6 GROUNDWATER MODELLING

6.1 BACKGROUND

The Ashton Underground Mine (AUM) Model that has been developed for the Bowmans Creek Diversion assessment is largely based on the model that was used for the Ashton Longwall/Miniwall 5-9 Subsidence Management Plan (LW/MW 5-9 SMP) (Aquaterra, 2008), but with additional model layers introduced for the strata below the Pikes Gully Seam. This, in turn, had been developed from the model that was created for the 2001 EIS (HLA, 2001), albeit with significant changes. The results of ongoing monitoring, as described in Sections 2 and 4, have been used to improve the model from the version used for the LW/MW 5-9 SMP, both in terms of conceptual behaviour and calibration. Some improvements to model geometry, recharge and boundary conditions have also been made. The improvements in understanding of Glennies Creek and its associated alluvium gained during the South East Open Cut (SEOC) mine EA investigations (Aquaterra, 2009a) have also been included within the modelling.

The model structure, modelling approach, and the results of simulations are discussed in the following sections. A model calibration report, which contains some further technical details of the model set up, and full results of the model calibration process, is provided in Appendix E.

One of the key differences between this model and the model used in the 2001 EIS assessment is that the pre-mining groundwater heads within the various strata layers are much more realistically represented. In particular, the current model adequately represents the general upwards pressure gradient that is known to have existed within the Permian across the study area prior to commencement of Ashton mining. This was not well represented in the 2001 modelling.

6.2 THE GROUNDWATER MODEL

6.2.1 MODELLING SOFTWARE

A 3-Dimensional finite difference model has been used, based on the MODLFOW code (McDonald and Harbaugh, 1988) in conjunction with SURFACT (Version 3) code to allow for both saturated and unsaturated flow conditions using the pseudo soil function in SURFACT. The modelling has been undertaken using the Groundwater Vistas (Version 5.16) software package.

The model was set up to simulate groundwater conditions over a 132km^2 area. Because of the strong influence of other mining activities in the area, the model has explicitly included the progressive mining of the North East Open Cut (NEOC), the proposed SEOC and the ongoing underground mining of the adjacent Ravensworth longwall mine, plus the effects of existing open cut mines such as the Narama pit and the former Ravensworth open cut.

6.2.2 CONCEPTUAL MODEL DESIGN

The conceptual model is a simplified representation of the real system, identifying the most important geological units and hydrogeological processes, while acknowledging that the real system is hydrologically and geologically more complex. The conceptual model forms the basis for the computational groundwater flow model. The key conceptual model features of the Ashton Underground Mine model that was used for the Bowmans Creek Diversion project are described below, and are illustrated in Figures 6.1 and 6.2.

Geology and Hydrogeology

The local geology has been represented by 15 model layers. These are largely defined by the main coal seams and the interburden intervals, and the top layer (Layer 1) physically represents the weathered regolith and the areas of river/creek alluvium. The overburden above the Pikes Gully seam has been divided into 6 layers to allow for meaningful hydrogeological representation of the overlying coal measures and the impact of longwall mining on those coal measures. A typical model cross section (representing the line A-A' on Figure 6.1) is shown in Figure 6.2. A summary description of the model layers that have been used is as follows:

- **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 – this has been split into a number of layers to allow the simulation of fracturing to be assigned progressively 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.

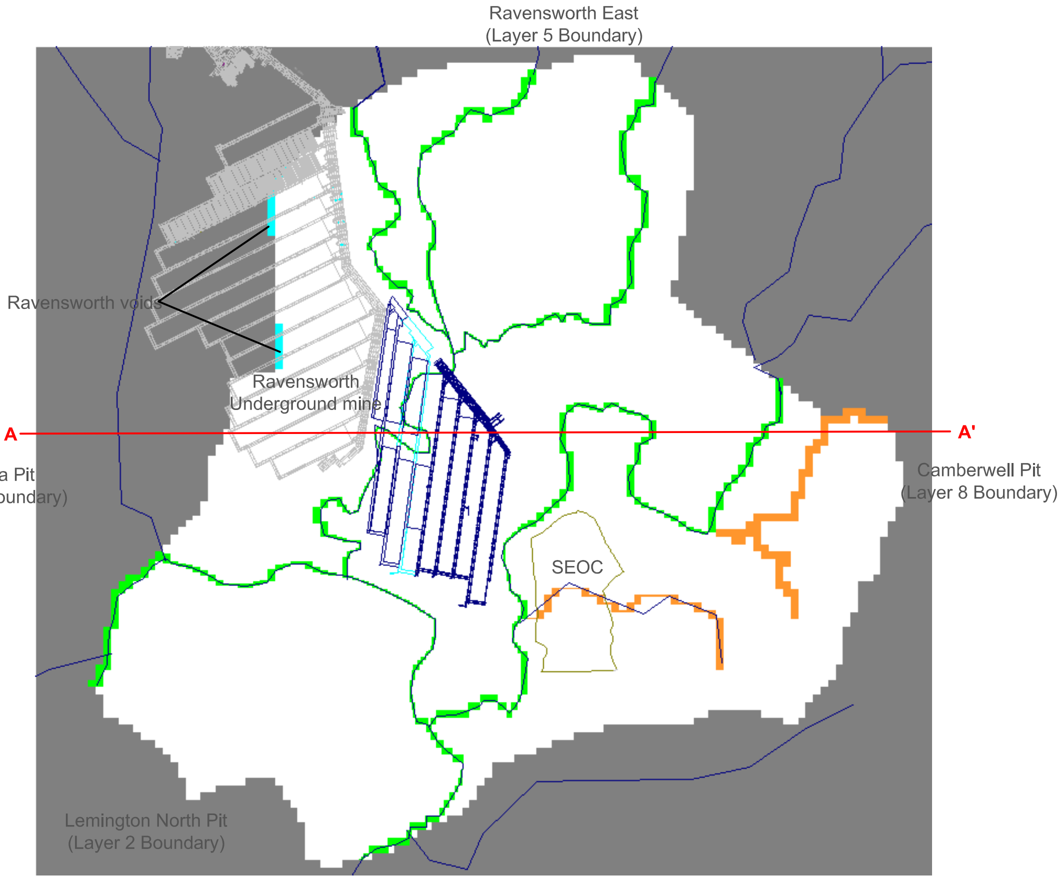


Figure 6.1

White Cells are Active
Grey Cells are inactive
(no flow)

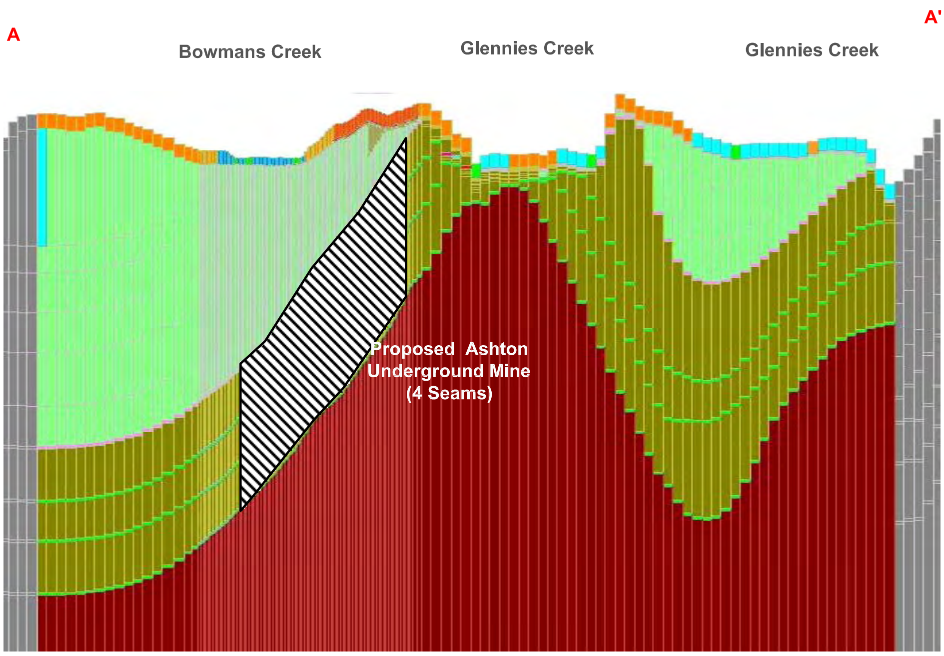


Figure 6.2

Date: 19 August 2009	Scale: as indicated	**Ashton Coal Operations Ltd**
Initials: JVDA	Job No: S55G	**Groundwater Model Domain and Model Cross Section**
Drawing No: S55G-030	Rev: A	
aquaterra		

The model geometry is largely defined by physical features. The boundaries of river alluvium have been defined using the findings of previous investigations and investigations for nearby projects, as discussed in Section 4 (including site visits, aerial reconnaissance, core samples and geochemistry) and layer thicknesses set up in accordance with drilling results. The deeper layers (Layer 8 downwards) have all been defined according to the Ashton coal resource models, with thicknesses as described in Table 4.2. For the overburden, thicknesses have been defined to allow for the different ‘zones’ of hydraulic impacts caused by the longwall subsidence, as described in Section 6.3.1.

The permeability and storage of the model layers has been assigned in accordance with the results of the hydraulic testing described in Section 4.5. Layer thicknesses and the final, calibrated values of horizontal and vertical permeability and storage that have been used within the model are shown in Table 6.1.

Table 6.1: Layer Thicknesses and Hydraulic Parameters*

Layer	Geological Unit	Thickness (m)	In Situ Kh (m/d)	In Situ Kv (m/d)	Confined Storage (Sc)	Unconfined Storage (Sy)
1	Bowmans Ck Alluvium	Variable, based on drilling results	0.5	5×10^{-6}	5×10^{-4}	0.05
	Regolith (weathered Permian)	10 (Nominal thickness)	0.1	5×10^{-6}	5×10^{-4}	0.001
	Glennies Creek Alluvium	Variable, based on drilling results	Variable, see Appendix E	5×10^{-6}	5×10^{-4}	0.05
	Hunter River Alluvium	Variable, based on 15m maximum depth and valley geometry	45	5×10^{-6}	5×10^{-4}	0.05
	Ravensworth spoil	Based on Bayswater Seam floor levels	0.02	5×10^{-6}	5×10^{-4}	0.001
2	PG overburden	Residual thickness between L1 and L3 (thickness variable due to dip on strata)	0.005	5×10^{-5}	3×10^{-4}	0.001
3	PG overburden	20	0.005	5×10^{-5}	3×10^{-4}	0.001
4	PG overburden	30	0.005	5×10^{-5}	3×10^{-4}	0.001
5	PG overburden	30	0.005	5×10^{-5}	3×10^{-4}	0.001
6	PG overburden	40	0.005	5×10^{-5}	3×10^{-4}	0.001
7	PG overburden	30	0.005	5×10^{-5}	3×10^{-4}	0.001
8	PG Seam	2	0.08	8×10^{-4}	3×10^{-4}	0.001
9	PG – ULD interburden	35 – 40	0.001	1×10^{-5}	3×10^{-4}	0.001
10	Upper Liddell Seam	2	0.02	2×10^{-4}	3×10^{-4}	0.001
11	ULD-ULLD interburden	30	0.001	1×10^{-5}	3×10^{-4}	0.001
12	Upper Lower	2	0.02	2×10^{-4}	3×10^{-4}	0.001

Layer	Geological Unit	Thickness (m)	In Situ Kh (m/d)	In Situ Kv (m/d)	Confined Storage (Sc)	Unconfined Storage (Sy)
	Liddell Seam					
13	ULLD – LB	40	0.001	1×10^{-5}	3×10^{-4}	0.001
14	Lower Barrett Seam	2	0.02	2×10^{-4}	3×10^{-4}	0.001

*these values represent general rock mass properties. Some other values are contained within the model to represent specific features. These are described, where appropriate, in the text within this section.

Groundwater Flow Pattern

As discussed in Section 6.4.1, the observed groundwater heads prior to underground mining at Ashton or Ravensworth have been used to calibrate the steady state model and ensure that the regional flow pattern is well represented. In particular, care has been taken to ensure that the model reflects the observed effect where groundwater contours in the deeper Permian layers are controlled by the heights of the elevated recharge zones. This results in an upward gradient from deeper to shallower layers, and artesian conditions in some parts of the Bowmans Creek valley. Modelled groundwater heads in the alluvium/regolith (model Layer 1) and the Pikes Gully seam (model Layer 8) prior to the Ashton underground mining are shown in Figure 6.3.

Flow within valley alluvium is largely dominated by local recharge by infiltration of rainfall, and connectivity with the creeks and rivers allowing baseflow to occur as the primary discharge mechanism. The amount of baseflow contribution to the rivers varies according to the amount of recharge and the permeability of the alluvium, and is small in magnitude through the Ashton mine area. Flow within the alluvium is generally along the valleys and inwards towards the rivers.

The deeper regional flow pattern around the mine area on the western side of the Camberwell anticline is generally towards the southwest. This has been well represented by the set up of recharge areas, creeks and boundary conditions contained within the model, including the presence of the former Ravensworth open cut mine. Because the target seams sub-crop on the western limb of the anticline, the hydrogeology of the model area to the east of the anticline has almost no influence on the area around the mine.

Surface Drainage and River Baseflow

Glennies Creek, Bowmans Creek and the Hunter River are represented in the model using river cells to allow for stream-aquifer interaction. River heights have been based on both topography and creek/river water levels at monitoring points to represent river stage heights as accurately as possible. Where measured river/creek stage elevations have been available, these have been checked against the stages contained in the model. The creek bed is assumed to be 1m below the stage elevation.

The effect of river bed sediments and geometry upon the hydraulic interaction between the creek/river and the alluvial aquifer is controlled by the streambed conductance parameter. This has been set to 25 m^2/d for smaller cells in Glennies Creek and Bowmans Creek, to up to 100 m^2/d for the bed of the Hunter River.

Baseflow contribution to river and creek features represents one of the primary natural groundwater discharge processes for the alluvium (the other main discharge process applicable to this area being evapotranspiration). When groundwater levels within the alluvium are higher than the stage elevations, the river/creek 'gains' water as dictated by the relative levels and the streambed conductance. When groundwater levels are lower than the river/creek stage they may lose water by seepage to adjacent or underlying aquifers, again in accordance with the relative levels and bed conductance. The river/creek is then considered to be 'losing' water to form groundwater recharge in those areas. The Ashton Underground Model is designed to allow both processes (i.e. 'gaining' baseflow discharge and 'losing' groundwater recharge) to occur.

Where ephemeral streams are present within the area, these have been represented within the model as drain cells. These simply drain water from the model once groundwater levels are higher than the drain bed level.

Because the Pikes Gully seam is known to outcrop within or alongside the channel Glennies Creek near the mine, a specific modelling approach has been used to represent this connection. A very high value of horizontal and vertical permeability (10 m/d) has been used in the alluvium, which ensures connection between the Pikes Gully seam and the Glennies creek alluvium. A zone of enhanced horizontal permeability was identified in this area during test pumping, probably a result of in-situ stress relief that is caused by the escarpment.

Recharge

Recharge processes in the model area are discussed in Section 4.9. Average long-term monthly rainfall data for the project area are presented in Section 4.2.1. The demarcation of recharge zones is shown in Appendix E.

Recharge input to the model largely follows that used in the previous modelling work (HLA, 2001; Aquaterra, 2008), although some modifications were made to improve steady state calibration and model stability. For areas where the Hunter River and Bowmans Creek 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 the Glennies Creek alluvium and the Ravensworth pit backfill is present. These values are based around a 'standard' 0.5% to 1% recharge for alluvium in this area, and have been modified to local conditions as part of the model calibration process.

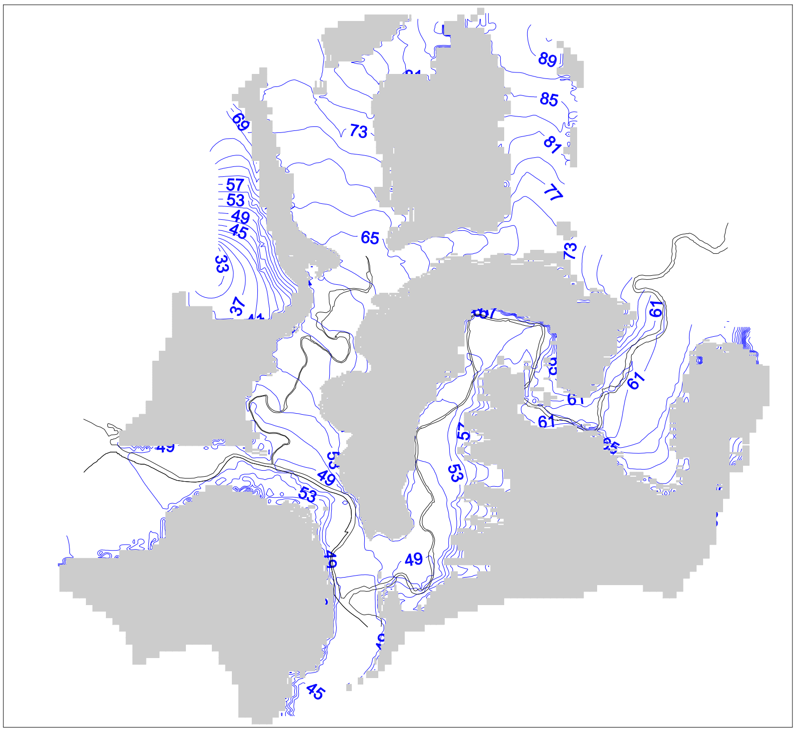
Everywhere else, the recharge rate is set to 0.2 % of average annual precipitation, except where the basal model layers sub-crop along the axis of the Camberwell syncline. Recharge has been halved in this area due to the highly impermeable nature of the strata. Recharge is modelled so it is applied to the highest active layer. Overall recharge rates have been maintained at an average of 0.17%, as detailed within the HLA report (HLA 2001).

Monitoring evidence indicates that a greater degree of recharge occurs to coal seams in sloping areas where the seams are present as sub-crops. A higher recharge rate of 0.4% has therefore been applied to the relevant parts of the hillside above the proposed mine workings where the Lemington seams are known to sub-crop. As this is a sub-crop area, localised increases in Kv have also been applied in overlying 'dummy' layers to ensure that recharged water is able to enter the relevant sub-cropping coal seams.

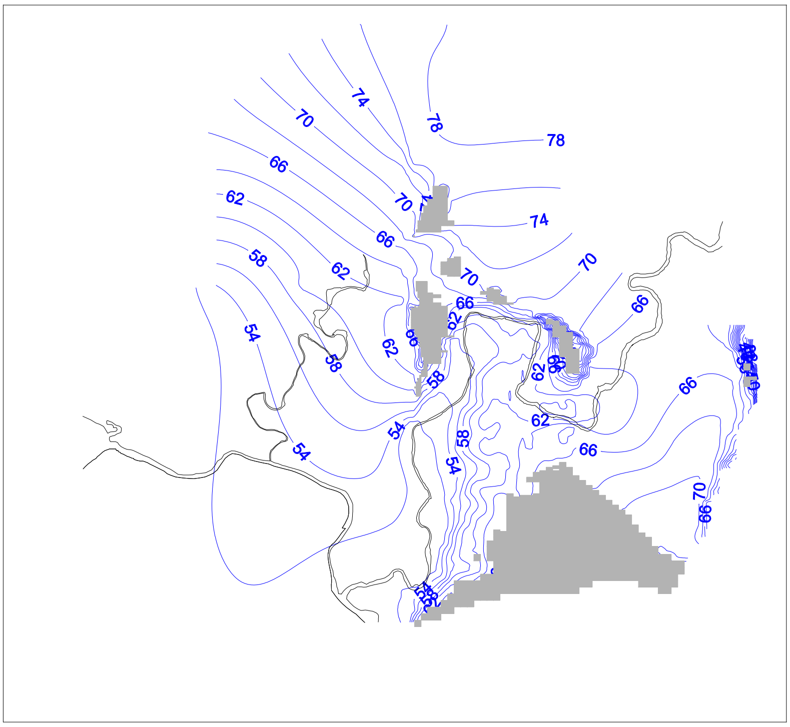
Evaporation is simulated using the Evapotranspiration (EVT) package of MODFLOW. An EVT extinction depth of 1.5 m has been used, which allows evapotranspiration to be active in areas of low topography and shallow water table. This generally occurs along surface watercourses such as Bowmans Creek, Glennies Creek and the Hunter River floodplain.

The creation of subsidence troughs and associated subsidence cracking within the Bowmans Creek flood plain caused by the proposed longwall mining creates specific, unusual recharge conditions that have been explicitly modelled as part of this impact assessment. The modelling processes that have been used are described in Section 6.3. Specific application of EVT to open pit voids is also described in Section 6.3.

Layer 1 Alluvium



Layer 8 Pikes Gully



Dry Cells

Groundwater elevation (mAHD)
2m Intervals

Date 20 August 2009	Scale As Shown	**Ashton Coal Operations Ltd**
Initials JVDA	Project S55G	**Modelled Groundwater Heads in the Steady State Model**
Drawing Number fig6.3.srf	Revision A	
aquaterra		**Figure 6.3**

6.2.3 MODEL DOMAIN AND BOUNDARY CONDITIONS

The domain and boundaries of the model are shown in Figure 6.1. Layer 1 groundwater levels are largely controlled by recharge (from rainfall) and discharge (to the creeks and rivers). For the remaining layers, groundwater levels are controlled by lateral and downward leakage, and the model boundary conditions. Most of the model has 'no flow' boundaries, which represent the general lack of movement in the deep Permian strata. However, the presence of other mines and regional de-watering can have an influence on these deeper groundwater conditions, so it is important to adequately represent the presence of other mines in the area. Based on currently available information and steady state calibration, the following mine related boundaries were represented using General Head Boundaries (GHBs) within the model during the steady state, pre Ashton underground modelling:

- Ravensworth No. 2 Pit and Ravensworth South Mine have been substantially backfilled with overburden. The GHB associated with the Ravensworth No.2 pit was set at the water level (+35 mAHD) monitored in the spoil in that area in 2008. The final void of the Ravensworth South Mine is believed to act as an evaporative discharge for groundwater, so the general head boundary in the model was set to 30 mAHD in this area.
- 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 GHB cells in this area were therefore set at the level of the Bayswater Seam.
- Towards the south-west, the model extends as far as the Hunter Valley Operations (HVO). The mining complex at HVO has grown through a process of expansion and acquisitions since 1979. The Lemington Pit marks the boundary of the groundwater model and GHB levels were set largely on the basis of iterations during the steady state calibration.
- Other pits such as the Camberwell and Glennies Creek mines were included in the model, but these are on the eastern side of the Camberwell anticline, so have less influence on groundwater levels in the Ashton underground area.

All GHB cells were assigned a conductance of 5 m^2/d.

During operational runs, strata above the RUM mine becomes progressively de-watered. In order to avoid water entering the model domain unrealistically by the presence of the GHBs close to DRAIN cells in the RUM and Narama open cut, these boundaries were progressively switched off as the RUM encroached upon them.

During the post mining phase, it was recognised that the model area encroaching upon the western no-flow boundary had become significantly de-watered by the underground mining at Ashton and Ravensworth. Once pumping ceases at Ravensworth, the regional groundwater levels outside of the model will cause water to flow back into the Permian model layers from that western side. This would not be adequately represented by a 'no flow' boundary, so a General Head Boundary (GHB) was set up for model layers 3 to 12 to represent flow back through the Permian strata into the western side of the model. The head at this boundary was set at 50m, which is representative of long term regional groundwater levels, and mimics the types of levels seen in the pre-mining steady state model. Conductance values for the GHB were calculated based on cell size and hydraulic conductivity in the Permian rock mass. This resulted in an assigned value of 0.0025 m^2/d.

6.3 SPECIFIC MODEL SIMULATION APPROACHES DURING OPERATIONAL MINING

There are a number of physical hydrogeological effects that are expected to occur during the proposed longwall mining project. These need to be represented using specific modelling approaches, including:

- Simulation of groundwater de-watering caused by both open cut and underground mining activities.
- Changes to the hydraulic nature of overburden material caused by the caving and subsidence above longwall panels.
- Changes to the hydrogeology of Bowmans Creek due to the creation of the diversion channels.

- Changes to the geometry and hydraulic nature of the Bowmans Creek alluvium due to the creation of subsidence toughs and surface cracking above LW6 and LW7.
- Effective impacts on groundwater recharge caused by the capture and infiltration of runoff within subsidence affected areas. Due to their low-lying, flat nature, this is particularly relevant for the subsidence affected areas within the Bowmans Creek floodplain.

6.3.1 SIMULATION OF UNDERGROUND MINE VOIDS

Underground mining and dewatering activity within the mined coal seams were represented in the AUM model using drain cells, with modelled drain elevations set to 0.1m above the base of the relevant coal seam layers. These drain cells were applied wherever workings occur, and were progressed in accordance to the Ashton and Ravensworth mine plans as detailed in Table 5.1. As well as the drains, the hydraulic conductivity of the goaf materials left within the coal seams was increased to a high value (50 m/d).

In order to simulate the active de-watering that will occur in the mine, all drain cells remained active in the model until the final end of mining. Post mining, all drain cells were switched off, although the high permeability of the remaining roadways and goaf materials within the seam was kept in place.

For the scenario that looked at ceasing mining after the Upper Liddell seam, drain cells within the Ashton area were switched off and the goaf and caved overburden properties were modelled as described for the recovery analysis in Section 6.3.6. The representation of drainage cells for the operational Ravensworth underground mine were continued for the remaining 9 years shown in Table 5.1, before the modelling of the recovery period started.

6.3.2 SIMULATION OF OVERBURDEN PERMEABILITY DURING MINING

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 the impact of progressive caving and fracturing associated with the mining of the four seams could be adequately represented.

The impact of multi-seam mining on the permeability of caved overburden has been based on experience of monitoring and groundwater modelling gained from the Ashton site to date, combined with the most recent research available for subsidence impacts on aquifer materials. The 'Aquifer Inflow Prediction above Longwall Panels' report to the Australian Coal Association Research Programme (ACARP) (SCT, 2008b) contains assessments of the impact of longwall caving on overlying rock mass permeability, based on the depth of overburden above the longwall seam and the degree of subsidence associated with the longwall panel. This includes more general assessments based on worldwide empirical experience, and some site specific computer modelling of permeability impacts in the Ashton area.

At lower subsidence values (i.e. during the Pikes Gully extraction), the modelling contained within the ACARP report, and the transient calibration for this study, indicate that three 'zones' of subsidence permeability should develop above the coal seam:

- A high permeability, caved zone that extends 60-70m above the seam (represented by Layers 6 and 7 in the model), where there is direct connectivity with the mined goaf, and vertical permeability has been increased to 5 m/d. Because of the blocky nature of the caving and the fact that a large degree of bed separation occurs, the horizontal permeability is assessed to be higher than this, at 50 m/d.

- A zone of 'tortuous cracking' that extends for a further 60-80m above that. Within this zone the enhanced permeability occurs due to discrete vertical fractures that connect with horizontal layer separation features, allowing water to travel between and along layer boundaries. The tortuous flow paths that are created along bed layers and down fractures result in a zone where the overall permeability is lower than the caved zone below. The SCT modelling indicates that the degree of connective horizontal and vertical fracturing should be similar within this zone, so a value of 0.05 m/d has been assigned to both the horizontal and vertical permeability. This has been set based on the SCT analysis, which suggests that the in-situ vertical permeability will increase by 3 orders of magnitude following subsidence.
- A 'barrier zone' above this, with no change to the in-situ permeability.

For higher amounts of subsidence (ULD extraction and below), permeability values from the SCT report have been used as a guideline, although experience has shown that these tend to over-estimate impacts. For the mining of the ULD seam (maximum surface subsidence of around 3m), the SCT report would suggest that a vertical conductivity of between 100 and 1000 m/d should be used. However, this only considers fracturing in the rock mass and does not allow for any infilling due to slaking of clays, mobilisation of fines, or variable plasticity leading to localised closing of fractures, and is believed to over-predict hydraulic continuity within the subsidence fracture system. A vertical permeability of 5 m/d has therefore been assumed for the 'tortuous' and 'barrier' zones (i.e. a 2 orders of magnitude increase), and 50 m/d has been assumed for the caved zone above the PG and ULD seams.

This assumption of lower permeability is supported by both the groundwater level and permeability testing discussed in Section 4.7. This shows that rock masses above the caved overburden are 'self healing' in some locations. This is almost certainly associated with swelling and sealing from mud rocks and silts, which serve to significantly reduce permeability values compared with the predictions of fissure dilation from the geotechnical modelling. Calibration against measured inflows for the Pikes Gully seam also supports this conclusion.

It should be noted that, as described in Section 6.10, analysis of the predicted impacts shows that they are not highly sensitive to the assumed value of vertical permeability within the caved overburden once the Pikes Gully seam has been mined. As discussed in Section 6.10, this is due to the geometry and hydrogeology of the site and overburden, which causes overburden Permian strata to become dewatered following relatively low levels of subsidence and increased permeability.

The SCT analysis shows that the subsidence associated with the ULLD and LB mining is likely to result in active, continuous cracking that extends through to the base of the alluvium/regolith. A maximum permeability of 50 m/d therefore been assigned to all overlying Permian layers. Again, this is below the SCT value, but it has been chosen as fairer representation of the actual permeability that would result from a highly fractured rock mass where fines and clays are available to provide at least partial clogging of the fractures. The adoption of this value is consistent with the observations of response to mining in panels LW1 to LW4 to date, but is considered to be conservative. This zone of high permeability has been extended down to the LB seam once that has been mined.

A summary of the modelled horizontal and vertical permeability of the rock mass above the longwall panels following extraction at the Ashton mine is shown in Table 6.2. These values have been determined based on the evidence discussed above.

Table 6.2: Hydraulic Parameters for Caved Overburden During Mining

Layer		Host permeability values		Hydraulic Conductivity following PG mining		Hydraulic Conductivity following ULD mining		Hydraulic Conductivity following ULLD mining		Hydraulic Conductivity following LB mining	
		Kh (m/d)	Kv (m/d)	Kh (m/d)	Kv (m/d)	Kh (m/d)	Kv (m/d)	Kh (m/d)	Kv (m/d)	Kh (m/d)	Kv (m/d)
2	Pikes Gully Seam Overburden	5.00E-03	5.00E-05	no change	no change	5.00E+00	5.00E+00	5.00E+01	5.00E+01	5.00E+01	5.00E+01
3	Pikes Gully Seam Overburden	5.00E-03	5.00E-05	5.00E-02	5.00E-02	5.00E+00	5.00E+00	5.00E+01	5.00E+01	5.00E+01	5.00E+01
4	Pikes Gully Seam Overburden	5.00E-03	5.00E-05	5.00E-02	5.00E-02	5.00E+00	5.00E+00	5.00E+01	5.00E+01	5.00E+01	5.00E+01
5	Pikes Gully Seam Overburden	5.00E-03	5.00E-05	5.00E-02	5.00E-02	5.00E+00	5.00E+00	5.00E+01	5.00E+01	5.00E+01	5.00E+01
6	Pikes Gully Seam Overburden	5.00E-03	5.00E-05	5.00E+01	5.00E+00	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01
7	Pikes Gully Seam Overburden	5.00E-03	5.00E-05	5.00E+01	5.00E+00	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01
8	Pikes Gully Seam	8.00E-02	8.00E-04	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01
9	Pikes Gully - Upper Liddell Interburden	1.00E-03	1.00E-05			5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01
10	Upper Liddell Seam	2.00E-02	2.00E-04			5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01
11	Upper Liddell - Upper Lower Liddell Interburden	1.00E-03	1.00E-05					5.00E+01	5.00E+01	5.00E+01	5.00E+01
12	Upper Lower Liddell Seam	2.00E-02	2.00E-04					5.00E+01	5.00E+01	5.00E+01	5.00E+01

Layer		Host permeability values		Hydraulic Conductivity following PG mining		Hydraulic Conductivity following ULD mining		Hydraulic Conductivity following ULLD mining		Hydraulic Conductivity following LB mining	
		Kh (m/d)	**Kv (m/d)**	**Kh (m/d)**	**Kv (m/d)**	**Kh (m/d)**	**Kv (m/d)**	**Kh (m/d)**	**Kv (m/d)**	**Kh (m/d)**	**Kv (m/d)**
13	Upper Lower Liddell - Lower Barrett Interburden	1.00E-03	1.00E-05							5.00E+01	5.00E+01
14	Lower Barrett Seam	2.00E-02	2.00E-04							5.00E+01	5.00E+01
15	Lower Barrett - Upper Hebden Interburden	5.00E-04	5.00E-06								

In addition to the modelling of the subsidence zone itself, it is necessary to include an adjustment to the horizontal hydraulic conductivity that results around the periphery of the subsidence zone. Because subsidence of the horizontal strata causes a dislocation of the predominantly horizontal flow paths at the edges of longwall panels, horizontal hydraulic continuity is reduced around the perimeter of the longwall extraction areas. This has been accounted for by a reduction in horizontal hydraulic conductivity in the strata above the chain pillars and around the perimeters of the longwall panels (in the model, Kh has been reduced by an order of magnitude).

