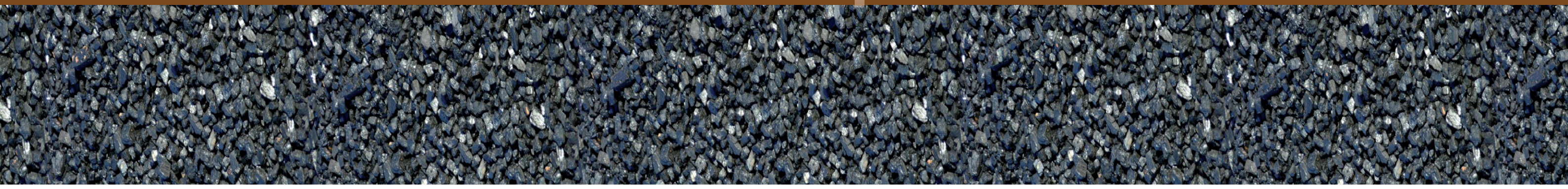
Narrabri Mine Modification 5

Environmental Assessment



APPENDIX B

Groundwater Assessment

Resource Strategies

WHITEHAVEN COAL

Narrabri Mine Modification Groundwater Assessment

FOR

Narrabri Coal Operations Pty Ltd

BY

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1 INTRODUCTION

The Narrabri Mine (NM) is an existing underground mining operation situated approximately 30 kilometres (km) southeast of Narrabri, New South Wales (NSW). The mine is located within Mining Lease (ML) 1609 and Exploration Licence (EL) 6243 (**Figure 1**) in the Gunnedah Coalfield within the Gunnedah-Oxley Basin.

The NM is operated by Narrabri Coal Operations Pty Ltd (NCOPL) on behalf of the Narrabri Joint Venture, which consists of Whitehaven Coal Limited's (Whitehaven) subsidiary Narrabri Coal; Pty Ltd (NCPL) (70%), Upper Horn Investments (Australia) Pty Ltd (7.5%), J Power Australia Pty Limited (7.5%), EDF Trading Australia Pty Limited (7.5%), and Daewoo International Narrabri Investment Pty Limited and Kores Narrabri Pty Limited (7.5%).

This report has been prepared for NCOPL to provide a groundwater assessment for a proposed operational mining modification.

1.1 MINING AT NARRABRI MINE

The NM was developed after substantial investigations were undertaken under EL 6243, granted in May 2004. In March 2007, NCOPL lodged an Environmental Assessment (EA) Report for the proposed development of surface infrastructure and initial underground mine development, with coal production by first workings of up to 2.5 million tonnes per annum (Mtpa). This part of the project is referred to as Stage 1.

A groundwater assessment was prepared and submitted (GHD, 2007) as part of the Stage 1 EA which supported the application for Project Approval. Stage 1 of the project was granted approval on 13 November 2007 (Project Approval 05_0102). Following approval, ML 1609 was granted on 18 January 2008. After completion of a box cut and drift tunnels, coal production from development headings commenced in June 2010.

A further groundwater assessment was prepared and submitted (Aquaterra, 2009) as part of the EA undertaken for Stage 2 comprising the development of longwall (LW) mining operations on ML 1609 for the extraction of coal up to 8 Mtpa. The Stage 2 groundwater assessment further developed the Stage 1 groundwater model to include longwall progression and the project was granted Part 3A approval (PA 08_0144) on 26 July 2010.

Longwall coal production commenced in June 2012.

The Approved NM layout is depicted in **Figure 2a**. It consists of 26 longwall panels, 306.4 metres (m) in width and between approximately 1600 m and 4000 m in length. **Figure 2a** shows the names associated with each of the longwall panels. The depth of cover varies from around 155 m to 380 m. Longwalls 101 and 102 have been completed with a mining height of 4.2 m. The mining height for LW103 and LW104 was increased to 4.3 m and maintenance of this height is planned for the duration of the NM.

1.2 PROPOSED MODIFICATION

Elements of the proposed Modification are:

- Shorter duration of mining;

- Reduction in the number of longwall panels from 26 to 20;
- Increased longwall panel widths; and
- Some reduction of longwall panel lengths.

Approval for NM is on the basis of mining extraction spanning the period from June 2012 to the end of December 2037 (25½ years) (noting however that Condition 5, Schedule 2 of Project Approval 08_0144 restricts mining operations to July 2031). The corresponding period for the Modification is June 2012 to the end of April 2031 (19 years and 11 months) – that is, 5 years and 7 months shorter.

Figure 2b shows the proposed Modified mine layout and the names associated with each of the longwall panels. The overall duration of mining for the Approved and Modified layouts differs as described above. For each layout, panels are planned to be executed in numerical sequence – that is, from east to west for the northern part of the Approved mine area, then from west to east for the southern part. However, since the number of panels is reduced for the Modified layout, there is not necessarily direct correspondence between the start and end of mining of panels with the same name.

Mining height for the Modified layout remains the same as for the Approved layout. The panel width for LW101 to LW106 is 306.4 m, and for LW107 to LW120 it is 405.4 m.

Relative to the Approved layout, some panel lengths for the Modified layout are reduced. The already completed longwalls (LW101 to LW104) were, in reality, completed to lengths less than approved lengths. The Modified layout reflects this reality.

1.3 SCOPE OF WORK

The key tasks associated with the development of this modification were:

- Update and summary of existing hydrogeological conditions.
- Validation of the existing calibrated model against recent groundwater levels in the vicinity of NM.
- Assessment of the existing/approved mine geometry for comparative assessment.
- Assessment of the revised mine geometry.
- Assessment of recovery of groundwater levels.
- Provision of a draft report including assessment of impacts in the context of the NSW Aquifer Interference Policy (AIP).
- Provision of a final report.
- A letter for EPBC water trigger self-evaluation for the NM Modification.

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

- AIP (NSW Office of Water [NOW]);

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

1.4 REGULATORY FRAMEWORK AND GROUNDWATER LICENSING

With respect to water management, the NM is located within the Namoi Water Management Area and is subject directly to the water sharing rules of the following Water Sharing Plans (WSPs) under the Water Management Act 2000.

- The NSW Murray-Darling Basin Porous Rock Groundwater Sources WSP

  Of specific relevance to the NM area is the Gunnedah-Oxley Basin MDB Groundwater Source consisting of the Permian and Triassic rocks associated with the Gunnedah Basin and the overlying younger Jurassic and Cretaceous rocks associated with the Oxley Basin.

  This Groundwater Source is listed under the WSP as having a high risk to its aquifer assets based on the likelihood of permanent habitat loss in GDEs in the event of significant groundwater level fluctuations. However, all of these GDEs are located well to the west of NM (NOW, 2012).

  The closest identified GDE is Yarrie Lake, about 27 km west of the mine site ((Bureau of Meteorology (BoM), 2012).

- The NSW Great Artesian Basin (GAB) Groundwater Sources WSP applies to management of the upper hard rock (sandstone) aquifers of the GAB.

  Of specific relevance to the NM area is the Southern Recharge Groundwater Source. This occupies most of the non-artesian portion of the GAB in New South Wales, and is limited to the sandstone aquifers of Jurassic age. At the time of commencement of the WSP (in 2008), there were 68 aquifer access licences with a total of 15,533 unit shares in the Southern Recharge Groundwater Source and a further 274 works approvals for domestic and stock basic water rights.

NCOPL holds water licences for a number of bores and wells located in the general area. Details of the water licences are provided in **Table 1**. The table provides specific reference to the WSP and Water Source relevant to each licence and cites some that lie beyond the NM area, specifically:

- The Upper and Lower Namoi Groundwater Sources WSP (Upper Namoi Zone 5 Namoi Valley (Gin's Leap to Narrabri) Groundwater Source); and
- Upper Namoi and Lower Namoi Regulated River Water Sources (Lower Namoi Regulated River Water Source).

Figure 3 provides a map of the NM site in relation to the areas covered by the relevant WSPs and Water Sources.

Table 1. NCOPL Water Licences

ISSUING AUTHORITY	LICENCE	COMMENTS	WATER SHARING PLAN	WATER SOURCE
NSW Office of Water (NOW)	90CA811347 / WAL15922	GAB – Water supply (248ML)	NSW Great Artesian Basin Groundwater Sources	Southern Recharge Groundwater Source
	90WA812891 / WAL20131	GW – Water supply (150ML)	Upper and Lower Namoi Groundwater Sources	Upper Namoi Zone 5 Namoi Valley (Gin's Leap To Narrabri) Groundwater Source
	90AL807276 / WAL12833	GW – Water supply (67ML)	Upper and Lower Namoi Groundwater Sources	
	90CA802130 / WAL6762	River – High Security (20ML)	Upper Namoi and Lower Namoi Regulated River Water Sources	Lower Namoi Regulated River Water Source
	90CA802130 / WAL2671	River (48ML)	Upper Namoi and Lower Namoi Regulated River Water Sources	
	90CA802130 / WAL2728	River (10ML)	Upper Namoi and Lower Namoi Regulated River Water Sources	
	90CA802130 / WAL20152	River (600ML)	Upper Namoi and Lower Namoi Regulated River Water Sources	
	90BL254679 / WA822539	Mining (Low Security) (818ML)	NSW Murray Darling Basin Porous Rock Groundwater Sources	Gunnedah - Oxley Basin MDB Groundwater Source
	90WA822539	Mine De-gassing/De-Watering	NSW Murray Darling Basin Porous Rock Groundwater Sources	

In summary, the licensed volumes in each water source are:

1. Southern Recharge Groundwater Source: 248 ML

2. Upper Namoi Zone 5 Namoi Valley (Gin's Leap To Narrabri) Groundwater Source: 217 ML
3. Lower Namoi Regulated River Water Source: 678 ML
4. Gunnedah - Oxley Basin MDB Groundwater Source: 818 ML

2 HYDROGEOLOGICAL SETTING

2.1 CLIMATE

The nearest BoM climate stations are located at Narrabri West Post Office (station 053030), and Narrabri Airport AWS (station 054038). Rainfall records, collected since 1891 from Narrabri West Post Office and since 2001 from Narrabri Airport, show a long-term average rainfall of 661.6 millimetres per annum (mm/a) and 567.5 mm/a respectively (**Table 2**).

Average monthly rain records (**Table 2**) show the highest mean rainfall occurring during the summer months and lower rainfall in winter months.

Table 2. Average Monthly Rainfall (mm) at BoM stations in the Region

STATION NAME	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	SUM
Narrabri West PO	83.3	63.2	58.5	38.2	47.3	48.3	46.5	40.3	42.1	51.9	61.2	77.1	661.6
Narrabri Airport AWS	74.2	68.2	36.8	26.1	24.4	54.5	32.9	26.0	34.4	33.9	76.4	79.7	567.5

Information on long-term rainfall trends is provided by the Residual Mass Curve (RMC) (**Figure 4**). This curve is generated by aggregating the residuals between actual monthly rainfall and long-term average rainfall for each month. The procedure is essentially a low-pass filter operation which suppresses the natural spikes in rainfall and enhances the long-term trends.

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

The RMC plot using rainfall data from the Narrabri West Post Office since 1960 is shown in **Figure 4**. This plot suggests that current mining operations have experienced fluctuating weather conditions, with pronounced dry conditions from late-2006 to late-2009 and from September 2012 to February 2014. Earlier dry periods occurred from early-1979 to late-1982, late-1993 to mid-1995, and from April 2002 to January 2003. Conditions have been wetter than average from early-1969 to early-1971, late-1982 to late-1984, early-1998 to mid-1999, late-2004 to mid-2006 and from mid-2011 to mid-2012.

The actual evapotranspiration (ET) in the district is about 680 mm/a according to BoM (2014). The definition for actual ET is: "... the ET that actually takes place, under the condition of existing water supply, from an area so large that the effects of any upwind boundary transitions are negligible and local variations are integrated to an areal average. For example, this represents the ET which would occur over a large area of land under existing (mean) rainfall conditions."

2.2 GEOLOGY

The NM is situated within the Permo-Triassic Gunnedah Basin, which forms the central part of the north-south elongate Sydney-Gunnedah-Bowen Basin. The mine is located near the northern and western boundaries of the Gunnedah Basin and the eastern margin of the Surat Basin, a sub-basin of the Great Artesian Basin. The outcropping geology within the model domain is shown in **Figure 5**.

The geology has previously been described in GHD (2007) and Aquaterra (2009). In summary, the stratigraphy in the Narrabri area is characterised by deposits in two main basins:

- Surat Basin Units of Jurassic age which includes Pilliga Sandstone, Purlawaugh Formation and Garrawilla Volcanics; and
- Gunnedah Basin Units:
    - Napperby and Digby Formations of Triassic age; and
    - Permian coal measures within the Black Jack Group which includes Hoskissons Seam, and Arkarula and Pamboola Formations.

Adjacent to the NM are alluvial sediments of Quaternary age (Narrabri Formation and Gunnedah Formation) within the upper Namoi Valley.

The Digby Formation Conglomerate is about 15 to 20 m thick. A dolerite sill intrudes the Napperby Formation about 40 m above the roof of the Digby Formation Conglomerate.

The coal resource of the NM is contained within the Hoskissons Coal Seam which strikes generally north-south, and dips gently to the west. The seam is 8-10 m thick over the western half of ML 1609.

2.3 GROUNDWATER USAGE

There are 87 registered bores belonging to other groundwater users within 10 km of NM. These are listed in **Table 3**. Boreholes registered on the NOW 'Pinneena' (v4.1) database are shown in **Figure 6**.

For the bores shown in **Table 3**, the mean and median depths are 42.0 m and 40.0 m, respectively. Except for two bores in the deepest part (Pamboola Formation) of the geological section, the bores are distributed in the shallower formations as shown below:

- Alluvium and regolith - 44 bores
- Pilliga Sandstone - 28 bores
- Purlawaugh Formation - 11 bores
- Garrawilla Volcanics - 1 bore
- Napperby Formation - 1 bore (above basalt sill)
- Digby Formation - Nil
- Hoskissons Coal Seam - Nil
- Arkarula, Pamboola Formations - 2 bores.

Table 3. Registered Bores within 10 km of Narrabri Mine

WORK NO.	LICENCE	EASTING	NORTHING	DEPTH (m)[1]	LAYER[2]
GW051128	90BL112469	773121	6634127	33	3
GW051980	90BL115713	770899	6633936	58	3
GW053774	90BL248187	773649	6633898	23	3
GW053849	90CA807210	784688	6620465	47.2	1
GW054227		775401	6630279	38.1	3
GW054228	90WA809762	775967	6630480	15.8	1
GW055085	90BL119116	763296	6615694	65	2
GW056030	90BL121913	785488	6622805	18.6	1
GW056964	90BL150047	778955	6629294	18.3	1
GW057478	90WA811393	768263	6631074	61.3	2
GW057740	90CA807232	780227	6628922	20.4	1
GW058777	90BL124298	768351	6632458	41.3	2
GW059278	90CA807144	785415	6614978	43.5	1
GW059354	90CA807240	780075	6629234	23.2	1
GW059365	90CA811343	768358	6631657	60	2
GW059552	90BL131305	773208	6632276	38.5	2
GW059838	90BL131534	784324	6621171	20	1
GW059958	90BL131661	763118	6613880	66	2
GW060055		784793	6615672	30.5	1
GW060267	90CA807243	784466	6617438	61	1
GW060422	90CA807243	784615	6617033	52	1
GW060423		784315	6616795	95	11
GW060609	90BL131325	774196	6632251	32.2	3
GW060688	90BL131813	770245	6634507	33.5	2
GW060976	90BL132595	776941	6617387	26.5	5
GW060977*		774351	6617299	0	1
GW060978*		777651	6616999	0	1
GW062391	90CA807235	786287	6621736	60	1
GW062433	90CA811347	769948	6632689	45.7	2
GW062614	90BL134412	766960	6629103	60	2
GW062695	90BL134535	774013	6631362	39.5	2
GW062918	90BL135023	769215	6630680	57.5	2
GW063058	90CA807185	785991	6623686	103	1
GW063061	90CA807280	785285	6624229	78.2	1
GW063065	90CA807243	782859	6619237	16.1	1
GW064089	90BL136121	767855	6632933	39	2
GW064094	90BL136088	784840	6624549	40	1
GW064478		767061	6631072	40	2
GW065032	90BL248152	784485	6626315	21.3	1
GW065982	90CA807199	781816	6630938	76.5	1

[1] Depth as listed in NOW Pinneena database

[2] Layer

1	Alluvium and regolith
2	Pilliga Sandstone
3	Purlawaugh Fm
4	Garrawilla Volcanics
5	Napperby Fm above Sill
6	Basalt Sill
7	Napperby Fm below Sill
8	Digby Fm
9	Hoskissons Coal Seam
10	Arkarula Fm
11	Pamboola Fm

Table 3. Registered Bores within 10 km of Narrabri Mine (continued)

WORK NO.	LICENCE	EASTING	NORTHING	DEPTH (m)[1]	LAYER[2]
GW067626	90BL139277	770930	6625737	88	3
GW067919	90BL138918	775023	6631477	39.6	3
GW068060	90BL139750	770452	6634386	35.6	2
GW068591	90BL141830	771621	6629594	54.9	2
GW068714	90BL141410	769188	6633107	34.4	2
GW068815		783343	6624003	33.5	1
GW070027	90BL150077	765835	6627897	48.7	2
GW070534	90CA807271	779651	6630386	41.5	1
GW070841	90BL151717	772227	6629373	51.82	2
GW071281	90CA807255	776977	6631317	N/A	1
GW071313	90BL153424	774294	6630920	30.5	2
GW071993		774993	6630229	49	3
GW072008	90BL152544	770340	6632964	36.5	2
GW098012		774011	6630801	N/A	2
GW900085	90CA811363	768174	6631558	64	2
GW900417	90CA807265	779771	6630907	45	1
GW901089	90CA807214	783462	6619869	40	1
GW901138	90CA807273	775404	6632707	22	1
GW901289	90BL246356	774721	6630671	35.94	3
GW901422	90CA807243	785076	6617483	49	1
GW901842	90CA807192	784256	6621269	45.5	1
GW901887	90BL248373	781201	6629335	18.7	1
GW902183	90BL252352	770015	6632121	14	2
GW902246	90CA807194	784507	6626129	60.96	1
GW902299	90CA811335	771611	6633561	42	2
GW902348	90BL246871	768481	6632332	41.3	2
GW902511		784759	6624551	60	1
GW902579	90CA807290	779823	6628830	15.55	1
GW902674	90BL249581	774468	6632460	17.5	3
GW965300	90WA810692	769790	6632931	60.3	2
GW965354	90CA807210	784248	6620385	44.5	1
GW965579	90BL250565	785306	6621445	67	1
GW965964	90CA807243	784128	6618532	53	1
GW965969	90BL251439	785788	6617002	23.75	1
GW966352	90BL247940	781436	6628235	18	1
GW966836	90BL246067	776382	6619701	30	4
GW966837	90BL155449	774580	6630789	35.34	3
GW967194	90CA807280	784527	6624478	61	1
GW967625	90BL252649	787255	6616647	24	1
GW967680	90BL252745	784931	6616287	31	1

[1] Depth as listed in NOW Pinneena database

[2] Layer

1	Alluvium and regolith
2	Pilliga Sandstone
3	Purlawaugh Fm
4	Garrawilla Volcanics
5	Napperby Fm above Sill
6	Basalt Sill
7	Napperby Fm below Sill
8	Digby Fm
9	Hoskissons Coal Seam
10	Arkarula Fm
11	Pamboola Fm

Table 3. Registered Bores within 10 km of Narrabri Mine (continued)

WORK NO.	LICENCE	EASTING	NORTHING	DEPTH (m)[1]	LAYER[2]
GW968251	90WA810748	767351	6629098	66	2
GW968260	90BL254652	784400.9	6622365	15	1
GW968261	90BL254159	784213.5	6622477	67.5	11
GW968262	90BL254159	784208.8	6622486	37	1
GW968264	90BL254159	784503.1	6622719	33	1
GW968265	90BL254159	784491.2	6622717	28	1
GW968801	90BL254718	769504	6633570	60	2

Notes * Indicates bore has collapsed according to NOW works summaries.

N/A Indicates not reported

[1] Depth as listed in NOW Pinneena database

[2] Layer

1	Alluvium and regolith
2	Pilliga Sandstone
3	Purlawaugh Fm
4	Garrawilla Volcanics
5	Napperby Fm above Sill
6	Basalt Sill
7	Napperby Fm below Sill
8	Digby Fm
9	Hoskissons Coal Seam
10	Arkarula Fm
11	Pamboola Fm

2.4 GROUNDWATER MONITORING

Groundwater monitoring for the NM is undertaken in accordance with the Groundwater Monitoring Program (GWMP) within the NM Water Management Plan (URS Australia, 2013). The objectives of the GWMP are to establish baseline groundwater quality and water level data and to implement a program of data collection that provides a basis for assessing potential impacts of mining activities on the groundwater resources of the area.

The groundwater monitoring network currently consists of more than 50 monitoring sites **(Figure 7)**. The details of monitoring bores in the network are summarised in **Table 4** and **Table 5**.

Table 4. Summary of Groundwater Monitoring Site Measurements

MONITORING SITE	PARAMETER	FREQUENCY
All Standpipes P1,P2, P3, P4, P5, P6,P7,P8, P9, P10, P11,P12, P13, P14, P15, P16, P17,P18, P19, P20, P28, P29, P30, P31, P32, P33, P34, P47, WB1, WB2, WB3a, WB3b, WB4, WB5a, WB5b, WB6a, WB6b, WB7 and WB8	Water level EC pH TDS Metals Anions and Cations	Quarterly (water level, pH and EC) Bi-annually (full water quality)
Vibrating Wire Piezometers P21,P22, P25 ,P26, P27 and P48	Water Level	Daily (Data Logger)
Multi-Level Vibrating Wire Piezometers P23, P24, P35, P36, P37, P38, P40, P44, P45 and P46	Water Level	Daily (Data Logger)

Table 5. Summary of Groundwater Monitoring Site Types

MONITORING SITE	LITHOLOGY	START DATE	TYPE
WB3A, WB3B, WB4, WB5A, WB5B, WB6A, WB6B, WB7	Alluvium	All from September 2008 except WB7 from November 2008	Standpipe
P6, P7	Pilliga Sandstone	From November 2007	Standpipe
P8, P9, P11, P17	Purlawaugh Formation	All from March 2008 P17 stopped on February 2009	Standpipe
P1,P13, P15, P16, P47, WB1, WB2	Garrawilla Volcanics	P1 from November 2007 P15 from January 2009 P13, P16 from March 2008 P32 from June 2012 WB1 from August 2008 – December 2008 WB2 from August 2008 – October 2011 P47, from June 2012	Standpipe
P2, P4, P10, P12, P14, P28, P29, P30, P31, P32, P33, P34	Napperby Formation	P2, P4 from November 2007 P10, P12 from March 2008 P14 from January 2009 – April 2012 P28, P29, P30, P31, P32, P33, P34 from June 2012	Standpipe
P18, P21, P22, P25, P26, P27	Hoskissons Seam	P18 from March 2008 P21, P22, P25, P26, P27 from June 2009	Standpipe Vibrating Wire
P23, P24, P35, P36, P37, P38, P40, P44, P45 AND P46	Multi- Level	Variable time	Multi-Level Vibrating Wire
P20	Arkarula Formation	From March 2008 to June 2010	Standpipe
P3, P5, P19	Pamboola Formation	P3, P5 from November 2007 P19 from March 2008	Standpipe

The locations of the bores in the groundwater monitoring network are shown in **Figure 7**.

2.5 BASELINE GROUNDWATER LEVEL DATA

The network of monitoring bores (piezometers) has been established in different formations associated with the principal drainage pathways. Multi-level vibrating wire piezometers (VWPs) have been installed within the Jurassic, Triassic and Permian formations (**Table 5**). Hydrographs for monitoring sites listed in **Table 5** are presented in **Attachments A** to **H**. For ease of reference the hydrographs are grouped according to type as summarised in **Table 6**.

Table 6. Monitoring Bore Groups

BORE TYPE	NO. OF MONITORING BORES	GROUP
Standpipe	26	1
Production	10	2
Vibrating Wire Piezometers	5	3
Multi-Level Vibrating Wire Piezometers	10	4
Total	**51**	

2.5.1 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 (**Figure 8**). 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 east towards the Namoi River.

2.5.2 TEMPORAL GROUNDWATER LEVELS IN ALLUVIUM

The key monitoring bores for this study are located within the alluvium associated with the Namoi River (at locations shown on **Figure 7**):

- WB3a and WB3b – located approximately 7 km northeast of the NM lease;
- WB4 — located approximately 5 km northeast of the NM lease;
- WB5a and WB5b – located approximately 9.5 km east of the NM lease;
- WB6a and WB6b — located approximately 11 km southeast of the NM lease; and
- WB7 — located approximately 6.5 km east of the NM lease.

Attachment A displays the groundwater level hydrographs for the above alluvial bores, compared with the rainfall RMC since March 2007, and with the commencement dates for longwall (LW) 101[1], LW102 and LW103. During a wetter than normal period, the curve climbs. Conversely, the curve falls during a drier than normal period. If rainfall is the primary driver for groundwater level dynamics, the groundwater hydrographs can be expected to follow a similar trend. The data in **Figures A2 to A6** show that the water table at alluvium bores responds rapidly to rainfall events with amplitude of between 1 and 4 m.

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[1] Longwall panel numbers cited in this Section refer to the Approved mine plan.

2.5.3 GROUNDWATER LEVELS IN PILLIGA SANDSTONE

Two monitoring bores are located in the Pilliga Sandstone: P6 located 1 km north of LW112 and P7 located 3.5 km west of LW113[2] (**Attachment B).**

P6 water level ranges between 235.8 and 237.2 mAHD and shows a good response to the rainfall event in late-2008 (**Figure B2**).

The P7 hydrograph (**Figure B3**) shows a sharp decline in water level from 226.8 mAHD in November 2007 to 199.3 mAHD in January 2008, roughly coincident with a dry period. The water level remained around this level until mid-2009 with one exception. Since then the water level has been quite stable around 226 mAHD irrespective of rainfall conditions. The occasional drawdowns of about 25 m are likely due to the influence of a nearby pumping bore[3]. A mining effect is not possible as the low water levels in 2008 precede the commencement of mining, and the bore is located 3.5 km west of LW113.

2.5.4 GROUNDWATER LEVELS IN PURLAWAUGH FORMATION

Four standpipe monitoring sites are located in the Purlawaugh Formation: P8, P9, P11 and P17 (**Attachment C**).

P8 is located in the middle of LW116. The P8 hydrograph (**Figure C2**) shows the water level fluctuates between 271.5 and 272 mAHD with only weak correlation to rainfall trends.

P9 is located near the main central heading on LW122. The P9 hydrograph shows a weak correlation with the rainfall mass curve (**Figure C3**); water level ranges between 266.7 and 268.9 mAHD over the period from March 2008 to March 2015.

P11 is located at the southern edge of LW119. The P11 water level ranges between 271.6 and 285.1 mAHD from March 2008 to March 2015. The P11 hydrograph (**Figure C4**) shows that the water level appears to respond to the rainfall trend but with a considerable time lag.

P17 is located at the western edge of LW113. The water level was measured only between March 2008 and February 2009, and had dramatic fluctuations between 243.8 and 259.8 mAHD (**Figure C5**). P17 is located approximately 3 km from P7 which had a sharp decline in water level at the same time as P17. The sudden decline in water level in these two bores could be from pumping effects from the same nearby production bore.

2.5.5 GROUNDWATER LEVELS IN GARRAWILLA VOLCANICS

Attachment D shows the hydrographs for seven standpipe monitoring sites located in Garrawilla Volcanics; these are P1, P13, P15, P16, P47, WB1 and WB2.

P1 is located approximately 3.6 km south of LW126. The P1 hydrograph (**Figure D2**) shows that the water level increases gradually from 264 mAHD in November 2007 to 295 mAHD in March 2015. The P1 hydrograph reveals that the water level is possibly recovering from a pumping effect as there is no apparent correlation with rainfall.

P13 is located on LW126 just south of LW101 and the main central headings. The P13 hydrograph (**Figure D3**) shows that the water level ranges between 265.8 and 271.6 mAHD with an average 268.8 mAHD over the period from March 2008 to March 2015. The water level decreased gradually from 271.2 mAHD in July 2013 to 269.1 mAHD in September 2013 to 267.5 mAHD in December 2013 and then to 265.8 mAHD in March 2015. This decline in water level is unlikely to be due to extraction of LW101 at that time (as the bore is about

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[2] References to Longwall panels are for the Approved mine layout

[3] The nearest registered bore is 2 km away

600 m away from LW101), but would be due to the dry period from September 2013 to March 2015 as shown in the rainfall residual mass curve.

P15 is located on LW105. The P15 hydrograph (**Figure D4**) shows that the water level ranges between 261.0 and 261.5 mAHD from January 2009 to March 2014 and declines rapidly thereafter to 250.8 mAHD at March 2015. The water level responds closely to the rainfall trend.

P16 is located at the western edge of LW113. The water level ranges between 247.3 and 257.5 mAHD over the period from March 2008 to March 2015. The P16 hydrograph (**Figure D5**) shows that the water level was low from March 2008 to December 2008, increased gradually, plateauing at about 257.3 mAHD during 2012 to 2014, then declined slowly thereafter. P16 is located in the same area as bores P7 and P17 that showed the same water level trend unrelated to rainfall.

The P47 Hydrograph (**Figure D6**) shows a slight increase in water level from 264.6 to 265 mAHD over the period from June 2012 to March 2015. The measured water level for this bore does not show any mining effect although this bore is located at the northern edge of LW102.

WB1 is located 600 m northeast of LW101. The water level was measured over a short period of time between August 2008 and December 2008 and had a steady water level around 257.4 mAHD (**Figure D7**).

WB2 is located around the middle of LW126. The water level ranges between 272 and 278 mAHD over the period August 2008 to October 2011 (**Figure D8**), independent of rainfall.

2.5.6 GROUNDWATER LEVELS IN NAPPERBY FORMATION

P2, P4, P10, P12, P14, P29, P31 and P32 are standpipe monitoring sites located in the Napperby Formation (**Attachment E**).

P2 is located southeast of the NM lease approximately 2 km east of LW123. The P2 water level (**Figure E2**) ranges from 245.3 mAHD to 247.7 mAHD over the period from November 2007 to March 2015. The hydrograph shows the water level appearing to respond to the rainfall events during 2008 to 2013 but the continued stable water level beyond that time does not correlate with the decline in the RMC.

P4 is located northeast of the NM lease approximately 3 km northeast of LW101. The water level (**Figure E3**) ranges from 230.4 mAHD to 231.2 mAHD over the period from November 2007 to March 2015. The hydrograph shows a good response to rainfall events to 2014 but the continued stable water level beyond that time does not correlate with the decline in the RMC.

P10 is located at the southern edge of LW119. The P10 water level ranges between 249.2 and 287.4 mAHD from March 2008 to March 2015. The P10 hydrograph (**Figure E4**) shows that the water level sharply declined from 282.5 mAHD in September 2008 to the minimum 249.2 mAHD in November 2008, then the water level started to recover gradually from January 2009 to reach a steady water level at 279.6 mAHD in February 2011. The 33 m drawdown (from September 2008 to November 2008) is probably caused by pumping from an unregistered bore[4]. There appears to be no correlation with rainfall.

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[4] The nearest registered bore is 3 km away

P12 is located on LW126 just south of the main central heading, approximately 650 m south of LW101. The water level (**Figure E5**) ranges between 234.2 mAHD and 240.2 mAHD over the period from March 2008 to March 2015. The hydrograph shows natural water level fluctuation from March 2008 until February 2011. It can be noticed that the water level started to gradually decline from early 2011 at the same time as the central development heading passed below bore P12. The water level continued to decline to reach 238.7 mAHD in June 2013 (at the end of extraction LW101) and to 234.2 mAHD in March 2015. Although the water level decline coincided with a dry period, a longwall mining effect is likely at bore P12 (given no similar response to climate at bore P10).

P14 is located on LW105. The water level measured between January 2009 and April 2012 ranged from 216.4 mAHD to 220.1 mAHD. The P14 hydrograph appears to respond to weather variations (**Figure E6**).

P29, P31 and P32 are located to the east of the main central development headings by approximately 500 m for P31 to 1.2 km for P32. These bores were installed at the beginning of mining LW101 (June 2012) to monitor potential seepage from the ponds in the rail loop. The hydrographs show some response to rainfall variation prior to mining commencement but P29 and P32 show recent water level rises that oppose the rainfall trend. For P29 (**Figure E7**), the water level rose significantly from mid 2013 (soon after commencement of LW102) then at an increasing rate as LW103 was activated. The same behaviour is demonstrated by the P32 water level (**Figure E9**) which rose from mid 2014, soon after commencement of LW103. These water level rises are likely to be caused by seepage from the ponds.

2.5.7 GROUNDWATER LEVELS IN HOSKISSONS SEAM

The Hoskissons Seam is monitored by standpipe piezometer P18, and vibrating wire piezometers P21, P22, P25, P26, P27, P35, P36, P37 and P38. **Attachment F** displays the hydrographs for these monitoring sites.

The P18 standpipe is located at just east of LW101. The P18 hydrograph (**Figure F2**) shows the water level was stable around 257.6 mAHD from March 2008 to June 2009; then the water level declined rapidly to 229.5 mAHD in September 2010 at which time measurements ceased. The sudden drop in water level would have been caused by the drift tunnel construction as it preceded the start of LW101 headings (January 2011).

The vibrating wires P21, P22, P25, P26, P27, P35, P36 and P37 are located on the main central heading just south and southeast of LW101. All hydrographs (**Figures F3** to **F10**) show a sharp decline in water level at the time of drift tunnel construction or development of main headings.

P38 is a multi-level vibrating wire within upper and lower Hoskissons Seam plies, located in the middle of LW101. The hydrographs (**Figure F11**) show the water level declined from 180 mAHD from November 2010 to 120 mAHD at December 2012. The sharp decline in water level for P38 is evident; due to the passage of LW101 headings with a smaller effect from LW101 extraction (LW101 started in June 2012 and ended in June 2013).

2.5.8 GROUNDWATER LEVELS IN ARKARULA FORMATION

P20, a standpipe located on LW101, measured the water level in the Arkarula Formation between March 2008 and June 2010. The hydrograph (**Attachment G, Figure G2**) shows the water level fluctuated around 259 mAHD from March 2008 to June 2009 and then declined sharply to reach 223.5 mAHD in June 2010. As at P18, the drawdown would have been caused by the drift tunnel construction as it preceded the start of LW101 headings (January 2011).

2.5.9 GROUNDWATER LEVELS IN PAMBOOLA FORMATION

Three standpipe monitoring sites are located in the Pamboola Formation: P3, P5 and P19.

P3 is located approximately 4 km east of LW126. P3 water level ranges between 226.2 and 227.5 mAHD over the period from November 2007 to March 2015. The P3 hydrograph shows no response to rainfall trend (apart from two anomalous readings that could be related to a rainfall event) (**Figure G3**).

P5 is located approximately 5.7 km northeast of LW101. The P5 hydrograph shows the water level increased gradually from 204.4 to 210.8 mAHD over the period from November 2007 to March 2015 (**Figure G4**) with no clear correlation with rainfall.

P19 is located just east of LW101. As P19 is located close to standpipe bores P18 and P20 but in a different formation, the P19 hydrograph (**Figure G5**) has a trend similar to these bores but much less drawdown magnitude and the decline starts earlier. The water level fluctuated around 259 mAHD from March 2008 until June 2009, then declined to 250.3 mAHD in August 2009. The water level started gradually to recover to reach 254.2 mAHD in March 2015. The initial decline cannot be attributed to mining.

2.5.10 GROUNDWATER LEVELS IN MULTI-LEVEL VIBRATING WIRE PIEZOMETERS

Attachment H shows VWP groundwater hydrographs from the monitoring network at locations shown in **Figure H1**. They include hydrographs in the Purlawaugh Formation, Garrawilla Volcanics, Napperby Formation, Digby Formation, Hoskissons Seam, Arkarula and Pamboola Formations.

The vibrating wire P23 is located on the LW101 heading about 150 m away from the central mains. **Figure H2** shows the hydrographs for four different depths; at 45 m depth (Garrawilla Volcanics), at 120 m (Napperby Formation), at 169 m (Digby Formation) and at 188 m depth (Hoskissons Seam). The hydrographs show that only the two deeper VWPs respond to the underground mining due to the drift tunnel construction and the start of the main development headings (June 2010). The water level in these two vibrating wires declined sharply initially from 240 mAHD in May 2009 then more gradually to about 200 mAHD in June 2010 before a further rapid decline of about 40 m to about 155 mAHD in late 2010. A gradual decline to below 140 mAHD occurred to December 2012. The water levels in the two upper vibrating wires were steady at about 260 mAHD and 240 mAHD at 45 m depth and 120 m depth, respectively.

The vibrating wire P24 is located just east of LW101 and about 600 m away from the central mains. The vibrating wires are installed at four different depths: at 112 m depth (Napperby Formation), at 148 m (Digby Formation), at 166 m (Hoskissons Seam) and at 180 m depth (Arkarula Formation). **Figure H3** shows the hydrographs for these depths from May 2009 to January 2015. The water level in the Hoskissons Seam (166 m depth) shows a strong response to the Narrabri underground mining since the drift tunnel construction and the start of the main development headings (June 2010). The water level declined sharply from 240 mAHD in May 2009 to about 121 mAHD in January 2015. The water levels in the Digby and Arkarula Formations declined slightly when drift construction commenced and declined markedly when the mains and LW101 headings started. The water level in the upper 120 m piezometer (Napperby Formation) was stable around 220 mAHD until the LW101 mining passed by P24 when the water level declined sharply to 195 mAHD in April 2013.

P40 is located on LW111 just north of the central mains. The vibrating wires were installed in November 2012 at six different depths: at 95 m depth (Purlawaugh Formation), at 135 m (Garrawilla Volcanics), at 307 m (Napperby Formation), at 322 m (Digby Formation), at 346 m (Hoskissons Seam) and at 357 m (Arkarula Formation). **Figure H4** shows the hydrographs for these depths from November 2012 to April 2015. The lower depths 322 m, 346 m and 357 m show some impacts from the mining of LW101 to LW103. In the Arkarula Formation, the water level decreased from about 240 mAHD in November 2012 to about 220 mAHD in April 2013. The upper 135 m and 307 m piezometers show a stable water level about 260 and 262 mAHD, respectively. The shallowest vibrating wire at 95 m depth in the Purlawaugh Formation showed a drawdown of about 20 m, unrelated to mining but probably due to nearby pumping from an unregistered bore.

P44 is located approximately 800 m northeast of LW101. It was installed in August 2012 to monitor the groundwater level at six different depths, at 95.5 m (Napperby Formation), 134 m (Digby Formation), 245 m (Pamboola Formation) and at 330 m, 375 m and 445 m (depths greater than the bottom layer of the groundwater model). The hydrographs for these vibrating wires are shown in **Figure H5**. The vibrating wire hydrograph at 134 m located in the Digby Formation shows a gradual decline in water level from 225 mAHD in August 2012 to 216 mAHD in April 2015 and this is likely due to the mining activities in LW101, LW102 and LW103. The water level in the 95.5 m and the 245 m vibrating wires are stable at about 208 mAHD and 242 mAHD, respectively, unaffected by mining. All of the represented depths demonstrate an upward hydraulic gradient at this location except for 375 m.

P45 is located approximately 3 km east of LW101. The P45 vibrating wires were installed in November 2012 at depths 42.5 m (Digby Formation), 80 m (Arkarula Formation) and 150 m, 200 m, 240 m and 276 m, all deeper than the lower-most layer (Pamboola Formation) of the groundwater model. The hydrographs for these vibrating wires (**Figure H6**) show that the water level is steady over the period from December 2012 to April 2015, about 205 mAHD and 226 mAHD at depths 42.5 m and 80 m respectively. All of the represented depths except 200 m demonstrate an upward hydraulic gradient at this location.

The vibrating wire P46 is located approximately 3 km southeast of LW101. The vibrating wires were installed in May 2013 at depths 70 m (Napperby Formation), 87 m (Digby Formation), 151 m (Pamboola Formation) and 250 m, 308 m and 343 m, all deeper than the lower-most layer (Pamboola Formation) of the groundwater model. Over the period of data record, the hydrograph for the 151 m vibrating wire shows a gradual decline in water level from 242 mAHD to 222 mAHD and the shallowest VWP also shows a mild decline (**Figure H7**). As the Digby Formation VWP shows a rise in water level, it is likely the responses are equilibration responses rather than mining effects.

2.6 GROUNDWATER CHEMISTRY

Assessments of groundwater quality can be useful in understanding conceptual hydrogeology. For example, groundwater salinity tends to be low in areas of high recharge or connectivity with surface waters.

Attachment I presents groundwater salinity data in microSiemens per centimetre (µS/cm) relating to the NM and environs. The locations of monitoring sites together with temporal plots are shown.

Sites monitoring groundwater salinity in the alluvium are all some distance (north and east) from the NM, located close to the Namoi River (**Figure I1a**). Only spot readings are available at most of the sites (**Figure I1b**) and with one exception values are below 1500 µS/cm. Site WB7 provides data consistently in the range 600-1000 µS/cm spanning 2008 to the present. None of the monitoring sites are located sufficiently close to the NM to suggest any impact of mining on alluvial groundwater.

Only two sites monitor salinity in the Pilliga Sandstone (**Figure I2a**). Site P7 is located approximately six kilometres west of NM and displays a low median salinity of 239 µS/cm, with values over time consistently lower than 500 µS/cm since 2009 (**Figure I2b**). In 2011 a single higher value (2320 µS/cm) was measured at P6, located about one kilometre north of the NM but this may not be representative.

For the Purlawaugh Formation four sites monitor salinity in the immediate vicinity of the NM (**Figure I3a**). Mid-range median values (2440, 4410 µS/cm) are apparent 3-4 km west and south of the existing mine and at the limits of proposed operation. Approximately one kilometre south west of the existing mine, site P9 has demonstrated high values (above 15000 µS/cm) almost consistently since 2009 (**Figure I3b**).

Seven sites monitor salinity in the Garrawilla Volcanics (**Figure I4a**). All are located within close proximity of existing or proposed mining, except for site P1, about six kilometres south of current extraction. For most sites, salinities since 2009 have been in the range 1000-4000 µS/cm. Greater variability is apparent for site P15 (**Figure I4b**); prior to 2012 values were consistently greater than 10000 µS/cm (gradually declining) but a significant and rapid decline (to less than 2000 µS/cm) occurred early in 2012 with a subsequent rapid rise from mid-2013. Since that time values have returned to around 10000 µS/cm.

Salinities within the Napperby Formation are represented by monitoring at eight sites that are distributed north, east and south of the existing mining area (**Figure I5a**). The highest values occur some distance from the existing mining area. Site P12, located about 600 m south of the present mine, exhibits the lowest median value (2790 µS/cm) with values consistently below 3500 µS/cm since 2009 (**Figure I5b**).

Only one site monitored salinity within the Hoskissons Seam: site P18 immediately east of the present mine (**Figure I6a**). From 2009 to 2010 values were above 4000 µS/cm (**Figure I6b**).

Within the Arkarula and Pamboola Formations, sites P19 and P20 (**Figure I7a**) are in the immediate vicinity of present operations. Monitoring at P20 ceased in 2010 (**Figure I7b**) at which time a value of about 6000 µS/cm represented a decline from above 10000 µS/cm in earlier years. At P19 salinity values have been consistently below 5000 µS/cm from 2009 to the present.

Cumulative probability distributions of groundwater salinity based on all available data represented in **Attachment I** are shown in **Figure 8.** This diagram clearly demonstrates that the lower salinities occur in the Pilliga Sandstone and the alluvium with a general (but not entirely consistent) increase with depth.

Table 7 summarises the probability of exceedance levels of groundwater salinity and clearly demonstrates the presence of the highest salinities in the Purlawaugh, Napperby and Arkarula and Pamboola Formations.

Table 7. Cumulative Probability Distribution of Groundwater Salinity (µS/cm)

PROBABILITY (%)	ALLUVIUM	PILLIGA SANDSTONE	PURLAWAUGH FM	GARRAWILLA VOLCANICS	NAPPERBY FM	HOSKISSONS SEAM	ARKARULA & PAMBOOLA FM
10	625	150	330	1158	2540	*	2456
20	688	165	362	1315	3060	1410	3652
50	796	239	4173	2490	7850	5125	15810
80	1120	390	17180	3944	18910	7490	22656
90	1175	475	19835	5935	24290	*	25884

Note: * Insufficient data.

2.7 CONCEPTUAL MODEL

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

- a porous hard rock groundwater system that occurs throughout the stratigraphic sequence of Jurassic and Triassic formations and Permian coal measures; and
- aquifers associated with the unconsolidated alluvial sediments of the Namoi River floodplain (i.e. the Upper Namoi Alluvial aquifer).

The conceptual model is illustrated in **Figure 9**. The dominant recharge process would be the infiltration from rainfall and runoff. The dominant natural discharge processes would be ET, seepage face flow and baseflow to the local streams.

2.7.1 ALLUVIAL GROUNDWATER SYSTEM

Groundwater flow patterns within the shallow alluvial aquifer reflect topographic levels and the containment of alluvium within the principal drainage pathways. 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, in places, contributing to baseflow of the perennial surface water features. In some areas upward or lateral flow may occur from the Permian and Triassic rock, but downward leakage seems to be the more common behaviour.

2.7.2 PERMIAN GROUNDWATER SYSTEM

Prior to the commencement of mining operations in the region, the piezometric surface within the NM 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.

The Permian groundwater system within the NM area is continuous through the major geological formations. The various sedimentary rocks at NM have low permeability 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 groundwater 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.

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 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 structure-related fracturing may play a role in local groundwater flow paths.

2.7.3 RECHARGE AND DISCHARGE MECHANISMS

The main recharge mechanism is infiltration of rainfall through the alluvium layer, and through weathered rock 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 limited due to the low vertical permeability of the underlying strata. Creeks may ‘lose’ or ‘gain’ groundwater from alluvium depending on the relative level of groundwater in the alluvium compared with the creeks. Connectivity with the regional hard rock aquifers is very low.

3 GROUNDWATER SIMULATION MODEL

3.1 EXISTING GROUNDWATER MODELS

Four groundwater models have been constructed to simulate and evaluate the impact of the stresses on the groundwater environment from the development and operation of the NM.

The first model was an 11-layer numerical groundwater model developed using MODFLOW 2000 by GHD (2007) to simulate the groundwater flow regime for the Stage 1 Project. This model supported the EA for the proposed development of surface infrastructure and initial underground mine development, with coal production by first workings of up to 2.5 Mtpa.

Version 2 of the model was constructed by Aquaterra (2009) as part of the EA undertaken for Stage 2 comprising the development of longwall mining operations on ML 1609 for the extraction of coal up to 8 Mtpa. The Stage 2 groundwater assessment further developed the Stage 1 groundwater model to include longwall progression. The Aquaterra model also defined 11 layers but its development was achieved with the use of MODFLOW-SURFACT version 3 software operating under the Groundwater Vistas Version 5 graphic user interface.

The Version 3 model was developed by HydroSimulations (2015). This model maintains the same layering as the earlier models but incorporates some changes to the layer geometry. It represents a recalibration of its predecessor and, consequently, it assigns updated values to some of the model parameters. The recalibration was based on observation data extending to June 2014 and was achieved with the use of more recent software tools (MODFLOW-SURFACT version 4).

Model Version 4, developed as part of this Modification, has also been developed by HydroSimulations. Initially, it represented a simple extension in time (to April 2015) relative to its predecessor. Subsequently, changes to the methodology applied to modelling the fractured zone developing in response to extraction were applied (**Section 3.6.2**). Given its close similarity to the calibrated Version 3 model, this model has not been subjected to rigorous calibration. However, its suitability for use is demonstrated (**Section 3.8**) by comparing relevant model outputs to the equivalent outputs generated by the Version 3 model.

The following description of features of 'the groundwater model' is generally applicable to both the Version 3 and Version 4 models. Areas of difference between the two models are discussed in some detail.

3.2 SOFTWARE

The software packages used to run the model for the current project are:

- MODFLOW-SURFACT v4 (by HydroGeoLogic Inc.), which allows for both saturated and unsaturated flow conditions. The TMP (Time-Varying Material Properties) package in MODFLOW-SURFACT has been used to change the model properties through time allowing mine scheduling to be run within a single model.
- Groundwater Vistas (Version 6.68) software package (ESI, 2011).

3.3 MODEL LAYERS AND GEOMETRY

The model domain is discretised into 798,930 cells comprising 269 rows, 270 columns and 11 layers. The dimensions of the model cells vary from 50 m at the NM to 500 m towards the model edges. The model extent is 75 km from west to east (Eastings 747000-822000) and 52.9 km from south to north (Northings 6591000-6643900), covering an area of approximately 3,970 km^2. The extent of the model domain and the regional topography are shown in **Figure 10**.

Representative model cross-sections are displayed in **Figure 11** for easting 772650 (model column 80) and northing 6622000 (model row 100) through the Project site in each direction.

Based on the conceptual hydrogeology described in **Section 2**, 11 layers are used in the model to represent the stratigraphic section:

- Layer 1: Alluvium and regolith.
- Layer 2: Pilliga Sandstone.
- Layer 3: Purlawaugh Formation.
- Layer 4: Garrawilla Volcanics.
- Layer 5: Napperby Formation (above Sill).
- Layer 6: Basalt Sill.
- Layer 7: Napperby Formation (below Sill).
- Layer 8: Digby Formation.
- Layer 9: Hoskissons Coal Seam.
- Layer 10: Arkarula Formation.
- Layer 11: Pamboola Formation.

The model domain was 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.

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

3.4 HYDRAULIC PROPERTIES

The geological formations are split into multiple model layers in recognition of the vertical hydraulic gradient through the stratigraphic column and the different ages of geological formations.

Previous studies and investigations within the region provided the basis for initial model hydraulic property parameter values used for the coal seam and interburden. The testing of the aquifer hydraulic parameters was reported for earlier investigations by GHD (2007) and Aquaterra (2009), respectively. Hydraulic properties from that work are summarised in **Table 8**.

Table 9 summarises the calibrated model hydraulic conductivities for the current model, compared with median field values. In addition to host layer hydraulic conductivities, **Table 9** also lists values for the mining-induced fractured zone (**Section 3.6**). Hydraulic properties for the present model differ somewhat from those of the earlier models, reflecting the availability of a larger and more recent observation data set used for the most recent calibration.

The adopted model hydraulic conductivity and storage areal distributions are displayed in **Attachment J**.

Table 8. Summary of Hydraulic Properties from Field Testing (Aquaterra, 2009)

					HYDRAULIC CONDUCTIVITY (m/d)			
MODEL LAYER	TARGET FORMATION	NEW BORE ID	FORMER BORE ID	SCREEN INTERVAL (m bgl)	GHD 2006	RCA 2007	AQUATERRA 2008	
							Method	
2	Pilliga Sandstone	P6	NG6	78 - 90	-	-	Slug	0.029
2	Pilliga Sandstone	P7	NG7	78 - 90	-	-	Slug	0.19
3	Purlawaugh Formation	P9	GWB5S	24 - 30	0.41	-	Slug	0.032
3	Purlawaugh Formation	P17	NC119S	47 - 56	-	-	Slug	0.0028
3	Purlawaugh Formation	P8	NC110S	57 - 63	-	-	Slug	0.017
3	Purlawaugh Formation	-	GWB4S	57 – 63	0.0011	-	-	-
4	Garrawilla Volcanics	P15	NC100S	24 - 30	0.047	-	-	-
4	Garrawilla Volcanics	P1	NG1	44 - 50	-	-	Slug	0.11
4	Garrawilla Volcanics	P16	NC119D	137 - 146	-		Slug	0.003
4	? Garrawilla Volcanics	-	Claremont Bore	?	-	-	Constant Rate - Drawdown	T = 150 m^2/d
							Constant Rate - Recovery	T = 75 m^2/d
							Constant Rate - Drawdown	0.44
4, 5	Garrawilla Volcanics/ Napperby Formation	P13	NC98S	24 - 30	0.068	-	Constant Rate - Recovery	0.016
							Slug	0.13
5	Napperby Formation above sill	P14	NC100D	72 - 78	?	?	-	-
5	Napperby Formation above sill	P12	NC98D	84 - 90	0.0016	-	Slug	0.09
5, 7	Napperby Formation	P4	NG4	24 - 30	-	-	Slug	0.004
5, 7	Napperby Formation	P2	NG2	44 - 50	-	-	Slug	0.057
5, 7	Napperby Formation (no sill at bore site)	P11	NC30S	44 – 50/ 24 - 40	0.0007	-	Slug	0.00055
5, 7	Napperby Formation (no sill)	P10	NC30D	118 - 130	-	-	Slug	0.049
9	Hoskissons Coal Seam	P18	NC122	143 -146	0.0086	0.0086	Slug	0.013
10	Arkarula Formation	P20	NC127	159 - 162	0.012	0.012	Slug	0.013
11	Pamboola Formation	P5	NG5	24 - 30	-	-	Slug	0.002
11 deep	Pamboola Formation	P3	NG3	34 - 40	-	-	Slug	0.03
11 deep	Pamboola Formation	P19	NC123R	184 - 187	0.0021	0.0028	Slug	0.023

Note: ? as interpreted from Aquaterra (2009).

Table 9. Calibrated Model Hydraulic Conductivities [m/day] Compared with Field Measurements

		Current (version 4) Model				
LAYER	**LITHOLOGY**	**ZONE**	**HOST Kx**	**HOST Kz**	**NARRABRI UNDERGROUND FRACTURE ZONE Kz**	**GHD / RCA / AQUATERRA Kx [MEDIAN]**
1	Alluvium	1	5.0E+00	5.0E-03	NA	-
2	Pilliga Sandstone	2	3.0E-01	5.0E-05	5.0E-05	1.1E-01
3	Purlawaugh Formation	3	5.0E-02	2.0E-05	5.1E-05	1.7E-02
4	Garrawilla Volcanics	4	2.4E-02	3.0E-05	5.5E-05	6.8E-02
5	Napperby Formation (above Sill)	5	4.0E-03	1.0E-06	7.1E-05	3.3E-02
6	Basalt Sill	6	1.2E-01	5.0E-05	8.5E-05	-
7	Napperby Formation (below Sill)	7	2.1E-02	2.4E-06	1.0E-04	4.0E-03
8	Digby Formation	8	4.0E-03	1.5E-06	1.0E-04	-
9	Hoskissons Coal Seam	9	5.0E-03	6.0E-06	10	8.6E-03
10	Arkarula Formation	10	1.0E-03	1.0E-05	3 x Kz host	1.2E-02
11	Pamboola Formation	11	4.0E-02	1.0E-05	NA	1.3E-02

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

Note:

For Layer 4, median value in final column is calculated using 6 values representing Layer 4 and one value representing Layers 4 and 5

For Layer 5, median value in final column is calculated using 4 values representing Layer 5, one value representing Layers 4 and 5 and 5 values representing Layers 5 and 7

For Layer 7, median value in final column is calculated using 5 values representing Layers 5 and 7

3.5 MODEL STRESSES AND BOUNDARY CONDITIONS

The model domain covers all of the potentially sensitive receptors. All significant creeks and rivers that could be affected by mining activities are fully contained within the model domain and have been represented in the model, as shown in **Figure 12**.

3.5.1 WATERCOURSES

All major waterbodies are represented using the MODFLOW River (RIV) package, as shown in **Figure 12**. Of the water bodies within the model domain, the Namoi River, Coxs Creek and Maules Creek are considered to be the most important watercourses. The Namoi River, Coxs Creek and Maules Creek and the associated alluvium occupy a large portion of the eastern model domain. Jacks Creek occupies the western sector of the model domain. River stage is not varied with time. These watercourses are represented by river cells allocated distinct reach numbers (**Figure 13**) to permit separate accounting of baseflows during model simulations.

The northerly flowing Namoi River was divided into three reaches: upstream of Boggabri, upstream of Maules Creek between Baan Baa and Boggabri, and downstream of Maules Creek between Baan Baa and Narrabri (**Figure 1**). The RIV package for the Namoi River was defined in the model with streambed below the stream stage by 2 m to allow water to move in either of two directions from the groundwater aquifer system into the stream as baseflow (if the water table rises above the water elevation of the stream) or from the stream into the aquifer as a river leakage (when the water table drops below the stream water level). The conductance varies from 2 to 2,300 square metres per day (m^2/day) for stream lengths from 1 to 1,160 m within the model cell, for hydraulic conductivity of the stream bed about 0.1 m/day.

Other creeks and minor drainage lines are also represented as RIV boundary cells in the model with stage equal to bed level. This allows groundwater to discharge to the drainage lines as baseflow, but does not allow these watercourses to recharge the underlying groundwater system. This has been done for the minor streams that cross the NM and the tributaries of Jacks Creek so that these cells will accept baseflow if the water table rises above the bed elevation of the stream, but they will never provide a source of water for the modelled groundwater system.

3.5.2 NARRABRI MINE

The underground mining and dewatering activity is defined in the model as MODFLOW Drain (DRN) cells with the head set to 1 m above the floor of the Hoskissons coal seam. These DRN cells were applied wherever workings occur, and were progressed through monthly increments in a transient model set-up. The set-up involved changing the parameters with time in the goaf and the overlying fractured zone directly after mining of each longwall panel, whilst simultaneously activating DRN cells along the development headings. The development headings were activated several months in advance of the active longwall mining and subsequent subsidence based on the mine plan. 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 1,000 m^2/day was applied during simulation. The hydraulic properties were varied with time using the TMP package of SURFACT v4.

3.5.3 RECHARGE AND EVAPOTRANSPIRATION

An overview of the recharge zones used within the model is provided in **Figure 14**. Rainfall recharge has been specified as a percentage of historical rainfall at NM Weather Station for transient calibration across four geologically-based zones:

Zone 1: Alluvium	1.5 %
Zone 2: Jurassic strata	0.2 %
Zone 3: Triassic and Permian strata	0.1 %

The adopted values for rainfall recharge expressed as percentages of long-term average rainfall are similar to those found in steady-state calibration (HydroSimulations, 2015).

The ET package was used in the NM model with an extinction depth of 2.0 m and a maximum ET rate of 146 mm/a. This was done to ensure that the model simulates the relatively high ET that can occur in low-lying areas where the water table is close to surface (along river/creek margins).

3.6 FRACTURED ZONE IMPLEMENTATION

3.6.1 BACKGROUND

The hydraulic properties of overburden material above a mined coal seam will change in time as a result of caving and subsidence above longwall panels. It is generally accepted that there will be a sequence of deformational zones consisting of the caved zone, the fractured zone (a lower zone of connective-cracking and an upper zone of disconnected-cracking), the constrained zone and the surface zone.

It is noted that the NM undertakes preconditioning of the strata, in particular the basalt sill, to assist this caving process for mine safety reasons.

High permeability is expected in the caved zone where there is direct connectivity with the mined goaf. In the lower part of the fractured zone, the collapsed rocks will have a substantially higher vertical permeability than the undisturbed host rocks. In the disconnected-cracking fractured zone, the vertical permeability 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, some increase in horizontal permeability can be expected in the constrained zone. Near-surface fracturing can occur due to horizontal tension at the edges of a subsidence trough in the surface zone.

3.6.2 MODEL SIMULATION

The fractured zone within the model is simulated with horizontal hydraulic conductivity enhanced by a factor of two (2), and with vertical hydraulic conductivity enhanced according to a log-linear monotonic (ramp) function. The function varies the vertical hydraulic conductivity field within the deformation zone overlying coal extraction areas and weights the permeability changes on layer thickness. For the present (Version 4) model, the lower and upper limits used for the ramp function are 3.0E-04 and 7.0E-04 m/day, respectively.

Deformation of floor strata, directly beneath longwall panels, occurs due to unloading as the coal seam is removed. To simulate this the host permeability values have been increased by a factor of three (3) in the model layer immediately beneath the mined seam within a longwall.

Storage properties (specific yield, Sy) were also increased in the mined coal seam layer to 15%. For the layer above the coal seam Sy was increased to 5% in areas overlying the longwall panels. The hydrostratigraphic unit (HSU) zonation facility in the Groundwater Vistas 6 software has been used to delineate the fractured zones and to attribute these in time consistent with mine progression. Groundwater Vistas then writes the TMP package for use with MODFLOW-SURFACT v4 (HydroGeoLogic Inc.).

The height of fracturing in the model is based on the Ditton and Merrick (2014) subsurface fracture height prediction model for longwall mines in the NSW Coalfields. This model includes the key fracture height driving parameters of panel width (W), cover depth (H), mining height (T) and local geology factors to estimate the A and B zone horizons above a given longwall panel. The A zone corresponds with the connective-cracking part of the fractured zone, while the B Zone corresponds with the disconnected-cracking part of the fractured zone which is equivalent to the lower dilated part of the constrained zone. Formulas are offered for two models:

- Geometry Model, which depends on W, H and T; and
- Geology Model, which depends on W, H, T and t' (where t' is the effective thickness[5] of the strata where the A Zone height occurs).

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

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

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

The 95th percentile (maximum) A-heights are estimated by adding a W' to A, where *a* varies from 0.1 for supercritical panels to 0.16 (geometry model) or 0.15 (geology model) for subcritical panels. The models have been validated to measured Australian case-studies (including West Wallsend, Mandalong, Springvale, Abel, Ashton, Austar, Berrima, Metropolitan and Wollemi/North Wambo Underground Mines) with a broad range of mining geometries and geological conditions included. The database also includes three cases in which connective cracking reached the surface (South Bulga, Homestead and Invincible Collieries).

For NM, LW101 and LW102 have been completed with a mining height of 4.2 m. The mining height for LW103 and LW104 was increased to 4.3 m following successful trials and maintenance of this height for all longwalls is planned for the duration of the NM. A uniform panel width of 306.4 m for all longwalls has also been approved.

The mine plan Modification retains mining heights of 4.2 m for LW101 and LW102 and 4.3 m for all subsequent longwalls but it entails a change to the number, lengths and widths of longwalls. The number of longwalls is proposed to be reduced from 26 to 20 (**Figure 2b**). Panel width is proposed to be 306.4 m for Longwalls 101 to 106 and 405.4 m for Longwalls 107 to 120. All of the proposed panels have length less than or equal to that of the approved panels (note these widths refer to total void width rather than panel width).

The A-Zone heights according to the Ditton Geology Model are listed in **Table 10** for the modified mine layout. Heights range from 117 m to 232 m.

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[5] Typically 15-20 m in the Gunnedah Coalfield.

Table 10. Ditton Geology Model A-Zone Heights (m). [Panel Width 306.4/405.4 m]

LONGWALL	Cover Depth Min [H (m)]	Cover Depth Max [H (m)]	Mining Height [T (m)]	A-Zone Height Min [A (m)]	A-Zone Height Max [A (m)]
101	160	175	4.2	117	128
102	175	185	4.2	128	135
103	190	200	4.3	139	146
104	180	215	4.3	133	157
105	200	235	4.3	146	165
106	220	250	4.3	160	171
107	240	285	4.3	174	204
108	265	305	4.3	190	213
109	290	325	4.3	207	220
110	310	335	4.3	214	224
111	325	360	4.3	220	232
112	340	360	4.3	225	232
113	320	350	4.3	218	229
114	300	330	4.3	211	222
115	275	305	4.3	197	213
116	245	280	4.3	177	200
117	225	245	4.3	163	177
118	200	225	4.3	146	163
119	190	210	4.3	139	153
120	180	205	4.3	133	150

The risk of adverse groundwater effects would be higher where the fractured zone heights are closer to the 95th percentile A-Zone height. In this case they could reach ground surface or the base of the surficial cracking zone (expected to be about 10 m deep at most). **Table 11** lists 95th percentile A-Zone heights. Values range from 140 m to 281 m. The depth from land surface to the top of the 95th percentile estimate of the top of the fractured zone ("vertical buffer") is also listed in **Table 11** for all longwalls for base case conditions. The vertical buffer ranges from 20 m to 79 m.

Since the vertical buffer significantly exceeds the expected depth of the surficial cracking zone for all longwalls, fracturing would not be expected to reach the ground surface except in the case of a significant increase in mining height. An increase in panel width would therefore have no deleterious effect.

Table 11. Ditton Geology Model 95th Percentile A-Zone Heights (m) and Vertical Buffer Depths (m). [Panel Width 306.4/405.4 m]

LONGWALL	Mining Height [T (m)]	95% A-Zone Height Min [A+ (m)]	95% A-Zone Height Max [A+ (m)]	Vertical Buffer Min (m)	Vertical Buffer Max (m)
101	4.2	140	152	20	23
102	4.2	152	160	23	25
103	4.3	166	174	24	26
104	4.3	158	187	22	28
105	4.3	174	198	26	37
106	4.3	191	206	29	44
107	4.3	207	244	33	41
108	4.3	227	256	38	49
109	4.3	248	265	42	60
110	4.3	258	270	52	65
111	4.3	265	281	60	79
112	4.3	272	281	68	79
113	4.3	263	277	57	73
114	4.3	253	268	47	62
115	4.3	236	256	39	49
116	4.3	211	240	34	40
117	4.3	195	211	30	34
118	4.3	174	195	26	30
119	4.3	166	183	24	27
120	4.3	158	178	22	27

3.7 MODEL VARIANTS

Models developed to aid the present groundwater assessment are summarised below.

- The (Version 4) transient validation model covers the pre-mining (January 2008) to present (April 2015) period, extending 10 months beyond the Version 3 model calibration period and incorporating the modified fracture zone modelling methodology (**Section 3.6**).

  In **Section 3.8**, outputs from this model are compared with corresponding outputs from the Version 3 model to assess the validity of future use of the Version 4 model for mining impact assessment purposes.

- A transient predictive model, representing an extension of the Version 4 model from pre-mining (January 2008) to the scheduled end of mining (December 2037) for the Approved mine plan to aid assessment of impacts to that date, and extending further to a total of 100 years from the end of mining (to December 2137) to enable assessment of long term recovery of groundwater levels (i.e. achievement of equilibrium).

- A transient predictive model, representing an extension of the Version 4 model from pre-mining (January 2008) to the scheduled end of mining (April 2031) for the Modified mine plan to aid assessment of impacts to that date, and extending further to a total of 100 years from the end of mining (to April 2131) to enable assessment of long term recovery of groundwater levels (i.e. achievement of equilibrium) and the extent of any differences relative to the Approved mine plan.
- Null transient predictive and recovery models for both the Approved mine plan and the Modified mine plan, providing a no-stress baseline for calculation of impacts at the same point in time.
- A brine injection simulation during the first two years of the 100 year recovery period, for the Modified mine plan.

3.8 MODEL VALIDATION

The aim of the validation exercise was to provide a basis for Version 4 model assessment (suitability for future use) given:

- the existence of observation data extending beyond the period on which model calibration was based; and
- the introduction into the model of the modified approaches to estimating the height of mining-induced fracturing and the vertical conductivity of the fractured zone.

Table 12 summarises the stress period (SP) distribution over the model duration. In total the validation model consists of 88 monthly stress periods (January 2008 to April 2015). During the extended period (i.e. the period following the Version 3 model calibration period) mining of Longwall 103 was completed and mining of Longwall 104 commenced.

The validation is based on all NM monitoring bores (standpipe and vibrating wires) located inside the model domain (i.e. P1, P2, P3, P4, P5, P8, P21, P22, P23, P24 and P25, etc.) (**Figure 7**).

Table 12. Stress Period Definition and Sequencing of Mining Activities for the Validation Model

Stress Period	Period Length (days)	Start	End	Mining	
SP1	31	1/01/2008	31/01/2008		Calibration
SP2	29	1/02/2008	29/02/2008		
SP3	31	1/03/2008	31/03/2008		
SP4	30	1/04/2008	30/04/2008		
SP5	31	1/05/2008	31/05/2008		
SP6	30	1/06/2008	30/06/2008		
SP7	31	1/07/2008	31/07/2008		
SP8	31	1/08/2008	31/08/2008		
SP9	30	1/09/2008	30/09/2008		
SP10	31	1/10/2008	31/10/2008		
SP11	30	1/11/2008	30/11/2008		
SP12	31	1/12/2008	31/12/2008		
SP13	31	1/01/2009	31/01/2009		
SP14	28	1/02/2009	28/02/2009	Drift Tunnels	
SP15	31	1/03/2009	31/03/2009		
SP16	30	1/04/2009	30/04/2009		
SP17	31	1/05/2009	31/05/2009		
SP18	30	1/06/2009	30/06/2009		
SP19	31	1/07/2009	31/07/2009		
SP20	31	1/08/2009	31/08/2009		
SP21	30	1/09/2009	30/09/2009		
SP22	31	1/10/2009	31/10/2009		
SP23	30	1/11/2009	30/11/2009		
SP24	31	1/12/2009	31/12/2009		
SP25	31	1/01/2010	31/01/2010		
SP26	28	1/02/2010	28/02/2010		
SP27	31	1/03/2010	31/03/2010		
SP28	30	1/04/2010	30/04/2010		
SP29	31	1/05/2010	31/05/2010		
SP30	30	1/06/2010	30/06/2010	Main Heading	
SP31	31	1/07/2010	31/07/2010		
SP32	31	1/08/2010	31/08/2010		
SP33	30	1/09/2010	30/09/2010		
SP34	31	1/10/2010	31/10/2010		
SP35	30	1/11/2010	30/11/2010		
SP36	31	1/12/2010	31/12/2010		
SP37	31	1/01/2011	31/01/2011		
SP38	28	1/02/2011	28/02/2011		
SP39	31	1/03/2011	31/03/2011		
SP40	30	1/04/2011	30/04/2011		
SP41	31	1/05/2011	31/05/2011		
SP42	30	1/06/2011	30/06/2011	LW101-LW102 Heading	
SP43	31	1/07/2011	31/07/2011		
SP44	31	1/08/2011	31/08/2011		
SP45	30	1/09/2011	30/09/2011		
SP46	31	1/10/2011	31/10/2011		
SP47	30	1/11/2011	30/11/2011		Calibration
SP48	31	1/12/2011	31/12/2011		
SP49	31	1/01/2012	31/01/2012		
SP50	29	1/02/2012	29/02/2012		
SP51	31	1/03/2012	31/03/2012	LW102-LW103 Heading	
SP52	30	1/04/2012	30/04/2012		
SP53	31	1/05/2012	31/05/2012		
SP54	30	1/06/2012	30/06/2012	LW101 start	
SP55	31	1/07/2012	31/07/2012		
SP56	31	1/08/2012	31/08/2012		
SP57	30	1/09/2012	30/09/2012		
SP58	31	1/10/2012	31/10/2012		
SP59	30	1/11/2012	30/11/2012		
SP60	31	1/12/2012	31/12/2012		
SP61	31	1/01/2013	31/01/2013		
SP62	28	1/02/2013	28/02/2013		
SP63	31	1/03/2013	31/03/2013		
SP64	30	1/04/2013	30/04/2013		
SP65	31	1/05/2013	31/05/2013		
SP66	30	1/06/2013	30/06/2013	LW101 complete	
SP67	31	1/07/2013	31/07/2013	LW102 Start	
SP68	31	1/08/2013	31/08/2013		
SP69	30	1/09/2013	30/09/2013		
SP70	31	1/10/2013	31/10/2013		
SP71	30	1/11/2013	30/11/2013		
SP72	31	1/12/2013	31/12/2013		
SP73	31	1/01/2014	31/01/2014	LW102 complete LW103 start	
SP74	28	1/02/2014	28/02/2014		
SP75	31	1/03/2014	31/03/2014		
SP76	30	1/04/2014	30/04/2014		
SP77	31	1/05/2014	31/05/2014		
SP78	30	1/06/2014	30/06/2014		
SP79	*31*	*1/07/2014*	*31/07/2014*		Validation
SP80	*31*	*1/08/2014*	*31/08/2014*		
SP81	*30*	*1/09/2014*	*30/09/2014*		
SP82	*31*	*1/10/2014*	*31/10/2014*	*LW103 complete*	
SP83	*30*	*1/11/2014*	*30/11/2014*	*LW104 start*	
SP84	*31*	*1/12/2014*	*31/12/2014*		
SP85	*31*	*1/01/2015*	*31/01/2015*		
SP86	*28*	*1/02/2015*	*28/02/2015*		
SP87	*31*	*1/03/2015*	*31/03/2015*		
SP88	*30*	*1/04/2015*	*30/04/2015*		
Total	**2677 days**				

3.8.1 STATISTICAL MEASURES OF MODEL PERFORMANCE

The overall performance of a groundwater model can be quantified by various measures of agreement between observed water levels and corresponding model simulated values. **Table 13** summarises several statistics commonly used for this purpose. Values for both the Version 4 and Version 3 models (covering largely coincident time periods and observation data sets) are provided.

Table 13. Model Performance Statistics

Statistics	Version 4	Version 3
Number of Data (n)	2,191	1,816
Root Mean Square (RMS) (m)	21.5	19.8
Scaled Root Mean Square (SRMS) (%)	11.0	10.0
Average residual (m)	0.89	-3.7
Absolute average residual (m)	14.4	12.7

Except for the ‘average residual’ statistic, the values for the two models do not differ significantly. The ‘average residual’ (0.89 m), however, is markedly improved for the more recent model.

The Scaled Root Mean Square (SRMS) measure of 10-11% is around the level normally sought for mining models. The MDBC flow model guideline (MDBC, 2001) suggests targets of 5-10% RMS for models of all types. However, 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*". There is always difficulty for mining models in matching absolute values and trends for VWP readings, as not all VWP sensors are reliable and a slight lag between actual and assumed mining progression can contribute to elevated RMS statistics.

3.8.2 GROUNDWATER LEVELS

Figures 15 and 16 show hydrographs at selected representative sites for the Version 3 calibrated model and the time-extended Version 4 validation model. Qualitative inspection over the coincident period (January 2008 to June 2014) reveals that, for the P9 (Purlawaugh Formation) and P24_180 (Arkarula Formation) data sets, the Version 4 model provides an improved match between simulated and observed water levels relative to the Version 3 model, and good agreement with observations over the extended period. For bores WB5b (alluvium) and P27 (Hoskissons Seam) there is little difference for the two models. These observations are consistent with the reduced ‘average residual’ statistic in **Table 13**.

