SCT Operations Pty Ltd
ABN 23 078 328 853
www.sct.gs

HEAD OFFICE
Cnr Kembla & Beach Streets Wollongong NSW 2500 Australia
PO Box 824 Wollongong NSW 2520 Australia
Telephone +61 2 4222 2777 Fax: +61 2 4226 4884
Email sctnsw@sct.gs

MACKAY OFFICE
Telephone/Fax: +61 7 4952 5717
Email: p.cartwright@sct.gs

BENDIGO OFFICE
Telephone: +61 3 5443 5941
Email s.macgregor@sct.gs

BRISBANE OFFICE
Telephone: +61 429 881 771
Email y.heritage@sct.gs

5 February 2016

David Clarkson
Group Environment and Approvals
Manager
Wollongong Coal
PO Box 281
FAIRY MEADOW NSW 2519

Dear David

RESPONSE TO PAC QUESTIONS

On 18 January 2016, Hansen Bailey forwarded a document containing a number of points of clarification relating to the second Planning Assessment Commission (PAC) review of the Russell Vale Colliery Underground Expansion Project (UEP). Wollongong Coal commissioned SCT Operations Pty Ltd (SCT) to respond to queries that relate to those areas of the project that SCT has been working on. This letter report presents SCT's response to height of depressurisation, effect of Bald Hill Claystone to affect Cataract Creek tolerance to valley closure, and contingency to manage pillar layout issues at the western end of Longwall 7. The questions numbers used correspond to the numbering in the Hansen Bailey document.

1. HEIGHT OF DEPRESSURISATION

1.1 Question 13 "What is the upper limit and how is it determined?"

SCT understands this issue is also being addressed by the groundwater modelling team, but there is some overlap and this issue is also addressed here.

The maximum height of depressurisation was determined using the piezometer network installed by Wollongong Coal to measure the heights of depressurisation across the site.

The measured heights of depressurisation in a multi-seam environment are found to be consistently greater than the heights indicated by the Tammetta (2012) approach for 3.2 m thick single seam mining in the Wongawilli Seam. The Tammetta approach does not apply to multi-seam mining operations, but estimating the height of depressurisation based on mining in one seam only does provide a lower limit on the height of depressurisation that would be expected when other additional seams are mined in the same area.

The measured heights of depressurisation bear this out and indicate the height of depressurisation increases as additional seams are mined as would be expected.

The Tammetta approach was considered as to whether it could be applied using the cumulative thickness of coal from the three seams mined and the groundwater modelling initially explored this approach. However, the approach was found to significantly overestimate the actual measured height of depressurisation. The groundwater modelling is therefore based on the measured height of depressurisation that is more than the height indicated by the Tammetta approach based on the Wongawilli Seam geometry alone and less than the height indicated by the Tammetta approach using the combined height of all three seams.

It should be noted that the piezometer network installed above Russell Vale East to measure the height of depressurisation has expanded during the period that this Project Application has been running. The holes aimed specifically to target available areas of double and triple seam pillar extraction and longwall mining have been installed as resources and time lags for approval have allowed. Some of the early reports relating to estimating the heights of depressurisation predate the installations and subsequent monitoring and the learnings that came from this work.

1.2 Question 15 "Why was the height of the caved zone increased in area of multi-seam mining ..."

The subsidence experience at Russell Vale East indicates that the overburden strata is softened by each additional seam that is mined and the observed subsidence is primarily a consequence of this softening effect. The softened overburden strata is not able to span across each of the narrow longwall panels as effectively as intact strata.

The mining in each of the seams follow a different layout geometry so that there are areas of single seam, double seam, and triple seam mining as well as total extraction below large standing pillars, small pillars, large areas of extracted pillars, and narrow panels of extracted pillars. It has been possible from the variety of different geometries to develop an understanding of the effects of longwall mining in these various situations through surface subsidence monitoring, first in the Balgownie Seam and more recently in the Wongawilli Seam.

This understanding indicates that the height of the caved zone increases with each additional seam mined. This result is consistent with the results of piezometer monitoring

1.3 Question 16 "Please address matters raised in the following extract"

An extract from the OEH Preliminary Comments raises issues about the potential for multi-seam mining to affect the area around the finishing end of Longwall 7 and asserts there are conflicts in the height of depressurisation calculated. The SCT Report referred to makes the observation that the Tammetta height is appropriate for single seam mining. The height of depressurisation calculated using the Tammetta approach for a single seam mining thickness provides a lower limit for a multi-seam mining environment because the extra extraction thickness associated with multi-seam mining would be expected to increase the height of depressurisation. Adapting the Tammetta approach to use the full thickness of all three seams has been found from measurement of the piezometric profile to overestimate the height of depressurisation. Piezometer monitoring experience at Russell Vale Colliery has confirmed that the height of depressurisation in a double seam mining environment such as at the finishing end of Longwall 7 and a triple seam mining situation such as over Longwall 4 does indeed overestimate the height of depressurisation as expected.

2. CRACKING OF CATARACT CREEK

2.1 Questions 17 and 18 "How was ductility determined and what are the respective ductility values?"

The *Response to Planning Assessment Commission Review Report Part 2* (Hansen Bailey, 2015) used the term "more ductile" to refer to the section of the bed of Cataract Creek located within the outcrop of the Bald Hill Claystone. The term used is not technically correct and was intended to convey the concept of the Bald Hill Claystone being more tolerant to valley closure movements than Hawkesbury Sandstone.

The basis for this assertion is that Longwall 11 in the Balgownie Seam mined directly under Cataract Creek and caused valley closure of approximately 310mm (estimated from horizontal strain measurements). Inspection of the bed of Cataract Creek which outcrops in this area shows no evidence of mining related impact. If the bed of Cataract Creek were located in Hawkesbury Sandstone and subject to 310mm of valley closure, the impacts expected would be expected to be clearly apparent.

There are several reasons why the Bald Hill Claystone may show greater tolerance to valley closure effects. Valley closure is primarily driven by dilation (lateral expansion) of the subsiding rock strata above the level of the valley floor on either side of the valley that is undermined. The basal shear plane that develops to accommodate the valley closure may preferentially develop above the level of the Bald Hill Claystone at the interface with the Hawkesbury Sandstone and therefore isolate the rock in the bed of the creek from compression effects.

Another possible reason for the absence of perceptible effects is the nature of the creek bed. Whereas Hawkesbury Sandstone strata tends to form large intact sheets separated by isolated bedding planes some distance apart, the Bald Hill Claystone is much more closely fractured in its natural state. When compressed laterally, the Hawkesbury Sandstone tends to fracture through fresh rock with significant dislocation of adjacent units in order to accommodate the movement. The more closely fractured Bald Hill Claystone can accommodate the movement more easily through smaller movements on multiple natural joints.

Where the bed of the creek is located in Bald Hill Claystone, the creek bed tends to have a pebbly base rather than the rock base characteristic of creeks that outcrop in Hawkesbury Sandstone. Mining induced movements tend to be less apparent where there is an overlay of pebbles although significant impacts would still be expected to be apparent.

3. Pillar Stability Inbye of Longwall 7

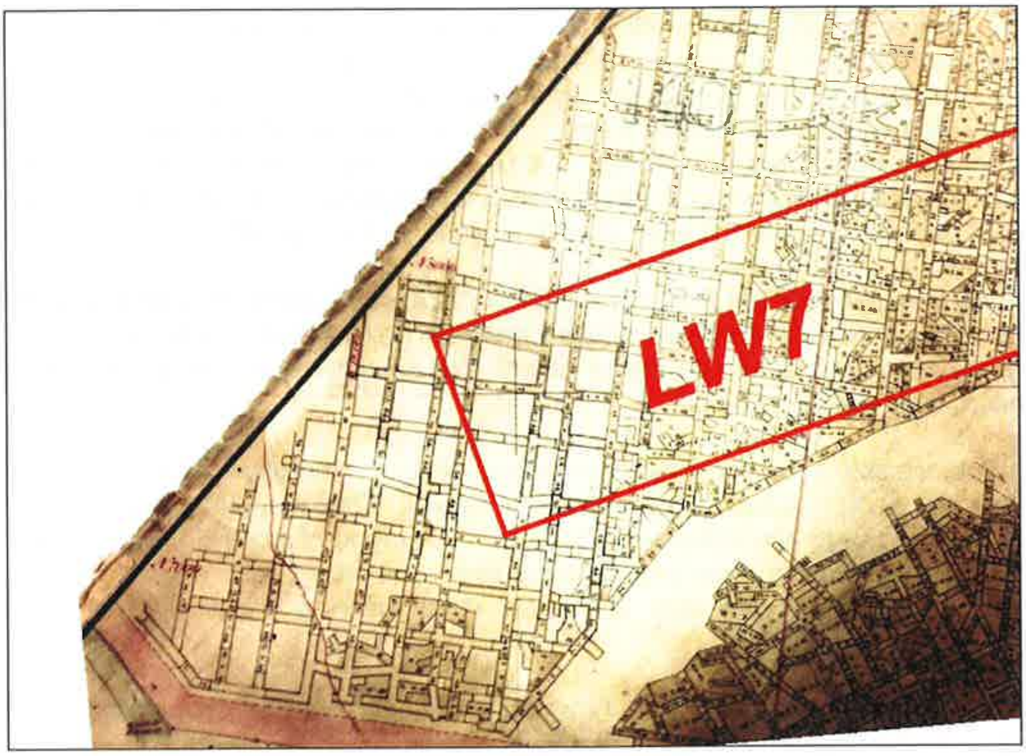
3.1 Question 19 "What contingency is proposed in the event that the reliability of the record tracing cannot be determine?"

The area in the Bulli Seam at the inbye end of Longwall 7 was mined in the period between about 1944 and 1949. Both the mine working plan and the record tracing for this area of the mine are available and have been reviewed. The mine working plan and record tracing reproduced in Figure 1 shows the dates of mining individual roadways and the individual pillar splits in areas of pillar extraction.

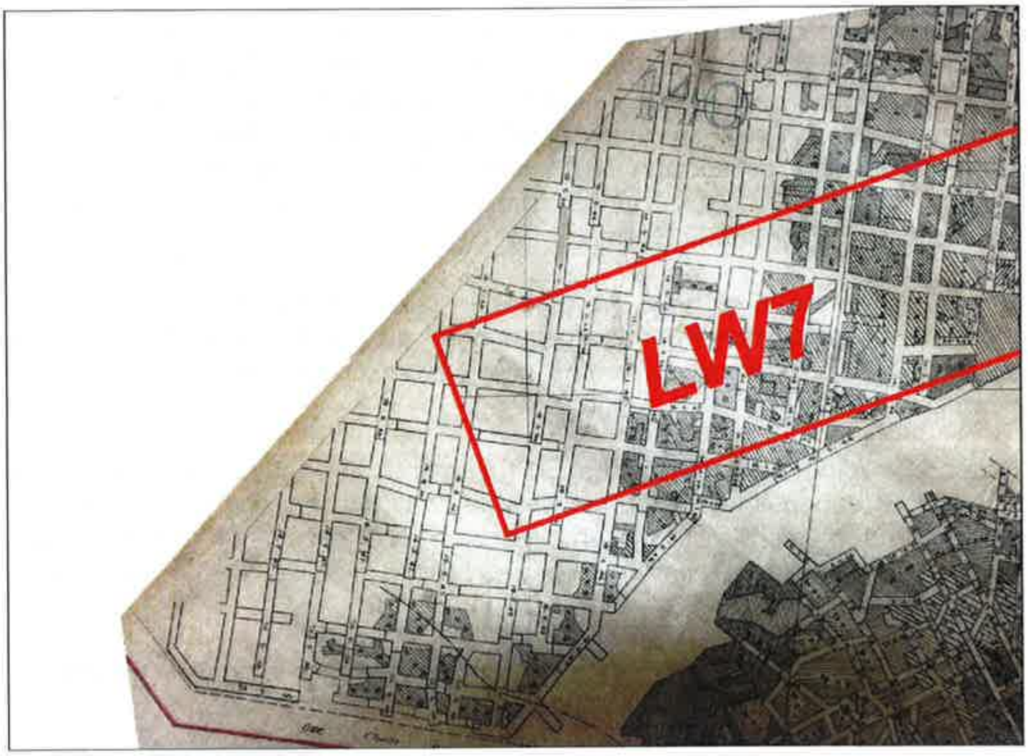
There is a mismatch at the boundary between two sheets of about 2m on the ISG version of the mine plan that is likely due to stretching of the medium on which the plans have been redrafted. However, this area of the mine is connected to the operating mine and the survey network is considered likely to be coherent with the known position of the main headings that are still accessible. On this basis, the actual position of the workings is expected to be accurate to within about 5 m. The relative accuracy of individual roadways and pillars is expected to be in the range of only a few metres.

The area itself is no longer accessible because of subsequent mining of longwall panels in the Balgownie Seam. However, experience of drilling upward from the Wongawilli Seam to intersect workings in the Bulli Seam and drain them of water has shown the plans to be accurate enough to allow intersections to be made consistently (± 5 m). Similarly, mining below the goaf edges in the Bulli and Balgownie Seams has been clearly apparent in the roadway conditions experienced in the Wongawilli Seam and correlates closely with mine plans.

Subsidence monitoring experience in the Balgownie Seam and the Wongawilli Seam to date shows the subsidence behaviour for mining under multiple different types of pillar geometries in the Bulli Seam. The presence of large pillars in the Bulli Seam, and the presence of fully extracted areas in the Bulli



a) Eastern mine working plan with proposed LW7 outline.



b) Eastern record tracing with proposed LW7 outline.

Figure 1: Eastern mine working plan and record tracing with proposed LW7 outline.

Seam do not significantly modify the goaf edge subsidence profile. The only areas where there has been some additional subsidence in the Bulli Seam from longwall mining in the Balgownie or Wongawilli Seams has been in areas of narrow extraction in the Bulli Seam. The narrowness of the extraction has limited subsidence during mining in the Bulli Seam and this subsidence is recovered when the area is mined under in the Balgownie or Wongawilli Seams. Such a geometry does not exist at the inbye end of Longwall 7.

The only credible risk for the protection of Cataract Reservoir is that the mine plans are incomplete and the pillars have been extracted to the point where they are small enough to be marginally stable as a panel and large enough not to have failed during mining.

It is not credible that the roadways shown on the mine plan do not exist. The dates that each roadway was mined are shown. The irregular detail indicates that the roadways are individually mapped. The issue of possible uncertainty is whether these pillars have been subsequently mined without any reference to such mining making its way onto the mine working plans or the record tracings.

It is unlikely that mining might have occurred across the large area at the inbye end of Longwall 7 without being recorded on the mine working plan and the record tracings and without such mining presenting a significant mine safety hazard during the period of mining.

The pillars shown on the mine working plan and the record tracing are large enough to be stable when Longwall 7 is mined. Some adjacent areas shown on these mine plans are shown as having been extracted. If all the area had been extracted beyond what is shown, which appears unlikely, the effect on subsidence and the protection of Cataract Reservoir from mining Longwall 7 would be slight based on experience at multiple locations of mining below areas of full extraction in the Bulli Seam.

It is difficult to visualise how the pillars in the Bulli Seam might be actually mined so as to reduce them to a small enough size to be vulnerable to collapse when Longwall 7 is mined given the pillar geometries indicated on the mine working plan.

Although the mine workings in the Bulli Seam at the inbye end of Longwall 7 are no longer accessible, SCT understands that Wollongong Coal proposes to drill boreholes to confirm that the location and nature of the workings is consistent with the mine working plan and record tracings in the area adjacent to the inbye end of Longwall 7.

3.2 Question 20 "What are the implications of this situation on the likelihood of pillar failure?"

The nominal geometry of 22m x 33m is considered to be representative of the pillar sizes shown on the mine plan. While there are a few smaller pillars as small as 12m wide, these smaller pillars still have a width to height ratio of greater than five and are therefore not susceptible to shedding significant load if they become overloaded. Furthermore, the stability of locally smaller pillars is not critical to the overall stability of the panel when the panel has a significant number of pillars with width to height ratios of ten or more.

These larger pillars continue to gain strength as they deform so irrespective of the abutment loading or proximity to existing goaf areas, the load bearing capacity of larger pillars continues to increase. In an operating mine, the increasing load on large pillars can cause deterioration of the adjacent roadways which are typically required to maintain ventilation and access so it is necessary to limit the load they are required to support. In abandoned workings there is no such requirement and any deterioration of the ribs and roof serves to provide additional confinement to the core of the pillar.

Subsidence in this circumstance is attributable to elastic compression of the overlying strata under the increased pillar load. This increased compression has the effect of reducing the hydraulic conductivity of the strata above and below the pillar. For the pillars at the inbye end of Longwall 7, a reduction in hydraulic conductivity would reduce the potential for flow from the reservoir to the mine through the barrier.

3.3 Question 21 "What are the implications if, as in the extreme case of Crandall Canyon pillar failure, failed coal has a much lower void content than the 50% assumed in the SCT analysis?"

Crandall Canyon was an example of extremely high loads causing large pillars to become suddenly overloaded and the roadways to become substantially filled with broken coal ejected from the ribs. The mine was extracting coal in an area at a depth of approximately 650 m below the surface between two already extracted longwall panels. The loads on the existing pillars were very high and much higher than could conceivably be generated at the inbye end of Longwall 7. At Crandall Canyon, the extraction of some of these pillars caused the loads to be elevated to a level where the edges of the remaining pillars failed suddenly and ejected coal into the adjacent roadways. Equilibrium was established by this failed material providing confinement to the pillar edges allowing them to carry the extremely high loads. Removal of this coal caused a second incident that was essentially similar to the first. Total subsidence at the surface from both events was about 250 mm.

The circumstance at the inbye end of Longwall 7 is sufficiently different to Crandall Canyon for there to be no potential for the type of behaviour observed at Crandall Canyon to occur in Longwall 7.

The issue of void volume is not really critical to re-establishing equilibrium under the loading that would be expected at the inbye end of Longwall 7. The value of 50% was used as an example of what might occur under very extreme loading conditions. The actual void content is expected to be much less than 50% under the loading conditions expected. Even if it were greater than 50%, the subsidence at the surface would be low and the loading conditions would be such that the hydraulic conductivity of the strata between the reservoir and the goaf of Longwall 7 would be reduced as a result of the additional load required to fail the pillars.

If you have any queries or would like further clarification of any of these issues, please don't hesitate to contact me.

Yours sincerely

Ken Mills
<u>Principal Geotechnical Engineer</u>

GeoTerra Pty Ltd
Suite 204 1 Erskineville Road
Newtown NSW 2042
PO Box 530 Newtown NSW 2042

Telephone: 61 2 9519 2190
Mobile: 0417 003 502
Email: geoterra@iinet.net.au

Email Transmission

To:	Wollongong Coal Ltd	**From:**	Andrew Dawkins
Attn:	Dave Clarkson	**Date:**	12/02/2016
Email:		**Our Ref:**	NRE12 E2
Cc:		**No. of Pages:**	

SUBJECT:	**Final Response to PAC Review**

Dave,

Enclosed is the final version of the response to selected questions raised by the PAC in January 2016.

Q10 - Are there any factors other than mining that would generate the observed hydraulic gradients?
A10 – No. Not at the quantum observed in the study area where the overburden has been significantly depressurised as a result of coal extraction in up to 3 seams along with the associated overburden subsidence fracturing and delamination over the Balgownie, Bulli and Wongawilli Seam workings at Russell Vale Colliery.

The phreatic surface within the overburden strata above the mining area is significantly below the level of the Cataract River and Cataract Creek. The only credible gradient is downward toward the mining horizons.

The depressurisation also extends over a significant regional extent associated with extraction in adjoining mines within the Bulli Seam to the east, south and north of Russell Vale Colliery.

Q11 - How does the pressure profile indicate enhancement and what is the enhanced vertical flow?
A11 – RV20 is a borehole located over Longwall 4 in an area where triple seam mining has caused significant strata fracturing, delamination and associated groundwater depressurisation. The head vs depth pressure profile of the piezometric array shown below indicates that all the strata from 35 – 65m below surface in the Hawkesbury Sandstone and then from 65- 85 m in the Bald Hill Claystone is highly depressurised.

The data indicates a head pressure rise at 105 mbgl in the top of the Bulgo Sandstone. However, the piezometer at 134 mbgl in the Bulgo Sandstone is depressurised.

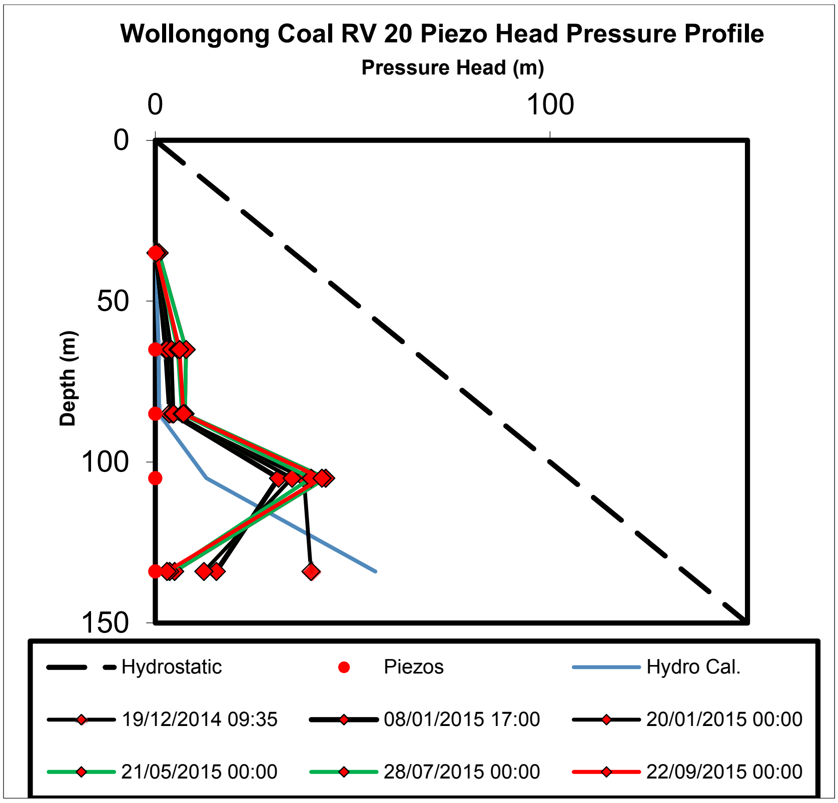
The enhanced vertical flow rate, in terms of hydraulic conductivity, has not been directly measured, however the quantum of inflow into the underground workings is separated into inflows into Longwall 4 and 5 and these inflows are consistent with downward flow through the overburden strata via a tortuous fracture network.

The non-hydrostatic nature of the piezometric profile indicates the tortuous / discontinuous nature of the fracture network.

Based on an analytical assessment of the measured heads and modelled vertical hydraulic conductivity using Darcyian flow over the triple seam mined area monitored by RV20, the interpreted enhanced vertical flow rates are estimated as shown in **Table 1.**

Table 1 Vertical Overburden Darcy Flow Rates at RV20

Interval	Kv (m/day)	Vertical Gradient	Area (m2)	Q =KiA (m3/day)
0 - 35	0.00001	0	1	0.000000
35 - 65	0.000069	0.80	1	0.000055
65 - 85	0.0000099	0.95	1	0.000009
85 - 105	0.0001	-0.75	1	-0.000075
105 - 134	0.00002	2.35	1	0.000047



However, it should be noted that all but one VWP transducer (105 mbgl) in RV20 has any significant head with essentially depressurisation occurring at other levels. The head gradient indicated between the VWP instruments at 105 and134 mbgl was applied at both intervals and compared to an area mass balance for the cell in which RV20 resides within the groundwater flow model with a cell size of 50 x 50m.

Table 3 shows the flux rates anticipated using this groundwater head difference. **Table 4** shows the model flux for the same area using the mass balance tool in Groundwater Vistas.

Table 1 Modelled Vertical Flow Rates at RV20 for Model Cell Area

Interval	Kv m/day	Vert Gradient	Area (m^2)	Q =KiA (m3/day)
85 - 105	0.0001	2.35	2500	0.589
105 - 134	0.00002	2.35	2500	0.118

Table 2 Model Flux at RV20

Layer	Surface	Base of Layer	Depth	Flux through Top (m3/day)	Flux through Bottom (m3/day)
5	354	260	94	0.8	0.9
6	354	238	116	0.9	1.8

Q13 – What is the upper limit (of the height of depressurisation) and how is this determined?

A13 – The upper limit of the height of depressurisation was derived based on vibrating wire piezometer (VWP) data over the various workings at Russell Vale East and Russell Vale West within Russell Vale Colliery.

The upper limit of the height of depressurisation varies depending on whether there has been 1, 2 or 3 phases of seam extraction, and on the interaction of the various adjoining mine, overlying fracture networks and strata delamination that has occurred as a result of mine subsidence.

The greatest height of strata depressurisation (or upper limit) measured within the Russell Vale Colliery VWP network is within RV20, which is within a triple seam mined area overlying Longwall 4 in the Wongawilli Seam. At this location, the height of depressurisation extends to between 105mbgl and 134mbgl (approximately 220-240 m above the mining horizon), with a perched horizon that maintains up to about 40 m of head as represented by the 105mbgl VWP intake. The low piezometric heads measured above the 105mbgl VWP at the 35, 65 and 85mbgl VWPs indicate this zone is highly fractured and hydraulically connected and does not support a positive piezometric profile.

The height of depressurisation calculated using Tammetta (2012) for a 3.2 m mining height and 150 m wide panel at 350 m depth is 148 m for just the Wongawilli Seam and 290-340 m if the equivalent seam thickness of 5.4-5.8 m for all three seams is used.

The measured height of 220-240 m used in the model is significantly greater than for mining the Wongawilli Seam alone and less than the combined height of mining all three seams. The Tammetta formula is intended for single seam mining only, but the measured values are consistent with the range that would be expected.

Q14 – What is the level of confidence, or risk, associated with the reliability of this alternative approach?
A14 – The conceptual model of caving, fracturing and associated strata depressurisation used in the groundwater model was principally based on the observed VWP head versus pressure data within the Russel Vale Colliery overburden.

The relevant site data was initially incorporated into the Tammetta (2012) strata fracturing / strata depressurisation theory that was developed for single seam mining over an extracted longwall panel, however, the derived theoretical values did not correlate with the observed in-situ VWP depressurisation profile/s.

Where multiple seam extraction was conducted, the Tammetta (2012) theory was then modified by adding the cumulative thickness of all workings. This approach overestimated the height of depressurisation measured by the piezometers. Subsequently, the Ditton and Merrick (2014) theory of strata fracturing / strata depressurisation (which was also developed for single seam mining over a longwall panel) was compared to the observed VWP data, and this theory also did not reliably predict the observed height of depressurisation using a RAMP function with a linear decline of enhanced vertical conductivity (weighted layer thickness) that did not match the observed groundwater pressures in the site VWP's, primarily in the Bulgo Sandstone.

As a result, the model utilised a modified version of a vertical conductivity ramp function enhancement whereby a greater degree of enhancement was made within the Lower and Mid Bulgo Sandstone as shown in **Figure 1**.

