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WOLLONGONG COAL

RUSSELL VALE COLLIERY REVISED UNDERGROUND EXPANSION PROJECT

Submissions Report – Part B

FINAL

February 2020

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Submissions Report – Part B

FINAL

Prepared by
Umwelt (Australia) Pty Limited
on behalf of
Wollongong Coal Limited

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1.0 Introduction

The Revised Preferred Project Report and Response to Second PAC Review (Revised Preferred Project Report) for the Russell Vale Revised Underground Expansion Project (Umwelt, 2019a) was placed on public exhibition from 1 August to 29 August 2019. This Submissions Report has been prepared to address the key issues raised in the submissions received during the public exhibition period. The Submissions Report is divided into two separate reports. Part A was submitted to DPIE in November 2019 and addressed all key issues raised, apart from groundwater. This Submissions Report - Part B responds to groundwater issues raised by the Department of Planning, Industry and Environment – Water (DPIE-Water) and other submissions.

The Russell Vale Colliery (the Colliery) is an existing underground coal mine located in Russell Vale, north of Wollongong in NSW (refer to Figure 1.1) that is owned and operated by WCL. The Colliery has been on 'care and maintenance' since 2015 and the current Project Approval applying to mining operations at the Colliery requires that no mining occur after 31 December 2015. WCL is seeking Project Approval under the *Environmental Planning and Assessment Act 1979* (EP&A Act) to expand the mining operations at the Colliery. This ongoing application is referred to as the Underground Expansion Project (UEP).

During public exhibition, 213 submissions were made on the Revised Preferred Project. This included 11 government agency submissions and 202 community and interest group submissions. The 202 submissions received from the community and interest groups included 131 submissions objecting to the Revised Preferred Project, 70 submissions in support, and one submission providing a comment on the Revised Preferred Project.

This Submissions Report - Part B includes:

- a summary of actions relating to groundwater that have been undertaken since exhibition. These include expert peer review of the groundwater assessment, conduct of detailed uncertainty analysis in relation to modelling predictions, and expert peer review of the uncertainty analysis (**Section 2.0**)
- a detailed response to matters raised by DPIE-Water relating to groundwater (**Section 3.0**)
- the additional management and mitigation measures proposed by WCL as an outcome of this Part B report (**Section 5.0**)
- an updated evaluation of the merits of the Revised Preferred Project (**Section 6.0**).

An overview of the Revised Preferred Project is provided in the Submissions Report - Part A (Umwelt 2019b), with the project described in detail in the Revised Preferred Project Report (Umwelt 2019a).

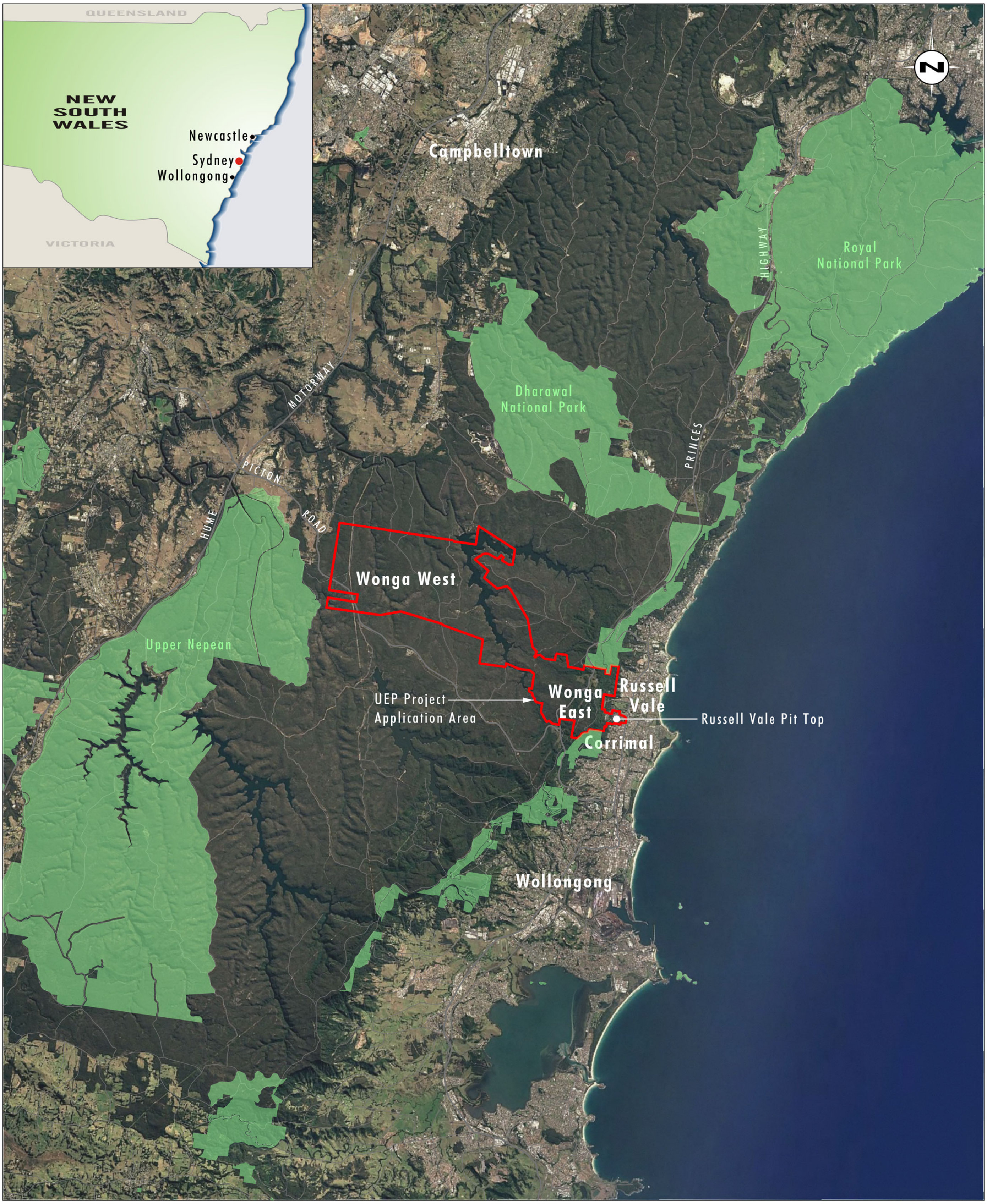

Image Source: Google Maps (2016)
Data Source:OEH (2016)

0 3.0 7.5 15.0km
1:300 000

Legend
UEP Project Application Area

FIGURE 1.1

Locality Plan

2.0 Actions Undertaken Since Exhibition

As outlined in Submissions Report – Part A (Umwelt 2019b), since the exhibition of the Revised Preferred Project, a number of actions have been taken based on the submissions received. These include:

- project changes to address issues raised in submissions
- further assessment of project changes and key aspects raised in submissions
- peer review of the Subsidence Assessment
- further agency consultation
- consideration of the Independent Expert Panel for Mining in the Catchment's (IEPMC) second report on the impact of mining activities in the Greater Sydney Water Catchment Special Areas that was released following exhibition.

In addition, further works have been undertaken in relation to the assessment of groundwater impacts of the Revised Preferred Project. The additional works undertaken have included:

- expert peer review of the Groundwater Assessment (refer to **Section 2.2**)
- detailed uncertainty analysis of the modelling predictions (refer to **Section 2.3**)
- expert peer review of the uncertainty analysis (refer to **Section 2.4**)
- update to the Groundwater Assessment Report to take account of the abovementioned further expert review and analysis, in addition to restructure and additional clarification in response to the DPIE - Water and other submissions (refer to **Section 2.1**)

2.1 Revised Groundwater Assessment Report

As a result of the submissions received and peer review processes undertaken, several revisions were made to the Groundwater Assessment Report to provide further clarity around model set-up and additional context regarding the history of mining at Russell Vale and the various studies undertaken as part of the Underground Expansion Project. The Revised Assessment Report prepared by Geoterra is included as **Appendix 1**. The revisions included:

- aligning the structure of the report to the general structure recommended (but not required) by the Australian Groundwater Modelling Guidelines, as requested by DPIE-Water
- provision of additional context relating to previous groundwater assessment completed as part of the ongoing assessment process for the Underground Expansion Project
- revision to figures to improve clarity on model setup, performance, results and uncertainties
- amendments to address peer review comments (refer to **Section 2.2**)
- inclusion of the detailed Uncertainty Analysis (as discussed in **Section 2.3**)
- clarifications and additional information to address Agency comments.

While the Revised Assessment Report includes a number of revisions and clarifications in response to submissions and the peer review process, there has been no material change to the overall groundwater assessment outcomes for the Revised Preferred Project.

2.2 Groundwater Peer Review

In response to the DPIE-Water submission, WCL commissioned a peer review of the Revised Groundwater Assessment Report by Dr Noel Merrick. A copy of the groundwater peer review report is provided as **Appendix 2**, with a summary of the key conclusions provided in this section.

It is noted that Dr Merrick also has prepared peer reviews for previous versions of the UEP groundwater assessment involving earlier longwall mine plans in both September 2015 and June 2014.

The peer reviewer notes that the impacts of importance for the Revised Preferred Project are stipulated in the NSW Aquifer Interference Policy, and the reviewer concludes that the relevant minimal impact considerations of this policy have been addressed in full.

The peer reviewer found that the Russell Vale Groundwater Model has been developed competently and is "fit for purpose" for addressing the potential environmental impacts from the proposed underground mining operations and for estimating indicative dewatering rates.

Independent assessment of water takes undertaken by the peer reviewer indicates close agreement for the nominated porous rock water take during Project mining, but about double the take from the surface water source due to reduction of baseflow reporting to the three major relevant streams, due to all Wongawilli Seam mining. The reviewer notes however that the impact magnitudes are small. Even at the "very unlikely to be exceeded" level, the worst-case impact attributable to the Revised Preferred Project is about 3 ML/year at Cataract Creek. The worst-case predicted impact on Cataract Reservoir is less than 1 ML/year.

The peer review notes that uncertainty in modelling predictions has been assessed by a rigorous IESC-compliant Monte Carlo uncertainty analysis and separately peer reviewed. The major finding of this analysis being that there is expected to be negligible drawdown, even at the 90th percentile, of the water table in surficial layers in contact with local streams and the Cataract Reservoir (refer to **Section 2.3**).

The peer review goes on to conclude that due to the substantial depressurisation that has been caused by earlier mining at the subject mine, and at neighbouring historical mines, the additional effects of mining the Wongawilli Seam with non-caving first workings are considered minor.

2.3 Uncertainty Analysis

In response to the DPIE-Water submission, WCL commissioned HydroAlgorithmics to prepare an Uncertainty Analysis for the Revised Groundwater Assessment Report (refer to Appendix C of **Appendix 1**).

The Uncertainty Analysis addresses parameter uncertainty by stochastic modelling using the Monte Carlo method: generating numerous alternative parameterisations of the deterministic flow model (realisations), executing the model independently for each, and then aggregating the results for statistical analysis.

Uncertainty was assessed on hydraulic conductivity, recharge, evapotranspiration, specific storage and specific yield properties throughout the model. Statistics on key predictive outputs were computed from the results of the 141 accepted model runs (refer to **Appendix 1**). Percentile results were calculated from the Monte Carlo outputs strictly on a conservative 'round to higher value' basis, and are represented as 'probabilities of exceedance' in five categories: 'very likely' (90%), 'likely' (67%) 'about as likely as not' (50%), 'unlikely' (33%) and 'very unlikely' (10%).

Drawdown, additional mine inflow and streamflow impact results were all computed on the difference between the impacted and baseline scenarios. The impacted scenario simulates all mining, including the proposed new workings. The baseline scenario simulates all prior and continuing mining except the proposed new workings. **Table 2.1** presents probabilities of exceedance for mine inflows and streamflow impacts. All flow results presented are the maximum flow over time. The distribution of model calibration error is also shown for reference.

Table 2.1 Probability of exceedance of mine inflows and streamflow impacts, and the calibration error distribution

	Very likely (90%)	Likely (67%)	About as likely as not (50%)	Unlikely (33%)	Very unlikely (10%)
Peak total mine inflow (ML/year)	447.3	471.6	487.2	507.7	543.8
Peak additional mine inflow due to proposed workings (ML/year)	261.9	281.3	293.7	305.7	325.6
Additional baseflow impact to Cataract River (ML/year)	0.6	0.8	1.0	1.2	1.6
Additional baseflow impact to Cataract Creek (ML/year)	1.3	1.8	2.1	2.6	3.4
Additional baseflow impact to Bellambi Creek (ML/year)	0.4	0.6	0.7	0.8	1.0
Calibration error (SRMS)	3.91%	4.37%	4.59%	4.74%	4.89%

A key finding of the uncertainty analysis is that there is expected to be negligible drawdown, even at the 90th percentile, of the water table in surficial layers in contact with local streams and Cataract Reservoir.

For reductions in baseflow to the three major local streams, the uncertainty bandwidths are wide but the impact magnitudes are small. Even at the “very unlikely to be exceeded” level, the worst-case impact is about 3 ML/year at Cataract Creek. The worst-case predicted impact on Cataract Reservoir via a transfer of water from the storage to depressurised strata below the reservoir is less than 1 ML/year.

2.3.1 Difference in Predictions from Uncertainty Analysis and GeoTerra/GES Groundwater Assessment

The Uncertainty Analysis results predict base flow impacts that are higher than those modelled by GeoTerra/ GES however the predicted impacts on baseflows remained small, with the worst-case impact about 3 ML/year at Cataract Creek and 1 to 1.6 ML/year at Bellambi Creek and Cataract River respectively (refer to Table 2.1).

In order to run the Uncertainty Analysis, some minor changes to the model settings were required which are identified in the Uncertainty Analysis and the original MODFLOW-SURFACT model was converted to an equivalent MODFLOW-USG model to allow model execution in the cloud.

As part of the Peer Review process, Dr Noel Merrick analysed three scenarios to identify the incremental impacts of existing mining in the Wongawilli seam at Russell Vale and the incremental impacts associated with the Revised Preferred Project. From these model runs the impacts on baseflows in Cataract Creek, Bellambi Creek and Cataract River for each of the existing approved and proposed mining in the Wongawilli Seam were obtained relative to a No-Wongawilli Seam mining scenario. These predictions generally align to incremental impacts relative to approved mining conditions prior to the start of the relevant water sharing plans.

Figure 2.1 graphs the predicted cumulative reduction in baseflow from Cataract Creek, Cataract River and Bellambi Creek over an approximately 200 year period following mining and is taken from data obtained from the model peer review process. The Existing scenario shown in **Figure 2.1** represents the impacts on baseflows that will occur over time if the Revised Preferred Project does not proceed. As can be seen from **Figure 2.1**, the Revised Preferred Project results in a minor increase in maximum take of approximately 2ML/year, and delays the recovery relative to existing approved conditions.

Table 2.2 shows the predicted maximum baseflow losses under the scenarios modelled. Due to the peak impacts on each stream system occurring at different times, the cumulative impact on the catchment is lower than the sum of the maximum impact to each catchment component. These predictions also represent reductions in inflows to the Cataract Reservoir.

While the predicted impacts from the HydroAlgorithmics model runs shown in **Table 2.2** are higher than identified in the Geoterra/GES Groundwater Assessment, the differences are not considered to be significant. These predicted cumulative impacts on baseflows and inflows to Cataract Reservoir represent less than 0.5% of streamflow from Cataract Creek alone and are unlikely to be measurable and these reductions are small relative to the operating storage of Cataract Reservoir of 97,190 ML.

2.4 Uncertainty Analysis Peer Review

An independent peer review of the uncertainty analysis was conducted by Dr Frans Kalf of Kalf and Associates. A copy of the Uncertainty Analysis peer review is included in **Appendix 3**.

The peer review of the Uncertainty Analysis indicated that '*the analysis presented by HydroAlgorithmics (HA) is considered to be suitable and valid*'.

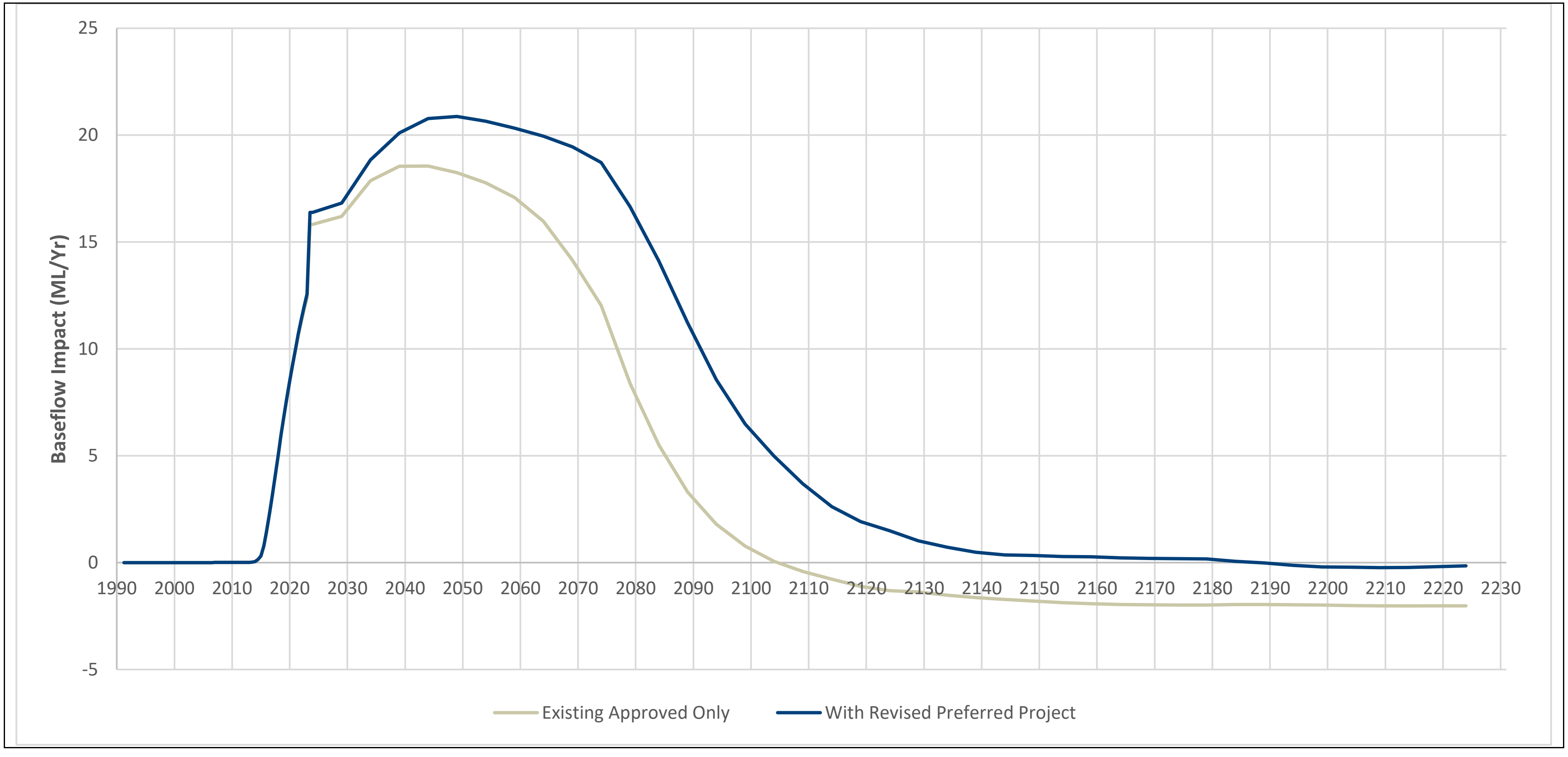

Figure 2.1 Cumulative Baseflow Impact due to Wongawilli Seam Mining at Russell Vale

Table 2.2 Maximum Baseflow Losses due to mining in Wongawilli Seam at Russell Vale

	Cataract Creek			Bellambi Creek			Cataract River			All Catchments		
	Cumulative (with Project)	Existing Wongawilli Seam Mining	Increment due to Project	Cumulative	Existing Wongawilli Seam Mining	Increment due to Project	Cumulative	Existing Wongawilli Seam Mining	Increment due to Project	Cumulative	Existing Wongawilli Seam Mining	Increment due to Project
Max Baseflow Loss (ML/day)	0.047	0.043	0.005	0.003	0.001	0.002	0.011	0.009	0.002	0.057	0.051	0.006
Max Baseflow Loss (ML/Year)	17.3	15.5	1.74	1.2	0.5	0.66	3.87	3.21	0.66	20.87	18.55	2.32

3.0 Department of Planning, Industry and Environment – Water

DPIE-Water provided a submission on the Revised Preferred Project on 3 October 2019 on behalf of both DPIE-Water and the Natural Resource Access Regulator (NRAR). This submission outlined some general concerns in relation to groundwater modelling, water licensing and groundwater monitoring.

In order to provide an appropriately detailed response to the concerns raised by DPIE-Water, WCL met with DPIE-Water on 21 October to seek further clarification of the issues raised. Following this meeting DPIE-Water provided a detailed set of comments dated 18 September 2019 expanding on the general concerns outlined in their submission dated 3 October 2019.

While DPIE-Water's comments have largely been addressed through the provision of a Revised Groundwater Assessment Report (refer to **Appendix 1**), Uncertainty Analysis (refer to Appendix C and **Appendix 1**) and peer reviews of the Revised Groundwater Assessment Report (refer to **Appendix 2**) and Uncertainty Analysis (refer to **Appendix 3**), a brief response to each of the matters raised in the initial and detailed submissions is provided in the following sections.

3.1 DPIE-Water – Initial Submission dated 3 October 2019

We advise there are a number of concerns related to the proposal:

- **The groundwater model requires further refinement to meet the requirements of the Australian Groundwater Modelling Guidelines (2012). It currently does not adequately consider cumulative effects of historic, current and planned operations by this proposal and other mines in the area.**
- **The proponent needs to demonstrate that they have or are able to obtain sufficient shares of water from relevant water sources.**
- **The groundwater monitoring information lacks the detail required to confirm the predictions derived from the modelling, as well as management measures to address unpredicted events or anomalous results.**

- ***The groundwater model requires further refinement to meet the requirements of the Australian Groundwater Modelling Guidelines (2012). It currently does not adequately consider cumulative effects of historic, current and planned operations by this proposal and other mines in the area.***

The groundwater model includes consideration of cumulative impacts from historical and approved mining as well as the proposed mine plan. The model was developed and run prior to the submission of the Dendrobium Mine Extension Project and does not include the mining proposed by this project. It is noted however that the predicted impacts from that Project are unlikely to be observable in the area potentially impacted by the Revised Mine Plan and the omission of this proposed (but not approved) mining from the cumulative impact considerations is not considered to be material.

It is also noted that considerable effort to calibrate the model based on monitoring of groundwater impacts associated with recent mining at Russell Vale Colliery was undertaken as part of the model set up.

To assist in the assessment of the Revised Preferred Project, a Revised Assessment Report (attached as **Appendix 1**) has been prepared which aligns the structure of the report to the general structure recommended (but not required) by the Australian Groundwater Modelling Guidelines. The model itself has not been updated however HydroAlgorithmics Pty Ltd has been engaged to undertake an uncertainty analysis of the groundwater model predictions and this is included as Appendix C of the Revised Assessment Report (refer to **Appendix 1**). Dr Noel Merrick has undertaken a peer review of the model and a draft of the Revised Assessment Report having regard to the comments raised by DPIE-Water and NRAR (refer to **Appendix 3**). As HydroAlgorithmics has undertaken the uncertainty analysis, this component of the modelling and report has been separately peer reviewed by Frans Kalf of Kalf and Associates Pty Ltd (refer to **Appendix 3**).

This Revised Assessment Report includes a clearer breakdown of the predicted cumulative impacts from historical and existing approved operations and predicted impacts from the proposed Revised Mine Plan.

In assessing the Revised Preferred Project, it is to be borne in mind that the primary driver of groundwater impacts associated with mining at Russell Vale Colliery is the existing approved and completed mining operations which include multi seam mining in three seams with adits accessing these workings from the eastern face of the Illawarra Escarpment. The proposed mine plan has been specifically designed to avoid subsidence induced cracking which further mitigates against significant additional groundwater impacts. No new adits will be constructed as a result of the Revised Preferred Project and the Revised Preferred Project itself will not result in any change to these adits. One of the predicted impacts from the Revised Preferred Project is the progressive flooding of the underground workings (which dip to the west) to the lowest point of the adit in the Wongawilli Seam and the eventual egress of water from the adit. This flooding and outflow will occur irrespective of whether the Revised Preferred Project occurs, with the Revised Preferred Project's primary impact being the delay to egress due to the slightly larger underground storage volume due to increased mined areas. Flow rates from the adit are predicted to be similar for both the existing approved conditions and the Revised Preferred Project and the Revised Preferred Project is unlikely to have any adverse impact on the quality of this water given the seam being mined is the same as has already been mined. The Revised Assessment Report has been updated to better clarify the context within which the Revised Preferred Project's impacts are to be considered.

- ***The proponent needs to demonstrate that they have or are able to obtain sufficient shares of water from relevant water sources.***

As discussed in Revised Preferred Project Report, Wollongong Coal hold sufficient groundwater licence allocation to cover maximum predicted licensable take associated with the Russell Vale Colliery operations.

Predicted surface water take associated with underground mining operations is modelled as being relatively small and is unlikely to be measurable in terms of changes to streamflow. It is noted that the predicted licensable take is well within Wollongong Coal's harvestable rights entitlements within the catchment.

As discussed in the Submissions Report - Part A, WCL is currently investigating trading options to acquire sufficient surface water entitlements to account for predicted levels of depressurisation from both historical mining operations and the Revised Preferred Project. In the event that sufficient entitlement cannot be acquired via trading options, WCL will consider a range of alternative mechanisms in consultation with the Natural Resources Access Regulator, including:

- Offset via apportionment from current groundwater entitlements
- Offset of surface water basic landholder right for harvestable rights from WCL Freehold land within the water sharing plan
- Direct controlled allocation by the Department/Minister of additional entitlement from the MZ under Section 65 of the *Water Management Act, 2000*
- Other mechanism to be determined in consultation with NRAR.

- ***The groundwater monitoring information lacks the detail required to confirm the predictions derived from the modelling, as well as management measures to address unpredicted events or anomalous results.***

There is a comprehensive groundwater and surface water monitoring network in place within the proposed mining area. The proposed mining methods employ well understood mining techniques with high factors of safety. The modelled groundwater impacts are consistent with what would be expected from the conceptual model having regard to the negligible (<0.01% per year) risk of pillar failure.

Existing management plans contain measure for managing unpredicted events and these management plans will be updated to cover the proposed mining.

3.2 DPIE-Water – Detailed Submission dated 19 September 2019

Responses to the issues raised in the detailed DPIE-Water Submission in relation to the Groundwater Assessment have been provided by Geoterra and are outlined below.

1 The report

a. Modelling work and results are presented as part of an environmental assessment report.

b. The report structure and content do not meet reporting requirements outlined in the Australian Groundwater Modelling Guidelines (AGMG–2012) and subsequent explanatory notes.

c. The report structure is difficult to follow and some information seems to be misplaced.

d. The report does not include a glossary and list of abbreviations, acronyms and symbols.

e. Many figures (including maps) are illegible and/or require corrections.

f. Relevant Director-General's Requirements (DGRs) and agency specific requirements are not clearly listed and shown to be addressed.

g. The report does not provide sufficient detailed, thorough, scientifically robust and holistic information as noted to be required in the last row in Table 14 of the report (p 109). Instead, it makes frequent reference to other reports that should not be expected to be readily available to readers/reviewers.

h. Additional discussion, maps, cross-sections, figures and tables are needed to understand the model set up, performance, results and uncertainties.

i. The report does not provide a complete, easy to understand picture of mining history in Russell Vale and the previous versions of the mine extension proposal.

j. The report does not provide a clear account of previous models and achieved enhancement, including improvements in the current model compared to the previous one.

a. Modelling work and results are presented as part of an environmental assessment report.

Comment is noted.

b. The report structure and content do not meet reporting requirements outlined in the Australian Groundwater Modelling Guidelines (AGMG–2012) and subsequent explanatory notes.

The AGMG-2012 do not prescribe specific reporting or formatting requirements for groundwater impact assessment reports.

The structure of the report has been amended to address other comments made by DPIE-Water and the structure of the overall report has been amended in response to these general comments about structure. The Revised Assessment Report is included as **Appendix 1**.

c. The report structure is difficult to follow and some information seems to be misplaced.

The report structure has been revised as discussed in response 1b above.

d. The report does not include a glossary and list of abbreviations, acronyms and symbols.

As part of the restructure, a glossary and list of abbreviations has been included in the report.

e. Many figures (including maps) are illegible and/or require corrections.

Figures have been reviewed and updated where necessary and better quality imagery is now included in the revised Groundwater Assessment report.

f. Relevant Director-General's Requirements (DGRs) and agency specific requirements are not clearly listed and shown to be addressed.

This report represents a response to issues raised in the Second PAC Review Report and not a report forming part of the EIS. The Report has been prepared to update assessment findings associated with the revised mine plan rather than form a stand-alone assessment of the Project that is at the EIS phase of the approval process.

g. The report does not provide sufficient detailed, thorough, scientifically robust and holistic information as noted to be required in the last row in Table 14 of the report (p 109). Instead, it makes frequent reference to other reports that should not be expected to be readily available to readers/reviewers.

This report represents a response to issues raised in the Second PAC Review Report and includes an updated assessment of changes to the mine plan in response to issues raised by the PAC. It is reasonable that the report referenced previous work provided as part of previous assessments given this is an ongoing assessment process. It is also noted that previous assessment reports prepared as part of the ongoing assessment process are publicly available on the DPIE Major Projects website.

h. Additional discussion, maps, cross-sections, figures and tables are needed to understand the model set up, performance, results and uncertainties.

See Revised Assessment Report (refer to **Appendix 1**) and uncertainty analysis undertaken by HydroAglorithmics (refer to **Appendix 1**)

i. The report does not provide a complete, easy to understand picture of mining history in Russell Vale and the previous versions of the mine extension proposal.

As noted above, the report was prepared as part of the Response to Second PAC Review Report, this context is provided in previous assessment documentation submitted as part of the initial assessment considered by DP&E (as it then was) and the PAC (as it then was).

Notwithstanding, the Revised Assessment Report includes further information on mining history to reduce the need for reference to other documentation.

j. The report does not provide a clear account of previous models and achieved enhancement, including improvements in the current model compared to the previous one.

See Revised Assessment Report (refer to **Appendix 1**). It is noted that many of the modelling uncertainties considered in the PAC reviews of earlier mine plans have been removed through the use of a long term stable mine plan design; accordingly, previous assessment comments on model set-up have only limited application to the modelling of the current mine plan.

2 Modelling good practice

a. **Based on the information reported, the model does not comply with the requirements of the AGMG–2012 and subsequent explanatory notes.**
b. **There is no assessment of the model confidence level class as described in AGMG–2012.**
c. **The model has not been independently peer reviewed as required in AGMG–2012.**
d. **There is no commitment for verification and updating of the groundwater model using new observations and knowledge that will become available through the mining process. Updating the numerical modelling is only mentioned at the end of the report (p 116) as a measure that may enhance adaptive management.**
e. **No adequate analysis is provided of relevant parametric sensitivity (importance of parameters in determining model output).**
f. **No adequate analysis is provided for model sensitivity to parametric changes (how output changes due to changing parameter values).**
g. **No adequate qualitative and quantitative uncertainty analysis is provided.**

a. Based on the information reported, the model does not comply with the requirements of the AGMG–2012 and subsequent explanatory notes.

The current model has been peer reviewed by Dr Noel Merrick and is deemed to be adequate. See also comments below.

b. There is no assessment of the model confidence level class as described in AGMG–2012.

The Revised Assessment Report identifies the groundwater model as being of Moderate Complexity with a Class 2 Confidence Level (refer to Section 8.2 of the Revised Assessment Report in **Appendix 1**). In accordance with SKM & NCGRT (2012), the proposed first workings extraction assessment is a Class 2 model.

c. The model has not been independently peer reviewed as required in AGMG–2012.

An independent peer review of the Groundwater Model and Revised Assessment Report has been undertaken by Dr Noel Merrick (refer to **Appendix 2**). A separate peer review of the Uncertainty Analysis has been undertaken by Dr. Frans Kalf of Kalf & Associates Pty Ltd and is provided as **Appendix 3**.

d. There is no commitment for verification and updating of the groundwater model using new observations and knowledge that will become available through the mining process. Updating the numerical modelling is only mentioned at the end of the report (p 116) as a measure that may enhance adaptive management.

This is not a requirement of the Groundwater Impact Assessment however recommendations regarding modelling and impact verification processes are contained in Section 17.15 of the Revised Groundwater Assessment Report. The commitments with regard to monitoring and model updates are set out in Section 5.3.8 of the Revised Preferred Project Report (Umwelt 2019a) and reiterated in **Section 4.0**.

e. **No adequate analysis is provided of relevant parametric sensitivity (importance of parameters in determining model output).**

This has been addressed by the HydroAlgorithmics Pty Ltd Uncertainty Analysis (refer to Section 11 and Appendix C of the Revised Groundwater Assessment Report).

f. **No adequate analysis is provided for model sensitivity to parametric changes (how output changes due to changing parameter values).**

This has been addressed by the HydroAlgorithmics Pty Ltd Uncertainty Analysis (refer to Section 11 and Appendix C of the Revised Groundwater Assessment Report).

g. No adequate qualitative and quantitative uncertainty analysis is provided.

It should be noted that the current modelling exercise was completed prior to release of the IESC Explanatory Guide on Uncertainty Analysis (IESC, 2019). Notwithstanding an Uncertainty Analysis has been undertaken for the model by HydroAlgorithmics Pty Ltd and is included in Appendix C of the Revised Assessment Report.

3. The conceptual model

- **a. It is not clear how the surface water and groundwater quality data and discussion in the report contribute or relate to the conceptual model.**
- **b. The geological model used as basis for layer definition and initial parameterisation is not presented.**
- **c. The schematic presentation of the conceptual model (Figure 9-1) is largely illegible and contains fundamental errors. For example, the springs shown on the right hand side in Figure 9-1 are hydrogeologically impossible.**
- **d. Russell Vale conceptual model is not compared to conceptual models in neighbouring mines.**
- **e. Perched surface water and groundwater systems, including groundwater dependent ecosystems (GDEs)**
  - **i. Are not clearly identified and mapped.**
  - **ii. Hydrogeological setting and relationships with the main groundwater flow system are unclear.**
  - **iii. Their effect on recharge and evapotranspiration to and from the main groundwater system is not clear.**
  - **iv. It is not clear how they are simulated in the numerical model.**
- **f. Surface water features are not clearly conceptualised, specifically in terms of being perched or hydraulically connected to the main groundwater system.**
- **g. Mining related subsidence**
  - **i. Not enough information (including maps) is provided to present and explain historical development and current situation.**
  - **ii. The current altered hydraulic properties are not well described in text or presented in figures to enable understanding their ranges and spatial distribution.**
  - **iii. The presented assessment is solely focused on the direct effects of the additional incremental subsidence on hydraulic properties, which the report considers to be negligible.**
- **h. The hypothesised “underground storages” are not mapped and it is unclear how they have been represented in the numerical model.**

a. **It is not clear how the surface water and groundwater quality data and discussion in the report contribute or relate to the conceptual model.**

The surface water and groundwater quality data and discussion was used as background information in developing the conceptual model, however, the conceptual model was primarily developed based on physical geological/hydrogeological parameters and features within the model domain, rather than hydro/geochemical information.

b. **The geological model used as basis for layer definition and initial parameterisation is not presented.**

Layer definition and initial parameterisation within the groundwater model was based on lithological drilling data within the Russell Vale lease area as well as from previous lithological regional strata layer definition from the BSO, Metropolitan and Tahmoor coal mines groundwater modelling in the more distal areas of the model domain.

c. **The schematic presentation of the conceptual model (Figure 9-1) is largely illegible and contains fundamental errors. For example, the springs shown on the right hand side in Figure 9-1 are hydrogeologically impossible.**

The comment regarding springs is incorrect. Springs will (and do) form in outcrops in cliff lines where the piezometric surface is above the point of outcrop.

Springs are prevalent along the escarpment and have been observed directly by the author of the Revised Groundwater Assessment Report in many places, such as at Thirroul/Stanwell Park area. Therefore, although not directly observed on the escarpment at Russell Vale, it is not unlikely that they would be present in the model domain as well.

d. **Russell Vale conceptual model is not compared to conceptual models in neighbouring mines.**

This type of comparison is not common practice for any groundwater assessment reporting.

Although there is not a definitive discussion regarding the Russell Vale model comparison to other neighbouring mine's conceptual models, they were used in the initial stages of the Russell Vale model conceptualisation, with the Russell Vale conceptual model then being tailored to the relevant specific features applicable to Russell Vale.

e. **Perched surface water and groundwater systems, including groundwater dependent ecosystems (GDEs)**

   i. **are not clearly identified and mapped.**

   Perched surface water and groundwater systems and GDE's are clearly identified and mapped in the surface water and biodiversity specialist assessment reports contained within the Revised Preferred Project Report (Umwelt 2019). The level of detail in those reports was not copied over to the groundwater report as the groundwater assessment/modelling focussed on a larger vertical and horizontal regional scale than the surface water/biodiversity reports.

ii. Hydrogeological setting and relationships with the main groundwater flow system are unclear.

Section 5.8 of the Revised Groundwater Assessment Report provides sufficient discussion for the groundwater assessment purposes of swamps and GDE's settings and relationships, whilst Sections 5.1 and 5.7 of the Revised Groundwater Assessment Report discuss surface water streams. Further details on these systems can be obtained from the associated specialist reports.

iii. Their effect on recharge and evapotranspiration to and from the main groundwater system is not clear.

The effect of perched surface water, groundwater and GDE systems on recharge and evapotranspiration was incorporated into the model set up as discussed in Section 8.5.3 of the Revised Groundwater Assessment Report.

iv. It is not clear how they are simulated in the numerical model.

The surface water, groundwater and GDE systems simulation in the model is outlined in Sections 8.5.3, 8.10, 9.1, 9.2, 9.3.1, 9.3.2 and Section 9.4 of the Revised Groundwater Assessment Report.

f. Surface water features are not clearly conceptualised, specifically in terms of being perched or hydraulically connected to the main groundwater system.

Surface water features (where perched or hydraulically connected to the main groundwater system) are conceptualised and have been incorporated into the model as discussed in Sections 9.1, 9.2, 9.3, 9.4 and Section 9.5 of the Revised Groundwater Assessment Report.

g. Mining related subsidence

i. Not enough information (including maps) is provided to present and explain historical development and current situation.

Sufficient information, maps and discussion are provided to present and explain the historical development and current situation of mining in the model domain, and specifically for within the Russell Vale lease area, in Section 3 and Section 4, and in Figures 1-1, 3-, 4-1, 5-1 and Figure 7-3 of the Revised Groundwater Assessment Report.

ii. The current altered hydraulic properties are not well described in text or presented in figures to enable understanding their ranges and spatial distribution.

Discussion of the mining impacted/altered hydraulic properties used in the model is provided in Sections 8.6.1, 8.8, 9.6, as well as being shown in detail in Table 8.8 of the Revised Groundwater Assessment Report.

iii. The presented assessment is solely focused on the direct effects of the additional incremental subsidence on hydraulic properties, which the report considers to be negligible.

The assessment includes identification of both cumulative and incremental impacts. It is appropriate that the assessment focusses on incremental impacts given previous mining is approved and largely completed.

h. The hypothesised “underground storages” are not mapped and it is unclear how they have been represented in the numerical model.

The underground storages referred to are not hypothesised. These are mined void areas in which groundwater inflows or flows down dip through the workings are impounded by retained coal barriers. These storages are unconfined and, when filled to the low point in the barrier will spill and flow to lower parts of the workings. The location of these flooded workings have been mapped and located wherever access has been possible within the mine workings. In inaccessible areas, they have been located based on the relative floor elevations and knowledge of surveyed drainage features and elevations within the Russell Vale mine.

The underground storages are represented in the model by using a starting head with a beach line, as well as increased porosity (2 orders of magnitude), specific yield (1 order of magnitude) and variably increased permeability. In addition, the pondage in the Corrimal and Russell Vale Bulli Seam workings was set as being constantly drained.

4 The numerical model

- **a. Some of the used/referenced data are relatively old, e.g. GEOTERRA/GES (2015) GEOTERRA/GES (2014) referenced in the discussion of groundwater system subsidence effects.**
- **b. No adequate reasoning is provided for the need to replace the previous model finite element code (FEMWATER) by a finite difference code (MODFLOW SURFACT), other than the request from the Planning Assessment Commission (PAC). Also, no other options have been considered, e.g. MODFLOW USG.**
- **c. MODFLOW SURFACT capabilities are not utilised in the model to simulate what the report presents as important hydrological characteristics of the groundwater flow system, specifically, multiple water tables to represent perched surface water and groundwater systems.**
- **d. Not enough detail is provided to enable understanding of the model set up and performance, e.g. the grid and boundary conditions are not presented in map format. Good reporting should enable fairly reasonable reproduction of the model using the reported information.**
- **e. Groundwater confinement conditions and changes in time are not presented clearly.**
- **f. Adopted boundary conditions**
  - **i. Are not clearly presented and not specified for each model layer.**
  - **ii. The basis for their selection is not justified.**
  - **iii. Alternative options have not been considered, e.g. there are different ways to represent certain surface water features.**
  - **iv. There are basic errors in boundary conditions description (e.g. in the drain cells description).**
- **g. Particle tracking modelling is required to determine areas of influence associated with surface water features. This will enable better informed assessment of licencing requirements.**
- **h. Temporal discretisation (stress periods and time steps) is not clearly presented.**
- **i. The basis for selecting and alternating hydraulic properties is not clear.**

a. **Some of the used/referenced data are relatively old, e.g. GEOTERRA/GES (2015) GEOTERRA/GES (2014) referenced in the discussion of groundwater system subsidence effects**

Although the references are claimed to be old, the data and assessments obtained in the previous assessments is still relevant and useful.

b. **No adequate reasoning is provided for the need to replace the previous model finite element code (FEMWATER) by a finite difference code (MODFLOW SURFACT), other than the request from the Planning Assessment Commission (PAC). Also, no other options have been considered, e.g. MODFLOW USG.**

No presentation of reasoning is required as the model was set up using current best practice at the time the model was developed based on industry practices and regulatory expectations.

At the time of MODFLOW SURFACT model development, MODFLOW-USG was not available.

It is noted that MODFLOW-USG has been used for the uncertainty analysis undertaken by HydroAlgorithmics.

c. **MODFLOW SURFACT capabilities are not utilised in the model to simulate what the report presents as important hydrological characteristics of the groundwater flow system, specifically, multiple water tables to represent perched surface water and groundwater systems.**

The MODFLOW SURFACT capabilities were utilised in the model, with multiple water tables being represented in the model by assigning suitable heads in each of the 17 model layers.

Shallow perched water tables and swamps were not able to be represented in the model as the Layer 1 thickness is approximately 20 m, and most of the ephemeral / highly variable saturation perched water tables would occur as thin (<0.5 – 1m thick) sub- sections within the upper / surficial section and in a limited and variable lateral extent within Layer 1.

d. **Not enough detail is provided to enable understanding of the model set up and performance, e.g. the grid and boundary conditions are not presented in map format. Good reporting should enable fairly reasonable reproduction of the model using the reported information.**

Clarification of detail regarding the model set up and performance is provided within Sections 8 to 12 of the Revised Groundwater Assessment Report.

e. **Groundwater confinement conditions and changes in time are not presented clearly.**

The current model has been peer reviewed by Dr Noel Merrick and is deemed to be adequate.

   i. **Adopted boundary conditions are not clearly presented and not specified for each model layer.**

   The current model has been peer reviewed by Dr Noel Merrick and is deemed to be adequate.

   ii. **the basis for their selection is not justified.**

   The current model has been peer reviewed by Dr Noel Merrick and is deemed to be adequate.

iii. Alternative options have not been considered, e.g. there are different ways to represent certain surface water features.

The current model has been peer reviewed by Dr Noel Merrick and is deemed to be adequate.

iv. There are basic errors in boundary conditions description (e.g. in the drain cells description).

The current model has been peer reviewed by Dr Noel Merrick and is deemed to be adequate.

f. Particle tracking modelling is required to determine areas of influence associated with surface water features. This will enable better informed assessment of licencing requirements.

Sufficient modelling of the potential impacts of the proposed workings and licencing have been conducted according to the modelling and reporting peer review, as well as the Uncertainty Analysis conducted by HydroAlgorithmics Pty Ltd.

Conceptually, the Revised Preferred Project is unlikely to result in any significant increase in impacts to surface water features and the predicted impacts are considered to be realistic.

g. Temporal discretisation (stress periods and time steps) is not clearly presented.

Stress periods and time steps are presented in Section 8.5.5, Figure 8.3 and Table 7 of the Revised Groundwater Assessment Report.

h. The basis for selecting and alternating hydraulic properties is not clear.

The selection and modification of hydraulic properties was based on initial on-site packer testing results, parameters used in previous similar models in the Southern Coalfields, as well as understanding/ modification of the height of fracturing predictions (Tammetta, 2012 and Ditton & Merrick, 2014). For fractured zones, the strata hydraulic parameters were changed using the Time-Varying Material Properties (TMP) package of MODFLOW-SURFACT, which allows varying property values to be applied over time.

Fracturing was instigated by altering host rock calibrated hydraulic properties in accordance with mine progression.

Horizontal shear zone formation predictions (SCT Operations, 2014) were incorporated into the model where sufficient data was available, followed by calibration with observed groundwater levels and mine inflows.

