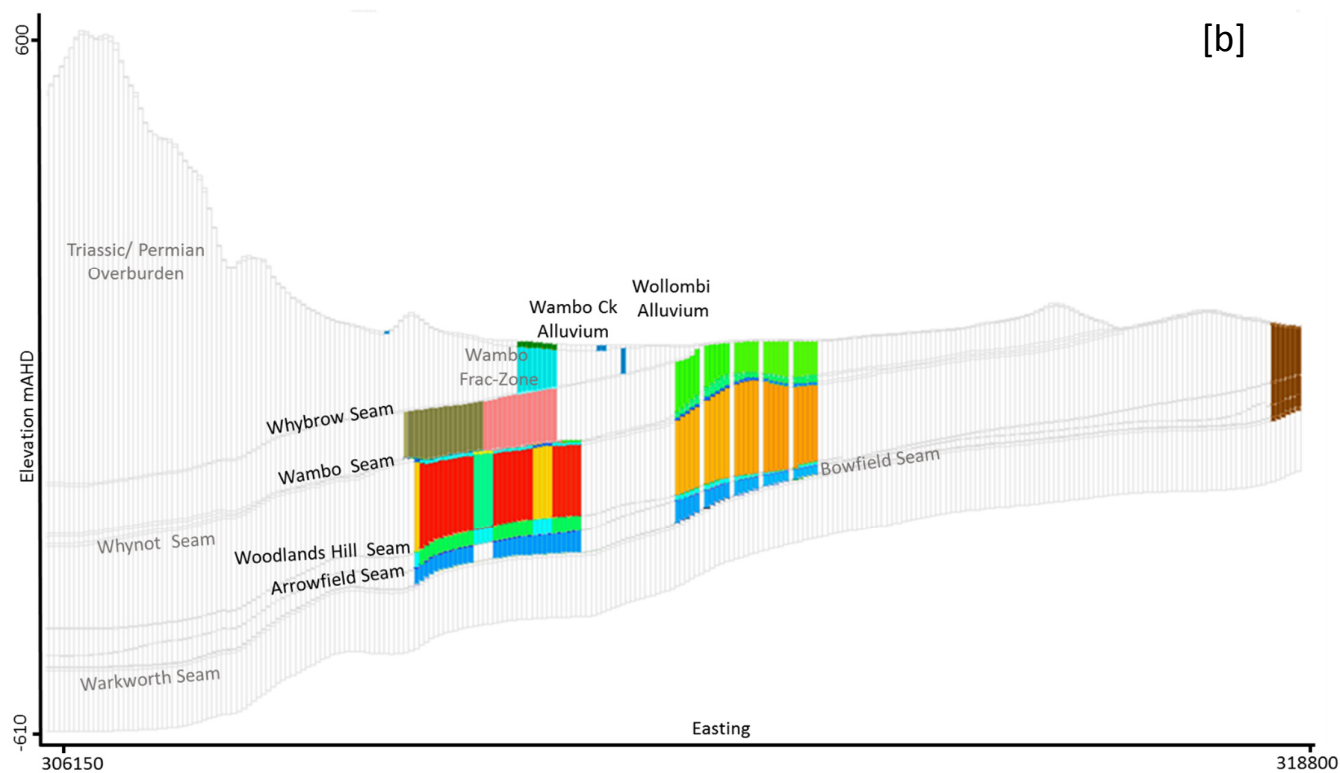
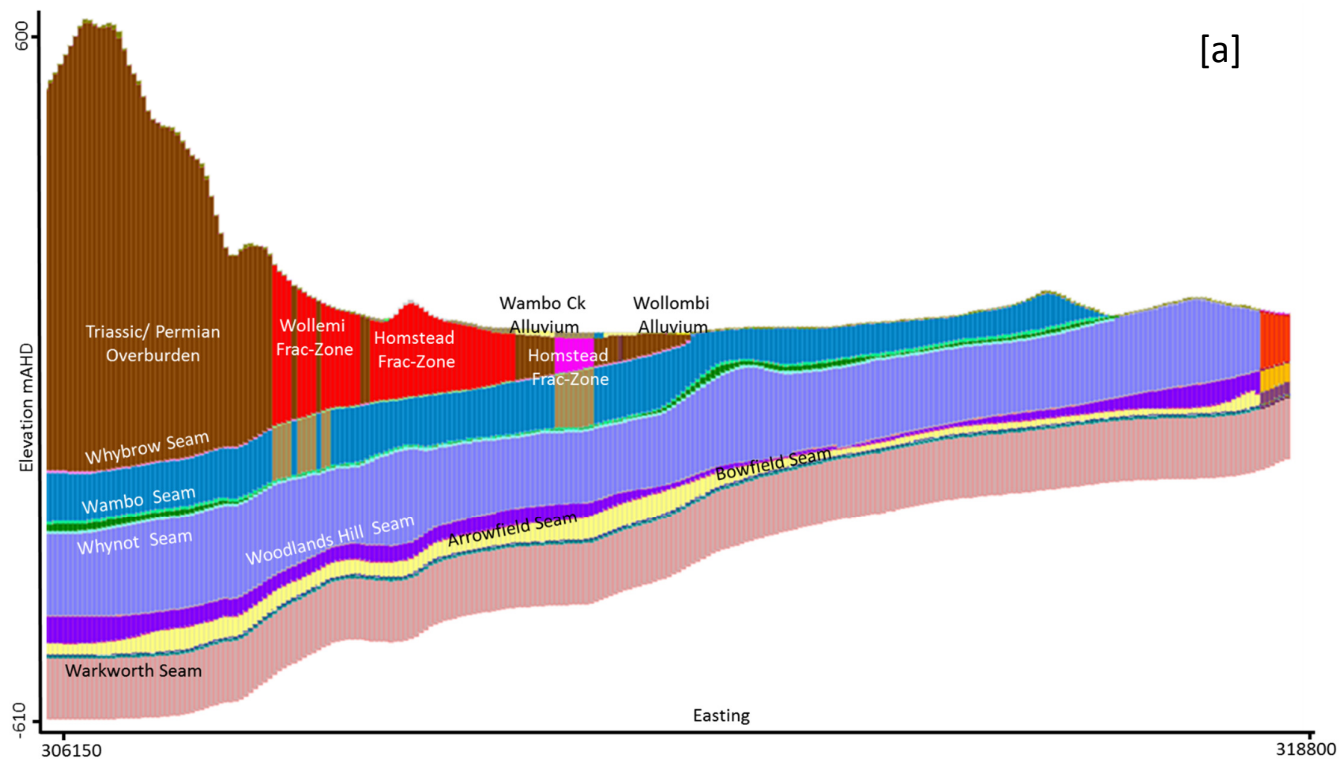


Figure D 4. Modified Scenario Model Row 250: (a) Hydraulic Conductivity Host Zones and Permanent Fracture Zones; (b) Dynamic Fractured Zones

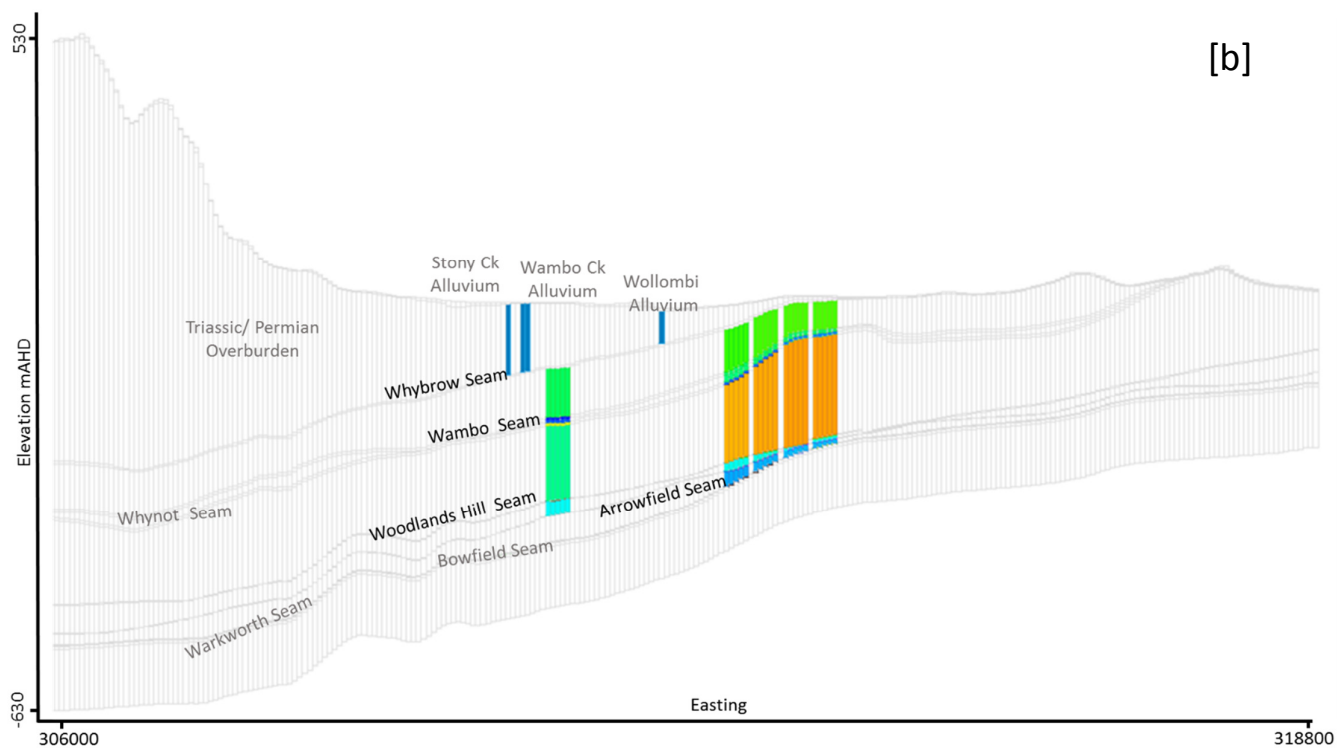
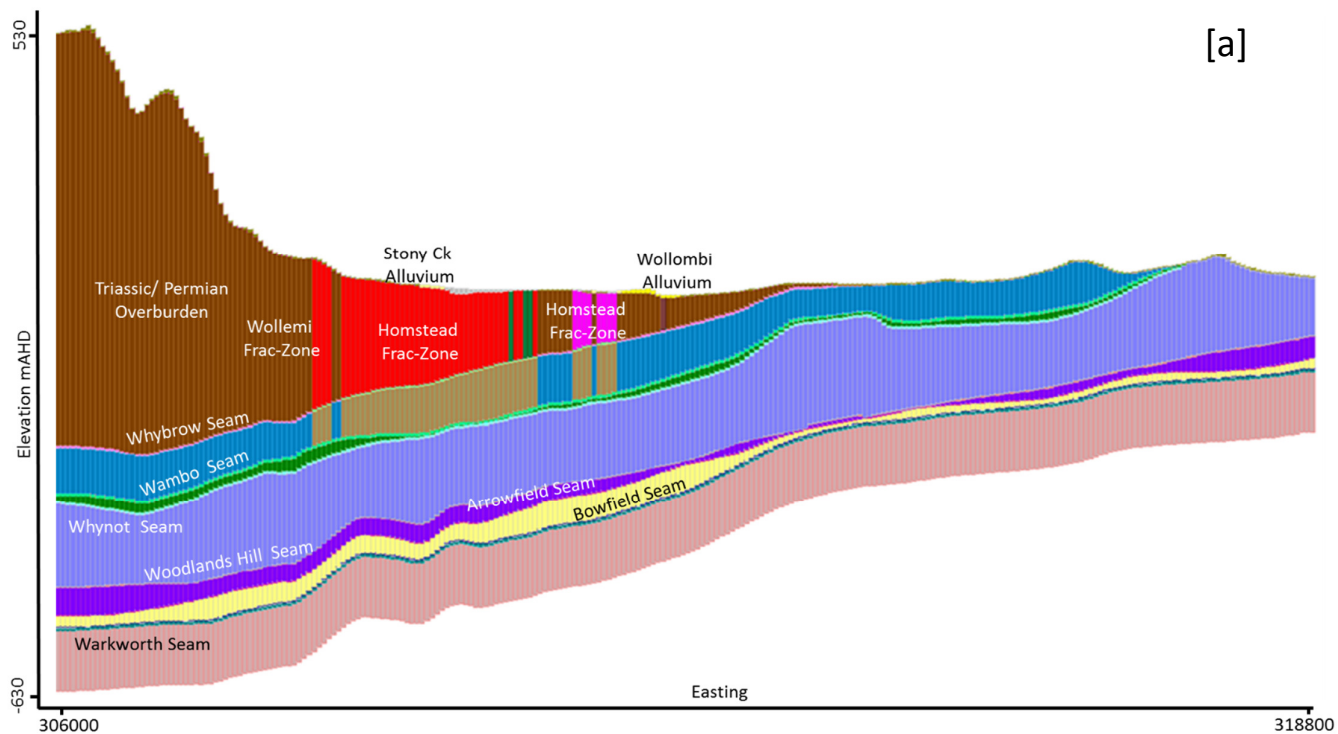


Figure D 5. Modified Scenario Model Row 263: (a) Hydraulic Conductivity Host Zones and Permanent Fracture Zones; (b) Dynamic Fractured Zones

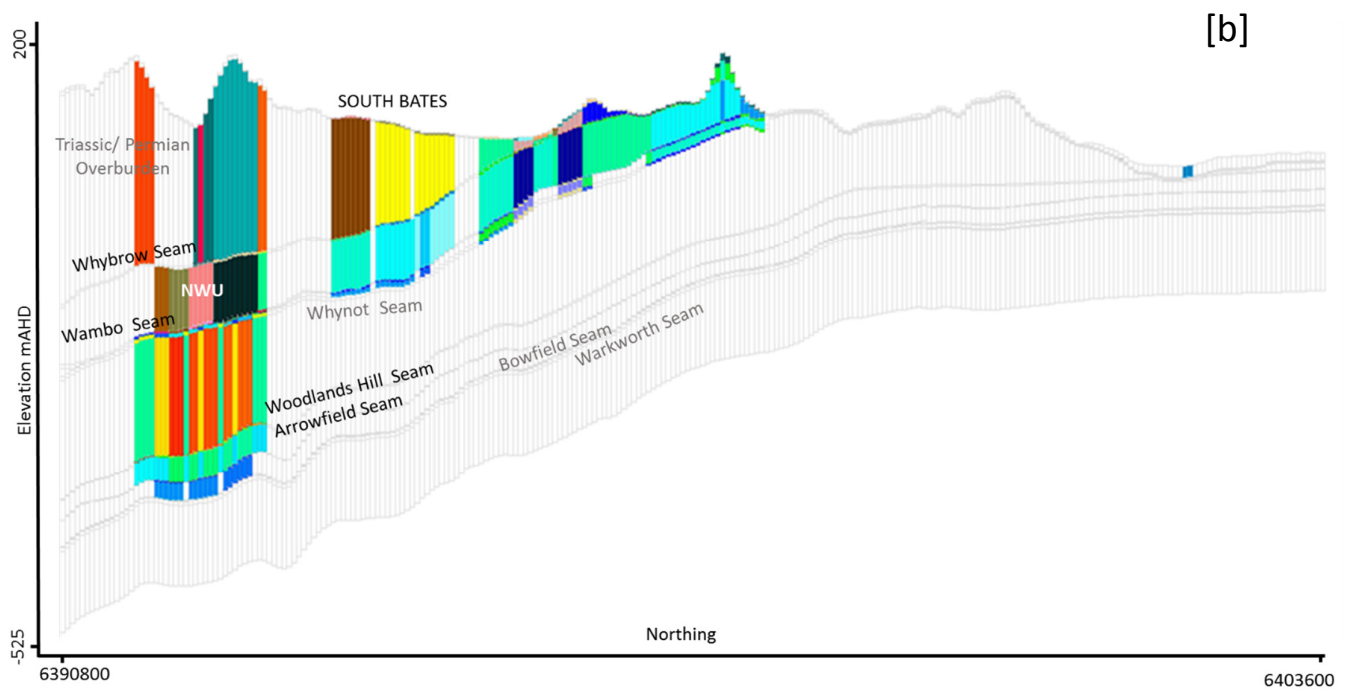
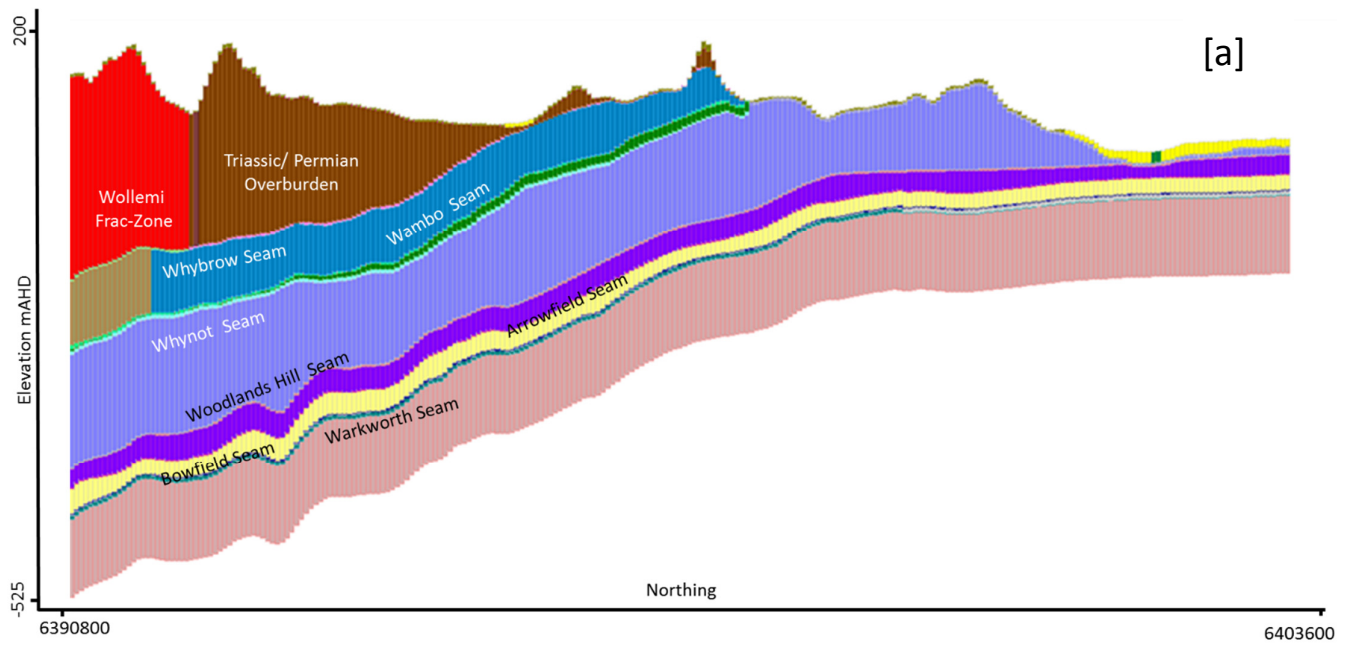
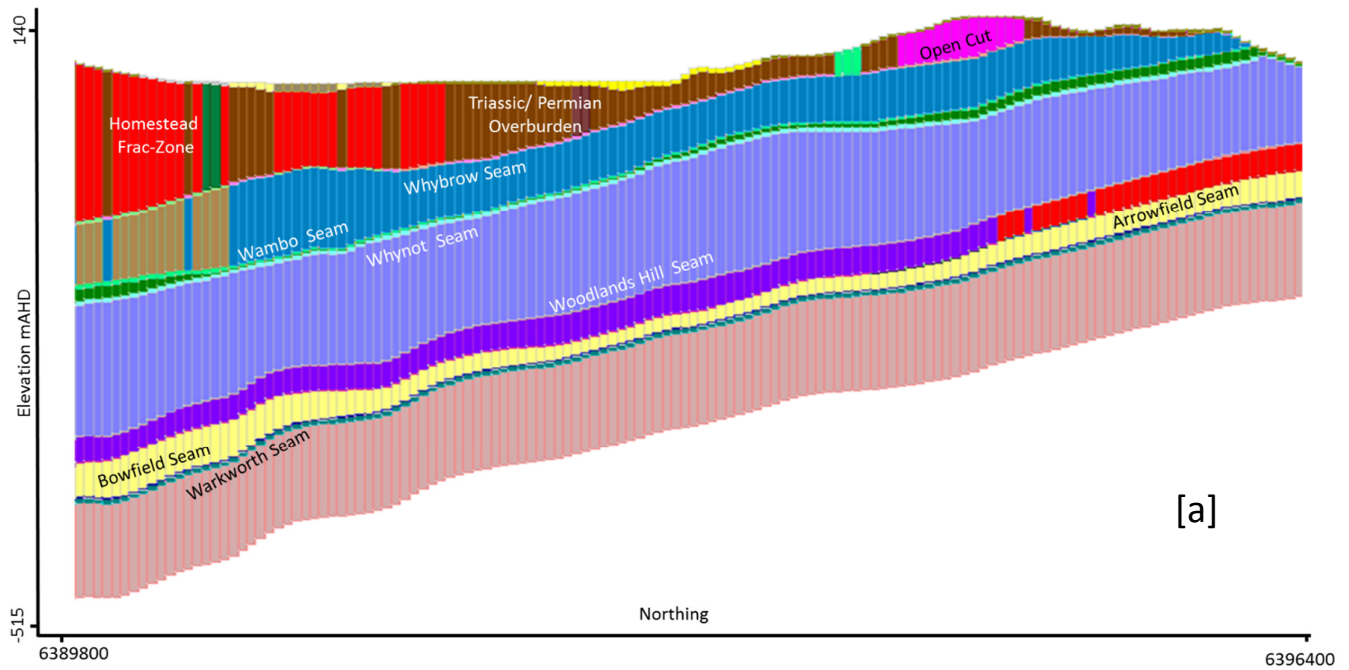
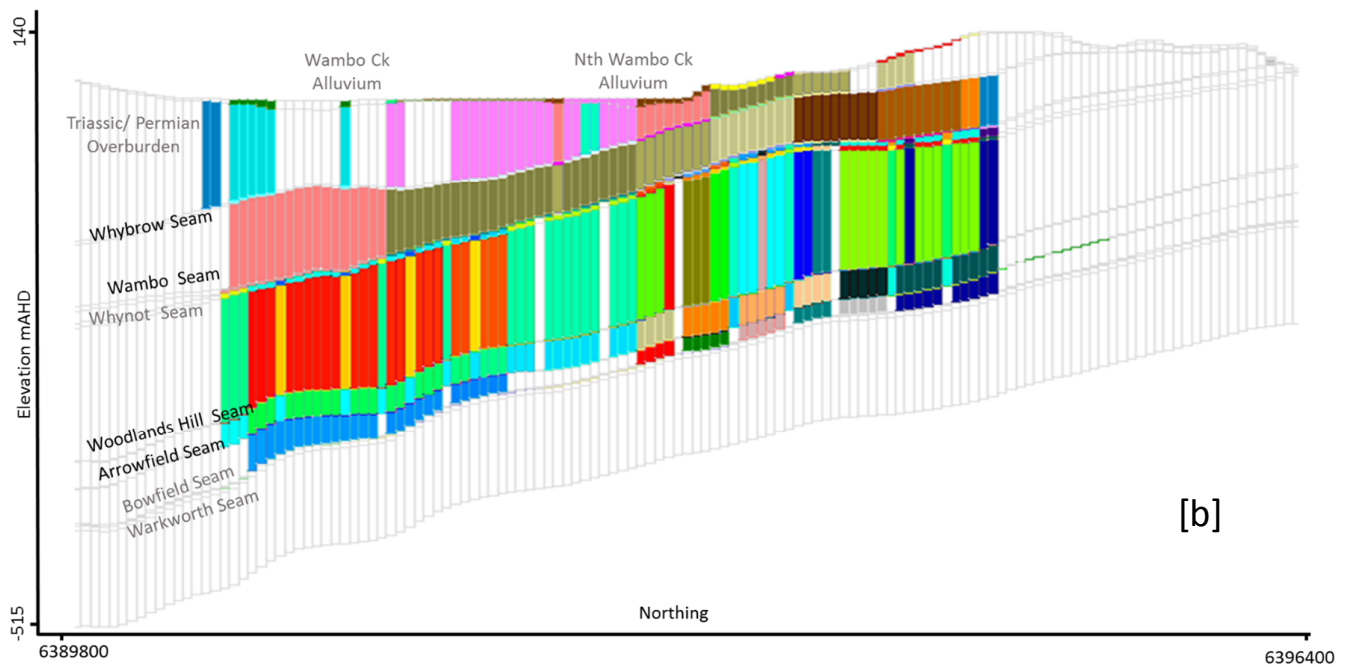


Figure D 6. Modified Scenario Model Column 174: (a) Hydraulic Conductivity Host Zones and Permanent Fracture Zones; (b) Dynamic Fractured Zones

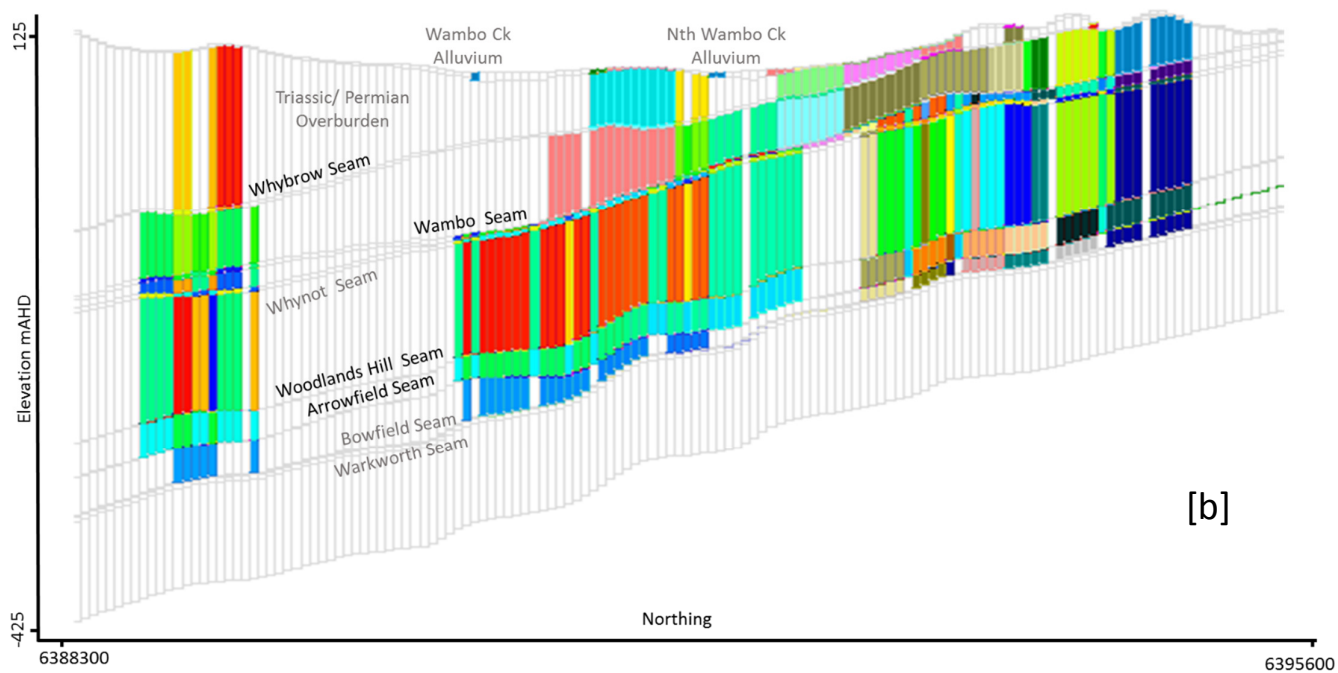
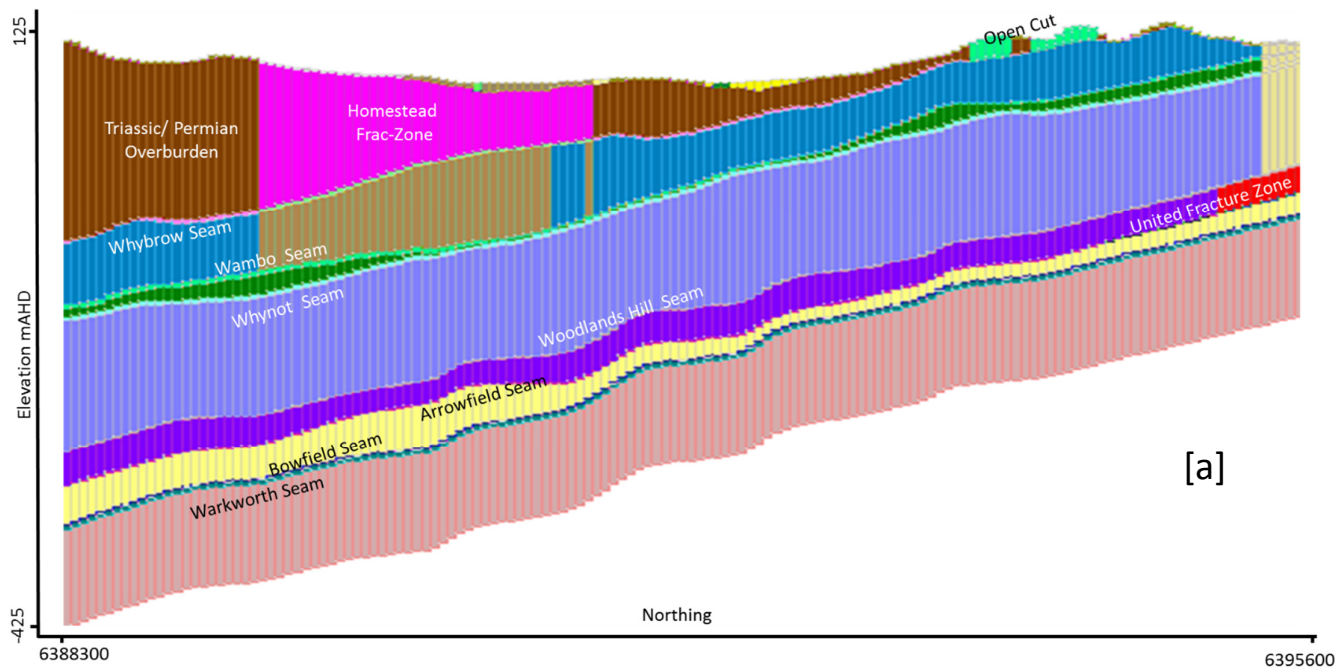


[a]



[b]

Figure D 7. Modified Scenario Model Column 220: (a) Hydraulic Conductivity Host Zones and Permanent Fracture Zones; (b) Dynamic Fractured Zones



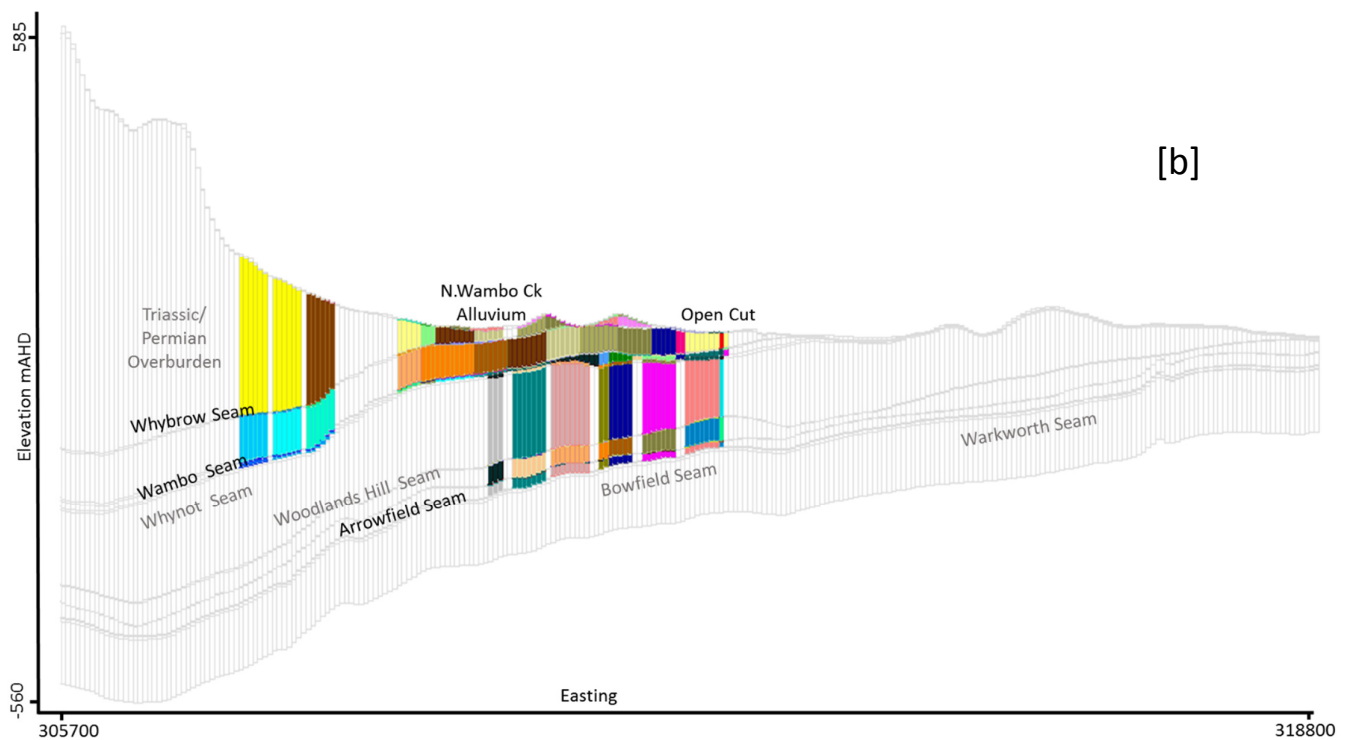
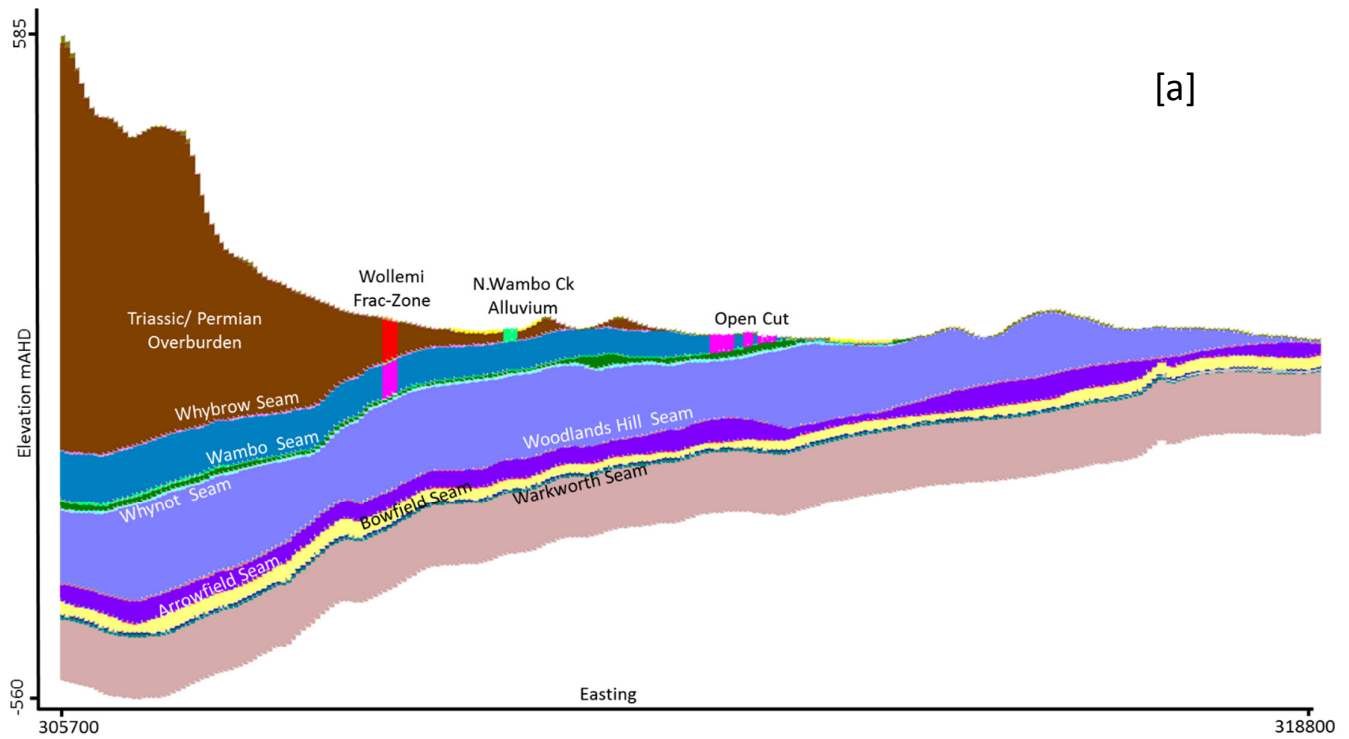


Figure D 9. Approved Scenario Model Row 200: (a) Hydraulic Conductivity Host Zones and Permanent Fracture Zones; (b) Dynamic Fractured Zones

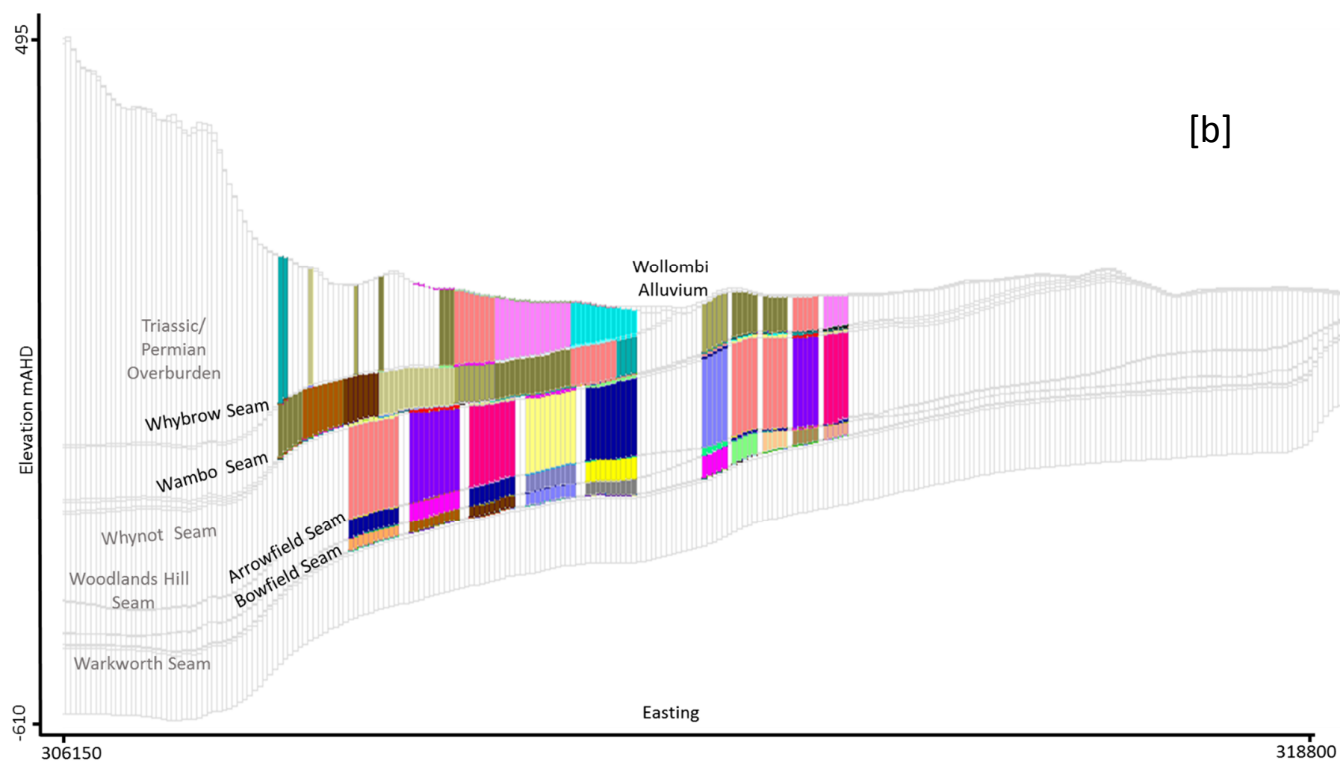
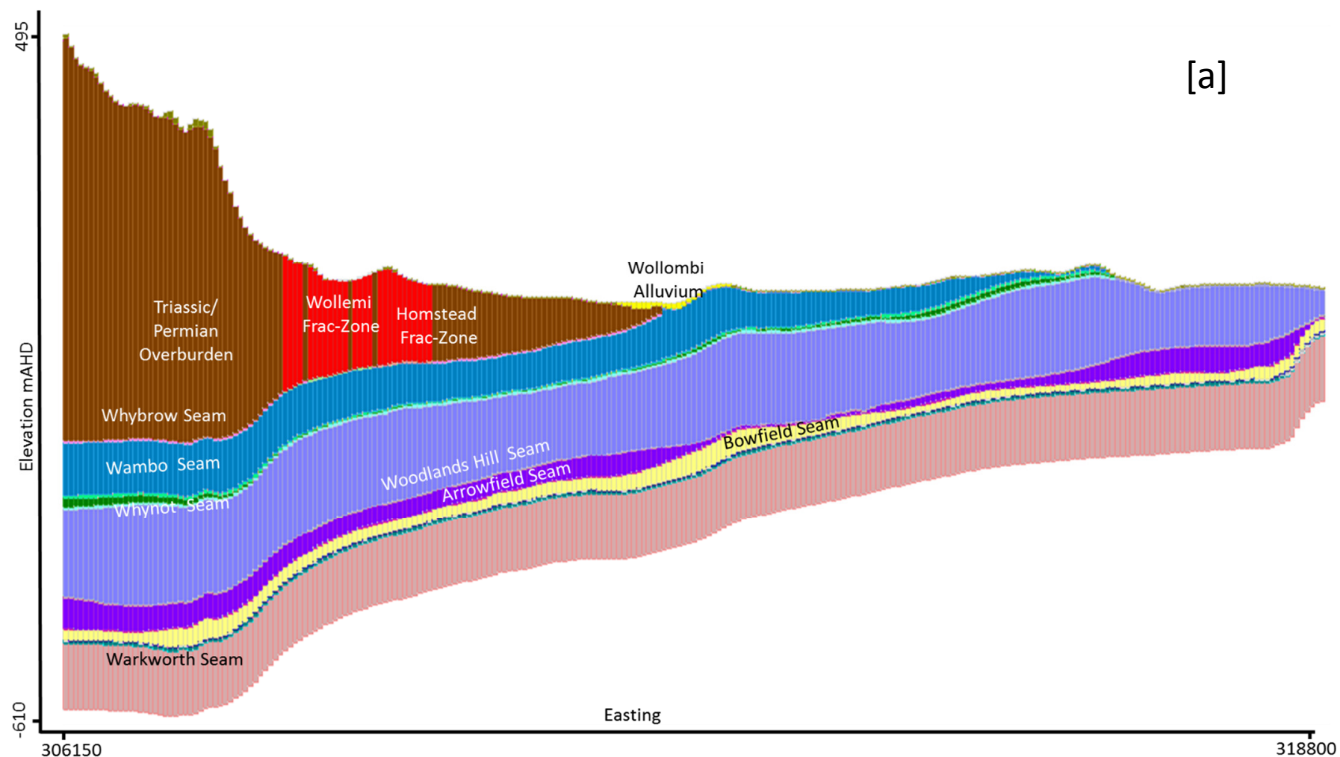


Figure D 10 Approved Scenario Model Row 235: (a) Hydraulic Conductivity Host Zones and Permanent Fracture Zones; (b) Dynamic Fractured Zones