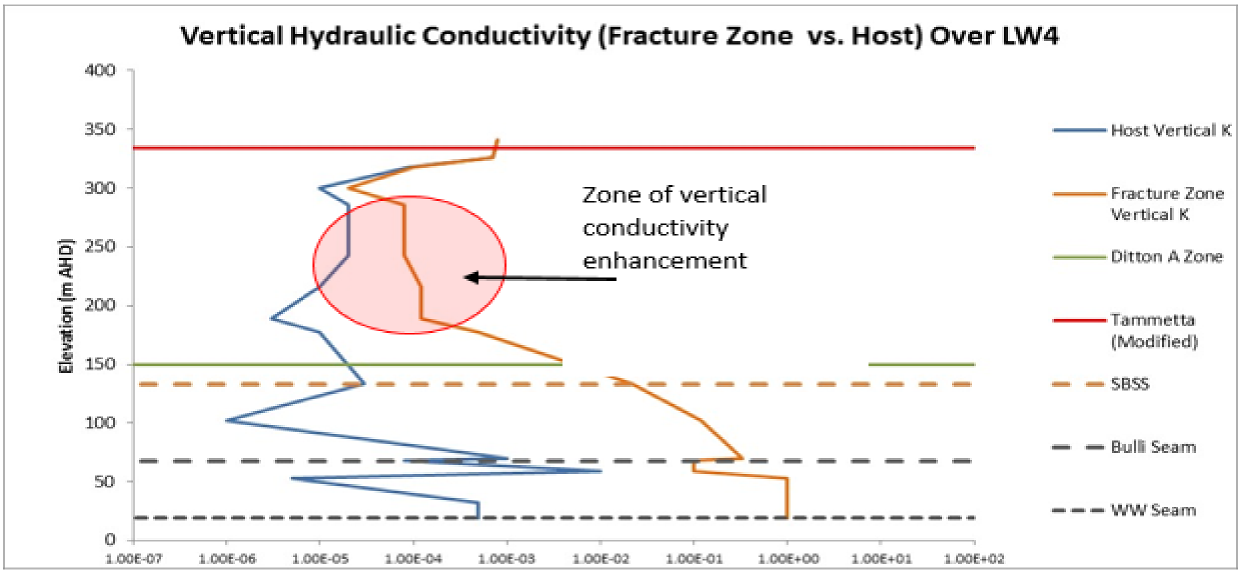


Figure 1 Vertical Hydraulic Conductivity (Fracture Zone vs Host) Over LW4

Q15 – Why was the height of the caved zone increased in areas of multi-seam mining when subsidence behaviour suggest that minimal additional voids result from extraction of second and subsequent seams that are in close proximity (that is, incremental subsidence approximates the extracted height of second and subsequent seams)

A15 – see response for A14

In essence, the measured depressurisation from the suite of VWPs was used in the groundwater model set up and calibration, however they did not correlate well to the modified Tammetta (2012) (using cumulative seam thickness) theory, whilst the Ditton Merrick (2014) approach was somewhat less conservative and also wasn't used.

Q16

Paragraph 1 – (OEH comment – Tammetta equation provides a lower limit to prediction of the height of depressurisation)

Answer - see Q15 answer

Paragraph 2 – (OEH comment – height of depressurisation was predicted to extend to the surface over many areas)

Answer - surface to seam depressurisation was initially predicted over parts of LW3 – LW8 (actually LW7 as LW8 doesn't exist) within the June 2014 Preferred Project groundwater modelling assessment (GeoTerra/ GES, 2014).

Following installation of the latest VWPs in July to December 2014 (RV16, 17, 22, 23, and particularly RV20) and subsequent detailed interpretation of the VWP steady state data, which was not available during the previous assessment, adherence to the previously modified (i.e., cumulative) Tammetta (2012) theory was assessed to be inappropriate.

The revised (GeoTerra / GES, 2015) groundwater report for the Preferred Project Report subsequently assessed that surface to seam depressurisation was not predicted to potentially occur at the end of the proposed mining of the Wongawilli Seam at Russell Vale East.

Depressurisation from surface to seam was predicted, however, by the model 100 years after mining Longwalls 1-3 in the southern tributary of Cataract Creek, whilst the larger, northern tributary is not predicted by the groundwater model to be affected.

The 2015 Independent Risk Assessment concluded that due to the 700mm of closure predicted in the southern tributary of Cataract Creek over LW1-3 (SCT 2014) that the tributary would be potentially cracked, with potentially no connective overland flow over Longwalls 1-3. Therefore the underlying surface to seam strata depressurisation predicted by the groundwater model 100 years after completion of LWs 1 -3 will have no additional detrimental effect on overland stream flow in the subsided and fractured tributary reach.

Although surface to seam depressurisation is predicted 100 years after cessation of mining over LWs 1-3, the actual annual flow loss from the stream in the latest version due to strata depressurisation, which incorporates the comments and model revisions provided in the January 2016 PAC suite of questions, is very low and is essentially indistinguishable from the previous (GeoTerra / GES, 2015) June 2015 assessment.

The surface water assessment (WRM Water & Environment, 2015) calculated that if, in the unlikely case that total loss from Tributary 1 of Cataract Creek over LWs 1- 3 occurred, it would equate to a maximum of 0.58ML/day median baseflow or 1.01ML/day median total flow.

Connection to surface is not predicted at the end of mining, however it is also predicted after 100 years of mining to the east of Cataract Creek, adjacent to, but not over, LW5. This is because in this reach of the creek, the Hawkesbury Sandstone has been eroded through to the Bulgo Sandstone.

The predicted maximum groundwater model stream baseflow losses associated with the potential surface to seam depressurisation adjacent to LW5 from Cataract Creek are 0.07ML/year and therefore not a significant proportion of total stream flow into Cataract Reservoir.

Paragraph 3 – (OEH comment) there is a serious risk to Cataract Creek from surface to seam hydraulic connection where Balgownie LW11, a Bulli Pillar extraction block and Wongawilli LW7 and LW8 coincide)
Answer – the assessment of potential areas of surface to seam depressurisation was based on a previous version of the groundwater modelling / reporting (GeoTerra / GES 2014) which utilised an analytical calculation of the revised (cumulative seam thickness) version of Tammetta (2012).

Subsequent to receipt, interpretation and incorporation in the study of additional VWP data after late 2014, and utilising a ramping depressurisation function in the (GeoTerra / GES, 2015) model, which was based on in-situ VWP pressure head distributions, the "risk" of the LW7, and, LW8 (which actually doesn't exist) region in or near Cataract Creek depressurising to surface was no longer predicted. The potential risk of surface to seam depressurisation was present in GeoTerra / GES (2015), however, in a small area to the west of Cataract Creek and east of LW5, and over LWs1 -3 as explained in the above (paragraph 2) answer

Paragraph 4 – (OEH comment) Tammetta's assessment of depressurisation underestimates the potential depressurisation due to multi seam mining, therefore the UEP risk assessment is out of step with statements predictions by SCT / Coffey / IESC.
Answer – As outlined above, the latest version (GeoTerra / GES 2015) moved away from using the modified (multi-seam cumulative extraction thickness) Tammetta (2012) approach as the current suite of VWP data does not support the Tammetta (2012) theory in the Russell Vale multi-seam extraction environment.
The latest assessment (GeoTerra / GES, 2015), which has been collaboratively derived between GeoTerra, GES and SCT Operations, is in joint agreement.

References

Ditton, S Merrick, N., 2014 A New Subsurface Fracture Height Prediction Model for Longwall Mines in the NSW Coalfields. Geological Society of Australia, 2014 Australian Earth Sciences Convention (AESC), Sustainable Australia. Abstract No 03EGE-03 (p.136) of the 22nd Australian Geological Convention, Newcastle, NSW

GeoTerra / GES, 2014 Russell Vale Colliery Underground Expansion Project Preferred Project Report Wonga East Groundwater Assessment, June 2014

GeoTerra / GES, 2015 Russell Vale Colliery Underground Expansion Project Russell Vale East Revised Groundwater Assessment, September 2015

Hansen Bailey, 2015 Russell Vale Colliery Underground Expansion Project Independent Risk Assessment Panel – Risk Assessment Supporting Technical Information, September 2015

SCT 2014 Update of Subsidence Assessment for Wollongong Coal Preferred Project Report Russell Vale No 1 Colliery, June 2014

SCT 2015 Assessment of Corrimal Fault and Dyke D8 at Russell Vale East as Risks to the Stored Waters of Cataract Reservoir, August 2015

Tammetta. P, 2012 Estimation of the Height of Complete Groundwater Drainage Above Mined Longwall Panels. Groundwater - Vol. 51, No. 5. (pp/723–734)

WRM Water & Environment, 2014 Russell Vale Colliery Wonga East Underground Expansion Project Surface Water Modelling, May 2014

WRM Water & Environment, 2015 Russell Vale Colliery Underground Expansion Project Surface Water Modelling: Response to Planning Assessment Commission, August 2015

Yours faithfully,

Andrew Dawkins Principal Hydrogeologist (CP Env)

Groundwater Exploration Services Pty Ltd

1/156 Arden Street,
Coogee
NSW 2034
Tel +61 2 96649782
andyfulton@gmail.com
ABN 22 150 946 615

12 February 2016

Dave Clarkson
Wollongong Coal Pty Ltd
Russell Vale Colliery
Bellambi Lane
Russell Vale NSW 2517

Attention: Dave Clarkson

Re: Russell Vale Colliery Underground Expansion Project – Groundwater Modelling PAC Review

1. INTRODUCTION

The groundwater modelling (GeoTerra / GES, 2015) for the proposed Underground Expansion Project at Russell Vale Colliery by Wollongong Coal Ltd (WCL) has been reviewed by the Planning Assessment Commission (PAC) in January 2016.

Following a subsequent meeting in late January 2016, the PAC recommended that further changes be made to facets of the model and the modelling code utilised to derive the predictions associated with the groundwater impacts and effects of the proposal.

This letter documents changes undertaken to the groundwater flow model for the Russell Vale Colliery Underground Expansion Project.

The groundwater model has been revised to address the issues raised by the PAC. Whilst the revised model is not substantially different from the previous iteration, it does contain updates which supersede the previous version. The details of which will be included in a technical addendum to be provide separately.

To describe how the implemented changes impact on the previous predictions, a precis of the issues raised by the PAC (and its independent experts) is restated below, followed by a description of changes that have been made to the model and a discussion of how this affects the revised modelling outcome.

Issues raised include

- Q1 – Model layers 1 – 15 have been treated as variably unconfined while model layers 16 – 19 have been treated as strictly confined.
- Q2 – Why has the upper section of the Wongawilli Seam been represented as the working section? What are the implications for model calibration?
- Q3 – How was the scaling for horizontal conductivity determined?

- Q4 – Can the proponent provide an explanation as to why scaling was applied over a stress period and to what extent the modified *[drainable]* porosity has affected the estimated mine water flux. What is the implication for calibration in the volumetric balance?
- Q5 – How were the heads and conductance terms determined for individual cells for General Head boundaries along active mine perimeter.
- Q6 – Model Layers 1 -10 have similar values for drainable porosity.
- Q7 – It has not been possible to replicate inflows. How were mine water influx estimates derived?
- Q8 – Were influx estimates only captured at the end of stress periods? If so what is the implication for calibration.
- Q9 – What is the cause of the regionally extensive complete loss of pore pressure and what field observations are there to support this?
- Q12 – Evaporation rate used in the modelling and implications for model calibration and outcomes.
- Layering continuation over the escarpment causing model layers to roll over at the escarpment.
- Groundwater Levels / Pressures
    - What factors other than mining could generate the observed hydraulic gradients.
    - Does the pressure profile indicate enhancement and what is the enhanced vertical flow
- What is the height of depressurisation (upper limit) and how was it determined
- What is the level of confidence, or risk, associated with the reliability of this alternative approach.
- Why is the height of the caved zone increased in areas of multi-seam mining relative to subsidence behaviour?
- Additional issues raised at the onsite meeting have also been addressed. These include:
    - Layering continuation over the escarpment causing model layers to roll over at the escarpment.
    - Vibrating Wire Piezometer NRE GW1 water levels and correlation with targets used in the model.

2. Discussion of Issues Raised and Actions Undertaken

2.1 Aquifer type

Q1 – Why are the Wongawilli seam and the overlying layer treated as strictly confined layers where drainable porosity is not taken into account when it is expected that the mined seam and the overlying strata will be completely dewatered during mining? What are the implications for model calibration?

The model domain can be separated into two almost distinct groundwater flow systems; one below the Bulli Seam and one above. These are currently essentially separated by the regional scale depressurisation and dewatering which has occurred in and above the Bulli Seam that is associated with historical mining activities.

Above the Bulli Seam, the groundwater model and resulting groundwater levels / pressures and stream base flow characteristics have been essentially unaffected by the recent changes to the aquifer type definition in the lower layers of the model which were used to report the updated mine groundwater inflows.

We believe there are no deleterious implications for calibration of groundwater levels derived in the model as all available monitoring data from vibrating wire piezometers at Russell Vale is located within the Scarborough Sandstone or higher strata (i.e. all above the Bulli Seam).

However, the model has been updated to address issues raised by the PAC.

As mine inflow estimates are an important calibration tool and there was no pressure data available for the Wongawilli Seam, it is acknowledged that there are calibration implications for matching mine inflows, as the previously used 'confined aquifer' setting did not account for the Sy component of dewatering. The result of this approach was that disproportionately high hydraulic conductivity in the lower coal measures were required to achieve an inflow estimate which correlated to the measured mine inflow data.

Accordingly, there was a requirement to re-calibrate hydraulic conductivities to recorded inflows in the lower coal measures only. The strata from Bulli Seam and above remain relatively untouched and there is negligible impact on previously recorded groundwater / surface water interaction.

These settings have been reset through an updated definition of hydraulic parameters within the coal measures strata in the lower layers of the model, and are in line with expected values gained from experience elsewhere within the Southern Coalfield.

2.2 Wongawilli Seam Working Section Drain Cells

Q2 – Why has the upper section of the Wongawilli seam been represented as the working section? What are the implications for model calibration?

Drain cell invert levels were originally placed mid-level within the Wongawilli Seam. There are 29,424 drain cells within the model of which approximately 1,300 represent workings in the Wongawilli Seam within the Russell Vale lease area. The vast majority of these drain cells (i.e. All Bulli Seam and Balgownie Seam Drain Cells) had head boundaries set 0.1m above the base, but it is acknowledged, as noted by the PAC's independent expert, that within the Wongawilli Seam these drain cells were set at 5m above the layer base. It was not initially considered that this created a serious mine inflow reporting issue as there is a significant dip to the west in the Wongawilli Seam in all but the most eastern panel in the original model version (Strata layer issue), and hence groundwater reported down dip to the next active longwall panel. Nevertheless, the drain cells have been reconfigured and set with an invert level at 0.1m above the base of the Wongawilli Seam in the revised model after discussion with the PAC.

2.3 Horizontal Scaling

Q3: How was the scaling factor for Kh determined? Given the significant influence of the enhanced material properties on the groundwater systems, what are the likely implications for model calibration and model outcomes if an equivalent porous media approach was adopted?

Enhancement of horizontal conductivity by a factor of 2 was used within the fracture zone using the TMP package of MODFLOW-SURFACT. This enhancement was used primarily based on experience in other groundwater modelling studies for underground mines in the Southern Coalfield.

We acknowledge that the horizontal permeability factor is likely to be low. However model calibration to mine inflow was not sensitive to variability of hydraulic conductivity in the horizontal direction within the fracture zone, as opposed to the hypersensitivity in the vertical direction within the fracture zone.

Additional sensitivity modelling has subsequently been undertaken to demonstrate this by increasing horizontal conductivity by a factor of 100 wherever changes to vertical conductivity are made (with the exception of the working level where increases to horizontal conductivity are made by greater than 2 orders of magnitude). The results of which are included in the technical addendum.

Q4 – Can the proponent provide an explanation as to why scaling was applied over a stress period and to what extent the modified *[drainable]* porosity has affected the estimated mine water flux. What is the implication for calibration in the volumetric balance?

The TMP package changes physical properties at the start of each stress period which changes hydraulic conductivity and storage properties in a linear fashion between the TMP start time and the next period. The issue was if a change in Sy was implemented in TMP (increased by some factor), then SURFACT conserved head in the cell but the mass balance can be off.

The implications are that a large volume of groundwater is dumped from affected model cells in the first time step, and if the model is not set up to report on these events, this volume of groundwater is not accounted for in the inflow rates.

It is also acknowledged that care must be taken in how this is applied to any outflow, as in reality, this does not occur, and is actually spread out over a stress period.

2.4 Boundary Head Conductance

Q5 – How were the heads and conductance terms determined for individual cells?

Generally, conductance of a boundary condition was set to match a formation hydraulic conductivity. In the model, conductance values were set higher than formation hydraulic conductivities.

There are four perimeter boundary condition areas, some of which are active or present in multiple layers.

1. These include the boundary conditions to the east, representing the coastline which is at least 2.5km at its closest point to the Wongawilli workings. The connection between the active Russell Vale mining area and the coastal boundary is also affected by the vertical separation between the underground mine through the escarpment to the coast on the eastern margin of the model. Following re-working of the structural contours of the model layering on the eastern margin, only two lowest layers have this boundary applied.

2. To the southeast, a boundary operates within the Wongawilli Seam at the northern edge of Dendrobium Mine. This boundary is approximately 10km from the proposed Wongawilli Seam workings.
3. To the west, Tahmoor Colliery is represented with a boundary at a distance of 18km. A significant area of extracted Bulli Seam workings lie between the proposed Wongawilli Seam workings and this boundary.
4. To the northwest, Appin Colliery is at a distance of 12km and also has intervening extracted Bulli Seam workings.

The distance to each of these boundaries and the presence of extracted workings between the Russell Vale workings and the boundaries means that the General Head Boundaries (GHBs) do not play a significant role in governing mine inflows at Russell Vale.

2.5 Drainable Porosity in Layers 1 -10

Q6 – Can the proponent provide an explanation for the adoption of similar values for widely differing lithologies?

These results are based on both model calibration and on porosity (not Sy) values obtained from core testing at Southern Coalfield mines (although not from Russell Vale).

2.6 Derivation of Mine Water Influx Estimate

Q7 – How were the mine water influx estimates derived?

The updating of the groundwater model has generated updated mine inflow curves. Details a contained within the technical addendum.

Inflow estimates from the updated adaptive time stepping are recovered from the cell by cell (CBB) utilising the Mass Balance Zone Budget Reporting out of the Groundwater Vistas (GWV).

Inflows are extracted from the zone budget file outside GWV using a macro driven spreadsheet application. Inflows for each drain reach are exported separately and each reach has identical time print signatures. These are then collated with correlating print times and the reaches are added. Within each stress period, flows are then weighted on the print time interval.

2.7 Stress Period Print Times

Q8 – Were influx estimates only captured at the end of stress periods? If so what is the implication for calibration?

Print times within the model prior to the current version were set at 100 days, that is, output times were set at 100 day intervals after the beginning of each stress period and also at the end of each stress period. . The implications are that due to the manner in which groundwater is removed from cells under the stresses applied by the TMP package in MODFLOW-SURFACT, the initial outflow can be very large. If the model is not set up to record these early stress period intervals, a considerable quantity of the actual outflow to the drain cell is not reported. Therefore, there is the potential to under-report total inflows.

The model has been revised to include adaptive time stepping. Each stress period now has 4 reporting print times. These include a 3rd order polynomial starting at day 1 (i.e. 1, 3, 9, 27, days) and at the end of each stress period where the Russell Vale Wongawilli Seam workings are active. The number of reporting print times varies depending on the length of the stress period.

The mine inflows have been re-calculated using a time-weighted average from each stress period as noted in Section 2.7.

2.8 Regionally Extensive Complete Loss of Pore Pressure

Q9 – What is the cause of the regionally extensive complete loss of pore pressure and what field observations are there to support this?

A regionally extensive area with complete loss of pore pressure was previously indicated in the prior model version to the north and south of the Project.

The changes made to the revised model includes changes in aquifer type (LAYCON) from confined variable confined nature of Layers 15 to 18 as noted in Section 2.1. This has also changed the nature of simulated groundwater pressures in these areas. The revised version has removed the completely dewatered areas of the Wongawilli Seam to the north and south of Russell Vale.

Although the completely dewatered areas are removed and the Wongawilli Seam remains saturated, these areas still have low pressures, below 10m to the north of Russell Vale Colliery, and therefore the water levels are close to the roof of the Wongawilli Seam.

These remnant low pressures within the Wongawilli Seam are due to the Russell Vale area being situated within the northern limb of a westerly plunging syncline which dips to the west in a localised basin structure.

To the north and south of Russell Vale, the Wongawilli Seam is at higher elevations than the adjacent excavated Bulli Seam workings in the Russell Vale lease area due to the dip of the syncline limbs.

Details of revised groundwater pressures prior to the start of mining in the Wongawilli Seam are provided within the technical supplement.

2.9 What Pan Evaporation Value Was Used

Q12 - Why has the rate of 1825 mm/annum been adopted rather than the much lower rates? What are the implications in respect of model calibration and model outcomes?

Full evaporation values have been routinely used, although it is acknowledged that it may also be warranted to use lower than that reported such as pan values. A lower evapotranspiration rate may lead to greater rates of groundwater discharge to surface water and thus affect simulated baseflow dynamics.

However, within Layer 1 (which is fully extensive and active across the model domain) groundwater levels are generally 5-10m below surface level, with only minor areas where the regional phreatic surface is <7m below ground level.

The extinction depth within the Evapo-transpiration package is set at 7m based on experience from other coal mining projects.

Sensitivity to variable evaporation was undertaken and is further discussed within the technical addendum.

2.1 Model Layer Structural Contours

The review process highlighted concerns with the model layering in the vicinity of the escarpment on the eastern margins of the groundwater model, and the use of continuous model layers in areas where geological units subcrop in the escarpment.

Part of the re-working of the model involved updating the layering and the use of no-flow cells where the layers subcrop / outcrop. This process re-shaped stratigraphic contours within approximately 1.0 – 1.5km from the escarpment with no changes required further west and down dip in the model.

The results of the updated parameters and subsequent re-modelling have been compared to previously reported key findings, which confirms there are no significant effects on the groundwater level calibration compared to that previously reported.

2.2 Vibrating Wire Piezometer NRE GW1 water levels and target / layer application

Some doubt was cast as to the application of groundwater level data in vibrating wire piezometer (VWP) NRE GW1. This has significant implications to calibration as it is the only key VWP which captures groundwater pressure reduction as a result of mining stresses resulting from extraction of three seams, including Longwall 4 and Longwall 5 in the Wongawilli Seam. Of the eight VWP transducers installed, transient data from seven were used as calibration targets.

GW1 is located near Cataract Creek in an area where Hawkesbury Sandstone and Bald Hill Claystone have been significantly eroded. The Bulgo Sandstone is close to surface in the groundwater model in the vicinity of Cataract Creek, with layering elsewhere where the Hawkesbury Sandstone and Bald Hill Claystone is present having a greater thickness and is more continuous. To account for this, shallow layers are thinned except for Layer 1 which has a uniform thickness of 20m and has been linked to the properties of the underlying Bulgo Sandstone.

Therefore layering of the horizons, and the corresponding application of target levels may appear to be erroneous, however a check of the target depths in the model confirm that the correct depths and layers were chosen for all but the instrument located within the Stanwell Park Claystone, as this could have been mode to Layer 9.

However, the reaction of pressures measured by this VWP transducer was near identical to that in the lower Bulgo Sandstone and there was some doubt as to the veracity of the data. **Table 2** shows the layer definition at NRE GW1 and the depth of the corresponding VWP data / target levels.

The key assessment from the GW1 VWP data is the large disparity in pressure between the Base of the Bulgo Sandstone and the Scarborough Sandstone, and also the reaction to stresses within the Bulgo Sandstone, as this is the stratum in which the bulk of the pressure transition occurs.

Table 2 NRE GW1 Layer Definition and VWP Relative Levels

Layer	Base	Top	VWP RL (m AHD)
1	294.1	314.1	_
2	291	294.1	_
3	289	291	_
4	280	289	288
5	269.5	280	273
6	250.3	269.5	255
7	227.3	250.3	_
8	202.5	227.3	193 / 225
9	190.3	202.5	178
10	145.2	190.3	153

Kind Regards

A S Fulton

Andrew Fulton

Groundwater Exploration Services Pty Ltd

1/156 Arden Street,
Coogee
NSW 2034
Tel +61 2 96649782
andyfulton@gmail.com
ABN 22 150 946 615

15 February 2016

Dave Clarkson
Wollongong Coal Pty Ltd
Russell Vale Colliery
Bellambi Lane
Russell Vale NSW 2517

Attention: Dave Clarkson

Re: Russell Vale Colliery Underground Expansion Project – Groundwater Modelling PAC Review – Technical Addendum

1. INTRODUCTION

The groundwater modelling (GeoTerra / GES, 2015) for the proposed Underground Expansion Project at Russell Vale Colliery by Wollongong Coal Ltd (WCL) has been reviewed by the Planning Assessment Commission (PAC) in January 2016.

Following a subsequent meeting on 28 January 2016, the PAC recommended that further changes be made to facets of the model and the modelling code utilised to derive the predictions associated with the groundwater impacts and effects of the proposal.

The groundwater model has been revised to address the issues raised by the PAC. Whilst the revised model is not substantially different from the previous iteration, it does contain updates which supersede the previous version.

This document is the technical addendum supporting the response to questions dated 12 February 2016 titled "Re: Russell Vale Colliery Underground Expansion Project – Groundwater Modelling PAC Review" (GES) which responds to individual questions raised by the PAC in its letter dated 15 January 2016.

This document outlines changes to the groundwater model for the Russell Vale Colliery Underground Expansion Project and provides the technical details and resulting outcomes from the updated model. These changes address the recommendations made by Dr Colin Mackie acting as an independent expert for the PAC.

Key updates to the revised groundwater model include:

1) All layers are treated as variably unconfined;
2) The base of the Wongawilli Seam is represented as the working section;
3) Minor changes were made to drainable porosity in clay rich stratum;
4) Application of adaptive time stepping;
5) The structural geometry of the layers was corrected at the escarpment; and

6) Additional sensitivity modelling undertaken to address and fracture zone horizontal conductivity scaling and evaporation concerns (Page 41).

1.1 Model Implementation of the Mine Schedule

The underground mining and dewatering activity is defined in the model using drain cells within mined coal seams, with modelled drain elevations set to 0.1m above the base of the Bulli Seam (Layer 13), Balgownie Seam (Layer 15) and Wongawilli Seam (Layer 17).

These drain cells were applied wherever workings occur and were maintained as constant within the Bulli and Wongawilli Seams and implemented in line with mine progression in the Wongawilli Seam. A variation in this version of the model is the reduction of drain cells within the Balgownie workings to replicate removal from actual pumping areas.

Mining prior to the transient modelling period was simulated as steady state within the Bulli Seam (Layer 13) and Balgownie Seam (Layer 15).

The model set-up involved changing the parameters with time in the goaf and overlying fractured zones directly after mining of each panel, whilst simultaneously activating drain cells along all development headings.

The development headings were activated in advance of the active mining and subsequent overburden subsidence.

Although the coal seam void is essentially dominated by the drain mechanism, the horizontal and vertical permeabilities as well as specific yields were increased to simulate the highly disturbed nature within the caved zone and overlying variable fracture zone of the overburden and interburden.

1.2 Existing Mine Workings

Adjacent to the proposed workings are large areas of abandoned Bulli seam workings to the north and south of the Russell Vale lease boundary, as well as the combined Corrimal / Cordeaux complex to the south.

The model maintains active sinks using drain cells which represent Bulli Seam workings at the following decommissioned operations:

- Old Bulli;
- Excelsior 1, 2 and B;
- North Bulli;
- South Clifton Tunnel;
- Darkes Forest;
- Coal Cliff;
- Corrimal;
- Cordeaux, and;
- Mt Kembla.

Drain cell invert levels were set at 0.1m above the seam floor and were maintained throughout transient modelling with the exception of small areas at Russell Vale West, where drain cell invert levels were raised slightly to mimic reported ponding areas.

A variation within this updated model includes the lowering of drain cell inverts within the Wongawilli Seam to represent the lower section of the seam as the working level.

The degree of hydraulic connectivity between the Corrimal / Cordeaux complex and the older mine workings adjacent to the Wollongong Coal lease area is not known and has been assumed in the model to be constrained by hydraulic conductivities of the host strata.

