ATTACHMENT C:

Australasian
Groundwater
and Environmental
Consultants Pty Ltd
(AGE)

Report on

Watermark Project

Response to submission from University of New South Wales

Prepared for
Shenhua Australia Holdings Ltd

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Australasian Groundwater and Environmental Consultants Pty Ltd

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Report on

Watermark Project

Response to submission from University of New South Wales

1. Introduction

The Watermark Coal Project (the Project) is located approximately 25 km south south-east of the township of Gunnedah and to the immediate west of the village of Breeza, within the Gunnedah Local Government Area.

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE 2012) prepared a groundwater study for the Project, which formed part of the Environmental Impact Statement (EIS). AGE also contributed to a separate report compiled by Hansen Bailey responding to submissions (RTS) on the EIS (Hansen Bailey 2013).

The Planning Assessment Commission (PAC) conducted a public meeting on 26 and 27 June 2014 to hear from persons and organisations wishing to speak about the project. The New South Wales Irrigators Council commissioned the University of New South Wales (UNSW) to review the EIS and RTS and present their findings to the public hearing arranged by the PAC. UNSW also provided a copy of their presentation, including notes to the PAC, which was loaded to the PAC website[1].

The NSW Irrigators submission is in the form of a 46 page 'PowerPoint' presentation. The presentation describes their findings to seven key questions they asked when reviewing the groundwater aspects of the EIS and RTS. They ask does:

1. Shenhua's modelling test and report on all plausible geologic scenarios?
2. the EIS two layer model adequately represent the vertical complexity of the Namoi Alluvium?
3. the model adequately represent aquifer connectivity?
4. the EIS refer to available verifiable supporting data to support its geological and hydrogeological model?
5. the model deliver adequate calibration?
6. the model get the water balance right?
7. the model adequately present the uncertainty of its predictions?

Their presentation includes an unreferenced graphic that compares the actual impacts of a hypothetical project with the range of impacts predicted by numerical modelling. The graphic indicates good science provides a plausible and conservative estimate of the impact. UNSW concluded the groundwater assessment for the EIS Project was *'plausible but almost certainly under-predicted, or just wrong.'*

This report responds to points raised by UNSW in their presentation to the PAC. Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) have prepared this report at the request of Shenhua Australia Holdings Ltd.

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[1] http://www.pac.nsw.gov.au/Projects/tabid/77/ctl/viewreview/mid/462/pac/308/view/readonly/myctl/rev/Default.aspx

2. Scope of work

The objective of the report was to respond to all key points raised in the review commissioned by the NSW Irrigators Council. Where a simple written response was required to clarify a point, we have done this. Where some uncertainty would remain if no new analysis were undertaken, we have used the numerical model from the EIS to explore further some of the questions raised in the UNSW review and provide a more definitive answer. This included additional permutations to the groundwater model. Sections below outline the additional model scenarios. These included extending the sand and gravel aquifer closer to the proposed southern and eastern mining areas increasing the thickness of the Clare sandstone, removing faults and creating a 'hypothetical fault pipe' connecting the pits and the alluvial aquifer.

This work follows on from work requested by Dr. Colin Mackie, the reviewer commissioned by the PAC. For completeness this work is included in Appendix 1.

3. Response to comments

3.1 Supporting data documents

The groundwater assessment prepared for the EIS (AGE 2013) contained references to several reports prepared by GHD. These reports documented geological, hydrogeological and geophysical investigations at the project site that GHD had supervised. UNSW commented that the GHD reports should have been exhibited with the EIS and referenced by Third Party Reviewers.

To understand why these documents were not included it is necessary to understand the work conducted at the Project site. Shenhua commissioned GHD to assess the feasibility of developing a mine at the project site. GHD gathered drilling data over three separate stages; the results of each stage informing work undertaken in the following stage. As the knowledge of the site characteristics grew the interpretation and approach to mining also changed. The early reports prepared by GHD therefore do not contain the complete dataset or understanding of the geological and hydrogeological system. They also contain out of date mine plans. To address this GHD prepared a single standalone report documenting all the hydrogeological investigations (Stages 1, 2 and 3) in a single report that was included with the EIS, as an appendix in the groundwater study. Therefore all relevant information referenced in the Stage 1, 2 and 3 reports is included within the Appendix 1 of AGE (2012).

GHD also prepared a report on the alluvial soils boundary proximal to the mining areas. UNSW requested this document from Hansen Bailey, and the document was subsequently provided.

3.2 Aquifer architecture

3.2.1 Weathered zone

UNSW note *'...weathering was incorporated into the EIS computer modelling, however it appeared to be represented as an afterthought as zones in model layers rather than a specific model layer....'*

It is correct that the model represented the weathered rock with zones within existing layers, rather than a separate layer. However, it is not correct to describe this as an afterthought. The model went through a careful planning process, with review of the model plan by the third party reviewer, Dr Noel Merrick at key stages. The addition of a discrete weathered layer in the model was not neglected in order to make the model "slightly faster". The geological model showed that numerous hydrostratigraphic units sub-cropped underneath the alluvium, or outcropped at surface. Applying a weathering factor allows the model to properly honour the change from weathered to fresh rock within each rock unit.

The weathering zone in each layer was defined by comparing the depth of weathering from the geological model with the elevation of each model layer. Firstly, the elevation of the centre of each model cell was compared to the elevation of the weathering surface from the geological model developed by GHD. If the centre of the model cell was equal to, or at a higher elevation than the weathering surface from the geological model the hydraulic properties for the cell were set to represent weathered bedrock. If the centre of the model cell was below the weathered surface then the cell adopted the properties of fresh rock.

The hydraulic conductivity of the weathered rock zones in the model was set by multiplying the base value for equivalent unweathered fresh rock by a factor determined during calibration. Table 3.1 shows the factors applied to the fresh rock by hydraulic conductivity to represent the weathered zone in the EIS.

Table 3.1 Weathering zone hydraulic conductivity

Unit	Model layer	Weathering factor	Fresh Kx (m/day)	Weathered Kx (m/day)
Tertiary Basalt	1, 2, 3	5x	6.5×10^{-1}	3.23
Piliga Sandstone	4	10x	1.2×10^{-3}	1.2×10^{-2}
Interburden	5	10x	1.0×10^{-3}	1.0×10^{-2}
Clare Sandstone	6	1.5x	2.0×10^{-1}	3.0×10^{-1}
Interburden	7	10x	1×10^{-3} to 1×10^{-4}	1×10^{-2} to 1×10^{-3}
Hoskissons Coal Seam	8	2x	5×10^{-3} to 8.6×10^{-6}	5×10^{-2} to 8.6×10^{-6}
Interburden	9	10x	1×10^{-3} to 1×10^{-4}	1×10^{-2} to 1×10^{-3}
Melvilles Coal Seam	10	2x	5×10^{-3} to 8.6×10^{-6}	5×10^{-2} to 8.6×10^{-6}

Table 3.1 shows the weathered rock units were set between 1.5 and ten times more permeable than the fresh rock.

After reviewing a graphic in the EIS UNSW commented that '*....zones of bedrock weathering that might increase connectivity were not indicated.*' It is correct the graphic did not represent a weathering zone, however the groundwater model did simulate the weathering profile in the proposed mining area and also underneath the alluvial aquifer to ensuring the alluvium and coal measures were represented as hydraulically interconnected.

Figure 3-1 shows a cross-section through the EIS groundwater model, indicating the hydraulic conductivity adopted within each model layer. The mapped depth of weathering has been highlighted to illustrate how the model represented the weathering rock zones.

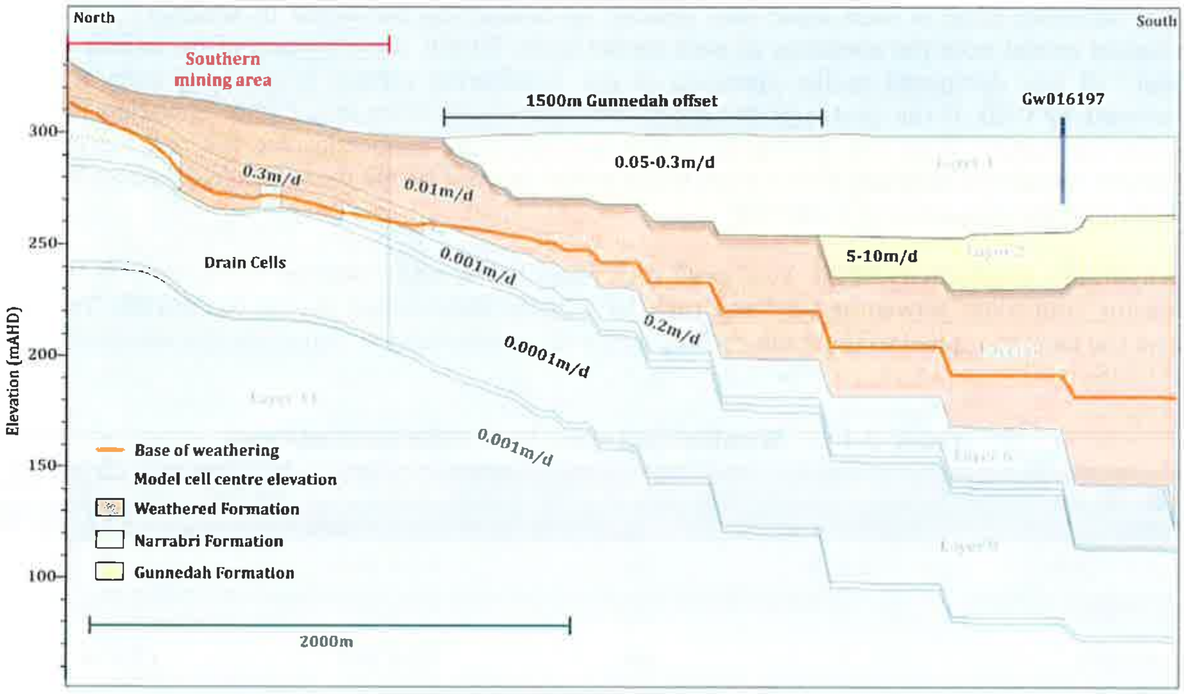


Figure 3-1 Cross-section through Southern Mining area/alluvium (Base EIS)

Figure 3-1 illustrates the groundwater model presented in the EIS adopted a relatively permeable connection (0.01 m/day) between the proposed mining area, and the saturated groundwater system in the alluvial formations.

The sensitivity analysis conducted for the EIS varied the hydraulic conductivity of the fresh and weathered rock. Figure 3-2 presents a cross section through a version of the model, which assumed a hydraulic conductivity rates of ten times higher than the base case for the weathered zone.

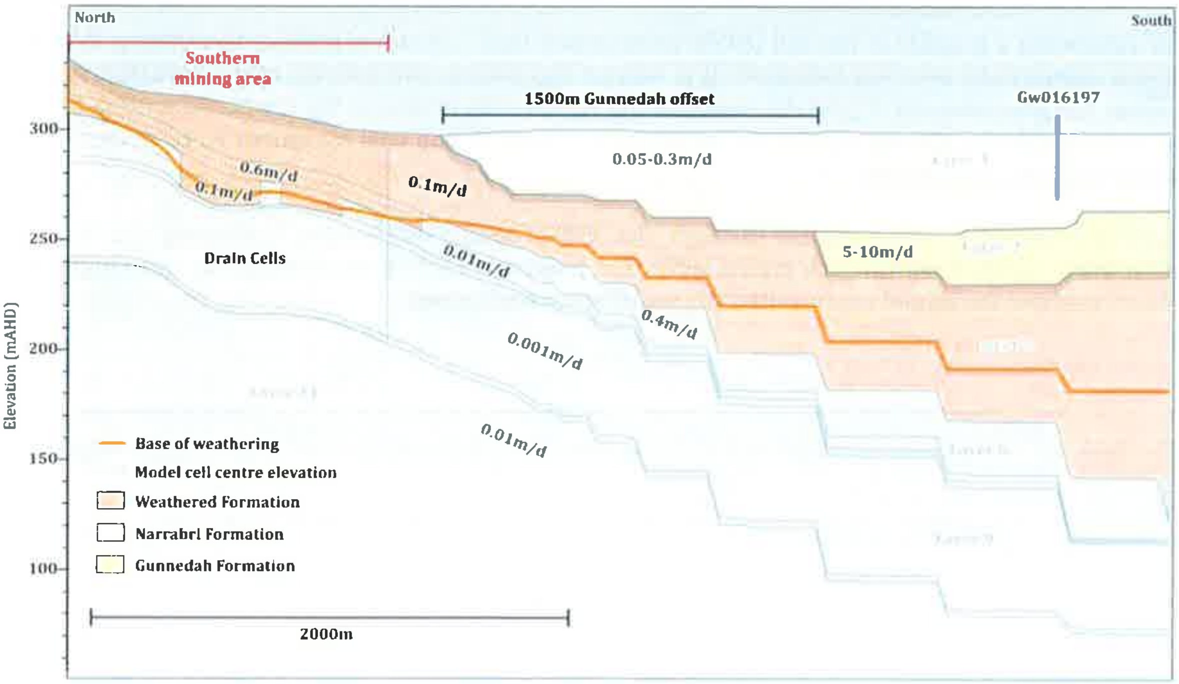


Figure 3-2 Cross-section through Southern Mining area/alluvium (Permian K+ 1 mag.)

Figure 3-2 shows that the sensitivity analysis simulated a permeable connection between the proposed mining area and the alluvium with a weathered zone hydraulic conductivity of 0.1 m/day. This represents hydraulic conductivity is equivalent to 'unconsolidated silty sand/ fine sand' (Fetter, 2001). Uncertainty realizations presented within the EIS also simulated permeable weathered zones with hydraulic conductivity exceeding 0.1 m/day between the Southern Mining area and the alluvium (EIS Appendix 9, Figure 3.5b).

In reality, weathering can increase the abundance of clay minerals and can therefore theoretically reduce the hydraulic conductivity of weathered material. The EIS however took a conservative approach assuming the weathering of rock always increases the hydraulic conductivity of the unit, therefore enhancing connectivity between the proposed mining area and the alluvium.

3.2.2 Namoi valley alluvium

The groundwater model presented by AGE (2012) divides the Upper Namoi alluvium into a low permeability upper unit known as the Narrabri Formation, overlying a higher permeability and productive sand and gravel unit referred to as the Gunnedah Formation. UNSW comment *'...reality is a more complex distribution of clays, silts, sands and gravels deposited over 2.5 million years. So how do you adequately represent all that in a two layer model? And the answer is, in close proximity to a mine body, you just can't.'*

We agree with UNSW that the concept of the Narrabri and Gunnedah Formation is a simplified representation of the actual geology and that there are lithologic units that are not represented by a two layer model of the alluvial system. However, we do not agree that a more accurate representation of individual lithologic units was required in the groundwater model for three reasons. Firstly it is simply impossible in incorporate all lithologic detail into a numerical model however, despite this the numerical model presented in the EIS, which represented the alluvium with two layers, replicated closely the water level trends measured in the NOW monitoring bore network in the alluvial system over a period of 30 years. This indicates the necessary simplicity in the representation of the geological detail did not prevent the model from achieving an acceptable calibration.

Secondly, the open cut mines do not propose to intersect the alluvium, and a barrier of bedrock will remain between the alluvium and the excavated area. It is therefore the properties of this bedrock barrier that are more important to the transfer of water, not the finer scale detail within the alluvium as this material will not be excavated and exposed within the pit, requiring any take of water from the alluvium to flow through the lower permeability bedrock. The investigations therefore focussed on the barrier zone and this was represented with ten layers to the floor of the open cut pits.

Finally, the groundwater model was detailed around the mine, whilst also being regional in scale. Correlating fine geological detail over such large distances is simply impossible, and we believe unnecessary. Even if it were possible over such a large model area, model cell counts and runtimes mean the model would become impractical to run. The model did represent the variability in hydraulic conductivity and transmissivity with 'pilot points' in the alluvial layers. This allowed the model to adjust the hydraulic properties to match the measured water level fluctuations. The uncertainty analysis also incorporated the use of stochastic parameter arrays within the alluvial formations, to replicate the variable nature of hydraulic conductivity further.

It should also be noted that contrary to UNSWs suggestions, numerous scaled cross sections directly from the groundwater model are presented throughout the report (Figures 8.3, 8.4, 10.3), along with structure contours for every layer in the model (Figure 8.5 to Figure 8.17).

UNSW reviewed geological logs and the geophysical data presented in the EIS and considered that the EIS groundwater model represented the more permeable sand and gravel units, referred to as the Gunnedah Formation in the EIS too distant from the proposed mining areas. UNSW refers to the fact that bore WM0365, which GHD identified as Narrabri Formation, intercepted sand and gravel at the base of the hole as indicating Gunnedah Formation occurred in this area. It is well known that the shallower Narrabri Formation can contain sand and gravel lenses at relatively shallow depths, however this does not mean they are hydraulically connected to the productive irrigation areas. Water quality data in the area close to the proposed mining shows the sand and gravel layers intercepted are saline (30,000 uS/cm), and therefore clearly not well connected to the fresher water in the main paleochannel where irrigation bores are concentrated.

The thickness and extent of the Narrabri and Gunnedah Formation in the EIS was based on PINEENA drillhole records, the 2010 groundwater model developed by New South Wales Office of Water (NOW) and Shenhua drilling results. During the EIS Shenhua installed a series of monitoring bores south of the Southern Mining area in the alluvium at approximately 500 m spacing. Hydraulic conductivity testing indicated low to moderate permeability ranging from 0.007 m/day to 0.5 m/day. These values are equivalent to 'unconsolidated silty sand/ fine sand' (Fetter, 2000) and designated as representing the Narrabri Formation in the EIS groundwater model. Therefore it is important to understand the Narrabri Formation, whist noted as being clay rich, was not set as having a low permeability in the groundwater model. The thicker more permeable gravels considered representative of the Gunnedah Formation were first intersected in bores WM0291 and WM0093A, at approximately 2 km south of the Southern Mining area and 3 km south of the Eastern Mining area at bore WM0427A. The extent and thickness of these more permeable sands and gravels was used in the EIS model to represent the extent of the Gunnedah Formation with a hydraulic conductivity of 5 m/day to 10 m/day.

The location of irrigation bores also provides a good indication of the more transmissive parts of the Namoi alluvial aquifer system termed the Gunnedah Formation. Consistent with the groundwater model, there are no major irrigators in the alluvium within 2 km of the proposed mine in the embayment where only the Narrabri Formation occurs due to poor yields and quality. Irrigation is generally located in the deepest part of the paleochannel channel, where yields are high, which is consistent with the hydraulic properties adopted in the EIS model.

We do not agree that the EIS model did not accurately represent the geology and hydrogeology, however to avoid doubt we constructed additional model scenarios where we represented the geology as presented by UNSW to determine the impact of their conceptualisation on the model predictions. Section 3.2.5 summarises the set up and results of the additional scenarios.

3.2.3 Colluvium

UNSW commented the EIS model did not represent colluvium layers that were depicted in geological cross sections. The EIS model did represent the presence of colluvium, not as a discrete model layer, but as part of the weathered zone. The colluvium, by its nature is a relatively thin, of limited extent and is largely unsaturated over the majority of the project area. Figure 3-3 and Figure 3-4 show cross sections through the EIS groundwater model with the mapped floor of the colluvium, the weathering surface and water table simulated in the model.

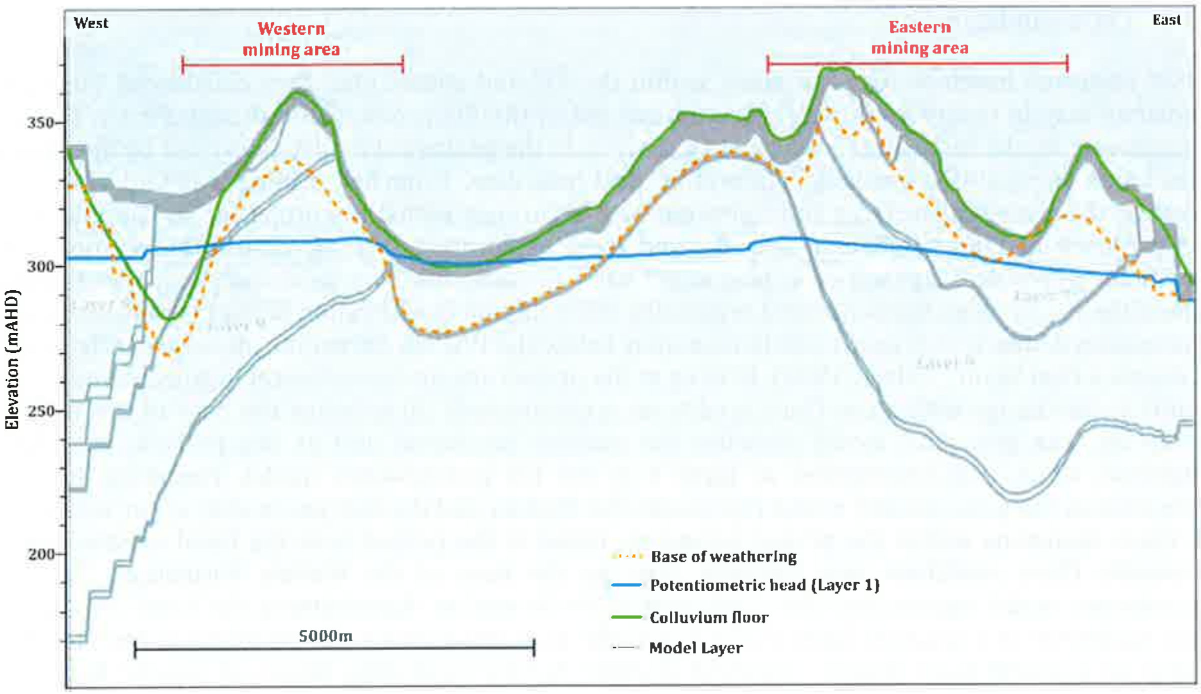


Figure 3-3 Cross-section showing colluvial extent (W-E)

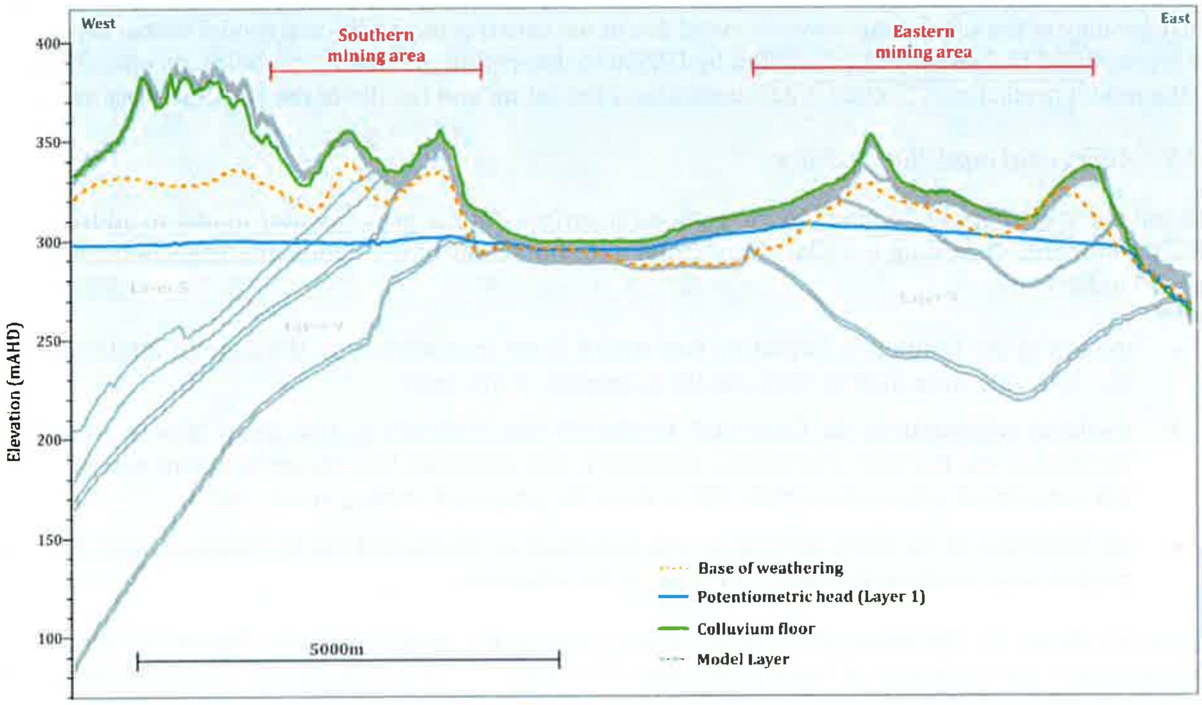


Figure 3-4 Cross-section showing colluvial extent (W-E)

The figures highlight that representing the colluvium with the weathered material readily accounts for this relatively insignificant unit. The colluvium is only saturated in a small area adjacent to the Western Mining area. There are two monitoring bores installed in this area (WM0035A and WM0293A). Permeability testing of the colluvial deposit recorded a relatively low permeability from 0.0006 to 0.008 m/day. The hydraulic conductivity of the model layers where the colluvium exists in the saturated zone is 0.01 m/day, which is conservatively high and considered an appropriate representation of this unit in the EIS model.

3.2.4 Clare sandstone

UNSW reviewed borehole logs contained within the EIS and commented they considered the Clare sandstone may in reality be thicker than represented in the EIS groundwater model. Firstly, the EIS groundwater model represented the layers exactly as in the geological model developed by Shenhua's consultants using all the available exploration drill hole data. Extensive drilling was undertaken to ascertain the geological surfaces and represent each accurately within the project area. The thickness and presence of Clare sandstone was derived from exploration drilling, core interpretation and downhole geophysical signatures. It was noted early on that the Clare sandstone unit was thinner around the Project area than observed regionally. The common classification of the Clare sandstone is a succession of quartz rich sandstone immediately below the Wallala Formation, directly overlying the Hoskissons Coal Seam (Tadros, 1995). Drilling at the project site and geophysical logging identified an abrupt facies change within the Clare sandstone, approximately 30 m below the base of the Wallala Formation. The geological model classifies the massive sandstone unit at this point as the Clare sandstone, which was represented as layer 6 in the EIS groundwater model. Therefore, layer 5 represents in the groundwater model represents the Wallala and the less permeable upper section of the Clare sandstone within the project boundary. Distal to the project area the basal massive more permeable Clare sandstone unit thickens reaching the base of the Wallala Formation. The EIS groundwater model represented this thickening of the formation. Representing the lower unit of the Clare sandstone as a separate layer in the EIS model does not indicate the structure of the model is wrong, as a model layer should represent discrete hydrostratigraphic layers of similar hydraulic parameters.

Again, whilst we do not agree that the EIS model did not accurately represent the geology and hydrogeology of the Clare sandstone, to avoid doubt we constructed additional model scenarios where we represented the geology as presented by UNSW to determine the impact of their conceptualisation on the model predictions. Section 3.2.5 summarises the set up and results of the additional scenarios

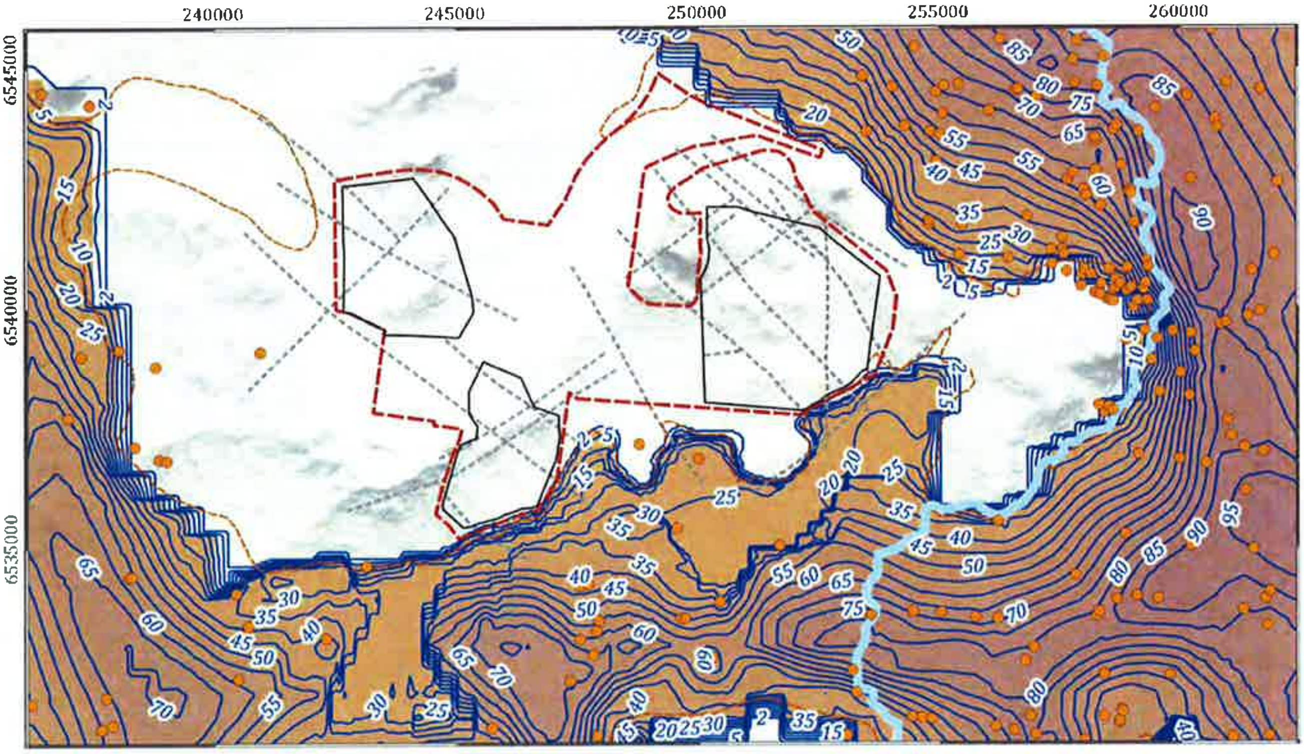
3.2.5 Additional modelling results

The following changes were made to the geological surfaces in the groundwater model to address the UNSW comments regarding the Clare sandstone and the extent of the sands and gravels termed the Gunnedah Formation:

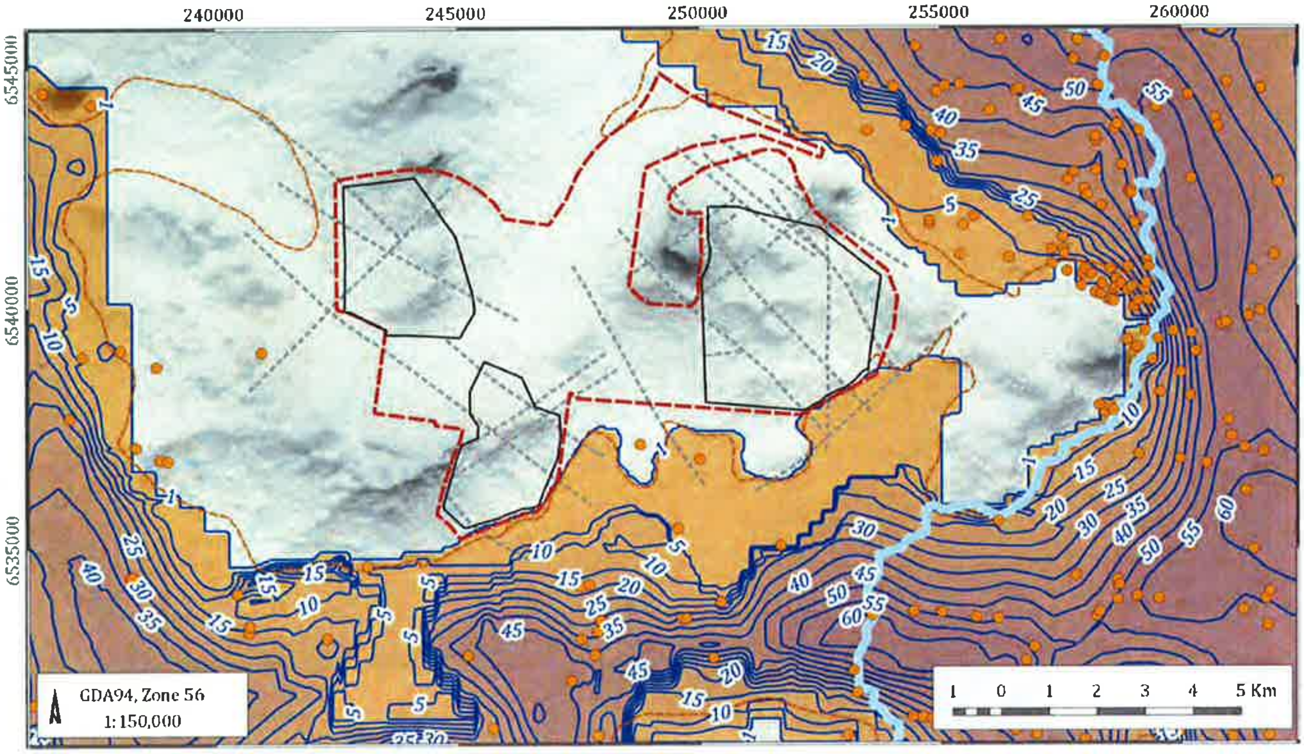
- the top of the Gunnedah formation was raised to be consistent with the base of WM0365, and the floor was smoothed to replicate the extension of this unit;
- the layer representing the Gunnedah formation was extended so that the unit was present at the limit of the Narrabri Formation, meaning it was extended into the embayment where it was not considered present to within 150 m from the proposed mining areas; and
- the thickness of the Clare sandstone was increased so it included the thickness of layer 5 in the project area resulting it directly underlying the alluvium.

