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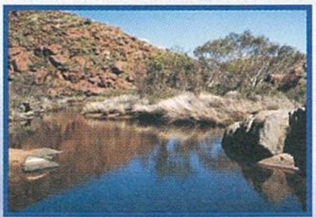
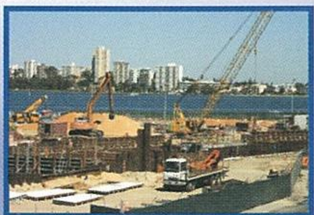
ASHTON UNDERGROUND MINE LW/MW 5-9 PIKES GULLY SEAM GROUNDWATER IMPACT ASSESSMENT REPORT



Prepared for: Ashton Coal Operations Ltd



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ASHTON UNDERGROUND MINE

LW5 TO 9 PIKES GULLY SEAM

GROUNDWATER IMPACT ASSESSMENT REPORT

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EXECUTIVE SUMMARY

Ashton is proposing to mine the Pikes Gully Seam beneath the Bowmans Creek floodplain using a combination of longwalls and miniwalls, to ensure that no direct hydraulic connection between the mine and the base of the alluvium can occur through subsidence cracking. The mine design proposed by Ashton is intended to maintain sufficient sound rock with in-situ hydraulic conductivities preserved, so that an effective aquaclude is retained between the alluvium and the goaf. The mine design proposes full width longwall panels in areas where there is no saturated alluvium, or high salinity alluvium/colluvium is present. Narrow width miniwalls are proposed in other areas, such that the panel width to cover depth ration is 0.6 or less. The mine plan is called the Longwall/Miniwall 5 to 9 (LW/MW 5-9) mine plan. Some interpanel areas remain unmined in this plan.

The Ashton groundwater flow model has been used to simulate mining of this proposed mine plan. The simulation commences from January 2004, the commencement of open cut mining, and extends to March 2012, the expected completion of extraction from the Pikes Gully Seam. The groundwater modelling has been carried out to investigate the potential impacts of the proposed mining on the groundwater flow system, including in particular, the potential impacts on baseflows to Bowmans Creek, Glennies Creek and Hunter River. Particular attention has been focused on baseflow impacts and alluvium drawdown impacts associated with Bowmans Creek.

The model was first run in steady state and transient modes to calibrate against observed impacts from open cut mining and underground mining from the Pikes Gully seam in LW1 and LW2 up to April 2008. The calibration modelling predicted baseflow reductions in Glennies Creek of 2.3 L/s by the end of the calibration period, which is consistent with observed inflows from the Glennies Creek alluvium into LW1 (around 2 L/s). Predicted groundwater level impacts also showed very good calibration with observed drawdowns in the large network of monitoring bores, which are distributed across the project area and in all the main hydrogeological units and model layers. Observed impacts are also at or below those predicted in the EIS studies.

After successful calibration, the model was then used to predict the potential impacts of future mining. The modelling has predicted a small baseflow reduction in Bowmans Creek due to the LW/MW 5-9 mine plan, reaching a maximum of 1.2 L/s at the end of extraction from the Pikes Gully Seam. This compares with an estimated leakage rate of 1.5 L/s from the Bowmans Creek alluvium, if mining were to take place across the full area occupied by the LW/MW 5-9 mine plan, but with extraction limited to first workings only (Aquaterra, 2008b).

The predicted impact of the LW/MW 5-9 plan is reflected as an average drawdown of approximately 0.8 m in the alluvium within the floodplain above the mine, which equates to a predicted reduction of 12% in the volume of groundwater storage in the Bowmans Creek alluvium between the New England Highway and the Hunter River.

The modelling predicted no further significant increase in seepage from the Glennies Creek alluvium, and negligible impact on Hunter River baseflows.

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SECTION 1 INTRODUCTION

The Ashton Coal Project is located 14km west of Singleton in the Hunter Valley region (**Figure 1)** between the villages of Camberwell and Ravensworth on the New England Highway **(Figure 2**). The Ashton Coal Project consists of both open cut and underground mining operations to access a series of coal seams within the Permian Foybrook Formation of the Whitingham Coal Measures.

The open cut mine, which is located north of the New England Highway, commenced operations in 2003. Coal is recovered from several seams of varying thickness, in two open cuts – the smaller Arties Pit and the larger Barrett Pit. The underground mine is located south of New England Highway, and is accessed from the northern side of the highway via a portal in the Arties pit.

The initial mine plan comprised eight longwall panels (LWs 1 to 8), four of which have been approved for mining of the Pikes Gully seam (LWs 1 to 4) under an SMP Application lodged and approved in 2006. Underground mine development commenced in December 2005, and mining of the first longwall panel (LW1) in the Pikes Gully seam began in March 2007. LW1 was completed in October 2007, and LW2 in July 2008. Mining of LW3 has commenced, and it is proposed to continue mining the Pikes Gully seam across the rest of the underground mine area, and then subsequently mine the underlying Upper Liddell, Upper Lower Liddell and Lower Barrett seams in a multi-seam longwall operation.

The first four longwall panels, LW1 to LW4, were designed to mine final voids 215m wide, separated by chain pillars of 25m width rib to rib, with cut-throughs at 100m centres. The layout of LWs 1 to 4, together with the progress of mining to date, is shown on **Figure 3**. The original 8-panel mine plan has been amended, and it is now proposed to mine the remainder of the Pikes Gully Seam from a further five panels referred to as Longwalls and Miniwalls 5 to 9 (LW/MW 5-9), also shown on **Figure 3**.

The main aquifers in the Ashton Coal Project area are the coal seams (with permeability developed in cleat fractures), and unconsolidated aquifers within the alluvium associated with the Hunter River and its tributaries Bowmans Creek and Glennies Creek. Glennies Creek and its alluvial floodplain are located to the east of the underground mine, and do not overlap the mining area. Likewise, the Hunter River and its alluvium do not overlap the mining area.

However, parts of LW/MW 5-9 in the western half of the underground mining area are overlain by Bowmans Creek and its associated alluvial sediments (**Figure 3**).

The mining operation was approved by a Development Consent granted on 11 October 2002. The consent conditions accompanying the project approval (Minister for Planning, 2002) include measures to protect Bowmans Creek and the alluvium. The relevant consent conditions are:

3.9 The Applicant shall design underground mining operations to ensure no direct hydraulic connection between the Bowmans Creek alluvium and the underground workings can occur through subsidence cracking. In order to achieve this criteria the Applicant shall assess levels of uncertainty in all subsidence predictions, and provide adequate contingency in underground mine design to ensure sufficient sound rock is maintained to provide an aquaclude between the Bowmans Creek alluvium, and the underground mine goaf.

4.13 *All surface and underground operations including long wall mining shall be conducted to minimise potential impacts on groundwater flow and quality of the alluvial groundwater resource, integrity of the alluvial aquifer and to minimise off-site effects.*

To meet the above consent conditions, the Ashton Coal Project assessed a number of longwall design options and has developed a current preferred mine plan which comprises panels of various widths and lengths (including some narrow width longwall blocks referred to as miniwalls and some areas with no mining) to prevent direct hydraulic connection between underground workings and the Bowmans Creek alluvium and minimise the impacts of underground mining on the alluvial groundwater. This mine plan is referred to as Longwalls and Miniwalls 5 to 9 (**Figure 3**). Ashton Coal Project has developed a Subsidence Management Plan (SMP) for the LW/MW 5-9 mine plan.

The development of the LW/MW 5-9 mine plan has been based on extensive interactive studies of subsidence impacts of various panel widths and mine layouts, and the resultant changes to the hydraulic properties of the coal measures overburden. The investigation of subsidence fracturing has been undertaken by SCT Operations (SCT, 2008a).

As part of the development of the LW/MW 5-9 mine plan and SMP, extensive investigations have also been undertaken to improve the understanding of the local hydrogeological conditions and to provide reliable predictions of the impacts of various mine plan alternatives. These investigations, undertaken by Aquaterra and/or Peter Dundon and Associates[1] (PDA) included:

- Ongoing review of groundwater (and surface water) responses to the existing longwalls, including the LW1 end of panel report (Aquaterra, 2008a) and work in progress on the LW2 end of panel report.
- Detailed investigation of the Bowmans Creek alluvium (Aquaterra, 2008b).
- Numerical groundwater modelling of the mine plan (subject of this report).

[1] Peter Dundon and Associates formally merged with Aquaterra in March 2008, and now operates as part of that organisation under the name Aquaterra.

SCT (2008a) has carried out an assessment of the relationship between longwall panel width and potential hydraulic connection to Bowmans Creek and its associated alluvium. The main conclusion from the SCT study was that panel widths in the Pikes Gully Seam up to 0.7 times cover depth would not be expected to lead to direct connected cracking between the longwall goaf and the surface. When considering the multi-seam effects of subsequent extraction from the underlying Upper Liddell Seam, SCT concluded that a panel width to cover depth ratio of 0.6 would be appropriate for design of extraction panels beneath the Bowmans Creek alluvium.

On the basis of these recommendations, Ashton Coal has designed a mine plan comprising longwalls and miniwalls of varying panel width for extraction of the Pikes Gully Seam beneath the Bowmans Creek floodplain in the western half of the underground mine area. This mine plan known as Longwalls and Miniwalls 5 to 9 (LW/MW 5-9) is shown on **Figure 3**. The planned mining schedule is displayed on **Figure 4**.

The LW/MW 5-9 mine layout incorporates the following elements:

- Full width (216m) panels beneath areas lacking alluvium or beneath alluvium/colluvium containing saline groundwater;
- Medium width panel LW9 (141m); and
- Miniwalls of varying width (60m to 93m) to ensure a panel width to cover depth ratio of 0.6 or less beneath Bowmans Creek and areas of saturated alluvium.

The panel widths and overburden depths for the LW/MW 5-9 preferred mine plan are listed in **Table 2.1** (SCT, 2008c).

Table 2.1

Panel Widths for LW/MW 5-9 Mine Plan

Longwall / Miniwall	Panel Width (m)	Overburden Depth (m)	W/D Ratio (Maximum)	W/D Ratio (Minimum)
LW5	216	110 – 155	2.0	1.4
MW5	60	100 – 125	0.6	0.5
LW6	216	130 – 160	1.7	1.3
MW6	70	115 – 170	0.6	0.5
MW7	81	130 - 170	0.6	0.5
MW8	87	140 – 175	0.6	0.5
MW9	93	160 - 190	0.6	0.5
LW9	141	140 – 180	1.0	0.8

The width of LW9 is limited by the proximity of the western lease boundary.

SECTION 3 PREVIOUS STUDIES

The results of previous work on review of performance of the LW1 and LW2 panels and the Bowmans Creek Alluvium are detailed in separate reports and will not be repeated verbatim here. However, the key outcomes/findings of these studies were as follows:

- The Bowmans Creek alluvium forms a shallow aquifer unit within the Bowmans Creek floodplain that is clearly distinct from both the underlying Permian coal measures and the Hunter River alluvium. It merges laterally with colluvium on the flanks of the floodplain, and with residual soils in the highly weathered upper part of the Permian sediments.
- The Bowmans Creek alluvium contributes some baseflow to Bowmans Creek, although the contribution from the planned mining area is very small. Baseflow is also derived locally from the Permian.
- There is only limited hydraulic connection between the Bowmans Creek alluvium and shallow weathered Permian sediments, and virtually no connection with the Pikes Gully coal seam or the deeper seams planned for future mining. This is supported by distinctly different groundwater levels, differences in groundwater quality, and differing responses to recharge and from mining activity.
- Despite the absence of direct hydraulic connection and the presence of an aquaclude between the Bowmans Creek alluvium and the Pikes Gully seam, there is potential for some leakage from the alluvium to the underground mine workings. Even if coal were extracted by first workings only, with no continuous subsidence-induced fracturing developed between the goaf and the base of the alluvium, the prevailing natural vertical permeability of the coal measures overburden would (based on simple analytical flow modelling) potentially allow leakage of the order of 125 m3/d (46 ML/year) from the alluvium to the mine.
- The impact of subsidence on leakage from the Bowmans Creek alluvium will be controlled by the height of interconnected fracturing and the residual vertical permeability of the Permian above the subsidence-affected zone. Provided that a zone of unfractured rock remains between the base of the alluvium and the top of the zone of continuous interconnected fracturing, vertical leakage from the alluvium will be limited by the low vertical permeability within the unfractured barrier zone (or “aquaclude” as described in Consent Condition 3.9).
- Monitoring of groundwater level impacts during mining of LW1 and LW2 has shown groundwater impacts in the Pikes Gully Seam and in the lower sections of the overlying coal measures. Reduced drawdowns occur at higher levels in the coal measures, but no impacts have been observed in the near-surface weathered Permian or in alluvium above the mine area. Cover depths in LW1 ranged from 35m to 90m, and in LW2 from 50m to 105m.
- Piezometers in the lower sections of the Pikes Gully seam overburden which initially showed drawdown response to subsidence above LW1 or LW2 have shown partial recovery after the initial mining impact. This suggests that some degree of self-healing of subsidence fractures is occurring.
- No drawdown impacts have been observed in the coal measures below the Pikes Gully Seam, even in the Arties Seam which is located just 5-10m below the Pikes Gully (eg WML189).

SECTION 4 ASSESSMENT OF GROUNDWATER IMPACTS – LW/MW 5-9

This report details an assessment of the potential impacts of the proposed mining of LW/MW 5-9 on the groundwater resources, in particular the Bowmans Creek alluvium.

Numerical groundwater modelling has been undertaken to provide predictions of the impacts of underground mining on local groundwater and surface water to support the SMP application for LW/MW 5-9.

Initially, the model used for the EIS studies (HLA, 2001) was re-established and run to confirm the EIS predictions. The model was then modified to improve its suitability for use with longwall mining and, after re-calibration, has been used to assess impacts of current and proposed future mining options. The modelling studies to date have largely focused on the impacts of mining coal from the Pikes Gully Seam, particularly on the alluvial aquifer associated with Bowmans Creek. The model has also been used to predict groundwater inflows to the underground workings.

One of the most important features of the model is the simulation of the progressive development of the underground mine voids and goafs, the subsidence fracturing above the goafs and associated changes to aquifer parameters over time (most importantly hydraulic conductivity). The model development has drawn heavily on the results of fracture prediction modelling by SCT (2008a), and the predictive groundwater modelling has been carried out in close consultation with both Ashton Coal and SCT.

The model domain extends well beyond the boundaries of the underground mine area, and includes the Ashton open cut and other nearby mines. Hence, the simulation modelling needs to consider the concurrent mining from both the open cut and the underground. The model will continue to be used for impact prediction and management through the life of the mining operation.

The long term objectives of the Ashton Groundwater Model are to:

1. Assess the potential inflow rates into the open cut and underground mine workings during longwall mining.
2. Assess the potential impacts from alternative underground mine plans and longwall/miniwall mine layouts.
3. Predict the potential impacts of the open cut and underground mining on local and regional groundwater levels and surface water resources.
4. Assess the potential impacts on alluvial aquifers associated with Bowmans Creek, Glennies Creek and Hunter River.

This report details the design, development and calibration of the Ashton Groundwater Model, and presents the results of model predictions of the impacts of the completion of mining from the Pikes Gully Seam for the preferred mine option which includes a series of longwalls and miniwalls beneath Bowmans Creek and its associated saturated alluvium.

These results are assessed in terms of the impacts of the proposed LW/MW 5-9 mine plan for the western half of the underground mining area, and this report is intended to provide support to the SMP for the LW/MW 5-9 plan. The results confirm earlier predictions (Aquaterra, 2008b) that there will be minimal impacts from this plan on the Bowmans Creek alluvium and surface water flows in Bowmans Creek.

5.1 GEOLOGY

The study area is located within the Hunter Coalfield of the Sydney Basin. The Permian aged coal reserves within the Ashton Coal Project mining lease are mostly within the Foybrook Formation of the Vane Sub-Group (Hebden to Lemington seams), with limited occurrence of the Bayswater Seam which is the basal unit of the Jerry's Plains Sub-Group. Both sub-groups are part of the Whittingham Coal Measures, the basal coal-bearing sequence of the Singleton Supergroup. Regional surface geology is shown on **Figure 5.**

The major mineable coal seams identified in the project area are (in descending stratigraphic order) the Pikes Gully, Upper Liddell, Upper Lower Liddell, and Lower Barrett Seams. The Bayswater Seam, which is stratigraphically higher than the Pikes Gully seam, was previously mined in the former Bayswater open cut, and is currently being mined at the Narama Pit, both to the west of the project area. The Bayswater Seam has only limited presence in the southwestern corner of the Ashton underground mine area. Lemington Seams 1-19 of varying thickness between the Pikes Gully Seam and the base of the Bayswater are present in the overburden across the LW/MW 5-9 mine area.

The target coal seams are separated by interburden sediments, which comprise sandstone, siltstone, conglomerate, mudstone, and shale, as well as occasional minor coal seams. The interburden between the Pikes Gully and Bayswater Seams, including the Lemington Seams, is essentially the overburden to the Pikes Gully Seam. A representative geological cross section through the area is presented in **Figure 6.**

The main regional geological structures in the area are the Bayswater Syncline, the axis of which is located to the west of Ashton in the Ravensworth South and Narama mines; the Camberwell Anticline, which passes to the east, through Camberwell village and the Camberwell open cut; and, further to the east, the Glennies Creek Syncline (**Figure 7**). The axes of these structures run from N to S and NNW to SSE respectively. The coal seams to be mined at Ashton are outcropping in the study area on the western and north-eastern limbs of the Camberwell anticline. The subcrop patterns for the seams derived from the Ashton geological model are shown in **Figure 7**. The geology was extrapolated out to the boundary of the groundwater model by making use of published mapping and geological references in various public company reports.

The Pikes Gully coal seam thickness in the study area varies between 2m and 3m, though it is generally in the range of 2.3 to 2.8m. The Pikes Gully seam outcrops/subcrops in the eastern part of the Ashton Coal Project area and is up to about 200m deep (around -140m AHD) in the south west. The Lower Barrett seam, which is the deepest seam considered for potential mining at Ashton, occurs at depths ranging from 40m to more than 300m below ground (0 to -240m AHD). The interburdens between the seams vary in thickness between 7m and 63m (refer **Table 5.1**).

Within the project area, alluvium occurs in association with the Hunter River and its tributaries Bowmans Creek and Glennies Creek. Investigation drilling of the Bowmans Creek alluvium (Aquaterra, 2008b) indicates up to about 15 metres of sandy silts, silts and silty clays, with horizons of silty sands and gravels. Maximum recorded saturated thickness is 4.5m.

The Glennies Creek alluvium comprises predominantly silty clay, with occasional sandy and gravelly horizons, and has been drilled to a maximum thickness of 9m (WML147). Maximum recorded saturated thickness is approximately 3m.

The nature of the Hunter River alluvium is not well known in this area, but where drilled it was found to comprise clay and silty clay, with gravel horizons. A basal gravel horizon 8.5m thick was drilled in RA27. The saturated thickness in this bore was 6m, but greater saturated thicknesses are expected.

Table 5.1
Thicknesses of Coal Seams and Interburden Layers in the Ashton Project Area (m)

Geological Unit	Average	Minimum	Maximum
Pikes Gully overburden (Pikes Gully to base of alluvium)	Variable from 0m to 200m, due to dip on strata		
Pikes Gully	2.2	1.8	3.0
Interburden – Upper Liddell to Pikes Gully	36	13	63
Upper Liddell Seam	2.2		3.2
Interburden – Upper Lower Liddell to Upper Liddell	28	7	47
Upper Lower Liddell Seam	2.1		6.1
Interburden – Lower Barrett to Upper Lower Liddell	40	24	62
Lower Barrett Seam	2.2		5.9

5.2 HYDROGEOLOGY

Two distinct aquifer systems occur in the study area:

- A fractured rock aquifer system in the Permian coal measures, with flow occurring predominantly in the coal seams.
- A shallow porous media aquifer system in the unconsolidated sediments of the alluvium associated with Bowmans Creek, Glennies Creek and Hunter River, merging into colluvium and residual soil (extremely weathered coal measures).

5.2.1 Hydraulic Parameters

The coal measures strata have little primary or intergranular permeability, but joints and fissures result in secondary or fracture permeability.

Generally, the coal seams are more brittle and more densely fractured than the interburden strata and therefore have a relatively higher hydraulic conductivity, typically one to two orders of magnitude higher than the interburden material. Within the coal seams, the groundwater flows predominantly through cleat fractures, with very little evidence of structure-related fracturing. Vertical permeability is significantly lower than horizontal (typically 3 or more orders of magnitude lower).

Within the Ashton Coal Project area, test pumping indicates hydraulic conductivity values for the Pikes Gully coal seam in the range 0.01 m/d to 10 m/d (PDA, 2006 and Aquaterra, 2008a), with the high end of the range considered to be representative of conditions near outcrop. Testing of the Pikes Gully seam at depth in bores WML20 and WML21 (**Figure 8**) revealed hydraulic conductivity values of 0.015 m/d to 0.02 m/d (PDA, 2006), which are considered to be representative of conductivity well removed from outcrop.

Similar hydraulic conductivities are expected to apply to other coal seams in the coal measures.

Hydraulic testing of standpipe piezometers completed in the upper parts of the Permian coal measures (generally free of coal seams) revealed hydraulic conductivities in the range 0.01 to 3.3 m/d with a median value of 0.1 m/d (Aquaterra, 2008b). In most cases, the tested section was within the weathered zone, which has properties more akin to alluvium or colluvium than fractured rock.

The results of packer testing and analysis for permeability over seventeen intervals within the Permian coal measures in borehole WMLC213 located southwest of the mine area (**Figure 8**) showed the following (SCT, 2008b):

- Most permeability results were in the order of 10^{-9}m/s (10^{-4}m/d).
- Some test results in the depth range 50m to 100m, where there was very little fracturing, indicated permeability less than 10^{-11}m/s ($<10^{-6}$m/d).
- Some permeabilities in the shallow, upper sections of the Permian were in the order of 10^{-8} to 10^{-7}m/s (10^{-3} to 10^{-2}m/d).

Hydraulic testing of the Bowmans Creek alluvium (Aquaterra, 2006b) revealed a high variability in hydraulic conductivity, with values in the range 0.0002 to 15 m/d, and a median value of 0.7 m/d. Testing of bores in the Glennies Creek alluvium revealed conductivities of 0.07 to 0.75 m/d in the area to the east of Ashton underground mine, with a median value of 0.3 m/d.

Floodplain alluvium of the Hunter River was tested at one site near the southern end of the Ashton underground mine area (RA27 – see **Figure 8**), revealing a hydraulic conductivity of 50 m/d (Aquaterra, 2006b). This is consistent with the results of extensive testing at the Hunter Valley No.1 mine, where an average permeability of about 45 m/day was established (HLA, 2001).

A summary of representative aquifer properties of the hydrogeological units in the study area is given in **Table 5.2**.

Table 5.2

Representative Aquifer Parameters for Main Hydrogeological Units.

Units	Horizontal Hydraulic Conductivity (m/d)		Confined Storativity	Unconfined Specific Yield
	Tested Range	Median		
Bowmans Creek alluvium	0.0002 to 15	0.7	0.0001	0.05
Glennies Creek alluvium	0.07 to 0.75	0.3	0.0001	0.05
Floodplain alluvium of the Hunter River	50	50	0.0001	0.1
Coal Seams	0.01 to 10	0.04	0.0001	0.005
Interburden/overburden	<0.000001 to 0.008	0.0003	0.00001	0.005

Vertical hydraulic conductivities are considered to be 2-3 or more orders of magnitude lower than the horizontal hydraulic conductivity for all units, based on the very strongly bedded nature of all units and the role of bedding plane features in controlling groundwater flow. This applies both to the coal seams (which are broken up by interbeds of siltstone/sandstone/claystone) and especially to the interburden sediments which comprise interbedded siltstones, sandstones, claystones and shale.

5.2.2 Groundwater Levels

Groundwater levels in the upper part of the Permian coal measures tend to reflect the local topography to some extent, with higher groundwater levels in elevated areas and lower levels in the valleys. However, groundwater levels at depth in the coal measures are more regionally-controlled, and are independent of the local topography.

A pre-mining potentiometric surface for the coal measures was established by HLA for the EIS modelling (HLA, 2001) on the basis of water levels measured in open holes drilled to the base of the Barrett Seam. This composite water level map of the coal measures indicated that in the study area groundwater flowed mainly to the southwest, believed to be under the influence of past or present nearby mining activity. Early monitoring data from Ashton indicates that prior to commencement of mining at Ashton, groundwater levels in the Pikes Gully seam were above the surface water levels in Bowmans Creek and Glennies Creek. Near the downstream end of the Bowmans Creek floodplain, bores drilled for piezometer installations (**Figure 8**) were freely flowing until the piezometers were installed and the holes grouted up (eg WML112). Groundwater pressures in some of the deeper coal seams are still at or above the ground surface in this area (eg WML111 and WML213).

Potentiometric contours for the Pikes Gully Seam have been prepared on the basis of monitoring of piezometers installed in 2006-7 (**Figure 9**). The potentiometric heads in the coal measures at this time have been influenced by the effects of open cut mining at Ashton (which began in 2003), underground mining (LW1 and LW2 longwall panels, LW3 development headings and the NW Mains) and probably some effect from longer-term mining at nearby mine sites. The potentiometric contours for other seams are expected to have quite different patterns – some of the lower Lemington seams would have a similar pattern to the Pikes Gully seam, but with a less pronounced response to the underground mining. Seams beneath the Pikes Gully would display no impacts from the underground mine, but may show some response to open cut mining. Shallower Lemington seams and the Bayswater seam would show some response to current mining at the Narama pit, and former Ravensworth open cut mining to the west, but no response to underground mining.

Contours of groundwater levels in the weathered coal measures, based on measured water levels in piezometers installed in the shallowest groundwater interval intersected in the Permian in drillholes, are shown on **Figure 10**. These contours tend to reflect the local topography.

Contours of the water table in the alluvium (**Figure 11**) have been developed on the basis of measured water levels in standpipe piezometers from the Bowmans Creek alluvium investigation program (Aquaterra, 2008b). **Figure 11** also shows the lateral extent of saturated Bowmans Creek alluvium, determined from a combination of drilling results, aerial photography, aeromagnetic survey, ground mapping and groundwater level monitoring. In the Bowmans Creek alluvium, groundwater levels show a gradient from north to south (ie upstream to downstream) but also converge about Bowmans Creek.

The boundary of saturated Glennies Creek alluvium is less well-defined, but is shown approximately on **Figure 11**.

The shallow groundwater levels are generally similar to or slightly higher than in the immediately underlying weathered Permian coal measures. However, in unstressed (pre-mining) conditions, the potentiometric surface in the deeper Permian coal measures is higher than the water table, and there is a tendency for increasing heads with depth (Aquaterra, 2008b).

5.2.3 Recharge

Table 5.3 summarises rainfall data from the Jerry's Plains weather station, situated approximately 14 km to the southwest of the Ashton Project. The table lists the mean monthly rainfall and mean annual rainfall, based on more than 100 years of rainfall data since 1884.

Table 5.3

Average Monthly and Yearly Rainfall and Evaporation Data (mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Rainfall*	80.3	69.7	58.4	43.9	41.2	47.7	43.7	36.7	42.1	51.7	57.1	66.8	639
Evaporation#	220	169	154	118	89	56	69	81	112	164	195	204	1630
Balance	-139.7	-99.3	-95.6	-74.1	-47.8	-8.3	-25.3	-44	-69.9	-112.3	-137.9	-137.2	-990.9

*BOM Jerry's Plains Meteorological Station
BOM Scone SCS Meteorological Station

Recharge to the aquifers occurs by the infiltration of rainfall and local runoff. The primary mode of recharge to the Permian coal seam aquifers is by direct recharge where the various seams outcrop or subcrop beneath the alluvium or regolith layer. It is considered that recharge via downward leakage through overburden and interburden layers subject to head differences is a very minor or negligible component of recharge. However, where the overburden/interburden becomes altered through subsidence fracturing, vertical leakage between seams will become more significant.

The alluvial and regolith aquifers are recharged by direct infiltration of rainfall and local runoff.

The nearest station for which average monthly and yearly A Class pan evaporation data are available is Scone SCS Meteorological Station, where the evaporation records date back to 1950 (see **Table 5.3**). The data indicate that evaporation generally exceeds rainfall, indicating that a soil water balance deficit occurs most of the time and only a small percentage of the rainfall is available for runoff and/or recharge of groundwater.

Regional studies suggest approximately 0.5% to 1.0 % of the annual rainfall percolates to the coal measures groundwater system (HLA, 2001). Based on observation of responses to rainfall in the Ashton project area, we consider that recharge rates are likely to be highest in areas where the coal seams either outcrop or subcrop beneath alluvium or colluvium, and a recharge rate of 1.7% has been assigned to these areas in the modelling studies. Conversely, recharge rates into weathered coal measures is generally quite low, probably in the order of 0.2% of rainfall. This would result in overall coal measures recharge rates similar to those suggested by HLA (2001).

Recharge rates to the alluvium are expected to be similarly quite low, based on observations of persistent ponded water following the June 2007 rainfall and flood event. Recharge rates of 0.8% have been assigned to the Hunter River alluvium and 0.6% to the Glennies Creek and Bowmans Creek alluvium.

5.2.4 Discharge

Groundwater discharge from the Permian coal measures occurs through evapotranspiration and baseflow contributions to the creeks and rivers, including discharge to the alluvium, and by groundwater abstraction/pumping.

Analysis of groundwater quality data (Aquaterra, 2008b) indicates that, while some baseflow to Bowmans Creek does occur within the Ashton Coal Project area, the contribution is very small and intermittent.

There is no existing groundwater abstraction from the coal measures in the study area, apart from the coal mine dewatering. Ashton Coal Project is currently extracting around 6 to 7 L/s of groundwater inflows from the underground operations (LW1 to LW3 longwall panels and the development headings).

Alluvial groundwater is only sparingly used for stock and domestic purposes, and a small number of registered bores and wells have been identified from a search of the DWE groundwater database. No registered bores are located within the Ashton mining lease area. The nearest registered bores are located in Camberwell Village (north-east of the underground mine), and on the south bank of the Hunter River, south-west of Ashton.

Alluvial groundwater in the Bowmans Creek valley discharges via evapotranspiration or baseflow discharge to Bowmans Creek, with a small component from the southern end of the valley possibly discharging to Hunter River.

5.3 SURFACE DRAINAGE

The Ashton Coal Project is located in an area of rolling hills typical of the central part of the Hunter Valley, with elevations ranging from approximately 60 mAHD in the valleys to approximately 100 mAHD on the ridge line running north-south adjacent to Glennies Creek (refer **Figure 8**). The area is drained by Bowmans Creek to the west and Glennies Creek to the east. Both creeks discharge into the Hunter River, which flows from west to east along the southern boundary of the Ashton project area.

The flow in Bowmans Creek is perennial for most years but it has been known to go dry for short periods. The DWE gauging station (Foy Brook 210130) located on Bowmans Creek midway between New England Highway and the Hunter River (**Figure 8**) reported a 50 percentile flow rate of 1.5 ML/d in the period 2003 to 2008, with zero flows on 4.3% of days. DWE gauging station Ravensworth 210042, located on Bowmans Creek 2km upstream from New England Highway, reported a 50 percentile flow rate of 2 ML/d from the period 1959 to 1999), with zero flows on 35% of days.

Glennies Creek flows are about 100 ML/day or more for 50% of the time, with a minimum sustained flow of approximately 10 ML/day. Flows are regulated by the Glennies Creek Dam which is located in the upper part of the catchment.

5.4 IMPACTS OF MINING ON AQUIFER PROPERTIES

The impacts of longwall mining on aquifer properties are three-fold:

- Coal extraction in development headings creates a void which will have semi-infinite permeability and a storativity/specific yield of 1 when filled with water.
- The goaf and immediate roof collapse zone will comprise a zone of very high permeability and storativity.
- The subsidence zone above the goaf will comprise a region of intense to moderate fracturing extending to heights that will be dependent on the longwall geometry (seam extraction thickness, panel width and chain pillar width) overburden cover depth, and the geological nature of the overburden, particularly rock strength properties and rock stress behaviour. This fractured zone will have moderately to highly altered vertical and/or horizontal permeability, and possibly minor increase in storativity.
- Shallow surface fracturing may occur within the subsidence zone above the goaf, which can result on temporary increase in near-surface vertical permeability, extending down to depths of 10-20m.

Subsidence predictions have been made by SCT for the LW/MW 5-9 area (SCT, 2008c). SCT predicted maximum subsidence of 200mm over isolated miniwalls (MW5 and MW9), 350mm over adjacent miniwalls (MW6 to MW8), 1100mm over longwalls LW5 and LW6, and 900mm over LW9.

SCT (2008b) have also undertaken computer modelling of caving and resultant overburden hydraulic conductivity due to mining, leading to the selection of appropriate panel widths for mining beneath the Bowmans Creek floodplain. This work, in conjunction with experience from other mines and the experience gained from mining of Ashton longwalls LW1 and LW2, has indicated that the hydraulic conductivity of the overburden beneath the alluvium could be maintained at similar to in situ values by controlling the amount of subsidence and cracking in the overburden. SCT found that this control can be accomplished by reducing the panel width/overburden depth ration to a value less than 0.7. When considering the additional effects of subsequent mining from the next seam (Upper Liddell), SCT recommended that a width/depth ratio of 0.6 be applied to the mine layout for the critical sections of LW/MW 5-9, to maintain a barrier of overburden below the aquifer which has hydraulic conductivity similar to the in situ conductivity (ie to satisfy the aquaclude requirement of Consent Condition 3.9).

6.1 MODEL SELECTION

The MODFLOW numerical groundwater flow modelling package (McDonald and Harbaugh, 1988) has been used for this study with the SURFACT module (SURFACT Version 3, HydroGeoLogic Inc., 2006), operating under the Groundwater Vistas Version 5 graphic interface software package (ESI, 2005).

The MODFLOW package, which had been used for the earlier EIS modelling, has industry-leading modules for simulating surface water and groundwater interaction which allows for the assessment of impacts on creeks and rivers. However, the standard MODFLOW modelling package has several limitations when simulating mining of longwall panels. Firstly, standard MODFLOW does not allow for aquifer properties to change with time during a simulation, which is necessary to simulate the progressive changes to properties in the goaf and subsidence zones above the longwall panels. Secondly, standard MODFLOW cannot routinely simulate free draining conditions of rock layers above a longwall panel.

The first constraint was overcome by running the simulation as a series of successive time slices, where aquifer properties are changed from one time slice to the next to reflect progressive changes in ground conditions within and above longwall panels as the underground mining proceeds. The second constraint was overcome by using the SURFACT module, which enables simulation of saturated/unsaturated flow conditions and provides for more stable drying and re-wetting of cells in thin model layers (such as coal seams).

Based on these aspects, the MODFLOW-SURFACT numerical code is considered to be appropriate for this study.

The hydrogeological investigations (including modelling) were also undertaken with reference to the DWE guideline for mining near stream/aquifer systems in the Hunter Valley (DNR, 2005), and the model was developed in accordance with the best practice guideline for groundwater flow modelling (MDBC, 2001). The degree of model complexity required to accomplish the study objectives in this case is termed a “medium complexity model” in this guideline.

6.2 MODEL DOMAIN, LAYERS AND GRID

The model set up, grid design and boundary layout of the model follows closely the previous model study undertaken by HLA (2001), but with a number of improvements as detailed in the following sections. The principal changes are the introduction of additional layers and the reduction in model cell size. Where conditions have changed, for instance through altered mine plans or updated geological unit elevation data, the new data has been incorporated in the model set-up.

The model domain which covers an area of around 132 km^2 is shown in **Figure 12**. It includes both underground and open cut mining areas at Ashton, and extends to the west to include the former Ravensworth open cut and the Narama Pit. Other nearby mining areas have been included as well. **Figure 13** shows a typical section through the model – at model row 158 (equivalent to 6404460m S).

6.2.1 Model Grid

The model has cell sizes of 100m by 100m on the outer edges of the model with the cell size reducing to 25m by 25m in the area of the Ashton underground mining operation. [Modelling for the EIS studies used 100m by 100m cells.] Smaller cells have been implemented in the underground mine area to more accurately represent the geometry of the coal seams and the mining operation, and to simulate the steep groundwater level gradients expected to occur from underground mining. A total of 253 rows and 188 columns are used.

6.2.2 Model Layers

The local hydrogeology has been represented by 15 model layers, where coal seams and interburden are represented independently:

- **Layer 1:** Bowmans Creek, Glennies Creek and Hunter River alluvium, colluvium, weathered Permian overburden (regolith) and Ravensworth spoil (backfill in the old Ravensworth open cut).
- **Layers 2, 3, 4, 5, 6 and 7:** Pikes Gully Seam overburden – split into a number of layers to allow the simulation of fracturing extending to different heights above the coal seam during mining impact assessment. These layers include the full range of coal measures lithologies, including the Lemington coal seams (1 to 19), and in the very western part of the area the Bayswater 1 and 2 seams.
- **Layer 8:** Pikes Gully Seam.
- **Layer 9:** Pikes Gully – Upper Liddell interburden
- **Layer 10:** Upper Liddell Seam.
- **Layer 11:** Upper Liddell – Upper Lower Liddell interburden.
- **Layer 12:** Upper Lower Liddell Seam.
- **Layer 13:** Upper Lower Liddell – Lower Barrett interburden.
- **Layer 14:** Lower Barrett Seam
- **Layer 15:** Basal layer – coal measures below Lower Barrett.

The model layers above were specified for the full proposed four seam extraction mine plan. However, for the calibration and predictive impact assessment modelling of Pikes Gully seam extraction which is the subject of this report, only Layers 1 to 9 were active in the model. The remaining layers will be invoked when modelling is carried out for the lower seam extractions.

The EIS model (HLA, 2001) incorporated 7 layers, with layers 1 and 2 representing the alluvium and Pikes Gully overburden, layers 3 to 6 representing the four target seams plus their respective overburden (seam and overburden contained in the same layer in each case), and layer 7 representing basement.

6.2.3 Model Boundaries

Ravensworth No. 2 Pit and Ravensworth South Mine have been substantially backfilled with overburden. Residual final voids remain, which are being used as repositories for power station fly-ash or coal washery tailings, or as water storages. The water level in the spoil is reportedly being kept depressed by pumping from some of the voids, and possibly from ongoing mining activity at Narama. The water level in the Ravensworth spoil is represented in the model using specified head cells.

The water level was measured at approximately +35 mAHD in one of the voids on the western side of the former Ravensworth No. 2 Pit area in February 2008. The final void of the Ravensworth South Mine is believed to act as an evaporative discharge area for the groundwater, and is represented in the model using a general head boundary with heads set to the base of the pit, ie ranging from 28 mAHD at the northern end to 5 mAHD at the southern end.

The Narama mine south of the former Ravensworth pits is still in operation and is being mined as a north-south strip advancing from the west towards the east. The pit has been simulated in the model using specified head cells at the level of the Bayswater Seam in Layer 2, with water level elevations ranging from 12 mAHD at the northern end to -18 mAHD at the southern end.

Towards the south, the model area extends as far as the Lemington North Open Cut mine, which is simulated in Layer 2 in the model using specified head cells, with water levels set to the level of the Piercefield Seam, ie water level elevations ranging from 42mAHD at the western end to 38mAHD at the southern end.

The eastern model boundary coincides with the location of the Camberwell Mine and Glennies Creek Underground mine. The Camberwell South Pit, where mining has advanced down to the Pikes Gully Seam in the southern part and the Upper Liddell Seam in the northern part, is represented in the numerical model by using specified head cells with levels set to the base of the respective seams.

The Camberwell North Pit extends to the Lower Barrett Seam, but mining has ceased and the mine area comprises a final void with the water level believed to be still rising back to a post-mining equilibrium level. This pit is also included in the numerical model using specified head cells at the level of the Lower Barrett Seam with a water level elevation of 85 mAHD, which was the estimated level during 2005.

The Glennies Creek mine is an underground operation currently mining within the Middle Liddell Seam. This mine is simulated in the model using specified head cells with heads fixed at the elevation of the Middle Liddell Seam.

Towards the north, the model extends as far as the Ravensworth East Pit. This pit consists of a north-south trending thin void extending down to the base of the Bayswater Seam. The water level in the pit was reported to be about 45 mAHD in 1999, however mining has ceased. The pit has been described using specified head cells in Layer 2 at the level of the Bayswater Seam, with a water level elevation of 50mAHD taken to be the approximate current water level elevation.

6.3 MODEL FEATURES

6.3.1 Rivers and Creeks

Glennies Creek, Bowmans Creek and the Hunter River are represented in the model using river cells to allow for stream-aquifer interaction due to leakage from the creek/river to the shallow aquifers and/or baseflow from the alluvial or Permian aquifers to the creeks. River heights have been based on both topography and nearby bore hydrographs to accurately represent river stage heights in the absence of any recorded field data. The stage elevation is assumed to be 1m above the creek bed and the streambed conductance (a term which reflects the degree of hydraulic connection between the surface water and the shallow aquifer) ranges between 6.25 m^2/d for the smaller river cells to 1000 m^2/d for the larger river cells.

6.3.2 Recharge and Evaporation

Recharge input to the model closely follows that used in the previous modelling work (HLA, 2001). For areas where the Hunter River alluvium is present, recharge to the water table is set to 0.8% of the average annual rainfall, while a recharge rate of 0.6% is applied in areas where Bowmans Creek alluvium, Glennies Creek alluvium and the Ravensworth Spoil mound is present. A recharge rate of 1.7% was applied to areas where the shallower coal seams are believed to outcrop. Everywhere else, the recharge rate is set to 0.2 % of average annual precipitation. Recharge is modeled so it is applied to the highest active layer.

Evaporation is simulated using the Evapotranspiration (EVT) package of MODFLOW. The EVT parameter values adopted are a constant rate of 250 mm/yr with an extinction depth of 1.5 m, which allows evapotranspiration to be active in areas of low topography and shallow water table, generally along surface watercourses such as Bowmans Creek, Glennies Creek and the Hunter River floodplain.

6.3.3 Underground Mine Workings

Underground mining and dewatering activity have been represented in the model using drain cells within the mined areas of the Pikes Gully coal seam (Layer 8). The drain cells allow for free drainage of groundwater into both the development headings and the goaf, and the overlying subsidence zone. The drain cells were set up wherever workings occur, and progress in accordance with the mining schedule, requiring a transient model set-up for both the calibration period (**Section 7**) and the prediction scenarios (**Section 8**).

The drain conductance has been set to 1000 m^2/d which is sufficiently high to completely drain all the water from the Pikes Gully seam and allow for free drainage from overlying fractured zones. The drain levels are set 0.5 m below the base of the Pikes Gully to insure no residual groundwater remains.

6.3.4 Layer Configuration and Goaf/Subsidence Zone Regime

The Pikes Gully Seam overburden has been subdivided into 6 layers to allow subsidence caving and fracturing effects to be simulated to various heights above the seam, so that mine plans involving different panel widths could be assessed. The adopted layer thicknesses and initial estimated parameter values are listed in **Table 6.1**.

SCT (2008a) concluded from their modelling that two distinct zones of altered hydraulic conductivity will develop above an excavated longwall panel, a lower zone of highly connected fractures, in which the hydraulic conductivity would be expected to increase by 4 to 5 orders of magnitude above in situ conductivities, and an upper tortuous zone, in which the fractures would be less interconnected and conductivity may increase to values at some intermediate point between in situ values and those in the lower highly connected zone. The thickness of this upper zone and magnitude of the conductivity increase would be dependent on the magnitude of subsidence, which in turn would be a function of the panel width to cover height ratio. For panel widths of 0.7 or less, the conductivity of the upper (tortuous) zone would be expected to be similar to in situ values.

Table 6.1

Model Layer Configuration

Layer	Geological Unit	Thickness (m)	In Situ Kh (m/d)	In Situ Kv (m/d)	Subsidence Altered Kh (m/d)	Subsidence Altered Kv (m/d)
1	Bowmans Ck Alluvium	Variable, based on drilling results	0.5	5×10^{-6}	0.5	5×10^{-6}
	Regolith (weathered Permian overburden)	10 (Nominal thickness)	0.1	5×10^{-6}	0.1	5×10^{-6}
	Ravensworth spoil	Based on Bayswater Seam floor levels	0.02	5×10^{-6}	0.02	5×10^{-6}
2	PG overburden	Residual thickness between L1 and L3 (thickness variable due to dip on strata)	0.005	5×10^{-5}	0.005	5×10^{-5}
3	PG overburden	20	0.005	5×10^{-5}	8 [b]	0.0003 [b]
4	PG overburden	30	0.005	5×10^{-5}	8 [c]	0.0003 [c]
5	PG overburden	30	0.005	5×10^{-5}	8 [d]	0.0003 [d]
6	PG overburden	40	0.005	5×10^{-5}	8 [e]	0.0003 [e]
7	PG overburden	30	0.005	5×10^{-5}	8 [e]	0.0003 [e]
8	PG Seam	2	0.08	0.0008	50 [e]	50 [e]
9	Basal layer (coal measures) [a]	35 – 40 (as per Ashton Geological Model)	0.001	1×10^{-5}	0.005	1×10^{-5}

[a] The basal layer for modelling of PG seam extraction is the PG-ULD interburden. Provision has been made for invoking 6 additional layers for modelling of deeper seam extractions.

[b] Full width panels only (LW1-LW4, LW5, LW6)

[c] Full width panels plus MW8, MW9 and LW9

[d] Full width panels, plus MW6, MW7, MW8, MW9 and LW9

[e] All LWs and MWs.

The two layers immediately above the Pikes Gully Seam (Layers 7 and 6) have been assigned thicknesses of 30m and 40m respectively in the model. Their combined thickness equates approximately to the zone of highly connected fracturing predicted by SCT (2008a) to develop immediately above a full width longwall panel. Layers 5, 4 and 3 have been assigned thicknesses of 30m, 30m and 20m respectively, to allow varying heights of fracturing in the upper tortuous zone to be simulated, for various panel width to height ratios.

Layer 2 has a varying thickness, as it represents the residual thickness of coal measures overburden between Layer 3 and Layer 1, which increases in thickness from north-east to south-west across the site due to the south-westerly dip on the strata. Layer 2 is absent over the eastern half of the underground mine area, where the cover depth is less than the combined thickness of Layers 3 to 7. Likewise, Layers 3 to 5 also pinch out to the east, and are absent over parts of LW1-4. The pinched out (inactive) layers have been represented in the model with a nominal thickness of 0.5m, but with the hydraulic properties changed to the properties of the uppermost underlying active layer, to maintain layer continuity across the model.

The reasoning behind the layer thicknesses in **Table 6.1** is to accommodate the subsidence zone regime which develops above an extracted longwall or miniwall panel. The goaf (Layer 8) and subsidence regime (Layers 7 to 3) are modelled by increasing the vertical and horizontal hydraulic conductivities within the mine footprint for both the Pikes Gully Seam (Layer 8) and various heights into the overburden layers.

The aquifer parameters adopted for the goaf and the overlying subsidence regime were based on the results of subsidence fracture modelling by SCT (2008a), and refined during the groundwater model calibration process. The adopted values for hydraulic conductivity are listed in **Table 6.1**.

The need to change aquifer parameters with time to simulate progressive advance of mining required a series of consecutive “time-slice” models, with hydraulic properties changed from one time slice to the next. Six-month time-slices were used, matched to the quarterly mine schedule shown on **Figure 4**. The output heads from each time-slice model were used as starting heads for the next successive time-slice, and hydraulic conductivities changed to reflect subsided strata above the extraction area for that time slice. This process was repeated until the entire mine plan had been simulated. This approach was necessary because MODFLOW does not permit aquifer parameters to change during a single model run.

Mined areas in each time slice included both development headings and longwall or miniwall panels. Both areas were represented in the model by drain cells using the MODFLOW drain (DRN) function. The development headings were represented only by drains, whereas the panels were represented by drains as well as by changed hydraulic parameters in both the seam (Layer 8) and one or more of the overlying layers (Layers 3 to 7) in accordance with the panel width, as discussed above. Drains were activated in both development headings and extraction panels in advance (ie at the start of the simulation for all cells to be mined in that period), whereas changes to hydraulic properties above the panels were made in arrears (ie for the panel area mined in the previous period).

The vertical extent of the subsidence-affected zone above the mined Pikes Gully seam was determined in accordance with the panel width to cover depth ratio (W/D). LW1 to LW4 comprised 216m wide panels, above which altered hydraulic properties would be expected to extend to the surface, ie the combined thickness of model layers 3 to 7. Similar impacts would be expected above the proposed 216m full width panels LW5 and LW6.

For the narrower miniwalls (MW5 – 60m; MW6 – 70m; MW7 – 81m; MW8 – 87m and MW9 – 93m), it has been assumed in the model that the hydraulic properties may change up to heights of approximately 1-1.2 times the panel width, above which the rock would remain substantially unimpacted, as suggested by SCT (2008a). Changes to hydraulic conductivity were assumed to extend up to Layer 4 for LW9 (width 141m), MW9 (width 93m) and MW8 (width 87m); up to Layer 5 for MW6 and MW7 (widths of 70m and 81m); and to Layer 6 for MW5 (width 60m). The residual overburden above these layers was assumed to retain its in situ hydraulic properties.

In addition to goaf and subsidence zone parameter changes, it became necessary in the calibration process to invoke a reduction in hydraulic conductivity in the overburden layers immediately outside extracted panels and above chain pillars between panels in order to achieve a satisfactory calibration between observed and predicted impacts on groundwater levels. The necessity for this is probably the result of subsidence causing dislocation of groundwater flow paths, which are predominantly parallel to bedding. Some continuity in these flow paths would remain by virtue of vertical subsidence fracture pathways, but in other instances, flow paths would be disrupted. The regional impact of this would be an apparent reduction in horizontal permeability. It is possible also that some reduction in horizontal permeability may result from redistribution of stresses onto the chain pillars and rib areas of the panels as a result of the extraction.

The calibration process is discussed further in the following section.

6.4 ATO4 AND PCG4 SOLVER

The standard MODFLOW code (Modflow 88/96 and 2000) uses a time stepping iterative approach with an associated solver, to run a model through time. The time step parameters such us number of time steps and time step multipliers are pre-determined by the user. This can be a problem for long model simulations, as the entire model will abort if it fails to converge at any time step.

To overcome the above difficulties and enhance efficiency of the solution process, the adaptive time-stepping and output control package ATO4, developed by HydroGeoLogic Inc (HydroGeoLogic, 2006) was used. The adaptive time-stepping scheme selects a time-step size depending on the anticipated non-linearities of the system for a given calculation. If the anticipated non-linearities are not significant, a larger time-step size is selected to aggressively move the simulation forward. If severe non-linearities are anticipated, a smaller time-step size is selected automatically to ensure convergence for that time step. In the event that the solution fails to converge for a given time step, the time-step size is further reduced, and the solution is repeated. The end result is that the simulation continues until a solution is achieved. The user decides whether the simulation should be ended, not the in-built solver.

The ATO4 package was used in conjunction with the PCG4 solver to run the MODFLOW-SURFACT model for this study.

6.5 INDEPENDENT MODEL REVIEW

Ashton Coal Operations retained the services of Associate Professor Noel Merrick, a leading groundwater modelling expert, to provide independent review of all stages of modelling and to provide input/advice to the modelling team. Associate Professor Merrick's review report is appended in **Appendix A**.

6.6 MODEL LIMITATIONS

All numerical models have limitations, due mainly to uncertainties in model input parameters, and also due to the computational methods. Due to the complexity of the Ashton model, model limitations exist, which need to be taken into consideration as summarised below:

- The model layer set-up is based on available bore log data and seam contours, supplied by Ashton Coal, which is well known within the Ashton lease, but is less accurate in areas outside Ashton's lease area. Ashton's data has been extrapolated out to the model boundaries, based on the regional geology. Some regional inaccuracies in layer elevations may have been introduced.
- Only moderate amounts of data are available on surface water flows in Bowmans Creek and Glennies Creek. The Hunter River, Bowmans Creek and Glennies Creek were implemented as MODFLOW River features, with specified constant stage levels, to allow for either baseflow from or leakage to the aquifer system. Induced leakage from Glennies Creek alluvium to LW1 has been used to assist the calibration performance of the model. However, no such calibration data are available for either Bowmans Creek or Hunter River.
- Recharge and evapotranspiration are assumed to be constant at average rates, and seasonal or climatic variability has not been included in the model. No measured values of recharge rates are

available, and hence there is uncertainty about actual recharge rates. Recharge values have been assigned within plausible ranges to obtain a calibrated model, but values cannot be verified. The maximum possible rate of evaporation assumed in the model is 250mm/yr, acting in areas of shallow water levels (<1.5m below surface). This is considered a best estimate based on available data and experienced judgement.

- There is a level of uncertainty with respect to both vertical and horizontal distribution of hydraulic conductivity. The assumed values are consistent with the SCT modelling results (SCT, 2008a), and are also consistent with values adopted and verified at other mine sites in the Hunter Valley coalfields.
- The model is discretised into 9 layers. Apart from the Pikes Gully Seam (Layer 8), the other model layers represent a mixture of lithologies with a range of individual hydraulic properties and differing hydrostatic heads. The model generates a single head value for each cell in each layer, and the resolution of heads with depth in the model cannot therefore be as detailed as field observations.
- The current data available which is used to calibrate the transient model covers a relatively short time period. Ongoing monitoring will improve knowledge about how the aquifer system responds to mining. Although consistent with best practice modelling guidelines, the current model predictions have a degree of uncertainty.
- Uncertainties exist on the “resistance to flow” between the overburden and the underground mine voids, and between the alluvium/regolith and the underlying coal measures, which were simulated in the model using specified drain conductance values. The match to hydrographs and mine inflows during the calibration process has helped minimise these uncertainties.
- The combination of very low hydraulic conductivities and extremely steep pressure gradients associated with underground mining results in long model run times. This makes running multiple predictive uncertainty runs infeasible, and only selected parameters were checked in the uncertainty analysis.
- Due to the potential for “perching” to occur during the underground mining period, as has been predicted also by SCT (2008a), a fully unsaturated flow model may be more suited due to the potential for unsaturated flow to occur. A fully unsaturated flow model would be expected to result in smaller drawdown effects from mining, and water retained in the unsaturated zone would act to mitigate water level declines in the alluvial aquifers, and would allow recharge to continue to occur in cells that have become dry during the model simulation. (The model used in this case can only allow recharge to occur to the highest active layer.) A fully unsaturated flow model would require an order of magnitude increase in the understanding of the unsaturated zone system, and is also beyond currently available computer processing capability.

In conclusion, the model prediction of mine inflows and drawdown effects discussed in the following sections of the report can be regarded as an appropriately conservative prediction based on the available data, determined by adoption of a best practice modelling approach. The sensitivity and uncertainty scenario analysis carried out indicates that the model calibration is robust, and the model results are not highly sensitive to potential errors or uncertainties in the assumed aquifer parameters.

7.1 CALIBRATION APPROACH

Model calibration involves comparing predicted (modelled) and observed data and making modifications to model input parameters where required (within reasonable limits defined by available data and sound hydrogeological judgment) to achieve the best possible match.

Model calibration performance is demonstrated in both quantitative (head value matches) and qualitative (pattern-matching) terms, by:

- Contour plans of modelled head, with posted spot heights of measured head.
- Hydrographs of modelled versus observed bore water levels.
- Water balance comparisons.
- Scatter plots of modelled versus measured head, and the associated statistical measure of the scaled root mean square (SRMS) value.