Active mining within the Bulli Seam is occurring in the northern periphery of the model in the South32 Illawarra Coal Appin workings. Additionally, active mining is occurring within the Wongawilli seam at Dendrobium at the southern boundary of the model area.

1.3 Model Calibration

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

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

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

Due to the complex interactive depressurisation effects of the existing subsidence and adjacent workings on groundwater levels and the predominantly “dry” nature of the Russell Vale workings, model calibration focussed on matching observed and modelled groundwater levels and mine inflows, particularly during periods where mining impacts have been observed.

Scaled RMS value is the RMS error term divided by the range of heads across the site and forms a quantitative performance indicator. Given uncertainties in the overall water balance volumes (e.g. it is difficult to directly measure evaporation and baseflow into the creeks), it is considered that a 10% scaled RMS value is an appropriate target for this study, with an ideal target for long term model refinement suggested at 5% or lower. This approach is consistent with the best practice Australian Groundwater Modelling Guidelines (SKM, 2012).

Steady state calibration was used to compare assumed long term average groundwater levels with groundwater levels prior to the transient calibration period (1993 – 2013).

Recent revision of aspects of the model have resulted in slightly poorer calibration statistics as compared to the previous model version, with a systematic over prediction of water levels within parts of the Bulgo Sandstone and below. However the statistics remain within accepted limits provided in the Australian Groundwater Modelling Guidelines.

1.3.1 Transient Calibration

Transient calibration against groundwater levels was carried out for the period 1993 to 2013 inclusive, utilising 24 target locations using water head or level data from single screen standpipes and multi-level vibrating wire piezometers.

Although this period covers an extended time where limited to no significant secondary extraction occurred in the lease area from 1998 to 2010, it covers two periods where groundwater hydrographs show a response to mining influences.

Mining was re-started at Russell Vale East with development of first workings in the Wongawilli Seam in 2011, followed by non-continuous extraction of Longwalls 4, 5 and the western portion of Longwall 6 (340m) after April 2012.

The RMS value for the calibration period is 9.0m, whilst SRMS error is 3.8%, which is within the target range of 5%.

The SRMS value is the RMS value divided by the range of heads across the site, and forms the main quantitative performance indicator. This result is consistent with the relevant groundwater modelling guideline (SKM, 2012).

A diagram of measured versus modelled potentiometric head targets is shown in Figure 1, and it can be seen that the model is reasonably well balanced against the targets (i.e. although in the changes undertaken in the model revision has resulted in some over prediction of pressures in deeper strata).

There are some significant departures from the matching curve, and these can be attributed to a number of reasons. These include what appears to be a delayed equilibration of vibrating wire transducers and the fact that the multi-level VWP network has doubled in number within the past 12 months. As a result, a short extent of data was used within the calibration data set which can be updated when longer monitoring records are available. This is, however, the key area where the model has not fully simulated observed groundwater pressures and there is, accordingly, a groundwater pressure separation between the Lower Bulgo Sandstone and the Scarborough Sandstone data.

The model has been unable to fully simulate these physical changes, resulting in variability of observed pressures and lack of variability within the computed heads, resulting in ‘flat lining’ of heads within the observed vs. computed calibration values shown.

Quantitatively, curve matching in GW1 detracts from the calibration statistics to some degree, yet, qualitatively, the results reasonably reflect the groundwater response, with the exception of the pressures occurring in the Stanwell Park Claystone.

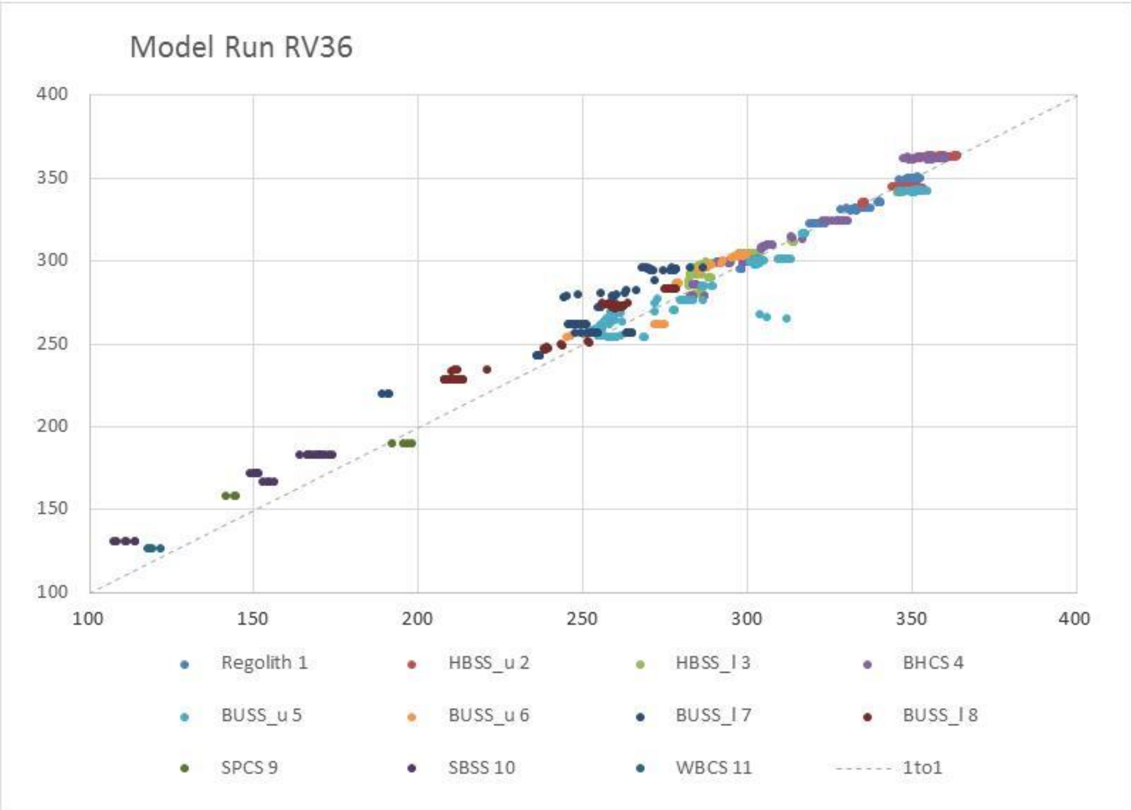


Figure 1 Observed vs. Modelled Heads

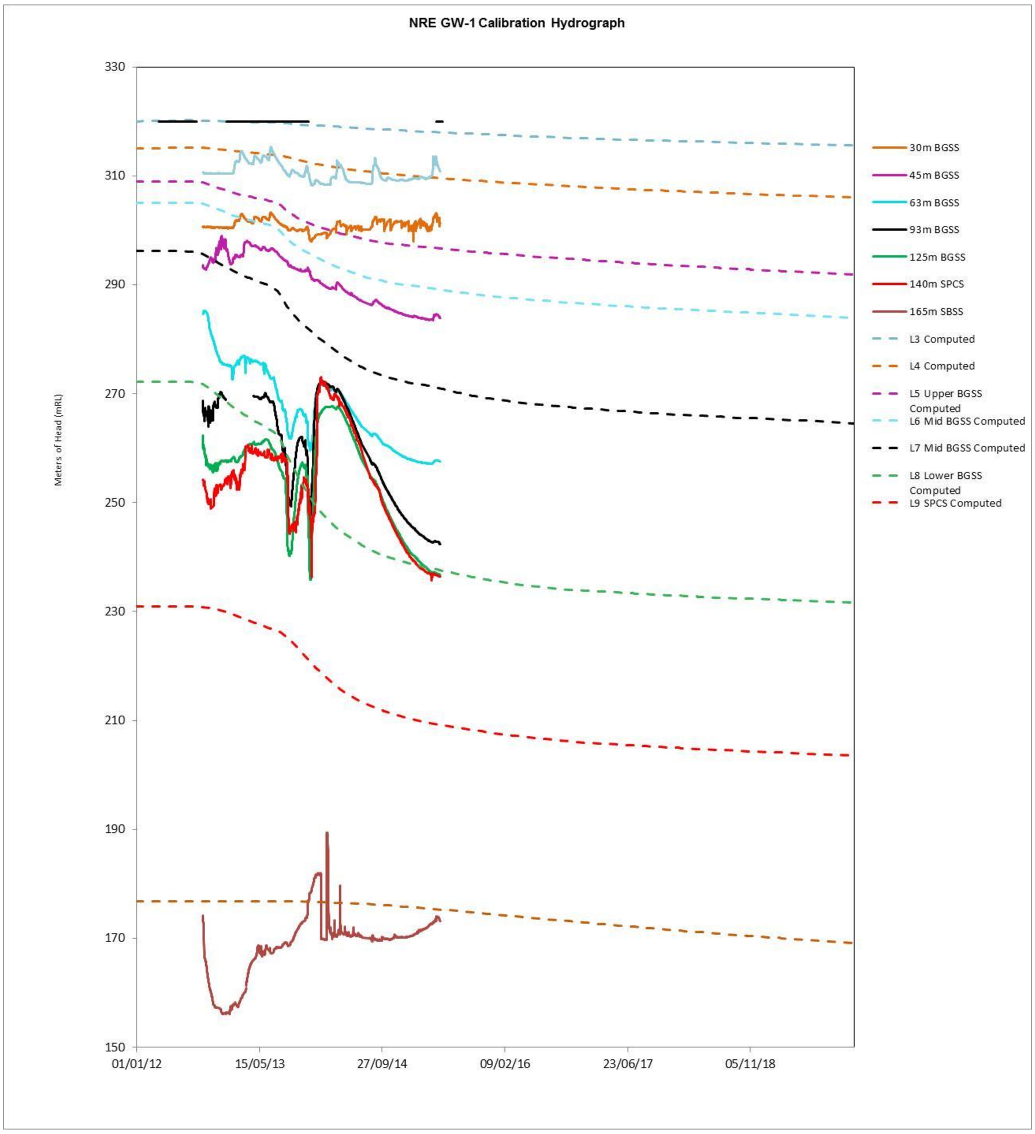


Figure 2 Observed vs. Computed Groundwater Levels for NRE GW1**Table** 1 summarises the calibrated hydraulic properties of the revised model layers

Table 1 Hydraulic Properties

Layer		Zone	Kx [m/day]	Kz [m/day]	Ss [m^{-1}]	Sy
1	Alluvium	1	10	3.00E-02	1.03E-04	1.14E-01
1	Regolith / Weathered Hawkesbury Sandstone	2	5.00E-01	2.00E-02	1.03E-04	3.00E-02
2	Hawkesbury Sandstone - mid	2	5.00E-05	1.00E-05	6.00E-06	1.10E-02
3	Hawkesbury Sandstone - lower	3	5.40E-04	6.90E-05	6.00E-06	1.10E-02
4	Bald Hill Claystone	4	2.00E-05	9.90E-06	6.00E-06	1.10E-03
5	Bulgo Sandstone - upper	5	6.00E-04	1.00E-04	6.00E-06	1.10E-02
6	Bulgo Sandstone - upper mid	17	5.00E-04	2.00E-05	6.00E-06	1.10E-02
7	Bulgo Sandstone - lower -mid	6	9.00E-09	3.00E-05	6.00E-06	1.00E-02

8	Bulgo Sandstone - lower	30	5.00E-05	1.00E-05	6.00E-06	1.10E-02
9	Stanwell Park Claystone	7	1.00E-04	3.00E-06	7.00E-06	2.50E-03
10	Scarborough Sandstone	8	8.00E-04	1.00E-05	4.50E-06	7.50E-03
11	Wombarra Claystone	9	1.70E-05	1.50E-06	6.00E-06	2.50E-03
12	Coal Cliff Sandstone	10	4.00E-04	4.00E-06	2.50E-06	6.00E-03
13	Bulli Coal Seam	11	9.50E-03	2.00E-03	5.00E-06	2.00E-02
14	Bulli-Balgownie Interburden	12	1.50E-04	1.50E-05	4.00E-06	6.00E-03
15	Balgownie Seam	13	5.00E-04	1.00E-04	7.00E-06	8.00E-03
16	Balgownie - Wongawilli Interburden	14	5.00E-04	3.00E-07	4.00E-06	5.00E-03
17	Wongawilli Seam	15	4.00E-04	9.00E-05	4.00E-06	5.00E-03
18	Shoalhaven Group	38	3.00E-04	9.00E-05	2.50E-06	5.00E-03
19	Shoalhaven Group	16	1.00E-04	7.00E-05	2.50E-06	5.00E-03

1.4 Mine Inflows

Based on available mine water balance records, the average daily groundwater inflow derived from strata leakage extracted from Russell Vale Colliery was 0.5 ML/day prior to extraction of LW4 and 1.5 – 2 ML/day during extraction of extraction of LW4 and LW5 as shown in **Figure 3**.

There is some uncertainty to inflow records prior to prior to the extraction of LW4, however more accurate mine water pumping records have been obtained since the start of LW4.

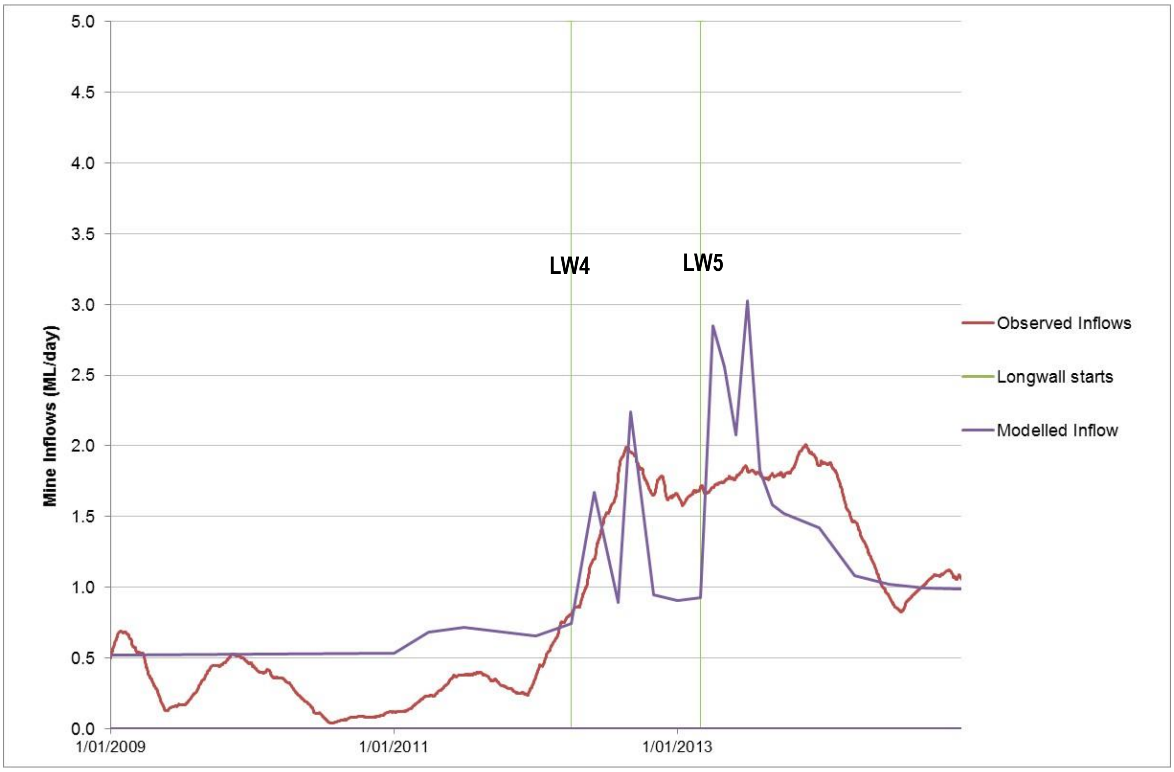


Figure 3 Mine Inflows During the Calibration Period

1.5 Water Balance

There are numerous opportunities for groundwater to discharge from, and recharge to, the groundwater system and into / out of the groundwater model domain. Those implemented in the model include:

- baseflow to major streams (represented by the river cells in MODFLOW);
- outflow / inflow to the eastern margin boundary representing the coastline, the northern margins representing the Appin mining area within the Bulli Seam and southern margin representing the Dendrobium mining area in the Wongawilli Seam (as general heads in MODFLOW), and;
- water inflows to active mining areas and the sinks caused by historical mining areas.

The average water balance across the transient model run up until the end of the mining period across the entire model area is summarised in **Table 2**. Key components of the water balance include a total inflow (recharge) to the aquifer system into the model domain is approximately 82ML/day comprising rainfall recharge (approximately 71%), inflow from the head dependent boundaries on the margins (approximately 0.5%) and leakage from streams into the aquifer (approximately 22%).

The remaining 6% is accounted for with changes in storage within the overburden strata.

Table 2 Simulated Water Balance at End of Mining

	Inflow (ML/d)	Outflow (ML/d)
Storage	3.69	8.28
Constant Head	0.001	0.03
Drains (Outflow = Groundwater Entering Mine Workings)	0	1.91
Recharge (Direct Rainfall)	58.86	9.00
Ponded Storage	1.33	0.63
Et (Evapotranspiration)	0	48.83
River (Leakage/Baseflow)	18.76	14.27
Head Dependent Boundary (GHB)	0.001	0.27
Total	87.27	0.099
% Discrepancy	-0.046%	

2. POTENTIAL SUBSIDENCE EFFECTS, IMPACTS AND CONSEQUENCES

2.1 Stream Bed Alluvium and Plateau Colluvium

There are no anticipated significant subsidence effects on stream bed alluvium or plateau colluvium as there is no significant accumulation of Quaternary sediments within the Russell Vale lease area.

The presence of alluvial sediments is limited to the upland swamps, which have been measured up to 1.8m deep, whilst the stream beds are either based on outcropping sandstone, or contain boulder fields or limited reaches of thin (<1m thick) sandy sediments.

2.2 Upland Swamps

Due to limitations of MODFLOW SURFACT and the regional scale model set up, the effect of subsidence on the thin (<2m) perched groundwater in upland swamps, with their limited and variable spatial extent, was not assessed in the model simulation.

Further discussion of the potential effects on swamps is contained in Biosis (2014).

2.3 Basement Groundwater Levels

Figure 4 to **Figure 9** show north - south and east – west cross sections of the overall modelled hydraulic head (m) and groundwater levels for modelled initial conditions at the end of the calibration period (i.e. the end of LW5 extraction) and at the end of proposed Wongawilli Seam extraction at Russell Vale East.

Figure 4 shows initial pre-mining pressure and head cross sections for a North-South section (Easting 303000) and **Figure 5** shows initial pre-mining pressure and head cross sections for an East-West section (Northing 6196700) conditions and de-saturated areas in elevated areas of the escarpment in the south eastern area of the model.

Zero pressures also extend into the Bulli Seam and overburden due to pre-existing mining voids from the lengthy period of mining in the region prior to the model simulation period.

Figure 6 and **Figure 7** show these same cross sections following completion of mining in the Wongawilli Seam where the over / interburden fracture zone has fully developed and caused further vertical propagation of the zero pressure contour.

The fracture zone and associated zero pressure contour has not formed a continuous, connected flow path from surface to the mined Wongawilli Seam.

Figure 8 and **Figure 9** show the same cross sections 50 years after mining has ceased. **Figure 8** shows the peak effect of mining on groundwater pressures where the height of effective depressurisation has broken through to surface at the northern end of LW3.

Within the process of groundwater system recovery, the adits along the Illawarra Escarpment within the study region will spill well before full recovery of the groundwater system. The lowest observed adit RL is at 54mAHD (SCT Operations, 2015B).

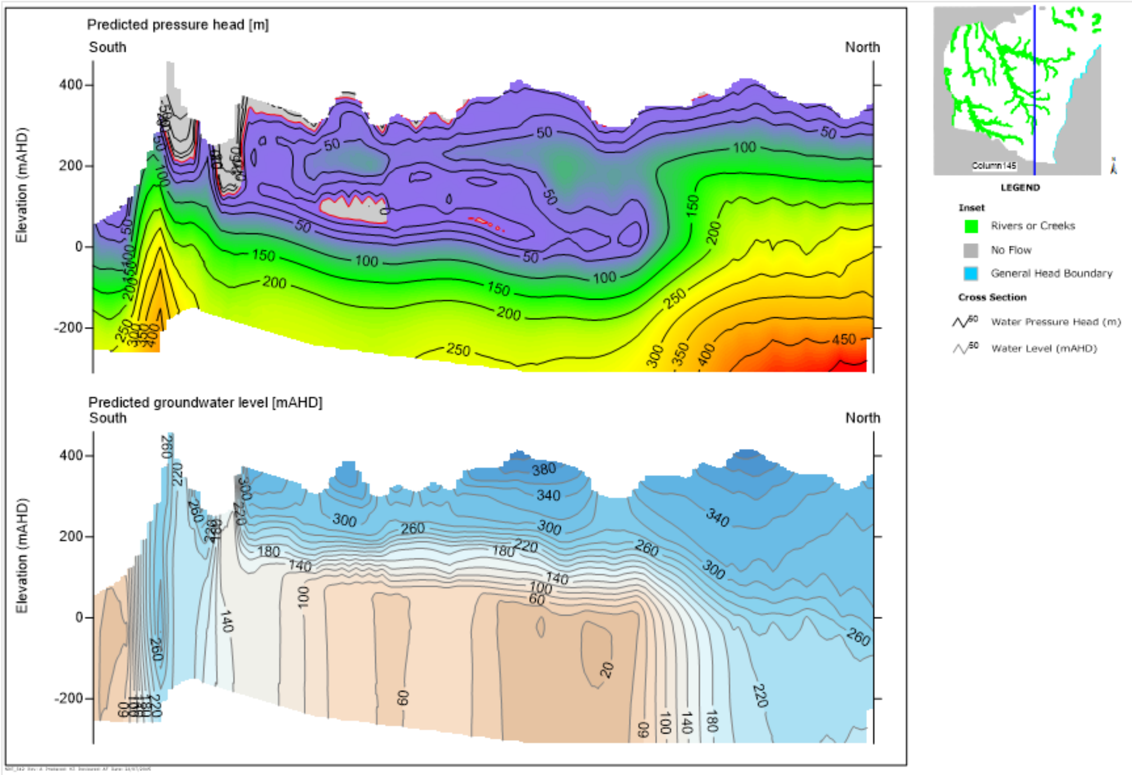


Figure 4 Predicted Pressure Head Initial Conditions (North – South Cross Section on Easting 303000)

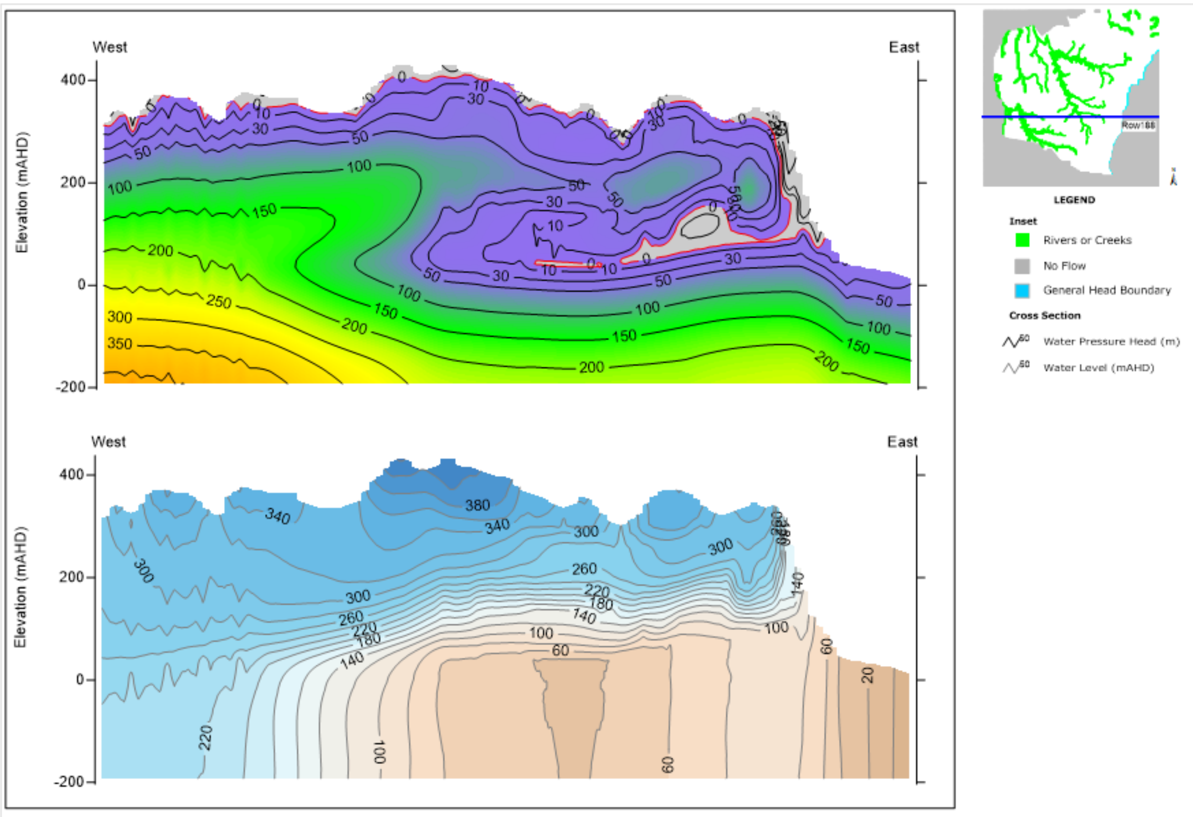


Figure 5 Predicted Pressure Head Initial Conditions at (East – West Cross Section on Northing 6196895)

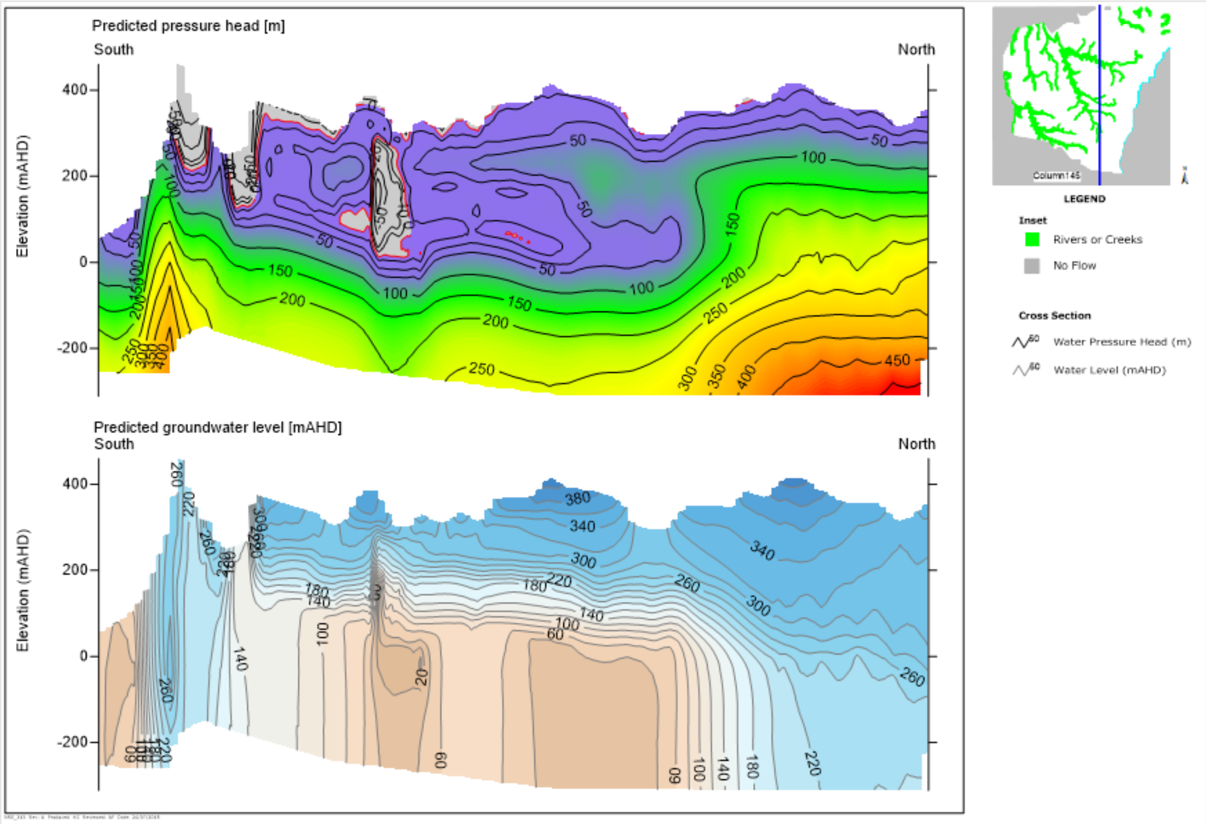


Figure 6 Predicted Depressurisation at the End of Mining (North – South Cross Section on Easting 303000)