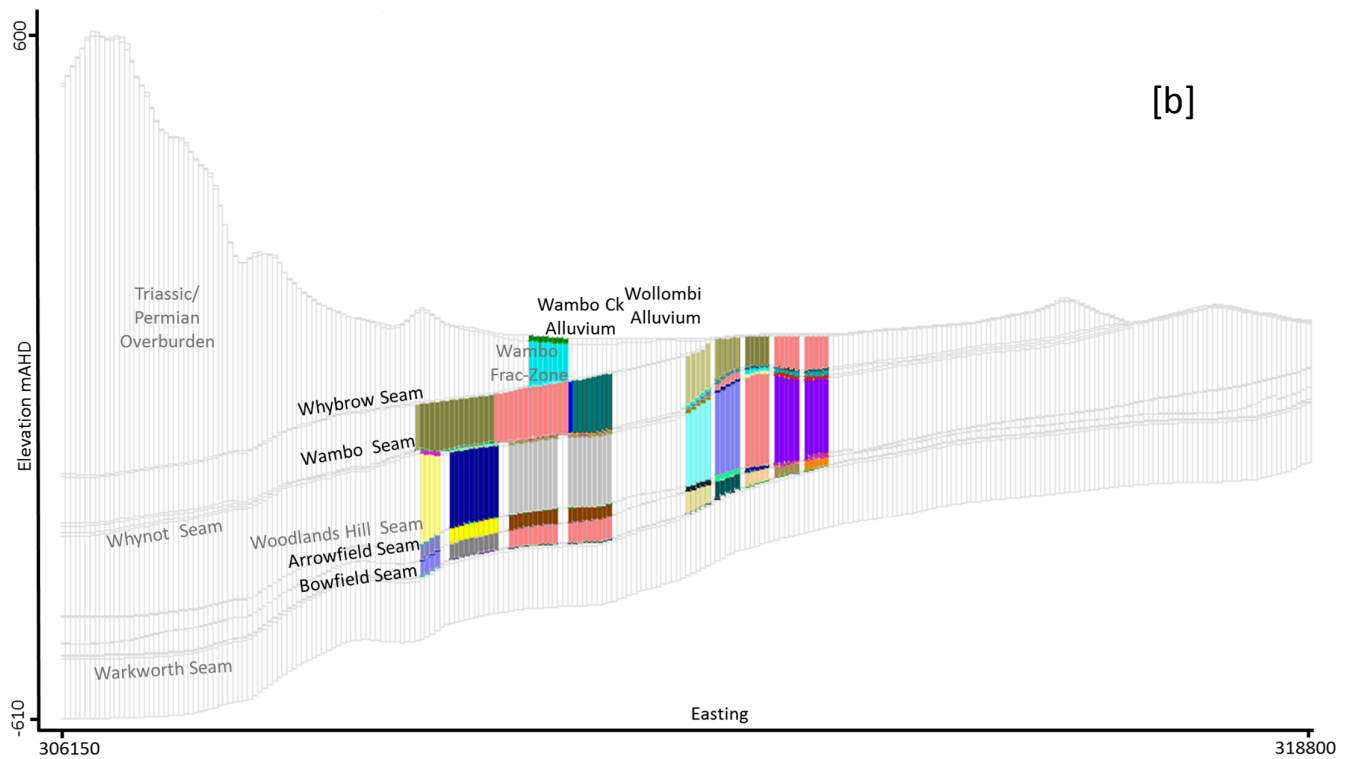
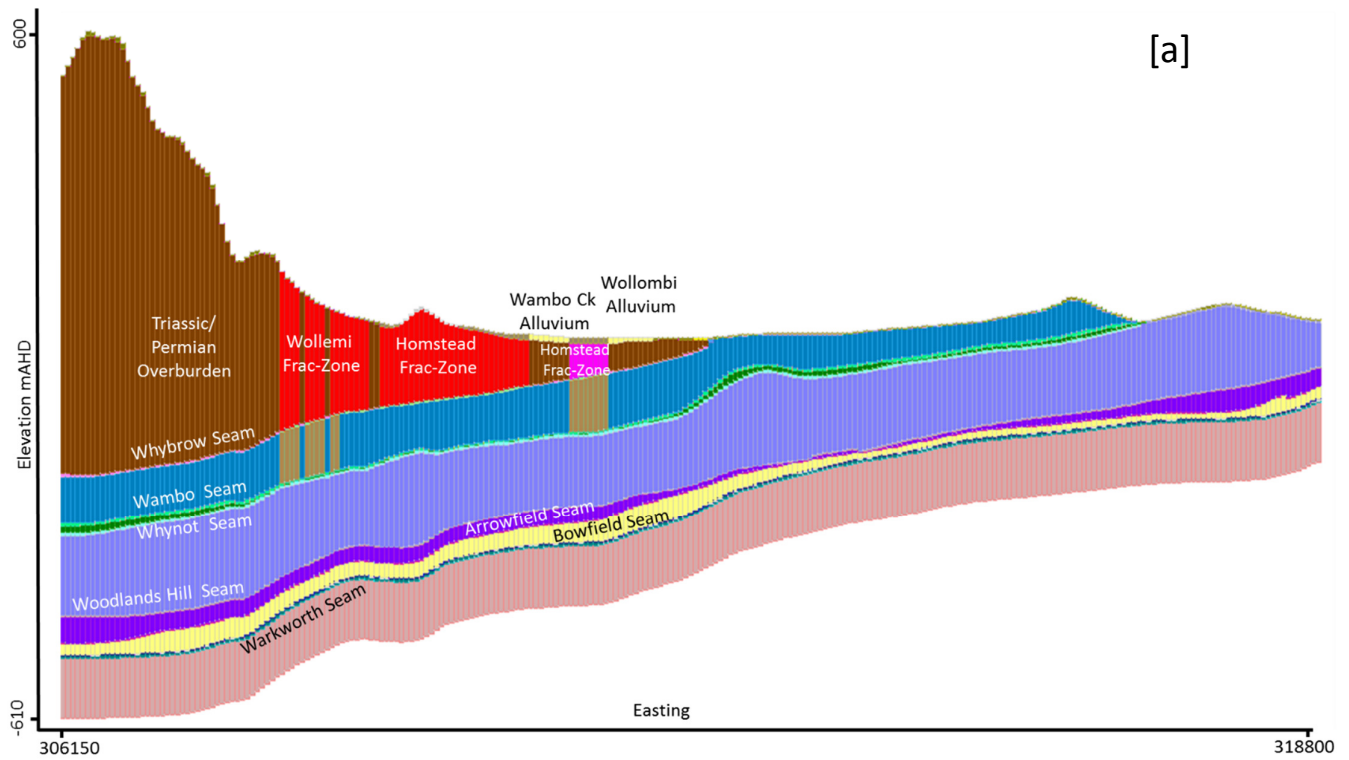


Figure D 11 Approved Scenario Model Row 250: (a) Hydraulic Conductivity Host Zones and Permanent Fracture Zones; (b) Dynamic Fractured Zones

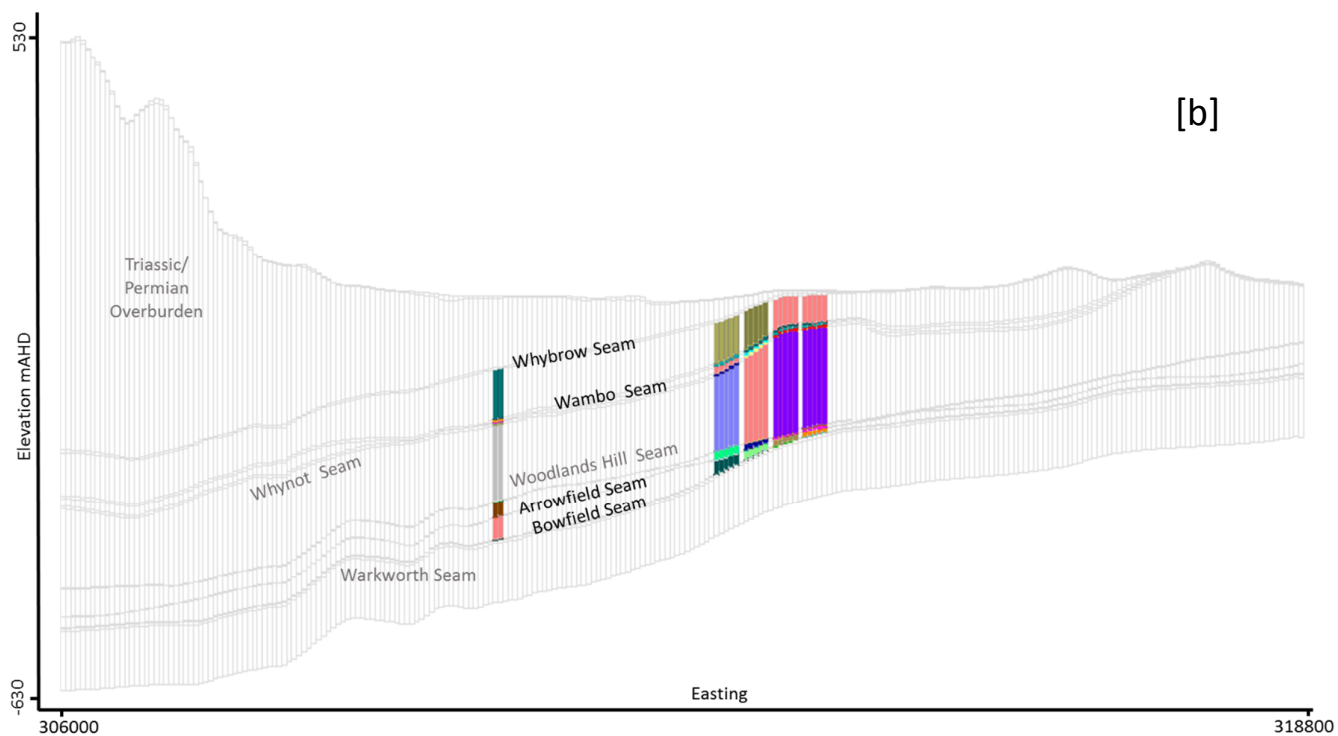
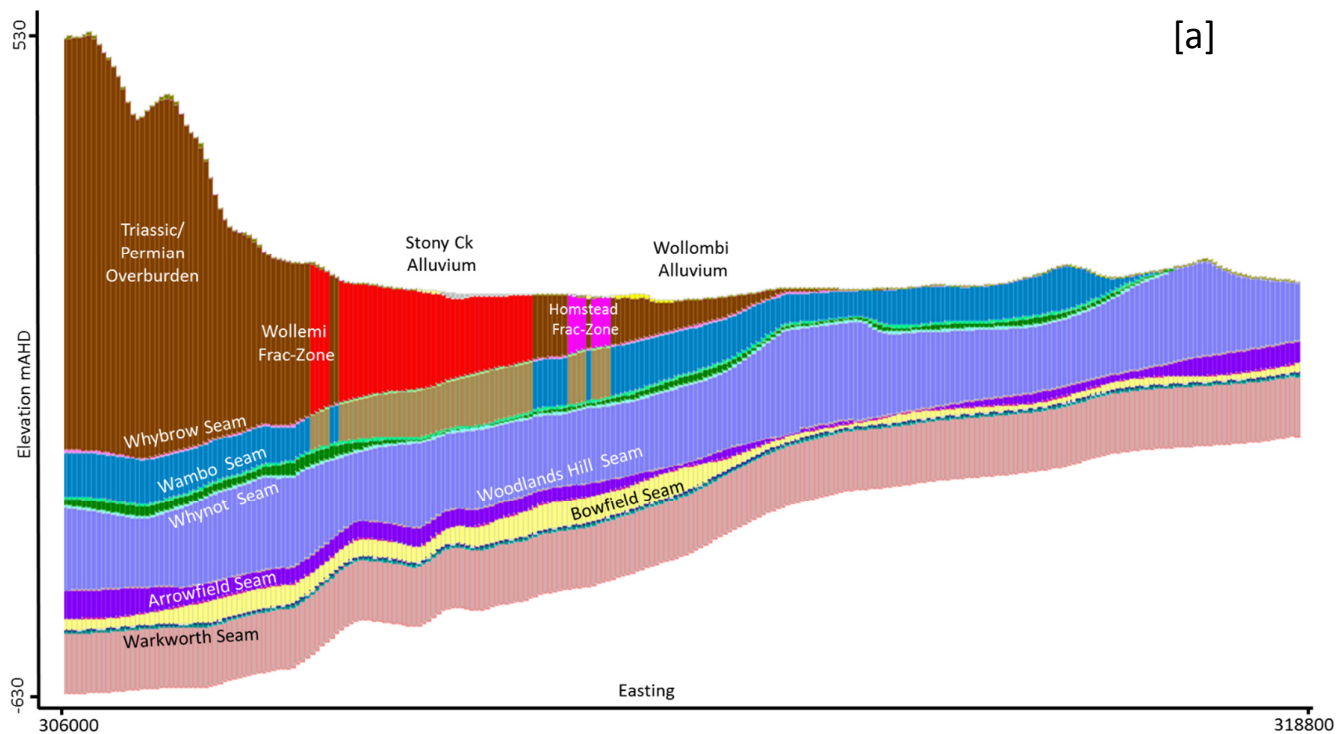


Figure D 12. Approved Scenario Model Row 263: (a) Hydraulic Conductivity Host Zones and Permanent Fracture Zones; (b) Dynamic Fractured Zones

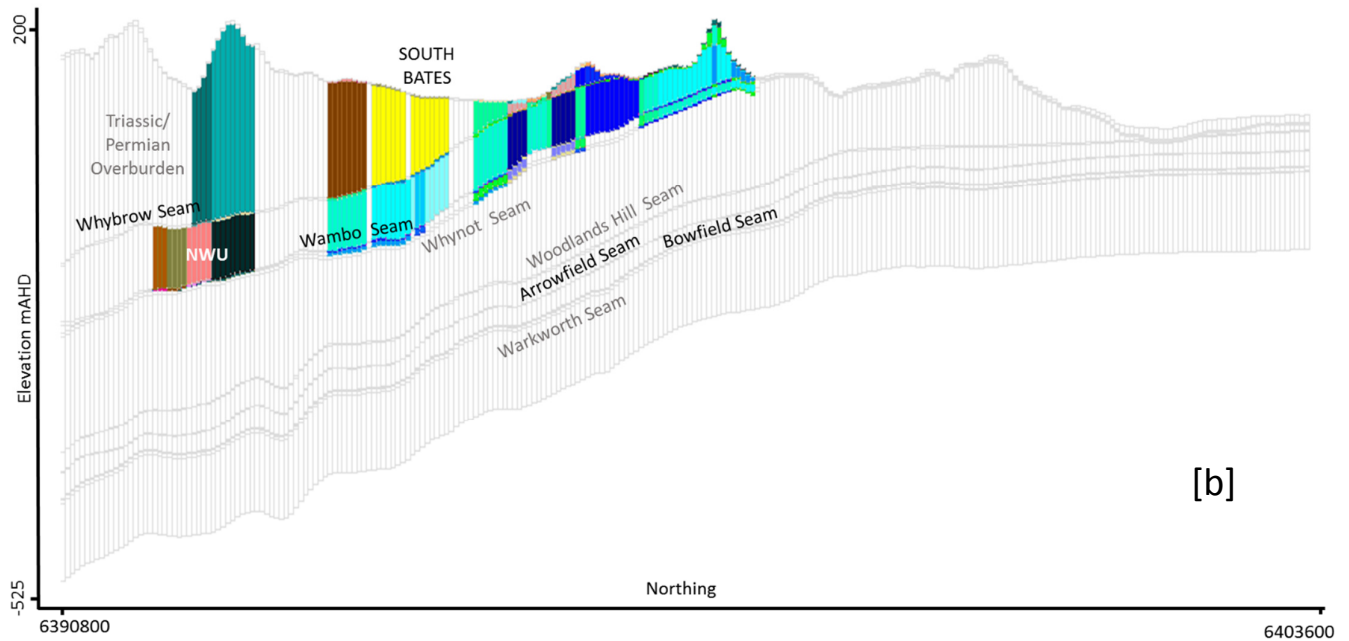
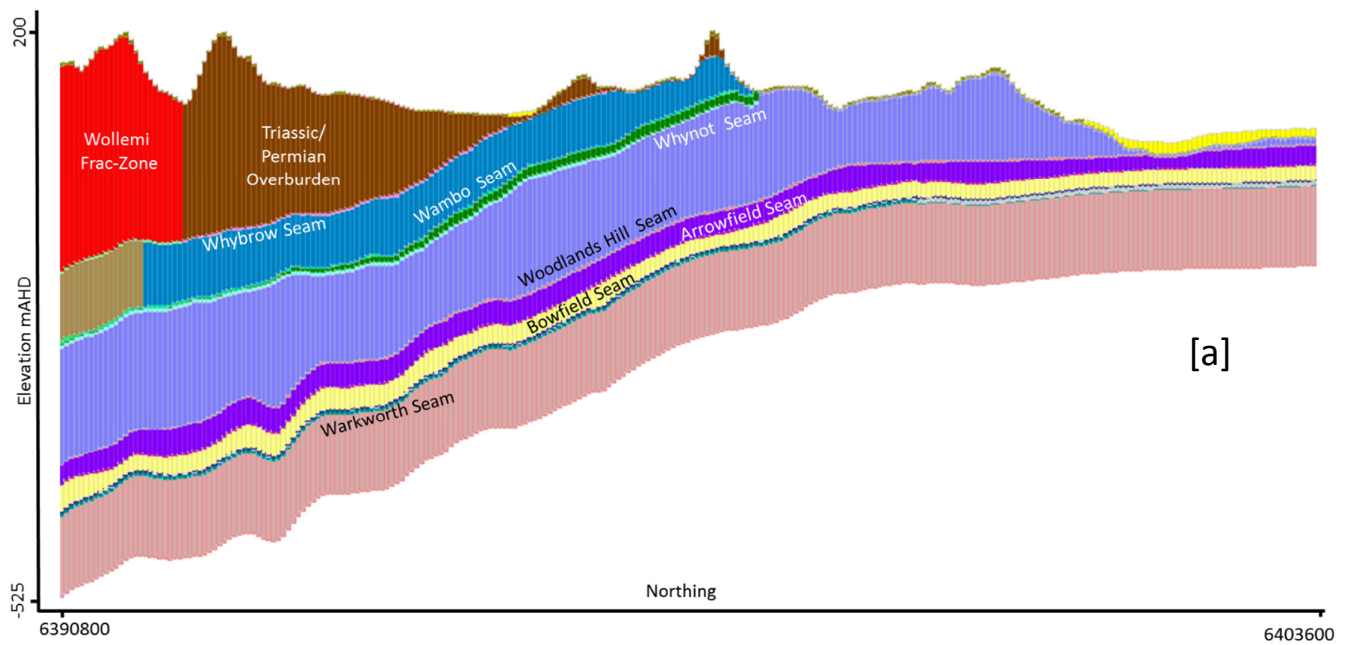


Figure D 13 Approved Scenario Model Column 174: (a) Hydraulic Conductivity Host Zones and Permanent Fracture Zones; (b) Dynamic Fractured Zones

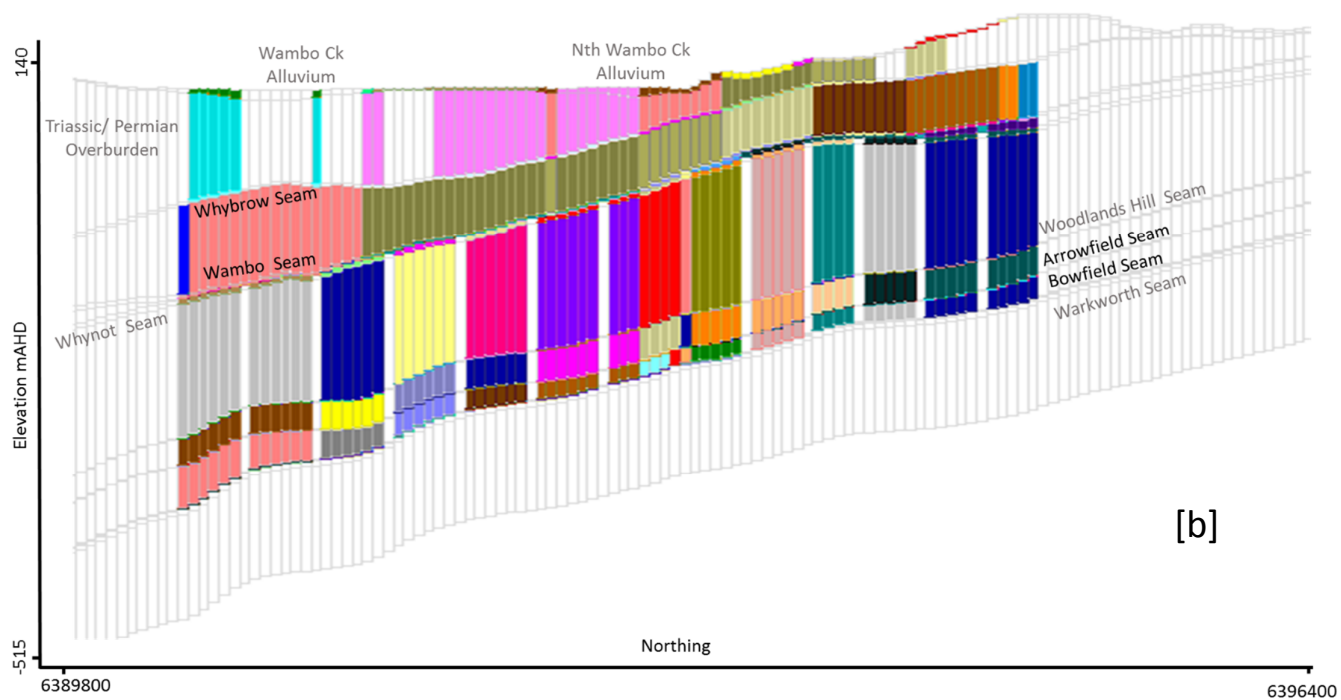
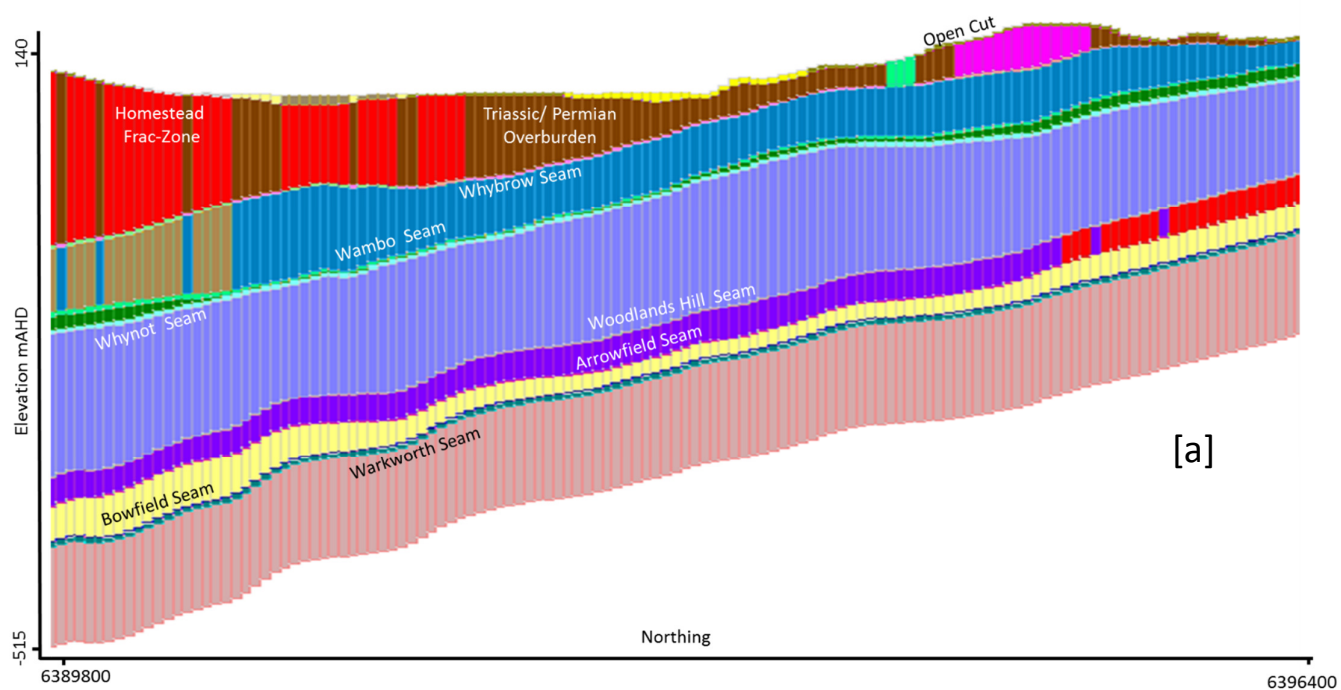


Figure D 14. Approved Scenario Model Column 220: (a) Hydraulic Conductivity Host Zones and Permanent Fracture Zones; (b) Dynamic Fractured Zones

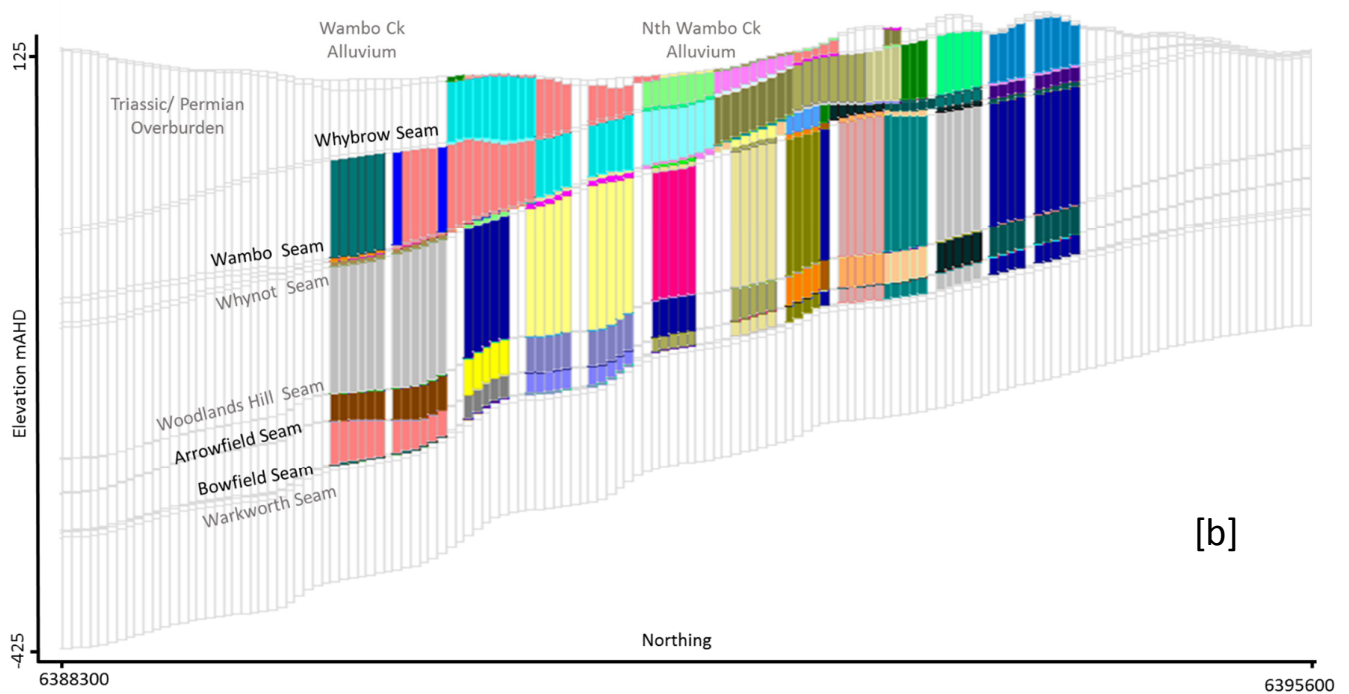
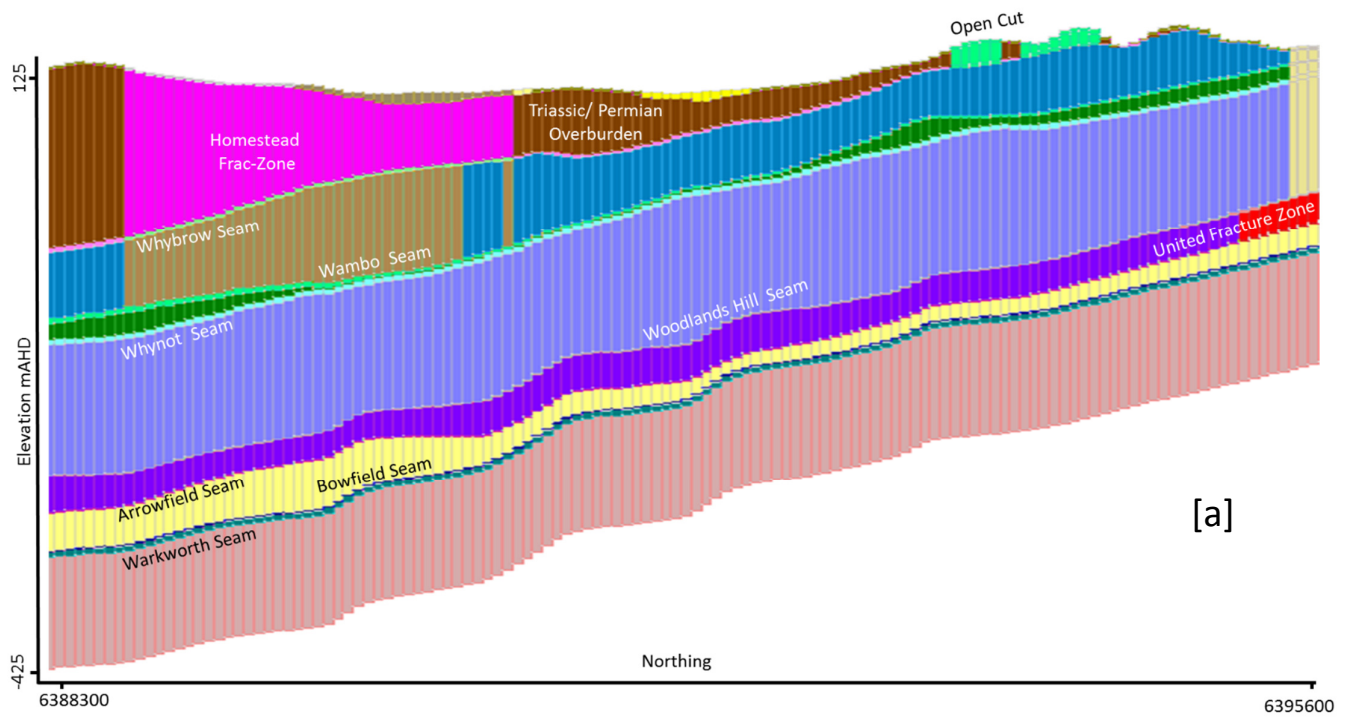


Figure D 15. Approved Scenario Model Column 232: (a) Hydraulic Conductivity Host Zones and Permanent Fracture Zones; (b) Dynamic Fractured Zones

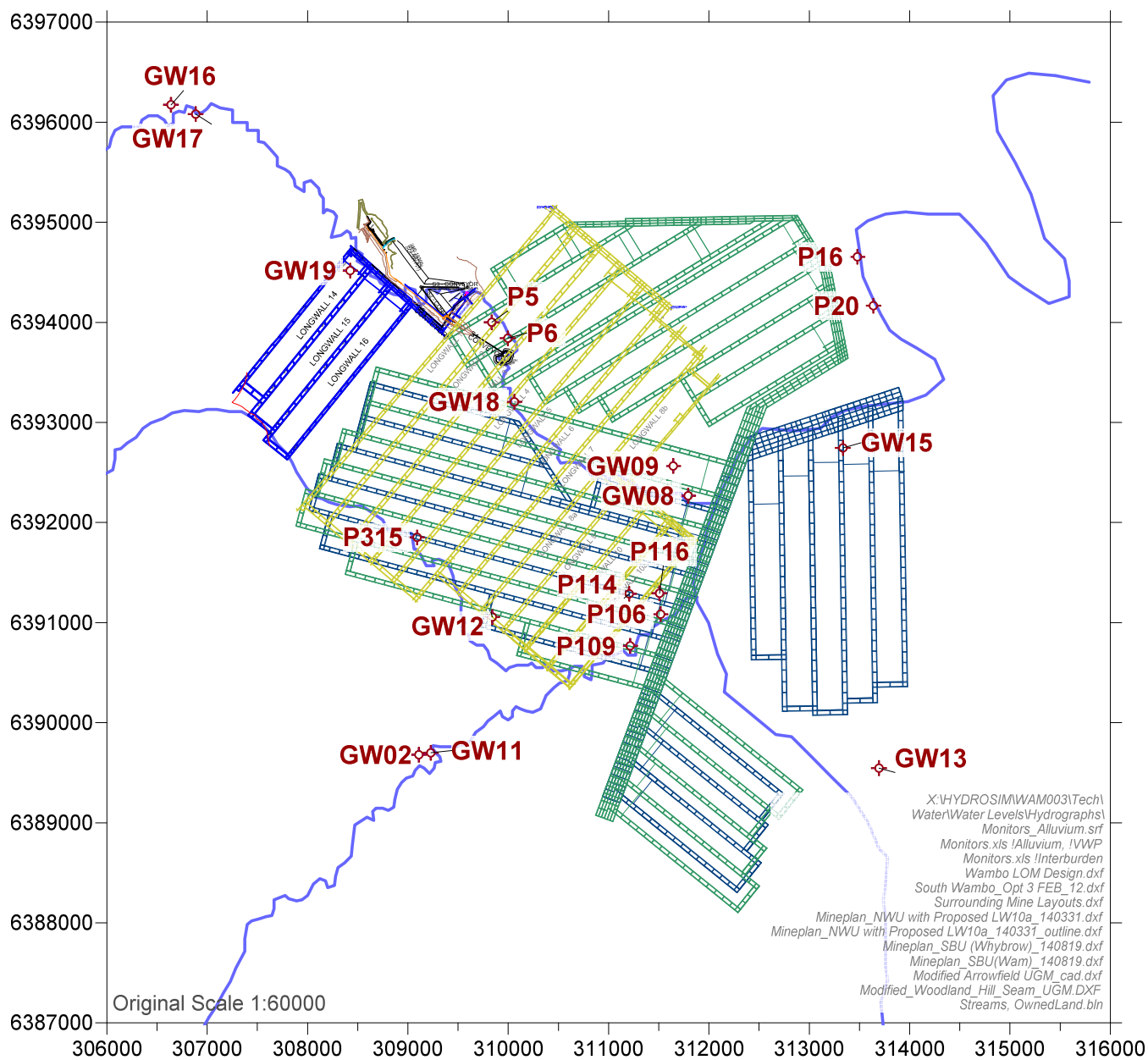


Figure E - 1 Alluvial Groundwater Monitoring Network.

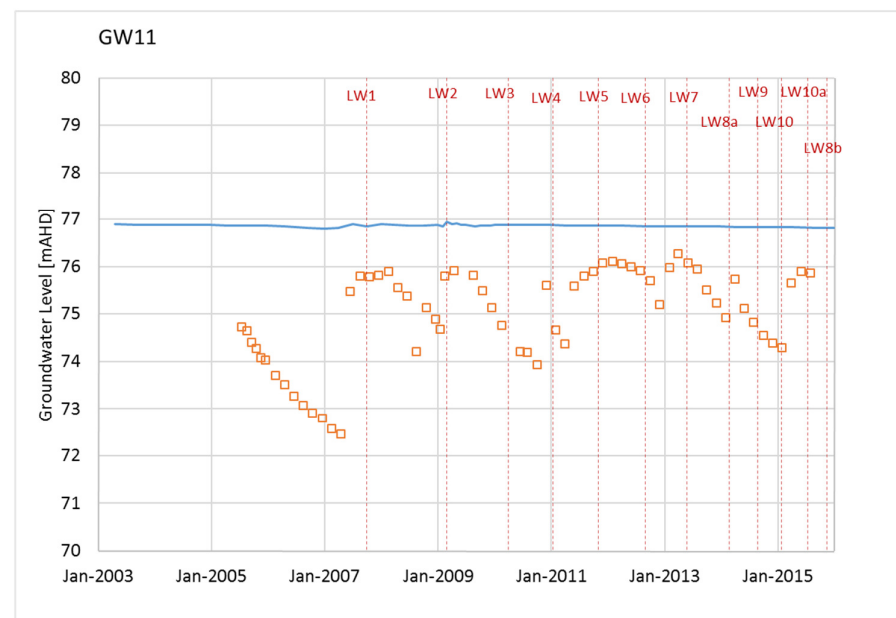
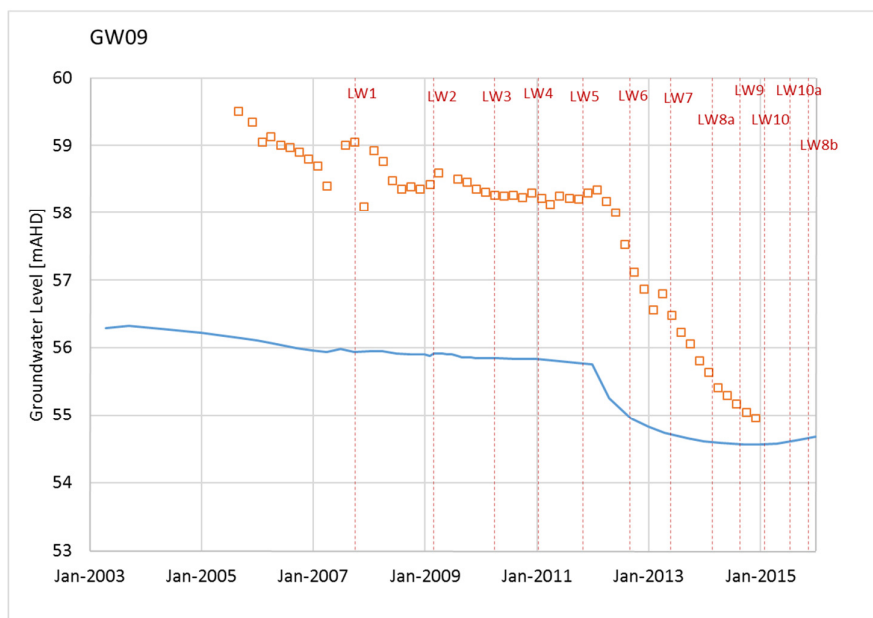
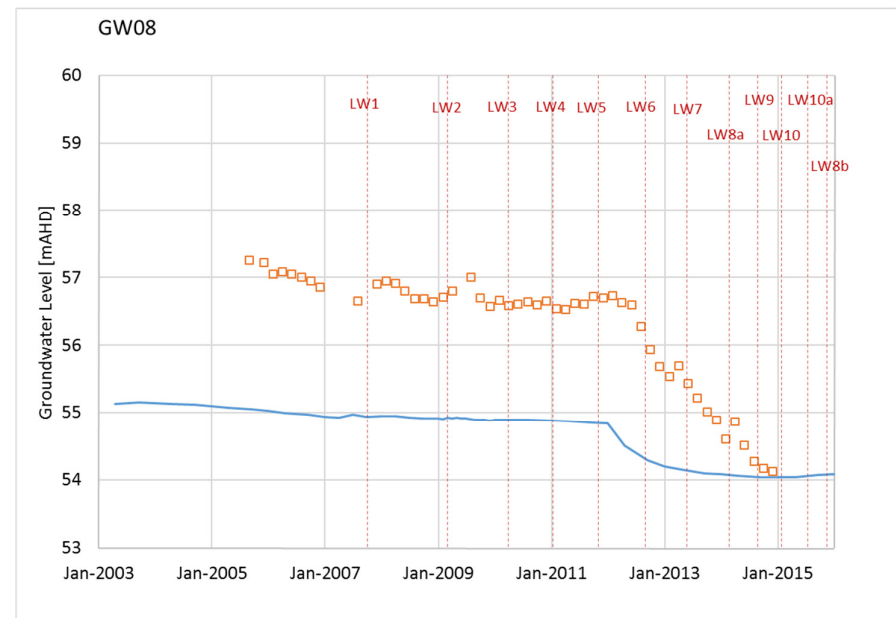
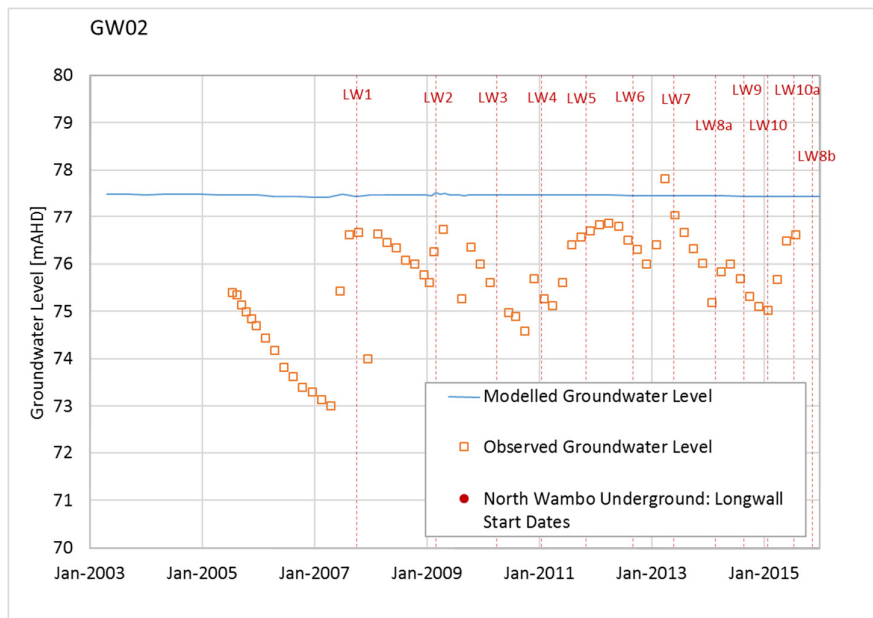