The entire suite of observed and simulated hydrographs covering the extended model period is presented in **Attachment K**.

As discussed by HydroSimulations (2015), model Version 3 simulated heads agreed well with measured heads across the whole range of measurements except for the VWPs in Groups 3 and 4. This observation applies, also, for the Version 4 model. Some discrepancy between model simulations and observation data is likely to be due to the activity of unlicensed bores.

HydroSimulations (2015) attributed the poorer performance at VWP sites as being possibly due in part to VWPs not having equilibrated or a mismatch between actual and simulated timing of excavation, especially for development headings. Some of the Group 1 and Group 2 bores (for example P1, P7, P10 and WB6b) show clear pumping effects. As the model does not include private pumping due to the difficulty in estimating timing and pumping rates, agreement at these sites between observed and simulated water levels is compromised.

3.8.3 SIMULATED MINE INFLOW

The simulated groundwater inflow rates to the NM for the Version 3 and Version 4 models are compared in **Figure 17** for the respective model time frames. Values for the two models are very similar overall, and have the same trend. For the Version 4 model, simulated inflows are marginally higher as from February 2013. The predicted peak annual inflow to the Hoskissons Coal Seam from the start of mining to April 2015 is approximately 2.0 ML/day (about 730 ML/a), reached at March 2015, beyond the Version 3 model period.

Table 14 compares measured and simulated mine inflows pertaining to mining already completed (LW101 to LW104). The first three rows correspond to annual reporting periods from April to March, while the fourth row covers the seven months to date since January 2015. Modelled inflows have been calculated as time-weighted averages for the exact stress periods that cover the respective reporting periods.

Table 14. Measured and Simulated Mine Inflows for the Version 4 Model

MINING PERIOD	LONGWALL	AVERAGE MEASURED MINE DEWATERING* (ML/d)	MODEL PERIODS	AVERAGE MODELLED MINE INFLOW (ML/d)
1/4/2012 – 31/3/2013	LW101	0.59	SP52-63	0.56
1/4/2013 – 31/3/2014	LW101, LW102 and start of LW103	0.81	SP64-75	0.94
1/4/2014 – 31/3/2015	LW103 and LW104	0.86	SP76-87	1.7
1/1/2015 – 31/7/2015	LW104	0.93	SP73-91	1.6

* Based on measured inputs, measured outputs and moisture calculations by NCOPL

The agreement between measured and modelled dewatering rates is very good for the 2012-2013 and 2013-2014 reporting periods, with differences of about 5-15%. Since April 2014, the model tends to overestimate the actual dewatering rates by a factor of 1.7 to 2. This suggests that the mine inflow estimates provided by the model in predictive mode are likely to be overestimates and that the consequent environmental impacts predicted by the model are likely to err on the conservative side. That is to say, the impacts are expected to be overestimated.

3.8.4 MODEL ASSESSMENT

The brief discussions in **Sections 3.8.1**, **3.8.2** and **3.8.3** individually suggest that the simulated outputs of model Versions 3 and 4 are very similar. The Version 4 model provides small improvement by some measures.

On this basis, the Version 4 model can be regarded as suitable for use in assessing the likely future impacts of the NM Modification.

4 SCENARIOS

The Version 4 groundwater model has been adopted for the work documented in this Section.

4.1 MODIFIED MINING LAYOUT AND SCHEDULE

The proposed modified mining layout is depicted in **Figure 2b**. As discussed previously, the proposed Modification entails:

- Shorter duration of mining.
- Reduction in the number of longwall panels from 26 to 20.
- Increased longwall panel widths.
- Some reduction of longwall panel lengths.

These changes will necessitate a change to the mining schedule relative to the currently approved layout.

Table 12 summarises the (monthly) stress period setup used for the NM transient groundwater model for the period from January 2008 to April 2015, representing the model calibration period and the validation period. The timing represented in this table is unaffected by the proposed modified mine layout.

Predictive model simulations have been run to aid assessment of the future impacts of mining. **Table 15** summarises the stress period setup used for the predictive transient model simulations for the Modification mine plan. The prediction period runs from:

- May 2015 (stress period 89) to April 2031 (stress period 108) — covering the full duration of NM; and
- May 2031 to December 2031 (stress period 109) and January 2032 to December 2131 (stress period 110) – to enable assessment of recovery water levels.

The stress periods for predictive modelling have a length of one month to the end of August 2015, then vary initially up to more than one year, mainly to facilitate reasonable model run times. Lengths are variable to ensure coincidence with the beginning and end of individual longwall panels. The final stress period of the predictive model extends for an additional 100 years. The relationship between stress periods and the mining schedule is shown in **Table 15**.

An analogous stress period setup was developed to enable predictive modelling for the Approved mine plan for the purpose of comparison with the Modification mine plan. For this setup, the prediction period runs from:

- May 2015 (stress period 89) to December 2037 (stress period 114) — covering the full approved duration of NM; and
- January 2038 to March 2038 (stress period 115) and April 2038 to March 2138 (stress period 116).

For both mine plans, mining progresses downdip from east to west for the northern portion of the mine layout. For the southern portion, mining progresses updip from west to east. As active dewatering will not be necessary for the downdip longwall panels, after the southern updip progression is commenced, the drain cells in the northern and southern panels to the west of the panel currently being excavated are deactivated in the model. This means that groundwater level recovery will commence at the downdip panels prior to completion of mining. For example, when the Modification LW113 is being mined, both LW111 (north) and LW112 (south) will be deactivated. They would no longer report any groundwater inflow that is required to be pumped out as there is no longer any need to keep the active workings dry. Mine inflow (to DRN cells) would be expected to increase roughly linearly with time as panels are mined downdip to LW111 and LW112. Similarly, mine inflow (to active DRN cells) would be expected to decrease roughly linearly with time as panels are mined updip to LW120.

Table 15. Stress Period Definition and Sequencing of Mining Activities for the Prediction and Recovery Models

Stress Period	Period Length (days)	Start	End	Mining	
SP89	31	1/05/2015	31/05/2015		Prediction
SP90	30	1/06/2015	30/06/2015		
SP91	31	1/07/2015	31/07/2015		
SP92	31	1/08/2015	31/08/2015	LW107 Heading	
SP93	304	1/09/2015	30/06/2016	LW105 start	
SP94	274	1/07/2016	31/03/2017	LW106 start /LW108 Heading	
SP95	334	1/04/2017	28/02/2018	LW107 start /LW9 Heading	
SP96	337	1/03/2018	31/01/2019	LW108 start /LW10 Heading	
SP97	394	1/02/2019	29/02/2020	LW109 start /LW111-112 Heading	
SP98	396	1/03/2020	31/03/2021	LW110 start /LW113-114 Heading	
SP99	395	1/04/2021	30/04/2022	LW111 start	Prediction
SP100	365	1/05/2022	30/04/2023	LW112 start /LW115-116 Heading	
SP101	366	1/05/2023	30/04/2024	LW113 start	
SP102	365	1/05/2024	30/04/2025	LW114 start /LW117-118 Heading	
SP103	365	1/05/2025	30/04/2026	LW115 start	
SP104	365	1/05/2026	30/04/2027	LW116 start /LW119-120 Heading	
SP105	366	1/05/2027	30/04/2028	LW117 start	
SP106	365	1/05/2028	30/04/2029	LW118 start	
SP107	365	1/05/2029	30/04/2030	LW119 start	
SP108	365	1/05/2030	30/04/2031	LW120 start	
SP109	245	1/05/2031	31/12/2031		Recovery
SP110	36525	1/01/2032	31/12/2131		

4.2 MODELLING APPROACH

The potential impacts of the Modification are facilitated by prediction model runs for both the current and modified mine layouts and comparison of model outputs.

The incremental impacts of the Modification are identified by ensuring that, for the two model runs, all parameters remain unchanged other than the mine layout (and associated mining schedule differences).

4.3 PREDICTED GROUNDWATER LEVELS

The sub-sections below describe the modelled depressurisation effects in the key model layers.

4.3.1 REGOLITH/ALLUVIUM – LAYER 1

Figure 18 shows layer 1 groundwater levels at the start of longwall panel mining (June 2012) and predicted levels at the end of mining for the Modified mine plan (April 2031). At June 2012, there would be some effects from drift and roadway construction prior to commencement of Longwall 101.

For this layer, comparison of **Figures 18a** and **18b** suggests that the impact of mining over the Modified mine plan duration would be small beyond a few kilometres from the mine site in all directions. Within the mine site, the impact would be large, with significant declines in water level over the period of mining.

Layer 1 drawdowns for the Modified and Approved mine plans are shown in **Figure 19**. The drawdown patterns are very similar for the Modified and Approved end of mining dates and the areas impacted by drawdown greater than two metres are almost identical for the two cases. However, **Figures 19a** and **19b** indicate some differences for the most affected areas, particularly the north eastern (updip) part of the mine site - the area of early mining, and the most prolonged period of active dewatering. The water levels over the western portion of the mine would start recovering before the end of mining, due to progressive deactivation of panel drains as mining moves updip. For the Modified mine plan the maximum predicted drawdown of 167 m occurs in the vicinity of LW105; drawdowns exceed 27 m over 1% of the model area. For the Approved mine plan the maximum predicted drawdown of 189 m (22 m greater than for the Modified plan) occurs in the same vicinity; drawdowns exceed 34 m over 1% of the model area.

Figure 20 shows the predicted difference[6] between groundwater levels at the respective end of mining dates for the Modified and Approved mine plans for layer 1. The area of difference greater than two metres is within a few kilometres north, east and south of the mine. In this area localised differences greater than 10 m are apparent. The greatest difference occurs in the north eastern corner of the mine site, where groundwater levels for the Modified mine plan are more than 50 m higher than for the Approved plan. The occurrence of two distinct drawdown "ellipses" reflects outcropping geology (**Figure 5**). By reference to the geological map in **Figure 5**, it is clear that the 2 m contour limits lie within regolith and do not extend into alluvium.

4.3.2 PILLIGA SANDSTONE – LAYER 2

Figure 21 shows layer 2 groundwater levels at the start of longwall panel mining (June 2012) and predicted levels at the end of mining for the Modified mine plan (April 2031). The Pilliga Sandstone outcrops over most of the mine site and to the west towards Jacks Creek (**Figure 5**).

For this layer **Figures 21a** and **21b** show that water levels are very similar over most of the area at the two dates, except for within a few kilometres of the mine site. This suggests that the impact of mining over the Modified mine plan duration would be relatively restricted. Within the mine site, the impact would be large, with significant declines in water level over the period of mining.

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[6] Difference is defined here as the Modification plan water level minus the Approved plan water level

Layer 2 drawdowns for the Modified and Approved mine plans are shown in **Figure 22**. The drawdown patterns are very similar for the Modified and Approved end of mining dates and the areas impacted by drawdown greater than two metres are almost identical for the two cases. However, **Figures 22a** and **22b** indicate some differences for the most affected areas, particularly the north eastern (updip) part of the mine site. For the Modified mine plan the maximum predicted drawdown is 152 m; drawdowns exceed 21 m over 1% of the model area. For the Approved mine plan the maximum predicted drawdown is 178 m (26 m greater than for the Modified plan); drawdowns exceed 27 m over 1% of the model area. The area of maximum drawdown is located similarly for the two cases.

Figure 23 shows the predicted difference between groundwater levels at the respective end of mining dates for the Modified and Approved mine plans for layer 2. Water levels for the Modified mine plan exceed levels for the Approved plan by 4.4 m only over 1% of the entire area. The area of greatest difference is confined to the north-east of the mine site.

4.3.3 NAPPERBY FORMATION – LAYER 5

Figure 24 shows layer 5 groundwater levels at the start of longwall panel mining (June 2012) and predicted levels at the end of mining for the Modified mine plan (April 2031). The Napperby Formation outcrops between the mine site and the Namoi River (**Figure 5**).

Figures 24a and **24b** suggest that, over the period of the Modification plan the Napperby Formation will experience significant decline that extends well beyond the mine site in all directions. The flow pattern is particularly affected west of the mine site. On **Figure 24a**, the early effects of drift and roadway construction can be seen as a localised ellipse at the eastern edge of the mine site.

Layer 5 drawdowns for the Modified and Approved mine plans are shown in **Figure 25**. The drawdown patterns are very similar for the Modified and Approved end of mining dates. For the Modified mine plan the maximum predicted drawdown is 146 m; drawdowns exceed 77 m over 1% of the model area. For the Approved mine plan the maximum predicted drawdown is 166 m (20 m greater than for the Modified plan); drawdowns exceed 82 m over 1% of the model area. The north-eastern quadrant of the mine area exhibits maximum drawdown in each case due to early commencement of groundwater recovery in the downdip panels.

Figure 26 shows the predicted difference between groundwater levels at the respective end of mining dates for the Modified and Approved mine plans for layer 5. Water levels for the Modified mine plan exceed levels for the Approved plan by 5.9 m only over 1% of the entire area. The area of greatest difference is confined to the north-east of the mine site. There is a broad area of more than 2 m differential surrounding the mine site. It should be noted, however, that the display window in **Figure 26** is much smaller than the model extent in **Figure 10**[7].

4.3.4 HOSKISSONS COAL SEAM – LAYER 9

Figure 27 shows layer 9 groundwater levels at the start of longwall panel mining (June 2012) and predicted levels at the end of mining for the Modified mine plan (April 2031).

For the Hoskissons Coal Seam there is a significant predicted decline in levels over the mining period in all directions. The anomaly east of the mine site relates to drift and development headings (**Figure 27a**). As is to be expected, the area of greatest impact closely coincides with the mined area.

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[7] The display window is 25km (E-W) x 24km (N-S) while the model extent is 75km (E-W) x 52km (N-S).

Figure 28 shows that layer 9 drawdowns over the respective Modified and Approved mine plan durations differ almost imperceptibly.

Figure 29 shows the predicted difference between groundwater levels at the respective end of mining dates for the Modified and Approved mine plans for layer 9. The difference between water levels for the Modified and Approved plans has a mean value of 1.9 m and exceeds 5.3 m over only 1% of the model area. Over most of the mine area predicted groundwater levels are nearly identical for the two end of mining dates although, immediately north and south of the eastern area, levels for the modified end of mining date are greater by 5-20 m. For the area in the vicinity of the western boundary of the mine, predicted levels for the Modified mine plan are significantly (more than 30 m) lower than those predicted for the Approved plan. This is because the Modified plan has a slightly greater western extent. There is a broad area of less than 5 m differential surrounding the mine site. Again, the display window in **Figure 29** is much smaller than the model extent in **Figure 10.**

4.3.5 LONG TERM WATER LEVELS AND RECOVERY

The model was run to 100 years beyond the end of the mine plan end dates for the Approved and Modified plans. Predicted groundwater levels at the end of the respective extended periods are presented in **Figures 30** (layers 1 and 2) and **31** (layers 5 and 9).

Discussion on the significance of this work is presented in **Section 5**.

4.4 PREDICTED BASEFLOW CAPTURE

Table 16 summarises the predicted baseflows to the river system to the end of mining for both the Approved mining plan and the Modification plan. The six river reaches represented in the groundwater model are referenced in the table by RIV11, RIV12, RIV13, RIV14, RIV15 and RIV20. (River reaches are defined in **Figure 13**.) The Namoi River upstream of Boggabri is represented by RIV11.

For river reaches other than the Namoi River, there is no effective difference in predicted baseflows for the two mining plans. For the Namoi River upstream of Boggabri, **Figure 32** shows predicted changes in baseflow (relative to corresponding null scenarios) from 2008 to the end of mining for both the Approved and Modification mine plan. There is a discernible but negligible difference for the two plans. The maximum impact by the end of mining is less than 0.3 ML/day for each plan.

Table 16. Predicted Baseflows to the End of Mining [ML/day]

	[ML/day]	RIV11	RIV20	RIV12	RIV13	RIV14	RIV15
Approved	MAX	11.5	4.4	1.0	9.4	5.7	1.6
	MEDIAN	8.7	3.5	0.22	8.2	4.8	0.86
	MIN	6.7	2.6	-0.73	7.4	4.2	0.41
Modification	MAX	11.5	4.4	1.0	9.4	5.7	1.6
	MEDIAN	8.8	3.6	0.24	8.2	4.9	0.88
	MIN	6.7	2.7	-0.64	7.4	4.2	0.41
Difference	MAX	0.00	0.00	0.00	0.00	0.00	0.00
	MEDIAN	-0.10	-0.02	-0.02	-0.03	-0.03	-0.02
	MIN	0.00	-0.09	-0.09	0.00	0.00	0.00

Note: +ve numbers represent baseflow; -ve numbers represent river leakage

River reach 12 (Maules Creek) is the only instance in which the predicted baseflow becomes negative (i.e. the minimum value in the table is negative), indicating variability with time between being a gaining and losing stream. All other reaches are predicted to be gaining over the respective mining periods.

4.5 PREDICTED MINE INFLOW

Figure 33 shows simulated annual mine inflow rates for both the approved and modified NM mining layouts and durations for each water year from July 2015. Rates of mine inflow increase progressively for both layouts, to peak values of 3.48 ML/day in water year 2024-2025 (about 1270 ML for the year) and 3.77 ML/day in water year 2022-2023 (about 1380 ML for the year) for the approved and modified layouts, respectively. The modified layout results in an incremental increase of 0.29 ML/day (106 ML/a) at peak inflow which occurs two years earlier. The earlier peak for the modified layout is expected given the shorter mining duration. For each of the layouts, inflows decrease progressively towards the scheduled end of mining due to cessation of dewatering for the downdip panels.

As noted in **Section 3.8.3**, based on actual mine dewatering to date, the model is likely to be overestimating mine inflows (by a factor of up to 2).

4.6 BRINE RE-INJECTION

Schedule 4, Condition 9 of PA 08_0144 states:

Within 2 years of the commencement of longwall coal extraction, and every 5 years thereafter, the Proponent shall undertake a transient calibration of the groundwater model presented in the EA, in consultation with NOW, and to the satisfaction of the Director-General. This re-calibration of the groundwater model must include forward impact predictions of brine re-injection to the mine's goaf at the conclusion of mining operations.

Accordingly, brine re-injection has been simulated in exactly the same way as was done previously by Aquaterra (2009) using their provided model files. A volume of 1023 ML was injected steadily over two years at 10 locations along the westernmost longwall panel to the north of the mains. The injection was at a uniform rate of 140 kL/day per bore into the fractured zone at the level of the Napperby Formation below the sill (model layer 7). The results of this modelling are discussed in **Section 5.2.3**.

5 POTENTIAL IMPACTS

5.1 POTENTIAL IMPACTS ON GROUNDWATER

The main effect of underground mining upon the groundwater regime comes 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, potentially impact on a number of components of the hydrogeological system, both during and following mining operations - for example:

- groundwater levels both within the exposed and deeper hard rock strata in the mine vicinity and the alluvium of the Namoi River;
- inflow of water to the underground mine and the management of that mine water;

- baseflow to the Namoi River and its tributaries; and
- brine re-injection.

5.2 POTENTIAL IMPACTS ON GROUNDWATER LEVELS

5.2.1 PERIOD OF MINING

Predicted impacts on groundwater levels over the period of mining have already been discussed in **Section 4.3**, in which changes in groundwater levels were individually addressed for layers 1 (regolith/alluvium), 2 (Pilliga Sandstone), 5 (Napperby Formation) and 9 (Hoskissons Coal Seam). The significant outcomes of that discussion are summarised below.

- For layers 1 and 2, the impact of mining will be small beyond a few kilometres from the mine site. For these areas, there will be little difference in water levels for the two mine plans.
- For layers 5 and 9, groundwater levels will exhibit a significant decline over a wide area beyond the mine site.
- For all layers, the difference between water levels at the end of the Approved mine plan and the end of the Modified mine plan will be small for areas well beyond the mine site.
- All layers will exhibit significant decline in water level over the mine site and its immediate vicinity. This impact will be most strongly focussed in the north-eastern quadrant.
- Within the mine site, drawdowns for the Modified mine plan will be smaller than for the Approved mine plan, except for the immediate vicinity of the western boundary of the mine site area.
- In the immediate vicinity of the western boundary of the mine site area, drawdowns for the Modified mine plan will be more than 30 m greater than for the Approved mine plan. This is directly related to the fact that the Modified mine plan has a slightly greater western extent than the Approved plan.

5.2.2 RECOVERY

Longer term impacts are addressed here by reference to the 100 year scenario model outputs.

Predicted groundwater levels at the end of Modification plan mining (April 2031) are shown in **Figure 30** for layer 1 (regolith/alluvium) and layer 2 (Pilliga Sandstone). For layer 1, the 100 year water levels are very similar to those depicted in **Figure 18a**, which shows water levels at the start of the mining period. For layer 2, the 100 year water levels are very similar to those depicted in **Figure 21a**, which shows water levels at the start of the mining period. For both layers, minor differences are apparent in the vicinity of the mine but the high degree of similarity between the two sets of water levels implies that long term water levels would recover, to a large extent, to pre-mining levels.

Predicted groundwater levels at the end of Modification plan mining are shown in **Figure 31a** for layer 5 (Napperby Formation). For this layer, the 100 year water levels are very similar to those depicted in **Figure 24a**, which shows water levels at the start of the mining period. Small differences are apparent well beyond the mine area but the high degree of similarity between the two sets of water levels implies that long term water levels are likely to recover, to a large extent, to pre-mining levels.

Predicted groundwater levels at the end of Modification plan mining are shown in **Figure 31b** for layer 9 (Hoskissons Coal Seam). The 100 year water levels are, overall, similar to those depicted in **Figure 27a**, which shows water levels at the start of the mining period. Minor differences are apparent well beyond the mine area and large differences are apparent in the vicinity of the mine. These differences relate to the initial drift tunnel and development headings (**Figure 27a**). The high degree of similarity suggests that long term water levels will recover, to a large extent, to pre-mining levels.

The likelihood of long term recovery of water levels is emphasised by the prediction/recovery hydrographs for Modification mining, shown in **Figures 34** to **37**, for four representative monitoring sites distributed about the mine site vicinity. Site P6 is a single standpipe in the Pilliga Sandstone located 1 km distant from the mine site, whereas P17 is a single standpipe in the Purlawaugh Formation over the westernmost longwall panel. Site P24 is a VWP site at the eastern updip edge of the mine site, while P40 is located over the mains at the western downdip end (where early recovery is promoted).

Figure 34 shows a drawdown of about 14 m in the Pilliga Sandstone at site P6. The water level recovers to a final level that is about 3 m lower than the natural pre-mining level. A recovery of 80% would take about 40 years after cessation of mining.

At site P17 in the Purlawaugh Formation, a drawdown of about 19 m is expected (**Figure 35**). As this site is over a downdip panel and the maximum drawdown occurs at the end of mining, the early recovery promoted at the downdip panels has not reached the Purlawaugh Formation at that time. The water level recovers to a final level that is about 3 m lower than the natural pre-mining level due to the permanently enhanced vertical hydraulic conductivity in the fractured zone above the mine area. A recovery of 80% would take about 30 years after mining.

Figure 36 represents recovery hydrographs at site P24, for sampling depths 112 m, 148 m, 166 m and 180 m. The maximum drawdown ranges from 90 m to 120 m for the four monitoring depths. Drawdown is very sudden and recovery is quite rapid, reaching 80% after about 20 years. The final water levels are expected to be 1-5 m higher than pre-mining levels.

Figure 37 represents recovery hydrographs at site P40 at the western boundary of the mine site over the mains. The maximum drawdown ranges from 30 m to 265 m for the six monitoring depths. Drawdown occurs later than at P24, as expected, but drawdown is also sudden and recovery is very rapid for the deeper sensors due to the promotion of early recovery at the downdip panels. Recovery reaches 80% after only 10 years. The final water levels are expected to be very similar to pre-mining levels, but the shallowest levels could be about 5 m lower.

5.2.3 BRINE RE-INJECTION

As discussed in **Section 4.6**, brine re-injection in the westernmost (down-dip) panels has been simulated using the Version 4 model. **Figure 38** shows the locations of the 10 injection wells and the hydrographic response at four representative locations:

- centre of Longwall 111;
- centre of Longwall 110;
- northern end of Longwall 111; and
- southern end of Longwall 111.

The hydrographs confirm that the effects of injection are localised and confined essentially to the target layer 7 (Napperby Formation below the sill) and the overlying layer 6 (basalt sill) where pressures are expected to be artesian at the centre of the longwall panel, near-artesian at the northern end of the panel, and sub-artesian at the southern end of the panel. Overlying layer 5 (Napperby Formation) and layer 4 (Garrawilla Volcanics) show no appreciable effect from the injection. This accords with the findings of Aquaterra (2009), who noted that the water level rise during injection did not reach the Garrawilla Volcanics (layer 4).

Aquaterra (2009) also conducted particle tracking to show that no upward migration of saline water would occur from the injection site to the GAB aquifers and that lateral outflow of saline water would be confined to a distance of 1-2 km after 100 years.

5.3 POTENTIAL IMPACTS ON GROUNDWATER FLOW DIRECTION

For layer 1 (regolith/alluvium), groundwater levels at the start of mining and predicted levels 100 years after the end of mining are represented in **Figures 18a** and **30a**, respectively.

For layer 2 (Pilliga Sandstone), groundwater levels at the start of mining and predicted levels 100 years after the end of mining are represented in **Figures 21a** and **30b**, respectively.

For both layers, the two relevant pairs of diagrams show contour patterns that are very similar, with exceptions limited to the immediate vicinity of the mine area. Groundwater lateral flow directions (inferred as being perpendicular to the contours) can, therefore, be assumed to be unaffected except for the limited area around the mine site. Within this area, the change of direction is spatially variable.

For layer 5 (Napperby Formation), groundwater levels at the start of mining and predicted levels 100 years after the end of mining are represented in **Figures 24a** and **31a**, respectively. The diagrams show contour patterns with few discernible differences, suggesting that lateral flow directions in this layer would be unaffected by mining.

For layer 9 (Hoskissons Coal Seam), groundwater levels at the start of mining and predicted levels 100 years after the end of mining are represented in **Figures 27a** and **31b**, respectively.

Well beyond the mine site, the diagrams exhibit very similar contour patterns and imply that lateral flow directions at this depth and at distance would be largely unaffected by mining. Closer to the mine there are discernible differences, near the eastern boundary of the mine site, from which it might be concluded that spatially variable disruption to lateral flow directions will occur. However, the water level contours in **Figure 27a** depict conditions in this area that were subject to early mining activity (drift and headings) and which, therefore, are not indicative of pre-mining conditions. It is likely that there would be little effective long term disruption to lateral flow directions for this layer.

The 100-year recovery hydrographs for sites P6, P7, P24 and P40 (**Section 5.2.2**) provide some insight into likely long term changes in vertical flow direction. For example, at the shallower depths at site P40 (95 m and 135 m), long term decline in water level is predicted and there is likely to be some reduction in the level of upward flow (or a reversal of flow direction). All of the remaining hydrographs discussed greater depths and show a rise in groundwater level caused by mining-induced increased pressure that would increase the extent of upward flow.

5.4 POTENTIAL IMPACTS ON GROUNDWATER QUALITY

Given that groundwater flow direction is little affected for all layers, except for the area limited to the vicinity of the mine, then there is likely to be negligible impact on water quality.

The brine re-injection simulation confirmed the localised entrapment of this potential source of salt, and particle track modelling by Aquaterra (2009) quantified a limited lateral movement of 1-2 km after 100 years.

5.5 PREDICTED GROUNDWATER INFLOWS

The predicted groundwater inflows to the NM are shown in **Figure 33** for the two mine plans.

For the Approved mine plan, inflow to the Hoskissons Coal Seam NM workings is expected to peak at about 3.5 ML/day (about 1270 ML) during 2024-2025. For the Modification mine plan, the predicted peak inflow occurs about two years earlier (during 2022-2023) and is about 88% higher at about 3.8 ML/day (about 1380 ML).

As noted in **Section 3.8.3**, based on actual mine dewatering to date, the model is likely to be overestimating mine inflows (by a factor of up to 2).

5.6 GROUNDWATER LICENSING

Quantification of water take is required for four relevant water sources (**Section 1.4**):

1. Southern Recharge Groundwater Source.
2. Upper Namoi Zone 5 Namoi Valley (Gin's Leap To Narrabri) Groundwater Source.
3. Lower Namoi Regulated River Water Source.
4. Gunnedah - Oxley Basin MDB Groundwater Source.

For water source 1, the net vertical flow at the base of the Jurassic Pilliga Sandstone has been examined for the Approved, Modification and Null mining simulations. Similarly, the net downward flow from alluvium to rock has been examined for the extent of Zone 5 alluvium (water source 2). For water source 3, the river features in the models have been interrogated for any reduced baseflow or increased leakage. Water source 4 is quantified by the simulated mine inflow less the takes from the other three water sources.

From 2010 to 2012 (stress period 31 to stress period 53) prior to the commencement of LW101, the loss of alluvial groundwater to the underlying rock is estimated to have been about 42 kL/day for both scenarios. The difference between the two scenarios is negligible, being in the order of 0.01 kL/day at most.

Figure 39 shows the predicted impact on GAB aquifers in the Southern Recharge Zone water source to the end of mining. The key features are:

- Maximum additional losses of 0.49 ML/d (Modification) and 0.56 ML/d (Approved) from the Pilliga Sandstone to underlying rock.
- Very small difference between Approved and Modification plans (about 0.07 ML/d at maximum; about 25 ML/a).
- The larger effect of Approved mining is due to the longer duration of mining.

Figure 40 shows the predicted impact on the Namoi Alluvium (Zone 5) water source to the end of mining. The key features are:

- Maximum 0.30 ML/d (Modification) and 0.33 ML/d (Approved) additional loss from alluvium to underlying rock, consisting of increased downflow (about 0.2 ML/d) and reduced upflow (about 0.1 ML/d).
- Very small difference between Approved and Modification plans (about 0.03 ML/d at maximum; about 11 ML/a).
- The larger effect of Approved mining is due to the longer duration of mining.

Figure 41 confirms that the maximum takes from the two groundwater sources occur at the end of mining. The takes are replenished rapidly during the 100 years of recovery. The take from the alluvium is completely restored by then, but there is a permanent loss of less than 0.1 ML/day (about 27 ML/a) from the GAB aquifers.

The take from the Lower Namoi Regulated River Water Source was investigated in **Section 4.4** and **Figure 32**. For river reaches other than the Namoi River, there is no effective difference in predicted baseflows for the two mining plans. For the Namoi River upstream of Boggabri, **Figure 32** shows predicted changes in baseflow (relative to corresponding null scenarios) from 2008 to the end of mining for both the Approved and Modification mine plans. There is a discernible but negligible difference for the two plans. The maximum impacts by the end of mining are 0.21 ML/d (Modification) and 0.25 ML/d (Approved).

The take from the Gunnedah **-** Oxley Basin MDB Groundwater Source was investigated in **Section 4.5** and **Figure 33**. The peak rates of mine inflow are predicted to be about 3.5 ML/day in water year 2024-2025 (about 1270 ML for the year) and about 3.8 ML/day in water year 2022-2023 (about 1380 ML for the year) for the Approved and Modification layouts, respectively.

The temporal variations for the groundwater takes are summarised in **Table 17** in terms of minimum, median and maximum rates for natural and mining conditions.

Table 17. Predicted Water Source Groundwater Takes to the End of Mining [ML/day]

WATER SOURCE	[ML/day]	NATURAL	APPROVED	MODIFICATION
Southern Recharge Zone	MIN	-0.32	-0.32	-0.32
	MEDIAN	0.01	0.02	0.02
	MAX	0.85	0.85	0.85
Namoi Alluvium Zone 5	MIN	-0.15	-0.13	-0.13
	MEDIAN	-0.11	-0.07	-0.07
	MAX	-0.03	0.22	0.21
Porous Rock	MIN	0	-0.10	-0.25
	MEDIAN	0	-2.17	-2.56
	MAX	0	-3.48	-3.77

Note: +ve numbers represent losses; -ve numbers represent gains to a water source

The predicted annual groundwater volumes required to be licensed over the life of the mine for the Approved and Modified mine plans are summarised in **Table 18**.

Table 18. Groundwater Licensing Summary for Narrabri Mine

Water Sharing Plan	Management Zone/ Groundwater Source	Predicted Annual Inflow Volumes requiring Licensing (ML/a)	
		Approved Mine Plan	Modification
NSW Great Artesian Basin Groundwater Sources	Southern Recharge Groundwater Source	**204**	**179**
Upper and Lower Namoi Groundwater Sources	Upper Namoi Zone 5 Namoi Valley (Gin's Leap To Narrabri) Groundwater Source	**122**	**110**
NSW Murray Darling Basin Porous Rock Groundwater Sources	Gunnedah - Oxley Basin MDB Groundwater Source	**856**	**1009**
Upper Namoi and Lower Namoi Regulated River Water Sources	Lower Namoi Regulated River Water Source	**91**	**78**
	TOTAL	**1273**	**1376**

From review of **Table 1**, it is noted that NCOPL holds sufficient licences to cover the predicted impacts for the Approved and Modification mine plans, with the exception of the NSW Murray Darling Basin Porous Rock Groundwater Sources Gunnedah - Oxley Basin MDB Groundwater Source (818 ML/annum held). NCOPL would monitor underground mine inflows versus model predictions and obtain additional licence(s) volumes of this water source to account for actual inflows, as necessary.

5.7 POTENTIAL IMPACTS ON REGISTERED PRODUCTION BORES

Figure 42 shows the locations of registered production bores in the vicinity of NM, in relation to the predicted drawdown in the alluvium and regolith (model layer 1) due to the Modification mine plan between the start and end of longwall mining. No alluvial bores have a drawdown in excess of 2 m (the threshold for the *Aquifer Interference Policy* minimal harm consideration).

Figure 43 shows the registered bores interpreted as drawing groundwater from the Pilliga Sandstone, a GAB aquifer. There are no bores with predicted drawdown greater than 2 m.

In **Figure 44**, one bore in the Purlawaugh Formation is expected to have a drawdown in excess of 2 m. The details of the bore are listed in **Table 19**.

Also, one bore in the Garrawilla Volcanics is expected to have a drawdown in excess of 2 m. The details of the bore are listed in **Table 19**.

Table 19. Predicted Drawdown Effects at Registered Bores

Work No. (bore)	Licence	Owner Type	Bore Depth (m)	Aquifer^	Predicted drawdown [m]	Comment
					Modification	
GW067626	90BL139277	Private	88	Purlawaugh	10	Layer 3
GW966836	90BL246067	NCOPL	30	Garrawilla Volcanics	>10	Layer 4

Drawdown effects on the privately-owned less productive bore would be managed in accordance with NM Water Management Plan.

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 New England/North West Region may include:

- increase in maximum and minimum temperatures, with the greatest warming in spring and winter (up to 3 Degrees Celsius (°C));
- increase in summer , spring and autumn rainfall (by 5-20%);
- decrease in winter rainfall (by 10-20%);
- increase in evaporation in all seasons (by 5-50%); and
- increase in the intensity of flood producing rainfall events.

More broadly, 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 °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 to be completed earlier than the Approved mine plan, and essentially the same volume of coal is to be extracted, it was not considered necessary to simulate the effects of climate change for this assessment.

5.9 ASSESSMENT AGAINST THE MINIMAL IMPACT CONSIDERATIONS

The NSW *Aquifer Interference Policy* (NSW Government, 2012) establishes minimal impact considerations for highly productive and less productive groundwater. From review of NOW mapping of highly productive groundwater in the vicinity of the NM, it is understood that the Namoi Alluvium and Southern Recharge Groundwater Source (GAB) are highly productive groundwater sources.

Tables 20 to **22** provide an assessment of the Modification against the minimal impact considerations in the *Aquifer Interference Policy* and include consideration of cumulative impacts where appropriate.

Table 20: Highly Productive Alluvial Aquifer – Minimal Impact Considerations

Aquifer	Upper and Lower Namoi Groundwater Sources – Upper Namoi Zone 5 Namoi Valley (Gin's Leap to Narrabri) Groundwater Source
Type	Alluvial Aquifer
Category	Highly Productive
Level 1 Minimal Impact Consideration	**Assessment**
Water Table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.	**Within Level 1** There are no high priority groundwater dependent ecosystems listed in the Upper and Lower Namoi Groundwater Sources Water Sharing Plan. There are no High Priority Culturally Significant Sites listed in the Upper and Lower Namoi Groundwater Sources Water Sharing Plan. NCOPL mining would not result in drawdown of more than 2 m at any privately owned water supply work in the declared alluvial aquifer.
Water pressure A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work.	**Within Level 1** NCOPL mining would not result in cumulative drawdown of more than 40% of the pressure head at any privately owned water supply work in an alluvial aquifer.
Water quality Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity. No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. No mining activity to be below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply". Not more than 10% cumulatively of the three dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200 m laterally from the top of high bank and 100 m vertically beneath a highly connected surface water source that is defined as a "reliable water supply".	**Within Level 1** There are no simulated risks of reduced beneficial uses of the highly productive alluvium as a result of the Modification (Section 5.4). The Modification would have no discernible impact on stream baseflow or natural river leakage for the Namoi River, beyond the effects of approved mining. Therefore the Modification would have negligible impact on the long-term salinity of the Namoi River. The Namoi River is a "reliable water supply" associated with Highly Productive groundwater. The proposed Modification longwall panels are located well away from the Namoi River. The Modification will not extract alluvial material associated with the Highly Productive alluvial groundwater system.

Table 21: Highly Productive Great Artesian Basin Aquifer – Minimal Impact Considerations

Aquifer	NSW Great Artesian Basin Groundwater Sources Southern Recharge Groundwater Source
Type	Porous Rock Water Sources (Great Artesian Basin) Aquifer
Category	Highly Productive
Level 1 Minimal Impact Consideration	**Assessment**
Water Table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: (c) high priority groundwater dependent ecosystem; or (d) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.	**Within Level 1 – Highly Productive** There are no high priority groundwater dependent ecosystems listed in the NSW Great Artesian Basin Groundwater Sources Water Sharing Plan. There are no High Priority Culturally Significant Sites listed in the NSW Great Artesian Basin Groundwater Sources Water Sharing Plan in proximity to the NM. NCOPL mining would not result in drawdown of more than 2 m at any privately owned water supply work in the highly productive Pilliga Sandstone. **Level 2 – Less Productive** There are two bores (GW067626 [privately owned] and GW966836 [NCOPL owned]) within the Purlawaugh formation and the Garrawilla Volcanics that are predicted to experience a drawdown effect of >2m and, although being less productive groundwater sources, are conservatively assigned to the NSW Great Artesian Basin Groundwater Sources Water Sharing Plan. NCOPL would implement "make good" provisions to privately owned bores.
Water pressure A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work.	**Within Level 1 – Highly Productive** NCOPL mining would not result in cumulative drawdown of more than 40% of the pressure head at any privately owned water supply work in the Pilliga Sandstone aquifer. **Level 2 – Less Productive** There are two bores (GW067626 [privately owned] and GW966836 [NCOPL owned]) within the Purlawaugh formation and the Garrawilla Volcanics that are predicted to experience a drawdown effect of >2m and, although being less productive groundwater sources, are conservatively assigned to the NSW Great Artesian Basin Groundwater Sources Water Sharing Plan. NCOPL would implement "make good" provisions to privately owned bores.
Water quality Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.	**Within Level 1** There are no simulated risks of reduced beneficial uses of the highly productive Great Artesian Basin Groundwater as a result of the Modification (Section 5.4).

Table 22: Less Productive Porous Rock Aquifer – Minimal Impact Considerations

Aquifer	NSW Murray Darling Basin Porous Rock Groundwater Sources Gunnedah - Oxley Basin MDB Groundwater Source
Type	Porous Rock Aquifer (Permian)
Category	Less Productive

Level 1 Minimal Impact Consideration	Assessment
Water Table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.	**Within Level 1** There are no high priority groundwater dependent ecosystems listed in the Murray Darling Basin Porous Rock Groundwater Water Sharing Plan in proximity to the NM. There are no High Priority Culturally Significant Sites listed in the Murray Darling Basin Porous Rock Groundwater Water Sharing Plan. NCOPL mining would not result in drawdown of more than 2 m at any privately owned water supply work in the Permian system
Water pressure A cumulative pressure head decline of not more than a 2 m decline, at any water supply work.	**Within Level 1** NCOPL mining would not result in drawdown of more than 2 m at any privately owned water supply work in the Permian system
Water quality Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.	**Within Level 1** There is not expected to be a migration of groundwater away from the NM in the Permian system either during mining or following completion of mining activities. On this basis, NCOPL would not lower the beneficial use category of the groundwater within the Permian system.

6 CONCLUSIONS

This Groundwater Assessment for the NM Modification has been carried out with reference to earlier work done by HydroSimulations, whereby an existing NM groundwater model was recalibrated.

The Modification consists of a shortening of the mining period by 5½ years (earlier date of completion) and changes to the number and geometry of longwall panels, with a slight western extension to the mine footprint.

A description of the groundwater model has been provided by HydroSimulations (2015). Since the development of that model, additional observation data (groundwater levels) and an improved methodology for estimating the mining-associated height of fracturing have been incorporated into the most recent (Version 4) model that underpins most of the work performed for this groundwater assessment.

The incremental impacts of the Modification have been considered as changes between the Approved mine plan and the Modification mine plan.

The key findings of this assessment are:

- The Version 4 groundwater model – based on its predecessor Version 3 model and developed as part of this Modification – has been validated against observation data. Simulated Version 4 model outputs corresponding to observed data show some improved correspondence relative to the Version 3 model, and validate the use of the model for future work.

- Assessment of likely fractured zone heights confirms that connective fracturing is not likely to reach land surface or the surficial zone of tensile cracking where the Hoskissons Coal Seam is mined according to the Modification mine plan.

- Over the period of mining for both the Approved and Modification mine plans, significant groundwater level declines would occur, for all layers down to the target Hoskissons Coal Seam, within a few kilometres of the mine site.

- Groundwater level decline would occur, as a result of mining, at greater distances from the mine site for deeper layers (represented, for this study, by the Napperby Formation and the Hoskissons Coal Seam).

- The area most impacted by water level decline over the period of mining is the north eastern quadrant of the mine site.

- Overall, drawdowns would be lower for the Modified mine plan than for the Approved plan.

- Water levels at the end of the respective mine periods would be similar.

- Results of the 100 year scenario model run suggest that groundwater levels for all layers would recover to an equilibrium level about 30 years after mining for the Approved mine plan and about 25 years after mining for the Modified plan.

- For the shallower layers, the equilibrium water level is likely to be between two and seven metres below pre-mining level. For the deeper layers, it is likely to be between five and seven metres higher than pre-mining level.

- The Modification could not be considered to have a significant impact on the recovery of groundwater levels.
- For shallower layers, a long term impact of mining is likely to be some reduction in the level of upward flow or a reversal of flow direction. For the deeper layers, mining-induced increased pressure is likely to increase the extent of upward flow.
- Changes in direction of lateral groundwater flow would be layer-dependant. For the shallow layers (regolith/alluvium and Pilliga Sandstone), changes would be restricted to the close environs of the mine site and would be spatially variable. Lateral flow direction would be unaffected for the Napperby Formation. For the Hoskissons Coal Seam (the deepest layer represented in the groundwater model), lateral flow direction in areas distant from the mine site would be largely unaffected. Areas close to the mine site would exhibit changes to flow direction for this layer.
- The difference between predicted baseflow to the Namoi River for the Modification mine plan and the Approved mine plan is negligible.
- Predicted mine inflows for the two mine plans are similar although higher for the Modified mine plan, consistent with its shorter duration. For this mine plan, the predicted peak inflow of about 1340 ML/a (3.77 ML/day) occurs during 2023.
- Based on actual mine dewatering to date, the model is likely to be overestimating mine inflows, and consequent environmental impacts.
- NCOPL holds sufficient licences to cover the predicted impacts for the Approved and Modification mine plans, with the exception of the NSW Murray Darling Basin Porous Rock Groundwater Sources Gunnedah - Oxley Basin MDB Groundwater Source (818 ML/annum held). NCOPL would monitor underground mine inflows versus model predictions and obtain additional licence(s) volumes of this water source to account for actual inflows, as necessary.
- Potential impacts on the highly productive Upper and Lower Namoi Groundwater Sources Water Sharing Plan and NSW Great Artesian Basin Groundwater Sources Water Sharing Plan would be within the Level 1 trigger of the AIP.
- Drawdown of one privately owned bore in less productive groundwater sources is predicted. This bore would be managed according to the NM Water Management Plan.

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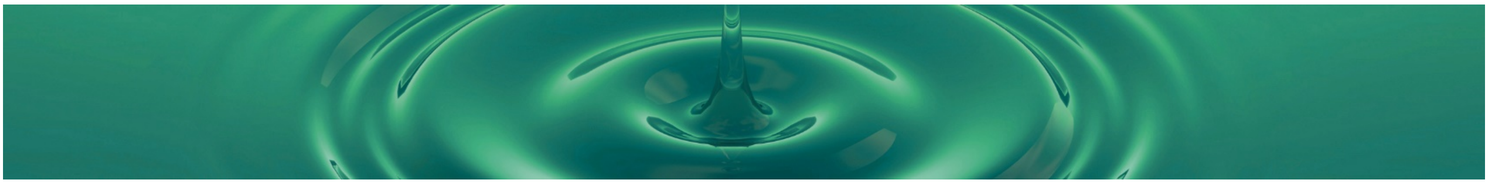


FIGURES

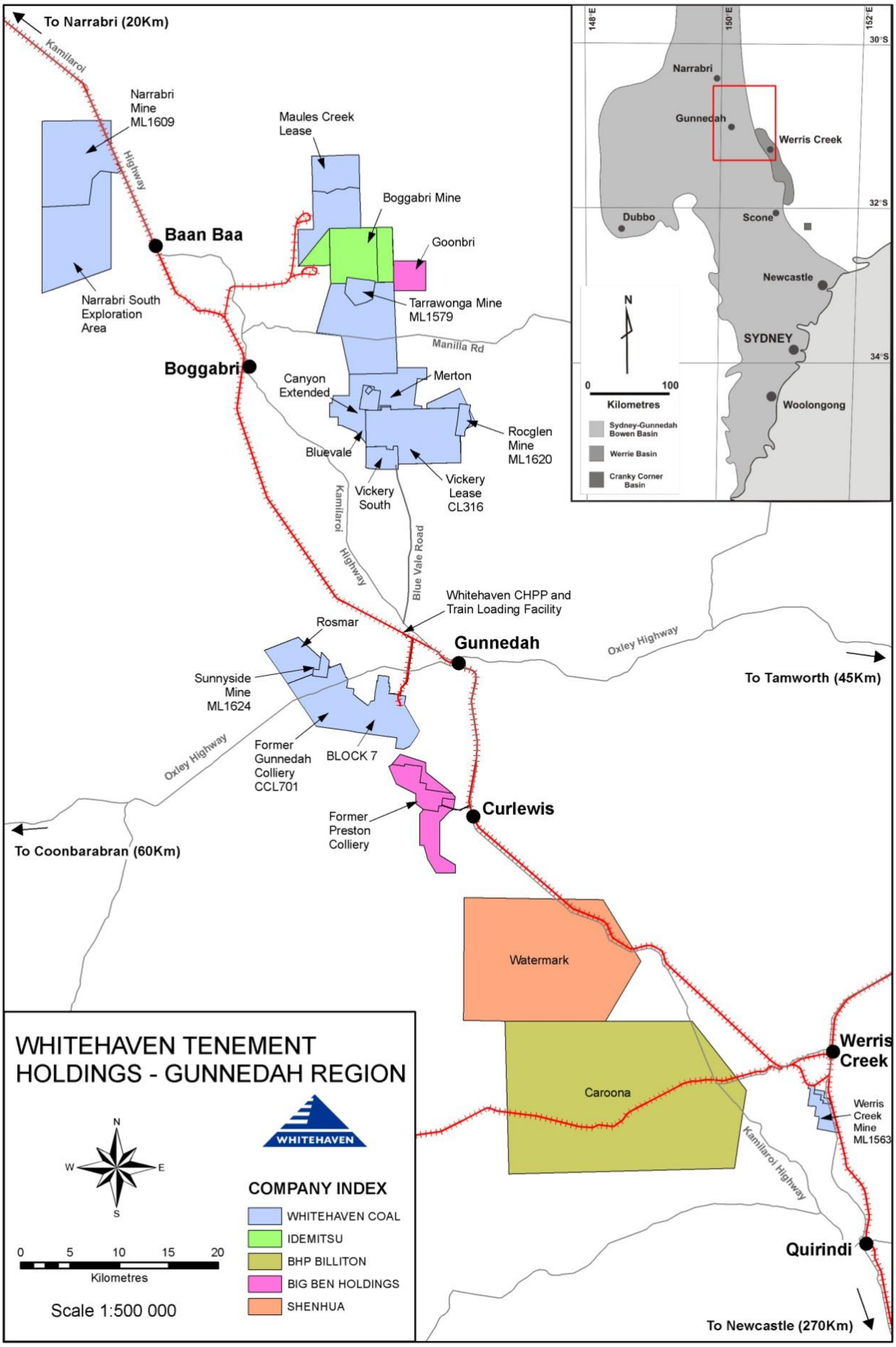
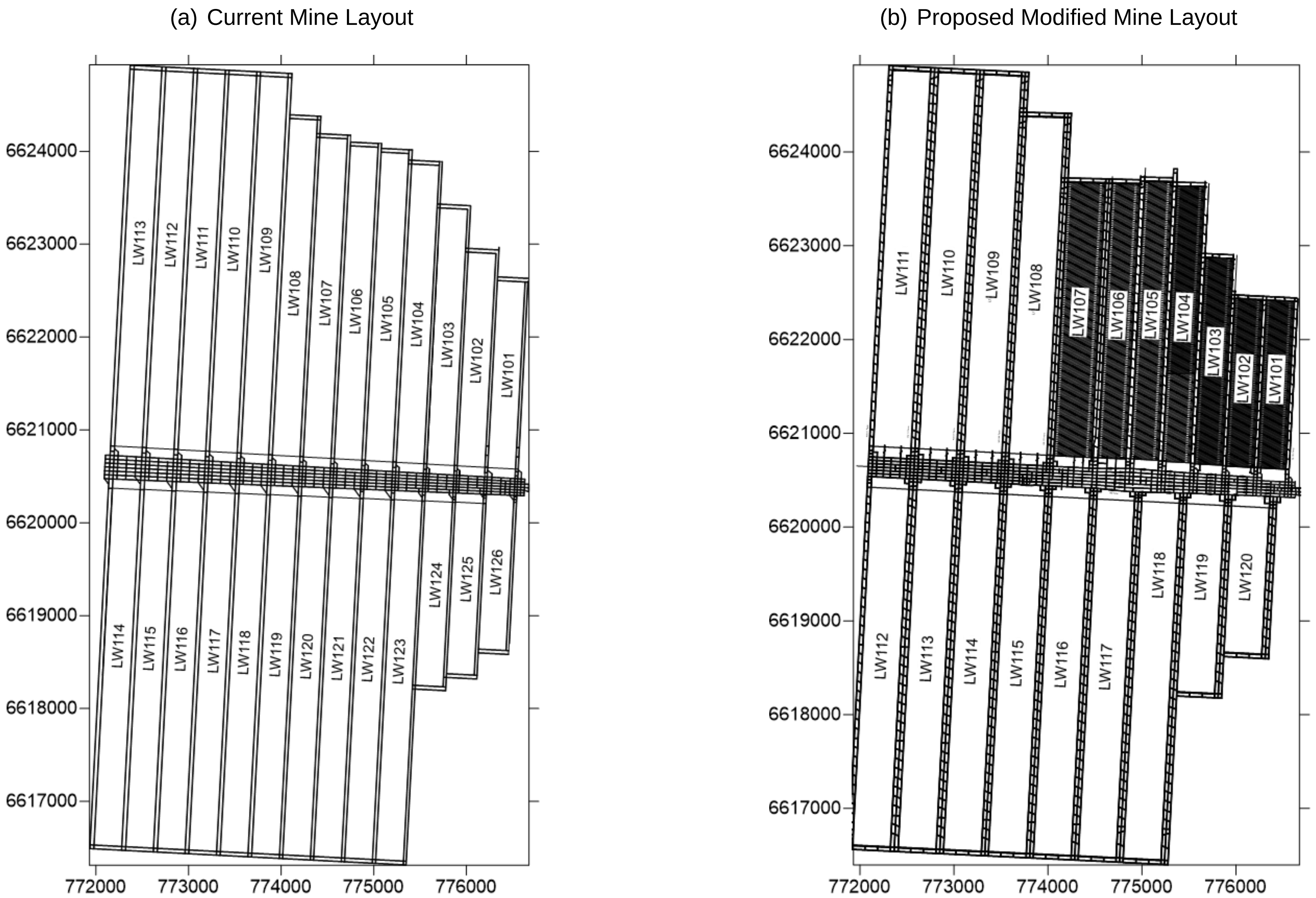
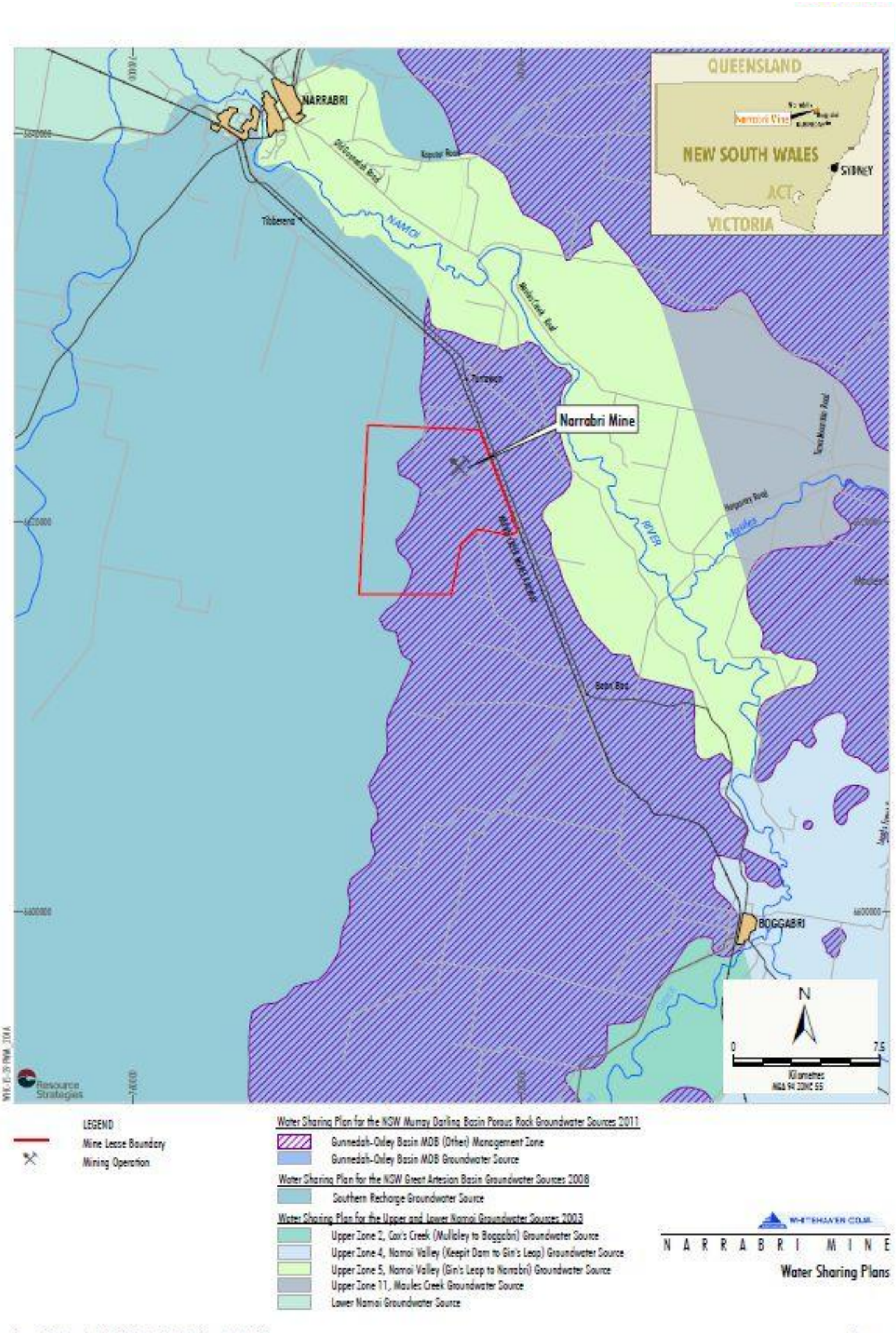


Figure 1. Regional Location


(a) Current Mine Layout

(b) Proposed Modified Mine Layout

Figure 2. Approved and Proposed Mine Layouts



Source: Geoscience Australia, 2006 and NSW Trade & Investment, 2013

Figure 3. Water Sharing Plan Areas and Narrabri Mine

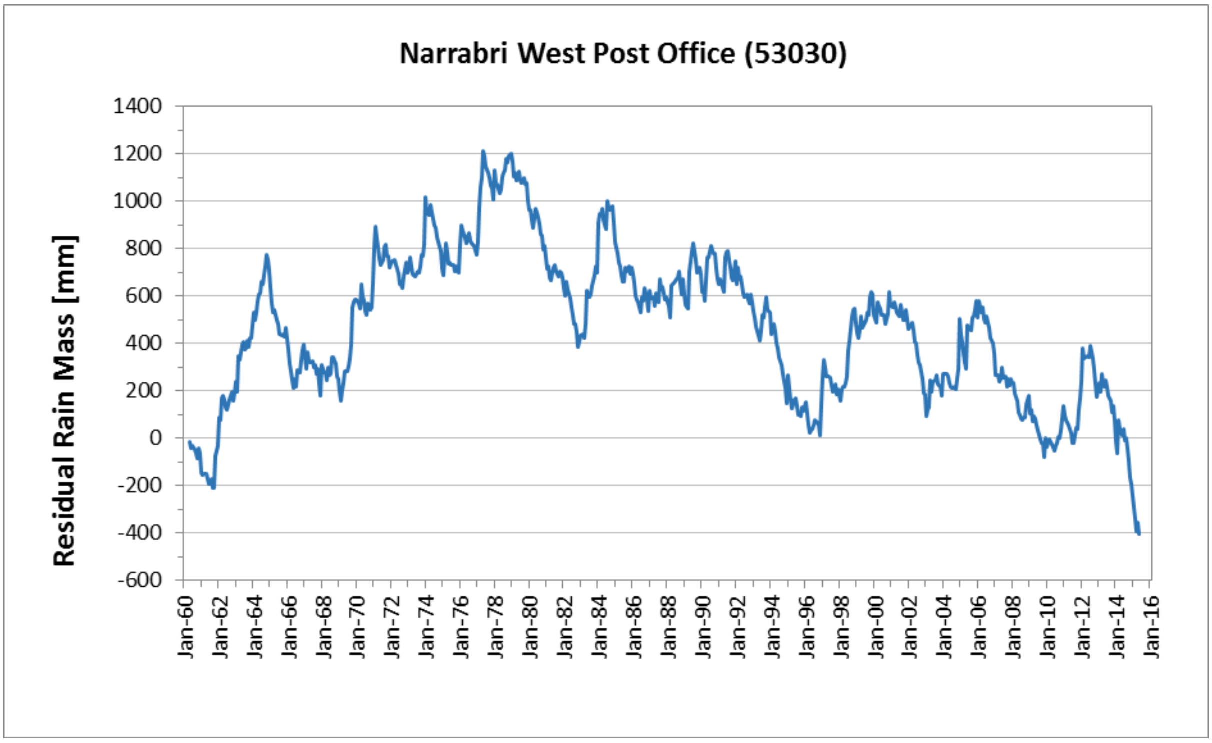


Figure 4. Rainfall Residual Mass Curve for Narrabri West Post Office

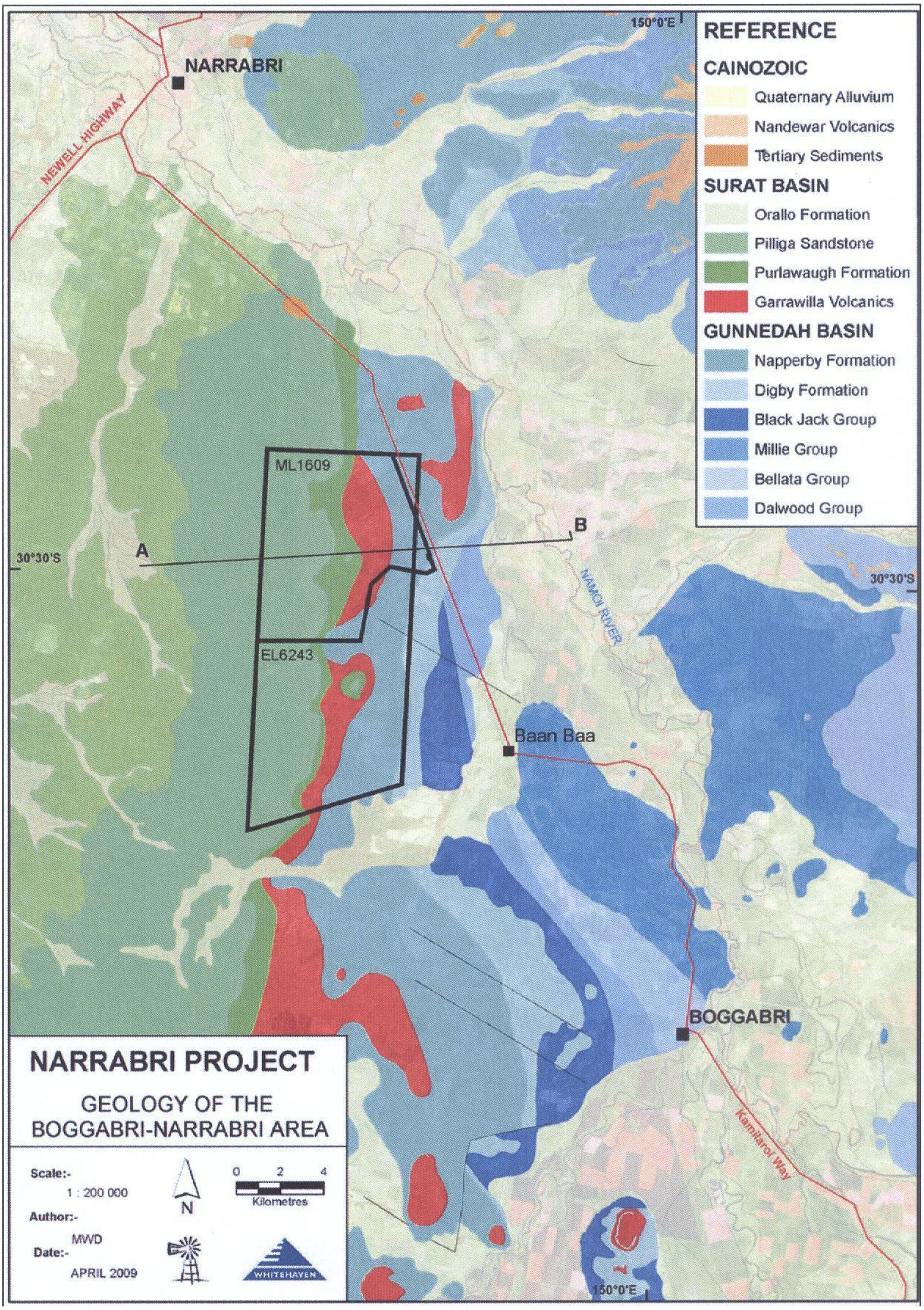


Figure 5. Geological Map

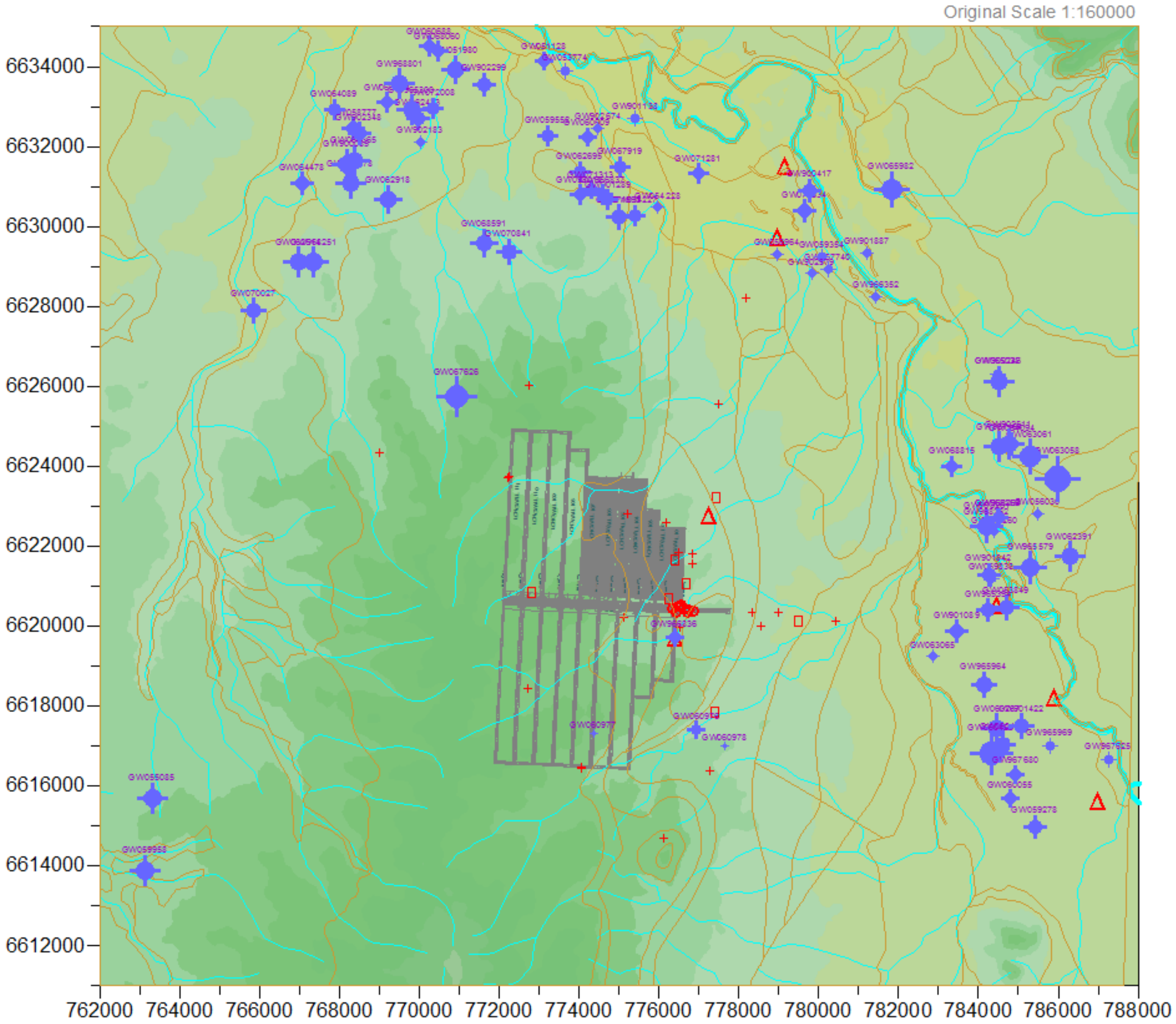


Figure 6. Registered Bores within 10 km of Narrabri Mine

Notes

1. Registered bores prior to 1980 are not shown
2. Symbol size is proportional to bore depth
3. Red symbols represent the Narrabri Mine groundwater monitoring network

.

