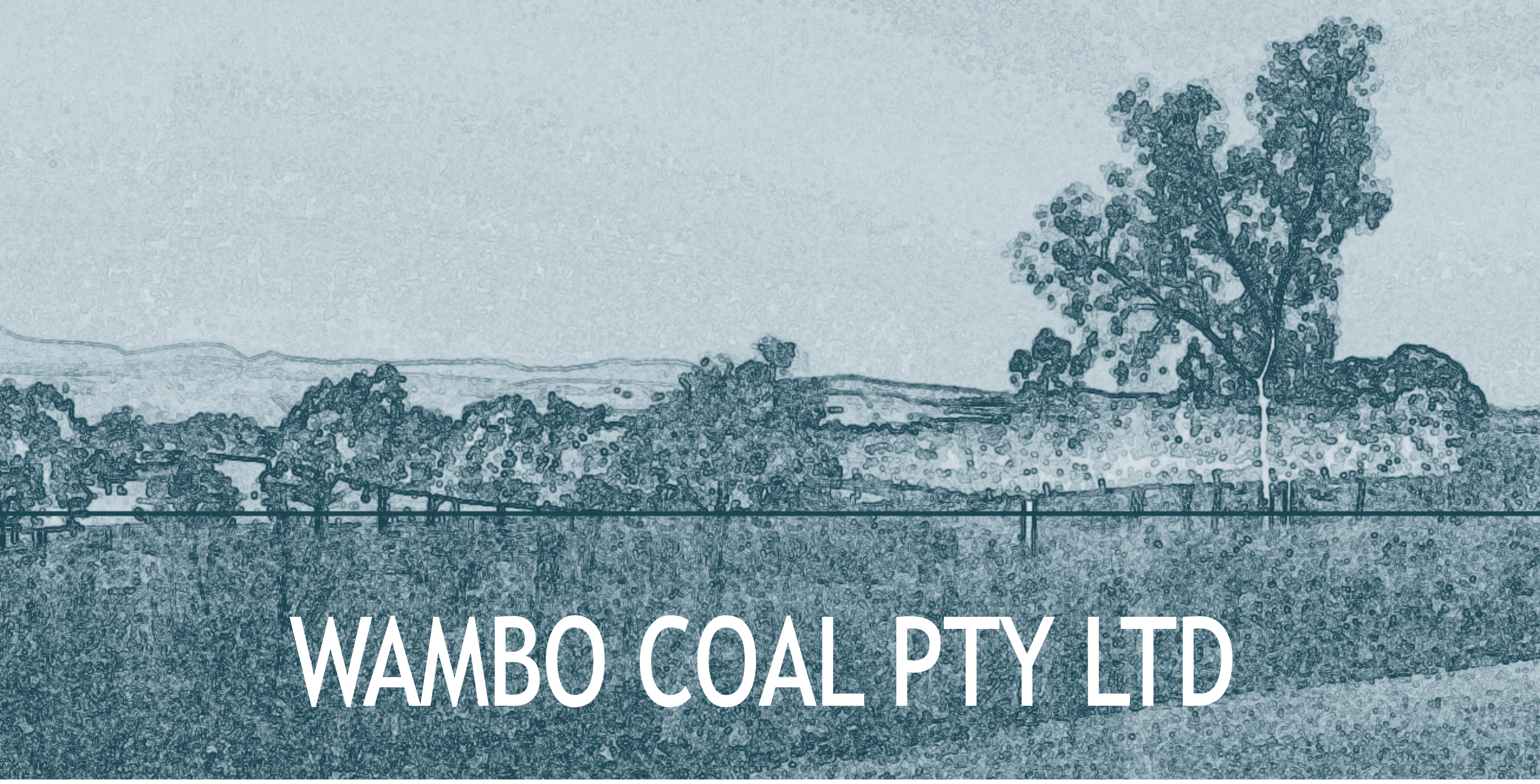


WAMBO COAL PTY LTD

NORTH WAMBO UNDERGROUND MINE MODIFICATION

ENVIRONMENTAL ASSESSMENT

APPENDIX B

GROUNDWATER ASSESSMENT

Peabody ENERGY

HERITAGE COMPUTING REPORT

NORTH WAMBO UNDERGROUND MINE MODIFICATION GROUNDWATER ASSESSMENT

FOR

WAMBO COAL PTY LIMITED

By

Dr N. P. Merrick and Dr M. Alkhatib

Heritage Computing Pty Ltd

Report: HC2012/13
Date: November 2012

EXECUTIVE SUMMARY

The Wambo Coal Mine (Wambo) is an existing open cut and underground mining operation situated approximately 15 kilometers west of Singleton, near the village of Warkworth, New South Wales (NSW).

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

This report has been prepared for WCPL to provide a groundwater assessment of the proposed North Wambo Underground Mine Modification (the Modification).

The Modification would include the development of two additional longwall panels in the Wambo Seam adjacent to the existing North Wambo Underground Mine (Longwalls 9 and 10) (**Figure ES-1**). Access to the modified longwall panels would be via the existing North Wambo Underground Mine. The Modification would use the existing surface infrastructure of the North Wambo Underground Mine.

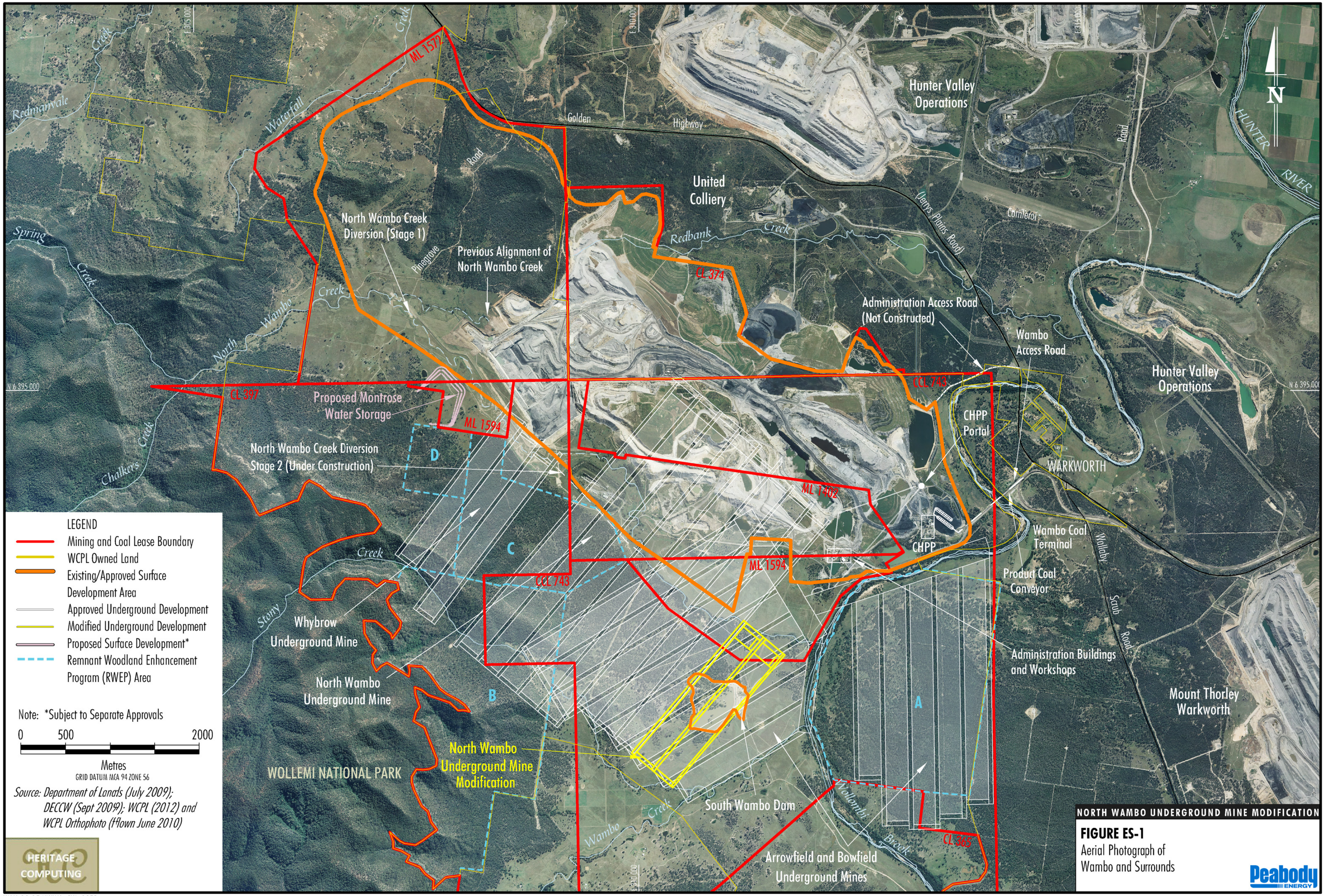
The groundwater assessment included the development of a numerical groundwater model in consideration of the MDBC Groundwater Flow Modelling Guideline (MDBC, 2001) and the New National Guidelines, announced in June 2012, sponsored by the National Water Commission (Barnett *et al*., 2012).

A full review of the data, literature and conceptual hydrogeology associated with previous groundwater models constructed for the Wambo Coal Mine area was carried out as a basis for model development. This was supported by a review of currently available information on geology, rock mass hydraulic properties, neighbouring mine workings and strata geometry for the area.

The complexity of the numerical groundwater model developed as part of this study is adequate for simulating contrasts in hydraulic properties and hydraulic gradients that may be associated with changes to the groundwater system as a result of the Modification.

The key findings of the groundwater assessment for the Modification are summarised in **Table ES-1**.

Based on the findings of the groundwater assessment, no additional groundwater impact management measures are proposed for the Modification. Groundwater levels and quality should continue to be monitored at Wambo in accordance with the currently approved Groundwater Monitoring Program with no augmentation required.



NORTH WAMBO UNDERGROUND MINE MODIFICATION

FIGURE ES-1
Aerial Photograph of Wambo and Surrounds

WAM-10-15 NWUM_GW_105B

Table ES-1: Key Findings of the Groundwater Assessment

Potential Groundwater Impact	Approved Mine Layout	Modified Mine Layout
Changes to stream baseflow and natural river leakage in Wollombi Brook, North Wambo Creek, Wambo Creek and Stony Creek.	The approved mine layout will cause a slight increase in leakage from the Wollombi Brook and Stony Creek in the order of 0.3 ML/day and 0.03 ML/day, respectively. The approved mine layout will cause a slight fluctuation in baseflow of about 0.01 ML/day at North Wambo Creek and a slight reduction in baseflow to Wambo Creek in the order of 0.05 ML/day.	The Modification would have no discernible impact on stream baseflow or natural river leakage for all simulated stream systems, beyond the effects of approved mining.
Inflow to the underground mine workings.	Peak mine inflows for the approved mine layout are predicted to be about 1.5 ML/day.	The Modification would add about 0.2 ML/day to the peak mine inflow rates predicted for the currently approved mine plan.
Groundwater loss from the alluvium.	The net loss of groundwater from the alluvium predicted for the approved mine plan is about 3.4 ML/annum based on the average cumulative loss over the period of mining.	The additional average loss from the alluvium due to the Modification is about 0.08 ML/annum based on the average cumulative loss over the period of mining.
Impacts to groundwater users.	There would be negligible impacts from the Modification on registered groundwater licence holders. No privately-owned registered bore would incur more than 1 m incremental drawdown due to the Modification.	
Recovery of Groundwater levels.	The Modification does not have a significant impact on the regional groundwater regime. The Modification could not be considered to have a significant impact on the recovery of groundwater levels.	

ML/day = Megalitres per day.

m = metre.

DOCUMENT REGISTER

Revision	Description	Date	Comments
A	Initial Draft	31 May 2012	Draft for external review
B	Final Draft	14 August 2012	Revised after external review
C	Final Report	16 November 2012	Revised after client review

ACKNOWLEDGMENTS

Person	Company	Activity
Andrew Fulton	Groundwater Exploration Services Pty Ltd	Report sections and figures

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF ATTACHMENTS

1 INTRODUCTION

The Wambo Coal Mine (Wambo) is an existing open cut and underground mining operation situated approximately 15 kilometers (km) west of Singleton, near the village of Warkworth, New South Wales (NSW) (**Figure 1.1**).

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

A range of open cut and underground mine operations has been conducted at Wambo since mining operations commenced in 1969. Mining under Development Consent DA 305-7-2003 commenced in 2004 and currently both open cut and underground operations are conducted. The approved run-of-mine (ROM) coal production rate is up to 14.7 million tonnes per annum (Mtpa) and product coal is transported from Wambo by rail.

This report has been prepared for WCPL to provide a groundwater assessment of the proposed North Wambo Underground Mine Modification (the Modification).

The approved North Wambo Underground Mine Layout consists of eight longwall panels within the Wambo Seam (Longwalls 1 to 8) (**Figure 1.2**).

The Modification would include the development of two additional longwall panels in the Wambo Seam adjacent to the existing North Wambo Underground Mine (Longwalls 9 and 10) (**Figure 1.2**). Access to the modified longwall panels would be via the existing North Wambo Underground Mine. The Modification would use the existing surface infrastructure of the North Wambo Underground Mine.

Further detail regarding the Modification description is provided in Section 3 in the Main Report of the Environmental Assessment.

There is substantial coal mining activity both historically and currently surrounding Wambo, by a number of companies, with development across several coal seams. Coal is extracted by means of both underground and open cut mining methods. Coal mines neighbouring Wambo include United Colliery to the north and east of Wambo, Mt Thorley Warkworth to the south-east, and a number of open cut and underground mines to the north and east within the Hunter Valley Operations (HVO) (**Figure 1.2**).

Historical mining at Wambo has involved four seams in the open cuts - Whybrow, Redbank Creek, Wambo and Whynot. WCPL operates four open cut pits: Bates; Bates South; Wombat; Homestead and Montrose. Underground mining has involved recovery from the Wambo and Whybrow seams. The Whybrow seam was mined at the Homestead underground mine between 1979 and 1999, and in the Wollemi underground mine between 1997 and 2002.

There is historical underground mining both above and below the Wambo Seam currently being mined by WCPL. The adjacent United Colliery mined the lower Arrowfield Seam until 2010 (United Underground Mine).

1.1 SCOPE OF WORK

The key tasks for this assessment are:

- Characterisation of the existing groundwater environment;
- Collation and review of baseline groundwater data including:
  - review of existing groundwater monitoring and assessment reports;
  - review of existing mine water management records;
  - review of existing WCPL groundwater monitoring data; and
  - collation of additional data if needed;
- Preparation of a Groundwater Assessment report for inclusion in the EA that includes the following:
  - assessment of potential underground mine groundwater impacts and cumulative impacts with other existing and approved mines in the area associated with the Modification;
  - assessment of post-mining groundwater impacts associated with the Modification; and
  - assessment of groundwater impacts on the Wollombi Brook, Wambo Creek and Stony Creek associated with the Modification; and
- Development of measures to avoid, mitigate and/or offset (if necessary) potential impacts on groundwater resources and provide recommendations for future groundwater monitoring to measure actual impacts on groundwater resources associated with the Modification.

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

- National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia (Agriculture and Resource Management Council of Australia and Australian and New Zealand Environment and Conservation Council [ARMCANZ/ANZECC]);
- NSW State Groundwater Policy Framework Document (NSW Department of Land and Water Conservation [DLWC]);
- NSW State Groundwater Quality Protection Policy (DLWC);
- NSW State Groundwater Quantity Management Policy (DLWC) Draft;
- NSW Groundwater Dependent Ecosystem Policy (DLWC);
- Murray-Darling Basin Groundwater Quality. Sampling Guidelines. Technical Report No 3 (Murray-Darling Basin Commission [MDBC]);
- MDBC Groundwater Flow Modelling Guideline (2001);
- Australian Groundwater Modelling Guidelines (2012); and
- Draft Guidelines for the Assessment & Management of Groundwater Contamination (NSW Department of Environment and Climate Change [DECC]).

1.2 PROPOSED MINE DEVELOPMENT

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

- Development of two additional longwall panels in the Wambo Seam adjacent to the existing North Wambo Underground Mine (Longwalls 9 and 10). Longwall panels 9 and 10 would be located to the south-east of the existing longwall panels and would be approximately 2.0 km long and approximately 260 metres (m) wide (**Figure 1.3**). Longwall panels 9 and 10 would be mined within the approved mine life, over approximately 2 years.
- Access to the modified longwall panels via the existing North Wambo Underground Mine.

2 HYDROGEOLOGICAL SETTING AND CONCEPTUALISATION

2.1 RAINFALL AND EVAPORATION

The nearest long term meteorological stations are located at Jerrys Plains Post Office (1884 to present), approximately 6 km to the north-west of Wambo and at Bulga (South Wambo) (1959 to present) located approximately 3 km to the south. Long-term rainfall data for these stations are provided in **Table 2.1**.

The annual rainfall at the Jerrys Plains site exhibits a moderate seasonal pattern with the highest mean rainfall occurring during the summer months and lower rainfall in winter months. Rainfall trends over recent years have been analysed by means of residual mass analysis (cumulative deviation from the mean) (**Figure 2.1**).

No evaporation data are available from the Jerrys Plains meteorological station. Average class A pan evaporation data based on data from the Cessnock station are given in **Table 2.1**. There is a clear annual rainfall deficit and potential evaporation exceeds rainfall for all months of the year. Occasional recharge could occur at any time of year following prolonged, heavy rains.

Table 2.1 Monthly Average Rainfall and Evaporation

Month	Monthly Average Rainfall (mm)		Monthly Average Pan Evaporation (mm)
	Jerrys Plains Post Office (61086) (1884 to present)	Bulga (South Wambo) (61191) (1959 to present)	Cessnock
January	77.0	84.7	182
February	72.4	84.6	143
March	59.1	61.5	127
April	43.9	45.4	96
May	40.5	43.7	68
June	47.6	44.6	57
July	43.3	31.5	67
August	36.4	35.4	93
September	41.7	39.5	120
October	51.9	56.8	149
November	59.7	60.8	167
December	67.9	72.2	200
Annual Average	**641.4**	**660.7**	**1470**

Source: Bureau of Meteorology (BoM) (2012).

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

Natural fluctuations in the groundwater table result from temporal changes in rainfall recharge to aquifers. Typically, changes in groundwater elevation reflect the deviation between the long-term monthly (or yearly) average rainfall, and the actual rainfall, often illustrated by the rainfall Residual Mass Curve (RMC).

The groundwater levels recorded during periods of rising rainfall RMC are expected to rise while those recorded during periods of declining rainfall RMC are expected to decline. RMC plots using rainfall data from the Jerrys Plains Post Office and Bulga (South Wambo) since 2003 are shown in **Figure 2.1**. These plots suggest that current mining operations have experienced fluctuating weather conditions, with pronounced dry conditions from late 2005 to the mid-2007. Conditions have been wetter than normal since mid-2007, especially around January 2009.

2.2 TOPOGRAPHY AND DRAINAGE

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

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

An overview map of the regional topography is shown in **Figure 2.2**.

Wambo is situated adjacent to the Wollombi Brook, south-west of its confluence with the Hunter River (**Figure 1.1**). Wollombi Brook drains an area of approximately 1,950 square kilometres (km^2) and joins the Hunter River some 5 km north-east of Wambo. The Wollombi Brook sub-catchment is bound by the Myall Range to the south-east, Doyles Range to the west, the Hunter Range to the south-west and Broken Back Range to the north-east (Hunter Catchment Management Trust, 2002).

The majority of lands within WCPL mining tenements drain via Wambo, Stony, North Wambo and Redbank Creeks to Wollombi Brook, while Waterfall Creek drains directly to the Hunter River (**Figure 1.2**). These watercourses are generally characterised by ephemeral and semi-perennial flow regimes (Gilbert and Associates, 2003).

2.3 LAND USE

Land use in the vicinity of Wambo is characterised by a combination of coal mining operations, agricultural land uses and the village of Warkworth. WCPL-owned lands that are not subject to mining operations are utilised for the agistment of stock (WCPL, 2003). Land use in the Modification longwall panel area includes approved underground mining areas, existing mining surface infrastructure, remnant vegetation, and cleared grazing land.

Neighbouring mining operations in the vicinity of Wambo include HVO and United Colliery, located directly to the north and east, and Mt Thorley Warkworth operations, located to the south-east.

2.4 STRATIGRAPHY AND LITHOLOGY

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

Folding, faulting and igneous intrusions have affected the Permian sediments after deposition. Geology within the model domain is shown in **Figure 2.3**. The model domain covers an area designed to be large enough to prevent boundary effects on model outcomes associated with mining-related stress on the groundwater environment and extends beyond the subcrop trace of the deepest coal seam that is likely to be mined in the future. Further discussion of the model domain is covered in Section 3.3.

The stratigraphy of the Wambo area and targeted coal seams at Wambo are presented in **Figure 2.4**. The target Wambo Seam lies within the Malabar Formation of the Jerrys Plains Subgroup of the Wittingham Coal Measures.

2.4.1 Alluvium/Regolith

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

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

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

A geophysical survey of the alluvium near the confluence of North Wambo Creek and Wollombi Brook was undertaken by GHD in 2007 to assess the thickness of the North Wambo Creek alluvium. The survey area was located above underground workings of the old Homestead Underground Mine. The investigation used bore logs and electromagnetic geophysics and found the thickness of alluvium to range from about 7 m to 19 m across the survey area.

The alluvium within floodplains associated with the main creeks merges gradationally at the margins with colluvium and unconsolidated weathered bedrock material (regolith) of limited thickness. The colluvium/regolith layer is an important component of the recharge process for the underlying Permian coal measures.

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

2.4.2 Triassic Narrabeen Group

The Triassic Narrabeen Group forms the prominent escarpment on elevated areas to the south-west of Wambo and unconformably overlies the Permian coal measures. The Narrabeen Group is not present within the Wambo mining lease area.

2.5 PERMIAN COAL MEASURES

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

2.5.1 Structural Geology

The Permian coal measures generally dip at approximately three degrees to the south-west with structure complicated by some local variations in seam dip and direction. Notwithstanding, seams generally have consistent thicknesses and interburden intervals.

Elevation contours of the base of the Wambo coal seam are shown on **Figure 2.5**. This shows the south-west dipping structure of Permian geology within the study area, as well as the two major fault structures within the Wambo area: the Redmanvale Fault and Hunter Valley Cross Fault (Department of Mineral Resources, 1993).

2.6 HYDROGEOLOGY

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

- a Quaternary alluvial aquifer system of channel fill deposits associated with Wollombi Brook, North Wambo Creek, Wambo Creek and Stony Creek; and
- underlying Permian strata of hydrogeologically "tight" and hence very low yielding to essentially dry sandstone and lesser siltstone and low to moderately permeable coal seams which are the prime water bearing strata within the Permian measures.

A conceptual summary of the regional flow patterns has been derived from monitoring bore groundwater levels for the alluvium and for the Permian hard rock aquifers, as shown in **Figure 2.6** for a typical west-east cross-section.

2.6.1 Alluvial Aquifers

Groundwater flow patterns within the shallow alluvial aquifer reflect topographic levels and the containment of alluvium within the principal drainage pathways. These are to a large degree independent of the underlying Permian hard rock fractured aquifers although contribution from these deeper aquifers may occur where upward leakage occurs. Evidence from temporal groundwater monitoring hydrographs (**Attachment A**) within the alluvium indicates that the shallow aquifer is responsive to rainfall recharge and it is likely that the alluvium plays an important role in supplying recharge to the underlying Permian strata as well as contributing to baseflow of the perennial surface water features.

2.6.2 Permian Aquifers

Prior to the commencement of mining operations in the region, the piezometric surface within the Wambo area most probably reflected the topography, with elevated water levels/pressures in areas distant from the major drainages and reduced levels in areas adjacent to the alluvial lands. Historical and ongoing open cut and underground mining within the Wambo area and adjoining mining operations has now created significant groundwater sinks. This has generated a regional zone of depressurisation within the Permian coal measures.

The Permian aquifer system within the Wambo area is continuous through the major geological formations. The various sedimentary rocks at Wambo have low permeability[1] due to their fine-grained nature, the predominance of cemented lithic sandstones and the common occurrence of a clayey matrix in the sandstones and conglomerates. The permeability of the aquifer system is related to the joint spacing and aperture width. Permeability of the rock units generally decreases with depth of burial as the joints tighten and become less frequent, with higher permeabilities encountered in the coal seams.

[1] Permeability and hydraulic conductivity are used interchangeably in this report.

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

The impact of fault structures such as the Redmanvale Fault is not known with certainty. However, it is likely that groundwater flow dynamics are complex in the vicinity of these structures. The permeability of the coal measures is generally low, with rock mass permeabilities more than two orders of magnitude lower than the unconsolidated alluvial aquifers. Within the coal measures, the most permeable horizons are the coal seams, which commonly have hydraulic conductivity one to three orders of magnitude higher than the siltstones, shales and sandstone units.

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

2.6.3 Recharge and Discharge Mechanisms

The main recharge mechanism is infiltration of rainfall through the weathered regolith layer, and from there into the underlying rock mass where favourable permeability is exposed in subcrop areas.

As there is an annual rainfall deficit and the permeability of underlying rock is low, recharge rates to the coal measures are low. Significant groundwater recharge will tend to occur only following major, prolonged rainfall events, or during the late autumn/early winter period when some longer term ground saturation and recharge is feasible.

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

Surface water associated with the principal drainage features will tend to be connected with the associated alluvium, and groundwater within the alluvium will discharge to the stream channels in some areas. However, connectivity with the wider geological environment is thought to be very limited due to the low vertical permeability of the underlying strata. Creeks may ‘lose’ or ‘gain’ groundwater from alluvium in some areas depending on the relative level of groundwater in the alluvium compared with the creeks, although under most conditions the streams are gaining, and act as discharges for both alluvial groundwater and hard rock groundwater. Connectivity with the regional hard rock aquifers is very low.

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

2.7 GROUNDWATER MONITORING

Groundwater monitoring at Wambo is undertaken in accordance with the Groundwater Monitoring Program (GWMP) (WCPL, 2010). The objectives of the GWMP are to establish baseline groundwater quality and water level data and to implement a programme of data collection that can be utilised to assess potential impacts of mining activities on the groundwater resources of the area.

The GWMP has been updated regularly as mining has progressed. The GWMP groundwater monitoring network currently consists of 30 monitoring sites as summarised in **Table 2.2.**

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

Groundwater data is also available for a number of monitoring sites in addition to the monitoring sites comprising the GWMP and these additional sites are summarised in **Table 2.3**.

The location of monitoring sites summarised in **Tables 2.2** and **2.3** are presented in **Figure 2.7**. Hydrographs for selected monitoring sites summarised in **Tables 2.2** and **2.3** are presented in **Attachment A**.

2.8 BASELINE GROUNDWATER LEVEL DATA

A network of monitoring bores (piezometers) has been established in the alluvial aquifers associated with the principal drainage pathways, and more recently multi-level vibrating wire piezometers have been installed within the Permian aquifer. **Figure 2.7** shows the locations of groundwater monitoring bores within the Wambo area and surrounds.

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

Table 2.2 Groundwater Monitoring Program Monitoring Sites

Monitoring Site	Parameters Monitored	Lithology Monitored	Monitoring Frequency
P1, P3, P5, P6, P11, P16, P20	• Depth to water. • Electrical Conductivity. • pH. • Temperature.	Alluvium	Bi-monthly [from December 2005]
P106, P109, P114, P116	• Depth to water. • Electrical Conductivity. • pH. • Temperature.	Alluvium	Bi-monthly [from July 2003]
P202, P206	• Depth to water. • Electrical Conductivity. • pH. • Temperature.	Shallow Permian Overburden	Bi-monthly [from July 2003]
P301, P315	• Depth to water. • Electrical Conductivity. • pH. • Temperature.	Alluvium, Shallow Permian Overburden	Bi-monthly [from March 2004]
GW02, GW08, GW09, GW11	• Depth to water. • Electrical Conductivity. • pH. • Temperature.	Alluvium	Bi-monthly [from July 2005]
GW12, GW13, GW14, GW15, GW16, GW17, GW18, GW19, GW21, GW22	• Depth to water. • Electrical Conductivity. • pH. • Temperature.	Alluvium, Shallow Permian Overburden	Bi-monthly [from December 2009]
GW20	• Groundwater pressure.	Alluvium, Permian Overburden, Whybrow Seam, Redbank Seam, Wambo Seam	Continuous [from January 2010; May 2011; January 2005]

Table 2.3 Additional Groundwater Monitoring Sites

Monitoring Site	Parameters Monitored	Lithology Monitored	Frequency
P12, P13, P15, P17, P18	• Depth to water. • Electrical Conductivity. • pH. • Temperature.	Alluvium	Bi-monthly [from December 2005]
P110, P111	• Depth to water. • Electrical Conductivity. • pH. • Temperature.	Alluvium	Bi-monthly [from July 2003]
P316, P317	• Depth to water. • Electrical Conductivity. • pH. • Temperature.	Alluvium, Shallow Permian Overburden	Bi-monthly [from March 2004]
MG06-01, MG06-02	• Groundwater pressure.	Alluvium, Permian Overburden, Whybrow Seam, Redbank Seam, Wambo Seam	Continuous [from January 2010; May 2011; January 2005]
P33, P34, P35*	• Groundwater pressure.	Alluvium, Permian Overburden, Whybrow Seam, Redbank Seam, Wambo Seam	Continuous [from January 2010; May 2011; January 2005]
GW04, GW05, GW06, GW07, P104, P108, P209, P302, P303, P310, P311, P312, P314, P318, P319	• Depth to water.	Shallow Permian Overburden	Various

* Part of the United Collieries network.

2.8.1 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. Groundwater would flow from elevated to lower-lying terrain.

Groundwater levels within the alluvium generally follow topography, draining from the centre of the study area north-east towards the Hunter River. Reduced water levels in the alluvium are shown in **Figure 2.8** for April 2007. This time was chosen for a reference point as it was just prior to a significant recharge event which occurred in June 2007 and provides groundwater levels that resulted from a long recession period following consistent below average rainfall.

Figure 2.8 also shows that drawdown has occurred within alluvium at a number of locations. A water table depression can be seen at the confluence of Wollombi Brook and Wambo Creek, with estimated maximum drawdown in the order of 5 m. This is in an area under which Longwalls 8 and 9 were mined at the Homestead Mine in 1999. An assessment of the impacts of Homestead Mine Longwall 9 extraction on surface water and groundwater has shown that groundwater levels in the vicinity of the panels were lowered following progression of the longwall panel (HLA-Envirosciences, 1999). **Figure 2.8** also shows a low groundwater level in alluvium overlying North Wambo Underground Mine Longwall 1 and 2, in the vicinity of monitoring bores P5 and P6, with a maximum depression in the order of 4 m.

2.8.2 Temporal Groundwater Levels in Alluvium

Attachment A shows select groundwater hydrographs from the monitoring network grouped into areas where bores are clustered. The hydrographs are presented with a rainfall RMC of long term rainfall data from the Bulga (South Wambo) BOM site in order to evaluate the response of alluvium to rainfall patterns.

Groundwater levels generally correlate well with rainfall trends, showing responses to recharge events and associated recession as the aquifer discharges water during periods between major recharge cycles. Additional influence is seen from Wollombi Brook and Wambo Creek on some bores close to the creeks, which tends to subdue rainfall response.

Deviations from this trend can be seen in a number of alluvium monitoring bores, which are attributed to impacts associated with mining operations. Specifically **Figure A1** (**Attachment A**) shows a cluster of monitoring bores screened within alluvium associated with North Wambo Creek. P5 and P6 show a punctuated decline in water levels in early 2008. This correlates with the timing of Longwall 1 progression. Water levels in these bores recovered in the following 12 months. In contrast, the records within GW08 and GW09 downstream away from mining areas show no such reaction but are sympathetic with rainfall trends.

Figure A4a (**Attachment A**) shows a cluster of monitoring bores screened within alluvium associated with Wollombi Brook located to the east of the United Underground Mine area downstream from the confluence with North Wambo Creek. Similar to the response described above, there is a punctuated decline in the groundwater levels in P3, P12, P13, P16 and P20 which deviates from the expected response to the RMC between December 2007 and May 2008. This is not reflected in **Figure 2.8** due to impacts occurring after the June 2007 recharge event. However, these responses do correlate with progression of Longwall 7 at the United Underground Mine, and indicate that fracturing above Longwall 6 near the access mains may have caused partial dewatering of the alluvium in this area.

2.8.3 Groundwater Levels in Permian Coal Measures

Originally the piezometric surface within the Wambo area most probably reflected the topography, with elevated water levels/pressures in areas distant from the major drainages and reduced levels in areas adjacent to the alluvial lands. Long periods of both open cut and underground mining within the WCPL-owned and adjoining mine leases has now created significant groundwater sinks. This is likely to have generated a regional zone of depressurisation within the Permian coal sequences.

2.8.4 Deep Groundwater Pressures (Wambo Vibrating Wire Piezometers)

Multi-level vibrating wire piezometers were installed at Wambo in late 2009 at groundwater monitoring site GW20 about 300 m west of North Wambo Underground Mine Longwall 1. The vibrating wire transducers were installed and fully grouted at the following depths:

- 9.3 m at the base of the soil profile;
- 61.5 m, approximate base of Whybrow Seam;
- 93 m, approximate base of Redbank Seam; and
- 129.5 m, approximate base of Wambo Seam.

Additional multi-level vibrating wire piezometers were installed in 2011 into two boreholes overlying Maingate 6 (MG06) (called MG06-01 and MG06-02). The Wambo Seam and strata just below and just above the seam were target horizons.

Figure A8 (**Attachment A**) shows water levels in GW20 which indicate that groundwater pressures within the Permian are in the order of 40 m below ground level. The pressure for the shallowest transducer located at the base of colluvium is atmospheric and therefore this elevation is essentially dry.

Pressures within the Whybrow seam remain relatively stable, with potentiometric heads fluctuating between 55.0 and 55.5 m AHD.

Within the Redbank Seam, pressures remain relatively stable, although a depressurisation trend from early to late data can be seen with heads falling from 49 m AHD in February to 46 m AHD in August 2010.

Within the Wambo Seam, heads are higher than those of the overlying Redbank Seam suggesting that there may be potential for upward leakage at least from coal measures underlying the Redbank Seam.

2.8.5 Deep Groundwater Pressures (United Colliery Vibrating Wire Piezometers)

Three multi-level vibrating wire piezometers (P33, P34, and P35) have been installed at the United Underground Mine adjacent to Wollombi Brook, with three to five vibrating wire transducers placed above the Woodlands Hill Seam (United Collieries, 2009).

The multi-level piezometers at the United Underground Mine were installed in January 2005. Hydrographs, based on data presented in the United Collieries Annual Environmental Managment Report (2009), for the three multi-level vibrating wire piezometers P33, P34, and P35 are presented in **Figures A5** to **A7** of **Attachment A** respectively.

All three piezometers indicate that there is significant depressurisation at depth just above the Arrowfield Seam which was mined during United Underground Mine operations. The records suggest that depressurisation had occurred prior to installation at these locations.

The hydrograph and pressure head profile at P33 are shown in **Figure A5**. A pronounced depressurisation which coincides with the completion of United Underground Mine Longwall 8 can be seen at all levels monitored although the signature is subdued at shallower depths. The reason for increase in pressures seen at depth during May to June 2008 is not clear.

Data from P34 and P35 (**Figures A6, A7**) indicate that there is a downward gradient throughout the stratigraphic profile. P35 shows depressurisation of the mid-level transducers (19 m, 51 m and 60 m) in late 2009. However, the deepest transducer set at 112 m depth shows groundwater pressures at this depth are about 60 m lower than those in the overlying Permian strata.

The hydrograph and pressure head profile at P34 are shown in **Figure A6**. There is a significant deviation away from the hydrostatic profile indicating depressurisation at depth which has not been transmitted to higher levels.

The transducer located at a depth of 144 m responds to mining activities in June 2009 which correlates with the progression of United Underground Mine Longwall 8. A similar but subdued response occurs in the transducer located at 68.5 m depth. A very weak response is seen at shallow depths (35 m depth), however, the data unusually suggests that pressures at 35 m depth are 5-10 m lower than at 68.5 m depth.

The hydrograph and pressure head profile at P35 are shown in **Figure A7** and the heads at this location differ significantly from P33 and P34 in that pressures at depth have deviated significantly from hydrostatic pressures. A drawdown response can be seen within transducers located at 51 m and 60 m depth although not seen just above mining levels as significant depressurisation had already occurred.

Elsewhere groundwater levels for Permian horizons have been estimated from open cut seam exposure levels.

2.9 GROUNDWATER CHEMISTRY

Several previous studies carried out in this area document the salinity of groundwater sampled from the Wambo site and surrounds. An assessment undertaken in 2002 shows that the groundwater quality in the vicinity of North Wambo Creek is variable in quality with total dissolved solids (TDS) concentrations ranging from 710 milligrams per litre (mg/L) to 2690 mg/L (Coffey, 2002). The study concluded that groundwater in the alluvium is recharged from multiple sources with varying qualities.

Assessments of groundwater quality can be useful in understanding conceptual hydrogeology, particularly by use of EC and Piper diagram plots. Groundwater salinity tends to be low in areas of high recharge or connectivity with surface waters.

The salinity of groundwater recently sampled from within Wambo and surrounding mining leases is variable, with TDS ranging from 314 mg/L to 6660 mg/L. The highest salinities are reported from the surficial groundwater, i.e. the colluvium and weathered Permian.

2.10 DEWATERING AND GROUNDWATER LICENCES

The Project is subject to the *Hunter Unregulated and Alluvial Water Sources Water Sharing Plan 2009*. This Plan covers the unregulated rivers and creeks and highly connected alluvial groundwater within the catchment of the Hunter River. Part of the proposed mining will pass beneath the Lower Wollombi Brook Water Source, which includes several tributary creeks (e.g. North Wambo Creek) and the alluvium associated with those creeks. The Lower Wollombi Brook Water Source has a total groundwater entitlement of 5,071 ML/year distributed between 38 groundwater licences, used 55% for irrigation and 44% for industrial purposes. Surface water in the Lower Wollombi Brook has a low flow index of 15.2 ML/day (80th percentile in December)[2].

WCPL currently holds water licences (under the *Water Act 1912* and *Water Management Act 2000*) for a number of bores and wells located across the mine site. Details of the current water licences for WCPL are presented in Table 2.4.

Table 2.4 Groundwater Licence Summary

Licence Number	Description	Facility	Valid to	Extraction Limits
Licences under the Water Management Act 2000				
WAL 23897[1]	Well No. 2	Well	Perpetuity	70 ML/year
Licences under the Water Act 1912				
20BL166910	Dewatering (Bore No. 1)	Bore	25/10/2018	450 ML/year
20BL167810	Well – Domestic, Stock	Well	Perpetuity	11 ML/year
20BL168017	Dewatering (Bore No. 2)	Bore	21/05/2012	750 ML/year
20BL168643	Dewatering Bore	Bore	7/08/2013	300 ML/year
20BL166438	Well - Stock	Bore	Perpetuity	5 ML/year

1 Assigned to the Lower Wollombi Brook Water Source.

2 August 2009 Report Card, NSW Department of Water and Energy.

2.11 RECEPTORS AND POTENTIAL IMPACT ASSESSMENT TARGETS

All potentially significant surface water receptors have been considered in this study, along with the potential mechanisms for surface/groundwater interaction. All permanent water bodies and ephemeral streams of third order or greater magnitude are shown on **Figure 1.2**.

2.11.1 Permanent Water Bodies

In terms of licensing and potential environmental impacts, water bodies generally form the most sensitive environmental receptors to any changes in the groundwater regime. A summary of the nature and hydrogeological significance of each of the waterbodies/ drainage pathways in the study area is provided in **Table 2.5**.

Table 2.5: Summary of Permanent/Ephemeral Waterbodies in the Study Area

Name of Waterbody	Description and Nature of Surface/Groundwater Interaction
North Wambo Creek	North Wambo Creek is associated with reasonably significant alluvial deposits near the confluence with Wollombi Brook, and these shallow alluvial aquifers are likely to be in hydraulic continuity with the creek and underlying Permian coal measures. North Wambo Creek becomes ephemeral upstream.
Wambo Creek	As for North Wambo Creek, Wambo Creek is associated with reasonably significant alluvial deposits near the confluence with Wollombi Brook, and these shallow alluvial aquifers are likely to be in hydraulic continuity with the creek. Wambo Creek becomes ephemeral upstream.
Stony Creek	Stony Creek is characterised by ephemeral drainage flowing into North Wambo Creek.
Wollombi Brook	Wollombi Brook drains directly to the Hunter River. Significant alluvium is present, and review of available data indicates baseflow connection between the creek and its alluvium.
Hunter River	The Hunter River has 10 to 20 m of associated unconsolidated materials including gravels, sands, silts and clays depending upon location.
Storage Dams (Numerous)	Storage dams are clay lined and not considered to impact on shallow groundwater regimes.

2.11.2 Groundwater Users

There are a number of other groundwater users in the area. Boreholes registered on the NSW Office of Water database are shown in **Figure 2.9**. Registered bores within 5 km of Wambo are listed in **Table 2.6**.

Table 2.6: Registered bores within 5 km of Wambo

Work No.	Licence	Easting	Northing	Final Depth (m)
GW017462	20BL008224	315339.2	6391460.3	0.0
GW060327	-	314180.8	6393441.5	9.8
GW060328	-	314205.2	6393534.3	10.0
GW060329	-	311903.5	6392474.4	6.4
GW060330	-	311726.7	6392163.0	6.2
GW060363	20BL132753	311697.8	6392316.5	6.3
GW060364	-	311636.3	6392808.3	5.1
GW060365	-	311690.8	6392686.1	6.6
GW060366	-	311195.9	6392645.9	5.2
GW060750	20BL132130	314309.8	6394922.8	24.4
GW043673	-	311486.3	6392466.6	9.4
GW043674	-	311302.6	6392524.7	8.2
GW043675	-	311432.9	6392527.2	8.5
GW065117	-	311153.9	6390734.8	6.0
GW066606	-	311207.2	6390674.2	2.5
GW037184	-	309685.0	6393911.3	21.0
GW038579	-	309737.7	6393881.5	20.9
GW005327	20BL009540	314682.9	6394498.4	10.4
GW037998	-	311589.4	6392530.1	10.9
GW037999	-	311481.6	6392713.0	13.7
GW038000	-	311457.3	6392620.1	9.4
GW079780	-	309588.9	6393931.5	0.0
GW078574	20BL167170	309174.3	6390604.7	12.0
GW078575	20BL167171	309504.8	6389686.6	12.0
GW078577	20WA208559	309968.7	6389972.8	10.0
GW080502	20BL168017	308897.0	6390159.8	250.0
GW080514	20BL168881	310973.0	6394353.4	55.0
GW080515	20BL168882	313418.0	6394794.3	8.1
GW080516	20BL168883	312898.8	6394953.7	15.0
GW080517	20BL168884	313572.7	6394741.6	15.0
GW080519	20BL168885	313622.4	6394161.1	10.5
GW079060	-	314595.5	6394851.7	14.6
GW047240	20CA209896	316826.7	6397095.2	12.7
GW078576	20BL167172	309763.7	6389784.0	7.0
GW079059	20BL153300	314595.5	6394851.7	0.0
GW060326	-	314104.3	6393347.6	9.8
GW043676	-	311479.9	6392805.4	10.6
GW080518	20BL168885	313585.8	6394232.3	10.8
GW080951	-	314619.0	6394877.5	3.1
GW080952	-	314643.0	6394904.5	1.6
GW078055	-	310104.9	6390489.7	198.5

Table 2.6: Registered bores within 5 km of Wambo (Continued)

Work No.	Licence	Easting	Northing	Final Depth (m)
GW080963	20BL170103	315994.0	6397209.5	84.0
GW200615	20BL168886	313434.0	6394246.0	11.5
GW200616	20BL168886	313473.4	6394445.8	8.5
GW200617	20BL168888	309987.4	6393973.8	9.0
GW200618	20BL168888	310100.4	6393819.8	11.5
GW200619	20BL168888	310182.4	6393655.8	11.5
GW200620	20BL168888	310489.4	6394096.8	49.0
GW200621	20BL168887	312857.0	6395909.0	37.0
GW200622	20BL168887	312901.0	6395806.0	30.0
GW200623	20BL168887	312982.1	6395319.1	31.0
GW200624	20BL168939	310165.9	6392650.1	260.0
GW200625	20BL168940	310901.0	6393375.0	270.0
GW200634	20BL168999	311470.0	6391252.0	20.0
GW200635	20BL168999	311659.0	6391236.0	20.0
GW200636	20BL168999	311749.0	6391078.0	20.0
GW200637	20BL168999	311662.0	6391094.0	15.0
GW200638	20BL168999	311452.0	6391103.0	20.0
GW200639	20BL168999	311455.0	6390889.0	20.0
GW200640	20BL168999	311638.0	6390920.0	50.0
GW200641	20BL168999	311761.0	6390921.0	20.0
GW200642	20BL168999	311696.0	6390688.0	20.0
GW200643	20BL168999	311454.0	6390685.0	15.0
GW200361	20BL170638	311832.9	6392209.0	0.0

3 GROUNDWATER SIMULATION MODEL

3.1 SUMMARY OF PREVIOUS MODELS

A number of previous groundwater models has been constructed to simulate the stresses on the groundwater environment from mining activities within this area, and much of the information contained within this report is based on the reports written for those models. A summary of the extent and use of the previous models is provided below.

The models discussed below were used to provide some of the seam geometry for the key coal seams in the regional model developed for this project (although generally this only related to thickness, as an updated geological model was made available for this study). Hydraulic testing and associated data on hydraulic properties contained within these modelling studies and other reports have been the basis for the hydraulic properties applied initially in the current regional modelling assessment. They were refined during model calibration.

3.1.1 Wambo Model

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

The numerical models were used to assess the influence of the proposed mining on the alluvial and Permian hydrogeological regimes and the rate of recovery of groundwater levels after the end of mining.

3.1.2 Mt Thorley Warkworth Model

The Mt Thorley Warkworth model developed by AGE in 2010 was produced as part of the Warkworth Extension Groundwater Impact Assessment.

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

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

3.1.3 Hunter Valley Operations Model

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

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

3.2 MODEL SOFTWARE AND COMPLEXITY

Groundwater modelling has been conducted in accordance with the MDBC Groundwater Flow Modelling Guideline (MDBC, 2001). As this is mostly a generic guide, there are no specific guidelines on special applications such as coal mine modelling. New National Guidelines were announced in June 2012, sponsored by the National Water Commission (Barnett *et al*., 2012). These guidelines build on the 2001 MDBC guide, with substantial consistency in the model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details. In the new guide, there are no specific guidelines on coal mine modelling.

The 2012 guide has replaced the model complexity classification by a "model confidence level". The Wambo model may be classified as Class 2 to Class 3 (effectively “medium to high confidence”), which is an appropriate level for this project context. Under the 2001 modelling guideline, the model is best categorised as an Impact Assessment Model of medium complexity. The guide (MDBC, 2001) describes this model type as follows:

“Impact Assessment model - a moderate complexity model, requiring more data and a better understanding of the groundwater system dynamics, and suitable for predicting the impacts of proposed developments or management policies.”

Numerical modelling has been undertaken using the Groundwater Vistas (Version 6 software interface marketed by Environmental Simulations Inc. [ESI] in conjunction with MODFLOW-SURFACT (Version 4) distributed commercially by Hydrogeologic, Inc. (Virginia, USA). MODFLOW-SURFACT is an advanced version of the popular MODFLOW code developed by the United States Geological Survey (McDonald and Harbaugh, 1988). MODFLOW is the most widely used code for groundwater modelling and is accepted as an industry standard.

MODFLOW-SURFACT is a three-dimensional modelling code that is able to simulate variably saturated flow and can handle desaturation and resaturation of multiple aquifers without the "dry cell" problems of Standard-MODFLOW. This is pertinent to the dewatering of layers within underground coal mines. Standard-MODFLOW can handle this to some extent, but model cells that are dewatered (reduced below atmospheric pressure) are replaced by "dry cells".

The most recent derivation of MODFLOW-SURFACT also allows the changing of model properties through time using the TMP package, allowing mine scheduling to be run within a single model.

The model complexity is adequate for simulating contrasts in hydraulic properties and hydraulic gradients that may be associated with changes to the groundwater system as a result of the Modification.

3.3 MODEL LAYERS AND GEOMETRY

The model domain is discretised into 1,945,600 cells comprising 320 rows, 380 columns and 16 layers. The dimensions of the model cells are uniformly 50 m in both lateral directions. The model extent is 16 km from west to east and 19 km from south to north, covering an area of approximately 300 km^2. Sixteen model layers represent the stratigraphic section indicated in **Figure 2.4**. **Figure 3.1** shows the extent of the groundwater model domain.

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

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

- **Layer 1**: Alluvium and regolith. The alluvium was set at variable thickness, generally between 5 m and 10 m. Depths were extended to 15 m along the centre line of Wollombi Brook and for short distances of Wambo and North Wambo Creeks upstream of the confluences with Wollombi Brook. The extent of alluvium is shown in **Figure 2.8**. Outside of alluvium areas, Layer 1 was assigned to regolith and was set at 2 m thickness across the model domain.
- **Layer 2**: Overburden and coal seams above the Whybrow seam. The representation of this layer is a simplification in that it covers the Narrabeen Group sandstones and Coal Measures siltstones above the Whybrow seam. The Triassic Narrabeen sandstones reach a thickness of 200 m in the south-west of the model domain, but they do not extend into mining areas. This Layer extends from the base of the Layer 1 down to the Whybrow seam in areas inside the Whybrow subcrop trace which occurs with a north-west to south-east strike. Elsewhere it was set as a 'dummy layer', with small nominal thickness and assigned properties identical with the next active underlying layer.

- **Layer 3**: Whybrow seam. Geometry was calculated based on the subcrop pattern with a slightly basinal structure. Layer thickness was assigned as a constant 6 m.
- **Layer 4**: Whybrow – Wambo Seam interburden. This interburden also contains Redbank Creek and Wambo Ryder seams, in addition to associated interburden units.
- **Layer 5**: Wambo Seam. The seam geometry was based on the updated resource model provided by WCPL. Some extension to the south-west to the model boundary was required, and the edges of the layer had to be modified to ensure that they reconciled with known subcrop geometry and known mining area excavation depths.
- **Layer 6**: Wambo Seam – Whynot Seam interburden.
- **Layer 7**: Whynot Seam. The seam geometry was based on the updated resource model.
- **Layer 8**: Whynot – Woodlands Hill Seam interburden.
- **Layer 9**: Woodlands Hill Seam. This was defined from resource model data and included to provide definition in overlying layers in the Whybrow subcrop area local to vibrating wire piezometers. These piezometers are important for calibration. The Woodlands Hill seam constitutes multiple plies with an average thickness for the unit of 70 m. The roof of Ply D was chosen to define the mining levels within this unit. Overlying plies were assigned to Layer 8. Layer 9 has been given a consistent thickness of 3 m.
- **Layer 10**: Woodlands Hill Seam - Arrowfield Seam interburden.
- **Layer 11**: Arrowfield seam. This seam was defined using the updated resource model, as the subcrop is reasonably well defined.
- **Layer 12**: Arrowfield – Bowfield interburden.
- **Layer 13**: Bowfield Seam.
- **Layer 14**: Bowfield - Warkworth Seam interburden.
- **Layer 15**: Warkworth seam. This is fairly consistent at around 5 m below the base of the seams mined at Wambo, with 7 m thickness.
- **Layer 16**: Basal Layer. This was set with a minimum thickness of 200 m at the base of the model. It includes the Warkworth – Mt Arthur interburden and Mt Arthur Seam.

It should be noted that all layers are fully present across the active model area. Where a layer becomes inactive, such as up-dip from its subcrop, the layer has been extended across the rest of the model domain as a 0.5 m to 1 m thick 'dummy' layer, which has the same properties as the first 'active' underlying layer that exists in that area. For example, in the north of the model, all layers except the basement (Layer 16) have subcropped. The model therefore contains an 'actual' Layer 1 regolith, underlain by 0.5 m to 1 m 'dummy' layers for Layers 2 to 15, which have the same hydraulic properties as the underlying Permian basal layer, Layer 16. This approach allows each layer to represent a single hydrogeological unit, so that impacts on specific hydrogeological units can be readily extracted from the model output files.

The elevations of the top and base of the Wambo Seam are well defined in the Wambo area. Structure contours have been extrapolated to the north and east to define the stratigraphy throughout the model area, guided by median thicknesses from exploration drilling.

The hydraulic zones and values are reflective of the conceptual model. The distributions of hydraulic properties in each model layer are shown in **Attachment B**.

Representative model cross-sections are displayed in **Figure 3.2** for northing 6,392,000 (MGA) (model row 232) and easting 310,000 (MGA) (model column 205) passing through the North Wambo Underground Mine.

The model domain has been designed to be large enough to prevent boundary effects on model outcomes associated with mining-related stress on the groundwater environment as a result of mining at Wambo. The model extends beyond the subcrop trace of the deepest coal seam that is likely to be mined in the future.

The model domain and boundaries have been selected to incorporate any potential receptors (i.e. surface water bodies) that could be adversely affected by mining, but also to satisfy the regulatory and operational constraints discussed in Section 2.

3.4 HYDRAULIC PROPERTIES

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

Previous studies and investigations within the region have provided the basis for chosen hydraulic property parameters used within the modelling component of this project for the coal seams and interburden. **Table 3.1** is a summary of previous work (Mackie, 2009) and of core laboratory measurements undertaken as part of this study.

3.4.1 Core Testing for Hydraulic Conductivity

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

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

Compiled results are included in **Table 3.1**. Laboratory core testing provides a means of assessing the hydraulic conductivity of materials at an intergranular scale where porous media flow is the primary mechanism of groundwater flow. It does not account for secondary mechanisms of flow (fracturing) which tend to dominate the movement of groundwater within the rock mass, and therefore this estimate is typically the lowest tenable hydraulic conductivity and is most representative of strata where fracturing and jointing are absent or disconnected.

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

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

Differences between vertical and horizontal permeability are also well documented, with vertical permeabilities typically an order of magnitude or so less than horizontal permeability, and in some cases several orders of magnitude lower. This is because fractures and fissures are generally oriented parallel with bedding, and because layers of claystones, mudstones or other low permeability strata tend to cause coherent barriers to flow perpendicular to the bedding. Vertical permeabilities of layers in a numerical model must be even lower because vertical aggregation is necessary and anisotropy is enhanced.

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

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

During calibration the upper and lower limits for the hydraulic conductivity field were varied in an attempt to match responses seen in alluvium groundwater levels.

Based on the results of the field testing, and the analysis provided above, a summary of the likely characteristics of the Coal Measures strata within the study area was prepared, as shown in **Table 3.2**.

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

3.4.2 Specific Yield/Specific Storage

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

Table 3.1: Summary of Hydraulic Properties

Unit	Thickness (m)	Core Testing Results[1]		K (m/day)[2]
		Kx (m/day)	Kz (m/day)	
Whybrow Overburden Sandstone/Siltstone	50	3.3×10^{-05}	4.0×10^{-06}	1.0×10^{-04}
Whybrow seam	5	-[3]	-[3]	2.5×10^{-02}
Whybrow - Redbank interburden (Sandstone/Siltstone)	20	1.0×10^{-05}	3.2×10^{-06}	1.0×10^{-04}
Redbank seam	5	-[3]	-[3]	2.5×10^{-02}
Redbank - Wambo interburden (Sandstone/Siltstone)	15	3.0×10^{-06}	2.4×10^{-05}	1.0×10^{-04}
Wambo seam	5	-[3]	-[3]	2.5×10^{-02}
Wambo - Whynot interburden (Sandstone/Siltstone)	20	3.2×10^{-06}	2.8×10^{-06}	1.0×10^{-04}
Whynot seam	5	-[3]	-[3]	4.4×10^{-02}
Whynot - Blakefield interburden (Sandstone/Siltstone)	20	2.8×10^{-06}	1.3×10^{-06}	1.0×10^{-04}
Blakefield seam	4	-[3]	-[3]	1.0×10^{-02}
Blakefield - Glen Munro interburden (Sandstone/Siltstone)	20	-[3]	-[3]	1.0×10^{-04}
Glen Munro seam	5	-[3]	-[3]	6.5×10^{-02}
Glen Munro - Woodlands Hill interburden (Sandstone/Siltstone)	23	-[3]	-[3]	1.0×10^{-02}
Woodlands Hill Seam	4	-[3]	-[3]	1.2×10^{-02}
Woodlands Hill - Arrowfield interburden (Sandstone/Siltstone)	25	-[3]	-[3]	1.0×10^{-04}
Arrowfield	0	-[3]	-[3]	5.1×10^{-02}
Arrowfield - Bowfield interburden (Sandstone/Siltstone)	25	-[3]	-[3]	1.0×10^{-04}
Bowfield seam	6	-[3]	-[3]	5.0×10^{-02}
Bowfield - Warkworth interburden (Sandstone/Siltstone)	5	-[3]	-[3]	1.0×10^{-04}
Warkworth seam	2	-[3]	-[3]	1.0×10^{-02}
Warkworth - Mt Arthur interburden (Sandstone/Siltstone)	20	-[3]	-[3]	1.0×10^{-06}
Mt. Arthur seam	10	-[3]	-[3]	4.6×10^{-04}
Below Mt. Arthur seam	8	-[3]	-[3]	1.4×10^{-01}

1 Results of core testing undertaken for this study.

2 Source: Mackie (2009)

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

3.4.3 Indicative Hydraulic Properties

The hydraulic properties in **Table 3.2** are indicative hydraulic conductivities for the various stratigraphic units incorporated into the groundwater model. Although automated sensitivity was used in the steady-state calibration process, care was taken to ensure that the hydraulic properties reflect the measured and estimated ranges for each of the strata types, as discussed in Section 3.4.1. These values were refined subsequently by transient calibration.

Table 3.2: Indicative Hydraulic Properties of Stratigraphic Units

Layer		Zone	Kx (m/day)	Kz (m/day)
1	Alluvium	1	10	1
1	Colluvium / Regolith	17	0.1	1.0E-03
1	Open Cut Backfill Material	-	1	1
2	Triassic Sandstone, Whybrow Seam overburden	2	1.0E-03	1.0E-04
3	Whybrow Seam	3	2.5E-02	2.5E-04
4	Whybrow Seam – Wambo Seam interburden	4	1.0E-4	1.0E-05
5	Wambo Seam	5	2.5E-2	2.5E-04
6	Wambo Seam – Whynot Seam interburden	6	1.0E-4	1.0E-05
7	Whynot Seam	7	4.4E-2	4.4E-04
8	Whynot Seam – Woodlands Hill Seam interburden	8	1.0E-4	1.0E-05
9	Woodlands Hill Seam	9	1.2E-2	1.2E-04
10	Woodlands Hill Seam - Arrowfield Seam interburden	10	1.0E-4	1.0E-05
11	Arrowfield Seam	11	5.1E-2	5.1E-04
12	Arrowfield Seam – Bowfield Seam interburden	12	1.0E-4	1.0E-05
13	Bowfield Seam	13	5.0E-2	5.0E-04
14	Bowfield Seam - Warkworth Seam interburden	14	1.0E-4	1.0E-05
15	Warkworth Seam	15	1.0E-2	1.0E-04
16	Basal Layer	16	1.0E-05	1.0E-06

3.5 MODEL STRESSES AND BOUNDARY CONDITIONS

The model domain covers all of the potentially sensitive receptors. All significant creeks and rivers that could be affected by mining activities were fully contained within the model domain and have been represented in the model, as shown in **Figure 3.1**.

All permanent water bodies are represented as river cells using the MODFLOW RIV package, as shown in **Figure 3.3**. Of the water bodies within the model domain, the Hunter River and Wollombi Brook are considered to be the most important streams. The Hunter River and associated alluvium occupies the northern sector of the model domain. Wollombi Brook occupies a large portion of the eastern model domain. River stage is mostly constant with time with occasional increases during times of high flow.

Specific river cells within the model representing the Hunter River and Wollombi Brook are set up with stage levels 1m below the surrounding topography, and a conductance of 50 square metres per day (m^2/day).

Other creeks and minor drainage lines are also represented as “River” cells in the model with stage equal to bed level. This allows groundwater to discharge to the drainage lines as baseflow. Due to narrower creek width, the conductances were set at 25 m^2/day except for a lower value (0.025 m^2/day) for the North Wambo Creek diversion to account for the engineered low permeability clay lining within the diversion. In the steeper terrain the stage level was set at 1.5 m below topography (representing the incised gullies that are known to occur in areas such as Stony Creek), reducing to 0.5 m below topography in lowland areas.

The underground mining and dewatering activity is defined in the model using drain cells within the mined coal seams, with modelled drain elevations set to 0.1 m above the base of the Wambo Seam (Layer 5). These drain cells were applied wherever workings occur, and were progressed through annual increments in a transient model set-up. The set-up involved changing the parameters with time in the goaf and overlying fractured zones directly after mining of each longwall panel, whilst simultaneously activating drain cells along all development headings. The development headings were activated 12 months in advance of the active mining and subsequent subsidence. Although the coal seam void should be dominated by the drain mechanism, the horizontal and vertical permeabilities were raised to 10 m/day to simulate the highly disturbed nature of materials within the caved zone. A drain conductance value of 1000 m^2/day was applied during calibration.

3.5.1 Recharge, Evapotranspiration and Seepage

An overview of the recharge zones used within the model is provided in **Figure 3.4**. Rainfall infiltration has been imposed as a percentage of actual Bulga (South Wambo) rainfall (for transient calibration) or long-term average rainfall (for prediction simulations) across three zones:

- Alluvium [Zone 1]: 1.2 %
- Regolith [Zone 2]: 0.25 %
- Exposed mining and backfilled areas [Zone 3]: 5.0 %

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

The ET package was used in the Wambo model with an extinction depth of 3.0 m and a maximum 365 mm per annum ET rate. This was done to ensure that the model simulates the high potential ET that can occur in low lying areas where the water table is close to surface (river/creek margins).

The Wambo area has been partially backfilled in the model with waste overburden as open cut extraction progresses. Rehabilitated areas are simulated progressing from east to west with the height of the backfill generally at the pre-existing topography although some voids remain at the end of mining.

3.5.2 Neighbouring Mine Workings

Neighbouring mining areas are represented within the model domain by means of drain cells.

The approach of using drain cells to simulate progression for the Wambo open cut and underground mine plans was applied also for neighbouring mining areas occurring within the model domain, including Mt Thorley Warkworth, HVO and United Colliery. In all cases, drain cells were applied to appropriate coal seams being mined.

The mining related dewatering activities are defined in the model using drain cells within the mined coal seams, with drain elevations set to 0.5 m above the base of the mined layer. These drain cells were applied wherever workings occur, and were progressed through annual increments in a transient model set-up. Implementation is further discussed in Section 4.3. Neighbouring mine workings represented in the model include:

- Lemington Open Cut;
- Lemington Underground;
- Riverview;
- Cheshunt;
- United Open Cut(s);
- United Underground;
- Mt Thorley Warkworth; and
- Homestead and Wollemi Underground.

The development of neighbouring mines within the model was based on information publicly available in the relevant impact assessment documentation. **Table 3.3** provides a summary of neighbouring mine workings represented in the model, the starting date of the various mining operations and ancillary information relating to the model build.

