APPENDIX C

GROUNDWATER ASSESSMENT

WILPINJONG COAL MINE MODIFICATION GROUNDWATER ASSESSMENT

FOR

WILPINJONG COAL PTY LTD

By

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trading as

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1. INTRODUCTION

The Wilpinjong Coal Mine (WCM) is an existing open cut coal mining operation situated approximately 40 kilometres (km) north-east of Mudgee, near the Village of Wollar, within the Mid-Western Regional Council Local Government Area, in central New South Wales (NSW) (**Figure 1**).

The WCM is owned and operated by Wilpinjong Coal Pty Limited (WCPL), a wholly owned subsidiary of Peabody Energy Australia Pty Limited (Peabody). Mining is undertaken within Mining Lease (ML) 1573 and the approved open cut and contained infrastructure area at the WCM comprises approximately 1,920 hectares (ha) (**Figure 2**).

The WCM was approved under Part 3A of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) by the NSW Minister for Planning in February 2006 (Project Approval 05-0021). The mine has been operating since 2006, and is approved to produce up to 15 million tonnes per annum (Mtpa) of run-of-mine (ROM) coal from six open cut pits.

The WCM lies within the Wollar Creek Water Source (**Figure 1**) of the Goulburn Extraction Management Unit which is governed by the *Hunter Unregulated and Alluvial Water Sources Water Sharing Plan* and the *Water Management Act 2000.* As this plan does not cover non-alluvial groundwater systems, licensing of the water take from the coal seams and adjacent hardrock is governed by Part 5 of the *Water Act 1912*.

This groundwater assessment will form a component of the Environmental Assessment (EA) to be lodged for a Modification to the WCM under section 75W of the EP&A Act (the Modification). Following a review of mine planning, coal handling and preparation plant (CHPP) capacity, waste rock bulking factors, planned building and demolition works and light vehicle servicing requirements, WCPL has determined that a number of minor alterations to the approved WCM are required, including:

- development of incremental extensions to the existing open cut pits (**Figure 2**) that would extend the open cuts by approximately 70 ha and would result in the recovery of approximately 3 million tonnes of additional ROM coal;
- higher rates of annual waste rock production (from 28 Million bank cubic metres [Mbcm] up to approximately 33.3 Mbcm) in order to maintain approved ROM coal production;
- minor CHPP upgrades to improve fine coal reject management (installation of a belt press filter) and an increase in the rate of ROM coal beneficiation in the CHPP to approximately 9 Mtpa;
- upgrade of the existing Reverse Osmosis (RO) Plant to a Water Treatment Facility with the addition of pre-filtration and flocculation/dosing facilities to improve plant efficiency;
- amendment of the waste emplacement strategy to include:
    - development of an elevated waste rock emplacement landform (up to approximately 450 metres [m] Australian Height Datum [AHD]) within the footprint of Pit 2 (**Figure 2**);
    - disposal of some inert building and demolition waste that is produced from off-site building demolition in the approved mine waste rock emplacements;
    - co-disposal of fine coal reject material produced by the belt press filter with coarse rejects; and

- operation of a light vehicle servicing workshop at an existing farm shed that is located in the north of the Project area (**Figure 2**).

There would be no extension to the existing approved 21 year mine life.

1.1 SCOPE OF WORK

The key tasks for this assessment are:

- Characterisation of the existing groundwater resources.
- Comparison/validation of prior/existing groundwater model predictions.
- Update of existing groundwater model to reflect:
    - outcomes of review of groundwater datasets;
    - comparison/validation of prior/existing groundwater model; and
    - proposed WCM mine incorporating the Modification.
- Modelling of the proposed Modification during operations and post closure.
- Preparation of a Groundwater Assessment report that includes:
    - Description of the hydrogeological characteristics of the WCM area and surrounds.
    - Description of the numerical model development.
    - Analysis and assessment of the numerical model outputs, with particular attention to:
        - potential WCM impacts on alluvial and hard rock groundwater sources;
        - potential WCM impacts on creeks/streams;
        - potential WCM impacts on other groundwater users;
        - potential cumulative impacts; and
        - the recovery of local and regional groundwater levels.
    - Assessment of the potential impacts of the Modification on groundwater quality.
    - Identification of measures to avoid, mitigate and/or remediate potential impacts on groundwater resources.
    - A recommended augmentation of the existing groundwater monitoring programme to measure potential impacts on groundwater resources, and associated auditing and complaint response measures.

An Environmental Risk Assessment (ERA) was undertaken to identify key potential environmental issues for further assessment in the EA (Safe Production Solutions, 2013). The risk assessment team included a representative from HydroSimulations.

The key potential groundwater related issues identified in the ERA (Appendix K of the EA) are summarised below and addressed in this report:

- Incremental reduced baseflow to creeks due to watertable lowering.
- Incremental induced leakage from creeks due to watertable lowering.
- Potential incremental and direct impacts on springs.

The Groundwater Assessment has been prepared in consideration of the NSW *Aquifer Interference Policy* (NSW Government, 2012). The numerical groundwater model has been reviewed in consideration of the *Australian Groundwater Modelling Guidelines* (Barnett et al., 2012).

1.2 GROUNDWATER LICENCES

Table 1 summarises bore licences under the *Water Act 1912* held by WCPL that are relevant to groundwater extraction at the WCM. WCPL also holds a series of bore licences for monitoring boreholes at the WCM.

In addition, Peabody holds a Water Access Licence (WAL 21499) for the alluvial aquifer in the Wollar Creek Water Source under the *Water Management Act 2000* with a share component of 474 units.

Table 1. Groundwater Licences under the Water Act 1912

Licence Number	Extraction Limit	Expiry	Purpose
20BL173517	1 ML/a	10 June 2014	Pit 1 Licence
20BL173516	190 ML/a	10 June 2014	Pit 2 Licence
20BL173514	680 ML/a	10 June 2014	Pit 3 Licence
20BL173515	350 ML/a	10 June 2014	Pit 4 Licence
20BL173513	800 ML/a	10 June 2014	Pit 5 Licence
20BL170147	110 ML/a	30 March 2016	Dewatering
20BL170148	110 ML/a	30 March 2016	Dewatering
20BL170149	110 ML/a	30 March 2016	Dewatering
20BL170150	110 ML/a	30 March 2016	Dewatering
20BL170151	110 ML/a	30 March 2016	Dewatering
20BL170152	110 ML/a	30 March 2016	Dewatering
20BL170153	110 ML/a	30 March 2016	Dewatering
20BL170063	110 ML/a	18 December 2016	Water Supply Bore (GWs10)
20BL170062	110 ML/a	18 December 2011*	Water Supply Bore (GWs11)
20BL170061	110 ML/a	18 December 2011*	Water Supply Bore (GWs12)
20BL170059	110 ML/a	18 December 2016	Water Supply Bore (GWs14)
20BL170058	110 ML/a	18 December 2011*	Water Supply Bore (GWs15)

ML/a = megalitres per annum.

* WCPL is in consultation with NSW Office of Water (NOW) regarding the renewal of these licences.

2 HYDROGEOLOGICAL SETTING

2.1 CLIMATE

The nearest Commonwealth Bureau of Meteorology (BoM) climate station is Wollar (Barigan St), station 062032, located about 3 km east of the south-eastern corner of the mining lease (E777602, N6415833). Rainfall records, collected there since February 1901, show a long-term average rainfall of 589 millimetres (mm) (**Table 2**). Average monthly rain records (**Table 2**) show that the highest rainfall occurs in January (mid-summer) and the lowest in May (late-autumn). The highest monthly rainfall exceeds the lowest by about 75%.

Table 2. Average Monthly Rainfall (mm) at Station 062032 at Wollar (Barigan St) from 1901 to 2012

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
66.6	62.9	51.9	38.9	38.1	43.9	42.9	41.6	40.9	51.9	55.8	59.3	588.9

The cumulative distribution function for annual rainfall at Wollar, shown in **Figure 3**, indicates the probability that a given annual rainfall will not be exceeded in any year. **Table 3** lists the annual rainfalls associated with a range of percentile values. The median (50%) value of 590 mm is very similar to the long-term average (589 mm).

Table 3. Annual Rainfall Statistics at Station 062032 at Wollar (Barigan St) from 1901 to 2012

Percentile (%)	10	20	25	50	75	80	90
Annual Rain (mm)	362	438	466	590	690	744	832

Information on long-term rainfall trends is provided by the Residual Mass Curve (RMC) (**Figure 4**). This curve is generated by aggregating the residuals 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 are expected to rise while those recorded during periods of declining RMC are expected to decline.

The RMC plot using rainfall data from the Wollar station since 1901 (**Figure 4**) shows a major dry period from 1918 to 1947 followed by a significant wet period from 1948 to 1956. Since then, less emphatic wet and dry cycles have occurred. There were wetter episodes from 1973 to 1978 and 1995 to 2012, with dry interludes during 2006, 2007 and 2009 since mining at WCM commenced in 2006.

Actual evapotranspiration for the region is up to approximately 600 millimetres per annum (mm/annum) (BoM, 2009)[1].

[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

The WCM lies within the Greater Wollar Creek Catchment where ground elevations range from 300 mAHD to 725 mAHD (**Figure 5**). The regional topography shown in **Figure 5** is based on the Geoscience Australia 9-second (~250 m) grid. **Figure 6** shows higher resolution ground topography over the mining lease and surrounds, where elevations range from 346 mAHD to 643 mAHD. These levels were extracted from the WCPL geological model on a 20 m grid.

The alluvial/colluvial lowlands associated with Wilpinjong Creek and its tributaries are bordered on the north by the Goulburn River National Park and on the south by the Munghorn Gap Nature Reserve (**Figure 1**).

Pre-mining surface water would have drained across the mining lease towards Wilpinjong Creek along a series of small creeks named, from west to east (**Figure 1**):

- Planters Creek;
- Spring Creek;
- Narrow Creek;
- Bens Creek; and
- Cumbo Creek.

The creeks range from semi-perennial spring-fed streams in the south to wide ephemeral streams in the north. The largest tributary drainage feature within the mining lease is Cumbo Creek.

According to Gilbert and Associates (2005): "Wilpinjong Creek is incised into the valley floor and forms a series of semi-permanent soaks fed primarily from drainage from the surrounding alluvial plain and colluvium which is recharged by runoff from the adjacent sandstone plateau".

Wilpinjong Creek originates in the Goulburn River National Park at an elevation of about 500 mAHD and is joined by Murragamba Creek which rises in the Munghorn Gap Nature Reserve (**Figure 1**). Wilpinjong Creek flows south-easterly from this confluence to join Wollar Creek about 14 km downstream, which then discharges into the Goulburn River a further 10 km downstream.

To the south-west of the mine is Moolarben Creek which flows north-westerly into Goulburn River, which skirts the northern boundary of the Greater Wollar Creek Catchment (**Figure 5**).

2.3 GEOLOGY

The WCM is located in the Western Coalfield on the north-western edge of the Sydney-Gunnedah Basin, which contains sedimentary rocks, including coal measures, of Permian and Triassic age. Mapped surface geology, shown in **Figure 7a**, indicates that the dominant outcropping lithology over the mining lease is Permian Illawarra Coal Measures. A substantial area of outcropping Permian Shoalhaven Group (containing the Marrangaroo Conglomerate and the underlying Nile Sub-Group) hosts Cumbo Creek in the south-eastern part of the mining lease. Smaller tongues of the Triassic Narrabeen Group (Wollar Sandstone) cross the boundary of the mining lease in the more elevated portions. Rocks of the Narrabeen Group form the cliffs and ridges of the Goulburn River National Park and the Munghorn Gap Nature Reserve.

To the west of the site are Carboniferous igneous rocks and volcanics, marking the eastern limit of the Lachlan Fold Belt. There are relatively few occurrences of Mesozoic igneous laccoliths and Tertiary basalt plugs and sills external to the mining lease.

The geological cross-section in **Figure 7b** shows that the Shoalhaven Group extends to about 300 m below ground surface, in the vicinity of Wilpinjong Creek. Below this is about 1,000 m of Permian Rylstone Volcanics which lie unconformably over Ordovician rocks.

Along the local watercourses is a thin and narrow veneer of Quaternary alluvium and colluvium. Alluvial deposits are best developed along a section of Wilpinjong Creek proximal to the mine site (typically about 5 m thick), along Cumbo Creek and along a southern reach of Wollar Creek. Outside the Greater Wollar Creek Catchment, alluvial sediments are expressed along the western part of the Goulburn River and along Moolarben Creek (**Figure 7a**). Colluvium is evident along the edges of sandstone escarpments, especially on the northern side of Wilpinjong Creek where the landform abuts the cliffs of the Goulburn River National Park.

The coal seam of interest, the Ulan Seam, outcrops at the southern limit of the mining lease. It is subdivided into plies a11 to g22 over the mining lease. In the more elevated parts there are remnants of the younger Moolarben Seam (plies m1 to m4). The coal seam has a dip of 1-2 degrees to the north- north-east.

There is no evidence of major faulting over the mining lease.

2.4 GROUNDWATER MONITORING

A groundwater monitoring network has been in place at the WCM since April 2006. The approved Groundwater Monitoring Programme is articulated in Document No. GWMP-R01-H dated March 2006 (WCPL, 2006a) and was updated in December 2010 (WCPL, 2010). Additional monitoring of production bore responses is outlined in the Surface and Groundwater Response Plan, Document No. SGWRP-R01-I dated July 2006 (WCPL, 2006b).

The details of monitoring bores in the WCM network are summarised in **Table 4**. For alluvium, there are eight bores being measured monthly for water level and another five logged every 15 minutes. For coal, there are five bores being measured monthly for water level and another five logged every 15 minutes. The datalogged sites were intended to monitor short-term responses to production bores which to date have only been utilised for only a short time.

The locations of the bores in the groundwater monitoring network are shown in **Figure 8**.

A network of production bores was drilled for dewatering (DB1-DB7) and water supply (WSB1 to WSB15), as shown in **Figure 9**. Five of the DB-series bores were pumped in May-June 2006 and all were used for water level measurement from July 2006 to April 2007. Of the WSB-series bores, only five were ever pumped (WSB10-WSB15) and then only for a few months (March to June 2007).

A set of 28 monitoring bores[2] (PZ01 to PZ28) was drilled adjacent to Pit 1 and Pit 2 to monitor tailings dam seepage (**Figure 10**). The first 14 piezometers (PZ01 to PZ14) were monitored for water level, pH and electrical conductivity (EC) from April 2008 to December 2011. The second group (PZ15 to PZ28) were monitored for water level, pH and EC from November 2009 to December 2011. Additional bores (PZ29 to PZ32) were installed in 2012 adjacent to Cumbo Creek in Proposed Pits 3 and 4.

[2] Installed depth to be determined

Table 4. Groundwater Monitoring Sites Summary

Monitoring Site	Lithology	Start Date	End Date	Frequency	Location
GWa1, GWa2, GWa3, GWa4	Alluvium	20 April 2006	-	monthly	Wilpinjong Creek
GWa7	Alluvium	14 April 2008	-	monthly	Wilpinjong Creek
GWa5, GWa6	Alluvium	20 April 2006	-	monthly	Cumbo Creek
GWa8	Alluvium	20 April 2006	-	monthly	Wollar Creek
GWd4, GWd5, GWd6	Alluvium	No record	-	-	Wilpinjong Creek
GWa10, GWa11, GWa12, GWa14, GWa15	Alluvium	May-June 2007	-	15 minutes	Wilpinjong Creek
GWc1, GWc2, GWc3	Ulan Coal	20 April 2006	-	monthly	Wilpinjong Creek
GWc4, GWc5	Ulan Coal	20 April 2006	-	monthly	Wollar Creek
GWc10, GWc11, GWc12, GWc14, GWc15	Ulan Coal	20 April 2006	-	15 minutes	Wilpinjong Creek
GWd1, GWd2	Ulan Coal	No record	-	-	Pit 1
DB1, DB2	Ulan Coal	23 May 2006	1 April 2007	monthly	Pit 1
DB6, DB7	Ulan Coal	30 July 2006	1 April 2007	monthly	Pit 1
DB3, DB4, DB5	Ulan Coal	30 July 2006	1 April 2007	monthly	Pit 2 - Pit 4
PZ01 - PZ14	Ulan Coal ?	28 April 2008	30 December 2011	monthly	Pit 1
PZ15 - PZ28	Ulan Coal ?	12 November 2009	30 December 2011	monthly	Pit 1 - Pit 2
PZ29 - PZ32	Ulan Coal ?	19 November 2012	-	-	Pits 3&4

Field pH and EC readings have been taken at the same time as monthly water level readings at GWa1-GWa8 in alluvium and at GWc1 to GWc5 in coal. Measurements were also made for a short time (from May-June 2006 to March 2007) at dewatering bores DB1-DB7.

2.5 GROUNDWATER USAGE

2.5.1 Mine Site

The WCM Annual Environmental Management Reports (AEMRs) record the monthly volumes of water pumped from the main pit sump, dewatering bores and production bores. The rate of water extraction, expressed in megalitres per day (ML/day) units for each month, is illustrated in **Figure 11** and the water production statistics are listed in **Table 5**.

Table 5. Groundwater Extraction Statistics (ML/day)

	Main Pit*	Dewatering^
Mean	1.6	0.27
Standard Deviation	1.3	0.40

* From September 2006 to December 2011
^ From May 2006 to June 2007

Although pumping from the pit has occasionally reached 4-6 ML/day (averaged over a month), the long-term average is 1.6 ML/day. There has been a steady increase in average pumping from about 1 ML/day at the start of mining to about 2 ML/day in 2011. The increasing trend in pit pumpage is parallel to the gradually increasing residual mass (**Figure 11**). Peak pumping corresponds with the onset of wet periods as indicated on the RMC.

The volumes pumped from the main pit include rainfall and surface runoff in addition to groundwater inflow, but exclude evaporation from the pit and from groundwater seepage faces. There is also likely to be a component of dam seepage for water that is recirculated across the site. The volumes are not metered but are estimated from the number of hours of pump operation multiplied by a representative pump capacity. Nevertheless, the estimated pumped volumes are likely to provide an upper limit estimate of groundwater inflows to the pits, although the estimate will have considerable uncertainty. Much of the predicted pit inflow will be lost by evaporation at seepage faces or from pools. The total recorded pit inflow volume for the period May 2006 to December 2011 is 3,160 ML (557 ML/a).

Bore dewatering at the northern edge of Pit 1 occurred only in May and June 2006, at the time mining commenced in Pit 1 (June 2006) (**Figure 11**). The peak rate was 0.4 ML/day (averaged over a month).

The production borefield along the foothills of the Goulburn River National Park, on the northern side of Wilpinjong Creek, was operated only for four months in mid-2007 at a maximum rate of 1.0 ML/day (**Figure 11**).

2.5.2 Registered Bores

A census of groundwater bores and wells in the vicinity of the WCM was conducted by WCPL in February 2005 and reported in Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) (2005).

In addition, WCPL developed a database of all groundwater bores on and licences held for Peabody owned land in 2013.

2.5.3 Springs

The bore census conducted by WCPL in February 2005, as reported in AGE (2005), identified seven springs, none of which is located in the Modification areas.

Springs are likely to occur along the foothills of the sandstone escarpments. Field inspections of the Modification open cut extension areas by HunterEco as part of flora surveys and separately by WCPL personnel identified no evidence of springs or soaks in these areas.

2.6 BASELINE GROUNDWATER LEVEL DATA

2.6.1 Spatial Groundwater Levels

Natural groundwater levels are sustained by rainfall infiltration and are controlled by ground surface topography, geology and surface water elevations. Typically, local groundwater would mound beneath hills and would discharge to incised creeks and rivers. During short events of high surface flow, streams would lose water to the host aquifer, but during recession the aquifer would discharge water slowly back into the stream from bank storage and also discharge from more remote zones due to rainfall infiltration. Groundwater would flow from elevated to lower-lying terrain.

A contour map of pre-mining measured and inferred watertable levels in the vicinity of the mine site is presented in **Figure 12**. This map has been prepared from measurements at 29 sites:

- long-term averages (April 2006 to June 2012) at eight bores in the alluvial monitoring network;
- long-term averages (April 2006 to June 2012) at two bores along Wollar Creek in the coal monitoring network;
- initial levels at three bores near Cumbo Creek, measured November 2012;
- initial levels at nine registered bores, measured in 2003;
- initial level at one registered bore, measured in 1996; and
- watertables in 2012 inferred at six exploration bores from geophysical logs (resistivity, temperature, velocity).

The groundwater flow direction (perpendicular to the contours) is generally to the north-east. The flexures in the contours over Cumbo Creek and Wollar Creek suggest that groundwater is likely to be discharging to these drainage lines, and that the creeks are gaining systems. As the contours along Wilpinjong Creek are poorly defined to the north of the creek, an inference of gaining or losing status is not definite, but given the high likelihood of elevated watertables beneath the Goulburn River National Park it is probable that Wilpinjong Creek is a gaining system under natural average conditions.

The increased spacing between contours along Wilpinjong Creek is indicative of higher permeability in the Wilpinjong Creek alluvium, and lower reaches of Cumbo Creek alluvium, than in the coal measures outcropping over the mining lease.

The associated depth to water map (**Figure 13**) shows several areas with pre-mining water within 2 m of ground surface, and therefore subject to evapotranspiration. The areas are focused on the Wilpinjong Creek floodplain and the southern and northern reaches of Cumbo Creek. This adds credence to the likelihood of Wilpinjong Creek and Cumbo Creek being gaining systems. The depths to water along Wollar Creek rule out the creek being a gaining system, except possibly in some of the southern reaches.

The difference between the Ulan Seam floor elevations and the pre-mining watertable elevations gives the distribution of saturated thickness of sediments above the Ulan Seam (**Figure 14**). The range is from 0 to 50 m across the area approved for mining, and the average saturated thickness is 20 m. The volume of water within these sediments, which will be removed through excavation or mine dewatering, is estimated to range from 3.3 gigalitres (GL) (for 1% porosity) to 16.5 GL (for 5% porosity).

Over the planned mining period of 21 years, the linear rate of removal of unreplenished water from storage would range from 165 to 825 ML/a, which serves as a lower limit for licensing purposes. This equates to a daily rate of 0.5 to 2.3 ML/day, which accords well with the long-term average pit pumping rate of 1.6 ML/day, and the range from about 1 ML/day in 2006 to about 2 ML/day in 2011 (**Section 2.5.1**). These estimates do not account for replenishment by rainfall, for water removed directly in excavated material, or for water drawn in across the boundary of the mine plan; however, they serve as useful order of magnitude estimates for expected dewatering at dry times and have been used to validate the numerical model predictions.

Figure 15 illustrates where the Ulan Seam would be expected to be dry (that is, zero saturated thickness) under natural conditions. This would occur over about 10% of the area approved for mining. Of course, the act of mining will cause the demarcation line, between "wet" and "dry", to migrate northwards. In practice, some of the southern areas to be mined would be dry.

2.6.2 Temporal Groundwater Levels

Available groundwater levels around the WCM site have been investigated in detail to check for cause-and-effect responses in temporal water level changes which could result from rainfall recharge, creek dynamics, short-term dewatering/production pumping or a mining effect.

Many paired monitoring bores have been drilled along the Wilpinjong Creek alluvium, with a shallow bore screened in the alluvium and a deeper bore screened across the coal seam.

Figure 16 shows the groundwater elevations (in the Ulan Coal Seam) adjacent to the central part of Pit 1 at pit piezometers PZ01 to PZ14. Tailings Dams TD1 and TD2 are alongside PZ10-14 and PZ01-09 respectively. As the water levels at PZ10-14 remain stable, apart from occasional rises that coincide with wet events, this suggests that equilibrium has been reached with the fluid in TD1[3]. The monitoring sites adjacent to TD2 (apart from PZ01 which remains generally stable) show generally rising water levels from 2010 onwards. However, this coincides with rises in the residual mass. On the whole, the responses at PZ02-PZ09 correlate closely with rainfall and do not seem to be affected by the proximity of TD2.

As monitoring at these piezometers started in April 2008, 22 months after Pit 1 commenced, there is no information at these locations on groundwater response at the onset of mining. However, it is possible to estimate the *maximum* mining-induced drawdown (in coal) from the pre-mining watertable presented in **Figure 12**. The results, listed in **Table 6**, indicate a drawdown of 2-6 m at PZ01 to PZ11, with hardly any effect (0-1 m) at PZ12 to PZ14.

Similarly, **Figure 17** shows the groundwater depths (in the Ulan Coal Seam) adjacent to Pit 2 and the eastern part of Pit 1 at pit piezometers PZ15 to PZ28[4]. Pit 2 West Dam (370±1 mAHD) and Tailings Dam TD3 are alongside PZ16-21 and PZ22-28 respectively. The water depths at the bores fluctuate from 1 to 5 m in general, but there is reasonable correlation with the RMC. There is no definitive connection with the adjacent dams.

[3] The fluid level is not known at TD1 or TD2
[4] Bore collar levels have not been surveyed at these sites

As monitoring at these piezometers started in December 2009, about three years after commencement of mining, there is no information on groundwater response at the onset of mining. However, it is possible to estimate the *maximum* mining-induced drawdown (in coal) from the pre-mining watertable depths presented in **Figure 13**. The results, listed in **Table 6**, indicate a drawdown of 4-5 m at PZ22 to PZ26, with hardly any effect (0-1 m) at PZ15 to PZ17 and PZ20.

Table 6. Inferred Groundwater Drawdowns at Pit Piezometers (m)

Piezometer	Drawdown (m)	Piezometer	Drawdown (m)
PZ01	4	**PZ15**	1
PZ02	5	**PZ16**	0
PZ03	6	**PZ17**	1
PZ04	6	**PZ18**	3
PZ05	5	**PZ19**	2
PZ06	6	**PZ20**	1
PZ07	5	**PZ21**	3
PZ08	5	**PZ22**	5
PZ09	4	**PZ23**	4
PZ10	2	**PZ24**	5
PZ11	4	**PZ25**	4
PZ12	0	**PZ26**	4
PZ13	0	**PZ27**	2
PZ14	1	**PZ28**	2

Figure 18 presents the groundwater hydrographs for all alluvial bores from the west (higher elevations) to the east (lower elevations), in relation to rainfall residual mass. There was a pronounced dry period from July 2006 to March 2007 which coincided with the commencement of Pit 1. Pit 2 commenced under normal climatic conditions but within two months was exposed to a very wet period. Both pits were exposed to another very wet period that commenced in October 2007. The transition from a very dry period to a very wet period explains the initial experience of unexpectedly low pit inflows followed by excessive groundwater discharges. Additional wet periods are indicated by the RMC, especially from 2010 onwards.

The groundwater table in the alluvium varies from about 385 mAHD to about 345 mAHD over a distance of 8.4 km from GWa1 to GWa7, with hydraulic gradient 0.5% (0.005). Groundwater responds to this gradient by flowing to the east through the alluvium.

Watertable rises are evident at most bores in correlation with rises in the RMC. This confirms the expectation that rainfall is an important source of recharge for the alluvial aquifer. Given the proximity of the alluvium to the elevated Goulburn River National Park to the north, groundwater discharge from the Park's Narrabeen sediments will provide another stable source of recharge to the alluvium.

Three of the monitored bores are adjacent to Pit 1 and Pit 2 excavations: GWa2, GWa10 and GWa11. Only GWa2 has data back to the commencement of mining. While there is a slight decline in water level from mid-2006 to early-2007, coincident with the commencement of mining, the decline also correlates with the fall in rainfall residual mass. Two other distant bores (GWa3, GWa6) show the same decline during the same period, which is definitely a climate effect as they are well away from any pit effects. The three bores near the two pits show no abnormal behaviour during 2007 and 2008 when compared with distant bores. This suggests that the pits are having no discernible effect on alluvial groundwater levels. There is no more than 1-2 m reduction from the inferred pre-mining water levels at any site in **Figure 12**, but this is within the natural fluctuation range.

Figure 19a presents the groundwater hydrographs for all coal bores from the west (higher elevations) to the east (lower elevations), in relation to rainfall residual mass and the commencement of mining in each pit. Three bores (GWc1, GWc2 and GWc3) have records extending back to 2006. These hydrographs show clearly the drawdown caused by excavation of Pit 1 and Pit 2. At the bore closest to mining in Pit 1 (GWc1), the drawdown is about 13 m. At the bores closest to Pit 2 mining (GWc2, GWc3), the drawdowns are about 7 m and 1 m respectively. The water level at GWc1 commenced recovering in mid-2007 and had returned to pre-mining levels by 2012.

At the other coal bores, the pre-mining water levels are not known exactly but can be inferred from the contour map in **Figure 12**. The hydrographs show the expected response of drawdown contingent upon the distance from mining, with gradual recovery over about five years in line with the increasing residual mass trend. The most distant site (GWc5 at Wollar) shows no discernible drawdown effect from mining.

Three of the monitored coal sites are considered to be unreliable (GWc14, GWc15 and possibly GWc12). The reported heads, shown in **Figure 19b**, are up to 8 m higher than surveyed casing levels.

Site GWa5 is in Cumbo Creek alluvium to the south of Pit 4 and to the east of the central part of Pit 2 (**Figure 8**). The hydrograph in **Figure A-1, Attachment A** shows an early drawdown of about 0.5 m that could be due to Pit 1 mining but could equally well be due to climate as this period coincides with dry conditions. The remainder of the hydrograph shows strong correlation with residual mass trend.

2.6.3 Vertical Head Differences

Exploration investigations prior to project approval (GeoTerra Pty Ltd, 2005) reported artesian pressures in the Ulan Seam that were up to 2.7 m above ground level within the mining lease area. A long-term 42 day pumping test was conducted to investigate the degree of hydraulic connectivity between the overburden and the Wilpinjong Creek alluvium. For the bores participating in the pumping test, artesian pressures up to 1.1 m above ground were noted in the Ulan Seam. The vertical head difference between the Ulan Seam and Coal Measures overburden was about 4 m, while the corresponding head difference between overburden and alluvium was about 3 m. A vertical head difference in the order of 7 m between the Ulan Seam and the alluvium is an indicator of poor vertical connectivity, although the direction of the hydraulic gradient makes possible some recharge of the alluvium from underlying aquifers.

Concerns were raised by the Department of Water and Energy in 2009 that the reduction in pressure in the Ulan Seam due to mining operations might reduce upward leakage to the alluvium, and consequently reduce baseflow from the alluvium to Wilpinjong Creek.

The hydrographs for paired piezometers in **Attachment A** show the vertical head differences between alluvium and coal at adjacent sites. At 300 m to the north-west of Pit 1 (**Figure A-2, Attachment A**), the head gradient is always downwards during the period of mining, with a maximum head difference of about 13 m. The coal water levels show steady recovery in line with the residual mass trend, whereas the alluvium shows no definitive effect from mining. However, there is a sharp drawdown of 2-3 m in 2007 which may have been caused by Pit 1 mining.

At 300 m to the north-east of Pit 1 (**Figure A-3, Attachment A**), the head gradient is downwards during the period of mining except after 2011 when the heads are coincident, with a maximum head difference of about 11 m. The coal water levels show steady recovery in line with the residual mass trend, whereas the alluvium shows no effect from mining.

At 300 m to the north of Pit 2 (**Figure A-4, Attachment A**), the head gradient is downwards until 2010, after which the heads appear to be similar. The maximum head difference is about 10 m in 2008. The coal water levels show steady recovery in line with the residual mass trend, whereas the alluvium shows no effect from mining.

At 500 m to the north of Pit 4 (**Figure A-5, Attachment A**), the head gradient is downwards only during 2007 when Pit 2 mining commenced. The coal water levels, if GWc12 is recording correctly, returned to artesian conditions rapidly (1-2 m above casing) with a maximum upwards head difference of about 4 m. The alluvium water levels show a possible mining effect in 2007 with very clear rainfall responses from 2008 onwards.

About 300 m to the east is another pair of piezometers (**Figure A-6, Attachment A**). These hydrographs show a pronounced Pit 2 effect and a possible Pit 1 effect on the coal seam water levels, with rapid reversion to artesian conditions with a maximum upwards head difference of about 3-4 m.

A further 500 m to the east is a pair of bores which are about 300 m north of Pit 4. These hydrographs (**Figure A-7, Attachment A**) also suggest an upwards gradient, but the reported coal head (GWc14) is up to 5 m above casing and may not be reliable. There appears to be a strong initial effect from Pit 2, followed by a rapid recovery.

Near the junction of Pit 4 and Pit 3 close to Cumbo Creek is a pair of piezometers whose hydrographs are displayed in **Figure A-8, Attachment A**. The coal heads are not artesian but they are always higher than the alluvium heads, even during a probable Pit 2 effect in 2007. The upwards head difference is consistently 1-2 m.

At 200 m north of Pit 3 on Wilpinjong Creek, artesian heads are indicated for the coal seam (GWc15), but the reported head is up to 9 m above casing and may not be reliable (**Figure A-9, Attachment A**). There is no mining effect on alluvium water levels.

The piezometers near Slate Gully (far east) are not paired as the alluvium and coal sites are separated by about 1.3 km. Nevertheless, their hydrographs are compared in **Figure A-10, Attachment A**. An upwards head difference of about 7 m is indicated. Both hydrographs are very stable and show much smaller fluctuations than elsewhere. There is a hint of a slight effect on coal water levels from distant Pit 1 and Pit 2 mining (5 km away) but the slight decline in water level in the early years could be a climatic effect.

The piezometers near Wollar are separated by about 800 m. Again, an upwards head difference of about 2-3 m is indicated (**Figure A-11, Attachment A**). Also, there is a hint of a slight effect on coal water levels from distant Pit 1 and Pit 2 mining (5 km away) but the slight decline in water level in the early years could be a climatic effect.

In summary, there has been no definitive effect on alluvial water levels observed in the monitoring bores to date. Some bores suggest that there may be upward leakage from the coal seam to the alluvium. The potential reduction in upflow has been modelled and assessed (**Section 4.7**).

2.6.4 Stream-Aquifer Interaction

The degree of interaction between creek waters and alluvial groundwater is informed by **Figures 20a and 20b**. Interpolated dynamic creek water levels (solid curves) adjacent to monitoring bores are compared with watertable responses (dashed curves) for upstream locations in **Figure 20a** and downstream locations in **Figure 20b**. There is uncertainty in the accuracy of absolute elevations, as creek bed level and bore ground level are estimates. It is recommended that WCPL conduct a ground survey of creek invert and all relevant bore ground levels.

In each upstream case, the creek level is consistently below the groundwater level, with head differences typically about 3 m near Pit 6 and 1 m near Pit 2. This reinforces the conceptualisation that Wilpinjong Creek is a gaining stream. At GWa2 (north-west Pit 1) there is expected to have been a brief reversal of gradient in 2007 at which time the creek would have been leaking at this location. At GWa10 and GWa11, it is likely that the creek would have converted from a gaining condition to a losing condition during all of 2009.

In each downstream case, the creek level is always below the groundwater level, with head differences typically 0.5 to 3 m. The creek generally appears to be gaining but there are indications of coincident water levels at some sites in mid-2007, associated with early mining, and at the end of 2009, late 2011 and mid-2012 during dry periods.

2.7 BASELINE SALINITY DATA

2.7.1 Spatial EC

An indication of the spatial pre-mining salinity pattern is given in **Figure 21**. This map represents the salinity at 13 monitoring sites averaged from April 2006 to June 2012, supplemented by initial measurements at nine registered bores in 2003 and 2006. In all, 935 measurements were considered. The median value of the measurements at the 13 monitoring sites is about 2500 microSiemens per centimetre (µS/cm). The average of 3900 µS/cm is considerably higher than the median, and the standard deviation (3100 µS/cm) is commensurate with the mean. The statistics for individual monitoring bores are given in **Table 7**.

The contours in **Figure 21** suggest that the highest salinities occur on Cumbo Creek to the south of Pit 4, on Wilpinjong Creek near Pit 6 and on Wilpinjong Creek to the north-east of Slate Gully. The lowest salinities are along Wilpinjong Creek from Pit 1 to Pit 4, upstream of the Cumbo Creek junction, and on Wollar Creek.

Table 7. Groundwater Electrical Conductivity Statistics (µS/cm)

	Mean	Standard Deviation		Mean	Standard Deviation	Location
ALLUVIUM:			*COAL:*			
GWa1	7500	2700				North of Pit 6: Far west
GWa2	1600	590	GWc1	2200	450	North of Pit 1
GWa3	1600	370	GWc2	1100	130	North of Pit 4
GWa4	2300	470				North-east of Pit 3
GWa5	10100	3000				South of Pit 4 on Cumbo Creek
GWa6	5400	2000	GWc3	3300	350	Northern end of Cumbo Creek
GWa7	9400	2000	GWc4	2300	190	North-east of Slate Gully
GWa8	2200	500	GWc5	4900	520	Wollar: South-east of Slate Gully

The lowest mean salinity in the alluvium holes is 1,600 µS/cm at GWa2 and GWa3, whereas the highest mean is 10,100 µS/cm at GWa5. The lowest mean salinity in the coal holes is 1,100 µS/cm at GWc2, whereas the highest mean is 4,900 µS/cm at GWc5. On the whole, the alluvial groundwaters are more saline than the coal seam waters. This suggests that the alluvial waters are sourced from Permian sediments and are concentrated through evapotranspiration. As the depth to water map in **Figure 13** shows that the watertable is within a few metres of ground surface at alluvial monitoring points, evapotranspiration is expected to be an active process.

2.7.2 Temporal EC

Temporal variations in groundwater salinity are illustrated in **Figure 22** in alluvium and in **Figure 23** for coal, and are compared with rainfall residual mass. Some alluvial sites have very high salinities and very large fluctuations that bear no apparent relationship with rainfall or mining. The salinities in the coal holes are consistently stable. The different signatures for shallow and deep waters reflect dynamic evapotranspiration acting preferentially on shallow groundwater.

2.8 CONCEPTUAL MODEL

A conceptual model of the groundwater regime has been developed based on the review of existing hydrogeological data, including:

- Gulgong 1:100000 Geological Map Sheet;
- WCPL exploration (geological) data, bore logs and downhole geophysics;
- Transient electro-magnetic (TEM) geophysics commissioned by WCPL in 2011;
- NOW Pinneena Groundwater Works Database records;
- Bore census conducted by WCPL in 2013;
- Previous hydrogeological assessments/reviews undertaken for the WCM and surrounding mines (i.e. GeoTerra Pty Ltd, 2004; AGE, 2005; GeoTerra Pty Ltd, 2005; Merrick, 2005; Wilton and Dundon, 2008; RPS Aquaterra, 2011; Mackie Environmental Research, 2009);
- Piezometric data from groundwater monitoring programs undertaken at the WCM and surrounding mines (**Attachment B**) (i.e. WCPL, 2006a, 2006b, 2010; RPS Aquaterra, 2011); and

- Groundwater investigation testwork (e.g. pumping tests) commissioned by WCPL (GeoTerra Pty Ltd, 2004; GeoTerra Pty Ltd, 2005; Merrick, 2005).

The groundwater system in the WCM area has five recognisable components as itemised by AGE (2005):

- "elevated sandstones of the Narrabeen Group;
- alluvium/colluvium along Wilpinjong Creek and alluvium along Cumbo Creek;
- overburden, encompassing Illawarra Coal Measures and lower sections of the Narrabeen Group;
- Ulan Seam; and
- Marrangaroo Sandstone".

Based on the above, and consistent with the relevant water sharing plans, the data supports two distinct groundwater systems:

- **Porous Rock groundwater system -** primarily the Illawarra Coal Measures; and
- **Alluvial groundwater system** – associated primarily with Wilpinjong Creek.

Alluvial deposits are associated with Wilpinjong and Cumbo Creeks in the WCM area and Moolarben Creek about 4 km to the south-west of the WCM area. Colluvial deposits are evident Wilpinjong Creek and the Goulburn River National Park.

None of the identified groundwater systems are significant aquifers. The most permeable units are the Ulan Seam and Marrangaroo Conglomerate, while the sandstones of the Narrabeen Group are of lower permeability and are elevated above the WCM area. The Illawarra Coal Measures include low permeability mudstones and siltstones.

Conceptual groundwater models are illustrated in **Figure 24** before and during mining.

Recharge to the groundwater systems would occur primarily from rainfall and runoff infiltration, and lateral groundwater flow especially from the elevated Narrabeen Group to the alluvium of Wilpinjong Creek. Seepage faces would be expected along the cliff faces bordering Wilpinjong Creek after rainfall events, and perched water tables might be sustained at high elevations due to the presence of occasional mudstone/siltstone beds between the sandstone layers. Although groundwater levels are sustained by rainfall recharge, they are controlled by topography, geology and surface water levels in local drainages. Local groundwater tends to mound beneath hills but mounding is expected to be slight to the south of the WCM area because subcropping coal seams are dry there. Wilpinjong Creek and Cumbo Creek are conceptualised as gaining systems under natural conditions. Groundwater, under natural conditions, is expected to discharge upwards from the Permian rocks to the alluvium associated with Wilpinjong Creek. Loss by evapotranspiration (ET) is likely along the riverine corridor where the watertable is near the ground surface (generally 2 m to 3 m below ground level).

During mining the watertable will be lowered in the vicinity of active open cut pits, but the watertable will tend to rise beneath waste emplacement mounds. Groundwater sourced from the coal measures and the emplacements will report to the open cut pit. Some reduction in creek baseflow and groundwater upflow would be expected. At times, or in some reaches, the natural groundwater upflow could be converted to downflow from the alluvium to the Permian rocks.

3 GROUNDWATER SIMULATION MODEL

3.1 EXISTING MODEL

The groundwater assessment for the original Environmental Impact Statement (EIS) was based on a regional MODFLOW groundwater model developed by AGE (AGE, 2005). Model predictions were made on the basis of calibration against steady-state groundwater levels prior to mining, without the benefit of mine inflow data.

The groundwater model predictions of mine inflows at that time were:

- Pit 1: 1.68 ML/day (612 ML/a);
- Pit 2: 0.23 ML/day (85 ML/a);
- Pits 1 and 2: 1.91 ML/day (697 ML/a).

When unexpectedly low pit inflows were observed in the early months of Pit 1 excavation, WCPL contracted AGE to update the EIS groundwater model. The results of the modelling were documented in a letter report dated 28 February 2007 (AGE, 2007).

The approach followed in the revised modelling was deliberately conservative in that its aim was to find the minimum pit inflow rates that were consistent with observed steady-state and transient groundwater levels. Model calibration was performed using seven months of water level data from July 2006 to January 2007, coinciding with a particularly dry period that prevailed at the commencement of Pit 1.