6.3.3 SIMULATION OF OPEN CUT MINES

For open cut mines, including the NEOC and SEOC, the active area of operation was represented using drain cells within all of the mined model layers. This effectively removes groundwater from the active parts of the open cut mine. Where appropriate, and in accordance with the mine plans, areas of backfill were then simulated by switching off the drain cells and adjusting the hydraulic properties to representative backfill properties, as follows:

- ▼ Horizontal hydraulic conductivity was set to 1 m/d.
- ▼ Vertical hydraulic conductivity was set to 1 m/d.
- ▼ Recharge was set to 6.125×10^{-5} m/d..

6.3.4 SIMULATION OF THE BOWMANS CREEK DIVERSION

The simulation of the Bowmans Creek diversion comprises two elements:

- ▼ Inclusion of the new, engineered channel as part of the groundwater model.
- ▼ Representation of the old channel within the model.

The representation of the diversion was relatively straightforward. The alignment has been taken from the outline engineering drawings, and has been represented in the model as stream cells, as shown in Figure 6.4. Stage elevations of the water surface for the low channel were linearly interpolated between the start and end points of the existing creek. MODFLOW uses the mathematical parameter of conductance to numerically represent the actual creek geometry and the degree of connectivity with the surrounding alluvium. In this case the conductance was calculated based on the geometry of the low permeability geotextile blanket that will be placed beneath the low flow channel. This represents the effective boundary between the saturated, flowing part of the diversion and the surrounding alluvium. The conductance was calculated based on:

- ▼ Effective cross sectional perimeter of the geotextile blanket = 10 m.
- ▼ Length of river in each cell = 25 m.
- ▼ Effective (wet) thickness of geotextile = 10 mm.
- ▼ As-laid permeability of geotextile layer (as per manufacturer's specification) = 1×10^{-11} m/s (1×10^{-6} m/d).

This resulted in a conductance value of 0.025 m^2/day.

Because the channel will be incised, the top of Layer 1 in the model within the engineered channel area was lowered by between 2 m and 5 m in accordance with the outline engineering design.

The 'abandoned' existing channel was represented by simply switching off the relevant stream cells within the model. The effect of local catchment runoff into the old creek channel and the impacts of occasional flood inundation were modelled separately, as described in the following sections.

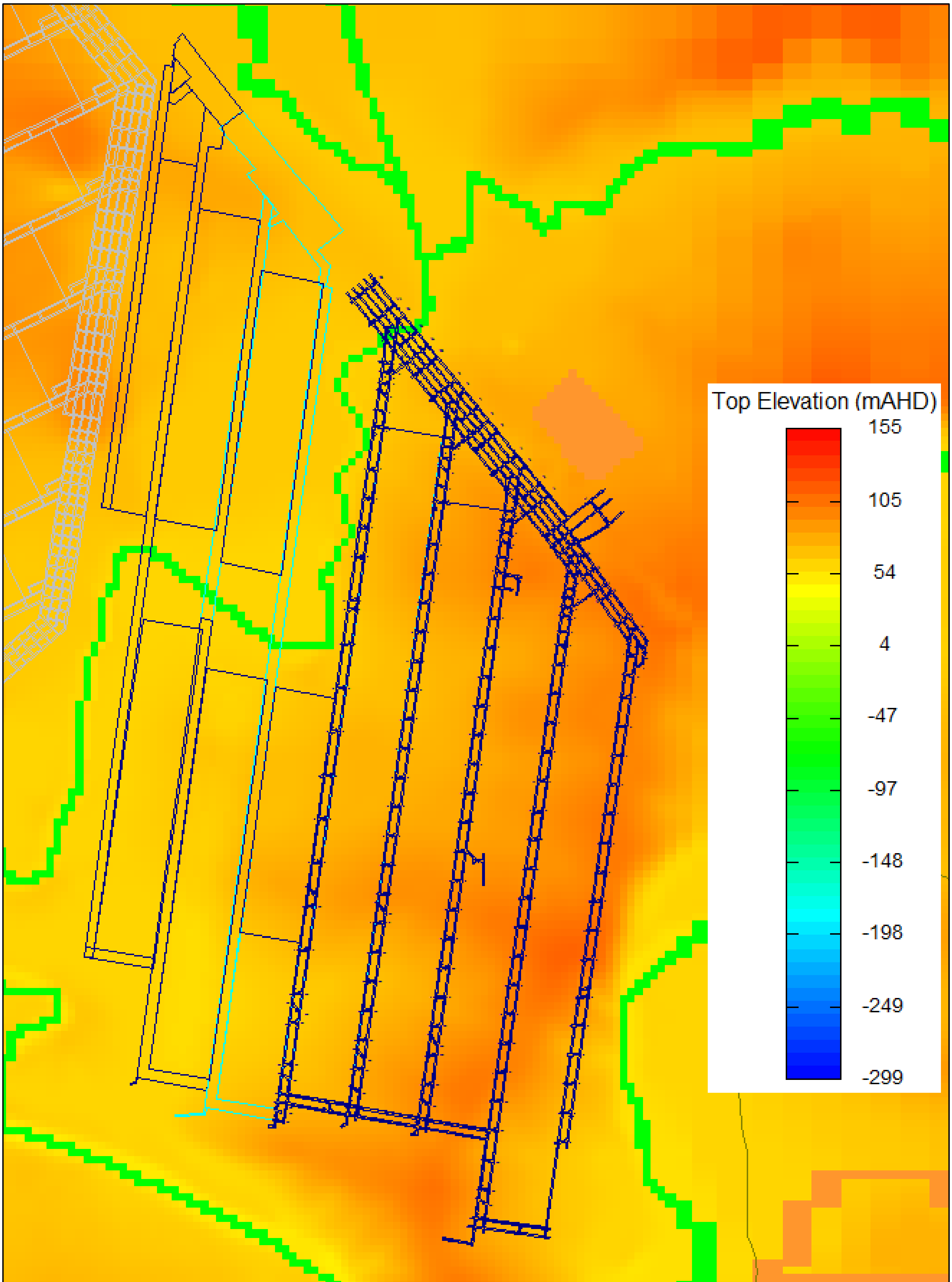
6.3.5 SIMULATION OF SURFACE SUBSIDENCE IMPACTS DURING MINING

The creation of the subsidence troughs associated with longwall panels 6 and 7 within the alluvial floodplain has two key impacts that had to be accounted for by the groundwater modelling and impact assessment:

- The physical presence of subsidence troughs means that the geometry of the alluvium will change (i.e. the base will drop by over 8m by the time the Lower Barrett seam is mined). The physical presence of the subsidence toughs at the surface also means that surface water could start to collect in the troughs and start to infiltrate into the ground. This will occur due to the direct 'capture' of local catchment runoff by the subsidence trough, and when water exceeds the flow capacity of the diversion (i.e. during a flood event with >5 year return period in Bowmans Creek). Most of the potential ponding of surface waters following flood events will be avoided by the control measures referred to in Section 5 – i.e. the subsidence areas will be largely filled to a level where they are 'free draining' following flood events.
- Surface cracking will eventually occur beneath the alluvium, which may start to connect with the sub-surface fracturing within the Permian, leading to rapid connection between surface waters, alluvial groundwater and the mine. Evidence from Ashton subsidence monitoring to date shows that clays in the regolith or alluvium are in some locations sufficiently mobile and have sealing properties sufficient to prevent or retard vertical leakage through cracks associated with subsidence from mining of the Pikes Gully seam. This effect was seen in the response to the June 2007 rainfall event that resulted in sheet flooding entering open surface cracks but not reaching the mine workings. It has subsequently been seen in farm dams above LW1-3, where surface subsidence fractures can be seen leading into and beyond the dam, but no leakage or cracking is visible in the wetted area, and water was retained in the dams. The risk of connective cracking therefore depends on the degree of movement within the alluvial clays (i.e. the amount of subsidence), and on the properties of the clay/silt layers in the alluvium. It is likely that this connective cracking would start to occur following the mining of the ULD seam.

Because water volumes will be controlled by filling of subsidence troughs and monitoring, and the occurrence of flood events is infrequent, possible inundation of surface flood waters into the mine was not included within the groundwater model during the operational period. The mining and environmental risks associated with potential flooding of the mine have been assessed separately from the groundwater modelling.

The capture of local surface runoff into the subsidence ponds was included within the model, as this will provide a steady, incremental increase to groundwater recharge and hence mine inflows in this area. Although the troughs will be progressively infilled as subsidence progresses, and will be designed to be largely 'free draining' in the event of a flood event, some of the surface runoff entering the area is likely to enter the ground as increased recharge due to the disturbance of the ground surface and lack of established planting. A conservative approach has therefore been adopted during the operational phase, whereby 40% of the runoff will enter the ground as recharge. This has been done to provide a conservative assessment of minewater inflows, and is subject to uncertainty analysis, as described in Section 6.8.



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Model Representation of Bowmans Creek Diversion

Figure 6.4

The amount of surface runoff entering the subsided areas from the 'captured' surface catchments was calculated from topographic analysis and an annual average runoff from the captured areas of 0.7ML/ha/yr (taken from the *NSW Farm Dams Assessment Guide* (1999)). For the base case, it was assumed that 40% of the runoff entering the subsided area would enter groundwater as recharge.

The timing of these rainfall related inflows is uncertain, as it depends on the degree of subsidence around the edge of the troughs, the amount of connective cracking through the alluvium and the approach to infilling during operations. Because infilling will be carried out to a 'free draining' surface, and not original ground level, some capture of runoff and flow of runoff water across the disturbed areas could start to occur following higher levels of subsidence. The operational groundwater model therefore assumed significant surface rainfall related inflow will only start to occur once the ULLD seam has been undermined; however, it is possible that this could occur following the mining of the ULD seam. This uncertainty only affects mine inflows and has been allowed for in the results presented in Section 6.8.

Subsidence-induced changes to the elevation of the ground surface and base of the alluvium, and the elevations of the Permian overburden layers, were also included within the modelling. The top and bottom elevations of Layers 1 to 4 were progressively lowered above the longwall panels LW6 and LW7 in accordance with the subsidence predictions as each seam is mined (up to -8.3 m once the Lower Barrett seam is mined). Because the alluvium becomes dewatered and there is no evapotranspiration of groundwater, it was not necessary to physically represent the backfilling of the subsidence troughs within the model during the operational phase.

For the full mining schedule it was assumed that continuous, open cracks that allow significant vertical transmission of water will start to occur once the ULD seam has been mined, and maximum surface subsidence reaches approximately 4m. These cracks will occur in the area of maximum tension around the perimeter of the trough. The actual degree of matrix disturbance and hence enhancement of vertical permeability within the alluvium is uncertain due to the highly variable nature of the alluvial material. The following methodology was therefore adopted in order to estimate infiltration rates from the base of the trough to the underground environment:

- It was assumed that most of the alluvium in the centre of the subsidence troughs will not experience a significant increase in permeability. The middle of the trough will only experience transient stresses as it is undermined, which will not be cumulative over multiple seams. The alluvium will have time to settle between the mining of each seam, and will experience a number of wetting and drying cycles that will promote filling and swelling of any cracks that do occur. Significant, continuous cracking and matrix disruption of the alluvium is therefore only likely to occur around the perimeter of the trough areas, where cumulative, progressive tensile stresses will accumulate in response to the multiple seam mining. It is therefore assumed that only around 10% of the trough area will experience a significant increase in vertical permeability.
- In order to provide a conservative estimate of the impact on permeability, it was assumed that alluvial material in the areas of cumulative tension will effectively take on the permeability characteristics of an unconsolidated soil. A range of permeability for representative materials within infiltration basins was obtained from international literature (WSUD, 2009; CIRIA, 2000; WSTC, 2005; Charman, 1991). Given the variable nature of the alluvium, material properties ranging from medium/fine sand (50 mm/hr) through to loamy sand and silty loam (3.3 mm/hr) were used in the assessment. Because of the heavy sediment load and biology of the surface water entering the ponds (it will either be floodwater or 'sheet' runoff), a reduction factor, as described in the literature for infiltration ponds, was used in the evaluation of effective permeability.

Once adjustments were made for model cell areas, this resulted in a modelled vertical permeability (Kv) of 5×10^{-2} m/d for the alluvial cells around the perimeter of the base of the subsidence trough.

During the operational phase, the impact of subsidence on surface recharge was only included within the Bowmans Creek floodplain area. Recharge rates on the hillsides away from Bowmans Creek are unlikely to be significantly enhanced beyond the baseline, except during the later stages of the mining period, when some connective cacking and ponding could occur. Mine inflows are not sensitive to this, so this was not included in the operational modelling.

6.4 MODELLING OF THE POST MINING RECOVERY PERIOD

For the main baseline run, the post recovery model was simply run for 100 years after the end of the mining schedule shown in Table 5.1. It was assumed that the Ravensworth mine stops at the same time as the Ashton underground mine. This is deliberately conservative, and has been done to ensure that water levels are able to reach equilibrium within the recovery period. (At the current rates of mining, it is expected that the Ravensworth underground mine will continue for some years after completion of underground mining at Ashton.)

In order to ensure that the effect of an unanticipated earlier completion of mining due to unexpected economic or technical reasons was properly considered, a second run was carried out to examine the hydrogeological environment post mining recovery if mining were to stop at the end of the ULD seam. To ensure consistency with the main run, this second run included ongoing operational mining at Ravensworth for the first 9 years, in accordance with Table 5.1.

6.4.1 RECOVERY SIMULATION – MINING OF THE LOWER BARRETT SEAM

In order to create the appropriate post mining recovery conditions, the following adjustments were made to the final operational model:

- All drain cells within the underground mines were switched off. The hydraulic properties associated with goaf areas and caved overburden were left in place, but reduced in comparison to the operational model. The presence of mud rocks and siltstones in the overburden means that the permeability of the caved material will reduce as fractures become clogged with fines and are closed by settling and swelling of rock. Vertical permeability of the caved material has therefore been reduced to 5 m/d. As discussed in Section 7, this effectively had no impact on the post mining recovery run, as hydraulic gradients within the mine and mine overburden are virtually flat (meaning they are very strongly interconnected in comparison to recharge volumes). It did, however help with the numerical stability of the recovery model. The permeability of the roadways has been left at the 50 m/d used in the pre-mining condition.
- The Ravensworth and Narama open cut voids were assumed to form an evaporation surface at the same level as the pre-mining condition. This is considered to be conservative given that the rehabilitated Ravensworth pit void has already reached equilibrium between seepage and evaporation at a level around 15-20m lower than pre-mining groundwater levels in that area.
- The specific yield (Sy) of the overburden material was increased to allow for bulking during subsidence. This was calculated based on an assumed subsidence rate of 85% (i.e. the ground subsides by 85% of the total extracted thickness). This means that the total specific yield of the overburden increases by 15% of the total extracted coal seam thickness (resulting in an average 1.5m increase). When divided by the thickness of the overburden, this results in an average increase in Sy of around 0.0075. It is likely that the increase in Sy will be higher than the average nearer the coal seams, and lower towards surface. However, this variation will not be known and makes no practical difference to the post recovery model. The average Sy value was therefore applied to all of the caved overburden above the longwall panels.
- The hydraulic nature of the subsidence troughs above longwall panels was modelled in a similar way as described in Section 6.3.5., but with the following adjustments:
  - the underlying, cracked alluvium will experience a number of wetting and drying cycles, it was assumed that the area of cracking around the base of the trough will extend outwards slightly. The overall permeability across the trough area has been maintained, but it has been applied over a slightly larger area than the operational model.

- the surface levels of the subsidence areas can affect evapotranspiration during recovery, it was necessary to change the surface of layer 1 in the subsidence areas to the level proposed by the rehabilitation strategy (i.e. the level required to allow 'free drainage' following flood inundation, except in the areas around the old creek channel above LW6B).
- because pumping from the mine workings will have stopped, and the assessment is being run over a long period (100 years), the recharge impact of the occasional flood inundation of the subsidence troughs has been allowed for within the recovery model. This will only occur in the old channel area above LW6B, following a 1 in 5 year (or greater) flood event. The balance between groundwater infiltration and evaporation for the ponded water has been calculated based on a spreadsheet model that allows for variation in hydrostatic head as the subsided area empties.
- although the subsidence areas will continue to have effective catchments and hence receive enhanced runoff in the post mining phase, these will have been finally rehabilitated and re-vegetated. Recharge equal to 10% of the total runoff entering the areas above LW7A and LW6A, and 33% of the runoff entering LW6B (this value is higher due to the presence of the subsided areas associated with the old channel) has therefore been allowed for in the model. This is a deliberately conservative assessment, and is likely to reduce as the area becomes more strongly vegetated and consolidated during the recovery period.

Figure 6.5. shows the post mining model setup and permeabilities for Layer 1, which includes the location of the subsidence areas that experience enhance recharge or become periodically inundated during flood events (parts of LW6B only).

In addition to the above modelling approaches, some additional recharge was included in the post recovery stage for the regolith on the hillside area above LW1-5, to allow for the potential minor ponding and possibility of enhanced vertical permeability due to ground disturbance. As discussed previously, this is unlikely to be very large due to the clay nature of the regolith, so the recharge zone above the main area of coal mining (zone 1) was doubled from the pre-mining condition.

6.4.2 RECOVERY SIMULATION – MINING ONLY TO THE UPPER LIDDELL SEAM

The approach to recovery following mining to the end of the ULD seam was essentially the same as for the main recovery run, except for the absence of voids and caving in the ULLD and LB seams, and the fact that the Ravensworth mining operations continued for the first 9 years of the recovery period. The following additional minor changes were made to the recovery model parameters:

- The increase in Sy was re-calculated based on the lower subsidence, a bulking factor of 20% and shallower overburden, however this resulted in the same increase in Sy (0.0075) as was used for the main model.
- The volume of floodwaters ponding within the subsided, old creek channel above LW6B was recalculated using the appropriate subsidence and invert levels. This resulted in a total volume of 46ML remaining after a flood event.
- Because the subsided area within LW6B was less, the amount of runoff recharge was reduced to 20% of the annual average catchment runoff

6.4.3 SIMULATION OF OPEN CUT MINES IN THE POST MINING RECOVERY PERIOD

Post mining, for areas where an open void was left within the open cut mine and dewatering had stopped, a mine void was simulated within the model. This was set by increasing the permeability and specific yield to 99 m/d and 0.99 respectively. Recharge and evaporation were then calculated as follows:

- Recharge was equal to the total direct rainfall, plus runoff equal to 10% of the total rainfall falling on the backfilled area that drains to the pit void.

- Evaporation was assumed to be equal to 60% of the evaporation value described in Section 4.2.1. This value was used as the data in Section 4.2.1 represents open pan evaporation. An adjustment of around 80% is normally used to adjust this to the open water evaporation value, but in this case the pit water is generally deep within the void, which means it experiences reduced wind speeds, higher humidity and less direct sunshine.

For the SEOC, the current proposal within the EA is to largely fill the mine except in the south eastern corner, where the tailings dam will be filled and clay capped to just below 40 mAHD. This was represented by an ET surface at 40mAHD within a low permeability zone in the relevant layer (Layer 9).

6.5 TIME SCALE SELECTION

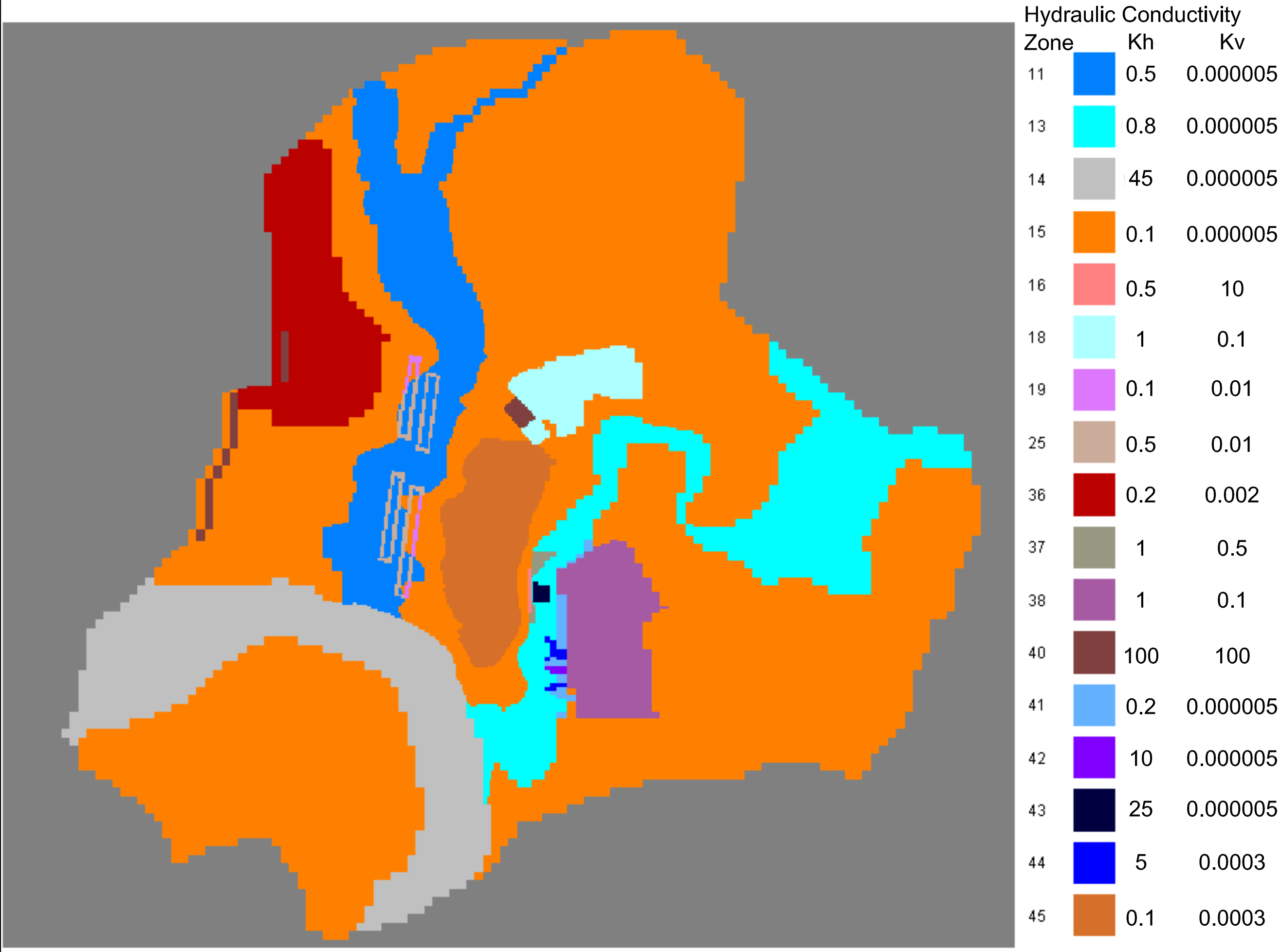
The need to change aquifer parameters with time to simulate the progressive advance of mining required a series of consecutive "time-slice" models, with hydraulic properties changed from one time slice to the next. For the transient calibration period, time slices of varying duration were used in order to match the progress of the completion of longwall panels as far as possible. For the predictive modelling, time slices were progressed as annual increments. 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.

Table 6.3 outlines the model time slice and stress period set-up for the transient calibration and prediction model runs. A stress period is the timeframe in the model when all hydrological stresses (e.g. recharge, mine dewatering) remain constant.

Table 6.3: AUM Model Stress Period Setup

Period	Time Slice	Stress Period	Length (days)	From	To	Ashton Mine		Ravensworth UG Mine		SEOC
						Development	Longwall Panels	Development	Longwall Panels	
TRANSIENT CALIBRATION (HISTORY MATCH)	Time Slice 1	1	91.25	1/01/2004	31/03/2004	n/a	n/a	n/a	n/a	n/a
		2	91.25	1/04/2004	30/06/2004					
		3	91.25	1/07/2004	30/09/2004					
		4	91.25	1/10/2004	31/12/2004					
		5	91.25	1/01/2005	31/03/2005					
		6	91.25	1/04/2005	30/06/2005					
		7	91.25	1/07/2005	30/09/2005					
		8	91.25	1/10/2005	31/12/2005					
		9	91.25	1/01/2006	31/03/2006					
		10	91.25	1/04/2006	30/06/2006					
		11	91.25	1/07/2006	30/09/2006	PG LW1				
		12	91.25	1/10/2006	31/12/2006					
		13	91.25	1/01/2007	31/03/2007		PG LW1			
		14	91.25	1/04/2007	30/06/2007					
	Time Slice 2	15	91.25	1/07/2007	30/09/2007	PG LW2		PG LW3-4		
		16	91.25	1/10/2007	31/12/2007					
		17	91.25	1/01/2008	31/03/2008	PG LW3	PG LW2	PG LW5		
	Time Slice 3	18	60	1/04/2008	31/05/2008				PG LW3	
		19	60	1/06/2008	31/07/2008					
	Time Slice 4	20	60	1/08/2008	30/09/2008	PG LW4	PG LW3		PG LW4	
		21	60	1/10/2008	30/11/2008					

Period	Time Slice	Stress Period	Length (days)	From	To	Ashton Mine		Ravensworth UG Mine		SEOC
						Development	Longwall Panels	Development	Longwall Panels	
	Time Slice 5	22	61	1/12/2008	31/01/2009			PG LW6	PG LW5	
		23	58	1/02/2009	31/03/2009					
PREDICTIVE PHASE	Time Slice 6	24	274	1/04/2009	31/12/2009	PG LW5 & LW6	PG LW4	PG LW7	PG LW5	
	Time Slice 7	25	365	1/01/2010	31/12/2010	PG LW7 & LW8	PG LW5 & LW6	PG LW8	PG LW6 & 7	Mine Yr 1
	Time Slice 8	26	365	1/01/2011	31/12/2011	ULD LW1&2	PG LW7 & LW8	PG LW9 & 10	PG LW8	Mine Yr 2
	Time Slice 9	27	366	1/01/2012	31/12/2012	ULD LW3&4	ULD LW1&2	PG LW11 & 12	PG LW9 & 10	Mine Yr 3
	Time Slice 10	28	365	1/01/2013	31/12/2013	ULD LW5&6A	ULD LW3&4	PG LW13 & 14	PG LW11 & 12	Mine Yr 4
	Time Slice 11	29	365	1/01/2014	31/12/2014	ULD LW6B,7&8	ULD LW5&6A	PG LW15	PG LW13 & 14	Mine Yr 5
	Time Slice 12	30	365	1/01/2015	31/12/2015	ULLD LW1&2	ULD LW6B,7&8	Outside Model	PG LW15	Mine Yr 6
	Time Slice 13	31	366	1/01/2016	31/12/2016	ULLD LW3&4	ULLD LW1&2	Outside Model	Outside Model	Mine Yr 7
	Time Slice 14	32	365	1/01/2017	31/12/2017	ULLD LW5&6A	ULLD LW3&4	ULD LW 2&3	Outside Model	Backfilled plus void
	Time Slice 15	33	365	1/01/2018	31/12/2018	ULLD LW6B,7&8	ULLD LW5&6A	MLD LW4&5	ULD LW 2&3	
	Time Slice 16	34	365	1/01/2019	31/12/2019	LB1&2	ULLD LW6B,7&8	MLD LW6&7A	MLD LW4&5	
	Time Slice 17	35	366	1/01/2020	31/12/2020	LB3&4	LB1&2	MLD LW7B&8	MLD LW6&7A	
	Time Slice 18	36	365	1/01/2021	31/12/2021	LB5&6A	LB3&4	MLD LW9&10	MLD LW7B&8	
	Time Slice 19	37	365	1/01/2022	31/12/2022	LB6B,7&8	LB5&6A	MLD LW11&12	MLD LW9&10	
	Time Slice 20	38	365	1/01/2023	31/12/2023	LB8	LB6B,7&8	MLD LW13&14	MLD LW11&12	
	Time Slice 21	39	366	1/01/2024	31/12/2024		LB8	MLD LW15	MLD LW13&14	



Date: 6 October 2009	Scale: as indicated	**Ashton Coal Operations Ltd**
Initials: PZ	Job No: S55G	**Model Set Up and Permeability for Layer 1 Post Mining**
Drawing No: S55G-036a	Rev: A	
aquaterra		**Figure 6.5**

Multiple stress periods have been used within the calibration time slices to ensure a more refined progression of the mine headings and longwalls within the mine in order to allow fits to observed data. This has been designed to be entirely consistent with the mine plan described in Section 5.1.

For the analysis of an unanticipated early end to mining, where Ashton mining ends at the ULD seam, the operational model was run to the end of time slice 12 (without the heading developments in the ULLD seam). The remaining 9 years of operational mining in the Ravensworth pit were then run as a single time slice at the start of the recovery model.

6.6 MODEL CALIBRATION

Calibration is the process by which the independent variables (parameters and boundary conditions) of a model are adjusted, within realistic limits, to produce the best match between simulated and measured data. The realistic limits on parameter values are constrained by the range of measured values from pumping tests and other hydrogeological investigations.

Full results of the model calibration have been included in Appendix E. This was an iterative process that involved both steady state and transient calibration. It included calibration against mine inflows recorded during the mining of LW1 to LW4, as well as the usual calibration against measured groundwater heads. Automated calibration was not used in this case due to the uncertainties over the steady state targets and the fact that transient calibration targets were undergoing significant stresses due to open cut and longwall mining (so hydraulic parameters were changing over time). Calibration statistics and sensitivity results from the steady state model were used as a guide to calibration, but automated PEST type calibration was not considered to be appropriate in this case.

The final calibrated hydraulic parameters that were used in the base model for this project have already been shown in summary in Table 6.1. Final values used for all layers, including specific zones that have been used to describe known, discrete hydrogeological features (such as the Pikes Gully shear zone, enhanced permeability near Glennies Creek and the vertical permeability of the Permian outcrop area) are provided in Appendix E.

6.6.1 STEADY STATE CALIBRATION

Steady state calibration was carried out entirely against pre-underground mining records of potentiometric head. Calibration was achieved through changes in recharge, hydraulic conductivity and modifications to boundary conditions. Steady state calibration statistics are provided in Appendix E.

It should be noted that a 'true' steady state calibration is not possible for this area, as groundwater level records are not available before the Ravensworth or Narama open cut mines were started. A steady state model effectively runs over an infinite timescale, which means that the Ravensworth/Narama boundary condition will have reached equilibrium with the hydrogeological regime within the steady state model. Although the Narama pit is relatively shallow, affecting the upper coal seams, the effective timescales involved in a steady state model will have resulted in depressurisation of lower levels as well.

The few early monitoring records that are contained within the HLA (2001) report were taken only 10 years after the start of the Narama open cut mining, so they will tend to show higher potentiometric heads within the Permian than the steady state model.

Conversely, although monitoring records are available from the Ashton monitoring network prior to the start of underground mining, some of the potentiometric heads down to the Lower Barrett seam will have been slightly affected by the early NEOC mining prior to installation of the monitoring bores. Some of these records will therefore tend to under-estimate 'steady state' groundwater levels.

Although this complicates the steady state calibration, a large number of bores were available as potential target levels. Suitable targets were therefore selected by screening all of the available monitoring data and selecting records that had not been too heavily influenced by perched aquifer conditions, the effect of NEOC mining, or any effects from early underground mining at Ashton. Others have been inferred by back-projection of hydrograph trends or hydrostatic head profiles.

This allowed 112 targets to be contained within the steady state calibration. Many of these (45) were in Layer 1 due to the intensive investigation programmes that have been carried out in the alluvium, but 67 targets were available for calibration across the Permian model layers.

The Scaled Root Mean Squared (SRMS) value is the major quantitative performance indicator for calibration, calculated as the RMS value divided by the range of measured heads across the site. Given uncertainties in the overall water balance volumes (e.g. it is difficult to directly measure evaporation, or baseflow into the creeks), it is generally considered that a 10% SRMS value on aquifer water levels is an appropriate target for models of this type, as described in the Australian best practice modelling guidelines (MDBC, 2001). The final SRMS value achieved for this project was 11.65%. This was considered acceptable given the large number of targets, the wide spatial and depth range involved, and the fact that target levels had been obtained at differing times in a non-static system.

The scatter diagram of measured versus modelled potentiometric head targets is plotted in Figure 6.6, and it can be seen that the model is well balanced against the targets (i.e. there is no systematic under or over prediction).