Figure 3-5 shows the thickness of the alluvial sequences in the model scenario. Figure 3-6 shows the revised extent and thickness of layer 5 and layer 6. Figure 3-7 presents a cross section through the Southern Mining area with the revised layering. The revised layering changed the extent of weathering in the model due to the reference level of the model cell centres changing (refer to Section 3.2.1).

Layer 1 and 2 - Alluvial Thickness



Layer 2 - Gunnedah Formation



LEGEND

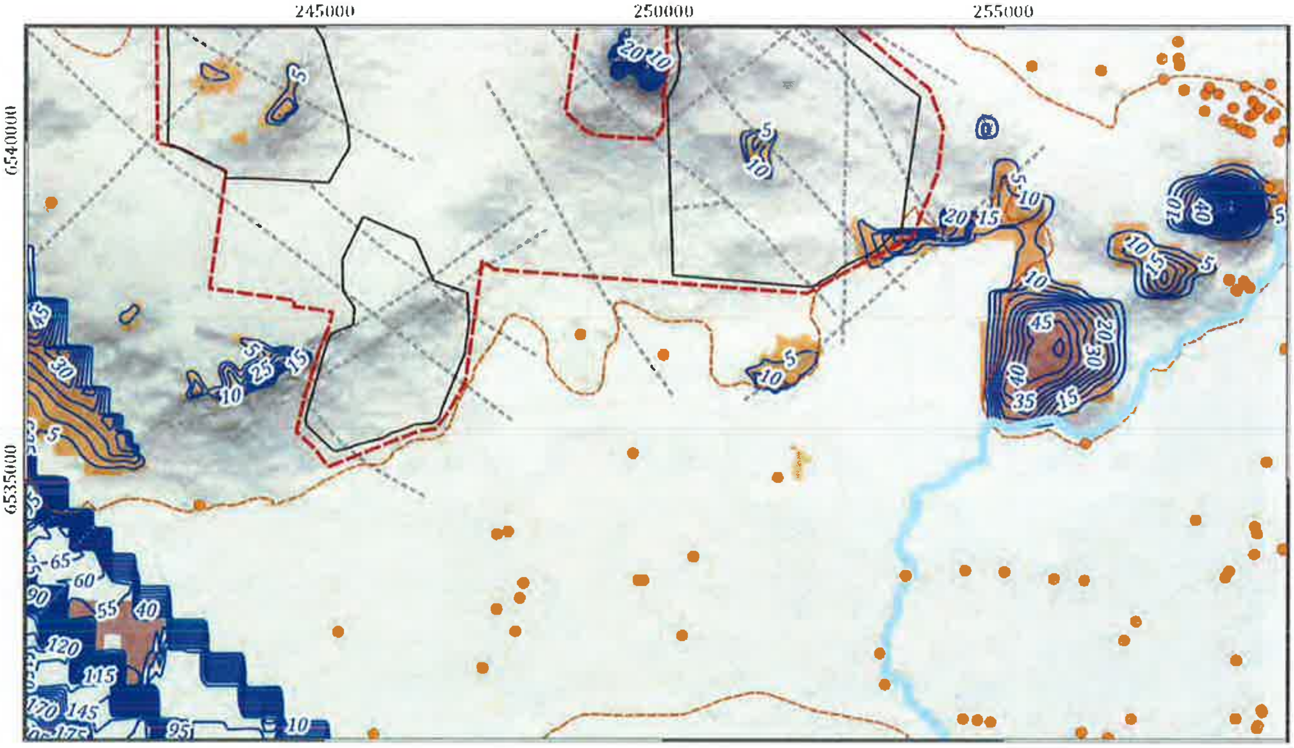
- ▭ Mining area
- ● PINEENA bore
- ╍ Project area
- ━ Mooki river
- ▭ Alluvial boundary
- ---- Surface Interpre Seism Faults
- ━ Thickness (m)

Watermark (G1501)

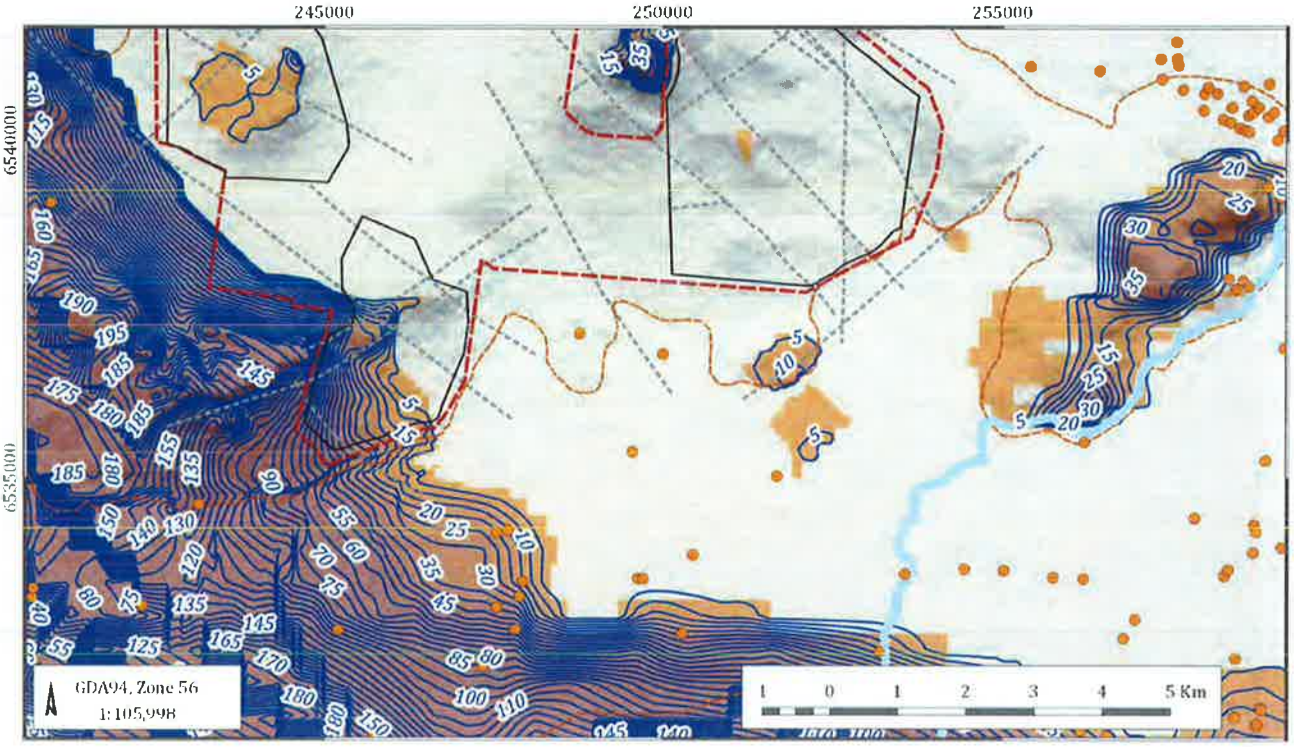
Namoi alluvium thickness (UNSW setup)

DATE	FIGURE No.
30/9/2014	**3-5**

Layer 5 - Interburden Thickness



Layer 6 - Clare Sandstone Thickness



LEGEND

☐ Mining area
● PINEENA bore
Project area
Mooki river
Alluvial boundary
Surface Interpre Seism Faults
Thickness (m)

Watermark (G1501)

Interburden and Clare Sandstone extents (UNSW setup)

DATE 30/9/2014

FIGURE No. **3-6**

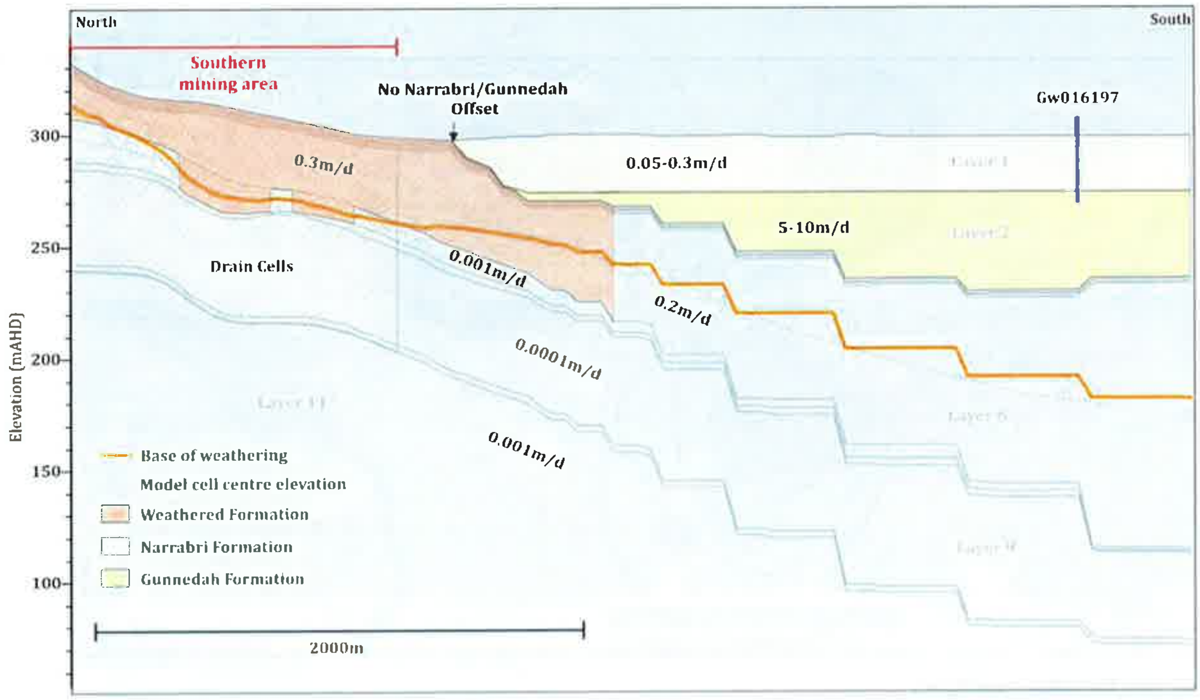


Figure 3-7 Cross section of UNSW model setup

The model with the revised layering was run using two different approaches to represent mining. Scenario 12 applied drain cells with the reference elevation to the base of the proposed mine pit (layer 10). Scenario 13 limited the drain cell reference elevation to the base of the model cell. This scenario was included as Dr Colin Mackie who reviewed the model for the PAC suggested that the EIS model was overly conservative in setting the reference elevation at the pit floor because it enhanced drawdown at the pit face, (refer Appendix 1). Table 3.2 summarises the set-up of the models.

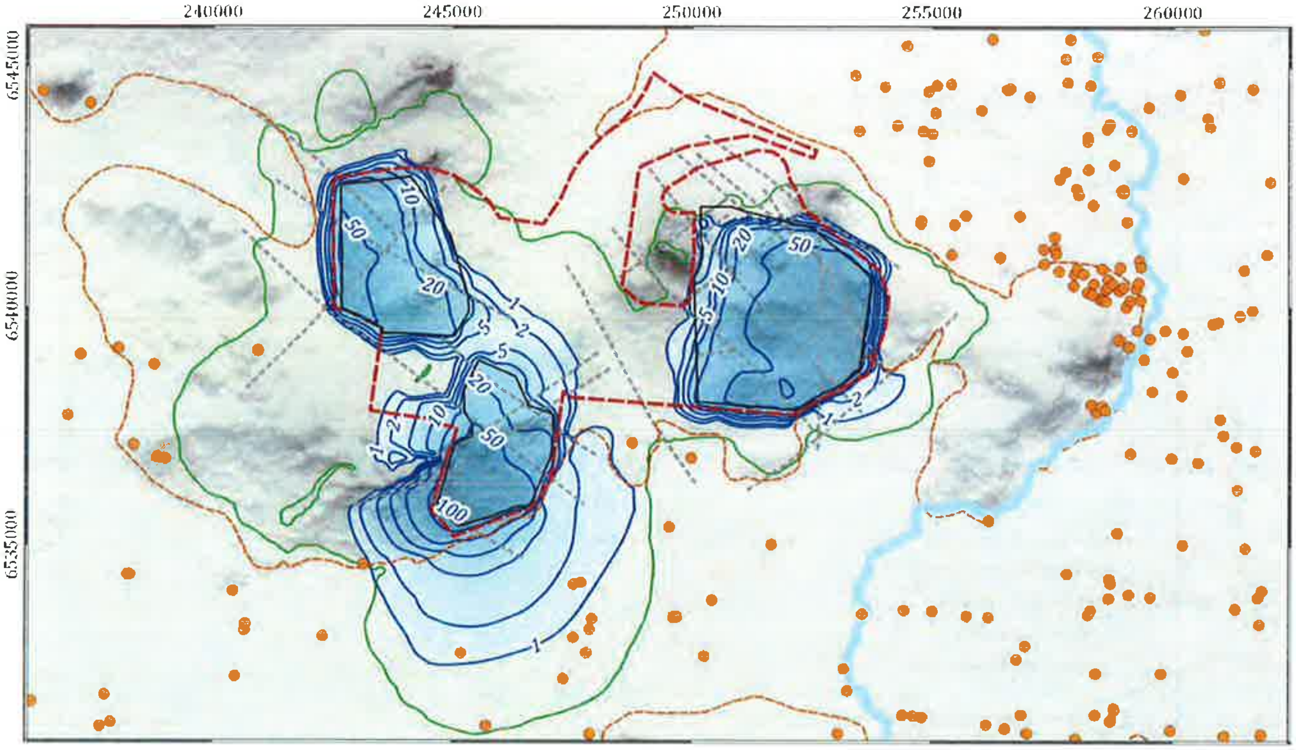
Table 3.2 Additional model scenarios

Scenario	Drain elevation	Mining method	Notes
12	Layer 10 base	Continuous backfilling	Layers adjusted to represent UNSW comments
13	Cell base	Continuous backfilling	Layers adjusted to represent UNSW comments

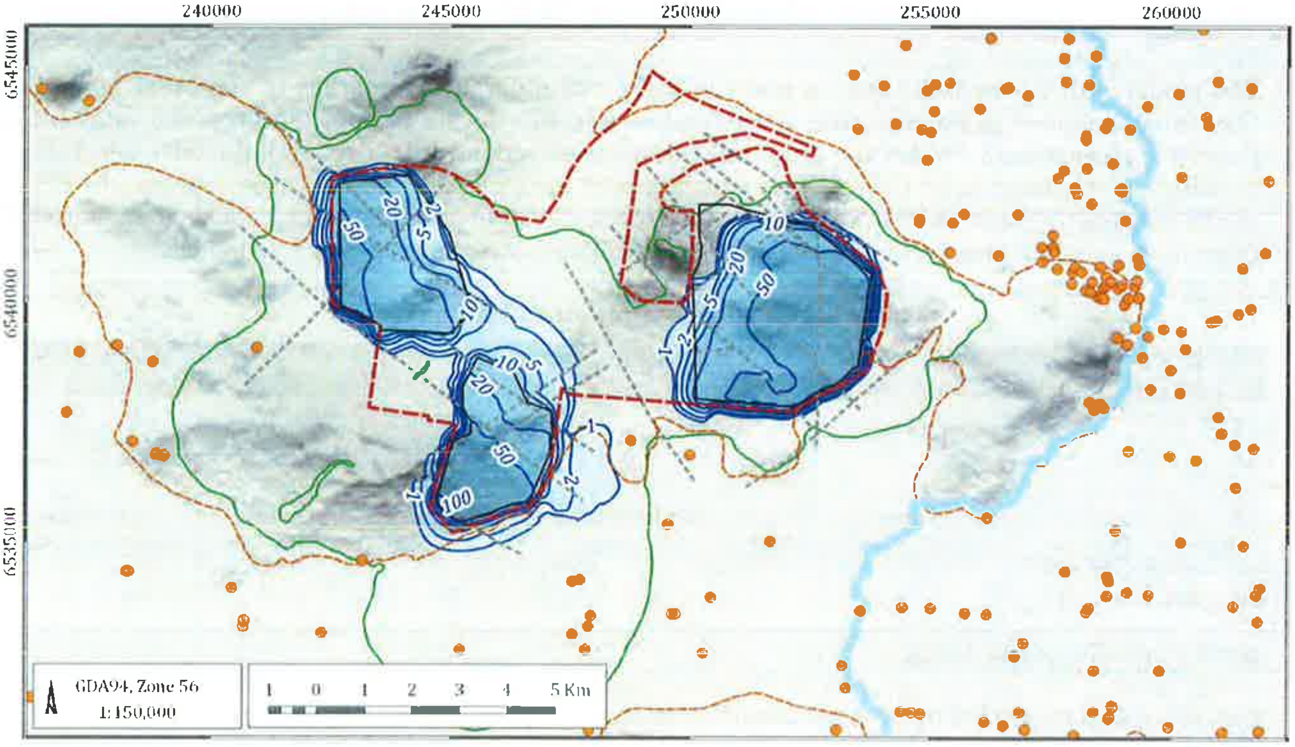
3.2.5.1 Groundwater levels

Figure 3-8 and Figure 3-9 present the maximum groundwater drawdown (at any time during the mine life) predicted by Scenarios 12 and 13 within the layers representing the Gunnedah Formation and the Clare sandstone.

Layer 2 - Gunnedah Formation



Layer 10 - Melvilles Coal Seam



LEGEND

☐ Mining area
● PINEENA bore
– – Project area
— Mooki river
☐ Alluvial boundary
- - - - Surface Interpreted Seismic Faults
— Groundwater Drawdown (m) EIS model (Uncert)
— Groundwater Drawdown (m)

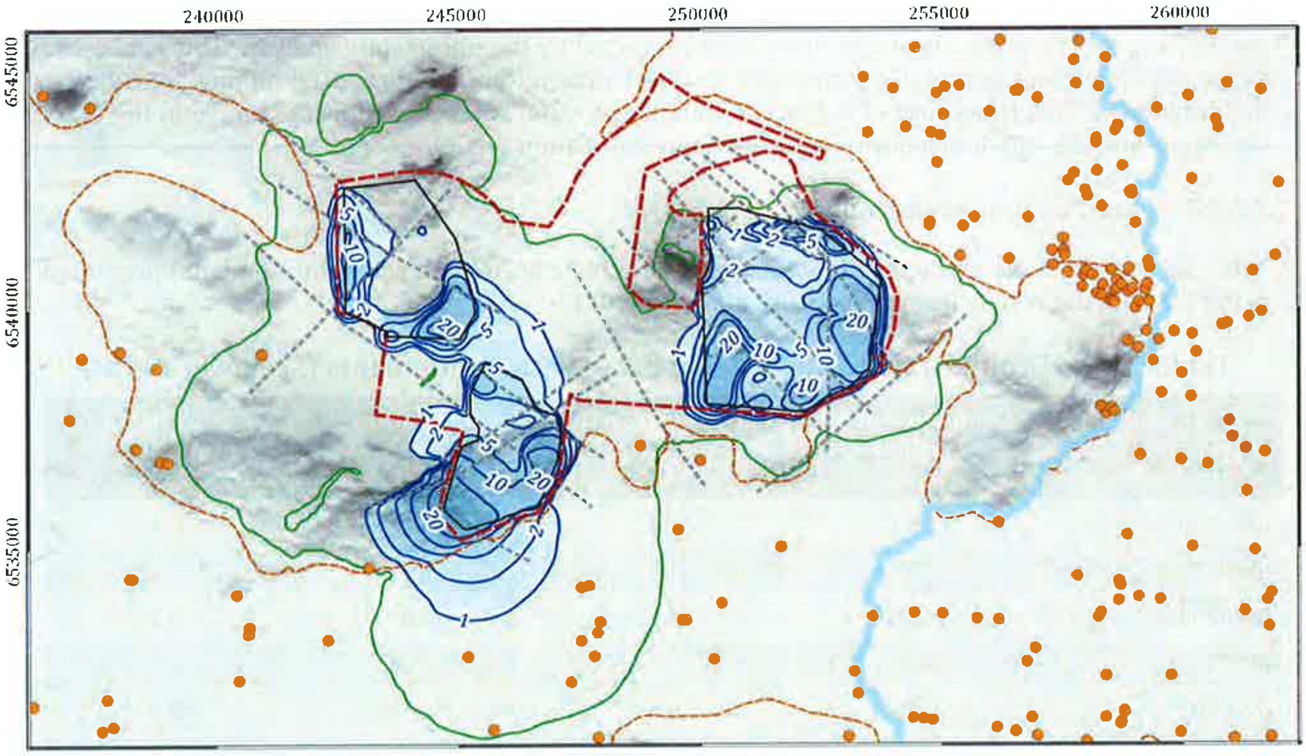
Watermark (G1501)

Groundwater Drawdown Impacts – Scenario 12

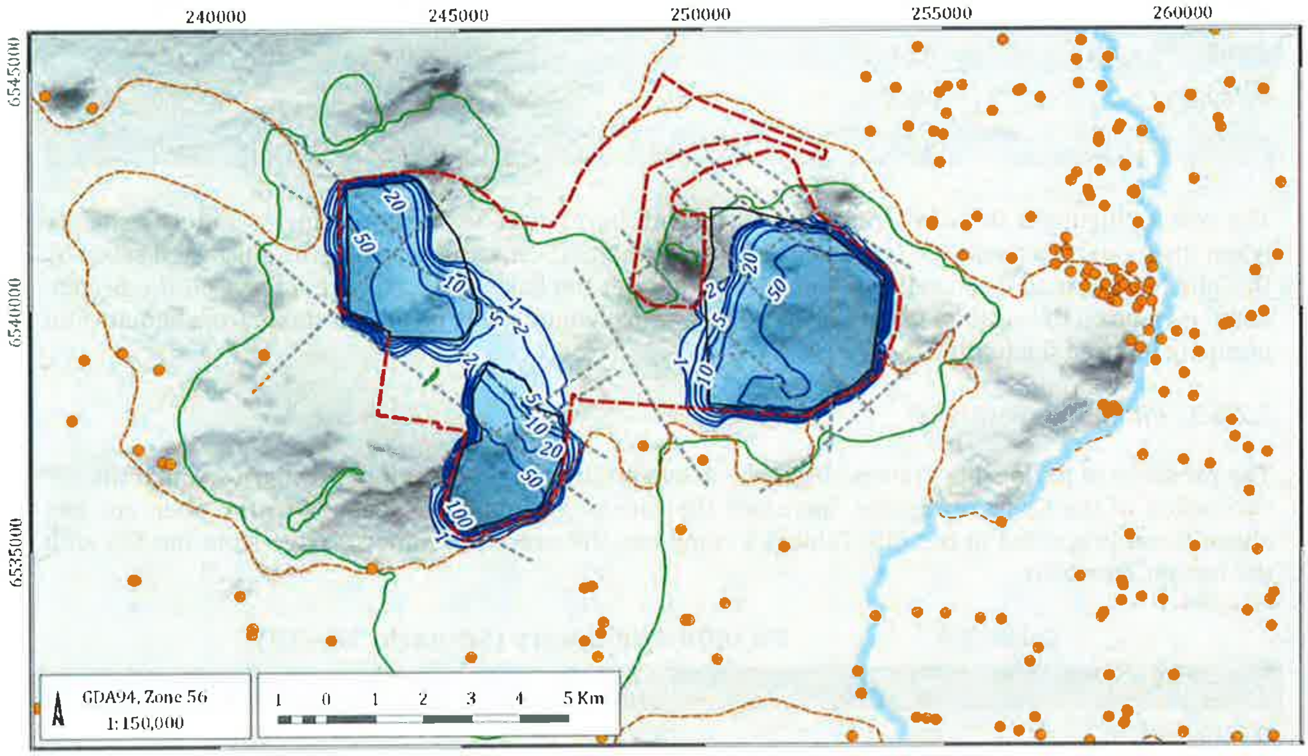
DATE
30/9/2014

FIGURE No.
3-8

Layer 2 - Gunnedah Formation



Layer 10 - Melvilles Coal Seam



LEGEND

- ☐ Mining area
- ● PINEENA bore
- – – Project area
- ━ Mooki river
- ⬚ Alluvial boundary
- ---- Surface Interpre Seism Faults
- ― Groundwater Drawdown (m) EIS model (Uncert)
- ― Groundwater Drawdown (m)

Watermark (G1501)

Groundwater Drawdown Impacts – Scenario 13

AGE

DATE 30/9/2014

FIGURE No. **3-9**

The results show that revised groundwater drawdown extents are very similar to results presented in the EIS, and less than the maximum drawdown predicted by the uncertainty analysis. This is because the presence of more permeable formations in closer proximity to the proposed mining areas buffer the drawdown. This is because of the larger volumes of water are released from storage in the Clare sandstone and the alluvium before significant depressurisation occurs.

3.2.5.2 Impact on groundwater users

Table 3.3 compares the predicted drawdown at each private bore (with water entitlements) presented in the EIS with the results from Scenario 12 and Scenario 13.

Table 3.3 Groundwater drawdown in bores with entitlements (Scenario 12-13)

Work Number	Completed depth (mbgl)	EIS drawdown (m)	Drawdown Scenario 12 (m)	Drawdown Scenario 13 (m)
GW015505	35.1	1.4	1.3	0.4
GW967790	70	1.1	0.5	0.2
GW029468	64.6	1.1	0.8	0.3
GW037713	64	1	0.6	0.2
GW060252	148.4	0.6	0.1	0.0
GW022622	45.1	0.3	0.0	0.0
GW967781	50	0.4	0.0	0.0
GW022984	45.1	0.3	0.0	0.0
GW022977	148.4	0.3	0.0	0.0
GW022620	48.8	0.3	0.0	0.0

The results highlight that the drawdown at private bores with water entitlements reduces slightly when the model is adjusted to represent the UNSW points (Scenario 12). Using the suggested setup by Dr Colin Mackie with drain cell reference elevations set the base of the cell the impact on the private bores is reduced to less than 0.5 m (Scenario 13), which would likely be undetectable from climate and pumping induced fluctuations.

3.2.5.3 Pit inflow sensitivity

The presence of permeable gravels closer the active pit area in the additional scenarios, and a thicker succession of the Clare sandstone, increases the rate of groundwater seepage to the open cut pits above those presented in the EIS. Table 3.4 compares the predicted mine seepage from the EIS with the further scenarios.

Table 3.4 Pit inflow summary (Scenario 12 - 13)

Scenario	Average inflow (ML/yr)	Total Cumulative Inflow (ML)
EIS base case	185	5,544
Scenario 12	624	18,720
Scenario 13	149	4,466

The results show that groundwater seepage rates are significantly higher using the conservative approach of setting the drain cell reference elevations (Scenario 12). Using a more realistic approach, (Scenario 13) results in groundwater inflows similar to the EIS base case.

3.2.5.4 *Groundwater management zone impacts*

Table 3.5 summaries the peak 'water take' from Groundwater Management Zone 7.

Table 3.5 Groundwater Management Zone 7 water take

Scenario	Peak water take (ML/yr)	Total Cumulative water take (ML)
EIS base case	29	871
Scenario 12	35	448
Scenario 13	9	48

Results indicate when the model is adjusted to represent UNSWs comments there is a small increase in the peak take from Groundwater Management Zone 7. Using a more realistic approach (Scenario 13) results in significantly reduced water take from Zone 7 compared to the base case. This is because increasing the thickness of the Clare sandstone increases the volume of water stored in this formation, which reduces the extent of drawdown in the bedrock. The more limited extent of drawdown in the bedrock reduces the area and calculated take from the alluvium.