Figure E - 2 GW02, GW08, GW09, GW11 Hydrographs

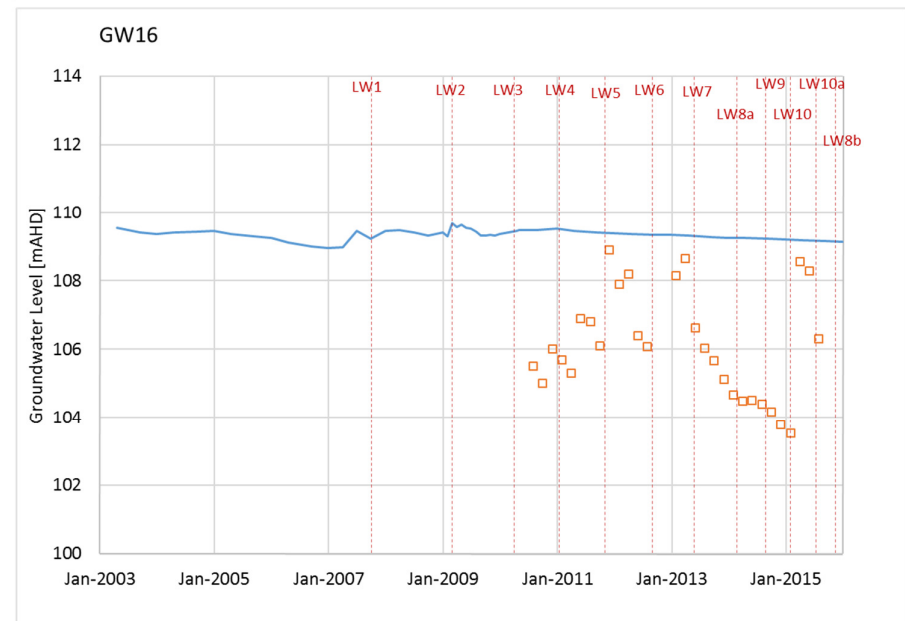
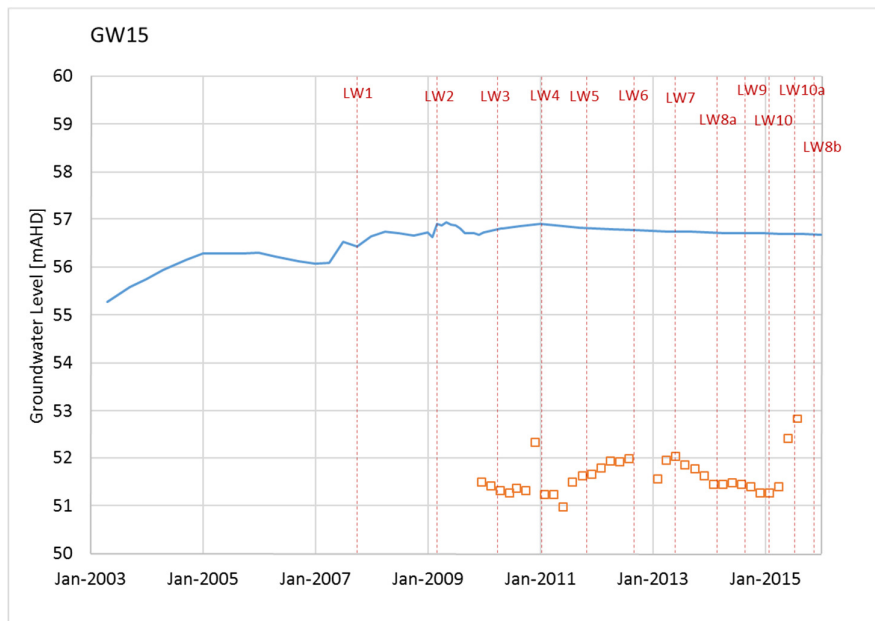
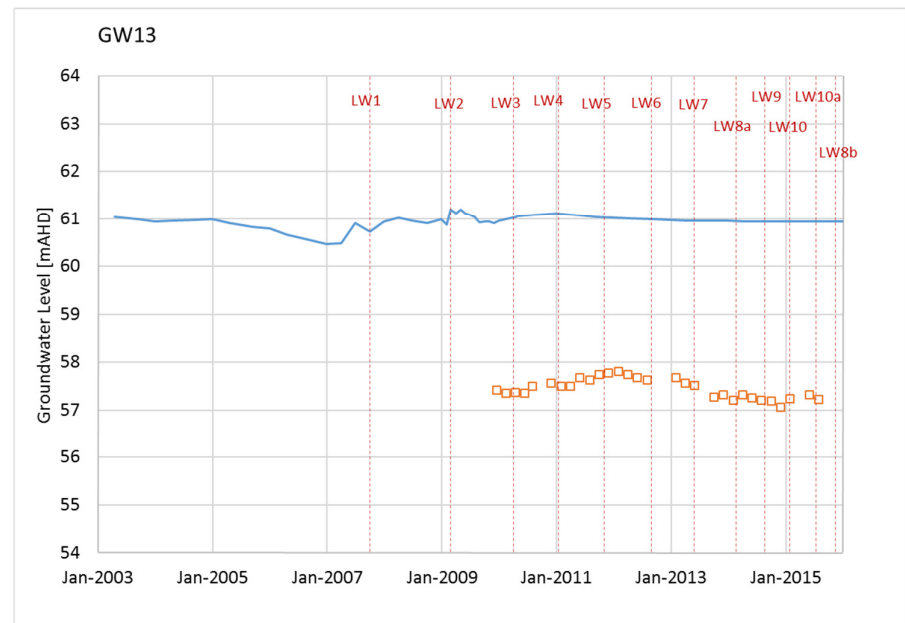
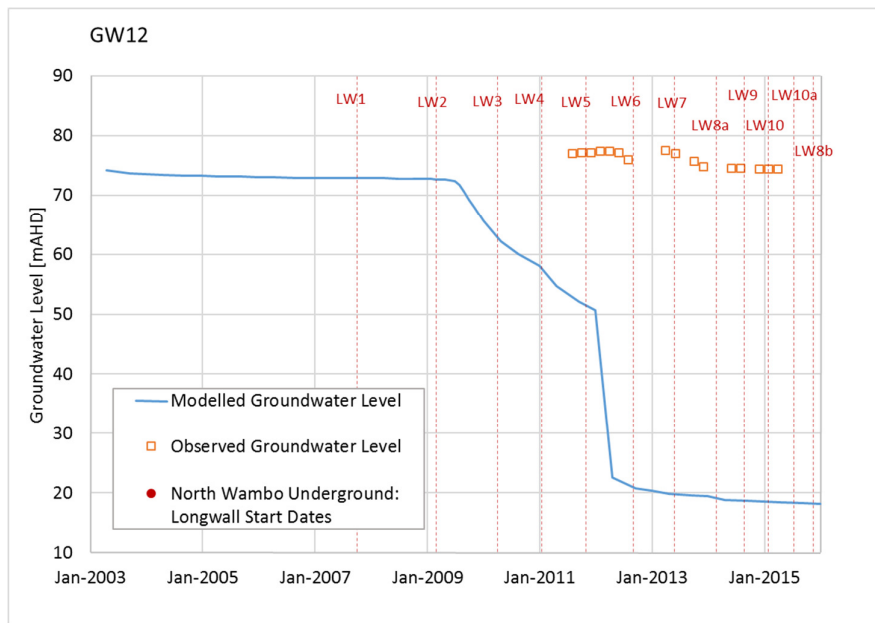


Figure E - 3 GW12, GW13, GW15, GW16 Hydrographs

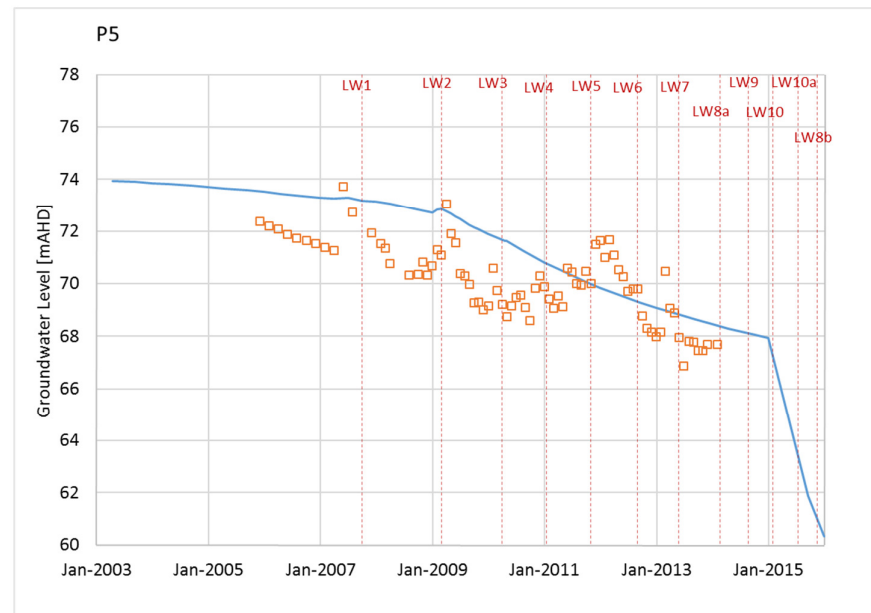
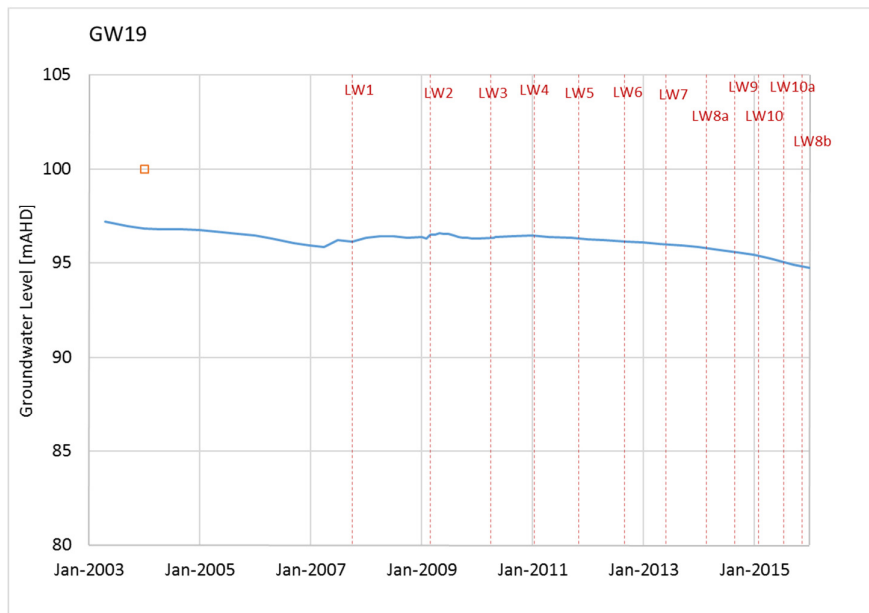
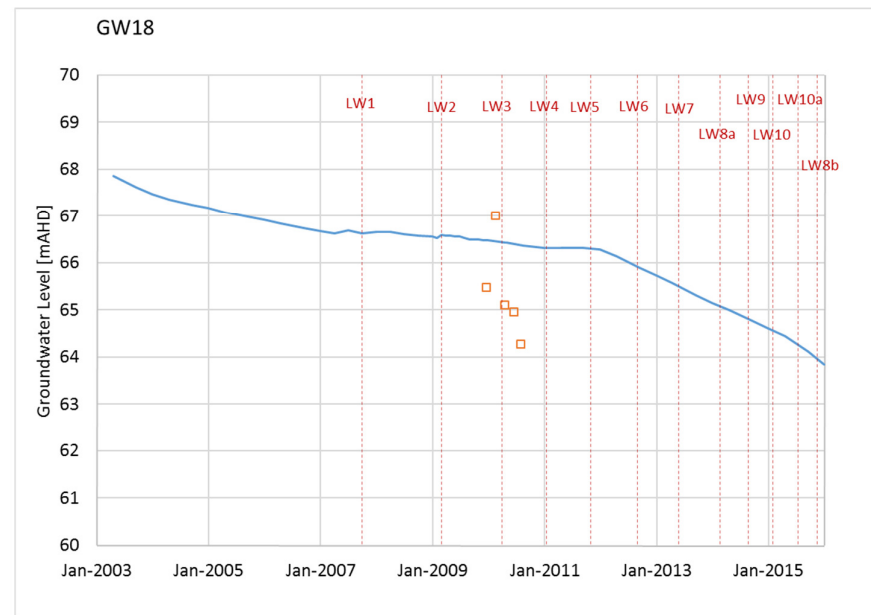
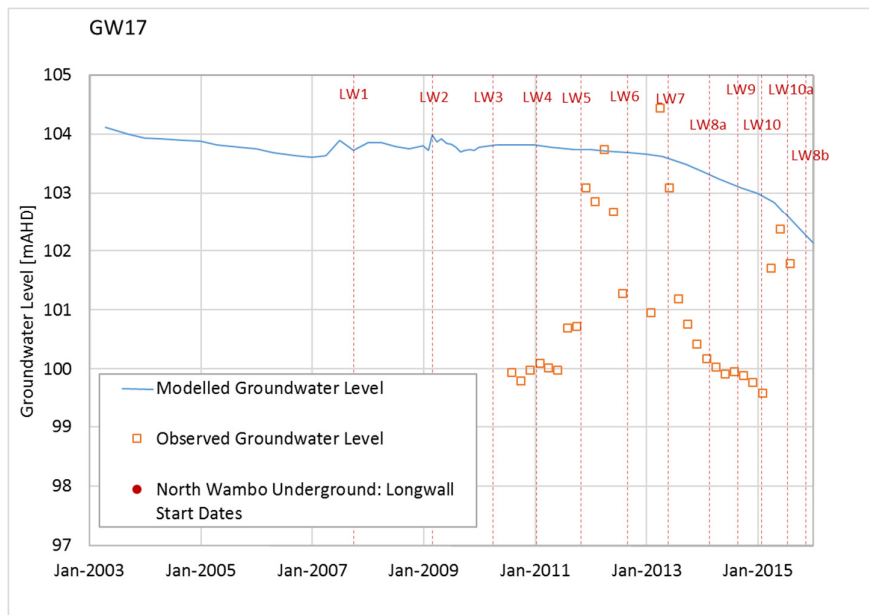


Figure E - 4 GW17, GW18, GW19, P5 Hydrographs

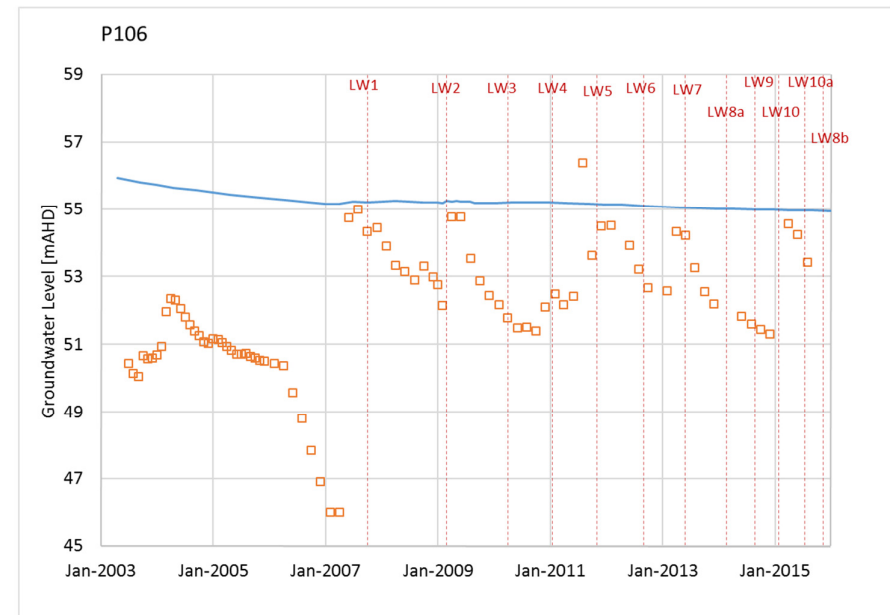
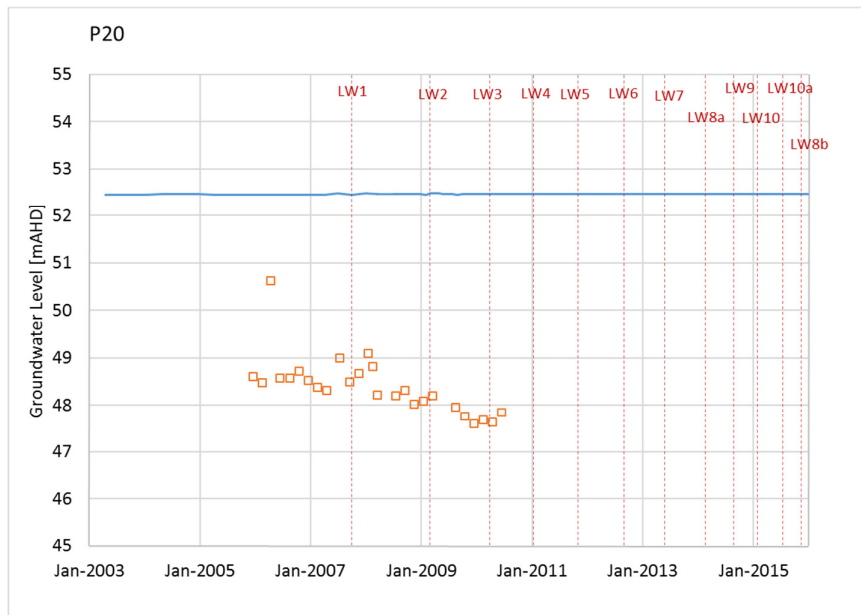
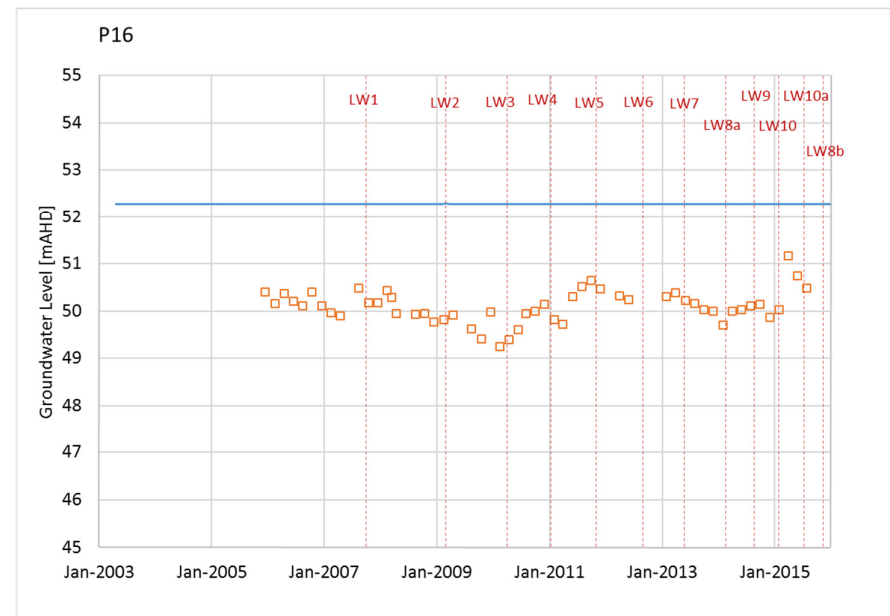
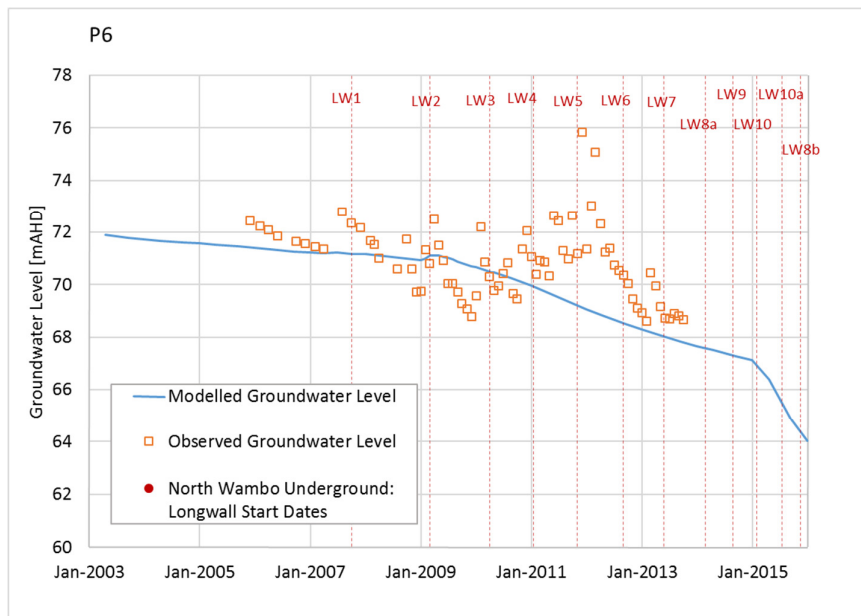


Figure E - 5 P6, P16, P20, P106 Hydrographs

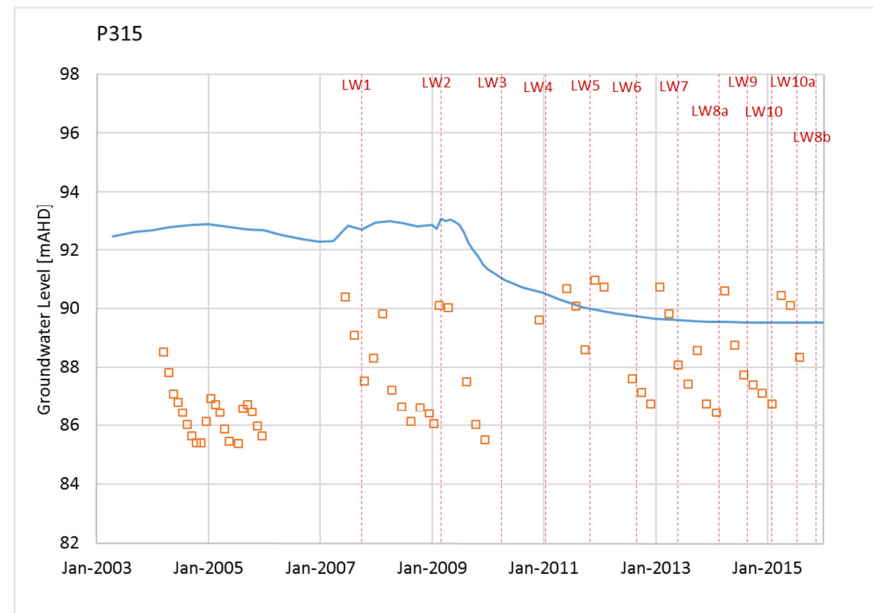
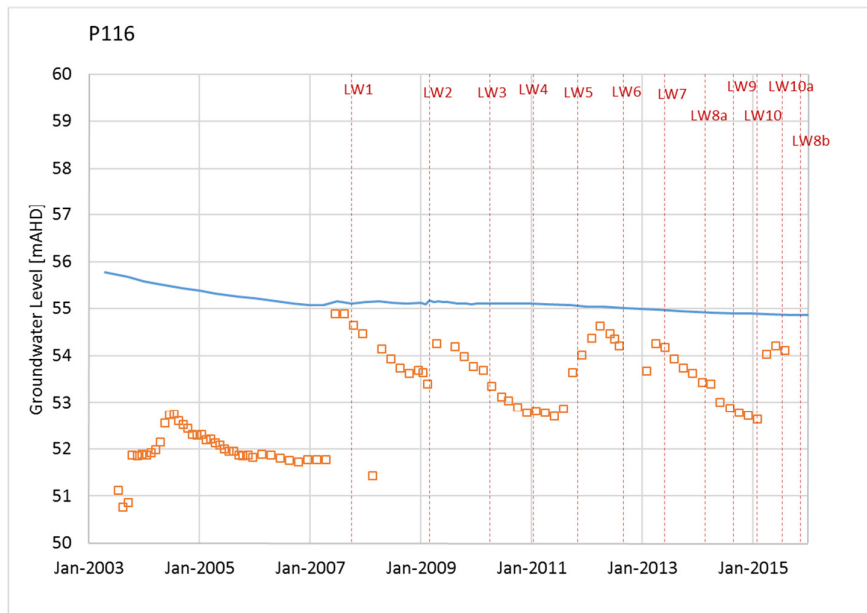
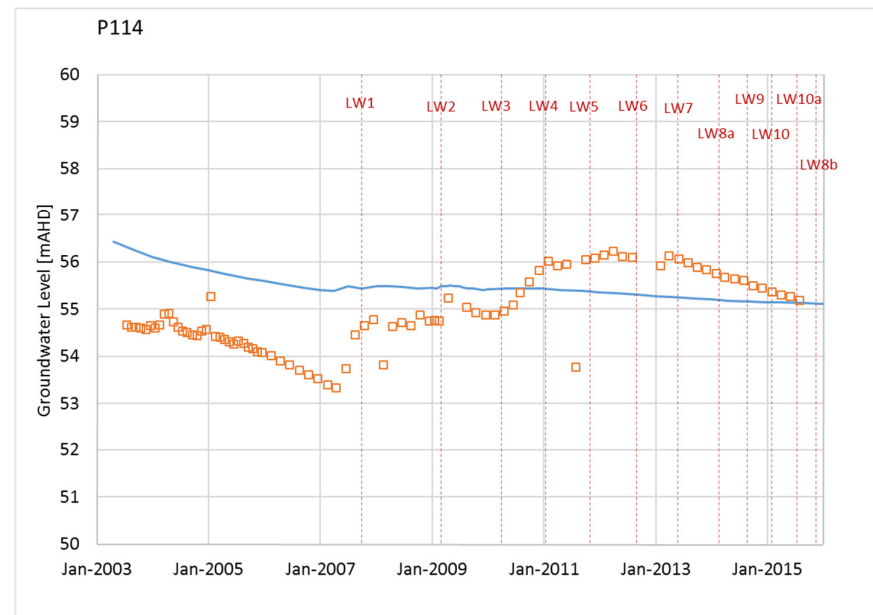
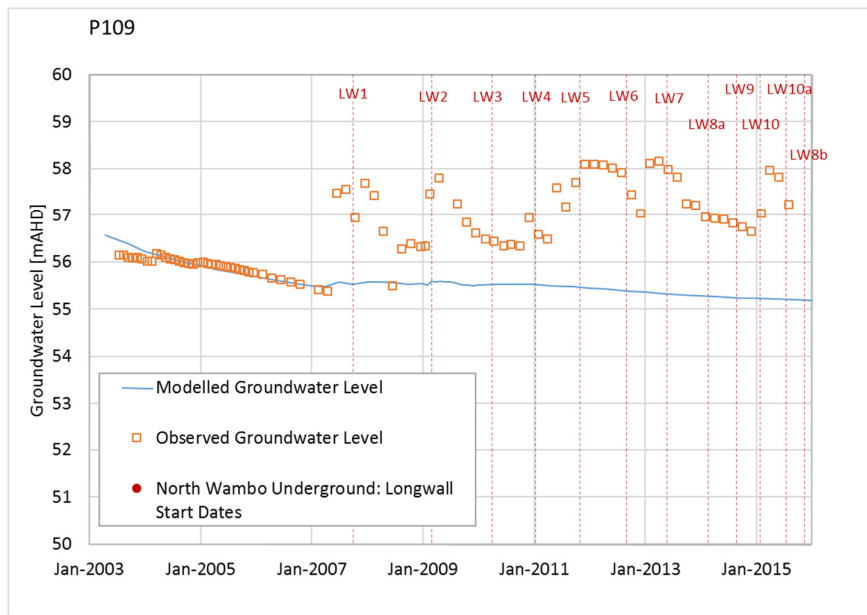


Figure E - 6 P109, P114, P116, P315 Hydrographs

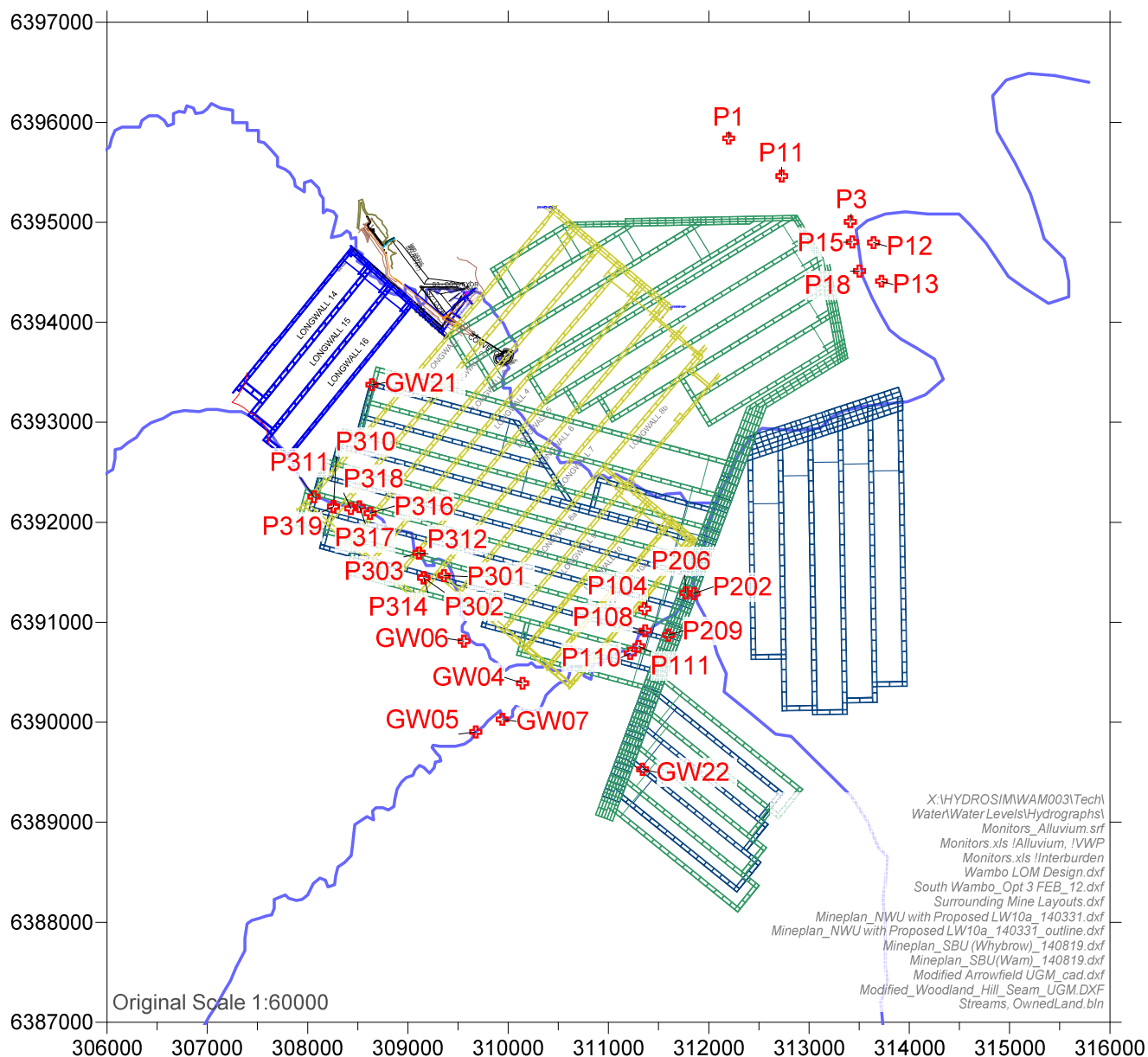


Figure F - 1 Interburden Groundwater Monitoring Network

Bore ID	Simulated Layer	Layer Litholgy
GW04	2	Overburden and coal seams above the Whybrow Seam.
GW05	2	Overburden and coal seams above the Whybrow Seam.
GW06	2	Overburden and coal seams above the Whybrow Seam.
GW07	2	Overburden and coal seams above the Whybrow Seam.
GW21	2	Overburden and coal seams above the Whybrow Seam.
GW22	2	Overburden and coal seams above the Whybrow Seam.
GW030732	16	Basal units.
GW030733	16	Basal units.
GW030740	16	Basal units.
GW043225	2	Overburden and coal seams above the Whybrow Seam.
GW080963	16	Basal units.
P1	2	Overburden and coal seams above the Whybrow Seam.
P3	8	Whynot–Woodlands Hill Seam interburden.
P11	7	Whynot Seam.
P12	2	Overburden and coal seams above the Whybrow Seam.
P13	2	Overburden and coal seams above the Whybrow Seam.
P15	2	Overburden and coal seams above the Whybrow Seam.
P18	2	Overburden and coal seams above the Whybrow Seam.
P104	2	Overburden and coal seams above the Whybrow Seam.
P108	2	Overburden and coal seams above the Whybrow Seam.
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P206	2	Overburden and coal seams above the Whybrow Seam.
P209	2	Overburden and coal seams above the Whybrow Seam.
P301	2	Overburden and coal seams above the Whybrow Seam.
P302	2	Overburden and coal seams above the Whybrow Seam.
P303	2	Overburden and coal seams above the Whybrow Seam.
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P311	2	Overburden and coal seams above the Whybrow Seam.
P312	2	Overburden and coal seams above the Whybrow Seam.
P314	2	Overburden and coal seams above the Whybrow Seam.
P316	2	Overburden and coal seams above the Whybrow Seam.
P317	2	Overburden and coal seams above the Whybrow Seam.
P318	2	Overburden and coal seams above the Whybrow Seam.
P319	2	Overburden and coal seams above the Whybrow Seam.

Table F - 1 Interburden bore lithology and model layer.

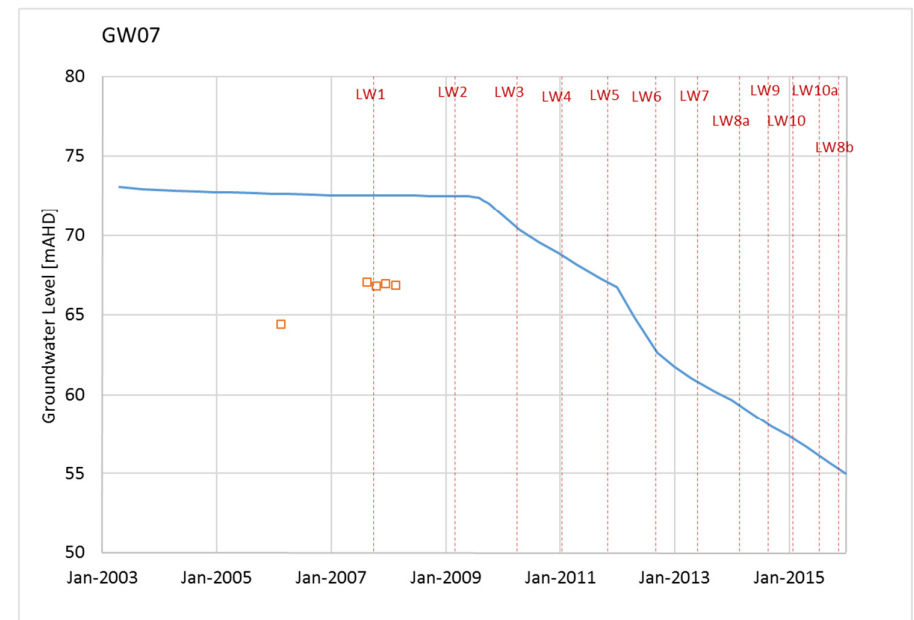
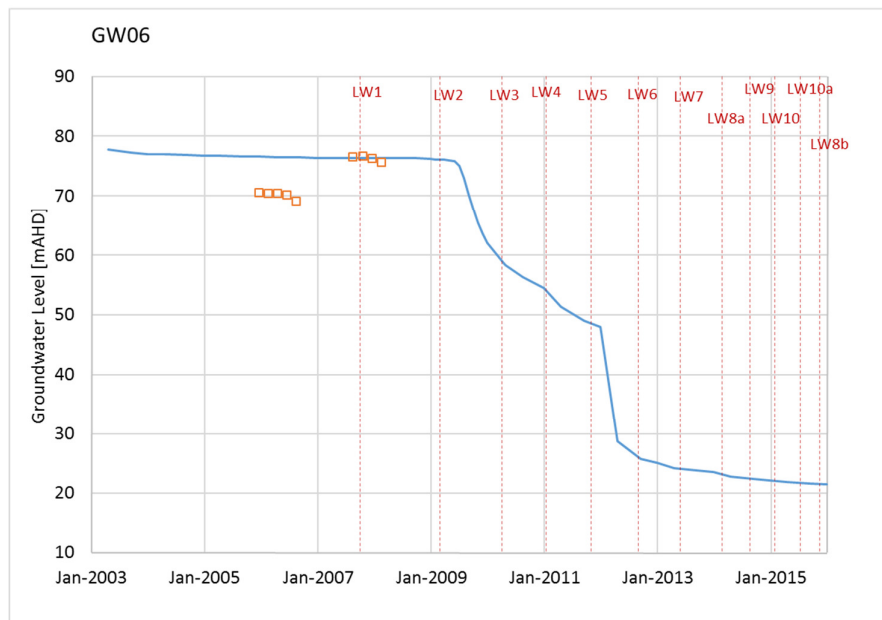
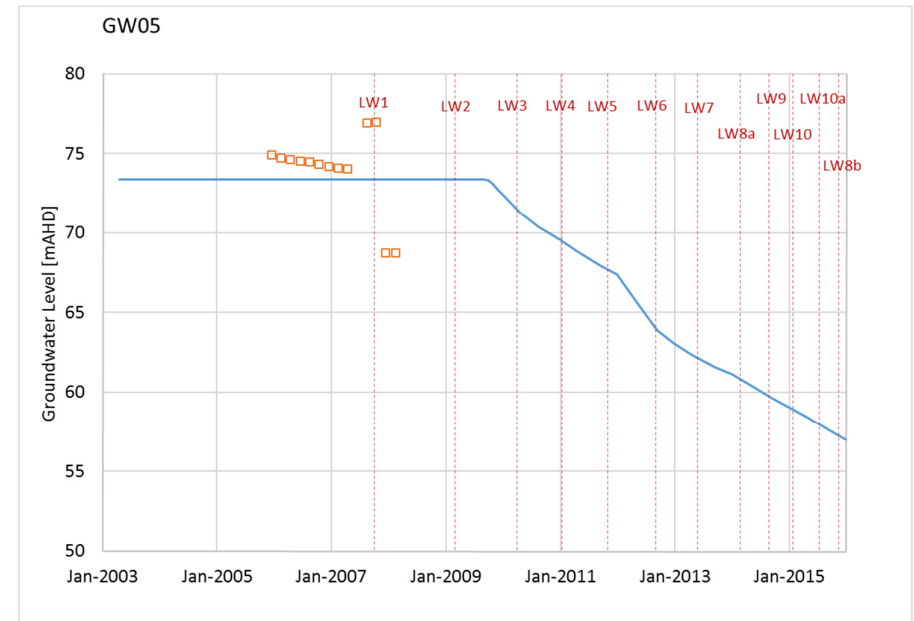
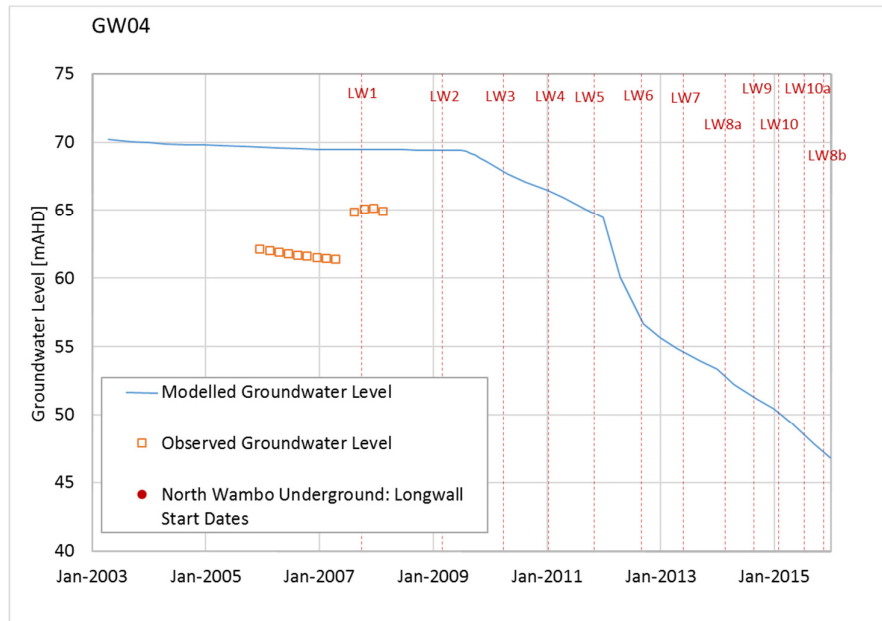


Figure F - 2 GW04, GW05, GW06, GW07 Hydrographs

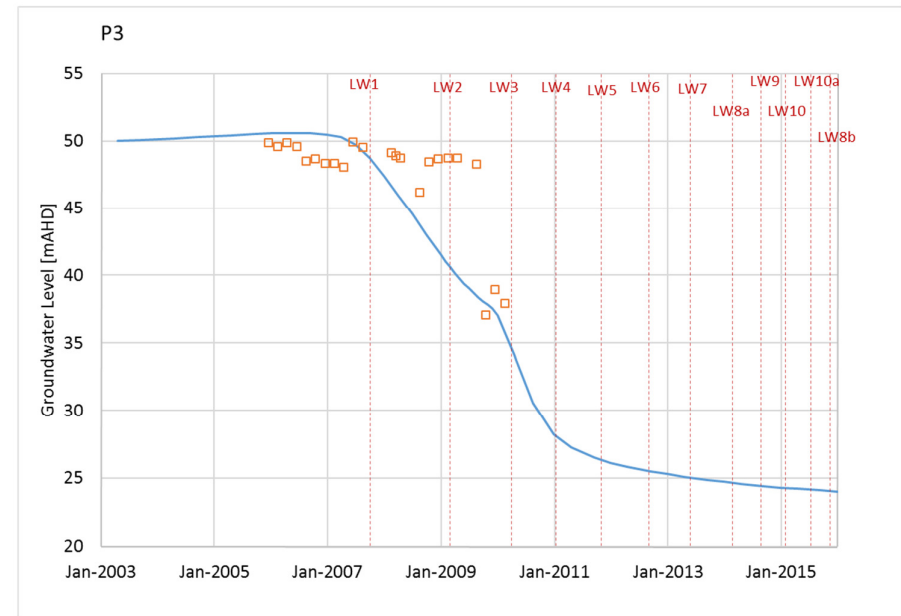
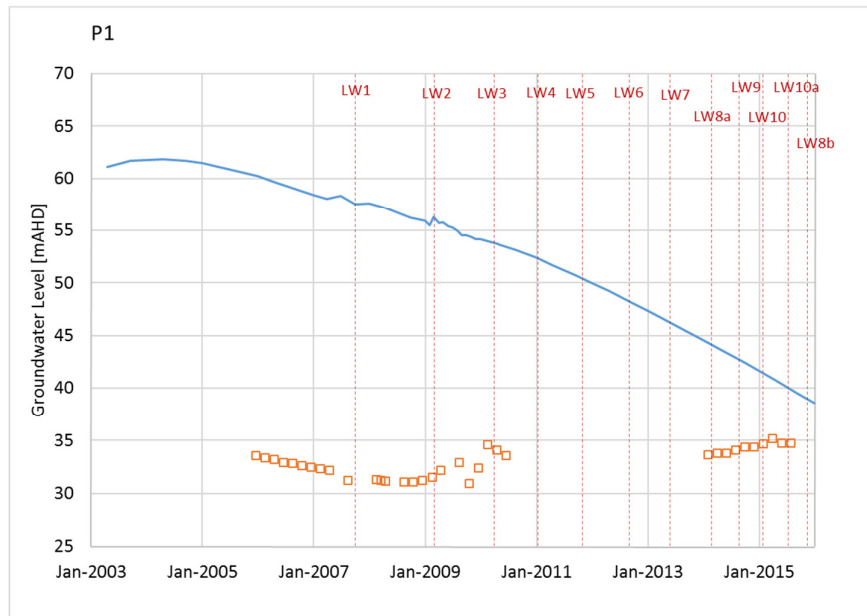
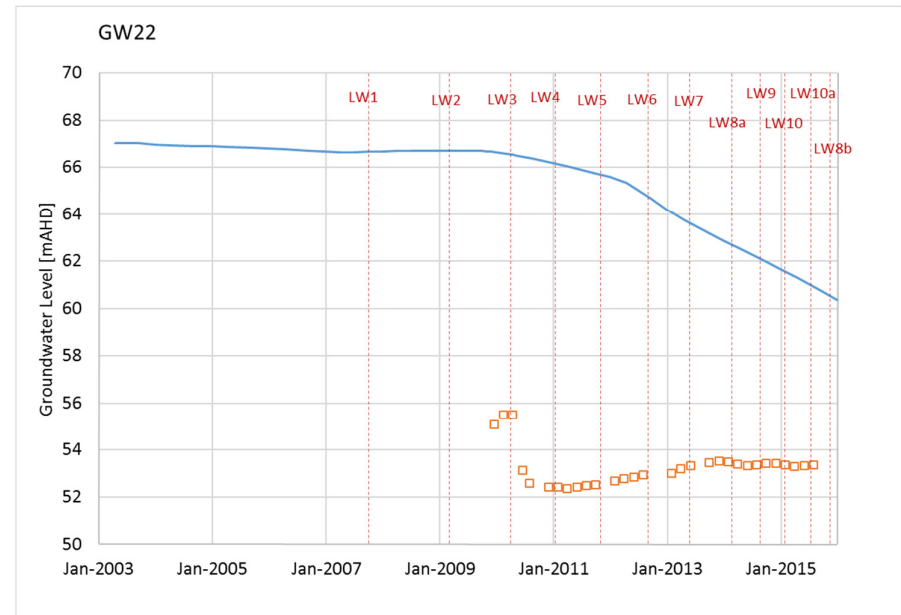
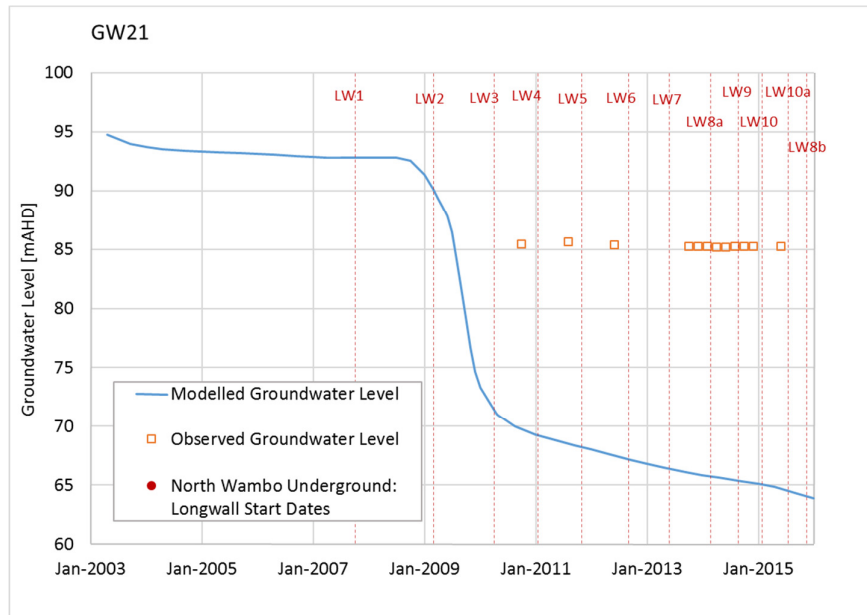