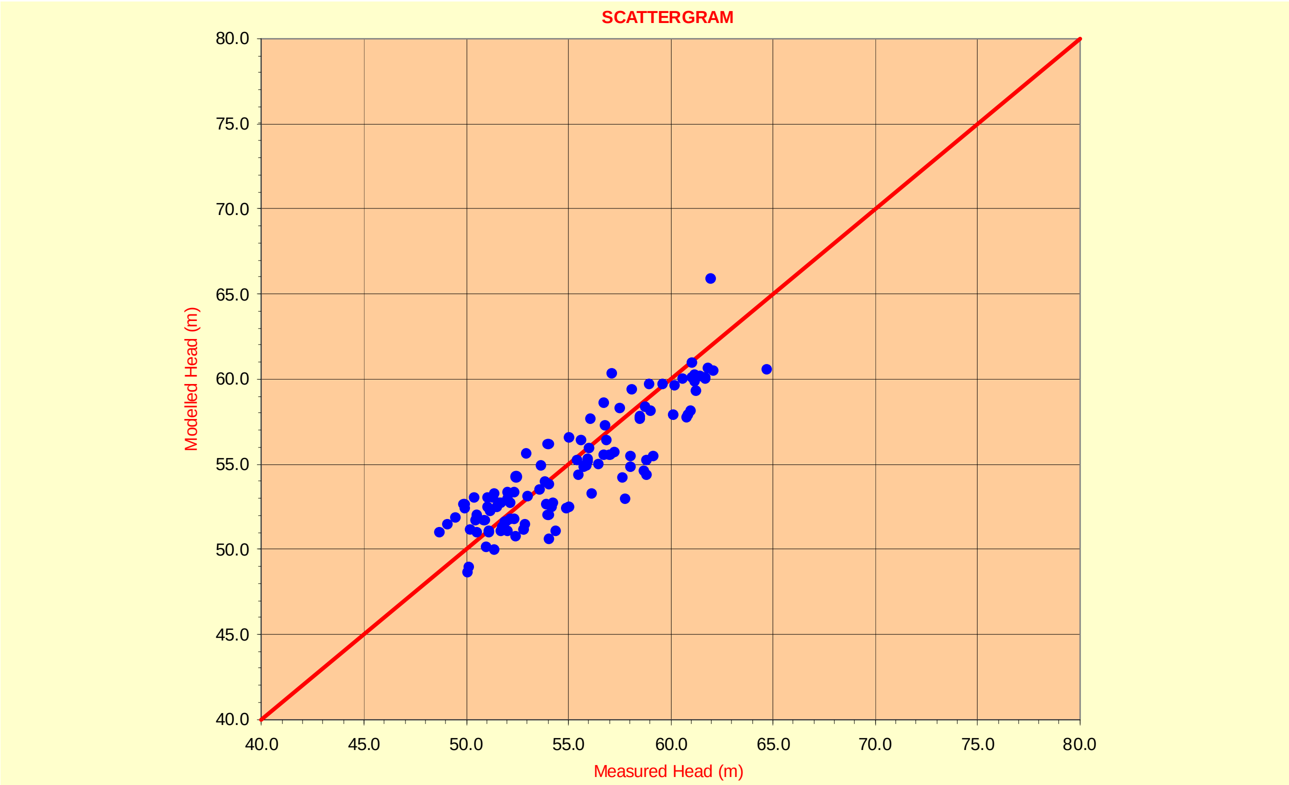
6.6.2 TRANSIENT MODEL CALIBRATION

Match to Measured Groundwater Heads

Transient calibration hydrographs were produced for around 150 piezometers, which measured groundwater levels in multiple seams from the alluvium right through to the Lower Barrett seam. Calibration hydrographs are presented in Appendix E. Results were generally extremely good, particularly given the stresses placed on the model by the mining activities, and the head differential that occurred within the different model layers at the start of the modelling period. A few observed effects were not well represented by the model, but these are not considered to be significant to the impact assessment. The hydrographs listed below, and displayed in Appendix E, showed levels or responses that were not well reproduced in the model:

- For Layer 1, the model consistently under-predicted against measured heads for bores WML110C and RA16. Both of these bores are located in areas where there are likely to be perched water tables in the weathered regolith/colluvium, due to the presence of a farm dam near RA16, and due to the presence of surface water drainage features near WML110C.
- Regional recession appears to have occurred in Layer 2 (upper Lemington seams and overburden) within bores WML111, 112 and 113 in the south eastern part of the proposed mining area. This may be associated with inter-annual variation, which is not allowed for in the model, or due to some unknown regional de-watering effect. This has led to a slight over-prediction in modelled heads in Layer 2 in this area.
- Bores WML114 and WML 109a in the mid Lemington seams (Layer 4) to the west of LW3 showed unexpectedly large responses to the mining of LW2. These are too distant to be caused by the direct movement of water to the longwall panel, and appear to have been caused by the effect of stress relaxation leading to increases in storage, as described in Section 4.7.2. WML 108a shows a similar, large response during the mining of LW3. Two of these bores show 'bounce back' in water levels, caused by re-compression of strata during the mining of subsequent longwall panels, or by settling of strata over time. The observed 'bounce back' supports the conclusion that the potentiometric response is being caused by changes in storage within these highly confined layers, rather than by dewatering. This hydrogeological effect is not included within the predictive model. It is noted that these effects occur at a significant horizontal distance from the longwall panels. This reconciles with the SCT modelling referred to in Section 6.3.2, which predicts that long distance horizontal bed separation is most likely to occur within the upper Permian layers.

- Bores WML 107A and WML 110 in the Pikes Gully overburden (Layers 6 and 7) initially match well with modelled data as they start to be affected by longwall mining, but then appear to recover. Neither of these bores was undermined in the monitoring period, and it appears that the enhanced permeability that is initially caused by the longwall mining has 'self healed' to a certain extent by the movement of fines and swelling of mud rocks. This effect is not included in the operational modelling, but does support the approach adopted during the recovery phase whereby the vertical permeability of the caved material is reduced in order to represent this effect. It also shows that the operational model tends to be conservative in its assessment of impacts in layers that are affected by mine dewatering.
- There is an unknown dewatering effect within the Pikes Gully (Layer 8) in bore WML213, next to the Hunter River. This is too distant from the Ravensworth or Ashton underground mining activities within the modelled period to have been caused by either of those mines, and must be related to some more distant but unidentified mine effect.



Date:	19 August 2009	Scale:	as indicated	**Ashton Coal Operations Ltd**
Initials:	JVDA	Job No:	S55G	**Scatter Plot for the Steady State Model Calibration**
Drawing No:	S55G-033	Rev:	A	
aquaterra				**Figure 6.6**

- Bore WML191 is located within the chain pillar between LW2 and LW3, and has a vibrating wire piezometer within the Pikes Gully seam (Layer 8). This clearly demonstrates a storage response to stress changes during the mining of LW3. These stress effects seem to penetrate right through to the ULD seam (Layer 10) and even the ULLD seam (Layer 12). Bore WML189, which is located in a different chain pillar between LW2 and LW3 to the north of WML191, shows a similar stress response in both the Pikes Gully and the floor of the Pikes Gully seam.
- For lower layers, bore GM3B in the ULLD has recorded dry and is not an effective target. Modelled predictions for bore WML144 are reasonable in Layers 11-14, but there is a slight, unknown, regional dewatering impact that is not reflected in either the model or in the overlying ULD seam (Layer 10).

The majority of the hydrograph effects that are not well represented within the model are therefore associated with changes in storage caused by stress re-distribution in the rock mass. These are transient effects that only occur in highly confined strata and have little or no impact on flow patterns within the general hydrogeological environment. They are not therefore contained within the modelling process as they have no effect on the overall impact assessment.

The source of the regional effects described in bores WML144 and WML213 is not known, but will not affect the degree of impact on the groundwater environment caused by the Ashton underground mine. This shows that there are sources of regional de-watering of the Permian that have not been included within the Ashton Underground Model.

Match to Underground Mine Inflows

Throughout the calibration run, the failure zones invoked in the model above the underground mine were progressed in accordance with the mine plan. A summary of the model predicted inflows compared with measured inflows is shown in Figure 6.7.

As noted in Section 4, the inflows to TG1 at the point where it passes closest to Glennies Creek have been measured separately to other mine inflows, as they are thought to be a fair representation of the amount of water that the Glennies Creek alluvium is losing to the underground mine. The model was therefore also calibrated against this measured inflow rate by comparing the model predicted baseflow losses in Glennies Creek against the measured inflows. A comparison of the model predicted baseflow losses versus measured TG1 inflow rates (adjusted according to the method described in Section 4.7.2) is also shown in Figure 6.7. This shows that there is generally a very good match against the initial inflow rate. The model does not re-produce the decrease in inflows that has been observed since the initial measurements were taken. This could have been modelled by a progressive reduction in the permeability of the Pikes Gully between the mine and the creek, but this has not been done in order to ensure that the model provides a conservative estimate of the impact of mining upon Glennies Creek and its associated alluvium.

6.7 SENSITIVITY ANALYSIS

Full automatic sensitivity analysis was carried out on the steady state model to determine sensitivity to the calibrated model parameters. Results of this are included in Appendix E.

Overall the steady state model was insensitive to most parameters, and the SRMS values for the calibrated model values were better than the sensitivity runs (indicating that the optimal hydraulic parameters had been used in the calibrated model). The model was found to be sensitive to the following parameters:

- Horizontal and vertical hydraulic conductivity in the main rock mass in the Permian overburden and interburden layers (permeability Zone 7).
- Recharge to the exposed Lemington seam subcrops in the hillside above the underground mine area (recharge zone 8).

The impact of changes to these parameters on the model predictions were therefore examined in the uncertainty analysis described within Section 6.10.

6.8 PREDICTION OF MINE INFLOWS

Model predictions of total mine inflows and inflows to each coal seam during the course of the operational mining are shown in Figure 6.8. These results are reasonably consistent with previous assessments, although they are generally lower than the 2001 EIS predictions. They also show that inflow rates may increase towards the end of the mining. This is largely caused by the assumption that localised catchment runoff could start to enter groundwater as recharge to the subsidence trough areas following the mining of the ULLD seam.

There is some uncertainty over these figures. As discussed in Section 6.3.5, there is some uncertainty about the timing and quantity of surface runoff that might enter the mine workings via the subsided areas. Although these are progressively backfilled during mining, some of the 'captured' catchment runoff will still enter groundwater within the subsidence affected floodplain area. The amount and timing of groundwater recharge in this area is also uncertain, although the sensitivity is only around 100 m^3/d. An uncertainty band has therefore been drawn around the central estimate shown in Figure 6.8. Overall it is likely that the base case is conservative, and actual inflows are likely to be at the lower end of the uncertainty band.

This uncertainty band only affects mine inflow rates and does not affect the impacts on groundwater levels or baseflows described below. As discussed previously, the predicted mine inflow rates exclude potential inflows associated with flooding events that enter and fill the old creek channel above LW6B.

6.9 PREDICTED WATER LEVELS DURING MINING

Model predicted groundwater levels before and during mining operations are shown in Figures 6.9 to 6.13. All of these figures show groundwater levels in the relevant layer with and without the presence of the Ashton underground mine (after mining has started in 2006), and the presence of 'dry cells' where the relevant layers of strata have become de-watered.

- Figures 6.9 and 6.10 show water levels in the alluvium and regolith (Layer 1) at the start of underground mining (2006), at the end of the Pikes Gully (PG) seam mining (2011), at the end of the Upper Lower Liddell (ULLD) seam mining (2019), and at the end of the Lower Barrett (LB) seam mining (2024).
- Figures 6.11 and 6.12 show water levels in the Pikes Gully overburden (Layer 5) in 2006, 2011, 2019 and 2024, as above.
- Figure 6.13 shows water levels in the Pikes Gully seam (Layer 8, the upper most mined seam) in 2006 and 2011 (it is dewatered in the mine area after this point).
- Figure 6.14 shows water levels in the Lower Barrett seam (Layer 14, the lowest mined seam) in 2006 and 2024.

The regolith in Layer 1 is generally unsaturated at the start of mining, with groundwater only occurring in the alluvium (and adjacent colluvium on the slopes adjacent to the valley alluvium). Figures 6.9 and 6.10 show that the effects of the Ashton underground mine on the Bowmans Creek alluvium are almost entirely limited to the area to the south of the New England Highway. The alluvium between the highway and the southern end of the western creek diversion becomes progressively dewatered during mining. By the end of mining, saturated alluvium only remains in the southern end, between the Hunter River and the Bowmans Creek western diversion, and an area immediately around the section of Bowmans Creek between the two proposed creek diversions.

Although there are some impacts on alluvial groundwater levels in the Bowmans Creek alluvium to the north of the New England Highway, a comparison between the 'with' and 'without' Ashton underground mining impacts show that this is almost entirely associated with the Ravensworth underground mine.

The majority of the small impacts on groundwater levels in the Glennies Creek alluvium and colluvium to the east of Glennies Creek come from the SEOC and NEOC mines. The Ashton underground mine has some impact on the colluvium to the south of LW1 (drying it out to the edge of the alluvium) and a very minor (<1 m) impact on groundwater levels in the alluvium to the south east of LW1.

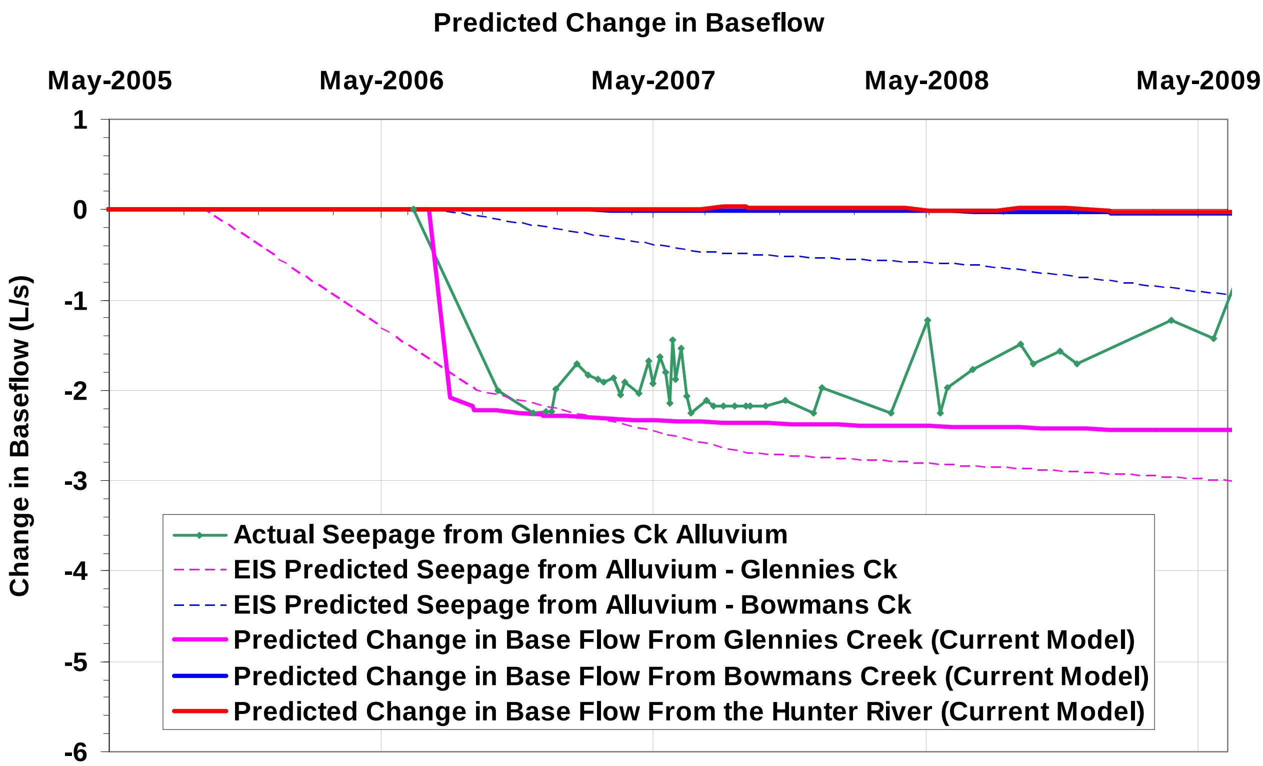
Impacts on the Hunter River alluvium are very limited, either from the Ashton mine, or from the combined effect of all of the mining in the area.

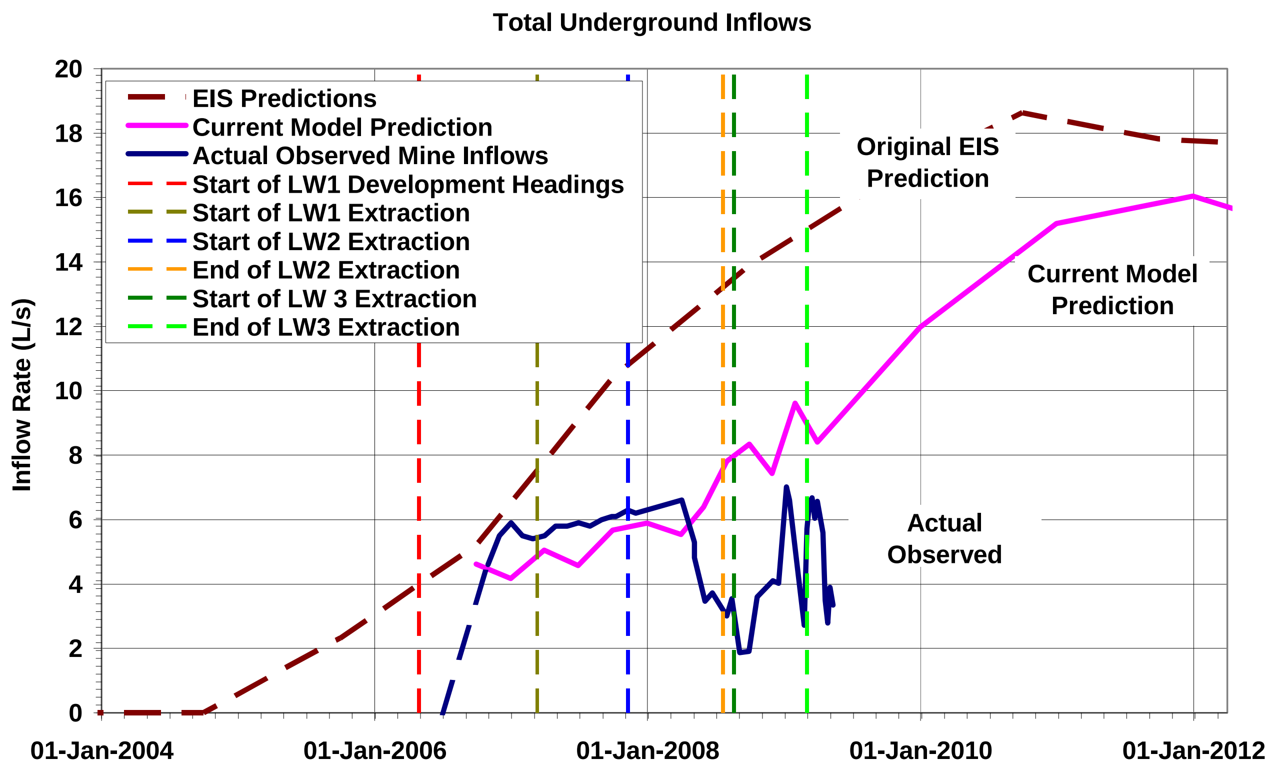
Figures 6.11 and 6.12 shows that there is a general regional dewatering of the Permian layers above the Pikes Gully seam due to mining activity in the area. The main impact from the Ashton underground occurs on the southern and eastern side of the mine, where the strata becomes de-watered in the mine area and drawdown impacts (as seen by the 40 m contour line) extend up to a kilometre further than they would without the presence of the Ashton underground mine. Because of the presence of the Ravensworth underground and NEOC, Ashton underground has almost no impact on groundwater levels to the north of the site.

The same effect is seen in the Pikes Gully seam (Figure 6.13), where the only significant impact from the Ashton underground mine occurs to the south and south east of the site.

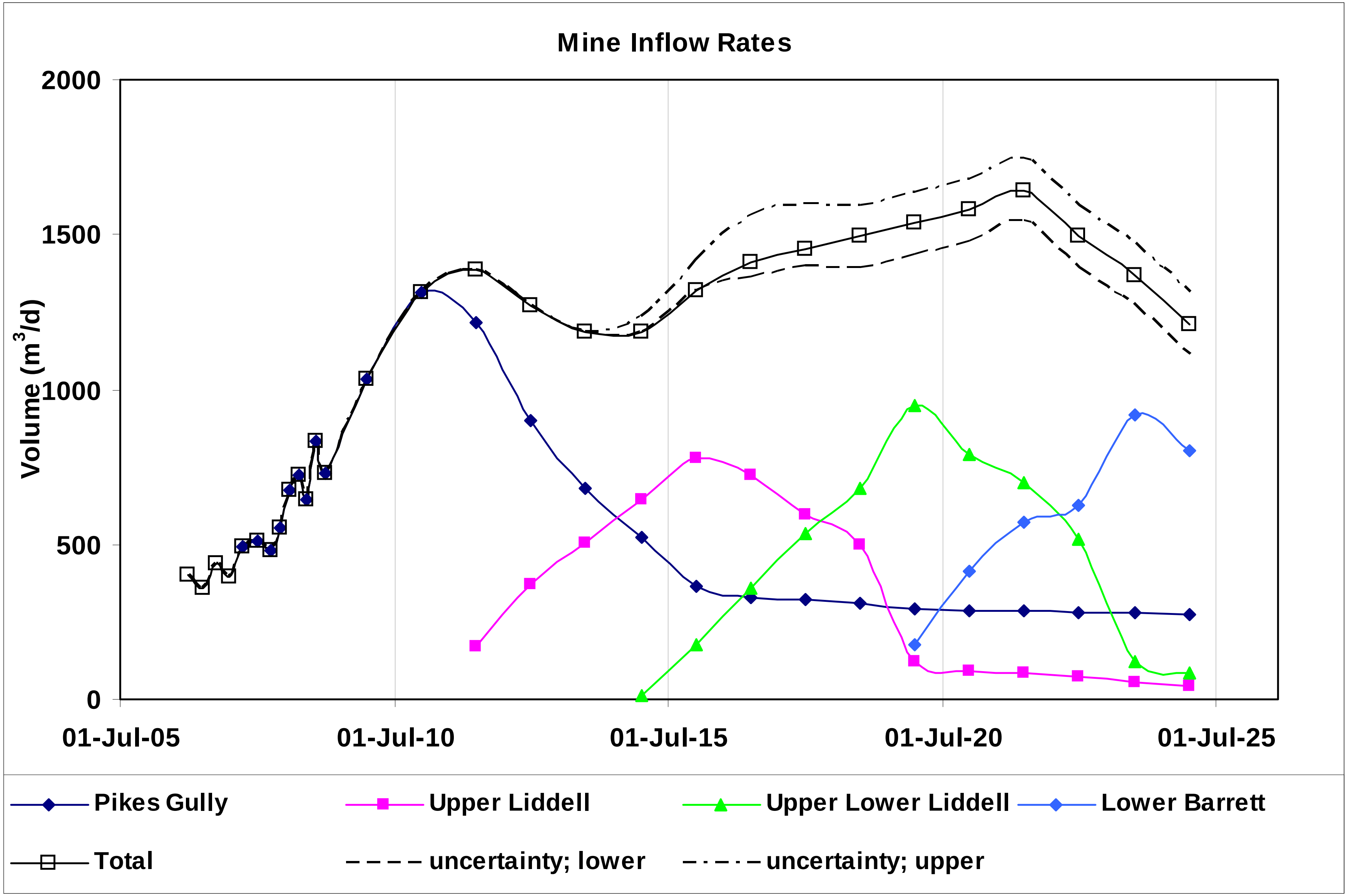
Because the NEOC only affects a small area of the Lower Barrett seam, and the Ravensworth mining has not started in the Lower Barrett by the time the Ashton underground is complete, the relative impact of Ashton is much larger in these lower layers (Figure 6.14).

The Ashton underground mine causes heads to drop to as low as -200 mAHD in the south western part of the workings, and drawdowns of 10m or more up to 2 km to the north, south and west of the workings. Relative impacts to the east are smaller due to the presence of the SEOC.



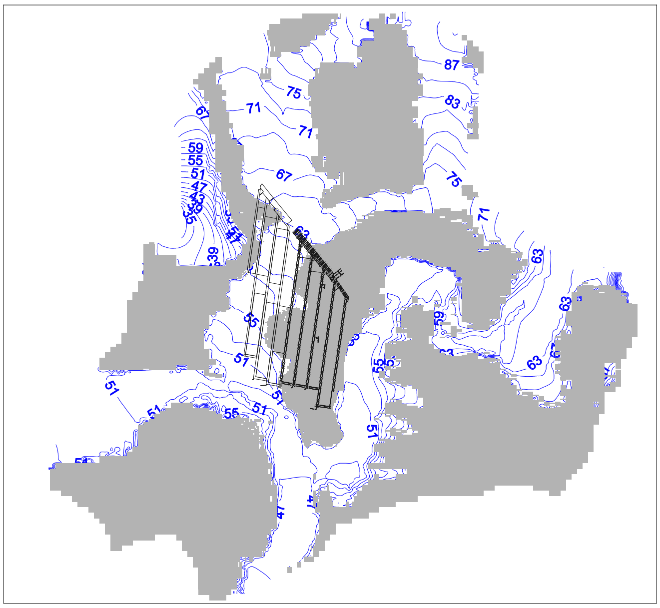


Date **20 August 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **JVDA**	Project **S55G**	**Predicted Baseflow and Groundwater Inflow Rates**
Drawing Number **fig6.7.srf**	Revision **A**	
aquaterra		**Figure 6.7**

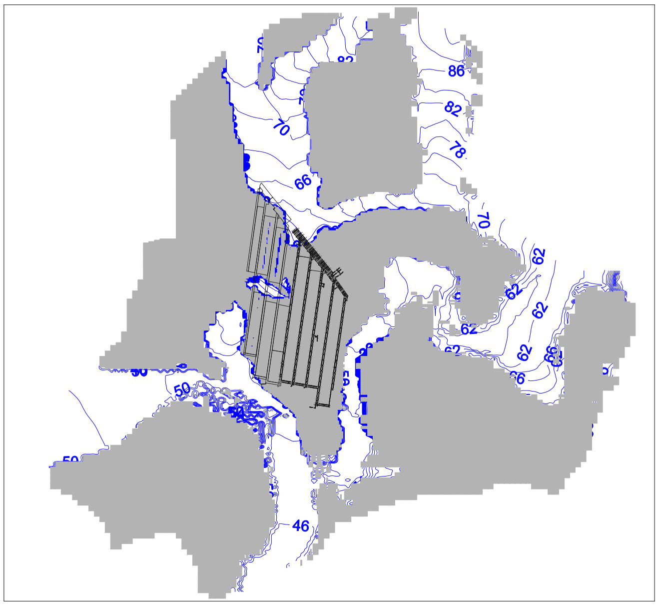


Date **31 September 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**	
Initials **PZ**	Project **S55G**	**Predicted Mine Inflow Rates**	
Drawing Number **fig6.8.srf**	Revision **A**		
aquaterra			**Figure 6.8**

WITH ASHTON UNDERGROUND MINE

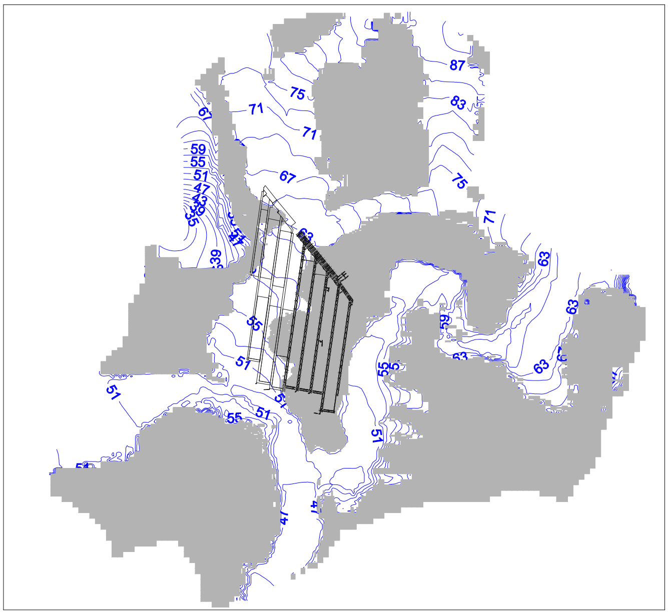


Year 2



Year 11

WITHOUT ASHTON UNDERGROUND MINE



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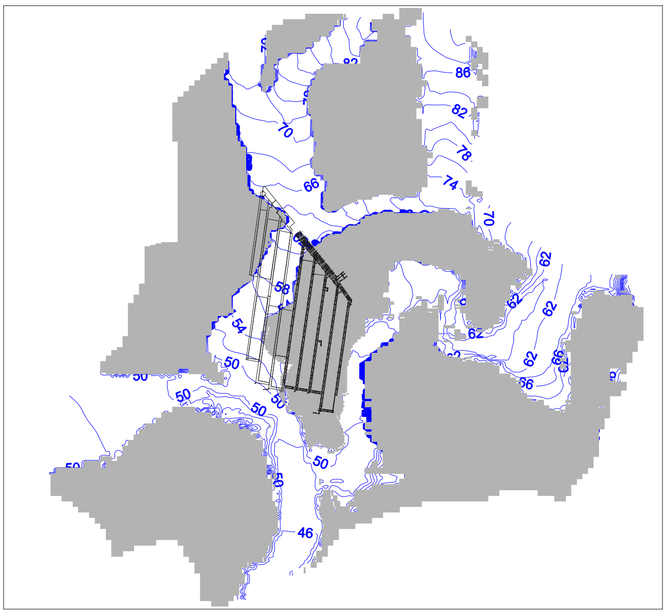


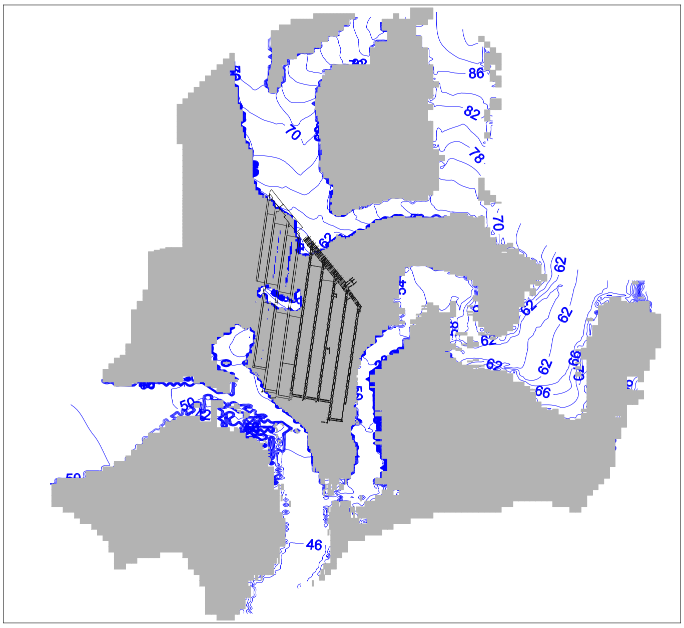
Year 11

Dry Cells

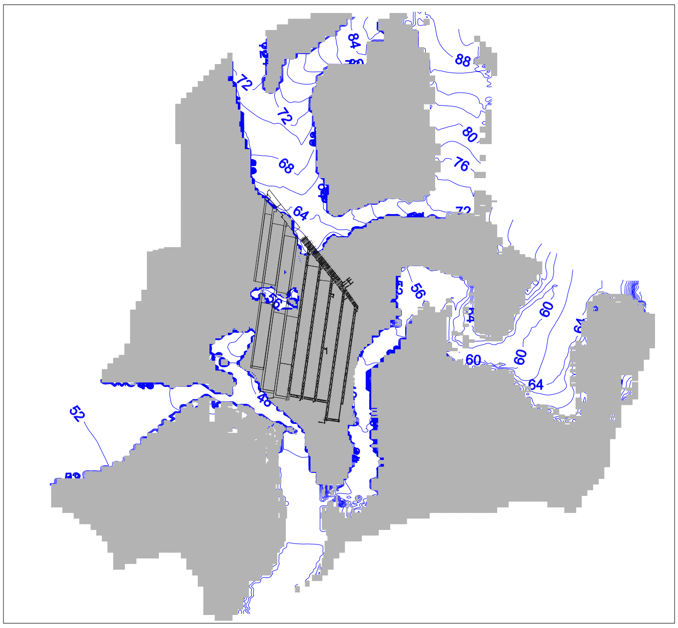
Groundwater elevation (mAHD)
2m Intervals