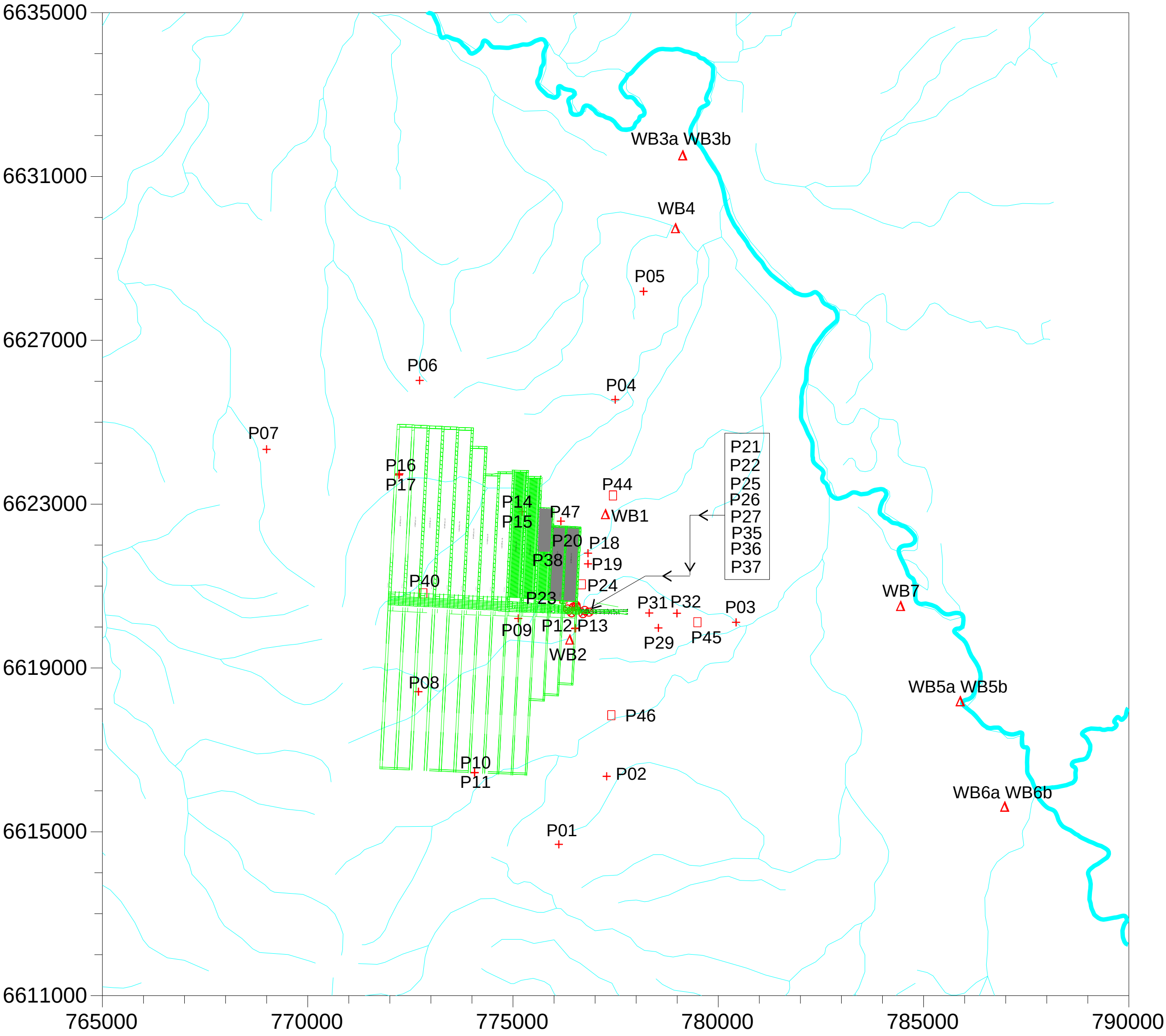


Figure 7. Location of Monitoring Bores

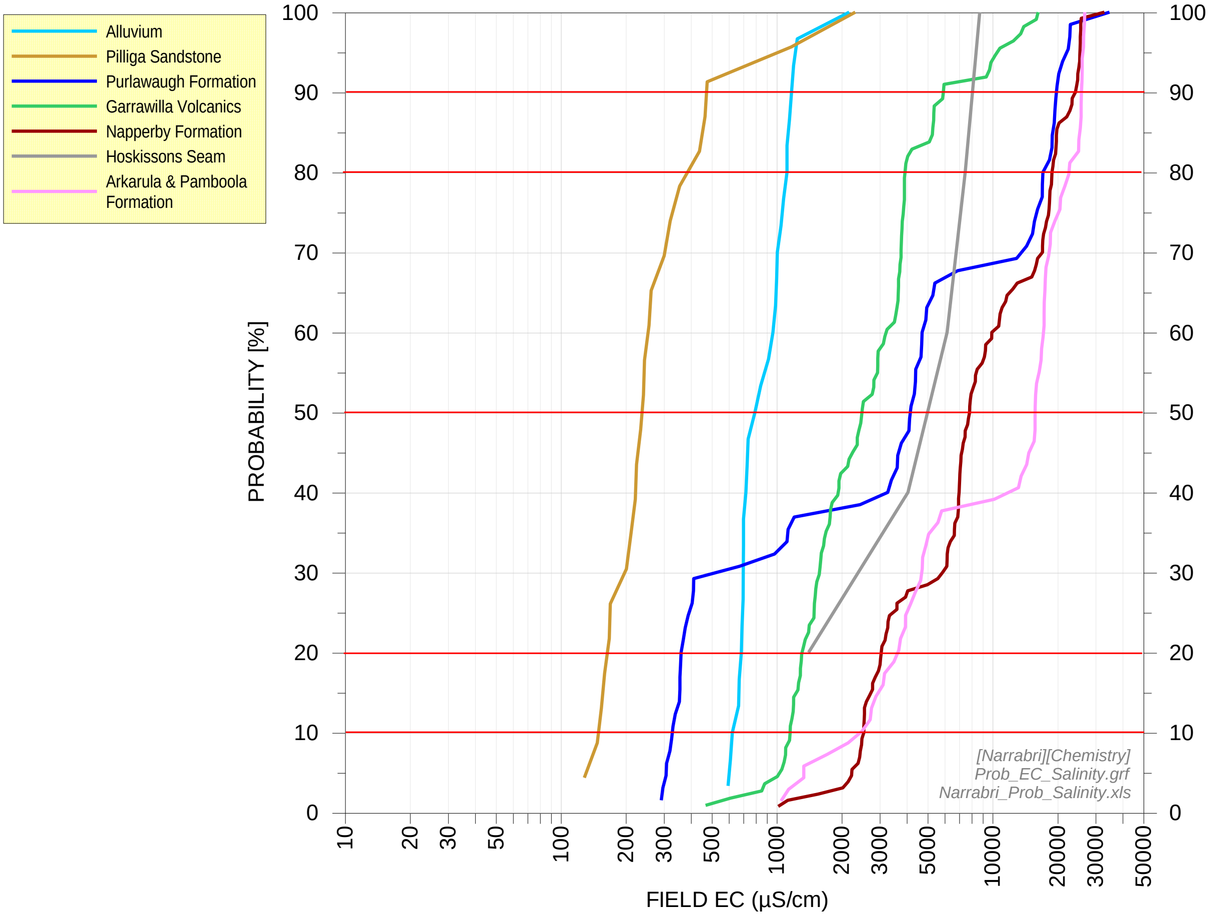


Figure 8. Cumulative Probability Distribution of Groundwater Salinities

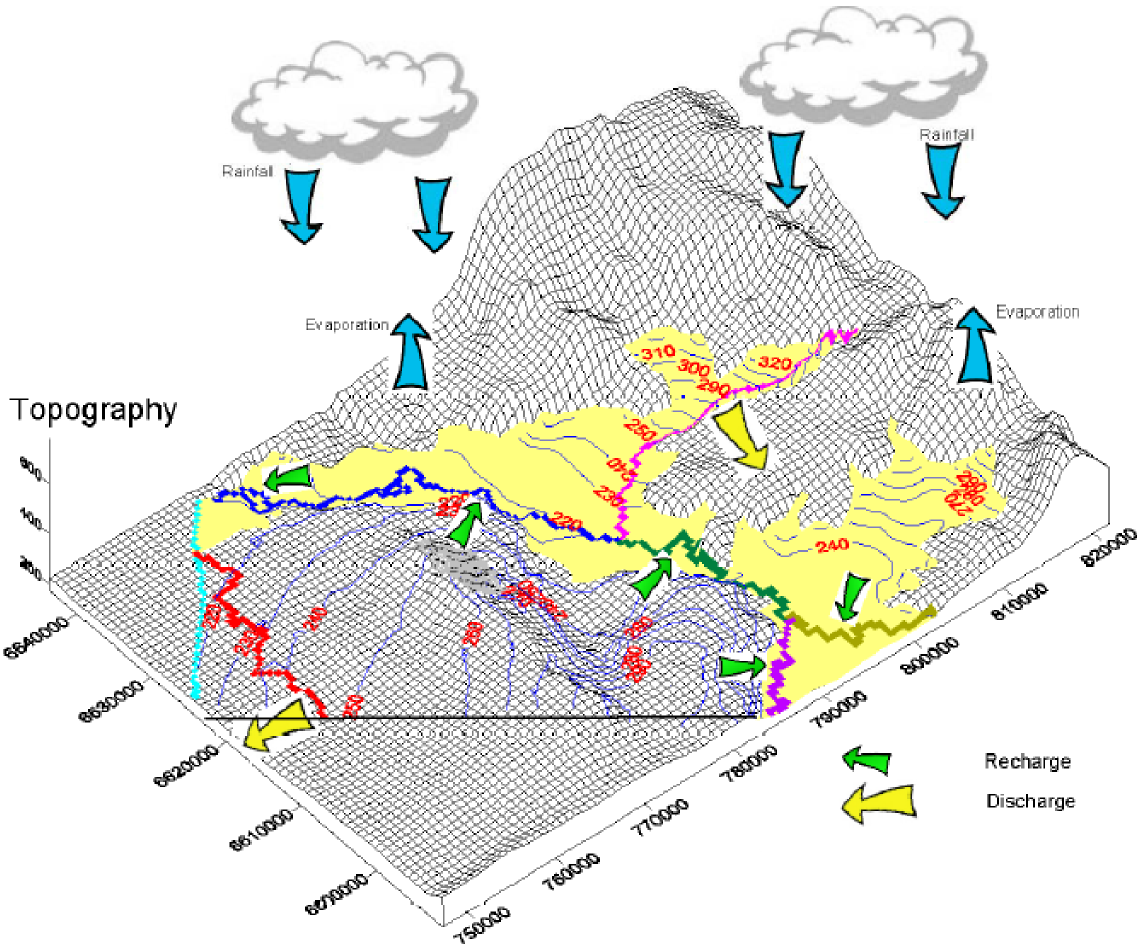


Figure 9. Conceptual Model (Aquaterra, 2009)

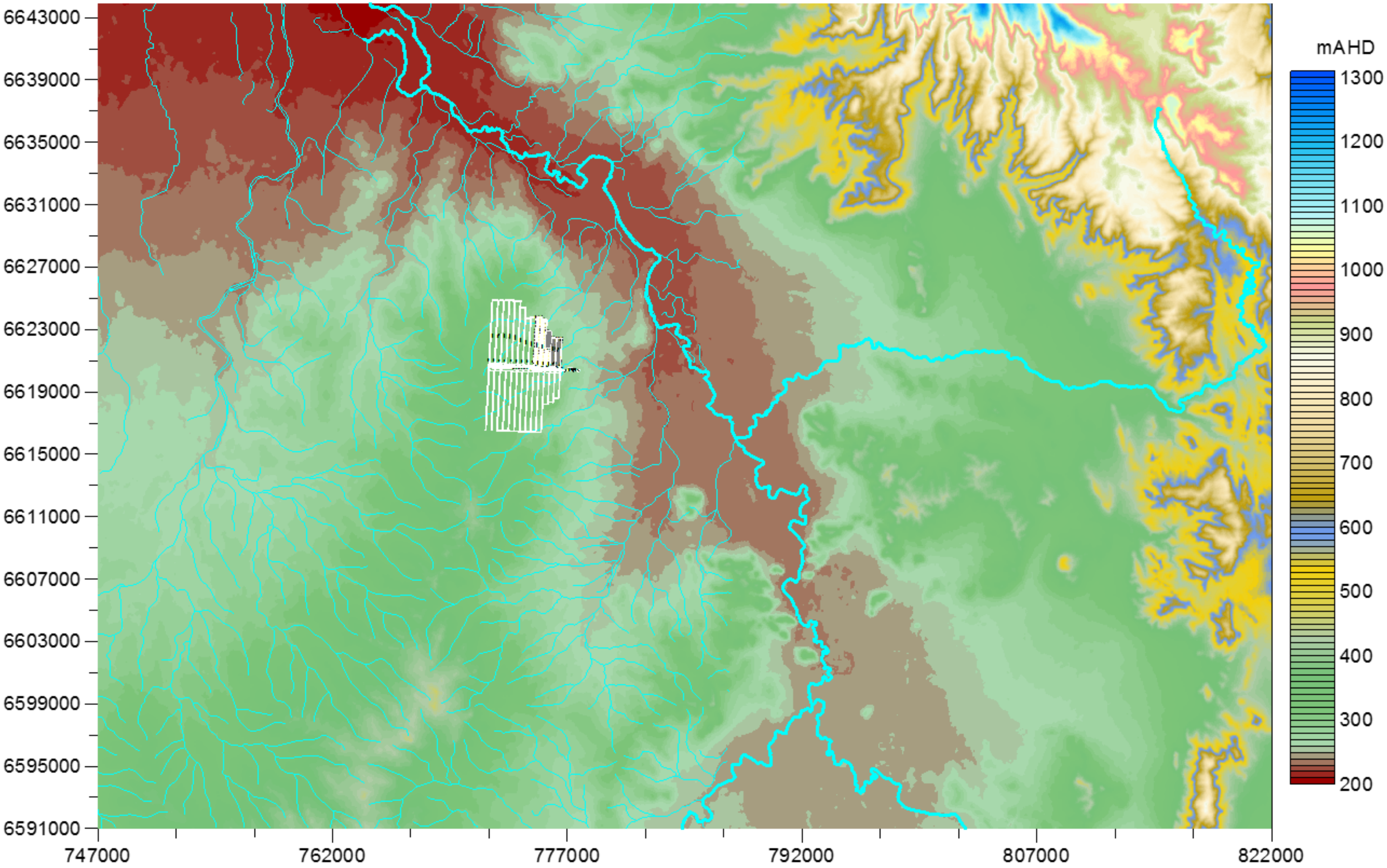


Figure 10. General Topography and Model Domain

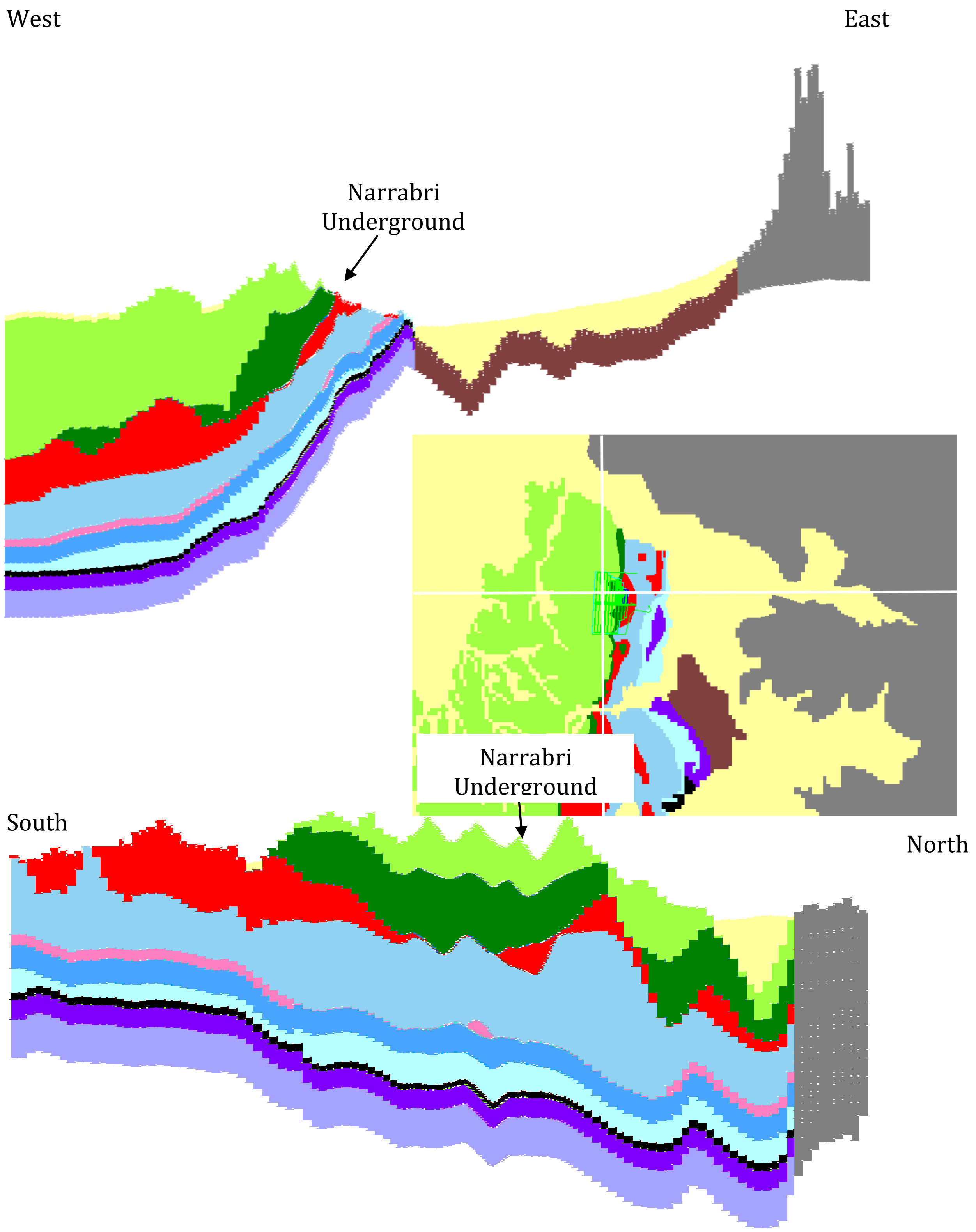


Figure 11. Representative Model Cross-sections through Narrabri Underground Mine at Easting 772650 and Northing 6622000

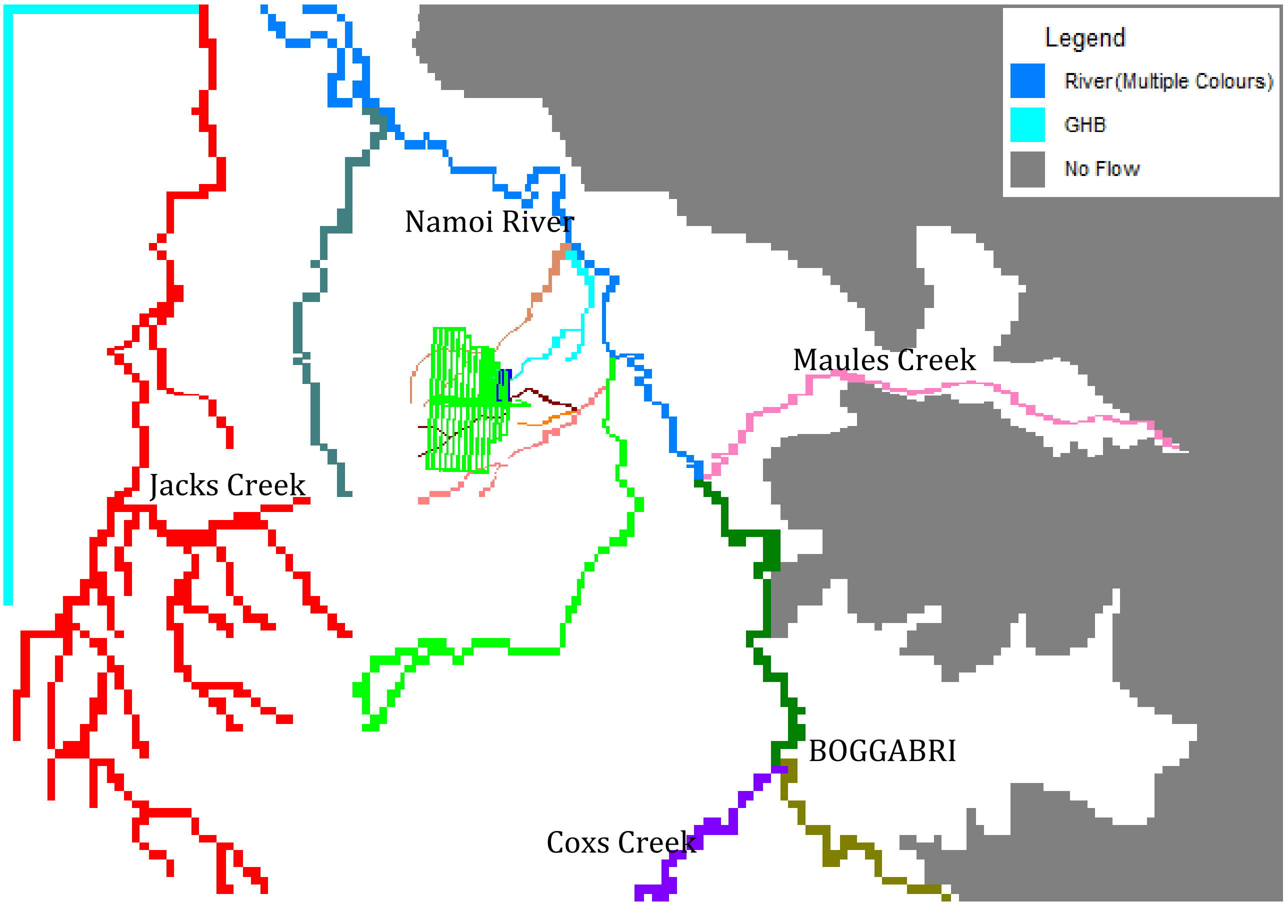
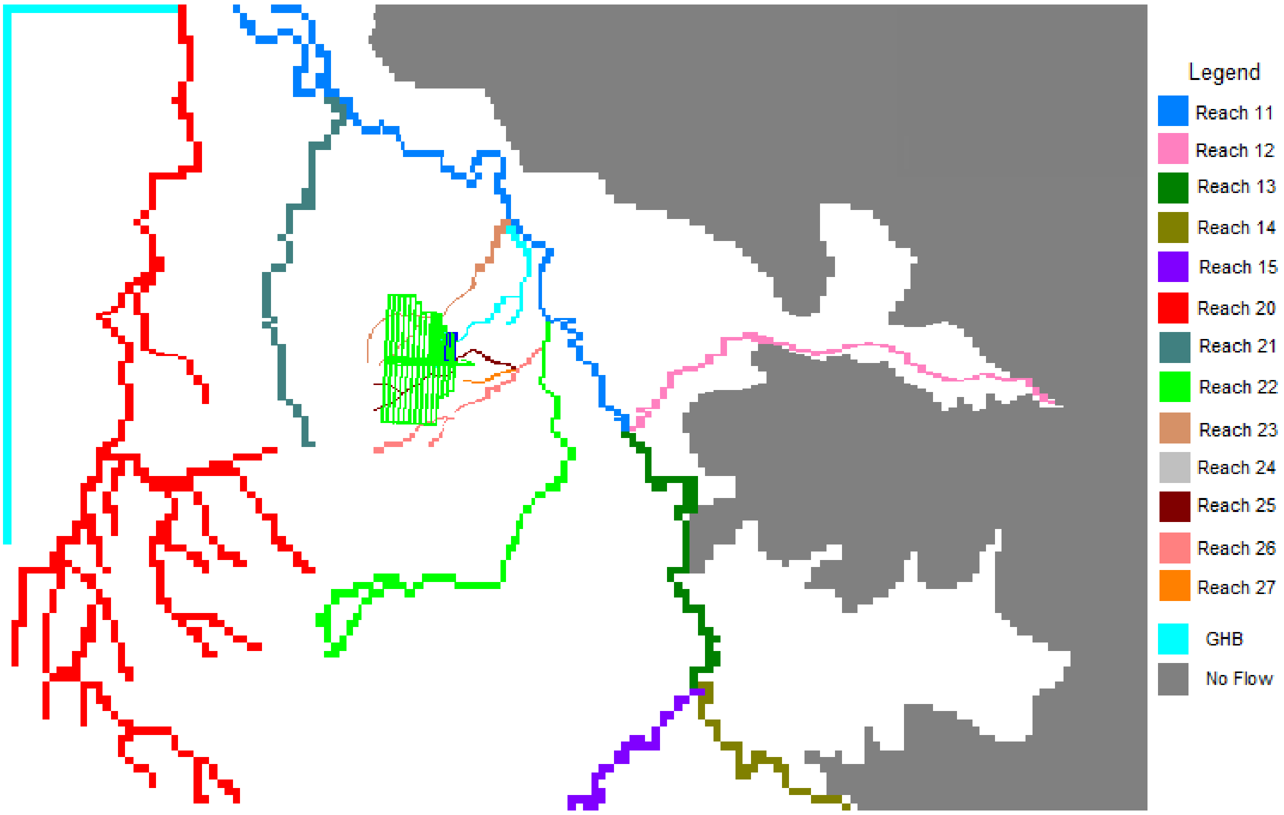


Figure 12. Groundwater Model Boundary Conditions



Reach	Location
11	Namoi River, downstream of Maules Creek between Baan Baa and Narrabri
12	Maules Creek – tributary flowing into Namoi River from the east
13	Namoi River, upstream of Maules Creek between Baan Baa and Boggabri
14	Namoi River, upstream of Boggabri
15	Coxs Creek flowing into Namoi River from the southwest at Boggabri
20	Jacks Creek west of Longwall Project area
21	Namoi River Tributary (west of Narrabri underground mine)
22	Namoi River Tributary (east and south of Narrabri underground mine)
23	Pine Creek
24	Pine Creek Tributary 1
25	Kurrajong Creek Tributary 1
26	Kurrajong Creek
27	Kurrajong Creek Tributary 2

Figure 13. Stream Reach Definitions

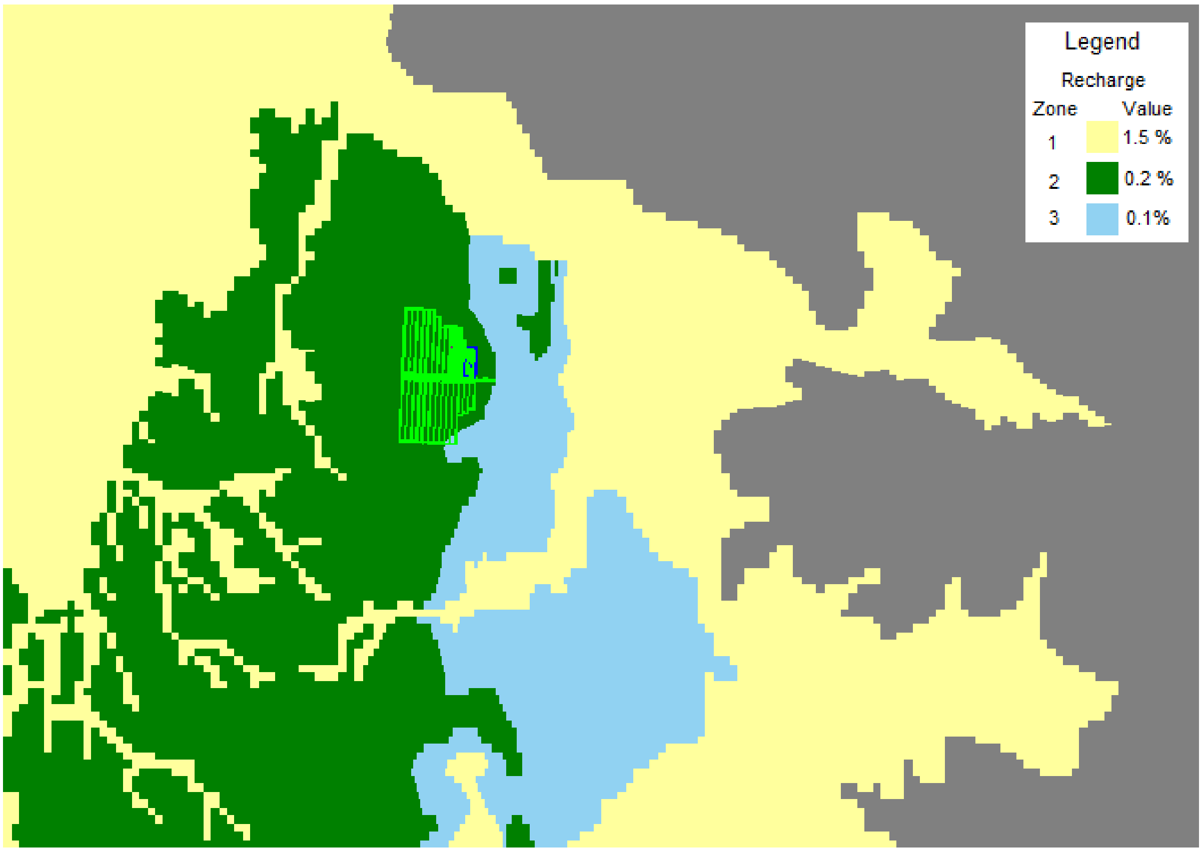
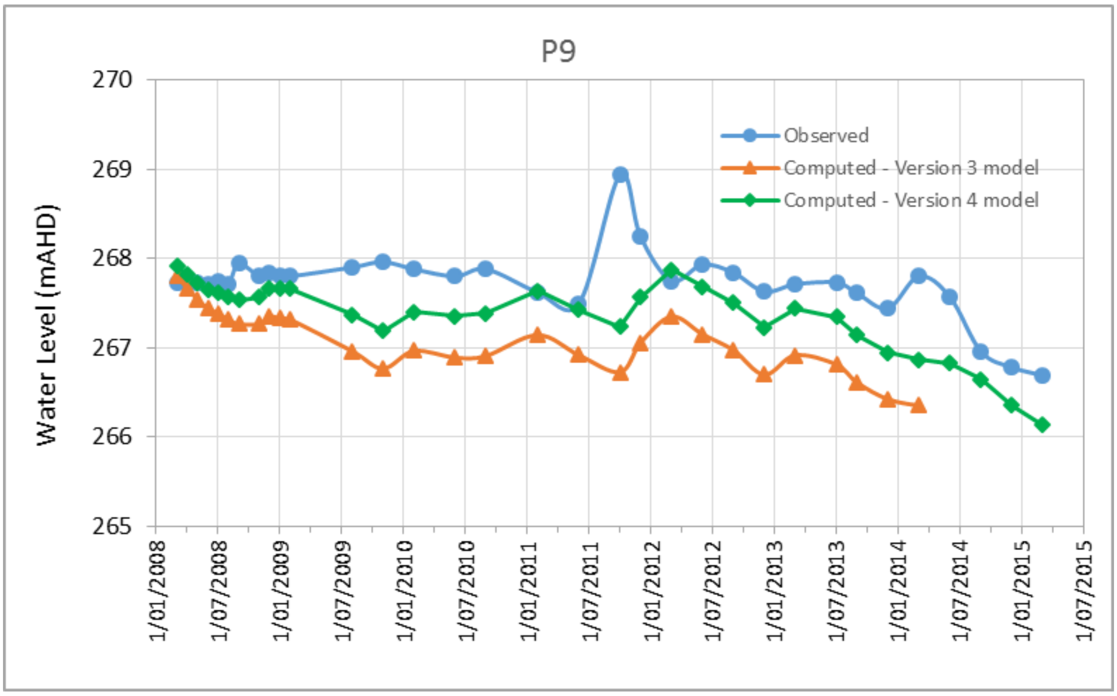


Figure 14. Rainfall Recharge Distribution as a Percentage of Rainfall

(a) Purlawaugh Formation, Group 1, Standpipe



(b) Alluvium, Group 2, Production Bore (adjacent to Namoi River)

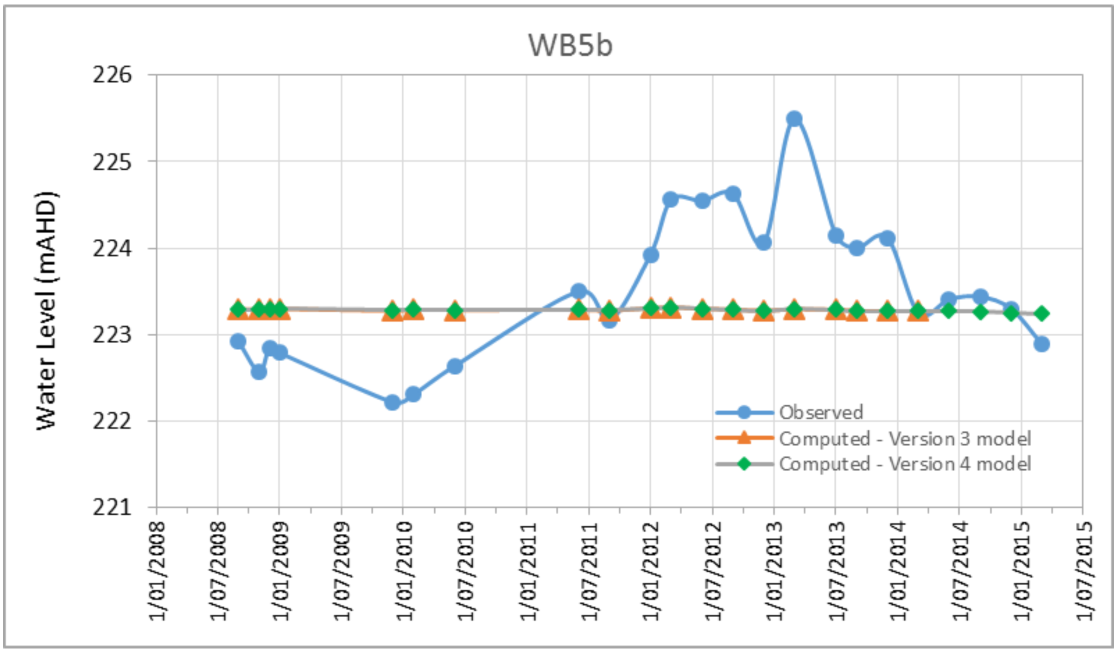
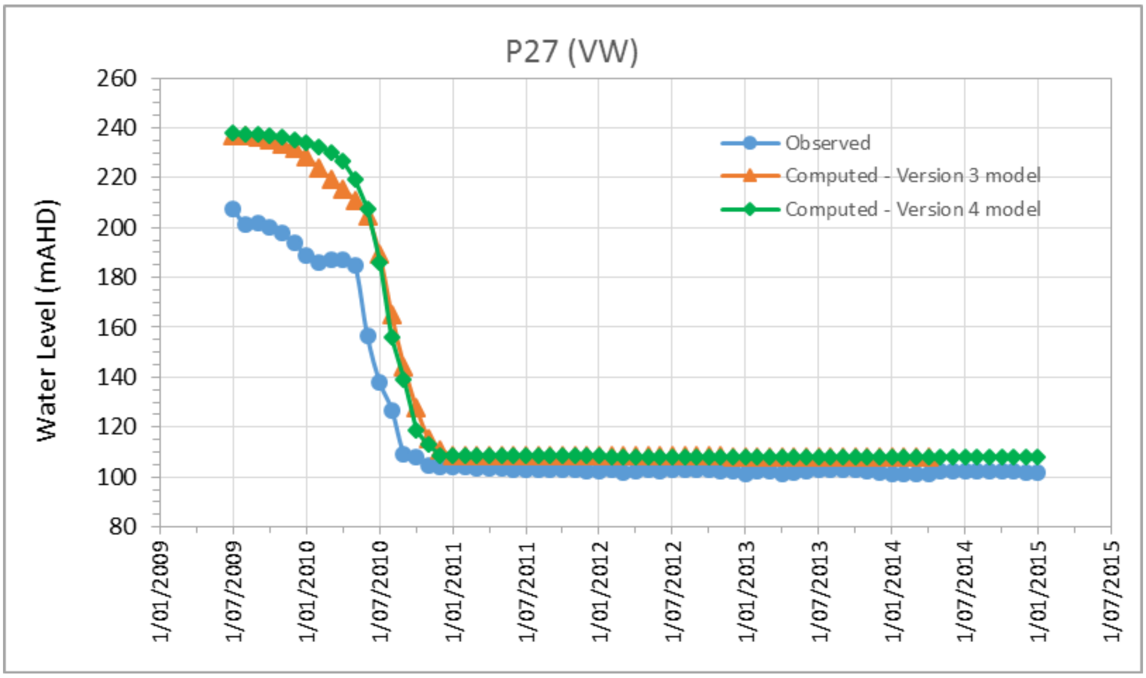


Figure 15. Representative Simulated and Observed Hydrographs:
(a) Purlawaugh Formation, Group 1, Standpipe;
(b) Alluvium, Group 2, Production Bore (adjacent to Namoi River)

(a) Hoskissons Seam, Group 3, Vibrating Wire



(b) Arkarula Formation, Group 4, Multi-Level Vibrating Wire

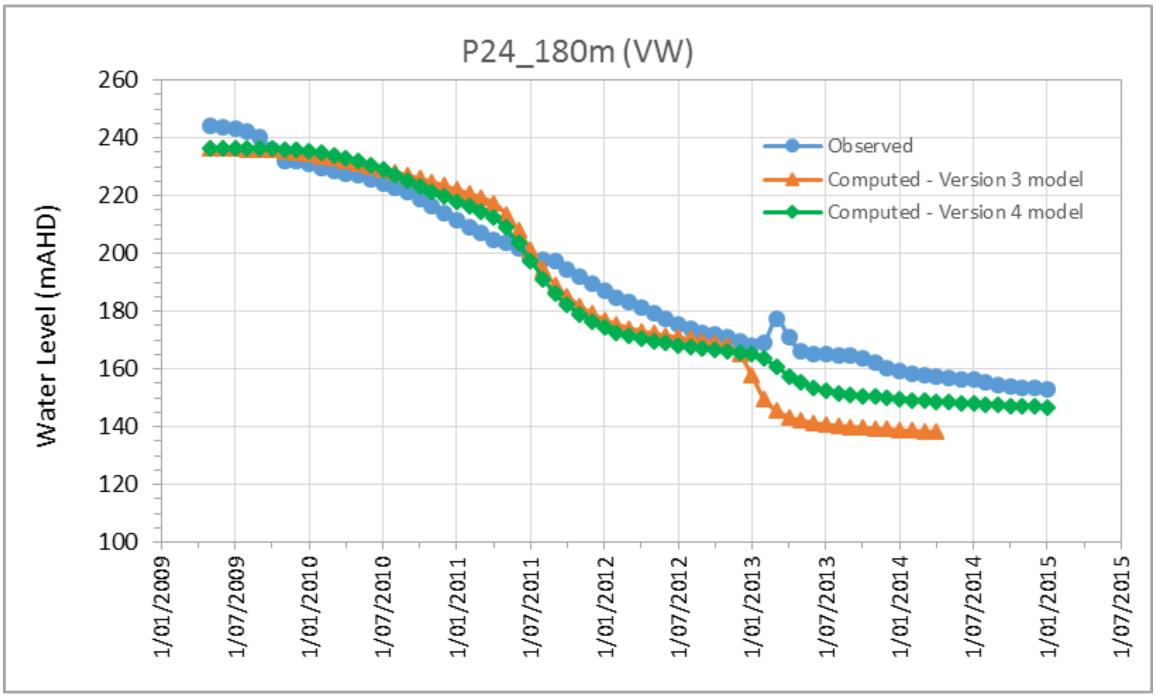


Figure 16. Representative Simulated and Observed Hydrographs:
(a) Hoskissons Seam, Group 3, Vibrating Wire
(b) Arkarula Formation, Group 4, Multi-Level Vibrating Wire

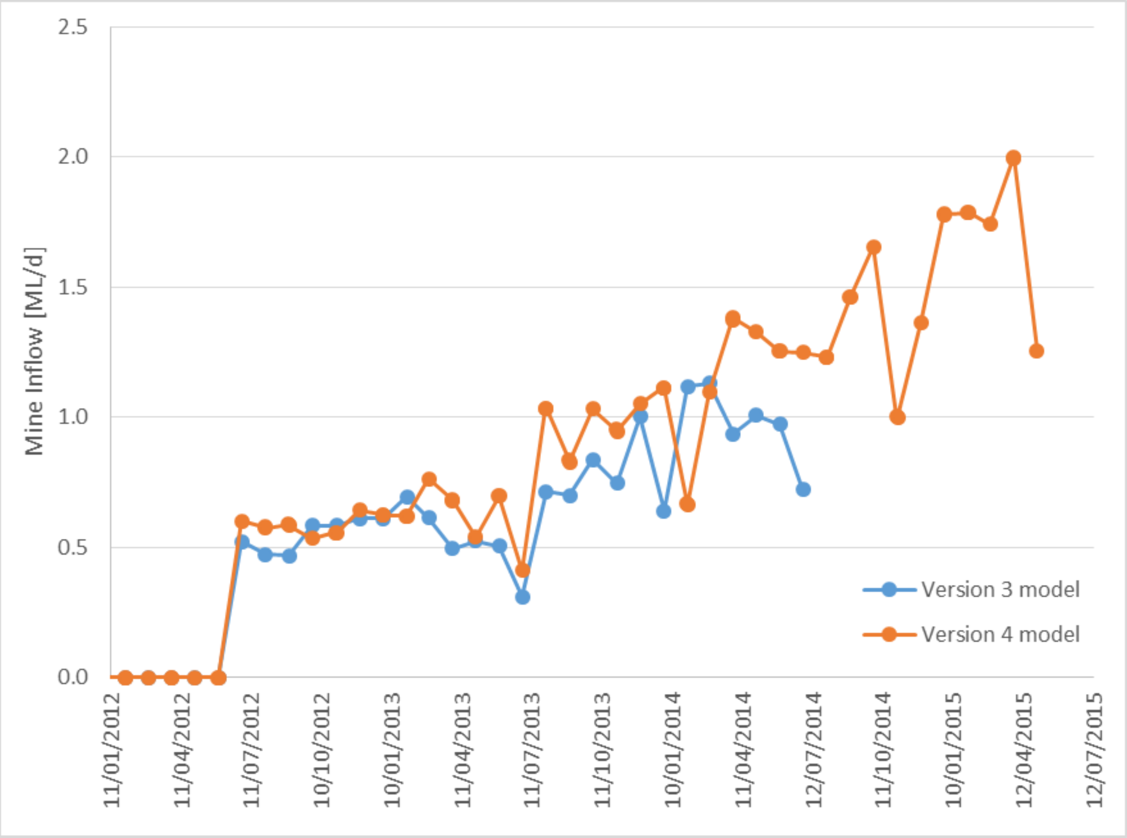


Figure 17. **Simulated Mine Inflow Rates for the Version 3 and Version 4 Models**

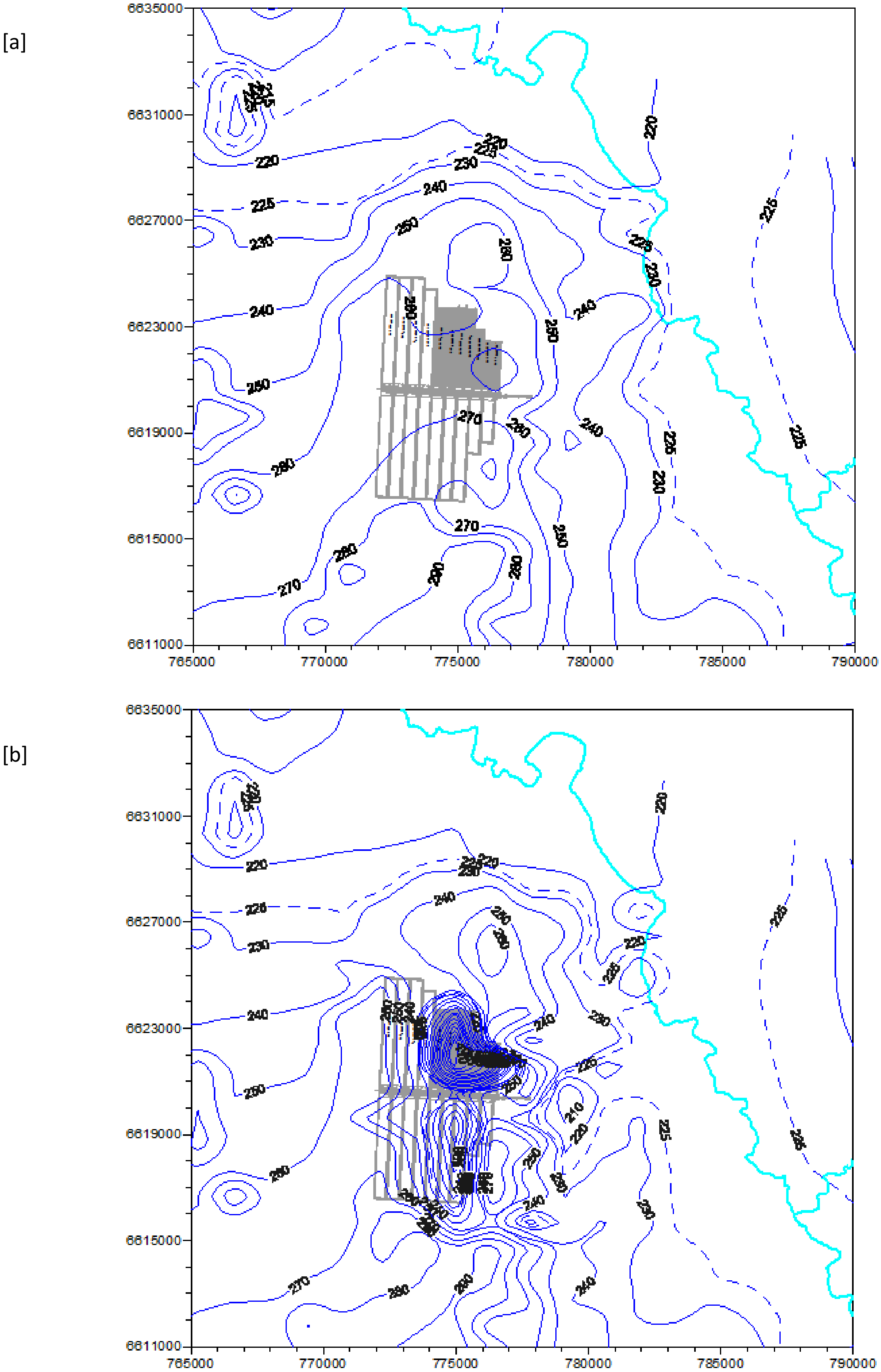


Figure 18. Regolith/Alluvium (Layer 1): Groundwater Level (mAHD) at:
[a] Start of Mining (June 2012); and
[b] End of Modification Mining (April 2031)

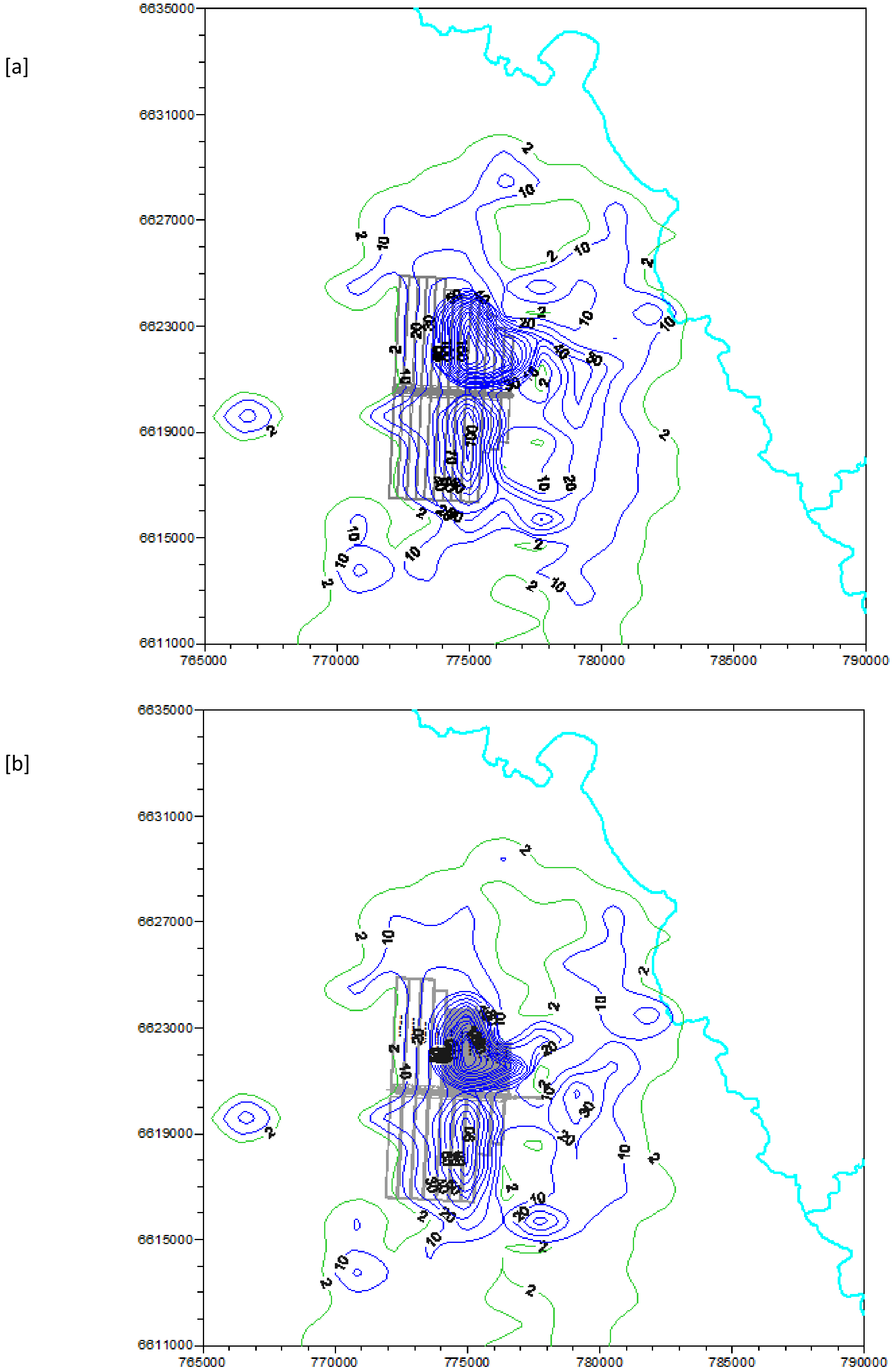


Figure 19. Regolith/Alluvium (Layer 1): Groundwater Drawdown (m) from Start of Mining (June 2012) to:
[a] End of Approved Mining (December 2037); and
[b] End of Modification Mining (April 2031)

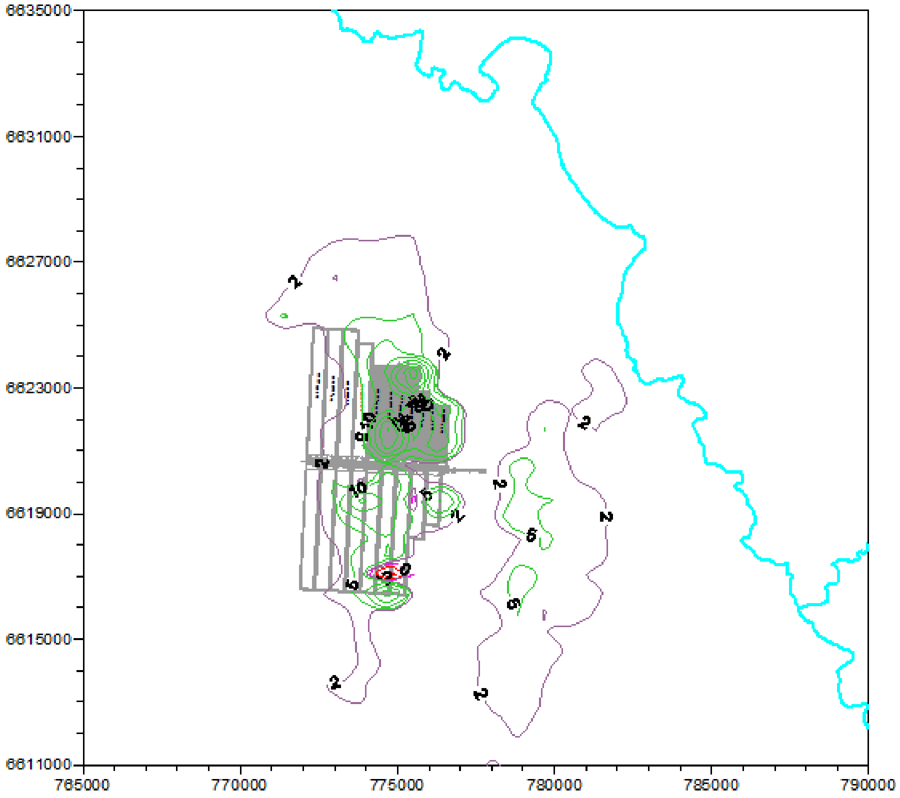


Figure 20. **Regolith/Alluvium (Layer 1): Incremental Groundwater Level Difference (m) between Modification and Approved Mine Plans at Respective Ends of Mining**

[Difference is defined as Modification - Approved]

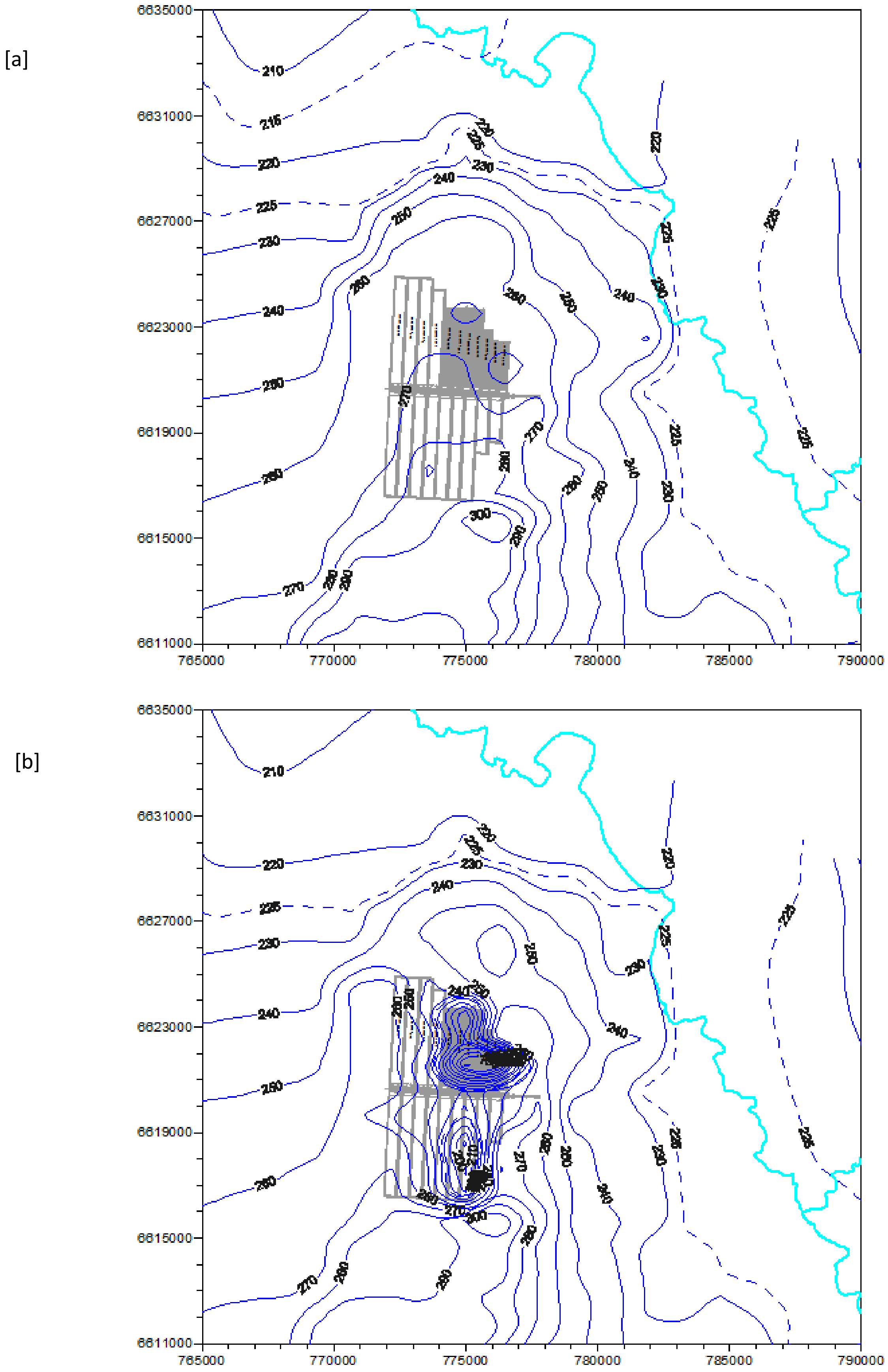


Figure 21. Pilliga Sandstone (Layer 2): Groundwater Level (mAHD) at:
[a] Start of Mining (June 2012); and
[b] End of Modification Mining (April 2031)

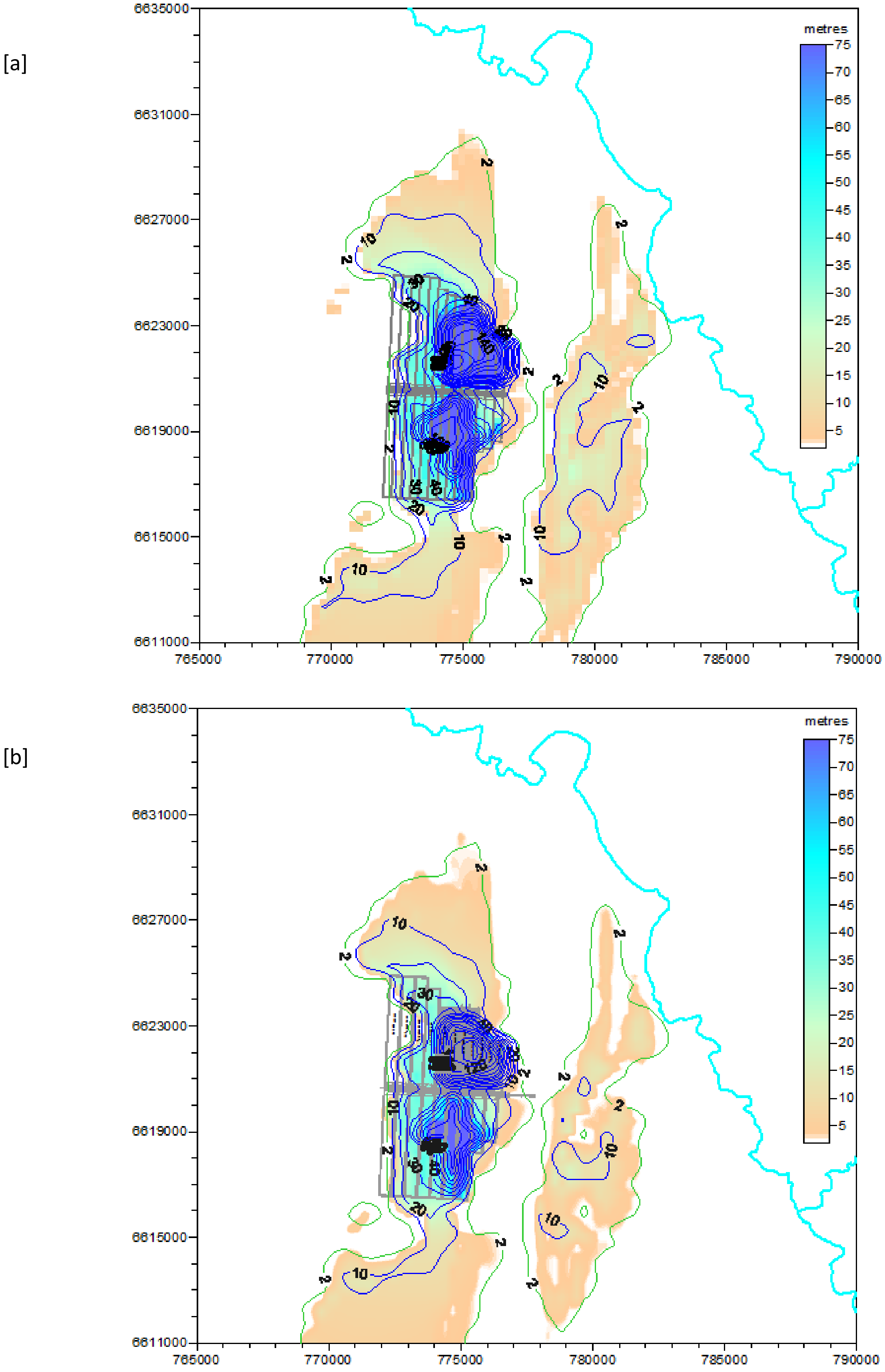


Figure 22. Pilliga Sandstone (Layer 2): Groundwater Drawdown (m) from Start of Mining (June 2012) to:
[a] End of Approved Mining (December 2037); and
[b] End of Modification Mining (April 2031)

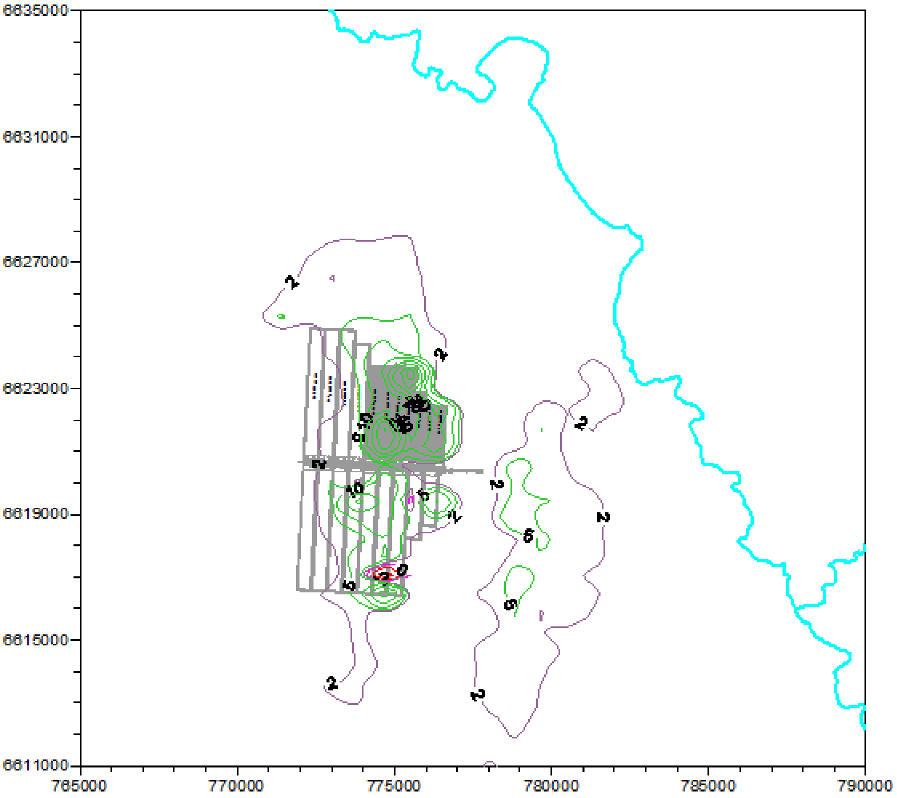


Figure 23. **Pilliga Sandstone (Layer 2): Incremental Groundwater Level Difference (m) between Modification and Approved Mine Plans at Respective Ends of Mining**

[Difference is defined as Modification - Approved]

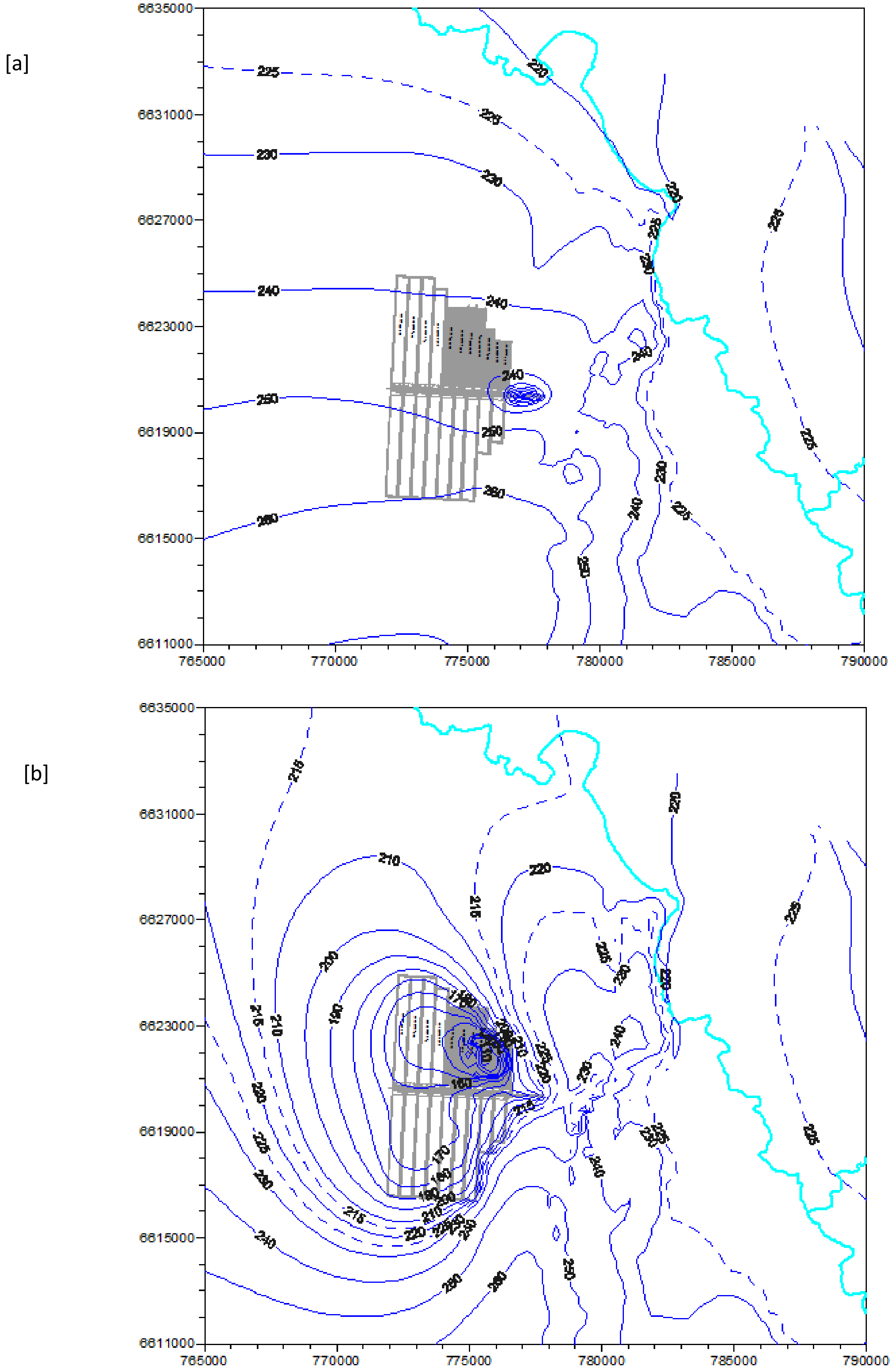


Figure 24. Napperby Formation (Layer 5): Groundwater Level (mAHD) at:
[a] Start of Mining (June 2012); and
[b] End of Modification Mining (April 2031)

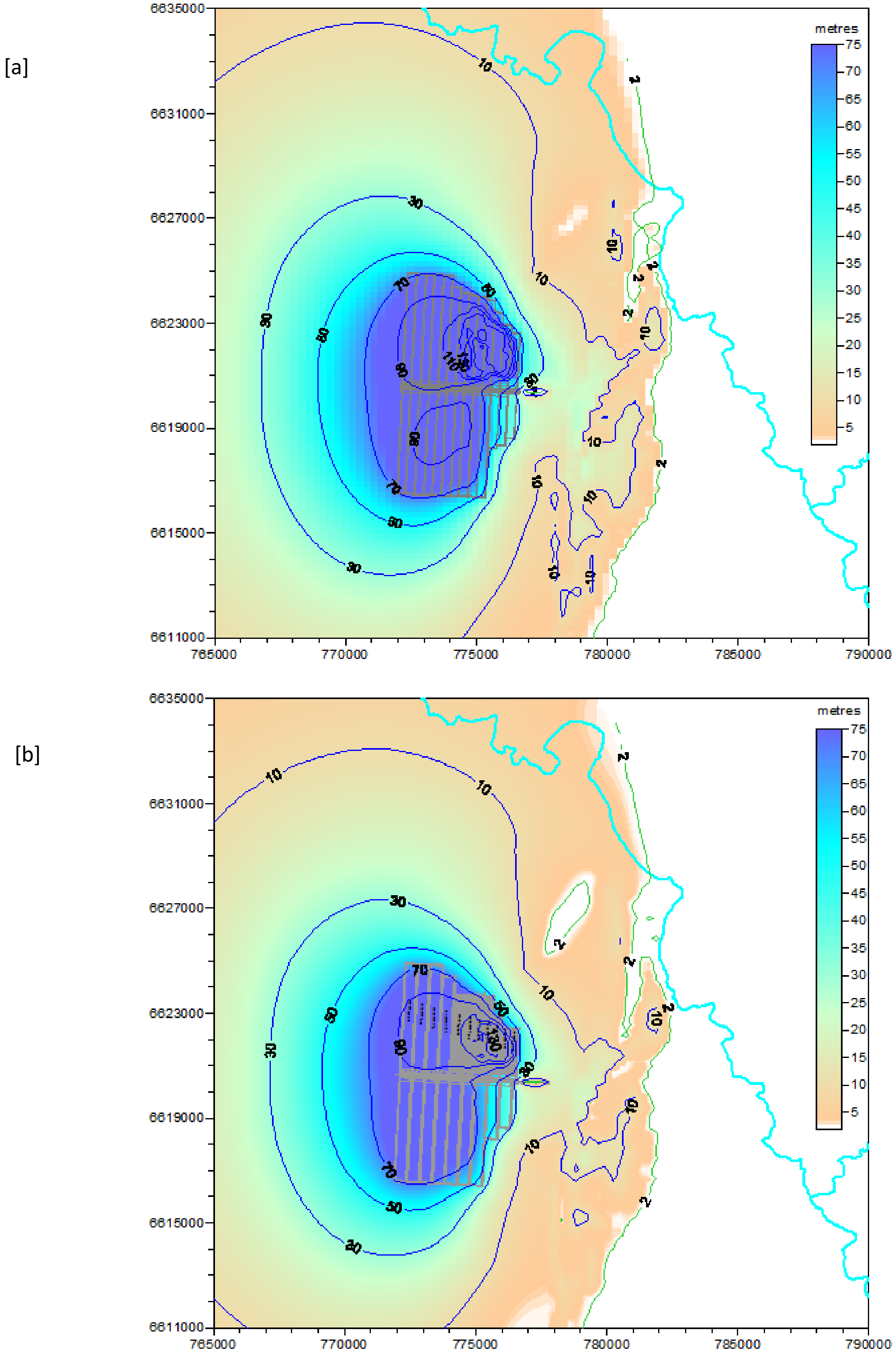


Figure 25. Napperby Formation (Layer 5): Groundwater Drawdown (m) from Start of Mining (June 2012) to:

[a] End of Approved Mining (December 2037); and

[b] End of Modification Mining (April 2031)

[a]

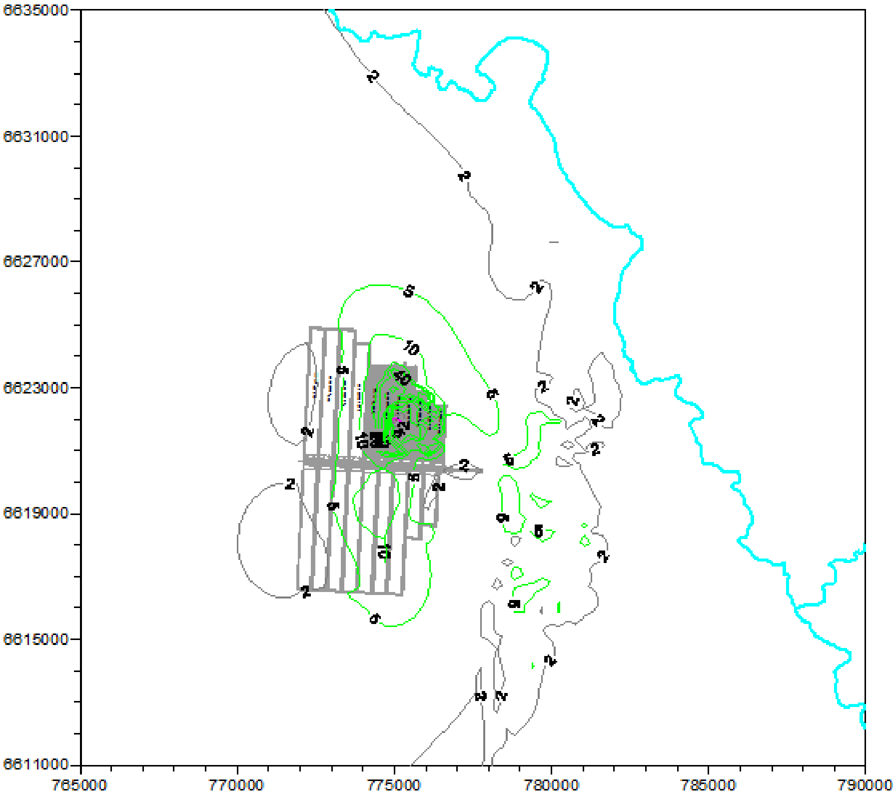


Figure 26. **Napperby Formation (Layer 5): Incremental Groundwater Level Difference (m) between Modification and Approved Mine Plans at Respective Ends of Mining**
[Difference is defined as Modification - Approved]

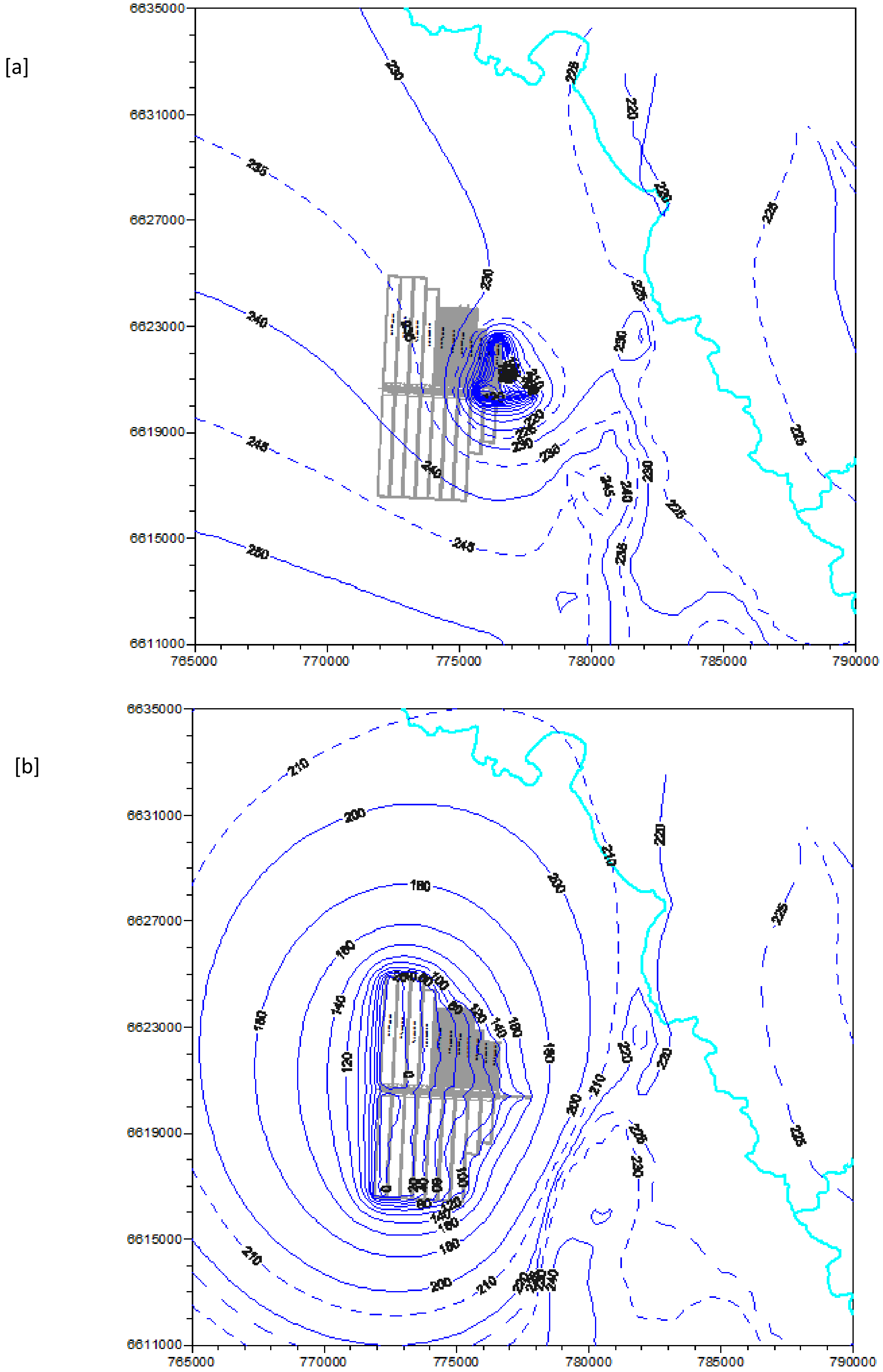


Figure 27. Hoskissons Coal Seam (Layer 9): Groundwater Level (mAHD) at:
[a] Start of Mining (June 2012); and
[b] End of Modification Mining (April 2031)

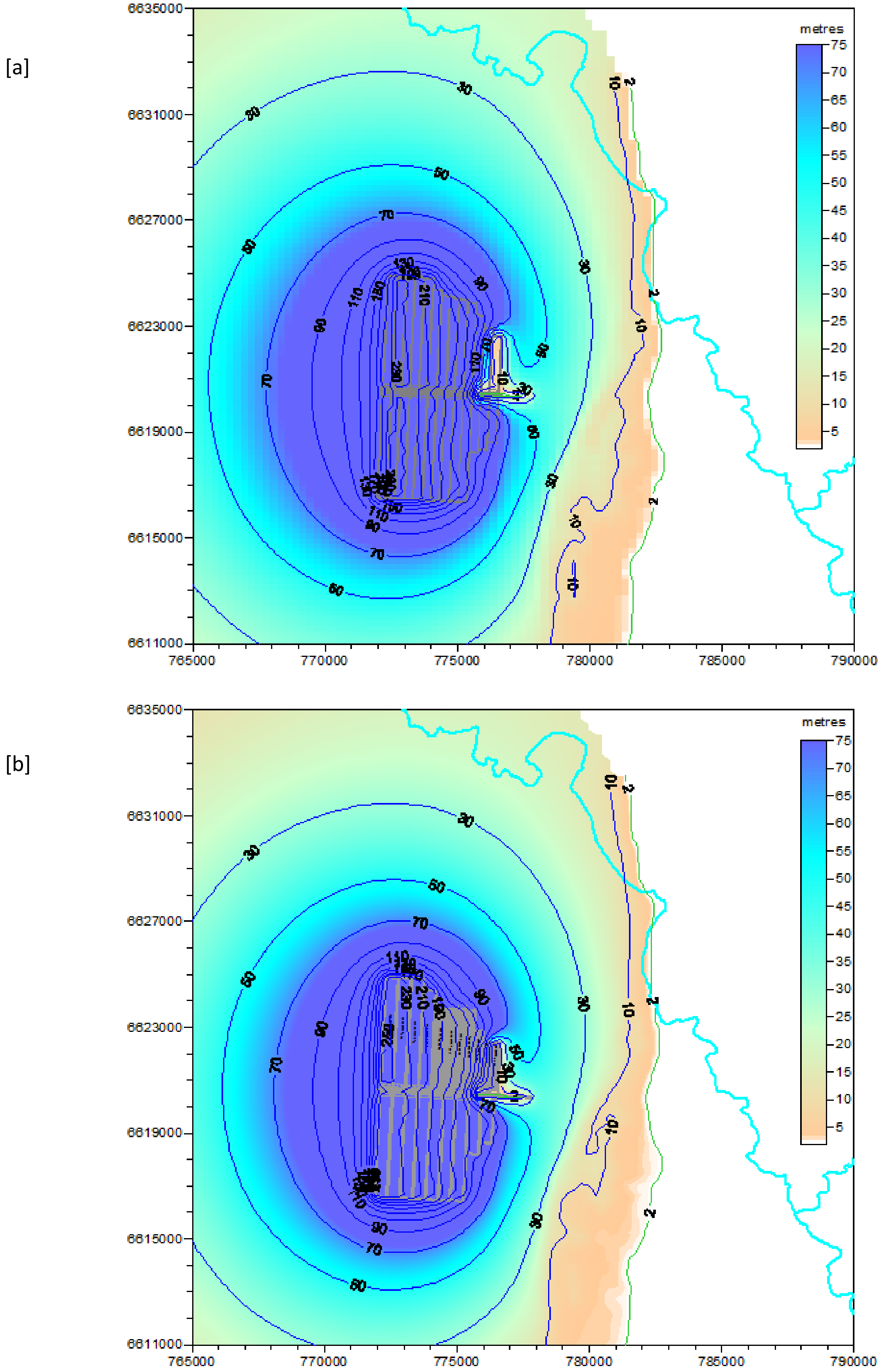


Figure 28. Hoskissons Coal Seam (Layer 9): Groundwater Drawdown (m) from Start of Mining (June 2012) to: [a] End of Approved Mining (December 2037); and [b] End of Modification Mining (April 2031)