The scaled RMS value is the RMS error term divided by the range of heads across the site and it forms a quantitative performance indicator. Given uncertainties in the overall water balance volumes (e.g. it is difficult to directly measure evaporation and baseflow into the creeks), it is considered that a 10% scaled RMS value is an appropriate target for this study , with an ideal target for long term model refinement suggested at 5% or lower. This approach is consistent with the Australian best practice groundwater modelling guidelines (MDBC, 2001).

Calibration can be carried out as either steady-state (ie calibration to assumed long-term equilibrium conditions) or transient (ie calibration to the impacts of time-dependent stresses such as pumping and or climatic variation).

Initial calibration was undertaken for steady state conditions, whereby the model was used to compare predicted long term average groundwater levels with groundwater levels for bores not affected by the Ashton mining operations.

Steady state calibration was followed by transient or “history match” calibration using the steady-state model to determine initial conditions. The transient calibration period included open cut mining and initial underground mining in LW1 and LW2 up to April 2008.

7.2 STEADY STATE MODEL

For the steady state model calibration, modelled groundwater levels were compared with data from bores that were initially not affected by the Ashton open cut mine. It is understood that dewatering commenced at the Ashton open cut mine in late 2003 or early 2004. The full 15 layer model was used for steady state calibration.

The steady state model has been calibrated to groundwater levels as close as possible to the beginning of 2004, assuming these to be close to long term average groundwater levels. Estimated pre-mining water levels were included in the calibration data set for a number of bores installed after 2004. However, the pre-mining water levels in all bores have, to some extent, been influenced by the surrounding mining operations.

With this in mind, the steady state model was principally used to provide a reasonable set of starting conditions for the transient calibration model.

The outcomes of the steady state calibration are summarised in **Table 7.1**.

Table 7.1
Steady State Model Calibration Groundwater Level Targets

Name	Easting (MGA)	Northing (MGA)	Model Layer	Observed Water Level (mAHD)	Modelled Water Level (mAHD)	Variance
Oxbow	318,330	6,405,744	2	57.0	58.7	-1.7
GM3A	320,247	6,405,968	1	50.6	56.0	-5.4
PB1	317,553	6,405,309	1	55.5	55.1	0.4
RA02	317,543	6,404,843	1	55.3	53.1	2.2
RM01	318,042	6,404,111	1	58.0	53.5	4.5
RM02	317,943	6,404,508	2	51.6	53.0	-1.4
RM03	317,668	6,404,845	1	52.0	53.2	-1.2
RM04	317,403	6,405,316	1	54.8	54.8	0.0
RM05	317,487	6,406,003	2	54.4	56.7	-2.3
RM06	317,872	6,405,890	1	57.9	57.7	0.2
RM07	318,092	6,405,763	1	58.0	57.8	0.2
RM08	318,281	6,406,321	1	60.8	60.3	0.5
RM09	318,167	6,406,382	1	60.0	60.1	-0.1
RM10	317,590	6,405,294	1	55.5	55.2	0.3
WML106-38m	318,861	6,403,493	6	61.5	56.5	5.0
WML106-68m	318,861	6,403,493	7	51.0	53.3	-2.3
WML106-84m	318,861	6,403,493	8	55.0	52.9	2.1
WML107B	318679	6403818	2	70.8	67.7	3.1
WML107-38m	318,679	6,403,818	5	65.0	66.1	-1.1
WML107-69m	318,679	6,403,818	6	60.0	57.2	2.8
WML107-98m	318,679	6,403,818	7	55.0	54.6	0.4
WML108B	318,447	6,403,975	2	58.8	60.7	-1.9
WML109B	318,217	6,404,080	2	56.7	61.0	-4.3
WML109-VW38m	318,217	6,404,080	2	57.5	61.0	-3.5
WML109-VW65m	318,217	6,404,080	4	59.0	57.0	2.0
WML110C	318,009	6,404,249	1	50.1	52.2	-2.1
WML110B	318,007	6,404,247	2	50.4	52.2	-1.8
WML111B	317,775	6,404,363	2	50.5	50.7	-0.2
WML112B	317,567	6,404,450	2	50.0	50.6	-0.6
WML113B	317,373	6,404,528	2	50.0	51.1	-1.1
WML114B	318,148	6,405,238	2	58.3	58.8	-0.5
WML115C	317881	6406703	1	61.5	61.1	0.4
WML115B	317,881	6,406,703	2	60.3	61.1	-0.8
WML115A-144m	317,881	6,406,703	8	37.0	60.2	-23.2
WML119	319255	6403930	8	52.0	50.9	1.1
WML120A	319292	6404580	8	52.7	51.8	0.9
WML120B	319294	6404588	1	53.0	51.8	1.2
WML145	319458.39	6404180.16	1	53.0	51.4	1.6
WML146	319419.3	6404178.1	1	53.0	51.3	1.7
WML148	319535.53	6404171.93	1	53.0	51.6	1.4

Name	Easting	Northing	Model Layer	Observed Water Level	Modelled Water Level	Variance
	(MGA)	(MGA)		(mAHD)	(mAHD)	
WML155	319383.03	6404519.74	1	53.0	51.8	1.2
WML157	319467.5	6404482.83	1	53.0	51.9	1.1
WML158	319522.86	6404462.95	1	52.8	52.0	0.8
WML166	319472.35	6403827.72	1	52.5	50.7	1.8
WML167	319524.2	6403841.79	1	52.4	50.7	1.7
WML181	319215.65	6403959.82	8	50.0	51.0	-1.0
WML186	319218.99	6404746.3	8	60.0	55.5	4.5
WML189-101m	318657.2	6404569.1	9	53.0	55.9	-2.9
WML189-49m	318657.2	6404569.1	6	60.0	60.0	0.0
WML189-93m	318657.2	6404569.1	8	60.0	56.6	3.4
WML191-100m	318623.94	6404334.66	9	56.0	55.1	0.9
WML191-52m	318623.94	6404334.66	6	64.0	59.4	4.6
WML20	318,362	6,404,331	8	56.5	55.7	0.8
WML21	318,245	6,406,340	8	56.7	60.6	-3.9

Steady state calibration achieved an SRMS of 11.6%, which is only marginally outside the adopted target of 10%. However, as indicated above, uncertainties as to actual pre-mining (or non-mining affected) water levels meant that a good steady state calibration was going to be difficult, and it was agreed with the independent reviewer that the results are suitable for providing starting conditions for the transient calibration.

The steady state calibration statistics are summarised in **Table 7.2** and the scatter plot of measured versus modelled head is shown in **Figure 14.** The predicted regional water levels for the various model layers generated from the steady state calibration model run are presented in **Figures 15 to 23,** which also show the “measured” (or assumed) groundwater levels. Generally, a good match was achieved between the modelled and observed groundwater levels.

Table 7.2

Steady State Model Calibration Statistics

Calibration Parameter		Value
Scaled Mean Sum of Residuals	SMSR	0.98 %
Root Mean Square	RMS	2.41 m
Scaled RMS	SRMS	11.60 %
Root Mean Fraction Square	RMFS	4.16 %
Scaled RMFS	SRMFS	11.18 %
Coefficient of Determination	CD	1.10

The steady-state water balance is summarised in **Table 7.3**, and yields an acceptable water balance discrepancy of 0.01%. The model results suggest that under pre-mining conditions, the groundwater outflow (baseflow to creeks) was about 740 m^3/day and inflow from river courses (via leakage) was around 690 m^3/day.

Table 7.3

Steady State Model Water Balance

Water Balance Component	Inflows into Model (m^3/d)	Outflows from Model (m^3/d)
Constant head boundaries (dewatering at nearby mines)	8.6	180.5
Recharge	513.7	-
Evapotranspiration	-	289.1
River Leakage (Hunter R, Glennies Ck and Bowmans Ck)	687.9	740.6
TOTAL	1210.2	1210.1
Discrepancy	0.01 %	

7.3 TRANSIENT CALIBRATION MODELLING (HISTORY MATCH)

7.3.1 Modelled Mine Plan

A transient calibration modelling run was carried out, covering the period from January 2004 to March 2008. This run compared the inflows and groundwater level impacts predicted by the model with observations of these parameters during mining to date.

Ashton Coal Project's adopted underground mine plan schedule for LW1-4 and LW/MW 5-9 is shown in **Figure 4**. It shows the monthly progression of development headings and longwall panel extraction from the commencement of underground development in December 2005. **Figures 24** and **25** depict the modelled drain cell progression which was used to incorporate the underground mine plan over the period from August 2004 to March 2008 into the transient calibration model. The details of the drain cell setup have been discussed previously in **Section 6.3**.

Open cut dewatering has also been simulated by the adoption of drain cells applied to the base of the pit as per mine progression plans, starting from January 2004. The open cut layout represented by drain cells is shown on **Figures 24** and **25**.

The transient calibration period includes three separate time-slice models, to simulate progressive mining and changing of goaf and subsidence zone parameters with time (refer to **Table 7.4**). The groundwater levels from the end of each time-slice model were used as initial heads for the next time-slice model.

The calibration period started at the commencement of the Ashton open cut in January 2004. The underground workings start at stress period 26 of Time-slice 1. The calibration period ended at April 2008, by which time approximately 30% of LW2 had been extracted.

Table 7.4

Stress Period Set-up for Transient Calibration Period

<table>
<tr><th>Period</th><th>Time Slice</th><th>Stress Period</th><th>Length (days)</th><th>From</th><th>To</th><th>Development Headings</th><th>Longwall Panels</th></tr>
<tr><td rowspan="34">TRANSIENT CALIBRATION (HISTORY MATCH)</td><td rowspan="28">Time Slice 1</td><td>1</td><td>31</td><td>01/01/2004</td><td>01/02/2004</td><td rowspan="25">n/a</td><td rowspan="27">n/a</td></tr>
<tr><td>2</td><td>29</td><td>01/02/2004</td><td>01/03/2004</td></tr>
<tr><td>3</td><td>31</td><td>01/03/2004</td><td>01/04/2004</td></tr>
<tr><td>4</td><td>30</td><td>01/04/2004</td><td>01/05/2004</td></tr>
<tr><td>5</td><td>31</td><td>01/05/2004</td><td>01/06/2004</td></tr>
<tr><td>6</td><td>30</td><td>01/06/2004</td><td>01/07/2004</td></tr>
<tr><td>7</td><td>31</td><td>01/07/2004</td><td>01/08/2004</td></tr>
<tr><td>8</td><td>31</td><td>01/08/2004</td><td>01/09/2004</td></tr>
<tr><td>9</td><td>30</td><td>01/09/2004</td><td>01/10/2004</td></tr>
<tr><td>10</td><td>31</td><td>01/10/2004</td><td>01/11/2004</td></tr>
<tr><td>11</td><td>30</td><td>01/11/2004</td><td>01/12/2004</td></tr>
<tr><td>12</td><td>31</td><td>01/12/2004</td><td>01/01/2005</td></tr>
<tr><td>13</td><td>31</td><td>01/01/2005</td><td>01/02/2005</td></tr>
<tr><td>14</td><td>28</td><td>01/02/2005</td><td>01/03/2005</td></tr>
<tr><td>15</td><td>31</td><td>01/03/2005</td><td>01/04/2005</td></tr>
<tr><td>16</td><td>30</td><td>01/04/2005</td><td>01/05/2005</td></tr>
<tr><td>17</td><td>31</td><td>01/05/2005</td><td>01/06/2005</td></tr>
<tr><td>18</td><td>30</td><td>01/06/2005</td><td>01/07/2005</td></tr>
<tr><td>19</td><td>31</td><td>01/07/2005</td><td>01/08/2005</td></tr>
<tr><td>20</td><td>31</td><td>01/08/2005</td><td>01/09/2005</td></tr>
<tr><td>21</td><td>30</td><td>01/09/2005</td><td>01/10/2005</td></tr>
<tr><td>22</td><td>31</td><td>01/10/2005</td><td>01/11/2005</td></tr>
<tr><td>23</td><td>30</td><td>01/11/2005</td><td>01/12/2005</td></tr>
<tr><td>24</td><td>31</td><td>01/12/2005</td><td>01/01/2006</td></tr>
<tr><td>25</td><td>212</td><td>01/01/2006</td><td>01/08/2006</td></tr>
<tr><td>26</td><td>122</td><td>01/08/2006</td><td>01/12/2006</td><td rowspan="3">LW1</td></tr>
<tr><td>27</td><td>62</td><td>01/12/2006</td><td>01/02/2007</td></tr>
<tr><td>28</td><td>150</td><td>01/02/2007</td><td>01/07/2007</td><td rowspan="3">LW1</td></tr>
<tr><td>Time Slice 2</td><td>29 to 31</td><td>31</td><td>01/07/2007</td><td>31/07/2007</td><td rowspan="2">LW2</td></tr>
<tr><td rowspan="3">Time Slice 3</td><td>32</td><td>50</td><td>31/07/2007</td><td>19/09/2007</td></tr>
<tr><td>33</td><td>50</td><td>19/09/2007</td><td>08/11/2007</td><td rowspan="2">LW3</td><td rowspan="2">LW2</td></tr>
<tr><td>34</td><td>144</td><td>08/11/2007</td><td>31/03/2008</td></tr>
</table>

7.3.2 Modelled vs Observed Groundwater Levels

The transient model was calibrated over the period January 2004 to April 2008 against water level data from bores in the vicinity of the open-cut and underground mines which have a medium to long term monitoring record. Figures 26 to 37 show the model predicted water level responses with time compared to the observed water levels. In summary, the model demonstrates a close calibration between modelled and observed bore hydrographs during the periods of open cut mining and the underground mining of LW1, and the commencement of LW2 up to March 2008.

All modelled water levels in shallow bores in Layers 1and 2 (Figures 26 to 33) match closely to the observed levels, which indicates that the recharge-evapotranspiration and surface water-groundwater interaction parameters adopted for both Bowmans and Glennies Creeks closely represent the real conditions. Modelled water levels in bores in Layer 8 (Figures 36 to 37) also match very well to the observed water levels, indicating that the approach to modelling the mine plan is sufficiently accurate, including the timing, location of drains and drain conductance parameters. The modelled and observed groundwater levels in Layer 8 respond more strongly to mining in the development headings than in the subsequent panel extractions.

7.3.3 Transient Water Balance

The water balance for the transient model at the end of each stress period is summarised in **Table 7.5**. An acceptable water balance discrepancy is achieved for most stress periods, with percentage errors generally less than 1%. As outlined in **Section 3.4**, the Adaptive Time Stepping Output scheme (ATO) was used with SURFACT PCG4 solver to allow the model to run without interruption. However, one of the consequences of using the ATO package is that it tends to produce larger water balance discrepancies unless a very small model convergence closure criteria is used, but using a small closure criteria results in extremely long model run times.

The water balance discrepancies become larger in the later stress periods when the underground mine is active (after stress period 25). The inflows from storage to support the increased outflows to drain cells representing the mine workings are the source of the discrepancies while the other "flow inputs" remain relatively stable. It was agreed with the independent reviewer that the mass balance errors achieved are acceptable considering the difficulty surrounding model convergence and large run times associated with a model of such size and complexity.

The transient model calibration runs suggest that the discharge of groundwater to rivers/creeks (as base flow) decreases by less than 0.2%, while the discharge from the rivers/creeks to the aquifer (ie recharge to the aquifer by leakage) increases by less than 0.1% during the development of the open cut mine (stress periods 1 to 25). Following the commencement of underground mining at LW1 (stress period 26), the predicted discharge from the rivers/creeks to the aquifer increases by approximately 25%. As discussed in the next section, the largest increase in predicted discharge to the aquifers is from Glennies Creek and is consistent with field observations.

Table 7.5

Transient Model Calibration Water Balance [m3/d]

End of Stress Period	Model date	Model Water Balance Inputs [m^3/day]					Model Water Balance Outputs [m^3/day]						Percentage Error
		River Discharge to Aquifer	Inflow across boundaries	Release from Storage	Recharge	Total Inflow	Aquifer Discharge to River	Dewatering Outflow	Outflow to nearby mines	Storage Gain	ET	Total Outflow	
1	01/02/2004	711.0	8.6	26.0	513.7	1259.4	731.5	11.3	200.6	31.6	288.7	1263.8	0.3
2	01/03/2004	711.2	8.6	16.7	513.7	1250.2	730.9	23.0	200.6	24.7	288.7	1267.9	1.4
3	01/04/2004	711.2	8.6	12.5	513.7	1246.0	730.8	16.5	200.6	21.2	288.7	1257.8	0.9
4	01/05/2004	711.1	8.6	10.2	513.7	1243.6	730.8	5.3	200.6	19.2	288.7	1244.6	0.1
5	01/06/2004	711.0	8.6	21.5	513.7	1254.8	730.9	17.5	200.6	17.7	288.7	1255.5	0.1
6	01/07/2004	710.9	8.6	17.0	513.7	1250.3	731.0	18.1	200.6	16.6	288.7	1255.0	0.4
7	01/08/2004	710.9	8.6	14.5	513.7	1247.6	731.1	14.4	200.6	15.7	288.7	1250.4	0.2
8	01/09/2004	710.8	8.6	29.5	513.7	1262.6	731.1	33.0	200.6	14.9	288.7	1268.3	0.4
9	01/10/2004	710.8	8.6	24.3	513.7	1257.4	731.1	26.1	200.6	14.2	288.7	1260.8	0.3
10	01/11/2004	710.7	8.6	21.4	513.7	1254.4	731.2	22.0	200.6	13.6	288.7	1256.1	0.1
11	01/12/2004	710.7	8.6	35.0	513.7	1268.0	731.2	45.0	200.6	15.3	288.7	1280.8	1.0
12	01/01/2005	710.7	8.6	21.6	513.7	1254.6	731.2	32.1	200.6	13.4	288.7	1266.1	0.9
13	01/02/2005	710.6	8.6	19.4	513.7	1252.4	731.3	30.6	200.6	12.6	288.7	1263.8	0.9

End of Stress Period	Model date	Model Water Balance Inputs [m^3/day]					Model Water Balance Outputs [m^3/day]						Percentage Error
		River Discharge to Aquifer	Inflow across boundaries	Release from Storage	Recharge	Total Inflow	Aquifer Discharge to River	Dewatering Outflow	Outflow to nearby mines	Storage Gain	ET	Total Outflow	
14	01/03/2005	710.6	8.6	14.0	513.7	1246.9	731.3	40.2	200.7	19.1	288.7	1280.0	2.6
15	01/04/2005	710.6	8.6	12.0	513.7	1244.9	731.4	8.3	200.7	15.8	288.7	1244.9	0.0
16	01/05/2005	710.6	8.6	10.8	513.7	1243.7	731.4	8.9	200.7	14.0	288.7	1243.7	0.0
17	01/06/2005	710.5	8.6	10.3	513.7	1243.1	731.5	45.1	200.7	12.7	288.7	1278.7	2.8
18	01/07/2005	710.5	8.6	9.6	513.7	1242.4	731.6	41.4	200.7	11.7	288.7	1274.2	2.5
19	01/08/2005	710.5	8.6	9.1	513.7	1241.9	731.7	40.4	200.7	11.1	288.7	1272.6	2.4
20	01/09/2005	710.5	8.6	20.5	513.7	1253.3	731.8	21.8	200.7	10.3	288.7	1253.3	0.0
21	01/10/2005	710.4	8.6	17.8	513.7	1250.5	731.8	22.0	200.7	9.9	288.7	1253.2	0.2
22	01/11/2005	710.4	8.6	50.0	513.7	1282.7	731.9	102.1	200.8	9.5	288.7	1333.0	3.8
23	01/12/2005	710.4	8.6	27.5	513.7	1260.1	732.0	29.5	200.8	9.2	288.7	1260.2	0.0
24	01/01/2006	710.4	8.6	23.8	513.7	1256.5	732.1	26.0	200.8	8.9	288.7	1256.5	0.0
25	01/08/2006	710.4	8.6	120.0	513.7	1352.7	732.3	228.2	200.8	7.6	288.8	1457.7	7.2
26	01/12/2006	885.2	8.6	170.0	513.7	1577.4	711.8	437.1	200.9	6.0	288.8	1644.5	4.1
27	01/02/2007	887.0	8.6	180.0	513.7	1589.3	711.3	407.8	200.9	5.6	288.7	1614.4	1.6
28	01/07/2007	890.4	8.6	200.0	513.7	1612.7	710.2	456.6	201.0	4.8	288.7	1661.2	2.9
29	11/07/2007	868.0	8.6	470.1	513.7	1860.5	717.0	666.7	180.9	27.2	288.8	1880.6	1.1
30	21/07/2007	867.8	8.6	399.4	513.7	1789.5	717.9	764.1	179.3	16.4	288.9	1966.6	9.0
31	01/08/2007	867.9	8.7	365.1	513.7	1755.3	718.1	524.8	179.2	12.3	289.0	1723.3	-1.9
32	20/09/2007	870.0	8.6	1150.0	513.7	2542.3	623.4	1829.5	199.3	13.4	260.1	2925.6	13.1
33	09/11/2007	840.4	8.6	400.0	513.7	1762.7	624.6	686.5	199.1	8.3	260.1	1778.7	0.9
34	01/04/2008	855.1	8.6	950.0	513.7	2327.4	623.9	1670.8	199.0	4.7	260.1	2758.5	15.6

7.3.4 Modelled vs Observed Mine Inflows

Figure 38 shows modelled mine inflow rates over the calibration period, including inflows predicted in the EIS (HLA, 2001) and measured underground mine inflow rates. These results show that:

- The modelled mine inflow rates are 30% to 50% less than those predicted in the EIS studies over the transient calibration period.
- The modelled mine inflows are a good match with the measured inflow rates.

7.3.5 Modelled vs Observed Baseflow Impacts

Figures 39 and **40** show the modelled net baseflows and the reductions to baseflows to Bowmans Creek and Glennies Creek respectively during the calibration period. **Figure 40** also shows the predicted impacts on baseflows to Glennies Creek during the EIS and the estimated reduction in actual baseflow to Glennies Creek based on measured inflows to LW1. These results indicate the following:

- The modelled impacts on baseflows to Glennies Creek match the trend in the observed data, with an initial spike followed by a relatively steady ongoing impact. The model conservatively over-estimates the impacts on baseflows to Glennies Creek during the calibration period by approximately 20% (ie the model predicted inflow from Glennies Creek is 2.4 L/s compared to an actual impact of 2 L/s).

- The model predicted impact on baseflows to Glennies Creek is consistent with the EIS prediction pre March 2007, but is much less than the EIS predictions thereafter.
- The model-predicted impact on baseflows to Bowmans Creek is less than the EIS prediction.

7.3.6 Overall Calibration Performance

The following calibration objectives have been achieved, which provide confidence that the dynamic flow processes are adequately represented during the transient model calibration runs:

- A good match (calibration) between modelled and observed bore water levels during the periods of open cut mining and the underground mining of LW1 and commencement of LW2. The transient model is calibrated to hydrographs close to the mining operations that have long term monitoring data (refer to **Figures 26** to **37**).
- Predicted dewatering volumes from LW1 and LW2 are consistent with measured dewatering volumes, currently around 0.5 ML/day (refer to **Figure 38**).
- Predicted impacts on baseflows to Glennies Creek are consistent with the current estimated inflows from Glennies Creek alluvium of approximately 2L/s (refer to **Figures 39** and **40**).

7.4 CALIBRATED MODEL PARAMETERS

7.4.1 Recharge and Evapotranspiration

Recharge has been applied directly to the water table, as follows:

- 11.0 mm/yr on coal seam outcrop areas
- 0.15 mm/yr recharge on other rock outcrop areas
- 3.8 mm/yr on Bowmans Creek and Glennies Creek alluvium
- 5.1 mm/yr on Hunter River alluvium
- 1.1 mm/yr elsewhere.

Evapotranspiration has been invoked in the model at a constant rate of 250 mm/year with an extinction depth of 1.5 m, therefore being active in areas of low topography and shallow water table along surface water courses such as Bowmans and Glennies Creeks and the Hunter River floodplain.

7.4.2 Hydraulic Conductivity and Storage

The calibrated hydraulic conductivity and storage parameters are summarised in **Table 7.6**.

Table 7.6
Hydraulic Conductivity and Storage Parameters for the Calibrated Model

Layer	Geological Unit	Kh (m/d)	Kv (m/d)	Confined S*	Unconfined Sy*
In Situ Parameters:					
1	Bowmans Creek alluvium	1	5×10^{-6}	0.0005	0.05
1	Glennies Creek alluvium	0.5	5×10^{-6}	0.0005	0.05
1	Hunter River alluvium	45	5×10^{-6}	0.0005	0.05
1	Regolith – weathered Permian overburden	0.1	5×10^{-6}	0.0005	0.001
1 to 4	Ravensworth spoil	0.02	0.002	0.0005	0.001
2 to 7	Permian overburden	0.003	0.0003	0.0003	0.001
2 to 7	Permian overburden west of Bowmans Creek	0.05	0.005	0.0003	0.001
8	Pikes Gully Coal Seam	0.08	0.008	0.0003	0.001
9	Interburden between Pikes Gully Seam and the Upper Liddell Seam	1×10^{-3}	1×10^{-5}	0.0005	0.001
Subsidence Altered Parameters:					
3-5	Subsidence zone area	8	3×10^{-4}	0.0003	0.001
6-7	Subsidence zone area	50	5	0.0003	0.001
3-7	Permian overburden above chain pillars	5×10^{-4}	5×10^{-5}	0.0003	0.001
8	Goaf	50	50	0.0003	0.001

*only applicable for transient model runs.

7.5 SENSITIVITY MODELLING

Sensitivity analysis has been undertaken on the steady state model. During the calibration process, the model was found to be most sensitive to adopted recharge and vertical hydraulic conductivity. As agreed with the independent model reviewer, the sensitivity analysis focused on the alluvium aquifer (Layer 1) since the drawdown in the alluvium aquifers and baseflow impacts on the creek systems (Hunter River, Bowmans Creek and Glennies Creek) are the key groundwater issues in relation to consent conditions for the project.

Table 7.7 below lists details of the six models used in the sensitivity analysis, including two model output (ie results) terms – the "recharge-in" volume term, and the SRMS % which is used to assess the model calibration performance (see **Section 7.2**).

Model A is the base case model – ie the model developed and refined during model calibration to be the most representative of actual conditions and observed responses to mining stresses. Models B, C and D involved variations to recharge rates and vertical hydraulic conductivities of Layer 1. Models E and F were applied to the transient calibration period, and involved variations to the specific yield of Layer 1, in conjunction with some of the changes in Models B to D.

Model B adopted double the recharge rates of Model A, which results in higher model heads and hence a larger SRMS %. Increasing the recharge rate by a factor of 2 resulted in a 7 % increase to the SRMS %.

Models C and D adopted higher vertical hydraulic conductivities in Layer 1 (by a factor of 2 and 100 respectively). Both models resulted in a slightly improved SRMS%.

Model E is an alternative calibrated model which not only calibrates well in steady state mode, but also matches the mine inflow rates and baseflow impacts to Glennies Creek during the transient calibration period. Model F adopted a very low (extreme) value of specific yield for the Bowmans Creek alluvium, to assess the potential effect of very low storage potential in the alluvium. Models E and F are discussed in further detail in **Section 8.3**, however from a sensitivity analysis point of view, the vertical hydraulic conductivities adopted in these models need to be three orders of magnitude higher than the base case, with only a slight improvement to the SRMS% value (0.8%).

On the basis of the sensitivity modelling, the model is more sensitive to recharge rate than to the vertical hydraulic conductivity of Layer 1.

Table 7.7
Sensitivity Analysis Results for Steady State Model

Model	Model Changes from Base Case (Model A)	Recharge-in Volume (m^3)	SRMS %
A	The adopted calibrated model – referred to as the base case model	513	11.6
B	Recharge is doubled	1027	12.4
C	Vertical hydraulic conductivity (Kv) of Layer 1 is doubled	513	11.3
D	Kv of Layer 1 is increased by a factor of 100	513	11.1
E	As for base case model (Model A), but with Layer 1 specific yield of 0.1%.	513	11.6
F	Alternative calibrated model with • approximately 20% higher recharge rates; • Layer 1 Kv approximately 1/10th of horizontal hydraulic conductivity Kh (see **Table 7.6**); and • Layer 1 specific yield of 0.1%.	620	10.8

8.1 PREDICTION METHOD

The calibrated Ashton Groundwater Model (Model A – refer **Table 7.7**) has been used for predictive transient modelling to assess the potential impact of progressive underground mining of the Pikes Gully seam from LW/MW 5-9 on the groundwater and surface water resources. Particular emphasis has been placed on the potential changes to flow to/from surface water courses (Bowmans Creek, Glennies Creek and Hunter River), regional changes in groundwater levels during mining, and on the potential water ingress into the mine workings through vertical leakage from the overlying Bowmans Creek alluvium.

A number of potential mine plans were considered and initial modelling considered a number of these options. The preferred mine plan known as the LW/MW 5-9 mine plan was developed to minimize groundwater impacts and to meet the project Consent Conditions. This report presents the modelling of the LW/MW 5-9 mine plan. The mining schedule for the LW/MW 5-9 plan is shown on **Figure 4**. Development headings and longwall/miniwall panels corresponding to each mining period are shown by a common colour. **Table 8.1** shows the stress-period setup used to simulate the proposed mine schedule. **Figures 41** to **44** show the modelled drain cell progressions which were used to simulate the mine plan schedules.

Each longwall or miniwall panel is mined from the southern end, taking approximately 6 to 9 months to complete. The Pikes Gully Seam is the target seam for the LW/MW 5-9 mine plan. The open cut is represented by drain cells, the configuration of which remains unchanged throughout the prediction period, and is based on the mine plan applying at the end of the calibration period (Time Slice 3, Stress Period 34).

The overall prediction run included 12 consecutive time-slice models (Time Slices 3 to 15) to simulate progressive mining and changing of goaf and subsidence zone parameters with time (**Table 8.1**). Time Slices 1 to 3 are equivalent to the transient calibration period (**Table 7.4**).

The prediction models start at April 2008, and run to the 4th quarter of the 2011/2012 year; consistent with the proposed mine schedules as shown on **Figure 4**. The duration of each time-slice model varies between 4 and 8 months, to give the necessary resolution to simulate mining and goaf/subsidence progression. The groundwater levels from the end of each time-slice model were used as initial conditions for the next time-slice model. The implementation of the subsidence and goaf regime is consistent with the method adopted in the calibration model and has been explained in **Section 3.3.4**.

Table 8.1
Stress Period Set-up for Life of Mine Simulation

Period	Time Slice	Stress Period	length (days)	From	To	Development Headings	Longwall/Miniwall Panels
LW2 to LW 4 PREDICTION	Time Slice 4	35	46	31/03/2008	16/05/2008	LW3	LW2
		36	46	16/05/2008	01/07/2008		
	Time Slice 5	37	31	01/07/2008	01/08/2008		LW3
		38	61	01/08/2008	01/10/2008	LW4	
	Time Slice 6	39	46	01/10/2008	16/11/2008		
		40	46	16/11/2008	01/01/2009		
	Time Slice 7	41	46	01/01/2009	16/02/2009		
		42	44	16/02/2009	01/04/2009		LW4
	Time Slice 8	43	45	01/04/2009	16/05/2009		
		44	46	16/05/2009	01/07/2009	LW/MW5	
	Time Slice 9	45	45	01/07/2009	15/08/2009		
		46	47	15/08/2009	01/10/2009		
LW/MW 5 to 9 PREDICTION	Time Slice 10	47	45	01/10/2009	15/11/2009		LW5
		48	47	15/11/2009	01/01/2010	LW/MW6	
	Time Slice 11	49	90	01/01/2010	01/04/2010	MW7	MW5
		50	91	01/04/2010	01/07/2010		LW6
	Time Slice 12	51	92	01/07/2010	01/10/2010		
		52	92	01/10/2010	01/01/2011	MW8	MW6 and MW7
	Time Slice 13	53	90	01/01/2011	01/04/2011	LW/MW9	
		54	91	01/04/2011	01/07/2011		MW8
	Time Slice 14	55	92	01/07/2011	01/10/2011		
		56	92	01/10/2011	01/01/2012		MW/LW9
	Time Slice 15	57	91	01/01/2012	01/04/2012		
		58	91	01/04/2012	01/07/2012		

8.2 PREDICTION RESULTS

The following is a summary of the results of the life of mine predictions.

8.2.1 Mine Inflow Rates

Figure 45 shows the model-predicted mine inflow rates over the calibration and prediction periods as compared to both the EIS prediction and the measured underground mine inflow rates to date. The following observations are made:

- The modelled mine inflow rates are about 40 percent lower than the EIS predictions over most of the mining period until about January 2011 when MW7 is nearing completion.
- After January 2011, during mining of MW8, MW9 and LW9, the predicted mine inflow rates are similar to the EIS predictions.
- Measured net groundwater inflow rates to the total underground mining operation (0.54 ML/d in mid August 2008) are consistent with the current model predictions.

8.2.2 Creek Baseflow Impacts

Figures 46 and **47a-c** show the model predicted net baseflows and baseflow impacts for Bowmans Creek, Glennies Creek and Hunter River during the mining period. **Figures 47a-c** also compare the modelled baseflow impacts with the impacts predicted in the EIS, and the observed baseflow impacts for Glennies Creek to date. The following observations can be made:

- The maximum predicted impact on Glennies Creek over the mining period is a reduction in flows of approximately 2.5 L/s (0.22 ML/d).
- Both the observed and modelled impacts on Glennies Creek are smaller than those predicted in the EIS estimate. The baseflow reduction predicted for Glennies Creek is approximately 20% smaller than the EIS predicted impact over the entire period of mining of LW/MW 5-9.
- The maximum baseflow reduction predicted for Bowmans Creek during the mining of LW/MW 5-9 is 1.2 L/s (0.10 ML/d).
- This baseflow reduction is substantially smaller than the EIS estimate, which ranged up to 4.3 L/s (0.37 ML/d) during longwall extraction of the Pikes Gully Seam.
- The modelled difference between the Bowmans Creek baseflow impacts predicted by the current modelling and those predicted during the EIS studies increases over time.
- Some of the Lemington seams within the overburden above the Pikes Gully Seam are expected to be impacted by subsidence fracturing within the subsidence zone above the full width LW5 and LW6 panels. These seams may occur in subcrop at the base of the Hunter River alluvium, potentially leading to impact on Hunter River baseflows. However as these coal seams will not be mined, connection between the Hunter River and underground workings will be limited. Baseflow reduction in the Hunter River from the LW/MW 5-9 mine plan is predicted by the model to reach a maximum of only 0.15 L/s (0.013 ML/d), much less than the EIS prediction of 3.1 L/s (0.26 ML/d) during longwall extraction of the Pikes Gully Seam (**Figure 47c**).

8.2.3 Groundwater Levels

The modelled versus observed hydrographs over the prediction period are shown in **Figures 48** to **59**.

The results show the following:

- Calibration between observed and predicted heads is generally good for piezometers in the Pikes Gully Seam (Layer 8) – **Figures 58** and **59**. Substantial water level declines are predicted, with the greatest declines at piezometers from the western parts of the mine area (WML115-144m and WML21), consistent with the dip to the south-west. It is expected that over the project life, the Pikes Gully Seam will become substantially dewatered across the underground mine area. Some recovery in water levels is noted in Pikes Gully Seam bores WML189-93m (**Figure 58**) and WML120A (**Figure 59**), suggesting that there may have been some self-healing of subsidence fractures after the initial subsidence events in the first two longwall panels.
- Water levels are also predicted to decline significantly in Layers 6 and 7 (**Figure 57**). There is generally a divergence between observed and predicted groundwater levels in these layers, with initial declines showing good calibration but with actual water levels showing partial recovery at later times, leading to significant divergence from the predicted trends. Partial recovery is observed at WML107-69m and WML191-52m (both in Layer 6) and in WML106-68m and WML107-98m (both in Layer 7). There is a pattern of initial drawdown in response to commencement of extraction from each new panel area, then a period of recovery until extraction starts in the next panel. This suggests that after initial declines due to the development of subsidence fractures above the LW1 and LW2 goafs, some

closing up or self-healing of fractures must be occurring. The drawdown impacts in Layers 6 and 7 therefore appear to be temporary.

- Predicted water levels in Layers 3 to 5 show good calibration with observed water levels (**Figure 56**). It is predicted that Layers 4 and 5 will be substantially dewatered within the longwall footprint (eg WML108B, WML109-65m), but only partially depressurized outside the mine footprint.
- Variable water level changes are predicted for Layer 2 (upper parts of the coal measures overburden). Responses will be greatest at sites above the full width panels, where the effects of subsidence fracturing are assumed in the model to extend up to Layer 3, with some resulting drawdown impact to occur in the overlying Layer 2 in such areas.
- Drawdowns are predicted to be limited in Layer 1 where it represents the Bowmans Creek alluvium. Drawdowns up to 2m are predicted at some sites, particularly those near the eastern margin of the floodplain. In the central parts of the floodplain, close to Bowmans Creek itself, drawdowns of less that 0.1m are predicted. Total desaturation of Layer 1 is predicted in areas outside the Bowmans Creek floodplain, where Layer 1 represents colluvium and/or weathered coal measures (regolith).

8.2.4 Bowmans Creek Drawdown Impacts

Contours of predicted drawdown in the Bowmans Creek alluvium by the completion of mining of LW/MW 5-9 are shown on **Figure 60**. The following observations can be made:

- Larger drawdowns are predicted to occur on the eastern side of the Bowmans Creek floodplain, and in the area north of the oxbow (**Figure 60**).
- The maximum drawdown in the Bowmans Creek alluvium predicted by the model is 2.9m, which occurs on the outer eastern edge of the floodplain, close to the oxbow on Bowmans Creek.
- Predicted average drawdown in the Bowmans Creek alluvium aquifer is approximately 0.8m.
- Drawdown of up to approximately 1 m is predicted at the inbye end of LW6. The drawdown is limited to a small area and is restricted by the limited extent of alluvium (**Figure 60**). Drawdown nearby, adjacent to the Hunter River, is predicted to be in the order of 0.1 m.
- The near-surface material above LW5 and the bulk of LW6 is either colluvium or highly weathered Permian, characterised by high salinity and low permeability.
- The alluvium that exists above LW6 contains saline groundwater, indicating that it is not strongly connected hydraulically with the less saline groundwater in the rest of the alluvium aquifer. The modelling predicts only minor impact in any case (**Figure 60**), and the impacts are contained within the total predicted storage reduction figure of 12%.

8.2.5 Impacts on Alluvium Aquifer Storage

One of the objectives of this assessment was to determine the potential impact of the proposed mining of LW/MW 5-9 on groundwater storage within the Bowmans Creek alluvium.

The change in saturated volume in the Bowmans Creek alluvium over the period of mining was calculated using the contouring and 3D surface mapping software package SURFER. The initial volume of groundwater storage was calculated based on the starting water table levels adopted for the beginning of the transient calibration, and the topography of the base of the alluvium, within the extent of saturated alluvium in

Bowmans Creek (**Figure 11**). The volume at the completion of mining was calculated using the modelled final water table distribution within the same area.

The results of this analysis are as follows:

- Starting saturated alluvium aquifer volume was 5.7 Mm^3. This would represent approximately 285,000 m^3 based on an assumed specific yield of 5%.
- The volume of saturated alluvium at completion of mining has been calculated as 5.0 Mm^3 (or an estimated groundwater volume of 250,000 m^3 using a specific yield of 5%).
- Thus the predicted reduction in groundwater storage volume within the Bowmans Creek alluvium is less than 12 %.

8.3 PREDICTIVE UNCERTAINTY ANALYSIS

To determine the level of uncertainty of the model results during the prediction period due to possible errors in the assumed parameter values or stresses, predictive uncertainty analysis has been undertaken to determine the "likely range" of model results caused by uncertainty in the aquifer parameter values and stresses used. In this case, the "likely range" of seepage rates into the mine workings, and impacts on Bowmans Creek and Glennies Creek and their respective alluvial aquifer systems, have been examined.

Three models (A, E and F – see **Table 7.7**) have been considered in the uncertainty analysis.

Model A is the base case model, the predictions arising from which are described in **Section 8.2**. Models E and F are alternative calibrated models which have been run through the prediction period. Model E differs from the base case Model A only by virtue of a very low value of specific yield Sy of 0.1%. Model F adopted a higher recharge rate than models A and E (Volume-in term of 620 m^3/d as compared to 513 m^3/d) as well as a low specific yield value Sy of 0.1%. Layer 1 Kv values had to be increased by several orders of magnitude in Model F to maintain a satisfactory calibration.

Figure 61 shows that the predicted mine inflows are near identical for all three models during the calibration period (January 2006 to July 2008). During the forward prediction modelling, the modelled drain inflows for Models A and E are very similar, while marginally higher mine inflow rates (15% higher) are predicted in later stages of mining for Model F.

Figure 62 and **Figure 63** compare the predicted net baseflows and baseflow impacts respectively for Models A, E and F throughout the modelled calibration and prediction periods.

Figure 63 shows that the predicted net reductions in Glennies Creek baseflow are quite similar for Models A and E, differing only by a maximum of 0.1 L/s over the entire modelled period. Predicted baseflow reductions are slightly (4%) higher with Model F.

For Bowmans Creek, predicted baseflow reductions are 1.2 L/s with the base case Model A, 1.7 L/s with Model E and 2.9 L/s with Model F

Even though Models A, E and F all calibrated satisfactorily, the calibrations of Models E and F could only be achieved by using an unrealistically high value of vertical hydraulic conductivity Kv for Layer 1 in the model.

For this reason, the prediction results from the base case (Model A), which uses the best estimates for all hydraulic parameters and stresses, including recharge and evapotranspiration, is more appropriate, and is the representative and conservative predictive outcome.

SECTION 9 CONCLUSIONS

The Ashton groundwater flow model has been used to simulate mining of the proposed LW/MW 5-9 mine plan. The simulation period commences at January 2004, the start of open cut mining, and extends to March 2012, the expected completion of extraction from the Pikes Gully Seam. The groundwater modelling was carried out to investigate potential impacts of the proposal on the groundwater flow system, in particular, potential impacts on baseflows to Bowmans Creek and predicted drawdown impacts in the Bowmans Creek alluvium. Baseflow impact and alluvium storage reduction were also assessed for Glennies Creek and the Hunter River.

Steady state and transient calibration modelling was first carried out to match against observed inflows, drawdown impacts and baseflow impacts due to mining to date (April 2008), which includes both open cut mining and underground mining from the Pikes Gully seam in LW1 and LW2. The Glennies Creek baseflow reduction predicted by the transient calibration modelling was 2.3 L/s by the end of the calibration period, which is slightly higher than the measured inflows from the Glennies Creek alluvium into LW1 (around 2 L/s), and is markedly less than the inflows predicted in the EIS studies. Predicted and measured drawdowns in the large network of monitoring bores, which are distributed across the project area and in all the main hydrogeological units and model layers also showed very good calibration.

After successful calibration, the model was then used to predict the potential impacts of future mining. The modelling has predicted a small baseflow reduction in Bowmans Creek due to the LW/MW 5-9 mine plan, reaching a maximum of 1.2 L/s at the end of extraction from the Pikes Gully Seam. This is substantially lower than that predicted for the EIS mine plan, which was for seepage losses to reach 4.8 L/s by the completion of Pikes Gully Seam extraction. The baseflow impact predicted for the LW/MW 5-9 plan is also less than the estimated leakage rate of 1.5 L/s from the Bowmans Creek alluvium, if mining were to take place across the full area occupied by the LW/MW 5-9 mine plan, but with extraction limited to first workings only (Aquaterra, 2008b).

The predicted impact of the LW/MW 5-9 plan is reflected as an average drawdown of approximately 0.8 m in the alluvium within the floodplain above the mine, which equates to a predicted reduction of 12% in the volume of groundwater storage in the Bowmans Creek alluvium between the New England Highway and the Hunter River.

The modelling predicted no further significant increase in seepage from the Glennies Creek alluvium, and negligible impact on Hunter River baseflows.

SECTION 10 REFERENCES

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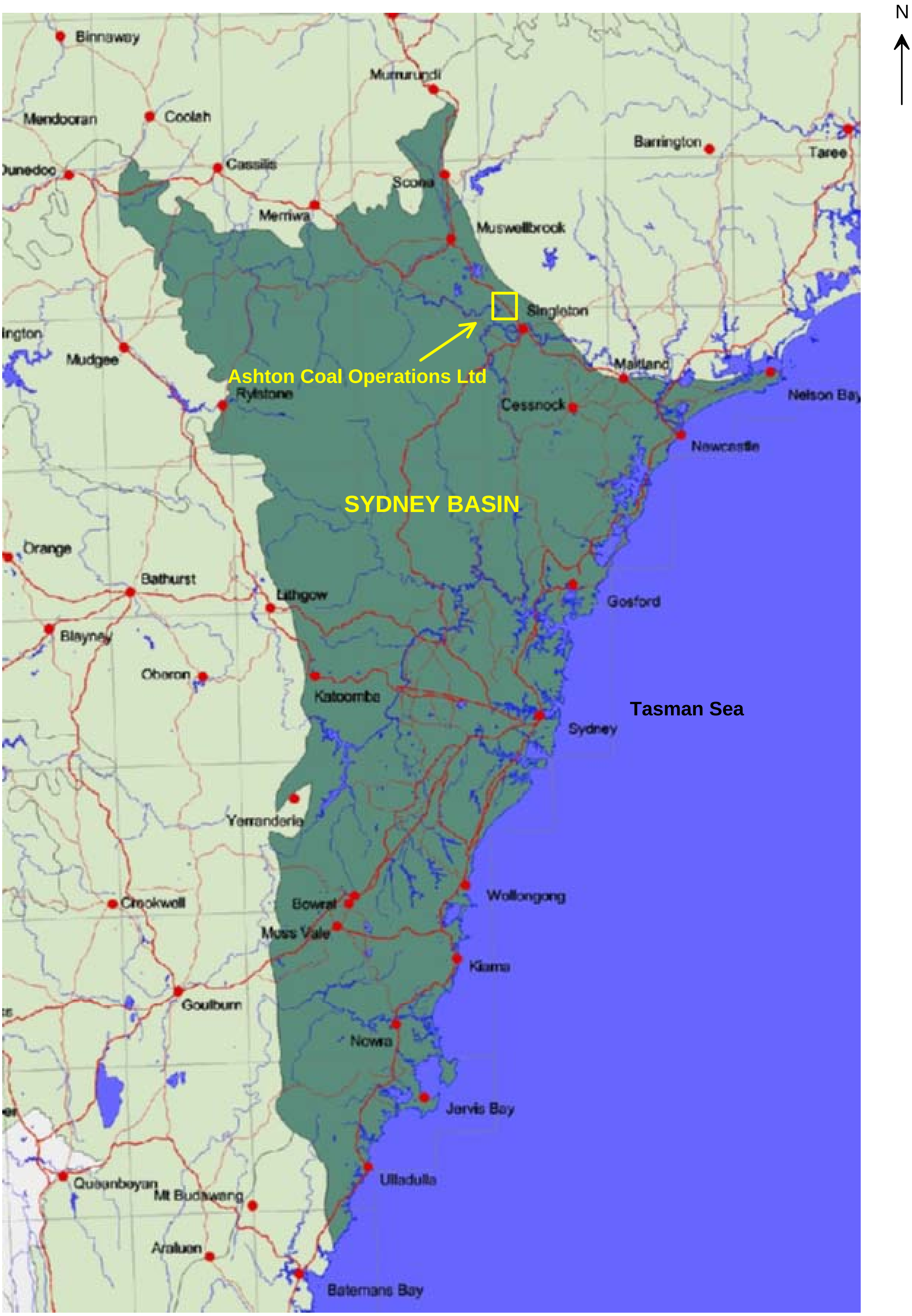
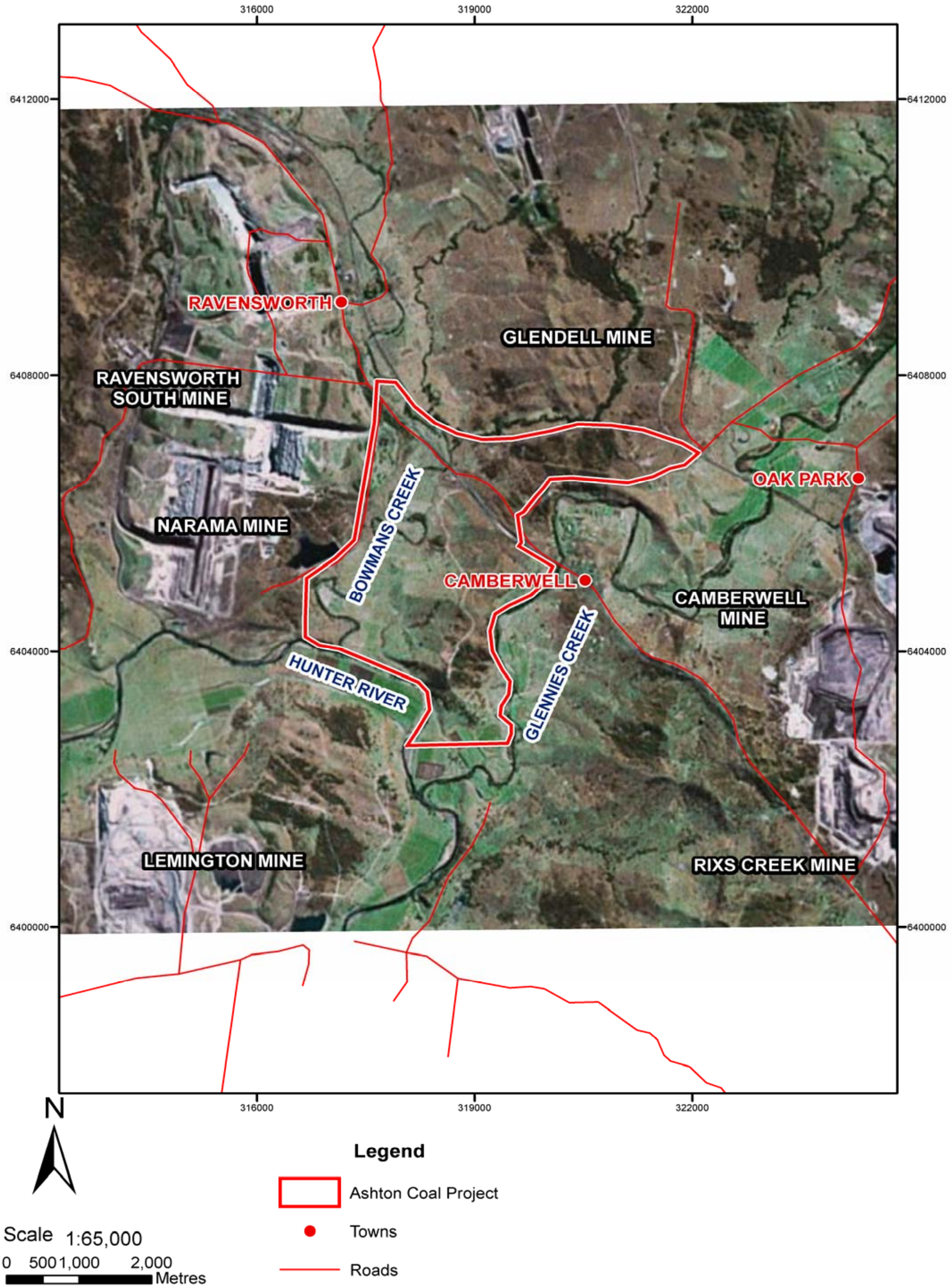


Basemap sourced from NSW National Parks and Wildlife Service



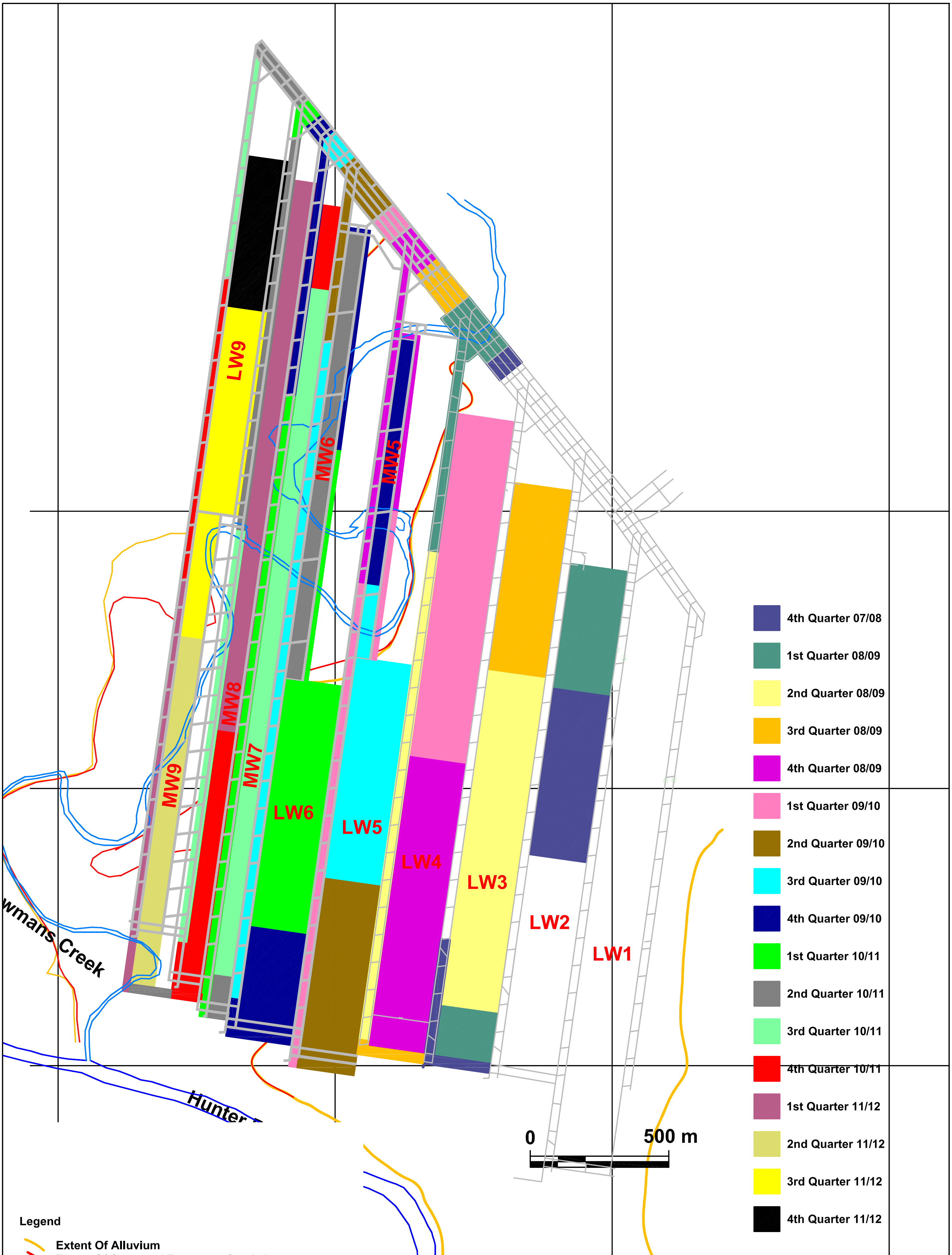
Ashton Project Area
Figure 2

Legend

Extent Of Alluvium
Extent Of Saturated Bowmans Creek Alluvium

Date: 14 October 2008	Scale: as shown	Ashton Coal Operations Ltd
Initials: TL	Job No: S03	ASHTON COAL MINE LW/MW5-9 PANEL LAYOUT
Drawing No: S03 -228_1	Revision: A	

Figure 3



Date: 9 October 2008	Scale: as shown	Ashton Coal Operations Ltd
Initials: TL	Job No: S03	LW/MW5-9 Mining Schedule
Drawing No: S03 -228_2	Revision: A	
		Figure 4