3.3 Connectivity

3.3.1 *Pumping tests*

UNSW were critical of the EIS for not including a long-term pumping test (>30 days) in the study. GHD carried out eight pumping tests as part of the EIS, which included a 48 hour and two 7 day constant flow tests. Table 3.6 summarises the three long-term pump tests from the hydrogeological testing program.

Table 3.6 Long-term GHD pumping test summary

Pumping test location	Duration (days)	Screened Formation	Bores Analysed	Tested connection
90BL254822	2	Gunnedah Fm	WM0093A WM0093B WM0092 WM00291 WM0002	Gunnedah Fm Narrabri Fm Hoskissons Coal Hoskissons Coal Benelabri Fm
GW0967044	7	Gunnedah Fm	WM0562 WM0563 WM0561	Gunnedah Fm Gunnedah Fm Watermark Fm
WM0036L	7	Fractured Interburden	WM00339 WM0036C WM0363 WM0363A	Fractured Interburden Fractured Interburden Benelabri Fm Benelabri Fm

A seven-day pumping test was undertaken on irrigation bore GW0967044, which is located in the main productive channel of the Gunnedah Formation to the east of the Project. The bore was pumped at a constant rate of 76 L/s for seven days and highlights the difference in yield achievable from the Gunnedah Formation compared to the Narrabri Formation. During testing water levels were monitored in the alluvium and the underlying weathered bedrock (Watermark Formation). The testing indicated a hydraulic connection between the alluvium and the weathered bedrock, which agrees with the conceptualisation represented in the groundwater model. A bore was installed in the fresh Watermark Formation following the pumping tests (WM0665), and GHD recommended future analysis during irrigation pumping.

Bore 90BL254822 installed within the Gunnedah Formation was pumped for two days and monitoring undertaken in the alluvium and coal measures. A very muted response was observed in the coal measures whilst pumping from the overlying Gunnedah Formation, indicating a limited hydraulic connection between the two units (refer Figure 3-10).

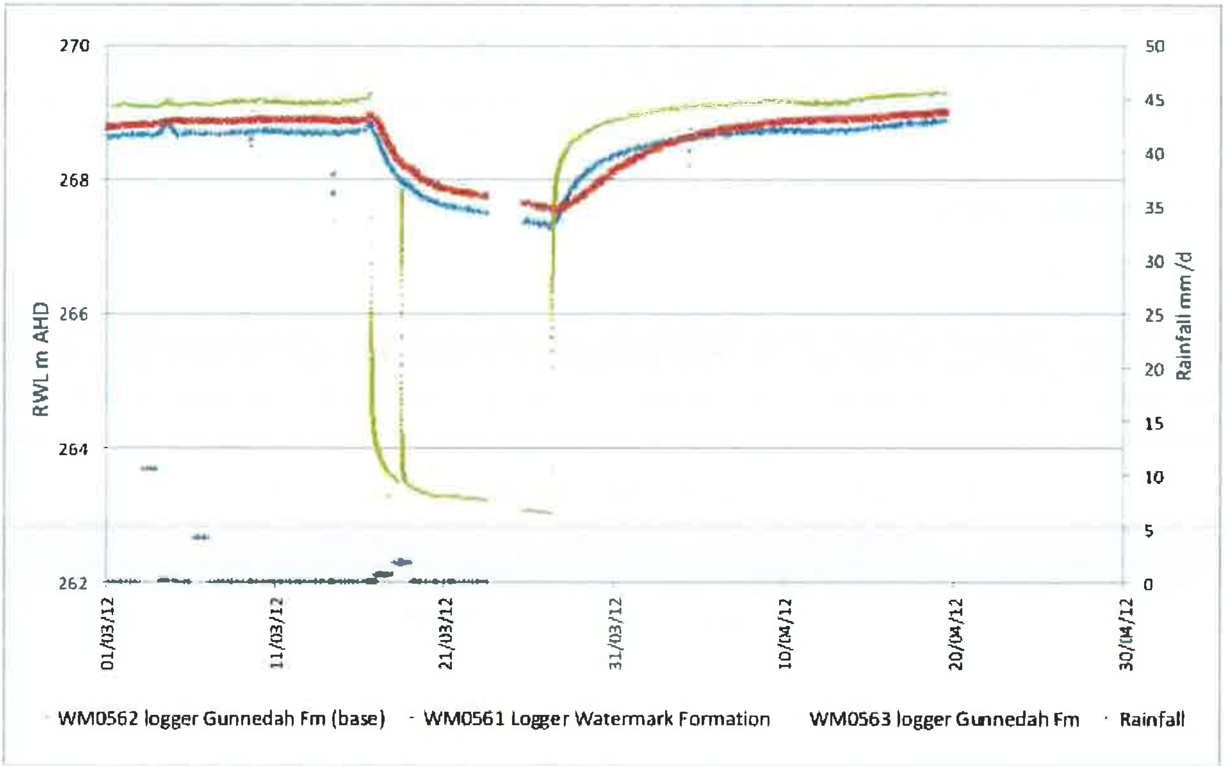


Figure 3-10 Pumping test results (90BL254822 – from GHD Hydrogeological report, 2012)

UNSW do not indicate why they recommend a pumping test period of 30 days. A pumping test should be of sufficient length to observe a response in the formations being tested, and in the case of the tests undertaken for the EIS the adopted pumping period was sufficient.

Another way to examine the interconnectivity is to examine the water levels in the bores installed in the ridge area to see if they fall when pumping occurs in the alluvial paleochannel supporting the irrigation bores east of the Project site. GHD have installed several bores in the eastern portion of the project site between the proposed mining areas and the main irrigation paleochannel where large volumes of groundwater are extracted. Figure 3-11 shows a selection of groundwater levels from the bores screening the bedrock in the ridge area, or are underlying the alluvial aquifer system.

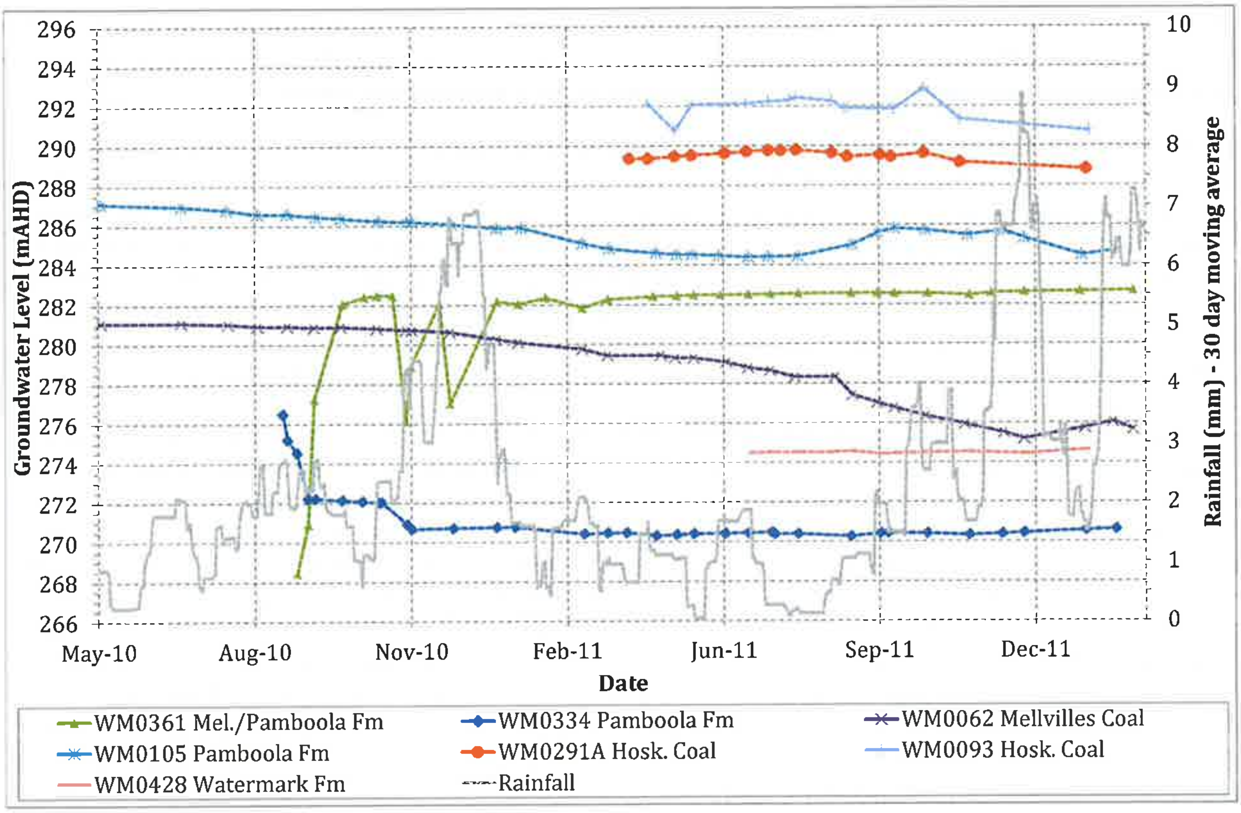


Figure 3-11 **Shenhua groundwater levels vs. rainfall**

The groundwater levels do not show any obvious responses to seasonal landholder irrigation. Bores such as WM0334, which has been monitoring groundwater levels since September 2010, do not exhibit any response from the highly fluctuating groundwater pressures within the Gunnedah Formation proximal to this location. This indicates the lower permeability units that outcrop in the ridge area retard the drawdown that occurs whilst pumping within the alluvial paleochannel, or that the drawdown from the irrigation bores in the main paleochannel does not reach the proposed mining area.

Despite this indication that there is a variable, but generally limited hydraulic interconnection between the ridge area and the alluvial paleochannel, the groundwater model allows these units to be hydraulically interconnected. MODFLOW SURFACT simulates porous media flow, with the degree of connectivity based on horizontal and vertical hydraulic conductivity and hydraulic gradients. As already noted, the weathered Permian formation is of a sufficient permeability to connect the mining areas and the alluvium in the model and the adopted approach is considered conservative.

3.3.2 Faults

UNSW noted in their review that *'we also saw evidence of inferred faults being modelled as impermeable barriers to flow without reference to definitive field evidence of their properties or existence. If any of these assumptions were wrong, the model would under-predict groundwater impacts.'*

The horizontal flow barrier package was used to represent faults in the EIS model in Layers 3 to 11, i.e. the bedrock only. It should be noted there is a graphical error in the EIS report that indicates faults were set in layers 1 and 2, i.e. the alluvium, but this was not the case in the model. GHD identified a series of potential faults across the Project area, based on the drilling data and geophysical surveys. Truncations of coal seams, gouge structures, slickensides, polished surfaces and abundant defects were considered indicators or faults. Groundwater levels in the numerous groundwater monitoring bores and vibrating wire piezometer did exhibit a highly variable potentiometric surface, which implies compartmentalisation of groundwater flow due to structures including faults.

The salinity of groundwater also varies significantly across the project site, further supporting the compartmentalisation conceptualisation. The optimal calibration of the groundwater model was also achieved with the faults retarding groundwater flow. The groundwater model adjusted the hydraulic conductance of these faults according to groundwater levels in the Permian strata over the Project area using parameter estimation software (PEST). To replicate the highly variable nature of the groundwater levels in the project area, the model calibrated the faults to a low hydraulic conductivity equivalent to 1×10^{-7} m/day. Despite being low, this is not impermeable as noted by UNSW in their review. It was recognised during the EIS that the way the faults were represented in the groundwater model could serve to increase the drawdown within the compartments being mined, but potentially reduce the drawdown in adjacent fault blocks beyond the mining area. Therefore, the sensitivity analysis in the EIS presented scenarios where the hydraulic conductance of the faults was increased, as well as a scenario completely removing the faults.

3.3.3 Modelling results

Whilst we consider the representation of the faults in the EIS model was the most appropriate approach, and other conceptualisations were explored including removing the faults in the sensitivity analysis, we have undertaken further modelling of scenarios to consider UNSWs comments. The model with the adjusted Gunnedah and Clare sandstone as outlined previously was further modified removing the faults completely. A second model was also developed simulating a series of 'hypothetical' highly permeable conductive fault conduits running directly from underneath the alluvium, and through the Western and Southern Mining areas. These hypothetical faults were represented by setting columns of model cells with high permeability and storage. Figure 3-12 shows the locations of the hypothetical faults with Table 3.7 summarising the model setup for each scenario.

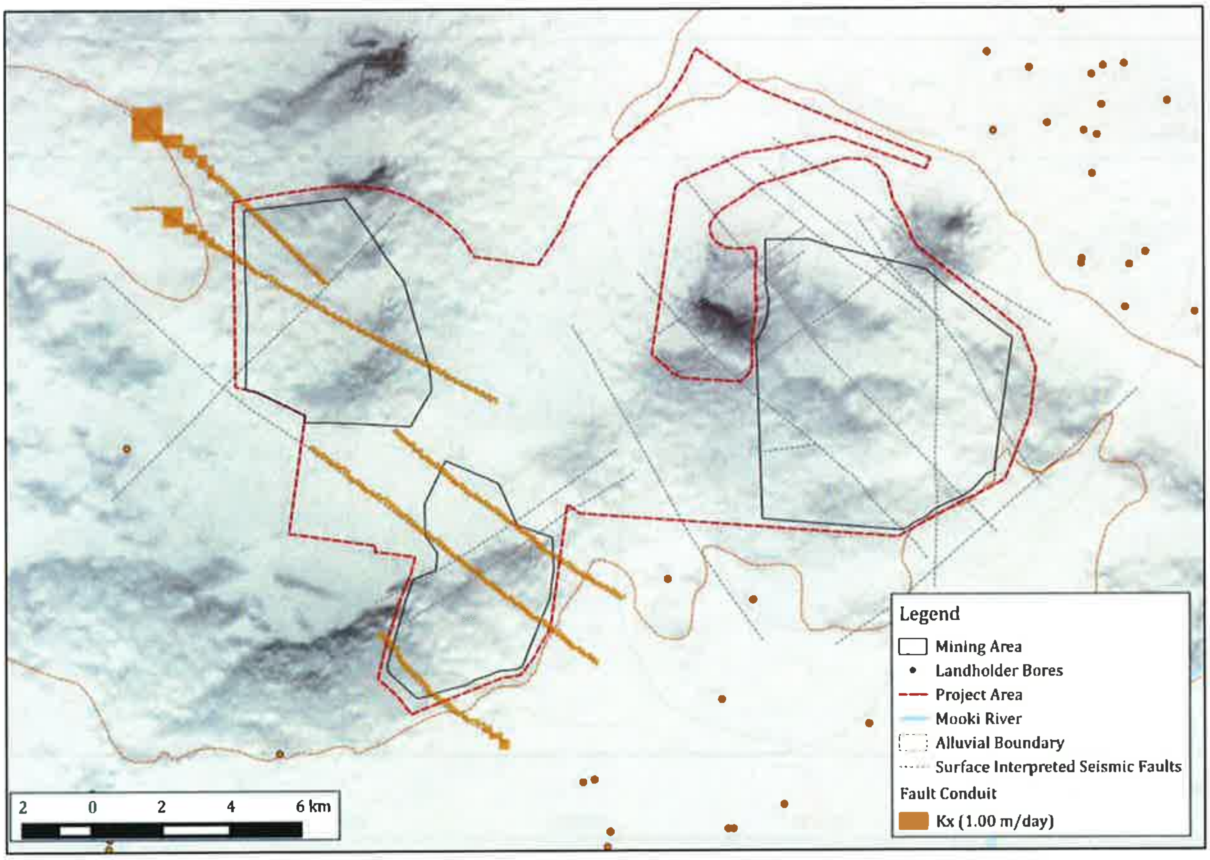


Figure 3-12 Hypothetical faults - Scenario 15

Table 3.7 Model scenarios (no barrier faults)

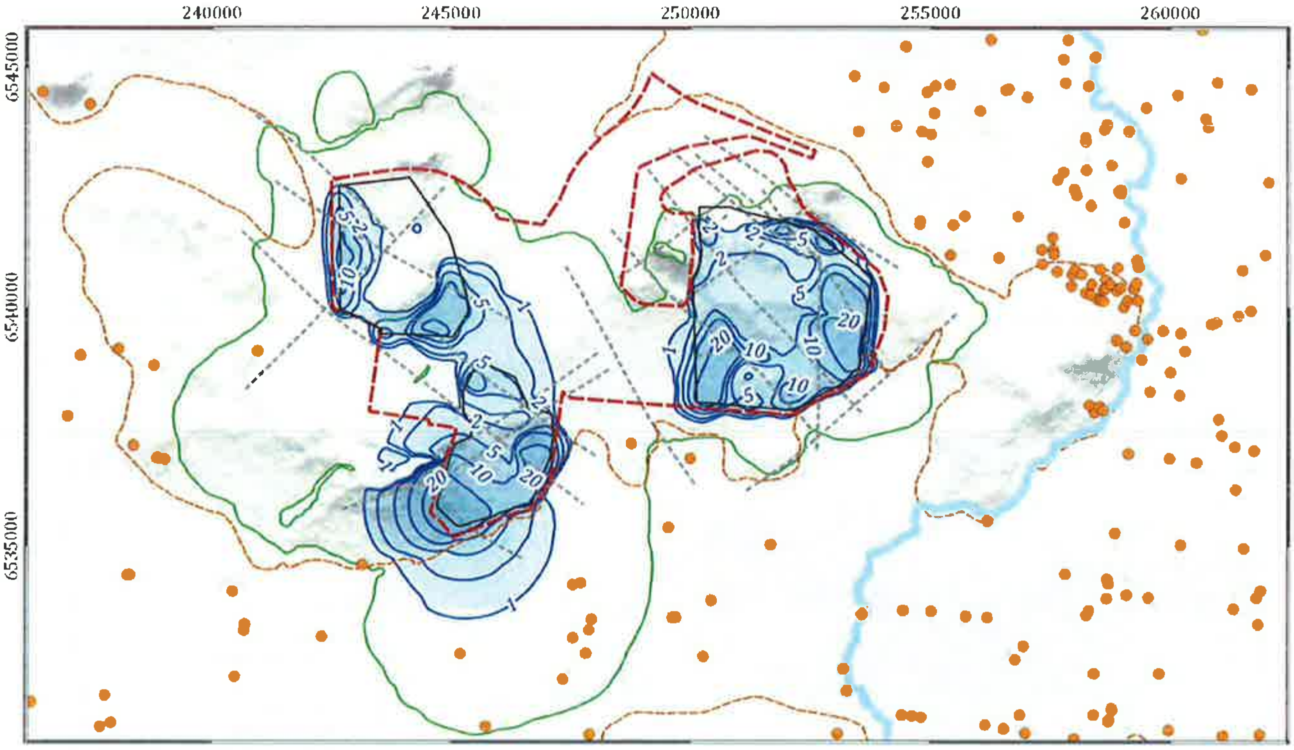
Scenario	Drain elevation	Mining method	Notes
14	Cell base	Continuous backfilling	Adjusted Gunnedah/Clare + no faults
15	Cell base	Continuous backfilling	Adjusted Gunnedah/Clare + conductive faults connecting alluvium to mine

Sections below outline the results of scenarios 14 and 15.

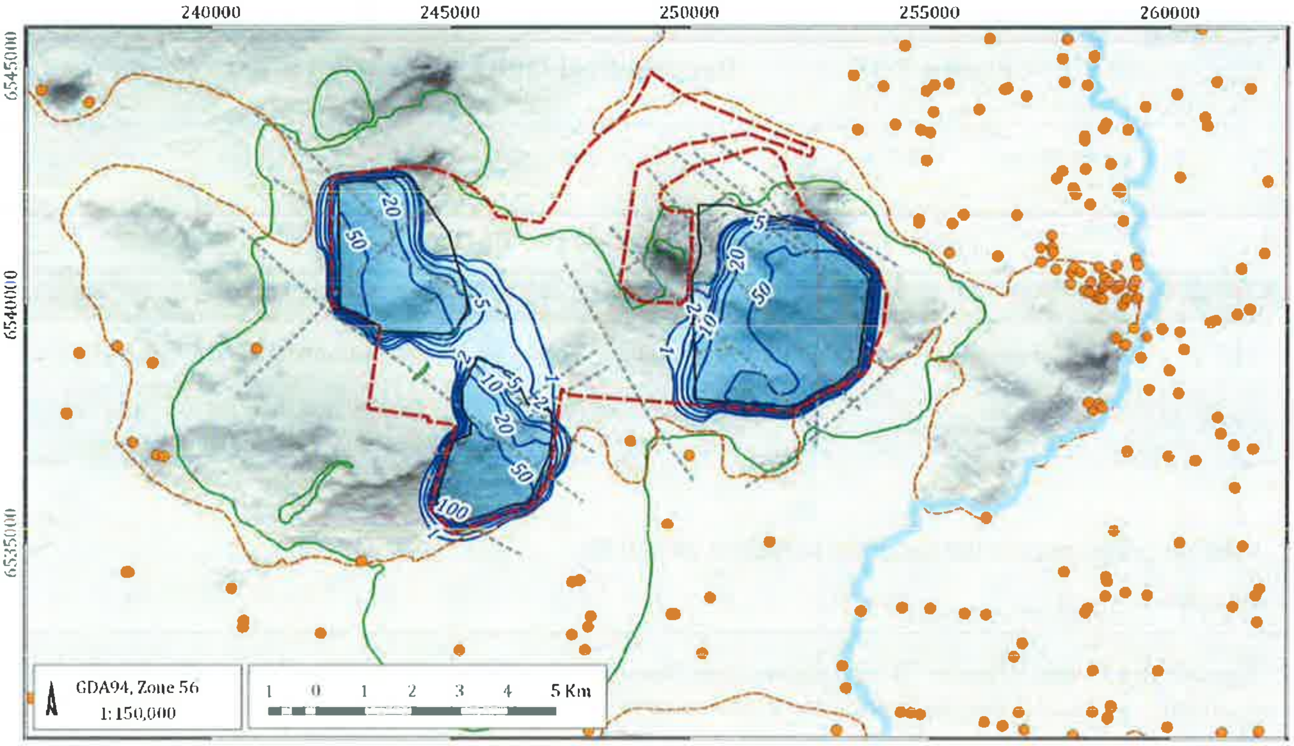
3.3.3.1 Groundwater levels

Figure 3-13 and Figure 3-13 show the maximum groundwater drawdown predicted by Scenarios 14 and 15, and again indicate both scenarios are within the bounds presented within the EIS.

Layer 2 - Gunnedah Formation



Layer 6 - Melvilles Coal Seam



LEGEND

☐ Mining area
● PINEENA bore
- - Project area
— Mooki river
☐ Alluvial boundary
---- Surface Interpreted Seismic Faults
— Groundwater Drawdown (m) EIS model (Uncert)
— Groundwater Drawdown (m)

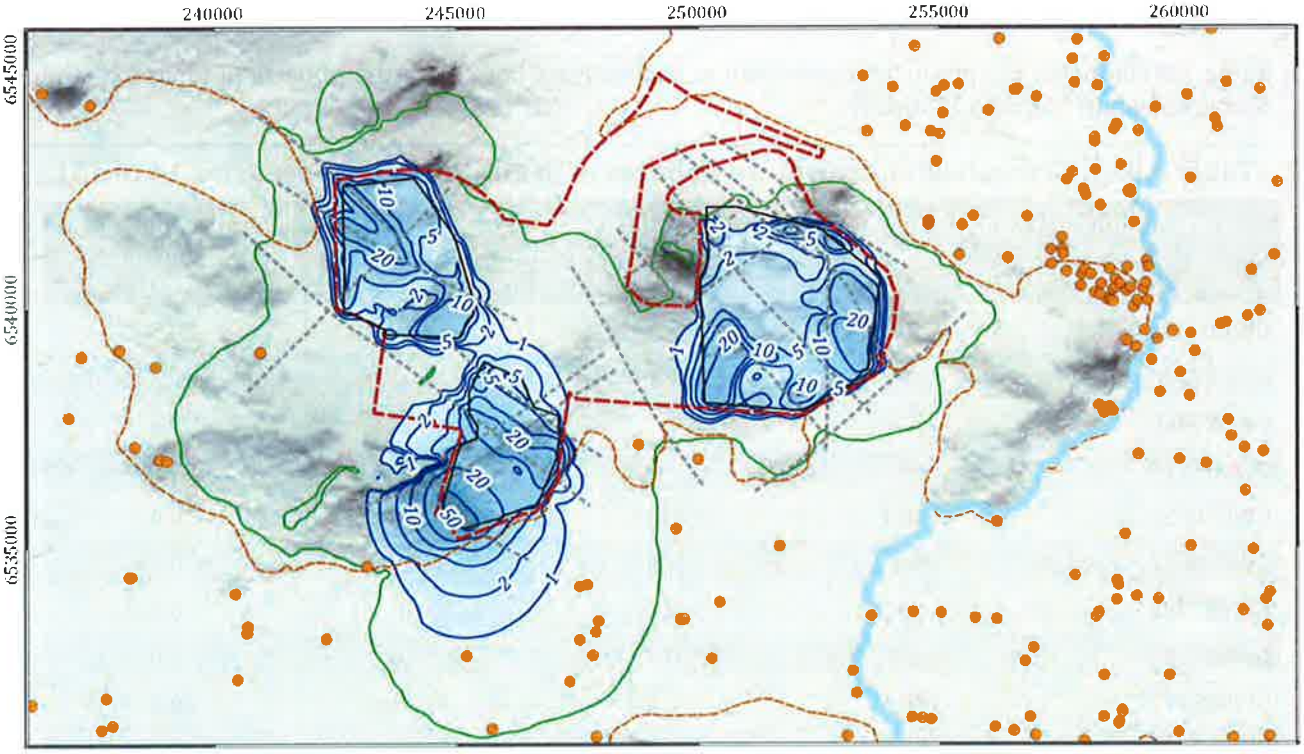
Watermark (G1501)

Groundwater Drawdown Impacts – Scenario 14

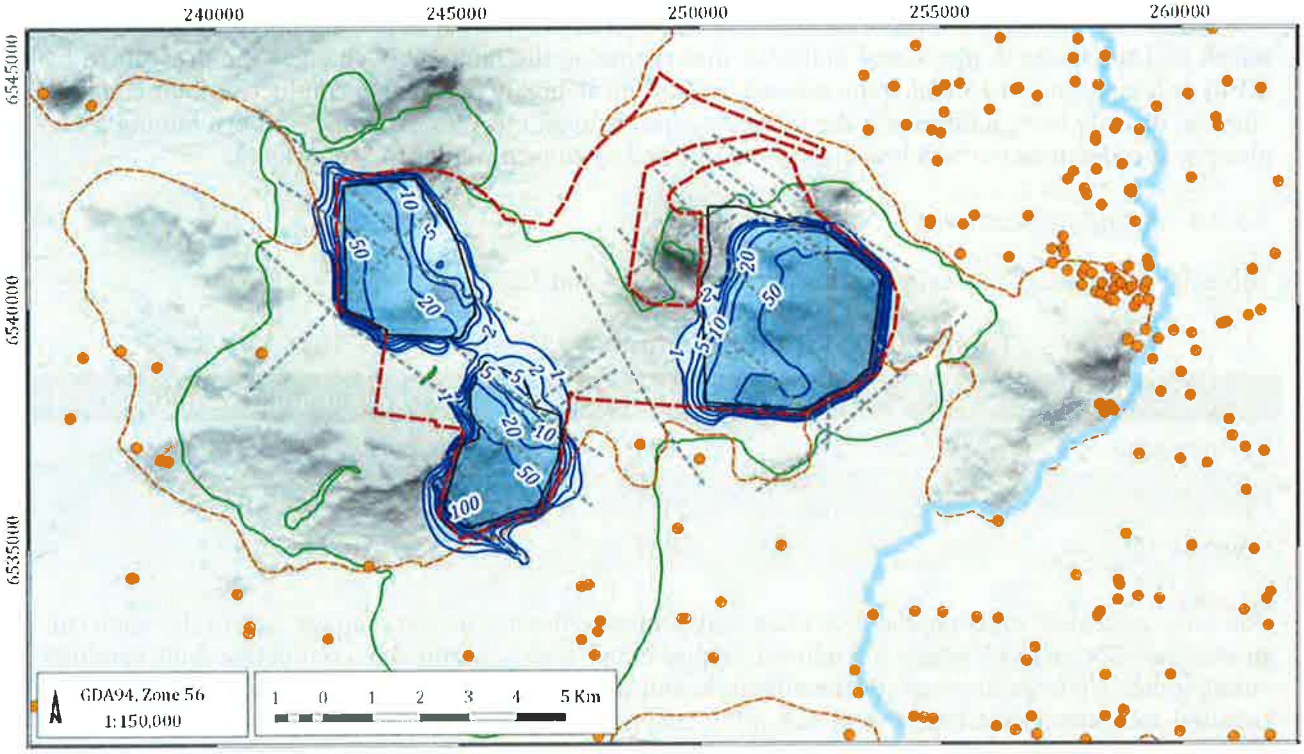
DATE
30/9/2014

FIGURE No.
3-13

Layer 2 - Gunnedah Formation



Layer10 - Melvilles Coal Seam



LEGEND

▭ Mining area
● PINEENA bore
- - Project area
▬ Mooki river
⬚ Alluvial boundary
- - - - Surface Interpre Seism Faults
— Groundwater Drawdown (m) EIS model (Uncert)
— Groundwater Drawdown (m)

Watermark (G1501)

Groundwater Drawdown Impacts – Scenario 15

AGE

DATE
30/9/2014

FIGURE No:
3-14

3.3.3.2 Impact on groundwater users

Table 3.8 compares the predicted drawdown at each private bore, with the impacts predicted by the Scenario 14 and Scenario 15 models.