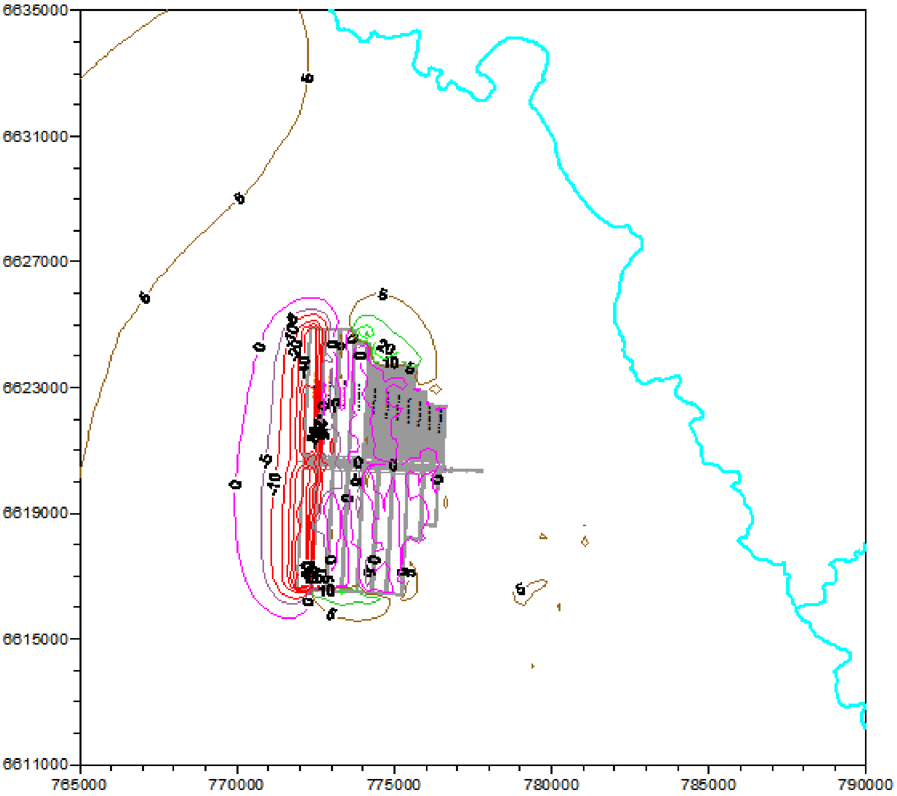


Figure 29. **Hoskissons Coal Seam (Layer 9): Incremental Groundwater Level Difference (m) between Modification and Approved Mine Plans at Respective Ends of Mining**
[Difference is defined as Modification - Approved]

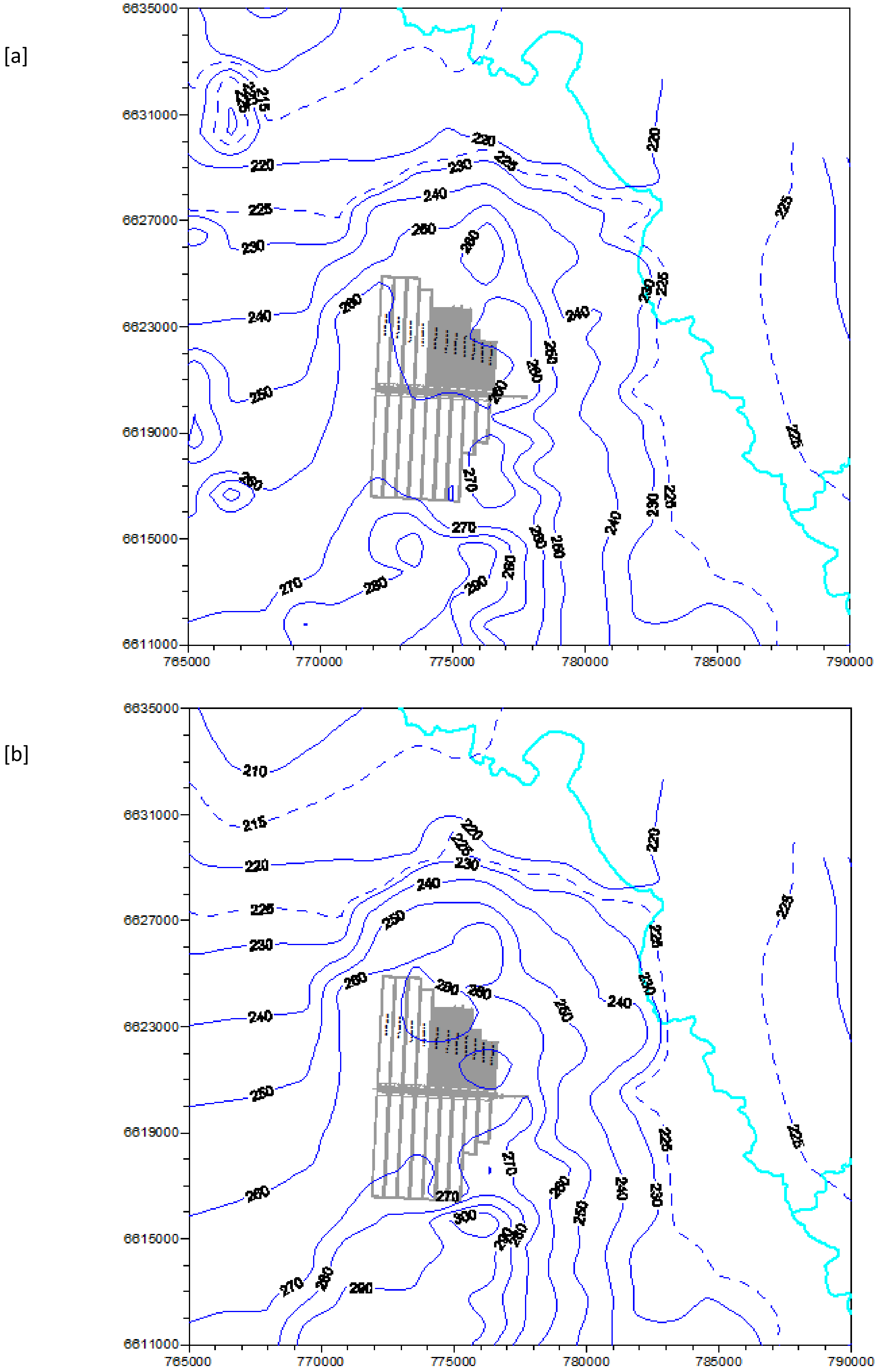


Figure 30. Predicted Modification Groundwater Levels (mAHD) 100 Years from the End of Mining:
[a] Regolith/Alluvium (Layer 1); and
[b] Pilliga Sandstone (Layer 2)

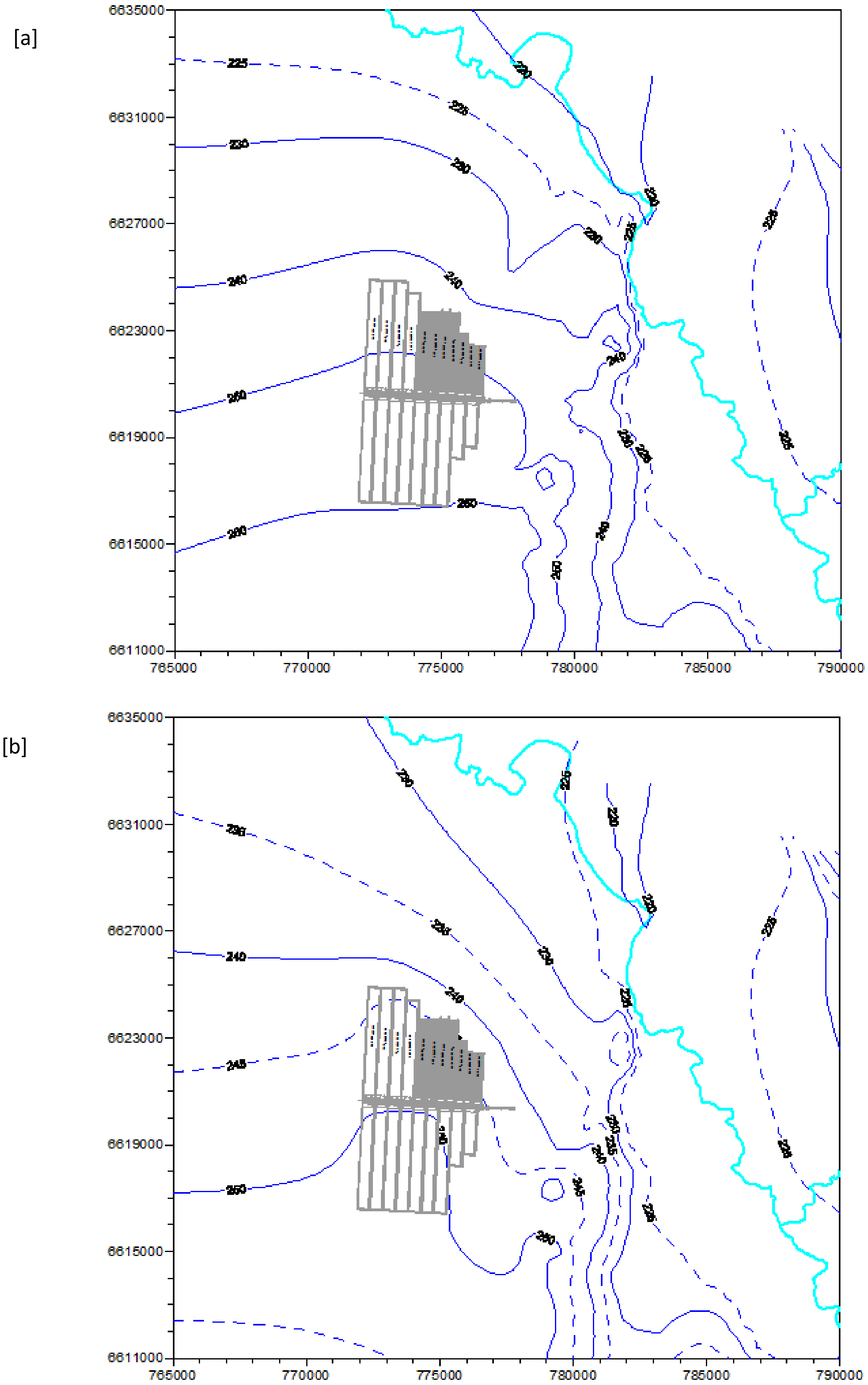


Figure 31. Predicted Modification Groundwater Levels (mAHD) 100 Years from the End of Mining:
[a] Napperby Formation (Layer 5); and
[b] Hoskissons Coal Seam (Layer 9)

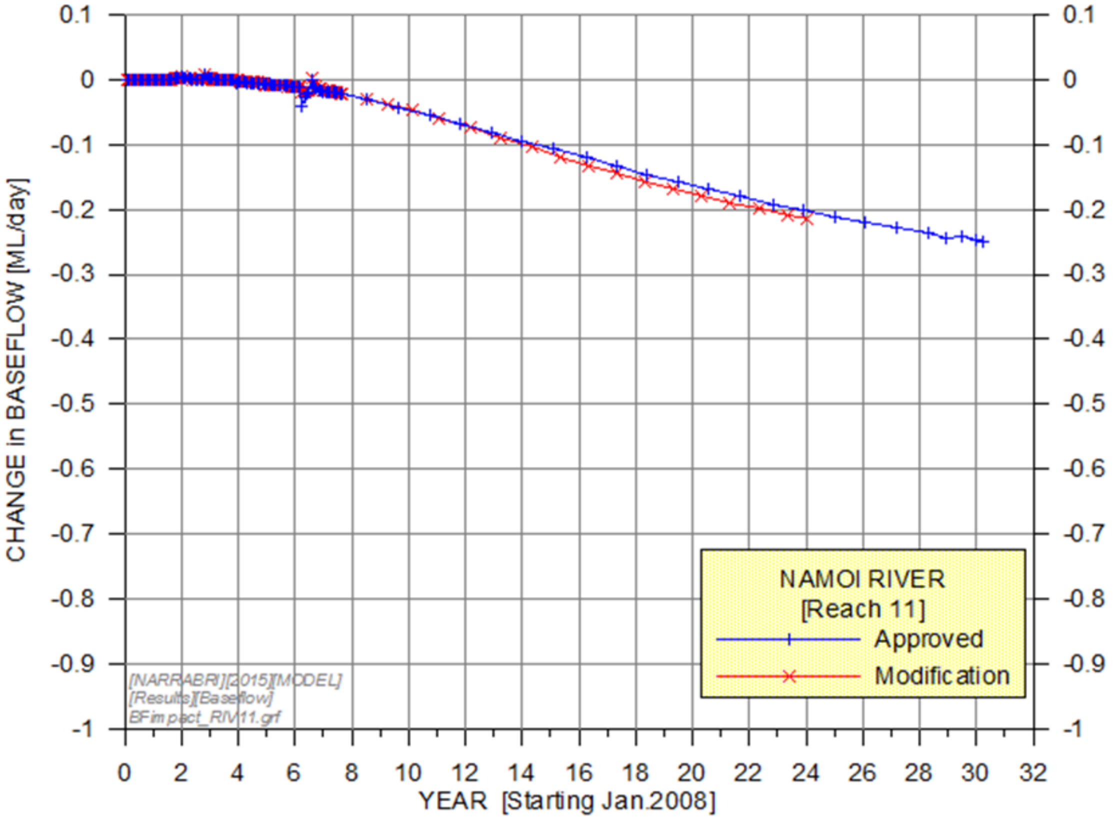


Figure 32. Namoi River Predicted Change in Baseflow – Approved and Modified Mine Plans

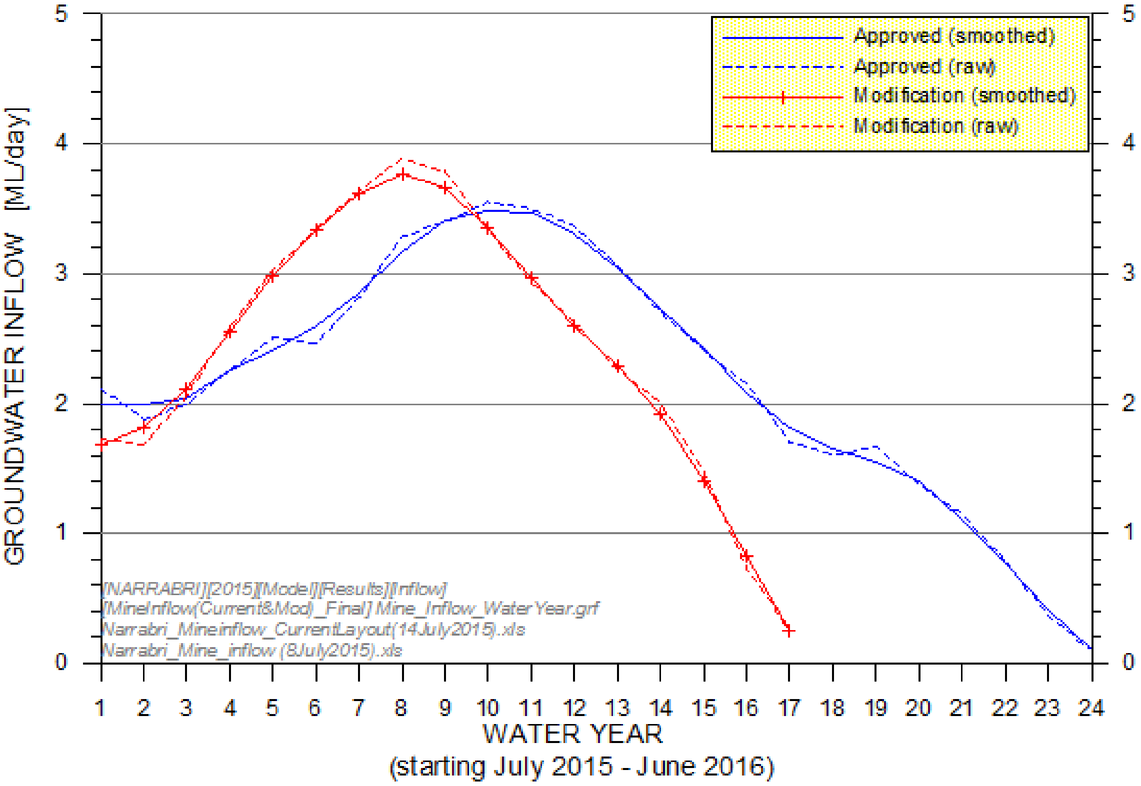


Figure 33. Simulated Inflow Rates – Modified and Approved Mining Plans

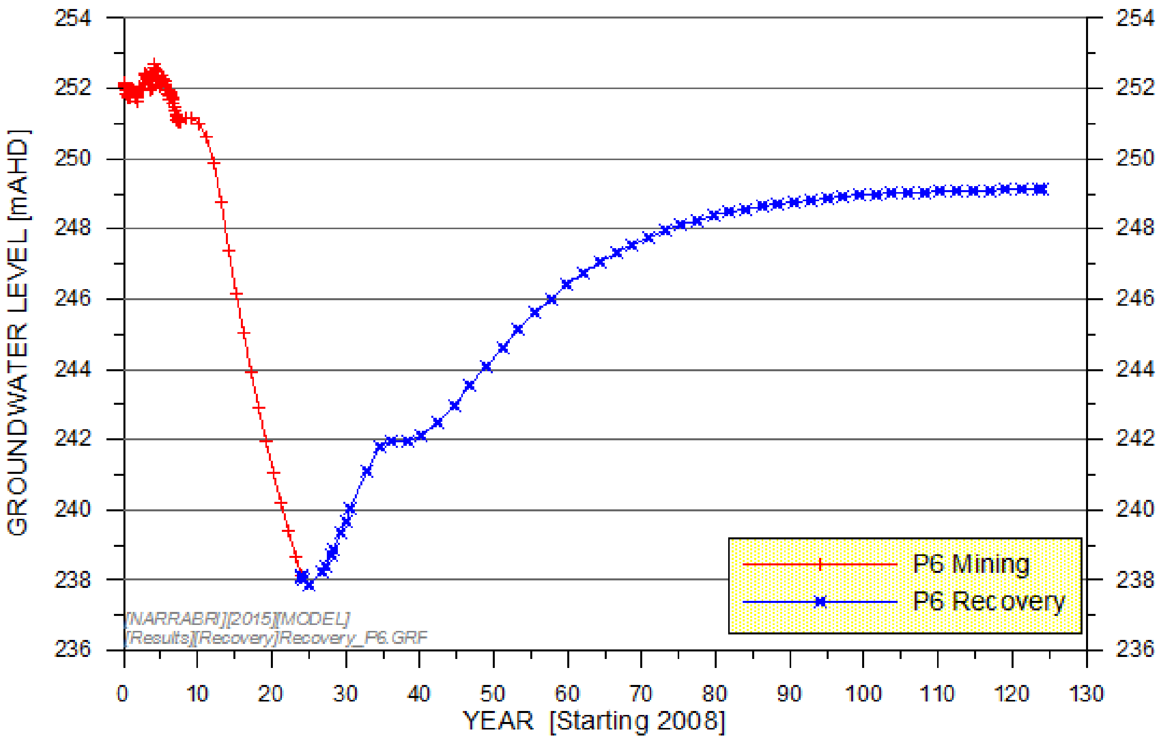


Figure 34. Simulated Hydrograph at P6 (Pilliga Sandstone) during Modification Mining and Subsequent Recovery

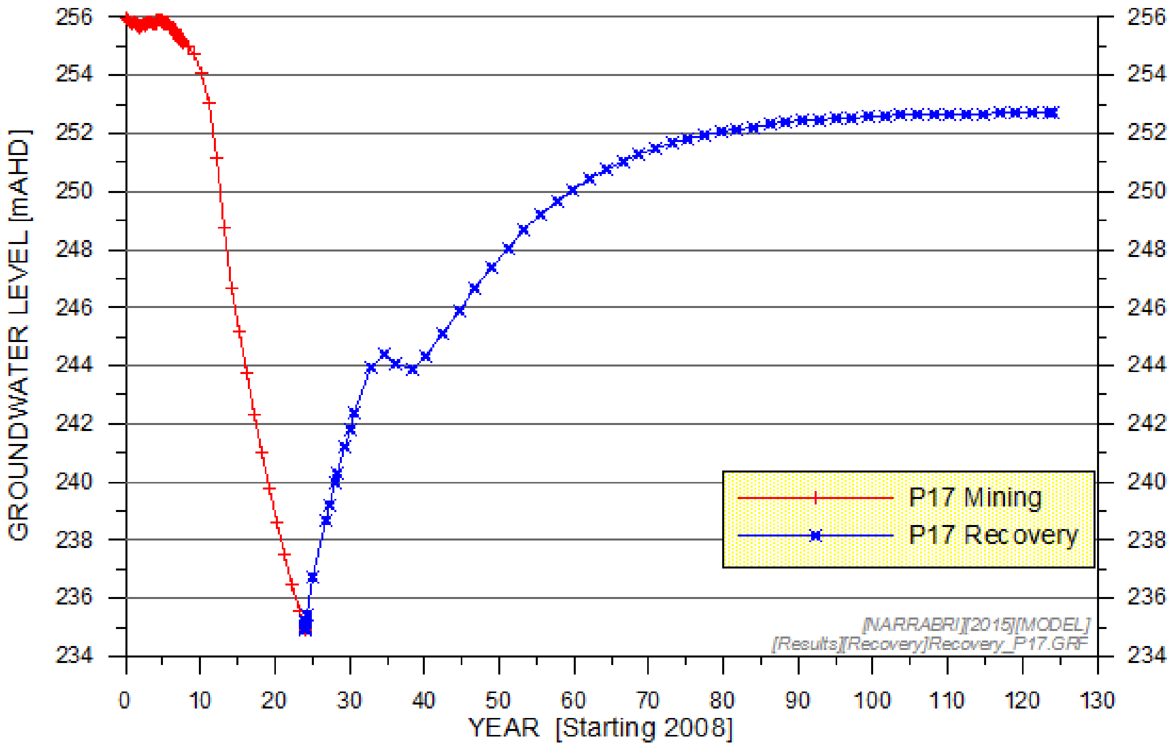


Figure 35. Simulated Hydrograph at P17 (Purlawaugh Formation) during Modification Mining and Subsequent Recovery

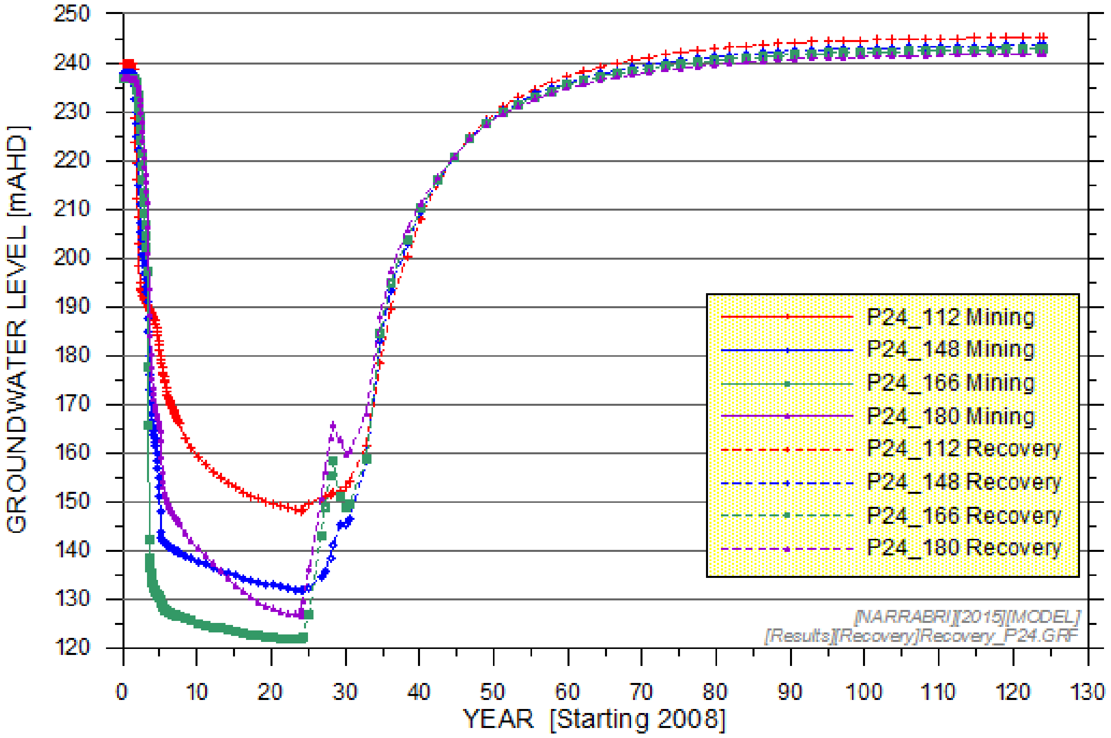


Figure 36. Simulated Hydrograph at P24 during Modification Mining and Subsequent Recovery

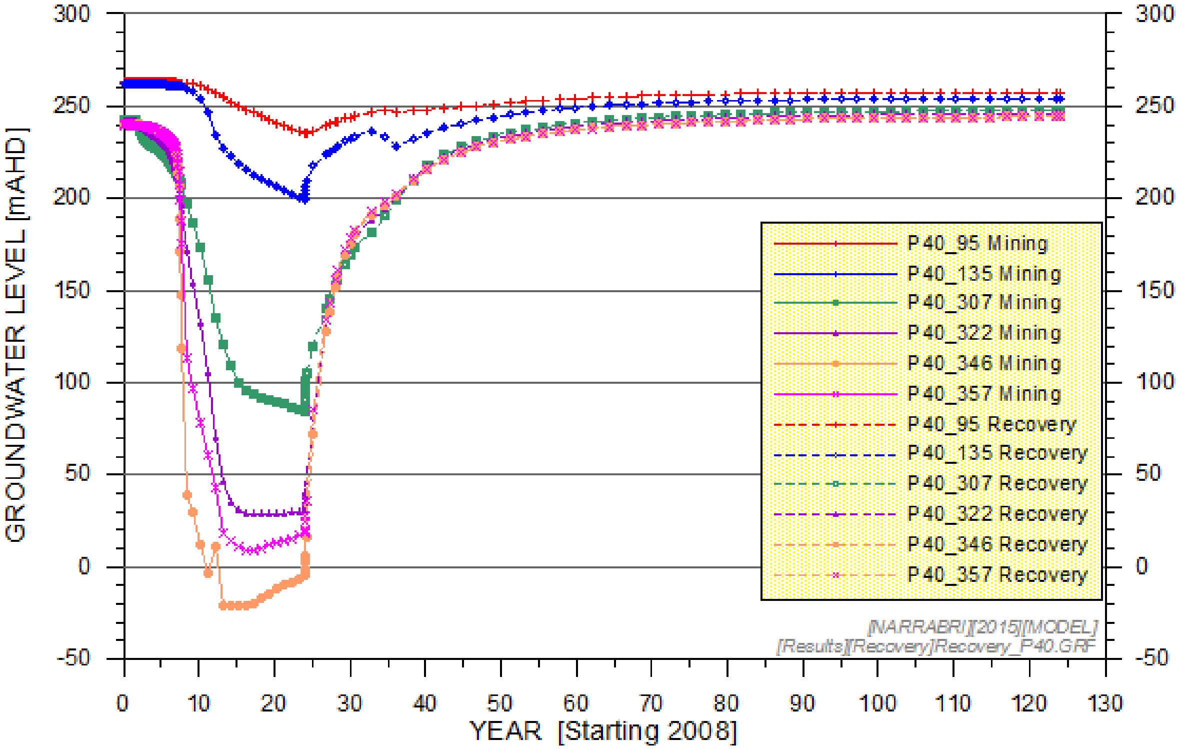


Figure 37. Simulated Hydrograph at P40 during Modification Mining and Subsequent Recovery

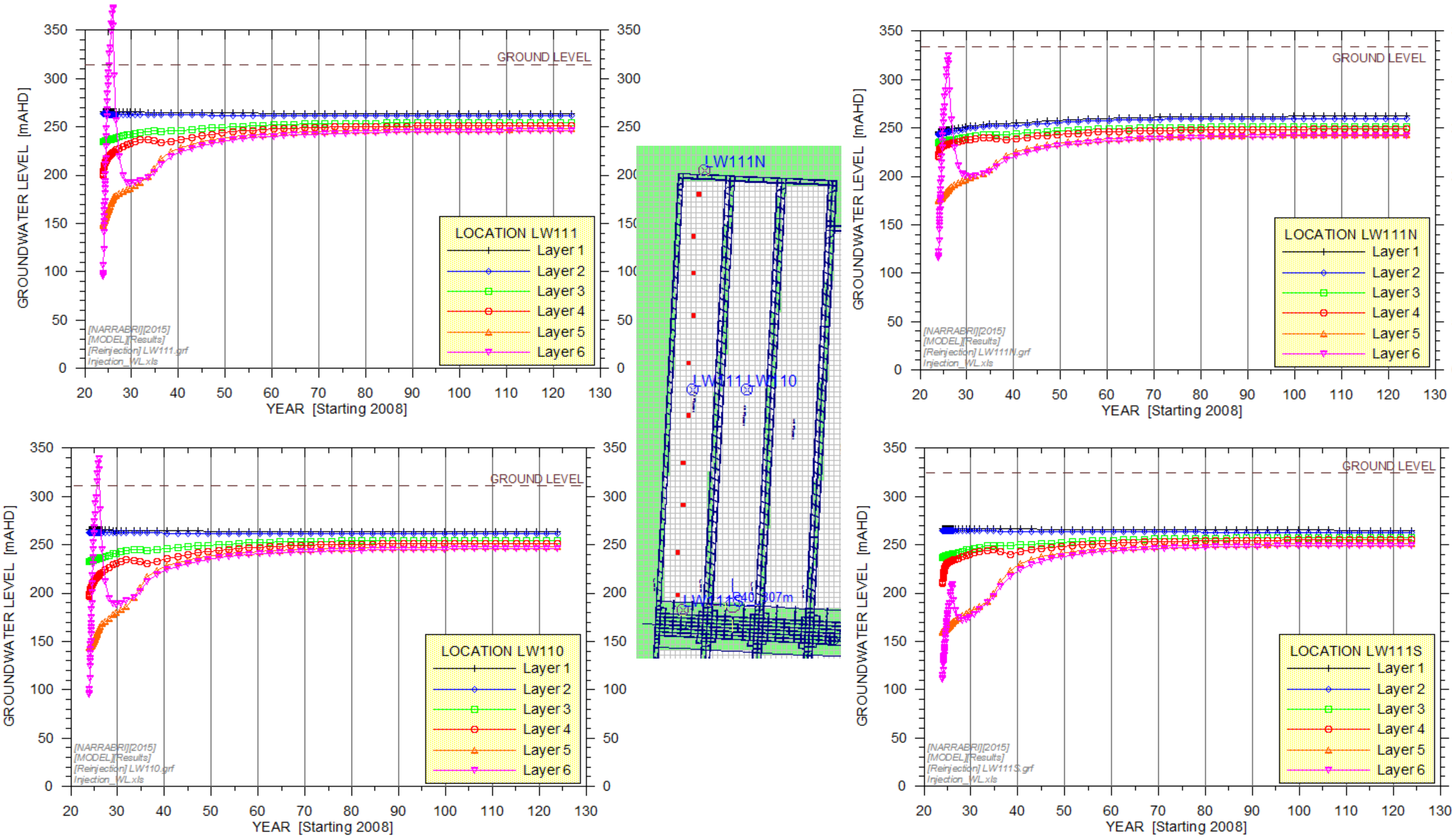


Figure 38. **Simulated Hydrographic Response to Brine Re-Injection**

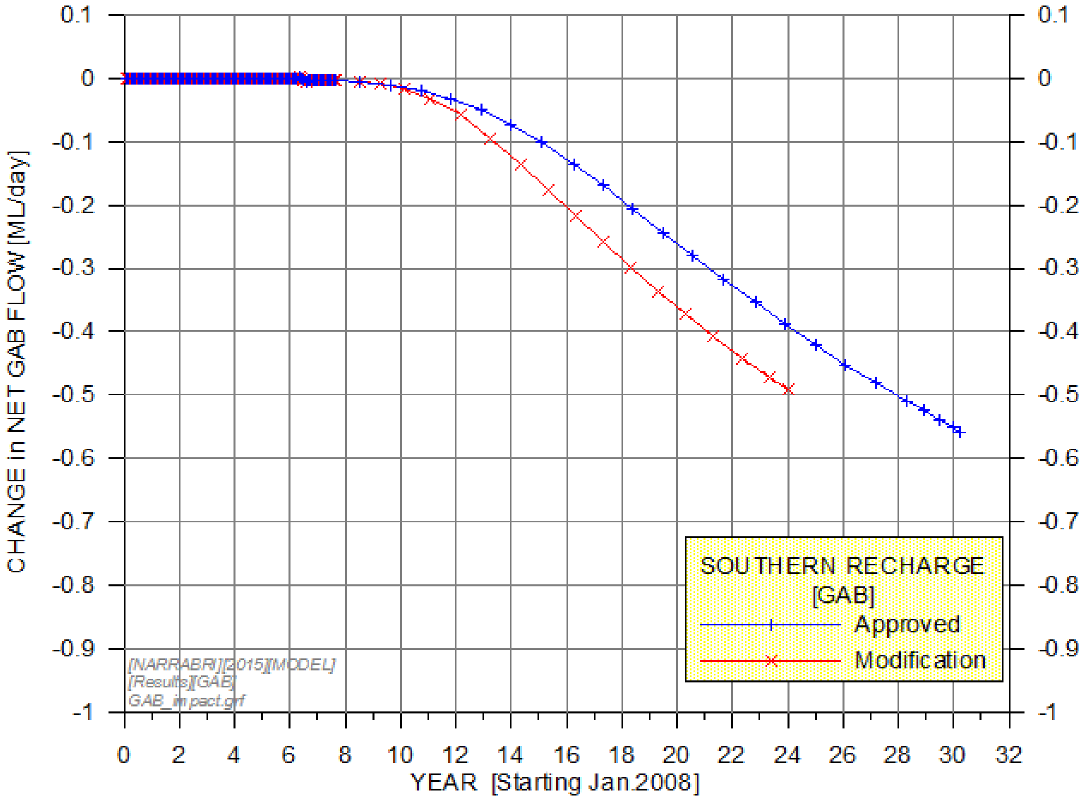


Figure 39. Predicted Impact on GAB Aquifers (Southern Recharge Zone)

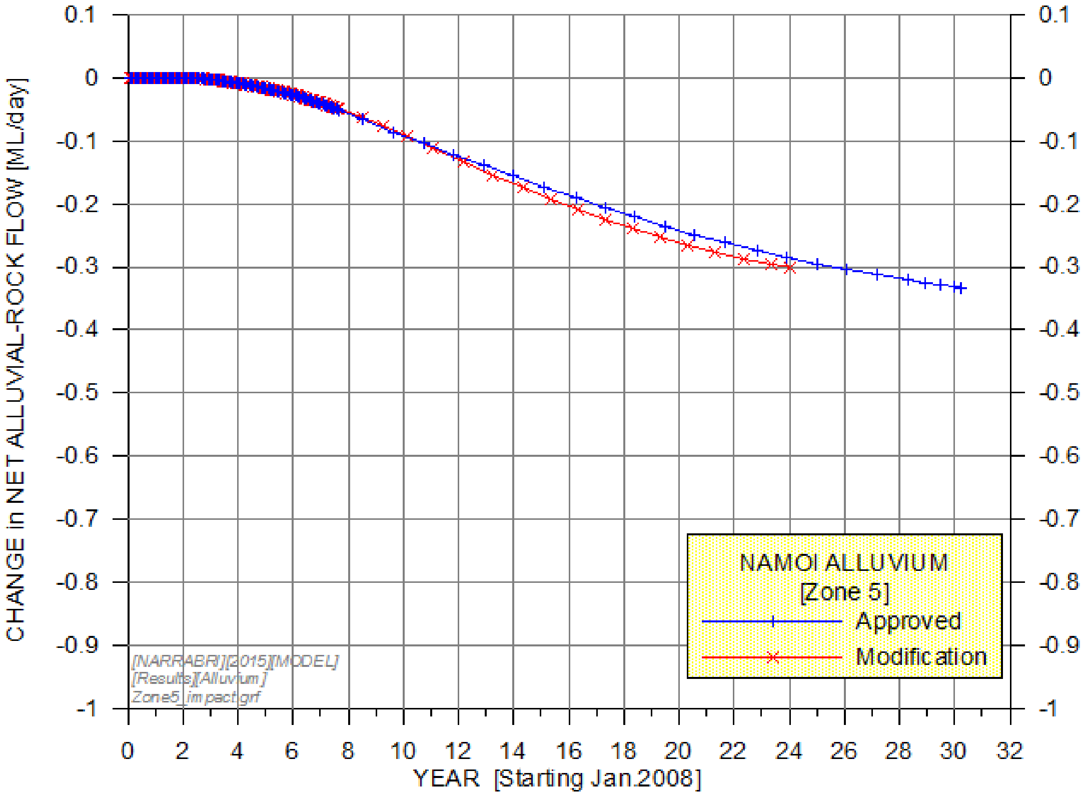


Figure 40. Predicted Impact on Namoi Alluvium (Zone 5)

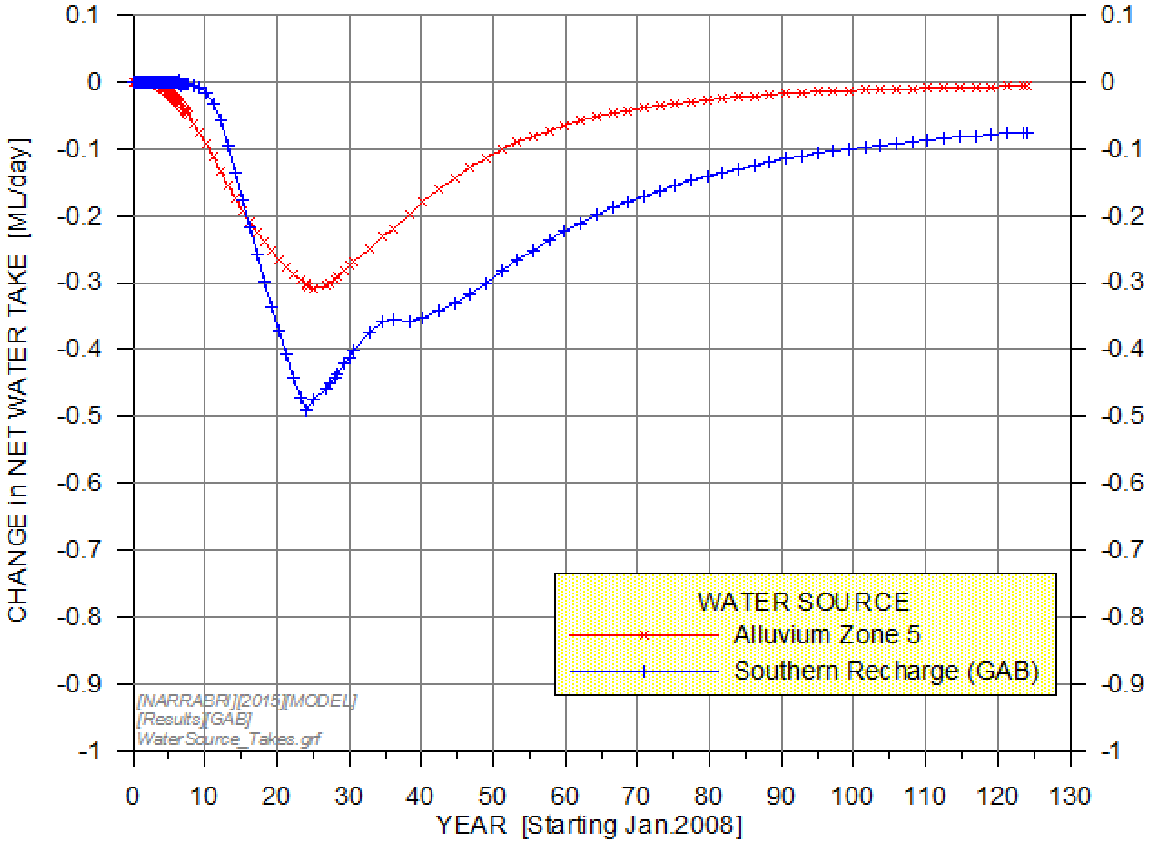


Figure 41. **Predicted Long-Term Impact on Alluvial and GAB Aquifers**

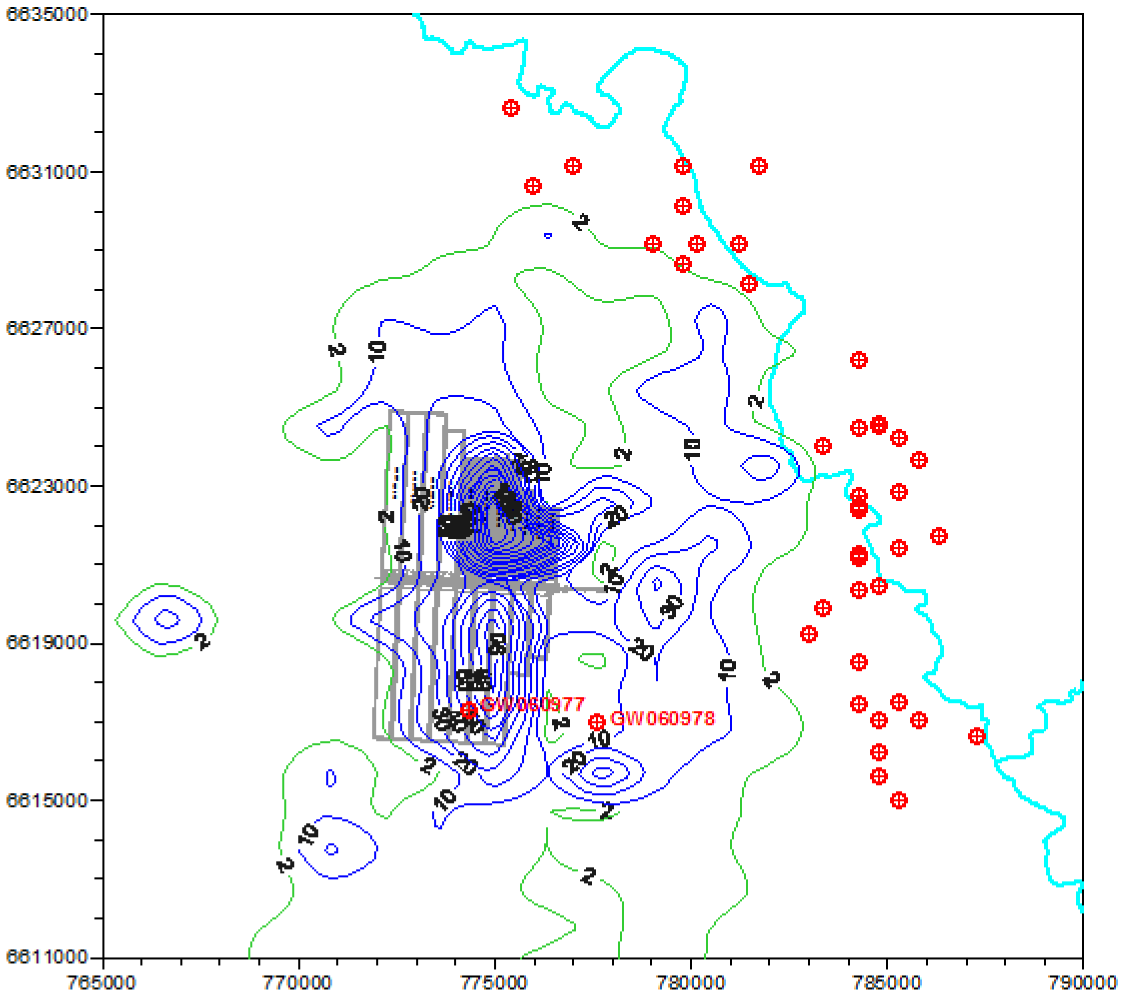


Figure 42. Proximity of Registered Bores to Modification Plan Drawdown in the Alluvium/Regolith (Model Layer 1)

Note: GW060977 and GW060978 are collapsed bores.

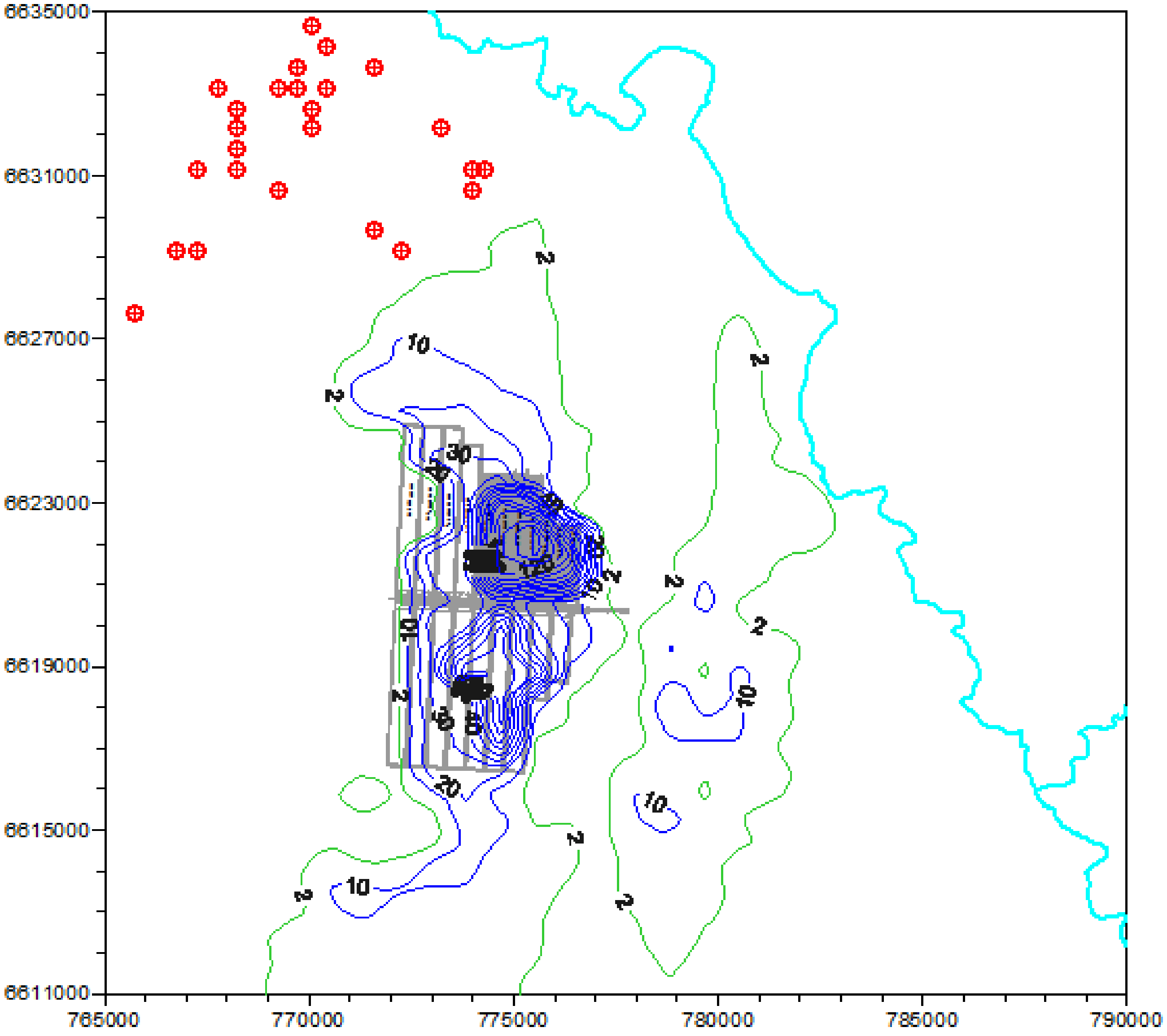


Figure 43. Proximity of Registered Bores to Modification Plan Drawdown in Pilliga Sandstone (Model Layer 2)

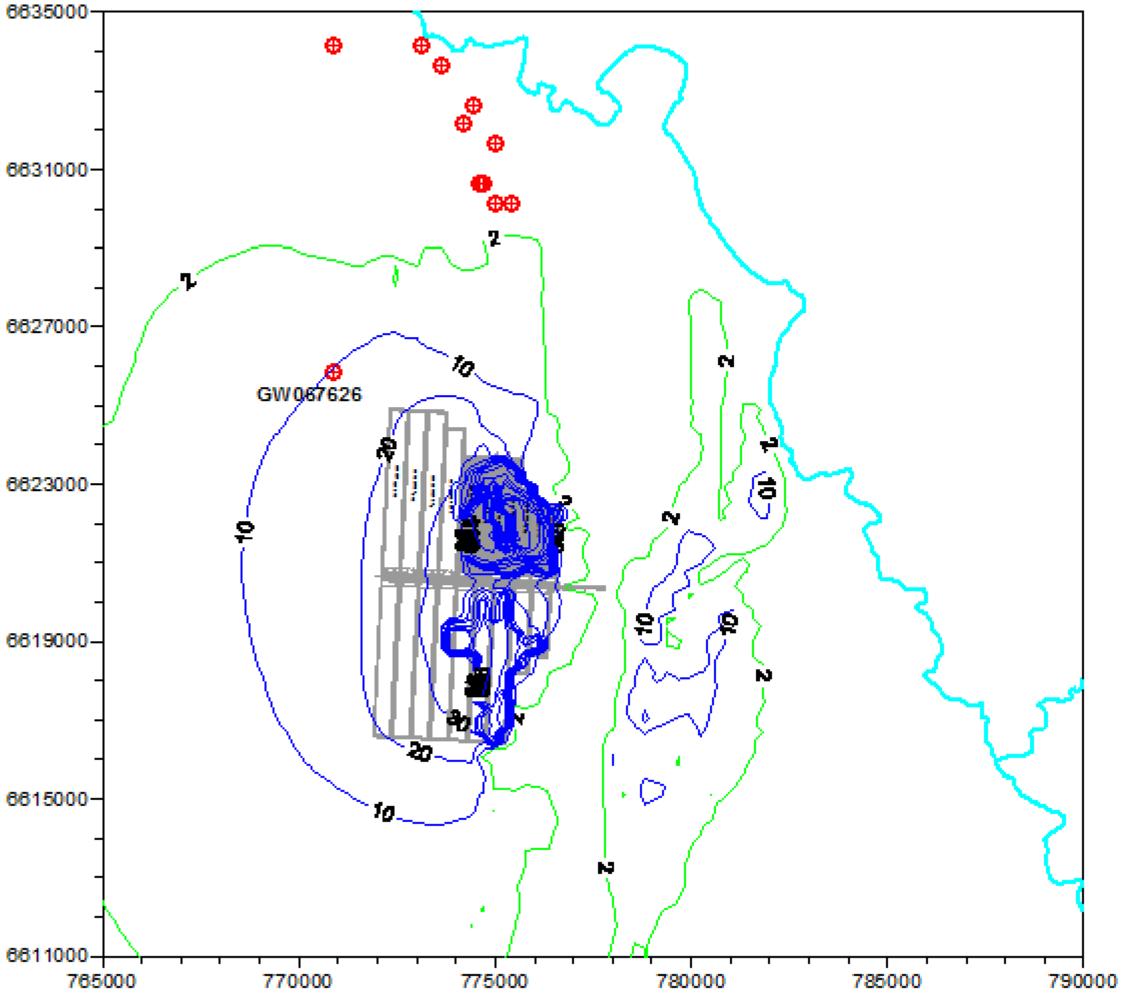


Figure 44. Proximity of Registered Bores to Modification Plan Drawdown in Purlawaugh Formation (Model Layer 3)