5 Model parametrisation and calibration

- **a. The level of model parametrisation is not clear. It is not known whether the model uses only limited property zones or if it is highly parametrised with parameters assigned to individual cells automatically (e.g. using functions) or manually.**
- **b. Insufficient information is provided, e.g. Section 8.1 does not provide any detail about hydraulic properties despite its header being "Basement Hydraulic Properties".**
- **c. No comparison is provided of hydraulic parameters adopted for Russell Vale and neighbouring mines and no comment is provided on how the new Russell Vale model parameters compare to previous versions.**
- **d. No evidence is presented regarding the use of mine void inflows and surface water flow data in model calibration.**
- **e. Steady-state parameters, water budget, calibration results and statistics are not presented.**
- **f. Better correlation between observed data and model estimates are required to provide higher confidence in model performance and, subsequently, predictions.**
- **g. Model performance is assessed using only the scaled root mean square (SRMS) measure. The AGMG-2012 lists this as one measure of model performance but clarifies that it is not the only measure and that associated limitations should be understood.**
- **h. The model has not been automatically calibrated. As a result, relevant parametric sensitivity analysis has not been completed.**
- **i. Heterogeneity in hydraulic properties has not been addressed thoroughly, for example, pilot point calibration.**
- **j. The bases are not clear for estimating recharge and direct evapotranspiration from the regional water table. The effects of the hypothesised "perched" surface water and groundwater system on these parameters are not considered.**
- **k. Effect of subsidence**
    - **i. The argument that "the proposed first workings are not predicted to result in any subsidence related impacts in this regard" should not be considered as grounds for disregarding the effects of historic and future mining related subsidence on the hydraulic properties of the sediment and rock in the area.**
    - **ii. The assessment/study approach is not clearly presented and its adequacy cannot be judged.**
    - **iii. When dealing the height of fracturing and height of groundwater depressurisation, the model should consider historic and future effects of subsidence because this is what will determine the hydraulic properties in the future. Separating historic subsidence effects from future effects is not realistic.**
- **l. Various model input and output elements have not been verified, i.e. have not been checked against other methods of estimation including analytical solutions.**

a. The level of model parametrisation is not clear. It is not known whether the model uses only limited property zones or if it is highly parametrised with parameters assigned to individual cells automatically (e.g. using functions) or manually.

Parameterisation was used in the model by starting with a ramping function and then manually calibrating the observed heads with modelled heads.

b. **Insufficient information is provided, e.g. Section 8.1 does not provide any detail about hydraulic properties despite its header being "Basement Hydraulic Properties".**

Section 7.1 of the Revised Groundwater Assessment Report (Section 8.1 of the original report) indicates that the full details of the hydraulic parameters developed from field testing was previously outlined in GeoTerra/GES (2015), and as those in situ hydraulic parameters have not changed, and no additional field data was available at the time of the current model development, then there was no need to reproduce the data. If required, the previous GeoTerra/GES (2015) report can provide this data.

c. **No comparison is provided of hydraulic parameters adopted for Russell Vale and neighbouring mines and no comment is provided on how the new Russell Vale model parameters compare to previous versions.**

The Uncertainty Analysis conducted by HydroAlgorithmics Pty Ltd (refer to Appendix C of the Revised Groundwater Assessment Report) does compare hydraulic parameters used in Russell Vale and neighbouring mines and it was established in the analysis that the parameters used in the current model compare favourably with models conducted for neighbouring mines.

d. **No evidence is presented regarding the use of mine void inflows and surface water flow data in model calibration.**

Measured/extrapolated mine inflow data was used to calibrate the model as outlined in Section 8.7.1 of the Revised Groundwater Assessment Report (refer to **Appendix 1**).

Surface water flow data from surface water assessments was used as a starting point, with subsequent manual adjustment applied to match stream heads from the following reports:

- WRM Water & Environment, 2014. Russell Vale Colliery Russell Vale East Underground Expansion Project Surface Water Modelling
- WRM Water & Environment, 2015A. Russell Vale Colliery Underground Expansion Project Surface Water and Salt Balance Modelling.

It should be noted that there is a large variable degree of stream bed/shallow groundwater saturation/ unsaturation along with highly variable stream head heights in response to rainfall within the catchments from the stream's headwaters to their discharge point into Cataract Reservoir.

e. **Steady-state parameters, water budget, calibration results and statistics are not presented.**

These items are presented in Sections 8.7.2, 8.10, 8.7 and 8.7.3 of the Revised Groundwater Assessment Report (refer to **Appendix 1**).

f. **Better correlation between observed data and model estimates are required to provide higher confidence in model performance and, subsequently, predictions.**

Sufficient correlation between observed data and model estimates have been obtained according to the modelling and reporting peer review conducted by Dr Noel Merrick.

g. **Model performance is assessed using only the scaled root mean square (SRMS) measure. The AGMG-2012 lists this as one measure of model performance but clarifies that it is not the only measure and that associated limitations should be understood.**

Model performance is adequate and appropriate according to the modelling and reporting peer review conducted by Dr Noel Merrick.

h. The model has not been automatically calibrated. As a result, relevant parametric sensitivity analysis has not been completed.

This has been addressed by the HydroAlgorithmics Pty Ltd Uncertainty Analysis (refer to Section 11 and Appendix C of the Revised Assessment Report).

i. Heterogeneity in hydraulic properties has not been addressed thoroughly, for example, pilot point calibration.

Pilot point calibration was not used as there was insufficient data available for this exercise.

j. The bases are not clear for estimating recharge and direct evapotranspiration from the regional water table. The effects of the hypothesised "perched" surface water and groundwater system on these parameters are not considered.

Recharge and evapotranspiration from the regional water table was utilised in the model from BOM SILO data.

Shallow perched water tables and swamps were not able to be represented in the model as the Layer 1 thickness is approximately 20m, and most of the ephemeral / highly variable saturation perched water tables would occur as thin (<0.5 – 1m thick) sub- sections within the upper/surficial section and in a limited and variable lateral extent within Layer 1. Therefore, recharge and evapotranspiration was holistically applied for Layer 1 within the model.

k. Effect of subsidence

i. The argument that "the proposed first workings are not predicted to result in any subsidence related impacts in this regard" should not be considered as grounds for disregarding the effects of historic and future mining related subsidence on the hydraulic properties of the sediment and rock in the area.

The impacts from historic mining are addressed in Sections 3, 6, 8.3, 8.6, 8.9 and 8.10 of the Revised Groundwater Assessment Report (refer to **Appendix 1**).

ii. The assessment/study approach is not clearly presented and its adequacy cannot be judged.

The modelling and reporting has been peer reviewed by Dr Noel Merrick and was assessed to be adequate and appropriate.

iii. When dealing the height of fracturing and height of groundwater depressurisation, the model should consider historic and future effects of subsidence because this is what will determine the hydraulic properties in the future. Separating historic subsidence effects from future effects is not realistic.

Both historic and future height of fracturing and associated height of depressurisation has been appropriately assessed and incorporated into the model as outlined in Section 8.8 of the Revised Groundwater Assessment Report (refer to **Appendix 1**).

l. Various model input and output elements have not been verified, i.e. have not been checked against other methods of estimation including analytical solutions.

Use of the 3 dimensional, steady state and transient assessment of the potential impacts from the proposed workings has been suitably studied via MODFLOW SURFACT and there is no benefit or requirement to also study the impacts via analytical methods.

6 Model prediction sensitivity and uncertainty

a. **The sensitivity of the model simulation of the past and predictions to changes in parameter values is not analysed and presented.**

b. **The model simulation of the responses of the groundwater system to historic stresses is unsatisfactory as shown in the presented calibration plots. Hence, the model predictions are largely uncertain and the degree of uncertainty is unknown.**

c. **The report makes frequent reference to modelling uncertainty but the discussion in Section 12 is unsatisfactory. It does not provide useful information on the model and prediction uncertainties, descriptive and unquantifiable. The AGMG-2012 and subsequent explanatory notes provide clear guidance on how to analyse uncertainty and report on it.**

d. **No attempt is made to quantify uncertainty.**

e. **Reporting of the modelling findings and estimates is not presented within a clear context of uncertainty to enable informed decision making.**

f. **No conceptual or numerical model based explanation is provided to the predicted over-recovery of groundwater head after the end of the proposed mining.**

These issues are addressed in the Uncertainty Analysis undertaken by HydroAlgorithmics Pty Ltd (refer to **Appendix 1**).

7 Cumulative and individualistic effects

a. **The uncertainty framework for effect predictions must be identified and quantified.**

b. **Differentiation of individualistic and cumulative effects is not made on a clear transparent basis.**

c. **The report's use of the term "cumulative effects" is confusing. It considers cumulative effects to be:**

   i. **Temporal, i.e. effects of historic Russell Vale mining and additional effects from the proposed expansion. The Department does not consider this cumulative effects as all these effects relate to the same proponent and general mining venture.**

   ii. **Cumulative, i.e. combined effects of Russell Vale and neighbouring mines. It is not clear whether the report accounts for historic and future mining, historic mining alone or future mining alone.**

d. **The assessment defines the individualistic effects of the proposed expansion as the total effects predicted by the model from the start of the proposed project less the effects of indefinite continuation of historical groundwater extraction. This is unrealistic and unacceptable because the proposed project will prevent recovery of system to pre-mining conditions. The individualistic effects of the proposed expansion must be calculated as the total effects less the expected recovery following the end of historic mining (i.e. end of mining LW6).**

e. **To clarify the potential for interference of effects of various mining operations, i.e. cumulative effects, the extent of the area of influence for the Russell Vale mine and neighbouring mines must be spatially delineated on mutually acceptable basis. This analysis must be based on field observations and numerical modelling results.**

The Revised Assessment Report includes consideration of historical mining. The Uncertainty Analysis also includes consideration of the incremental impacts associated with the Revised Preferred Project and cumulative impacts. Refer also to the discussion in **Section 2.3.1** above.

It should also be noted that the existing mining adits into the Wongawilli Seam, Balgownie Seam and Bulli Seam prevent recovery of groundwater levels to pre-mining conditions. The Revised Preferred Project does not alter the ultimate level of recovery but will delay the recovery to this level due to the increased mining void volume and increased duration of pumping. This delay in recovery is shown in Figure 2.1**.**

Conceptually, the Revised Preferred Project will have only localised impacts on the groundwater system. Impacts to aquifers outside of the target seam itself will effectively only be impacted in terms of a delay in recovery. The slightly increased maximum in cumulative baseflow reductions (approximately 2ML/year based on HydroAlgorithmics modelling outputs – refer to Table 2.2) is associated with the interactions with the multi-seam mining but, again, is primarily associated with the temporal effects of extended duration of mining. This increased impact on baseflows is not considered to be significant in terms of either incremental or cumulative impacts.

8 Licencing requirements

- **a. Estimates of groundwater and surface water licencing requirements are based on water budget calculations from the reported model, without considering uncertainty in model predictions.**
- **b. The water balance information and discussion in the report are insufficient. More detail is required, including water balance for specific hydrogeological elements to help with licencing requirements estimates.**
- **c. The argument that "water make sourced from abandoned workings does not constitute the taking of water from the water source" is invalid. All water pumped from the mine workings are considered part of the mine water make.**

a. Estimates of groundwater and surface water licencing requirements are based on water budget calculations from the reported model, without considering uncertainty in model predictions.

The Revised Assessment Report (refer to **Appendix 1**) includes an updated assessment of water licensing requirements including consideration of the outcomes presented in the uncertainty analysis.

The results of the uncertainty analysis are reported in Table 2.1**.** Table 2.2 and **Figure 2.1** contains the predicted maximum baseflow take (based on the Uncertainty Analysis modelling results) relative to the start of the relevant Water Sharing Plan.

b. The water balance information and discussion in the report are insufficient. More detail is required, including water balance for specific hydrogeological elements to help with licencing requirements estimates.

Refer to **Section 2.3.1** and Section 13 of Revised Groundwater Assessment Report (refer to **Appendix 1**).

c. The argument that "water make sourced from abandoned workings does not constitute the taking of water from the water source" is invalid. All water pumped from the mine workings are considered part of the mine water make.

This take should be accounted for as part of the take calculations from the abandoned operations. It is noted that the interactions between the Russell Vale Colliery Workings and other abandoned workings predate the start of the Water Sharing Plans regulating this resource and should have been accounted for in the available take calculations in setting the Water Sharing Plan extraction limits.

The Revised Preferred Project does not increase the magnitude of these interactions.

9 Further work

a. **The report does not include a clear plan or commitment to verify and update the model.**

b. **The report does not commit to using the model as a tool to check the adequacy of the monitoring network and guide its updates.**

a. The report does not include a clear plan or commitment to verify and update the model.

The Statement of Commitments provided in Table 6.1 of the Revised Preferred Project Report and Response to the Second PAC Review (Umwelt 2019) clearly states that monitoring data would be used to update the Groundwater Model as required.

Section 17 of the Revised Assessment Report (refer to **Appendix 1**) includes a range of proposed monitoring measures. Consistent with current NSW regulatory practice, the detail regarding the means in which the model and monitoring will be used to assess impacts will be contained in the updated Water Management Plan for the Russell Vale Colliery.

The Updated Statement of Commitments presented in Section 6.0 of the Submissions Report – Part A (Umwelt 2019b), included a commitment to the updating of the Russell Vale East Water Management Plan which includes the mechanisms for updating groundwater modelling. As identified in **Section 4.0**, this commitment is clarified to make it clear that the report update includes consideration of the role of updating this groundwater model. DPIE-Water and WaterNSW will be consulted as part of the Water Management Plan update process.

b. The report does not commit to using the model as a tool to check the adequacy of the monitoring network and guide its updates.

Section 17 of the Revised Assessment Report (refer to **Appendix 1**) includes a range of proposed monitoring measures. Consistent with current NSW regulatory practice, the detail regarding the means in which the model and monitoring will be used to assess impacts will be contained in the updated Water Management Plan for the Russell Vale Colliery. Refer also to the comments above regarding the clarified Statement of Commitments in **Section 4.0.**

4.0 Updated Statement of Commitments

An updated Statement of Commitments was provided in Section 6.0 of the Submissions Report – Part A (Umwelt 2019b). The following additional clarifications are provided in relation to the groundwater commitments presented in Part A. The proposed revisions are underlined for clarity.

Groundwater	
The existing Russell Vale East Water Management Plan will be reviewed and updated in consultation with DPIE-Water, WaterNSW and DPIE-Planning and the updated plan will be implemented for the Revised Preferred Project. The updated plan will include the proposed approach to the updating of the groundwater model for use in the verification of monitoring.	Within 3 months of approval and ongoing
The existing groundwater monitoring network will continue to be utilised to monitor impacts associated with the Revised Preferred Project. The existing groundwater monitoring program will be reviewed and updated to reflect the Revised Preferred Project as part of an update to the existing Russell Vale East Water Management Plan. The groundwater monitoring program will include monitoring of groundwater levels, water quality, mine water inflows, pumping volumes and stream flows. The ongoing collection and interpretation of the data will be used to update the TARP trigger levels and the groundwater model as required.	Within 3 months of approval and ongoing
Existing monitoring and management measures associated with the mining of longwalls 4 to 6, as set out in the existing Russell Vale East Water Management Plan and LW5 Water Management Plan will remain in place.	Ongoing, with regular review of the results, effectiveness and ongoing need for monitoring as set out in the Water Management Plan
WCL will obtain WALs, or alternative mechanisms agreed in consultation with the Natural Resources Access Regulator, for all groundwater or surface water take in the course of mining.	Ongoing

5.0 Updated Evaluation of Project Merits

Following consideration of the submissions received on the Revised Preferred Project, additional impact assessment and further refinement of the Revised Preferred Project design has been undertaken in order to address issues raised in submissions. Two detailed Submission Reports have been prepared (Part A dated November 2019 and this report, Part B) to address the issues raised in agency and community submissions. These reports provide an analysis of the issues raised, outline the extent of additional assessment work completed since exhibition, provide clarifications and, where relevant, explain the findings of the technical studies that have been completed as part of the Revised Preferred Project Report in order to address all of the issues raised.

This process has sought to provide greater certainty in relation to assessment findings and, in some cases, further mitigate the impacts of the Revised Preferred Project through amendments to project design, in particular in relation to noise impacts on the local community. It is considered that at the conclusion of this process, the overall merits of the Revised Preferred Project remain consistent with those discussed in the Revised Preferred Project Report (Umwelt 2019a). Some minor improvements to the potential noise impacts experienced by the local community from the Pit Top Facilities will result from changes to the noise bund arrangements outlined in the Submissions Report – Part A.

As discussed in the Revised Preferred Project Report (Umwelt 2019a), the Revised Preferred Project represents the culmination of an exhaustive process of reviewing project alternatives to address issues raised in agency and public submissions and by the PAC Second Review Report. This included consideration of options to:

- Undertake further investigation and assessment work on the UEP Preferred Project mine plan design to reduce uncertainty in impact predictions and address issues raised by the PAC.
- Amend the UEP Preferred Project mine plan by redesigning second workings to address impact issues raised by the PAC. This would be supported by additional research and assessment of subsidence impacts to remove uncertainty in subsidence impact predictions. This scenario was likely to result in reduced resource recovery.
- Amend the UEP Preferred Project mine plan to be first workings only with workings designed to be long term stable. This scenario was likely to result in significantly reduced production rates and resource recovery.
- Withdraw the UEP application and close Russell Vale Colliery. The option was not considered a feasible alternative due to the significant investment in the UEP from WCL to date and the extent of valuable coal resources remaining in the colliery holding.

It is noted that the proposed changes to the Revised Preferred Project to reduce subsidence impacts have been noted by the IESC and WaterNSW in their submissions on the project in the following way:

IESC submission dated 19 November 2019:

> *Bord-and-pillar (first workings only) extraction will greatly reduce the risk of subsidence compared with other subsurface mining approaches (e.g. longwall mining), and its use is strongly commended by the IESC.*

WaterNSW submission dated 29 August 2019:

> *WaterNSW considers that:*
>
> - *the first workings mining method is much safer than the previous proposal for longwall mining and is unlikely to cause significant surface subsidence or significant interaction with the overlying seams*
> - *the mining method is likely to minimise the potential groundwater impacts by limiting depressurisation within and immediately above the mined coal seam, and*
> - *the proposed first workings are likely to have negligible impacts on natural surface features including upland swamps, cliffs, steep slopes, drainage lines, creeks, Cataract Creek, Cataract River, and Cataract Reservoir.*

It is considered that the Revised Preferred Project, as proposed, is not expected to cause any material surface subsidence. This change in mine plan avoids significant interaction with the overlying seams or significant interaction with existing groundwater systems. Importantly, the proposed mine plan is not considered to have any potential to perceptibly impact natural surface features including upland swamps, cliffs including the Illawarra Escarpment, steep slopes, drainage lines, creeks, Cataract Creek and Cataract Reservoir. This is primarily due to the proposed first workings mining method that has been designed to be long-term stable. Additionally, due to the small magnitude of subsidence effects expected from the proposed mining layout, there is a high level of confidence in the reliability of the subsidence impacts forecast. Further risk analysis undertaken by SCT (2020) quantifies the risk of individual pillar failure in the Wongawilli Seam from the Revised Preferred Project to be less than 1 in 100,000 (0.001% ever and therefore less than 0.01% per year). As has been noted by SCT (2020), there remains a low risk of ongoing subsidence impacts associated with historical mining in the Bulli Seam and Balgownie Seam and settlement associated with the previous mining in the Wongawilli Seam however this is not exacerbated by the Revised Preferred Project.

Not proceeding with the Revised Preferred Project would likely sterilise the coal resource as it would be difficult and significantly more expensive to access these resources from an alternate operation. Any separate future operations are unlikely to be considered commercially viable as the benefits of being able to continue mining within an approved mining area and utilise existing infrastructure may not be available if the Revised Preferred Project does not proceed.

The Social Impact Assessment prepared for the Revised Preferred Project has identified that the social impacts of the Revised Preferred Project have been minimised where possible through project design and the proposed management and mitigation measures proposed by WCL. Substantial improvements to the Pit Top layout and adoption of a range of additional feasible and reasonable noise control measures, including restricting hours of operation, have been proposed to reduce the noise impact of the Pit Top facilities and trucks accessing the site.

As outlined in the Revised Preferred Project Report (Umwelt 2019a), the Revised Preferred Project has been assessed against the principles of Ecologically Sustainable Development (ESD) as required by the EP&A Act and EP&A Regulation. This assessment has indicated that while the Revised Preferred Project will have impacts, these impacts can be effectively managed and mitigated and the development will result in economic benefits. The assessment therefore concluded that the Revised Preferred Project is consistent with the principles of ESD and after consideration of the submissions made and the responses provided in Submissions Report – Part A and this report, there is no change to that conclusion.

The Economic Assessment (refer to Appendix 10 of the Revised Preferred Project Report) describes a range of positive benefits from the Revised Preferred Project at a local, regional and State level. A cost benefit analysis was undertaken for the Revised Preferred Project which assessed the net benefit of the Revised Preferred Project when all external and internal costs were considered, including environmental and social externality costs. The cost benefit analysis determined that the Revised Preferred Project would result in a net economic benefit of approximately $174.3 million in NPV terms for the NSW community, approximately $17.0 million in NPV terms to the Wollongong local area through employment and expenditure in the local area.

On this basis, it would be reasonable to consider that with the implementation of existing and proposed management and mitigation measures, the Revised Preferred Project can proceed within acceptable environmental standards and would result in a net benefit to the NSW community.

6.0 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 2015. Russell Vale colliery Underground Expansion Project Preferred Project Report Wonga East Groundwater Assessment

IESC 2019. *Information Guidelines Explanatory Note – Uncertainty Analysis – Guidance for Groundwater Modelling Within a Risk Management Framework*

SCT, 2014. *Assessment of Groundwater Data for Russell Vale Colliery and Implications for Further Mining in the Russell Vale East Area*

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APPENDIX 1

Revised Groundwater Assessment Report

GeoTerra

Groundwater Exploration Services

WOLLONGONG COAL LTD

RUSSELL VALE COLLIERY UNDERGROUND EXPANSION PROJECT RUSSELL VALE EAST FIRST WORKINGS GROUNDWATER ASSESSMENT

Bellambi, NSW

NRE16 – R1G

5 February, 2020

Revised Assessment Report

NRE16 - R1G (5 February, 2020)

GeoTerra/GES

Wollongong Coal Ltd
PO Box 281
Fairy Meadow NSW 2519

Attention: Ron Bush

Ron,

RE: Russell Vale Colliery – Underground Expansion Project, Russell Vale East, Revised Mine Plan Groundwater Assessment

Please find enclosed a copy of the above mentioned report.

Yours Faithfully

GeoTerra Pty Ltd

Andrew Dawkins
Principal Hydrogeologist (MAusIMM CP-Env)

GES Pty Ltd

Andy Fulton
Principal Hydrogeologist

Distribution:	Original	GeoTerra Pty Ltd / GES Pty Ltd
	1 electronic PDF copy	Wollongong Coal Ltd
	1 electronic copy	Umwelt

Authorised on behalf of GeoTerra Pty Ltd / GES Pty Ltd:	
Name:	Andrew Dawkins / Andy Fulton
Signature:	
Position:	Principal Hydrogeologist

Date	Rev	Comments
27/06/2017		Draft
20/12/2018	A	Incorporate review comments
29/01/2019	B	Incorporate review comments
23/04/2019	C	Incorporate review comments
11/07/2019	D	Incorporate review comments
15/01/2020	E	Incorporate Peer review comments
29/01/2020	F	incorporate DPIE-W / Umwelt comments
05/02/2020	G	incorporate Peer Review / Umwelt comments

EXECUTIVE SUMMARY

GeoTerra Pty Ltd and Groundwater Exploration Services Pty Ltd were commissioned by WCL to undertake a revised groundwater modelling based assessment and updated reporting of the regional groundwater system in the proposed first workings mining area prior to, during and after the proposed first workings extraction within the Wongawilli Seam.

This document is a revised report that has been prepared in response to DPIE-W comments and a peer review by Noel Merrick of HydroAlgorithmics Pty Ltd.

Desktop assessments, field monitoring, laboratory analysis and computer modelling studies were used to prepare a baseline assessment of the groundwater system, groundwater quality and aquifer hydraulic parameters within the proposed first workings mining area.

Six hydrogeological domains are present in the Russell Vale East area:

- Hydraulically disconnected (perched) upland swamps
- Hydraulically disconnected (perched), ephemeral weathered Hawkesbury Sandstone
- Deeper Hawkesbury Sandstone
- Narrabeen Group sedimentary lithologies,
- Illawarra Coal Measures, which contains the Bulli, Balgownie and Wongawilli Seam aquifers, and
- Sedimentary sequence underneath the Wongawilli Seam.

Due to the steep topography and limited alluvium within the Cataract Creek and upper Cataract River catchment areas, there is no notable groundwater bearing stream based alluvium within Russell Vale East area.

There are no private bores or wells within the Russell Vale East Area.

Numerical modelling was undertaken to assess the existing groundwater system status and predict the potential effects from extraction of the proposed workings.

Due to the change in mining method and the considerations in the mine plan layout, subsidence impacts associated with the proposed mining are considered to be imperceptible.

This removes much of the previous uncertainty associated with the modelling of previously considered mine plans.

Groundwater modelling indicates that the influence of the proposed first workings can be broken down into the depressurisation of two separate regimes:

- within the Wongawilli Seam, and
- overburden above the Wongawilli Seam.

The Wongawilli Seam and overburden immediately overhead would be depressurised to atmospheric pressure in the immediate footprint of the workings, however there would be minimal transgression of depressurisation above the Bulli Seam at the end of the mining period due to the lack of goaf development and associated subsidence cracking and strata delamination associated with the first workings extraction.

The overlying Balgownie and Bulli seams have previously been mined and therefore significant depressurisation has occurred historically.

The shallower surficial strata groundwater levels/pressures will be unaffected by the proposed first workings.

There are no anticipated subsidence effects on stream bed alluvium or plateau colluvium as there is minimal predicted subsidence or transmitted overburden depressurisation over and due to the proposed first workings extraction.

The proposed workings are not considered to have any potential to perceptibly impact on upland swamps, with impacts limited to induced depressurisation impacts associated with the depressurisation of sub-cropping strata below the swamps.

Perched, ephemeral, shallow groundwater within the upper Hawkesbury Sandstone could undergo a water level reduction over the proposed workings after subsidence, but as a consequence of transmitted depressurisation from the triple seam mined areas, and not due to the proposed first workings.

The minimal predicted subsidence of the shallow upper layer of the Hawkesbury Sandstone due to the proposed first workings is not anticipated to have an observable effect on stream baseflow or stream water quality where the temporary aquifers seep into local catchments.

Modelling of the surficial 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 cumulative drawdown compared to pre Wongawilli Seam development. The effect, however is related to previous mining, and not the proposed first workings mine plan.

The Project is not considered to result in any strata deformation or cracking impacts, with minor (negligible) reduction in Cataract Creek baseflow.

The maximum stream flow loss as a consequence of only the proposed first workings is modelled to be 0.0006ML/day (0.22ML/yr) in Cataract Creek during 2073, which will be unobservable for practical purposes. Cumulative impacts on baseflow in Cataract Creek associated with all previous and currently proposed mining in the Wongawilli Seam at Russell Vale are predicted to peak at 0.024ML/day (8.76 ML/year) and are therefore unlikely to be observable.

No observable change in stream flow or groundwater seepage in the Cataract River (upstream of Cataract Reservoir) and Bellambi Creek catchments are anticipated as a result of the proposed first workings due to the very low proportion of the two catchments that may be partially depressurised.

Modelling predicts a maximum reduction in stream flow, due only to the proposed first workings, of 0.0002ML/day (0.07ML/yr) in Cataract River (upstream of Cataract Reservoir) and 0.0005ML/day (0.18ML/yr) in Bellambi Creek occurring in the period 2072 to 2088, which will be practically unobservable.

The predicted reductions in stream base-flows associated with the Revised Preferred Project are considered to be negligible (less than 0.5 ML/year).

An analysis of the work undertaken in the Noel Merrick Peer Review and the HydroAlgorithmics Uncertainty Analysis indicates the above predictions of baseflow losses are slightly lower and occur later than those identified in the modelling done in the Uncertainty Analysis.

As identified in the Peer Review Report, this difference is likely to be associated with the treatment of drain cells in the models and both estimates of baseflow losses are considered to be minimal and are unlikely to be measurable in all affected systems.

Due to the distance of the previously mined longwall panels (LW 4, 5 and 6) and the proposed first workings from the Cataract Reservoir, and the lack of subsidence impacts from the proposed first workings, no adverse impacts on stored water quantity or quality have been observed, or are predicted to occur, as a result of the proposed first working extraction on Cataract Reservoir.

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 not measurable at the end of the proposed first workings extraction.

The maximum total annual groundwater inflow to the workings, including all previous mining impacts from the Russell Vale lease workings, is predicted to be 288ML/year, with the contribution from the proposed first workings (and the continuing gradual increase from previous workings) being up to 36.5ML/year. These predictions are within the uncertainty range modelled by HydroAlgorithmics.

The groundwater inflow rate gradually increases during extraction of the proposed first workings as they are dewatered. After the proposed first workings mining is completed, the model assumes the pumps are turned off and the mine gradually fills up and re-pressurises the overburden until the recovery reaches the 117.5m AHD elevation of the existing adits within and opening out onto the Illawarra escarpment, uphill of the current pit top area, at around 2057.

A similar situation would also occur for existing approved operations, although the time for the workings to recover to the adit spill point would occur earlier for the existing approved workings due to the smaller mining void.

The Project is covered by the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 (Groundwater WSP). The current Water Access Licence (WAL) under the Water Management Act, 2000 is held by Wollongong Coal Ltd for 515 ML (units)/year (Licence No. WAL36488) and is located within Nepean Management Zone 2 of the Sydney Basin Nepean Groundwater Source.

Wollongong Coal Limited were advised by DPIE-Water during January 2020 that the Company has been successful in the bid for allocation under the Controlled Allocation Order 2017 for an additional 100 units (equates to 100 ML) within the Sydney Basin Nepean Groundwater Source – Nepean Management Zone 2.

Wollongong Coal Limited intend to apply the allocated 100 units to the existing WAL36488 to increase the entitlement held under this WAL to 615 ML (units)/ year.

Based on the predicted maximum groundwater inflow, during the extraction period of the proposed workings, of 288ML/year, Wollongong Coal currently hold a sufficient quantity of units in their WAL. Subsequently, the mine water inflow is predicted to stabilise at around 110ML/year once the groundwater level recovery reaches and spills out of the basal elevation of the adit in the Illawarra Escarpment.

These conditions and a similar flow rate would also occur for the currently approved operations.

This modelled level of spill is equal to the long term groundwater take and is well within existing groundwater licence allocations held by Wollongong Coal.

Baseflow reductions are considered to be take regulated by the Greater Metropolitan Region Unregulated River Water Sources Water Sharing Plan – Upper Nepean & Upstream Warragamba Water Source – Upper Nepean River Tributaries Management Zone (Surface Water WSP), which encompasses the overall Study Area.

A maximum annual (cumulative) take of up to 9.91 ML/yr of stream base-flow and leakage from the associated catchments resulting from depressurisation of deeper aquifers is modelled as a result of ALL mining at the Wongawilli Seam at Russell Vale, not just the Revised Preferred Project impacts.

As noted above, the predicted maximum cumulative take is slightly lower than that identified by HydroAlgorithmics in the Peer Review Report (20.87 ML/Year). The incremental effect of the Revised Preferred Project on baseflows is, however, considered to be small under both modelled scenarios and would not be measurable in practice.

Wollongong Coal hold sufficient harvestable rights within this management zone to cover the modelled maximum take.

The modelled reduction in baseflow is similarly not expected to have any measurable impact on surface water quality due to strata depressurisation as the scale of the predicted surface water take from Cataract Creek, Cataract River and Bellambi Creek is minimal compared to the relative to flow and catchment discharge into Cataract Reservoir.

No observable impact is anticipated on groundwater quality as a result of the proposed workings extraction.

Extrapolation of the monitored mine water quality within the underground workings indicates that any adit discharge that may potentially occur, when the groundwater system reaches the adit spill elevation, may be;

- alkaline (approximately pH 8.6);
- slightly brackish (approximately 2,200µS/cm), mostly due to elevated bicarbonate;
- slightly elevated in sulfate, and;
- above the ANZECC 2000 95% Level of Protection for fresh water species trigger for copper, nickel and zinc.

By comparison Bellambi Creek, upstream of the Russell Vale Pit Top area has an equal or slightly higher alkalinity (pH <8.97) and fresher salinity (213 – 913µS/cm).

As a result of the slightly elevated salinity and above criteria metals (Cu, Ni, Zn), the adit discharge of up to 110ML/year may require treatment if it adversely impacts the receiving Bellambi Creek water quality and if the future Regulatory authority requires treatment.

This scenario also applies to the currently approved operations, and the Project is not expected to have any significant impacts on either the rate of flow from the adit or the quality of this water.

Treatment of this adit outflow water for different uses, including potable uses, is reasonable and feasible.

There will be no loss of bore yield as a result of the proposed first workings as there are no registered private bores or wells located within the modelled zone of drawdown.

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FIGURES

TABLES

1. INTRODUCTION

This document is a revised report that has been prepared in response to Department of Planning Industry and Environment – Water (DPIE-W) comments and peer review comments provided by Noel Merrick of HydroAlgorithmics Pty Ltd.

1.1 Project Background

Wollongong Coal Limited (WCL) is seeking approval under the Environmental Planning and Assessment Act 1979 to extend mining operations at the Russell Vale Colliery, referred to as the Underground Expansion Project (UEP).

The UEP application has been through several iterations to minimise its potential adverse impacts.

The original UEP application involved a substantial expansion of longwall mining in the Russell Vale East and Wonga West areas to extract 31 Mt of ROM coal over 18 years.

In 2014, a Preferred Project was exhibited based on a reduced mine plan of eight longwalls in the Russell Vale East area only. The Preferred Project has been reviewed by the Planning Assessment Commission (PAC) on two occasions, most recently in 2016. A key issue for the PAC in its consideration of the Preferred Project was the uncertainty associated with subsidence and groundwater impacts as a result of proposed longwall mining in the multi-seam mining environment present at Russell Vale.

To address the residual uncertainty regarding impacts of longwall mining, WCL has developed a revised mine design based on a non-caving first workings mining system that will result in imperceptible subsidence. Longwall mining is no longer proposed as part of the UEP. This revised mine plan is referred to as the Revised Preferred Project.

The Revised Preferred Project mine plan has been specifically re-designed to avoid any secondary extraction beneath Cataract and Bellambi Creeks or Cataract River and their associated swamps, as well as Cataract reservoir. No secondary extraction is proposed, including beneath the main creek channels of streams as part of the proposed mining. The Project does not include any mining under the Cataract reservoir.

Historic mining in the area and previous iterations of the UEP are described in **Section 3.0,** whilst the Revised Preferred Project is outlined in **Section 4.0**.

1.2 General Context

The general site context, including historical workings and the Revised Preferred Project Mine Plan are shown in **Figure 1-1**. The existing and proposed workings are contained within Consolidated Coal Lease 745 (CCL745) and Mining Lease 1575 (ML1575).

The extent of historic and proposed mining within the Wongawilli Seam in the Russell Vale East mining domain is shown in **Figure 1-2**.

The proposed and historic workings are predominantly located within the Metropolitan Special Area, which is a restricted area managed by WaterNSW.

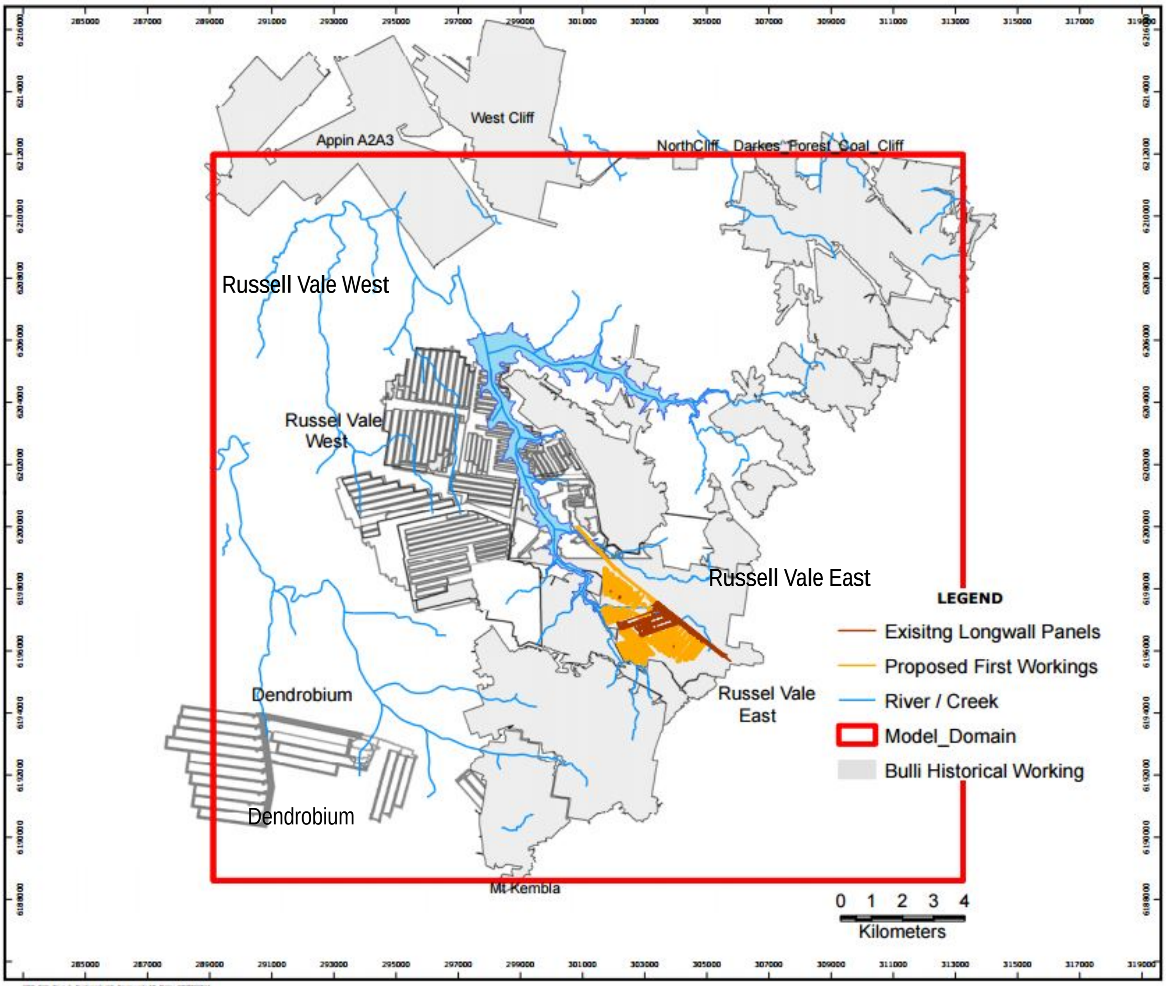


Figure 1-1 Site Context

1.3 Scope of Work

GeoTerra Pty Ltd (GeoTerra) and Groundwater Exploration Services Pty Ltd (GES) were commissioned by WCL to assess the potential groundwater and stream base flow impacts relating to the proposed extraction of the Wongawilli Seam and associated overburden fracturing and ground surface subsidence in the Russell Vale East mining area, as proposed for the UEP.

This assessment follows on from, and is a refinement of, an earlier proposal to extract longwalls from the Wongawilli Seam within Russell Vale East after Longwalls 4, 5 and 340m of Longwall 6 had been extracted between April 2012 and July 2015.

A brief summary of the previous groundwater assessments prepared for earlier mine plans is provided in **Appendix A** and a copy of these previous assessments can be viewed on the NSW Department of Planning, Industry and Environment's Major Projects website at http://majorprojects.planning.nsw.gov.au/index.pl?action=view_job&job_id=3448.

This document describes a revised groundwater modelling based assessment and updated reporting of the regional groundwater system in the Application Area prior to, during and after the proposed first workings extraction within the Wongawilli Seam.

This report has been prepared following regulatory reviews by NSW and federal agencies of previous groundwater assessments for the UEP area (GeoTerra / GES, 2014 and GeoTerra / GES, 2015) and provides an updated predictive groundwater model and interpretive report in relation to extraction of first workings only within the Wongawilli Seam.

This report is designed to address the Planning Assessment Commission (PAC) and Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) groundwater related issues outlined for the previous assessments (GeoTerra / GES 2014 and GeoTerra / GES 2015).

The specific responses to the PAC and IESC issues are outlined in GeoTerra / GES (2015).

The current report has also been through a consultation and review process involving:

- Department of Planning, Industry and Environment (DPIE)
- the Department of Industry – Water (DIW), and;
- Water-NSW.

In accordance with the DGRs for Project Application 09_0013, (20/3/2009), the requirements for the groundwater component of the assessment are:

- *a description of the existing environment, using sufficient baseline data;*
- *an assessment of the potential impacts of all stages of the project, including any cumulative impacts, taking into consideration any relevant guidelines, policies, plans and statutory provisions and the findings and recommendations of the recent Southern Coalfield inquiry;*
- *a description of the measures that would be implemented to avoid, minimise, mitigate, rehabilitate/remediate, monitor and/or offset the potential impacts of the project, including detailed contingency plans for managing any potentially significant risks to the environment, and;*
- *a detailed assessment of the potential impacts of the project on the quantity, quality and long-term integrity of the groundwater resources in the project area, paying particular attention to the Upper Nepean River sub-catchment (Metropolitan Special Area)*;

This document addresses submissions from the relevant NSW based regulators in response to the Underground Expansion Project Preferred Project Report provided by Gujarat NRE Coking Coal Ltd (now Wollongong Coal) to DP&E, on 28 August 2013.

The document also addresses issues subsequently raised by the federal Department of the Environment (DoE) and, specifically, issues regarding the revision of groundwater modelling and associated reporting that were raised by the NSW PAC and its independent peer reviewer.

The PAC recommended that changes and further discussion be made to a number of facets of the groundwater model and the modelling code utilised to derive predictive outcomes. As discussed further in Sections 9, 12 and 13, these included:

- reasoning behind the use of the same value of drainable porosity for all strata in the groundwater model since this parameter significantly influences the evolution of the phreatic surface and mine inflows;
- discussion of revised model calibrations including presentation of hydrographs showing measured and predicted pressure heads using the 'pseudo soil' option;
- illustration of model pressure heads (in plan) in the coal seams, Bulgo Sandstone and Hawkesbury Sandstone prior to, during and after mining (50 and 100 years);
- assessment of the long term steady state groundwater flow systems post mining and identification of shallow and surficial areas that are likely to be dewatered;
- assessment of potential leakage via the adit and assessment of the role played by the abandoned overlying workings (and their adits) in constraining the recovery of pore pressures;
- risk assessment associated with potential leakage from Cataract Dam via the proposed panel extractions and adit; and
- mitigation measures that might be invoked to minimise impacts.

This groundwater investigation was conducted to assess the current and historic:

- standing water levels and / or hydrostatic pressures within formations overlying the existing and proposed workings;
- groundwater quality of the formations overlying the existing and proposed workings;
- hydraulic parameters of selected overburden formations within the Russell Vale lease area, and;
- any observed or inferred groundwater discharge zones into local streams.

In addition, the study aims to:

- identify potential groundwater dependent ecosystems;
- collate and review mine water management data;
- collate and review additional data from adjacent mines and government agencies;
- develop a conceptual groundwater model and represent the Application Area with a numerical MODFLOW SURFACT groundwater model to assess potential underground mining impacts on the local and regional groundwater system;
- provide a qualitative and quantitative assessment of cumulative impacts from adjacent existing and approved mines;

- assess post mining groundwater impacts in regard to groundwater level recovery;
- develop measures to avoid, mitigate and/or remediate potential impacts on groundwater resources, and;
- indicate groundwater monitoring methods that will measure any impacts on the local and regional groundwater system.

The study provides a baseline, pre-mining assessment of the potentially affected groundwater systems within the proposed mining area and has been conducted to satisfy the requirements for an Environmental Assessment.

The Russell Vale Vale East stream assessment is discussed separately in WRM Water and Environment (2014) and (2015), whilst the swamp assessment is detailed in Biosis (2014), (2015) and (2018).

1.4 Previous Groundwater Related Studies

A brief summary of previous groundwater investigations at Russell Vale is included in **Appendix A**.

2. REGULATORY CONTEXT

The relevant Plans, Policies, Guidelines and Legislation in relation to groundwater at the study site are detailed in **Appendix B**.

3. HISTORIC MINING AT RUSSELL VALE

Previous underground mining in the Russell Vale lease area has been conducted through longwall mining of the Bulli Seam in Wollongong Coal's lease areas to the west, east and beneath Cataract reservoir, as well as in South32's Cordeaux and Corrimal lease areas to the south and the BHP Bulli workings to the north of the Russell Vale lease area.

As shown in **Figure 3.1**, multi seam mining has been conducted at Russell Vale East through:

- bord and pillar, as well as pillar extraction of the Bulli Seam at Russell Vale East, along with predominantly bord and pillar mining, and to a lesser degree, longwall extraction in the old Australian Iron and Steel (AIS) (subsequently BHP, BHP Billiton, then South32) Bulli Colliery workings to the north and Corrimal colliery to the south of Russell Vale East.
- longwall extraction of the Balgownie Seam at Russell Vale East, and;
- extraction of Longwalls 4, 5 and 340m of Longwall 6 in the Wongawilli Seam at Russell Vale East. Previous Mining at Russell Vale Colliery.

Three coal seams have been mined at Russell Vale Colliery, with access to all seams provided by drives and headings that all connect to access portal (adits) into each of the target seams within the pit top area in the escarpment.

3.1.1 Bulli Seam

The uppermost is the 2.0 - 2.5m thick Bulli Seam where most of the previous mining activity has occurred. It was mined between the late 19th Century and about 1950, initially as a hand worked bord and pillar operation and then with some mechanised pillar extraction. Bulli Seam mining continued under and to the west of Cataract reservoir, initially as a continuation of Continuous Miner pillar extraction operations and then as a longwall mining operation until 2002.

3.1.2 Balgownie Seam

The 1.3m thick Balgownie Seam is located 5 - 10m below the Bulli Seam, with mining starting in the late 19th Century in the Russell Vale East area using hand worked methods for a brief period. Mining restarted in the late 1960s with continuous miners, then from 1970 to 1982 as one of the first longwall operations in Australia. To the north, some additional mining in the Balgownie Seam included a first workings continuous miner bord and pillar thin seam mining operation between 2001 and 2003 in Gibson's Colliery (S Wilson, pers comm.).