Figure F - 3 GW21, GW22, P1, P3 Hydrographs

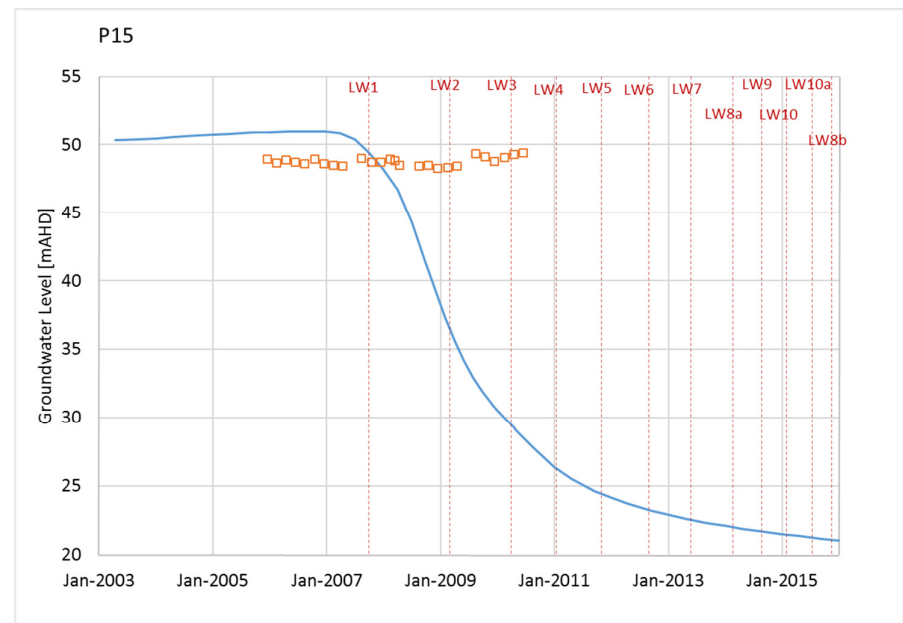
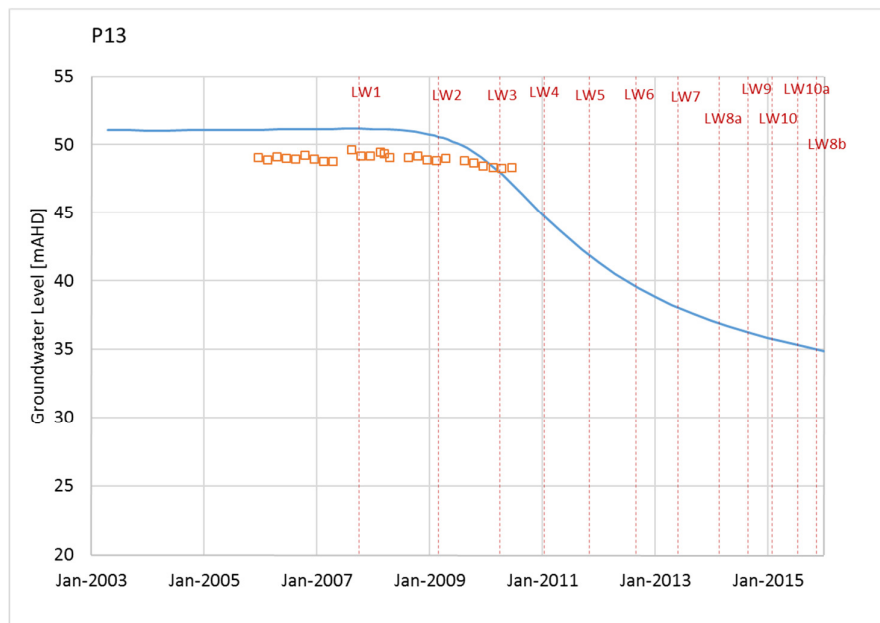
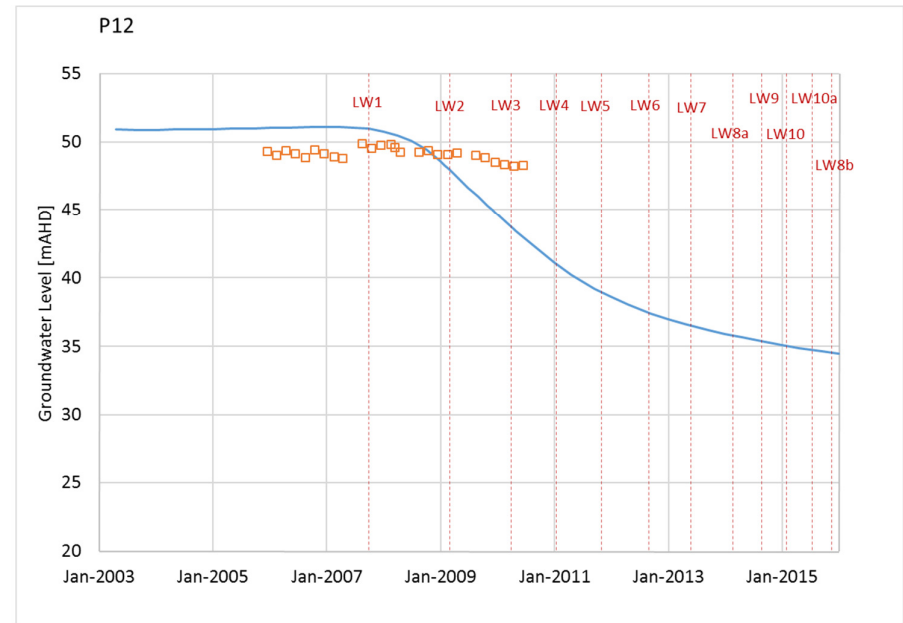
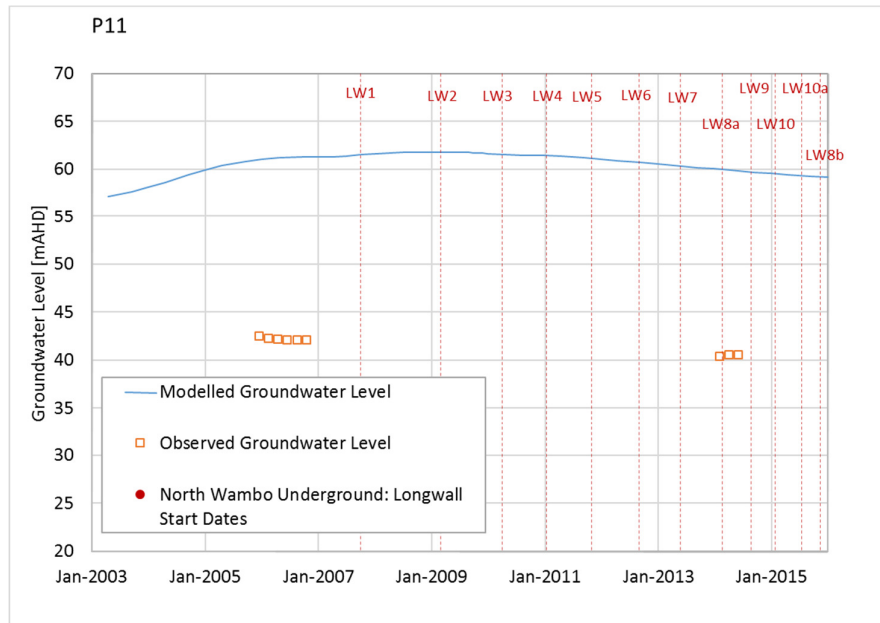


Figure F - 4 P11, P12, P13, P15 Hydrographs

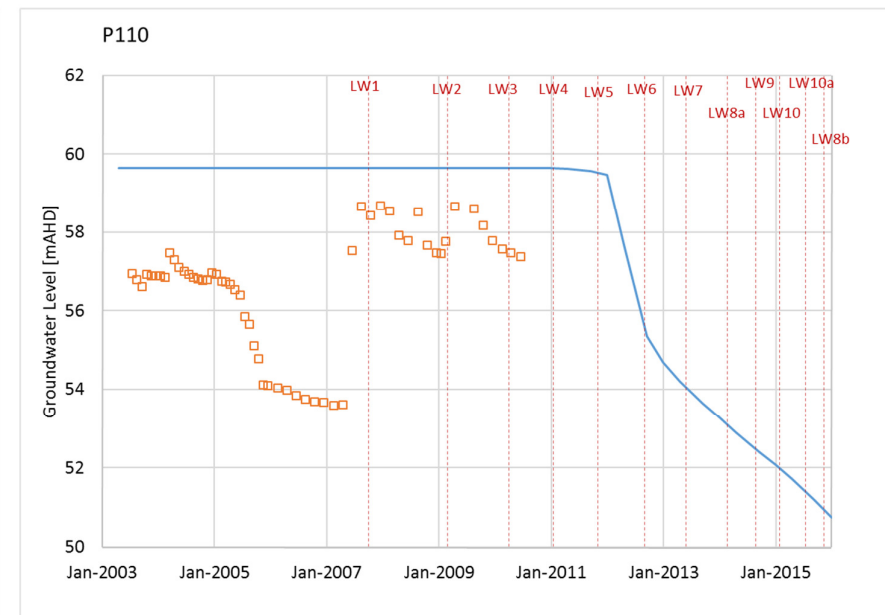
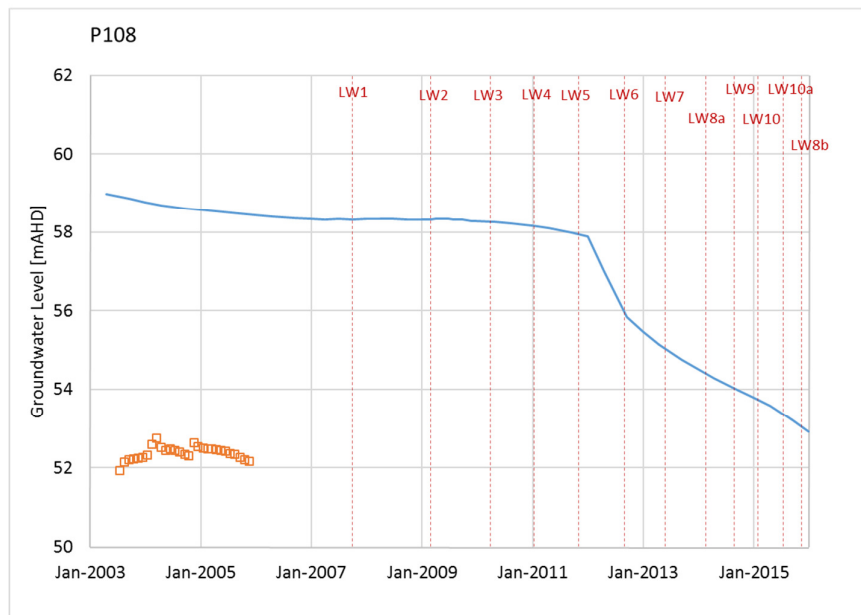
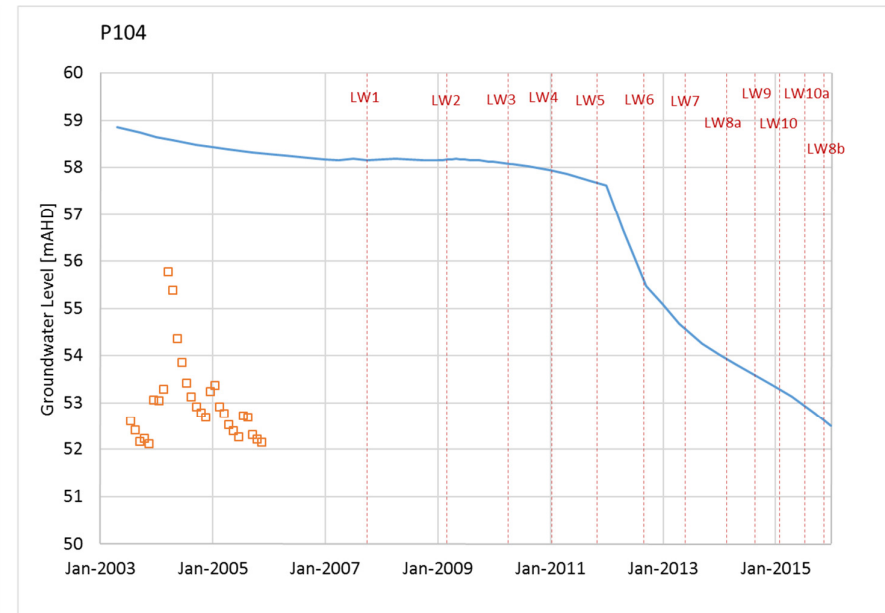
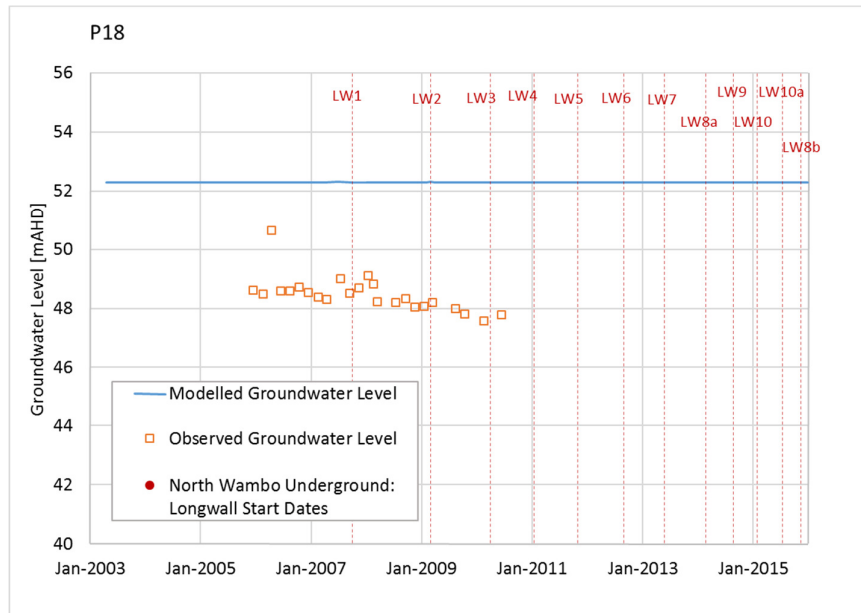


Figure F - 5 P18, P104, P108, P110 Hydrographs

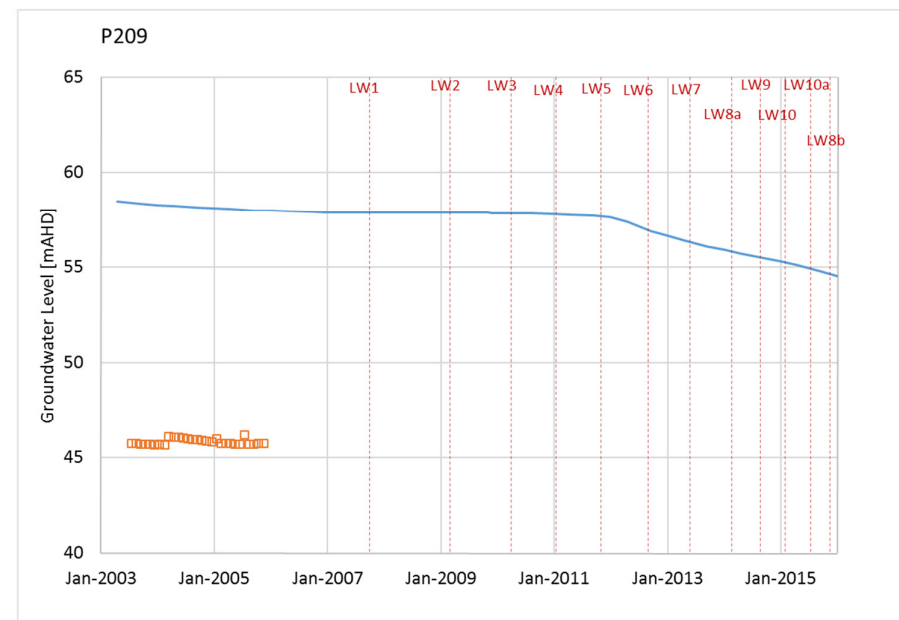
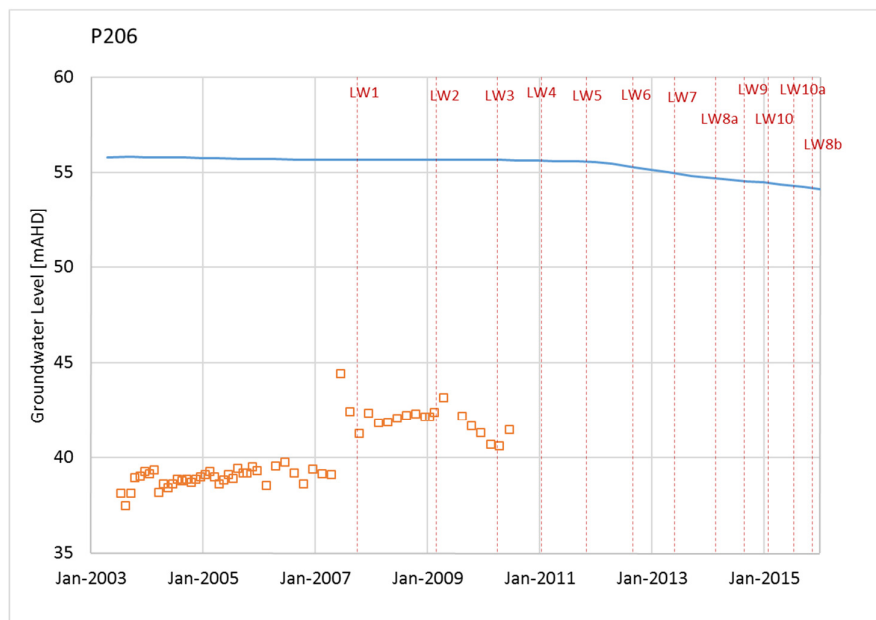
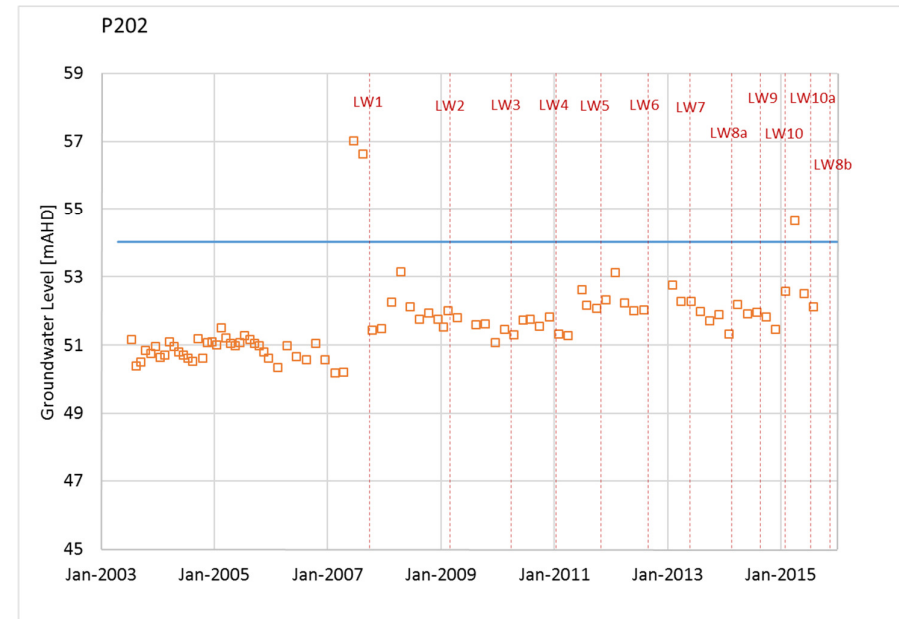
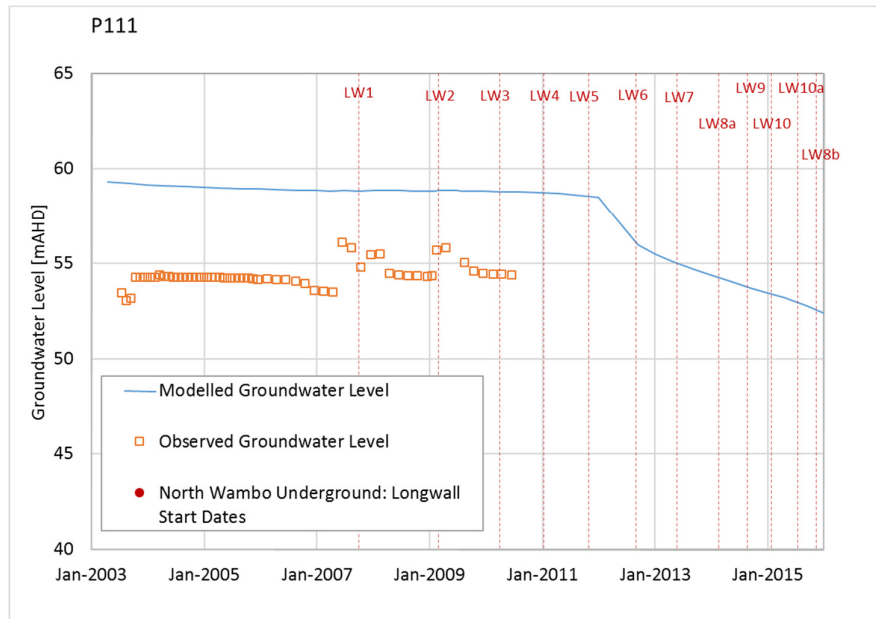


Figure F - 6 P111, P202, P206, P209 Hydrographs

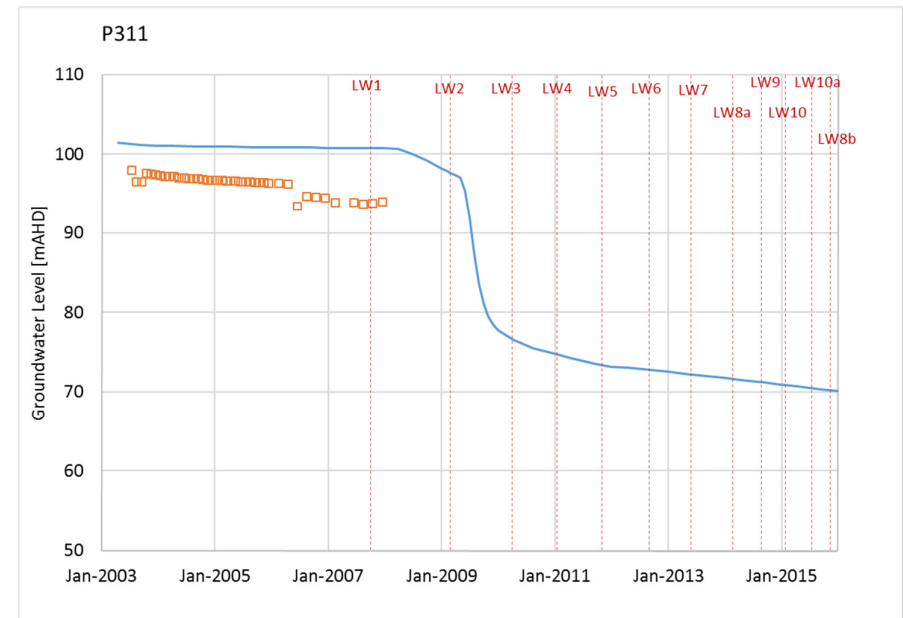
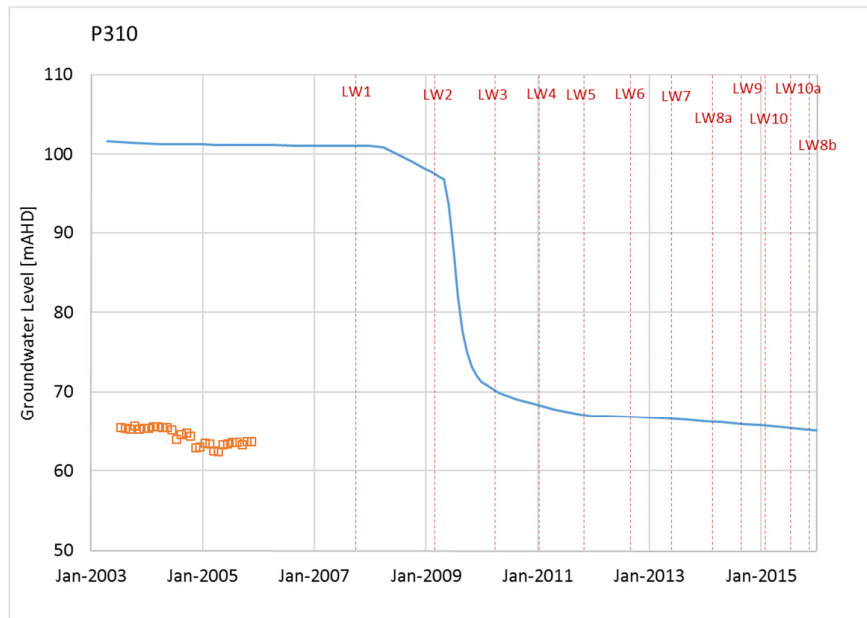
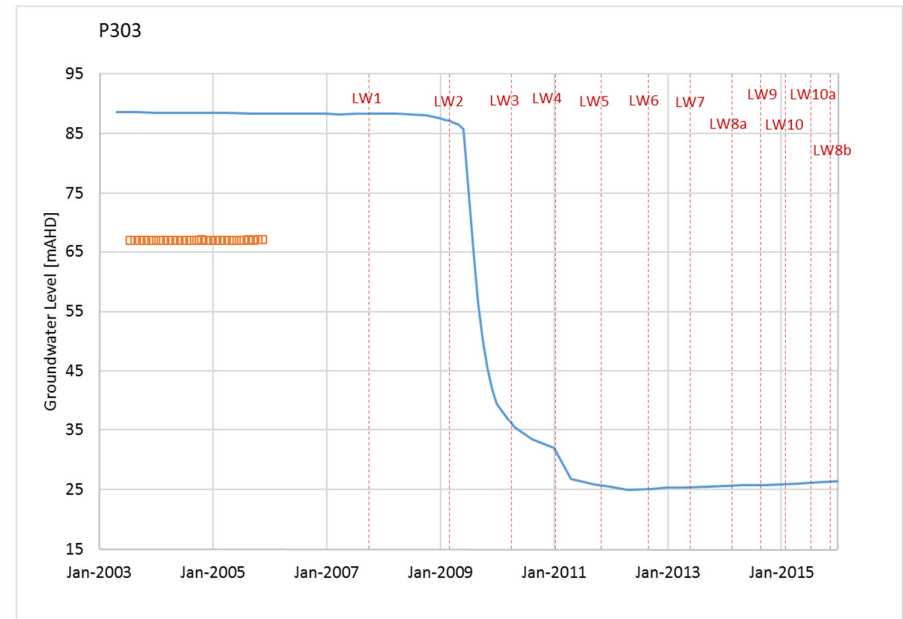
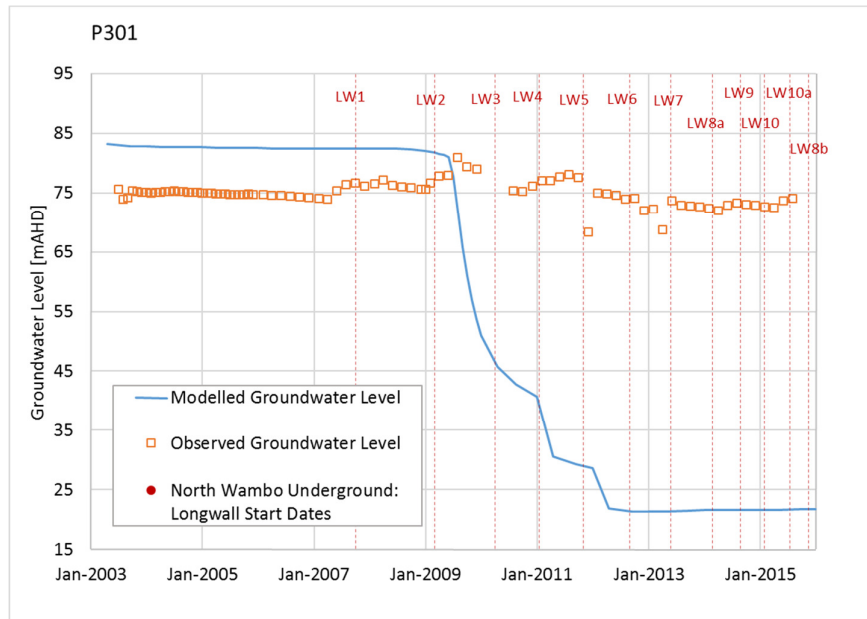


Figure F - 7 P301, P303, P310, P311 Hydrographs

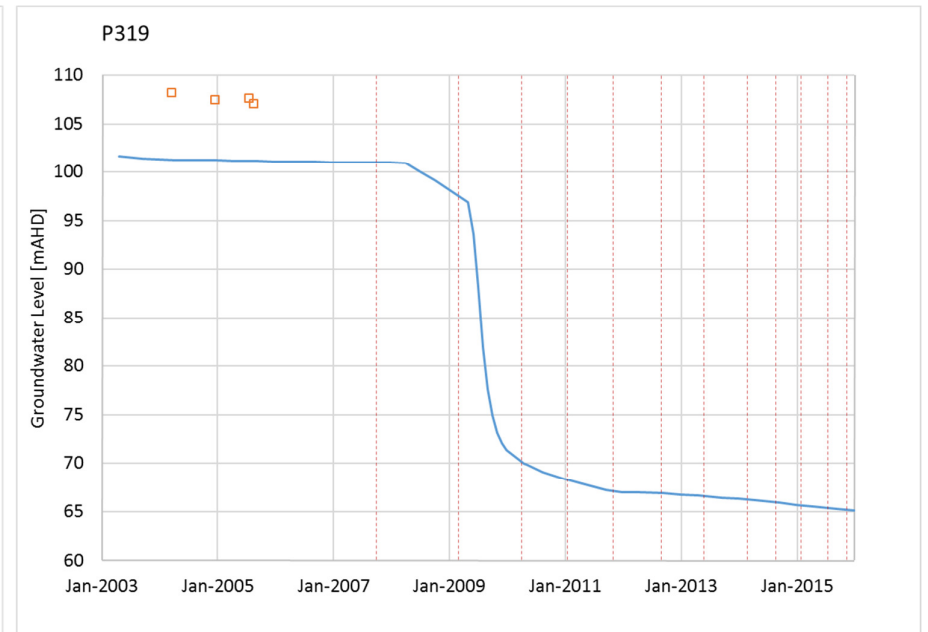
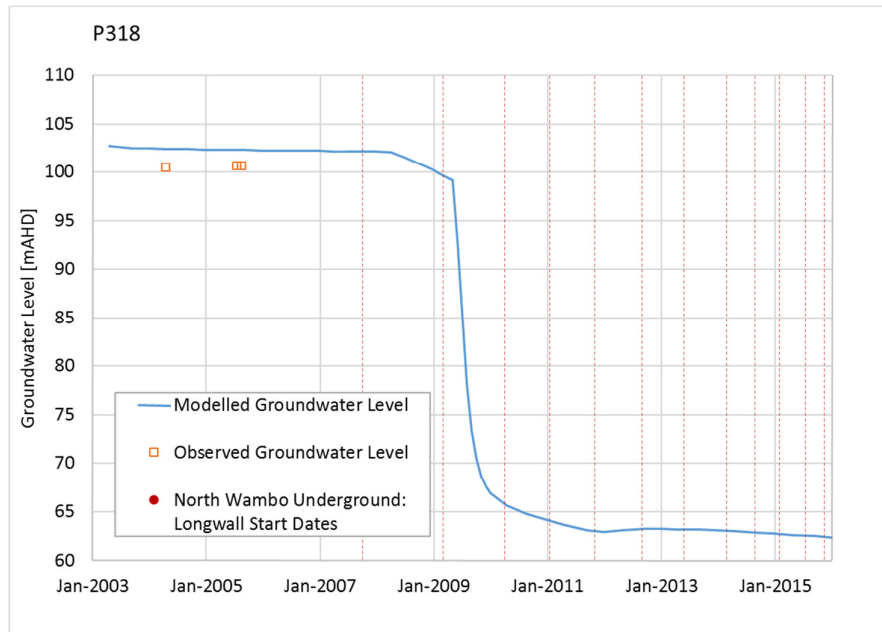