ATTACHMENT A

Alluvial Groundwater Hydrographs

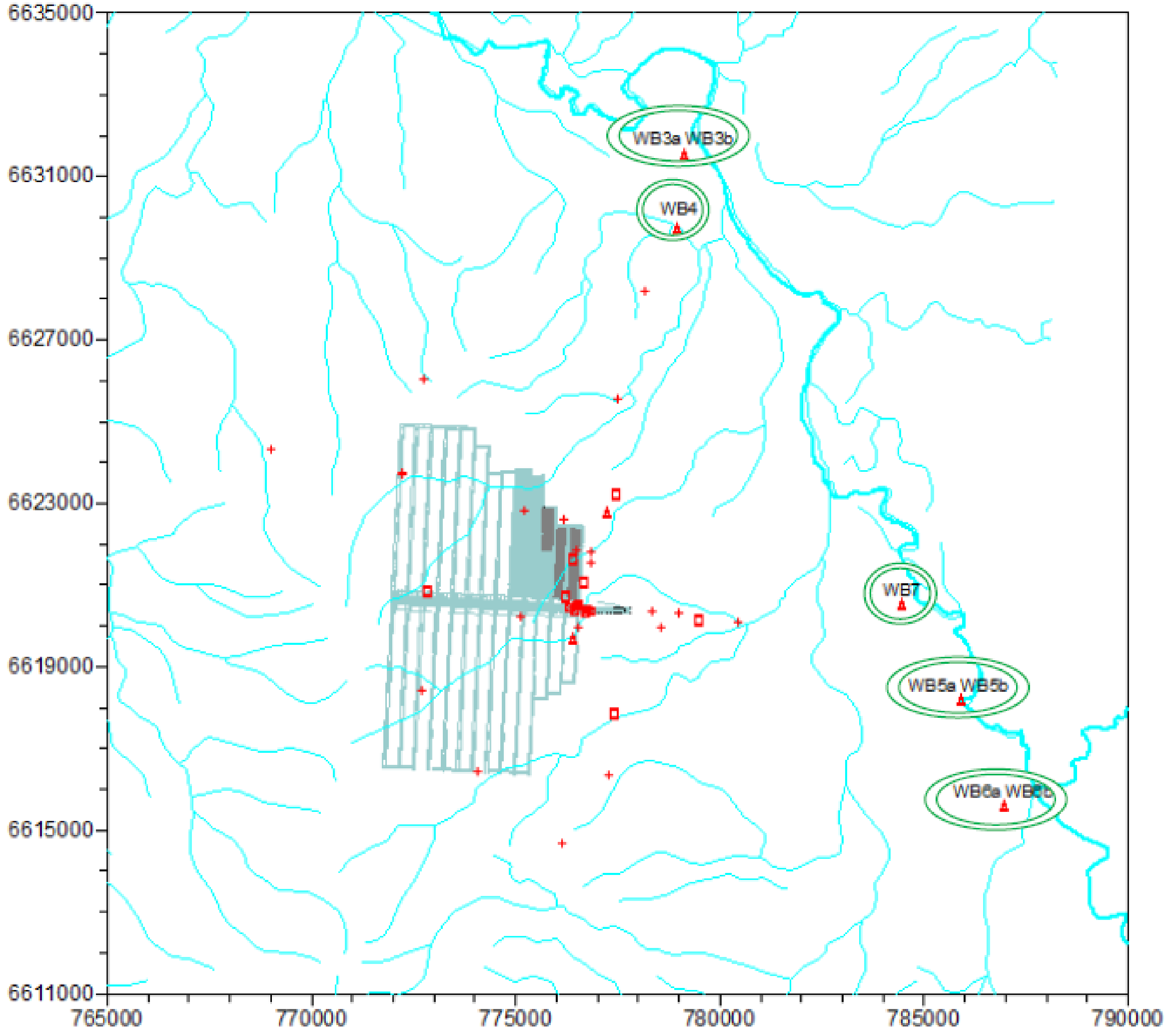


Figure A1. Groundwater Monitoring Network Location Map

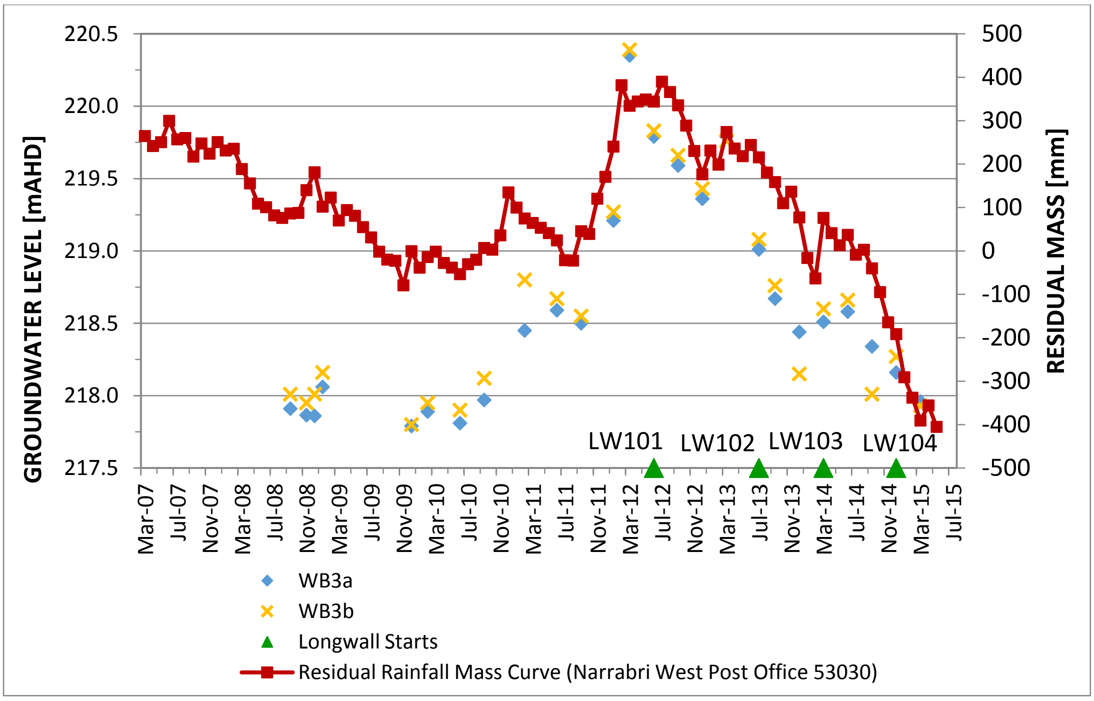


Figure A2. WB3a and WB3b Alluvial Hydrographs

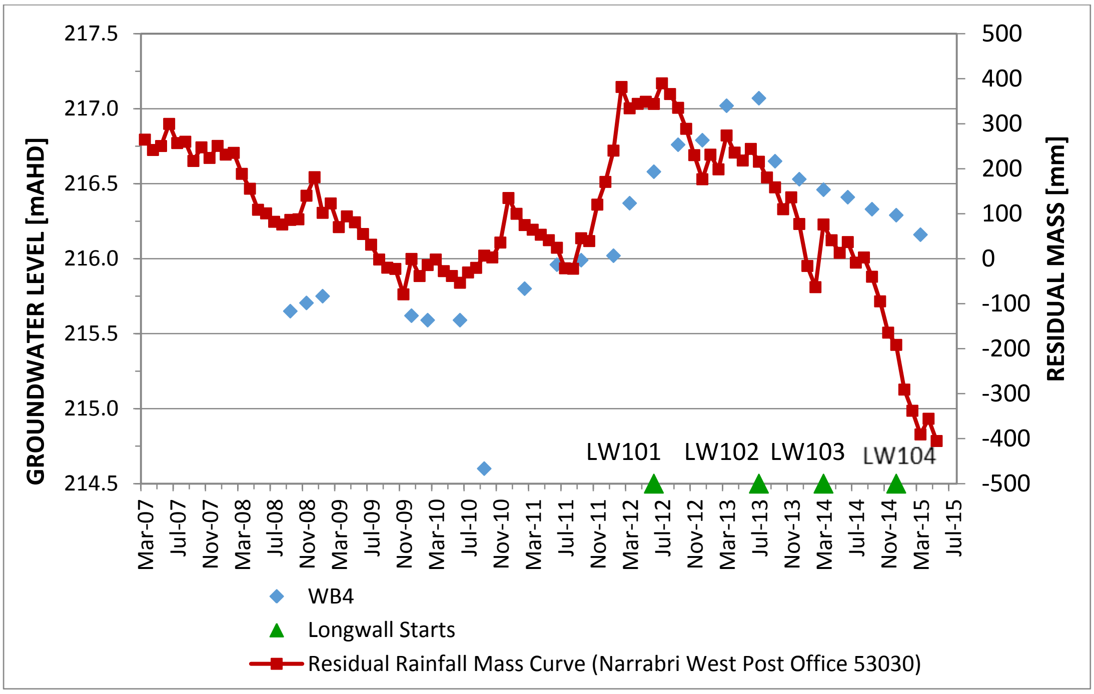


Figure A3. WB4 Alluvial Hydrograph

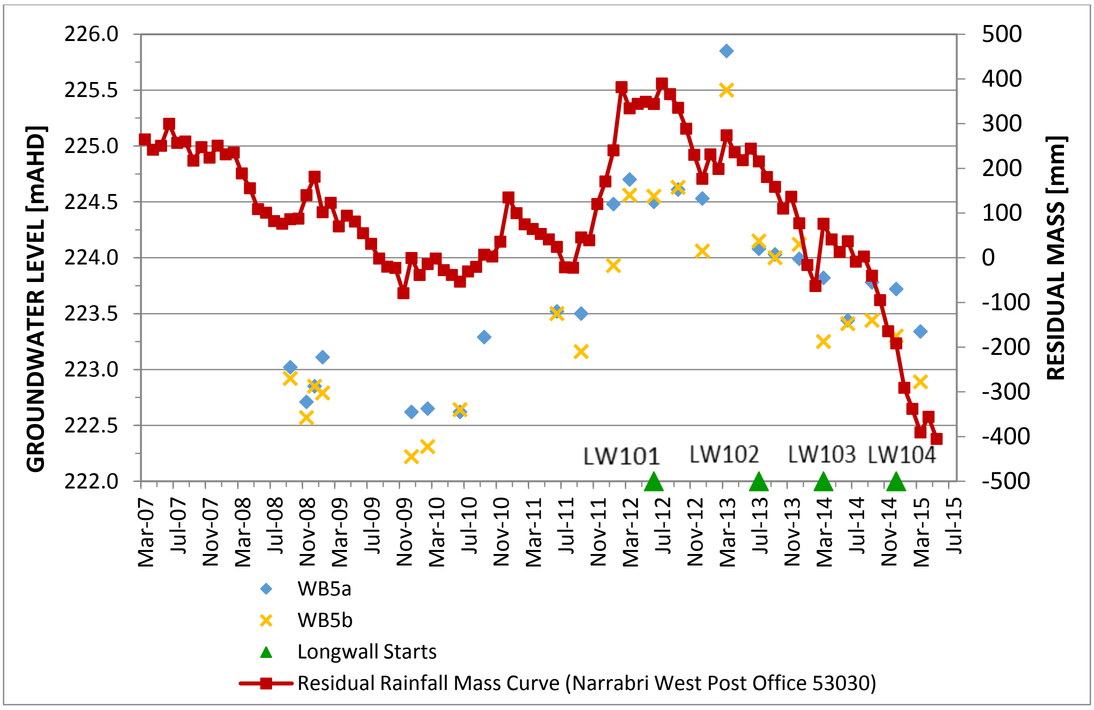


Figure A4. WB5a and WB5b Alluvial Hydrographs

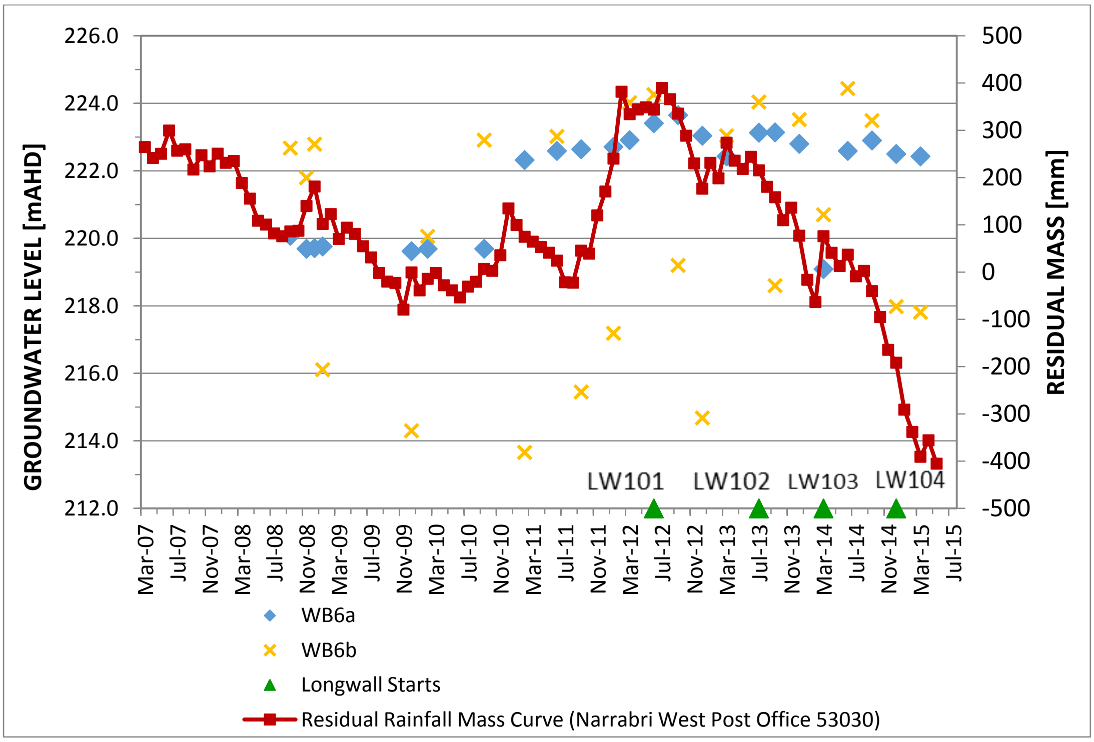


Figure A5. WB6a and WB6b Alluvial Hydrographs

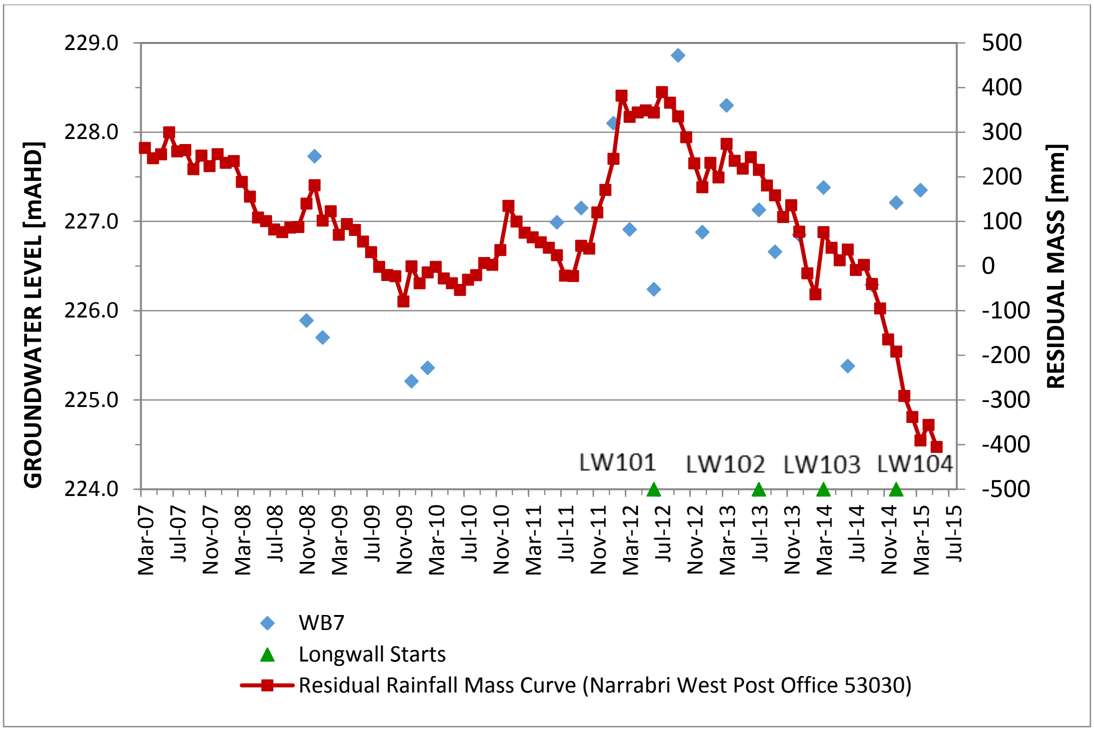


Figure A6. WB7 Alluvial Hydrograph

ATTACHMENT B

Pilliga Sandstone Groundwater Hydrographs

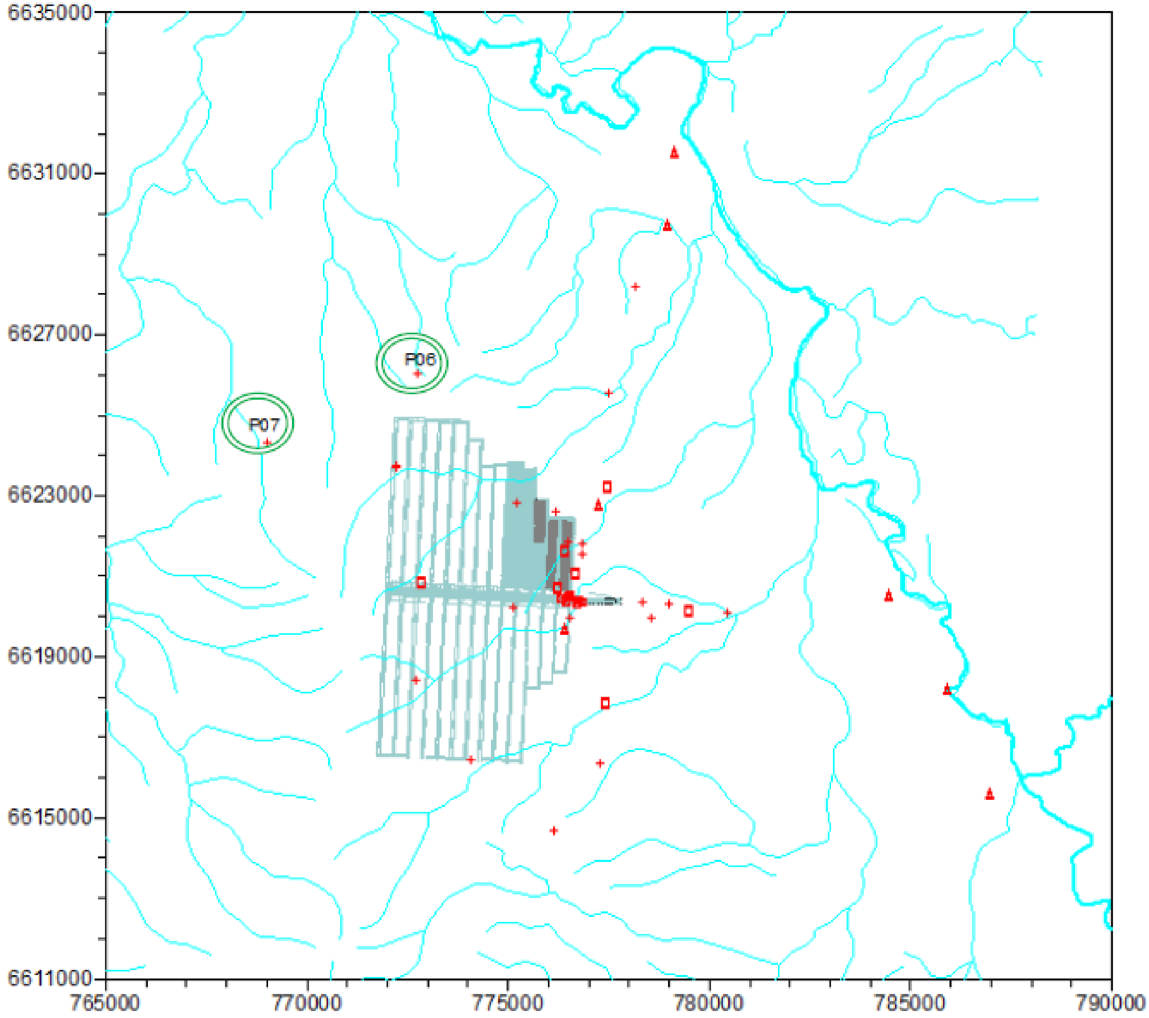


Figure B1. Groundwater Monitoring Network Location Map

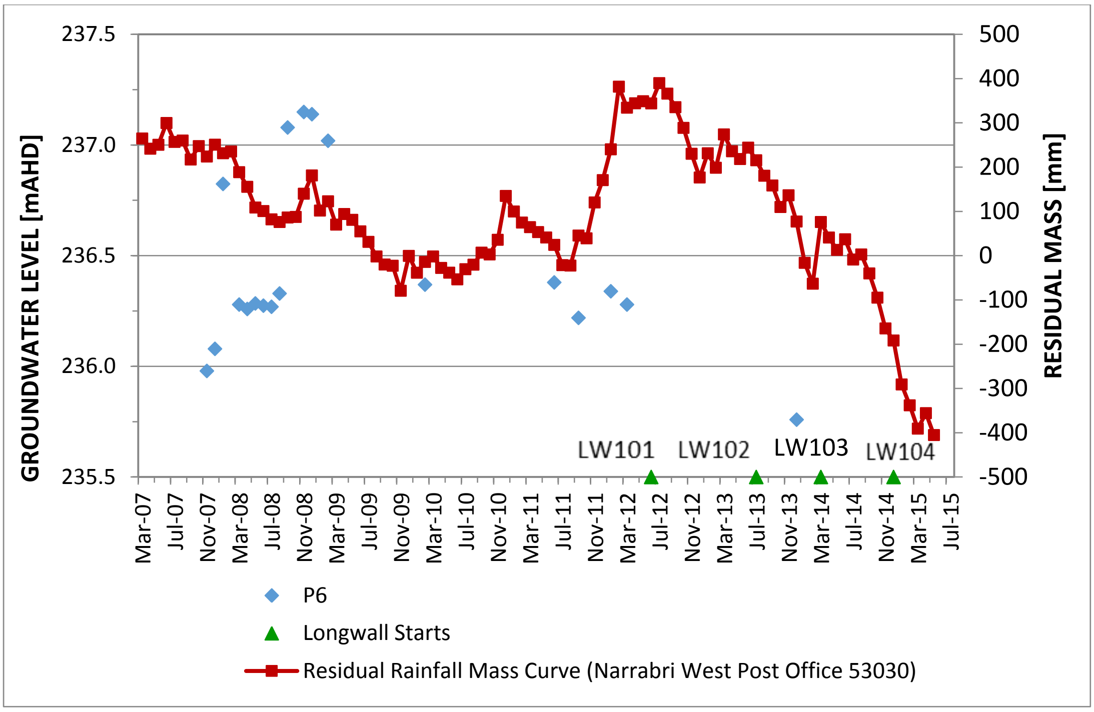


Figure B2. P6 Pilliga Sandstone Hydrograph

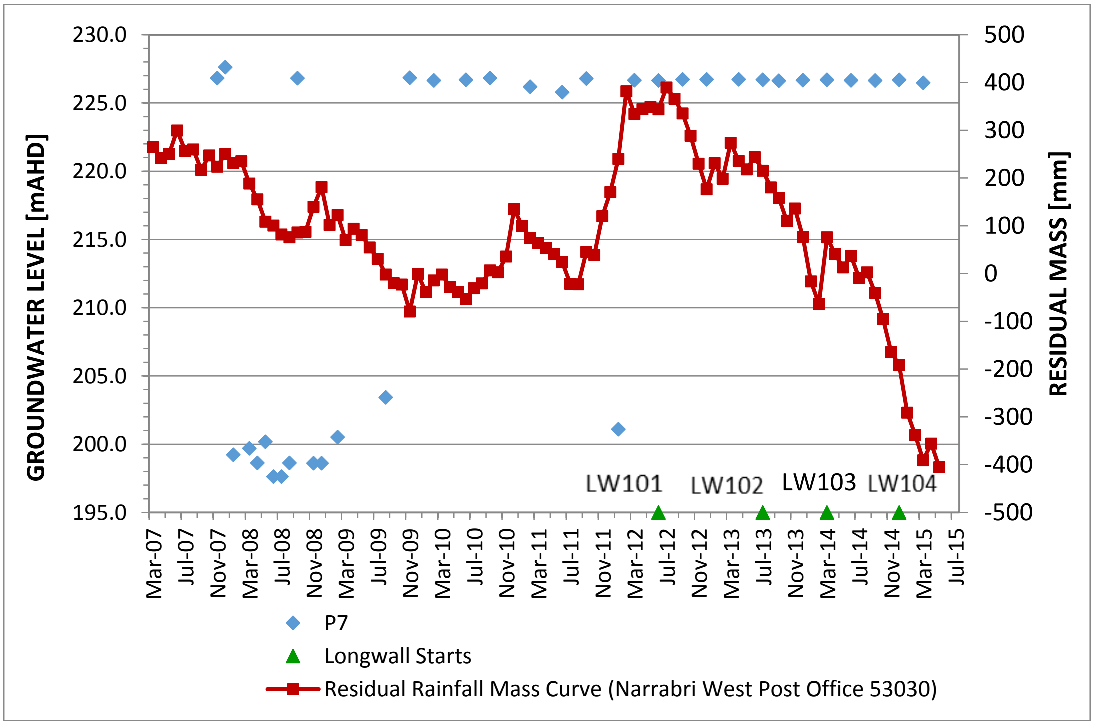


Figure B3. P7 Pilliga Sandstone Hydrograph

ATTACHMENT C

Purlawaugh Formation Groundwater Hydrographs

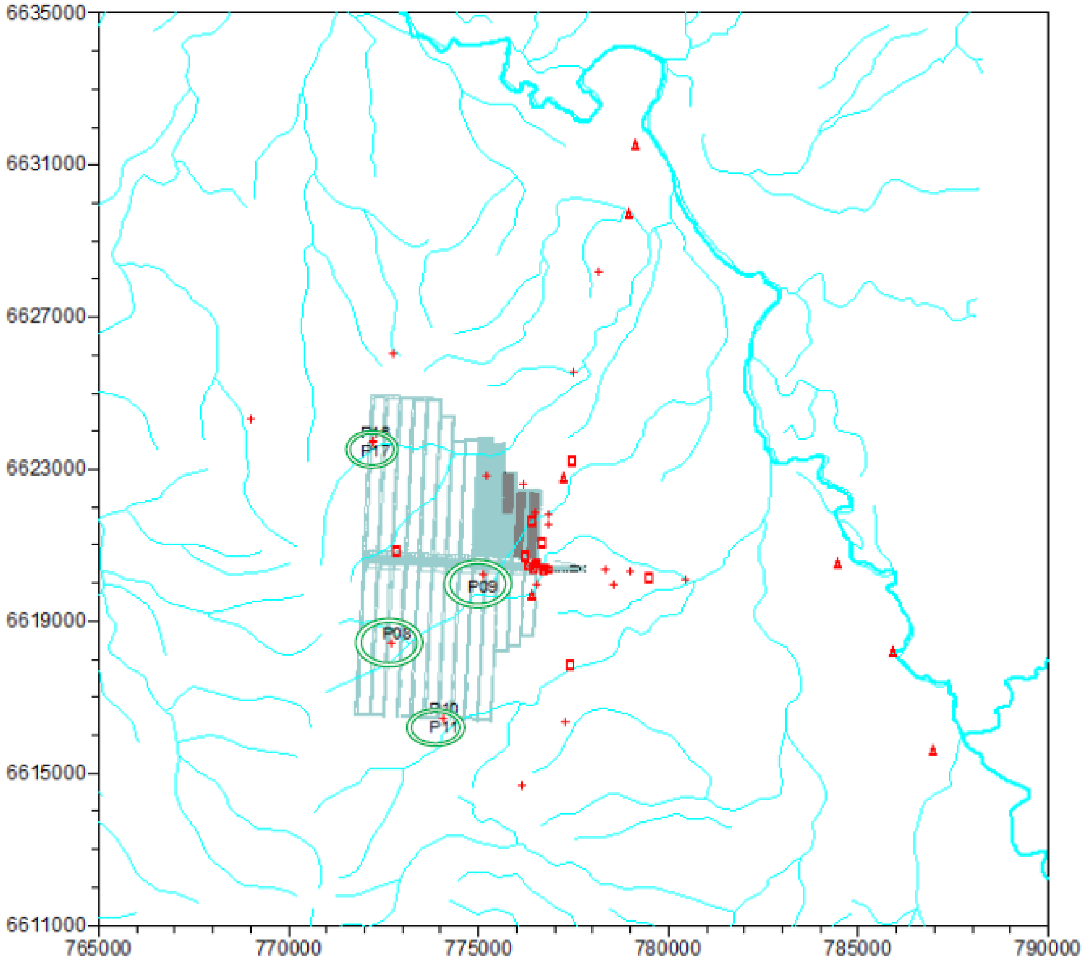


Figure C1. Groundwater Monitoring Network Location Map

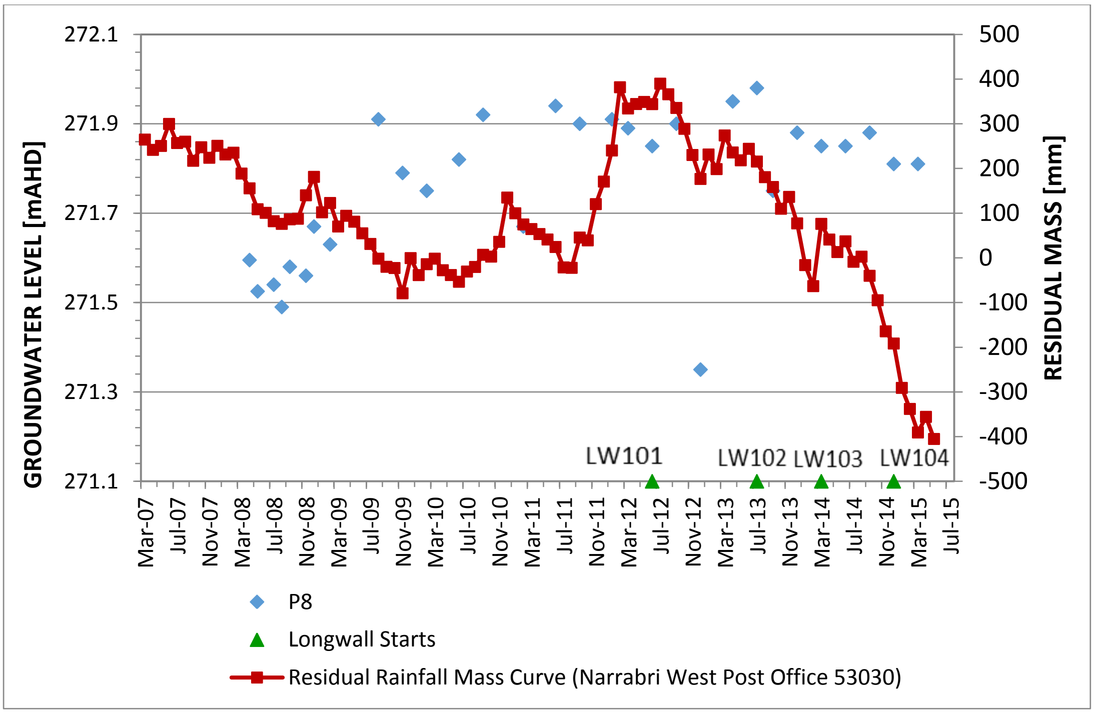


Figure C2. P8 Purlawaugh Formation Hydrograph

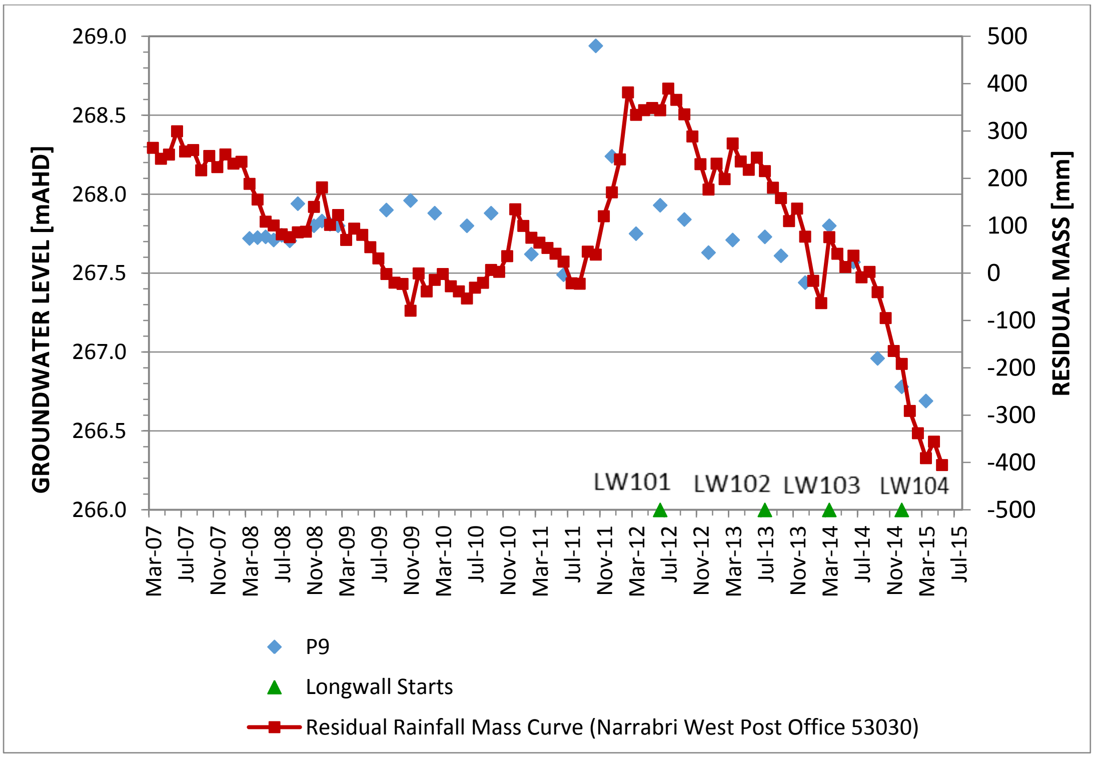


Figure C3. P9 Purlawaugh Formation Hydrograph

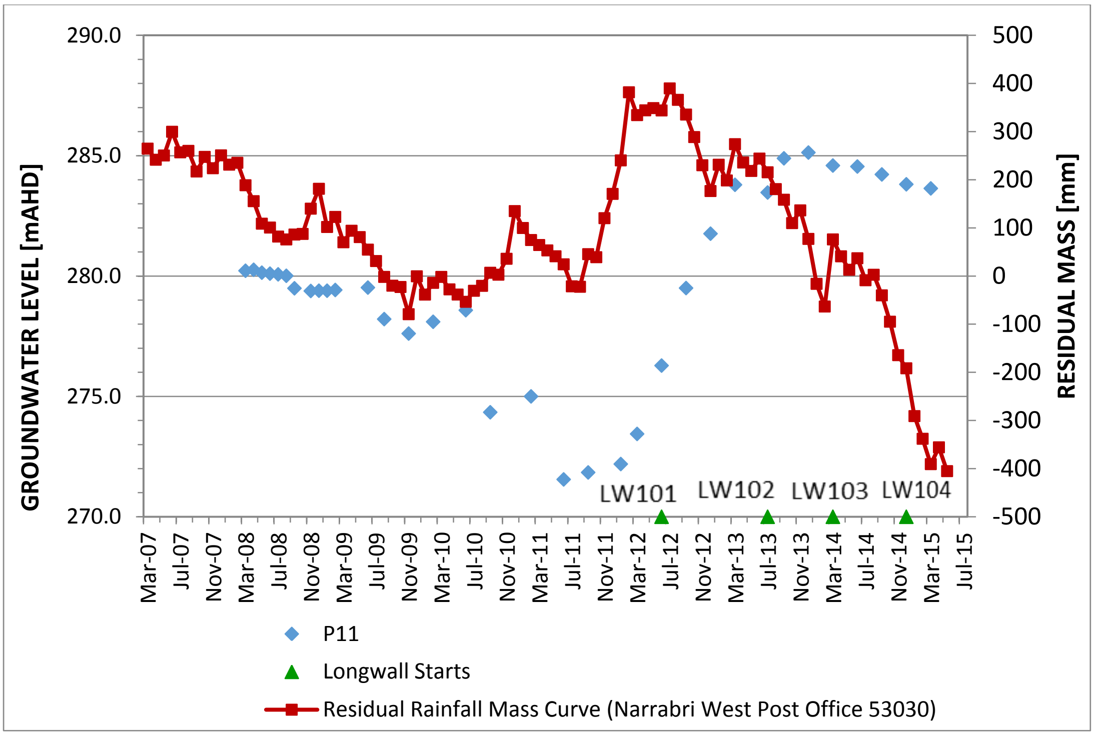


Figure C4. P11 Purlawaugh Formation Hydrograph

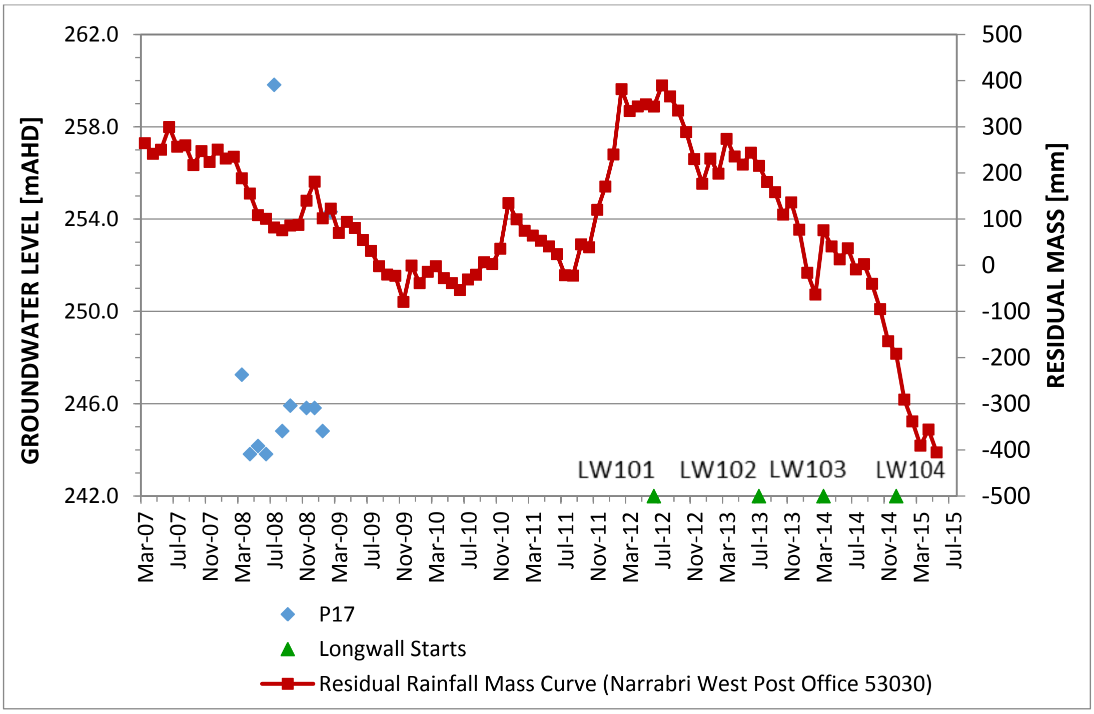


Figure C5. P17 Purlawaugh Formation Hydrograph

ATTACHMENT D

Garrawilla Volcanics Groundwater Hydrographs

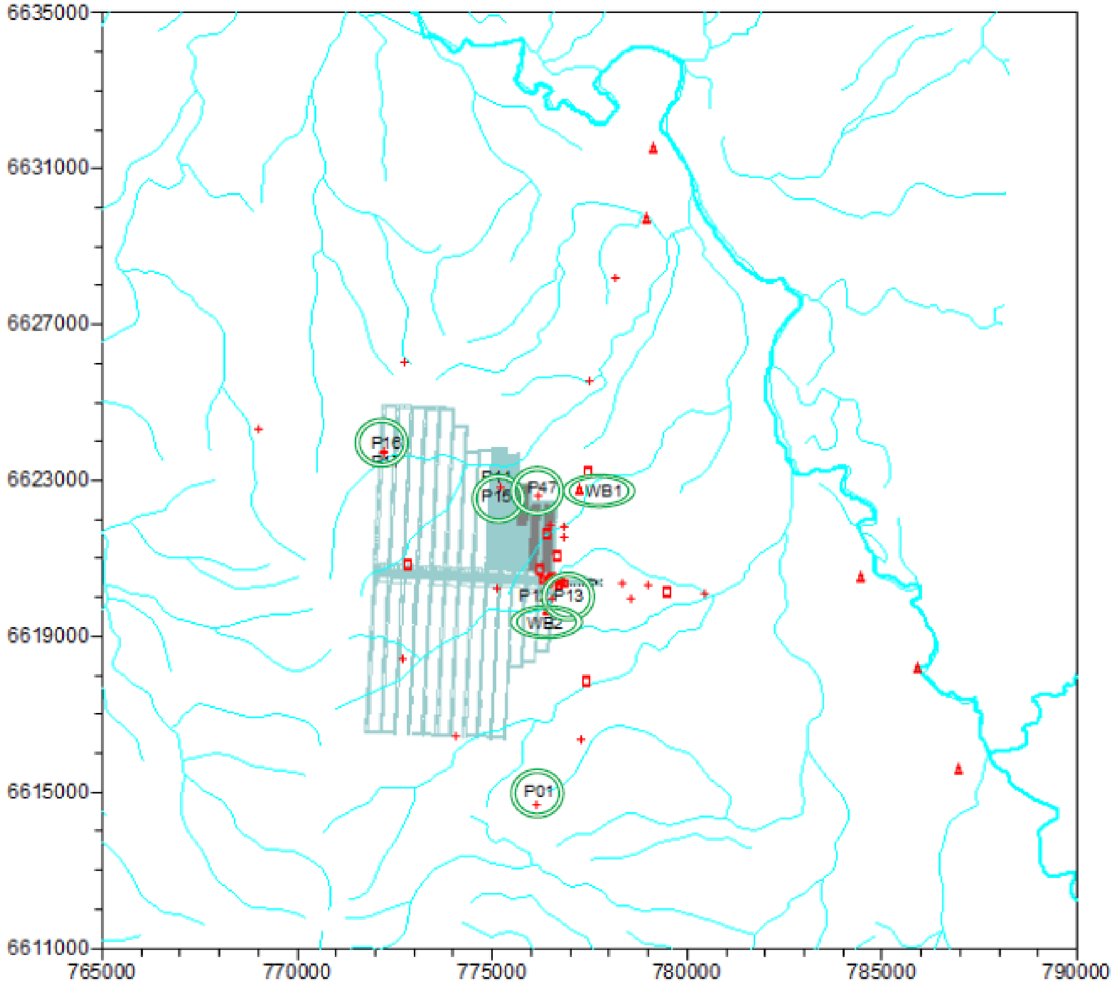


Figure D1. Groundwater Monitoring Network Location Map

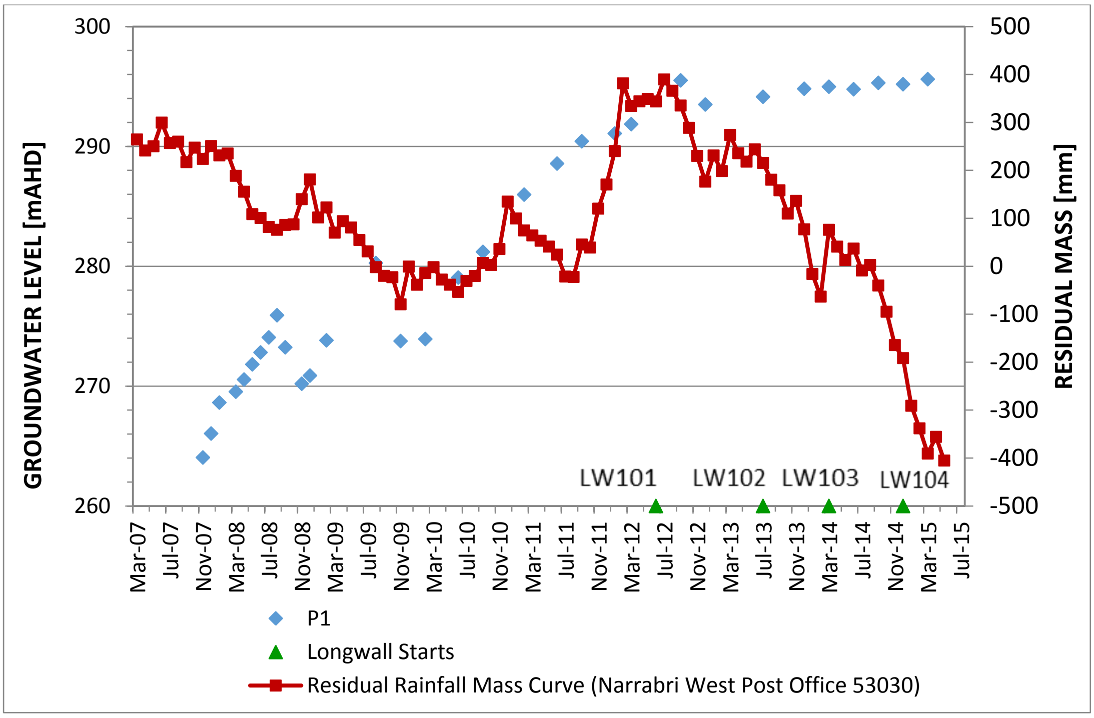


Figure D2. P1 Garrawilla Volcanics Hydrograph

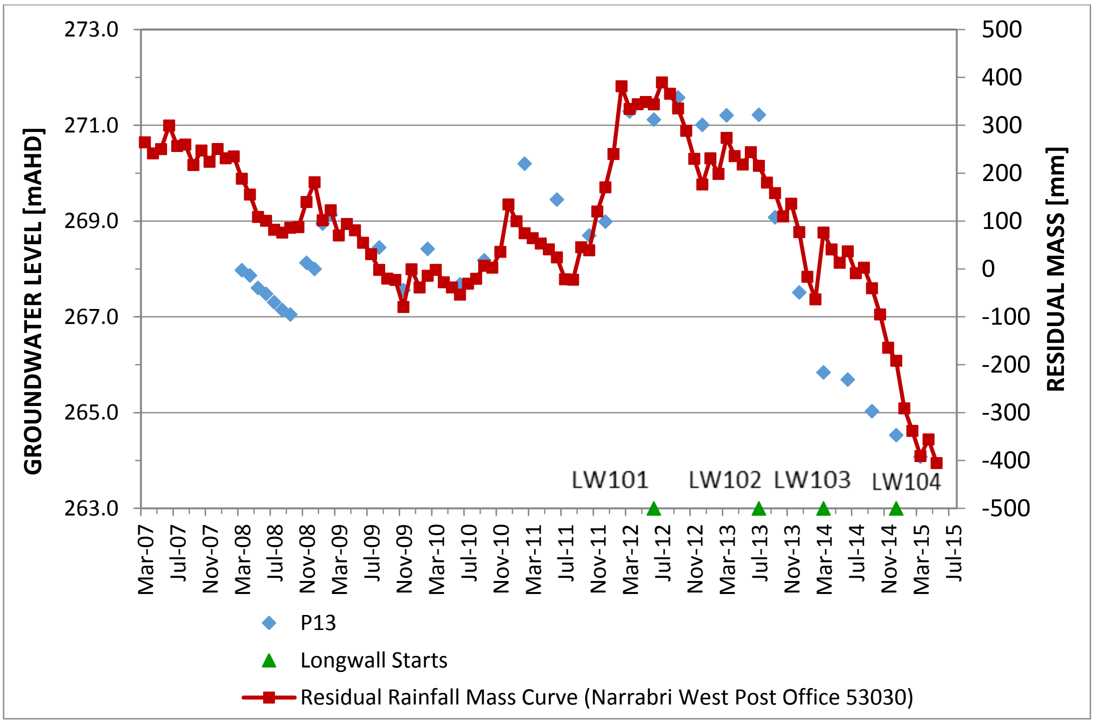


Figure D3. P13 Garrawilla Volcanics Hydrograph

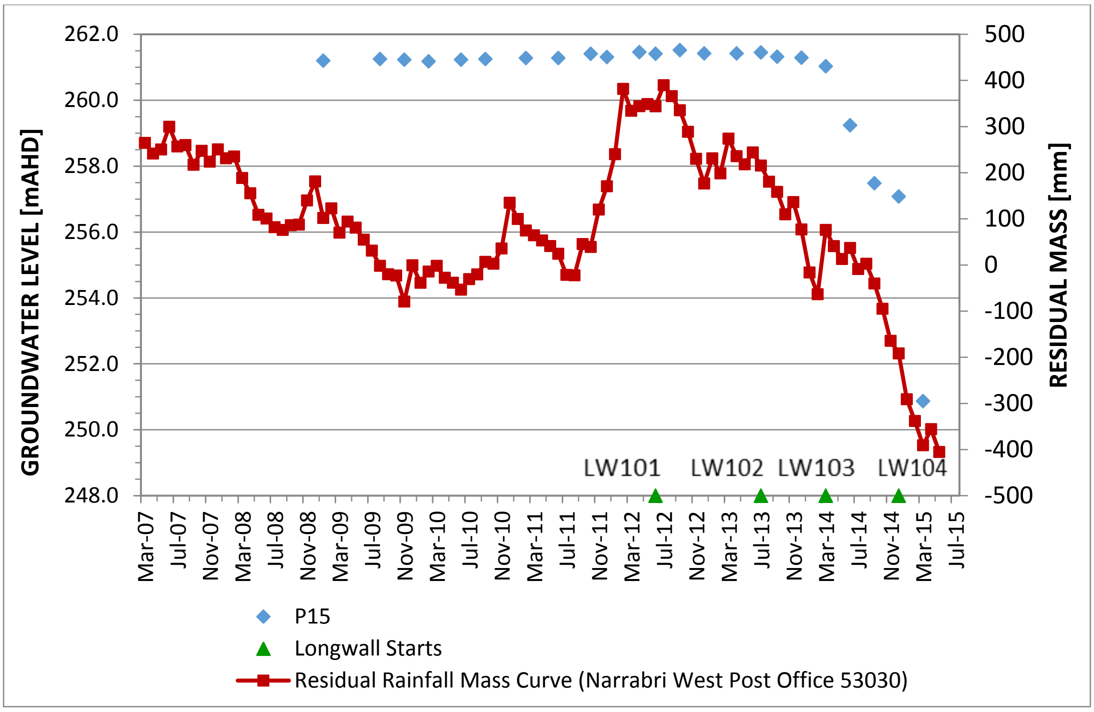


Figure D4. P15 Garrawilla Volcanics Hydrograph

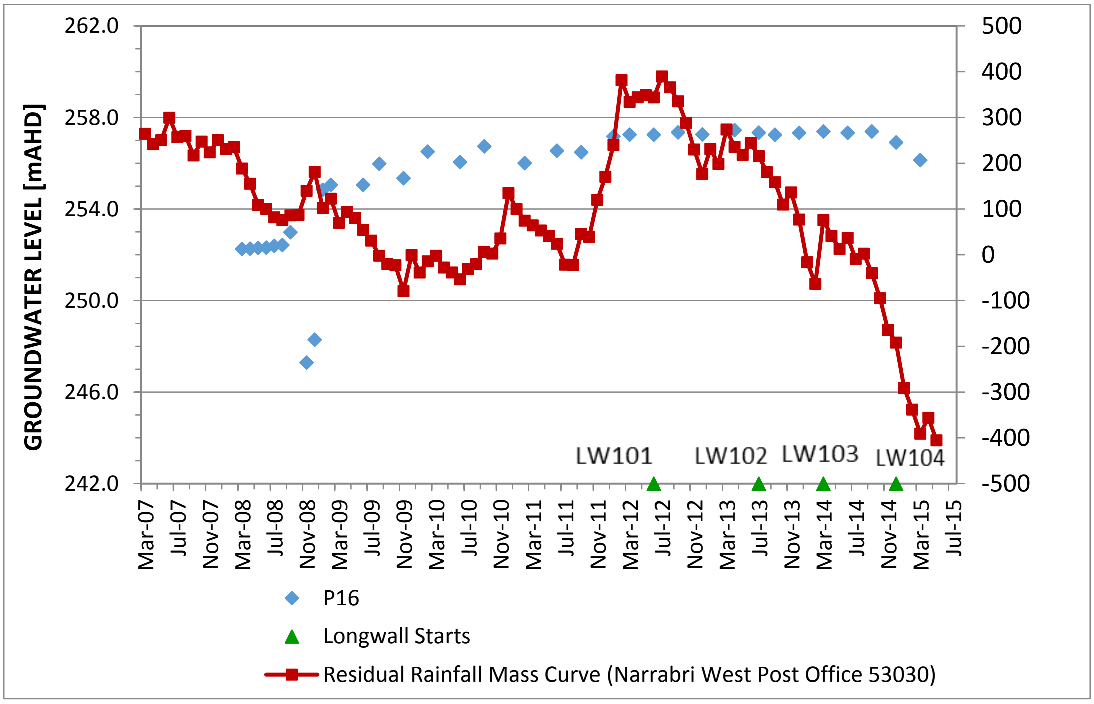


Figure D5. P16 Garrawilla Volcanics Hydrograph

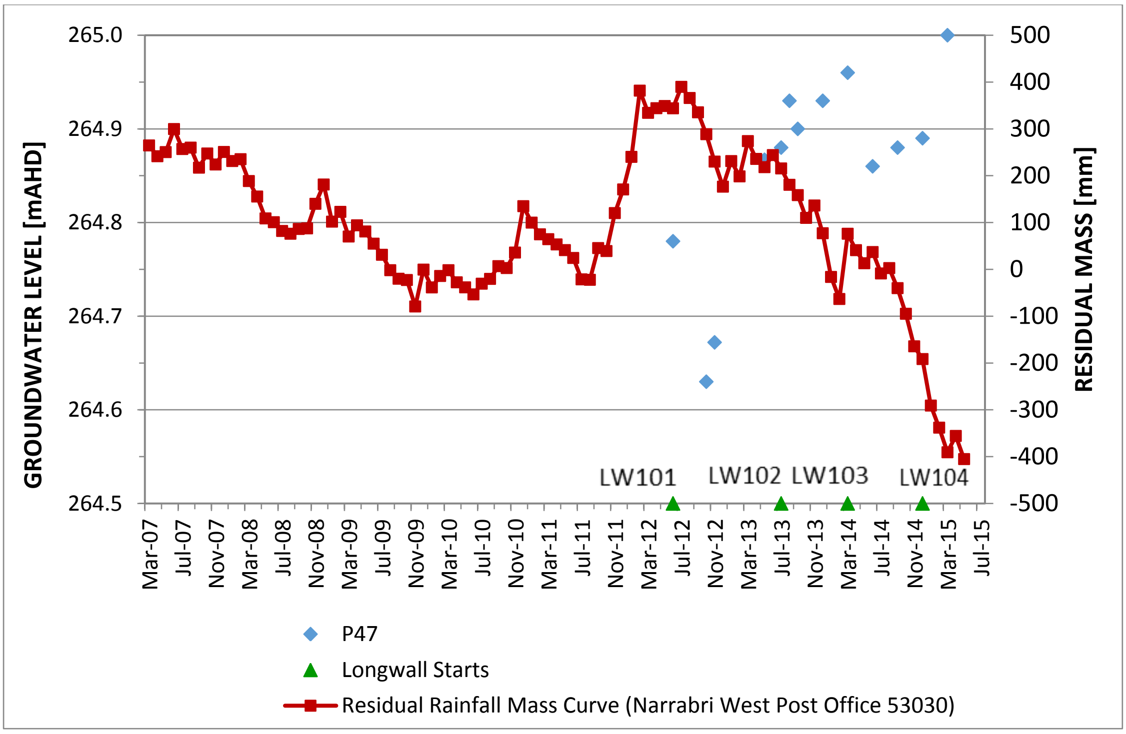


Figure D6. P47 Garrawilla Volcanics Hydrograph

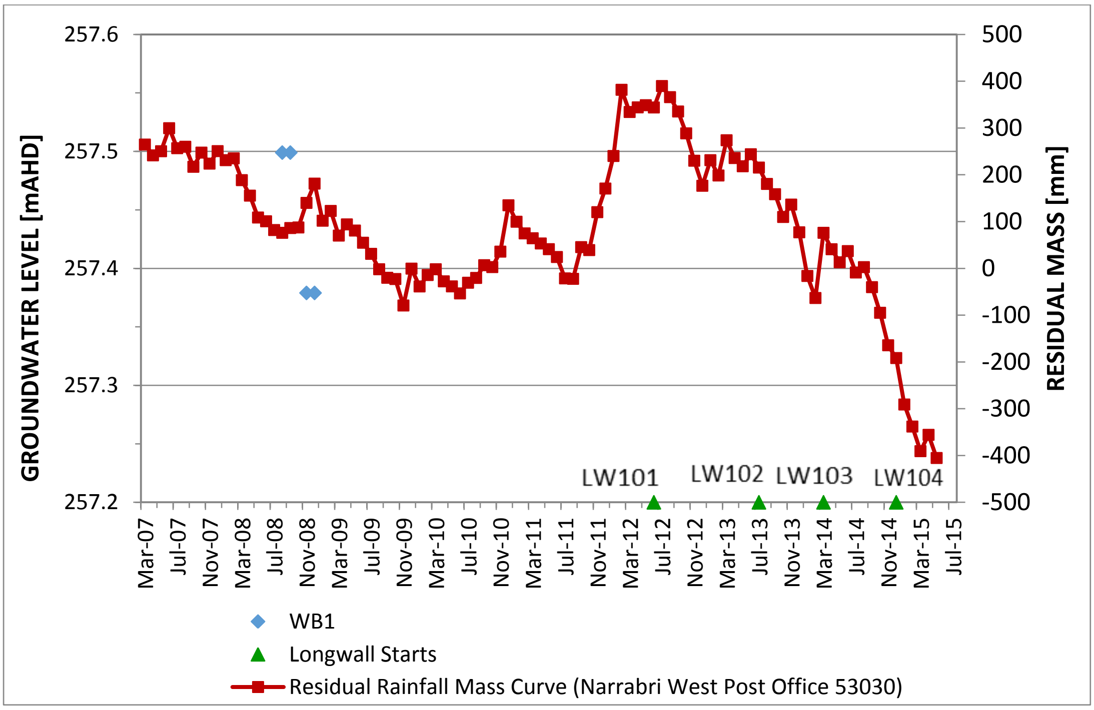


Figure D7. WB1 Garrawilla Volcanics Hydrograph

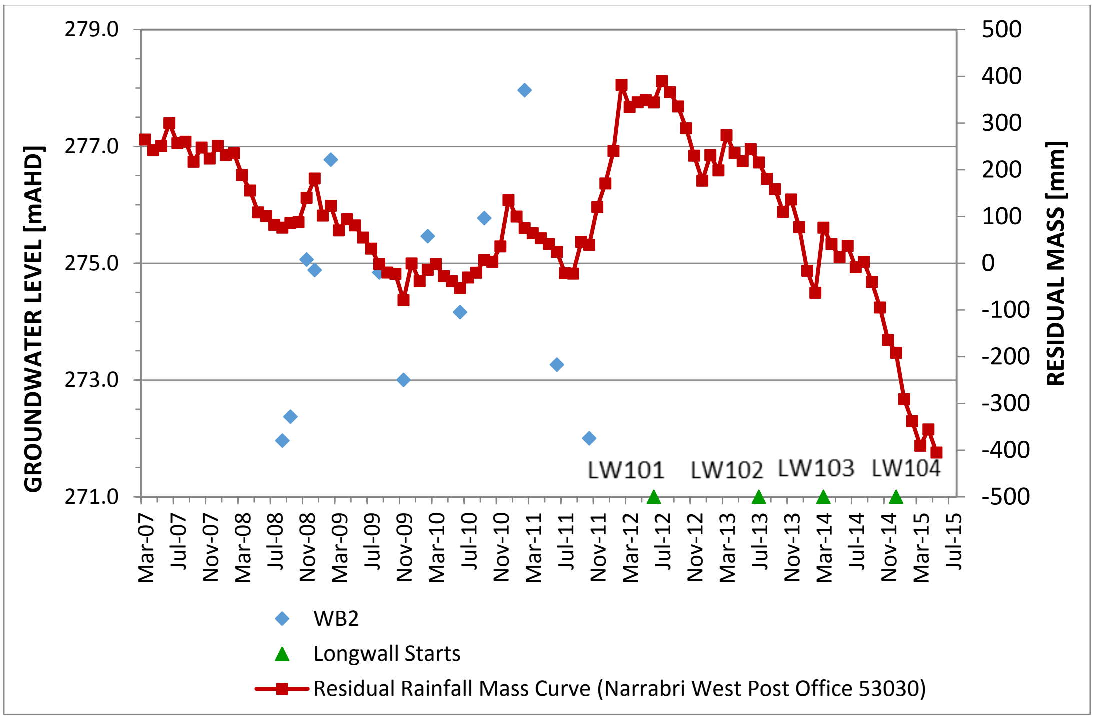


Figure D8. WB2 Garrawilla Volcanics Hydrograph

ATTACHMENT E

Napperby Formation Groundwater Hydrographs

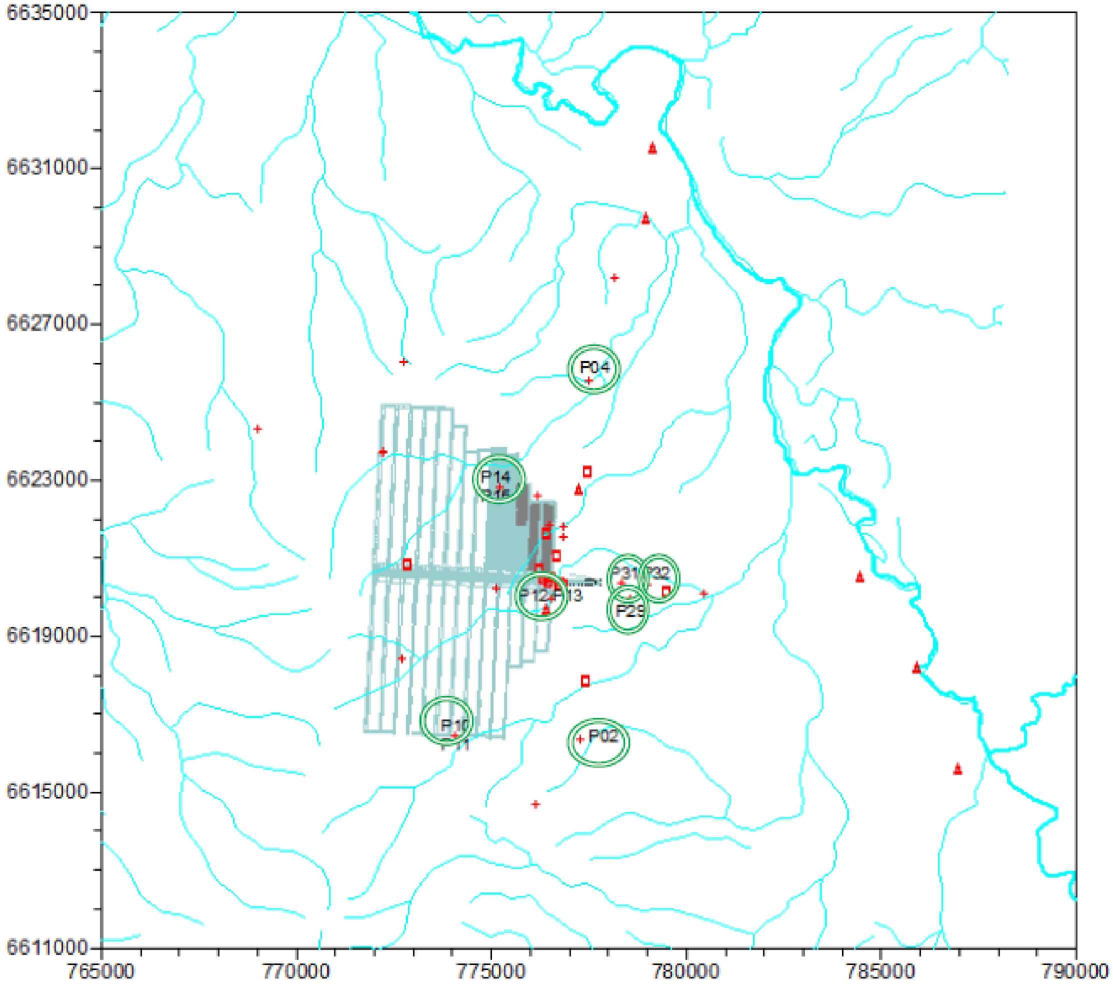


Figure E1. Groundwater Monitoring Network Location Map

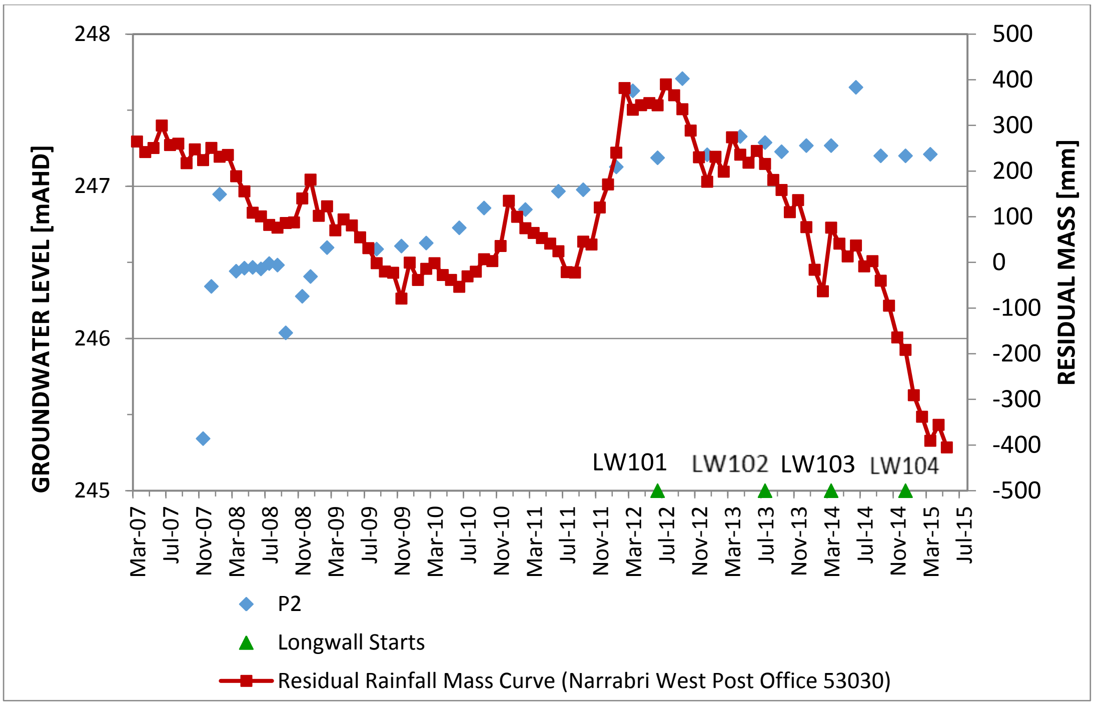


Figure E2. P2 Napperby Formation Hydrograph

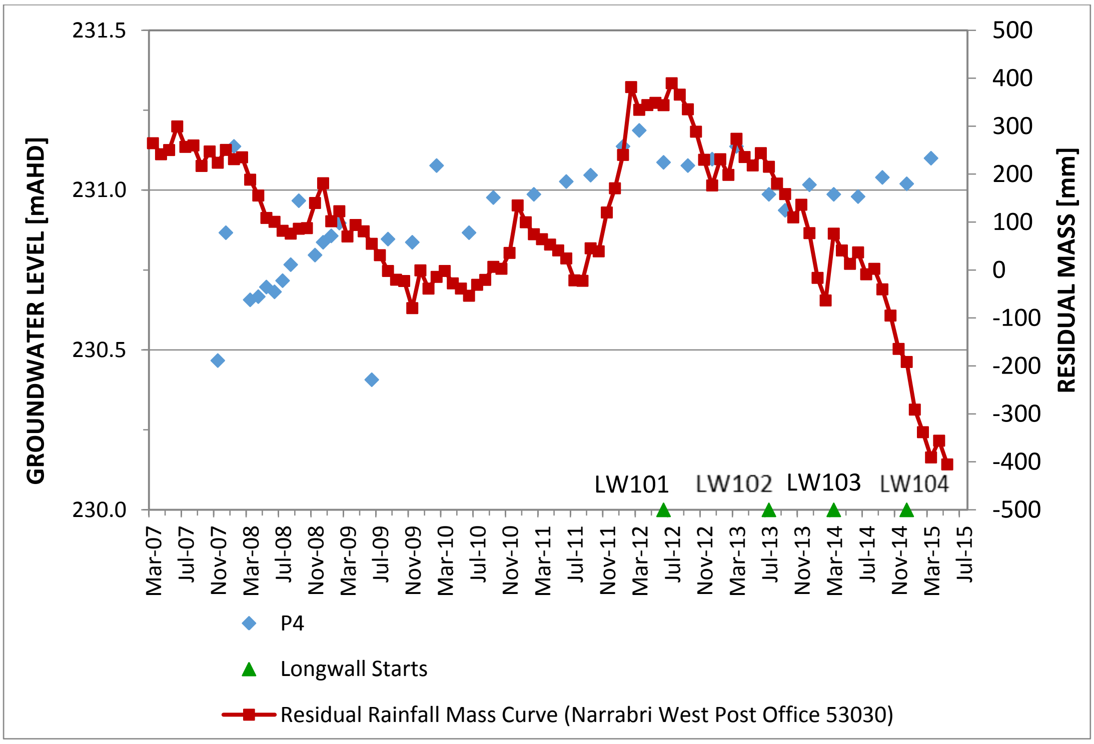


Figure E3. P4 Napperby Formation Hydrograph

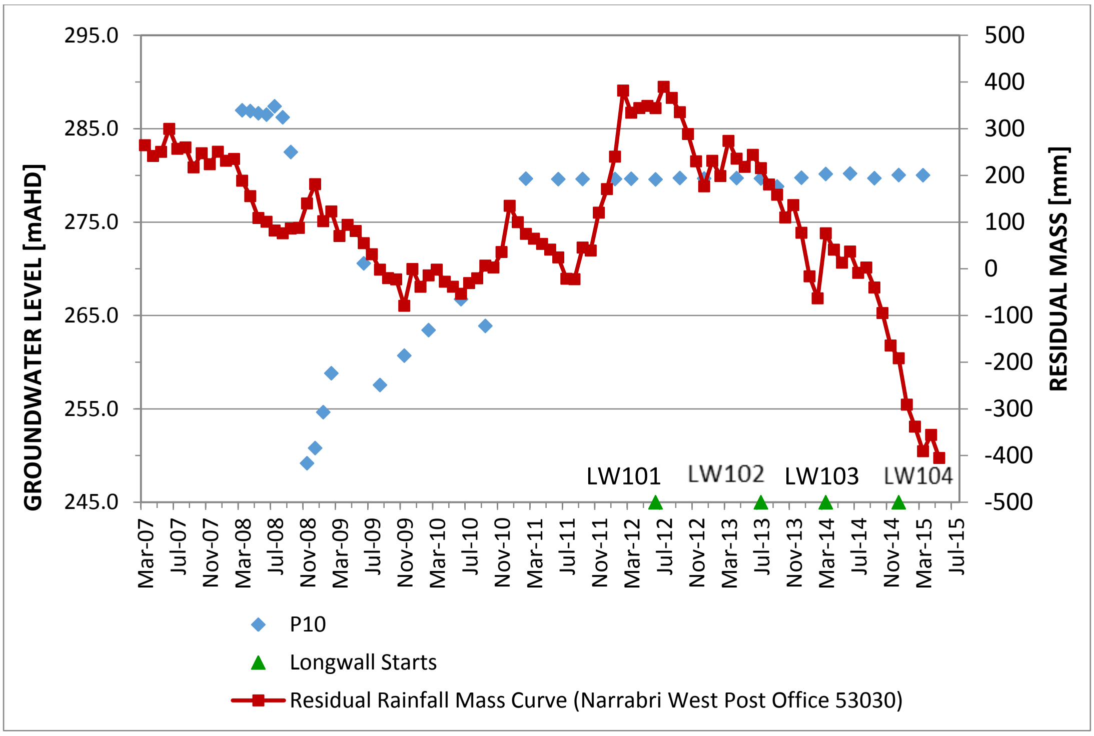


Figure E4. P10 Napperby Formation Hydrograph

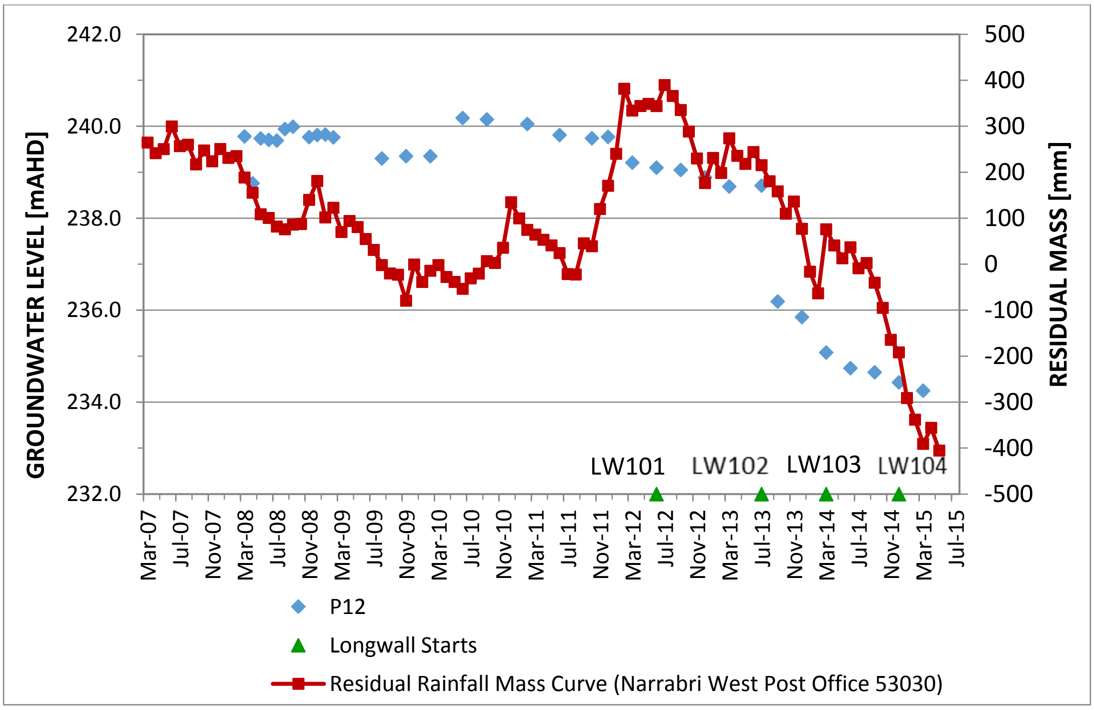


Figure E5. P12 Napperby Formation Hydrograph

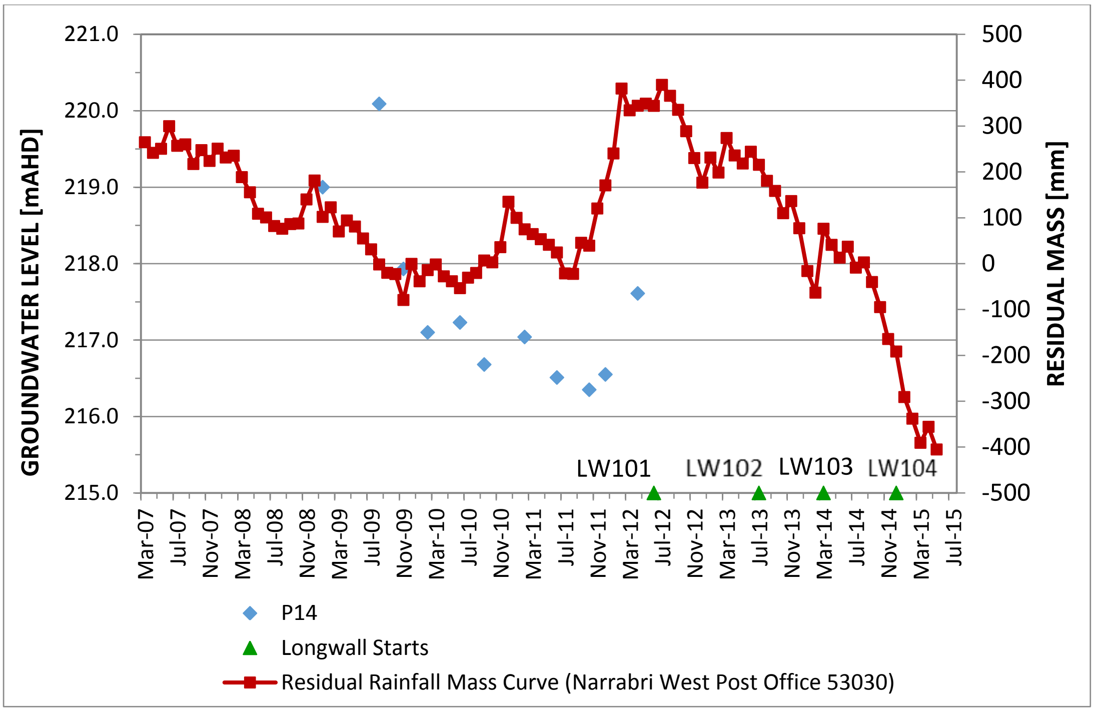


Figure E6. P14 Napperby Formation Hydrograph

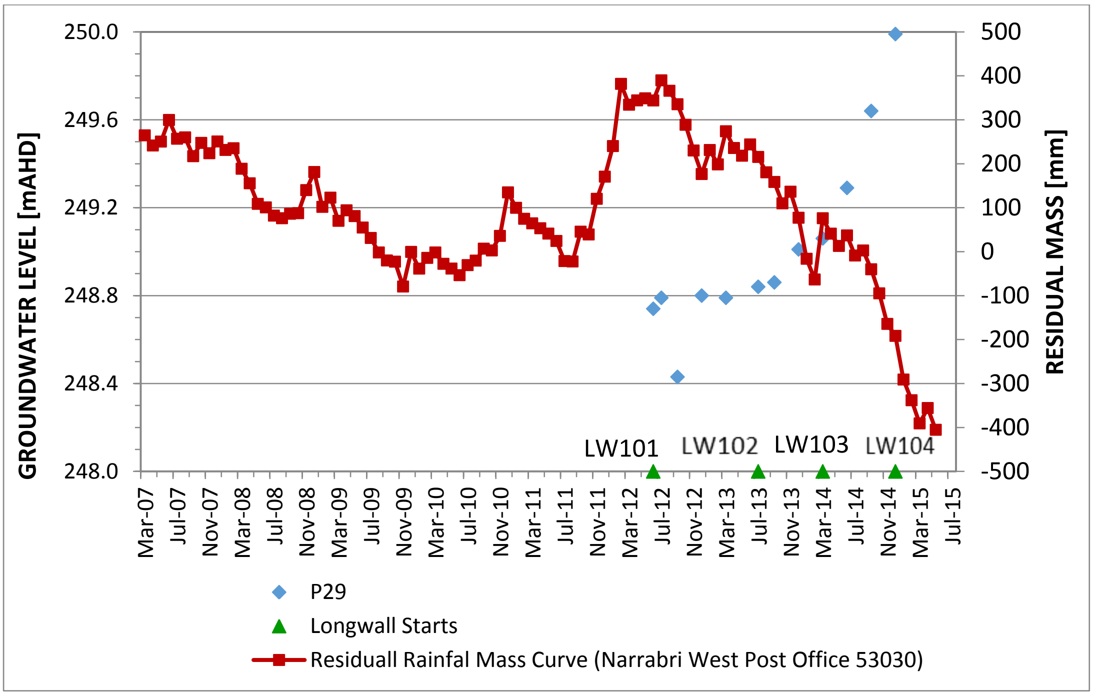


Figure E7. P29 Napperby Formation Hydrograph

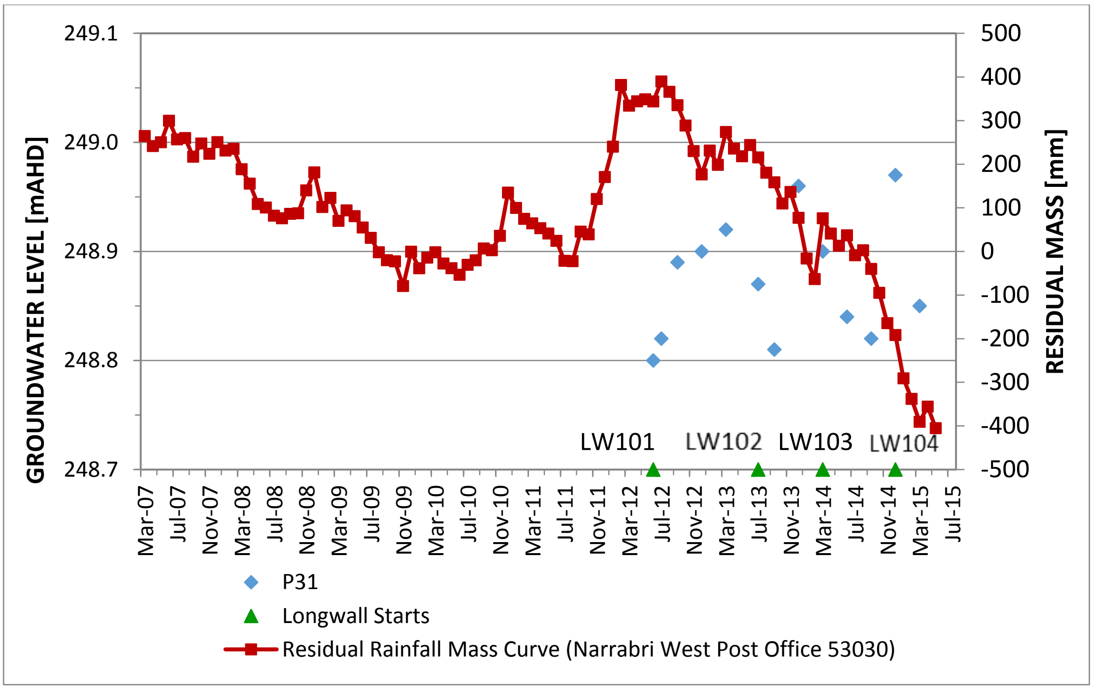


Figure E8. P31 Napperby Formation Hydrograph