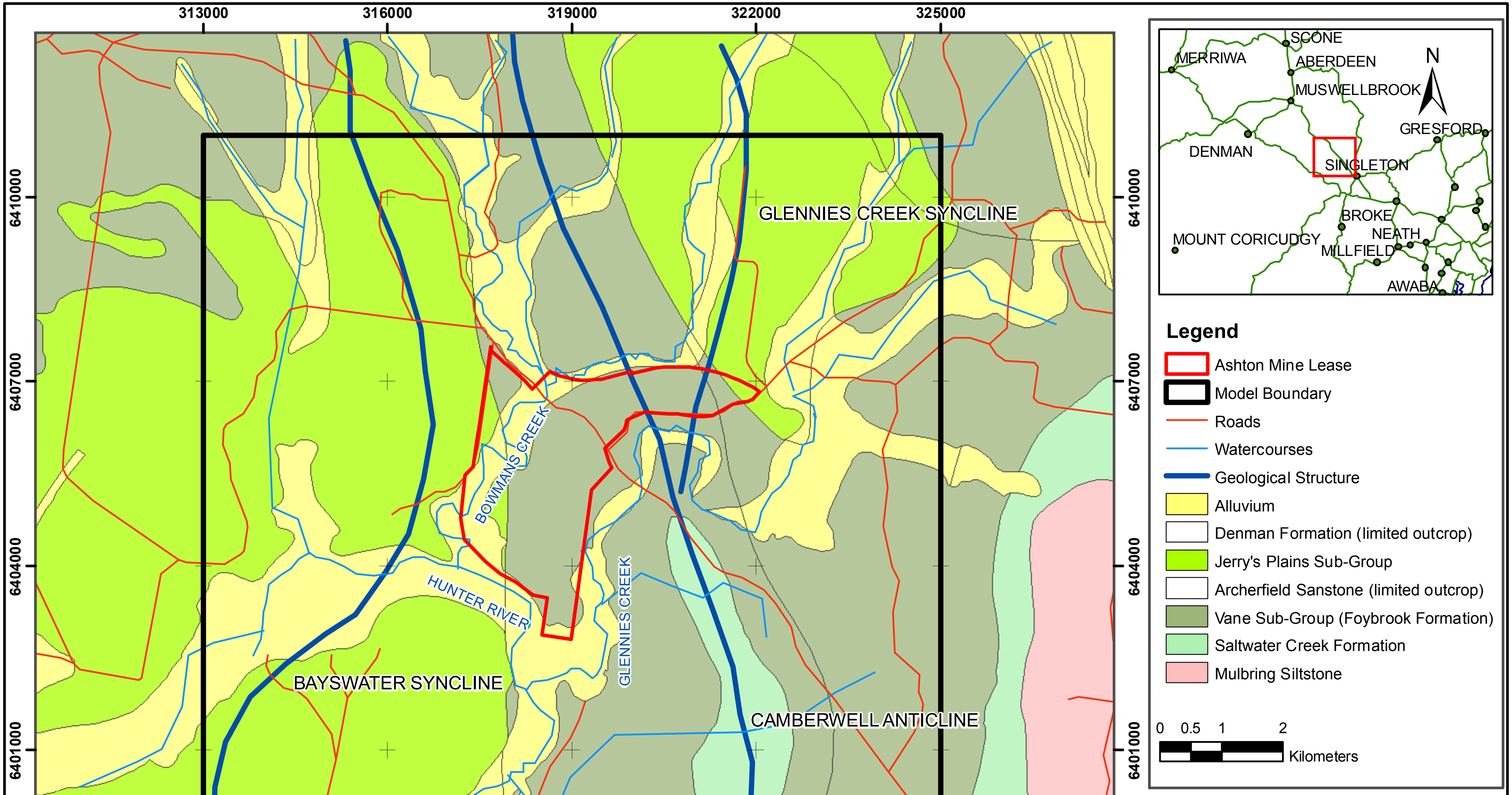


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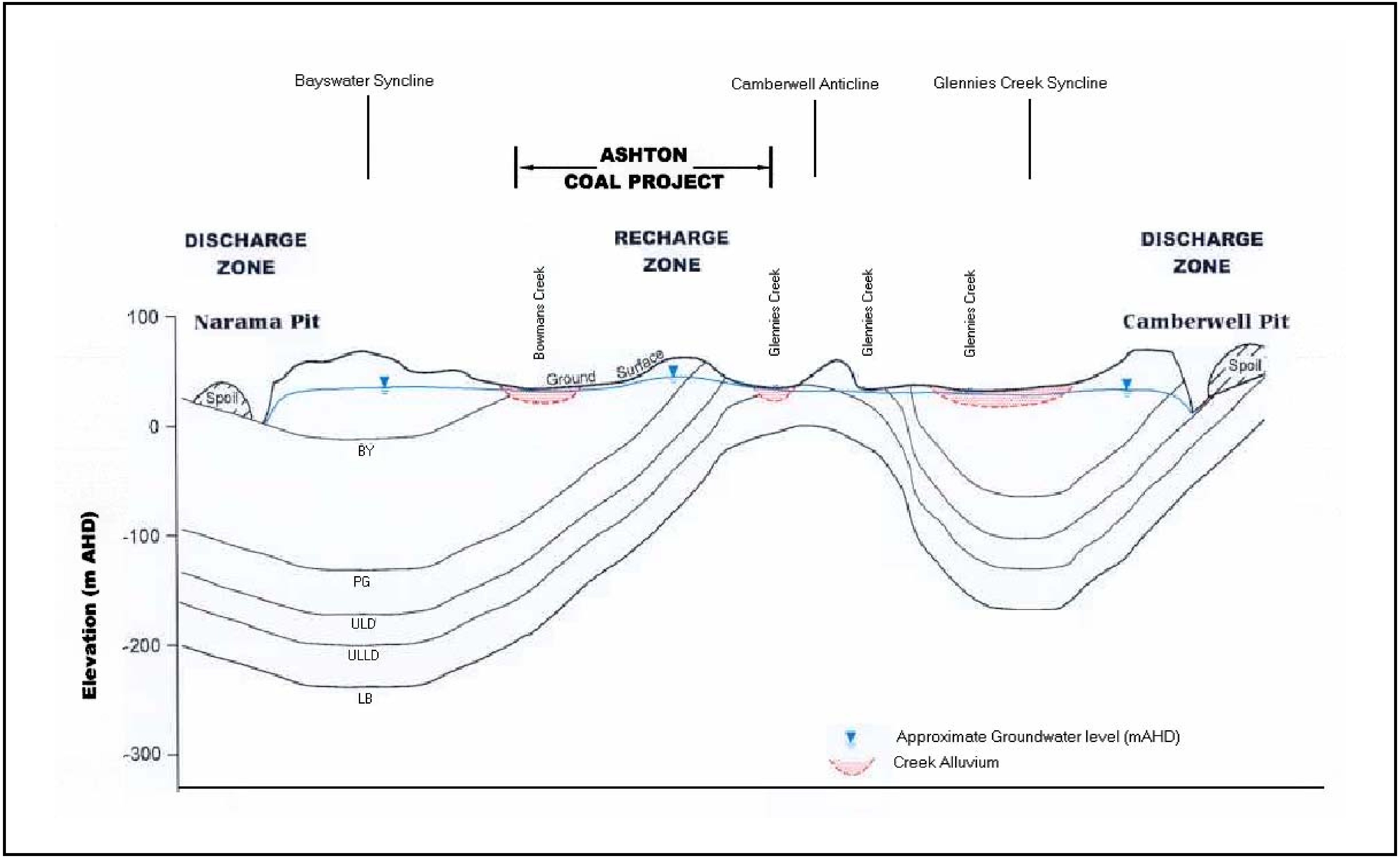
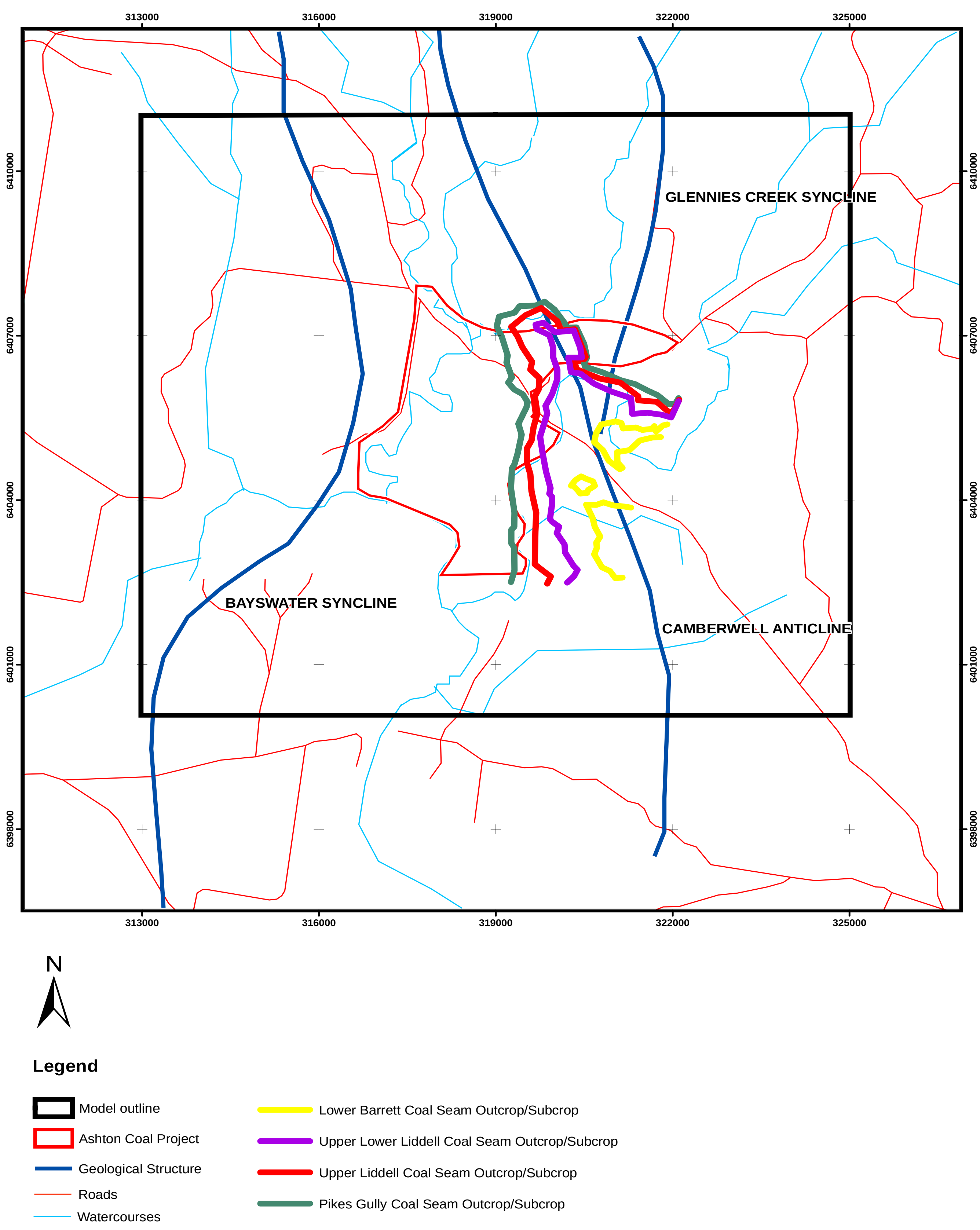
Figure 5: Ashton Project - Regional Geology

Author: VR	Date: 13/10/2008
Drawn:	Revised:
Job No: S3	Report Revision:
Projection: GDA94 MGA Z56	Scale: 1:45,000

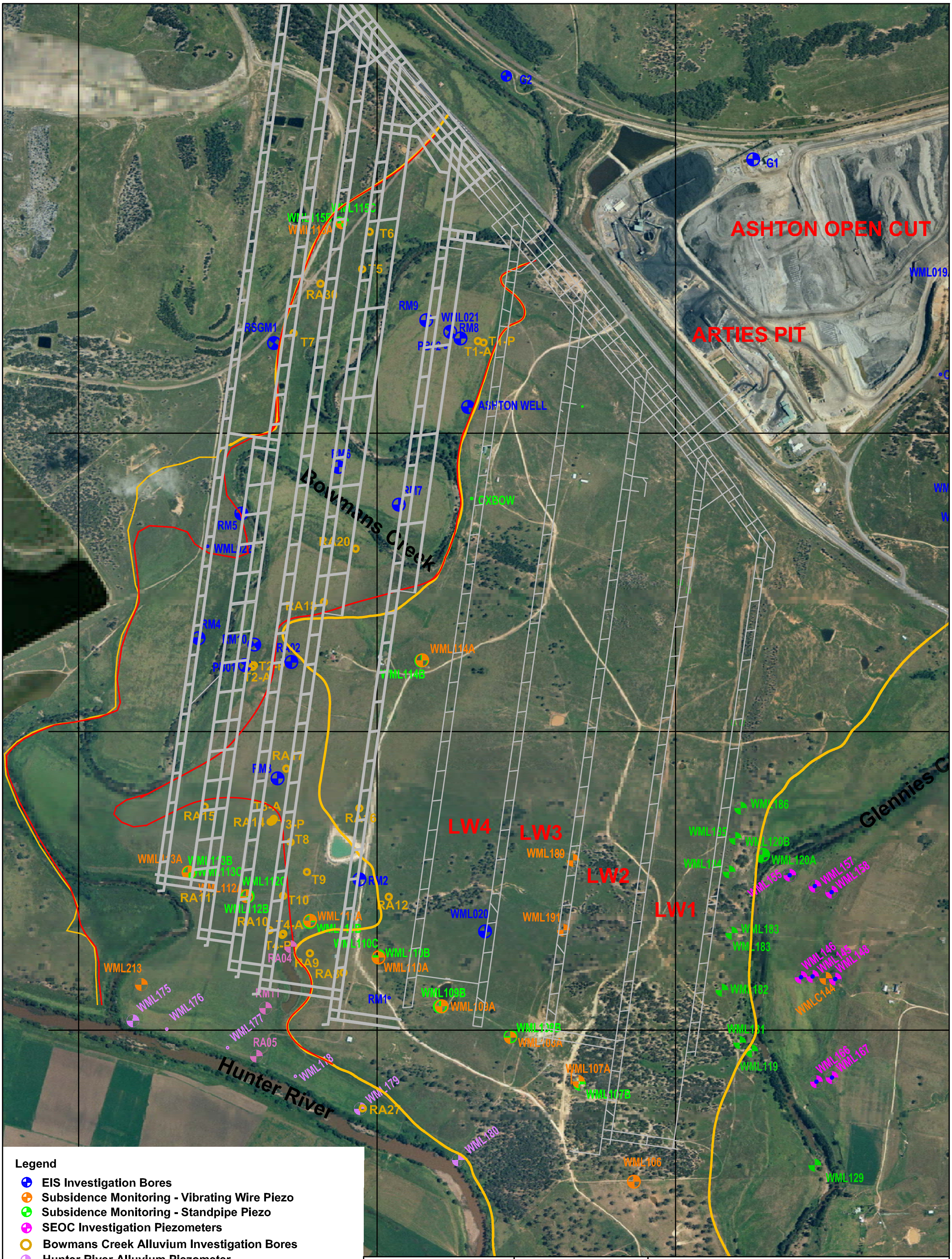


Representative Geological Cross-Section – Ashton Project

Figure 6



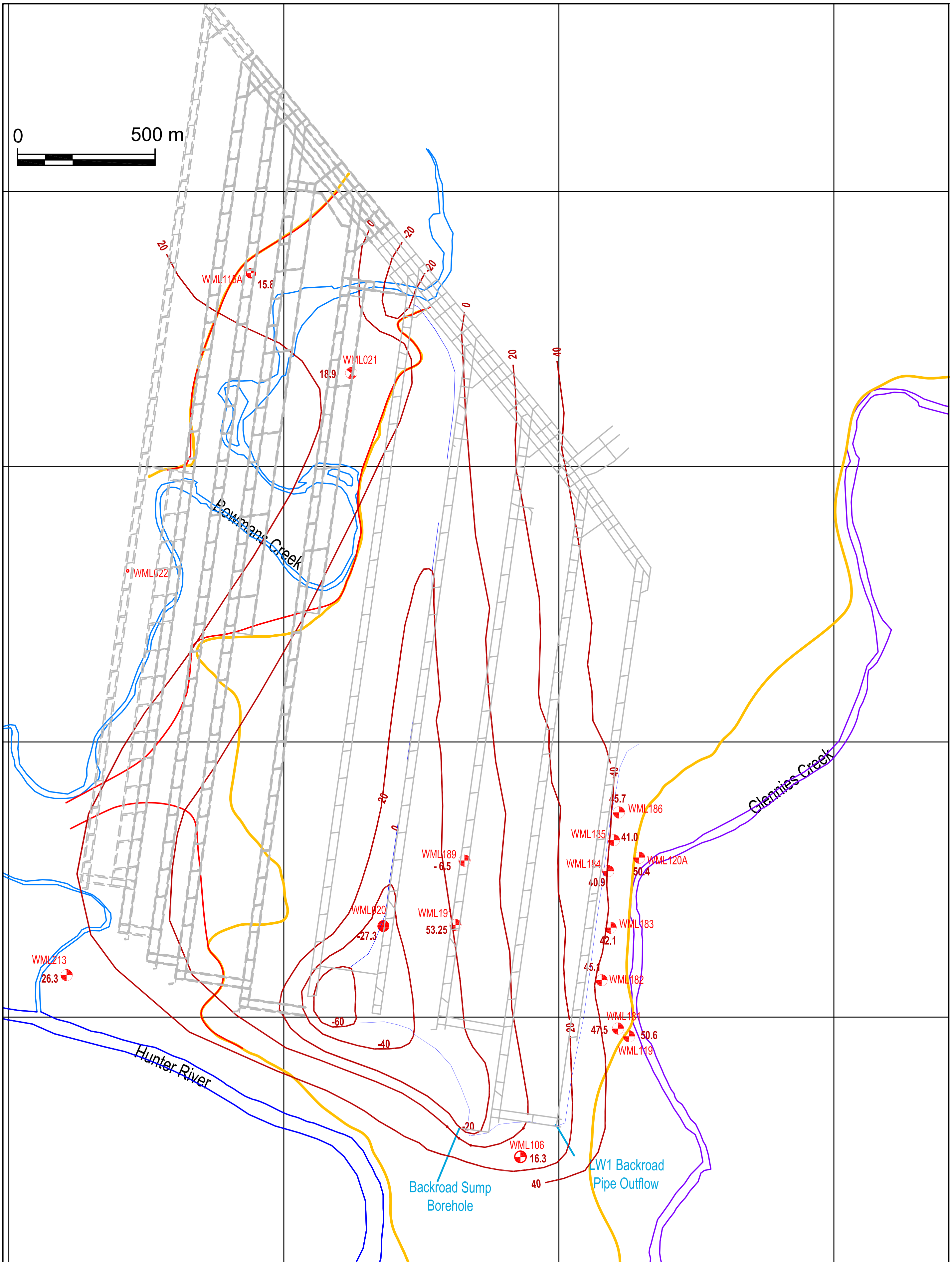
Approximate Coal Seam Outcrops – Ashton Project
Figure 7



Legend

- EIS Investigation Bores
- Subsidence Monitoring - Vibrating Wire Piezo
- Subsidence Monitoring - Standpipe Piezo
- SEOC Investigation Piezometers
- Bowmans Creek Alluvium Investigation Bores
- Hunter River Alluvium Piezometer
- LW1 - Glennies Ck Barrier Piezometers
- Abandoned / Lost Bore
- Extent Of Alluvium
- Extent Of Saturated Bowmans Creek Alluvium

Date: 14 October 2008	Scale: as shown	Ashton Coal Operations Ltd
Initials: TL	Job No: S03	ASHTON COAL MINE LW/MW 5-9 PIEZOMETER LOCATION PLAN
Drawing No: S03 -228a	Revision: A	
aquaterra		Figure 8

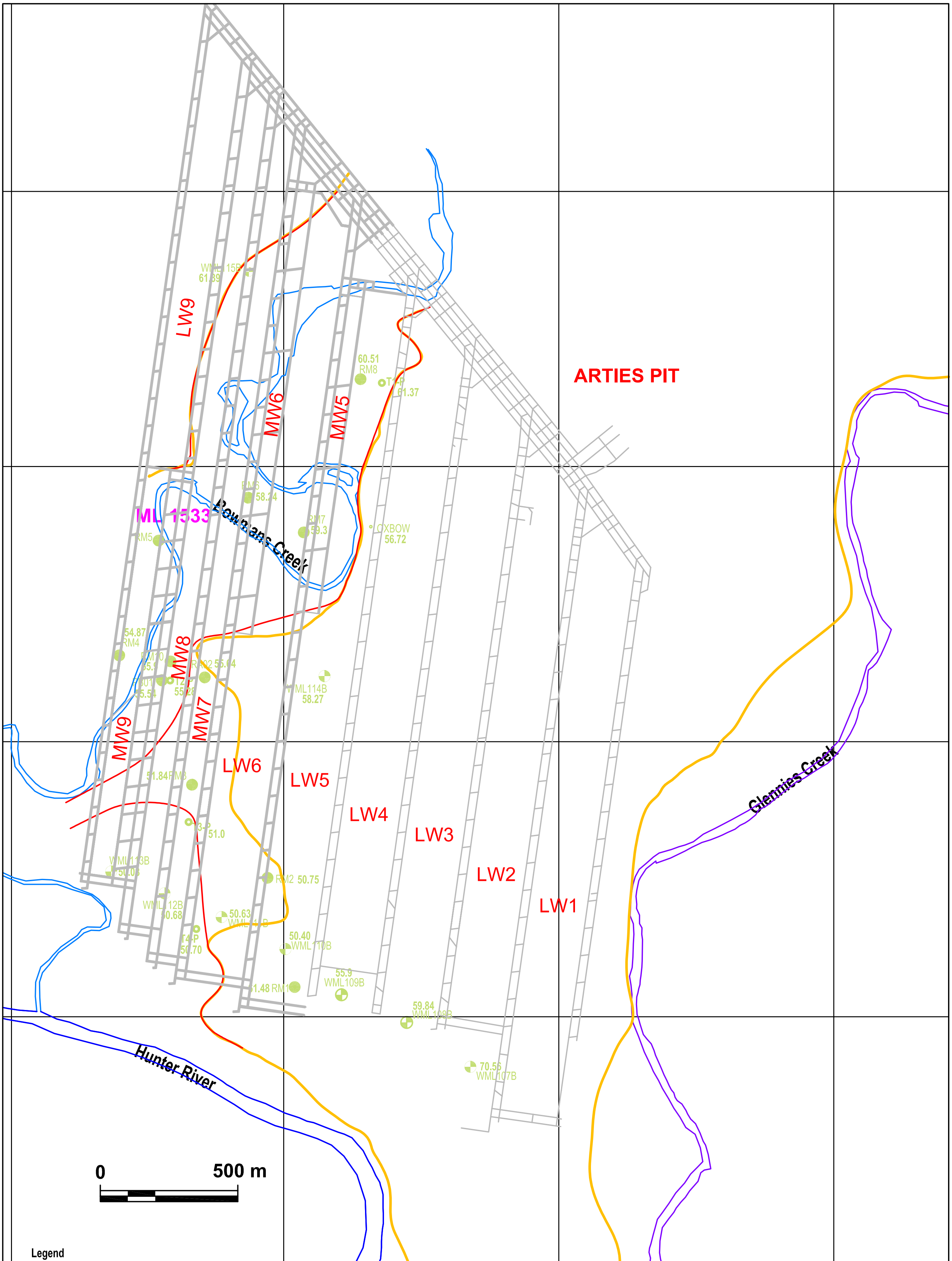


-26.3 GW Level (mAHD)

Pikes Gully Piezometer

Extent of dewatered Pikes Gully Seam

Date: 25 July 2008	Scale: as shown	**Ashton Coal Operations Ltd**	
Initials: PJD	Job No: S03	**GROUNDWATER LEVELS - PIKES GULLY (mAHD)**	
Drawing No: S03-171a	Revision: A		
aquaterra			**Figure 9**



Legend

- Bowmans Creek Alluvium Piezometer
- Bowmans Creek Alluvium Piezometer
- Colluvium Piezometer
- Alluvium Groundwater Level (mAHD)
- Boundary of Alluvium
- Boundary of Saturated Alluvium

Date:	15 October 2008	Scale:	as shown	Ashton Coal Operations Ltd
Initials:	PJD	Job No:	S03	GROUNDWATER LEVELS - WEATHERED PERMIAN (mAHD)
Drawing No:	S03-163	Revision:	0	

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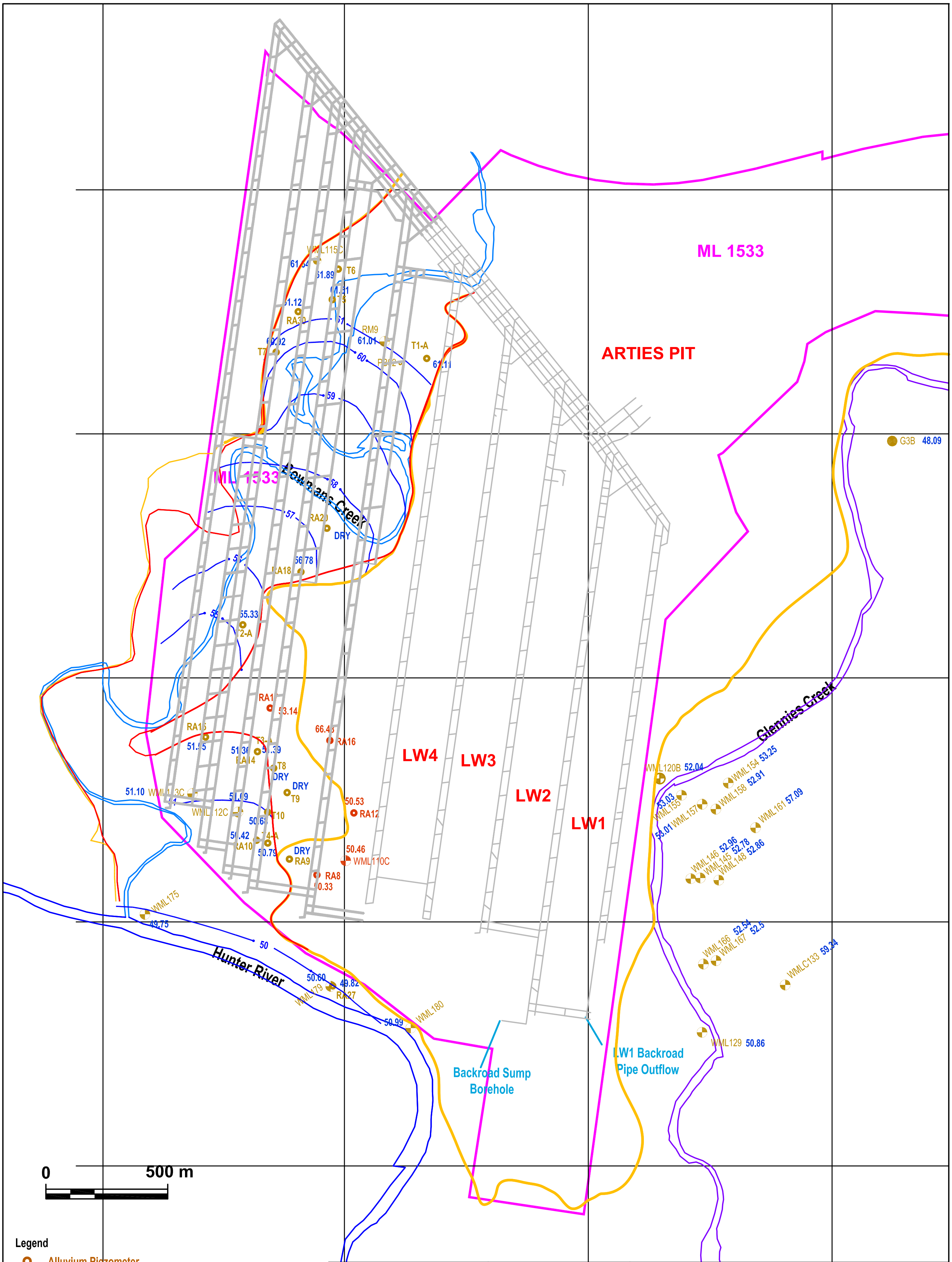
Figure 10



Legend

- Alluvium Piezometer
- Alluvium Piezometer
- Colluvium Piezometer
- Alluvium Groundwater Level (mAHD)
- Boundary of Alluvium
- Boundary of Saturated Alluvium

Date:	9 October 2008	Scale:	as shown
Initials:	TL	Job No:	S03
Drawing No:	S03-163	Revision:	0

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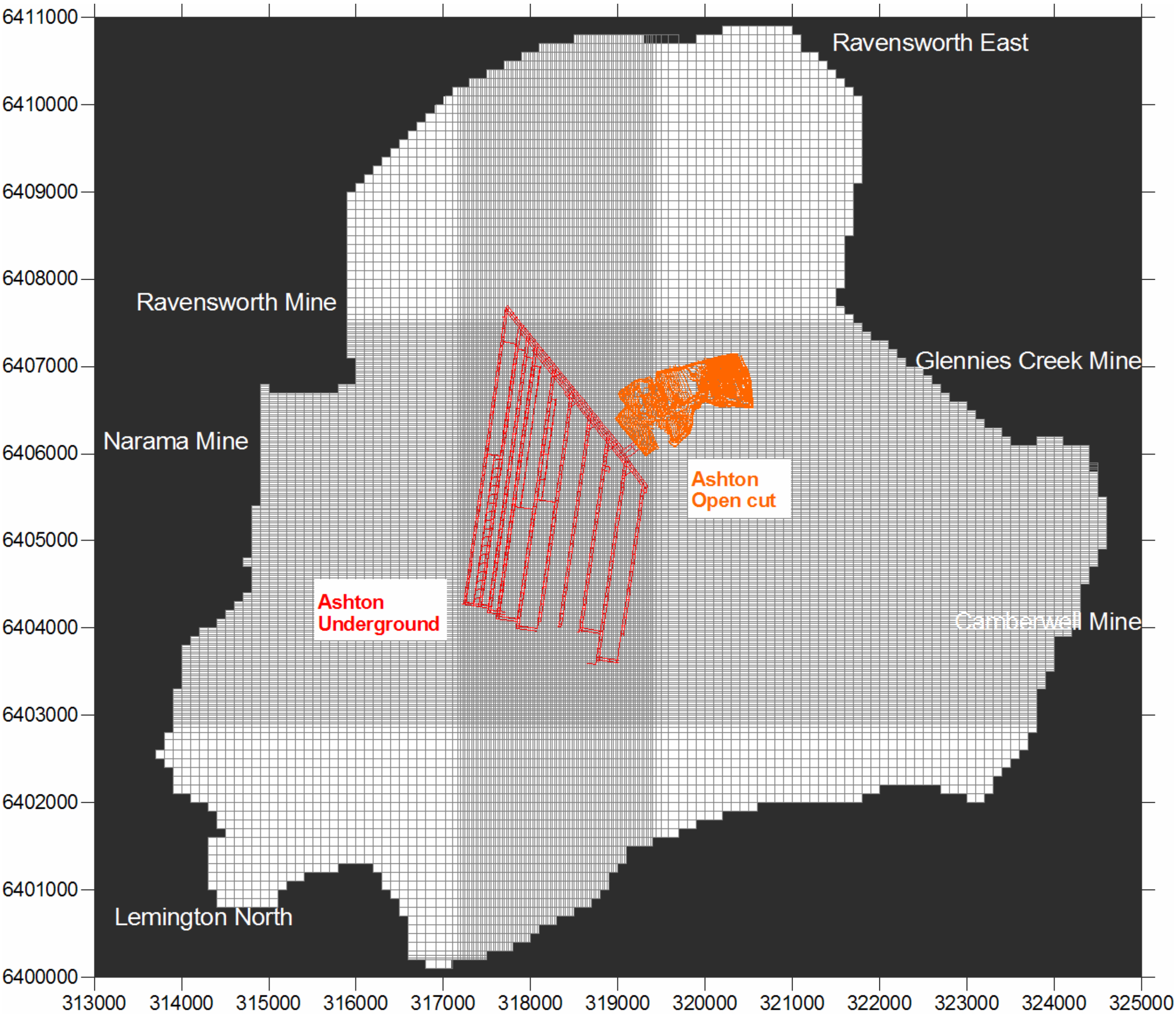
Ashton Coal Operations Ltd

ALLUVIUM GROUNDWATER CONTOURS (mAHD)

Figure 11



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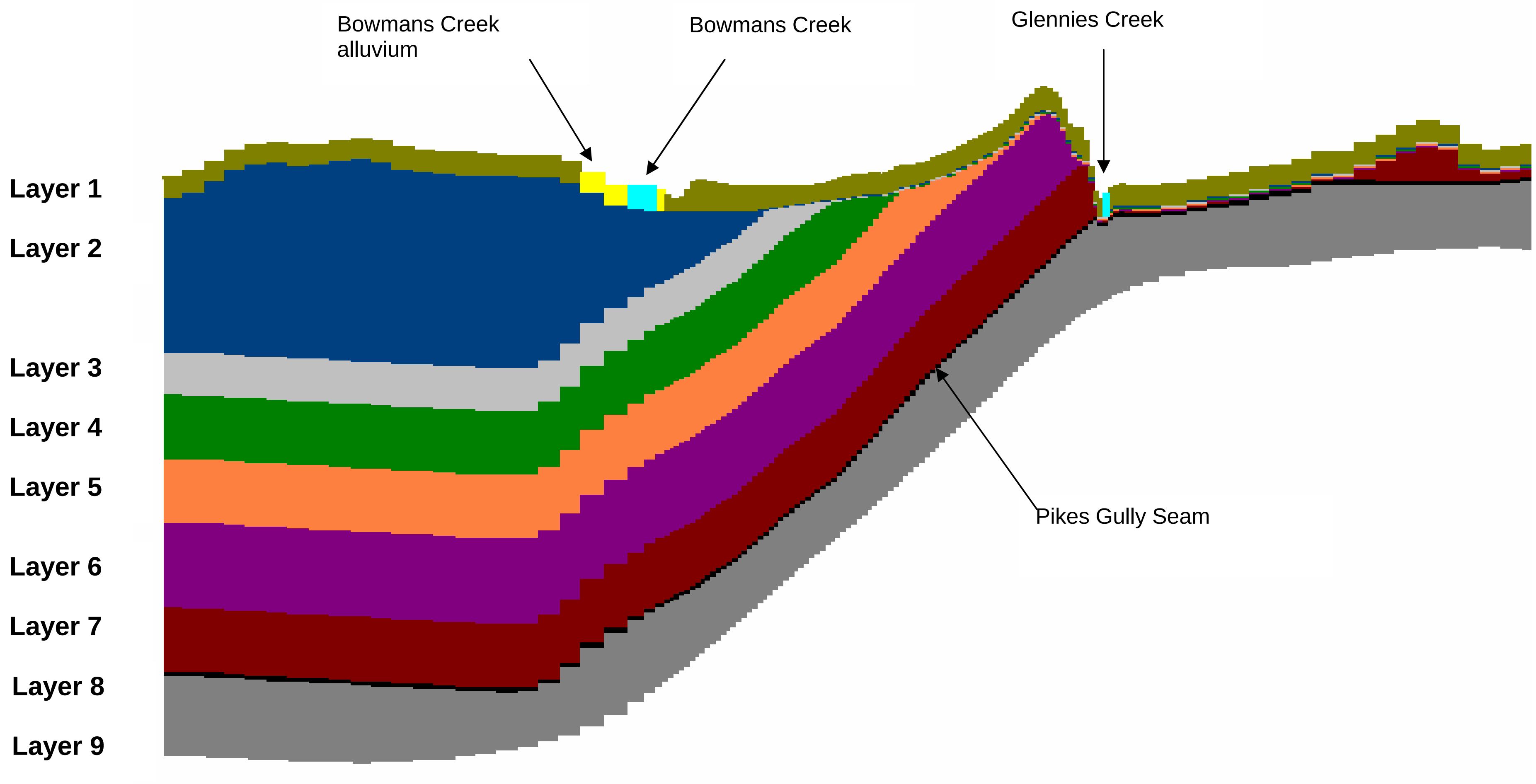
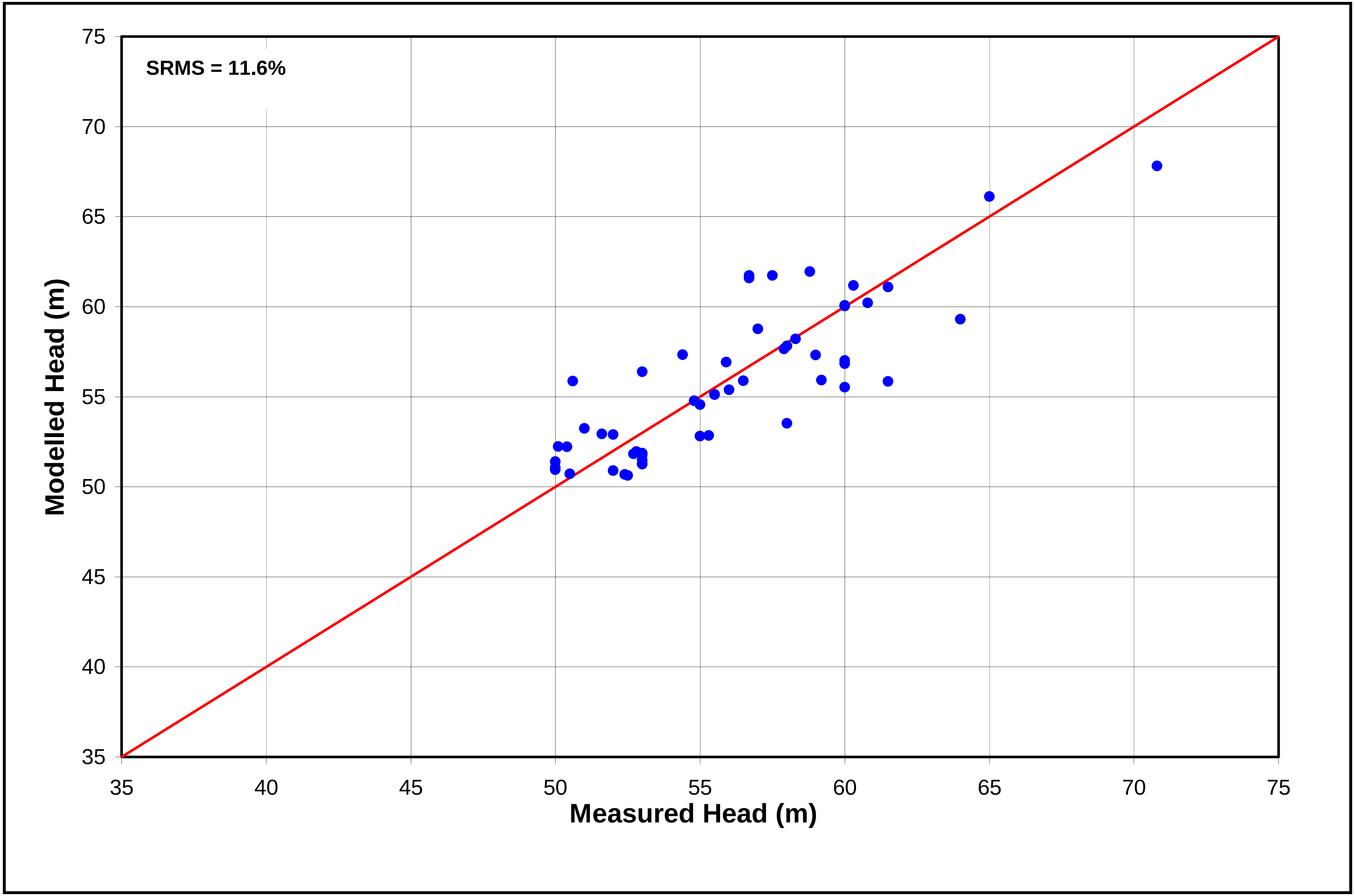
Model Domain, Model Grid and Ashton Mine Layouts
Figure 12



Modelled East-West Cross Section through Northing 6404460
Figure 13



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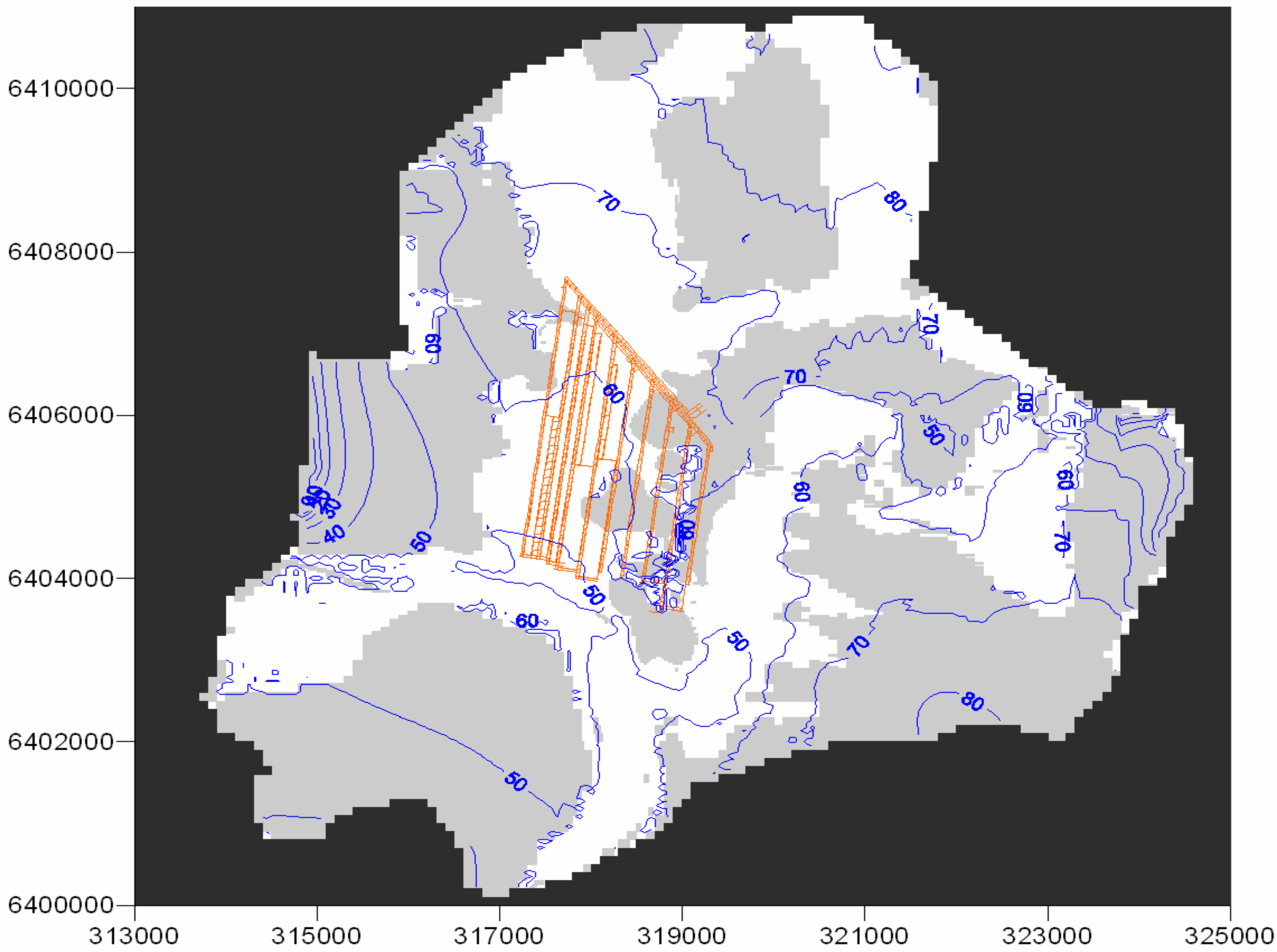
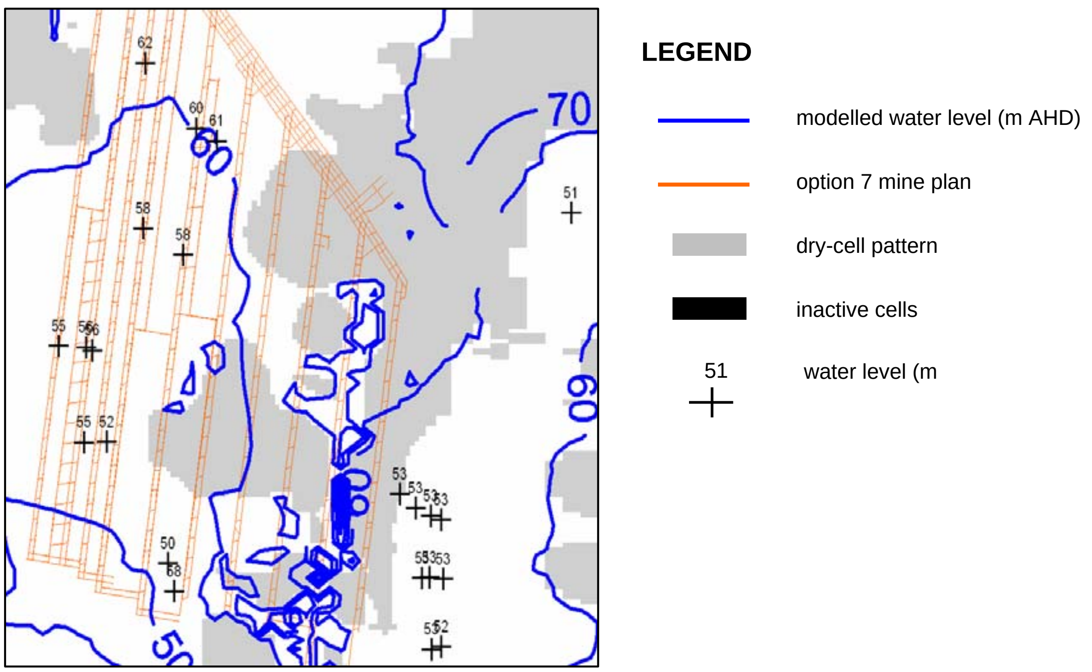
Modelled vs Measured Steady-State Groundwater Levels
Figure 14





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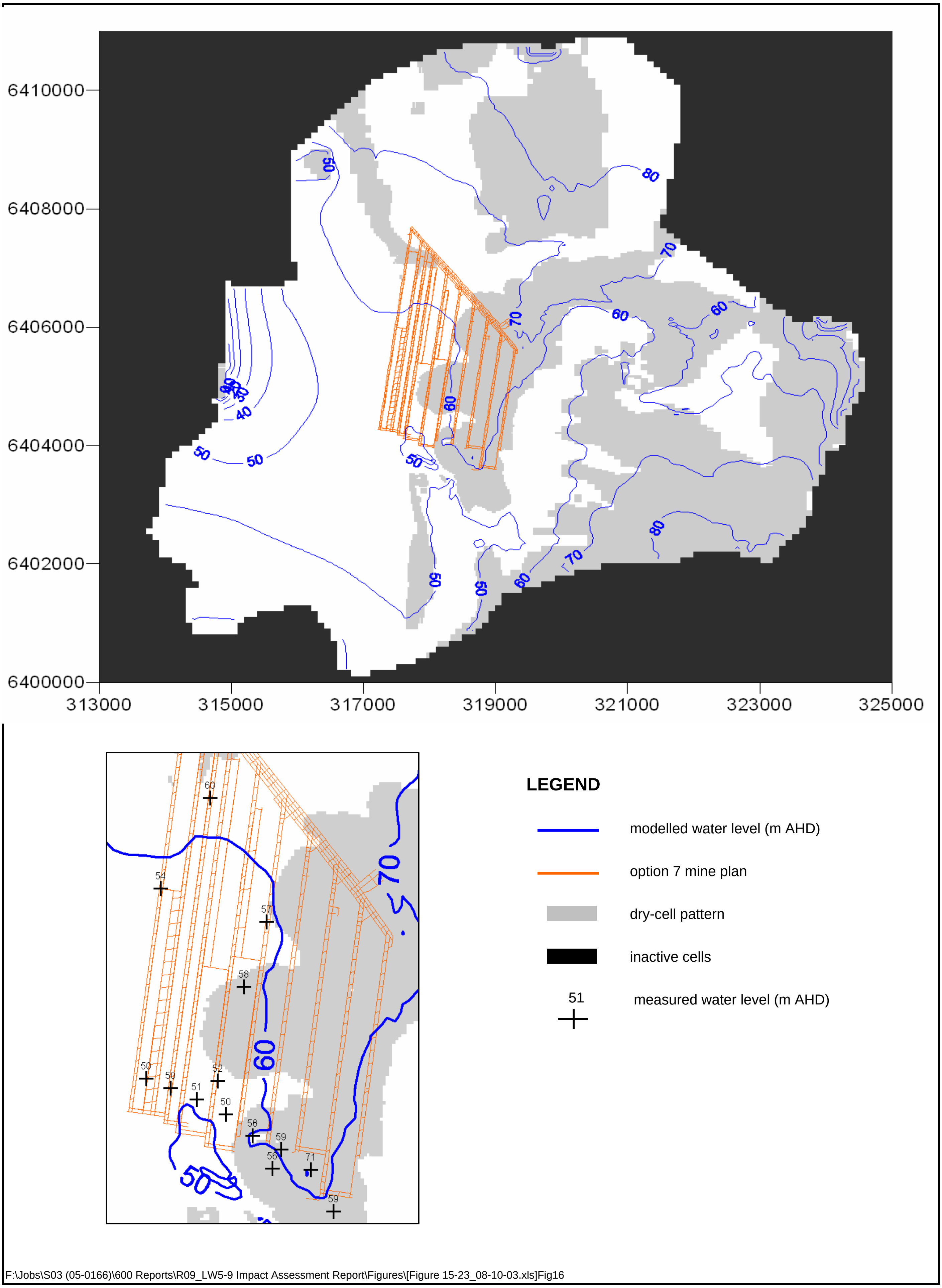
Plan View of Modelled Heads - Layer 1

Figure 15



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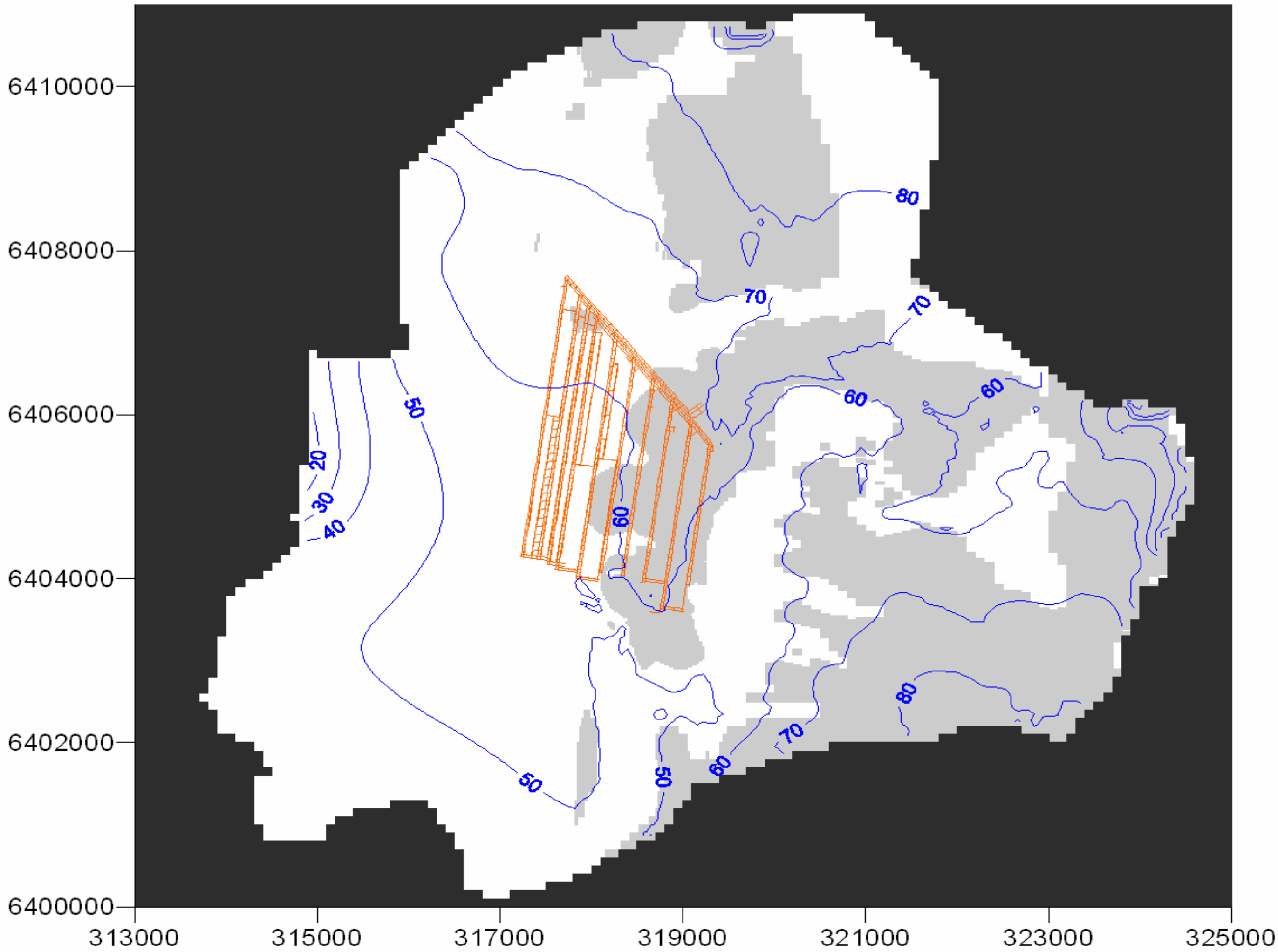
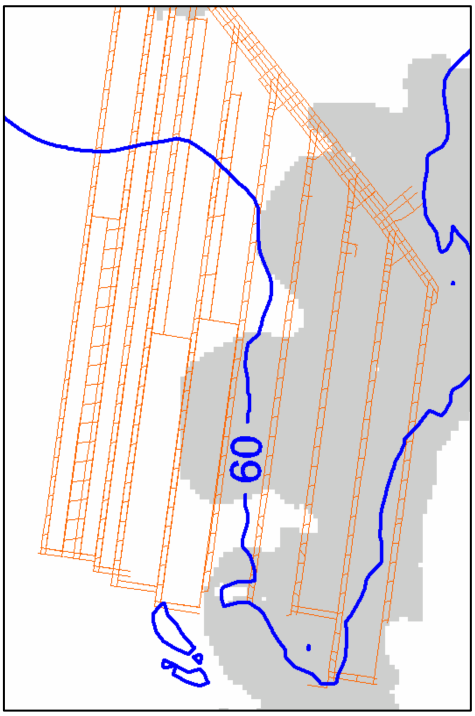
Plan View of Modelled Heads - Layer 2

Figure 16





LEGEND

modelled water level (m AHD)

option 7 mine plan

dry-cell pattern

inactive cells

51 measured water level (m AHD)