Table 3.3: Summary of Mine Workings in the Model Domain

Mine Area	Type	Mine Name	Coal Seam	Model Layer	Start	End
Wambo	Open Cut	Bates Open Cut	Whybrow	3	1980	1987
		Ridge Open Cut	Whybrow	3	1986	1988
		Eastern Open Cut	Whybrow	3	1974	1982
		Western Open Cut	Whybrow	3	1974	1983
		Bates North Open Cut	Whybrow	3	1997	1997
		Whynot Open Cut	Whynot	7	1991	1998
		North East Open Cut	Wambo	5	1988	1998
		United Open Cut	Whynot	7	1989	1992
		Hunter Pit (current Tailing Dam)	Whynot	7	1969	2016
		Wombat Pit	Whynot	7	1969	2016
		Homestead Pit	Whynot	7	1969	2016
		Bates Pit	Whynot	7	1969	2016
		Bates South Pit	Whynot	7	1969	2016
	Underground	Ridge Underground	Whybrow	3	1976	1983
		Homestead and Wollemi Underground	Whybrow	3	1979	2002
		Bates/Whybrow Underground	Whybrow	3	-[1]	-[1]
		Wambo No.1 Underground	Wambo	5	1969	1977
		North Wambo Underground	Wambo	5	2007	2015
		Arrowfield Seam Underground	Arrowfield	9	-[1]	-[1]
		Bowfield Seam Underground	Bowfield	11	-[1]	-[1]
Mt Thorley Warkworth	Open Cut	North Pit	Warkworth	13	1981	2031
		West Pit	Mt Arthur	15	1981	2031
		Woodlands Pit	Mt Arthur	15	1981	2031
		South Pit	Mt Arthur	15	1981	2031
		CD Pit	Mt Arthur	15	1981	2031
		Loders Pit	Mt Arthur	15	1981	2017
		Abbey Green	Mt Arthur	15	1981	2017

Table 3.3 (Continued): Summary of Mine Workings in the Model Domain

Mine Area	Type	Mine Name	Coal Seam	Model Layer	Start	End
HVO	Open Cut	North Lemington Open Cut	Bowfield	11	1971	Unknown
		South Lemington Pit 1 Open Cut	Bowfield	11	1998	2024
		South Lemington Pit 2 Open Cut	Bowfield	11	2010	2019
		Lemington Underground Mine No.1 &2	Mt Arthur	15	1971	1991
		RiverView Pit Open Cut	Warkworth	13	1991	2019
		Chestnut Pit Open Cut	Mt Arthur	15	2001	2028
United Colliery	Open Cut	United Open Cut	Whynot	7	1989	1992
	Underground	Underground Operations	Arrowfield	11	1992	2010

[1] Assumed mining does not occur during the calibration or prediction period and therefore start and end dates have not been specified.

3.5.3 Open Cut Areas

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

Completed open cut mining areas are backfilled with waste overburden as the extraction proceeds. Backfill was given uniform permeability of 1 m/day, specific yield 0.2 and rainfall recharge 5%. Properties were varied with time using the TMP package of SURFACT 4.

3.5.4 Underground Mining Areas

Underground mining and dewatering activity is represented in the model using drain cells within the mined coal seams, with modelled drain elevations set to 0.1 m above the floors of the relevant coal seams.

These drain cells were applied wherever workings occur, and were progressed in accordance with the North Wambo Underground Mine plan shown in **Figure 1.3** and the scheduled mine development in **Table 3.4**. The hydraulic conductivity of the mine voids and goaf materials left within the coal seams was increased to a high value (10 m/day).

In order to simulate the active de-watering that will occur in mines which are represented within the model, all drain cells remain active in the model until cessation of mining activities or active dewatering in each mine.

3.6 FRACTURED ZONE IMPLEMENTATION

3.6.1 Background

The impact of mining on the permeability of caved overburden has been based on experience of monitoring and groundwater modelling gained to date, combined with the most recent research available for subsidence impacts on aquifer materials.

It is generally accepted that there will be a sequence of deformational zones (**Figure 3.5**) usually described as:

- the caved zone;
- the fractured zone, consisting of
  - a lower zone of connective-cracking; and
  - an upper zone of disconnected-cracking;
- the constrained zone; and
- the surface zone.

Table 3.4: Stress Period Definition and Modelled Mine Evolution

Model Purpose	Model Type	Stress Period	Start Date	End Date	Period Length	North Wambo Longwalls UG Approved Layer 5	North Wambo Longwalls UG Modification Layer 5	United Longwalls UG Layer 11	United Bord and Pillar UG Layer 11	Wombat OC Pit Layers 1-7	Homestead OC Pit Layers 1-7	Warkworth North OC Pit Layers 1-15	Warkworth West OC Pit Layers 1-16	Riverview OC Pit Layers 1-16	Cheshunt OC Pit Layers 1-16	South Lemington OC Pit Layers 1-13
						Timing of Operation										
CALIBRATION	Transient	1	1/01/2003	31/12/2003	Yearly			LW1, LW2								
	Transient	2	1/01/2004	31/12/2004	Yearly			LW3								
	Transient	3	1/01/2005	31/12/2005	Yearly			LW4								
	Transient	4	1/01/2006	31/12/2006	Yearly			LW5								
	Transient	5	1/01/2007	31/03/2007	Quarterly			LW6								
	Transient	6	1/04/2007	30/06/2007	Quarterly			LW6								
	Transient	7	1/07/2007	30/09/2007	Quarterly			LW6								
	Transient	8	1/09/2007	31/12/2007	Quarterly	LW1	LW1	LW6, LW7								
	Transient	9	1/01/2008	31/03/2008	Quarterly	LW1	LW1	LW7								
	Transient	10	1/04/2008	30/06/2008	Quarterly	LW1	LW1	LW7								
	Transient	11	1/07/2008	30/09/2008	Quarterly	LW1	LW1	LW7								
	Transient	12	1/09/2008	31/12/2008	Quarterly	LW1	LW1	LW7, LW8	Bord and Piller UG	Open Cut and Backfilled	Open Cut and Backfilled	Open Cut	Open Cut	Open Cut	Open Cut	
	Transient	13	1/01/2009	31/01/2009	Monthly	LW1	LW1	LW8								
	Transient	14	1/02/2009	28/02/2009	Monthly	LW1	LW1	LW8								
	Transient	15	1/03/2009	31/03/2009	Monthly	LW1	LW1	LW8								
	Transient	16	1/04/2009	30/04/2009	Monthly	LW1	LW1	LW8								
	Transient	17	1/05/2009	31/05/2009	Monthly	LW2	LW2	LW8								
	Transient	18	1/06/2009	30/06/2009	Monthly	LW2	LW2	LW8								
	Transient	19	1/07/2009	31/07/2009	Monthly	LW2	LW2	LW8								
	Transient	20	1/08/2009	31/08/2009	Monthly	LW2	LW2	LW8								
	Transient	21	1/09/2009	30/09/2009	Monthly	LW2	LW2	LW10								
	Transient	22	1/10/2009	31/10/2009	Monthly	LW2	LW2	LW10								
	Transient	23	1/11/2009	30/11/2009	Monthly	LW2	LW2	LW10								
	Transient	24	1/12/2009	31/12/2009	Monthly	LW2	LW2	LW10								
PREDICTION	Transient	25	31/12/2009	30/04/2010	120 days	LW2	LW2	LW10								
	Transient	26	30/04/2010	31/12/2010	245 days	LW3	LW3	LW11								
	Transient	27	31/12/2010	16/11/2011	320 days	LW4	LW4	LW11								
	Transient	28	16/11/2011	1/09/2012	290 days	LW5	LW5	All Longwalls Active								
	Transient	29	1/09/2012	14/05/2013	255 days	LW6	LW6	All Longwalls Active								
	Transient	30	14/05/2013	24/01/2014	255 days	LW7	LW7	All Longwalls Active	Bord and Piller UG	Open Cut and Backfilled	Backfilled	Open Cut	Open Cut	Open Cut	Open Cut	Open Cut
	Transient	31	24/01/2014	18/06/2014	145 days	LW8A	LW8A	All Longwalls Active								
	Transient	32	18/06/2014	10/11/2014	145 days		LW9	All Longwalls Active								
	Transient	33	10/11/2014	4/04/2015	145 days		LW10	All Longwalls Active								
	Transient	34	4/04/2015	13/07/2015	100 days	LW8B	LW8B	All Longwalls Active								
	Transient	35	13/07/2015	12/07/2016	365 days	All Longwalls Active	All Longwalls Active	All Longwalls Active								
RECOVERY	Transient	1	13/07/2016	13/07/2216	200 Years	Inactive	Inactive	Inactive	Inactive	Open Cut and Backfilled	Backfilled	Open Cut	Open Cut	Open Cut	Open Cut	Open Cut

The rocks in the connective-cracking part of the fractured zone will have a substantially higher vertical permeability than the undisturbed host rocks. This will encourage groundwater to move out of rock storage downwards towards the goaf. In the upper part of the fractured zone, where disconnected-cracking occurs, the vertical movement of groundwater should not be significantly greater than under natural conditions.

Depending on the width of the longwall panels and the depth of mining, and the presence of low permeability lithologies, there will be a constrained zone in the overburden that acts as a bridge. Rock layers are likely to sag without breaking, and bedding planes are likely to open. As a result, some increase in horizontal permeability can be expected.

In the surface zone, near-surface fracturing can occur due to horizontal tension at the edges of a subsidence trough. Fracturing will be shallow (<20 m), often transitory, and any loss of water into the cracks will not continue downwards towards the goaf.

The strata movements and deformation that accompany subsidence will alter the hydraulic and storage characteristics of aquifers and aquitards. As there will be an overall increase in rock permeability, groundwater levels will be reduced either due to actual drainage of water into the goaf or by a flattening of the hydraulic gradient without drainage of water (in accordance with Darcy's Law).

At the base of the fractured zone, groundwater pressures will reduce towards atmospheric pressure.

3.6.2 Model Simulation

The layer definition within the model has allowed most mined coal seams to be represented individually. A single layer of overburden separates each coal seam in the model. As the target coal seam is model layer 5, there is flexibility in the model to simulate the fractured zone to various heights. This ensures that the impact of progressive caving and fracturing associated with the mining is adequately represented.

As the proposed North Wambo Underground Mine longwall panels are 260 m wide, the fracture zone height was assumed to be about 170 m (0.67 x width) but could range from 100 m (factor 0.4) to 200 m (factor 0.8). As the depth of cover for the Wambo Seam across the North Wambo Underground Mine varies from 50 m to 350 m (**Figure 3.6**), fracturing is expected to reach ground surface over the eastern 60% of the mine footprint. For previous mining, nearly all of the Homestead-Wollemi mining area is likely to have fractured to the ground surface. For the United Underground Mine longwalls, the eastern 30% of the mining footprint zone is likely to have fractured to the surface (**Figure 3.6**).

The fractured zone was simulated with horizontal hydraulic conductivity enhanced by a factor of two, and with vertical hydraulic conductivity enhanced according to a log-linear monotonic (ramp) function. The function varied the vertical hydraulic conductivity field within the deformation zone overlying coal extraction areas and weighted the permeability changes on layer thickness. Limits for the variability were governed by predicted fracture height and assigned upper and lower bounds on hydraulic conductivity. Assigned fractured zone properties are presented in Section 3.9.2.

Separate ramp functions were found necessary in areas of variable cover depth and this was a key variable in the calibration process. Because cover depth varies over the various underground mining areas, differing fracture elevations were applied.

The permeability of the model layer directly beneath underground mined areas was also increased with a uniform increase in vertical hydraulic conductivity of 3 x host values being applied.

Storage properties (Sy) were also increased in the coal seam layer to 15% for the longwalls and 25% for Bord and Pillar. For the two layers above the coal seam Sy was increased to 4% in areas overlying the longwall panels. For the Bord and Pillar, Sy was increased to 4% only in one layer above the coal seam where active mining has occurred.

For fractured zones during the calibration period, the properties were changed using hydrostratigraphic unit (HSU) zonation and the TMP package of SURFACT 4 which allows varying property values with time. Fracturing was instigated by altering host properties in accordance with mine progression using a ratio multiplier within the HSU zoning feature.

3.7 MODEL VARIANTS

Both steady-state and transient models have been developed for use in the groundwater assessment as summarised below:

- steady-state model of pre-mining conditions: Calibration against the inferred pre-mining groundwater levels and used to formulate transient model starting heads;
- transient model of the transition from pre-mining to early mining: Calibration against the groundwater hydrographs in **Attachment C**;
- transient predictive model extending to the end of mining; and
- transient recovery simulation to equilibrium conditions.

3.8 STEADY-STATE CALIBRATION

Steady-state (or baseline ‘long term’) calibration was carried out as the first stage of the calibration process. The primary purposes of initial steady-state calibration are to check assumptions on the conceptual hydrogeological processes and to generate initial head distributions for all model layers for subsequent transient simulation.

The steady-state model has been calibrated to groundwater levels approximating conditions in early 2003, as these are likely to be close to long term average groundwater levels. However, the pre-mining water levels in all bores have, to some extent, been influenced by the surrounding mining operations. Estimated pre-mining water levels were included in the calibration data set for a number of bores installed after 2003.

Calibration was carried out against 48 target water levels, using a combination of auto-sensitivity analysis and manual modification of zones and model parameters. Steady-state calibration performance was good at 8.3% Scaled Root Mean Square (SRMS), which is below the target 10% SRMS suggested in the MDBC flow model guideline (MDBC, 2001). The 2012 Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012) warn against prescriptive performance targets but note that "*Targets such as SRMS < 5% or SRMS < 10% ... may provide useful guides*".

Distribution of calibration targets through the model layers is limited as monitoring bores are predominantly screened within the alluvium / colluvium associated with the main drainage pathways. Calibration targets assigned to the Permian coal measures surrounding Wambo consist of a range of depths and coal seams including the Arrowfield Seam (near subcrop) to the east of the United open cut and the Wambo Seam at Wambo (GW20).

3.9 TRANSIENT CALIBRATION

3.9.1 Piezometric Levels

Transient calibration against groundwater levels was carried out for the period January 2003 to December 2009 which includes the period when North Wambo Underground Mine Longwalls 1 and 2 were mined. Available data from early 2010 to present was then used to validate the stress response of Longwalls 3 and 4 extraction.

The calibration period included the development of numerous underground and open cuts including Mt Thorley Warkworth, HVO and United Colliery open cut and underground operations (**Table 3.4**). Simulation of neighbouring mines was undertaken in a transient fashion utilising drain cells with start and end dates indicated in **Table 3.3**.

Stress period lengths are listed in **Table 3.4**. A stress period is the time duration in a model when all hydrological stresses (e.g. recharge, mine dewatering) remain constant. For the first four years annual stress periods were used. After that, the stress periods were quarterly until the end of 2008 and then monthly during 2009. This allowed the mine plan progression including heading development and panel extraction to be simulated in detail. The shorter time stress periods in 2009 allowed calibration against pronounced depressurisation within the Wambo Seam during mine progression. The TMP package allowed hydraulic properties to change through time to represent coal extraction and changes in overburden to reflect enhanced permeability associated with subsidence related fracturing during mining of Longwalls 1 and 2.

Transient groundwater levels were taken from all records at each borehole where data were available. The calibration target sites, including the layers monitored, is included in **Attachment C** along with a graphical comparison of actual versus modelled groundwater heads.

Mine inflow rates have not been utilised for the purposes of calibration.

3.9.2 Results

Table 3.5 summarises the final calibrated hydraulic conductivities for the stratigraphic section, and for the constrained and fractured zones. The host values are consistent with field measurements.

3.9.3 Calibration Performance

Calibration was carried out at 66 groundwater monitoring locations against 1398 individual target points, using a combination of auto-sensitivity analysis and manual modification of zones and model parameters.

The scatter diagram of measured versus modelled groundwater level targets is plotted in **Figure 3.7**. It can be seen that the model is reasonably well balanced against the measured targets (i.e. there is no systematic under- or over-prediction). The monitored piezometers show reasonable agreement between observed and computed water levels across both shallow and deep model layers. Vibrating wire piezometers P34 (144m) and P35 (112m) have large residuals where the model has over-predicted the heads. These bores show a sharp measured response to underground mining activities but the absolute groundwater levels are difficult to reproduce. Although the drawdown response trends are simulated well, the correlation between observed and modelled heads is not absolute. This is probably more the result of the relative levels where these instruments have been installed and the associated layering definition within the model not allowing identical responses to occur rather than systemic calibration errors.

The overall performance of the transient calibration is quantified by a number of statistics in **Table 3.6**. The key statistic is 6.6% SRMS, which is below the target 10% SRMS suggested in the MDBC flow model guidelines (MDBC, 2001). The 2012 Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012) regard SRMS as a useful descriptor of goodness of fit when the only objective is to fit historical measurements of heads, but is less useful when automated calibration methods are used. As a key component of the calibration process has been to match historical transient head data, the SRMS is still seen as a useful tool in measuring calibration performance.

Mass balances were generally good, at less than 1% imbalance for the steady state run, and less than 0.1% for the transient calibration periods.

The model was generally stable and relatively insensitive to most model parameters. Some of the parameters did have a large potential influence, but the values selected were realistic and represented the best fit for the model calibration.

3.9.4 Verification Performance

Model verification was carried out using available data from early 2010 to present, which included 46 groundwater monitoring locations and 115 individual target points. The performance of the model verification is quantified by a number of statistics in **Table 3.6**. The key performance statistic is 6% SRMS which is better than the performance achieved during the calibration period (**Table 3.6**). This enhances the credibility of the model when used for prediction.

3.9.5 Water Balance

There are multiple opportunities for groundwater to discharge from and recharge to the groundwater system. Those implemented in the model include:

- baseflow to streams (represented by the river cells in MODFLOW);
- outflow / inflow to the western margin boundary (represented by general heads in MODFLOW); and
- mine inflows to active mining areas including North Wambo Underground Mine.

In addition to the water balance components described above, WCPL undertakes dewatering of existing workings in the Whybrow Seam in advance of active mining as a safety measure. This dewatering has not been included in the model due to its variability in space and time and rate. By not including dewatering of the Whybrow Seam, the model will report conservative groundwater inflow rates for purposes of water management and will report maximum drawdowns due to mining of the Wambo Seam for environmental impact assessment.

The average water balance for the transient calibration period across the entire model area is summarised in **Table 3.7**. The total inflow (recharge) to the aquifer system is approximately 23 megalitres per day (ML/day), comprising rainfall recharge (10%), inflow from the general head boundary on the western margins (38%), and leakage from streams into the aquifer (52%).

It is assumed that any water carried by ephemeral streams would have a negligible contribution to groundwater recharge through leakage.

Groundwater discharge is dominated by stream baseflow (approximately 70%), with lesser roles played by mine inflow (15%) and ET (14%). A net loss of about 1.3 ML/day from storage is expected to have occurred.

Table 3.5: Calibrated Hydraulic Conductivities [m/day]

Layer	Lithology	Zone	Host Kx	Host Kz	North Wambo Underground Fracture Zone Kz	United Underground Western Fracture Zone Kz	United Underground Eastern Fracture Zone Kz	Homestead Fracture Zone Kz
1	Alluvium	1	10	1	5 x Kz host	NA	5 x Kz host	5 x Kz host
1	Colluvium/Regolith	17	5.0E-1	1.0E-2	5 x Kz host	NA	5 x Kz host	5 x Kz host
2	Triassic Sandstone, Whybrow Seam overburden	2	1.0E-3	1.0E-5	2.5E-5	NA	2.1E-5	1.0E-4
3	Whybrow Seam	3	2.5E-3	5.0E-5	5.5E-5	NA	4.3E-5	10
4	Whybrow Seam – Wambo Seam interburden	4	1.0E-4	5.0E-6	7.5E-5	1.5E-5	5.0E-5	3 x Kz host
5	Wambo Seam	5	2.5E-3	1.5E-5	10	2.2E-5	5.8E-5	NA
6	Wambo Seam – Whynot Seam interburden	6	1.0E-4	3.0E-6	3 x Kz host	2.4E-5	5.9E-5	NA
7	Whynot Seam	7	4.4E-3	1.4E-5	NA	2.6E-5	6.1E-5	NA
8	Whynot Seam – Woodlands Hill Seam interburden	8	1.0E-4	1.5E-6	NA	5.0E-5	7.8E-5	NA
9	Woodlands Hill Seam	9	1.2E-3	1.3E-5	NA	8.0E-5	8.0E-5	NA
10	Woodlands Hill Seam - Arrowfield Seam interburden	10	1.0E-4	1.1E-6	NA	8.0E-5	8.0E-5	NA
11	Arrowfield Seam	11	5.1E-3	1.1E-5	NA	10	10	NA
12	Arrowfield Seam – Bowfield Seam interburden	12	1.0E-4	1.0E-6	NA	3 x Kz host	3 x Kz host	NA
13	Bowfield Seam	13	5.0E-3	1.0E-5	NA	NA	NA	NA
14	Bowfield Seam - Warkworth Seam interburden	14	1.0E-4	1.0E-6	NA	NA	NA	NA
15	Warkworth Seam	15	1.0E-3	9.7E-6	NA	NA	NA	NA
16	Basal Layer	16	1.0E-4	6.2E-7	NA	NA	NA	NA

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

Table 3.6: Calibration and Verification Statistics

Performance Statistic	Calibration	Verification
Number of Observation Bores	66	46
Number of Data Points	1398	115
Root Mean Square m	9.9	8.8
Scaled Root Mean Square (SRMS) (%)	6.6	6.0

Table 3.7: Average Simulated Water Balance during the Calibration Period

Component	Inflow (ML/day)	Outflow (ML/day)
Drains (Mine Inflow)	-	3.7
Recharge (Direct Rainfall)	2.4	-
ET (Evapotranspiration)	-	3.5
River (Leakage/Baseflow)	12.1	17.4
Head Dependent Boundary (GHB)	8.8	0.1
Total	23.4	24.7
Storage	1.3 Loss	

4 PREDICTIVE MODELLING

4.1 MODIFIED MINE SCHEDULE

A summary of the schedule that has been used for the North Wambo Underground Mine in the groundwater model is provided in **Table 3.4**. This table outlines stress period setup for the transient calibration, prediction and recovery model runs. The prediction period runs from stress period 25 (January 2010) to stress period 35 (July 2015). The lengths of the stress periods were set to match the scheduled longwall extraction.

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 North Wambo Underground Mine.

Although the mining of the underground seams at Wambo has a substantial transient impact on the local hydrogeological regime, this has to be set within the context of the other mining activities that are being carried out simultaneously in the area, and the effects of past mining. Similarly, the effects of the Modification should be considered in the context of the effects generated by the approved North Wambo Underground Mine. 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 North Wambo Underground Mine and the Modification.

Two suites of prediction modelling have been run – one with the approved layout and one with the modified layout (**Table 3.4**). This allows the net impact of the Modification on the hydrogeological environment to be evaluated separately from the other regional impacts. Neighbouring mining operations within the model domain were simulated identically in both cases, as indicated in **Table 3.4**.

4.3 MODEL IMPLEMENTATION

The underground mining and dewatering activity is defined in the model using drain cells within the mined coal seams, with drain elevations set to 0.1 m above the base of the coal seam. These drain cells were applied wherever workings occur, and were progressed through time increments coincident with the stress period durations.

The model setup involved changing the parameters with time in the goaf and overlying fractured zones directly after mining of each panel, whilst simultaneously activating drain cells along development headings. The development headings were activated in advance of the active mining and subsequent subsidence.

In general, the duration of the mining and the high degree of caving associated with longwall extraction means that most of the strata within the North Wambo Underground Mine, United Underground Mine, and open cut mining areas become dewatered during operations. This creates a deep cone of depression in the Permian. The low permeability of the *in situ* rock mass means that a steep hydraulic gradient would develop near the edges of the mine footprint and the effects would diminish rapidly away from the areas of mining.

4.4 WATER BALANCE

The average water balance for the prediction model across the entire model area is summarised in **Table 4.1** for scenarios with and without the Modification.

The results for the two scenarios are almost identical, the only differences being a 4% increase in mine inflow for the Modification (4.40 to 4.58 ML/day) and a 6% increase in the net loss from storage (2.95 to 3.13 ML/day).

For both scenarios, the total inflow (recharge) to the aquifer system is approximately 21 ML/day, comprising rainfall recharge (12%), inflow from the general head boundary on the western margins (43%), and leakage from streams into the aquifer (45%). Groundwater discharge is dominated by stream baseflow (67%), with lesser roles played by mine inflow (19%) and ET (14%).

Table 4.1: Average Simulated Water Balance during the Prediction Period with and without the Modification

COMPONENT	APPROVED MINING		MODIFICATION	
	Inflow (ML/day)	**Outflow (ML/day)**	**Inflow (ML/day)**	**Outflow (ML/day)**
Drains (Mine Inflow)	-	4.4	-	4.5
Recharge (Direct Rainfall)	2.5	-	2.5	-
ET	-	3.4	-	3.4
River (Leakage/Baseflow)	9.3	15.6	9.3	15.6
Head Dependent Boundary (GHB)	8.7	0.1	8.7	0.1
Total	20.5	23.5	20.5	23.6
Storage	3.0 Loss		3.1 Loss	

4.5 PREDICTED WATER LEVELS

Model predicted groundwater levels at the end of mining operations for scenarios with and without the Modification are shown in **Figures 4.1** to **4.4**. These figures show groundwater levels in the Whybrow and Wambo Seams where they exist, and in model layers 3 and 5 (respectively) to the east of seam subcrops. Contours for the Wambo and Whybrow Seam have been presented due to their relevance to Wambo (e.g. these seams were historically mined and are currently mined at Wambo).

Figures 4.1 and **4.2** show water levels in the Whybrow Seam (Layer 3) at the end of mining (2015), for the Approved Layout and theModification**. Figures 4.3** and **4.4** show water levels in the Wambo Seam (Layer 5) at the end of mining for the approved mine plan and proposed modified mine plan.

For a particular coal seam, there is little perceptible difference between the water level contours with and without the Modification, except in the vicinity of the two additional longwall panels. Better resolution is afforded by differential water levels discussed in Section 5.4.

4.6 PREDICTED BASEFLOW CHANGES

Predicted changes in baseflow and natural river leakage have been assessed for Wollombi Brook, North Wambo Creek, Wambo Creek and Stony Creek from the commencement of the prediction period in January 2010 (midway through Longwall 2). The predicted changes are shown in **Figures 4.5** to **4.8** where comparison is made with and without the inclusion of the Modification.

The model results show that the Modification has no discernible impact on stream baseflow or natural river leakage for all simulated stream systems, beyond the effects of approved mining.

Both Wollombi Brook (**Figure 4.5**) and Stony Creek (**Figure 4.8**) behave as losing streams on average. The model results show that the approved North Wambo Underground Mine will cause a slight increase in leakage from each stream in the order of 0.3 ML/day and 0.03 ML/day, respectively, and that this would not change as a result of the Modification. Therefore the Modification would cause no additional increase in leakage from Wollombi Brook or Stony Creek.

North Wambo Creek (**Figure 4.6**) and Wambo Creek (**Figure 4.7**) behave as gaining streams on average. The model results show that the approved North Wambo Underground Mine will cause a fluctuation in baseflow of about 0.01 ML/day at North Wambo Creek, and a slight reduction in baseflow to Wambo Creek in the order of 0.05 ML/day, and that this would not change as a result of the Modification. Therefore the Modification would cause no additional reduction in baseflow to North Wambo or Wambo Creek.

4.7 PREDICTED INFLOW

Throughout the calibration and predictive periods, the fracture zones invoked in the model above the underground mine were progressed in accordance with the approved and modified mine plans.

Model predicted inflows are shown in **Figure 4.9** for the North Wambo Underground Mine, with and without the Modification. The inflow rates are predicted to increase fairly linearly from 0 ML/day at the start of underground mining activities to about 1.5 ML/day by the end of Longwall 8A (mid-2014) for the approved mine plan. The final mine inflow rate for the approved mine plan is about 0.96 ML/day. The peak inflow for the modified mine plan was found to be approximately 1.7 ML/day in mid-2015 prior to tailing off to about 1.1 ML/day one year after cessation of Longwall 8B in mid-2016. Therefore the final inflow rate is about 0.14 ML/day higher for the Modification than for the Approved layout. Additionally the peak mine inflow rate is about 0.2 ML/day higher for the Modification than for the Approved layout.

5 POTENTIAL IMPACTS

5.1 POTENTIAL IMPACTS ON GROUNDWATER

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

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

5.2 GROUNDWATER LEVELS AND FLOWS PRIOR TO MINE DEVELOPMENT

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

- the general flow within the Permian is to the east and north-east, flowing from elevated areas on the western side of the model domain, through to the deeper Permian associated with the Wittingham coal measures to the east;
- due to the general lack of vertical hydraulic connectivity, measured potentiometric head in the Permian is higher than the alluvium groundwater levels, and is above ground level in some low-lying areas; and
- North Wambo and Wambo Creeks, Wollombi Brook and the Hunter River would have been generally gaining water courses in the pre-mining hydrogeological environment (i.e. groundwater discharges as baseflow into the creeks and river). Some reductions in baseflow from these surface water features are likely due to the change in hydrogeological regime in the complex mining environment. Therefore, groundwater flow paths in the vicinity of these drainage pathways are likely to be complex.

5.3 PREDICTED IMPACTS ON GROUNDWATER LEVELS

The approved North Wambo Underground Mine will cause depressurisation of the Permian strata. The Permian coal measures within the mine footprint are predicted to be essentially dewatered during mining of the target Wambo coal seam. Outside the mine footprint, the main impact from the approved North Wambo Underground Mine on potentiometric pressures within Permian strata would occur to the south and south-west of the mine. Impacts to the north, east and north-east would be minimal due to the influence of neighbouring mines to the east and the fact that the areas to the north and north-east are up-dip of the Wambo mine and near to subcrop location.

The impact on water levels due to the Modification is negligible regionally as shown in Section 4. Groundwater levels in the Whybrow Seam and the Wambo Seam following completion of mining activities at the North Wambo Underground Mine for the approved mine plan are shown in **Figures 4.1** and **4.3** respectively. Groundwater levels in the Whybrow Seam and the Wambo Seam following completion of mining activities at the North Wambo Underground Mine for the modified mine plan are shown in **Figures 4.2** and **4.4** respectively.

The cumulative impacts of the approved North Wambo Underground Mine, approved Wambo open cut mining, and neighbouring mines active during 2003-2016, are presented as drawdowns in **Figure 5.1** to **Figure 5.4** for the Alluvium / Regolith (Layer 1), Whybrow Seam overburden (Layer 2), Whybrow Seam (Layer 3) and Wambo Seam (Layer 5).

Shallow drawdowns (in alluvium and regolith), due to the cumulative impacts of approved mines, are expected to be generally 1-5 m above the North Wambo Underground Mine, more than 20 m at the Wambo open cut, and about 10 m above the United Underground Mine.

Local impacts due to the Modification are best presented by comparing relative drawdowns from model scenarios with and without the Modification (i.e. the incremental changes resulting from the Modification). The incremental change resulting from the Modification at the end of mining operations at the North Wambo Underground Mine are shown in **Figure 5.5** to **Figure 5.8**. These figures respectively show the differential impacts of the Modification for the Alluvium / Regolith (Layer 1), Whybrow Seam overburden (Layer 2), Whybrow Seam (Layer 3) and Wambo Seam (Layer 5).

The regolith in Layer 1 is generally unsaturated (dry) at the start of mining, with groundwater only occurring in the alluvium (and adjacent colluvium on slopes adjacent to valley alluvium). Model results show that the impacts of the Modification on the North Wambo Creek alluvium are limited to the area where alluvium is present overlying Longwall 9 and Longwall 10. The predictive modelling indicates a maximum additional localised drawdown of 1.5 m in the regolith above Longwall 9 and drawdown of less than 0.5 m in alluvium. The additional drawdown extent resulting from the Modification (based on the 0.1 m contour) would be confined to the mine footprint (**Figure 5.5**).

Within the Whybrow Seam overburden, additional drawdown due to the Modification is expected to reach about 3 m over Longwall 9 and Longwall 10. Additional drawdown due to the Modification of up to 0.1 m would extend outside the mine footprint up-gradient along Wambo Creek, Stony Creek and North Wambo Creek for a distance of no more than approximately 2 km from the North Wambo Underground Mine footprint (**Figure 5.6**).

Within the Whybrow Seam the Modification would result in a maximum additional drawdown for the proposed modification of about 12 m limited to the area overlying Longwall 9 and Longwall 10. Additional drawdown resulting from the Modification of up to 0.1 m would extend outside the mine footprint up-gradient along Wambo Creek, Stony Creek and North Wambo Creek for a distance of no more than approximately 1.5 km from the North Wambo Underground Mine footprint (**Figure 5.7**).

Within the Wambo Seam, additional drawdown due to the Modification would generally be limited to the footprint of Longwall 9 and Longwall 10. This reflects the steep drawdown cone that exists due to low inherent hydraulic conductivities within the Permian coal measures. The Modification would result in a maximum incremental drawdown of about 200 m at the southern end of Longwall 10. The drawdown in the northern area of Longwall 9 and Longwall 10 is predicted to be about 100 m. The additional drawdown (based on the 0.1 m contour) would extend outside the mine footprint for a distance of no more than approximately 700 m from the mine footprint (**Figure 5.8**). Comparatively, predictions within the Wambo Seam for the approved North Wambo Underground Mine include a maximum predicted drawdown of about 300 m above Longwall 1 and an extent of drawdown more than 1,000 m from the mine footprint (**Figure 5.4**).

5.4 PREDICTED GROUNDWATER INFLOWS

The Modification would add about 0.2 ML/day to peak inflow rates predicted for the currently approved mine plan, resulting in a peak inflow rate of approximately 1.7 ML/day at the completion of the North Wambo Underground Mine.

5.5 GROUNDWATER LICENSING

For the alluvial extent in **Figure 5.1**, the model outputs have been interrogated to derive an estimate of the natural flux between the alluvium and the underlying rock, and comparative values during mining for both the approved and the modified mining plans. The results are displayed in **Figure 5.9**.

Prior to mining, there was a natural downwards flow of groundwater of about 0.025 ML/day on average. Upon the commencement of mining (year 5 on **Figure 5.9**), vertical flux increased by about 0.010 ML/day until Longwall 1 passed beneath the alluvium of North Wambo Creek (around 6 years on **Figure 5.9**), at which time the flux fluctuated between positive and negative values. When Longwall 2 commenced (6.4 years on **Figure 5.9**), the change in flux settled down to a stable value that gradually reduced to near-zero towards the end of mining.

The cumulative loss of water from the alluvium is best illustrated by the cumulative loss diagram in **Figure 5.9 [b]**. Apart from the spikes associated with Longwall 1, there is a clear pattern of loss with time, with the rate of loss reducing each year. When the cumulative loss is averaged over the period of mining, the net loss of groundwater from the alluvium is about 3.4 ML/annum. The additional loss due to the Modification is about 0.08 ML/annum.

The predicted annual groundwater volumes required to be licensed over the life of the Project for the approved and modified cases are summarised in **Table 5.1**.

Table 5.1: Project Groundwater Licensing Summary

Water Sharing Plan	Management Zone/ Groundwater Source	Predicted Annual Inflow Volumes requiring Licensing (ML/annum)	
		Approved Project	Modification
Hunter Unregulated and Alluvial Water Sources Water Sharing Plan 2009	Lower Wollombi Brook	Av. 3.36	Av. 3.45
Water Act 1912	Porous Rock	Av. 223 Max. 548	Av. 241 Max. 617

Table 2.4 shows that WCPL currently has licence entitlements of 70 ML/annum for the Lower Wollombi Brook Water Source and 1,816 ML/annum for water derived from porous rock. The amounts are sufficient to cover the predicted impacts for the approved mine plan and the Modification.

5.6 POTENTIAL IMPACTS ON REGISTERED PRODUCTION BORES

Figure 5.10 shows the proximity of registered private bores and mine bores, in the vicinity of the North Wambo Underground Mine, to predicted incremental drawdown in alluvium and regolith (model layer 1). All bores lie outside the 0.1 m contour.

Figure 5.11 shows the registered bores in relation to predicted incremental drawdown in model layer 2 (Triassic Sandstone and Permian overburden). Only bores outside the alluvial boundary would potentially extract water from these formations. All bores outside the alluvial boundary have an incremental drawdown of less than 1 m.

The closest privately-owned bores are located on a privately-owned property which is approximately 270 m from the footprint of Longwalls 9 and 10. All registered bores on this property are predicted to observe incremental drawdowns due to the Modification of less than 1 m.

5.7 RECOVERY OF GROUNDWATER LEVELS

A recovery simulation has been run in transient mode for 200 years after completion of mining activities at the North Wambo Underground Mine. For the recovery simulation all underground mine drains were deactivated and all open cut mines were replaced by spoil properties.

Representative hydrographs for the recovery period are displayed in **Figure 5.12** for various distances from the modified mine plan:

a) Bore P114 approximately 150 m east of Longwall 10 in Layer 1 (in alluvium);
b) Bore P202 approximately 650 m east of Longwall 10 in Layer 2 (in overburden);
c) Bore P301 approximately 800 m west of Longwall 9 at the south-west end of LW6 in Layer 2 (in overburden); and
d) Bore P311 approximately 2.3 km west of Longwall 9 at the south-west end of Longwall 1 in Layer 2 (in overburden)

The response at the alluvium bore P114 shows only a mild increase in water level with time. It appears that a new equilibrium level will be attained that is lower than the pre-mining natural levels.

The overburden bore P202 also shows only mild recovery with stabilisation at levels lower than occurred pre-mining.

Bores P301 and P311 are more directly affected by the North Wambo Underground Mine as they are positioned at the south-western ends of the mined longwalls. Recovery from low levels is apparent. The timeframe for recovery is about 30 years for 50% recovery and about 75 years for 75% recovery.

For the hydrographs shown in **Figure 5.12**, there is no difference between drawdown and recovery hydrographs for the Approved layout and the Modification. The localised drawdown impacts show that the Modification does not have a significant impact on the regional groundwater regime (**Figures 5.5** to **5.8)**. Therefore, the Modification could not be considered to have a significant impact on the recovery of groundwater levels.

5.8 CLIMATE CHANGE AND GROUNDWATER

The effects of climate change on groundwater are projected to be negative in some places on earth, but positive in other places.

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

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

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

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

Further to this, given that the Modification is for the addition of two longwall panels to a currently approved block of eight longwall panels, and that the two additional longwall panels would be mined over a relatively short period (i.e. approximately 2 years), it was not considered necessary to simulate the effects of climate change for this assessment.

6 CONCLUSIONS

The Wambo Regional Groundwater Model has been designed to meet the following key criteria:

- All of the potential mines within Wambo Coal's mining leases were adequately contained within the model domain, and the model would be capable of examining the synergistic impacts between other operational mines and abandoned mine workings. Abandoned mines and mines belonging to other companies (e.g. HVO, United Colliery and Mt Thorley Warkworth) were also included within the model with spatial representation for past, present and future mining activities (up to 2016) as currently understood.
- The model would form a suitable platform for future impact assessments associated with new mining developments within this area.
- The model could be used to carry out operational assessments of potential mine inflow rates and other operational issues.

A full review of the data, literature and conceptual hydrogeology associated with previous models was carried out as a basis for model development. This was supported by a review of currently available information on geology, rock mass hydraulic properties, neighbouring mine workings and strata geometry for the area. Due consideration was given to the setup and creation of model boundaries and surface water/groundwater interaction processes. Justification for all of the modelling approaches that were used has been given within this report. Care was taken to ensure that hydraulic parameters within the model were maintained within realistic ranges that were based on actual measured data or published information for this region. Recharge rates were based largely on estimates, but the zones and values used within the model reflect the conceptual hydrogeology for the study area.

This assessment is for a modification that consists of the development of two additional longwall panels (Longwalls 9 and 10) in the Wambo Seam to the immediate south of the existing approved longwall panels at the North Wambo Underground Mine. The incremental impacts of the Modification have been considered within the context of the impacts likely to be generated by active approved Wambo mining. Cumulative impacts of neighbouring mines have also been considered.

The key findings of this assessment are:

- The Modification would have no discernible impact on stream baseflow or natural river leakage for all simulated stream systems, beyond the effects of approved mining.
- The Modification would add about 0.2 ML/day to peak mine inflow rates predicted for the currently approved mine plan.

- The Modification would cause less than 0.5 m additional drawdown in the alluvium overlying the proposed Longwalls 9 and 10 and the additional drawdown extent would be confined to the modified North Wambo Underground Mine footprint.
- The Modification would result in a maximum additional localised drawdown of 1.5 m in the regolith (occurring above Longwall 9) and the additional drawdown extent would be confined to the modified North Wambo Underground Mine footprint.
- In the Triassic Sandstone and Permian overburden, above the Whybrow Seam, the additional drawdown due to the Modification is expected to reach about 3 m over Longwall 9 and Longwall 10. The additional drawdown extent would propagate up-gradient along Wambo Creek, Stony Creek and North Wambo Creek for a distance of no more than 2 km. However there would be no discernible impact on stream baseflow or natural river leakage as described above.
- Within the Whybrow Seam, additional drawdown due to the Modification would be about 12 m maximum over Longwall 9 and Longwall 10. Additional drawdown of about 0.1 m would extend outside the mine footprint along Wambo Creek, Stony Creek and North Wambo Creek for a distance of no more than 1.5 km. However there would be no discernible impact on stream baseflow or natural river leakage as described above.
- Within the Wambo Seam, substantial additional drawdown due to the Modification would be limited to the footprint of Longwall 9 and Longwall 10. A maximum incremental drawdown of about 200 m is expected at the southern end of Longwall 10. The additional drawdown extent of about 0.1 m would be no more than 700 m from the mine footprint.
- The net loss of groundwater from the alluvium predicted for the approved mine plan is about 3.4 ML/annum based on the average cumulative loss over the period of mining. The additional loss due to the Modification is about 0.08 ML/annum based on the average cumulative loss over the period of mining.
- There would be negligible impacts from the Modification on registered groundwater licence holders.
- The closest privately-owned bores are located on a privately-owned property which is approximately 270 m from the footprint of Longwalls 9 and 10. All registered bores on this property are predicted to observe incremental drawdowns due to the Modification of less than 1 m.
- No privately-owned registered bore would incur more than 1 m incremental drawdown due to the Modification.
- The Modification could not be considered to have a significant impact on the recovery of groundwater levels.

Based on the above, no additional groundwater impact management measures are proposed for the Modification. Groundwater levels and quality should continue to be monitored at Wambo in accordance with the currently approved GWMP with no augmentation required.

Consistent with the currently approved Surface and Groundwater Response Plan (SGRP) (WCPL, 2010b), in the event that a groundwater quality or level trigger level specified in the GWMP is exceeded, an investigation should be conducted in accordance with the SGRP. Consistent with the *Aquifer Interference Policy* (NSW Government, 2012), management measures that may be implemented as a result of the investigation described above could include relinquishment of an equivalent portion of water access licences as a direct offset for potential groundwater inflows into the underground.

7 BIBLIOGRAPHY

ANZECC, 2000, ‘Australian and New Zealand Guidelines for Fresh and Marine Water Quality’. Australian and New Zealand Environment and Conservation Council, 2000.

Australasian Groundwater and Environmental Consultants Pty Ltd, 2003, Wambo Development Project Groundwater Impact Assessment. Report prepared for Wambo Coal Pty Ltd. April 2003.

Australasian Groundwater and Environmental Consultants Pty Ltd, 2010, Warkworth Mine Extension Groundwater Impact Assessment Report prepared for Warkworth Mining Pty Ltd, April 2010.

Barnett, B, Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A. and Boronkay, A., 2012, Australian Groundwater Modelling Guidelines. Waterlines report 82, National Water Commission, Canberra.

Coal and Allied Operations Pty Ltd, 2007, Hunter Valley Operations Annual Environmental Management Report January - December 2006.

Coffey Geosciences Pty Ltd, 2002, United Colliery Hydrogeological Assessment – United Colliery Mine Extension, Warkworth NSW. 24 April 2002.

Department of Mineral Resources, 1993, Hunter Coalfield Regional Geology 1:100,000 Sheet.

Department of Environment, Climate Change and Water, 2010, NSW Climate Impact Profile – The Impacts of Climate Change on the Biophysical Environment of New South Wales.

Environmental Resource Management Australia, 2008, HVO South Coal Project, Groundwater Assessment Report.

Forster, I. and Enever, J., 1992, Hydrogeological Response of Overburden Strata to Underground Mining - Central Coast New South Wales. Office of Energy Report OOE 92/105. ISBN 0 7305 6964 0. Volume 1: 78p + 26 figs.

GHD Pty Ltd, 2007, Report for Lower Section, North Wambo Creek Geophysical Survey.

Gilbert and Associates, 2003, Wambo Development Project Surface Water Assessment.

Harbaugh A W, Banta E R, Hill M C, and McDonald M G, 2000, MODFLOW-2000 - The USGS Modular Groundwater Flow Model – User Guide to Modulization Concepts and the Groundwater Flow Process: U. S. Geological Survey Open-File Report 00-0092.

HLA-Envirosciences Pty Ltd, 1999, Effect of Longwall Panel 9 Mining on Surface and Groundwater – Homestead Underground Mine Warkworth NSW.

Hunter Catchment Management Trust, 2002, Integrated Catchment Management Plan for the Hunter Catchment 2002.

Hydrogeologic Inc., MODFLOW SURFACT Software (Version 3.0), Herdon, VA, USA.

Laubach S.E., R.A. Marrett, J.E. Olsen and A.R. Scott, 1998, Characteristics and origins of coal cleat: A review. Int. Journal of Coal Geology Vol. 35, p 175-207.

Mackie, C.D., 2009, Hydrogeological Characterisation of Coal Measures and Overview of Impacts of Coal Mining on Groundwater Systems in the Upper Hunter Valley of NSW. PhD Thesis submitted to Faculty of Science, University of Technology, Sydney N.S.W. Australia

Mackie Environmental Research, 2002, Extension of Warkworth Coal Mine: Assessment of Environmental Impacts, Surface and Groundwater Management Studies. Aug. 2002.

McDonald, M. G. and Harbaugh, A. W., 1988, MODFLOW: A modular three-dimensional finite-difference ground-water flow model. U.S.G.S., Scientific Publications Co., Washington.

Murray Darling Basin Commission, 2001, Groundwater Flow Modelling Guideline. Prepared by Aquaterra Pty Ltd, November 2000, Project No. 125, Final guideline issued January 2001.

NSW Department of Planning, 2008, Impacts of Potential Underground Coal Mining in the Wyong Local Government Area: Strategic Review. ISBN 978 0 7347 5900 9, July 2008, 99p.

NSW Government, 2012, Aquifer Interference Policy. Released September 2012.

Pittock, B, 2003, Climate Change – An Australian Guide to the Science and Potential Impacts. Australian Greenhouse Office.

SCT Operations Pty Ltd (SCT), 2008, ACARP Project C13013: Aquifer Inflow Prediction above Longwall Panels. Report to the Australian Coal Association Program, September 2008.

Sinclair Knight Merz and National Centre for Groundwater Research and Training, 2012, Australian Groundwater Modelling Guidelines. Waterlines Report Series No.82, National Water Commission, Canberra.

United Collieries Pty Ltd, 2006, Annual Environmental Management Report January - December 2006.

United Collieries Pty Ltd, 2007, Annual Environmental Management Report January - December 2007.

United Collieries Pty Ltd, 2008, Annual Environmental Management Report January - December 2008.

United Collieries Pty Ltd, 2009, Annual Environmental Management Report January - December 2009.

Wambo Coal Pty Limited, 2003, Wambo Development Project Environmental Impact Statement.

Wambo Coal Pty Limited, 2009, Annual Environmental Management Report — July 2007 to June 2008.

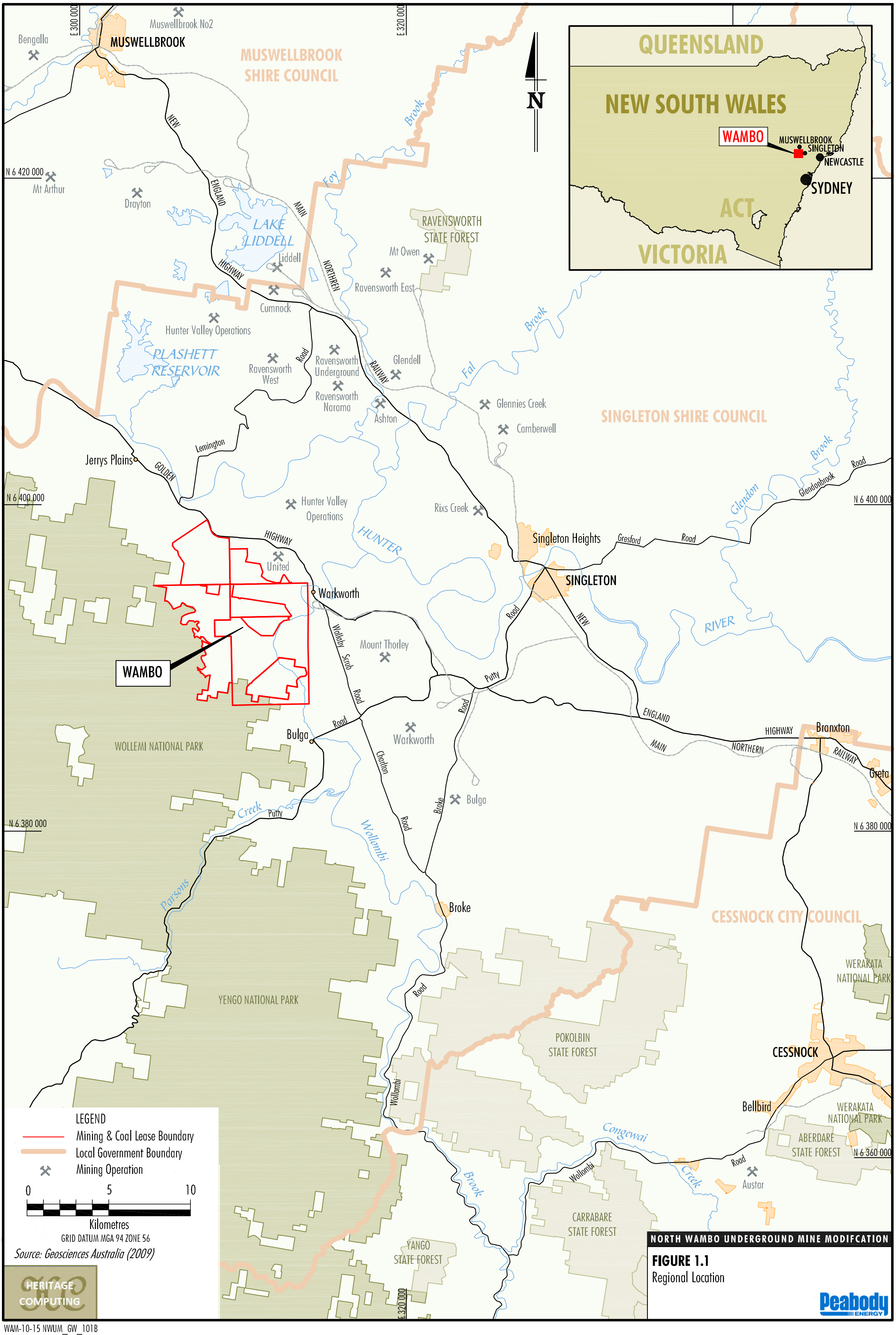
Wambo Coal Pty Limited, 2009, Annual Environmental Management Report — July 2008 to June 2009.

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

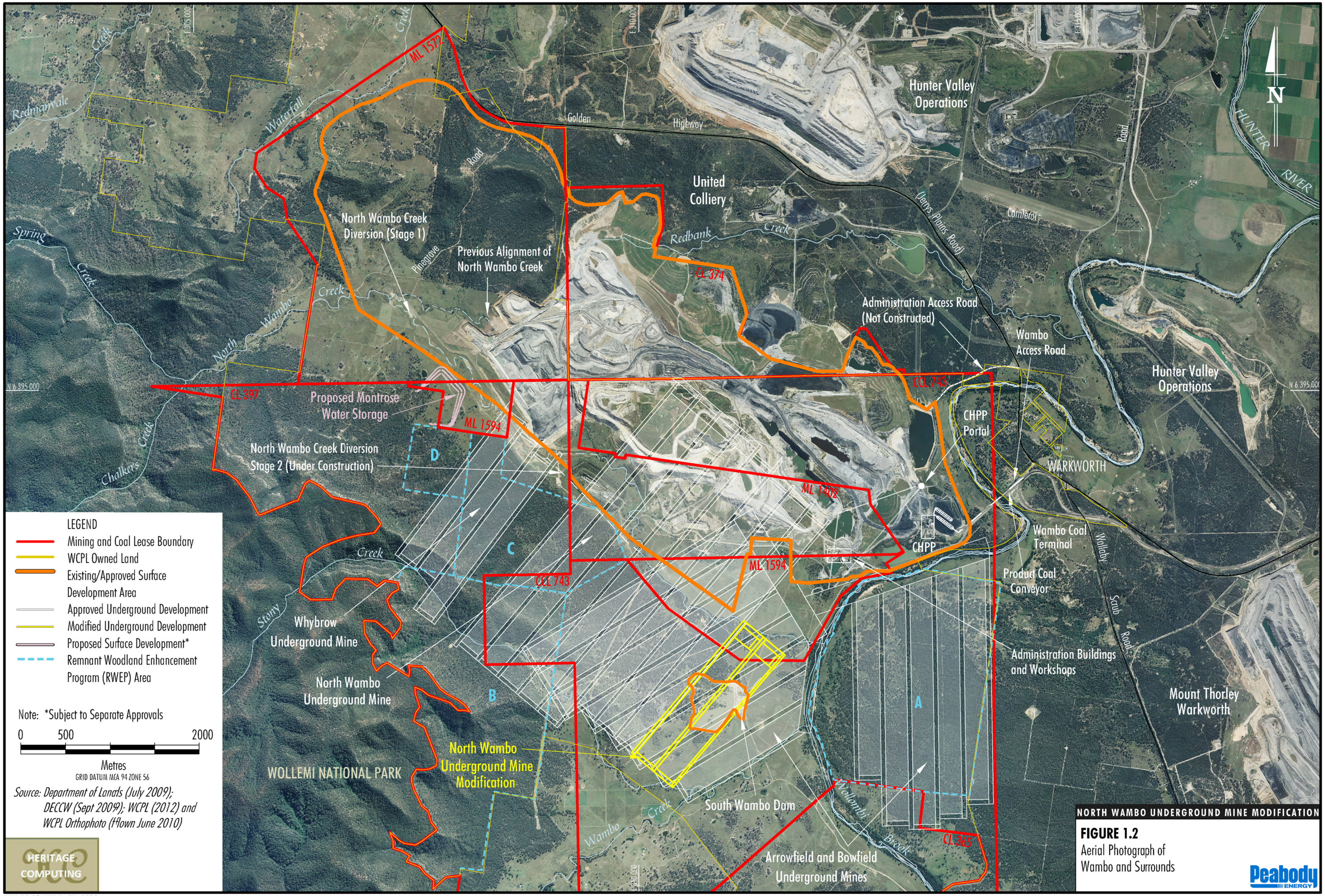
Wambo Coal Pty Limited, 2010, Groundwater Monitoring Program.

Wambo Coal Pty Limited, 2010, Surface and Groundwater Response Plan.