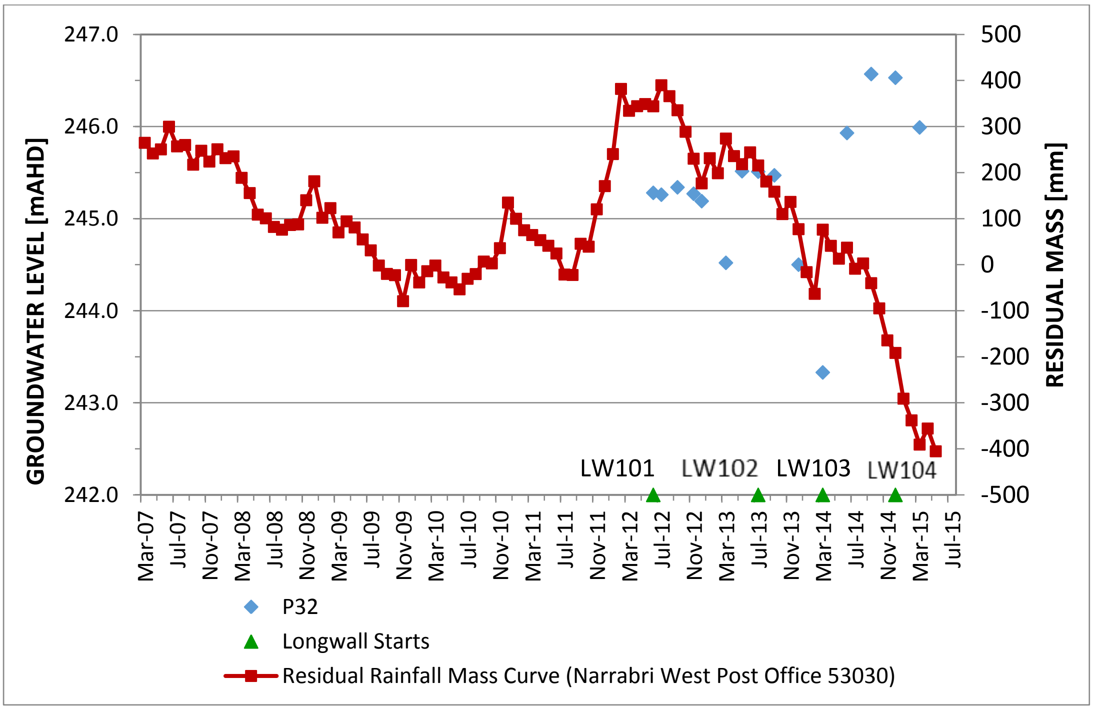


Figure E9. P32 Napperby Formation Hydrograph

ATTACHMENT F

Hoskissons Seam Groundwater Hydrographs

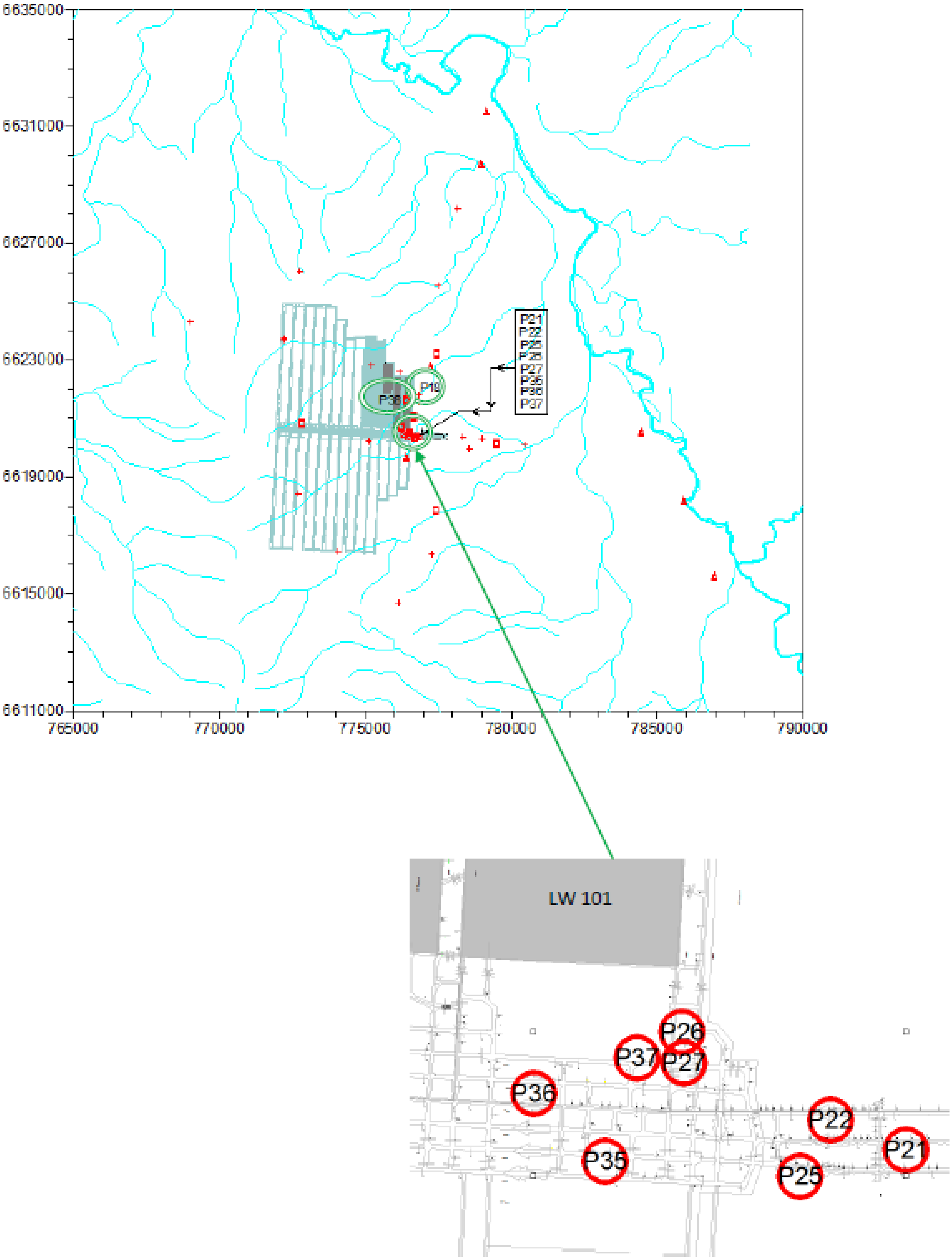


Figure F1. Groundwater Monitoring Network Location Map

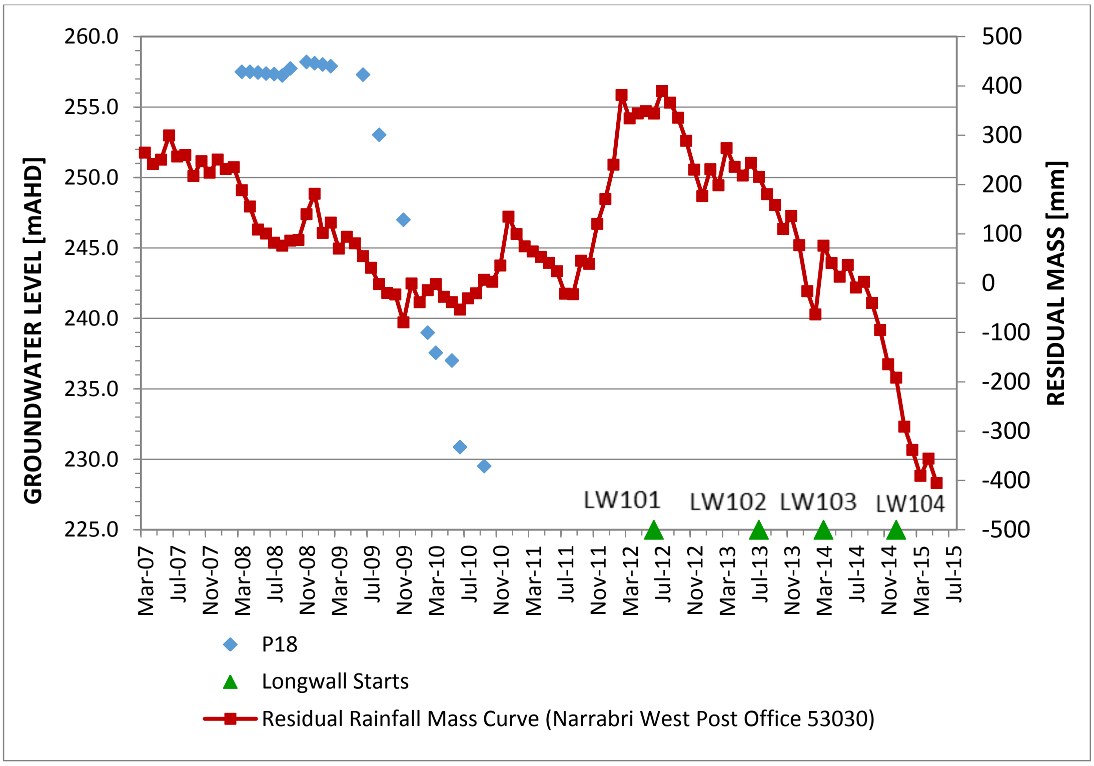


Figure F2. P18 Hoskissons Seam Hydrograph

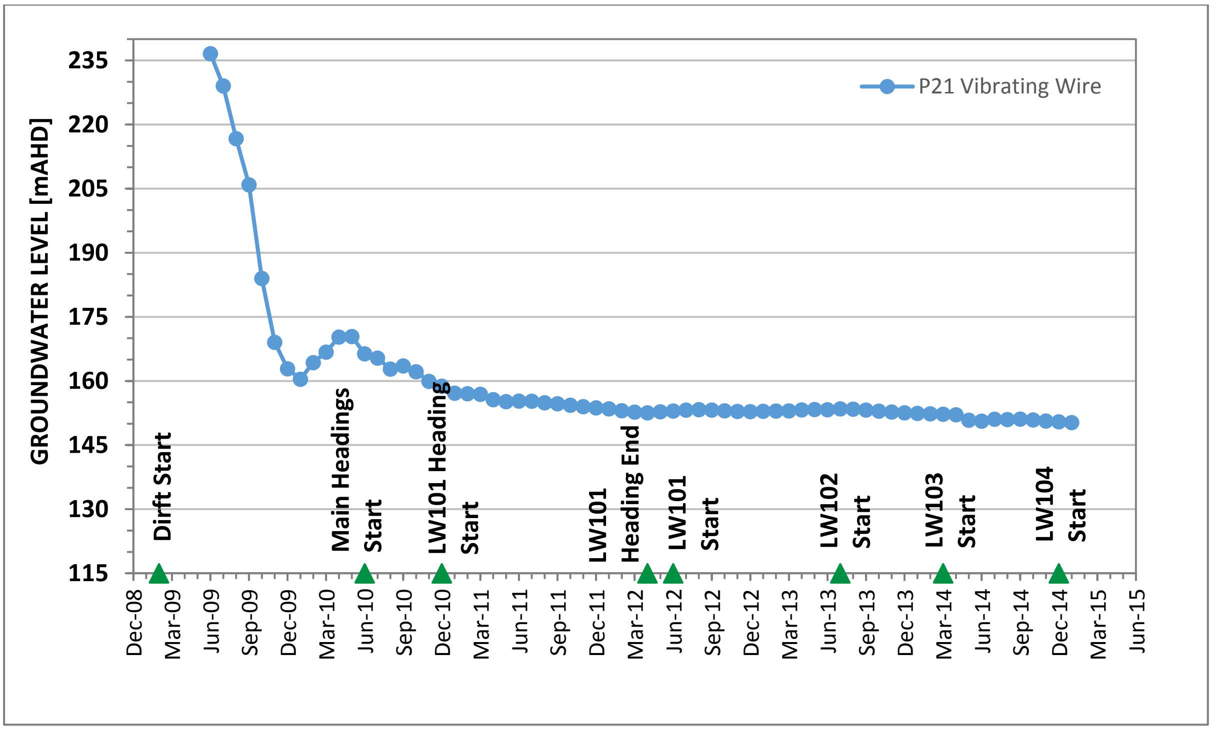


Figure F3. P21 Hoskissons Seam Hydrograph

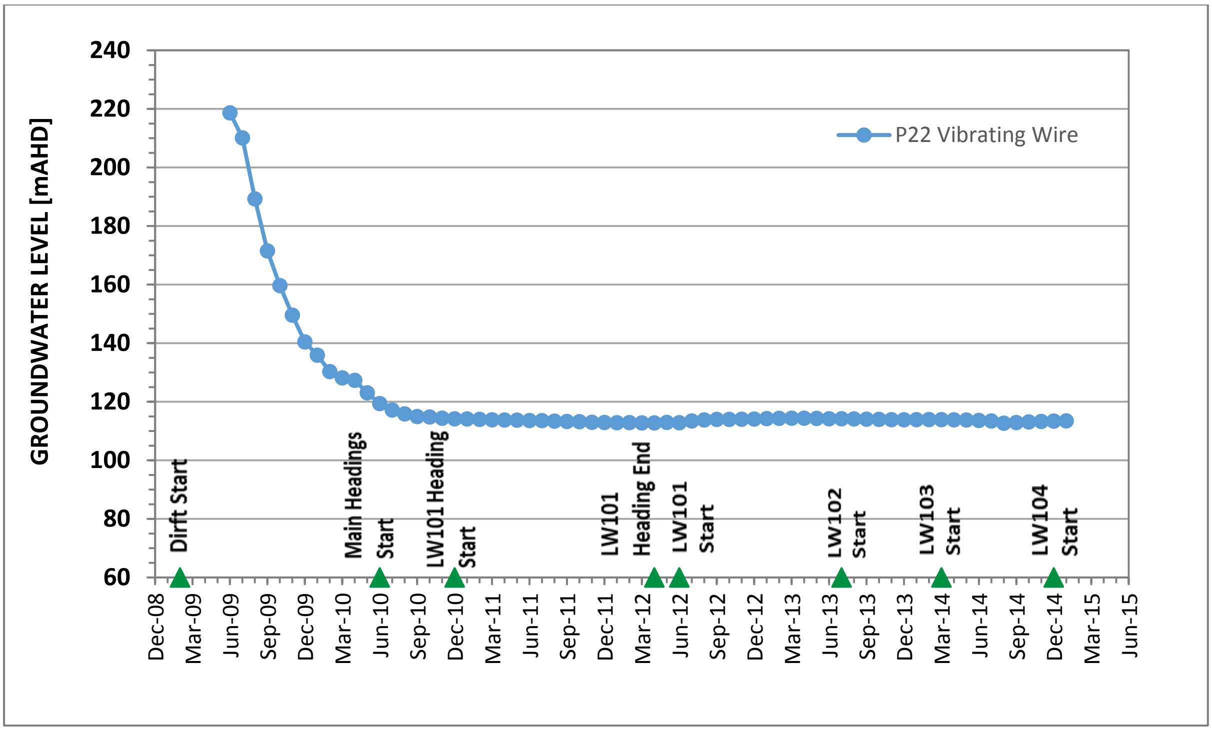


Figure F4. P22 Hoskissons Seam Hydrograph

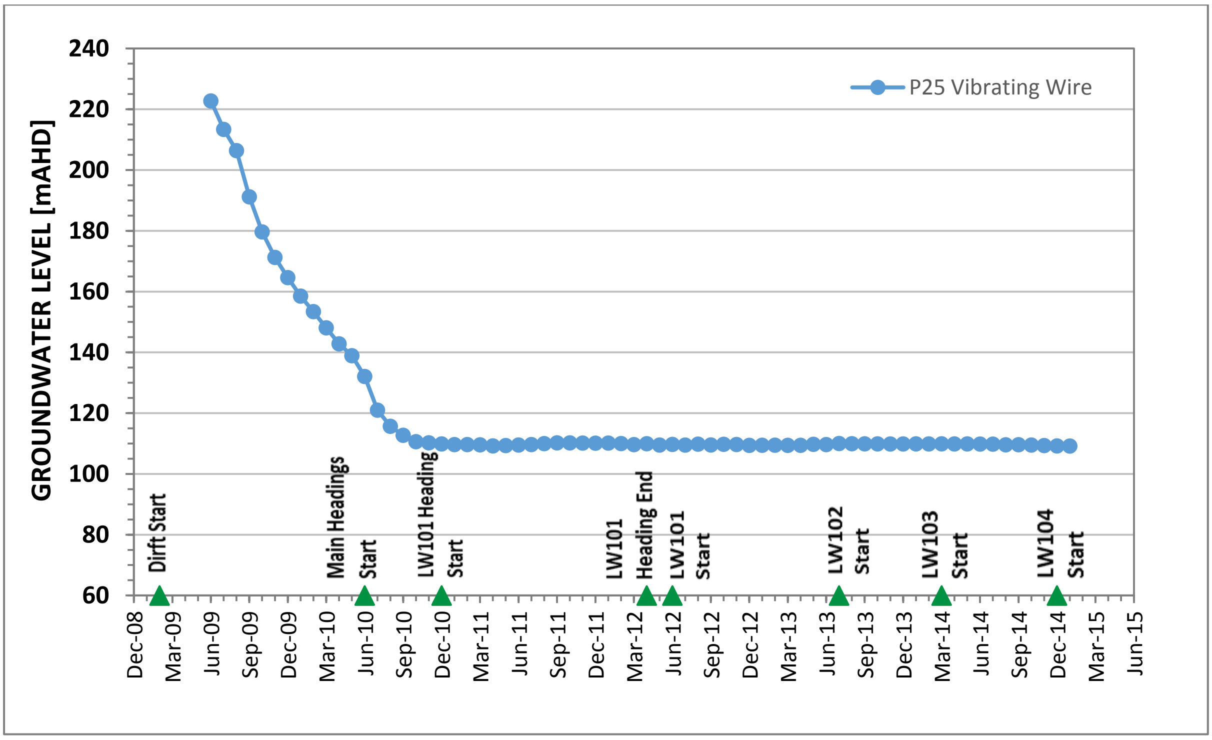


Figure F5. P25 Hoskissons Seam Hydrograph

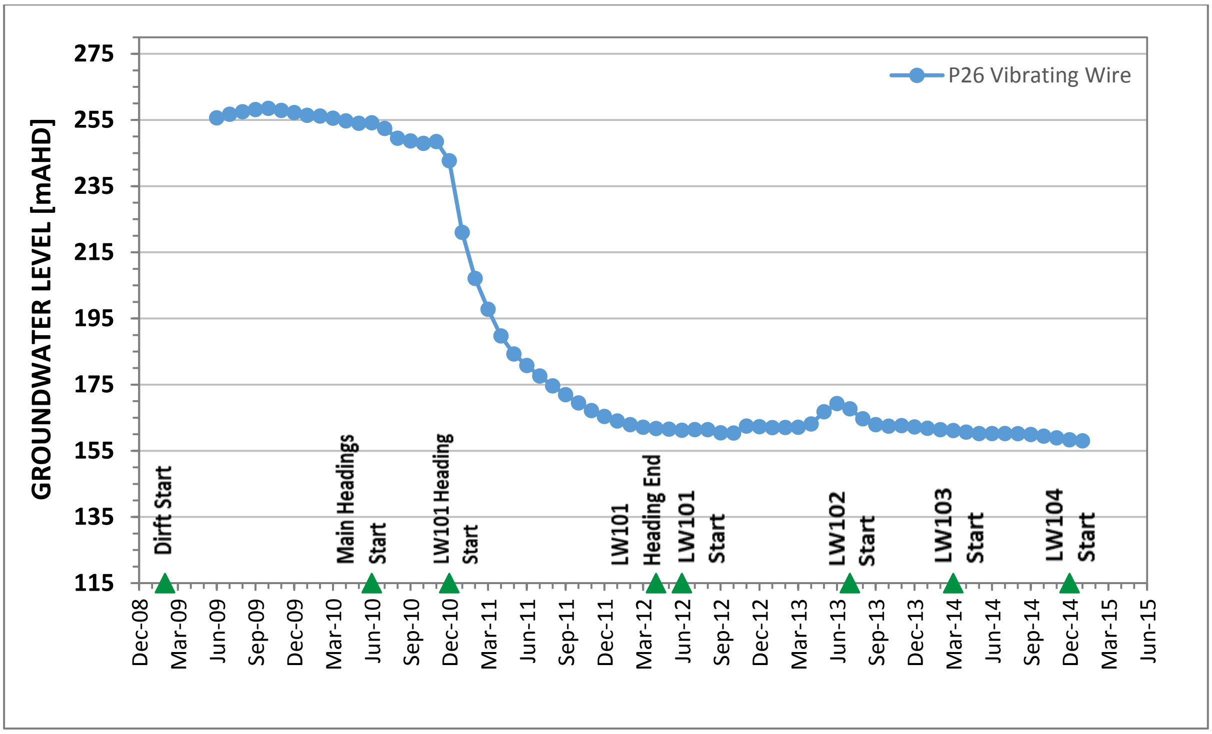


Figure F6. P26 Hoskissons Seam Hydrograph

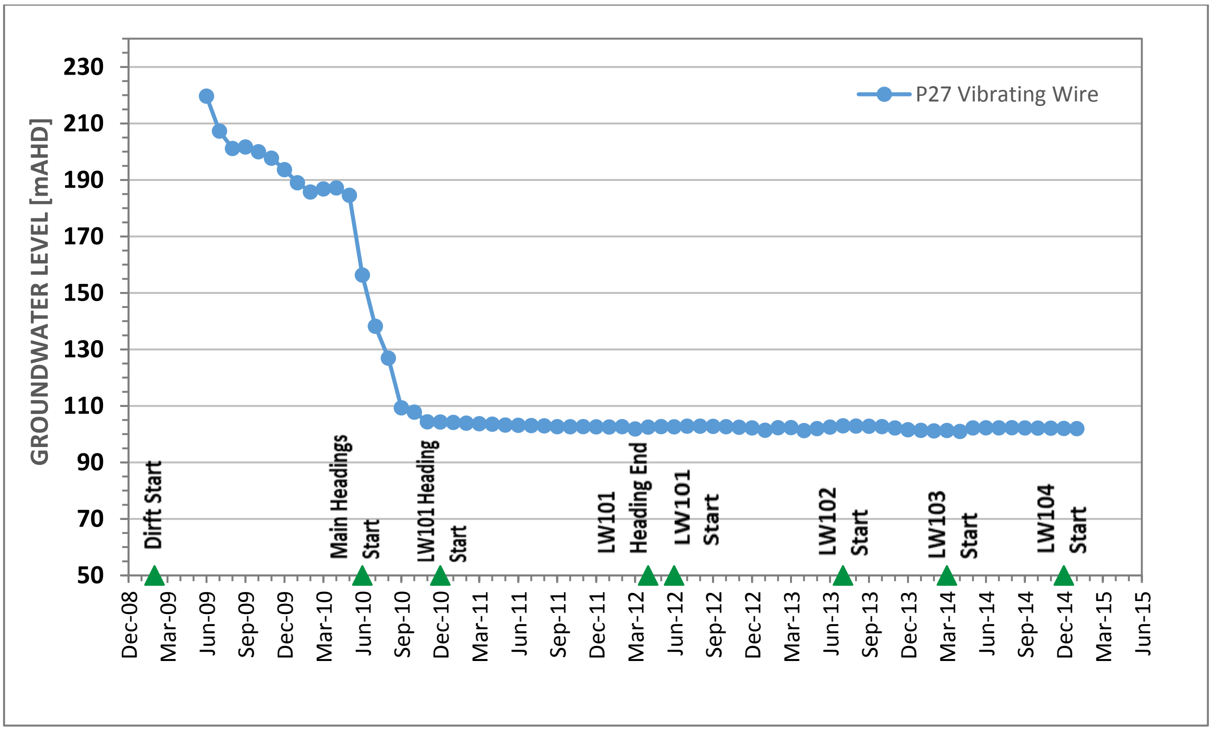


Figure F7. P27 Hoskissons Seam Hydrograph

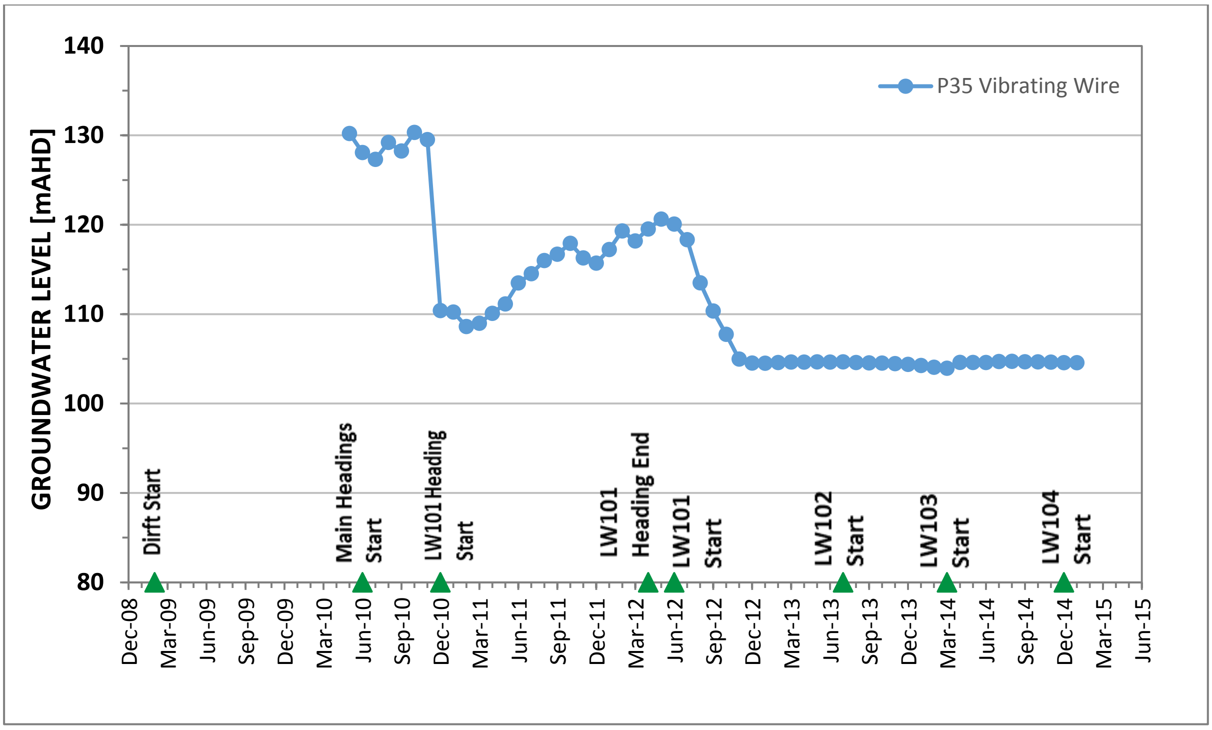


Figure F8. P35 Hoskissons Seam Hydrograph

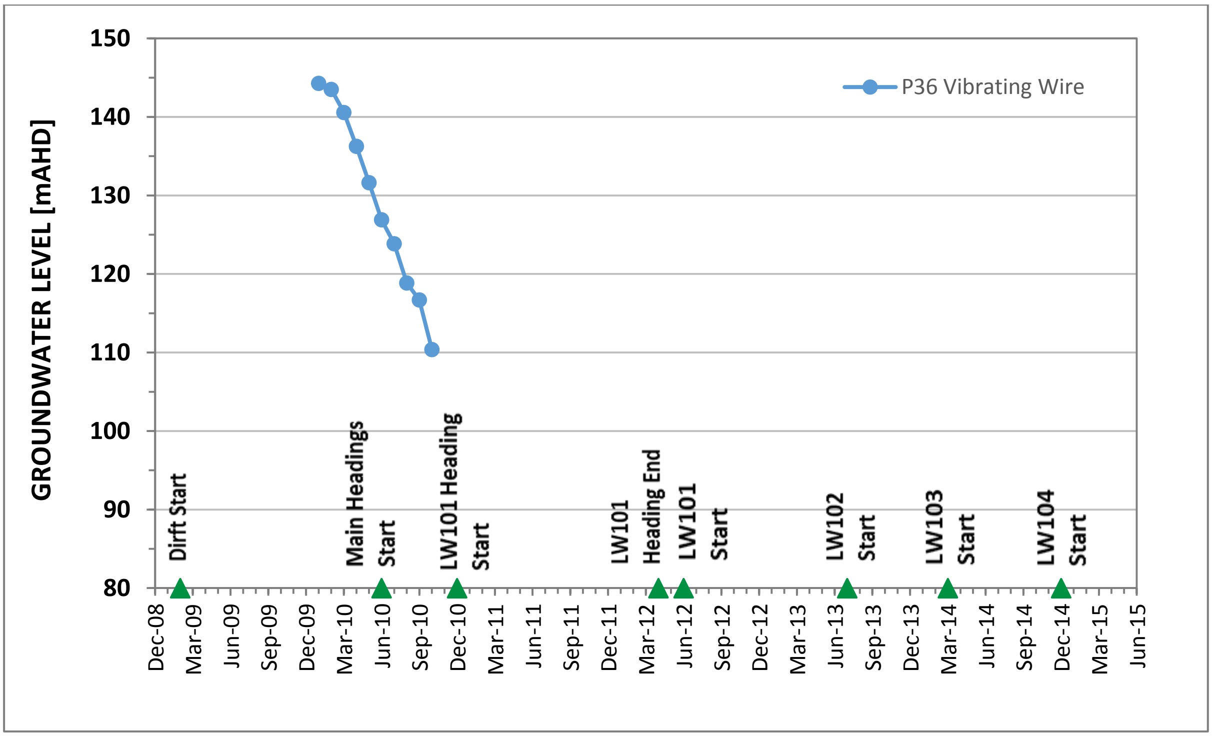


Figure F9. P36 Hoskissons Seam Hydrograph

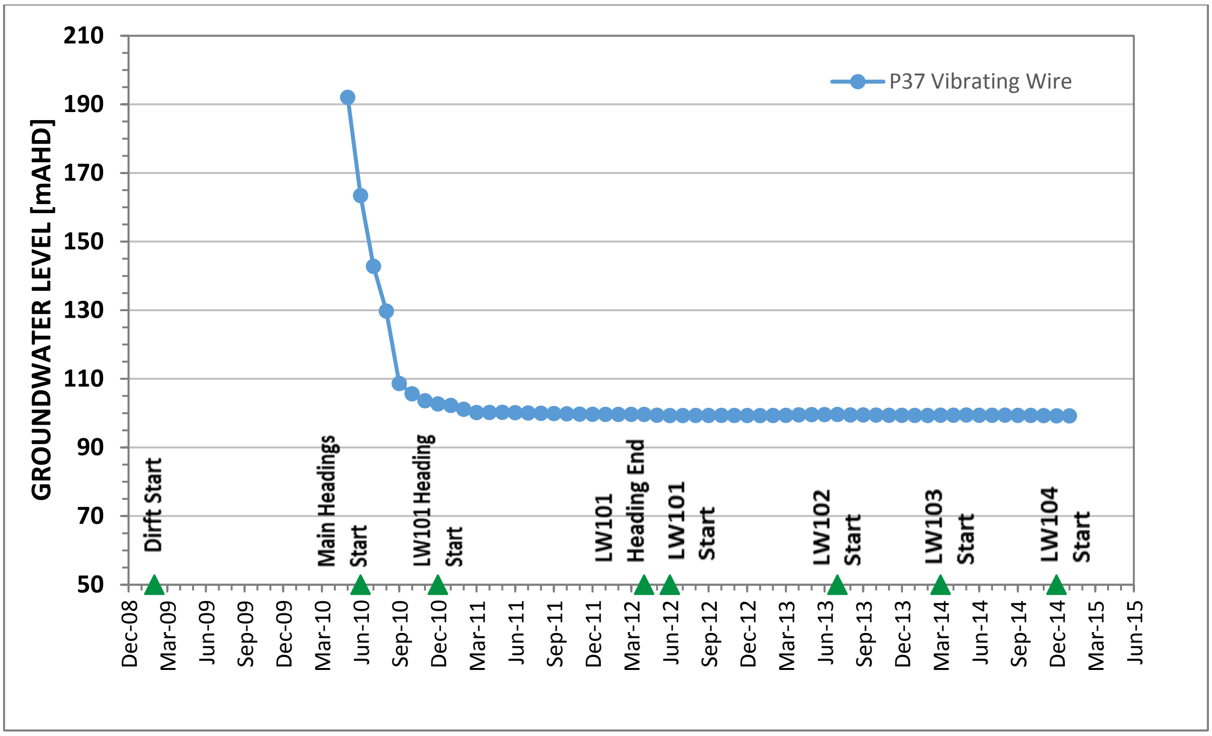


Figure F10. P37 Hoskissons Seam Hydrograph

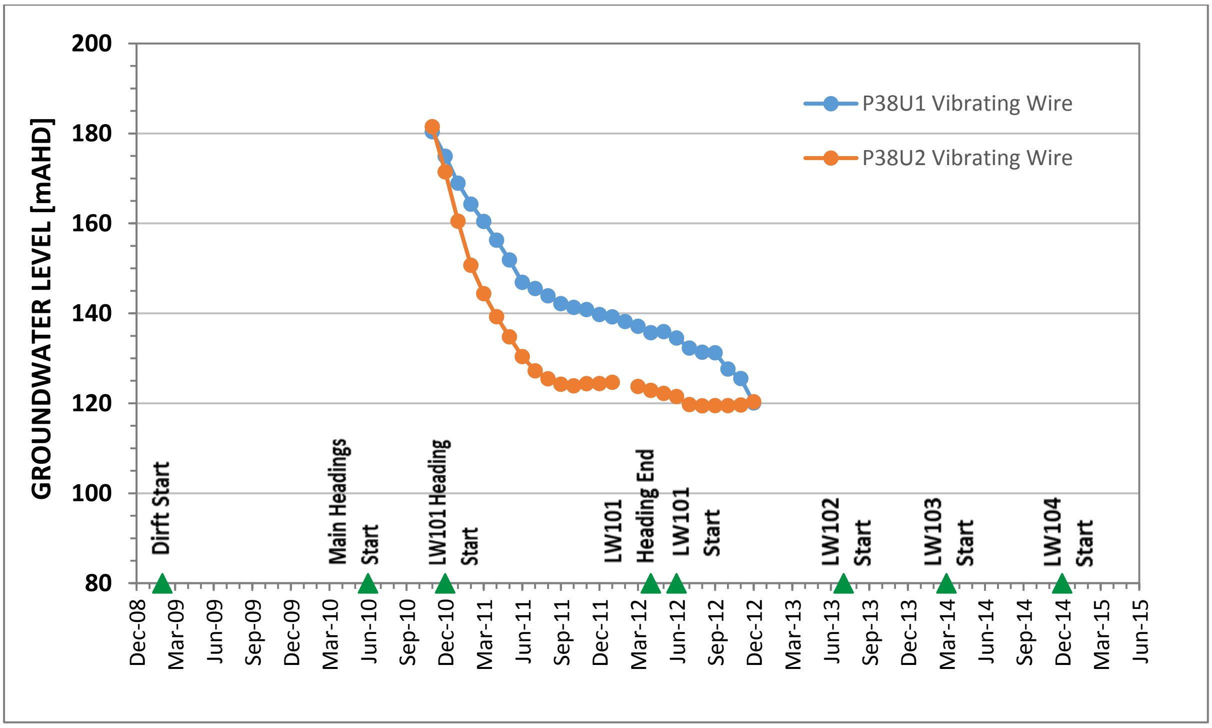


Figure F11. P38 Unit 1 and P38 Unit 2 Hoskissons Seam Hydrographs

ATTACHMENT G

Arkarula and Pamboola Formations Groundwater Hydrographs

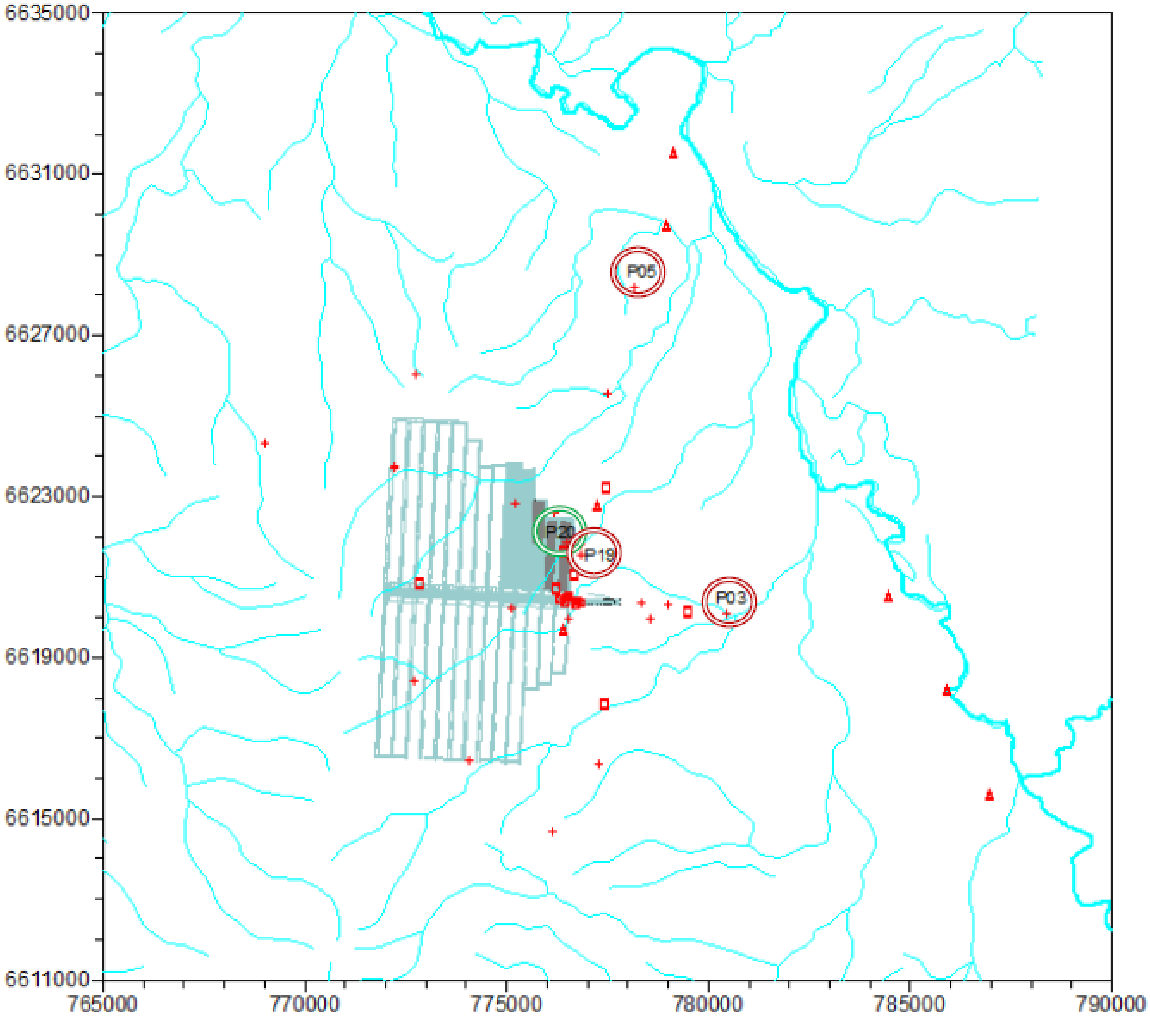


Figure G1. Groundwater Monitoring Network Location Map

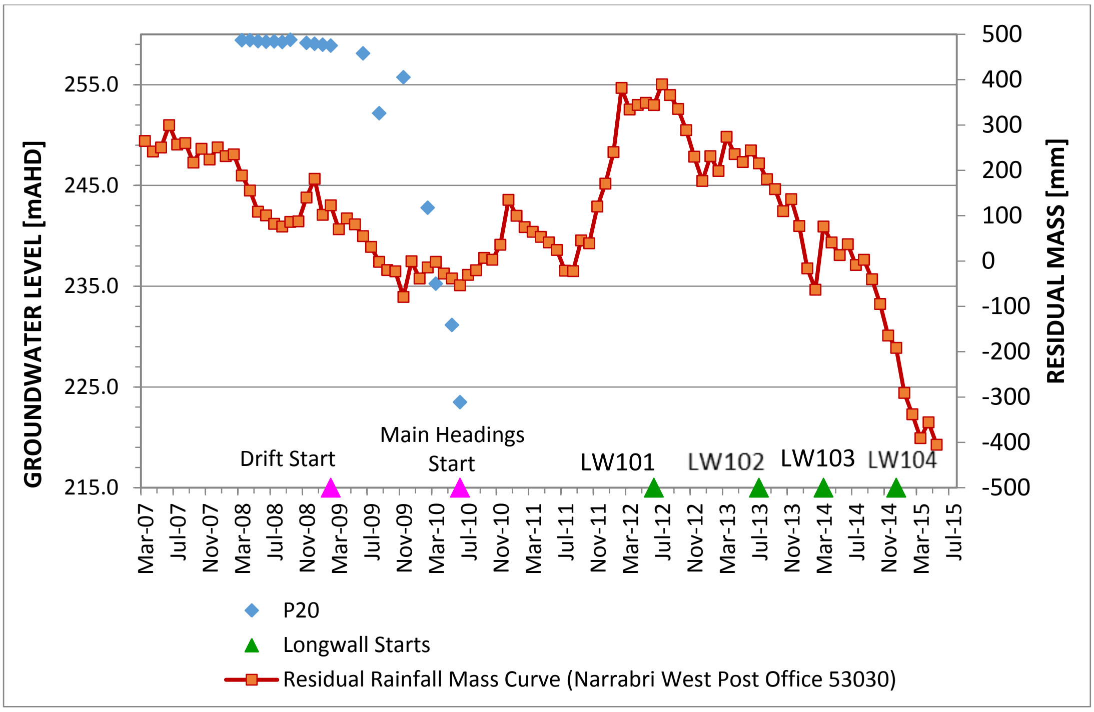


Figure G2. P20 Arkarula Formation Hydrograph

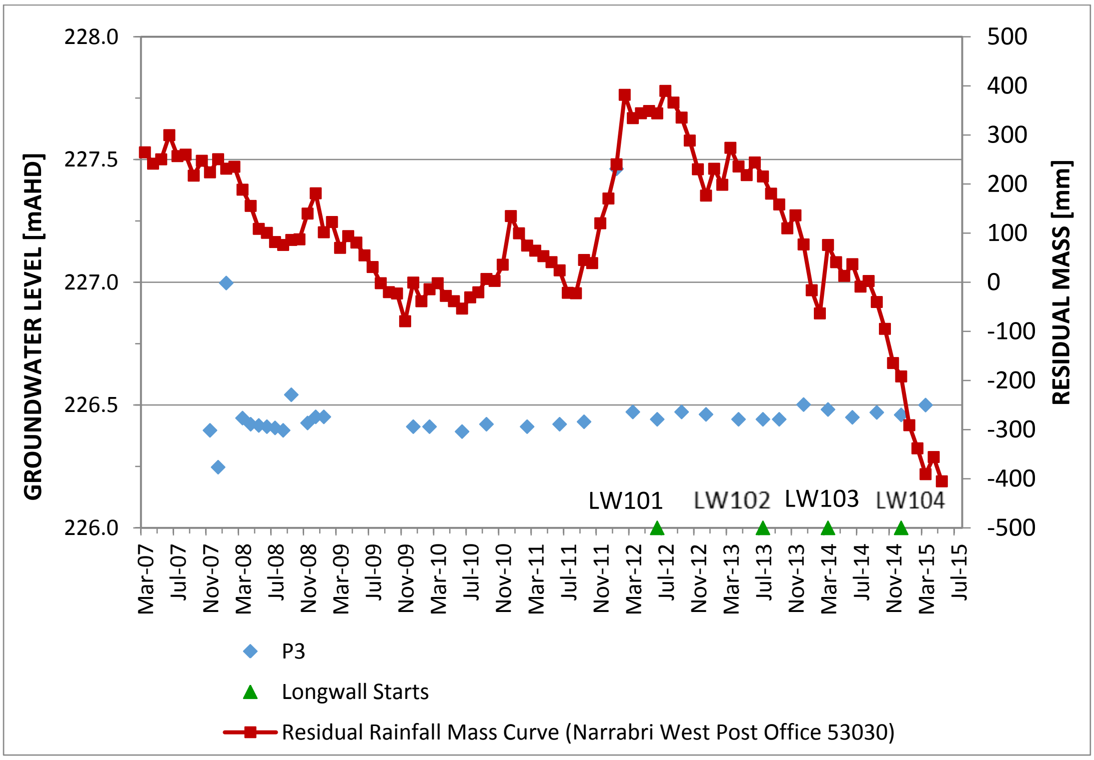


Figure G3. P3 Pamboola Formation Hydrograph

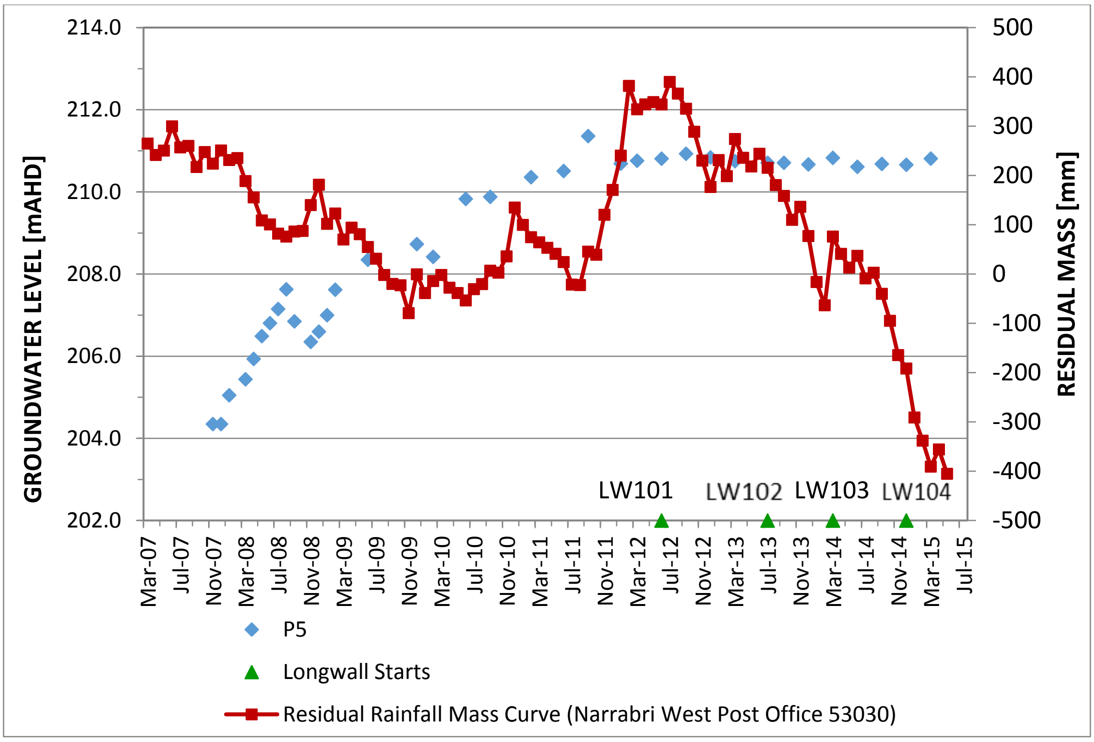


Figure G4. P5 Pamboola Formation Hydrograph

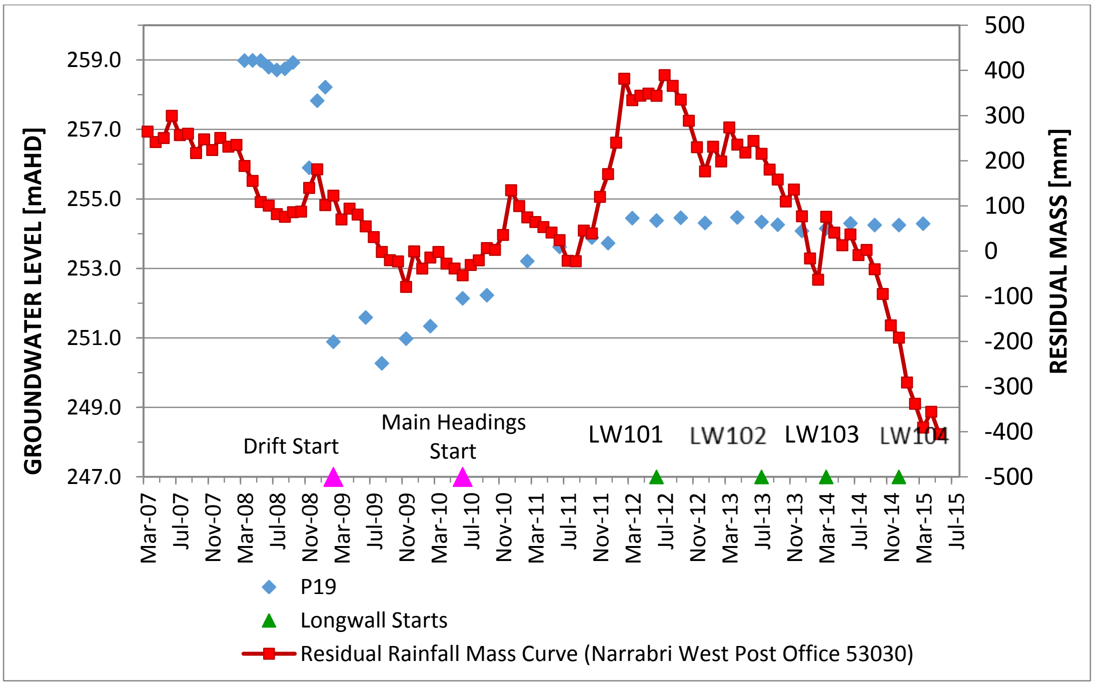


Figure G5. P19 Pamboola Formation Hydrograph

ATTACHMENT H

Multi-Level Vibrating Wire Groundwater Hydrographs

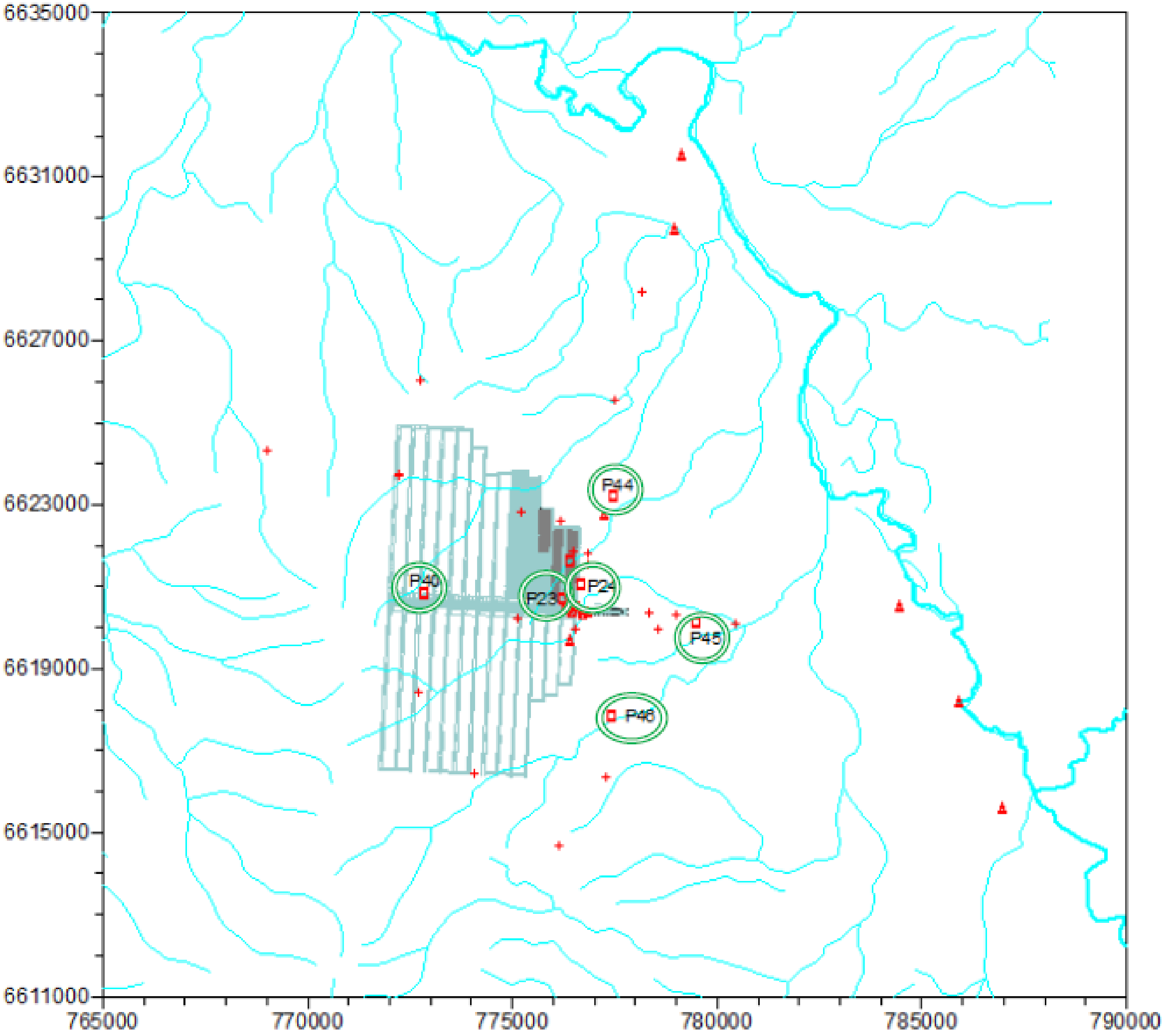


Figure H1. Groundwater Monitoring Network Location Map

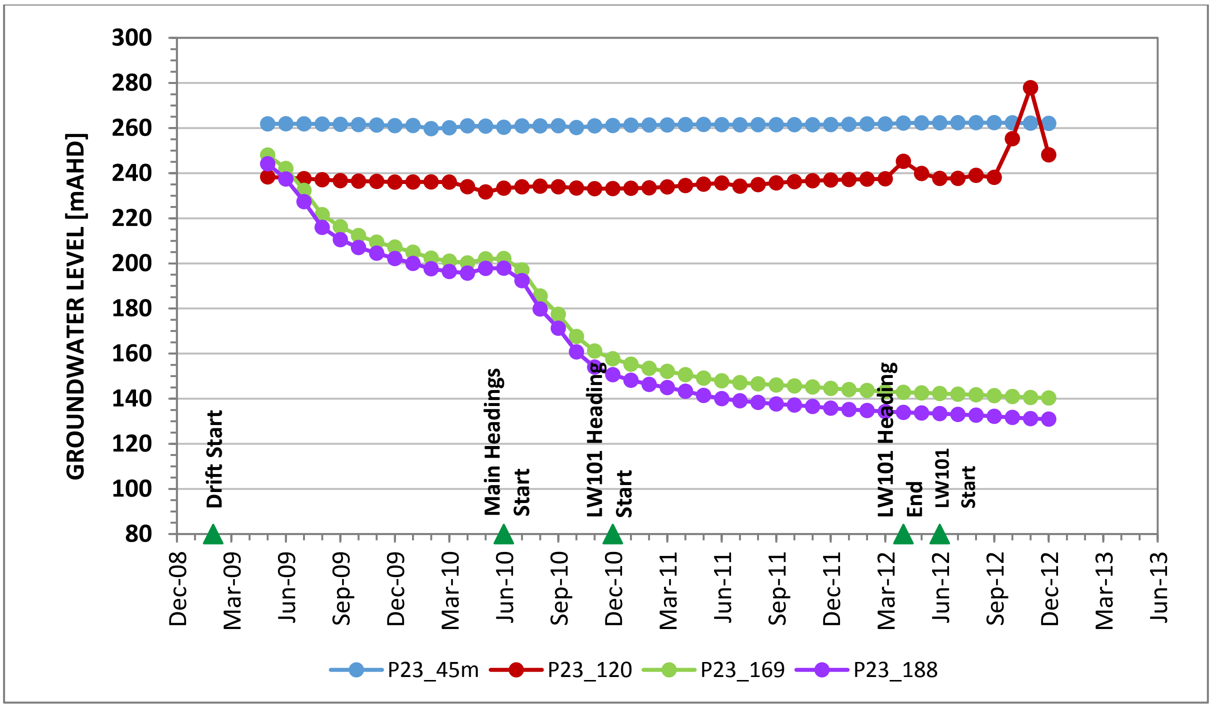


Figure H2. P23 Hydrographs (multi-level vibrating wire)

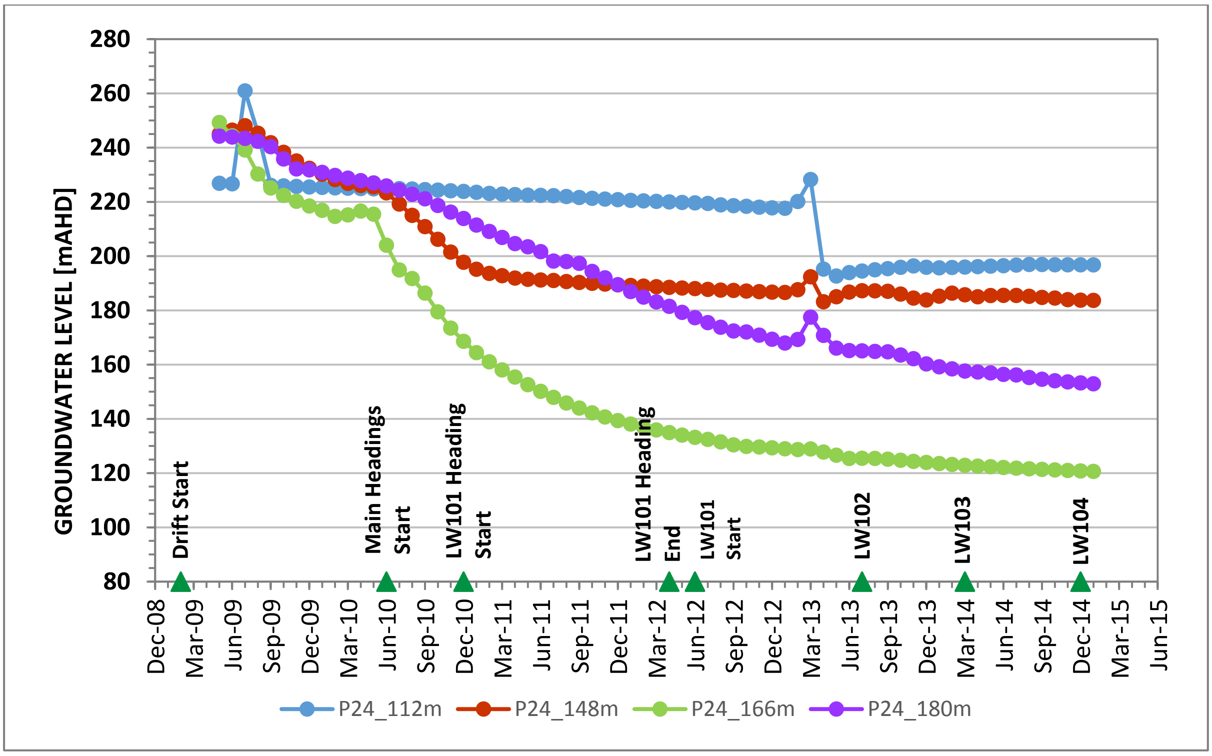


Figure H3. P24 Hydrographs (multi-level vibrating wire)

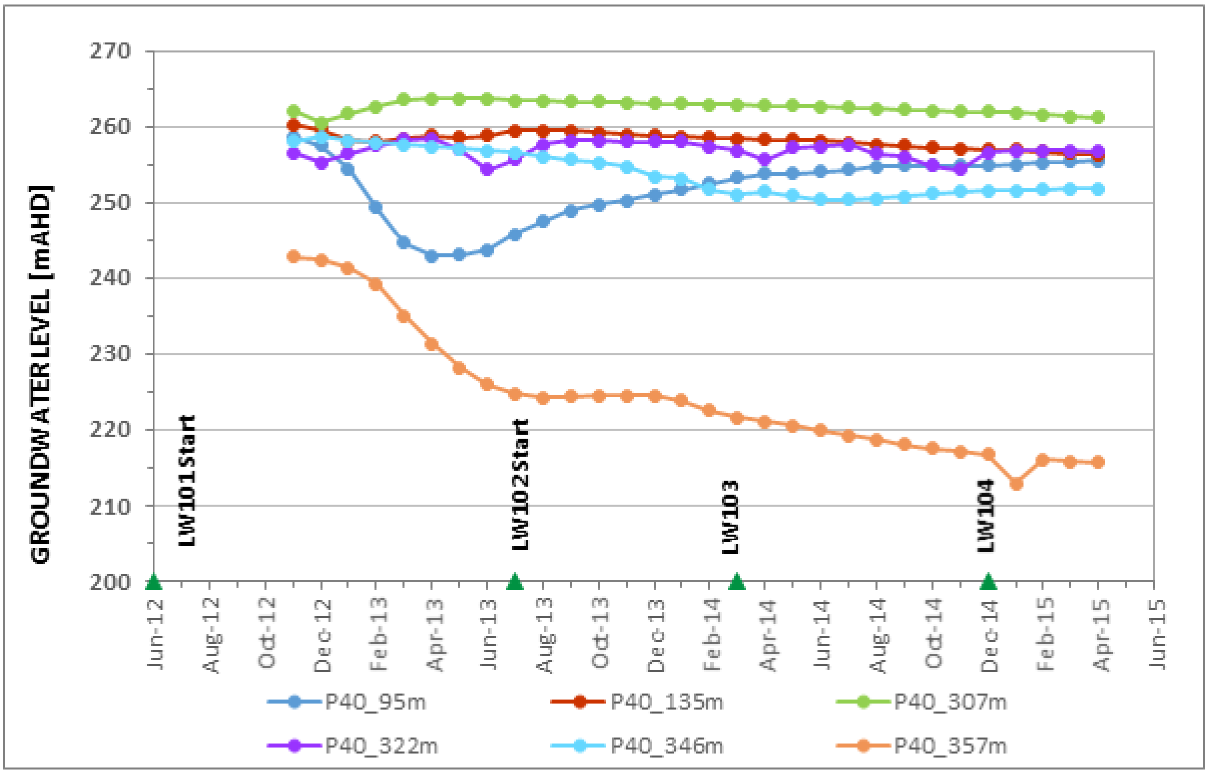


Figure H4. P40 Hydrographs (multi-level vibrating wire)

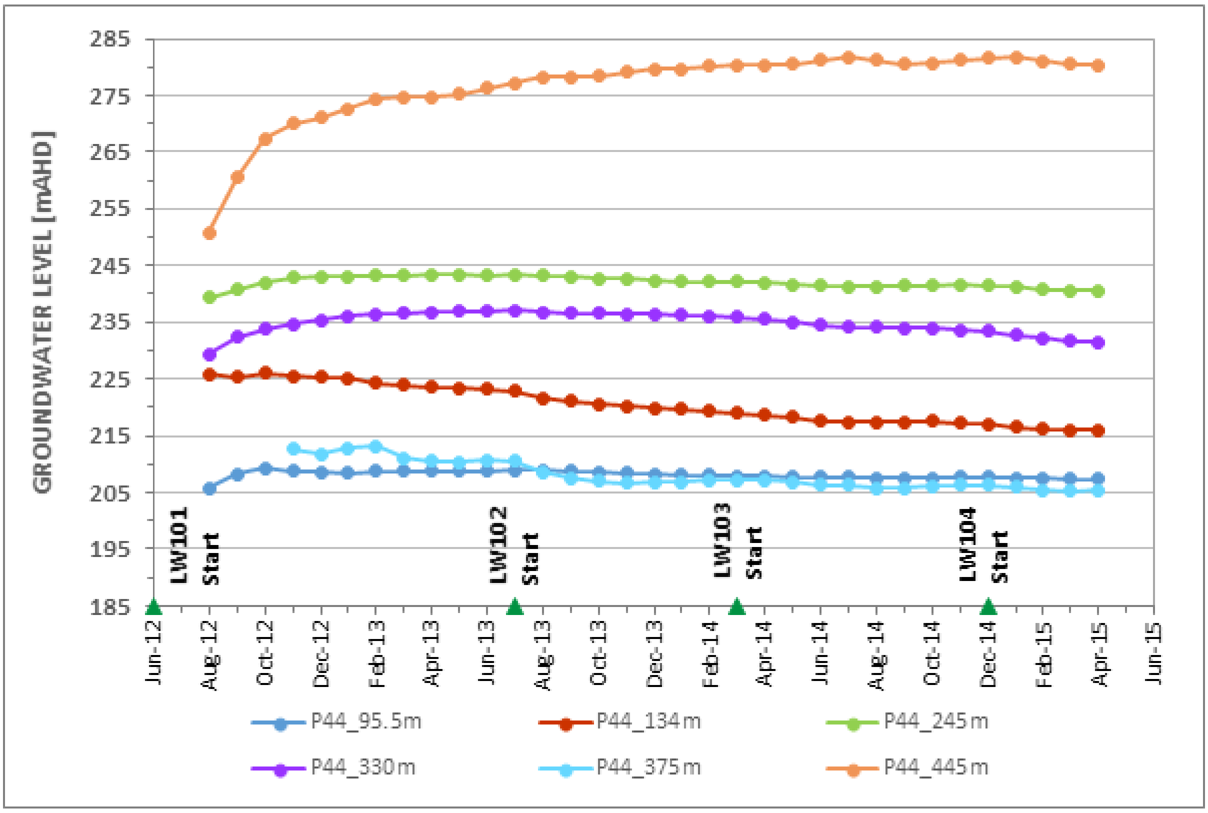


Figure H5. P44 Hydrographs (multi-level vibrating wire)

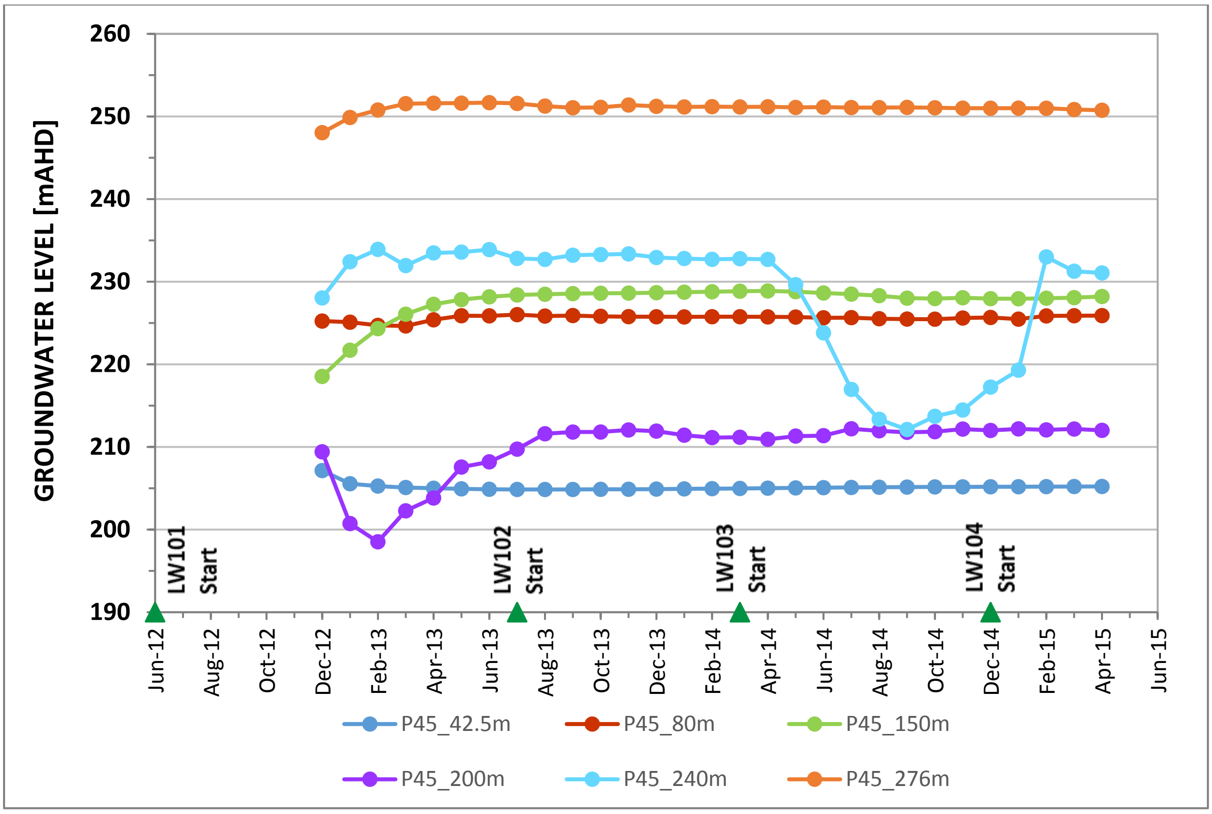


Figure H6. P45 Hydrographs (multi-level vibrating wire)

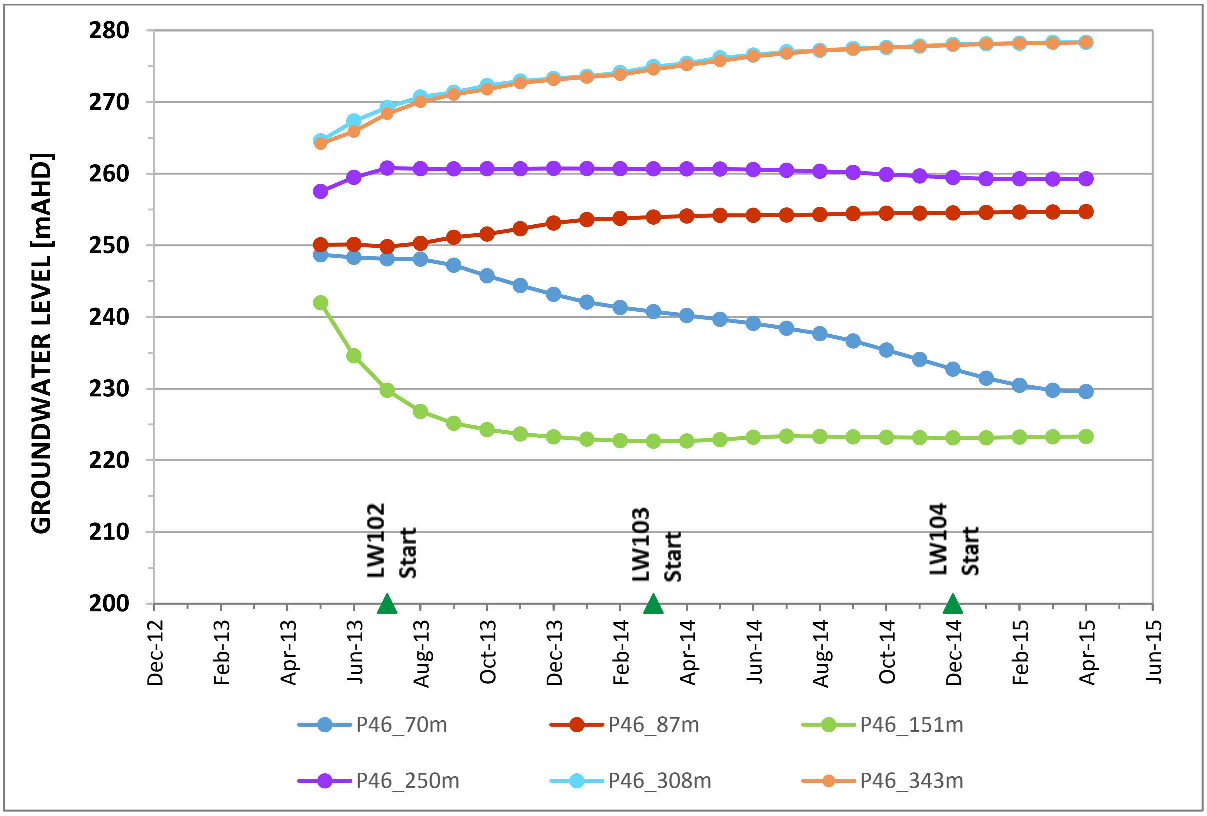


Figure H7. P46 Hydrographs (multi-level vibrating wire)

ATTACHMENT I

Groundwater

Salinity

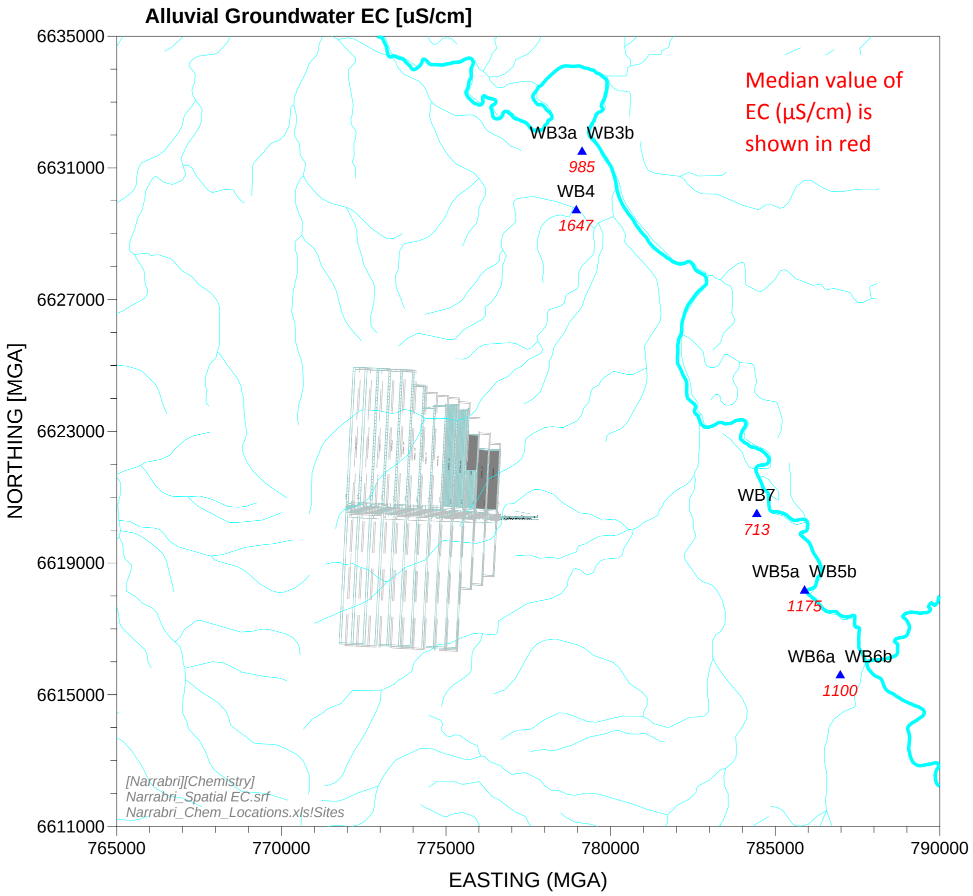


Figure I1a. Salinity Monitoring Site Locations and Median Value - Alluvium

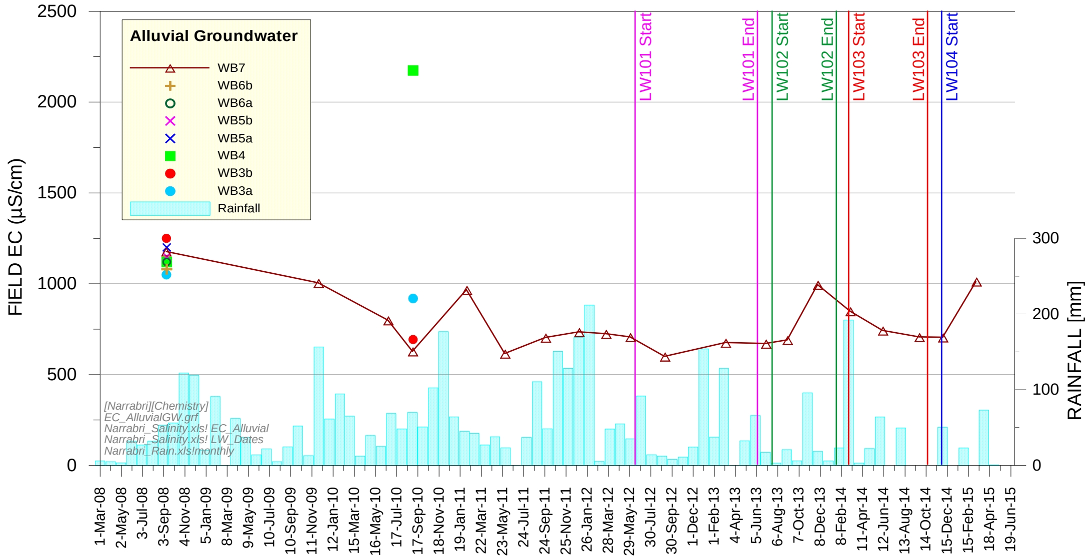


Figure I1b. Temporal Salinity Data - Alluvium

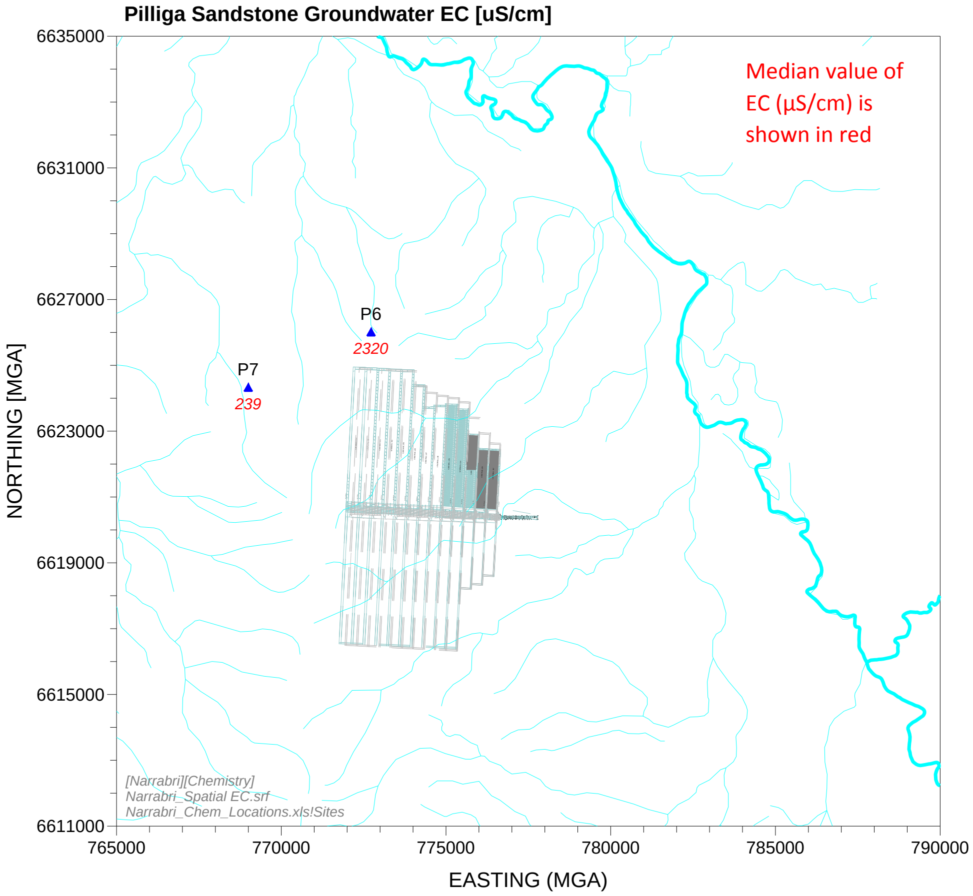


Figure I2a. Salinity Monitoring Site Locations and Median Value – Pilliga Sandstone

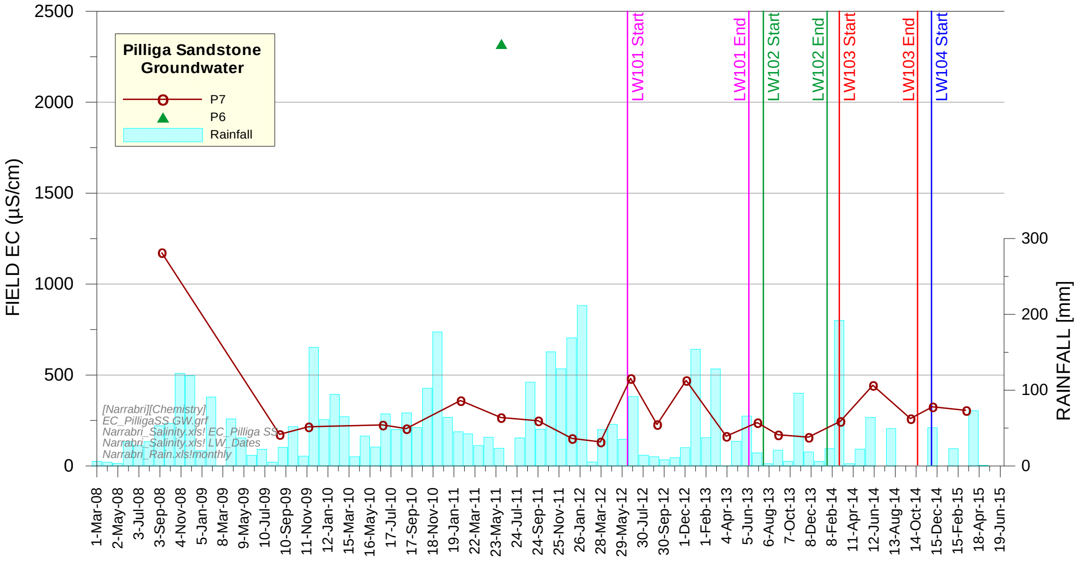


Figure I2b. Temporal Salinity Data – Pilliga Sandstone

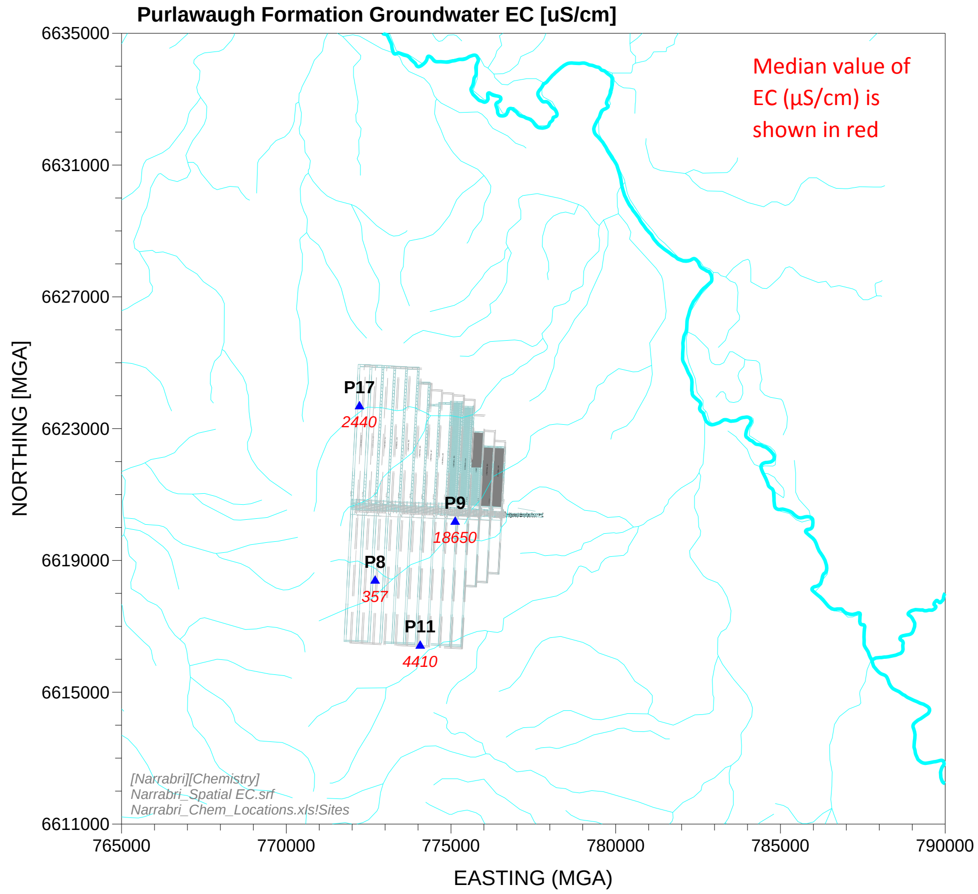


Figure I3a. Salinity Monitoring Site Locations and Median Value – Purlawaugh Formation