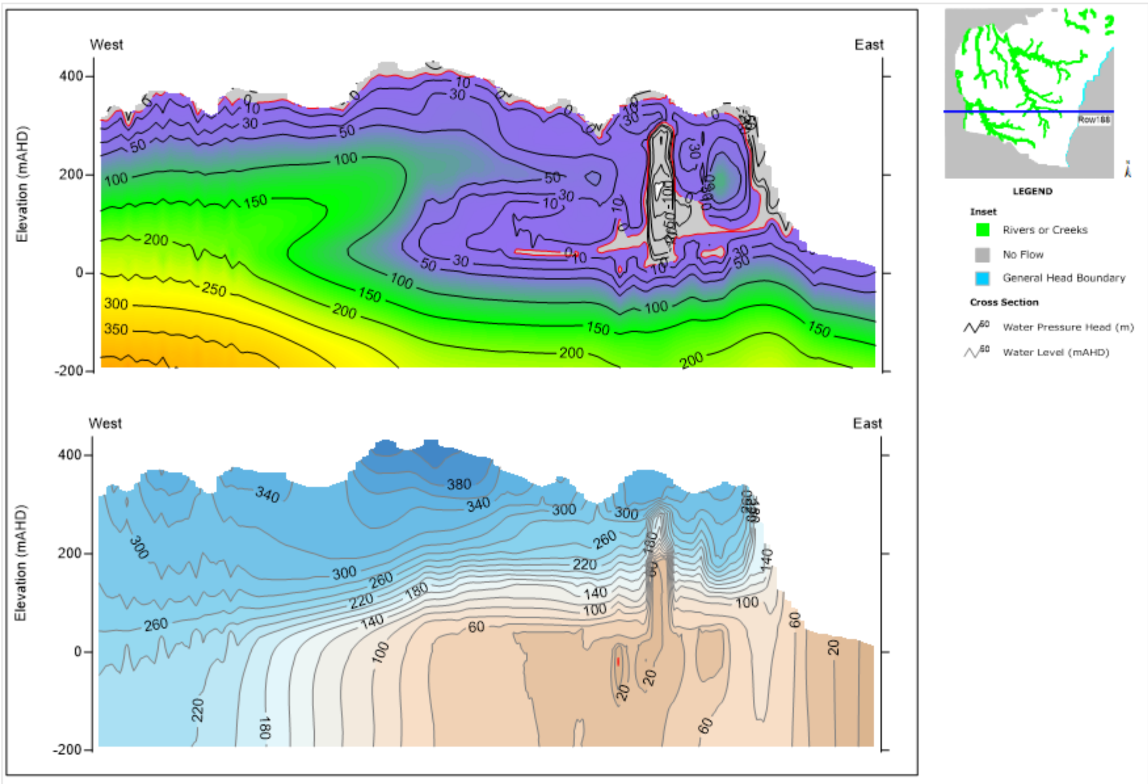


Figure 7 Predicted Depressurisation at the End of Mining (East – West Cross Section on Northing 6196895)

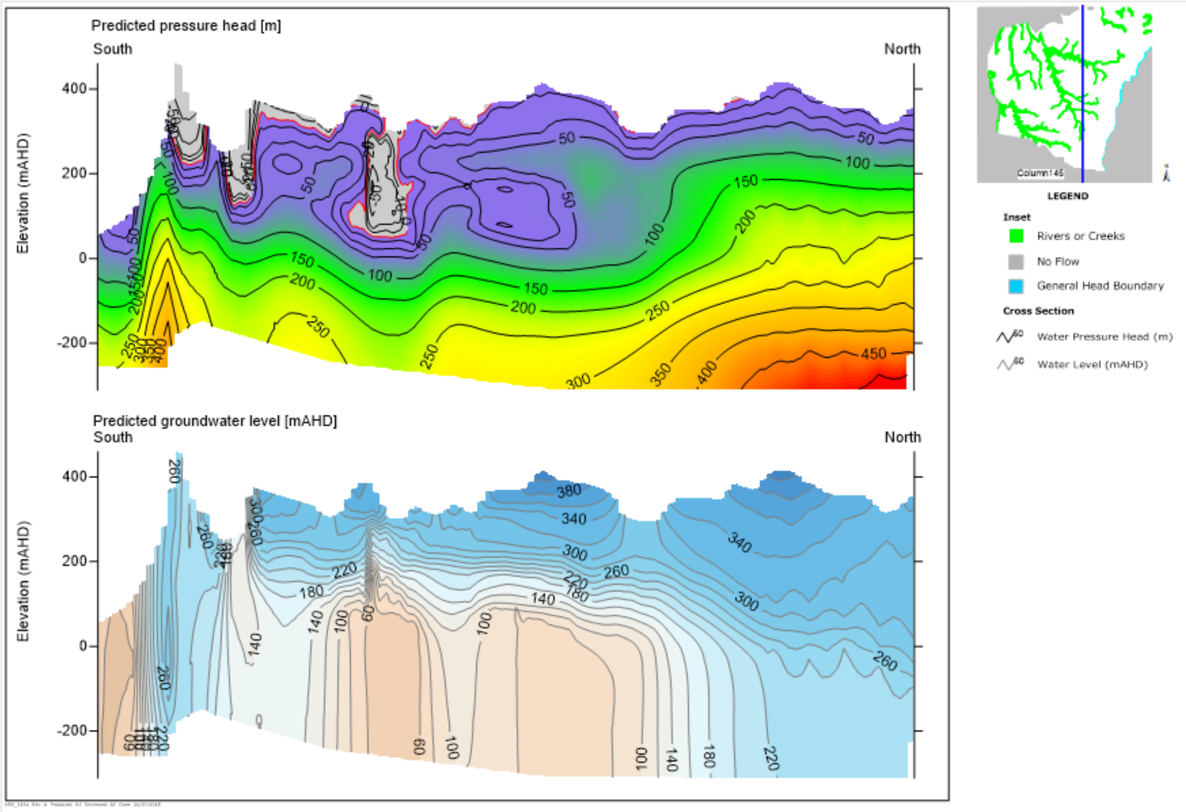


Figure 8 Predicted Pressure Head at 50 Years after End of Mining (North – South Cross Section on Easting 303000)

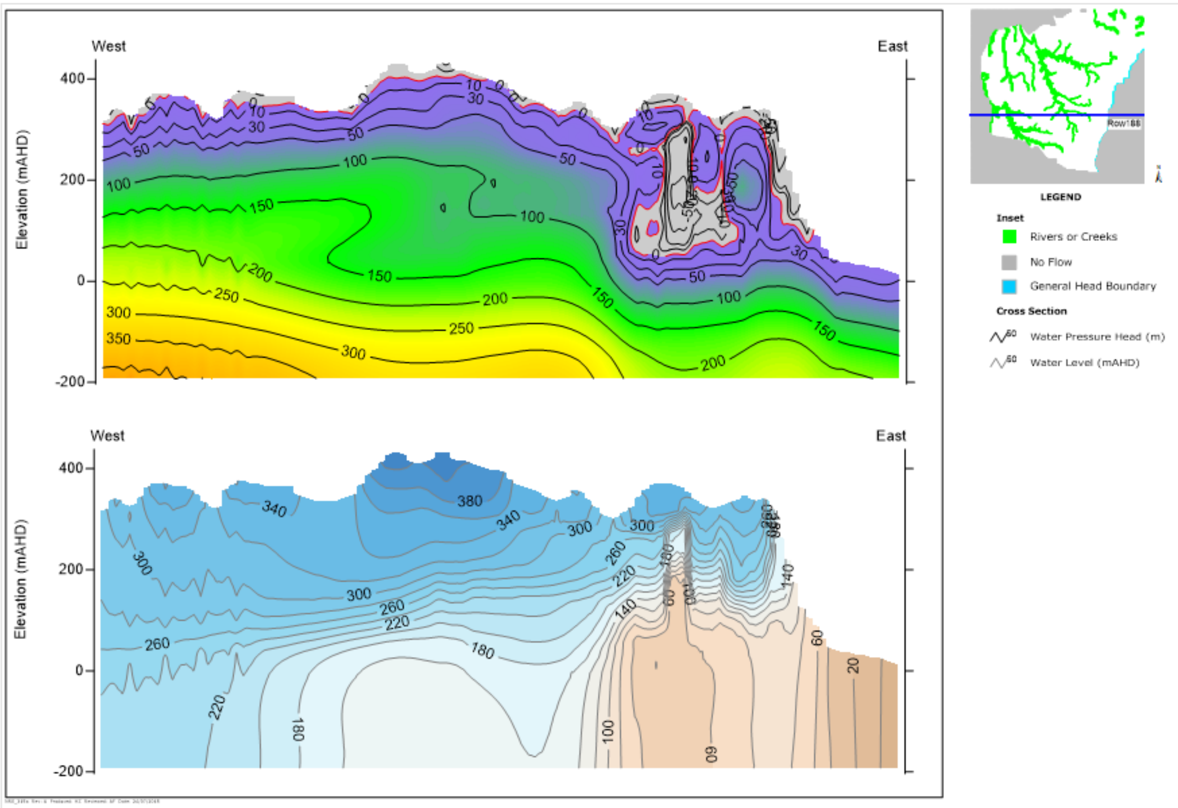


Figure 9 Predicted Depressurisation at 50 Years after End of Mining (East – West Cross Section on Northing 6196895)

2.3.1 Shallow, Perched, Ephemeral, Hawkesbury Sandstone

Perched, ephemeral, shallow groundwater within the upper Hawkesbury Sandstone (within Layer 1) have a potential to undergo a water level reduction over the proposed workings after subsidence.

However, as the ephemeral shallow Hawkesbury Sandstone aquifers desiccate after extended dry periods, the effect on the mostly disconnected, shallow, perched aquifers with limited areal extent was not modelled. However, it is logical to conclude that fracturing of the upper, shallow strata would enhance the leakage rate from the perched aquifers into underlying strata over subsided areas, as well as enhancing rainfall recharge and subsequent seepage rates from these perched aquifers into local streams or the underlying aquifers.

2.3.2 Upper Hawkesbury Sandstone / Regolith

The upper Hawkesbury Sandstone aquifer extends across the Study Area, with piezometer data indicating phreatic water levels ranging from 1 – 20m below surface within Russell Vale East. It should be noted that the monitored water level is affected by semi-confined head pressures, whereas the first drilling water intercept, which indicates the upper bound of the aquifer varied from 17 – 48m below surface at Russell Vale East.

After a piezometer is installed, the subsequent water level measurements indicate a combination of head pressure in the aquifer, variability of recharge and other associated factors.

Based on past experience in the Southern Coalfields, the upper regional Hawkesbury Sandstone water levels can rise by up to 2m ahead of a piezometer being undermined, then reduce by up to 15m after development of cracking and additional secondary void space (porosity) in the aquifer. Apart from GW1, all of the piezometers installed by Wollongong Coal have monitored the post mining period in the Bulli and / or Balgownie mining phases.

GW1 was installed after Longwall 4 in the Wongawilli Seam was extracted and observed a water level reduction of up to 25m, with subsequent recovery by up to 31m due to the intermittent stop /start method by which Longwall 5 was mined.

The reduced water level generally recovers over a few months, depending on rainfall recharge in the catchment and the post subsidence outflow seepage rate, if it occurs, to local streams.

Modelling of Layer 1 (including the Hawkesbury Sandstone, Newport / Garie Formation, Bald Hill Claystone and upper Bulgo Sandstone in eroded creek bed locations) after the end of mining in Russell Vale East indicates up to 10m of drawdown as shown in **Figure 10** in comparison to pre Wongawilli Seam development. **Figure 11** shows drawdown after mining is completed in comparison to post LW5 groundwater levels.

Groundwater pressures relative to the end of mining are shown in **Figure 12** to **Figure 15**, which represent 10, 50, 100 and 150 years respectively. Negative groundwater levels indicate that pressures continued to fall post-mining. However, the continued depressurisation appears to stabilise by 50 years after mining and shows partial recovery at 100 years over all mined Russell Vale East longwall panels. At 150 years post mining, Layer 1 shows significant recovery over LWs 9 to 11. However LW’s 1-2 remain dewatered at 150 years after mining.

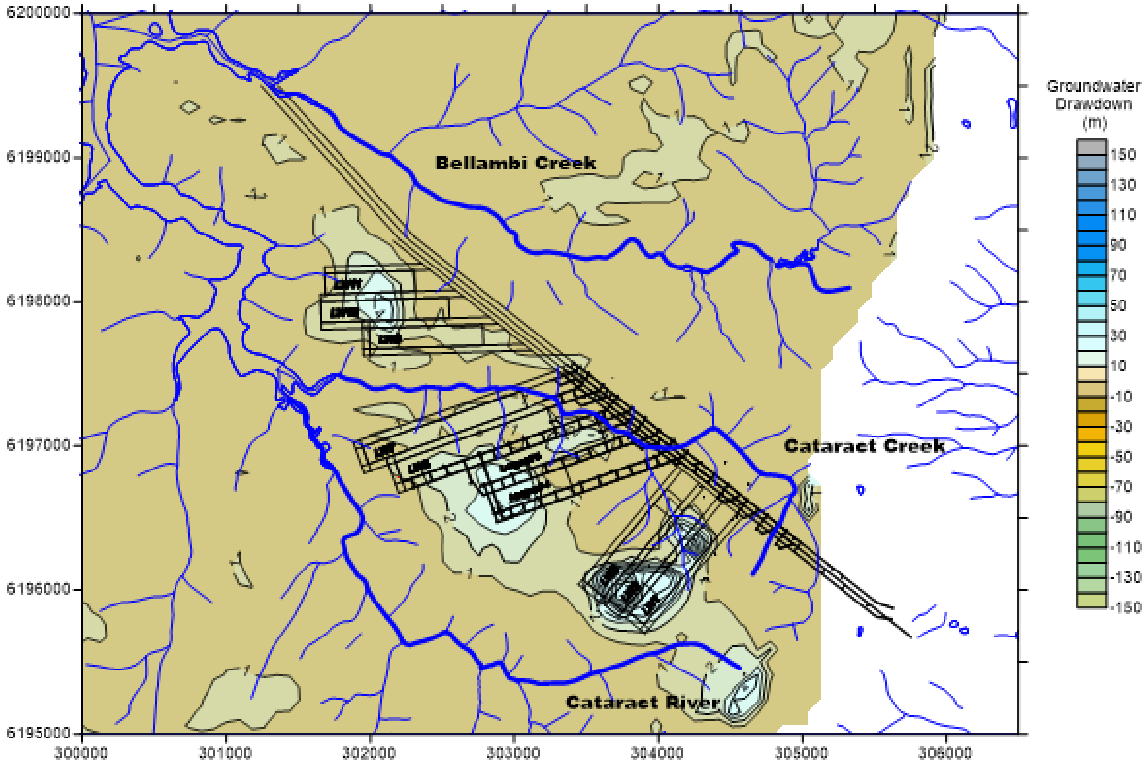


Figure 10 Layer 1 Drawdown After Mining in Comparison to Pre Wongawilli Seam Development

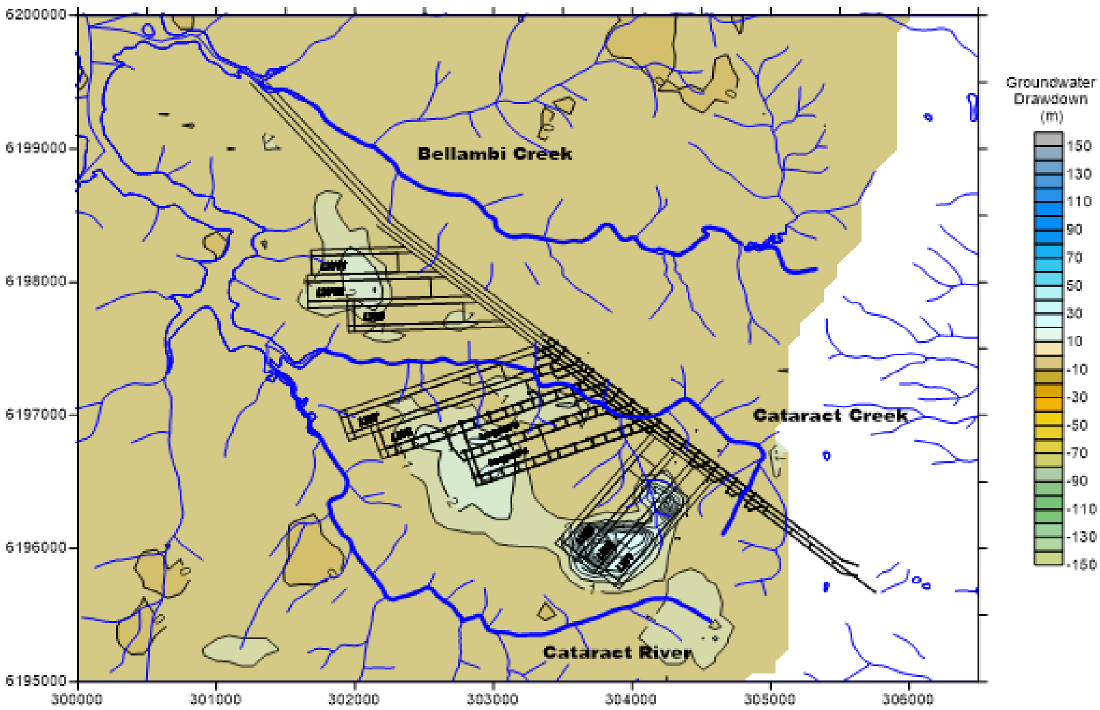


Figure 11 Layer 1 Drawdown After Mining in Comparison to Post LW5 Development

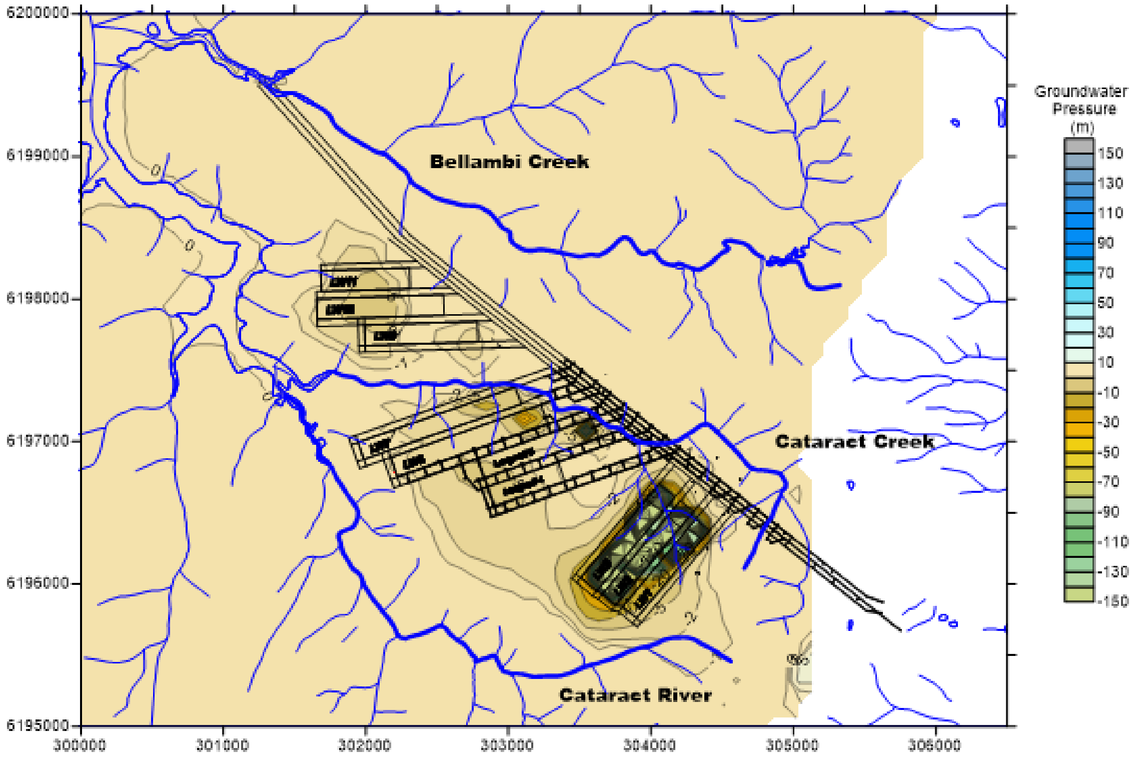


Figure 12 Layer 1 Pressure Difference 10 Years After End of Mining

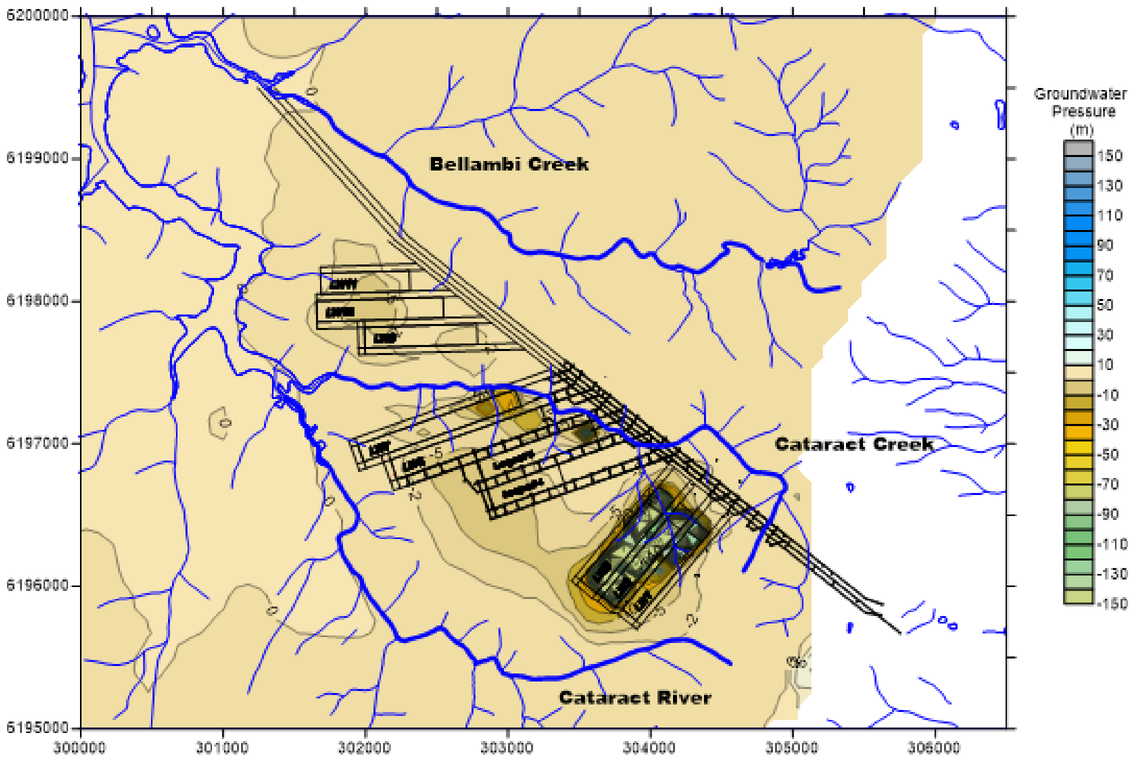


Figure 13 Layer 1 Pressure Difference 50 Years After End of Mining

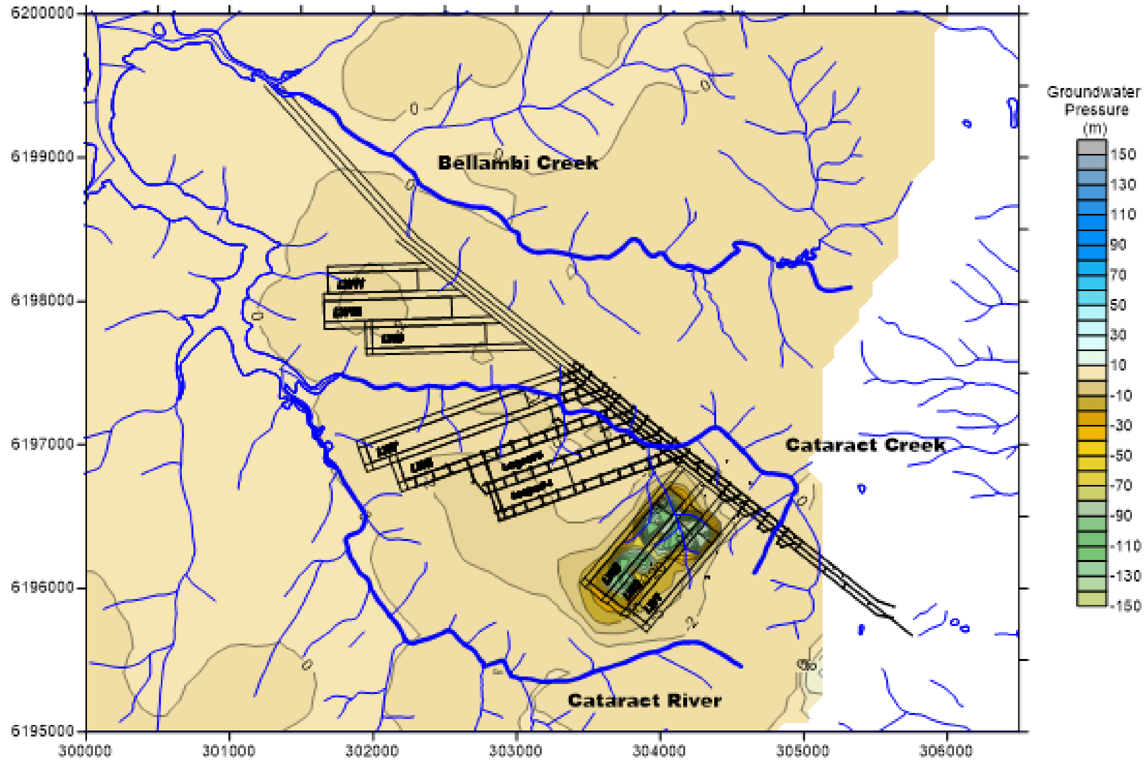


Figure 14 Layer 1 Pressure Difference 100 Years After End of Mining

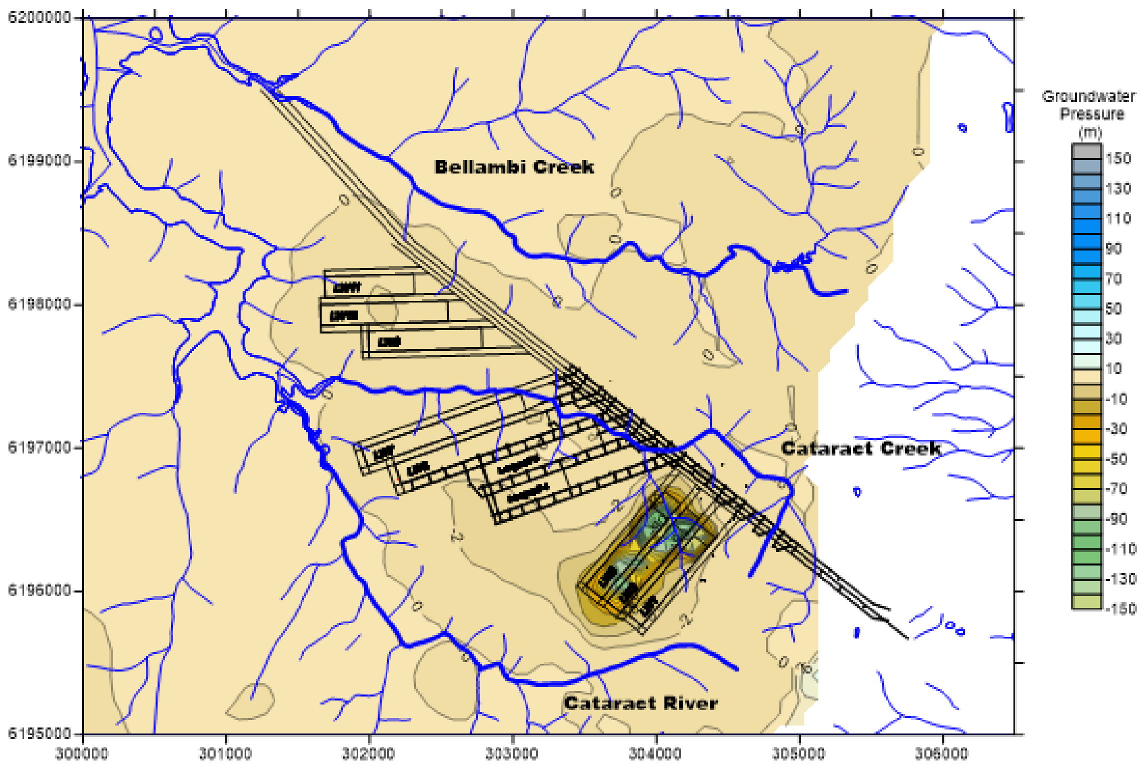


Figure 15 Layer 1 Pressure Difference 150 Years After End of Mining

Modelling of Layer 3 (Lower Hawkesbury Sandstone, Newport / Garie Formation, Bald Hill Claystone and upper Bulgo Sandstone) in eroded creek bed locations after the end of mining at Russell Vale East indicates up to 50m of drawdown occurs over LW1, LW2 and LW3, and a small area in LW6 as shown in **Figure 16** in comparison to pre Wongawilli Seam development. This suggests that the Hawkesbury Sandstone in this layer over LWs 1-3 will become unsaturated. **Figure 17** shows drawdown after mining is completed in comparison to post LW5 groundwater levels.