Date **21 September 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **JVDA**	Project **S55G**	**Model Predictions of Alluvium Groundwater Levels (Early Mining)**
Drawing Number **fig6.9.srf**	Revision **A**	
aquaterra		**Figure 6.9**

WITH ASHTON UNDERGROUND MINE

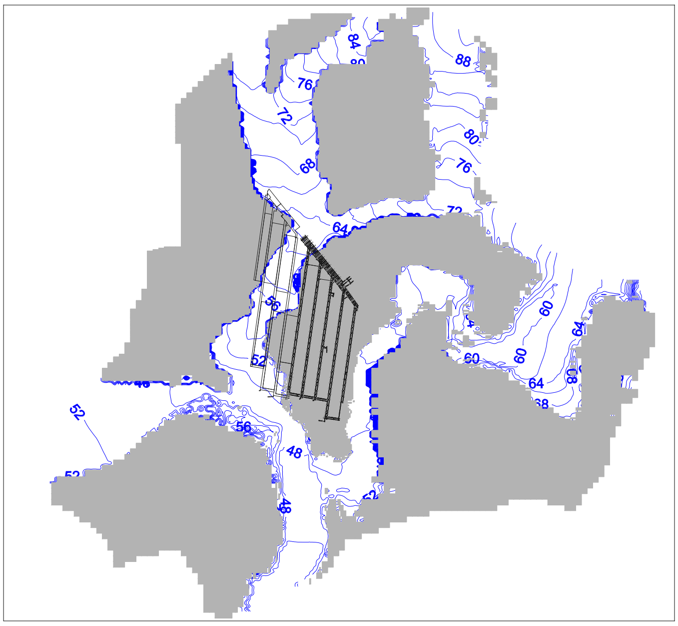


Year 15

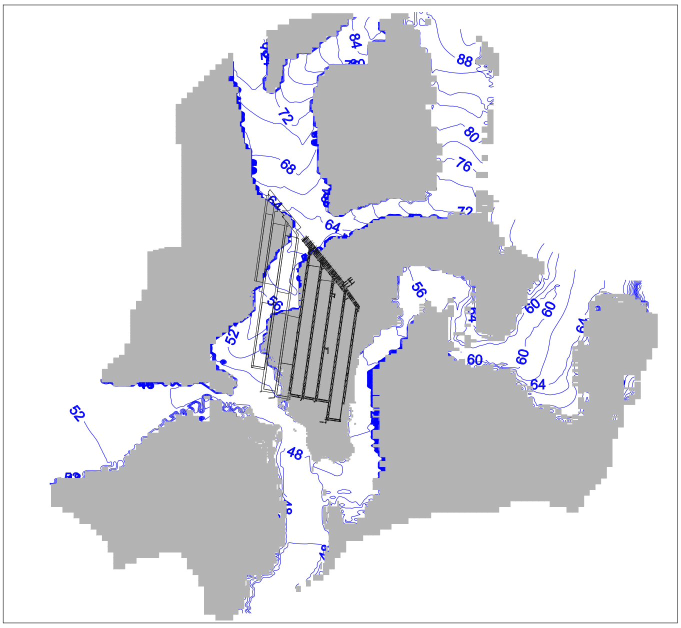


Year 20

WITHOUT ASHTON UNDERGROUND MINE



Year 15



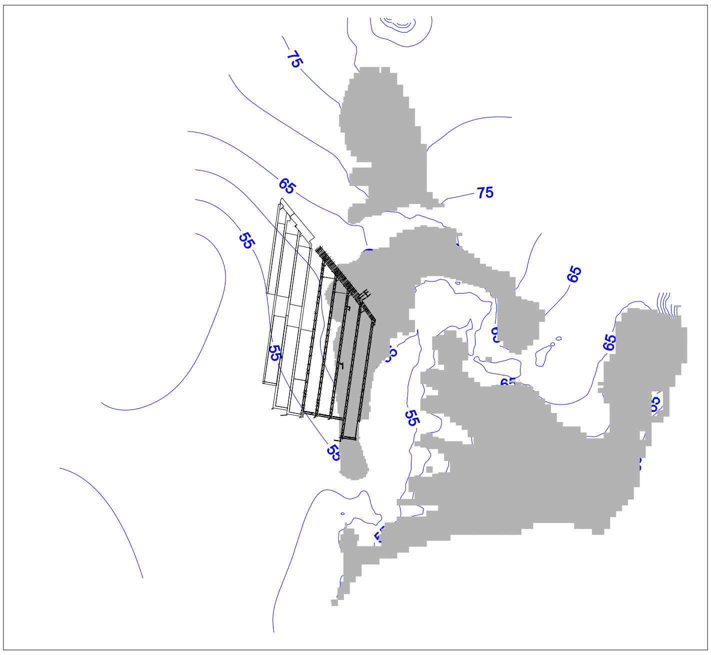
Year 20

Dry Cells

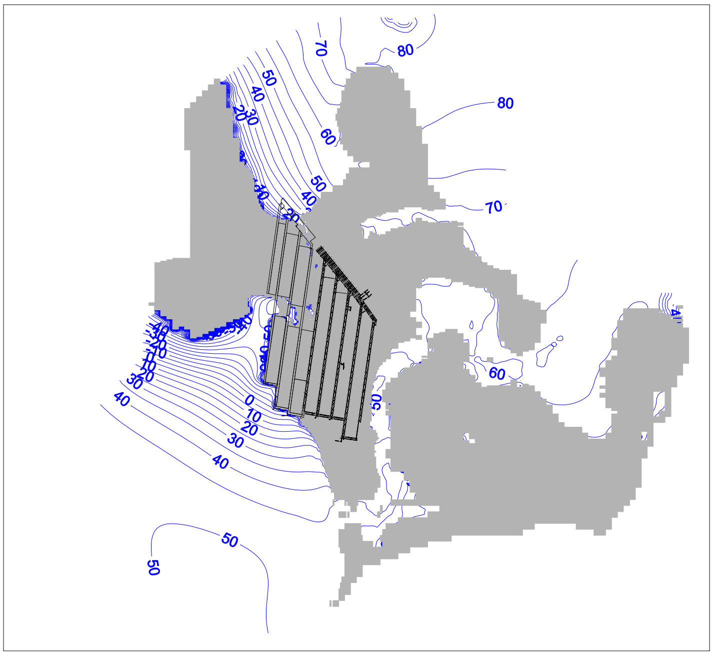
Groundwater elevation (mAHD)
2m Intervals

Date **19 August 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **JVDA**	Project **S55G**	**Model Predictions of Alluvium Groundwater Levels (Late Mining)**
Drawing Number **fig6.10.srf**	Revision **A**	
aquaterra		**Figure 6.10**

WITH ASHTON UNDERGROUND MINE

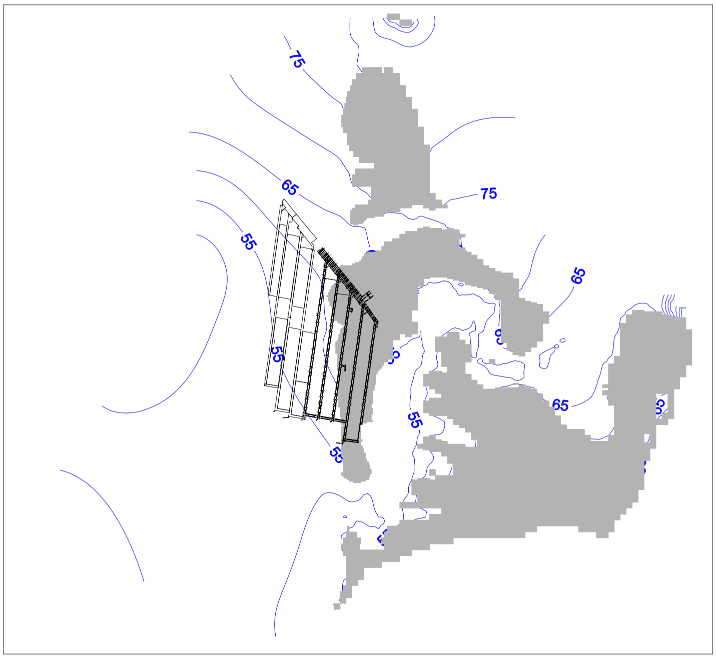


Year 2

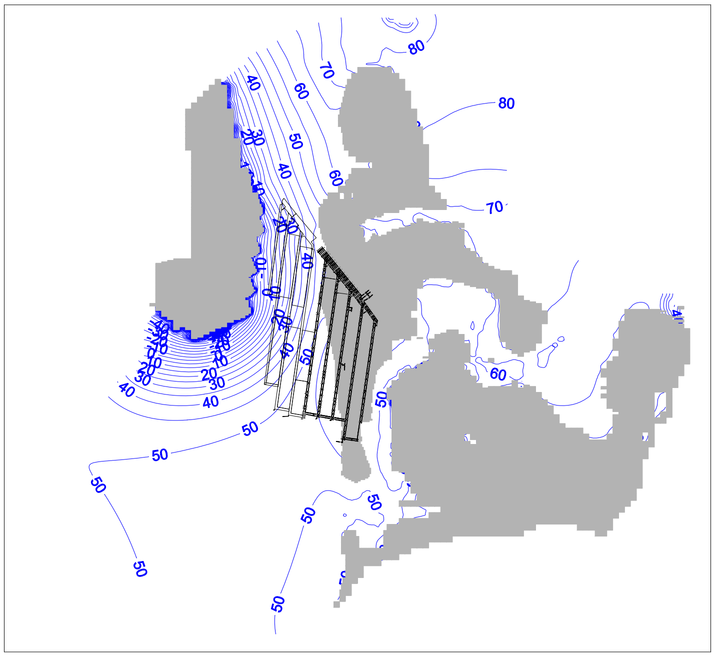


Year 11

WITHOUT ASHTON UNDERGROUND MINE



Year 2



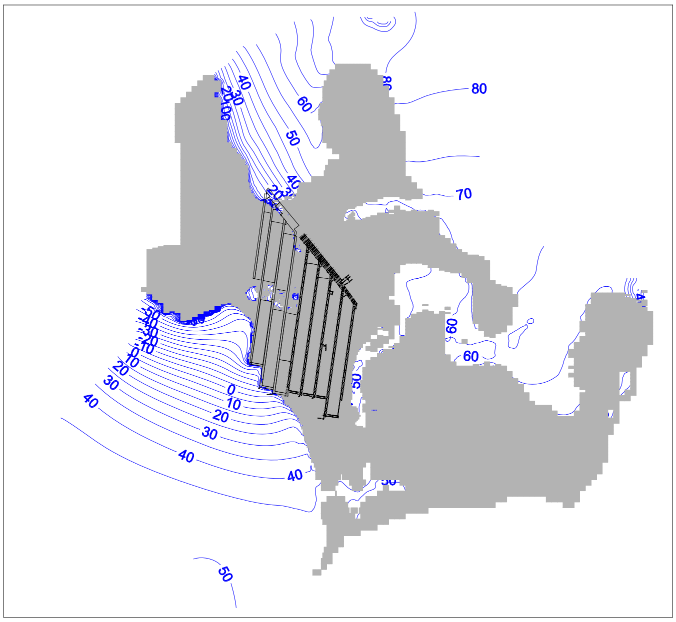
Year 11

Dry Cells

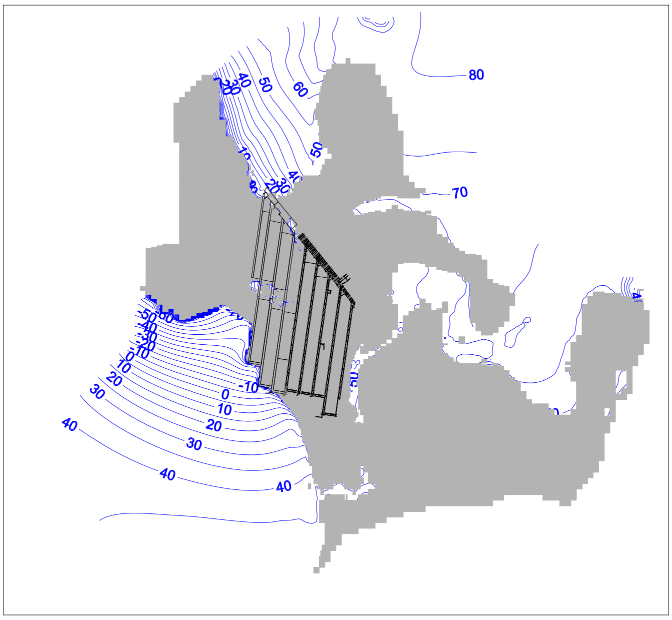
Groundwater elevation (mAHD)
5m Intervals

Date **21 September 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **JVDA**	Project **S55G**	**Model Predictions Groundwater Levels in the Pikes Gully Overburden (Early Mining)**
Drawing Number **fig6.11.srf**	Revision **A**	
aquaterra		**Figure 6.11**

WITH ASHTON UNDERGROUND MINE

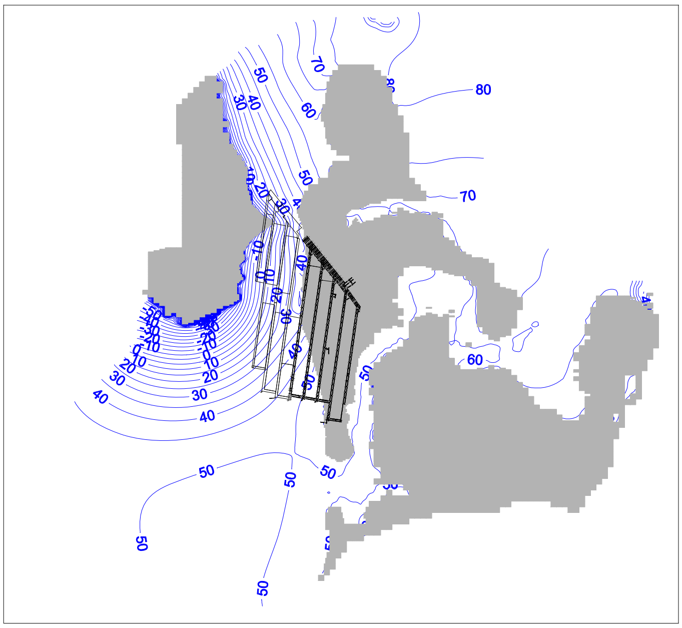


Year 15

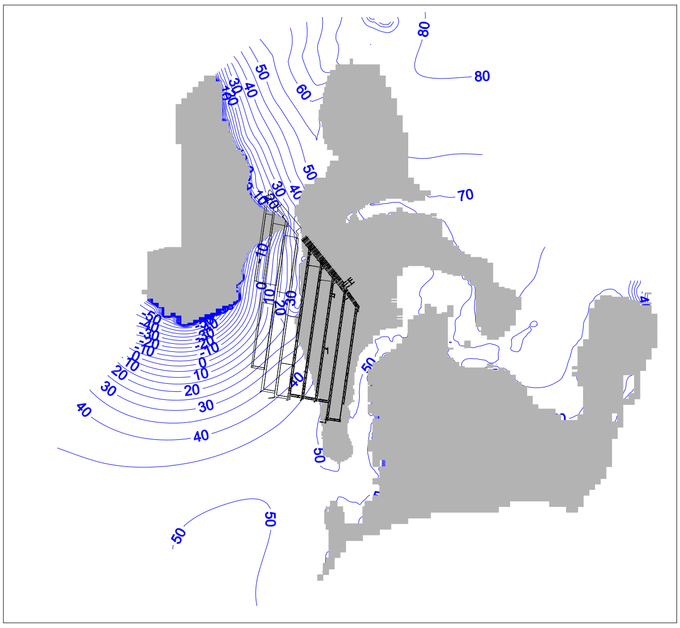


Year 20

WITHOUT ASHTON UNDERGROUND MINE



Year 15



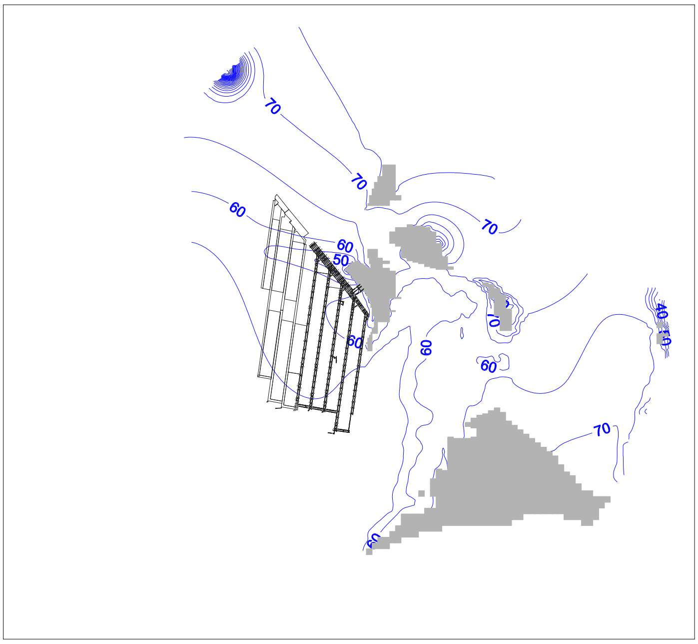
Year 20

Dry Cells

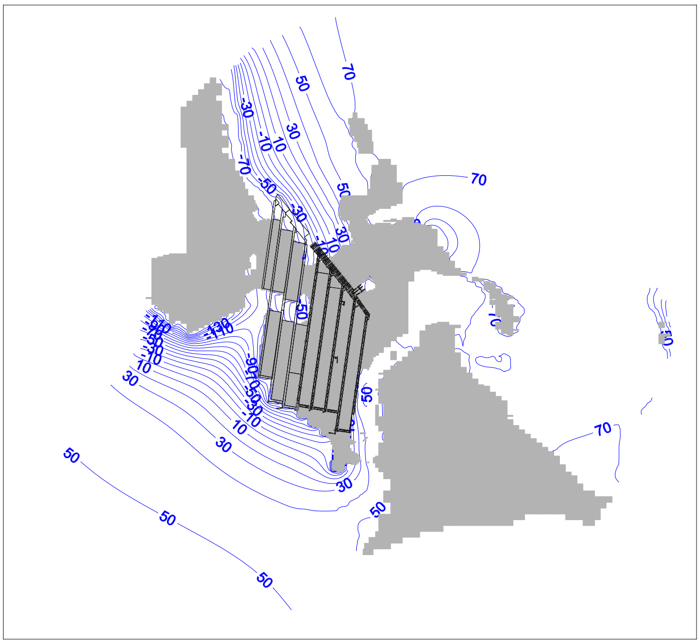
Groundwater elevation (mAHD)
5m Intervals

Date **19 August 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **JVDA**	Project **S55G**	**Model Predictions Groundwater Levels in the Pikes Gully Overburden (Late Mining)**
Drawing Number **fig6.12.srf**	Revision **A**	
aquaterra		**Figure 6.12**

WITH ASHTON UNDERGROUND MINE

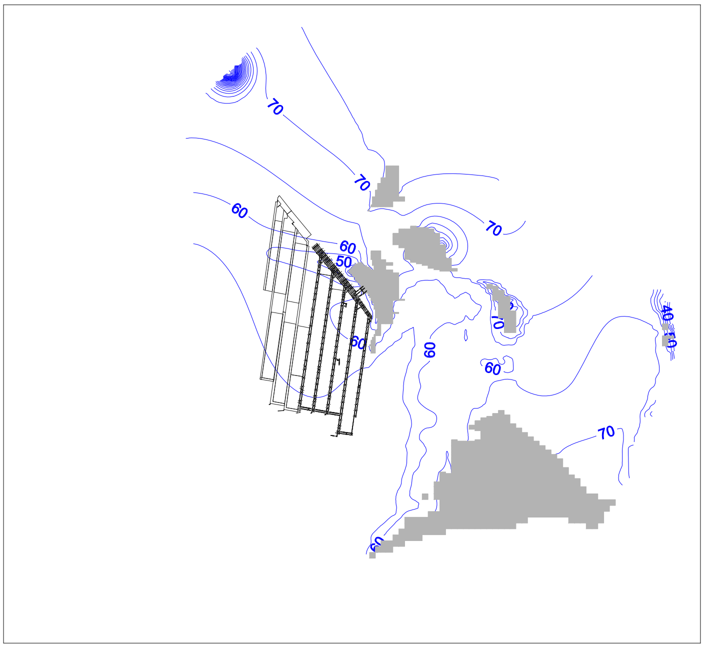


Year 2

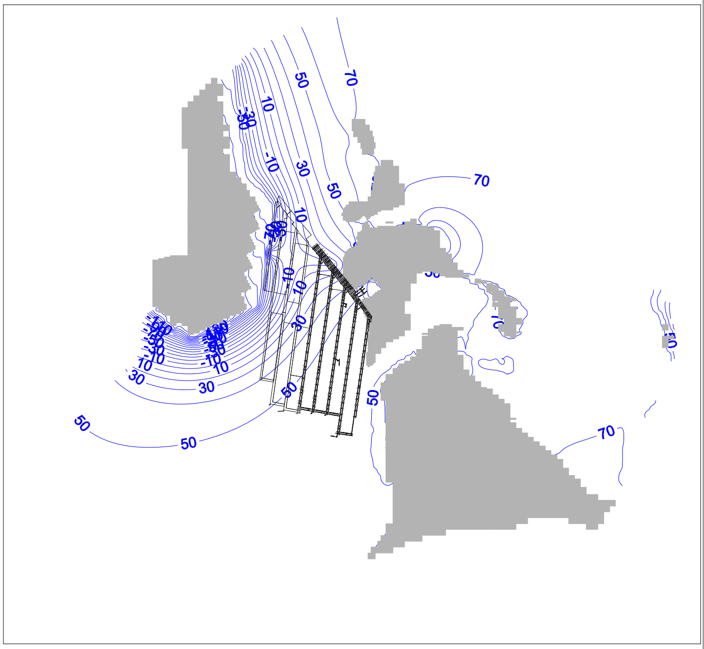


Year 11

WITHOUT ASHTON UNDERGROUND MINE



Year 2



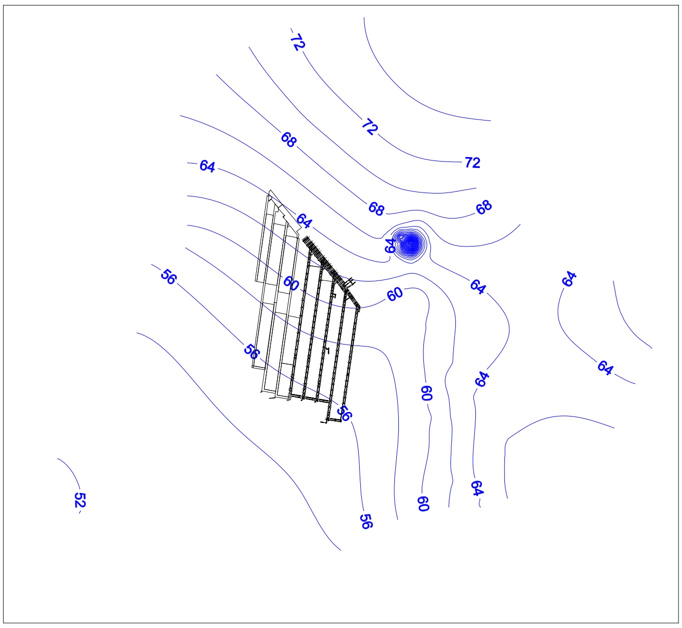
Year 11

Dry Cells

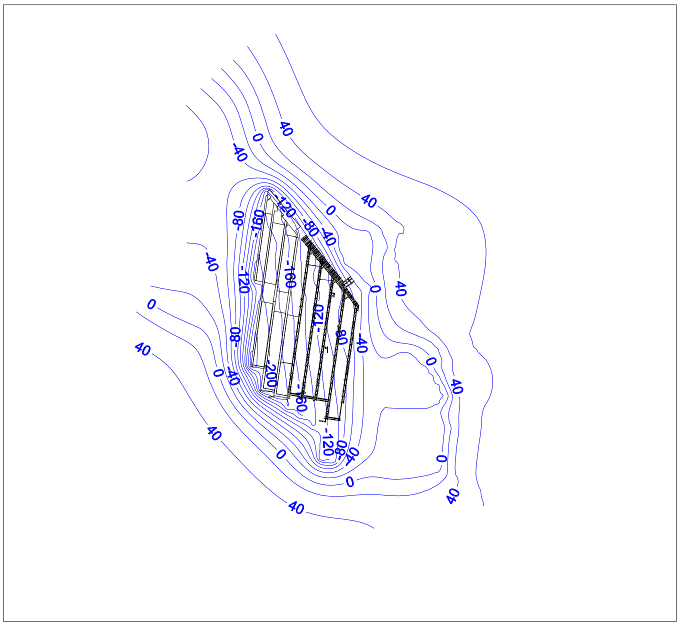
Groundwater elevation (mAHD)

Date **19 August 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **JVDA**	Project **S55G**	**Model Predictions of Groundwater Elevations in the Pikes Gully Seam**
Drawing Number **fig6.13.srf**	Revision **A**	
aquaterra		**Figure 6.13**

WITH ASHTON UNDERGROUND MINE

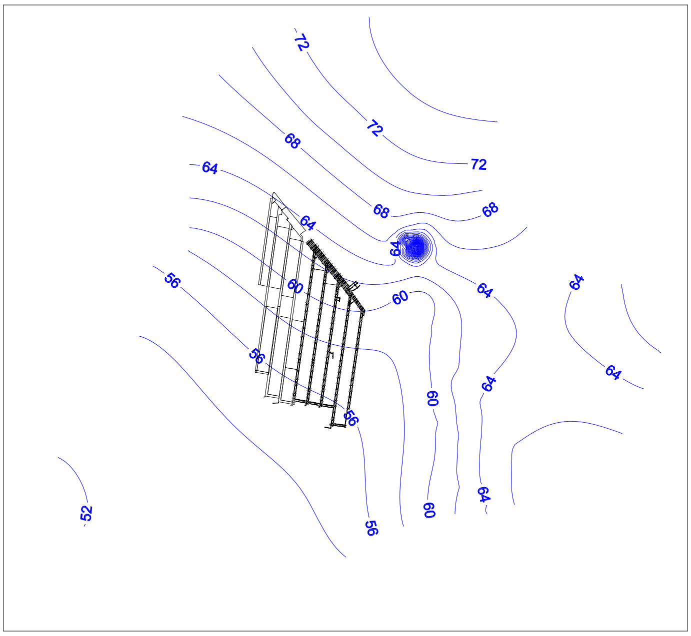


Year 2

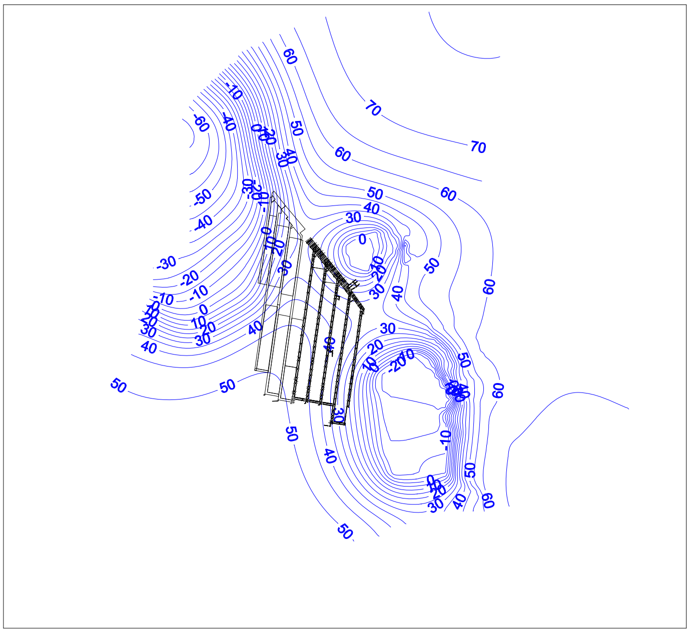


Year 20

WITHOUT ASHTON UNDERGROUND MINE



Year 2



Year 20

Dry Cells

Groundwater elevation (mAHD)

Date **19 August 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **JVDA**	Project **S55G**	**Model Predictions of Groundwater Elevations in the Lower Barrett Seam**
Drawing Number **fig6.14.srf**	Revision **A**	
aquaterra		**Figure 6.14**

6.10 MODELLED BASEFLOWS DURING MINING

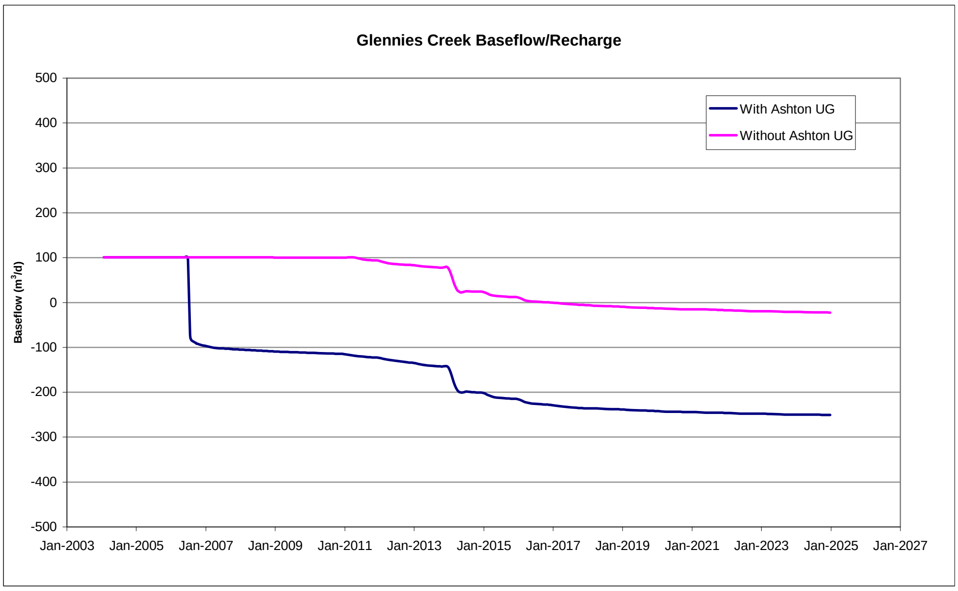
Modelled baseflows in Bowmans Creek, Glennies Creek and the Hunter River during the pre-mining and operational mining phases are shown in Figure 6.15. Each of these modelled baseflow profiles is shown with and without the effects of the Ashton underground mine, to illustrate the impact that the Ashton underground mine has over and above the impacts from other mining operations. Overall mining impacts on the three surface water systems are as follows:

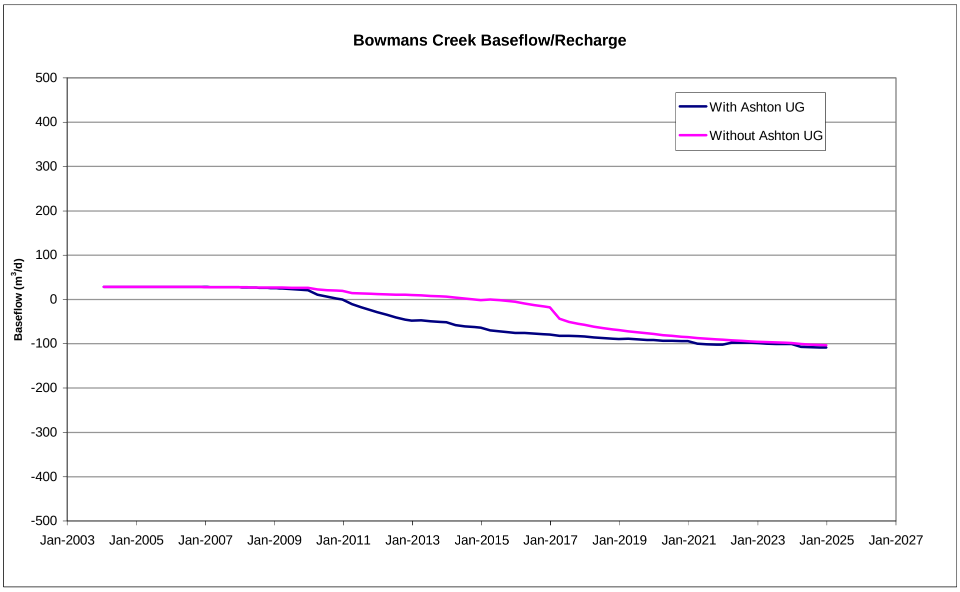
- Bowmans Creek within the section below the New England Highway changes from a slightly gaining creek to a creek that loses around 100 m^3/d (0.01 ML/d) by the end of underground mining. Interestingly the same level of impact is seen if the Ashton mine is not present. This is caused by the lack of the creek diversions in the 'without Ashton' model, as discussed in Section 7.
- Glennies Creek changes from a gaining stream to a losing stream during the course of mining. Some of this is due to the impacts of the SEOC mine, which accounts for most of the incremental reduction in baseflow that is seen between 2013 and 2025. As discussed previously, the initial change from a gaining to a losing stream in 2006 was caused by mining of the development headings for LW1, which allowed water to flow into the mine through the Pikes Gully seam near the point where the creek runs closest to the mine. From then on the progressive underground mining only has a slightly increasing impact on baseflow losses. Overall the underground mining causes a maximum reduction in flow of around 230 m^3/d (0.23 ML/d) in Glennies Creek.
- Underground operations are predicted to cause a moderate reduction in the baseflow contribution to the Hunter River, reducing flow rate by up to 60 m^3/d (0.06 ML/d).

