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MEMORANDUM

COMPANY:	Rix's Creek Pty Limited		
ATTENTION:	John Hindmarsh		
FROM:	RPS Water		
DATE:	23 March 2016	JOB NO: WS00066E	DOC NO: 005c
SUBJECT:	Rix's Creek EIS - Supplementary Groundwater Information		

1. Introduction

This document provides supplementary groundwater information in response to the DPI Water submission on the Rix's Creek Continuation of Mining Environmental Impact Statement.

An initial phase of this response to submissions was to invite DPI water representatives to meet on site at Rix's Creek and undertake a site tour for familiarisation with subsequent discussion of the specific issues raised.

The meeting was undertaken on 21 January 2016, with the following in attendance:

- DPI Water – John Williams and Andrew Druzynski
- Rix's Creek – Garry Bailey and John Hindmarsh
- AECOM – Simon Murphy
- RPS Water – Greg Sheppard

A register of DPI Water Issues and our understanding of the requirements and outcomes following the site meeting is provided in Appendix A.

2. Background

2.1 Coal Seams

The Project is confined within a geological basin-like north–south trending syncline that hosts the Permian coal reserves that are part of the Whittingham Coal Measures. The syncline is approximately 8 km long by 3 km wide and is bounded by the Camberwell and Darlington Anticlines. The syncline is asymmetrical, the western limb generally dipping at a steeper angle than the eastern limb. The syncline is also locally double-plunging forming the synclinal basin structure centred on the Rix's Creek operations. North of the Rix's Creek mining lease, the syncline plunges to the north.

The major coal seams identified in the Rix's Creek syncline are (in descending stratigraphic order):

- Lemmington Seam
- Pikes Gully Seam
- Arties Seam
- Liddell Seam
- Barrett Seam
- Hebden Seam.

The seams typically out-crop within the syncline, with the outcrop of Barrett and Hebden seams to the east, west, and south, marking the limit of the mineable seams. The target coal seams vary widely throughout the area and often occur as several dispersed splits, separated by interburden sediments that comprise alternating sandstone, siltstone, conglomerate, mudstone and shale, as well as occasional minor coal seams. The Interburden between the Barrett and Upper Hebden seams increases to in excess of 20 m in the northern and western regions, rendering the Upper Hebden seam uneconomical to mine.

2.2 Mining

Pit 1

Pit 1 has mined down to the Lower Liddell Seam. Mining is now complete and the pit has been progressively backfilled. The south-easterly void, the Old North Pit, is currently being used for water storage. The remaining void in the south of Pit 1 is the current location for in-pit tailings deposition.

Pit 2

Pit 2 is situated south of the New England Highway and was mined down to the Hebden Seam. Mining of Pit 2 ceased in 2003, and the void was subsequently used for tailings deposition. Deposition has now ceased and moved to Pit 1. Pit 2 is now backfilled and awaiting rehabilitation.

Pit 3

Pit 3 is the focus of the continuation of mining and will increasingly provide a sink for groundwater as the pit expands northwards and extraction approaches the planned maximum depth of the Hebden Seam.

2.3 Monitoring Bores

Since the submission of the original groundwater assessment, two new monitoring bores, BH7 and BH8, have been installed.

Monitoring bore details are provided on Table 1, with locations presented on Figure 7. Composite borelogs for BH7 and BH8 are provided in Appendix B.

Rix's Creek are also willing to commit to installing an additional monitoring bore. The notional location will be adjacent to BH4 with installation to a notional depth of 60m, or to the base of the coal measures. This location represents the low point of the coal measures (base of Hebden Seam) of the southern extent of the Rix's Creek Syncline (Figure 2).

Table 1: Details of Monitoring Bores

Bore ID	Easting	Northing	Screen Depth (mbgl)	Monitored Formation
BH1	323190	6400562	115 to 130	Arties Seam
BH3	325457	6401923	5 to 8	Regolith and shallow coal measures
BH4	323982	6398666	7 to 10	Regolith
BH5	324562	6399924	63 to 66	Lower Barrett Seam
BH7	323345	6401709	150.5 to 198.5	Hebden Seams
BH8	321803	6401175	5 to 14	Alluvium / Regolith

3. Hydrogeology

3.1 Aquifers

Two main types groundwater systems are present within the project area, these being unconsolidated alluvium/ and or regolith, and the Permian Coal Measures.

The unconsolidated alluvium is associated with drainage lines and creeks and the regolith comprises clay-bound and silt-bound sands and gravels. Within the project area only minor alluvium, associated with Rix's Creek exists to the south of the mine lease, these deposits generally consist of low permeability clay underlain by marginally higher permeability clayey gravel and clayey sand. At Rix's Creek, alluvial aquifers are typically thin and poorly developed, and do not comprise extensive aquifers such as those associated with Glennies Creek or the Hunter River.

The Permian Coal Measures consist of a variable sequence of aquitards (predominantly siltstone and sandstone) and low permeability aquifers (coal seams). The permeability of the coal seams is typically 1 to 2 orders of magnitude greater than that of the associated interburden and overburden units, with groundwater flow within the Coal Measures predominantly confined to the cleat fractures in the coal seams. This means the coal seams themselves form the main aquifer within the hard rock system.

Within the Coal Measures, the higher permeability coal seams are the main influence the bulk horizontal hydraulic conductivity, while the lower permeability interburden sandstones, siltstones and shales influence the overall vertical hydraulic conductivity.

Increased permeability can be associated the crests and limbs of the major folds like the Camberwell and Muswellbrook anticlines and Rix's Creek Syncline, and areas of localised bedding flexure. Such deformation may result in enhanced cleating within the coal seams or enhanced fracturing and jointing within adjacent strata. Although it is noted from mining to date at Rix's Creek, enhanced permeability and associated groundwater inflows have not been encountered.

The hydrogeological basement lithologies on site are comprised of low permeability siltstones of the basal Saltwater Creek Formation of the Whittingham Coal Measures, and the underlying Mulbring Siltstone of the Maitland Group.

3.2 Regional Groundwater Flow

Regional groundwater flow within the Coal Measures is sustained by rainfall recharge to generally elevated areas of regolith and subcropping/outcropping strata. Downward recharge to deeper strata is aided in areas of enhanced jointing and fracturing, particularly dilated joints and bedding planes in the upper weathered horizons. Downwards recharge will typically be limited by reduced fracture connectivity with depth.

Mackie (2009) compiled a regional piezometric surface from reports submitted in support of mining approvals over the period 1993 to 2004. The map typically shows groundwater flow from areas of high ground towards the Hunter River and associated alluvium, and towards major tributary drainages such as Glennies Creek and Wollombi Brook. In the vicinity of Rix's Creek this flow is generally to the west in the vicinity of Deadman's Gully (west of Pit 1) and south to southwest in the vicinity of Rix's Creek (south of Pits 2 and 3). The regional flow regimes are altered around major mining operations where groundwater sinks prevail.

The majority of regional groundwater flow in the Coal Measures and Permian strata will occur in the upper-most 20 to 50m of weathered strata including the regolith where joint and fracture flow has a greater influence. The typically low permeability and high vertical anisotropy (low Kv) limit groundwater recharge and flow to deeper strata.

Mackie (2009) noted that in areas where mining has not impacted upon the Coal Measures strata, the deep pore pressure regime is observed to be generally stable in time with seasonal movements being commonly less than one metre, even during periods of sustained drought.

Groundwater discharge is typically to the regional drainage and alluvial aquifers of the Hunter River and its tributaries with upwards leakage associated with the sub-cropping of Coal Measures in these areas. In areas un-impacted by mining operations, upwards hydraulic gradients are often identified, and reduced water quality is often associated with areas of leakage of more saline groundwater from the Coal Measures.

Groundwater levels within the Rix's Creek Syncline are dominated by the groundwater sinks presented by the current Rix's Creek open cut mining operation at Pit 3 and the adjoining Integra mining operations to the north.

3.3 Formation Hydraulic Properties

Mackie (2009) undertook a study of hydraulic properties of coal seams and interburden in the Upper Hunter Valley region. Key results relevant to the Rix's Creek project are summarized below.

3.3.1 Coal Seam Hydraulic Conductivity

The intrinsic permeability of coal seams is generally very low and is comparable to massive (un-jointed or fractured) carbonaceous shale (less than 1.0E-06 m/day). The permeability of the coal seams therefore, is dominated by the cleat network that develops as a result of regional stress fields present during the coalification process.

Coals of the Upper Hunter region typically exist as banded dull and bright coal types, with dull coals tending to be weakly cleated, while bright coals are typically strongly cleated.

Typical ranges of coal seam horizontal hydraulic conductivities, based on seam description and degree of cleating, as presented by Mackie (2009), are summarised on Table 2.

Generally, the hydraulic conductivity of the coal seams declines rapidly with greater depth of cover, with Mackie (2009) reporting a mean trend of an order of magnitude decline in hydraulic conductivity per 180m depth of cover.

Table 2: Coal Seam Horizontal Hydraulic Conductivity Range

Seam description	0 to 100m depth (m/day)	100 to 200m depth (m/day)	200 to 300m depth (m/day)
mostly dull coal	2.0E-03 to 6.0E-04	6.0E-04 to 1.8E-04	1.8E-04 to 5.0E-05
dull coal with bright bands	2.2E-02 to 6.0E-03	6.0E-03 to 1.9E-03	1.9E-03 to 5.4E-04
dull and bright banded coal	7.0E-02 to 2.0E-02	2.0E-02 to 6.0E-03	6.0E-03 to 2.0E-03
bright coal with dull bands	2.2E-01 to 7.0E-02	7.0E-02 to 2.0E-02	2.0E-02 to 6.0E-03
mostly bright coal	2.7E+00 to 8.0E-01	8.0E-01 to 2.3E-01	2 .3E-01 to 7.0E-02

Mackie also provided a compilation of coal seam packer testing data undertaken at numerous sites throughout the Upper Hunter region. Of these tests, 35 tests coincide with seams present at Rix's Creek. The results of these tests are summarised below on Table 3.

Table 3: Compilation of Packer Testing Hydraulic Conductivity Values

Seam	No. Tests	Depth Range		Hydraulic Conductivity (m/day)		
		Min	Max	Min	Max	Average
Lemmington	4	39.5	68.5	1.00E-03	9.30E-02	2.58E-02
Pikes Gully	6	44.5	163	1.40E-03	1.30E-01	5.15E-02
Arties	2	83	126	2.60E-03	4.90E-02	2.58E-02
Liddell	13	106	205	1.00E-03	3.80E-01	5.38E-02
Barrett	9	15.5	254.5	1.50E-03	4.40E-02	1.07E-02
Hebden	1	189.5	1.90E+02	9.00E-04	9.00E-04	9.00E-04

3.3.2 Interburden Hydraulic Conductivity

Mackie (2009) provides a schedule of hydraulic conductivity values based upon lithology and derived from core testing. These data are provided in Table 4.

Mackie reported that these values have been found to generate estimates of strata depressurisation and mine pit influx rates consistent with subsequently observed rates when employed in aquifer numerical models of mine pits to depths of 150 to 200 m.

It was noted that these values may also be modified (increased) by the presence of jointing and de-stressing, and estimated hydraulic conductivities based upon fracture flow and de-stressing are also provided on Table 3. Jointing, and therefore increased permeability, is commonly observed to be more prevalent in more thinly bedded strata, and often absent in the more massive sandstones and siltstones.

Indicative values for non-weathered sandstone and siltstone are of the order of 1.0E-5 to 1.0E-6 m/d with claystone as low as 5.0E-7 m/d. Weathered and de-stressed (near surface) values of sandstone are typically 1.0E-1 to 1.0E-2 m/d. The shallow regolith tested at MW8, is consistent with these values at 4.0E-2 m/d.

Table 4: Interburden Representative Hydraulic Conductivity

Interburden Description	K single value (m/day)	K range (m/day)	K limited joints (m/day)	K de-stressed (m/day)
Conglomerate - weathered	1.0E-02	5.0E-04 - 5.0E-02	2.0E-02	2.0E-01
Sandstone (nt)- weathered	5.0E-03	2.0E-04 - 2.0E-02	1.0E-02	1.0E-01
Sandstone (nt) – semi weathered	5.0E-04	1.0E-05 - 5.0E-03	1.0E-03	1.0E-02
Sandstone (nt) - coarse grained	5.0E-05	2 .0E-05 - 1.0E-03	2.0E-04	5.0E-03
Sandstone (nt) - medium grained	1.0E-05	1.0E-06 - 1.0E-04	2.0E-04	2.0E-03
Sandstone (nt) – fine grained	5.0E-06	1.0E-07 - 1.0E-05	1.0E-04	1.0E-03
Interbedded sandstone/siltstone (nt)	2.0E-06	5.0E-07 - 5.0E-05	2 .0E-03	2.0E-02
Tuffaceous sandstone	1.0E-06	1.0E-07 - 5.0E-05	1.0E-06	5.0E-06
Siltstone	1.0E-06	1.0E-07 - 1.0E-05	1.0E-04	1.0E-03
Siltstone - claystone	8.0E-07	5.0E-08 - 2.0E-06	1.0E-04	1.0E-03
Claystone	5.0E-07	5.0E-08 - 1.0E-06	1.0E-04	1.0E-03
Conglomeratic sandstone	5.0E-05	1.0E-06 - 5.0E-05	1.0E-04	1.0E-03
Conglomerate	5.0E-06	5.0E-07 - 5.0E-05	1.0E-04	1.0E-03
Dolerite	1.0E-07	1.0E-08 - 1.0E-06	1.0E-04	1.0E-03

Note: nt = non tuffaceous.

3.3.3 Other Mining Operations

Hydraulic Conductivities adopted in the Groundwater Model for the nearby Glennies Creek Colliery Longwalls 10 to 17, Environmental Assessment (ERM, 2007), were based on a range of hydraulic conductivity and specific storage values presented in available reports for the surrounding mining operations. The adopted values are presented on Table 5.

Table 5: Glennies Creek Colliery Hydraulic Conductivity

Unit	Horizontal Conductivity (m/d)	Vertical Conductivity (m/d)	Specific Yield (-)	Specific Storage (m^{-1})
Weathered Sandstone	4.3E-3	4.3E-4	0.03 to 0.005	1.0E-5 to 5.0E-6
Fresh Sandstone /Shale	4.3E-4	4.3E-5 to 8.64E-4	0.03 to 0.005	1.0E-5 to 5.0E-6
Arties and Middle Liddell Seams	0.052 to 8.64E-3	5.2x10-3	0.03	1.0E-5 to 5.0E-6
Hebden and Barrett Seams	0.00173 to 6.9E-3	1.73E-4 to 6.9E-4	0.03	1.0E-5 to 5.0E-6

3.3.4 Storage

Specific storage for coal and interburden strata can be estimated based on the relationship with Young's Modulus. Estimates of specific storage can be generated utilising the following equation:

$S_S = \alpha \gamma_w$ (m^{-1})

Where:

α = Compressibility of the bulk ground (LT^2/M) = $(1+\nu)(1-2\nu)/E(1-\nu)$,

γ_w = Unit weight of water (M/L^2T^2),

ν = Poisson's Ratio; and

E = Young's Modulus (M/LT^2)

Mackie (2009) presents a range typical specific storage values for coal and interburden strata with saturated densities of 1.5 and 2.4 t/m3 respectively, and Poisson's ratio of 0.3. The typical specific storage range for coal seams is provided as being 5.0E-06 to 5.0E-05 m-1. Based on typical values of Young's Modulus for interburden strata, representative specific storage values would be of the order of 1.0E-04 to 1.0E-06 m-1.

Adopted specific storage values from nearby operations range from 1.0E-5 to 5.0E-6 m-1 for coal seams and interburden (Table 4).

3.4 Site Permeability Testing

Site specific permeability testing undertaken at Rix's Creek has comprised rising and falling head testing at a number of monitoring bores. Derived permeabilities are provided on Table 6.

Table 6: Interburden Representative Hydraulic Conductivity

Monitoring Bore	Screened Formation	K (m/day)
MW1	Arties Seam	1.5E-03
MW5	Lower Barret	2.3E-02
MW7	Barrett / Hebden Seams	6.3E-04
MW8	Regolith	4.0E-02

It is noted that the site derived hydraulic conductivity values are consistent with the regional results provided on Tables 2 to 4.

3.5 Site Water Levels

Hydrographs depicting site water level monitoring, including pit water levels and monitoring bore water levels are shown on Figure 1. The water levels are compared with the cumulative rainfall residual (CRR) from Bureau of Meteorology station number 61397 in Singleton.

Early water levels in the Old North Pit, Pit 2 tails and the Production Bore, installed into the old underground workings, show a close resemblance to the CRR, however there is then a dominance by site water management practices, with only the larger rainfall events showing any significant influence.

Water levels in the Production Bore and BH5 are shown to be strongly influenced by site water management practices, and increase with the deposition of tailings at Pit 2, and then subsequently decline following the end of Pit 2 tailings deposition.

Water levels at Pit 1 - Tails show an increase that corresponds with tailing deposition. Water levels at Pit 1 - North show a gradual equilibration as water levels within the backfilled pit increase.

Water levels at monitoring bore BH1 have shown a gradual decline with the development of Pit 3, and then went dry following the last recorded water level in May 2014.

The recently installed BH7 adjacent to Pit 1 displays water levels that that are likely being maintained by the tailings deposition in Pit 1.

Shallow monitoring bores BH3, BH4 and BH8, are shown to be unaffected by mining and current site water management practices.

3.6 Conceptual Hydrogeological Model

3.6.1 Aquifer Geometry and Aquifer Parameters

The conceptual hydrogeological model for Rix's Creek is relatively simple in that the basin-like structure of the Rix's Creek Syncline acts to isolate the Coal Measures from the broader regional hydrogeological regime, with little groundwater interaction through the bounding low permeability siltstones.

The basin-like structure as defined by the base of the Hebden Seam (and upper surface of the Saltwater Creek Formation) is depicted on Figures 2 and 3. Hydrogeological cross sections depicting current and post mining scenarios a provided on Figures 4 and 5. The cross sections show the stratigraphic location of the Rix's Creek project relative to the surrounding lithology and neighbouring operations.

The limbs of the anticline have a relatively shallow dip on the eastern limb with the western limb dipping at a much steeper angle. The syncline axis also plunges from the north and south with the deepest part of the synclinal basin centred beneath the proposed Pit 3 continuation area. The lowest point the Coal Measures in the synclinal basin is approximately -130mAHD.

Although geologically more complex on the local scale due to the splitting and merging of multiple minor seams, the aquifer system at Rix's Creek has been simplified and represented by a layer cake style system, with the layer geometry reflecting the synclinal basin structure. Within the layer cake, the major coal seams represent the main aquifers, with the interburden units providing low permeability aquitards between the aquifers. Within the coal seam aquifers, preferential groundwater flow is normal to bedding. Large scale groundwater flow perpendicular to bedding is impeded by the low permeability interburden units.

Within the groundwater model each major coal seam and interburden unit is assigned a separate layer. A summary of the adopted hydraulic parameters are provided on Table 7.

Table 7: Adopted Hydraulic Conductivity and Storage Parameters

Lithology	Horizontal Hydraulic Conductivity (m/day)	Vertical Hydraulic Conductivity (m/day)	Specific Storage (m^{-1})	Specific Yield
Coal Seams	1.0E-02 to 8.0E-02	1.0E-04 to 8.0E-04	4.0E-06	0.01
Interburden / Overburden	5.0E-03	5.0E-05	1.0E-06	0.06
Basement - Saltwater Creek Formation / Mulbring Siltstone	1.0E-03 to 5.0E-03	1.0E-05 to 5.0E-05	1.0E-06 to 4.0E-06	0.01 to 0.06

It is noted that the adopted hydraulic conductivities are typically elevated compared to the typical regional parameters discussed in Section 3.3. This is a conservative feature that has been adopted in the model to reflect the degree of structural deformation that has taken place at Rix's Creek and the potential for more extensive jointing and fracturing than is typically observed away from the major fold structures. It is also noted, however, that extensive jointing and fracturing have not been noticed during historical mining operations and observed mine inflows have been relatively low.

3.6.2 Water levels and Groundwater Flow

Extraction from Pit 1 down to the Liddell Seam, Pit 2 to the Barret and Hebden Seams, and the current Pit 3 down to the Barret seam at Rix's Creek, has created a groundwater sink within the synclinal basin, as has extraction of Integra North and South pits to the base of the Hebden Seam to the north. The sinks are driven by evaporation as well as active dewatering to facilitate mining operations.

A composite of current (December 2015 to January 2016) water levels is provided on Figure 6 along with inferred interaction of groundwater and stored pit water. These water levels are also depicted in section view on Figure 4. Water levels are shown to be dominated by the groundwater sinks of Integra South Pit and Western Extension and Rix's Creek Pit 1.

Water levels at Integra monitoring bores GCP32, in shallow Coal Measures, and GCP36, in Glennies Creek Alluvium, appear largely unaffected by mining. GCP34, GCP35, and GCP37 show varying degrees of depressurisation, particularly at vibrating wire piezometer installation GCP35, where the lower most sensor shows a pressure elevation of -37mAHD.

In-pit water levels are artificial maintained at the Old North Pit, for water storage, and at Pit 1 through tailings deposition. Seepage through the backfilled Pit 1 is inferred to the North of Pit 1 where the large hydraulic gradient will drive seepage through the remnant Coal Measures towards the Integra pit. Seepage from Pit 1 is also likely to the west, maintaining heads in the as yet unmined Coal Measures.