One of the assumptions in this conservative model was that there was zero rainfall recharge during the calibration period. This assumption was applied also to the prediction of pit inflows out to 2011, for Pits 1 and 2 only. This implies that the only source of water for pit inflows was that residing in storage in the coal seam and the underlying Marrangaroo Sandstone, and that groundwater discharges to the pit were sourced only by lateral and vertical flow. No overburden or alluvium was included in this model.

The revised dry-period groundwater model predictions of mine inflows were:

- Pits 1 and 2 (average to December 2011): 1.17 ML/day (427 ML/a);
- Pits 1 and 2 (minimum): 0.49 ML/day (180 ML/a);
- Pits 1 and 2 (maximum): 2.25 ML/day (821 ML/a).

Comparison of the inflow estimates for normal weather conditions and for a dry period suggests that about 60% of the inflow is sourced from persistent lateral groundwater seepage and about 40% is due to rainfall surcharge.

In a letter report dated 3 March 2010, AGE provided estimates of mine inflow for each pit out to December 2026 for three rainfall recharge scenarios (zero, 1%, 2%) (AGE, 2010). No additional calibration was performed, and only the bottom two layers of the model (Ulan Seam and Marrangaroo Sandstone) were included in the simulation. For 1% rainfall recharge, the average total pit inflow was 103 ML/month (1,236 ML/a) over 20 years. As the modelling pre-dated the release of the Aquifer Interference Policy (AIP), no assessment of take from the alluvium or the creeks was considered. This was not possible anyway with the model as the upper layers hosting the creeks and the alluvium were excluded from simulation.

In order to quantify incidental water loss from the alluvium to the hardrock, and to re-assess the impact on creek baseflows, the original EIS Groundwater Model that incorporates the alluvium and the creeks has been converted in this assessment to a more suitable software platform for water balance interrogation[5]. As the EIS model has performed well in terms of predicting aggregate dewatering volumes and drawdowns at monitoring sites, the EIS model was used without substantive amendment for evaluating the incremental impacts of the Modification. The only changes that have been made are:

- an increase in the vertical permeability of the Wilpinjong Creek alluvium (an Independent Hearing and Assessment Panel [IHAP] recommendation [Kearns et al., 2005]); and
- incorporation of the actual mine sequence to 2012 and the projected mine sequence or the Modification mine sequence from 2013 to 2026.

For consistency with the EIS model, MODFLOW96 was retained as the modelling software as it remains a robust modelling option. However, conversion was made from PMWIN to the more capable Groundwater Vistas graphic user interface.

3.2 MODEL LAYERS AND GEOMETRY

The model domain is discretised into 142,085 cells of which 79,536 are active. The grid consists of 157 rows, 181 columns and 5 layers, and is rotated 40 degrees clockwise (**Figure 25**). The dimensions of the model cells vary from 70 m x 70 m within the WCM area to 500 m x 1,050 m at the edges. The model covers an area of about 450 km^2 and extends approximately 27 km from west to east and 26.5 km from south to north.

The following layers are defined in the model:

- Layer 1: Narrabeen Group;
- Layer 2: Alluvial/Colluvial Deposits and Narrabeen Group;
- Layer 3: Illawarra Coal Measures and Narrabeen Group;
- Layer 4: Ulan Seam; and
- Layer 5: Marrangaroo Conglomerate.

The southern boundary of the model is constrained by where the Ulan Seam and Marrangaroo Conglomerate either subcrop, abut granite extrusions or are believed to thin to less than 2 m thickness.

3.3 HYDRAULIC PROPERTIES

The EIS groundwater assessment by AGE (2005) included a summary of pumping tests and slug tests undertaken within the WCM area by GeoTerra Pty Ltd (2004) to determine hydraulic properties of various formations. The tests showed little difference between the Ulan Seam and the underlying Marrangaroo Conglomerate. The summary is reproduced here as **Table 8**.

[5] Converted from PMWIN to Groundwater Vistas software.

Table 8. Field-Derived Hydraulic and Storage Properties (AGE, 2005)

Bore	Seam/Strata	Depth (mbgl)	Transmissivity T (m^2/day)	Hydraulic Conductivity K (m/day)	Storativity S (-)	Test Method
EW 2012	Ulan Seam	6.5-22.1	27.9	1.8	$8.1x10^{-4}$	24hr pump out test at constant rate – 3L/sec
EW 5001	Marrangaroo Sandstone	23.5-28	27.9	6.2	$1.3x10^{-3}$	24hr pump out test at constant rate – 3L/sec
EW 2014	Ulan Seam	23.6-36.1	150/79*	11.5/6.0*	0.23/ $3.2x10^{-3}$	24hr pump out test at constant rate – 3L/sec
EW 2006	Coal and siltstone – Illawarra Coal measures	0-7.9		0.01		Slug Test
EW 2011	Sandstone/siltstone/ coal – Illawarra Coal Measures	0-11.7		0.05		Slug Test
EW 2013	Sandstone/siltstone/ coal – Illawarra Coal Measures	0-15.2		0.09		Slug Test
EW 5052	Ulan Seam	6-12		0.01		Slug Test
EW 1005	Marrangaroo Sandstone	43-46		0.01		Slug Test
EW 5032	Marrangaroo Sandstone	18-19.7		0.01		Slug Test
EW 5049	Marrangaroo Sandstone	13-14		0.02		Slug Test
EW 5053	Marrangaroo Sandstone	10.5-13.5		0.01		Slug Test

mbgl – metres below ground level.
m^2/day – square metres per day.
m/day – metres per day.
* Parameters determined during drawdown/recovery.

Since the EIS, Merrick (2005) assessed alluvial-rock leakance by using the HotSpots analytical model to interpret the data acquired in a 42-day pumping test by GeoTerra Pty Ltd (2005). Over that limited period of time, no observable response was found in the alluvial aquifer due to pumping from the Ulan Seam. Modelling demonstrated that the leakance for the materials between the alluvium and the coal could be no higher than 1.5×10^{-6} day^{-1}. The hydrographic analysis in **Section 2.6.3** demonstrates a lack of hydraulic connectivity in a vertical direction between the Wilpinjong Creek alluvium and the underlying sedimentary rocks, consistent with the pre-mining analysis of the pumping test. This confirms that the leakance must be very low, without being able to assign a precise quantitative value.

Substantial groundwater assessments have been undertaken for the adjacent coal mines to the west of the WCM: Ulan Coal Mine (Mackie Environmental Research, 2009) and Moolarben Coal Mine (Wilton & Dundon, 2008; RPS Aquaterra, 2011). There are some significant differences between the physical properties adopted in the two groundwater models that underpin the respective assessments. In general, nearly all adopted values are defensible on the basis of packer and core measurements (**Table 9**), as field and laboratory measurements cover a wide range of values. The Moolarben horizontal hydraulic conductivity values are usually at the upper end of what is reasonable, while the corresponding Ulan values are generally closer to the median. A comparison of model-calibrated hydraulic conductivities is offered in **Table 10**, along with an opinion on which estimates are more likely.

Table 9. Packer Test and Core Test Hydraulic Properties at Ulan and Moolarben Mines

	PACKER TESTS			CORE TESTS		
Lithology	**Kx (min) [m/day]**	**Kx (mode) [m/day]**	**Kx(max) [m/day]**	**Kx (min) [m/day]**	**Kx (mode) [m/day]**	**Kx(max) [m/day]**
Upper Triassic	1.00E-05	3.00E-04	0.1	1.00E-05	3.00E-02	10
Lower Triassic				1.00E-06	3.00E-04	0.1
Upper Permian						
Middle Permian	1.00E-05	3.00E-03	1	1.00E-08	3.00E-06	1
Lower Permian						
Ulan Seam	1.00E-04	3.00E-02	10			

Table 10. Comparison of Model-Calibrated Hydraulic Properties at Ulan and Moolarben Mines

MOOLARBEN MODEL					ULAN MODEL				
Layer	**Lithology**	**Kx [m/day]**	**Kz [m/day]**	**Kx/Kz**	**Layer**	**Lithology**	**Kx [m/day]**	**Kz [m/day]**	**Kx/Kz**
2	**Upper Triassic**	0.5 *at upper limit*	1.00E-04 *OK*	5000 *OK*	**4** **5**	**Triassic quartzose sandstone**	0.15 *at upper limit*	0.08 *high*	2 *very low*
3	**Lower Triassic**	0.2 *at upper limit*	5.00E-05 *OK*	4000 *OK*	**6**	**Triassic lithic sandstone**	0.004 *near median*	2.00E-04 *OK*	20 *low*
4	**Upper Permian**	0.1 *near upper limit*	2.50E-05 *OK*	4000 *OK*	**7**	**Upper Permian**	1.00E-04 *near median*	5.00E-06 *OK*	20 *low*
5	**Middle Permian**	0.1 *near upper limit*	2.50E-05 *OK*	4000 *OK*	**8**	**Middle Permian**	4.00E-04 *near median*	8.00E-06 *OK*	50 *OK*
6	**Lower Permian**	0.05 *near upper limit*	1.00E-05 *OK*	5000 *OK*					
7	**Ulan Sean**	1 *near upper limit*	5.00E-04 *low*	2000 *high*	**9**	**Ulan Seam**	0.42 *near upper limit*	0.3 *OK*	1 *OK*

3.4 MODEL STRESSES AND BOUNDARY CONDITIONS

The rotated model grid and boundary conditions are displayed in **Figure 26**. MODFLOW river (RIV) cells are applied along Goulburn River, Wilpinjong Creek, Cumbo Creek and Wollar Creek. MODFLOW drain (DRN) cells are applied to the escarpments of the Goulburn River National Park and Munghorn Gap Nature Reserve, and to the drainage lines issuing from elevated ground.

The model layers in which the RIV and DRN boundary conditions are applied, are indicated in **Figure 27**, which also shows the definition of active and inactive ("no-flow") cells in each layer.

Rainfall recharge is applied to each active model cell as a percentage of actual rainfall (using the MODFLOW RCH mechanism). Four recharge zones are defined:

- Zone 1: Alluvium 19%;
- Zone 2: Permian regolith 0.7%;
- Zone 3: Narrabeen Group 15%; and
- Zone 4: Coal Seam Subcrops / Colluvium 5%.

These rainfall recharge rates are based on conceptualisation of the groundwater system and model calibration.

MODFLOW drain (DRN) cells are used to simulate mining, with the drain invert set at the floor level of the Ulan Seam.

3.5 MODEL VALIDATION

To confirm that the EIS Groundwater Model is sufficiently robust for this groundwater assessment, the predicted cumulative inflow has been compared to reported pumpage from the main pit sump and dewatering bores at the WCM since 2006. The volumes pumped from the main pit include rainfall and surface runoff in addition to groundwater inflow, but exclude evaporation from the pit and from groundwater seepage faces. There is also likely to be a component of dam seepage for water that is recirculated across the site. The volumes are not metered but are estimated from the number of hours of pump operation multiplied by a representative pump capacity. Nevertheless, the estimated pumped volumes are likely to provide an upper limit estimate of groundwater inflows to the pits, although the estimate will have considerable uncertainty. Much of the predicted pit inflow will be lost by evaporation at seepage faces or from pools.

The total volumes for the period May 2006 to December 2011 between predicted and recorded values are very close:

- Predicted total volume 3,110 ML (549 ML/a); and
- Recorded total volume 3,160 ML (557 ML/a);

Given the two estimates have the same order of magnitude, and coincidently close agreement over this period, it is considered that the model is dependable for assessing the impacts of the Modification.

An assessment was made also of the accuracy of drawdown predictions by the EIS model. The AGE (2005) report presented contour maps of drawdown at the end of mining (21 years) for the Illawarra Coal Measures and the Ulan Seam. These maps show similar cones of depression that extend approximately 2.5 km to the east, 5 km to the west and 6.5 km to the north. The drawdown beneath the Wilpinjong Creek corridor was predicted to be about 10 m where the monitoring bores are located. To refine the predictions, the EIS model was re-run as part of this assessment so that simulated hydrographs could be produced for comparison with observed hydrographs. Apart from differences in the onset of drawdown due to the difference between the EIS and actual mine plans, the predicted drawdowns at all coal monitoring bores were in good agreement with those observed. The maximum predicted drawdown was 10 m at GWc1, in good agreement with the drawdown indicated in **Attachment A** immediately after the commencement of Pit 1.

4 SCENARIO ANALYSIS

4.1 MINING SCHEDULE

A summary of the mining schedule that has been used for the WCM in the groundwater model is provided in **Figure 28**. This table outlines stress period setup for transient simulation for historical, prediction and recovery model runs. The historical period ran from 1 July 2006 to 31 December 2012 and included partial excavation of Pit 1, Pit 2, Pit C (located within the southern end of the Pit 1 disturbance area), Pit 5 and Pit 4.

The prediction period ran from stress period 15 (January 2013) to stress period 42 (December 2026) in half-yearly steps. This period included excavation in all pits other than Pit C. The lengths of the stress periods and the spatial distributions of active pits were set to match advice from WCPL regarding mine progression.

4.2 MODELLING APPROACH

The potential impacts of the Modification have been assessed by making comparisons between the currently approved and the proposed modified mine plan for the WCM.

The effects of the Modification should be considered in the context of the effects generated by the approved WCM. While this assessment presents the local and regional drawdowns that result from all mining activities, the focus is on incremental changes in potential impacts for the currently approved mine plan for WCM and the modest pit extensions associated with the Modification (**Figure 2**).

Two suites of prediction modelling have been run – one with the approved layout and one with the modified layout (**Figure 2**). This allows the net impact of the Modification on the hydrogeological environment to be evaluated separately from the other regional impacts.

4.3 MODEL IMPLEMENTATION

Active open cut pits were simulated in the model using MODFLOW drain cells with the invert elevation set to the floor of the Ulan Seam. Each drain cell was kept active for one year, after which time it was taken to be infilled with spoil. The permeability of the spoil was not altered from the host value as MODFLOW96 does not allow material values to vary in time, and the focus in this assessment is on the differential effects of the approved mine plan and the Modification. The two runs are, therefore, equivalent in all respects except for some additional active mine cells in the Modification simulation (**Figure 2**). However, the infiltration characteristics of spoil were accommodated by allowing no recharge for 5 years on spoil cells to allow the waste emplacement to wet up (**Figure 28**). After that time, the spoil cells were allocated enhanced rainfall recharge (5%).

Constant head cells were allocated to the major dams in the WCM area (Pit 1 South, Recycle Water Dam, Pit 2 West) in accordance with the schedule in **Figure 28**.

After completion of the prediction runs, a recovery simulation was undertaken for 200 years (**Figure 28**). All pit drain cells were deactivated and replaced with spoil, except for the locations of two final voids associated with Pit 3 and Pit 6.

4.4 WATER BALANCE

The average water balance for the simulation model (historical and prediction periods) across the entire model area is summarised in **Table 11** for scenarios with and without the Modification. The water balance reports the inflows, outflows and change in storage over the entire model domain.

The results for the two scenarios are almost identical, the only differences being an increase in mine inflow for the Modification of 0.01 ML/day and corresponding changes in the total budget and the storage loss. The water balance is consistent with the model conceptualisation.

For both scenarios, the total inflow (recharge) to the aquifer system within the model extent is approximately 29 ML/day, comprising almost entirely rainfall recharge. Leakage from streams is only 0.02 ML/day. Groundwater discharge is dominated by discharge to drainage lines and the escarpments (49%), stream baseflow (42%), with lesser roles played by mine inflow (8%) and ET (2%).

Table 11. Average Simulated Water Balance during the Historical and Prediction Periods with and without the Modification

COMPONENT	MODEL WITH APPROVED MINING		INCREMENTAL CHANGE DUE TO MODIFICATION	
	Inflow (ML/day)	Outflow (ML/day)	Inflow (ML/day)	Outflow (ML/day)
Drains (Creeks and Cliff Faces)	-	15.73	-	0
Recharge (Direct Rainfall)	29.36	-	0	-
ET	-	0.66	-	0
River (Leakage/Baseflow)	0.02	13.49	0	0
Open Cut Pits	-	2.52	-	0.01
Total	29.38	32.39	0	0.01
Storage	3.02 Loss		0.01 Loss	

4.5 PREDICTED PIT INFLOW

The average inflows for each pit are compared in **Table 12** for the approved mine plan and the Modification. The differences are no more than 0.01 ML/day for any pit, and the total inflows differ by less than 0.01 ML/day. The estimates of annual pit inflows for the Modification mine plan for each year to 2026 are displayed in **Figure 29** in ML/a units and equivalent ML/day units (assuming steady flow on each day of a year).

The estimates of annual pit inflows from 2014 onwards are listed in **Table 13.** The maximum total inflow in any one year is estimated to be about 2,038 ML/a in year 2015 with the Modification, with a difference of about 4 ML/a between the approved mine plan and the Modification. Clearly, the maximum is a function of the mine plan sequence. The average inflow rate is predicted to be about 974 ML/a over the remainder of the mine life for the Modification, and about 3 ML/a less for the approved mine plan.

Table 12. Average Simulated Pit Inflows during the Historical and Prediction Periods [ML/day]

	PIT 1	PIT 2	PIT 3	PIT 4	PIT 5	PIT 6	TOTAL
Approved	0.89	0.34	0.85	0.58	0.89	1.12	2.57
Incremental Change Due to Modification	0.0	0.0	-0.01	0.01	0.0	0.0	0.0

Table 13. Water Source Losses Due to the WCM (including the Modification) [ML/a]

		APPROVED MINING			INCREMENTAL CHANGE DUE TO MODIFICATION		
MINING YEAR	CALENDAR YEAR	PIT INFLOWS	REDUCED BASEFLOW	REDUCED UPFLOW	PIT INFLOWS	REDUCED BASEFLOW	REDUCED UPFLOW
		Porous Rock Water Source	River Water Source	Alluvium Water Source	Porous Rock Water Source	River Water Source	Alluvium Water Source
9	2014	1739	103	7	36	1.5	0.1
10	2015	2034	131	8	4	0.9	0.0
11	2016	1856	145	9	7	0.6	0.0
12	2017	1065	148	9	-2	0.5	0.0
13	2018	908	150	9	0	0.4	0.0
14	2019	266	148	9	0	0.4	0.0
15	2020	24	142	8	0	0.5	0.0
16	2021	630	147	8	-4	0.4	0.0
17	2022	797	156	9	0	0.5	0.0
18	2023	963	157	9	0	0.5	0.0
19	2024	1520	164	10	0	0.3	0.0
20	2025	815	175	9	0	0.3	0.0
21	2026	0	166	9	0	0.3	0.0
	MAX	**2034 (in 2015)**	**175**	**10**	**36 (in 2014)**	**1.5**	**0.1**
	MEAN	**971**	**149**	**9**	**3**	**0.5**	**0.01**

4.6 PREDICTED BASEFLOW AND EVAPOTRANSPIRATION CHANGES

Approved WCM

The model suggests that Wilpinjong Creek receives baseflow from the groundwater system in the order of 1.6 ML/day pre-mining. The temporal variation in estimated baseflow in Wilpinjong Creek is shown in **Figure 30b**. There is predicted to be a mild decline in baseflow from 2006 to the end of mining. This is consistent with the EIS conclusion (AGE, 2005) which predicted the maximum loss of flow as a result of the Project to be about 11% of annual average flow in Wilpinjong Creek (immediately upstream of Wollar Creek).

Figure 30b also shows the estimated magnitude for ET from the Wilpinjong Creek alluvium. The finding of the model is that there is no perceptible variation in ET, and hence no effect on groundwater dependent vegetation.

The model also suggests that Cumbo Creek receives baseflow from the groundwater system of less than 0.1 ML/day pre-mining. The temporal variation in estimated baseflow in Cumbo Creek is shown in **Figure 31b**. A mild decline in baseflow is expected from 2006 to 2012, followed by a sudden and sustained reduction in baseflow from 2013 when Pit 4 commences near Cumbo Creek. There is also a very mild reduction in ET at this time, associated with the Cumbo Creek alluvium. By 2018 the alluvium will have been excavated. The loss of water associated with excavation of the alluvium has been estimated for groundwater licensing purposes (**Section 6.2**).

The reductions in baseflow for the two creeks are illustrated in **Figure 32** and **Figure 33** (in ML/day units) and are listed in **Table 13** (in ML/a units). The maximum reduction is expected to be about 175 ML/a and the average loss is expected to be about 149 ML/a over the remainder of the mine life.

Incremental Impacts of the Modification

The incremental changes in baseflows for the two creeks, due to the Modification, are listed in **Table 13** with the temporal variation shown in **Figure 30a** and **Figure 31a**. The maximum additional reduction in baseflow is about 1.5 ML/a, while the average is about 0.5 ML/a which is about 0.6% of the average estimated for the approved mine plan.

4.7 PREDICTED UPFLOW CHANGES

Approved WCM

The model suggests that the Wilpinjong Creek alluvium receives upflow from the underlying groundwater system in the order of 0.02 ML/day pre-mining. The temporal variation in estimated upflow in the Wilpinjong Creek alluvium is shown in **Figure 34b**. There is a gradual decline expected for upflow from 2006 to 2015, at which time a reversal to downflow (in the order of 0.005 ML/day) is possible until the end of mining.

The model also suggests a very minor upflow to the Cumbo Creek alluvium in the order of 0.00001 ML/day pre-mining. The temporal variation in estimated upflow in the Cumbo Creek alluvium is shown in **Figure 35b**. The effect of mining is to quickly convert the natural upflow to downflow, but the magnitude remains very low.

The reductions in upflow for the two alluvial systems are illustrated in **Figure 36** and **Figure 37** (in ML/day units) and they are listed in **Table 13** (in ML/a units). The maximum reduction is expected to be about 10 ML/a. The average loss is expected to be about 9 ML/a over the remainder of the mine life. These volumetric amounts are considered negligible for the purposes of licensing.

Incremental Impacts of the Modification

The incremental changes in upflows, due to the Modification, are listed in **Table 13** with the temporal variation shown in **Figure 34a** and **Figure 35a.** The maximum additional reduction in upflow is about 0.1 ML/a, while the average is about 0.01 ML/a which is about 0.1% of the average estimated for the approved mine plan.

4.8 PREDICTED DRAWDOWNS

Approved WCM

The maximum drawdowns predicted as a result of mining at the alluvium monitoring bores are listed in **Table 14**, ordered from west to east. At each site, there is no more than 0.1 m expected drawdown. Most sites are expected to have less than 0.01 m drawdown due to mining.

Table 14. Predicted Maximum Drawdown (m) at Alluvium Monitoring Bores

	GWa1	GWa2	GWa10	GWa12	GWa3	GWa14	GWa6	GWa15	GWa4
Approved	0.09	0.04	0.00	0.00	0.00	0.01	0.08	0.00	0.00
Incremental Change Due to Modification	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

For the coal monitoring bores, the maximum drawdowns range from 0.6 m at GWc4 (far east) to about 40 m at GWc3 (south of the confluence of Cumbo and Wilpinjong Creeks). The maximum predicted drawdowns are listed in **Table 15**, ordered from west to east.

Table 15. Predicted Maximum Drawdown (m) at Coal Monitoring Bores

	GWc1	GWc10	GWc11	GWc12	GWc2	GWc14	GWc3	GWc15	GWc4
Approved	14	13	11	13	16	20	43	17	0.6
Incremental Change Due to Modification	0.3	0.3	0.6	0.6	0.4	0.2	0.1	0.0	0.0

The predicted hydrographs for the coal monitoring bores are displayed in **Figure 38** as water levels (mAHD) and as drawdowns (m). The largest drawdowns are expected to occur while Pit 3 and Pit 4 are being excavated[6].

The regional drawdown pattern in the Ulan Seam is presented in **Figure 39** at the end of mining (year 2026). The 2 m drawdown contour is likely to extend about 1 km west, 4 km north and 3 km east of the proposed mining footprint. There is no drawdown to the south of the WCM as the Ulan Seam is expected to be dry under natural conditions (**Figure 15**).

Incremental Impacts of the Modification

The incremental changes in drawdowns at the monitoring bores, due to the Modification, are listed in **Table 14** for alluvium and in **Table 15** for coal. The maximum additional drawdown is no more than 0.01 m in alluvium and about 0.6 m in coal. The largest relative increment in drawdown would be about 5% at GWc11 to the north of Pit 2. The average incremental drawdown, due to the Modification, at all coal monitoring bores for the duration of mining is estimated to be about 0.03 m.

4.9 CUMULATIVE IMPACTS

Approved WCM

The Principle of Superposition has been applied for an indicative assessment of cumulative effects due to the proposed Moolarben Stage 2 Project. **Figure 39** shows the predicted 1 m and 5 m Ulan Seam drawdown contours in the year 2031 in the vicinity of the WCM (RPS Aquaterra, 2011; prediction updated June 2012).

At the western edge of Pit 6, the cumulative drawdown is expected to be about 15 m with contributions of 10 m from the WCM and 5 m from the Moolarben Mine. Where a 2 m drawdown effect is predicted for the WCM only (west of Pit 6), the combined drawdown is expected to be at least 7 m.

Incremental Impacts of the Modification

In the year 2031, the average additional drawdown, due to the Modification, at all coal monitoring bores is expected to be about 0.02 m. For such small increments, changes in the drawdown contour pattern for the approved mine plan and the Modification are imperceptible. It follows that the Modification would not contribute to any measurable incremental cumulative effect.

4.10 POST-MINING EQUILIBRIUM

Approved WCM

The post mining landform plan (at the completion of mining) remains largely unchanged from that proposed in the WCM EIS (WCPL, 2005). However, it includes some increased elevation in-pit waste rock emplacement landforms. Consistent with the approved mine, two final voids are planned at the end of 2026 – at the northern limit of Pit 3 and south of Pit 6. In accordance with the requirements of the Project Approval (Conditions 42 and 43) a Final Void Management Plan and Mine Closure Plan are to be prepared for the WCM.

[6] The oscillating drawdowns in some curves are an artefact due to assumed mining progression in half-yearly steps.

A recovery simulation has been run for 200 years. All pit drain cells were deactivated and replaced with spoil[7], except for the locations of the two final voids. The voids were simulated as highly permeable and highly porous media[8], equivalent to open water, with evapotranspiration set at the pan evaporation rate[9].

The recovery of the system is illustrated with predicted hydrographs at the coal monitoring bores (**Figure 40**). All bore water levels will have recovered completely prior to 200 years after the cessation of mining. After 100 years, all bores will have recovered to 95% of final equilibrium levels (within 0.4 m of final levels). The water levels in the coal bores are expected to recover about 55% in 25 years and 80% in 50 years.

The baseflow in Wilpinjong Creek should recover by 50% in about 25 years and by 90% in about 100 years (**Figure 30**, **Figure 32**).

The upflow from Permian rocks to Wilpinjong Creek alluvium should recover by 50% in about 15 years, by 75% in about 40 years and by 90% in about 80 years (**Figure 34**, **Figure 36**).

Incremental Impacts of the Modification

As there is an imperceptible difference between groundwater levels at the end of mining and for the Modification, there can be no difference between the two cases during recovery. The same final post-mining equilibrium conditions will be attained.

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[7] Hydraulic conductivity 1.5 m/day, specific yield 0.1
[8] Hydraulic conductivity 1,000 m/day; unit storage properties
[9] 1619 mm/a = 4.4×10^{-3} m/day

5 IMPACTS ON THE GROUNDWATER RESOURCE

5.1 POTENTIAL IMPACTS ON GROUNDWATER

Approved WCM

The main permanent impacts on the groundwater regime due to approved open cut mining would come from changes in bulk rock mass permeability caused by the replacement of native materials (Permian sediments, colluvium and some alluvium) by higher permeability emplaced waste. This will have the general effect of lowering the lateral hydraulic gradient (according to Darcy's Law) for the same volume of throughflow. However, the waste is likely to support higher rainfall recharge, and that will have a counteracting effect on the changes to the hydraulic gradient.

During mining, the active pits will act as groundwater sinks. Groundwater flow would be towards the pits from all directions.

Figure 39 shows that the maximum effect (WCM specific) at the end of mining would be a drawdown in the Ulan seam of about 10 m at the edges of the mining footprint. The 2 m drawdown contour is likely to extend about 1 km west, 4 km north and 3 km east of the proposed mining footprint. Less than 0.1 m drawdown is expected in the alluvium monitoring bores at any time during or after mining.

The model suggests that the Wilpinjong Creek alluvium receives upflow from the underlying groundwater system in the order of 0.02 ML/day pre-mining. There is expected to be a gradual decline in upflow from 2006 to 2015, at which time a reversal to downflow is possible until the end of mining.

The model also suggests a very minor upflow to the Cumbo Creek alluvium in the order of 0.00001 ML/day pre-mining. The effect of mining is to quickly convert the natural upflow to downflow, but the magnitude remains very low.

The reductions in upflow for the two alluvial systems are expected to be about 10 ML/a at most. The average loss is expected to be about 9 ML/a over the full duration of mining.

As there is a net reduction in upflow, there can be no negative impact on the groundwater quality in the alluvium due to discharge of saline water from Permian sediments to the alluvium.

Incremental Impacts of the Modification

There is no perceptible difference between the drawdown contour maps for the approved mine plan and the Modification. Additional average drawdowns at the coal monitoring bores due to the Modification are expected to be in the centimetre range. The maximum additional drawdown is expected to be no more than 0.01 m in alluvium and about 0.6 m in coal.

The incremental changes in upflows from Permian rock to alluvium are expected to average about 0.01 ML/a which is about 0.1% of the average upflow estimated for the approved mine plan.

5.2 POTENTIAL IMPACTS ON SURFACE WATERBODIES

Approved WCM

The model suggests that Wilpinjong Creek receives baseflow from the groundwater system in the order of 1.6 ML/day pre-mining. There is predicted to be a mild decline in baseflow from 2006 to 2026. This is consistent with the EIS conclusion which predicted the maximum loss of flow as a result of the Project to be 11% of annual average flow in Wilpinjong Creek (immediately upstream of Wollar Creek).

The model also suggests that Cumbo Creek receives baseflow from the groundwater system of less than 0.1 ML/day pre-mining. A mild decline in baseflow is expected from 2006 to 2012, followed by a sudden and sustained reduction in baseflow from 2013 when Pit 4 commences near Cumbo Creek. By 2018 the Cumbo Creek alluvium will have been excavated.

The reductions in baseflow for the two creeks are expected to reach a maximum of about 175 ML/a and the average loss is expected to be about 149 ML/a.

As there is a net reduction in baseflow, there can be no negative impact on the water quality in Wilpinjong Creek due to discharge of saline groundwater.

The finding of the model is that there is no perceptible variation in evapotranspiration, and hence no effect on groundwater dependent vegetation.

Incremental Impacts of the Modification

The maximum incremental change in baseflows for the two creeks is expected to be about 1.5 ML/a, while the average would be about 0.5 ML/a which is about 0.6% of the average estimated for the approved mine plan.

5.3 ASSESSMENT AGAINST THE MINIMAL IMPACT CONSIDERATIONS

The AIP (NSW Government, 2012) establishes minimal impact considerations for highly productive and less productive groundwater. **Figure 2** shows the NOW mapping of highly productive groundwater in the vicinity of the WCM, which indicates that an area of highly productive alluvial aquifer exists to the north-east of the WCM on Wilpinjong Creek.

It follows that the remaining alluvial aquifers and porous rock aquifers in the vicinity of the WCM are less productive.

Tables 16 to 18 provide an assessment of the Modification against the minimal impact considerations in the AIP and include consideration of cumulative impacts where appropriate.

Table 16. Highly Productive Alluvial Aquifer – Minimal Impact Considerations

Aquifer	Alluvial Aquifer
Category	Highly Productive
Level 1 Minimal Impact Consideration	**Assessment**
Water Table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.	**Within Level 1** The closest high priority groundwater dependent ecosystem listed in the *Hunter Unregulated and Alluvial Water Sources Water Sharing Plan* is approximately 130 km away and would not be affected by drawdown from the WCM. There are no high priority culturally significant sites listed in the *Hunter Unregulated and Alluvial Water Sources Water Sharing Plan*. The WCM would not result in cumulative drawdown of more than 2 m at any privately owned land (and privately owned water supply work) (refer to **Figure 39** for predicted drawdown in the Ulan Seam which is greater than the predicted drawdown in alluvial aquifers).
Water pressure A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work.	**Within Level 1** The WCM would not result in cumulative drawdown of more than 40% of the pressure head at any privately owned land (and privately owned water supply work).
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** As there is a net reduction in baseflow, there can be no negative impact on water quality in Wilpinjong Creek due to discharge of saline groundwater. Wilpinjong Creek displays typical behaviour with EC reducing with increasing flow rate (Gilbert & Associates, 2013). Under most conditions, RO Plant discharge would lead to some decrease in Wilpinjong Creek salinity. During low salinity periods, RO Plant discharge would be subject to significant dilution and the resulting increase in EC would be negligible (Gilbert & Associates, 2013). Wilpinjong Creek downstream of the confluence of Cumbo Creek meets the definition of a "reliable water supply" as it is a fifth order stream according to the Strahler system. The Modification open cut extension areas are more than 200 m from the top of the high bank of Wilpinjong Creek downstream of the confluence of Cumbo Creek. The WCM does not extract alluvial material associated with the highly productive alluvial groundwater (**Figure 2**).

Table 17. Less Productive Alluvial Aquifer – Minimal Impact Considerations

Aquifer	**Alluvial Aquifer**
Category	**Less Productive**
Level 1 Minimal Impact Consideration	**Assessment**
Water Table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.	**Within Level 1** The closest high priority groundwater dependent ecosystem listed in the *Hunter Unregulated and Alluvial Water Sources Water Sharing Plan* is approximately 130 km away and would not be affected by drawdown from the WCM. There are no high priority culturally significant sites listed in the *Hunter Unregulated and Alluvial Water Sources Water Sharing Plan*. The WCM would not result in cumulative drawdown of more than 2 m at any privately owned land (and privately owned water supply work) (refer to **Figure 39** for predicted drawdown in the Ulan Seam which is greater than the predicted drawdown in alluvial aquifers).
Water pressure A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work.	**Within Level 1** The WCM would not result in cumulative drawdown of more than 40% of the pressure head at any privately owned land (and privately owned water supply work).
Water quality Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity. No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. No mining activity to be below the natural ground surface within 200 m laterally from the top of high bank or 100 m vertically beneath (or the three dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply".	**Within Level 1** As there is a net reduction in baseflow, there can be no negative impact on water quality in Wilpinjong Creek due to discharge of saline groundwater. Wilpinjong Creek displays typical behaviour with EC reducing with increasing flow rate (Gilbert & Associates, 2013). Under most conditions, RO Plant discharge would lead to some decrease in Wilpinjong Creek salinity. During low salinity periods, RO Plant discharge would be subject to significant dilution and the resulting increase in EC would be negligible (Gilbert & Associates, 2013). Wilpinjong Creek downstream of the confluence of Cumbo Creek meets the definition of a "reliable water supply" as it is a fifth order stream according to the Strahler system. The Modification open cut extension areas are more than 200 m from the top of the high bank of Wilpinjong Creek downstream of the confluence of Cumbo Creek.

Table 18. Less Productive Porous Rock Aquifer – Minimal Impact Considerations

Aquifer	**Porous Rock**
Category	**Less Productive**

Level 1 Minimal Impact Consideration	Assessment
Water Table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.	**Within Level 1** There is no water sharing plan relevant to the porous rock aquifer. The WCM would not result in cumulative drawdown of more than 2 m at any privately owned land (and privately owned water supply work) (refer to **Figure 39**).
Water pressure A cumulative pressure head decline of not more than a 2 m decline, at any water supply work.	**Within Level 1** The WCM would not result in cumulative drawdown of more than 2 m at any privately owned land (and privately owned water supply work).
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.	**Within Level 1** There is not expected to be a migration of groundwater away from the WCM areas in the Permian system either during mining or following completion of mining activities. On this basis, the WCM would not lower the beneficial use category of the groundwater within the Permian system.

6 MANAGEMENT AND MITIGATION MEASURES

WCPL should implement the proposed upgrades to the groundwater monitoring program outlined in **Section 6.3.**

The updated EIS groundwater model developed as part of this groundwater assessment should be used as a management tool for validating the predicted groundwater impacts throughout the life of the WCM. The results of the upgraded groundwater monitoring program should be used to inform progressive development, verification and refinement of the numerical model. Revised outputs from the numerical model should be reported in subsequent relevant groundwater assessments over the life of the WCM.

Consistent with the Groundwater Monitoring Program (WCPL, 2010), a review of groundwater monitoring data will be undertaken on an annual basis (or more frequently as required) to compare actual groundwater drawdown levels to those predicted by the numerical model.

6.1 GROUNDWATER USERS

As can be seen on **Figure 39**, potential end of mining drawdown is not expected to exceed 1 m at any privately owned land. Drawdown is shown for the Ulan Coal Seam as this will be the maximum for any lithology.

As the average additional drawdown during the period of mining, due to the Modification, at all coal monitoring bores is expected to be about 0.03 m, differences in the drawdown contour pattern for the approved mine plan and the Modification are imperceptible. It follows that the Modification would not contribute to any measurable incremental effect at any privately owned bores.

Notwithstanding that no impacts on privately owned bores are predicted, WCPL implements an approved Surface and Groundwater Response Plan (WCPL, 2006b). The Surface and Groundwater Response Plan includes:

- process to deal with a groundwater-related complaint;
- groundwater impact investigation protocol; and
- response plan, in the event that an investigation conclusively attributes an adverse impact to an existing groundwater supply user to WCM operations.

Appropriate contingency measures for an impact on a groundwater supply user may include:

- deepening the affected groundwater supply; or
- construction of a new groundwater supply; or
- provision of a new alternative water supply.

6.2 GROUNDWATER LICENSING

For the Modification, the recommended annual volumes for licensing are listed in **Table 19** based on predicted future pit inflows. The increment above what would have been required for the approved mine plan is listed in the last column of **Table 19**.

Table 19. Recommended Licensed Water Volumes

Water Source	Legislation	Water Type	Maximum Annual Volume [ML]	Incremental Change due to Modification [ML]
Porous rock	*Water Act 1912* Part 5	Pit inflows	2,038 (max.) or 974 (average)	4 (max.) or 3 (average)
Wollar Creek Water Source	*Water Management Act 2000*	Baseflow reduction	175	0.5
Wollar Creek Water Source^	*Water Management Act 2000*	Alluvial upflow reduction	10	0

^ Loss of water from excavated alluvium: 30 ML/a (90 ML distributed over 3 years from 2015 to 2017)
^ Loss of rainfall recharge to excavated alluvium: 14 ML/a (for 5 years from 2015)

Table 20 provides recommended volumes for licensing if licences are required pit-by-pit.

In this case, adoption of the maximum annual volume would not be appropriate as the combined maximum for all pits (3,383 ML/a) would be about 65% greater than the maximum (2,038 ML/a) applicable to the whole mine, for any one year, due to inflows peaking in different years for different pits. Adoption of the average for each pit would give a combined volume of 1,000 ML/a which is about 50% of the maximum for the whole mine in **Table 19**. The last column in **Table 20** shows that the Modification would make a negligible contribution to the volumes to be licensed pit-by-pit.

Table 20. Recommended Licensed Water Volumes for Each Pit

Water Source	Legislation	Location	Annual Volume [ML]	Incremental Change due to Modification [ML]
Porous rock	*Water Act 1912* Part 5	Pit 1	**0 (max.)** or 0 (average)	**0 (max.)** or 0 (average)
Porous rock	*Water Act 1912* Part 5	Pit 2	**0 (max.)** or 0 (average)	**0 (max.)** or 0 (average)
Porous rock	*Water Act 1912* Part 5	Pit 3	**761 (max.)** or 256 (average)	**-4 (max.)** or -1 (average)
Porous rock	*Water Act 1912* Part 5	Pit 4	**689 (max.)** or 179 (average)	**-1 (max.)** or 3 (average)
Porous rock	*Water Act 1912* Part 5	Pit 5	**905 (max.)** or 224 (average)	**-1 (max.)** or 1 (average)
Porous rock	*Water Act 1912* Part 5	Pit 6	**1,028 (max.)** or 341 (average)	**0 (max.)** or 0 (average)

6.3 PROPOSED GROUNDWATER MONITORING PROGRAM

The current groundwater monitoring network is shown in **Figure 41** in association with the locations of exploration bores planned for 2013. To improve regional groundwater monitoring at the WCM, seven of the exploration bores have been recommended for conversion to groundwater monitoring piezometers. An eighth site (R1) is recommended between Pit 5 and Wilpinjong Creek (on the southern side as recommended by the NOW during the meeting on 8 February 2013).

Approximate coordinates for the proposed new monitoring sites are given in **Table 21** along with a rationale for selection of the sites. Sites R1, R2, R7 and R8 would be installed with dataloggers measuring hourly. Sites R3, R4, R5 and R6 would be dipped monthly.

Table 21. Proposed New Groundwater Monitoring Sites

Bore ID	Easting	Northing	Rationale
R1	769537	6420894	Between Pit 5 and Wilpinjong Creek. Will respond to mining moving northwards towards the creek. To be screened in alluvium and coal.
R2	768523	6420995	North-west of Pit 5 (in Pit 6). Adjacent mining in 2013-2014. To be screened in coal.
R3	767998	6420505	West of Pit 5 (in Pit 6). Adjacent mining in 2014. To be screened in coal.
R4	767254	6418729	South-west of Pit 5. Adjacent mining in 2016. To be screened in coal.
R5	768146	6417589	In southern Pit 5. To be mined in 2017-2018. To be screened in coal.
R6	771483	6416987	South of Pit 2. Adjacent mining in 2014. To be screened in coal.
R7	772768	6419236	In Pit 4. To be mined in 2016-2017. Should be on the edge of the Cumbo Creek alluvium. To be screened in alluvium (if sufficient saturated thickness) and coal.
R8	773995	6418003	In Pit 3. To be mined in 2018. To be screened in coal.

It is recommended that WCPL also conduct a ground survey of creek invert and all relevant bore ground levels.

7 CONCLUSIONS

This groundwater assessment is for a Modification that consists of minor incremental extensions to approved open cuts and alteration of the sequence of mining, but with no material extension to the existing approved 21 year mine life.

The incremental impacts of the Modification have been considered within the context of the impacts likely to be generated by active approved mining. Cumulative drawdown impacts of the neighbouring Moolarben mine has also been considered.