Figure 18 to **Figure 21** represent 10, 50, 100 and 150 years respectively after mining. As in the upper Hawkesbury Sandstone and regolith in Layer 1, negative groundwater levels indicate that pressures continued to fall post-mining. This is most prevalent in LW7 and part of LW 6 and also in LWs 1-3 where dewatering has occurred. These figures show that further reduction in groundwater pressures are expected to occur to 10 years after mining. By 50 years after mining, loss of pressure peaks and begins to show recovery. By 100 years after mining, the layer has re-saturated in all areas, except over LW1-3.

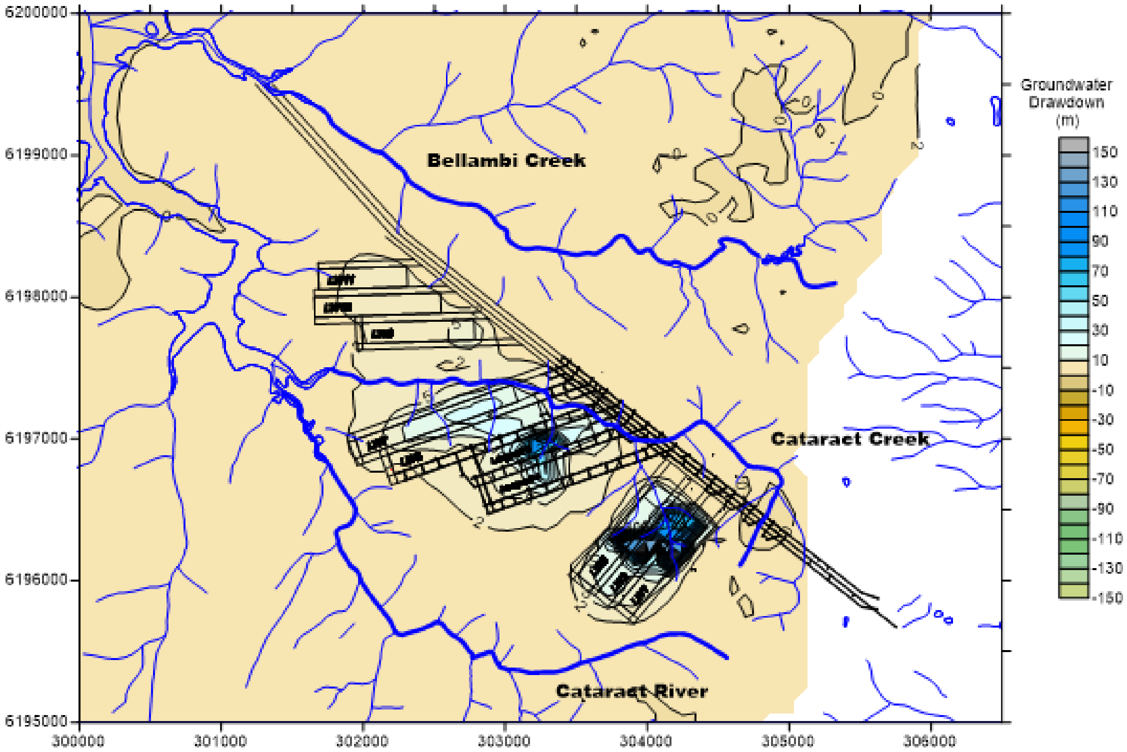


Figure 16 Layer 3 Drawdown After Mining in Comparison to Pre Wongawilli Seam Development

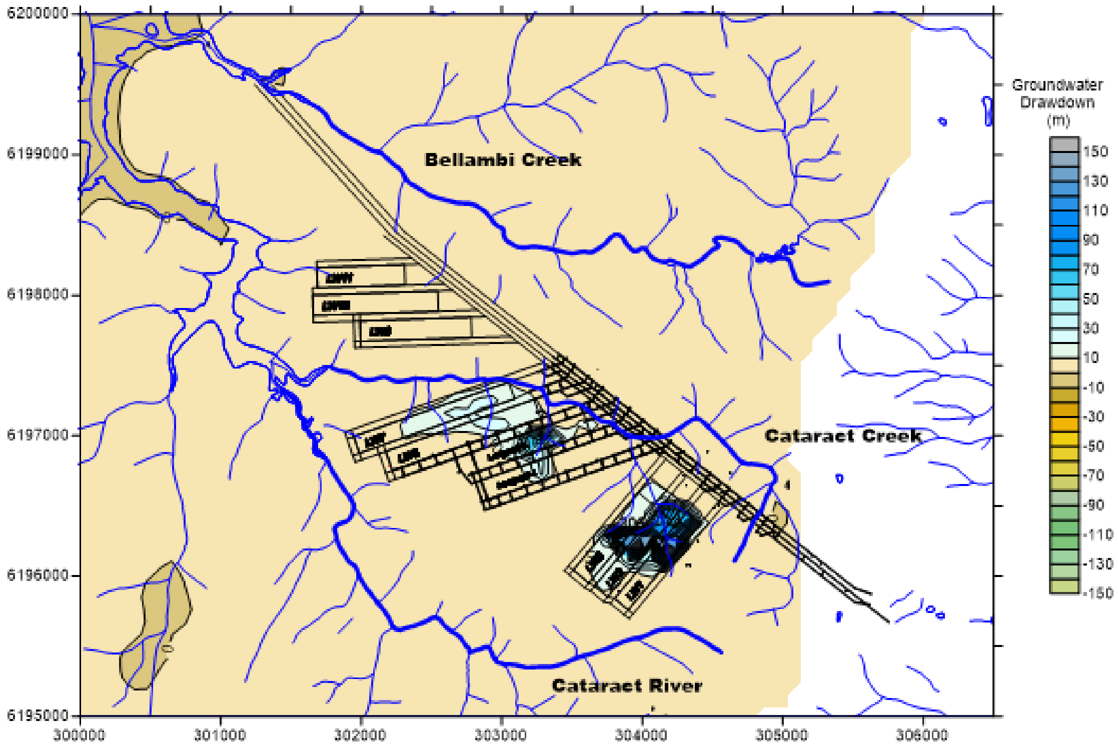


Figure 17 Layer 3 Drawdown After Mining in Comparison to Post LW5 Development

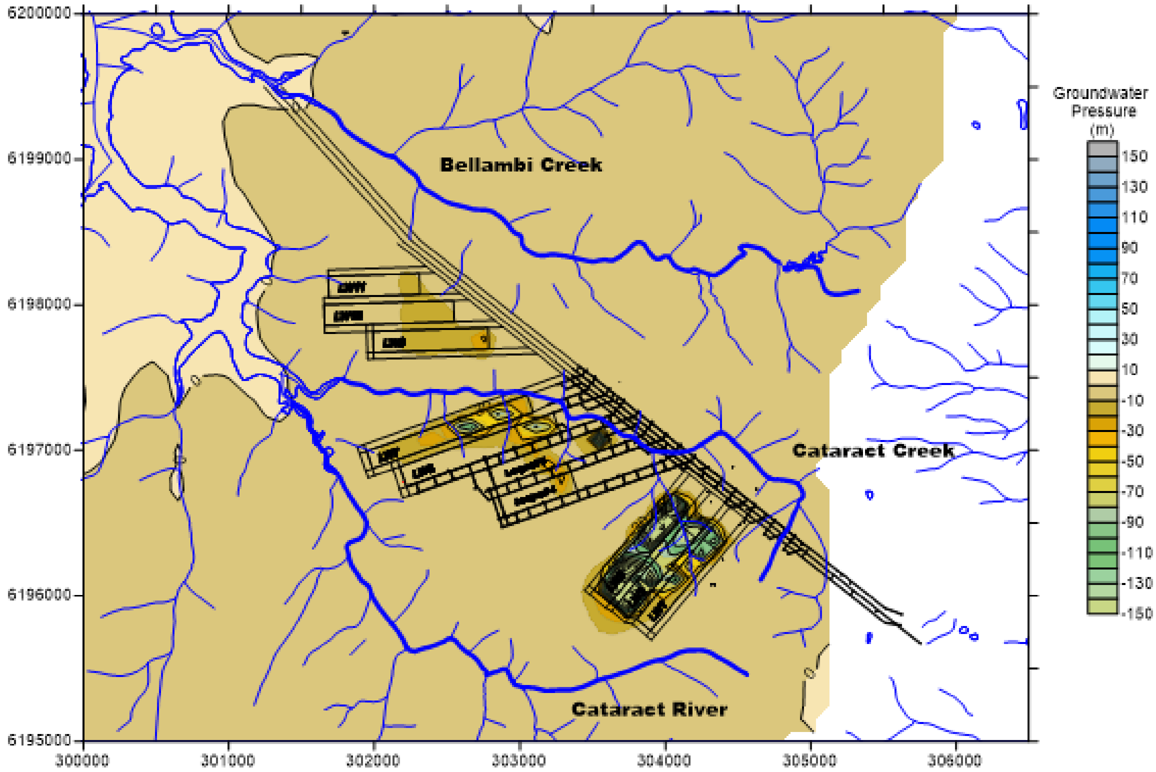


Figure 18 Layer 3 Pressure Difference 10 Years After Mining at Russell Vale East

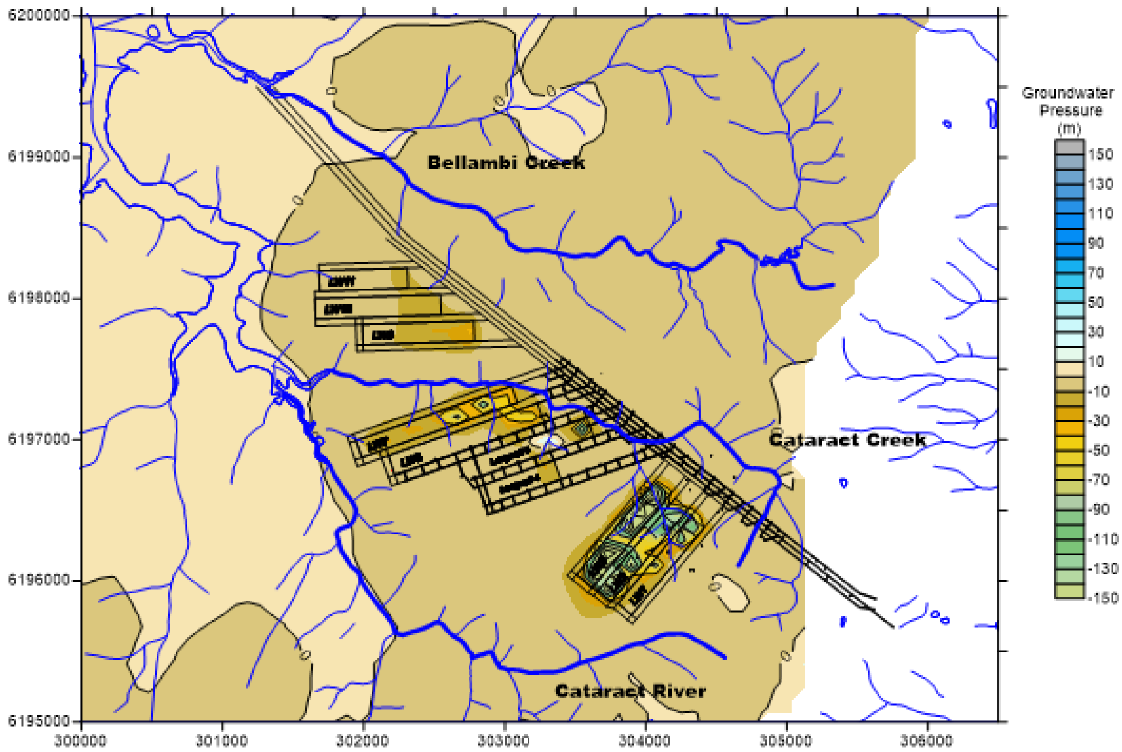


Figure 19 Layer 3 Pressure Difference 50 Years After Mining at Russell Vale East

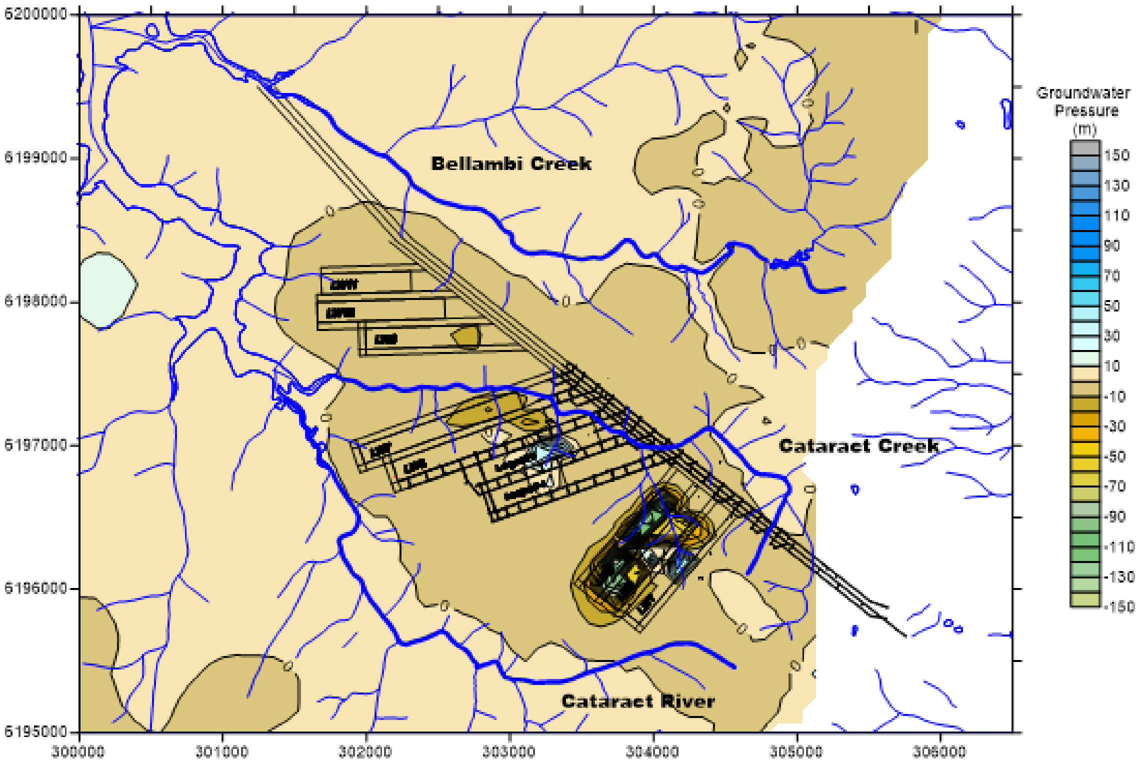


Figure 20 Layer 3 Pressure Difference 100 Years After Mining at Russell Vale East

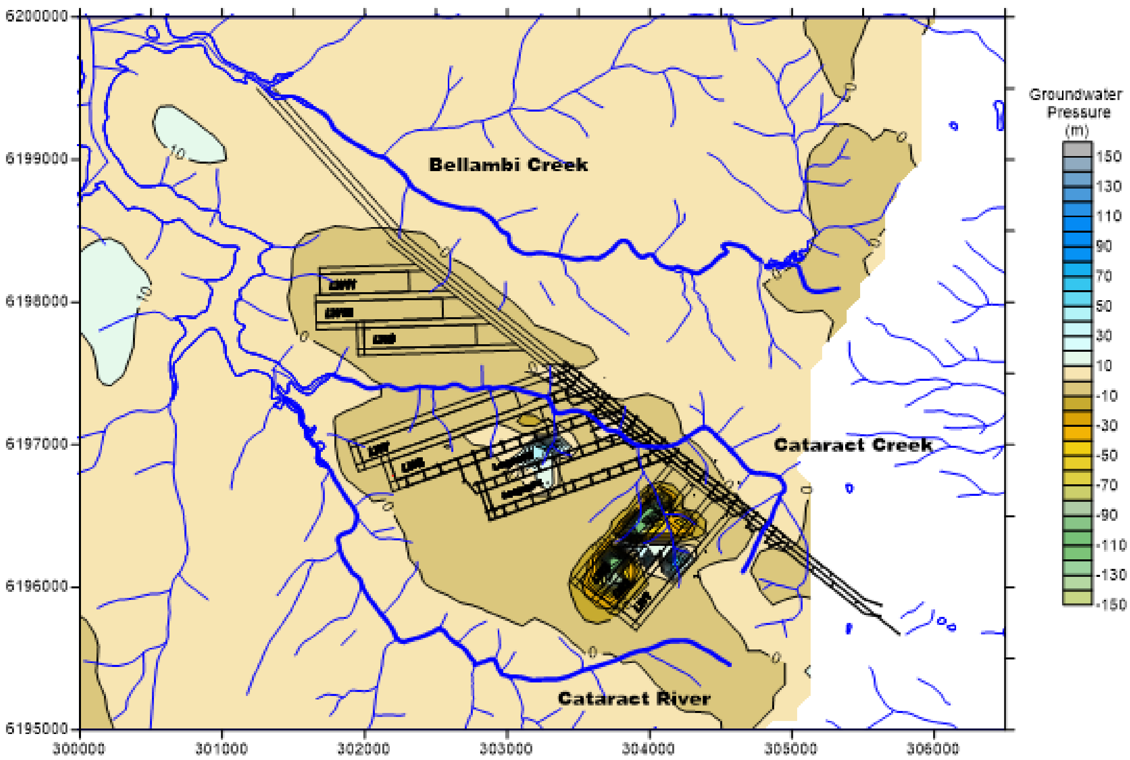


Figure 21 Layer 3 Pressure Difference 150 Years after Mining at Russell Vale East

2.3.3 Upper Bulgo Sandstone

Figure 22 shows modelling results for Layer 5 (Upper Bulgo Sandstone) after the end of mining, which indicates up to 45m of drawdown over Russell Vale East, which occurs within the footprint of LWs 1-7 and part of LW9, in comparison to pre Wongawilli Seam development. **Figure 23** shows drawdown after mining is completed in comparison to post LW5 groundwater levels. As was the case for the overlying layers, the main difference between these two drawdown periods is the drawdown over LW4 and LW5.

Elsewhere over LW1 to LW3, drawdown of up to 25m occurs after the completion of mining.

Modelling indicates that drawdown of up to 2m extends a maximum of 1km to the west of LW7 following completion of mining.

Figure 24 to **Figure 27** represent 10, 50, 100 and 150 years after mining respectively. Negative groundwater levels indicate that pressures continue to fall post-mining. The drawdown cone remains relatively steep and pressure loss appears to peak at approximately 50 years after mining, although a significant proportion of the mining footprint remains unsaturated throughout the recovery period.

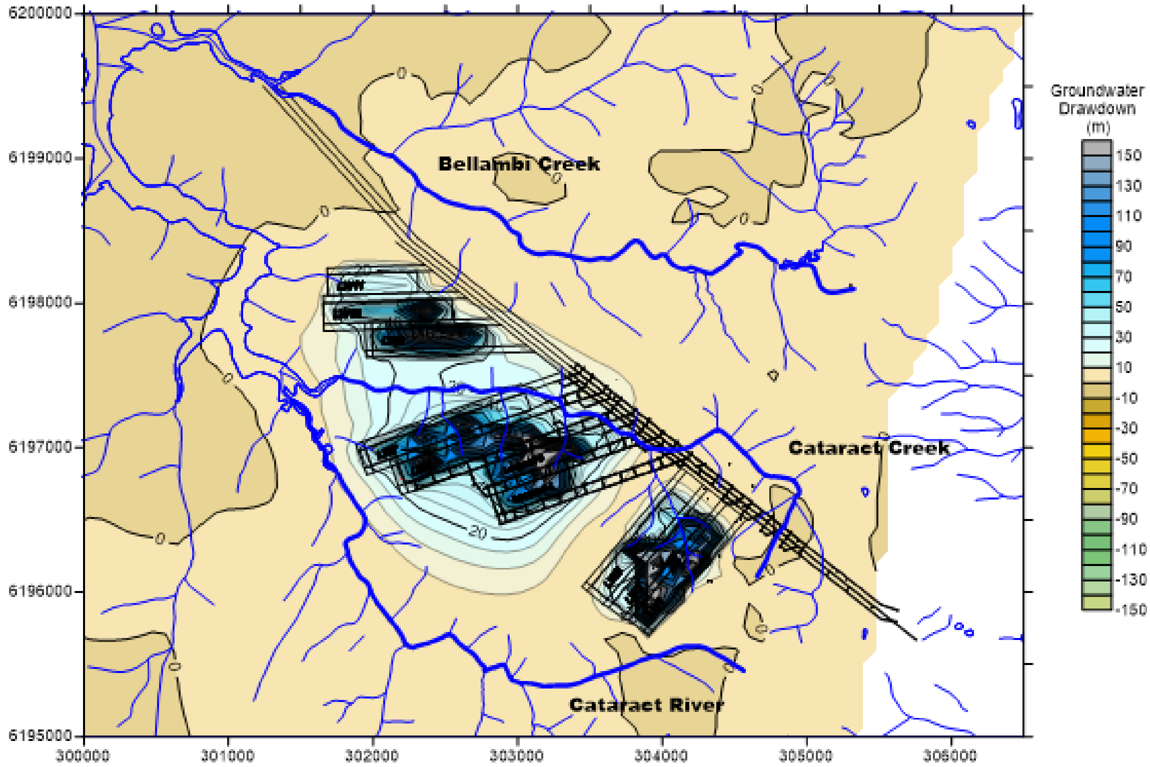


Figure 22 Upper Bulgo Sandstone Drawdown After Mining in Comparison to Pre Wongawilli Seam Development

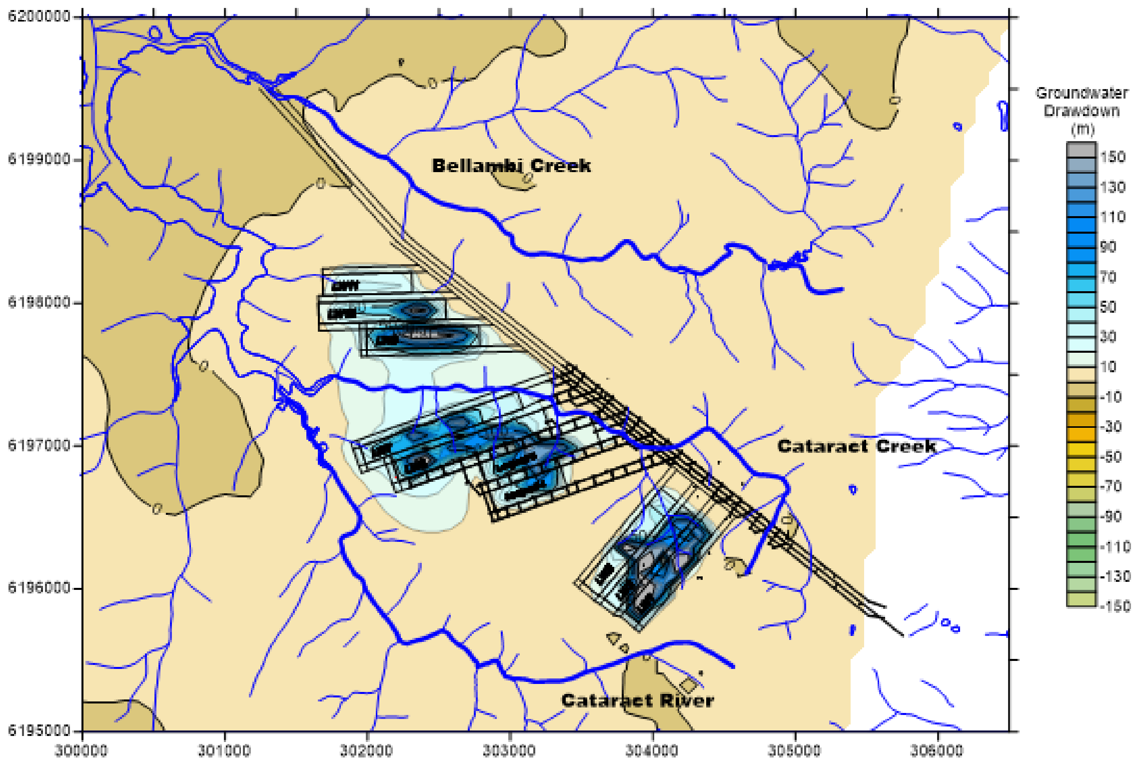


Figure 23 Upper Bulgo Sandstone Drawdown After Mining in Comparison to Post LW5 Development