From Old North Pit, seepage is inferred to the historical underground workings and then to Pit 2. From Pit 2 a small amount of seepage will occur through the remnant Coal Measures to Pit 3. This seepage face is evident in the eastern barrier wall with Pit 2. Some seepage may also occur through the remnant Coal Measures between the Old North Pit and Pit 1.

Within the Rix's Creek Syncline, groundwater flow will be predominantly towards the two main groundwater sinks, resulting in a groundwater divide within the Coal Measures, which is inferred to broadly coincide with the mining boundary between the two operations.

Outside of the syncline and within overlying alluvial or regolith aquifers, groundwater flows are inferred to remain relatively undisturbed and follow the regional groundwater flow regime.

Water levels at Rix's Creek monitoring bores BH5 and BH7 are currently influenced by in-pit water management practices and movements described above, while BH3, BH4 and BH8 are largely unaffected by mining operations.

Recharge

Rainfall recharge and infiltration will occur on remnant subcrop/regolith areas, as well as rehabilitated mine areas, and direct rainfall to open cut areas. A degree of artificial recharge and infiltration will also occur from the Old North Pit water to storage, and the deposition of tailings slurry in Pit 1.

The lack of impacts observe at shallow monitoring bores BH3 and BH4, located within the limit of Coal Measures outcrop, demonstrates the disconnection of the shallow regolith and alluvial aquifers from the deeper groundwater regime. It also shows that the aquifers in these locations are reliant on direct rainfall recharge, which has not been diminished through mining operations.

Effect of Continuation of Mining

The main effect of the continuation of mining at Rix's Creek will be the deepening and northwards migration of the groundwater sink in the expanded Pit 3. Pit 3 will be progressively backfilled as it is developed. This will act to effectively depressurise and dewater the bulk of the remaining Coal Measures within the syncline.

Groundwater inflows will be predominantly derived from the water currently held in storage in the deeper Coal Measures, supplemented by a minor amount of recharge. No significant propagation of drawdown or depressurisation is anticipated outside of the syncline area. The Integra operations to the north have already mined down to the base of the syncline (Hebden Seam) and created a groundwater sink, thus limiting any northwards propagation of potential impacts.

3.6.3 Post Mining Scenario

Post mining water levels and interactions are provided on Figure 7 and in section view on Figure 5. As mining progresses mine voids will be backfilled and rehabilitated. At the end of mining a final void will remain in the area of the Pit 3 extension (Figure 7). The final void will comprised contoured slopes at an angle of approximately 18 degrees.

An internal drain within the final void is proposed, commencing at the northern void crest and running along the western and southern walls. The drain will intercept clean runoff to be diverted to the Rix's Creek drainage and will minimize the volume of runoff entering the final pit lake.

The post mining water level scenario is shown of Figure 7. Figure 7 also show the extent of the final pit lake and the catchment area of the final void. The pit lake is expected to reach an equilibrium level of 50 mAHD and remain as a long term groundwater sink. Post mining water levels within the remaining Coal Measures and the backfilled mine voids are anticipated to reach a long term equilibrium level of around 55mAHD.

4. Modelling

A detailed response to modelling related issues is provided in Appendix C and the independent model review, undertaken by Dundon Consulting Pty Ltd, is provided in Appendix D.

In general, a number of the issues raised related to the fact that many of the modelling figures were not legible. It appears that the PDF files submitted were subject to file size reduction, thus reducing the resolution of the figures. A full set of figures pertaining to the original groundwater modelling, and including model calibration hydrographs, is therefore provided in Appendix E.

Key modelling issues raised related to the conceptual hydrogeological model, model calibration, the presence of a general head boundary, and the independent model review. The conceptual hydrogeology is addressed above, while other more general modelling related issues are addressed in Appendix C.

4.1 Model Confidence Level

The Australian Groundwater Modelling Guidelines (Barnett et. al., 2012), describes the use of model confidence levels as a means of franking the relatives confidence with which a model can be used in predictive mode.

The Rix's Creek groundwater model is designed as a Class 2 Confidence Level model being used for the purpose of impact assessment of a continuing mining operation in hard rock that has been operating successfully and without incident for 25 years.

Key characteristics and indicators of a Class 2 confidence level model as presented in Barnett *et.al.* (2012) are provided on Table 8.

Table 8: Class 2 Model Confidence Level - Characteristics and Indicators

Criteria	Characteristics and Indicators
Data	• Groundwater head observations and bore logs are available but may not provide adequate coverage throughout the model domain. • Metered groundwater-extraction data may be available but spatial and temporal coverage may not be extensive. • Streamflow data and baseflow estimates available at a few points. • Reliable irrigation-application data available in part of the area or for part of the model duration.
Calibration	• Validation is either not undertaken or is not demonstrated for the full model domain. • Calibration statistics are generally reasonable but may suggest significant errors in parts of the model domain(s). • Long-term trends not replicated in all parts of the model domain. • Transient calibration to historic data but not extending to the present day. • Seasonal fluctuations not adequately replicated in all parts of the model domain. • Observations of the key modelling outcome data set are not used in calibration.
Prediction	• Transient calibration over a short time frame compared to that of prediction. • Temporal discretisation used in the predictive model is different from that used in transient calibration. • Level and type of stresses included in the predictive model are outside the range of those used in the transient calibration. • Validation suggests relatively poor match to observations when calibration data is extended in time and/or space.
Key Indication	• Key calibration statistics suggest poor calibration in parts of the model domain. • Model predictive time frame is between 3 and 10 times the duration of transient calibration. • Stresses are between 2 and 5 times greater than those included in calibration. • Temporal discretisation in predictive model is not the same as that used in calibration. • Mass balance closure error is less than 1% of total. • Not all model parameters consistent with conceptualisation. • Spatial refinement too coarse in key parts of the model domain. • The model has been reviewed and deemed fit for purpose by an independent hydrogeologist.
Examples of Specific Uses	• Prediction of impacts of proposed developments in medium value aquifers. • Evaluation and management of medium risk impacts. • Providing estimates of dewatering requirements for mines and excavations and the associated impacts. • Designing groundwater management schemes such as managed aquifer recharge, salinity management schemes and infiltration basins. • Estimating distance of travel of contamination through particle-tracking methods. Defining water source protection zones.

4.2 Model Limitations

The Rix's Creek groundwater model has been constructed to assess potential groundwater inflows to the continuation of mining at Rix's Creek and the associated groundwater impacts and water licensing considerations. The mine plans and scheduling used to simulate current and future operations at Rix's Creek can be considered to be a reasonably accurate representation of the planned foot print and extent of mining at the time of model development. However, given the limitations imposed by numerical modelling, and the need to keep model sizes manageable and run times sensible, a degree of simplification of the mine plan, and the simulation of mine progression, is required.

Peripheral and historical operations and stresses, such as the presence and extent of historical underground workings, and past and future plans and schedules of neighbouring mining operations have been approximated based on the best understanding of these operations at the time of model development, generally from publically available information at the time (AEMRs/EISs etc.). The timing and scale of neighbouring operations should be treated as indicative only and are incorporated to assess for potential cumulative impacts within the broader model domain.

4.3 Model Layers

Table 8.2 of the Groundwater Impact Assessment provided minimum layer thicknesses that included the thicknesses of inactive dummy layers. Dummy layers are incorporated into the model where hydrostratigraphic units being simulated in the model out crop or pinch out. Modflow requires that layers are continuous throughout the model domain. To get around this the layers are reduced to a minimum thickness and acquire the hydraulic properties of the next underlying active layer.

A revised Table 8.2, incorporating only active layer thicknesses is provided below on table 9. It is noted that prior to becoming inactive the model layer need to be pinched out and the minimum thicknesses reported are indicative of this. The median values are therefore more typical of model layer thickness within the project area.

Table 9: Groundwater Impact Assessment Table 8.2 Updated.

Layer	Median Thickness (m)	Minimum Thickness (m)	Maximum Thickness (m)	Hydrogeological Unit	Source (.DXF)
1	4.05	2.0	20.0	Regolith/Alluvium	Topo-5, NSW 25m DTM or Alluvium
2	9.57	0.04	69.5	Overburden	P29_Roof
3	14.4	0.06	del inOverburden	Overburden	Split
4	24.0	0.10	173.8	Overburden	Split
5	1.57	0.2	21.9	Pikes Gully	P26_Floor
6	8.24	0.2	66.5	Interburden	UA25_Roof
7	2.49	0.2	13.4	Arties	LA22_Floor
8	3.35	0.2	30.6	Interburden	UL21_Roof
9	1.16	0.2	15.2	Upper Liddell	UL20_Floor
10	5.66	0.2	28.6	Interburden	ML19_Roof
11	2.44	0.2	16.2	Middle Liddell	ML16_Floor
12	9.06	0.2	38.8	Interburden	LL13_Floor + 2m
13	1.10	0.2	2.15	Lower Liddell	LL13_Floor
14	15.3	0.2	46.8	Interburden	LB11_Roof
15	1.88	0.2	6.95	Lower Barrett	LB9_Floor
16	6.95	0.2	57.5	Interburden	H7_Roof
17	12.9	0.2	34.8	Hebden	H1_Floor
18	I., 20.2	0.2	106.2	Saltwater Creek	H1_Floor - 50
19	93.6	21.5	103.4	Mulbring Siltstone	Saltwater - 100

4.4 Model Calibration

In the DPI Water submission, it was stated that the model was not calibrated, with a reported SRMS value of 16%. Given the contained hydrogeological setting for the project, an SRMS of 16.2% overall is considered reasonable for a Class 2 Confidence Level model being used for the purpose of impact assessment of a continuing mining operation in hard rock, that has been operating successfully and without incident for 25 years.

It is also noted that this SRMS value is based on a transient calibration. On review of other modelling assessments in support of project approvals in the Upper Hunter valley, it is noted that it is more common practice to present results for the steady state calibration, which are typically neater and offer a reduced scatter, and therefore a reduced SRMS error. In this case a steady state calibration has not been undertaken.

The Australian Groundwater Modelling Guidelines also go to significant length to explain that calibration is more complex than just presenting SRMS, and that model acceptance should be based on a number of other performance measures (such as model convergence and water balance) to demonstrate that the model is robust, simulates the water balance as required, and is consistent with the conceptual model on which it is based (Barnett et. al., 2012)[1]. In this respect, it is considered that the model is appropriately calibrated for the Confidence Class of model it was constructed for, namely impact assessment.

The plot of transient modelled versus observed target values (Figure 8.13 of the Groundwater Impact Assessment) shows a number of outliers. It is noted that a number of the deeper elevations are associated with the Integra operations and a likely being influenced by the underground operations to the north. Mining operations in this area were obtained from publically available information at the time and should be considered as indicative of actual operations only. It is also noted that the modelled values are greater (deeper) than observed. This shows that the model is over-predicting the propagation of dewatering and depressurisation in this area, and is considered to be conservative in this respect.

The fit to observation data is considered reasonable in the vicinity of Rix's Creek operation for the purpose of impact assessment.

4.4.1 Mass Balance

The mass balance error for the calibration model is <0.001% and is considered to be very good. Key water balance components for the calibration model are summarized on Table 10. Given the scale of the model, and that the model encompasses the Hunter River, the water balance components provided on Table 10 are considered to be reasonable.

Table 10: Calibration Model Water Balance - Entire Model

Water In (m^3)		**Water Out (m^3)**	
Storage	44,072,848.00	Storage	13,320,090.00
Constant Head	0.00	Constant Head	0.00
Drains	0.00	Drains	38,741,544.00
Recharge	24,399,776.00	Recharge	0.00
ET	0.00	ET	21,332,654.00
River Leakage	9,044,115.00	River Leakage	3,369,780.50
Head Dependent Boundaries	0.00	Head Dependent Boundaries	752,387.75
TOTAL IN	**77,516,739.00**	**TOTAL OUT**	**77,516,455.25**

4.5 Uncertainty

Model uncertainty analysis was undertaken for the variation of rainfall, and therefore recharge, only. The variation in rainfall was undertaken to assess for the potential effects of extreme climatic variation and climate change.

The variation of model hydraulic parameters was not deemed to be necessary. The adopted hydraulic conductivity values are considered to be very conservative, with the potential for encountering higher average formation permeability very unlikely. It was, therefore, not deemed necessary to assess potential effects of higher than adopted hydraulic conductivity and or storage. The eventuation of lower values and therefore reduced inflows would not impact on the mining operation as it is not reliant of groundwater for water supply.

[1] Barnett *et. al.*, 2012. *Australian Groundwater Modelling Guidelines. Waterlines Report Series No 82.* Reference No. ISBN 978-1-9218553-91-3, dated June 2012. National Water Commission, Canberra.

4.6 General Head Boundary

Concerns were raised over the inclusion of a general head boundary, approximately 7km to the west of the project area, and to the west of the Hunter River, and whether the presence of the boundary may be unduly influencing model outcomes in the vicinity of the project.

The general head boundary was placed to represent known groundwater levels from a monitoring bore adjacent to the Hunter Valley Operations mine site. A sensitivity run has been undertaken on the calibration model with the general head boundary switched off (refer Appendix C). The sensitivity run shows the general head boundary to locally reduce water levels in the vicinity of the boundary (<40mAHD with boundary on and <60mAHD with boundary off), but has no significant effect on water levels east of the Hunter River, and none whatsoever at the Rix's Creek project area.

4.7 Independent Review

An independent model review has been completed by Peter Dundon, of Dundon Consulting Pty Ltd and a copy of the review is provided in Appendix D. The model was assessed against the Australian Groundwater Modelling Guideline (Barnett, et., 2012).

In terms of the Australia Groundwater Modelling Guideline check-list, the modelling was found to be satisfactory and is fit for purpose. The review further concluded that the modelling predictions were assisted by a long period of monitoring of the Rix's Creek operation and the neighbouring Glennies Creek and Integra mines and that the monitoring history provided confidence that the modelling predictions were sound, and predicted impacts were consistent with past impacts.

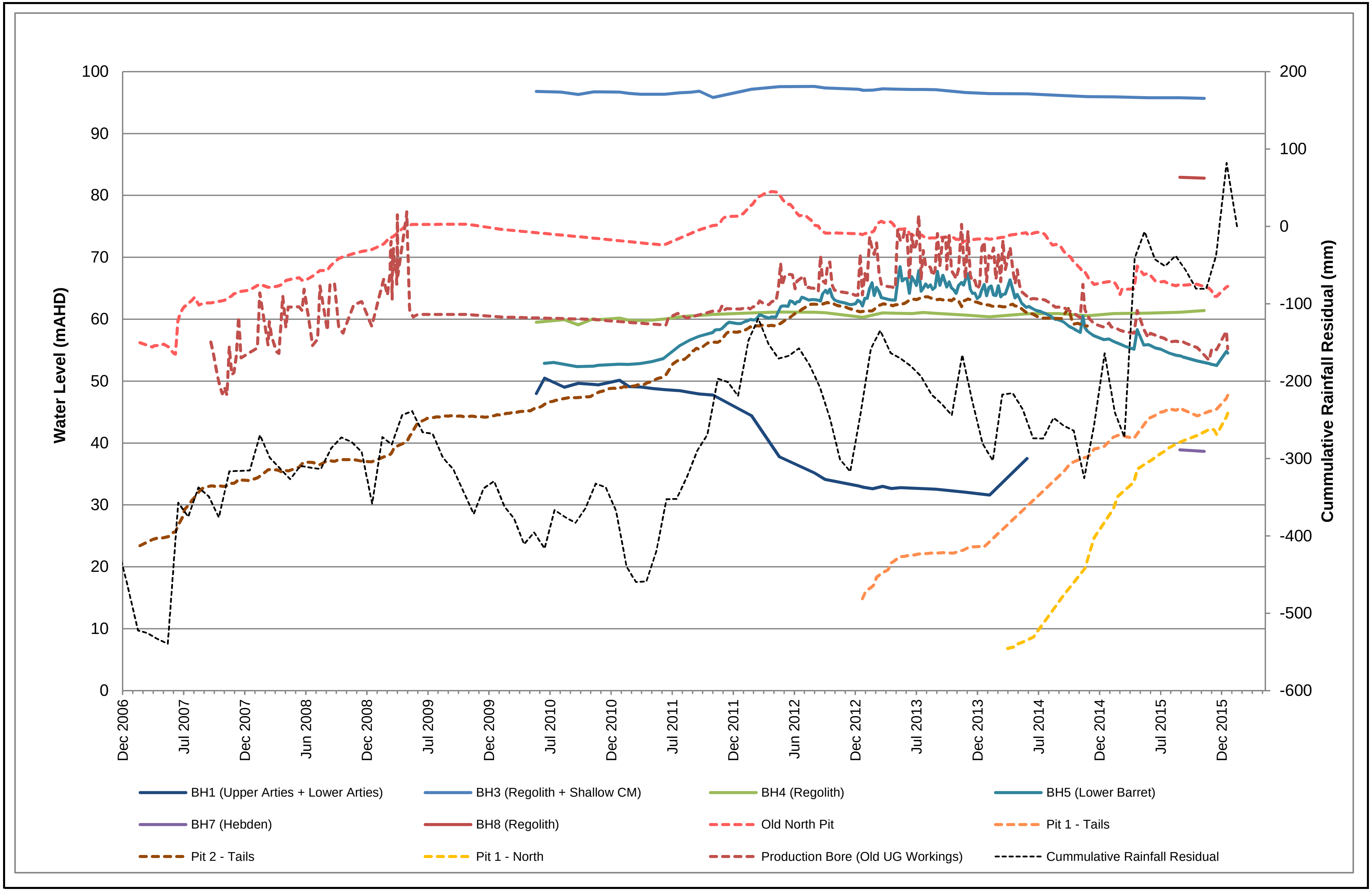
5. Close

We trust that the above, and attached, sufficiently addresses the concerns and issues raised by DPI Water. In general, the continuation of mining at Rix's Creek poses a very low risk, with no significant impacts to groundwater resources outside of the enclosing syncline.

Yours sincerely,
RPS Water

Greg Sheppard
Principal Hydrogeologist

FIGURES



RPS

Rixs's Creek Water Level Monitoring FIGURE 1

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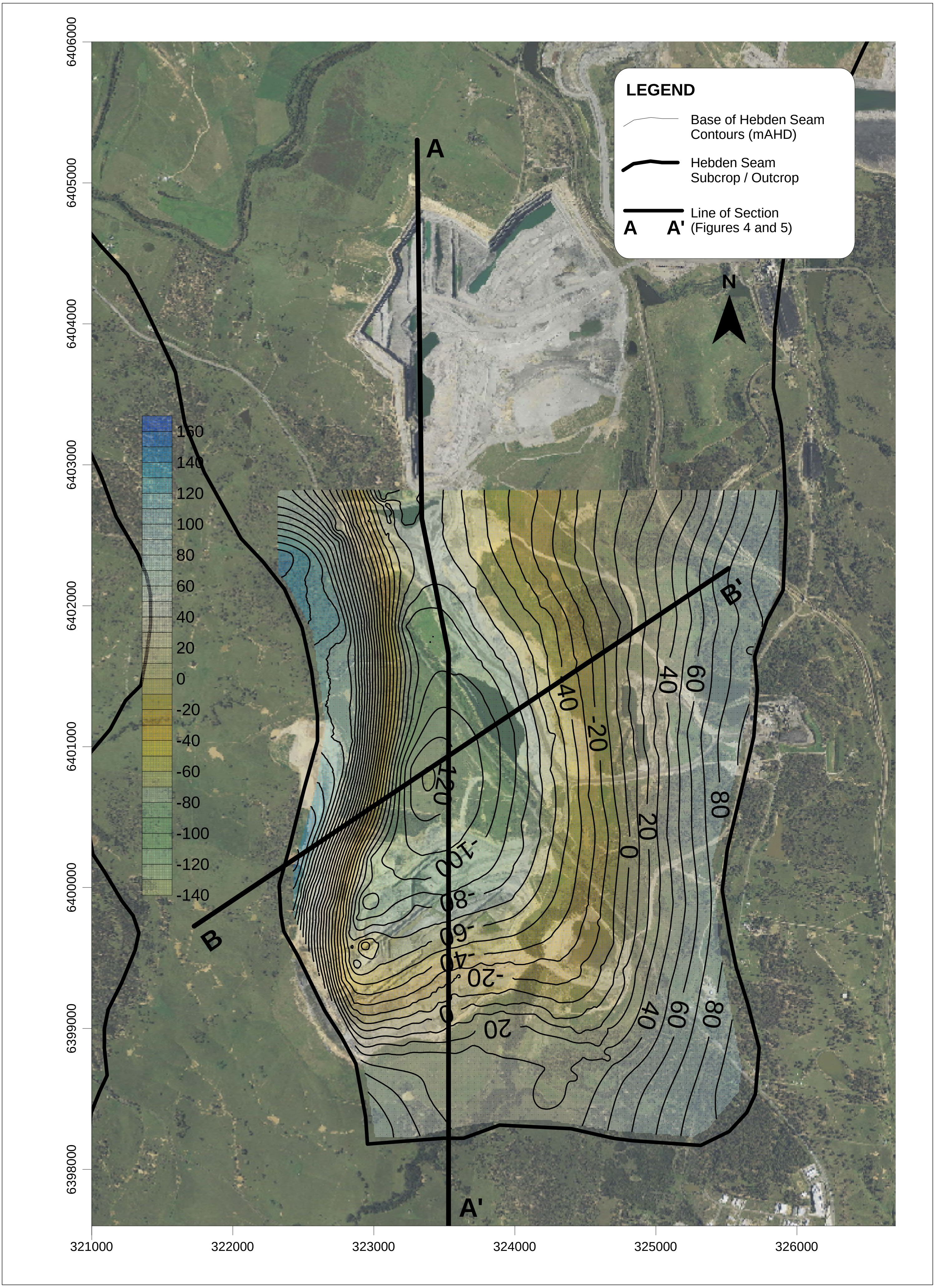