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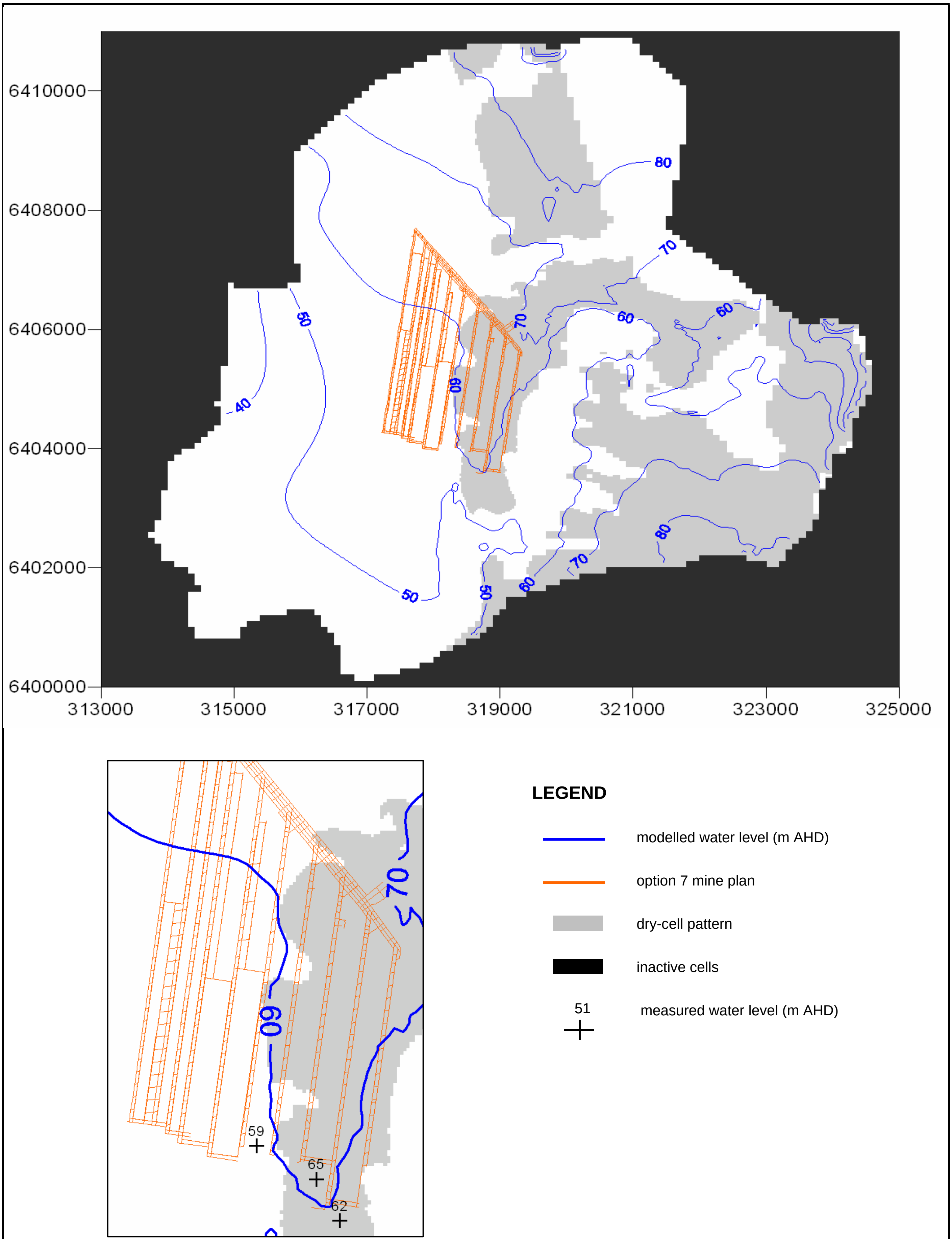
Plan View of Modelled Heads - Layer 3
Figure 17



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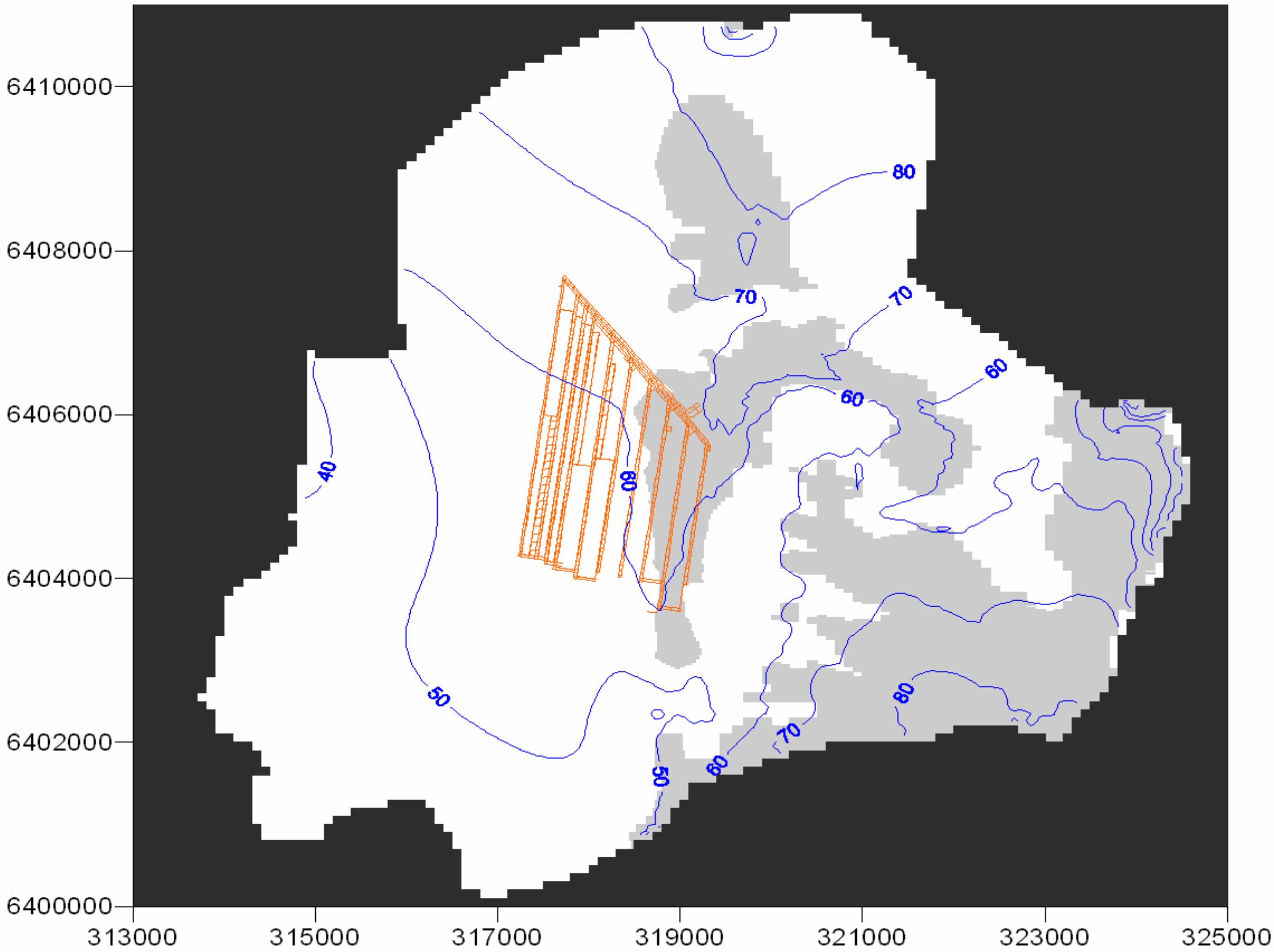
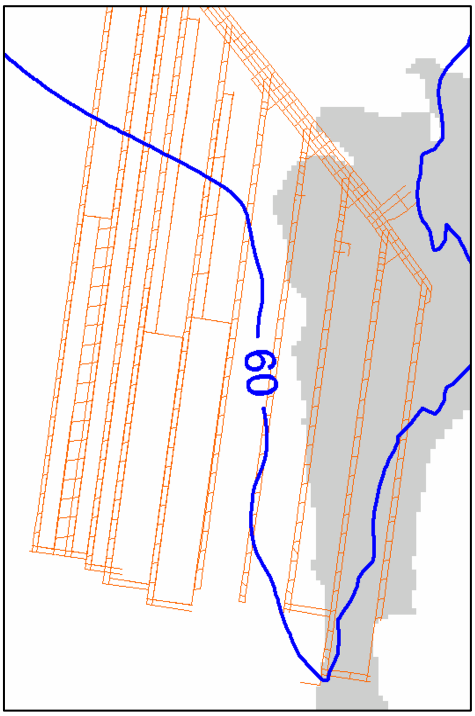
aquaterra

Plan View of Modelled Heads - Layer 4

Figure 18





LEGEND

- modelled water level (m AHD)
- option 7 mine plan
- dry-cell pattern
- inactive cells
- 51 measured water level (m AHD)

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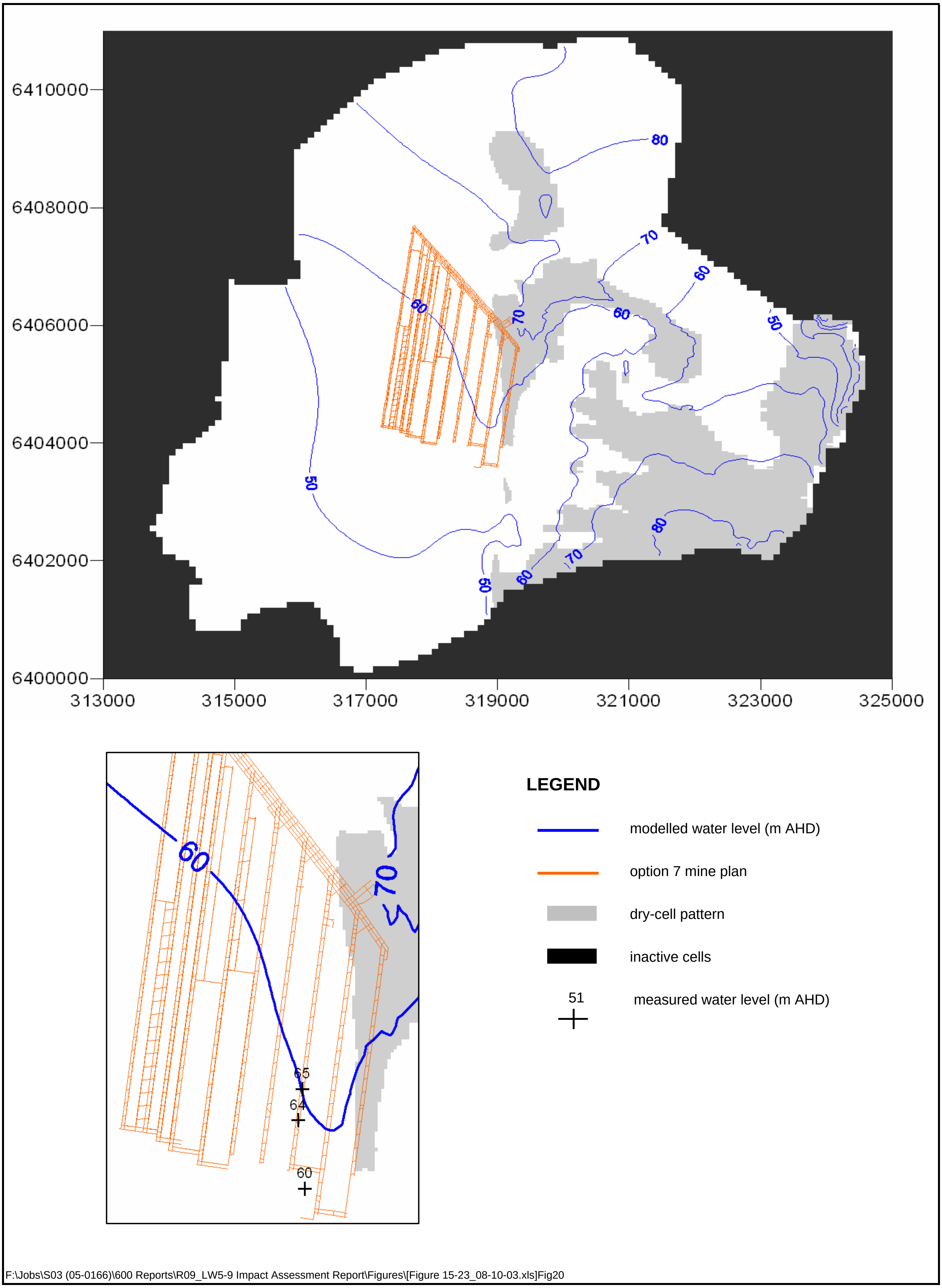
aquaterra

Plan View of Modelled Heads - Layer 5

Figure 19



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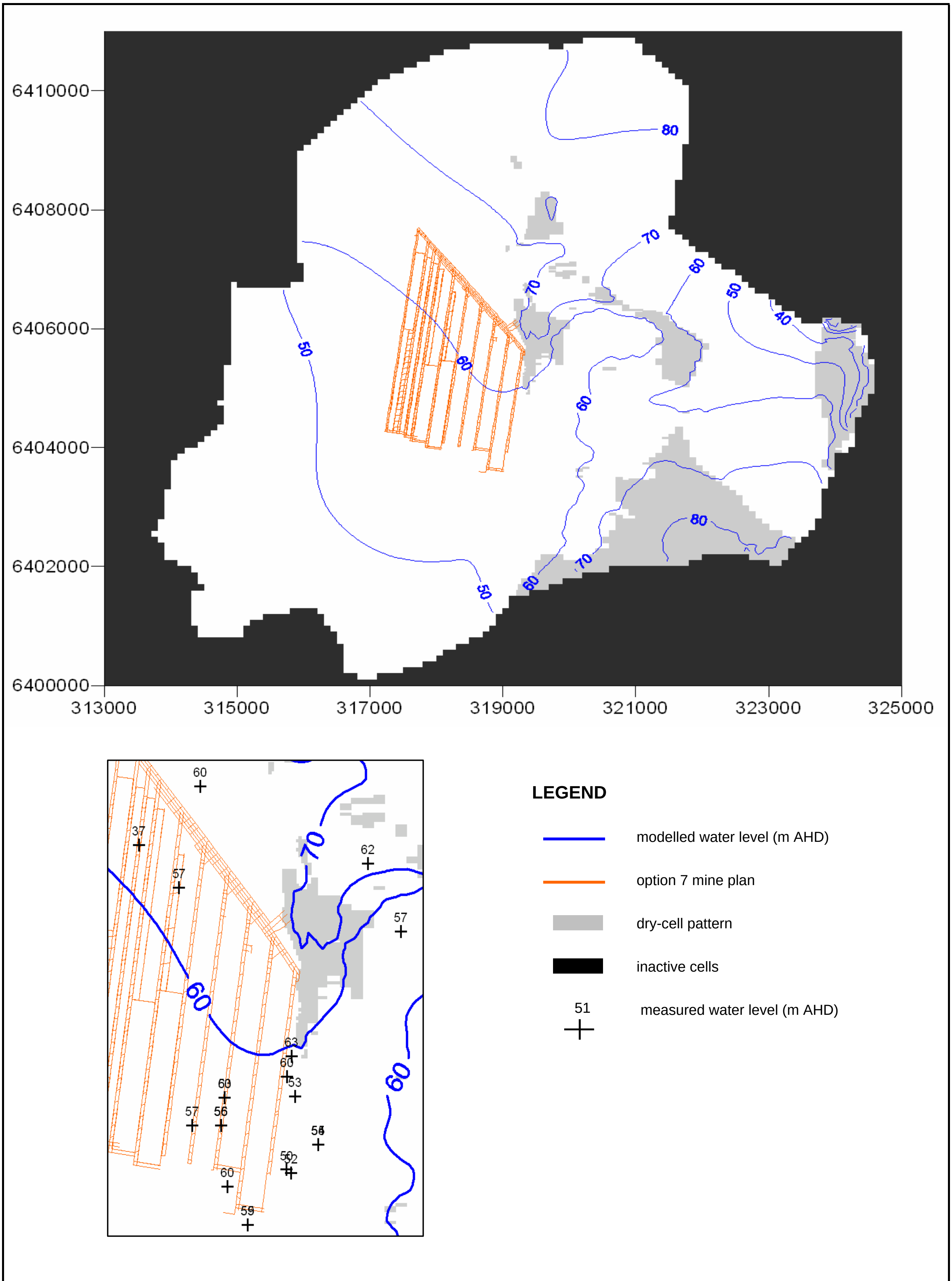
Plan View of Modelled Heads - Layer 6
Figure 20



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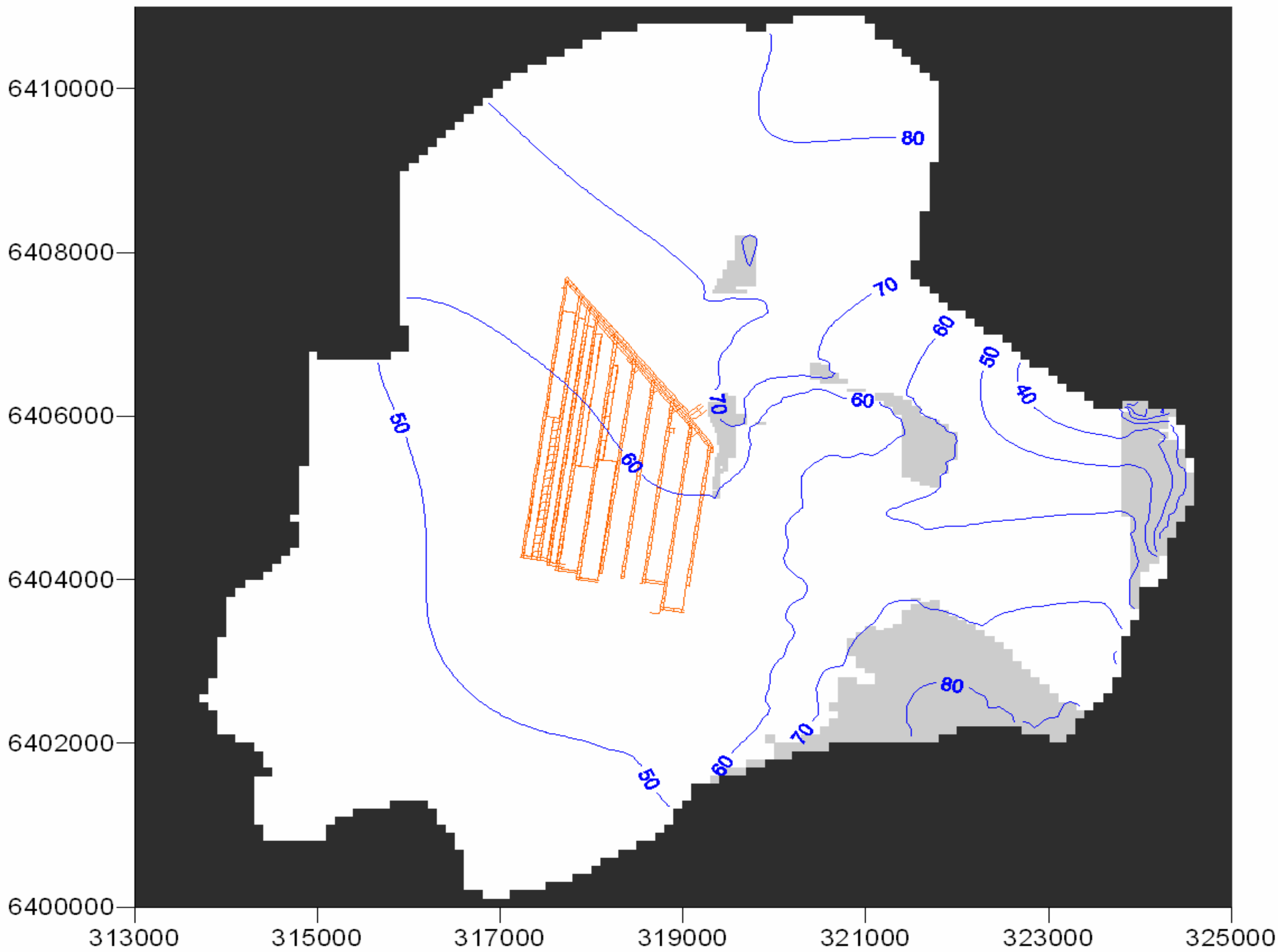
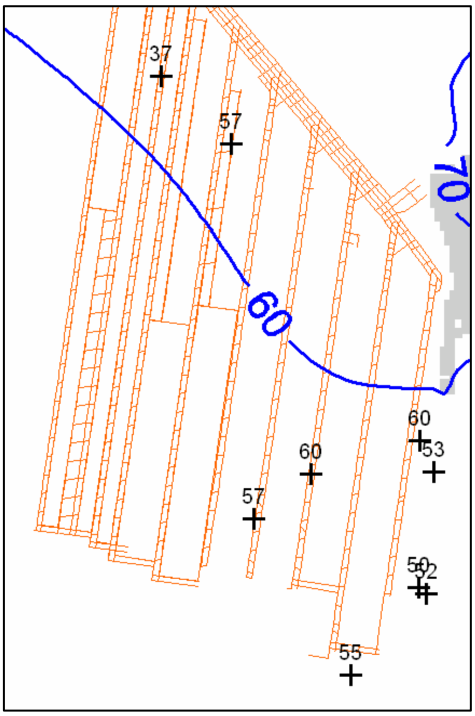
Plan View of Modelled Heads - Layer 7

Figure 21





LEGEND

modelled water level (m AHD)	
option 7 mine plan	
dry-cell pattern	
inactive cells	
51	measured water level (m AHD)

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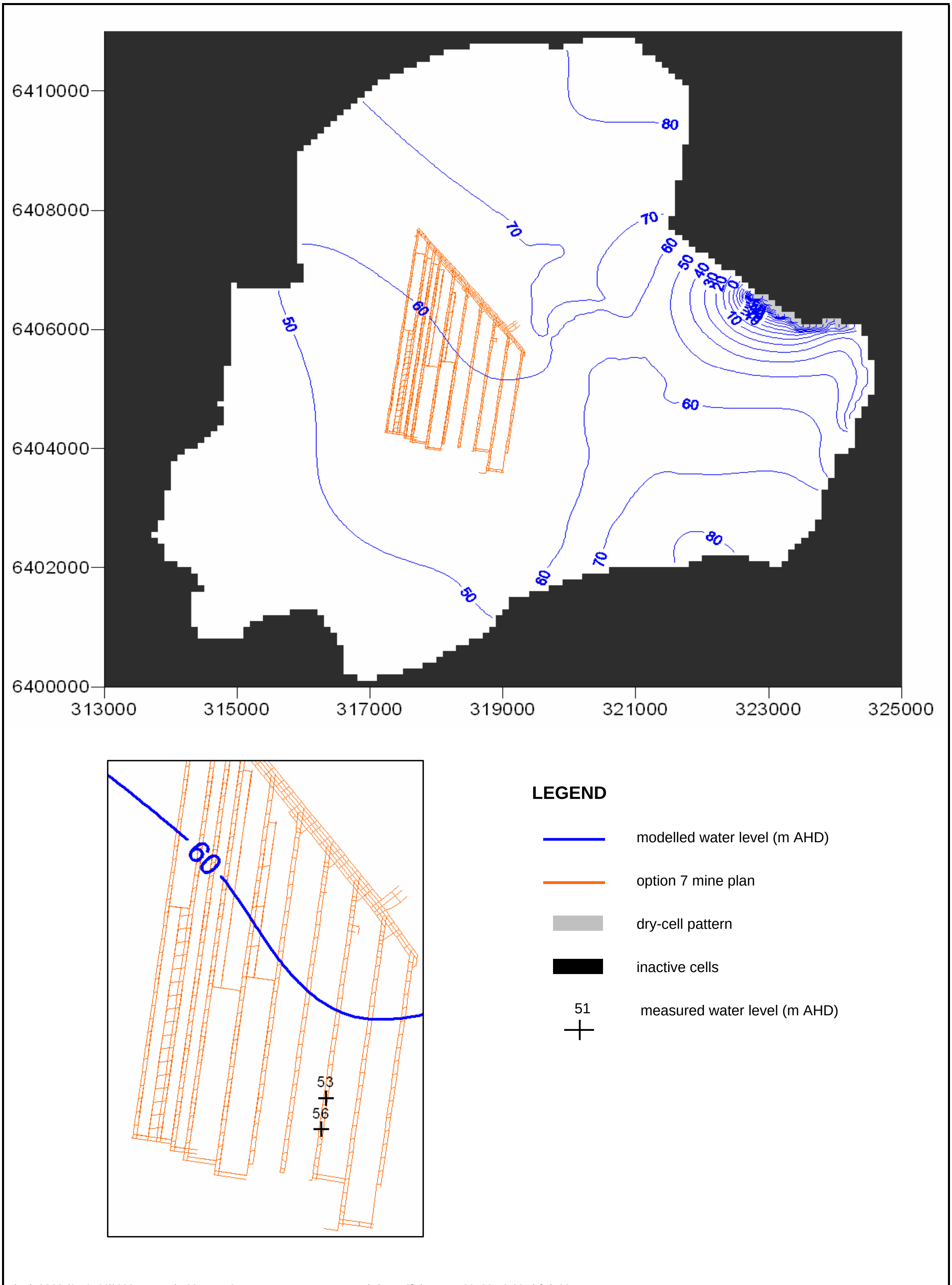
aquaterra

Plan View of Modelled Heads - Layer 8

Figure 22



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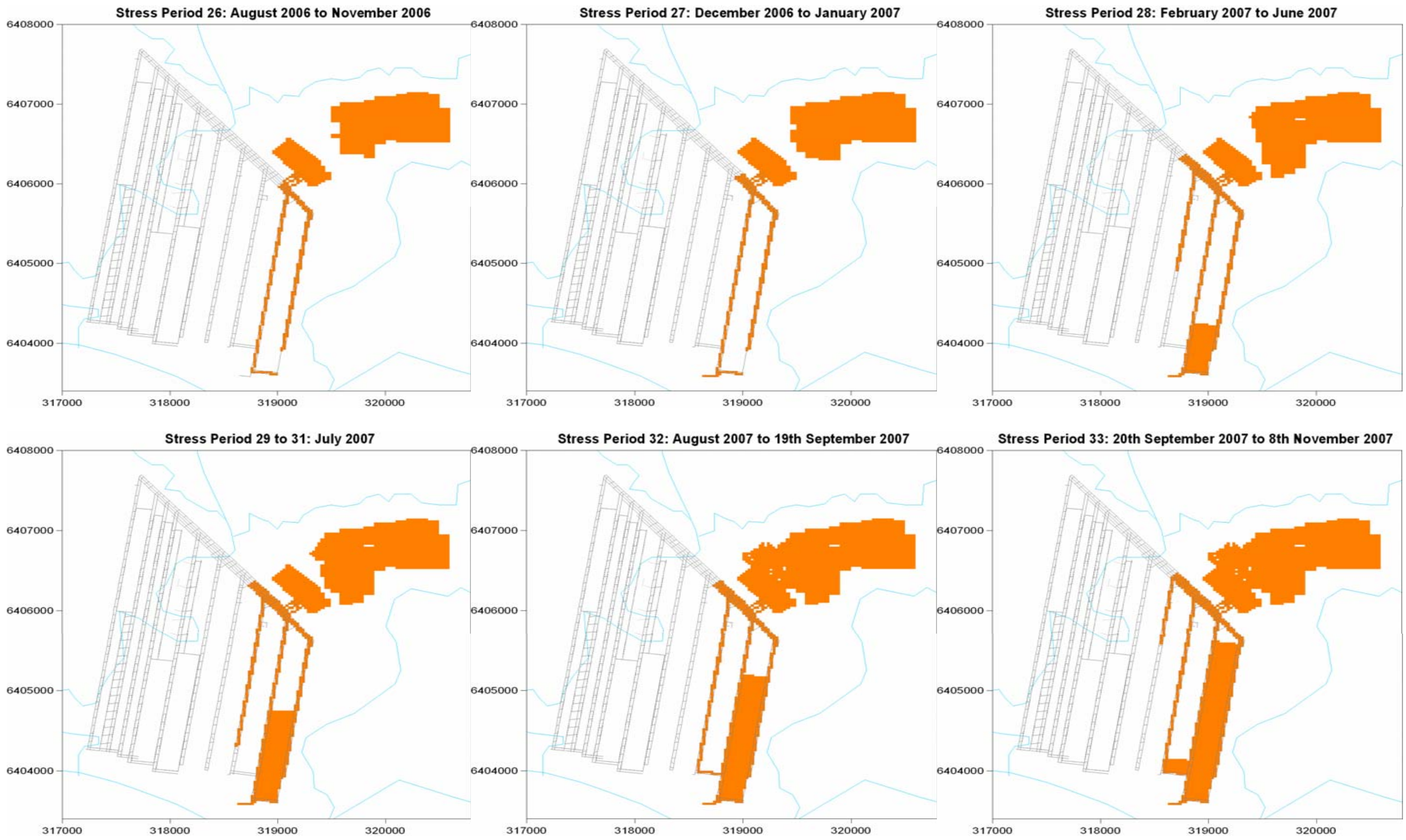
aquaterra

Plan View of Modelled Heads - Layer 9
Figure 23



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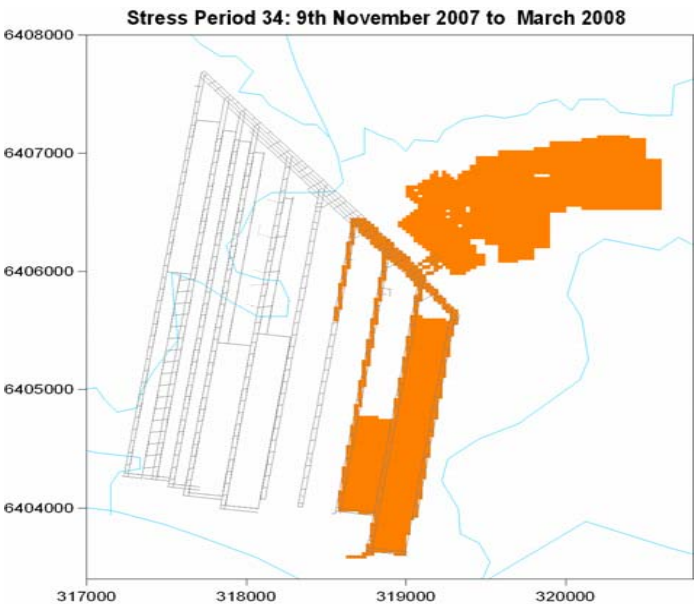
Modelled Mine Plan for Transient Calibration Period

Figure 24



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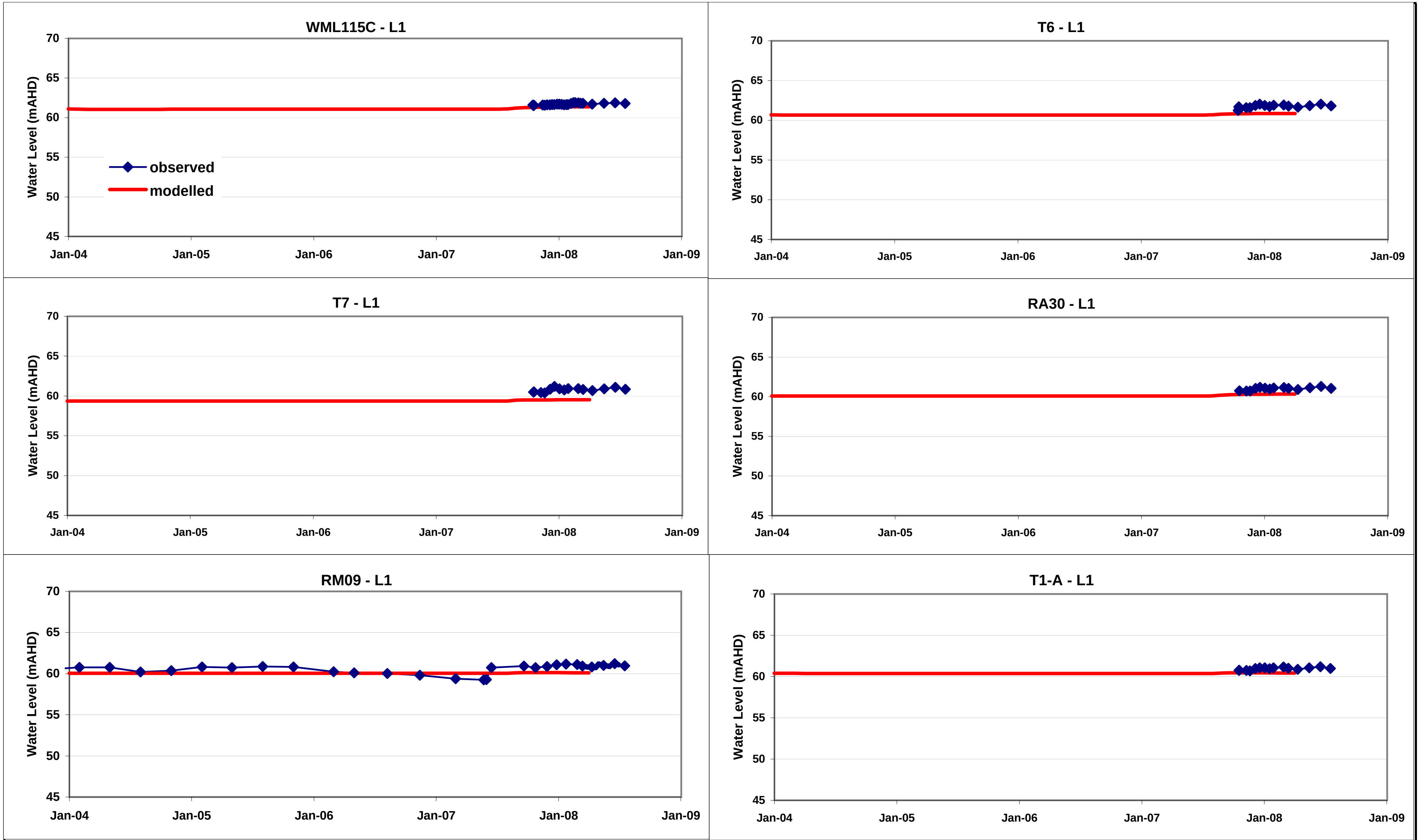
aquaterra

Modelled Mine Plan for Transient Calibration Period

Figure 25



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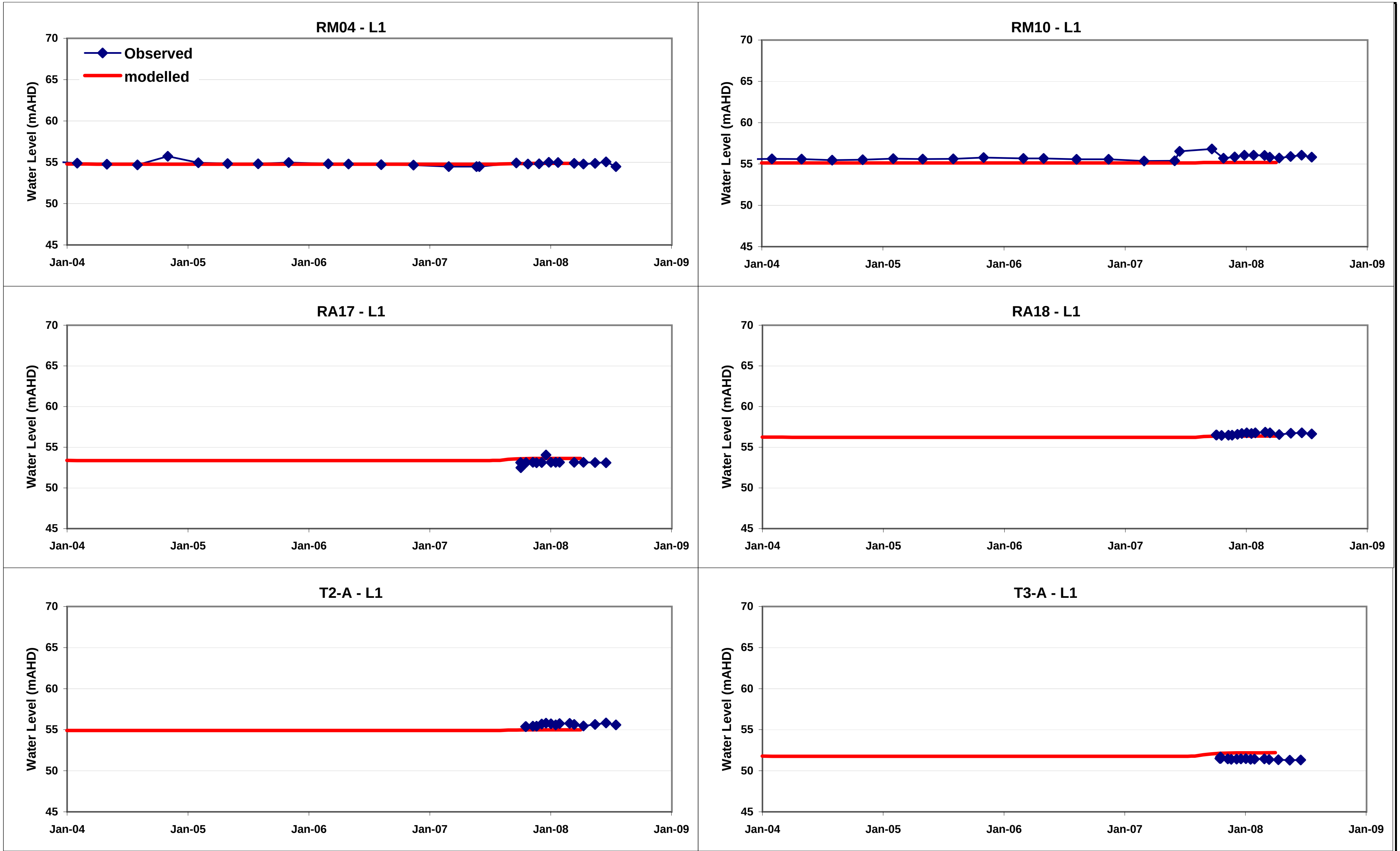
aquaterra

Layer 1 Modelled vs Observed - Bowmans Creek Alluvium Water Levels

Figure 26



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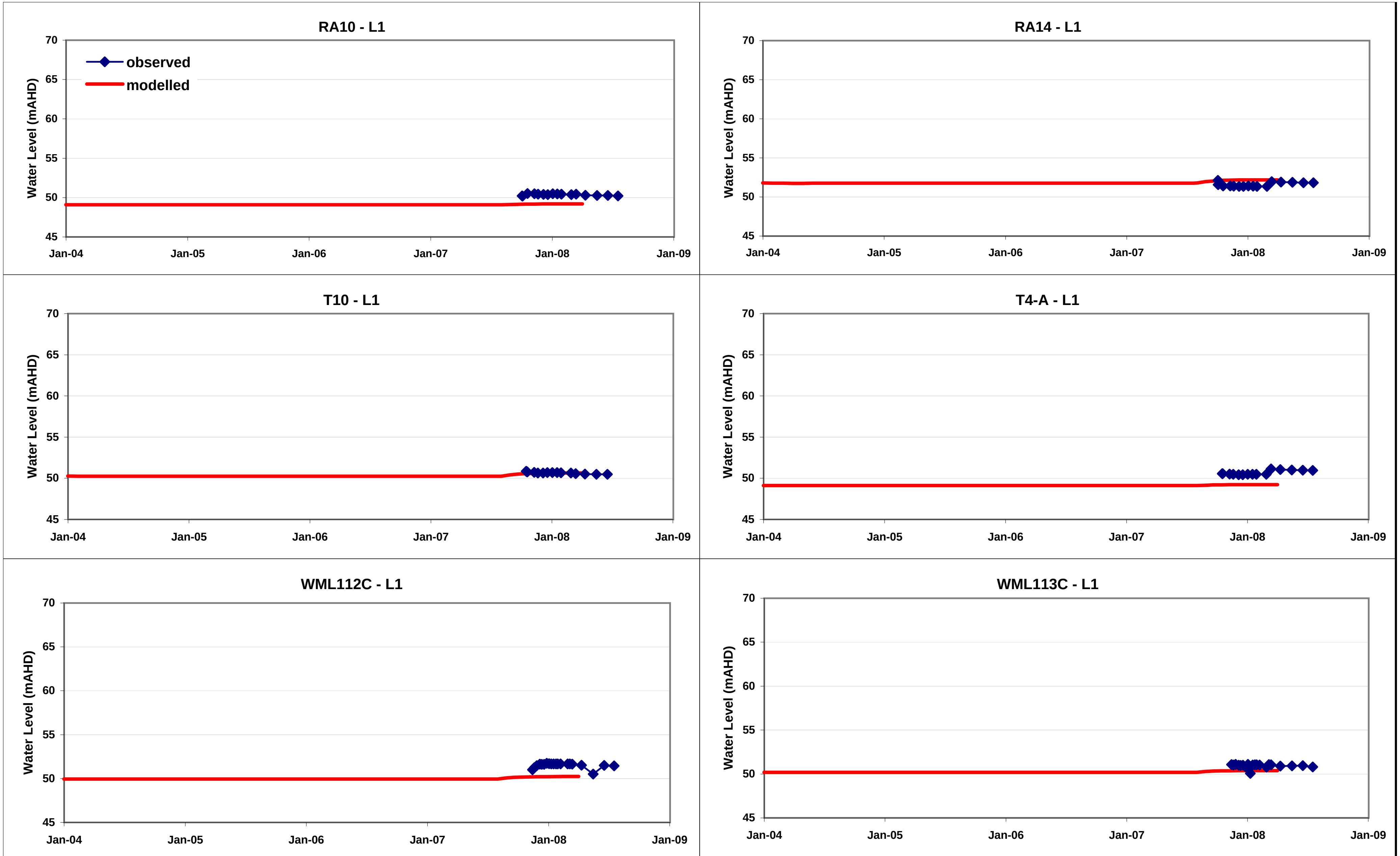
aquaterra

Layer 1 Modelled vs Observed - Bowmans Creek Alluvium Water Levels

Figure 27



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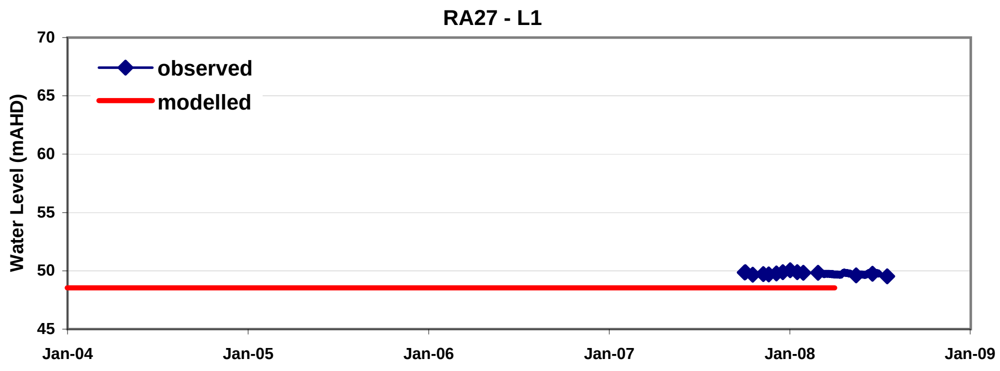
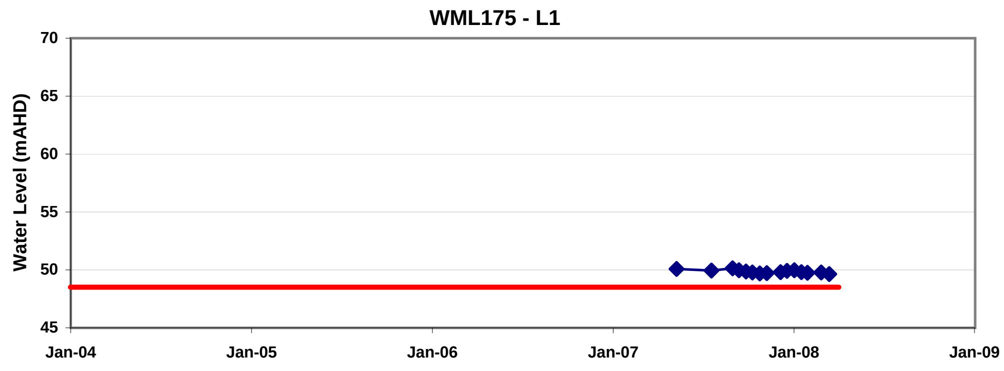
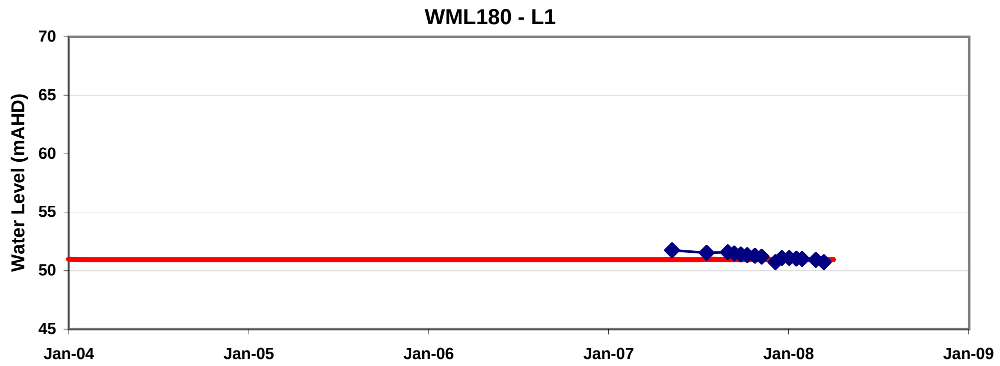
aquaterra

Layer 1 Modelled vs Observed - Bowmans Creek Alluvium Water Levels

Figure 28







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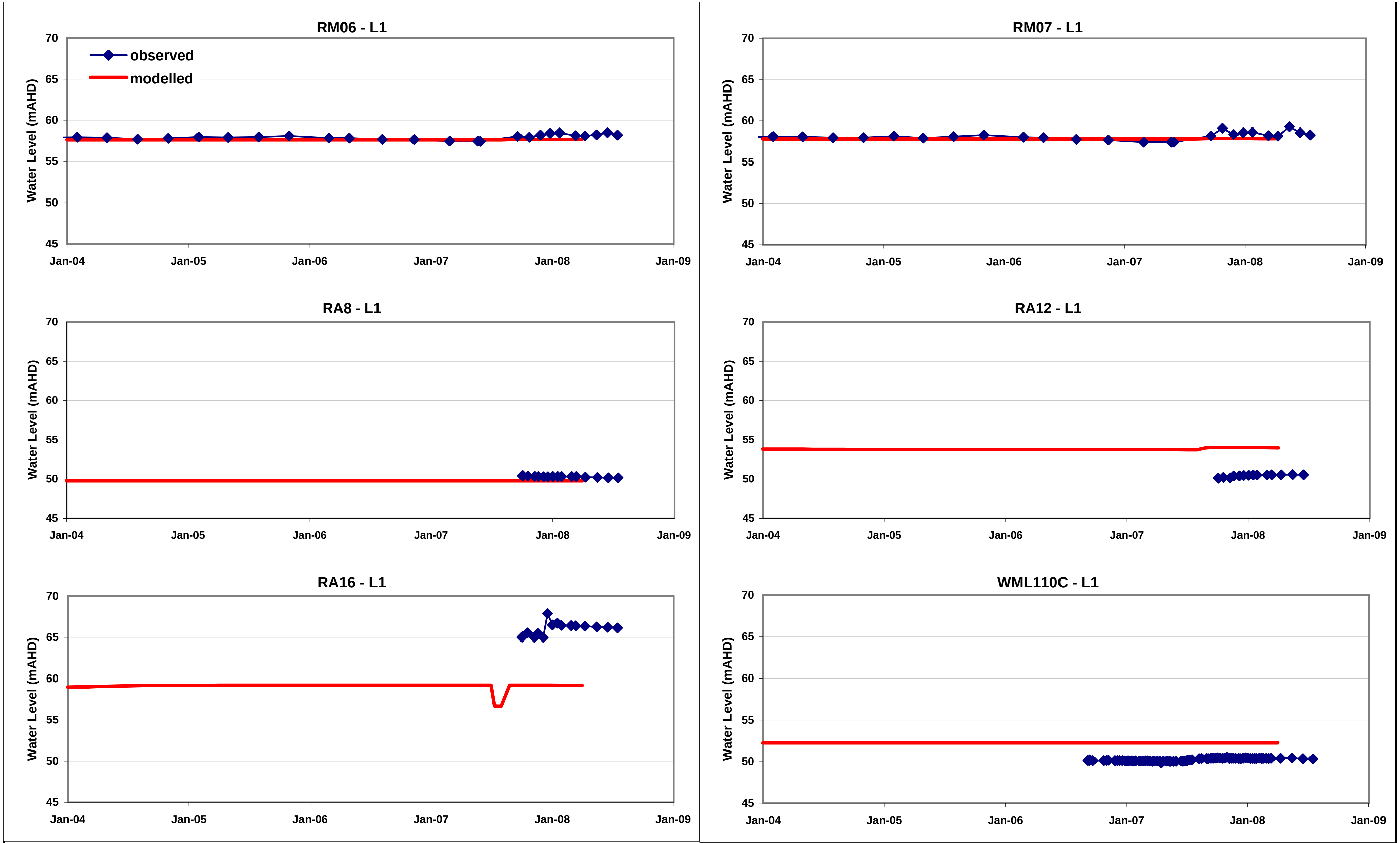
Layer 1 Modelled vs Observed - Hunter River Alluvium Water Levels

Figure 29



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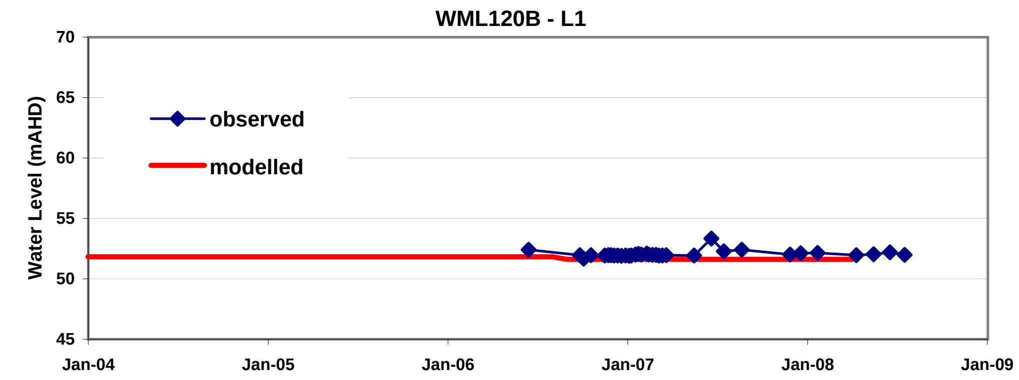
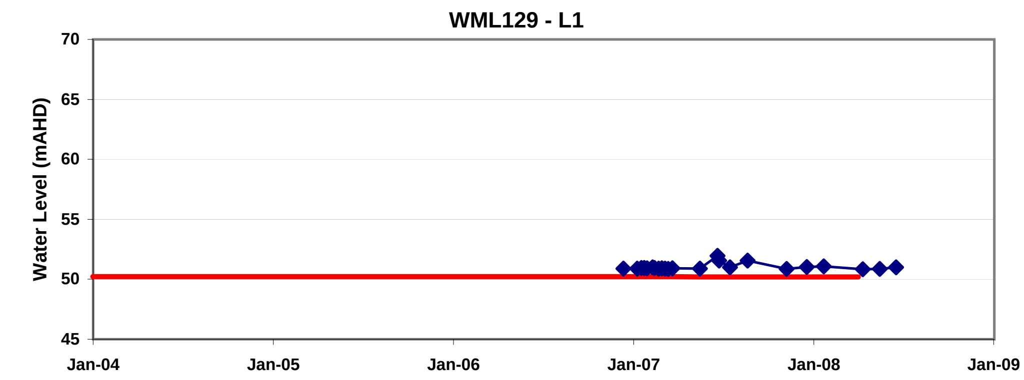
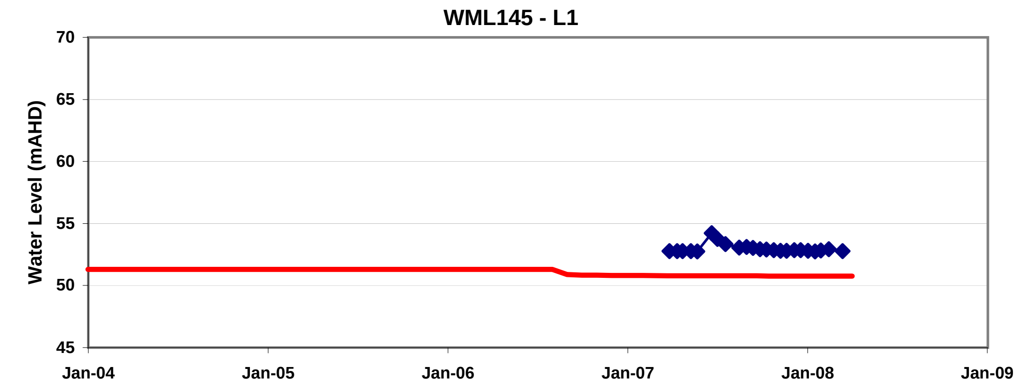
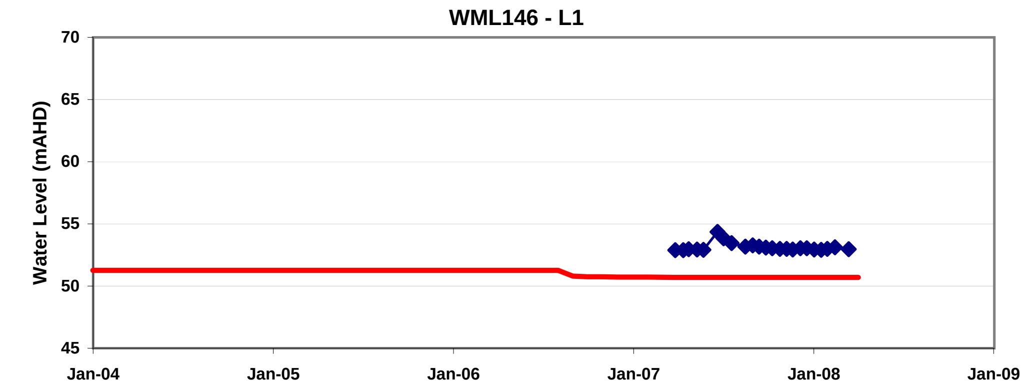
Layer 1 Modelled vs Observed - Colluvium/Weathered Permian Water Levels