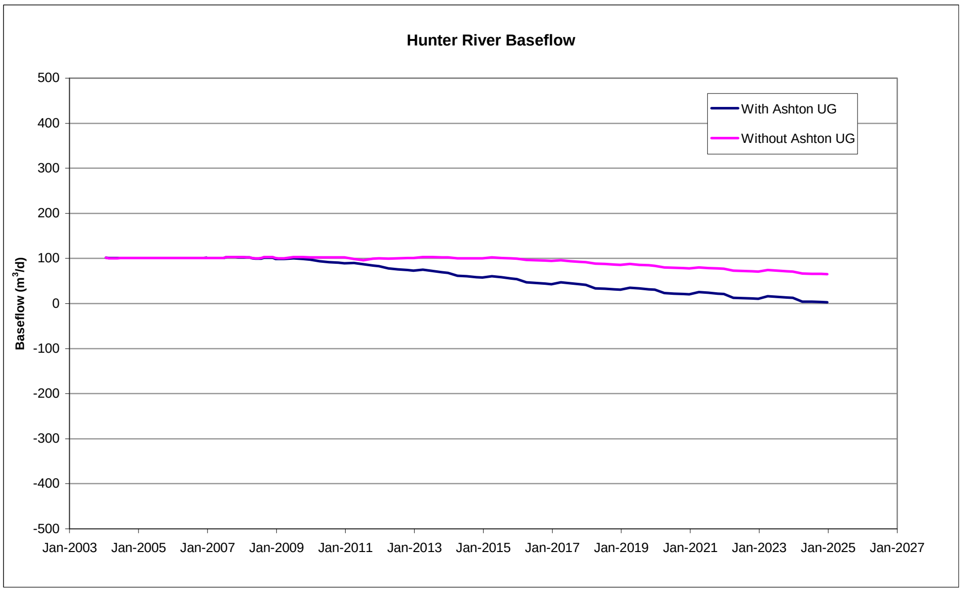
6.11 MODELLED POST MINING IMPACTS

The behaviour of the groundwater environment has potential implications to groundwater and surface water quality, as well as levels and baseflows. Results from the mining recovery runs are discussed along with implications to the hydrogeological environment within Section 7.

It should be noted that there have been no uncertainty runs carried out on the hydraulic properties of the mine during the recovery phase, as this is not considered necessary for the impact analysis. In all cases, the 5 m/d value for Kv and Kh for the caved material results in a very high degree of connectivity within the abandoned mine. This results in a relatively flat potentiometric groundwater surface within the mine workings and caved overburden. Increasing the permeability of the caved overburden would not therefore affect the results.







Date **20 August 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **JVDA**	Project **S55G**	**Modelled Baseflow for Glennies Creek, Bowmans Creek and the Hunter River**
Drawing Number **fig6.15.srf**	Revision **A**	
aquaterra		**Figure 6.15**

6.12 UNCERTAINTY ANALYSIS

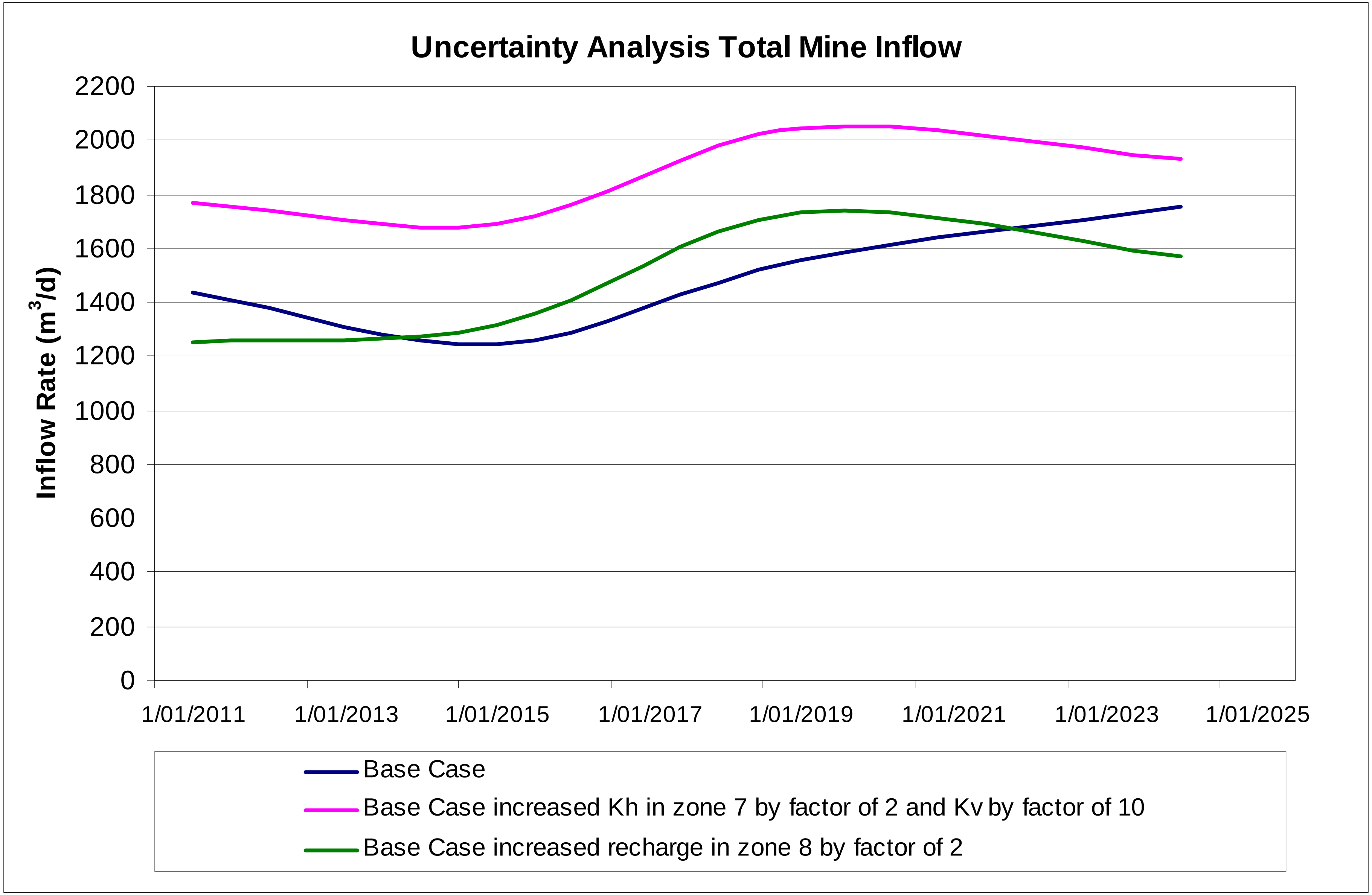
Uncertainty analysis is the process by which the impacts of variations in critical parameters (identified as being "sensitive") on model predictions and model reliability is assessed. The sensitivity analysis for the steady state model showed that results are most significantly affected by assumptions over recharge to the Permian subcrop areas and the permeability of the in-situ rock mass within the Permian overburden and interburden layers. In order to assess the impact that this could have on mine inflows, drawdown and baseflow, a simplified setup was used whereby the model was run over 4 time slices, one at the end of mining within each seam. Two uncertainty models were run in addition to the modified baseline model, to reflect the key uncertainties identified in the sensitivity analysis:

- Uncertainty model 1, whereby recharge to the coal seam sub-crop area above the underground mine (zone 8) was doubled.
- Uncertainty model 2, where horizontal permeability of the Permian (Zone 7) was doubled and the vertical permeability increased by an order of magnitude.

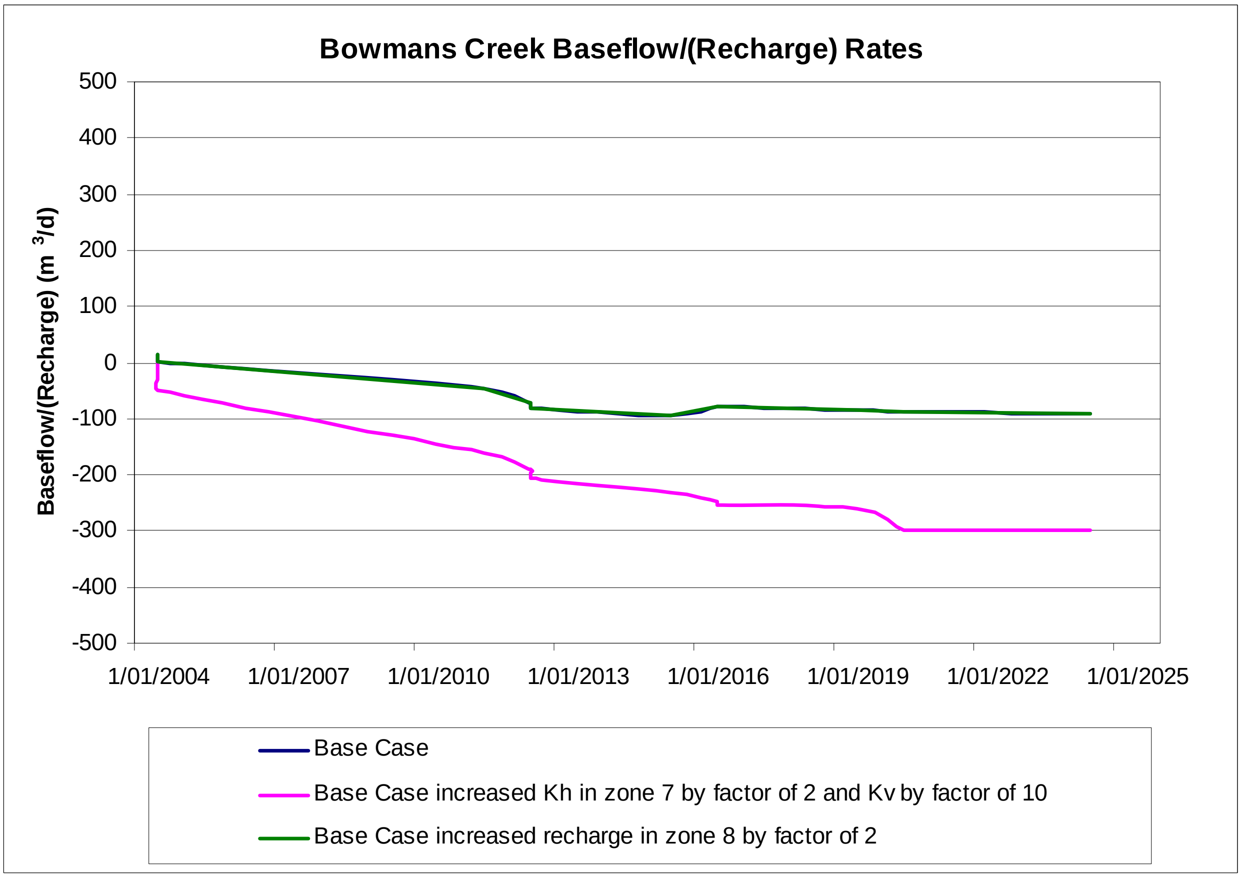
Results of the uncertainty analysis are shown in **Figures 6.16 and 6.17.** These show that:

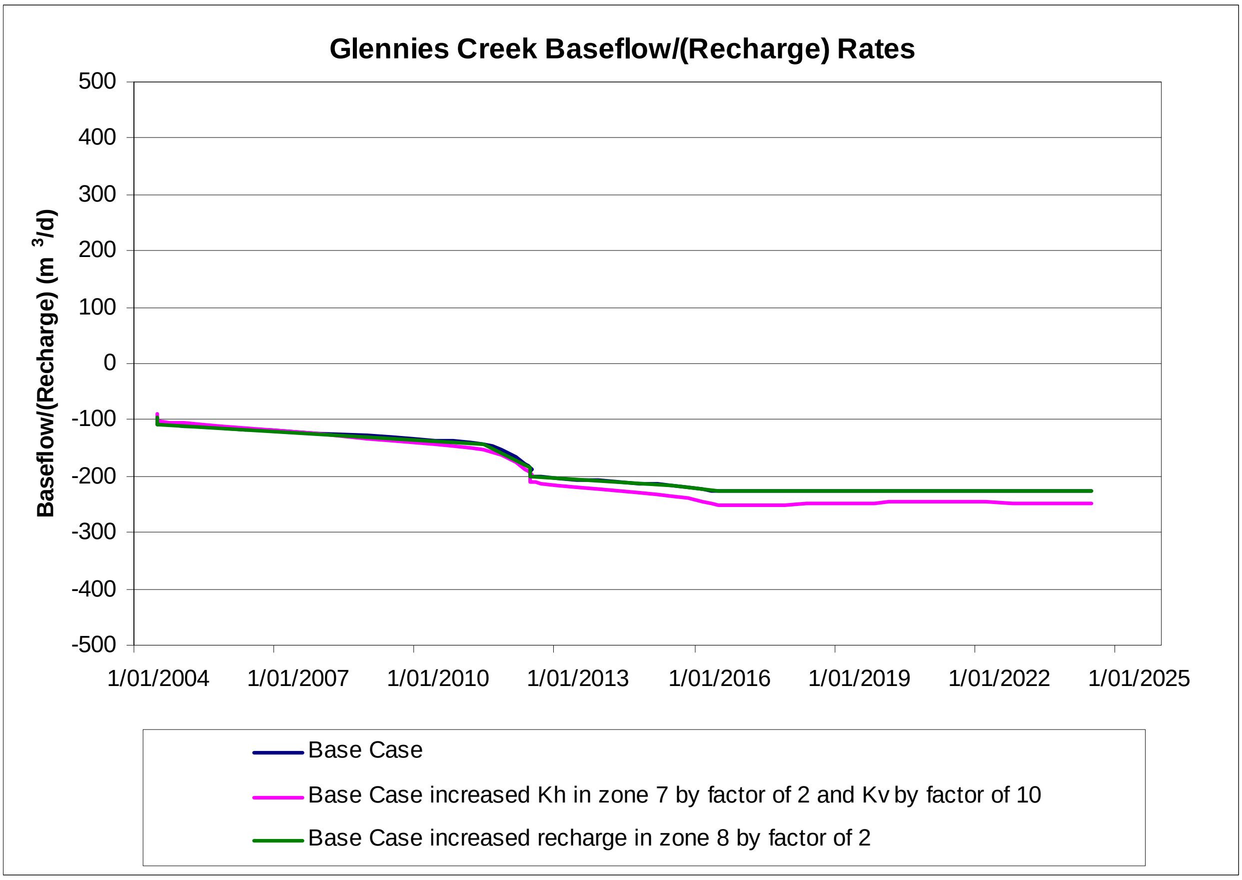
- Predicted mine inflow rates are largely unaffected by the increase in recharge, and only generally increase by around 200m^3/d when vertical and horizontal permeability in the Permian rock mass is increased.
- Baseflow losses from Glennies Creek are largely unaffected by the uncertainty analysis. Baseflow losses from Bowmans Creek are relatively sensitive to the vertical/horizontal permeability of the Permian rock mass, resulting in 200m^3/d (0.2 ML/d) additional losses. This is caused both by increased vertical connectivity in the Permian, and by a wider cone of depression caused by the mine workings. However, it should be noted that this represents the combined impact of Ashton and Ravensworth underground mining, and the overall sensitivity of the Ashton workings will only be around half of this.

The results described in Section 6.9 show that the strata layers above the longwall mine become de-watered relatively quickly during mining, so further impacts on the strata above the longwall mine are not possible. This means that the model is not sensitive to values of permeability within the caved overburden above the longwall mines. This reconciles with the experience of the modelling of longwall mining elsewhere, which shows that the level of impacts are more generally associated with the vertical extent of subsidence fracturing, rather than the assumed hydraulic parameters (Merrick, pers comm). Changing the hydraulic parameters will not therefore have any significant effect on final groundwater levels or baseflow impacts, although they could result in mine inflow rates that peak earlier than the results in Section 6.8. Uncertainty analysis has not therefore been carried out on the assumptions relating to the permeability of the caved overburden for this mine.



Date **6 October 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **TL**	Project **S55G**	**Uncertainty Analysis of Groundwater Inflow Rates**
Drawing Number **fig6.16.srf**	Revision **0**	
aquaterra		**Figure 6.16**





Date **09 September 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **TL**	Project **S55G**	**Uncertainty Analysis** **Bowmans Creek and Glennies Creek Baseflows**
Drawing Number **fig6.17.srf**	Revision **0**	
aquaterra		**Figure 6.17**

7 POTENTIAL GROUNDWATER IMPACTS

7.1 OVERVIEW OF POTENTIAL IMPACTS ON THE GROUNDWATER SYSTEM

This section contains a summary of the impacts on the hydrogeological environment from the proposed progressive multi-seam mining of four seams (Pikes Gully, Upper Liddell, Upper Lower Liddell and Lower Barrett), and a subsequent 100 year period of post-mining recovery. The section also includes an assessment of the impacts of mining and recovery, if mining were to be terminated at the end of the Upper Liddell seam due to unforseen economic or technical issues, as discussed in Section 1.2.

It should be noted that the 'baseline' used for the impact analysis in this report refers to the condition where there is no underground mining at Ashton at all. All impacts contained within this section therefore relate to the total effect of longwall mining, including the impacts from the longwall panels that have already been mined in the Pikes Gully seam.

Although the mining of the underground seams at Ashton has a significant, transient impact on the local hydrogeological regime, this has to be set within the context of the other mining activities that are being carried out simultaneously in this area, and the effects of past mining. Two suites of prediction modelling have been run – one with the Ashton underground mine and one without Ashton underground. Where appropriate, all results relating to the period of operational mining have therefore been presented as both the total change from the baseline conditions, and the change that would have occurred due to other mining if the Ashton underground is not mined. This allows the net impact of Ashton underground on the hydrogeological environment to be evaluated separately from the other regional impacts.

The main effect of the underground mining upon the groundwater regime comes from changes in bulk rock mass permeability caused by the fracturing associated with longwall subsidence, and the pumping out of groundwater that enters the mine as a consequence. Further details of these mechanisms, and the quantification of the effects on rock mass permeability, are given in Section 4.7.2 and Section 6.3. This caving, and associated extraction of groundwater have a number of effects on the hydrogeological system during mining operations that have been evaluated as part of the impact assessment. These can be summarised as follows:

- Inflow of water to the underground mine and the management of that mine water.
- Impacts on groundwater levels during operational mining, both within the Permian hard rock strata and the alluvium associated with Bowmans Creek, Glennies Creek and the Hunter River.
- Impacts on baseflow to Bowmans Creek, Glennies Creek and the Hunter River during operational mining.

In the post mining recovery phase, the presence of subsidence within the Bowmans Creek floodplain, the presence of caved strata above the longwall panels and the presence of goaf areas and open roadways in the coal seams will result in long term changes to the hydrogeological environment. As described in the 2001 EIS, this has the potential to effect:

- Groundwater levels in both the alluvium and Permian strata, caused by the changes in underground flow regimes and changes in recharge patterns in the Bowmans Creek alluvium.
- Long term baseflow in Bowmans Creek, Glennies Creek and the Hunter River.
- Water quality within Bowmans Creek, Glennies Creek and Hunter River, and their associated alluvium, in the post mining phase.

These primary impacts could lead to secondary impacts on groundwater receptors, including Groundwater Dependent Ecosystems (GDEs), other groundwater users and in-stream aquatic ecology. Impacts on aquatic ecology are described in more detail in the ecology specialist report.

The NSW Office of Water (NOW) has also indicated that there are potential concerns over the impact of mining on the 'buffering capacity' of the Bowmans Creek alluvium.

This refers to the ability of the intermediate salinity water contained within the Bowmans Creek alluvium to act as a buffer between the creek and the upwelling, saline, Permian groundwaters during drought periods. It is thought that the presence of the less saline water within the alluvium delays the encroachment of the saline Permian groundwater and hence reduces the rate of increase of salinity within the creek during drought periods. This potential impact has been addressed within this Section.

7.1.1 GROUNDWATER LEVELS AND FLOWS PRIOR TO MINE DEVELOPMENT

The pre-mining hydrogeological environment has been fully described within Section 4 of this report. Key features that are relevant to the impact assessment include:

- The general flow within the Permian is to the south-west, flowing from the elevated areas of sub-crop on the eastern side of the underground mine, through to the deeper Permian associated with the Bayswater syncline to the west.
- Because of the general lack of vertical hydraulic connectivity, potentiometric head in the Permian was higher than the Bowmans Creek alluvium groundwater levels, and were above ground level in some low-lying areas, particularly in the south of the Bowmans Creek floodplain near the Hunter River confluence. A similar situation occurs within the Glennies Creek alluvium, with potential for upward flow from the Permian to the alluvium in the baseline condition.
- Bowmans Creek, Glennies Creek and the Hunter River are all generally gaining water courses in the pre-mining hydrogeological environment (i.e. groundwater discharges as baseflow into the creeks and river).

7.2 EVALUATON OF IMPACTS DURING MINE OPERATIONS

7.2.1 GROUNDWATER LEVEL IMPACTS

Water level contours for the alluvium/regolith, Pikes Gully overburden, Pikes Gully seam and the Lower Barrett seam during underground mining operations have already been described in Section 6.7, and are shown graphically in Figures 6.9 to 6.13. The Pikes Gully and Lower Barrett seams have been selected for presentation as these are the top and bottom seams to be mined.

In general, the duration of the mining and the high degree of caving associated with longwall extraction means that most of the strata within the Ashton underground, Ravensworth underground, and NEOC and SEOC mining areas become de-watered during operations. This creates a deep cone of depression down to -200 mAHD in the Permian (or to –120 mAHD if mining were to cease at the Upper Liddell seam), although the low permeability of the in-situ rock mass means that this has a steep gradient and the effects diminish rapidly away from the area of mining.

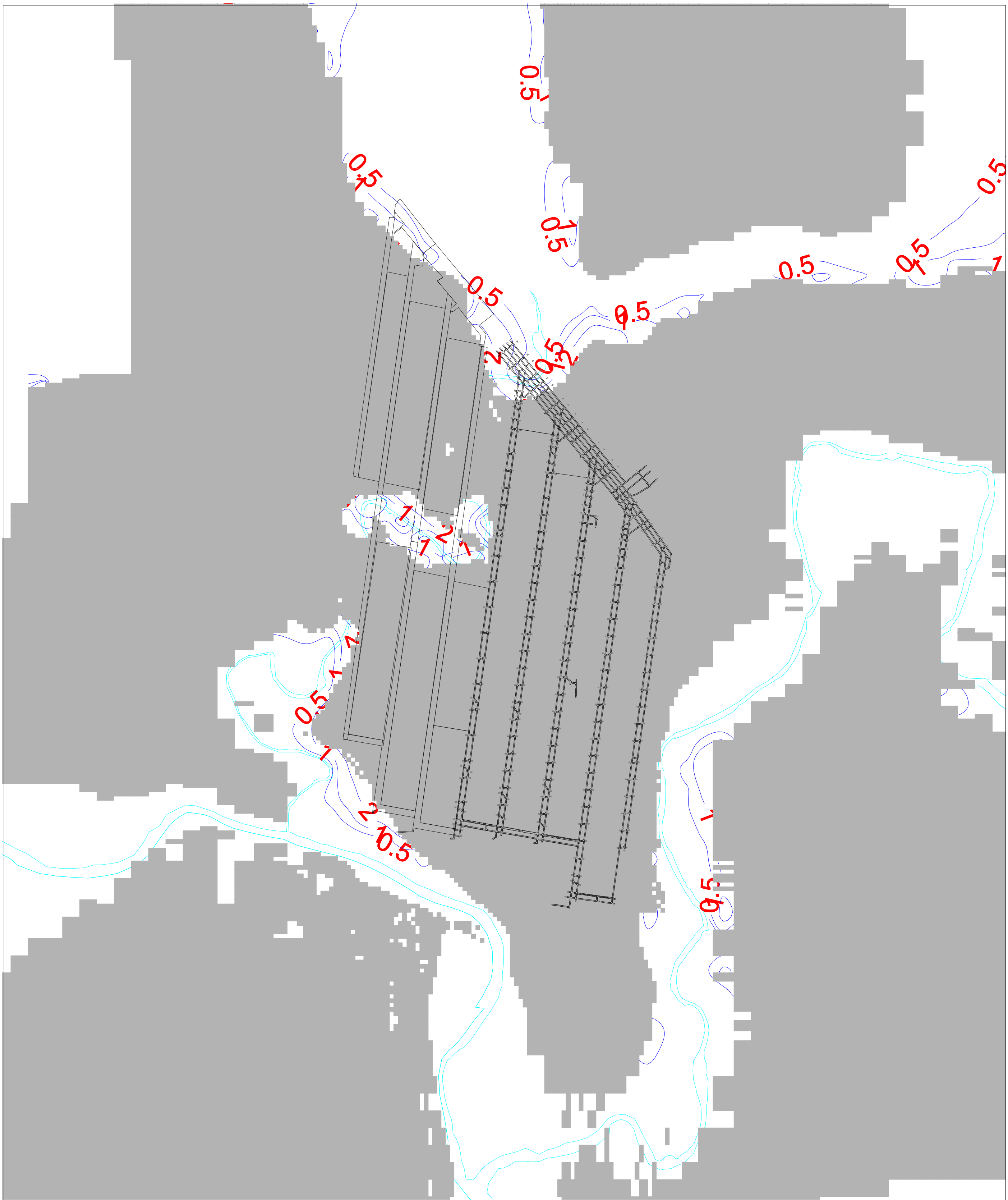
As discussed in Section 6.7, comparisons between the 'with Ashton' and 'without Ashton' underground mine modelling runs show that Ashton contributes only a small additional impact on groundwater levels to the north and west, where substantial drawdowns are predicted to occur as a result of the other mining activities.

Drawdowns in the alluvium at the end of mining in the ULD Seam are shown in Figure 7.1. Drawdowns in the alluvium at the end of mining in the LB seam are shown in Figure 7.2. The comparison of the 'with' and 'without' Ashton underground mining water levels contained in Figures 6.9 and 6.10 show that drawdowns in the Bowmans Creek alluvium to the north of the RTA bridge (i.e. north of the New England Highway) would occur even without the Ashton underground mine. The alluvium south of this, between the RTA Bridge and the Hunter River, is predicted to be largely de-watered by the end of mining activities, which is as a direct result of the proposed Ashton underground mine. (This would occur even if mining were to stop at the end of the ULD seam.) The alluvium remains saturated only in the southern end of this reach, between the Hunter River and the Bowmans Creek western diversion, and in a small area of alluvium around the section of creek that is left in place between the two diversions. Drawdown impacts following completion of mining range from around 2m to 0.5m in the remaining areas of saturated alluvium. (Drawdowns at the end of the ULD seam are smaller, with most of the saturated alluvium in the southern section experiencing drawdowns of less than 0.5m.)

Because there is relatively little alluvium on the western side of Glennies Creek in the area closest to the underground mine, the main impact from Ashton is on baseflows in Glennies Creek, rather than on water levels in the Glennies Creek alluvium. Impacts on alluvial groundwater levels are generally in the order of 0.1m or less by the end of mining. Some larger impacts occur on the far western side of the alluvium, but these are less than 0.4m

Although the Ashton underground does cause some depressurisation of the Permian strata below the Hunter River alluvium, impacts on alluvial water levels are minimal. The 0.5m drawdown contour (Figure 7.2) lies within the Bowmans Creek alluvium and does not encroach into the Hunter River alluvium. Drawdowns reduce rapidly near the interface, and the impact on the Hunter River alluvium is limited to 0.1m or less by the completion of mining of all four seams.

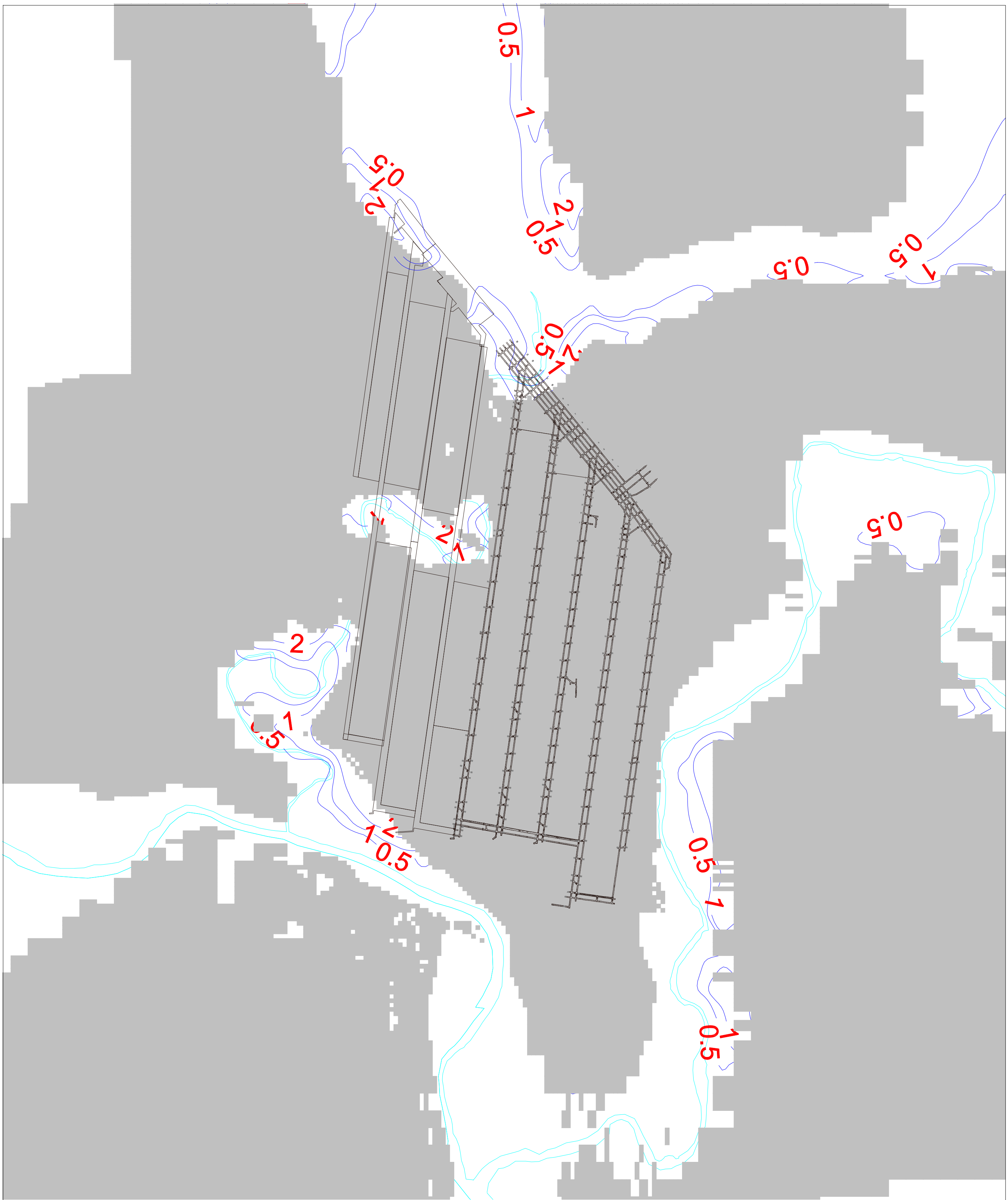
Drawdowns in the Pikes Gully seam (Layer 8) at the end of mining the ULD seam, with and without the Ashton underground mine, are shown in Figure 7.3. Outside of the mine footprint, the main impact from the Ashton underground mine on potentiometric pressures within Permian strata occurs to the south and south east of the mine, where drawdowns of 10m or more could occur up to 1.5km from the mine. Impacts to the north, west and north-east are minimal due to the influence of other mines to the west and the fact that the areas to the north and north east are up-dip of the Ashton mine. Drawdowns at the end of LB mining are shown in Figure 7.4. Again, impacts are limited to the south and south east, where drawdowns within the Pikes Gully seam of 10m or more could occur up to 2km from the mine.