3.1.3 Wongawilli Seam

The 7 - 9m thick Wongawilli Seam is located 18 - 26m below the Balgownie Seam. However, only the bottom 3.0 - 3.5m of the seam has been mined.

Installation of the Wongawilli Seam mining access started in 2008 at Russell Vale East, with subsequent secondary extraction occurring as shown in **Table 1**.

Table 1 Russell Vale East Wongawilli Seam Longwall Extraction Summary

Longwall	Start	Finish	Depth of Cover (mbgl)	LW Width (m)	LW Length (m)
4	21/4/2012	21/9/2012	267 - 275	140	523
5	15/01/2013	12/01/2014	272 - 279	140	844
6 (340m)	04/05/2015	08/07/2015	312 - 333	140	340*

**Total length of LW 6 was originally 1,120 m, but only 340 m has been extracted to date.*

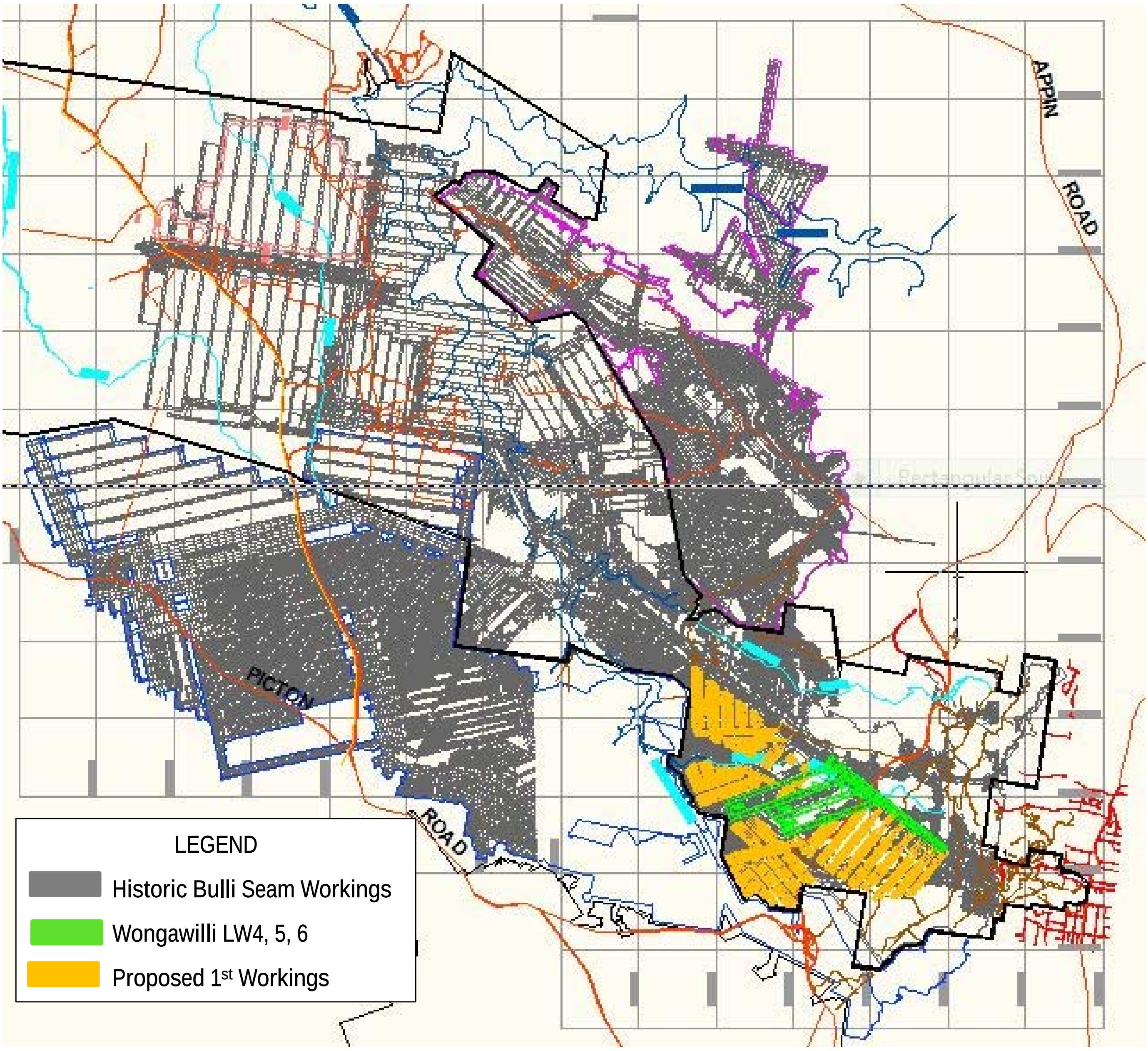


Figure 3-1 Russell Vale Historic Mining Plus Proposed Workings

3.2 Previous Proposals

After consideration of submissions from the community, as well as NSW government agencies, to its earlier Underground Expansion Project Part 3A (Pt3A) application that comprised longwall mining in the Russell Vale East and Russell Vale West areas, Wollongong Coal (then Gujarat NRE Coking Coal) modified its application to DP&E through a Preferred Project Report assessment that limited longwall mining to the Russell Vale East area only.

The Preferred Project groundwater study excluded mining in the Russell Vale West area.

A subsequent proposal included extraction of the remainder of Longwall 6 and Longwall 7 in the Wongawilli Seam to the south of Cataract Creek, as well as Longwalls 9 to 11 to the north of Cataract Creek between Mt Ousley Road and Cataract Reservoir within Water-NSW managed land.

Longwall 8 was excluded from the Underground Expansion Project application during the Preferred Project Report mining plan revision.

To the east of Mt Ousley Road, Wollongong Coal proposed to extract Longwalls 1 to 3 in the Wongawilli Seam on private land.

This proposal was subsequently modified as outlined in **Section 4.0**.

4. THE REVISED PREFERRED PROJECT

In order to address residual uncertainty regarding the impacts of longwall mining raised by the PAC Second Review Report, a revised mine design has been developed based on a non-caving first workings mining system.

The revised mine plan has been designed to be long term stable with negligible risk of pillar failure to address potential subsidence-related mining impacts on groundwater, surface water and biodiversity within the Cataract Reservoir catchment.

Key elements of the Revised Preferred Project are:

- Access to proposed underground mining areas in the Wongawilli Seam via the existing adit located within the Illawarra Escarpment into the Wongawilli Seam and existing mains headings.
- Mining by means of first working mining techniques only, with the workings designed to be long term stable with minimal subsidence impacts. No longwall mining is proposed;
- Extraction of approximately 3.7 Mt of ROM coal over 5 years at a production rate that will not exceed 1 Mt of product coal per year;
- Construction and use of a coal processing plant to improve the quality of product coal;
- Redesign of the Pit Top layout to strategically relocate infrastructure to more shielded locations;
- Reduced hours of operation for surface facilities relative to the Preferred Project mine plan; and
- Additional noise mitigation works at the Russell Vale Pit Top including a new noise barrier, extension to the height of existing bunds and acoustic treatment of coal processing infrastructure.

4.1 Revised Preferred Project Objectives and Key Design Considerations

The following key objectives have guided the refinement of the UEP mine plan subsequent to the PAC Second Review Report:

- develop a mine design that eliminates residual uncertainty regarding subsidence predictions, geotechnical constraints and potential impacts on groundwater, surface water and biodiversity associated with longwall mining
- gain access to sufficient resources to enable mining to recommence and occur over a sufficient time frame to undertake the necessary assessments to confirm a suitable mine plan in the Wonga West area that would extend the life of Russell Vale Colliery for a period similar to that sought in the initial UEP application
- develop comprehensive mitigation and management strategies to reduce environmental and social impacts associated with the Revised Preferred Project in order to meet relevant criteria where-ever practicable and feasible
- conduct mining in an environmentally responsible manner to minimise project specific and cumulative environmental and social impacts
- create additional employment opportunities within the local and regional community

- co-exist with the local community.

Furthermore, the mine design for the Revised Preferred Project has also taken account of:

- surface constraints (such as the Cataract Reservoir, ecological and Aboriginal Heritage constraints as well as built features),
- underground geological discontinuities (dykes, faults, roof strata sill and lease boundary) and
- existing workings above the targeted Wongawilli Seam, in the Balgownie and Bulli seams.

The mine plan for the Revised Preferred Project shown in **Figure 4-1** has been designed as a non-caving first workings mining system using continuous miners to limit potential for interaction with existing overlying workings or subsidence-related impacts to natural or built surface features or groundwater.

The pillars remaining are designed to be long-term stable with a large width to height ratio. The proposed mining is not expected to cause perceptible subsidence at the surface, significant interaction with the overlying seams or significant interaction with existing groundwater systems.

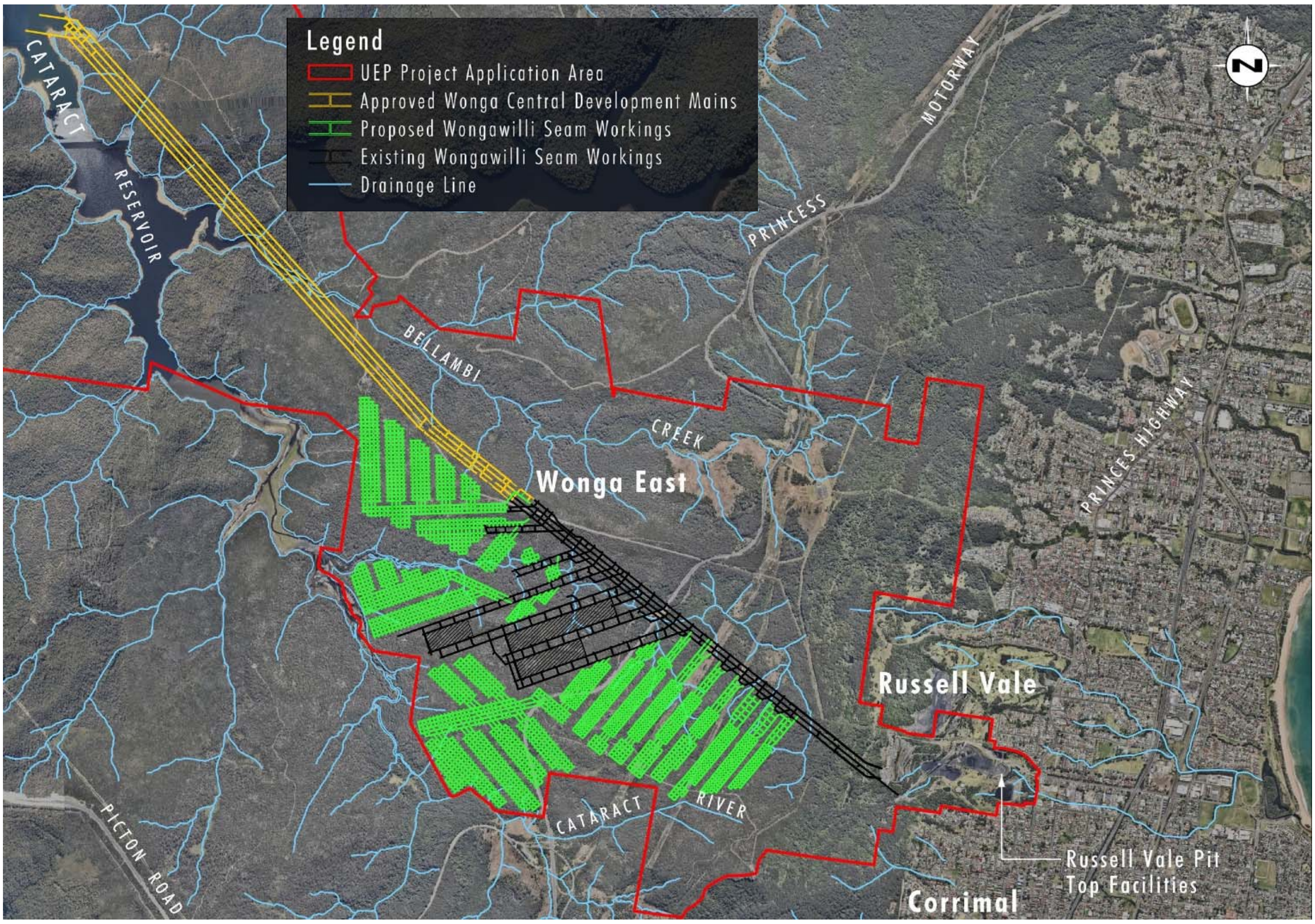


Figure 4-1 Revised Preferred Project Mine Plan

These development mains were previously approved under Project Approval PA 10_0046 (Preliminary Works Project) granted by the PAC on 13 October 2011 under Section 75(J) of the EP&A Act. With the exception of the previously approved development mains into the Wonga Central area, the revised mine plan has been restricted to the Russell Vale East area. No mining is proposed beneath the full supply level of Cataract Reservoir.

The proposed mine plan aims to minimise potential subsidence-related mining impacts while maximising the extraction of available resources. The mine design and pillar size are based on the provision of permanently stable pillars to reduce the potential for subsidence. The mine plan utilises existing roadways and avoids underground constraints such as faults and dykes where possible. The revised mine plan also restricts mining to the south of the existing development mains due to the presence of a sill in the northern parts of the Wongawilli Seam in the Russell Vale East area.

The mining panels are generally designed as 5 headings of 5.5 m width with a separately ventilated conveyor located within the centre of one roadway. Underground mining operations will be undertaken 24 hours per day, 7 days per week.

4.1.1 Retrieval of Longwall Equipment

WCL will not be seeking future approval for longwall mining within the Russell Vale Colliery lease holding.

To confirm this commitment, the existing longwall mining equipment that is currently located within LW6 will be retrieved and sold.

The longwall face equipment is currently located approximately 25 m short of the next gate road access point that would allow for its safe removal. Recovery will therefore require mining of this 25 m section of LW6 to facilitate removal.

This mining has been previously assessed and approved under the existing *Russell Vale East - LW6 (365m) Extraction Plan* (Hanson Bailey, 2015c) and represents the panel retreat between 340 - 365 m of LW6.

5. SITE CONTEXT

Within Russell Vale East, 1st and 2nd order tributary creeks drain into the 3rd, and subsequently 4th order catchment of Cataract Creek, downstream of Mount Ousley Road, and the 3rd order catchments of Cataract River.

The Russell Vale East catchments drain directly into Cataract Reservoir and subsequently, to Broughton's Pass weir. Cataract River subsequently drains downstream to the off-take to the Macarthur Water Treatment plant at Broughton's Pass Weir.

Cataract River is regulated by Cataract Dam, which is upstream of the Lizard Creek / Wallandoola Creek confluence, as well as by Broughton's Pass Weir, which is downstream of their confluence with Cataract River.

The Russell Vale East mining area assessments underlies the main channel, catchments and swamps of Cataract Creek and Bellambi Creek as well as the eastern catchment (excluding the main channel) of Cataract River.

Russell Vale East contains steep gradient valleys that drain off the western slopes of the Illawarra Escarpment to Cataract Reservoir in the west, whilst the proposed workings predominantly underlie the Cataract Creek and Cataract River catchments, and to a lesser degree, the Bellambi Creek catchment.

Thirty nine upland headwater swamps that meet the definition of being a Coastal Upland Swamp Endangered Ecological Community are present in the Russell Vale East area within the Cataract Creek, Cataract River and Bellambi Creek catchments (Biosis, 2014).

Land use within Russell Vale East generally consists of undeveloped bushland, including some limited fire access and electricity transmission line easements.

This study provides a baseline assessment of the current status of potentially affected groundwater systems within the proposed mining area in accordance with the NSW Department of Planning and Environment (DP&E) Director-General's Requirements (DGRs), as well as subsequent Preferred Project Report, as well as federal Department of Environment (DoE) and NSW PAC correspondence for the previous application.

Desktop assessments, field monitoring, laboratory analysis and computer modelling studies have been used to prepare a baseline assessment of the groundwater system, groundwater quality and aquifer hydraulic parameters within Russell Vale East and overall Application Area.

The study assesses the potential mining impact on the groundwater and surface water systems, as well as providing a potential indicative management and monitoring strategy that will be suitable to manage any potential adverse effects that may be caused by subsidence.

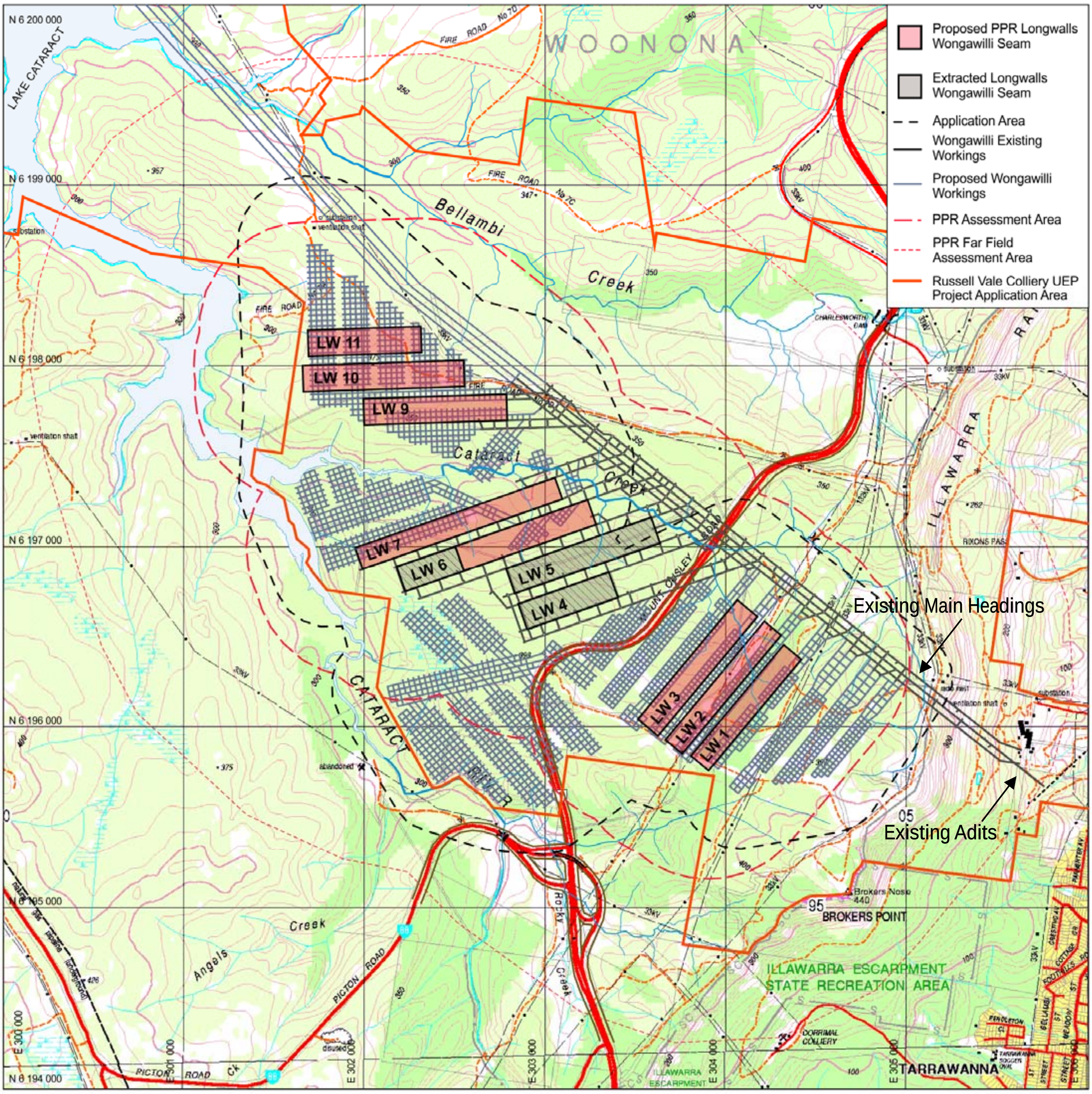


Figure 5-1 Russell Vale East Historic and Previously Proposed Longwalls with Proposed First Workings

Related groundwater features within Russell Vale East include:

- a regional water table which has been intersected between 17m to 48m below surface within the Hawkesbury Sandstone. Where paired measurements are available, the regional aquifer has been shown to be hydraulically separated from the upland swamps by up to 15m of dry to unsaturated, weathered Hawkesbury Sandstone;
- shallow, perched, ephemeral aquifers within the upper (<20m deep) Hawkesbury Sandstone;
- headwater swamps within the Cataract Creek, Bellambi Creek and Cataract River catchments;
- shallow (<1.9m deep) perched, ephemeral highly variable water level aquifers within the swamps, and;
- "Losing" streams, which predominate in the upper catchments, where stream water permeates into the regional Hawkesbury Sandstone aquifer, and "gaining" streams in incised sections, where groundwater seeps under gravity into the main creek channels.

5.1 Russell Vale East Catchments and Topography

Stream water level monitoring in pools and at selected flow constriction sites in Cataract Creek and Cataract River have been conducted since November 2010, with volumetric stream flow assessment conducted as outlined in WRM Water and Environment (2015).

The following sections describe individual catchments within Russell Vale East.

5.1.1 Cataract Creek

Cataract Creek is a 4^{th} order stream for most of its length and is approximately 5.5km long from its headwaters to the full supply level of Cataract Reservoir.

Channel invert elevations fall from approximately 340m AHD to 285m AHD, with the channel being relatively gently sloping at a gradient of 0.9% for most of its length, except for a 0.5km reach in its headwaters, which slopes at 2.5%.

Approximately 2.5km of the stream reach is located upstream, 2km within and 0.9km is downstream of the Application Area.

5.1.2 Cataract River

Cataract River is a 3^{rd} order stream upstream of the Link Road crossing, and 4^{th} order from the confluence near the crossing to the Cataract Reservoir backwater. It is approximately 6.7km long from its headwaters to the upstream reaches of the Lake Cataract storage.

Channel invert elevations fall from approximately 430m AHD to 285m AHD and the channel is relatively gently sloping at a gradient of 0.5%, for much of its length, except for a steep upstream 0.5km reach, which slopes at around 17%.

The proposed Russell Vale East workings within the Application Area do not underlie the Cataract River.

5.1.3 Bellambi Creek

Bellambi Creek is a 3rd order stream upstream for the first 5.5km, then 4th order to the Cataract Reservoir backwater. It is approximately 6.4km long from its headwaters to the full supply level of Cataract Reservoir.

Channel invert elevations fall from approximately 453m AHD to 286m AHD, with the channel being relatively gently sloping at a gradient of 0.6%, except for the first 1km upstream reach, which slopes at around 2.8%.

The Application Area does not underlie or interact with the main Bellambi Creek stream channel.

5.2 Climate

5.2.1 Rainfall

Daily rainfall has been recorded by the Bureau of Meteorology (BOM), Water-NSW and its predecessors, and the nearest stations with the longest records are located at Cataract and Cataract Dam, with good quality records extending from 1883 to 1966 and 1904 to 2016 respectively.

The BOM's SILO data service has prepared Patched Point Datasets (PPDs) from the Cataract and Cataract Dam records. Gaps in the records are infilled with data interpolated from other nearby stations to provide continuous records between 1889 and the present day.

Annual rainfall at Cataract Dam between 1889 and 2013 varied from 480mm in 1944 to 2,293mm in 1950, with a mean annual rainfall of 1,085mm/a.

Cataract Dam rainfall is highest between January and June, and lowest between July and December as shown in **Figure 5-2**.

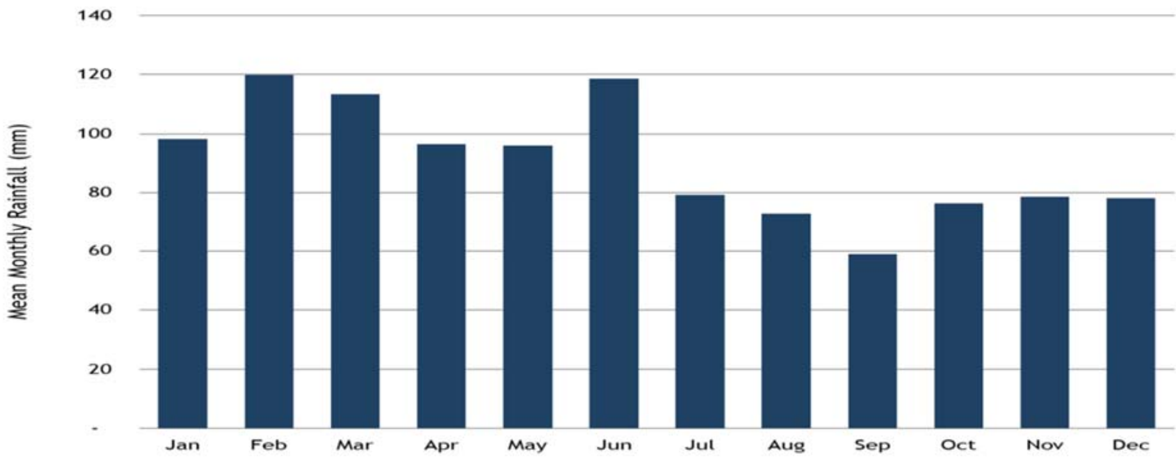


Figure 5-2 Annual Monthly Average Variation in Mean Rainfall at Cataract Dam

Figure 5-3 shows a plot of cumulative rainfall residual at Russell Vale East between November 2009 and the present. The cumulative rainfall residual shows departures from the long-term average, with upward sloping lines indicating relatively wet periods and downward sloping lines indicating relatively dry periods.

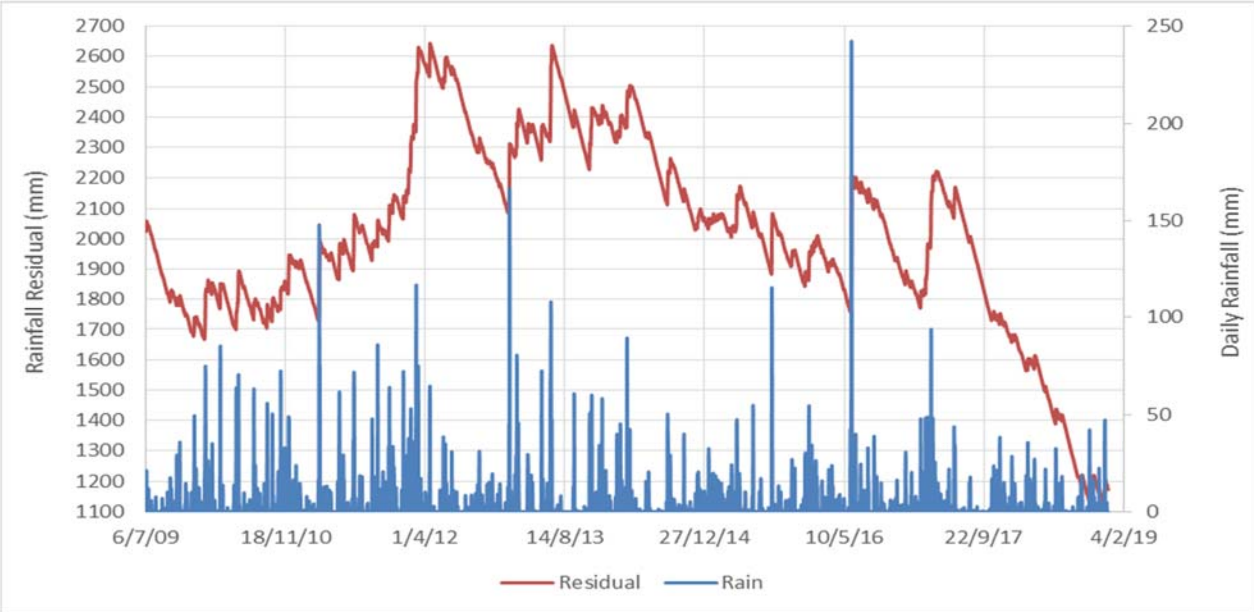


Figure 5-3 Rainfall Residual

5.2.2 Evaporation

The mean annual pan evaporation at Cataract Dam is approximately 1,420 mm/yr as shown in the PPD data in **Figure 5-4**, and is highest in the summer months. There is no Bureau of Meteorology evaporation data available for this location.

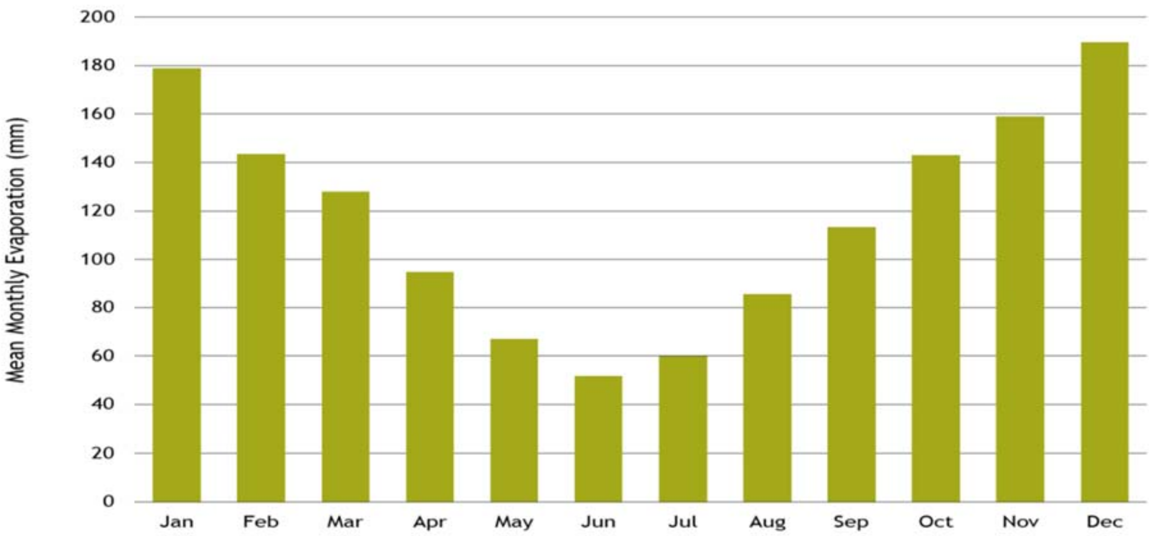


Figure 5-4 Annual Average Monthly Pan Evaporation at Cataract Dam

On the basis that the reservoir has a surface area of 8,500ha, this equates to an average annual evaporation rate (at 1,420 mm/yr) of 120,700ML/year off the surface of the reservoir, when it is at Full Supply Level.

5.3 Geology

Russell Vale Colliery is situated at the southern end of the Permo-Triassic (225-270 million years) Sydney Basin within the Illawarra Coal Measures, which contains the Bulli, Balgownie and Wongawilli seams.

The Russell Vale East area is predominantly covered by shallow hillslope-based colluvium, with very thin to no alluvial sedimentary deposits in the valley floors as shown in **Figure 5-5**.

Outside of the upland swamps, there are no alluvial deposits of any significance within the Wollongong Coal lease area except for possibly within, or under, Cataract Reservoir.

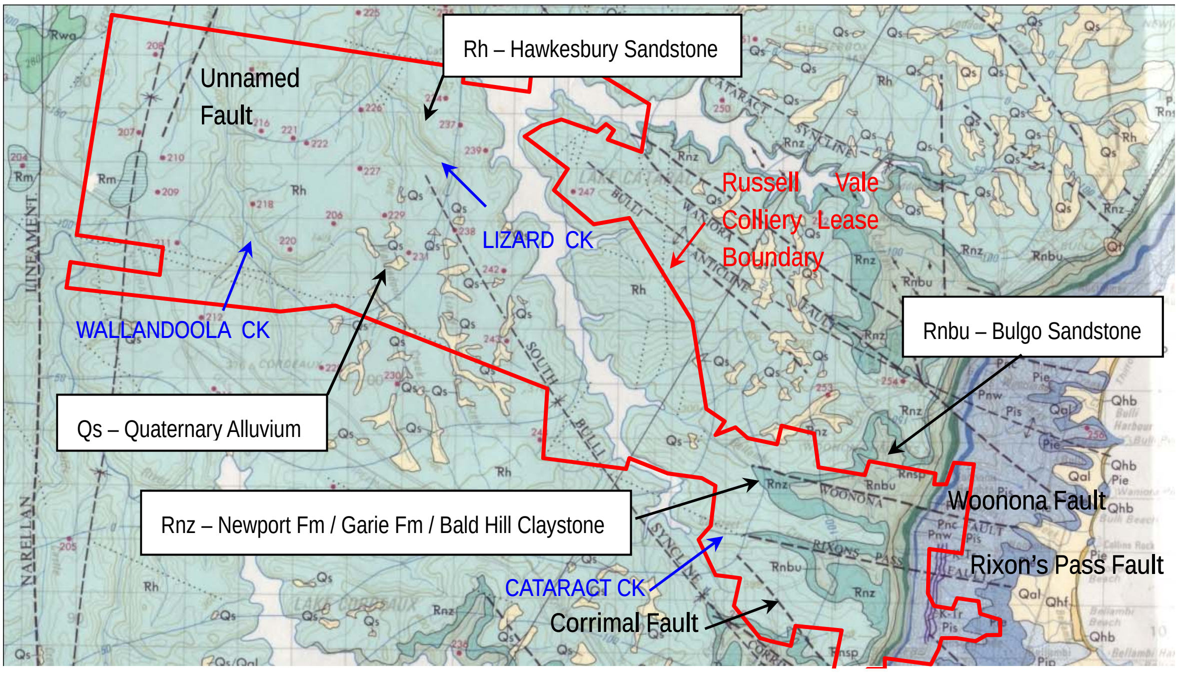


Figure 5-5 Published Regional Surface Geology

Quaternary unconsolidated alluvial and colluvial sediments are also present within both valley fill and headwater upland swamps, and are generally less than 2m thick, comprising humic sands and clayey sands overlying weathered Hawkesbury Sandstone.

The Quaternary sediments in the Russell Vale East area are, in turn, sequentially underlain by the:

Wianamatta Group (due to erosion, this formation is absent at Russell Vale East)

Hawkesbury Sandstone (absent to 181m thick) – the bedded to massive quartzose sandstone with grey shale lenses up to several metres thick is uppermost in the stratigraphic sequence in the majority of the Application Area except where it has been eroded in the headwater valleys of Cataract and Bellambi Creeks in the Russell Vale East area. Exposed Hawkesbury Sandstone is prevalent across the central and western areas of the lease. The Hawkesbury Sandstone also outcrops in the catchment headwaters of Russell Vale East, with the underlying Newport and Garie Formations, Bald Hill Claystone and Bulgo Sandstone being exposed in reaches of Cataract Creek.

It can contain up to 4% manganiferous siderite and up to 0.5% of iron sulfide (principally marcasite) with minor solid solution incorporation of nickel, zinc and manganese sulfides.

Narrabeen Group – the Narrabeen Group consists of the following units as described below.

- **Newport and Garie Formations** (4.6 - 36m thick) – The Newport Formation has interbedded grey shales and sandstones which has a variable thickness across the Application Area. The Garie Formation is generally around 3m thick and contains cream to brown, massive, characteristically oolitic claystone with a relatively constant thickness across the Application Area.

- **Bald Hill Claystone** (17 - 42m thick) – The unit is typically a chocolate brown to red brown kaolinitic marker bed claystone with silty and sandy grey and mottled grey - brown zones with a relatively constant thickness over the Application Area. It predominantly consists of 50 - 75% kaolinite with hematite and siderite as accessories, which give it its distinctive colour.
- **Bulgo Sandstone** (113 - 154m thick) - thickly bedded, medium to coarse grained lithic sandstone with occasional conglomerate and shale.
- **Stanwell Park Claystone** (15 - 26m thick) - greenish-grey mudstone and sandstone, with a general thickening of the claystone to the north west.
- **Scarborough Sandstone** (16 - 31m thick) - thickly bedded sandstone with shale and sandy shale lenses up to several metres thick.
- **Wombarra Claystone** (35 - 61m thick) – has a similar lithology to the Stanwell Park Claystone and generally thickens to the south east.
- **Coal Cliff Sandstone** (8 - 13m thick) - shales and mudstones contiguous with the underlying Bulli seam and varies from a quartzose sandstone in the east to a more shale/mudstone dominated unit in the west.

Illawarra Coal Measures – The Illawarra Coal Measures consist of interbedded shales, mudstones, lithic sandstones and coal seams, including the Bulli Seam, Loddon Sandstone, Balgownie Seam, Lawrence Sandstone, Eckersley Formation, Wongawilli Seam and Kembla Sandstone. The major coal seams in sequentially lower order are described below.

- **Bulli Seam** (2.0 - 4.7m thick) – Coal from the Bulli Seam has been worked extensively by both longwall as well as bord and pillar methods within and surrounding the Wollongong Coal lease area. The depth of cover to the Bulli Seam varies from 205 - 290m at Russell Vale East, with a seam dip to the north-west of approximately 1 in 30 with modification in the vicinity of the north west / south east trending South Bulli Syncline to the west of Cataract Reservoir, and a north south trending unnamed syncline to the west of Wallandoola Creek. A small scale north south trending syncline is present in the Bulli Seam workings. The Bulli Seam overlies the Balgownie Seam by 5.5 - 13.6m with a median 9.9m separation in the lease area.
- **Loddon Sandstone** (5 - 8m thick) – shale, mudstone, siltstone, sandstone with a sharp conglomeratic base

- **Balgownie Seam** (0.8 - 1.5m thick) – The Balgownie Seam has not been worked extensively in the southern coalfield, although limited longwall extraction has been conducted in the Russell Vale East area. The Balgownie Seam overlies the Wongawilli Seam by 10.6 - 24.7m with a median 18.7m in the lease area.
- **Lawrence Sandstone** (16 - 17m thick) – mudstone, siltstone to sandstone at the base
- **Cape Horn Seam** (0.1 - 0.4m thick) – a thin seam that is not mined commercially
- **Eckersley Formation and Hargraves Coal Member** (6 - 8m thick) – mudstone, claystone, siltstone and shales with the intercalated very thin (0.1 -0.3m), uncommercial Hargraves Coal Seam
- **Wongawilli Seam** (6.2 - 10.5m thick) – comprised of up to 11 sub seams. It has predominantly been mined in the southern area of the Southern Coalfields, although has also been mined by Longwalls 4 and 5 in the Wollongong Coal lease. The depth of cover for Wongawilli Seam varies from 237 - 321m at Russell Vale East. In the lease area the Wongawilli Seam underlies the Bulli Seam by 24.1 - 36.4m with a median of 30.4m.

Lithologies underlying the Wongawilli Seam – the following units underlie the Wongawilli Seam:

- **Kembla Sandstone** (5 - 9m thick) – shale, siltstone and finer to coarse grained sandstone
- **American Creek Coal Member** (0.3 - 3.5m thick) – this seam has not been mined in the Southern Coalfields
- **Allens Creek Formation** (14 - 15m thick) – shale, siltstone and finer to coarse grained sandstone
- **Darkes Forest Sandstone** (5 - 9m thick) – fine to medium grained sandstone
- **Bargo Claystone** (10 - 12m thick) – mudstone, siltstone, shale
- **Tongarra Seam** (1.5 - 2.0m thick) – this seam was mined to a limited extent in the southern part of the Southern Coalfields
- **Wilton Formation** (minimum 4m thick) – claystone, siltstone and shale

5.3.1 Outcrop Mapping

Outcrop mapping of the surface geology, faults and dykes in the Russell Vale East area was completed by Wollongong Coal geologists in 2013 (Gujarat NRE Coking Coal, 2014) as shown in **Figure 5-6**.

For discussion of the Russell Vale East geology, refer to Gujarat NRE Coking Coal (2013).

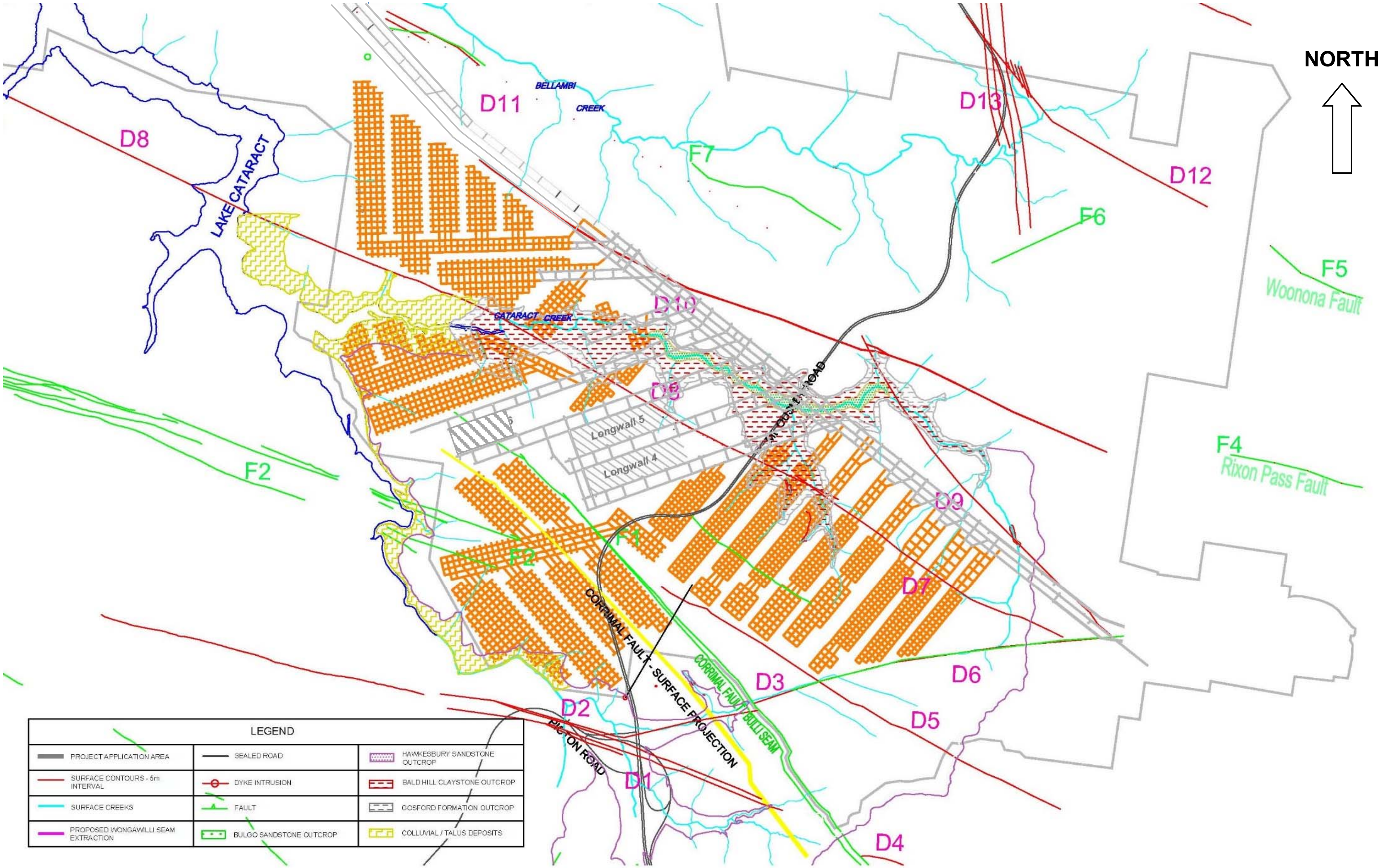


Figure 5-6 Russell Vale East Outcrop Geology and Structures

5.3.2 Underground Mapped Faults

There are no known major faults in the overburden above the proposed Russell Vale East workings, apart from the Corrimal Fault which has only been mapped in the Bulli workings in the western periphery of Russell Vale East as shown in **Figure 5-7**.

No known or observed groundwater inflows have been associated with any faults intersected by the workings at Russell Vale East in the Bulli, Balgownie or Wongawilli Seams (SCT Operations, 2019).

At the Bulli Seam level, the Corrimal Fault has a 1.3 – 3.0m displacement in the vicinity of the proposed workings. The Corrimal Fault trends in a SE / NW direction, and is located to the west of Longwalls 4 and 5, but passes through Longwall 6 (340m). It then phases out to the north of Longwall 6.

The maximum displacement of the Corrimal Fault within a 20m wide faulted zone is 28.7m, which reduces toward zero to the north of Longwall 6, and is not interpreted to be present between the proposed first workings and Cataract Reservoir (SCT Operations, 2019).

A NW / SE trending splay off the Corrimal Fault (associated with Dyke D5) and a SW / NE fault (associated with Dyke D6) are located to the south of the eastern block of workings, with the D6 fault crossing under Cataract River, to the west of the proposed eastern block.

The north-west south-east trending Rixon's Pass Fault is shown at surface on the 1:100,000 geological map to be sub-parallel to Cataract Creek, however, no trace of it has been identified in the Bulli or Balgownie workings.

Outside of the historic mine workings, the exact location, throw and inclination of the faulted zones are not known, and their potential position is extrapolated from drilling data and in-seam mapping.

5.3.3 Underground Mapped Intrusives

The proposed Wongawilli Seam workings are bound by dkyes D1,2,3,5,9, 10 and D11.

The SE / NW trending Dyke D7 cuts through the south eastern group of workings, then phases into Dyke D8, which cuts through the eastern end of Longwall 5 and within Longwall 6, before passing to the north west to the south of the northern group of workings. Limited in-seam silling has been mapped within the western end of Longwall 5, which significantly affected the extraction rate of LW5 and into Longwall 6 (340m).

Dyke D8 underlies Cataract Creek between the two northern groups of workings, but does not intersect Cataract Reservoir until it is approximately 720m west of the proposed first workings.

Dyke D8 has been mapped at surface as a highly weathered illite / montmorillonite clay, or totally eroded feature of up to 0.5m wide and with up to 0.8m of displacement. It is associated with smaller first order SE / NW trending gullies over the proposed south eastern workings as well as LWs 4 to 6 (340m).

No inflows to any of the three seams of workings have been observed in association with Dyke D8 (SCT Operations, 2019). No diatremes have been identified within the proposed subsidence area, however a large sill is located to the east and north of Russell Vale East. For further discussion of underground structures and intrusives, the reader is referred to Gujarat NRE Coking Coal (2014) as well as SCT Operations (2019A, B).