With respect to the Modification, the key findings of this assessment are:

- The Modification would have no discernible impact on creek baseflow, beyond the effects of approved mining, and hence no incremental effect on groundwater dependent ecosystems dependent on baseflow.
- The Modification would have no discernible impact on groundwater upflow from the Permian sediments to overlying alluvium, beyond the effects of approved mining.
- The Modification would have no discernible impact on evapotranspiration, beyond the effects of approved mining, and hence no effect on groundwater dependent ecosystems dependent on shallow groundwater.
- The Modification would add no more than 4 ML/a to the peak whole-of-mine inflow rates predicted for the currently approved mine extent.
- The Modification would add no more than 10 ML/a to the peak inflow rate for any single pit as predicted for the currently approved mine extent.
- The Modification would cause imperceptible additional drawdown at any of the alluvium or coal bores in the monitoring network.
- The Modification could not be considered to have a significant impact on the recovery of groundwater levels, beyond the effects of approved mining.
- The Modification could not be considered to have a significant impact on groundwater quality, beyond the effects of approved mining.

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ILLUSTRATIONS

Figures 1 to 41

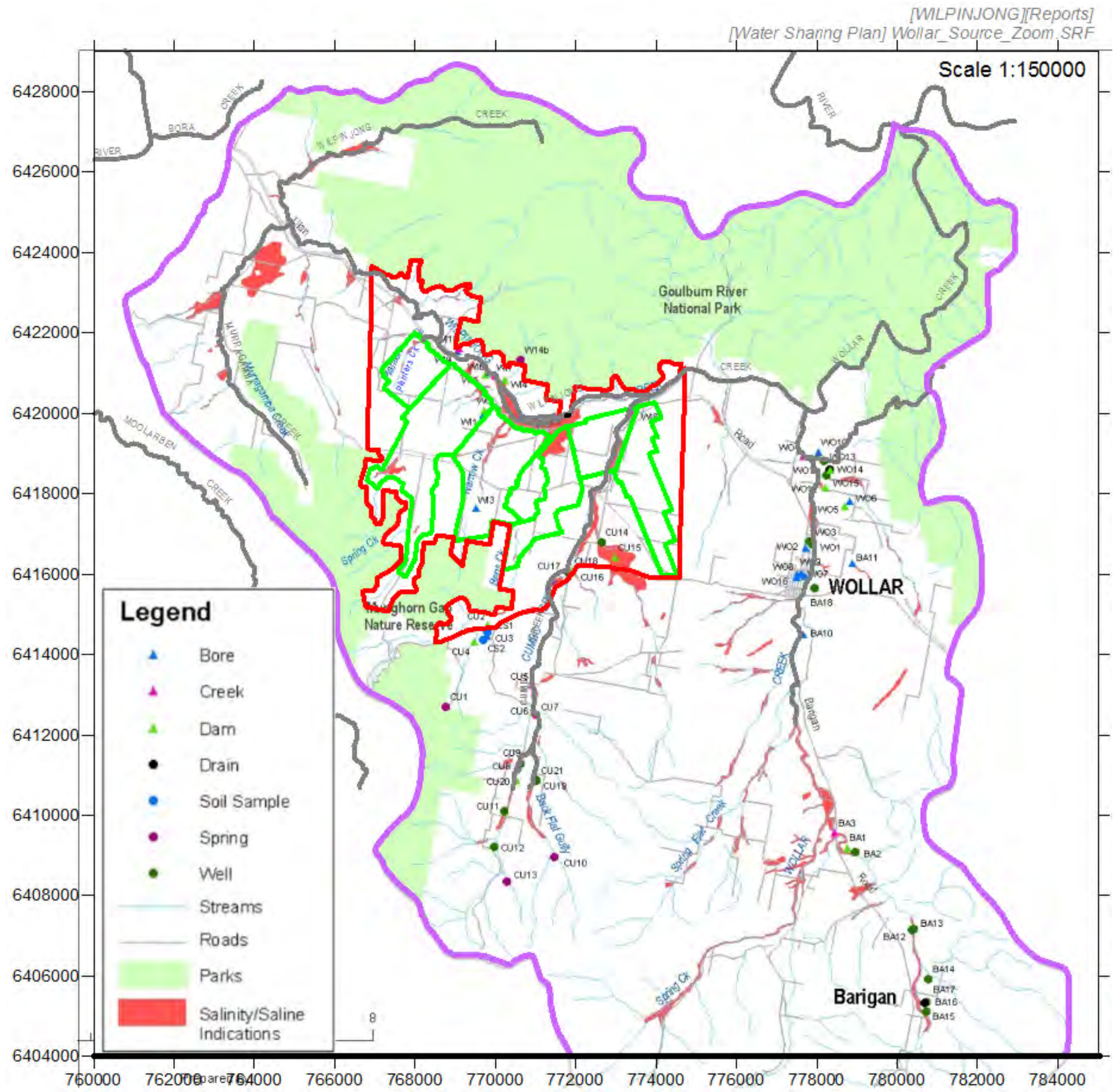


Figure 1. Location Plan for the Wilpinjong Coal Mine and the Wollar Creek Water Source

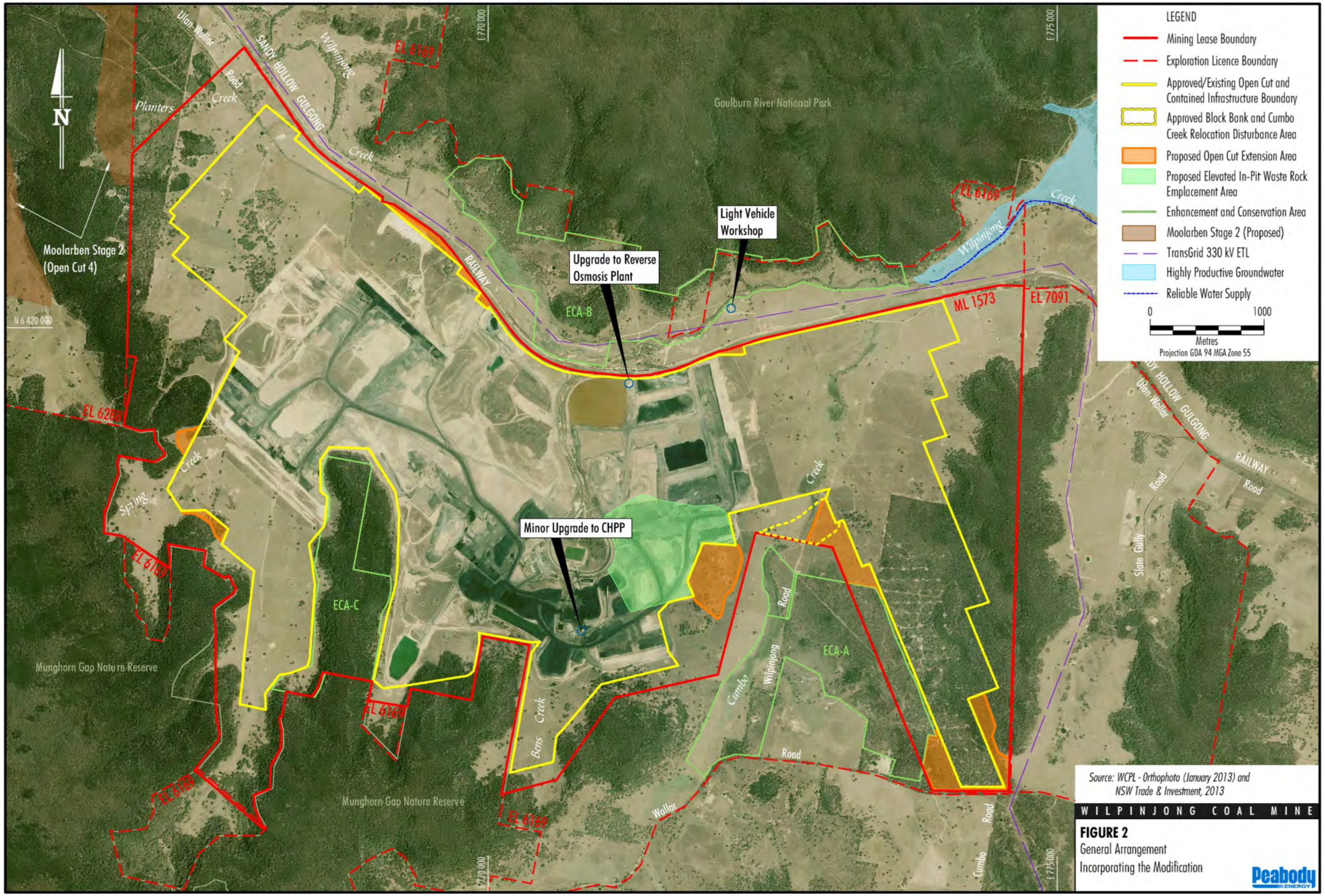


Figure 2. Proposed Modification to the Open Cut Area for the Wilpinjong Coal Mine

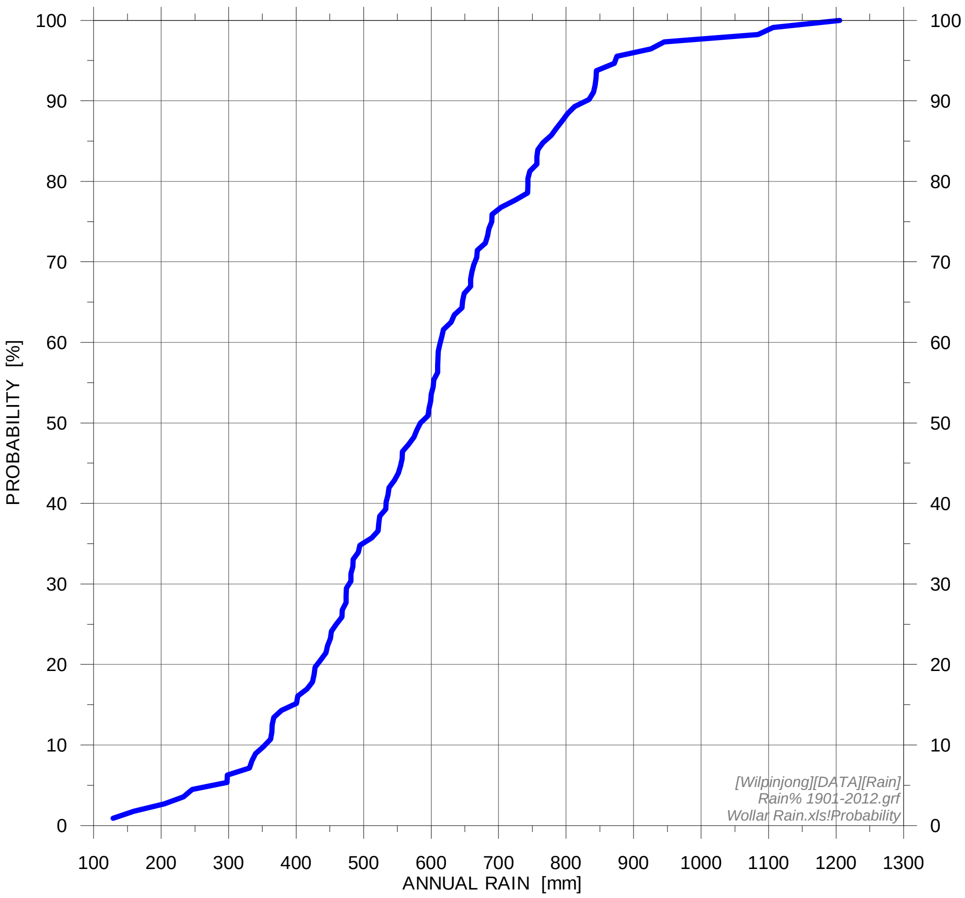


Figure 3. Annual Rainfall Cumulative Distribution Function for Station 062032 at Wollar (Barigan St) from 1901 to 2012

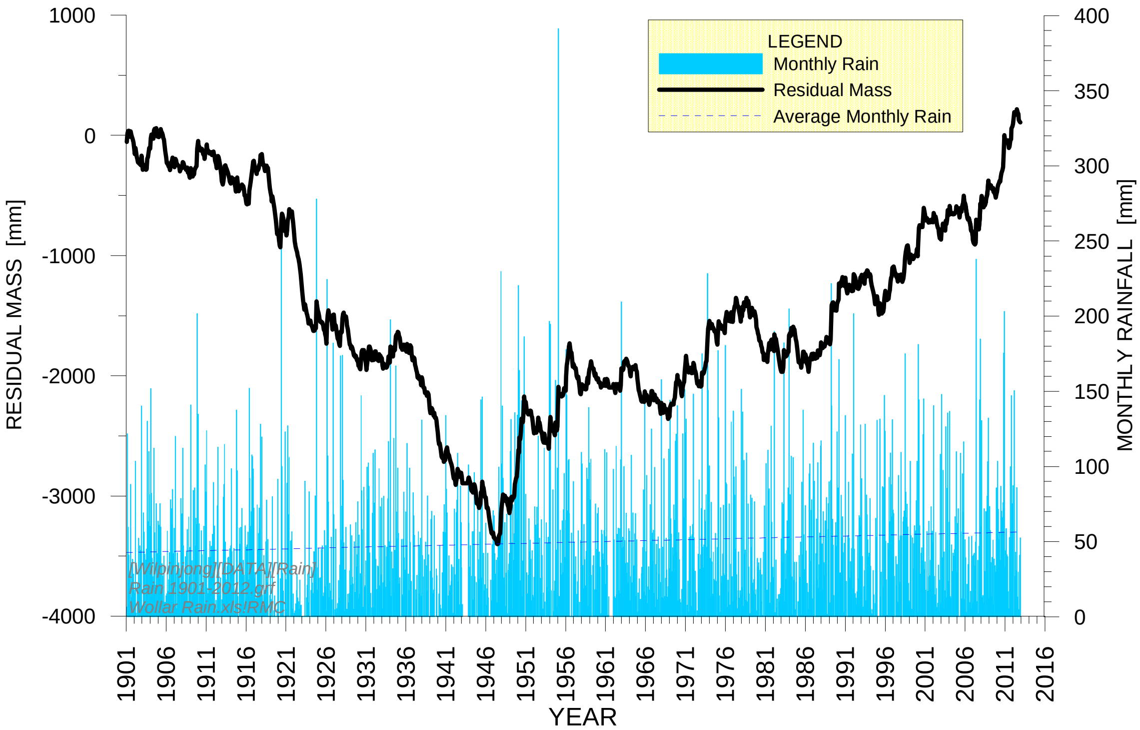


Figure 4. Monthly Rainfall and Residual Mass Curve for Station 062032 at Wollar (Barigan St) from 1901 to 2012

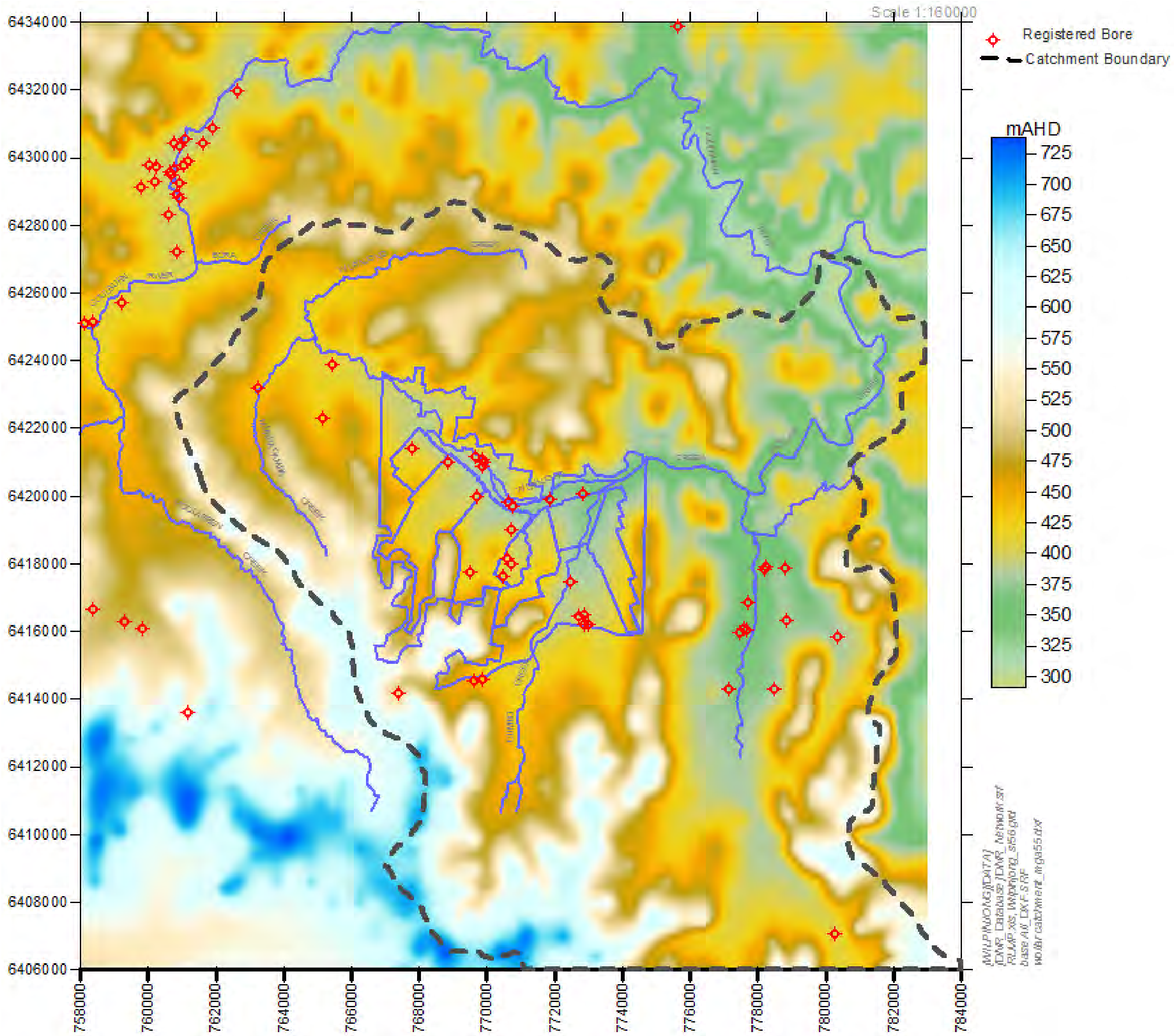


Figure 5. Regional Topography

[Note: Registered bores shown as at mine commencement (2006)]

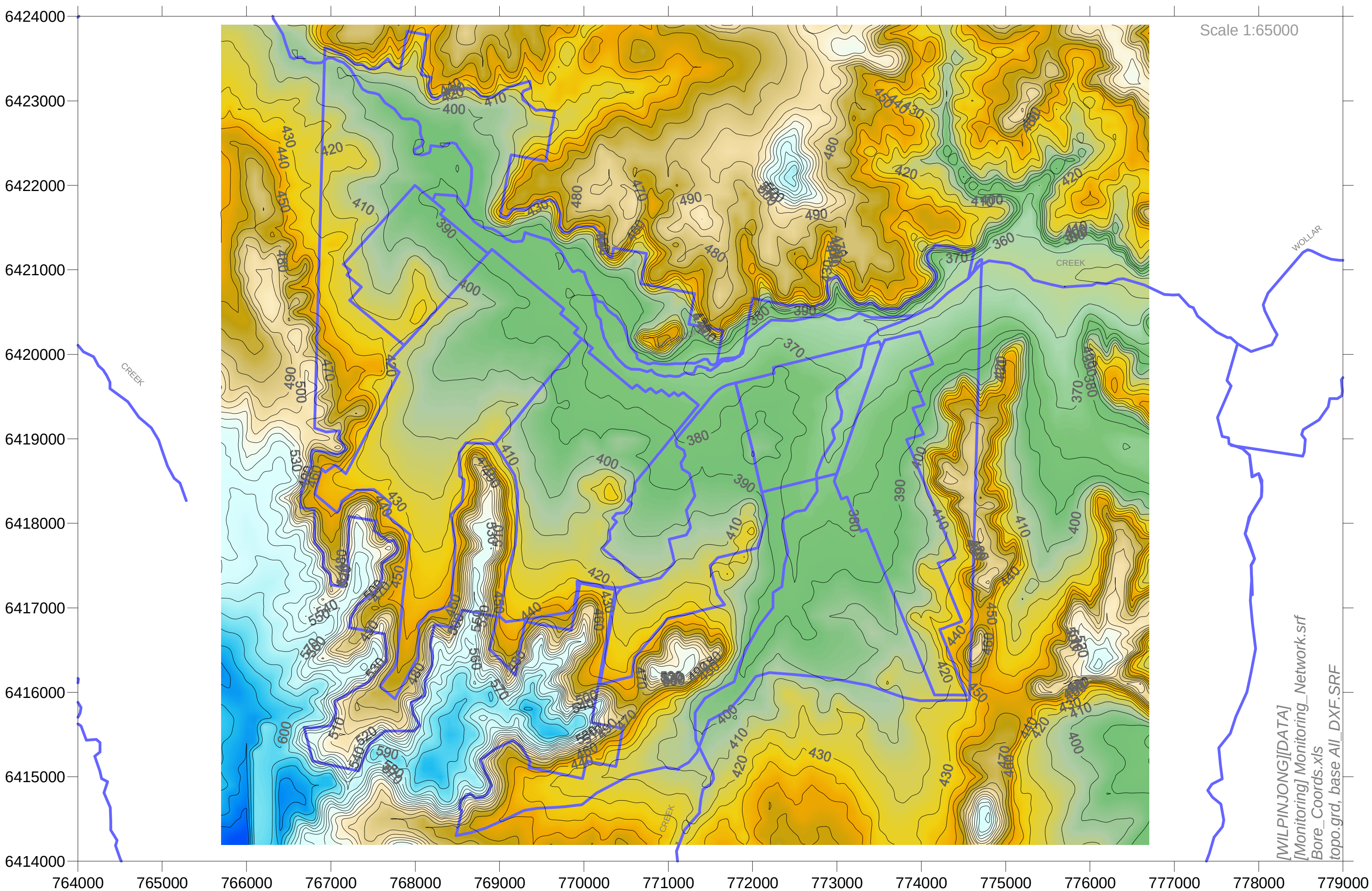


Figure 6. Local Ground Topography [mAHD]

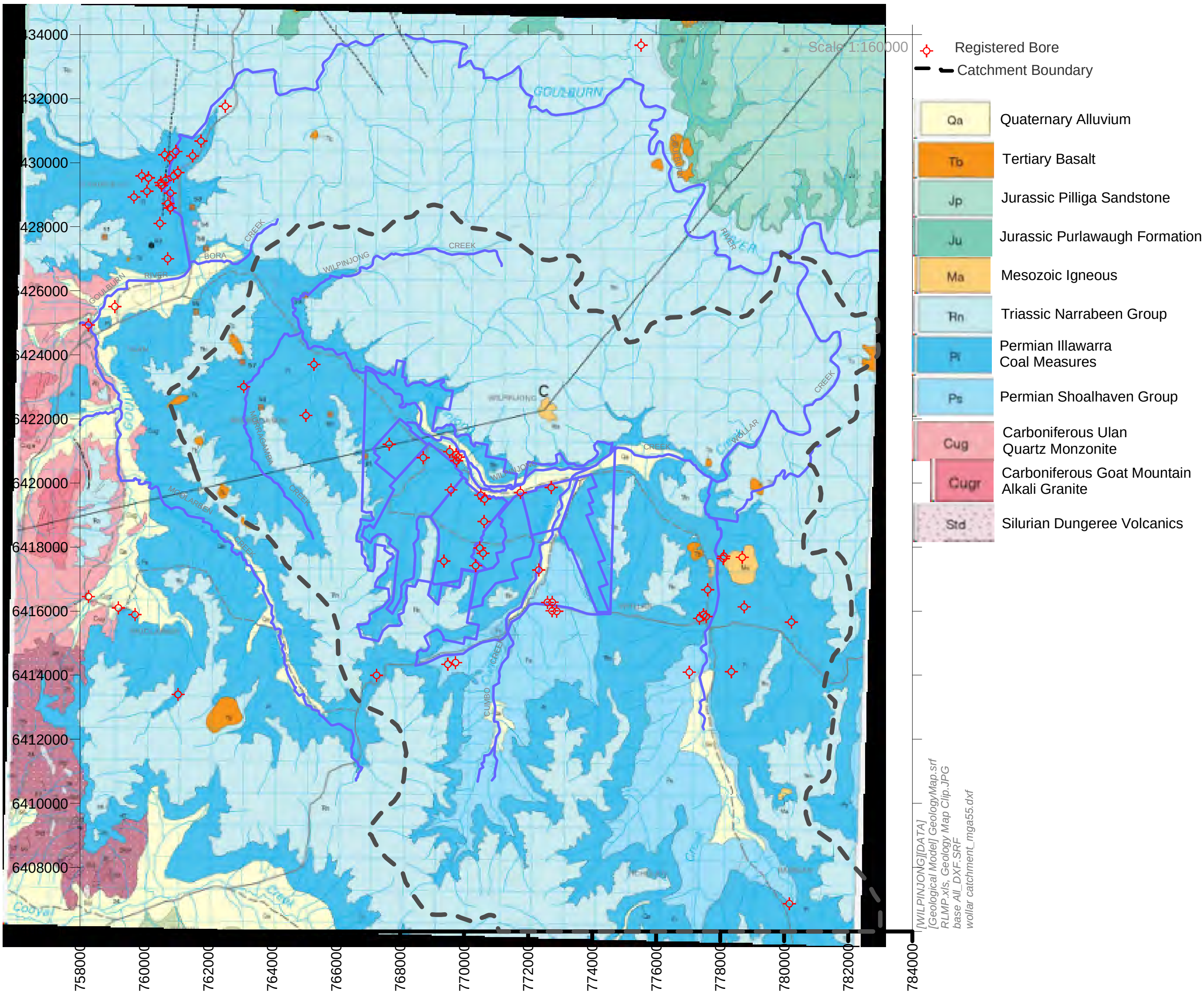
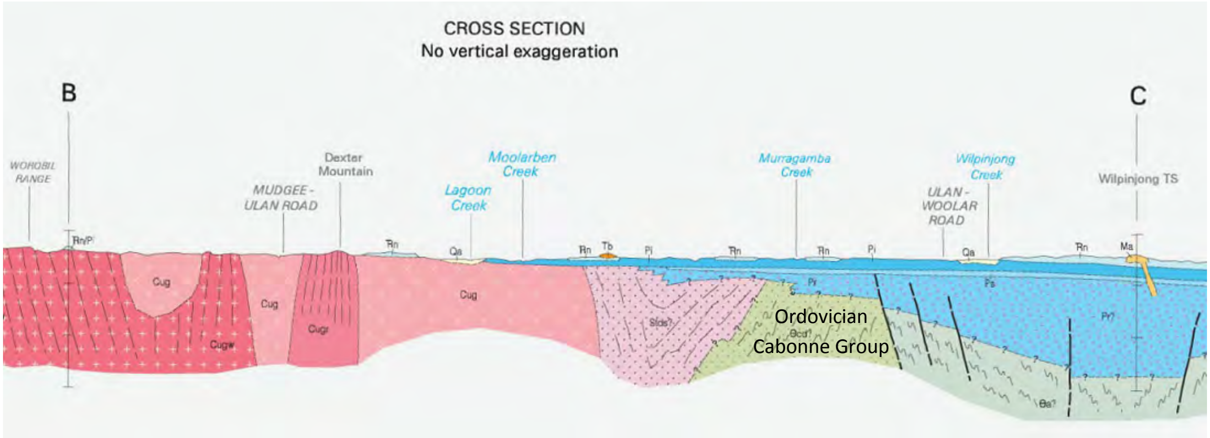


Figure 7a. Regional Surface Geology

[Source: Gulgong 1:100000 Geological Map Sheet_8833_1st_edition_2000]



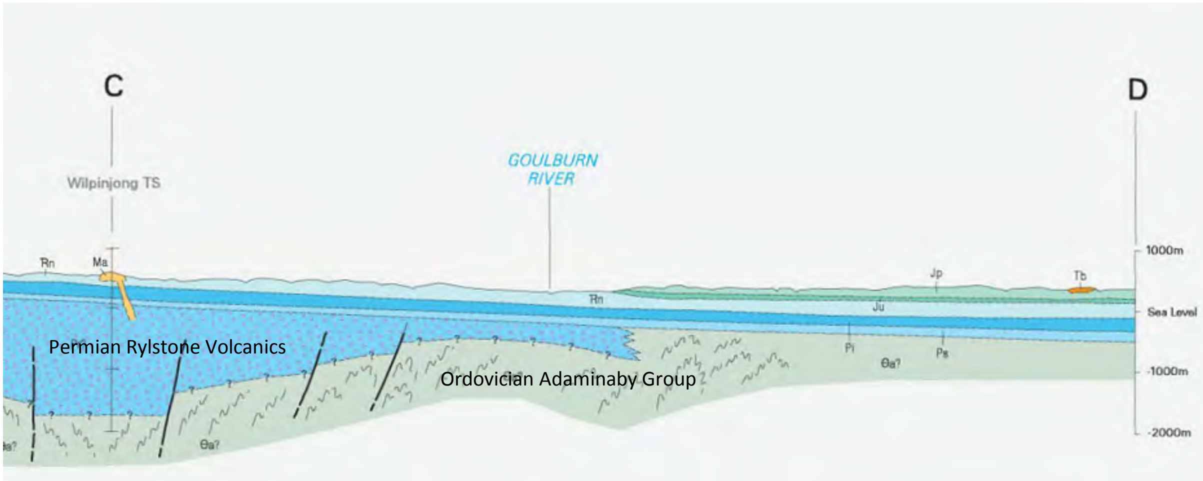


Figure 7b. Geological Cross Section

Refer to legend in Figure 7a

[Source: Gulgong 1:100000 Geological Map Sheet_8833_1st_edition_2000]

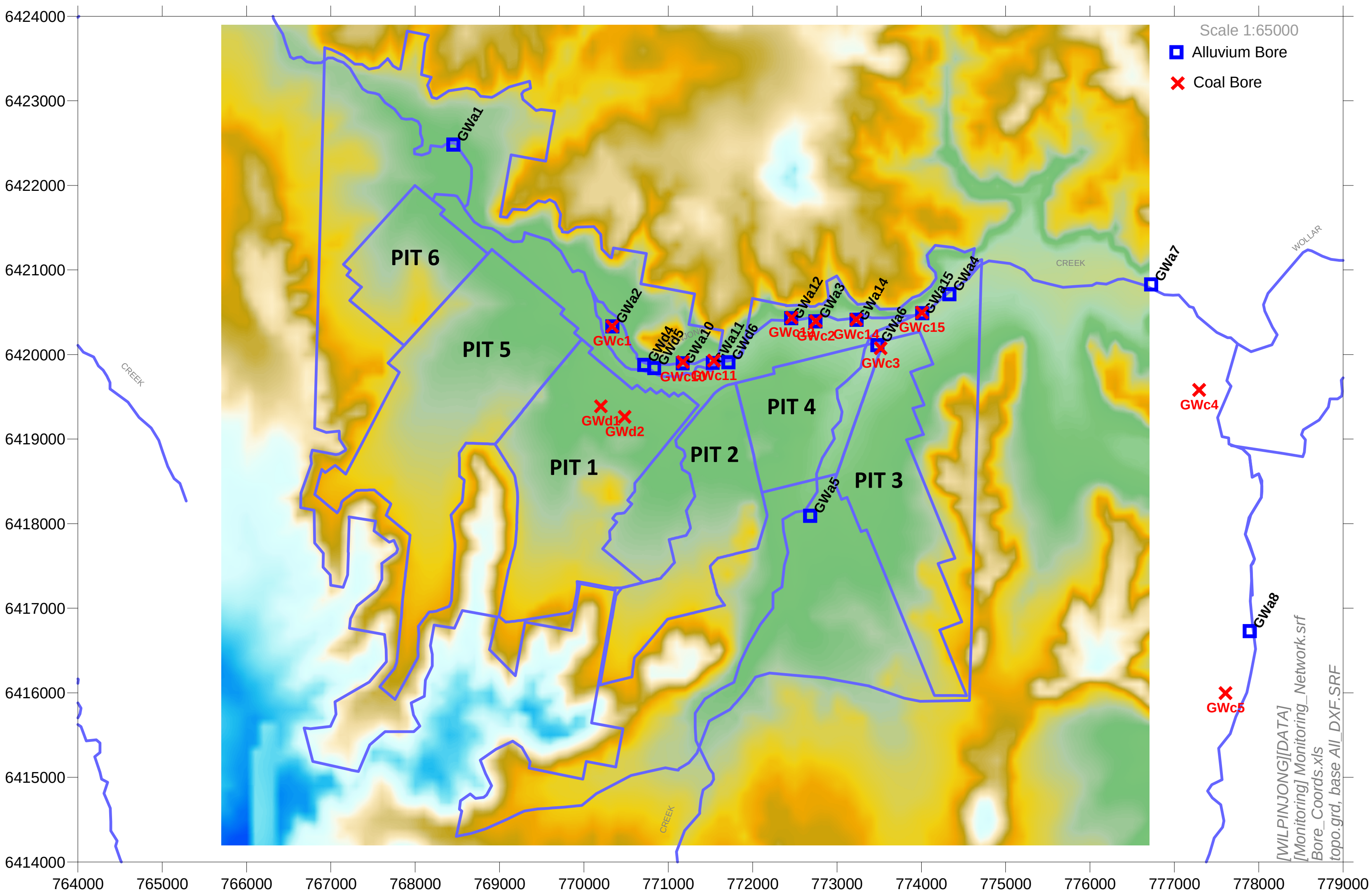


Figure 8. Groundwater Monitoring Network - Coal and Alluvium Bores

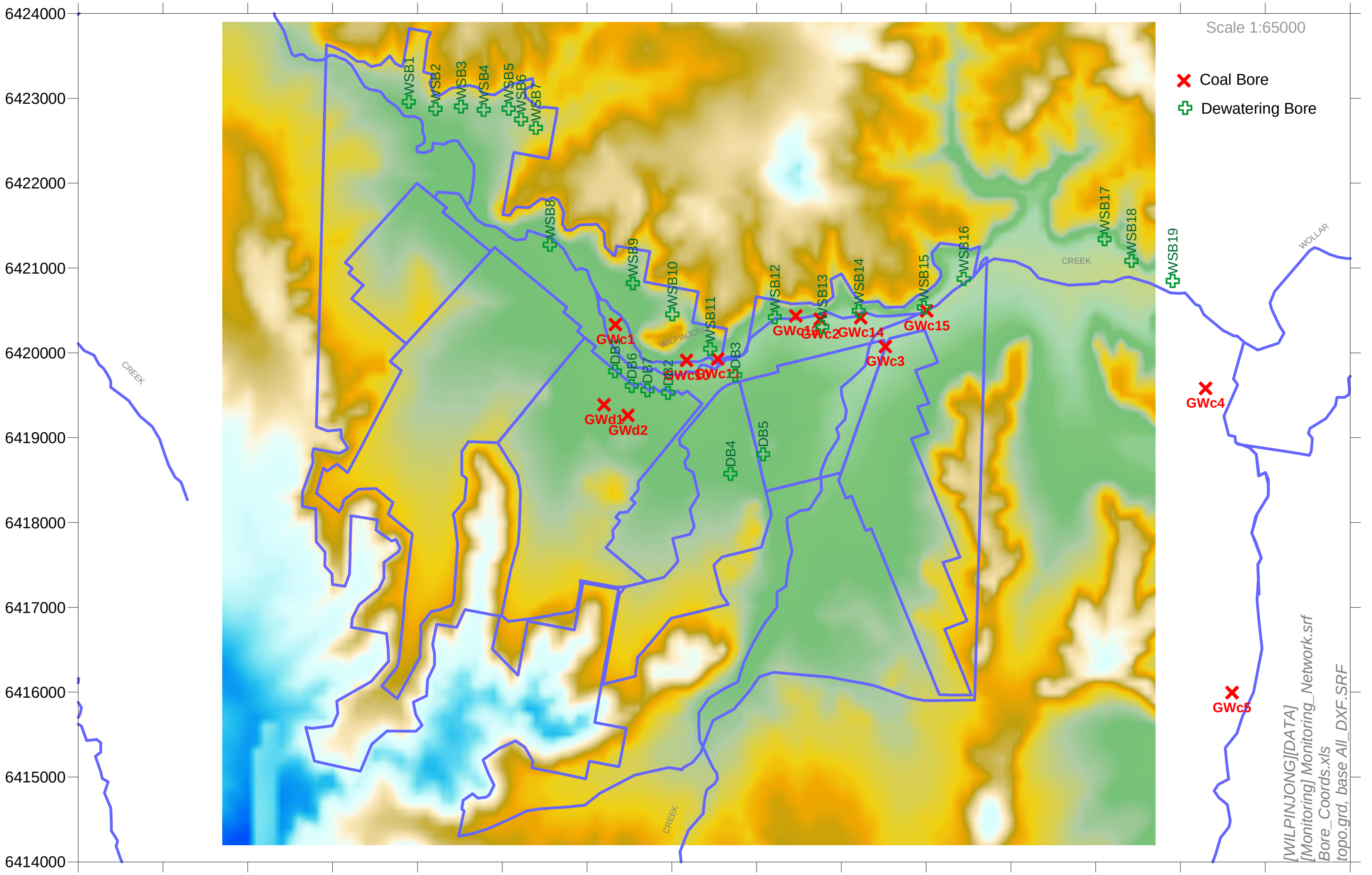


Figure 9. Coal Bores - Groundwater Monitoring, Dewatering and Water Supply Bores

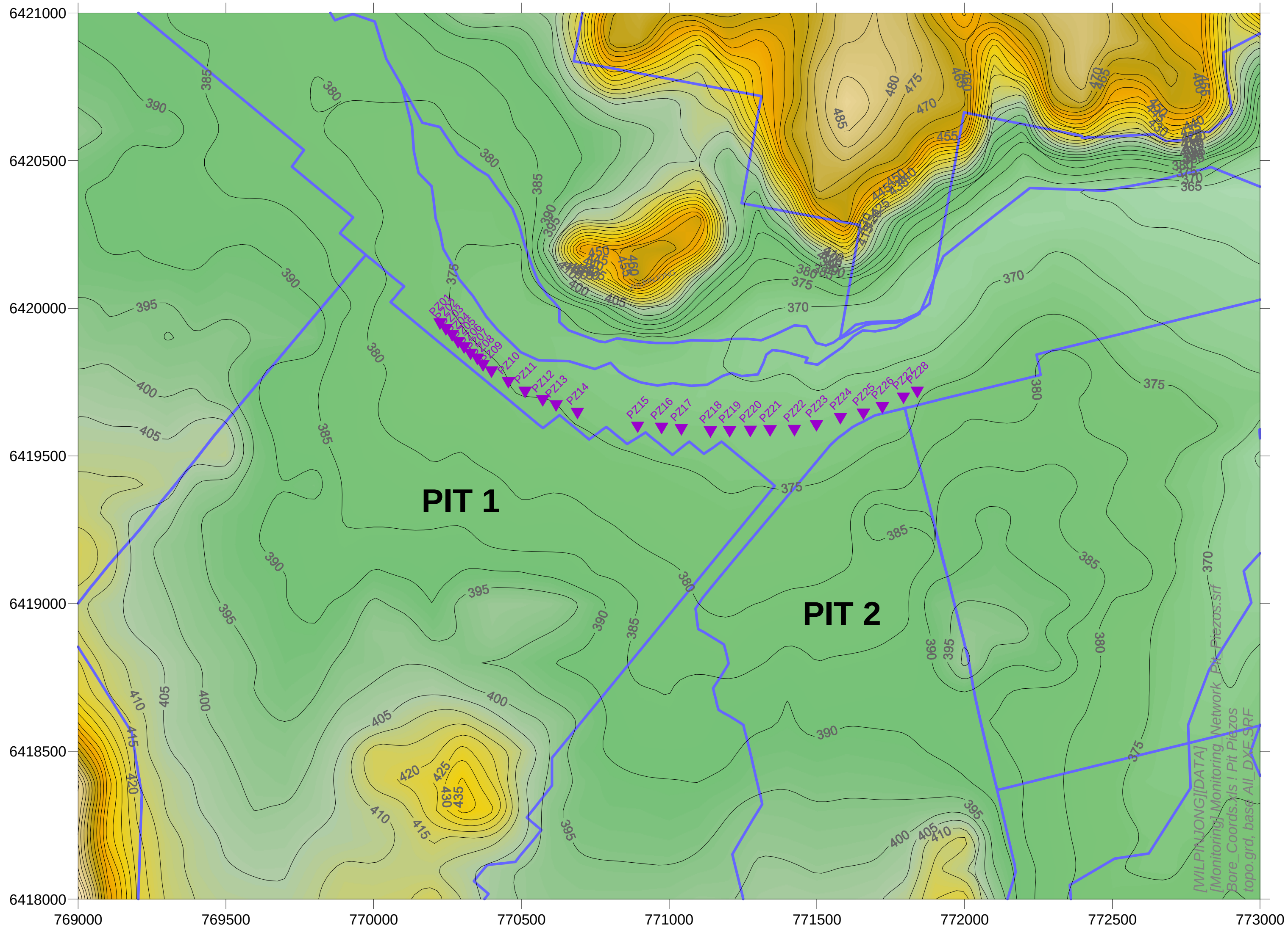


Figure 10. Coal Bores - Pit Piezometers

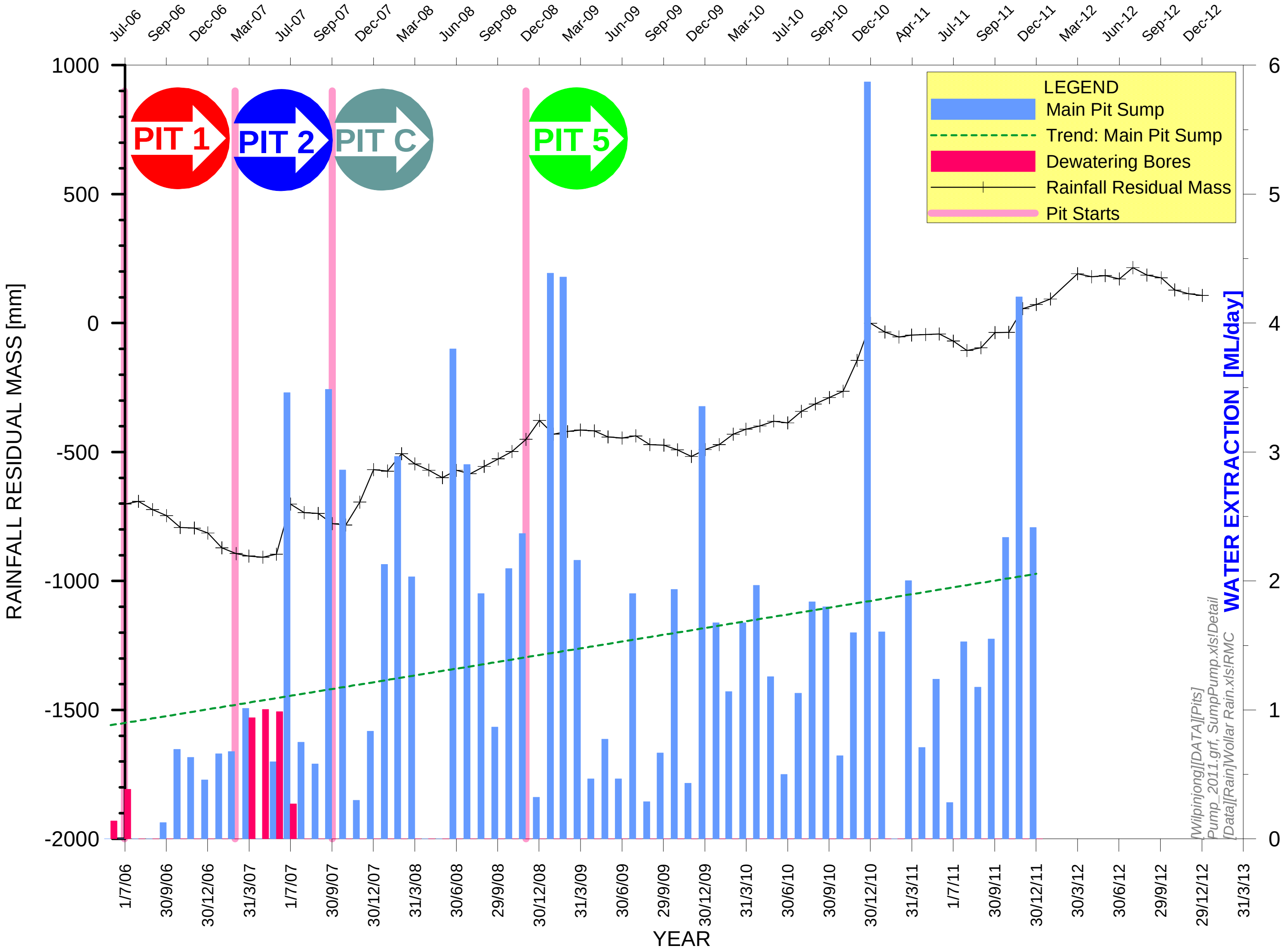


Figure 11. Main Pit and Dewatering Bore Extraction Record [ML/day]