Table 3.8 Groundwater drawdown in bores with entitlements (Scenarios 14 to 15)

Work number	Completed depth (mbgl)	EIS drawdown (m)	Drawdown Scenario 14 (m)	Drawdown Scenario 15 (m)
GW015505	35.1	1.4	0.5	0.5
GW967790	70	1.1	0.2	0.2
GW029468	64.6	1.1	0.3	0.3
GW037713	64	1	0.2	0.2
GW060252	148.4	0.6	0.0	0.0
GW022622	45.1	0.3	0.0	0.0
GW967781	50	0.4	0.0	0.0
GW022984	45.1	0.3	0.0	0.0
GW022977	148.4	0.3	0.0	0.0
GW022620	48.8	0.3	0.0	0.0

The results for Scenario 14, report a very similar level of drawdown at private bores to Scenario 13, which had the faults in place, and indicates that removing the faults only changes the drawdown by 0.1 m or less. Scenario 15 which introduced 'hypothetical' highly permeable conductive fault conduits running directly from underneath the alluvium, and through the Western and Southern Mining areas also produced almost impacts less than in the EIS, and by chance similar to Scenario 14.

3.3.3.3 Pit inflow sensitivity

Table 3.9 summarises pit seepage rates for Scenarios 14 and 15.

Table 3.9 Pit inflow summary (Scenario 14 - 15)

Scenario	Average inflow (ML/yr)	Total Cumulative Inflow (ML)
EIS base case	185	5,544
Scenario 14	161	4,832
Scenario 15	805	24,134

The table indicates removing the faults has only limited influence on the seepage rate to the open cut. In contrast, Scenario 15 which introduced 'hypothetical' highly permeable conductive fault conduits running directly from underneath the alluvium, and through the Western and Southern Mining areas resulted in a significant increase to the mine seepage rates. This is primarily because of the high storage in the fault zone and also within the thicker succession of the Clare sandstone. When interpreting the results of this scenario is important to understand it is considered completely improbable because the model represented the faults as being a single cell wide, which is 50 m, with a hydraulic conductivity of 1 m/day. This is equivalent to having a 50 m wide channel filled with sand running vertically from the mining area to the alluvium. In our experience faults in Australian coal mining region do not generate expansive zones of fractured rock either side of the slippage plane, and the zone where hydraulic properties are changed is typically only a few metres wide, not 50 m.

If faults of this magnitude were present the significant contrast in the hydraulic properties mean they would be have been detected by drilling and had a very strong signature in geophysical surveys. There is also no geological reason why such faults would have formed. The offset in the faults in the project area is not large and it is expected an offset of many hundreds of metres would be required to grind the host rock either side of the fault plane significantly. Despite the implausible nature of this scenario the volume of groundwater inflow remains manageable averaging 2.2 ML/day. Also because faults are confined to a limited area within the mining pit face they are amenable to engineering measures to control the seepage subject to geotechnical constraints.

3.3.3.4 Groundwater management zone impacts

Table 3.10 summarises the water take from the Groundwater Management Zone 7 for Scenarios 14 and 15.

Table 3.10 Groundwater Management Zone 7 water take

Scenario	Peak water take (ML/yr)	Total cumulative water take (ML)
EIS base case	29	871
Scenario 14	10	55
Scenario 15	6	23

Somewhat counter-intuitively the results for both scenarios indicate a lesser 'water take' from Groundwater Management Zone 7. This is because the drain reference elevation is set at the base of the cell and because the groundwater depressurisation in the bedrock underlying the alluvium reduces, due to the higher volume of groundwater storage within the faults and Clare sandstone, which needs to be displaced before depressurisation of the alluvium occurs. This higher storage in the bedrock buffers the drawdown within the alluvium, and illustrates that faults can result in more water seeping to the proposed open cut pits, without inducing additional impacts on the alluvial aquifer systems.

3.4 Lake Goran and model water balance

UNSW commented on the representation of Lake Goran within the EIS model, and considered it may not account for recharge events when it fills with rainfall runoff. It is true that the groundwater model represented Lake Goran as an evaporative sink removing groundwater from the alluvium on a net basis. We also agree that this is a simplification of Lake Goran's behaviour, but we do not believe it has any material impact on the predicted impact of the project. Lake Goran is remote from the project area and the modelling did not predict the zone of drawdown would interact with the Lake.

The conceptualisation that the lake is a net discharge zone was reached by reviewing data from bores surrounding the lake to ascertain water levels and flow directions. Groundwater quality records surrounding the area were also reviewed to understand how the lake interacts with the groundwater system. Results indicate flow towards Lake Goran, with evaporation causing salts to accumulate within the underlying alluvium. For the purposes of groundwater modelling it was concluded on a net basis the lake acts as an evaporative sink. The model represented Lake Goran using the river package and assigned a zero stage height, so continuous groundwater discharge occurred.

Figure 3-15 presents a snapshot through the predictive groundwater model, illustrating the interaction between the groundwater table and the SURFACT river cells.

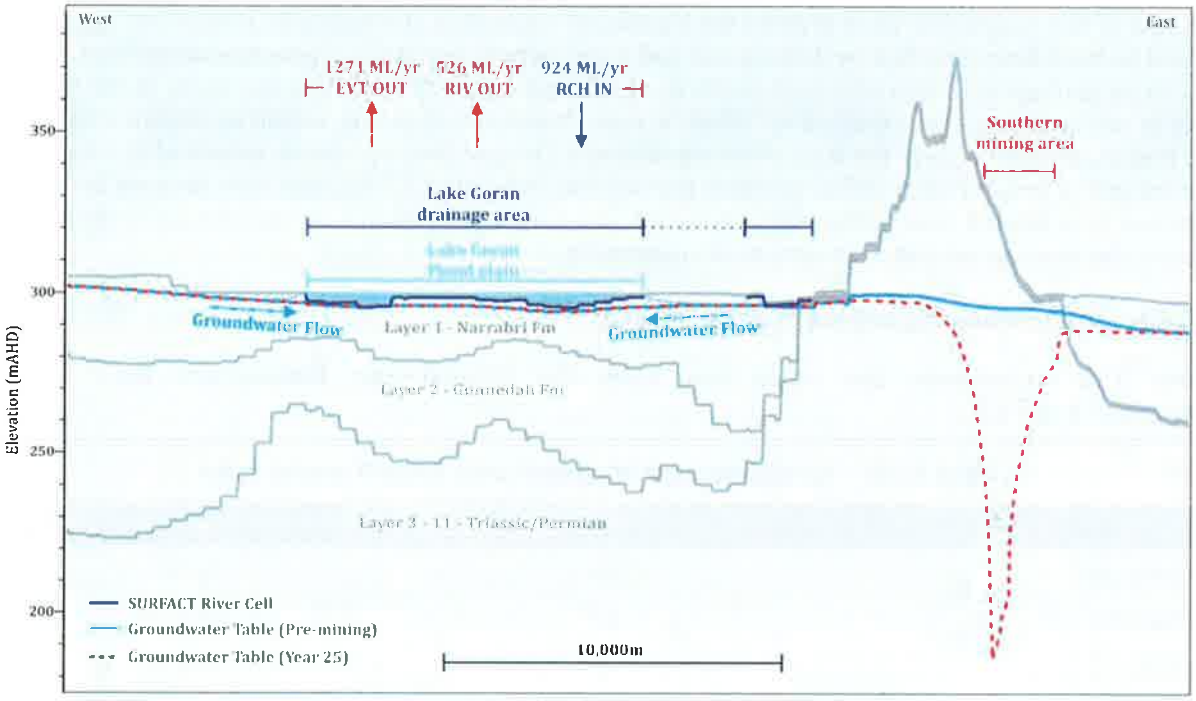


Figure 3-15 **Cross section through Lake Goran**

The results show that Lake Goran is a localised feature, which does not directly interact with the Watermark Project. Groundwater flows into Lake Goran, which represents a groundwater depression.

Whilst events where the lake fills were not simulated, if they did occur the net effect would be to provide additional recharge to the groundwater system. Assuming Lake Goran heavily influenced the alluvial aquifer system during wet periods, groundwater impacts would be buffered due to increased groundwater through-flow surrounding the Project area. We anticipated this, and preferred to take a more conservative approach to representing the surface water/groundwater system in this area.

UNSW also imply Dr Noel Merrick of Heritage Computing disagreed with the conceptualisation of Lake Goran representing a net discharge zone. This is not correct – Heritage Computing simply outlined a change in the initial conceptualisation of Lake Goran from the start of the project to the final report.

UNSW also expresses concerns about other water budgets in the model. The EIS report is completely transparent regarding the model budgets across the steady state, transient, predictive and recovery scenarios. All budgets for surface water interactions, recharge, evapotranspiration, flows between major aquifer systems, pumping and storage are clearly presented for review. The other reviewers Dr Noel Merrick, Dr Franz Kalf and Dr Colin Mackie have all agreed the model budgets are plausible.

3.5 Project Water balance

All of the additional model scenarios, except the implausible fault scenario, resulted in lower seepage rates to the active mining areas than reported in the EIS report. WRM Water and Environment developed the mine water balance, and used groundwater seepage rate from the EIS that was corrected for evaporative losses from the mining areas. This same correction was applied to Scenarios 10 and 11. Table 3.11 compares the values for groundwater seepage used in the water balance, with the results from scenarios 10 and 11.

Table 3.11 'Pumpable' groundwater seepage

Year	EIS (ML/a)	Scenario 10 (ML/a)	Scenario 11 (ML/a)	Scenario 10 difference (ML/a)	Scenario 11 difference (ML/a)
2	0	0	0	0	0
5	14	0	0	-14	-14
10	57	0	0	-57	-57
15	43	22	34	-21	-9
21	175	0	0	-175	-175
25	371	171	487	-200	116
30	132	126	0	-6	-132

The table shows the corrected seepage rates and the net difference between the EIS and Scenarios 10 and 11. WRM water balance modelling predicted a 90th percentile off-site water demand of approximately 600 ML in the EIS study. The revised results indicate that the volume of water required to be supplied from external sources is likely to be higher than indicated by the EIS water balance modelling. The increase in water supply requirement will be similar to the reduction in groundwater inflow, so in the initial 15 years, the additional water supply required is likely to be less than 60 ML, increasing to a maximum of 200 ML around year 25.

3.6 Uncertainty

The Watermark EIS project conducted an extensive and detailed Monte Carlo uncertainty analysis, which Heritage Computing concluded was *'done more thoroughly than is normal best practice'*.

UNSW made several comments about the uncertainty analysis noting *'50% of the uncertainty analysis results are discarded without recalibration'*. If all realisations that did not calibrate well were recalibrated the approach would be referred to as a 'null space' Monte Carlo analysis. To understand why a 'null space' Monte Carlo analysis was not undertaken, it is important to understand the work required to complete an uncertainty analysis on a large regional model.

The uncertainty analysis involved creating 500 versions of the model using stochastic parameters based on the calibrated value as the mean, and the 90th percentile of hydraulic testing results as the upper and lower bounds. All parameters were explored in the model, including:

- aquifer parameters, including fault conductance;
- boundary conditions, including general head boundary / river bed conductance;
- pumping rates; and
- recharge rates.

Due to the nature of the analysis, 250 model runs had to be rejected from the analysis, as they were not representative of the calibrated model. Additional to this, model results from the worst ten percent of model results were rejected in order to filter out unrealistic parameter sets within the extreme realized arrays.

Unlike the majority of research models that utilise 'null space' uncertainty analysis and recalibrate each model, the Watermark model was a large and therefore slow running model that contained a very large number of parameters (380). Pilot points were limited to the Namoi alluvial aquifer system, and coal seam hydraulic conductivity decreased with depth – all other layers had uniform parameters. Null space uncertainty analysis lends itself to models calibrated using a number of regularized pilot points throughout all layers.

Null space Monte Carlo analysis is a lengthy process, which involves creating a direct projection of the relationship between the model parameters and the observation records used to calibrate the model. This is achieved by creating a stochastic array (realization) of parameters , 'normalising' the results to better fit the observed hydraulic testing data, and then testing the calibrated result. Each realization of the model requires recalibration so that the relationship is untouched. By way of example, if the Watermark model maintained the same pilot point resolution in all 11 layers, the total of model parameters would exceed 4,150 parameters. The transient calibration model ran in approximately 30 minutes, meaning one single realization would require 2,075 hours of computing time to analyse. Additional to this, it is common practice to perform two calibration optimisations, which could add an additional 1,000 hours per realization. This whole process must be repeated approximately 500-1000 times before the predictive uncertainty analysis can commence. For this reason, we did not perform a recalibration of each realization. To try and practically replicate an approach similar to null space Monte Carlo, we tested a calibration target using a cut-off limit, which represented noticeable de-calibration of the model. We did not 'normalise' the upper and lower bounds within each realization due to the absence of pilot points in lower layers.

Our approach is considered more conservative than the null space approach where recalibration occurs. This is because our approach allows for slightly more model de-calibration than using the null space technique. We also allow our upper and lower bounds to extend past the limits applied during normalisation, depending on where the mean calibrated value ended up compared to the range of testing data.

UNSW argue that the upper ends of the model impacts represent scenarios that have extreme impacts to the groundwater system. However we consider these impacts manageable as:

- no landholder bores are impacted by more than 2m of drawdown
- a maximum of approximately 0.6 ML/day will be intercepted from the Permian to the alluvium (less than majority of pumping at a single irrigators bore); and
- the maximum pit seepage rates is 5 ML/day compared with 2 ML/day base case - this peak is similar to another project in the region, being the Maules Creek Project that predicted a peak of about 5 ML/day in the sensitivity analysis and was deemed manageable (AGE 2011).

3.7 Model calibration

Due to proximity of the Watermark Project to highly productive aquifers, it was decided early on that the model should represent the regional aquifer system right down to the Liverpool Ranges where significant recharge to the system occurs. The model covered 75 x 91 km, and required calibration to a very large dataset over highly variable observation ranges. The Australian modelling guidelines (Barnett, 2012) do not specify an absolute calibration target at each observation location (e.g. less than 10m at each observation location). A calibration target must respect the range of data, and ultimately the objective of the project. In this instance, a Class 2 model was required to analyse the impacts sufficiently. A class 2 model requires:

- validation demonstrated (yes);
- Scaled Root Mean Squared error (SRMS) is below 5% (2.7%);
- long term trends in seasonal fluctuations and response to groundwater extraction replicated in majority of monitoring bores (yes);
- recent transient calibration data used (yes); and
- fluxes of regional flow calibrated from surface water exercises (yes).

The Watermark project met and sometimes exceeded all calibration acceptance criteria to meet the requirements of a class 2 model.

Calibrating the model to groundwater responses in the Namoi alluvial aquifer system was the primary focus in this study. The groundwater study does not hide the fact that groundwater levels within the fractured rock in the Project ridge area do not display excellent calibration signatures. This is because the fractured rock system displays high vertical gradients through the stratigraphic column, and exhibits localised perching and depressions spatially over the site.

Figure 3-16 shows a selection of observed and calculated groundwater pressures in the vertical stratigraphic column at Shenhua pressure sensors.

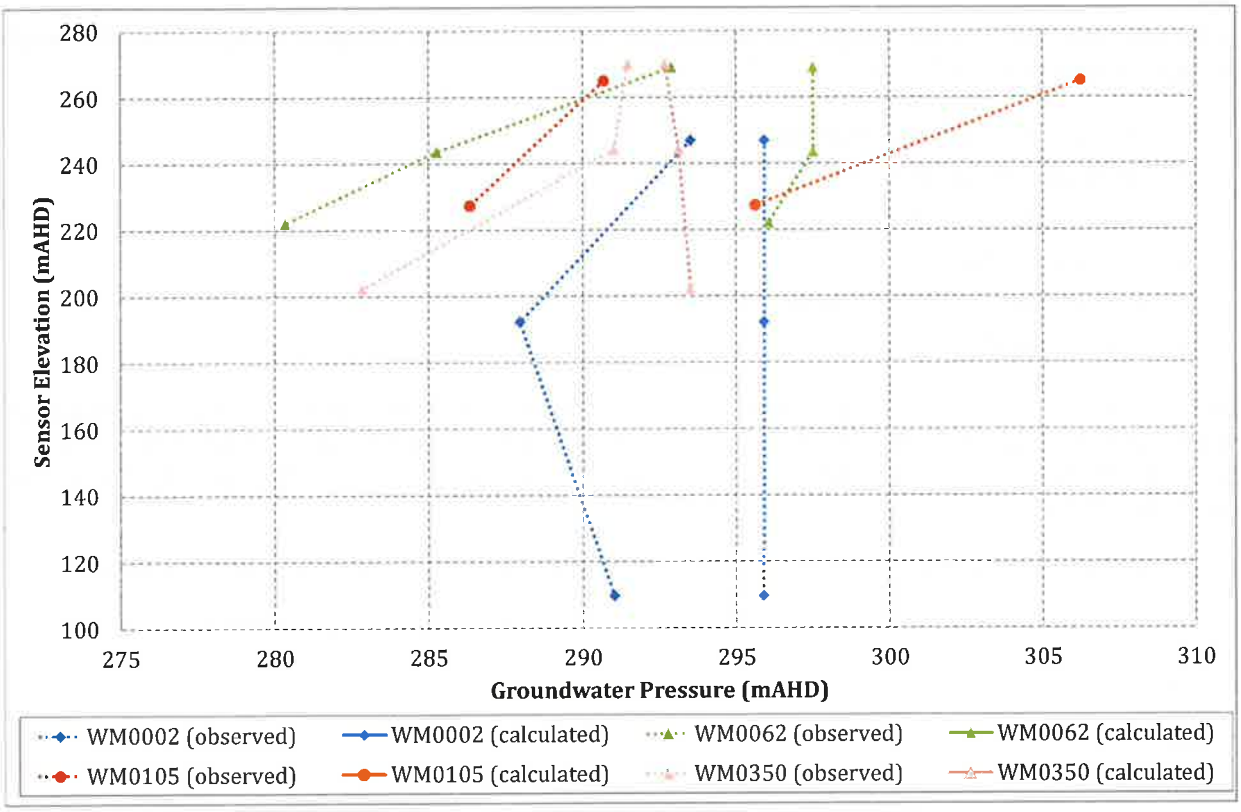


Figure 3-16 Vertical gradients (Observed vs. calculated)

The results show that observed downward groundwater pressures are highly variable. The groundwater model replicates the general downward trend in some bores, however it is clear that is it hard to replicate all of these trends in a regional groundwater porous media model.

UNSW incorrectly assumes this is the result of the misrepresentation of faults and colluvium. MODFLOW SURFACT simulates porous media flow, and therefore represents a homogenous aquifer system. The project represented heterogeneity in the form of vertical discretisation of model layers, weathering multiplying factors, and compartmentalisation of faults. It is clear the fractured rock aquifer system would benefit from increased vertical discretization to replicate extremely variable vertical hydraulic conductivity inferred in the vibrating wire piezometer data. Introducing pilot points in the Permian strata would also improve calibration statistics within the Project area. However the results from the sensitivity and uncertainty analysis suggest that it is unlikely that improvements in the calibration statistics within the Project area, would have had significant influence on the magnitude of the regional groundwater impacts predicted by the model.

UNSW also incorrectly states that very few bores were included in the calibration. Slide 6 in the UNSW presentation comments that only a handful of bores were actually used to calibrate the model. The EIS report clearly states that this figure (EIS Figure 9.24) represents a 'selection' of key bores, which represent the main irrigators surrounding the Project. A total of 94 site bores and 351 NOW PINEENA bores were used in the calibration (EIS Figure 9.1), which are clearly included in the calibration statistics and hydrographs in the report.

3.8 Management and Mitigation

A detailed management and mitigation section was included in the EIS report, which outlined several mitigation measures, including;

- injection of water into depressurised aquifers;
- grouting and cut-off measures;
- sourcing of water from other sources ;
- treatment of water;
- bore enhancement / new bores; and
- monitoring plan.

Although not reported in the EIS report, we ran two predictive scenarios simulating re-injection of water into the Narrabri alluvial aquifer system. Four injection bores were situated south of the Southern Mining area to stimulate low flow injection (maximum of <1.5 L/s to 3 L/s) into the depressurised area.

Figure 3-17 shows a hydrograph at bore GW015505 for the EIS model and re-injection scenarios.

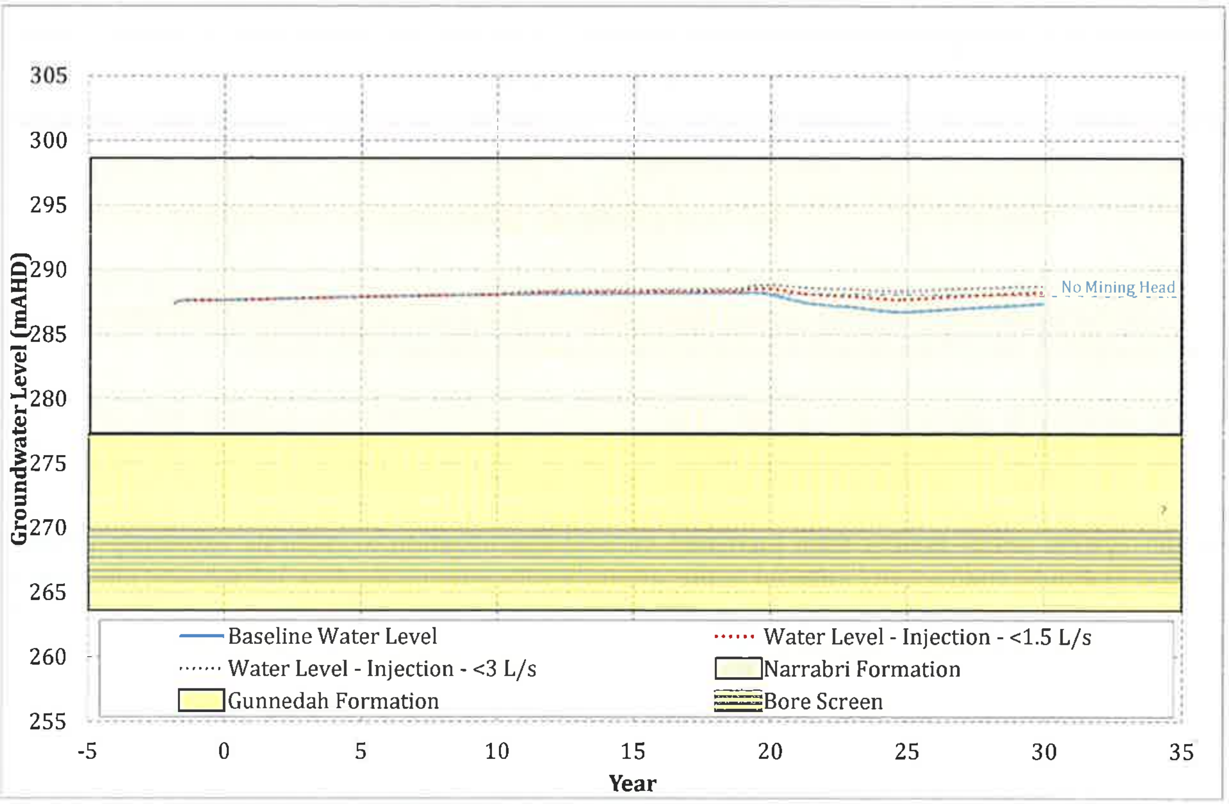


Figure 3-17 Hydrograph (GW015505) – Re-injection scenarios

The results show that re-injection of water back into the aquifer system during mining completely reverses groundwater depressurisation at the closest landholder irrigation bores.

3.9 Model conservatism

UNSW consider good science provides a plausible and conservative estimate of impacts, and go on to conclude the groundwater assessment for the Project was *'plausible but almost certainly under-predicted, or just wrong.'* They show this graphically in their presentation as reproduced in Figure 3-18 below.

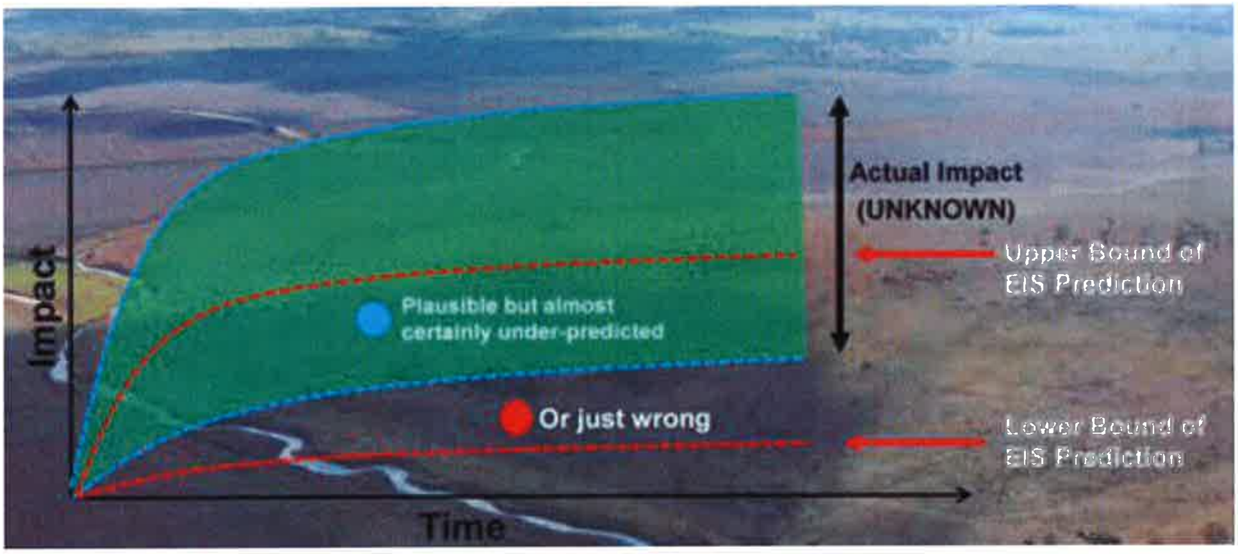


Figure 3-18 UNSW Impact Graphic

UNSW appear to reach this conclusion simply because the groundwater model was not set up in a manner they would recommend. Of course we understand there are many different ways to represent natural processes in models, but UNSW appear to conclude without any modelling evidence, that because the model was not set up in a manner they would recommend the impacts predicted by the EIS must be under-predicted or wrong. They don't seem to consider the scenario that setting the model up in a manner they recommend could result in lesser impacts.

The EIS Report states that 'a conservative approach was taken' and a subsequent review of the models performance by Dr Colin Mackie, on behalf of the PAC has confirmed conservative assumptions.

To demonstrate the conservatism of the model we have attempted to present some of the key datasets from the project in a similar graphical format to the above graphic used by UNSW. Figure 3-19 and Figure 3-20 and shows the predicted cumulative pit seepage and 'water take' presented in the EIS over the active mining project life, along with the additional modelling addressing points raised by Dr Colin Mackie and UNSW.

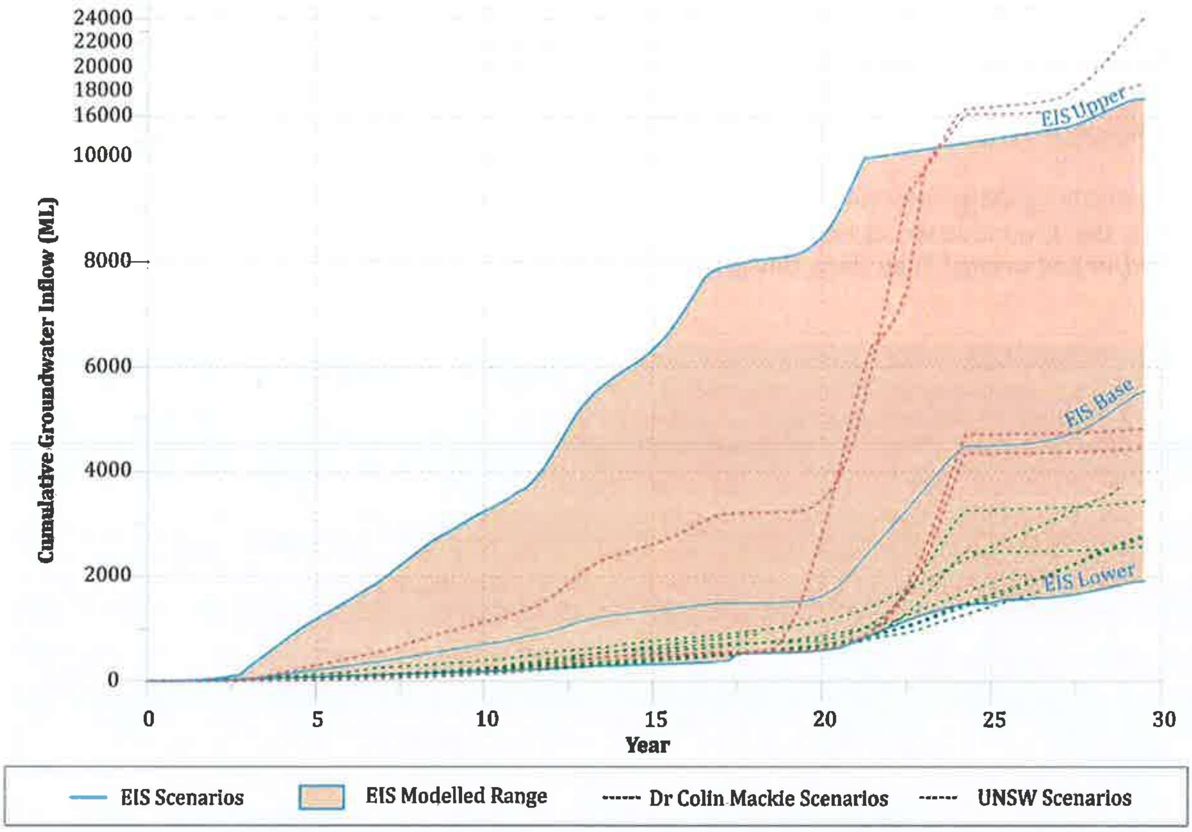


Figure 3-19 Cumulative groundwater inflow flow

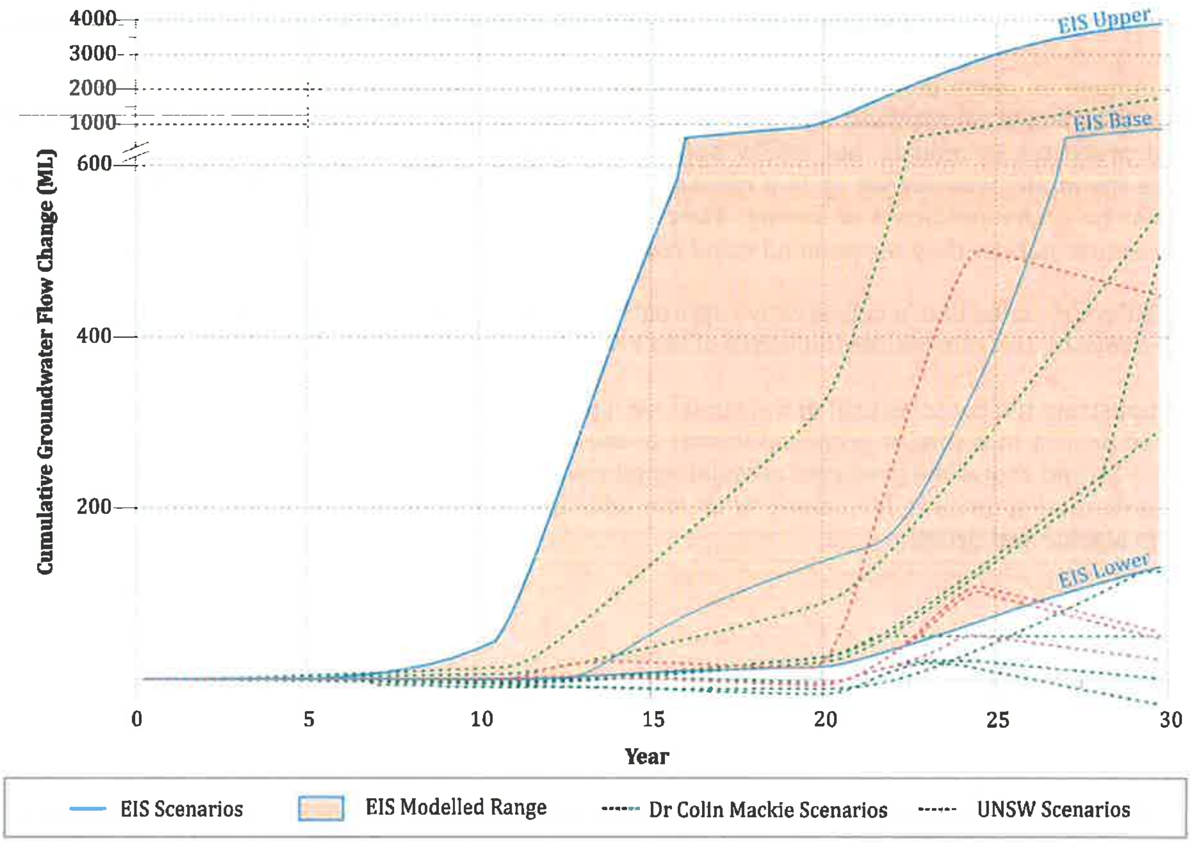


Figure 3-20 Cumulative 'water take' from Groundwater Management Zone 7

The graphics show all the additional scenarios investigated to address points by the reviewers produced impacts within the range presented in the EIS, or even below this range. The exception was the hypothetical 50 m wide faults that are considered completely implausible.