Date **21 September 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **PZ**	Project **S55G**	**Predicted Groundwater Drawdowns in the Alluvium, at the end of ULD Mining**
Drawing Number **fig7.1.srf**	Revision **A**	

aquaterra

Figure 7.1

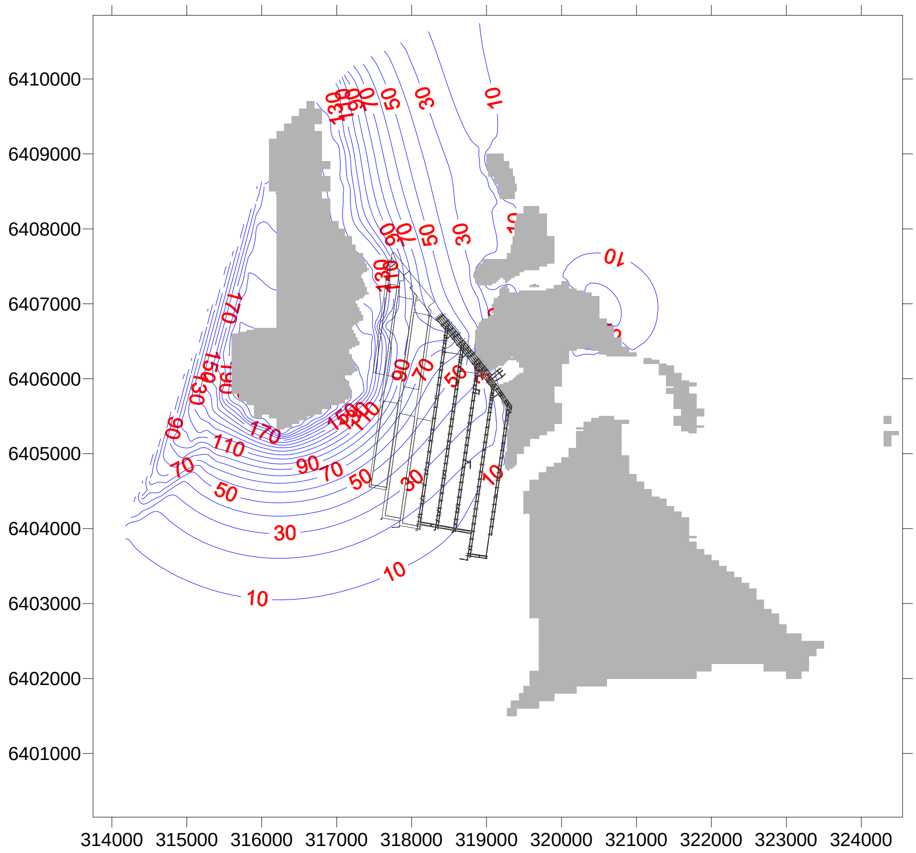


Dry Cells (Unsaturated Areas)

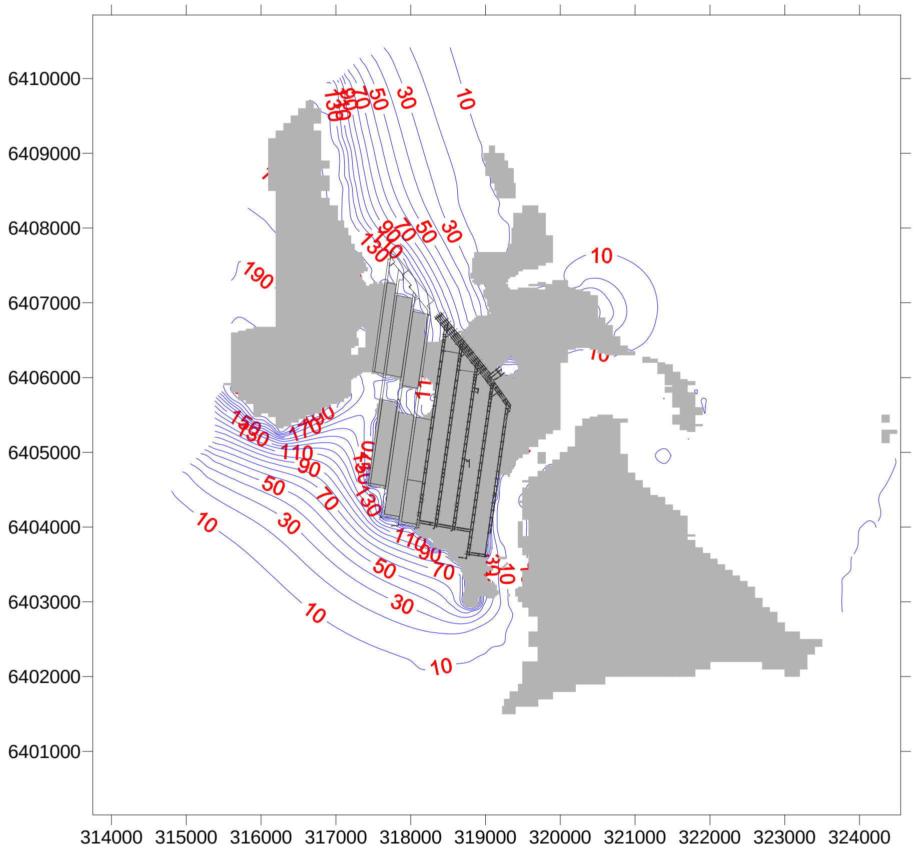
Groundwater drawdown (m)
0.5m Intervals

Date **21 September 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **PZ**	Project **S55G**	**Predicted Groundwater Drawdowns in the Alluvium, at the end of Lower Barrett Mining**
Drawing Number **fig7.1.srf**	Revision **A**	
aquaterra		**Figure 7.2**

Without Ashton UG



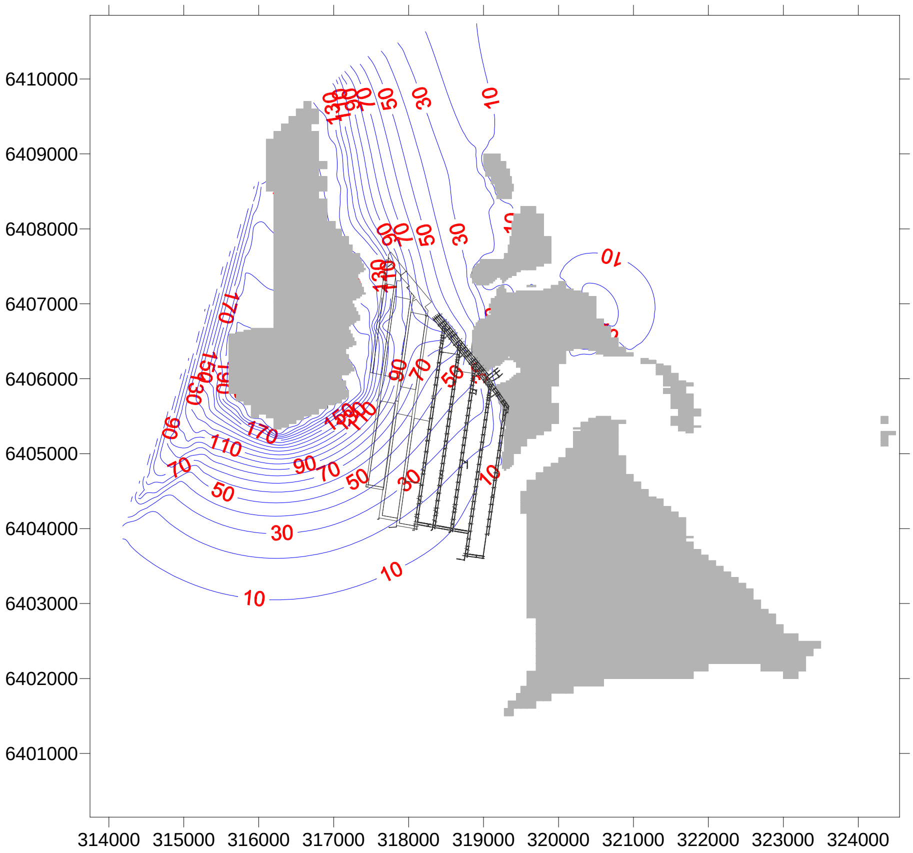
With Ashton UG



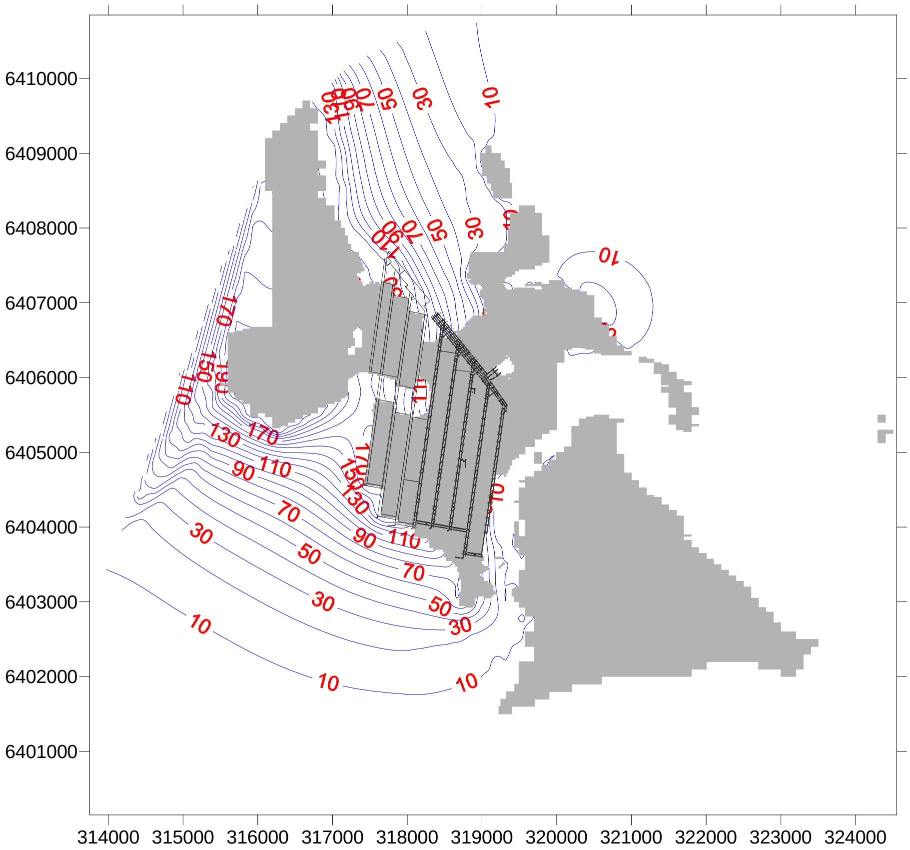
Dry Cells

Groundwater drawdown (m)
10m Intervals

Date **21 September 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **PZ**	Project **S55G**	**Predicted Groundwater Drawdowns in the Pikes Gully Seam at the End of Upper Liddell Seam Mining**
Drawing Number **fig7.3.srf**	Revision **A**	
aquaterra		**Figure 7.3**



Without Ashton UG



With Ashton UG

Dry Cells

Groundwater drawdown (m)
10m Intervals

Date **21 September 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **PZ**	Project **S55G**	**Predicted Groundwater Drawdowns in the Pikes Gully Seam At the End of Lower Barrett Mining**
Drawing Number **fig7.2.srf**	Revision **A**	
aquaterra		**Figure 7.4**

7.2.2 POTENTIAL BASEFLOW IMPACTS

Modelled impacts on baseflows during the mining period are described in Section 6.8 and shown in Figure 6.15. Overall, the Ashton underground mine is predicted to have the following net impact on baseflows by the end of mining operations (impacts at the end of ULD mining are indicated in brackets):

- Flow in Glennies Creek is predicted to reduce by around 230 m^3/d (0.23 ML/d) due to the Ashton underground mine.
- Flow in the Hunter River is predicted to reduce by around 60 m^3/d (0.06 ML/d) due to the Ashton underground mine.
- The modelling indicates that Bowmans Creek will change from gaining about 30 m^3/day (0.03 ML/d) to losing about 100 m^3/day (0.10 ML/d) by the end of mining. It should be noted that this is likely to occur even if the Ashton underground mining is not carried out, as impacts from other mines result in a similar baseflow position by 2020. The Ashton underground mine does cause impacts to occur earlier than they would otherwise, but the model indicates that final baseflow losses would be the same with or without the Ashton underground mine. Although impacts on alluvium water levels are greater with the Ashton underground mine, the construction of the diversion hydraulically isolates large sections of the creek, so overall there is little incremental change due to the Ashton underground mining.
- If the underground mining at Ashton were to cease after the Upper Liddell seam, the maximum reduction in Glennies Creek baseflow would be about 220 m^3/d (0.22 ML/d); reduction in Hunter River baseflow would be 50 m^3/d (0.05 ML/d); and Bowmans Creek baseflow would reduce by around 100 m^3/d (0.1 ML/d).

7.2.3 PREDICTED MINE INFLOWS

As shown in Figure 6.8, mine inflow rates during operations are predicted to reach an initial peak of around 1.4 ML/d during the start of the mining of the ULD seam. This is followed by a slight reduction, before flow rates rise again once the mining of the ULLD occurs beneath the floodplain. Maximum inflows of just over 1.6 ML/d are predicted to occur near the start of the LB seam mining, although this peak rate could be lower, or could be reached earlier, as shown by the uncertainty range in Figure 6.8. This range represents the uncertainty over the timing and amount of surface runoff that might enter the subsidence affected area within the Bowmans Creek floodplain. This is associated with runoff recharge (rather than flooding) and the mechanisms and values used are fully described in Section 6.3.5. As discussed in Section 6, these uncertainties only affect mine inflow rates, and not groundwater levels or baseflow impacts.

The calibration discussed in Section 6 shows that predictions of peak inflows towards the end of the LB mining are almost certainly conservative, as the model does not allow for the 'self healing' and reduction in permeability in strata around the caved areas that has been observed in monitoring bores across the site. It also assumes that a proportion of 'captured' rainfall runoff that enters the subsidence areas effectively becomes groundwater recharge during operational mining due to the ground disturbance associated with ongoing subsidence and backfilling activities.

There is a risk that the subsided area of the old creek channel above longwall 6B could become inundated by flood events during the mining operation period, resulting in transient increases in mine inflow rates. This has not been included in the assessment of mine inflow rates, as it would be a very intermittent event that represents an operational, rather than environmental, risk. However, in a year when a flood occurred, it could increase groundwater recharge by about 15% of the long term average mine inflow (the total additional infiltration would be about 130 ML, or around 75% of the total 178 ML captured in the flooded area). Monitoring and construction controls to reduce the risk from such events are described in Section 8.

7.3 IMPACTS FOLLOWING POST MINING RECOVERY

The long term impacts of mining following 100 years of recovery after the end of mining are described below. This includes an assessment of post mining recovery impacts in the event that mining were to cease early (at the end of ULD seam mining), as discussed elsewhere in this report.

7.3.1 GROUNDWATER RECHARGE AND GROUNDWATER LEVELS

Final predicted groundwater heads in the alluvium (Layer 1), the Pikes Gully overburden (Layer 5) and the Pikes Gully seam (Layer 8), following 100 years of post-mining recovery are shown in Figure 7.5. The recovery impacts in the event that mining ceased after the ULD seam are shown in Figure 7.6. These figures show that:

- Potentiometric heads are uniform (i.e. there is little gradient) within the Permian in the mined area. This is due to the very high hydraulic connectivity within the mine.
- By the end of the recovery period, alluvium within the Bowmans Creek floodplain re-saturates, and groundwater levels return to values that are similar to the pre-mining condition, for both recovery models. Groundwater levels in the Hunter River and Glennies Creek alluvium return to their pre-mining condition for both recovery models.

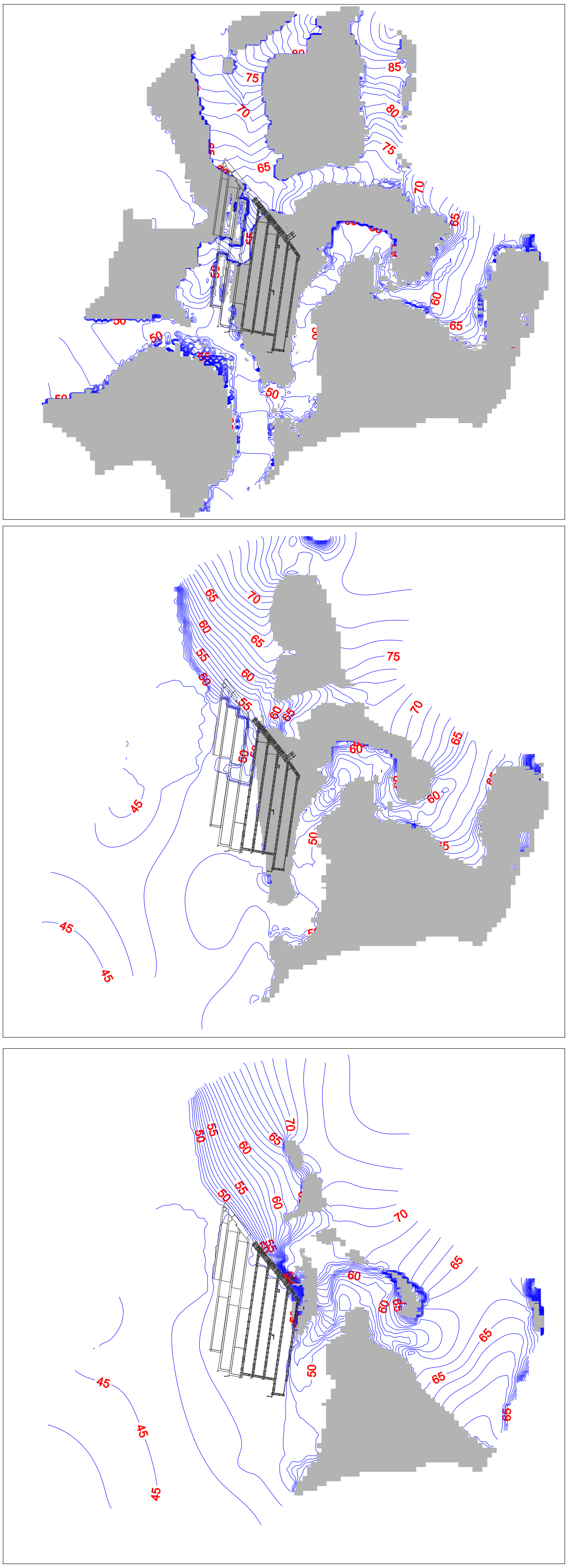
In order to examine the rate of recovery within the various strata layers, 'target' locations have been introduced to the groundwater model at key points within the Bowmans Creek floodplain. Target 1 is located to the west of LW6A, within the southern area of alluvium that remains saturated during mining. Target 2 is set within the fully de-saturated area between the eastern diversion and LW6B. The recovery hydrographs for the alluvium (model Layer 1), the Permian overburden (model Layers 3 and 5) and the Pikes Gully seam (Layer 8) are shown in Figure 7.7. The following conclusions can be drawn from this analysis:

- Recovery occurs primarily due to recharge into the alluvium, which then percolates to the mine workings. Although the rate of percolation from the alluvium to the underground mine is rapid in the mining area, recovery is still 'top down', even in the area of initially unsaturated alluvium between LW6B and the eastern diversion. This means that potentiometric heads within the alluvium recover before the Permian, and groundwater flow is generally downwards in the Permian during the recovery period.
- Groundwater heads reach near equilibrium within both model runs. This indicates that the final potentiometric heads shown in Figures 7.5 and 7.6 represent equilibrium, or near equilibrium conditions. Analyses carried out during the development of the recovery models indicated that the final potentiometric levels within the mine workings are controlled by the balance between the rate of recharge to the mine and fractured overburden, and the rate at which water can exit through the Permian strata to the south and west. Mass balance analysis shows that the majority of the water that enters the mine workings comes from the Bowmans Creek area, primarily through the vertical fracturing associated with the subsidence zones. Significant inflows also occur from the east due to the sub-crop of the Pikes Gully seam beneath Glennies Creek alluvium.

Alluvium

Pikes Gully Overburden

Pikes Gully



Dry Cells

Groundwater elevation (mAHD)
5m Intervals

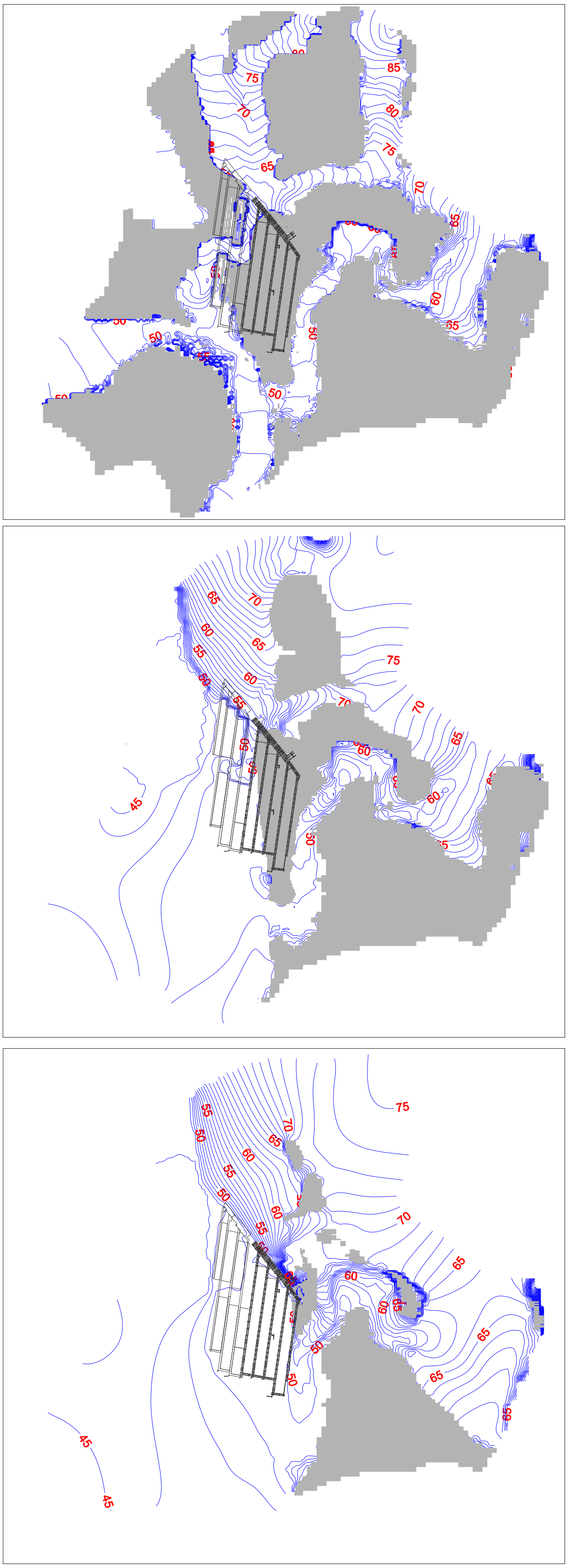
Date **26 August 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **PZ**	Project **S55G**	**Final Groundwater Heads in the Alluvium (layer 1), Pikes Gully Overburden (layer 5) and Pikes Gully (layer 8) for the Lower Barrett Recovery Run**
Drawing Number **fig7.5.srf**	Revision **A**	**Figure 7.5**

aquaterra

Alluvium

Pikes Gully Overburden

Pikes Gully



Dry Cells

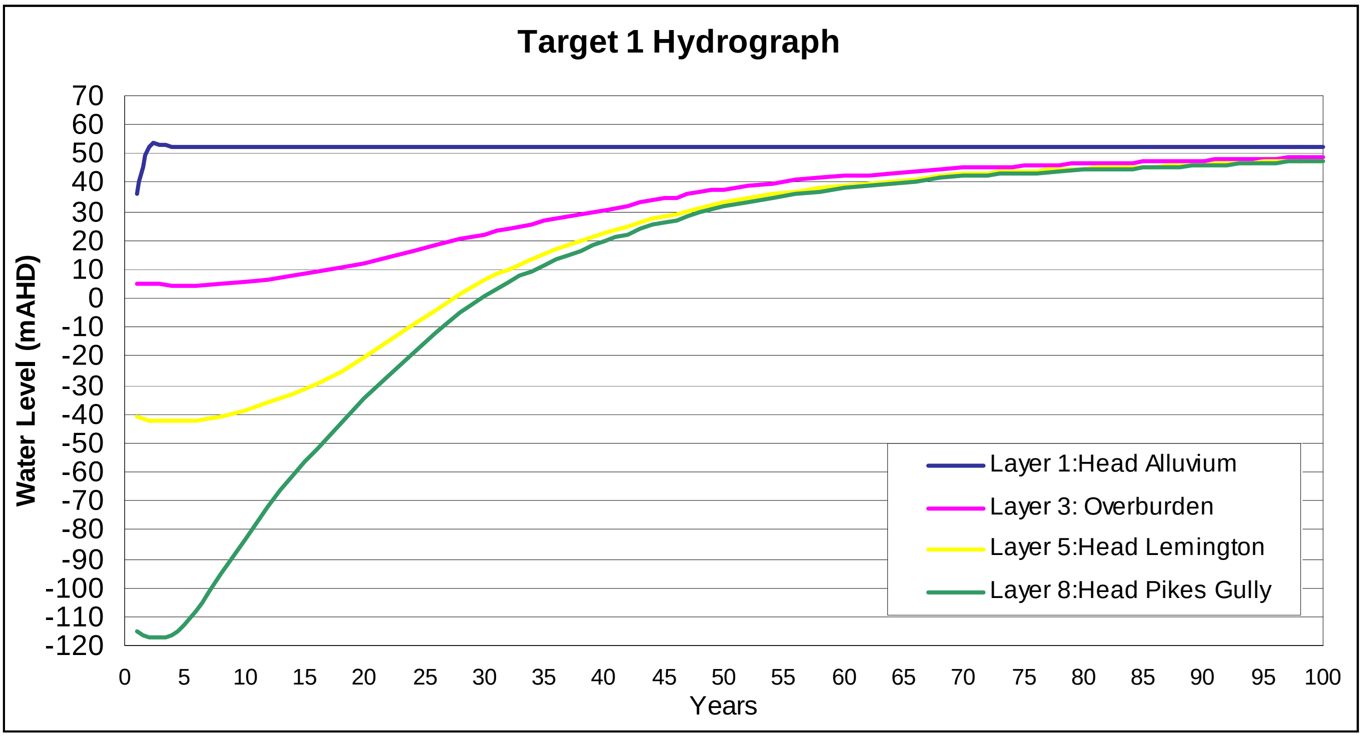
Groundwater elevation (mAHD)
5m Intervals

Date 21 September 2009	Scale As Shown	**Ashton Coal Operations Ltd**
Initials PZ	Project S55G	**Final Groundwater Heads in the Alluvium (layer 1), Pikes Gully Overburden (layer 5) and Pikes Gully (layer 8) for the ULD Recovery Run**
Drawing Number fig7.5.srf	Revision A	

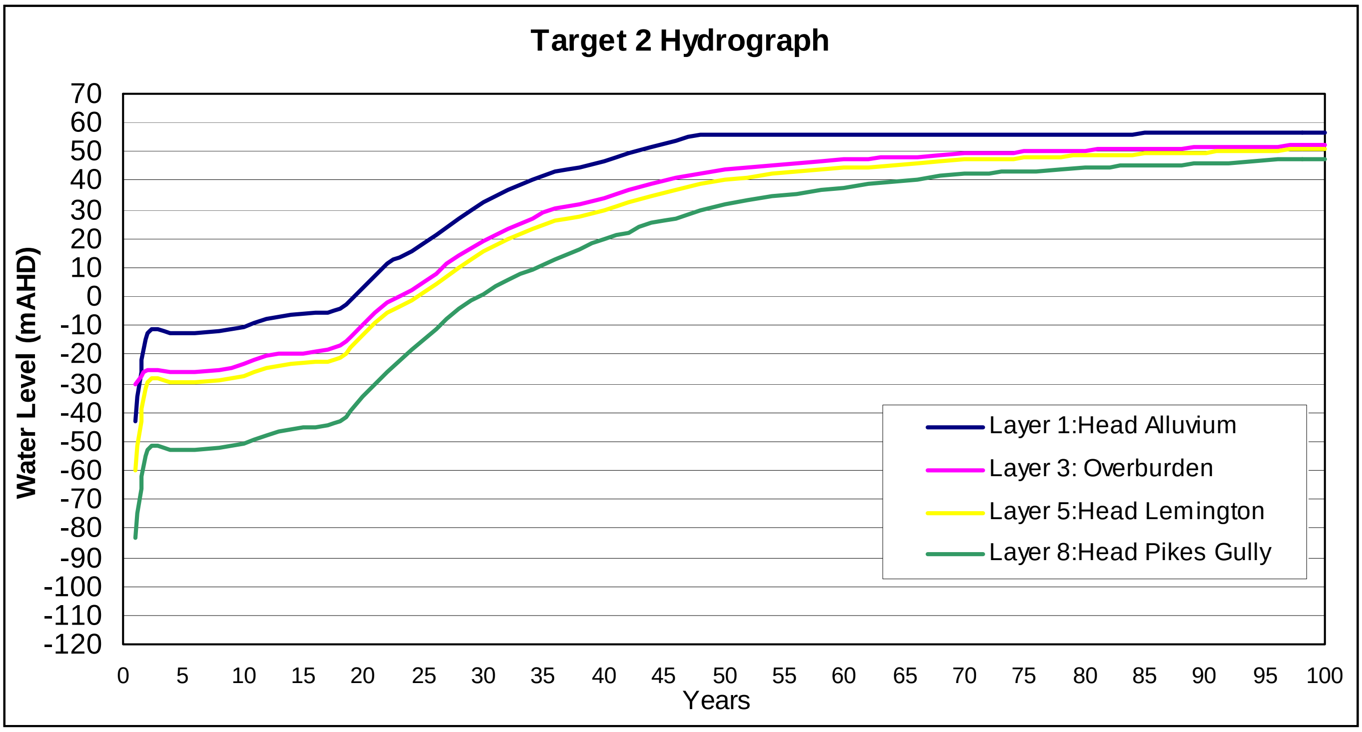
aquaterra

Figure 7.6

Target 1 Hydrograph



Target 2 Hydrograph



Date **8 October 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **PZ**	Project **S55G**	**Lower Barrett Recovery Hydrographs for Alluvium, Lower Lemington and Pikes Gully Seam**
Drawing Number **fig7.7a.srf**	Revision **A**	
aquaterra		**Figure 7.7**

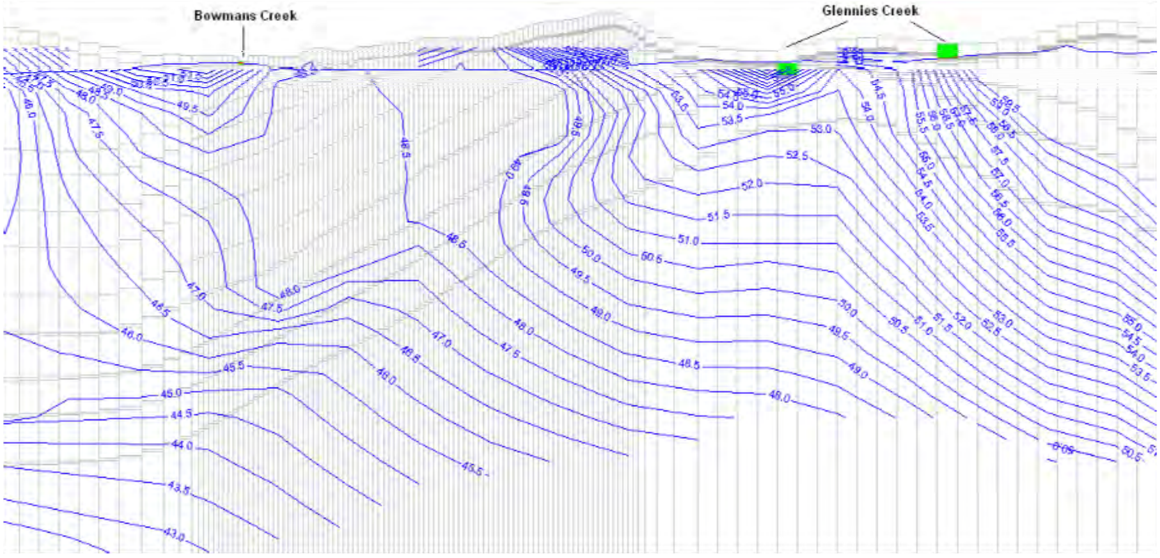
Groundwater heads at the end of the recovery period are shown on a cross-section through the mine area on Figure 7.8. This cross section runs west-east through the middle of LW6A and LW7A. This figure further illustrates the conclusions drawn above, showing the flat groundwater heads within the mine workings, and the relative gradients between the mine workings and Bowmans Creek and Glennies Creek.