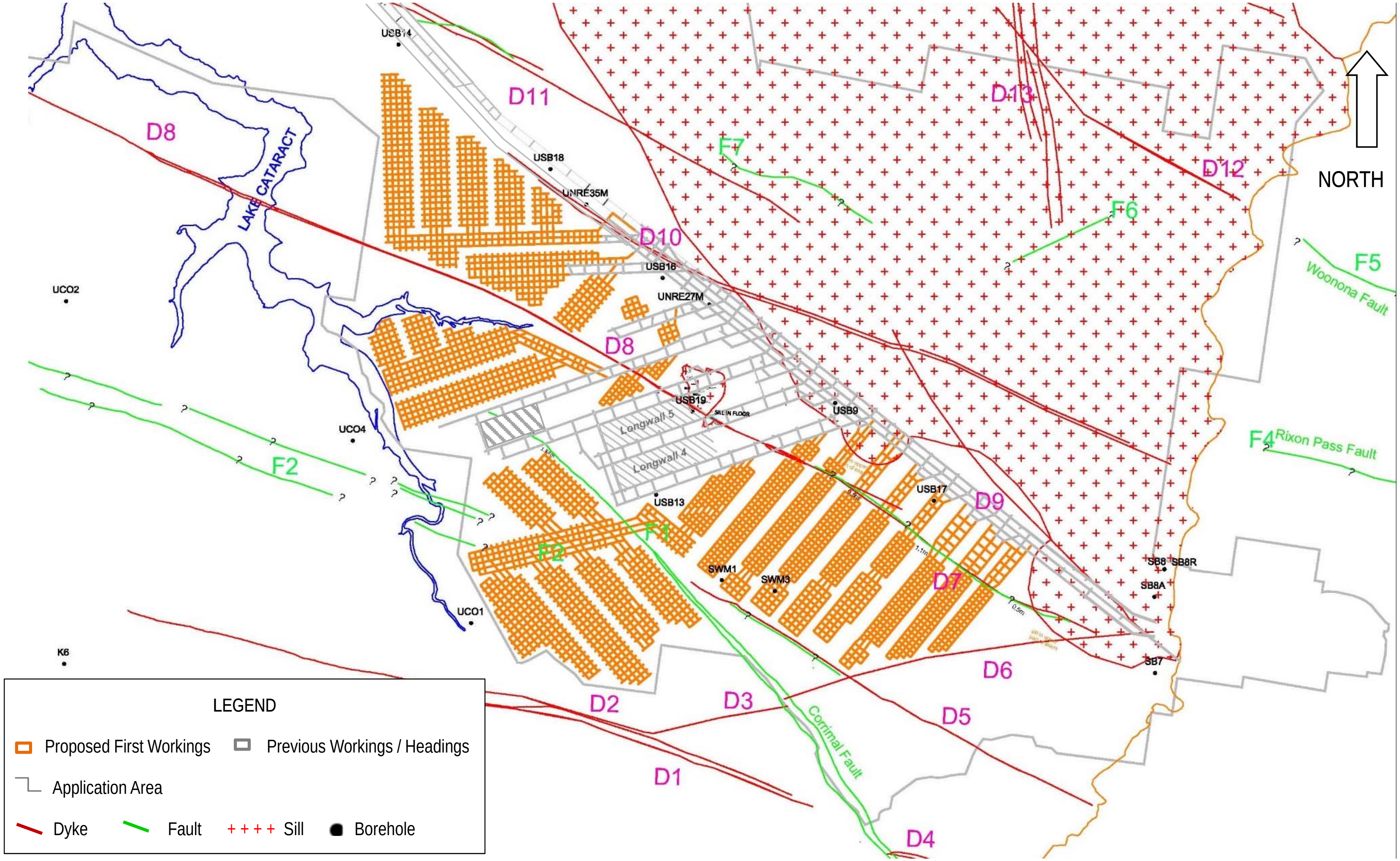


Figure 5-7 Russell Vale East (Wongawilli Seam) Structures and Intrusives

5.4 Strata Hydrogeology

Six general hydrogeological domains are present in the Russell Vale East and overall Application Areas, including the:

- hydraulically disconnected (perched) upland swamps;
- hydraulically disconnected (perched), ephemeral weathered Hawkesbury Sandstone;
- deeper Hawkesbury Sandstone, which is hydraulically separated from the underlying Bulgo Sandstone and deeper lithologies by the Bald Hill Claystone, except where the claystone is fractured by subsidence or eroded away in the channel of Cataract Creek;
- Narrabeen Group sedimentary lithologies, the lower portions of which have already been locally fractured and depressurised above the existing Wongawilli, Bulli and Balgownie seam workings and are interpreted to be fractured and/or depressurised over areas of triple seam mining up to the shallow surficial strata, whilst areas only mined in the overlapping Bulli and Balgownie secondary extraction areas are interpreted to extend to the upper Bulgo Sandstone;
- Illawarra Coal Measures, which contains the Bulli, Balgownie and Wongawilli Seam aquifers that have also been fractured and depressurised to varying degrees by the existing workings and will be locally fractured and depressurised by the proposed workings, and the;
- sedimentary sequence underneath the Wongawilli Seam.

Due to the steep topography and limited alluvium within the Cataract Creek and upper Cataract River catchments, there is no notable groundwater bearing stream based alluvium within Russell Vale East.

5.4.1 Hawkesbury Sandstone

Apart from aquifers in the coal seams, the main aquifer in the Application Area is the dual porosity (i.e interstitial pore space along with fractures and joint porosity) Hawkesbury Sandstone which, although having generally low permeability, can provide relatively higher groundwater yields compared to other lithologies in the area.

The Hawkesbury Sandstone outcrops over the majority of the lease area although it has been partially eroded in the central valley of Cataract Creek where the upper Bulgo Sandstone is exposed.

Regional water levels within the sandstone result from interaction between rainfall infiltration (recharge) through the shallow weathered zone into the underlying clastic rocks and with topography over geologic time. Rainfall infiltration elevates the water table whilst drainage channels incised through to the water table can provide seepage pathways that constrain groundwater levels to the elevation of stream beds through seepage into “gaining” streams.

Evapo-transpiration losses from deep and shallow rooted vegetation would also reduce the phreatic surface of the water table to varying degrees.

The low groundwater flow rates within the Hawkesbury Sandstone are primarily horizontal with minor vertical leakage due to the dominant horizontal bedding planes and bedding discontinuities interspersed with generally poorly connected vertical joints.

Ephemeral perched water tables within the upper 20m of the Hawkesbury Sandstone that are hydraulically disconnected from the underlying regional aquifer, can occur following extended rainfall recharge periods.

In rainfall recharge periods, water levels in shallow aquifers respond by rising, whilst in dry periods, levels are lowered through seepage to the local watercourses. During dry periods the salinity in surface drainages normally rises as the strata baseflow seepage proportionally increases.

Measured standing water levels in the Hawkesbury Sandstone range from to 12m to 39m below surface.

High yields of up to 30L/s have been identified outside of the local area by Water-NSW in the Kangaloon and Leonay-Wallacia areas where the sandstone is distinctly affected by deep regional scale fracturing associated with igneous intrusions or a major regional lineament along the base of the Blue Mountains associated with the Lapstone Monocline (SCA, 2006).

These high yielding sandstones are not located in or near the Russell Vale lease area.

Water quality in the Hawkesbury Sandstone generally has low salinity (81 - 420µS/cm) with relatively acidic pH (3.22-5.45) and can contain high iron levels up to 12.0mg/L in the Application Area.

5.4.2 Narrabeen Group

The Narrabeen Group lithologies have significantly lower yielding aquifers compared to the Hawkesbury Sandstone, with very minor productive supplies obtained in the Southern Coalfields due to its generally deeper elevation below surface and its very low permeability. The Bulgo Sandstone can contain salinities of up to 2300µS/cm (KBR, 2008) whilst the Scarborough Sandstone (Short et al. 2007) can average around 850µS/cm.

The Narrabeen Group is generally low yielding (<1.0L/sec), with its highest yields obtained from the coarser grained or fractured units.

The Narrabeen Group has generally low permeabilities, where the sandstones can provide porous storage with limited fracture flow and with low transmissivity, whilst mudstones, siltstones and shales effectively impede vertical flow. In some localities, groundwater flow may be enhanced by localised, secondary fracturing where faulting and/or jointing associated with bedding flexure or igneous intrusions can increase the hydraulic conductivity.

Hydraulic connection between the lithologies occurs through fractures and joints. Where vertical connectivity is present, more laterally uniform pressure distributions are exhibited. Some local scale faults and dykes are present in the Russell Vale lease area as shown in **Figure 5-7** although they are not anticipated to be large enough to enable loss of stream flow into the workings if dislocated by subsidence.

The Newport and Garie Formations, along with the underlying Bald Hill Claystone and the upper Bulgo Sandstone outcrop within the base of the headwater valleys within the Russell Vale East area would be directly recharged by stream flow leakage from Cataract Creek and Bellambi Creek.

The base of the Narrabeen Group is marked by the Wombarra Claystone which has very low permeability in its unsubsided state.

5.4.3 Illawarra Coal Measures

Water quality varies regionally both within and between coal seams and inter-burden in the Illawarra Coal Measures due to the complexity of groundwater flow, with the water being mostly brackish to saline.

The Balgownie, Bulli or Wongawilli Seams do not outcrop within the Application Area, although they outcrop along the lower section to the base of the Illawarra Escarpment. They would be recharged by vertical infiltration from overlying lithologies, and there is no direct connection between the seams and the surface creeks.

5.5 Registered Bores and Piezometers

There are no private bores or wells within the Russell Vale East Area.

The nearest registered bore on the Woronora Plateau is a test bore at Appin Colliery registered to BHP, which is located approximately 4.9km to the north of the proposed workings.

At present, one monitoring piezometer P514 (GW102223) is recorded in the NSW Natural Resource Atlas database in the vicinity of the proposed workings.

No local data within the proposed extraction area is available on bore yields, as there are no production bores present.

5.6 Geomorphology

The Application Area contains the regulated catchment of Cataract Creek, as well as portions of Cataract River and Bellambi Creek, upstream of Cataract Reservoir at Russell Vale East, which drain into Cataract Reservoir.

The catchments are described in detail in an associated report (WRM Water and Environment, 2015) to which the reader is referred for further discussion.

5.7 Stream Flow and Stream Water Quality

Conversion of stream pool depths to volumetric flows at Sites CC3, CC4, CC8 and CR2, as shown in **Figure 5-8**, has been conducted and is presented in WRM Water and Environment (2015), with subsequent data presented in Umwelt (2019).

Based on drilling information and site observations, streams are interpreted to be “losing” in the Russell Vale East catchment headwaters and “gaining” near Cataract reservoir.

However, due to the lack of drill rig accessibility to install piezometers in the valley floors, there is insufficient data to map where the transition occurs within the lease area.

Surface water drainage from the plateau to the local streams is through ephemeral first and second order gullies. The smaller gullies discharge into the major streams from elevated stream beds after sufficient rain, whilst the majority of rain would infiltrate into the plateau and swamp soils and weathered sandstone.

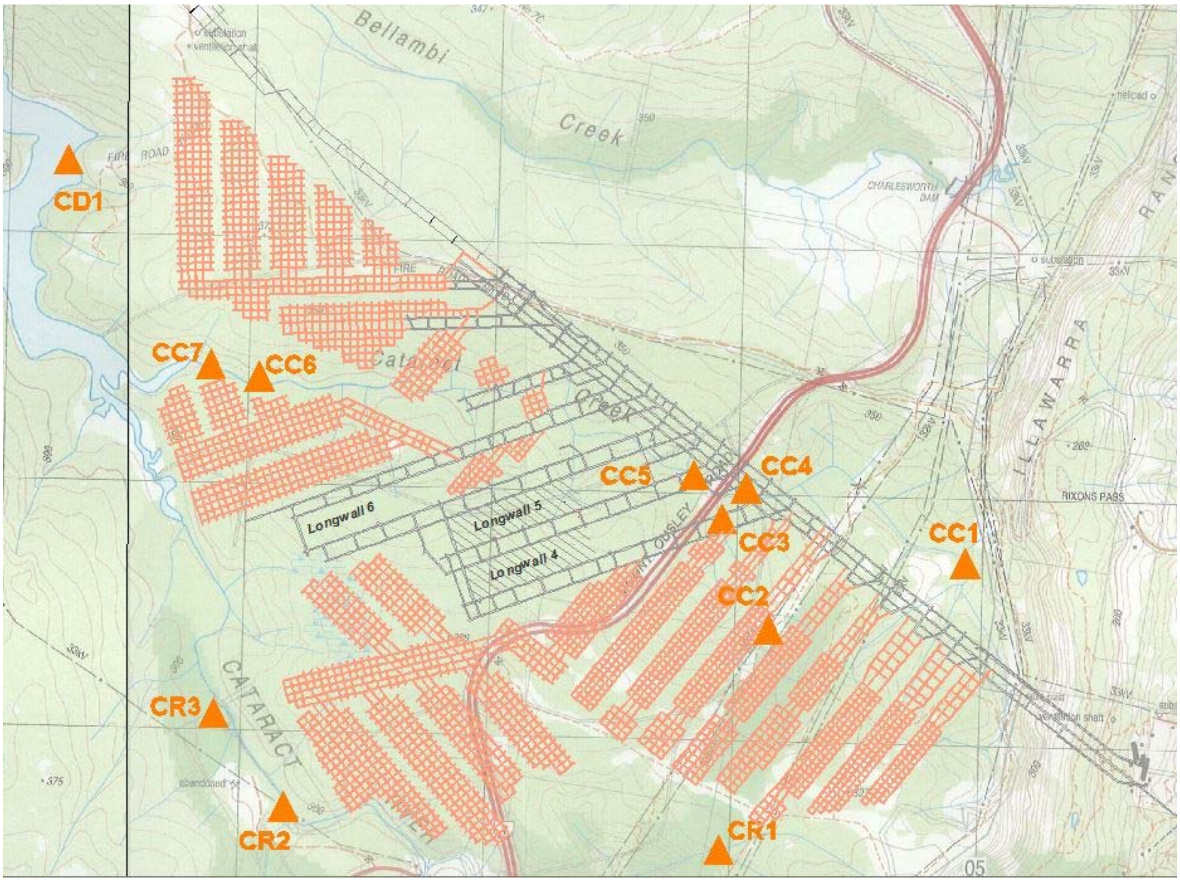


Figure 5-8 Russell Vale East Stream Monitoring Sites

Recharge to the shallow, and subsequently the deeper regional groundwater system, would occur over an extended delay of months to years. It would occur after the meteoric water has soaked through the plateau's soil and bedrock, with the majority of water discharging back into the creek system from temporary seeps in the swamps and creek beds along preferential horizontal flow regimes in the shallow outcropping bedrock.

The predominantly horizontal flow regime and restricted vertical recharge is essentially determined by the:

- horizontally bedded strata with preferential flow along bedded zones with coarser grain size,
- claystone/mudstone banding at the base and tops of sedimentary facies which restrict vertical migration and enhance horizontal flow at the base of the more porous unit,
- fracture zones enhancing horizontal flow through the strata, and;
- bedding planes or unconformities located immediately above finer grained sediments or iron rich zones.

Groundwater seepage to the local streams can occur at isolated iron stained seeps along the creek beds, where low volume and variable duration seeps discharge for a few days to weeks after significant rainfall. The seeps are generally located at the interface between coarser and underlying finer sandstone or shale/ sandstone interfaces which restrict vertical flow through the bedrock and enhance lateral flow. Most observed seeps in the local streams are anticipated to flow at less than 1L/sec.

The current interaction between surface water, perched and regional groundwater systems is postulated to be that pre-mining conditions prevail in that during wet periods there is a net contribution of groundwater to the surface system, while in dry conditions there is a net loss of surface water, with the resulting surface flow depending on the relative balance between seepage baseflow and stream outflow.

Mapping of the stream reach over the proposed workings indicates Cataract Creek is an ephemeral, "losing" stream in its first order headwater tributaries over the eastern and southern section of the southern proposed first workings, then becomes perennial downstream of that point where a seepage face is present in a 3m high sandstone rock face, down to its junction with Cataract Reservoir.

The surface water and shallow groundwater system is interpreted to be hydraulically isolated from the Bulli Seam workings in areas where only overlapping Bulli and Balgownie secondary extraction is present, although may not be separated where the overlapping workings of the Wongawilli Seam (Longwalls 4, 5 and 6(340m) have also been subject to longwall mining.

At present there are local scale aquifer systems at Russell Vale East over the subsided zone of the Bulli, Balgownie and Wongawilli Seam workings.

It is assessed an upper fractured unit is present from surface to approximately 20m below ground, which transitions into an elevated horizontal permeability zone caused by vertical bedding dilation, which does not necessarily contain a hydraulically connected, subsidence enhanced, vertical permeability component. This zone subsequently transitions into a sequentially higher permeability zone in the goafed and overlying deeper lithologies which can have a higher potential hydraulic connection to the Wongawilli Seam workings.

The Hawkesbury Sandstone and Bulgo Sandstone groundwater systems are not interpreted to be hydraulically separated in the valley of Cataract Creek where the Bald Hill Claystone is eroded through to the Bulgo Sandstone, downstream of the freeway. In addition, they may not be separated where the sandstone may have locally enhanced permeability due to its lack of lithostatic pressure where it has limited or no overburden, or where the Bald Hill Claystone has been fractured by subsidence.

The creeks and perched swamps are separated from the underlying regional groundwater system by a profile of unsaturated strata.

5.8 Groundwater Dependent Ecosystems and Upland Swamps

As no change to the potential effects on groundwater dependent ecosystems has occurred since the last two groundwater assessment reports, further discussion of the stream and upland swamp groundwater dependent ecosystems is contained in GeoTerra / GES (2014).

6. POTENTIAL STRATA DEFORMATION AND ASSOCIATED GROUNDWATER EFFECTS

6.1 Observed and Predicted Subsidence from Previous Mining

Table 2 summarises subsidence that has occurred as a result of mining the Bulli Seam (estimated), Balgownie Seam (measured) and Wongawilli Seam (measured subsidence for Longwalls 4, 5 and the westernmost 340m of Longwall 6) within the Russell Vale East domain.

For further discussion of the relevant subsidence observations and predictions, refer to SCT Operations (2019).

Table 2 Predicted and Measured Subsidence

	Previous Subsidence (m)	Predicted (Measured) Subsidence (m)	Predicted (Measured) Tilt (mm/m)	Predicted (Measured) Tensile Strain (mm/m)	Predicted (Measured) Compressive Strain (mm/m)	Maximum Cataract Creek Closure (mm)
LW1	1.3	2.1	40	+12	-24	650
LW2	1.1	2.1	40	+12	-24	610
LW3	1.3	2.6	51	+15	-31	350
LW4	1.9	2.1 **(1.6)**	35 **(30)**	+10.5 **(7.5)**	-21 **(-14)**	N/A
LW5	0.9	1.9 **(1.8)**	36 **(30)**	+10.8 **(6)**	-22 **(-12)**	**(49) closure site CS4**
LW6 (340m)	1.5	2.1 **(0.42)**	38 (TBA)	+11 **(+1.3)**	-23 **(-2)**	400 **(59) CS4**

NOTE: measured parameters are shown in brackets

6.2 Predicted Subsidence from Revised Preferred Project Mine Plan

SCT (2019) assessed the potential subsidence movements associated with the proposed Revised Preferred Project Mine Plan and found that the proposed mining layout is likely to be long-term stable with a low potential to cause significant:

- surface subsidence;
- interaction with the overlying seams, or;
- interaction with existing groundwater systems.

The proposed layout is not considered to have any potential to perceptibly impact natural surface features including;

- upland swamps;
- cliffs, including the Illawarra Escarpment;
- steep slopes;
- creeks and drainage lines, and;
- Cataract Reservoir.

Assuming the overlying workings are not required to be drained for mining in the Wongawilli Seam, any impacts on groundwater are expected to be limited only to the immediate vicinity of the Wongawilli Seam and only in the area of the proposed mining.

A peer review of the subsidence assessment has also been completed. The peer review supported the findings of the subsidence assessment for the Revised Preferred Project.

The peer review stated the following in relation to the risk of potential surface and groundwater interactions:

- the proposed mining is not expected to result in any significant subsidence impacts on either the surface or sub-surface groundwater regimes;
- there is no credible risk of water flow along major structures from Cataract Reservoir as a result of the proposed first workings in the Wongawilli Seam;
- the proposed mining is not considered likely to alter the status of mining/groundwater or surface interaction;
- impacts on groundwater are not expected to occur beyond the immediate vicinity of the Wongawilli Seam.

Table 3 summarises predicted subsidence as a result of the proposed first workings mine plan in the Wongawilli Seam within the Russell Vale East domain.

Table 3 Predicted First Workings Subsidence

	Previous Subsidence (m)	Predicted Subsidence (m)	Predicted Tilt (mm/m)	Predicted Tensile Strain (mm/m)	Predicted Compressive Strain (mm/m)	Maximum Cataract Creek Closure (mm)
Proposed 1st Wkgs	1.2	<0.1	imperceptible	imperceptible	imperceptible	imperceptible

7. HYDROGEOLOGICAL INVESTIGATIONS

Within the Wollongong Coal Russell Vale lease area, groundwater level and / or hydrostatic water pressure monitoring has been conducted for the Hawkesbury Sandstone and underlying lithologies over the 500 series Longwalls adjacent to the western side of Cataract reservoir (Singh, R.N. Jakeman, M. 2001) as shown in **Figure 7-1**.

The extent of historic fracturing and overburden depressurisation due to subsidence over previous Wollongong Coal workings was initially assessed in SCT Operations (2014) and also updated by their assessment of the hydraulic and geological characteristics of the Corrimal Fault and Dyke D8 (SCT Operations, 2015). Their findings are discussed in subsequent sections of this report.

Groundwater investigations specifically focussed on mining within the Wongawilli Seam in Russell Vale East area have involved installation of:

- 13 open standpipes, including 5 piezometers installed since September 2014, as well as;
- 12 vibrating wire array piezometers, including 5 additional VWP arrays installed since July 2014,

as shown in **Figures 7-1** and **7-2**, with drilling extending to 374m below surface.

Drilling was contained within the Russell Vale lease area, although the groundwater model domain extends out to include the adjacent South32 lease areas and current / decommissioned / proposed workings as well as peripheral areas within the major watersheds outside of the lease (refer to **Figure 1-1**).

Ongoing monitoring of stream water quality, groundwater seepage and stream flow studies conducted since 2001, as well as installation and monitoring of the open standpipe and vibrating wire piezometer suite up to the completion of 340m of extraction in Longwall 6 is reported in GeoTerra (2015).

Vibrating wire piezometers in open standpipe bores P501 and P502 were used to monitor groundwater levels since December 1992 and August 1993 over Longwalls 501 and 502 respectively.

An open standpipe piezometer was installed in P514 over Longwall 514 in November 1998.

The locations of P501, P502 and P514 and their relative location to the historic longwalls (LW501, 502 and LW514) are shown in **Figure 7-3**.

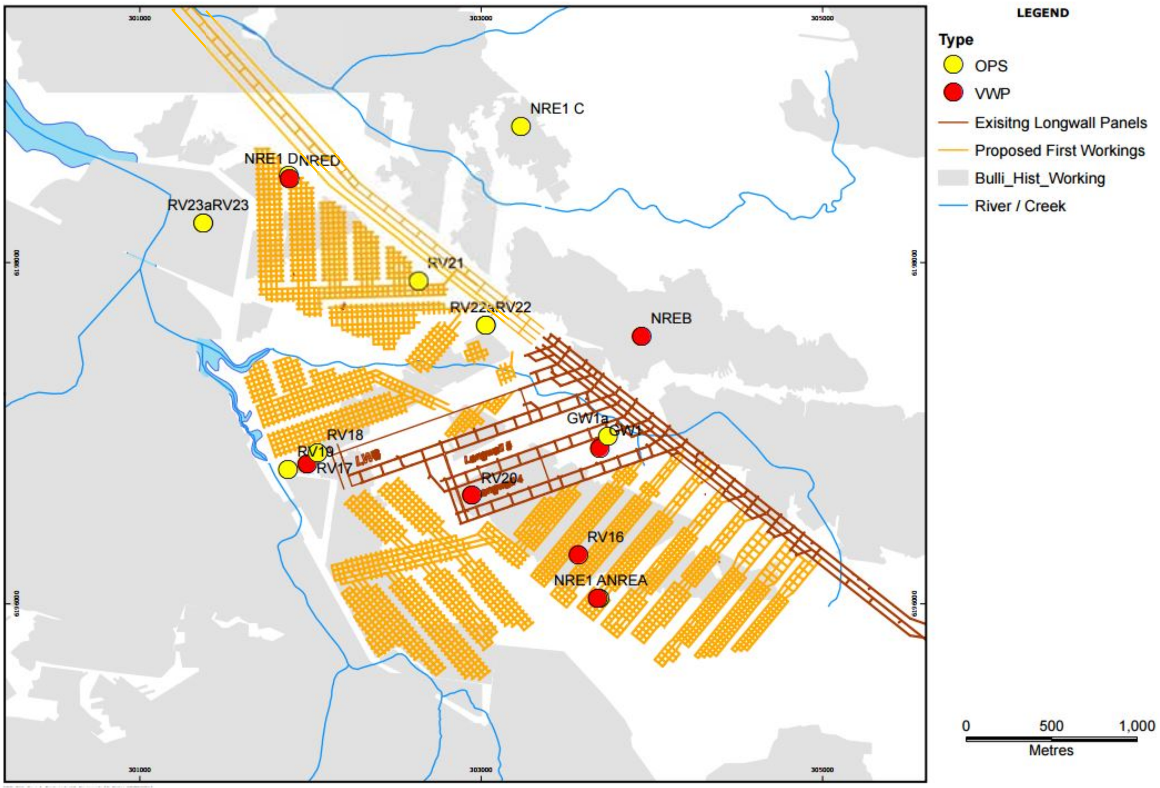


Figure 7-1 Russell Vale East Colliery Piezometer Location

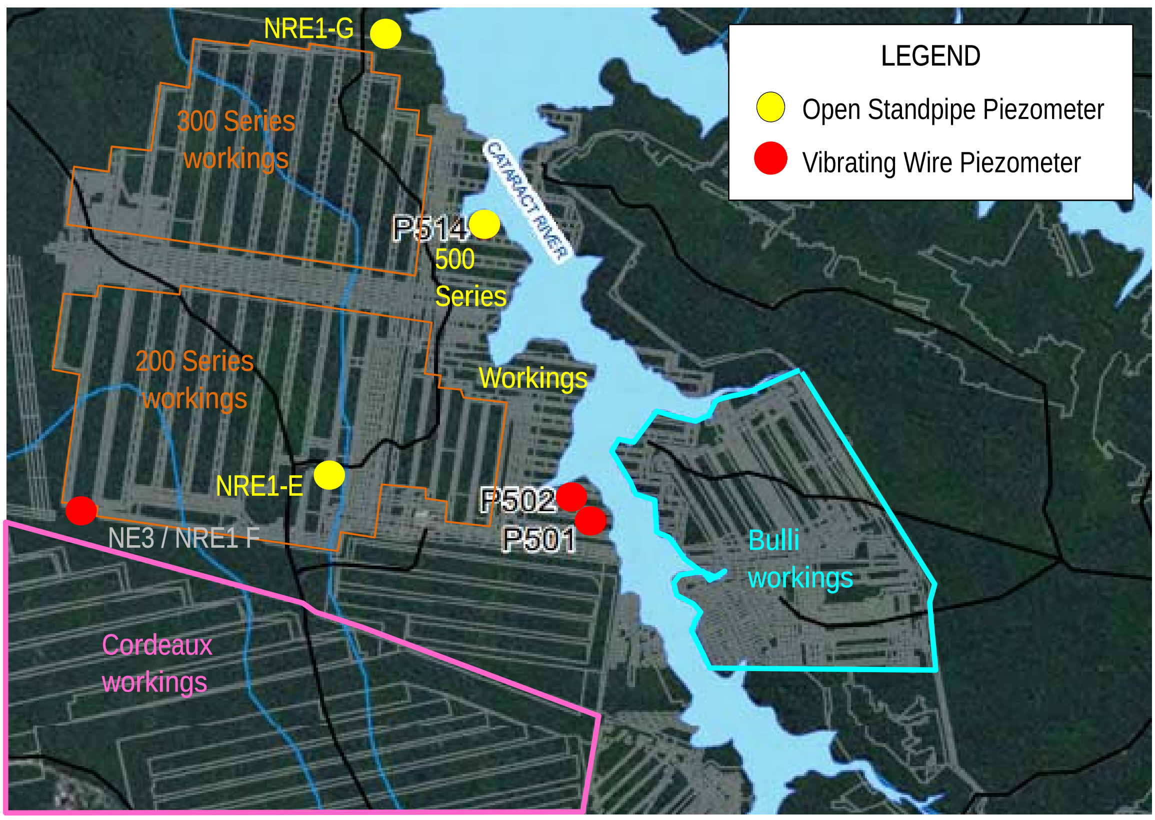


Figure 7-2 Russell Vale West Piezometers and Associated Workings

7.1 Strata Hydraulic Properties

The strata hydraulic properties have previously been outlined, and for further information refer to GeoTerra / GES (2015).

7.2 Hawkesbury Sandstone Open Standpipe Shallow Groundwater Levels

Thirteen open standpipe piezometers (OSP) have been installed in the upper Hawkesbury Sandstone within the Russell Vale Lease area, with their locations shown in **Figures 7-1** and **7-2** and their details are summarised in **Table 4**.

Table 4 Open Standpipe Piezometers

Bore	Installed	E	N	Total Depth (m)	Screen Interval (mbgl)
NRE1 A	21/11/09	303692.00	6196033.00	47.20	24.0 – 47.0
NRE1 C	3/12/09	303233.42	6198796.75	24.00	18.0 – 24.0
NRE1 D	6/11/09	301870.50	6198509.26	52	40.0 – 52.0
NRE1 E	23/10/09	296727.38	6202286.29	29.00	26.0 – 29.0
NRE1 F	5/12/09	294803.00	6201954.00	60.0	n/a
NRE1 G	20/10/09	296949.41	6205677.70	53.00	50.0 – 53.0
GW1A	22/8/12	303741.80	6196983.10	27.00	21 - 27
WCRV18	10/9/14	302041.00	6196884.80	20.05	8 – 20
WCRV19	17/9/14	301867.70	6196787.10	18.40	10 – 18.4
WCRV21	28/11/14	302633.00	6197894.00	22.85	9 – 22.65
WCRV22A	28/10/14	303026.00	6197634.00	37.35	7 – 37.35
WCRV23A	26/11/14	301370.00	6198233.00	26.35	7 – 26.4
P514	01/11/98	297917.00	6204280.00	191.00	160 - 188

Water level variability has been measured in open standpipe piezometers installed in the upper Hawkesbury Sandstone as shown in **Figures 7-3** and **7-4**.

The monitoring data indicates that the Russell Vale East piezometers are generally more responsive to rainfall than in the western part of the lease area, with the variability principally due to the degree of subsidence and overburden fracturing that has occurred over the Russell Vale East workings.

The upper Hawkesbury Sandstone aquifer extends across the Application Area, with piezometer data indicating phreatic water levels range 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 GW1A, all of the piezometers installed by Wollongong Coal have monitored the post mining period in the Bulli and / or Balgownie mining phases.

GW1A 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.

GW1 subsequently had no discernible effect from extraction of Longwall 6 (340m) between 4/5/15 and 8/7/15, although a minor recovery in the Stanwell Park Claystone was evident after extraction ceased.

Re-establishment of the pre-mining water level generally occurs over a number of years, although to date, no recovery has occurred below the lower Bulgo Sandstone, with steady state reduced levels being predominant in the GW1 overburden. Water levels may not necessarily fully recover depending on rainfall recharge in the catchment and the post subsidence outflow seepage rate, if it occurs, to local streams.

The open standpipe piezometers in the vicinity of the recently active Wongawilli Seam Longwalls 4, 5 and 6 (i.e. GW1A, RV18 and RV19) do not show depressurisation resulting from subsidence induced fracturing of the overburden, whilst other piezometers such as NRE A and NRE D exhibit a heightened response to rainfall recharge as a result of shallow sandstone overburden subsidence induced fracturing.

Interestingly, the WCRV21 water levels have been tracking down to lower elevations in accord with the rainfall residual plot since the piezometer was installed in December 2014.

The high water level variability in NRE F is unusual, and is interpreted to be due to incomplete sealing of the surface casing annulus, which allows overland surface water runoff to enter the casing and “artificially” raise the standing water level in the piezometer.

All of the shallow sandstone piezometers show a variable responsiveness to climatic variability and rainfall recharge that replicates, in a subdued manner, the variability of the rainfall residual plot.

7.2.1 NRE1 A

As shown in **Figure 7-1** NRE1 A is located next to the VWP array (also called NRE A) on a ridge in the Hawkesbury Sandstone in an area with only first workings in the Bulli Seam (approx. 285 mbgl), with nearby longwall mining in the Balgownie Seam and no nearby mining in the Wongawilli Seam.

Pre-existing tension cracks are present close to NRE A, with the high level of vertically connected cracking and consequently a high level of vertical conductivity considered to result from vertical fractures and opening of existing joints caused by horizontal tensional stretching of the shallow overburden (SCT Operations, 2019).

NRE A was installed to 47mbgl in Hawkesbury Sandstone. It is located approximately 750m south east (and upgradient) of Wongawilli Seam Longwall 4 and is well outside the area of depressurisation influence from Longwalls 4, 5 or 6(340m).

It is also located approximately 450m southwest of Cataract Creek and, like NRE A (VWP) has a strong correlation to the rainfall residual plot.

7.2.2 NRE1 C

As shown in **Figure 7-1** NRE1 C is located on a ridge in the Hawkesbury Sandstone in an area with predominantly first workings in the Bulli Seam and no workings in the Balgownie or Wongawilli Seams.

No pre-existing tension cracks have been observed near NRE1 C.

NRE1 C was installed to 24mbgl in Hawkesbury Sandstone. It is located well outside the area of depressurisation influence from Longwalls 4, 5 or 6(340m) and is located approximately 430m north of Bellambi Creek, with a moderate correlation to the rainfall residual plot.

7.2.3 NRE1 D

As shown in **Figure 7-1** NRE1 D is located on a ridge in the Hawkesbury Sandstone, adjacent to NRE1 D (VWP) in an isolated area of pillar extraction and first workings in the Bulli Seam and no workings in the Balgownie or Wongawilli Seams.

No pre-existing tension cracks have been observed near NRE1 D.

NRE1 D was installed to 52mbgl in Hawkesbury Sandstone and is located well outside the area of depressurisation influence from Longwalls 4, 5 or 6(340m).

It is located approximately 580m east of Cataract Reservoir and has a moderate to strong correlation to the rainfall residual plot.

7.2.4 NRE1 F and NRE1 G

As shown in **Figure 7-2,** the two piezometers are located in the Russell Vale West mining area, to the west of Cataract Reservoir and all overlie first workings and longwalls in the Bulli Seam.

No pre-existing tension cracks have been observed near any of the piezometers.

NRE1 F was installed to 60mbgl and NRE1 G to 53mbgl in Hawkesbury Sandstone.

NRE1 F and NRE1 G have a low correlation to the rainfall residual plot.

7.2.5 RV18 and RV19

As shown in **Figure 7-1** RV18 is located approximately 135m west of Longwall 6 (340m), whilst RV19 is located approximately 330m west of Longwall 6, with both piezometers overlying first workings within the Bulli Seam. RV18 was installed to 20mbgl and RV19 to 17.5mbgl in the Hawkesbury Sandstone.

Both piezometers lie between the Longwall 6 and the Cataract Reservoir and both have a moderate correlation to the rainfall residual plot.

The water level in RV18 ranges from 7.6 to 10.3mbgl, or 332.1 – 329.3 mAHD, which is at least 39.4m above the reservoir FSL of 289.87 mAHD.

The monitoring data does not indicate a correlation to, or depressurisation resulting from, extraction of Longwall 6 (340m) in either piezometer, although there is a definitive rise and fall in associated with an east coast low rain event in mid to late April 2015 that occurred whilst LW6 was being mined as well as in June 2016.

7.2.6 RV21, 22A and RV23A

As shown in **Figure 7-1** RV21 and RV22A are located on a ridge and south facing hillslope to the north of Cataract Creek, whilst RV23A is located approximately 85m east of the reservoir FSL over first workings in the Bulli Seam of Corrimal Colliery, with no workings in the Balgownie or Wongawilli Seams.

No pre-existing tension cracks have been observed near any of the three piezometers.

RV21 was installed to 22.7mbgl, RV22A to 37.4mbgl and RV23A to 26.6mbgl in Hawkesbury Sandstone, and they are all located well outside the area of depressurisation influence from Longwalls 4, 5 or 6(340m).

RV21 has a very strong, whilst RV22 and RV23 both have a moderate to strong correlation to the rainfall residual plot.

7.2.7 GW1A

As shown in **Figure 7-1** GW1A was installed to a depth of 27m in September 2012 after completion of Longwall 4. It is located above Longwall 7B in the Balgownie Seam where the Hawkesbury Sandstone has been completely eroded and is installed at the same stratigraphic depth in the Bulgo Sandstone as the 30m intake in the VWP array in bore GW1.

The bore is located between the VWP piezo (GW1) and Cataract Creek, which is approximately 105m to the north east. It is approximately 420m from the northern end of LW4 and 125m to the southeast of LW 5.

The piezometric pressure profile in GW1A is essentially the same as the 30mbgl VWP intake water level within the Bulgo Sandstone.

The water level in GW1A is near the level of Cataract Creek (RL300m) with a moderate correlation to the rainfall residual plot.

The slight reduction in the phreatic surface that commenced soon after LW5 started and continued throughout the period of mining LW5 correlates to a reducing trend in the rainfall residual plot and is not definitively associated with Longwall 5 subsidence effects.

The intake zone of GW1A may be hydraulically connected to Cataract Creek, possibly via a horizontal shear/s located just below the level of Cataract Creek, where rainfall recharge and / or stream water is able to flow within the shear horizon.

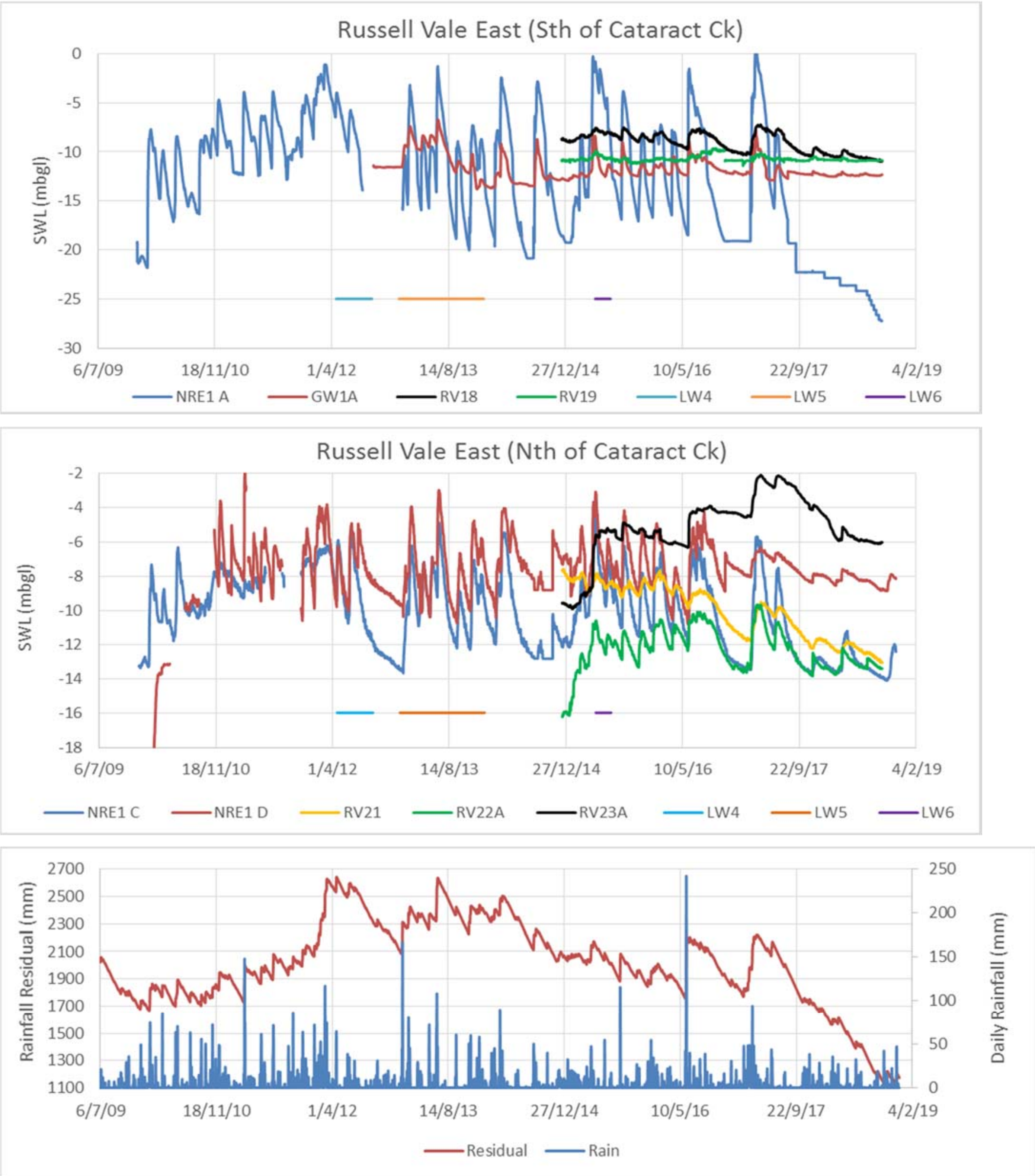


Figure 7-3 Russell Vale East Open Standpipe Groundwater Levels (mbgl) and Rainfall

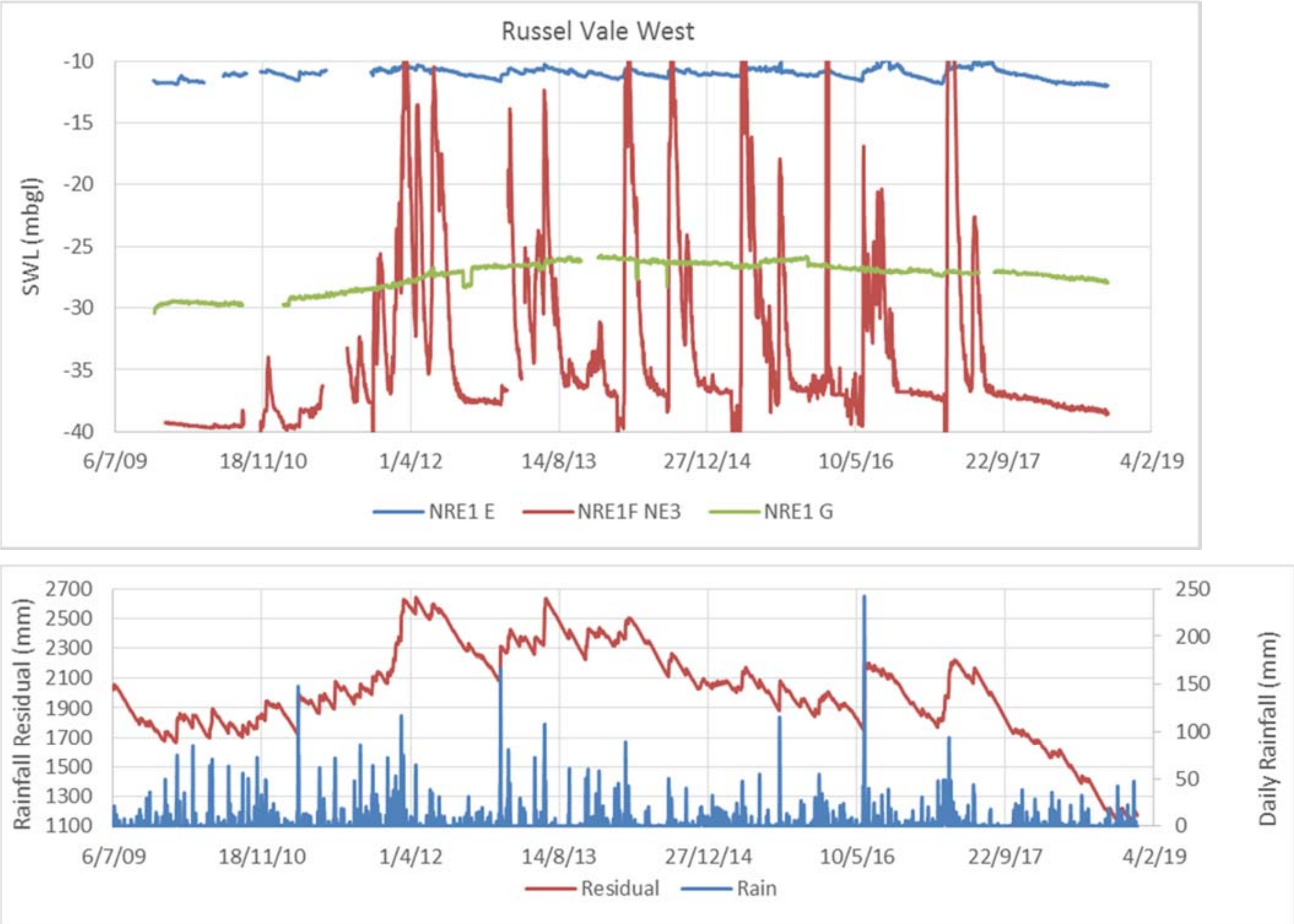


Figure 7-4 Russell Vale West Open Standpipe Groundwater Levels (mbgl) and Rainfall

A contour plot of the regional upper Hawkesbury Sandstone piezometric surface based on data from the open standpipe and upper vibrating wire piezometer intakes as well as assumed water levels in the base of valleys and along Cataract Reservoir is shown in **Figure 7-5**.

The plot indicates a general flow at Russell Vale East toward Cataract Reservoir.