ILLUSTRATIONS



MUSWELLBROOK
Muswellbrook No2
Bengalla
MUSWELLBROOK SHIRE COUNCIL
E 300 000
E 320 000
Mt Arthur
Drayton
LAKE LIDDELL
Liddell
Cumnock
Hunter Valley Operations
PLASHETT RESERVOIR
Ravensworth West
Ravensworth Underground
Ravensworth Narama
Ashton
Glendell
Mt Owen
Ravensworth East
RAVENSWORTH STATE FOREST
Glennies Creek
Camberwell
SINGLETON SHIRE COUNCIL
Jerrys Plains
Hunter Valley Operations
Rixs Creek
Singleton Heights
SINGLETON
United
Warkworth
WAMBO
Mount Thorley
Bulga
Warkworth
Bulga
WOLLEMI NATIONAL PARK
Broke
Branxton
Greta
YENGO NATIONAL PARK
POKOLBIN STATE FOREST
CESSNOCK CITY COUNCIL
WERAKATA NATIONAL PARK
CESSNOCK
Bellbird
ABERDARE STATE FOREST
Austar
CARRABARE STATE FOREST
YANGO STATE FOREST
N 6 420 000
N 6 400 000
N 6 380 000
N 6 360 000
QUEENSLAND
NEW SOUTH WALES
WAMBO
MUSWELLBROOK
SINGLETON
NEWCASTLE
SYDNEY
ACT
VICTORIA
LEGEND
Mining & Coal Lease Boundary
Local Government Boundary
Mining Operation
0 5 10
Kilometres
GRID DATUM MGA 94 ZONE 56
Source: Geosciences Australia (2009)
HERITAGE COMPUTING
NORTH WAMBO UNDERGROUND MINE MODIFCATION
FIGURE 1.1
Regional Location
Peabody ENERGY
WAM-10-15 NWUM_GW_101B



WAM-10-15 NWUM_GW_102C

00487790

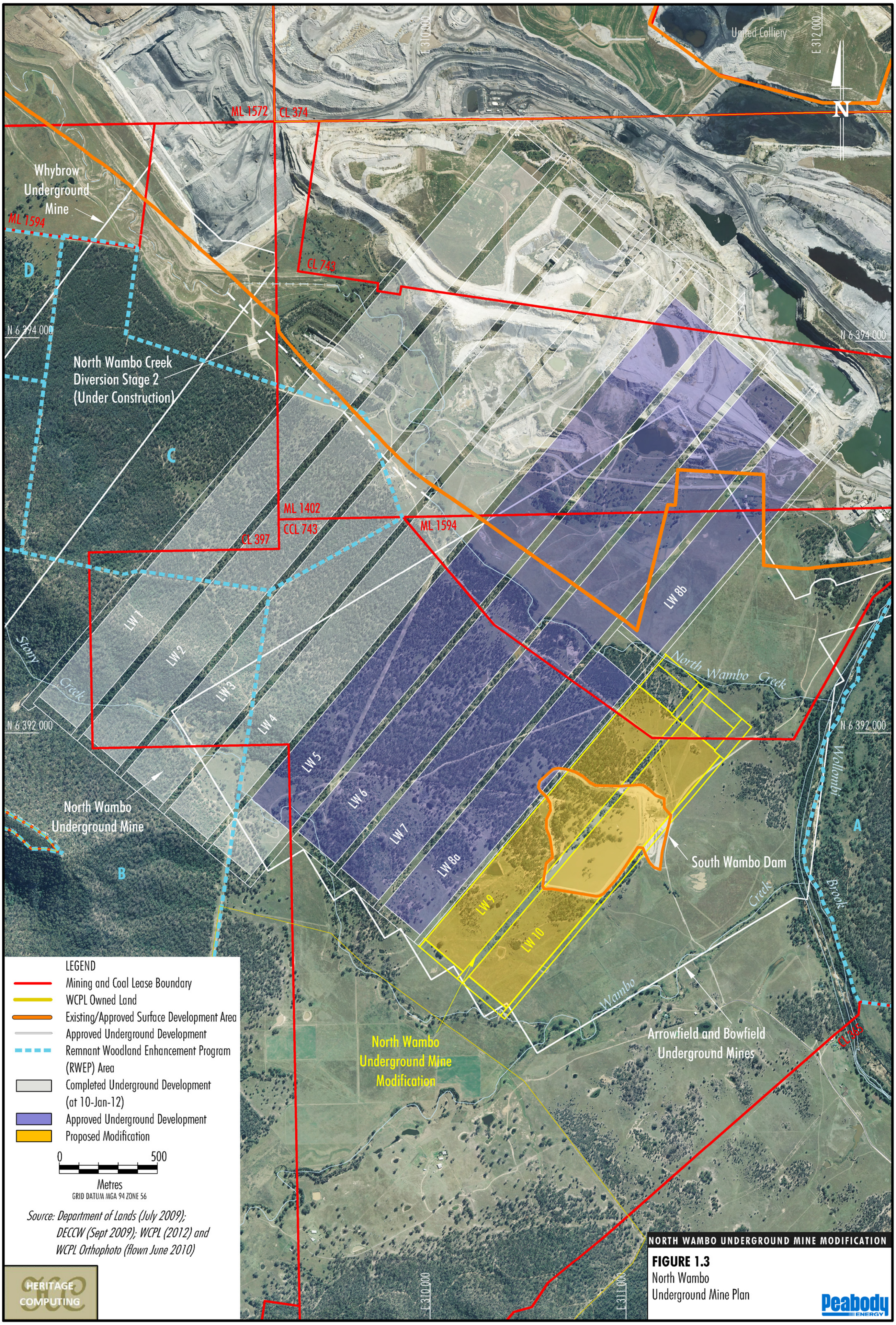
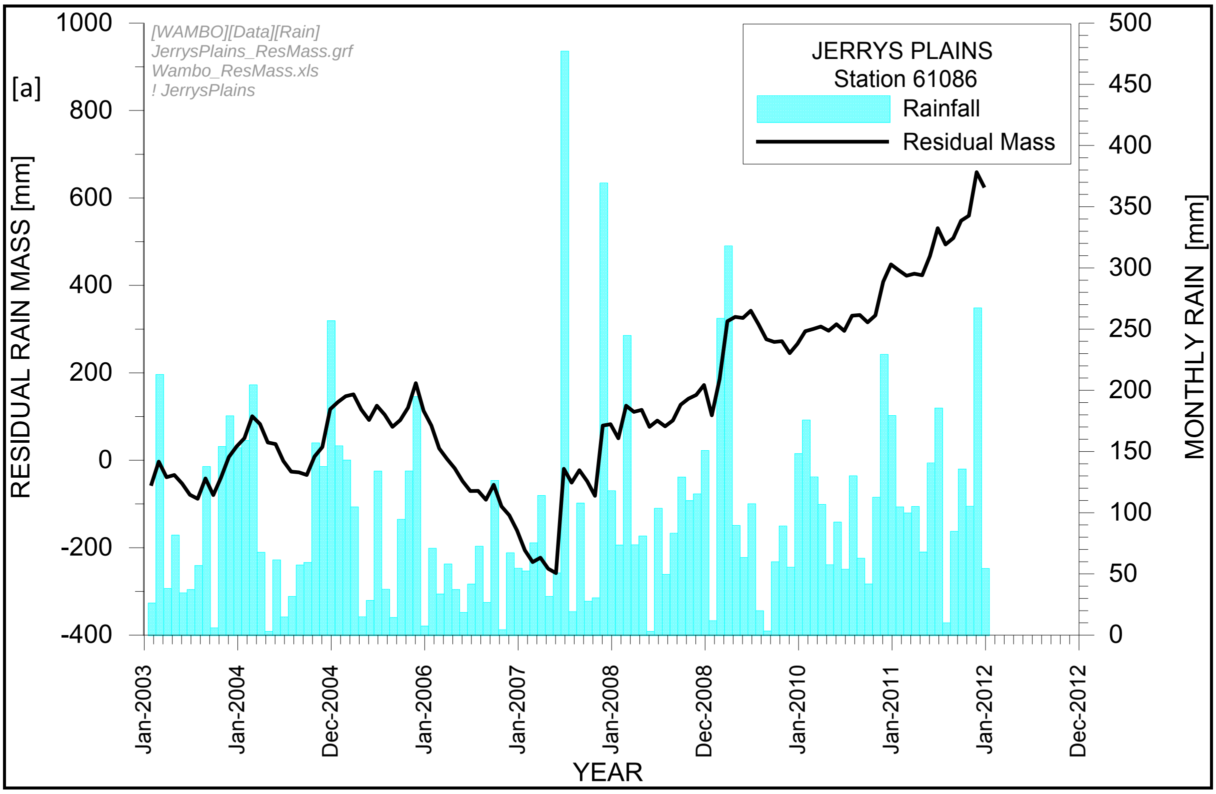


FIGURE 1.3
North Wambo
Underground Mine Plan

WAM-10-15 NWUM_GW_104B



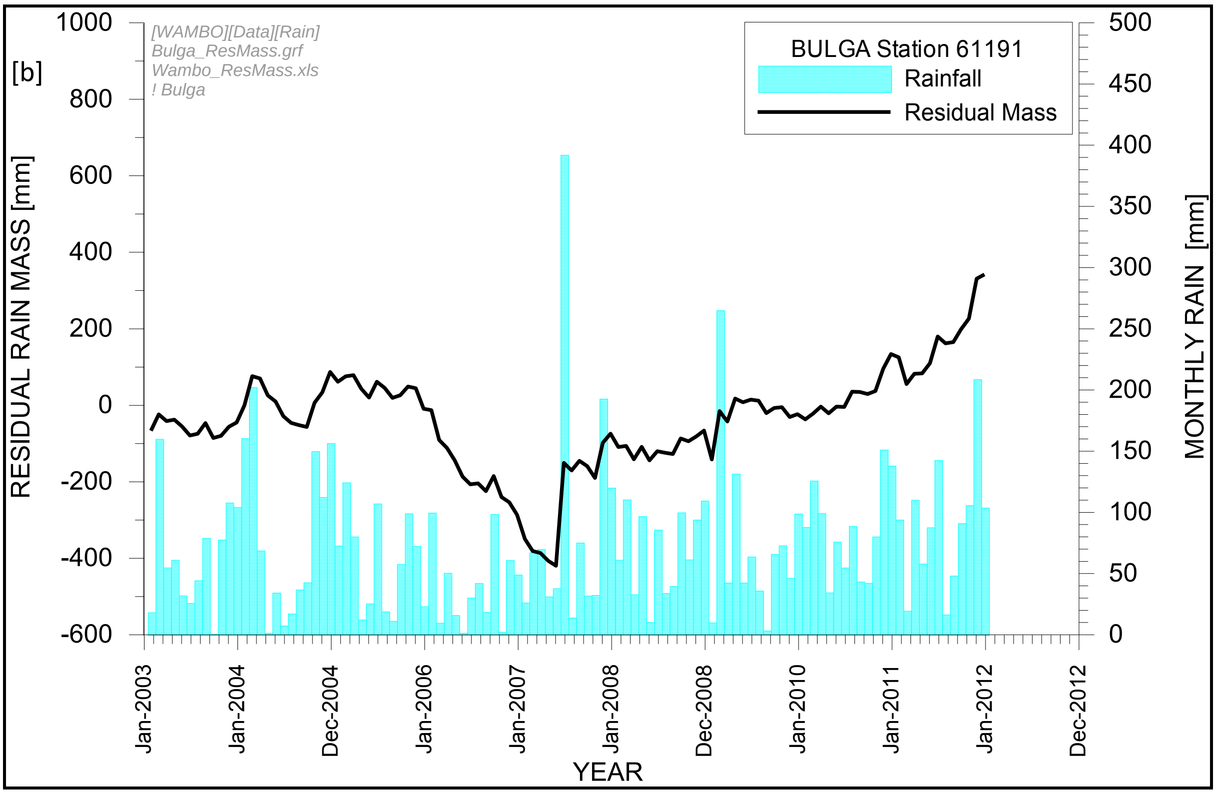
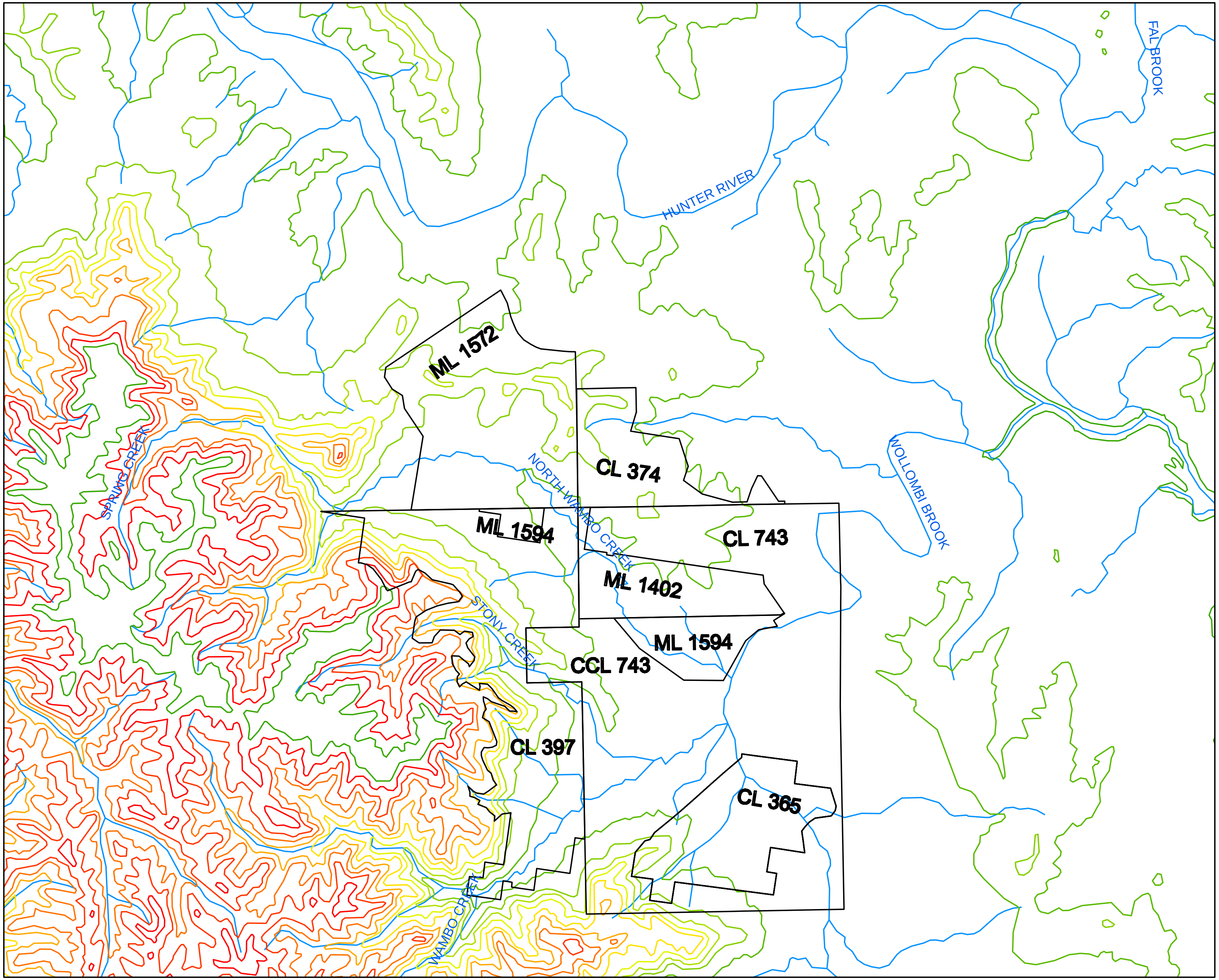


Figure 2.1: Rainfall Residual Mass Curves for [a] Jerrys Plains Post Office and [b] Bulga (South Wambo)



HERITAGE COMPUTING

Legend

Mine Lease
Watercourse Lines
Regional Topography Contours
50
100
150
200
250
300
350
400
450
500
550

0 1 2 4 Km

Project:	Date: 7/08/2012
Drawing No.	Revision :
Drawn: af	Datum: WGS1984

Figure 2.2
REGIONAL TOPOGRAPHY

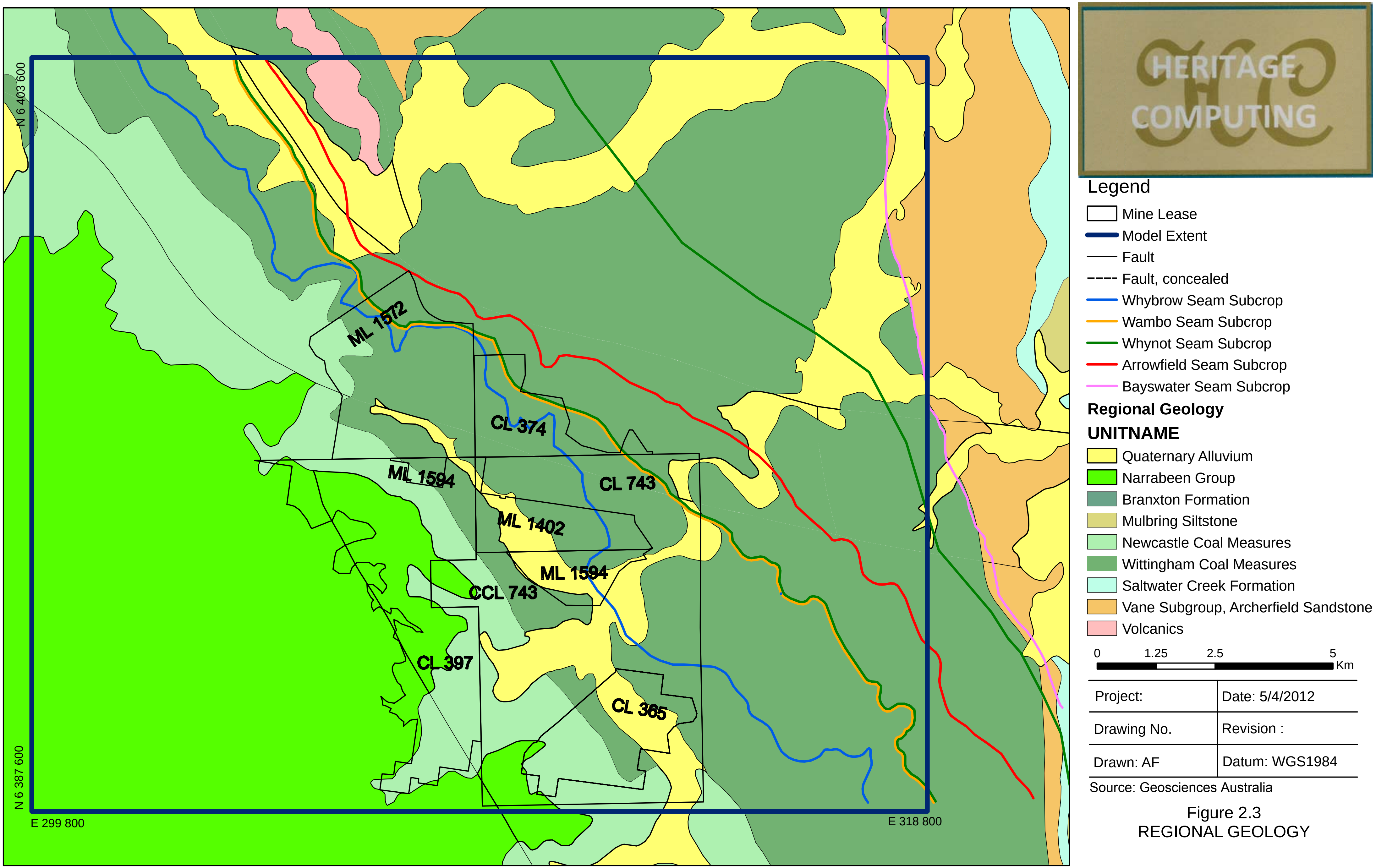


Figure 2.3
REGIONAL GEOLOGY

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

[1] Previously known as the Wollombi Coal Measures.
[2] Coal reserves currently, previously and proposed to be mined at the Wambo Coal Mine.
[3] Coal reserves to be mined by the Wambo Coal Mine where the upper three plies of the Warkworth Seam combine with the two plies of the Bowfield Seam.

After: DMR (1993)

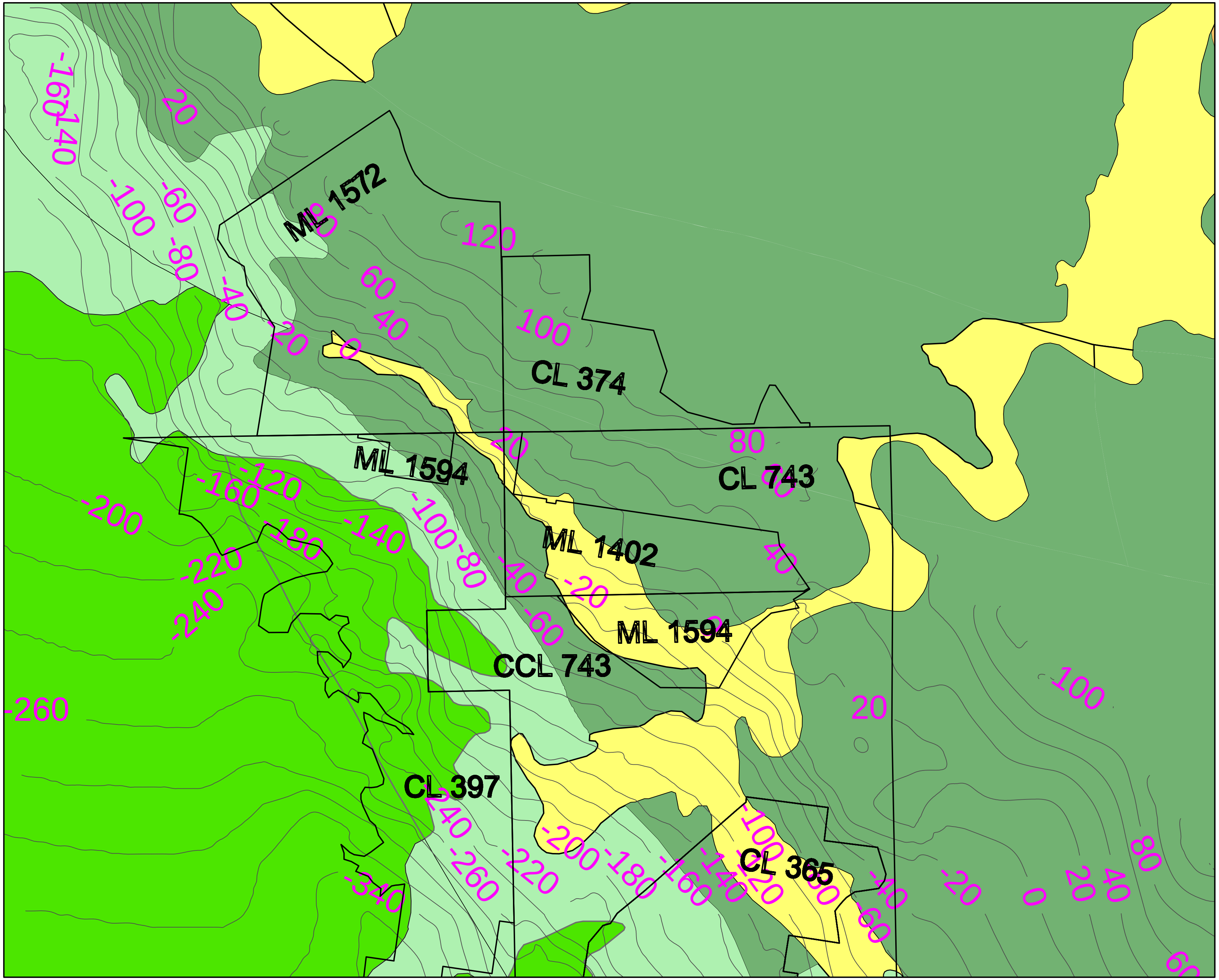
NORTH WAMBO UNDERGROUND MINE MODIFICATION

FIGURE 2.4
Stratigraphy of the Wambo Coal Mine Area

Peabody ENERGY

HERITAGE COMPUTING

WAM-09-15_NWUM GW_001E



HERITAGE COMPUTING

Legend

Mine Lease

Regional Geology

UNITNAME

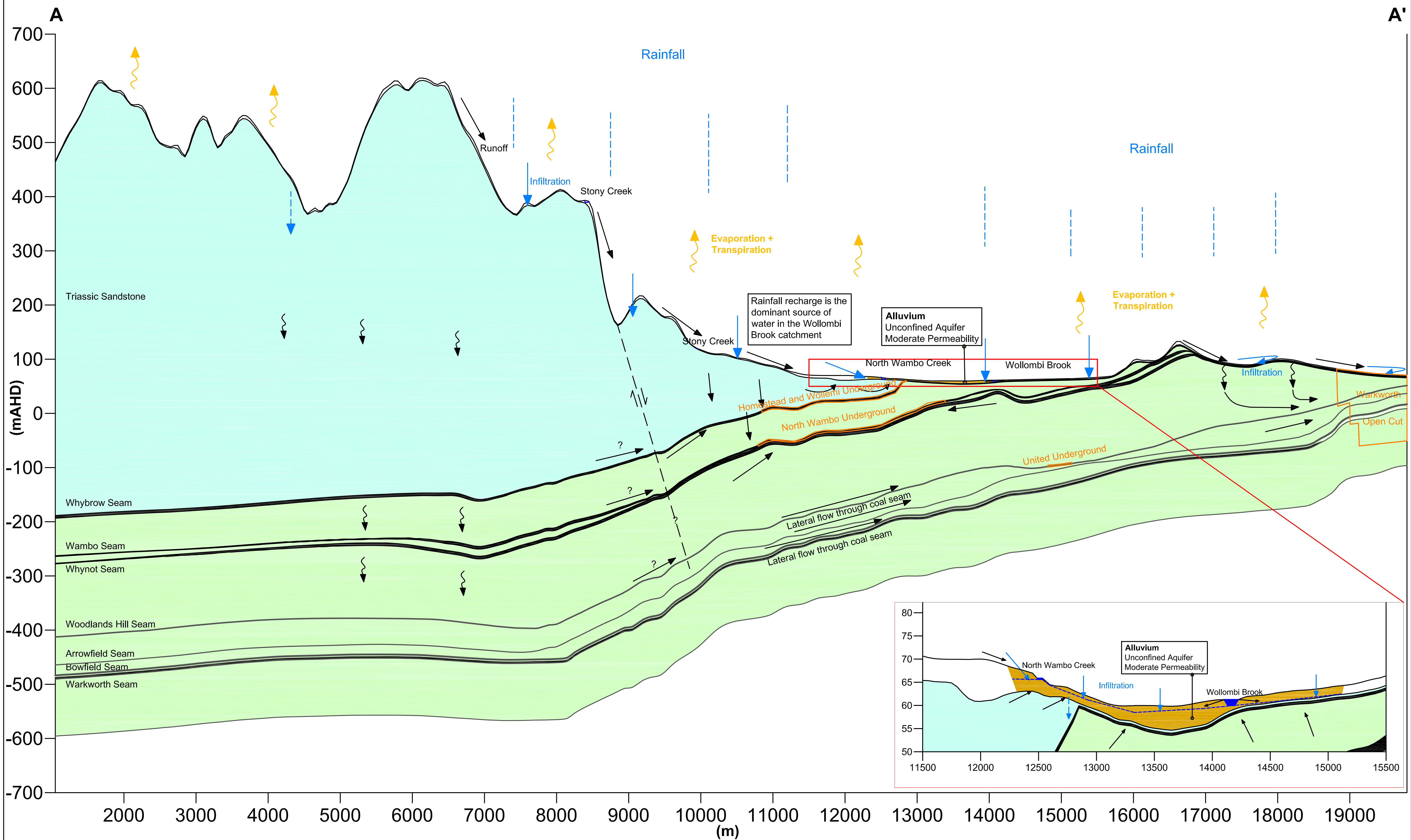
- Quaternary Alluvium
- Narrabeen Group
- Branxton Formation
- Mulbring Siltstone
- Newcastle Coal Measures
- Wittingham Coal Measures
- Saltwater Creek Formation
- Vane Subgroup, Archerfield Sandstone
- Volcanics

Source: Geoscience Australia

0 0.5 1 2 Km

Project:	Date: 5/8/2012
Drawing No.	Revision :
Drawn: AF	Datum: WGS1984

Figure 2.5
Wambo Seam Structural Contours
(m AHD)



Legend

- Water table (Alluvium)
- Coal Seam
- Mine Outline
- Evaporation + Transpiration
- Primary infiltration
- Secondary infiltration
- Flow

SCALE: as indicated

HERITAGE COMPUTING

CONCEPTUAL HYDROGEOLOGICAL CROSS SECTION

Figure 2.6

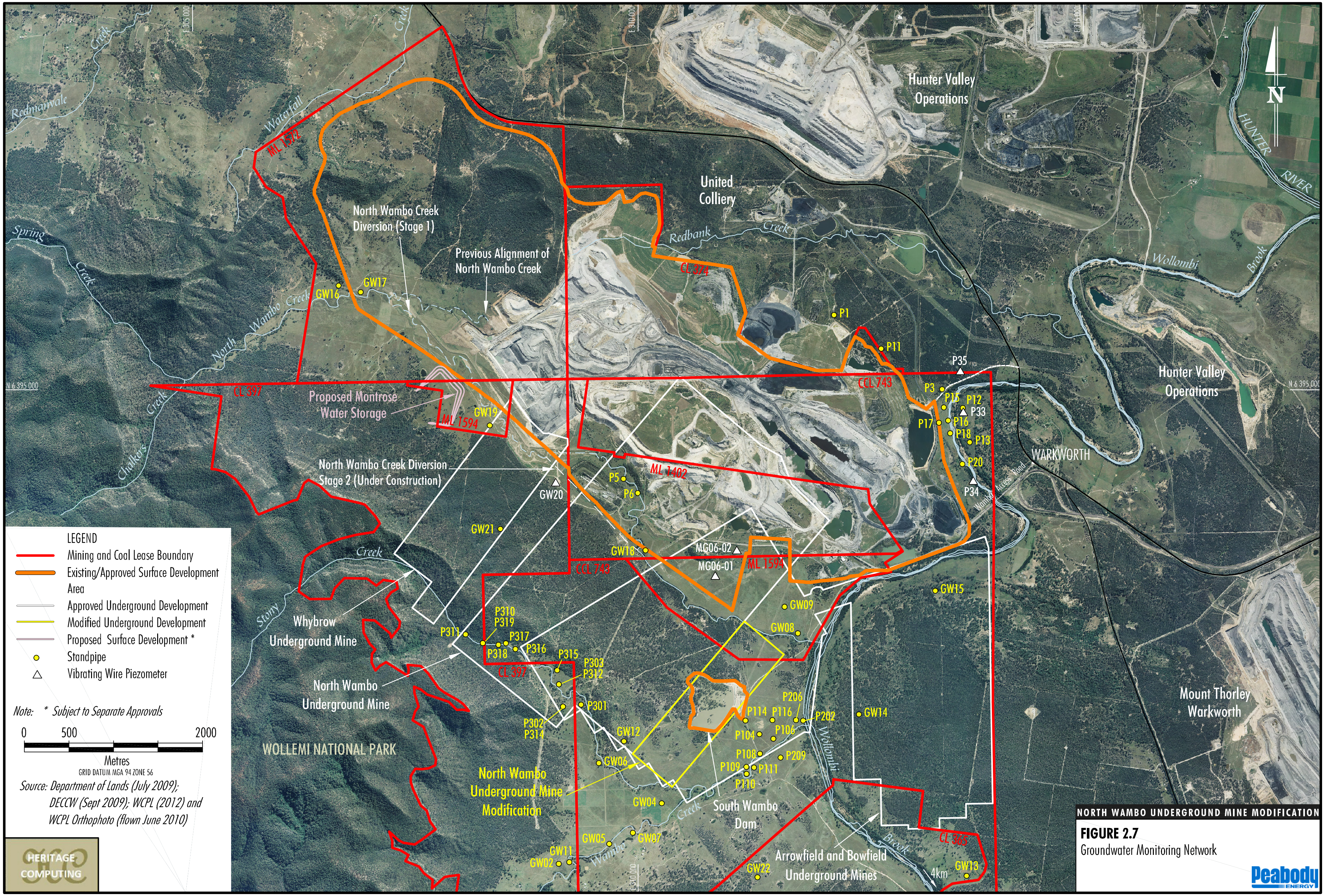
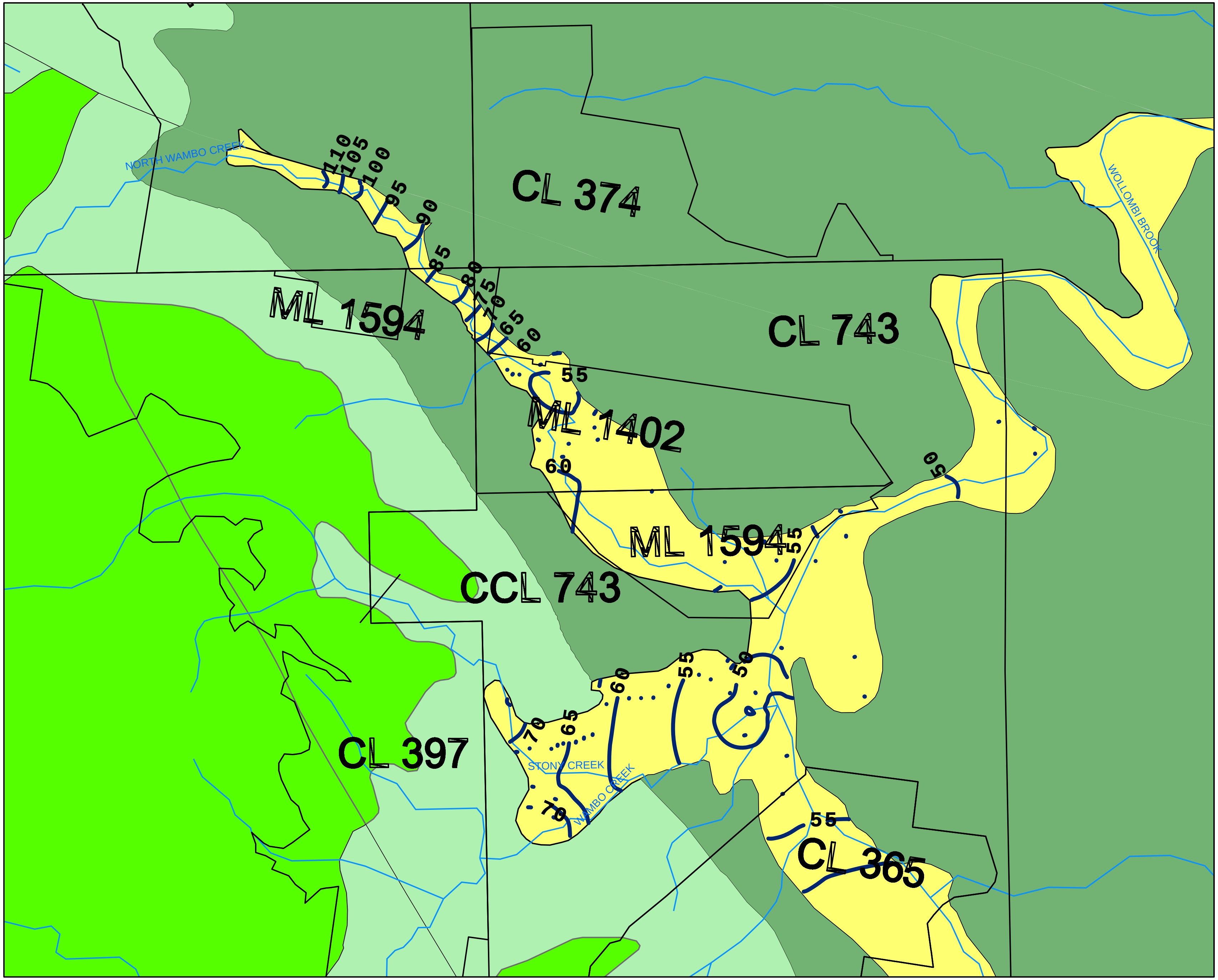


FIGURE 2.7
Groundwater Monitoring Network

WAM-10-15 NWUM_GW_103D



HERITAGE COMPUTING

Legend

Mine Lease

Watercourse Lines

Regional Geology

UNITNAME

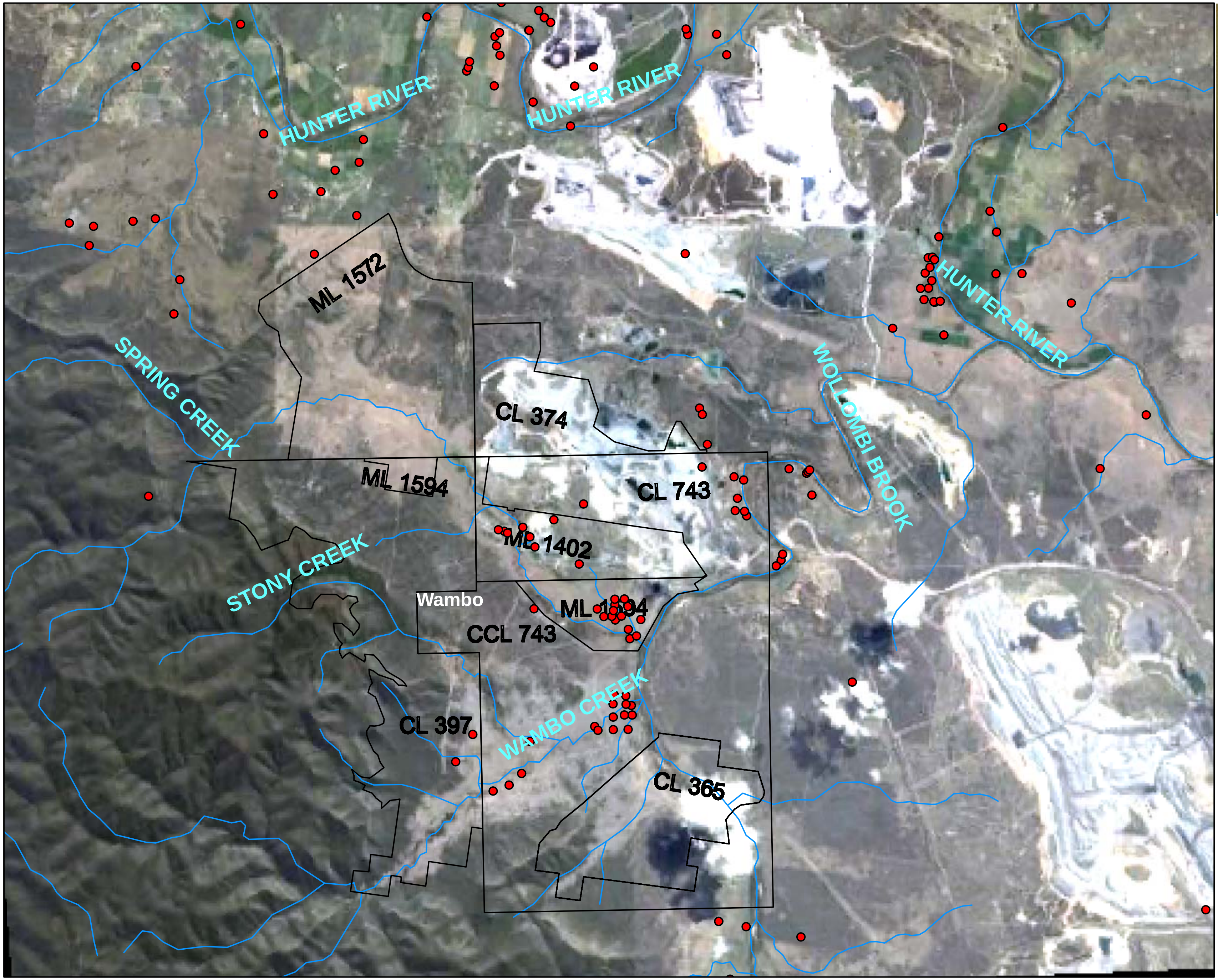
- Quaternary Alluvium
- Narrabeen Group
- Branxton Formation
- Mulbring Siltstone
- Newcastle Coal Measures
- Wittingham Coal Measures
- Saltwater Creek Formation
- Vane Subgroup, Archerfield Sandstone

Source: Geoscience Australia

0 0.5 1 2 Km

Project:	Date: 6/8/2012
Drawing No.	Revision :
Drawn: AF	Datum: WGS1984

Figure 2.8
2007 Alluvium Groundwater Levels



HERITAGE COMPUTING

Legend

Mine Lease

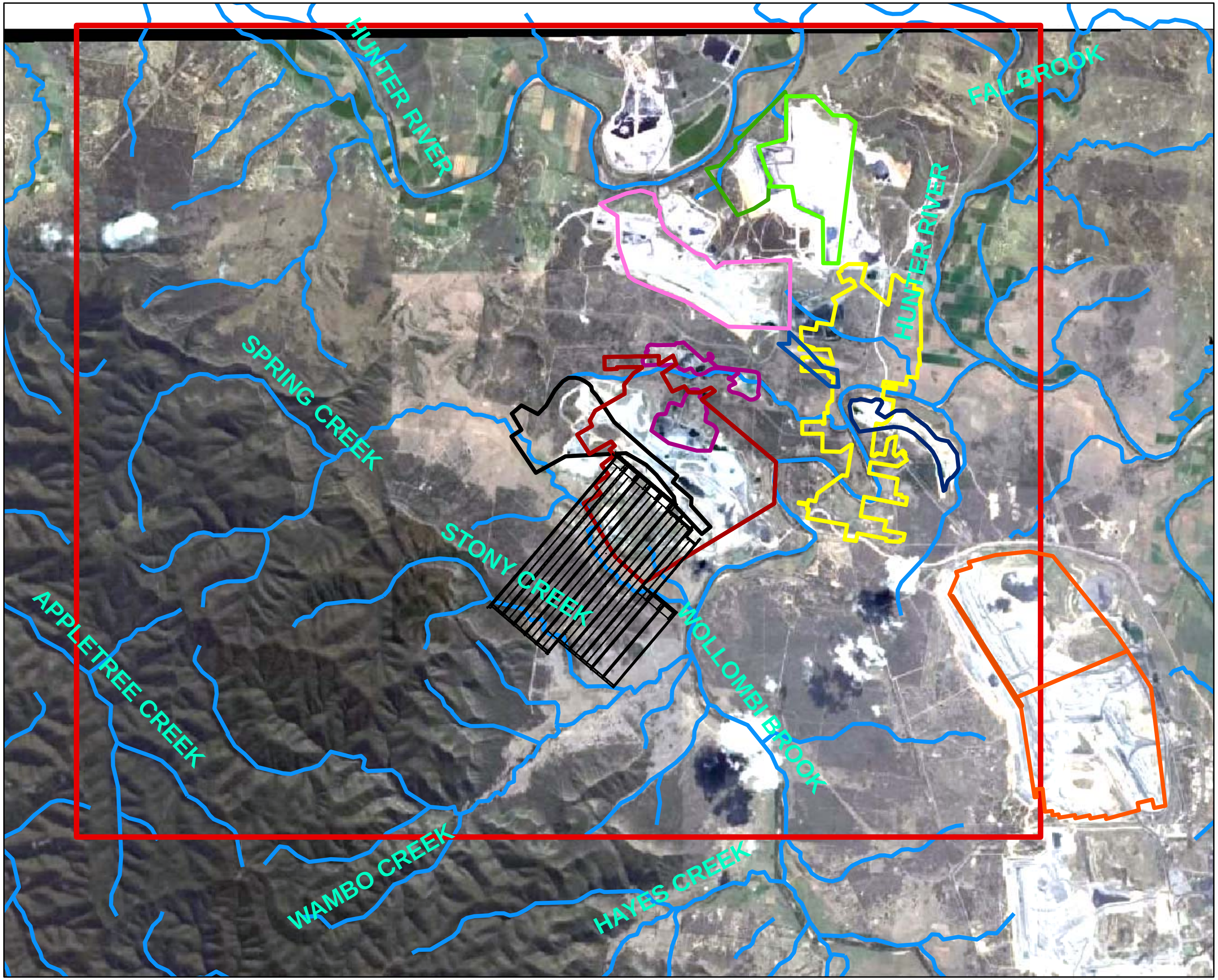
Watercourse Lines

Registered Groundwater Bores

0 1 2 4 Km

Project:	Date:6/8/2012
Drawing No.	Revision : 0
Drawn: AF	Datum: WGS1984

Figure 2.9
REGISTERED GROUNDWATER BORES



HERITAGE COMPUTING

Legend

Mining Areas

- Cheshunt Dump
- Cheshunt Pit
- Lemington Underground
- Riverview
- South Lemington 1
- South Lemington 2
- United Open Cut
- United Underground
- Warkworth North
- Wambo
- Model Area
- Watercourse Lines

0 1 2 4 Km

Project:	Date: 12/04/2012
Drawing No.	Revision :
Drawn: AF	Datum: WGS1984

Figure 3.1
MODEL DOMAIN

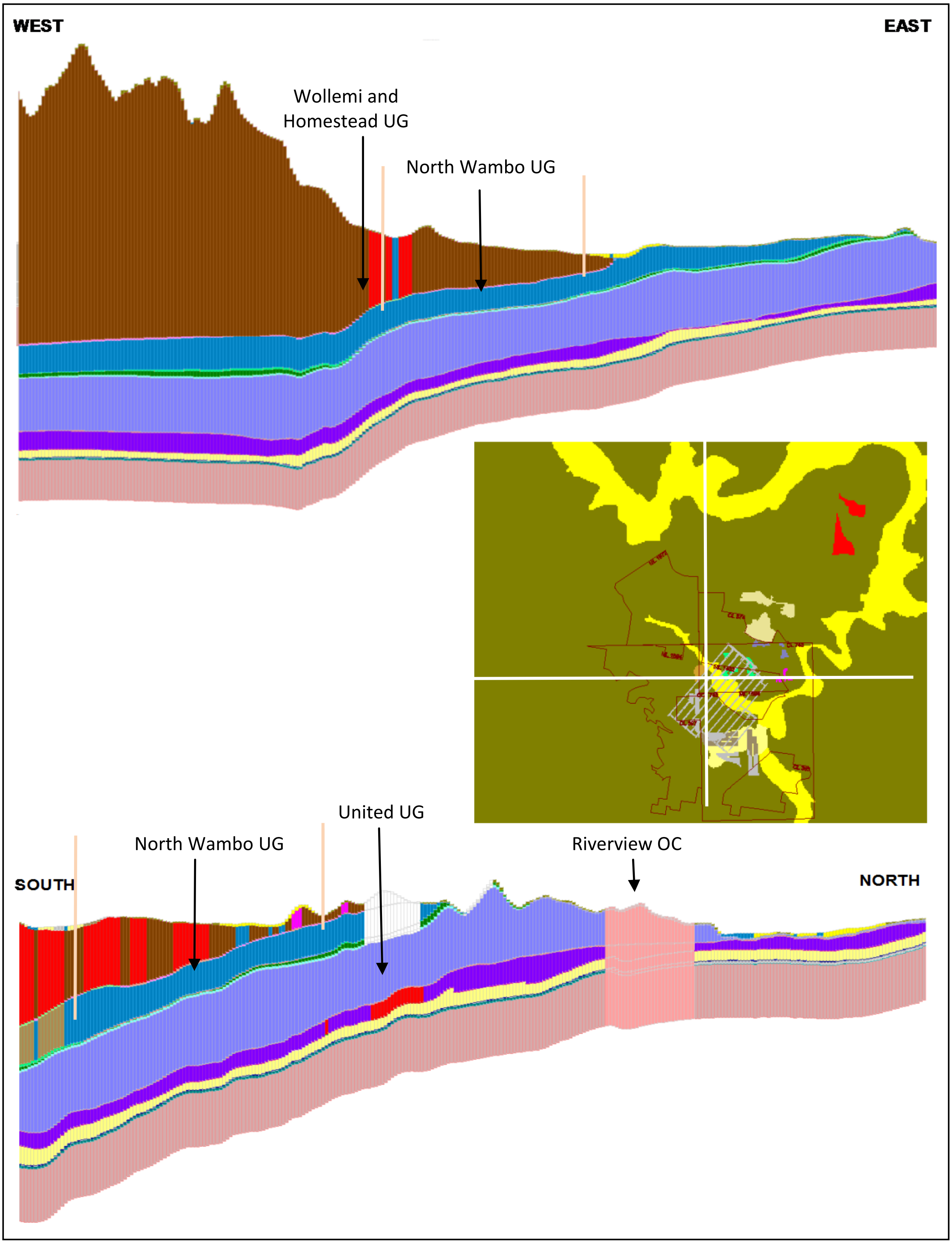


Figure 3.2 Model Cross-section [a] Northing 6392000 (model row 232), [b] Easting 310000 (model column 205)

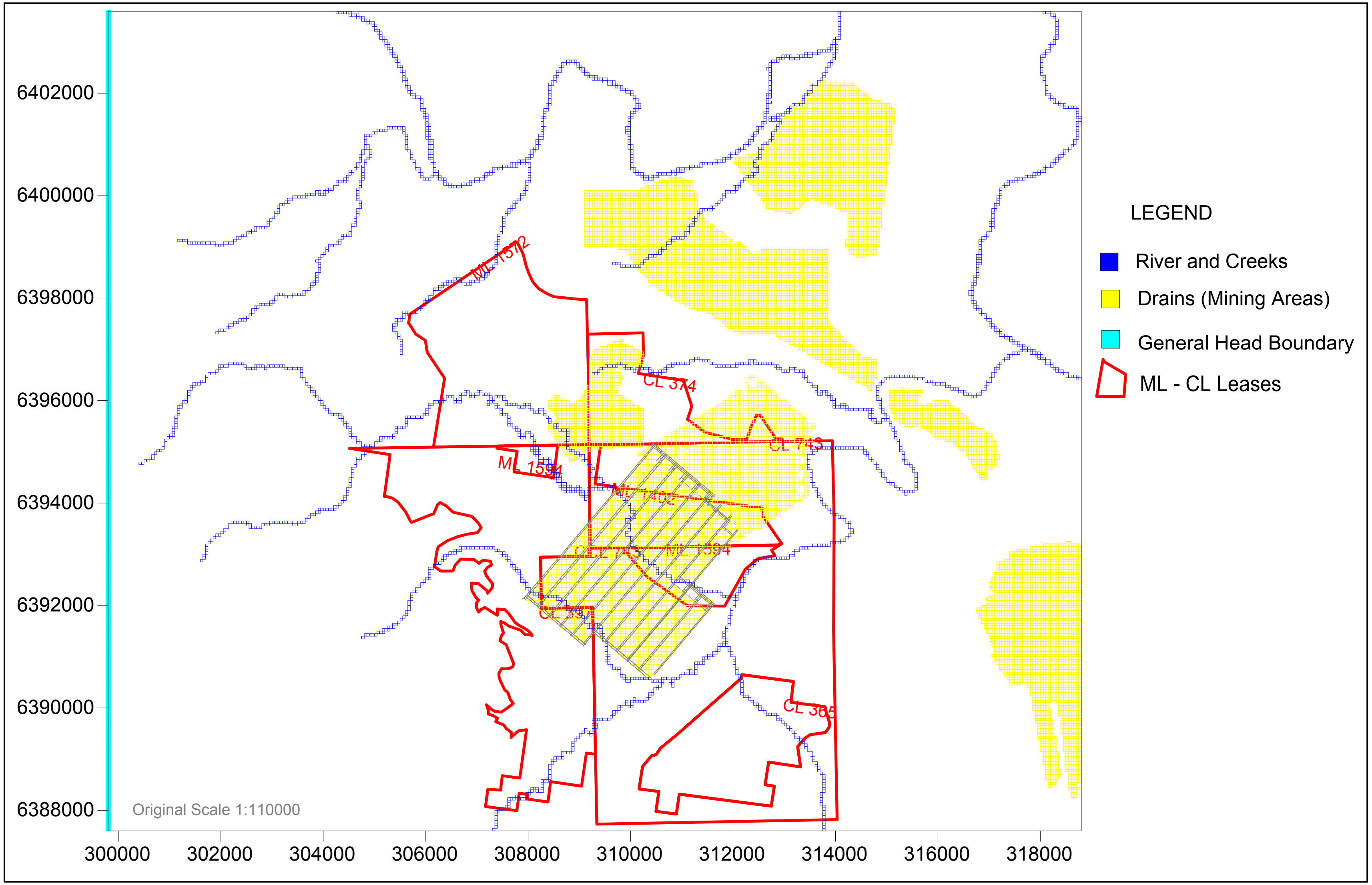


Figure 3.3 Boundary Conditions

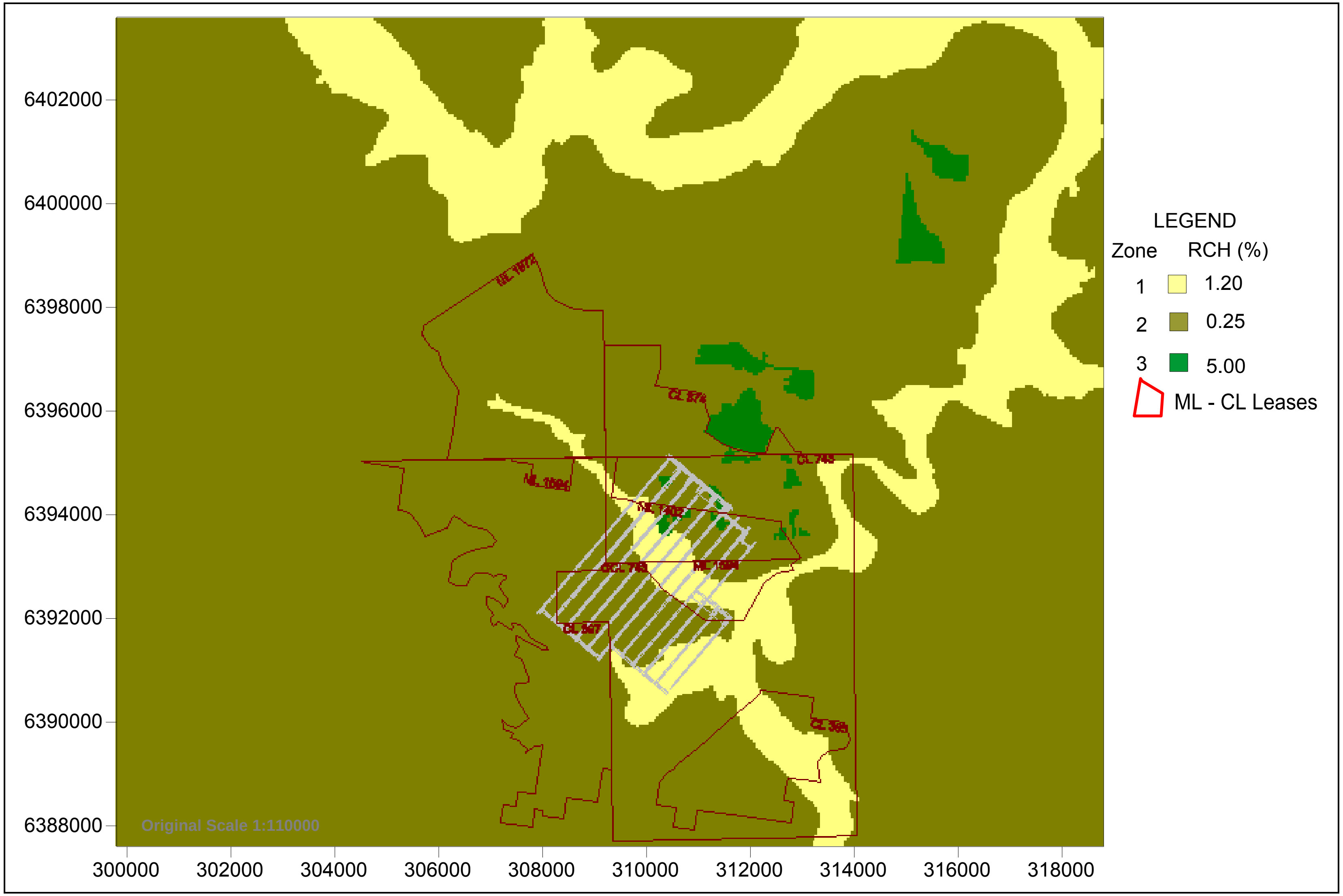
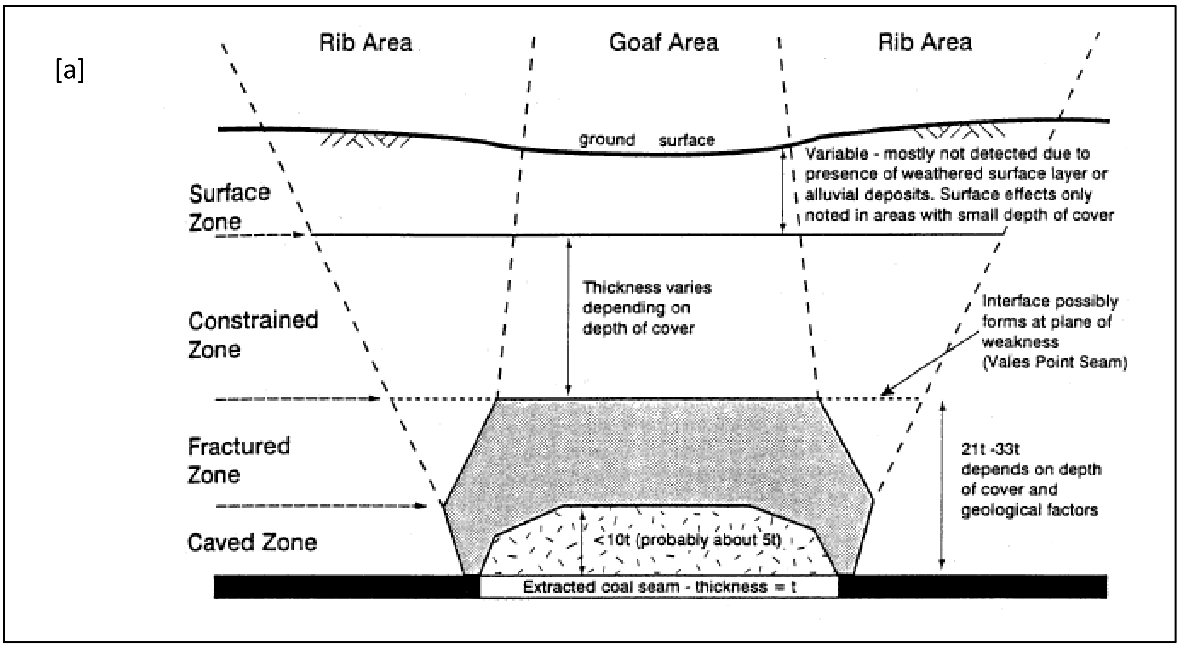


Figure 3.4: Modelled Recharge Zones



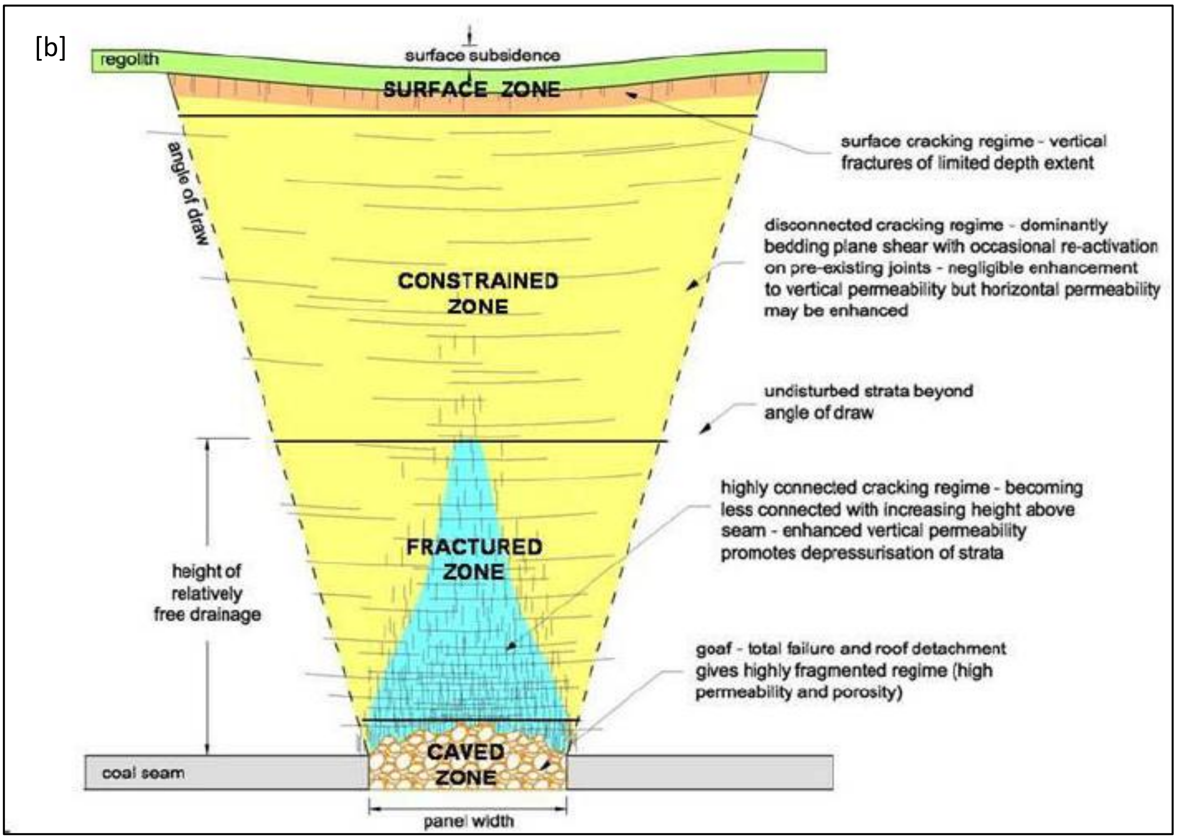
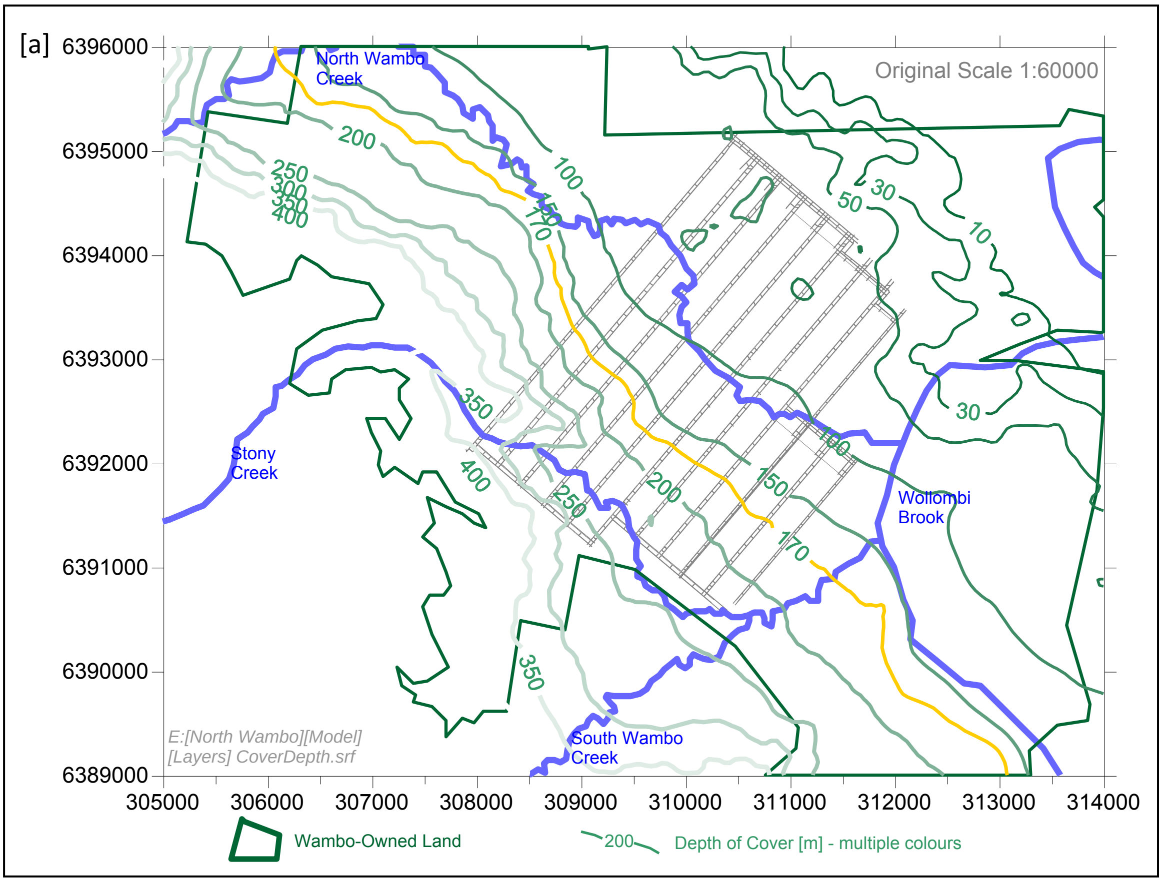


Figure 3.5: Conceptual Models of Deformation Zones Related to Underground Mining

[Sources: [a] Forster & Enever, 1992; [b] NSW Department of Planning, 2008]



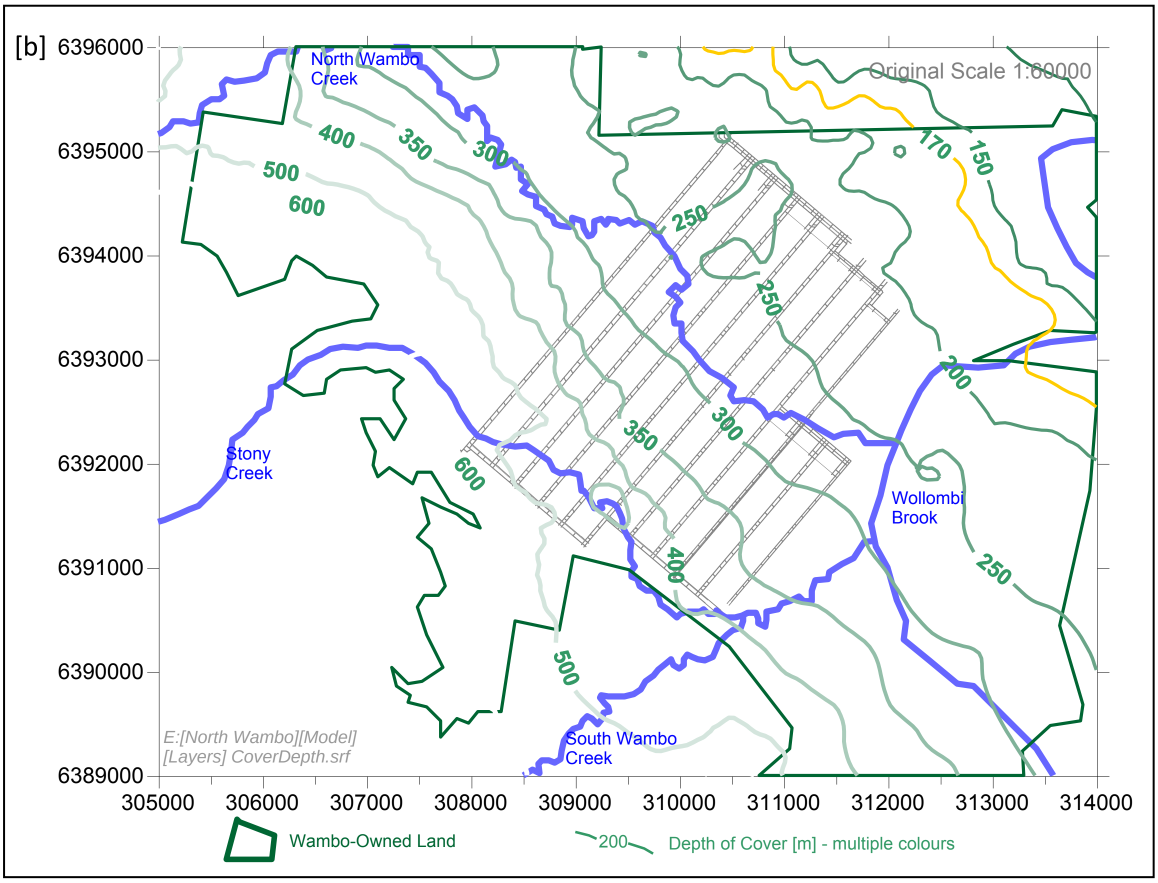


Figure 3.6: Depths of cover for [a] Wambo Seam, and [b] Arrowfield Seam [m]

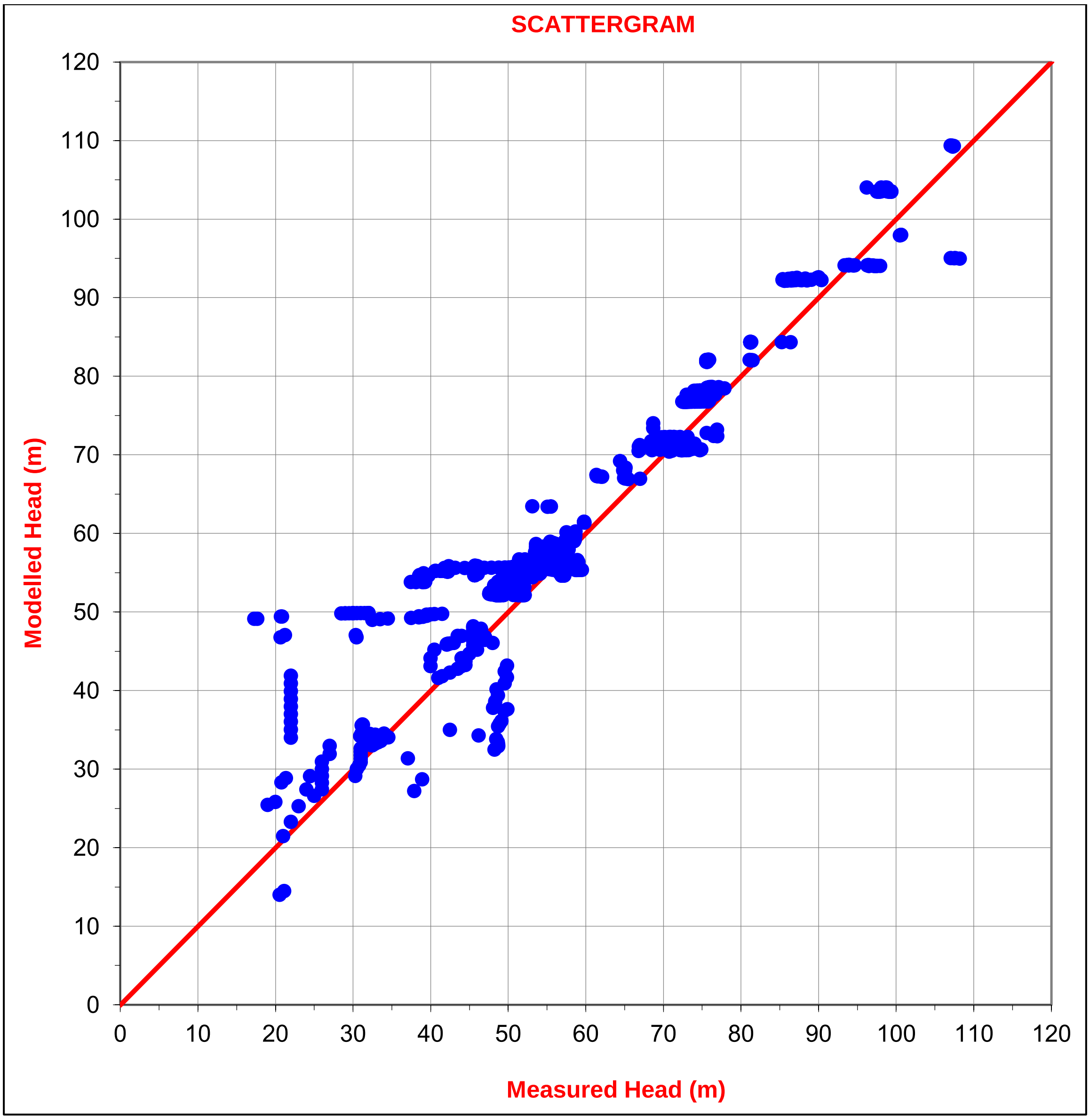


Figure 3.7: Calibration Scatter Diagram - Calibrated vs Observed Water Levels

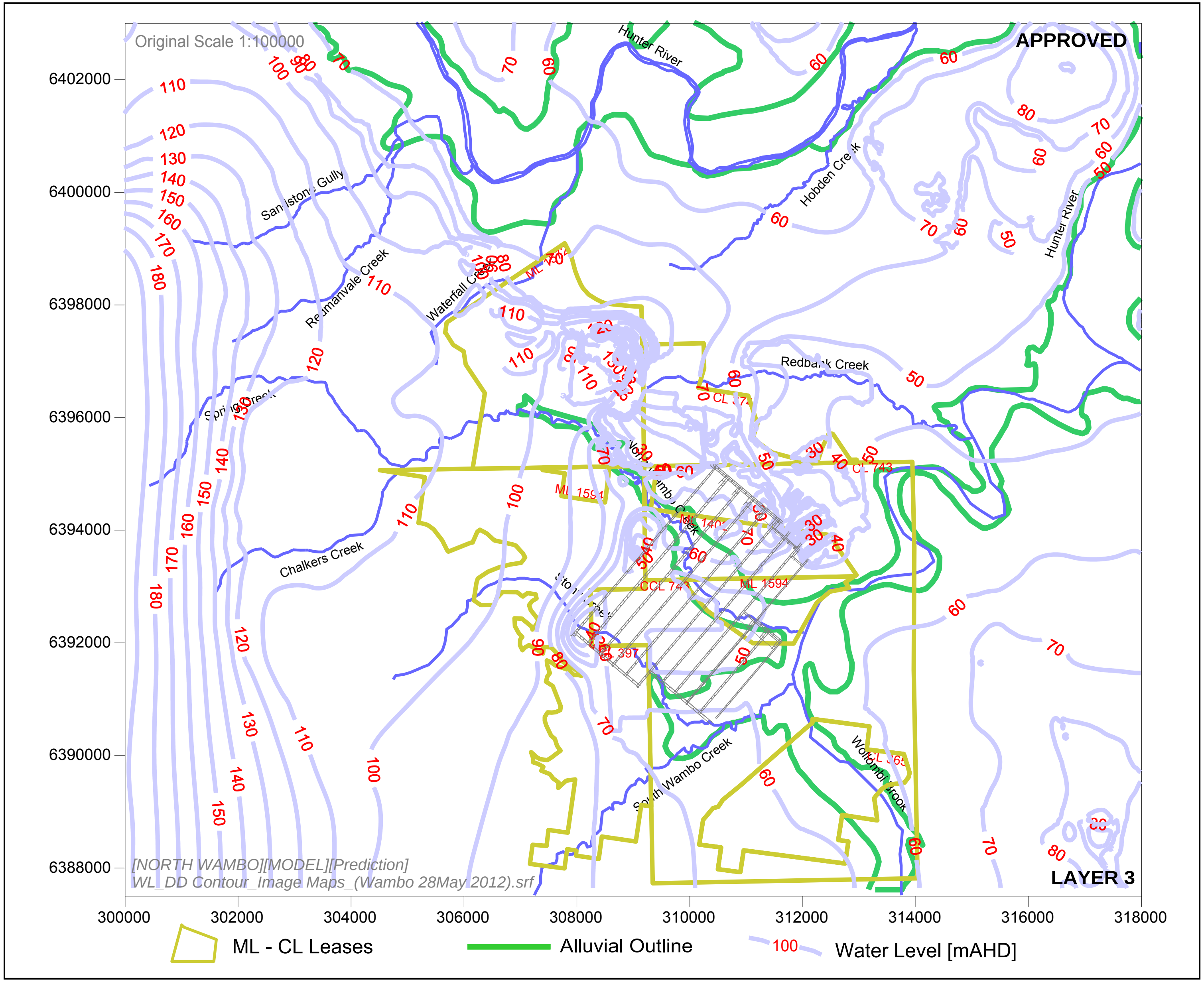


Figure 4.1: Predicted Water Levels in the Whybrow Seam (and Model Layer 3) at the End of Mining - Currently Approved Mine Plan (m AHD)