Rixs Creek Syncline Basin Structure - Base of Hebden Seam FIGURE 2

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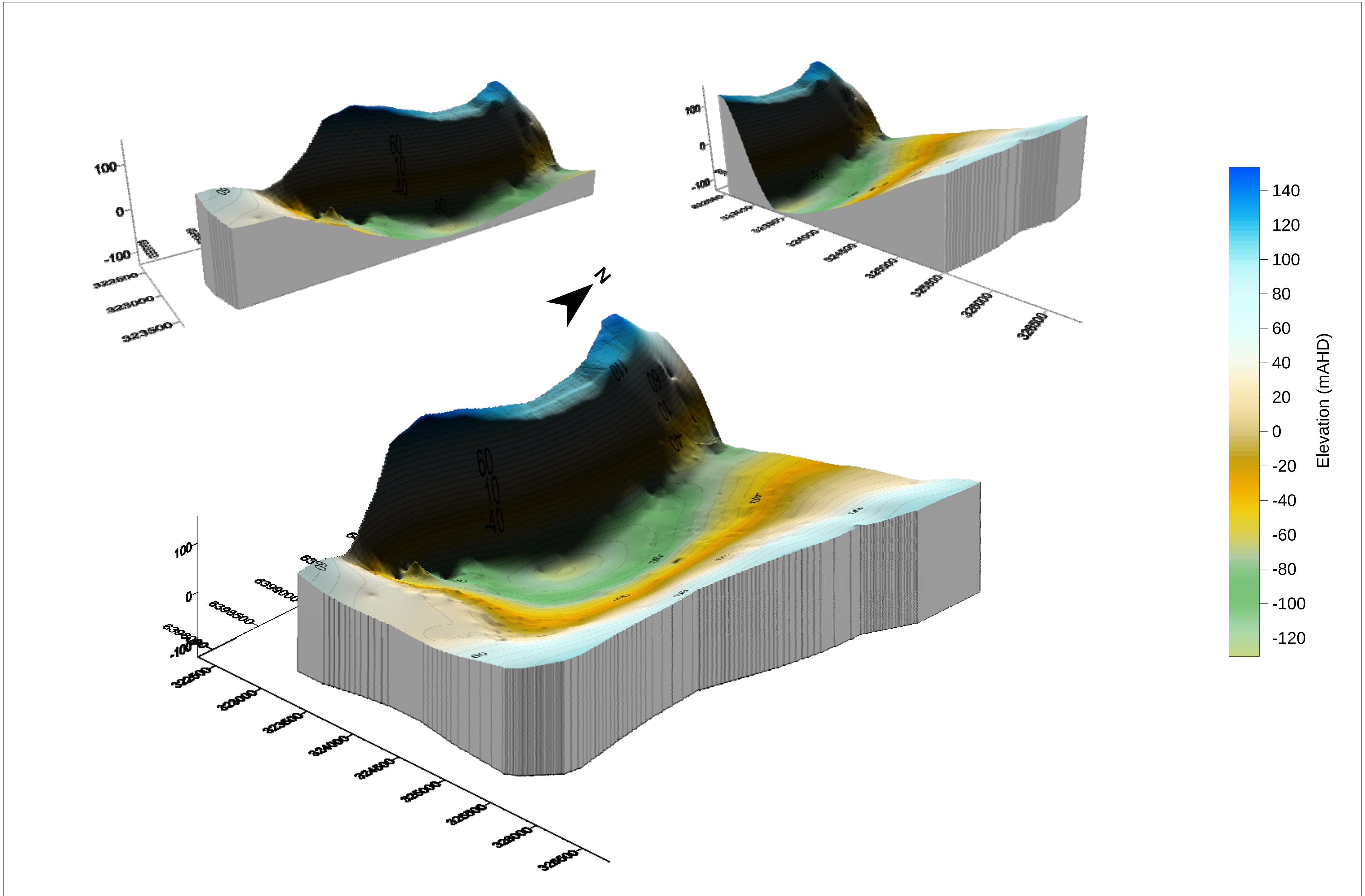

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Rixs Creek Syncline Basin Structure - Base of Hebden Seam FIGURE 3

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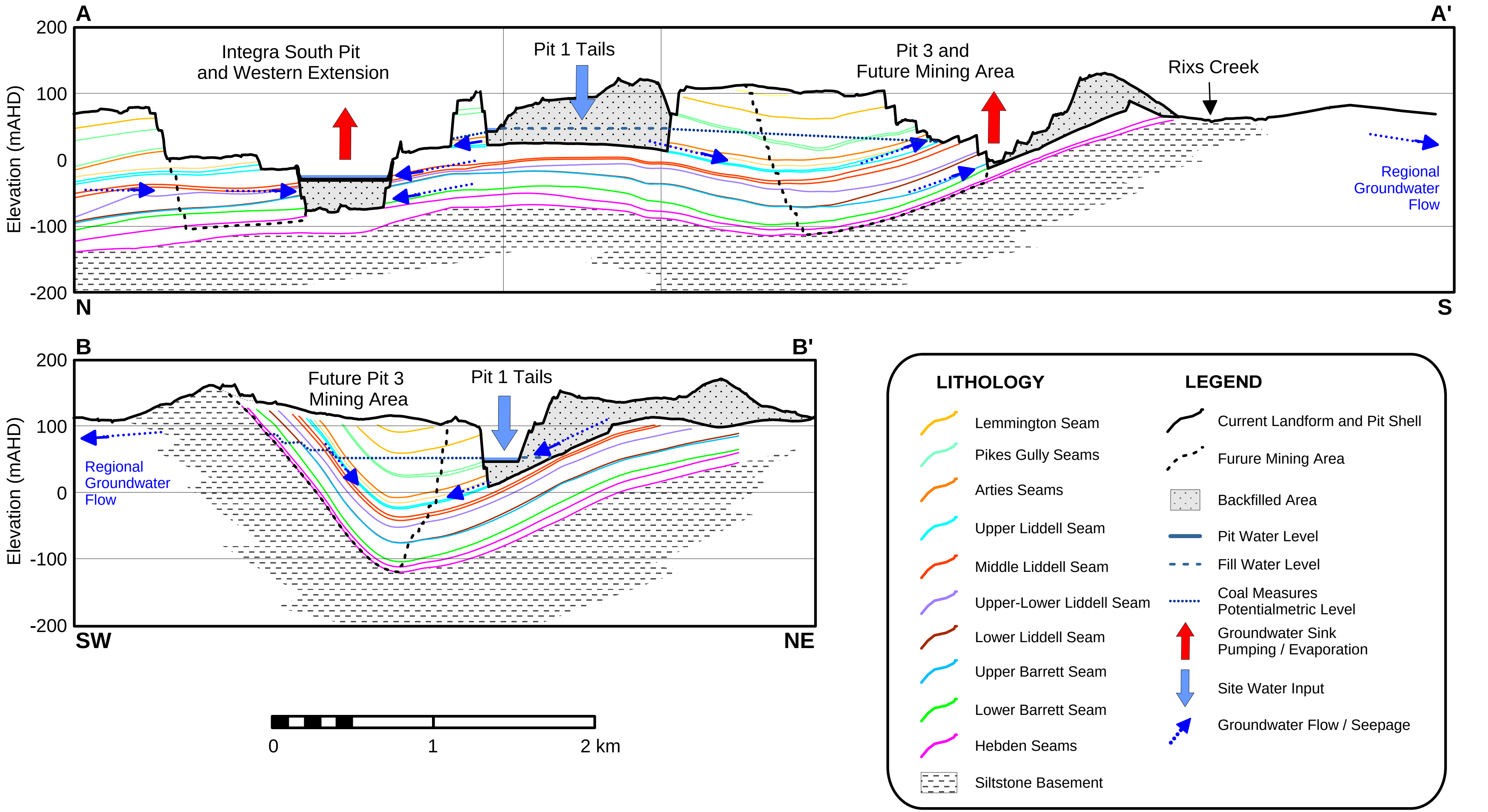

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CONCEPTUAL HYDROGEOLOGICAL SECTIONS - CURRENT SCENARIO FIGURE 4

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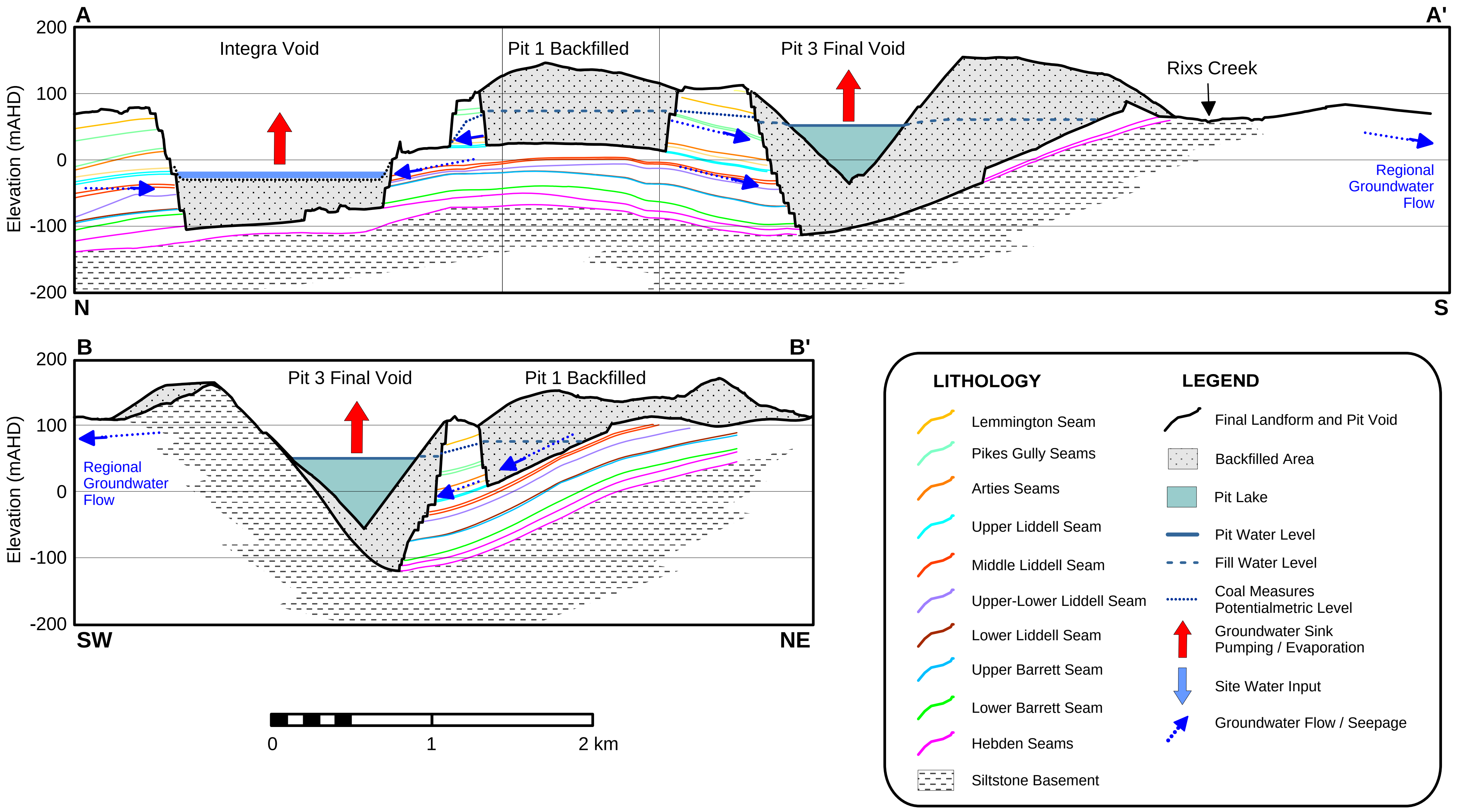

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CONCEPTUAL HYDROGEOLOGICAL SECTIONS - POST MINING SCENARIO FIGURE 5

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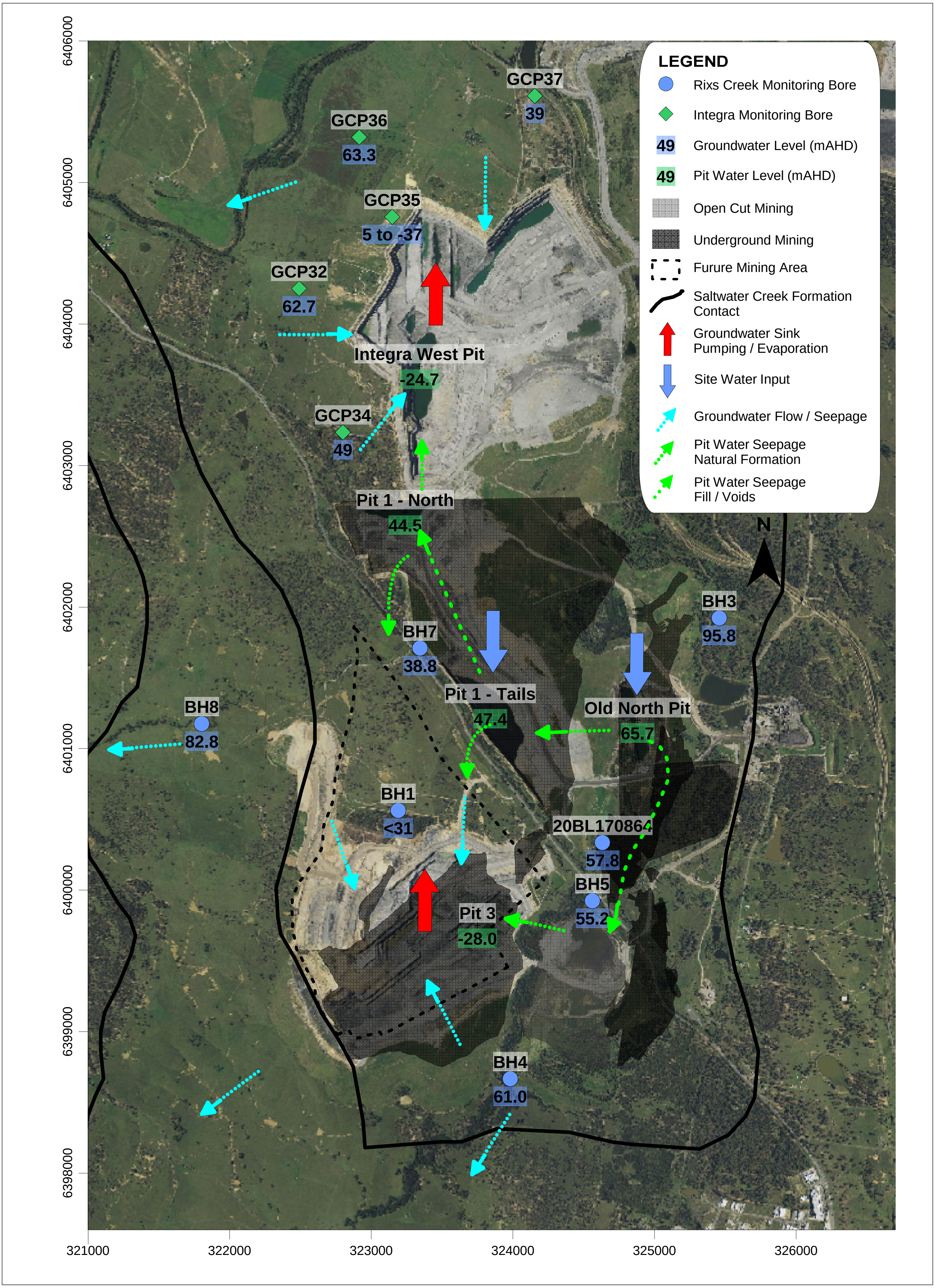

Rixs Creek Indicative Water Levels - December 2015 to January 2016 FIGURE 6

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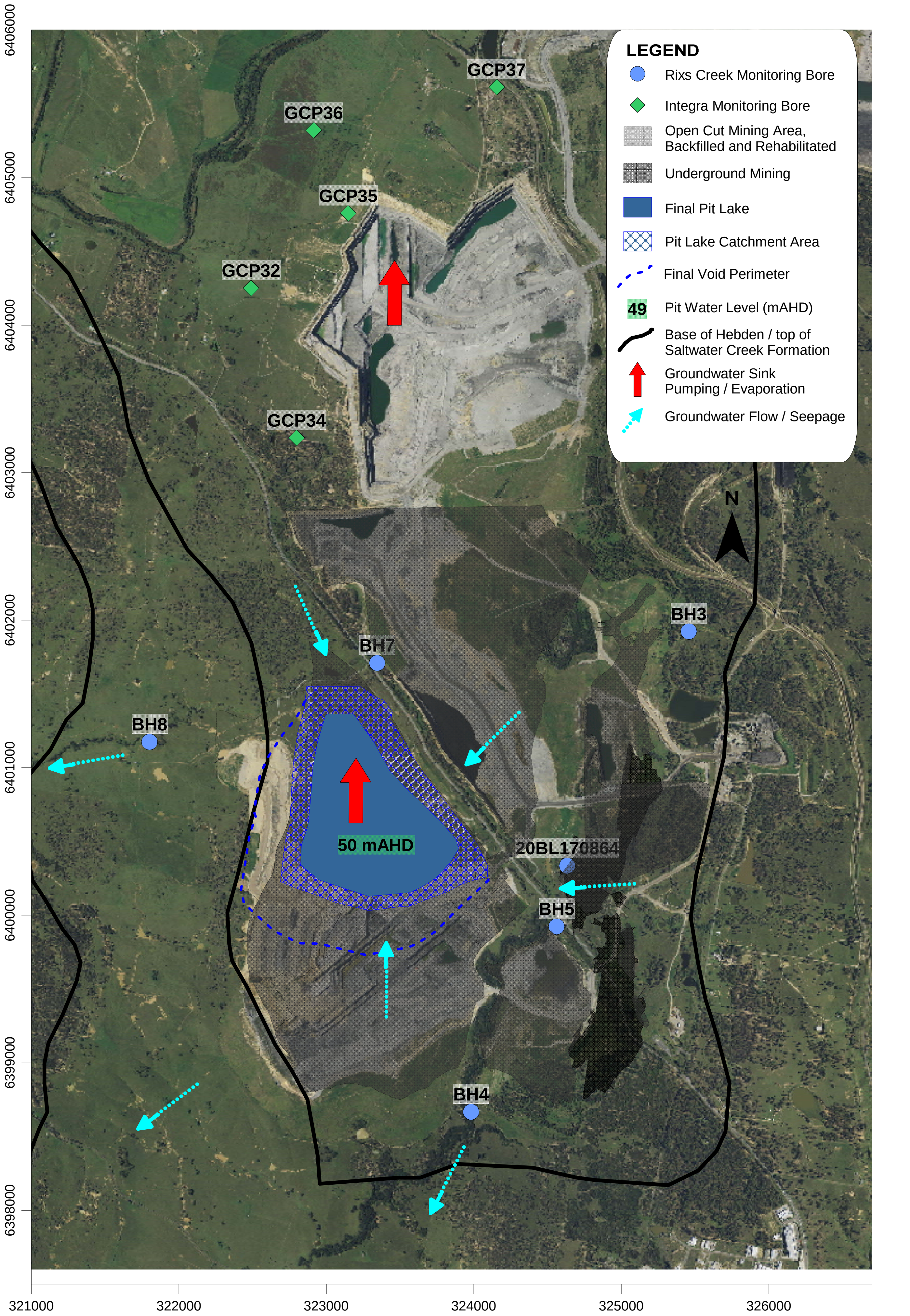
RPS



Rixs Creek Final Void Water Levels FIGURE 7

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APPENDIX A:
GROUNDWATER AND LICENCING ISSUES

Groundwater and Licencing Issues

Summarised from NSW Department of Planning and Environment letter dated 7/12/15, Reference OUT15/34461.

Rix's Creek Mine Extension Project (SSD_6300), Response to exhibition of Environmental Impact Statement

Table 11: Main Letter

Issues	Response	Outcomes from Site Meeting – 21/01/16 (RPS)
• As required under the Aquifer Interference Policy (AIP), an independent review of the groundwater model is required to ascertain in the expert's opinion if the groundwater model is: o Calibrated against suitable baseline data, and in the case of a reliable water source, over at least two years; o Consistent with the Australian Modelling Guidelines; and o Independently reviewed, robust and reliable, and deemed fit for purpose.	reviewed by Peter Dundon We have marked up review notes – not sure if it is marked up by Peter or a final version is available?	Review by Peter Dundon to be finalized and supplied.
• A number of data & information gaps are noted in attachment A, and these are requested to be addressed prior to preparation of the Water Management Plan. This information should be provided within (or attached to) the Water Management Plan.	see below…	

Table 12: Attachment A

Issues	Response	Outcomes from Site Meeting – 21/01/16 (RPS)	Additional Information
1. There is uncertainty about how groundwater is hydraulically connected between the various pits and underground workings. Specifically it is not understood via which aquifers (or via weathering, fracturing or faults) and which part of the old underground mine workings, groundwater is flowing. There is therefore uncertainty as to how groundwater will behave during: a. Pit 3 expansion and attainment of final void depth b. rehabilitation by filling of mine voids c. once mining ceases and re-equilibration occurs.	Old North Pit storage is in hydraulic connection with U/G assumed by subsidence induced fracturing through to Liddell Seam. Old north pit appears to be the main point of recharge to the U/G working although some connective cracking to	RPS to prepare and supply schematic diagrams and sections illustrating pit and monitoring bore water levels and inferred groundwater dynamics – current and post mining scenarios.	Refer to supplementary groundwater information.