4. Summary and conclusions

The EIS model represents a geological model, which was a direct representation of the exploration drillhole data within the Project boundary, and also used the most recent representation the aquifer system from the NOW 2010-groundwater model, which was based on landholder and government drillhole data. Further information regarding the weathering zone and the application to the model parameters has been presented in this report. EIS modelling explored more than one geological setup in the uncertainty analysis by removing the faults, and increasing the hydraulic parameters so that the suggested representation of a highly transmissive Clare sandstone unit was directly connected to alluvial formations. Subsequent re-modelling addressing points raised by UNSW have revealed the EIS model was conservative.

Whilst the EIS did not consider it necessary to present any mitigation measures, detailed re-injection scenarios were undertaken during the EIS process. Results show that re-injection of water back into the alluvial aquifer system is sufficient to mitigate groundwater depressurisation at affected landholder bores.

After investigating the points raised by UNSW we have concluded it is likely the groundwater assessment does not under predict the impacts of the project, but it more likely over-predicts the impacts. The impacts are therefore considered plausible and under predicted, which is UNSWs definition of good science.

5. References

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Appendix 1

Response to Third Party Review

Memorandum

Project number G1501

To Paul Jackson

Company Shenhua Australia Holdings Ltd

From Neil Manewell

Date 30th September 2014

RE **Response to PAC – Dr Colin Mackie Review**

Executive summary

The Planning Assessment Commission (PAC) engaged Dr Colin Mackie to review the Watermark Project groundwater study. Dr Mackie raised a number of questions and requested adjustments to the model so he could examine the effects on the model predictions. AGE made the requested adjustments to the model and ran a number of scenarios to investigate Dr Mackie's concerns.

The Watermark EIS model set the drain reference elevation in the mining areas to the base of the pit floor to introduce conservatism to modelling predictions, and to aid model stability for the recovery scenario. Revised modelling shows that setting drain reference elevations to the base of each cell reduces impacts to surrounding groundwater users and the groundwater regime.

The predicted seepage rates to the mining areas are sensitive to the adopted closure criterion. The EIS adopted closure criterion that ensured the model converged to an accurate solution, and provided accurate pit seepage rates. Revised scenarios using a head closure criteria of less than 0.1 m produced numerically stable results, although non-convergence did occur using the pseudo-soil function in some instances. Simulated groundwater levels are insensitive to variances in model closure criterion. No erratic behaviour in heads was observed in any of the scenarios explored.

AGE adopted the residual saturation function for EIS modelling due to its ability to aid model convergence following desaturation of model cells. Our experience using this function indicates it produces results comparable to using the rewetting function in MODFLOW NWT/USG, at significantly faster runtimes. Fast runtimes (<8 hours) were essential to maintain 50m x 50m cell resolution in the mining areas, and to perform an uncertainty analysis. Our experience has been that adopting the pseudo soil function further reduces the predicted impacts during both mining, and long-term post mining. Therefore this review shows that the EIS model produces conservative impacts when compared to the other approaches suggested and can be used as a functioning predictive baseline that the observed impacts can be compared to once mining commences.

1. Introduction

This memo describes the results of groundwater modelling requested by Dr Colin Mackie who has been engaged by the Planning Assessment Commission (PAC) to review the Watermark Project (the Project) groundwater study which was appended to the Environmental Impact Statement (EIS). Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) have prepared this memo at the request of Shenhua Australia Holdings Ltd.

2. Response to queries

The PAC engaged Dr Colin Mackie to review the Watermark Project groundwater study[1]. During the review process, Dr Mackie raised a number of questions and requested adjustments to the model so he could examine the effects on the model predictions. AGE made the requested adjustment to the model and provided the results in a letter to Shenhua Australia Holdings Ltd dated 22 July 2014.

The PAC's Review Report included a letter from Dr Mackie dated 14 August 2014 in which he raises some additional concerns about the groundwater model, and requests further adjustments. The concerns raised by Dr Mackie in his correspondence can be categorised into:

- the way the groundwater model represents the mining process;
- the potential for numerical instability in the model; and
- the method and parameters the models uses to represent flow within the unsaturated zone.

This memo documents the results of additional model scenarios run to address the above concerns. Table 2-1 summarises the set up for a further 10 permutations to the groundwater model.

Table 2-1 Summary of models

Scenario	Drain elevation	Mining method	Soil saturation	Notes
0	Layer 10 base	Growing drains – no backfill	Residual saturation[1]	
1	Cell base	Growing drains – no backfill	Residual saturation	
2	Layer 10 base	Growing drains – no backfill	Pseudo-soil	
3	Cell base	Growing drains – no backfill	Pseudo-soil	
4	NA	NA	Residual saturation	Steady state recovery
5	NA	NA	Pseudo-soil	Steady state recovery
6	Cell base	Growing drains – no backfill	Pseudo-soil	No faults
7	Cell base	Growing drains – no backfill	Pseudo-soil	High storage
8	Layer 10 base	Growing drains – no backfill	Residual saturation	No faults
9	Cell base	Growing drains – no backfill	Residual/Pseudo-soil	
10	Cell base	Backfilled approach	Residual saturation	
11	Cell base	Backilled approach	Pseudo-soil	

1. Residual saturation = van Genuchten method

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[1] Australasian Groundwater and Environmental Consultants Pty Ltd (2013). Watermark Coal Project, Groundwater Assessment prepared for Hansen Bailey Pty Ltd Project No.G1501 January 2013

2.1 Representation of mining

The predictive model used in the EIS groundwater study was set up with 126 quarterly (each 91.3 days) stress periods which simulated mining (dewatering of mine cells) on a quarterly basis until the end of mining after 30 years.

At the end of each quarter, the model stopped and aquifer parameters in the recently mined areas changed to represent the spoil. These changes were required to represent the resultant increase in the hydraulic conductivity, porosity and recharge rate to the spoil. This approach allows groundwater pressure recovery in the mined workings, and therefore the ability for spoil seepage to flow into the mine workings to be simulated. The version of the model, which used this approach, is referred to as the staged backfilled model in this memo.

Dr Mackie has requested that AGE simulate a worst case (for comparison purposes only), which assumes the mines are not backfilled and dry pits (once mined) remain dry for the remainder of the 30-year mine life. This model abandons the staged approach, and simulates the 30-year mine life using 120 stress periods in a single model run. This version of the model is referred to as the non-backfilled model for the remainder of this memo for which approval is not being sought. Therefore, Scenarios 0 to 3 and Scenarios 6 to 9 represent an unrealistic 'worst case' which is not approvable by DPE as the waste rock is not accounted for. Scenarios 10 and 11 simulate the progression of the active mining area, and the subsequent dumping of waste rock behind the mine, which is a more realistic approach.

2.1.1 Emplacement of spoil

Dr Mackie raised a concern that the EIS model which emplaces spoil behind the active mining area (in line with the Project mine plans) might be buffering the drawdown impacts by allowing water pressures within the mined areas to begin recovering after mining passes through.

The rate of groundwater recovery within the spoils depends on a number of factors including recharge rate, pit geometry, location and hydraulic properties. Table 2-2 summaries the hydraulic parameters used to represent spoils behind the active mining area.

Table 2-2 Hydraulic parameters of waste rock

Geology type	Parameter	Value
Waste Rock	Horizontal Hydraulic Conductivity kh	1 m/day
	Vertical Hydraulic Conductivity kv	0.1 m/day
	Specific Yield Sy	0.1
	Specific Storage Ss	1×10^{-3} m^{-1}
	Recharge	5.5% Annual rainfall

The spoils were represented with a relatively high hydraulic conductivity and storage parameters, typical of a productive aquifer. The effect of this is to slow recovery of water levels within the spoils. The parameters within the EIS model are considered likely to be at the upper end of the range in the spoil heaps, and therefore slow recovery and do not significantly impact on the zone of depressurisation around the mining areas. Figure 2-1 shows the groundwater level recovery at points within the emplaced waste rock areas in each mining area from the EIS model.

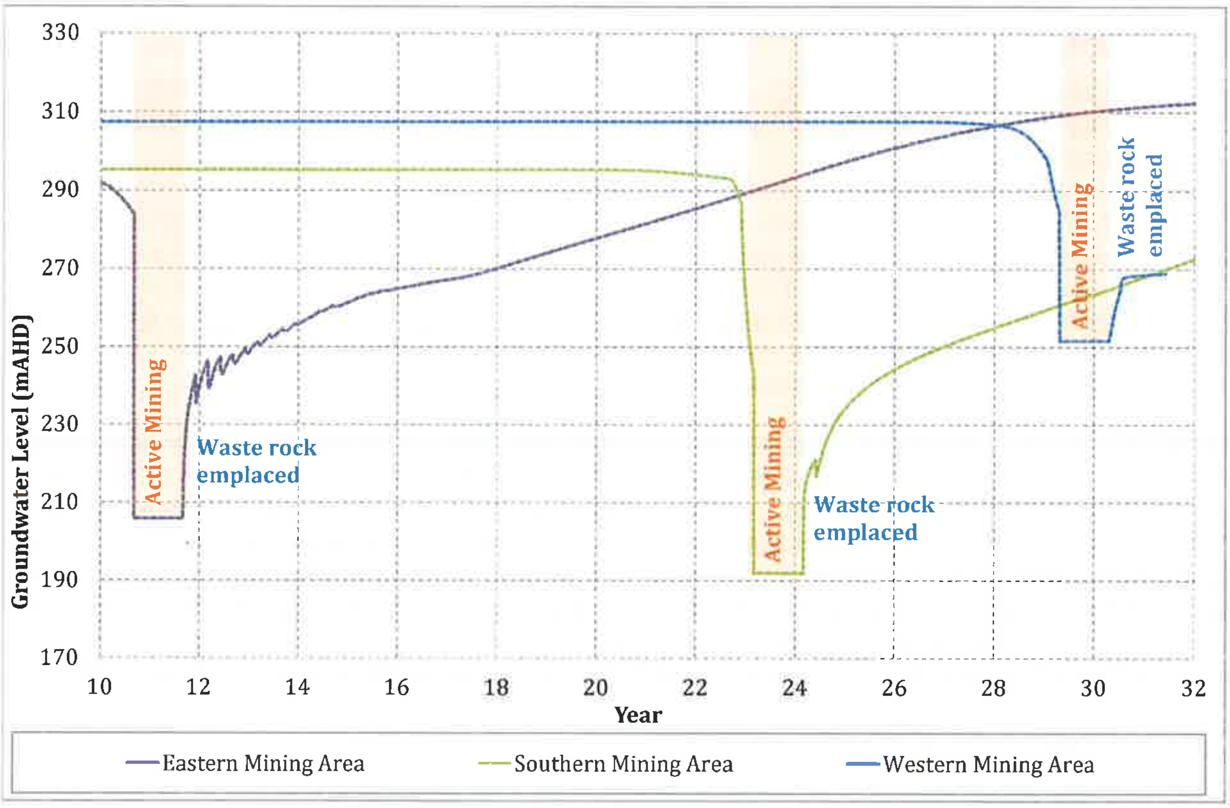


Figure 2-1 Groundwater recovery of the waste rock areas (EIS model)

The results show a rapid recovery following the emplacement of spoil (~30m after 90 days), although a groundwater sink for regional groundwater levels remains for approximately 10 years after the closure of each mining area. For this reason, it is considered the recovery of groundwater levels within the spoil does not overly influence the regional groundwater drawdown predictions, and the staged approach adopted by the EIS model is valid, assuming the mine plan is implemented as proposed.

Dr Mackie commented that if each of the mining areas were to remain open longer than proposed there would be potential for the impacts to be larger than predicted by the EIS model. Dr Mackie proposed the WST model be investigated as a worst case that assumes the open pits remain pumped dry for the entire mine life. Sections below discuss further model runs using both the backfilled and non-backfilled models.

2.1.2 Drain cell elevation method

Following a detailed review of the model files, Dr Mackie noted:

"Inspection of the supplied model data files reveals the reference elevations of the drain cells within each of the mine pits have been set to the lowest drain cell (layer 10 – Melvilles seam) of a vertical column of cells. That is, for all drain cells above layer 10, the reference elevation is below the base of the cells. This is an unconventional use of the drain reference elevations that may lead to quite different outcomes to the conventional assignment of drain elevations. The conventional procedure requires the referenced elevation to be set at or above the bottom of the cell in which a drain boundary is specified. Indeed the popular Graphical User Interfaces (GUI) for Modflow SURFACT normally warn the user if the reference elevation is set below the base of the cell."

Setting the drain reference elevations at the floor of the pits in the EIS model was intentional and is AGE's standard method applied to mining related groundwater models. This was based on AGE's previous experience simulating the re-saturation of pit voids following the removal of drain cells. AGE has observed previously that when using the van Genuchten method in MODFLOW-SURFACT, small quantities of residual saturation remains within the vertical column of cells above the pit floor. Upon changing the storage properties of the very partially saturated cell to reflect that of an open void (Kx-Kz = 1000 m/day, Sy, Sc = 1), convergence issues can occur during the re-saturation of the vertical profile. This issue does not occur when using the pseudo-soil function (see Figure 2-2). This is because this pseudo-soil function does not allow for residual saturation in unsaturated model cells. This means the approach in the EIS is conservative, as it allows more drawdown close in the pit walls than other methods. This is outlined in sections below.

2.1.3 Groundwater level impacts

The backfilled and non-backfilled model have been re-run to demonstrate the sensitivity of the drain reference elevations to the predicted impacts. Figure 2-2 shows the difference in potentiometric heads in layer 2 and layer 10 in the backfilled model at Year 23 using:

- EIS model - drain reference elevations to the bottom of Layer 10 (green);
- Scenario 10 - drain reference elevations to the base of the cell (blue); and
- Scenario 11 - drain reference elevations to the bottom of each cell with the pseudo-soil function (red).

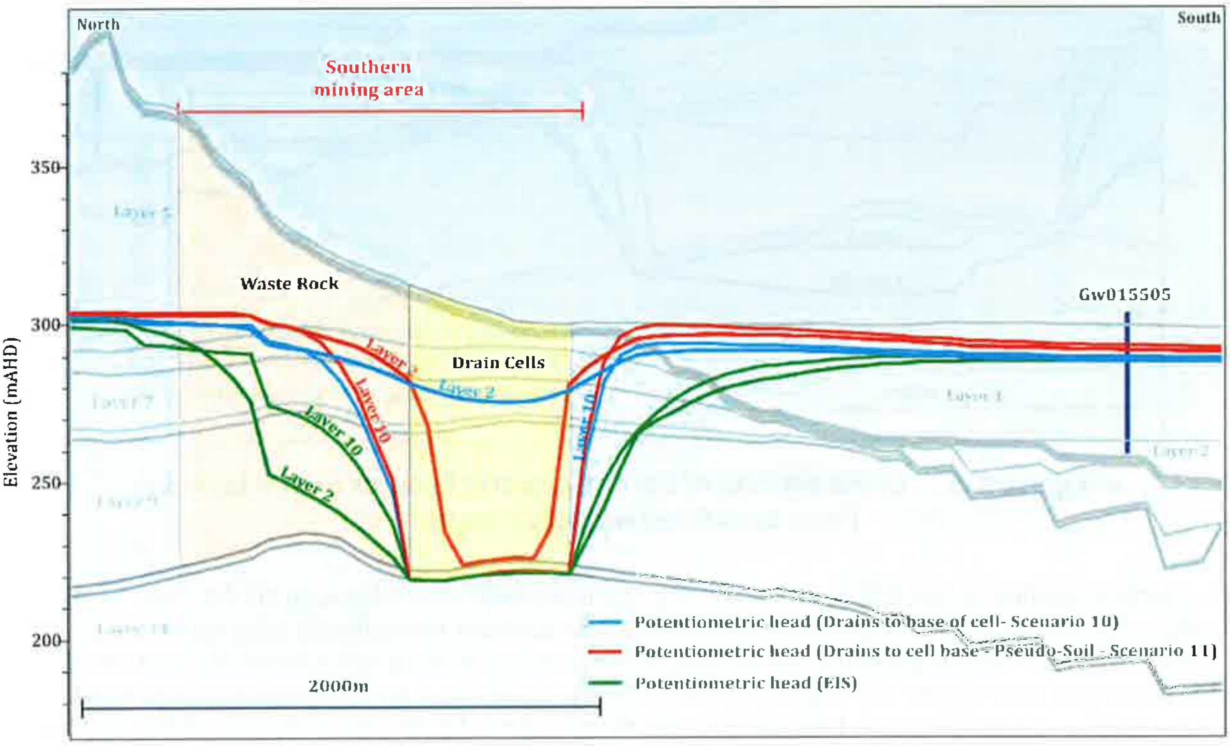


Figure 2-2 Cross-section of potentiometric head vs model layers (Backfilled model drain scenarios)

The results show that varying the drain reference elevation influences the predicted heads using the staged backfilling approach. The method employed in the EIS model results in increased drawdown immediately adjacent to the pit wall, which in turn implies that more water enters the drain cells. Setting drain cell elevations to the base of each cell floor results in steeper hydraulic gradients adjacent to the pit walls, and therefore a more rapid recovery in groundwater levels behind the active mining area, which is progressively backfilled with spoil. This indicates that setting drain cell elevations to the base of each cell reduces the regional groundwater impacts predicted by the model.

Figure 2-3 shows the potentiometric heads in layer 2 and layer 10 model layers in the non-backfilled model at Year 30 using:

- Scenario 0 – drain reference elevations to the base of the pits (blue);
- Scenario 1 - drain reference elevations to the base of the cell (red); and
- Scenario 3 - drain reference elevations to the base of the cell with the pseudo-soil function (green).

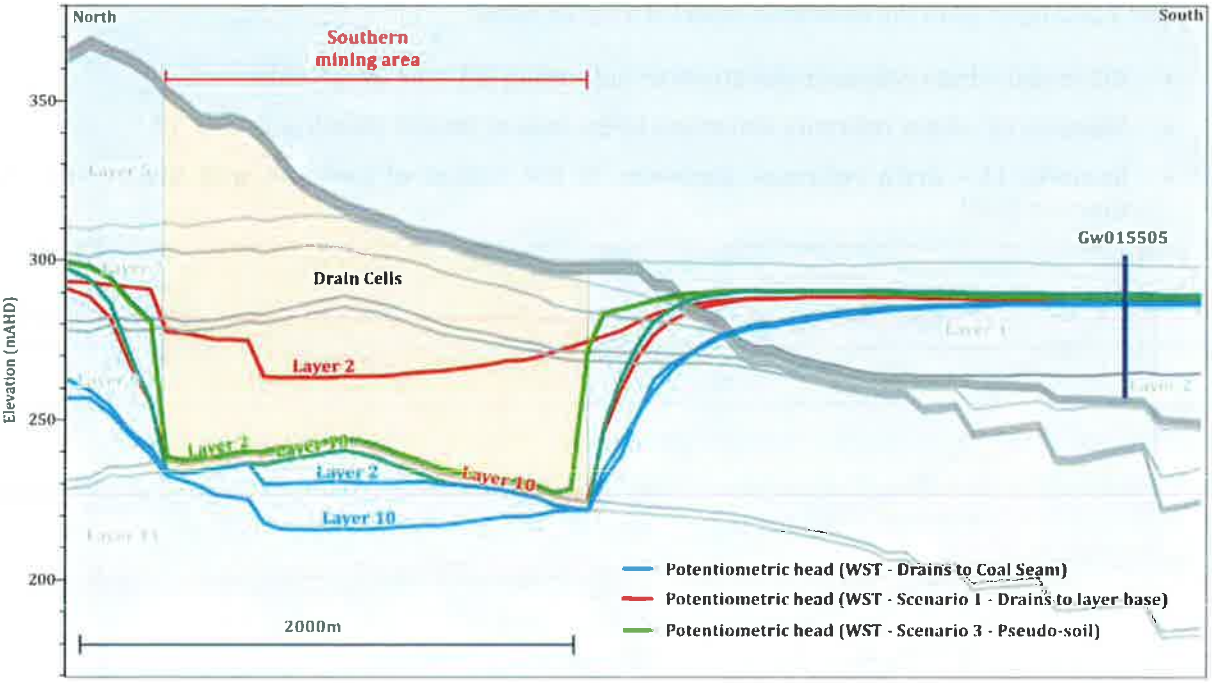
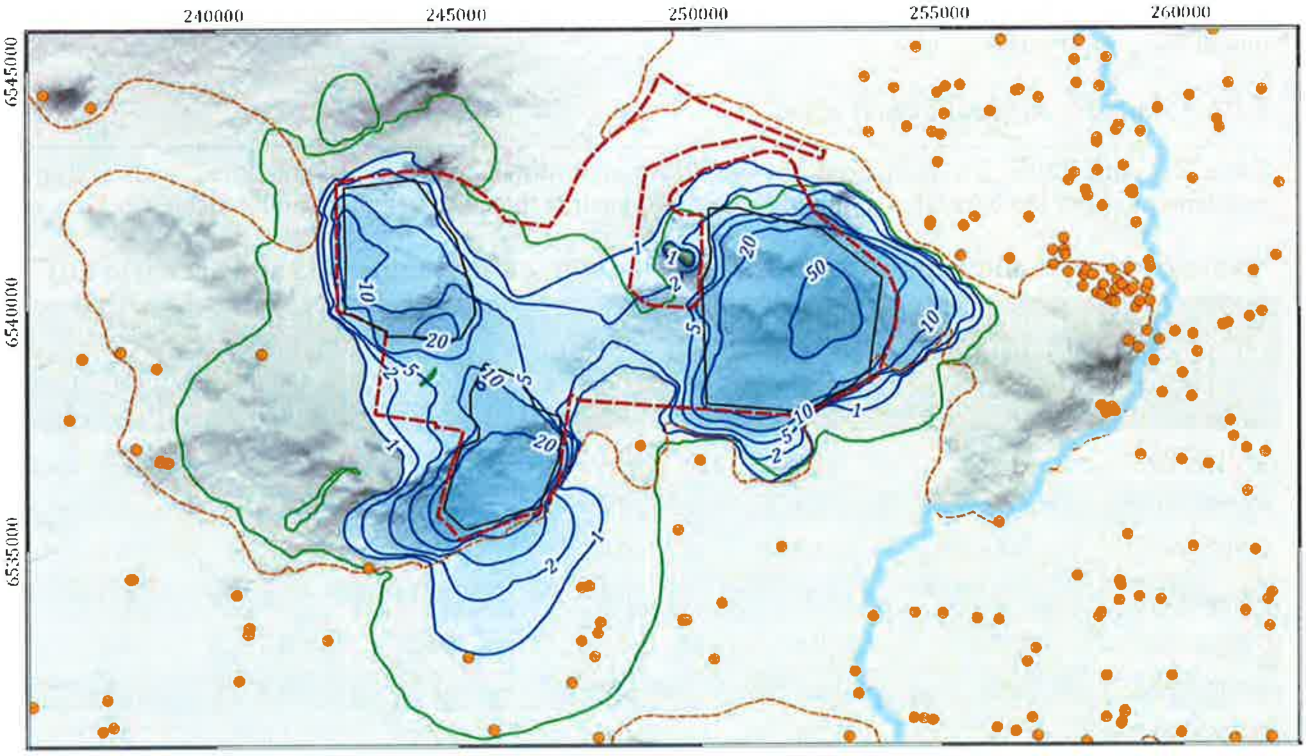


Figure 2-3 Cross-section of Potentiometric head vs model layers (Non-backfilled model scenarios)

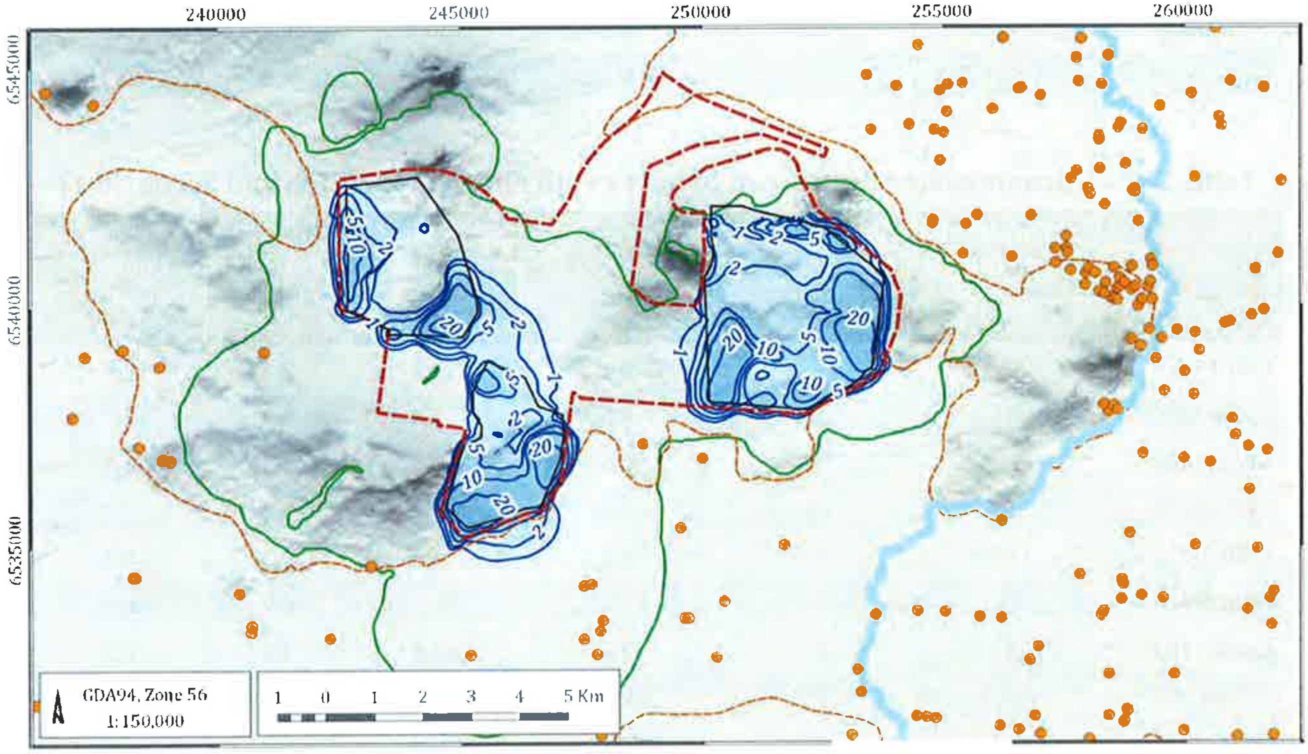
The method applied in the EIS model of setting the drain reference elevation to the floor of the pit (Scenario 0) results in similar potentiometric heads and surfaces immediately adjacent to the pit wall within each layer. Clearly, groundwater drawdown impacts using drain cell reference elevations to the base of the pit floor (layer 10) results in conservative predictions as the potentiometric heads are dragged below the base of each layer in the cells surrounding the pit. The influence of this approach becomes less apparent with distance from the mining areas.

Figure 2-4 shows the maximum drawdown in Layer 2 (Gunnedah Formation and weathered Permian where not present) predicted by the non-backfilled model (Scenario 1) and the backfilled versions of the model (Scenario 10) during the mine life.

Scenario 1



Scenario 10



LEGEND

- ☐ Mining area
- ● PINEENA bore
- ― ― Project area
- ― Mooki river
- ☐ Alluvial boundary
- ― Groundwater Drawdown (m)
- ― Groundwater Drawdown (m) EIS model (Uncert)

Watermark (G1501)

Groundwater Drawdown - Gunnedah Formation (Scenario 1 and 10)

DATE	FIGURE No.
30/9/2014	**2-4**

Figure 2-4 shows the approach to setting the drain reference cell to the floor of the mine pit in the EIS model was conservative.

2.1.4 *Impacts on groundwater users*

Table 2-3 and Table 2-4 compared the predicted drawdown at each private bores with water entitlements from the backfilled model (Scenario 10) against the non-backfilled model (Scenario 1).