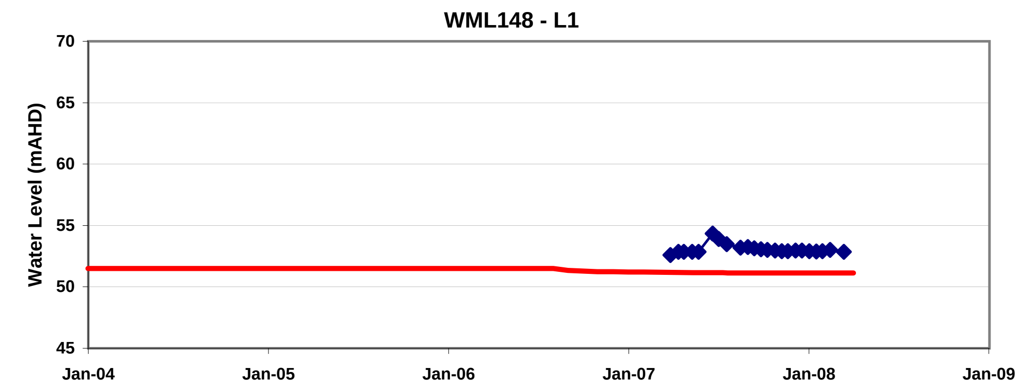
Figure 30











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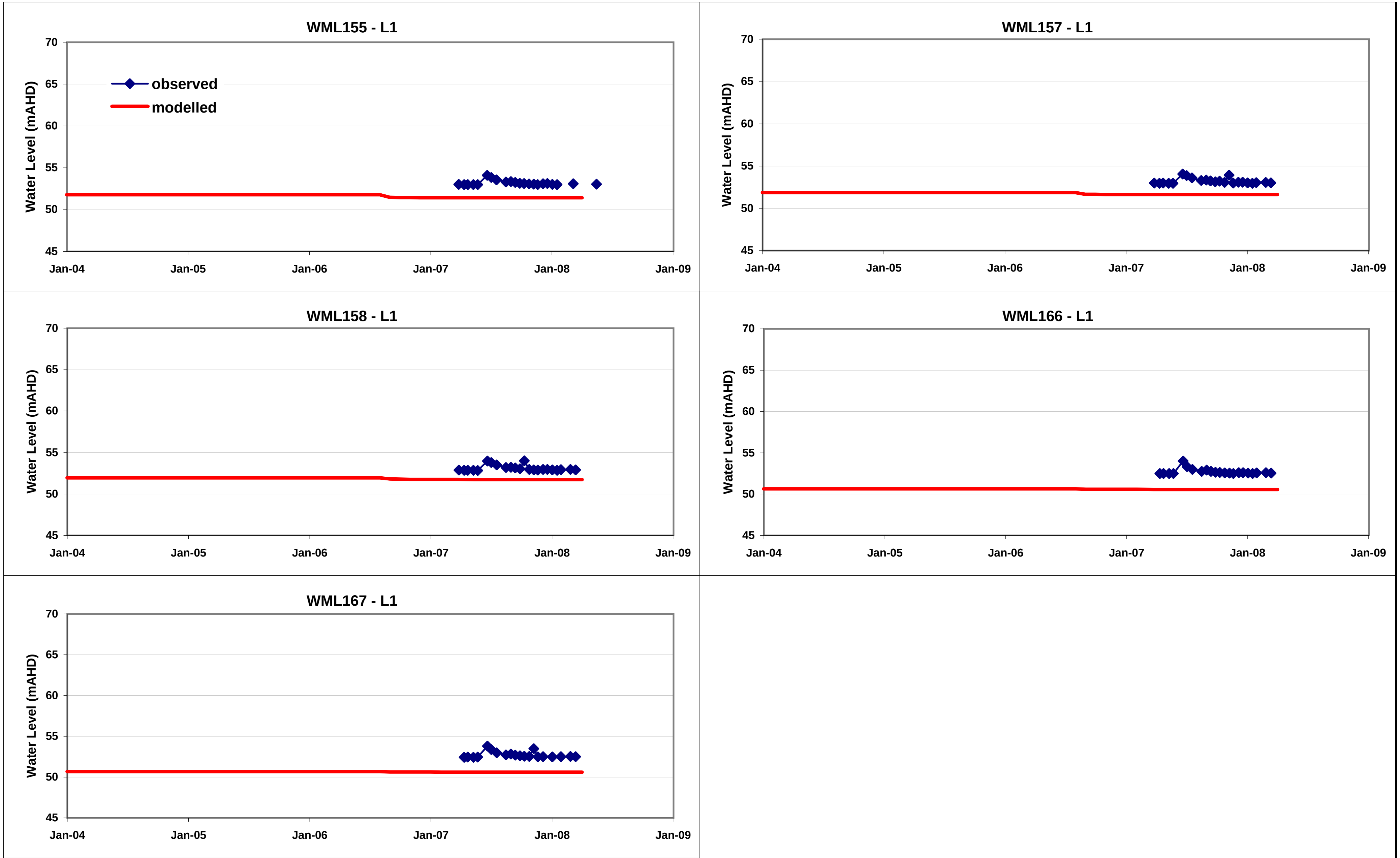
Layer 1 Modelled vs Observed - Glennies Creek Alluvium Water Levels

Figure 31



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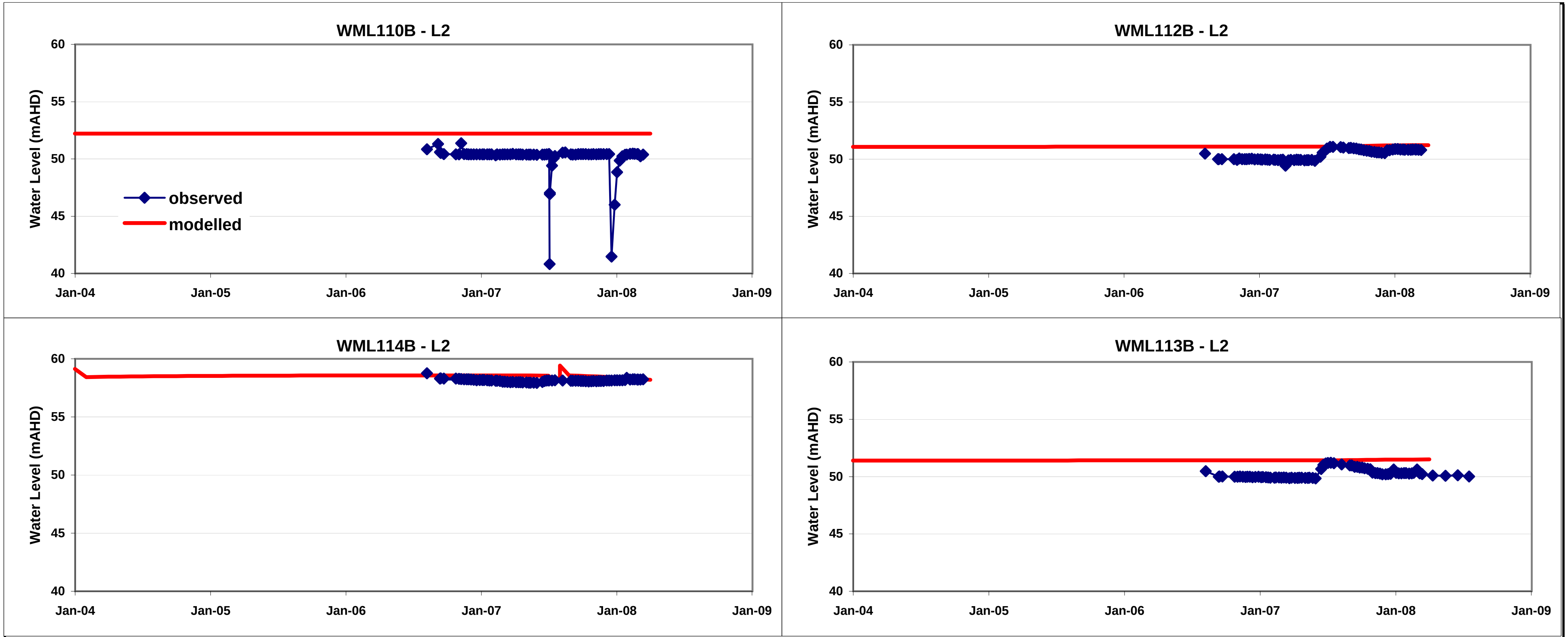
aquaterra

Layer 1 Modelled vs Observed - Glennies Creek Alluvium Water Levels

Figure 32



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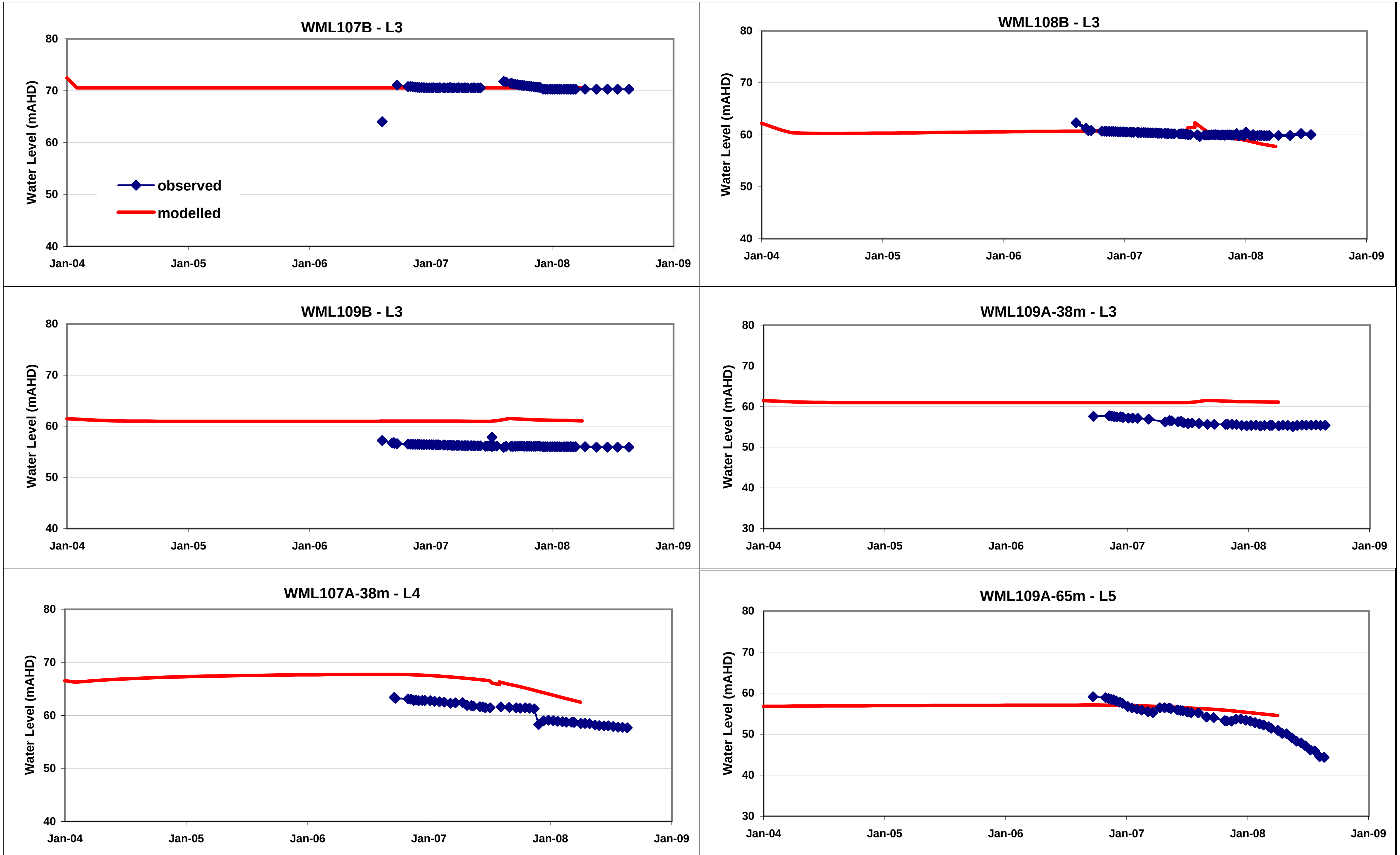
Layers 2 Modelled vs Observed - Permian Coal Measures Overburden Water Levels

Figure 33



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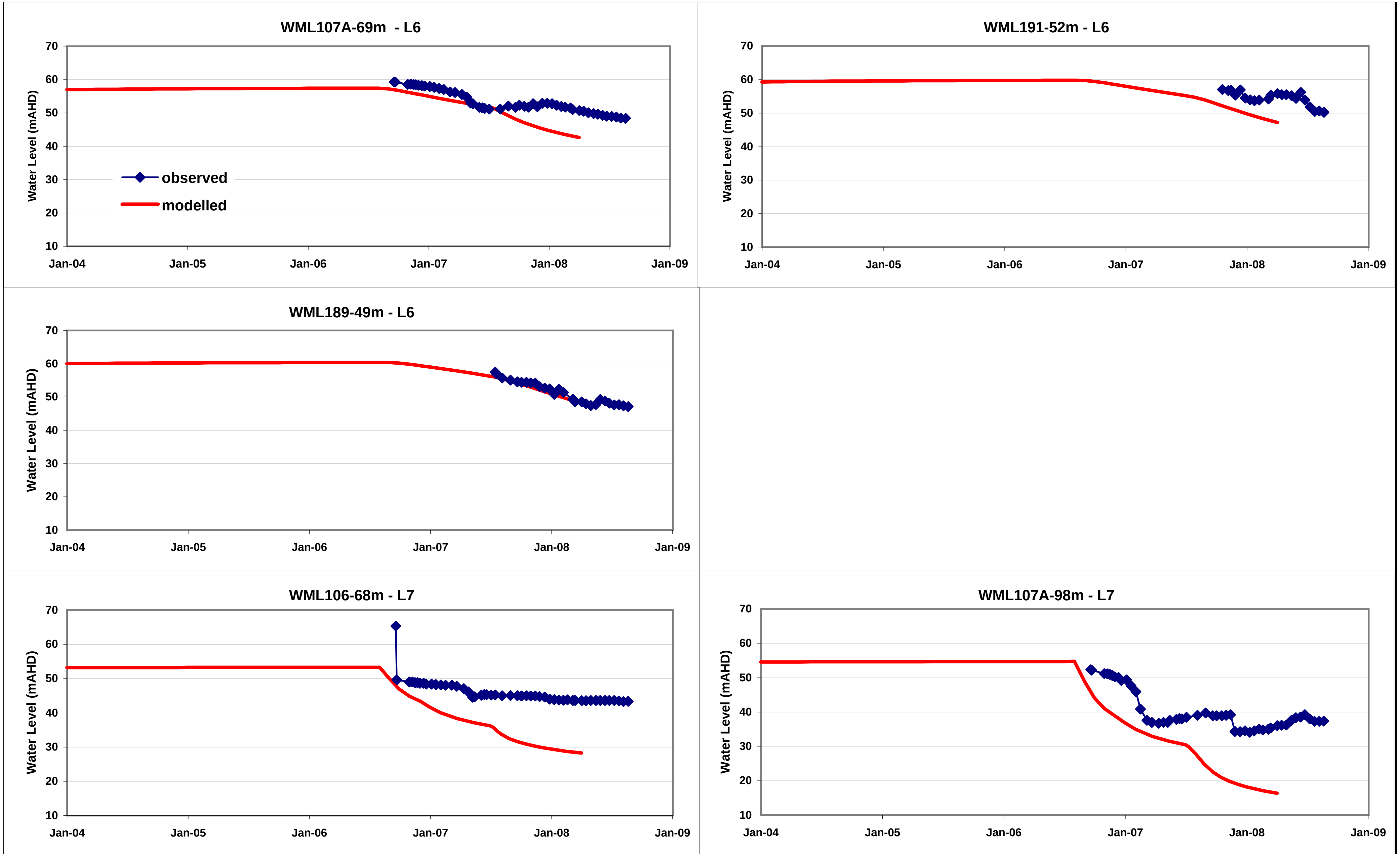
Layers 3-5 Modelled vs Observed - Lemington 7-9 Seams (L3), Lemington 11 (L4), Lemington 12 (L5) Water Levels

Figure 34



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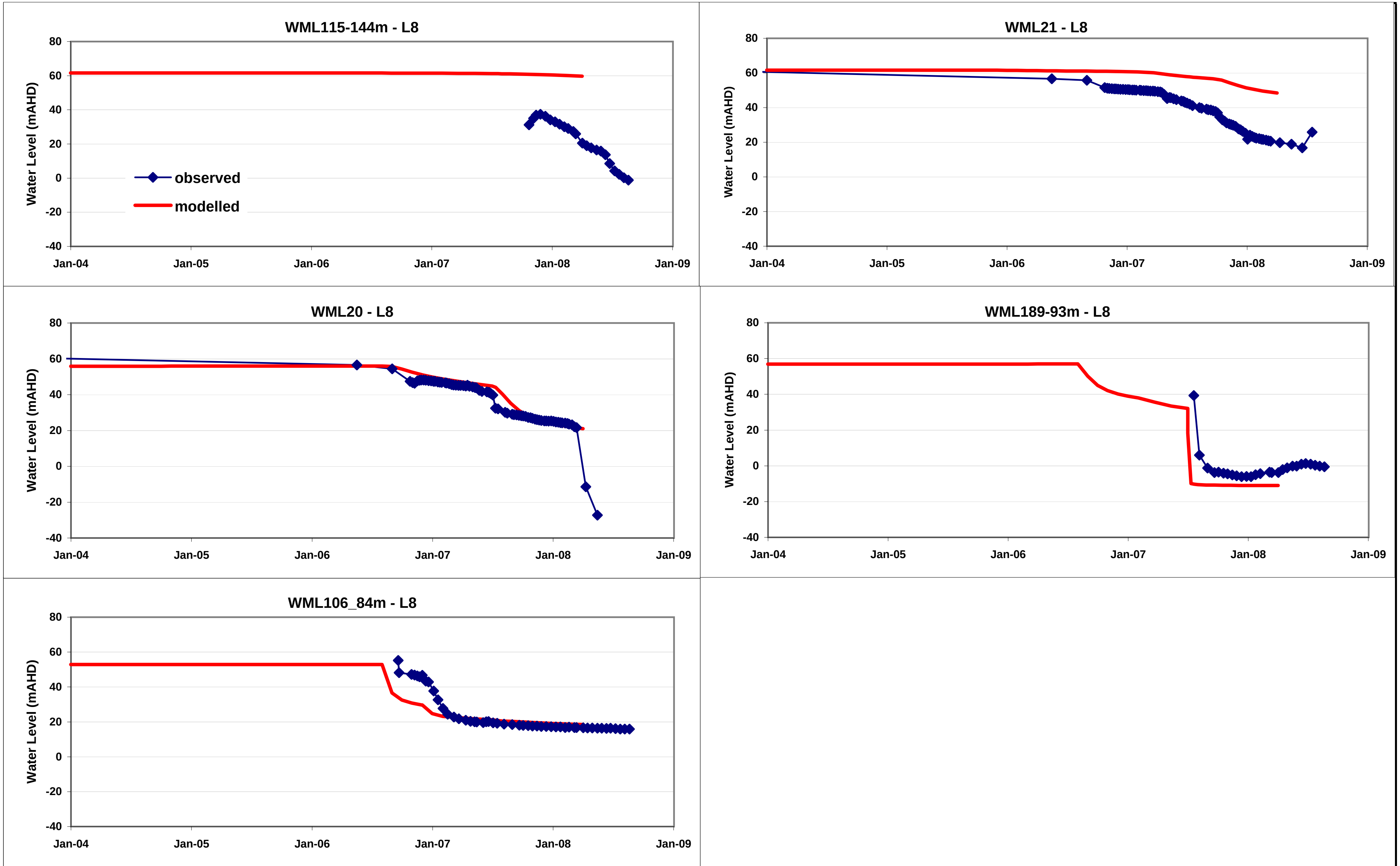
Layers 6 to 7 Modelled vs Observed - Lemington 15 (L6), Lemington 19 (L7) Water Levels

Figure 35



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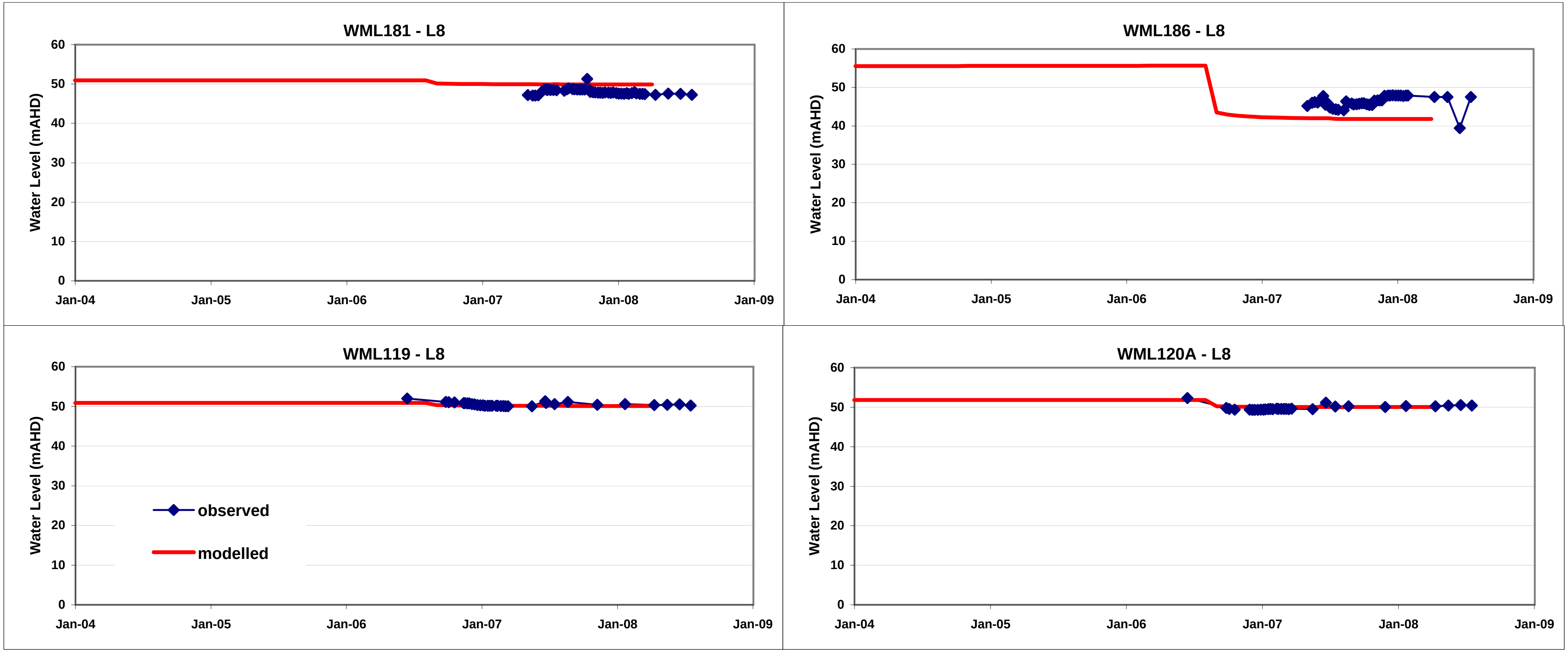
Layer 8 Modelled vs Observed - Pikes Gully Seam Water Levels

Figure 36



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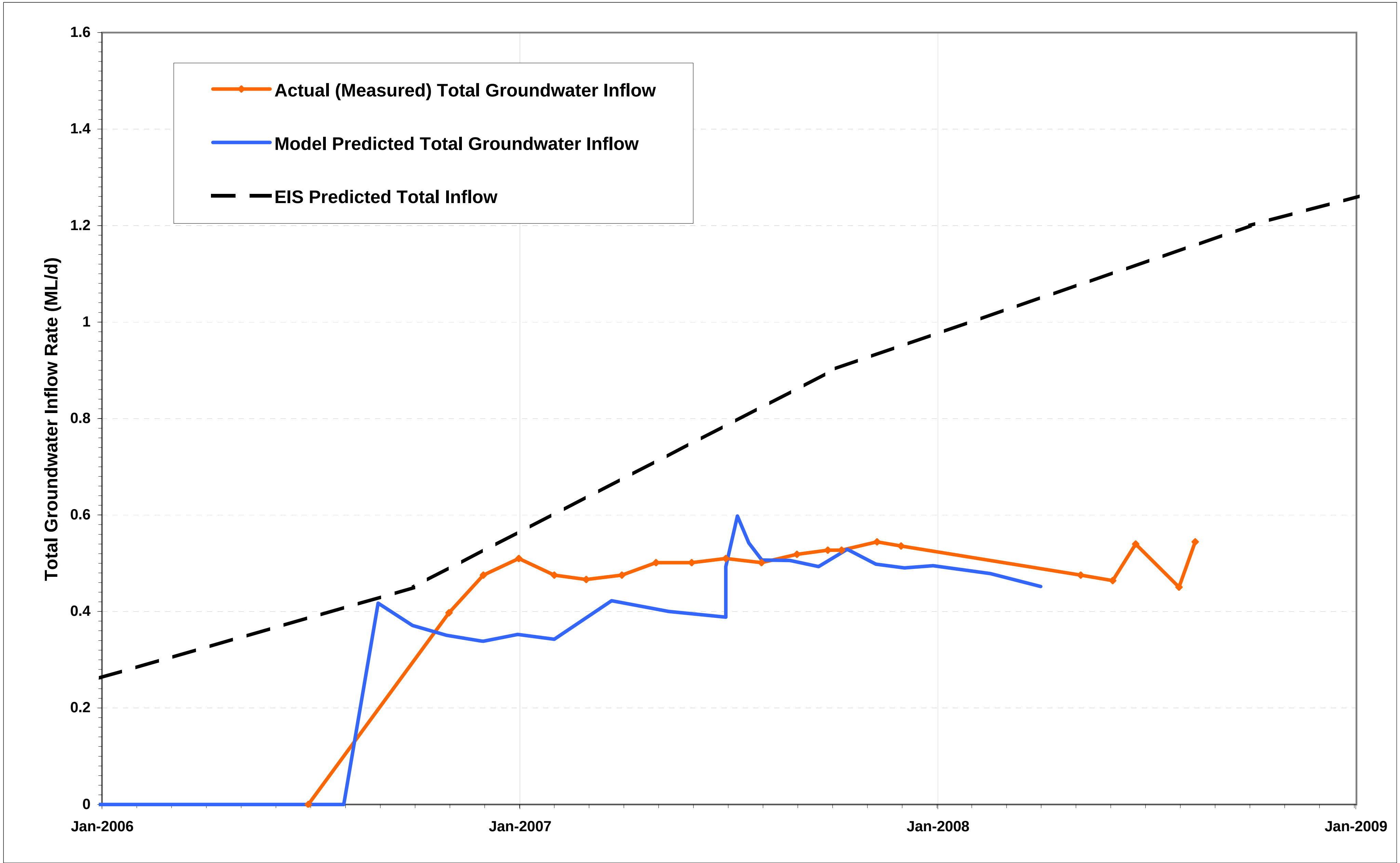
aquaterra

Layer 8 Modelled vs Observed - Pikes Gully Seam Water Levels

Figure 37



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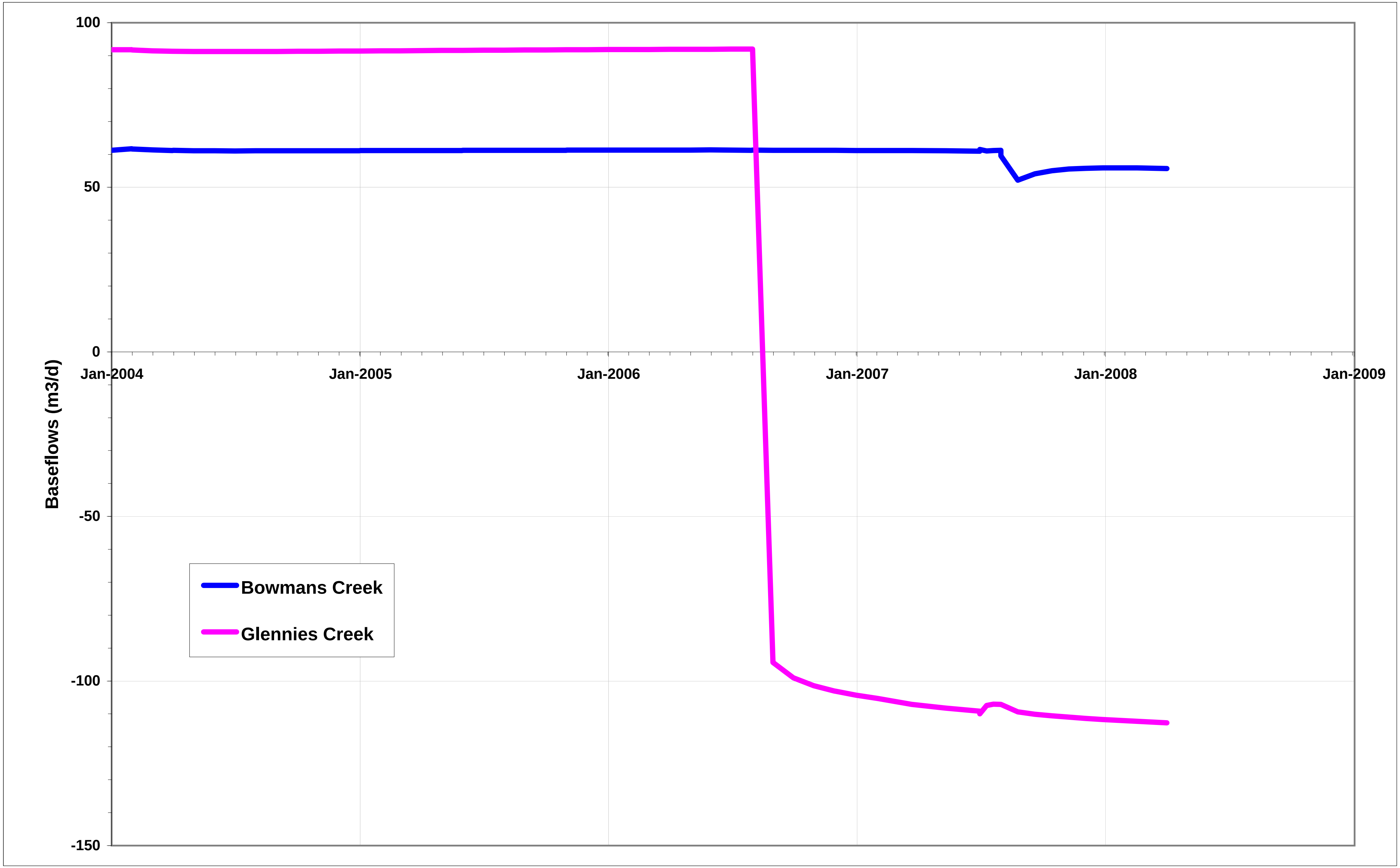
Predicted Total Groundwater Inflow Rates v Measured Inlfows and EIS Predictions
Figure 38



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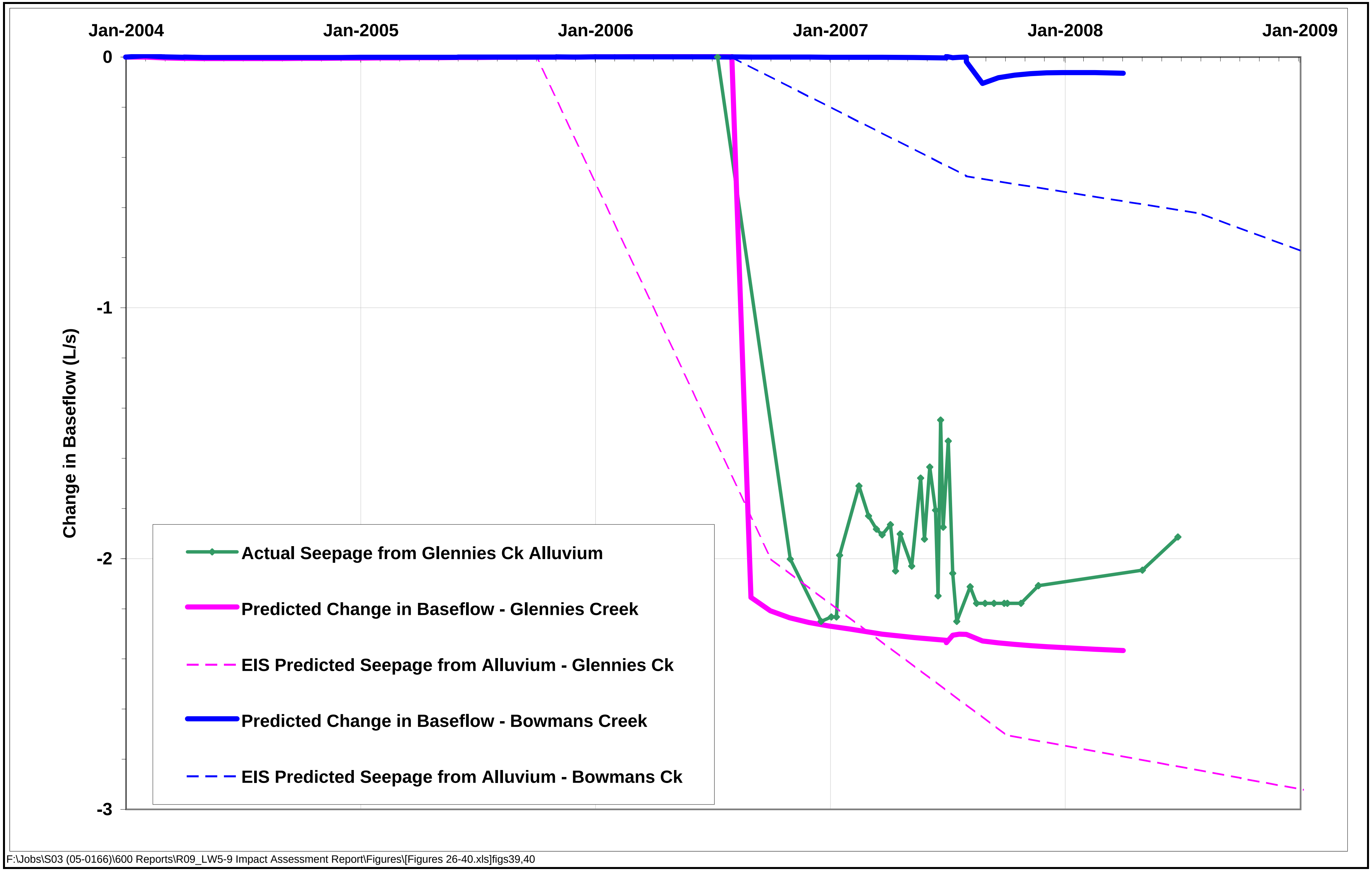
Creek Baseflows Over the Transient Calibration Period

Figure 39



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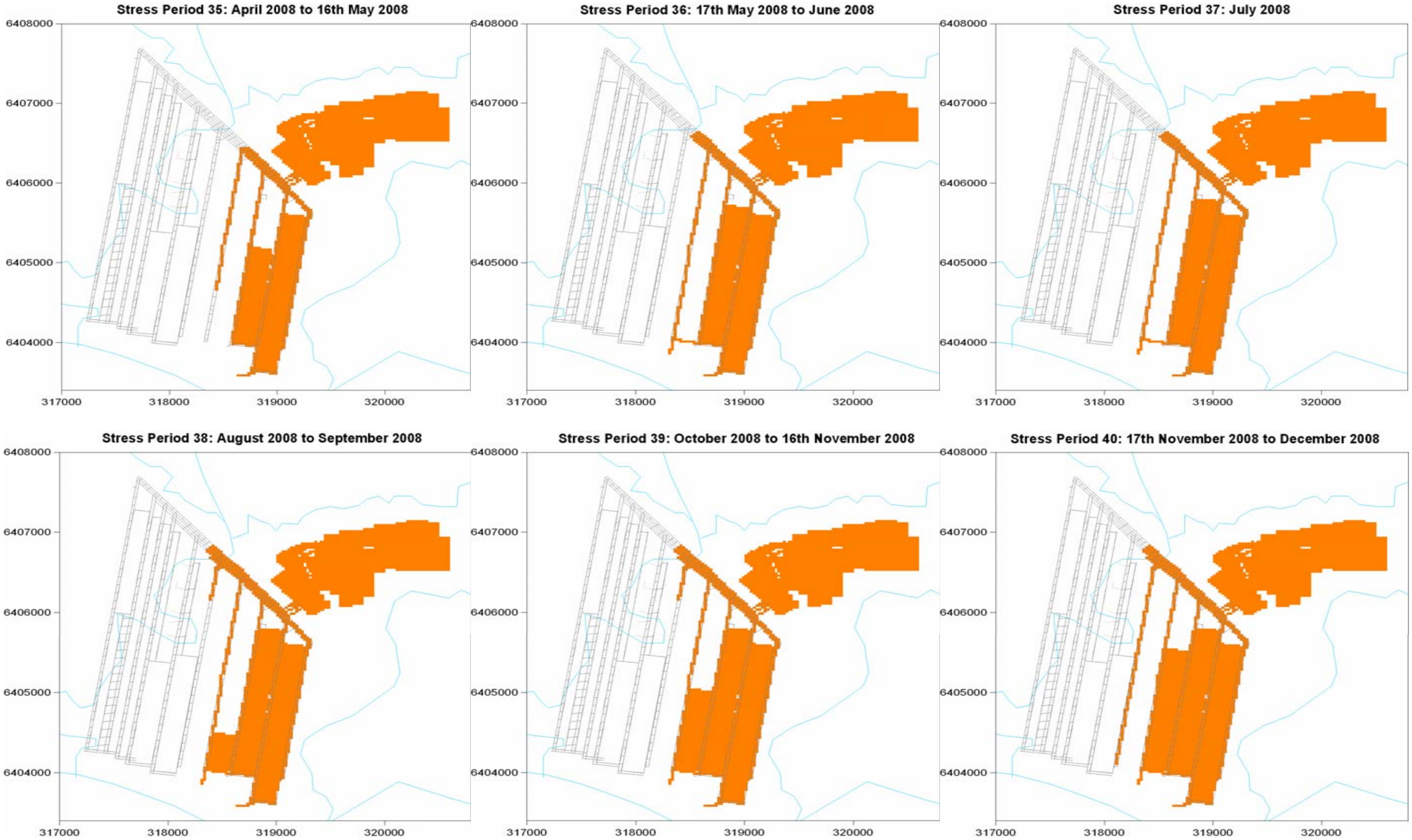
Predicted Baseflow Changes Over the Transient Calibration Period
Figure 40



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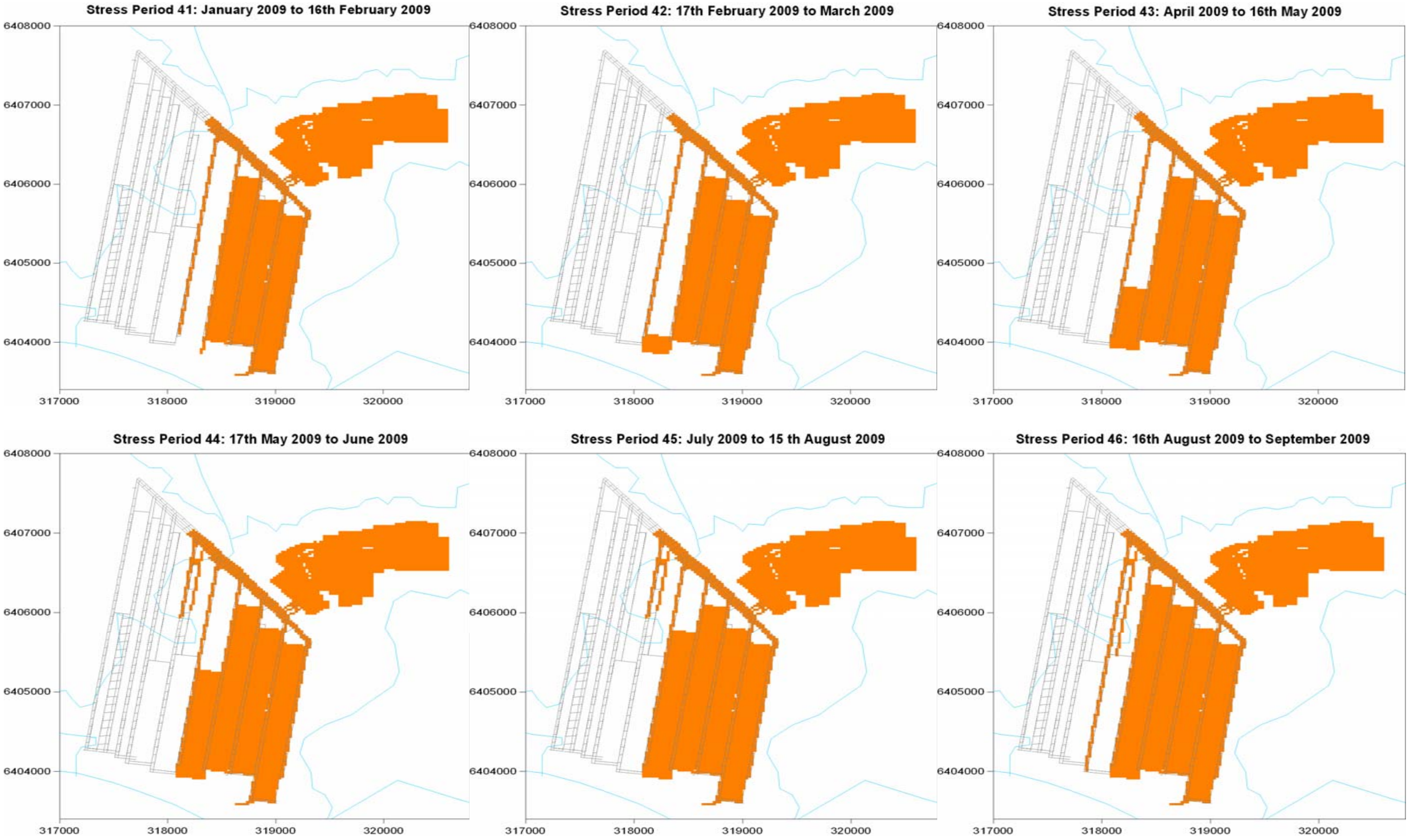
Modelled Mine Plan for LW/MW 5-9 - Stress Periods 35 to 40

Figure 41



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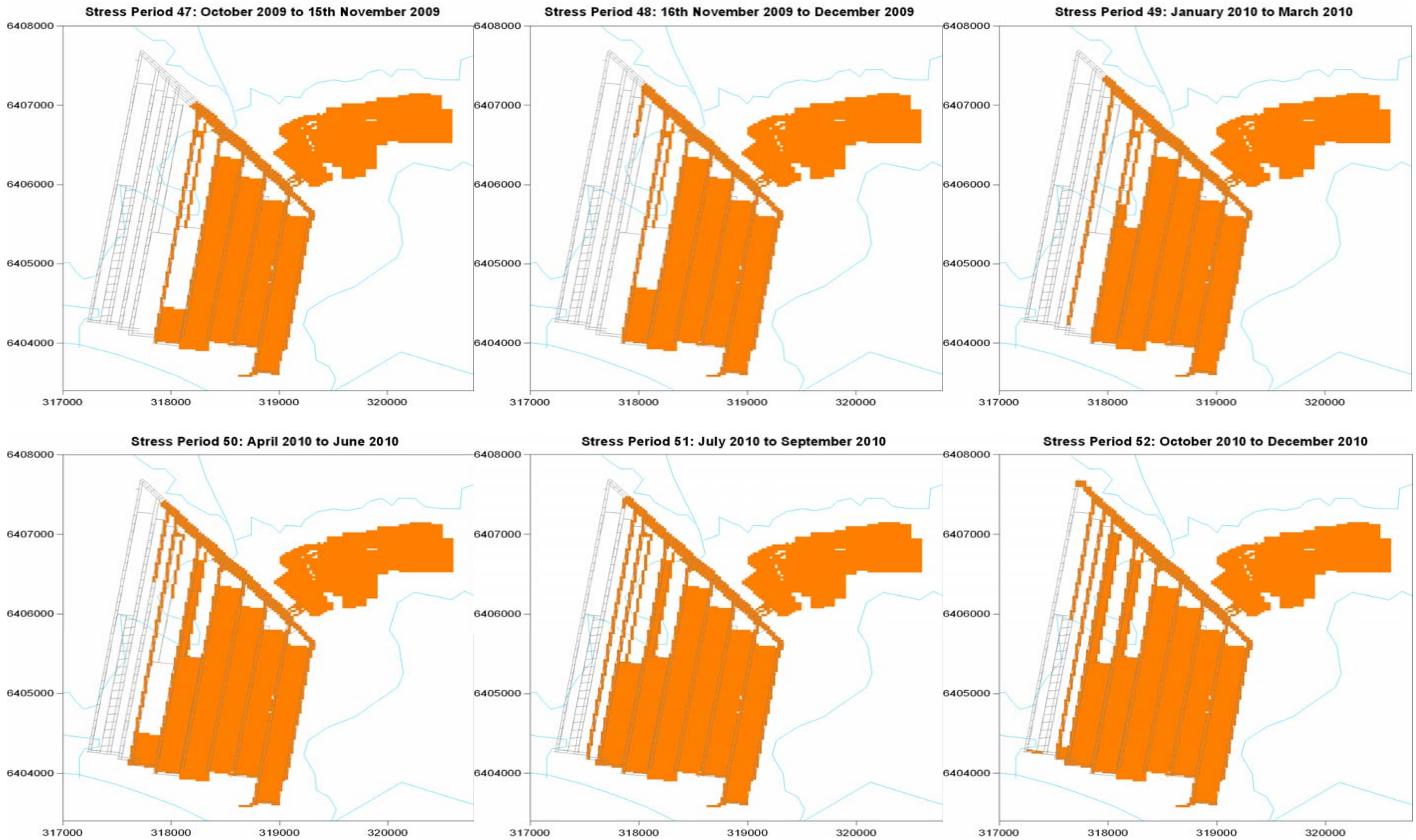
Modelled Mine Plan for LW/MW 5-9 - Stress Periods 41 to 46

Figure 42



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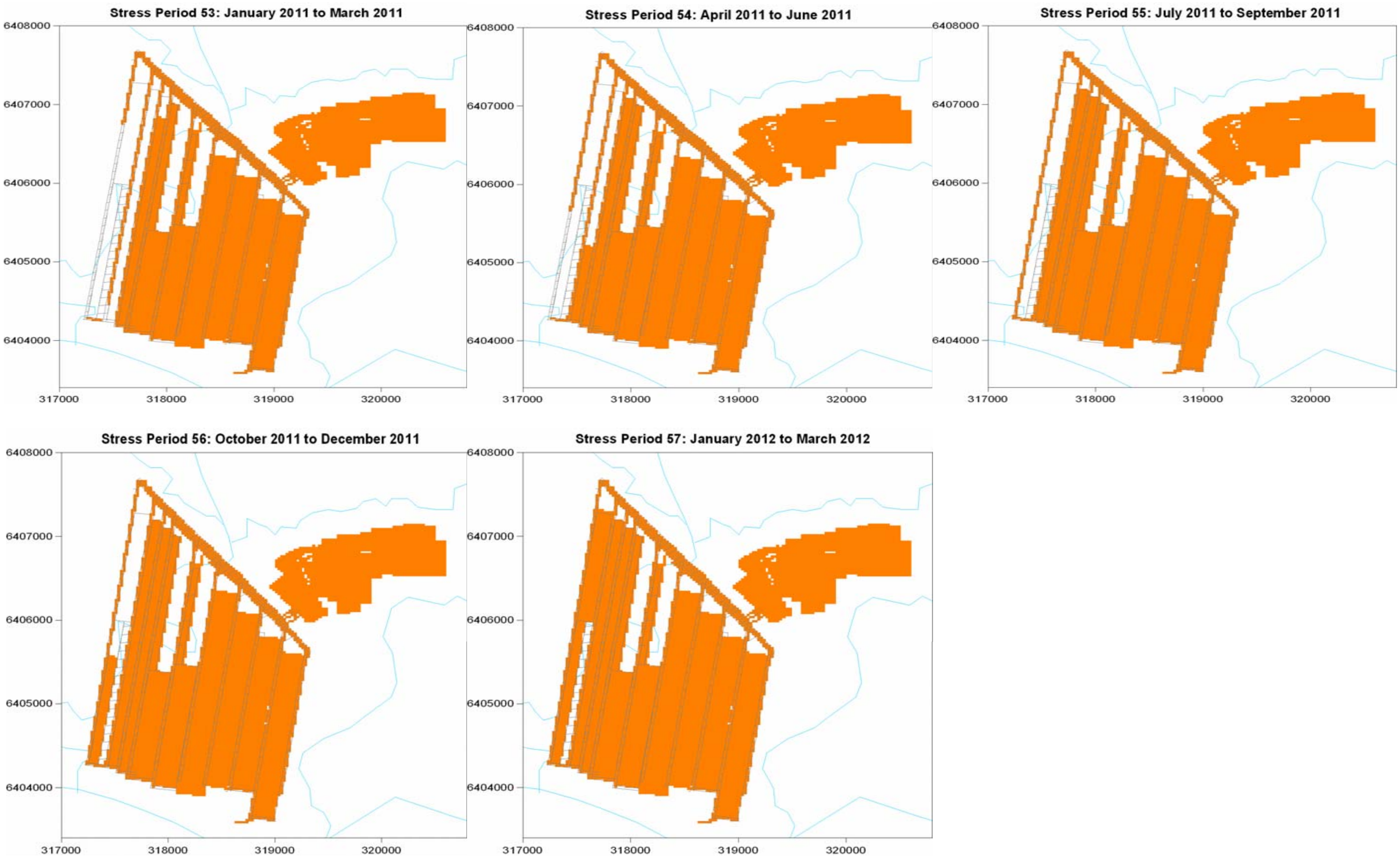
Modelled Mine Plan for LW/MW 5-9 - Stress Periods 47 to 52

Figure 43



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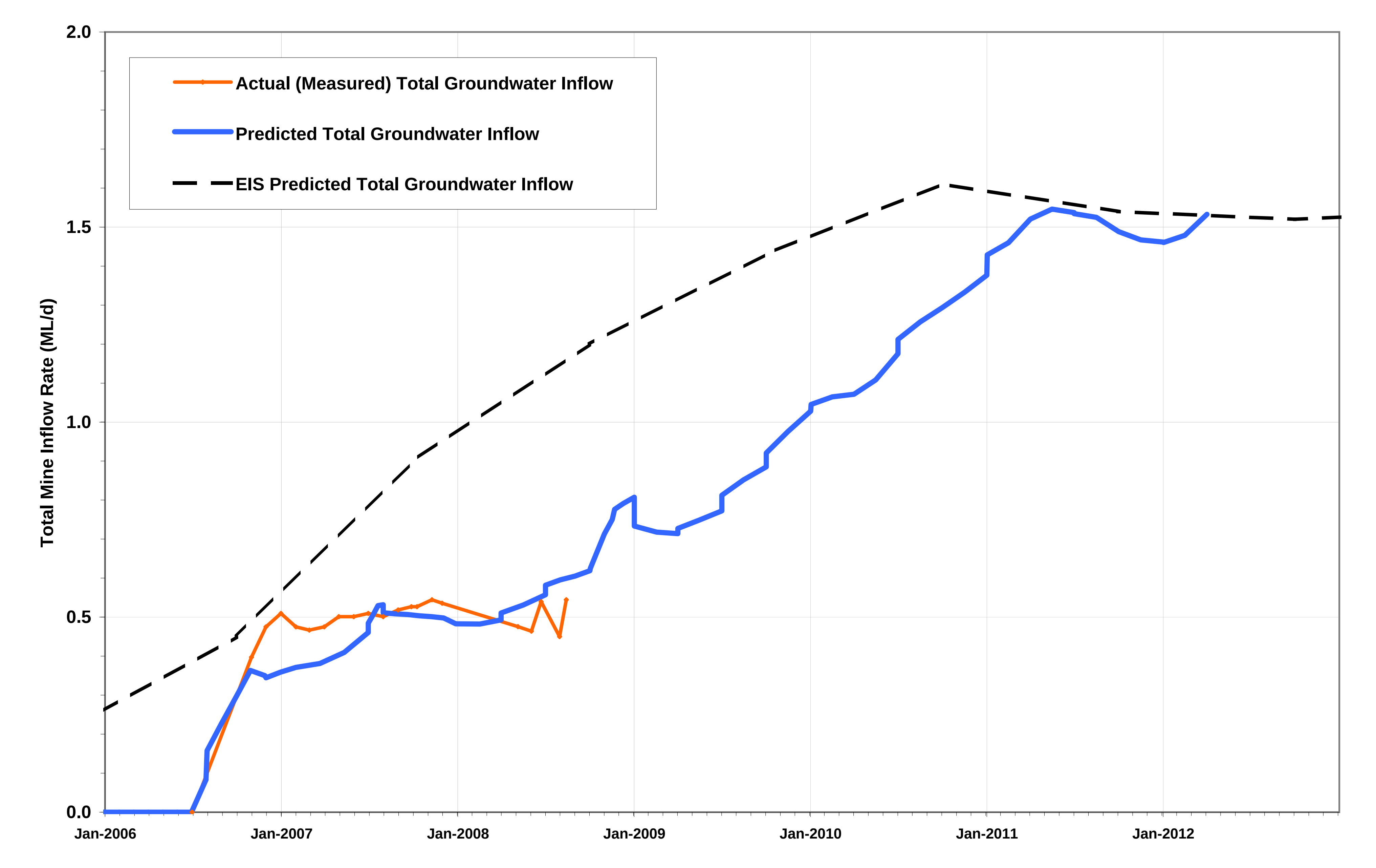
Modelled Mine Plan for LW/MW 5-9 - Stress Periods 53 to 57

Figure 44



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Predicted Total Groundwater Inflow Rates

Figure 45

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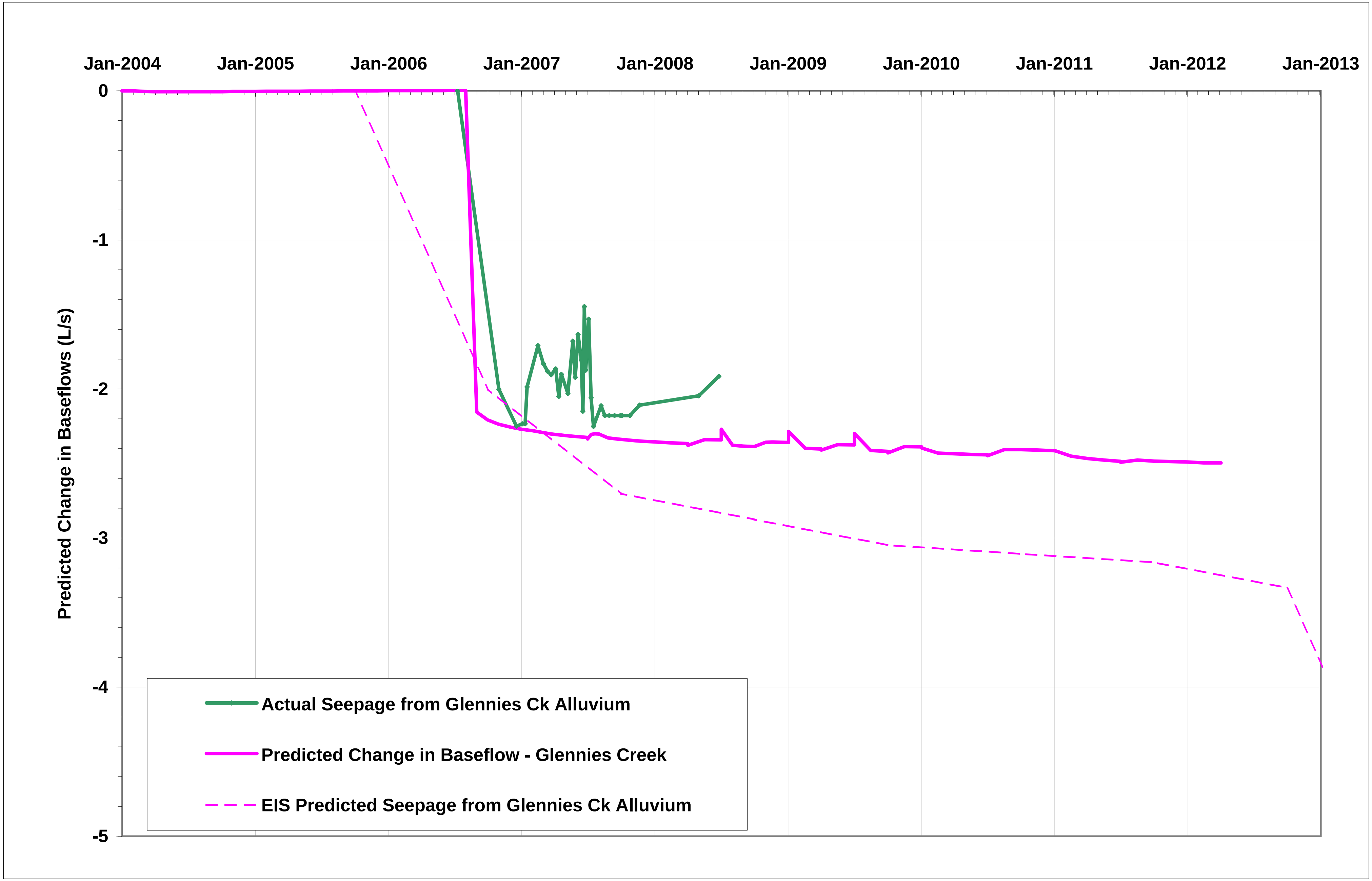
Predicted Creek Baseflows for LW/MW 5-9 Mine Plan