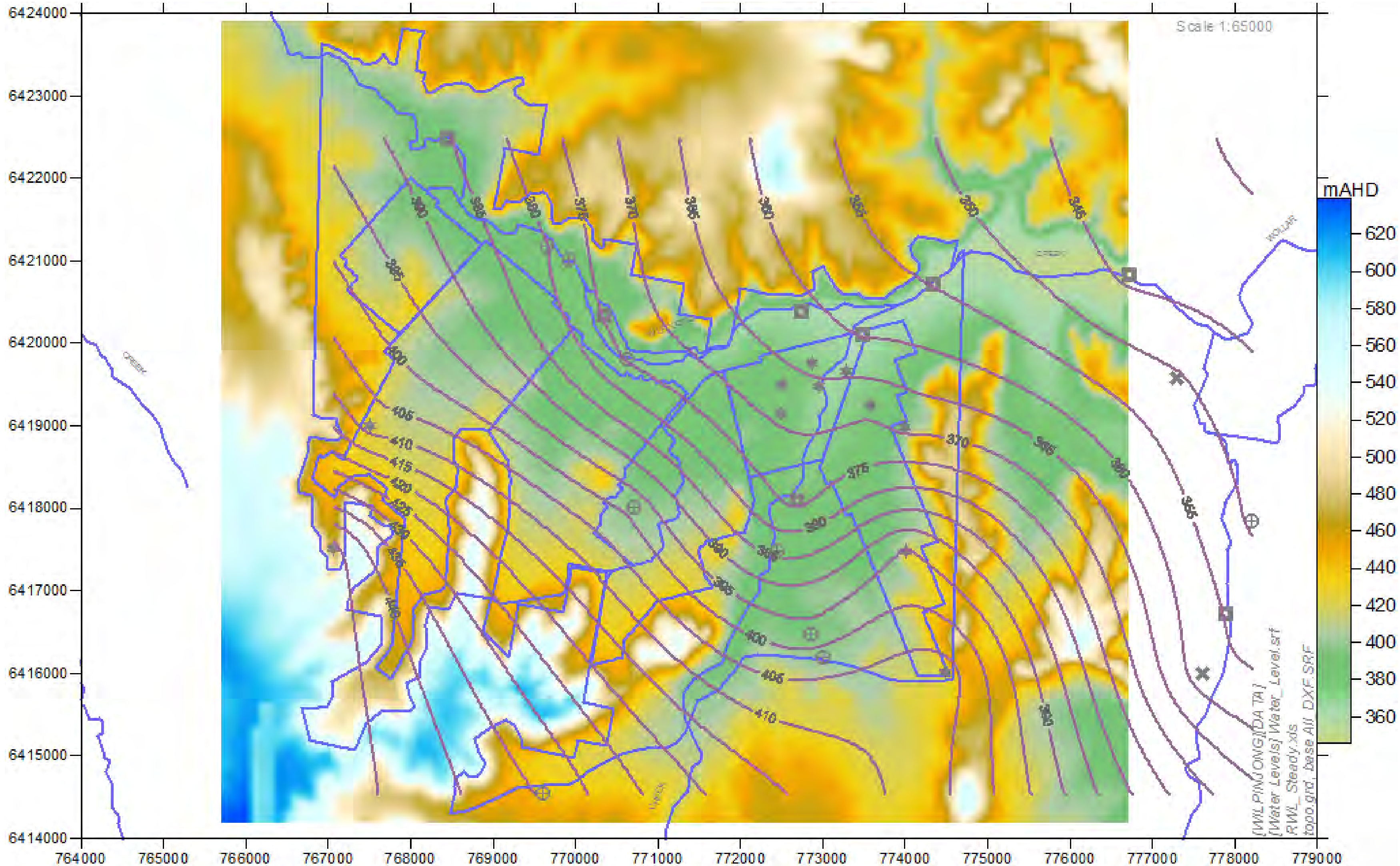


Figure 12. Pre-Mining Water Table Contours and Local Ground Topography [mAHD]

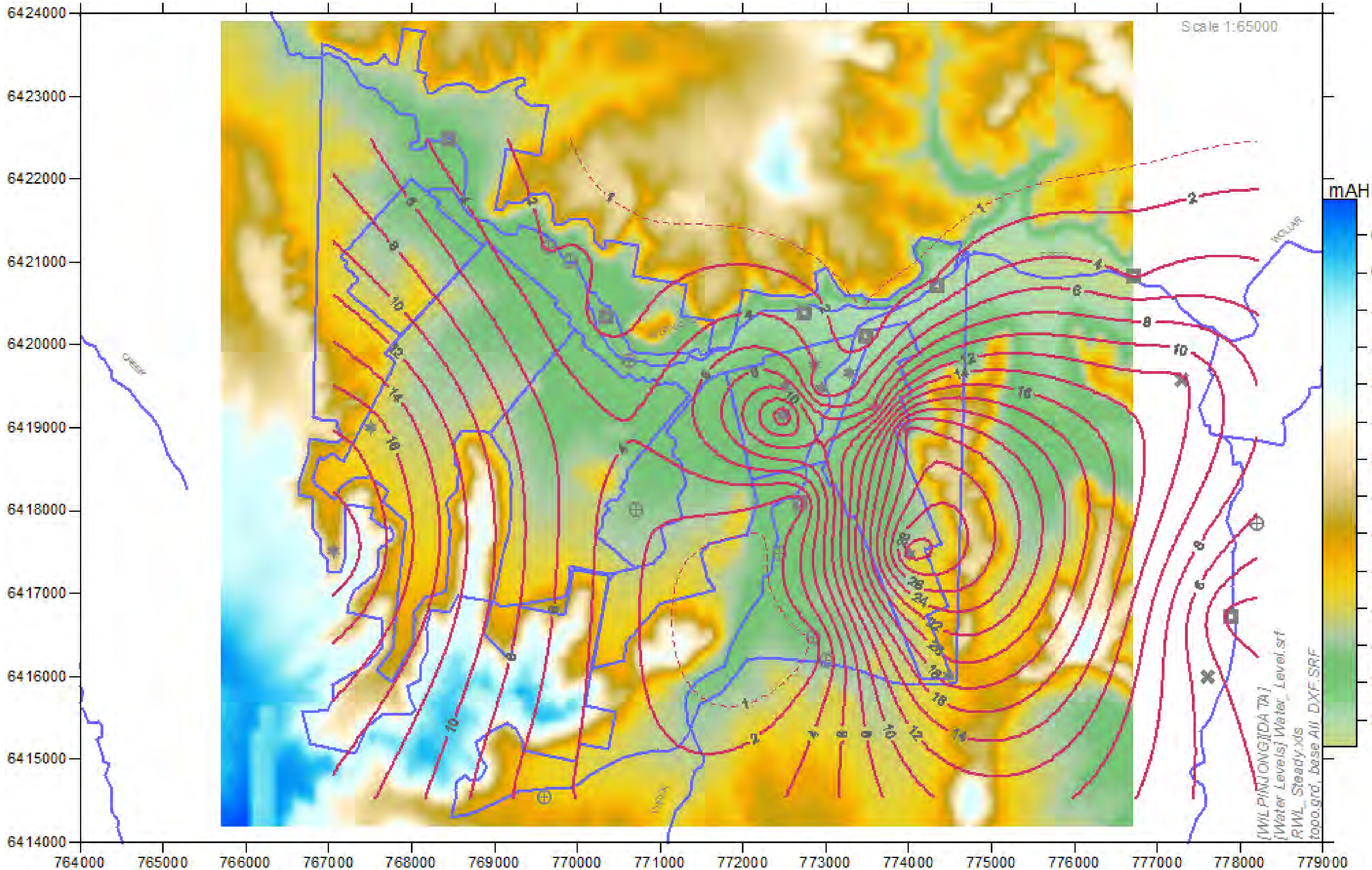


Figure 13. Pre-Mining Depth to Water (m) Contours and Local Ground Topography [mAHD]

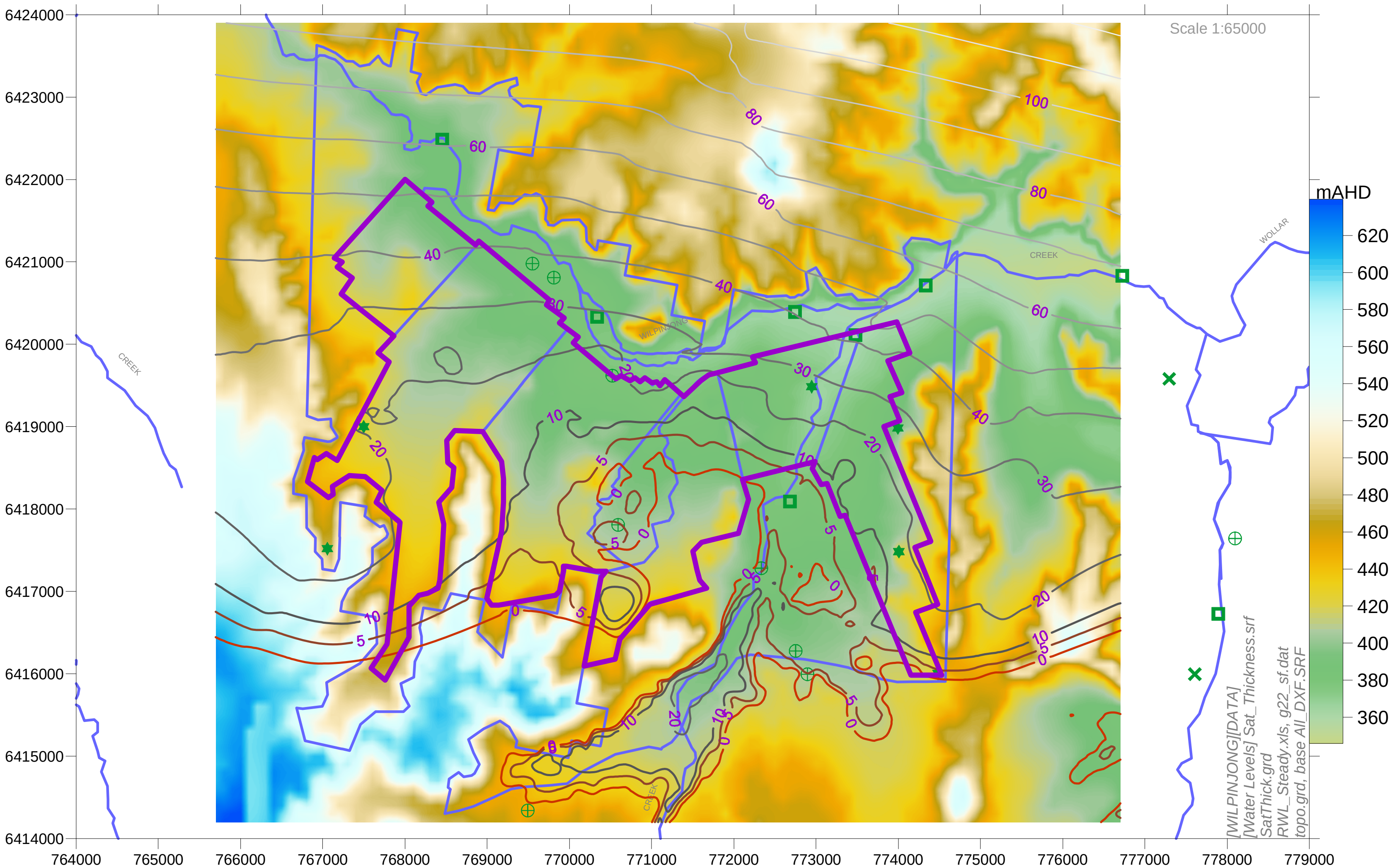


Figure 14. Pre-Mining Saturated Thickness (m) Contours above the Ulan Seam Floor, and Local Ground Topography [mAHD]

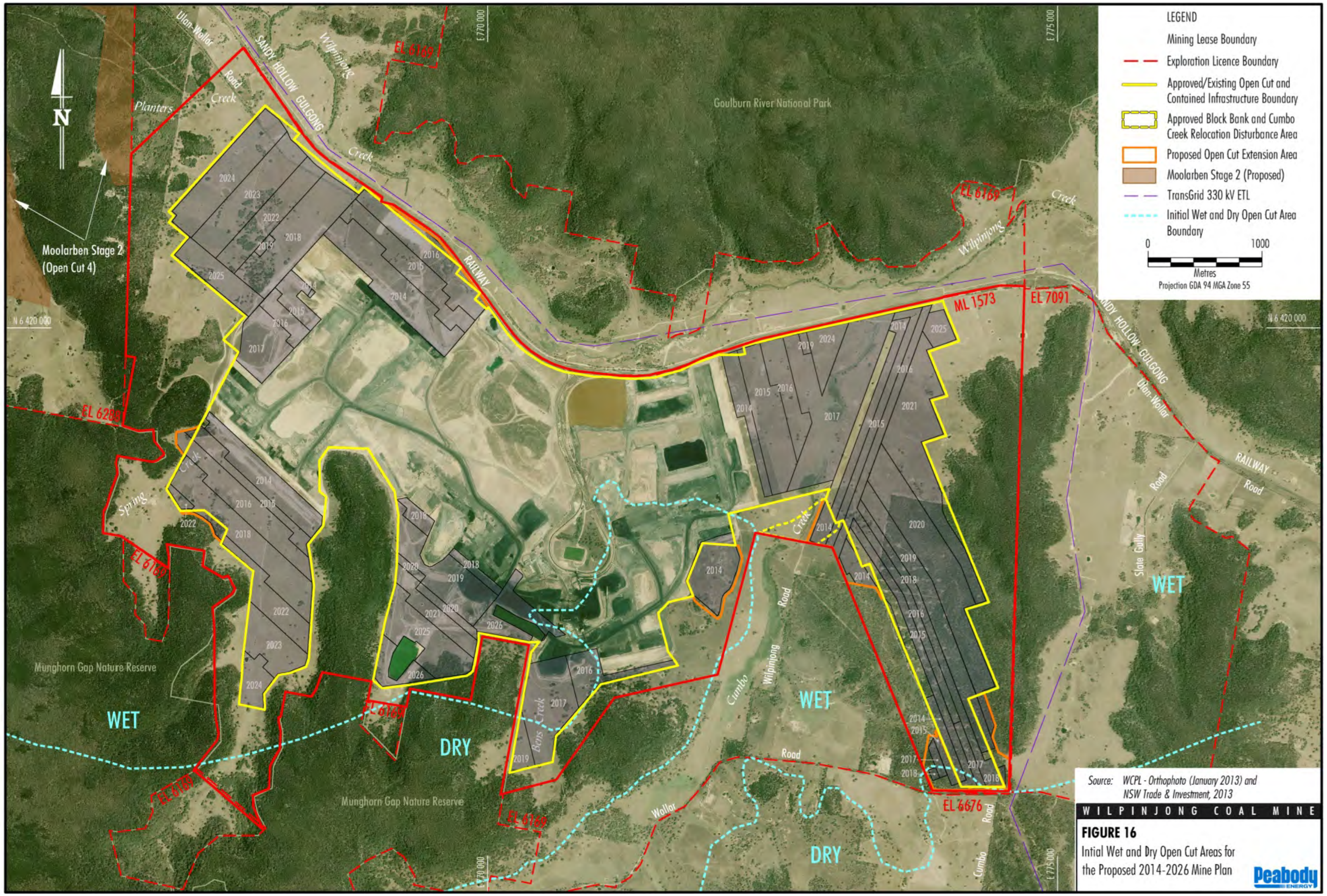


Figure 15. Initial Wet and Dry Open Cut Areas for the Proposed 2014-2026 Mine Plan

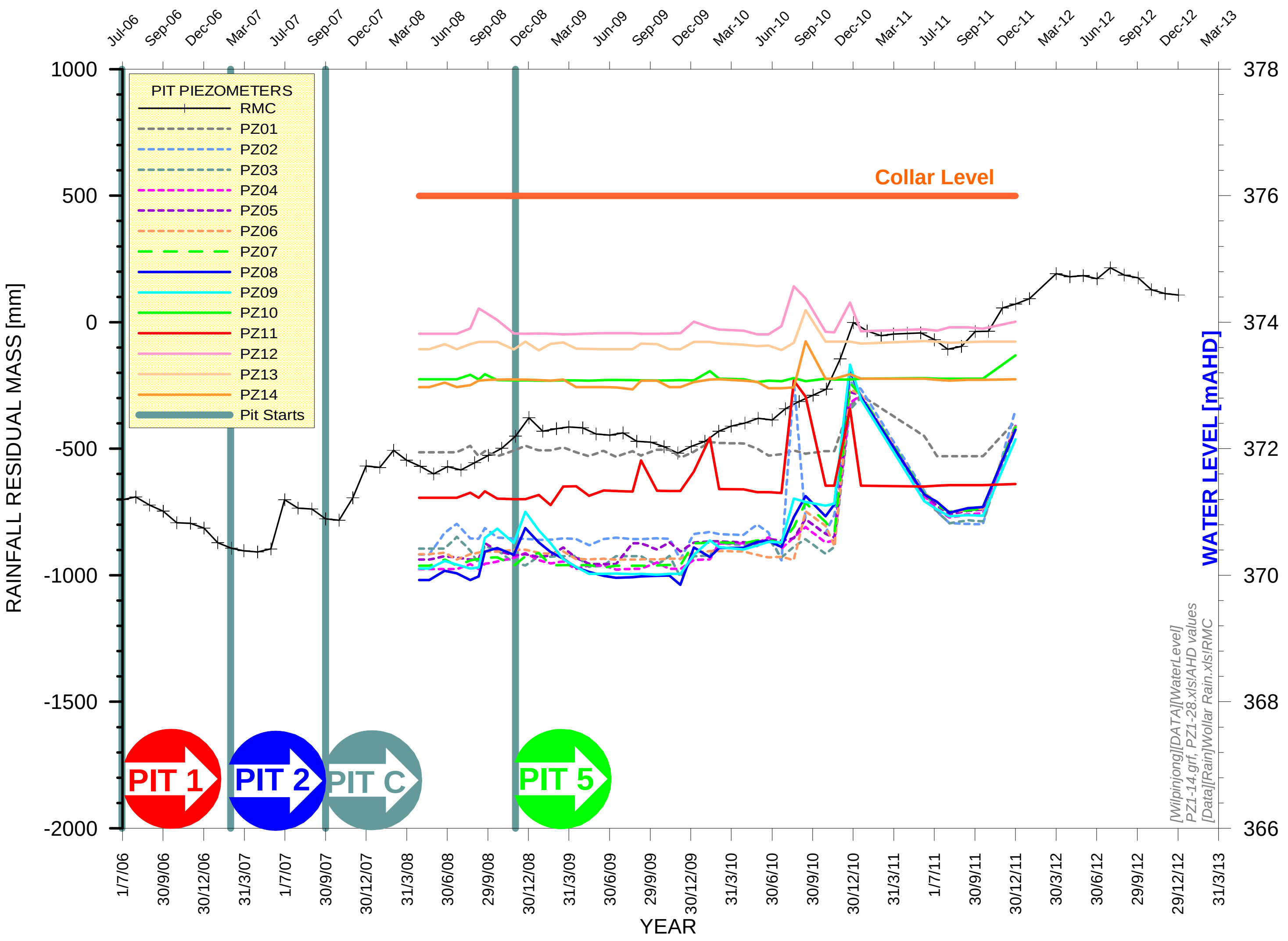


Figure 16. Transition in Pit Piezometer Groundwater Levels from West to East Adjacent to Pit 1 [mAHD]

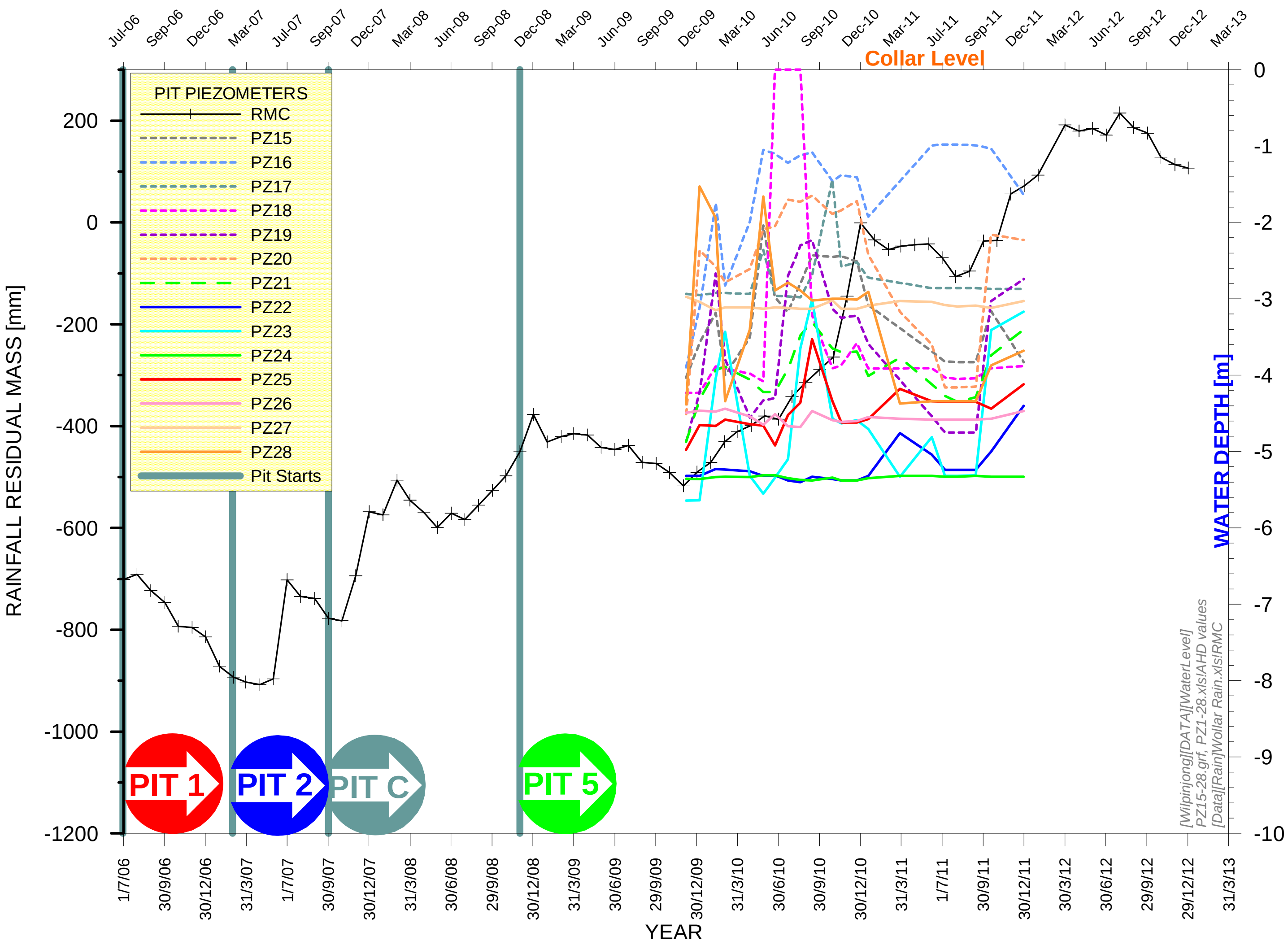


Figure 17. Transition in Pit Piezometer Groundwater Depths from West to East Adjacent to Pit 1 and Pit 2 [m]

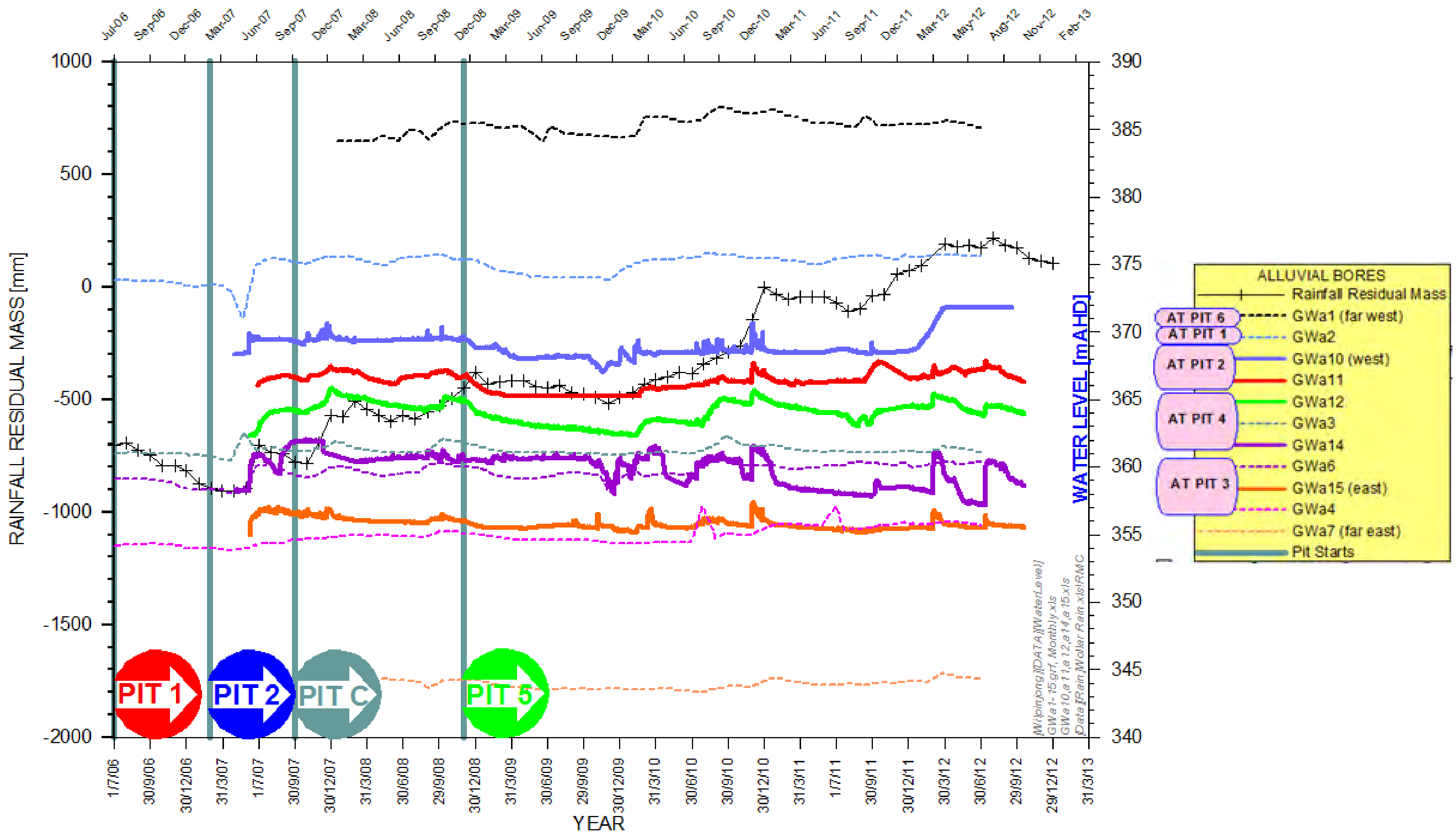


Figure 18. Transition in Alluvial Bore Groundwater Levels from West to East

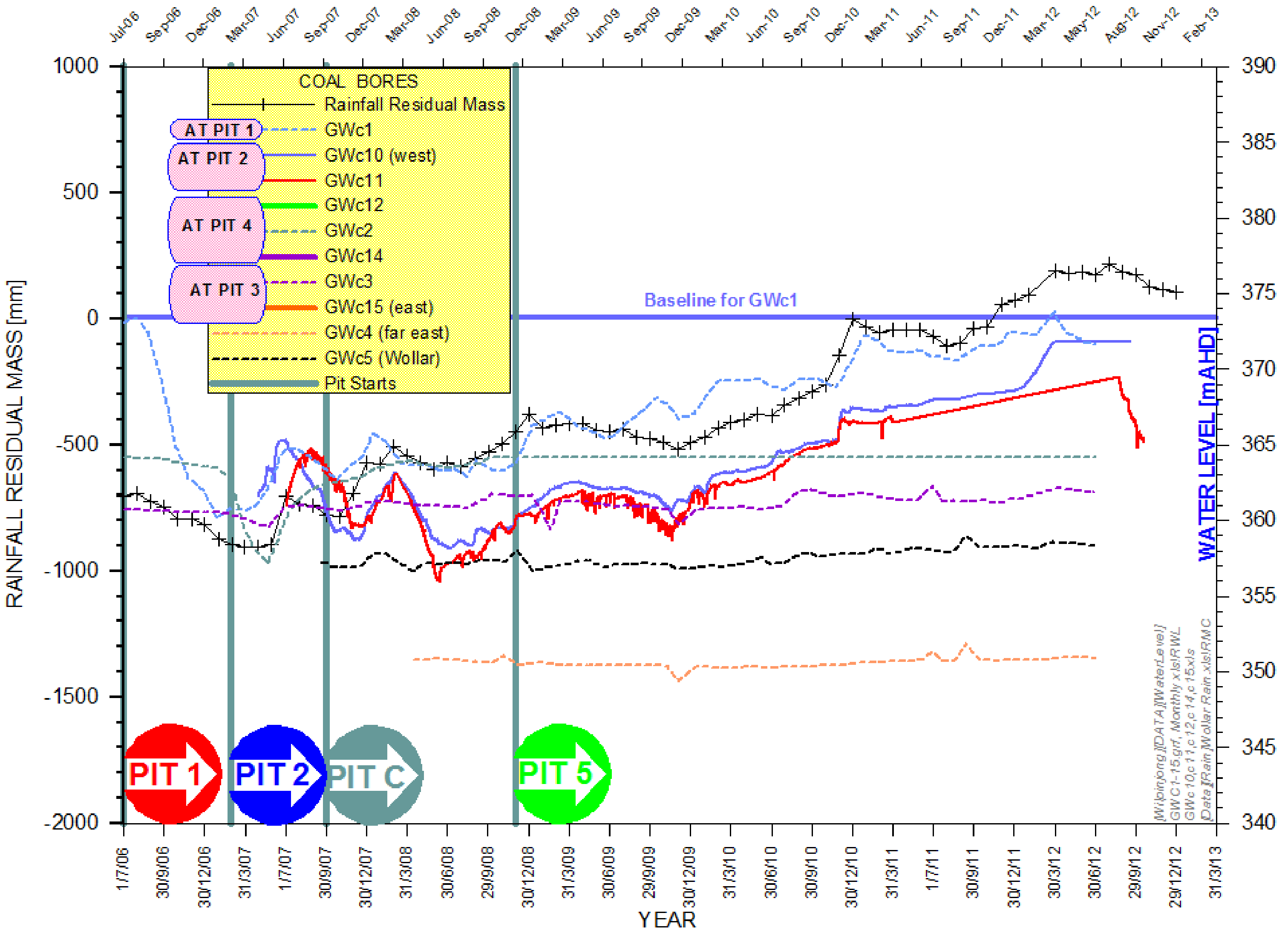


Figure 19a. Transition in Coal Bore Groundwater Levels from West to East

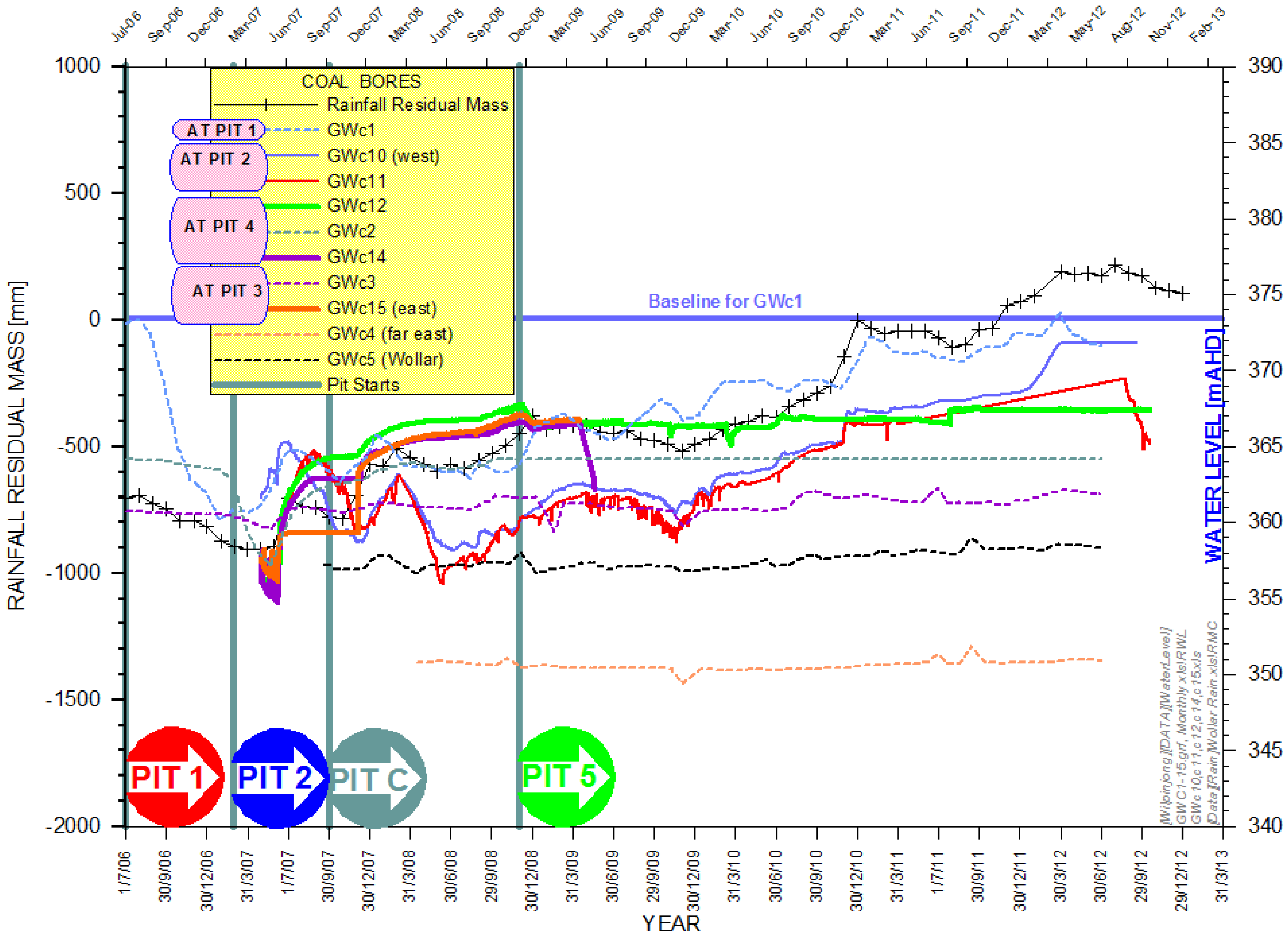


Figure 19b. Transition in Coal Bore Groundwater Levels from West to East, Showing Erroneous Bores GWc12, GWc14 and GWc15

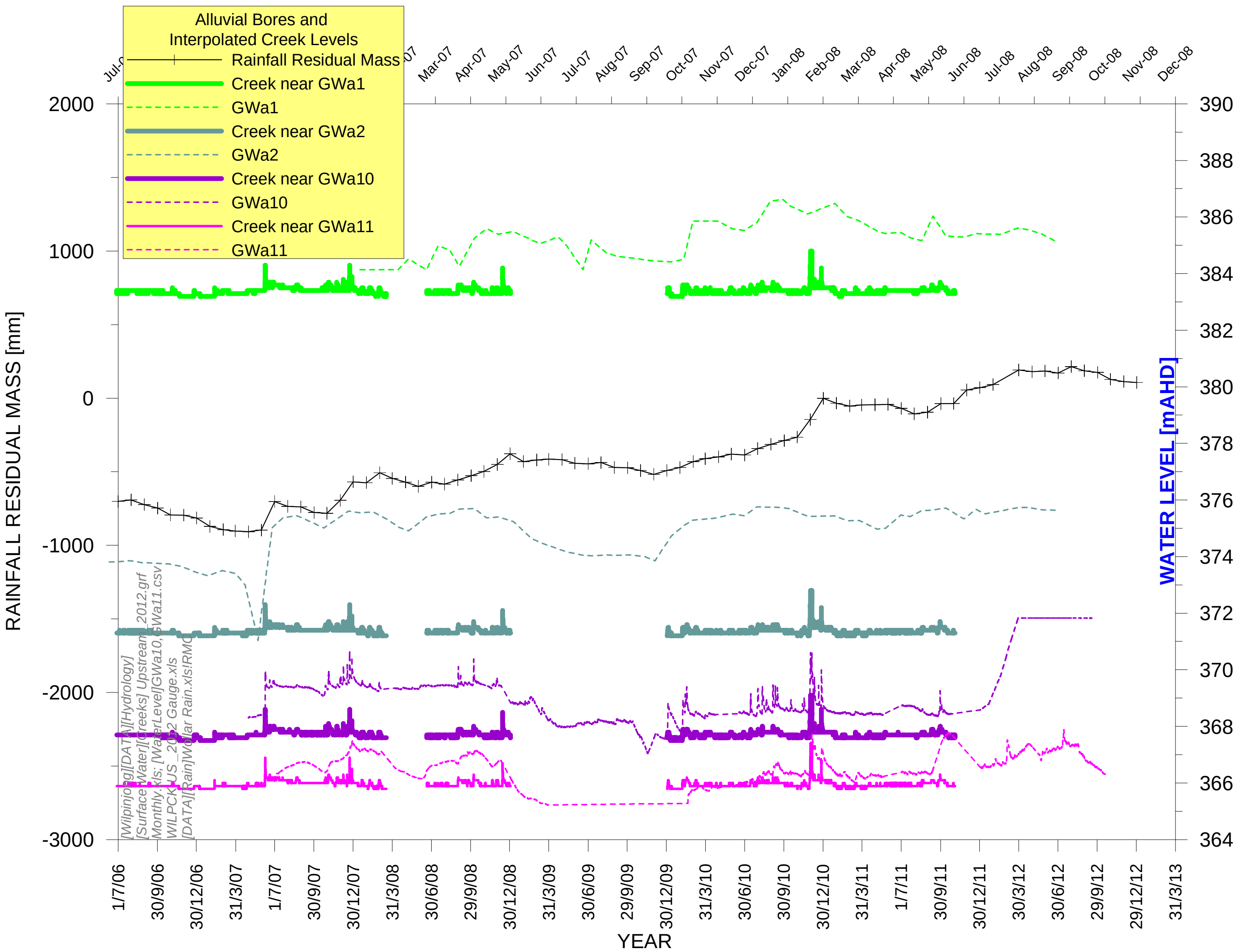


Figure 20a. Upstream Groundwater Hydrographs Compared with Interpolated Wilpinjong Creek Hydrographs, Assuming Linear Interpolation between Upstream and Downstream Gauging Station Elevations