Table 2-3 Groundwater drawdown in bores with entitlements (EIS and Scenario 10)

Work Number	Completed depth (mbgl)	EIS drawdown (m)	Drawdown - (Scenario 10) (m)	Head Available (m)	EIS Percent Change (%)	Percent Change – (Scenario 10) (%)
GW015505	35.1	1.4	0.1	19.2	7.4	0.3
GW967790	70	1.1	0.0	55.9	1.9	0.0
GW029468	64.6	1.1	0.0	48.6	2.3	0.1
GW037713	64	1	0.0	47.7	2.2	0.0
GW060252	148.4	0.6	0.0	136.5	0.5	0.0
GW022622	45.1	0.3	0.0	32.8	0.9	0.0
GW967781	50	0.4	0.0	37.4	1.0	0.0
GW022984	45.1	0.3	0.0	33.4	0.9	0.0
GW022977	148.4	0.3	0.0	136.6	0.2	0.0
GW022620	48.8	0.3	0.0	36.3	0.9	0.0

Table 2-4 Groundwater drawdown in bores with entitlements (EIS and Scenario 1)

Work Number	Completed Depth (mbgl)	EIS Drawdown (m)	Drawdown - (Scenario 1) (m)	Head Available (m)	EIS Percent Change (%)	Percent Change - (Scenario 1) (%)
GW015505	35.1	1.4	0.7	19.2	7.4	3.6
GW967790	70	1.1	0.6	55.9	1.9	1.0
GW029468	64.6	1.1	0.6	48.6	2.3	1.1
GW037713	64	1	0.5	47.7	2.2	1.1
GW060252	148.4	0.6	0.3	136.5	0.5	0.2
GW022622	45.1	0.3	0.2	32.8	0.9	0.6
GW967781	50	0.4	0.2	37.4	1.0	0.5
GW022984	45.1	0.3	0.2	33.4	0.9	0.5
GW022977	148.4	0.3	0.1	136.6	0.2	0.1
GW022620	48.8	0.3	0.1	36.3	0.9	0.4

The results highlight that the drawdown at private bores with water entitlements reduces significantly when the drain reference elevation is set at the base of the cell (Scenario 10). When the drain cells remain open for the mine life with a reference elevation at the base of each cell (Scenario 1) the impact on private bores is about half of that presented in the EIS model.

2.1.5 Pit inflow sensitivity

Figure 2-5 compares the pit seepage rates predicted in the EIS model with Scenario 10 that set the drain reference elevation to the base of the cell.

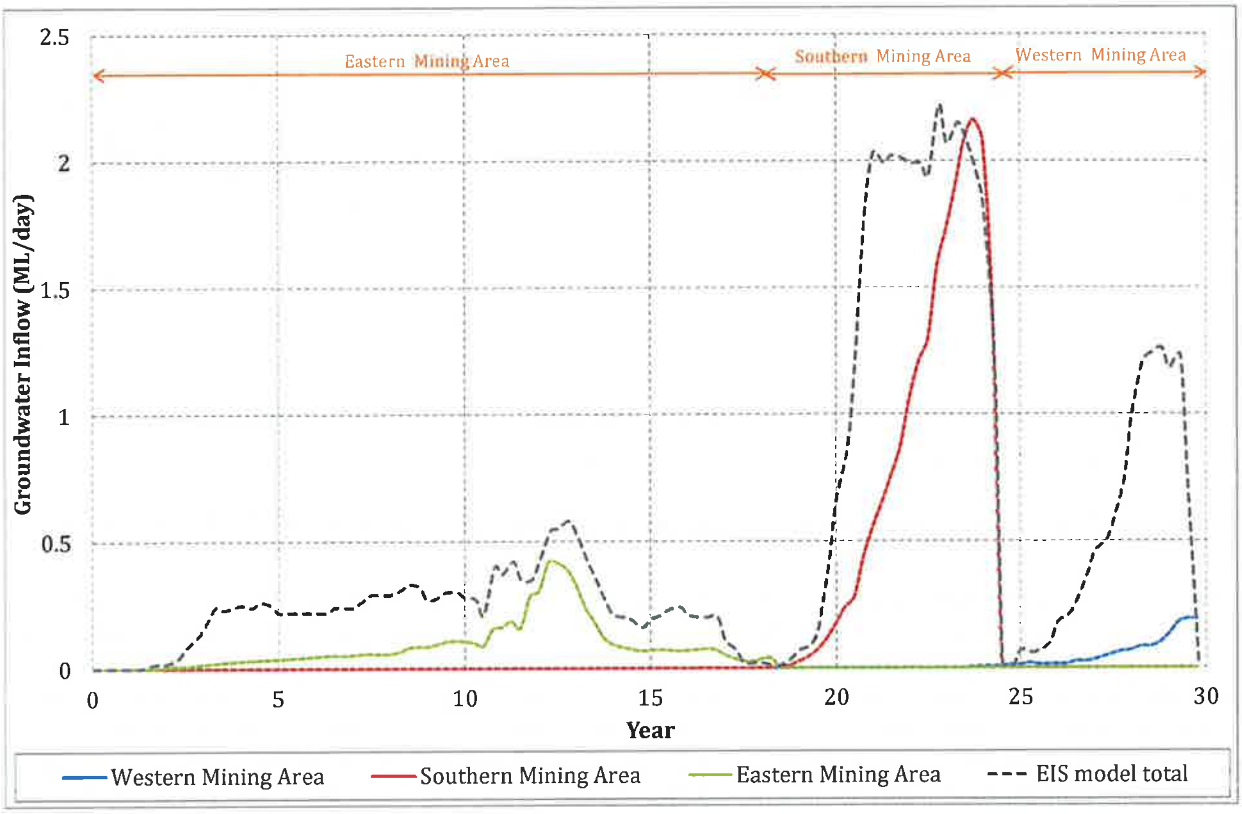


Figure 2-5 Pit seepage rates during mining (Staged Backfill model – Scenario 10)

The results shows that groundwater seepage rates to the mining areas reduce when the drain reference elevation is set to the base of the layer, particularly in the Eastern Mining Area, where inflows are 10% of values presented in the EIS model. This is because of changed hydraulic gradients in the cells surrounding the pit walls. Figure 2-5 highlights the models sensitivity to the drain cell reference elevation.

Figure 2-6 compares the EIS model inflow rates into the mining areas with the non-backfilled approach (Scenario 1).

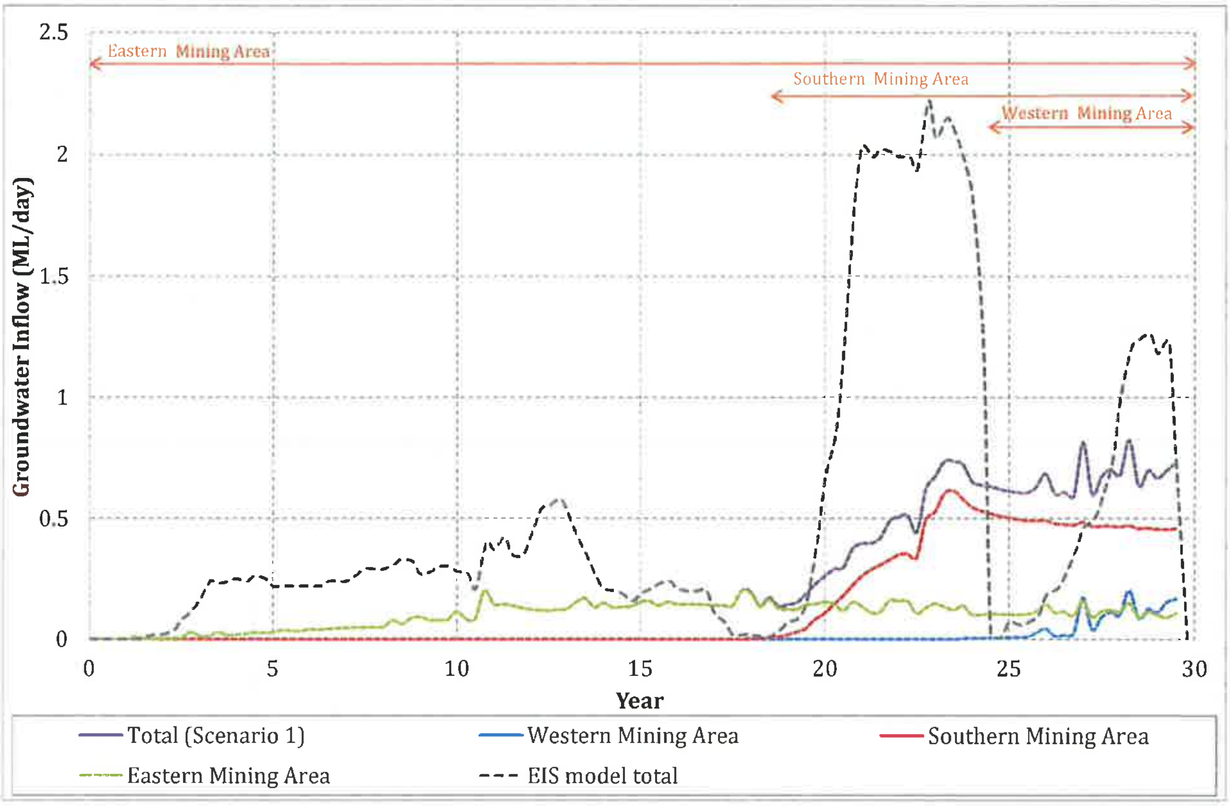


Figure 2-6 Pit seepage rates during mining (Non-backfilled model – Scenario 1)

Figure 2-6 indicates groundwater inflow rates are also lower than presented in the EIS report when the drain reference elevation is set at the base of the cell and the cells remains active for the mine life. Despite the larger footprint of drain cells continuously pumping until mine closure in the WST model, groundwater inflows are predicted to reduce to approximately 20-30% of mining area inflows presented in the EIS. This is because of the reduced hydraulic gradient into the mining areas due to the shallower cells, and the fact that spoils are not represented and therefore do not capture water and contribute to pit seepage. This demonstrates the EIS model provides a more conservative prediction of the groundwater inflows to the mining areas.

2.1.6 Groundwater management zone impacts

The results presented in the preceding sections suggest that 'water take' from the surrounding Groundwater Management Zones would also reduce in the models that represent the drain reference elevation at the base of the cell. Figure 2-7 compares the predicted water take from Zone 7 presented in the EIS, with the results from Scenario 1 (non-backfilled model with drain reference elevation to base of cell). Zone 7 was chosen as it is predicted to experience the highest level of impact due to its proximity to the deepest mining areas.

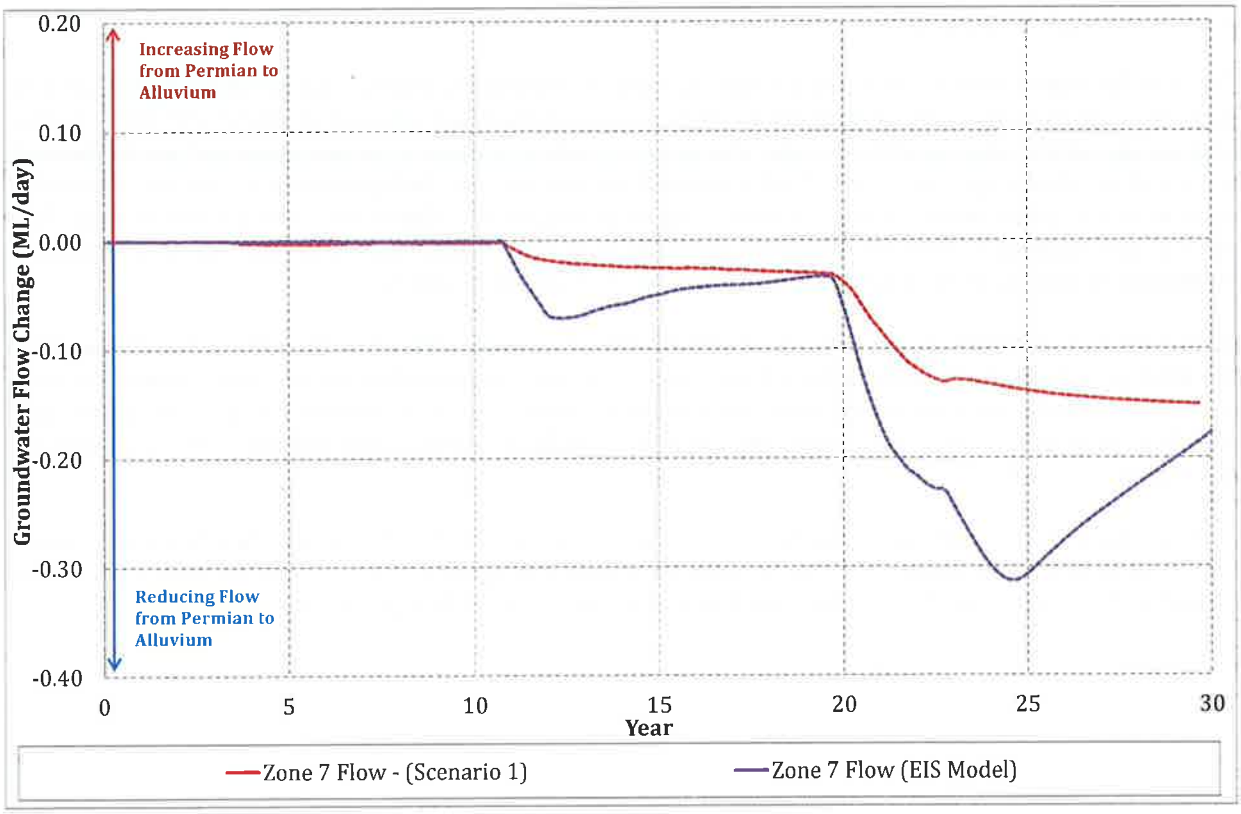


Figure 2-7 Simulated net change in flow from bedrock to alluvium

The EIS model indicated that once mining commences, the Permian strata depressurises. Within the zone of influence (drawdown), upward flow from the Permian strata to the alluvium (Narrabri and Gunnedah Formations) reduces. This is due to changes in vertical gradients between the alluvium and Permian that reduces upward flow, and creates flow reversal to downward flow in areas adjacent to the mining areas. The results show that groundwater flow changes to the groundwater management zones are further reduced when the drain reference elevation is set at the base of the cell. This is because the level of depressurisation underneath the alluvium is less than predicted in the EIS report.

2.2 Model instability

The EIS model made use of the adaptive time stepping package (ATO) and Preconditioned Conjugate-Gradient package (PCG5) to ensure the model ran as quickly as possible, whilst still retaining sufficient accuracy. The EIS model performed well, with limited water budget discrepancies and head change errors. This was due to the lesser number of drain cells active at any one time using the moving drain method. Fast runtimes (<8 hours) during the EIS process were essential to maintain 50m x 50m cell resolution in the mining areas, and to undertake the uncertainty analyses.

2.2.1 Pit inflow sensitivity

The non-backfilled model simulates a larger number of drain cells, which interact with horizontal flow barriers applied within the mining areas. This process introduced additional numerical error to the first version of the non-backfilled model (Scenario 0), which simulated drain cell elevations to the coal seam and pit floor (layer 10) floor. During the PAC review process, AGE provided Dr Mackie a working version of the model, with the head closure criteria increased to address the slow model run time. The percent discrepancies were inspected at the time to ensure numerical error was below prescribed Australian modelling guidelines of <2% at any time step (Barnett, 2013)[2].

Dr Mackie noted *"While the EIS inflows exhibit a relatively smooth trend line, the same cannot be said for the WST (non-backfilled) model where highly erratic behaviour is evident for the Eastern and Western pits. This erratic behaviour includes correlatable 'spikes' in the inflows across all three pits simultaneously (red arrows) suggesting underlying instability or abnormal behaviour in the model which needs to be resolved."*

The non-backfilled model (scenario 0) has been re-run using a tighter maximum head change criteria of 0.05 m to assess the changes to the groundwater inflow budgets. Figure 2-8 compares the pit inflow from the EIS model with the non-backfilled model applying two different closure criterion.

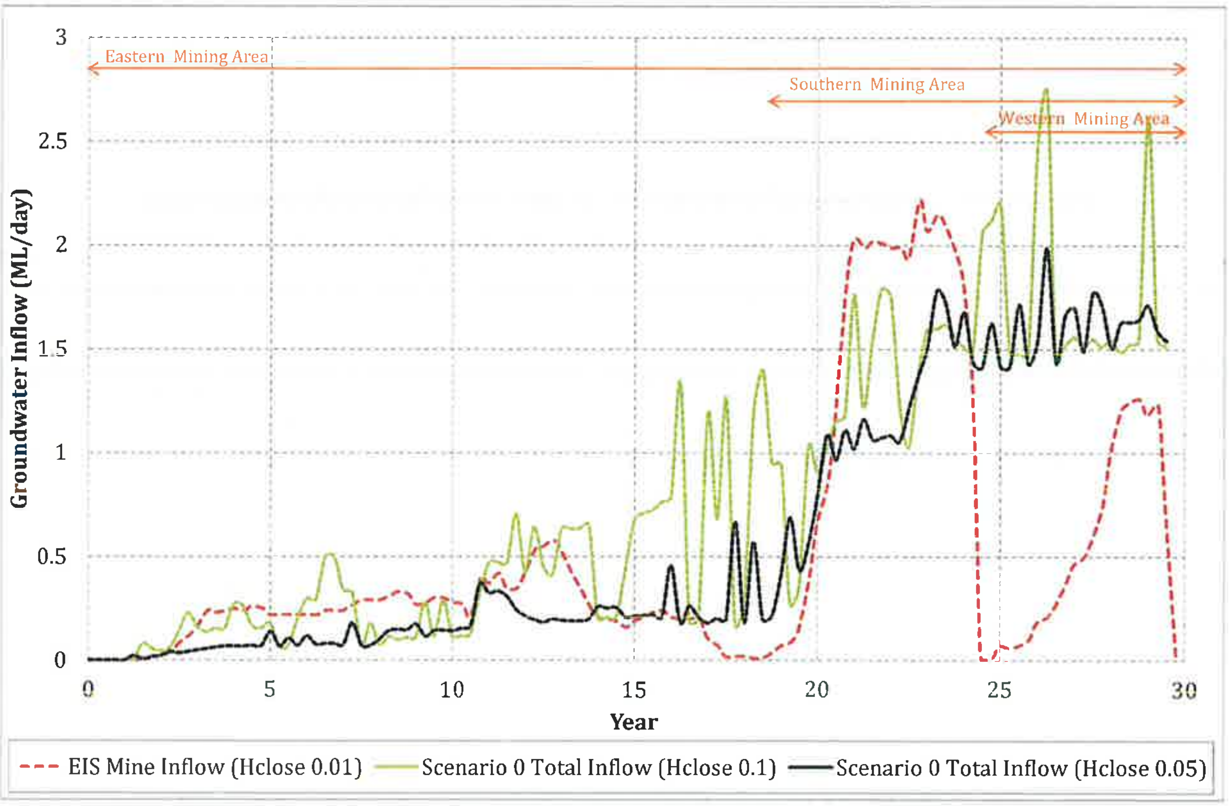


Figure 2-8 Pit seepage sensitivity to Hclose – (Scenario 0)

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[2] Barnett et al, 2012, Australian groundwater modelling guidelines, Waterlines report, National Water Commission, Canberra

The results show that pit seepage is sensitive to model solution acceptance criteria. The reason for this is due to the large amounts of groundwater within the model, compared with the relatively low seepage rates in the proposed mining areas.

Table 2-5 presents a snapshot of the budgets in the non-backfilled model using an Hclose value of 0.1 m.

Table 2-5 Maximum numerical error statistics

Feature	Total In (ML/day)	Total Out (ML/day)	Difference (ML/day)	Percent Discrepancy (%)
Entire Model	295.87	296.87	-1.00	-0.34
Drain cells	0.00	2.42	-	-

The results suggest that in order to obtain a pit seepage accuracy of <±0.1ML/day, the percent error at any time step for the Watermark model should not exceed 0.03%. The EIS model produced percent discrepancy errors of less than 0.01% at any time step, and therefore using this loosely based logic relevant to the non-backfilled model, mine inflows could be considered accurate to approximately ±0.03 ML/day.

A practical HClose of 0.05m was chosen for all revised model scenarios presented in this memo where possible, which produced a relatively stable model, with only minor fluctuations in observed inflow predictions (see Figure 2-6). Figure 2-9 shows the percent discrepancies for a selection of scenarios explored in this study.

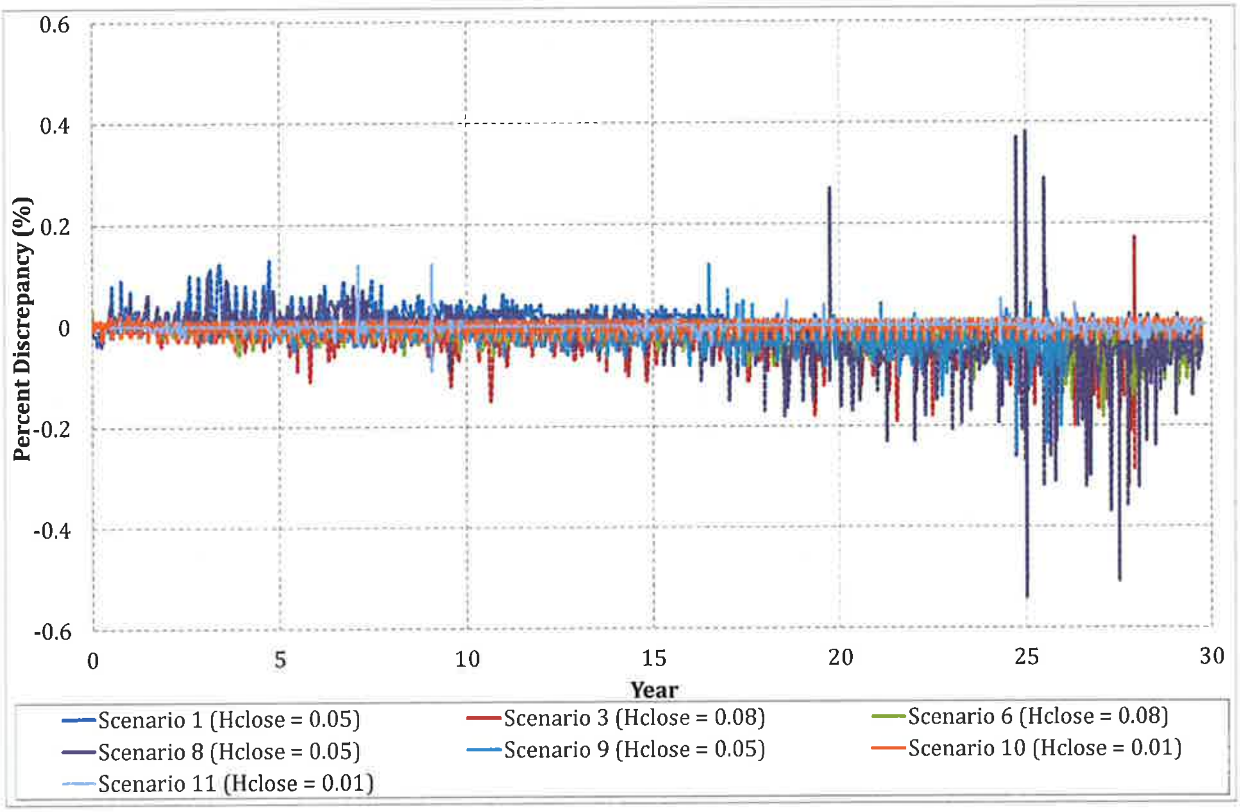


Figure 2-9 Percent discrepancy error

The results show that generally a sufficient precent discrepancy is maintained, although some time steps show fluctuations of less than ±0.6%. These percent discrepancy peaks cause small 'wobbles' in the pit seepage inflow calculations, which could be misinterpreted as an artificially high groundwater inflow peaks. Similar to the EIS model, Scenarios 10 and 11 are generally less than ±0.02%, which is reflected in the smoother predicted pit inflows. Results also suggest that high percent discrepancies are directly related to the number of drain cells in the non-backfilled model, when all three mining areas are active.

2.2.2 Groundwater head behaviour

The above sections show the predicted pit seepage rate is sensitive to solution acceptance criteria. Several model scenarios were tested using varying Hclose settings to explore the influence of this on groundwater levels. Table 2-6 shows the head differences at year 30 for Scenario 0 and 1 using different Hclose values.

Table 2-6 Potentiometric head difference vs Hclose settings (Year 30)

Scenario	Hclose 1 (m)	Hclose 2 (m)	Max head difference at Year 30 (m)
Scenario 0	0.1	0.05	0.033
Scenario 1	0.1	0.05	0.027

The table indicates the solution criteria settings have limited impact upon the predicted heads. It should be noted that the maximum difference in heads occurred to the east of the Watermark project area, and variance within the Project area was generally less than 0.01 m.

Dr Mackie noted that large maximum head changes occurred during the models iterative process of finding an acceptable solution.

AGE have analysed the output files in scenarios 1 and 2 to identify the location of the cells that experience large maximum head changes during the predictive simulation. Analysis of the output files reveal the majority of the larger errors (>10m) occur during the first time-step. This is because the model begins to 'warm up' after having adopted the averaged stress parameters carrying over from the transient calibration model. Errors of up to 60m can also occur during the first time step of a new stress period as the drain cells progress.

AGE anticipated that the source of head change error during the predictive model simulation is the drain cells interacting with the horizontal flow barrier walls. It should be noted that these maximum head changes must eventually reach less than the Hclose settings before the model can converge and progress to the next time step.

Figure 2-10 shows a 3d representation of model cells that experience maximum head change errors of greater than ±1 m at any time during the simulation. Model cells with maximum head change of less than ±1 m have been made translucent to highlight problem cells in three dimensions.

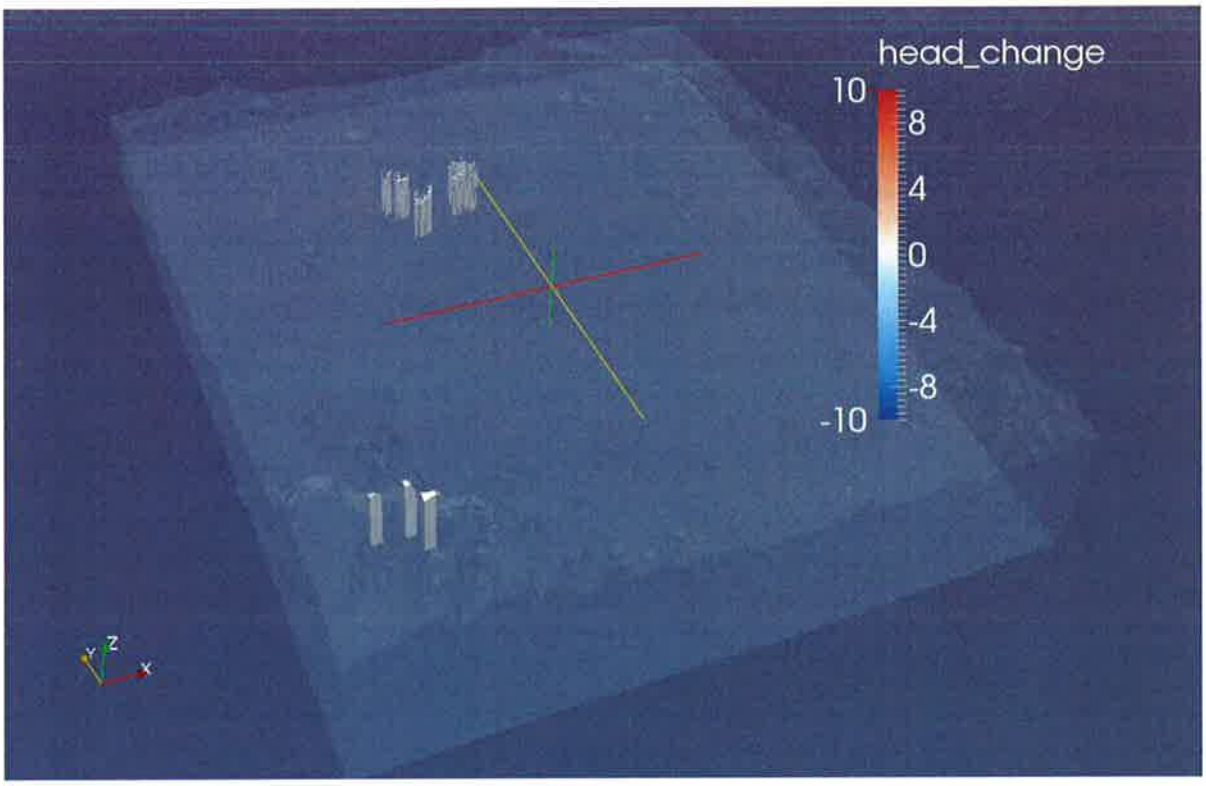


Figure 2-10 Maximum head change error locations (Scenario 1)

The results show that the majority of problem cells which struggle to reach the specified Hclose settings during the simulation are directly associated with the drain cells from layers 1 to 11, particularly in the pit cell boundaries and surrounding Horizontal Flow Barrier (HFB) walls.

Figure 2-11 shows the location of model cells that experience continual maximum head change errors in the Scenario 3 model, which employs the pseudo-soil function.