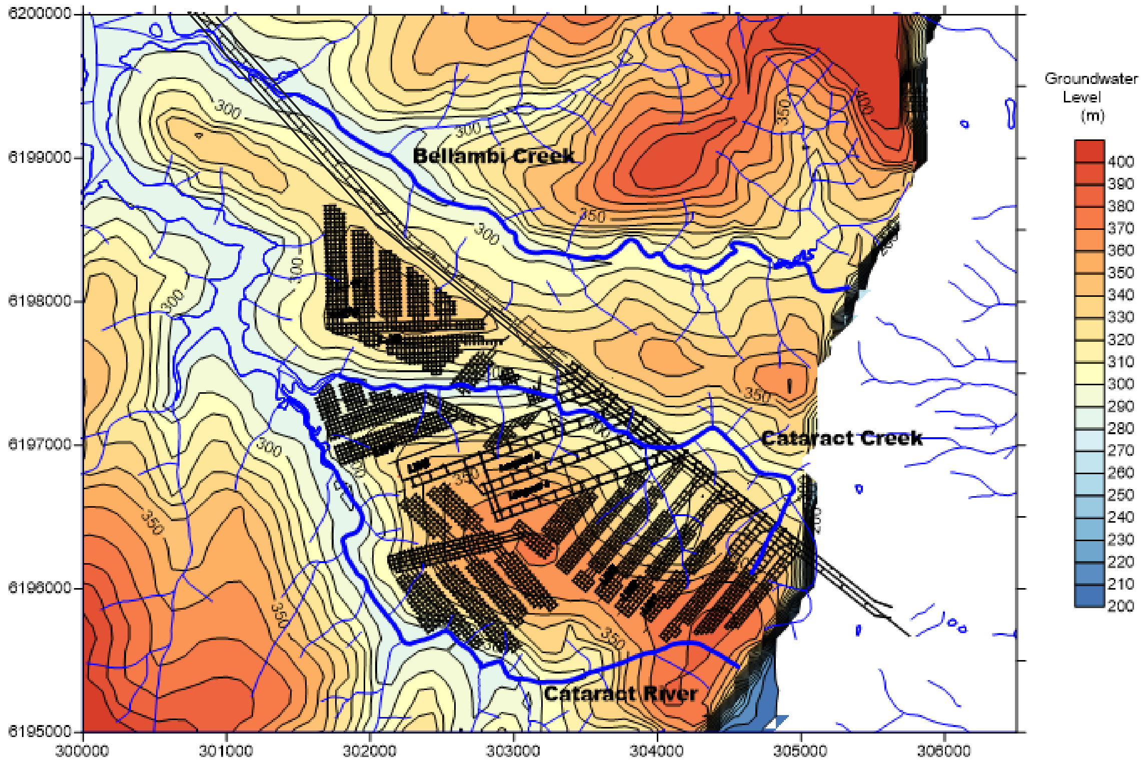


Figure 7-5 Russell Vale Colliery Phreatic Surface Groundwater Contours

7.3 Vibrating Wire (Multi-Level) Piezometers

Twelve multi-level vibrating wire piezometers (VWP) have been installed at selected depths between the Upper Hawkesbury Sandstone and the Stanwell Park Claystone at Russell Vale East and Wonga West as summarised in GeoTerra / GES (2015) and detailed in **Table 5**. The location of VWPs in the Russell Vale East and Russell Vale West areas are shown in Figure **7-1** and **7-2**

Two of the VWP's were originally installed in 1992 as part of an investigation of the Russell Vale West 500 series longwall subsidence and groundwater response in piezometers P501, P502 (Singh R.N, Jakeman, M. 2001).

Although they are no longer active, these earlier piezometer arrays augment the latter VWP installations at Russell Vale East and Russell Vale West as discussed in GeoTerra / GES (2014).

Table 5 Vibrating Wire Piezometers

Piezometer	E	N	TD mbgl	Intakes (mbgl)
P501*	298771.00	6201855.00	335.00	110 (HS), 174, 26, 274 (BS) 325 (SS)
P502*	298598.00	6202049.00	167.00	90 (HS) 167, 218 (BS)
NRE A VWP	303680.00	6196034.00	153.00	45, 60(HS) 75 140(BS)
NRE B	303939.00	6197567.00	170.00	27.5(HS) 43 63(BS) 168(SPCS)
NRE D VWP	301875.00	6198493.00	176.00	33, 60(HS) 73(BHCS) 135(BS)
NRE3	294802.60	6201953.62	282.40	100, 130, 155 (HS) 255 (BS)
GW1	303693.00	6196913.00	107.10	18, 30 (HS) 45 (BHCS) 63, 93, 125 (BS) 140 (SPCS) 165 (SS)
WCRV16 VWP	303567.40	6196288.10	322.20	21.8(HS), 51.8 (BHCS) 91.8, 131.8, 161.8 (BS) 196.8 (SPCS) 241.8 (SBSS)
WCRV17 VWP	301797.00	6196818.40	79.90	20 (HS) 40 (NP) 60, 75 (BS)
WCRV20 VWP	302944.27	6196635.72	134.65	35, 50.5 (HS) 75, 100, 140, 175 (BS) 200(SPCS) 230 (SS)
WCRV22 VWP	303026.00	6197634.00	234.30	25 (HS) 50 (BHCS) 75, 100, 140, 175 (BS) 200 (SPCS) 230 (SS)
WCRV23 VWP	301370.00	6198233.00	222.35	20 (NP) 40 (BHCS) 70, 90, 130, 170 (BS) 200 (SPCS) 220(SS)

NOTE: HS - Hawkesbury Sandstone NP - Newport Formation BHCS - Bald Hill Claystone BS - Bulgo Sandstone SPCS - Stanwell Park Claystone SS - Scarborough Sandstone
* P501 and P502 are no longer actively working

7.3.1 GW1

GW1 was installed in September 2012 to 165mbgl into the Scarborough Sandstone after completion of Longwall 4 and prior to extraction of Longwall 5.

It is approximately 350m east of Longwall 4 and 130m south east of Longwall 5 in an area mined by Bulli Seam bord and pillar, Bulli Seam pillar and Balgownie Seam longwall extraction.

GW1 is located above the goaf of Balgownie Seam Longwall 7B where the Hawkesbury Sandstone has been completely eroded away, and is approximately 175m west of Cataract Creek.

Two groundwater systems are indicated in the VWP array, with a near surface perched water table around 30mbgl and a deeper system within the Bulgo Sandstone and below with limited vertical hydraulic connection between the two as shown in **Figure 7-6**.

The phreatic surface of the perched water table, as indicated by the 18mbgl intake, is close to, although above the level of Cataract Creek (approximately RL300m). The 30mbgl intake is near the level of Cataract Creek (RL300m) whilst the 45mbgl intake is below the creek, between 298.9 and 289.3mAHD.

Apart from the 30mbgl intake, the VWP array has a weak responsiveness to rainfall, with a slightly enhanced response in the deepest two intakes.

The array responded to extraction of Longwall 5, particularly in the mid to lower Bulgo Sandstone and Stanwell Park Claystone, but not in the Scarborough Sandstone, with depressurisation in the shallow Bulgo Sandstone intakes possibly due to basal shear plane activation whilst the lower responses were due to enhanced secondary fracture porosity and enhanced vertical and horizontal permeability in the overburden.

Longwall 5 was extracted in stages, with the VWPs showing depressurisation whilst the longwall was active and recovery when it temporarily stopped. A longer term depressurisation response occurred when the longwall was completed, which is sympathetic with the decline in rainfall shown in the rainfall residual plot.

The uppermost piezometer at 18m below the surface does not change significantly over time whilst the 30m intake shows enhanced responsiveness to rainfall and catchment runoff / streamflow after the extraction of Longwall 5, although there is no long term depressurisation at that intake depth.

The 45mbgl intake has a muted response to rainfall but shows a definitive depressurisation during and after extraction of Longwall 5.

The relative pressure heads shown by the shallowest three piezometers indicates a slight downward gradient, with flow into the lower overburden, with a downward hydraulic gradient also being evident throughout the Bulgo Sandstone.

The height of depressurisation in GW1 lies between 140 and 165mbgl.

The pressure profile indicates that the vertical flow rate is likely to be relatively insignificant in comparison with rainfall recharge.

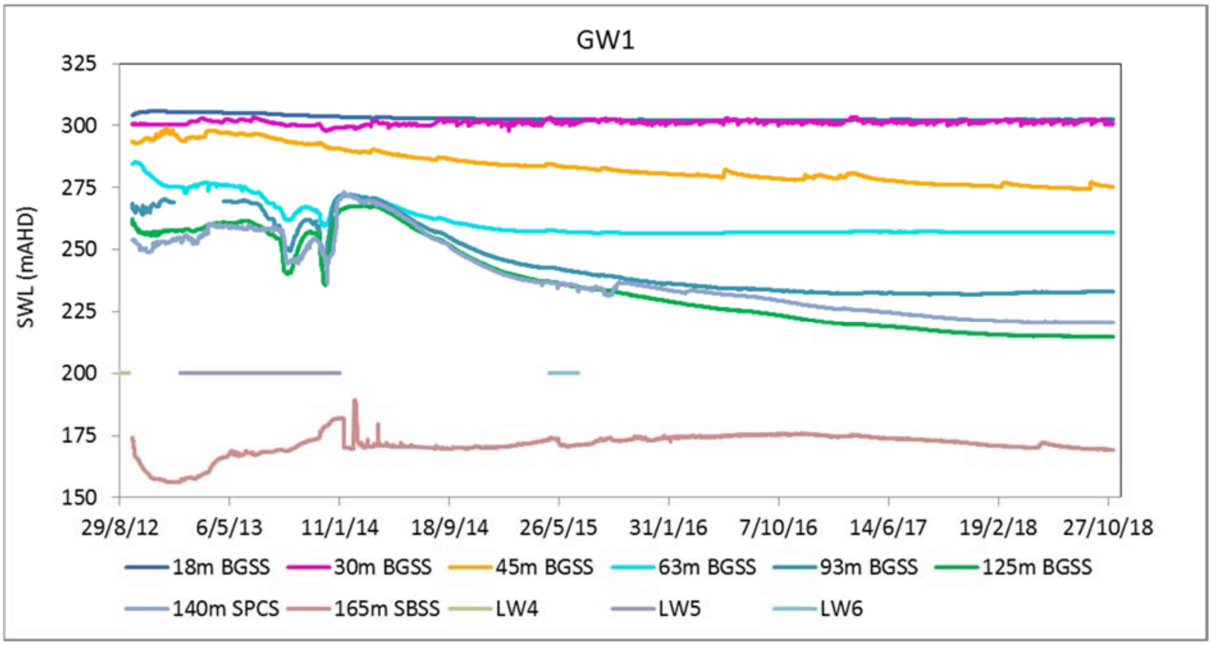


Figure 7-6 GW1 VWP

7.3.2 NRE A (VWP)

NRE A (VWP) was installed in mid November 2009 to a depth of 140mbgl in the mid to lower Bulgo Sandstone.

It is located on a ridge in the Hawkesbury Sandstone in an area where there are only first workings in the Bulli Seam (approx 285 mbgl), with nearby longwall mining in the Balgownie Seam and no nearby mining in the Wongawilli Seam.

Pre-existing tension cracks are present close to NRE A (VWP), with the high level of vertically connected cracking and consequently a high level of vertical conductivity observed in NRE A (VWP) is considered to be a result of the presence of vertical fractures and opening of existing joints caused by horizontal tensional stretching of the shallow overburden (SCT Operations, 2014).

It is located approximately 750m south east (upgradient) of Wongawilli Seam Longwall 4 and is well outside the area of depressurisation influence from Longwalls 4, 5 or 6.

The VWP array is located approximately 540m north of Cataract River and 485m south west of Cataract Creek.

The elevation of the phreatic surface ranges from RL340m to RL360m which is at the level of the upper headwaters of Cataract Creek and is likely to be contributing to an intermittent to perennial base flow into Cataract Creek as shown in **Figure 7-7**.

No definitive shallow system perched water table is evident, and it has an essentially hydrostatic gradient from 45 – 140mbgl.

The VWP array has a strong responsiveness to rainfall in all intakes, albeit slightly subdued at 140mbgl consistent with the full column being vertically connected through the Hawkesbury Sandstone, the Bald Hill Claystone and approximately 75m into the Bulgo Sandstone as a result of mine subsidence indicating a high degree of vertical connectivity, with the Bald Hill Claystone not reducing vertical downward flow at this location.

Given the high vertical conductivity indicated by the rainfall response, the presence of a downward hydraulic gradient indicates a potential for this area to be a significant area of rainfall recharge.

The array did not respond to extraction of Longwalls 4, 5 or 6 (340m) due to its separation distance from the workings.

The bore does not extend deep enough to assess the height of depressurisation, however, the data indicates there is a downward hydraulic gradient, although the hydraulic properties of the overburden is sufficiently low to generate a very small downward flow component.

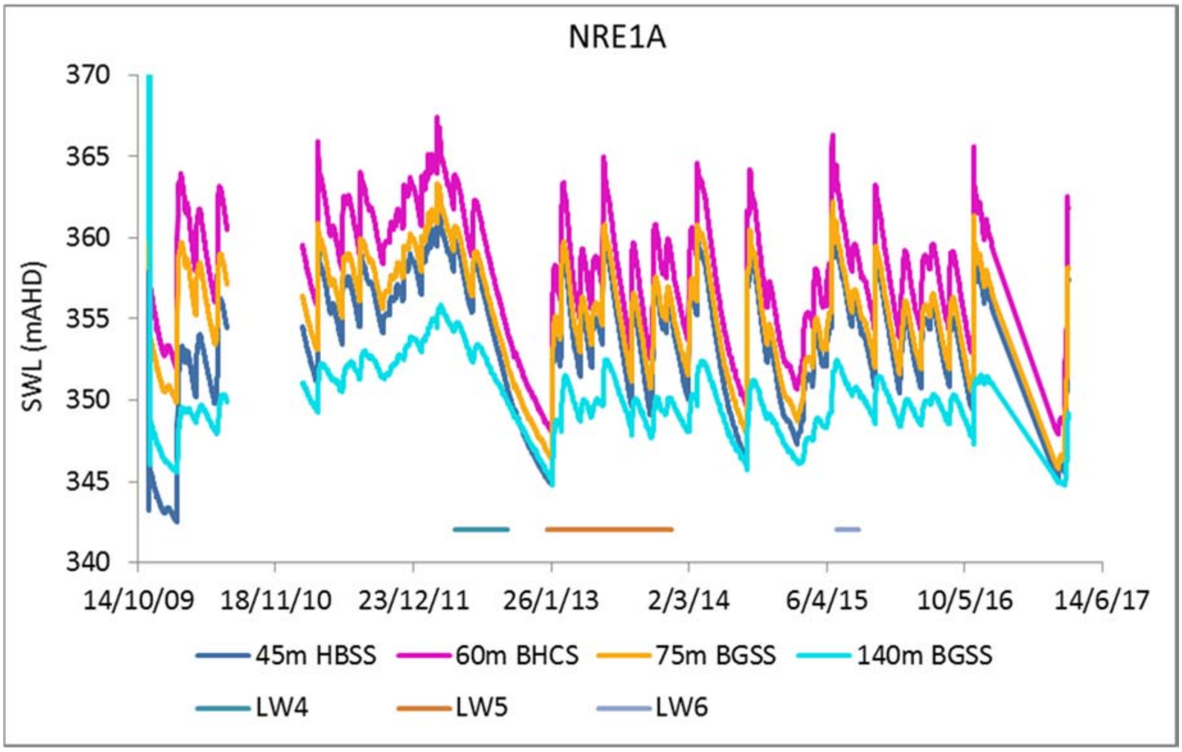


Figure 7-7 NRE A (VWP)

7.3.3 NRE B

NRE B was installed in late November 2009 to a depth of 168mbgl into the Bulgo Sandstone.

It is located on a watershed in Hawkesbury Sandstone in an area with only pillar extraction in the Bulli Seam and is approximately 790m ENE of the proposed eastern end of Longwall 6 in the Wongawilli Seam and is well outside the area of depressurisation influence from Longwalls 4, 5 or 6 (340m).

No pre-existing tension cracks are present close to NRE B, and its shows a low degree of vertical conductivity.

The VWP array is located approximately 515m north east of Cataract Creek.

An elevated phreatic surface is present to approximately 43mbgl (RL330m) which is likely to be contributing to base flow in Cataract Creek, however the profile is essentially depressurised at 63mbgl as shown in **Figure 7-8**.

The VWP array has an overall low responsiveness to rainfall.

Pore pressures in the Hawkesbury Sandstone are perched well above the level of Cataract Creek and the Cataract Reservoir, whilst pore pressure in the Bulgo Sandstone is below the 289.87mAHD Full Supply Level (FSL) of Cataract Reservoir.

The VWP array did not respond to extraction of Longwall 4, 5 or 6 due to its separation distance from the workings.

The bore does not extend deep enough to assess the height of depressurisation, however, the data indicates there is a downward hydraulic gradient, although the hydraulic properties of the overburden is sufficiently low to generate a very small downward flow component.

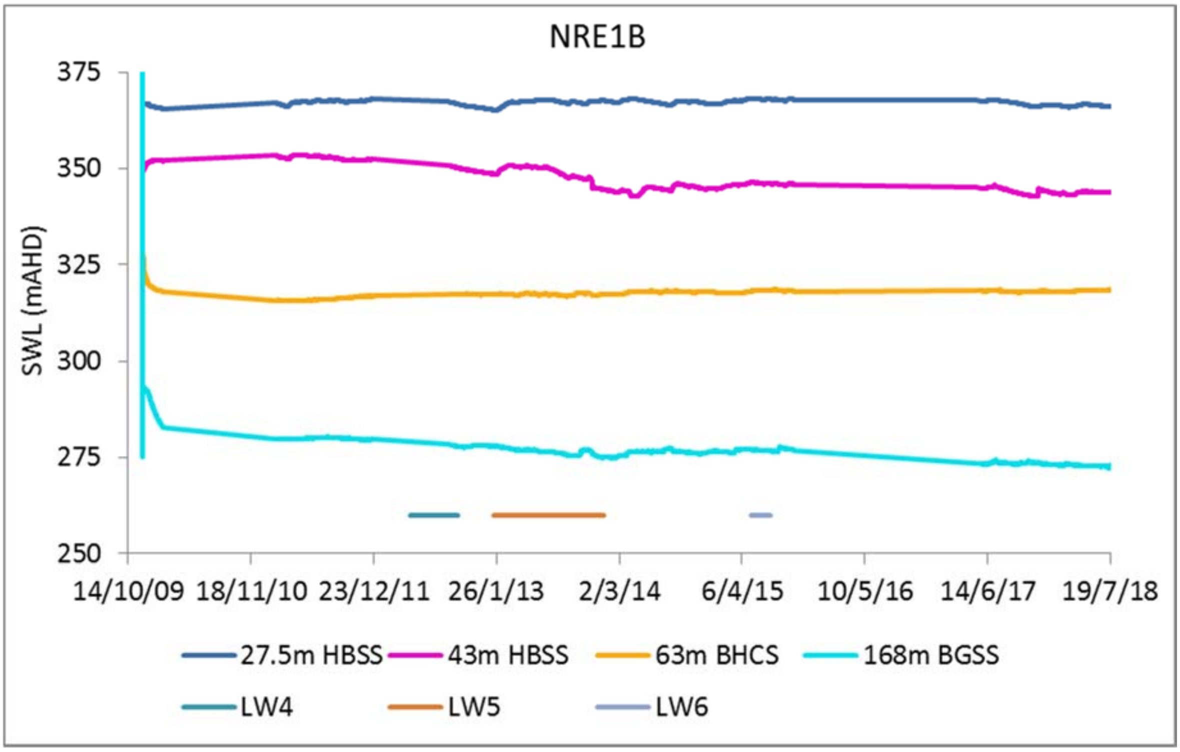


Figure 7-8 NRE B

7.3.4 NRE D

NRE D was installed in December 2009 to a depth of 160mbgl into the Bulgo Sandstone.

It is located on a watershed in Hawkesbury Sandstone in an area with limited pillar extraction in the Bulli Seam and is approximately 1650m north of Longwall 6 (340m) and is well outside the area of depressurisation influence from Longwalls 4, 5 or 6 (340m).

No pre-existing tension cracks are present close to NRE D, and its shows a low degree of vertical conductivity.

The VWP array is located approximately 1030m north of Cataract Creek and 575m east of the full storage level of Cataract Reservoir.

Insufficient shallow depth VWP intakes are present to assess the presence of an elevated phreatic surface, as the shallowest intake lies at 70mbgl as shown in **Figure 7-9**.

The VWP array has an overall low responsiveness to rainfall at 70mbgl in the Hawkesbury sandstone, and a moderate responsiveness at 90 and 110mbgl.

Pore pressures in the Hawkesbury Sandstone are perched at approximately 5m above the Cataract Reservoir 289.87mAHD Full Supply Level (FSL) in the 90mbgl intake.

The VWP array did not respond to extraction of Longwall 4, 5 or 6 (340m) due to its separation distance from the workings.

The bore does not extend deep enough to assess the height of depressurisation, however, the data indicates there is a downward hydraulic gradient, with the overburden hydraulic properties being sufficiently low to generate a very small downward flow component.

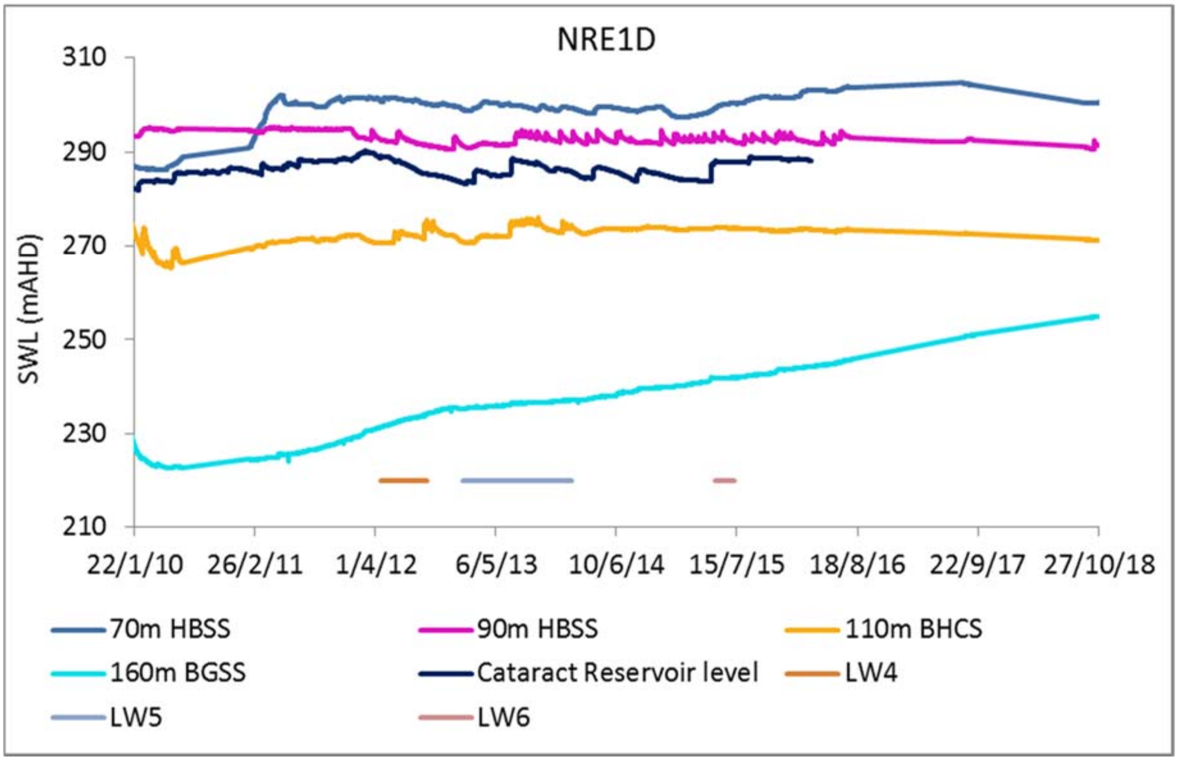


Figure 7-9 NRE D

7.3.5 RV16

RV16 (aka WCRV16) was installed in early July 2014 to a depth of 242mbgl in the Scarborough Sandstone.

It is located on a lower elevation of the same ridge line as NREA in Hawkesbury Sandstone in an area with pillar extraction in the Bulli Seam and is over a chain pillar between two longwalls in the Balgownie Seam, with no nearby mining in the Wongawilli Seam.

No pre-existing tension cracks are present close to RV16, and it shows a low degree of vertical conductivity.

It is located approximately 460m southeast (upgradient) of Wongawilli Seam Longwall 4 and is well outside the area of depressurisation influence from Longwalls 4, 5 or 6 (340m).

The VWP array is located approximately 850m north of Cataract River and 570m southwest of Cataract Creek.

The elevation of the phreatic surface a ranges from RL340m to RL360m which is at the level of the upper headwaters of Cataract Creek and is likely to be contributing to an intermittent to perennial base flow into Cataract Creek as shown in **Figure 7-10**.

No definitive shallow system perched water table is evident.

The VWP array has an overall low responsiveness to rainfall, albeit slightly more enhanced in the Bald Hill Claystone at 52mbgl.

The array did not respond to extraction of longwalls 4, 5 or 6 (340m) due to its separation distance from the workings.

The height of depressurisation lies between 197 and 242mbgl at RV16.

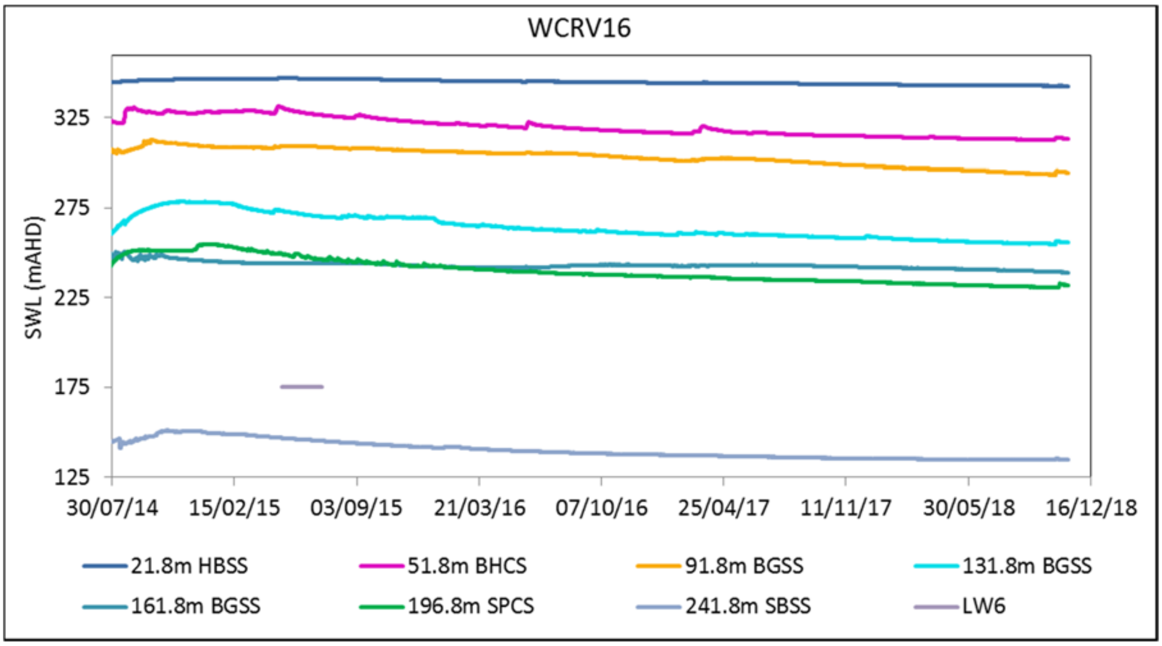


Figure 7-10 RV16

7.3.6 RV17

RV17 (aka WCRV 17) was installed in mid-September 2014 to a depth of 79.5mbgl in the upper Bulgo Sandstone, after Longwall 5 was completed, but prior to extraction of Longwall 6 (340m).

It is located approximately 205m west of Longwall 6 and overlies Bulli Seam first workings, with no Balgownie or Wongawilli extraction.

RV17 is in an area with remnant Hawkesbury Sandstone and is approximately 220m east of Cataract River. Shallow pressures within the Hawkesbury Sandstone remain stable at 298m AHD and are slightly elevated above the adjacent Cataract River.

No definitive shallow system perched water table is evident, with a reduced hydraulic gradient down to the base of the bore at 79.5mbgl as shown in **Figure 7-11**.

The VWP array has a minor, delayed responsiveness to rainfall at 40mbgl in the Bald Hill Claystone and 60mbgl in the upper Bulgo Sandstone.

The array did not observably respond to extraction of longwall 6 (340m), but did respond in an intake approximately 60m below surface, to a high rainfall event associated with an east coast low system in mid to late April 2015. This occurred whilst extraction of Longwall 6 (340m) was underway.

The height of depressurisation in RV17, as a result of single seam first workings in the Bulli Seam has not been identified as the drill hole was not deep enough (due to drill rig limitations).

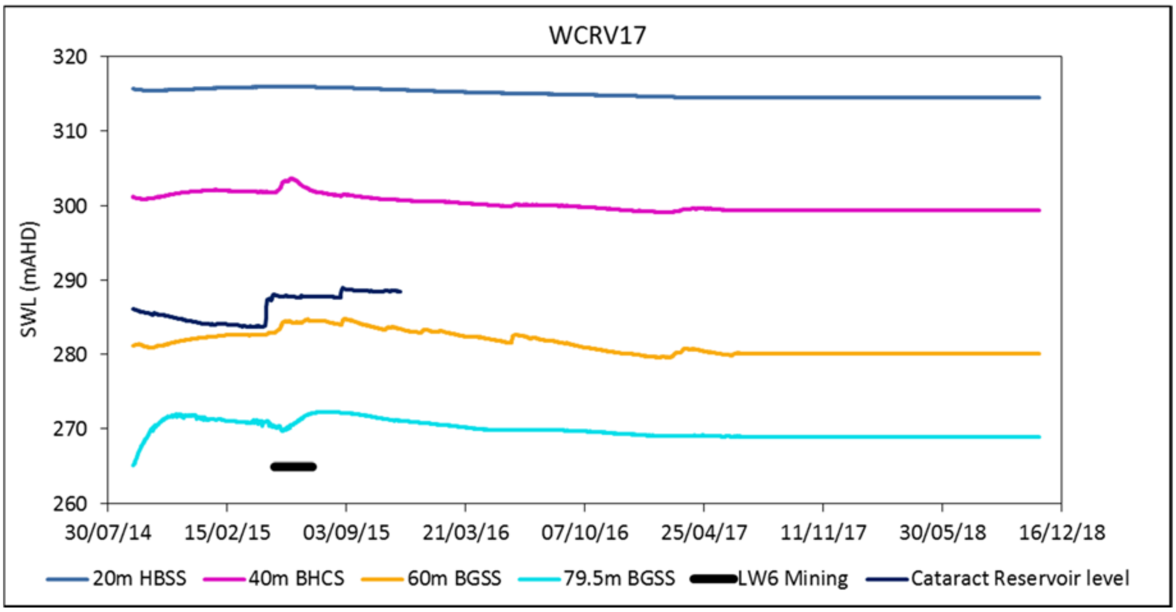


Figure 7-11 RV17

7.3.7 RV20

RV20 (aka WCRV20) was installed in mid December 2014 to a depth of 134mbgl in the lower Bulgo Sandstone, after Longwall 5 was completed although prior to extraction of Longwall 6 (340m).

It is located over the Wongawilli Seam Longwall 5, as well as Bulli Seam pillar and Balgownie Seam longwall extraction areas.

RV20 is in an area with remnant Hawkesbury Sandstone and is approximately 715m south southwest west of Cataract Creek.

No definitive shallow system perched water table is evident, with a deeper pressurised system in the mid to lower Bulgo Sandstone, whilst the lower Bulgo Sandstone contains limited pressures. As a result of drilling difficulties, no data is available deeper than 134m in the Bulgo Sandstone as shown in **Figure 7-12**.

The VWP array has an overall weak responsiveness to rainfall, with no responses observed at 134mbgl in the Bulgo Sandstone, whilst a weak response is evident at the shallower 105mbgl intake in the Bulgo Sandstone.

The array did not observably respond to extraction of Longwall 6 (340m), but did respond by its water level rising to approximately 105mbgl in response to a high rainfall event associated with an east coast low system in mid to late April 2015. This occurred whilst extraction of Longwall 6 (340m) was underway.

The height of depressurisation in RV20, as a result of triple seam extraction, lies between 105 and 134mbgl, whilst there is no significant pressure in the upper overburden between 35 and 85mbgl, with pressure being maintained in the 105mbgl intake.

The pressure profile indicates that the vertical flow rate is likely to be enhanced at this location.

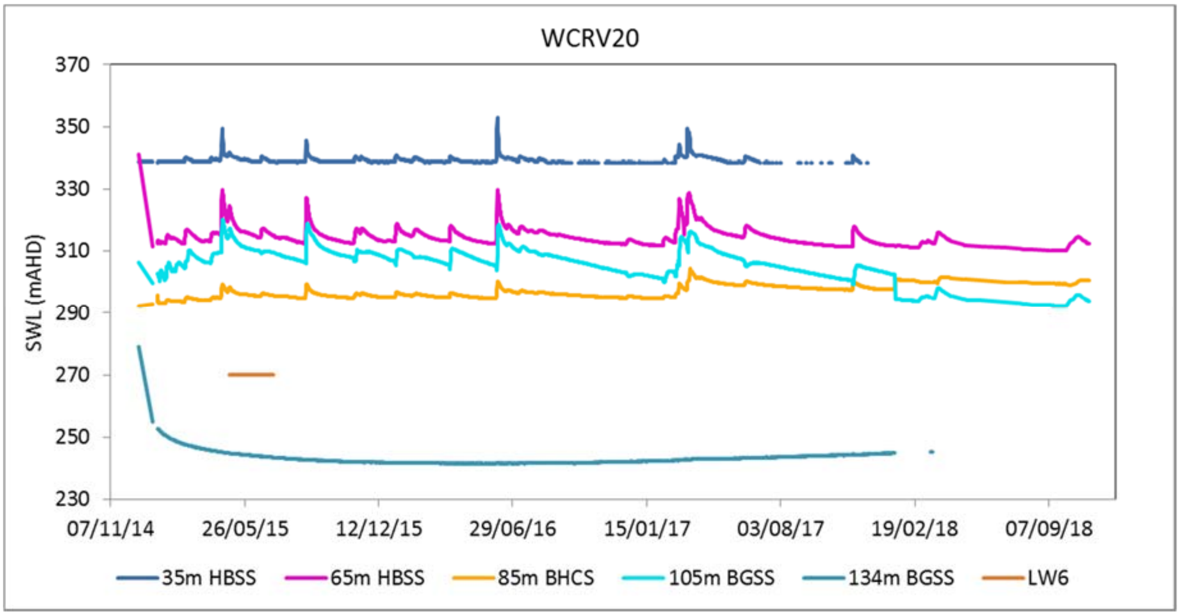


Figure 7-12 RV20

7.3.8 RV22

RV22 (aka WCRV22) was installed in late October 2014 to a depth of 230mbgl in the Scarborough Sandstone, after Longwall 5 was completed although prior to extraction of Longwall 6 (340m).

It is located to the north of Wongawilli Seam Longwall 6, as well as being over Bulli Seam pillar and Balgownie Seam longwall extraction areas.

RV22 is in an area with remnant Hawkesbury Sandstone and is approximately 715m south southwest west of Cataract Creek.

No definitive shallow system perched water table is evident, with a deeper pressurised system in the mid to lower Bulgo Sandstone, whilst the lower Bulgo Sandstone contains limited pressures as shown in **Figure 7-13**.

The VWP array has an overall weak responsiveness to rainfall, with no responses observed in the Bulgo Sandstone, Stanwell Park Claystone or Scarborough Sandstone.

The array did not observably respond to extraction of Longwall 6 (340m).

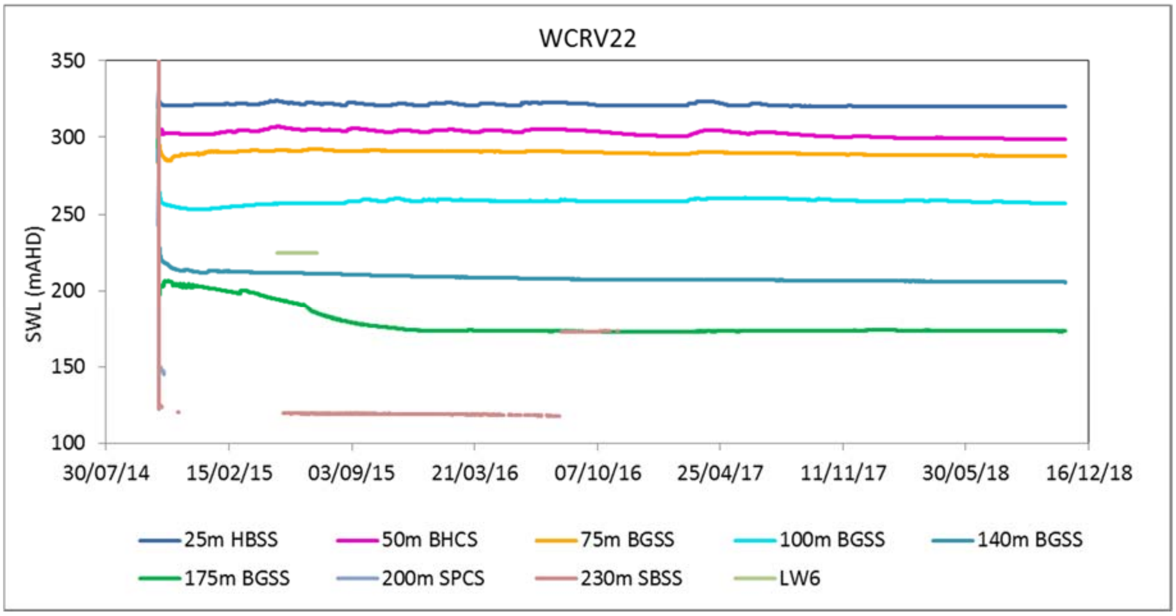


Figure 7-13 RV22

7.3.9 RV23 (VWP)

RV23 (VWP) (aka WCRV23) was installed in late November 2014 to a depth of 220mbgl into the Scarborough Sandstone.

It is located approximately 85m east of Cataract Reservoir FSL in the Bald Hill Claystone in an area of first workings extraction within the Corrimal Colliery.

No pre-existing tension cracks are present close to RV23, and its shows a low degree of vertical conductivity.

It is located approximately 1570m north west of Wongawilli Seam Longwall 6 (340m) and is well outside the area of depressurisation influence from Longwall 4, 5 or 6.

It has an essentially hydrostatic head increase down to 90mbgl, below which a marked drop in pressure is observed, with no evident perched water table. It also has a rise in head pressures between the 200 and 220mbgl intake depths.

The VWP array has a low responsiveness to rainfall as shown in **Figure 7-14**.

The array did not respond to extraction of Longwalls 4, 5 or 6 due to its large separation distance from the workings.

The height of depressurisation lies between 197 and 242mbgl at RV23.

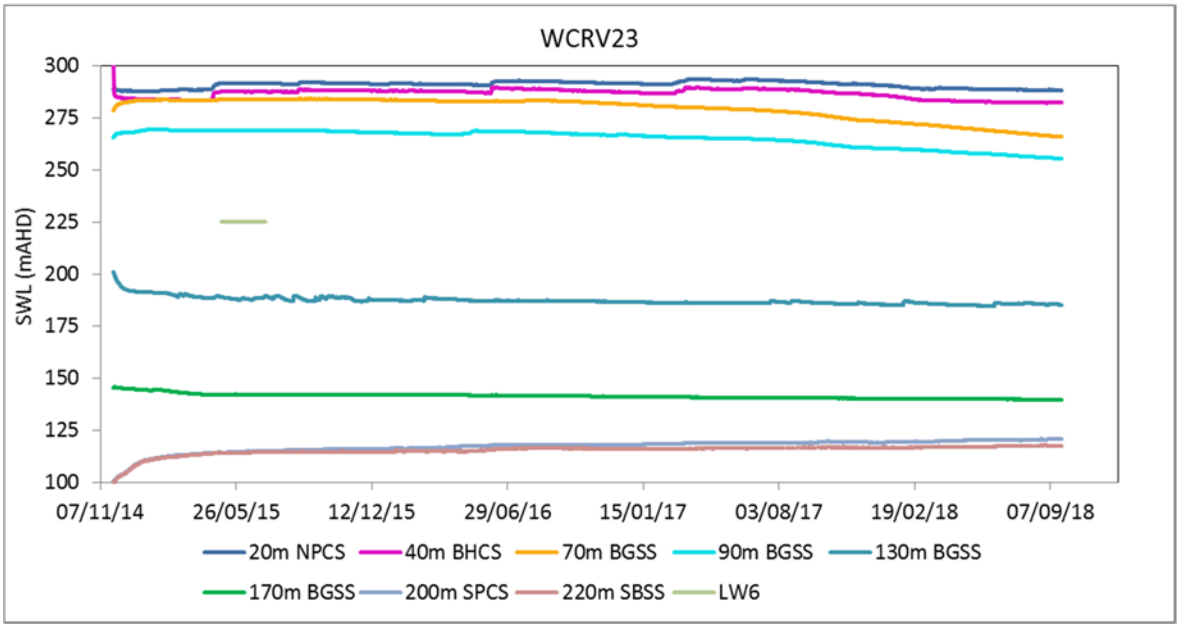


Figure 7-14 RV23 (VWP)

7.3.10 NRE3 (Wonga West)

NRE3 is located approximately 1,300m west of Cataract Reservoir and was installed in mid December 2009 to a depth of 255mbgl into the Bulgo Sandstone over Bulli Seam Longwalls.

NRE3 is significantly west of the Russell Vale East workings, on the western side of Cataract Reservoir, and is therefore too far away to be influenced by the Russell Vale East workings extraction.

No pre-existing tension cracks are present close to NRE3, and its shows a low degree of vertical conductivity.

The VWP array is located approximately 190m west of Lizard Creek.

Insufficient shallow depth VWP intakes are present to assess the presence of an elevated phreatic surface, as the shallowest intake lies at 100mbgl.

It has an essentially hydrostatic pressure gradient from 100mbgl (Upper Hawkesbury Sandstone) to 155mbgl (Lower Hawkesbury Sandstone), with a decrease away from hydrostatic from 155mbgl to the Bulgo Sandstone at 255mbgl as shown in **Figure 7-15**.

The VWP array has a moderate responsiveness to rainfall in the 130mbgl and 155mbgl intake depths.

The array did not respond to extraction of Longwall 4, 5 or 6 (340m) due to its very large separation distance from the workings, whilst its height of depressurisation was not established below the deepest intake of 255mbgl.

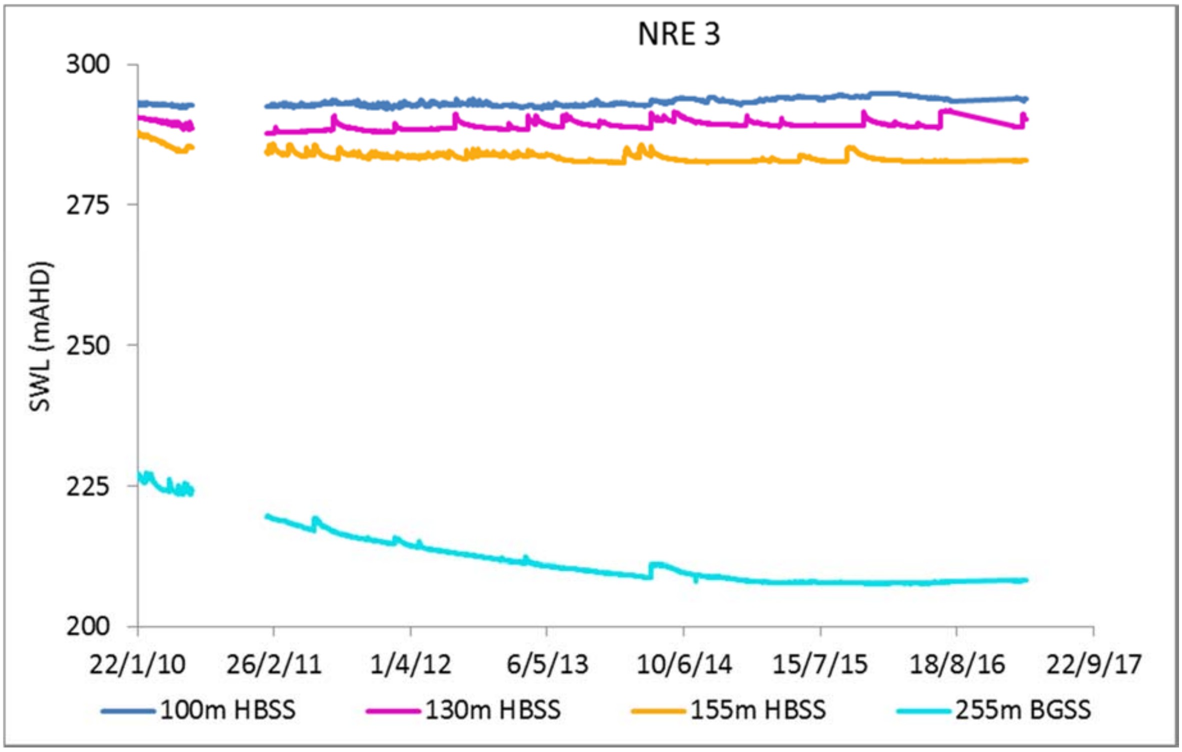


Figure 7-15 NRE3

7.4 Comparison of VWP and OSP Groundwater Levels

A number of open standpipe piezometer (OSP) and vibrating wire piezometer (VWP) arrays are located adjacent to each other within the Russell Vale lease area that could potentially provide a cross correlation / calibration between pressure readings in the VWP and OSP data files.

However, the deepest OSP of these pairs, at 60mbgl within NRE1F (at Wonga West), as shown in **Table 6**, are all in Hawkesbury Sandstone except for the RV23 / 23A pair, which lie within the Newport Formation.