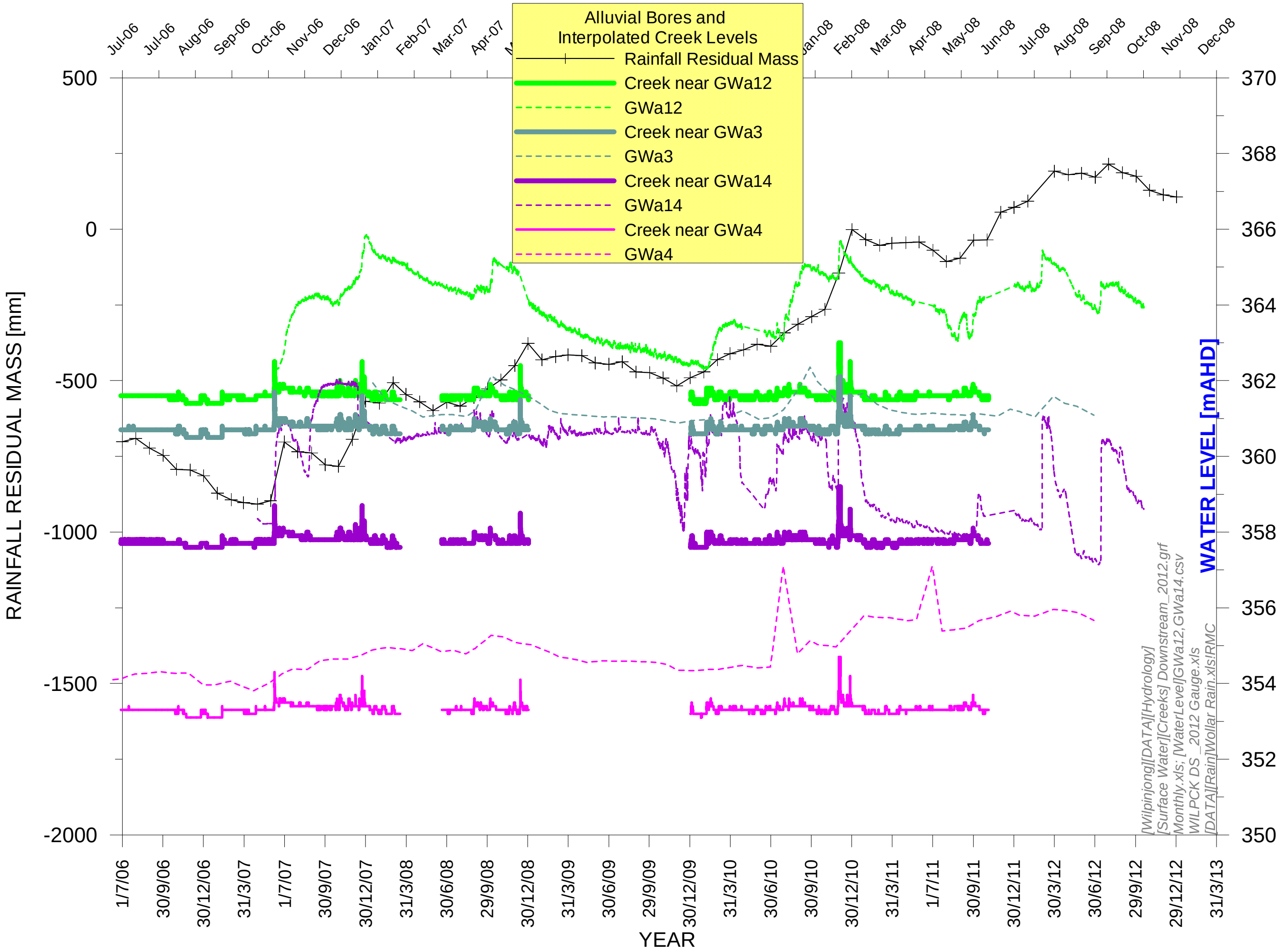


Figure 20b. Downstream Groundwater Hydrographs Compared with Interpolated Wilpinjong Creek Hydrographs, Assuming Linear Interpolation between Upstream and Downstream Gauging Station Elevations

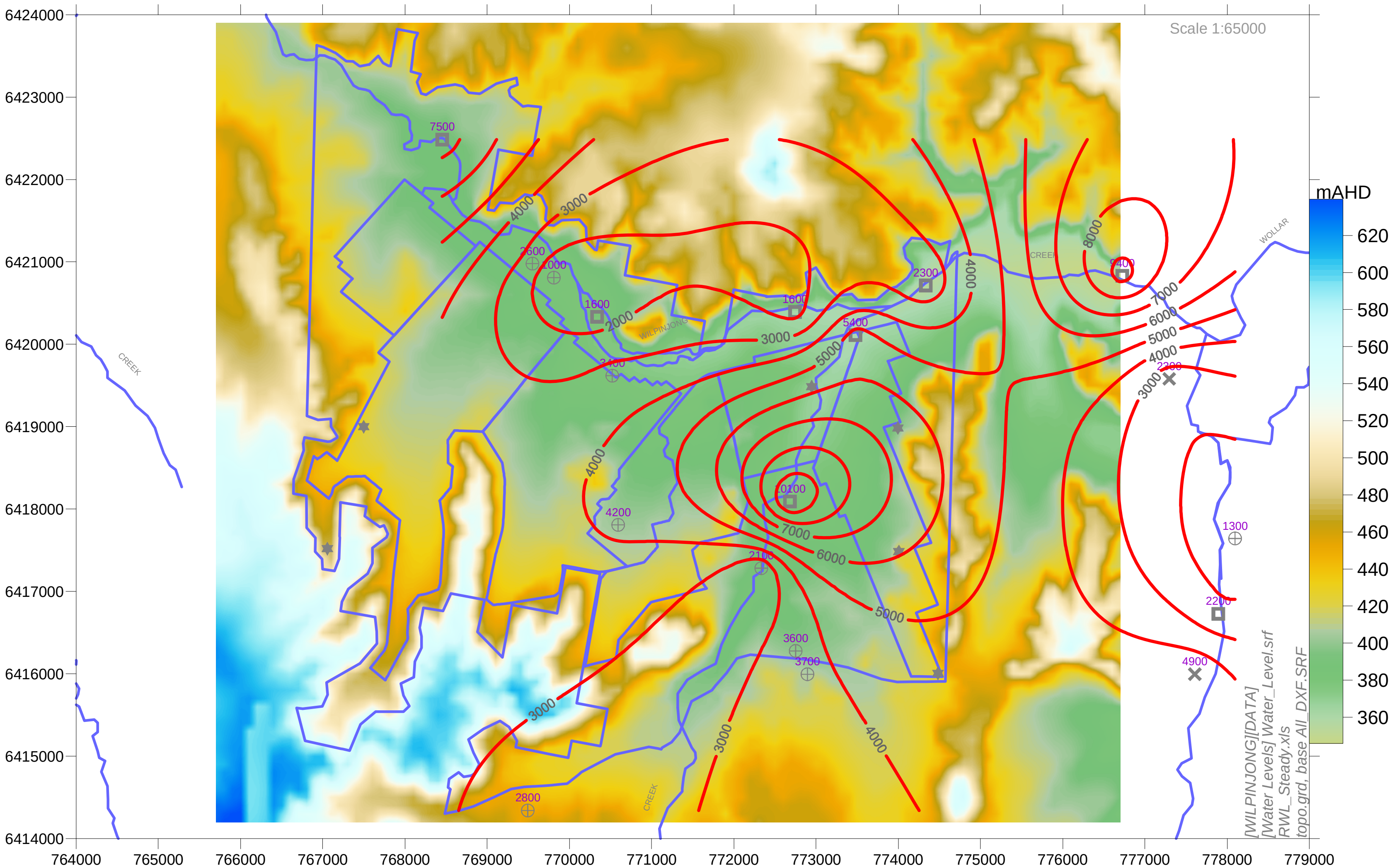


Figure 21. Pre-Mining Electrical Conductivity (µS/cm) Contours and Local Ground Topography [mAHD]

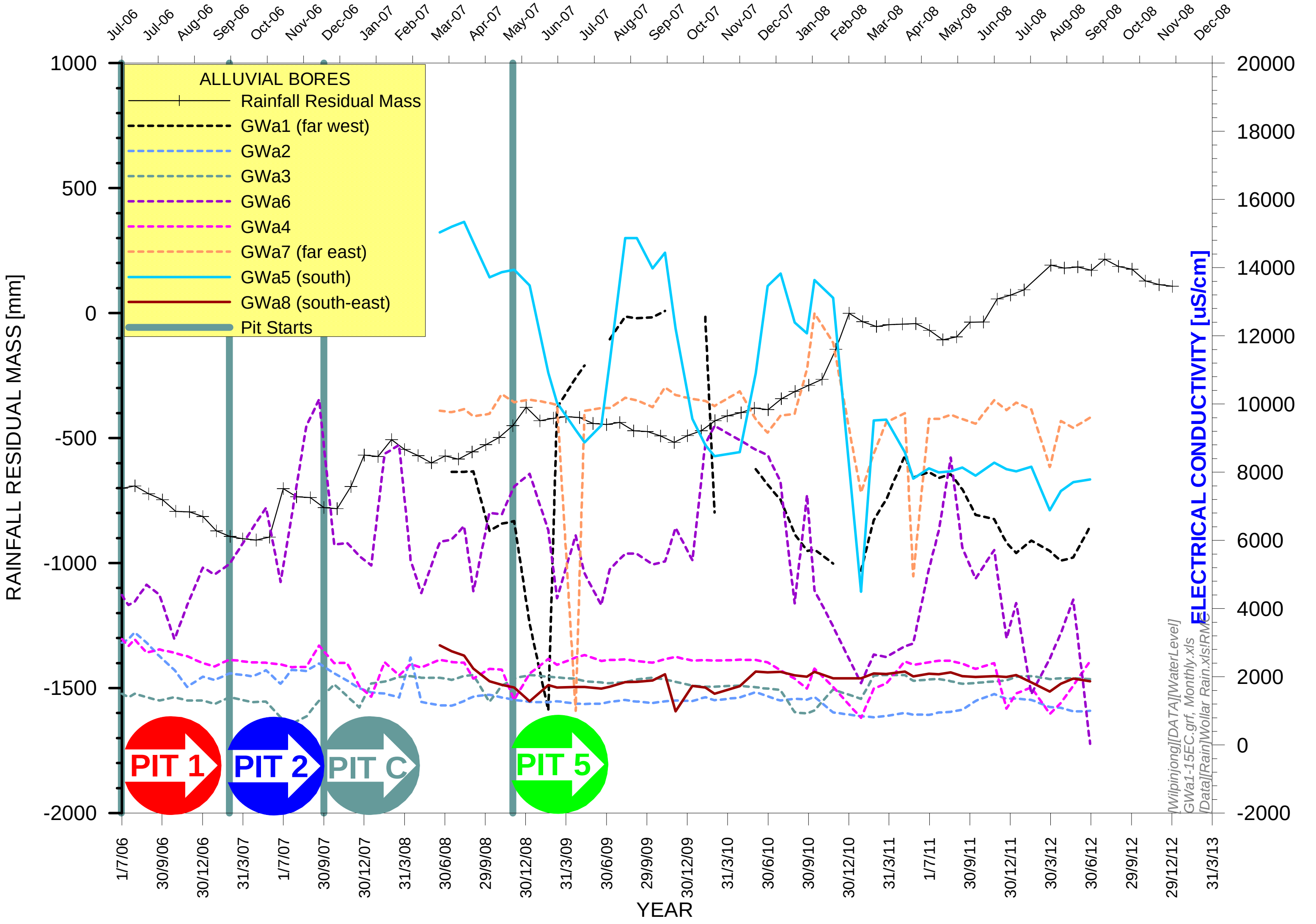


Figure 22. Electrical Conductivity Temporal Variations in Alluvium (µS/cm)

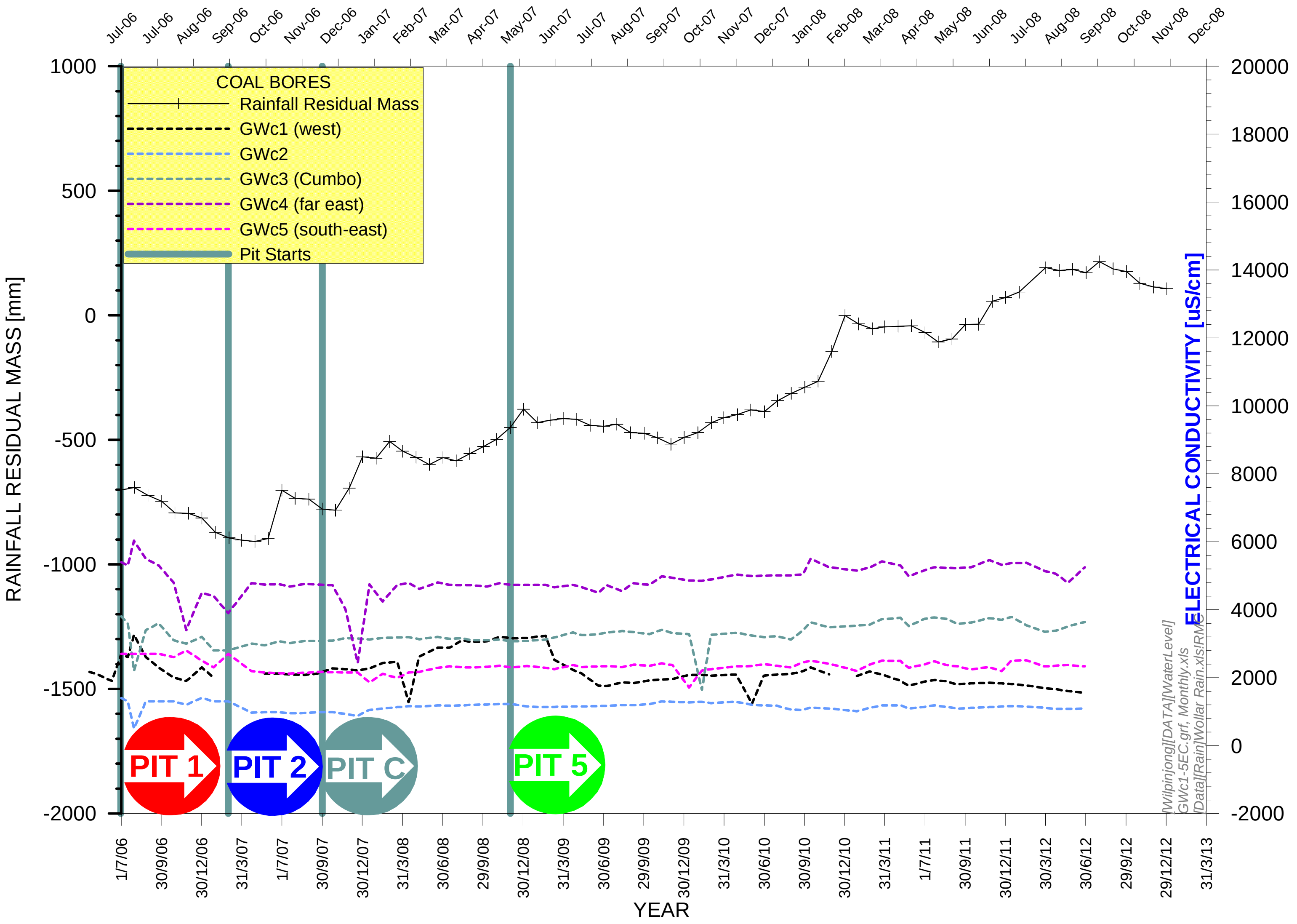


Figure 23. Electrical Conductivity Temporal Variations in Coal (µS/cm)

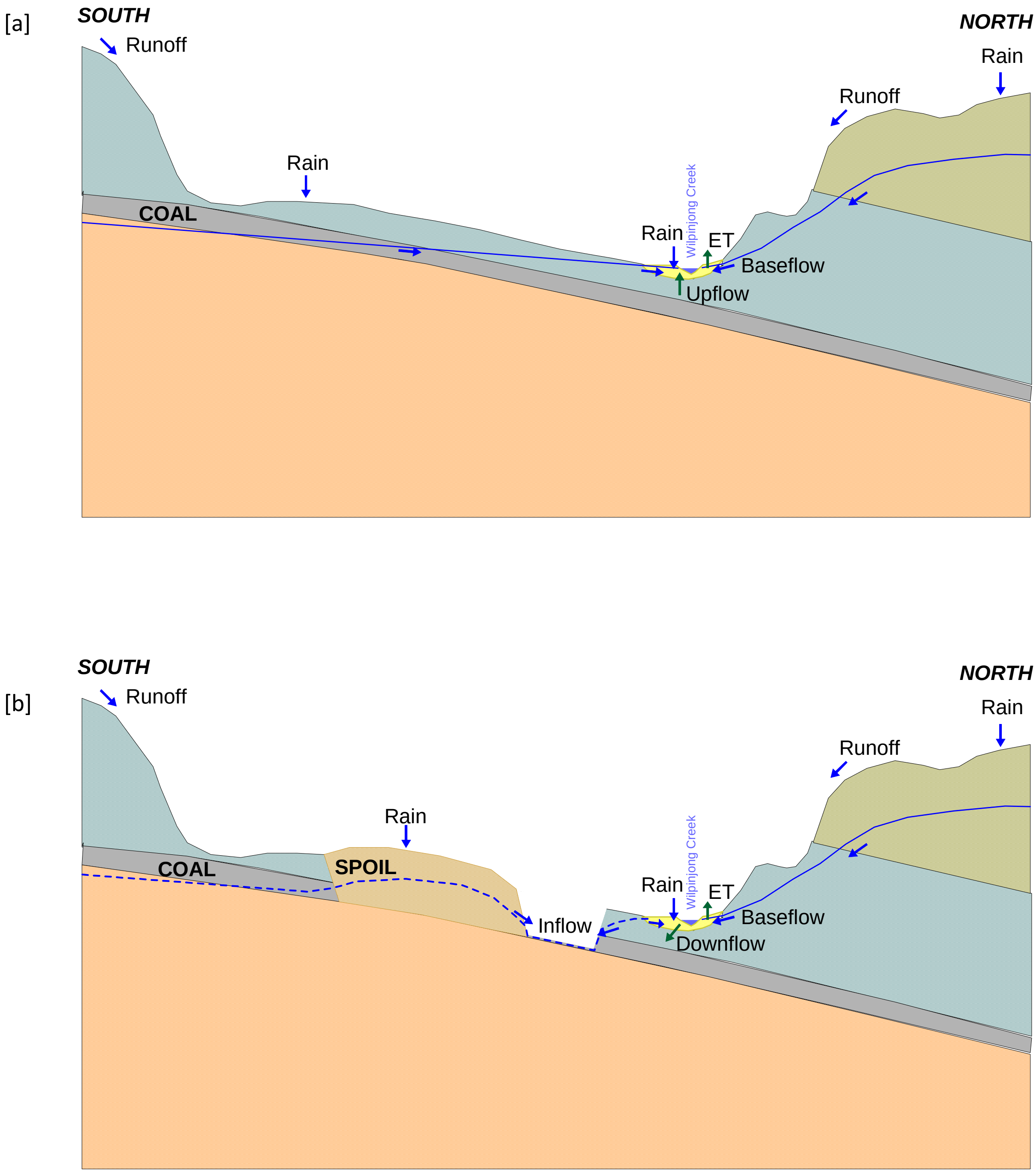


Figure 24. Hydrogeological Conceptual Model: [a] Before Mining; [b] During Mining

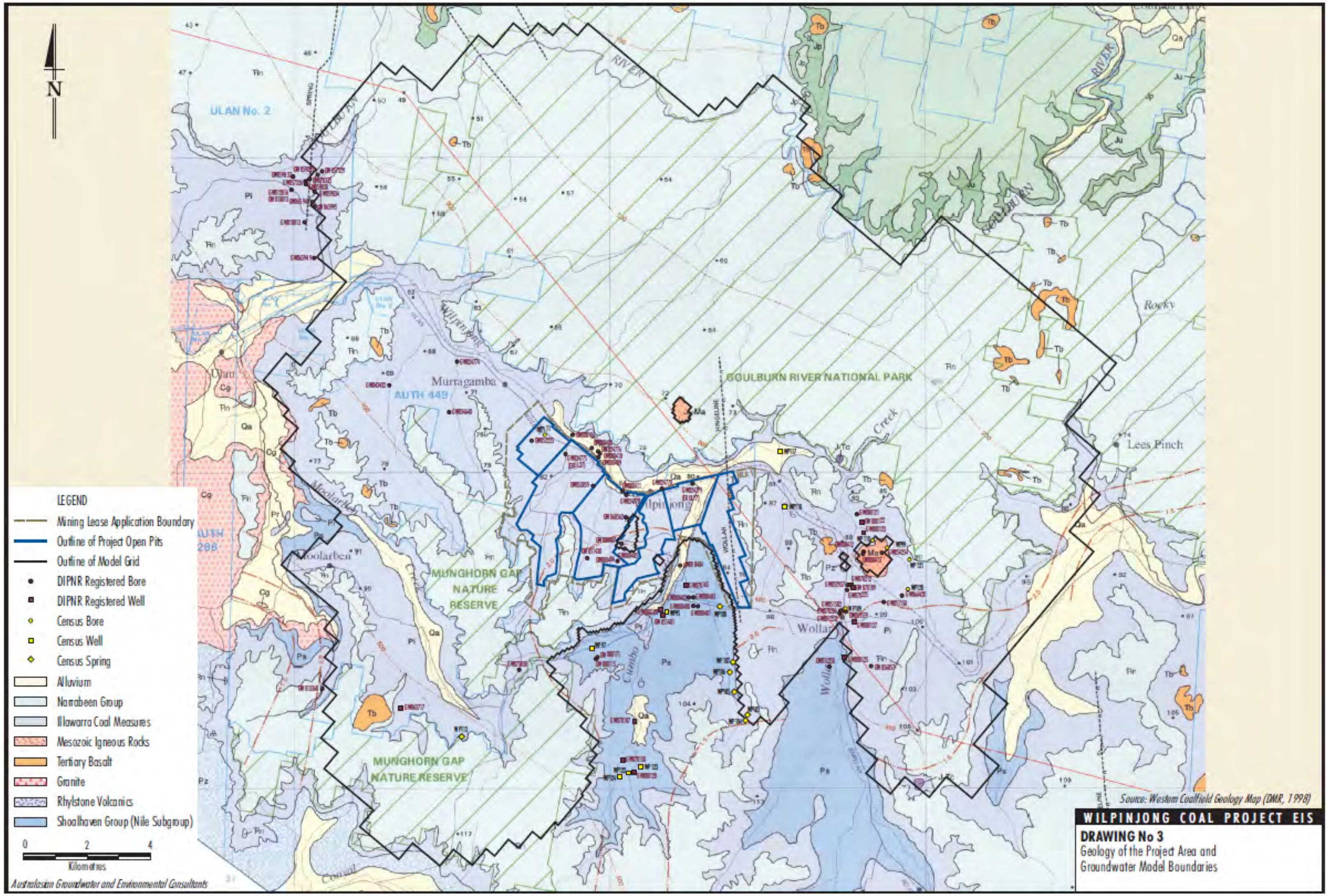


Figure 25. Groundwater Model Extent

[Source: After AGE, 2005]

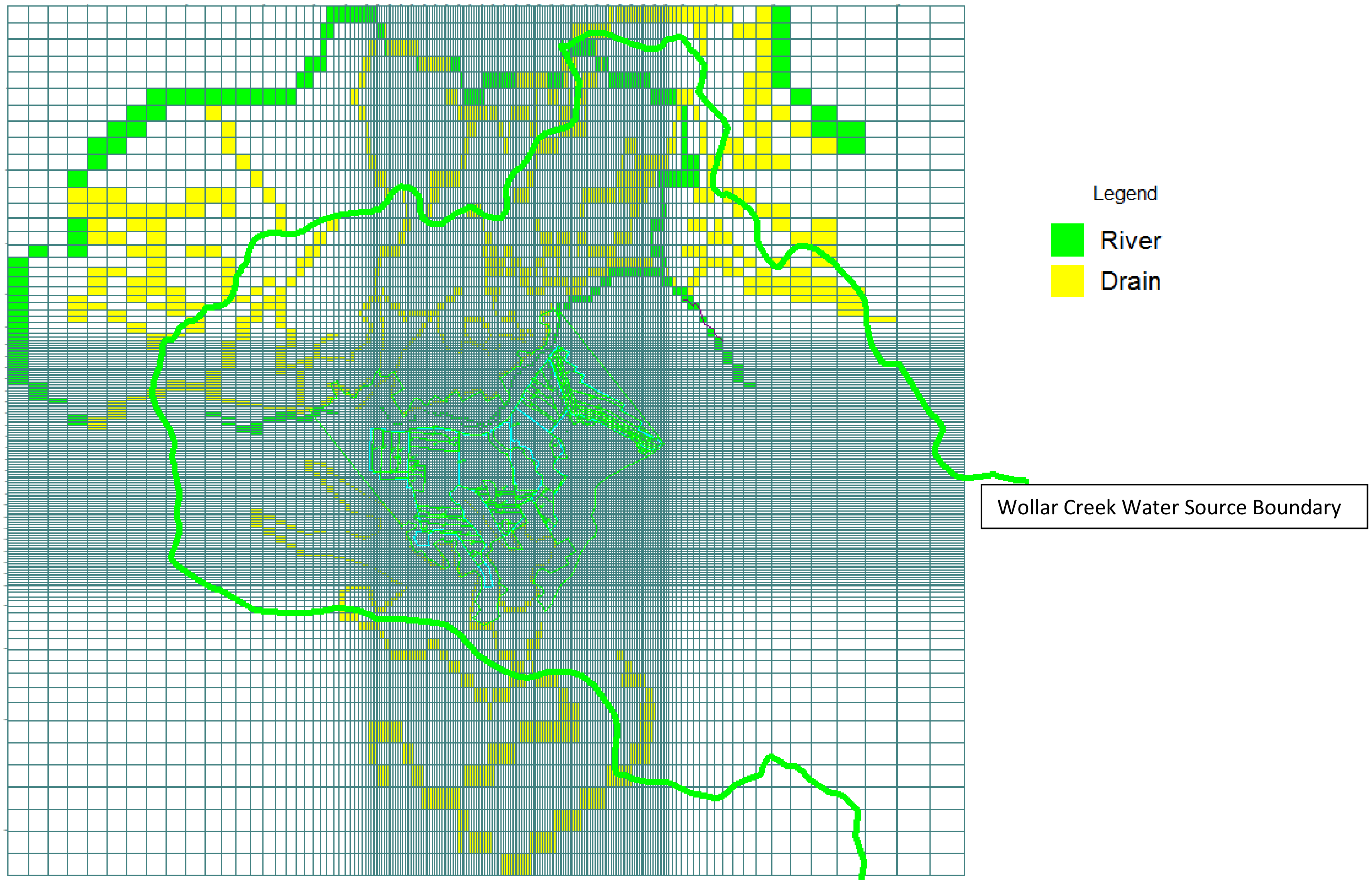


Figure 26. Groundwater Model Grid and Boundary Conditions

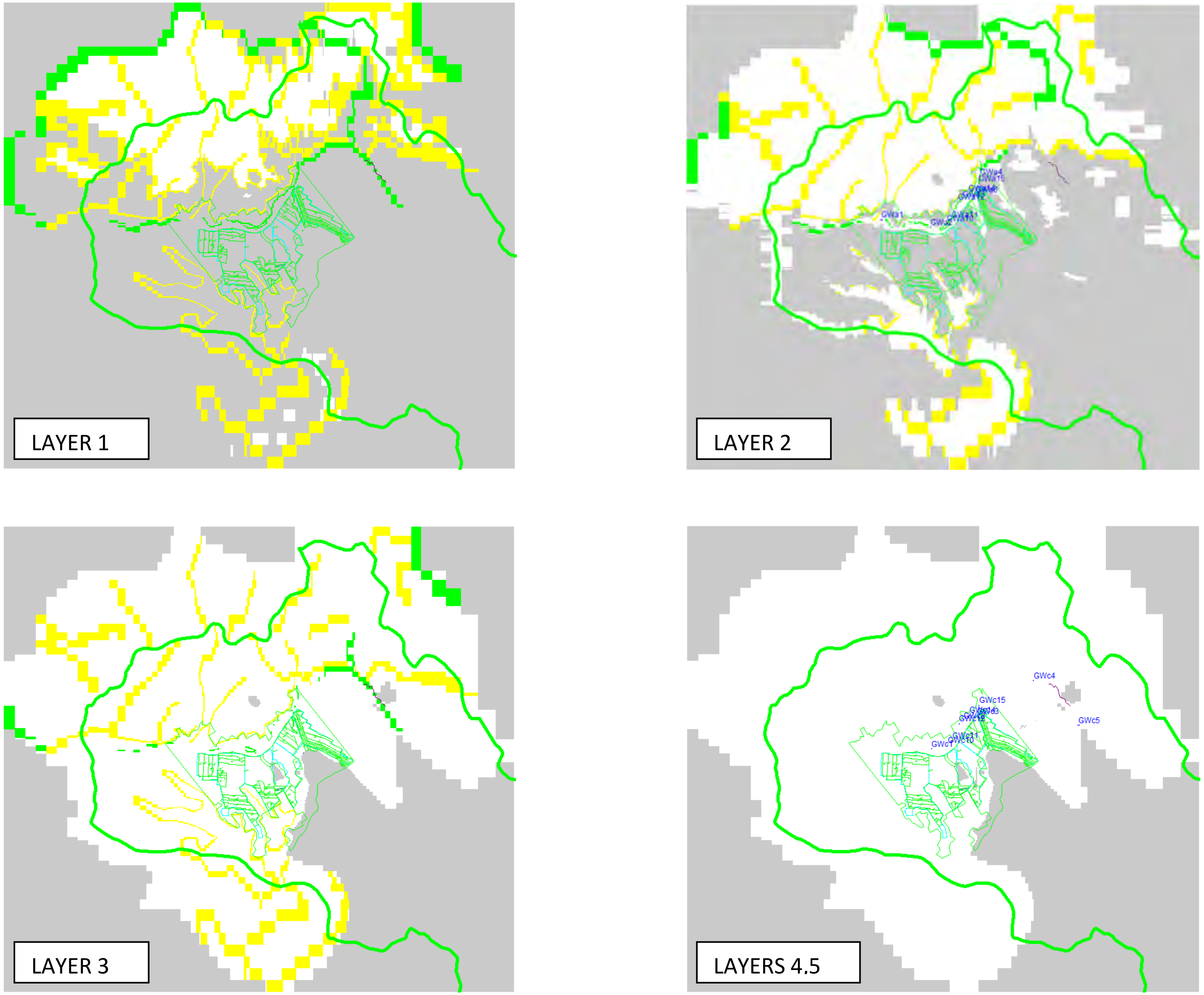
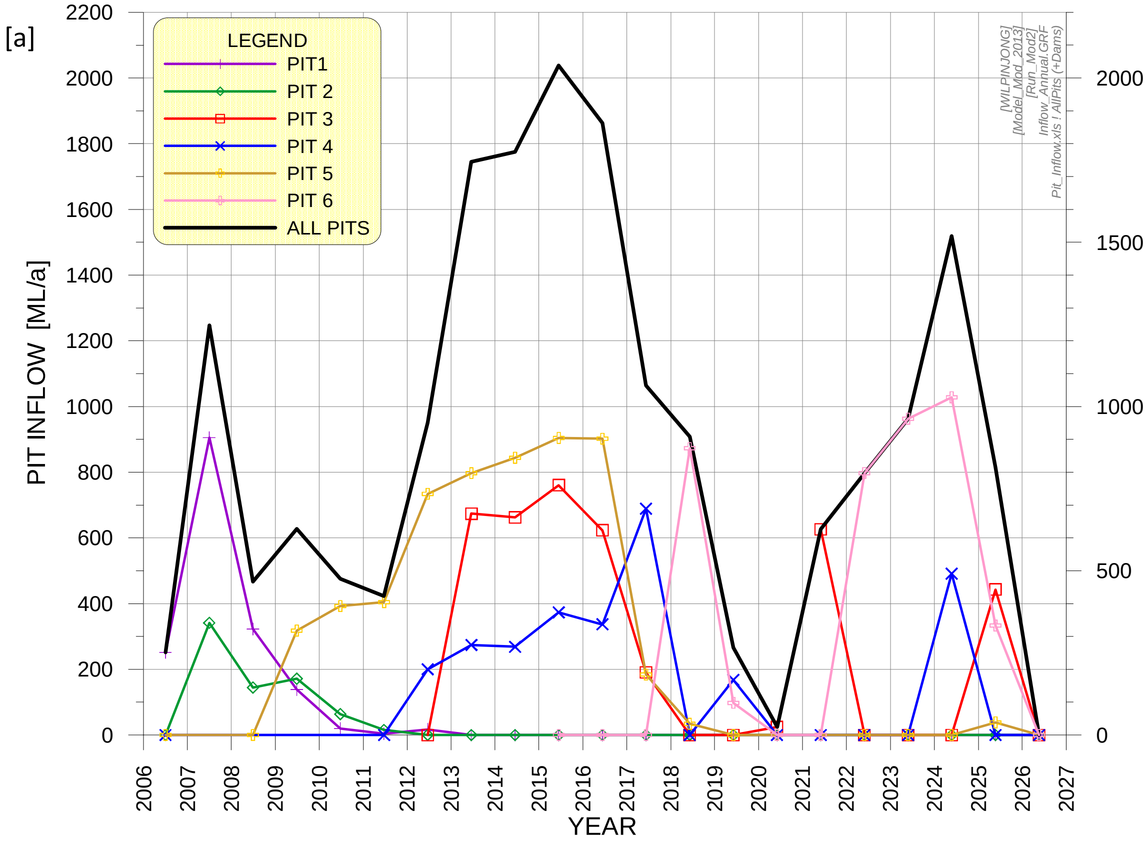


Figure 27. Groundwater Model Active/Inactive Regions and Boundary Conditions

Model Purpose	Stress Period	Start Date	End Date	Days Period Length	Days Total	PROJECT YEAR	EXCAVATION PIT 1	PIT 2	PIT C	PIT 5	PIT 4	PIT 3	PIT 6	SPOIL RECHARGE PIT 1	PIT 2	PIT C	PIT 5	PIT 4	PIT 3	PIT 6	DAMS PIT1 SOUTH	DIRTY WATER	PIT2 WEST
HISTORICAL	1	30/06/2006	30/06/2006	1	1									1%	1%	1%	1%	1%	1%	1%			
	2	1/07/2006	28/02/2007	242	243	1	June							0%	1%	1%	1%	1%	1%	1%			
	3	1/03/2007	30/06/2007	121	364	2		March						0%	0%	1%	1%	1%	1%	1%			
	4	1/07/2007	31/12/2007	183	547	2			October					0%	0%	0%	1%	1%	1%	1%			
	5	1/01/2008	30/06/2008	181	728	3								0%	0%	0%	1%	1%	1%	1%			
	6	1/07/2008	30/11/2008	152	880	3								0%	0%	0%	1%	1%	1%	1%			
	7	1/12/2008	30/06/2009	211	1091	4				December				0%	0%	0%	5%	1%	1%	1%			
	8	1/07/2009	31/12/2009	183	1274	4								0%	0%	0%	0%	1%	1%	1%			
	9	1/01/2010	30/06/2010	180	1454	5								0%	0%	0%	0%	1%	1%	1%			
	10	1/07/2010	31/12/2010	183	1637	5								0%	0%	0%	0%	1%	1%	1%			
	11	1/01/2011	30/06/2011	180	1817	6								0%	0%	0%	0%	1%	1%	1%			
	12	1/07/2011	31/12/2011	183	2000	6								0%	0%	0%	0%	1%	1%	1%			
	13	1/01/2012	30/06/2012	181	2181	7								5%	0%	0%	0%	1%	1%	1%			
	14	1/07/2012	31/12/2012	183	2364	7								5%	5%	5%	0%	0%	1%	1%			
PREDICTION	15	1/01/2013	30/06/2013	180	2544	8								5%	5%	5%	0%	0%	0%	1%			
	16	1/07/2013	31/12/2013	183	2727	8								5%	5%	5%	0%	0%	0%	1%			
	17	1/01/2014	30/06/2014	180	2907	9								5%	5%	5%	0%	0%	0%	1%			
	18	1/07/2014	31/12/2014	183	3090	9								5%	5%	5%	5%	0%	0%	1%			
	19	1/01/2015	30/06/2015	180	3270	10								5%	5%	5%	5%	0%	0%	1%			
	20	1/07/2015	31/12/2015	183	3453	10								5%	5%	5%	5%	0%	0%	1%			
	21	1/01/2016	30/06/2016	181	3634	11								5%	5%	5%	5%	0%	0%	1%			
	22	1/07/2016	31/12/2016	183	3817	11								5%	5%	5%	5%	0%	0%	1%			
	23	1/01/2017	30/06/2017	180	3997	12								5%	5%	5%	5%	0%	0%	1%			
	24	1/07/2017	31/12/2017	183	4180	12								5%	5%	5%	5%	0%	0%	1%			
	25	1/01/2018	30/06/2018	180	4360	13								5%	5%	5%	5%	5%	0%	0%			
	26	1/07/2018	31/12/2018	183	4543	13								5%	5%	5%	5%	5%	5%	0%			
	27	1/01/2019	30/06/2019	180	4723	14								5%	5%	5%	5%	5%	5%	0%			
	28	1/07/2019	31/12/2019	183	4906	14								5%	5%	5%	5%	5%	5%	0%			
	29	1/01/2020	29/06/2020	180	5086	15								5%	5%	5%	5%	5%	5%	0%			
	30	30/06/2020	30/12/2020	183	5269	15								5%	5%	5%	5%	5%	5%	0%			
	31	31/12/2020	29/06/2021	180	5449	16								5%	5%	5%	5%	5%	5%	0%			
	32	30/06/2021	30/12/2021	183	5632	16								5%	5%	5%	5%	5%	5%	0%			
	33	31/12/2021	29/06/2022	180	5812	17								5%	5%	5%	5%	5%	5%	0%			
	34	30/06/2022	30/12/2022	183	5995	17								5%	5%	5%	5%	5%	5%	0%			
	35	31/12/2022	29/06/2023	180	6175	18								5%	5%	5%	5%	5%	5%	0%			
	36	30/06/2023	30/12/2023	183	6358	18								5%	5%	5%	5%	5%	5%	5%			
	37	31/12/2023	28/06/2024	180	6538	19								5%	5%	5%	5%	5%	5%	5%			
	38	29/06/2024	29/12/2024	183	6721	19								5%	5%	5%	5%	5%	5%	5%			
	39	30/12/2024	28/06/2025	180	6901	20								5%	5%	5%	5%	5%	5%	5%			
	40	29/06/2025	29/12/2025	183	7084	20								5%	5%	5%	5%	5%	5%	5%			
	41	30/12/2025	28/06/2026	180	7264	21								5%	5%	5%	5%	5%	5%	5%			
	42	29/06/2026	29/12/2026	183	7447	21								5%	5%	5%	5%	5%	5%	5%			
RECOVERY	43	30/12/2026	1/01/2227	73050	80497	221						FINAL VOID	FINAL VOID	5%	5%	5%	5%	5%	5%	5%			

Figure 28. Simulated Pit Excavation and Spoil Recharge Schedules



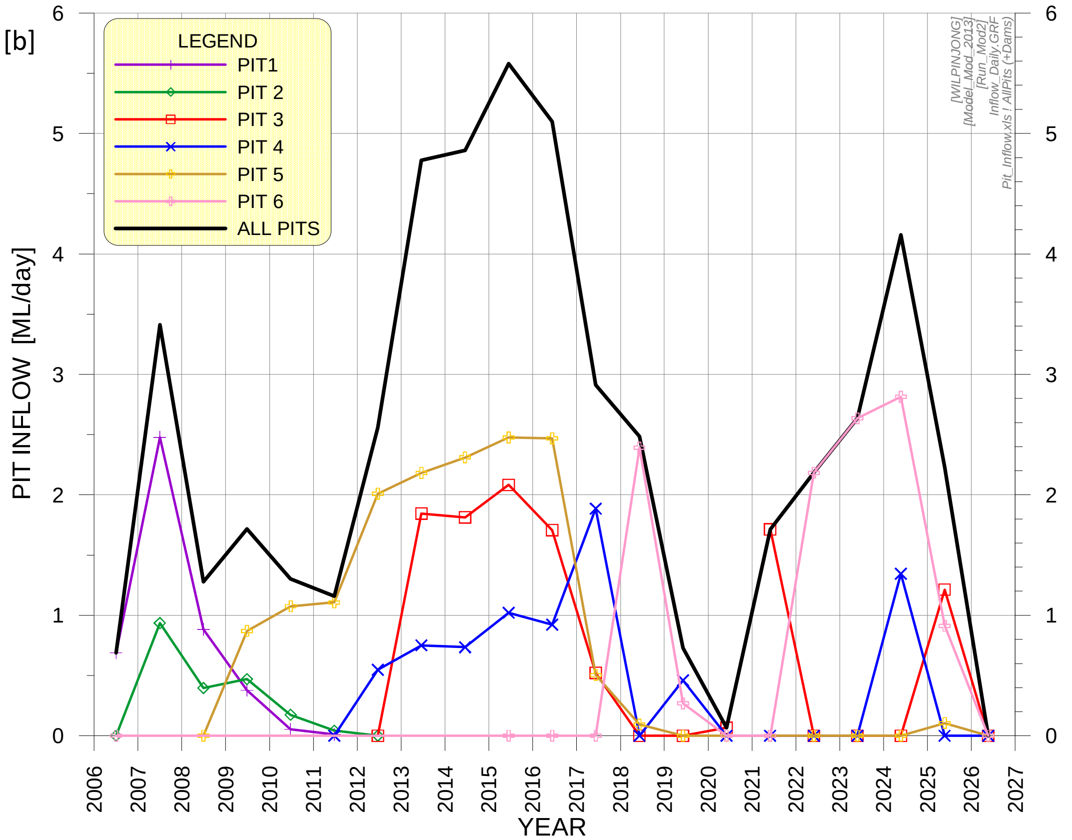
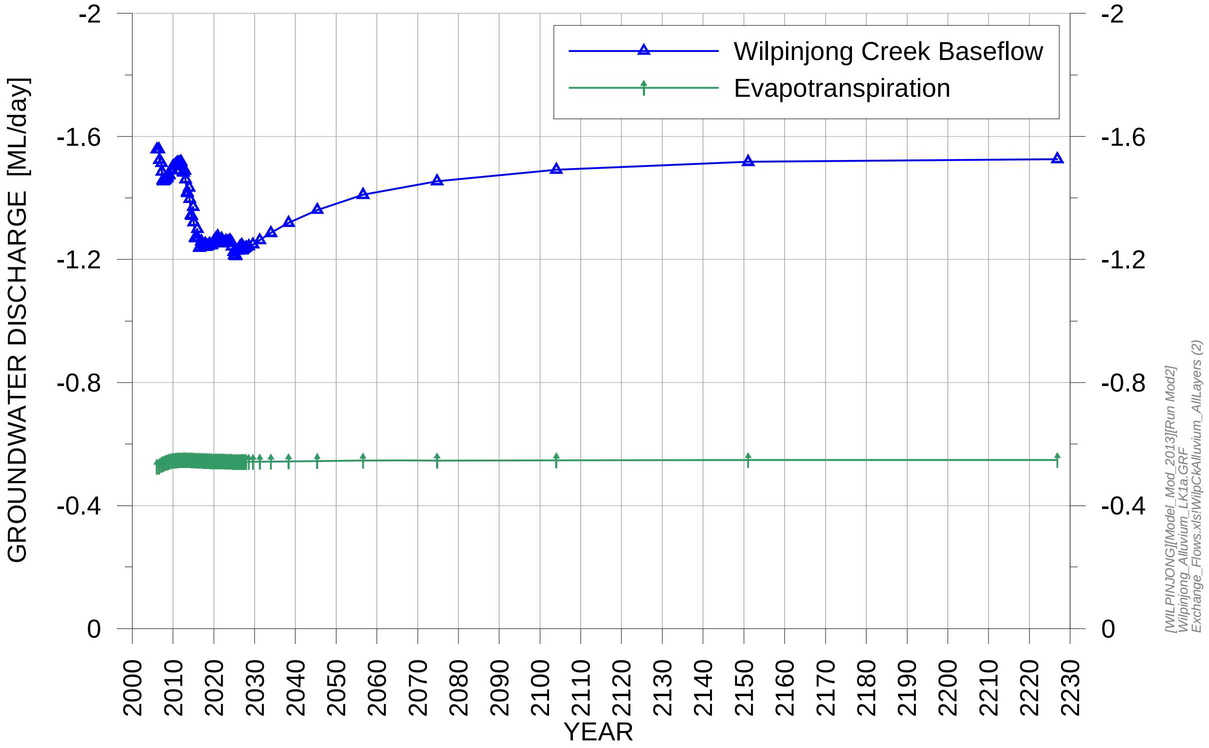