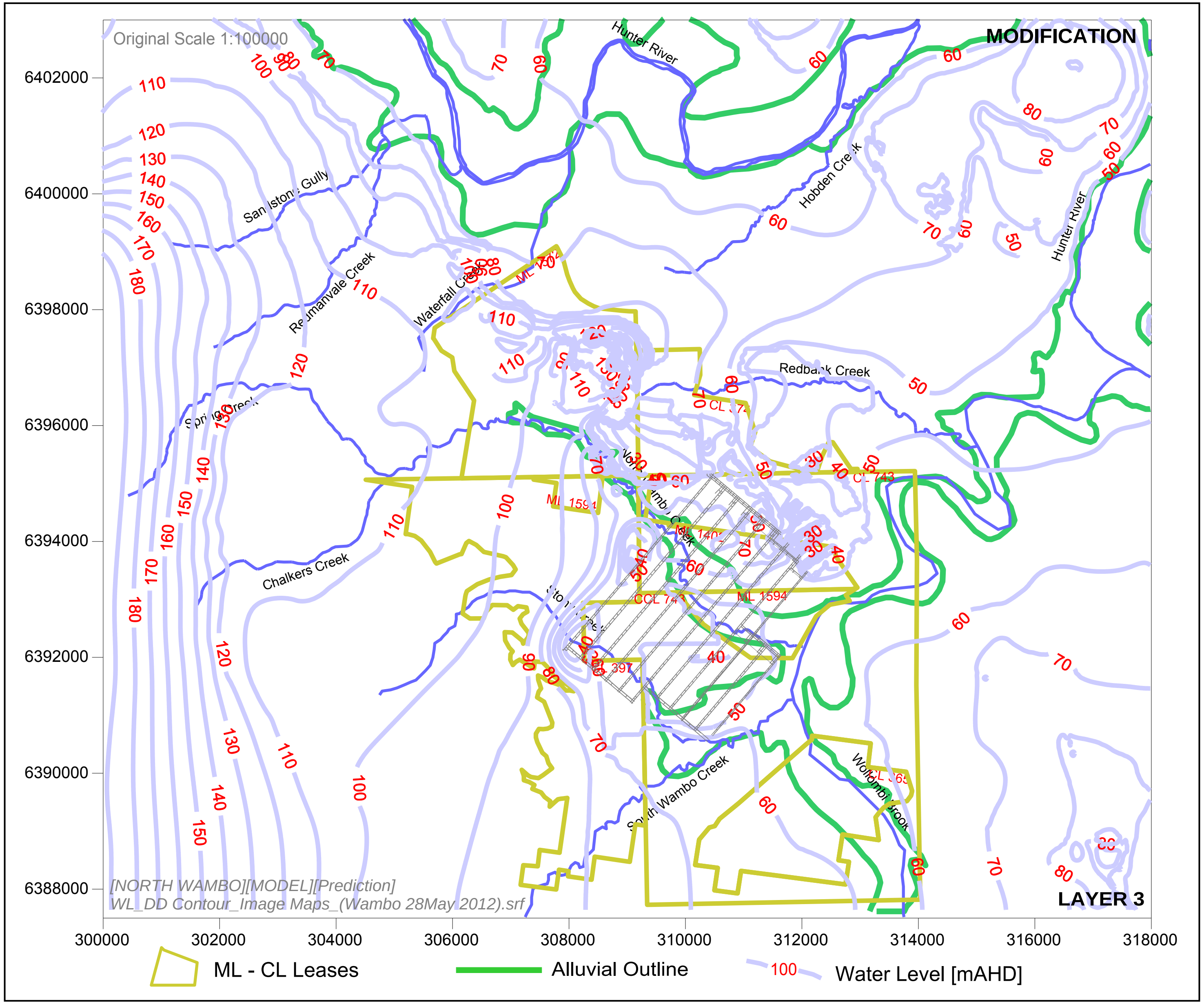


Figure 4.2: Predicted Water Levels in the Whybrow Seam (and Model Layer 3) at the End of Mining - Modified Mine Plan (m AHD)

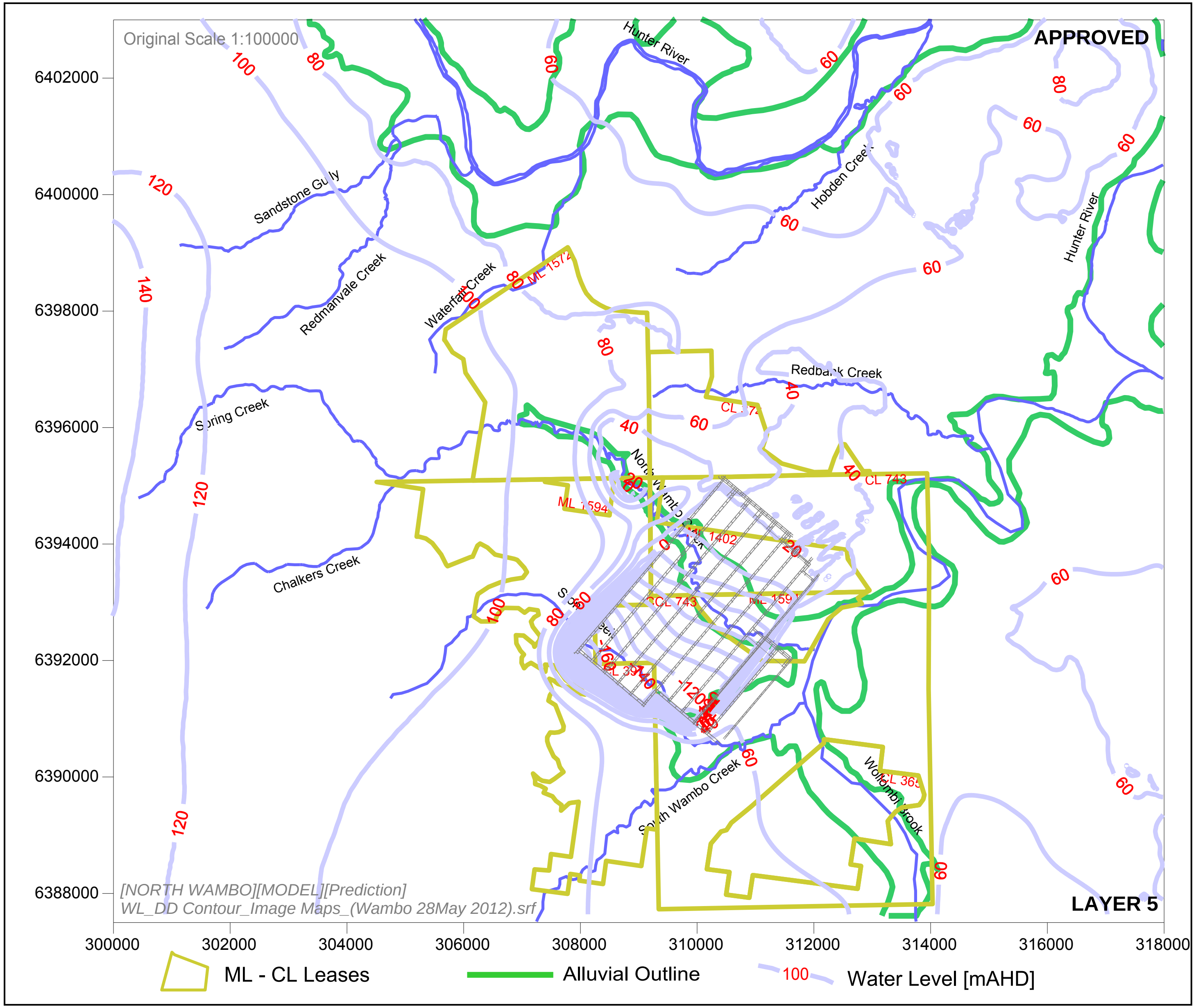


Figure 4.3: Predicted Water Levels in the Wambo Seam (and Model Layer 5) at the End of Mining - Currently Approved Mine Plan (m AHD)

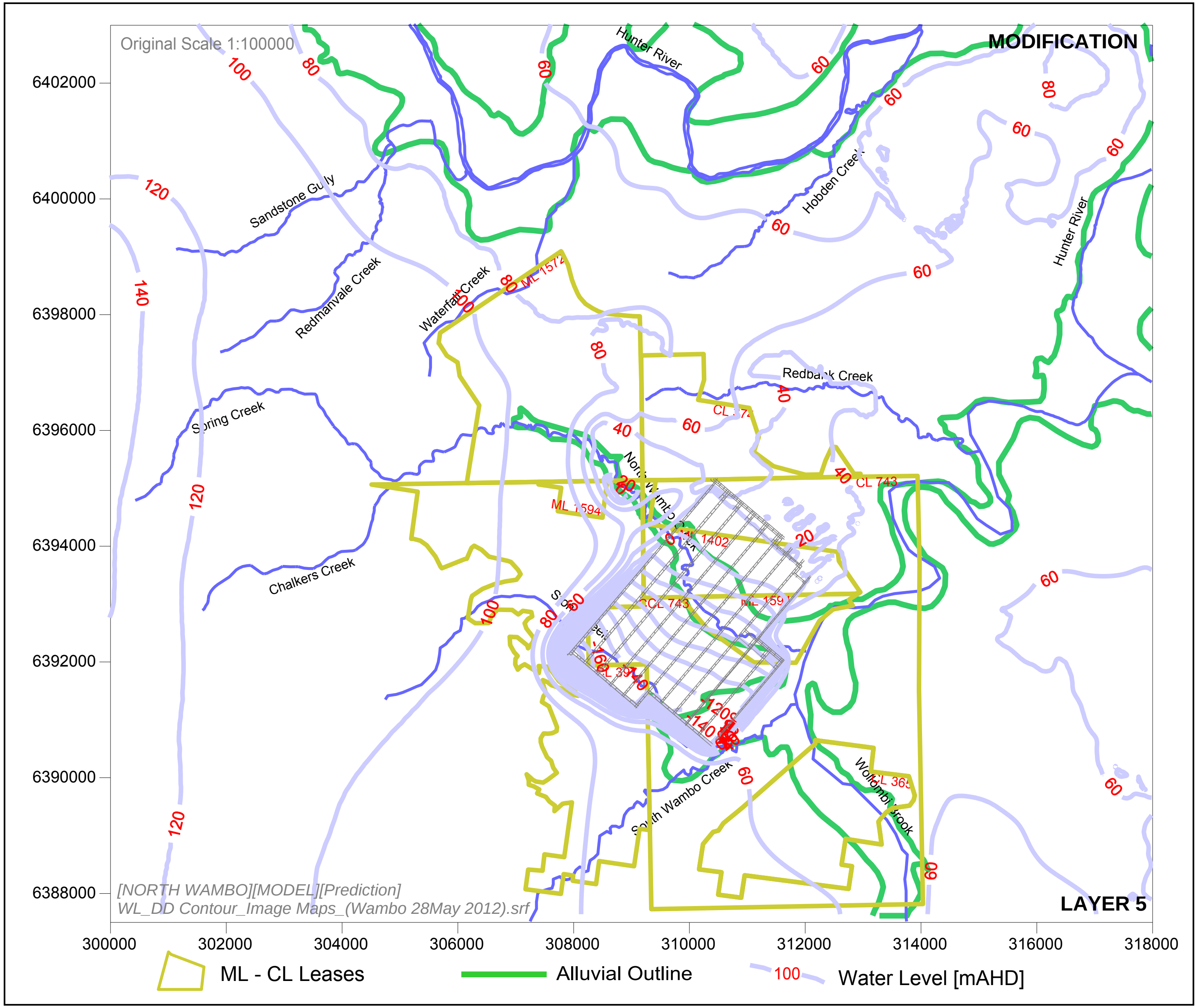


Figure 4.4 Predicted Water Levels in the Wambo Seam (and Model Layer 5) at the End of Mining - Modified Mine Plan (m AHD)

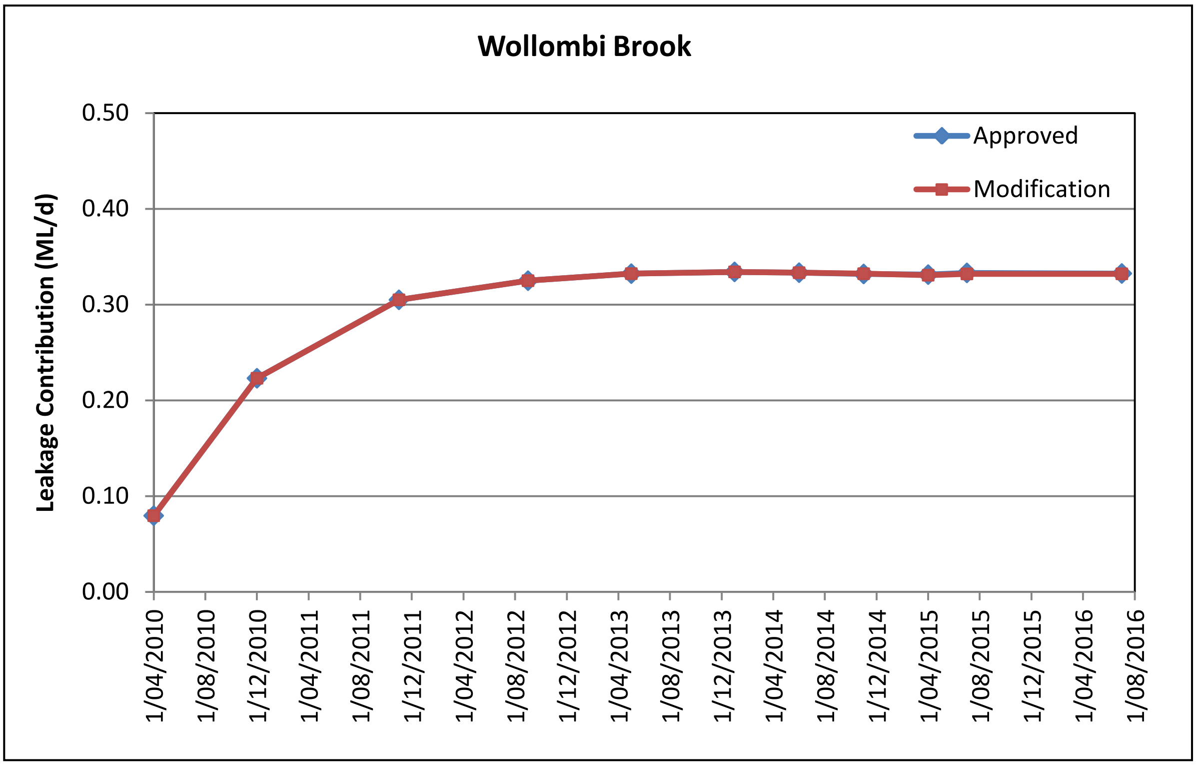


Figure 4.5: Wollombi Brook Baseflow Change

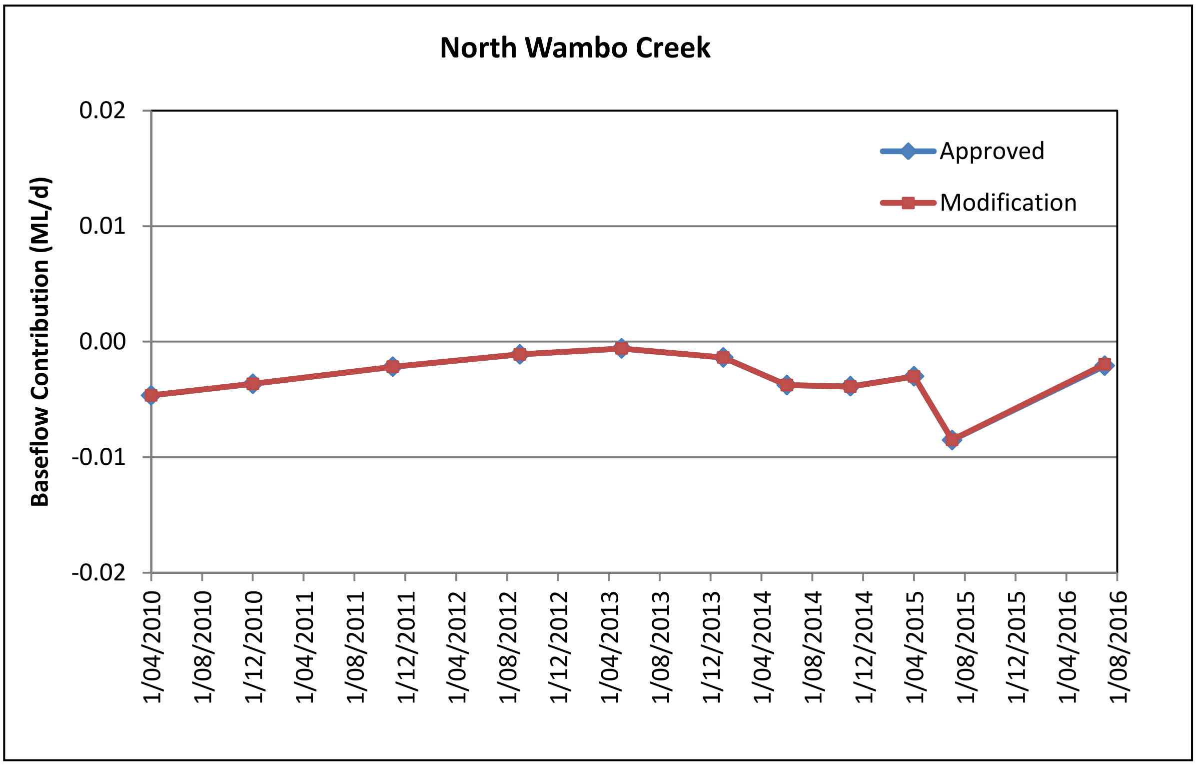


Figure 4.6: North Wambo Creek Baseflow Change

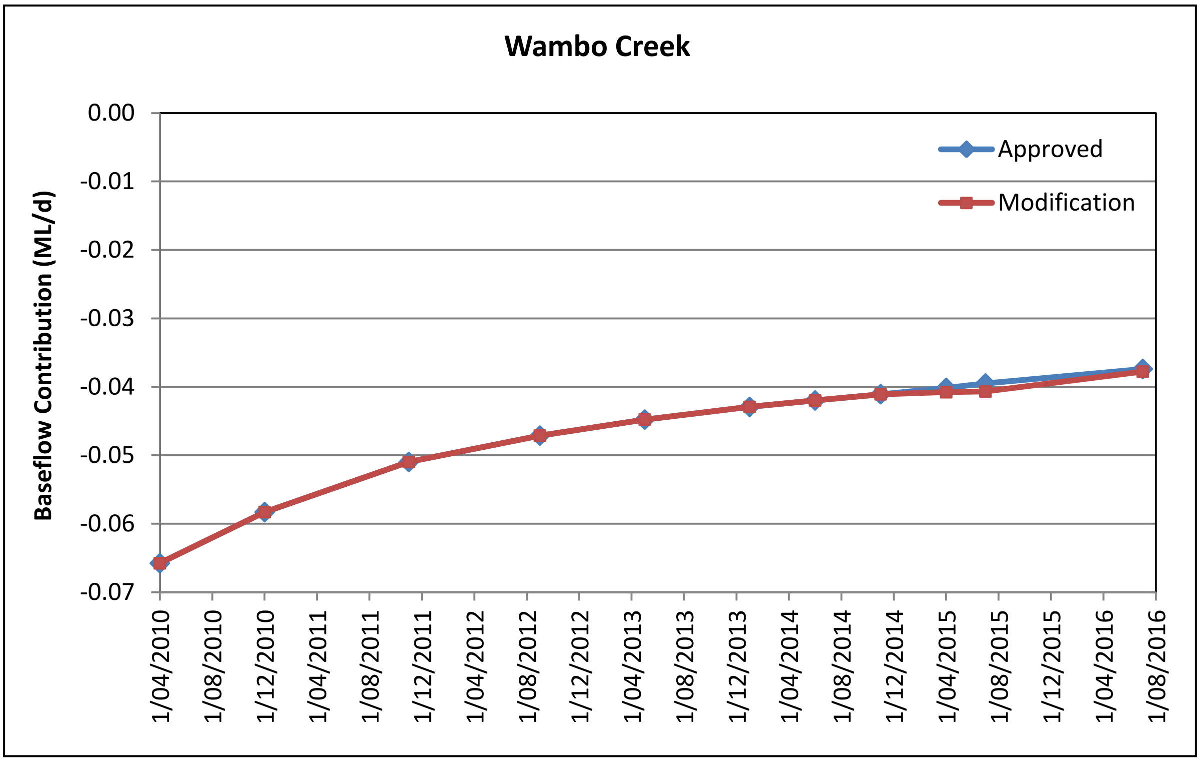


Figure 4.7: Wambo Creek Baseflow Change

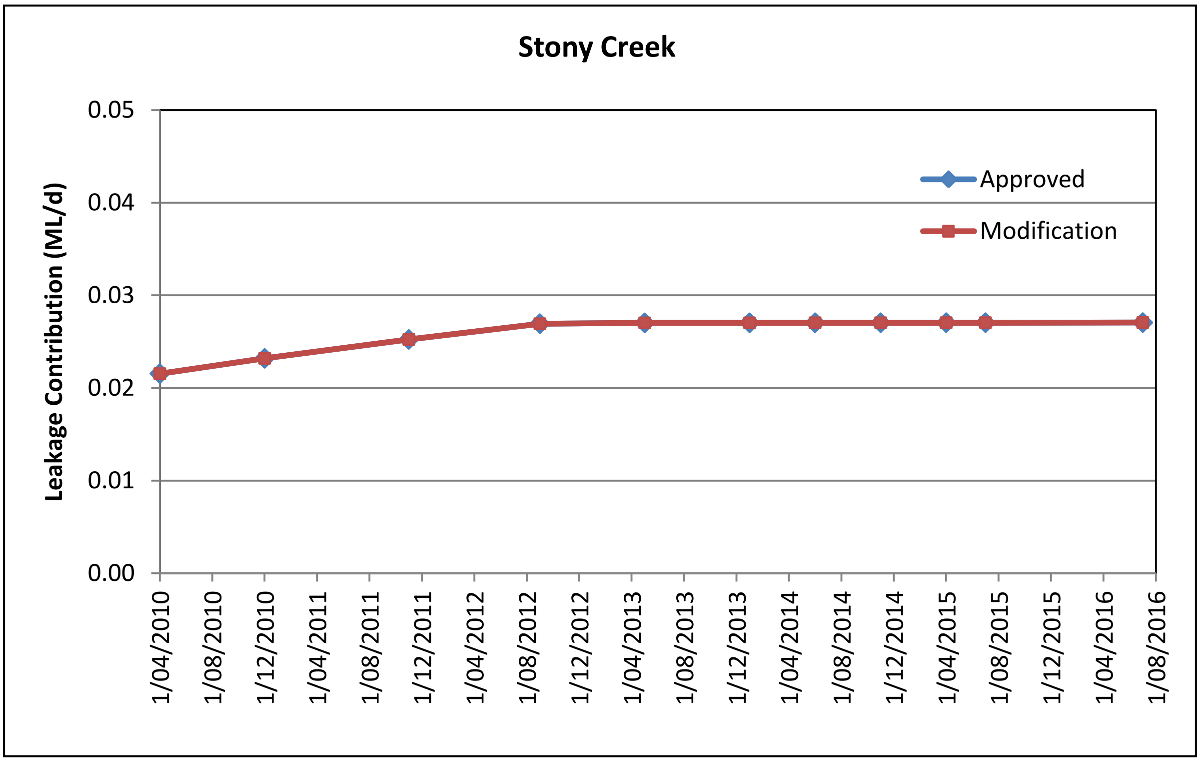


Figure 4.8: Stony Creek Baseflow Change

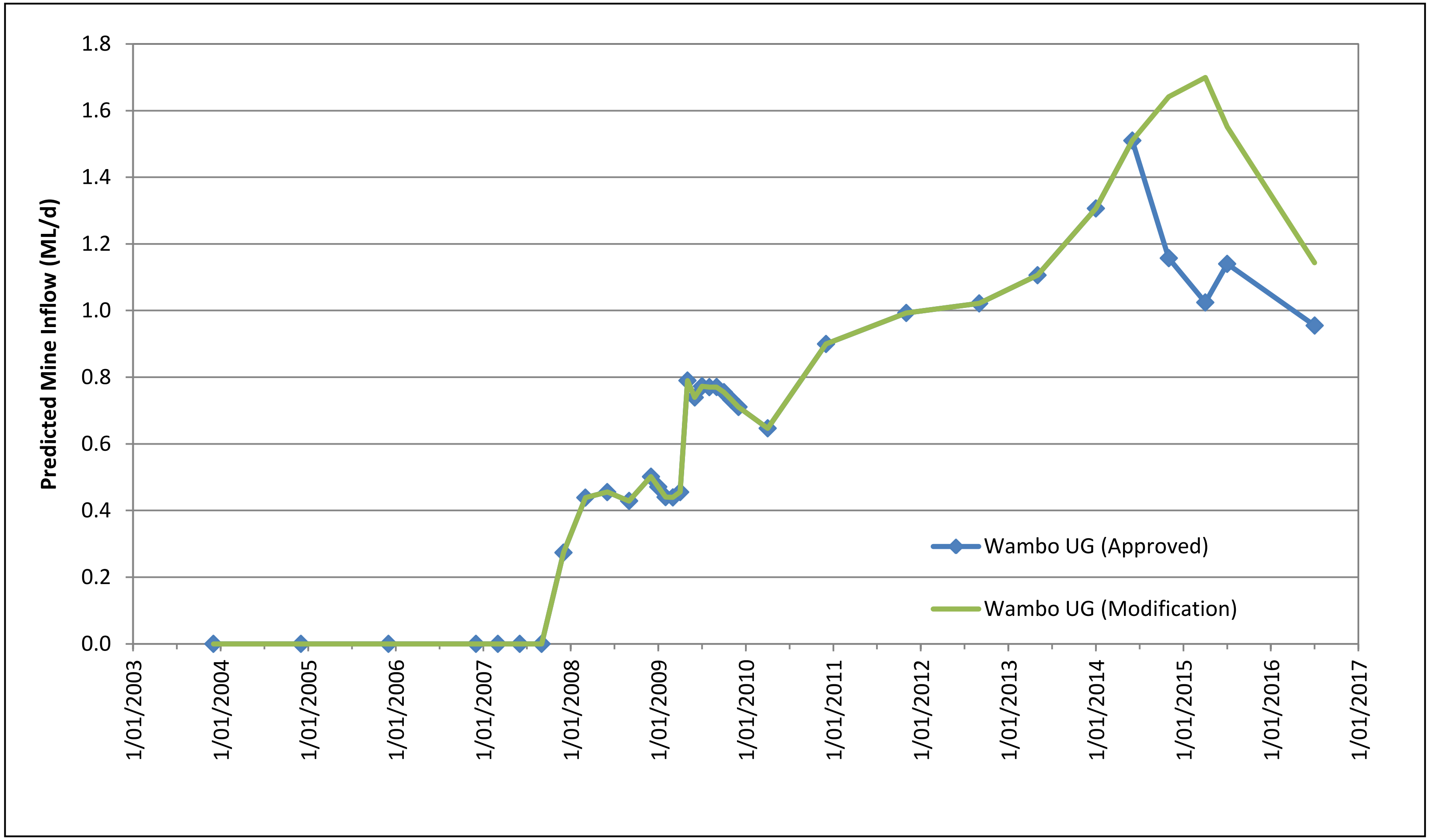


Figure 4.9: Predicted Mine Inflow Rates

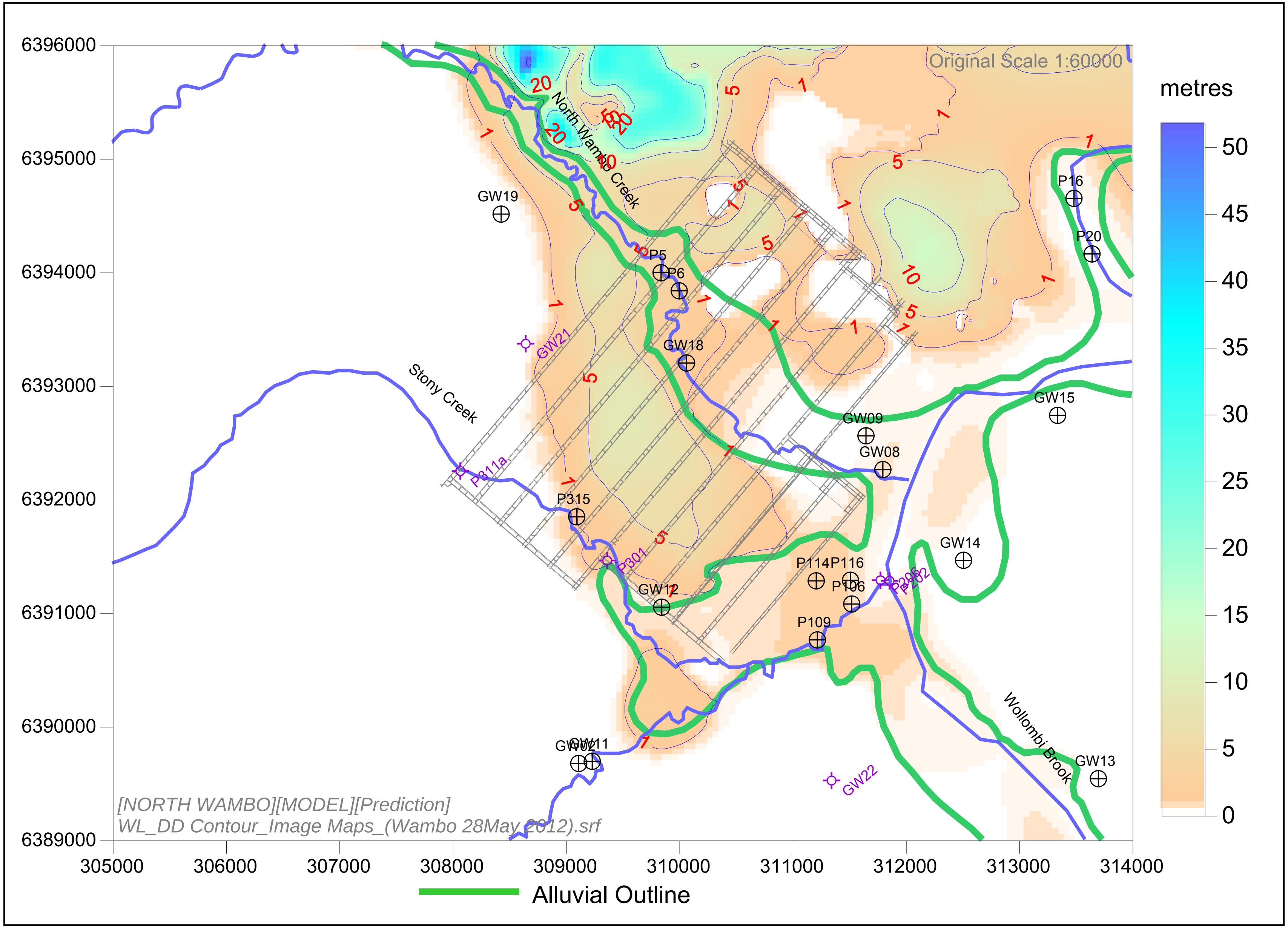


Figure 5.1: Cumulative Drawdown Impact in Alluvium / Regolith at End of Approved Mining (m)

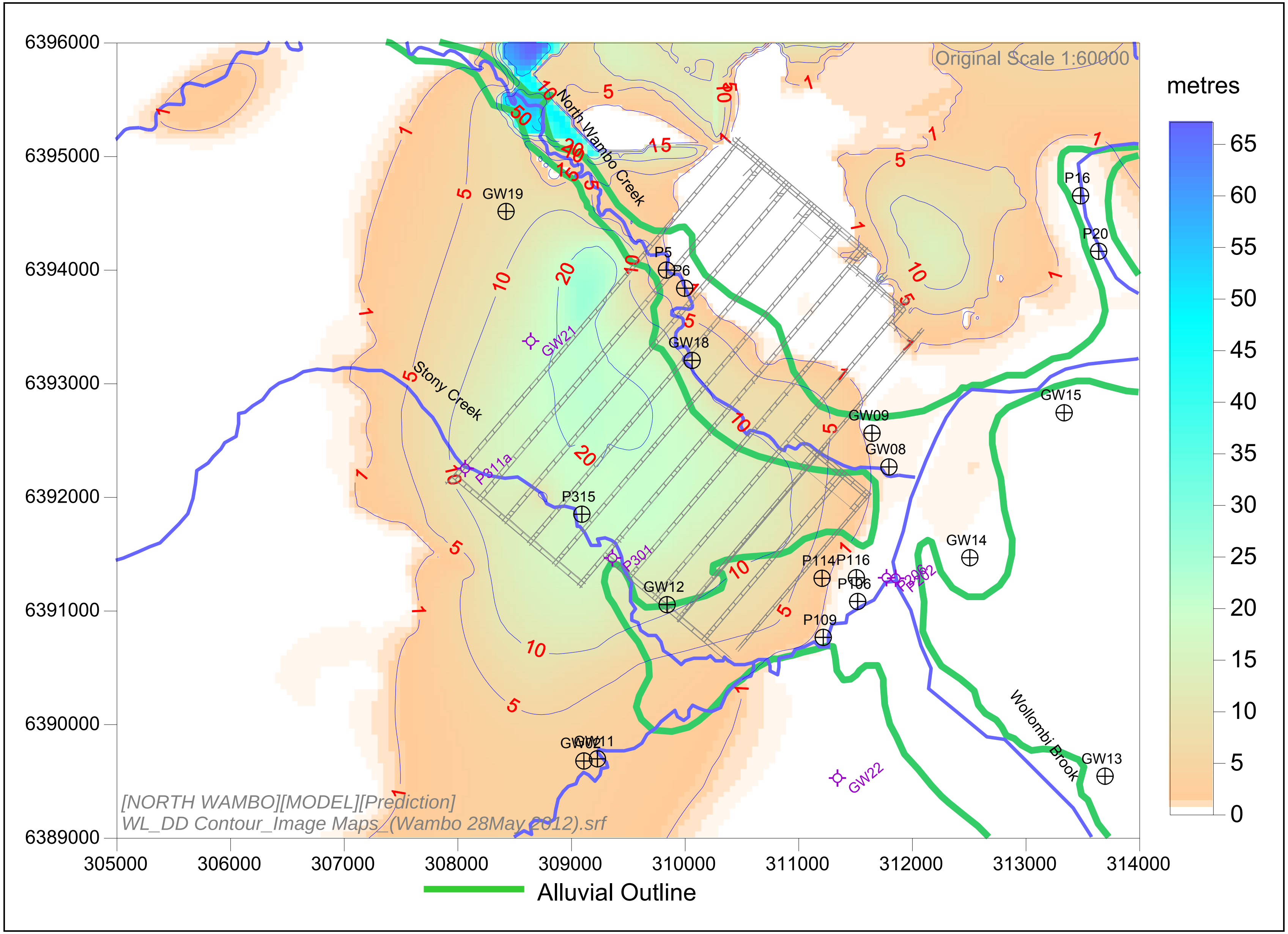


Figure 5.2: Cumulative Drawdown Impact in Whybrow Seam Overburden at End of Approved Mining (m)

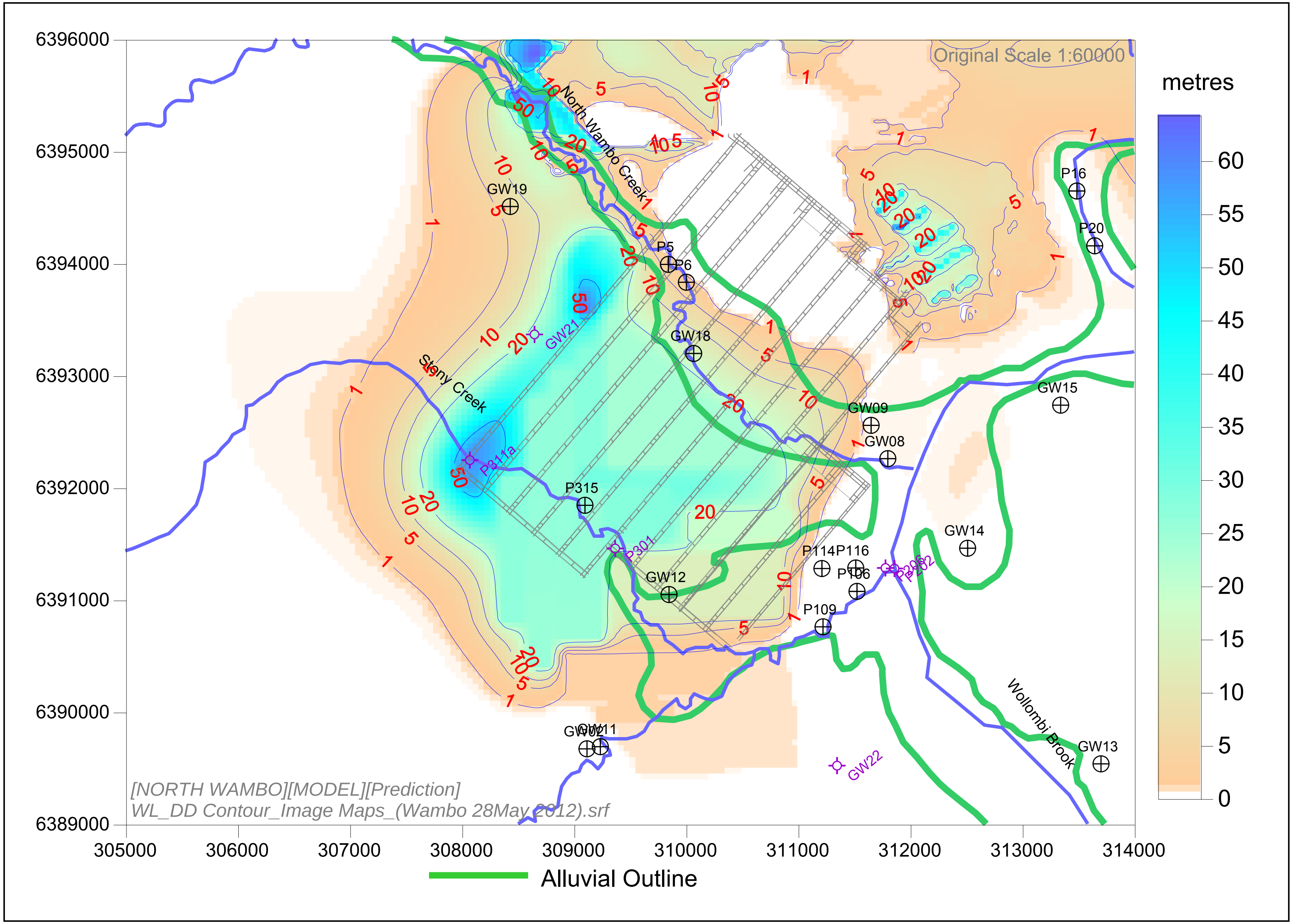


Figure 5.3: Cumulative Drawdown Impact in Whybrow Seam at End of Approved Mining (m)

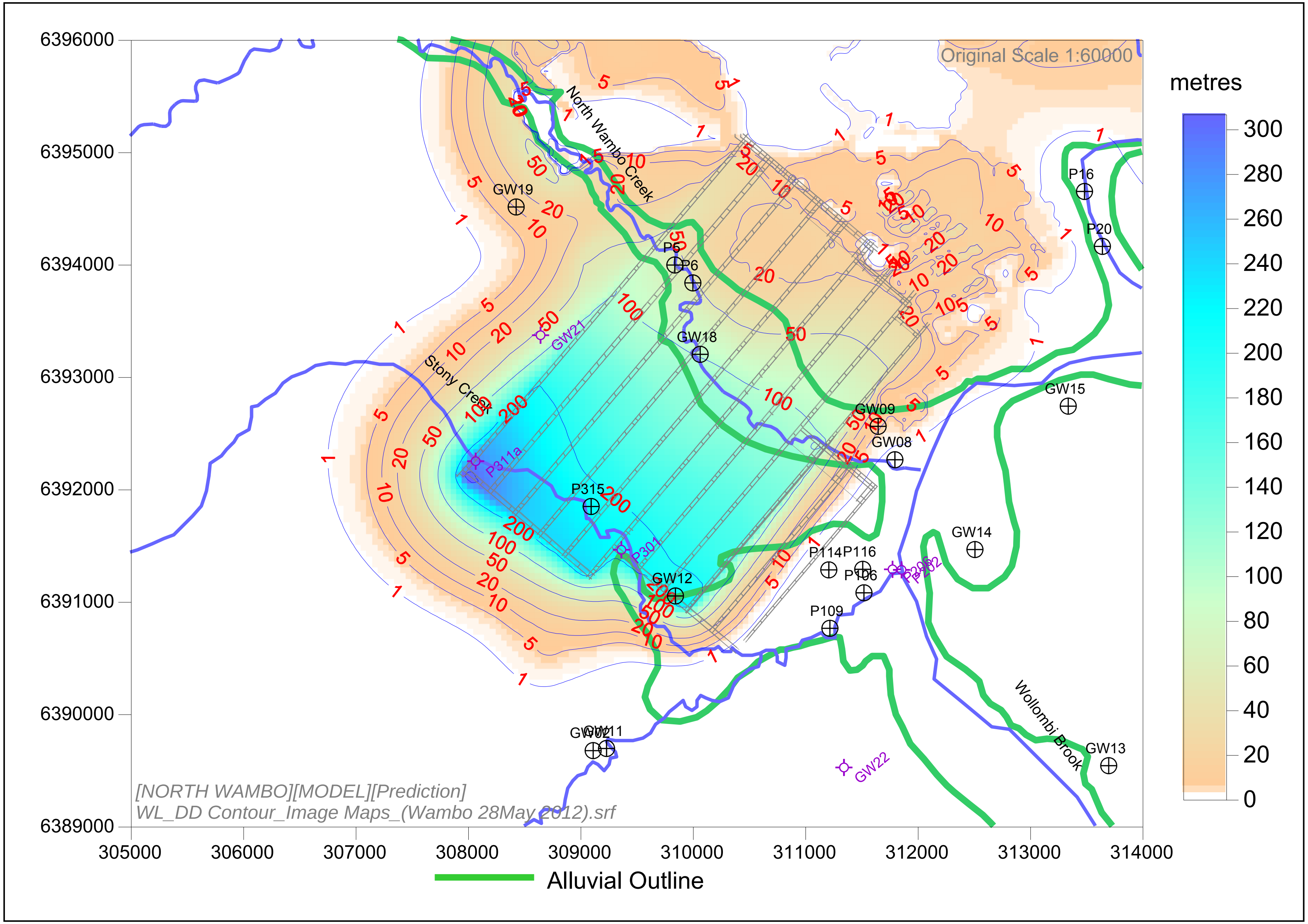


Figure 5.4: Cumulative Drawdown Impact in Wambo Seam at End of Approved Mining (m)

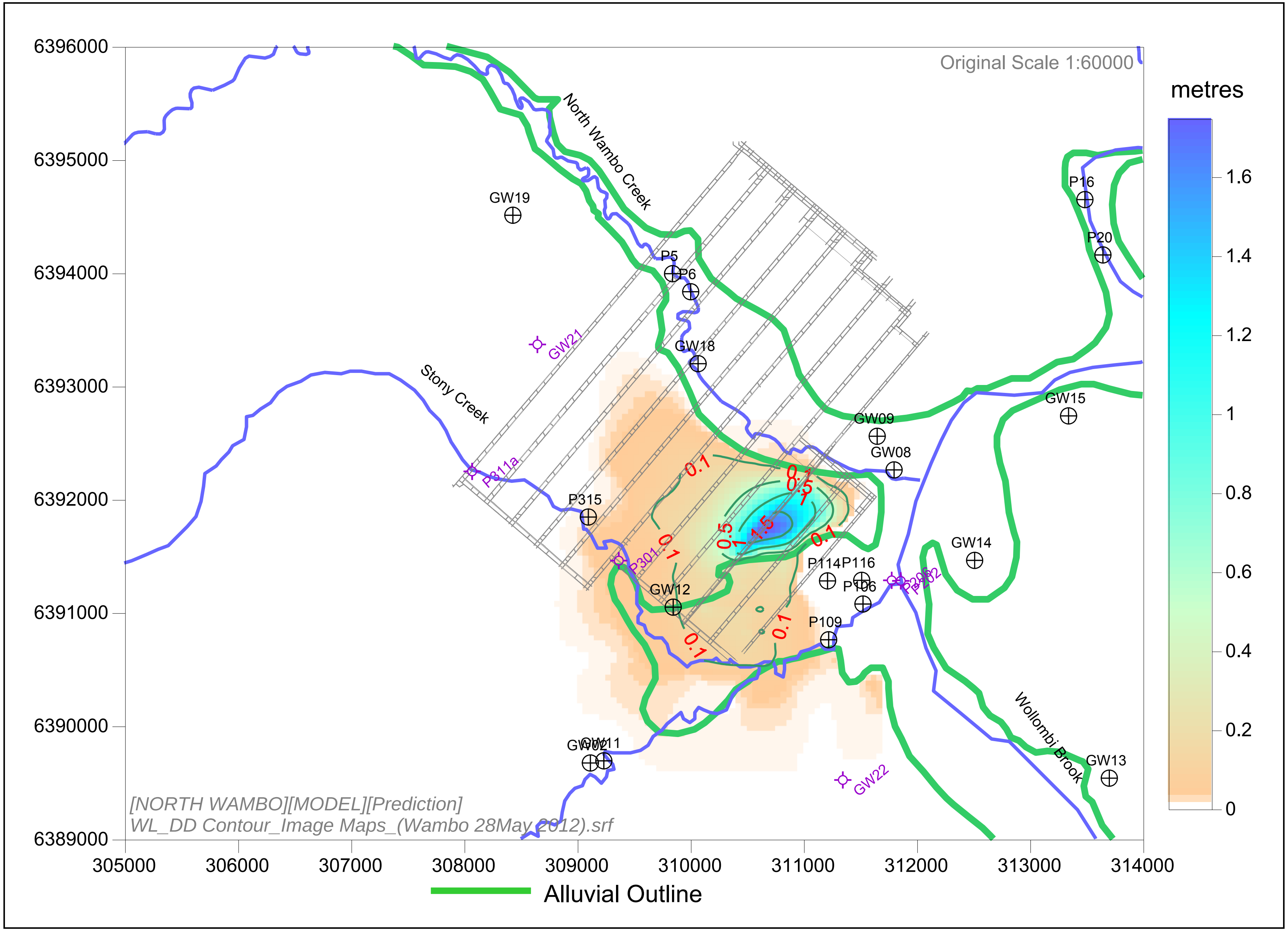


Figure 5.5: Incremental Drawdown in Alluvium / Regolith due to the Modification (m)

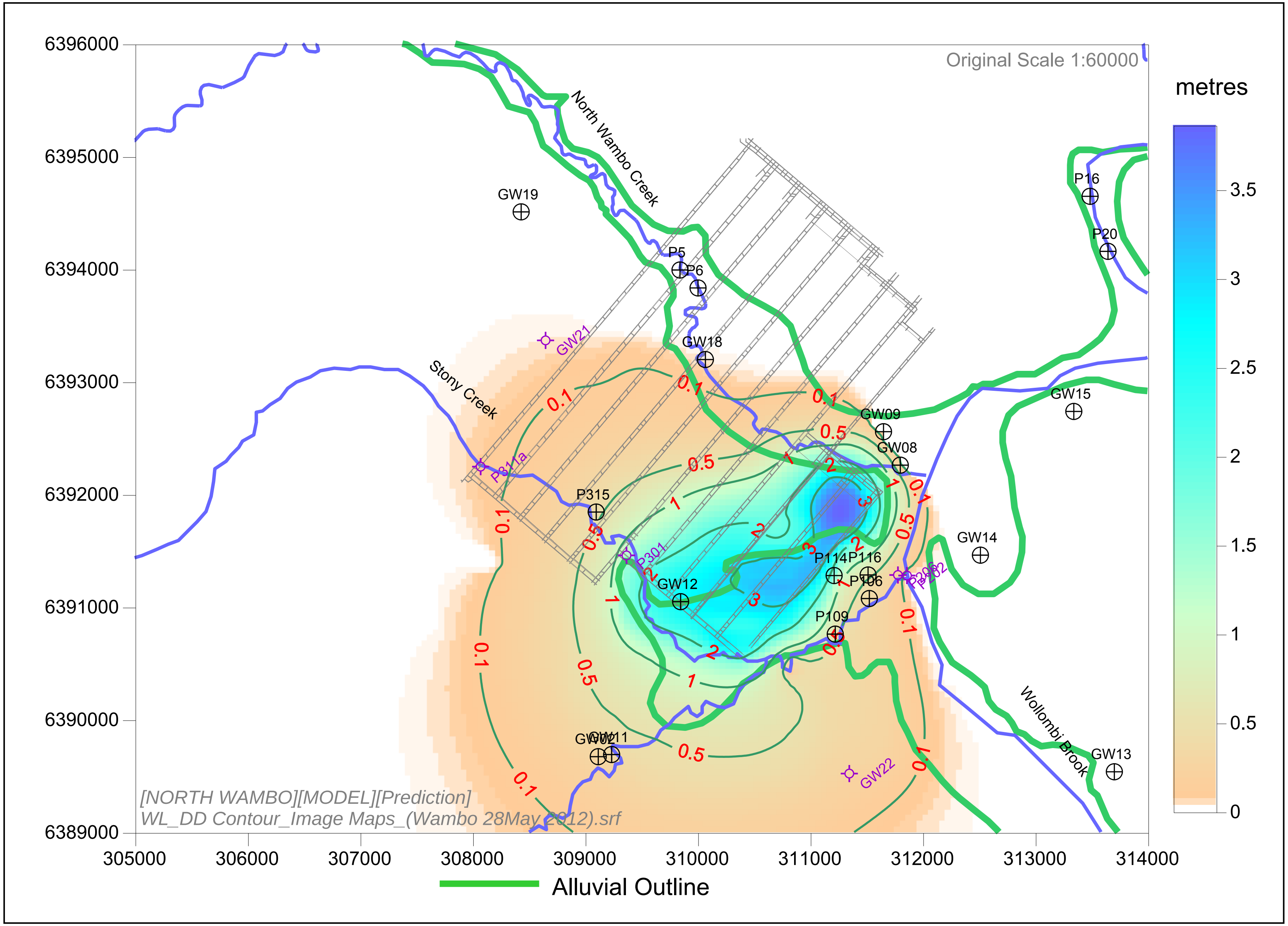


Figure 5.6: Incremental Drawdown in Whybrow Seam Overburden due to the Modification (m)

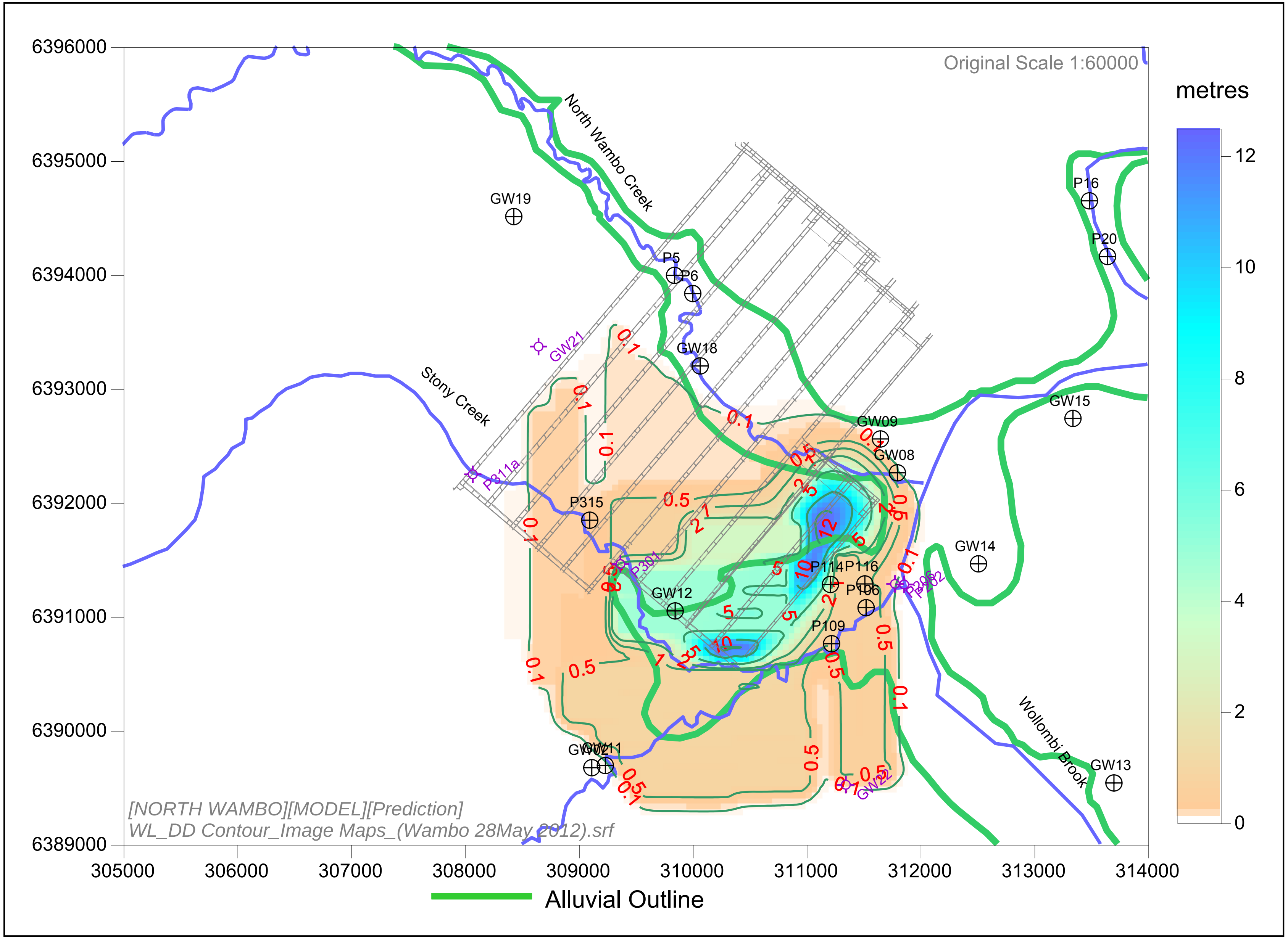


Figure 5.7: Incremental Drawdown in Whybrow Seam due to the Modification (m)

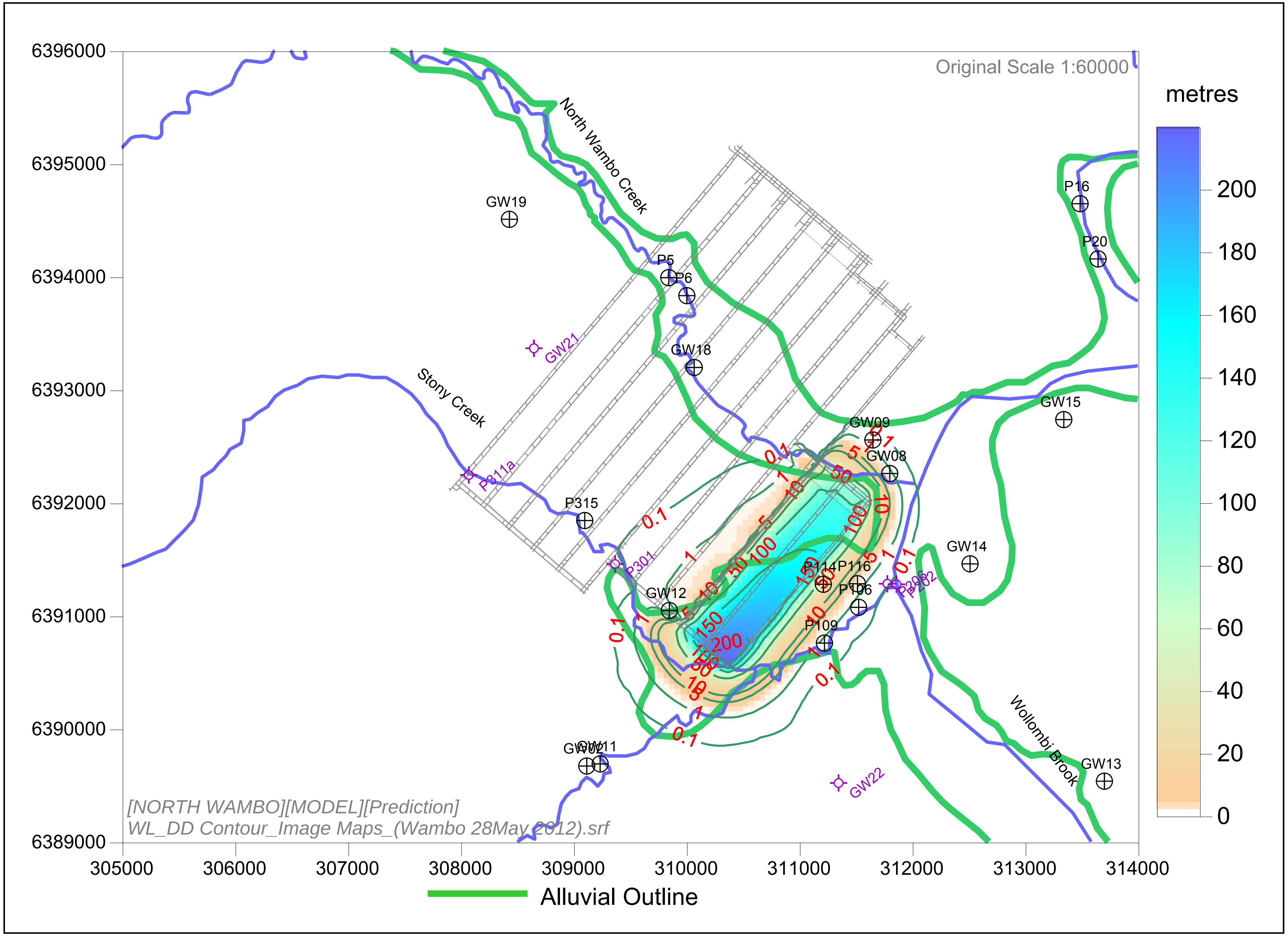
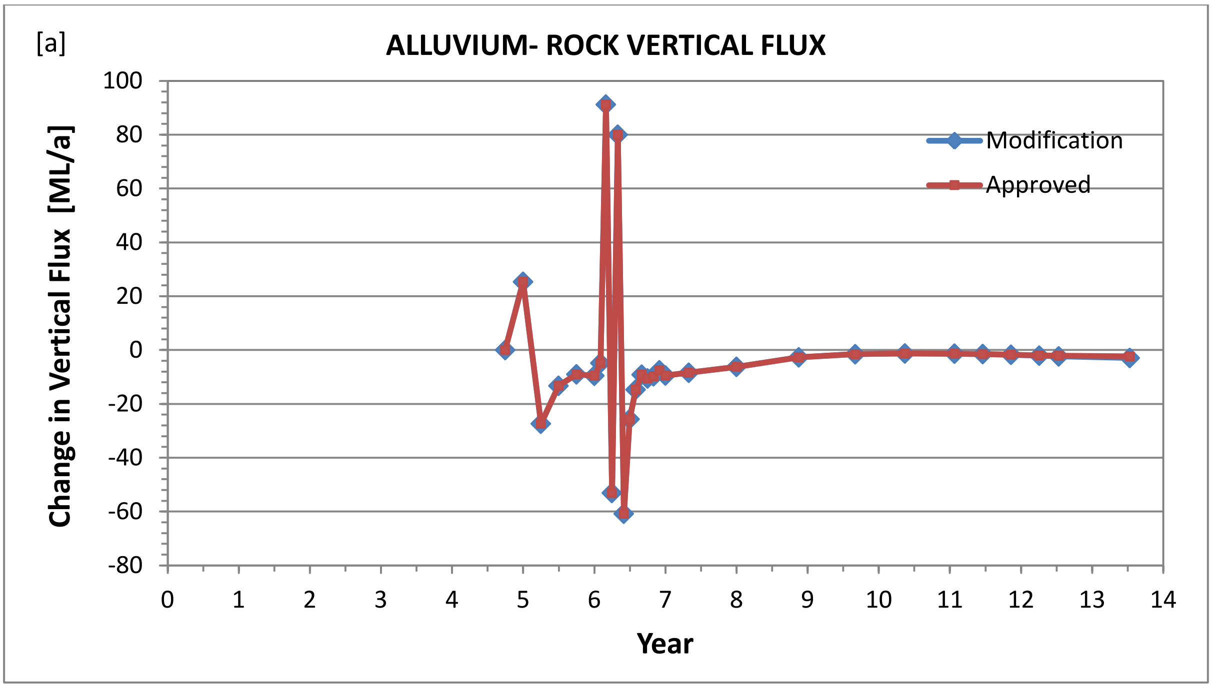