Figure F - 8 P318, P319 Hydrographs

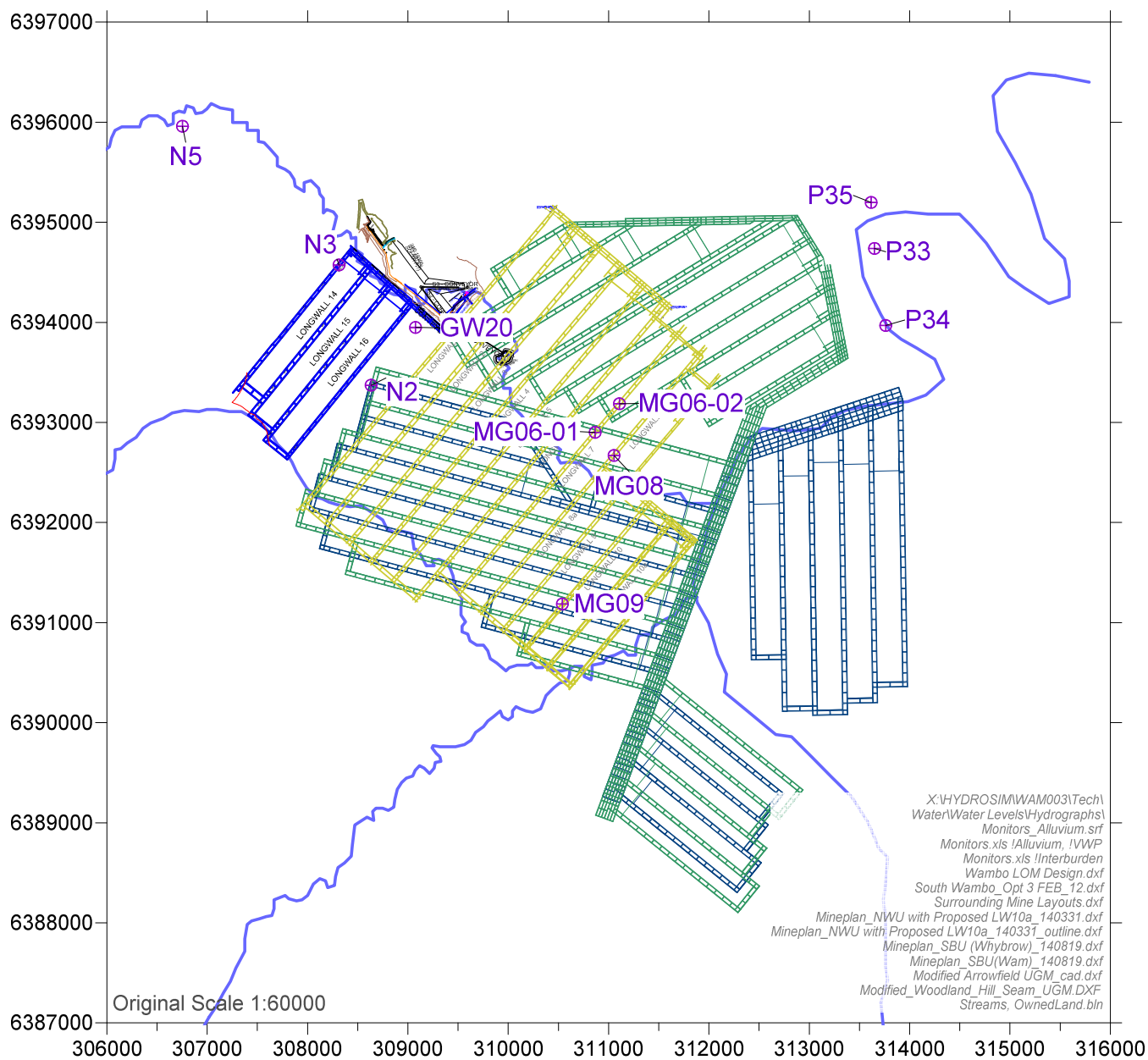


Figure G - 1 Vibrating Wire Piezometer Monitoring Network

VWP - GW20

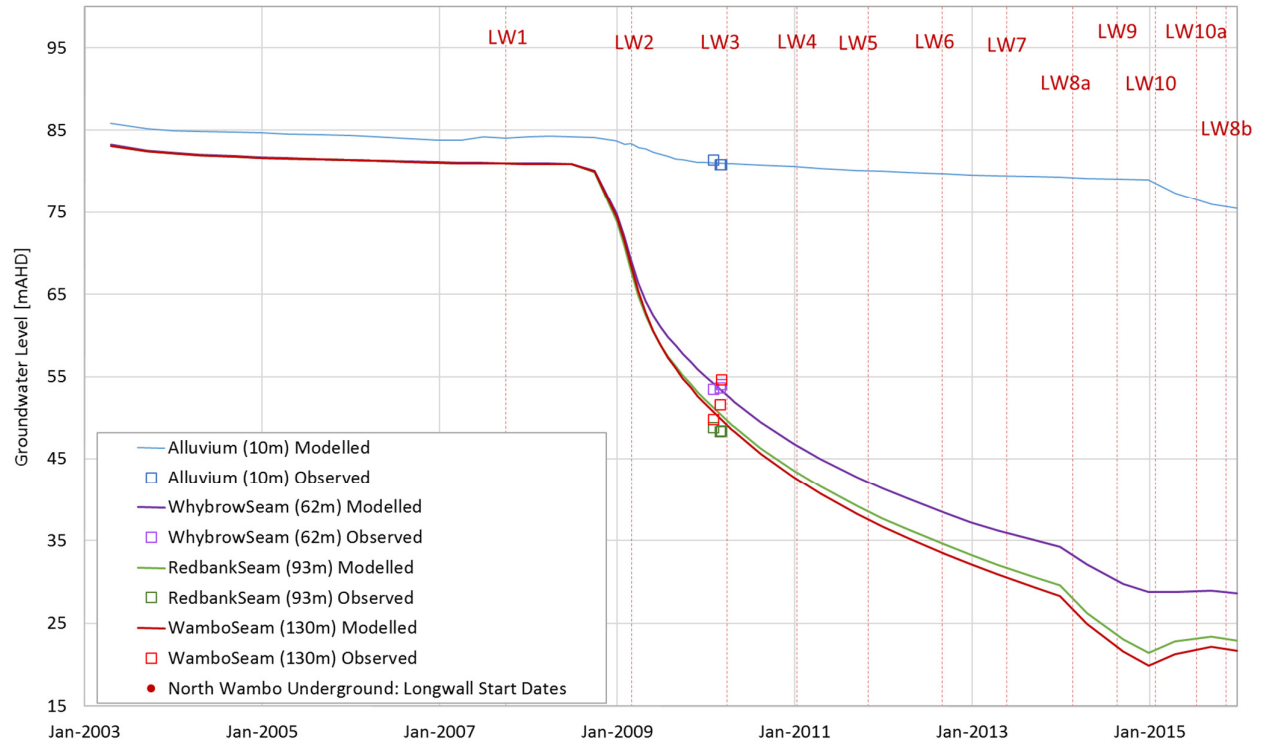


Figure G - 2 GW20 Hydrographs

VWP - MG08

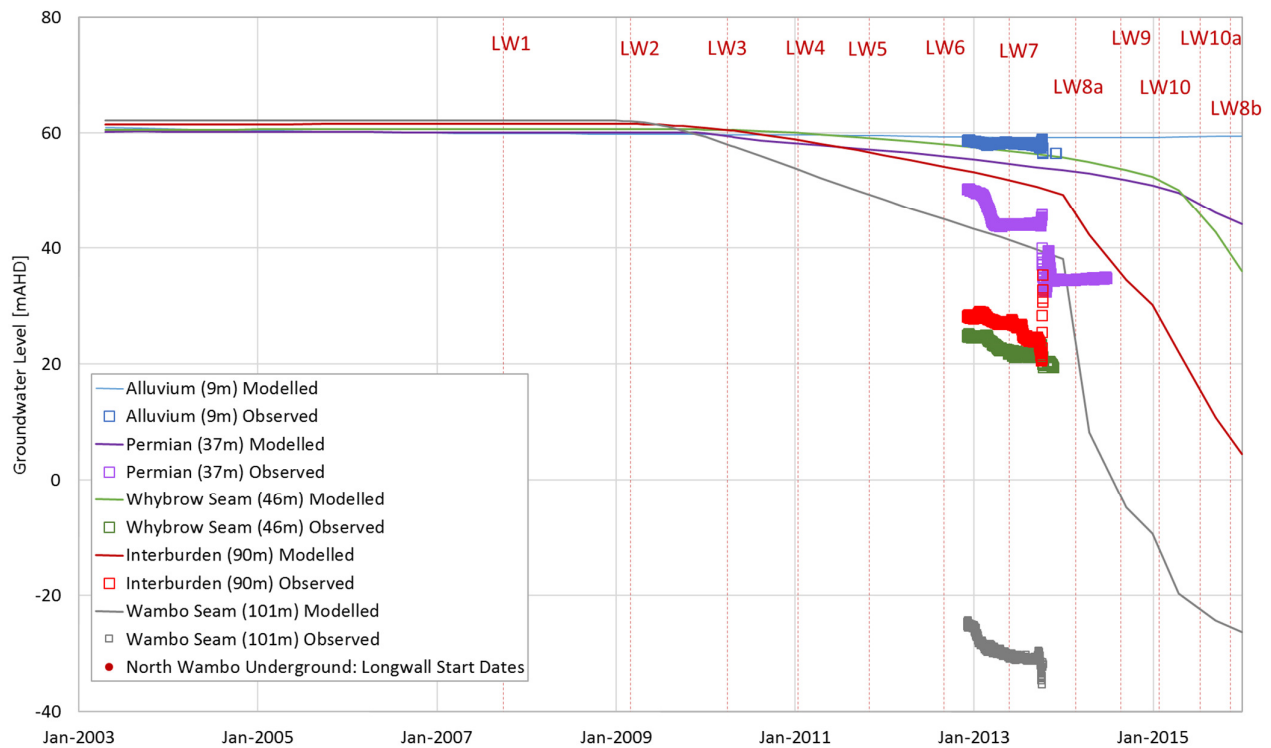


Figure G - 3 MG08 Hydrographs

VWP - MG09

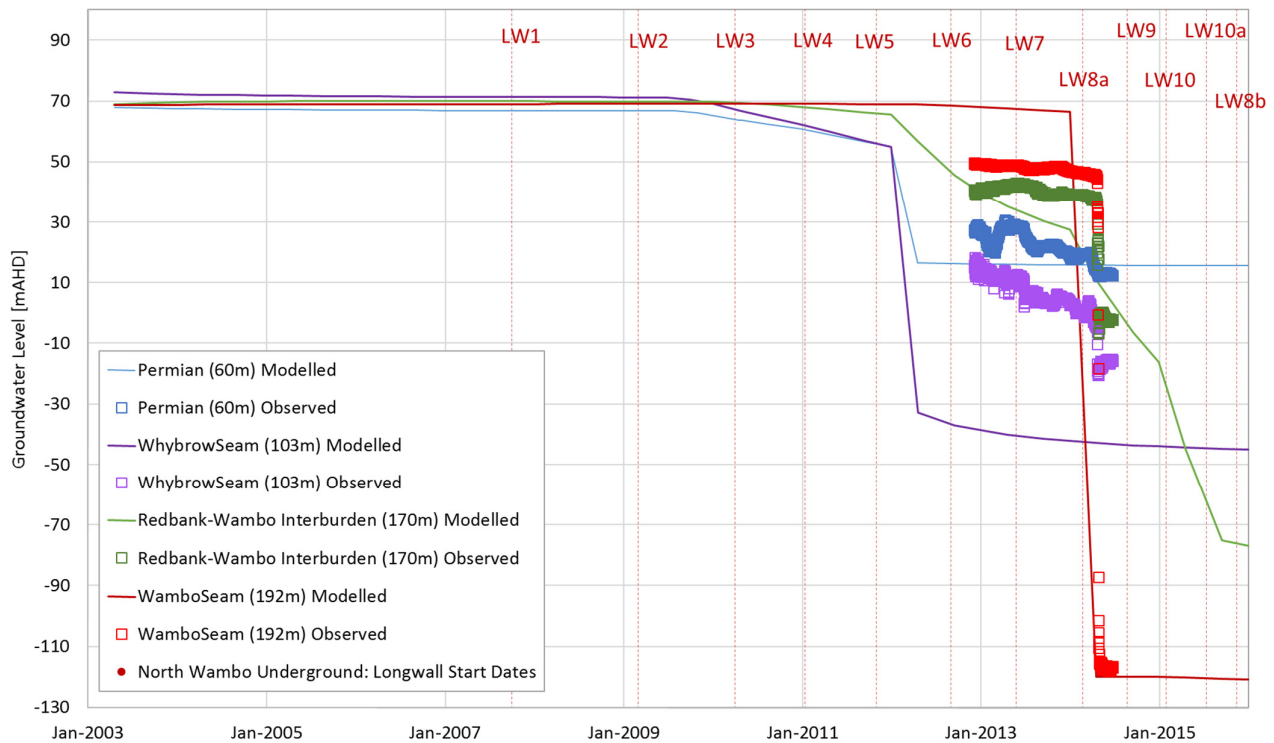


Figure G - 4 MG09 Hydrographs

VWP - P33

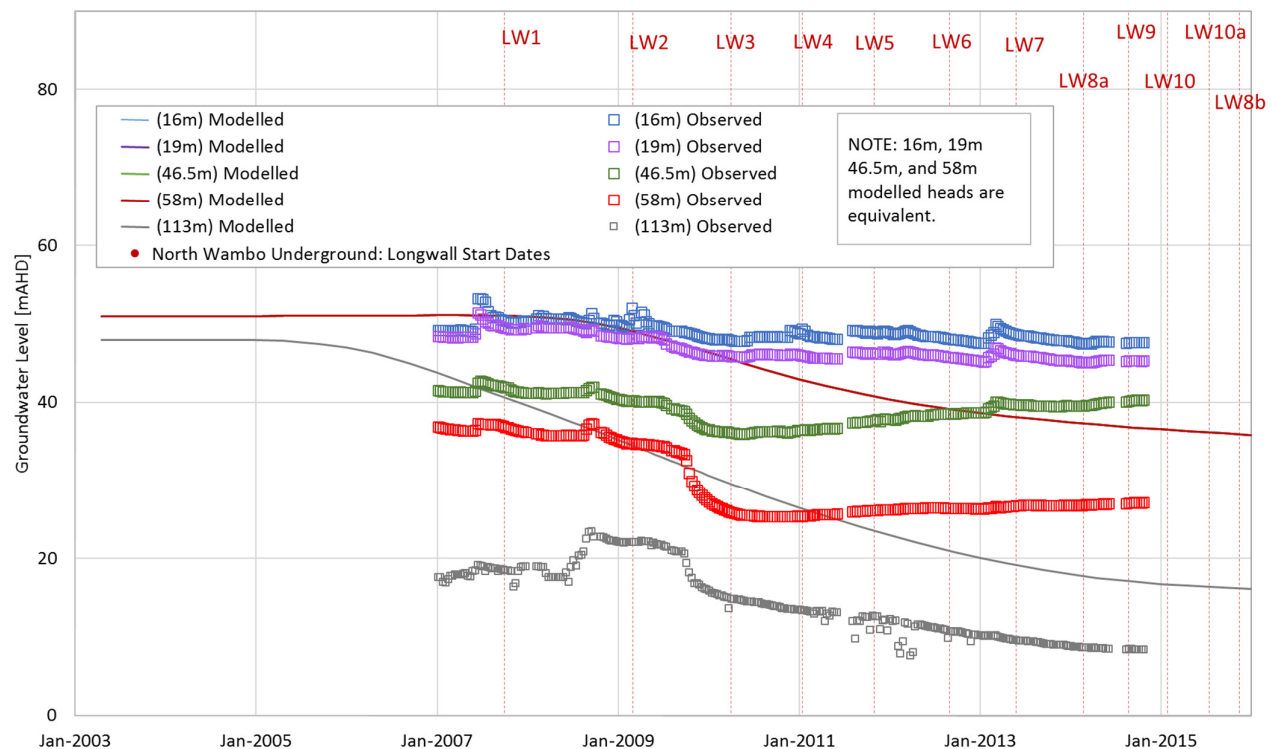


Figure G - 5 P33 Hydrographs

VWP - P34

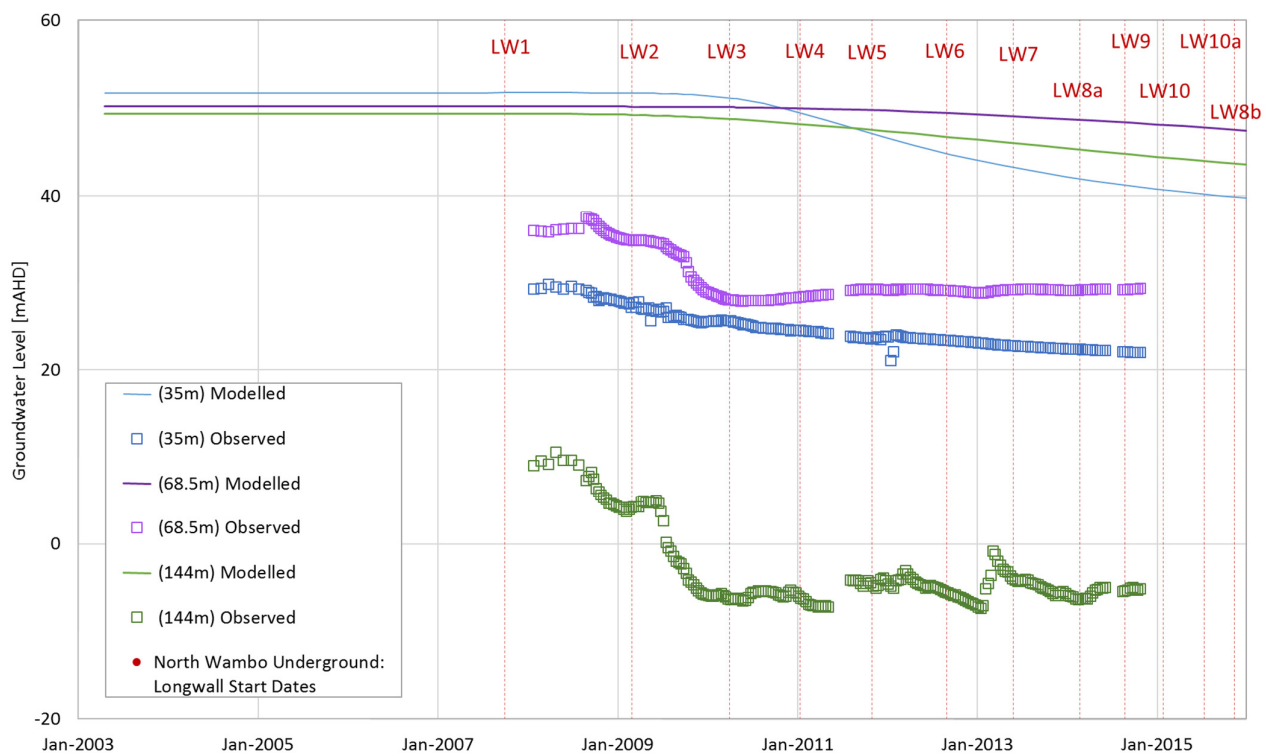


Figure G - 6 P34 Hydrographs

VWP - P35

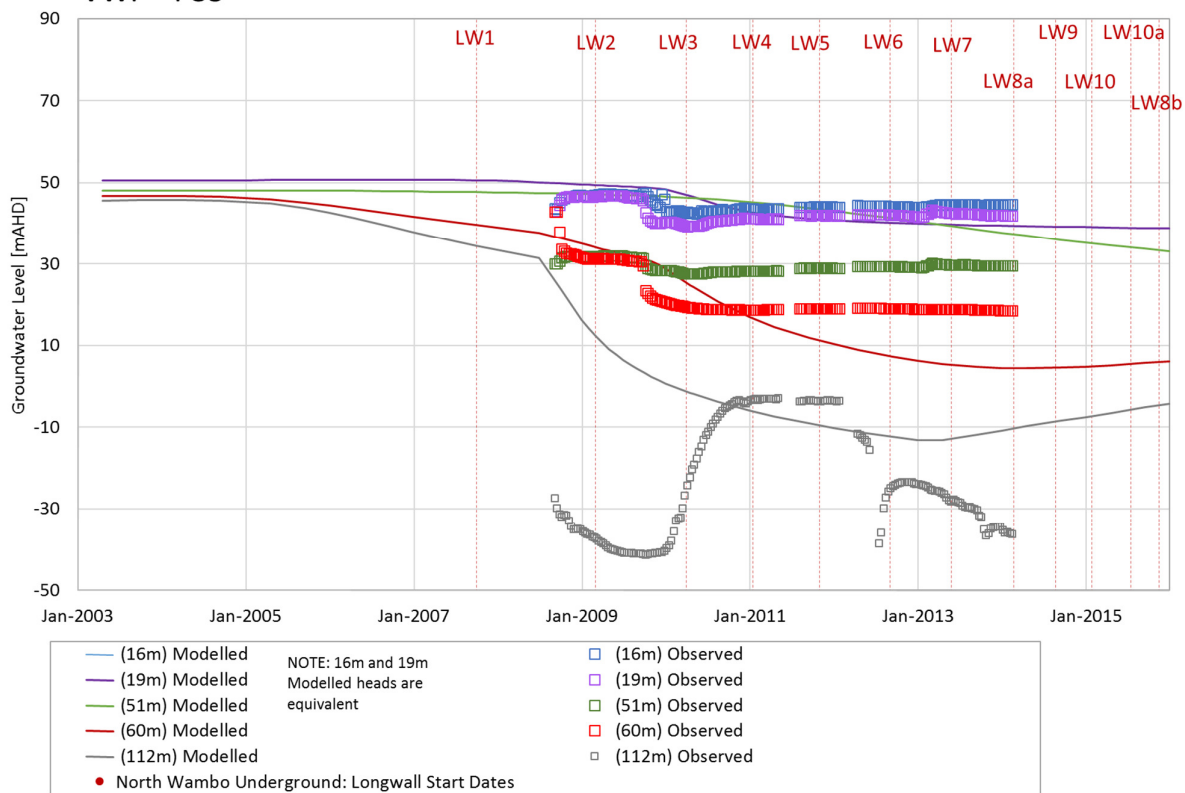


Figure G - 7 P35 Hydrographs

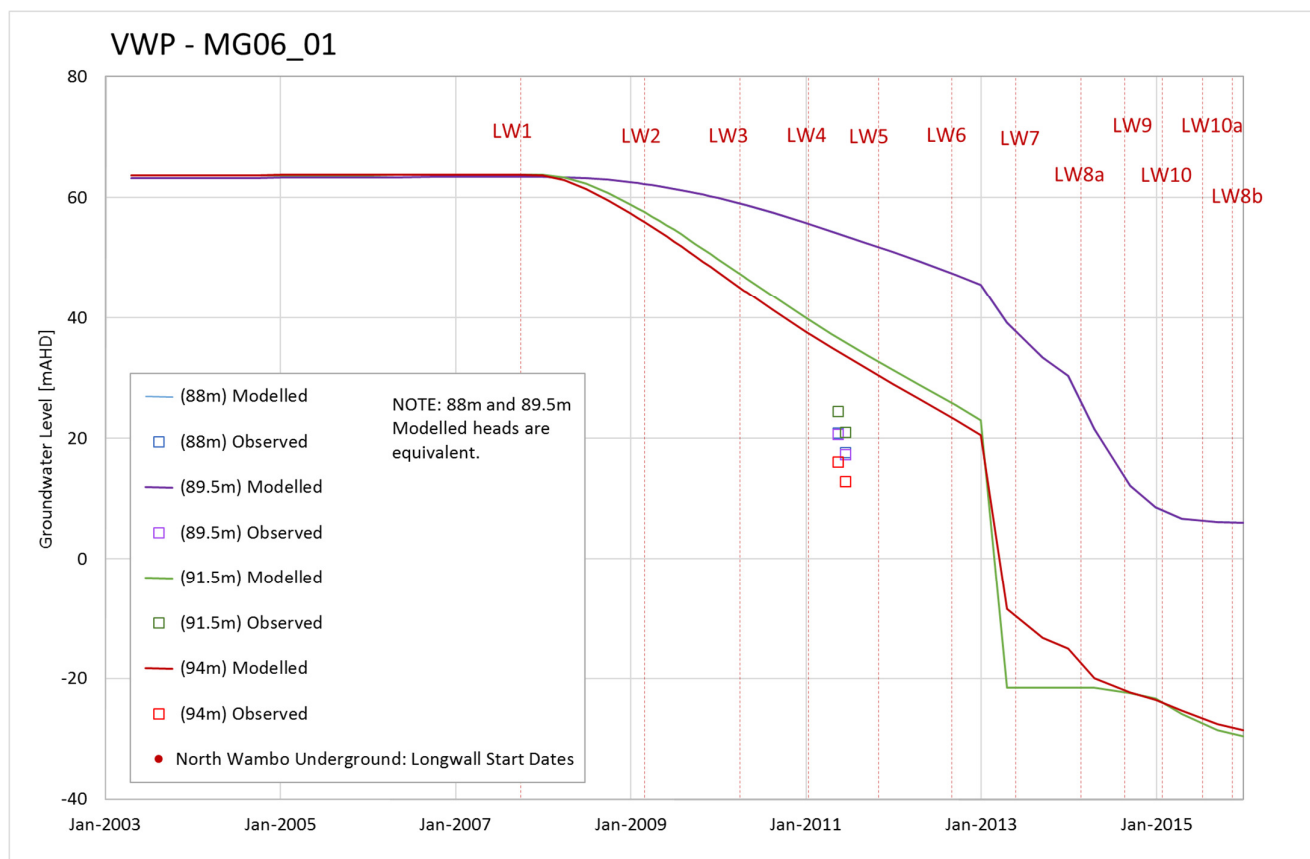


Figure G - 8 MG06_01 Hydrographs

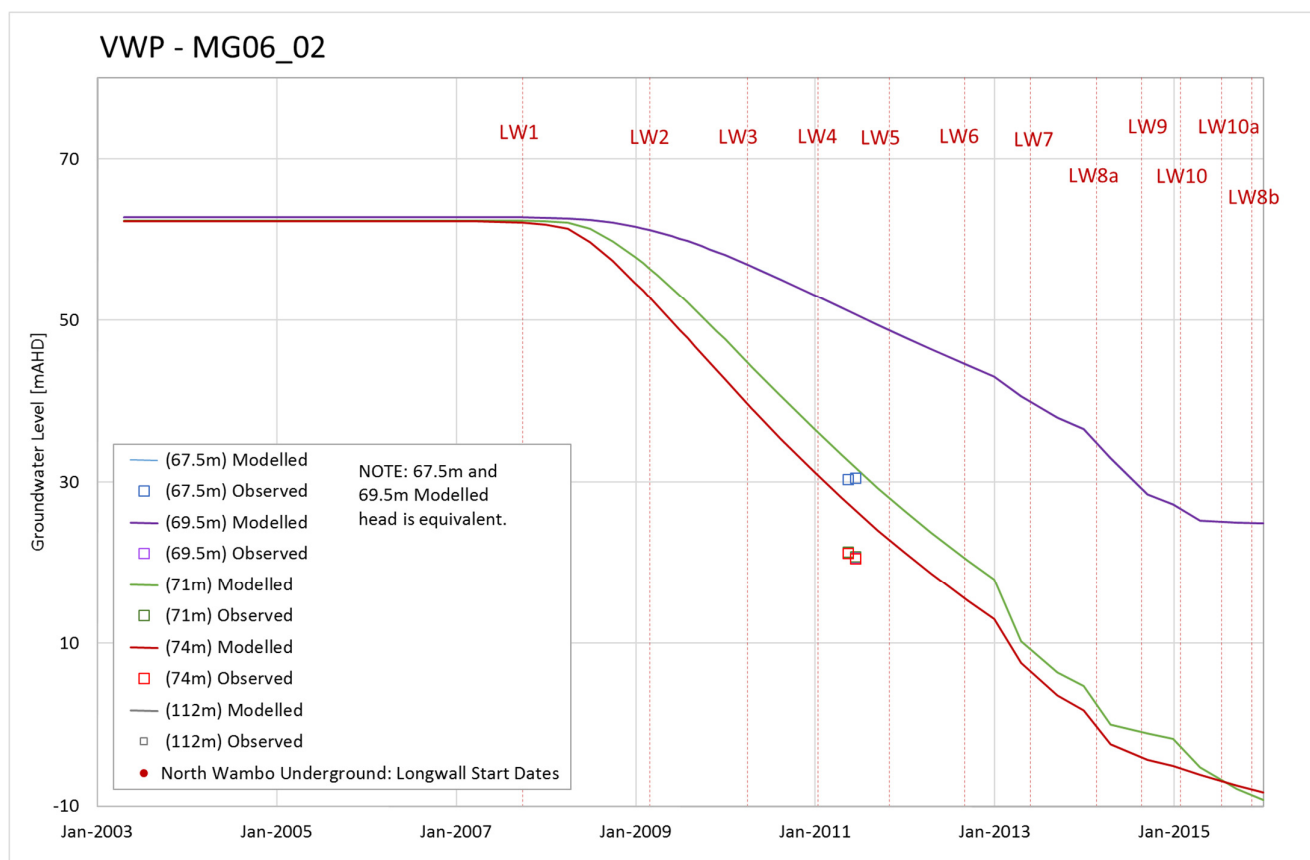


Figure G - 9 MG06_02 Hydrographs

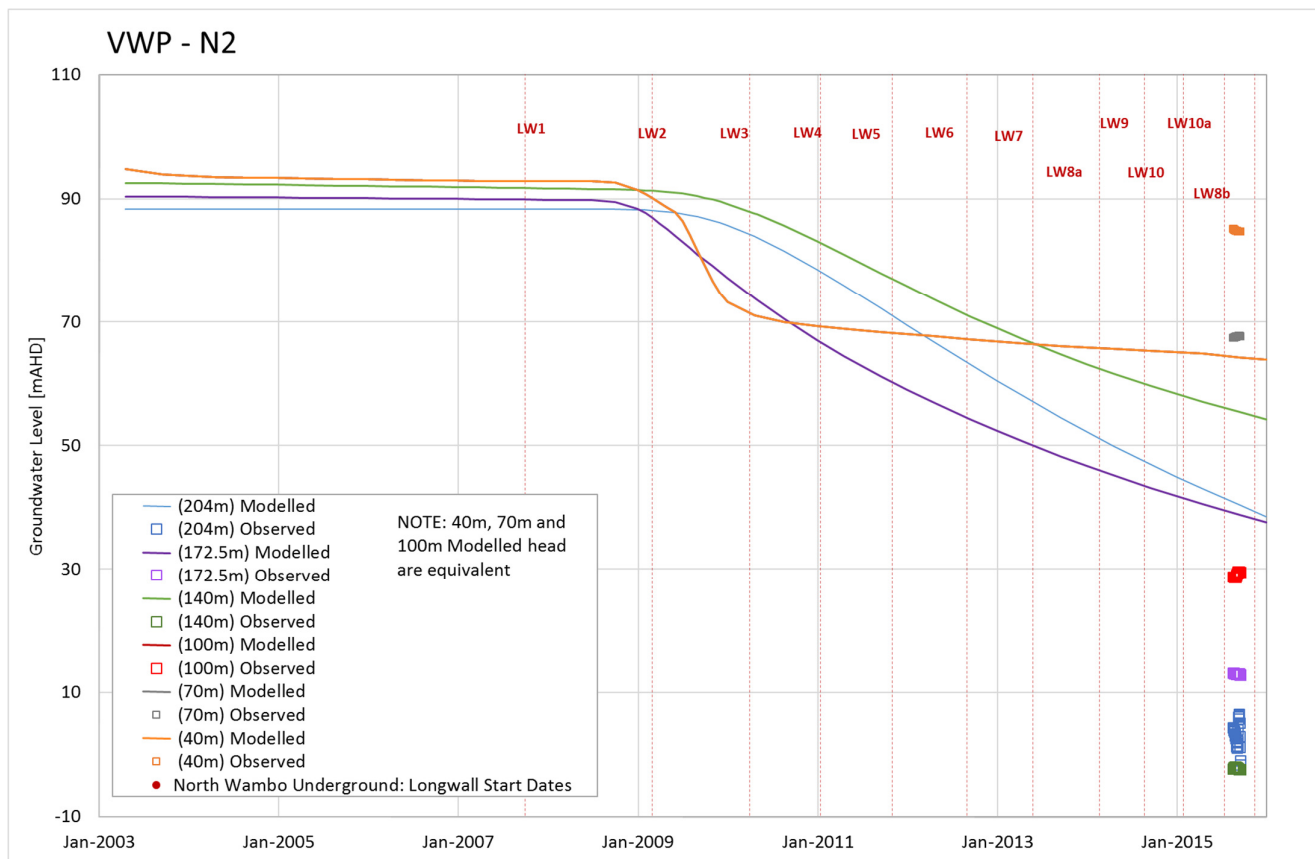


Figure G - 10 N2 Hydrographs

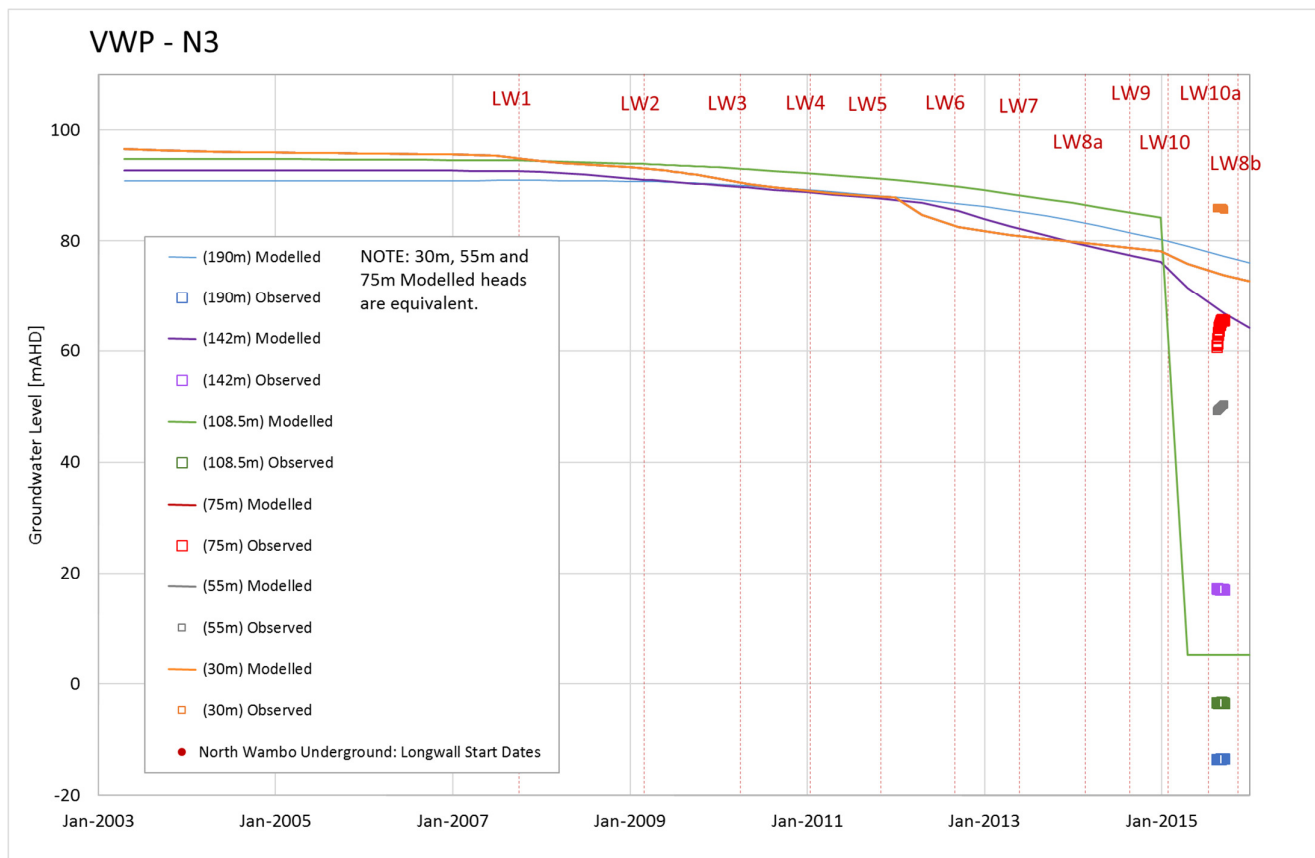


Figure G - 11 N3 Hydrographs

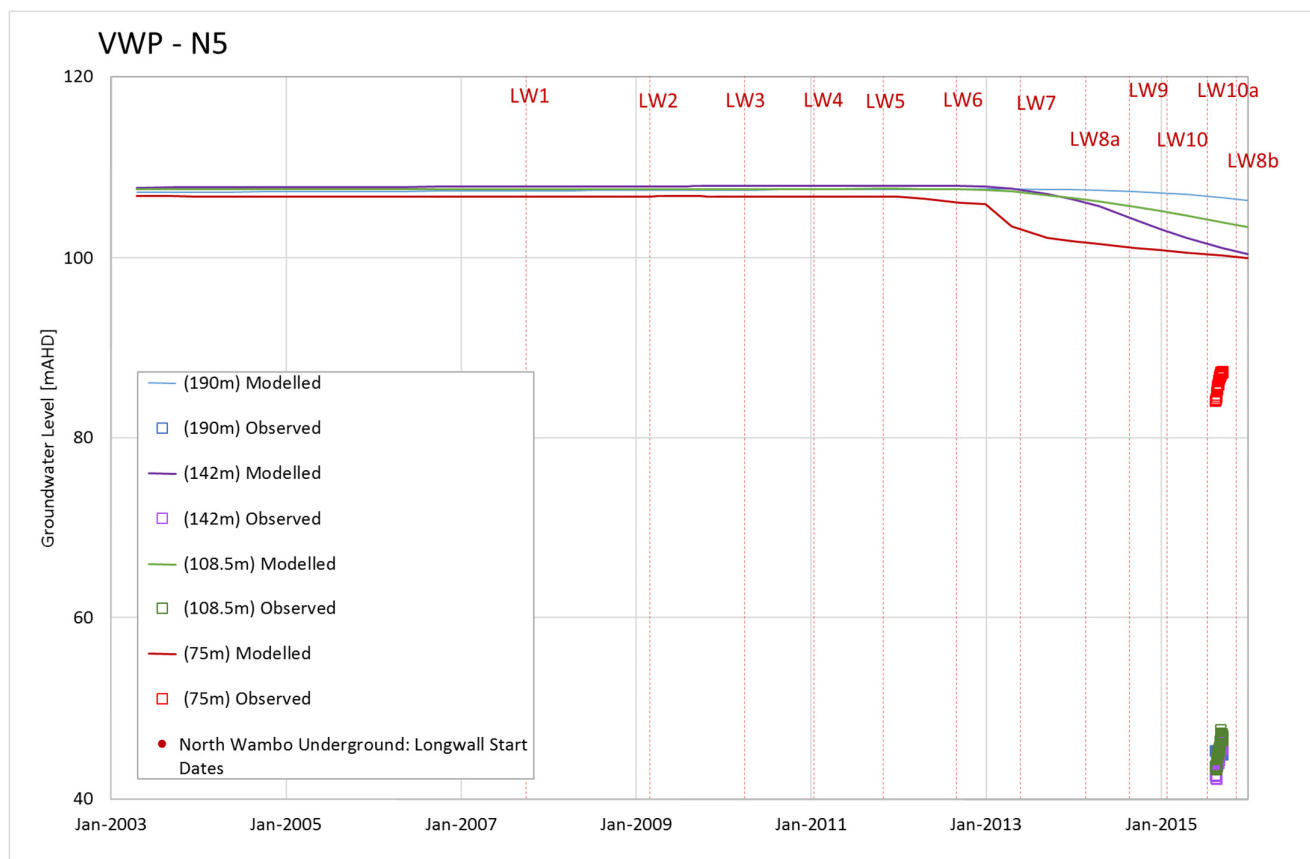


Figure G - 12 N5 Hydrographs

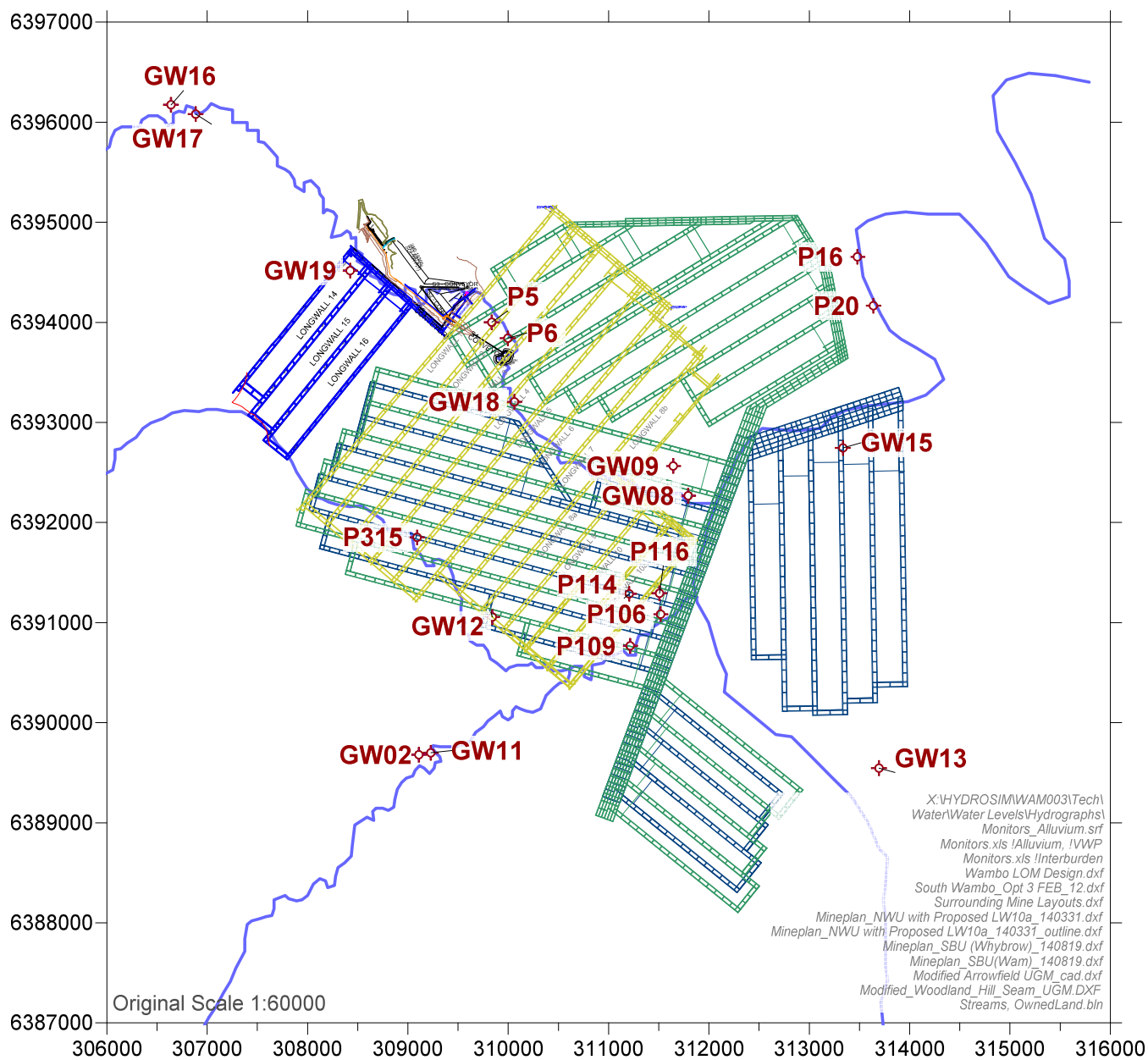


Figure H - 1 Alluvial Groundwater Monitoring Network.

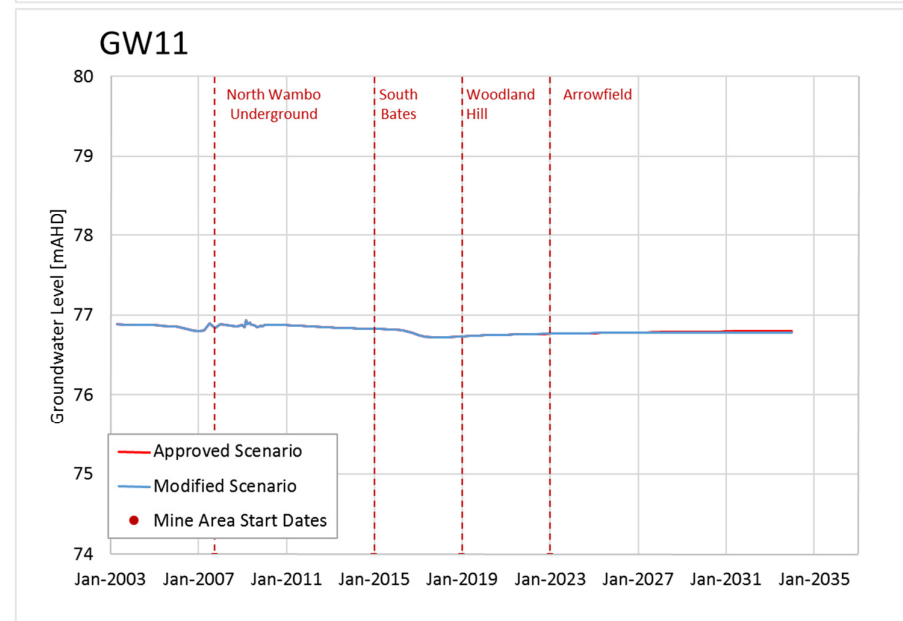
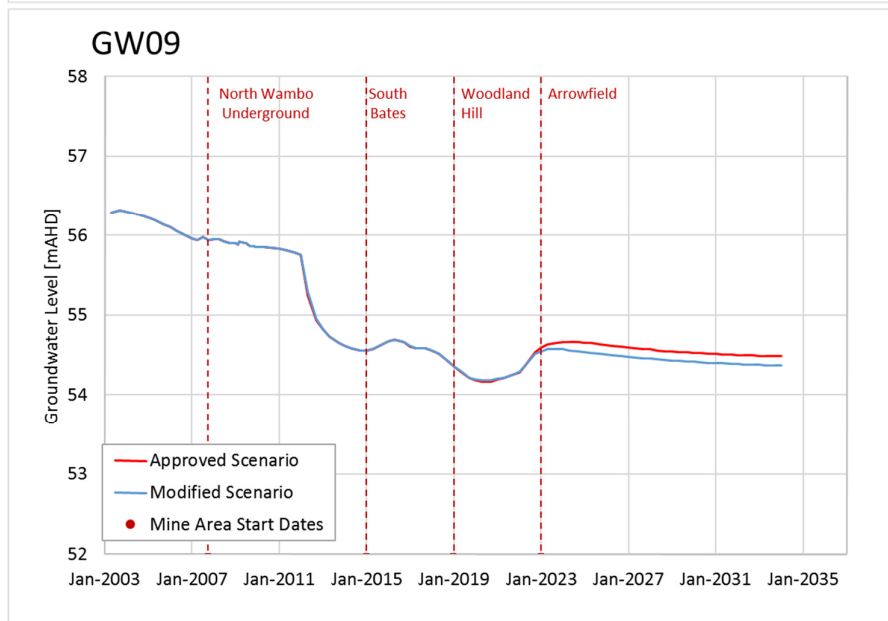
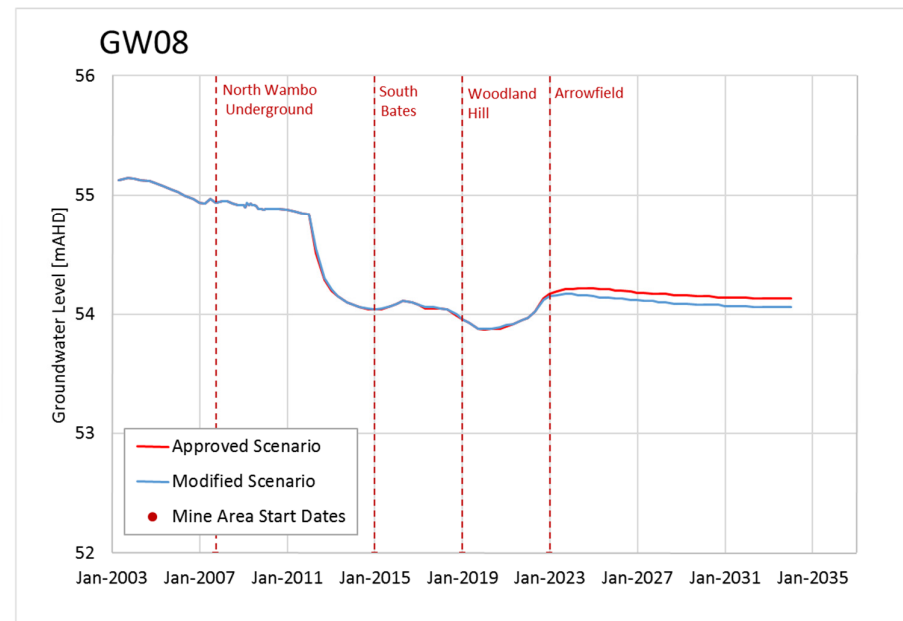
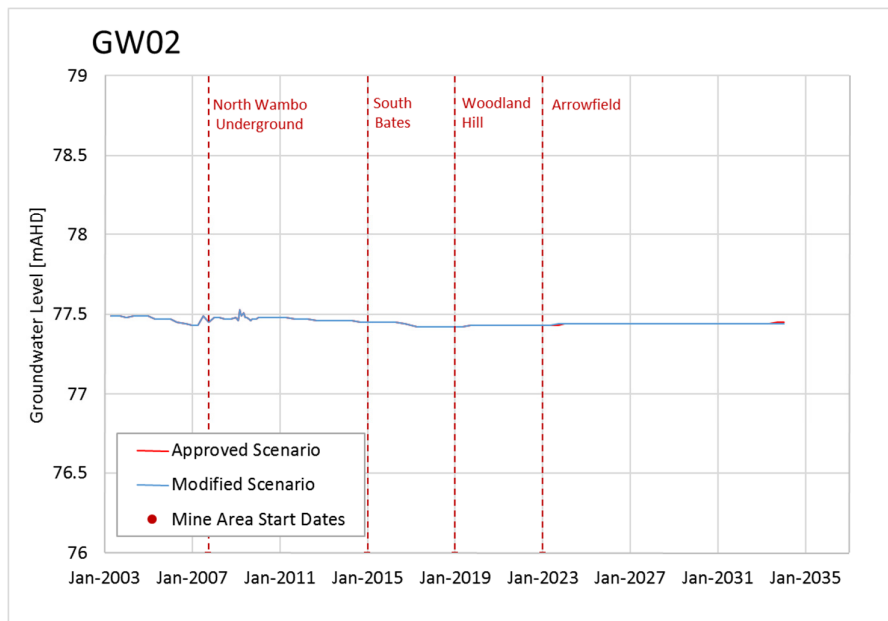


Figure H - 2 GW02, GW08, GW09, GW11 Predictive Hydrographs

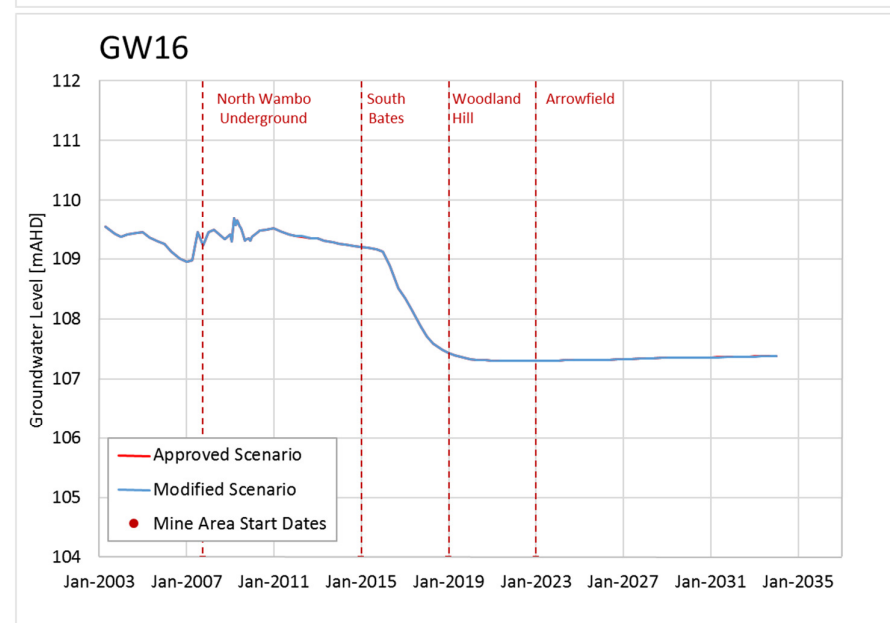
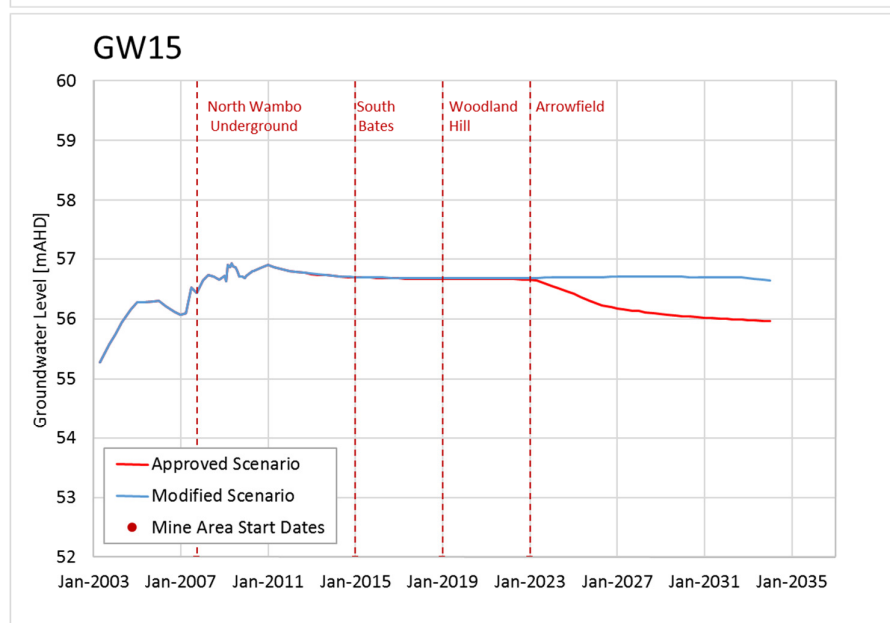
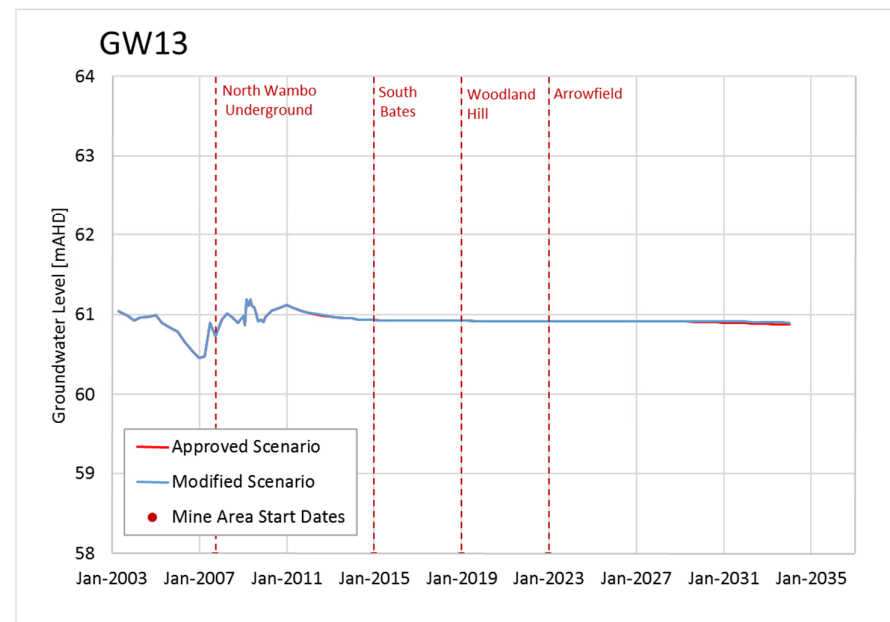
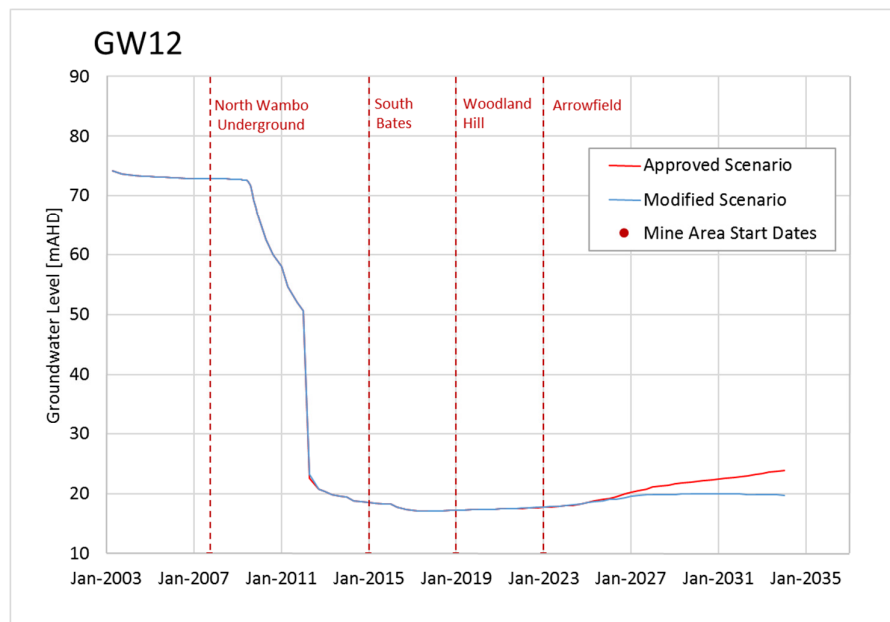