Figure 29. Simulated Pit Inflows for the Modification Mine Plan: [a] ML/a units; [b] ML/d units

[a]



[b]

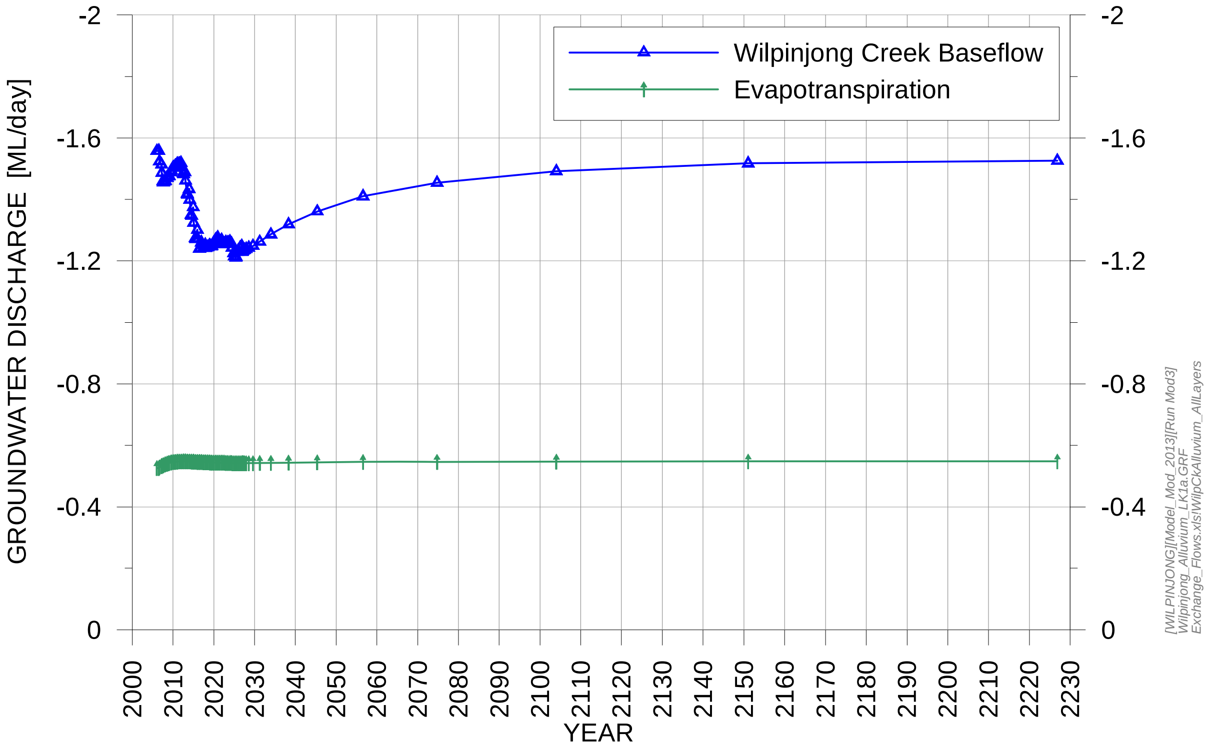
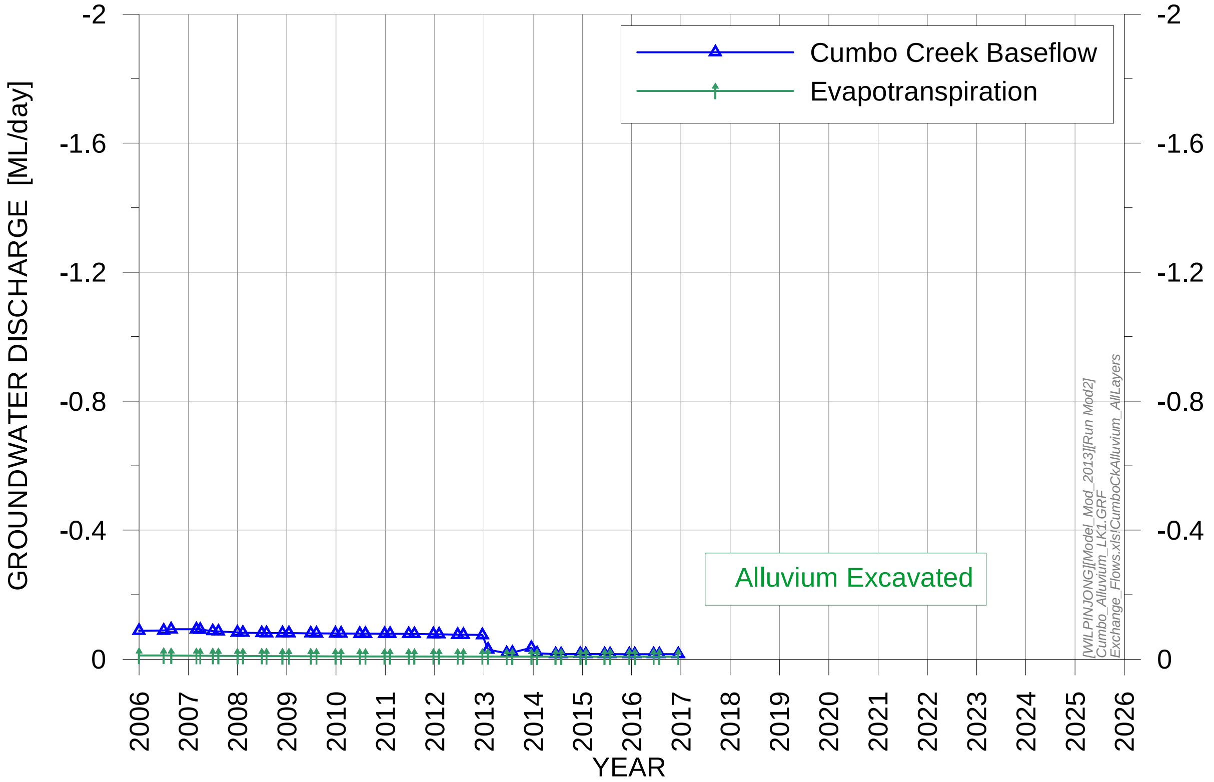


Figure 30. Baseflow and Evapotranspiration Estimates for Wilpinjong Creek and Wilpinjong Creek Alluvium: [a] Modification Mine Plan; [b] Approved Mine Plan

[a]



[b]

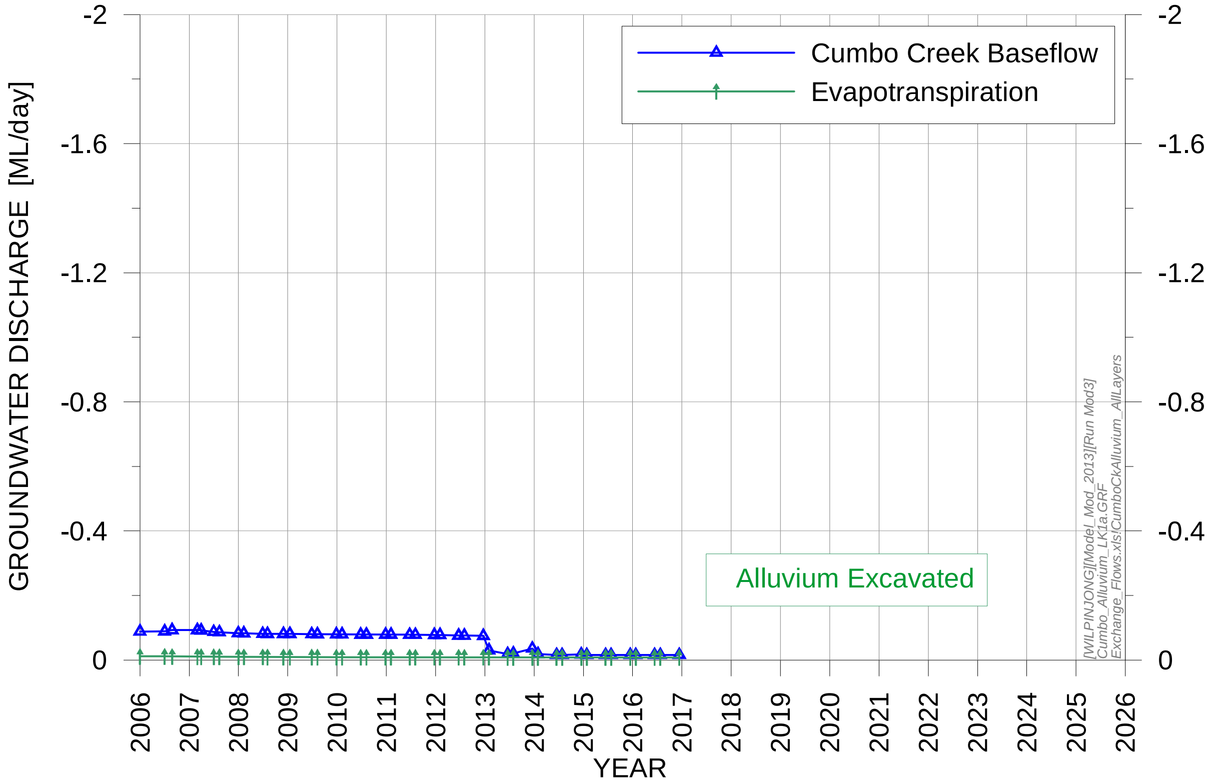
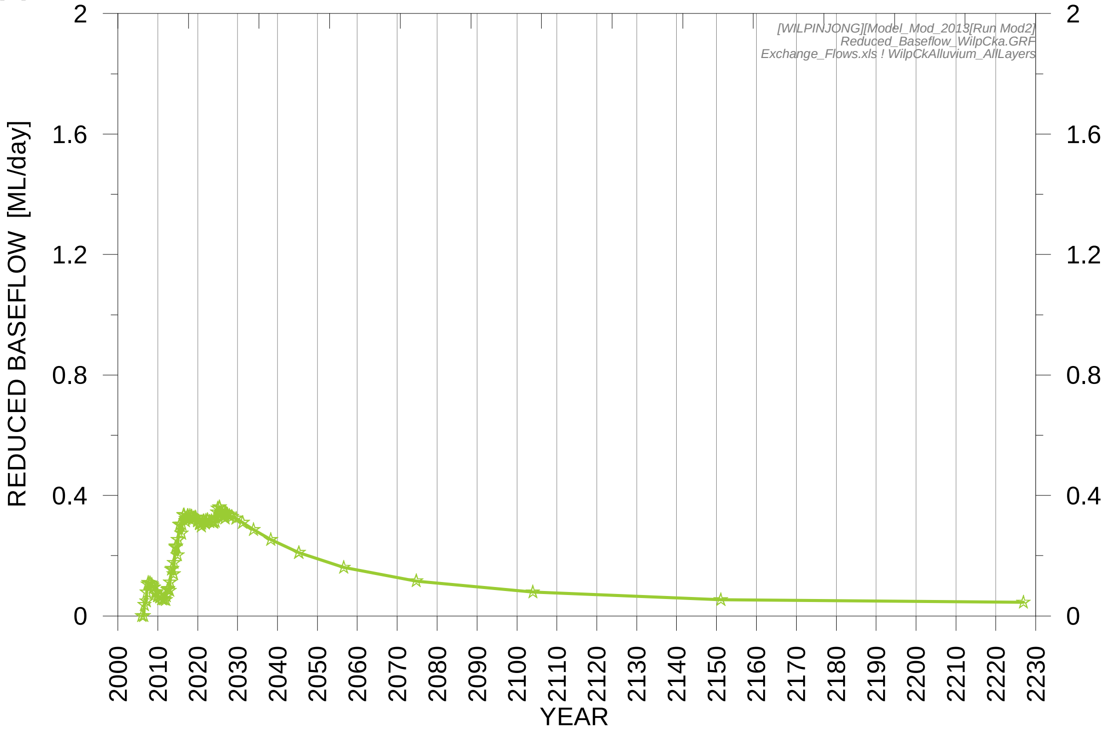


Figure 31. Baseflow and Evapotranspiration Estimates for Cumbo Creek and Cumbo Creek Alluvium: [a] Modification Mine Plan; [b] Approved Mine Plan

[a]



[b]

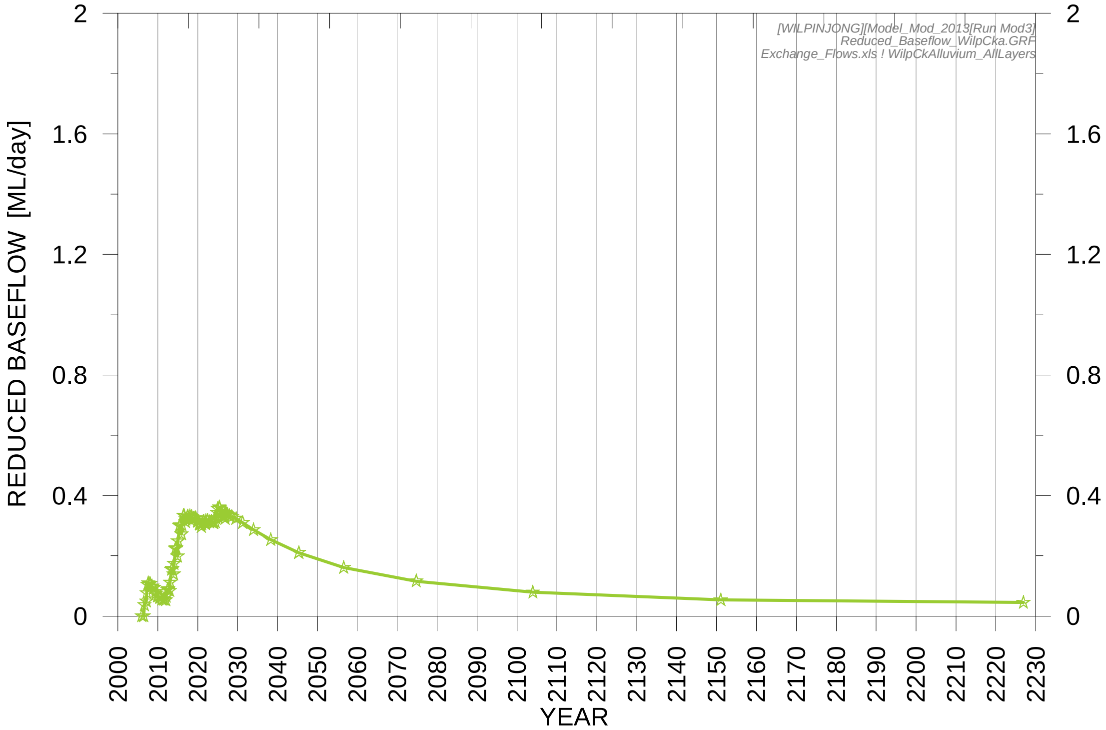
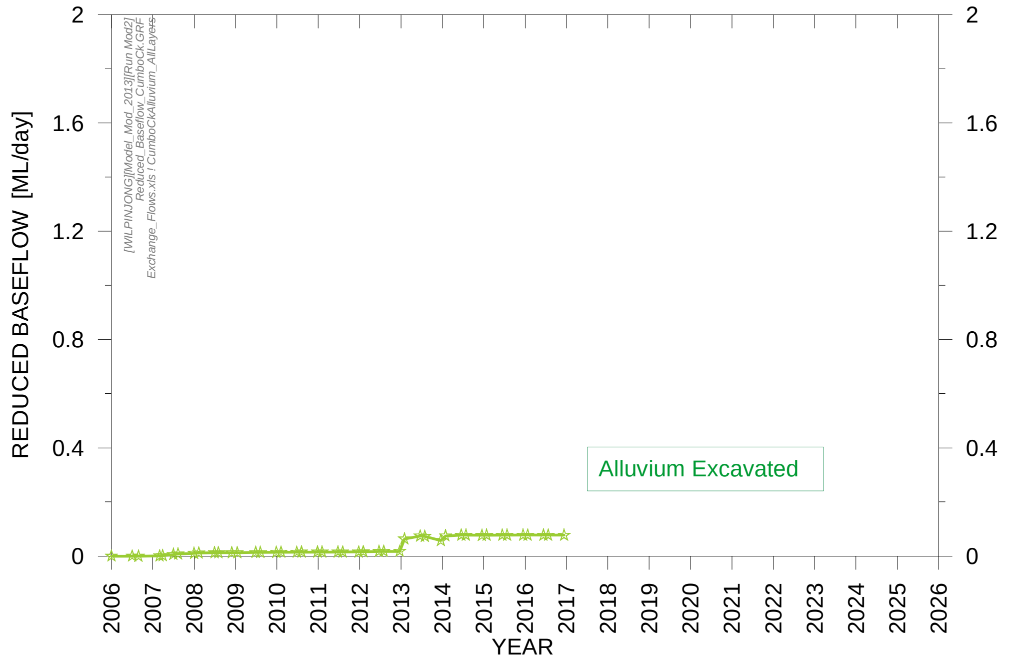


Figure 32. Reduced Baseflow to Wilpinjong Creek: [a] Modification Mine Plan; [b] Approved Mine Plan

[a]



[b]

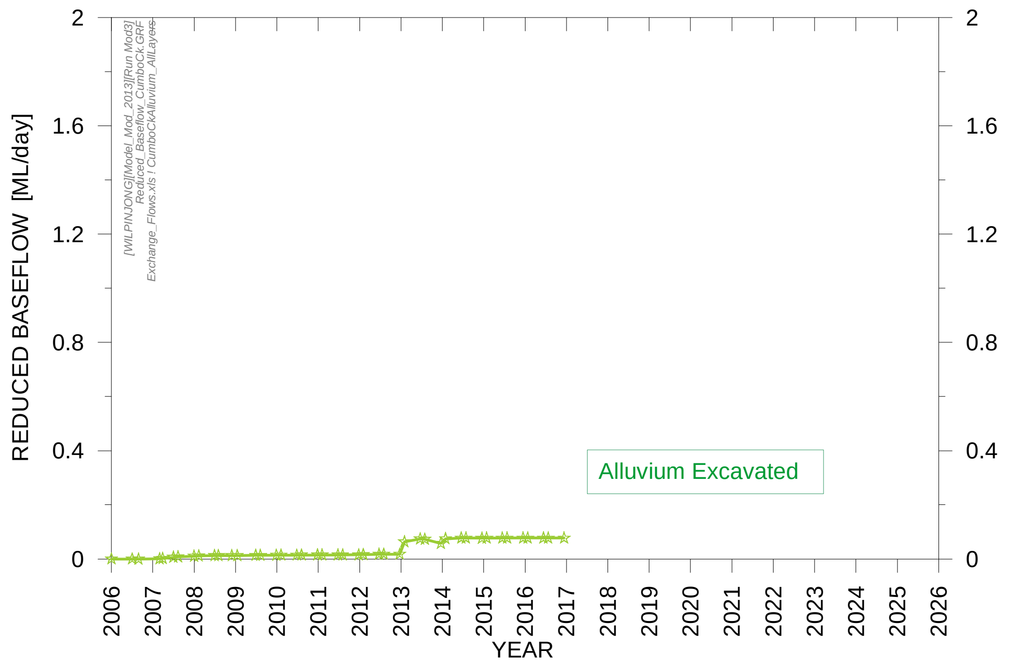
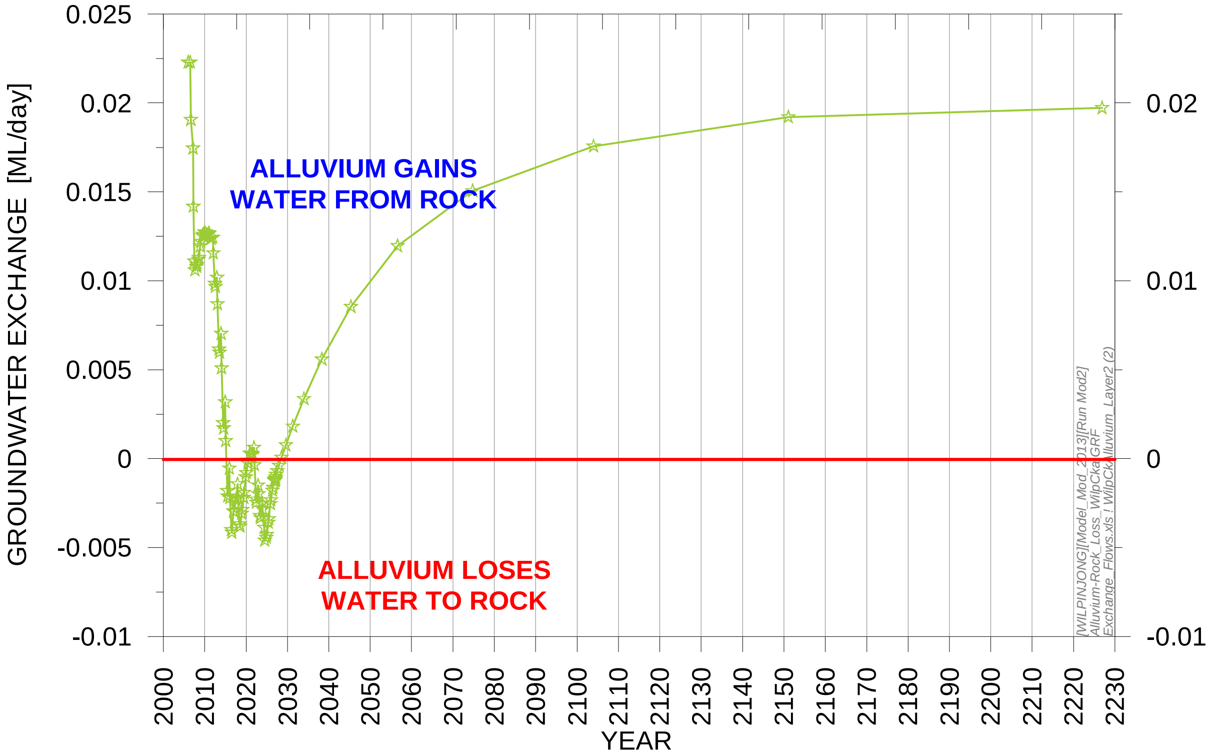


Figure 33. Reduced Baseflow to Cumbo Creek: [a] Modification Mine Plan; [b] Approved Mine Plan

[a]



[b]

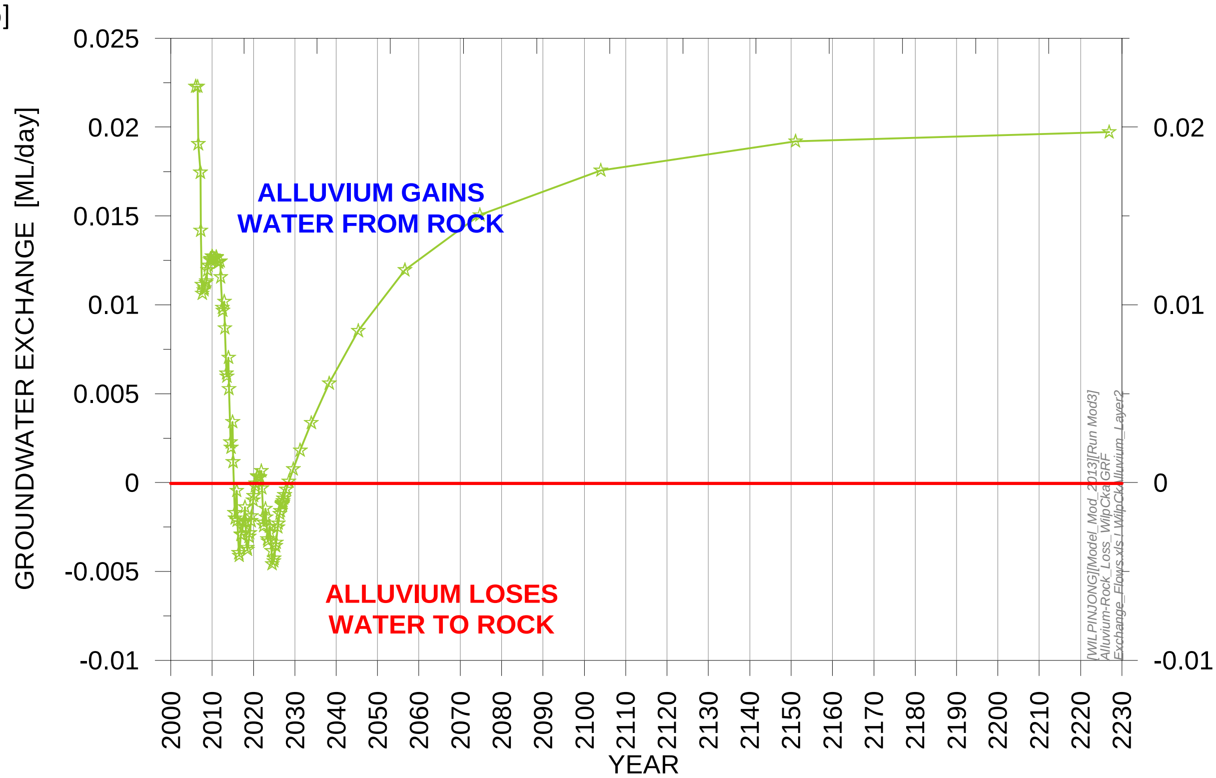
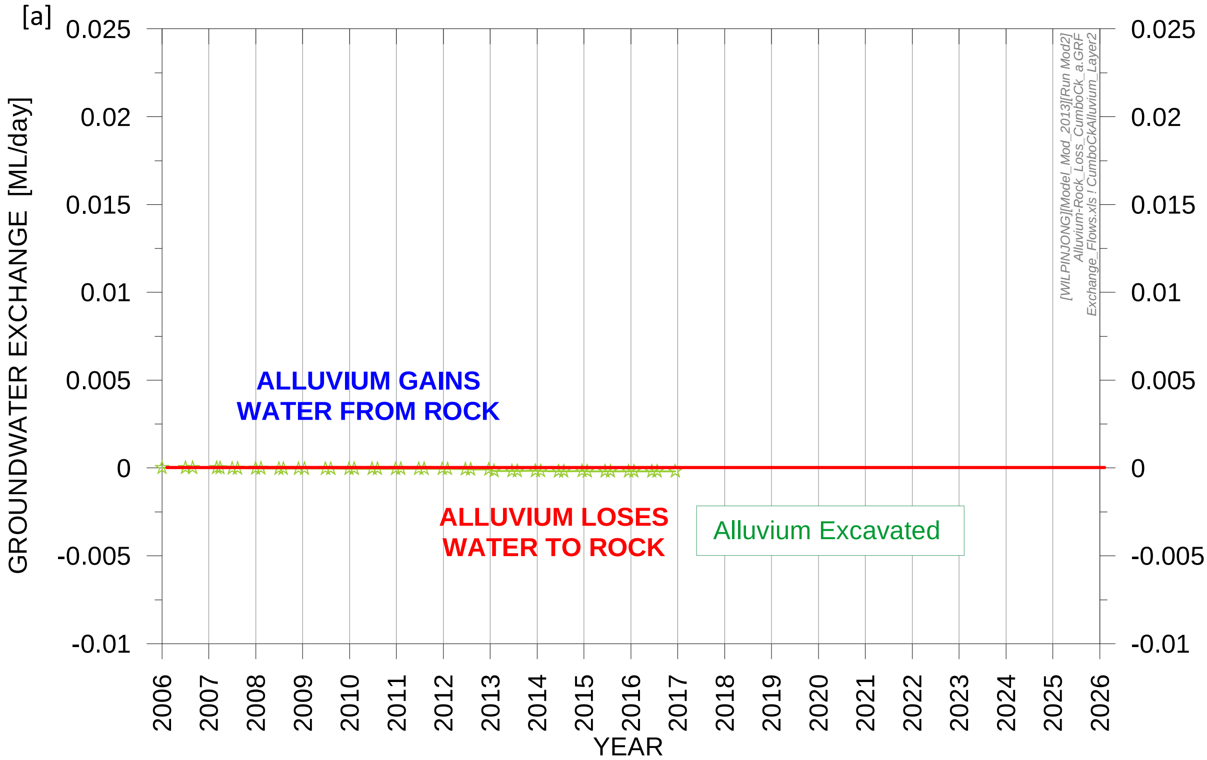


Figure 34. Time-Varying Upflow (positive) and Downflow (negative) of Groundwater between Hardrock and Wilpinjong Creek Alluvium: [a] Modification Mine Plan; [b] Approved Mine Plan

[a]



[b]

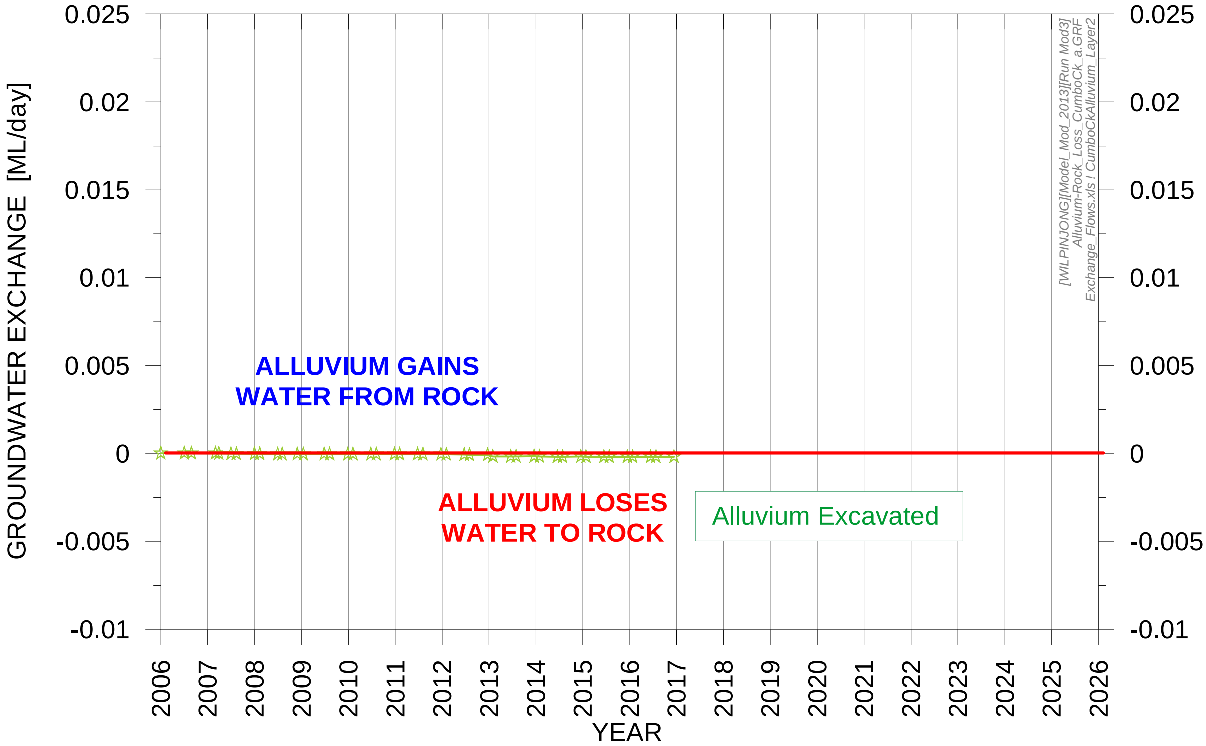
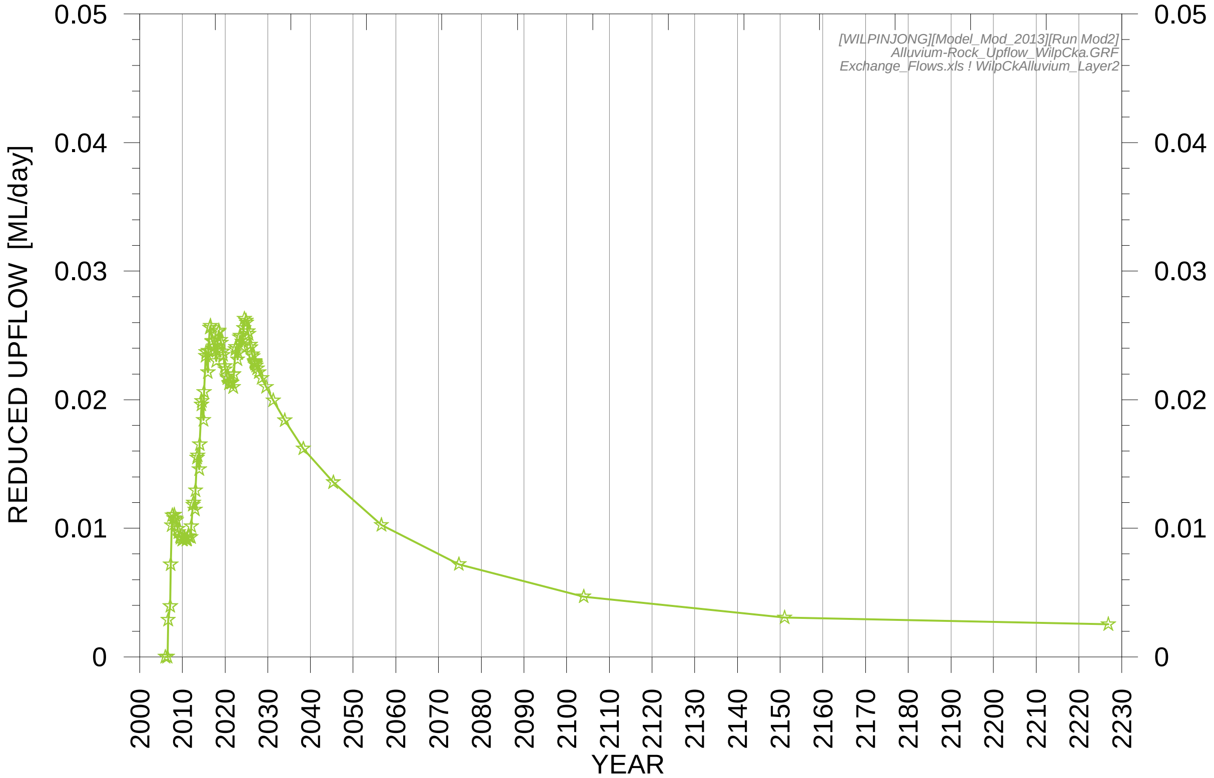


Figure 35. Downflow of Alluvial Groundwater from Cumbo Creek to Hardrock from 2007: [a] Modification Mine Plan; [b] Approved Mine Plan

[a]



[b]

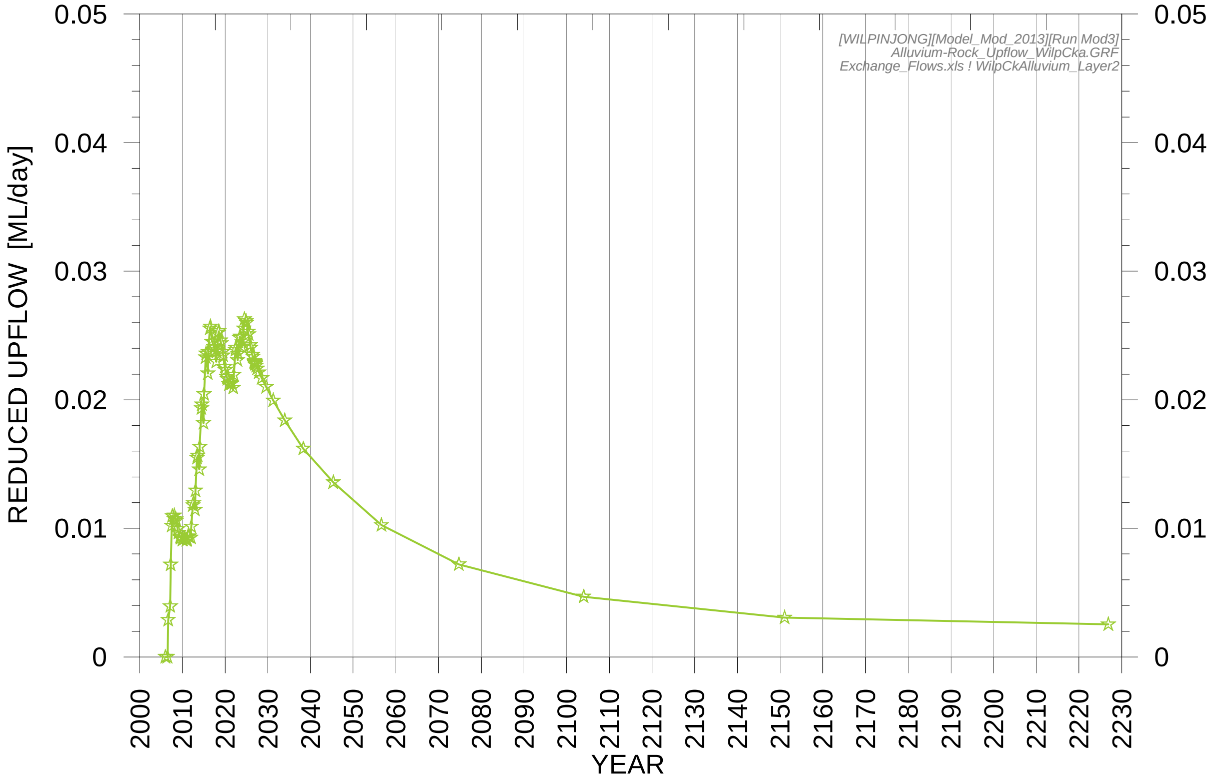
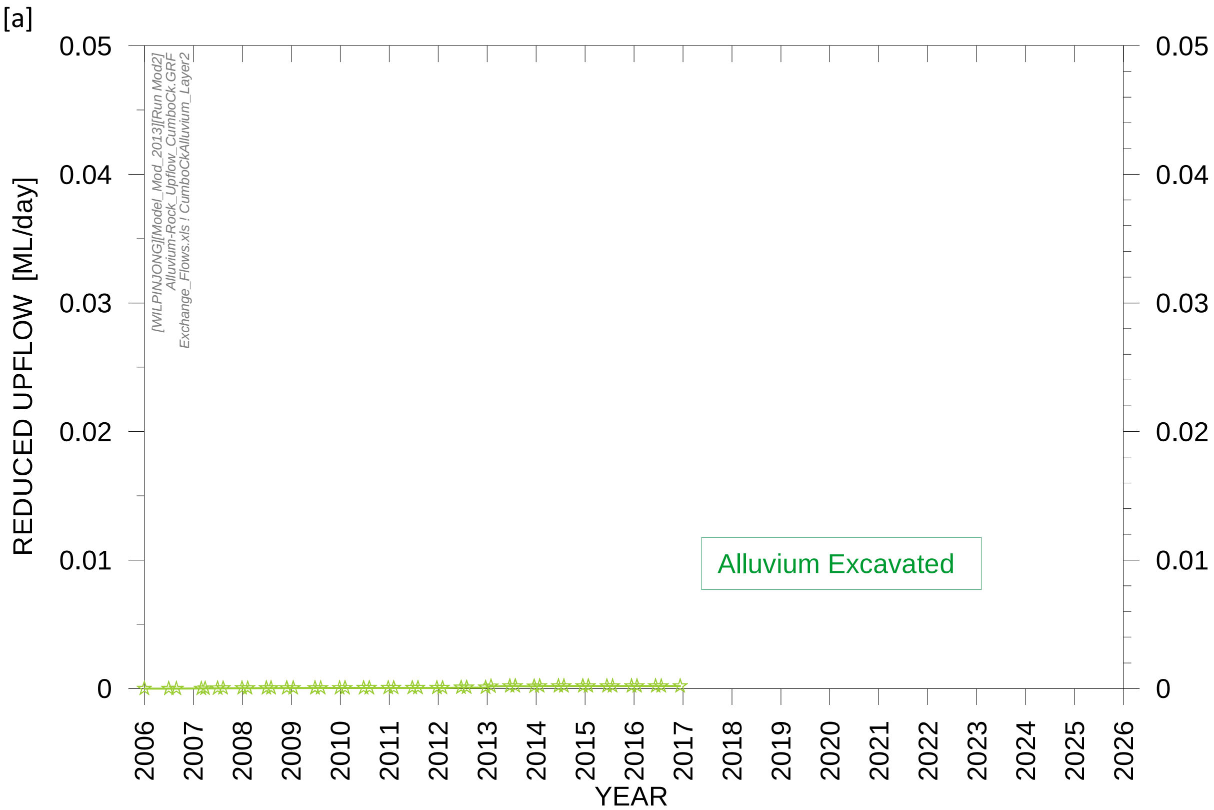


Figure 36. Reduced Upflow from Hardrock to Wilpinjong Creek Alluvium: [a] Modification Mine Plan; [b] Approved Mine Plan