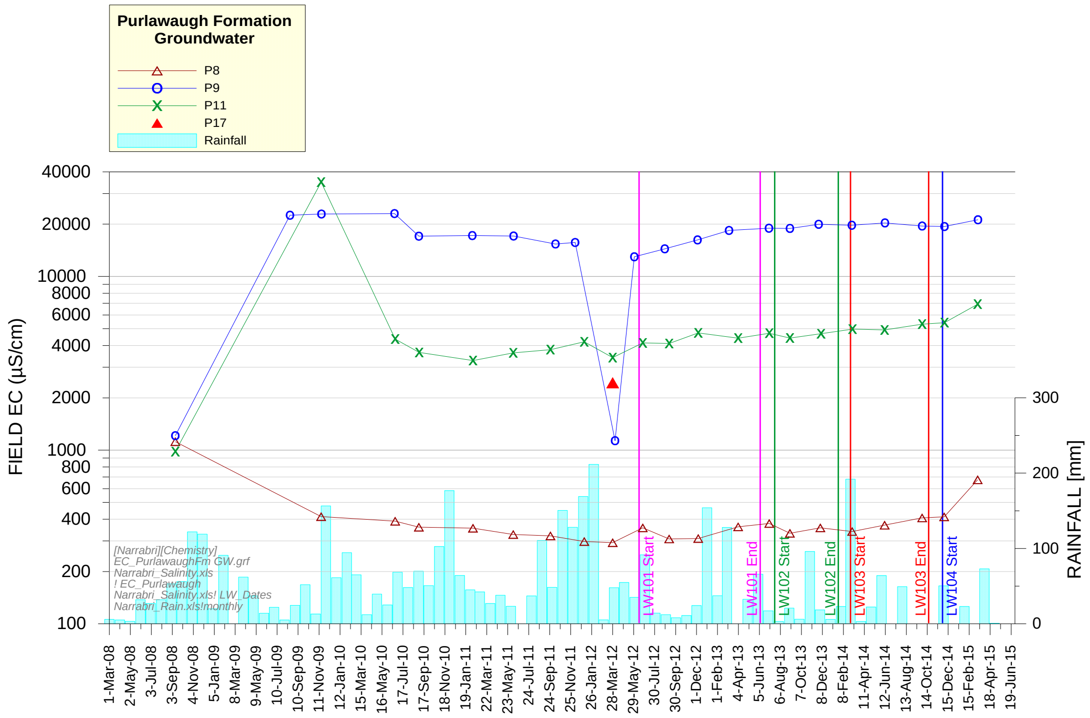


Figure I3b. Temporal Salinity Data – Purlawaugh Formation

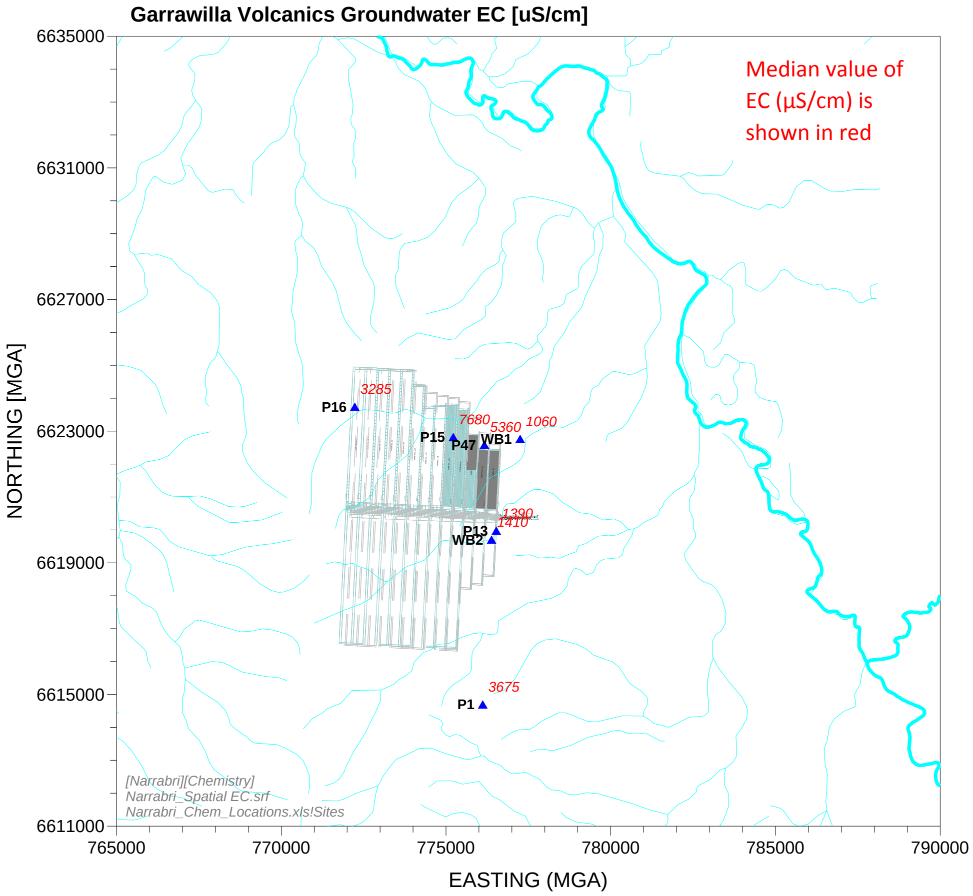


Figure I4a. Salinity Monitoring Site Locations and Median Value – Garrawilla Volcanics

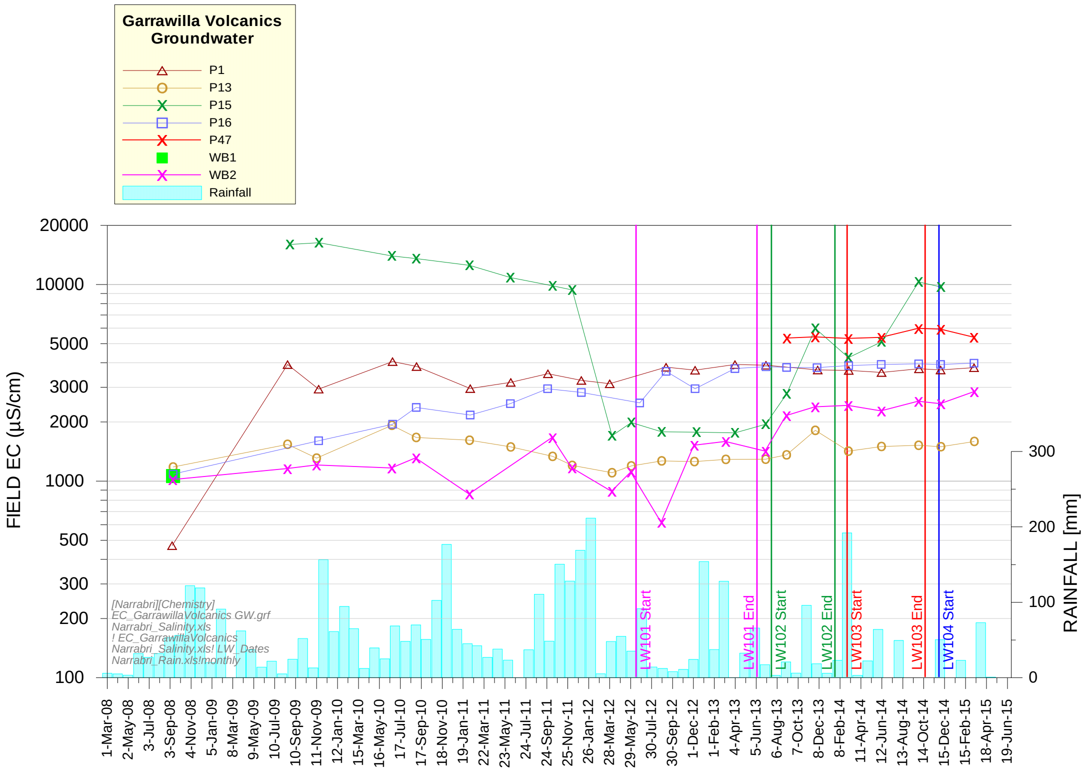


Figure I4b. Temporal Salinity Data – Garrawilla Volcanics

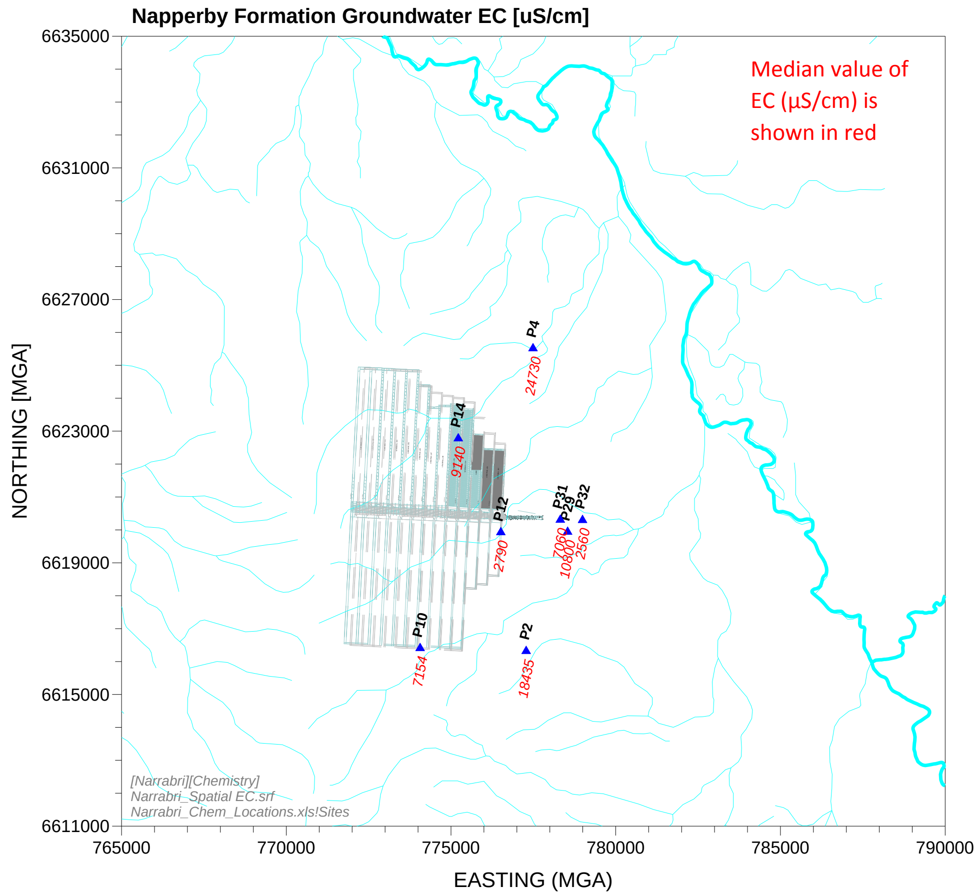


Figure I5a. Salinity Monitoring Site Locations and Median Value – Napperby Formation

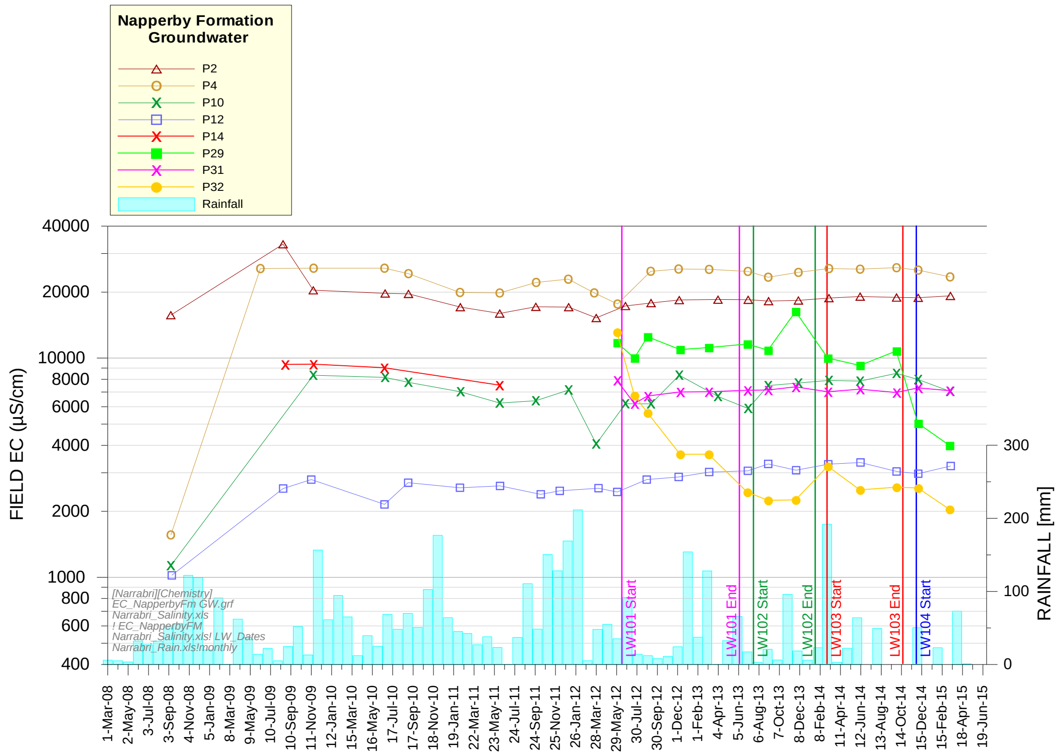


Figure I5b. Temporal Salinity Data – Napperby Formation

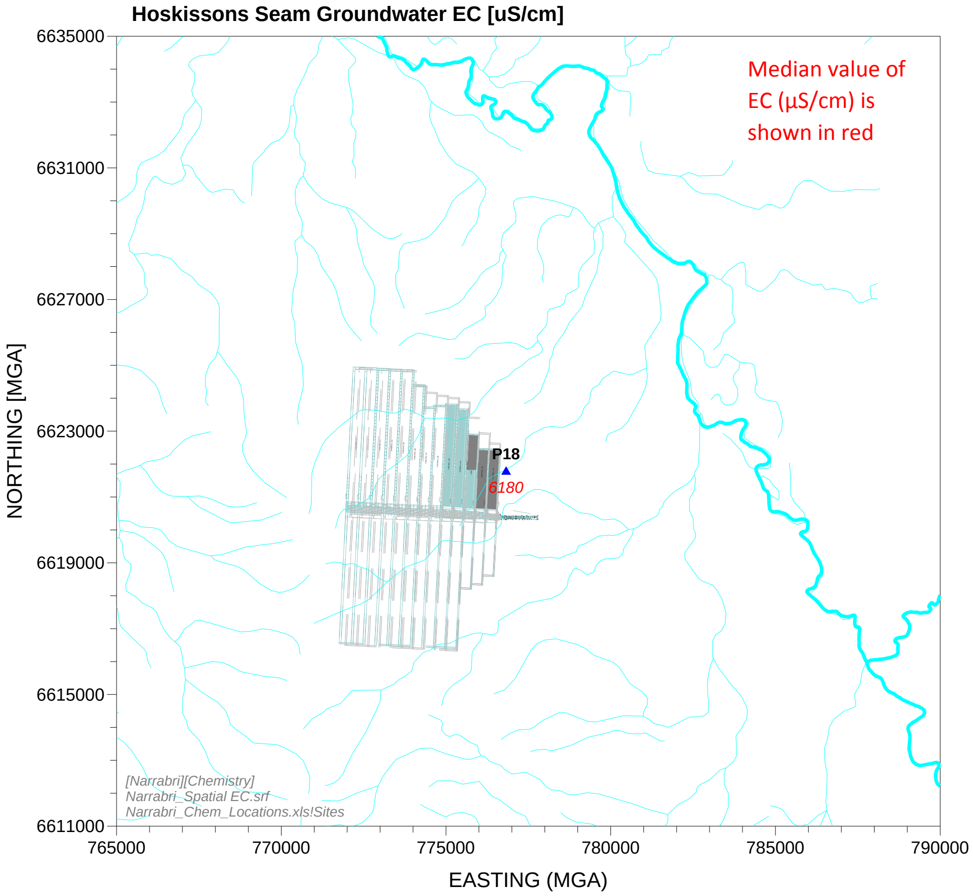


Figure I6a. Salinity Monitoring Site Locations and Median Value – Hoskissons Seam

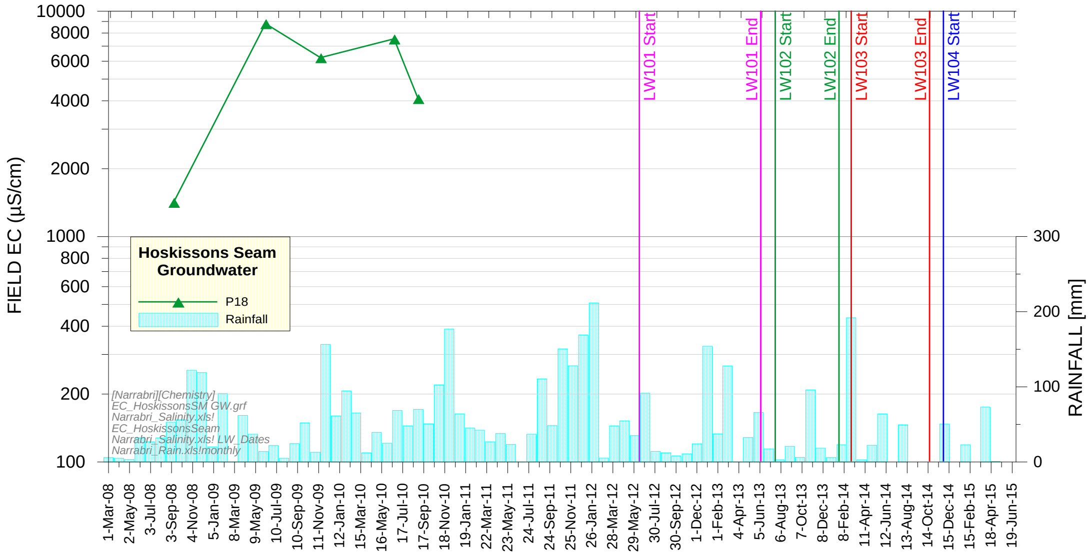


Figure I6b. Temporal Salinity Data – Hoskissons Seam

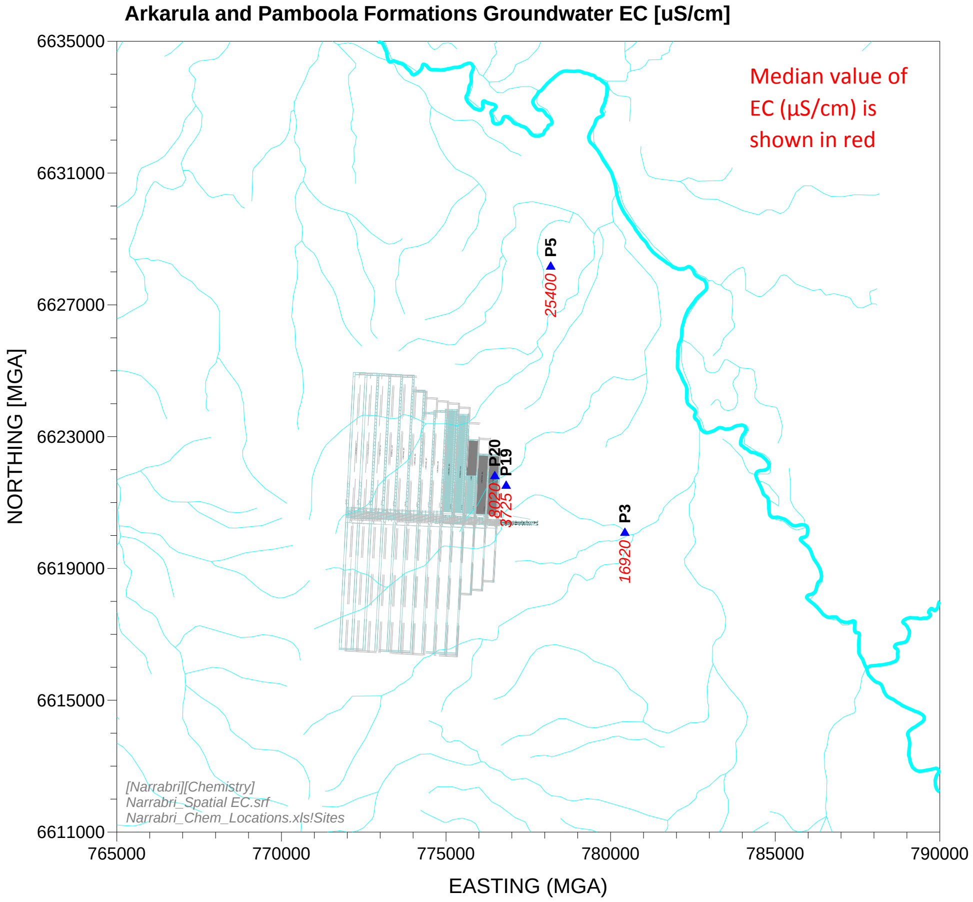


Figure I7a. Salinity Monitoring Site Locations and Median Value – Arkarula, Pamboola Formations

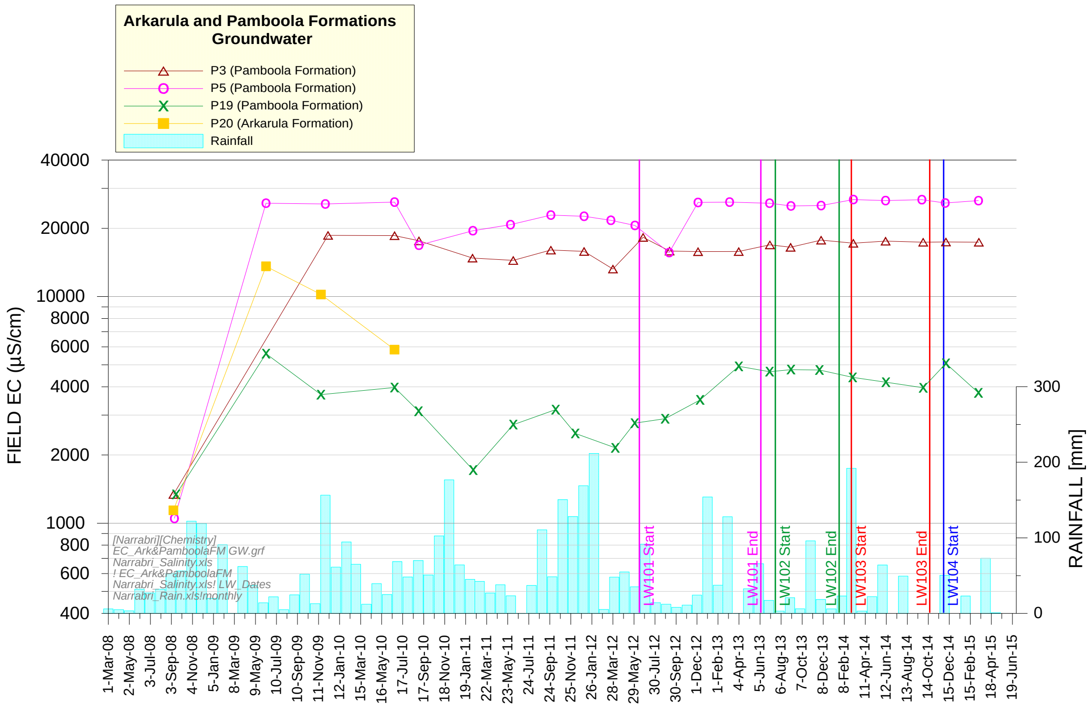


Figure I7b. Temporal Salinity Data – Arkarula, Pamboola Formations

ATTACHMENT J

Hydraulic and Storage Property Distributions

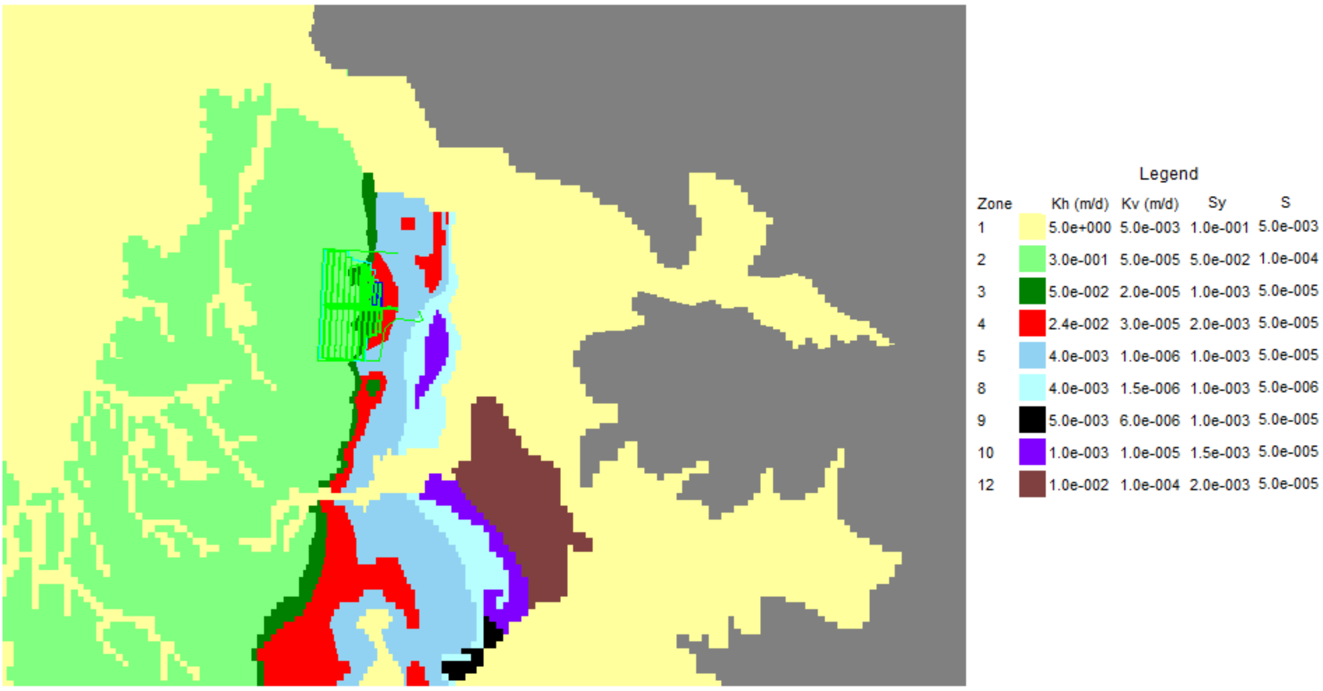


Figure J1. Hydraulic Property Zones for Model Layer 1

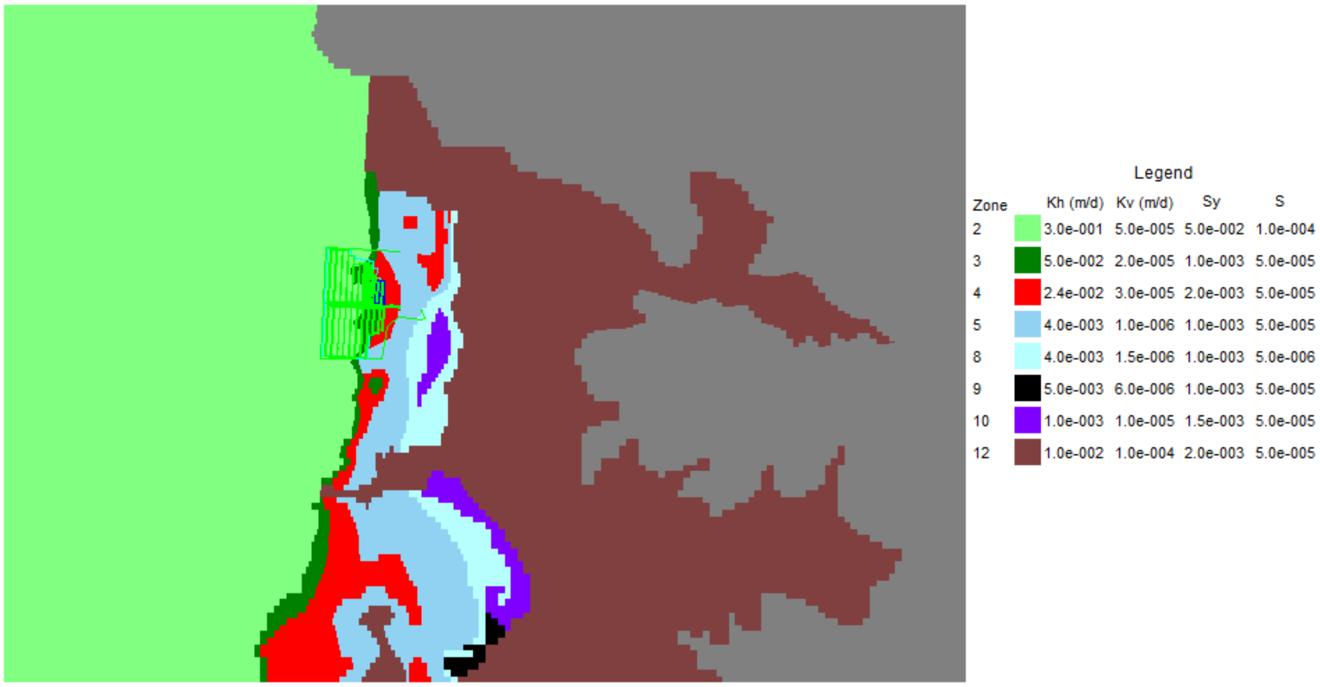


Figure J2. Hydraulic Property Zones for Model Layer 2

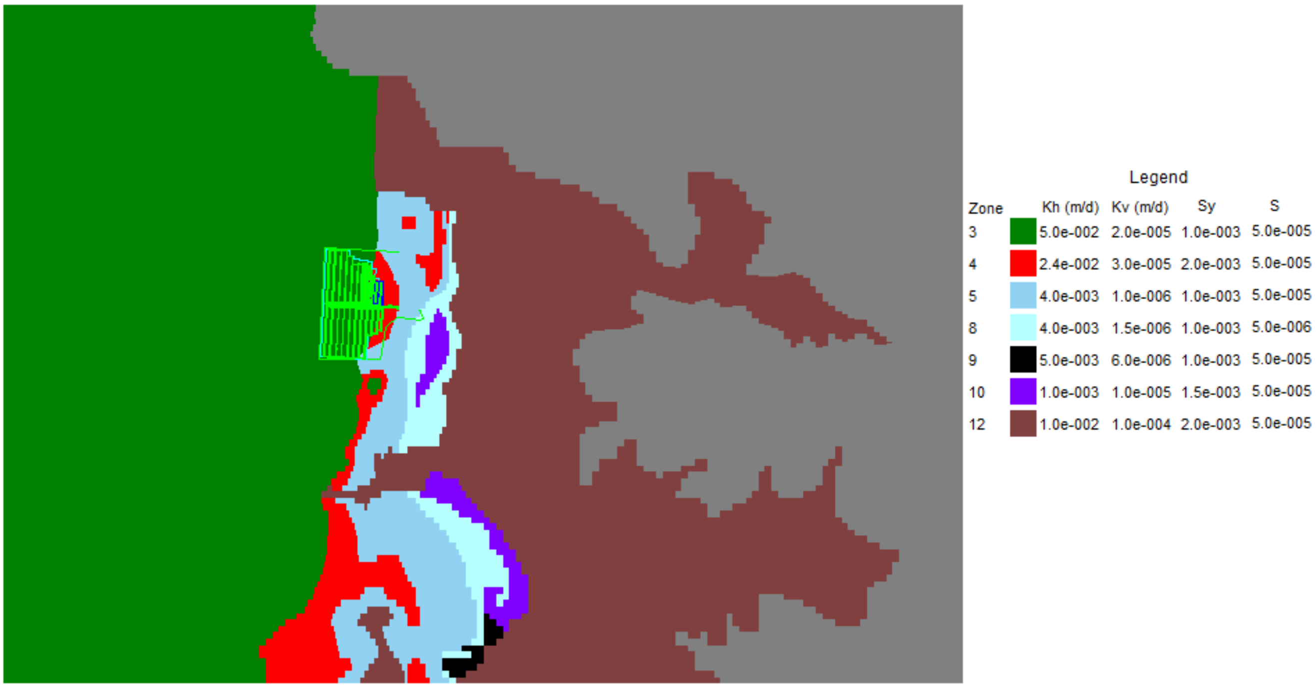


Figure J3. Hydraulic Property Zones for Model Layer 3

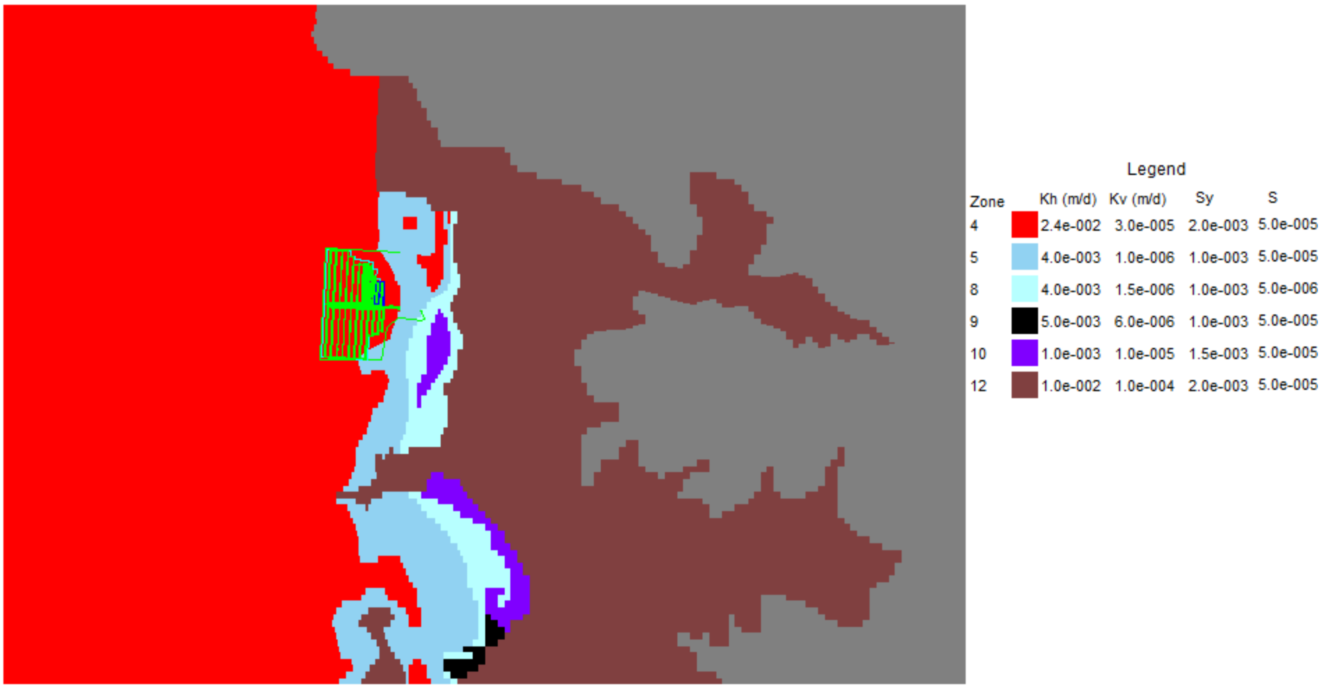


Figure J4. Hydraulic Property Zones for Model Layer 4

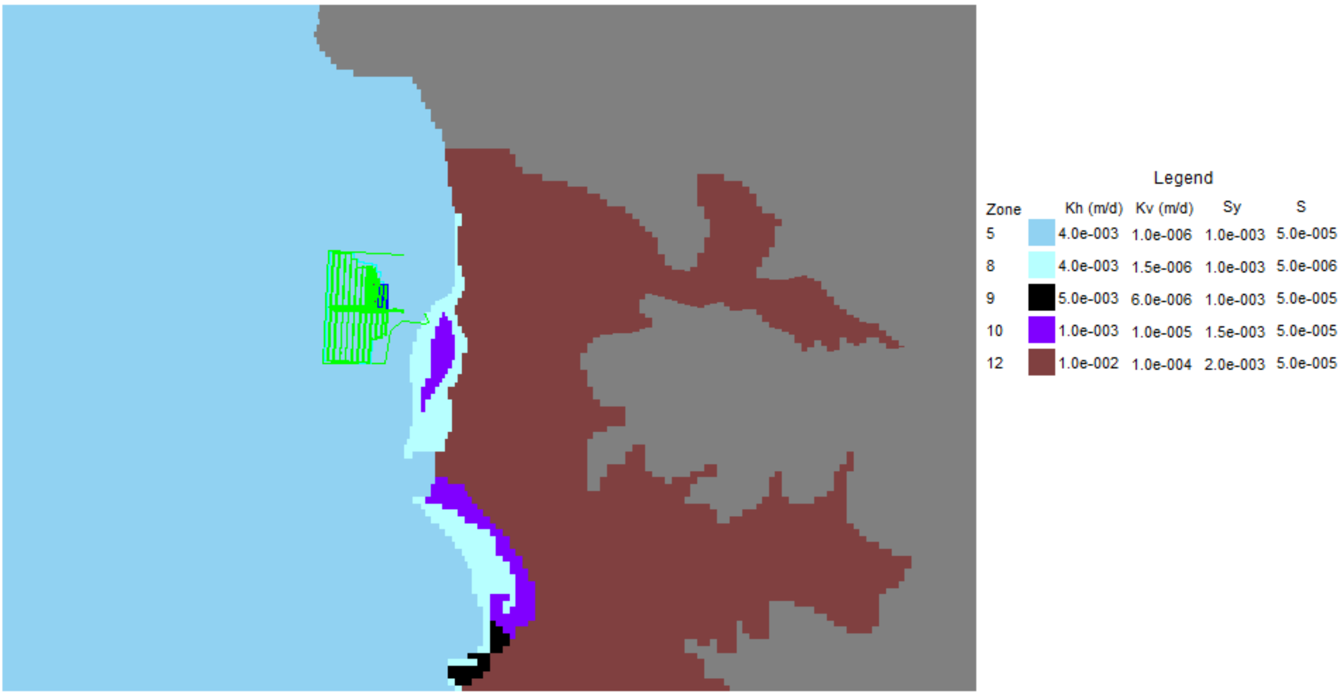


Figure J5. Hydraulic Property Zones for Model Layer 5

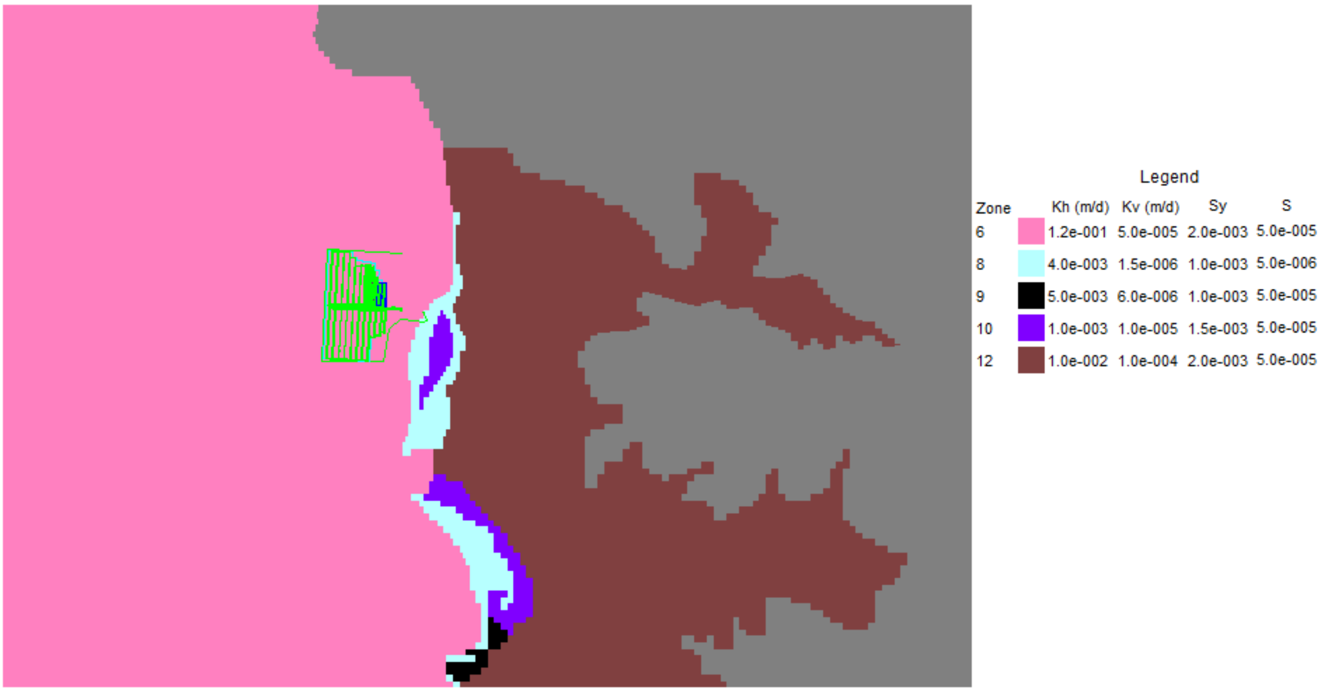


Figure J6. Hydraulic Property Zones for Model Layer 6

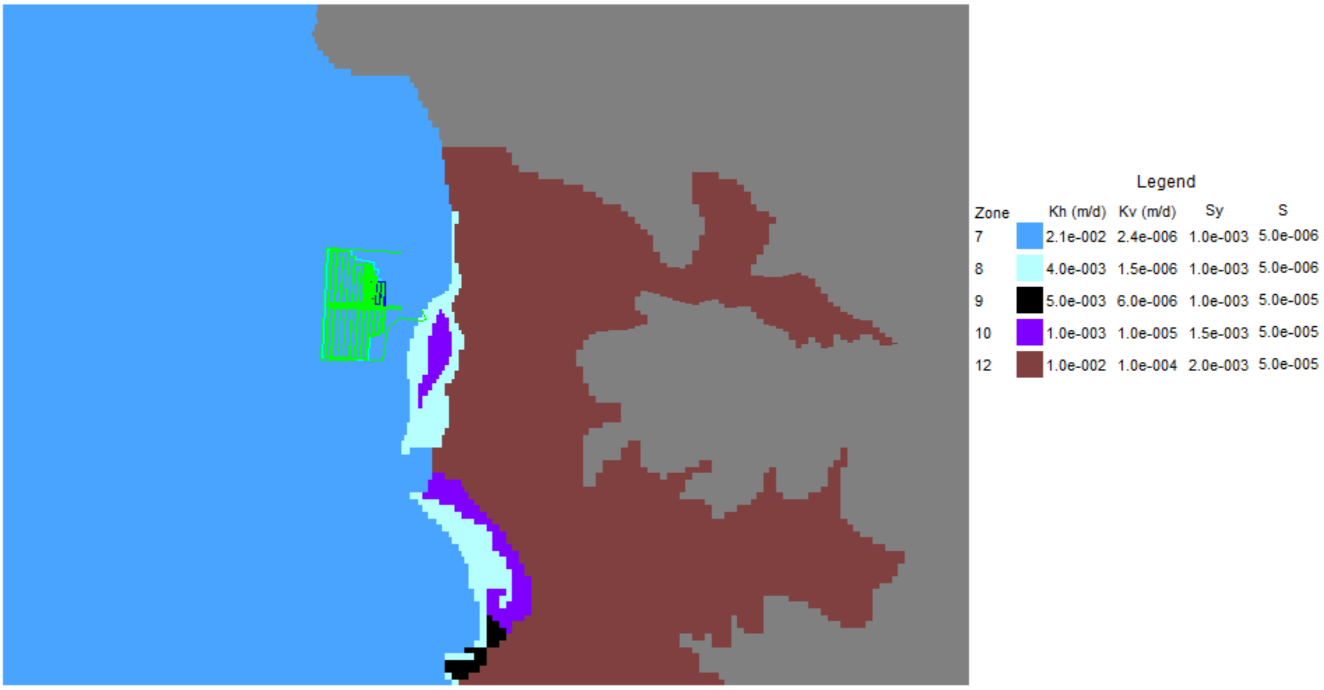


Figure J7. Hydraulic Property Zones for Model Layer 7

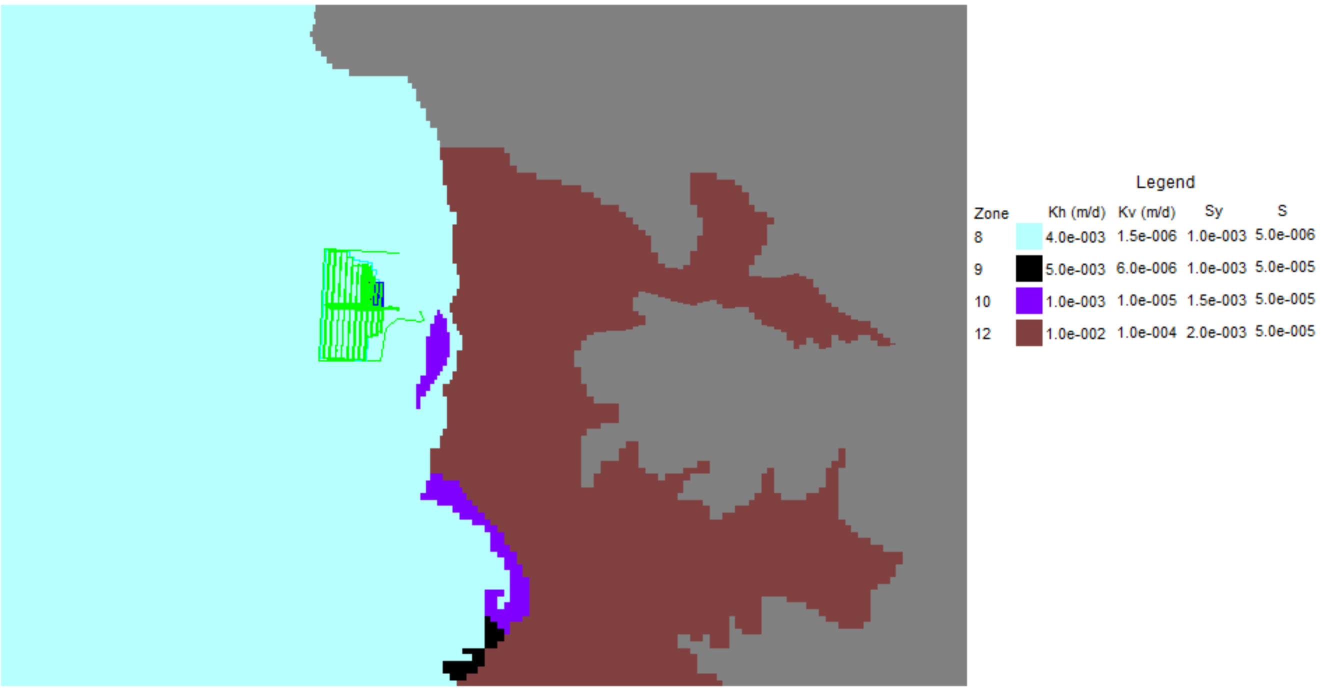


Figure J8. Hydraulic Property Zones for Model Layer 8

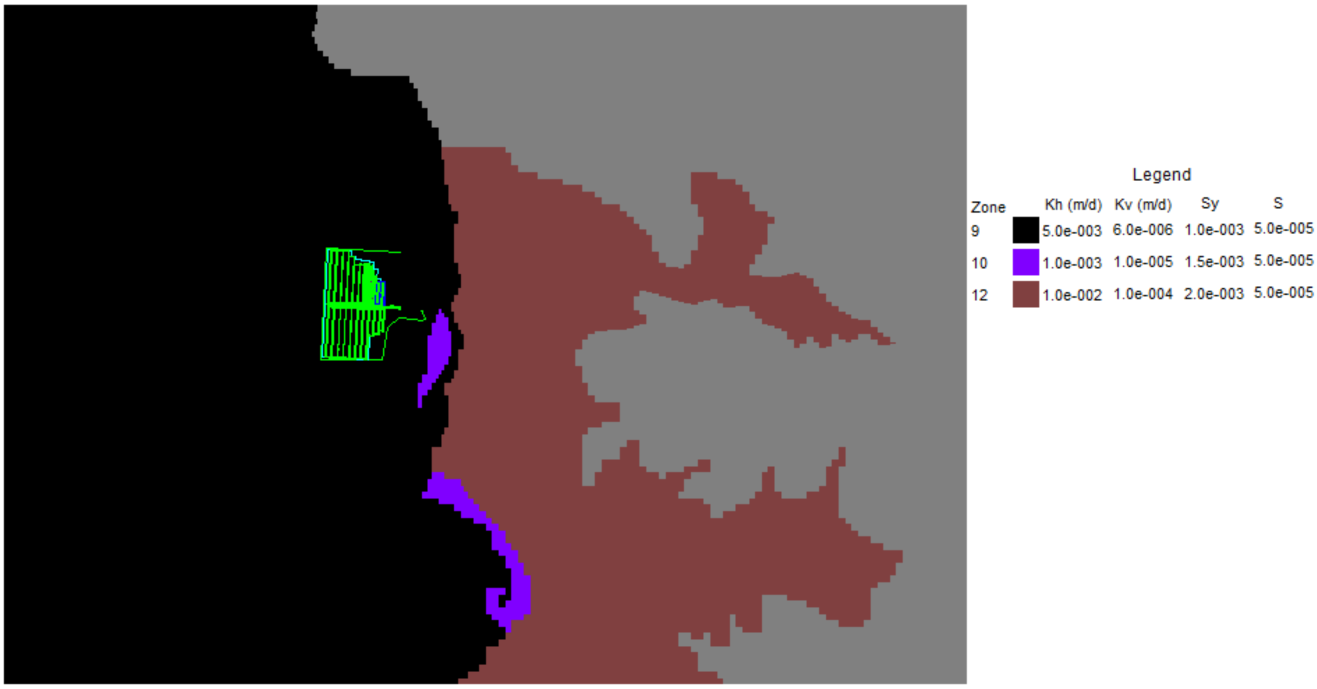


Figure J9. Hydraulic Property Zones for Model Layer 9

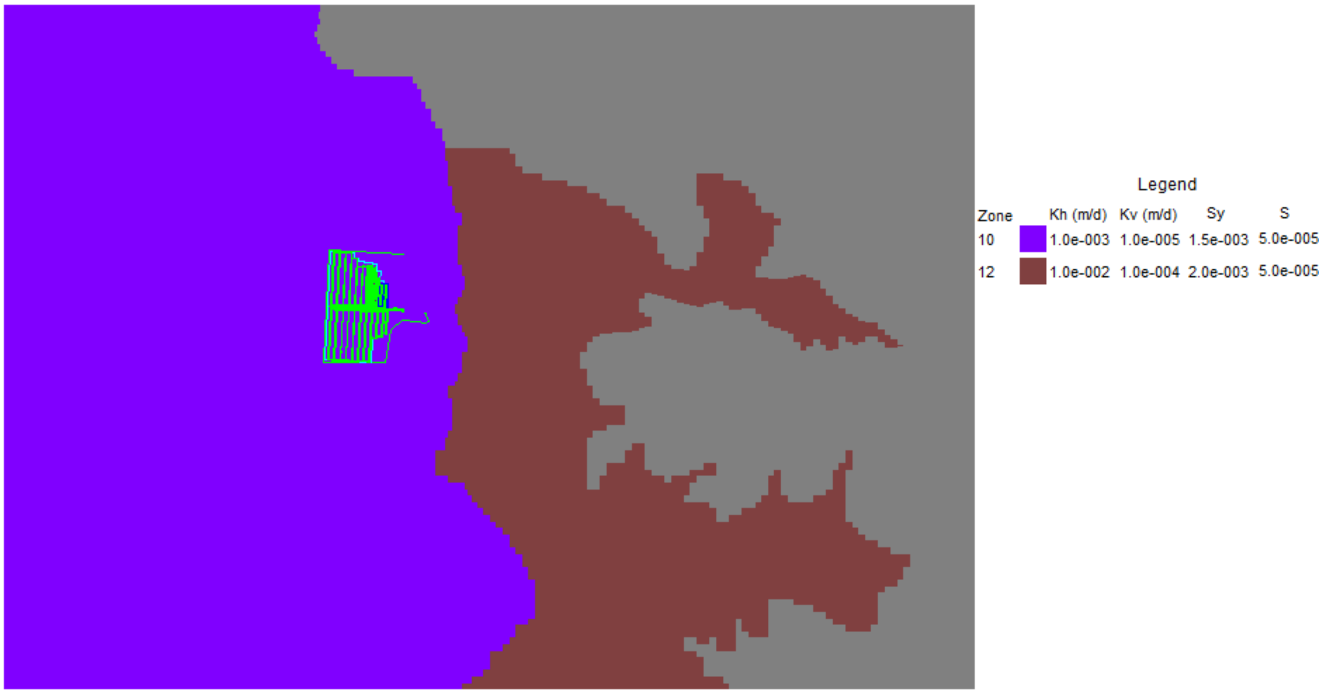


Figure J10. Hydraulic Property Zones for Model Layer 10

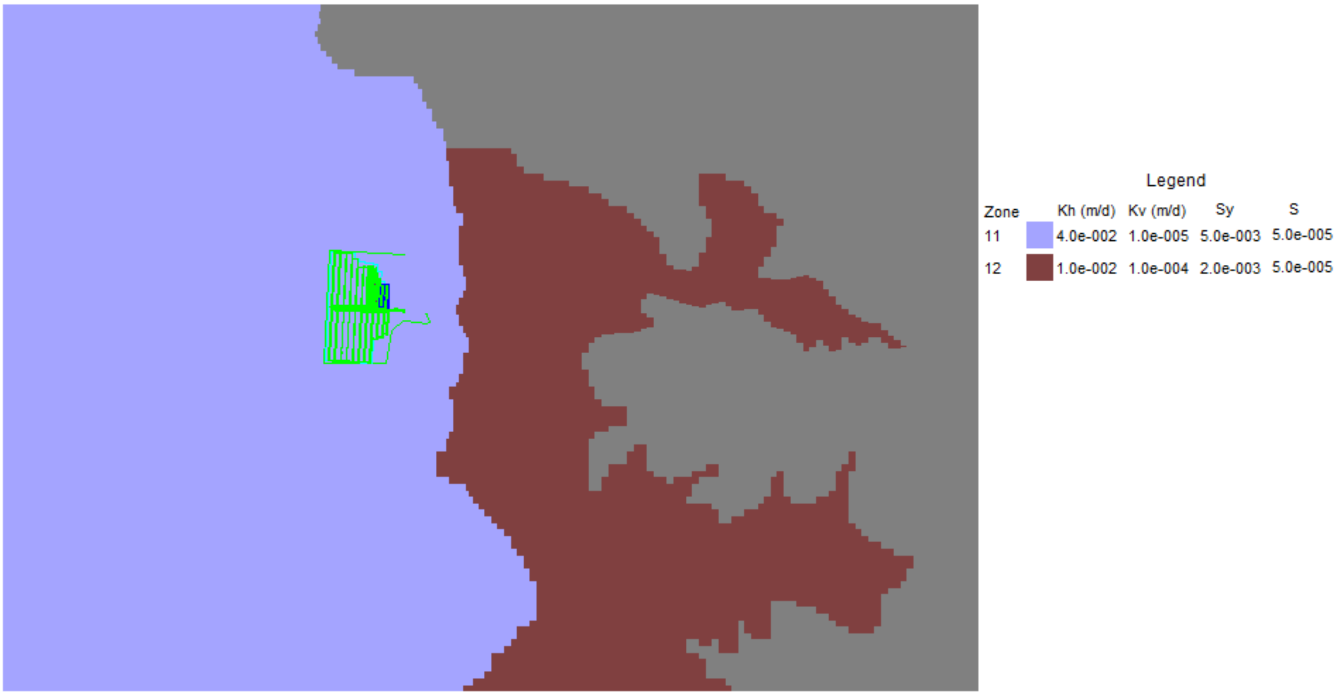


Figure J11. Hydraulic Property Zones for Model Layer 11

ATTACHMENT K

Observed and Simulated Hydrographs - Version 4 Model

Group 1: Standpipe Bores

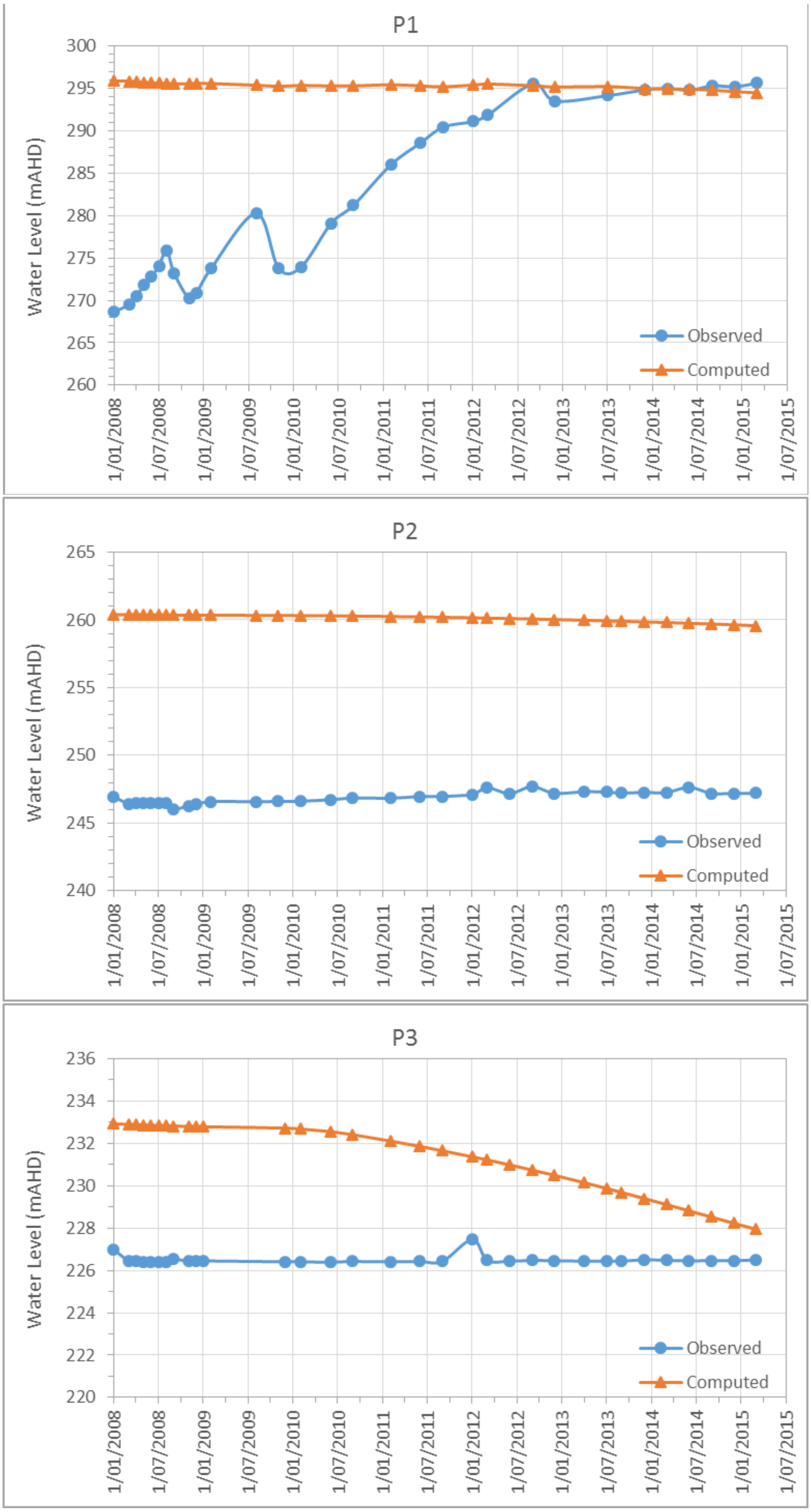


Figure K1. Observed and Simulated Hydrographs - Version 4 Model – Group 1: P1, P2, P3

Group 1: Standpipe Bores

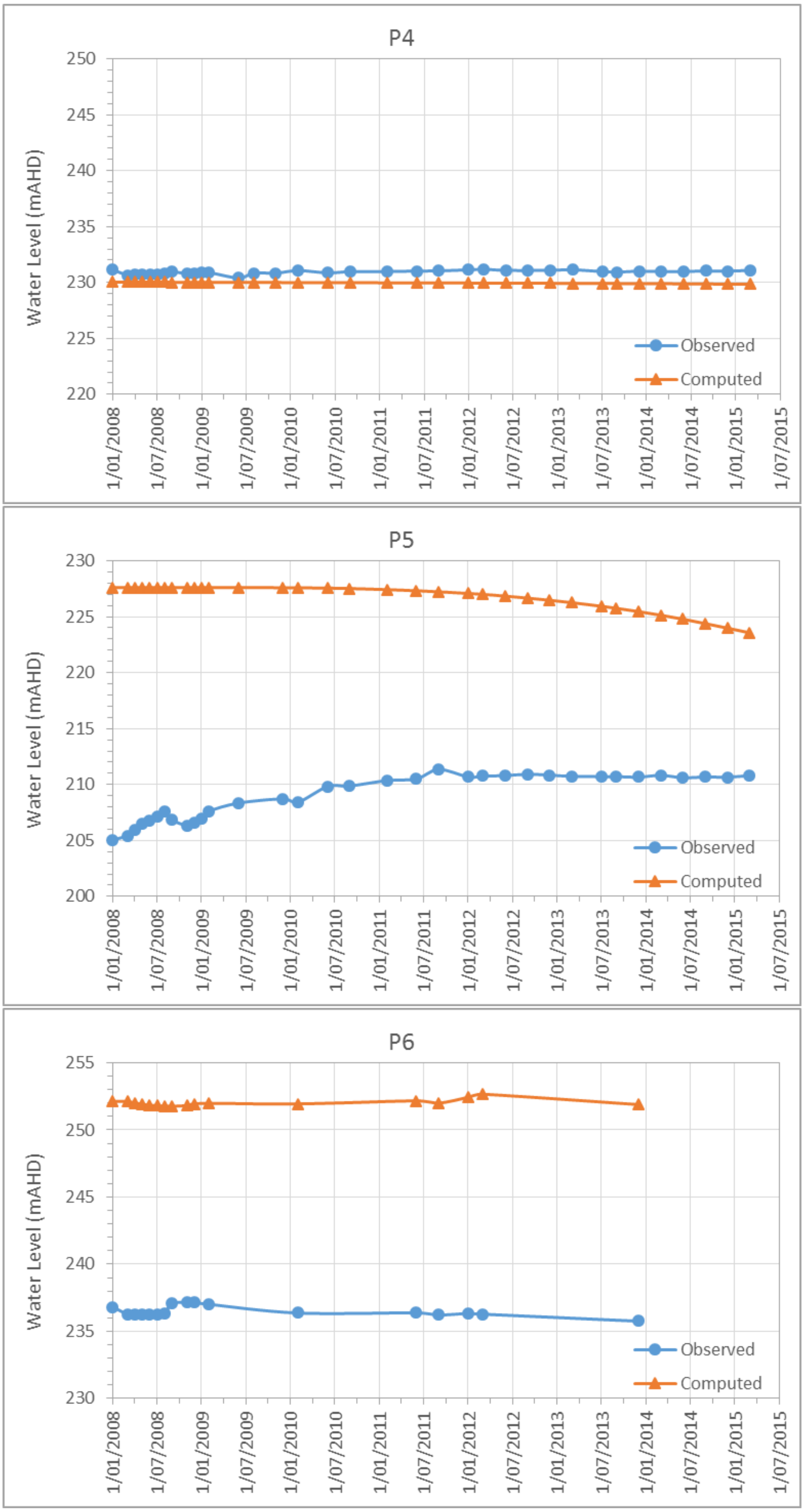
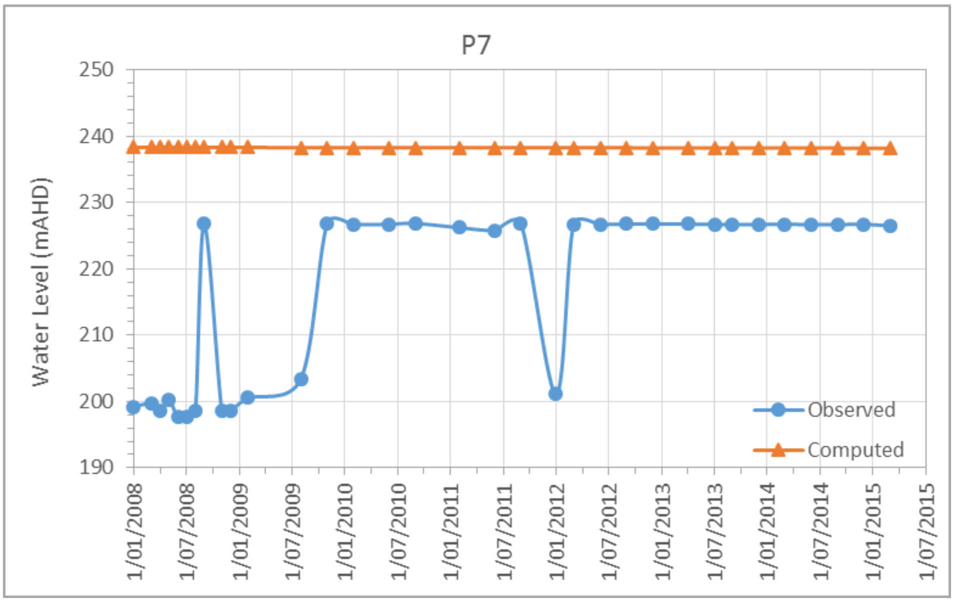
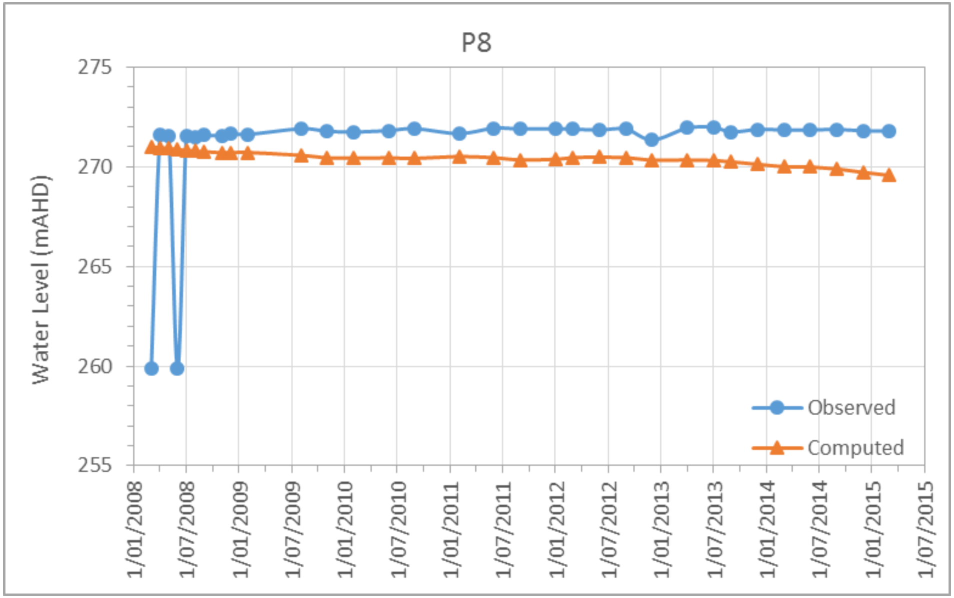


Figure K2. Observed and Simulated Hydrographs - Version 4 Model – Group 1: P4, P5, P6

Group 1: Standpipe Bores





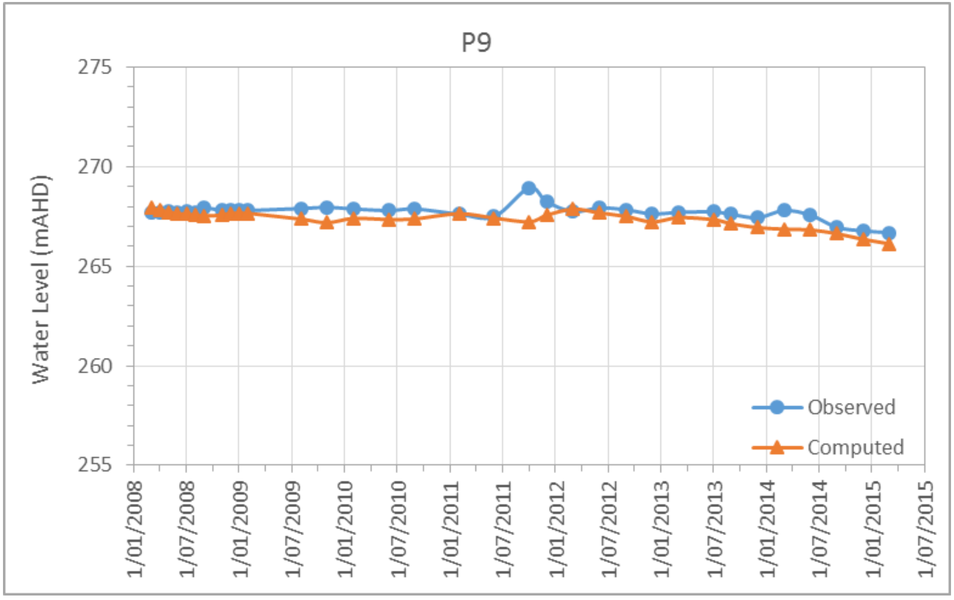


Figure K3. Observed and Simulated Hydrographs - Version 4 Model – Group 1: P7, P8, P9

Group 1: Standpipe Bores

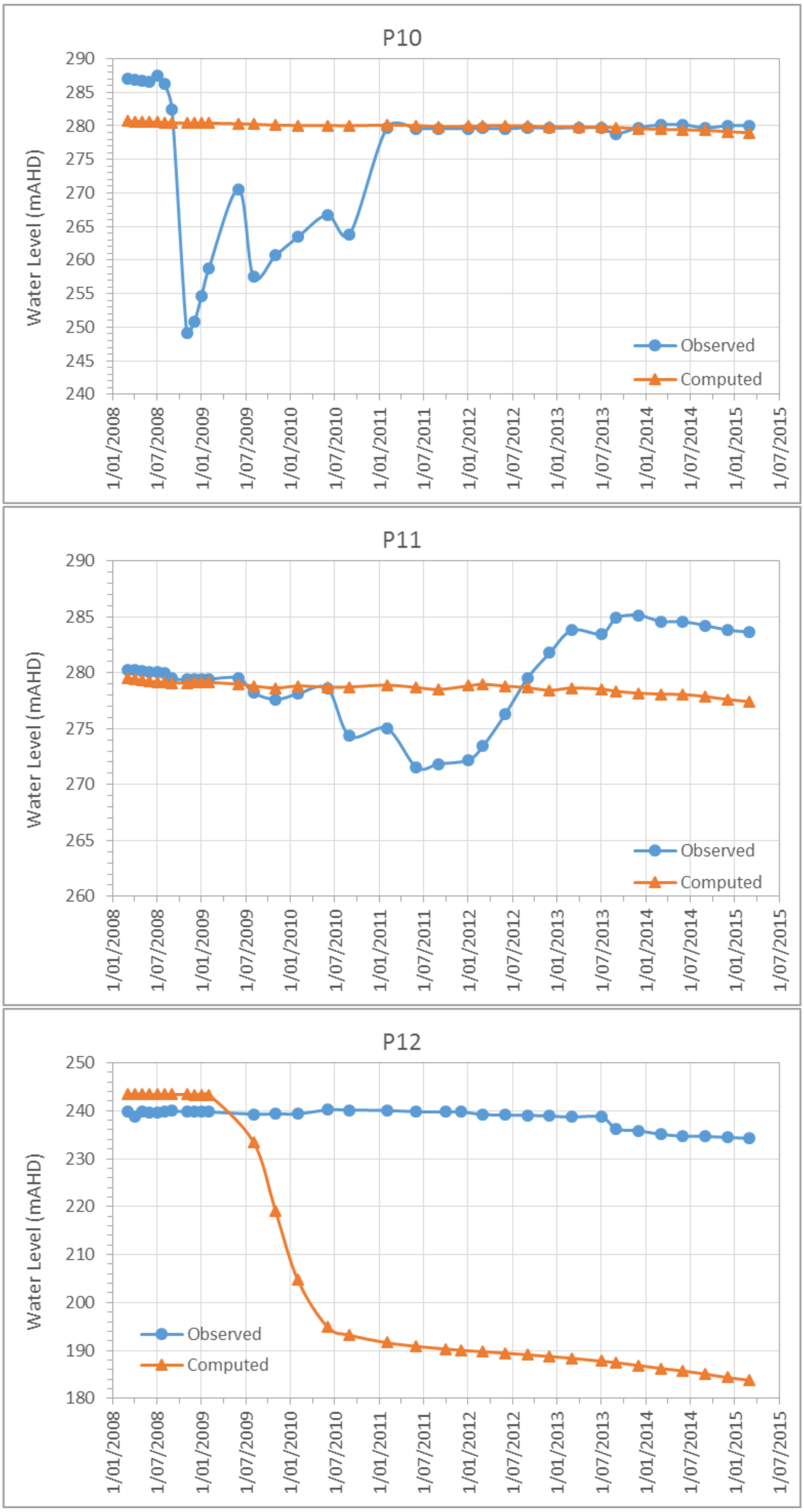


Figure K4. Observed and Simulated Hydrographs - Version 4 Model – Group 1: P10, P11, P12