Issues	Response	Outcomes from Site Meeting – 21/01/16 (RPS)	Additional Information
	surface may be indicated? When rehabilitated will limit recharge. Pit 2 mined adjacent to the U/G working in the Barrett seam and is in direct hydraulic connection via Barrett seam– although now backfilled. Pit 1 and Pit 3 have no direct hydraulic connection with U/G.		
2. Further clarification and details should be provided as to how underground dewatering of the underground works (via a single production bore screened over all aquifers) and maintenance of the water level in the North Pit at 78m AHD, results in no seepage into Pit 2 from the underground workings.	U/G workings were not "dewatered" – rather the head was reduced such that seepage to Pit 2 via the Barrett seam was reduced. The maintenance of heads in the Old North Pit to below 78mAHD is a management measure to limit surface expression of seepage, not seepage to Pit 2, which is now infilled.	as above – incorporate into schematic representation and highlight basin effect of siltstone basement.	Refer to supplementary groundwater information
3. The proponent has stated that: "the Permian coal measures form confining aquifers at the end of mining" It is not fully understood what the Proponent means by this as it was not described. It should be clarified if all aquifers on site would be unconfined due to the final void depth causing all confined aquifers on site to drain, despite infilling, and if they are suggesting this will be a permanent situation.	Appears to be a misunderstanding… Closest match found is from Table 9.1 "The Permian Coal Measures aquifer at the end of mining is not a confined aquifer inside/outside of the proposed Project Applicable Area boundary."	Clarified during meeting – no further action required.	

Issues	Response	Outcomes from Site Meeting – 21/01/16 (RPS)	Additional Information
	The project is within a syncline. All the formations within the syncline outcrop laterally or down gradient outside the project boundary, and are therefore unconfined at the point of outcrop / subcrop.		
4. The Proponent should improve the description of the aquifers and aquicludes on site according to the detailed stratigraphy. The Proponent tends to combine all groundwater into a two aquifer conceptual description of either Alluvials or consolidated Permian rock coal seam aquifers The Proponent does not consider multiple, confined water levels in their conceptual model. This is despite providing evidence for a multiple aquifer and aquiclude conceptualisation with confinement that is not restricted exclusively to the coal seam aquifers within the Permian rocks.	That multiple aquifers are present at site is implicit in the model layering that includes a dedicated layer for each of the main seams and interburdens. Refer Table 8.2. Calibrated hydraulic conductivities also clearly represent a layered aquifer system – Table 8.10. Section 4.6.2 discusses that fact that within the Permian strata, the coal seams are the main aquifers with permeabilities elevated with respect to hard rock strata.	Improved discussion/descriptions to be provided. Discussion and references as to low permeability nature of basement lithologies.	Refer to supplementary groundwater information
5. The proponent provided borehole log information for only 5 monitoring bores (1 bore has since been destroyed by mining). There are other bores on site and during model calibration other sites were calibrated against, but these were not described nor were their spatial locations provided. Further detail should be provided.	At the time of writing only the five monitoring bores and the production bore existed on site. Two additional monitoring bores have subsequently been installed. Other calibration points comprised a collection	Bore logs of BH7 and BH8 to be provided.	Refer to supplementary groundwater information rainfall recharge was applied over the entire catchment.

Issues	Response	Outcomes from Site Meeting – 21/01/16 (RPS)	Additional Information
	of monitoring data from surrounding mines – it is noted that some of these were obtained from AEMR data. In most cases the data do not provided good calibration results. Maps can be provided.		
6. In general for a site of such complexity, additional groundwater monitoring bore sites are recommended. Information should be provided about temporal monitoring of pit water levels. Further information on water quality monitoring from the site, and analysis for organic water chemistry should be provided to form a baseline standard.	In consultation with DPI Water – two additional monitoring bores have been installed.	Consider additional bore to the south of the site. Depending on site access bore will ideally target potential structure associated with faulting of synclinal axis. Notional depth 30 to 50m to be confirmed with ground conditions. Paired bore with BH4?	Propose to install bore in basement low, and syncline axis, as defined by base of Hebden surface – coincides with location of BH4
7. The proponent in their report refers to the discharge of unknown volumes of tailings water to the south. This information cannot be considered to be insignificant if it provides uncertainty to the site water balance and the discharge is towards the Rix's Creek Alluvials or Hunter River, and should be considered in greater detail in the Water Management Plan and site water balance: "The tailings dam embankments comprise undisturbed ground to the north, east and west and uncompacted mine spoil to the south. The mine spoil does allow some seepage to the south, which is unmeasured and hence a source of uncertainty to the site water balance."	JP?	Clarified during meeting – this is an historical issue that has been remediated by the rehabilitation of Pit 2 TSF - no further action required.	
Comments on Modelling			
1. Many of the report conclusions and outputs were based on the modelling outputs and not on real field derived data. The vast majority of the modelling output figures, including contour maps, hydraulic conductivity maps, drawdown impact maps and calibration hydrographs were illegible and could not be used in the review. No units were provided for hydraulic conductivity maps and a table.	Unsure re this initial sentence as the report conclusions are of predicted impacts from a future mine and can only be based on model output or hydrogeological assessment.	Clearer figures will be provided.	Refer to supplementary groundwater information

Issues	Response	Outcomes from Site Meeting – 21/01/16 (RPS)	Additional Information
	Agreed – output figures are poorly presented and units are missing.		
2. The model was not calibrated. A scaled root mean squared error (SRMS) of 16% was achieved. The Australian Groundwater Modelling Guideline recommends ~10%. The calibration hydrographs were not legible so no analysis of the calibration was performed by DPI Water.	The model is calibrated and has an SRMS error of 16% as reported. This could have been improved by "disregarding" unfavorable calibration points that skew the results, however it was decide to keep in all available data. It should also be noted that by only utilizing data points within the syncline the calibration statistics would also have been improved. Mismatches in predicted versus observed values are typically the result of other locailised stresses that are not included in the model. Agreed hydrographs are not clearly presented. Aside from the SRMS the model water balance was sound and provided reasonable results. For the potential risks posed by the development the calibration was deemed to be sufficient.	Provide calibration statistics for local monitoring points only to eliminate unknown regional stresses. Previous version of model with closer boundaries had a calibration of 9.6% SRMS.	Refer to supplementary groundwater information

Issues	Response	Outcomes from Site Meeting – 21/01/16 (RPS)	Additional Information
3. The model was not independently peer reviewed prior to submission. A review should be required, along with implementation of any findings of the reviewer through revised modelling and incorporation within the Water Management Plan, prior to commencement of the project.	Review by Peter Dundon	Review by Peter Dundon to be finalized and supplied.	
4. The method for calculating recharge relied on several assumptions in creating an artificial average rainfall dataset. A multiplication factor was applied to the rainfall datasets and it is uncertain what the resulting data set represents. The multiplication factor was not justified with a description of whether it was accounting for overland flow, transpiration or error in the spatial and temporal rainfall datasets. Further consideration is requested in the Water Management Plan.	The rainfall data used in the predictions is an actual rainfall data set, from 1973 to 1994, representing the median rainfall over a 24 year period out of a 128 year record. Some months were missing and were patched with the median monthly value from the whole data set. This does not compromise the integrity of the data. The multiplication factors are recharge as a percentage of total rainfall and are applied as a net flux to the top of the model. This is a standard method of applying rainfall recharge.	Clarified during meeting – no further action required.	
5. The method for calculating evaporation should be further justified or refined. A Pan Factor was applied to the top layer of the model but no justification for doing so or for applying certain values was provided. Pan evaporation rates applied, to the top layer of the model are usually only justified if constrained to be within the top 10 cm of the model. Evaporation decreases highly non-linearly with depth to evaporation extinction depth. “Evaporation was incorporated into the model using the EVT module and was applied to Top Layer only. The evaporation rate (Class A Pan) was obtained from long-term monthly average of the	I don’t believe this is anything out of the ordinary	RPS to check and review final void calculations to see if catchment area is incorporated. Rix’s to consider potential for installing Class A Pan.	The catchment area of the final void was incorporated into the final void assessment. The assessment was conservative in that 100%

Issues	Response	Outcomes from Site Meeting – 21/01/16 (RPS)	Additional Information
BOM Station Scone SCS (No. 061089) with a Pan Factor of 50% across the model domain. An exception was during the recovery simulation where the Pan A Factor was set at 70% over the extent of the final void.”			
6. There is uncertainty if the adopted parameters for Van Genuchten’s and Brooks-Corey are representative for the soils found on site and there is little detail about the how these equations were applied within the model, and this should be considered further.	I believe this is getting a little into the realm of academia and away from practical modelling. VG should be a suitable approximation for unsaturated flow. The parameters applied should represent desaturation behaviour approximately halfway between a ‘clay-like’ material and a free-draining ‘sand-like’ material.	Clarified during meeting – no further action required.	
7. A general head boundary condition was applied to layers 3 and 4 of the model based on a linear extrapolation from bore GW080963. A conductance of 100 m3/day was applied to this fixed head. This feature provides an infinite supply of water into the model and it is uncertain whether this approximation is hydrogeologically justifiable in representing the long-term impact of mining activity in the south-west corner of the model domain. The effects that the feature may have on the model domain in maintaining water level elevations is unknown without inspection of the model.	The boundary is far enough from the project that it should not unduly influence model results – it is also located on the far side of the Hunter River. Model layers 3 and 4 are also not continuous (as hydrostratigraphic units) between the boundary and the project area. Drawdown in the Hebden Seam (Fig 8.19.6) are shown to attenuate at the syncline margin and do not approach the model boundary to the south	Check sensitivity in model by re-running with boundary switched off.	The presence or not of the General Head Boundary was found to have no observable impact on water levels at site and would not constrain the propagation of any associated impacts. Also refer to supplementary groundwater information JB

Issues	Response	Outcomes from Site Meeting – 21/01/16 (RPS)	Additional Information
	west.		
8. The calibration dataset type should be better described and it is unclear where the calibration points are situated as no legible map has been provided.	agreed	Provide map and description of calibration dataset.	Refer to supplementary groundwater information
9. The monthly stress periods that were adopted in the model overly simplify the complexity inherent in groundwater/surface water modelling and it is more usual for the daily time step to be utilised which has a stabilising effect on the model.	A monthly stress period for an impact assessment for 24 year mine plan is considered suitable. Key stresses in the model are mine progression and seasonal recharge, there is no necessity for a finer than monthly stress period.	Clarified during meeting – no further action required.	
10. In Section 8.7.3 it was stated that, the model predicted inflow to pits, was calibrated against unmeasured, anecdotal observations. It is uncertain how this can be used to justify calibration.	This is validating the calibration results. The calibrated inflows were low as were the historic inflows, there were no large (order of magnitude) discrepancies, and therefore for practical purposes, the results were considered to be reasonable.	Clarified during meeting – no further action required.	
11. It is recommended that the reviewer consider given the current model calibration how meaningful the results, reporting groundwater contribution to Rix's Creek, are.	The results are considered to be reasonable and in all likelihood conservative.	Review by Peter Dundon to be finalized and supplied.	
12. An uncertainty analysis was performed by using the 10th percentile and 90th percentile of the rainfall applied over a 24 year dry period and another 24 year wet period. It is uncertain how relevant an analysis of uncertainty this provides given that: a. the fixed head applied in the model has not been hydrogeologically justified. b. recharge and evaporation have not been represented in a physically meaningful manner and applied at monthly time	The uncertainty analysis approach is sound and represents realistic upper and lower bounding rainfall (and therefore recharge) conditions.	Model sensitivity to fixed heads will be assessed by re-running with boundary switched off. Other issues clarified during meeting – no further action required.	no action already covered

Issues	Response	Outcomes from Site Meeting – 21/01/16 (RPS)	Additional Information
steps with both these values temporally and spatially averaged over the 24 year periods. c. a multiplication factor that minimises the impact of rainfall has been applied, and d. the model is poorly calibrated to only a few bores.	a. The fixed head has been shown not to influence model predictions in the project area. b. Recharge and evaporation have been applied at monthly time steps – they have not been averaged over 24 years. A representative 24 year monthly data set has been used. c. Rainfall recharge factors applied are consistent with other studies in the area – ie between 1% and 4% of rainfall. d. -		
13. There is uncertainty why the model experiences such instantaneous, rapid increases and declines in inflows into the pits as shown in Figures 8.11; 8-16 and 9.1 and discussed in Sections 8.7.3; 8.8.2 and 9.2.1 respectively. Clarification is sought from the proponent to show that these artefacts are indeed related to the progressive implementation of the mine plan, pit development and back filling and are not related to model instability.	It is confirmed that the step-wise inflows (fluxes) are the product of progressive implementation of the mine plan and are not the result of model instability.	Clarified during meeting – no further action required.	
14. In regard to figures 8.19.5 and 8.19.6. These are the only legible drawdown figures, which depict drawdown in the Hebden seam, presumably confined, as this seam is the lowest stratigraphically elevated coal seam aquifer. However in Section 8.8.2 - Prediction Results, the text describes this drawdown as being in the uppermost water table and does not refer to the Hebden seam whatsoever. Clarification should be provided by the proponent.		Review and provide correct figures if required.	Refer to supplementary groundwater information

Issues	Response	Outcomes from Site Meeting – 21/01/16 (RPS)	Additional Information
15. Again in regard to figures 8.19.5 and 8.19.6. Clarification of uncertainty is sought regarding the shape of the drawdown contours. There is uncertainty about whether the steep contours observed on the western side of the Hebden seam drawdown figure are simply not an artefact of the applied fixed head boundary condition. If this is the case than the 2 m drawdown contour could extend past the boundary of the mine site and could impact on the assessment against the NSW Aquifer Interference Policy if the fixed head was removed. "From Figure 8.19, the predicted decline in the uppermost water table is more than 50 m within the active mining area. However, at the boundary of the site the predicted decline in the uppermost water table is less than 2 m the site at all extracted time stamps."	It should be noted that Figures 8.19.5 and 8.19.6 are zoomed in on the project area and do not show the project boundaries. The concentration of contours is a result of the discontinuity of the strata as they outcrop on the steeper western limb of the syncline.	Clarified during meeting – no further action required.	
16. Table 8.15 and Table 8.16 refer to the, "prediction model", "null case" (no extension to Pit 3) and the "cumulative impact null case" (no Mine) models. It is not clear what constitutes the prediction model and how it differs to the other two models.	The prediction model includes the existing mine, the Pit 3 extension, associate backfilling of voids, and surrounding mines. The null case is the same model but without the stresses associated with Pit 3 extension and progressive backfilling – i.e. mining ends at the end of the current mine plan. The cumulative impact null case assumes no mine development at Rixs Creek. The various models, particularly the prediction model and the null case, are required to determine potential impacts that are attributable to the Pit 3 extension and the continuation of mining.	Clarified during meeting – no further action required.	

Issues	Response	Outcomes from Site Meeting – 21/01/16 (RPS)	Additional Information
Comment on off-site impacts			
1. In the discussion on inflows into Integra pits as a result of Rix's Creek operations it is stated: "From Table 8.16, the predicted difference to inflows at Integra due to continuation of Rix's Creek Colliery is negligible. The explanation of this finding is due to the hydrogeological divide between the two sites" It is unclear why the Proponent suggests that such a divide exists and clarification is sought utilising real field data. Furthermore in Section 4.6.2 Local Hydrogeology it was stated that: "The Integra Mine is extracting coal measures within the Rix's Creek syncline and represents significant dewatering of the coal measures up hydraulic gradient of the Project. This operation is considered to create a groundwater sink for the majority of the southerly trending groundwater within the coal measures". However the cross-section provided (Figure 3) shows coal seam aquifers dipping towards the south. It would be expected however that if impermeable layers are present as overburden between the coal seam aquifers, that groundwater would continue to flow towards the south, down dip, against an impermeable base. Clarification is therefore sought regarding the location of the groundwater divide.	The existing Camberwell Mine and Pit 1 will have largely depressurized the intervening formations with the development of a hydraulic groundwater divide between the two pits, with each Pit acting as a groundwater sink. Camberwell is also up-dip and up hydraulic gradient, and as such the majority of inflows will be derived from the upgradient formations. The development of the project downgradient will therefore have little impact on the inflows to the Integra mine.	To be incorporated and illustrated in the schematic diagrams and sections.	Refer to supplementary groundwater information
2. Further detail should be provided of the impacts to or by "Surrounding developments with potential to impact on the hydrogeological system within the study area are depicted in Figure 1.1, and include: • Integra South Pit and its Western Extension. This development is located immediately to the north of Pit 1. The Integra Pit accesses coal from the Pikes Gully to Upper Hebden Seams • The Ashton Coal Underground Mine. Located to the north-west of the mine and on the eastern side of Glennies Creek • Ashton access coal from the Pikes Gully to Lower Barrett Seam."	Basically nil impacts to or by other mines with the exception of Integra which is discussed.	Integra Pit now owned by Bloomfield. – no action required at present. An integrated water management plan incorporating the two sites will be developed.	
Recommendations for addressing Groundwater Issues			

Issues	Response	Outcomes from Site Meeting – 21/01/16 (RPS)	Additional Information
With regard to the AIP 'minimal impact considerations', the following is recommended: • A number of data limitations were identified with the model leading to concerns with robustness of the model predictions for water take. An independent model review as required under the AIP was not submitted. The model has not yet been deemed 'fit for purpose' and warrants further improvements for a project of this size. • Proponent to provide a site water balance for the entire site that includes the detailed hydrogeology, creeks and pits and accounts for the partitioning of rainfall into recharge, evapotranspiration and overland flow. • The proponent to provide estimates of water flows into each of the pits post 2038 from individual water sources and account for ongoing evaporative losses. • It is recommended that proper aquifer pump testing (not slug tests or rising head tests) of sufficient duration and that include monitoring at nearby bores, be conducted in each individual aquifer in order to confirm the hydrogeology.	• I think the limitations have generally been addressed above. • Further permeability (pump) testing is not warranted, particularly by each individual aquifer	Final review will be undertaken. Site water balance studies are being undertaken. Additional schematic diagrams and section will show notional water movements. Permeability testing to be undertaken on future monitoring bores.	
With regard to aquifer conceptualisation, the following is recommended: • Provide a hydrogeological conceptual model as a series of surfaces and including sufficient legible hydrogeological cross-sections showing all the pit, top and bottom elevations and water levels and include the underground mine workings, to understand groundwater flow at the site. Provide details about changes to the flow regime as the mine plan progresses and hydraulic gradients change. • Provide a detailed hydrogeological description of each individual aquiclude and aquifer on site that is aligned with the known detailed geological stratigraphy. • Supplement the monitoring network by drilling additional nested bores (with site supervision and logging by a suitably qualified and experienced professional hydrogeologist), between the pits to various depths, to understand the groundwater flow within each individual aquifer of the multiple aquifer system:	• Installing nested bores at 8 separate locations is not warranted, specifically given the contained and relatively simple hydrogeology. • Dewatering/depressurization responses with various layer may be academically of interest but not pragmatically useful for the impact assessment or mine operations.	Conceptual hydrogeological model will be addressed as additional schematic diagrams and section. Discussion of aquifers/aquitards will be provided including anecdotal evidence of inflows related to coal seams. Clarified during meeting – suggested monitoring network not required. Noting new piezometer to be installed south of site. Schematic diagrams and sections will be provided. Logs for BH7 and BH8 will be provided.	The conceptual hydrogeology has been explained in detail in the supplementary groundwater information. The conceptual hydrogeology has not been provided as a series of surfaces, as this is not considered to be consistent with, or convey, the key hydrogeological concept of the project area.

Issues	Response	Outcomes from Site Meeting – 21/01/16 (RPS)	Additional Information
o between Camberwell Pit and Pit 1 o between Pit 1 and North Pit o between North Pit and underground workings o between underground workings and Pit 2 o between Pit 2 and Pit 3 o between Pit 3 and Pit 1 o between Pit 3 and North Pit o between Pit 3 and Camberwell Pit The locations of monitoring sites and depths to be discussed with DPI Water. • Provide groundwater contour maps for each of the individual various aquifers. • Provide a detailed bore log for production bore 20BL170864 and all other bore logs from site not provided with the EIS application and including their surveyed spatial coordinates			
With regard to the groundwater model, it is recommended: • The proponent to implement future improvements to the groundwater modelling by incorporating data from future drilling and monitoring of bores. It is recommended that a physics based calculation of the partitioning of rainfall into overland flow, recharge infiltration to the water table and evapotranspiration be performed. Alternate modelling codes could be considered for this purpose. It is recommended that future modelling extends the western and southern boundary of the model to the Hunter River. • That the updated model be submitted to a suitably qualified independent reviewer. • Provide recharge maps showing aquifer outcrop (subcrop) within existing pits to understand how water is expected to move between pits and to inform monitoring bore locations. • Perform quarterly groundwater quality (including organic chemistry) for an initial 12 months and monthly water level monitoring at all monitoring sites (including recommended nested bore sites and all dams and pits plus including underground mine workings). It is	• "It is recommended that future modelling extends the western and southern boundary of the model to the Hunter River." – the Hunter River is already included in the model within the model boundaries	Generally addressed elsewhere. Future model updates will consider retracting the southern and western boundaries to coincide with the Hunter River. Rixs to consider viability of a Class A pan.	