Figure H - 3 GW12, GW13, GW15, GW16 Predictive Hydrographs

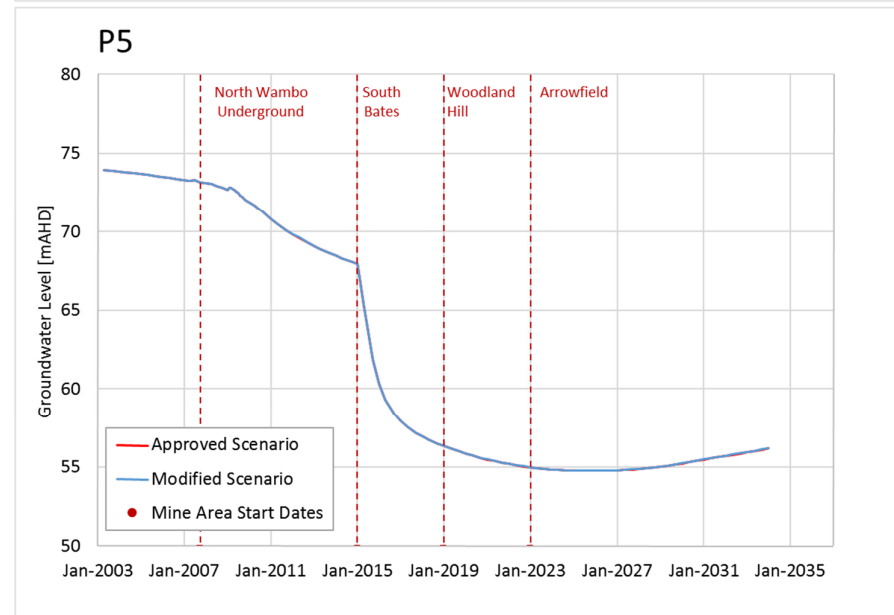
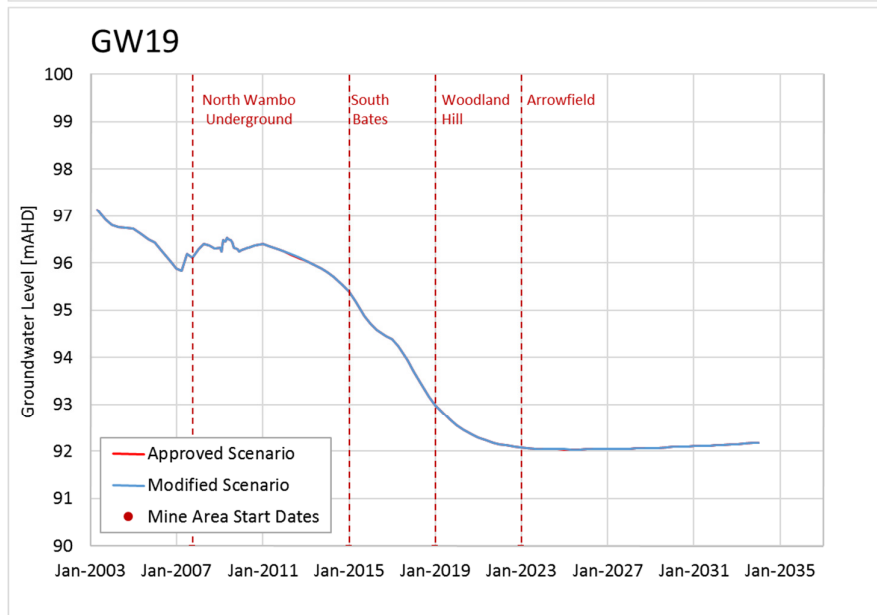
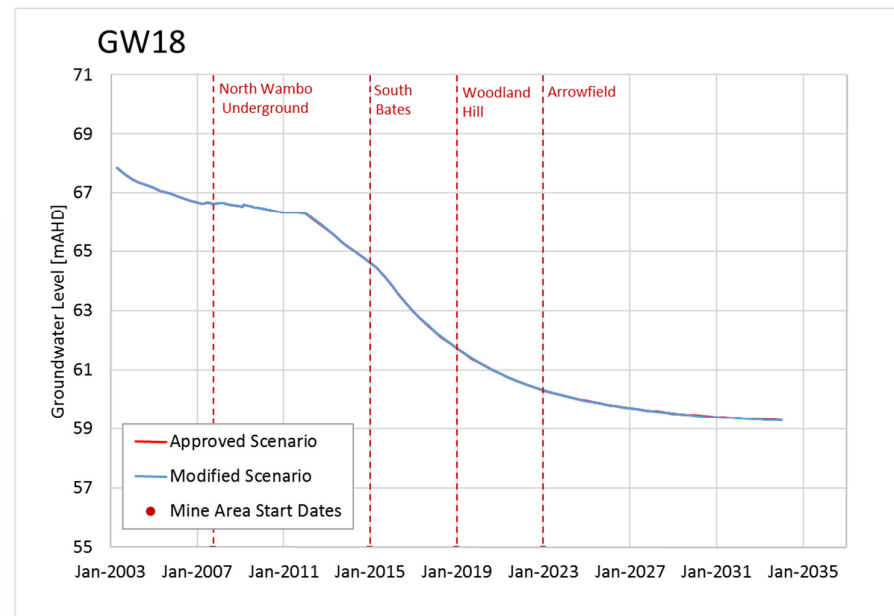
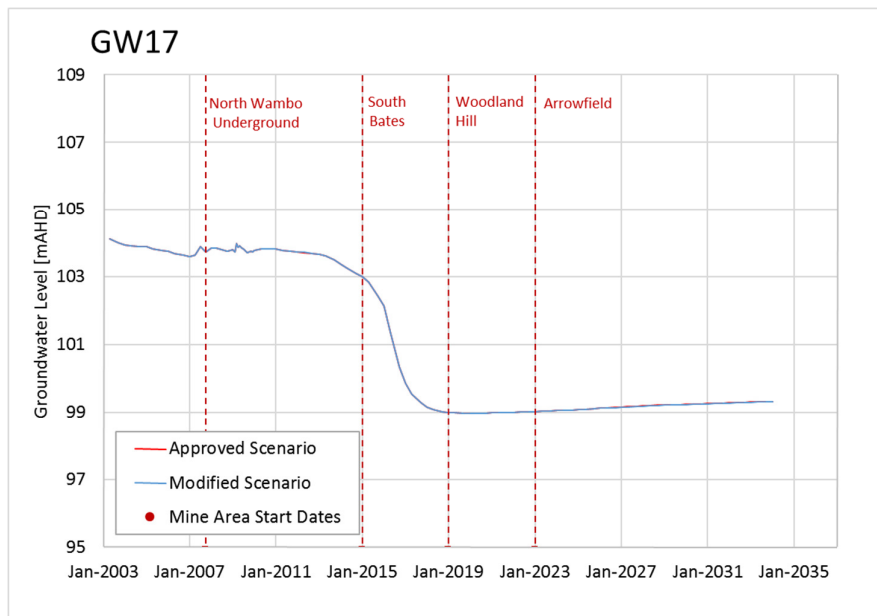


Figure H - 4 GW17, GW18, GW19, P5 Predictive Hydrographs

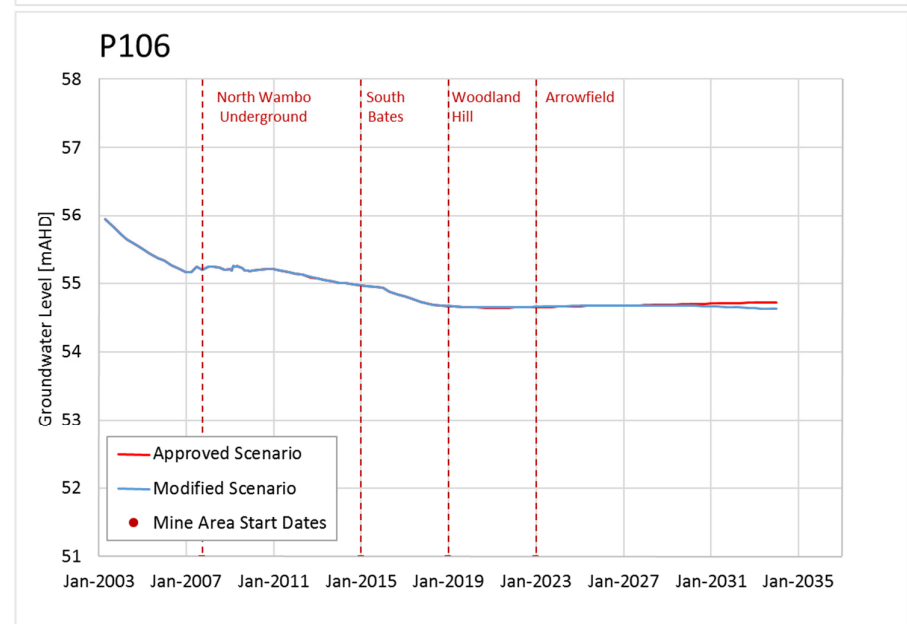
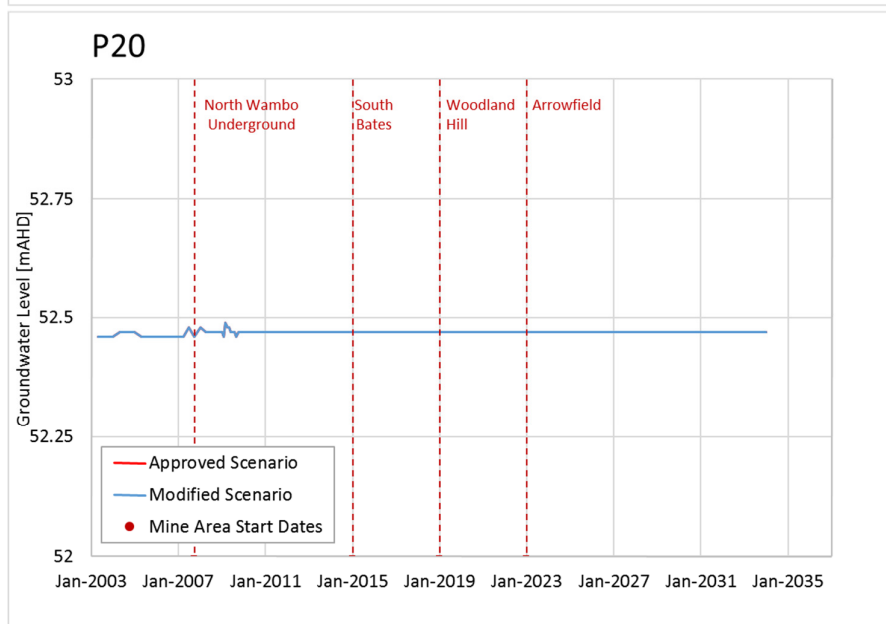
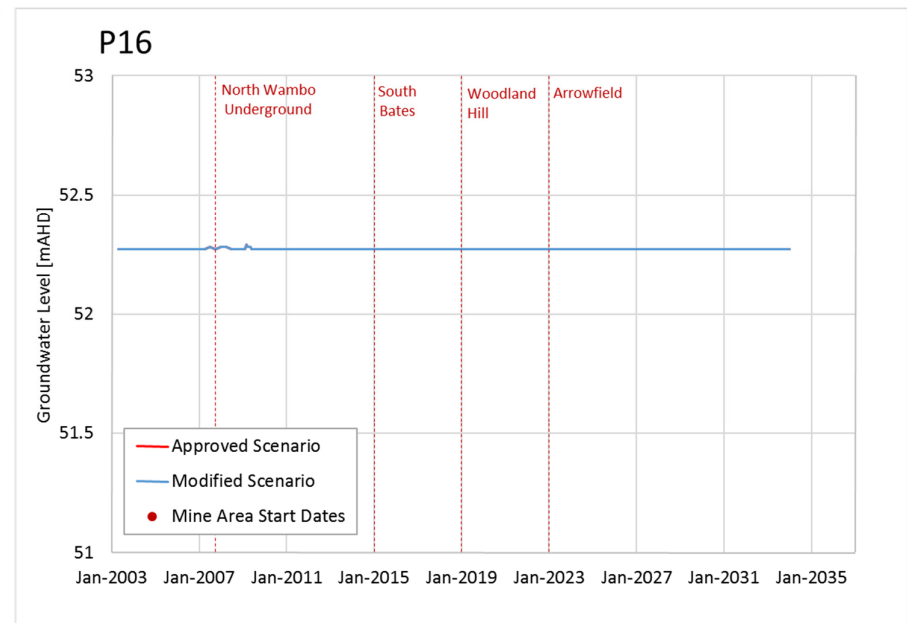
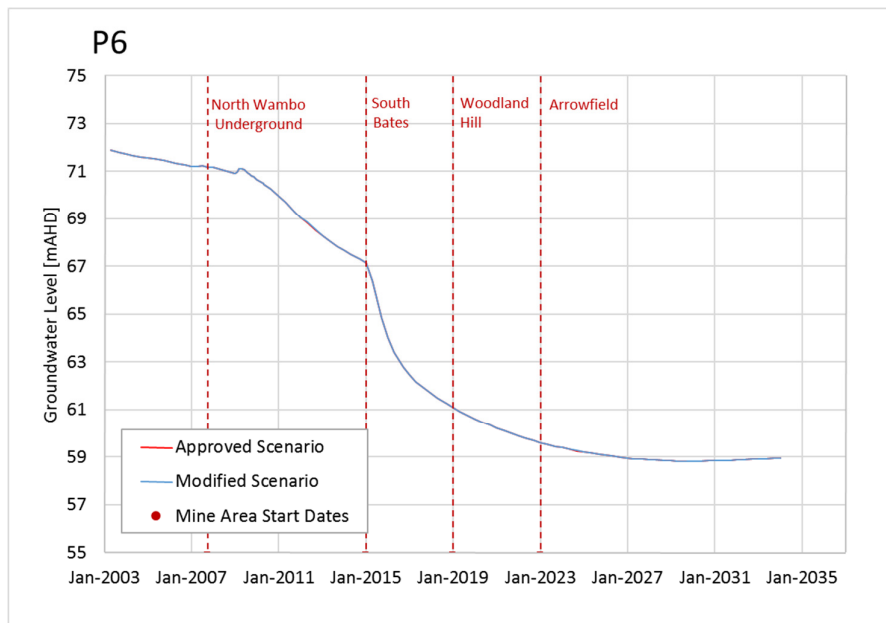


Figure H - 5 P6, P16, P20, P106 Predictive Hydrographs

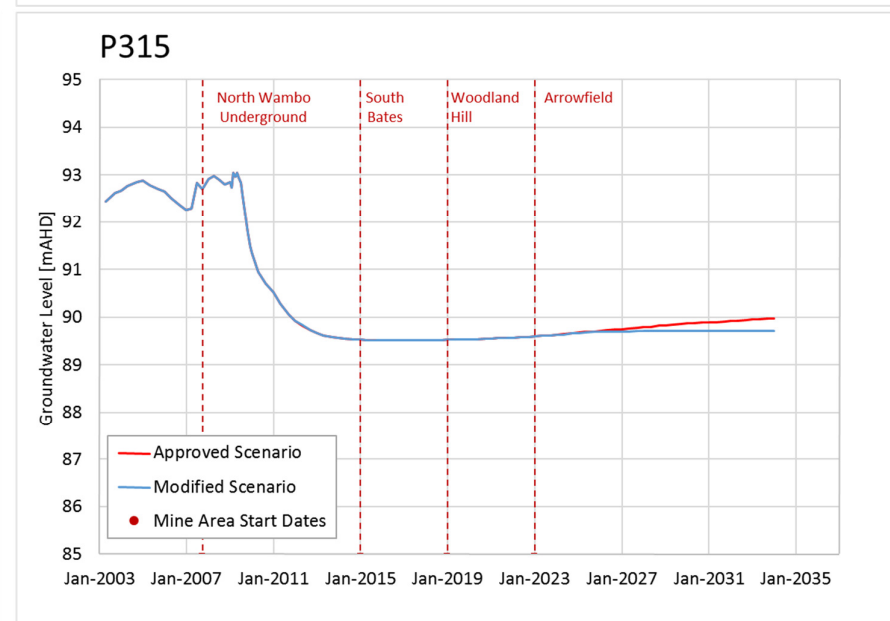
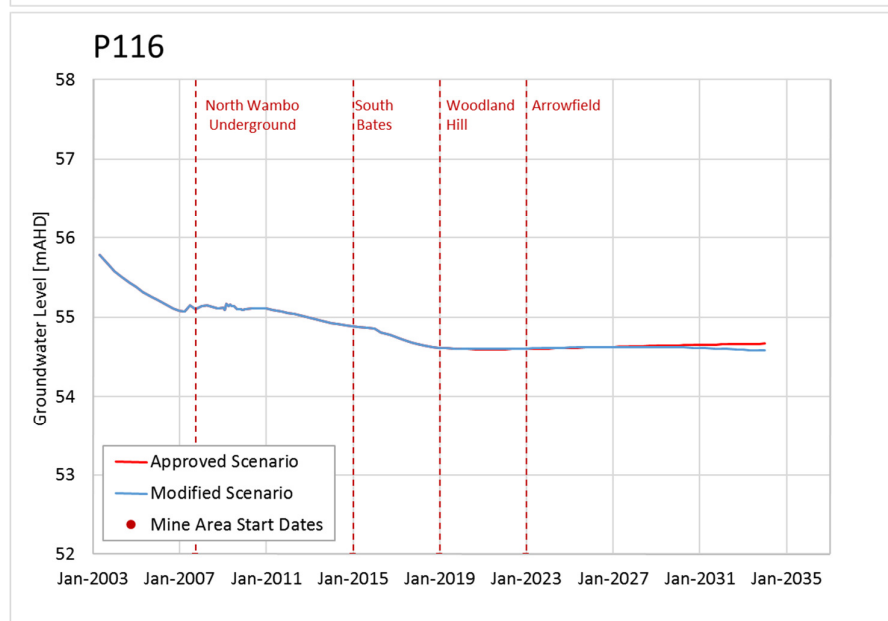
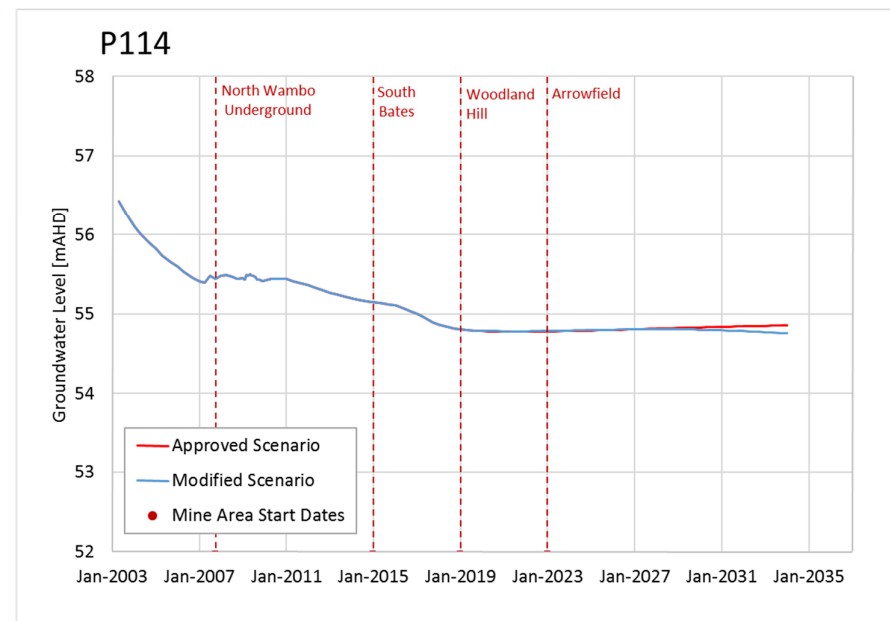
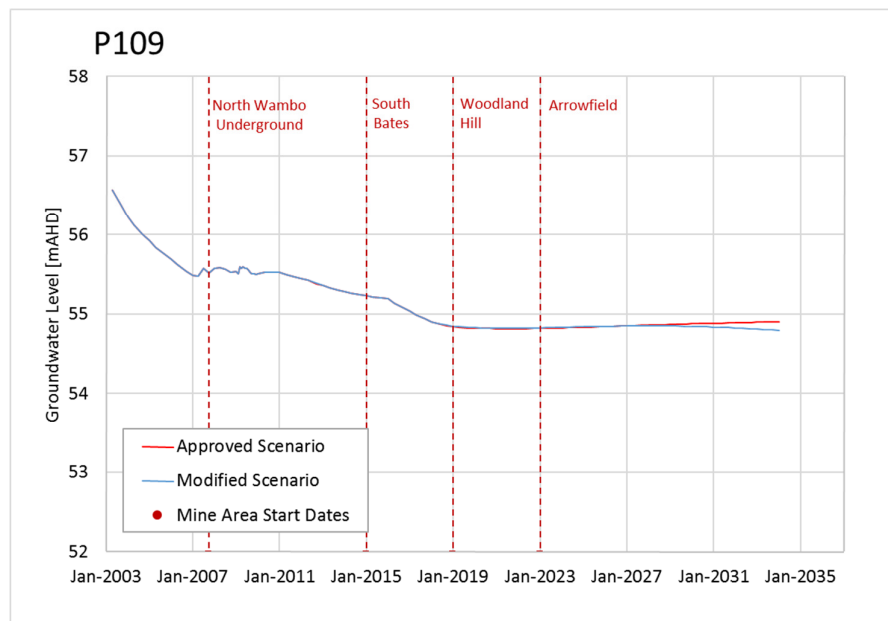


Figure H - 6 P109, P114, P116, P315 Predictive Hydrographs

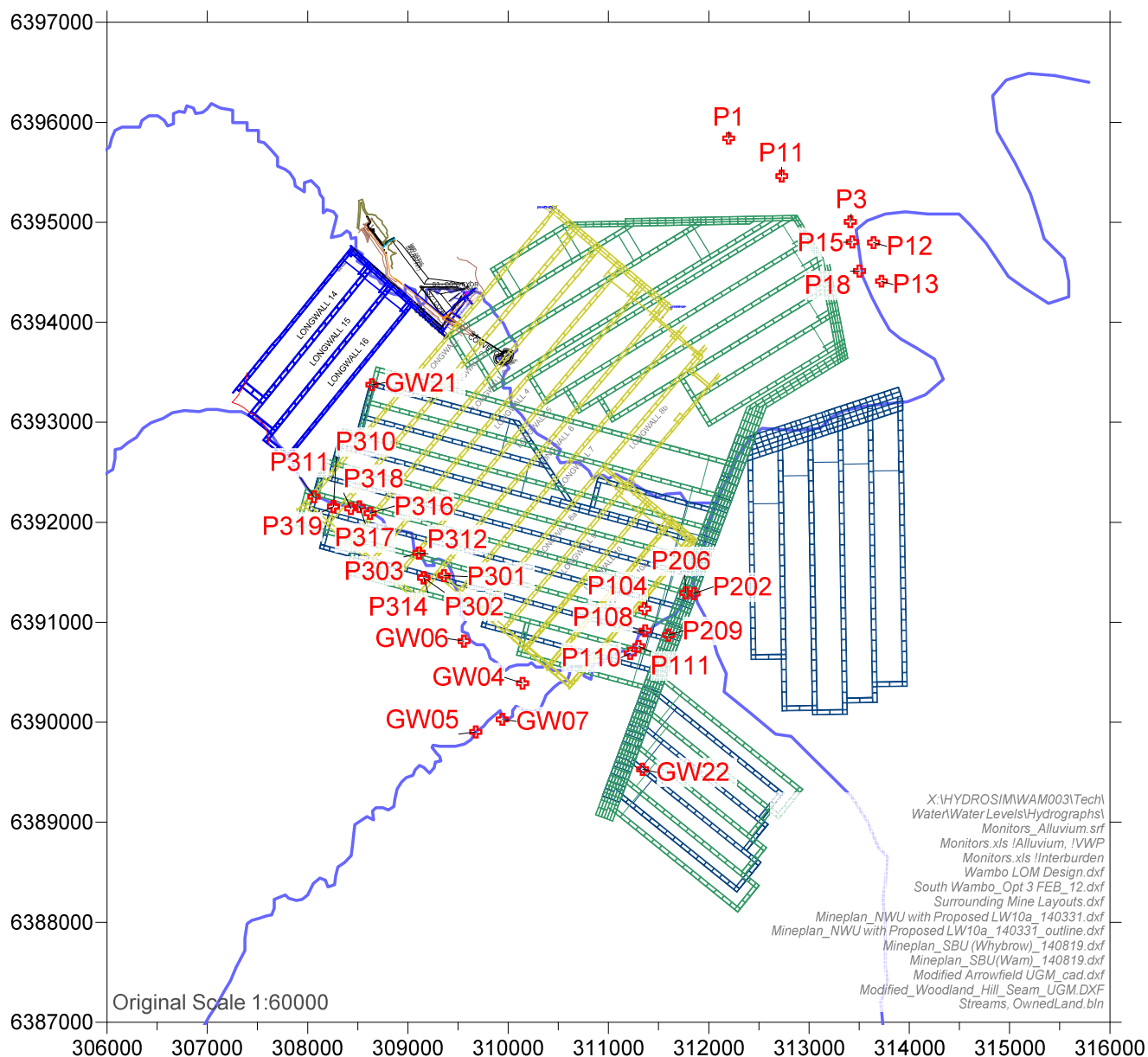


Figure I - 1 Interburden Groundwater Monitoring Network

Bore ID	Simulated Layer	Layer Litholgy
GW04	2	Overburden and coal seams above the Whybrow Seam.
GW05	2	Overburden and coal seams above the Whybrow Seam.
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GW21	2	Overburden and coal seams above the Whybrow Seam.
GW22	2	Overburden and coal seams above the Whybrow Seam.
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GW030733	16	Basal units.
GW030740	16	Basal units.
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GW080963	16	Basal units.
P1	2	Overburden and coal seams above the Whybrow Seam.
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P202	2	Overburden and coal seams above the Whybrow Seam.
P206	2	Overburden and coal seams above the Whybrow Seam.
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P316	2	Overburden and coal seams above the Whybrow Seam.
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P319	2	Overburden and coal seams above the Whybrow Seam.

Table I - 1 Interburden bore lithology and model layer.

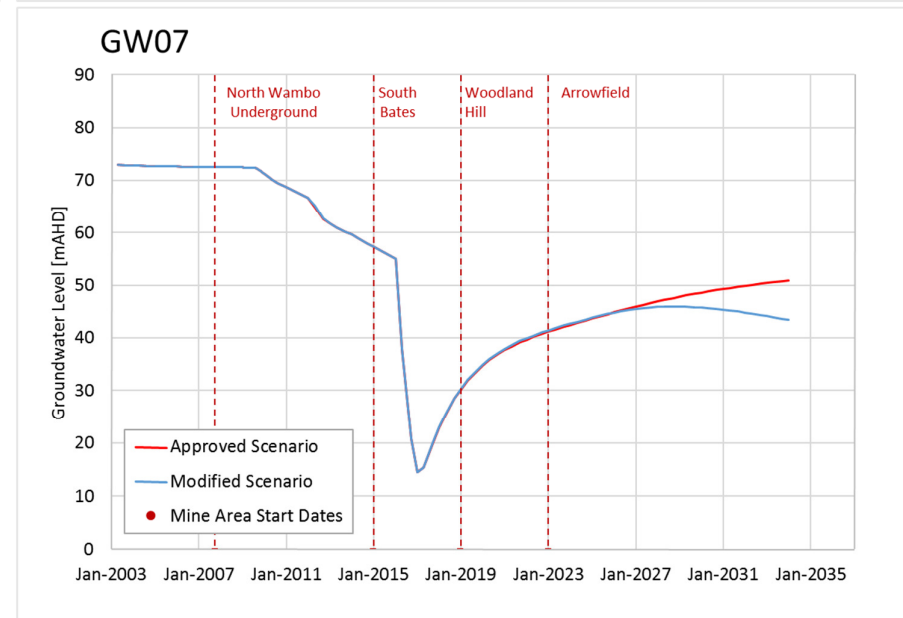
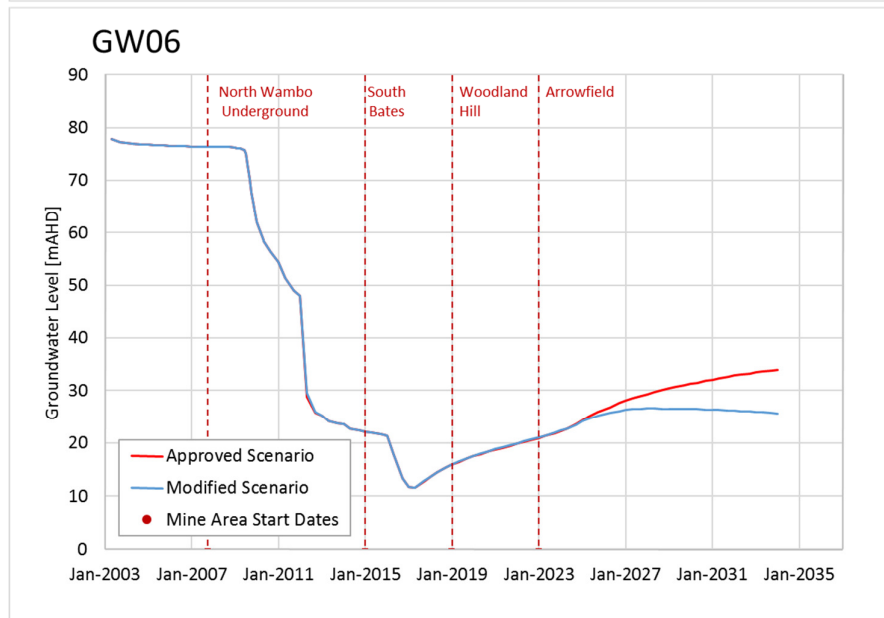
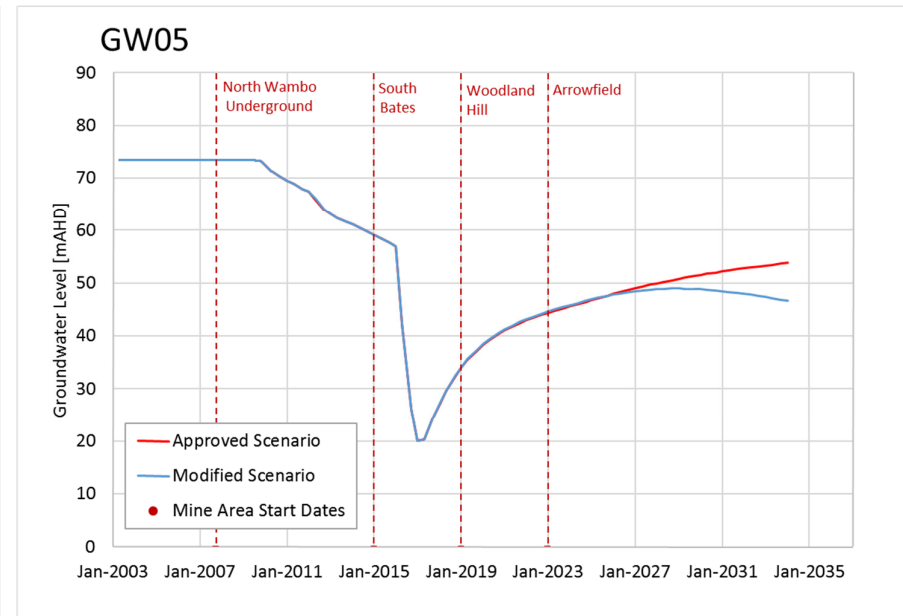
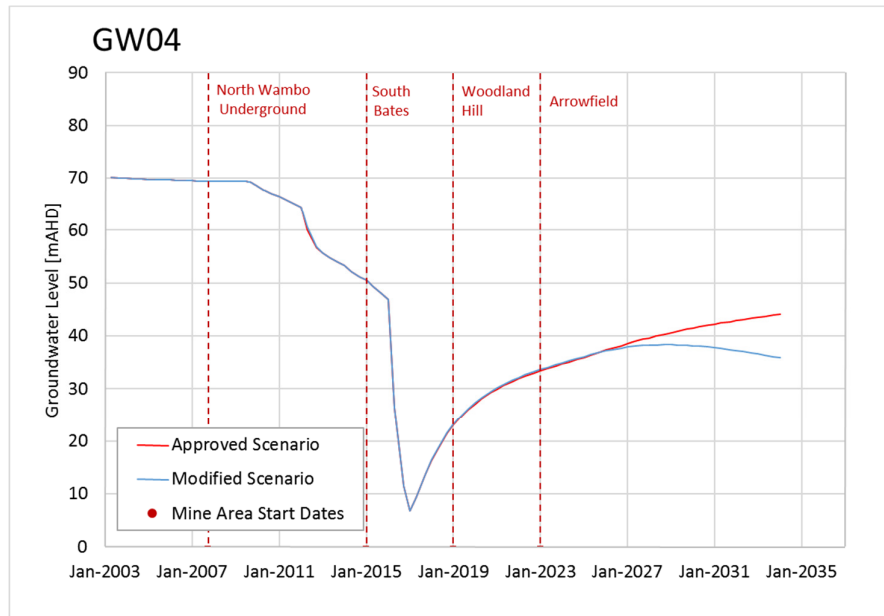


Figure I - 2 GW04, GW05, GW06, GW07 Predictive Hydrographs

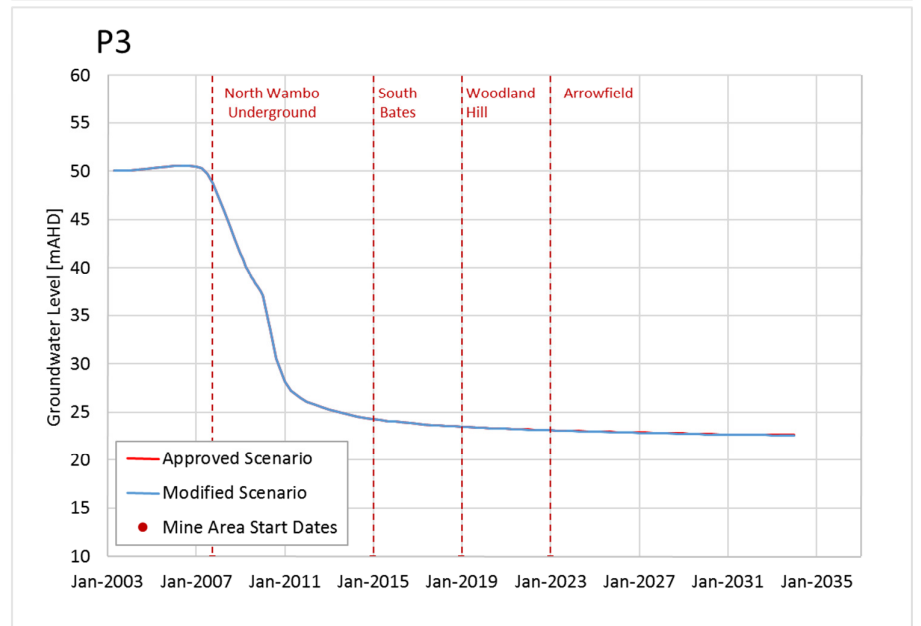
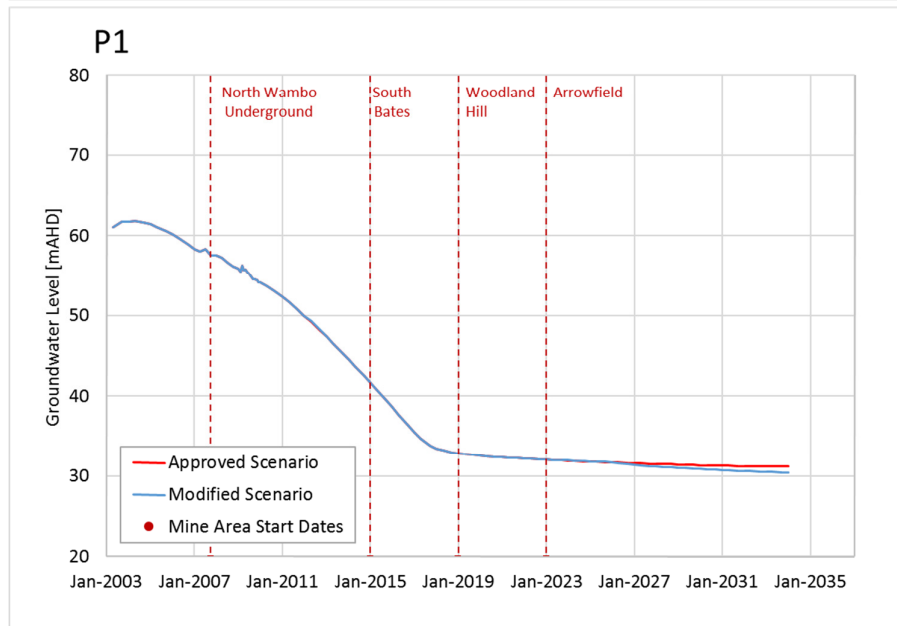
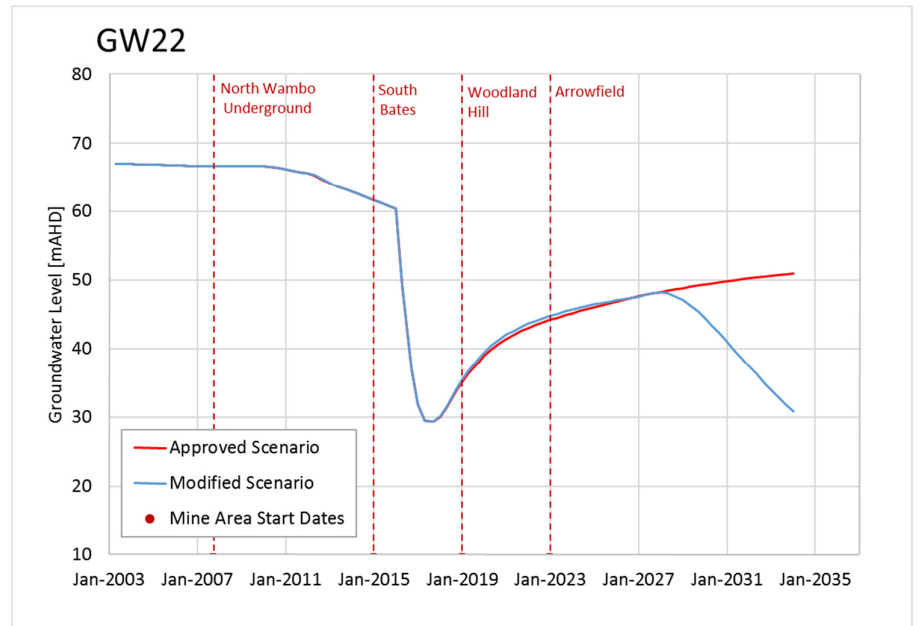
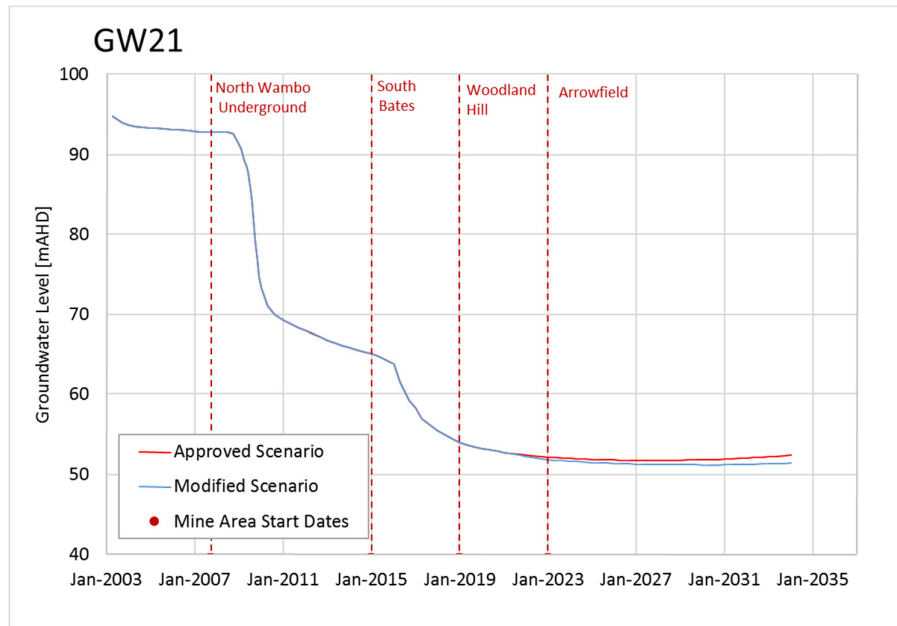