As a result, with the available data, cross correlation of VWP and OSP data files is only possible for VWP intakes at or less than 60m below surface.

In addition, cross correlation of OSP / VWP water level and pressure readings is complicated by;

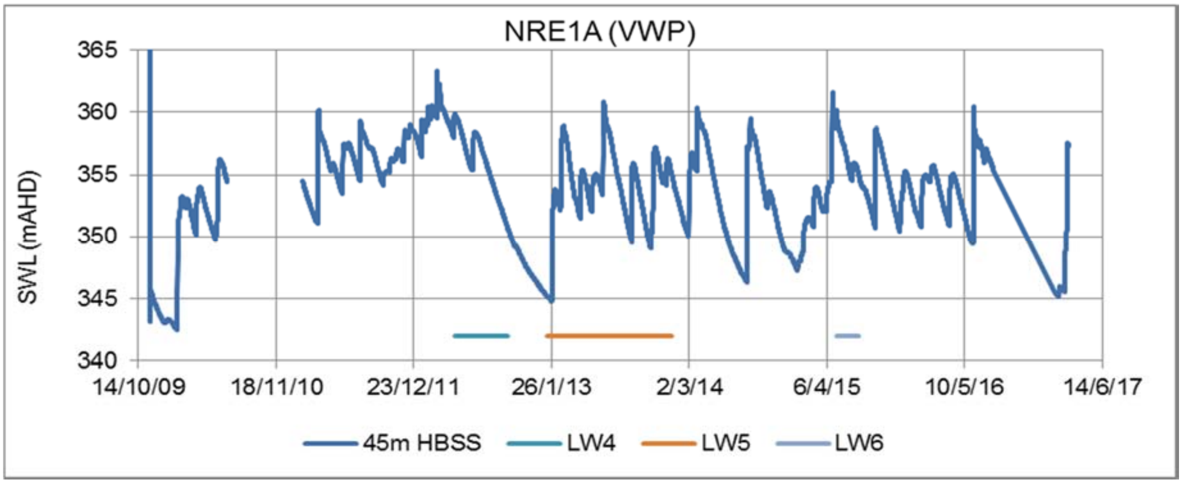
- each VWP intake is only over 10cm or less length within a borehole, whereas the OSP intakes range from 6 - 30.35m long, and;
- the OSPs and VWPs may not be located in the same position or distance from a longwall in regard to subsidence and fracturing that develops in association with / over the longwalls (such as GW1 (VWP) and GW1A (OSP), as well as RV17 (VWP) compared to RV18 and RV19.

To illustrate the above points, select hydrographs are shown in **Figures 7-16 to 7-18**.

Table 6 Adjacent VWP and Open Standpipe Piezometers

VWP / Open Standpipe Piezometer	Easting	Northing	Total Depth (m)	Piezometer Intake Depth (mbgl)	Formation
NRE3 (VWP)	294802.60	6201953.62	282.40	100	Hawkesbury Sandstone
NRE1 F	294803.00	6201954.00	60.0	n/a (<60)	Hawkesbury Sandstone
NRE A (VWP)	303680.00	6196034.00	153.00	45	Hawkesbury Sandstone
NRE1 A	303692.00	6196033.00	47.20	24.0 – 47.0	Hawkesbury Sandstone
GW1 (VWP)	303693.00	6196913.00	107.10	18, 30	Hawkesbury Sandstone
GW1A	303741.80	6196983.10	27.00	21.0 – 27.0	Hawkesbury Sandstone
RV17 (VWP)	301797.00	6196818.40	79.90	20	Hawkesbury Sandstone
RV18	302041.00	6196884.80	20.05	8 – 20	Hawkesbury Sandstone
RV19	301867.70	6196787.10	18.40	10 – 18.4	Hawkesbury Sandstone
NRE D (VWP)	301875.00	6198493.00	176.00	33, 60	Hawkesbury Sandstone
NRE1 D	301870.50	6198509.26	52	40.0 – 52.0	Hawkesbury Sandstone
RV22 (VWP)	303026.00	6197634.00	234.30	25	Hawkesbury Sandstone
RV22A	303026.00	6197634.00	37.35	7 – 37.35	Hawkesbury Sandstone
RV23 (VWP)	301370.00	6198233.00	222.35	20	Newport Formation
RV23A	301370.00	6198233.00	26.35	7 – 26.4	Newport Formation

NOTE: HS - Hawkesbury Sandstone NP - Newport Formation



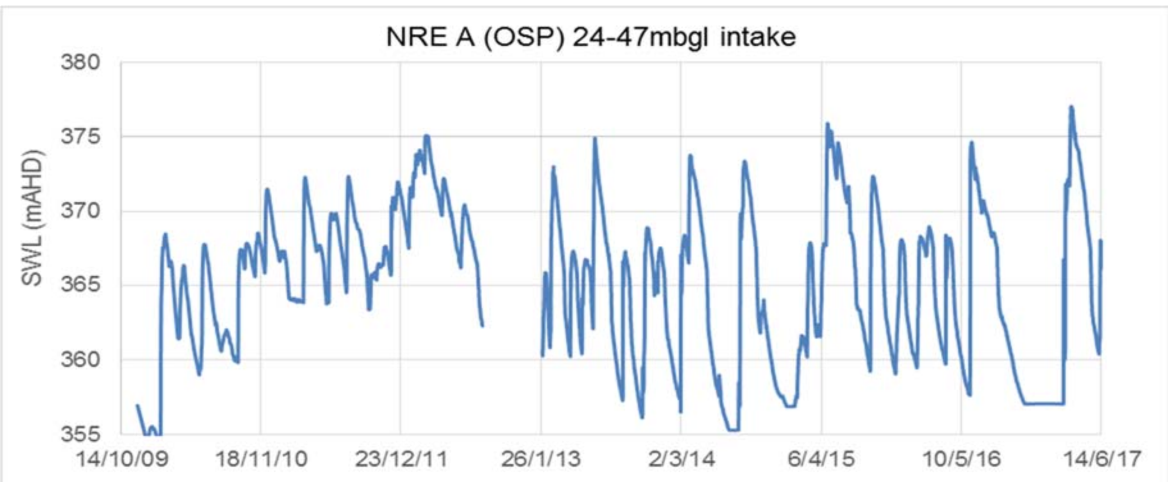
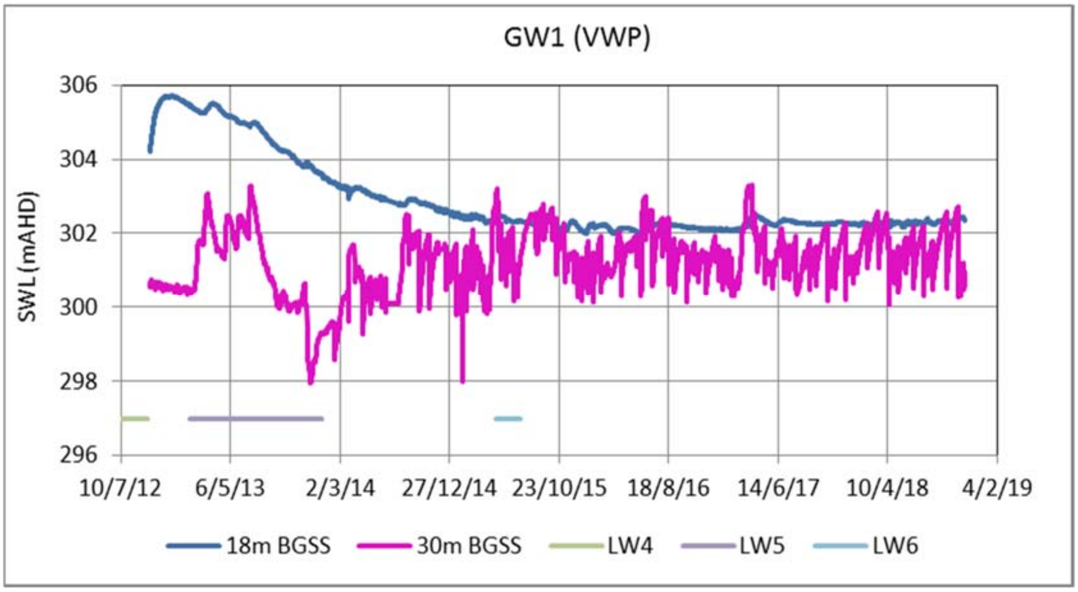


Figure 7-16 NRE A (VWP) and NRE1A (OSP)



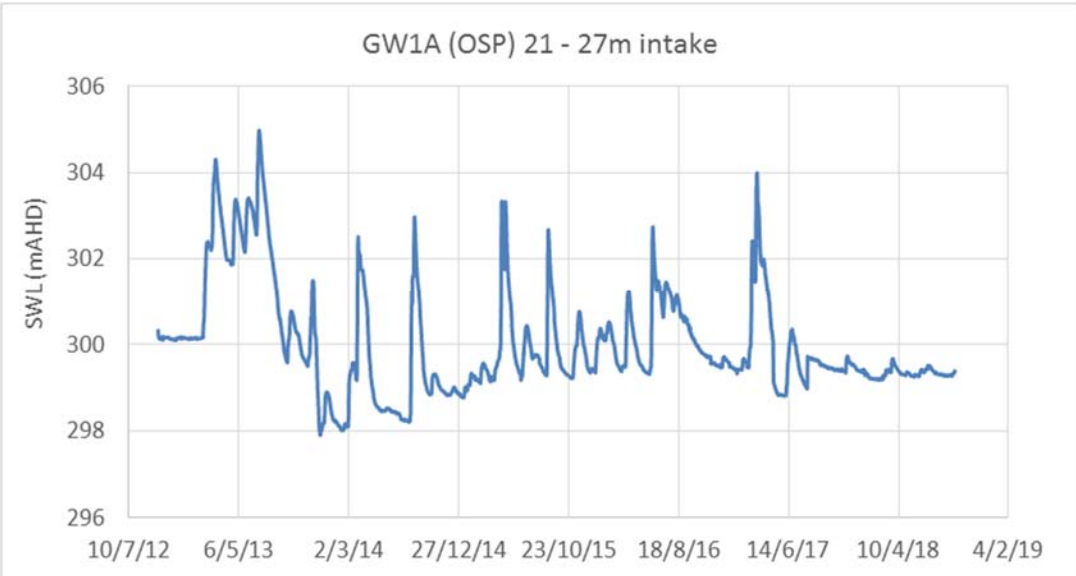
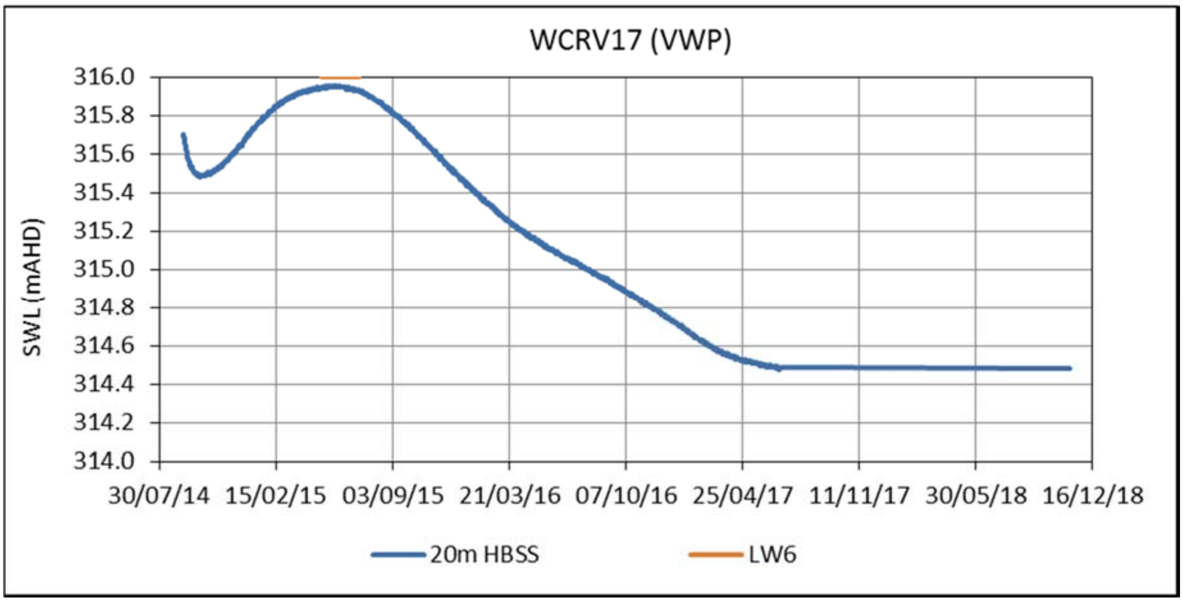
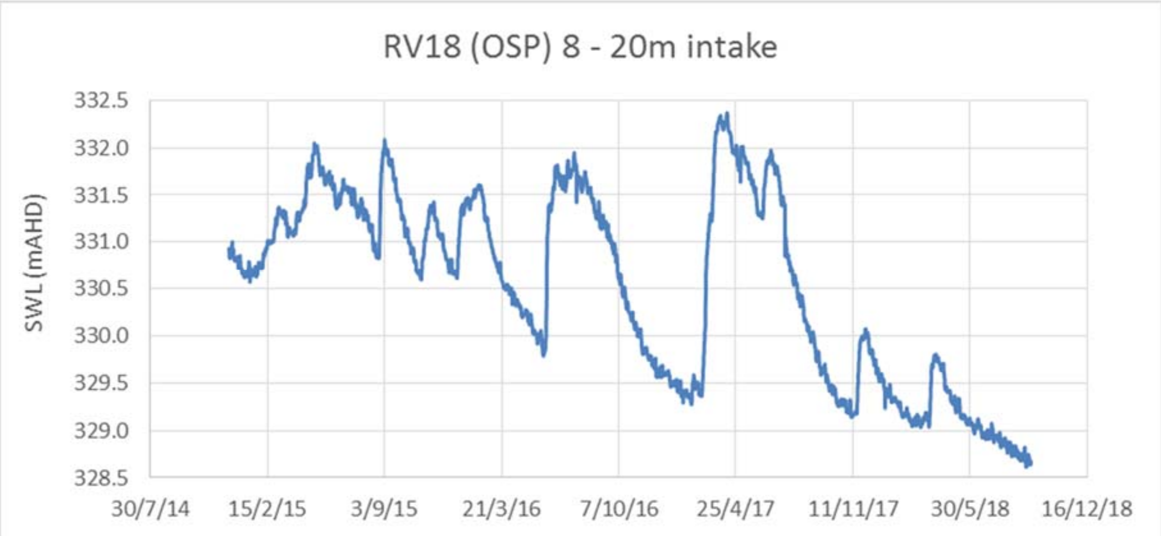


Figure 7-17 GW1 (VWP) and GW1A (OSP)





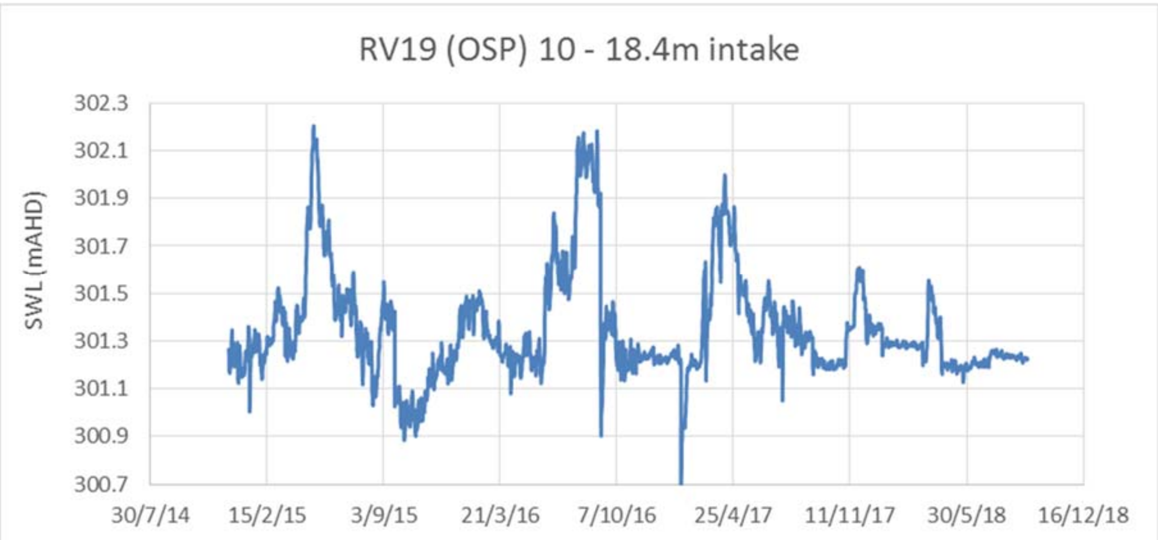


Figure 7-18 RV17 (VWP) and OSPs RV18 and RV19

Unfortunately, due to the wide range of variables in regard to the relative position of one piezometer to the nearest workings and another piezo, as well as the variable intake thicknesses and depths of adjacent OSP and VWP monitoring points, to name a few, there is no clear comparison between the OSP and VWP hydrographs discussed in the above examples.

7.5 Mine Water Pumping

This section outlines an adaptation of a mine water balance and groundwater assessment conducted by SCT Operations (2019).

All three seams dip to the west towards a low point in the 200 series longwall panels, which are located to the west of Cataract Reservoir.

The natural pathway for water flow underground is from the outcrop on the Illawarra Escarpment down to the low point in the 200 series longwall panels. However, because of the irregular nature of the lease boundaries and the various panels within the mine, there are numerous underground storages created where water is impounded in mining void areas behind coal barriers within the mines and between mines.

In the Wongawilli Seam, the inflow data suggests that rainfall recharge has an influence, however this is likely to be coincidental as increases in the flow rates also align with the mining progression down dip into saturated strata. Detailed rainfall trends are not absolutely reflected in the flow rates emanating from the Wongawilli Seam and are more representative of mining progression, however as there is a small amount of water from the Bulli Seam making its way to the Wongawilli Seam through the fracture zone, it may account for some of the small scale inflow variability along with the variable pump rates.

Water flowing from up dip flows into these underground storages until they become full and overtop allowing flow to continue down into the lowest point in the mine. Over time, all the storage areas have filled up and so any additional flow occurs through a chain-of-ponds along each of the barriers. A similar process is occurring in the Bulli and Corrimal Collieries.

Water is removed from the mine by active pumping and through passive means either by moisture content in coal removed from the mine and within ventilation system exits. Water within the mine workings occurs through groundwater entry to excavated areas and through the use of water for dust suppression and general service underground during periods of use for active mining.

The removal of water through pumping has two main components. Water is removed from the Bulli Seam where everything captured in-bye from the old South Bulli Mine plus some of the trickle down through the overburden strata that occurs above Longwalls 4, 5 and 6 (340m). This outlet also captures water in the Balgownie Seam which is pumped from 48 cut-through (C/T) to 27 C/T as shown in **Figure 7-19**.

As outlined by SCT Operations (2019) it is also considered likely that there is some inflow through the barriers from Corrimal, Cordeaux, and Old Bulli mining area, but it is not possible for these various components to be differentiated from the flows that come from South Bulli.

It is estimated that total leakage from other background mining areas is in the order of 0.2 ML/day and is likely to be dominated by leakage across the barrier with Cordeaux where down dip areas are believed to be flooded.

The removal of water from the Wongawilli Seam is from the main sump at 18 ½ C/T through to 12 ½ C/T and then via the Wongawilli portal. This captures some of the flow from up dip in the Bulli and Balgownie that makes its way down through the Wongawilli Seam goaf and through to the southern (in-bye) end of Longwalls 4 and 5.

The volumetric recording of flows of water removed from the mine is calculated from the pump hours which have had flow rates calibrated to running pump rates. Active pumping is not continuous and the periodic pump operation means that the measured pump rates recorded daily are extremely variable and the recognition of trends has been undertaken using averaged data over weekly and monthly periods.

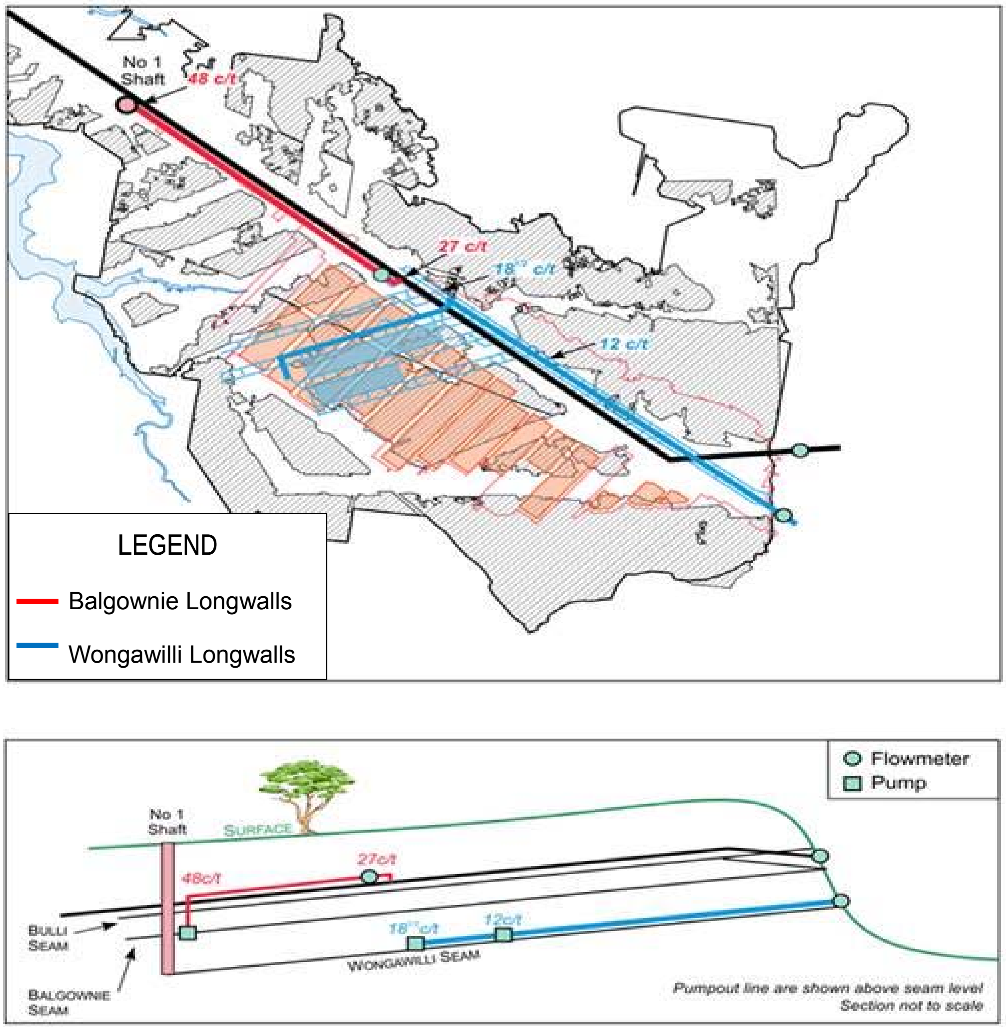


Figure 7-19 Underground Water Management Schematic

Investigation into the dynamics of the various inflow components has led to an improved understanding of these trends. Groundwater make to the mining areas increases as would be expected with down dip mining progression in the Wongawilli Seam. However recent scrutiny of the various components of the water inflow totals has shown that there is a component of the inflow variability which can be partially correlated to rainfall trends. This is particularly the case for the Bulli Seam component where a correlation can be seen as shown in **Figure 7-20** albeit with some time lag that suggests a tortuous flow path.

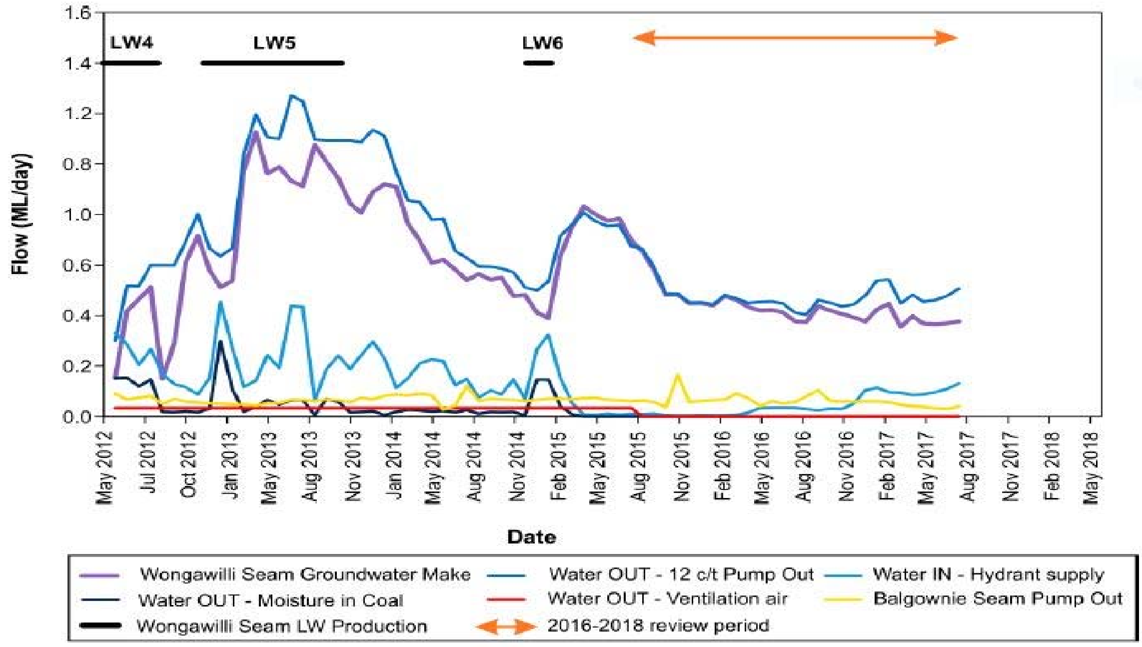


Figure 7-20 Wongawilli Seam Mine Water Pump Out

Figure 7-20 indicates that groundwater inflow to the mine peaked at approximately 1.1ML/day (or 402 ML/year) during extraction of Longwall 5 in mid 2013, and subsequently, after extraction of Longwall 6 in mid to late 2015, peaked at approximately 0.75ML/day (or 274 ML/year).

7.5.1 200 and 300 Series Longwalls West of Cataract Reservoir

It is assessed there is no free drainage through the Bald Hill Claystone at Russell Vale West, as the existing workings are currently depressurised and essentially dry, although ponded water is present in a syncline in the central, southern section of the 200 series longwalls as well as within the South32 Cordeaux workings (S Wilson, pers comm.).

Monitoring of mine water pump-out from workings to the west of Cataract Reservoir, along with observations from underground supervisors (SCT Operations, 2019) indicate there is no short term increase in mine water make from the current workings following significant rain in the Lizard and Wallandoola Creek catchments.

Monitoring of water level trends in piezometers over the 200 and 300 series longwalls indicates the upper Hawkesbury Sandstone does not have an enhanced response to rainfall recharge.

7.5.2 Current Workings East of Cataract Reservoir

It is assessed there is no free drainage into the existing workings to the east of Cataract Reservoir as they are currently depressurised and essentially dry apart from a few small ponding areas at the down dip end of the old workings where the dewatering pump is not able to extract the water, until it “spills” into a downgradient section of the workings (SCT Operations, 2019).

Monitoring of water pump-out from the Russell Vale East workings indicates there is no observed associated short term increase in mine water make from the current Russell Vale East workings following significant rain in the Cataract Creek, Cataract River or Bellambi Creek catchments.

7.5.3 Mine Water Pumping Volumes

The total mine water pumping rate from the Wongawilli Seam, which is the lowest drainage point in Russell Vale Colliery, peaked at around 1.3ML/day (475L/yr) as shown in **Figure 7-20** and has since reduced to 0.4ML/day (SCT Operations, 2019).

The above mentioned volumes are not, however, the total groundwater inflow into the workings, which, as discussed in **Section 7.5**, peaked at 1.1ML/day (401.5ML/year) during extraction of Longwall 5.

Of the total mine water pump out volumes, inflows entering the Russell Vale mine (i.e. not related to strata groundwater seepage generated within the Russell Vale Colliery lease area) comprised approximately;

- 0.14 ML/day background inflow from Wongawilli Seam first workings;
- 0.17 ML/day background inflow from Longwall 4 and 5 goafs (primarily Longwall 4) from the previously mined Bulli / Balgownie workings;
- 0.07ML/day from Longwall 6, and;
- during active mining periods, an average of 0.15ML/day pumped into the mine for dust suppression, drilling operations and other purposes (with a peak of 0.35ML/day during Longwall production periods) minus 0.1 to 0.3 ML/day of moisture extracted from the mine in coal product when the mine is in production, with less than 0.02ML/day extracted at other times.

7.6 Groundwater Chemistry

7.6.1 Hawkesbury Sandstone Hydrochemistry

Based on data supplied by WCL, groundwater in the Hawkesbury Sandstone at Russell Vale East ranges from 76 - 776µS/cm with a pH from 3.2 – 6.8 as shown in **Figure 7-21**.

The moderate pH acidification and low salinity indicate meteoric rainfall recharge into the Hawkesbury Sandstone, with the salinity and pH range being typical of similar lithologies in the Southern Coalfields. It is noted that the pH readings monitored between August and December 2013 are anomalously alkaline and may be inaccurate.

On the basis that the shallow groundwater discharges through seeps into the local streams, monitoring indicates the groundwater salinity is generally within the acceptable range for potable water, however it is predominantly outside the ANZECC 2000 South Eastern Australia Upland Stream criteria for pH and can be above the ANZECC 2000 95% Species Protection Level for Freshwater Aquatic Ecosystem Guidelines for:

- filtered copper, lead, zinc and aluminium (where the pH exceeds 6.5, which rarely occurs), as well as;
- total nitrogen and total phosphorus.

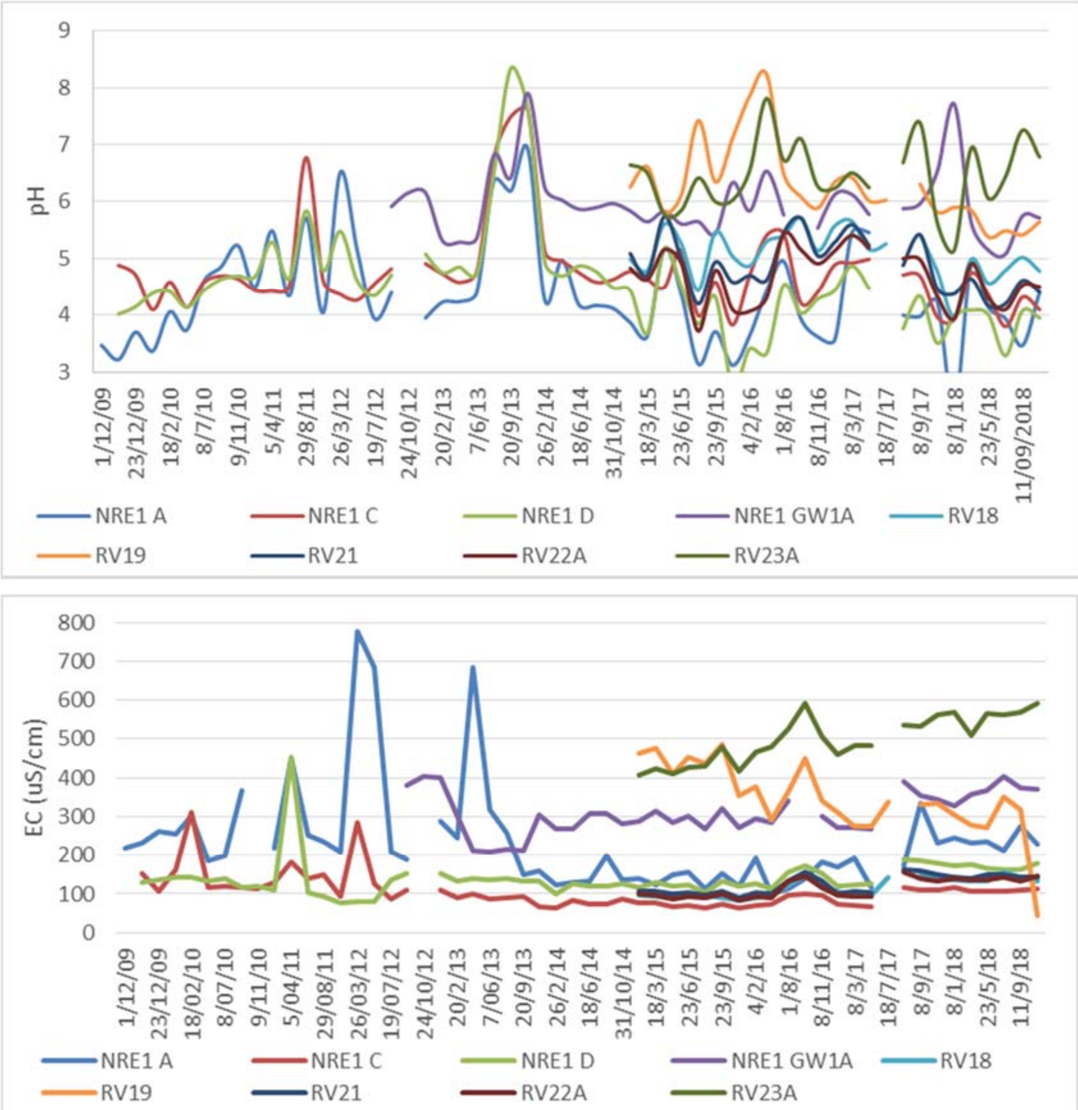


Figure 7-21 Russell Vale East Hawkesbury Sandstone Salinity and pH

Further detailed analysis of groundwater chemistry in the Russell Vale East area is contained in GeoTerra (2017) and WCL Ltd (2017).

7.6.2 Mine Workings and Discharge Hydrochemistry

Analysis of groundwater samples collected within the Wongawilli Seam workings between 2014 and 2017 as shown in **Figure 7-22** and **Table 7** indicates that groundwater seepage into the lowermost mine workings is alkaline pH (8.4 – 8.55) and relatively fresh to brackish (1,390 – 2,210 µS/cm).

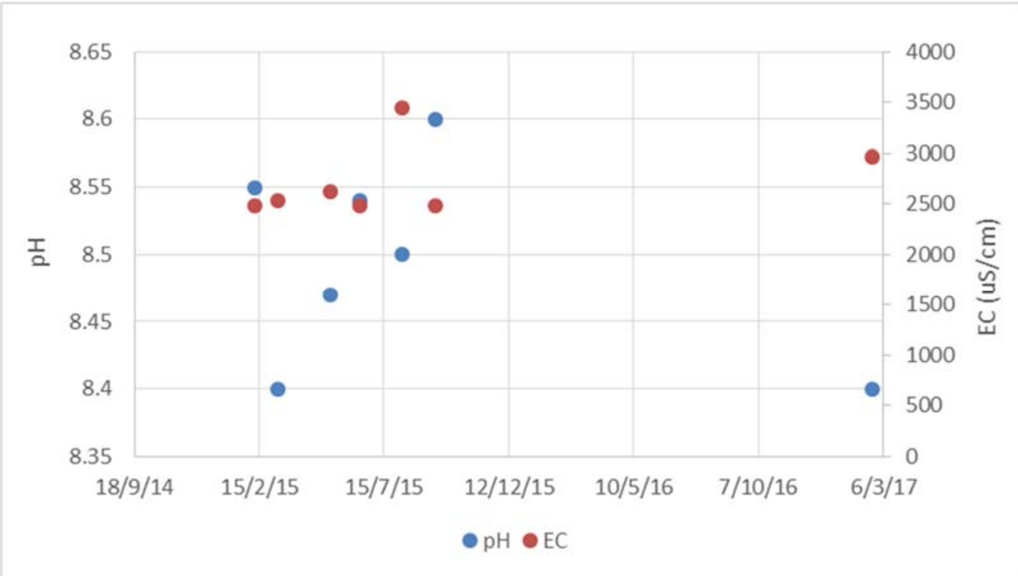


Figure 7-22 Underground Workings Groundwater Seeapge Chemistry

Table 7 indicates the seepage has;

- elevated bicarbonate alkalinity (HCO3), which forms the bulk of the salinity;
- elevated sulfate;
- below detection limit Radon 222 and tritium, and;
- above ANZECC 2000 95% Level of Protection for fresh water species trigger criteria for copper, nickel and zinc

Table 7 Underground Workings Groundwater Seepage Chemistry

Major Ions	OH	CO3	HCO3	Tot Alk	F	SO4	Cl	Ca	Mg	Na	K	Radon 222 (Bq/L)	Tritium (Bq/L)
10/02/2015	0.5	92	1340	1430	1.3	34	32	3	2	678	2	<5.0	<2
10/03/2015	0.5	93	1320	1410	1.2	35	27	4	1	691	2	<5.0	<2
11/05/2015	0.5	52	1440	1490	1.3	38	19	5	2	695	2	_	_
16/06/2015	0.5	64	1210	1280	1.2	32	21	4	2	647	2	_	<5
05/08/2015	0.5	135	1620	1760	1.6	46	31	4	1	868	2	_	<5.0
14/09/2015	0.5	86	1190	1280	1.3	35	22	4	2	661	2	_	<13.7
21/02/2017	0.5	76	1550	1620	1.4	9	47	3	1	819	2	_	_

Other	pH	EC (uS/cm)	TDS	TSS	B	Ba	Br	NO2 / NO3	TKN	TN	T P	DOC
10/02/2015	8.55	2480	1410	82	0.07	0.38	0.05	1.7	0.2	1.9	0.01	0.5
10/03/2015	8.4	2530	1390	2.5	0.07	0.438	0.05	1.62	0.2	1.8	0.005	0.5
11/05/2015	8.47	2620	1420	2.5	0.473	0.0005	0.05	1.52	0.2	1.7	0.02	37
16/06/2015	8.54	2490	1430	2.5	0.433	0.0005	0.05	1.71	0.2	1.9	0.005	0.5
05/08/2015	8.5	3450	1720	2.5	0.564	0.0005	0.05	0.51	0.5	1	0.31	0.5
14/09/2015	8.6	2480	1140	2.5	0.414	0.0005	0.1	1.72	0.05	1.7	0.005	2
21/02/2017	8.4	2970	2210	11	0.458	0.0005	0.05	0.2	0.6	0.8	0.04	0.5
		uS/cm										

Metals	Al	As	Sr	Cu	Li	Mn	Ni	Pb	Zn	Fe	Si
ANZECC 2000	**0.055**	**0.024**	_	**0.0014**	_	**1.9**	**0.011**	**0.0034**	**0.008**	_	_
10/02/2015	0.01	0.004	0.273	0.004	0.294	0.0005	0.001	0.0005	0.006	0.025	6.32
10/03/2015	0.005	0.004	0.277	0.0005	0.293	0.0005	0.0005	0.0005	0.0025	0.025	6.87
11/05/2015	0.01	0.004	0.002	**0.3**	0.001	0.001	**0.293**	0.006	**0.07**	0.025	6.25
16/06/2015	0.01	0.003	0.002	**0.295**	0.0005	0.001	**0.282**	0.0025	**0.08**	0.025	6.34
05/08/2015	0.02	0.006	0.001	**0.436**	0.003	0.003	**0.386**	0.0025	**0.08**	0.025	10.5
14/09/2015	0.03	0.004	0.001	**0.294**	0.0005	0.0005	**0.261**	0.0025	**0.07**	0.1	5.82
21/02/2017	0.01	0.007	0.001	**0.092**	0.003	0.003	**0.325**	0.0025	**0.025**	0.025	9.96

8. GROUNDWATER MODELLING

8.1 Background

A number of groundwater modelling studies have been undertaken within the Russell Vale Underground Expansion Project (UEP) area.

A FEFLOW groundwater model and associated interpretation was reported in GeoTerra (2012B) which assessed proposed mining in both the Russell Vale West and Russell Vale East areas.

Subsequently, a revised mine plan within Russell Vale East (Longwalls 1-7 and 9-11) was assessed via a MODFLOW SURFACT groundwater model for the UEP Preferred Project Report (PPR) in GeoTerra / GES (2014).

Finally, a third model and associated report was developed by GeoTerra / GES (2015) in response to State and Federal regulatory review of the proposed development, culminating in the PAC review, and incorporated additional piezometer installations and groundwater monitoring duration.

This version of the MODFLOW SURFACT modelling and associated reporting was conducted following review of the previous state and federal assessments and assesses the potential impacts of a first workings only extraction in the Wongawilli Seam within a bord and pillar layout, following extraction of Longwalls 4, 5 and 6 (340m).

In accordance with SKM & NCGRT (2012), the proposed first workings extraction assessment is based on at least a Class 2 model, with the calibration, prediction and key indicator components of a Class 3 model.

The current model structure, approach and simulations generated by Groundwater Exploration Services (GES) in association with GeoTerra Pty Ltd are detailed in the following sections.

8.2 Model Code and Objectives

Numerical modelling has been undertaken using the Groundwater Vistas software interface (Environmental Simulations) in conjunction with MODFLOW-SURFACT (Hydrogeologic).

MODFLOW-SURFACT is an advanced version of the MODFLOW code.

This version builds on previous MODFLOW SURFACT Russell Vale groundwater models and incorporates the “Pseudo Soil” option to simulate the unsaturated zone.

The groundwater model is of Moderate Complexity (under the MDBC Guidelines) with a Class 2 Confidence Level (under the NWC guidelines).

It provides an assessment of the existing groundwater system status and predicts the potential effects from extraction of the proposed workings.

The key objective of the model is to simulate the current and proposed first workings (bord and pillar) mining within the Wongawilli Seam in the Russell Vale East area, and to understand the effects to the groundwater and surface water environment in a local and regional context.

There is extensive pre-existing depressurisation from existing workings at Russell Vale, as well as the adjoining Cordeaux, Corrimal and Bulli mines as a result of mining activities over many decades starting from the late 1800s, along with a long hiatus since mining activities in the Russell Vale East area after the Balgownie Seam was mined by longwalls in the 1970s.

8.3 Conceptual Hydrogeological Model

A conceptual model of the Russell Vale lease area hydrogeological regime has been developed based on a review of existing hydrogeological data as described in **Section 7** and a conceptual model shown in **Figure 8-1** based on the Southern Coalfield 1:100,000 geology mapping, mine seam mapping and geological drill logs available from within the Russell Vale lease area.

It should be noted that the modelling, of necessity, requires simplification of the regional and local groundwater system in regard to strata lithological thicknesses, hydraulic properties and applied stresses including previous subsidence, rainfall infiltration, creek leakage and underground seepage.

It is assumed that any water carried by the limited extent and duration of flow in ephemeral streams would have a negligible contribution to groundwater recharge via leakage from the stream bed.

Cataract Reservoir is incised into the Bald Hill Claystone in the deepest sections of the storage adjacent to the proposed mining area, whereas the periphery, edge and banks of the reservoir are predominantly within the Newport and Garie Formations and subsequently at higher elevations, in Hawkesbury Sandstone.

The outcropping upper catchments and stream beds are sequentially incised down the stream thalweg into Hawkesbury Sandstone, Newport and Garie Formations, Bald Hill Claystone Formation and the Bulgo Sandstone.

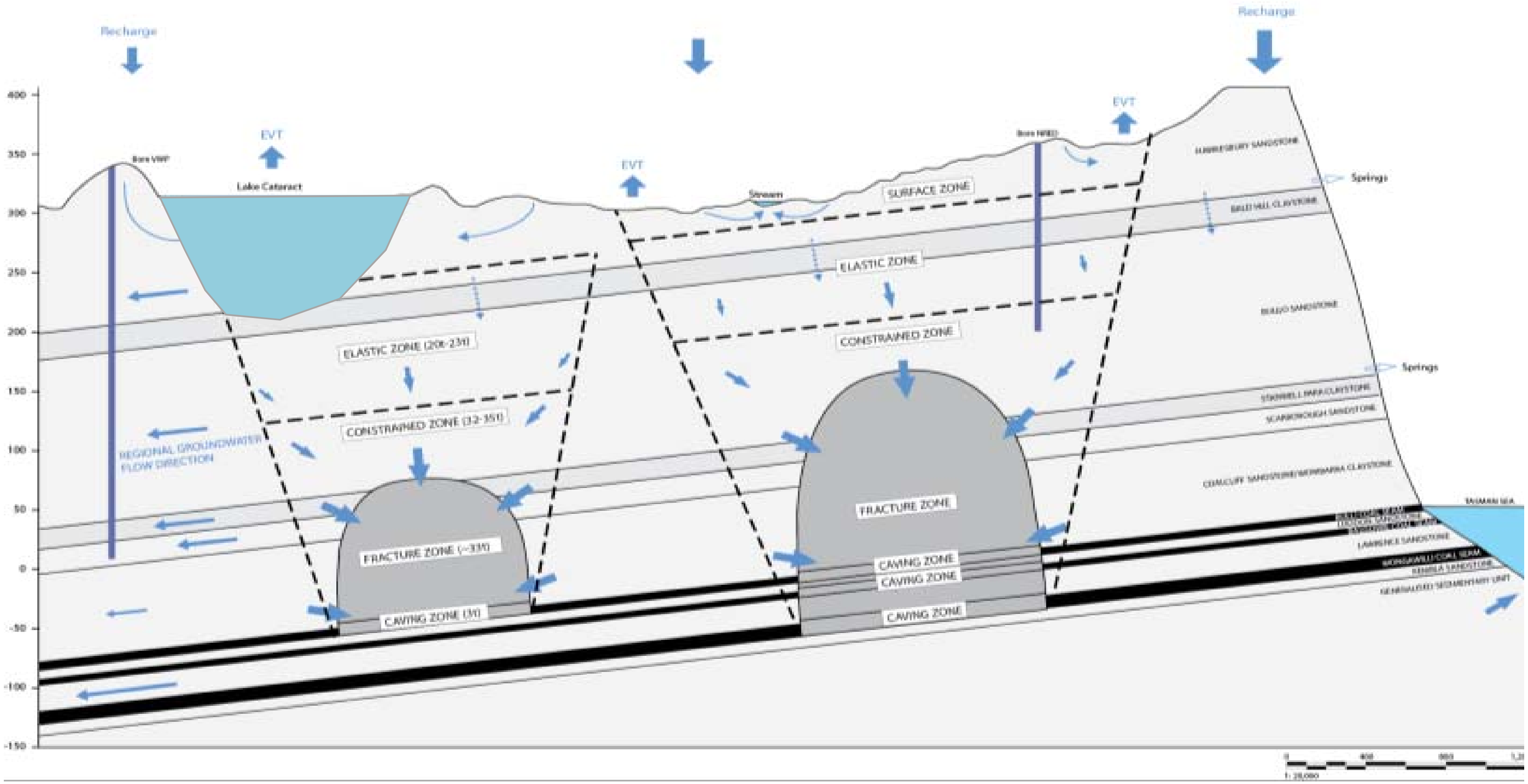


Figure 8-1 Conceptual Groundwater Model

Input data has also been gathered from geological and hydrogeological assessments undertaken for the Appin, West Cliff, Dendrobium and other Southern Coalfield mine lease areas.