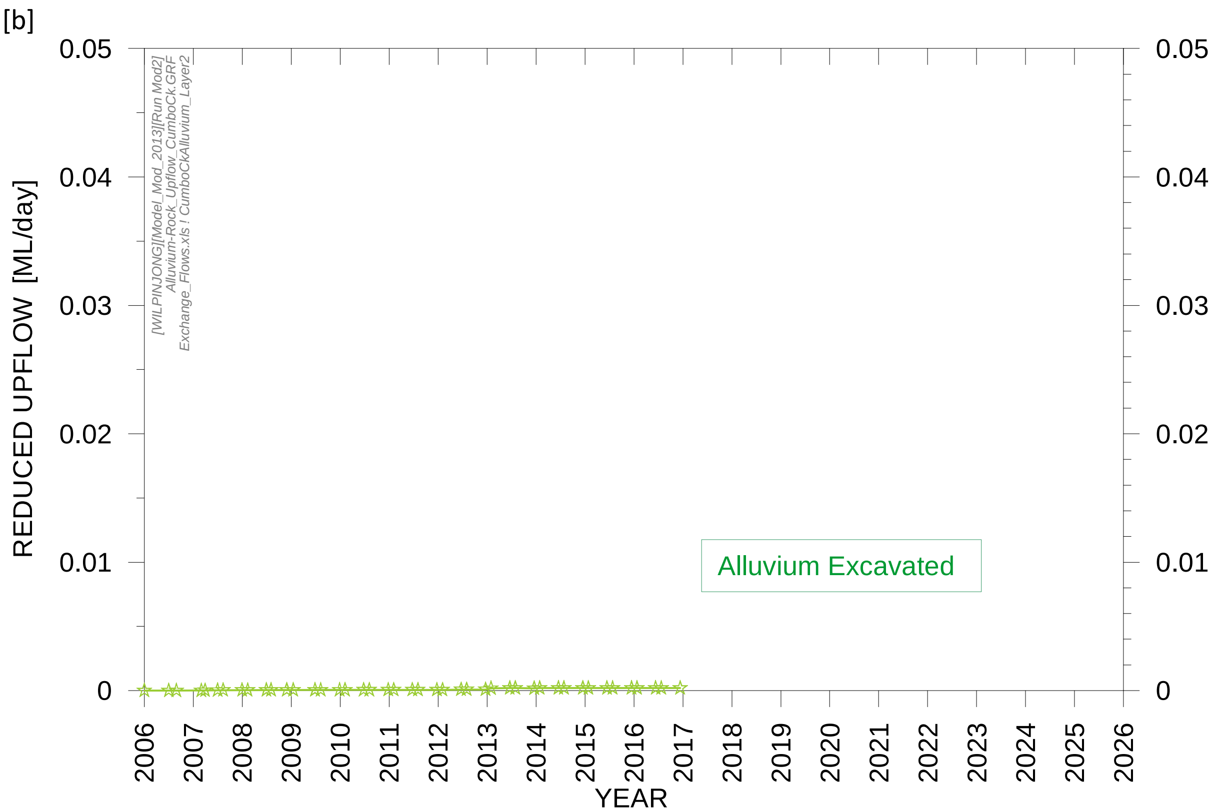


Figure 37. Reduced Upflow from Hardrock to Cumbo Creek Alluvium: [a] Approved Mine Plan; [b] Modification Mine Plan

[a]

[b]

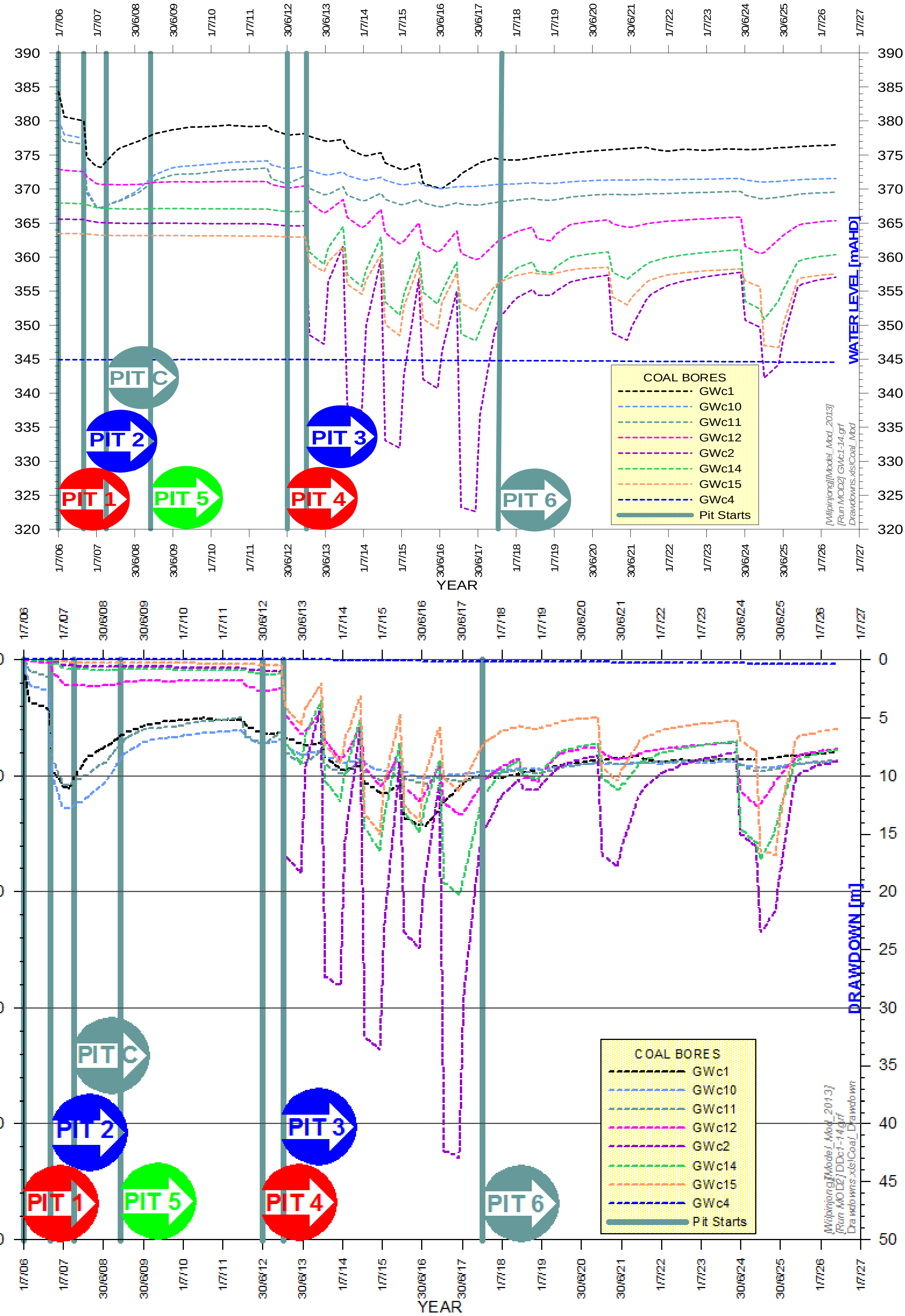


Figure 38. Predicted Hydrographs for Coal Monitoring Bores for the Duration of Mining: [a] Water Level (mAHD); [b] Drawdown (m)

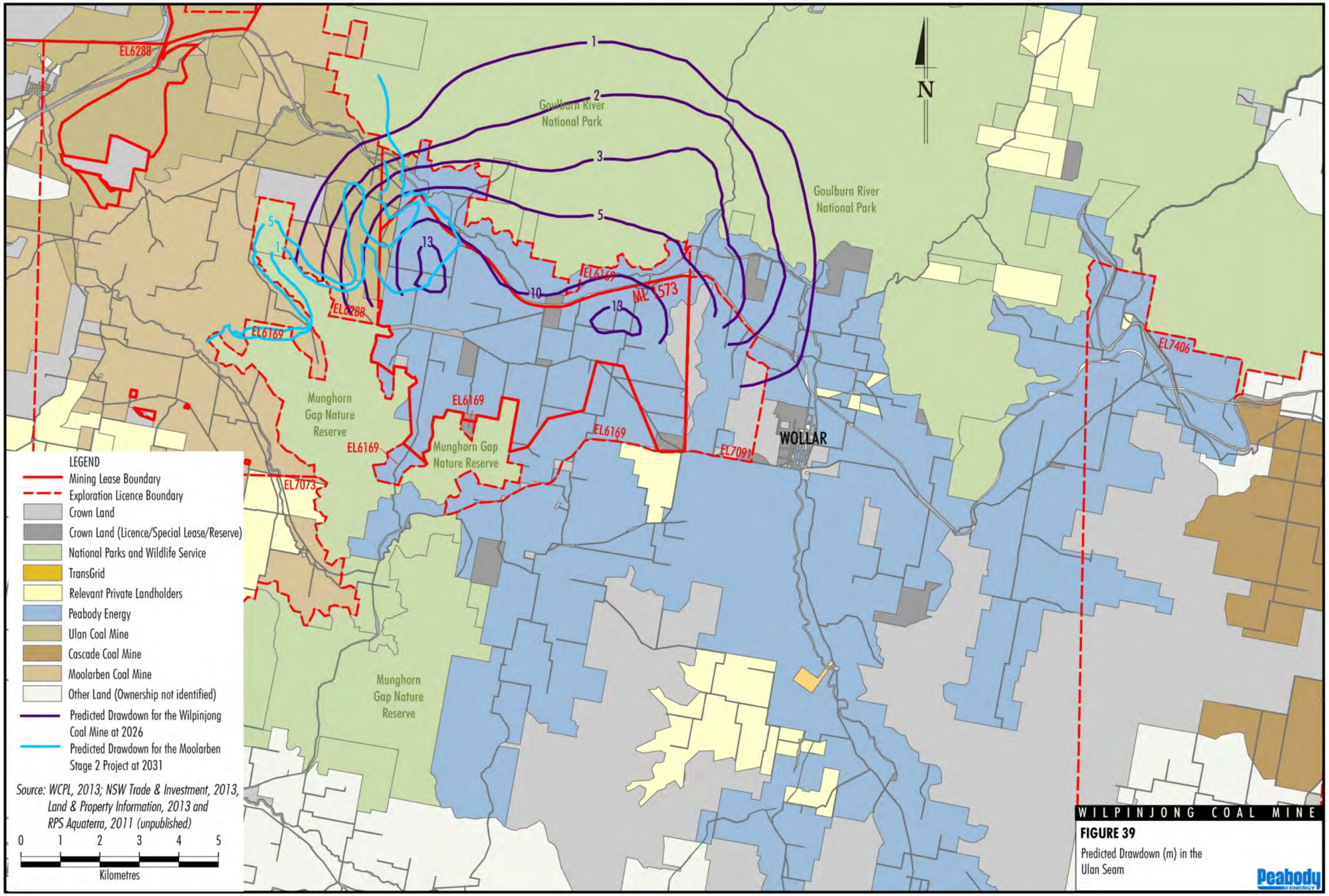


Figure 39. Predicted Drawdown (m) in the Ulan Seam for the Wilpinjong Mine at 2026 and for the Moolarben Mine at 2031

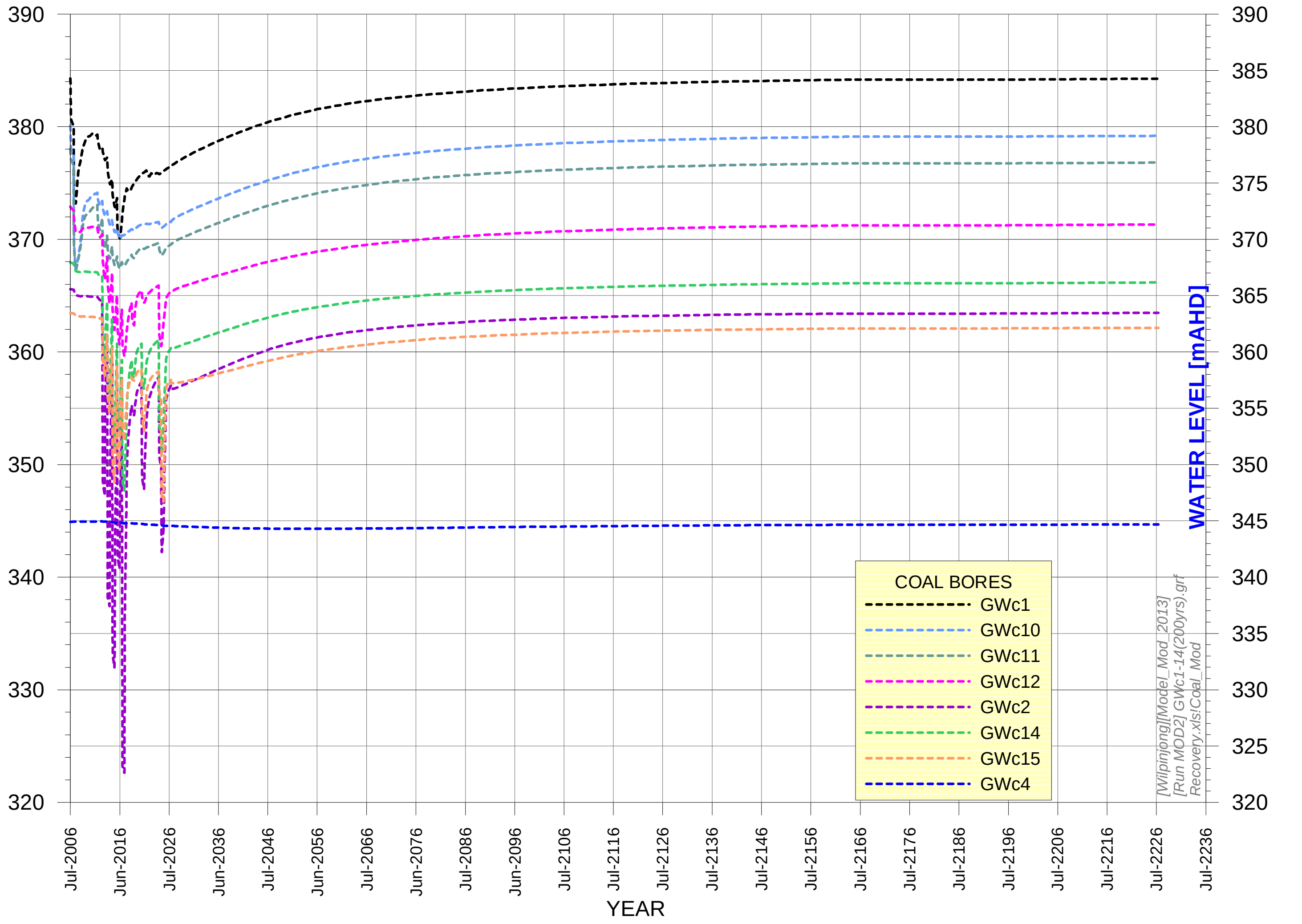


Figure 40. Predicted Water Level Hydrographs for Coal Monitoring Bores for 200 Years Beyond the Duration of Mining (mAHD)

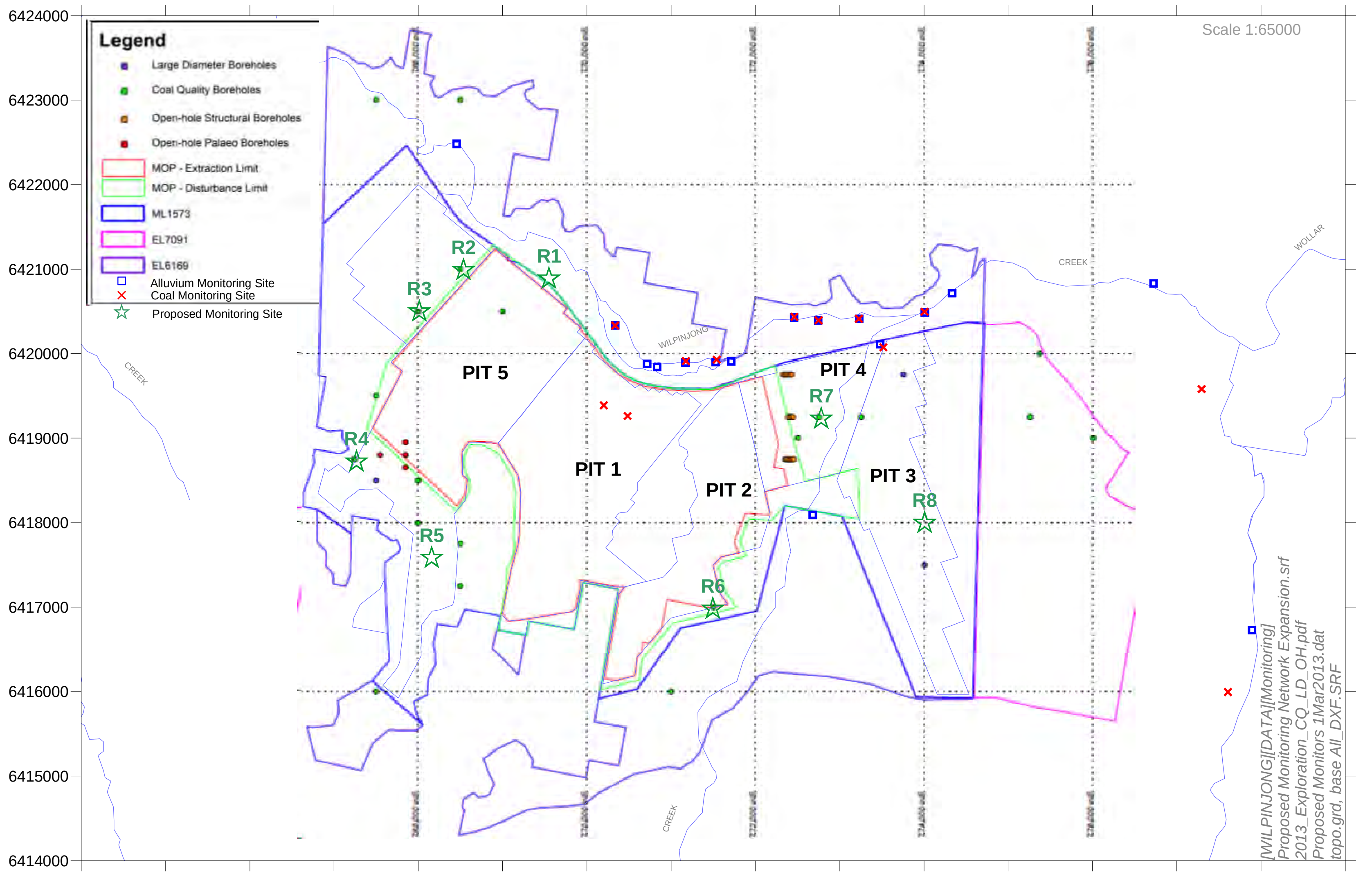


Figure 41. Planned Exploration Bore Sites (2013 Program) and Proposed New Groundwater Monitoring Sites

ATTACHMENT A

Wilpinjong Coal Mine Hydrographs

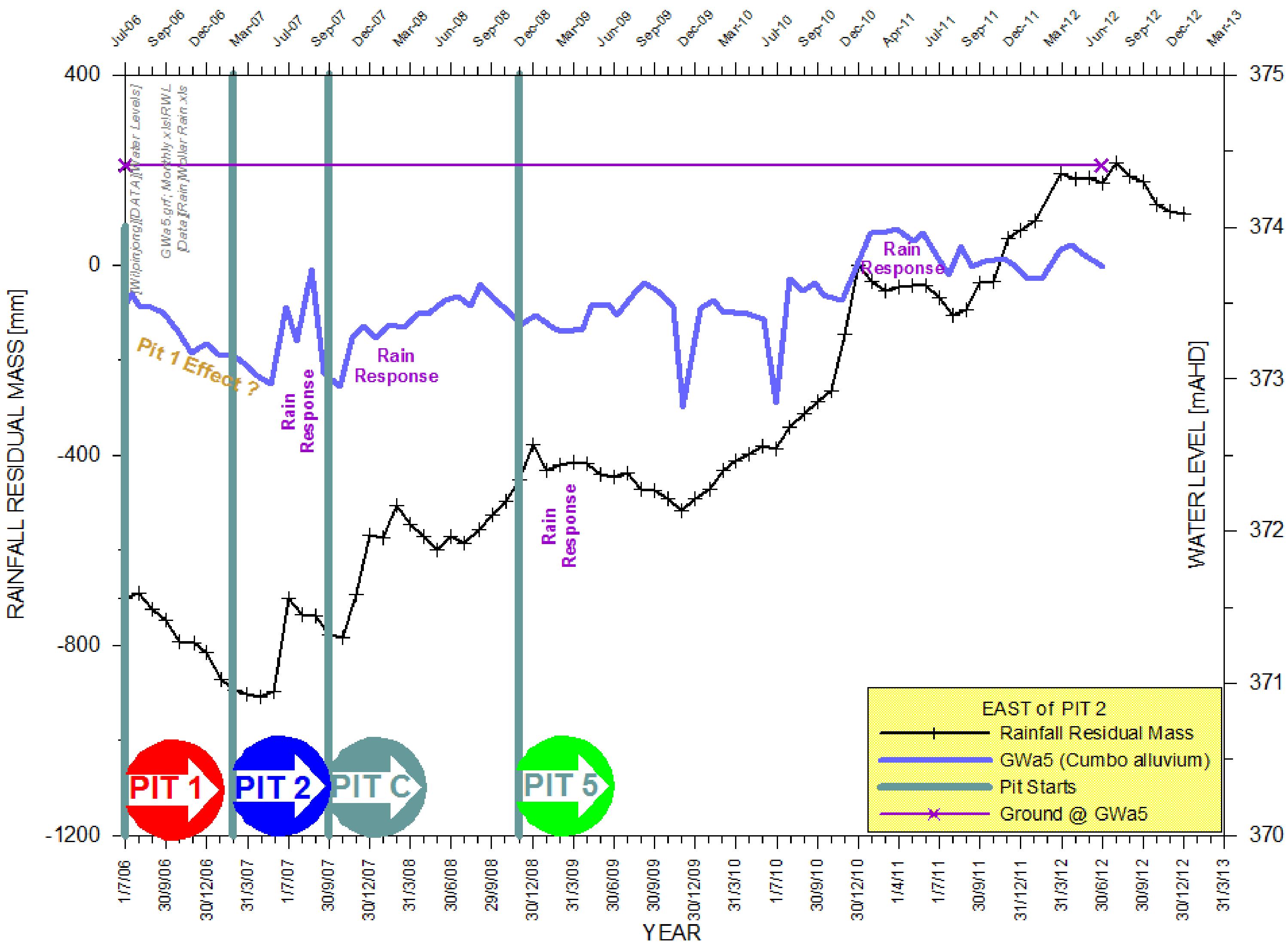


Figure A-1. Alluvial Groundwater Hydrograph at GWa5 to the East of Pit 2

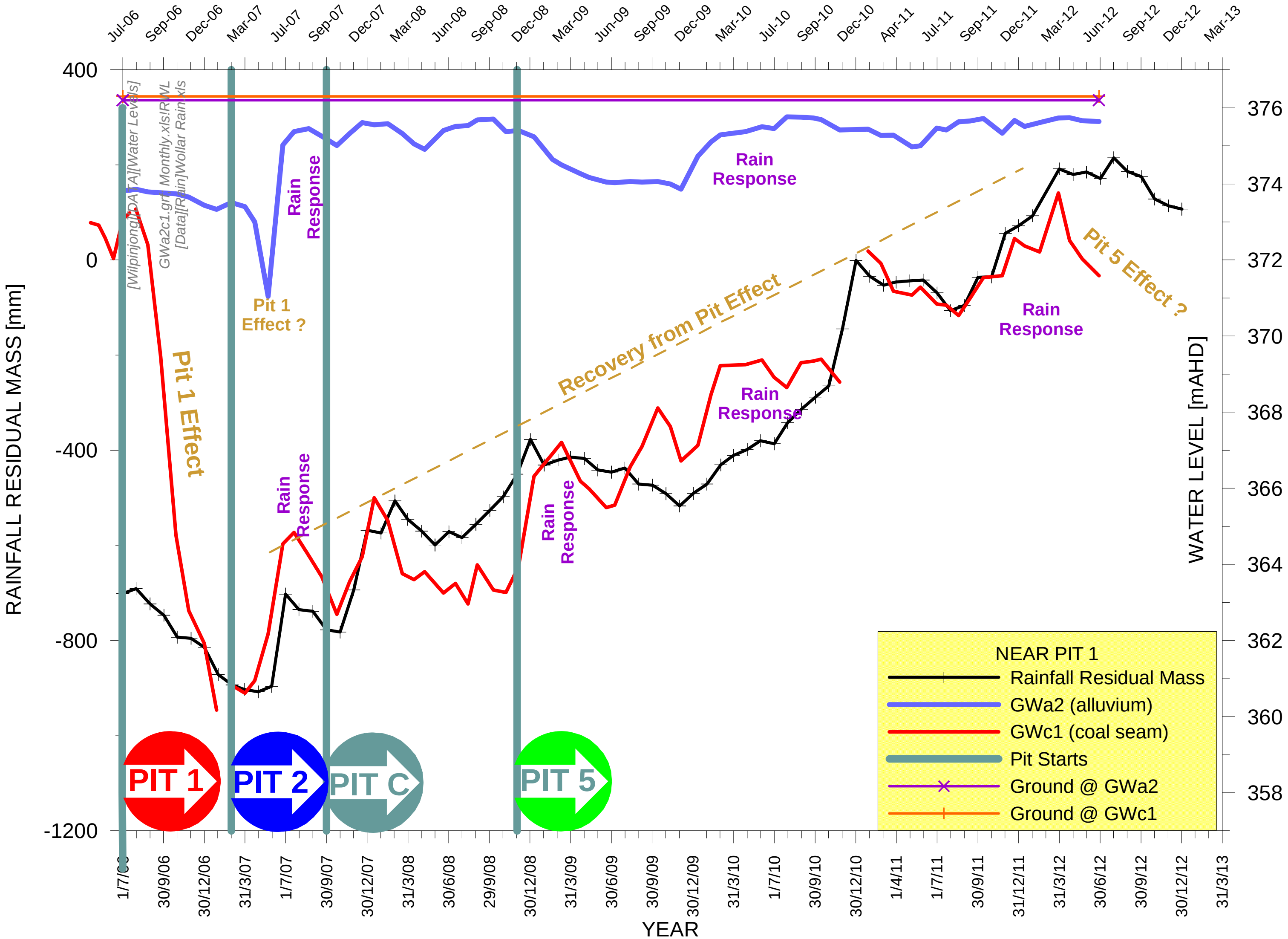


Figure A-2. Groundwater Hydrographs at GWa2 and GWc1 at 0.3 km North-West of Pit 1

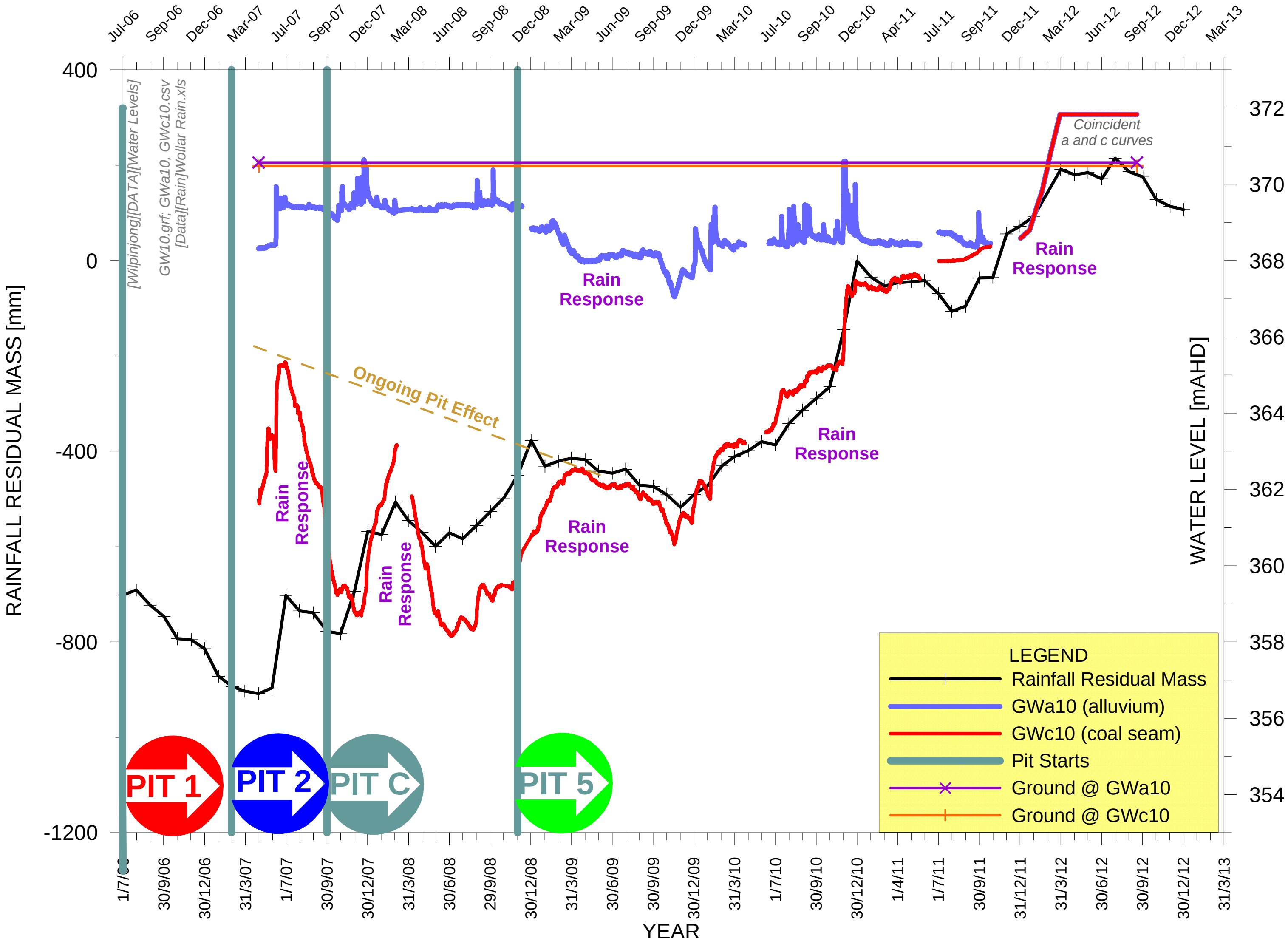


Figure A-3. Groundwater Hydrographs at GWa10 and GWc10 at 0.3 km North-East of Pit 1