Issues	Response	Outcomes from Site Meeting – 21/01/16 (RPS)	Additional Information
recommended that water level loggers be installed within bores and a single barometric pressure logger to also be installed. • Proponent to install an A Class evaporation pan and rain gauge on site.			

APPENDIX B:
BORELOGS

RPS
Level 9, 17 York St, Sydney, NSW, Australia, 2000
GPO Box 4401, Sydney, NSW, 2001.
Tel: (+61) (02) 8270 8388
Fax: (+61) (02) 8270 8399

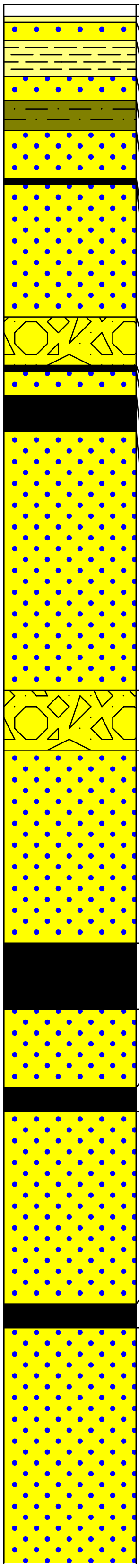
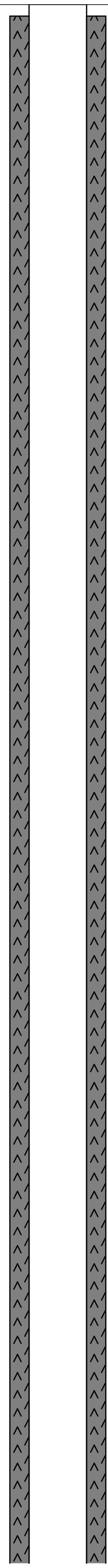
COMPOSITE WELL LOG

Well No: BH7

Client: Bloomfield Colliery Pty Ltd **Project:** S66D

Commenced:	**Method:** Mud Rotary	**Area:** Rixs Creek
Completed:	**Fluid:** Mud	**East:** 323346
Drilled: Lennard Drilling	**Bit Record:** 150mm (0 - 6m)	**North:** 6401706
Logged By: J Fennell	123mm (6 - 228.5m)	**Elevation:**

Drilled Depth: 228.5 mbgl **Static Water Level:** 61.95 mbgl **Date:** 28/08/2015

Depth (mbgl)	Graphic Log	Lithological Description	Field Notes	Well Completion Diagram	Well Completion Notes
0		CLAY			
		SANDSTONE			
		CLAY			
10		SANDSTONE: Interlayed with Mudstone.			Grout to surface
		MUDSTONE			
		SANDSTONE			
20		COAL			
		SANDSTONE: Interlayed with Mudstone, Clay and Siltstone.			
30		CONGLOMERATE			
		COAL			
		SANDSTONE: Interlayed with Mudstone and Siltstone.			
40		COAL: Dull, interlayed with Sandstone, Mudstone and Siltstone.			
50		SANDSTONE: Interlayed with Mudstone and Siltstone.			
60		CONGLOMERATE			
70		SANDSTONE: Interlayed with Siltstone.			
80		COAL: Dull, interlayed with Mudstone and Siltstone.			
		SANDSTONE: Interlayed with Mudstone.			
90		Coal: Dull.			
100		SANDSTONE			50mm blank PVC casing (0 - 150.5m)
		COAL: Dull.			
110		SANDSTONE: Interlayed with Conglomerate and Siltstone.			
120					

RPS

Level 9, 17 York St, Sydney, NSW, Australia, 2000
GPO Box 4401, Sydney, NSW, 2001.
Tel: (+61) (02) 8270 8388
Fax: (+61) (02) 8270 8399

COMPOSITE WELL LOG

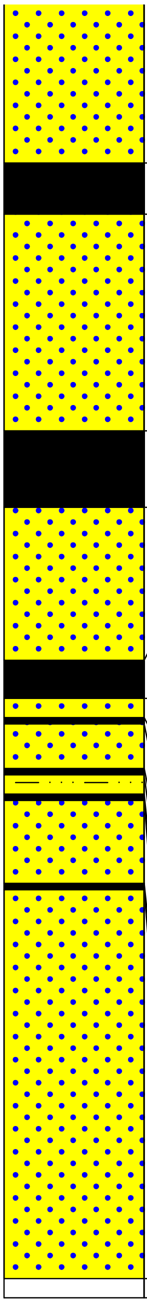
Well No: BH7

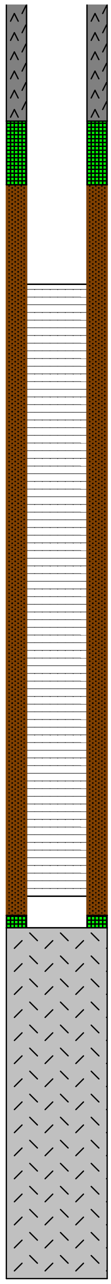
Client: Bloomfield Colliery's Rixs Creek **Project:** S66D

Commenced:	**Method:** Mud Rotary	**Area:** Hunter Valley Coal Fields
Completed:	**Fluid:** Mud	**East:** 0323346
Drilled:	**Bit Record:** 150mm (0 - 6m)	**North:** 6401706
Logged By: Earth Data	123mm (6 - 228.5m)	**Elevation:**

Drilled Depth: 228.5 mbgl **Static Water Level:** **Date:**

Depth (mbgl)	Graphic Log	Lithological Description	Field Notes	Well Completion Diagram	Well Completion Notes
130					
140		COAL: Dull to minor bright.			Bentonite seal (137.7 - 142.7m)
		SANDSTONE: Interlayed with Mudstone and Siltstone.			
150					
160		COAL: Dull, interlayed with Sandstone, Mudstone and Siltstone.			Gravel pack (142.7 - 200m)
170		SANDSTONE: Interlayed with Mudstone and Siltstone.			50mm slotted PVC scren (150.5 - 198.5m)
180		COAL: Dull, interlayed with Sandstone, Mudstone and Siltstone.			
		SANDSTONE: Interlayed with Siltstone.			
		COAL: Dull.			
190		SANDSTONE			
		COAL: Dull.			
		SILTSTONE			50mm PVC sump with 50mm end cap (198.5 - 201m)
200		COAL: Dull.			Bentonite seal (201 - 202m)
		SANDSTONE: Interlayed with Conglomerate.			
		COAL: Dull.			
210		SANDSTONE: Interlayed with Siltstone and Conglomerate.			Backfill (202 - 228.5m)
220					
230					





COMPOSITE WELL LOG

Well No: BH8

RPS

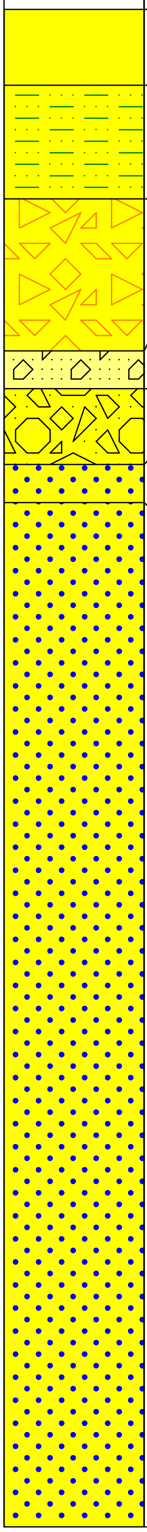
Level 9, 17 York St, Sydney, NSW, Australia, 2000
GPO Box 4401, Sydney, NSW, 2001.
Tel: (+61) (02) 8270 8388
Fax: (+61) (02) 8270 8399

Client: Bloomfield Collieries Pty Ltd **Project:** S66D

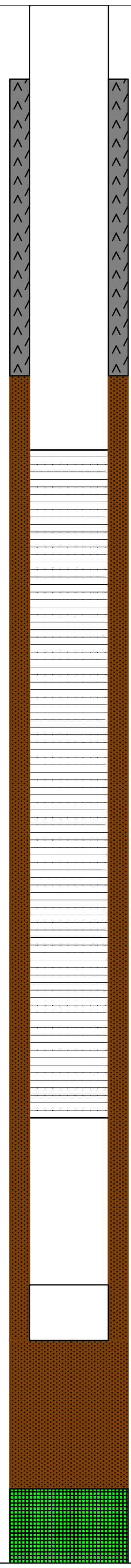
Commenced:	**Method:** Mud Rotary	**Area:** Rixs Creek
Completed:	**Fluid:** Mud	**East:** 323351
Drilled: Lennard Drilling	**Bit Record:** 150mm (0 - 3m)	**North:** 6401715
Logged By: J Fennell	123mm (3 - 19.89m)	**Elevation:**

Drilled Depth: 19.89 mbgl **Static Water Level:** 2.53 mbgl **Date:** 28/08/2015

Depth (mbgl)	Graphic Log	Lithological Description	Field Notes
0		CLAYEY SILT: Brown.	
		CLAYEY SAND: Brown grey, moderate fine to medium grained sand with minor weak clay.	
		GRAVELLY CLAY: Light brown, weak to moderate plasticity, sandy, gravel increasing with depth.	
		GRAVELLY SAND: Light brown, gravel becoming finer with depth, minor silt.	
5		SANDY GRAVEL: Brown, moderate fine to medium grained sand, moderate weak clay.	
		SANDSTONE: Blue grey, moderately weathered, fine to medium grained, competent.	
		SANDSTONE: Blue grey, fresh, fine to medium grained.	
10			
15			
20			



Well Completion



Notes

Grout to surface (0 - 4m)

50mm blank PVC casing (0 - 5m)

Gravel pack (4 - 19m)

50mm slotted PVC screen (5 - 14m)

50mm PVC sump (14 - 17m)

50mm PVC end cap

Bentonite seal (19 - 20m)

APPENDIX C:
GROUNDWATER MODELLING

100 Christie Street
St Leonards NSW 2065 Australia
PO Box 164 St Leonards NSW 2065
Australia
T +61 2 9928 2100
F +61 2 9928 2500
www.jacobs.com

23 March 2016

Attention: Greg Sheppard
RPS Australia Asia Pacific Pty Ltd
GPO Box 4401
SYDNEY
NSW 2001

Project Name: Rixs Creek Continuing Operations
Project Number: IA106700

Subject: Hydrogeological Advice on Issues Raised by DPI Water on the Rix's Creek Model

Dear Greg

1. Introduction

We have prepared this letter in accordance with our proposal (503000.PR/002a, dated 18 February 2016) seeking assistance in preparation of response to comments received from DPI Water as part of Adequacy Assessment on the Rix's Creek Continuing Operations Groundwater Impact Assessment, specifically in regard to the Groundwater Model.

This letter has been prepared based on email correspondence received from RPS Australia Asia Pacific Pty Ltd (RPS) (BELL/SHEPPARD, 15 and 18 February 2016) outlining the interim response to DPI Water thusfar.

It is noted that Jacobs Group (Australia) Pty Ltd (Jacobs's) engineer was responsible for preparation of the model whilst an employee at RPS and presented the numerical model calibration and prediction, upon which the Groundwater Impact Assessment is based, directly to DPI Water on 8 September 2014 at their Parramatta offices. The PowerPoint presentation presented on that day is recommended to be provided to DPI Water's modeller, if it was not provided at the time.

In addition, if it is deemed acceptable, the model files could be provided to DPI Water to assist in completion of their assessment, however, given the minor lateral extent of predicted impacts with respect to off-site groundwater impact on other users / operations, providing the model to DPI Water is not considered essential.

2. Proposed Response

2.1 Comments on Modelling by DPI Water

Issue DPI Model 01) Many of the report conclusions and outputs were based on the modelling outputs and not on real field derived data. The vast majority of the modelling output figures, including contour maps, hydraulic conductivity maps, drawdown impact maps and calibration *hydrographs were illegible and could not be used in the review. No units were provided for hydraulic conductivity maps and a table.*

The current Development Consent for Rixs Creek Mine (DA49/94, File No. N90/00356) was granted in October 1995 and it is understood that the mine has been in operation since 1990.

Accordingly, there has been extensive historical experience of groundwater behaviour at the site, during the past 25 years. Continuation of mining operations at the site does not comprise a different approach to groundwater management than has been applied in the past and has been demonstrated in the model output, the expected magnitude of stress to the groundwater system is comparable to that which has been experienced historically. Detailed responses to queries on model calibration and other modelling-related matters are addressed below.

Model figures prepared for the Groundwater Impact Assessment were set to a smaller scale so as to reduce the overall size of the report. It appears that the PDF on the Major Projects NSW website (http://majorprojects.planning.nsw.gov.au/index.pl?action=view_job&job_id=6300), however, has been subject to a File Size Reduction process. We apologise for the inconvenience and the original PDF should have been provided to DPI Water for their review. A full set of figures, in their original quality, is recommended to be provided to DPI Water as an attachment to this letter.

The location of model calibration targets is presented in Figure 8.14.6 to 8.14.8 of RPS (2014) with respect to each layer. **Figure 1** below presents the same information, however, with all targets local to the site, presented on a single figure, regardless of which model layer they reside in. It is highlighted that the scale of the model domain is large so as to account for potential cumulative impact from the adjacent mining operations to the north, northwest and far southwest as well as the Hunter River.

Hydrographs of local calibration points are provided in **Figure 2** and are replicates of the hydrographs presented in Appendix A of RPS (2014).

Reproduction of hydraulic conductivity distribution plots was not considered necessary as it is assumed a full set of figures will be provided to DPI Water and these will be legible. Figures submitted for the public exhibition phase will be at full original quality.

Issue DPI Model 02) The model was not calibrated. A scaled root mean squared error (SRMS) of 16% was achieved. The Australian Groundwater Modelling Guideline recommends ~10%. The calibration hydrographs were not legible so no analysis of the calibration was performed by DPI Water.

As discussed in the response to Query Model 01, it appears that the PDF on the Major Projects NSW website has been subject to File Size Reduction. Whilst not the responsibility of DPI Water, this matter could have been rectified if it had been raised.

The Australian Groundwater Modelling Guidelines (Barnett et. al., 2012) does not recommend that a 10% SRMS is used to define whether a model is calibrated or otherwise. As stated in RPS (2014), an SRMS of ~10% is an indicator of adequate calibration and Barnett et. al. (2012) go to significant length to explain that calibration is more complex than just SRMS. The relevant section from Barnett et. al. (2012) is replicated below in **Figure 3**.

Further discussion of the basis for evaluating calibration is presented in the Companion to the Guidelines for the Australian Groundwater Modelling Guidelines (SKM, 2013). The relevant section is replicated below in **Figure 4**.

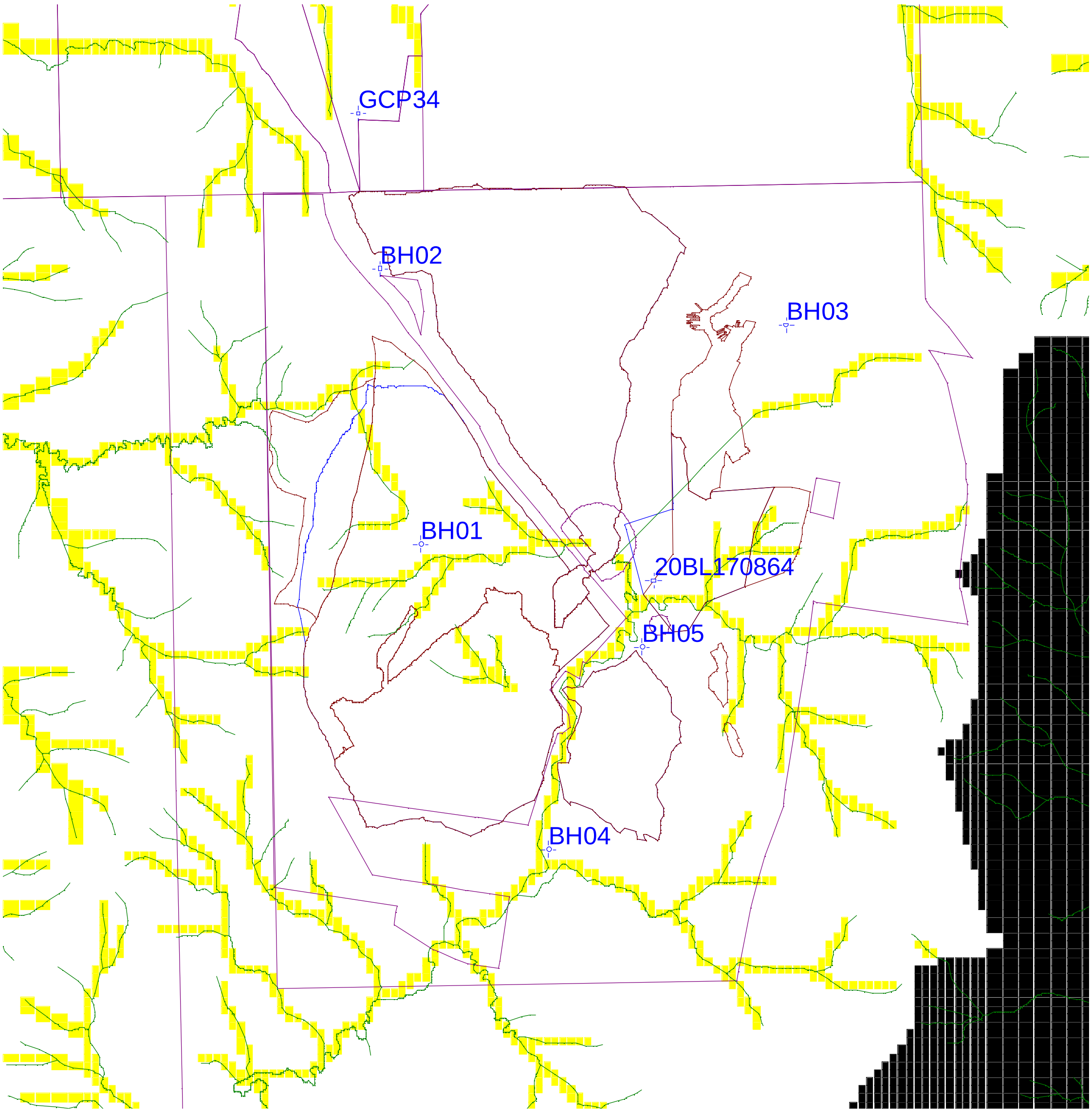


Figure 1 : Location of Calibration Targets (Local to Site)

23 March 2016

Subject: Hydrogeological Advice on Issues Raised by DPI Water on the Rix's Creek Model