Figure 46



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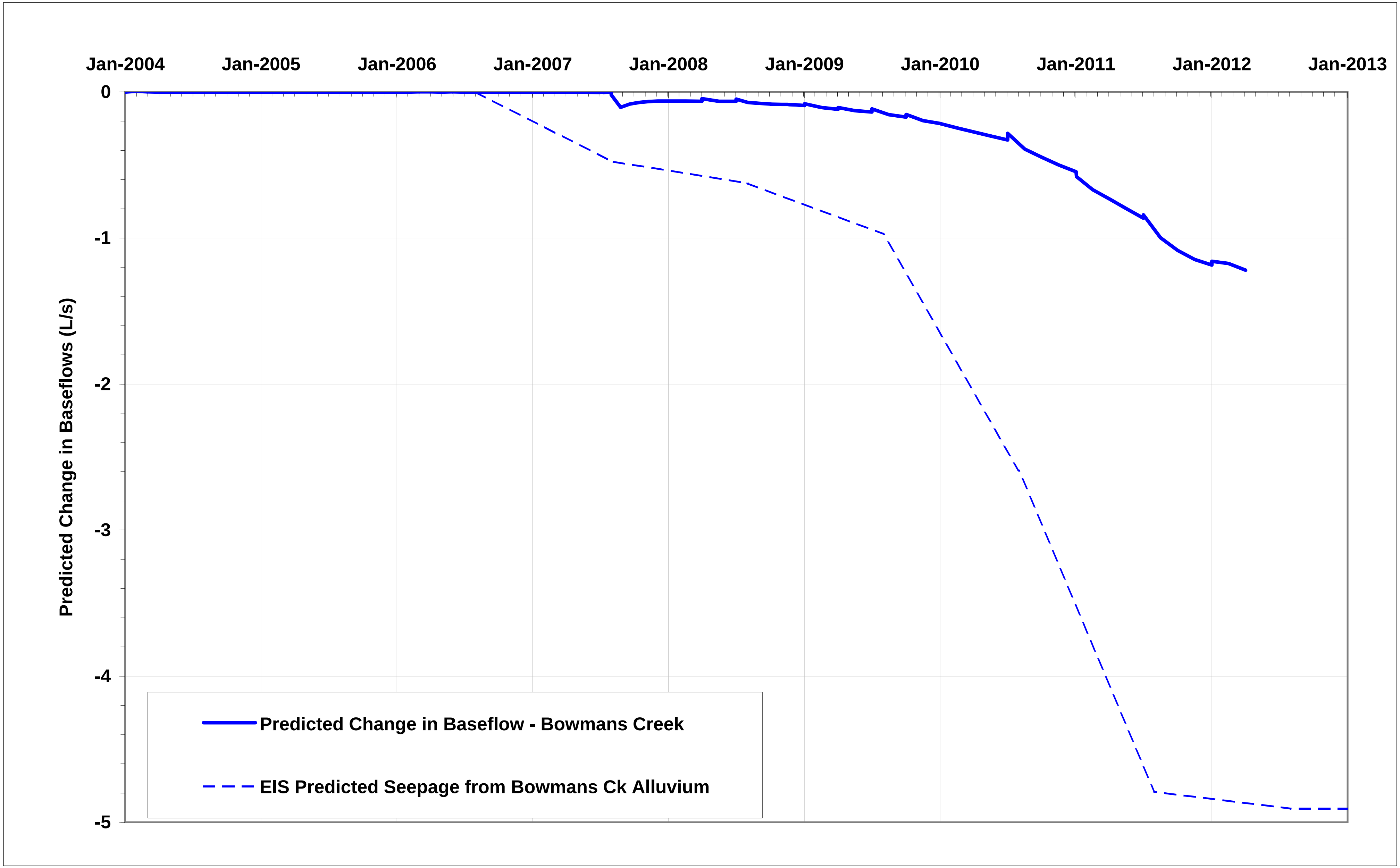
Predicted Baseflow Impacts on Glennies Creek for Option LW/MW 5-9

Figure 47a



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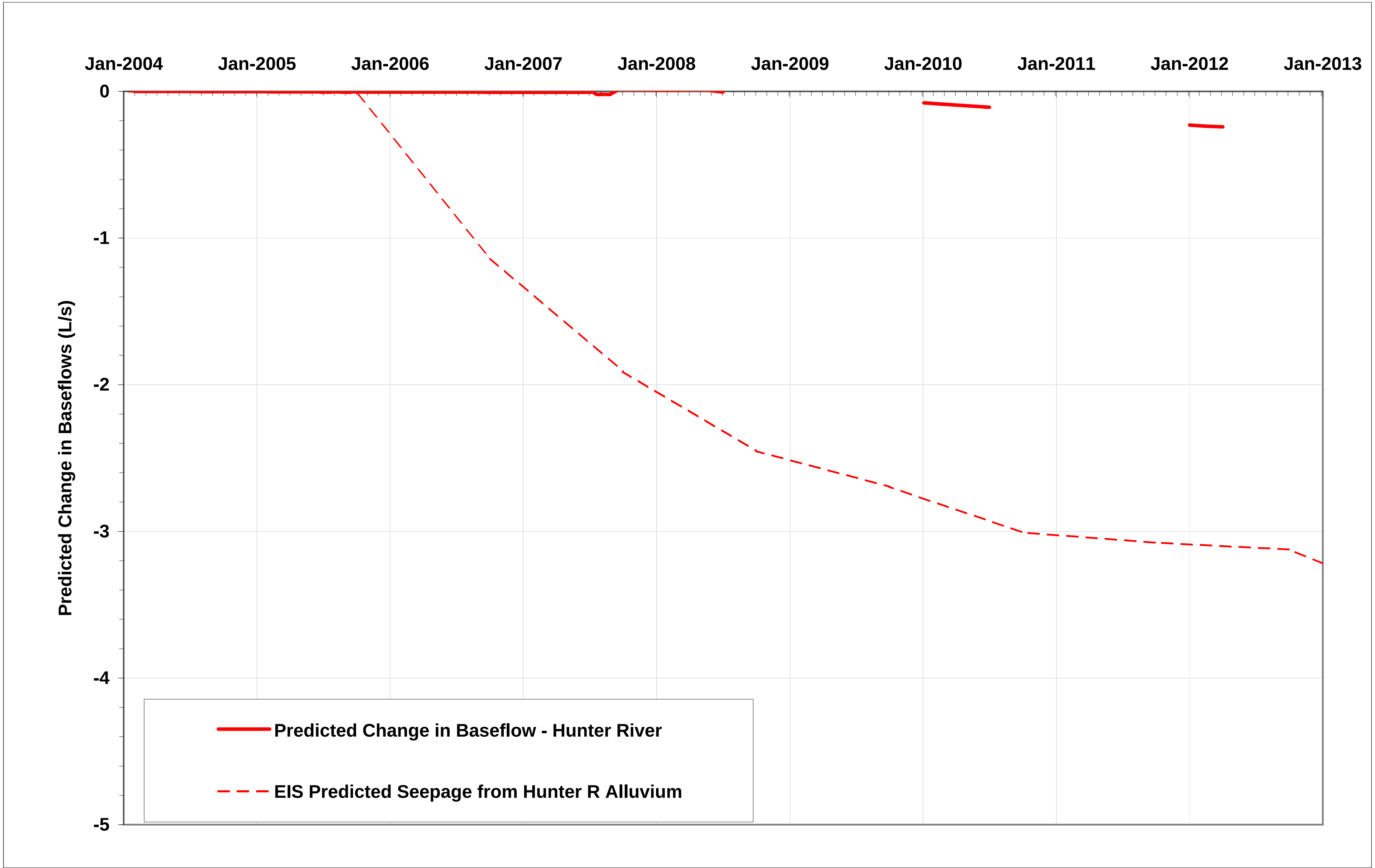
aquaterra

Predicted Baseflow Impacts on Bowmans Creek for Option LW/MW 5-9

Figure 47b



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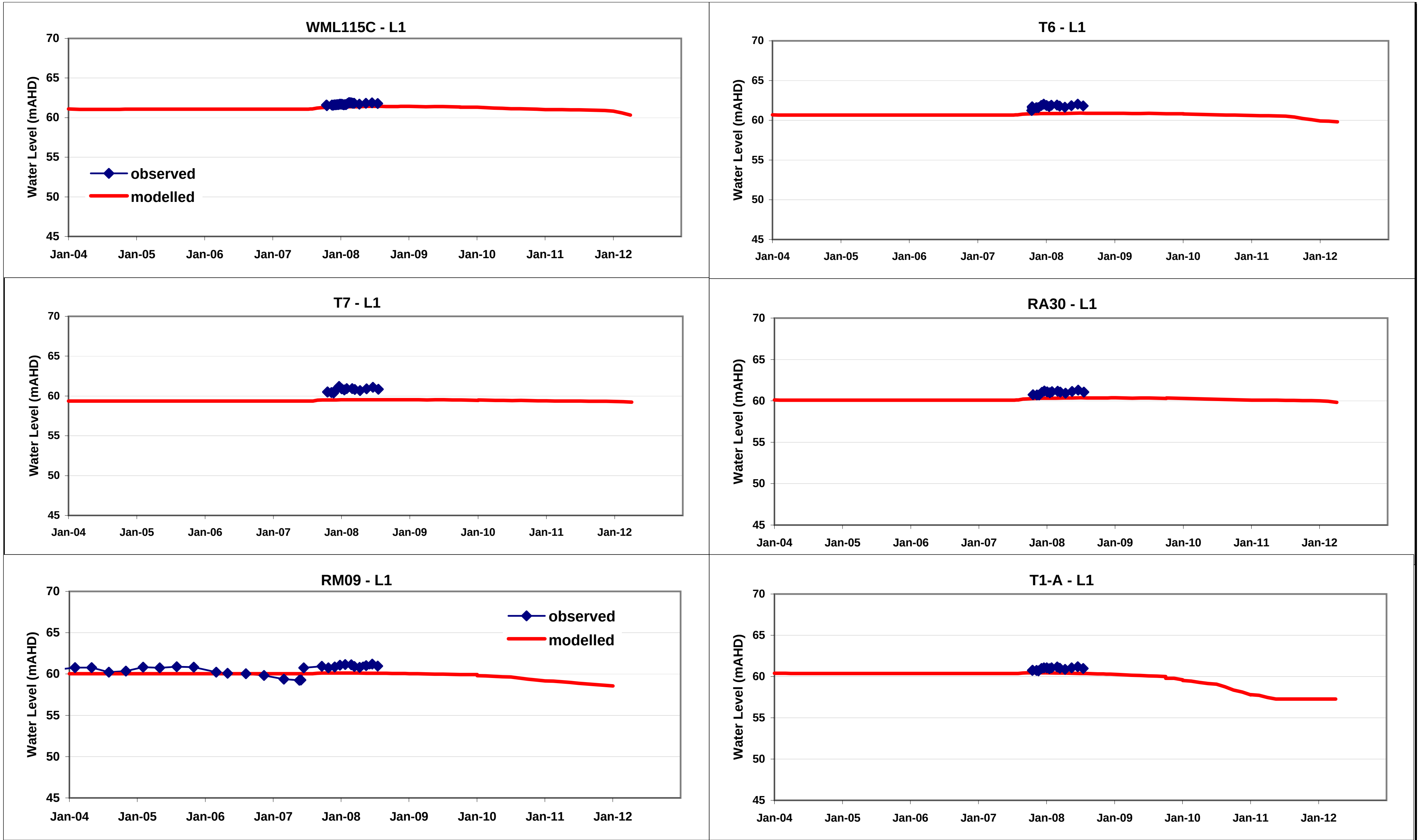
aquaterra

Predicted Baseflow Impacts on Hunter River for Option LW/MW 5-9
Figure 47c



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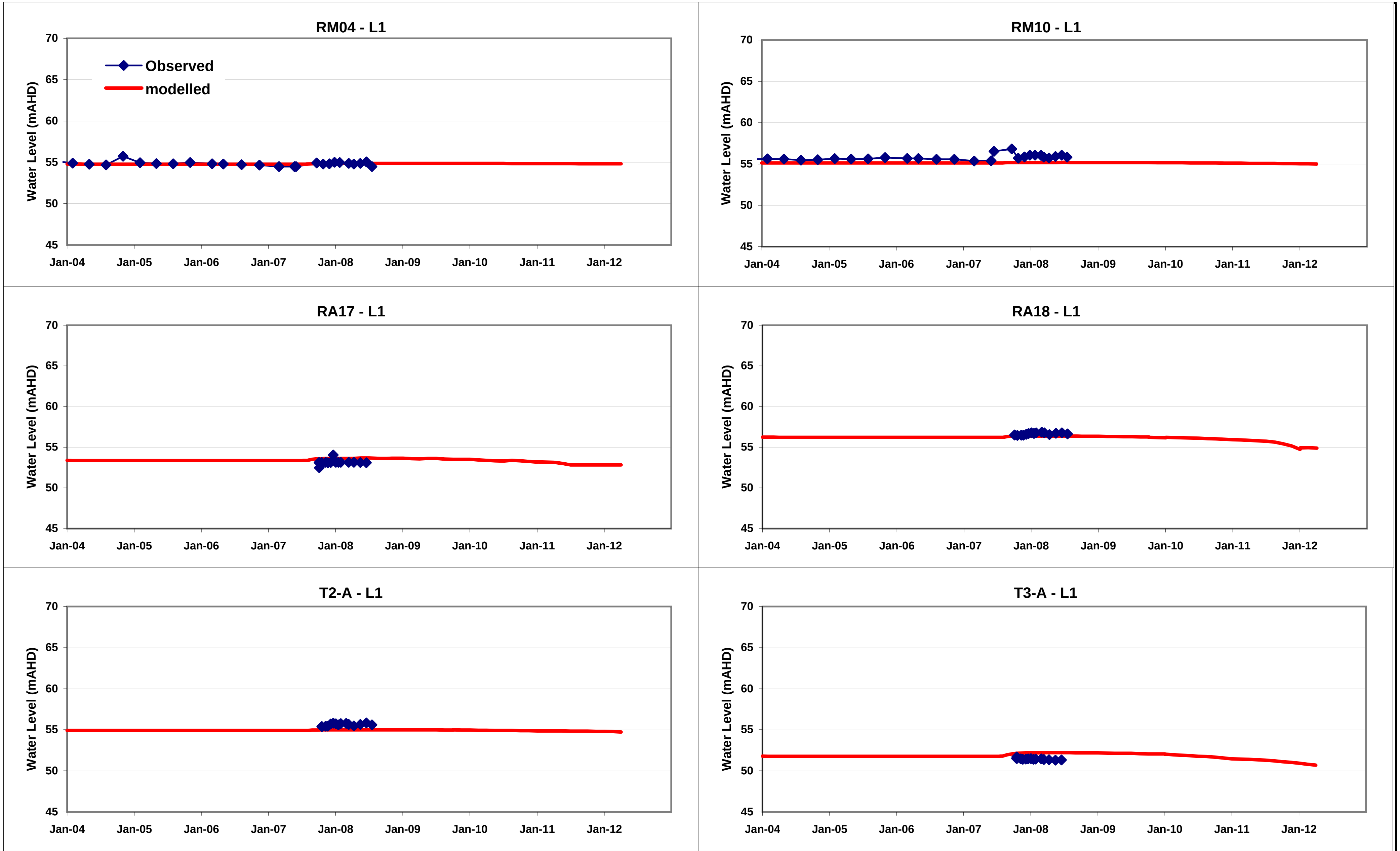
Layer 1 Modelled vs Observed - Bowmans Creek Alluvium Water Levels

Figure 48



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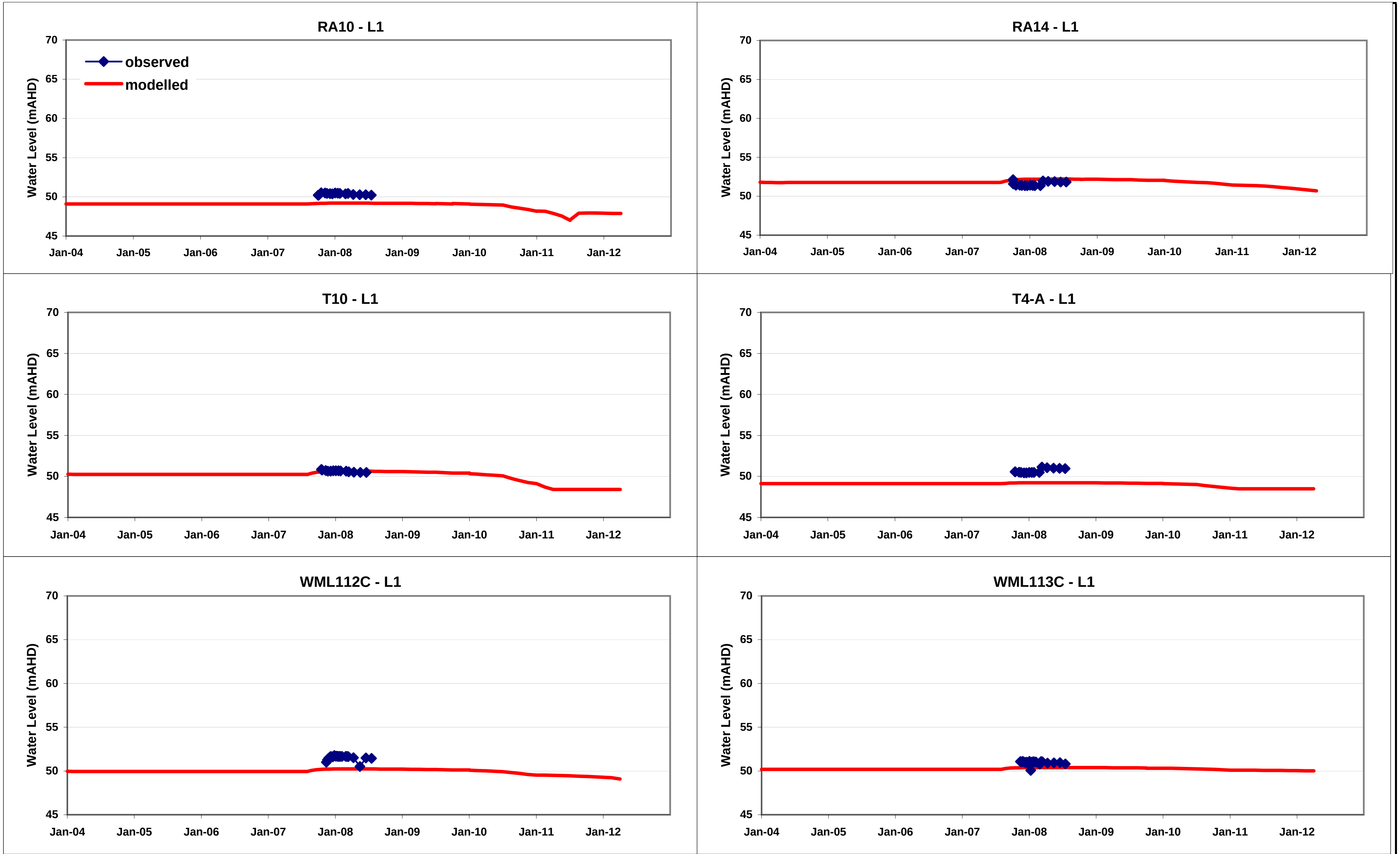
aquaterra

Layer 1 Modelled vs Observed - Bowmans Creek Alluvium Water Levels

Figure 49



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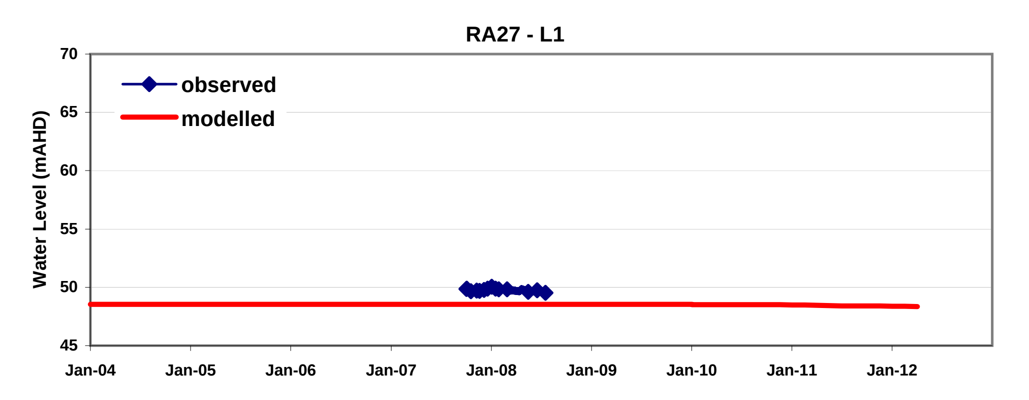
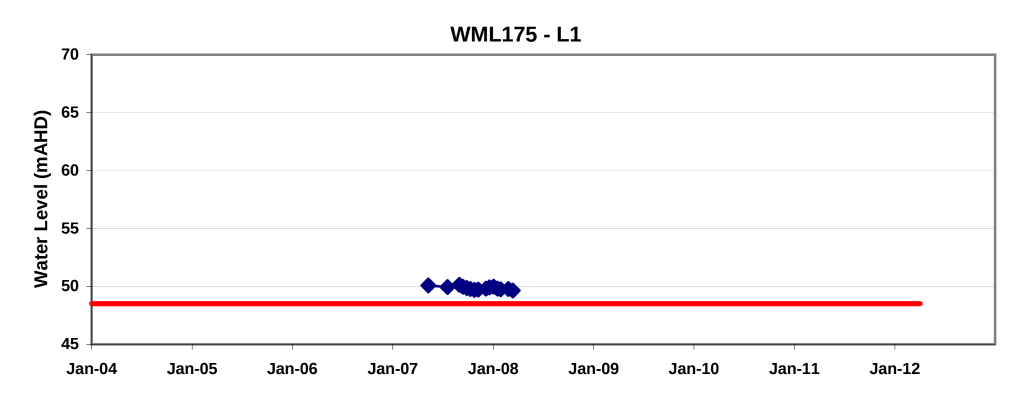
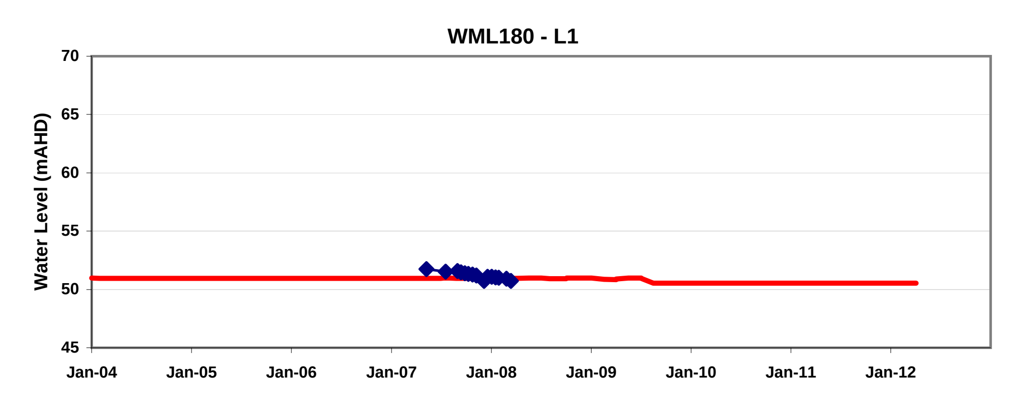
aquaterra

Layer 1 Modelled vs Observed - Bowmans Creek Alluvium Water Levels

Figure 50







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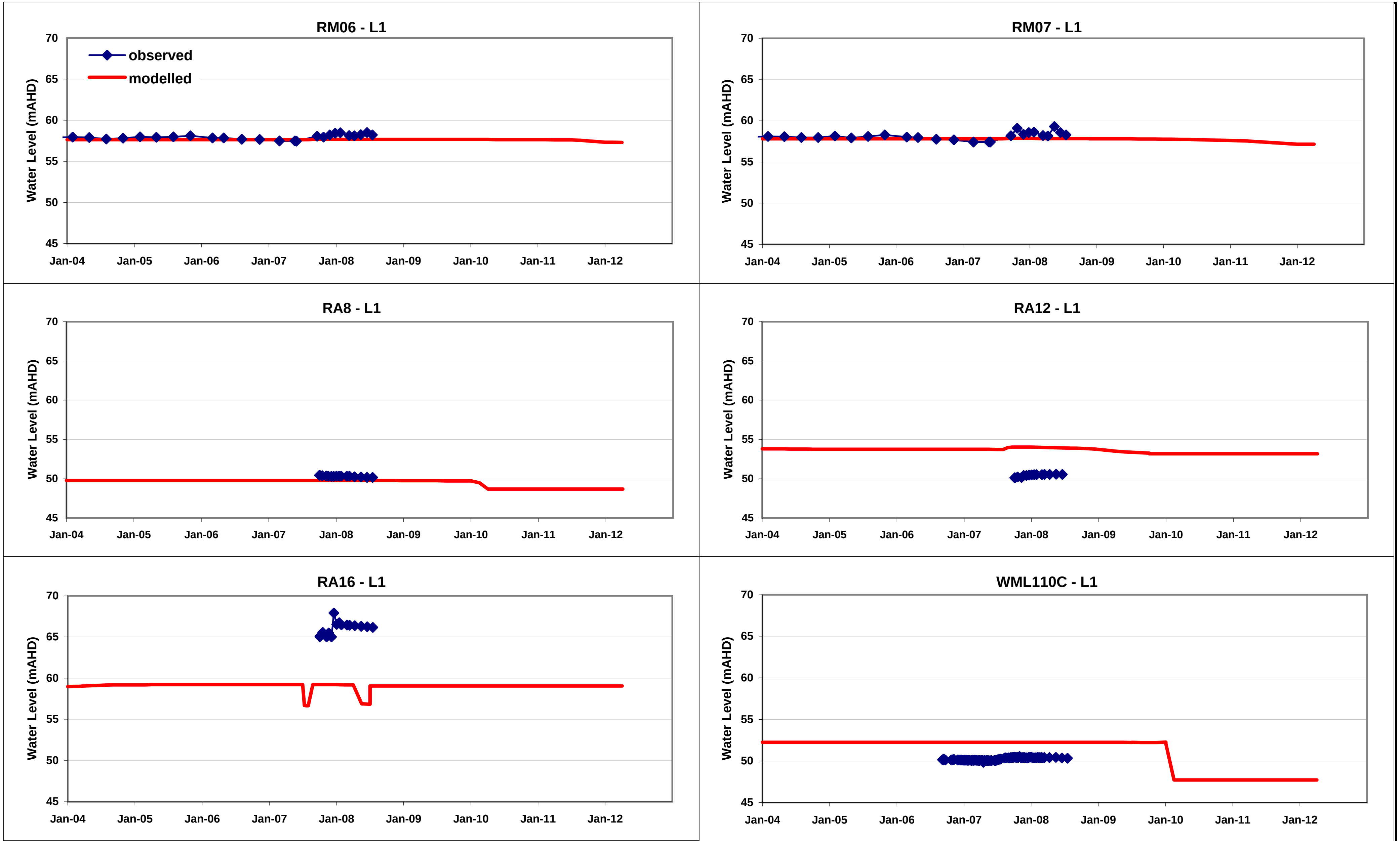
aquaterra

Layer 1 Modelled vs Observed - Hunter River Alluvium Water Levels

Figure 51



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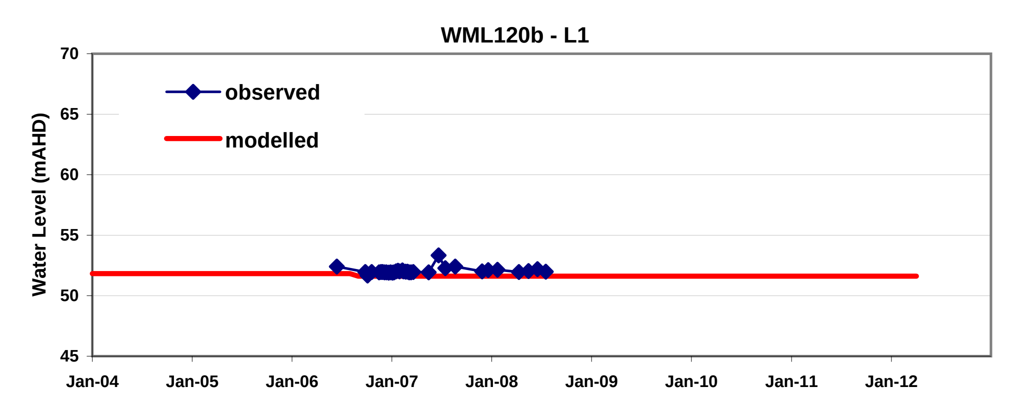
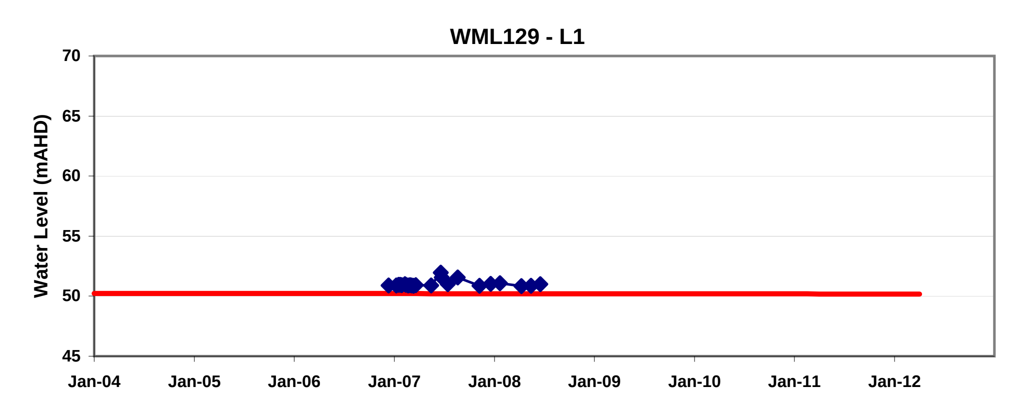
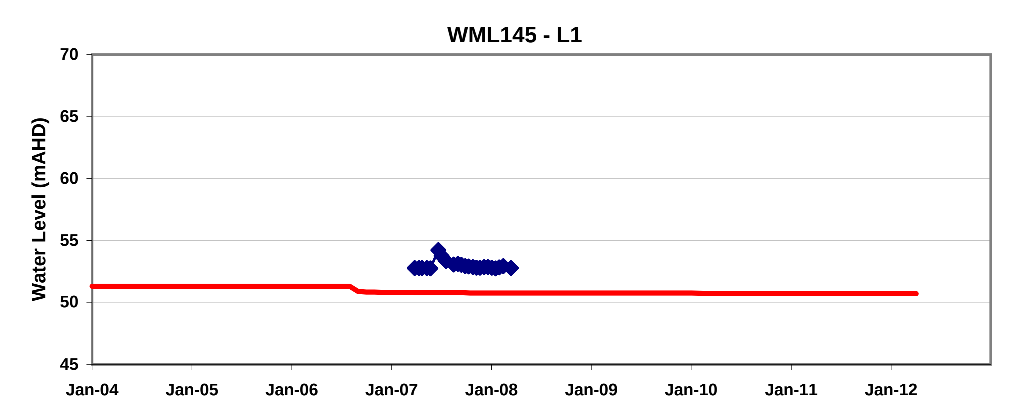
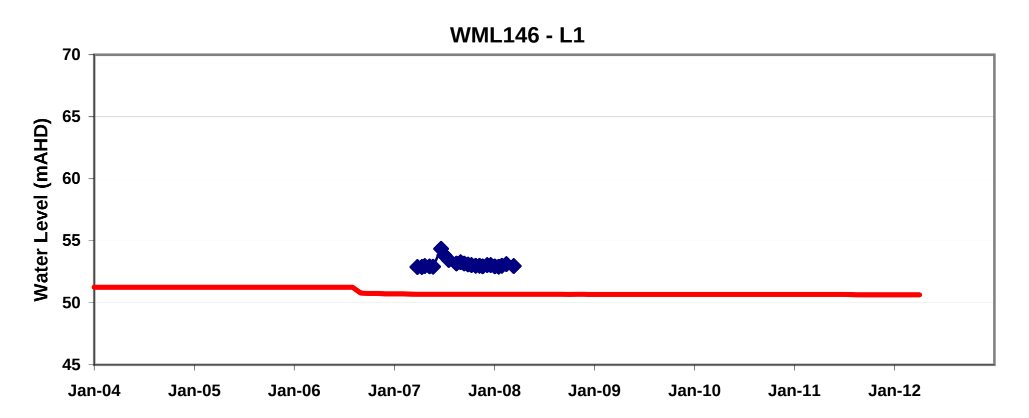
Layer 1 Modelled vs Observed - Colluvium/Weathered Permian Water Levels

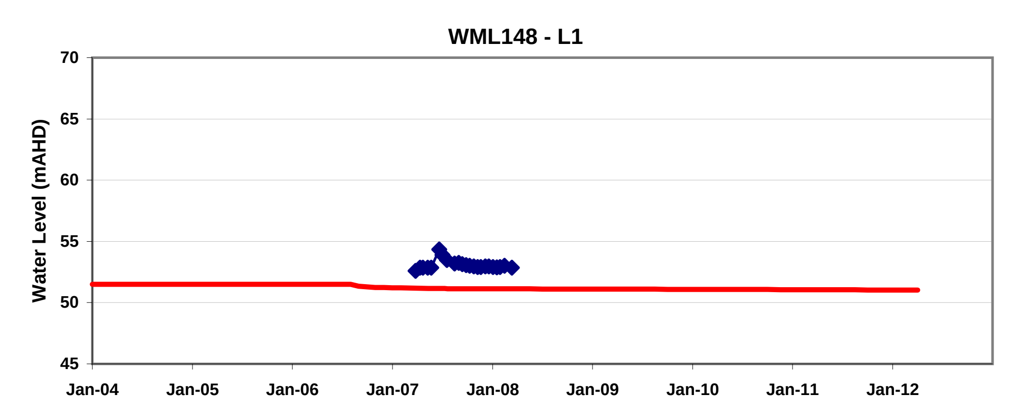
Figure 52











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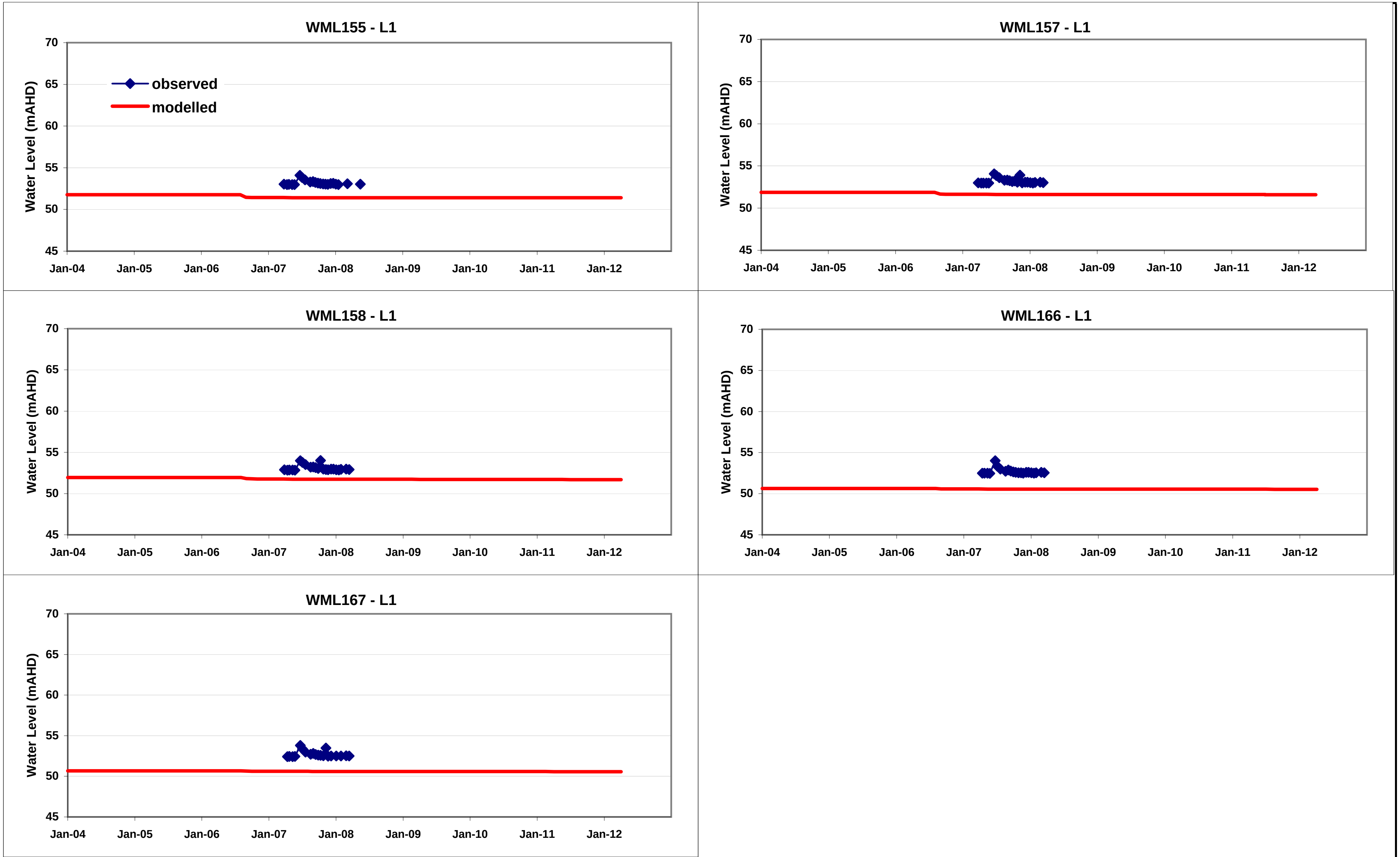
Layer 1 Modelled vs Observed - Glennies Creek Alluvium Water Levels

Figure 53



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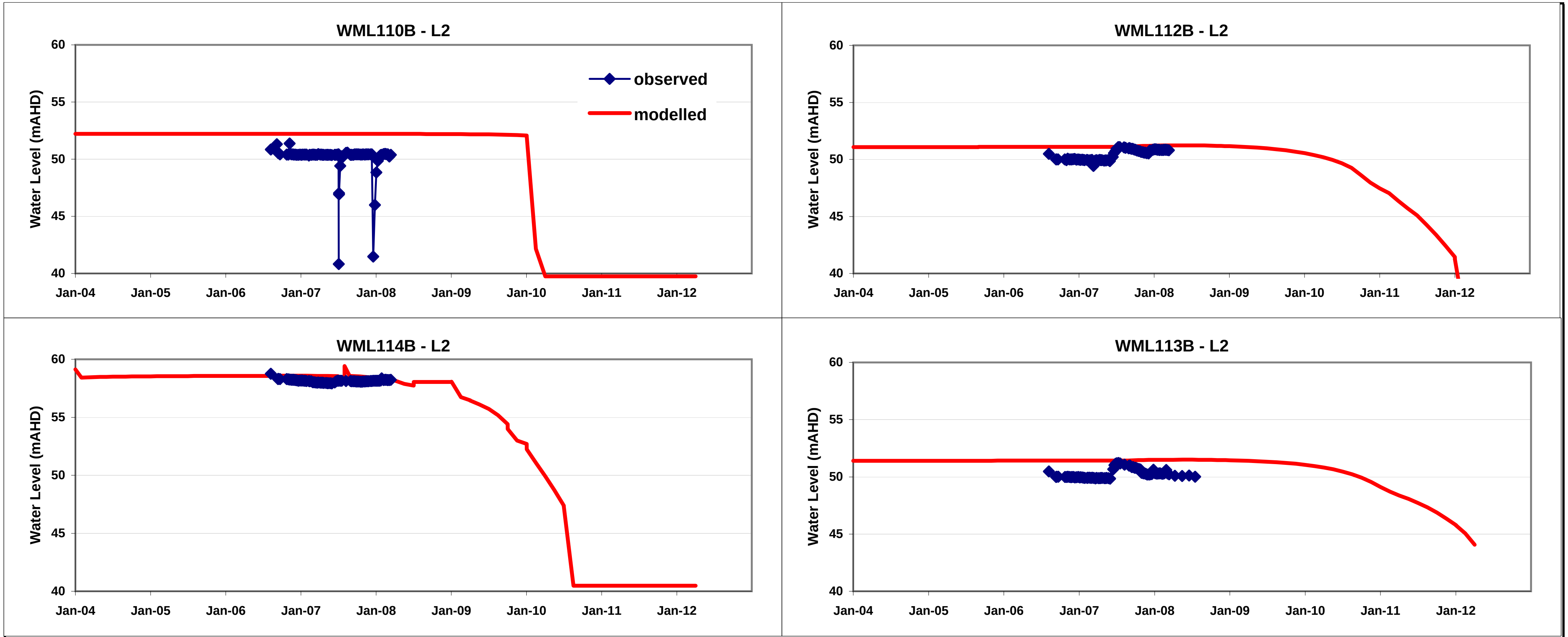
Layer 1 Modelled vs Observed - Glennies Creek Alluvium Water Levels

Figure 54



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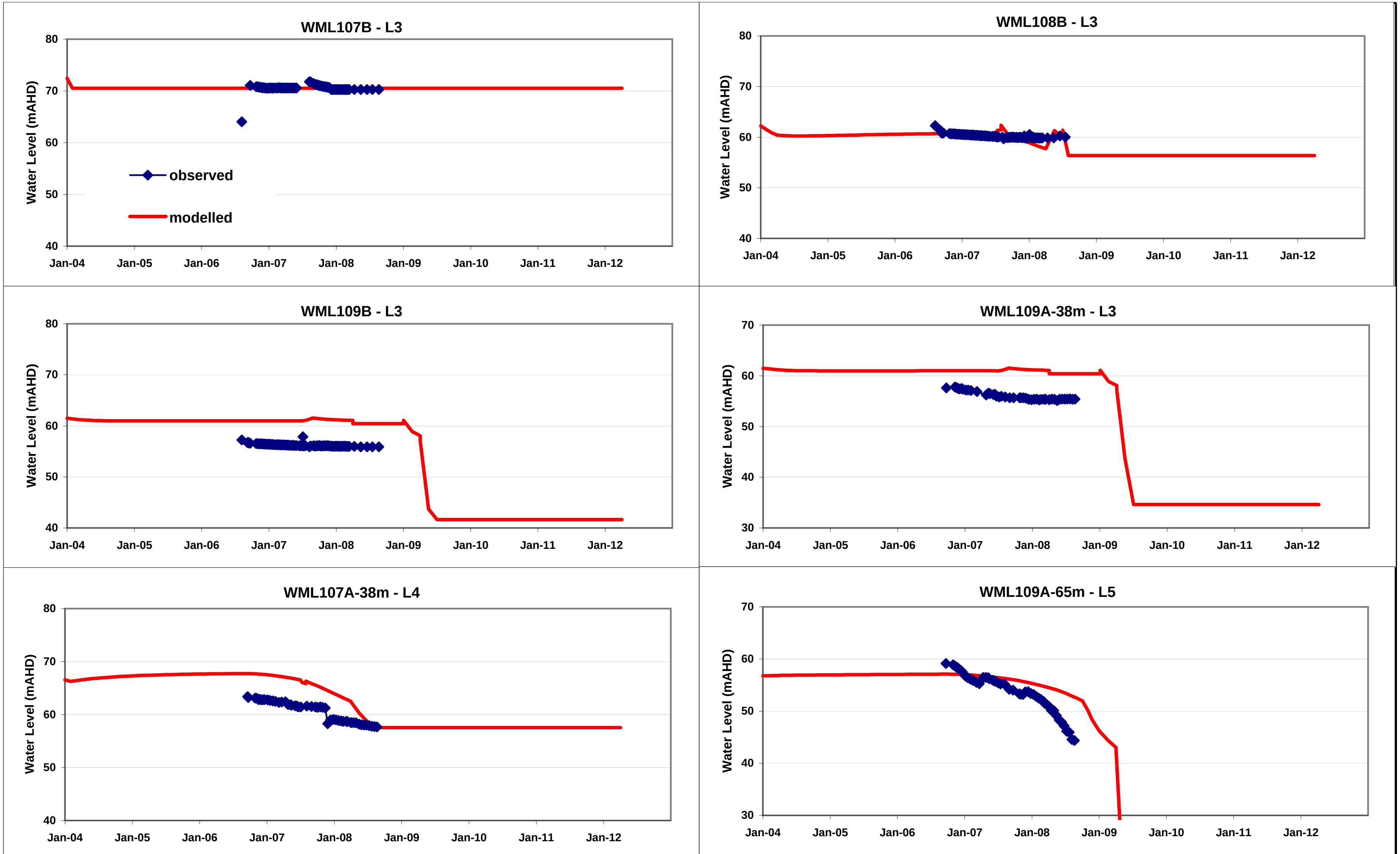
Layers 2 Modelled vs Observed - Permian Coal Measures Overburden Water Levels

Figure 55



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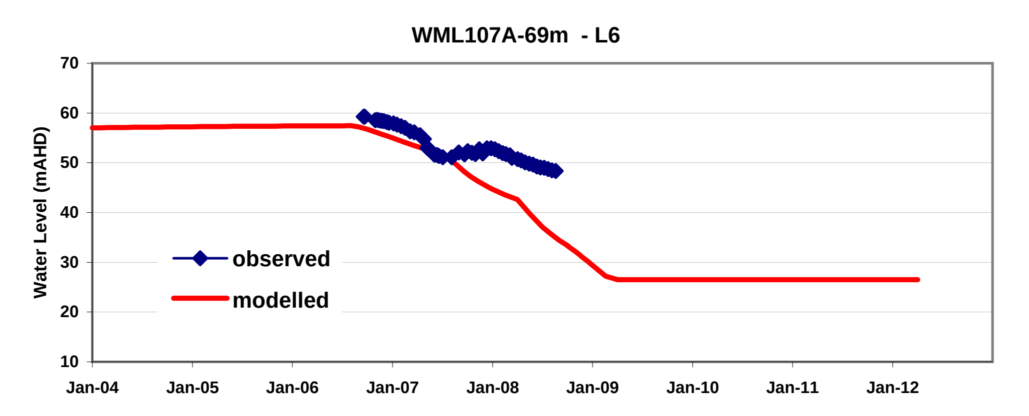
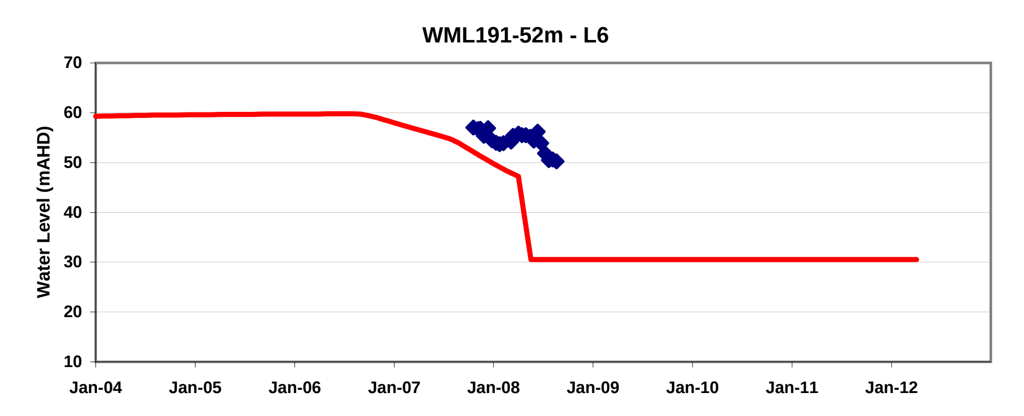
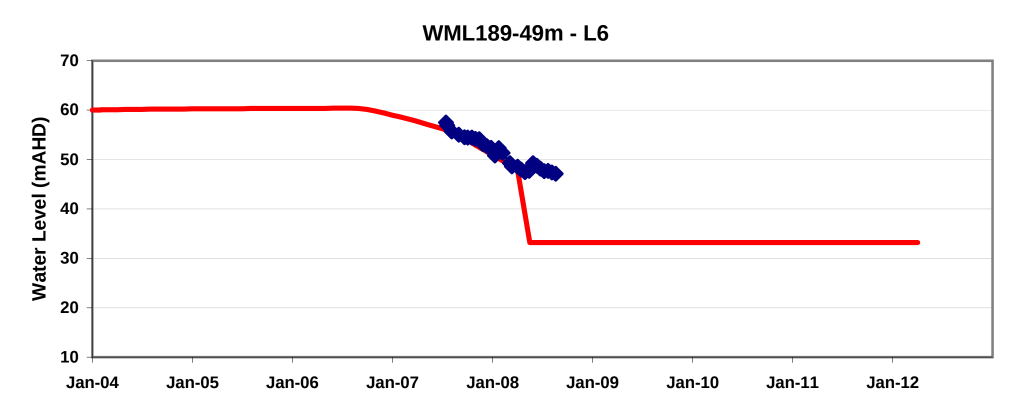
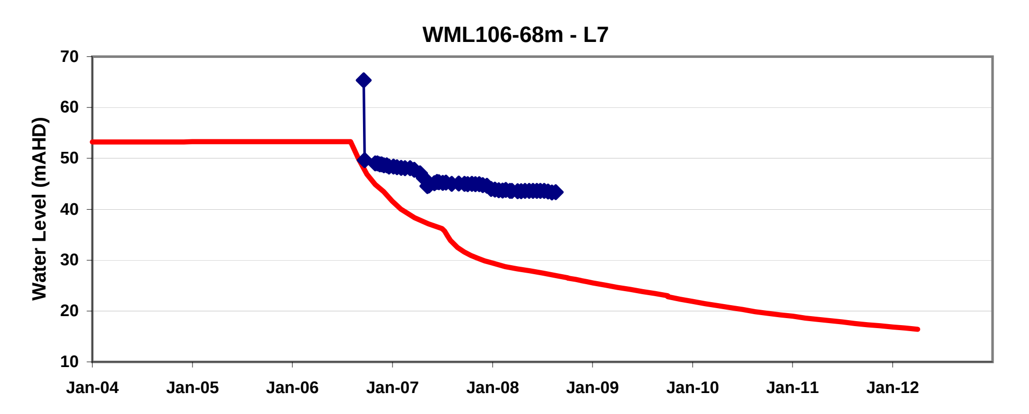
Layers 3 to 4 Modelled vs Observed - Lemington 7-9 Seams (L3), Lemington 11 (L4), Lemington 12 (L5) Water Levels

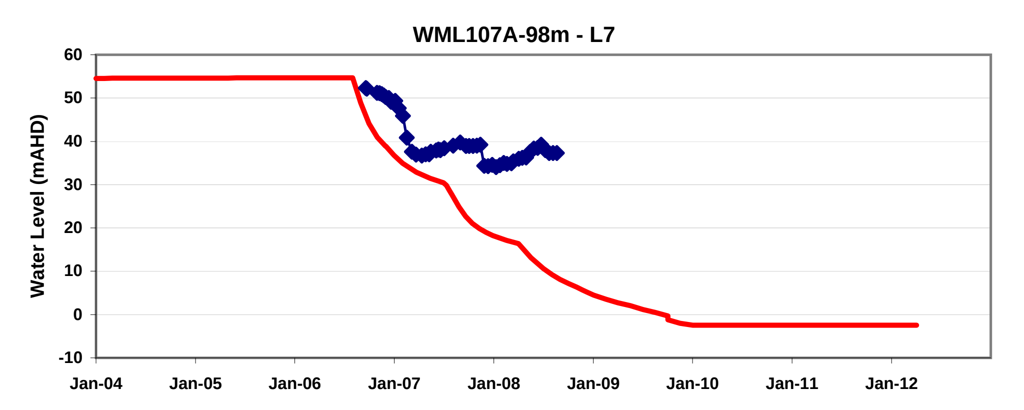
Figure 56











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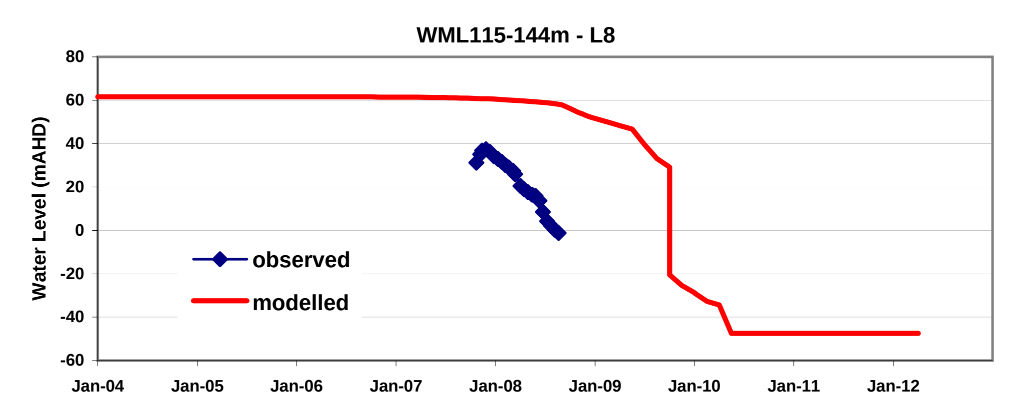
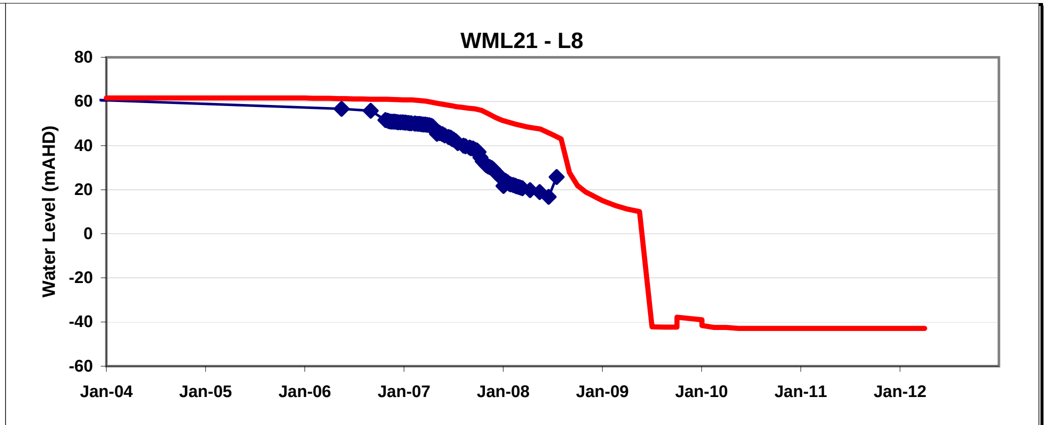
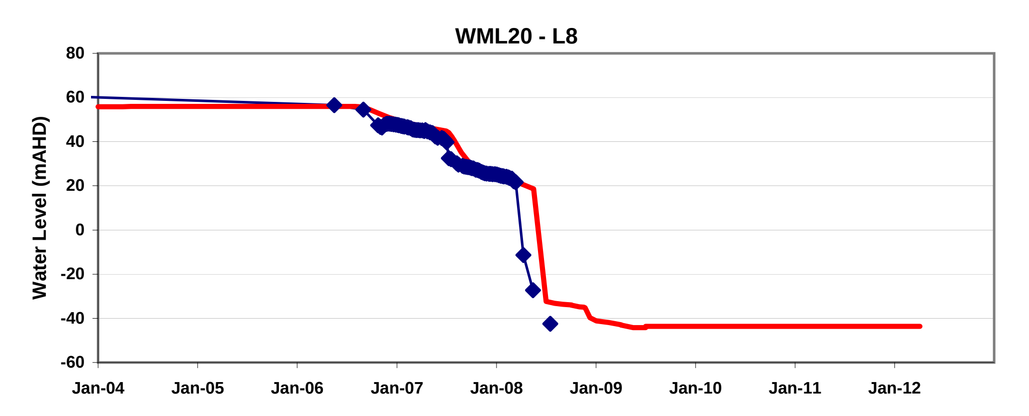
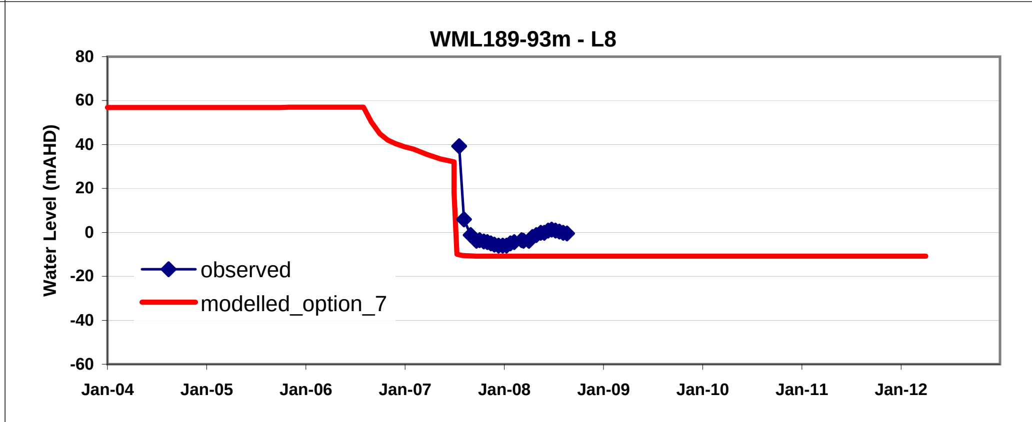
Layers 6 to 7 Modelled vs Observed - Lemington 15 (L6), Lemington 19 (L7) Water Levels