Residual drawdowns, comparing final, post-recovery groundwater levels against pre-mining steady state conditions in the alluvium and the Pikes Gully seam, are shown in Figures 7.9 and 7.10.

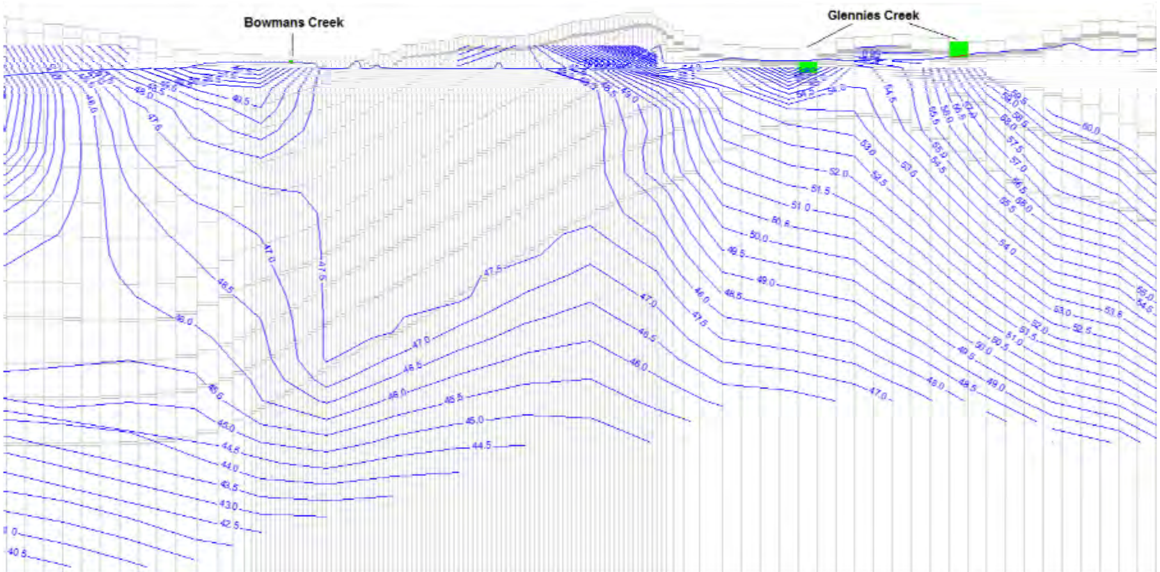
These figures show that there is negligible residual drawdown in the Hunter River or Glennies Creek alluvium. Residual drawdowns in the Bowmans Creek alluvium are generally small (<1 m) and are largely caused by the fact that the sections of the Bowmans Creek alluvium will be more directly connected to the underlying Permian post-mining due to the subsidence fracturing impacts. Some small sections directly overlying fracture zones around the edges of the subsidence areas are likely to remain unsaturated in the post mining period due to these changes in the hydrogeological environment.

Following 100 years of recovery, residual drawdowns of up to 15m are seen within the Pikes Gully seam in the mine area, extending to the south and south west in response to the 'flattening' of potentiometric heads in the Ashton and Ravensworth underground mine areas. It should be noted that the drawdowns to the north and northwest would occur irrespective of whether the Ashton underground mining is carried out, as they are caused by the Ravensworth and NEOC mines.

A similar post-mining recovery response is seen if mining were to cease early after mining of the ULD seam, although potentiometric heads around the mine workings are slightly higher, and residual drawdowns therefore slightly lower, but only by 1 or 2 m.



Upper Liddell Recovery Run

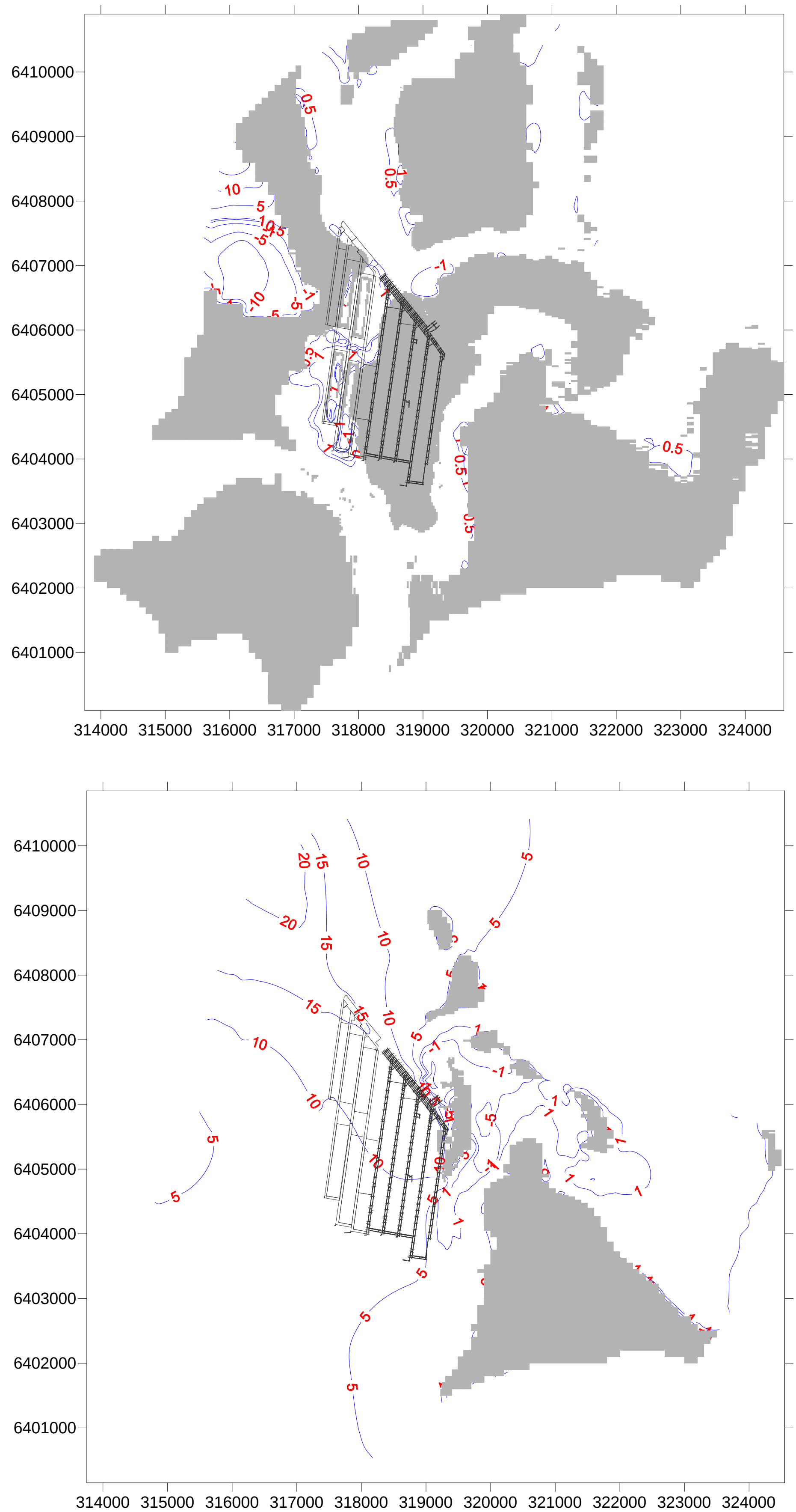


Lower Barrett Recovery Run

Date 6 October 2009	Scale As Shown	**Ashton Coal Operations Ltd**
Initials PZ	Project S55G	**East-West Cross Section of Groundwater Heads Following Post Mining Recovery**
Drawing Number fig7.7.srf	Revision C	
aquaterra		**Figure 7.8**

Alluvium

Pikes Gully Seam



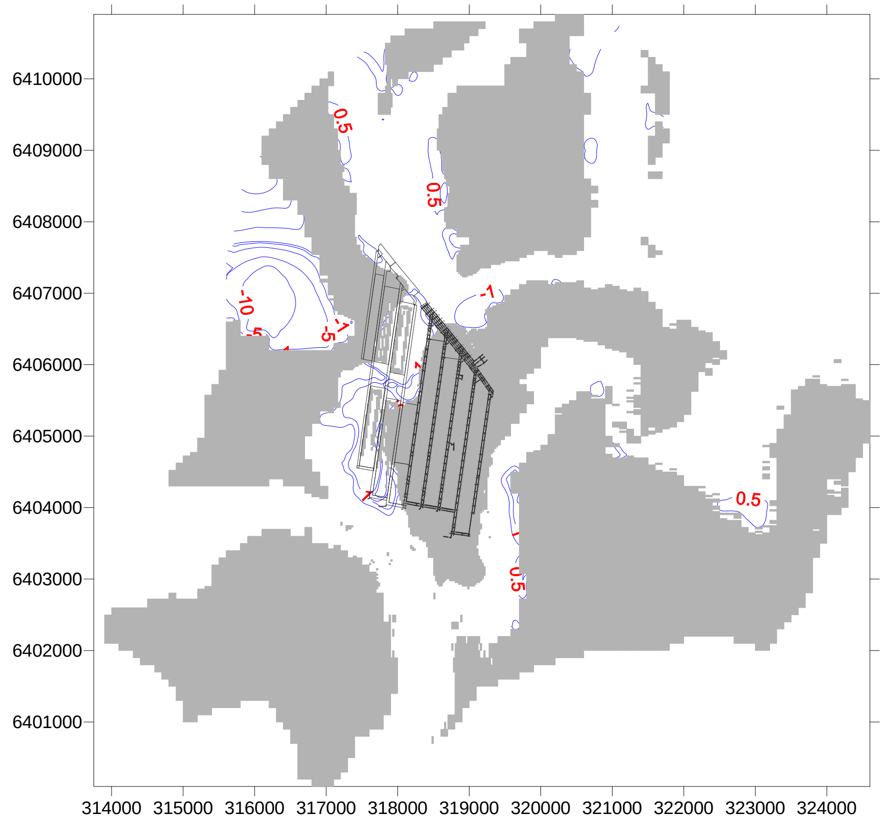
Dry Cells

Drawdowns (m)

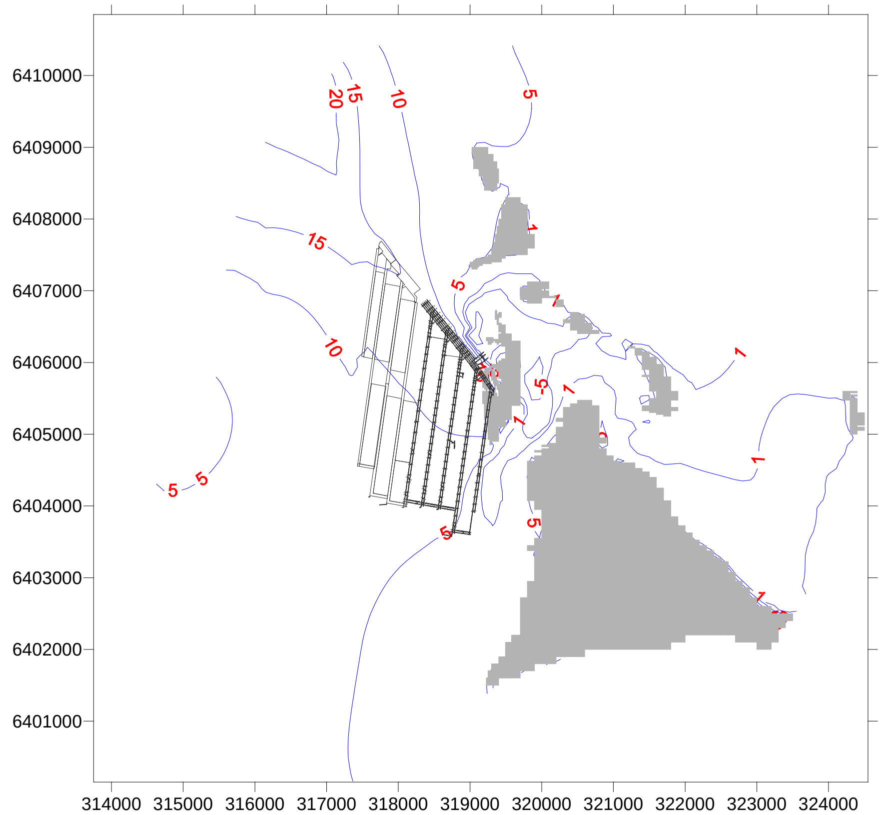
(Note: negative values indicate heads at higher in the post mining than the pro-mining condition)

Date **26 August 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **PZ**	Project **S55G**	**Residual Drawdowns in the Alluvium (layer 1) and Pikes Gully Seam for the Lower Barrett Recovery Run**
Drawing Number **fig7.9.srf**	Revision **0**	
aquaterra		**Figure 7.9**

Alluvium



Pikes Gully Seam



Dry Cells

Drawdowns (m)

(Note: negative values indicate heads at higher in the post mining than the pro-mining condition)

Date **22 September 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **PZ**	Project **S55G**	**Residual Drawdowns in the Alluvium (layer 1) and Pikes Gully Seam for the Upper Liddell Seam Recovery Run**
Drawing Number **fig7.10.srf**	Revision **0**	
aquaterra		**Figure 7.10**

7.3.2 GROUNDWATER AND SURFACE WATER QUALITY

Impacts on Alluvium Water Quality

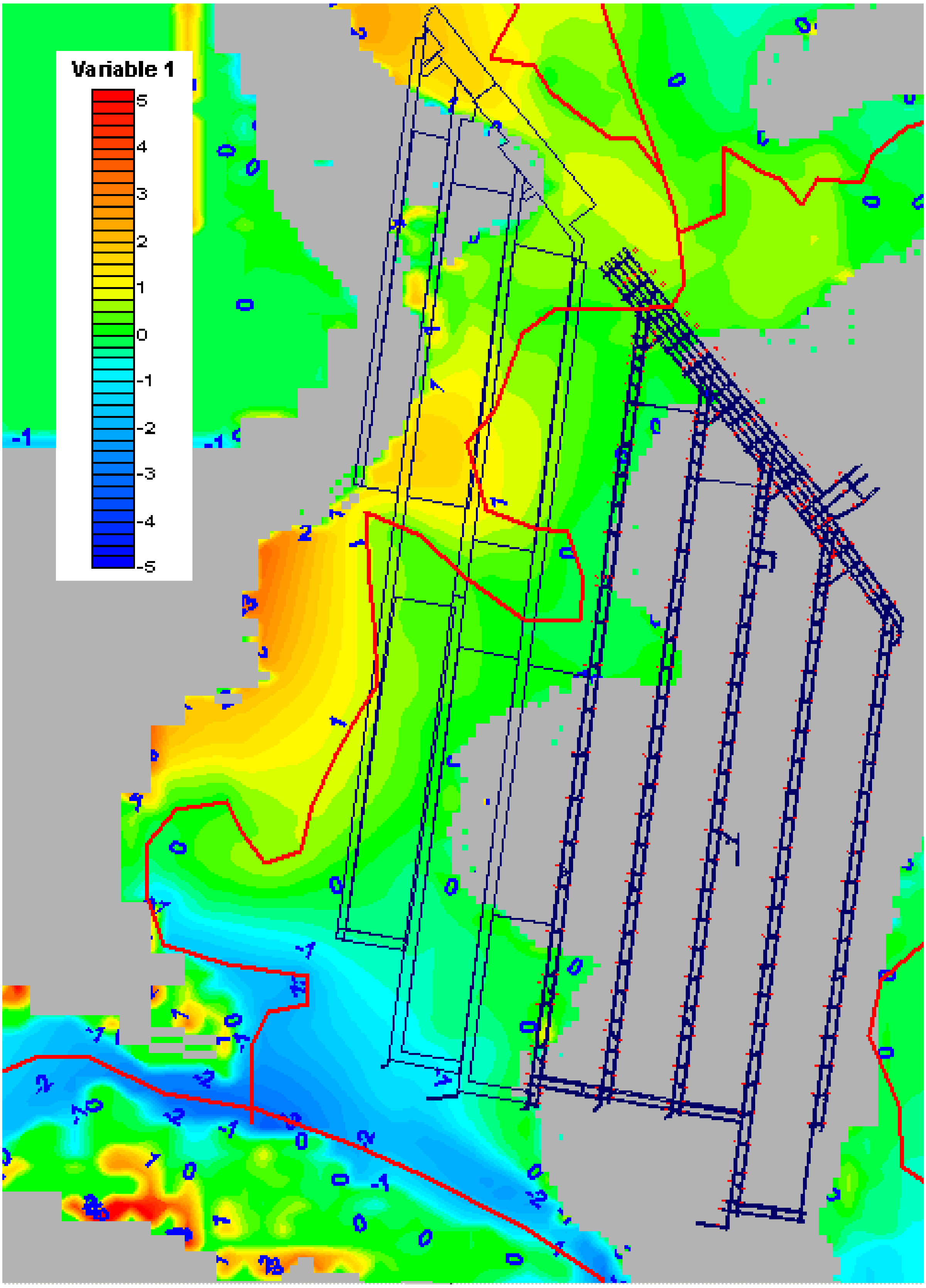
The monitoring results from the groundwater investigation programme to date have shown that the only significant risk to groundwater quality from the proposed scheme is due to the high in-situ salinity of the Permian groundwater. The Permian rocks do not appear to contain any significant acid forming potential, and there is no identified risk of iron precipitation or potential pollution due to heavy metals from the Permian groundwater.

Risks to groundwater quality could occur if saline water was generated within the mine workings and then entered alluvial aquifers. This could occur post-mining only if there were an upward gradient from the mine workings to the alluvium associated with the Hunter River, Glennies Creek or Bowmans Creek. As there are significant in-situ barriers between the mine workings and the Hunter River and Glennies Creek alluvium, the risk to these groundwater and surface water bodies is considered to be negligible.

The potential for upflow of water from the mine workings to the Bowmans Creek alluvium has been analysed by calculation of the head differential between the alluvium (model Layer 1) and the top of the Permian (model Layer 2**).** Figures 7.11 to 7.13 show this head differential in the Bowmans Creek area in the pre-project steady state condition, following recovery after mining to the LB seam, and following recovery from a mining operation ceasing after the ULD seam respectively. Where differentials are zero or positive (red, yellow and green colours in the figures), then water does not flow from the Permian to the alluvium and there is no risk of upwards movement. Where differentials are negative (blue colours), then there is some upwards gradient and hence flow in that area.

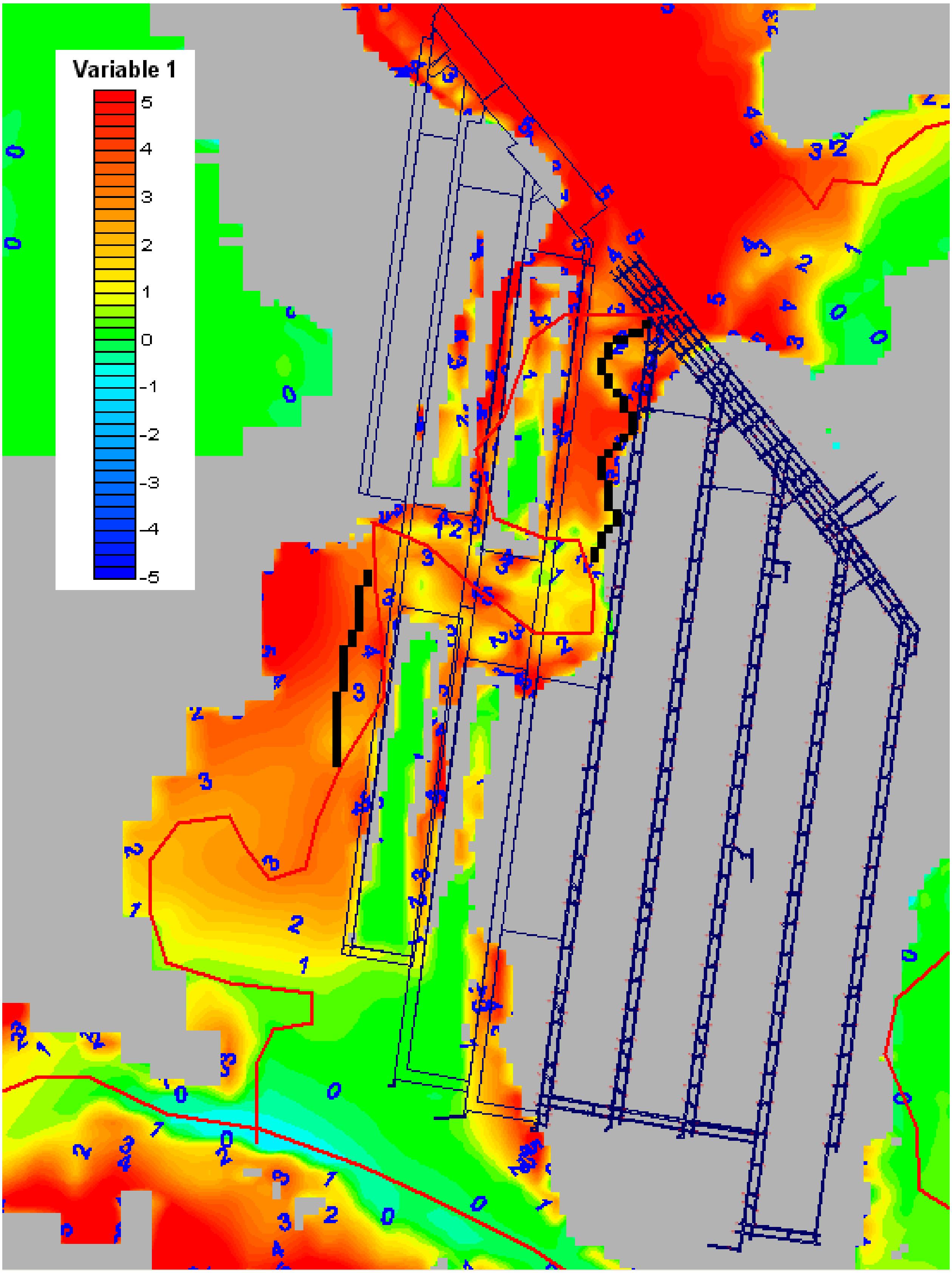
These figures show that there is no risk of upward flow from the Permian to the alluvium following recovery, even if the project were to be terminated early at the end of the ULD seam. This will result in an improvement in alluvium water quality compared with the pre-mining baseline condition.

This occurs due to the change in the hydrogeological regime caused by the presence of the Ashton and Ravensworth underground mines. These ‘flatten’ piezometric heads in the Permian at a level where inflows to the mining areas from the alluvium and Permian to the north and east match outflows in the Permian to the south and west. The system is largely ‘self regulating’, as recharge to the Permian from the Bowmans Creek alluvium tends to reduce as piezometric levels in the Permian rise towards the level of the alluvium water table. This is shown in the recovery hydrographs contained in Figure 7.7. The large perimeter of the combined Ashton and Ravensworth underground mines also means that relatively large amounts of outflow can occur towards the south and west within the Permian coal seams. Overall, even the conservative assumptions about recharge and inflow to the mine workings used in the assessment are not enough to cause water levels in the mine workings to rise to a level where upwards flow occurs in the mined area.



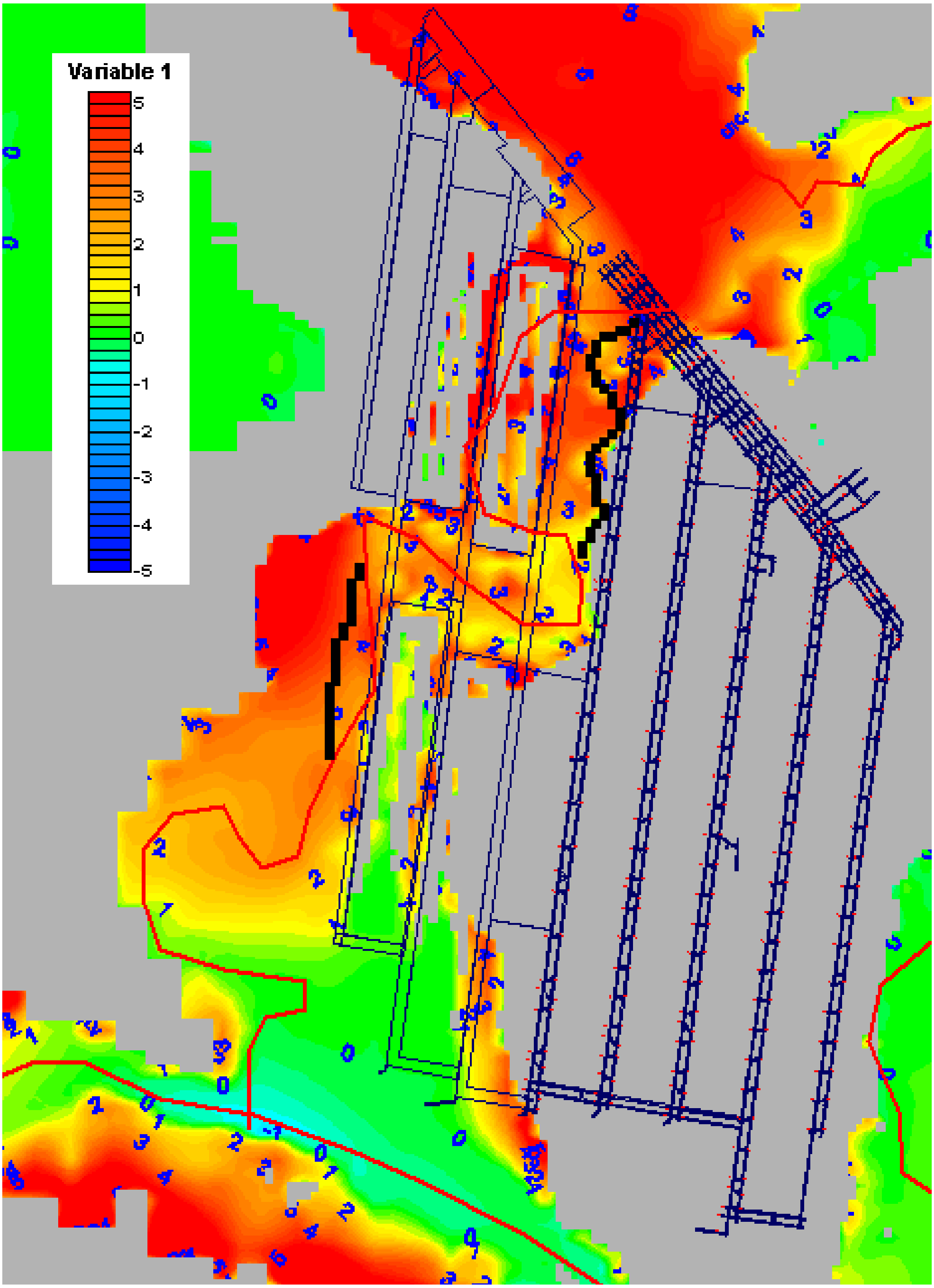
Green / Red = Flow from Alluvium to Permian
Blue = Flow from Permian to Alluvium
Grey = Dry Cells

Date **1 October 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **PZ**	Project **S55G**	**Head Difference between Alluvium (layer 1) and Permian (layer 2) for Steady State Model (Pre Ashton Underground Mining)**
Drawing Number **fig7.11a.srf**	Revision **A**	
aquaterra		**Figure 7.11**



Green / Red = Flow from Alluvium to Permian
Blue = Flow from Permian to Alluvium
Grey = Dry Cells

Date	**6 October 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials	**PZ**	Project **S55G**	Head Difference between Alluvium (layer 1) and Permian (layer 2) for the Lower Barrett Recovery Run
Drawing Number	**fig7.12b.srf**	Revision **B**	
aquaterra			**Figure 7.12**



Green / Red = Flow from Alluvium to Permian
Blue = Flow from Permian to Alluvium
Grey = Dry Cells

Date	**1 October 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials	**PZ**	Project **S55G**	Head Difference between Alluvium (layer 1) and Permian (layer 2) for the Upper Liddell Seam Recovery Run
Drawing Number	**fig7.13a.srf**	Revision **A**	
aquaterra			**Figure 7.13**

Impacts on Surface Water Quality

The recovery runs indicate that in the post mining condition, the upward migration of salt from the Permian to the alluvium that was present in the pre-mining baseline is effectively removed. Surface water quality in Bowmans Creek and the Hunter River should therefore experience an improvement compared with the pre-mining condition.

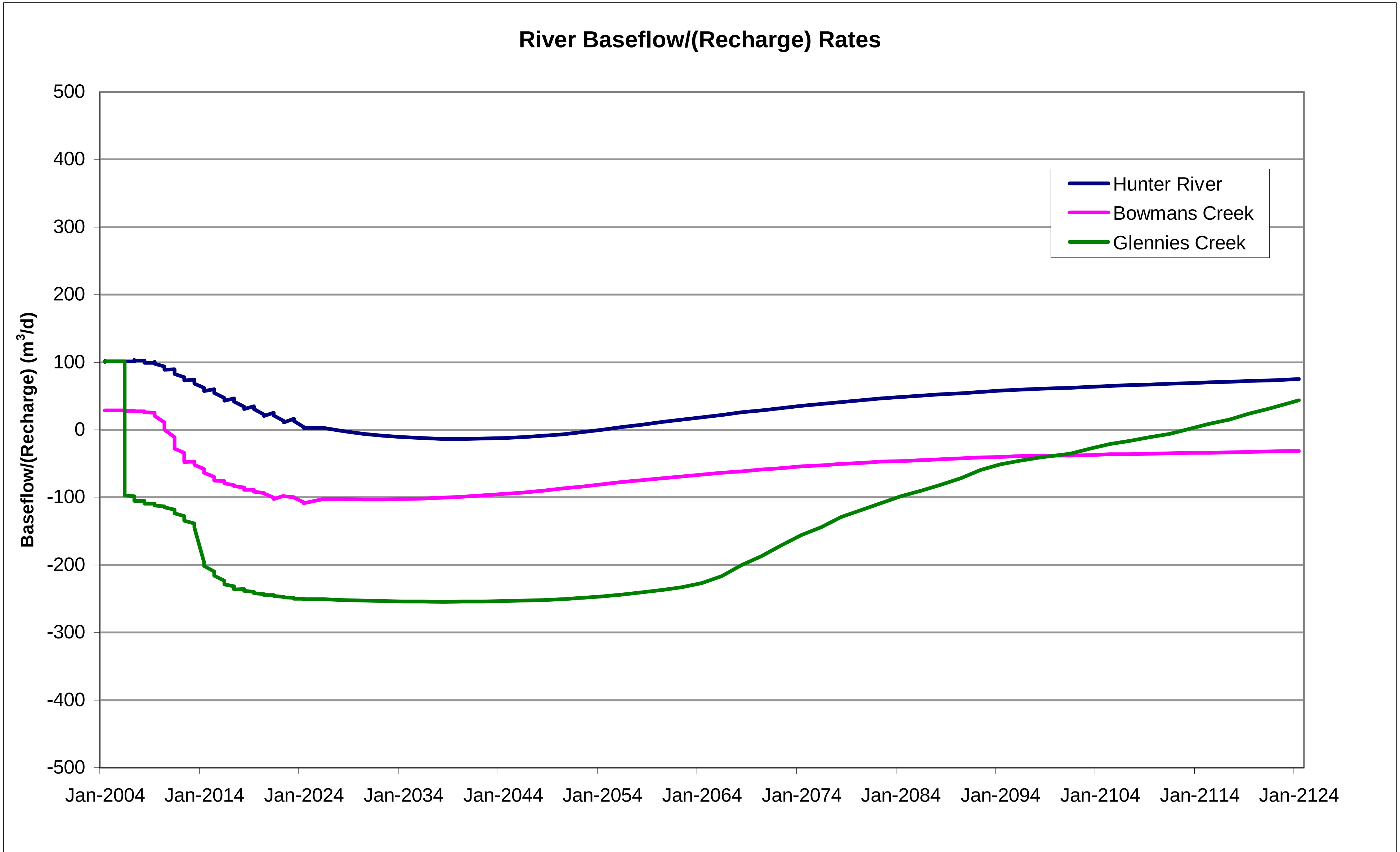
Impacts on Bowmans Creek Alluvium 'Buffering Capacity'

The recovery hydrographs shown in Figure 7.7 conclusively show that groundwater recovery occurs first within the Bowmans Creek alluvium, before potentiometric heads within the mine workings come close to surface level. Any 'buffering capacity' that was lost due to de-saturation during mining operations will therefore have returned by the time there is any risk of significant flow from the Permian to the alluvium or Bowmans Creek. This is not therefore an issue for the post-mining phase.