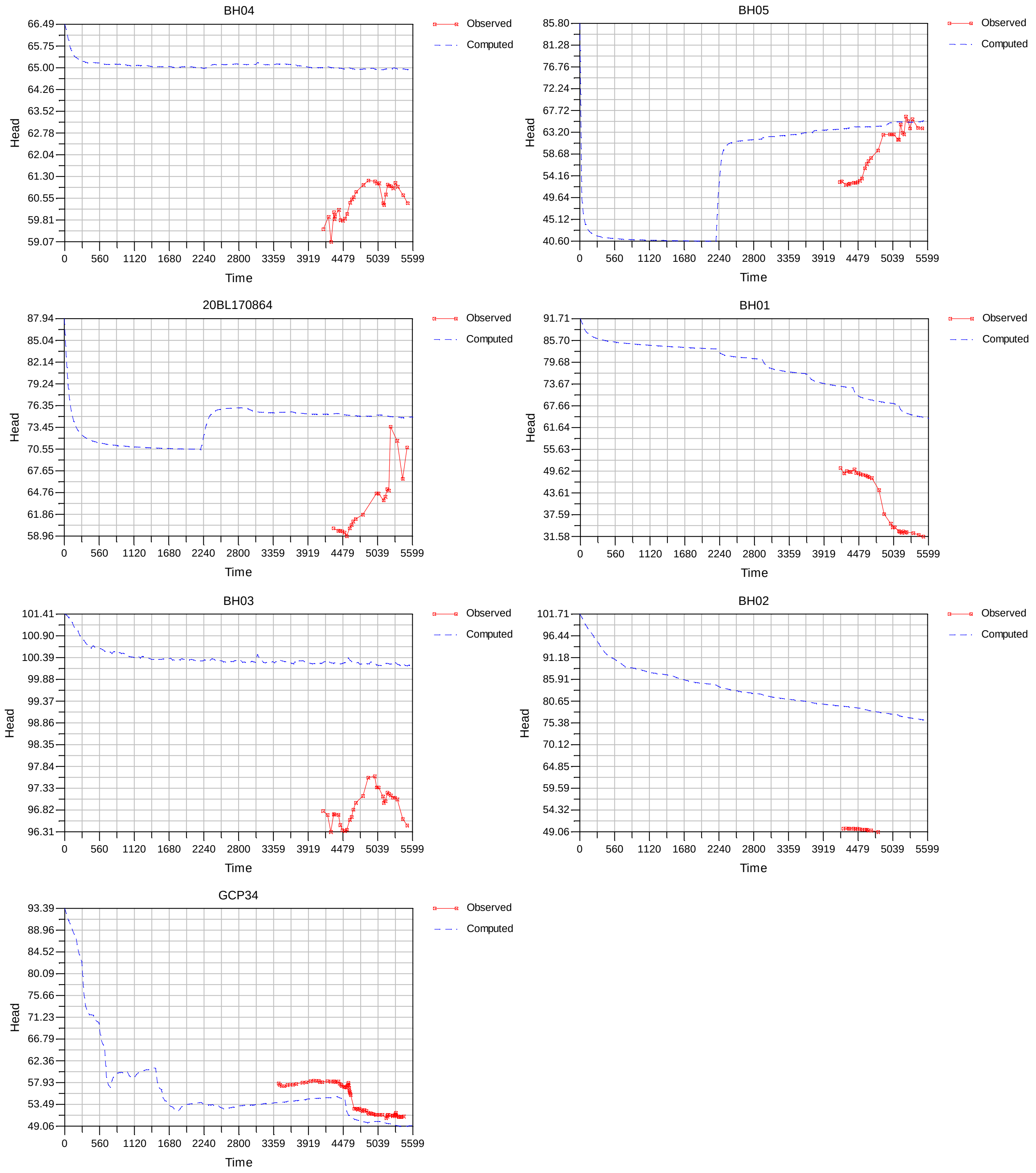
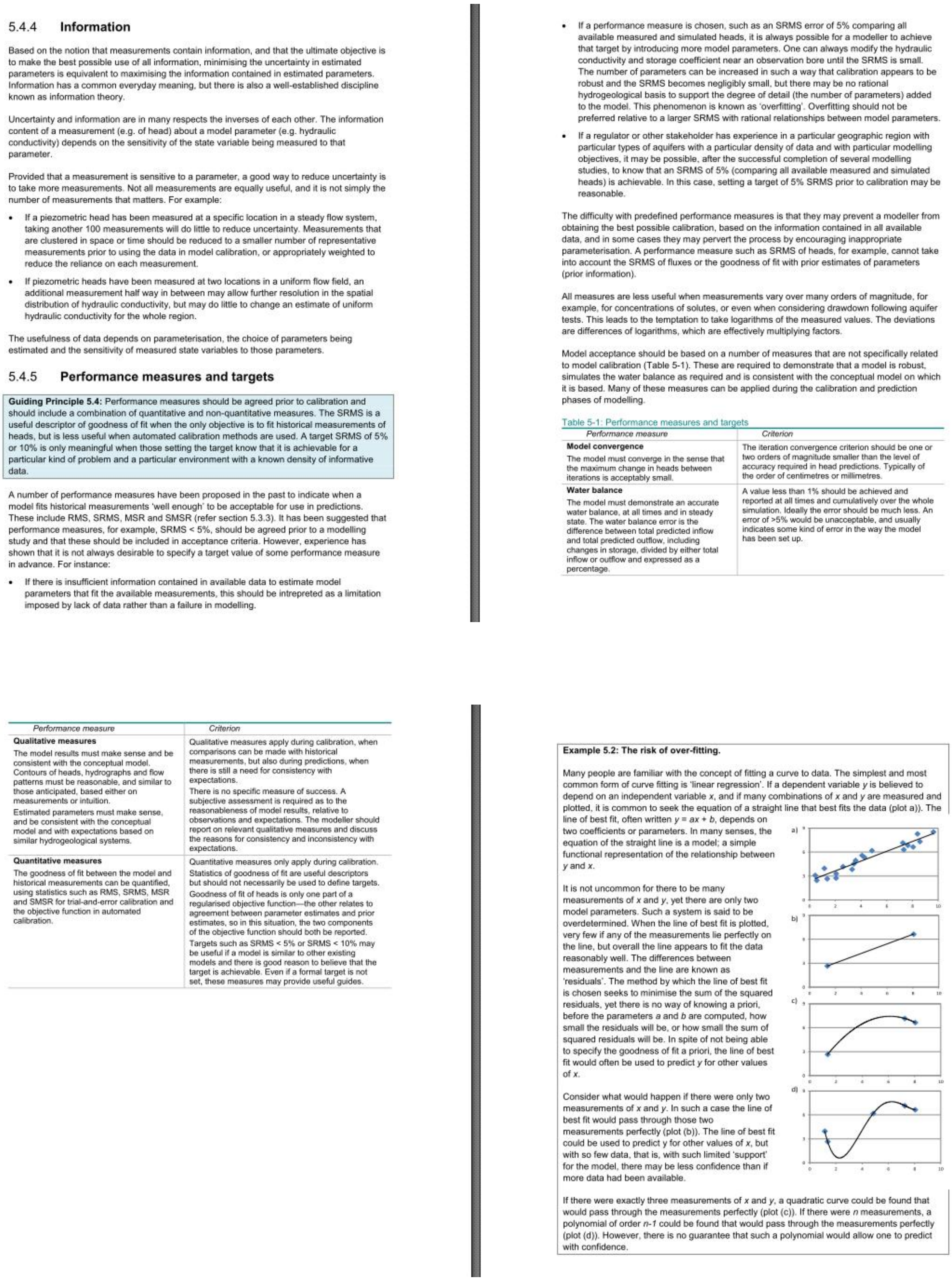


Figure 2 : Hydrographs of Calibration Targets (Local to Site)



5.4.4 **Information**

Based on the notion that measurements contain information, and that the ultimate objective is to make the best possible use of all information, minimising the uncertainty in estimated parameters is equivalent to maximising the information contained in estimated parameters. Information has a common everyday meaning, but there is also a well-established discipline known as information theory.

Uncertainty and information are in many respects the inverses of each other. The information content of a measurement (e.g. of head) about a model parameter (e.g. hydraulic conductivity) depends on the sensitivity of the state variable being measured to that parameter.

Provided that a measurement is sensitive to a parameter, a good way to reduce uncertainty is to take more measurements. Not all measurements are equally useful, and it is not simply the number of measurements that matters. For example:

- If a piezometric head has been measured at a specific location in a steady flow system, taking another 100 measurements will do little to reduce uncertainty. Measurements that are clustered in space or time should be reduced to a smaller number of representative measurements prior to using the data in model calibration, or appropriately weighted to reduce the reliance on each measurement.
- If piezometric heads have been measured at two locations in a uniform flow field, an additional measurement half way in between may allow further resolution in the spatial distribution of hydraulic conductivity, but may do little to change an estimate of uniform hydraulic conductivity for the whole region.

The usefulness of data depends on parameterisation, the choice of parameters being estimated and the sensitivity of measured state variables to those parameters.

5.4.5 **Performance measures and targets**

Guiding Principle 5.4: Performance measures should be agreed prior to calibration and should include a combination of quantitative and non-quantitative measures. The SRMS is a useful descriptor of goodness of fit when the only objective is to fit historical measurements of heads, but is less useful when automated calibration methods are used. A target SRMS of 5% or 10% is only meaningful when those setting the target know that it is achievable for a particular kind of problem and a particular environment with a known density of informative data.

A number of performance measures have been proposed in the past to indicate when a model fits historical measurements 'well enough' to be acceptable for use in predictions. These include RMS, SRMS, MSR and SMSR (refer section 5.3.3). It has been suggested that performance measures, for example, SRMS < 5%, should be agreed prior to a modelling study and that these should be included in acceptance criteria. However, experience has shown that it is not always desirable to specify a target value of some performance measure in advance. For instance:

- If there is insufficient information contained in available data to estimate model parameters that fit the available measurements, this should be intrepreted as a limitation imposed by lack of data rather than a failure in modelling.
- If a performance measure is chosen, such as an SRMS error of 5% comparing all available measured and simulated heads, it is always possible for a modeller to achieve that target by introducing more model parameters. One can always modify the hydraulic conductivity and storage coefficient near an observation bore until the SRMS is small. The number of parameters can be increased in such a way that calibration appears to be robust and the SRMS becomes negligibly small, but there may be no rational hydrogeological basis to support the degree of detail (the number of parameters) added to the model. This phenomenon is known as 'overfitting'. Overfitting should not be preferred relative to a larger SRMS with rational relationships between model parameters.
- If a regulator or other stakeholder has experience in a particular geographic region with particular types of aquifers with a particular density of data and with particular modelling objectives, it may be possible, after the successful completion of several modelling studies, to know that an SRMS of 5% (comparing all available measured and simulated heads) is achievable. In this case, setting a target of 5% SRMS prior to calibration may be reasonable.

The difficulty with predefined performance measures is that they may prevent a modeller from obtaining the best possible calibration, based on the information contained in all available data, and in some cases they may pervert the process by encouraging inappropriate parameterisation. A performance measure such as SRMS of heads, for example, cannot take into account the SRMS of fluxes or the goodness of fit with prior estimates of parameters (prior information).

All measures are less useful when measurements vary over many orders of magnitude, for example, for concentrations of solutes, or even when considering drawdown following aquifer tests. This leads to the temptation to take logarithms of the measured values. The deviations are differences of logarithms, which are effectively multiplying factors.

Model acceptance should be based on a number of measures that are not specifically related to model calibration (Table 5-1). These are required to demonstrate that a model is robust, simulates the water balance as required and is consistent with the conceptual model on which it is based. Many of these measures can be applied during the calibration and prediction phases of modelling.

Table 5-1: Performance measures and targets

Performance measure	*Criterion*
Model convergence The model must converge in the sense that the maximum change in heads between iterations is acceptably small.	The iteration convergence criterion should be one or two orders of magnitude smaller than the level of accuracy required in head predictions. Typically of the order of centimetres or millimetres.
Water balance The model must demonstrate an accurate water balance, at all times and in steady state. The water balance error is the difference between total predicted inflow and total predicted outflow, including changes in storage, divided by either total inflow or outflow and expressed as a percentage.	A value less than 1% should be achieved and reported at all times and cumulatively over the whole simulation. Ideally the error should be much less. An error of >5% would be unacceptable, and usually indicates some kind of error in the way the model has been set up.
Qualitative measures The model results must make sense and be consistent with the conceptual model. Contours of heads, hydrographs and flow patterns must be reasonable, and similar to those anticipated, based either on measurements or intuition. Estimated parameters must make sense, and be consistent with the conceptual model and with expectations based on similar hydrogeological systems.	Qualitative measures apply during calibration, when comparisons can be made with historical measurements, but also during predictions, when there is still a need for consistency with expectations. There is no specific measure of success. A subjective assessment is required as to the reasonableness of model results, relative to observations and expectations. The modeller should report on relevant qualitative measures and discuss the reasons for consistency and inconsistency with expectations.
Quantitative measures The goodness of fit between the model and historical measurements can be quantified, using statistics such as RMS, SRMS, MSR and SMSR for trial-and-error calibration and the objective function in automated calibration.	Quantitative measures only apply during calibration. Statistics of goodness of fit are useful descriptors but should not necessarily be used to define targets. Goodness of fit of heads is only one part of a regularised objective function—the other relates to agreement between parameter estimates and prior estimates, so in this situation, the two components of the objective function should both be reported. Targets such as SRMS < 5% or SRMS < 10% may be useful if a model is similar to other existing models and there is good reason to believe that the target is achievable. Even if a formal target is not set, these measures may provide useful guides.

Example 5.2: The risk of over-fitting.

Many people are familiar with the concept of fitting a curve to data. The simplest and most common form of curve fitting is 'linear regression'. If a dependent variable *y* is believed to depend on an independent variable *x*, and if many combinations of *x* and *y* are measured and plotted, it is common to seek the equation of a straight line that best fits the data (plot a)). The line of best fit, often written $y = ax + b$, depends on two coefficients or parameters. In many senses, the equation of the straight line is a model; a simple functional representation of the relationship between *y* and *x*.

It is not uncommon for there to be many measurements of *x* and *y*, yet there are only two model parameters. Such a system is said to be overdetermined. When the line of best fit is plotted, very few if any of the measurements lie perfectly on the line, but overall the line appears to fit the data reasonably well. The differences between measurements and the line are known as 'residuals'. The method by which the line of best fit is chosen seeks to minimise the sum of the squared residuals, yet there is no way of knowing a priori, before the parameters *a* and *b* are computed, how small the residuals will be, or how small the sum of squared residuals will be. In spite of not being able to specify the goodness of fit a priori, the line of best fit would often be used to predict *y* for other values of *x*.

Consider what would happen if there were only two measurements of *x* and *y*. In such a case the line of best fit would pass through those two measurements perfectly (plot (b)). The line of best fit could be used to predict y for other values of *x*, but with so few data, that is, with such limited 'support' for the model, there may be less confidence than if more data had been available.

If there were exactly three measurements of *x* and *y*, a quadratic curve could be found that would pass through the measurements perfectly (plot (c)). If there were *n* measurements, a polynomial of order *n-1* could be found that would pass through the measurements perfectly (plot (d)). However, there is no guarantee that such a polynomial would allow one to predict with confidence.

Figure 3 : Extract from Australian Groundwater Modelling Guidelines (Barnett et. al., 2012)

5. Calibration

Calibration is the process where the reliability or accuracy of the model is tested by assessing how well it is able to reproduce or match historically observed groundwater behaviour. Typically, calibration is used to refine or modify the key groundwater parameters in the model that control the flow and storage of water. In practice, the model is run many times either in a trial-and-error approach or through an automated procedure until a satisfactory match to observations is attained.

Historically, in Australia, groundwater modellers and model owners have used quantitative measures to illustrate the adequacy of calibration and to judge the reliability of the model as a whole. These measures provide a numerical value that indicates the goodness of fit between the modelled and observed data sets (for example the Scaled Root Mean Square (SRMS) error). Such measures are not necessarily useful as experience has indicated that it is difficult to define rules that are applicable to all models. Experience has shown that efforts solely aimed at achieving a target calibration indicator can lead to poorly structured models where unnecessary complexity is used simply to meet the calibration target. In such cases a model with simpler structure and poorer calibration statistics may well be a better tool for prediction.

As part of the calibration process it is advisable to undertake a sensitivity analysis. This process is aimed at illustrating the sensitivity of calibration to variation in key model parameters and assumptions. The analysis usually involves making small changes to one model parameter or assumption, re-running the calibration model and displaying a model result that can be compared to similar results obtained from the best calibration model and from other sensitivity model runs. The analysis can help identify those model parameters and assumptions that exert a strong influence on model results.

Guiding Principles

5.1 All available information should be used to guide the choice of model parameters and model calibration. All parameters should initially be considered to be uncertain.

5.2 The calibration process should be used to find model parameters that prepare a model for use during predictions of future behaviour, rather than finding model parameters that explain past behaviour.

5.3 The modeller should find a balance between simplicity (parsimony) and complexity (highly parameterised spatial distribution of some properties). Non-uniqueness should be managed by reducing the number of parameters or by regularisation, which is a way of ensuring that parameter estimates do not move far from initial estimates that are considered to be reasonable.

5.4 Performance measures should be agreed prior to calibration, and should include a combination of quantitative and non-quantitative measures. The scaled root mean squared error (SRMS) is a useful descriptor of goodness of fit when the only objective is to fit historical measurements of heads, but is less useful when automated calibration methods are used. A target SRMS of 5% or 10% is only meaningful when those setting the target know that it is achievable for a particular kind of problem and a particular environment with a known density of informative data.

5.5 Sensitivity analysis should be performed to compare model outputs with different sets of reasonable parameter estimates, both during the period of calibration (the past) and during predictions (in the future).

5.6 A formal verification process should only be attempted where a large quantity of calibration data is available and it is possible to set aside a number of key observations that could otherwise be used for calibration.

Clarification

The guidelines adopt the following definitions:

"Validation" is the process of comparing a groundwater model result to simple, but exact, mathematical solutions (analytical solutions) that include various simplifying assumptions.

"Verification" is a process of reserving a subset of the calibration data set (observed historic data) and testing the calibrated model against this data.

"Post-audit" (refer to Chapter 11) is the process where predictive scenario results are reviewed and compared against actual groundwater behaviour measured during the period within which predictions have been made. The post-audit is undertaken some time after the model is initially developed and allows the original model predictions to be tested against observations.

The guidelines acknowledge that all three methods can be used to good effect in a modelling project. Verification will not always be appropriate as there is often a lack of suitable data for calibration and in many cases it is more efficient to use all available data in calibration. In the event that the model fails to accurately replicate the verification data set, the model will most likely be re-calibrated to rectify this problem. In effect, all of the available data is used in calibration. It is not the intention of the guidelines to discredit the verification or validation approaches.

Clarification

The guidelines promote the use of many different types of data in calibration. Calibration can be improved by increasing the types of observations included in the calibration data set and by using observations of the model features that are of most importance in prediction. While the types of calibration data may be broadly categorised as heads and fluxes, there are many semi-quantitative observations that may be used in calibration. For example, calibration may include targets such as the locations in which springs occur and the locations in which there are artesian aquifer conditions.

Figure 4 : Extract from the Companion to the Guidelines of the Australian Groundwater Modelling Guidelines (SKM, 2013)

An SRMS of 16.2%, overall, is considered reasonable, for a Class 2 Confidence Level model being used for the purpose of impact assessment of a continuing mining operation in hard rock that has been operating successfully and without incident for 25 years.

Figure 5 presents the modelled contours of head (mAHD) in Layer 11 of the calibration model (RPS Run # 015a_CAL-Apr14_07a.gwv), as at April 2014 (SP185TS5) together with the hydraulic conductivity zonation. It is noted that all calibration targets are displayed in **Figure 5** whereas, in the model, only target BH01 is located in Layer 11. Contour intervals presented in Layer 11 are 10m increment and the boundary condition (DRN cells) at the relevant timestep are displayed in yellow. As presented in RPS (2014), Section 8.5.5, DRN cells were used to represent progression of the open cut mine, based on mine landform surfaces (approximately 2 yearly during the calibration simulation).

From **Figure 5**, the influence of dewatering of the previous Integra operation and Pit 3 lead to development of a cone of depression with a north-south alignment. Target BH01 is located to the northwest of active mining area in Pit 3 and the drawdown is underestimated in the model. Target BH02 is located between Pit 3 and Pit 1, adjacent the hillside, where the local hydraulic gradient in the model is quite steep. As presented in RPS (2014), predicted impacts of continuation of mining at Rix's Creek are consistent with the conceptual hydrogeological model, namely hydrogeological impacts are constrained to the west, south and east due to outcropping of the various coal seams. **Figure 2** presents the hydrograph for monitoring location GCP34, which is located to the north of BH02. The fit to observation at GCP34, which is situated at the point where off-site impacts may propagate northward is closely matched.

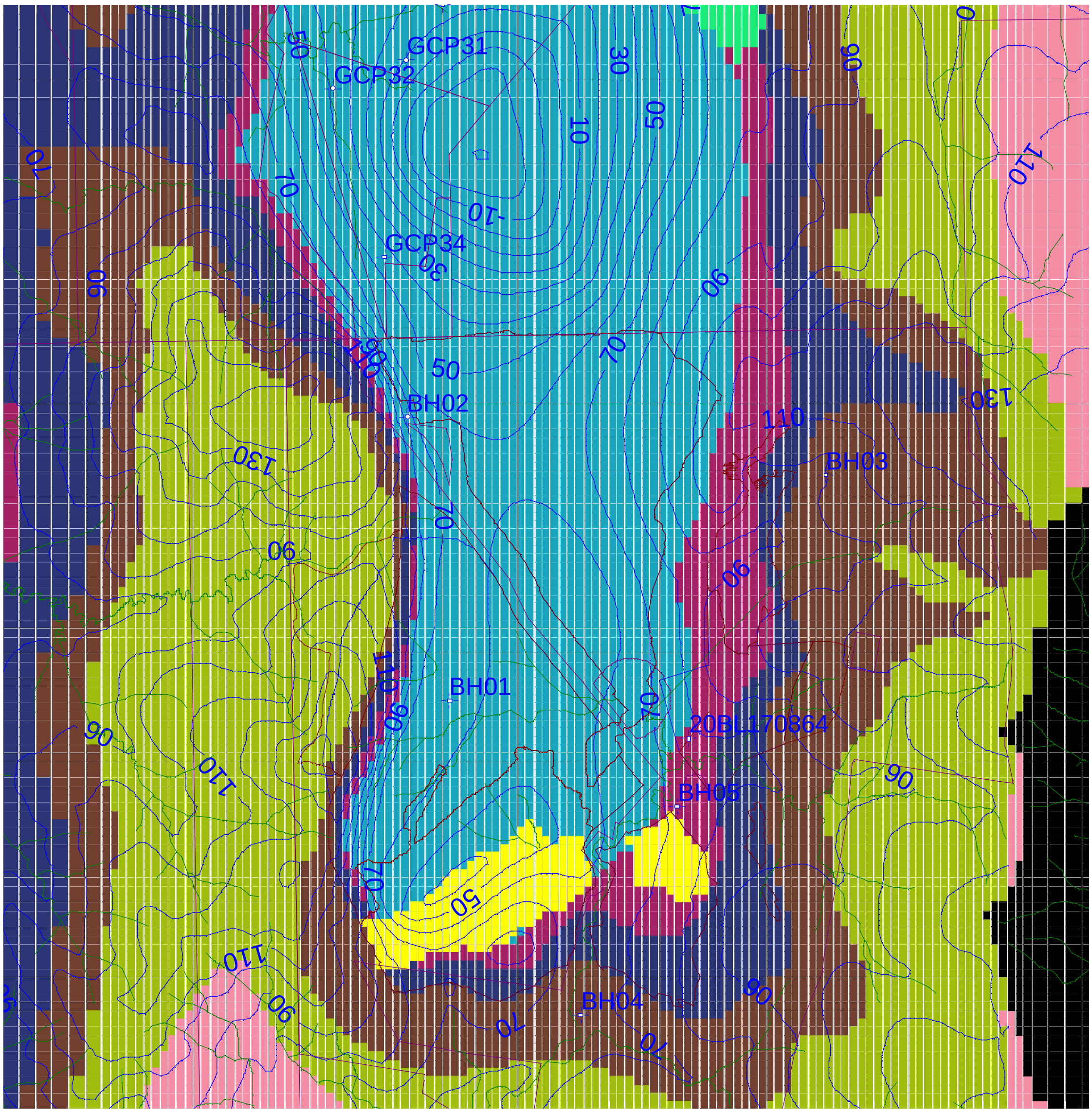


Figure 5 : Modelled Groundwater Elevation (mAHD) (Layer 11, April 2014 (SP185TS5)) – Current Calibration Model (RPS Run # 015a_CAL-Apr14_07a.gwv)

To investigate the observed north-south alignment of the drawdown cone, an additional calibration simulation was prepared.