Figure 5.8: Incremental Drawdown in Wambo Seam due to the Modification (m)



Note: a negative change means a loss of water from the alluvium

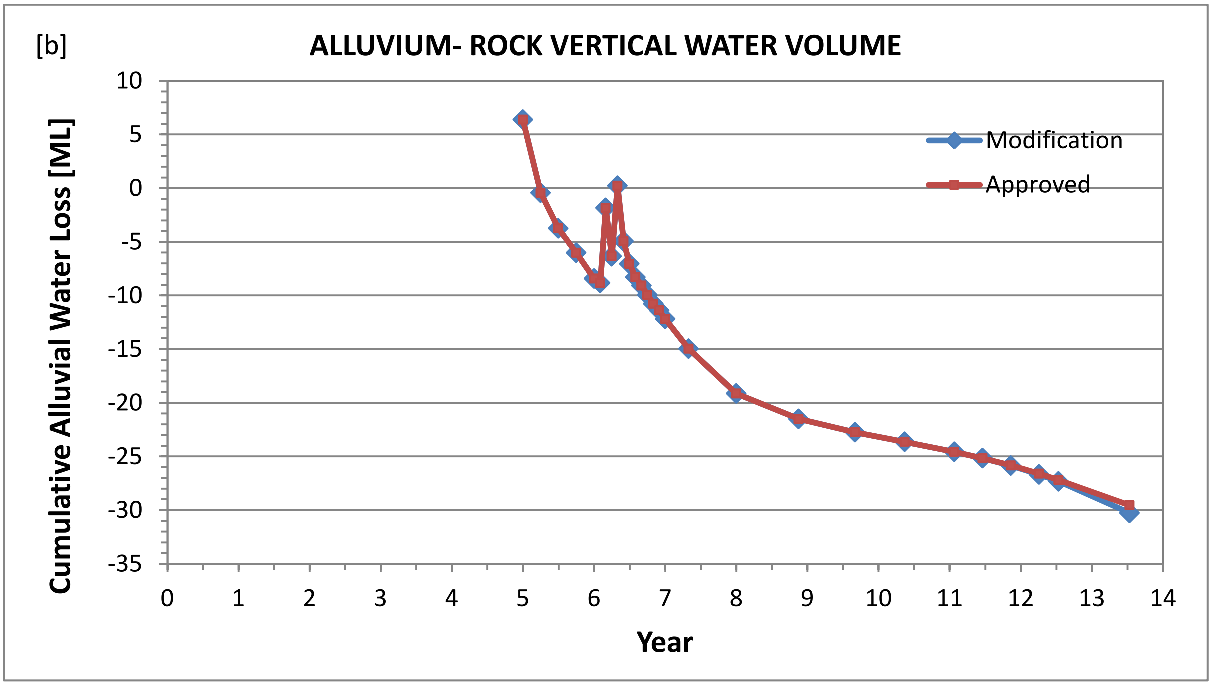


Figure 5.9: Groundwater Flux between Alluvium and Underlying Rock: [a] Changes due to Mining; [b] Cumulative Loss of Water from Alluvium due to Mining

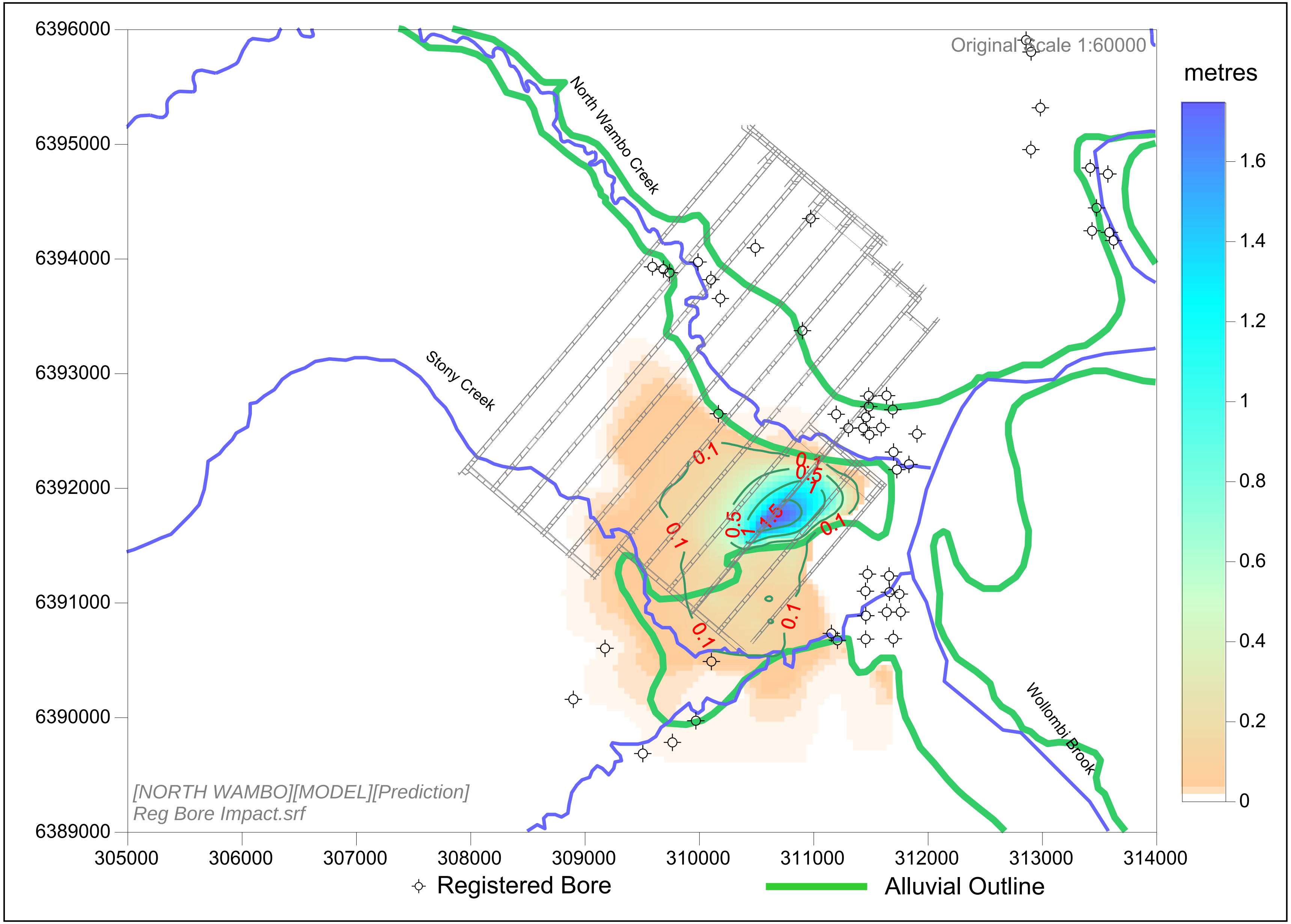


Figure 5.10: Proximity of Registered Bores to Incremental Drawdown in Alluvium / Regolith due to the Modification (m)

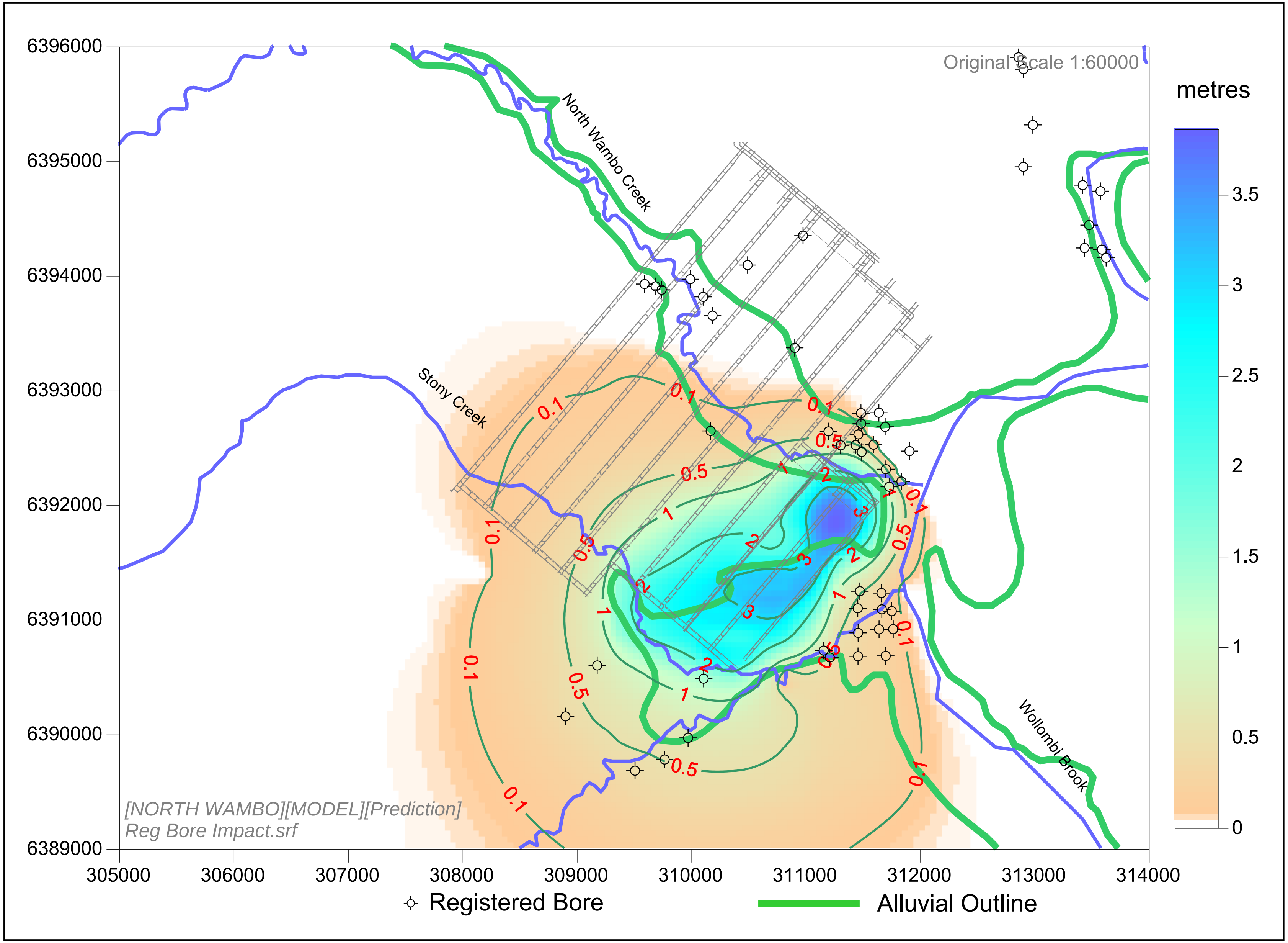


Figure 5.11: Proximity of Registered Bores to Incremental Drawdown in Triassic Sandstone and Permian Overburden due to the Modification (m)

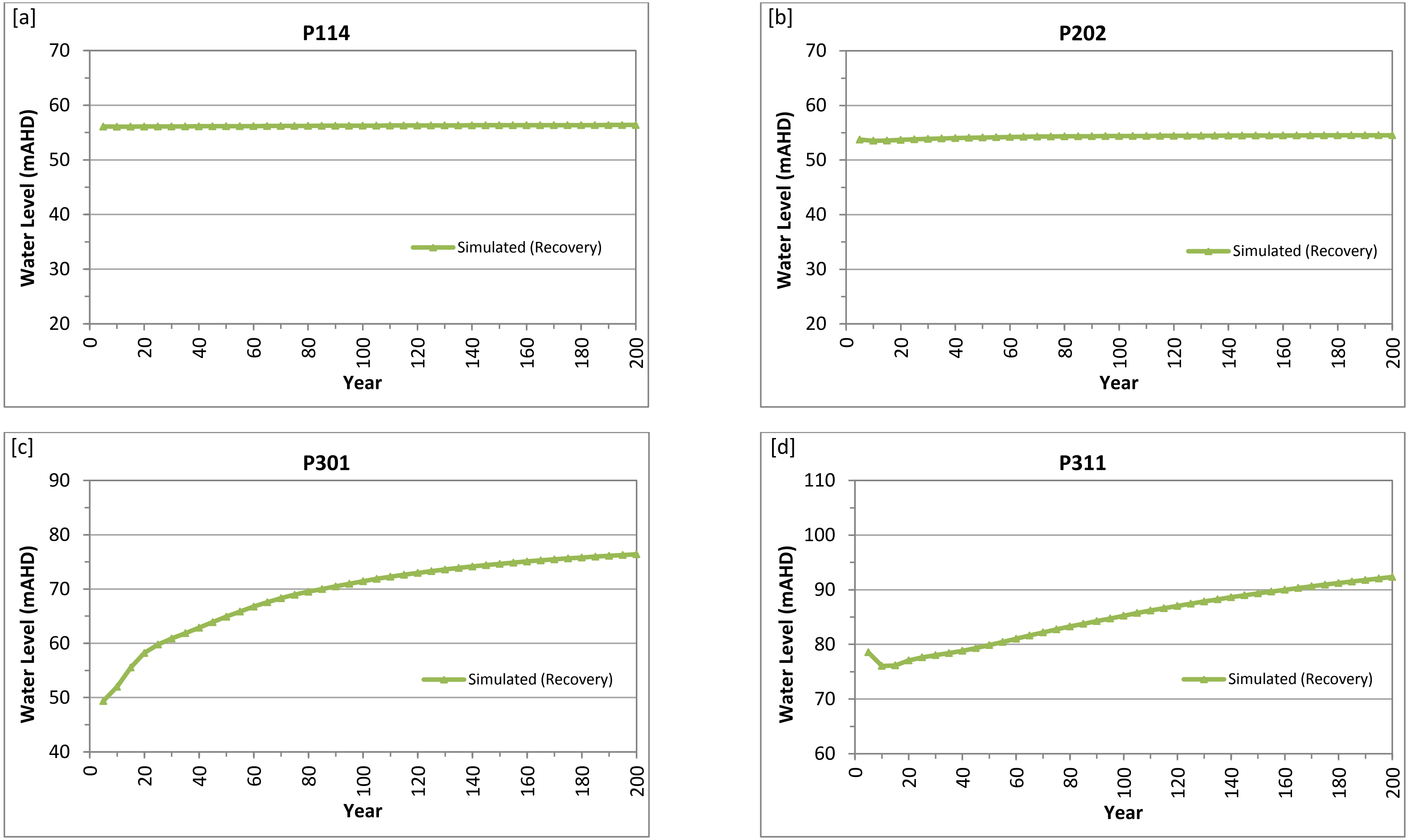


Figure 5.12: Representative Recovery Hydrographs: [a] P114 at 150 m east of LW10 in Layer 1 (alluvium); [b] P202 at 650 m east of LW10 in Layer 2 (overburden); [c] P301 at south-west end of LW6 in Layer 2 (overburden); and [d] P311 at south-west end of LW1 in Layer 2 (overburden)

ATTACHMENT A

Groundwater

Hydrographs

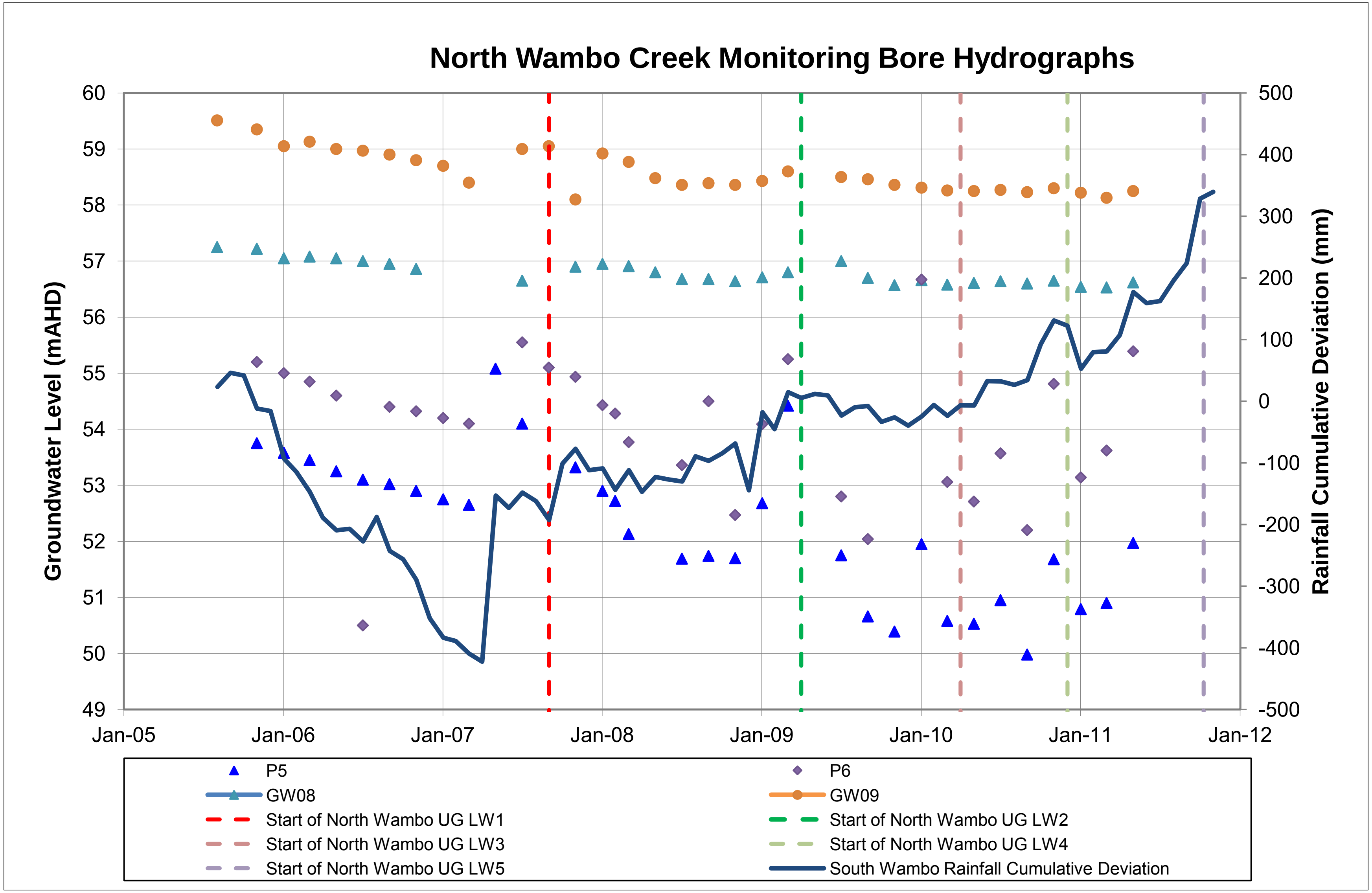


Figure A1a: North Wambo Creek Monitoring Bore Hydrographs

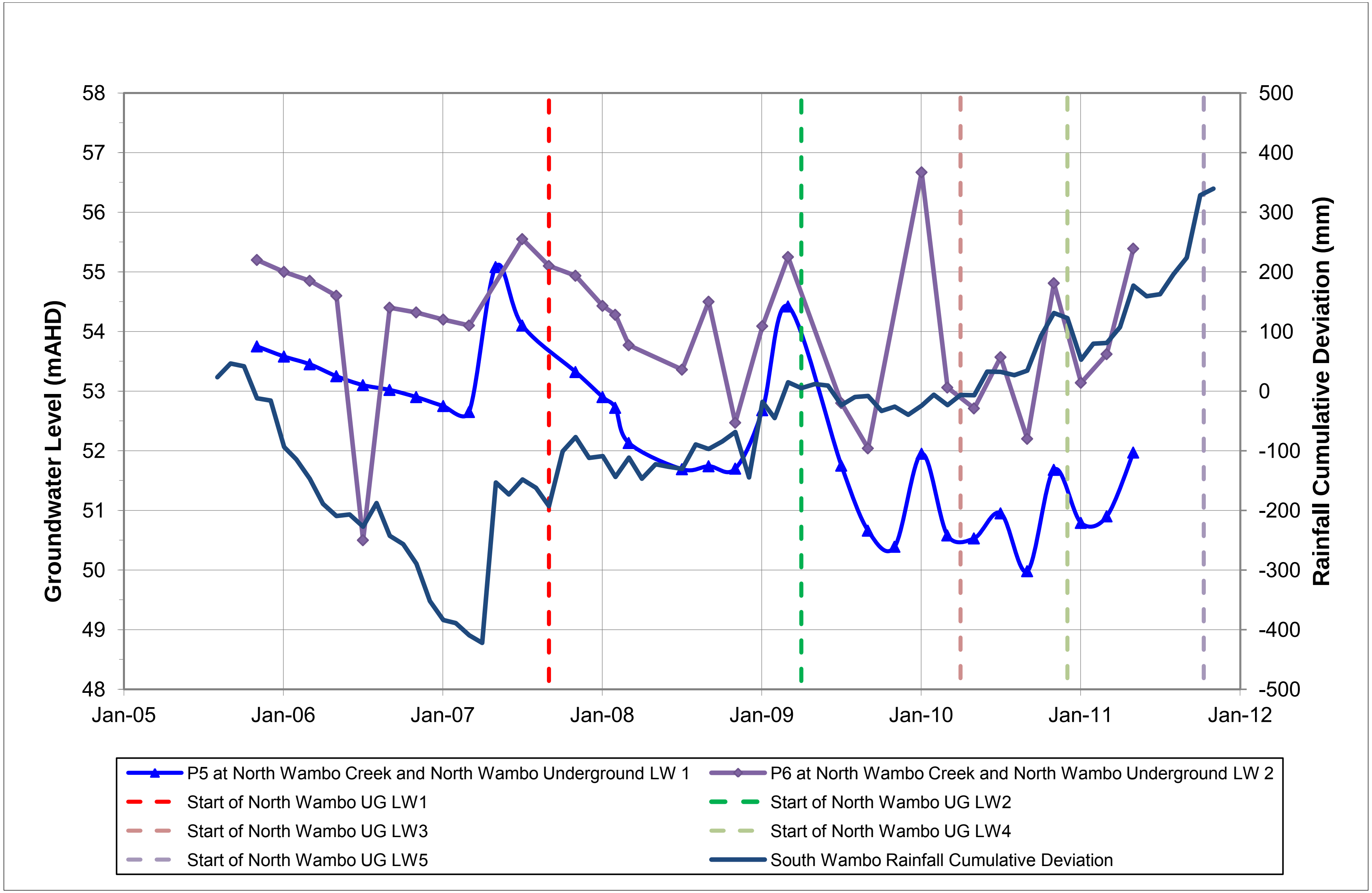


Figure A1b: North Wambo Creek Monitoring Bore Hydrographs at Piezometers P5 and P6

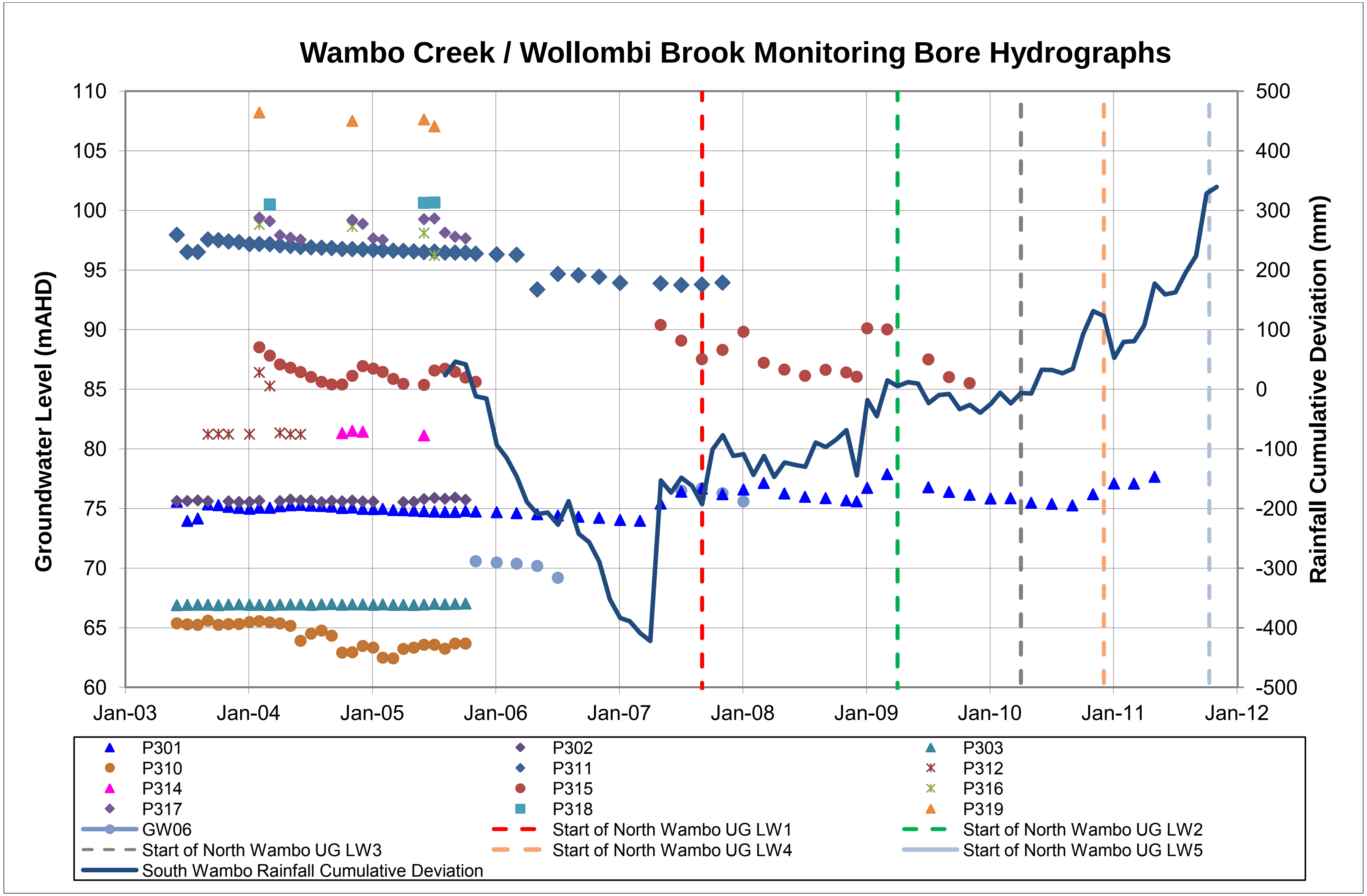


Figure A2a: Wambo Creek / Wollombi Brook Monitoring Bore Hydrographs

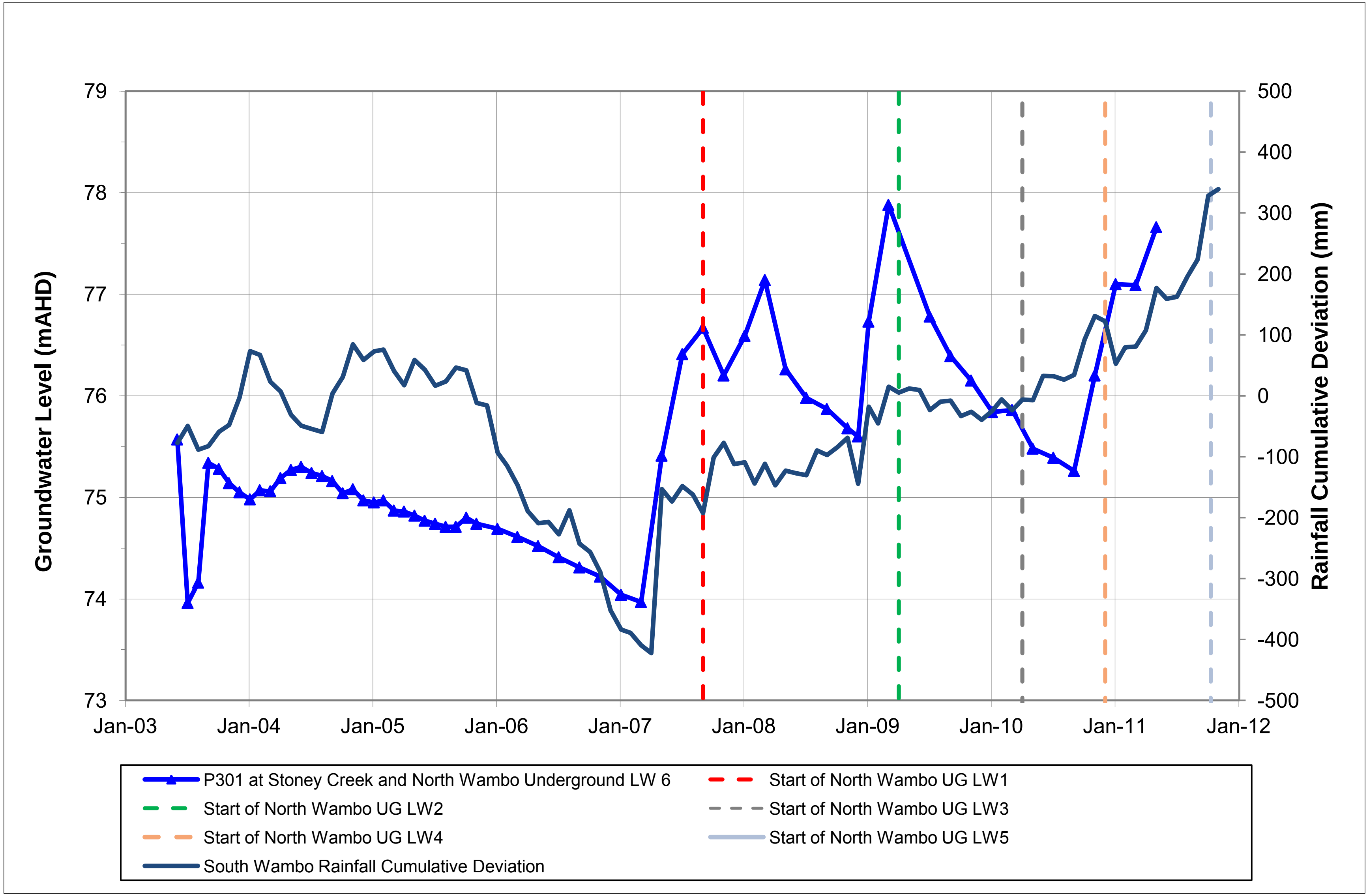


Figure A2b: Stony Creek Monitoring Bore Hydrograph at Piezometer P301

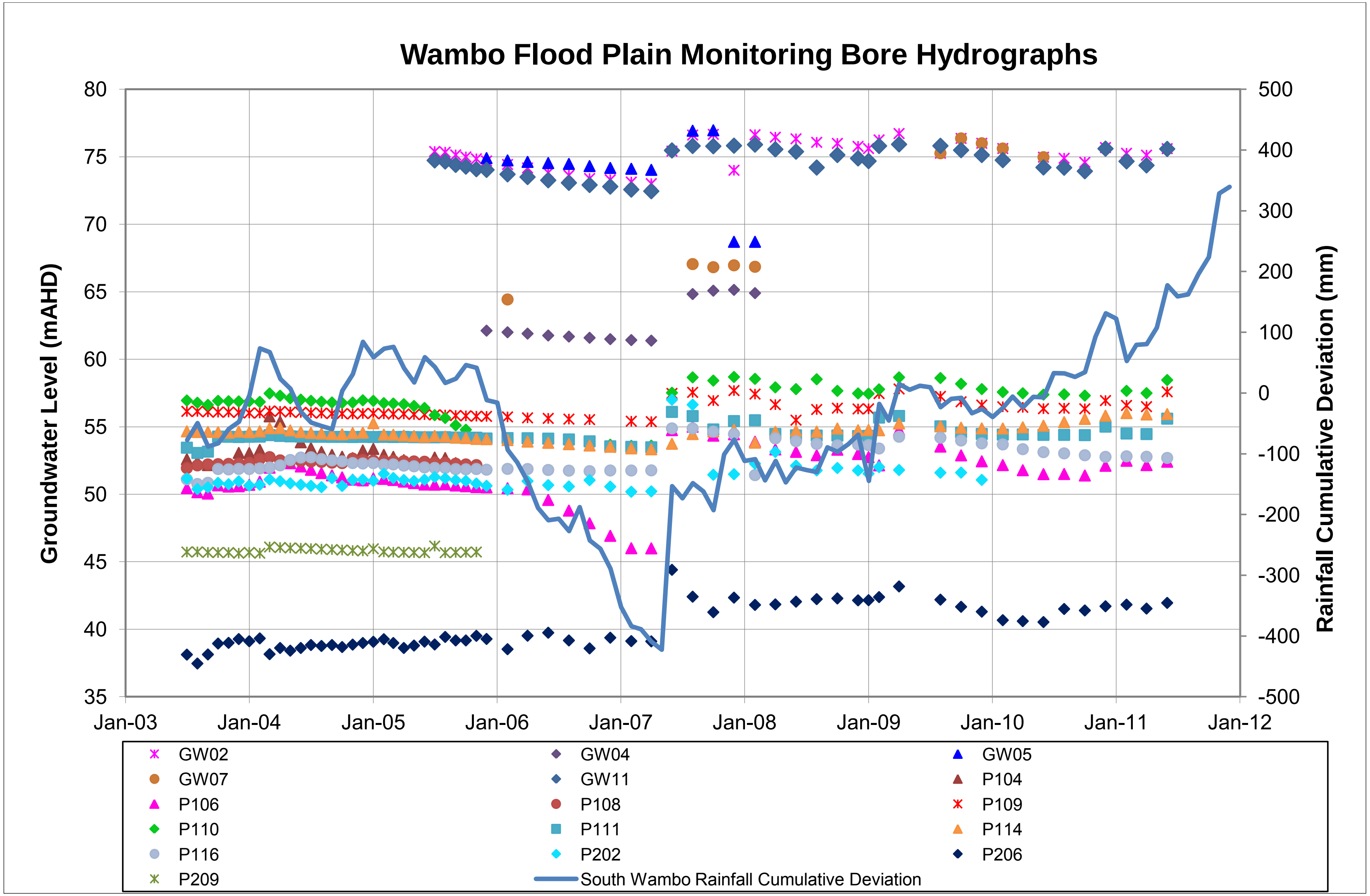


Figure A3a: Flood Plain Monitoring Bore Hydrographs

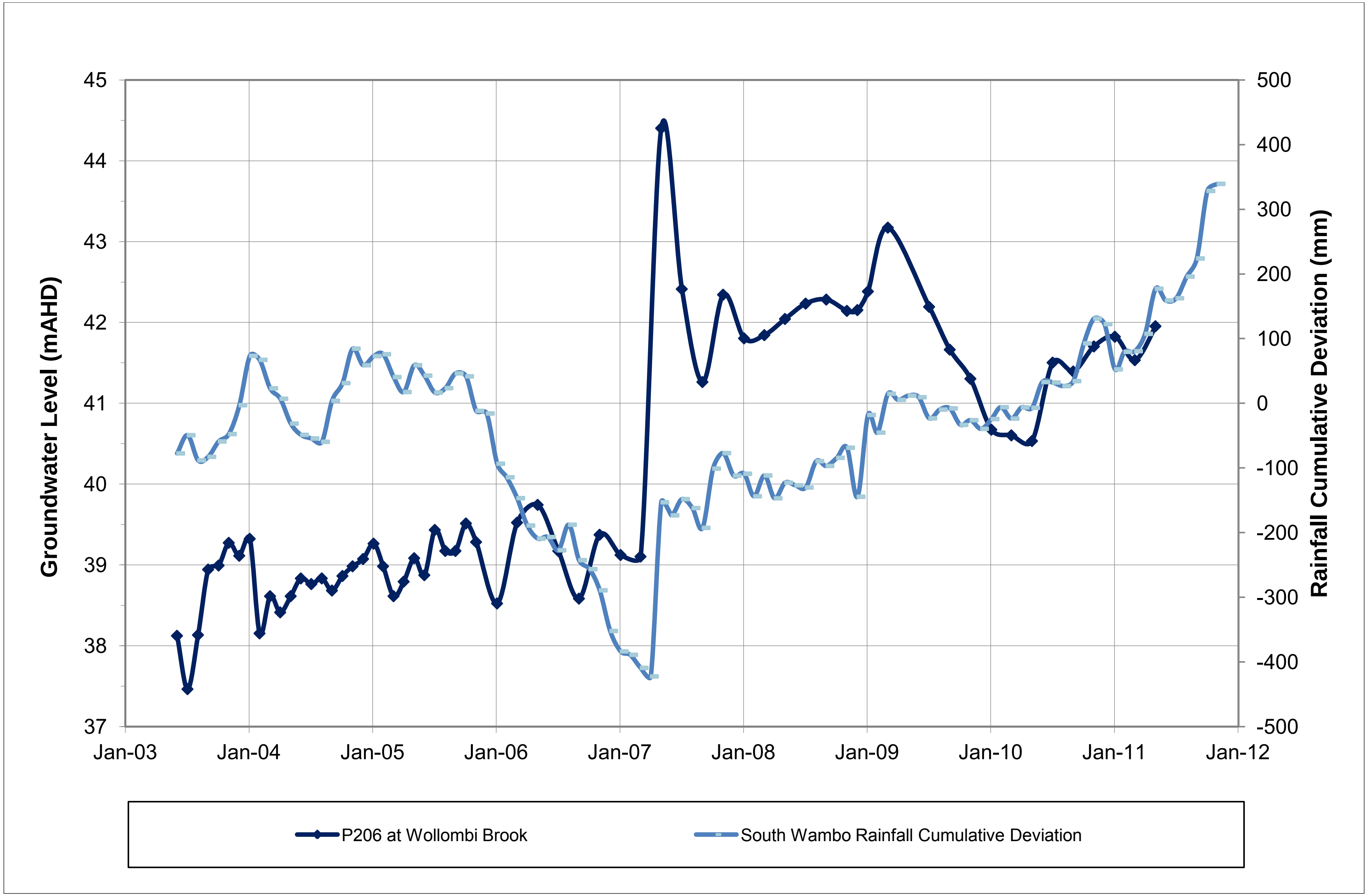


Figure A3b: Wollombi Brook Flood Plain Monitoring Bore Hydrograph at Piezometer P206 near Junction with Wambo Creek

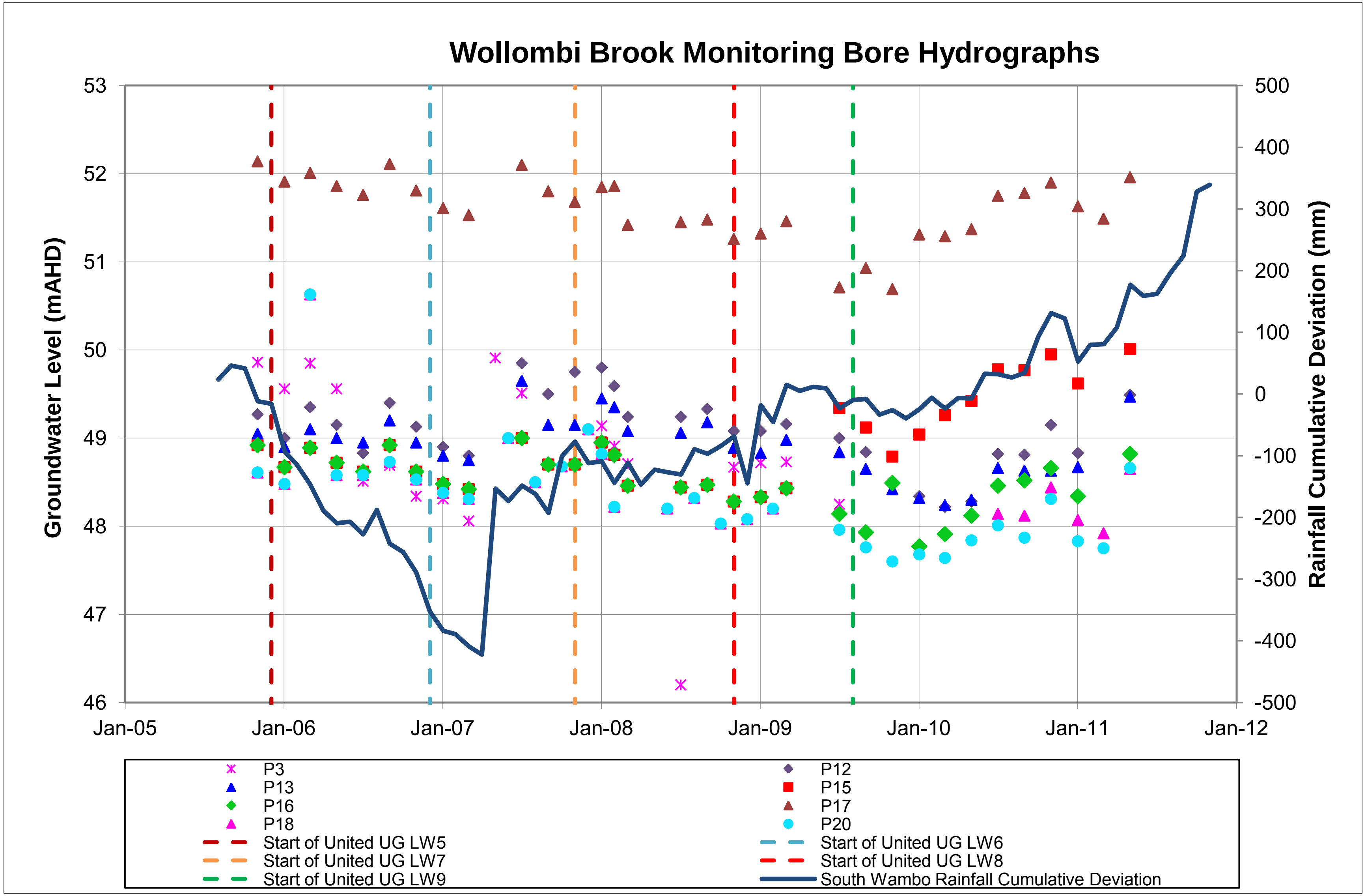


Figure A4a: Wollombi Brook Monitoring Bore Hydrographs

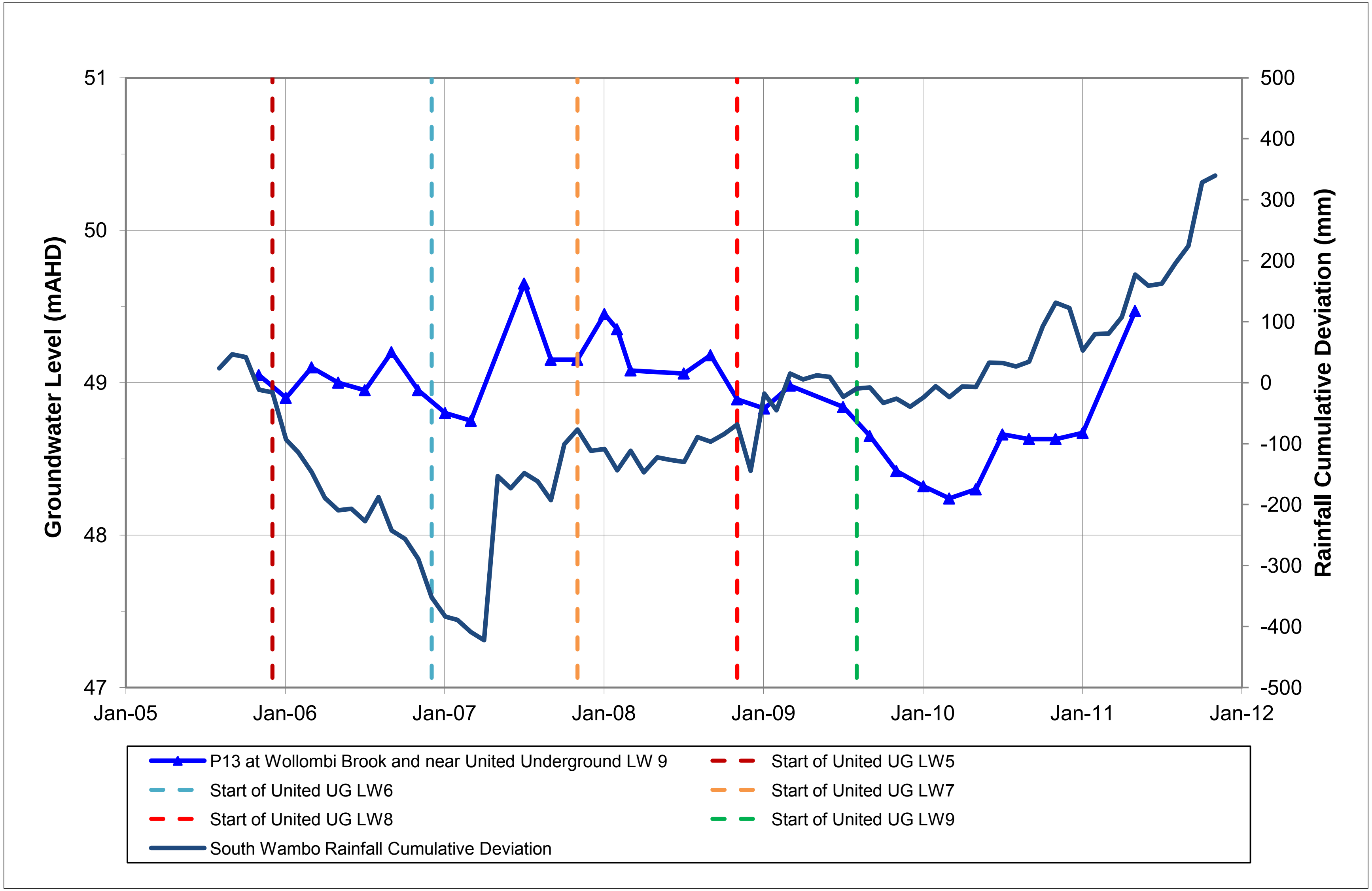
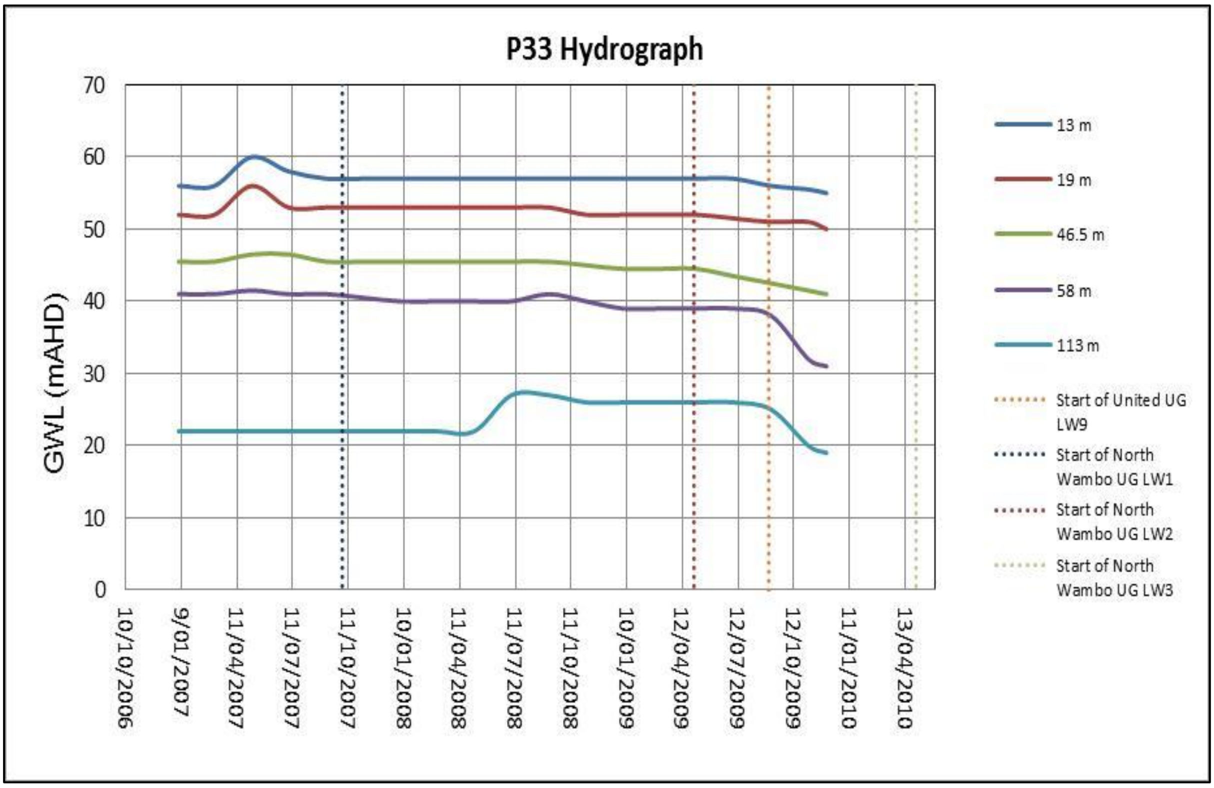


Figure A4b: Wollombi Brook Monitoring Bore Hydrograph at Piezometer P13



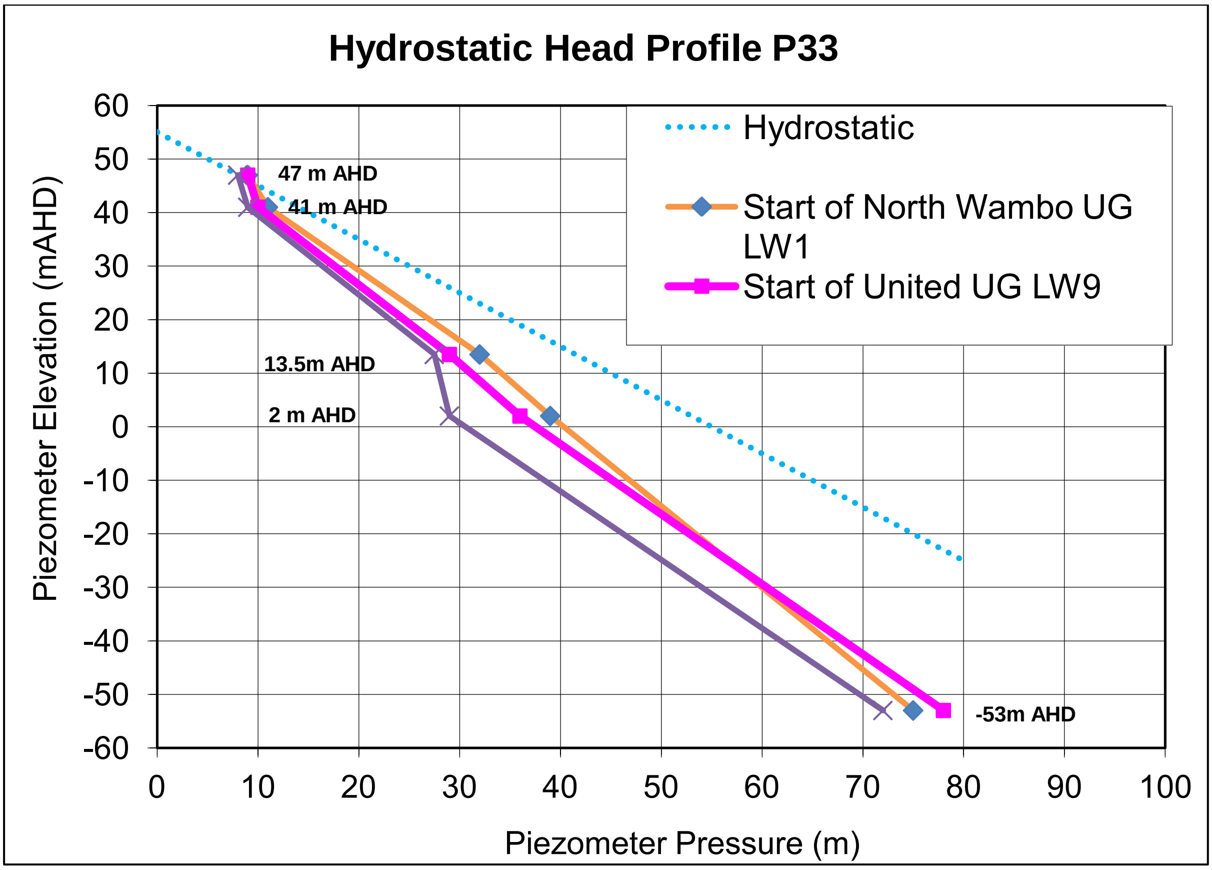
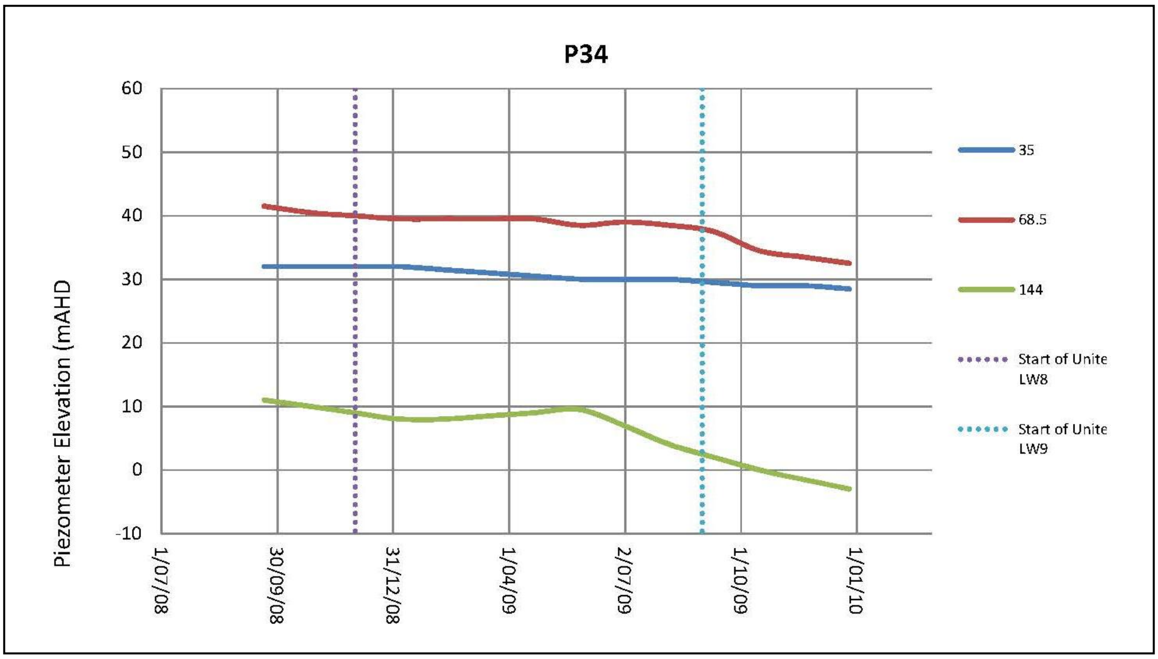


Figure A5: Hydrograph and Pressure Head Profile at P33



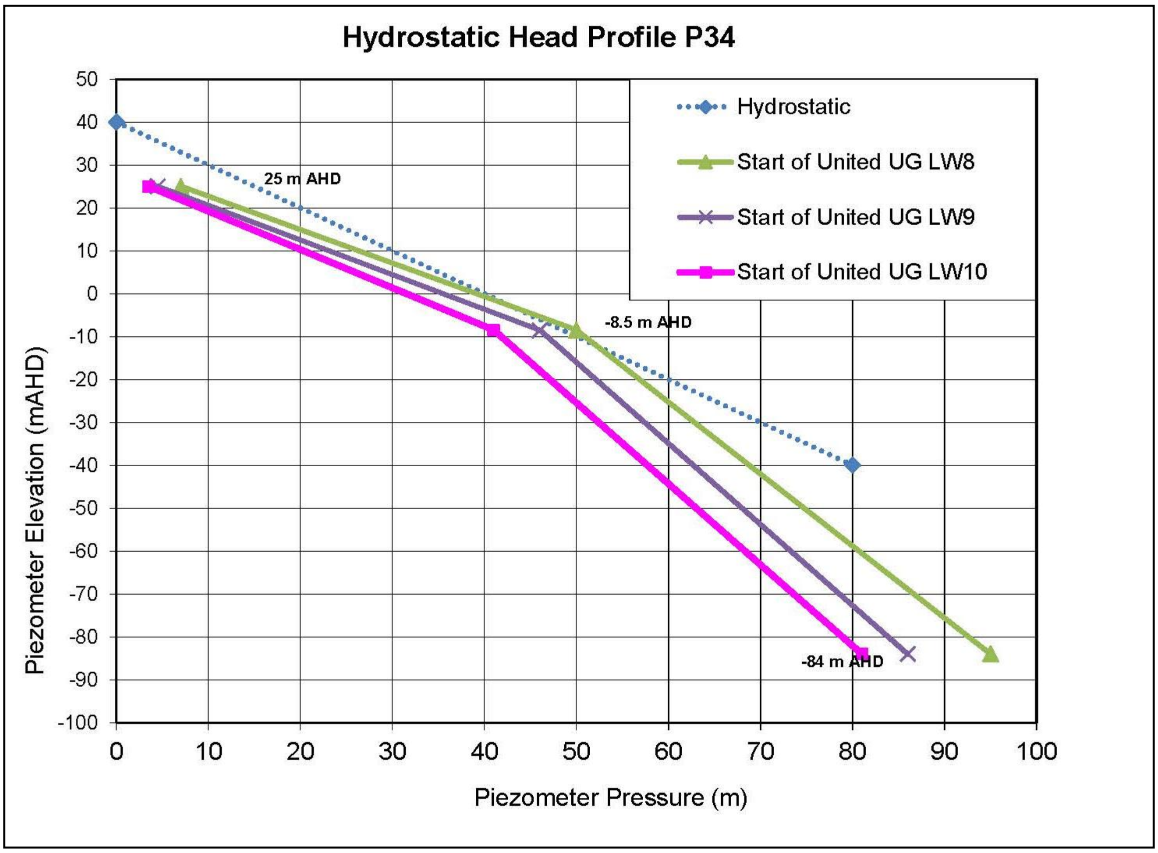
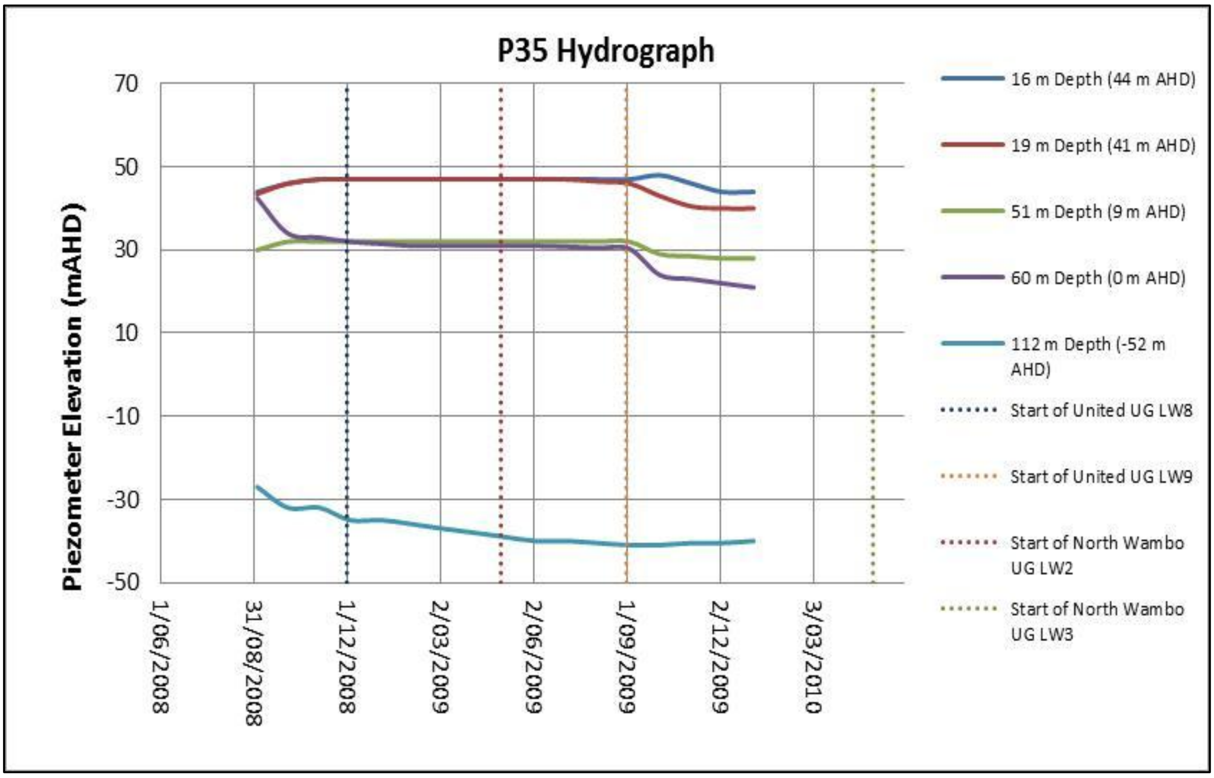