Lithological layer depths and thicknesses within the Russell Vale lease area were based on in-situ piezometer and coal exploration drilling results and drilling data sourced from other Southern Coalfield projects.

Six conceptual groundwater sub-domains are present:

- intermittent to ephemeral, hydraulically disconnected (perched) upland swamps which provide limited and intermittent baseflow to local streams;
- a perched, weathered Hawkesbury Sandstone profile which provides ephemeral baseflow to the local streams.
- the deeper Hawkesbury Sandstone, which is hydraulically separated from the overlying Quaternary sediments and weathered sandstone perched aquifers as well as from the underlying Bulgo Sandstone at Russell Vale West, although not at Russell Vale East, both before and after subsidence. Following mining, as has been observed in the piezometers to the east of the reservoir, the groundwater levels exhibit a heightened response to recharge and increased recharge due to higher subsidence related secondary porosity, as well as interconnected permeability of the aquifers;
- the Narrabeen Group sedimentary lithologies, which have already been locally fractured and depressurised above the existing workings up to the mid to lower Bulgo Sandstone, and are anticipated to be fractured and partially depressurised over the proposed Wongawilli Seam longwall workings up to the mid to upper Bulgo Sandstone;
- the Illawarra Coal Measures, which contain the Bulli, Balgownie and Wongawilli Seam aquifers, which have also been fractured and depressurised by the existing workings and will be locally fractured and depressurised by the proposed workings; and
- the sedimentary sequence underneath the Wongawilli Seam.

8.3.1 Horizontal Strata Shear Zone Formation

Based on studies conducted in the Southern Coalfield at the South32 Appin Colliery, Sandy Creek waterfall (Walsh R.W, et al 2014), Waratah Rivulet at the Peabody Coal Metropolitan Colliery (Mills, K.W. 2007) and the Wollongong Coal Russell Vale East area, SCT Operations Pty Ltd (2014) has inferred that lateral movement of hillsides in toward the valley floor and associated horizontal to sub-horizontal shearing of the strata is possible.

The lateral shear mechanism occurs naturally in valleys, however it may be exacerbated by dilational hillslope shearing movement from the hillslopes toward the valley floor associated with mining induced subsidence as shown in **Figure 8-2**.

This mechanism is inferred to occur where lateral shear movement, which is not necessarily associated with pre-existing bedding plane or strata discontinuities, is mobilised following periods of intense rainfall.

At Russell Vale, the horizontal shearing of pre-existing natural bedding planes and vertical joints is inferred to have occurred in association with previous mining induced subsidence and hillslope dilational movement following extraction of the Balgownie and Bulli Seams.

The inferred shear plane (or multiple en-echelon planes) may have been re-mobilised following extraction of Longwalls 4, 5 and 6 (340m) in the Wongawilli Seam, particularly after the heavy rain periods.

SCT Operations (2014) infer that the main shearing may be located between 6 – 10m below the valley floor and may extend from the creek bed, under the subsided hillslope within the zone of subsidence for up to approximately 400 - 450m away from the creek.

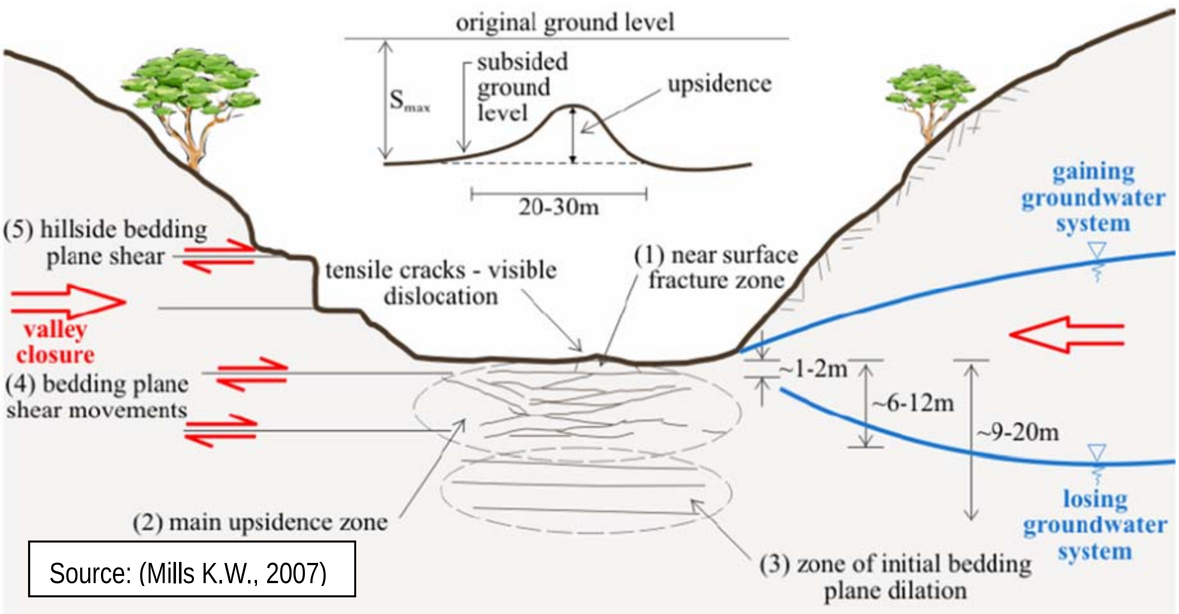


Figure 8-2 Conceptual Valley Closure Shearing

A definitive assessment of the location, presence and complex nature of the potential shear plane/s is not possible with current field / drilling data in the valleys and hillslopes overlying subsided areas at Russell Vale East, however, the horizontal shear zones do not pose a risk of direct hydraulic connection of stream flow from the stream beds in the upper catchments to the mine workings.

8.3.2 Height of Fracturing and Associated Strata Depressurisation Prediction

Two empirical based methods for the height of fracturing (Tammetta, 2012) as well as Ditton and Merrick (2014), and by association, the height of groundwater depressurisation, have been proposed using the height of single seam longwall extraction, width of extraction and the depth of cover, as well as a geological factor in Ditton and Merrick (2014) over the centre of single seam longwall panels.

No reliable comparison between the theoretically predicted and observed Russell Vale East in-situ height of depressurisation was able to be established from VWP data over the Russell Vale East multiple seam longwall extraction area.

Comparison of the predicted versus observed depressurisation height is also complicated in that a VWP array may not directly overlie the centre of secondary extracted workings, as most of the VWPs at Russell Vale are installed to the side of the Balgownie and Wongawilli Seam workings.

As a result, the observed depressurisation response in the subsided strata does not conform to a tacit assumptions in the strata depressurisation theories, in that a VWP is located over the centre of a single longwall panel.

Neither of the two theoretical approaches are applicable to the Russell Vale East triple seam or first workings extraction environment.

Accordingly, this document is based on a conceptual groundwater model (refer to **Section 8.3**) using geological lithologies (refer to **Section 5.3**) along with open standpipe and VWP water pressure data (refer to **Section 7)** to predict the impacts, consequences and effects of the historic longwall and proposed Wongawilli Seam first workings extraction on the groundwater system at Russell Vale East.

8.4 Model Domain

The spatial relationship of the proposed and the existing workings within the groundwater modelling domain is shown in **Figure 1-1**.

8.5 Model Design

The model was set up to represent both the existing undisturbed strata lithologies and Bulli / Balgownie Seam subsidence affected areas, as well as to account for the anticipated change in hydraulic properties following extraction of the proposed Wongawilli Seam first workings.

The model was not designed, however, to definitively represent the impacts of subsidence on perched aquifers, and in particular, upland swamps, as the upper (Layer 1) thickness and definition was too coarse for this purpose.

The existing Russell Vale Colliery workings within the model in the Bulli Seam were assumed to be partially flooded in the central southern section of the mine area to the west of Cataract Reservoir, as well as in the Cordeaux workings, and partially flooded in the Bulli Colliery bord and pillar workings. This is based on reported ponded areas within the Bulli Seam in the Russell Vale West area and estimated ponding levels within the Corrimal workings.

Drain cell stages were limited to elevations above the seam allowing for ponding to occur.

Russell Vale West drains were limited to -140m AHD and Corrimal drains were limited to -95m AHD, which has led to minor ponding within the seam and has removed dry cells from these areas. However, the levels are marginally higher than the base of the layers and have not led to wholesale flooding in any area.

Where the workings are dry, they were modelled with seepage boundaries with head levels set to the elevation of the mine floor to simulate atmospheric pressure effects.

The adjoining Cordeaux and Bulli workings were assumed to be separated from Russell Vale Colliery by at least a 40m wide intact coal barrier.

8.5.1 Model Layers

Nineteen layers are conceptualised for the purpose of numerical modelling as shown in **Table 8**.

The major sandstone formations (Hawkesbury and Bulgo) are split into multiple layers in order to reproduce natural or subsidence induced variations to vertical hydraulic gradients.

In the mid-reach of Cataract Creek, the Hawkesbury Sandstone and underlying Newport /

Garie Formation and the Bald Hill Claystone have been eroded away to expose the Bulgo Sandstone. Where this occurs, the appropriate hydraulic parameters have been propagated into overlying layers where each unit outcrops.

As a result, although Layer 1 is dominated by the upper Hawkesbury Sandstone, it also contains the Newport / Garie Formation, Bald Hill Claystone and upper Bulgo Sandstone in the eroded reach of Cataract Creek.

Similarly, but to a sequentially lesser degree, the mid and lower Hawkesbury Sandstone in Layers 2 and 3 are also eroded in the reach of Cataract Creek near the freeway, so these layers also contain the Newport / Garie Formation, Bald Hill Claystone and upper Bulgo Sandstone.

Layer 4, which predominantly contains the Bald Hill Claystone also contains the upper Bulgo Sandstone in the eroded reach of Cataract Creek.

All subsequent underlying layers contain one lithology.

Table 8 Model Layers

Layer	Unit
1	Upper Hawkesbury Sandstone + NGF + BHCS +UBS
2	Mid Hawkesbury Sandstone + NGF + BHCS +UBS
3	Lower Hawkesbury Sandstone + NGF + BHCS +UBS
4	Bald Hill Claystone +UBS
5	Upper Bulgo Sandstone
6	Mid Bulgo Sandstone
7	Mid Bulgo Sandstone
8	Lower Bulgo Sandstone
9	Stanwell Park Claystone
10	Scarborough Sandstone
11	Wombarra Claystone
12	Coal Cliff Sandstone
13	Bulli Seam
14	Loddon Sandstone
15	Balgownie Seam
16	Lawrence Sandstone
17	Wongawilli Seam
18	Kembla Sandstone
19	Basement

NOTE: NGF = Newport / Garie Formation BHCS = Bald Hill Claystone UBS = Upper Bulgo Sandstone

8.5.2 Boundary Conditions

The model areal extent has been chosen so the peripheral boundary conditions are of a sufficient distance from the proposed workings to significantly reduce the potential for a change in flow conditions across the model boundaries as a result of the Project.

The boundary conditions at the periphery of the model consist of:

- general head boundaries representing active mining areas in the Wongawilli Seam including Appin (to the north) in the Bulli Seam and Dendrobium in the Wongawilli Seam in the south;
- constant head boundaries representing the coast line to the east of the escarpment and coastal plain;
- no-flow boundaries at topographic divides representing the western boundary of the model domain;
- historic mining areas, principally within the Bulli Seam, as represented by the Drain Package in MODFLOW-SURFACT, have been conceptualised to remain as regional hydrogeological sinks, and;
- drainage channels which were simulated using the River Package. River stages were set 1m above base of surficial layer to allow the package to act as drainages, with their conductance set to 5m^2/day to allow the aquifer hydraulic properties to control leakage to and from the model. While this is acknowledged as not appropriate for the upper, ephemeral reaches of Cataract Creek, it is assessed as appropriate in the perennial reaches, which is where the focus was applied to address potential changes to drainage as a result of the proposal.
- WaterNSW reservoirs, Cataract Reservoir and Cordeaux Reservoir were also simulated utilising (Steady State) River Package boundary cells with levels set at 290m AHD and 305m AHD respectively.

Groundwater head pressures in Vibrating Wire Piezometer (VWP) arrays and standing water level data from open standpipe piezometers within the Russell Vale lease area were used as a basis for initial conditions, whilst groundwater levels over the Cordeaux and Bulli workings were approximated, as no direct data was available from these locations.

Direct measurements of hydraulic parameters from bores within the Russell Vale lease area were used, and where data was unavailable, approximated parameters were sourced from other studies as starting points for calibration. Other projects include the South32 workings to the north at Appin (Heritage Computing, 2010) and to the south at Dendrobium (Coffey Geotechnics, 2012).

Underground dewatering was represented by inclusion of the proposed mine voids in the Bulli, Balgownie and Wongawilli Seams through the use of drains as well as incorporating the associated changes in overburden hydraulic parameters in the overlying sedimentary units due to subsidence.

8.5.3 Recharge and Evapotranspiration

Recharge was set at 4% of rainfall from BOM Silo data for Cataract Dam across the majority of the model domain and to 6% over the elevated terrain west of the escarpment and coastal plain.

Evapotranspiration was applied uniformly to the model with rate of 0.005 m/d and an extinction depth of 4m.

8.5.4 Grid

A variable cell size is employed across the model domain which contains a total of 1,021,183 active cells.

A grid size of 250m x 250m occupies the periphery of the model domain, reducing to 100m x 100m nearer to the Russell Vale lease area, then 50m x 50m over most of Wollongong Coal Lease area and further reduced to 50m x 25m in an east – west alignment overlying the main channel of Cataract Creek.

While the potential impacts from the mining activities relate to regional scale effects, experience has shown that providing more detailed grid discretisation has no significant impact on predicted mine inflows or groundwater levels, as long as a mine plan can be appropriately represented.

However, the adopted grid refinement allowed for improved detailing of the mine plan scheduling and increased accuracy surrounding baseflow effects in creeks overlying the Russell Vale East area.

The changes in grid size obeyed the 50% convention rule regarding changes between grid size between rows and columns with minimum ratio of cell size change being 0.75 (Environmental Simulations Inc. 2009).

8.5.5 Mining Schedule

The adopted mine schedule for the historic development and extraction within the Bulli and Wongawilli seams is shown in **Table 9**.

The model start date is 1/1/1993, whilst the calibration period is from 1/1/1993 to 30/6/2017.

This includes the 500 series longwalls in Russell Vale West within the Bulli seam in 1993 and the initial mine development in the Wongawilli Seam at Russell Vale East, which began in early 2011.

The interim period included a long period where no significant mining activities occurred.

The recovery period includes the subsequent 200 years to 31/12/2223.

Detailed time stepping has been used to simulate the Wongawilli Seam development and mining progression in the Russell Vale East area which is shown in **Figure 8-3**.

In order to investigate the incremental effects of mining, the predicted operational mining impacts and the post mining recovery have been assessed in accordance with the adopted schedule that applied at the time the model was developed.

Due to various delays in preparing the overall Application, the actual dates / years initially used in the model have changed, however there is no material impact on the results of the modelling.

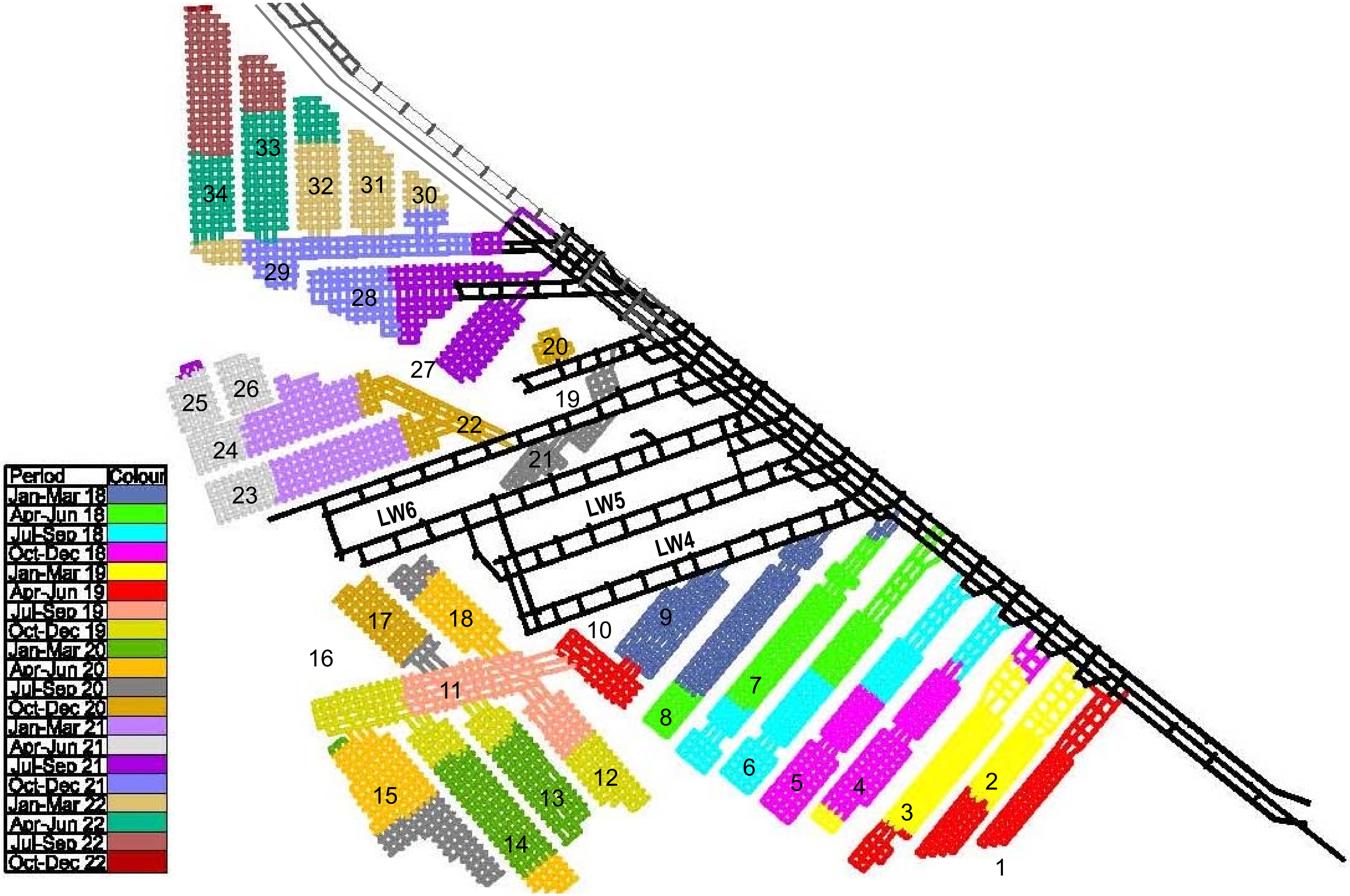


Figure 8-3 Mining Schedule in Wongawilli Seam

Table 9 Impact Assessment Mine Schedules

Model Type	Purpose	SP	SP_START	SP_END	DAYS	start day	end day	Russell Vale East Develop Heading	Russell Vale East LW Panels and FW Mining Areas	Wonga West	Cordeaux	All Other Bulli Seam Mines
Steady State	'PRE-MINING'	1	01-Jan-91	31-Dec-92	731	0	731				modelled as constant	modelled as constant
Transient Calibration	HISTORIC	2	1/01/1993	11/07/1993	192	732	923					
	HISTORIC	3	12/07/1993	13/12/1993	155	924	1078			501	Turn off DRN	Turn off DRN
	HISTORIC	4	14/12/1993	18/05/1994	156	1079	1234			502		
	HISTORIC	5	19/05/1994	28/09/1994	133	1235	1367			503		
	HISTORIC	6	29/09/1994	6/02/1995	131	1368	1498			504		
	HISTORIC	7	7/02/1995	19/06/1995	133	1499	1631			505		
	HISTORIC	8	20/06/1995	26/11/1995	160	1632	1791			506		
	HISTORIC	9	27/11/1995	16/08/1996	264	1792	2055			507		
	HISTORIC	10	17/08/1996	25/05/1997	282	2056	2337			508		
	HISTORIC	11	26/05/1997	31/12/1997	220	2338	2557			509		
	HISTORIC	12	1/01/1998	31/12/1998	365	2558	2922					
	HISTORIC	13	1/01/1999	31/12/1999	365	2923	3287					
	HISTORIC	14	1/01/2000	31/12/2000	366	3288	3653					
	HISTORIC	15	1/01/2001	31/12/2001	365	3654	4018					
	HISTORIC	16	1/01/2002	31/12/2002	365	4019	4383					
	HISTORIC	17	1/01/2003	31/12/2003	365	4384	4748					
	HISTORIC	18	1/01/2004	31/12/2004	366	4749	5114					
	HISTORIC	19	1/01/2005	31/12/2005	365	5115	5479					
	HISTORIC	20	1/01/2006	31/12/2006	365	5480	5844					
	HISTORIC	21	1/01/2007	31/12/2007	365	5845	6209					

Model Type	Purpose	SP	SP_START	SP_END	DAYS	start day	end day	Russell Vale East Develop Heading	Russell Vale East LW Panels and FW Mining Areas	Wonga West	Cordeaux	All Other Bulli Seam Mines
	HISTORIC	22	1/01/2008	31/12/2008	366	6210	6575					
	HISTORIC	23	1/01/2009	31/12/2009	365	6576	6940					
	HISTORIC	24	1/01/2010	31/12/2010	365	6941	7305					
	HISTORIC	25	1/01/2011	31/03/2011	90	7306	7395	Mains		Turn off DRN		
	HISTORIC	26	1/04/2011	30/06/2011	91	7396	7486	Mains				
	HISTORIC	27	1/07/2011	31/12/2011	184	7487	7670	MG4				
	HISTORIC	28	1/01/2012	31/03/2012	91	7671	7761	TG4				
	HISTORIC	29	1/04/2012	31/05/2012	61	7762	7822	TG5				
	HISTORIC	30	1/06/2012	31/07/2012	61	7823	7883					
	HISTORIC	31	1/08/2012	31/08/2012	31	7884	7914		LW4			
	HISTORIC	32	1/09/2012	31/10/2012	61	7915	7975					
	HISTORIC	33	1/11/2012	31/12/2012	61	7976	8036					
	HISTORIC	34	1/01/2013	14/02/2013	45	8037	8081					
	HISTORIC	35	15/02/2013	31/03/2013	45	8082	8126					
	HISTORIC	36	1/04/2013	31/05/2013	61	8127	8187					
	HISTORIC	37	1/06/2013	31/07/2013	61	8188	8248					
	HISTORIC	38	1/08/2013	14/08/2013	14	8249	8262		LW5			
	HISTORIC	39	15/08/2013	31/08/2013	17	8263	8279					
	HISTORIC	40	1/09/2013	14/09/2013	14	8280	8293	TG6				
	HISTORIC	41	15/09/2013	30/09/2013	16	8294	8309					
	HISTORIC	42	1/10/2013	14/10/2013	14	8310	8323					
	HISTORIC	43	15/10/2013	31/10/2013	17	8324	8340					

Model Type	Purpose	SP	SP_START	SP_END	DAYS	start day	end day	Russell Vale East Develop Heading	Russell Vale East LW Panels and FW Mining Areas	Wonga West	Cordeaux	All Other Bulli Seam Mines
	HISTORIC	44	1/11/2013	14/11/2013	14	8341	8354					
	HISTORIC	45	15/11/2013	30/11/2013	16	8355	8370					
	HISTORIC	46	1/12/2013	14/12/2013	14	8371	8384					
	HISTORIC	47	15/12/2013	31/12/2013	17	8385	8401					
	HISTORIC	48	1/01/2014	28/02/2014	59	8402	8460					
	HISTORIC	49	1/03/2014	30/06/2014	122	8461	8582					
	HISTORIC	50	1/07/2014	30/09/2014	92	8583	8674	TG7				
	HISTORIC	51	1/10/2014	31/12/2014	92	8675	8766	Mains	LW6			
	HISTORIC	52	1/01/2015	28/02/2015	59	8767	8825					
	HISTORIC	53	1/03/2015	30/06/2015	122	8826	8947					
	HISTORIC	54	1/07/2015	30/09/2015	92	8948	9039					
	HISTORIC	55	1/10/2015	31/12/2015	92	9040	9131					
	HISTORIC	56	1/01/2016	31/03/2016	91	9132	9222					
	HISTORIC	57	1/04/2016	30/06/2016	91	9223	9313					
	HISTORIC	58	1/07/2016	30/09/2016	92	9314	9405					
	HISTORIC	59	1/10/2016	31/12/2016	92	9406	9497					
	HISTORIC	60	1/01/2017	31/03/2017	90	9498	9587					
	HISTORIC	61	1/04/2017	30/06/2017	91	9588	9678					
Prediction	IMPACT	62	1/07/2017	30/09/2017	92	9679	9770					
	IMPACT	63	1/10/2017	31/12/2017	92	9771	9862					
	IMPACT	64	1/01/2018	31/03/2018	90	9863	9952		8,9,30			
	IMPACT	65	1/04/2018	30/06/2018	91	9953	10043		6, 7			
	IMPACT	66	1/07/2018	30/09/2018	92	10044	10135		4, 5			

Model Type	Purpose	SP	SP_START	SP_END	DAYS	start day	end day	Russell Vale East Develop Heading	Russell Vale East LW Panels and FW Mining Areas	Wonga West	Cordeaux	All Other Bulli Seam Mines
	IMPACT	67	1/10/2018	31/12/2018	92	10136	10227					
	IMPACT	68	1/01/2019	31/03/2019	90	10228	10317		2, 3			
	IMPACT	69	1/04/2019	30/06/2019	91	10318	10408		1			
	IMPACT	70	1/07/2019	30/09/2019	92	10409	10500		11, 12			
	IMPACT	71	1/10/2019	31/12/2019	92	10501	10592		13, 14			
	IMPACT	72	1/01/2020	31/03/2020	91	10593	10683		15			
	IMPACT	73	1/04/2020	30/06/2020	91	10684	10774					
	IMPACT	74	1/07/2020	30/09/2020	92	10775	10866					
	IMPACT	75	1/10/2020	31/12/2020	92	10867	10958		22			
	IMPACT	76	1/01/2021	31/03/2021	90	10959	11048		23, 24			
	IMPACT	77	1/04/2021	30/06/2021	91	11049	11139		25, 26			
	IMPACT	78	1/07/2021	30/09/2021	92	11140	11231		27, 28			
	IMPACT	79	1/10/2021	31/12/2021	92	11232	11323		29			
	IMPACT	80	1/01/2022	31/03/2022	90	11324	11413		30, 31			
	IMPACT	81	1/04/2022	30/06/2022	91	11414	11504		32, 33			
	IMPACT	82	1/07/2022	30/09/2022	92	11505	11596		34			
	IMPACT	83	1/10/2022	31/12/2022	92	11597	11688					
	RECOVERY	84	1/01/2023	31/12/2073	18628	11689	30316		Turn off DRN			
	RECOVERY	85	1/01/2074	31/12/2123	18261	30317	48577					
	RECOVERY	86	1/01/2124	31/12/2173	18263	48578	66840					
	RECOVERY	87	1/01/2174	31/12/2223	18261	66841	85102					

8.5.6 Model Implementation of Mine Schedule

The underground mining and dewatering activity is defined 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 Seam and implemented in line with mine progression in the Wongawilli Seam.

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 subsidence.

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

Within the Wongawilli Seam, Sy was increased on host values by a factor of 150 raising Sy to 20%. Within the Wongawilli – Balgownie Interburden, Sy was increased by a factor of 20 and the Balgownie by a factor of 10.

Specific Storage (Ss) was increased by the same factors in the recovery model only.

8.6 Existing Mine Workings

Extensive abandoned mine workings occur regionally within the Bulli seam and extend the length of the escarpment within the model domain as shown in **Figure 1-1**.

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

The model maintains active sinks using drain cells with invert levels of 0.1m representing 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.

No flooding was indicated in any of these areas as the degree of ponding are not reported to be extensive.

The 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 Appin workings. Additionally, active mining is occurring within the Wongawilli seam at Dendrobium at the southern boundary of the model area.

8.6.1 Height of Fracturing and Associated Zone of Depressurisation

The hydraulic characteristics of the Bulli Seam and overlying or adjacent strata to the extracted Bulli, Balgownie and Wongawilli Seam workings have been altered due to subsidence that may have generated atmospheric depressurisation up to the lower Bulgo Sandstone following extraction of Longwalls 4, 5 and 6 (340m) in the Wongawilli Seam.

Where longwall extraction in all three seams has occurred, there is a potential for interaction between surface water features and the top of the depressurised groundwater zone that is recharged from rainfall and adjacent creeks.

The potential may be enhanced if there is interaction between hillslope basal shear plane/s that may be present due to lateral shearing associated with hillslope subsidence and the top of the zone of depressurisation above each longwall panel.

However, due to the modified mine plan where only first workings are proposed to be extracted, there is considered to be no potential for interaction between the zone of depressurisation and the basal shear planes in the shallower areas over the proposed first workings.

Ongoing piezometric monitoring will be used to establish the height of depressurisation as mining progresses.

To date, retrospective multi-seam height of depressurisation assessment is possible at GW1 and RV20.

GW1 is not located over the centre of a Wongawilli Seam longwall, however as it is located within the confines of the main gate and tailgate of Longwall 4, proximity mining activities makes this a valuable tool in understanding related impacts. Although GW1 was not installed until after Longwall 4 was completed, it captured the response to stresses imposed by Longwalls 5 and 6 (340m). Ongoing in-situ field assessment in RV20 has been used to determine the height of depressurisation above the southern end of Longwall 4 where three seams have been mined.

Based on mine water balance monitoring and rainfall observations, free drainage through vertically connected fracturing from the surface streams and in the overall catchment is not apparent over the existing workings at Russell Vale East (SCT Operations, 2019).

In the groundwater model, it was assumed that enhanced hydraulic conductivity after extraction of (and over) the longwalls could enable free drainage within the goaf and overlying fractured strata, with vertical connective fracturing up to the Upper Bulgo Sandstone / Lower Hawkesbury Sandstone.

Plastic deformation with bed delamination, without significantly enhanced vertical hydraulic connectivity, was interpreted to be present from the mid / upper Bulgo Sandstone to 20m below surface, where overlapping triple seam extraction was not present.

The partial “depressurisation” zone generally extends higher up into the subsided strata than the “fractured”, vertically connected, enhanced hydraulic conductivity zone.

Due to limitations of the setup, capability and scale of the model, it was not possible to represent any changes in hydraulic conductivity of the thin (<2m) Quaternary alluvial / colluvial and upland swamp profiles in the upper section of model Layer 1.

In the model, it was assumed that enhanced hydraulic conductivity after extraction of (and over) the proposed first workings could enable free drainage within the goaf and overlying fractured strata, with vertical connective fracturing only extending into the upper section of the Wongawilli Seam (in areas where Balgownie or Wongawilli Seam Longwall or Bulli Seam first workings are absent).

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

Calibration was conducted initially as steady state (i.e. calibration to assumed long-term equilibrium conditions) and subsequently transient (i.e. calibration to the impacts of time-dependent stresses such as pumping and climatic variation).

Steady state calibration was used to compare assumed long term average groundwater levels with groundwater levels prior to the transient calibration period (1993 – 2017).

Subsequent transient or “history match” calibration was conducted using the steady state model to determine initial conditions. The transient calibration period included underground mining in the Bulli Seam in the 500 Series longwalls at Russell Vale West and more recently in the Wongawilli Seam at Russell Vale East.

Transient calibration was to a degree restricted by the lack of monitoring locations within the Permian groundwater system, although sufficient locations were available for a reasonable calibration.

Attention was placed on achieving a level of inter-connection of underground mining areas to match the assessed drawdown response seen, particularly in the monitoring points over the 500 series longwall panels.

8.7.1 Calibration Targets

The model compares target values against model results and interpolates results in both space and time to compute an error or residual. A total of 32 groundwater monitoring locations including open standpipes and multi-level vibrating wire piezometers were used for steady state calibration.

A total of 64 monitored horizons from 32 monitoring locations provided a total of 832 temporal head targets which were included in the transient calibration.

The available monitoring based target points are distributed through the upper overburden layers, with no monitoring data available from beneath the Scarborough Sandstone.

Transient groundwater levels were taken from records at each borehole where data was available. A full list of the calibration targets, including the monitored layers and a comparison of actual versus modelled groundwater heads is outlined in GeoTerra / GES (2015).

Groundwater inflows to active mining areas provide a valuable calibration measure and are critical for achieving a robust calibration.

Water balance records and, particularly mine inflow records for the Russell Vale Mine lease and other adjacent mining operations, were initially not well recorded. Considerable effort has recently been undertaken by Wollongong Coal and SCT Operations (2019) to better understand water balance variables from available data from which a review of inflows led to revised groundwater make estimates, which were used in the calibration process.

8.7.2 Steady State Calibration

Steady state (or baseline ‘long term’) calibration was carried out as the first stage of the calibration process.

Given that the hydrogeological environment in this region is highly impacted from historical mining activities, achieving pre-mining steady state conditions was not the focus of the initial steady state modelling, rather it was focused on attaining realistic starting head conditions for transient calibration as the primary objective.

The steady state calibration allowed for initial head distributions in the model layers to be generated and to check assumptions on the conceptual hydrogeological processes.

It is acknowledged that steady state target heads were gathered from monitoring data that has considerable temporal range. However, this was the best achievable option with the available monitoring data.

Target heads were derived from numerous monitoring periods including 1992 – 1998 and 2007 – 2011. While the appropriateness of this may be questioned, the lack of any monitoring data with sufficient spatial distribution prior to the calibration period provided little opportunity to derive starting heads with sufficient confidence and hence monitoring data with a range of dates was used to derive initial heads.

The steady state model was calibrated to groundwater levels as close as possible to the beginning of 1991, assuming these to be close to long term average groundwater levels in which time there was a stable climate and preceded a period of drought.

In the Russell Vale East area, transient mining stresses have not occurred since completion of the Balgownie Seam extraction in the 1980s, and hence groundwater levels were assumed to have reached a relatively stable state, particularly within the shallower stratigraphy where most of the monitoring network is screened.

The pre-mining water levels in all piezometers have, to some extent, been influenced by the surrounding mining operations over an extended period of time. With this in mind, the steady state model calibration was principally used to provide an acceptable set of starting conditions for the transient calibration model.

8.7.3 Transient Calibration

Transient calibration against groundwater levels was carried out for the period 1993 to 2017 inclusive, utilising 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.

Following completion of mining in the 500 series longwalls, apart from some limited areas of pillar extraction, no longwall mining was undertaken within the Russell Vale West area.

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 6 (340m) after April 2012.

The RMS value for the calibration period is 8.0m, whilst scaled root mean square (SRMS) error is 3.4%, 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 8-4**, and it can be seen that the model is reasonably well balanced against the targets (i.e. there is no systematic under or over prediction).

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 multilevel VWP network has been increased in the past 2 years was used within the calibration data set which could be adjusted when a longer monitoring record is available. This is, however, the key area where the model has failed to simulate observed groundwater pressures and there is, accordingly, a groundwater pressure separation between the Lower Bulgo Sandstone and the

Scarborough Sandstone data.

In addition, the shallow water levels in Layer 1 show some systematic departure from absolute values although trends can be simulated reflecting recharge pattern. This is quite likely to be the result of steeper terrain and its effect on model layers where horizontal and vertical hydraulic conductivities in particular which are assigned in the model and dictate the flow calculations do not reflect actual conditions. While this is not considered to impact greatly on overall model results, further model development will focus on detail within Layer 1 where these high elevation changes occur.

Figure 8-4 illustrates both of the considerations posed above. That being, the failure to accurately simulate indicated groundwater pressures within the Stanwell Park Claystone, which in areas maintains pressures very close to, if not higher than, the Lower Bulgo Sandstone, and the complexity of the groundwater pressure response to mining activities.

In the case of GW1, the response in the Bulgo Sandstone and Stanwell Park Claystone as LW4 approached its closest point to GW1 is interpreted to be the effect of transient storage changes occurring during changing tensional and compressional stress regimes as shown in **Figure 8-5**.

The model has been unable to simulate these physical changes and the result is variability in 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.

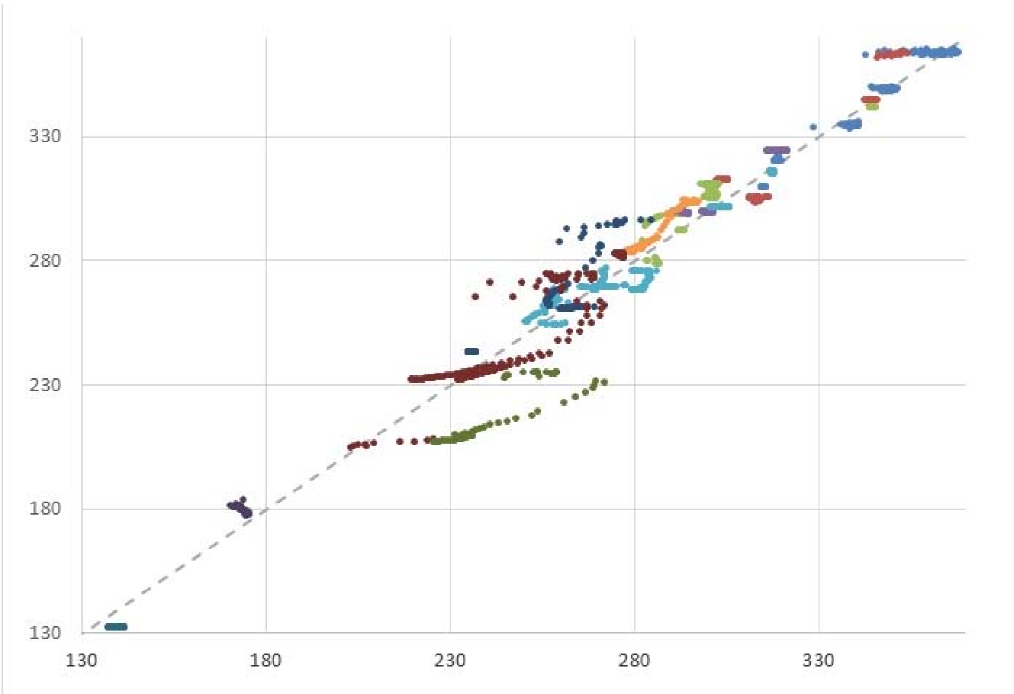


Figure 8-4 Measured Vs Modelled Potentiometric Head Targets

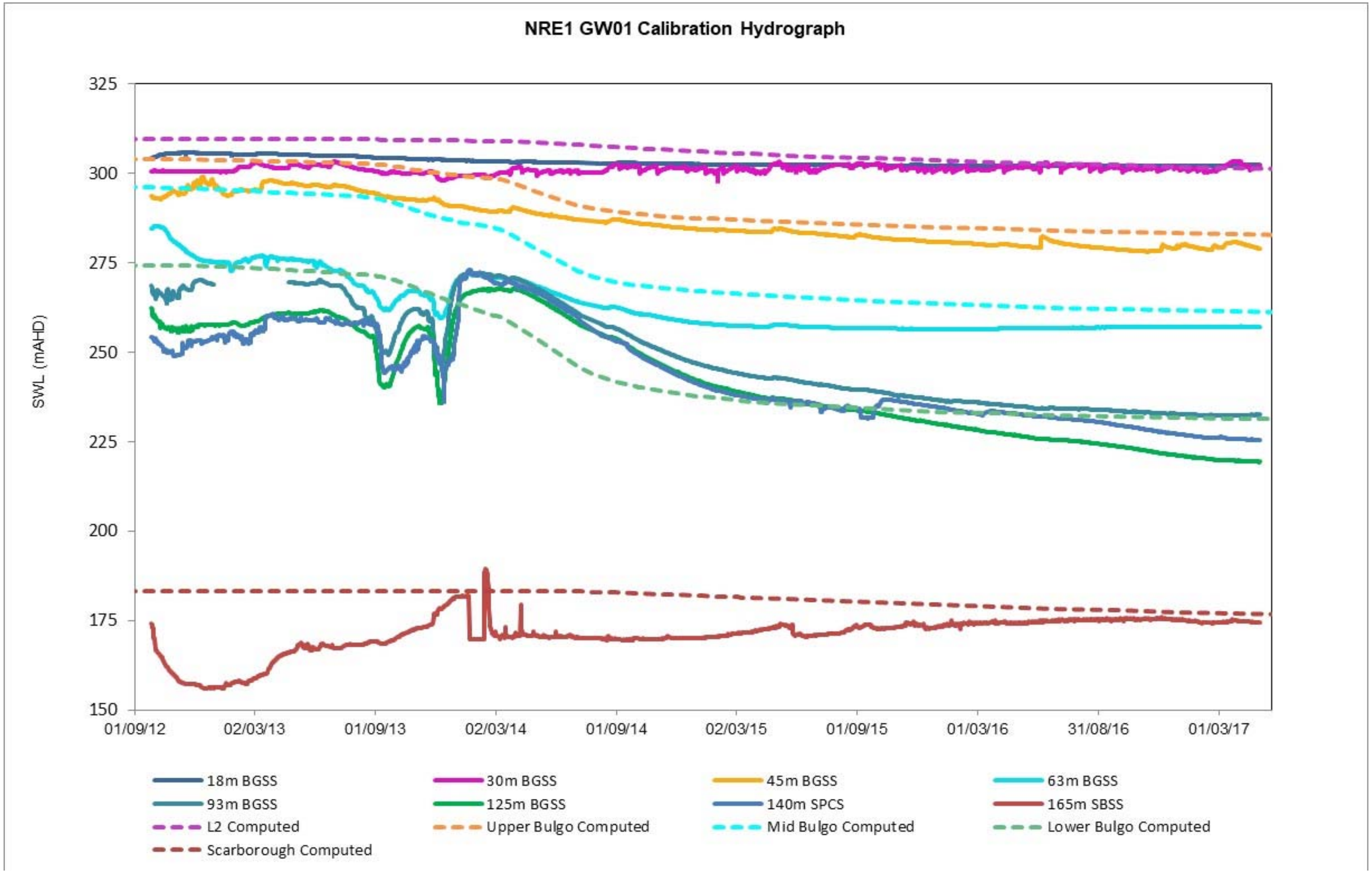


Figure 8-5 Observed vs. Computed Groundwater Levels for NRE GW1

8.8 Fracture and Depressurisation Zone Implementation

In the current model, the fracture zone design and implementation within the triple seam mined area at Russell Vale focussed in the calibration process on matching heads to key piezometer data, primarily GW1 and RV20.

The approach utilised an empirical log-linear ramp function for the simulated height of fracturing in order to calibrate the observed vertical hydraulic head profiles. This was manually adjusted in order to match data from GW1 and RV20. The post Wongawilli Seam extraction subsidence parameter distribution was based on a conceptual understanding of longwall mine subsidence geomechanics and fracture development as detailed in SCT Operations (2019).

Layer definition within the model allowed primary mined coal seams to be represented individually and for the overburden to be subdivided into multiple layers. This allowed subsidence caving and fracturing effects to be simulated to various heights above each mined seam so that the impact of progressive caving and fracturing associated with the mining could be adequately represented.

The fractured zone was simulated with horizontal hydraulic conductivity enhanced by a factor of five within all fractured zone components within the footprint of the longwall panes and extending laterally up to 100m outside the footprint in order to simulate enhanced conductivity resulting from tensional stresses. Vertical hydraulic conductivity was enhanced by a function which varied the vertical hydraulic conductivity field within the deformation zone overlying extraction areas and “weighted” the permeability changes based on layer thickness. In the caved and mined zones, horizontal hydraulic conductivity was set to 10 m/day.

The height of the caved zone was assumed to be five times the mined seam thickness, although this was increased where zones of multi-seam mining occurred and where caved zone parameters were extended to the Bulli Seam, which limited an increase in Sy into the Balgownie Seam only.

For fractured zones, the strata hydraulic parameters were changed using the Time-Varying Material Properties (TMP) package of MODFLOW-SURFACT, which allows varying property values to be applied over time.

Fracturing was instigated by altering host rock calibrated hydraulic properties in accordance with mine progression.

Layer resolution within the model allowed the mined Wongawilli Seam to be represented in Layer 17, with the other layers above it available to simulate the collapsed or caved zone and connected and disconnected fractured zones to specific heights depending on the style and cumulative impacts of seam extraction. This ensured that the impact of variable combinations of first and second workings and the progressive caving and fracturing impacts associated with the different types and combinations of extraction was adequately represented in the model.

Vertical hydraulic conductivity was set to 1m/day within the mined and caved zones in highly fractured overburden.

The vertical hydraulic conductivity in the fractured zone was enhanced according to a log-linear monotonic (ramp) function which varied the vertical hydraulic conductivity field within the deformation zone overlying mining areas and weighted the hydraulic conductivity changes on layer thickness. However, a departure from the ramp function was used to calibrate the observed pressure variations in RV20 and GW1. Limits for the variability were governed by fracture height and assigned upper and lower bounds on hydraulic conductivity in the fractured zone. Assigned fractured zone properties are presented in **Table 10**.