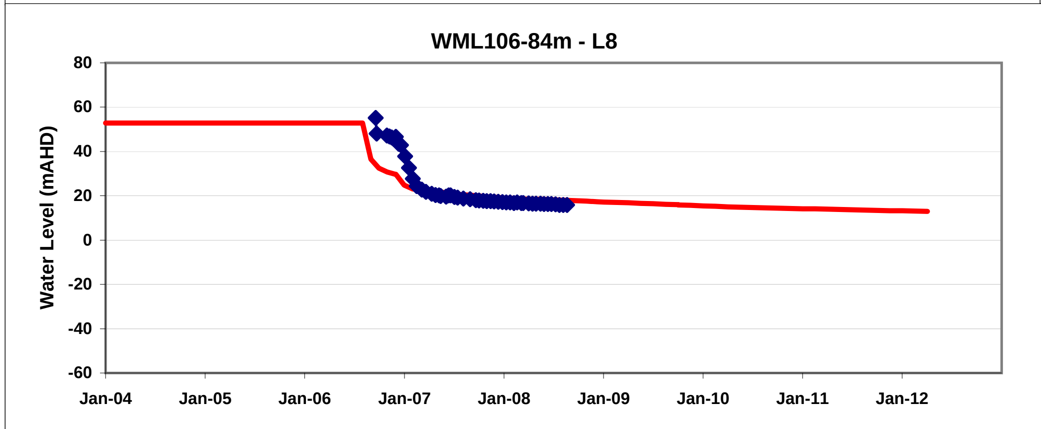
Figure 57











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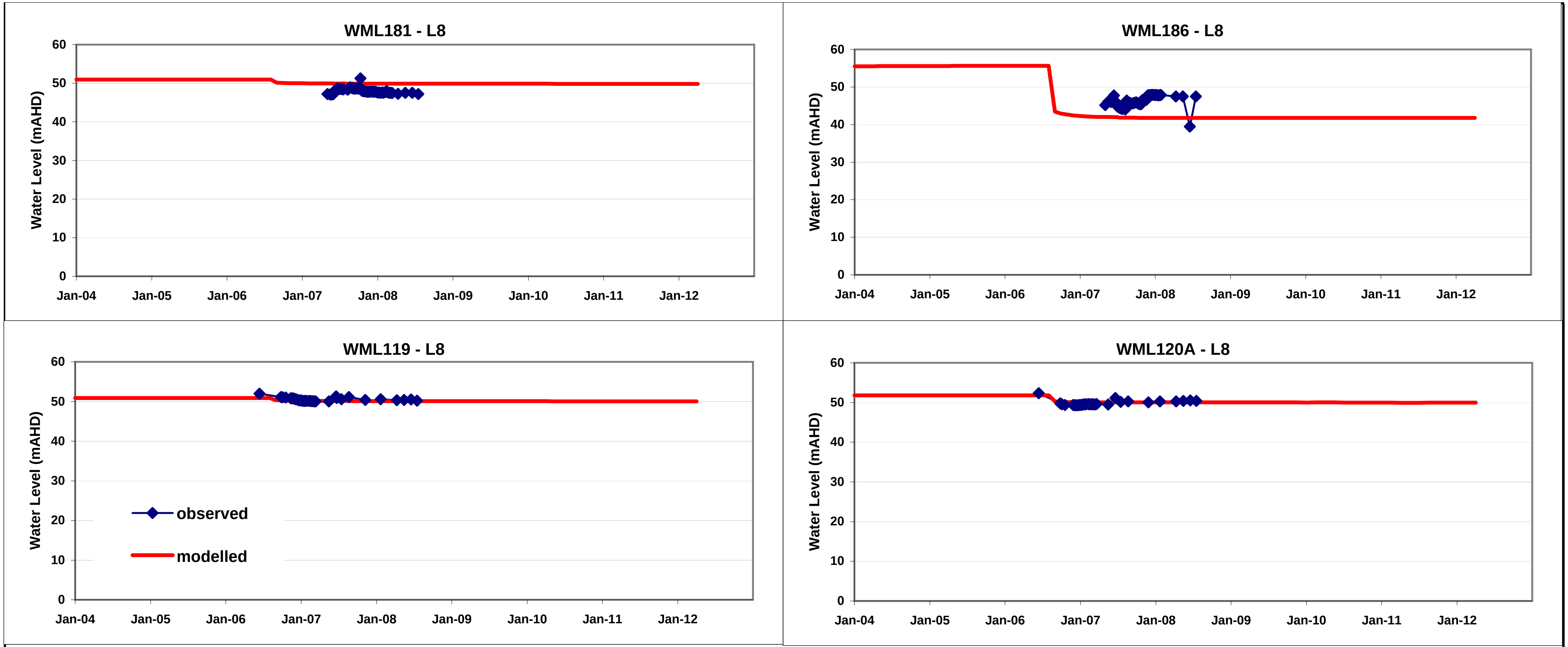
Layer 8 Modelled vs Observed - Pikes Gully Seam Water Levels

Figure 58



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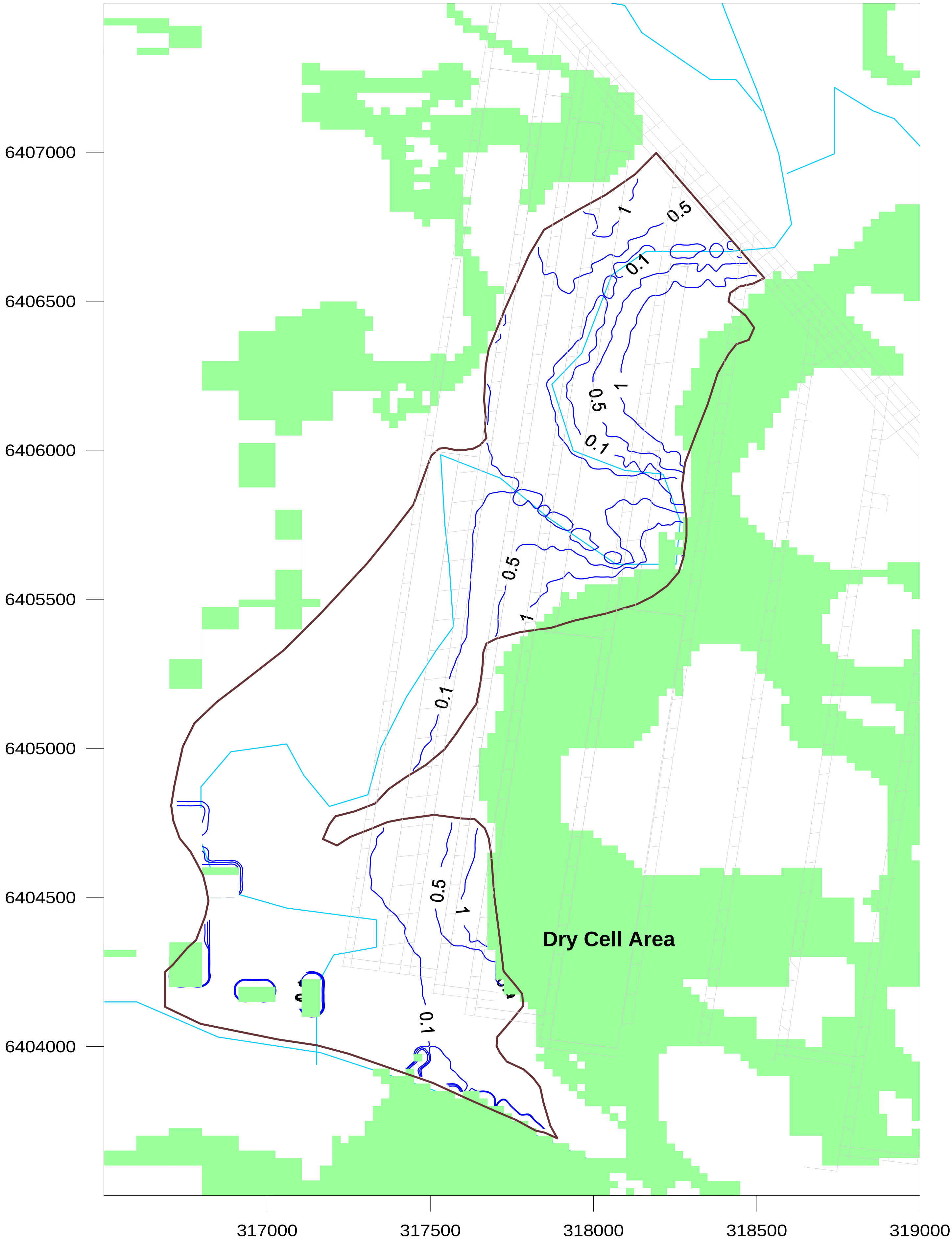
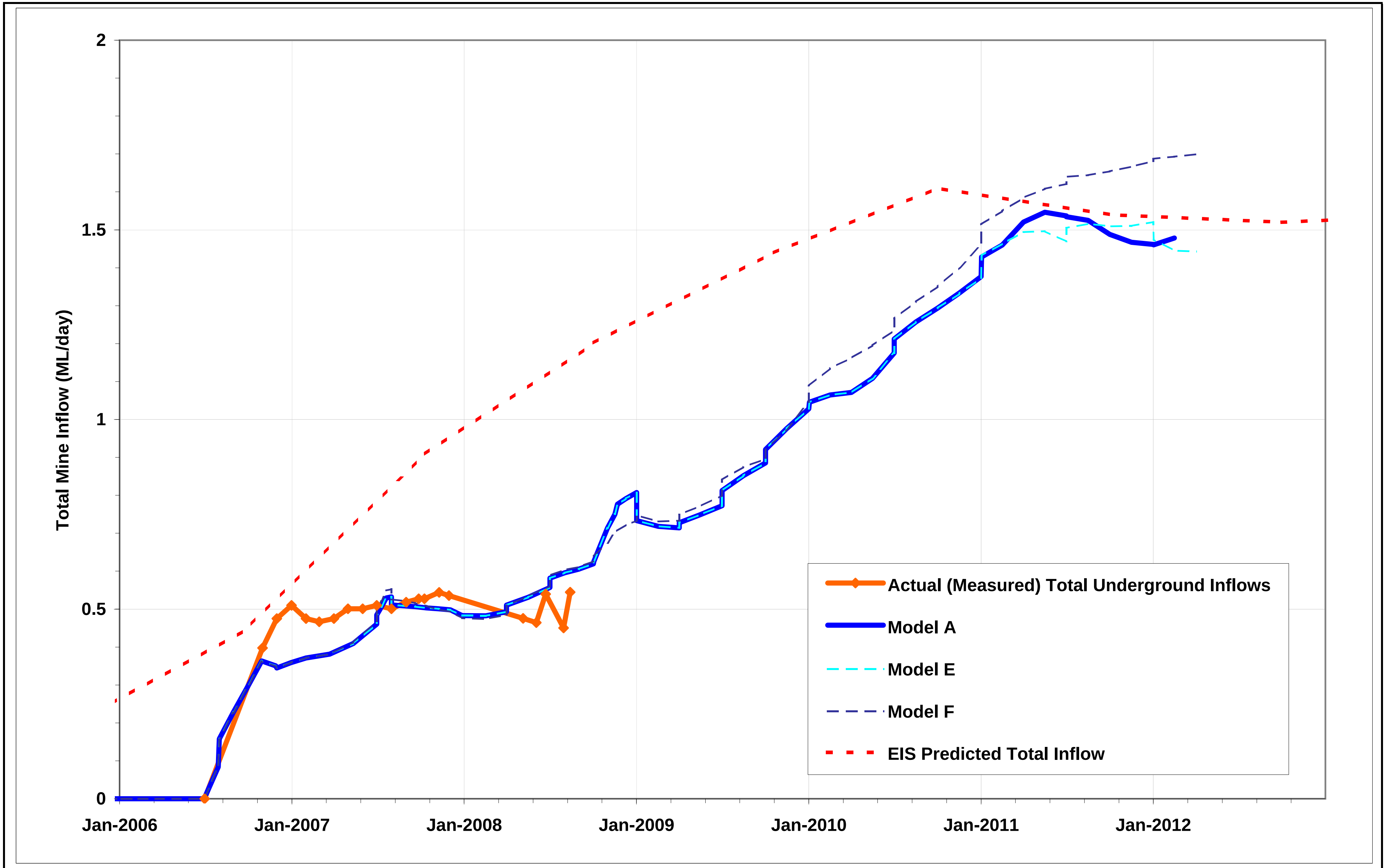
Layer 8 Modelled vs Observed - Pikes Gully Seam Water Levels

Figure 59



LW/MW 5-9 Mine Plan - Predicted Drawdown in Bowmans Creek Alluvium

Figure 60



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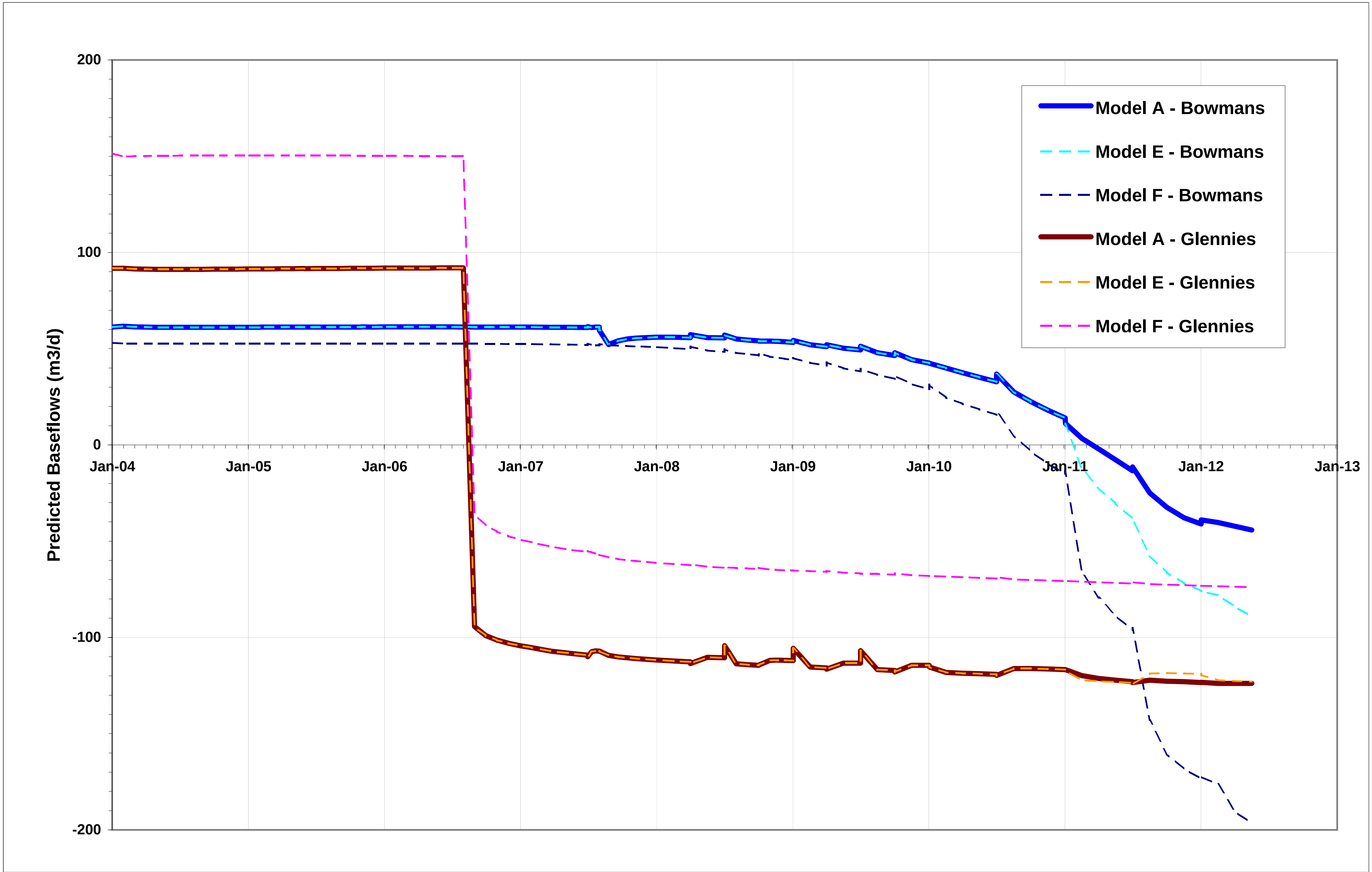
Uncertainty Analysis - Predicted Total Groundwater Inflows

Figure 61



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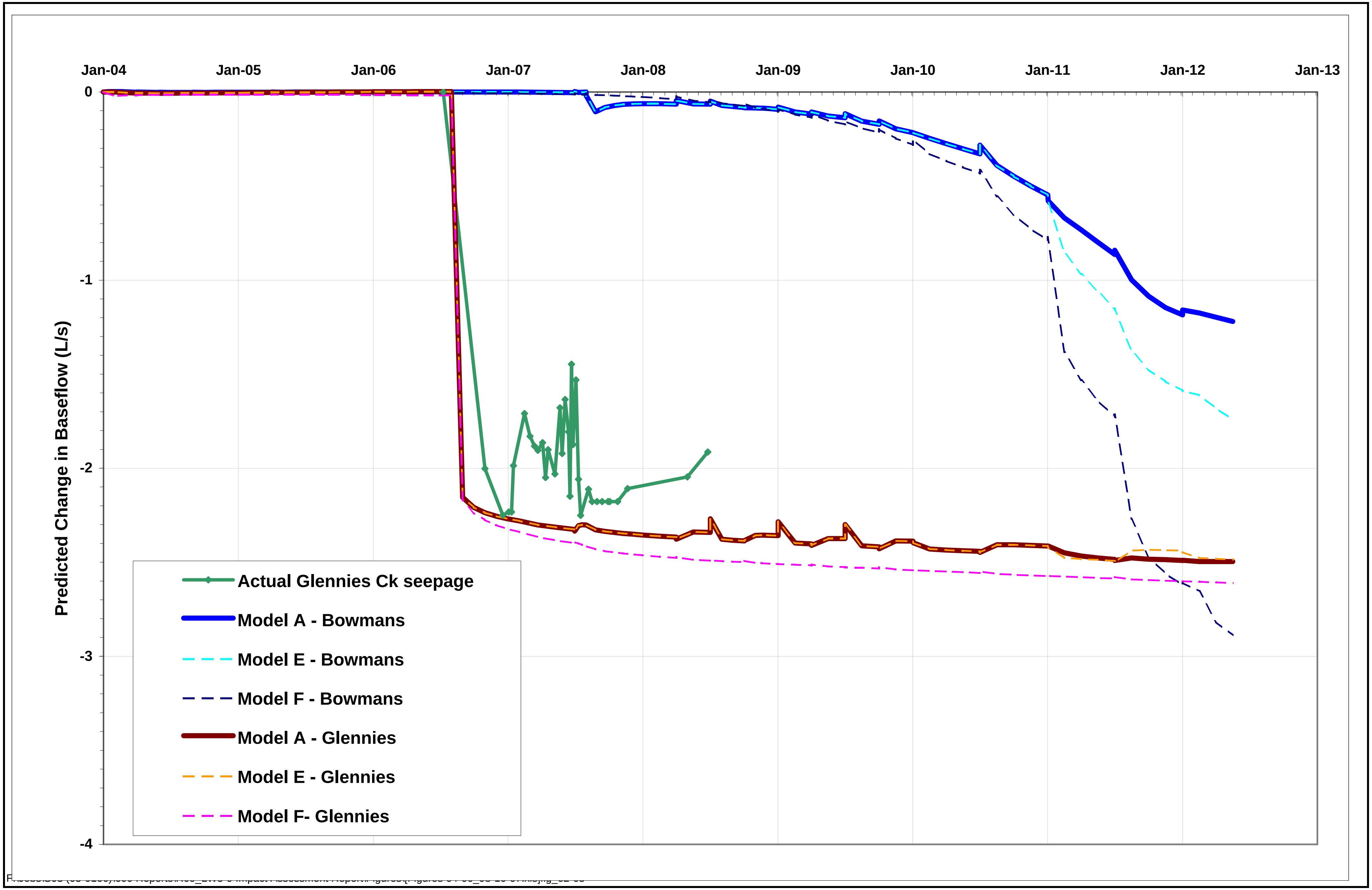
Uncertainty Analysis - Predicted Baseflows for Bowmans Creek and Glennies Creek

Figure 62



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Uncertainty Analysis - Predicted Baseflow Changes on Bowmans Creek and Glennies Creek

Figure 63

APPENDIX A

GROUNDWATER MODELLING
INDEPENDENT REVIEW REPORT
BY
ASSOCIATE PROFESSOR NOEL MERRICK

HERITAGE COMPUTING REPORT

REVIEW OF THE ASHTON UNDERGROUND COAL MINE GROUNDWATER IMPACT ASSESSMENT

FOR

ASHTON COAL OPERATIONS PTY LTD

PO Box 699, Singleton, NSW 2330

By

Dr N. P. Merrick

Report Number: HC2008/9
Date: October 2008

DOCUMENT REGISTER

REVISION	DESCRIPTION	DATE	AUTHOR
A	DRAFT	14 OCTOBER 2008	NPM
B	FINAL	29 OCTOBER 2008	NPM

EXECUTIVE SUMMARY

A groundwater model of continued longwall mining of the Pikes Gully Seam at the Ashton Underground Mine in the Hunter Coalfield of New South Wales has been developed by Aquaterra Consulting Pty Ltd for Ashton Coal Operations Pty Ltd. The purpose of the modelling is to assess potential impacts on local alluvial aquifers and surface water bodies, Bowmans Creek in particular, and to update the assessment of mine dewatering requirements.

This report provides a peer review of the model according to Australian modelling guidelines (MDBC, 2001). The review is based on a checklist of 36 questions across nine (9) model categories.

The review finds that the model has been developed competently, and is suitable for addressing environmental impacts and for estimating indicative dewatering rates.

The model has adopted a few innovative practices which raise the standard of best practice. First, development headings are recognised as early causes of depressurisation and are explicitly represented in the model. Second, pillars between mined panels are retained explicitly in the model, as depressurisation above the pillars is less severe than in the fractured zone above the goaf. Third, the material property values above the goaf are informed by external leading-edge subsidence modelling.

This study has the advantage of a substantial data set that consists of more than four (4) years of monitored groundwater levels at a dense network of piezometers spread across the proposed mine site, with measurements made at a number of depths through the stratigraphic column. Of importance is the fact that many deep piezometers record the aquifer response to earlier mining of the Pikes Gully Seam (since December 2005). This has provided an excellent data set for transient model calibration.

The aquifer system appears to suffer little stress from natural rainfall and stream-aquifer processes. Most groundwater hydrographs show a quiescent response, suggesting a minor role for rainfall infiltration and no groundwater abstraction by bores.

Several lines of evidence are provided in support of steady-state calibration in the form of a scatter plot, a table of performance statistics, a list of residuals at each of 54 targets, and maps for each layer of simulated groundwater level contours with posted measurements in a zoomed inset. The overall performance statistics are satisfactory: 12 % SRMS and 2.4 m RMS.

Less substantive lines of evidence are provided for transient calibration. The main performance indicator is qualitative comparison of 62 simulated and observed hydrographs. No statistical performance measures are offered. If this were done, it is likely that the statistics would be better than the steady-state ones. However, simulated mine inflow (at Longwall 1) is used as a transient calibration target for simulating the aquifer interaction with Glennies Creek. More effort could have been put into getting a likely baseflow magnitude for Bowmans Creek (e.g. the 10% exceedance flow) to provide an independent check on simulated baseflow magnitude.

Subsidence modelling, groundwater modelling and mine planning have been iterative processes, with the models informing the mine plan of potential impacts. As a result of this feedback, the mine plan has been modified on a number of occasions in terms of mining sequence and panel widths so that simulated impacts are reduced. The groundwater modelling report restricts discussion to what is considered the optimal (least environmental impact) mine plan.

The model predicts a reduction in baseflow in the order of 2 L/s (about 0.2 ML/d) at Bowmans Creek and much the same at Glennies Creek. The anticipated total mine inflow at the end of LW9 in the Pikes Gully Seam is in the order of 17 L/s (about 1.5 ML/d).

The degree of sensitivity analysis that can reasonably be done is limited by the very long run-time of each simulation. Accordingly, sensitivity analysis has been limited to key parameters that influence the predicted degree of environmental impact, namely rainfall infiltration rate and the vertical hydraulic conductivity of the uppermost model layer. It is reassuring that sensitivities to these parameters are mild. Although the vertical hydraulic conductivity of the top layer has been investigated across a wide range, the resulting predictions of Bowmans Creek baseflow reduction remain within a narrow range of 1.2 - 2.9 L/s (0.1 - 0.25 ML/day).

TABLE OF CONTENTS

1.0 INTRODUCTION

This report provides a peer review of the groundwater model of longwall mining of the Pikes Gully Seam in the Ashton Underground Mine Project, a continuing mining operation in the Hunter Coalfield of New South Wales (NSW). The mine is situated between Camberwell and Ravensworth, about 14 km west of Singleton. The model has been developed for Ashton Coal Operations Pty Ltd by Aquaterra Consulting Pty Ltd, who are undertaking the environmental impact hydrogeological investigations and groundwater modelling.

The modelling forms a component of the environmental assessment for the project. The purpose of the modelling is to assess potential impacts on local alluvial and hard rock aquifers, as well as interactions with Bowmans Creek, Glennies Creek and Hunter River. The model also provides a re-assessment of dewatering requirements for the Ashton mine, updating EIS predictions made in 2001.

2.0 SCOPE OF WORK

This reviewer was charged with the following key tasks:

- Review the groundwater model as documented against the guidelines developed for the Murray Darling Basin Commission;
- Provide an independent review in the form of a written report.

The model review was conducted in two stages: after conceptualisation and model setup; and after model calibration, prediction, and draft reporting.

3.0 MODELLING GUIDELINES

The review has been structured according to the checklists in the Australian Flow Modelling Guideline (MDBC, 2001). This guide, sponsored by the Murray-Darling Basin Commission, has become a *de facto* Australian standard. This reviewer was one of the three authors of the guide, and is the person responsible for creating the peer review checklists. The checklists have been well received nationally, and have been adopted for use in the United Kingdom, California and Germany.

The modelling has been assessed according to the 2-page Model Appraisal checklist in MDBC (2001). This checklist has questions on (1) The Report; (2) Data Analysis; (3) Conceptualisation; (4) Model Design; (5) Calibration; (6) Verification; (7) Prediction; (8) Sensitivity Analysis; and (9) Uncertainty Analysis.

The effort put into a modelling study is very dependent on timing and budgetary constraints that are generally not known to a reviewer. The reviewer is aware in this case that considerable time and funds were expended on the many revisions of the model, and in no way was model development constrained.

4.0 EVIDENTIARY BASIS

The primary documentation on which this review is based is:

1. *Georgiou, J. and Passfield, G., 2008, Ashton Underground Mine LW/MW 5-9 Pikes Gully Seam Groundwater Impact Assessment Report. Aquaterra Consulting Report S03/85/09e [14 October 2008]. Revision E. Final Report.*

No other documentation was considered. However, the review benefitted from a full day workshop with one of the modellers (J. Georgiou) on 12 June 2008.

5.0 PEER REVIEW

In terms of the modelling guidelines, the Ashton coal model is categorised as an *Impact Assessment Model* of medium complexity, as distinct from an *Aquifer Simulator* of high complexity.

The Australian best practice guide (MDBC, 2001) describes the connection between model application and model complexity as follows:

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

- Aquifer Simulator - a high complexity model, suitable for predicting responses to arbitrary changes in hydrological conditions, and for developing sustainable resource management policies for aquifer systems under stress.

The appraisal checklists are presented in Tables 1 and 2 (at the back of this report). The current review has been based mainly on a written report, but some electronic model files were examined during a workshop. Discussion on each modelling aspect is provided in Section 6.

6.0 DISCUSSION

6.1 THE REPORT

The Model Report (Document #1) is a substantial, high quality document of about 120 pages total, including 37 pages in the main body of the report. To an external reader with no prior knowledge of the study area, the report is very good as a standalone document. There is very little assumed knowledge.

The objectives of the modelling study are stated in Document #1 as:

1. "Assess the potential inflow rates into the open cut and underground mine workings during longwall mining.
2. Assess the potential impacts from alternative underground mine plans and longwall/miniwall mine layouts.
3. Predict the potential impacts of the open cut and underground mining on local and regional groundwater levels and surface water resources.
4. Assess the potential impacts on alluvial aquifers associated with Bowmans Creek, Glennies Creek and Hunter River."

The report addresses the project objectives satisfactorily. However, there is no reporting of open cut inflow rates (part of Objective 1). Although alternative mine plans have been considered (Objective 2), only the one regarded as optimal is reported.

There is comprehensive coverage of the modelling component of the study, with full disclosure in an Appendix of layer elevations and aquifer parameterisation.

The report has sufficient description of the modelling process and extensive reporting of modelling results. Water balance estimates are reported globally at steady state (Table 7.3) and for the period of transient calibration (Table 7.5). For prediction runs, water balance reporting concentrates on baseflow, baseflow reduction and pit inflows, the primary outputs of the modelling study.

6.2 DATA ANALYSIS

This study has the advantage of four (4) years of monitored groundwater levels at 62 sites spread across the proposed mine site, at multiple depths. In addition, responses to early longwall mining provide excellent control for model calibration, and recorded mine inflow (at LW1) removes much of the uncertainty in prediction of future inflows.

Groundwater elevation contours are provided in the alluvium, in the Pikes Gully coal seam, and in the Pikes Gully overburden. Early measurements (2004) are used as surrogate equilibrium levels for initial steady state calibration.

Reported stream hydrographic data, by contrast, is weak. Although there are two gauging stations on Bowmans Creek, only 50 percentile flow is reported. It is recognised that a companion investigations report (Fulton, 2008) contains two flow duration curves, which suggest that baseflow is about 0.3 ML/d at Foy Brook gauging station, and zero at Ravensworth gauging station. This information could have been used as a calibration target in support of the model-predicted baseflow (<0.1 ML/d at Bowmans Creek).

The aquifer system appears to suffer very little stress due to natural processes such as rainfall and stream-aquifer interaction. Most hydrographs show a quiescent response, suggesting a minor role for rainfall infiltration and no groundwater abstraction by bores. There are minor fluctuations in the order of 1 m, often noticeable in association with the major (Pasha Bulker) storm in June 2007.

Dewatering during longwall mining that commenced in December 2005 has caused depressurisation responses in piezometers that give good insight into the behaviour of the aquifer system. Some hydrographs show episodic partial recovery which is attributed to self-healing of fractures. The climatic variations at that time should be examined (through rainfall residual mass analysis) to check if there might be some climate component in the observed recovery.

Quantifying the permeability and storage characteristics of the fractured zone that develops above a mined seam is extremely difficult. This study applies an innovation by adopting values predicted by state-of-art subsidence modelling.

6.3 CONCEPTUALISATION

The modelling team's conceptualisation is discussed in detail, in terms of geology and key recharge/discharge processes. Although a geological cross-section is shown to illustrate the stratigraphic column and formation attitudes, a graphic illustration of the conceptual model would be more informative for a reader.

A conceptual model diagram is a simplified 2D or 3D summary picture (without stratigraphic detail) that conveys the essential features of the hydrological system, denoting all recharge/discharge processes that are likely to be significant. The diagram can serve a dual purpose for displaying the magnitudes of the water budget components derived from data sources or from simulation.

The stratigraphic section in Figure 6 (Document #1) is approximated appropriately by five (5) coal seams with intervening sedimentary formations, topped by a layer of alluvium or weathered regolith.

6.4 MODEL DESIGN

There is an existing prior model of the mine site dating from 2001, which has been used as a base for an enhanced model.

The model has been built with Groundwater Vistas software and MODFLOW Surfact, an advanced version of standard MODFLOW which is regarded widely as a standard, particularly by government agencies. This version was selected to reduce numerical issues with dry cells (common in mining and dewatering operations). The pseudo-soil option was used, rather than full simulation of variable saturation.

One limitation that all versions of MODFLOW have for coal mining simulations is that they do not permit material properties to vary in time. In this study, a stop-start process across three time slices has been adopted to allow progressive incorporation of the fractured zone above goaf areas during model calibration. An additional 10 time slices are used during the prediction phase. Variable fracture heights are used according to varying panel widths, as informed by detailed subsidence modelling. The Pikes Gully overburden has been divided into six (6) model layers to allow for variable fracture height.

Discretisation in space is appropriate. Model cells are 25 m square across the mine site, with 100 m at model edges. There are 253 rows and 188 columns. The fine scale has allowed the unusual simulation of development headings as well as discrete pillar widths, both of which proved necessary for effective transient calibration. The model has been built for 15 layers, to allow future expansion to deeper seams, but only the top nine (9) layers are activated in this assessment of the Pikes Gully seam mining.

There is very little option in selection of model extent (about 11 km by 11 km) as the mine is surrounded by other existing mines. Rather than simulate each of these mines in detail, it is appropriate to represent them in terms of specified boundary heads, usually at seam levels. For the Camberwell North Pit and the Glennies Creek mine, which respectively mine the Lower Barrett and Middle Liddell seams, it is not clear how their boundary conditions have been accommodated in the 9-layer model, as both seams belong to deeper layers.

The report is not clear as to the boundary conditions away from neighbouring mines. If no-flow conditions are imposed, the external mine constraints could bias the entire aquifer system to groundwater levels that are too low.

Active mining is represented appropriately by MODFLOW "drain" cells which remain active for the entire model simulation.

Streams are handled as MODFLOW "river" features that are time-invariant.

In general, the stress period is one month for calibration (with occasional longer periods up to 7 months) and 1-3 months for prediction according to longwall panel durations.

6.5 CALIBRATION

Calibration has been performed for both steady-state and transient conditions.

Several lines of evidence are provided in support of steady-state calibration in the form of a scatter plot, a table of performance statistics, a list of residuals at each of 54 targets, and maps for each layer of simulated groundwater level contours with posted measurements in a zoomed inset. Given the uncertainty in use of measured recent water levels as surrogates for pre-development conditions, calibration is generally good. The overall performance statistics are satisfactory: 12 % SRMS and 2.4 m RMS. The steady-state scatter plot in Figure 14 (Document #1) shows no apparent bias in residuals at any elevation.

Less substantive lines of evidence are provided for transient calibration. The main performance indicator is qualitative comparison of 62 simulated and observed hydrographs. No statistical performance measures are offered. If this were done, it is likely that the statistics would be better than the steady-state ones. Hydrographs not influenced by mining are represented well in terms of absolute elevation, and lack of fluctuations. Hydrographs influenced by mining are replicated quite well in terms of drawdown magnitude and timing of depressurisation. Some hydrographs match extremely well. There are some observed instances of partial recovery which cannot be handled by the model, as the model has no built-in mechanisms for this.

In addition, simulated mine inflow (LW1) is used as a transient calibration target. More effort could have been put into getting a likely baseflow magnitude for Bowmans Creek (e.g. the 5% exceedance flow reported in Fulton, 2008) to provide an independent check on simulated baseflow magnitude.

Calibrated material properties and rain recharge rates are generally plausible. Rain recharge rates range from 0.2% to 1.7%, with higher values at coal seam subcrops. There is full disclosure of calibrated property distributions in an Appendix.

There is no specific comment in the report on whether observed vertical head gradients are preserved in the model. The report notes a tendency for increasing head with depth under pre-development conditions.

6.6 PREDICTION

Predictions are based on transient simulation for 4.25 years of calibration followed by 4.25 years of continued mining. No long-term recovery following mining is investigated. No natural dynamic stresses from rainfall or river flow are applied during prediction, so that the hydrological effects of mining can be isolated.

For each stress period, development headings and longwalls/miniwalls are specified in advance as active drain cells. Enhanced permeability in fracture zones is specified in arrears for each time-slice.

Subsidence modelling, groundwater modelling and mine planning have been iterative processes, with the models informing the mine plan of potential impacts. As a result of this feedback, the mine plan has been modified on a number of occasions in terms of mining sequence and panel widths so that simulated impacts are reduced. The report restricts discussion to what is considered the optimal (least environmental impact) mine plan.

The model predicts a reduction in baseflow in the order of 2 L/s (about 0.2 ML/d) at Bowmans Creek and at Glennies Creek. The anticipated total mine inflow at the end of LW9 in the Pikes Gully Seam is in the order of 17 L/s (about 1.5 ML/d).

6.7 SENSITIVITY ANALYSIS

The degree of sensitivity analysis that can reasonably be done is limited by the very long run-time of each simulation. Accordingly, sensitivity analysis has been limited to key parameters that influence the predicted degree of environmental impact, namely rainfall infiltration rate and the vertical hydraulic conductivity of the uppermost model layer. Most sensitivity analysis has been limited to steady-state simulation, with performance measured by the SRMS statistic based on groundwater heads. Other parameters that could affect flow predictions, but are not tested for sensitivity, are river conductance and drain conductance.

Rainfall infiltration has been tested for increases from the calibrated rate by factors of 1.2 and 2.0. Layer 1 vertical hydraulic conductivity has been tested across a wide range, as this parameter controls the degree of hydraulic connectivity between the alluvial aquifers and the underlying hard-rock aquifers. Values of 0.1, $5x10^{-4}$, $1x10^{-5}$, and $5x10^{-6}$ m/d have been tested. It is reassuring that sensitivities to these parameters are mild, as the SRMS statistic varies only from 10.8% to 12.4% (steady-state).

Instead of the conventional perturbation approach, the sensitivity analysis for transient simulation has been done using alternative calibrated models called Model A, Model E and Model F. Model A is the base calibrated model. The other models differ in the amount of rainfall recharge, the specific yield in the Bowmans Creek alluvium, and the vertical hydraulic conductivity of the surficial layer. Each model gives a similar replication of recorded mine inflow (LW1). The models differ in their prediction of the level of impact on Bowmans Creek baseflow from 2010 onwards. As Models A and E investigate the extremes of possible vertical hydraulic conductivity (0.1 m/d to $5x10^{-6}$ m/d), the model predictions are likely to give the outer limits of possible baseflow impacts. In mid-2012, at the end of LW9 mining, the model predicts a reduction in baseflow at Bowmans Creek in the range 1.2-2.9 L/s (0.1-0.25 ML/d).

6.8 UNCERTAINTY ANALYSIS

Uncertainty analysis has been performed by the use of alternative models having different values for rainfall infiltration and vertical permeability of the top model layer, as discussed in the previous section on Sensitivity Analysis.

Model limitations are discussed at length in Section 6.6 of the report. The main issues are:

- Extrapolation of geological interface elevations away from the Ashton lease;
- Inadequate knowledge of baseflow conditions in Bowmans Creek and Glennies Creek;
- Inability to verify regional recharge and evapotranspiration rates by field measurement;
- Uncertainty in the precision of adopted horizontal and vertical hydraulic conductivities, especially in the fracture zones above goaf;
- Necessity to represent stratigraphy by a limited number of model layers, thereby mixing lithologies and disguising vertical head gradients;
- Model dependence on a short period of record of piezometric responses and mine inflows;
- Inability to verify river and mine drain conductance values by field measurement;
- Very long model run-times caused by low permeabilities and steep hydraulic gradients;
- Simplified representation of unsaturated flow, to avoid prolonging model run-times.

7.0 CONCLUSION

The Ashton Coal groundwater model has been developed competently. It is a suitable model for addressing likely environmental impacts from longwall/miniwall mining of the Pikes Gully Seam, and for estimating indicative mine inflow rates.

The model has adopted a few innovative practices which raise the standard of best practice. First, development headings are recognised as early causes of depressurisation and are explicitly represented in the model. Second, pillars between mined panels are retained explicitly in the model, as depressurisation above the pillars is not as severe as it is in the fractured zone above the goaf. Third, the material property values above the goaf are informed by external leading-edge subsidence modelling.

This study has the advantage of four (4) years of monitored groundwater levels at 62 sites spread across the proposed mine site, at multiple depths. In addition, responses to early longwall mining provide excellent control for model calibration, and recorded mine inflow (at LW1) removes much of the uncertainty in prediction of future inflows.

Predicted baseflow reductions at Bowmans Creek are likely to be bracketed in the range 1.2 - 2.9 L/s (0.1 - 0.25 ML/day).

Predicted mine inflow at the end of LW9 in 2012 is expected to be about 17 L/s (1.5 ML/day).

8.0 REFERENCES

MDBC (2001). Groundwater flow modelling guideline. Murray-Darling Basin Commission. URL:
www.mdbc.gov.au/nrm/water_management/groundwater/groundwater_guides

Georgiou, J. and Passfield, G. (2008). Ashton Underground Mine LW5 to 9 Pikes Gully Seam Groundwater Impact Assessment Report. Aquaterra Consulting Report S03/85/09e [14 October 2008]. Final Report.

Fulton, A. (2008). Ashton Underground Mine Bowmans Creek Alluvium Investigation. Aquaterra Consulting Report S03/R06/22G [13 October 2008]. Final Report.

Table 1. MODEL APPRAISAL: Ashton Coal

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
1.0	THE REPORT								
1.1	Is there a clear statement of project objectives in the modelling report?		Missing	Deficient	Adequate	Very Good			Section 4.
1.2	Is the level of model complexity clear or acknowledged?		Missing	No	Yes				Section 6.1: Impact Assessment Model, medium complexity
1.3	Is a water or mass balance reported?		Missing	Deficient	Adequate	Very Good			Steady state (Table 7.3); transient (Table 7.5) – global. Detail for predicted baseflow.
1.4	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	Very Good			Subject to stated limitations.
1.5	Are the model results of any practical use?			No	Maybe	Yes			Some uncertainty, but well constrained
2.0	DATA ANALYSIS								
2.1	Has hydrogeology data been collected and analysed?		Missing	Deficient	Adequate	Very Good			
2.2	Are groundwater contours or flow directions presented?		Missing	Deficient	Adequate	Very Good			For alluvium, overburden and coal seam.
2.3	Have all potential recharge data been collected and analysed? (rainfall, streamflow, irrigation, floods, etc.)		Missing	Deficient	Adequate	Very Good			Minor coverage of rainfall & stream stage – held constant in model. No residual mass analysis to check if hydrographs respond to climate. Streamflow 50% exceedance is given; 10% would be more informative for baseflow magnitudes. No mention of likelihood of flooding on alluvium (but minor footprint).
2.4	Have all potential discharge data been collected and analysed? (abstraction, evapotranspiration, drainage, springflow, etc.)		Missing	Deficient	Adequate	Very Good			Evapotranspiration reasonable (using 15% of evap in model). No stock & domestic wells. Only mine dewatering at Ashton, and depressed heads at neighbouring mines.

2.5	Have the recharge and discharge datasets been analysed for their groundwater response?		Missing	Deficient	**Adequate**	Very Good			Some discussion on hydrographic cause and effect during calibration, from mining and possible self-healing of fractures. No comment on climate influence, but very minor natural fluctuations.
2.6	Are groundwater hydrographs used for calibration?			No	Maybe	**Yes**			62 hydrographs over 4 years. Large number, many show informative mining stresses.
2.7	Have consistent data units and standard geometrical datums been used?			No	**Yes**				Mix of ML/day and L/s in prediction phase; best to use both in text. Wrong units for conductance.
3.0	CONCEPTUALISATION								
3.1	Is the conceptual model consistent with project objectives and the required model complexity?		Unknown	No	Maybe	**Yes**			
3.2	Is there a clear description of the conceptual model?		Missing	Deficient	Adequate	**Very Good**			
3.3	Is there a graphical representation of the modeller's conceptualisation?		Missing	**Deficient**	Adequate	Very Good			Cross-section provided, but no schematic or perspective view highlighting major recharge and discharge processes.
3.4	Is the conceptual model unnecessarily simple or unnecessarily complex?			Yes	**No**				Sensible stratigraphic division.
4.0	MODEL DESIGN								
4.1	Is the spatial extent of the model appropriate?			No	Maybe	**Yes**			11km x 11km. Extent is defined by other surrounding mines. 25-100m cell size is fine enough to represent development headings, pillar width and panel width. 9 (15) layers, 253 rows, 188 columns.
4.2	Are the applied boundary conditions plausible and unrestrictive?		Missing	Deficient	**Adequate**	Very Good			Generally head boundaries set by neighbouring mines, often at seam RL. Unsure which layer hosts Middle Liddell and Lower Barrett heads in 9-layer model (as they are deeper). Unclear if non-mine boundaries are no-flow or GHB. Unsure of the need to set DRN inverts at 0.5m below floor. River package for streams.

4.3	Is the software appropriate for the objectives of the study?			No	Maybe	Yes			Groundwater Vistas and MODFLOW Surfact. Pseudo-Soil option to reduce numerical effects of dry cells. Cannot handle time varying material properties directly – done in time slices.

Table 2. MODEL APPRAISAL – Ashton Coal

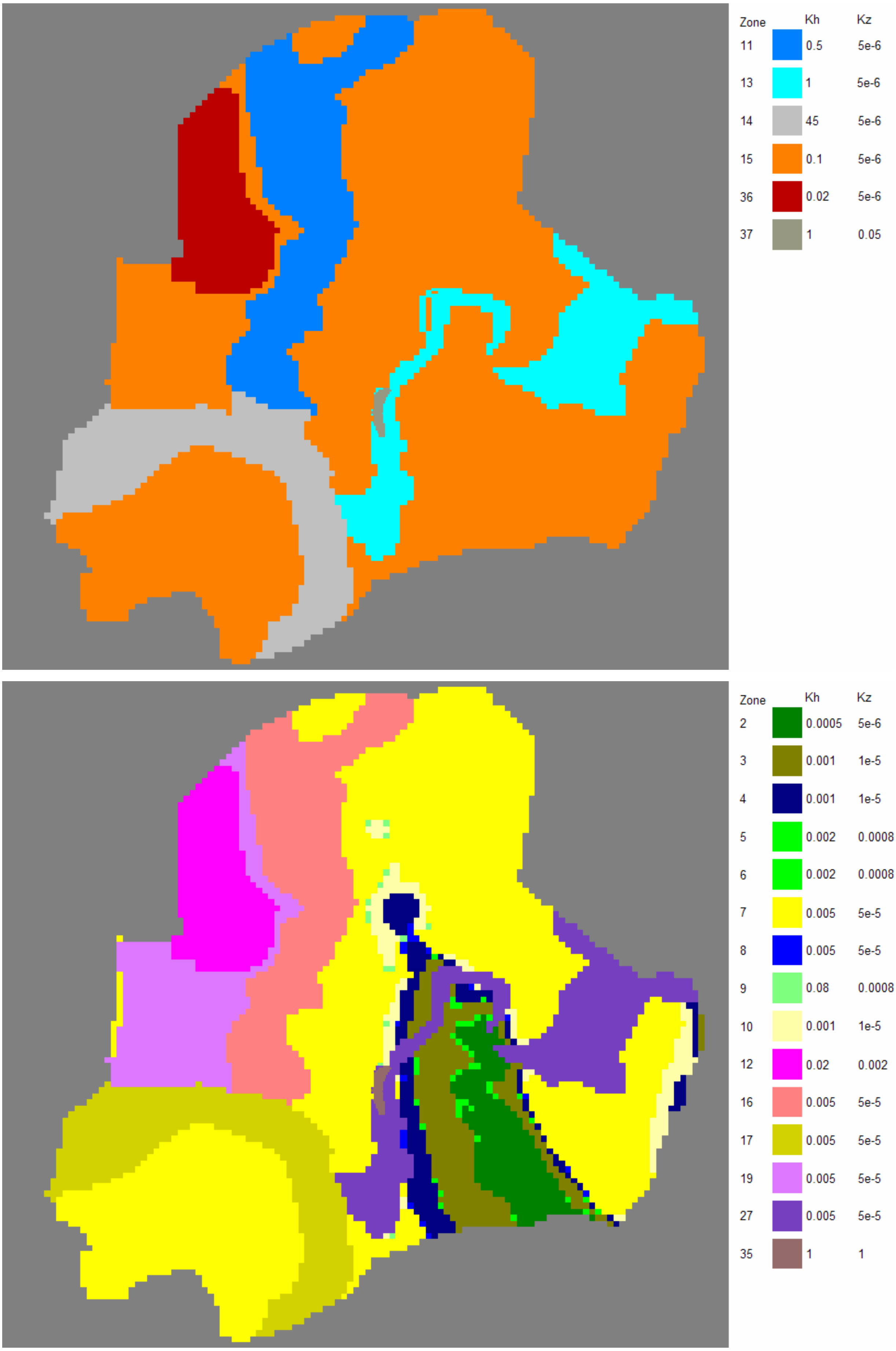
Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
5.0	CALIBRATION								
5.1	Is there sufficient evidence provided for model calibration?		Missing	Deficient	Adequate	Very Good			Several lines of evidence: scattergram for steady state (Fig 14) – not for transient; statistics; lists of observed and simulated steady state heads; steady state contours with posted measured values; hydrograph comparisons. Done manually, or automated?
5.2	Is the model sufficiently calibrated against spatial observations?		Missing	Deficient	Adequate	Very Good			11.6% SRMS and 2.4m RMS. Uncertainty in measured heads being representative of "steady" conditions.
5.3	Is the model sufficiently calibrated against temporal observations?		Missing	Deficient	Adequate	Very Good			No statistics given – expect low SRMS; 62 hydrographs, large number (unstated) of target water levels. Calibrated against heads and LW1 mine inflow as surrogate for baseflow reduction in Glennies Creek. Insufficient check against baseflow in Bowmans Creek. Hydrographic magnitudes match well, but climatic fluctuation matching is not attempted. Generally very good replication of responses to mine dewatering – magnitude and timing.

5.4	Are calibrated parameter distributions and ranges plausible?		Missing	No	Maybe	Yes			Rain recharge rates consistent with earlier modelling; range from 0.2% to 1.7% - plausible. Permeability values are consistent with other studies. Values in fractured zones are informed by SCT subsidence modelling (rarely linked to groundwater models). Comprehensive reporting of property values and distributions in Appendix.
5.5	Does the calibration statistic satisfy agreed performance criteria?		Missing	Deficient	Adequate	Very Good			Steady state 12% is reasonable. No statistic is given for transient calibration.
5.6	Are there good reasons for not meeting agreed performance criteria?		Missing	Deficient	Adequate	Very Good			Uncertainty as to whether steady state targets are influenced by mining.
6.0	VERIFICATION								
6.1	Is there sufficient evidence provided for model verification?	N/A	Missing	Deficient	Adequate	Very Good			All data needed for calibration.
6.2	Does the reserved dataset include stresses consistent with the prediction scenarios?	N/A	Unknown	No	Maybe	Yes			
6.3	Are there good reasons for an unsatisfactory verification?	N/A	Missing	Deficient	Adequate	Very Good			
7.0	PREDICTION								
7.1	Have multiple scenarios been run for climate variability?		Missing	Deficient	Adequate	Very Good			No climate variability is simulated, as this will have a minor effect on deeper groundwater levels compared to mining depressurisation.
7.2	Have multiple scenarios been run for operational /management alternatives?		Missing	Deficient	Adequate	Very Good			Several mine plans during model development; amendments to mine plans to reduce impacts (panel width). Optimal (least impact) mine plan is the only one reported.
7.3	Is the time horizon for prediction comparable with the length of the calibration / verification period?		Missing	No	Maybe	Yes			4.25 years prediction compared to 4.25 years calibration.