Group 1: Standpipe Bores

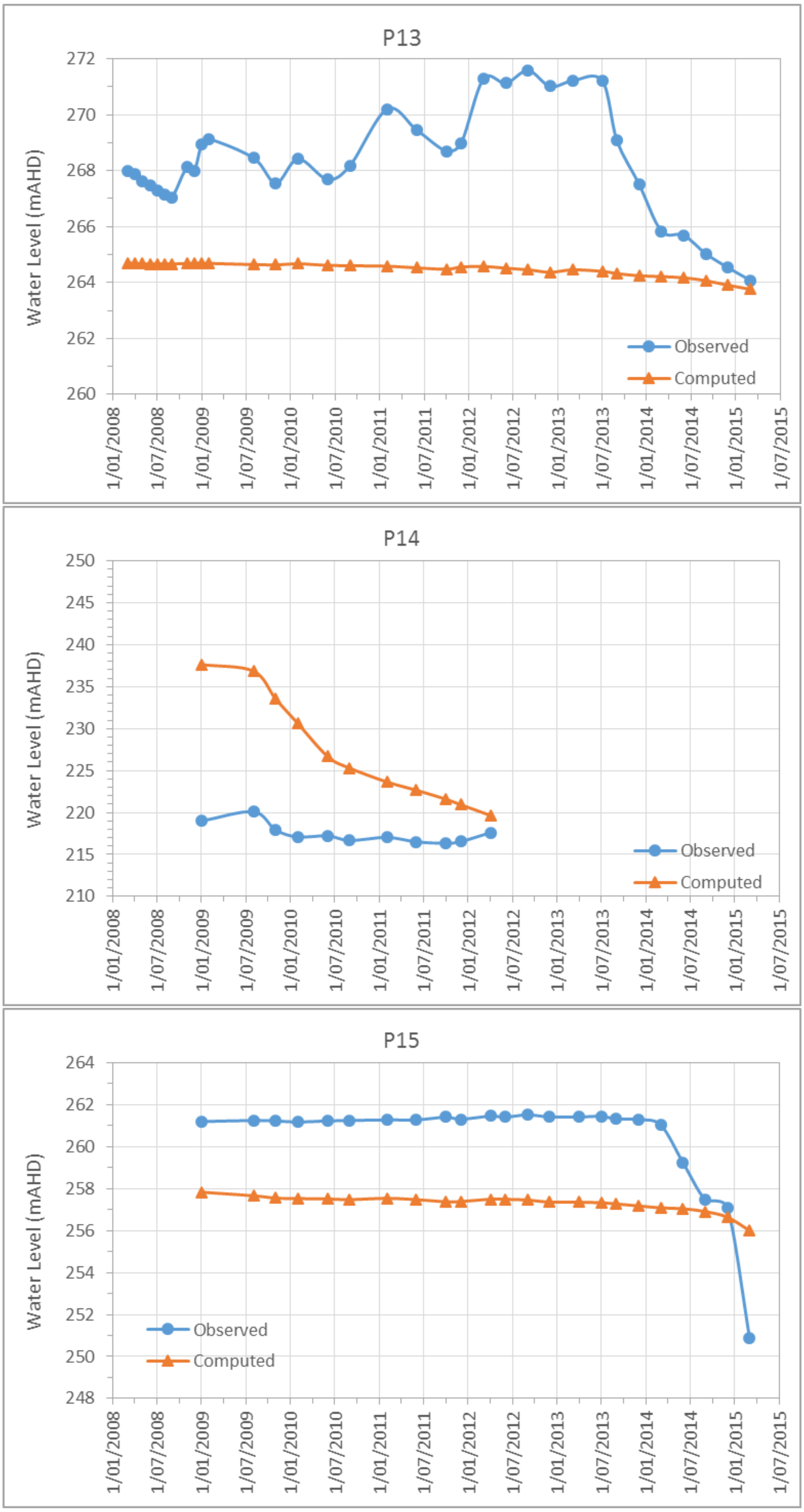
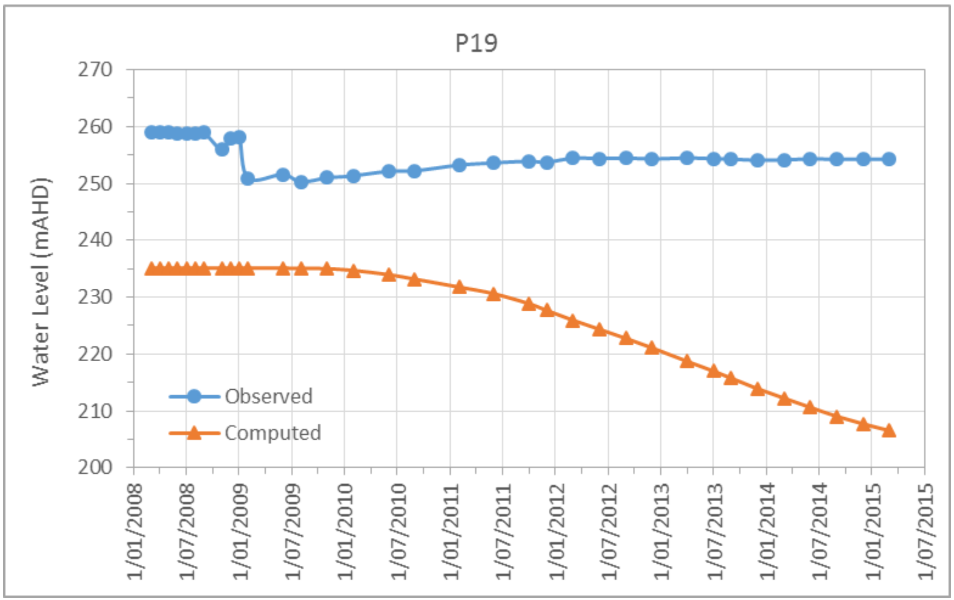


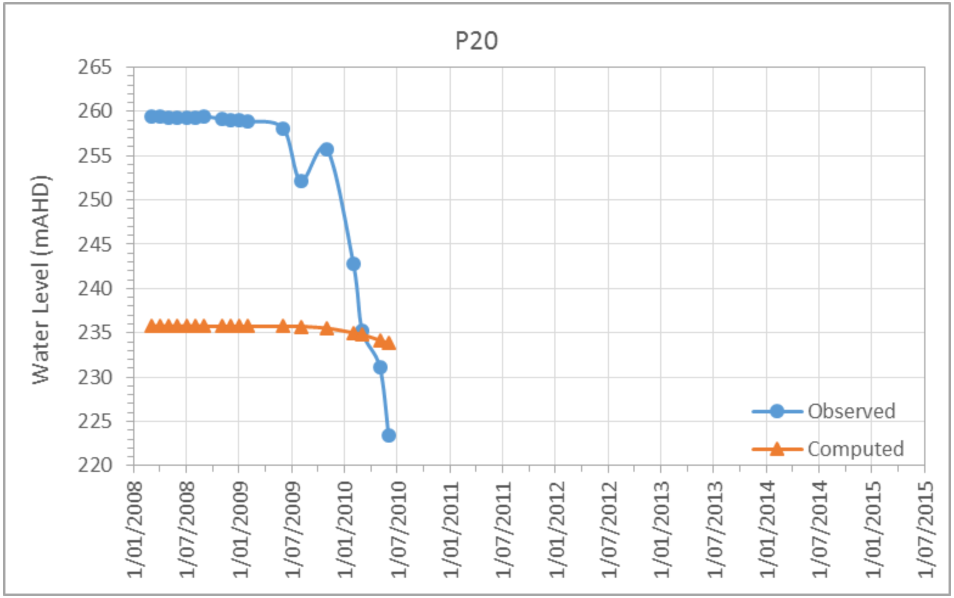
Figure K5. Observed and Simulated Hydrographs - Version 4 Model – Group 1: P13, P14, P15

Group 1:
Standpipe
Bores

Figure K6. Observed and Simulated Hydrographs - Version 4 Model – Group 1: P16, P17, P18

Group 1: Standpipe Bores





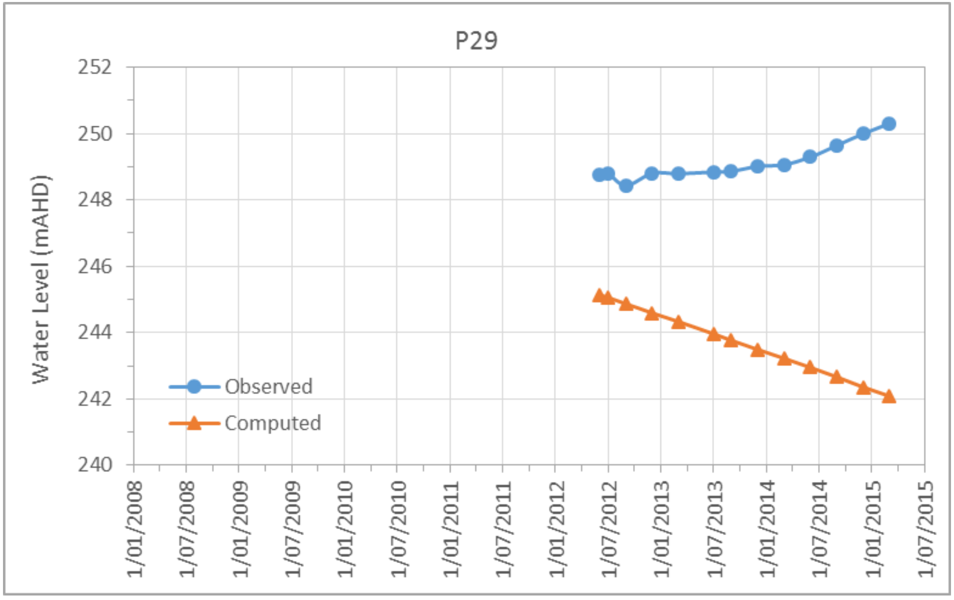


Figure K7. Observed and Simulated Hydrographs - Version 4 Model – Group 1: P19, P20, P29

Group 1: Standpipe Bores

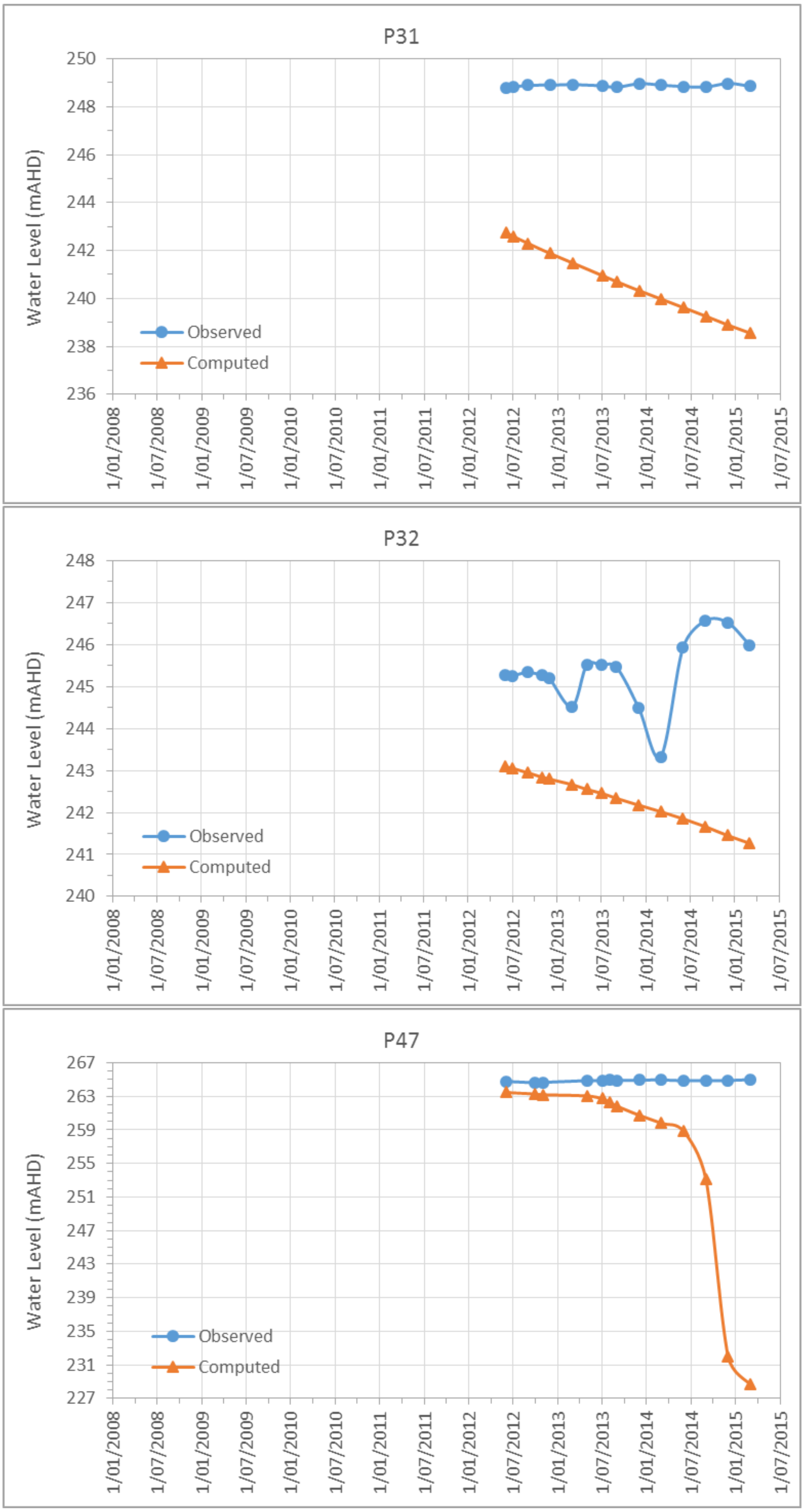
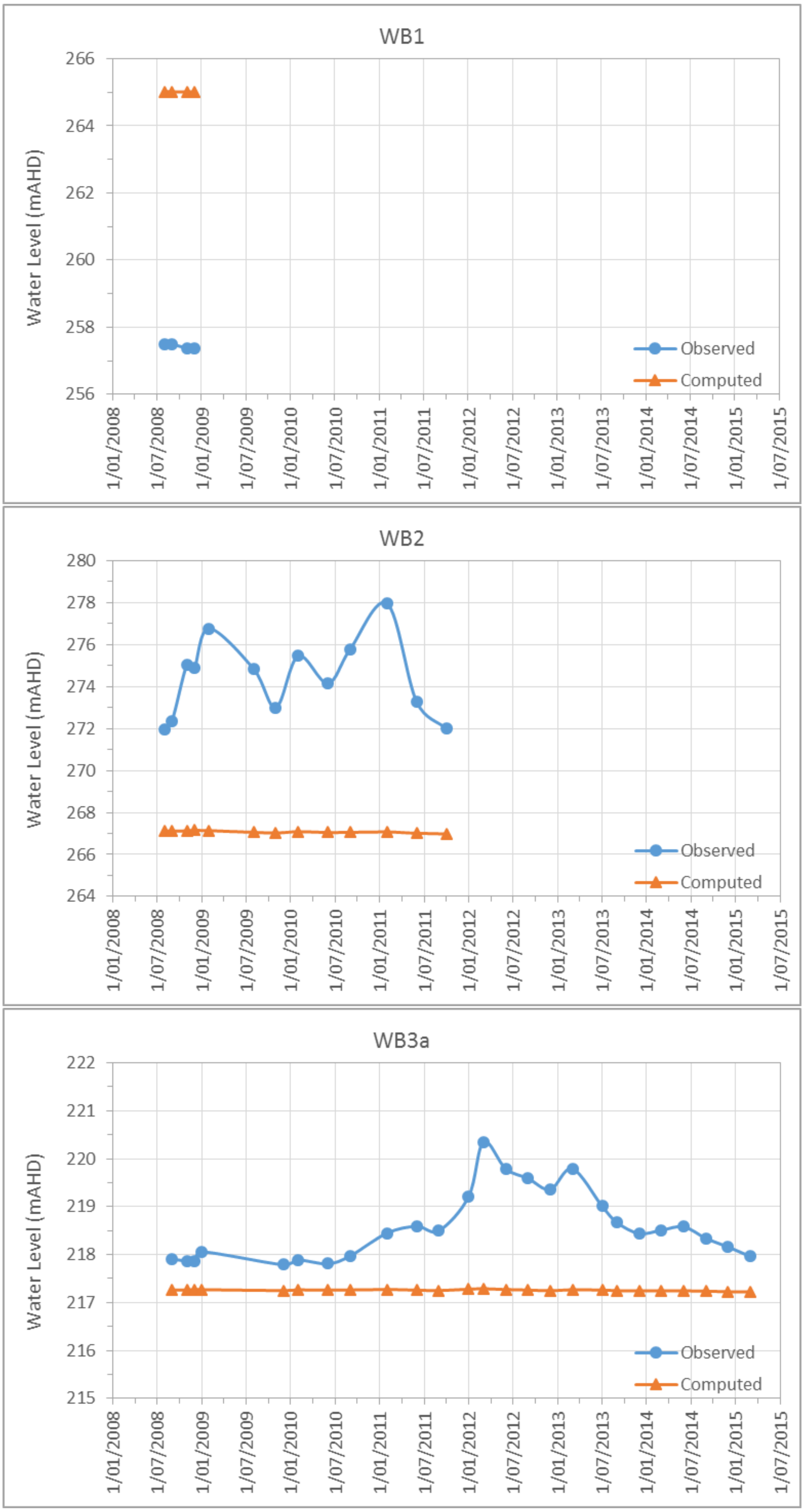
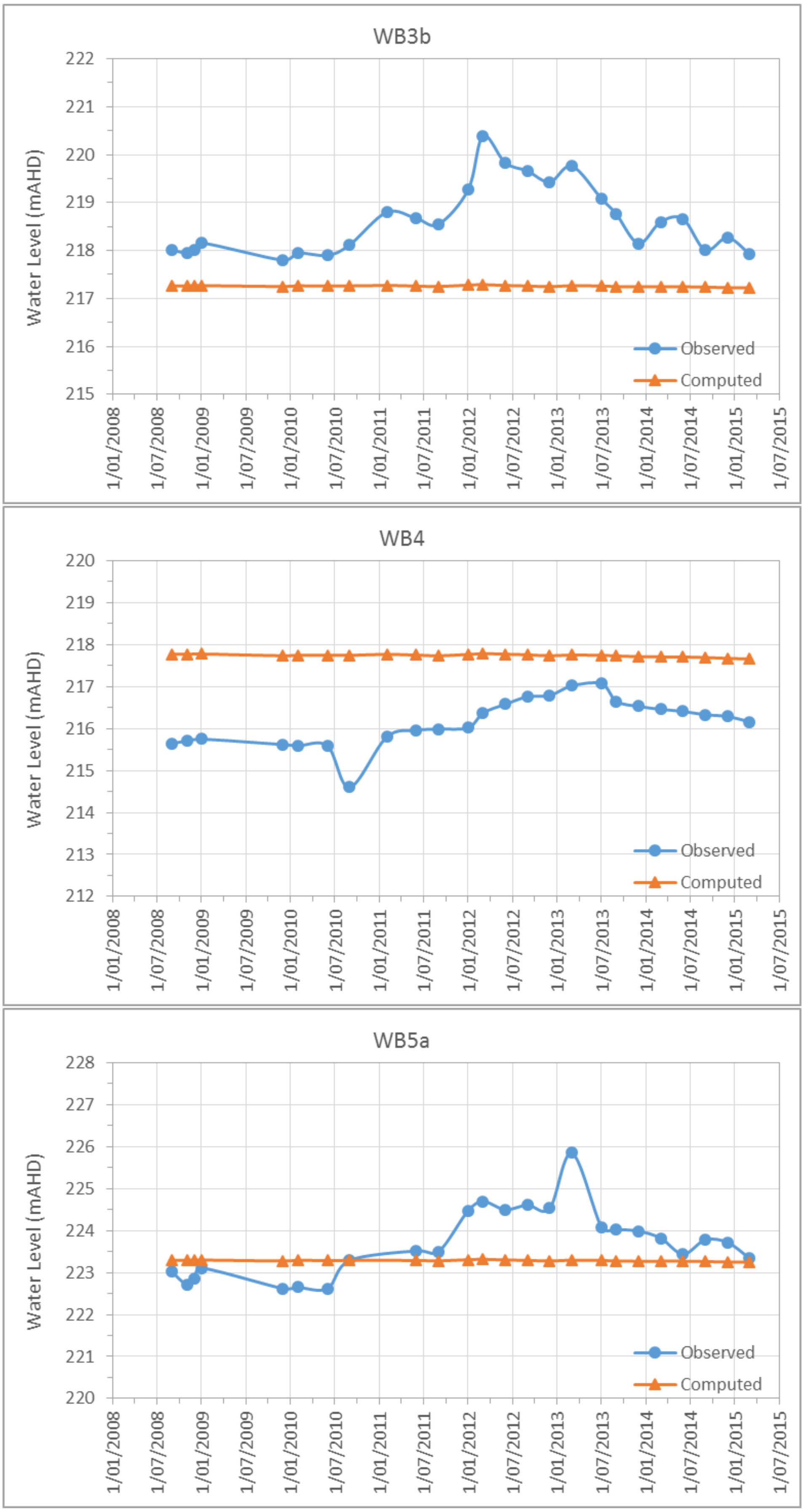


Figure K8. Observed and Simulated Hydrographs - Version 4 Model – Group 1: P31, P32, P47



**Group 2:
Production
Bores**

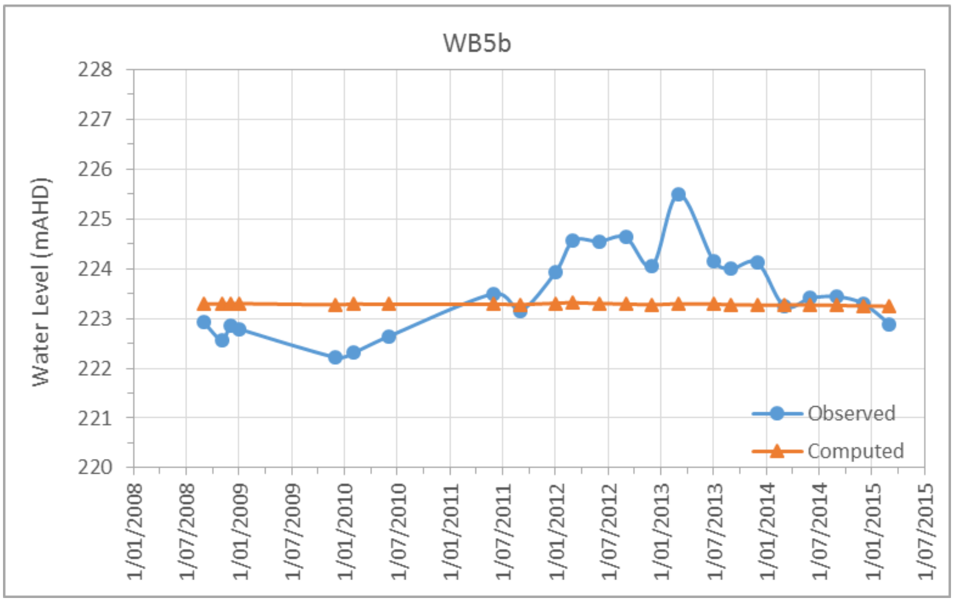
Figure K9. Observed and Simulated Hydrographs - Version 4 Model – Group 2: WB1, WB2, WB3a

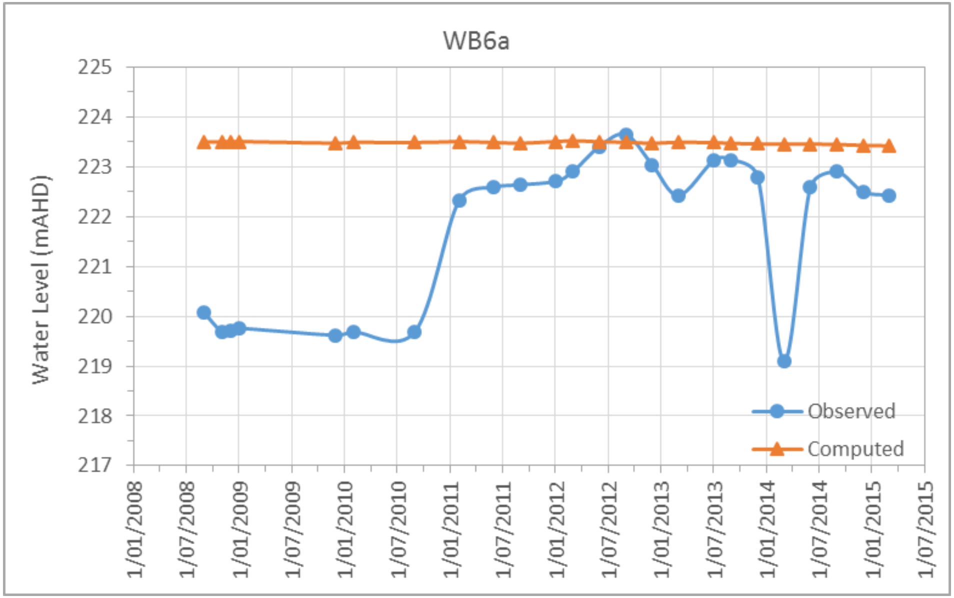


Group 2: Production Bores

Figure K10. Observed and Simulated Hydrographs - Version 4 Model – Group 2: WB3b, WB4, WB5a

Group 2: Production Bores





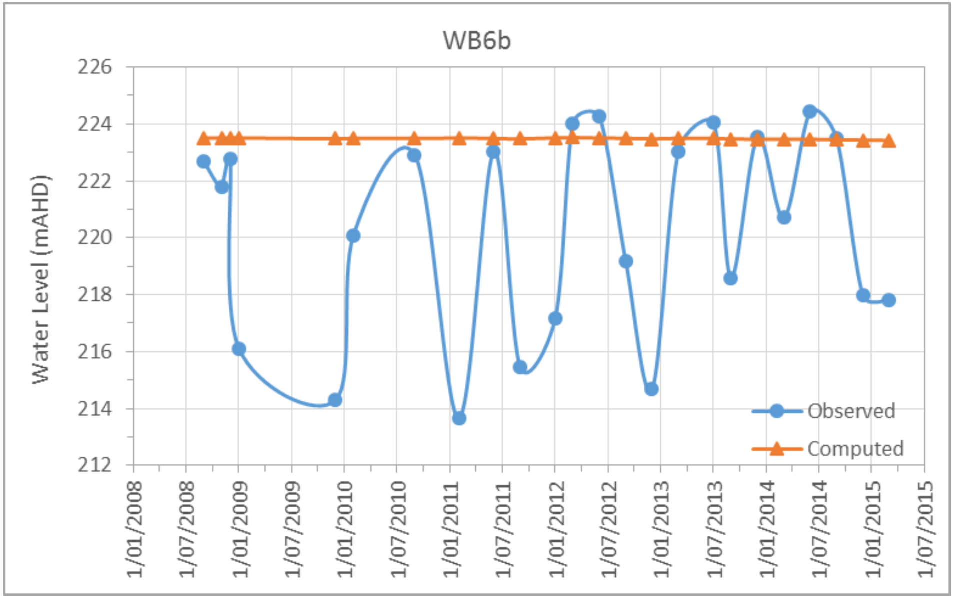
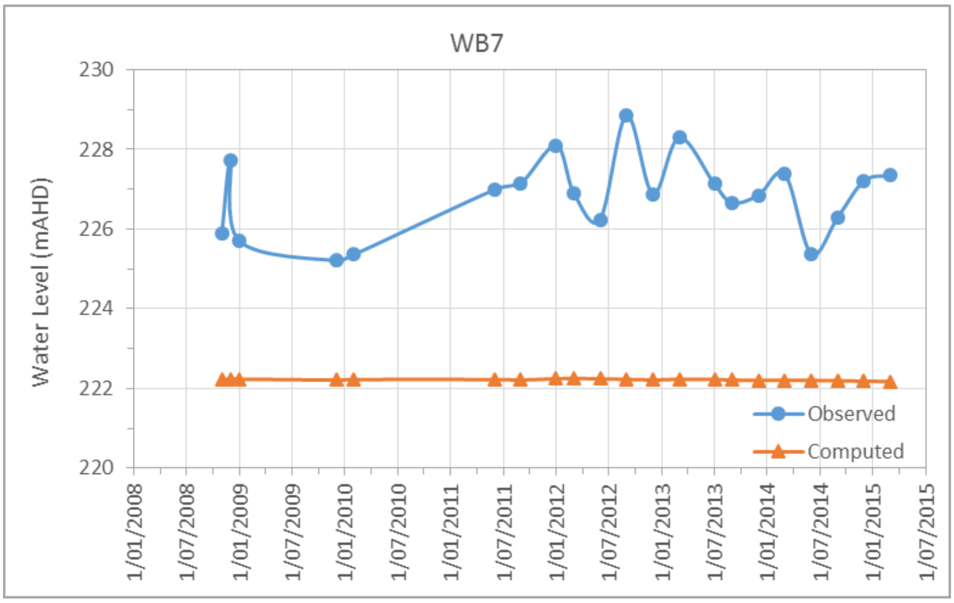


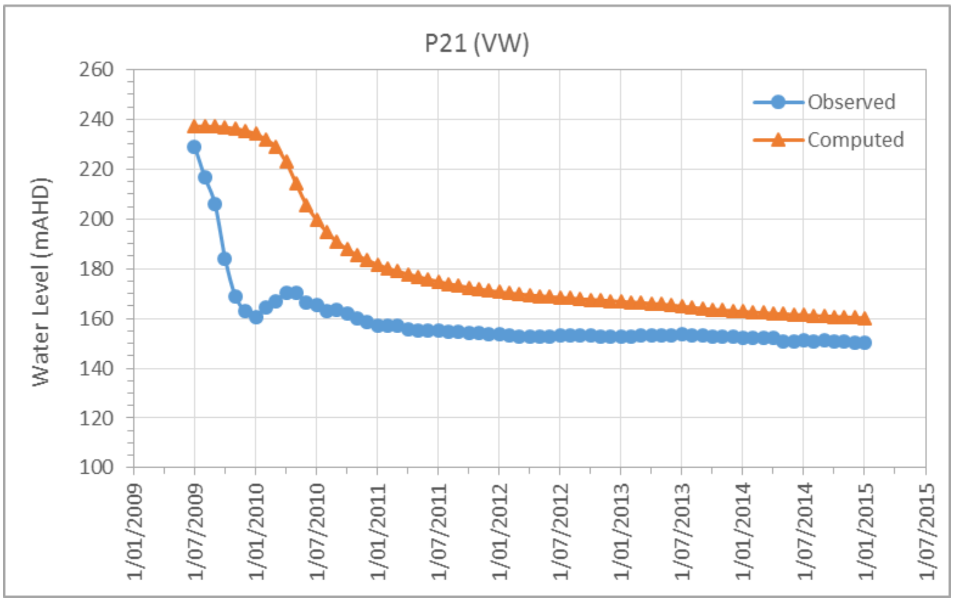
Figure K11. Observed and Simulated Hydrographs - Version 4 Model – Group 2: WB5b, WB6a, WB6b

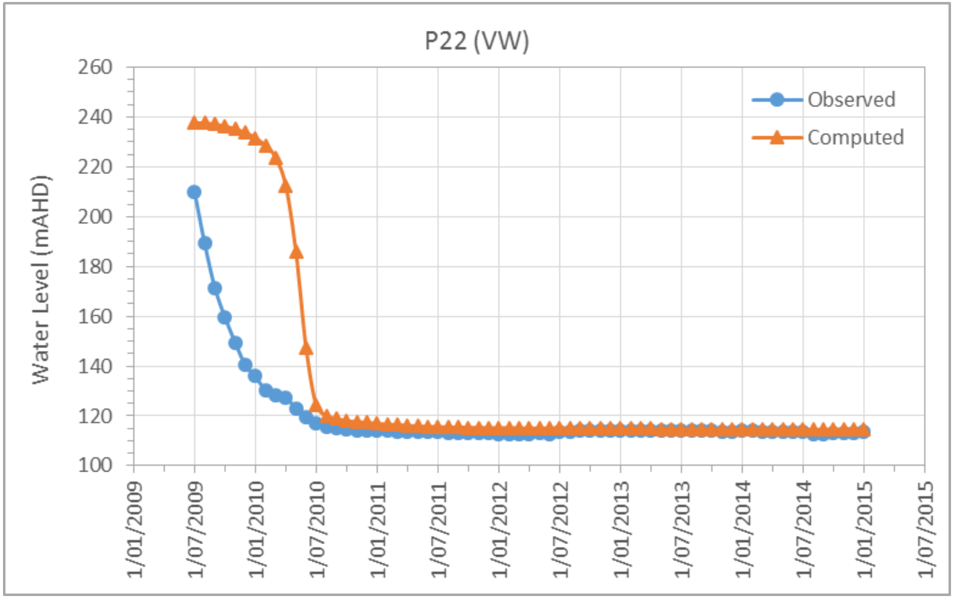


Group 2: Production Bores

Figure K12. Observed and Simulated Hydrograph - Version 4 Model – Group 2: WB7

Group 3: Vibrating Wires (Single Depth)





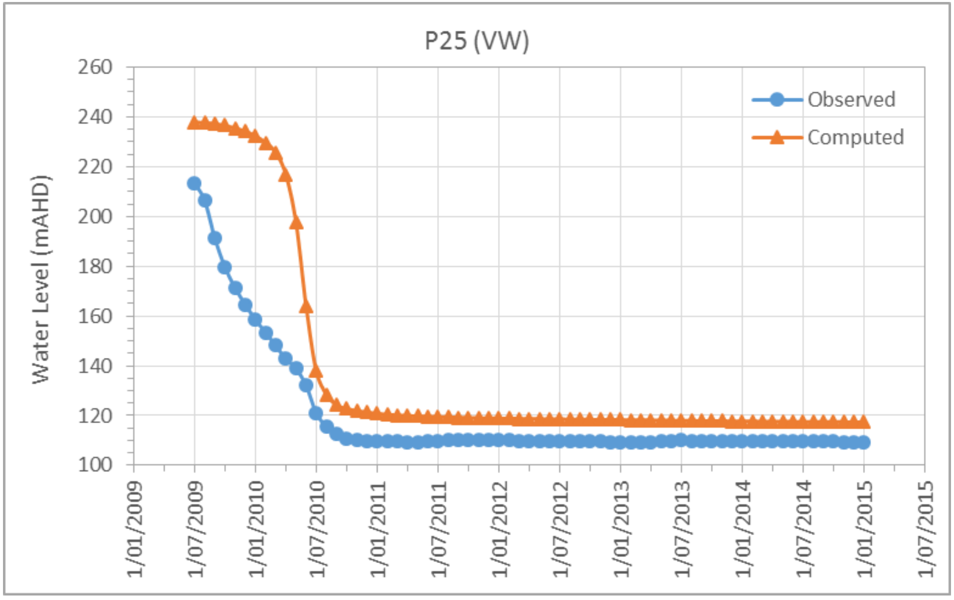
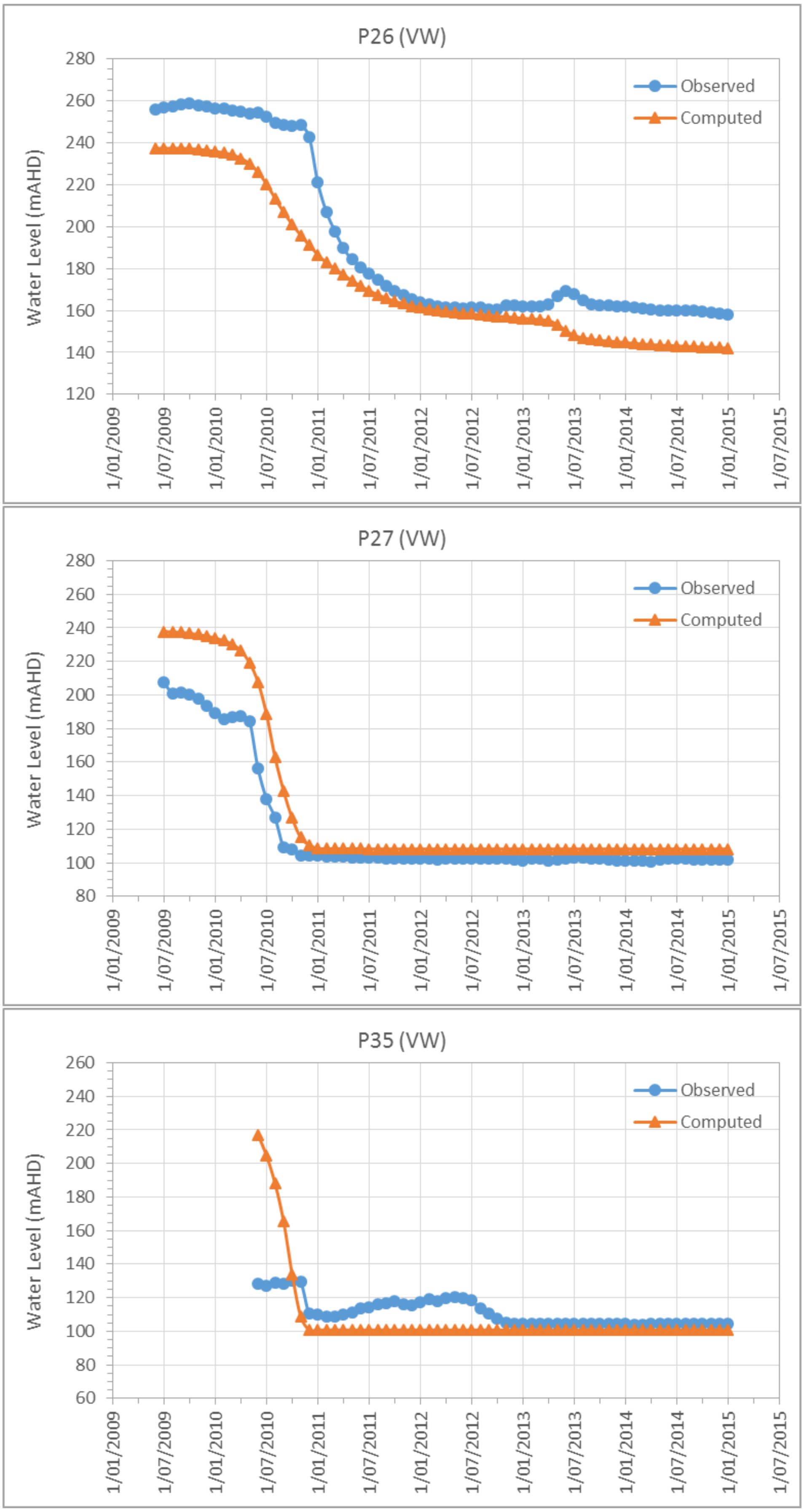
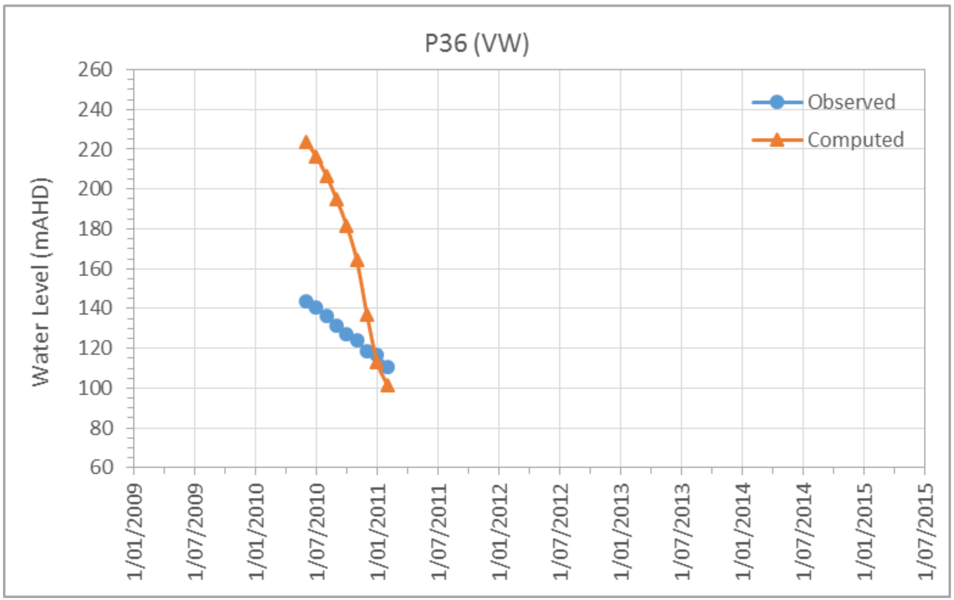


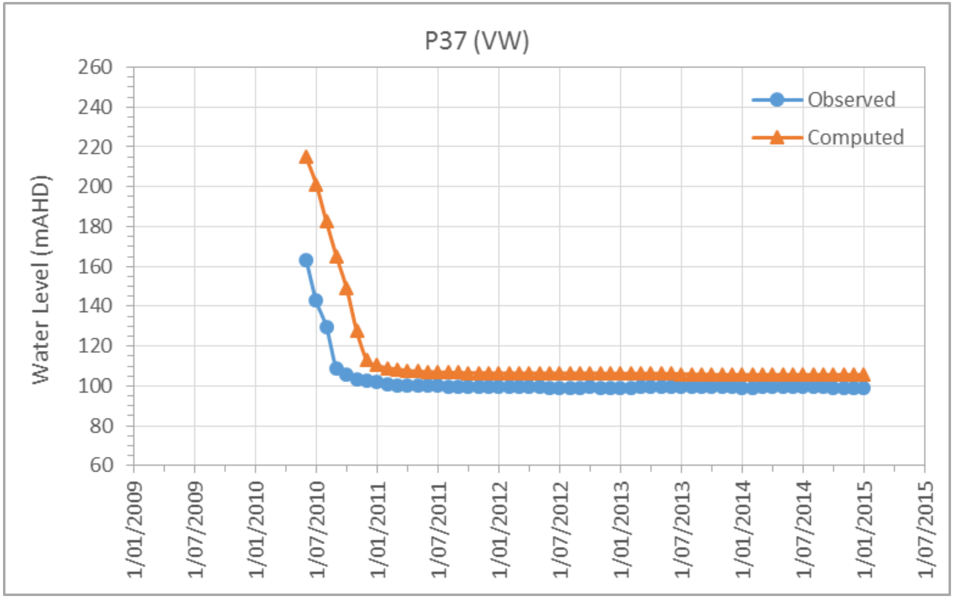
Figure K13. Observed and Simulated Hydrographs - Version 4 Model – Group 3: P21, P22, P25

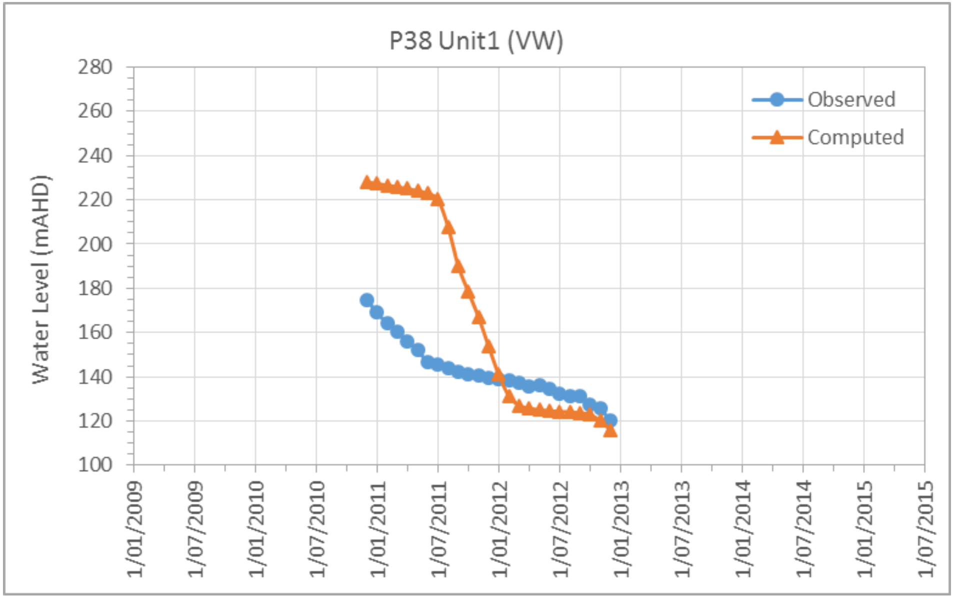


Group 3: Vibrating Wires (Single Depth)

Figure K14. Observed and Simulated Hydrographs - Version 4 Model – Group 3: P26, P27, P35

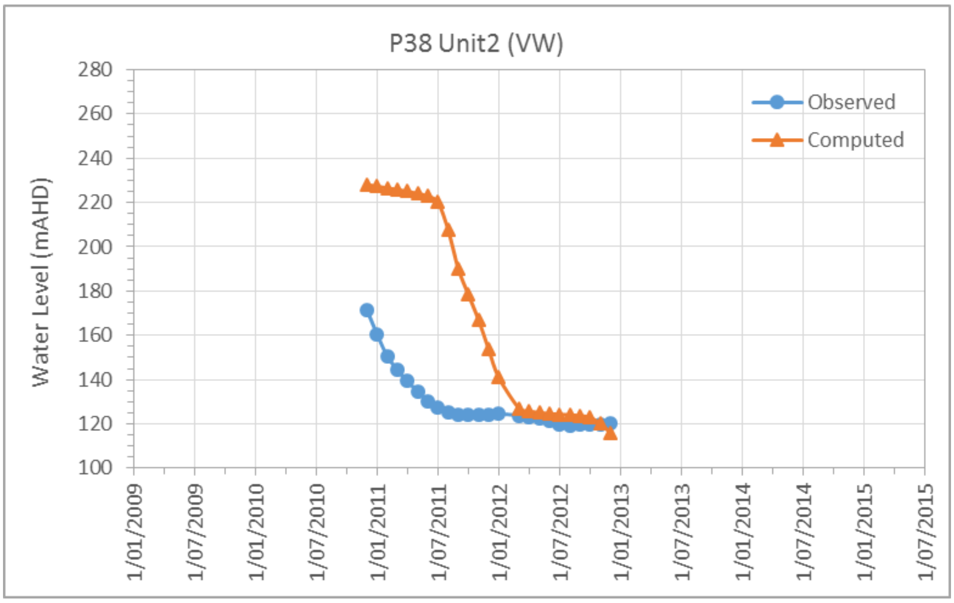






Group 3: Vibrating Wires (Single Depth)

Figure K15. Observed and Simulated Hydrographs - Version 4 Model – Group 3: P36, P37, P38



Group 3: Vibrating Wires (Single Depth)

Figure K16. Observed and Simulated Hydrographs - Version 4 Model – Group 3: P38

Group 4: Vibrating Wires (Multi Depth)

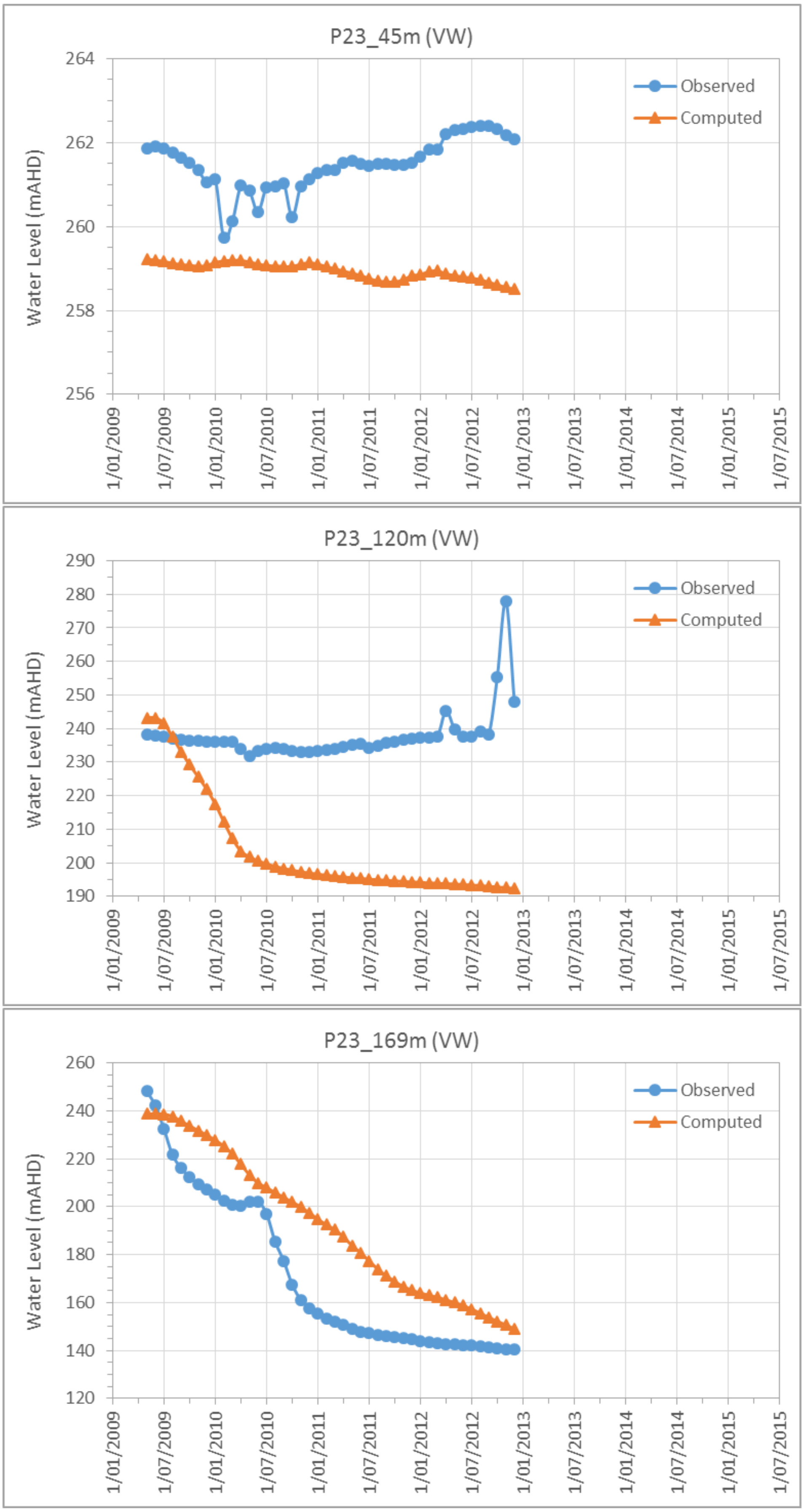


Figure K17. Observed and Simulated Hydrographs - Version 4 Model – Group 4: P23

Group 4: Vibrating Wires (Multi Depth)

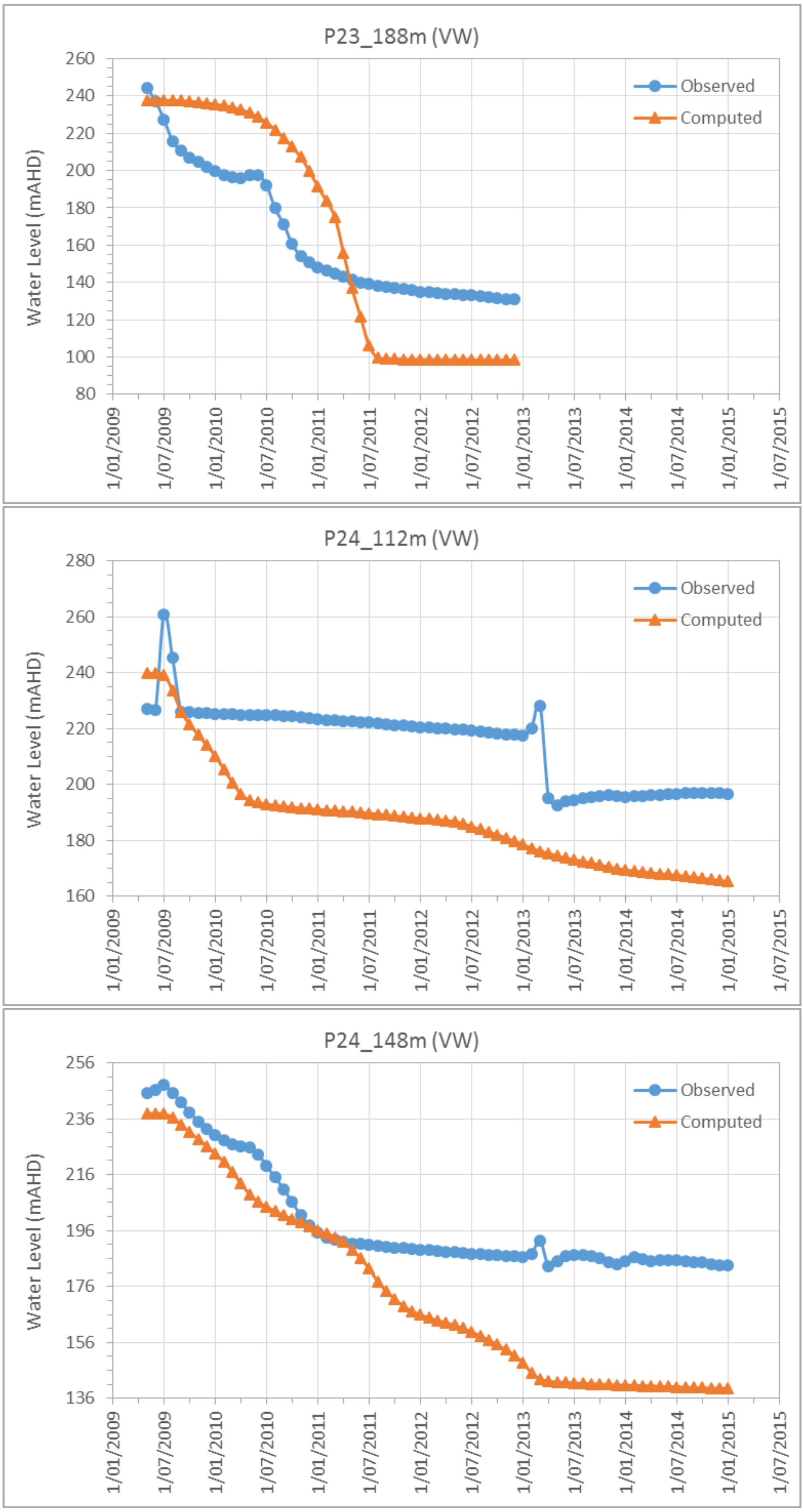


Figure K18. Observed and Simulated Hydrographs - Version 4 Model – Group 4: P23, P24

Group 4: Vibrating Wires (Multi Depth)

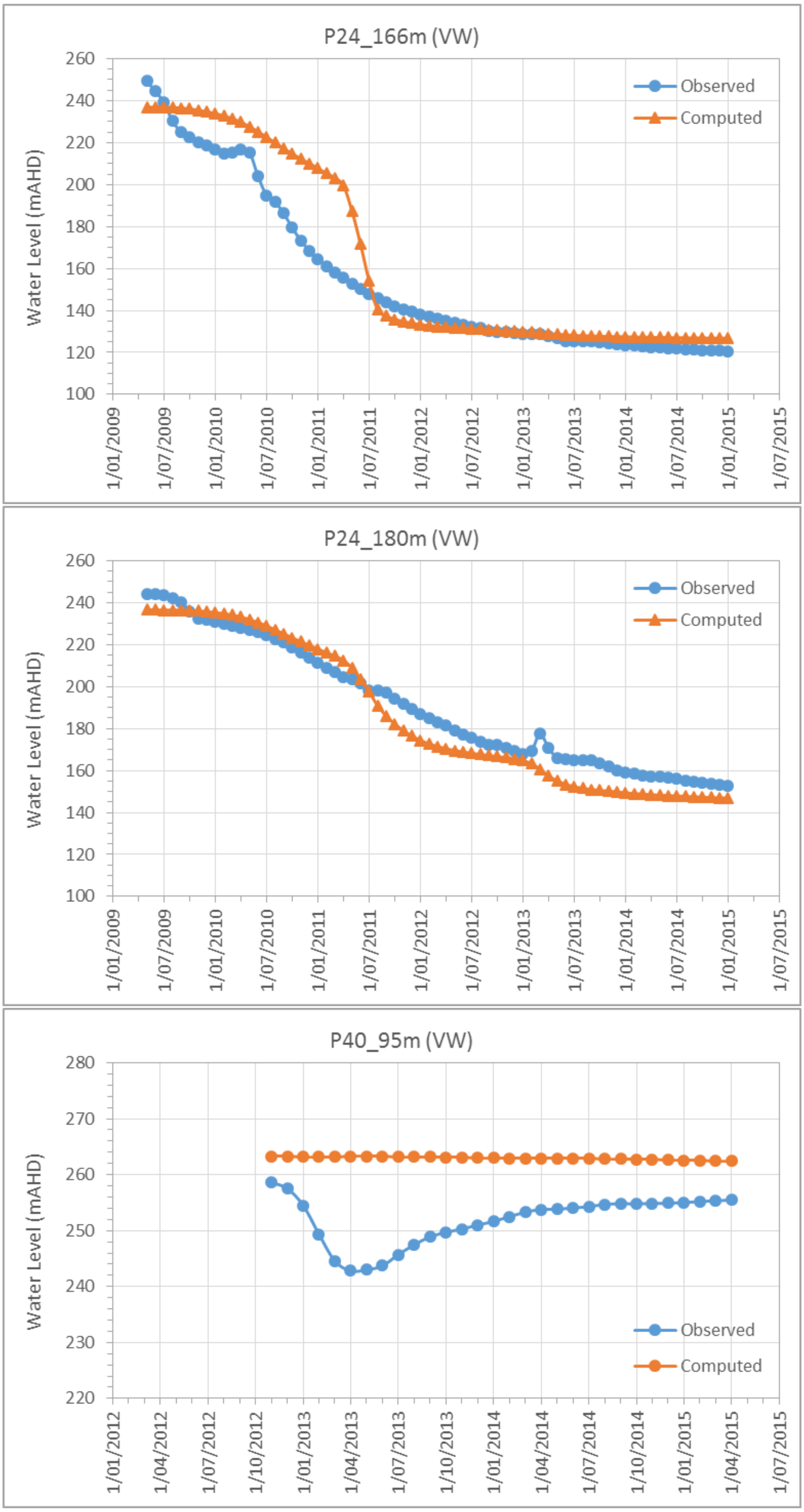


Figure K19. Observed and Simulated Hydrographs - Version 4 Model – Group 4: P24, P40

Group 4: Vibrating Wires (Multi Depth)

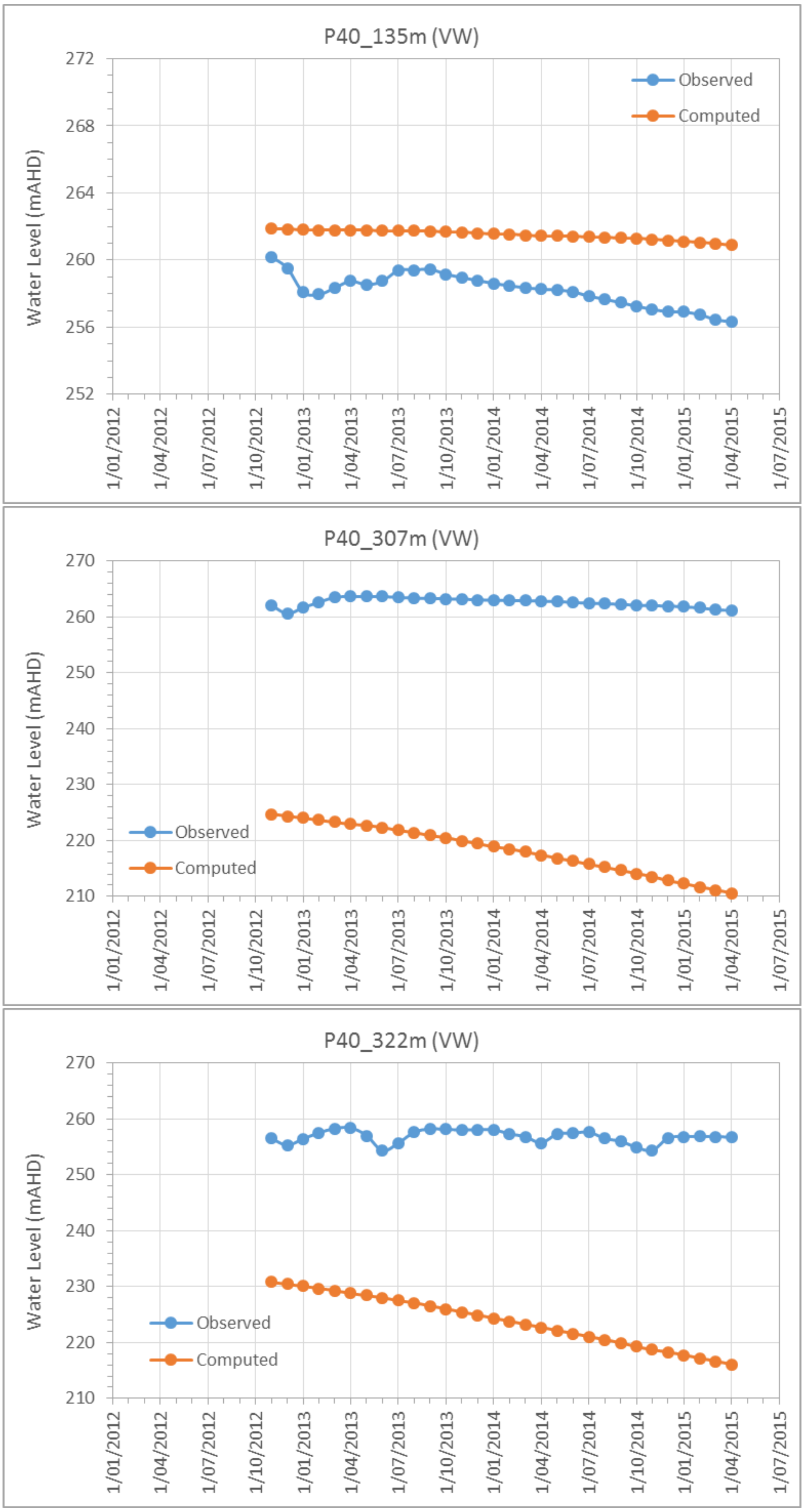
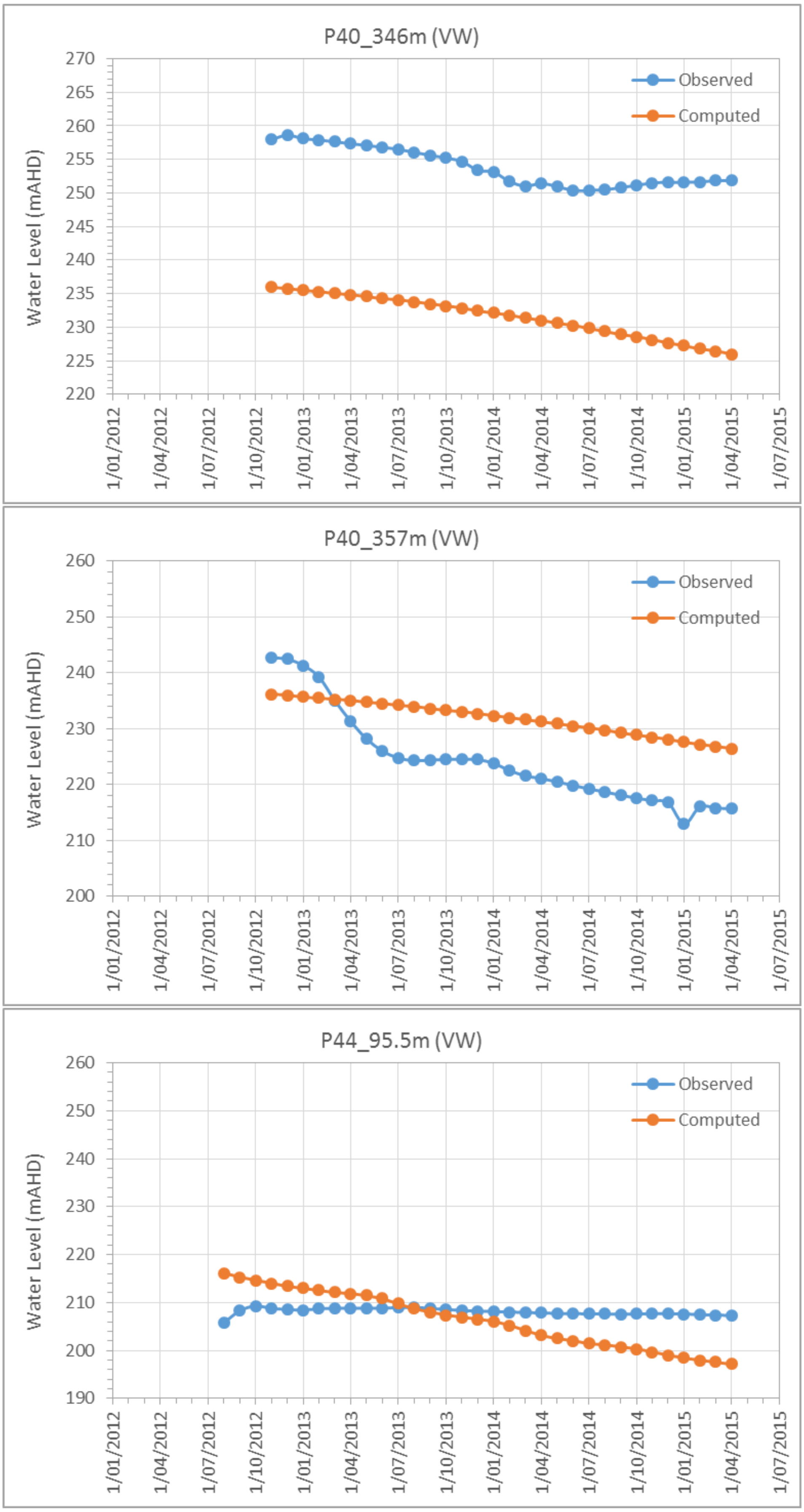


Figure K20. Observed and Simulated Hydrographs - Version 4 Model – Group 4: P40



Group 4: Vibrating Wires (Multi Depth)

Figure K21. Observed and Simulated Hydrographs - Version 4 Model – Group 4: P40, P44

Group 4: Vibrating Wires (Multi Depth)

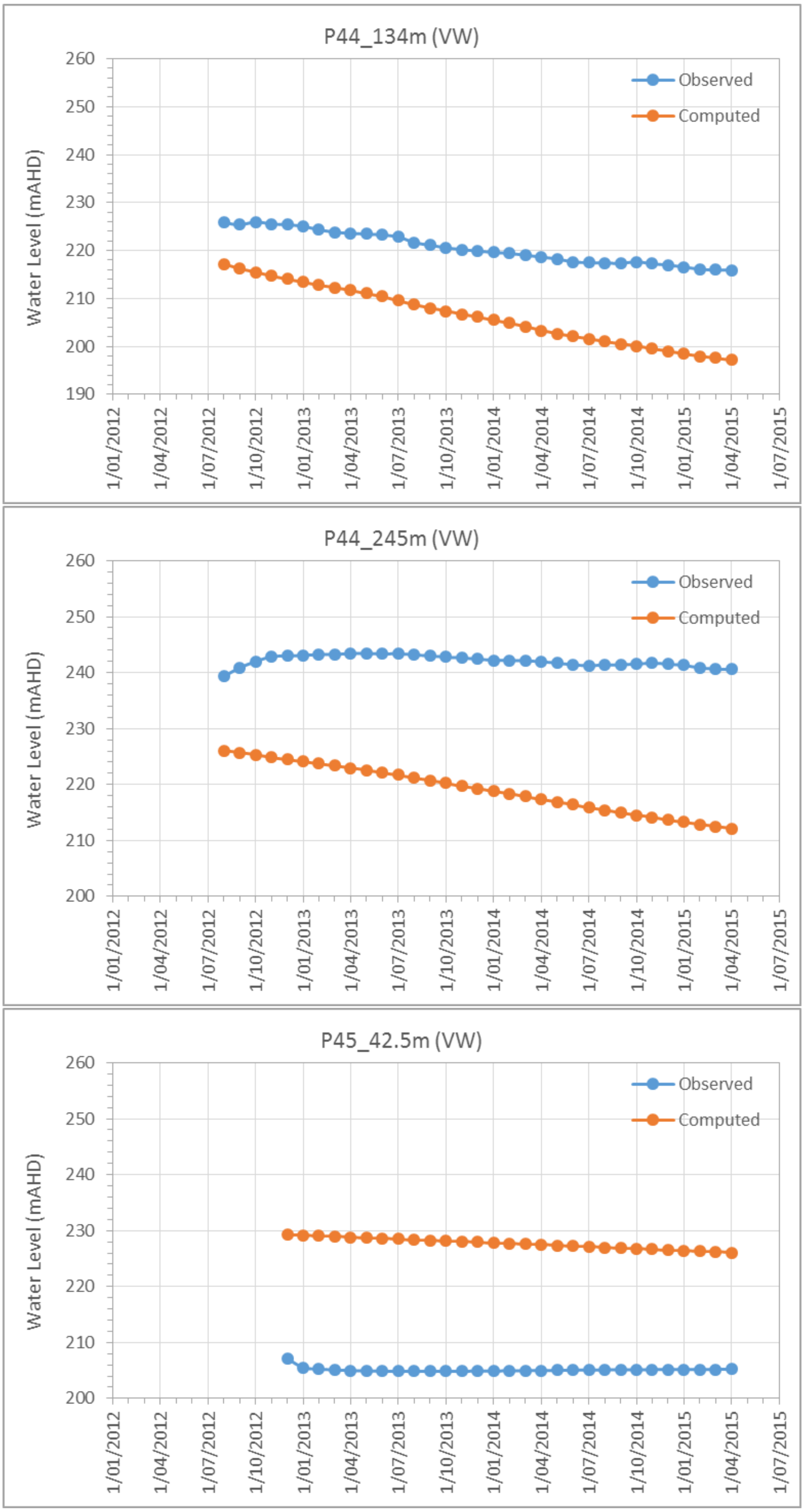
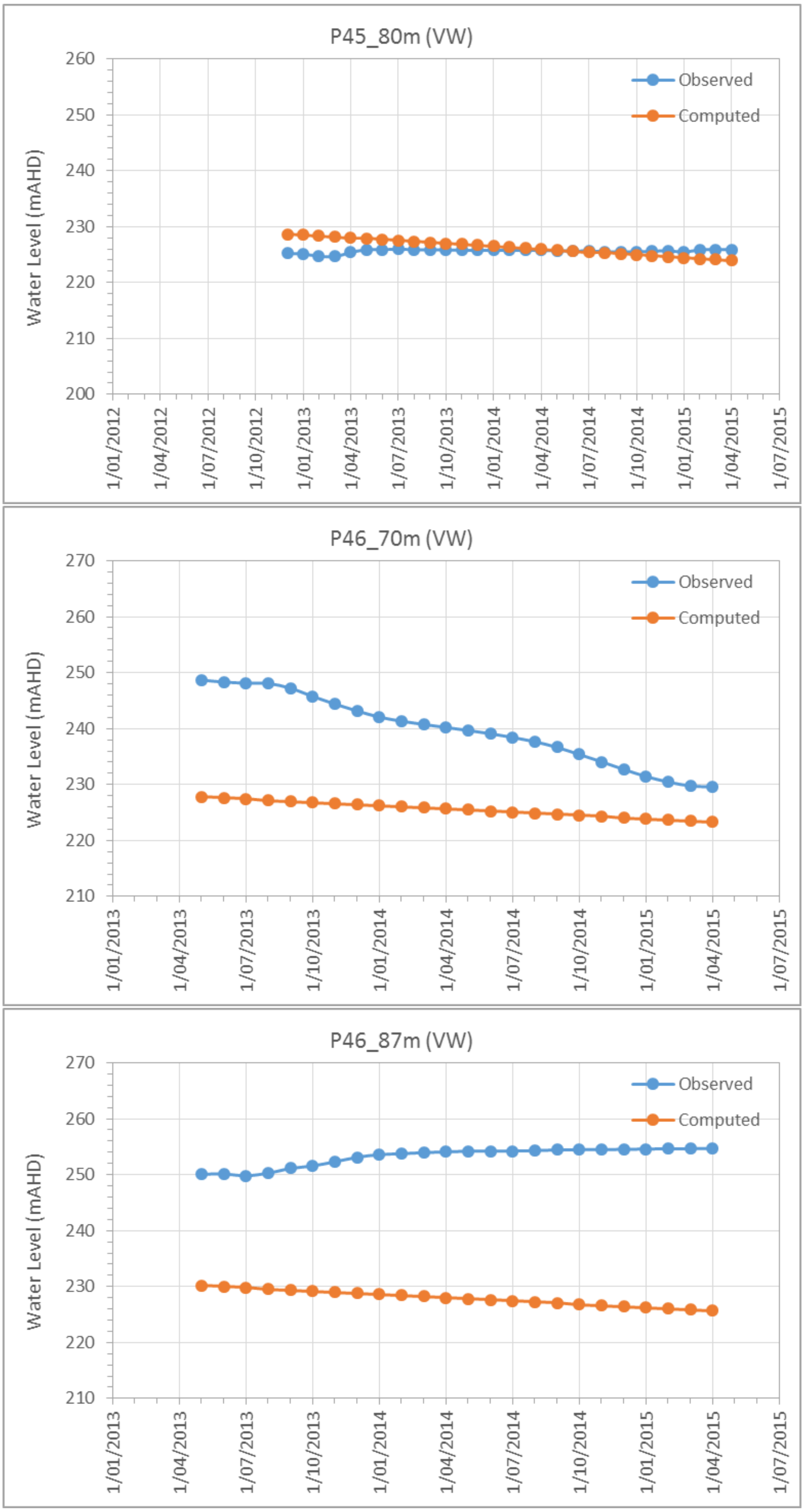
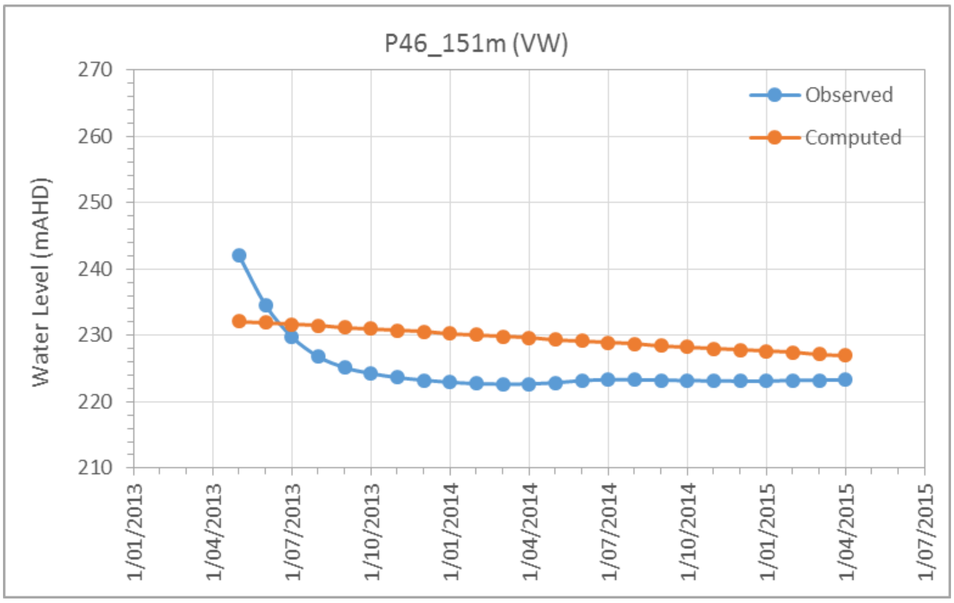


Figure K22. Observed and Simulated Hydrographs - Version 4 Model – Group 4: P44, P45



Group 4: Vibrating Wires (Multi Depth)

Figure K23. Observed and Simulated Hydrographs - Version 4 Model – Group 4: P45, P46



Group 4: Vibrating Wires (Multi Depth)

Figure K24. Observed and Simulated Hydrograph - Version 4 Model – Group 4: P46