Figure I - 3 GW21, GW22, P1, P3 Predictive Hydrographs

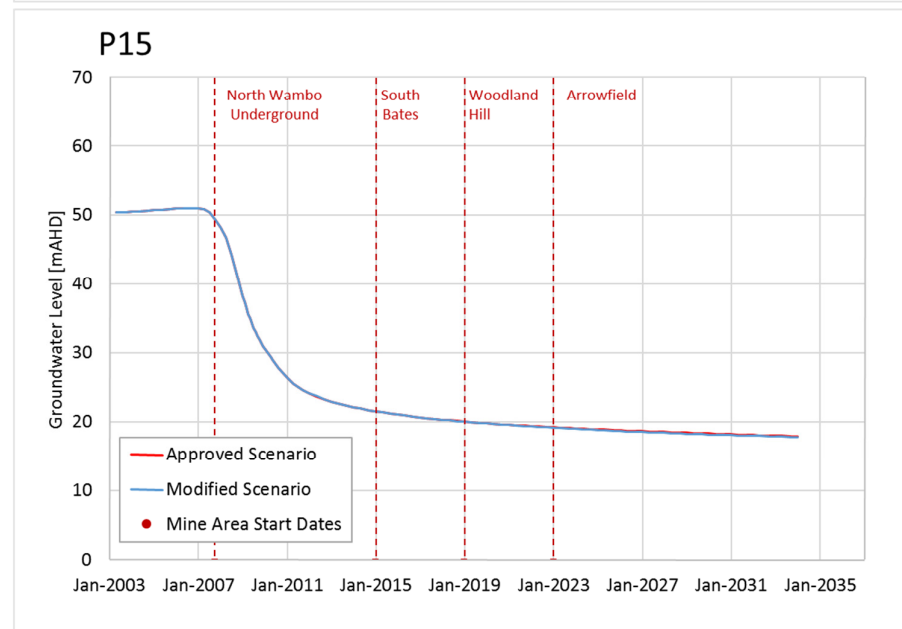
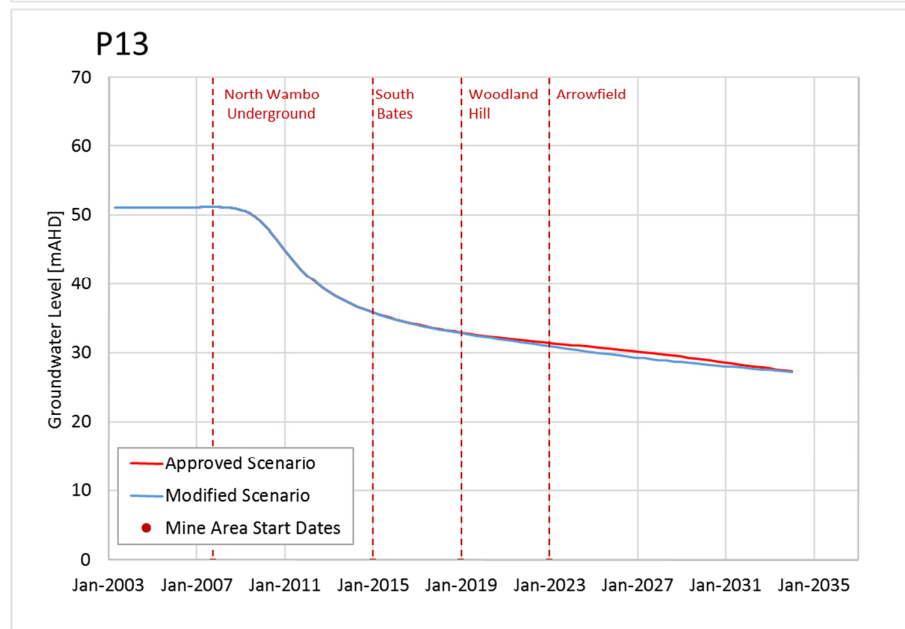
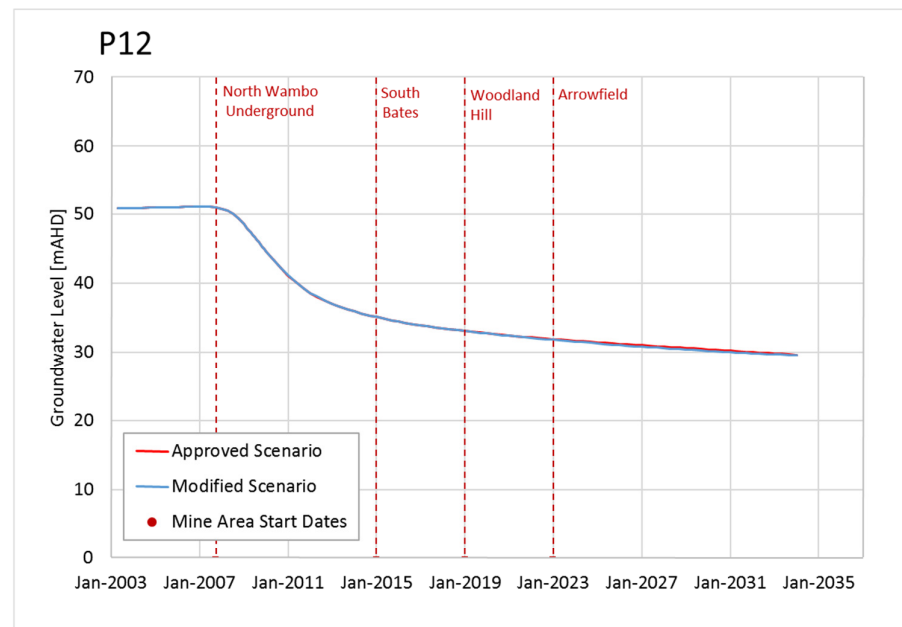
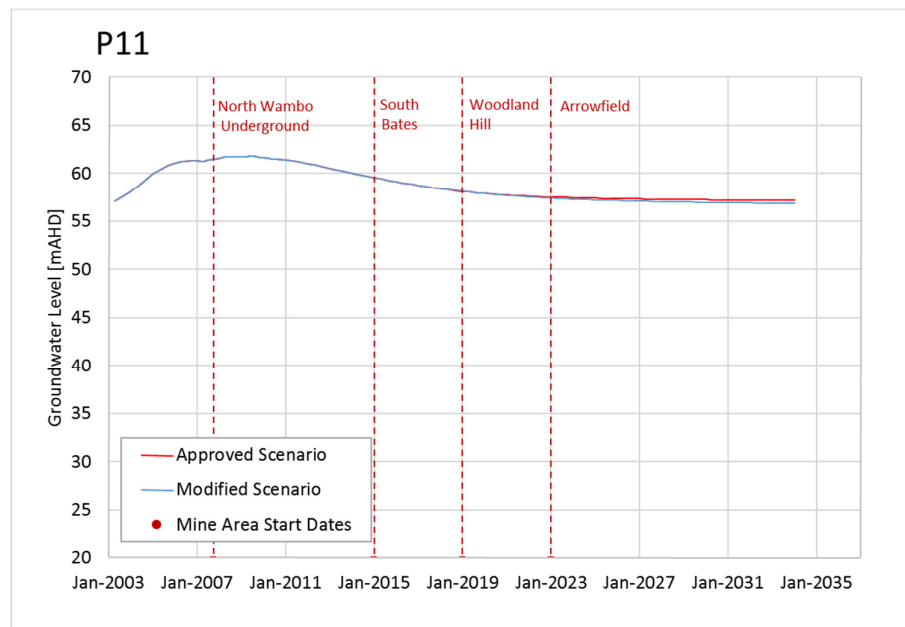


Figure I - 4 P11, P12, P13, P15 Predictive Hydrographs

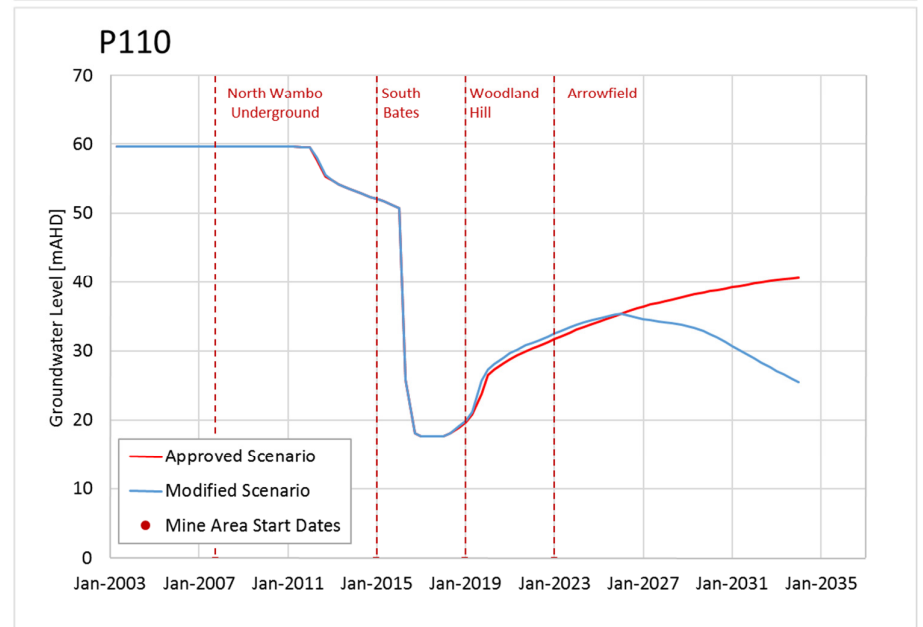
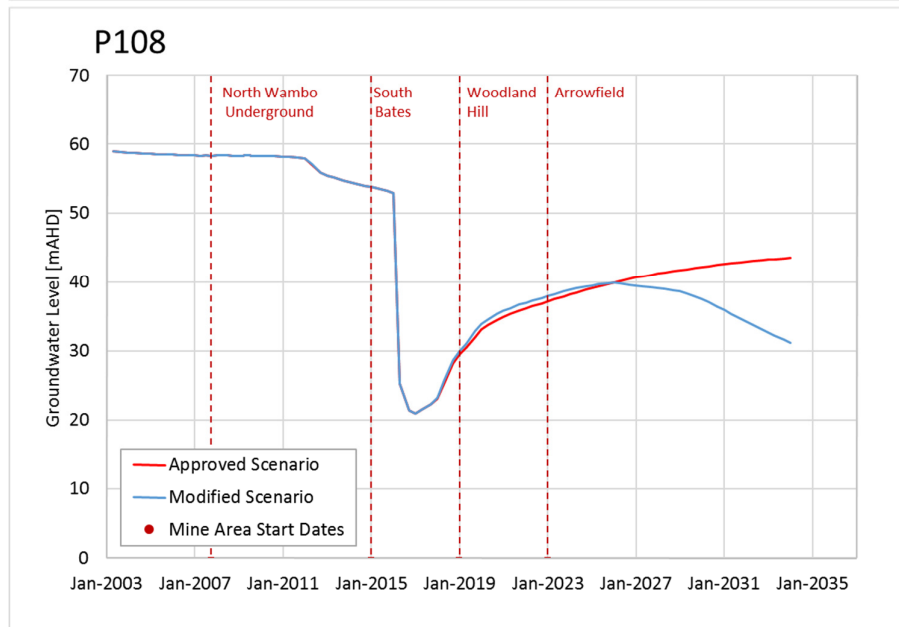
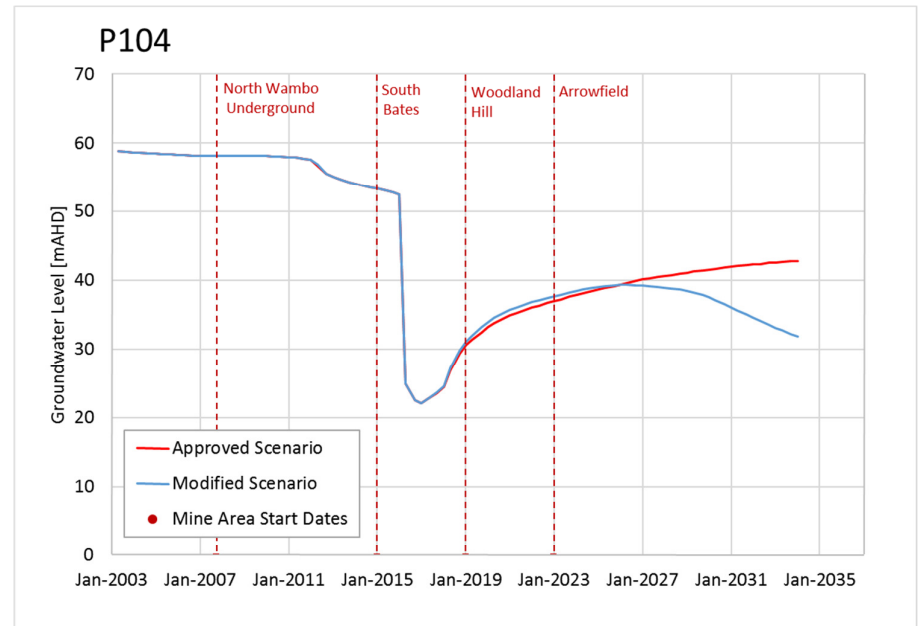
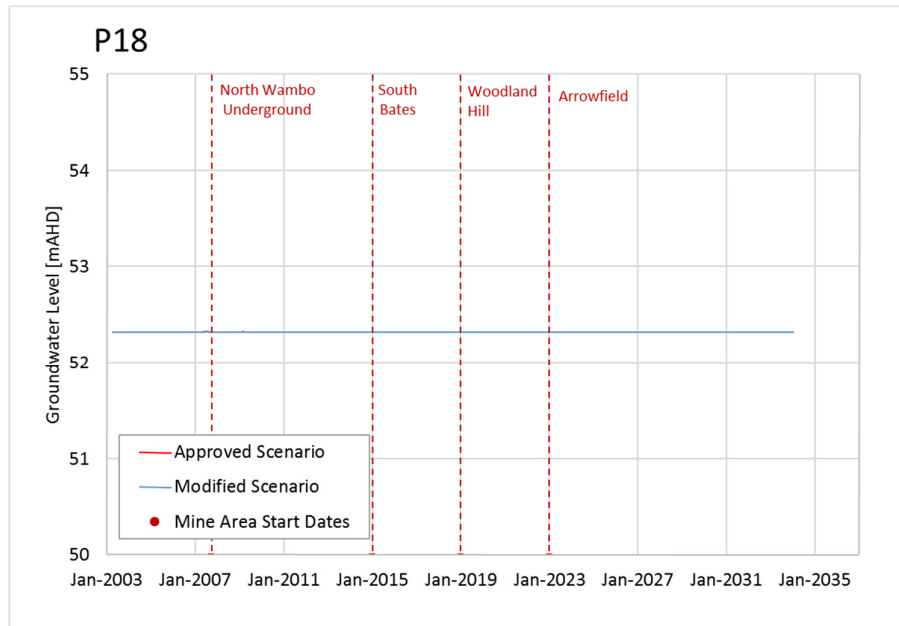


Figure I - 5 P18, P104, P108, P110 Predictive Hydrographs

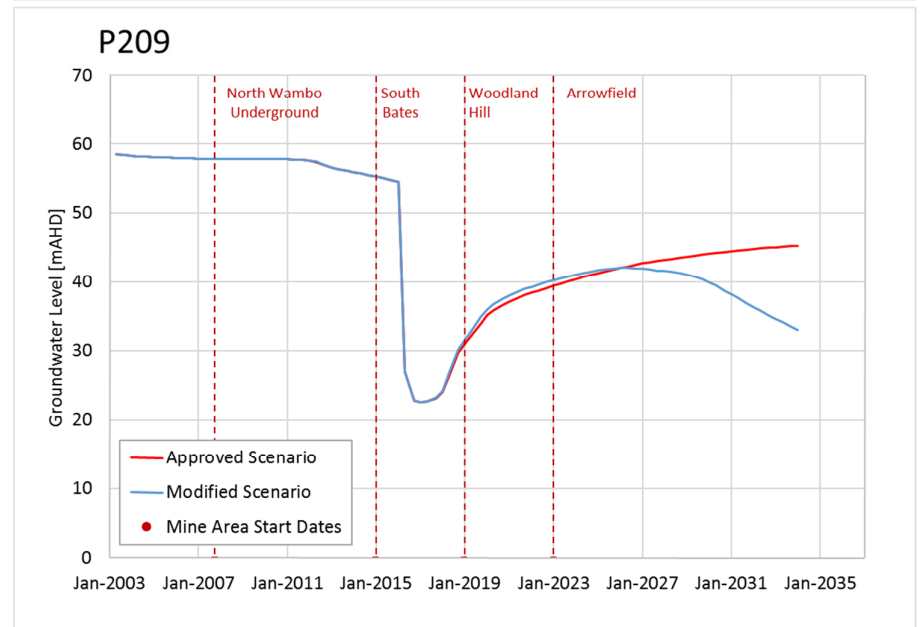
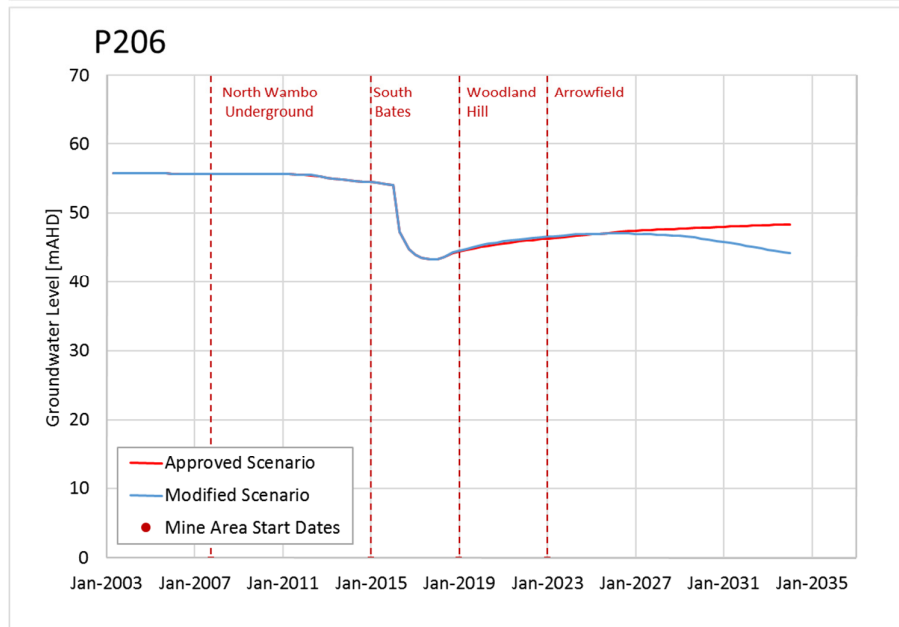
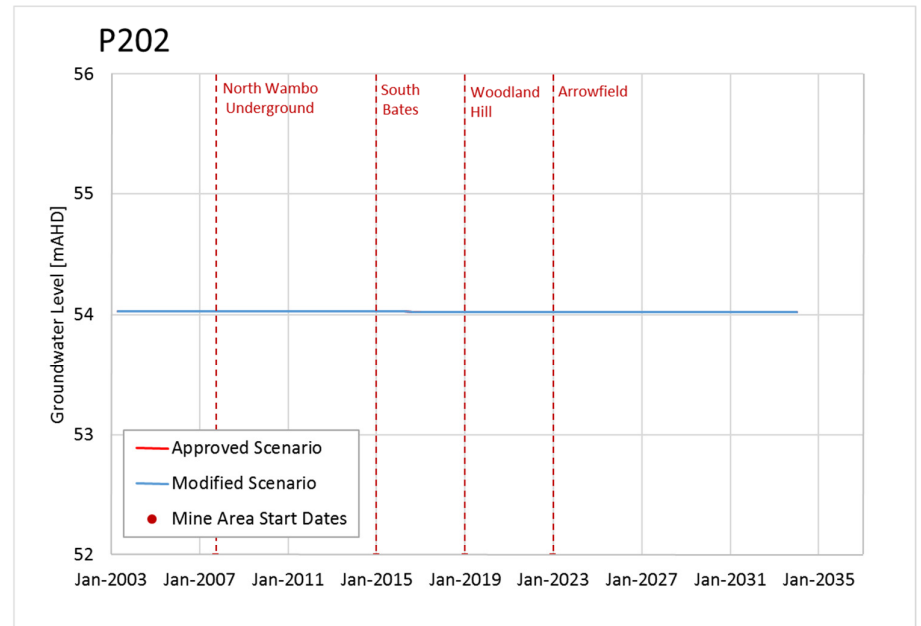
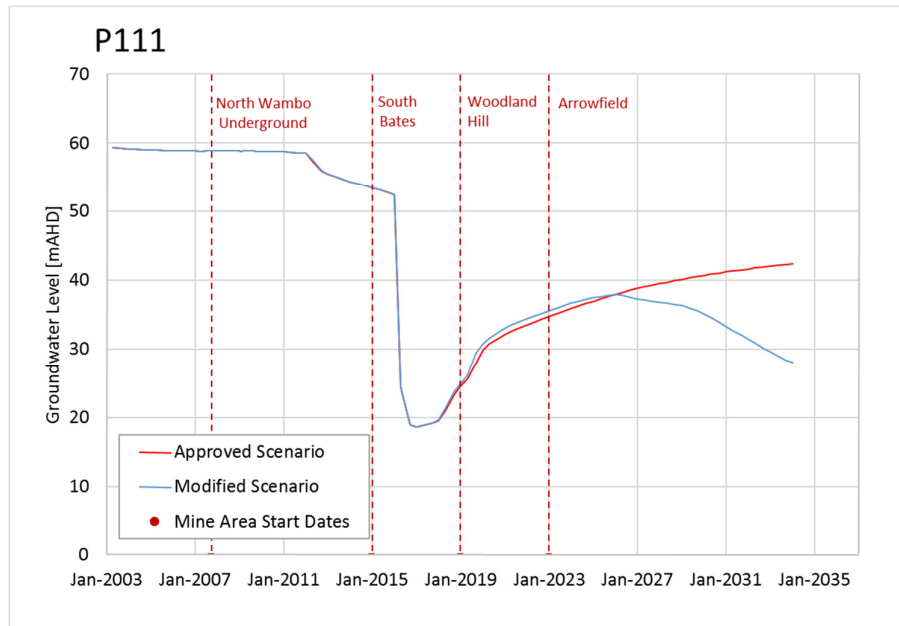


Figure I - 6 P111, P202, P206, P209 Predictive Hydrographs

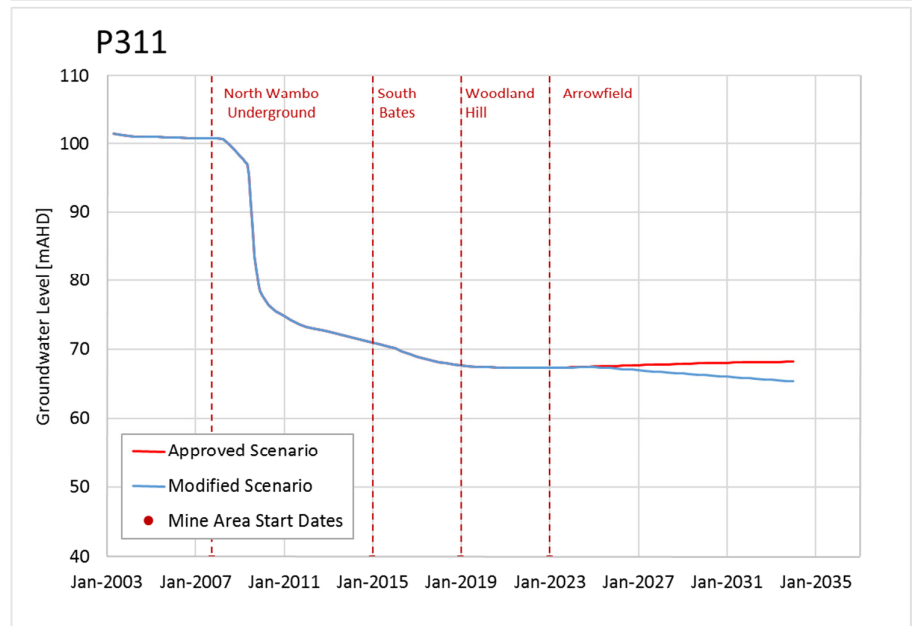
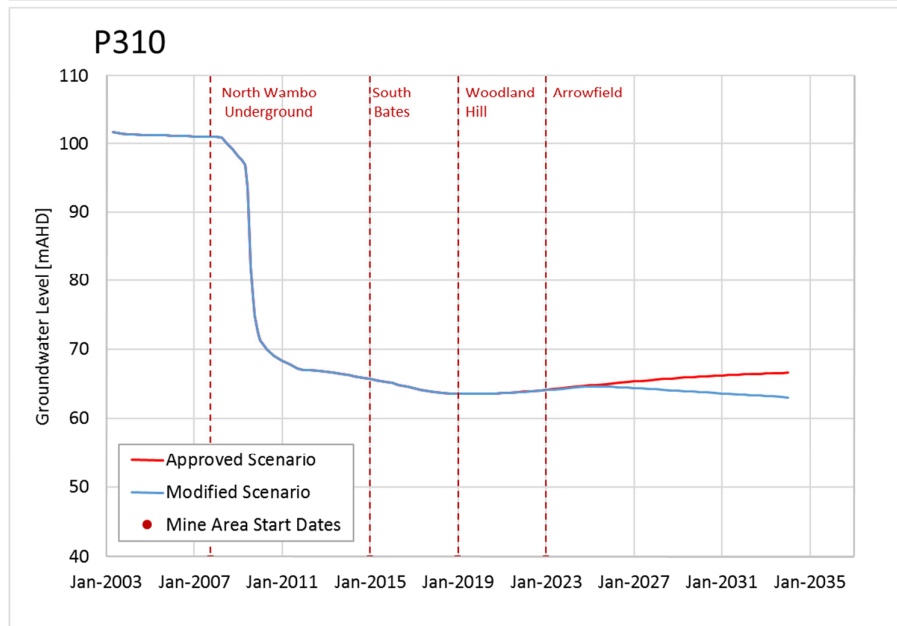
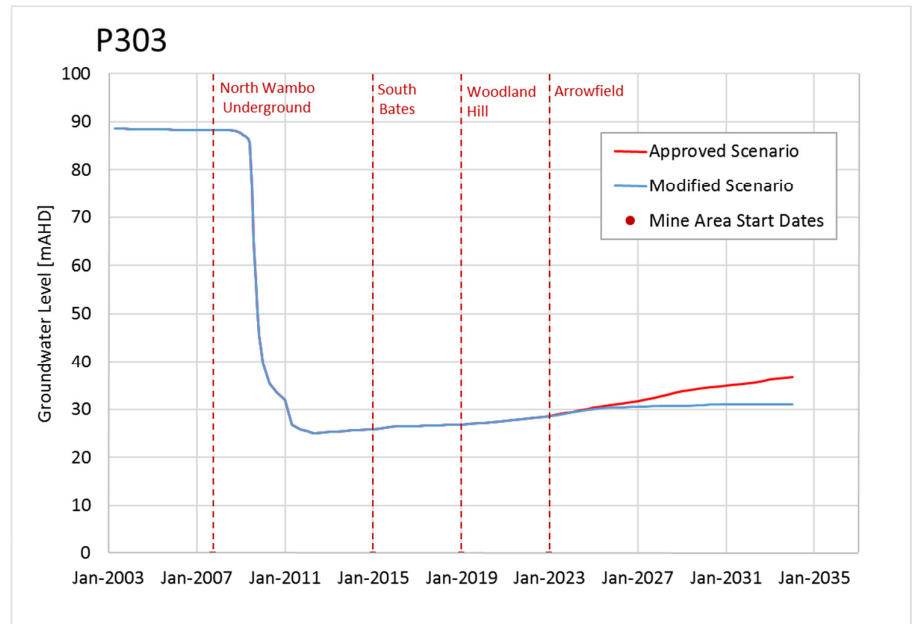
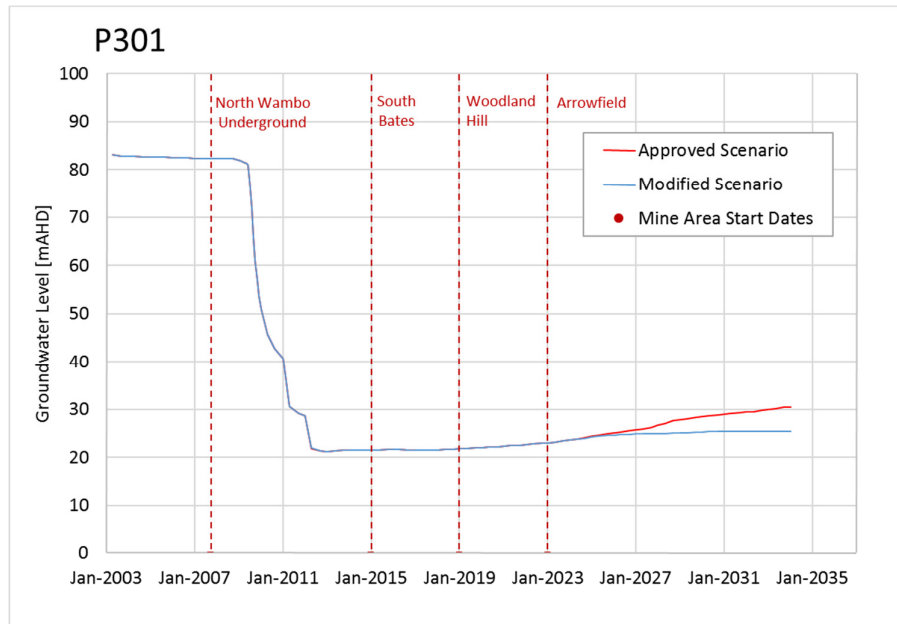
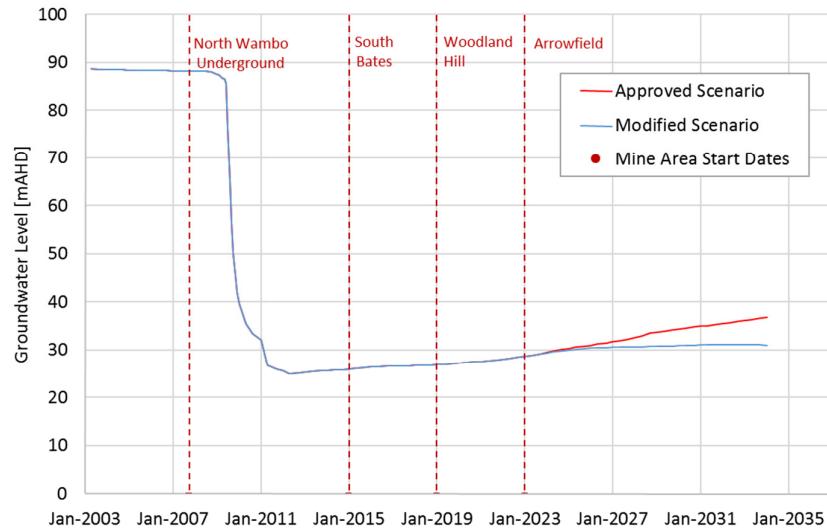
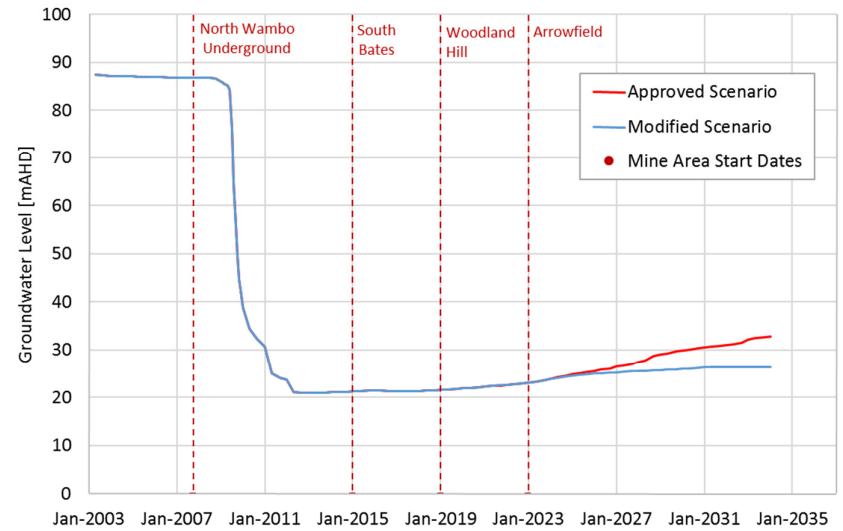


Figure I - 7 P301, P303, P310, P311 Predictive Hydrographs

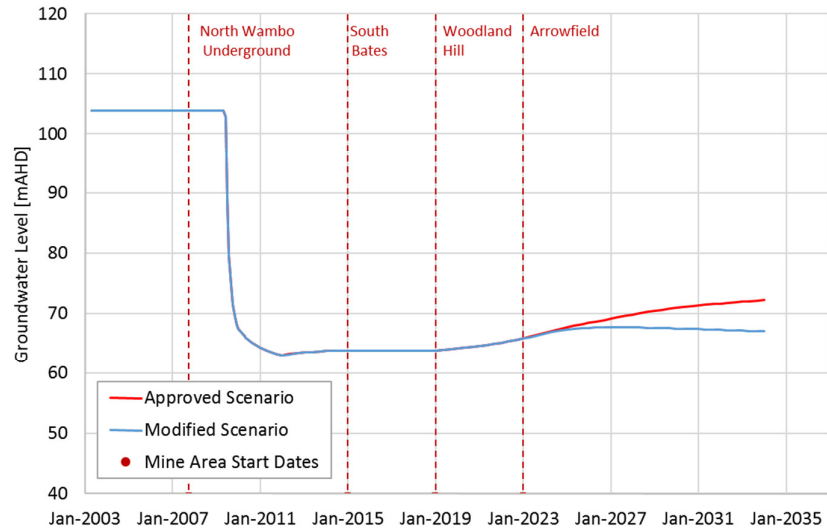
P312



P314



P316



P317

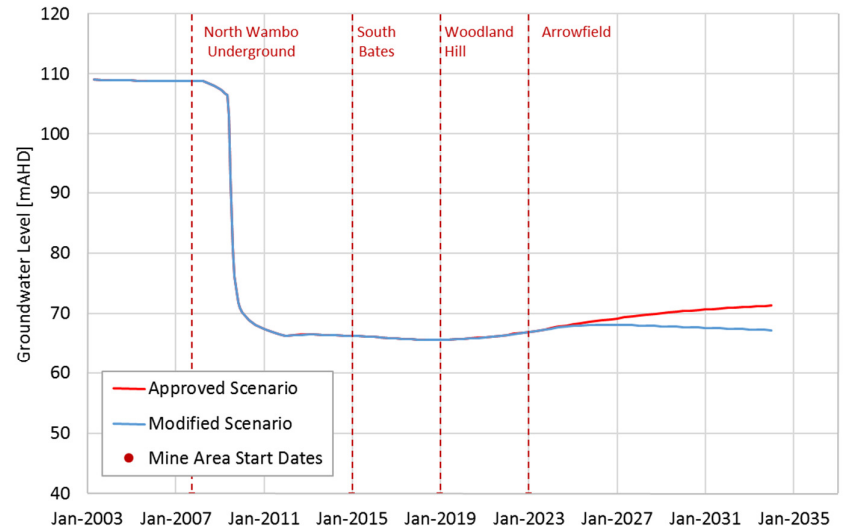


Figure I - 8 P312, P314, P316, P317 Predictive Hydrographs

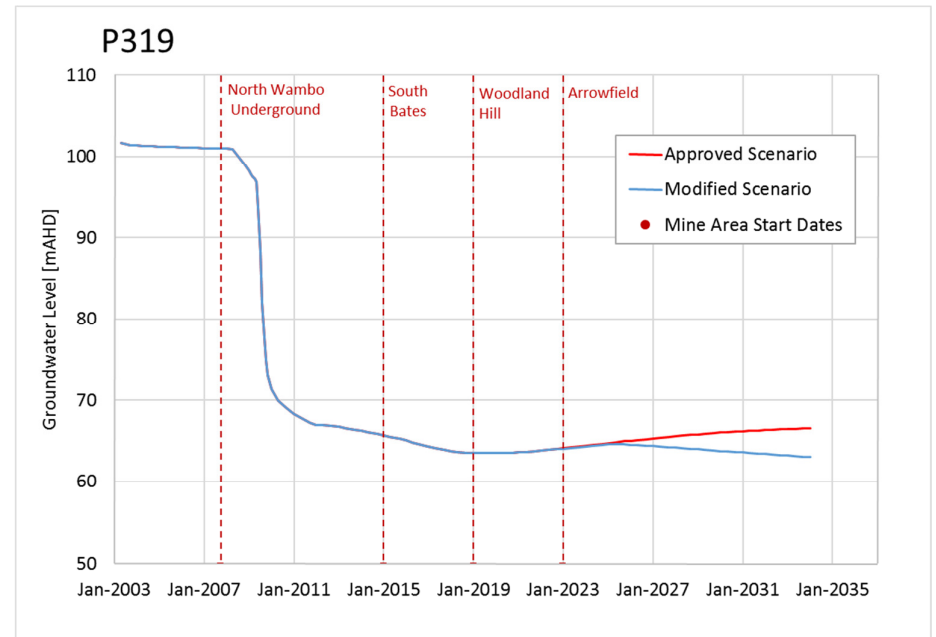
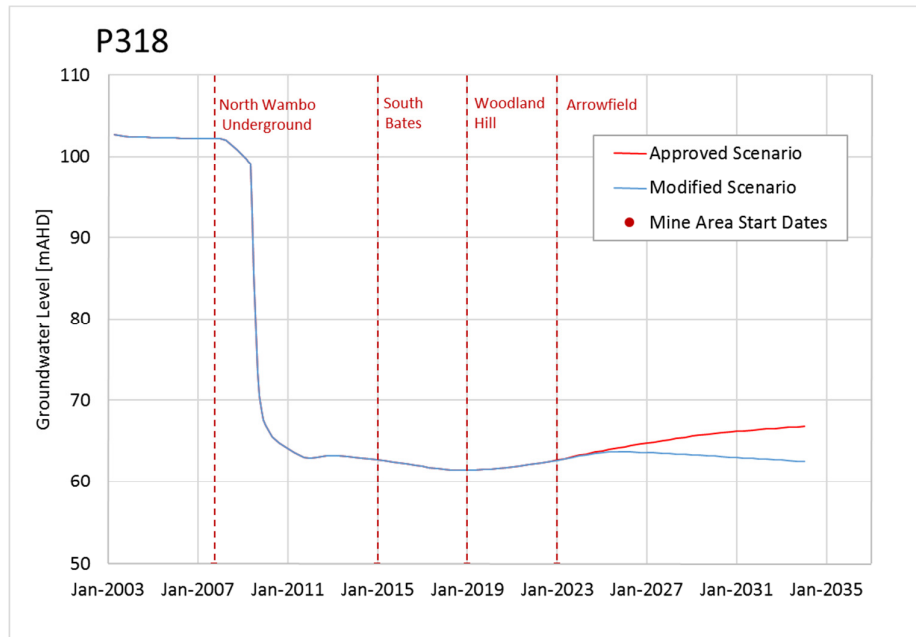