As presented in RPS (2014), the site is situated in the Rix's Creek Syncline and is bounded to the west by the Camberwell Anticline and to the east by the Darlington Anticline. Due to the close proximity of these structures to each other, it is possible there is an anisotropic distribution of hydraulic conductivity. **Figure 6** presents the modelled contours of head (mAHD) in Layer 11 of a simulation where *Ky* (horizontal hydraulic conductivity in the north-south direction) was 10 times higher than *Kx* (horizontal hydraulic conductivity in the east-west direction) and *Kz* (vertical hydraulic conductivity) was 10 times higher within the Pit 3 area. An additional change was to reduce the rainfall recharge factor from 2.5% to 1.0% (Jacobs Run # 004a_CAL-Apr14_01m.gwv). As per **Figure 5**, model results were presented as at April 2014 in Layer 11.

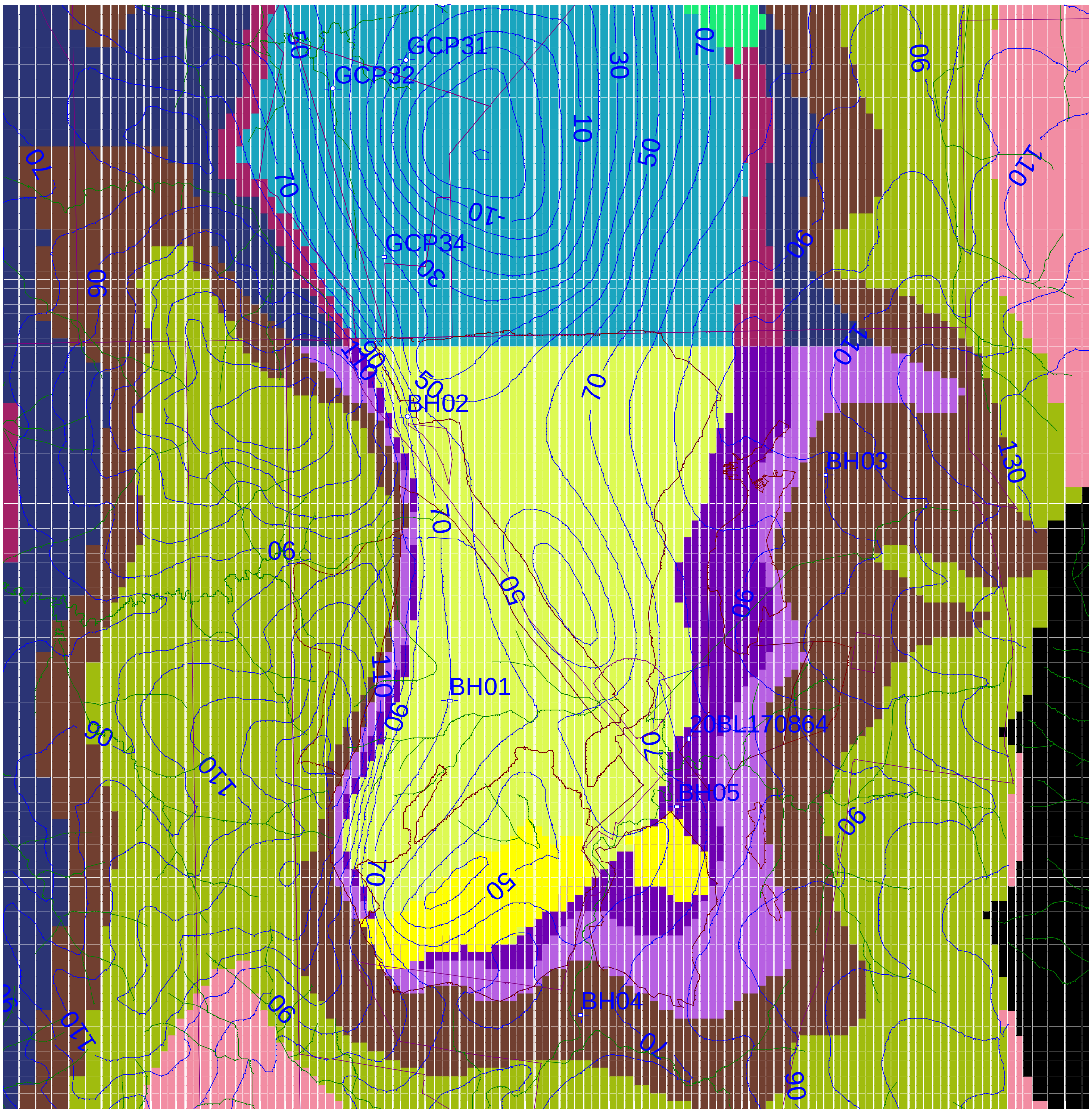


Figure 6 : Modelled Groundwater Elevation (mAHD) (Layer 11, April 2014 (SP185TS5)) – Calibration Model (Local Anisotropy) (Jacobs Run # 004a_CAL-Apr14_01m.gwv)

From **Figure 6**, these changes lead to propagation of the north-south aligned drawdown cone between Pit 3 and Pit 1, although does not locally impact the modelled groundwater level in BH01. Local anisotropy, however, will not have a significant effect on prediction simulations already presented in RPS (2014) since the model approach is to use DRN cells to represent mining progress, as outlined in Section 8.5.5 of RPS (2014) and there are only mining operations (Pit 1 and Integra) to the north of Pit 3. The Integra operations are now owned by Bloomfield Group.

Accordingly, it is considered that the model is appropriately calibrated for the Confidence Class of model it was constructed for, namely impact assessment.

Issue DPI Model 03) The model was not independently peer reviewed prior to submission. A review should be required, along with implementation of any findings of the reviewer through revised modelling and incorporation within the Water Management Plan, prior to commencement of the project.

As it is understood, the statement of Fitness for Purpose by the 3rd Party Reviewer is currently being prepared.

Issue DPI Model 04) The method for calculating recharge relied on several assumptions in creating an artificial average rainfall dataset. A multiplication factor was applied to the rainfall datasets and it is uncertain what the resulting data set represents. The multiplication factor was not justified with a description of whether it was accounting for overland flow, transpiration or error in the spatial and temporal rainfall datasets. Further consideration is requested in the Water Management Plan.

It is standard industry practice in groundwater modelling to apply a factor to the rainfall record. The factors are selected based on geological and environmental settings and generally range between less than 1% to 15%. The reason that a factor is applied in groundwater modelling is to approximate the difference between rainfall-runoff processes and groundwater infiltration, including the effect of temporal scale. If this was not a reasonable approximation and rainfall was used directly, the order of magnitude of recharge flux would be higher than the vertical hydraulic conductivity and groundwater elevations would be at ground surface everywhere, which is not observed. In the case of this model, as presented in Section 8.5.2 of RPS (2014), for the calibration model, historical monthly rainfall was used. For the prediction simulation, the 50th percentile 24 year consecutive rainfall total was calculated and corresponded with the period 1973 to 1996. The historical monthly rainfall over that periods was then used in the prediction model.

The practicalities of temporal scale at monthly stress periods compared to daily stress periods is discussed further in the response prepared to DPI Model 09, further below.

Issue DPI Model 05) The method for calculating evaporation should be further justified or refined. A Pan Factor was applied to the top layer of the model but no justification for doing so or for applying certain values was provided. Pan evaporation rates applied, to the top layer of the model are usually only justified if constrained to be within the top 10 cm of the model. Evaporation decreases highly non-linearly with depth to evaporation extinction depth.

"Evaporation was incorporated into the model using the EVT module and was applied to Top Layer only. The evaporation rate (Class A Pan) was obtained from long-term monthly average of the BOM Station Scone SCS (No. 061089) with a Pan Factor of 50% across the model domain. An exception was during the recovery simulation where the Pan A Factor was set at 70% over the extent of the final void."

A Class A Pan is a one metre diameter, circular, shallow steel pan. Data obtained from climatic records (BOM) is determined by measurement of the daily difference in water level within that pan. As such, Class A Pan evaporation data is open water evaporation. It is accepted that the approach adopted in MODFLOW (public domain software published by the United States Geological Survey) in the EVT module is a simplistic representation of the effect of evaporation from soil and transpiration. As per the MODFLOW manual (McDonald and Harbaugh, 1988), the extinction depth is set to account for factors such as rooting depth and limits of soil capillarity. A Pan Factor of 50% is a typical value used in groundwater modelling. A higher value was used to represent evaporation from the Pit Lake Void, but was not set at 100% since there will be local shading and sheltering from the wind.

Issue DPI Model 06) There is uncertainty if the adopted parameters for Van Genuchten's and Brooks-Corey are representative for the soils found on site and there is little detail about the how these equations were applied within the model, and this should be considered further.

The variably saturated flow formulation of MODFLOW, implemented in MODFLOW-Surfact, was adopted as it effectively overcomes the well known constraint of MODFLOW in modelling drying/wetting cells. Whilst the current revision of MODFLOW-2005 includes a better numerical method for treatment of resaturation of cells, referred to as MODFLOW-NWT, MODFLOW-Surfact is the most stable. As noted in RPS (2014), the adopted parameters are typical for desaturation behaviour halfway between a "clay-like" material and a free-draining "sand-like" material.

Issue DPI Model 07) A general head boundary condition was applied to layers 3 and 4 of the model based on a linear extrapolation from bore GW080963. A conductance of 100 m3/day was applied to this fixed head. This feature provides an infinite supply of water into the model and it is uncertain whether this approximation is hydrogeologically justifiable in representing the long-term impact of mining activity in the south-west corner of the model domain. The effects that the feature may have on the model domain in maintaining water level elevations is unknown without inspection of the model.

As stated in Section 8.5.4 of RPS (2014), the general head boundary was used to represent groundwater level history record at GW080963, which is located in the southwest corner of the model domain. The change in groundwater level at this location reflects the effect of Rio Tinto's Hunter Valley Operations site. **Figure 7** presents the modelled versus observed hydrograph at GW080963. To ameliorate the potential for an infinite supply of water to the model a general head boundary was used in place of a constant head boundary.

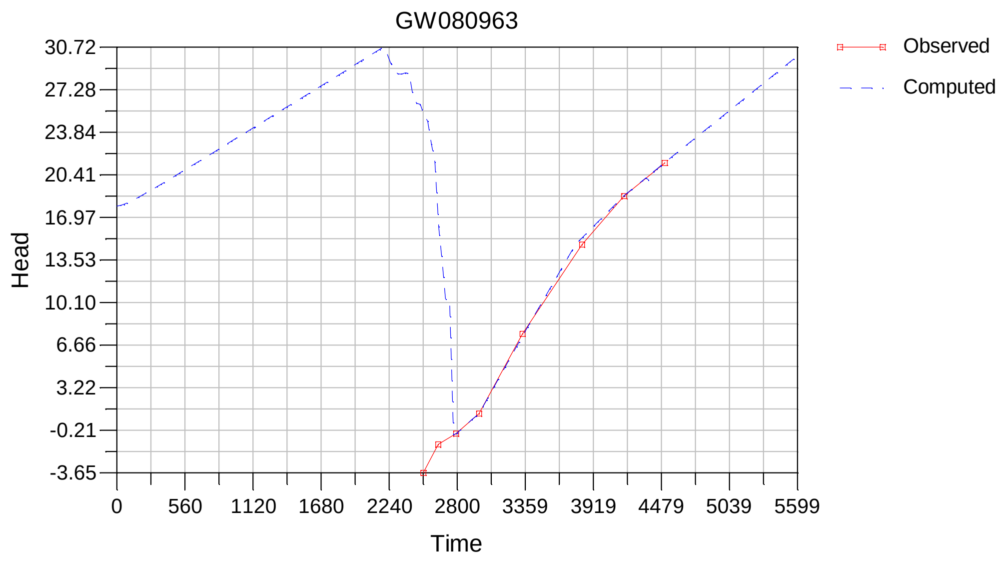


Figure 7 : Groundwater Elevation Hydrograph (mAHD) – Current Calibration Model (RPS Run ID. 015a_CAL-Apr14_07a.gwv)

To respond to the query from DPI Water a sensitivity analysis simulation of the current calibration was prepared (Jacobs Run # 004a_SEN-GHB_01a.gwv). The simulation comprised disabling the general head boundary and comparing modelled groundwater elevations as at April 2014 for equivalent layers (Layer 3).

Figure 8 presents the modelled contours of head (mAHD) in Layer 3 for the calibration model (RPS Run # 015a_CAL-Apr14_07a.gwv). **Figure 9** presents the modelled contours of head (mAHD) in Layer 3 for the sensitivity analysis simulation (Jacobs Run # 004a_SEN-GHB_01a.gwv). From **Figure 8** and **Figure 9**, there is essentially no difference in groundwater elevation between the simulations at the location of the mine.

It is noted that 'dry' cells are not displayed in **Figure 8** and **Figure 9,** such that model output can be compared. MODFLOW-Surfact presents model output in 'dry' cells but is a pseudo-head. Quoting from MODFLOW-Surfact Frequently Asked Questions "In dry cells, it writes the heads calculated for the dry cell, which will be equal to the water-table head with no recharge. With recharge, it will be slightly higher than that, to allow for the recharge to go down to the water table. So, in essence, it is a pseudo-head, but it may be used to see where the first water-table lies since it shouldn't be much different unless confinement at the surface is large."

Issue DPI Model 08) The calibration dataset type should be better described and it is unclear where the calibration points are situated as no legible map has been provided.

Please refer to the response provided to query DPI Model 01 presented above.

Issue DPI Model 09) The monthly stress periods that were adopted in the model overly simplify the complexity inherent in groundwater/surface water modelling and it is more usual for the daily time step to be utilised which has a stabilising effect on the model.

Standard groundwater modelling practice is evolving to monthly stress periods, so as to account for seasonal variation. For mine dewatering assessments, similar to Rix's Creek, yearly stress periods have been used extensively in the past. Whilst computation power continues to increase, there are practical limitations to calculation time in environmental modelling. For the Rix's Creek model, the number of active cells are 645,107, distributed through 19 layers. The physical computer run-time of the calibration model is 42 minutes currently, comprising 185 stress periods, with typically 5 computational timesteps per stress period. That calculation time would increase to 5,598 stress periods (in a daily timestep simulation) and potentially take 21 hours, scaling linearly. A 21 hour run-time for a calibration model is considered impracticable.

Issue DPI Model 10). In Section 8.7.3 it was stated that, the model predicted inflow to pits, was calibrated against unmeasured, anecdotal observations. It is uncertain how this can be used to justify calibration.

As stated in Section 8.7.3 of RPS (2014), experience at the site over the past 25 years of mining is that groundwater inflow was relatively minimal. Inflows of 2 to 5L/s on the scale of the various mine pits is considered reasonably described as relatively minimal and would be close to being immeasurable on-site.

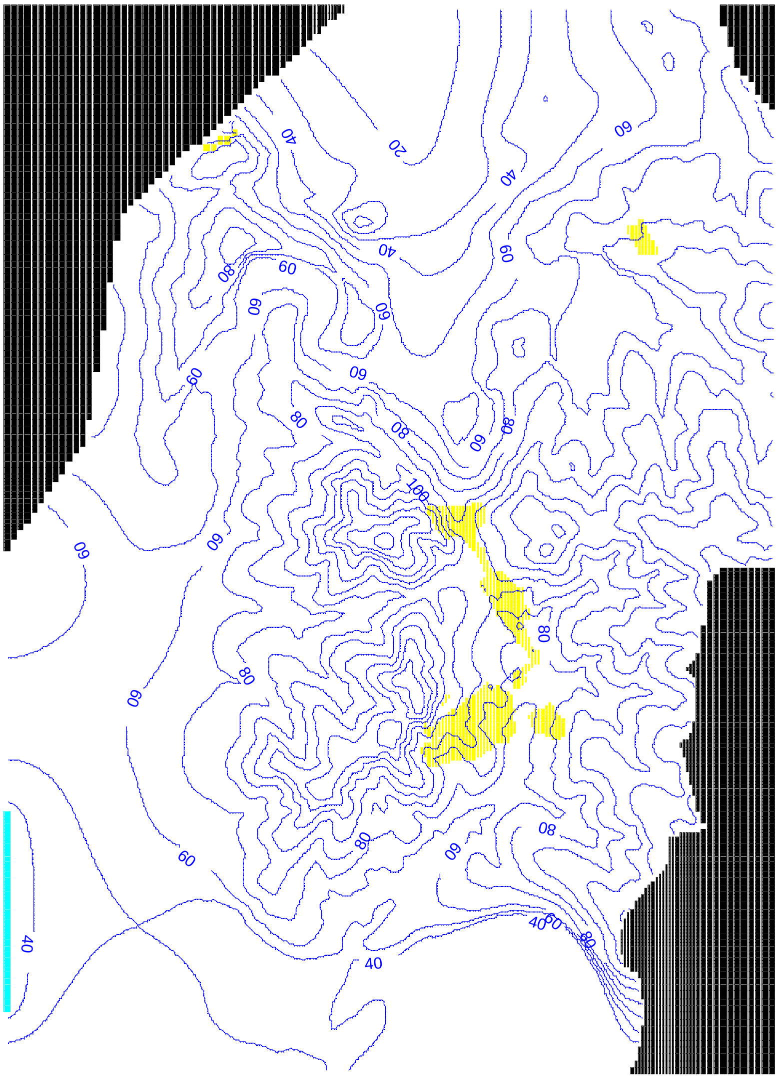


Figure 8 : Modelled Groundwater Elevation (mAHD) (Layer 4, April 2014 (SP185TS5)) – Current Calibration Model (RPS Run # 015a_CAL-Apr14_07a.gwv)

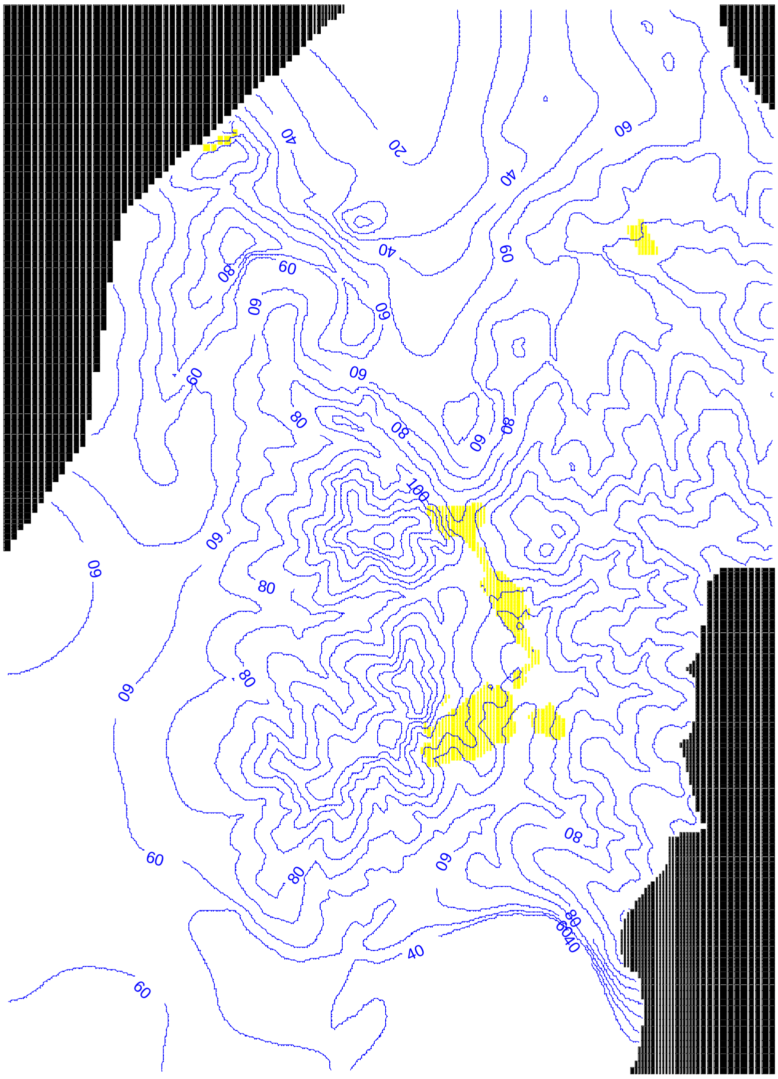


Figure 9 : Modelled Groundwater Elevation (mAHD) (Layer 3, April 2014 (SP185TS5)) – Sensitivity Analysis Model (General Head Boundary) (Jacobs Run # 004a_SEN-GHB_01a.gwv)

Issue DPI Model 11). It is recommended that the reviewer consider given the current model calibration how meaningful the results, reporting groundwater contribution to Rix's Creek, are.