7.4	Are the model predictions plausible?			No	Maybe	Yes			The availability of responses to early mining lessens the uncertainty in prediction; original EIS predictions quite good. Three alternative models, differing mainly in Bowmans Creek baseflow interception.
8.0	SENSITIVITY ANALYSIS								
8.1	Is the sensitivity analysis sufficiently intensive for key parameters?		Missing	Deficient	Adequate	Very Good			Limited by very long model runtimes. Done for steady state for 2 parameters:, Kz1 (0.1, 5e-4, 1e-5, 5e-6 m/d), rain recharge (x1.2, x2). Sensible perturbations. Performance indicator based on heads only. Transient done for 3 alternative models rather than systematic perturbation; performance based on mine inflow. Not done for river or mine drain conductance (which can affect baseflow and mine inflow estimates).
8.2	Are sensitivity results used to qualify the reliability of model calibration?		Missing	Deficient	Adequate	Very Good			SRMS reported for each steady state perturbed run. Best run gives 10.8% compared to calibrated parameter set run 11.6% (not much change). Transient run is constrained to sensible mine inflow.
8.3	Are sensitivity results used to qualify the accuracy of model prediction?		Missing	Deficient	Adequate	Very Good			Alternative models are used in prediction uncertainty analysis: varying Kz (Layer 1).
9.0	UNCERTAINTY ANALYSIS								
9.1	If required by the project brief, is uncertainty quantified in any way?		Missing	No	Maybe	Yes			Uncertainty is explored in part by sensitivity analysis, and is discussed under model limitations. Alternative models are used in prediction to illustrate uncertainty in baseflow impacts.
	TOTAL SCORE								PERFORMANCE:

APPENDIX B

MODEL AQUIFER PARAMETERS, RECHARGE DISTRIBUTION AND LAYER ELEVATIONS



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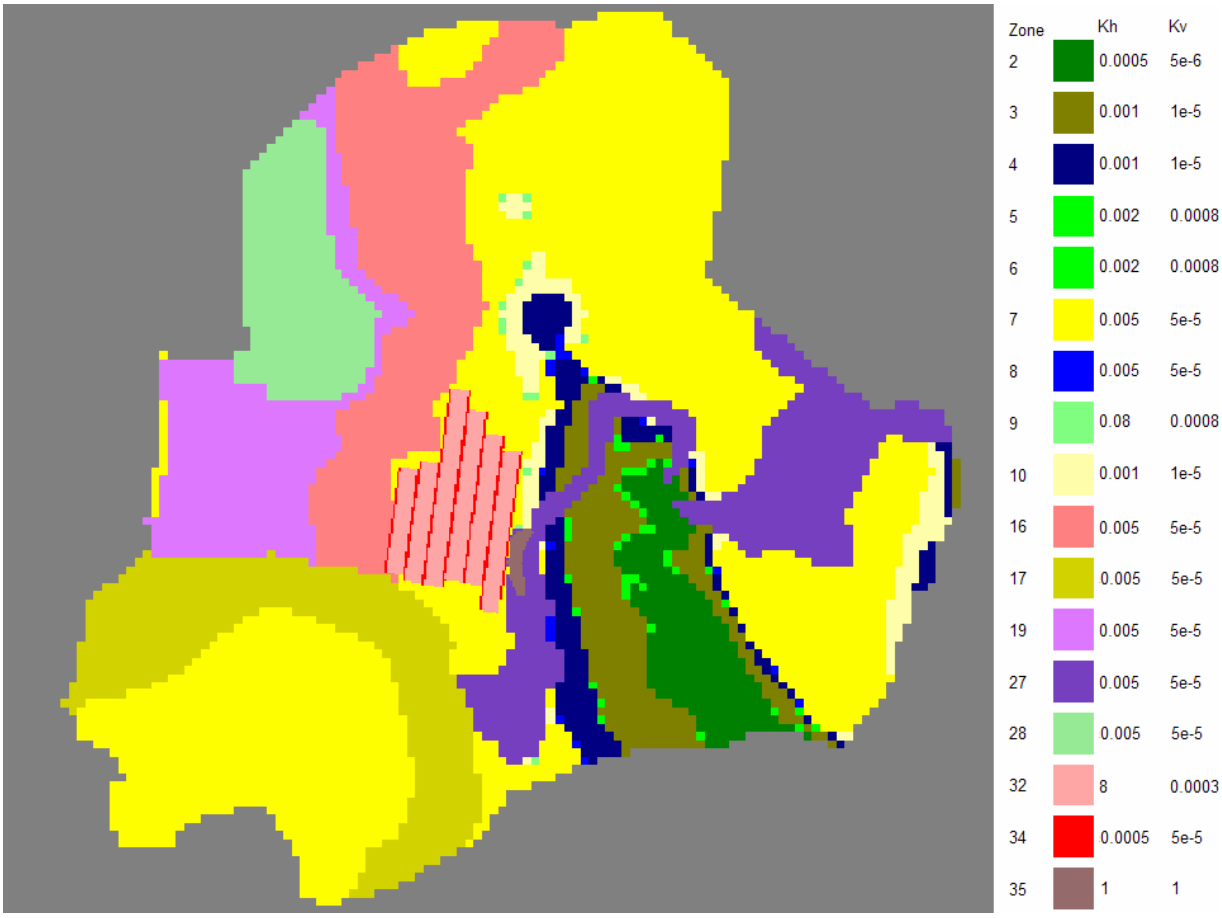
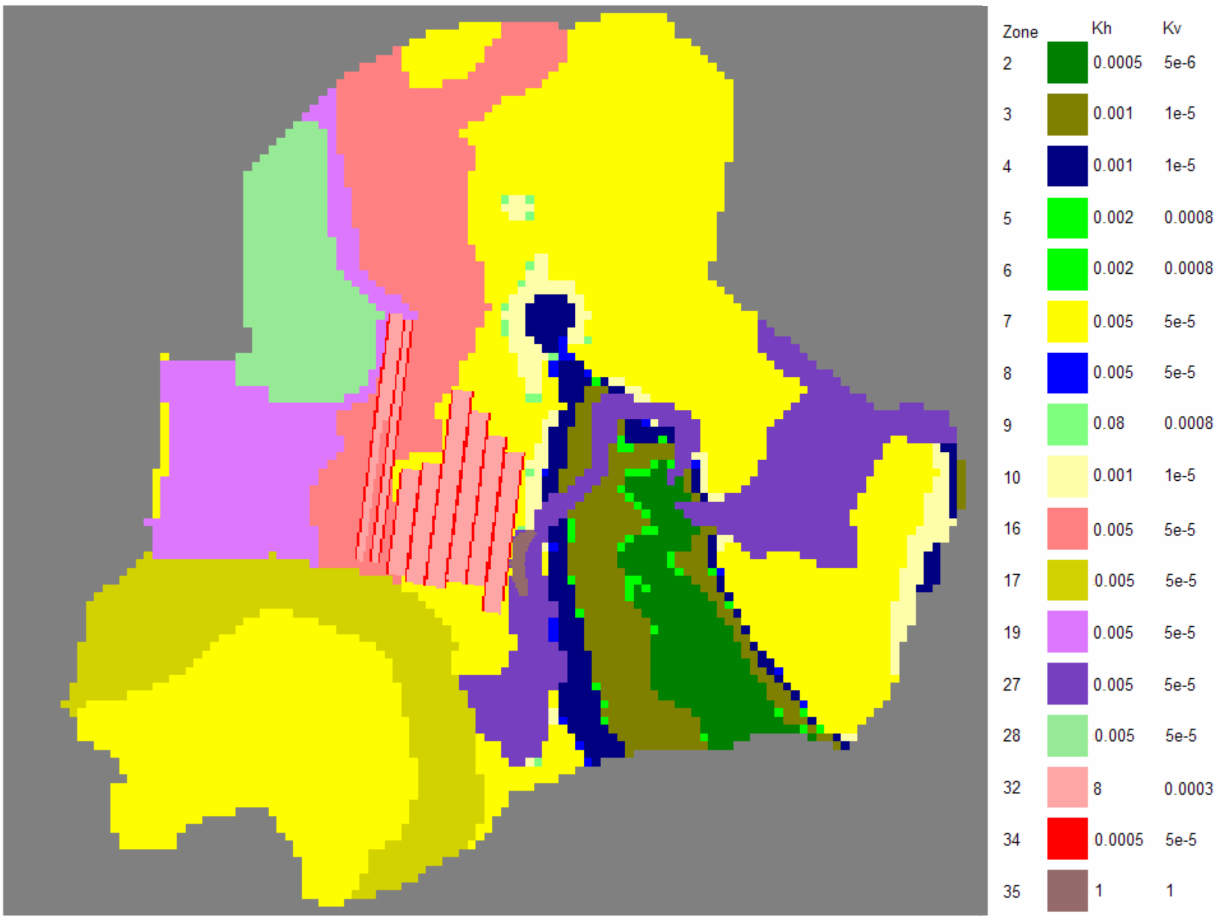
Hydraulic Conductivity in Layers 1 and 2
Figure B1





Note: Parameters shown are at the end of mining (stress period 57)

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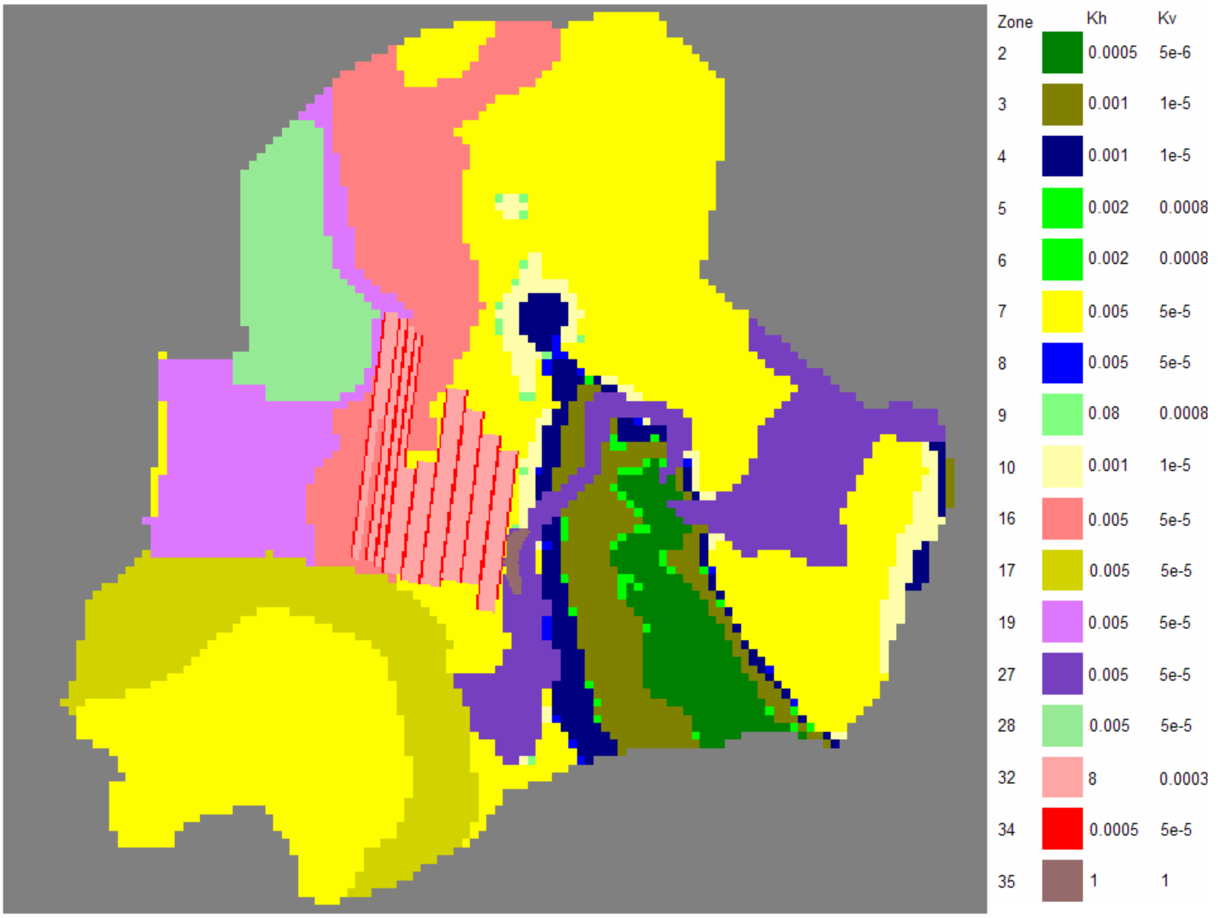
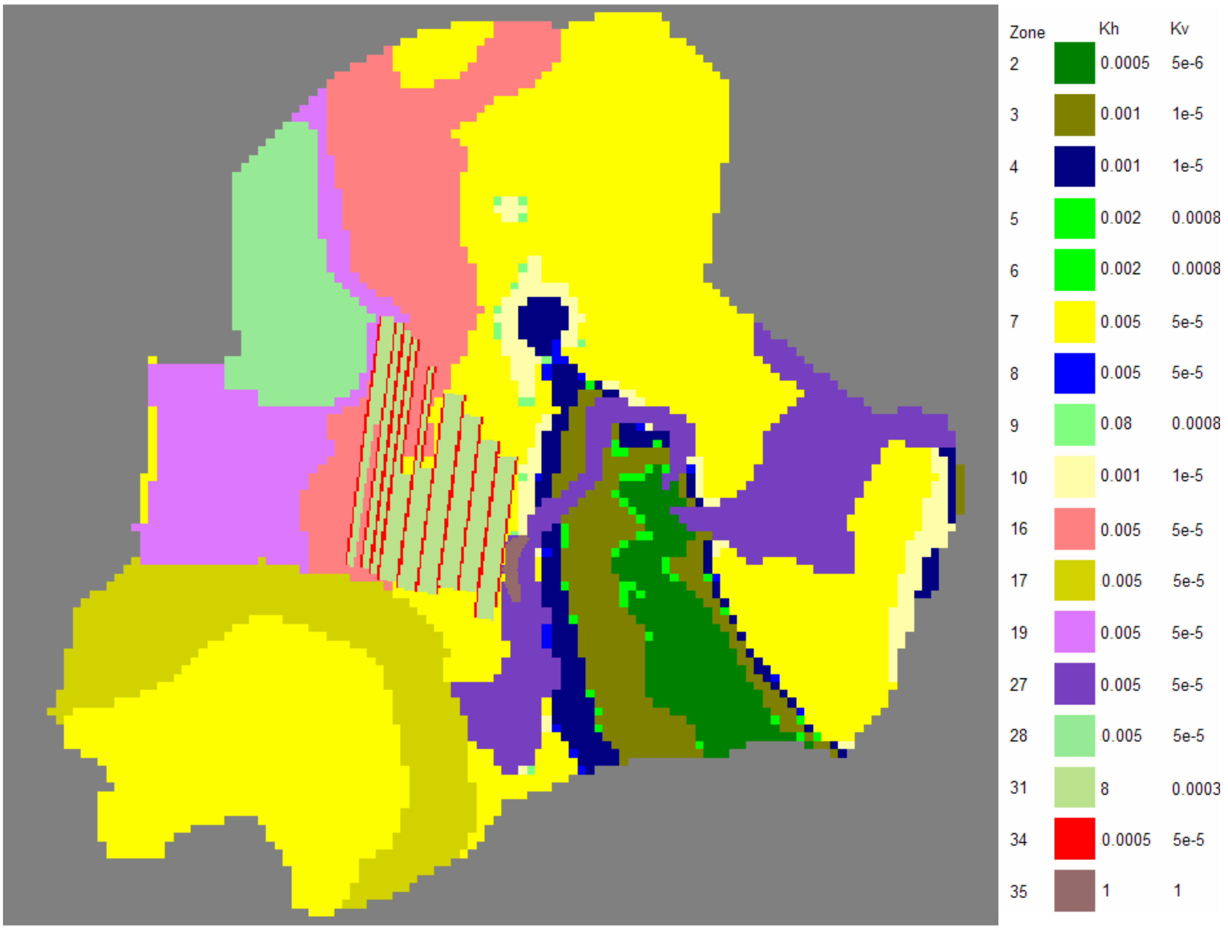
Hydraulic Conductivity in Layers 3 and 4
Figure B2





Note: Parameters shown are at the end of mining (stress period 57)

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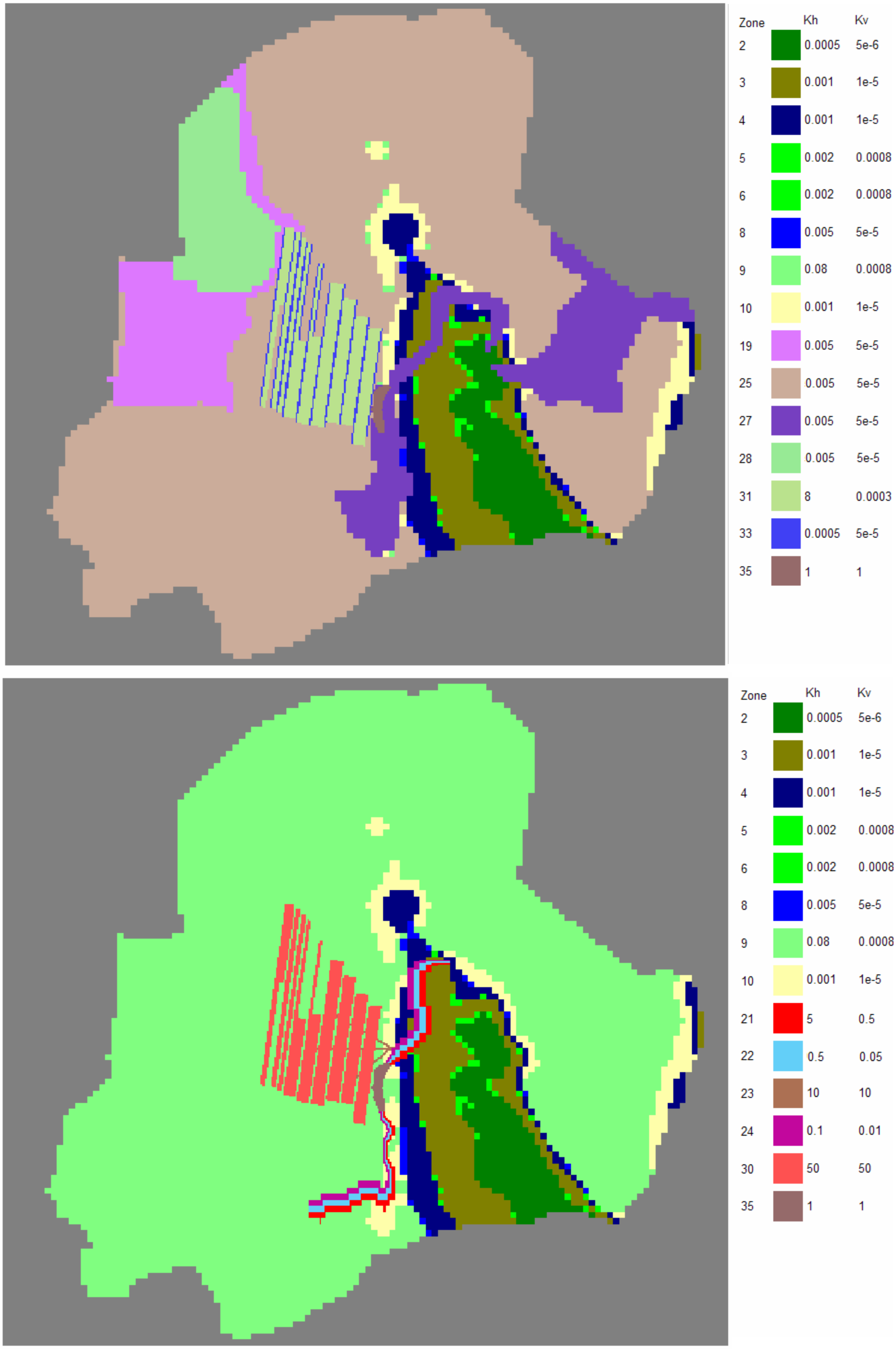
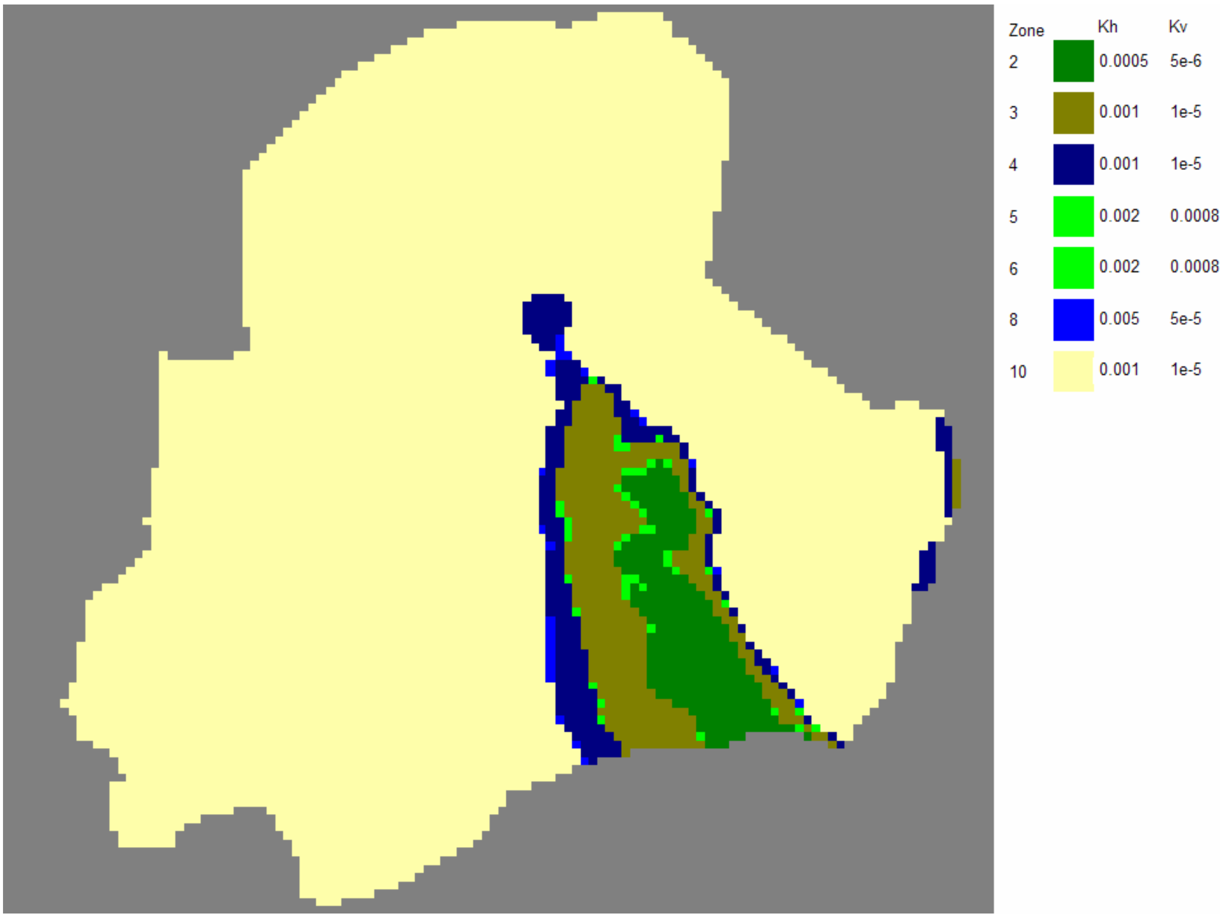
Hydraulic Conductivity in Layers 5 and 6
Figure B3



Note: Parameters shown are at the end of mining (stress period 57)



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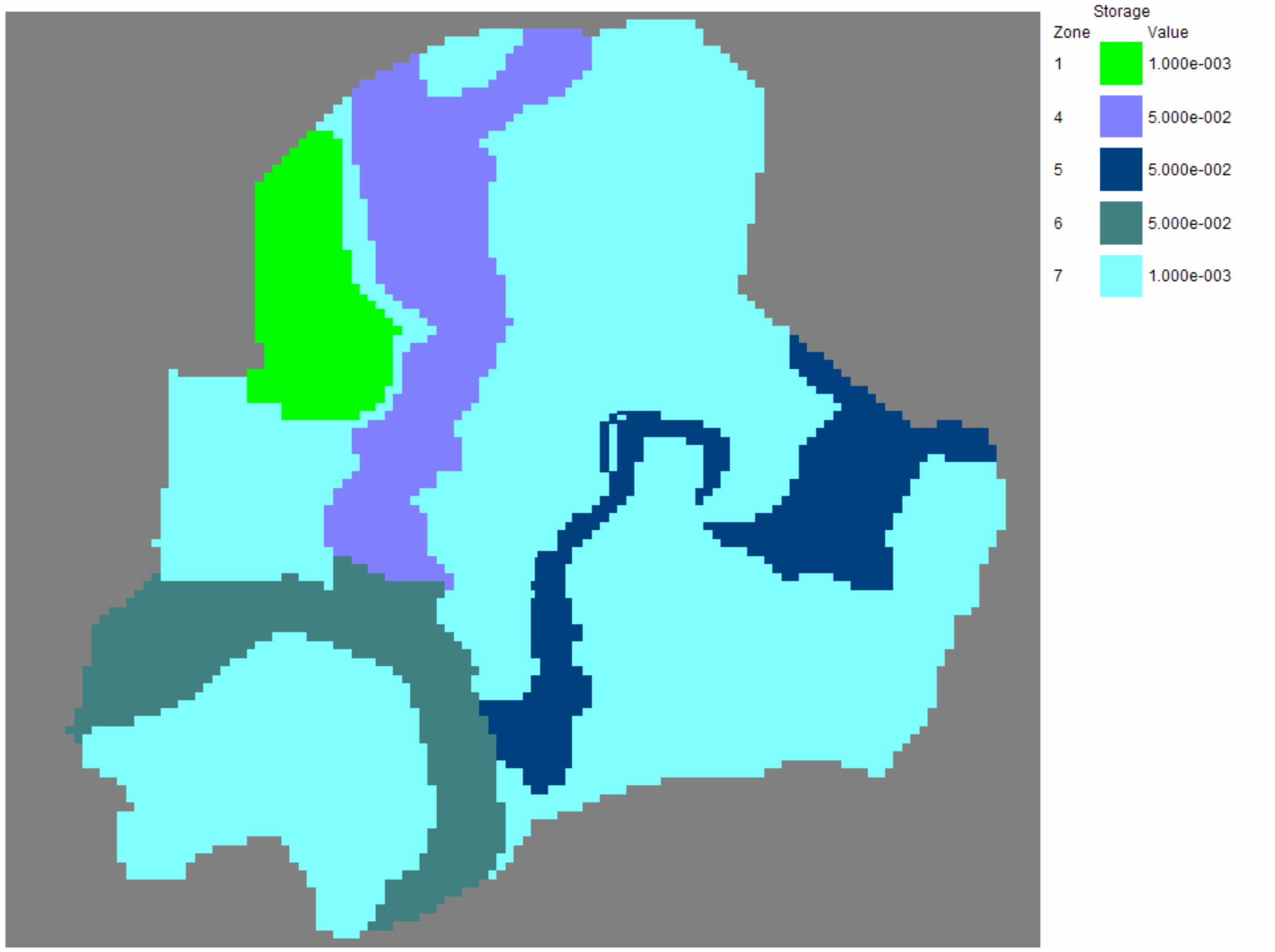
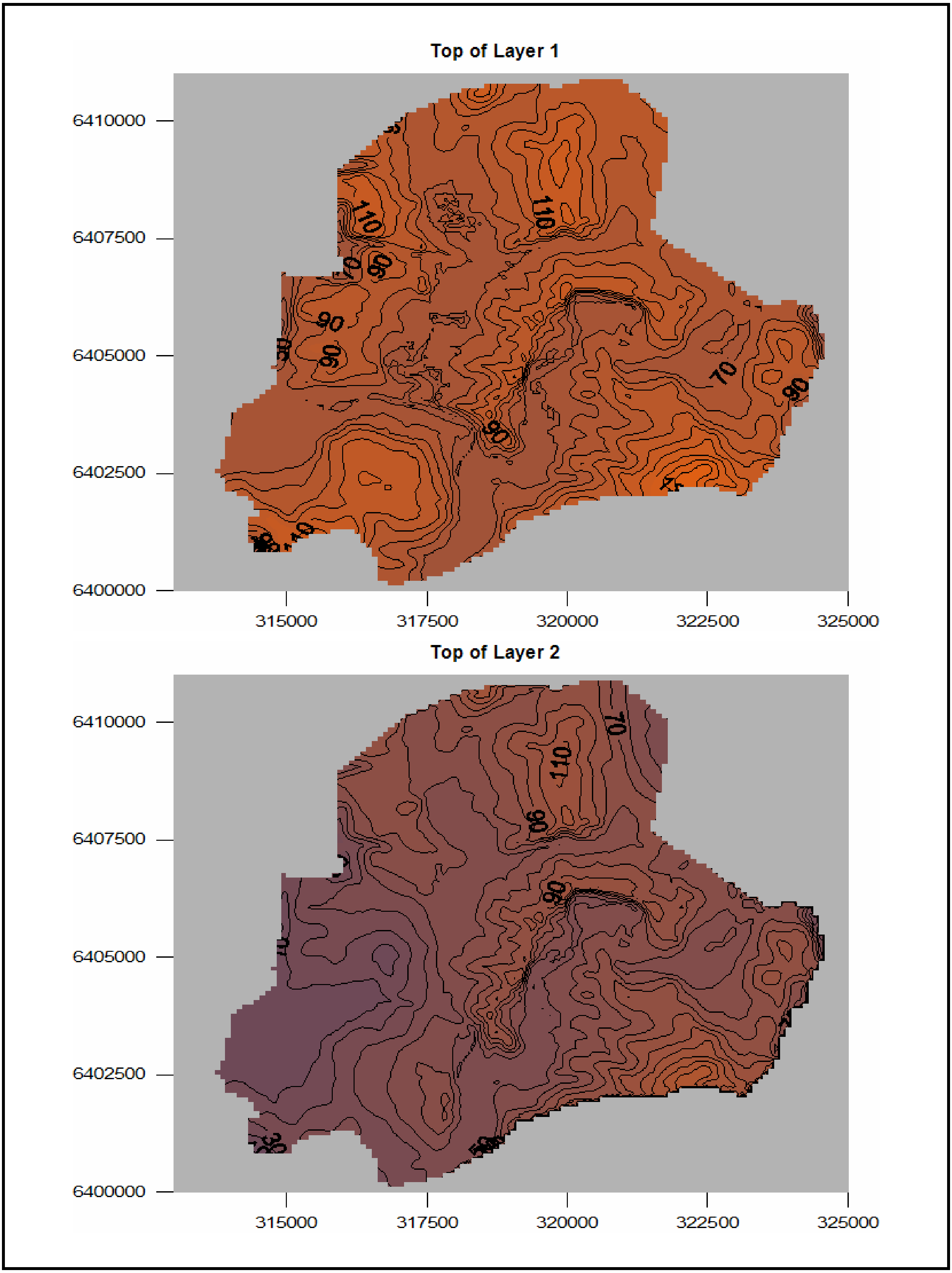
Hydraulic Conductivity in Layer 9
Figure B5



Note:

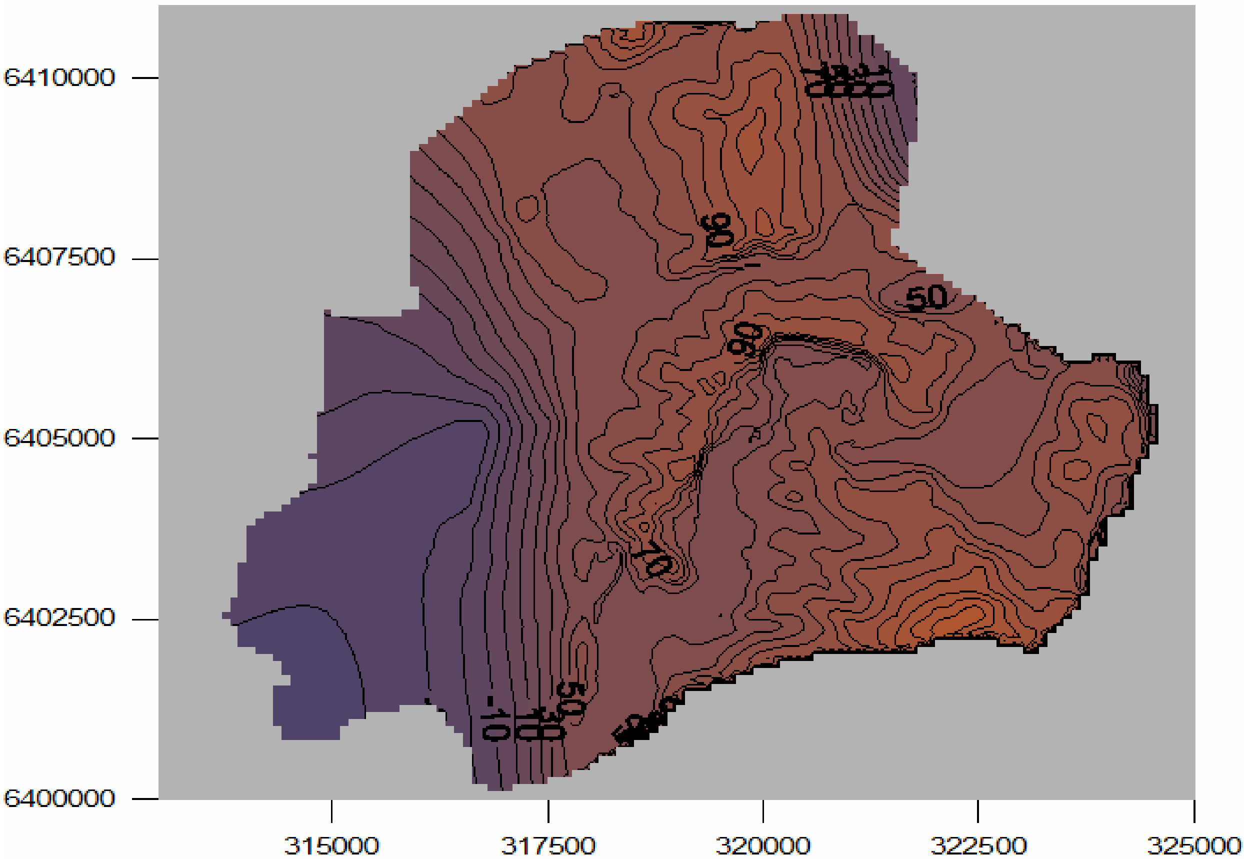
- Specific yield for layers 2 to 9 is set at $1e^{-3}$
- Storage coefficient is set at $5e^{-4}$ for layer 1 & 9 and $3e^{-4}$ for layers 2 to 8

Storage in Layer 1
Figure B6

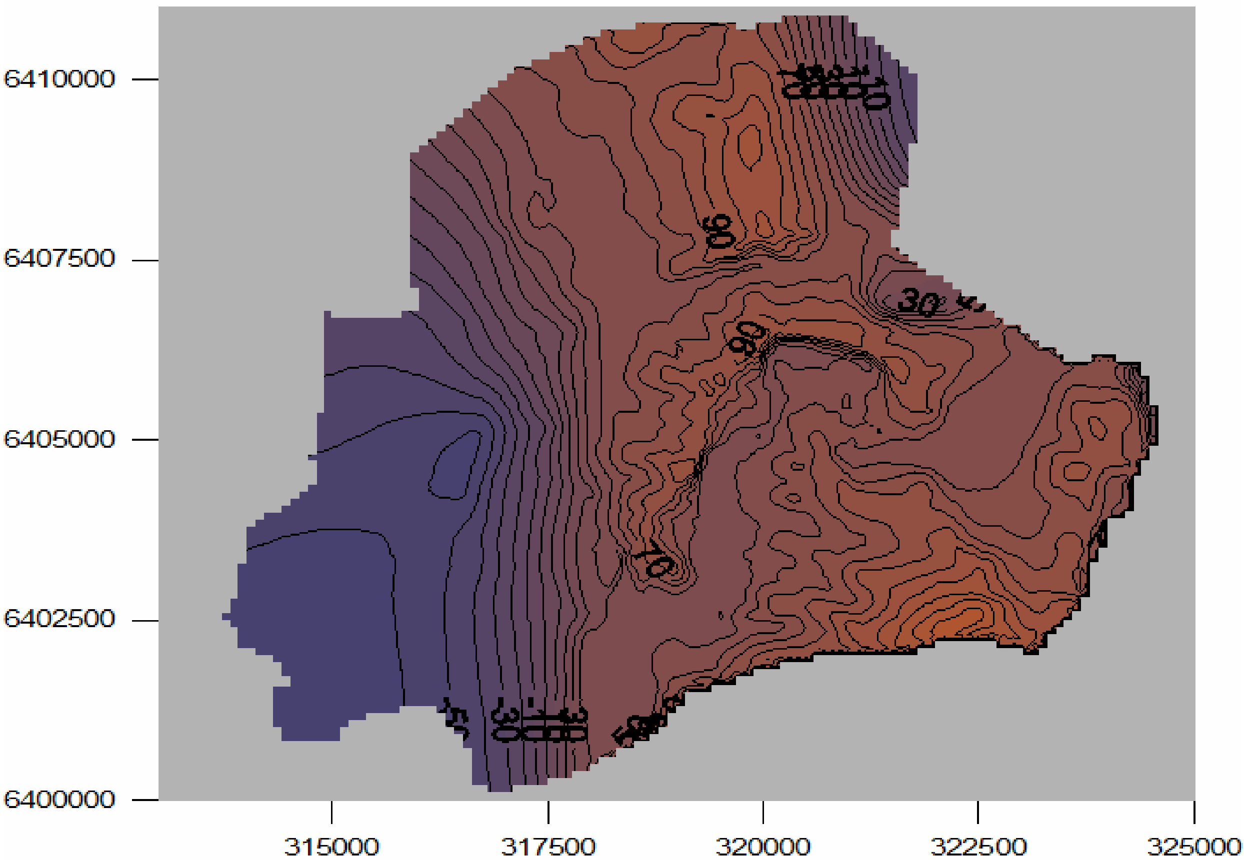


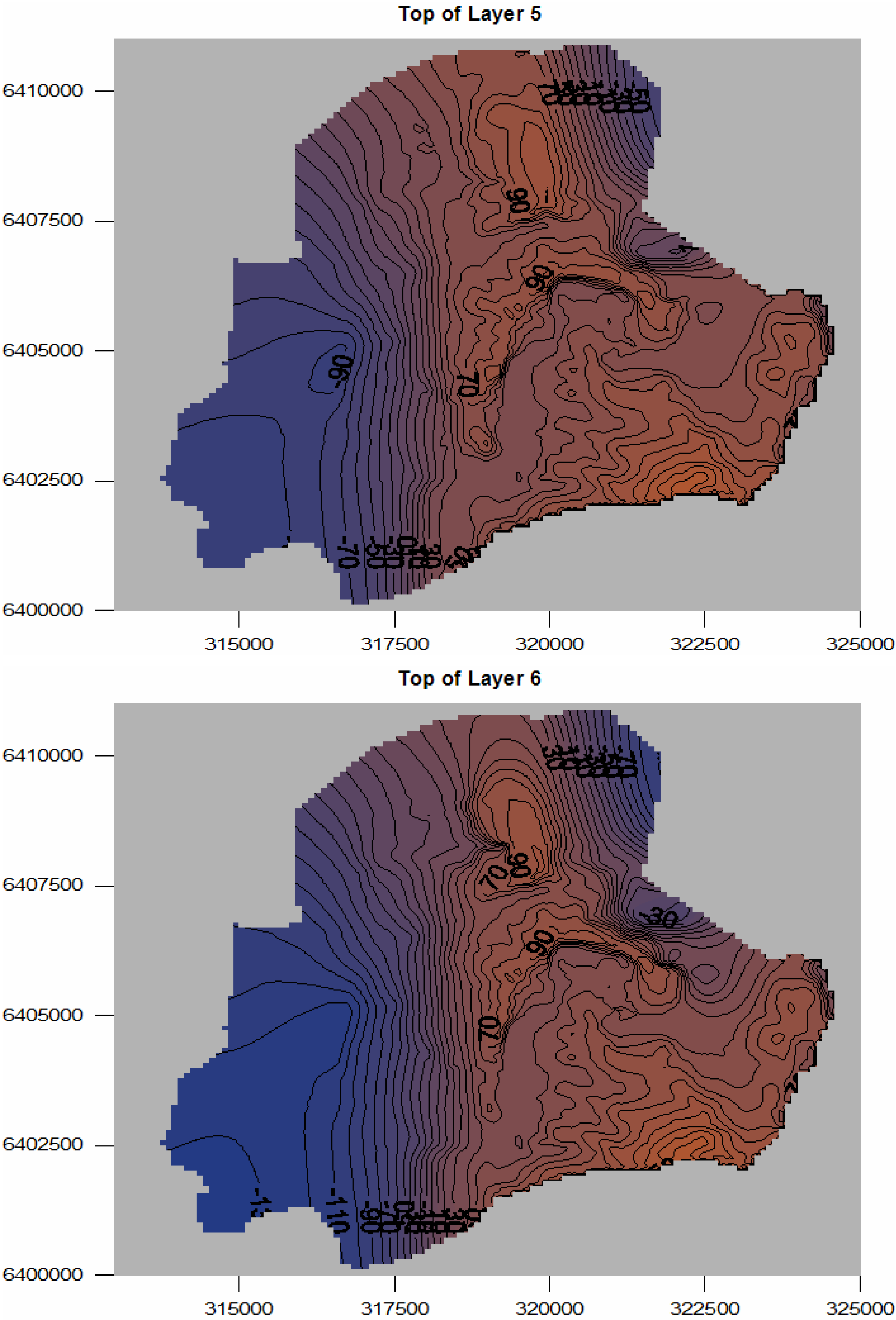
Top of Layers 1 and 2
Figure B7

Top of Layer 3

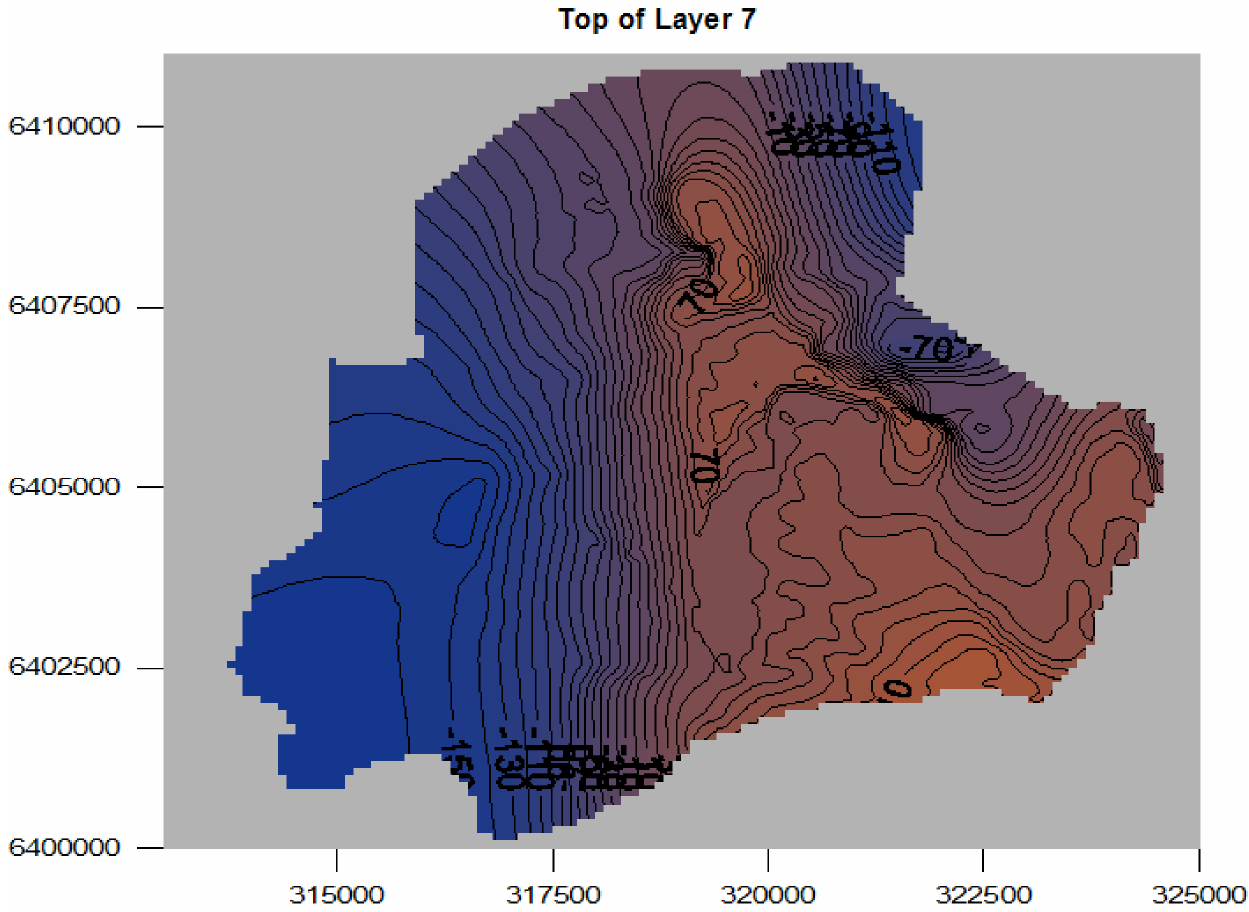


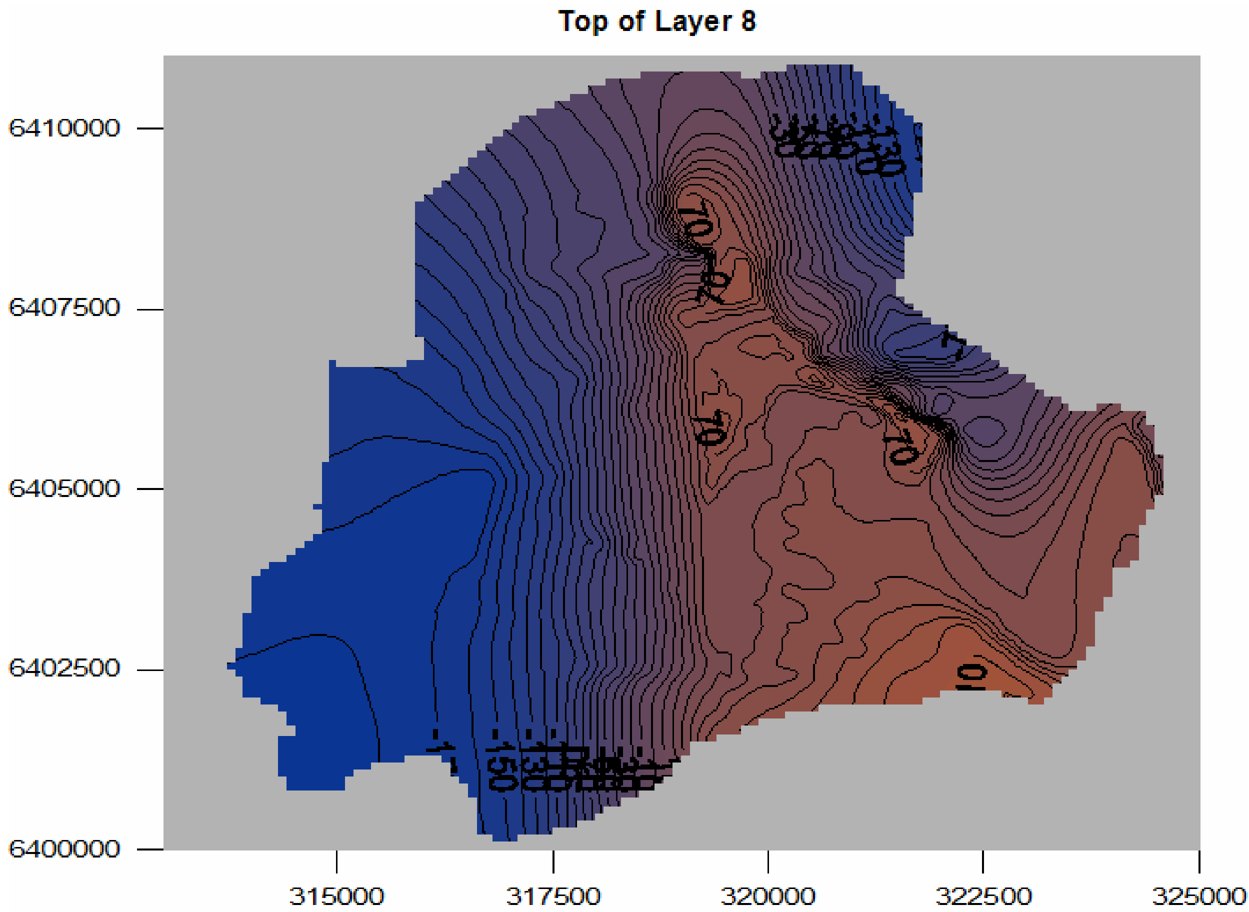
Top of Layer 4



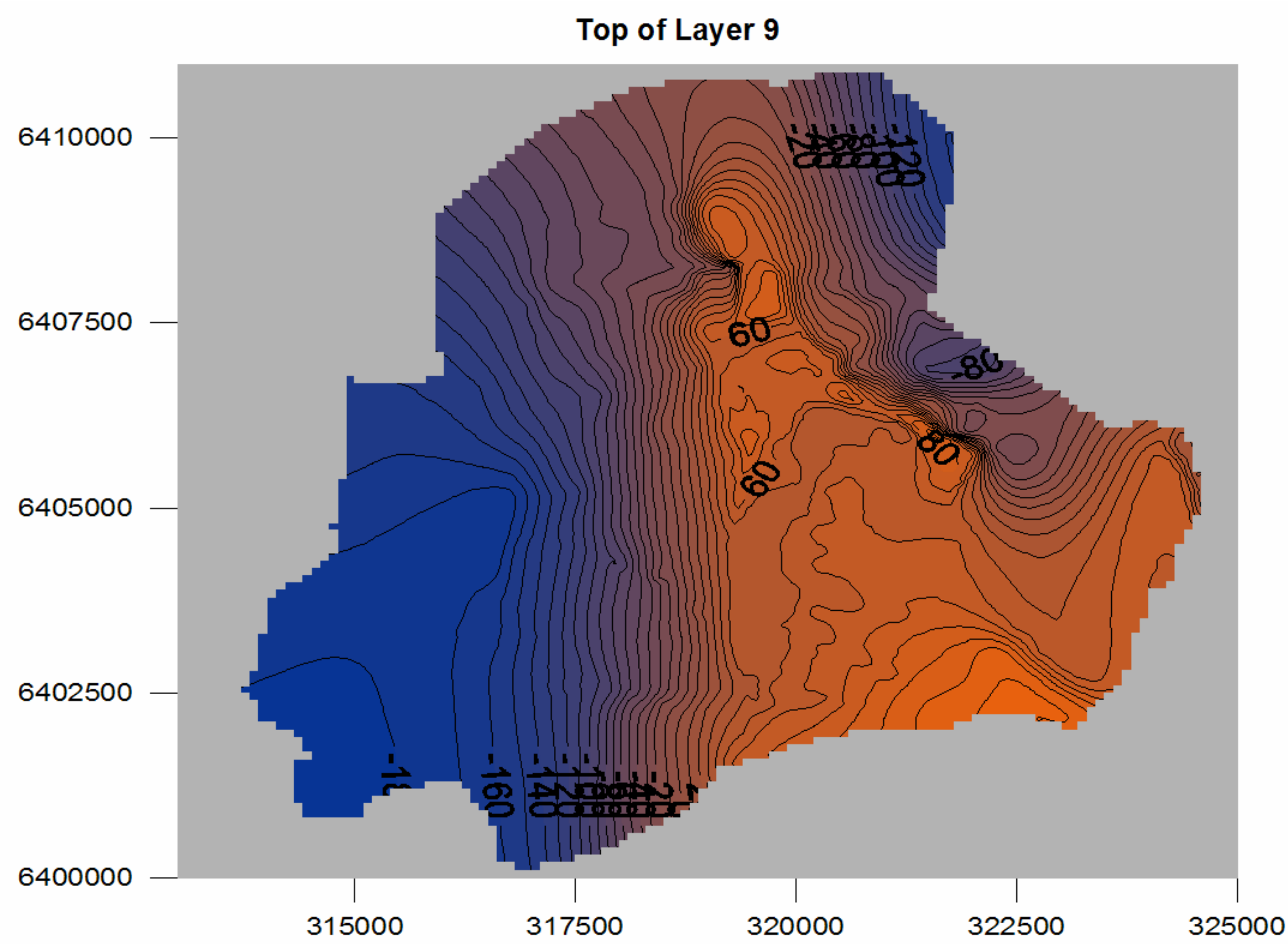


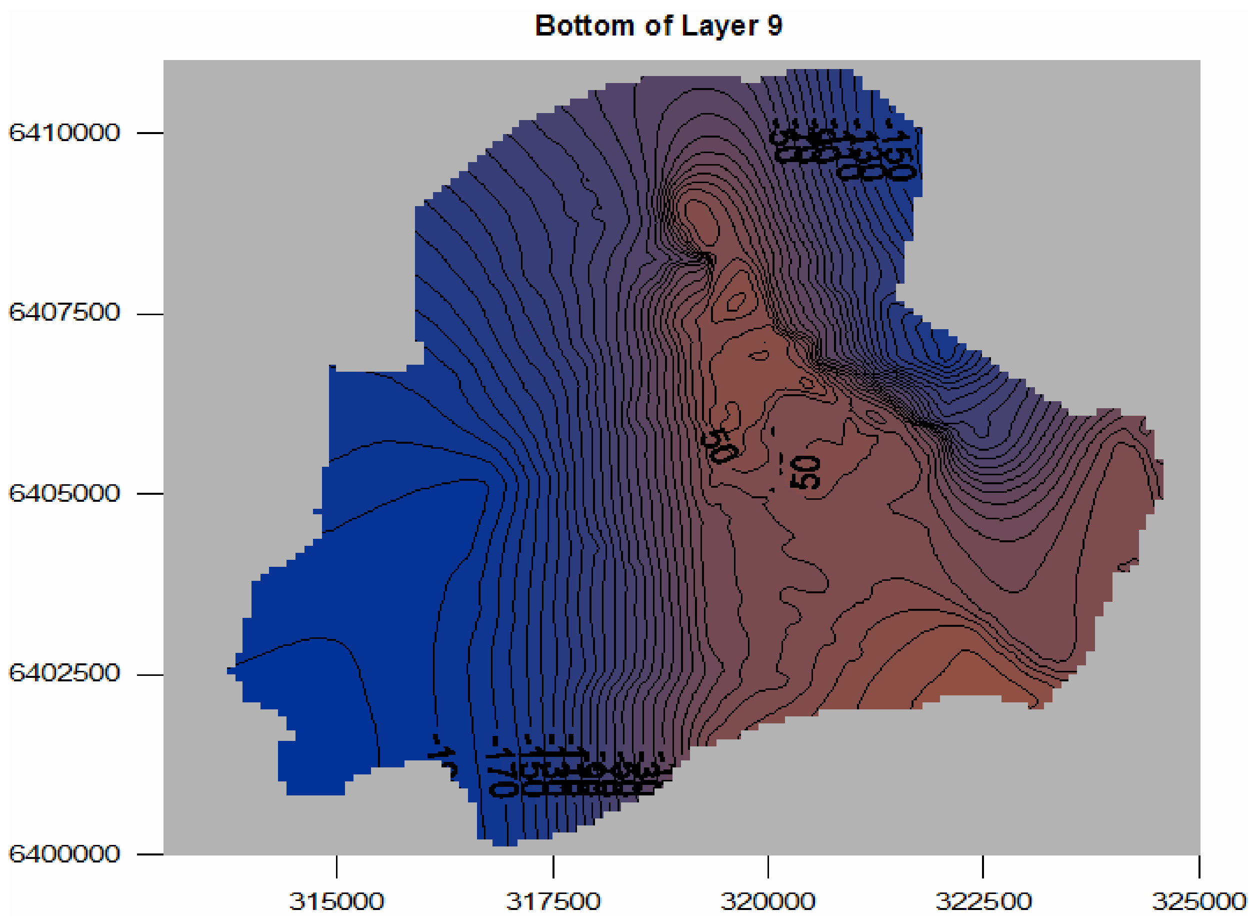
Top of Layers 5 and 6
Figure B9





Top of Layers 7 and 8
Figure B10





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Top and bottom of Layer 9
Figure B11