Figure I - 9 P318, P319 Predictive Hydrographs

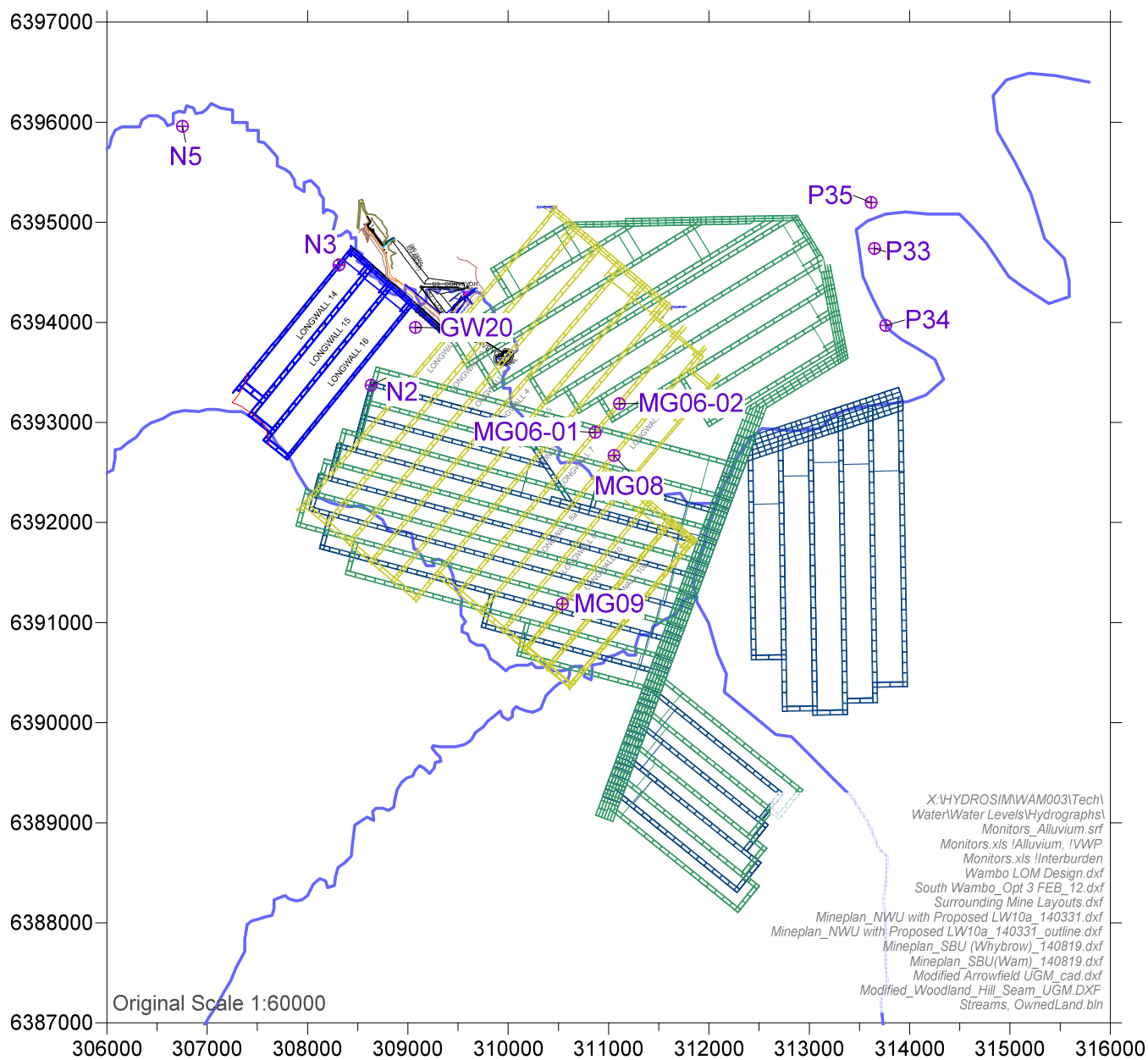


Figure J - 1 Vibrating Wire Piezometer Monitoring Network

VWP - GW20

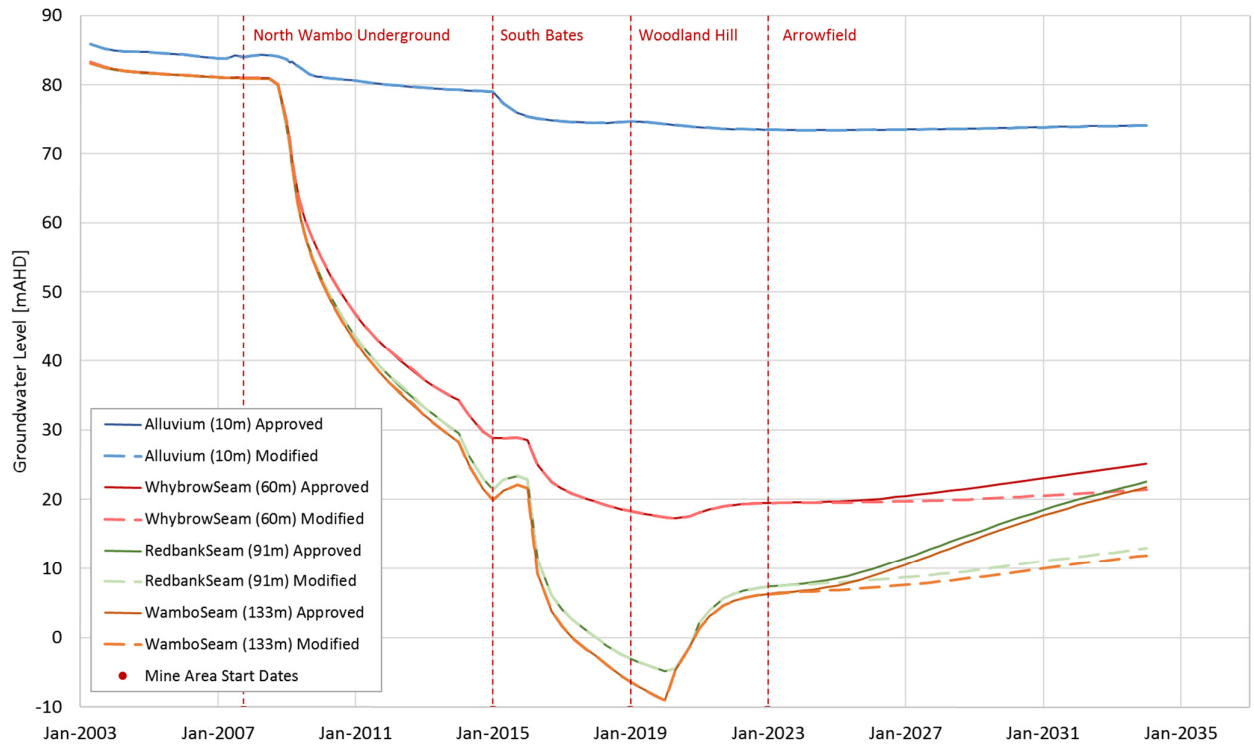


Figure J - 2 GW20 Predictive Hydrographs

VWP - MG08

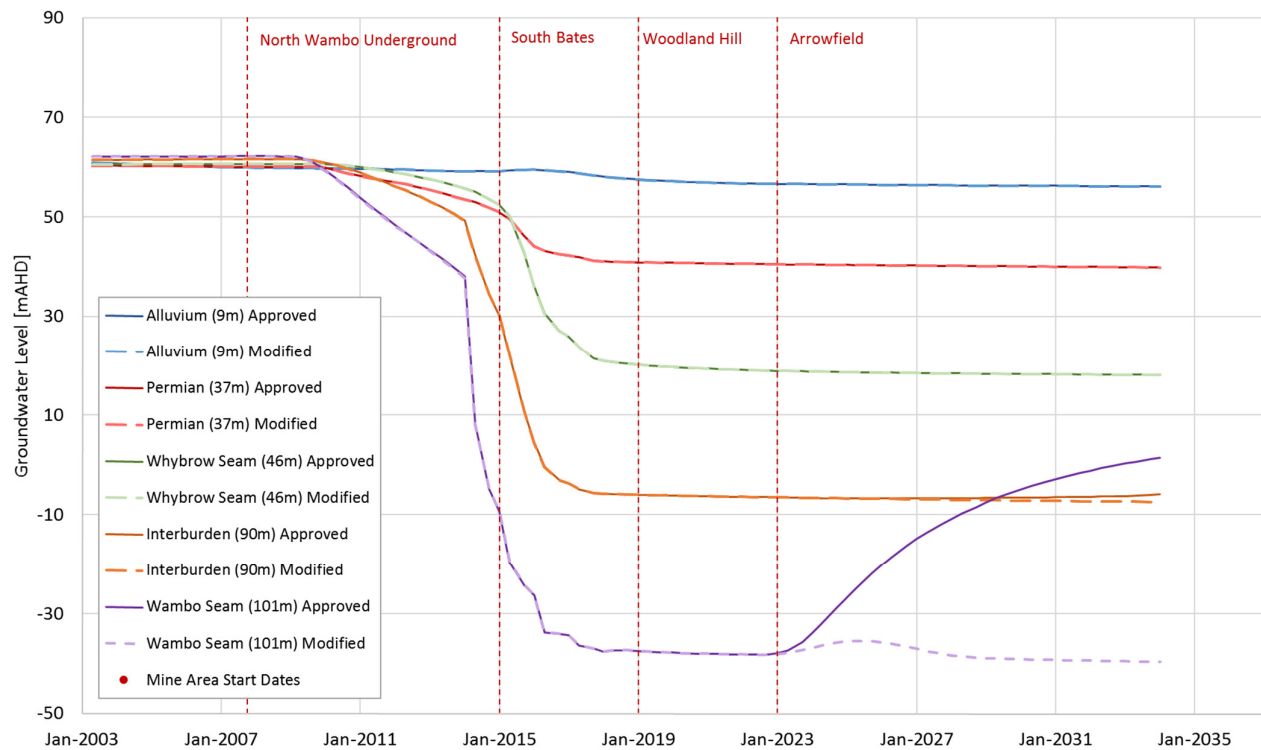


Figure J - 3 MG08 Predictive Hydrographs

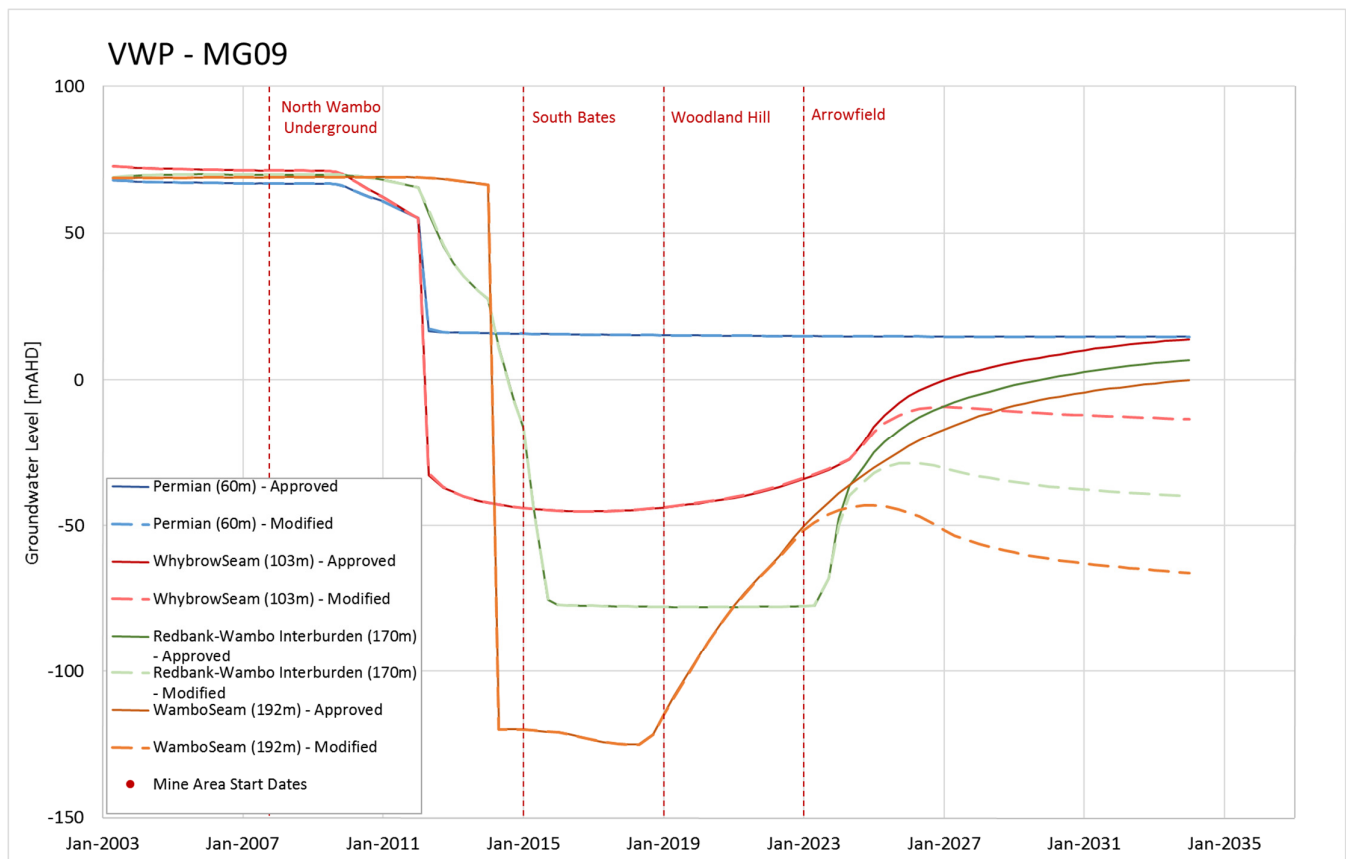


Figure J - 4 MG09 Predictive Hydrographs

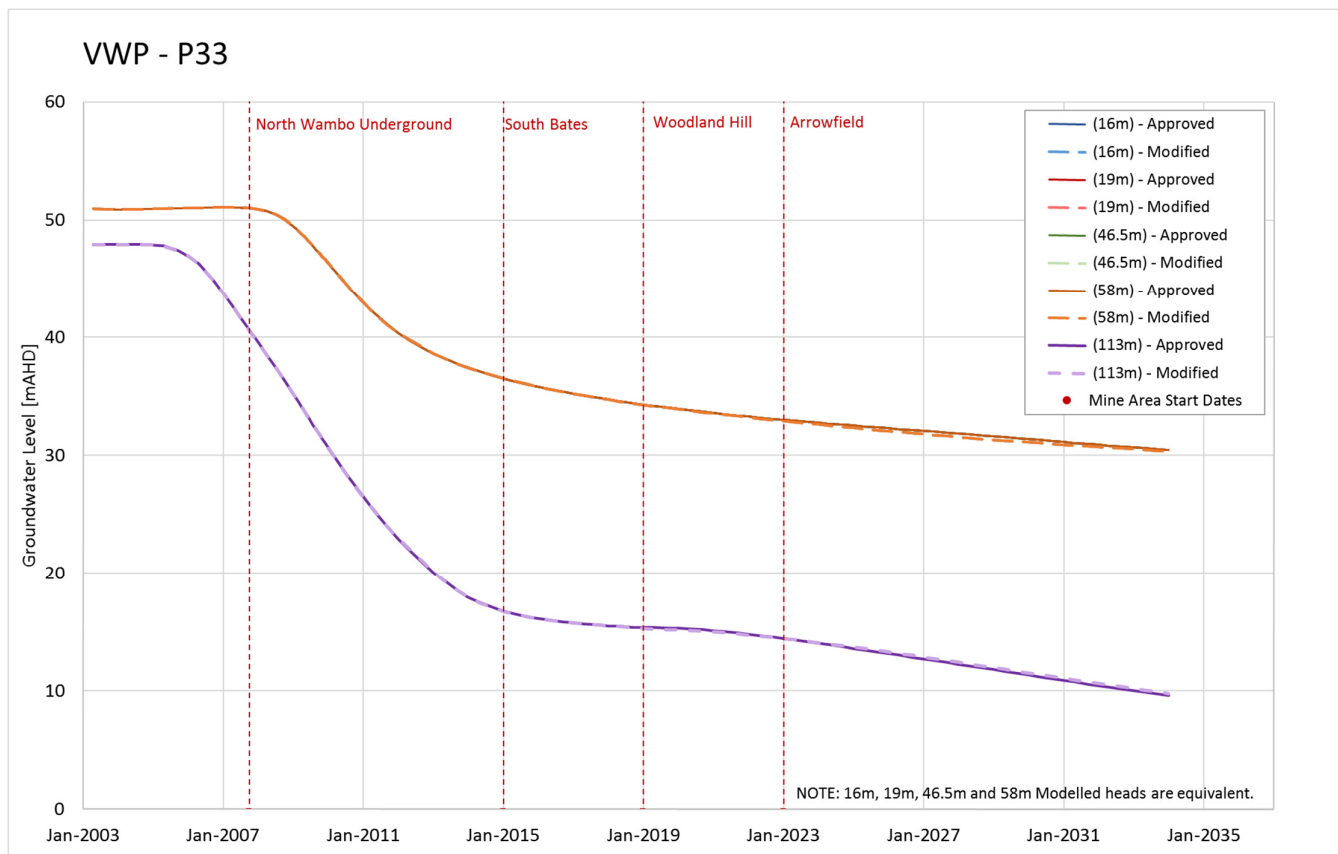


Figure J - 5 P33 Predictive Hydrographs

VWP - P34

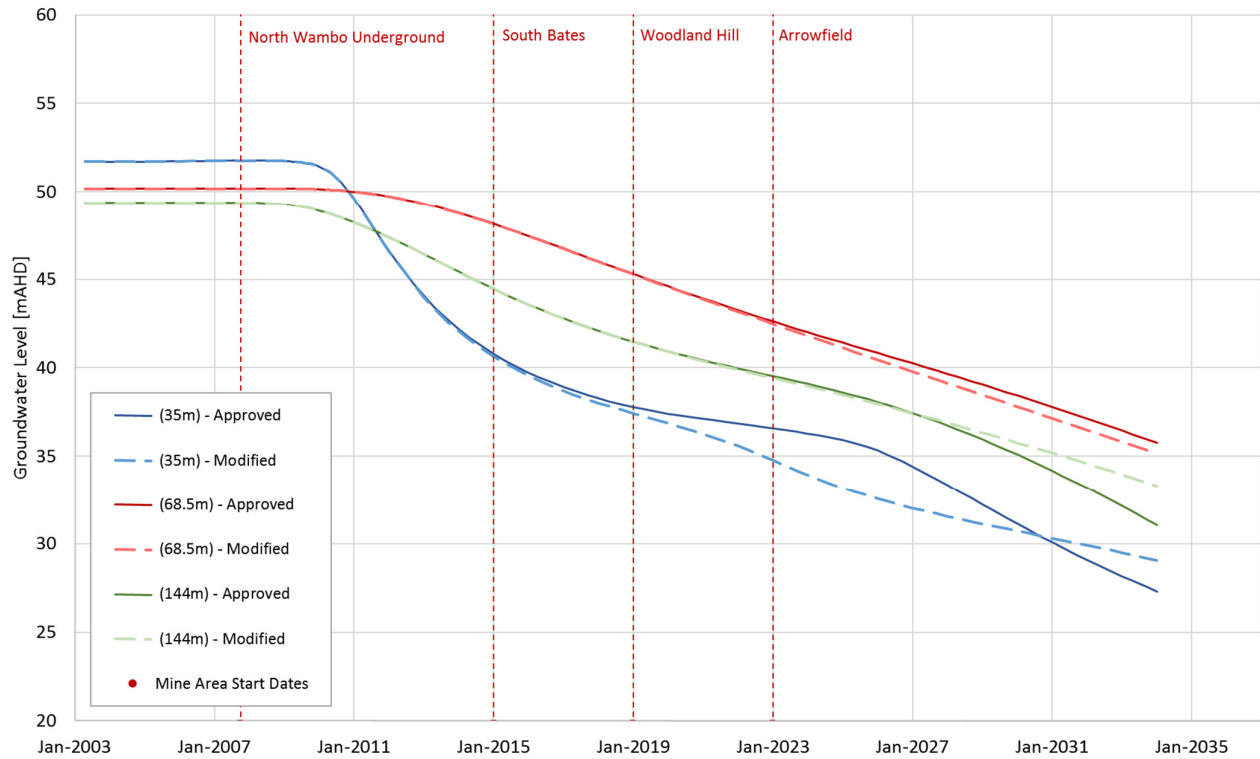


Figure J - 6 P34 Predictive Hydrographs

VWP - P35

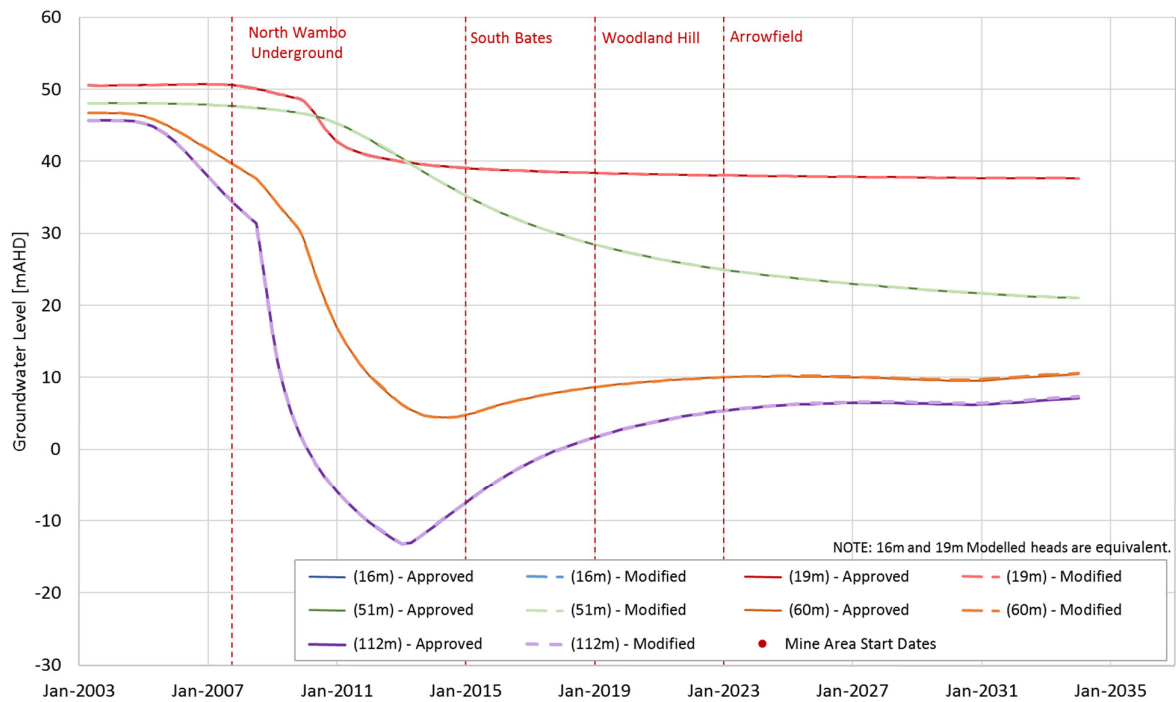


Figure J - 7 P35 Predictive Hydrographs

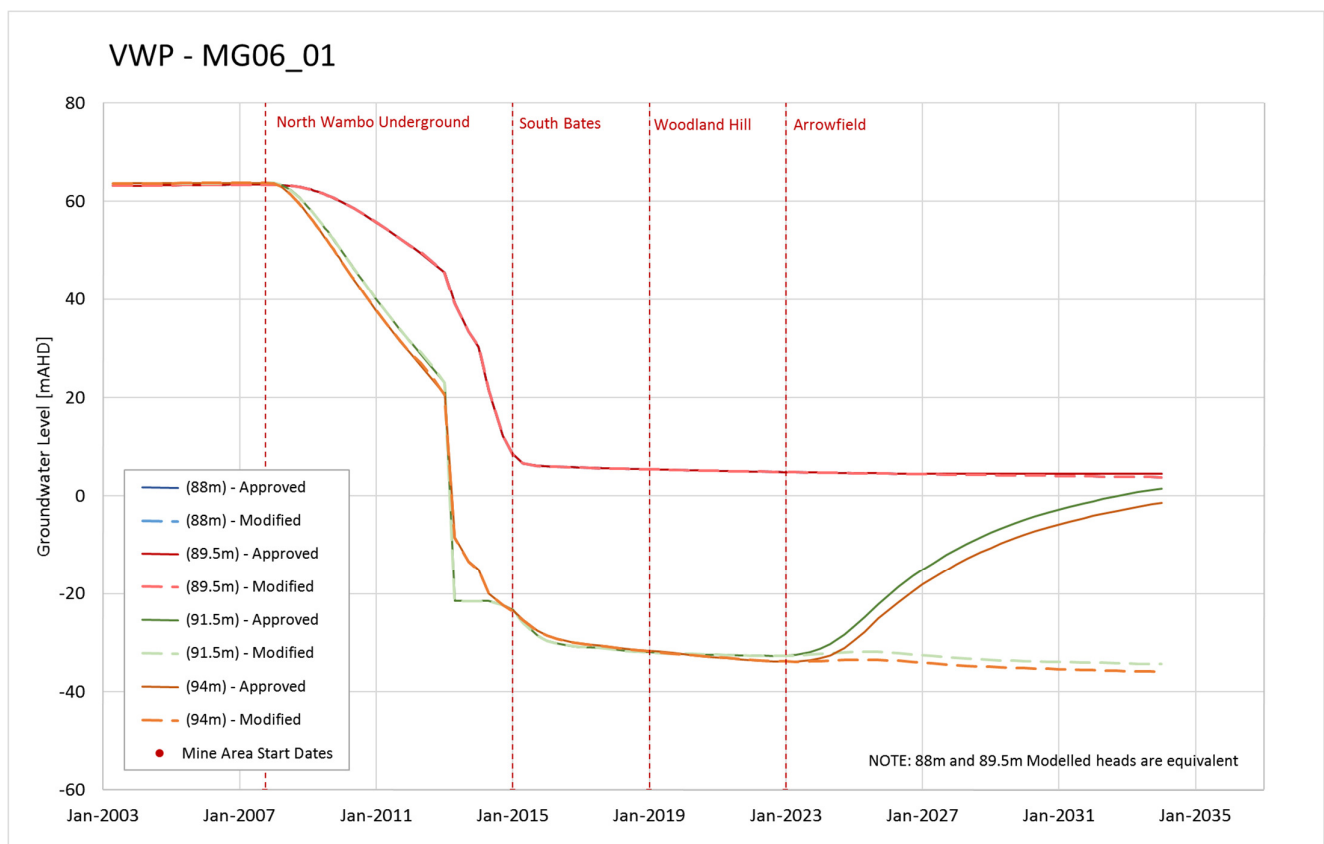


Figure J - 8 MG06_01 Predictive Hydrographs

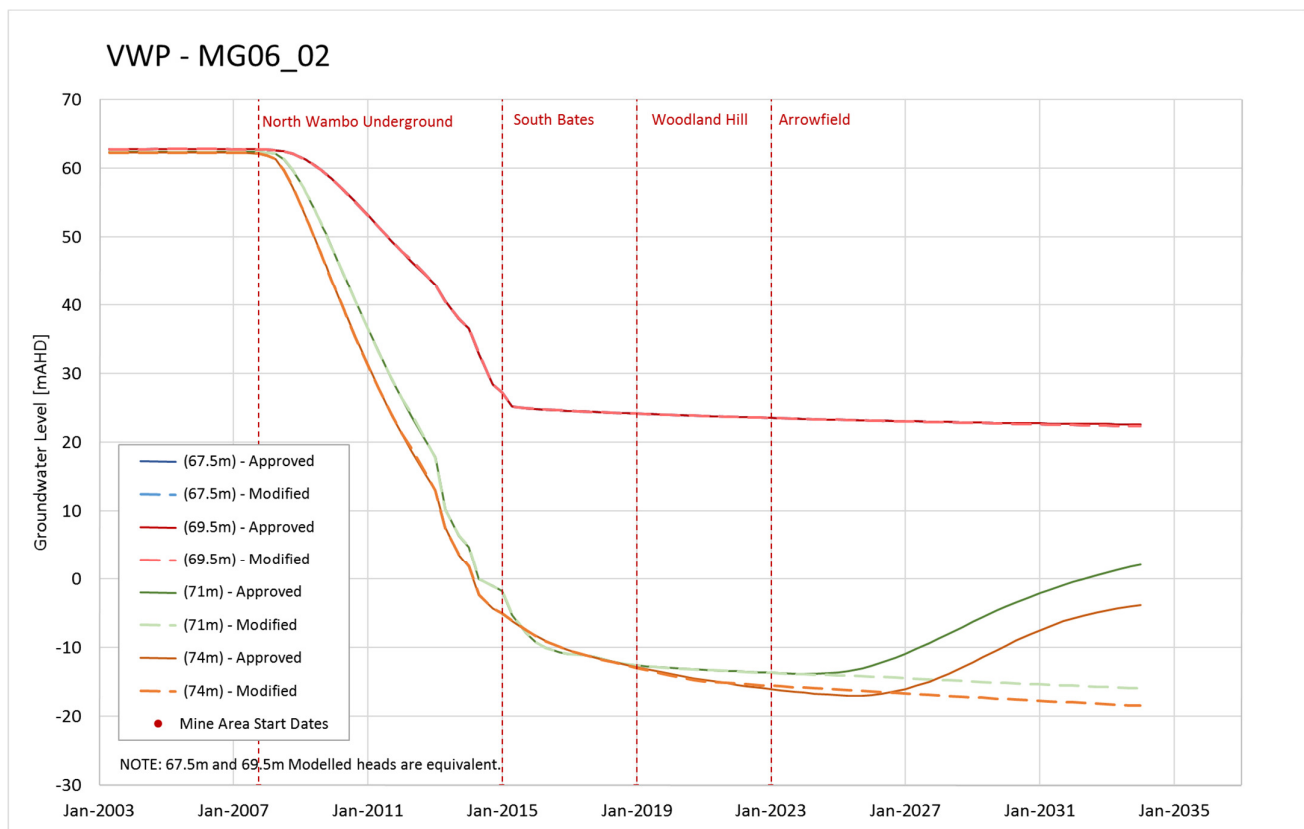


Figure J - 9 MG06_02 Predictive Hydrographs

VWP - N2

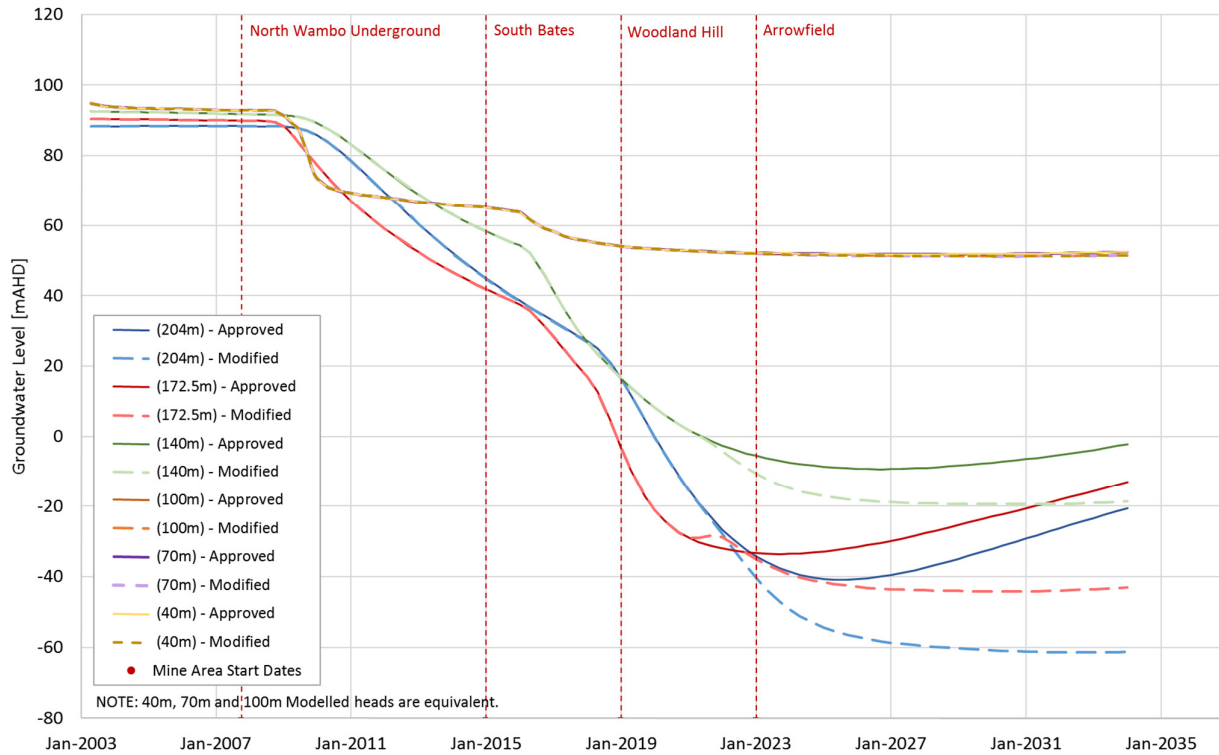


Figure J - 10 N2 Predictive Hydrographs

VWP - N3

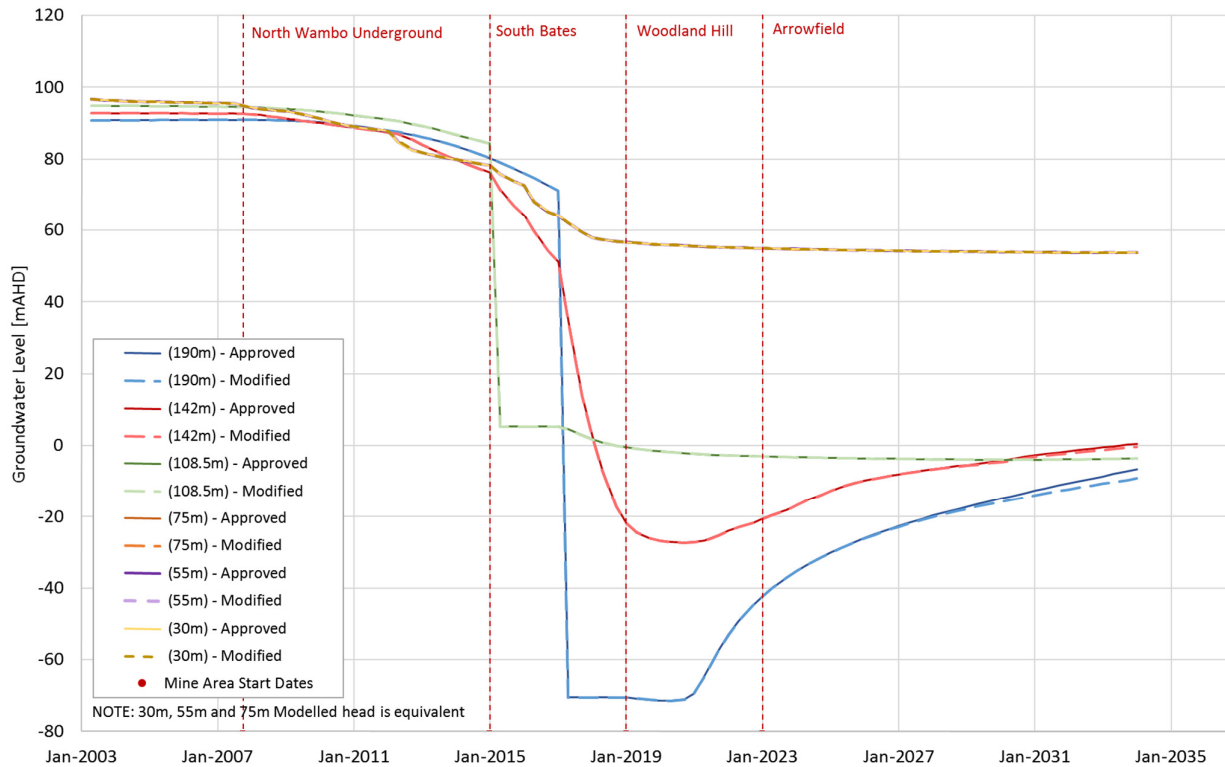


Figure J - 11 N3 Predictive Hydrographs

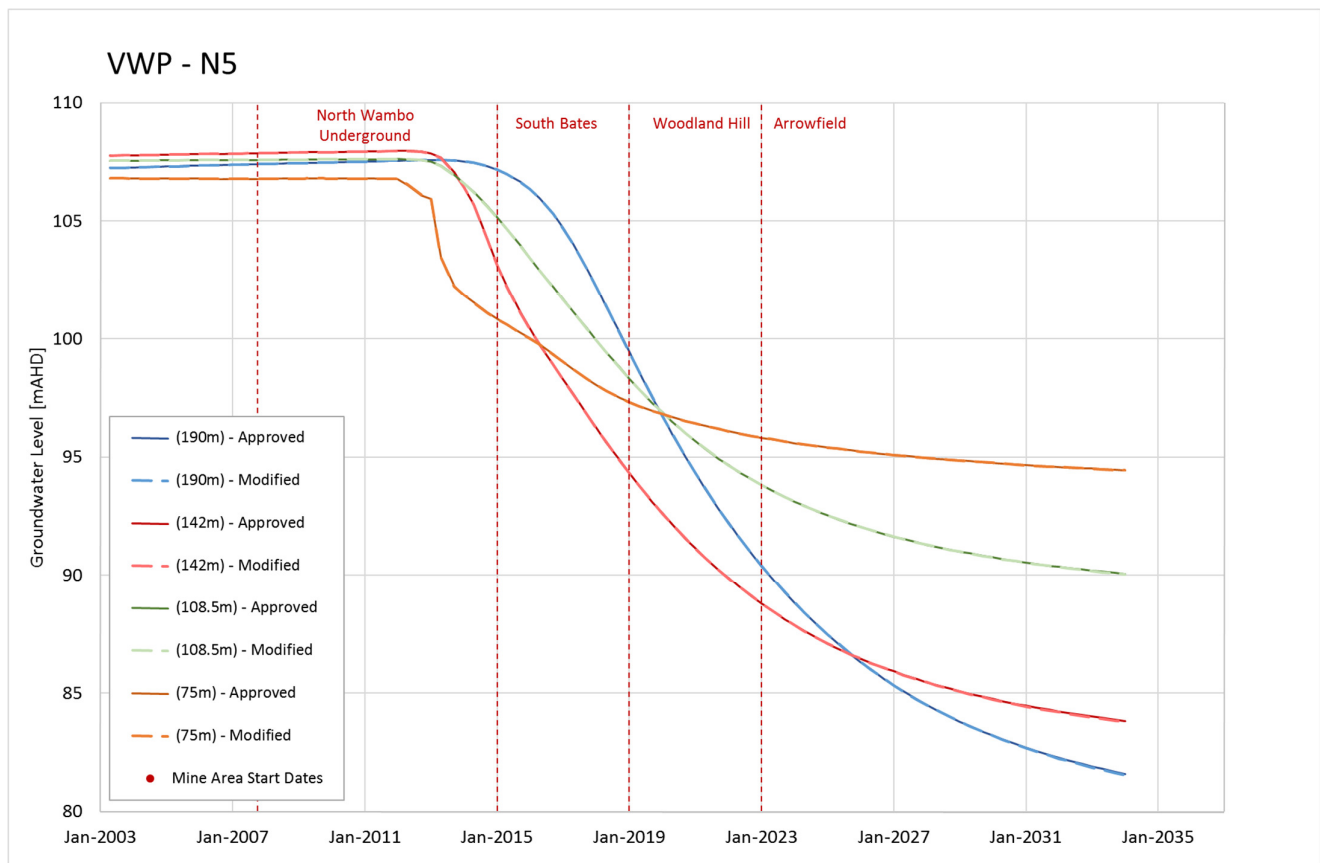


Figure J - 12 N5 Predictive Hydrographs

										Predicted Drawdown (m)	
Work No.	Licence	Use	Comment	Final Depth (m)	Standing Water Level (mBGL)	Easting	Northing	Elevation (mAHD)	Aquifer (interpreted by HydroSimulations)	South Wambo Modification	Cumulative
GW005327	20BL009540	Unknown	Within WCPL Owned Land	10.4		314683	6394498	59.92	Permo-Triassic	1.2	1.9
GW017462	20BL008224	Water supply for livestock				315339	6391460	98.43	Regolith	0.3	-1.1
GW030732		Monitoring		16		316678	6398365	56.25		1.4	1.4
GW030733		Monitoring		15.9		316661	6397633	56.69		1.4	1.4
GW030740		Monitoring		16.3		316641	6397642	54.61		0.7	0.6
GW037184		Exploration or research	Within WCPL Owned Land	21		309685	6393911	81.31	Permo-Triassic	2.2	21.5
GW037998		Irrigated agriculture	Within WCPL Owned Land	10.9		311589	6392530	62.38	Alluvium	3.5	8.3
GW037999		Irrigated agriculture	Within WCPL Owned Land	13.7		311482	6392713	64.01	Permo-Triassic	2	10
GW038000		Irrigated agriculture	Within WCPL Owned Land	9.4		311457	6392620	63.59	Alluvium	3.3	13.3
GW038579		Exploration or research	Within WCPL Owned Land	20.9		309738	6393882	78.4	Permo-Triassic	2.3	20.6
GW043225		Irrigated agriculture		22.5		303653	6398949	116		0	-0.1
GW043673		Exploration or research	Within WCPL Owned Land	9.4		311486	6392467	63.11	Alluvium	6.2	17.3

										Predicted Drawdown (m)	
Work No.	Licence	Use	Comment	Final Depth (m)	Standing Water Level (mBGL)	Easting	Northing	Elevation (mAHD)	Aquifer (interpreted by HydroSimulations)	South Wambo Modification	Cumulative
GW043674		Exploration or research	Within WCPL Owned Land	8.2		311303	6392525	64.6	Alluvium	0.9	2.5
GW043675		Exploration or research	Within WCPL Owned Land	8.5		311433	6392527	63.73	Alluvium	0.7	2.1
GW043676		Exploration or research	Within WCPL Owned Land	10.6		311480	6392805	64.24	Permo-Triassic	1.6	8.6
GW047240	20CA209896	Irrigated agriculture		12.7		316827	6397095	55.22	Alluvium	0	0
GW060326		Mining	Within WCPL Owned Land	9.8		314104	6393348	58.38	Alluvium	0.1	-0.1
GW060327		Mining	Within WCPL Owned Land	9.8		314181	6393442	58.24	Alluvium	0.1	-0.2
GW060328		Mining	Within WCPL Owned Land	10		314205	6393534	57.69	Alluvium	0.1	-0.1
GW060329		Mining	Within WCPL Owned Land	6.4		311904	6392474	60.91	Alluvium	-0.5	0.8
GW060330		Mining	Within WCPL Owned Land	6.2		311727	6392163	62.13	Alluvium	7.8	17.5
GW060363	20BL132753	Irrigated agriculture	Within WCPL Owned Land	6.3		311698	6392317	61.01	Alluvium	6	12.6

										Predicted Drawdown (m)	
Work No.	Licence	Use	Comment	Final Depth (m)	Standing Water Level (mBGL)	Easting	Northing	Elevation (mAHD)	Aquifer (interpreted by HydroSimulations)	South Wambo Modification	Cumulative
GW060364		Irrigated agriculture	Within WCPL Owned Land	5.1		311636	6392808	63.17	Permo-Triassic	-0.5	1.9
GW060365		Irrigated agriculture	Within WCPL Owned Land	6.6		311691	6392686	62.06	Alluvium	-14.1	19.5
GW060366		Irrigated agriculture	Within WCPL Owned Land	5.2		311196	6392646	65.06	Alluvium	1.2	3.1
GW060750	20BL132130	Household	Mine Owned	24.4		314310	6394923	58.99	Permo-Triassic	1	2.1
GW065117		Irrigated agriculture	Within WCPL Owned Land	6		311154	6390735	64.23	Alluvium	-4.6	35.9
GW066606		Household	Within WCPL Owned Land	2.5	1	311207	6390674	60	Alluvium	0	0.8
GW078055		Monitoring	Purpose = 'Test bore' (WCPL test bore?)	198.5		310105	6390490	73.48	Permo-Triassic	-11.9	65.3
GW078574	20BL167170	Irrigated agriculture		12		309174	6390605	89.07	Regol or Permo-T	-12.3	43.4
GW078575	20BL167171	Irrigated agriculture		12		309505	6389687	80.23	Regol or Permo-T	-10.9	23.1
GW078576	20BL167172	Irrigated agriculture	KHARLIBE	7		309764	6389784	78.42	Regol or Permo-T	-12	26
GW078577	20WA208559	Irrigated agriculture		10		309969	6389973	72.91	Alluvium	-12.9	28.9
GW079059	20BL153300	Monitoring	NSW Office of Water			314596	6394852	56.96	Alluvium	0	-0.1

										Predicted Drawdown (m)	
Work No.	Licence	Use	Comment	Final Depth (m)	Standing Water Level (mBGL)	Easting	Northing	Elevation (mAHD)	Aquifer (interpreted by HydroSimulations)	South Wambo Modification	Cumulative
GW079060		Monitoring	NSW Office of Water	14.6	7	314596	6394852	56.92	Alluvium	0.4	0.7
GW079780		Unknown	Within WCPL Owned Land			309589	6393932	77.28	Regolith	-1.2	17.8
GW080502	20BL168017	Mining	Purpose = "mining", BROS I PROPERTY	250	105	308897	6390160	99.8	Permo-Triassic	-2.4	36.5
GW080513	20BL168880	Mining		10		312345	6394818	99.8		4	3.7
GW080514	20BL168881	Monitoring	Within WCPL Owned Land	55		310973	6394353	113.34	Permo-Triassic	1.4	3.6
GW080515	20BL168882	Monitoring	Within WCPL Owned Land	8.1	5	313418	6394794	56.38	Alluvium	2.2	33.4
GW080516	20BL168883	Unknown	Within WCPL Owned Land	15	7	312899	6394954	71.93	Permo-Triassic	13.7	28.4
GW080517	20BL168884	Monitoring	Within WCPL Owned Land	15	7	313573	6394742	55.44	Permo-Triassic	3.6	25.6
GW080518	20BL168885	Monitoring	Within WCPL Owned Land	10.8		313586	6394232	57.65	Permo-Triassic	6.6	32.9
GW080519	20BL168885	Unknown	Within WCPL Owned Land	10.5	7	313622	6394161	57.98	Permo-Triassic	7.4	30.8
GW080951		Unknown		3.1	3	314619	6394878	55	Alluvium	0	-0.1
GW080952		Unknown		1.6	1	314643	6394905	54	Alluvium	0	-0.1

										Predicted Drawdown (m)	
Work No.	Licence	Use	Comment	Final Depth (m)	Standing Water Level (mBGL)	Easting	Northing	Elevation (mAHD)	Aquifer (interpreted by HydroSimulations)	South Wambo Modification	Cumulative
GW080963	20BL170103	Monitoring	NSW Office of Water	84	60	315994	6397210	55.35	Permo-Triassic	4.6	5.4
GW200361	20BL170638	Unknown	Within WCPL Owned Land			311833	6392209	60.97	Alluvium	-0.1	0.6
GW200615	20BL168886	Monitoring	Within WCPL Owned Land	11.5	7	313434	6394246	63.01	Permo-Triassic	5	43
GW200616	20BL168886	Monitoring	Within WCPL Owned Land	8.5	5	313473	6394446	58.85	Alluvium	4.2	38.4
GW200617	20BL168888	Monitoring	Within WCPL Owned Land	9	4	309987	6393974	90.64	Permo-Triassic	1.8	2.3
GW200618	20BL168888	Monitoring	Within WCPL Owned Land	11.5	5	310100	6393820	83.03	Permo-Triassic	1.7	4.6
GW200619	20BL168888	Monitoring	Within WCPL Owned Land	11.5	5	310182	6393656	77.32	Permo-Triassic	1.7	7.9
GW200620	20BL168888	Monitoring	Within WCPL Owned Land	49	39	310489	6394097	104.62	Permo-Triassic	1.3	18.5
GW200621	20BL168887	Monitoring		37	24	312857	6395909	80.54	Permo-Triassic	4.1	20.9
GW200622	20BL168887	Monitoring		30	30	312901	6395806	82.84	Permo-Triassic	5.4	20.7
GW200623	20BL168887	Monitoring		31	13	312982	6395319	65.27	Permo-Triassic	1.8	14.2
GW200624	20BL168939	Drainage of groundwater	Within WCPL Owned Land	260	6	310166	6392650	77.34	Permo-Triassic	124.7	195.3

										Predicted Drawdown (m)	
Work No.	Licence	Use	Comment	Final Depth (m)	Standing Water Level (mBGL)	Easting	Northing	Elevation (mAHD)	Aquifer (interpreted by HydroSimulations)	South Wambo Modification	Cumulative
GW200625	20BL168940	Mining	Within WCPL Owned Land	270		310901	6393375	83.56	Permo-Triassic	56	133.4
GW200634	20BL168999	Monitoring	Within WCPL Owned Land	20		311470	6391252	59.65	Permo-Triassic	-1.1	25.1
GW200635	20BL168999	Monitoring	Within WCPL Owned Land	20		311659	6391236	59.4	Permo-Triassic	-0.2	19.3
GW200636	20BL168999	Monitoring	Within WCPL Owned Land	20		311749	6391078	60.15	Permo-Triassic	-0.5	14.6
GW200637	20BL168999	Monitoring	Within WCPL Owned Land	15	8	311662	6391094	59.92	Alluvium	-0.5	19.6
GW200638	20BL168999	Monitoring	Within WCPL Owned Land	20	5	311452	6391103	60.21	Permo-Triassic	-0.7	24.5
GW200639	20BL168999	Monitoring	Within WCPL Owned Land	20	8	311455	6390889	60.22	Permo-Triassic	-1.5	26.4
GW200640	20BL168999	Monitoring	Within WCPL Owned Land	50		311638	6390920	60.61	Permo-Triassic	-1.1	22.7
GW200641	20BL168999	Monitoring	Within WCPL Owned Land	20	7	311761	6390921	61.41	Permo-Triassic	-1	17

										Predicted Drawdown (m)	
Work No.	Licence	Use	Comment	Final Depth (m)	Standing Water Level (mBGL)	Easting	Northing	Elevation (mAHD)	Aquifer (interpreted by HydroSimulations)	South Wambo Modification	Cumulative
GW200642	20BL168999	Monitoring	Within WCPL Owned Land	20	15	311696	6390688	59.88	Permo-Triassic	-2.8	25.5
GW200643	20BL168999	Monitoring	Within WCPL Owned Land	15	7	311454	6390685	65.38	Permo-Triassic	-4.5	30.6
GW200827	20BL172237	Monitoring		9		312505	6391469	69.44	Permo-Triassic	21.5	22.7
GW200828	20BL172237	Monitoring		11.5		310061	6393206	75.4	Permo-Triassic	1	13.4
GW200829	20BL172237	Monitoring		36		308641	6393376	119.35	Permo-Triassic	2.6	41.3
GW200830	20BL172240	Monitoring		16.8		313335	6392745	66.03	Permo-Triassic	2.8	2.8
GW200833	20BL172255	Monitoring		54		311340	6389530	91.49	Permo-Triassic	4.8	35.9
GW200834	20BL172257	Monitoring		15		313695	6389546	63.77	Permo-Triassic	0.6	0.5
GW200835	20BL172256	Monitoring		11		308424	6394517	102.68	Permo-Triassic	2.2	41
GW200942	20BL167947	Monitoring		37		312325	6395750	91.82	Permo-Triassic	2.4	27.2
GW200943	20BL167947	Monitoring		30		312332	6395760	91.82	Permo-Triassic	2.3	26.5