Figure A6: Hydrograph and Pressure Head Profile at P34



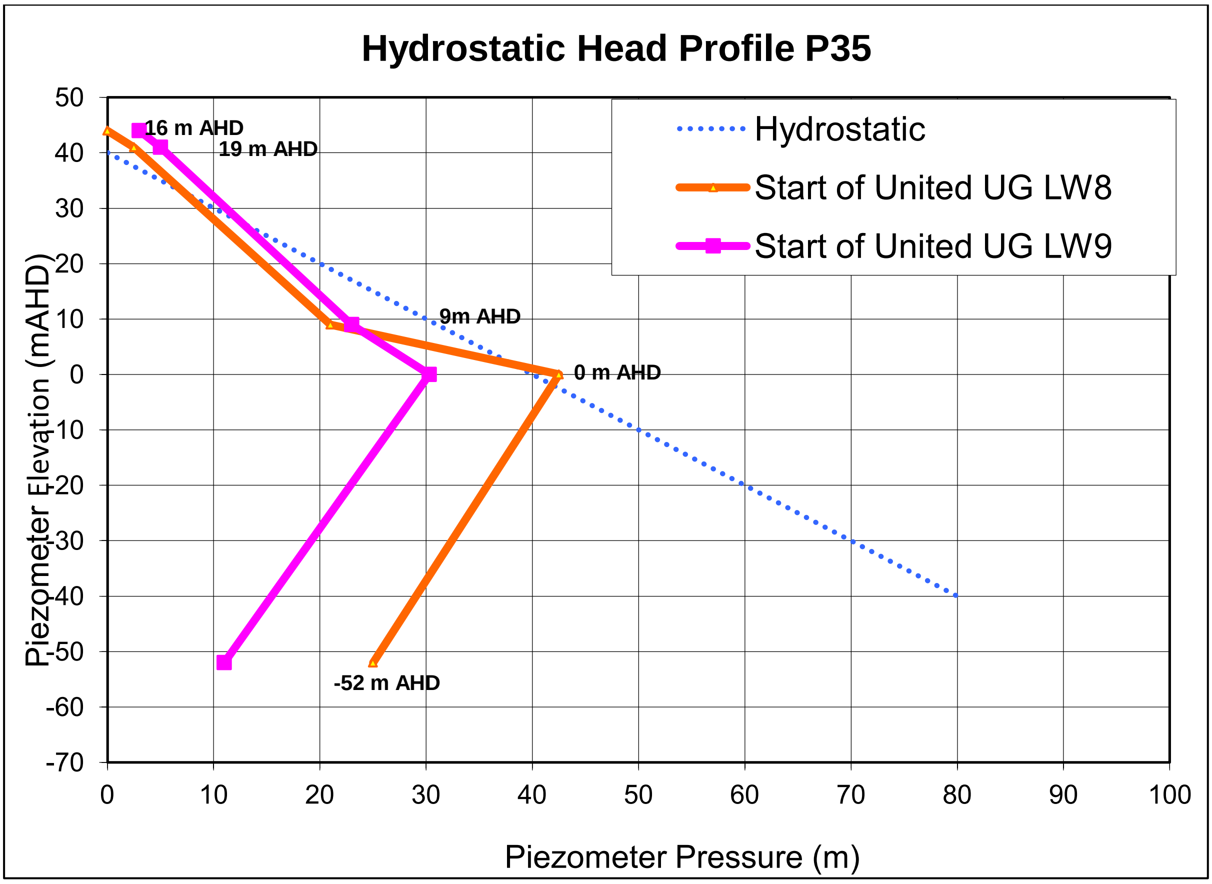
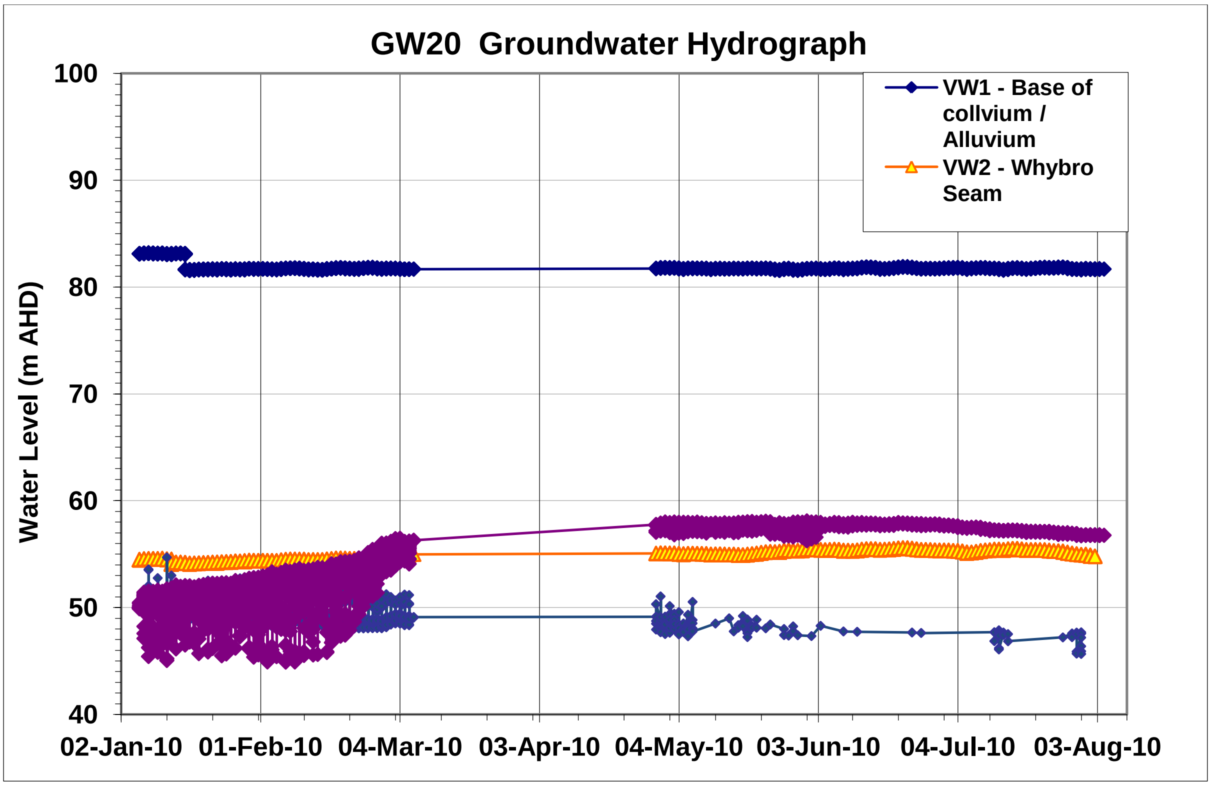


Figure A7: Hydrograph and Pressure Head Profile at P35



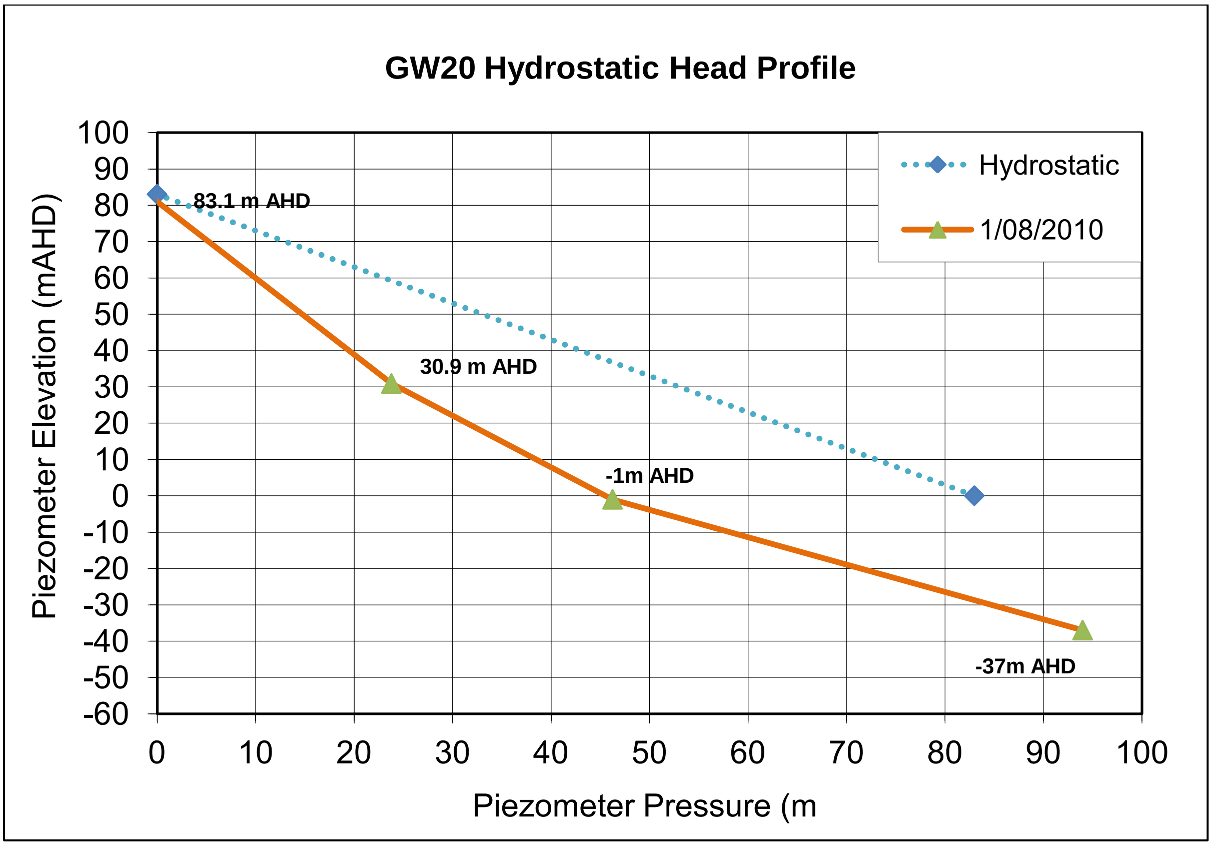


Figure A8: Hydrograph and Pressure Head Profile at GW20

ATTACHMENT B

Hydraulic Properties

Figure B1 Hydraulic Conductivity Zones - Layer 1 [m/day]

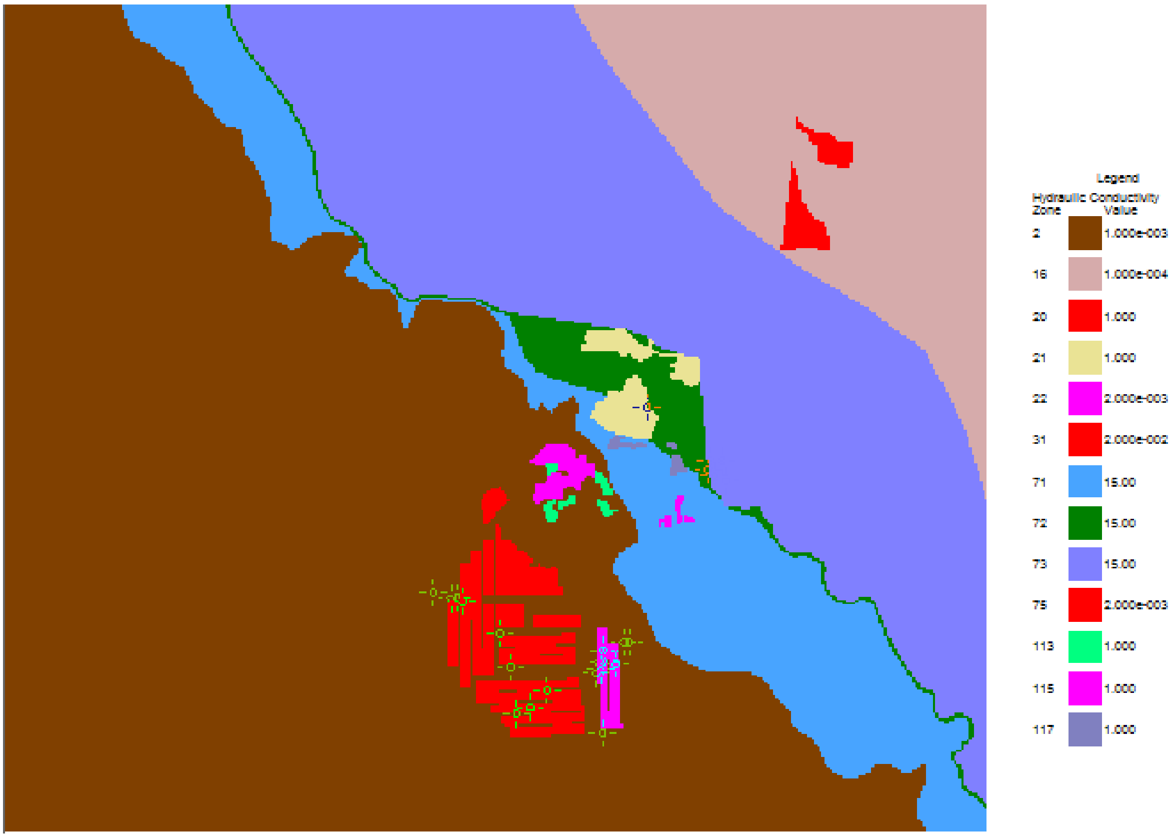


Figure B2 Hydraulic Conductivity Zones - Layer 2 [m/day]

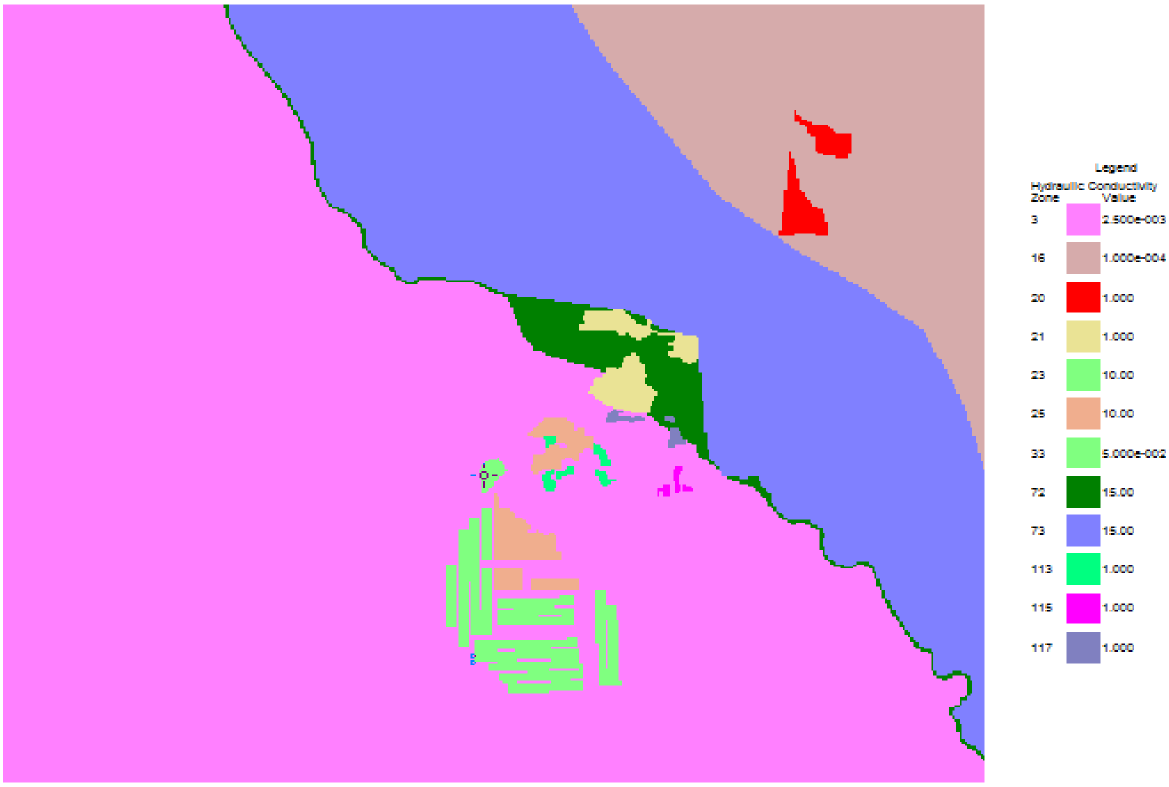


Figure B3 Hydraulic Conductivity Zones - Layer 3 [m/day]

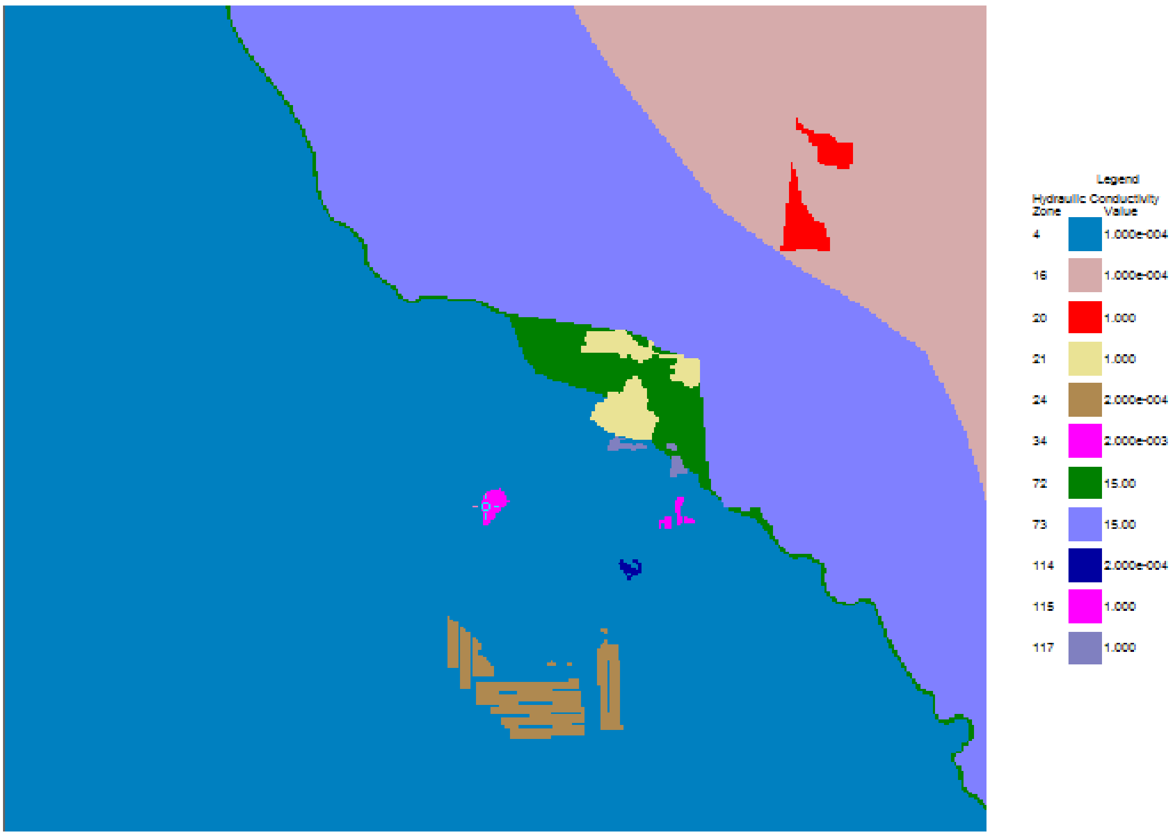


Figure B4 Hydraulic Conductivity Zones - Layer 4 [m/day]

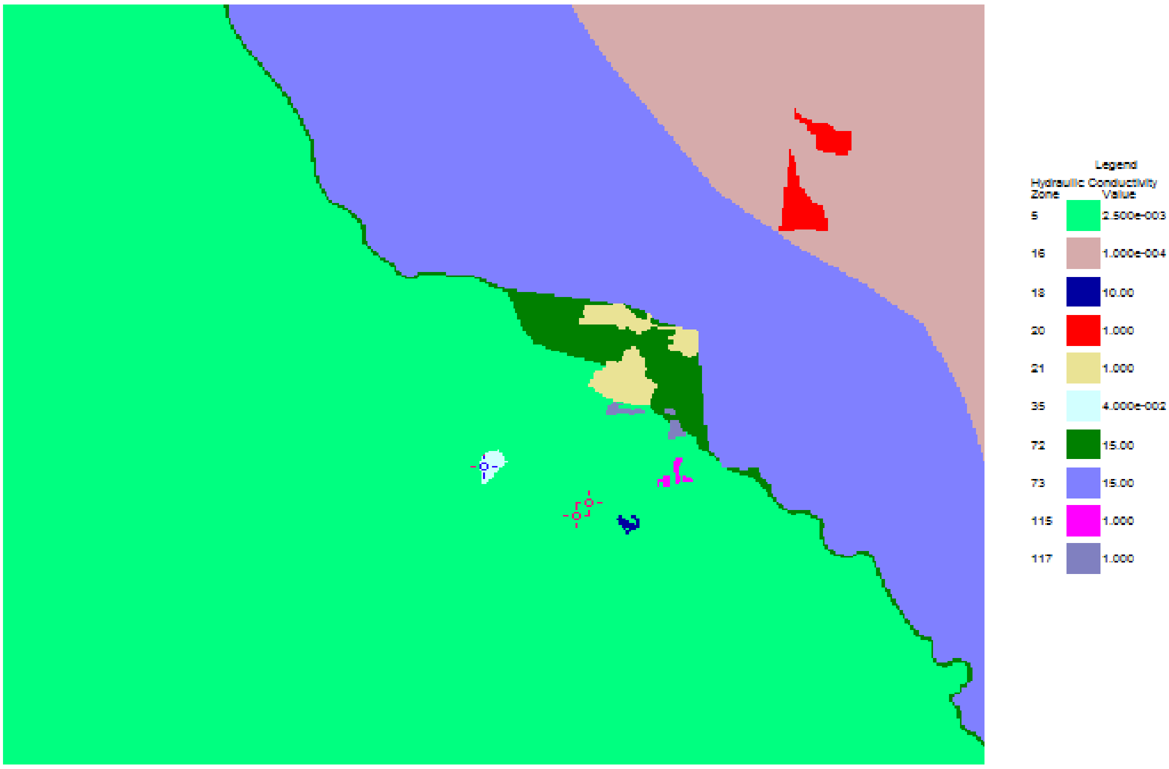


Figure B5 Hydraulic Conductivity Zones - Layer 5 [m/day]

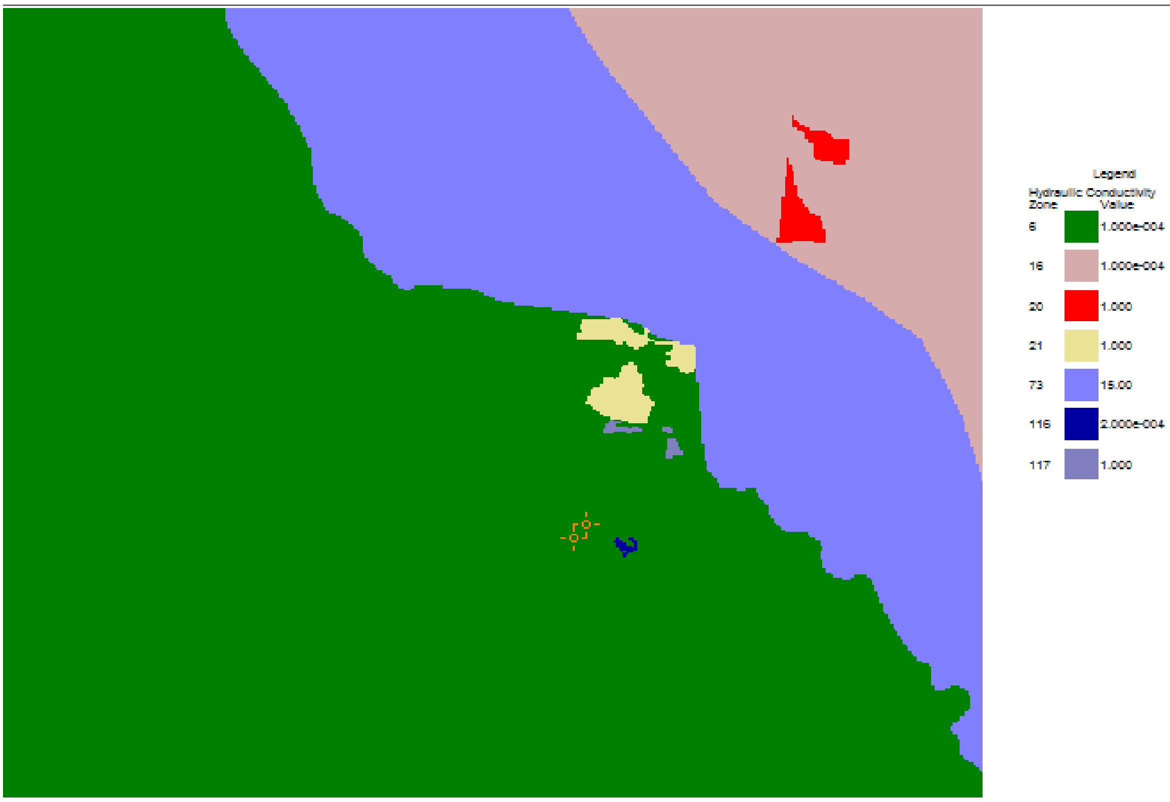


Figure B6 Hydraulic Conductivity Zones - Layer 6 [m/day]

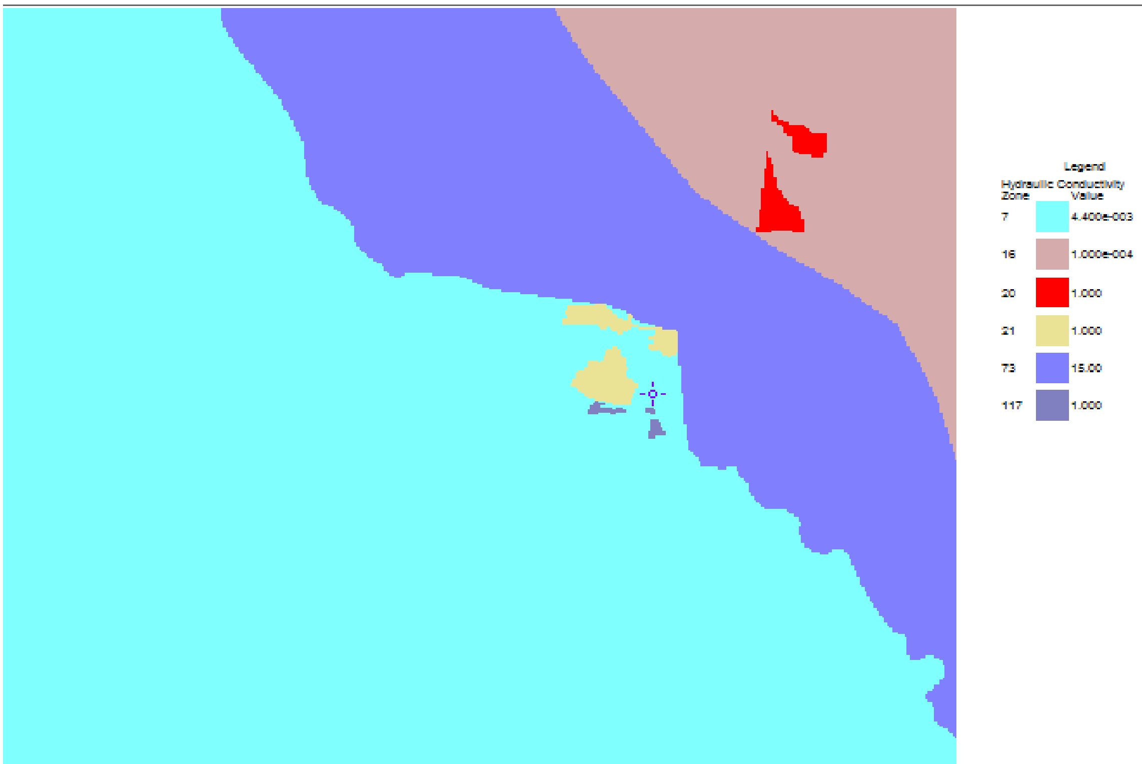


Figure B7 Hydraulic Conductivity Zones - Layer 7 [m/day]

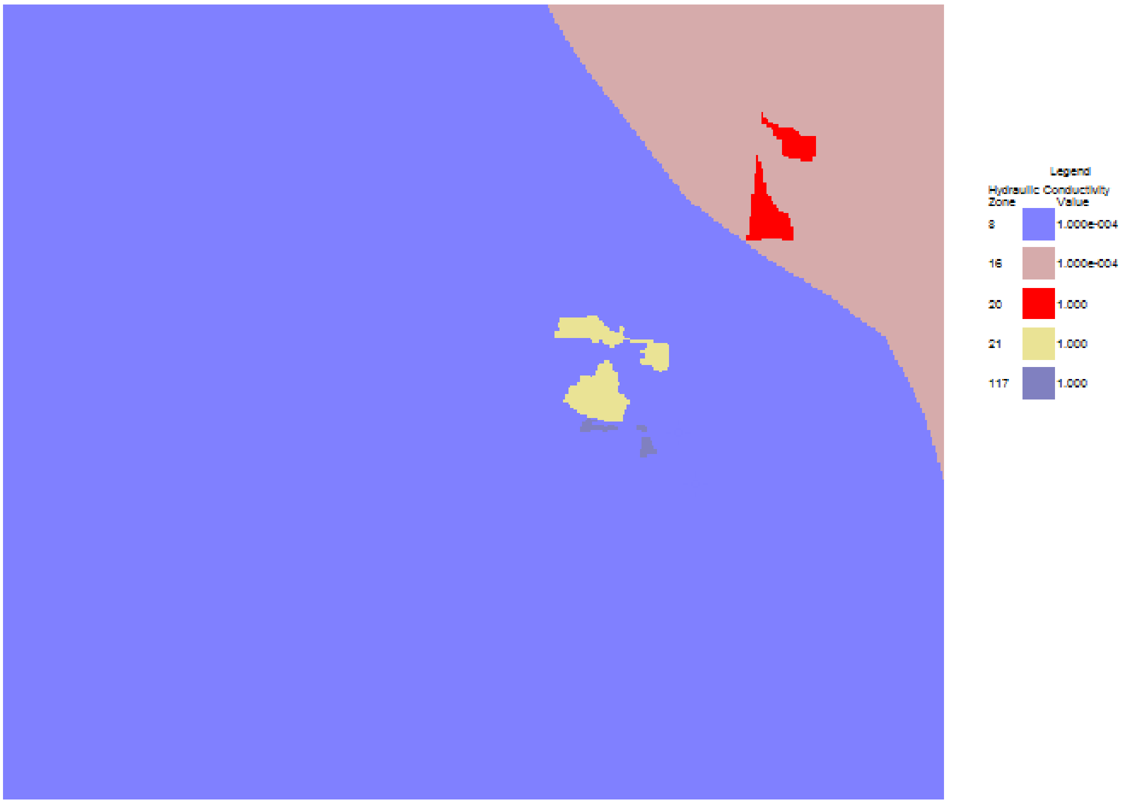


Figure B8 Hydraulic Conductivity Zones - Layer 8 [m/day]

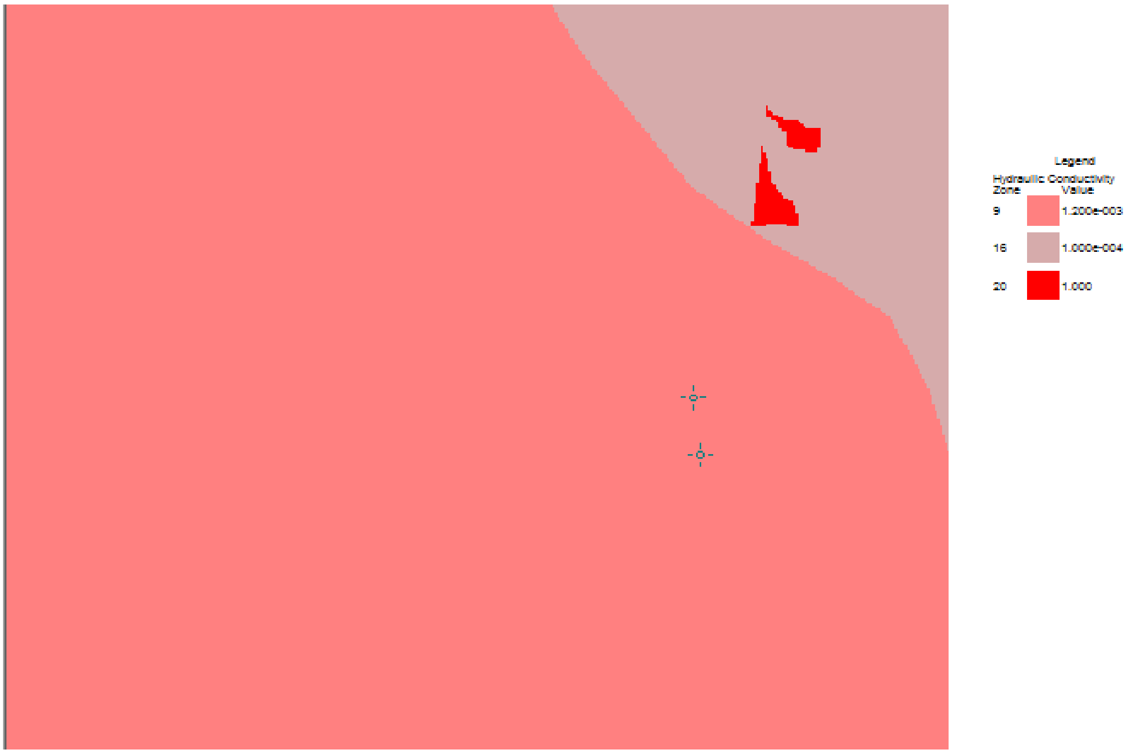


Figure B9 Hydraulic Conductivity Zones - Layer 9 [m/day]

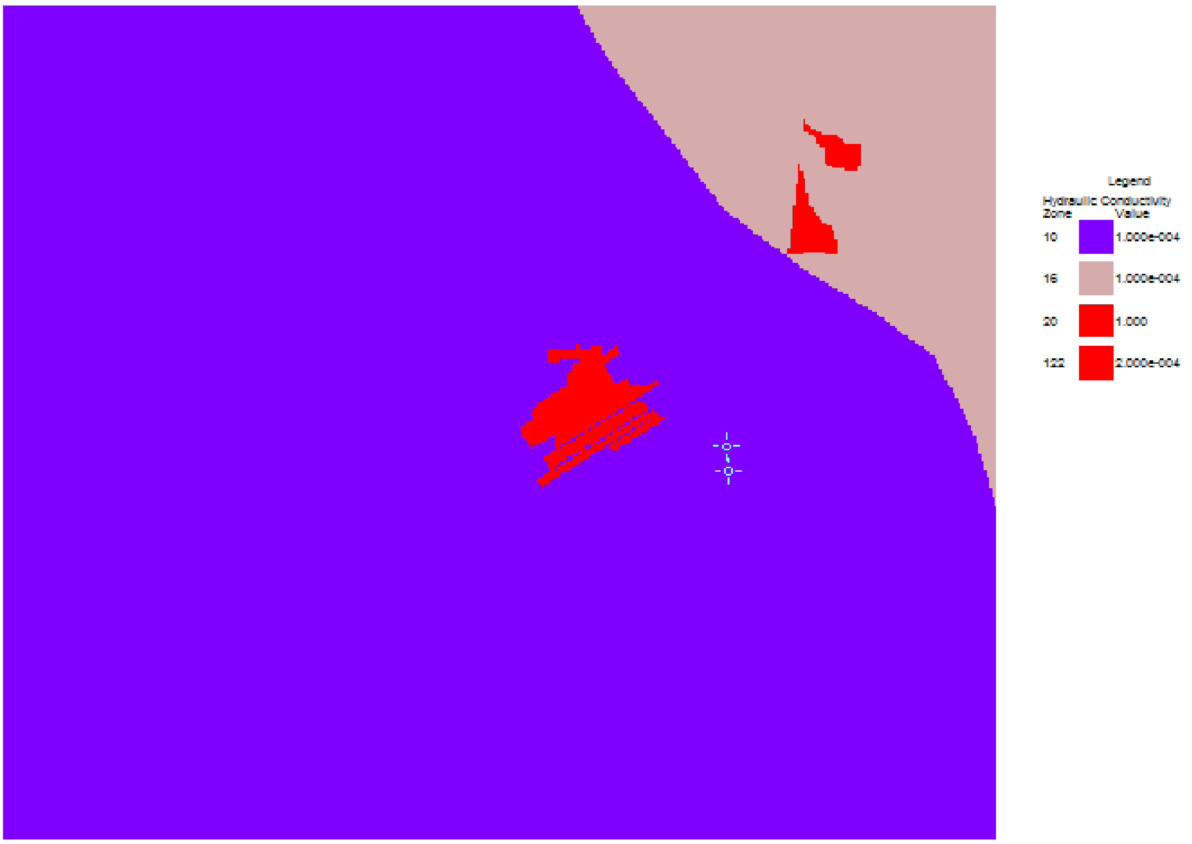


Figure B10 Hydraulic Conductivity Zones - Layer 10 [m/day]

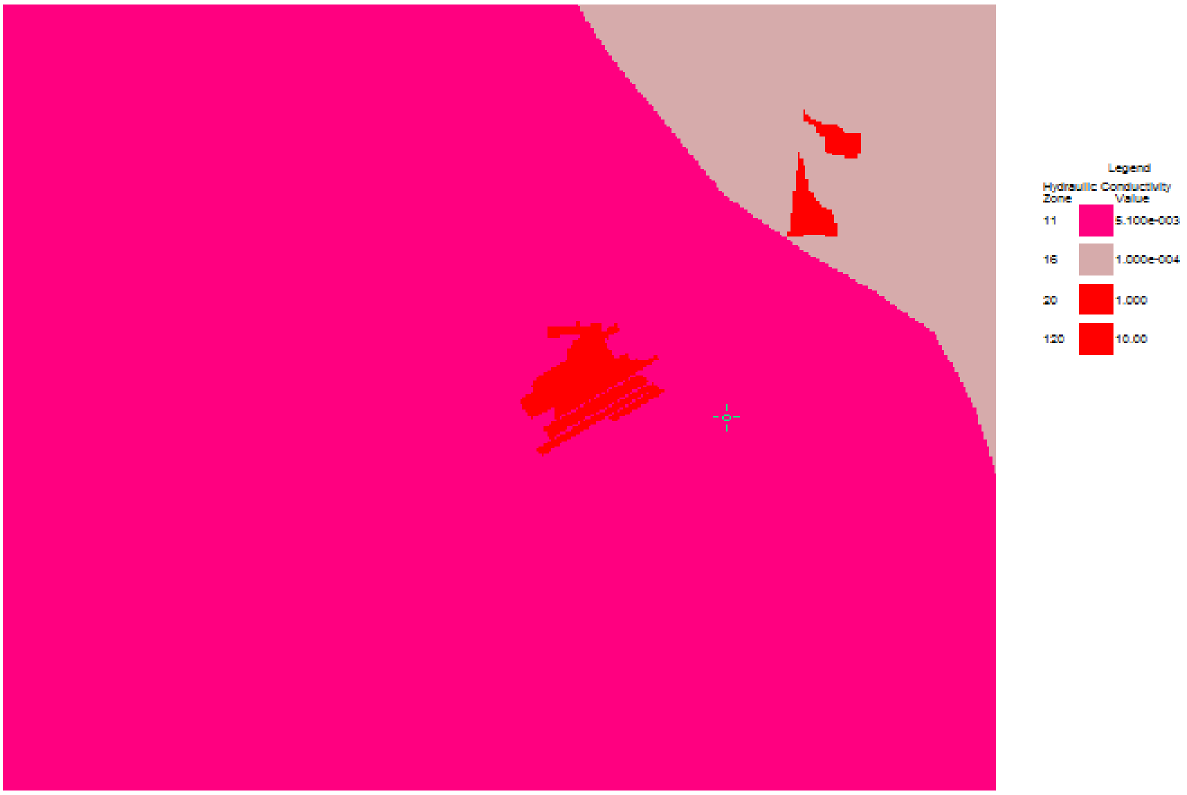


Figure B11 Hydraulic Conductivity Zones - Layer 11 [m/day]

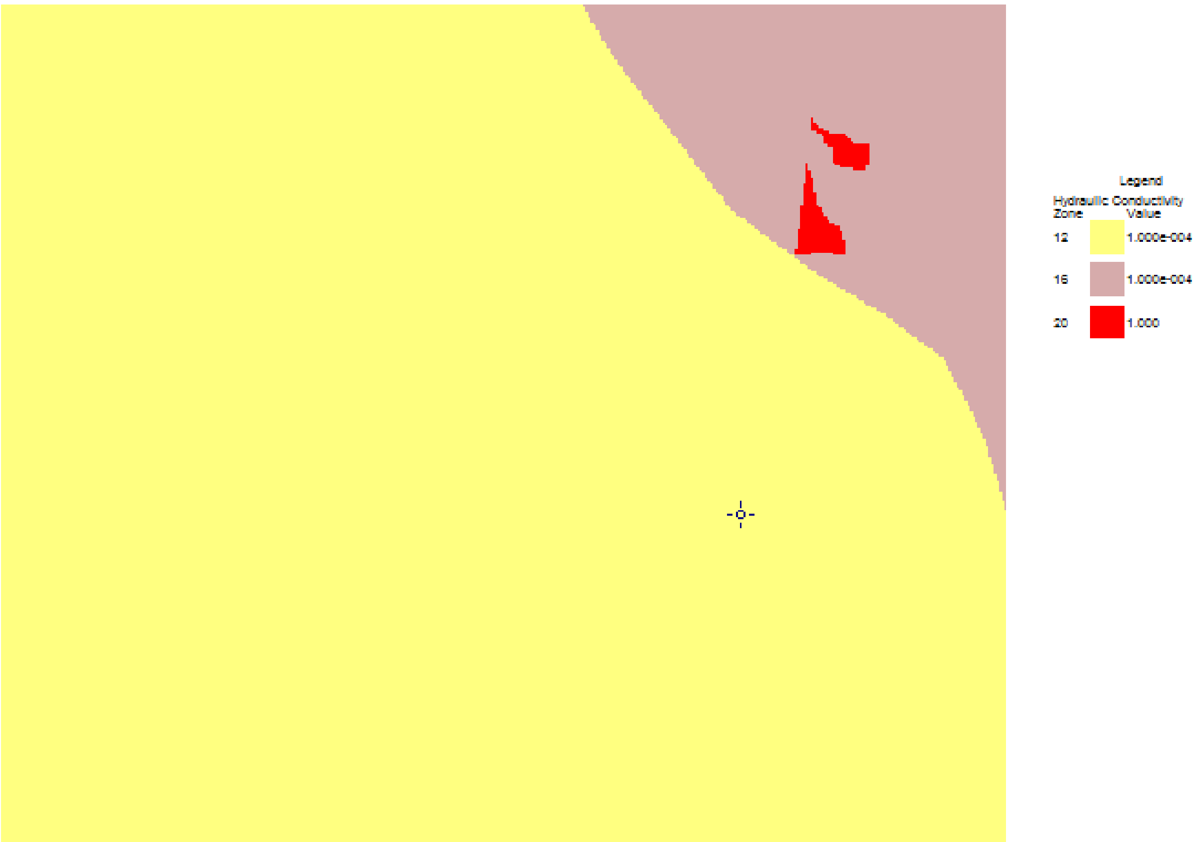


Figure B12 Hydraulic Conductivity Zones - Layer 12 [m/day]

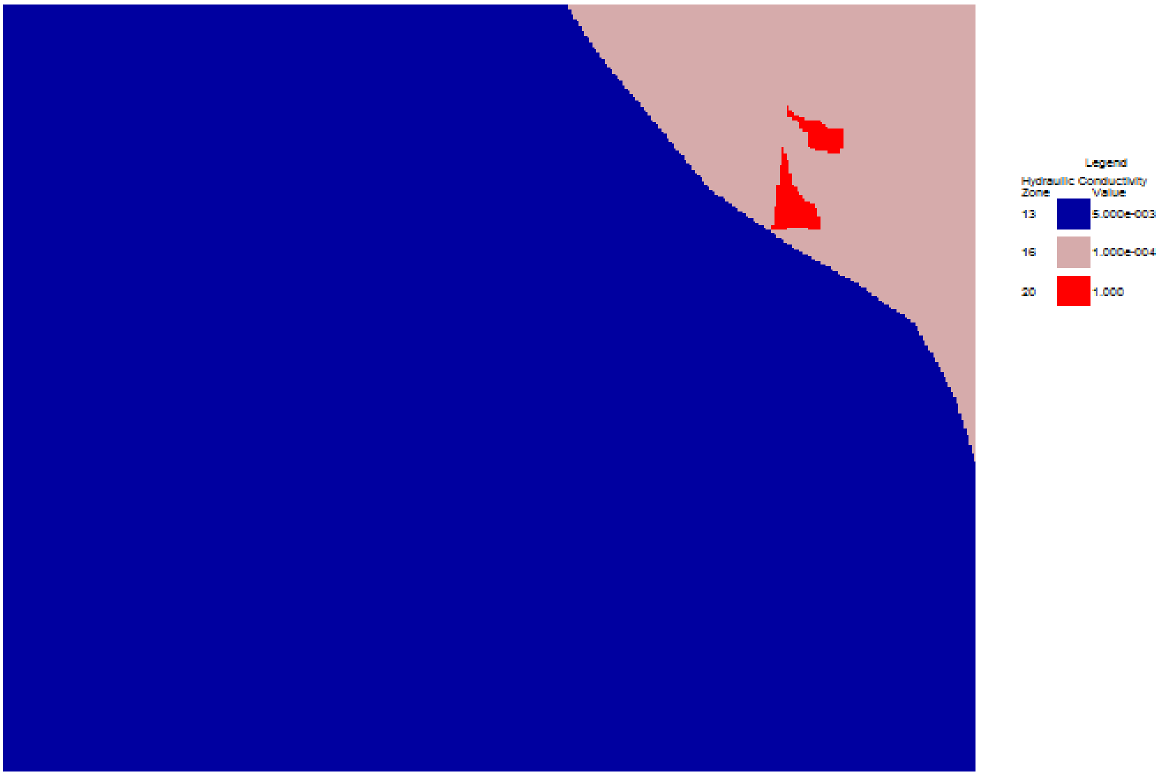


Figure B13 Hydraulic Conductivity Zones - Layer 13 [m/day]

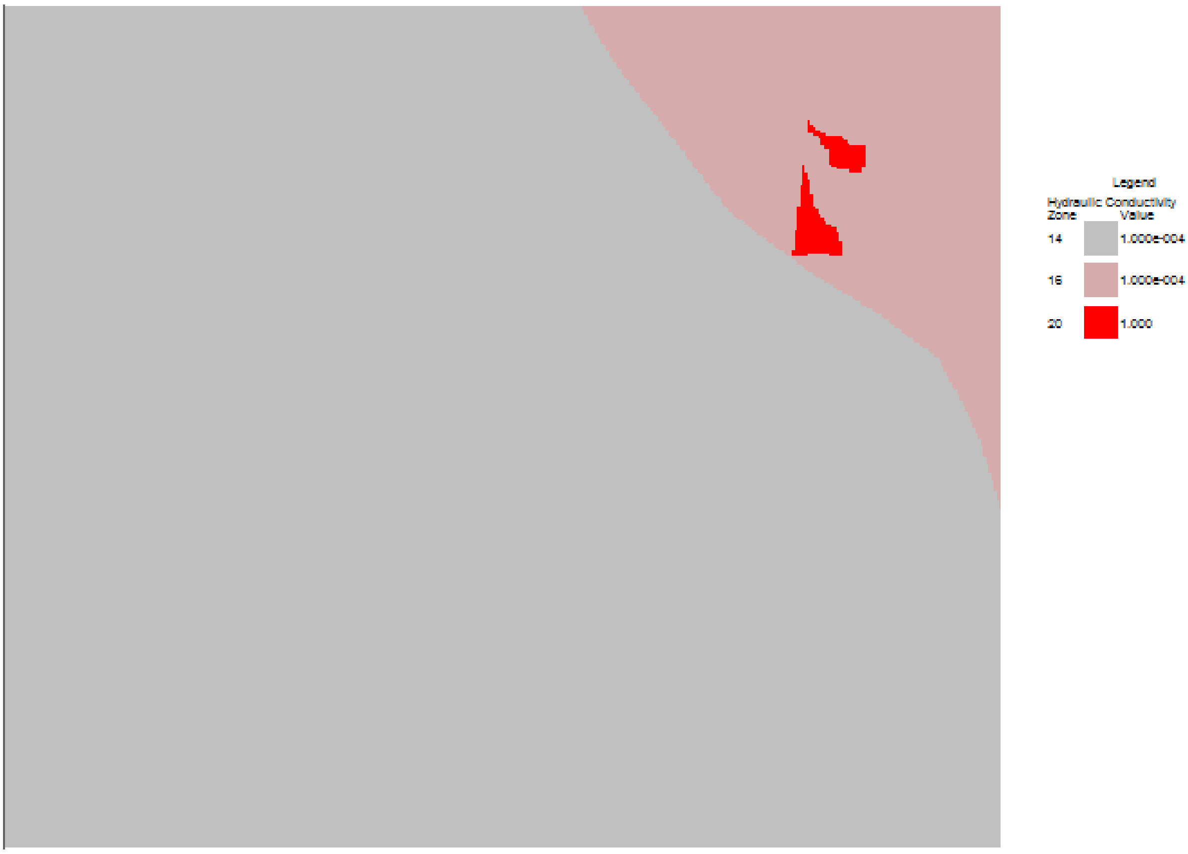


Figure B14 Hydraulic Conductivity Zones - Layer 14 [m/day]

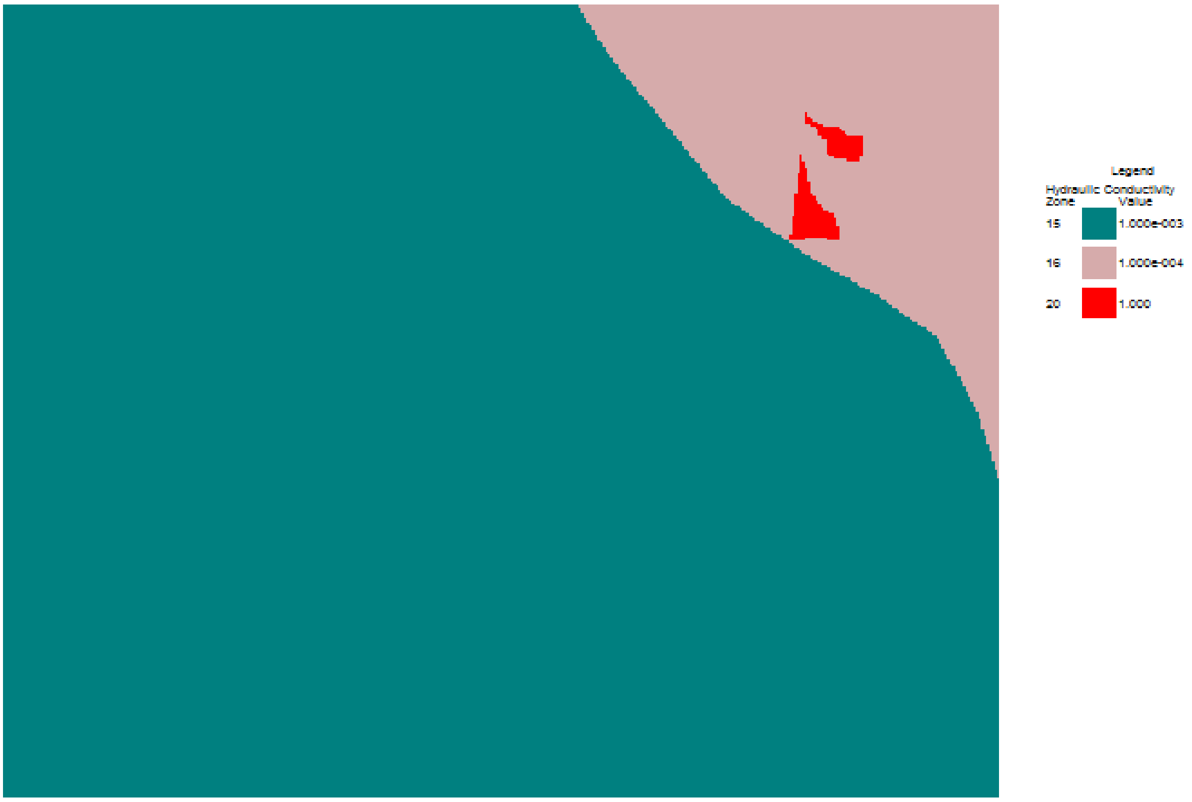


Figure B15 Hydraulic Conductivity Zones - Layer 15 [m/day]

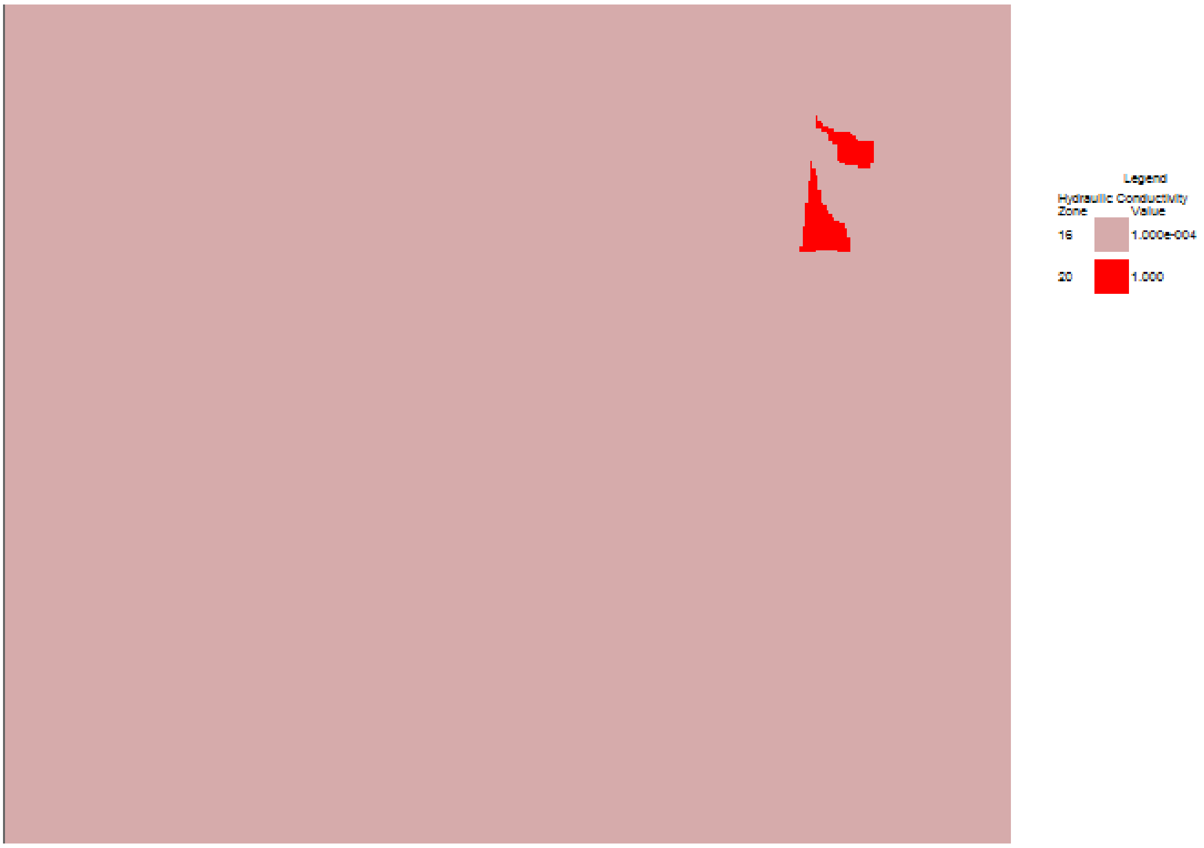


Figure B16 Hydraulic Conductivity Zones - Layer 16 [m/day]

ATTACHMENT C

Calibration Hydrographs

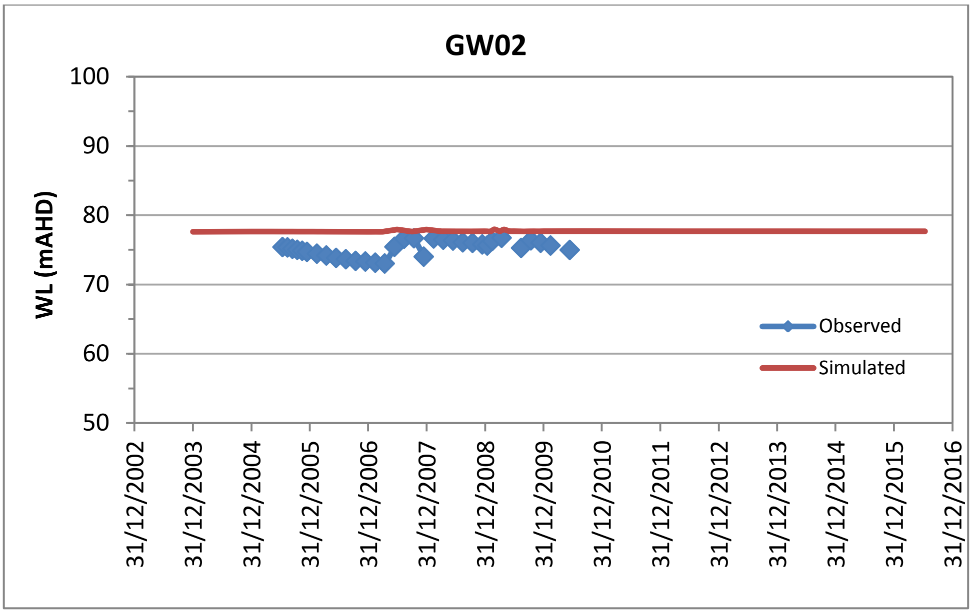
Table C1: Transient Calibration Target Sites

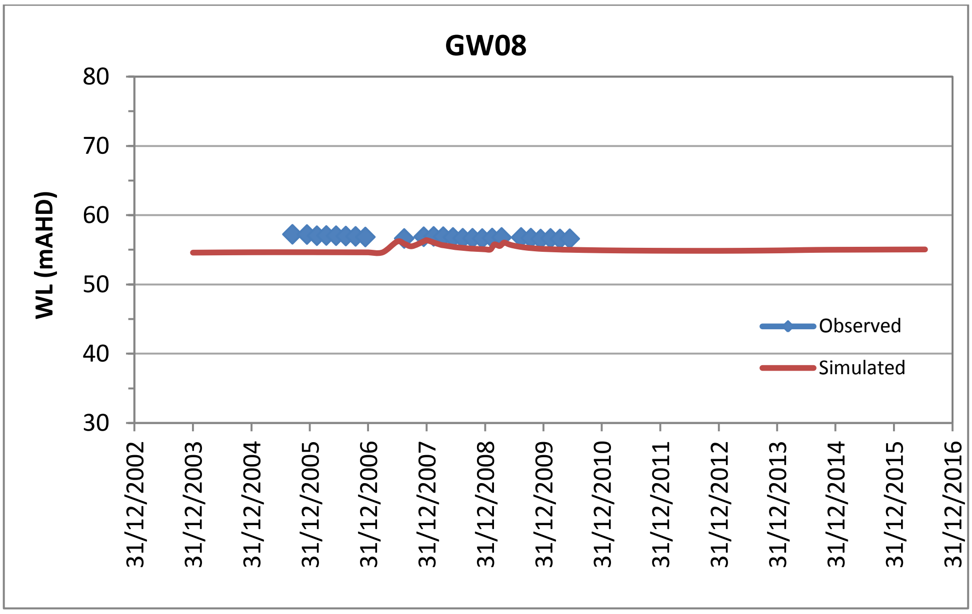
Name	Easting	Northing	Layer
P104	311361	6391135	2
P106	311518	6391084	1
P108	311367	6390916	2
P109	311215	6390768	1
P110	311217	6390690	2
P111	311301	6390761	2
P114	311205	6391288	1
P116	311507	6391293	1
P202	311852	6391288	2
P206	311772	6391293	2
P209	311599	6390873	2
P301	309360	6391467	2
P302	309157	6391445	2
P311	308064	6392255	2
P312	309111	6391694	2
P314	309157	6391445	2
P315	309091	6391852	1
P316	308623	6392091	2
P317	308516	6392156	2
P318	308432	6392138	2
GW02	309109	6389680	1
GW04	310265	6390360	2
GW05	309676	6389904	2
GW06	309559	6390811	2
GW07	309941	6390029	2
GW08	311793	6392268	1
GW09	311644	6392565	1
GW11	309228	6389699	1
P1	312198.6	6395840	2
P3	313411.8	6395006	8
P5	309835.5	6394001	1
P6	309995.8	6393841	1
P11	312728	6395462	7
P12	313643.9	6394797	2
P13	313722.2	6394412	2
P15	313431.3	6394803	2
P16	313479.5	6394655	1
P17	313376.3	6394631	2
P18	313502.7	6394512	2
P20	313638.8	6394166	1
GW13	313687	6389545	1

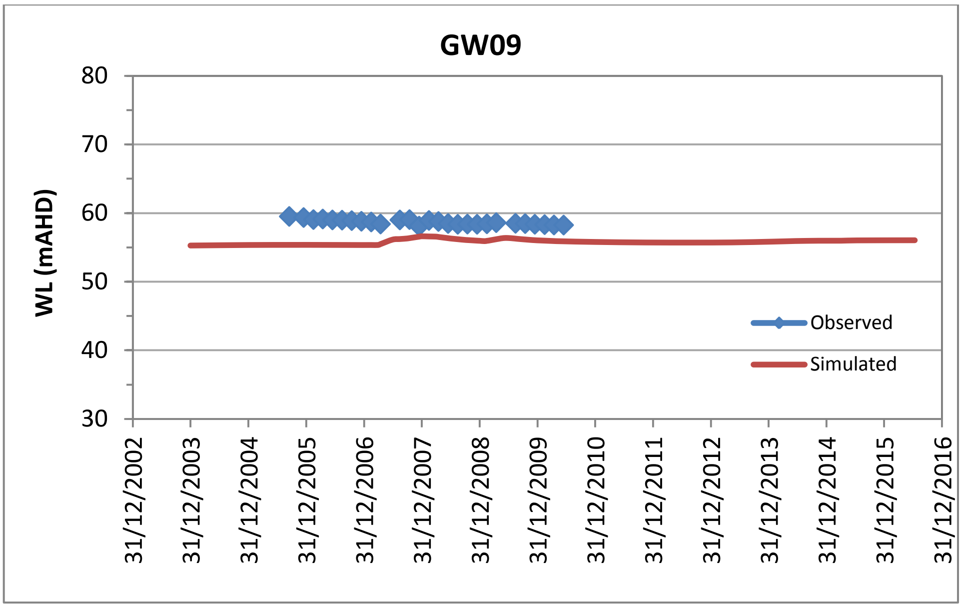
Table C1: Transient Calibration Target Sites (Continued)

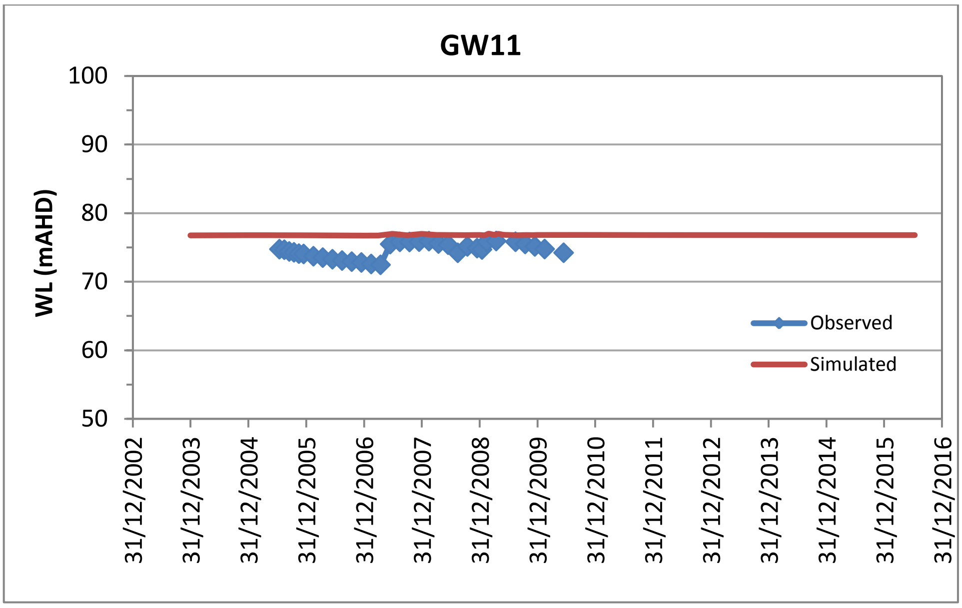
Name	Easting	Northing	Layer
GW15	313335	6392745	1
GW16	306638	6396169	1
GW17	306886	6396096	1
GW18	310083	6393199	1
GW22	311340	6389530	2
P33_13m	313650.1	6394738	8
P33_19m	313650.1	6394738	8
P33_46.5m	313650.1	6394738	8
P33_58m	313650.1	6394738	8
P33_113m	313650.1	6394738	10
P34_35m	313761.5	6393968	8
P34_68.5m	313761.5	6393968	9
P34_144m	313761.5	6393968	12
P35_16m	313616.2	6395198	8
P35_19m	313616.2	6395198	8
P35_51m	313616.2	6395198	9
P35_60m	313616.2	6395198	10
P35_112m	313616.2	6395198	11
MG06_02_67.5m	311108	6393187	4
MG06_02_69.5m	311108	6393187	4
MG06_02_71m	311108	6393187	5
MG06_02_74m	311108	6393187	6
MG06_01_88m	310866.1	6392901	4
MG06_01_89.5m	310866.1	6392901	4
MG06_01_91.5m	310866.1	6392901	5
MG06_01_94m	310866.1	6392901	6
GW20_VW1_Alluvium	309075.5	6393949	1
GW20_VW2_WhybrowSeam	309075.5	6393949	3
GW20_VW4_RedbankSeam	309075.5	6393949	4
GW20_VW5_WamboSeam	309075.5	6393949	5