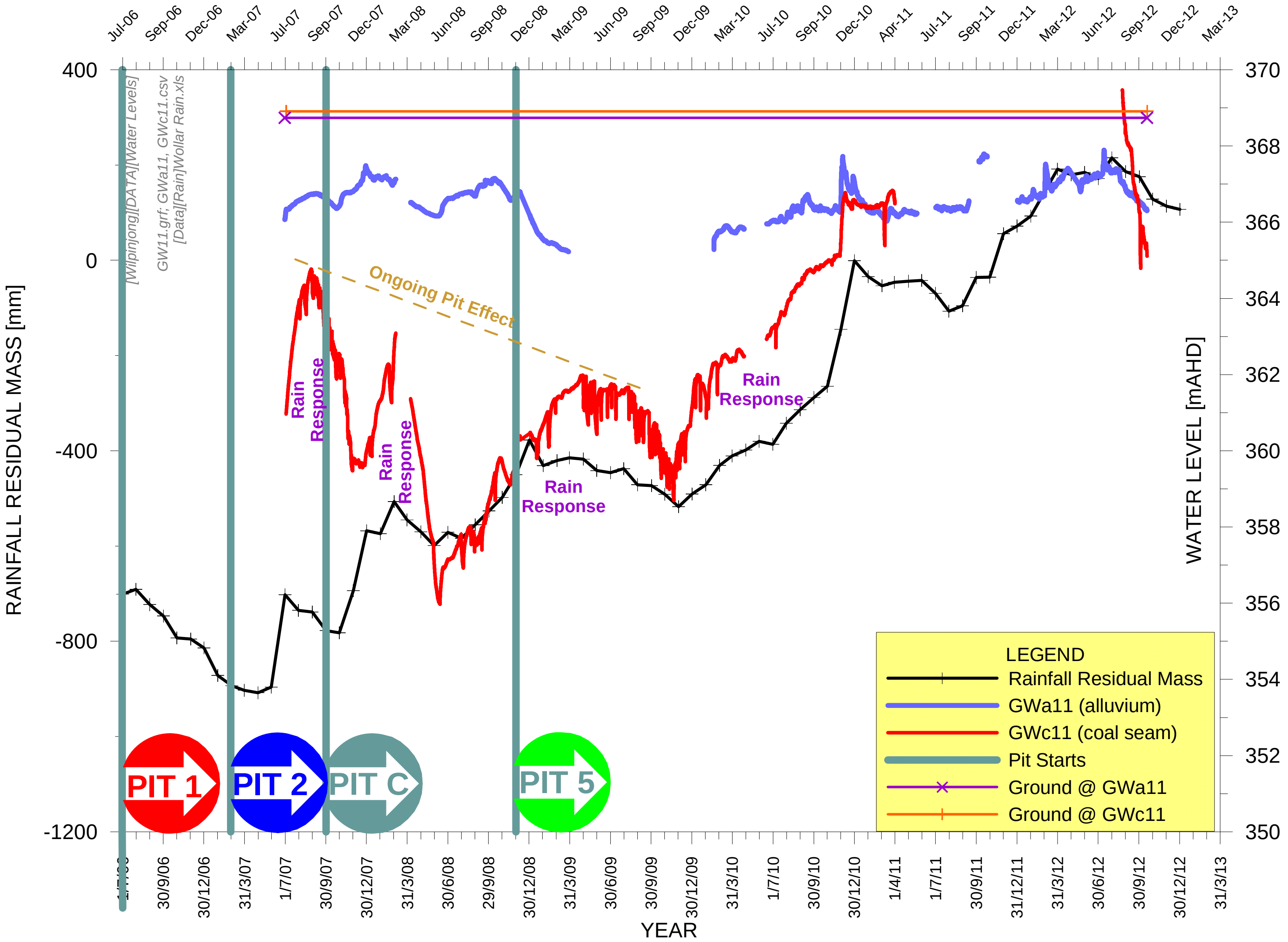


Figure A-4. Groundwater Hydrographs at GWa11 and GWc11 at 0.3 km North of Pit 2

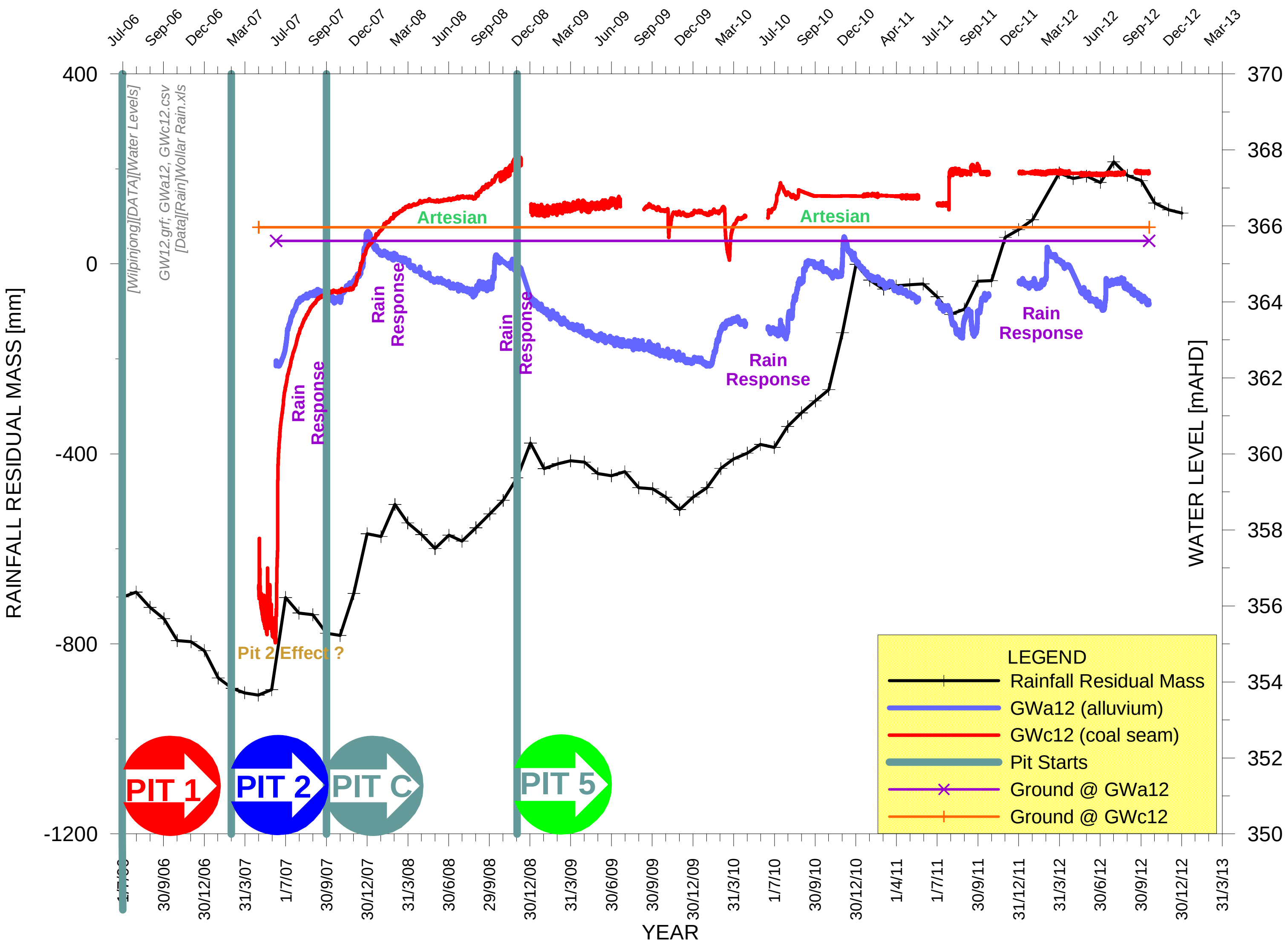


Figure A-5. Groundwater Hydrographs at GWa12 and GWc12 at 0.5 km North of Pit 4

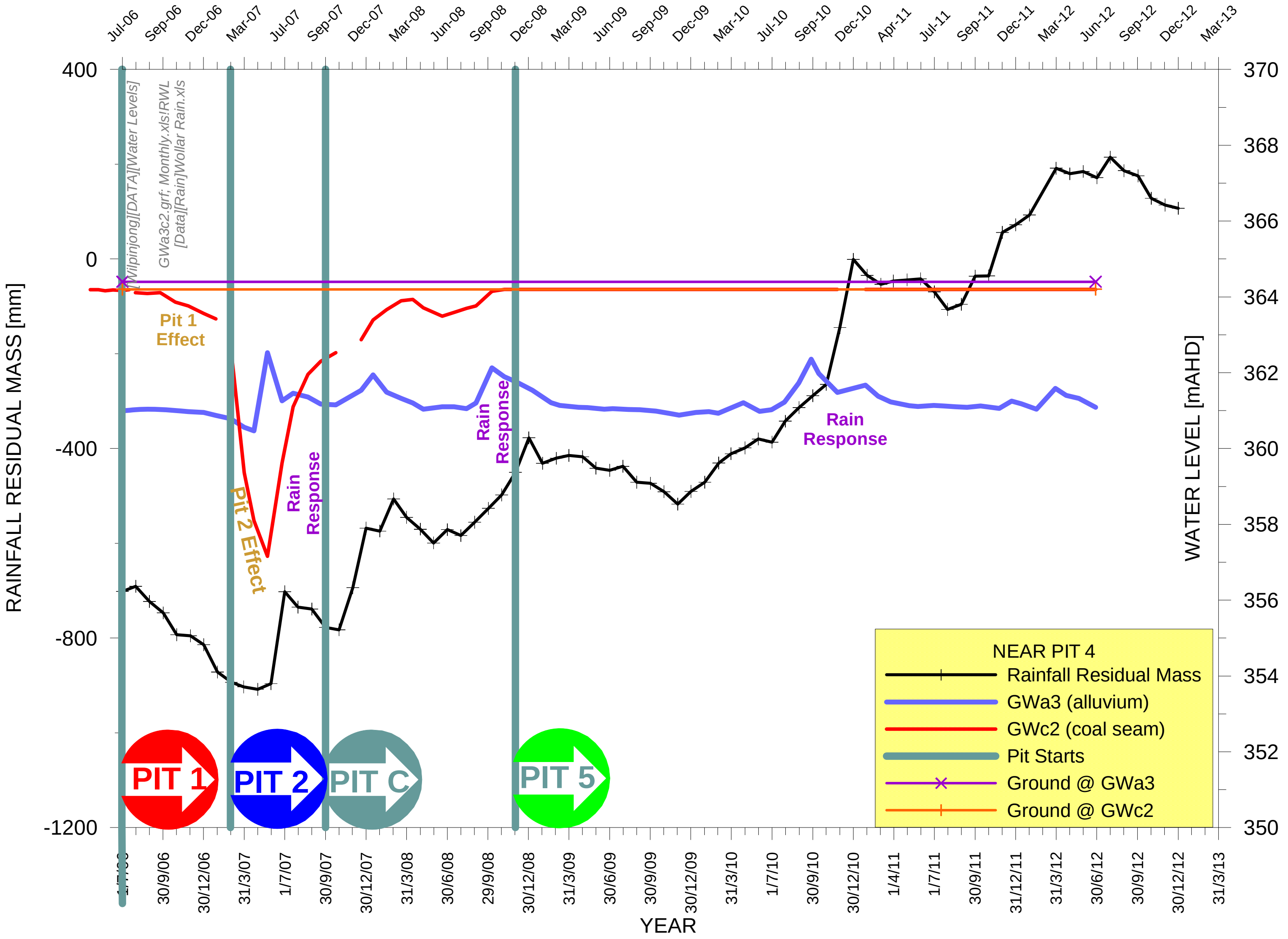


Figure A-6. Groundwater Hydrographs at GWa3 and GWc2 at 0.45 km North of Pit 4

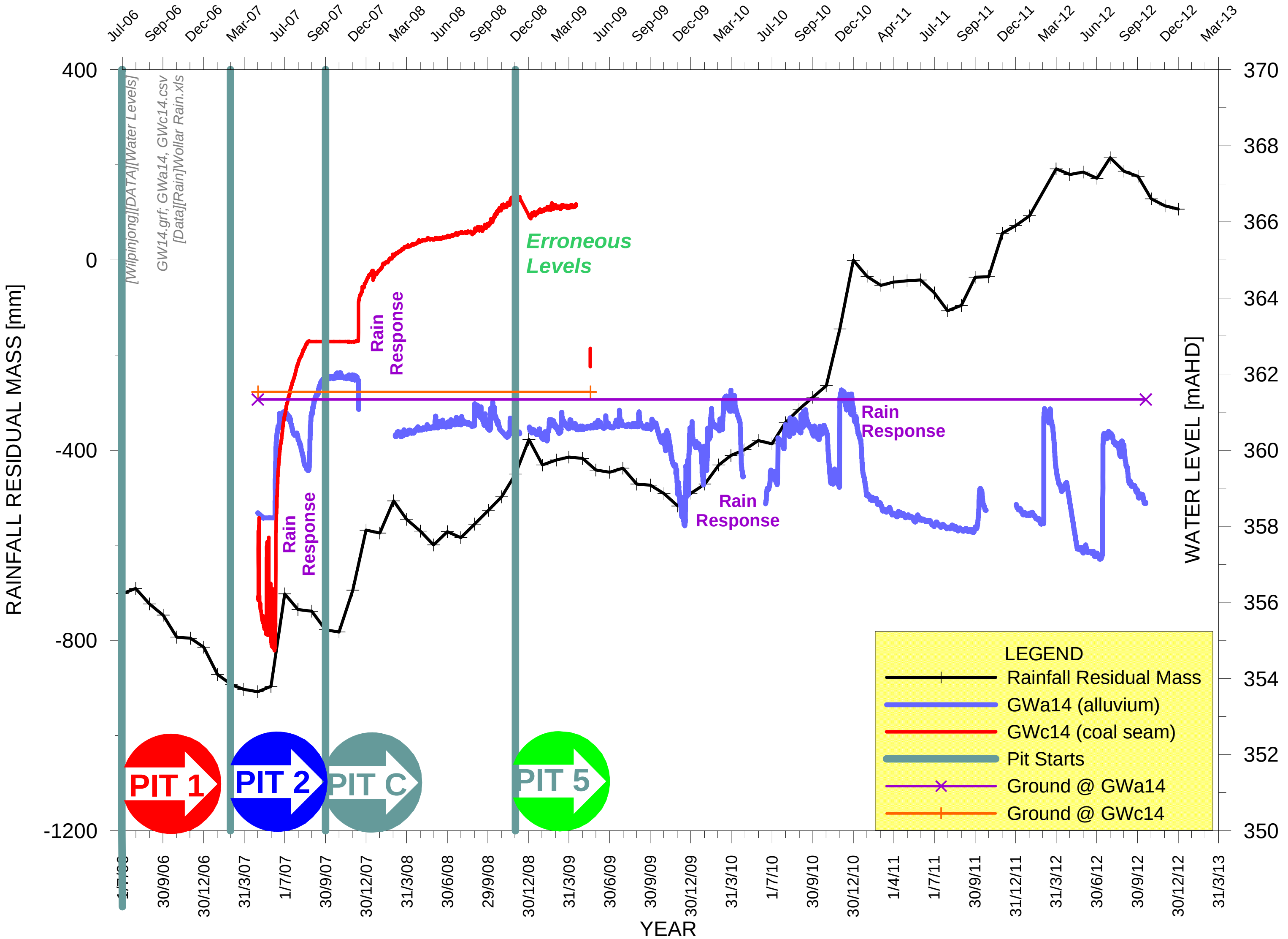


Figure A-7. Groundwater Hydrographs at GWa14 and GWc14 at 0.3 km North of Pit 4

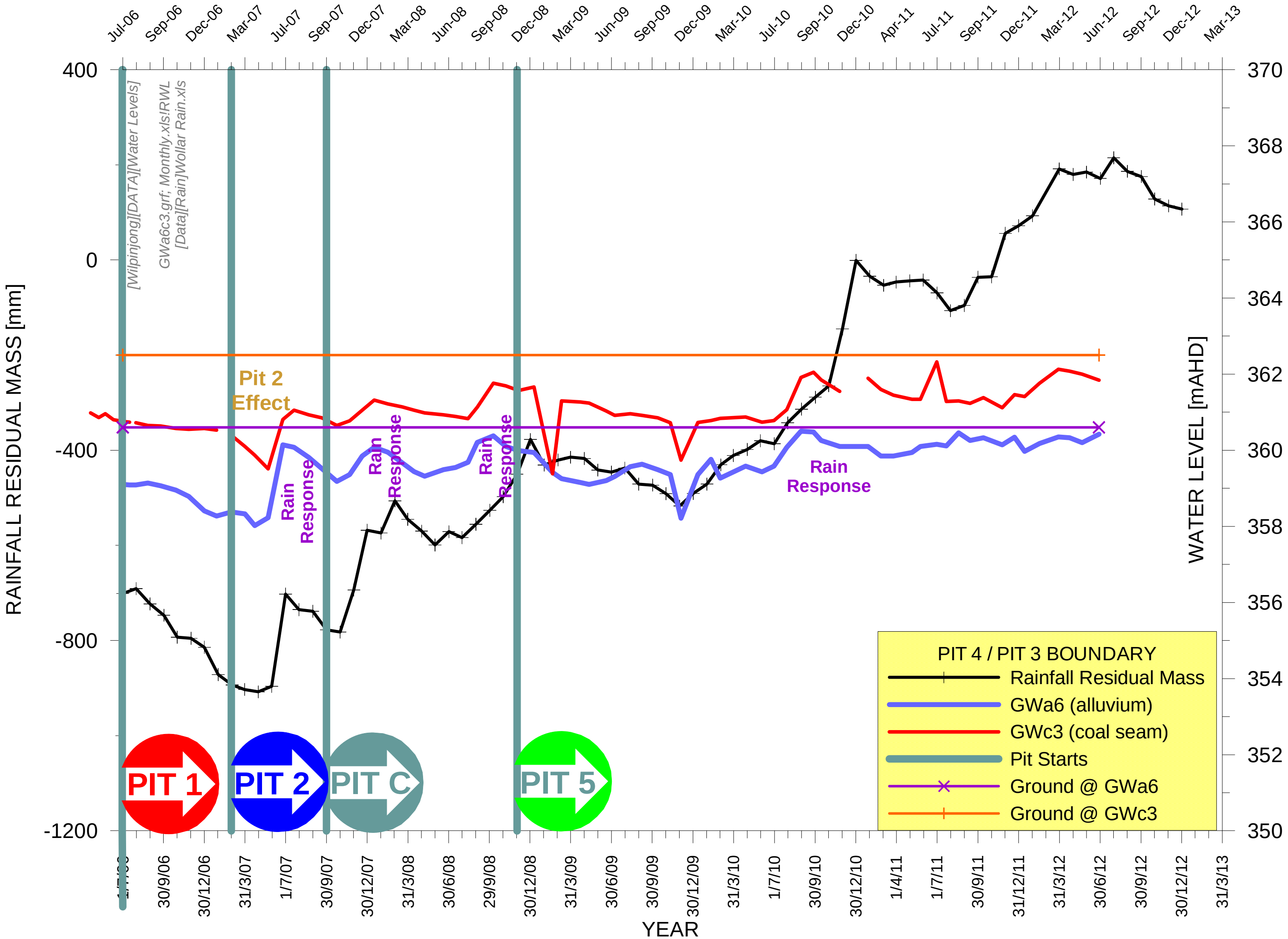


Figure A-8. Groundwater Hydrographs at GWa6 and GWc3 at Northern Junction of Pits 3 and 4, Adjacent to Cumbo Creek

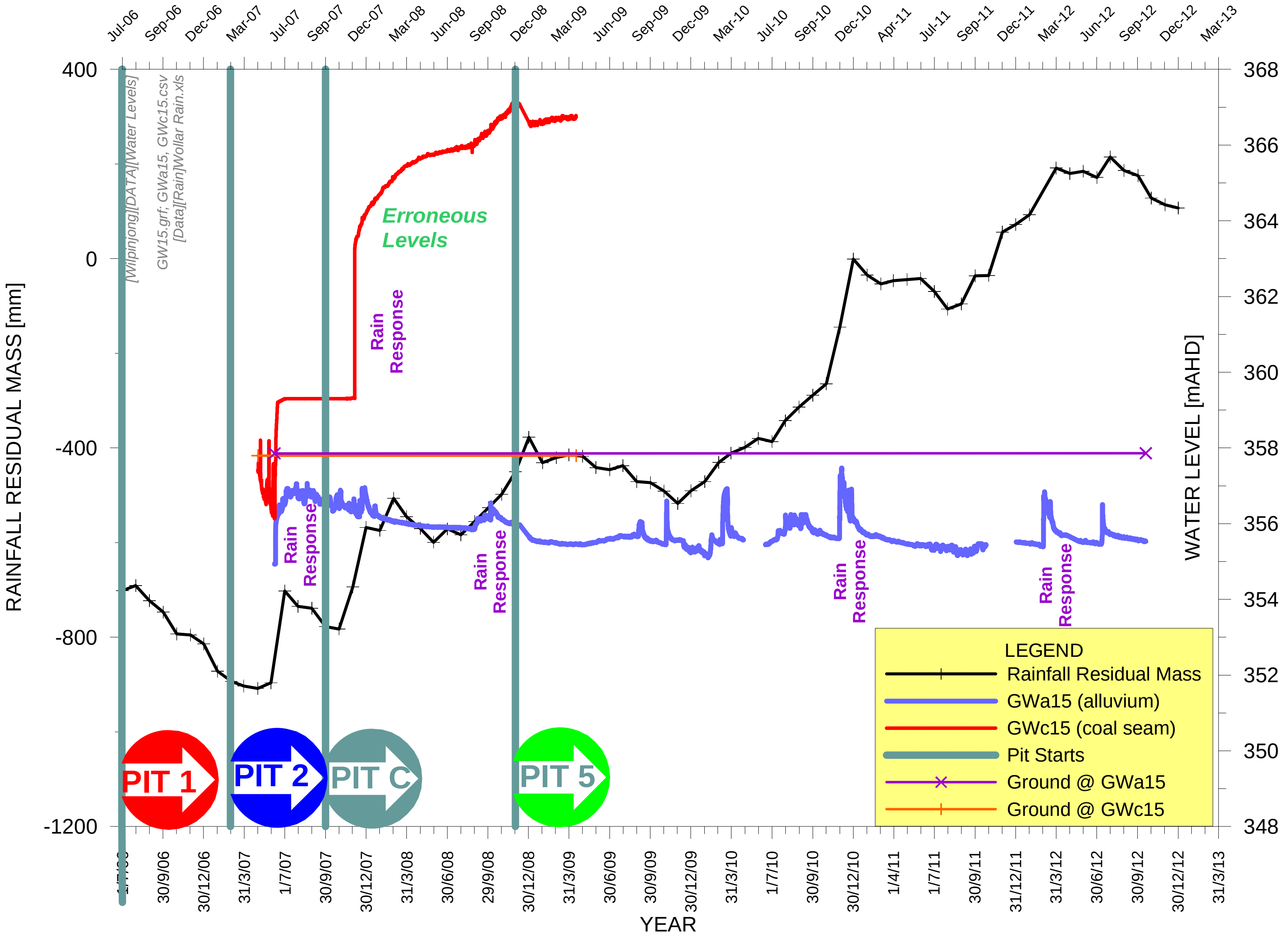


Figure A-9. Groundwater Hydrographs at GWa15 and GWc15 at 0.2 km North of Pit 3

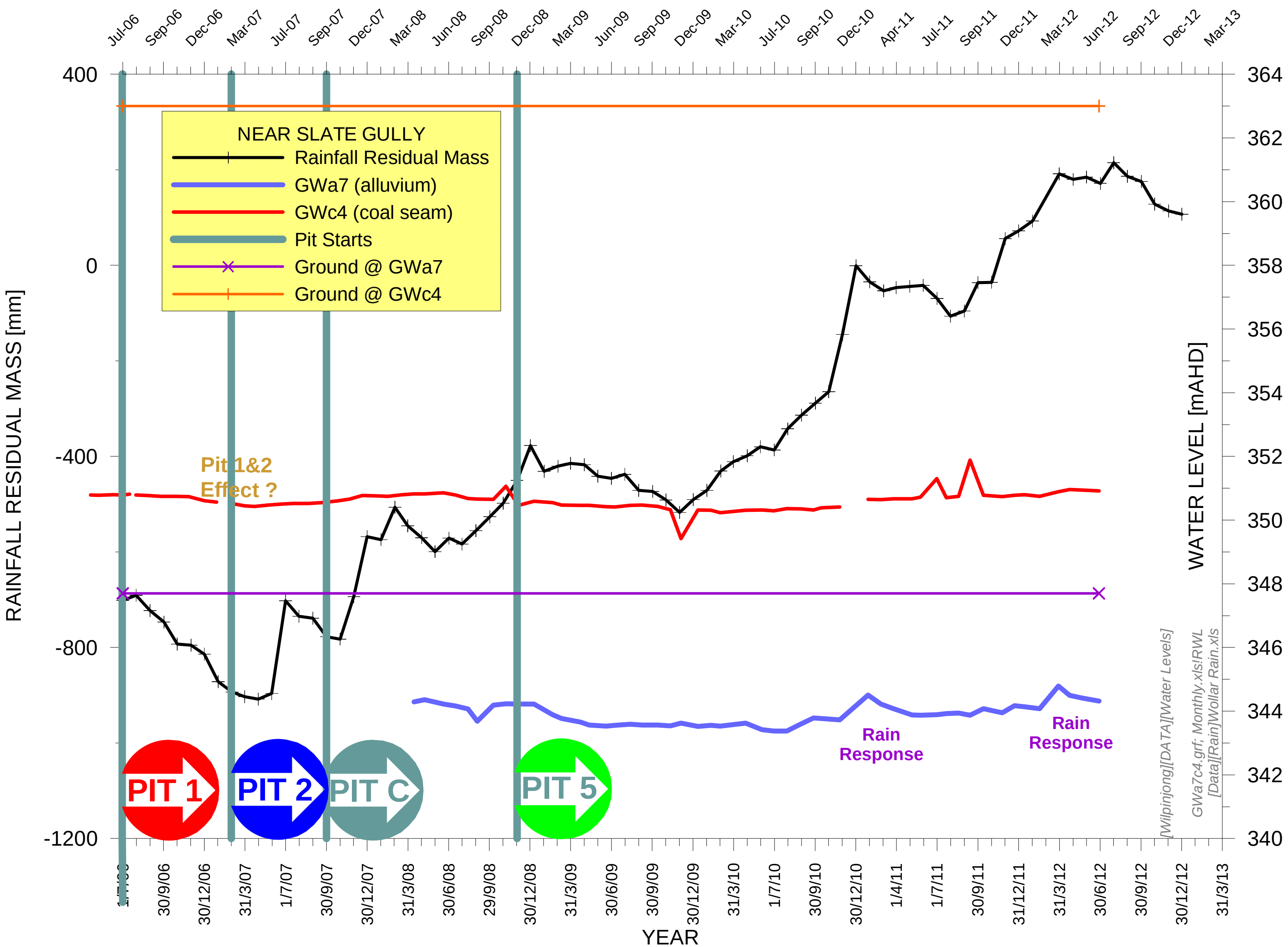


Figure A-10. Groundwater Hydrographs at GWa7 and GWc4 near Slate Gully

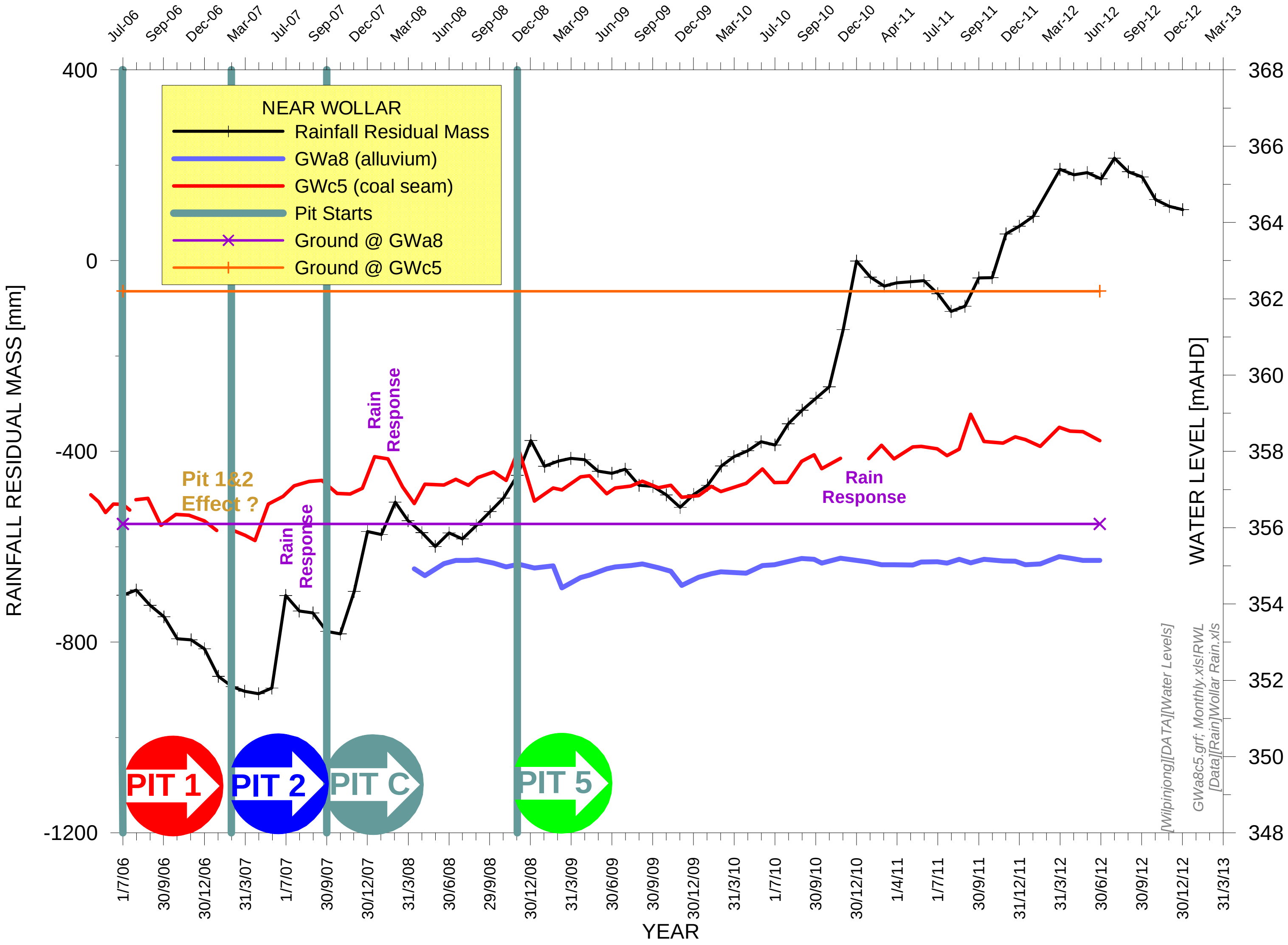


Figure A-11. Groundwater Hydrographs at GWa8 and GWc5 near Wollar

ATTACHMENT B

Moolarben Hydrographs

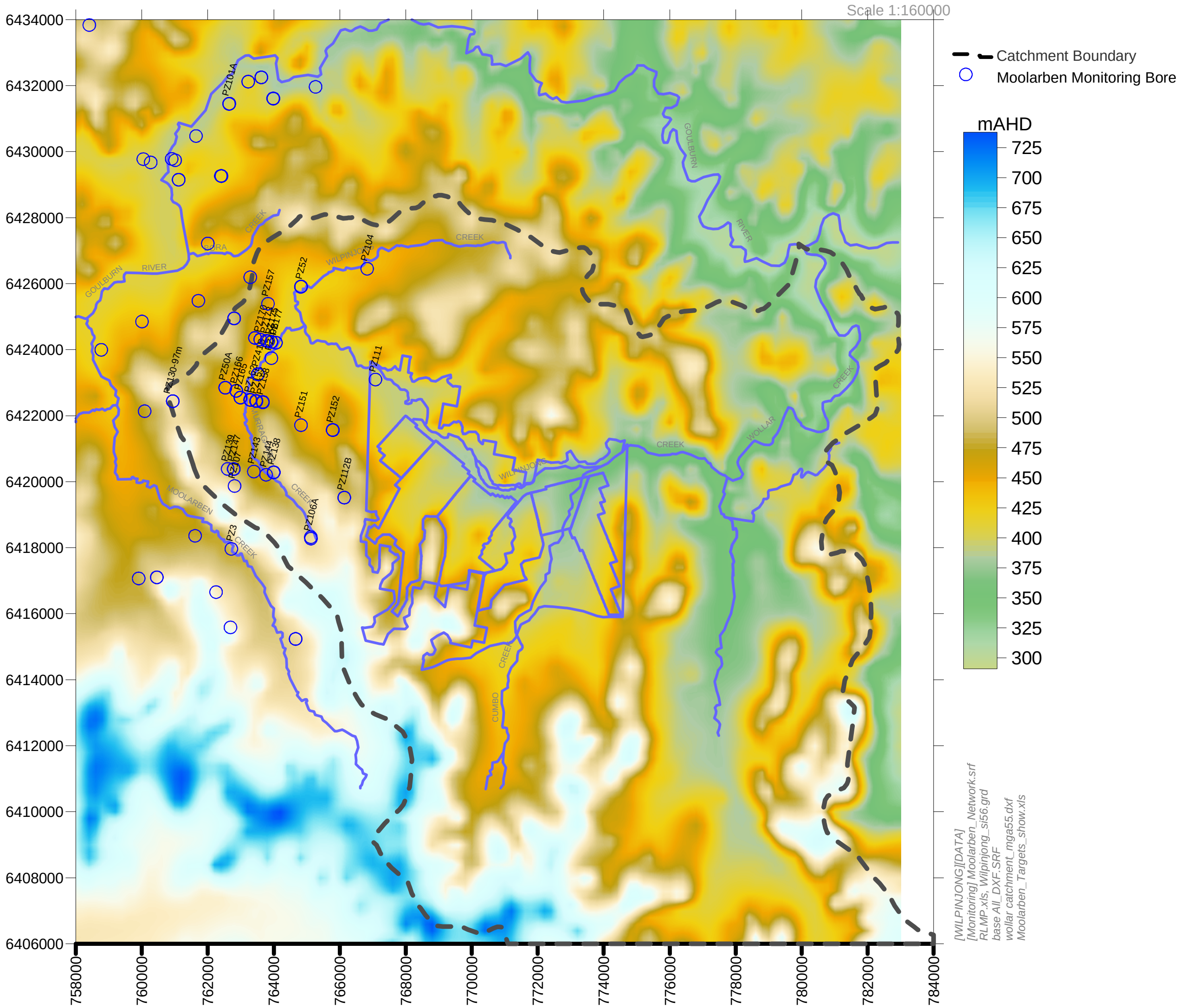


Figure B-1. Moolarben Groundwater Monitoring Network

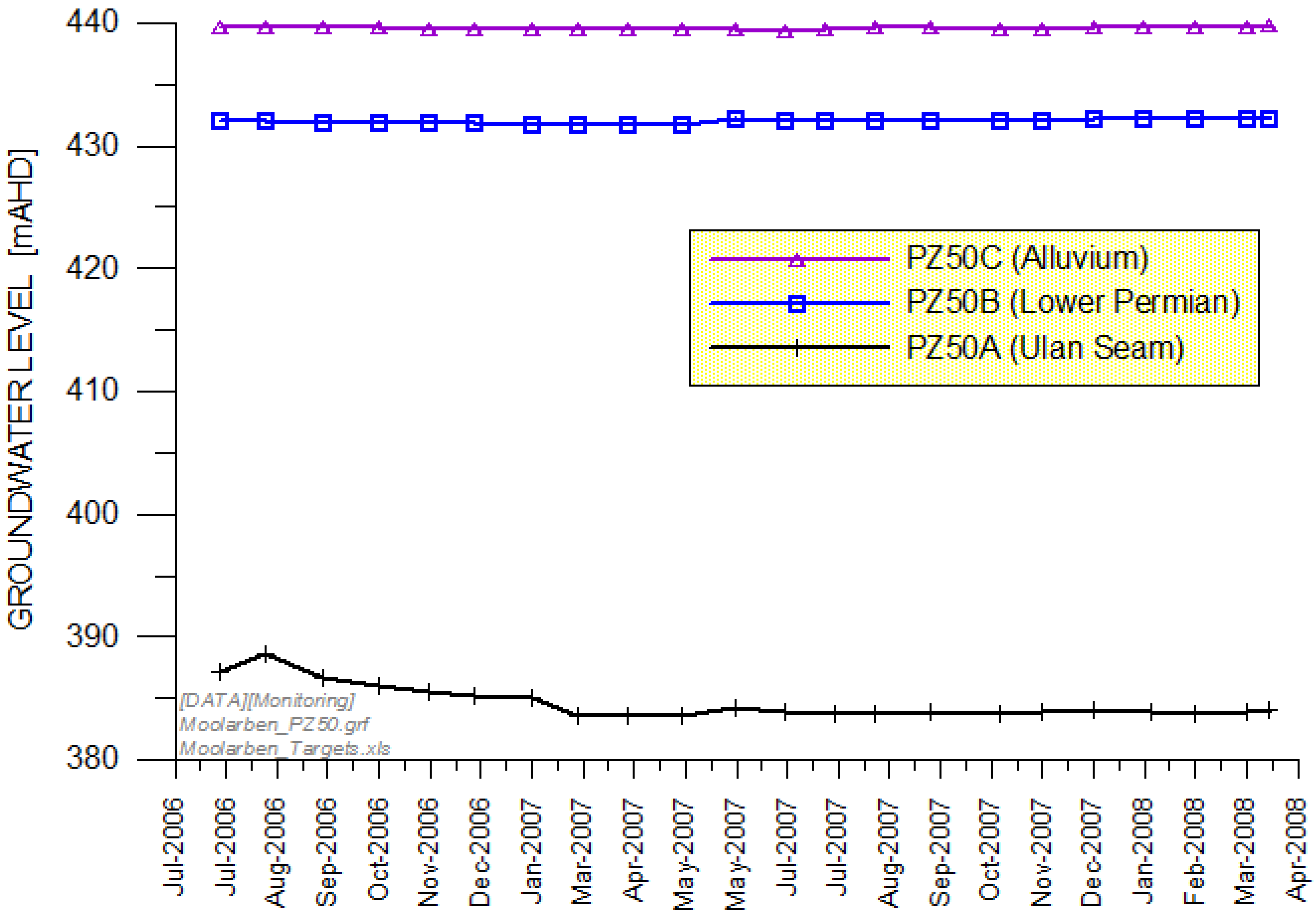


Figure B-2. Moolarben Groundwater Hydrographs at Bore PZ50, 5 km from WCM Pit 6

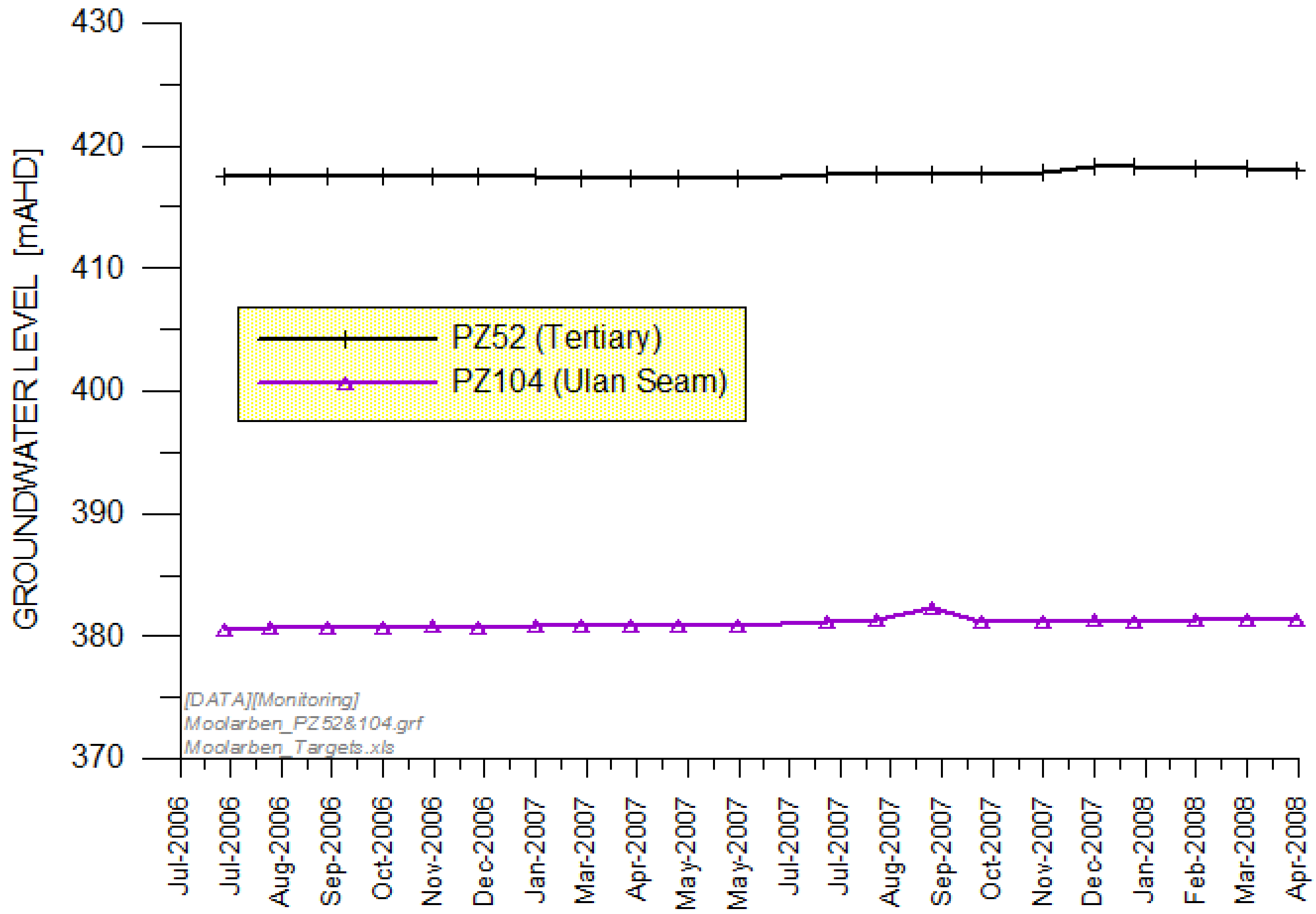


Figure B-3. Moolarben Groundwater Hydrographs at Bores PZ52 and PZ104, 5 km from WCM Pit 6

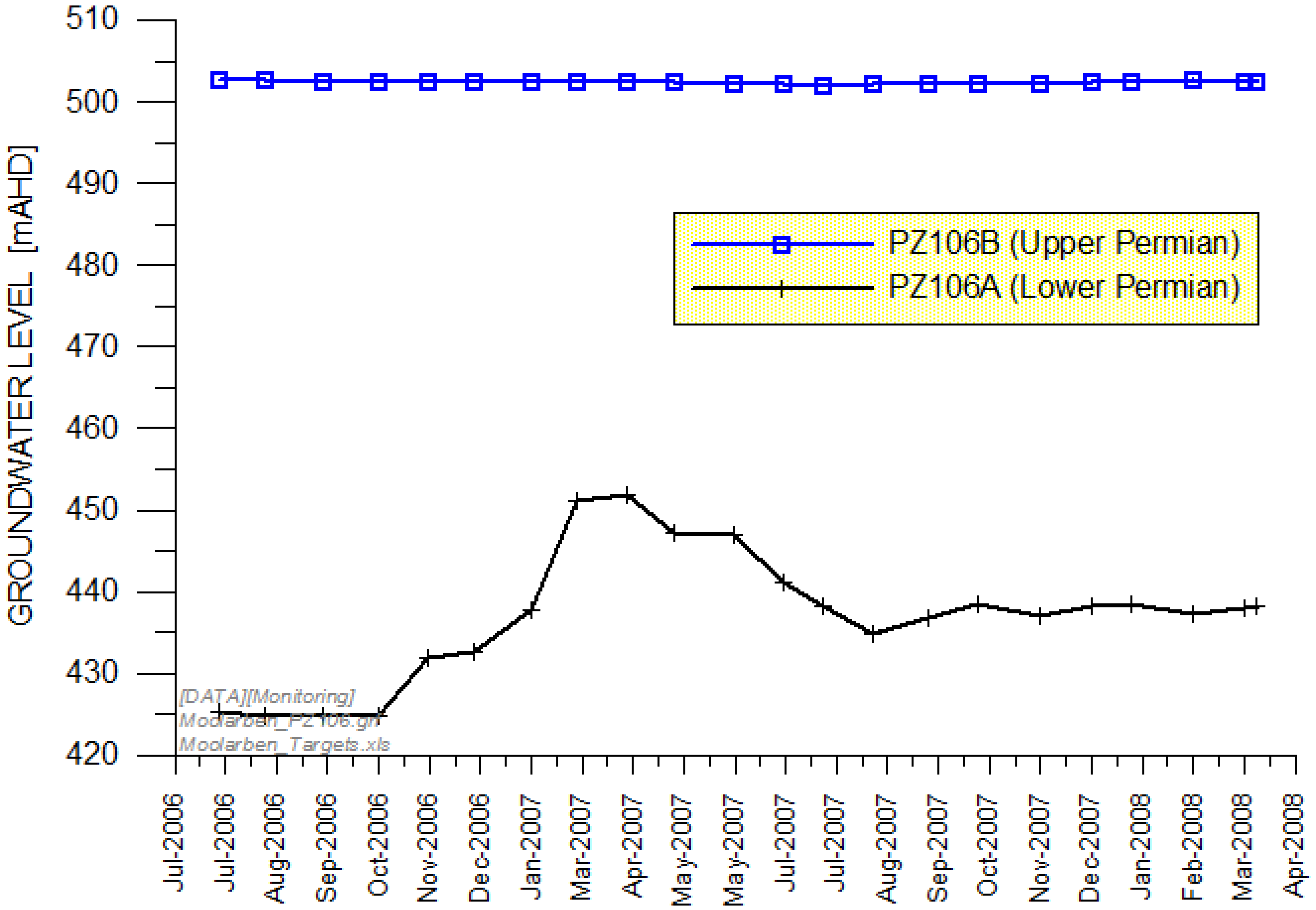


Figure B-4. Moolarben Groundwater Hydrographs at Bore PZ106, 3 km from WCM Pit 6

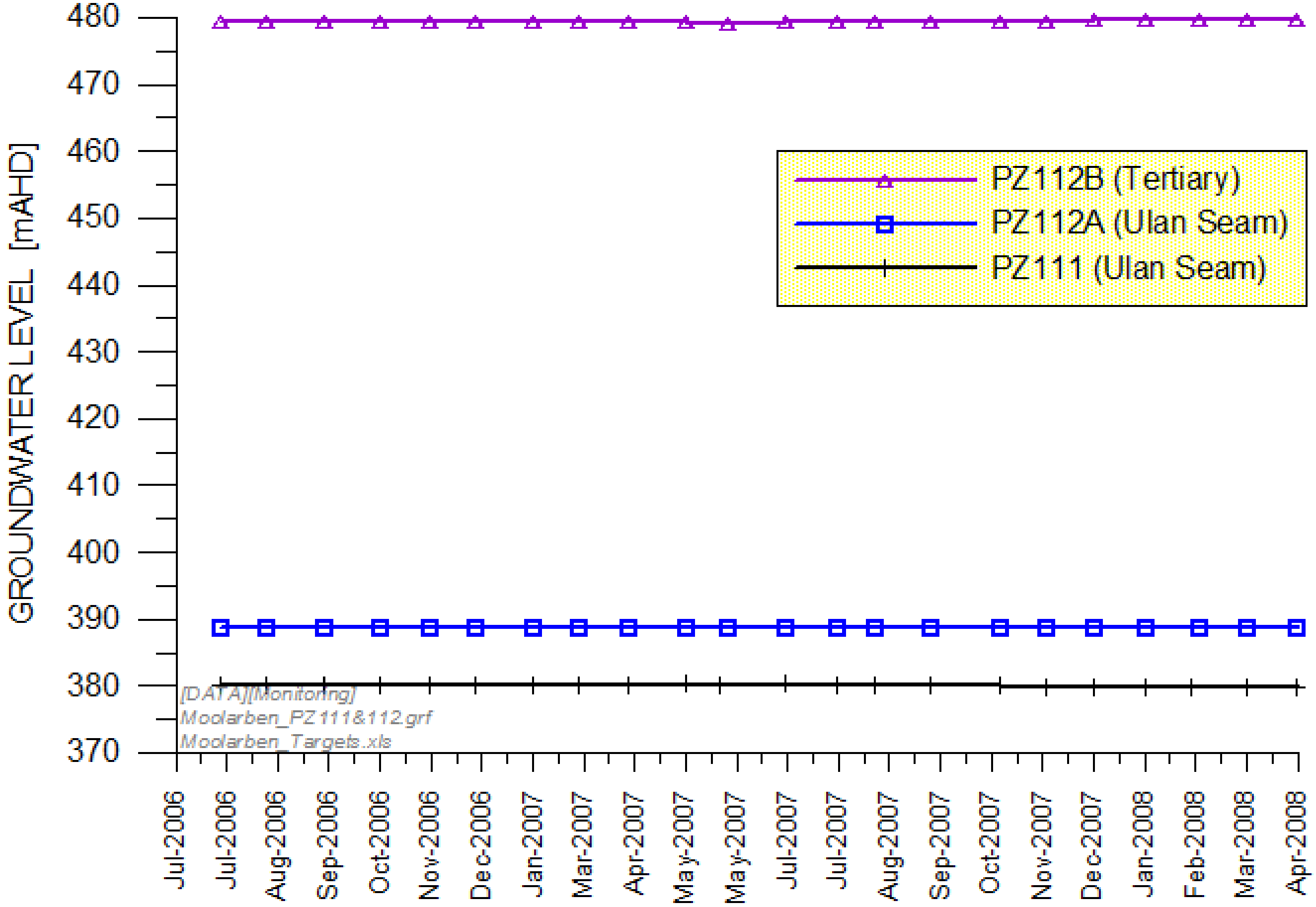


Figure B-5. Moolarben Groundwater Hydrographs at Bores PZ111 and PZ112, 1.5 km from WCM Pit 6

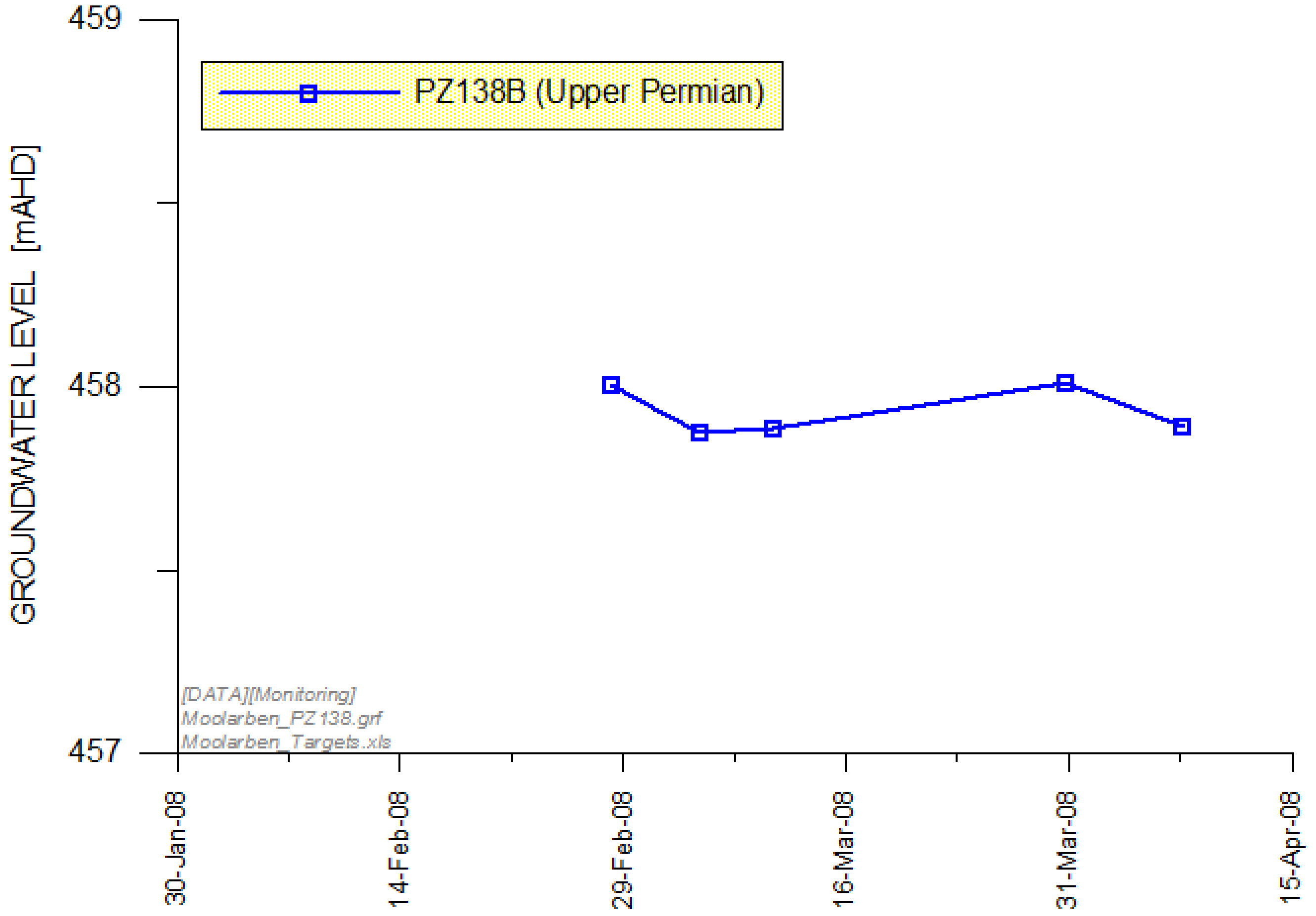


Figure B-6. Moolarben Groundwater Hydrographs at Bore PZ138, 3 km from WCM Pit 6