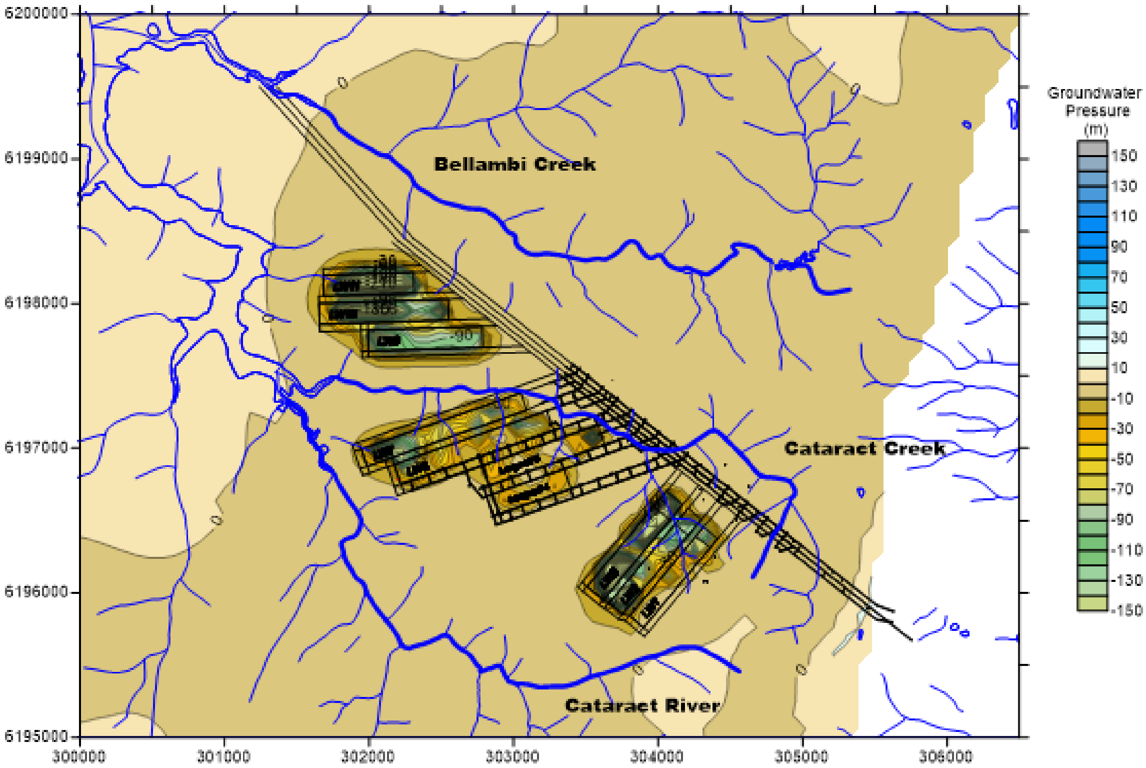


Figure 24 Upper Bulgo Sandstone Recovery at 10 Years After Mining

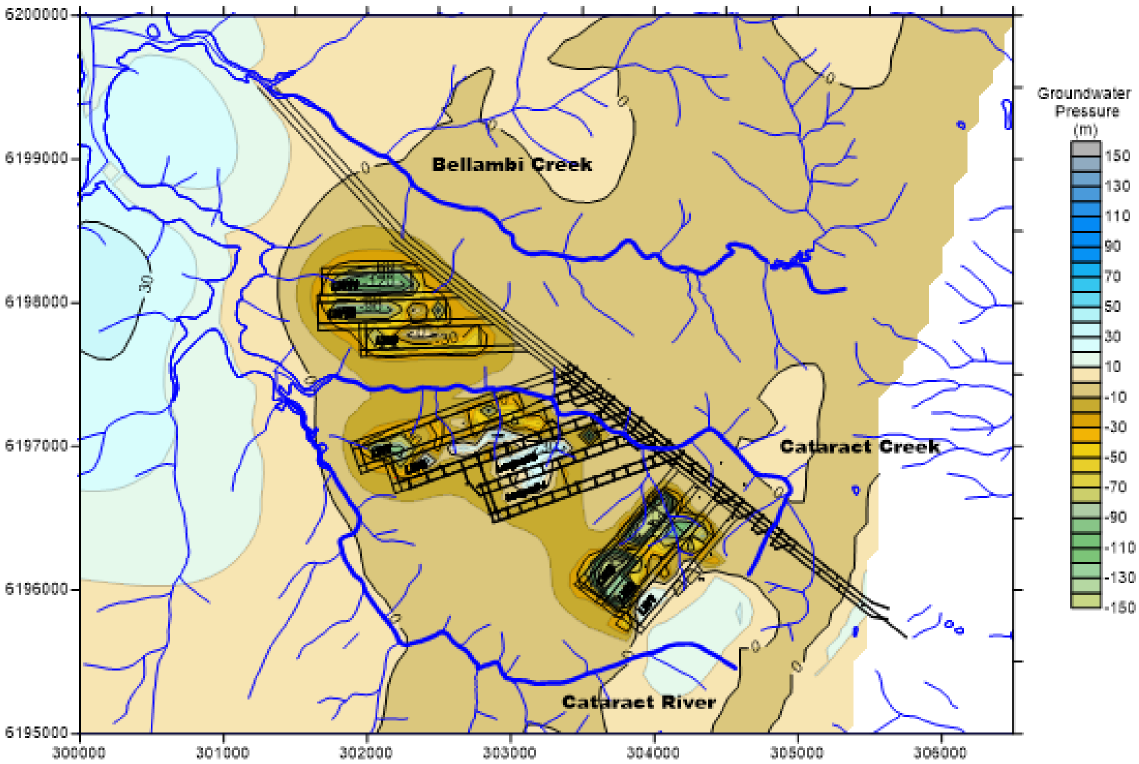


Figure 25 Upper Bulgo Sandstone Recovery 50 Years After Mining East

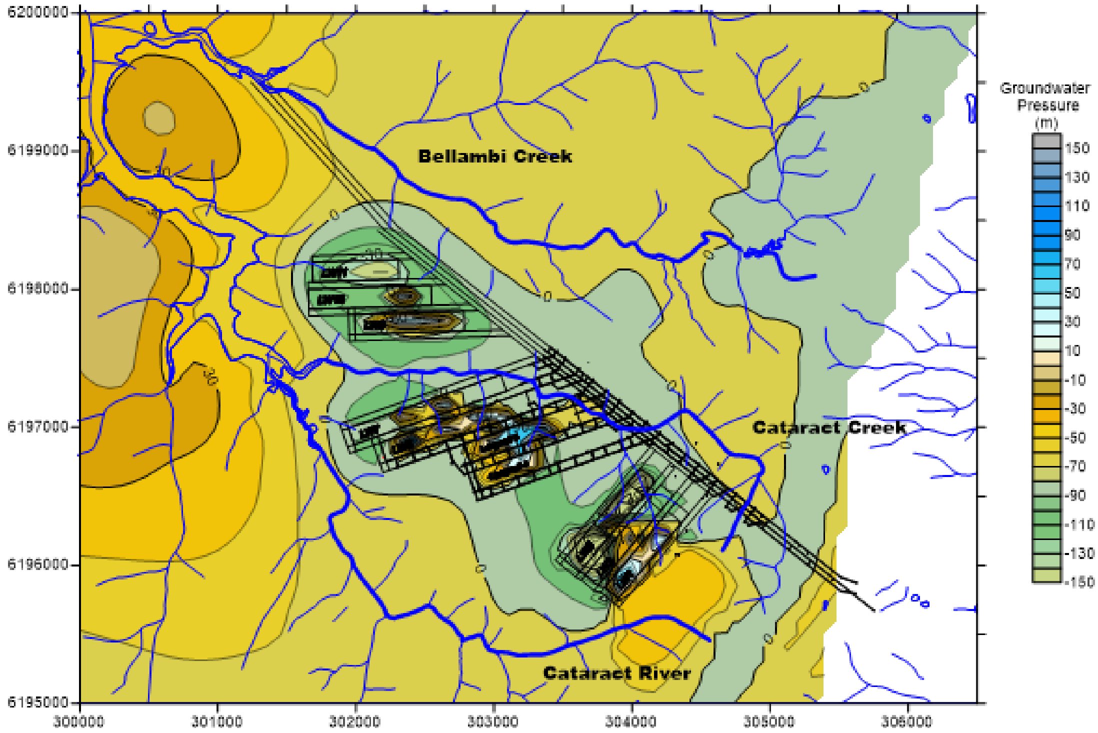


Figure 26 Upper Bulgo Sandstone Recovery 100 Years After Mining

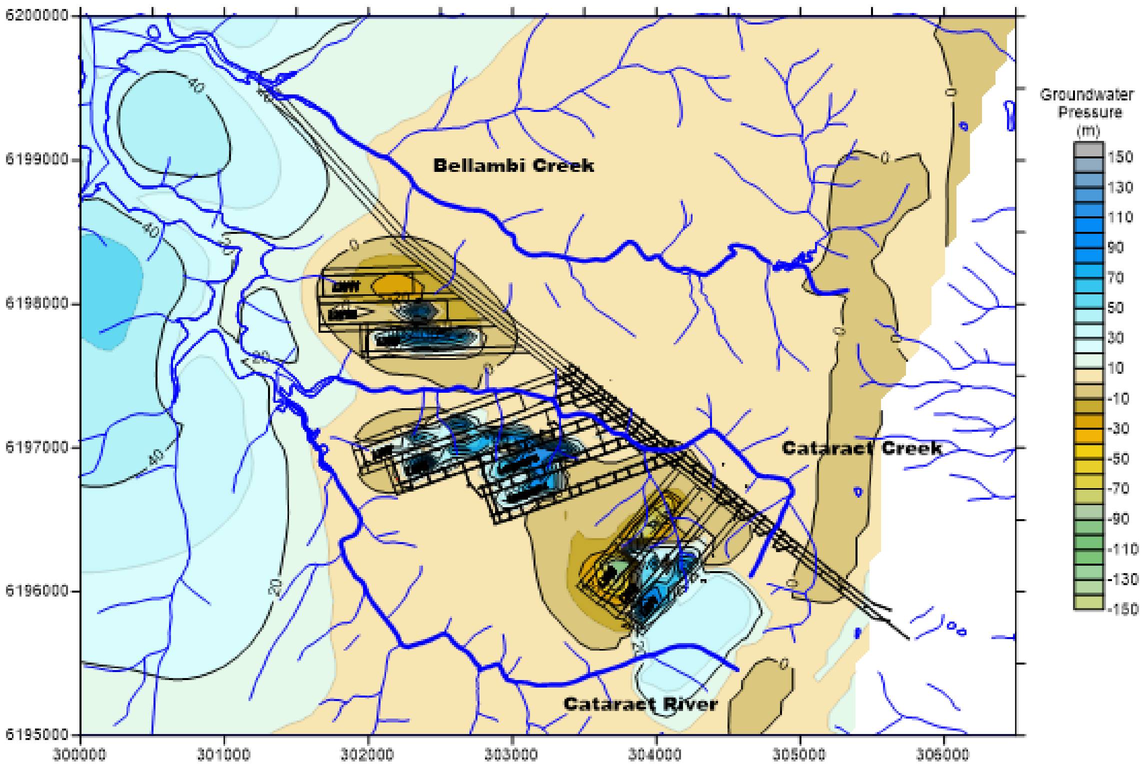


Figure 27 Upper Bulgo Sandstone Recovery 150 Years After Mining

2.3.4 Scarborough Sandstone

Modelling of Scarborough Sandstone (Layer 10) after the end of mining at Russell Vale East indicates drawdown below the base of the layer within the footprint of the proposed Wongawilli Longwalls as shown in Figure 28. The extent of depressurisation is limited by already impacted water levels from previous regional mining activities. The predicted areal extent of drawdown at the end of mining shows 0m extending a maximum of 2km to the south of LW4. Depressurisation at the end of mining relative to the end of LW5 is shown in **Figure 29**.

Figure 30 shows pressures 10 years after mining has been completed, relative to the end of mining and **Figure 31** shows groundwater levels (mAHD) for the same period. These show that a level of recovery has begun. A wave of pressure is pushing in from the west as all drain cells are turned off following the end of mining the Wongawilli Seam at Russel Vale.

Similarly, **Figure 32** and **Figure 33** show the same situation at 50 years after mining is completed which shows a greater degree of recovery within the longwall footprint but still some residual drawdown is present.

Figure 34 and **Figure 35** show the situation at 100 years after mining is completed. **Figure 36** and **Figure 37** show the situation simulated at 150 years after mining is completed. These show progressive recovery beyond initial conditions.

2.3.5 Bulli Seam

No Bulli Seam drawdown figures are presented in this section as the seam is generally dry at Russell Vale East.

2.3.6 Wongawilli Seam

Drawdown in the Wongawilli Seam at the end of mining in comparison to pre Wongawilli Seam development in Russell Vale East is modelled to reach up to 42m over LW1 and to 67m over LW10. The areal extent of the 2m drawdown contour at the end of mining at Russell Vale East extends a maximum of 2km to the north and south of the main workings as shown in **Figure 38**.

Figure 39 shows drawdown after mining is completed in comparison to post LW5 groundwater levels. As in overlying layers, the main difference between these two drawdown periods is the drawdown over LW4 and LW5. There is a significant difference in the areal extent of the drawdown cones observed between the two scenarios due to the drawdown associated with the currently approved mining of LW5 and development headings for LW6.

At 10 years after completion of mining, the Wongawilli Seam is predicted to recover by up to 20m in the western areas (LW10) in comparison to end of mining conditions as shown in **Figure 40**. Groundwater pressure (mAHD) at the same period are shown in **Figure 41**.

At 50 years after completion of mining, the Wongawilli Seam is predicted to recover by up to 120m over LW10 which is above initial conditions and again brought about by the removal of all regional drains. **Figure 42** shows groundwater pressures in comparison to end of mining conditions over Russell Vale Colliery. At this time there, is 80m recovery in the vicinity of LW10 and 30m in the vicinity of LW2. Groundwater pressure (mAHD) at the same period are shown **Figure 43.**

This trend continues following 100 years after mining as indicated in **Figure 44** and **Figure 45** respectively.

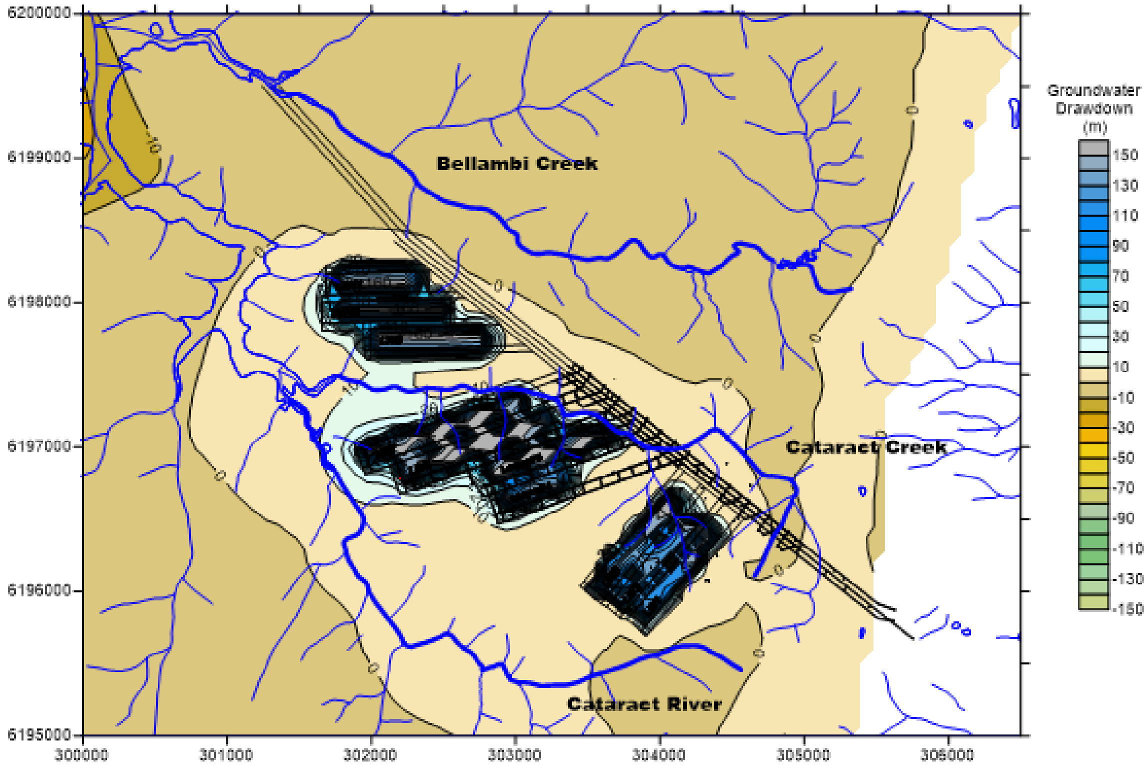


Figure 28 Scarborough Sandstone Drawdown After Mining in Comparison to Pre Wongawilli Seam Development

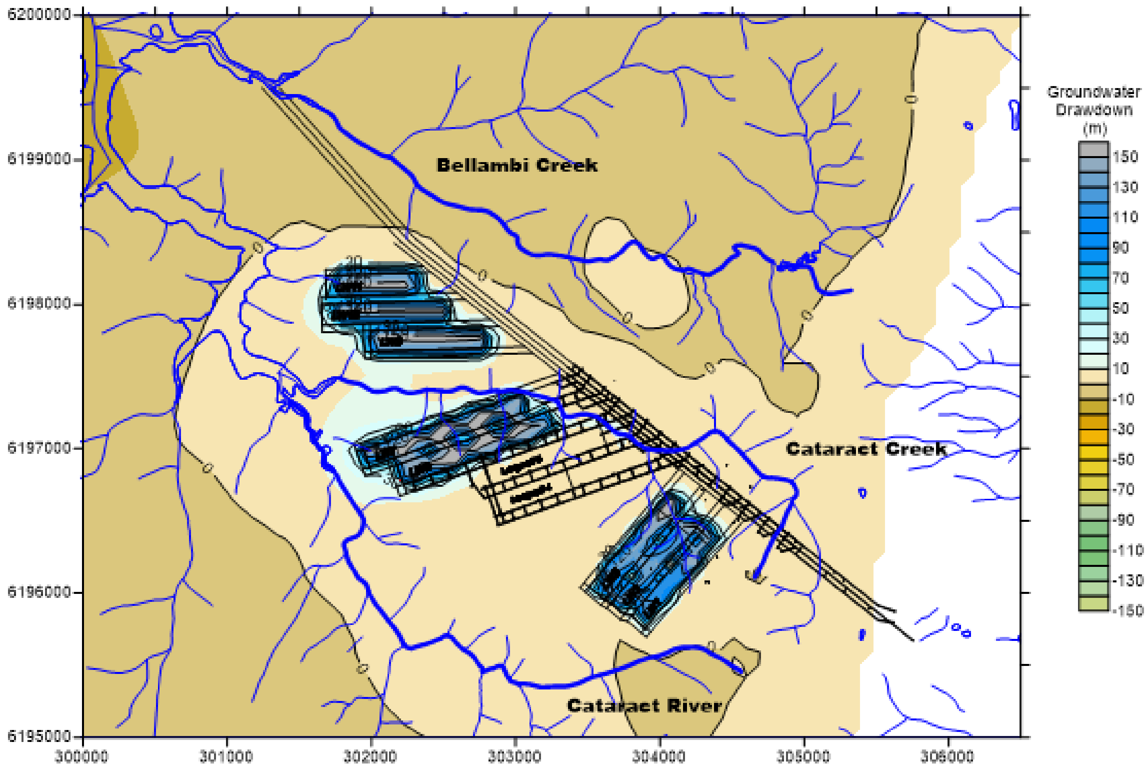


Figure 29 Scarborough Sandstone Drawdown After Mining in Comparison to Post LW5 Development

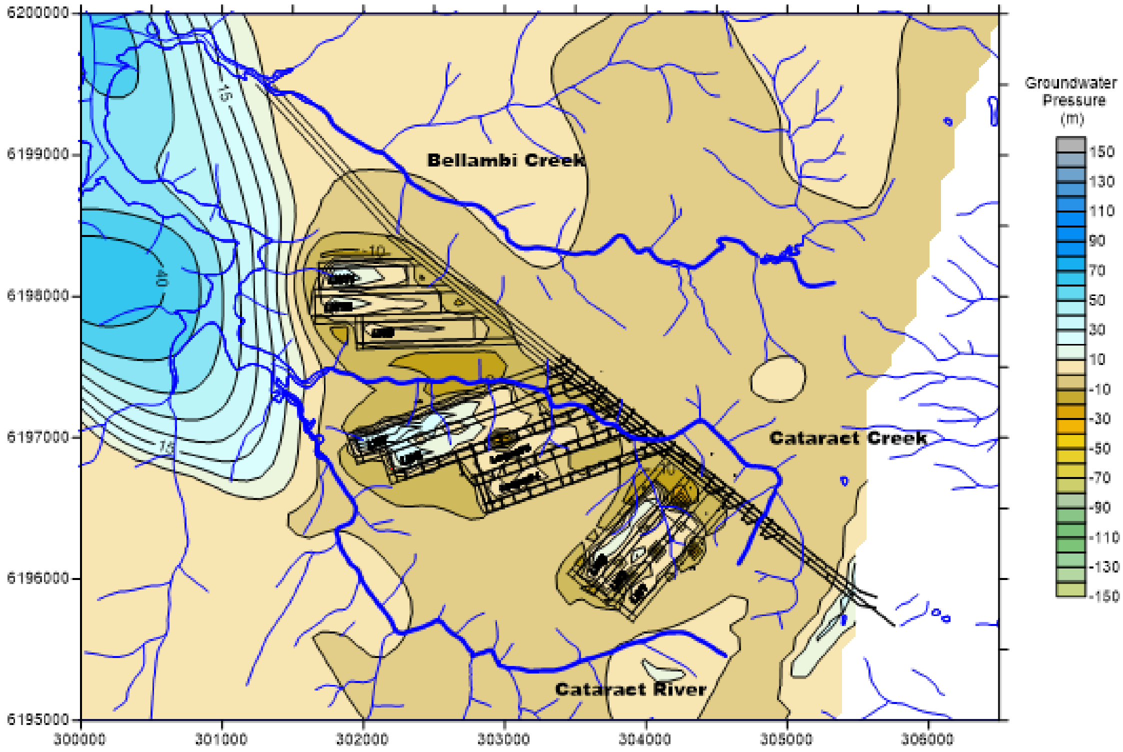


Figure 30 Scarborough Sandstone Pressure Recovery at 10 Years After End of Mining

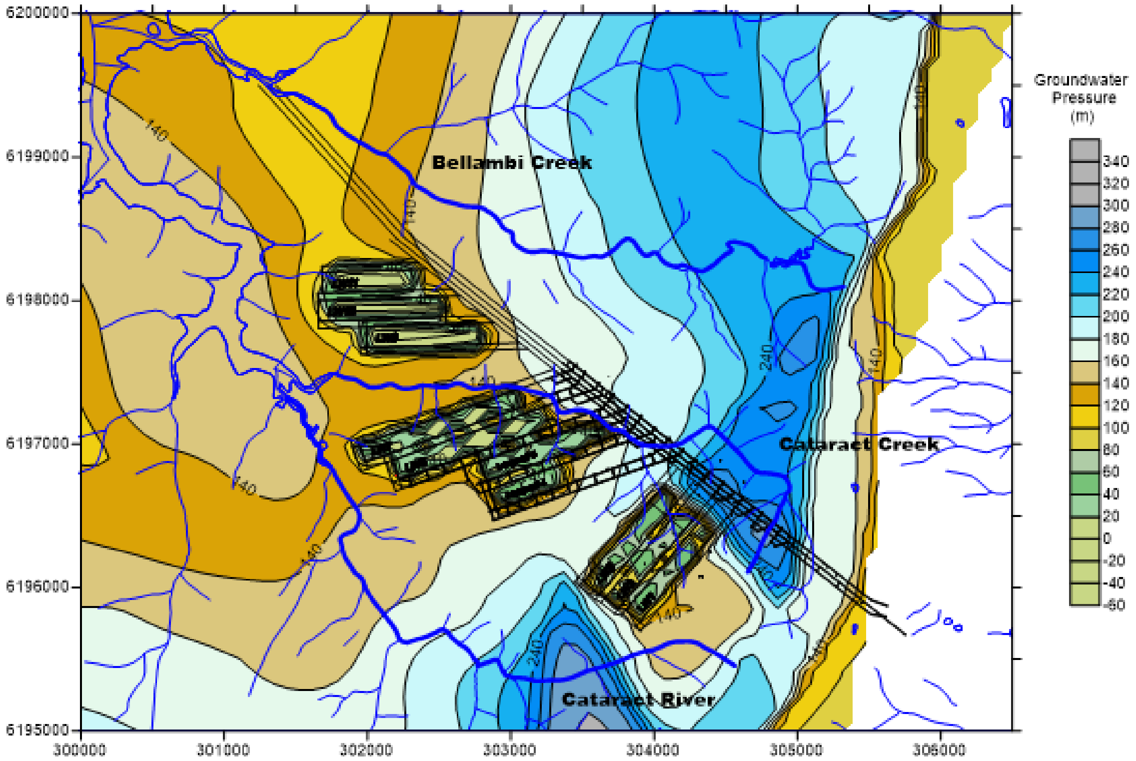


Figure 31 Scarborough Sandstone Groundwater Pressures 10 Years After Mining (mAHD)