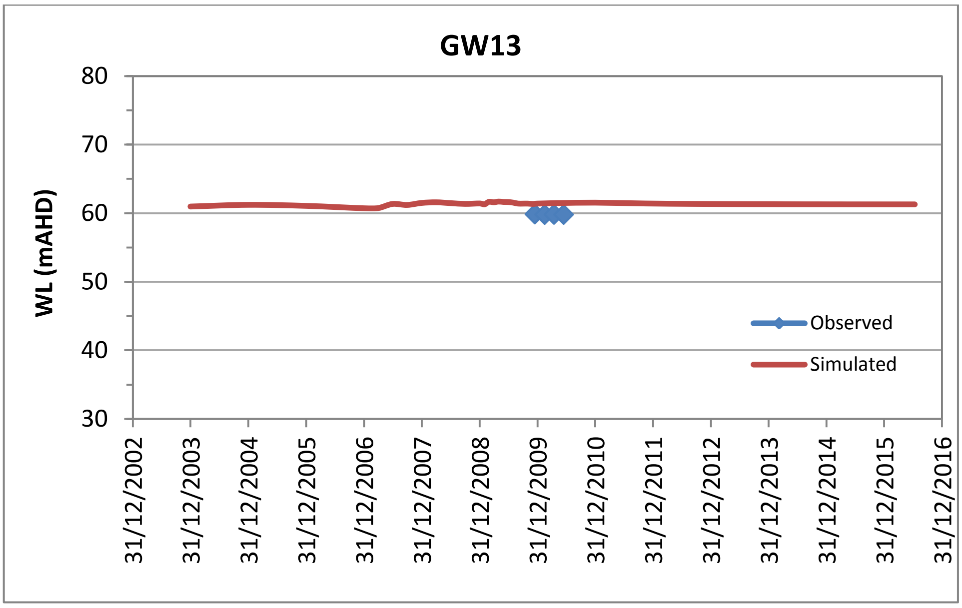
Layer 1

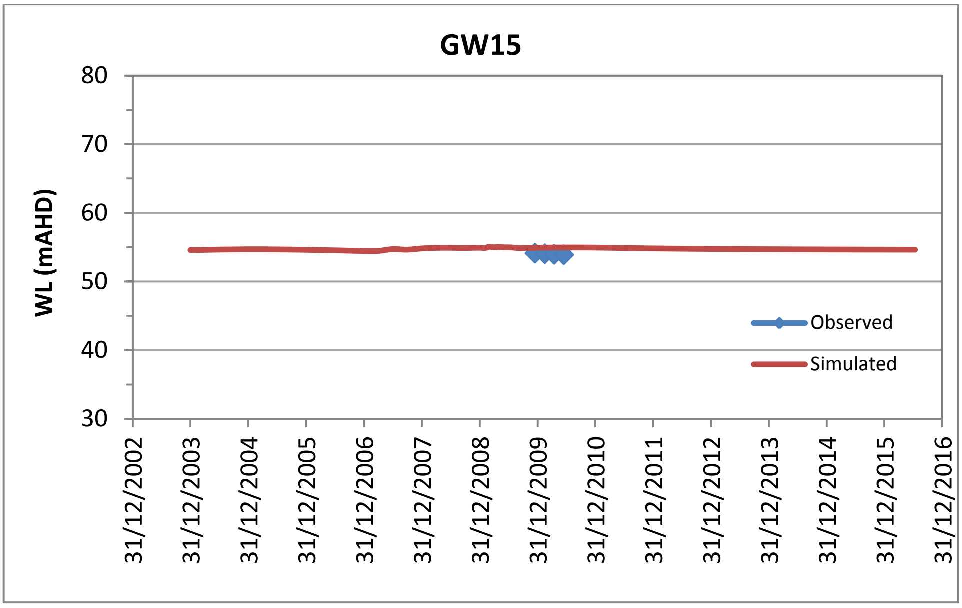

GW02
WL (mAHD)
100
90
80
70
60
50
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

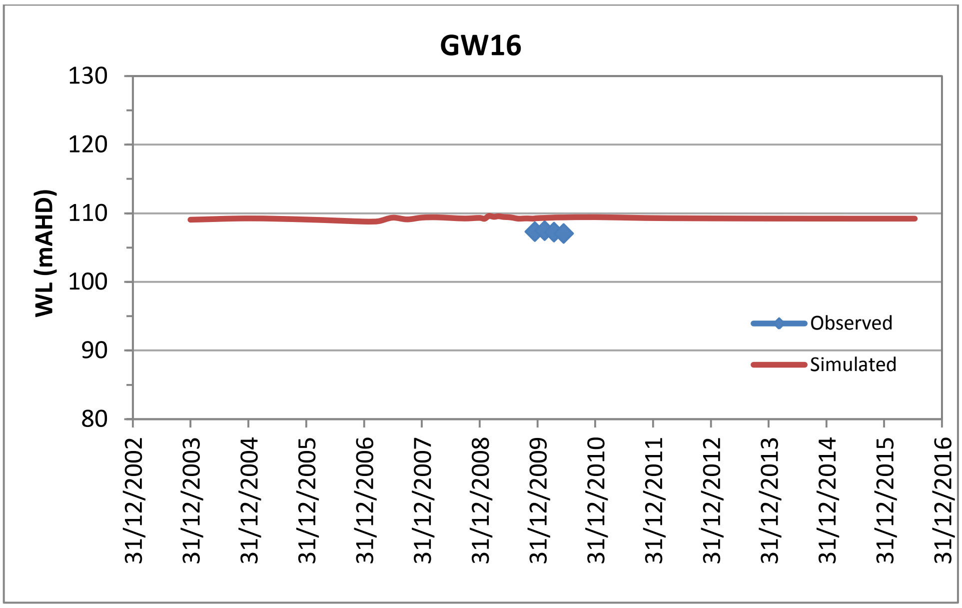

GW08
WL (mAHD)
80
70
60
50
40
30
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

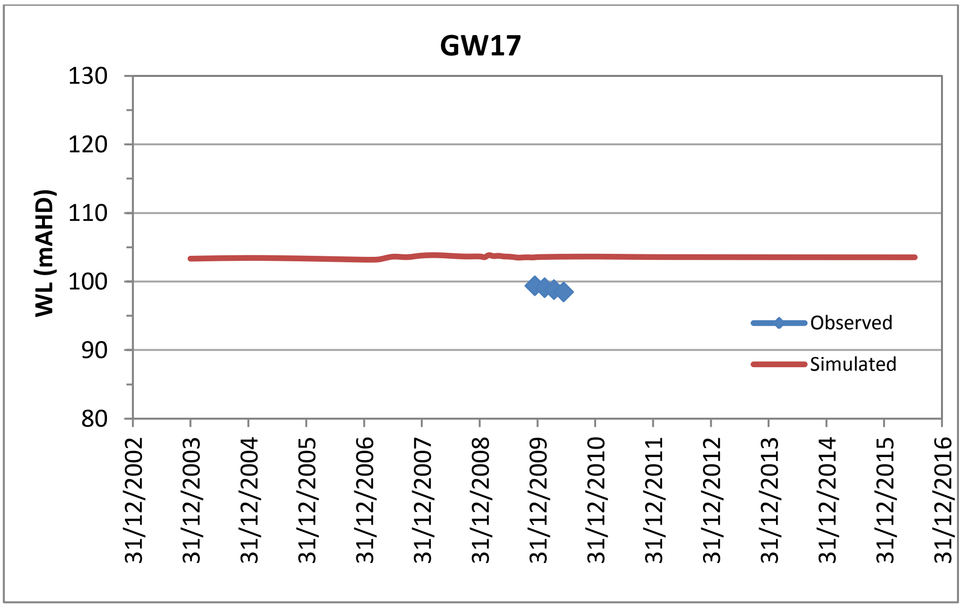

GW09
WL (mAHD)
80
70
60
50
40
30
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

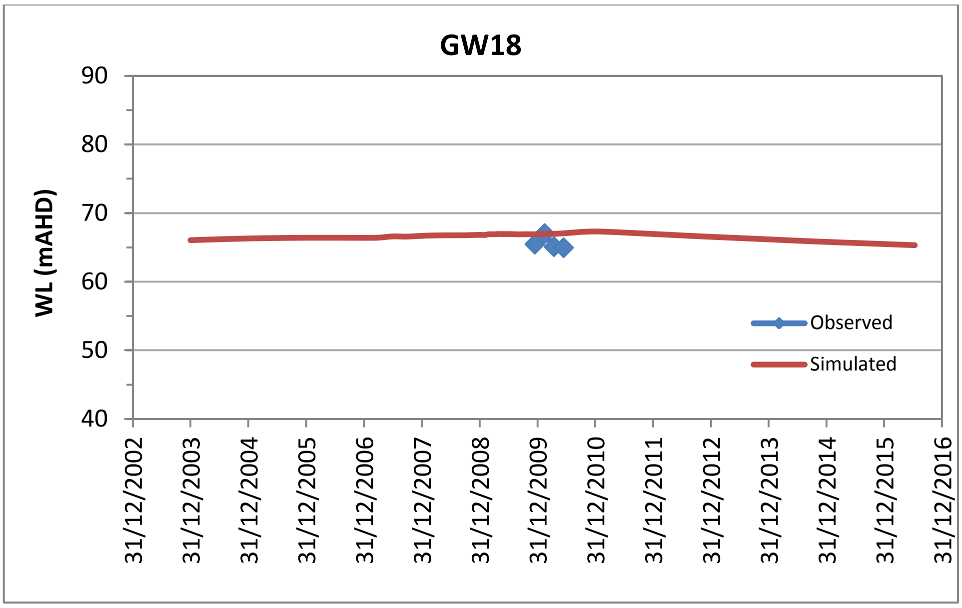

GW11
WL (mAHD)
100
90
80
70
60
50
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

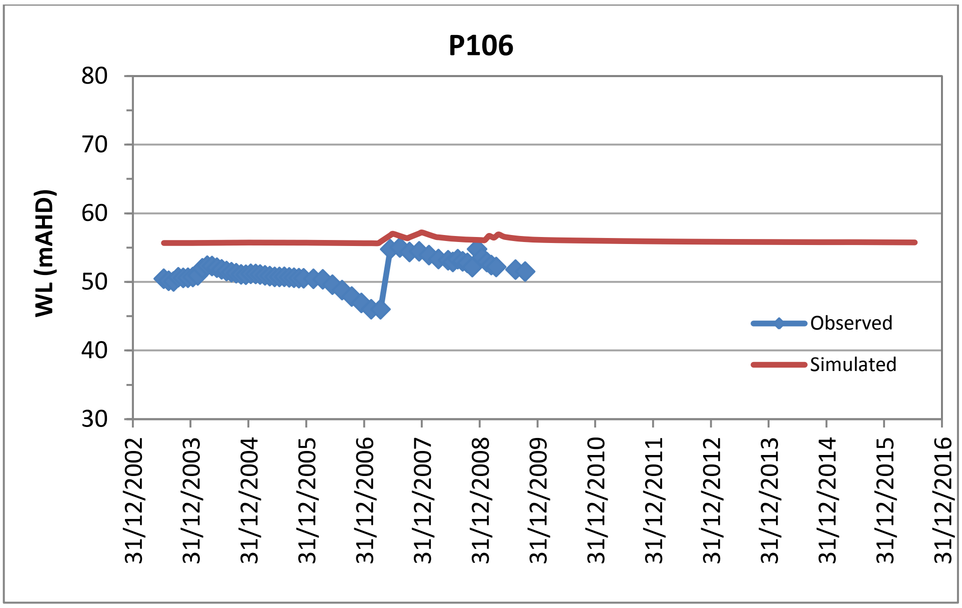

GW13
WL (mAHD)
80
70
60
50
40
30
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

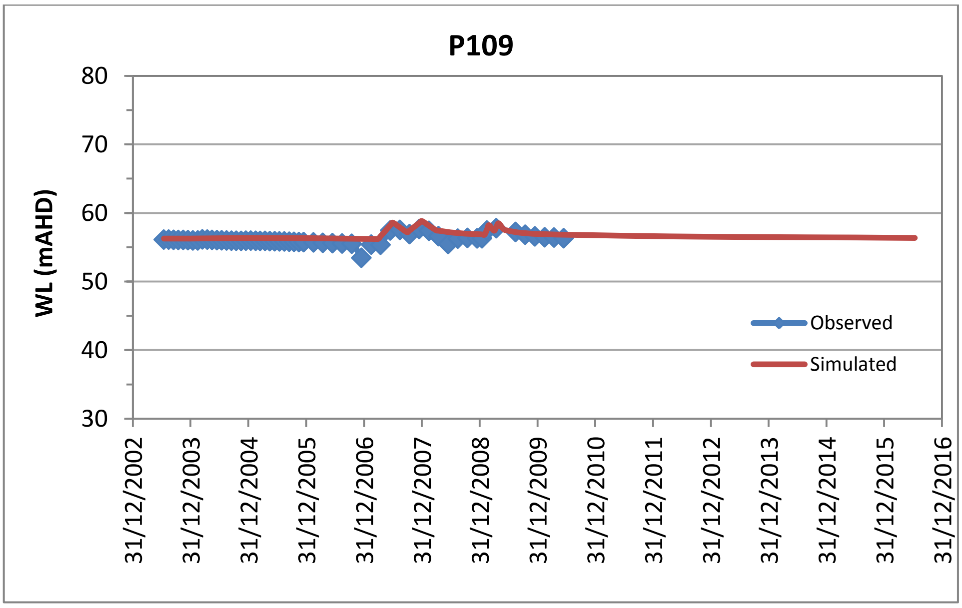

GW15
WL (mAHD)
80
70
60
50
40
30
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

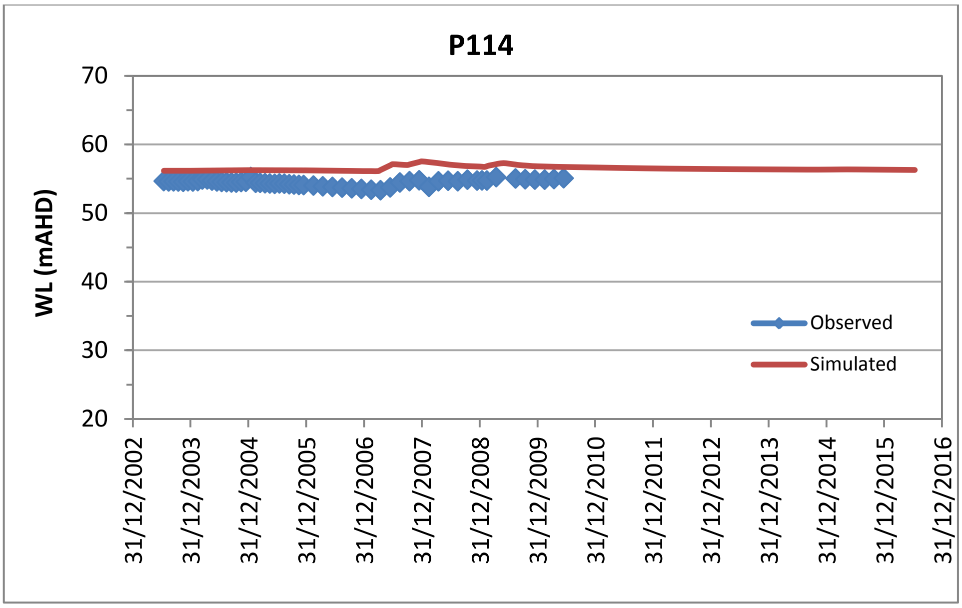

GW16
WL (mAHD)
130
120
110
100
90
80
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

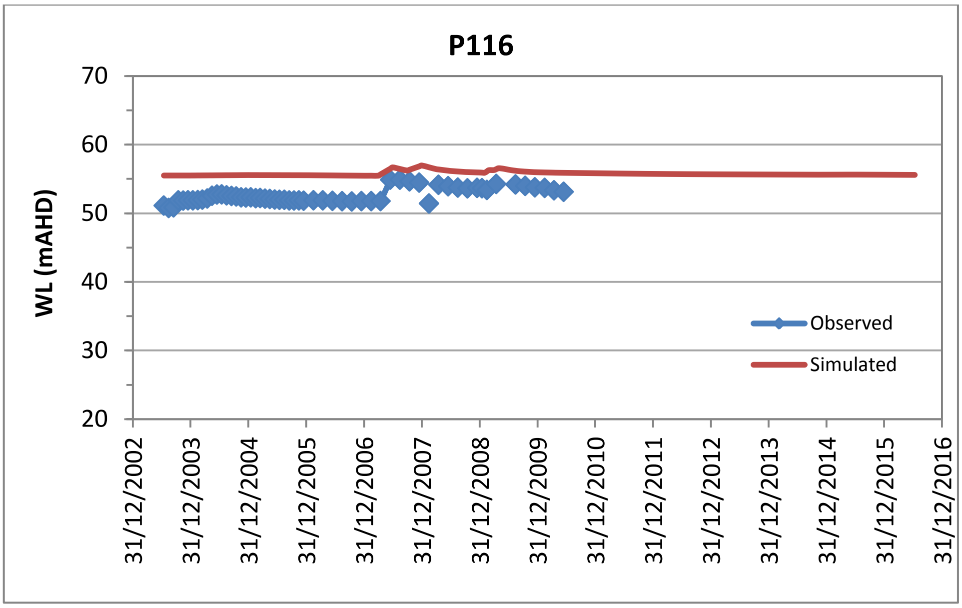

GW17
WL (mAHD)
130
120
110
100
90
80
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

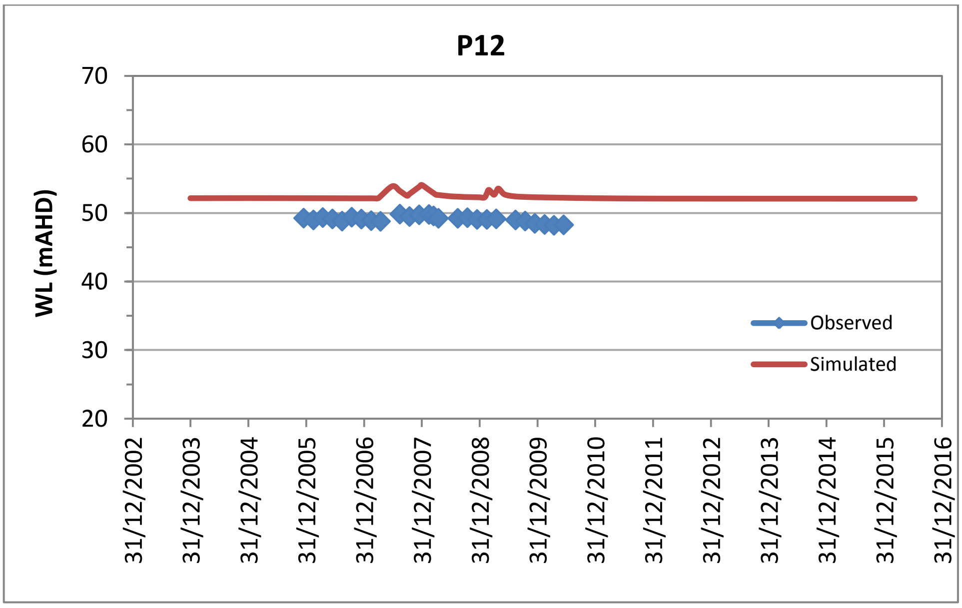

GW18
WL (mAHD)
90
80
70
60
50
40
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

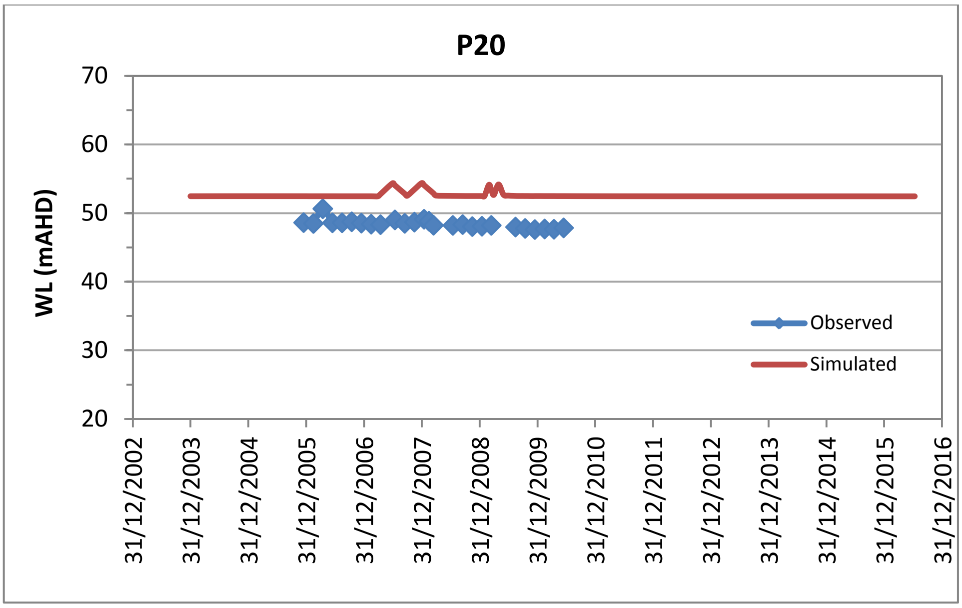

P106
WL (mAHD)
80
70
60
50
40
30
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

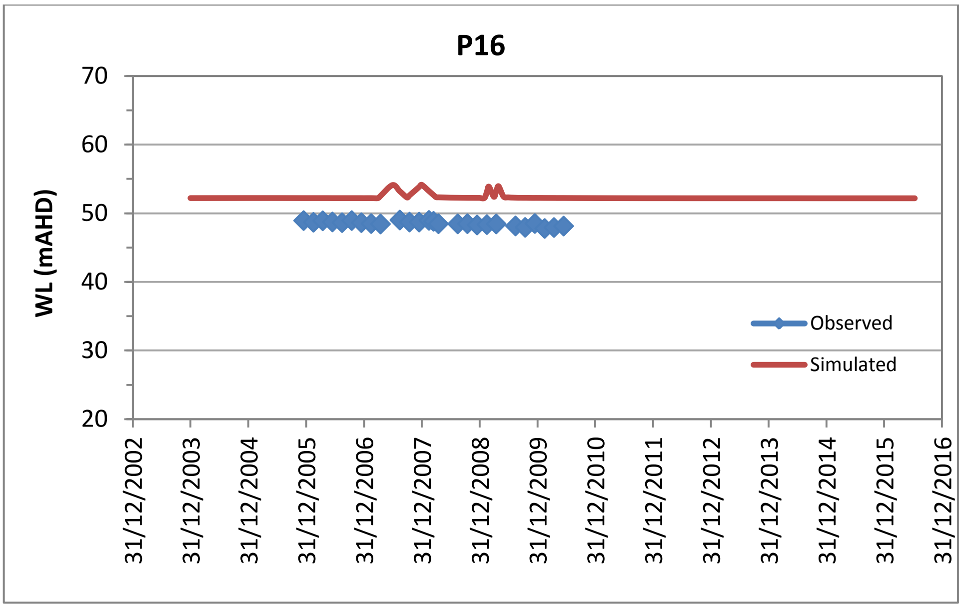

P109
WL (mAHD)
80
70
60
50
40
30
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

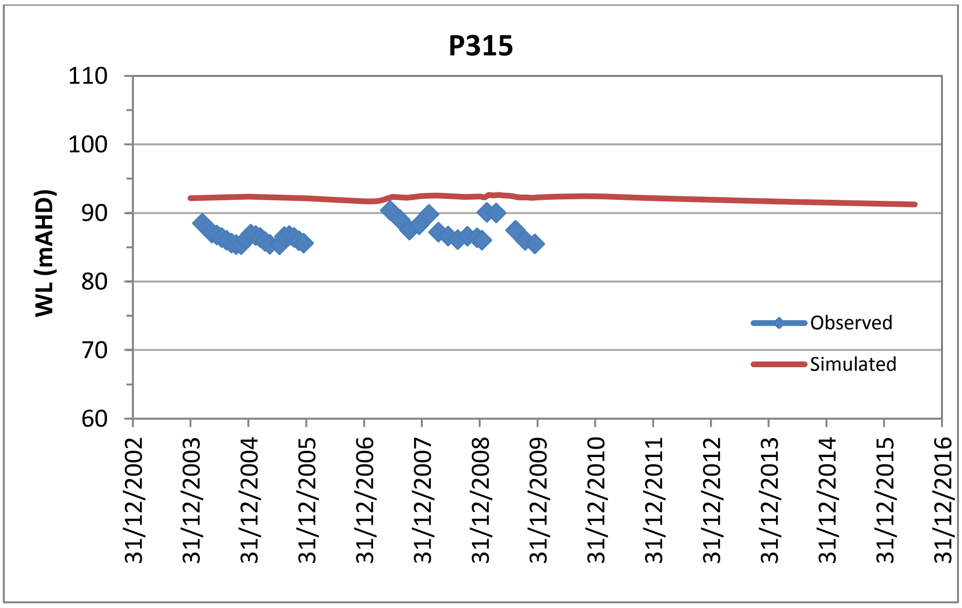

P114
WL (mAHD)
70
60
50
40
30
20
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

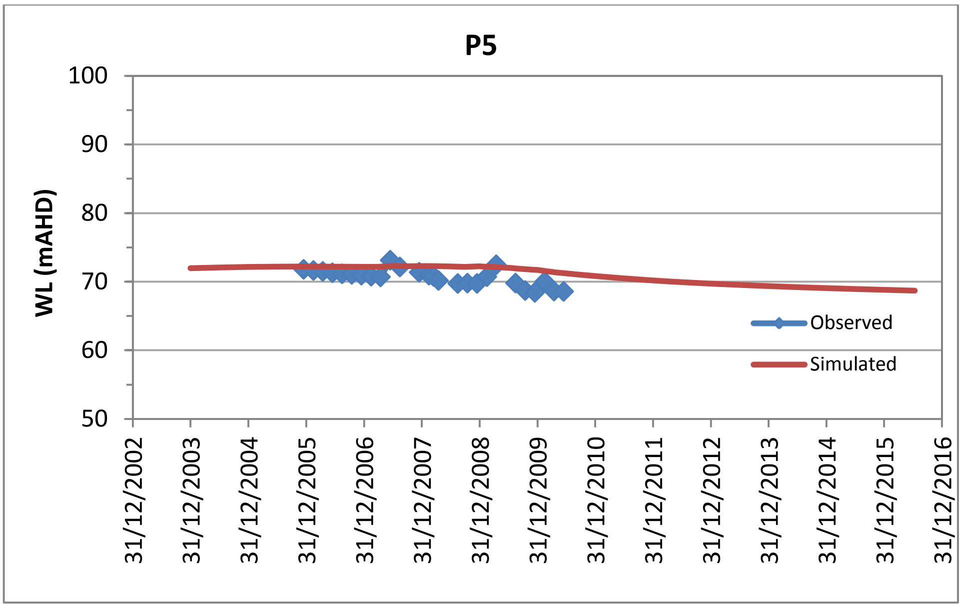

P116
WL (mAHD)
70
60
50
40
30
20
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

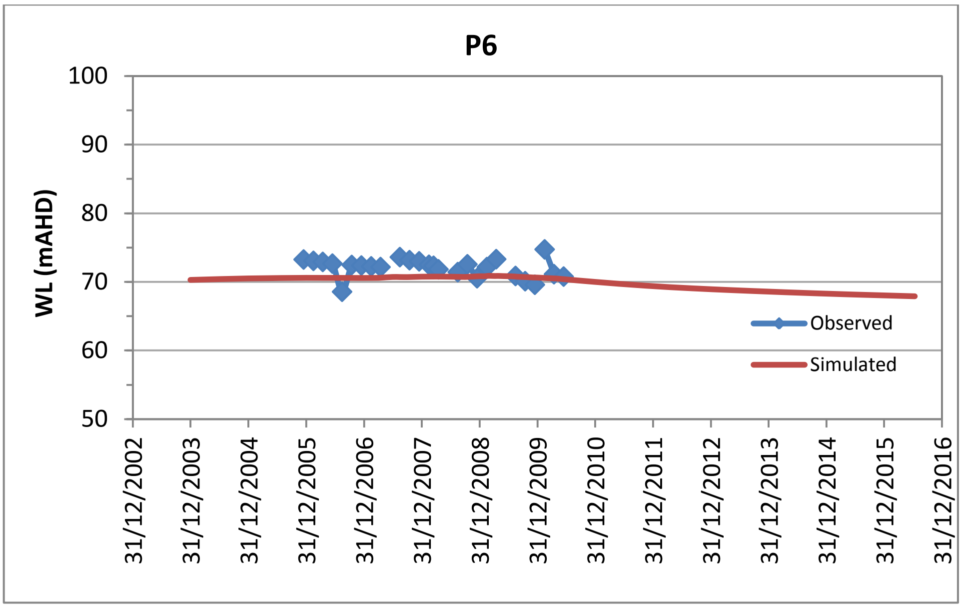

P12
WL (mAHD)
70
60
50
40
30
20
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

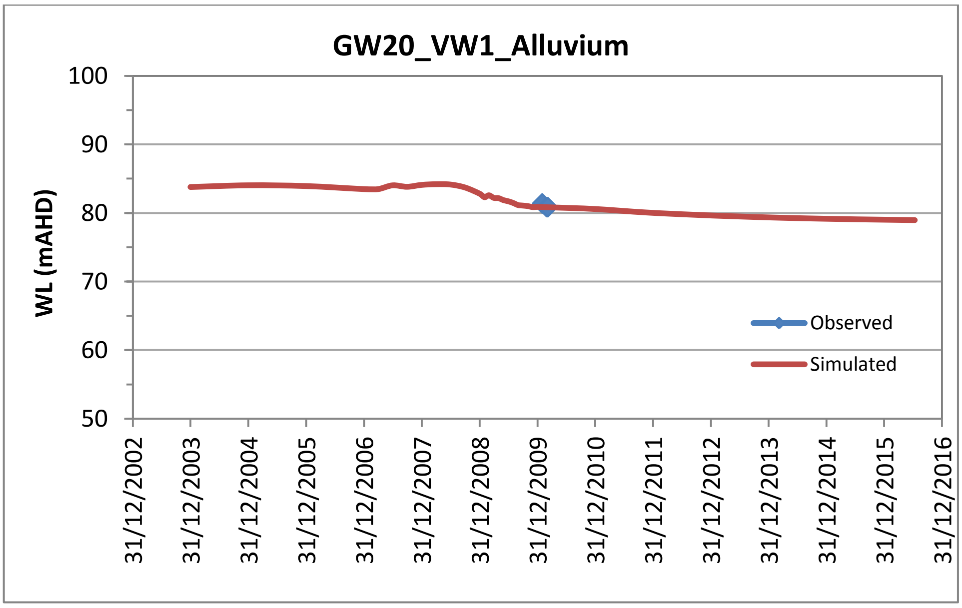

P20
WL (mAHD)
70
60
50
40
30
20
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated


P16
WL (mAHD)
70
60
50
40
30
20
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

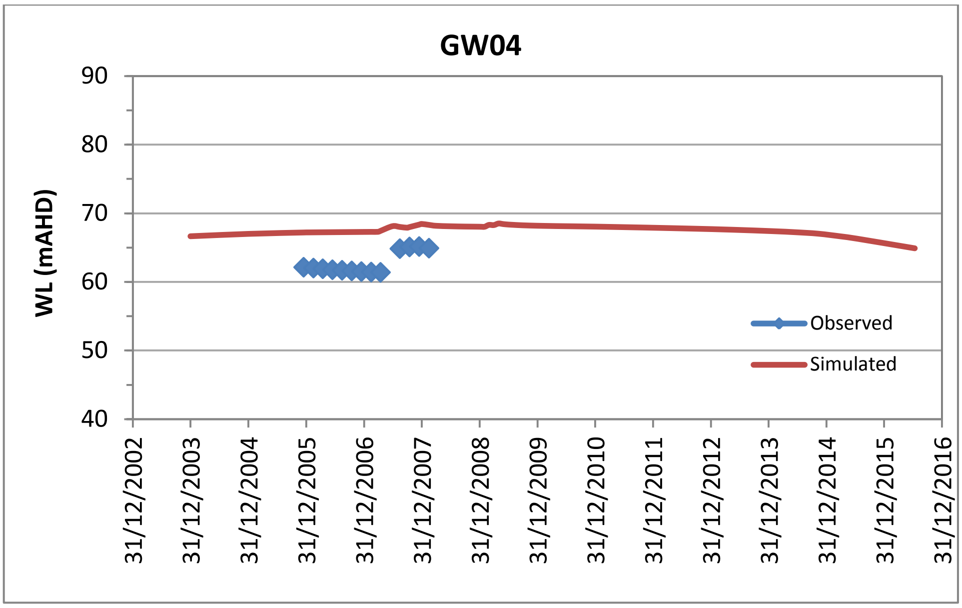

P315
WL (mAHD)
110
100
90
80
70
60
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

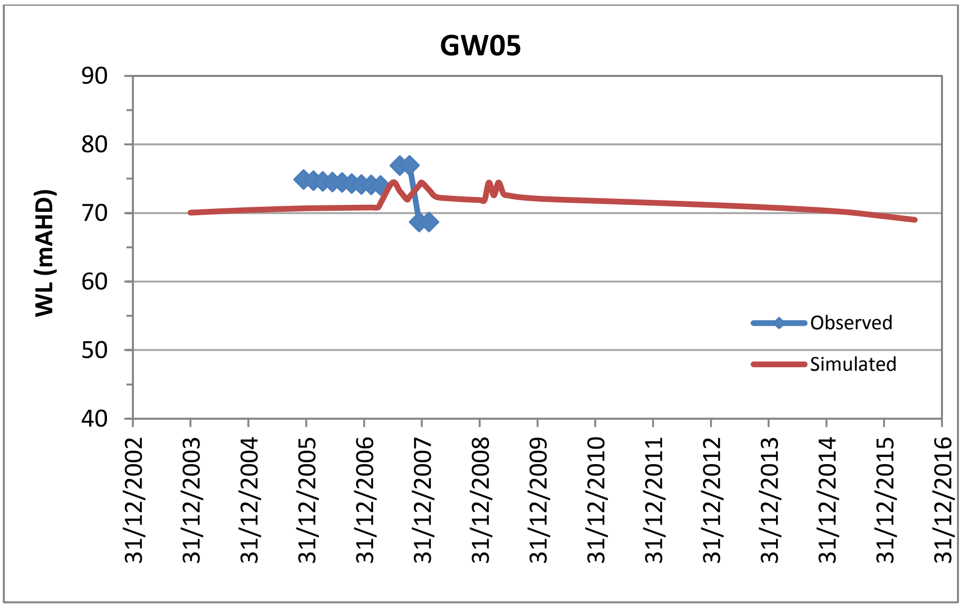

P5
WL (mAHD)
100
90
80
70
60
50
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

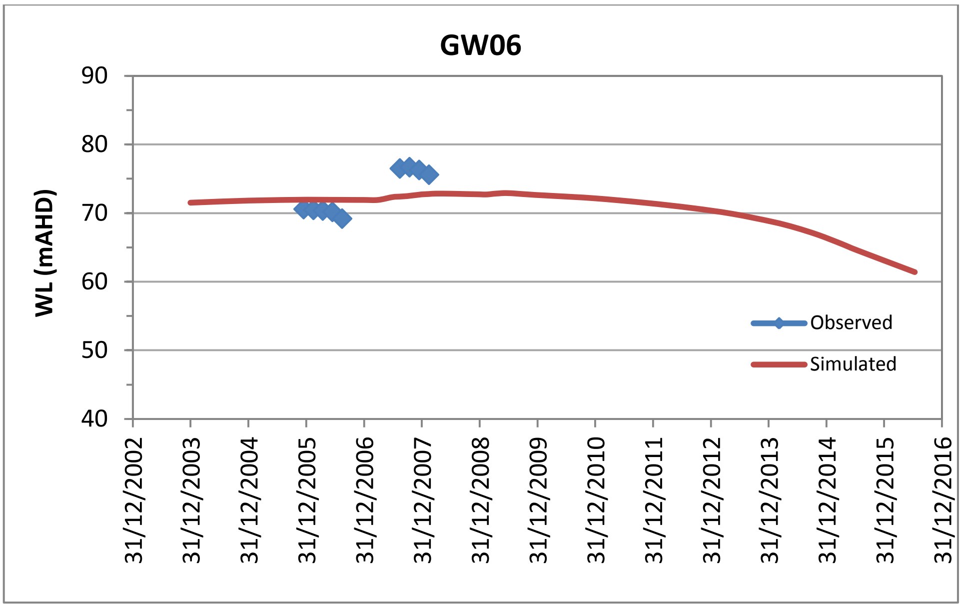

P6
WL (mAHD)
100
90
80
70
60
50
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

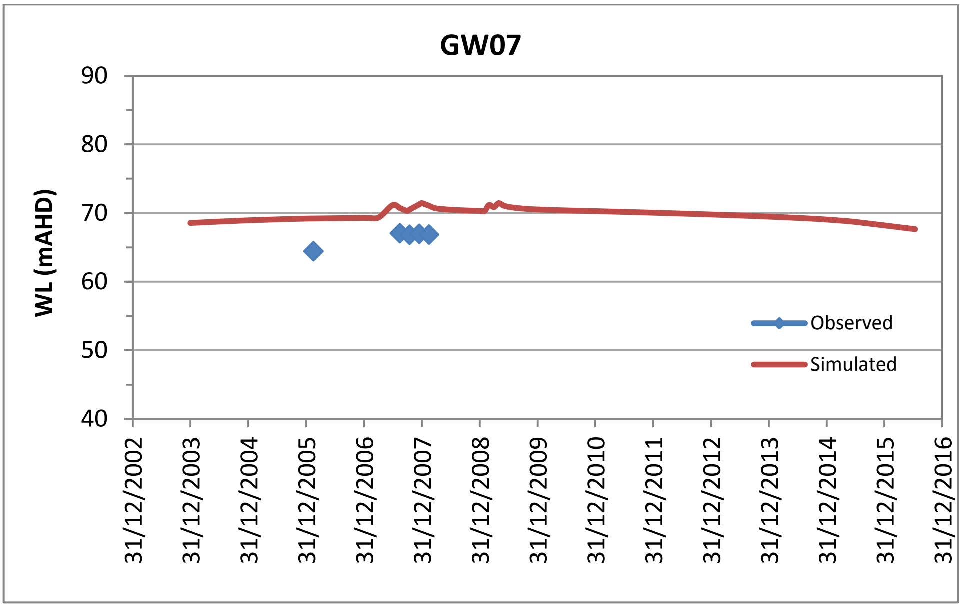

GW20_VW1_Alluvium
WL (mAHD)
100
90
80
70
60
50
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

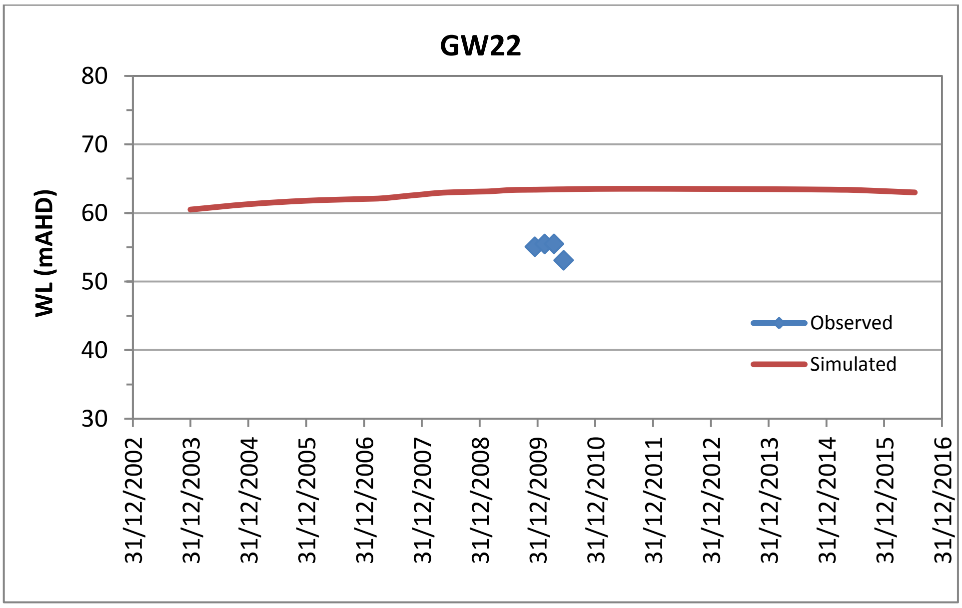
Layer 2

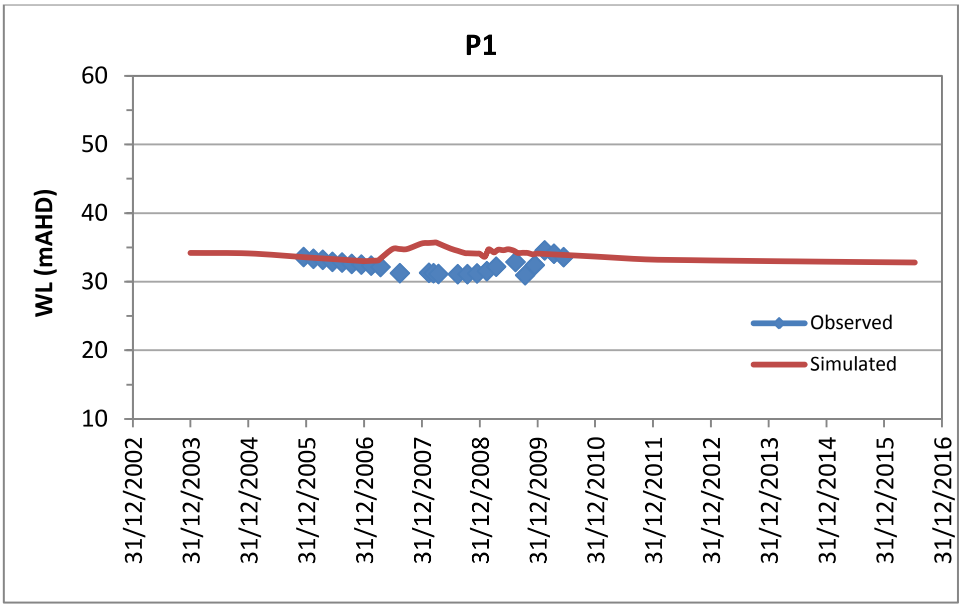

GW04
WL (mAHD)
90
80
70
60
50
40
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

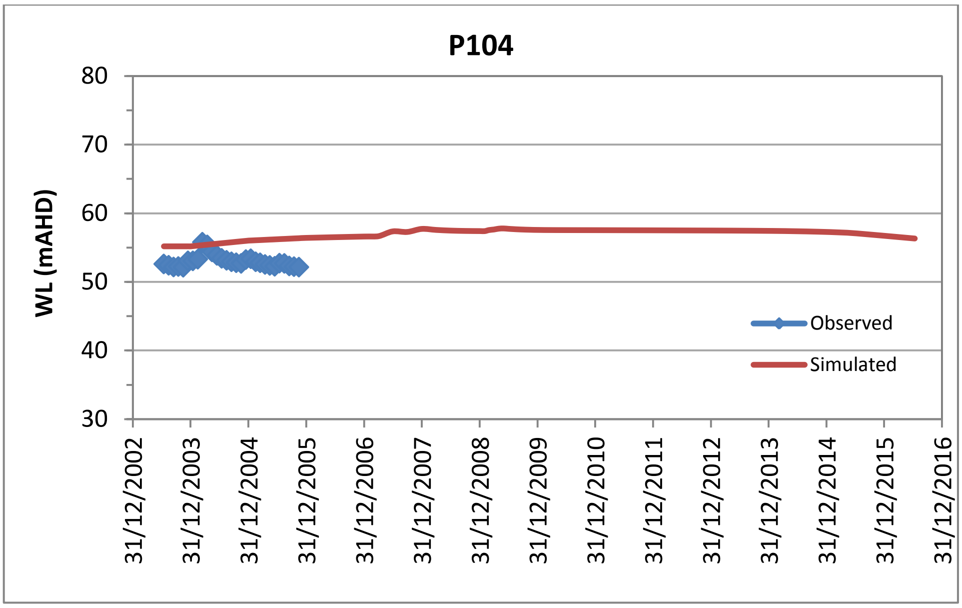

GW05
WL (mAHD)
90
80
70
60
50
40
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

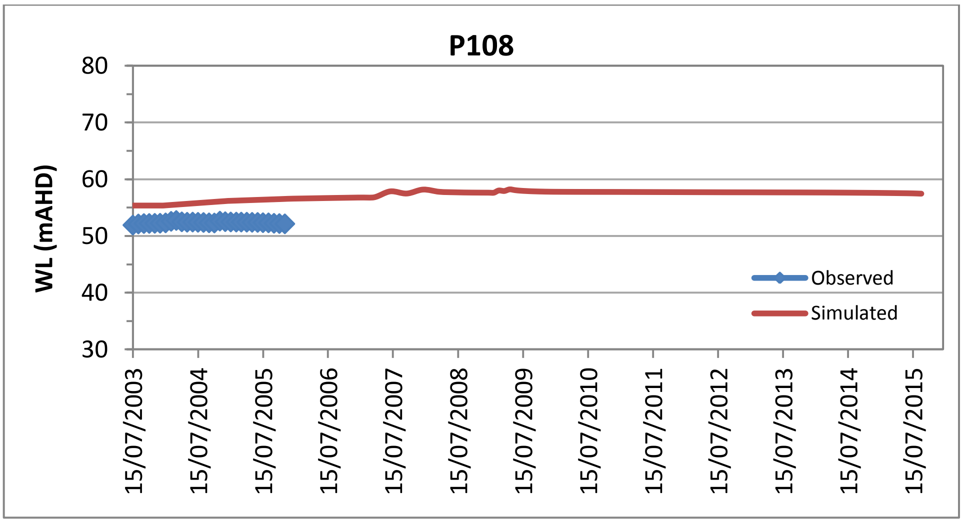

GW06
WL (mAHD)
90
80
70
60
50
40
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

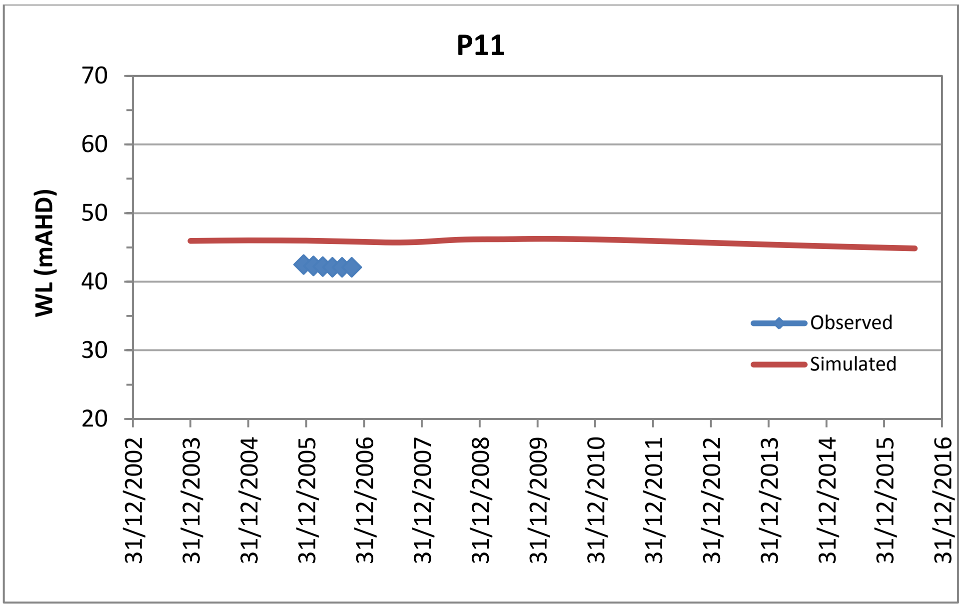

GW07
WL (mAHD)
90
80
70
60
50
40
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

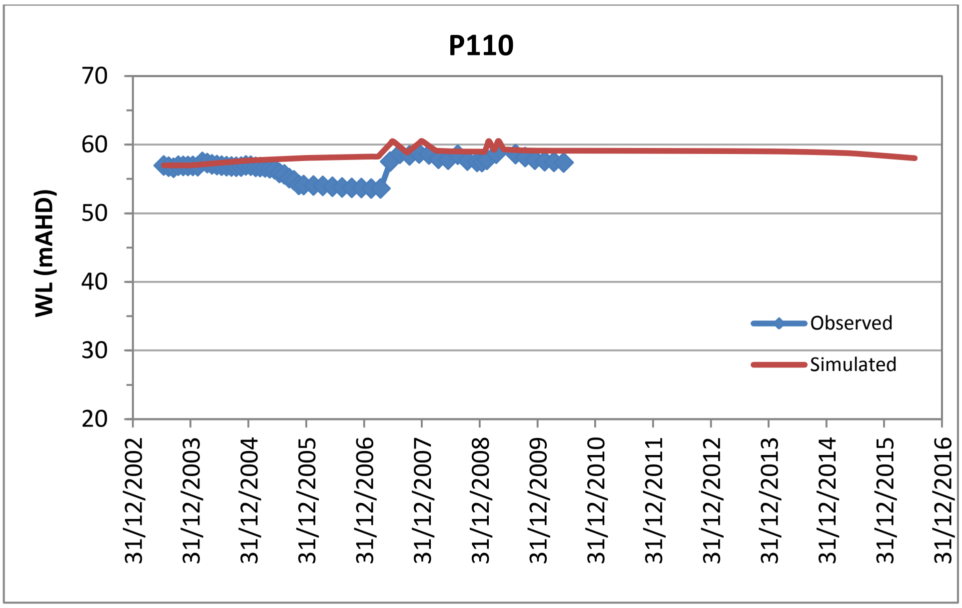

GW22
WL (mAHD)
80
70
60
50
40
30
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

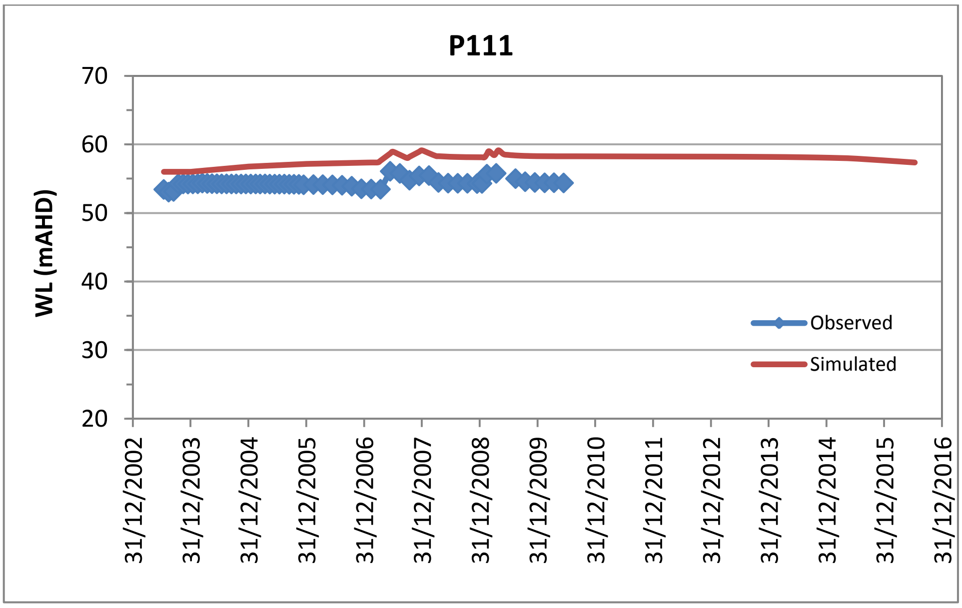

P1
WL (mAHD)
60
50
40
30
20
10
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

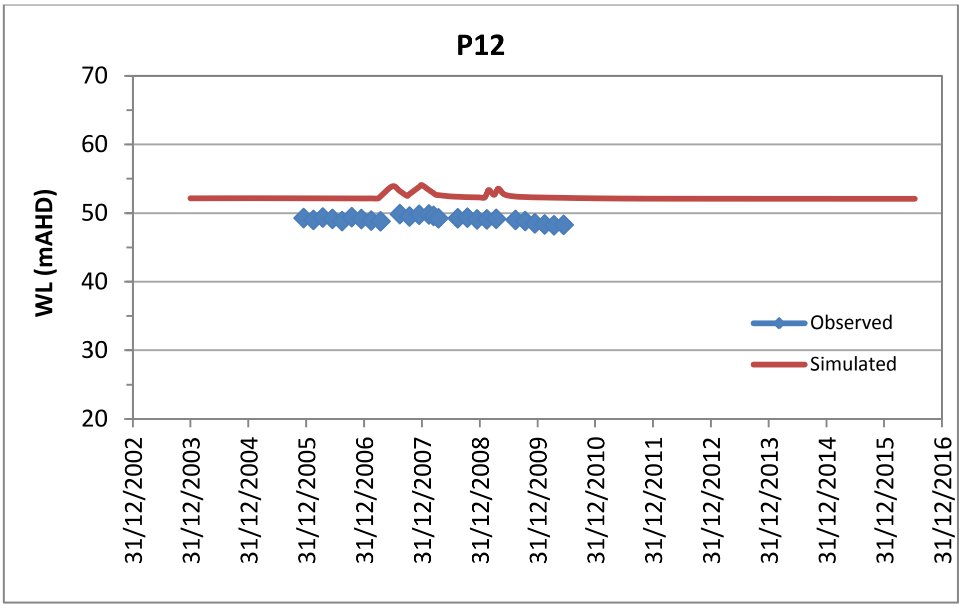

P104
WL (mAHD)
80
70
60
50
40
30
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

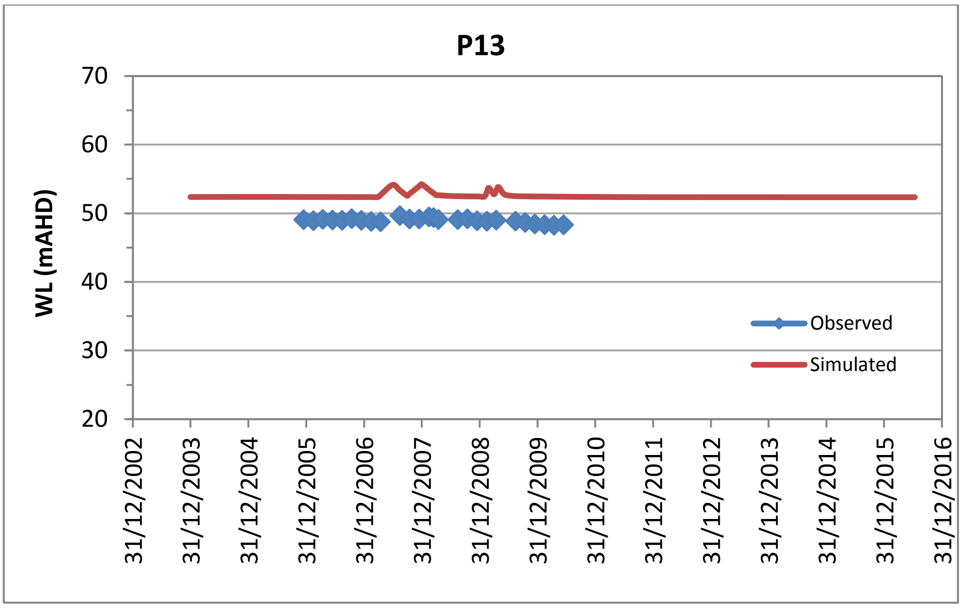

P108
WL (mAHD)
80
70
60
50
40
30
Observed
Simulated
15/07/2003
15/07/2004
15/07/2005
15/07/2006
15/07/2007
15/07/2008
15/07/2009
15/07/2010
15/07/2011
15/07/2012
15/07/2013
15/07/2014
15/07/2015

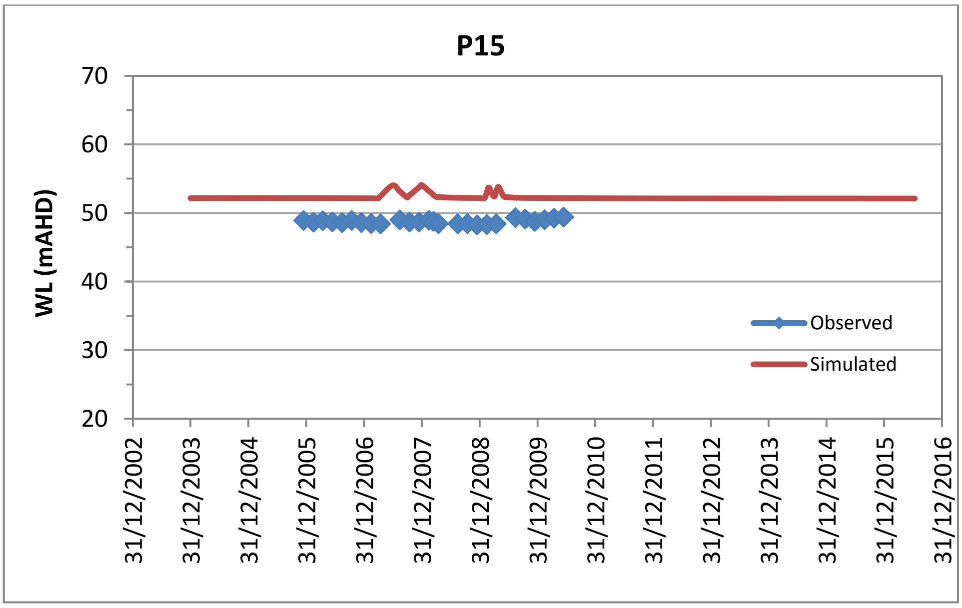

P11
WL (mAHD)
70
60
50
40
30
20
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

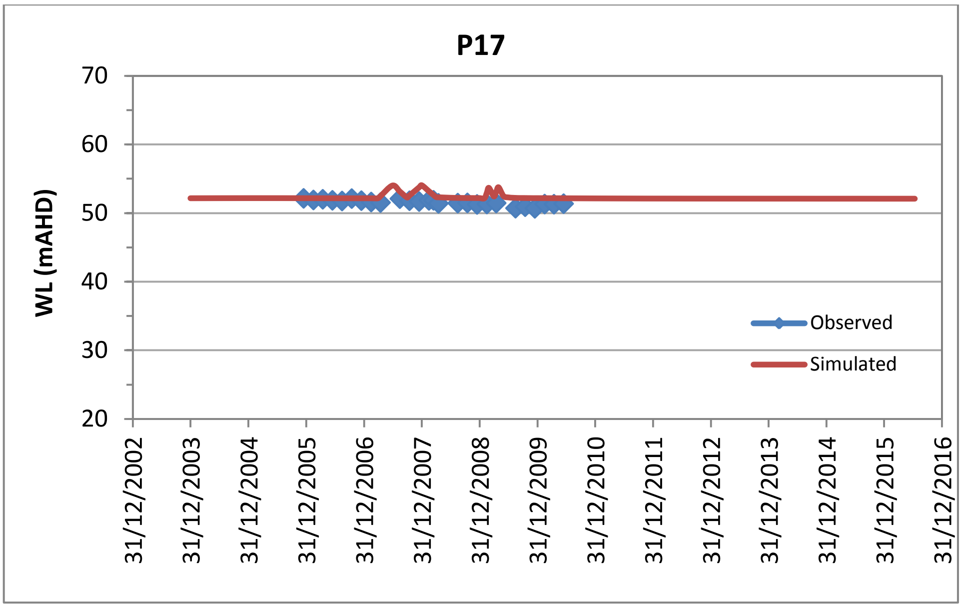

P110
WL (mAHD)
70
60
50
40
30
20
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

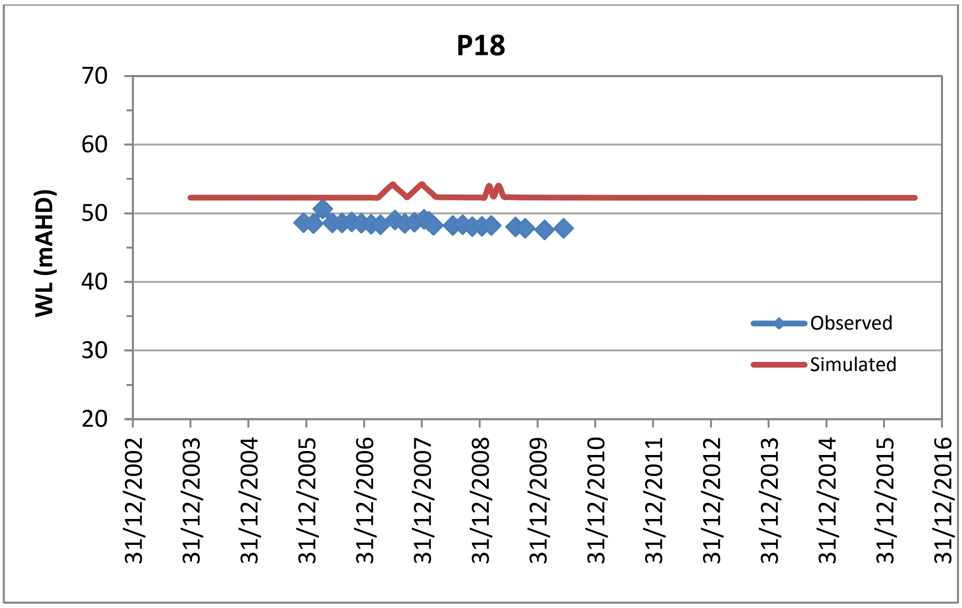

P111
WL (mAHD)
70
60
50
40
30
20
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

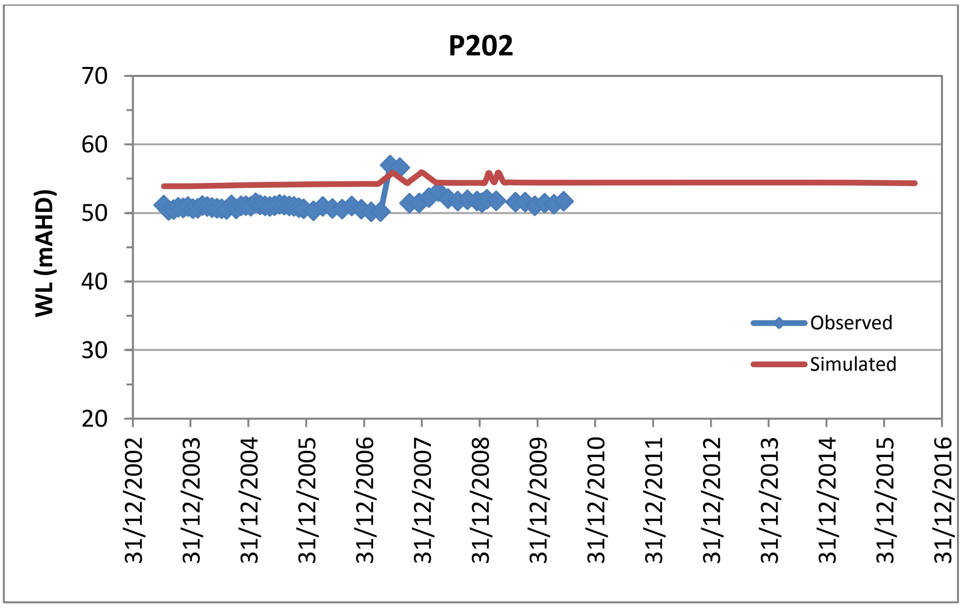

P12
WL (mAHD)
70
60
50
40
30
20
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

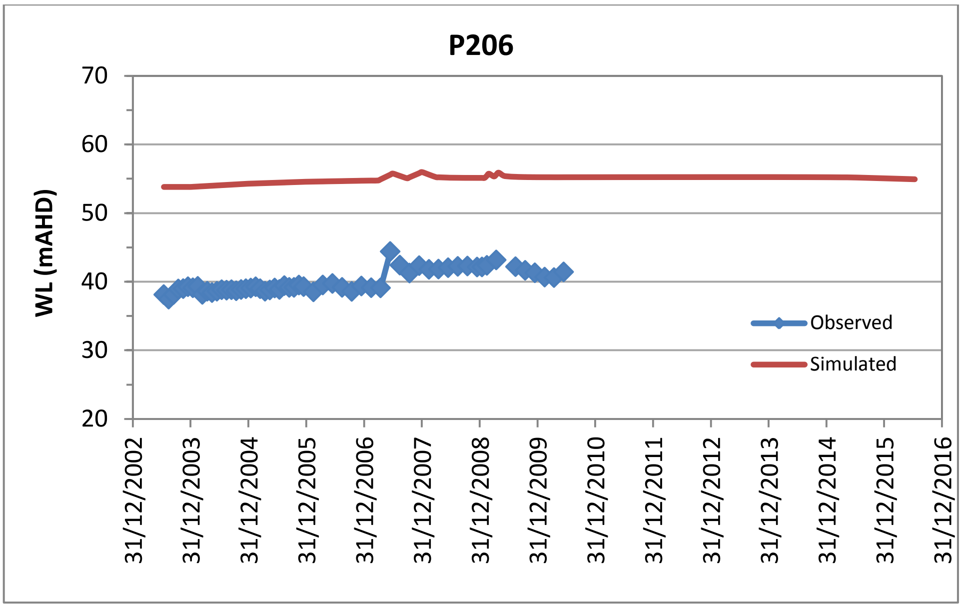

P13
WL (mAHD)
70
60
50
40
30
20
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