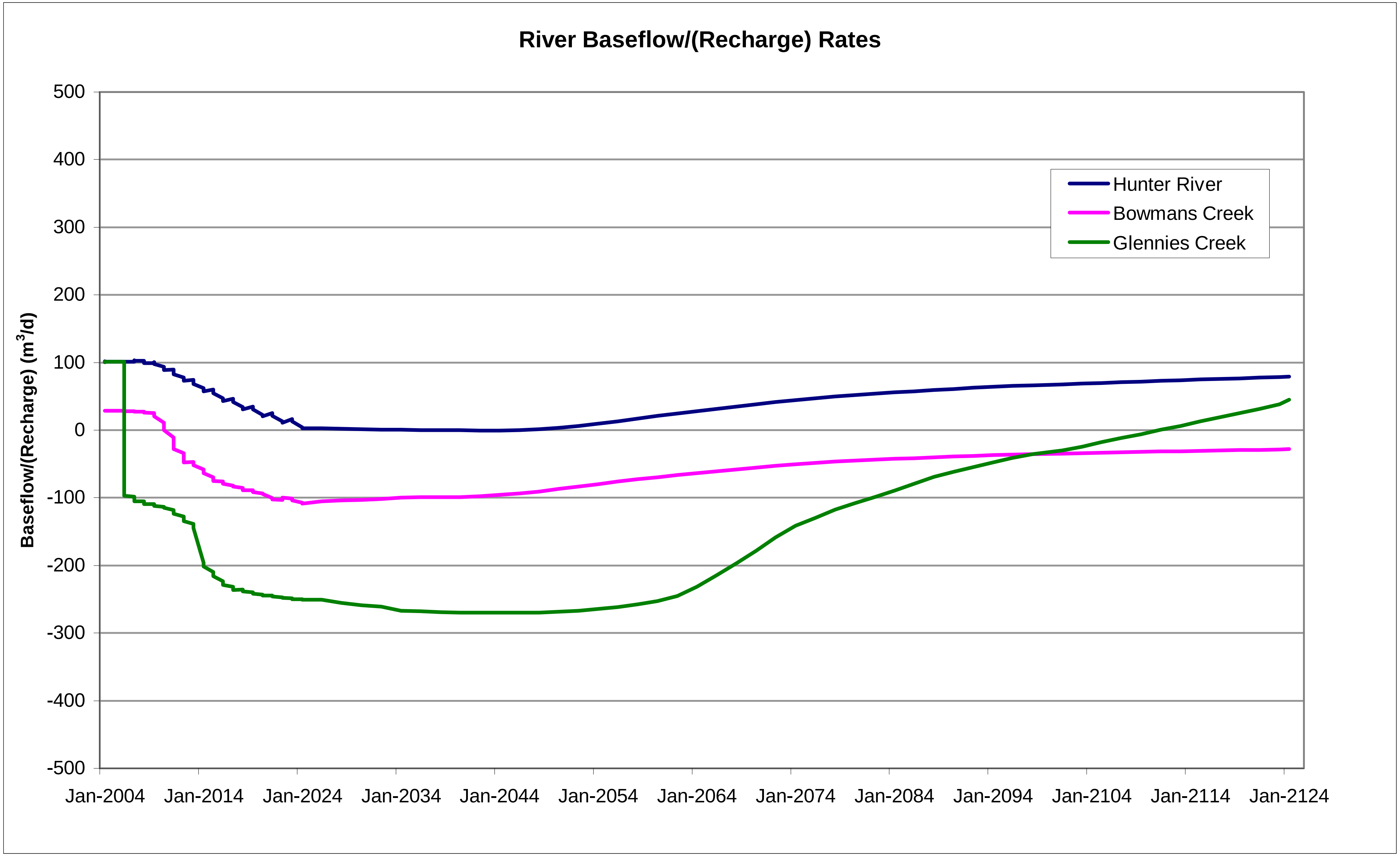
7.3.3 RIVER AND CREEK BASEFLOWS

Graphs of baseflow impacts and recovery for Glennies Creek, Bowmans Creek and the Hunter River for the proposed four seam mining down to the LB seam, and the case where mining is assumed to cease after the ULD seam are shown in Figures 7.14 and 7.15 respectively. This shows that:

- Baseflow in the Hunter River returns relatively quickly to near the pre-mining condition. There is a slight residual impact, with baseflow around 25 m^3/d (0.025 ML/d) lower post-mining. As with the operational phase, around 60% of this impact would occur even without the Ashton underground mine, so the additional post-recovery impacts from the Ashton underground mine are only around 15 m^3/d (0.015 ML/d).
- Baseflows in Glennies Creek experience a delay in recovery, as inflows to the mine workings only start to reduce once water levels recover to around the level of the Pikes Gully seam on the eastern side of the mine. Recovery in Glennies Creek is not quite complete after 100 years, and baseflow is predicted to be around 55 m^3/d (0.055 ML/d) lower than pre-mining baseflow. The modelled value is conservative, as it does not allow for progressive clogging of the cleats within the Pikes Gully seam between the Glennies Creek alluvium and the mine workings. As detailed in Section 4, this effect has already been observed in the TG1 mine inflow records and groundwater levels in the barrier zone. These clearly show the hydraulic conductivity within the Pikes Gully seam between the Glennies Creek alluvium and the mine workings has already reduced significantly, and is likely to reduce by at least half by the time mining is completed. Maximum baseflow impact is therefore more likely to be in the order of 30 m^3/d (0.03 ML/d) following post mining recovery.
- Because of the changes to the hydrogeological regime caused by the presence of the Bowmans Creek diversion, and the reduction in upflow from the Permian, Bowmans Creek does not experience the baseflow contributions from the alluvium that it received in the pre-mining condition. Overall, baseflow is predicted to be around 60 m^3/d (0.06 ML/d) lower than the baseline condition following recovery after mining. Most of this residual impact is due to the presence of the Bowmans Creek diversion and the connectivity with the lower Permian groundwater heads associated with the Ashton underground mine.
- In the event that mining were to cease at the end of the ULD seam, post-mining baseflow to Hunter River would be 20 m^3/d (0.02 ML/d) lower than pre-mining, baseflow to Glennies Creek would be 55 m^3/d (0.055 ML/d) lower, and Bowmans Creek baseflow would be 56 m^3/d (0.056 ML/d) lower, after 100 years of post-mining recovery.



Date **6 October 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **PZ**	Project **S55G**	**Baseflow Hydrographs for the Lower Barrett Recovery Run**
Drawing Number **fig7.14.srf**	Revision **A**	
aquaterra		**Figure 7.14**



Date **22 September 2009**	Scale **As Shown**	**Ashton Coal Operations Ltd**
Initials **PZ**	Project **S55G**	**Baseflow Hydrographs for the Upper Liddell Seam Recovery Run**
Drawing Number **fig7.15.srf**	Revision **A**	
aquaterra		**Figure 7.15**

7.4 COMPARISON WITH 2001 EIS

7.4.1 OPERATIONAL MINING PERIOD

Modelled predictions of drawdowns in the Permian Coal Measures in the 2001 EIS did not include the impacts from the Ravensworth underground mine or the ongoing Narama open cut, so direct comparisons of drawdown are difficult. However, impacts on water levels in the Permian caused by the Ashton underground mine should be reasonably similar given the similar hydraulic properties adopted for the two assessments, and the relative lack of sensitivity to assumptions over the hydraulic properties of the overburden.

The 2001 EIS did contain predicted impacts on alluvium water levels and 'leakage from the alluvium'. Although not explicitly stated, it appears that these alluvium leakage rates relate to calculations of creek and river baseflow. Comparisons of the impacts on alluvium baseflows and alluvium water levels are therefore summarised in Table 7.3.

Table 7.1: Comparison of Current (2009) Assessment and 2001 EIS

	2009 Ashton Underground Mine Proposal	2001 EIS	Comments
Bowmans Creek – baseflow losses	0.13 ML/d	0.4 ML/d	2001 EIS did not include modelling of the diversion.
Bowmans Creek – alluvium groundwater levels	Partly dewatered (0.5m to 2m in saturated areas). Impacts limited to the section south of the RTA bridge	Partly dewatered	2001 EIS did not include modelled assessment of the impact of connective fracturing. The text indicates partial dewatering if fracturing does occur.
Glennies Creek – baseflow losses	0.23 ML/d	0.6 ML/d	Current model has much better calibration of levels and calibration against measured mine inflows on Glennies Creek side.
Glennies Creek – alluvium groundwater levels	Maximum 0.4m, although generally less than 0.1m	Maximum 2.5m	Previous model assumed an unrealistic degree of vertical connection between Glennies Creek alluvium and the underlying Permian.
Hunter River – baseflow losses	0.06 ML/d	0.3 ML/d	Previous model included mining in the Pikes Gully closer to the Hunter River
Hunter River – alluvium groundwater levels	0.1m	No significant change	Impact limited to area next to interface with Bowmans Creek alluvium

Predicted total mine inflow rates are slightly lower in the current assessment than in the 2001 EIS. The 2001 EIS modelling predicted a maximum inflow rate of 1.9 ML/d, to occur at the start of the ULD mining. Predictions from the current assessment indicate a maximum inflow rate of 1.4 ML/d at that point.

7.4.2 POST MINING RECOVERY PERIOD

In terms of water quality, the current model predicts there will be no upward flow of groundwater from the Permian to the alluvium, where there was an upflow prior to mining, so there will be a general improvement in surface water quality compared with the pre-mining condition. This compares with predicted salinity increases in the EIS of 50 μS/cm EC for Bowmans Creek and 14 μS/cm in the Hunter River, compared with pre-mining conditions.

The current assessment indicates that, in comparison with the pre-mining condition, baseflows will be reduced by around 60 m^3/d for Bowmans Creek, 30 m^3/d for Glennies Creek and 15 m^3/d for the Hunter River 100 years after mining has ceased. This compares with the minor increases in baseflow predicted by the 2001 EIS.

7.5 POTENTIAL IMPACTS ON GROUNDWATER DEPENDENT ECOSYSTEMS

Because impacts on river flows and groundwater levels within the Hunter River, Glennies Creek and their associated alluvium are so small, both during mining and in the post mining condition, it is very unlikely that there would be any impact on GDEs associated with those water courses.

For Bowmans Creek, monitoring carried out by ERM indicates that there are no GDEs in the alluvium that is forecast to become fully de-watered. Some stands of red gum have been reported along the river to the south of the western diversion, in the area where the alluvium is predicted to remain saturated. Model results show that maximum groundwater drawdowns in this area will be less than 0.5m.

7.6 POTENTIAL IMPACTS ON EXISTING GROUNDWATER USERS

Because the Ashton mine does not significantly affect alluvium groundwater levels to the north of the New England Highway, or on the south side of the Hunter River, there will be no impacts from the scheme on any registered groundwater bore or well. Maximum predicted drawdown in the Glennies Creek alluvium around Camberwell village is <0.1m, so there will be no adverse impact on the registered borehole in that location, even if it is still operational.

8 MONITORING AND MANAGEMENT

8.1 IMPACTS OF GROUNDWATER EXTRACTION / DEWATERING

The groundwater regime in this area is already being closely monitored as part of the ongoing underground mining activities, as detailed in the site Groundwater Management Plan (GWMP) (Aquaterra, 2008d). It is recommended that the current network is maintained. It includes:

- Maintaining monitoring of inflow rates and inflow water quality to the mine. This includes monitoring the flows into PG Tailgate 1 in order to assess the impacts on Glennies Creek and to monitor any changes that may occur in the permeability of the Pikes Gully between the tailgate and the Glennies Creek alluvium. Monitoring of water extracted from the mine should extend to the lower seams as these are mined. Once Bowmans Creek has been undermined, then inflows to that section of the mine should be recorded separately, if possible.
- Regular measurement of groundwater levels within all vibrating wire piezometers and standpipes.

The current network is extensive and comprehensive over most of the site. One additional borehole is also recommended on the south side of the mining area (to the south of LW2) to provide monitoring down to the Lower Barrett seam in this area. Some monitoring bores may need to be replaced if any key existing piezometers are undermined during the extraction of the ULD or lower seams. Monitoring should be carried out using nested vibrating wire piezometers, with one in each of the target seams.

In order to evaluate the potential operational risk that is posed by flows entering the old creek channel and entering the workings via connective cracking above LW6B, it is recommended that additional monitoring is installed in the alluvium and Pikes Gully overburden to the southwest of LW6A and to the east of LW6B. This is particularly necessary during the early stages of the diversion, during mining of the Pikes Gully seam, when considerable diversion flows may be directed down the old creek channel. For LW6B, it is recommended that two monitoring points are installed (one to the north east and one to the south east). This should allow a background relationship between the Permian dewatering and the alluvium to be established. If connective cracking occurs then this should be observed by a rapid drop in groundwater levels within the alluvium that is not consistent with previous readings. Initial observations can be made during the mining of LW6A, before the flooding becomes a risk, but the varying nature of the overburden and alluvium mean that a ‘negative’ reading for LW6A cannot be taken to mean there will be no risk for panel LW6B.

8.2 SUBSIDENCE IMPACT MONITORING

The survey line across LW1 should be maintained throughout the life of the mine, as this can be used to assess possible lateral movement in the Pikes Gully between LW1 tailgate and Glennies Creek.

Subsidence monitoring of Bowmans Creek alluvium should be undertaken across one of the longwall panels within the Bowmans Creek alluvium to ensure that monitored results are the same as the predictions.

8.3 REVIEW AND REPORTING

The existing GWMP should be updated to reflect the above monitoring recommendations. As detailed within the existing GWMP, collated monitoring data should be subjected to an annual review by an approved experienced hydrogeologist in order to assess the impacts of the project on the groundwater environment, and to compare any observed impacts with those predicted from groundwater modelling.

It is also recommended that, in accordance with industry best-practice (MDBC, 2001), a modelling post-audit should be carried out once the Bowmans Creek has been diverted and undermined in the Pikes Gully. Following this review, if necessary, the AUM model should be re-calibrated and confirmatory forward impact predictions made.

Inflow rates and modelling should then be reviewed at the end of mining for the ULD, ULLD and LB seams as appropriate. In particular, the impact and inflow rates from any inundation of subsidence troughs within Bowmans Creek floodplain should be reviewed and checked against predictions within this report.

Should any review or post-audit indicate a significant variance from the model predictions with respect to either water quality or groundwater levels, then the implications of such variance should be assessed, and appropriate response actions implemented in accordance with the protocols described in the GWMP.

8.4 RECOMMENDATION FOR DEVELOPMENT OF RESPONSE PLANS

Trigger Action Response Plans (TARPs) have already been developed as part of the existing GWMP. These should be reviewed to include the issues highlighted above. In particular the TARP for Glennies Creek inflows should be reviewed and extended to include monitoring of the lower seam inflows as they are mined. Monitoring triggers should be extended to include the boreholes drilled to investigate the ULD seam, as described in Section 3.

In addition to these environmental TARPs, specific operational responses to connective cracking through the alluvium above LW6B should be implemented to minimise the risk of entry of flood waters into the underground workings. During the early stages of the diversion, the design currently allows water to enter the old channel more frequently than a 1 in 5 year event, in order to help establish vegetation and ecology. If monitoring indicates that connective cracking has occurred, then the triggers discussed within the design section of this EA relating to the implementation of the block bank should be followed. Capability and readiness to pump out any flooding should also be reviewed if connective cracking is detected.

9 CONCLUSIONS

This groundwater impact assessment contains a review of the potential hydrogeological impacts of the proposed multi-seam longwall mining at the Ashton underground mine. The coal seams to be mined in this proposal are (in descending stratigraphic order) the Pikes Gully, Upper Liddell, Upper Lower Liddell, and Lower Barrett Seams. The proposal involves diverting and then under-mining parts of Bowmans Creek. Because mining beneath the Bowmans Creek alluvium could involve the formation of large subsidence troughs within the floodplain, the project includes proposals to progressively backfill the troughs to maintain a free draining landscape

This groundwater impact assessment detailed in this report examined the effect on the groundwater regime of the progressive mining of all four seams, and the recovery of groundwater levels following mining. The assessment also included the cumulative effects of the Ashton proposal, together with other mining in the area, including past mining. The main conclusions from the study are as follows.

Pre-Mining Groundwater Conditions

The overall groundwater flow regime in the pre-mining condition was controlled by natural recharge and discharge mechanisms. For the shallow alluvium, this was dominated by rainfall recharge, and discharge to the river/creeks. For the Permian coal measures, groundwater recharge occurred primarily by rainfall infiltrating directly to the seams in locations where they outcrop or sub-crop beneath alluvium or the weathered zone. Low mobility of groundwater within the strata at depth means that groundwater heads in the Permian were largely controlled by the physical elevation of these recharge areas. The Permian then generally had higher potentiometric heads than the alluvium, and in low-lying areas the heads were often above ground level. Thus there was potential for discharge by upward seepage to the rivers and creeks, and their associated alluvium.

Elevated salinity is found within much of the Permian coal measures aquifer system, ranging from around 6,000 µS/cm EC (electrical conductivity) in the more permeable coal seams to more than 11,000 µS/cm EC within some of the less permeable overburden/interburden units. Some samples taken from shallower horizons near subcrop can be much less saline, down to less than 2,000 µS/cm EC. This reflects the influence of proximity to relatively direct rainfall recharge in areas of sub-crop beneath shallow alluvium or weathered zone.

Samples taken from colluvium on the flanks of the floodplain areas were also generally saline, with values recorded between 8,000 and 17,000 µS/cm EC.

Groundwater salinity within the Bowmans Creek alluvium is variable, and moderately saline conditions (up to 6,400 µS/cm EC) were encountered within much of the alluvium that was tested during the Bowmans Creek alluvium investigation programme in 2008. Salinity of Glennies Creek alluvium groundwater is generally moderate to low, particularly in the more permeable alluvium that supports a higher rate of groundwater throughflow. In these areas the salinity is generally below 2,000 µS/cm. However, higher ECs (up to 6,000 µS/cm) have been recorded in some parts of the less permeable, more 'stagnant' alluvium.

Relevance of the 2001 Ashton Coal Project EIS

The 2001 EIS resulted in a number of conclusions about the groundwater environment that are no longer considered to be valid following the extensive groundwater investigations and improved understanding that have been used to underpin the above conclusions. These included:

- Previously it was thought that Bowmans Creek was highly connected to its alluvium, and that there was a significant rate of groundwater flow through the alluvium. *In reality, the hydraulic conductivity of the Bowmans Creek alluvium is relatively low (around 0.5 m/d on average), and the ground-water throughflow rate is therefore limited.*
- Similarly, it was though that the Bowmans Creek alluvium was a 'high quality' resource, with good water quality. *Recent investigations have shown that the lack of connectivity with the creek results in varying, sometimes poor, water quality, with measured salinity of up to 6,400 µS/cm.*

- It was concluded in the 2001 EIS that prior to mining, there was a net downward flow of low salinity groundwater from the alluvium to the underlying Permian coal measures, and that after mining, there will be a net upward flow of saline groundwater from the Ashton underground mine area to the alluvium within the central part of the Bowmans Creek floodplain. Thus, it was concluded that the effect of the Ashton underground mining project would be a long-term increase in salt load to the Hunter River, leading to an increase in the salinity of low flows in the Hunter River of 14 µS/cm EC. *It is now known that prior to mining, groundwater potentiometric heads in the Permian coal measures were higher than groundwater levels in the alluvium, leading to a potential for upward seepage of more saline water from the Permian into the alluvium. As a result, the water quality in the Bowmans Creek alluvium is sometimes poor, with measured salinities in the floodplain up to 6,400 µS/cm EC. As stated below, the modelling carried out for this proposal concluded that post-mining there would be no upflow of saline groundwater from the Permian to the alluvium within the mining affected parts of the Bowmans Creek floodplain. Hence, the project would lead to a net decrease in salt load to the Hunter River, not an increase as concluded in the 2001 EIS.*

Groundwater Modelling to Assess Impacts

The MODFLOW-SURFACT groundwater model used for assessment of impacts from the Ashton underground mine proposal was first calibrated against interpreted 'steady state' pre-mining conditions, and was then subjected to transient calibration against observed inflows and groundwater level drawdowns during the mining of LW1 to LW3. This included calibration against the measured inflows from the Glennies Creek alluvium to the mine through the tailgate of LW1.

The groundwater modelling included a number of specific approaches that were used to simulate potential impacts from the proposed mining activities:

- Simulation of groundwater dewatering caused by both open cut and underground mining.
- Changes to the hydraulic properties of overburden material caused by the caving and subsidence above longwall panels.
- Changes to the hydrogeology of Bowmans Creek due to the creation of the diversion channels.
- Changes to the geometry and hydraulic nature of the Bowmans Creek alluvium due to subsidence and subsidence-induced fracturing within the floodplain above LW6 and LW7.
- Inclusion of the effective impacts on groundwater recharge that could result from the 'capture' of local catchment runoff within the subsidence areas on the floodplain, and the ponding of flood water in the subsided part of the old creek channel above LW6B.

The groundwater model was used to predict the potential impacts of the proposed project on groundwater levels in the alluvium and Permian, and stream 'baseflow' impacts (the rate of groundwater flow to, or leakage from, rivers and creeks) in the Hunter River, Bowmans Creek and Glennies Creek.

The groundwater model was also used to examine the post mining recovery of groundwater levels and stream baseflows. For the recovery run, it was assumed that the Ravensworth underground mine ceased at the same time as Ashton, even though it would still not have reached the Lower Barrett seam by that time. This was done to ensure clear visibility of the maximum post mining recovery impacts from the Ashton underground mine.

As discussed above, the recovery was also assessed for a scenario in which mining ceases after the Upper Liddell Seam, to assess the potential impact of not taking the project to its intended conclusion due to unforeseen economic or technical issues. For this run, the Ravensworth mine was run operationally for the first 9 years of the recovery run, in order to ensure consistency with the main recovery run.

It should be noted that the 'baseline' used for the impact analysis refers to the condition where there is no underground mining at Ashton at all, but includes the effects of other nearby current open cut and underground mining, and past mining activity. All assessed impacts therefore relate to the total effect of Ashton underground mining.

This includes impacts that have already occurred on site in association with the four longwall panels (LW1 to LW4) and associated development headings that have already been mined within the Pikes Gully seam. Suitable model runs and allowances have been made for the other mining activities in the area. This has allowed the net impact of underground mining at Ashton to be evaluated against a baseline that includes the nearby mining activities.

Predicted Impacts on Groundwater Levels/Pressures

Model results show that the impacts of the Ashton underground mine on the Bowmans Creek alluvium are limited to the area south of New England highway. The alluvium between the New England Highway and the Hunter River is predicted to be largely de-watered by the end of the underground mining at Ashton. Model predictions show that saturated alluvium only remains in the southern end of the Bowmans Creek floodplain, between the Hunter River and the Bowmans Creek western diversion, and in a small area of alluvium around the section of Bowmans Creek that is left in place between the two diversions. Drawdown impacts from the mining project range from around 2m to 0.5m in the areas of remnant saturation.

Impacts on alluvial groundwater levels on the eastern side of Glennies Creek are in the order of 0.1m or less by the end of mining. There is limited alluvium on the western side of Glennies Creek in the area closest to the underground mine, but in this area, drawdowns of up to 0.4m are predicted to occur.

The Ashton underground is predicted to cause some depressurisation of the Permian strata below the Hunter River alluvium, but predicted impacts on alluvial water levels are minimal (less than 0.1m).

The Permian coal measures within the mine footprint are predicted to be essentially de-watered during mining, from the lowest target coal seam (the Lower Barrett seam) to the surface. Outside of the mine footprint, the main impact from the Ashton mine on potentiometric pressures within Permian strata occurs to the south and south east of the mine, where drawdowns of 10m or more could extend up to 2km from the mine by the end of mining. Impacts to the north, west and north east are minimal due to the influence of other mines to the west and the fact that the areas to the north and north east are up-dip of the Ashton mine.

In the event that the project were to cease earlier than proposed due to unforeseen economic or technical issues, then a cessation at the end of the Upper Liddell seam would result in drawdown impacts slightly less than those stated above. A similar area of the Bowmans Creek alluvium would be fully dewatered, however the drawdowns in the remnant saturated alluvium would be less, with a predicted maximum drawdown of less than 0.5m in the southern section between the mine and Hunter River. Maximum drawdown in Glennies creek alluvium would be less than 0.4m (less than 0.1m on the eastern side of Glennies Creek). Drawdowns of 10m or more in the Permian coal measures are predicted to extend up to 1.5km from the mine.

Predicted Impacts on Stream Baseflows

The impacts on groundwater levels described above are predicted to result in the following impacts on groundwater baseflow to the river and creeks around the mine:

- Bowmans Creek is predicted to change from a gaining to losing stream, from a pre-mining baseflow (discharge from groundwater to the creek) of 30 m^3/day (0.03 ML/d) to a loss of about 100 m^3/day (0.10 ML/d) post-mining. It should be noted that the proposed creek diversions significantly mitigate the losses that would have occurred. If the Ashton mining beneath the Bowmans Creek alluvium does not take place and the diversions are not constructed, the impact from other mines results in a similar impact on Bowmans Creek baseflows occurring in any case.
- Flow in Glennies Creek is predicted to reduce by around 0.23 ML/d due to the Ashton underground mine.
- Flow in the Hunter River is predicted to reduce by around 0.06 ML/d due to the Ashton underground mine.
- If the project were to cease earlier than proposed due to unforeseen economic or technical issues, then a cessation at the end of the Upper Liddell seam would lead to maximum baseflow reductions in Bowmans Creek, Glennies Creek and Hunter River of 0.10 ML/d, 0.22 ML/d and 0.05 ML/d respectively, slightly less than the impacts predicted from the proposed mining to the Lower Barrett seam.

Predicted Groundwater Inflows

Inflows to the proposed underground mine have also been predicted using the updated groundwater model. Mine inflow rates during operations are predicted to reach an initial peak of around 1.4 ML/d during the initial stages of mining of the ULD seam. This is followed by a slight reduction before flow rates rise again with the mining of the ULLD and LB seams, and predicted increases in runoff recharge start to occur. Maximum inflows of just over 1.6 ML/d are predicted to occur near the start of the Lower Barrett seam mining.

There is some uncertainty over the timing and amount of surface waters that might enter the mine due to runoff recharge to the disturbed subsidence areas in the floodplain, although these have a relatively minor impact (approximately 0.1ML/d after mining in the ULD seam reaches the Bowmans Creek floodplain). Calibration against observed impacts to mining to date (discussed in Section 6) shows that mine inflow predictions are almost certainly conservative, as the model does not allow for the ‘self healing’ and reduction in permeability in caved strata that has been observed in site flooding responses and hydrograph responses in monitoring bores.

Impacts on Recharge from Surface Flooding

The subsidence troughs within the floodplain will be backfilled so they are largely ‘free draining’ following flood events, and there is therefore little risk that surface flooding within the Bowmans Creek floodplain will have a significant impact on minewater inflows during operations. The only risk comes from the inundation of the old, subsided creek channel above LW6B. This would be an occasional (1 in 5 years or greater) event, so it has not been included within the base mine inflow assessment, although recommendations for monitoring and response plans are contained within Section 8 of this report.

Post-Mining Recovery

During the post mining period, the groundwater within the mine workings and caved overburden will be highly connected. Post-recovery groundwater levels within the workings and caved overburden are predicted to reach a dynamic equilibrium, where inflows from the surface and other strata balance outflows from the mine area. Conservative allowances were made within the modelling to allow for runoff recharge to the backfilled subsidence areas on the Bowmans Creek floodplain, and for the occasional flood inundation of the old creek channel above LW6B.

These changes result in some long term impacts to water levels within the Permian strata. Following recovery, residual drawdowns of up to 15 m are seen within the Pikes Gully seam in the mine area, extending to the south and south west in response to the ‘flattening’ of piezometric heads in the Ashton and Ravensworth underground mine areas. Residual drawdowns would be slightly lower, at between 10 and 15m, if mining were to cease early after the Upper Liddell seam.

These changes in the Permian do not significantly affect the alluvium and there is negligible residual drawdown in the Hunter River or Glennies Creek alluvium. Some small parts of the alluvium directly overlying highly connected cracking in the Permian may not re-saturate, such as around the perimeter of each of the subsidence troughs. However, it is predicted that the alluvium will re-saturate over most of the floodplain, and in these areas, residual drawdowns in the Bowmans Creek alluvium are predicted to be less than 1m.

The model results show that there will be no upward flow of water from the mine workings to the alluvium anywhere within the Bowmans Creek alluvium. As there was an upflow of saline water from the Permian to the alluvium pre-mining, this represents an improvement in water quality compared with the baseline condition.

The lower groundwater levels/pressures in the Permian do mean that there will be a slight reduction in post-mining baseflows when compared with the pre-mining baseline condition, as follows:

- Baseflows to the Hunter River return to near baseline conditions, and are only around 0.015 ML/d less following recovery, or around 0.012 ML/d less if mining were to cease after the Upper Liddell seam.
- For Bowmans Creek, the changes to the hydrogeological regime and the construction of the diversion mean that post-mining baseflows will be around 0.06 ML/d lower than the pre-mining condition or 0.056 ML/d if mining ceased at the Upper Liddell seam. This change is almost entirely attributable to the Ashton underground mine and results from the creation of the diversion and the connective cracking to the alluvium.
- Post-mining baseflows in Glennies Creek are predicted to be around 0.055 ML/d lower than they were in the baseline condition. This is due to the groundwater heads in the Pikes Gully seam being lower than in the pre-mining condition, so there will still be some leakage from Glennies Creek to the mine workings on the eastern side of LW1. These are modelled values, which do not allow for any reduction in permeability that has been seen within the monitored flows from the Glennies Creek alluvium to the mine workings since mining first started. The seepage reduction observed to date is thought to be caused by progressive clogging of cleats and fissures in the coal seam, and in the long term it is expected that the permeability would reduce even further. This means that the modelled impact on Glennies Creek is likely to be over-stated, and actual post mining recovery baseflow is likely to be less than 0.03 ML/d below pre-mining baseflow.

It is predicted that any role played by the Bowmans Creek alluvium as a buffer between saline coal measures and Bowmans Creek will be restored post-mining. The modelled recovery hydrographs conclusively show that groundwater recovery will occur first within the Bowmans Creek alluvium, before potentiometric heads within the mine workings come close to surface level. This, combined with a lack of upward flow from the Permian to the alluvium, means that impacts on 'buffering capacity' are not an issue for the recovery phase.

Comparison with 2001 EIS Predictions

Overall this assessment shows that predicted impacts during the mining phase are generally lower than the 2001 EIS predictions, both in terms of baseflow losses from the three river/creek systems, and in terms of alluvium groundwater level impacts. Mine inflow rates are also lower during the early part of mining, although predicted inflows towards the end of mining are similar to the 2001 EIS.

The post-mining baseflow impacts are marginally worse than the 2001 EIS predictions, which predicted minor increases in baseflow for all three rivers following post mining recovery. However, the 2001 EIS also predicted salinity increases of 50 μS/cm for Bowmans Creek and 14 μS/cm in the Hunter River. Current predictions show that these should not occur, and that the lack of saline upflow at the end of the post mining recovery period represents an improvement in water quality in comparison to the baseline condition.

Potential Impacts on Groundwater Dependant Ecosystems (GDEs)

Monitoring carried out by ERM indicates that there are no GDEs in the Bowmans Creek alluvium that is forecast to become fully dewatered between the New England Highway and the Hunter River. Some stands of red gum have been reported along the river to the south of the western creek diversion, in the area where the alluvium is predicted to remain saturated. Model results show that groundwater drawdowns in this area are less than 0.5m, even at the end of mining to the Lower Barrett seam.

Because impacts on river flows and groundwater levels within the Hunter River, Glennies Creek and their associated alluvium are so small, both during mining and in the post mining condition, it is very unlikely that there would be any impact on GDEs associated with those water courses.

Potential Impacts on Other Groundwater Users

As the Ashton underground mine does not significantly affect alluvium groundwater levels to the north of the New England Highway, or on the south side of the Hunter River, there will be no impacts from the scheme on registered groundwater licence holders. The maximum predicted drawdown in Glennies Creek alluvium around Camberwell village is less than 0.1m, so there will be no adverse impact on the registered borehole there, even if it is still operational.

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