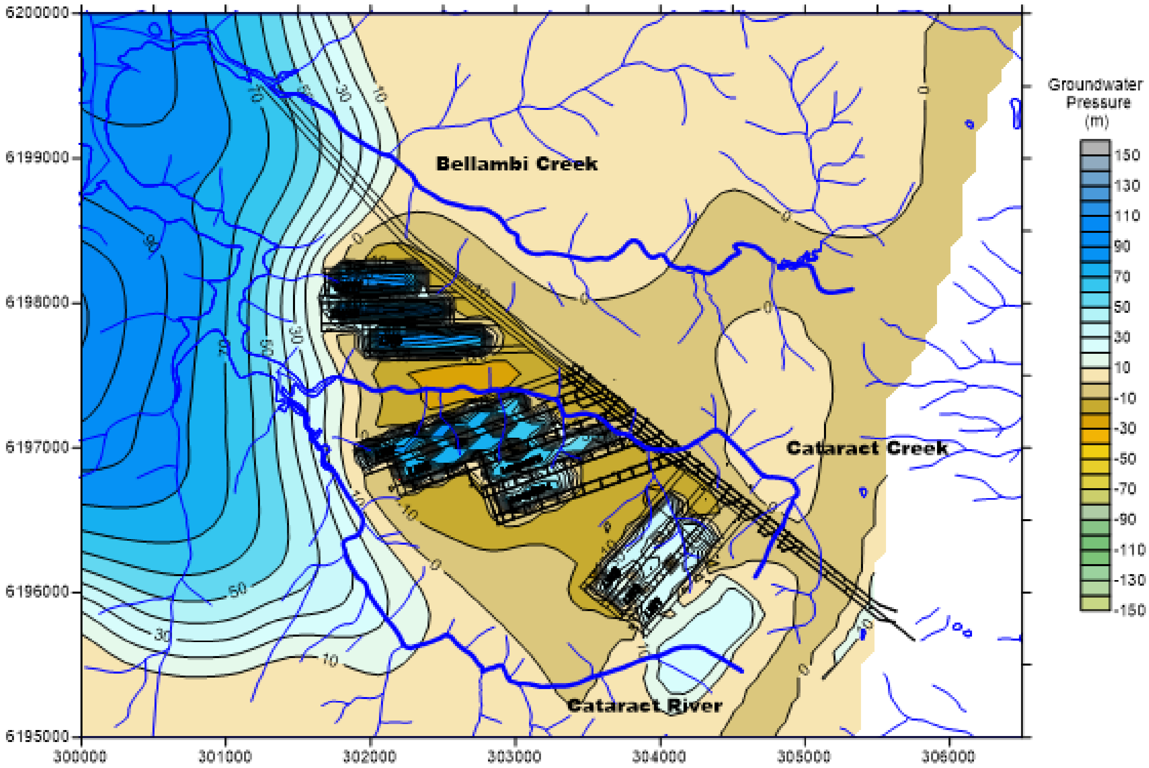


Figure 32 Scarborough Sandstone Pressure Recovery at 50 Years After Mining

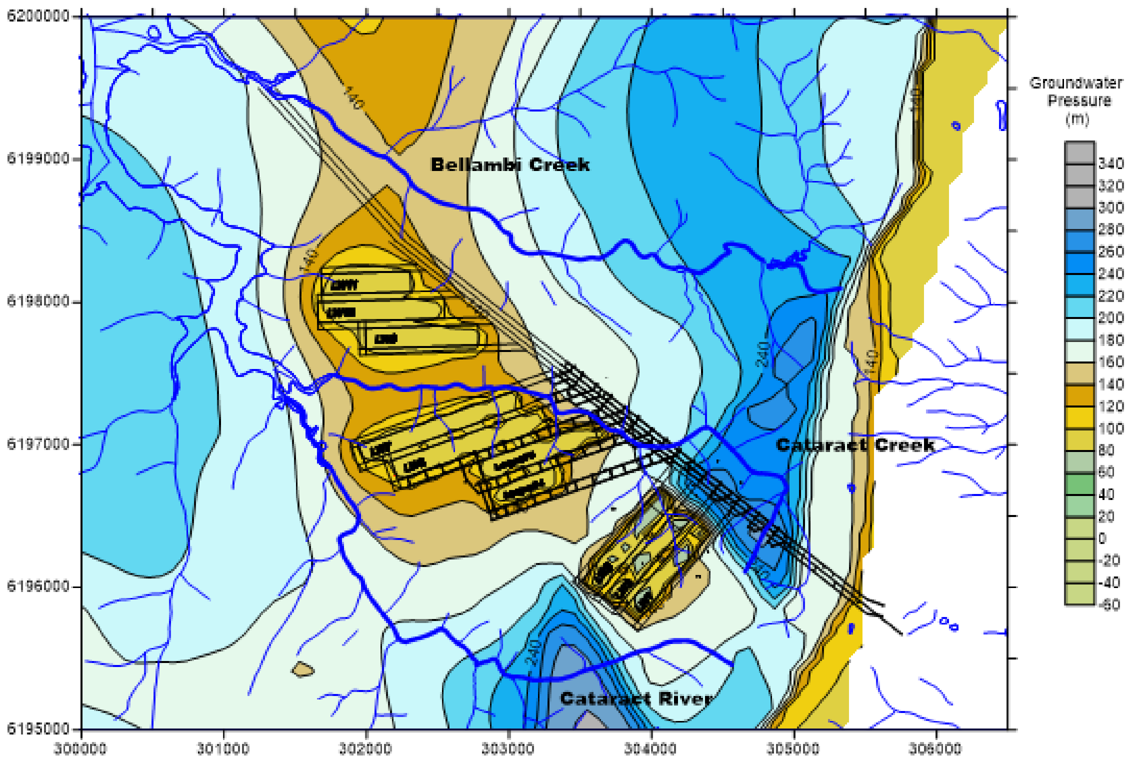


Figure 33 Scarborough Sandstone Groundwater Pressures at 50 Years After Mining (mAHD)

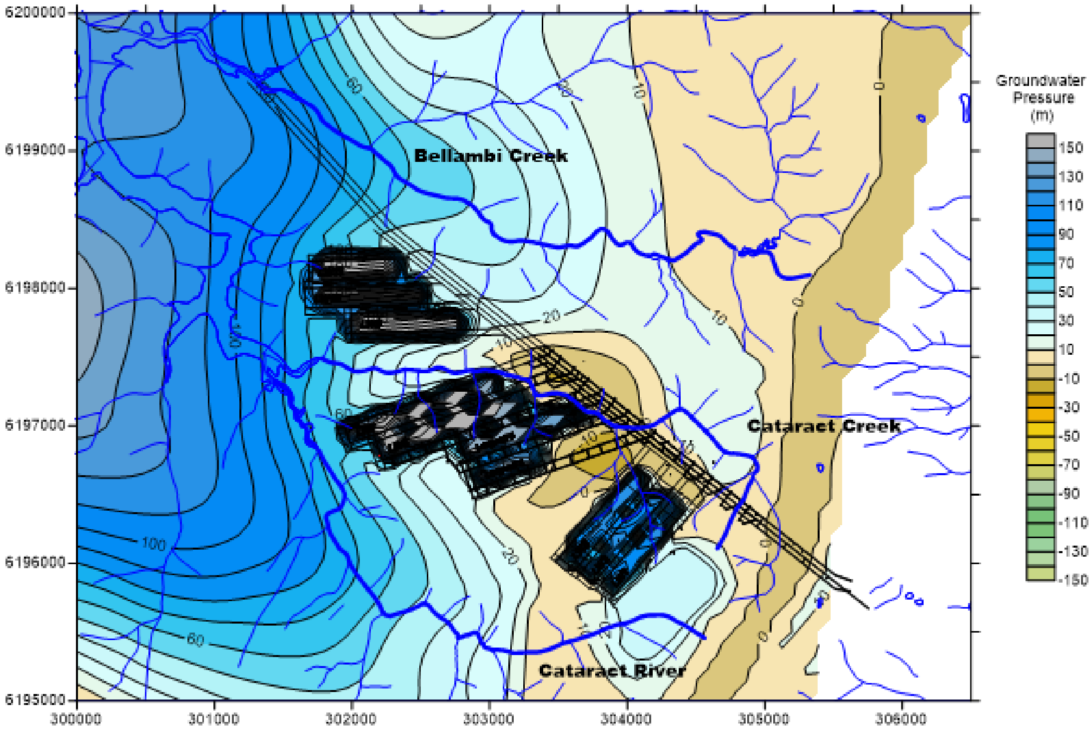


Figure 34 Scarborough Sandstone Pressure Recovery at 100 Years After Mining

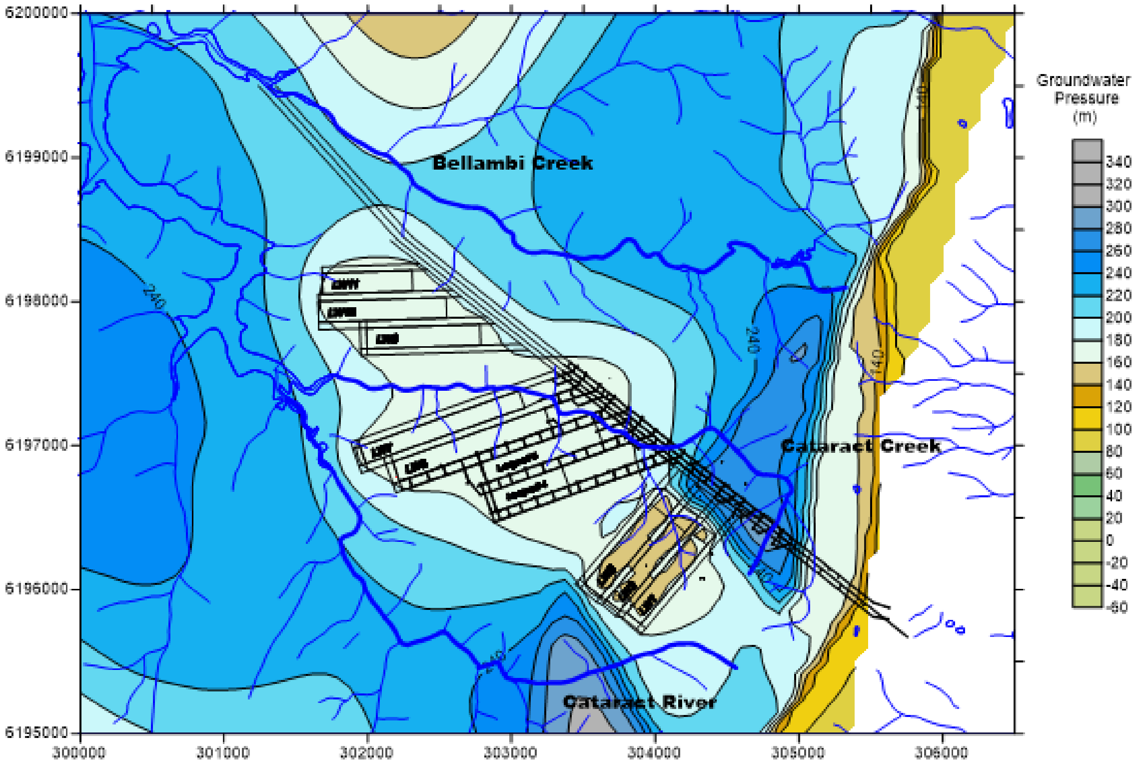


Figure 35 Scarborough Sandstone Groundwater Pressures at 100 Years After Mining (mAHD)

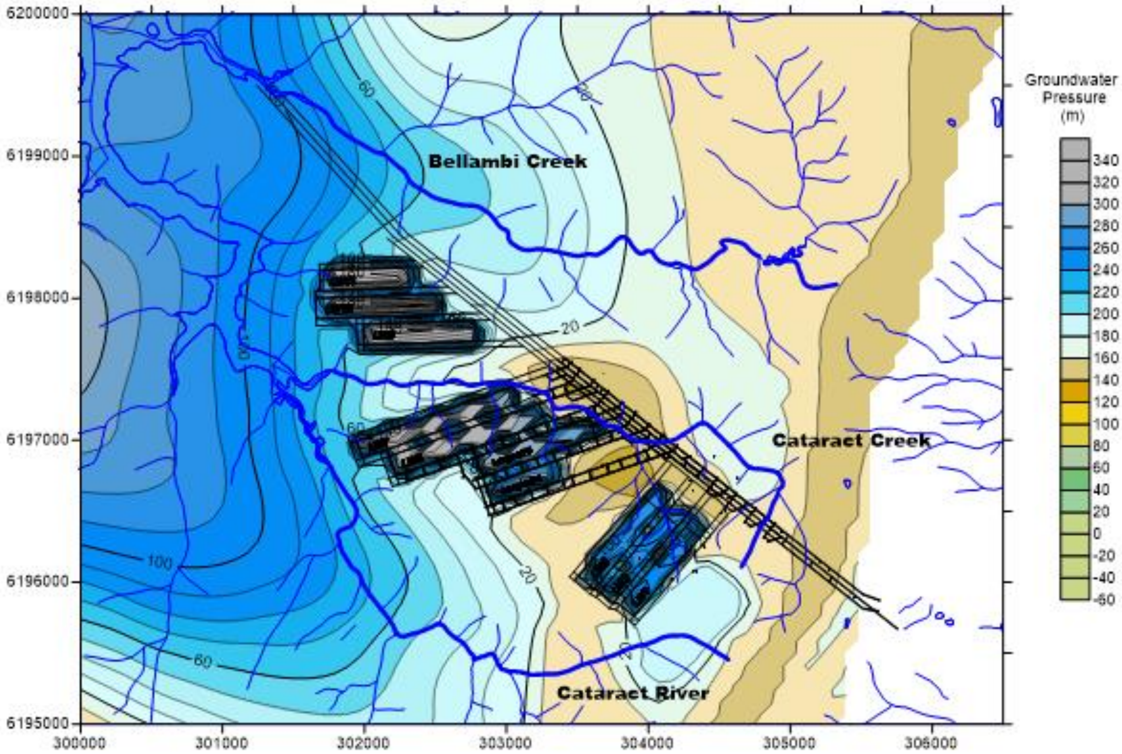


Figure 36 Scarborough Sandstone Pressures Recovery at 150 Years After Mining

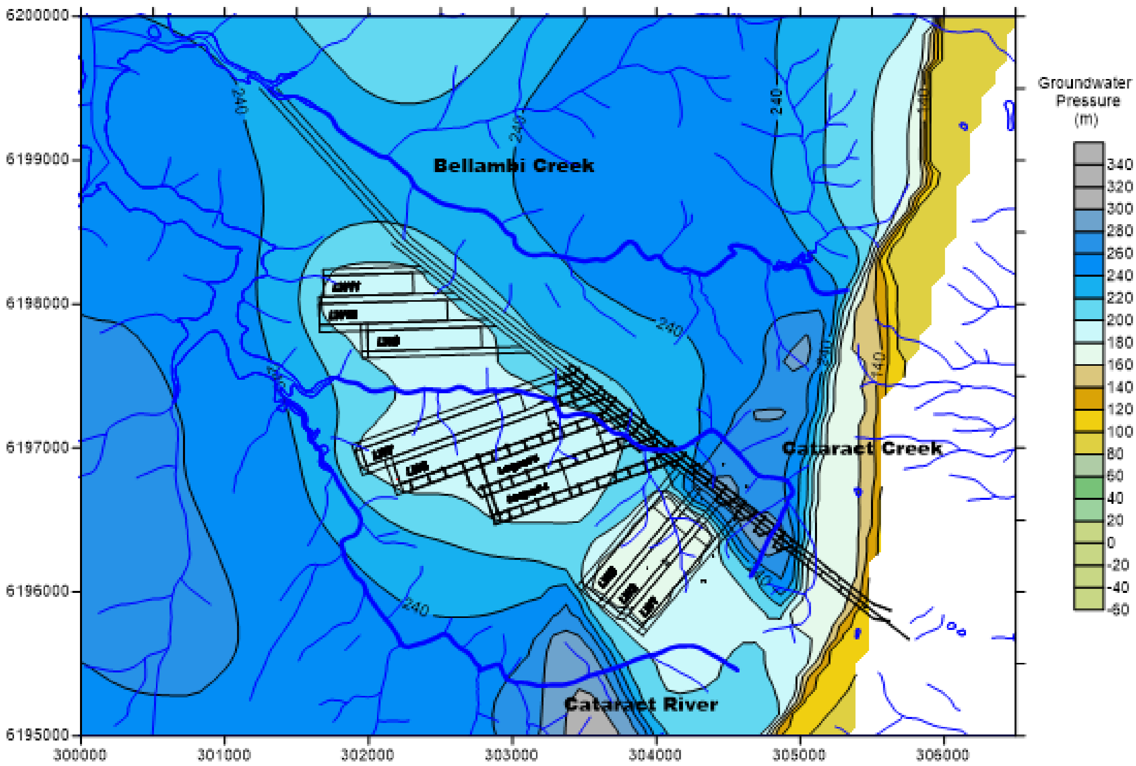


Figure 37 Scarborough Sandstone Groundwater Recovery at 100 Years After Mining (mAHD)

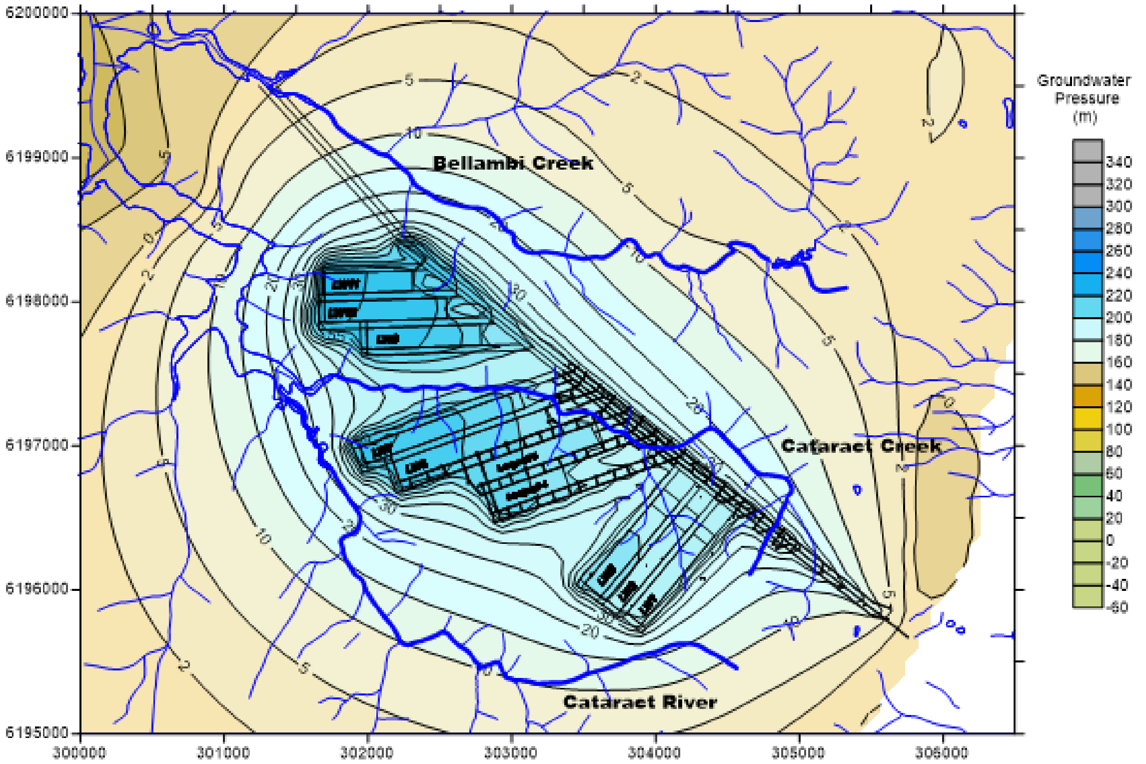


Figure 38 Wongawilli Seam Drawdown After Mining Russell Vale East in Comparison to Pre Wongawilli Seam Development

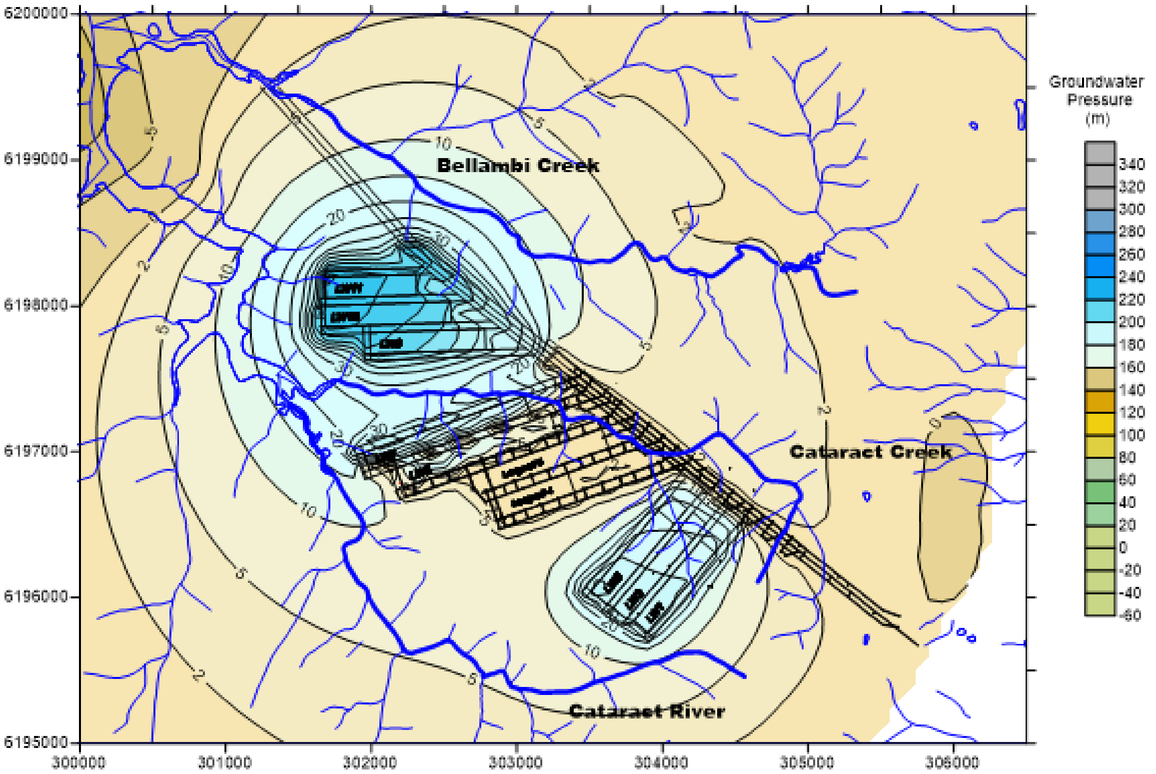


Figure 39 Wongawilli Seam Drawdown After Mining at Russell Vale East in Comparison to Post LW5 Development

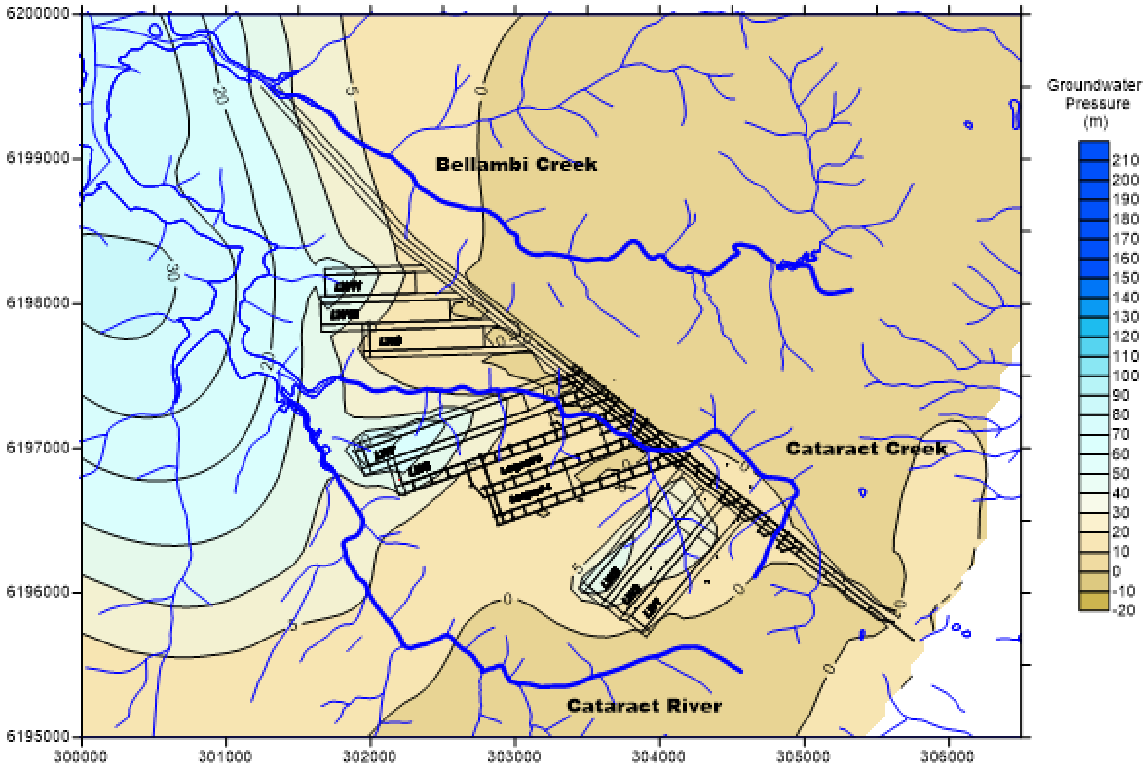


Figure 40 Wongawilli Seam Pressures Recovery at 10 Years After Mining

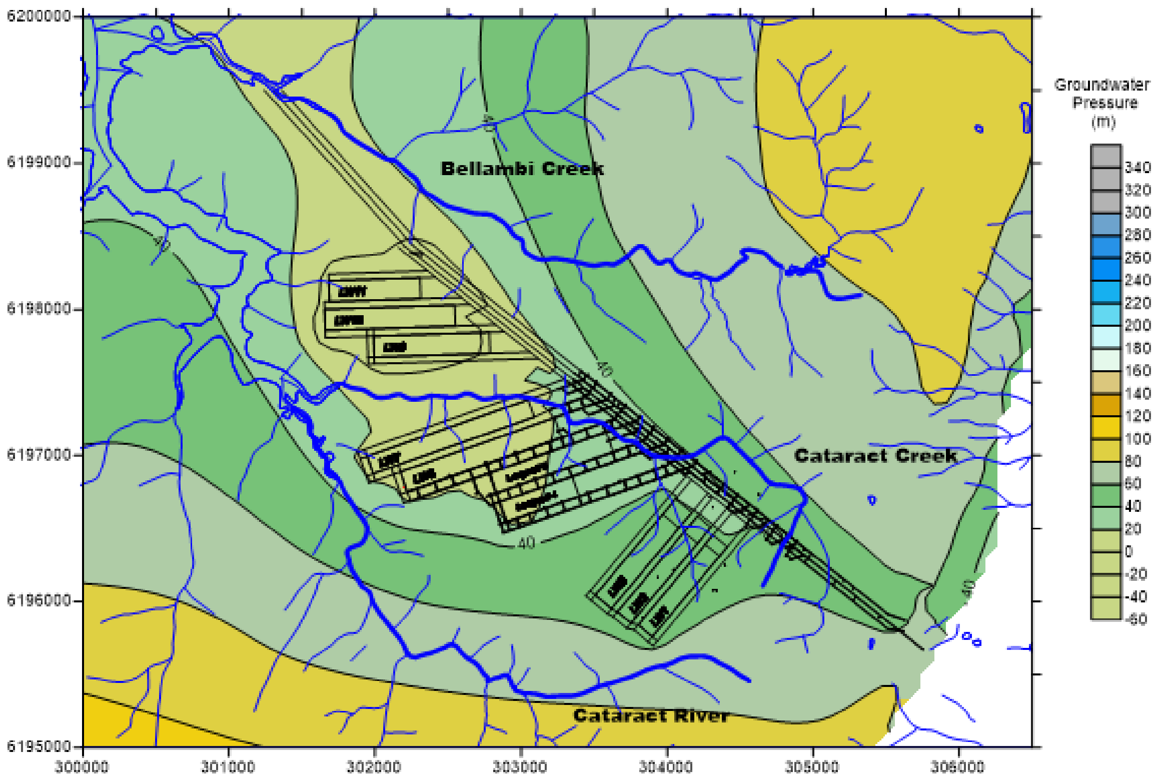


Figure 41 Wongawilli Seam Groundwater Pressures at 10 Years after Mining (mAHD)