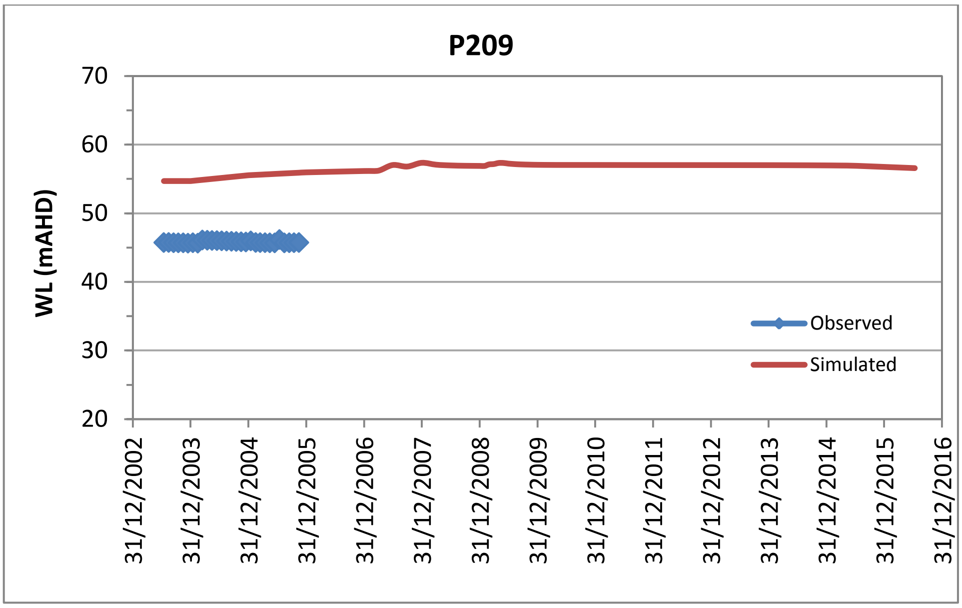

P15
WL (mAHD)
70
60
50
40
30
20
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

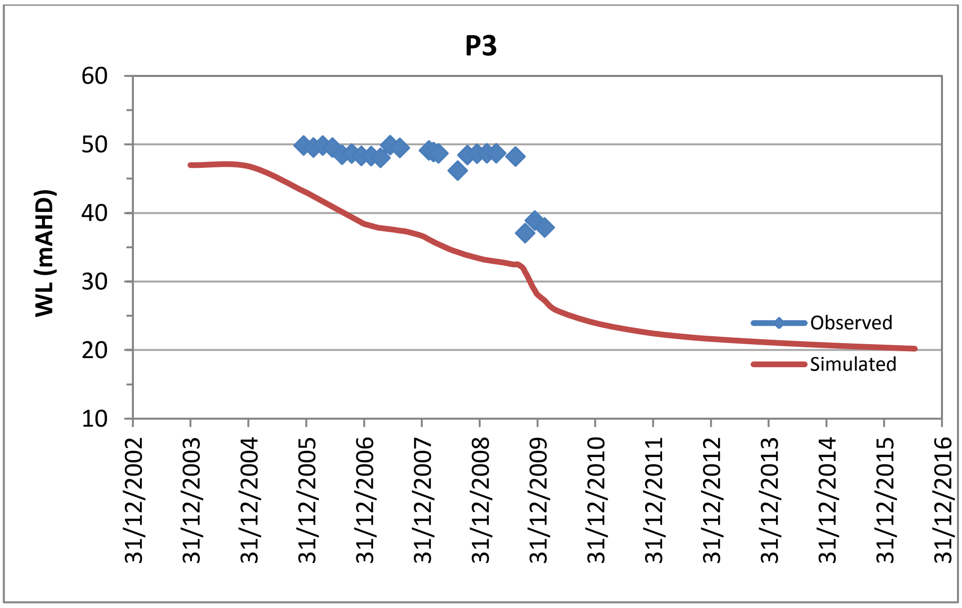

P17
WL (mAHD)
70
60
50
40
30
20
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

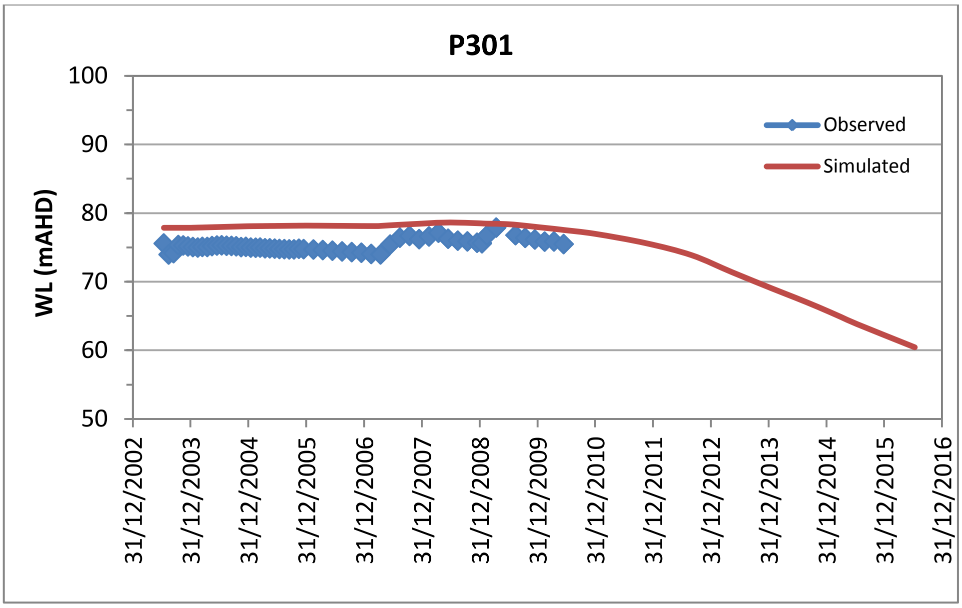

P18
WL (mAHD)
70
60
50
40
30
20
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

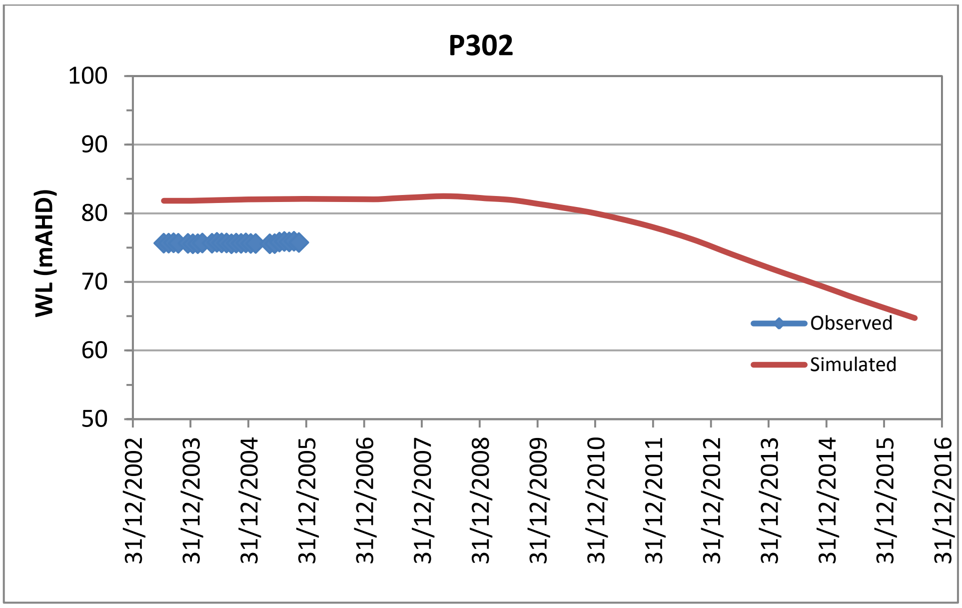

P202
WL (mAHD)
70
60
50
40
30
20
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

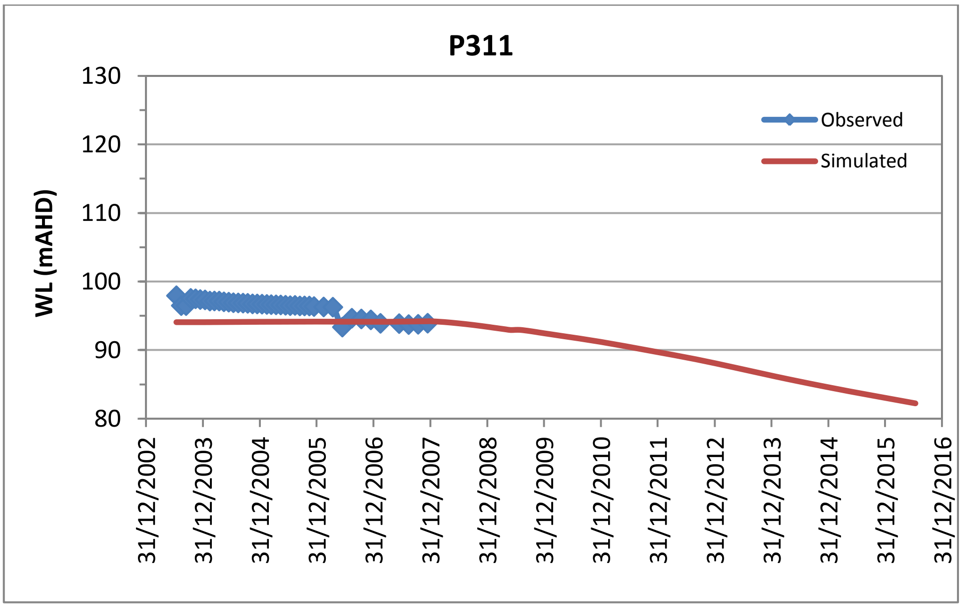

P206
WL (mAHD)
70
60
50
40
30
20
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

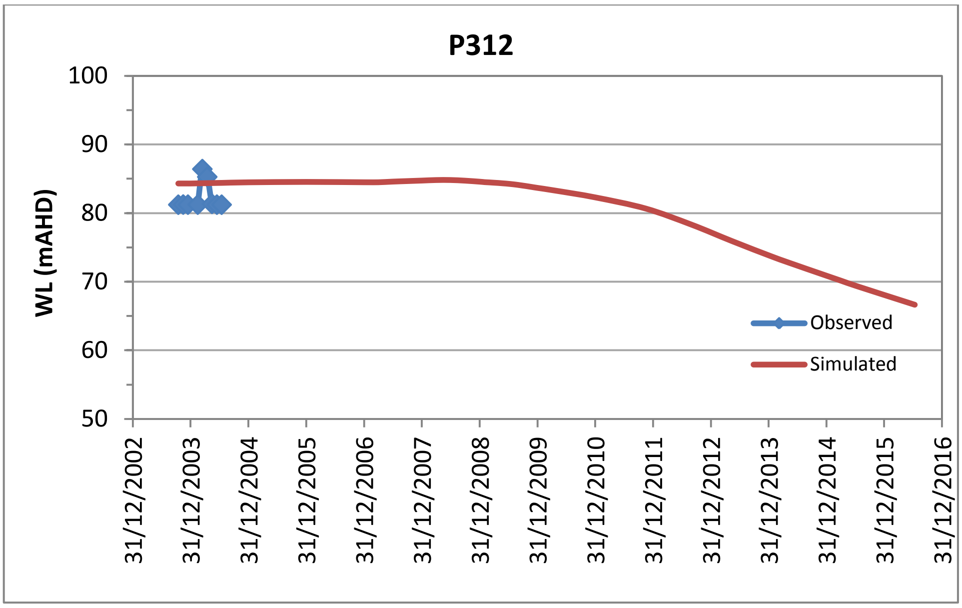

P209
WL (mAHD)
70
60
50
40
30
20
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

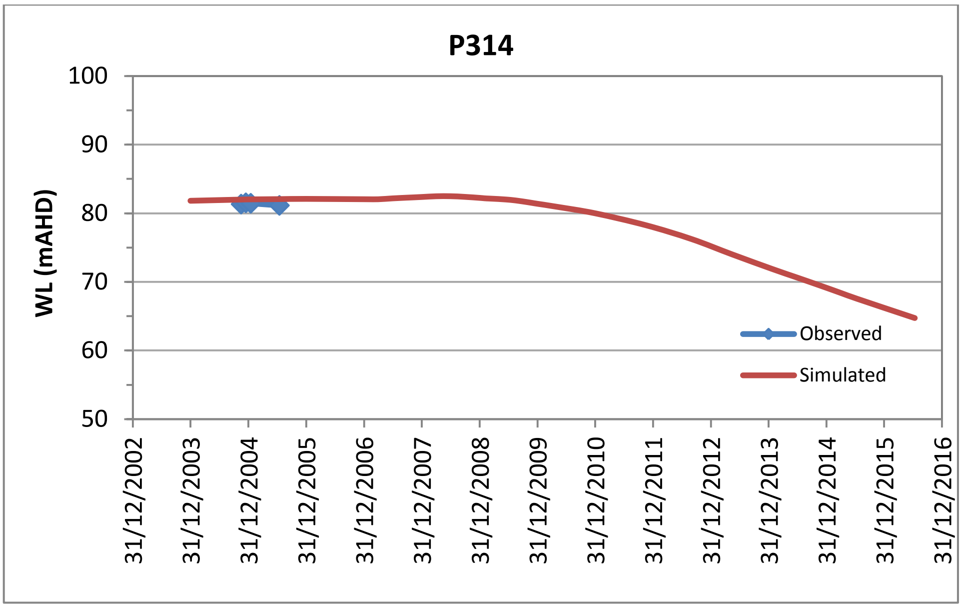

P3
WL (mAHD)
60
50
40
30
20
10
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

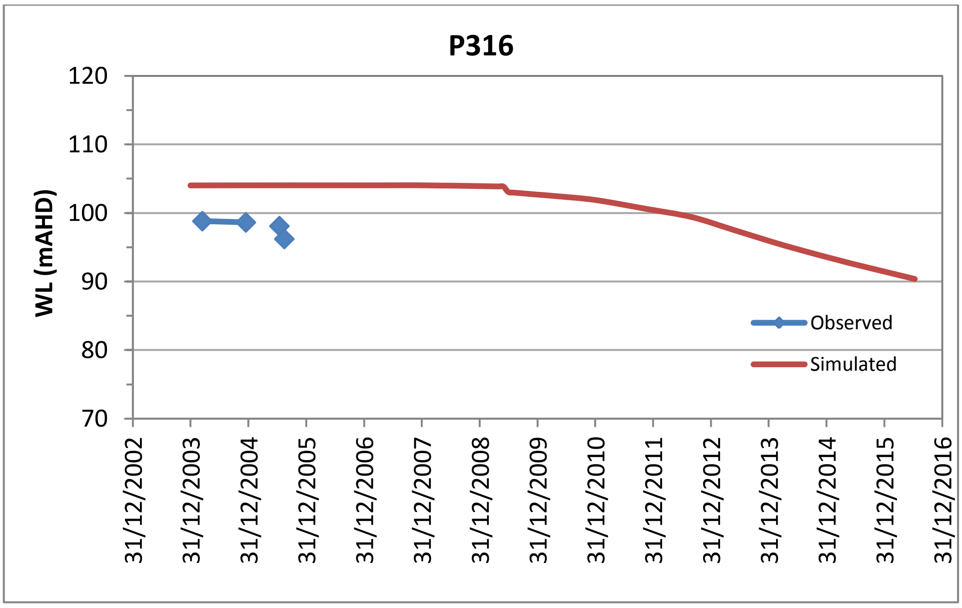

P301
WL (mAHD)
100
90
80
70
60
50
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

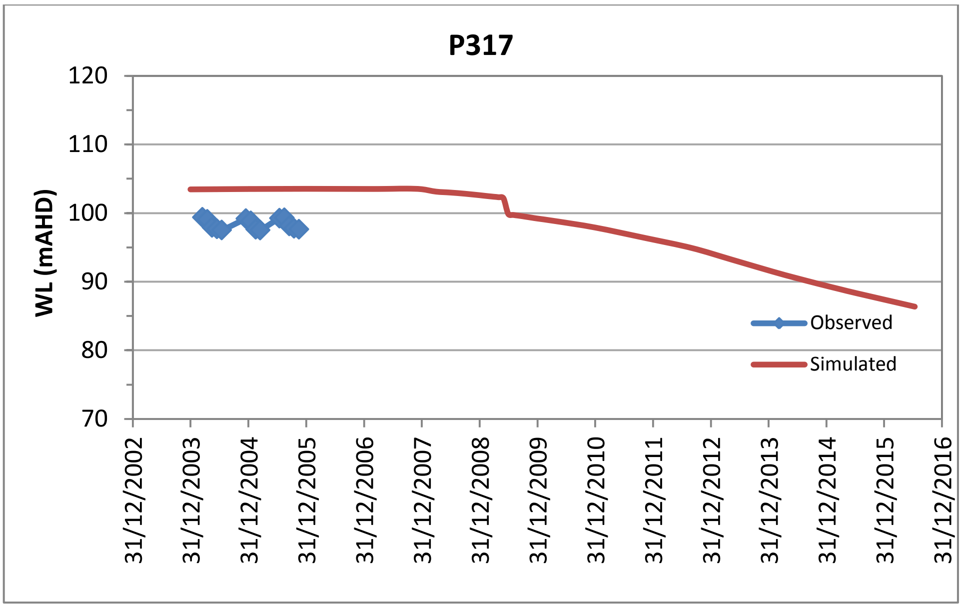

P302
WL (mAHD)
100
90
80
70
60
50
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016


P311
WL (mAHD)
130
120
110
100
90
80
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

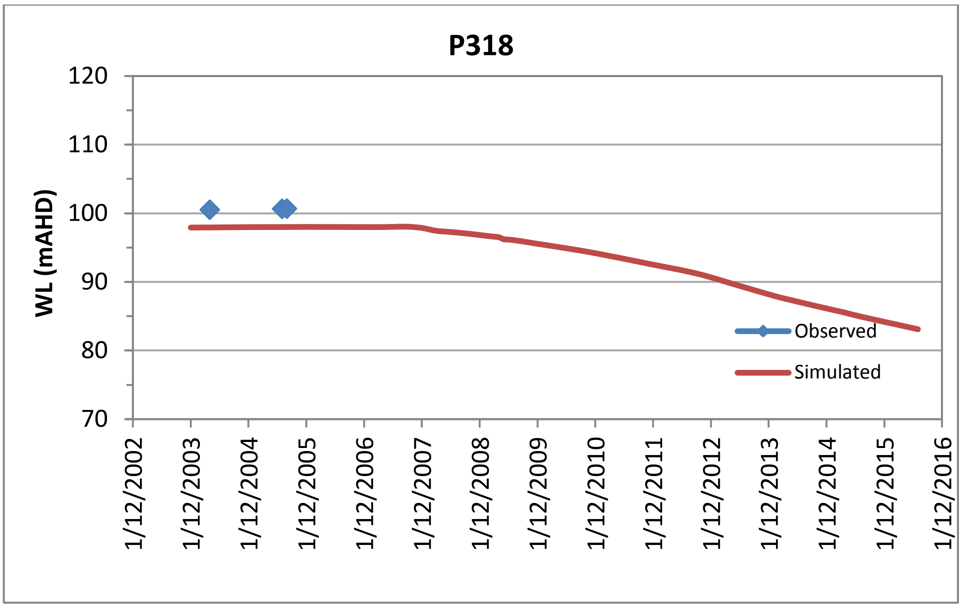

P312
WL (mAHD)
100
90
80
70
60
50
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated


P314
WL (mAHD)
100
90
80
70
60
50
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated


P316
WL (mAHD)
120
110
100
90
80
70
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

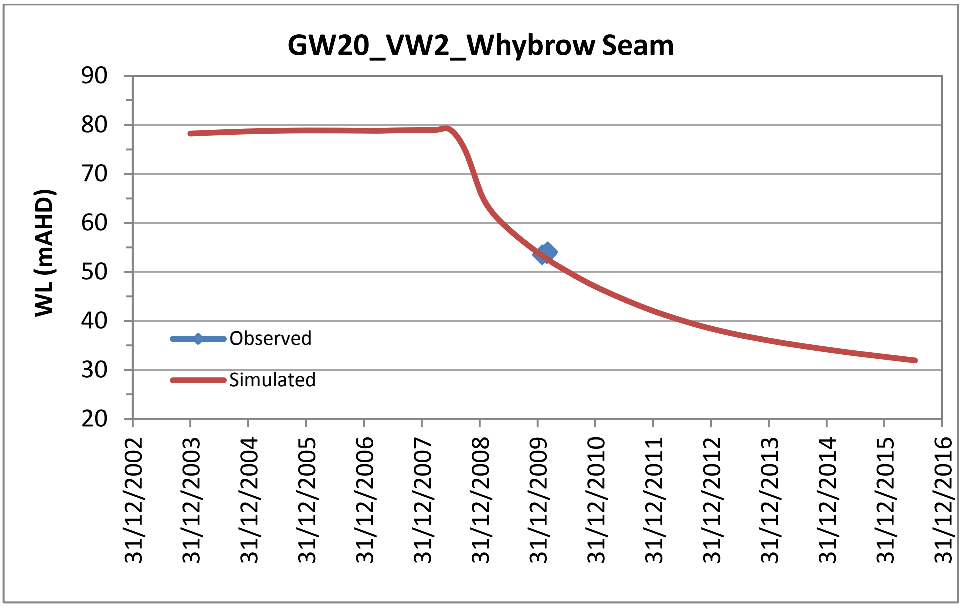


P317
WL (mAHD)
120
110
100
90
80
70
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated



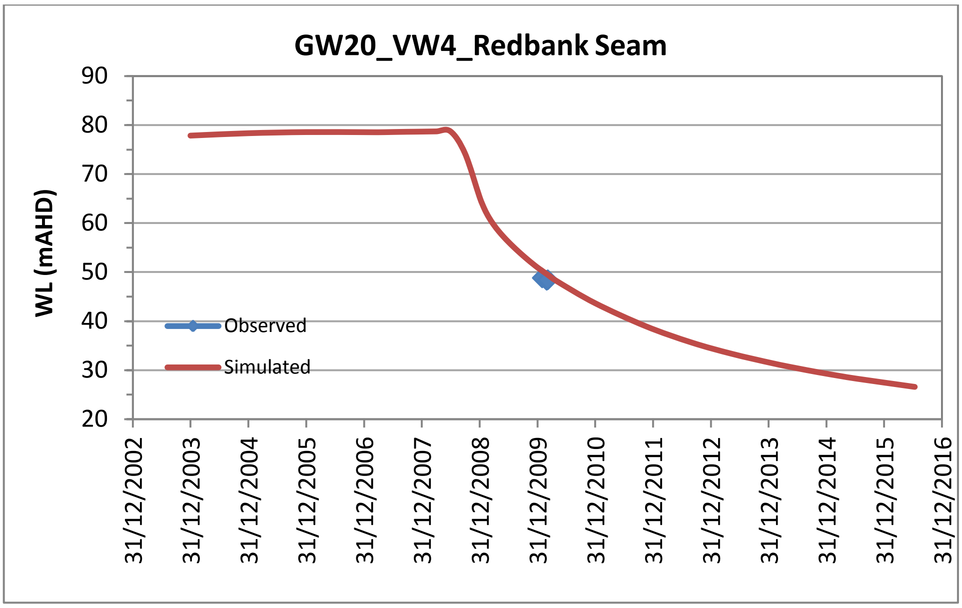
P318
WL (mAHD)
120
110
100
90
80
70
1/12/2002
1/12/2003
1/12/2004
1/12/2005
1/12/2006
1/12/2007
1/12/2008
1/12/2009
1/12/2010
1/12/2011
1/12/2012
1/12/2013
1/12/2014
1/12/2015
1/12/2016
Observed
Simulated

Layer 3

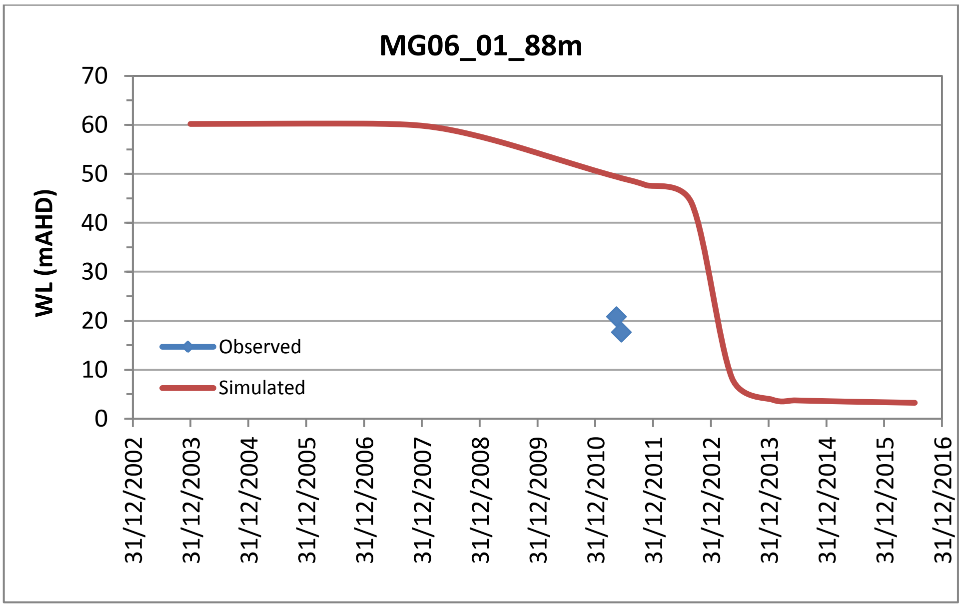


GW20_VW2_Whybrow Seam
WL (mAHD)
90
80
70
60
50
40
30
20
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

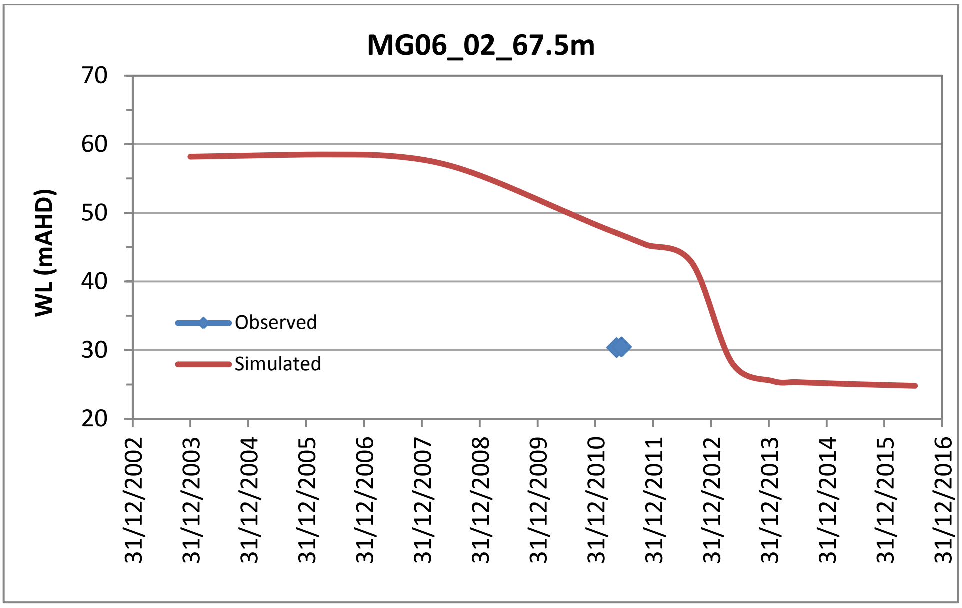
Layer 4

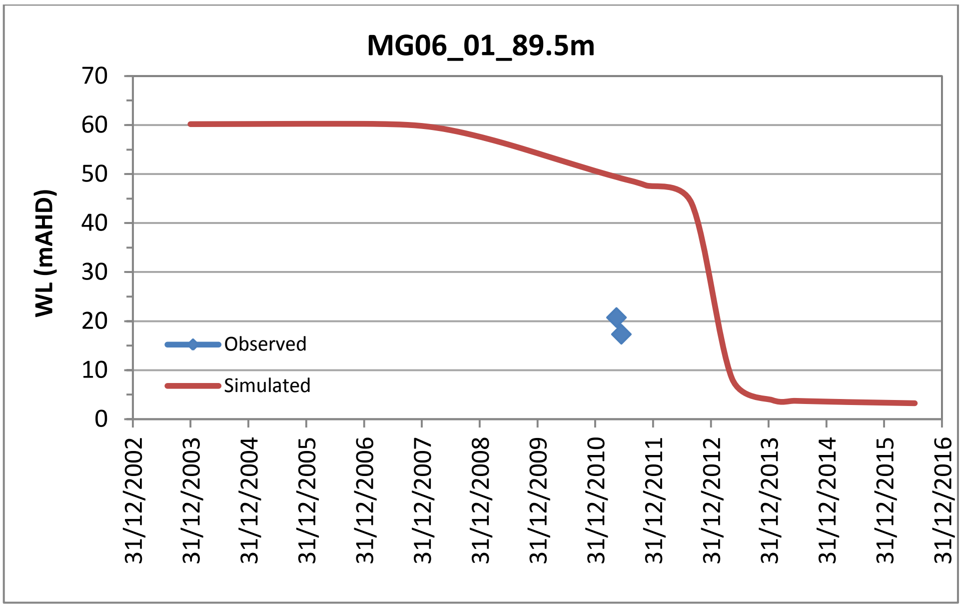


GW20_VW4_Redbank Seam
WL (mAHD)
90
80
70
60
50
40
30
20
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

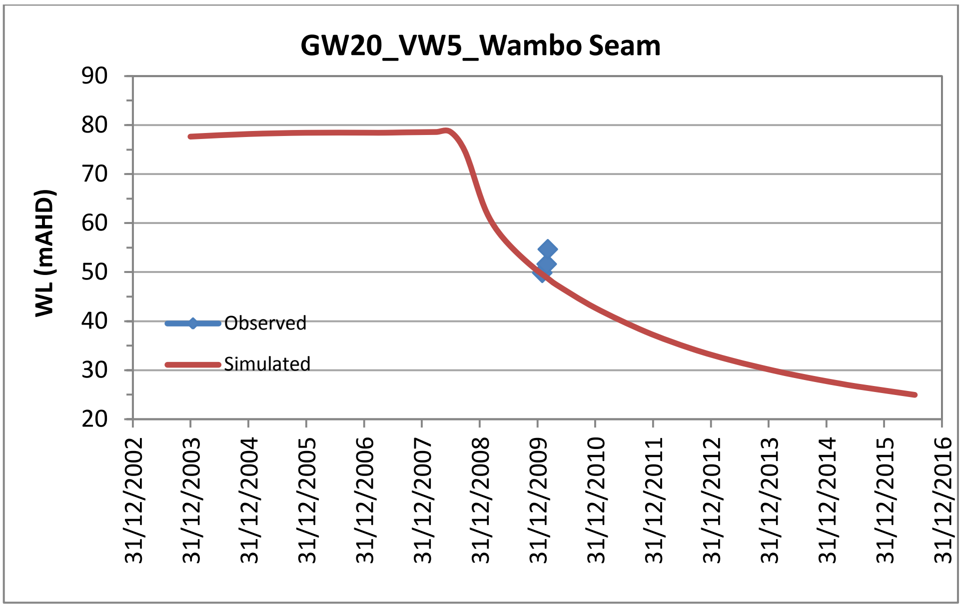


MG06_01_88m
WL (mAHD)
70
60
50
40
30
20
10
0
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

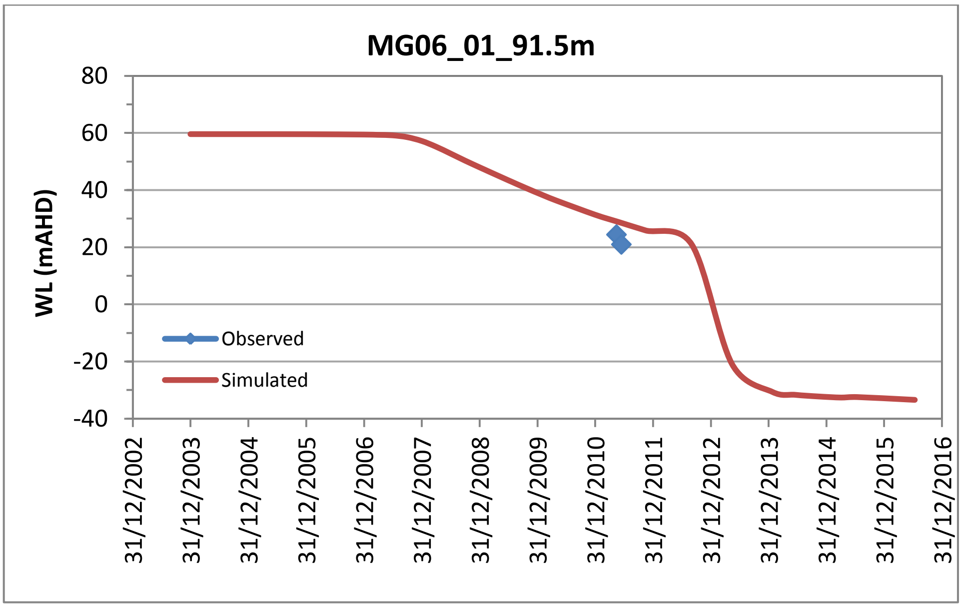

MG06_02_67.5m
WL (mAHD)
70
60
50
40
30
20
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016


MG06_01_89.5m
WL (mAHD)
70
60
50
40
30
20
10
0
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

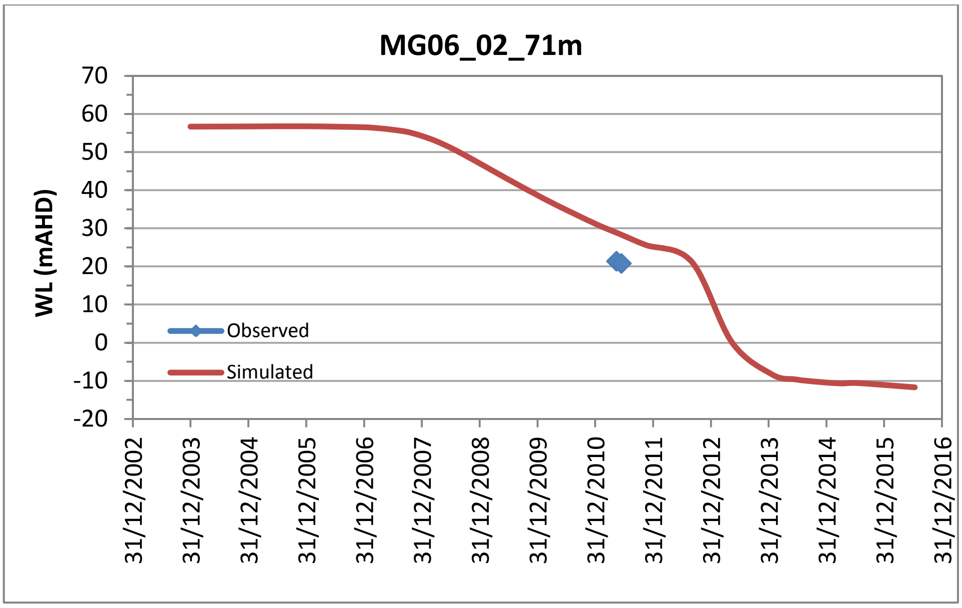
Layer 5



GW20_VW5_Wambo Seam
WL (mAHD)
90
80
70
60
50
40
30
20
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

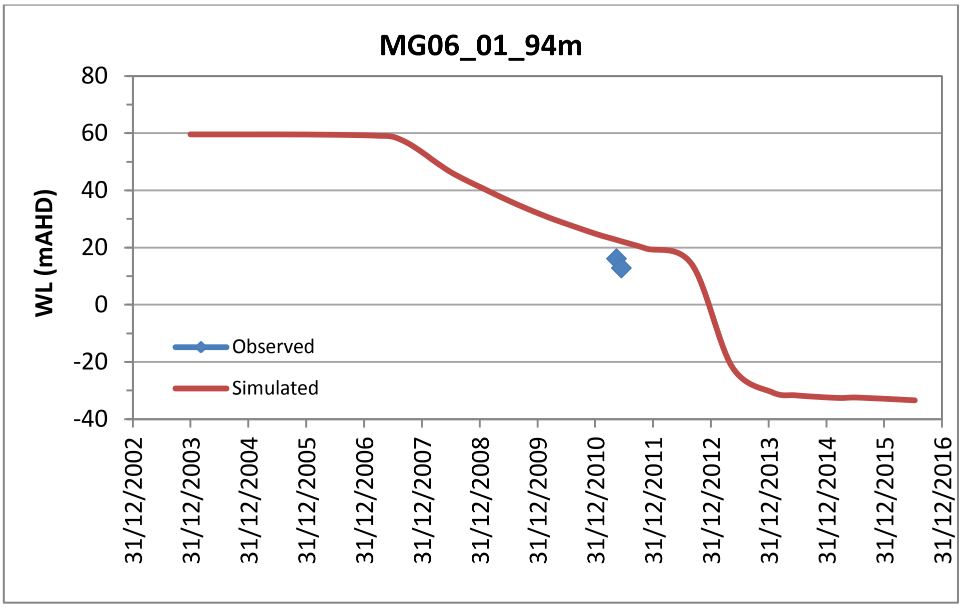


MG06_01_91.5m
WL (mAHD)
80
60
40
20
0
-20
-40
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016



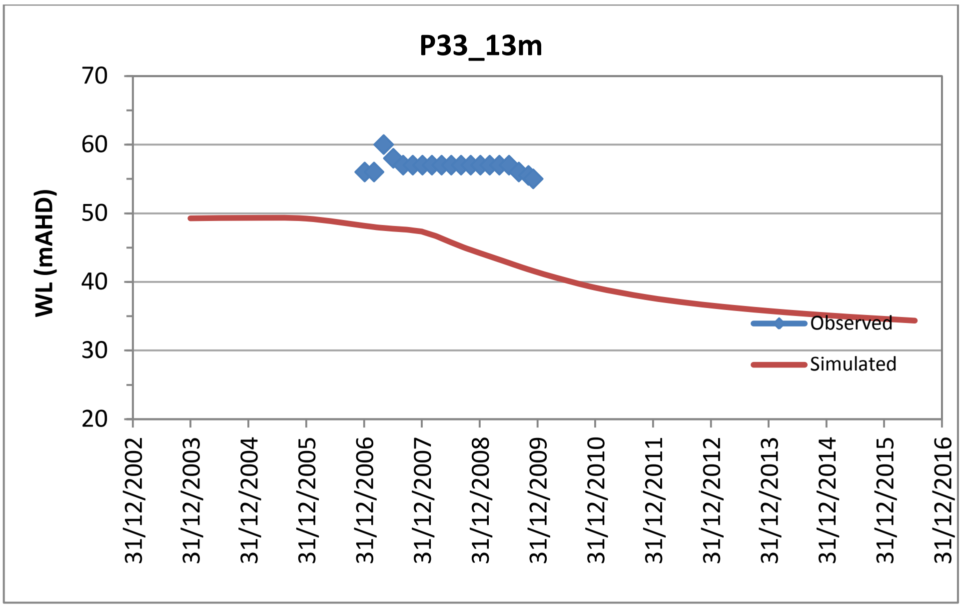
MG06_02_71m
WL (mAHD)
70
60
50
40
30
20
10
0
-10
-20
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

Layer 6

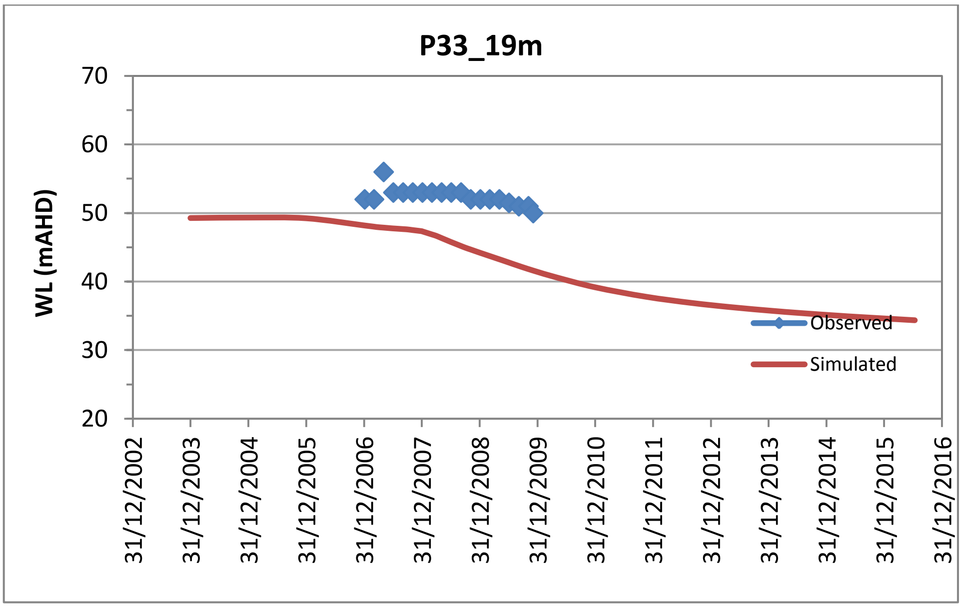


MG06_01_94m
WL (mAHD)
80
60
40
20
0
-20
-40
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

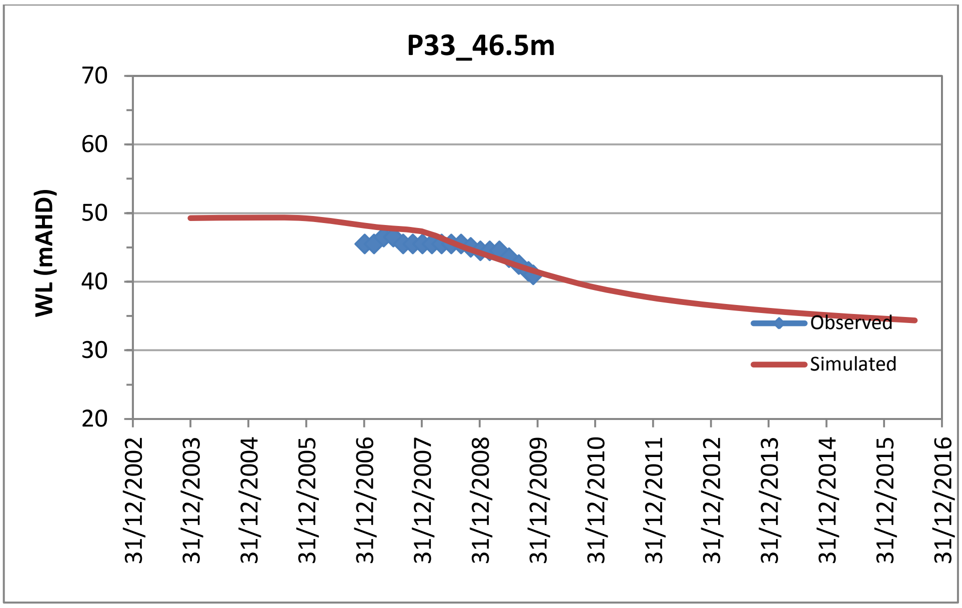
Layer 8

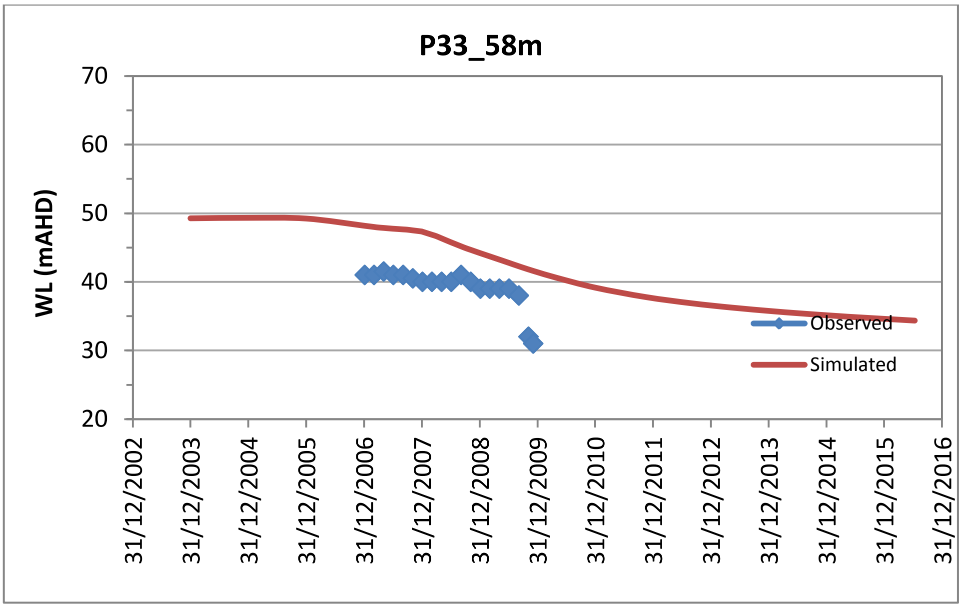


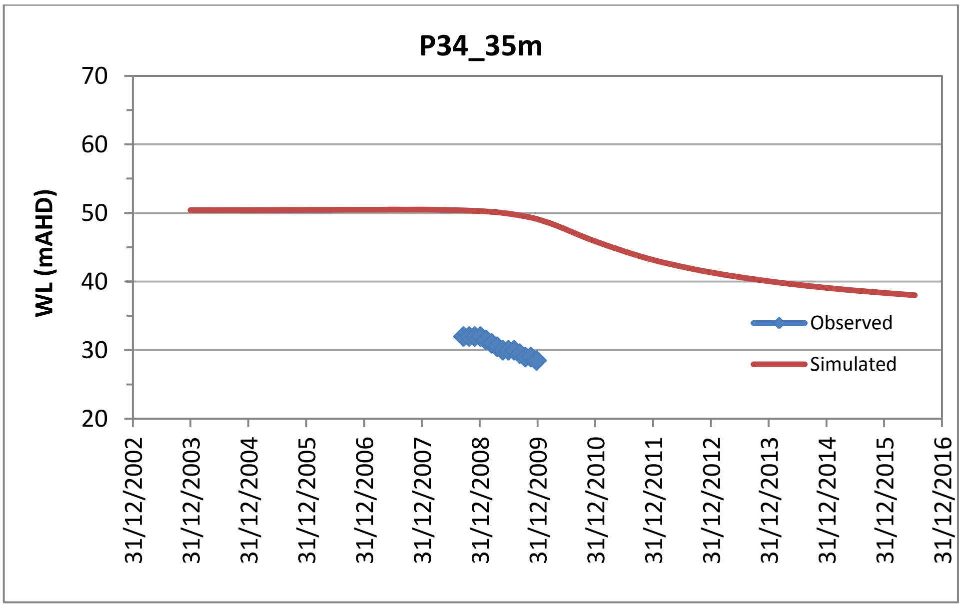
P33_13m
WL (mAHD)
70
60
50
40
30
20
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

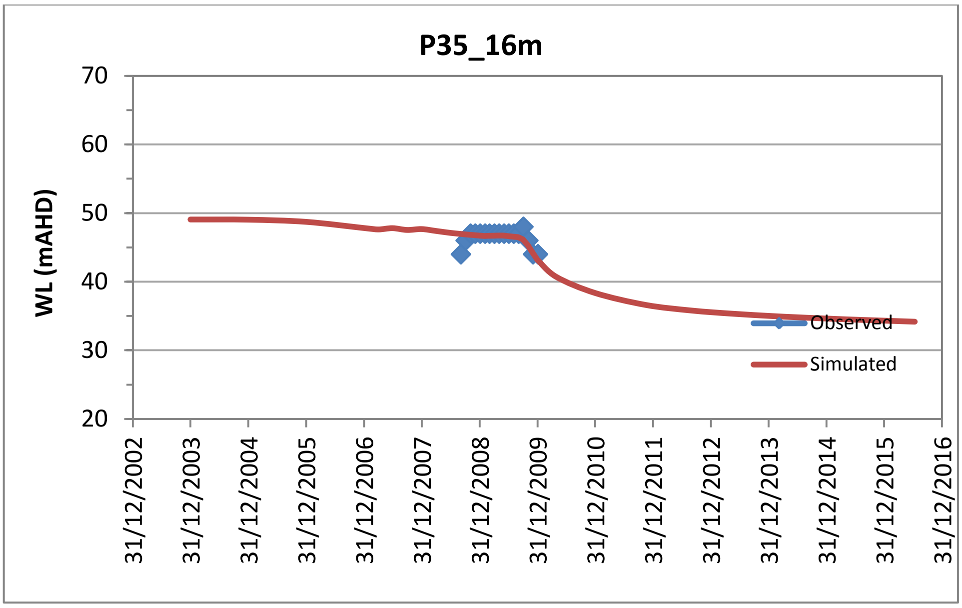


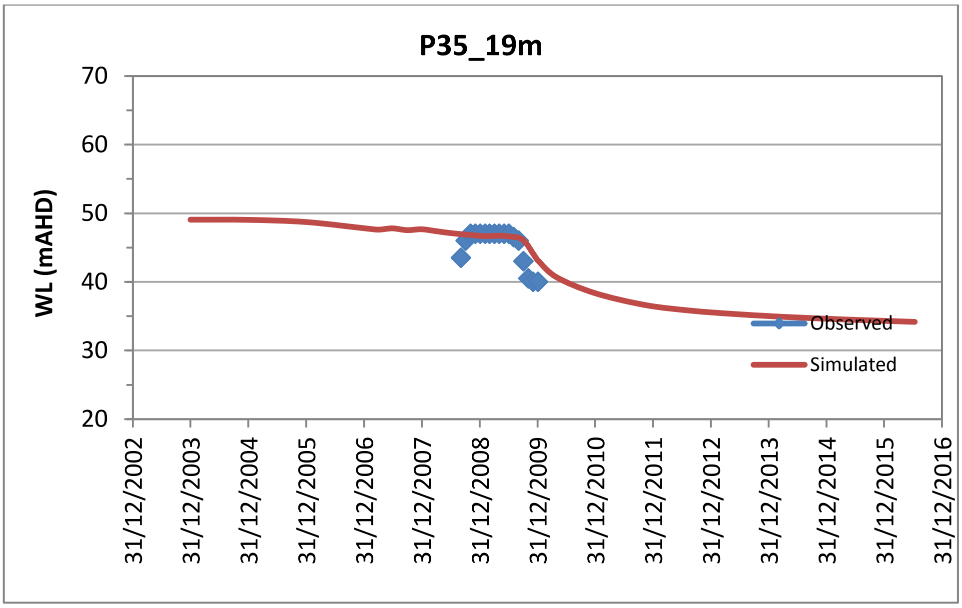
P33_19m
WL (mAHD)
70
60
50
40
30
20
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated


P33_46.5m
WL (mAHD)
70
60
50
40
30
20
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

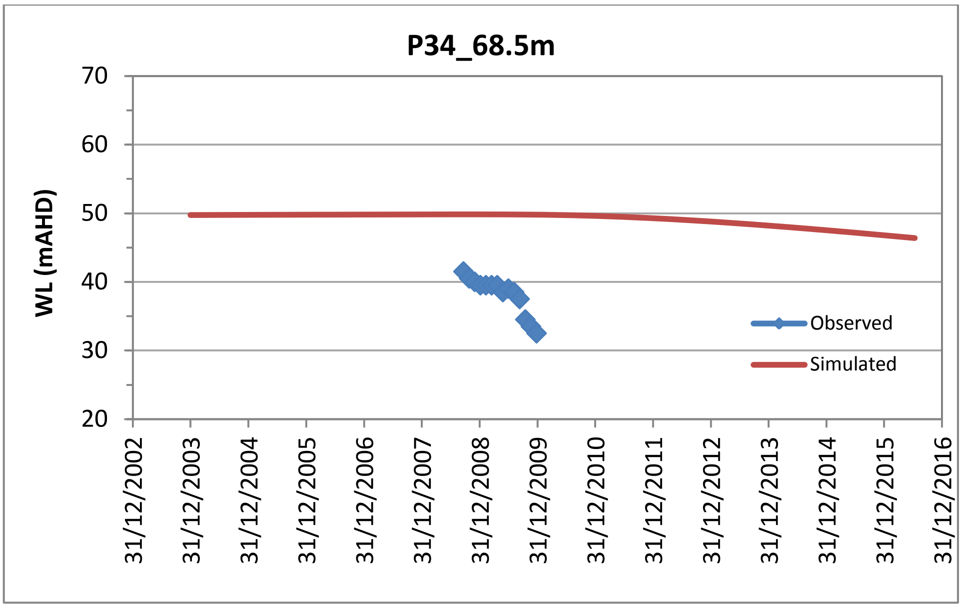

P33_58m
WL (mAHD)
70
60
50
40
30
20
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

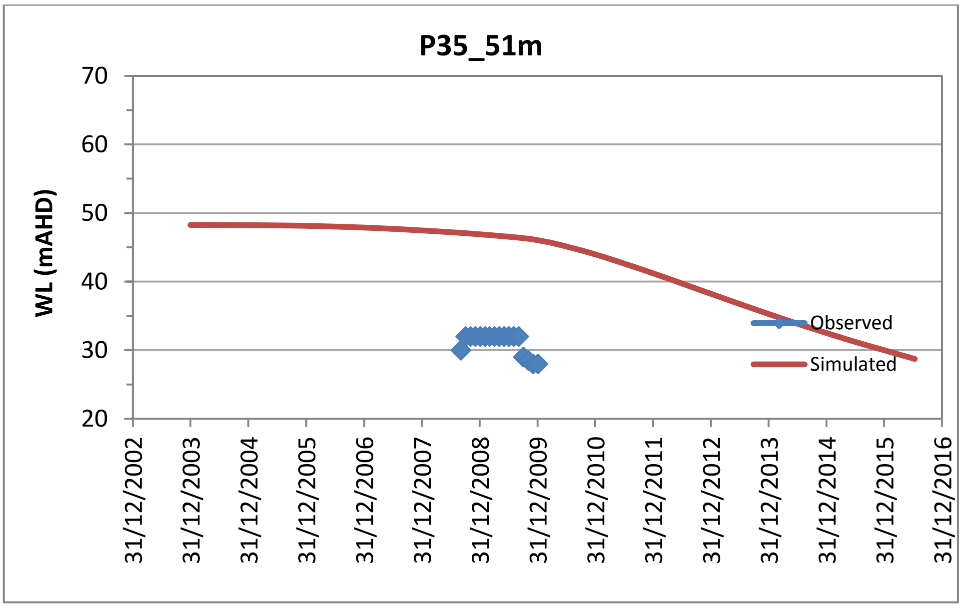

P34_35m
WL (mAHD)
70
60
50
40
30
20
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016


P35_16m
WL (mAHD)
70
60
50
40
30
20
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

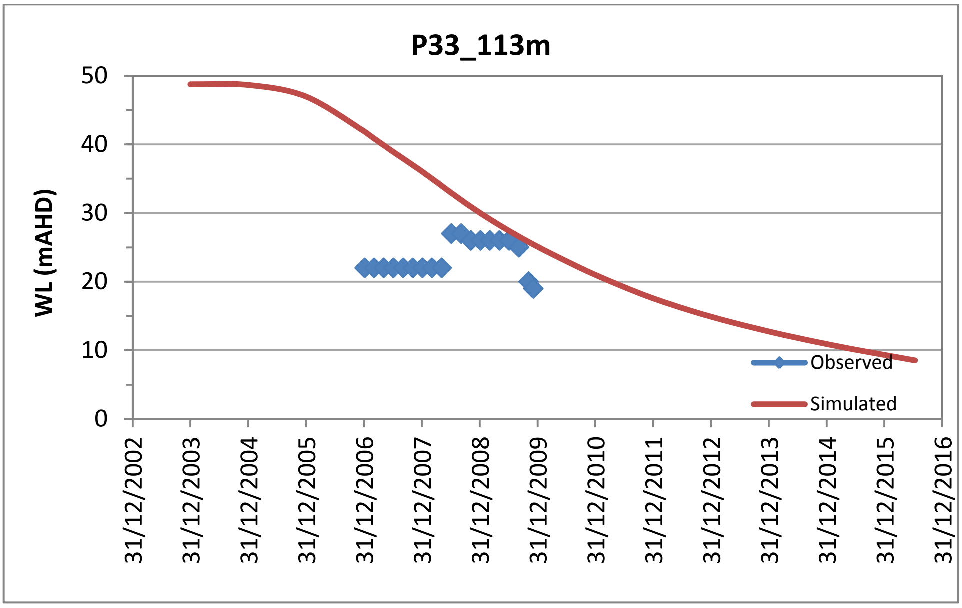

P35_19m
WL (mAHD)
70
60
50
40
30
20
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

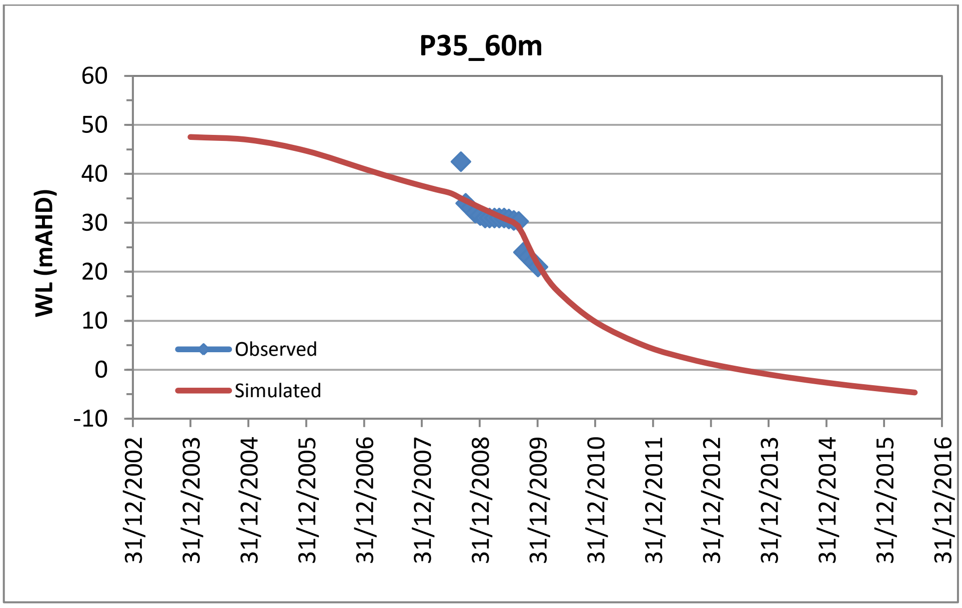
Layer 9


P34_68.5m
WL (mAHD)
70
60
50
40
30
20
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

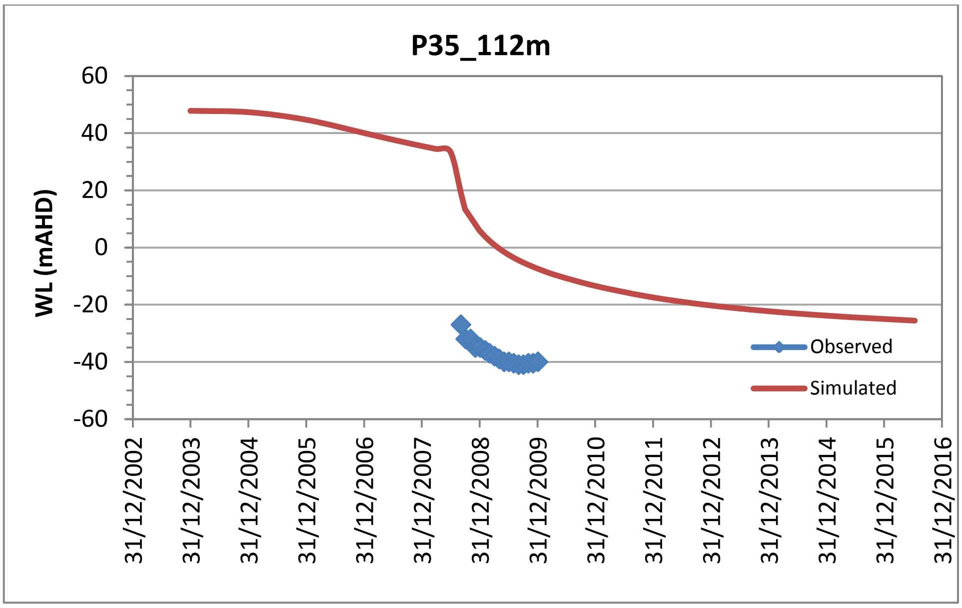

P35_51m
WL (mAHD)
70
60
50
40
30
20
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

Layer 10

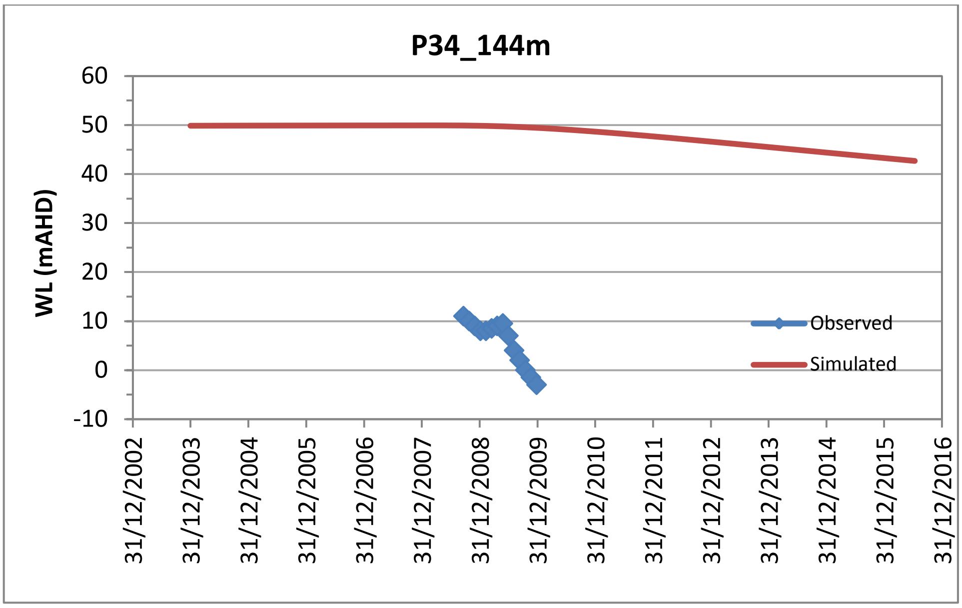

P33_113m
WL (mAHD)
50
40
30
20
10
0
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016


P35_60m
WL (mAHD)
60
50
40
30
20
10
0
-10
Observed
Simulated
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016

Layer 11


P35_112m
60
40
20
0
-20
-40
-60
WL (mAHD)
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated

Layer 12



P34_144m
WL (mAHD)
60
50
40
30
20
10
0
-10
31/12/2002
31/12/2003
31/12/2004
31/12/2005
31/12/2006
31/12/2007
31/12/2008
31/12/2009
31/12/2010
31/12/2011
31/12/2012
31/12/2013
31/12/2014
31/12/2015
31/12/2016
Observed
Simulated