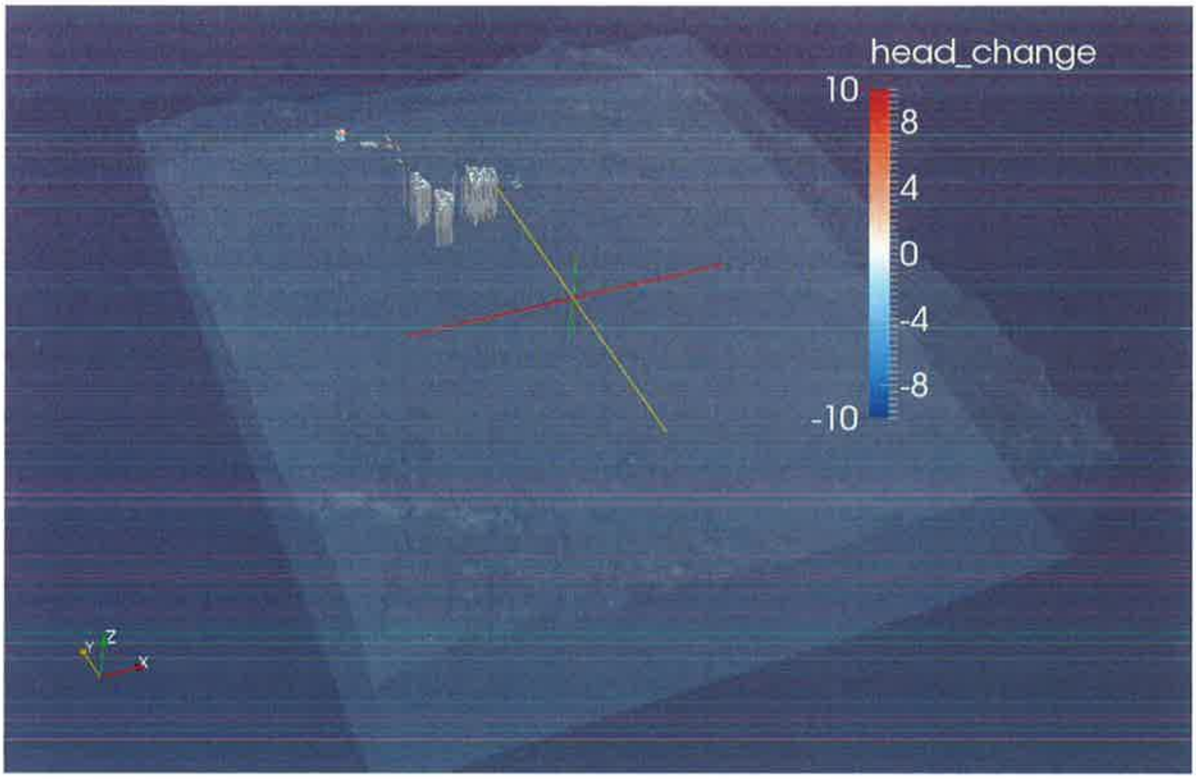


Figure 2-11 **Maximum head change error locations (Scenario 3)**

Similar to the Scenario 1 version, the majority of problem cells which struggle to reach the specified Hclose settings during the simulation are directly associated with the drain cells from layers 1 to 10. A patch of cells North West of the mining area within layers1 to 3 also exhibits struggles with model convergence criteria, which is caused by a combination of high break of slope recharge rates over a relatively low permeable outcrop. This is further exacerbated by a high groundwater level surface, resulting in interaction with the Evapotranspiration surface in these cells.

Dr Mackie also noted that: *"Figure 6 represents the EIS model with pore pressures indicated by the white contours. Close inspection of the zero pore pressure (water table) contour in the Southern Pit shows a highly erratic surface. Normally are relatively smooth surface that reflects the floor of the mined coal seam, would be expected (see Figure 7 for dewatered pit profile). The erratic surface identified in Figure 6 may be indicative of more general problems probably associated with recharge to spoils, or to unconventional assignment of drain cells or possibly discretisation issues. It is important to identify the reason for this behaviour since it may have implications for regional water table drawdown and mine water inflows."*

Upon analysis of the groundwater potentiometric heads, there is no visible erratic behaviour of the groundwater potentiometric surface throughout the model run. AGE provided Dr Mackie a figure which represented a model cell pressure head , which was contoured against the finite difference cell centres in the groundwater model. As such, the zero pressure contour represented an interpolated saturation surface, which was intended to display absolute saturation extents rather than represent the saturation surface. Graphical user interfaces (e.g. Groundwater Vistas 6) perform additional corrections in cells experiencing unconfined conditions ensure the zero pressure head contour is equal to the water table.

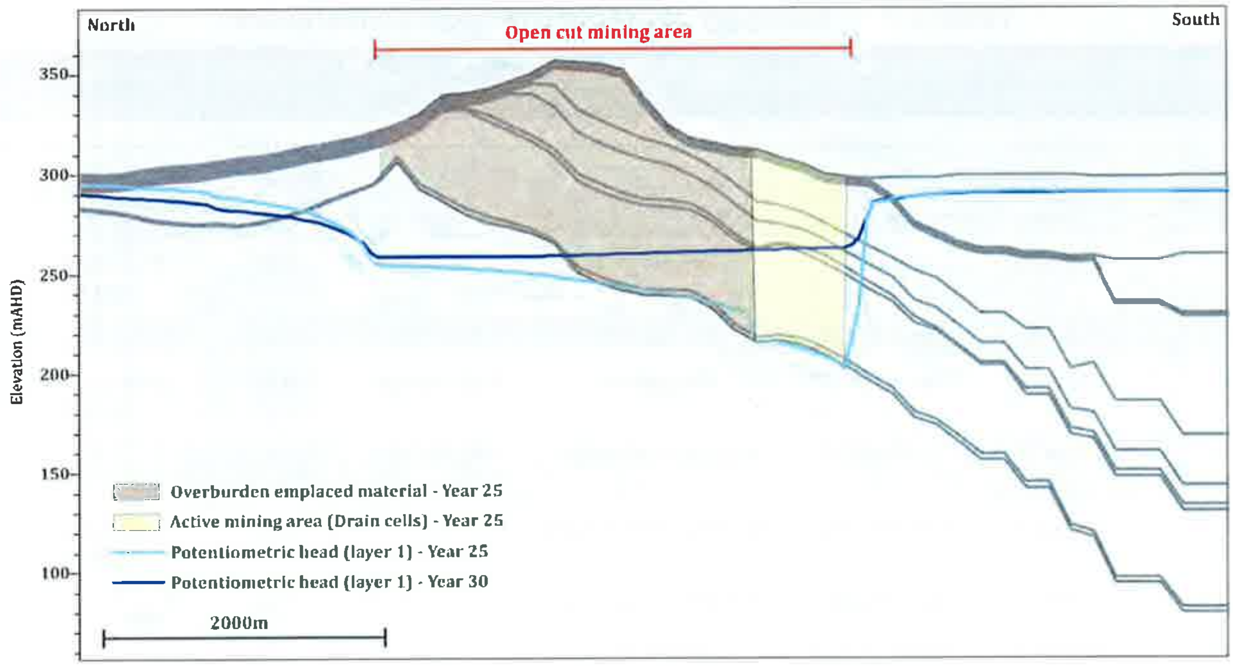


Figure 2-12 Cross section of water table surface (EIS model)

Figure 2-12 shows the water table surface at years 25 and 30 for the EIS model. Clearly, there is no erratic behaviour in the groundwater levels, and the re-saturation of groundwater levels in the waste rock appears realistic.

2.2.3 Model variants

Our experience indicates using the van Genuchten method and applying unsaturated zone parameters result in models to generally solve quickly. Scenarios using the pseudo-soil function resulted in slower model run times. Combining the pseudo-soil function with the method where drain cells were set to the base of the pit floor (layer 10) introduced significant instability, causing extremely long run times (days), and ultimately non convergence using tight convergence acceptance settings.

Table 2-7 summaries the performance of the models.

Table 2-7 Summary of predictive model convergence

Scenario	Drain elevation	Mining Method	Soil saturation	Notes	HCLOSE	Convergence
1	Cell base	Non-backfill	Residual saturation		0.05	-
2	Layer 10 base	Non-backfill	Pseudo-soil		0.10	Non-conv. @ SP86
3	Cell base	Non-backfill	Pseudo-soil		0.08	Non-conv. @ SP112
6	Cell base	Non-backfill	Pseudo-soil	No faults	0.08	-
7	Cell base	Non-backfill	Pseudo-soil	High storage	0.08	Non-conv. @ SP117
8	Layer 10 base	Non-backfill	Residual saturation	No faults	0.05	-
9	Cell base	Non-backfill	Residual/Pseudo-soil		0.05	Non-conv. @ SP104
10	Cell base	Staged Backfill	Residual saturation		0.01	-
11	Cell base	Staged Backfill	Pseudo-soil		0.01	-

Model non-convergence generally occurred in scenarios using the pseudo-soil function, typically when the Eastern Mining area was being actively mined, which is when the number of active drain cells is at a maximum. Scenarios using residual saturation parameters and/or a staged modelling approach did not experience model convergence issues, with the exception of Scenario 3.

It should be noted that all variants of the model where mining was removed from the simulation performed well, resulting in quick run times with minimal convergence error.

2.3 Unsaturated zone modelling

The EIS model simulated unsaturated soil properties (α, β, and Rs) to allow for residual saturation and improve groundwater model stability.

The pseudo-soil function is an add-on to MODFLOW SURFACT which doesnot allow for residual saturation of soil. It is based on a gravitational based function, which relates to transmissivity being a function of the saturated thickness. The pseudo-soil function has no parameters as it is assumed linear between the top and bottom of a cell.

Dr Mackie noted: *"In contrast to the saturated zone properties, there is no reference anywhere in the EIS to the vadose zone parameters yet they are fundamental to the operation of the model and the prediction of the water table. The same parameter values have also been assigned to all layers of the model, which seems counter-intuitive since there are notable differences in lithologies in the measured hydraulic properties of different strata under saturated conditions. I am not aware of any testing pertaining to the Namoi alluvial aquifer to support the adopted vadose zone values, nor any data to support these same properties in consolidated rocks like the Clare Sandstone or the coal seams. The adopted values are considered to be based entirely on conjecture while the use of the same properties for all strata has no factual basis."*

Often EIS level models have a total cell count of over 1-3 million cells to meet the resolution requirements of the project. The selection of uniform saturated zone properties was based primarily on model stability. The pseudo-soil function was not used as previous experience indicated slower run times and convergence issues. Our experience using the residual saturation function indicates it produces results comparable to using the rewetting function in MODFLOW NWT/USG, at significantly faster runtimes. As detailed in our previous correspondence, we have varied the van Genuchten parameters and concluded that groundwater impacts are relatively insensitive to these parameters.

The sections below outline in more detail the impacts of the adopted unsaturated zone simulation method on the predicted impacts.

2.3.1 *Model calibration*

The EIS model was calibrated over the period 1980 to 2011. This model simulated historical groundwater pumping from bores with entitlements and the response the groundwater system in the absence of mining. The unsaturated zone parameters in the calibration model were also applied without change to the predictive model. Figure 2-13 shows the performance of the EIS model. Figure 2-14 shows the calibration statistics for the same calibration model using the pseudo-soil function.

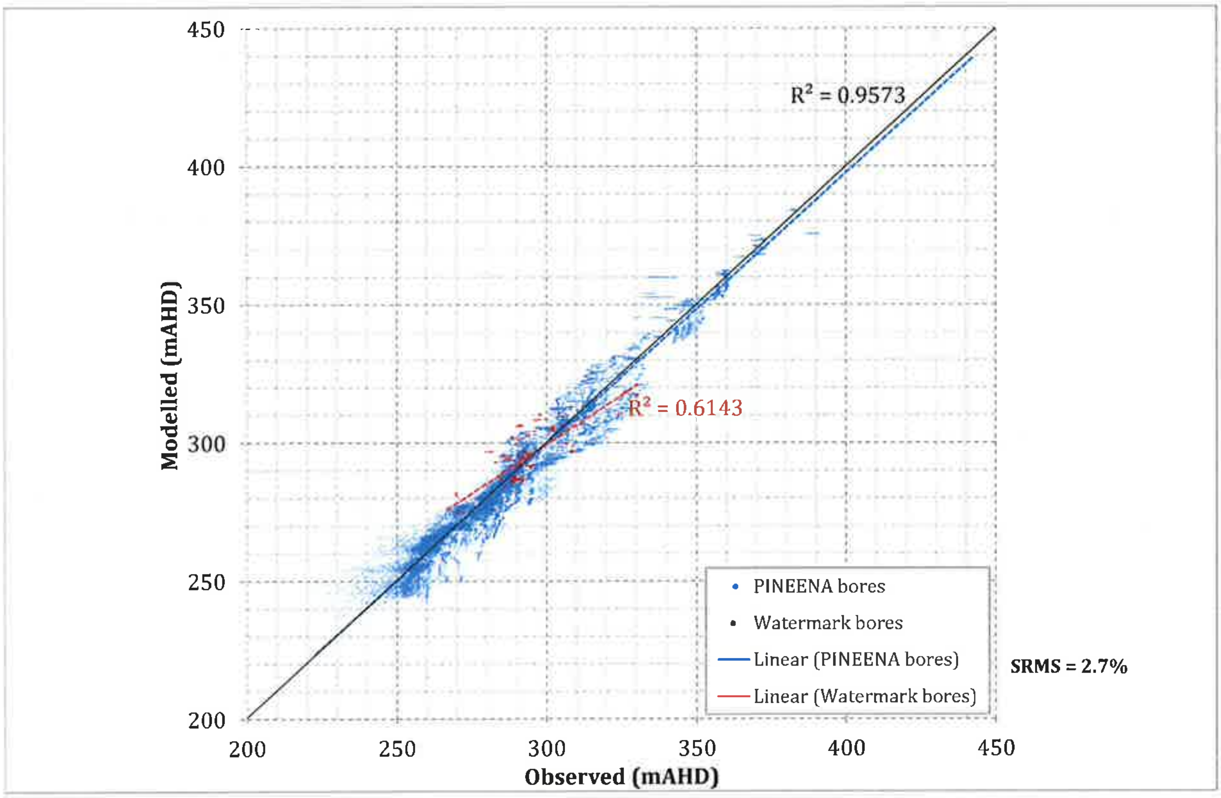


Figure 2-13 **Measured vs modelled heads – EIS transient model**

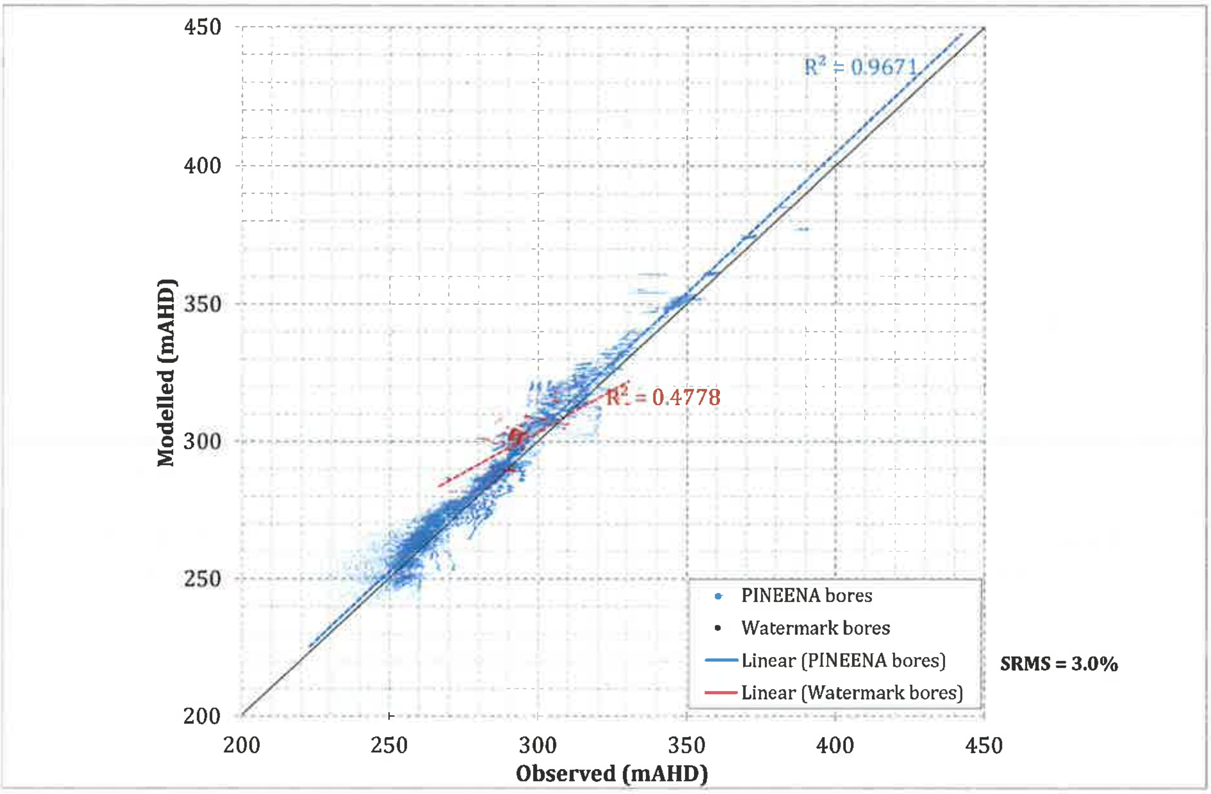


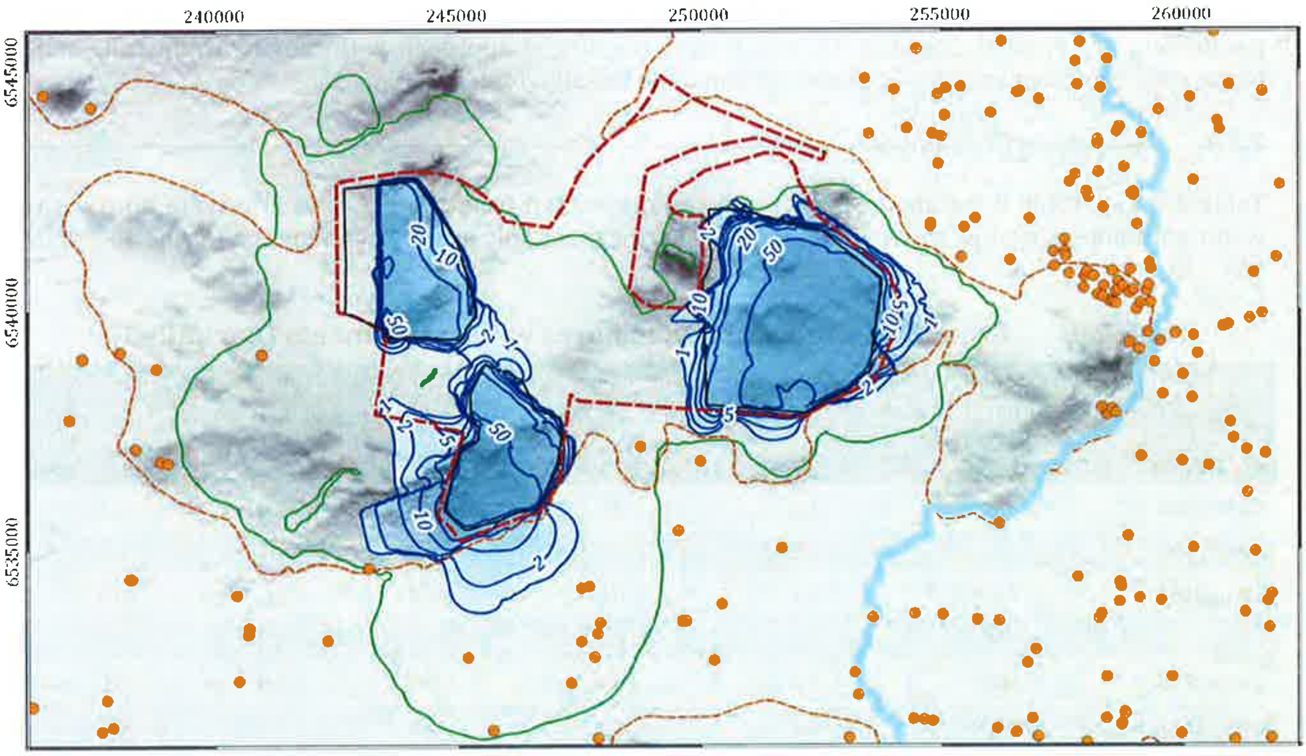
Figure 2-14 Measured vs modelled heads - Pseudo soil transient model

The results show that no significant de-calibration of the model occurs when using the pseudo-soil function. The pseudo-soil function increases the SRMS marginally from 2.7% in the EIS to 3%, which is within the prescribed calibration limits recommended by Barnett (2013) of 5.0%.

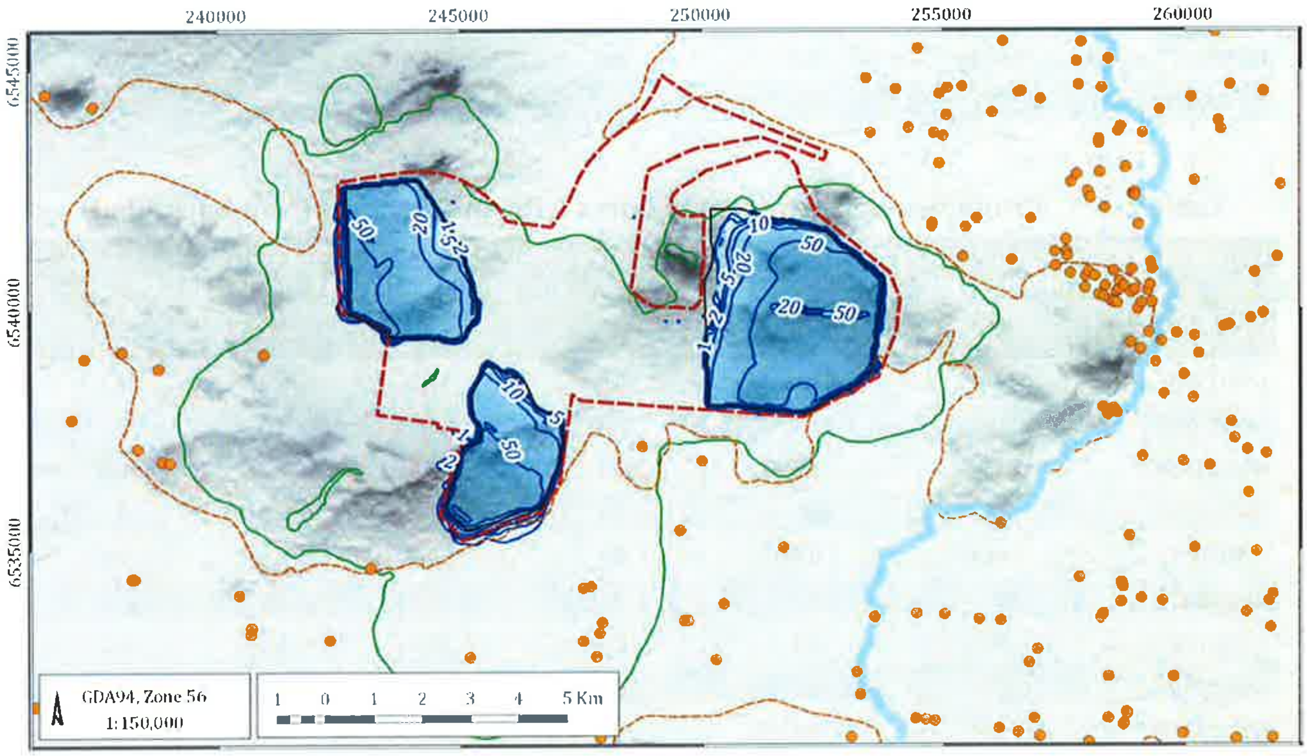
2.3.2 Groundwater level impacts

Section 2.1.3 shows cross-sections of groundwater drawdown using the pseudo soil function. Figure 2-15 shows maximum groundwater level drawdown for scenarios 3 and 11 both applying the pseudo soil function.

Scenario 3



Scenario 11



LEGEND

☐ Mining area
● PINEENA bore
- - Project area
— Mooki river
☐ Alluvial boundary
— Groundwater Drawdown (m) EIS model (Uncert)
— Groundwater Drawdown (m)

Watermark (G1501)

Groundwater Drawdown Impacts – Gunnedah Fm – Pseudos-soil (Scenarios 3 and 11)

DATE 30/9/2014

FIGURE No: **2-15**

Figure 2-15 shows groundwater drawdown is less extensive than when residual saturation parameters are applied. Scenario 11, which uses the staged approach with moving drain cells and waste rock emplacement, shows almost no impact to the alluvium.

2.3.3 Impacts on groundwater users

Table 2-8 and Table 2-9 compared the predicted drawdown from the EIS at each private bore with water entitlement, against the revised model scenarios that apply pseudo-soil function (Scenario 3 and 11).

Table 2-8 Groundwater drawdown in bores with entitlements (Backfilled)

Work Number	Completed Depth (mbgl)	EIS Drawdown (m)	Drawdown – (Scenario 11) (m)	Head Available (m)	EIS Percent Change (%)	Percent Change – (Scenario 11) (%)
GW015505	35.1	1.4	0.0	19.2	7.4	0.0
GW967790	70	1.1	0.0	55.9	1.9	0.0
GW029468	64.6	1.1	0.0	48.6	2.3	0.0
GW037713	64	1	0.0	47.7	2.2	0.0
GW060252	148.4	0.6	0.0	136.5	0.5	0.0
GW022622	45.1	0.3	0.1	32.8	0.9	0.2
GW967781	50	0.4	0.1	37.4	1.0	0.2
GW022984	45.1	0.3	0.1	33.4	0.9	0.2
GW022977	148.4	0.3	0.0	136.6	0.2	0.0
GW022620	48.8	0.3	0.0	36.3	0.9	0.1

Table 2-9 Groundwater drawdown in bores with entitlements (Non-backfilled)

Work Number	Completed Depth (mbgl)	EIS Drawdown (m)	Drawdown - (Scenario 3) (m)	Head Available (m)	EIS Percent Change (%)	Percent Change - (Scenario 3) (%)
GW015505	35.1	1.4	0.5	19.2	7.4	2.3
GW967790	70	1.1	0.4	55.9	1.9	0.7
GW029468	64.6	1.1	0.4	48.6	2.3	0.8
GW037713	64	1	0.4	47.7	2.2	0.7
GW060252	148.4	0.6	0.1	136.5	0.5	0.1
GW022622	45.1	0.3	0.1	32.8	0.9	0.2
GW967781	50	0.4	0.1	37.4	1.0	0.2
GW022984	45.1	0.3	0.1	33.4	0.9	0.2
GW022977	148.4	0.3	0.0	136.6	0.2	0.0
GW022620	48.8	0.3	0.0	36.3	0.9	0.1

The results indicate the groundwater impacts on surrounding groundwater users are reduced from the results presented in the EIS report when the pseudo soil function is adopted. This is most significant when the pit is continually backfilled during mining (Scenario 11).

2.3.4 Pit inflow sensitivity

Figure 2-16 shows the sensitivity of the backfilled model to using the pseudo-soil function. Figure 2-17 compares the EIS model with the non-backfilled model using the pseudo-soil function.

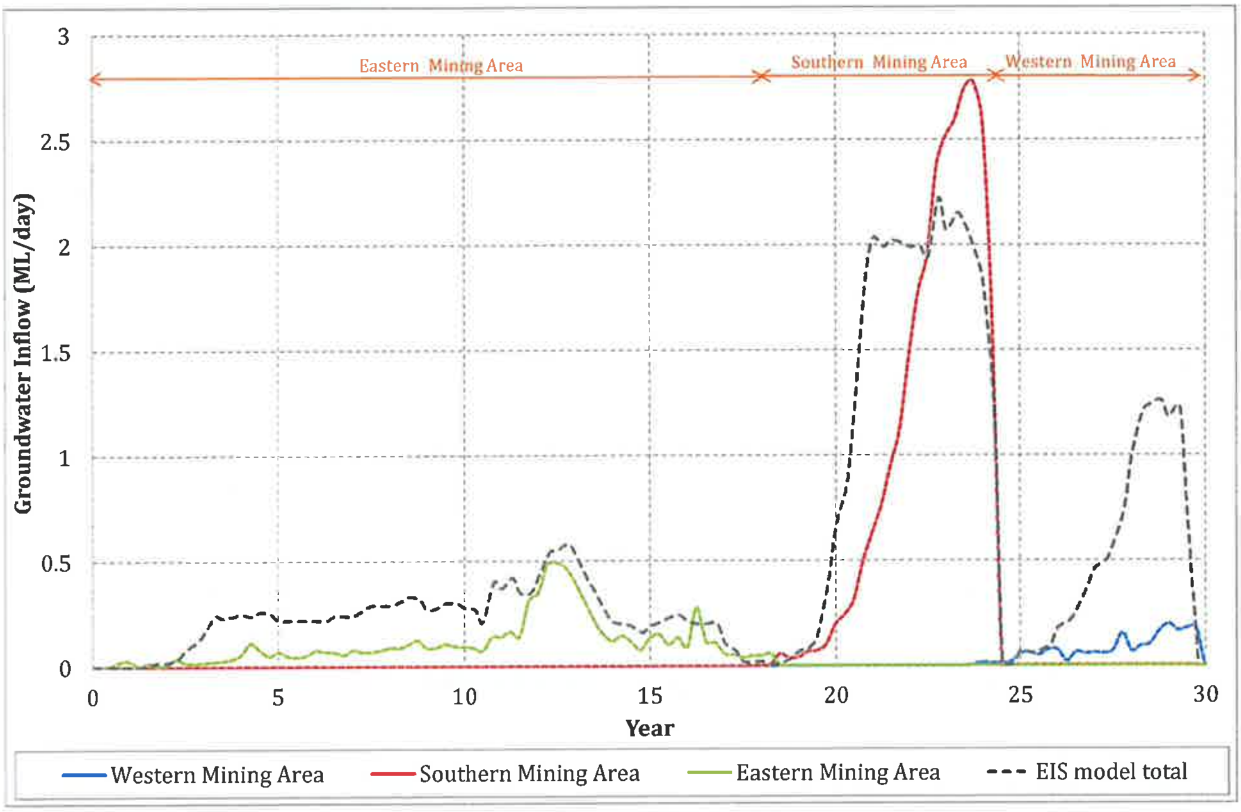


Figure 2-16 **Pit seepage rates – backfilled (Scenario 11)**

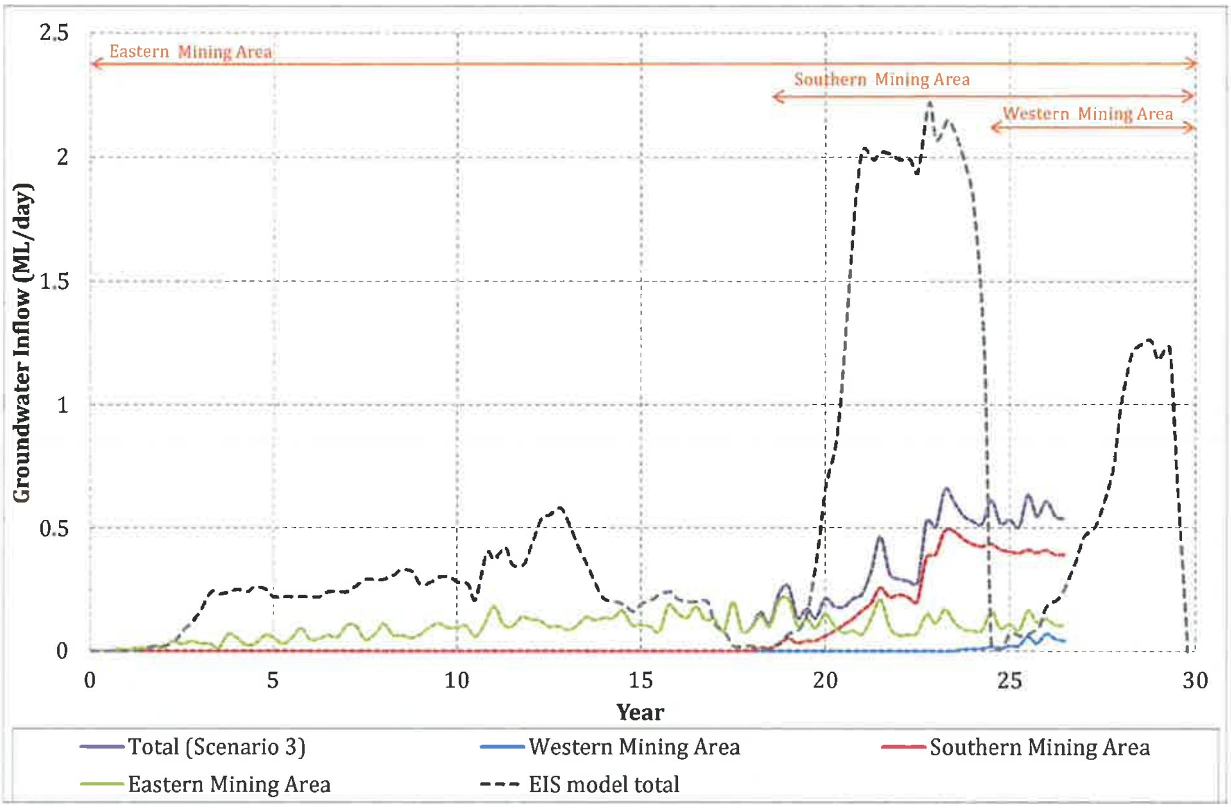


Figure 2-17 Pit seepage – Non-backfilled (Scenario 3)

When the backfilled model adopts the pseudo-soil function, the groundwater inflow rates are similar to results using the residual saturation function. The non-backfilled model using the pseudo-soil function predicts significant lower seepage rates. As discussed previously, this model does not include spoil backfilling and therefore seepage from the spoils that report to the pits.