It is stated in Section 8.8.2 of RPS (2014) that there is no modelled impact of the mine on the lower part of Rix's Creek or the Hunter River. For the upper part of Rix's Creek, the predicted change is of the order of 0.1L/s and is considered to be insignificant.

The approach adopted to modelling of future conditions was to present both a proposed condition and a null case. The reason this is done in environmental modelling is to accommodate any residual issues with model conceptualisation and / or calibration (although considered to be minor), whether it is positive or negative, into both the proposal and the null cases, thereby allowing evaluation of the impact of the proposal on an equivalent platform.

Issue DPI Model 12) An uncertainty analysis was performed by using the 10th percentile and 90th percentile of the rainfall applied over a 24 year dry period and another 24 year wet period. It is uncertain how relevant an analysis of uncertainty this provides given that:

a. the fixed head applied in the model has not been hydrogeologically justified.

b. recharge and evaporation have not been represented in a physically meaningful manner and applied at monthly time steps with both these values temporally and spatially averaged over the 24 year periods.

c. a multiplication factor that minimises the impact of rainfall has been applied, and

d. the model is poorly calibrated to only a few bores.

As presented in the response to query DPI Model 07, the general head boundary was used to represent a known groundwater level record. A DRN boundary could equally have been used to represent the impact of the Rio Tinto Hunter Valley Operations. As demonstrated, the effect of the boundary condition on modelled groundwater elevation at the site is negligible.

It is established in the response to query DPI Model 04, 05 and 09 that recharge, evaporation and temporal discretisation adopted in the model is reasonable.

A discussion of model calibration is presented in the response to query DPI Model 01.

Issue DPI Model 13) There is uncertainty why the model experiences such instantaneous, rapid increases and declines in inflows into the pits as shown in Figures 8.11; 8-16 and 9.1 and discussed in Sections 8.7.3; 8.8.2 and 9.2.1 respectively. Clarification is sought from the proponent to show that these artefacts are indeed related to the progressive implementation of the mine plan, pit development and back filling and are not related to model instability.

The approach to representation of mine progression in the groundwater model is explained in Section 8.5.5 of RPS (2014), namely mine surface landforms from December 2004 to December 2013, with respect to calibration simulation, and mine surface landforms at 2017 to 2037, with respect to prediction and recovery simulations. MODFLOW is based on temporal discretisation into stress periods. Stress periods in the Rix's Creek model are monthly. Boundary conditions can only change between stress periods and the large increase in inflow is due to the change in mine surface landform as represented by DRN cells. In reality, mine progression is incremental. This cannot be implemented efficiently in a model, therefore volumetric average is presented in Figure 9.1 of RPS (2014).

It is noted that licensing requirements were calculated based on volumetric inflows, area under the curve, rather than taking an average of the inflow rate, so as to account for this model limitation.

Issue DPI Model 14) In regard to figures 8.19.5 and 8.19.6. These are the only legible drawdown figures, which depict drawdown in the Hebden seam, presumably confined, as this seam is the lowest stratigraphically elevated coal seam aquifer. However in Section 8.8.2 - Prediction Results, the text describes this drawdown as being in the uppermost water table and does not refer to the Hebden seam whatsoever. Clarification should be provided by the proponent.

It is presented in RPS (2014) that coal seams variably outcrop at the peripheries of the Rix's Creek site. A comprehensive approach was adopted to model layering so as to represent the multiple aquifers and interburden units (aquitards). The uppermost water table was determined from model results, as it variably could have existed in Layer 1 through 12. Comparison was made then between the uppermost water tables (prediction and null cases) and presented thematically. Direct comparison of model output from Layer 1 in the proposed case and the null case would not be meaningful if the water table did not reside in Layer 1 at all locations.

For the Hebden Seam, Layer 17, which does not include many 'dry' cells, output in Layer 17 for proposed condition and the null case were compared directly.

Issue DPI Model 15) Again in regard to figures 8.19.5 and 8.19.6. Clarification of uncertainty is sought regarding the shape of the drawdown contours. There is uncertainty about whether the steep contours observed on the western side of the Hebden seam drawdown figure are simply not an artefact of the applied fixed head boundary condition. If this is the case than the 2 m drawdown contour could extend past the boundary of the mine site and could impact on the assessment against the NSW Aquifer Interference Policy if the fixed head was removed.

"From Figure 8.19, the predicted decline in the uppermost water table is more than 50 m within the active mining area. However, at the boundary of the site the predicted decline in the uppermost water table is less than 2 m at all extracted time stamps"

It is established in the response to query DPI Model 07 that the general head boundary on the edge of the model has no impact on model predictions in the centre of the model.

Issue DPI Model 16) Table 8.15 and Table 8.16 refer to the, "prediction model", "null case" (no extension to Pit 3) and the "cumulative impact null case" (no Mine) models. It is not clear what constitutes the prediction model and how it differs to the other two models.

The prediction case is the proposed continuation of mining.

The null case is cessation of mining at the end of the current approval. i.e. the EIS is for continuation of mining operations at Rix's Creek, and is not a "greenfield" application.

The cumulative impact assessment null case is no mining at Rix's Creek in any form, including historical mining. It is a requirement in the assessment process to present the impact of the proposal as well as the cumulative impact (both of the site in the case of "brownfield" operation, as well as neighbouring operations). In this way, a combination of several, separately approved, incremental impacts do not lead to an unacceptable cumulative impact.

For this Groundwater Impact Assessment, the cumulative impact assessment null case was selected to be the Rix's Creek operation.

3. References

Barnett et. al., 2012. *Australian Groundwater Modelling Guidelines. Waterlines Report Series No 82.* Reference No. ISBN 978-1-9218553-91-3, dated June 2012. National Water Commission, Canberra.

McDonald, M.G. and Harbaugh, A.W. (1988). *A modular three-dimensional finite-difference ground-water flow model*. *Techniques of Water-Resources Investigations, Book 6, Modelling Techniques.* Reference No. TWI6-A1, dated 1988. United States Geological Survey, Colorado.

RPS, 2014. *Rix's Creek Continuation of Mining Project – Groundwater Impact Assessment*. Reference No. S66D/015d, dated 30 September 2014.

SKM, 2013. *Australian Groundwater Modelling Guidelines – Companion to the Guidelines*. Reference No. ISBN 978-1-9122136-23-7, dated July 2013. National Water Commission, Canberra.

4. Closing

Should you require additional information then please do not hesitate to contact our office.

Yours sincerely

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APPENDIX D:
INDEPENDENT MODEL REVIEW

Dundon Consulting Pty Limited
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ABN 27 083 246 459

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17 April 2016

Rix's Creek Coal Mine
Rix's Creek Lane
SINGLETON, NSW 2330

Attention: Mr John Hindmarsh

Dear John,

Re: Rix's Creek Continuing Operations Groundwater Impact Assessment – Independent Model Review

RPS carried out a groundwater impact assessment to support the application for consent renewal to allow continuing operations at the Rix's Creek mine. Their assessment was documented in a draft report 'Rix's Creek Continuation of Mining Project Groundwater Impact Assessment', dated 23 July 2014.

Dundon Consulting was engaged to conduct an independent model review, as required by the Aquifer Interference Policy (AIP). The review commenced with a meeting with RPS on 14 May 2014, at the conceptual model stage. RPS then produced a draft report on their groundwater impact assessment, which was reviewed by me in October 2014. I provided initial comments on the modelling component of the assessment study in a draft letter, and discussed these comments with RPS at a meeting on 19 October 2014.

DPI Water provided comments on the RPS report during Adequacy Assessment in a submission dated 7 December 2015. RPS has subsequently prepared a document entitled 'Rix's Creek EIS – Supplementary Groundwater Information', which addressed matters raised in my October 2014 review and the DPI Water review of December 2015. The RPS supplementary report included a letter report by Jacobs, dated 14 March 2016, addressing the modelling issues. This was appended to the RPS report as Appendix C.

Dundon Consulting has now been asked by RPS to finalise the independent peer review of the modelling for the Rix's Creek consent renewal. This is the subject of this letter. Matters raised by DPI Water and the responses provided in RPS's March 2016 Supplementary report, have been considered along with the initial groundwater impact assessment report from July 2014.

The modelling has been assessed against the Australian Groundwater Modelling Guideline (Barnett, et al, 2012), using the review checklist in Table 9-2 of the guideline. The checklist is reproduced below.

Modelling Review Checklist (from Table 9-2 of Barnett, et al, 2012)

Review questions	***Yes/No***	***Comment***
1. Planning		
1.1 Are the project objectives stated?	Yes	Project objectives were not explicitly stated in the report. However, objectives are implicit in the DGRs, and summarised in Section 1.3 (page 2).
1.2 Are the model objectives stated?	Yes	The model objective is clearly stated in Section 4.2 of the supplementary report.
1.3 Is it clear how the model will contribute to meeting the project objectives?	Yes	

Review questions	***Yes/No***	***Comment***
1.4 Is a groundwater model the best option to address the project and model objectives?	Yes	
1.5 Is the target model confidence-level classification stated and justified?	Yes	Section 4.1 of Supplementary Report.
1.6 Are the planned limitations and exclusions of the model stated?	Yes	Section 4.2 of Supplementary Report.
2. Conceptualisation		
2.1 Has a literature review been completed, including examination of prior investigations?	Yes	
2.2 Is the aquifer system adequately described?	Yes	Section 4 (pages 11 to 15)
2.2.1 hydrostratigraphy including aquifer type (porous, fractured rock ...)	Yes	
2.2.2 lateral extent, boundaries and significant internal features such as faults and regional folds	Yes	Section 4.6; Figures 2.1, 4.2 and 4.3
2.2.3 aquifer geometry including layer elevations and thicknesses	Yes	Section 8.3, including Table 8.2.
2.2.4 confined or unconfined flow and the variation of these conditions in space and time?	Yes	Clarifying description provided at Point 3 of table 9 of Appendix A to Supplementary Report.
2.3 Have data on groundwater stresses been collected and analysed?	Yes	Dewatering; rainfall
2.3.1 recharge from rainfall, irrigation, floods, lakes	Yes	Rainfall
2.3.2 river or lake stage heights	NR	
2.3.3 groundwater usage (pumping, returns etc)	Yes	
2.3.4 evapotranspiration	Yes	
2.3.5 other?		
2.4 Have groundwater level observations been collected and analysed?	Yes	
2.4.1 selection of representative bore hydrographs	Yes	
2.4.2 comparison of hydrographs	Yes	
2.4.3 effect of stresses on hydrographs	Yes	Comparison with rainfall residual mass curve trends.
2.4.4 watertable maps/piezometric surfaces?	No	Insufficient data to be meaningful.
2.4.5 If relevant, are density and barometric effects taken into account in the interpretation of groundwater head and flow data?	NR	
2.5 Have flow observations been collected and analysed?	No	Anecdotal evidence has been used, and is considered to be appropriate in this case.
2.5.1 baseflow in rivers	No	
2.5.2 discharge in springs	NR	
2.5.3 location of diffuse discharge areas?	Yes	
2.6 Is the measurement error or data uncertainty reported?	No	
2.6.1 measurement error for directly measured quantities (e.g. piezometric level, concentration, flows)	No	
2.6.2 spatial variability/heterogeneity of parameters	Yes	
2.6.3 interpolation algorithm(s) and uncertainty of gridded data?	NR	
2.7 Have consistent data units and geometric datum been used?	Yes	

Review questions	***Yes/No***	***Comment***
2.8 Is there a clear description of the conceptual model?	Yes	Section 3.1 of Supplementary Report
2.8.1 Is there a graphical representation of the conceptual model?	Yes	Figures 4.2 and 4.3
2.8.2 Is the conceptual model based on all available, relevant data?	Yes	
2.9 Is the conceptual model consistent with the model objectives and target model confidence level classification?	Yes	
2.9.1 Are the relevant processes identified?	Yes	
2.9.2 Is justification provided for omission or simplification of processes?	NR	
2.10 Have alternative conceptual models been investigated?	No	
3. Design and construction		
3.1 Is the design consistent with the conceptual model?	Yes	
3.2 Is the choice of numerical method and software appropriate (Table 4-2)?	Yes	Best practice approach adopted.
3.2.1 Are the numerical and discretisation methods appropriate?	Yes	
3.2.2 Is the software reputable?	Yes	Industry standard.
3.2.3 Is the software included in the archive or are references to the software provided?	Yes	
3.3 Are the spatial domain and discretisation appropriate?	Yes	Some alterations were made to spatial domain following review at the conceptualisation stage.
3.3.1 1D/2D/3D	3D	
3.3.2 lateral extent	Yes	See Section 8.3, and refer Figure 8.1. Scale on Figure 8.1 would assist.
3.3.3 layer geometry?	Yes	Appropriate layer geometry for the modelling objectives. 19 model layers, including all major coal seams and interburdens represented as discrete layers, with overburden represented by 3 layers.
3.3.4 Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model and target confidence level classification?	Yes	Cell widths range from 50m to 100m.
3.3.5 Is the vertical discretisation appropriate? Are aquitards divided in multiple layers to model time lags of propagation of responses in the vertical direction?	Yes	Model layer thicknesses based on geological model.
3.4 Are the temporal domain and discretisation appropriate?	Yes	Project life and post-project recovery addressed in prediction simulations.
3.4.1 steady state or transient	Yes	Transient for calibration. Transient for predictions.
3.4.2 stress periods	Yes	185 for calibration; 294 for prediction; 94 for recovery
3.4.3 time steps?	Yes	Variable time steps used, with appropriate multiplication factors.
3.5 Are the boundary conditions plausible and sufficiently unrestrictive?	Yes	Discussed thoroughly at conceptual stage.
3.5.1 Is the implementation of boundary conditions consistent with the conceptual model?	Yes	

Review questions	***Yes/No***	***Comment***
3.5.2 Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained?	Yes	Predicted impacts minimal at boundaries
3.5.3 Is the calculation of diffuse recharge consistent with model objectives and confidence level?	Yes	
3.5.4 Are lateral boundaries time-invariant?	Yes	GHBs
3.6 Are the initial conditions appropriate?	Yes	First stress period of calibration run is steady state.
3.6.1 Are the initial heads based on interpolation or on groundwater modelling?		Interpolation.
3.6.2 Is the effect of initial conditions on key model outcomes assessed?	NR	Steady state start and long calibration period
3.6.3 How is the initial concentration of solutes obtained (when relevant)?	NR	
3.7 Is the numerical solution of the model adequate?	Yes	
3.7.1 Solution method/solver	Yes	Described in detail in Section 8.1.2 (page 28).
3.7.2 Convergence criteria	Yes	As above
3.7.3 Numerical precision	yes	As above
4. Calibration and sensitivity		
4.1 Are all available types of observations used for calibration?	Yes	
4.1.1 Groundwater head data	Yes	
4.1.2 Flux observations	NR	
4.1.3 Other: environmental tracers, gradients, age, temperature, concentrations etc.	NR	
4.2 Does the calibration methodology conform to best practice?	Yes	
4.2.1 Parameterisation	Yes	
4.2.2 Objective function	Yes	
4.2.3 Identifiability of parameters	Yes	
4.2.4 Which methodology is used for model calibration?		Transient.
4.3 Is a sensitivity of key model outcomes assessed against?	No	
4.3.1 parameters		
4.3.2 boundary conditions		
4.3.3 initial conditions		
4.3.4 stresses	Yes	Uncertainty analysis assessed for rainfall.
4.4 Have the calibration results been adequately reported?	Yes	
4.4.1 Are there graphs showing modelled and observed hydrographs at an appropriate scale?	Yes	
4.4.2 Is it clear whether observed or assumed vertical head gradients have been replicated by the model?	NR	Insufficient data
4.4.3 Are calibration statistics reported and illustrated in a reasonable manner?	Yes	Section 8.7 (pages 37 to 41). SRMS – 16.2% (Figure 8.13 shows significant scatter).

Review questions	*Yes/No*	*Comment*
		Mass balance error – see Figure 8.12.
4.5 Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated?	Yes	
4.5.1 spatially		SRMS plot
4.5.2 temporally		hydrographs
4.6 Are the calibrated parameters plausible?	Yes	
4.7 Are the water volumes and fluxes in the water balance realistic?	Yes	
4.8 has the model been verified?	No	Insufficient data for verification.
5. Prediction		
5.1 Are the model predictions designed in a manner that meets the model objectives?	Yes	
5.2 Is predictive uncertainty acknowledged and addressed?	Yes	
5.3 Are the assumed climatic stresses appropriate?	Yes	
5.4 Is a null scenario defined?	Yes	
5.5 Are the scenarios defined in accordance with the model objectives and confidence level classification?	Yes	
5.5.1 Are the pumping stresses similar in magnitude to those of the calibrated model? If not, is there reference to the associated reduction in model confidence?	Yes	Pit inflows derived from DRN fluxes.
5.5.2 Are well losses accounted for when estimating maximum pumping rates per well?	NR	
5.5.3 Is the temporal scale of the predictions commensurate with the calibrated model? If not, is there reference to the associated reduction in model confidence?	Yes	Calibration model – 15 years. Prediction model – 24 years. Recovery model – 100 years.
5.5.4 Are the assumed stresses and timescale appropriate for the stated objectives?	Yes	
5.6 Do the prediction results meet the stated objectives?	Yes	
5.7 Are the components of the predicted mass balance realistic?	Yes	
5.7.1 Are the pumping rates assigned in the input files equal to the modelled pumping rates?	NR	
5.7.2 Does predicted seepage to or from a river exceed measured or expected river flow?	NR	
5.7.3 Are there any anomalous boundary fluxes due to superposition of head dependent sinks (e.g. evapotranspiration) on head-dependent boundary cells (Type 1 or 3 boundary conditions)?	No	
5.7.4 Is diffuse recharge from rainfall smaller than rainfall?	Yes	
5.7.5 Are model storage changes dominated by anomalous head increases in isolated cells that receive recharge?	No	
5.8 Has particle tracking been considered as an alternative to solute transport modelling?	NR	
6. Uncertainty		
6.1 Is some qualitative or quantitative measure of uncertainty associated with the prediction reported together with the prediction?	Yes	Uncertainty analysis based on rainfall.
6.2 Is the model with minimum prediction-error variance chosen for each prediction?	NR	

Review questions	***Yes/No***	***Comment***
6.3 Are the sources of uncertainty discussed?	Yes	
6.3.1 measurement of uncertainty of observations and parameters	Yes	
6.3.2 structural or model uncertainty	Yes	
6.4 Is the approach to estimation of uncertainty described and appropriate?	Yes	
6.5 Are there useful depictions of uncertainty?	No	
7. Solute transport	NR	
8. Surface water–groundwater interaction		
8.1 Is the conceptualisation of surface water–groundwater interaction in accordance with the model objectives?	Yes	
8.2 Is the implementation of surface water–groundwater interaction appropriate?	Yes	
8.3 Is the groundwater model coupled with a surface water model?	No	
8.3.1 Is the adopted approach appropriate?	Yes	
8.3.2 Have appropriate time steps and stress periods been adopted?	Yes	
8.3.3 Are the interface fluxes consistent between the groundwater and surface water models?	NR	

In terms of the Australia Groundwater Modelling Guideline check-list, I consider that the modelling has been satisfactory and is fit for purpose. The modelling predictions are assisted by a long period of monitoring of the Rix's Creek operation and the neighbouring Glennies Creek and Integra mines since mining commenced in the project area around 1990, and the water management measures proposed to be applied to continuation of mining at Rix's Creek are similar to those that have been practised at the mine in the past. This history provides confidence that the modelling predictions are sound, and predicted impacts are consistent with past impacts.

Comments made during my initial review of the impact assessment in October 2014 have been addressed to my satisfaction in the Supplementary Report. Comments made in the checklist table above have been amended as appropriate. Additional comments on the modelling have been partly addressed as follows:

- The use of "dummy" model layers to represent missing lithological units was not well explained in the draft assessment report, but has been partly clarified in the supplementary report. Dummy thicknesses and hydraulic conductivity values are assigned to a layer where the geological unit represented by that layer is absent from the model by virtue of having been eroded away Using dummy layers allows the model outputs for each model layer to represent a single geological unit. By assigning dummy properties (nominal 0.2m thickness and the same hydraulic conductivity as the next underlying active model layer), the dummy part of the model layer acts as if it were part of the underlying layer.

  Table 8.2 of the draft report showed minimum layer thicknesses of 0.04 to 0.20m for most layers, and these remain in the revised table (Table 9 of the supplementary report), but Table 9 also shows median layer thicknesses. This is still somewhat misleading in my opinion, as it does not indicate the minimum thickness of each layer in the areas where that layer is active. It would be more meaningful if this table showed the minimum **active** layer thickness, ie ignoring the assigned nominal thickness when a layer becomes a dummy layer. Where the layer becomes a dummy layer, it is no longer active as the hydraulic properties assigned are those of the highest underlying active layer.

- Legends should have been added to Figure 8.6 and Figure 8.7A.

- Figure 8.13 of the draft report showed a lot of data points that do not fit the SRMS line of best fit very well. There are two large groups of outliers that fall well below the 45° line. Some comment was needed in the report to explain why they do not fit, and why the scatter is not significant in this instance. This has been addressed in the text of the supplementary report at Section 4.4.

I am happy to confirm that the groundwater modelling has been completed satisfactorily in accordance with the Australian Groundwater Modelling Guideline (Barnett, et al, 2012).

Yours faithfully,

Peter Dundon

APPENDIX E:
ORIGINAL GROUNDWATER ASSESSMENT MODELLING FIGURES AND CALIBRATION HYDROGRAPHS