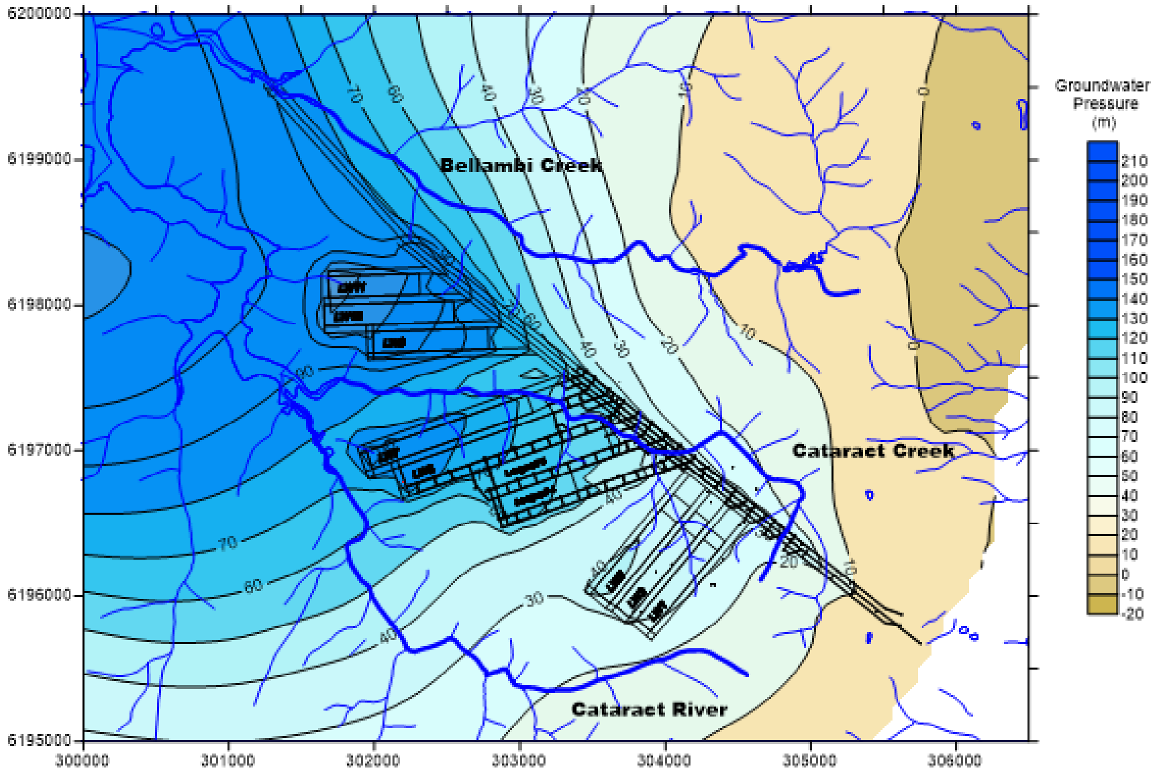


Figure 42 Wongawilli Seam Pressure Recovery at 50 Years After Mining

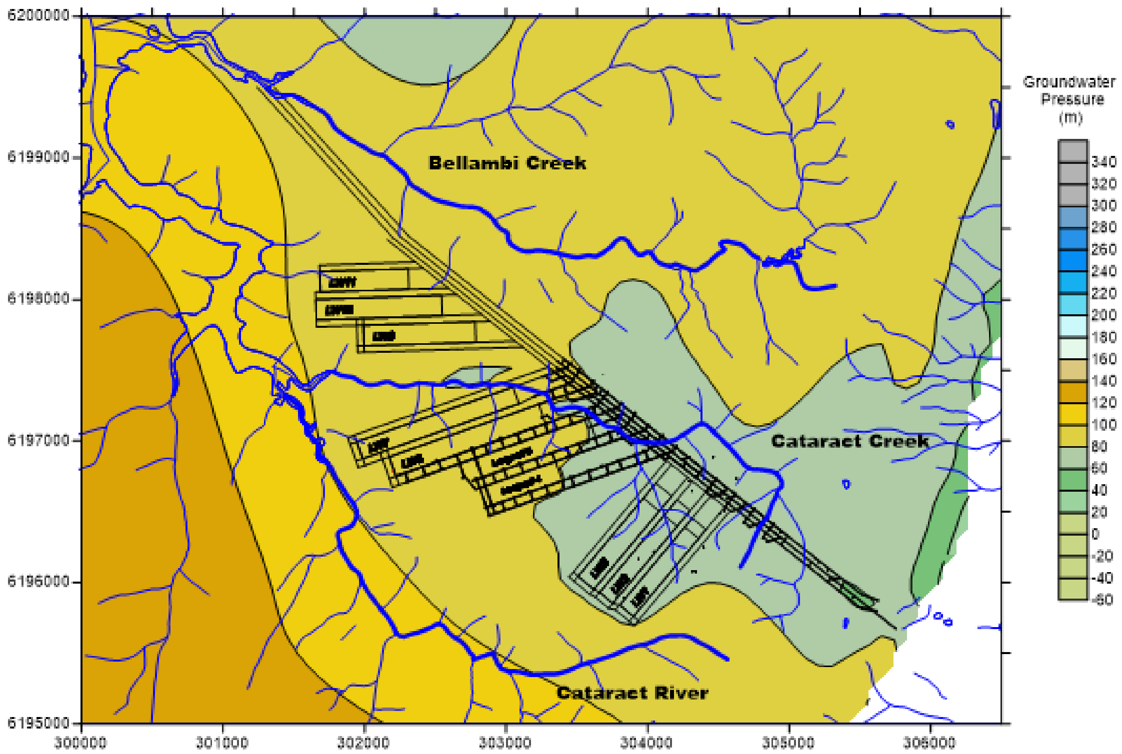


Figure 43 Wongawilli Seam Groundwater Pressures at 50 Years after Mining (mAHD)

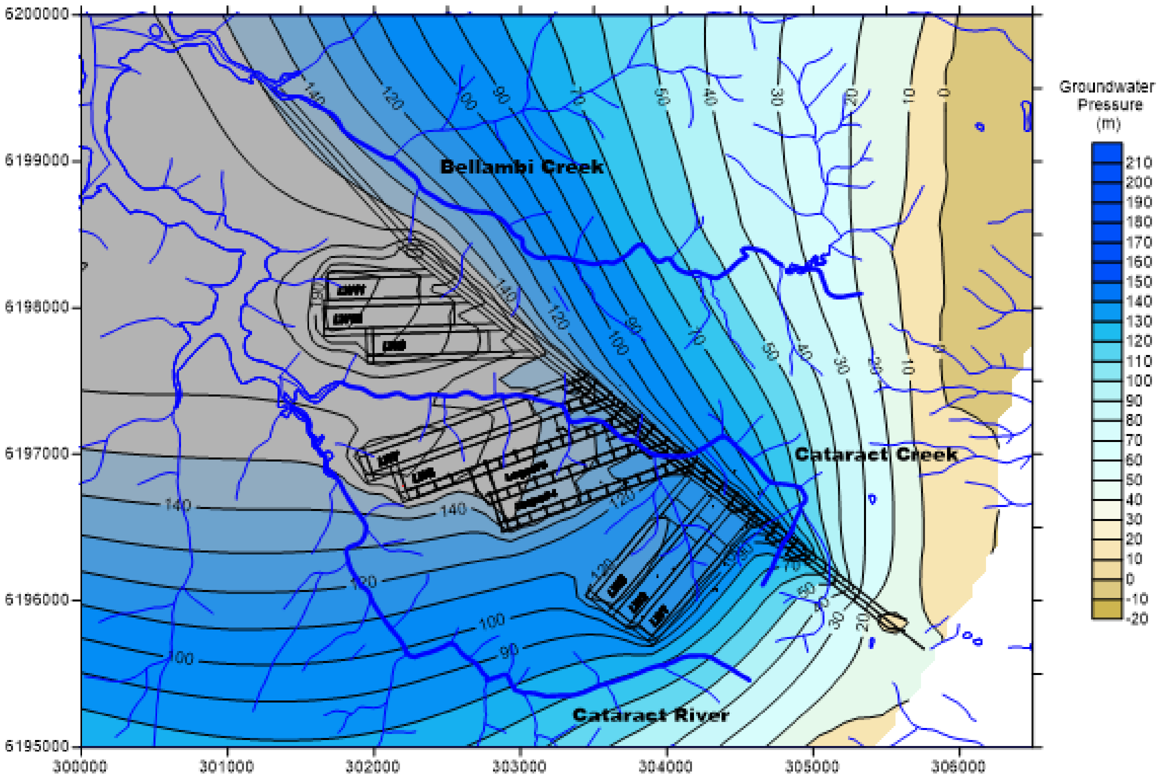


Figure 44 Wongawilli Seam Pressure Recovery at 100 Years After Mining

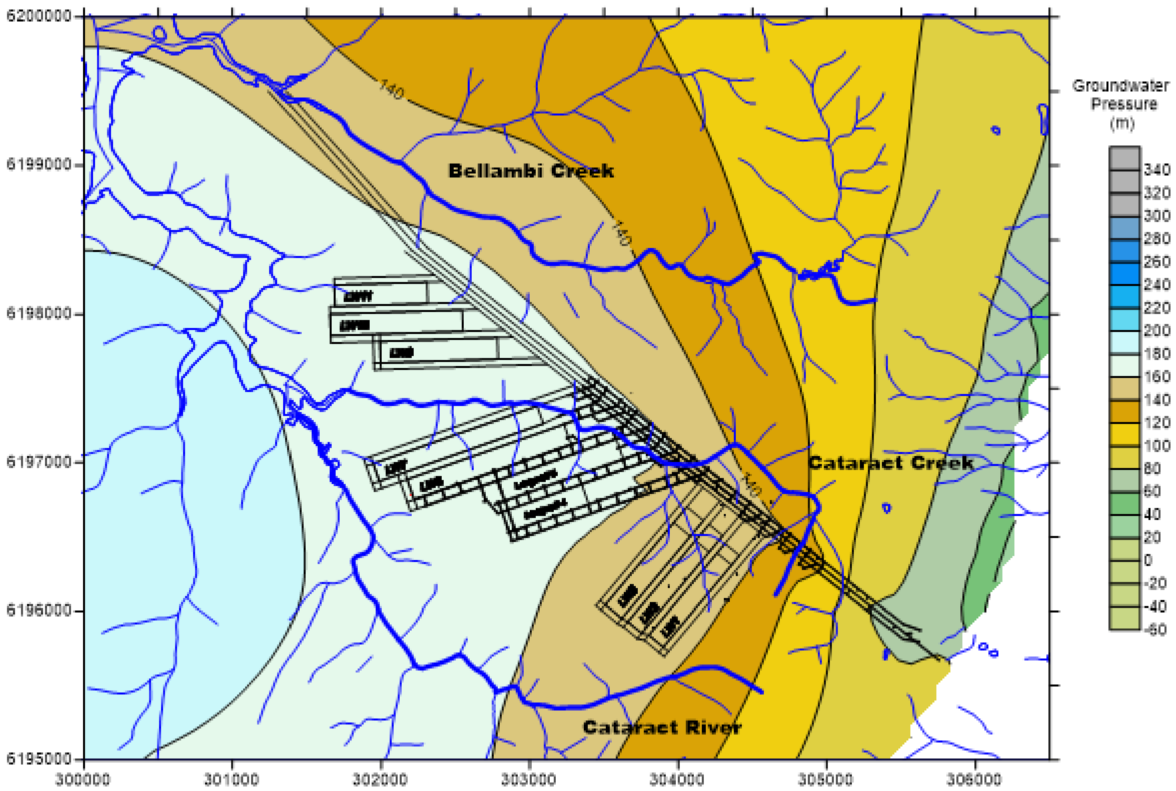


Figure 45 Wongawilli Seam Groundwater Pressures at 100 Years after Mining (mAHD)

2.4 Stream and Groundwater System Connectivity

A number of mechanisms can potentially occur within shallow groundwater systems which cause interaction with streams or other surface water features. These include::

- direct flow of surface water into mining induced fracture systems with vertical drainage into the shallow basement groundwater system;
- inter-connection of the depressurised strata and horizontal to sub-horizontal or "stepped" shear plane/s located beneath a stream bed and associated subsided hill slopes;
- flow of surface water from "losing" streams into the shallow groundwater system migrates along the local hydraulic gradient and re-emerges further downstream, with no hydraulic connection to the workings if there is no continuous, vertically connected fracturing, or;
- reversal of water transfer from the shallow groundwater system to the "gaining" streams during periods of high recharge;

2.4.1 Cataract Creek

The modelled, localised reduction in shallow groundwater pressures is anticipated to reduce the regional phreatic surface gradient from the plateau to Cataract Creek, as well as toward Cataract Reservoir, thereby potentially reducing baseline seepage flow volumes to the creek and dam.

2.4.2 Cataract River (Upstream of Cataract Reservoir) and Bellambi Creek

Although groundwater level reductions are predicted over the Russell Vale East workings, the majority of the changes are contained within the Cataract Creek catchment.

As such, there is anticipated to be no observable change in stream flow or groundwater seepage in the Cataract River (upstream of Cataract Reservoir) and Bellambi Creek catchments due to the very low proportion of the two catchments that may be partially depressurised as shown in **Table 3** and **Figure 46.**

The modelling predicts a peak reduction in baseflow of 0.0035 ML/day (1.64 ML/yr) in the Cataract River (upstream of Cataract Reservoir) and a reduction of 0.005ML/day (1.83 ML/yr) in Bellambi Creek.

Table 3 Modelled Cataract Creek, Cataract River and Bellambi Creek Stream Flow Changes

	Baseflow Loss (ML/day) / (ML/year)	Change Due to Proposed Mining Compared to Current Flows (ML/day) / (ML/year)
Cataract Creek (Upstream of Cataract Reservoir)		
End of LW5	0.001 / 0.37	-
End of Mining	0.0075 / 2.73	0.0065 / 2.37
Peak During Recovery **(Years after completion of mining)**	0.07 / 25.5 (50)	0.069 / 25.19
Cataract River (Upstream of Cataract Reservoir)		
End of LW5	9 $\times 10^{-6}$ / 0.03	-
End of Mining	0.003 / 0.11	0.003 / 0.11
Peak During Recovery **(Years after completion of mining)**	0.0045 / 1.64 (50)	0.0045 / 1.64
Bellambi Creek		
End of LW5	6 $\times 10^{-6}$ / 0.002	-
End of Mining	4.9 $\times 10^{-5}$ / 0.018	4.3 $\times 10^{-5}$ / 0.016
Peak During Recovery **(Years after completion of mining)**	0.005 / 1.83 (100)	0.0049 / 1.81
Cataract Reservoir		
End of LW5	1.4 $\times 10^{-7}$ / 5 $\times 10^{-5}$	-
End of Mining	0.0005 / 0.18	0.0005 / 0.18
Peak During Recovery **(Years after completion of mining)**	0.007 / 2.56 (50)	0.007 / 2.56
Peak change		**0.085 / 31.7**

2.5 Cataract Reservoir

Cataract Reservoir has a full operating storage of 97,190ML. The lowest level of the storage as advised by Water NSW is 27,620ML or 29.3% capacity on 20 July 2006.

2.5.1 Stream Inflow

Due to the setback of the proposed workings from the Cataract Reservoir, no adverse impacts on stored water quantity or quality are predicted to occur on, or in, Cataract Reservoir, based on the factors discussed in previous sections.

It is anticipated, however, that the water will flow via subsurface fractures and discharge down gradient into the lower section of the streams, and / or into Cataract Reservoir. As such, the change is anticipated to be essentially a sub-surface diversion within the stream reaches over the subsidence areas, as opposed to an overall loss to the surface water balance, outside of the strata depressurisation related stream flow losses.

The modelled sub-surface total transfer of 0.0784 ML/day (28.64ML/year) from the Cataract Creek, Cataract River and Bellambi Creek catchments at the peak of losses occurring post proposed mining at Russell Vale East is 0.1% of the low level storage, or 0.029% of its full storage capacity.

2.5.2 Strata Depressurisation

The modelled transfer of stored water within Cataract Reservoir to the underlying groundwater system due to depressurisation of the regional groundwater system in the vicinity of the reservoir is 0.0005ML/day (0.18ML/year) at the end of mining. This increases to a peak approximately 50 years after completion of mining to 0.007ML/day (2.56ML/year) as shown in **Figure 46.** The modelled sub-surface transfer of 0.18ML /year from the stored waters at the end of the proposed mining is less than 0.0006% of the low level, or 0.0002% of its full storage capacity.

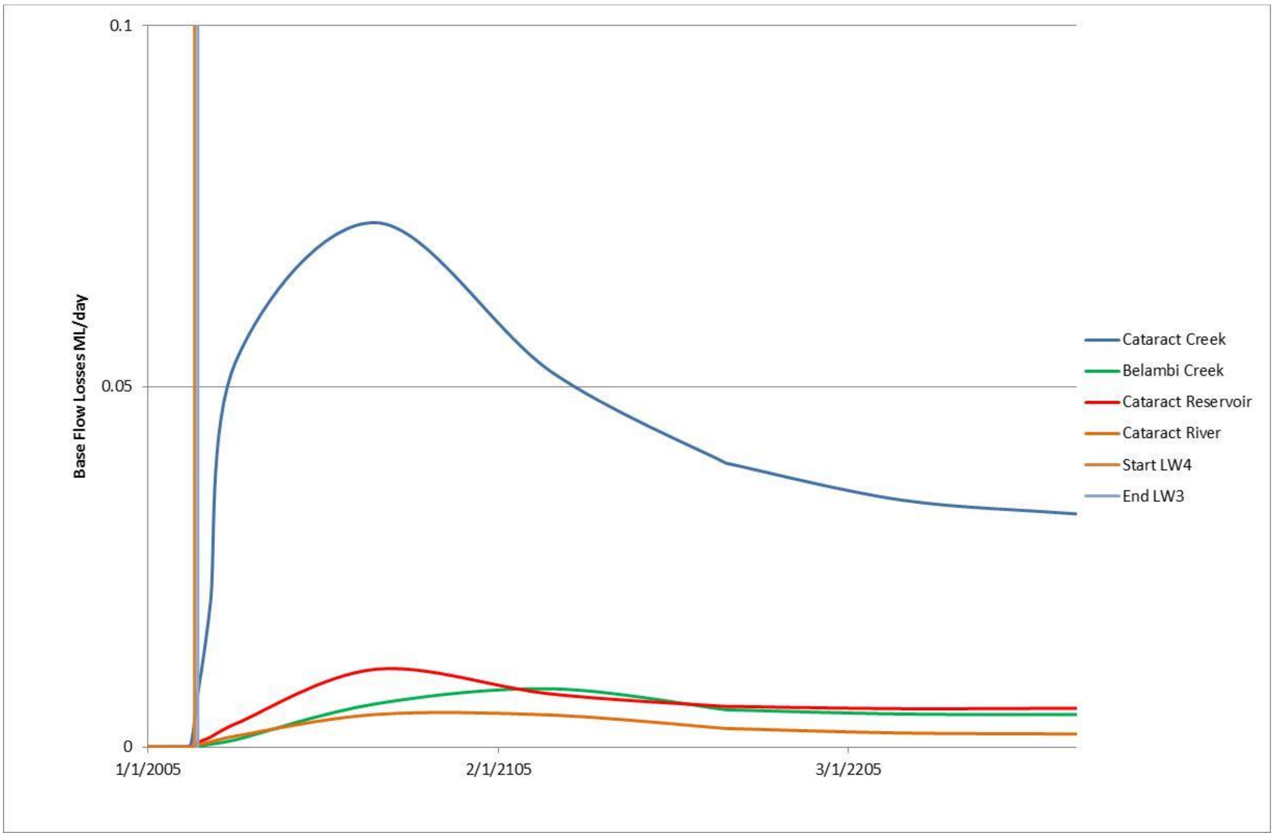


Figure 46 Russell Vale East Stream and Cataract Reservoir Depressurisation Related Base Flow Losses

2.6 Groundwater Inflow to the Workings

Groundwater reports to drain cells representing the working levels which include historical, current and proposed working levels. Table 4 shows the drain reaches which represent the relevant areas within the Wollongong Coal Russell Vale Mine.

The predicted modelled groundwater inflows to the proposed Russell Vale East and the old Bulli Seam workings at Russell Vale East and West workings for each stage of mining are shown in **Table 5** and **Figure 47.**

Table 4 Drain Cell Reaches

Coal Seam	Area - Development	Drain Reaches
Bulli	Wongawilli East	1107
	Wongawilli West	1117
Balgownie	Wongawilli East	1330
Wongawilli	Mains / Main Gate / Tail Gate	1501 1502 1503 1504 1505 1506 1507 1508 1509 1510 1511 1512 1513 1514 1515
	Longwall Panels	1529 1531 1534 1535 1536 1537 1538 1539 1540 1541 1546 1550 1551 1553 1554 1555 1556 1558 1559 1561 1562 1563 1564 1565

The proposed extraction at Russell Vale East will start with Longwall 6, progress to Longwall 11 and then re-locate and extract Longwalls 1 to 3, which are higher up in the catchment and also up dip of initial extraction in the Wongawilli Seam.

A background groundwater inflow of approximately 0.5ML/day is currently measured from the dormant Bulli Seam workings including that from the western side of Cataract Reservoir. These inflow rates are variable in the recorded flow data however the average rate for the period from 1/1/2013 – 31/12/2014 is 0.5ML/day (182.5ML/year). These rates decrease in eastern areas as groundwater makes its way vertically into Wongawilli Seam workings as mining progresses.

However, it should be noted that approximately 0.5ML/day is pumped out at Russell Vale portal from the Bulli seam workings from the Russell Vale East and West areas. It is assumed that this includes 0.2ML/day (73ML/year) of inflow that is thought to be generated in the up-gradient Cordeaux Colliery lease area as this area is partially flooded and there is a potential head gradient across the barrier with the western Bulli Seam workings in the order of 40m.

In addition, 0.2ML/day (73ML/year) of groundwater seepage inflow from Russell Vale East is also thought to be generated from the up-gradient Bulli Colliery.

Table 5 Predicted Groundwater Mine Inflows

Stage	Bulli Seam Inflow (ML/day) and (ML/year)	Predicted Russell Vale Wongawili Seam Inflow (ML/day) and (ML/year)	Total Mine Inflow (ML/day) and (ML/year)
Pre Longwall 4	0.52 / 190	0.16 / 58	0.68 / 248
Post Longwall 5	0.47 / 172	1.02 / 365	1.45 / 529
Post Longwalls 6 and 7	0.47 / 172	2.6 / 949	3.09 / 1004
Post Longwalls 9 to 11	0.47 / 172	2.5 / 913	3.01 / 1128
Post Longwalls 1 to 3	0.46 / 168	1.9 / 694	2.39 / 872

Figure 47 Predicted Total Groundwater Seepage Inflows

3. SENSITIVITY

3.1 Fracture Zone Horizontal Conductivity

It had been noted that the horizontal permeability factors are likely to be low, and a uniform scaling with a factor of 2 was applied to enhanced horizontal conductivities within the fracture zone in the GeoTerra / GES (2015) model version. However, the PAC outlined that the groundwater model was potentially not sensitive to variability of hydraulic conductivity in the horizontal direction within the fracture zone during the calibration period.

Accordingly, the model was re-run with enhanced horizontal conductivity in the fracture zone using the TMP function. Wherever vertical conductivities where enhanced, horizontal conductivities were also increase by a factor of 100.

The resulting increase in groundwater inflows reporting to drains within the Russell Vale area shown in **Figure 48** indicates that the increase in fracture zone horizontal conductivities results in an increase of mine inflows of approximately 2%.

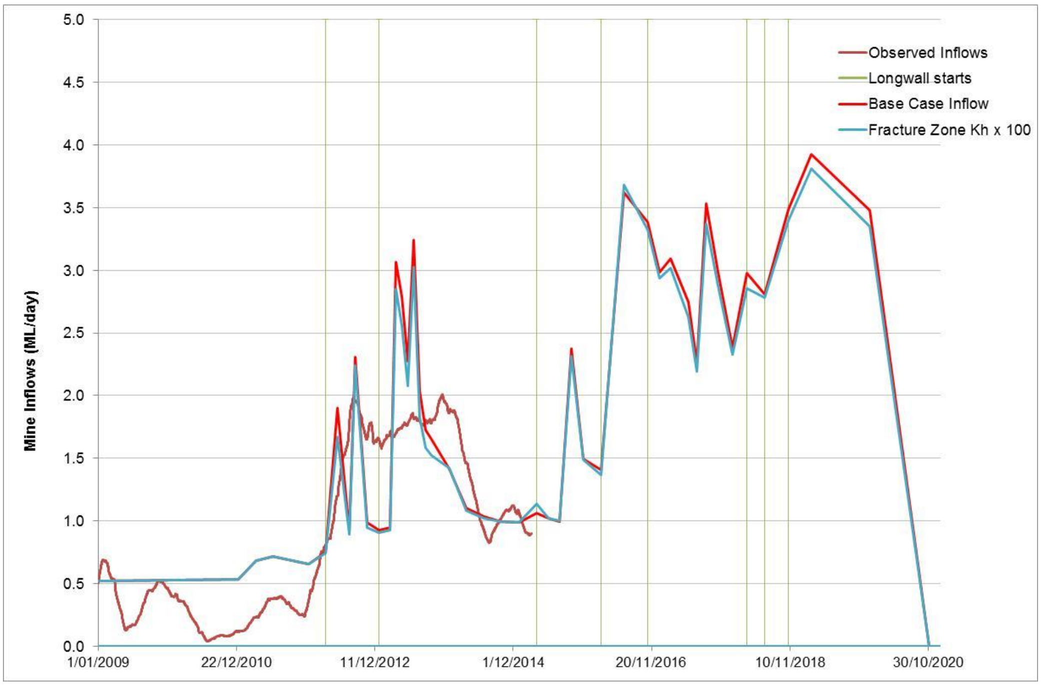


Figure 48 Mine Inflow Sensitivity to Increase Fracture Zone Horizontal Conductivity

3.2 Evaporation Rates

It was also noted in the PAC review that the evaporation rates used in the GeoTerra / GES (2015) model were full reported evaporation rates and may be too high, with the implication that this could affect stream base flow estimates and losses.

It is noted that as groundwater levels are generally below the extinction zone within Layer 1, the baseflow calculations would be relatively unaffected by the perceived high evaporation rates applied within the groundwater flow model.

Accordingly, a sensitivity run was undertaken with evaporation rates reduced to an arbitrary rate of 1m/yr as compared to the 1.825m/yr (basecase) used in GeoTerra / GES (2015).

Figure 49 indicates the results of re-appraisal using the lower evaporation rates and shows that the difference between the pre and post PAC review are negligible.

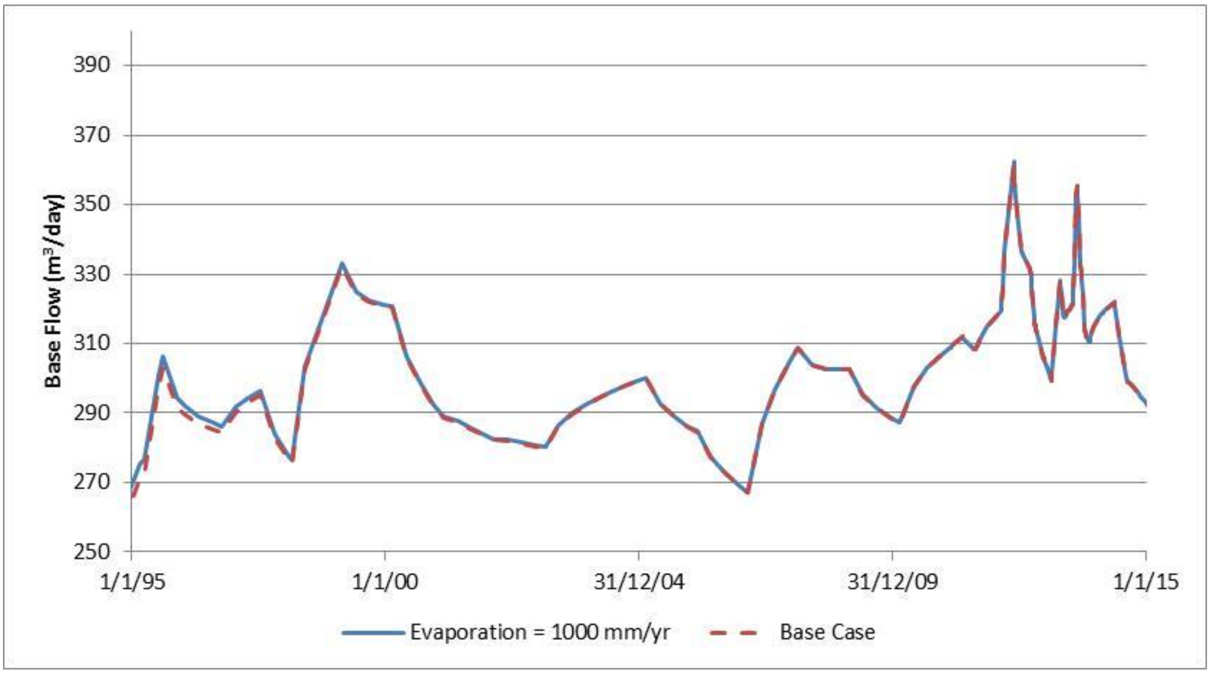


Figure 49 **Cataract Creek Baseflow Sensitivity to Variable Evaporation**