2.3.5 Groundwater management zone impacts

Figure 2-18 compares the 'water take' from Groundwater Management Zone 7 predicted by the backfilled model and the same model using the pseudo-soil function. The figure indicates the predicted water take is reduced (Gunnedah Formation/Permian drawdown) when the pseudo-soil function is applied to the model. The small wobble in the data is directly related to the percent discrepancy error, which reaches 0.1% during this time step (see Figure 2-9).

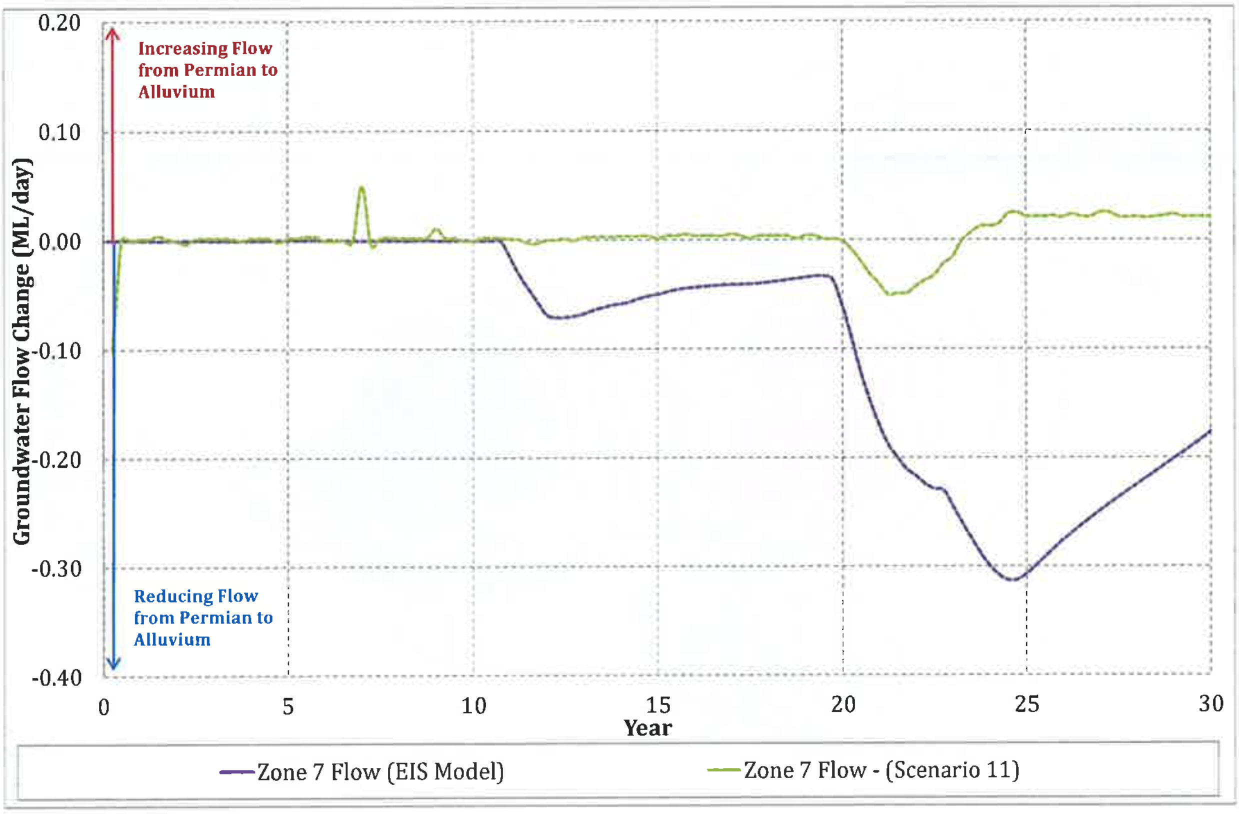


Figure 2-18 **Flow change to groundwater management zone (Scenario 11)**

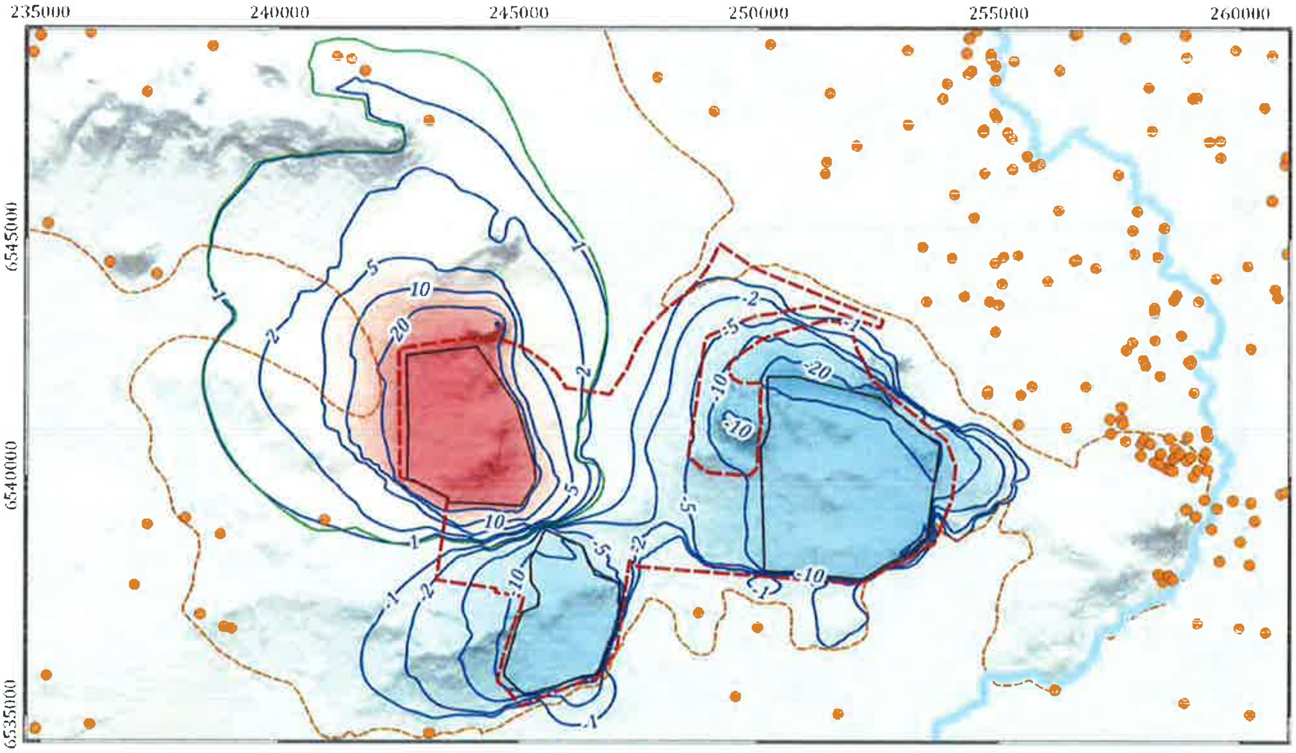
2.3.6 Steady state recovery model

Following mine closure, the EIS model (and subsequent RTS model) changed hydraulic parameters, recharge and evapotranspiration rates in the mining area to represent the mined final landform. This model was run in transient mode for a total of 2,000 years to assess the rate of groundwater recovery, and the time to reach equilibrium.

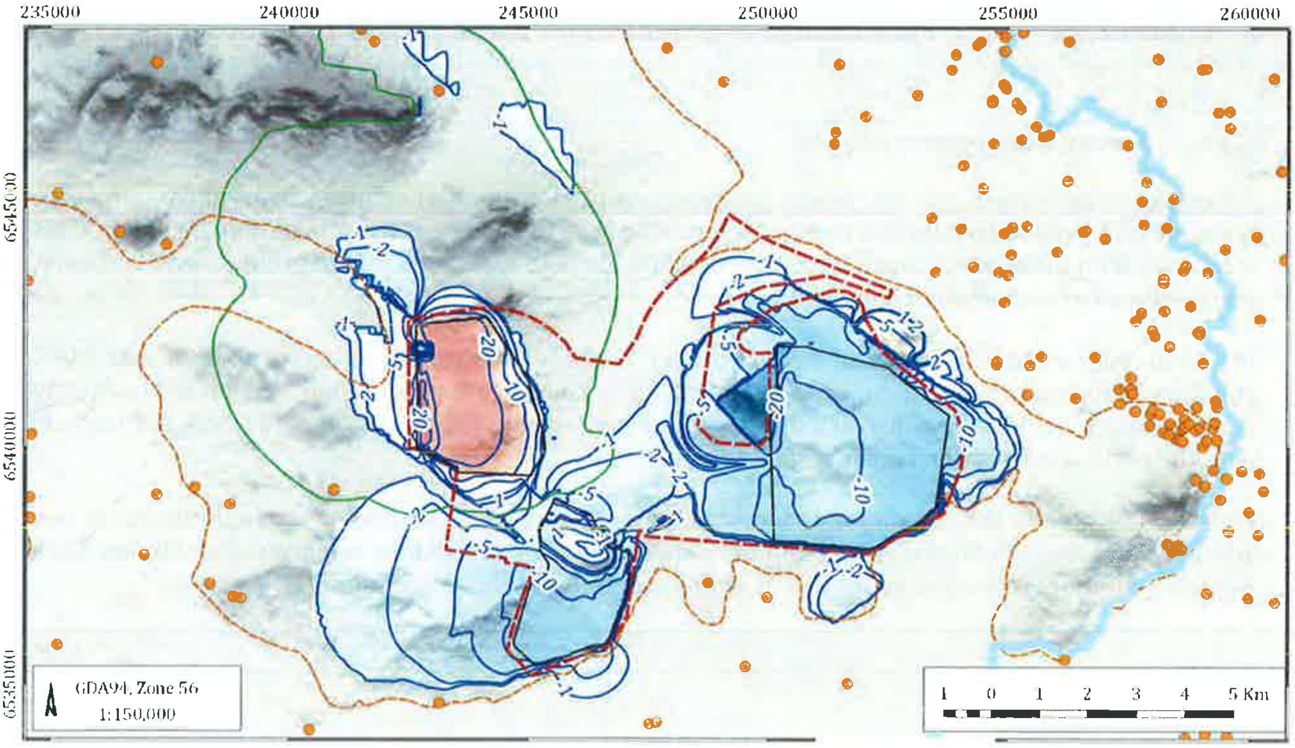
Dr Mackie requested AGE to re-run the RTS model in steady state conditions to ensure that year 2,000 conditions represent true equilibrium conditions. For completeness, a second version of the steady state recovery model was constructed, using the pseudo-soil function to compare predicted impacts with the residual saturation recovery model.

Figure 2-19 shows the extent of the post-mining groundwater mounding around the backfilled Southern and Eastern Mining Areas, and the depressurisation around the open Western Mining Area. Negative contours represent mounding of groundwater levels above pre-mining.

Scenario 4



Scenario 5



LEGEND

- ▭ Mining area
- ● PINEENA Bore
- — — Project area
- — Mooki river
- ⬚ Alluvial boundary
- — Groundwater Drawdown (m) EIS model (Uncert)
- — Groundwater Drawdown (m)

Watermark (G1501)

Post-mining groundwater drawdown extents – Sensitivity – Layer 2

DATE 30/9/2014

FIGURE No. **2-19**

The results show that year 2,000 conditions are almost identical to steady state conditions, and therefore the results presented in the RTS modelling report are representative of equilibrium conditions. Results using the pseudo-soil function are significantly different and residual drawdown extents are limited to the areas within the emplaced waste rock areas.

2.4 Sensitivity scenarios

Results using the pseudo-soil function were different to model runs using the residual saturation parameters. Generally the predicted impacts were reduced.

In order to explore some of the issues raised by Dr Mackie further, AGE developed some additional model scenarios described in sections below.

It is noted that groundwater drawdown appeared to be impeded by the presence of faults when the pseudo-soil function was adopted. To determine if the HFB (horizontal flow barrier) package was reducing impacts, a scenario using the pseudo-soil function and completely removing faults was undertaken (Scenario 6).

A scenario where storage parameters were increased by one order of magnitude in combination with the pseudo-soil function was also undertaken (Scenario 7).

As an absolute worst case, a version of the model was run using the original drain cell elevation approach using drains down to the base of the coal seam, with all faults removed (Scenario 8).

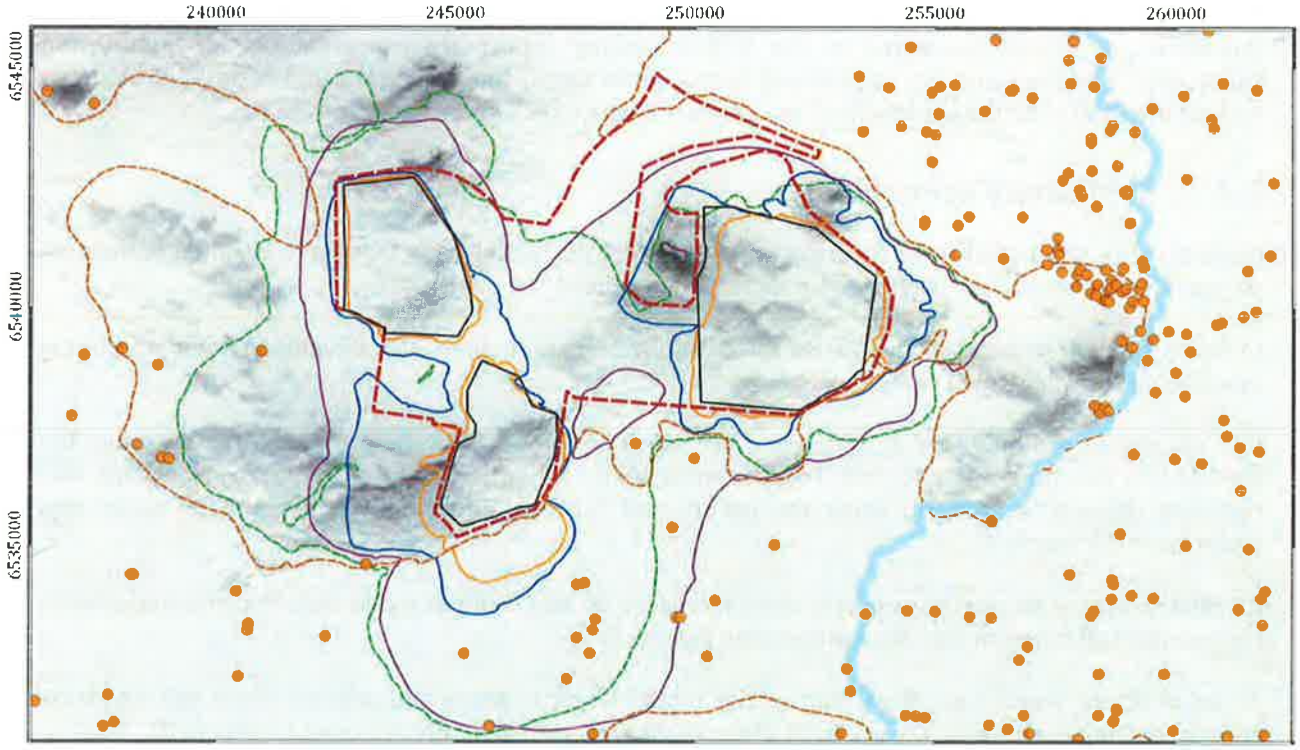
MODFLOW SURFACT has a function in which it allows a combination of pseudo-soil and residual saturation parameters in varying layers. As an experiment, layer 1 and layer 2 were assigned residual saturation parameters (type 43), while layer 3 to layer 11 were assigned to type 44, which invokes the pseudo-soil function (Scenario 9).

The sections below compare the impacts predicted by these scenarios with the EIS base case, and the upper bounds predicted in the EIS uncertainty analysis.

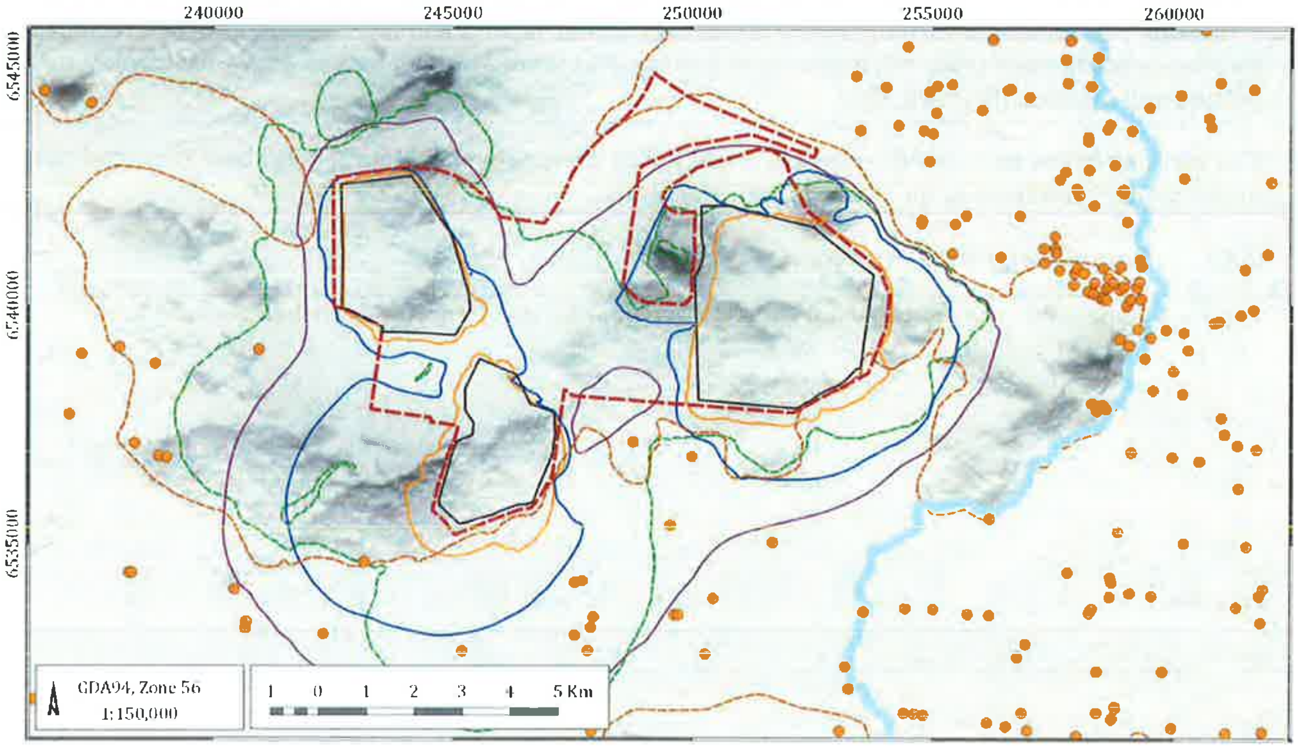
2.4.1 Groundwater level impacts

Figure 2-20 presents the groundwater drawdown extent for the scenarios described above.

Layer 2 - Gunnedah Formation



Layer 10 - Mellvilles Coal Seam



LEGEND

▭ Mining area
● PINEENA bore
- - Project area
▬ Mooki river
▭ Alluvial boundary
- - - Groundwater Drawdown (m) EIS model (Uncert)
— Groundwater Drawdown (1m) Scenario 6
— Groundwater Drawdown (1m) Scenario 7
— Groundwater Drawdown (1m) Scenario 8

Watermark (G1501)

Groundwater Drawdown Impacts – Sensitivity Scenarios

DATE	FIGURE No.
30/9/2014	**2-20**

The results show that all the scenarios are within the depressurization zone presented in the EIS report, and no bores outside the project area are predicted to have drawdown of more than 2m.

2.4.2 Pit inflow sensitivity

Figure 2-21 shows the sensitivity of the total pit seepage rates into the proposed mining areas.

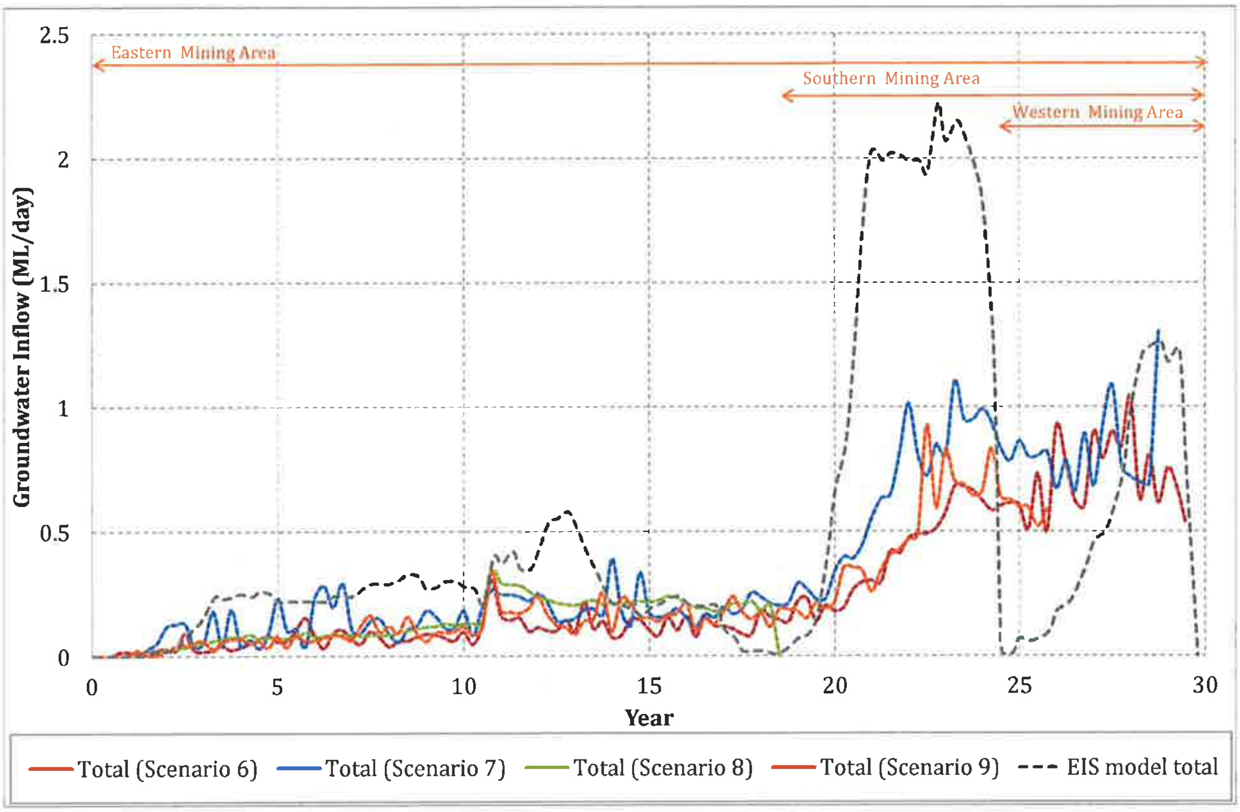


Figure 2-21 Pit seepage sensitivity

The figure shows the pit seepage rates are similar across all sensitivity scenarios completed. Groundwater inflow peaks relate to the accuracy of the model solution at each time step, which has been discussed in section 2.2.

2.4.3 Groundwater management zone impacts

Figure 2-22 shows the sensitivity of groundwater flow change to Groundwater Management Zone 7 for the sensitivity runs.

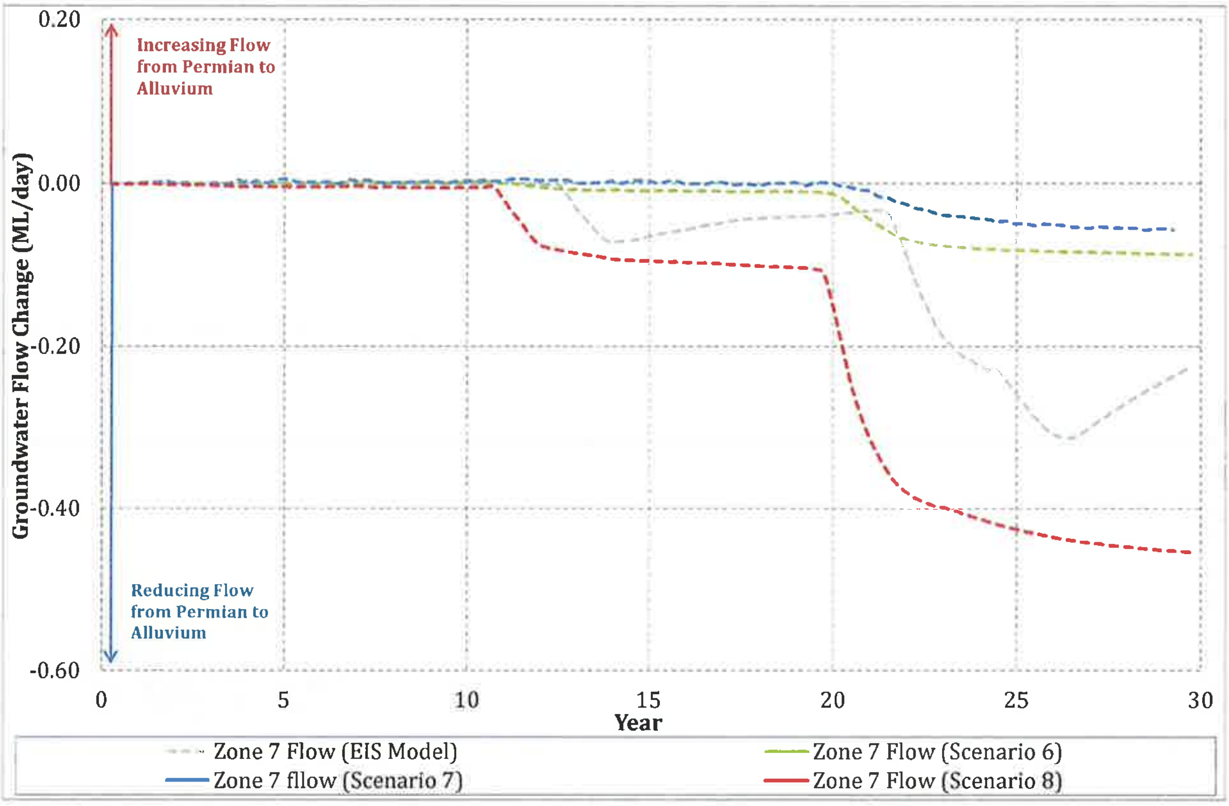


Figure 2-22 **Groundwater management zone 7 flow change sensitivity**

The graph shows that the scenarios setting the drain elevation to the base of the cell produces impacts less than using the method used in the EIS model.

Removing faults from the model and using the EIS drain cell elevation with 'growing drains' results in more impacts than presented in the EIS model. However, these impacts are less than the worst case predictions presented in the uncertainty and sensitivity sections of the EIS report.

3. Conclusions

The EIS model applied AGE's standard methodology and set the drain reference elevation in the mining areas to the base of the pit floor to introduce conservatism to modelling predictions, and to aid model stability for the recovery scenario. This memo presents results demonstrating that setting drain reference elevations to the base of each cell further reduces predicted impacts to surrounding groundwater users and the groundwater regime.

The predicted seepage rates to the mining areas was also found to be sensitive to the closure criterion adopted. The EIS model adopted closure criterion that ensured the model converged to an accurate solution, and provided accurate pit seepage rates. Simulated groundwater levels are insensitive to variances in model closure criterion. No erratic behaviour in heads was observed in any of the scenarios explored.

The residual saturation function adopted by AGE for the EIS modelling due to its ability to aid model convergence following desaturation of model cells. Our experience using this function produces results comparable to using the rewetting function in MODFLOW NWT/USG, at significantly faster runtimes. Fast runtimes (<8 hours) were essential to maintain 50m x 50m cell resolution in the mining areas, and to perform an uncertainty analysis. Our experience has been that adopting the pseudo soil function reduces the predicted impacts both during mining, and long term post mining. Therefore, this review shows that the EIS model produces conservative impacts when compared to the other approaches suggested and can be used as a functioning predictive baseline that the observed impacts can be compared to once mining commences.

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