The vertical hydraulic conductivity of the model strata directly beneath mined areas was also increased with a uniform increase in vertical hydraulic conductivity of 100 times the host values being applied. Similarly, horizontal hydraulic conductivity of the underlying layer was increased by a factor of 2 times the host (pre-mine calibrated) values.

Specific yields (Sy) were increased to simulate the highly disturbed nature within the caved zone and overlying variable fracture zone. Specific yield (Sy) was also increased in the Wongawilli Seam to 20% in the footprint of the Wongawilli Seam longwalls, which represents the increased storage occurring in the caved zone as overburden collapses. Above the mined coal seam Sy was increased, along with an increase in porosity to 10%. Within the Wongawilli – Balgownie Interburden, Sy was increased to 10% and the Balgownie to 5%.

Specific Storage (Ss) was increased by the same factors in the mined seam and within the overlying caved zone by applying an increase in the rock porosity component of the Ss parameter, in the same degree as for Sy.

8.8.1 Calibrated Hydraulic Properties

Table 10 summarises the calibrated hydraulic properties of the modelled layers and **Figure 8-6** shows a schematic of the stratigraphic profile of the vertical hydraulic conductivity of host vs. fractured zone showing the higher relative increase of vertical hydraulic conductivity (Kv) in the lower strata above mining levels.

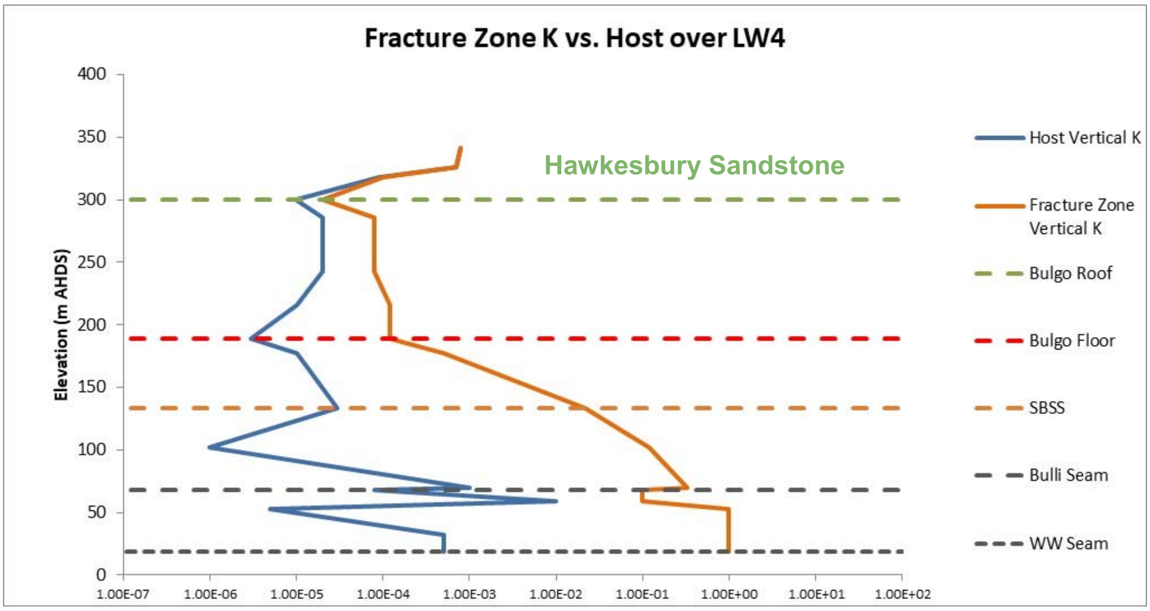


Figure 8-6 Fracture Zone Vertical K vs. Host Kv

Table 10 Calibrated Hydraulic Properties

Layer	Stratigraphic Unit	Host (Kx)	Host (Kz)	Ss [1/m]	Sy	Fracture Zone Wonga West (Kz)	Fracture Zone Russell Vale East Historic Workings Bulli Seam (Kz)	Fracture Zone Wongawilli Longwalls (Kz)	Fracture Zone Wongawilli Longwalls (Kx)*
1	Upper Hawkesbury Sandstone	3.00E-02	2.00E-03	1.00E-04	1.00E-02				
1	Layer 1 (Coastal Plain)	3.03E-01	9.58E-02	8.00E-04	1.50E-01				
2	Mid Hawkesbury Sandstone	5.00E-04	1.00E-05	6.00E-06	1.10E-02				
3	Lower Hawkesbury Sandstone	5.55E-04	6.90E-05	6.00E-06	1.10E-02			6.00E-04	4.0E-05
4	Bald Hill Claystone	2.00E-05	9.88E-06	6.00E-06	1.10E-02			4.00E-04	1.20E-03
5	Mid Upper Bulgo Sandstone	6.00E-04	1.00E-04	6.00E-06	1.10E-02			4.00E-04	1.40E-03
6	Mid Lower Bulgo Sandstone	7.00E-04	1.00E-04	6.00E-06	1.10E-02			5.60E-04	1.80E-03
7	Lower Bulgo Sandstone	9.00E-04	3.50E-05	6.00E-06	1.10E-02			5.00E-04	1.00E-03
8	Lower Bulgo Sandstone	5.00E-04	1.00E-05	6.00E-06	1.10E-02			1.33E-04	2.80E-05
9	Stanwell Park Claystone (West)	1.40E-05	8.00E-07	7.00E-06	1.00E-02			4.98E-04	2.80E-04
9	Stanwell Park Claystone (East)	1.40E-04	3.00E-06	7.00E-06	1.00E-02			4.00E-04	1.20E-03
10	Scarborough Sandstone	8.00E-04	1.00E-05	7.00E-06	1.00E-02			2.16E-02	1.60E-03
11	Wombarra Claystone	1.68E-05	1.50E-06	6.00E-06	2.50E-03	5.00E-06	2.00E-05	1.00E-01	3.36E-05
12	Coal Cliff Sandstone	4.00E-04	4.00E-06	2.50E-06	6.00E-03	1.60E-03	variable	1.00E+00	8.00E-04
13	Bulli Seam (West)	2.00E-04	5.00E-05	5.00E-06	2.00E-03	1.47E-01	1.00E-02	1.47E-01	1.00E-02
13	Bulli Seam (East)	9.50E-03	2.00E-03	5.00E-06	2.00E-03			4.00E-01	1.90E-02
14	Interburden	1.50E-04	1.50E-05	4.00E-06	6.00E-03			1.00E-01	3.00E-04
15	Balgownie Seam	5.50E-04	1.00E-04	7.00E-06	8.00E-03			1.00E+00	1.10E-03
16	Interburden	5.00E-05	1.00E-05	4.00E-06	5.00E-03			1.00E+00	1.00E-04
17	Wongawilli Seam	4.00E-04	9.00E-05	4.00E-06	5.00E-03			1.00E+00	1.00E+01
18	Kembla Sandstone	3.00E-04	9.00E-05	2.50E-06	5.00E-03				
19	Basement	1.00E-04	7.00E-05	2.50E-06	5.00E-03				

8.9 Mine Groundwater Inflows

Based on available mine water balance records, the average daily groundwater inflow derived from strata leakage extracted from Russell Vale East Colliery was simulated as 0.2 ML/day prior to extraction of LW4 and 0.7 – 1.1 ML/day during extraction of extraction of LW4, 5 and 6 (340m) as shown in **Figure 8-7**.

Records for mine inflows prior to the extraction of LW4 are considered to be uncertain and the lack of any reported inflow during the development stage is also considered to be implausible, however more accurate mine water pumping records have been obtained since the start of LW4.

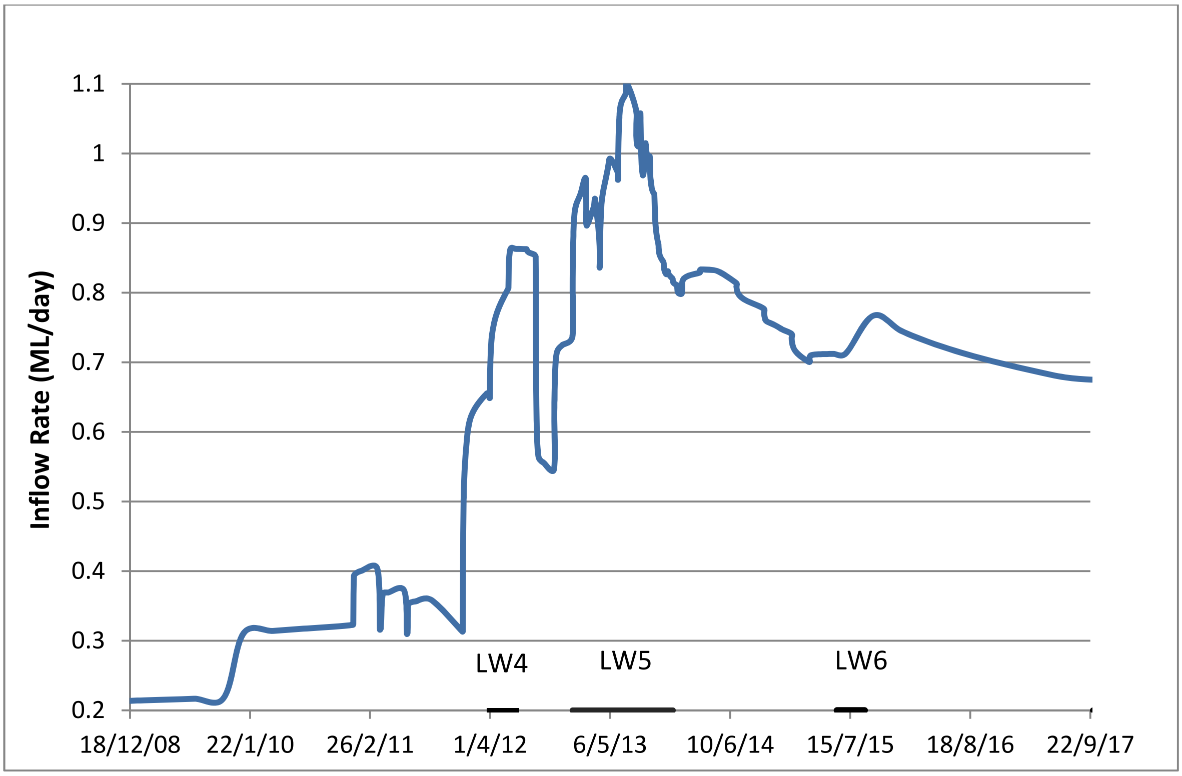


Figure 8-7 SCT Operations (2019) Simulated Mine Inflows During the Calibration Period

Figure 8-7 indicates that groundwater inflow to the mine peaked at approximately 1.1ML/day (or 402 ML/year) during extraction of Longwall 5 in mid 2013, and subsequently, after extraction of Longwall 6 in mid to late 2015, peaked at approximately 0.75ML/day (or 274 ML/year).

8.10 Water Balance

There are numerous opportunities for groundwater to discharge from, and recharge to, the groundwater system and into / out of the groundwater model. 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 over 61 stress periods from 1991 to June 2017 in the transient model run up until the end of the calibration period across the entire model area is summarised in **Table 11** and includes continued mining in Russell Vale West.

The total inflow (recharge) to the aquifer system into the model domain is approximately 77ML/day, comprising rainfall recharge (approximately 80%), 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 11 Simulated Water Balance over the Calibration Period

	Inflow (ML/d)	Outflow (ML/d)
Storage	5.9	10.69
Constant Head	0.001	0.03
Drains (Outflow = Groundwater Entering Mine Workings)	0	1.4
Recharge (Direct Rainfall)	62.2	7.7
Et (Evapotranspiration)	0	42.6
River (Leakage/Baseflow)	8.9	14.6
Head Dependent Boundary (GHB)	0.001	0.1
Total	77.11	77.16
% Discrepancy	-0.06%	

8.11 Effect of Structures

Due to the limitations and constraints inherent with the model set up and code, as well as uncertainty in the location, stratigraphic persistence and hydraulic properties of geological structures in the Russell Vale lease area, structures are not simulated in the model.

Observations of intersections of the Corrimal Fault and Dyke D8 within the three levels of extraction have not encountered any observable water make in the workings (SCT Operations, 2015).

As a result, and as outlined in SCT Operations (2019), neither the Corrimal Fault or Dyke D8 are assessed as being able to provide a credible risk of enablng hydraulic connection between Cataract Reservoir and the underground mine workings.

9. PREDICTIVE MODELLING

9.1 Stream Bed Alluvium and Plateau Colluvium

There are no anticipated subsidence effects on stream bed alluvium or plateau colluvium as there is no significant accumulation of Quaternary sediments within the Russell Vale lease area and there is no perceptible predicted subsidence or transmitted overburden depressurisation over and due to the proposed first workings extraction.

The presence of alluvial sediments is limited to the upland swamps, which have been measured up to 1.8m deep.

Where the swamps are absent in the lower catchment, the stream beds are dominated by either exposed sandstone or boulder reaches without significant alluvial deposits.

9.2 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 (within the 20m thick Layer 1) with their limited and variable spatial extent was not assessed in the simulation.

It was observed that Layer 1 could go dry in some locations over triple seam longwall extraction areas, however this impact is not added to by the proposed first workings extraction.

Further discussion of the potential effects on swamps is contained in Biosis (2019).

9.3 Strata Groundwater Levels

Figures 9-1 to **9-6** 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 LW6 extraction and at the end of proposed mining at Russell Vale East.

Figures 9-1 and **9-2** show initial conditions, and de-saturated areas underlying 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.

Figures 9-3 and **9-4** show the same cross sections following the completion of LW6. Here early fracture zone implementation over LW4, 5 and 6 (340m) has caused a vertical propagation of the zero pressure contour. This does not propagate through to surface but positive pressures are maintained in the Upper Bulgo Sandstone. The fracture zone developed within the model is pushed into the Lower Hawkesbury Sandstone and a decline in head within the Hawkesbury Sandstone is also evident.

Figures 9-5 and **9-6** show these cross sections following completion of mining in the Wongawilli Seam where the triple seam longwall fracture zone has fully developed and caused a further vertical propagation of the zero pressure contour. However, it has not broken through to surface.

Within the process of groundwater system recovery, the adits within the Illawarra Escarpment will spill well before full recovery of the groundwater system and adit sealing will be ineffective as the low lithostatic head pressure in the strata due to the low depth of cover on the escarpment will not be able to hold the water pressure (SCT Operations, 2015B).

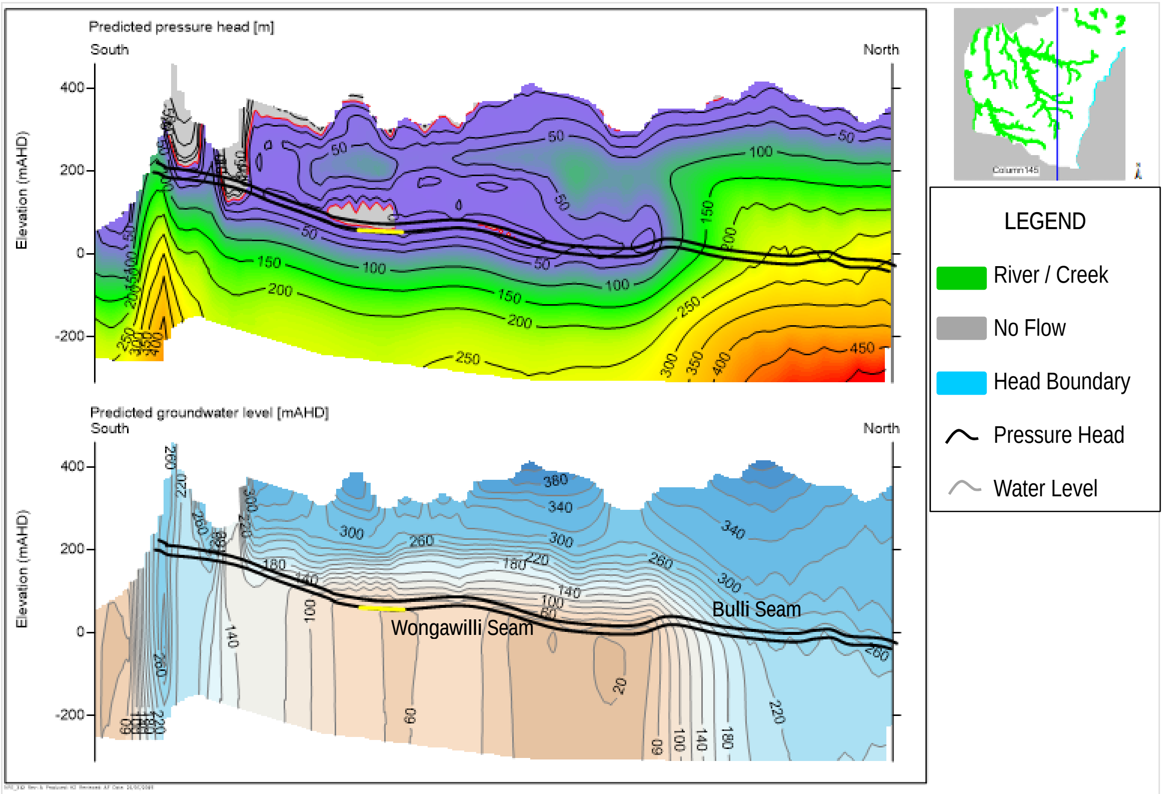


Figure 9-1 Predicted Pressure Head and Potentiometric Head Initial Conditions at Russell Vale East (North – South Cross Section on Easting 303000)

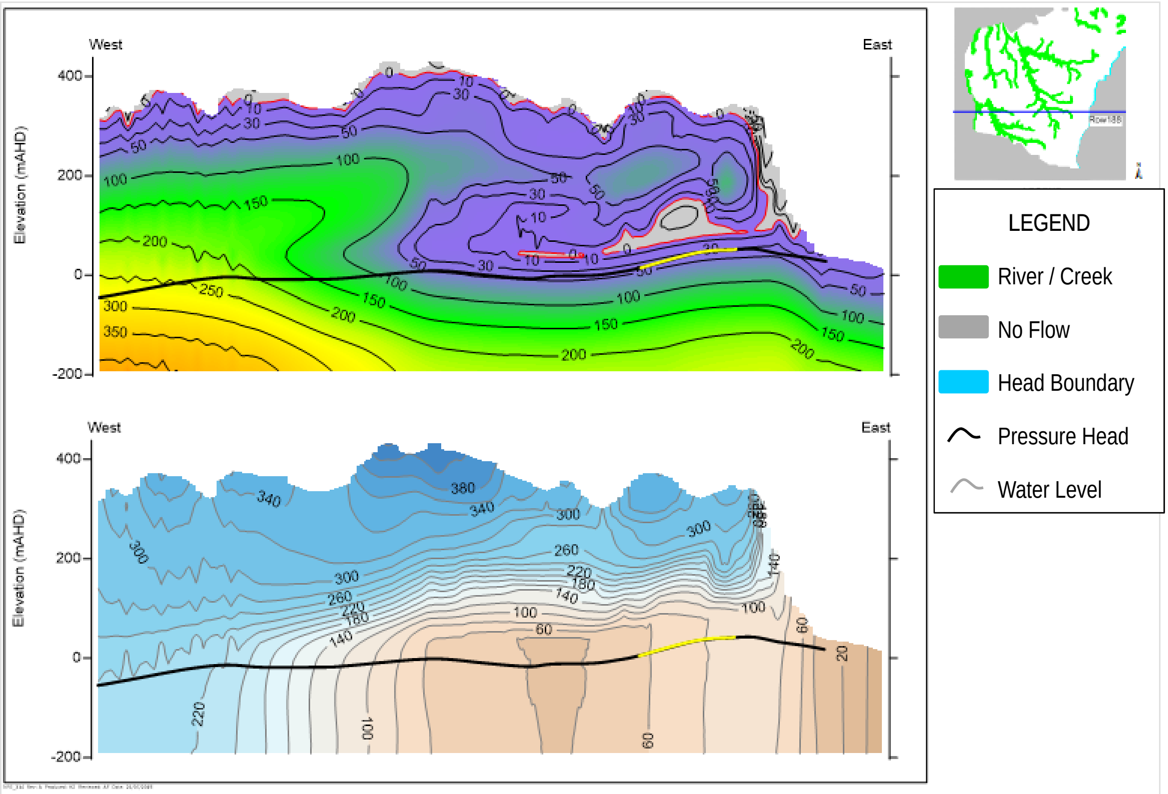


Figure 9-2 Predicted Pressure Head and Potentiometric Head Initial Conditions at Russell Vale East (East – West Cross Section on Northing 6196895)

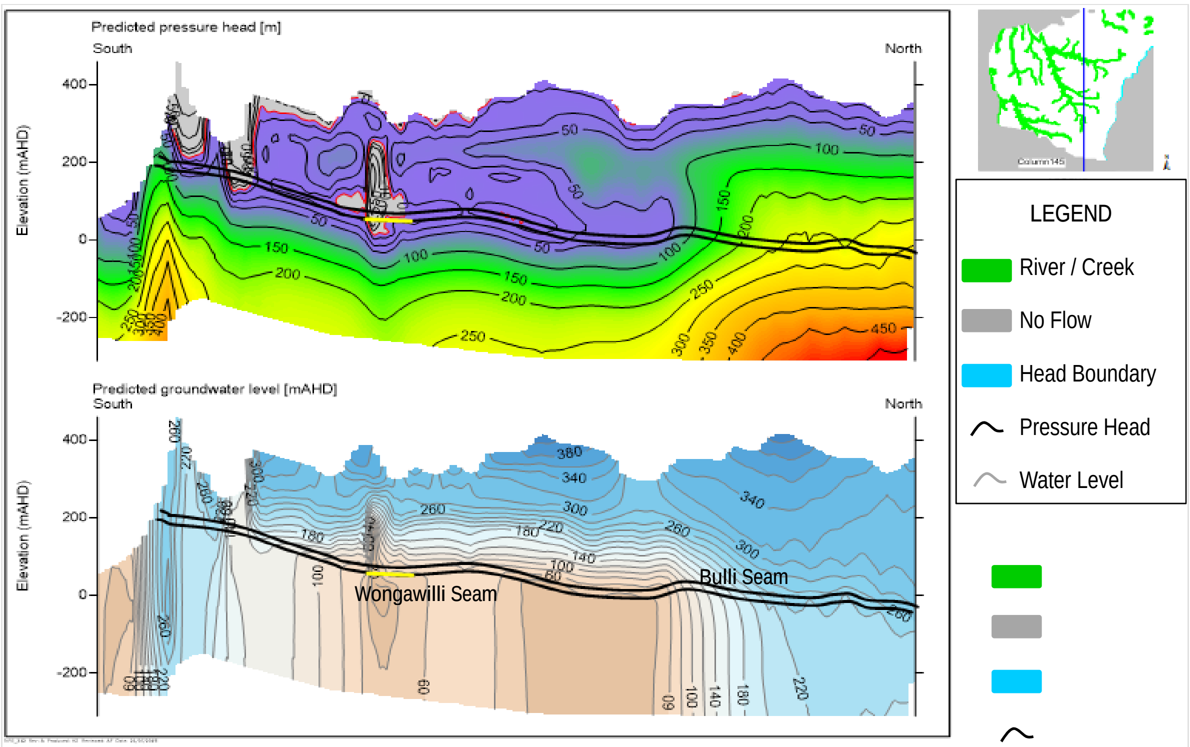


Figure 9-3 Predicted Pressure Head and Potentiometric Head at Russell Vale East at the End of LW6 (North – South Cross Section on Easting 303000) update

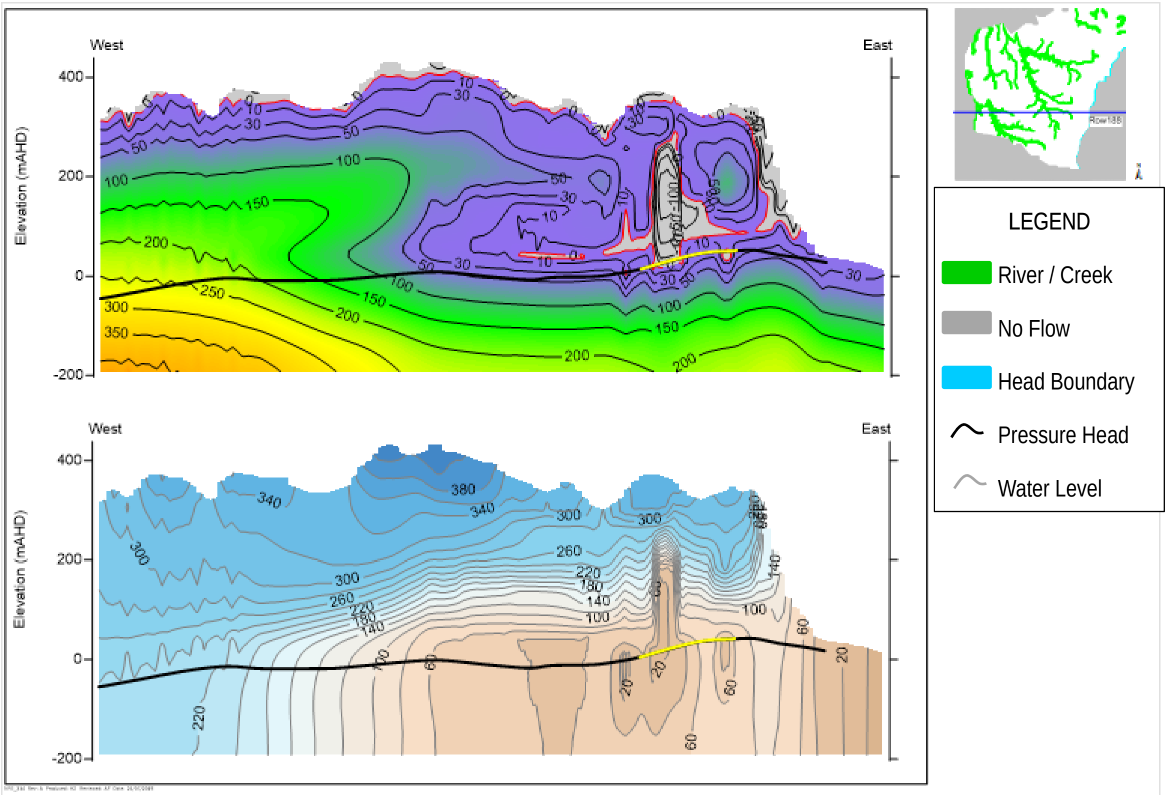


Figure 9-4 Predicted Depressurisation at Wonga at the End of LW6 (East – West Cross Section on Northing 6196895)

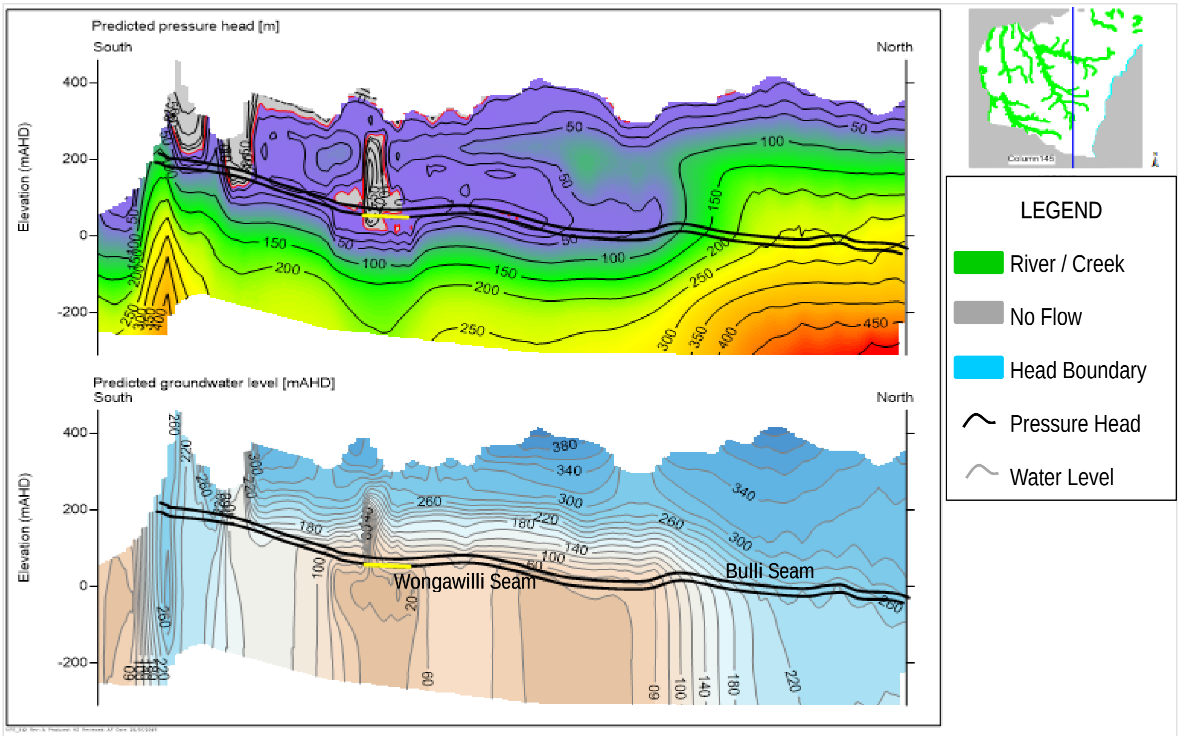


Figure 9-5 Predicted Depressurisation at Russell Vale East at the End of Mining (North – South Cross Section on Easting 303000)

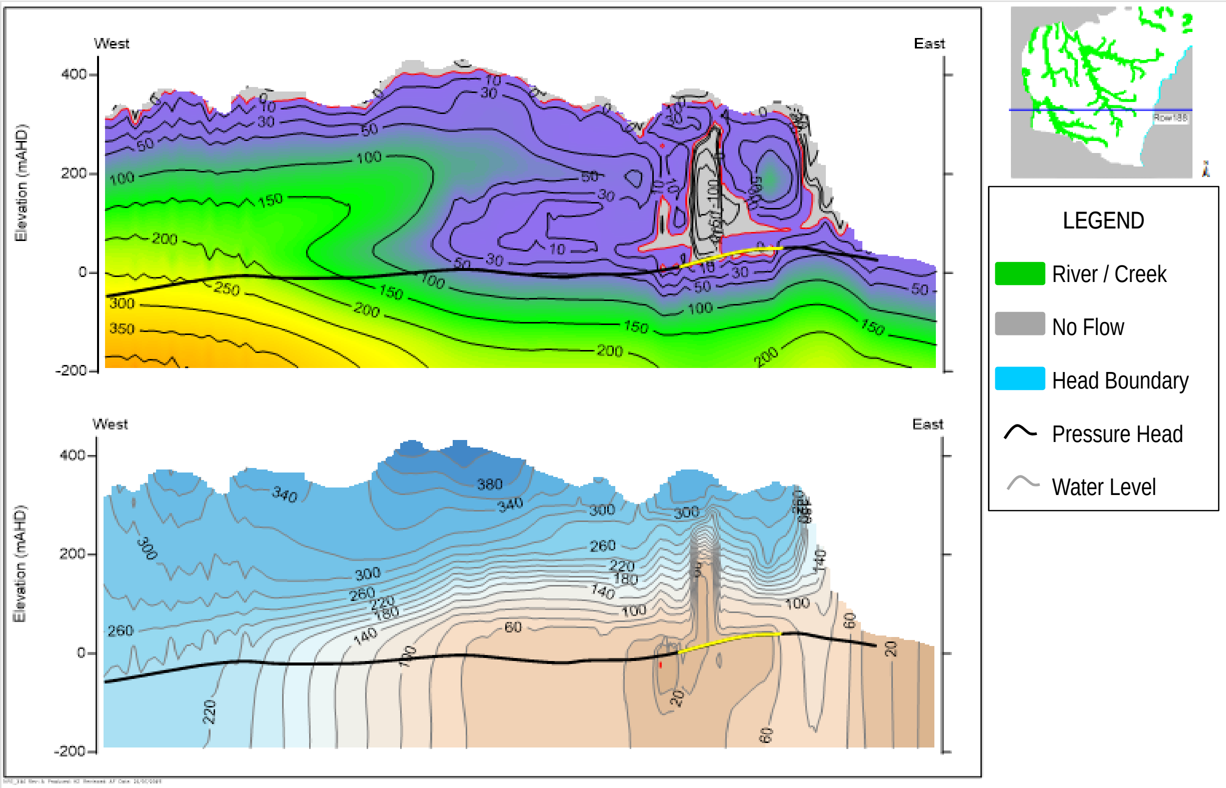


Figure 9-6 Predicted Depressurisation at Russell Vale East at the End of Mining (East – West Cross Section on Northing 6196895)

9.3.1 Shallow, Perched, Ephemeral, Hawkesbury Sandstone

Perched, ephemeral, shallow groundwater within the upper Hawkesbury Sandstone (Layer 1) could undergo a water level reduction over the proposed workings after subsidence, but as a consequence of transmitted depressurisation from the triple seam mined areas, and not due to the proposed first workings.

However, as the ephemeral shallow Hawkesbury Sandstone aquifers desiccate after extended dry periods, the effect on the mostly disconnected, perched aquifers with limited extent was not modelled.

However, it is logical to conclude that fracturing of the upper, shallow strata over the previously mined triple seam extraction areas could enhance the leakage rate from the perched aquifers into underlying strata over subsided areas, as well as enhancing rainfall recharge and subsequent seepage rate from these perched aquifers into local streams or the underlying aquifers. This impact is not perceptibly added to by the proposed first workings.

The minimal predicted subsidence of the uppermost, 20m thick Layer 1 (<100mm) due to the proposed first workings is not anticipated to have an observable effect on stream baseflow or stream water quality where the temporary aquifers seep into local catchments.

9.3.2 Upper Hawkesbury Sandstone / Regolith

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 9-7** in comparison to pre Wongawilli Seam development, although there is no direct depressurisation linkage between the proposed first workings and the Layer 1 depressurisation.

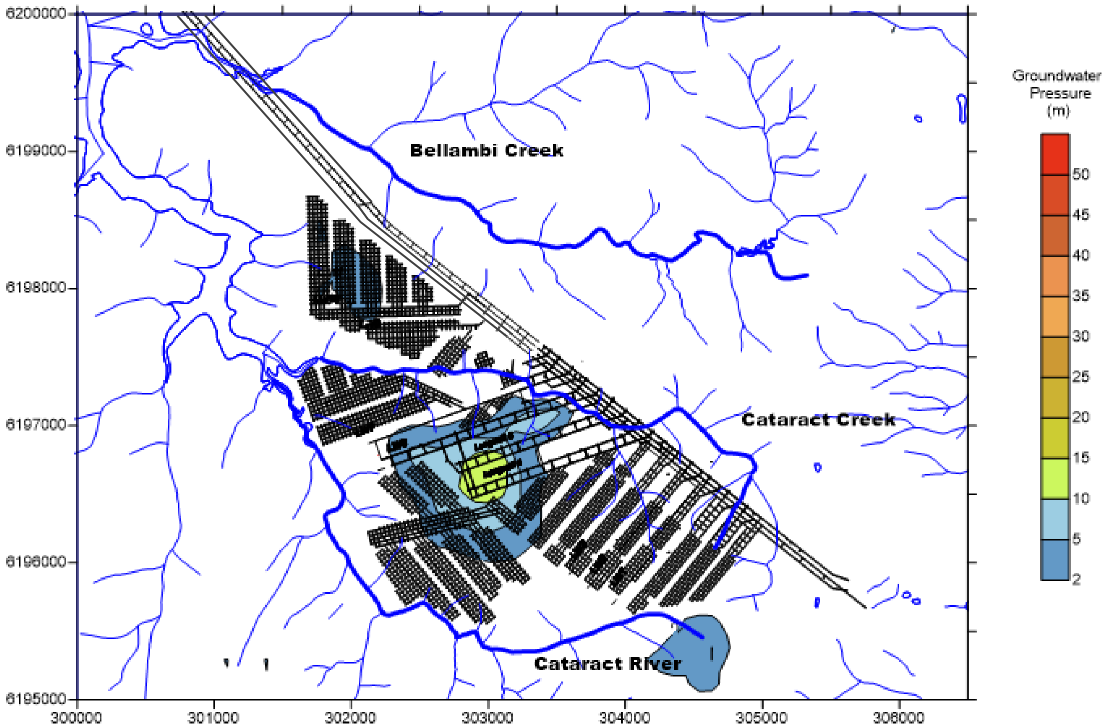


Figure 9-7 Layer 1 Drawdown after Mining the Proposed Workings Relative to the Start of Mining in Wongawilli Seam

The isolated area of approximately 2m drawdown shown in **Figure 9-7**, to the south of the proposed workings, is interpreted to be an artifact of data post processing. While it was known at the time of reporting to be an error, a reason was not identified and time prevented further analysis. Rather than remove the area for reporting purposes, it was left in for transparency.

It is suspected that it is the result of using a Pseudo Steady State head for grid math purposes but could also be a small model geometry / architecture issue that went un-noticed.

Further small examples are noted outside the subject area of the figure, along the escarpment. Given that the effect was minor, it was not interpreted to have any impact on the overall interpretation of mine subsidence related groundwater impacts on Layer 1.

Figure 9-8 illustrates that the drawdown after the proposed first workings extraction is completed, compared to the post LW6 (340m) groundwater levels, is negligible, with a +/- 1cm change in Layer 1 water levels, which essentially represents noise within the model.

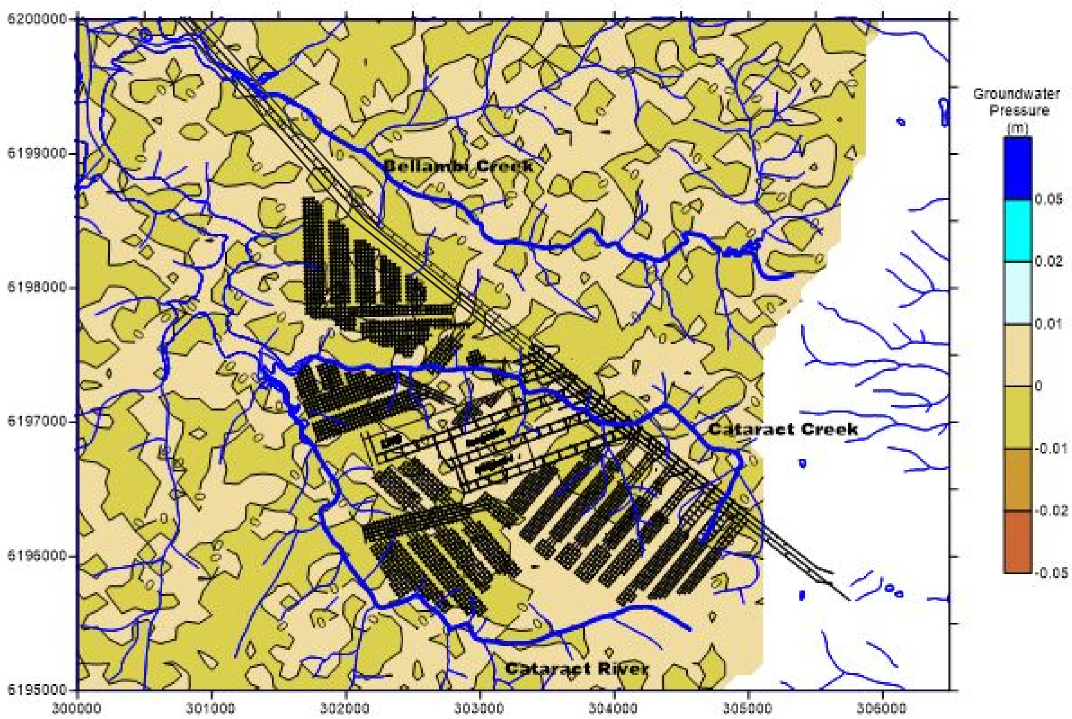


Figure 9-8 Layer 1 Drawdown after LW6 Relative to the End of the Proposed Mining

Although the legend polarity in **Figure 9-8** is shown as both negative and positive, the actual positive (recovery) values are very small and represent isolated areas of noise within the modelling results.

Figures 9-9 and **9-10,** which represent 40 and 200 years after completion of the proposed first workings, indicate that groundwater levels in Layer 1 continue to initially fall after extraction of the previously mined Wongawilli Seam longwalls and proposed first workings. At 40 years there is up to 5m drawdown evident over Longwall 4.

However, 10m of recovery occurs after 200 years.

The Layer 1 drawdown effects at both 40 and 100 years are linked to depressurisation associated with historic workings, in particular, LWs 4-6.

There is, however, no observable Layer 1 drawdown effect associated with the proposed first workings.

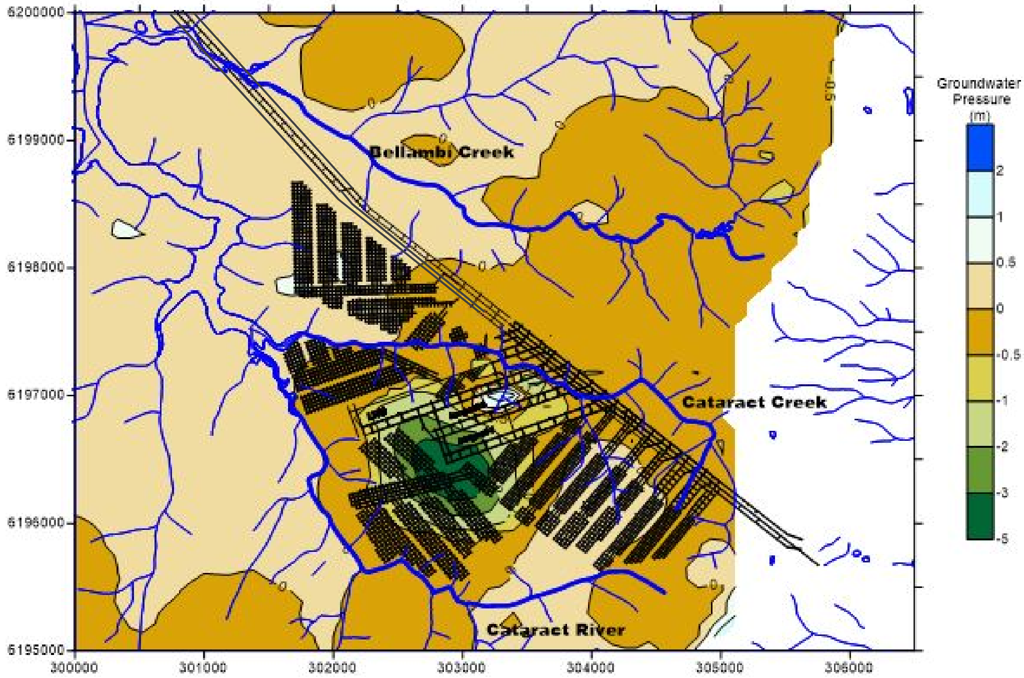


Figure 9-9 Layer 1 Recovery 40 Years After Completion of the Proposed First Workings

Although the legend polarity in **Figure 9-9** is shown as both negative and positive, the actual positive (recovery) values are very small and represent isolated areas of noise within the modelling results.

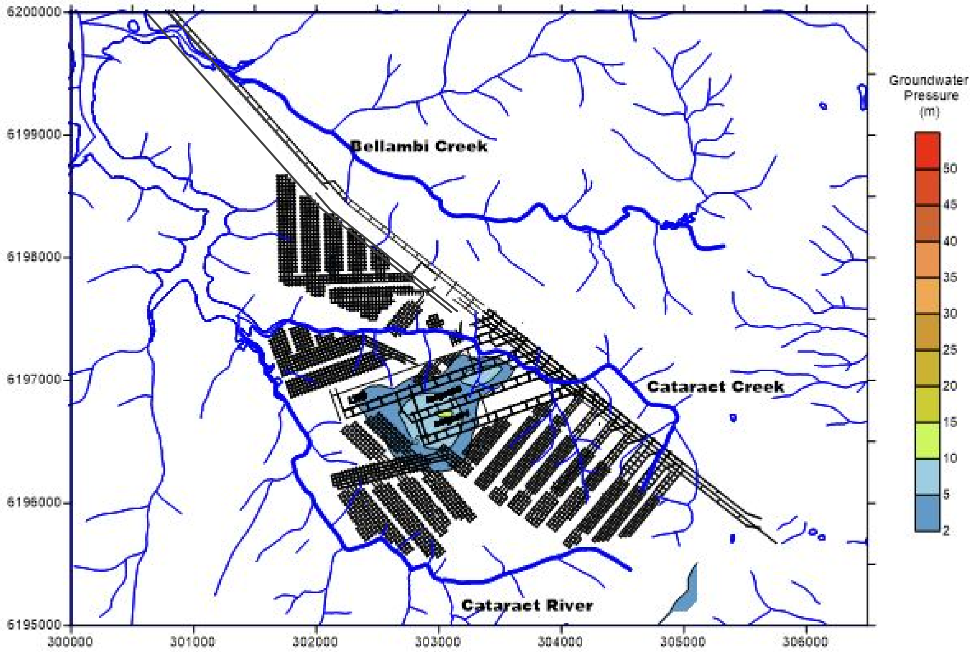


Figure 9-10 Layer 1 Recovery 200 Years After Proposed Mining at Russell Vale East

The legend scale difference in recovery time between **Figure 9-9** and **Figure 9-10** is due to the different elapsed time periods (i.e. 40 versus 200 years), with the greater elapsed time frame in **Figure 9-10** enabling greater recovery.

9.3.3 Hawkesbury Sandstone to Wombarra Claystone

Impacts on the Bulli Seam overburden which includes Hawkesbury Sandstone to Wombarra Claystone are not presented in this report.

This is because the previous model and this current model iterations are essentially identical as there is no influence on these layers from the proposed first workings extraction.

For commentary and figures of the impacts in this zone, refer to report GeoTerra / GES (2015).

9.3.4 Bulli Seam

The Bulli Seam over a large area regionally has been mined over a very long period of time.

Within the Russell Vale area where there is over 100 years of historical mining activity, unsaturated voids still exist and continue to be drained. As such the Bulli seam with its atmospheric pressures in the Russell Vale area separates the groundwater systems in the overburden and the underlying coal seam stratigraphy which includes the Wongawilli Seam

Bulli Seam drawdown figures are not presented in this section as the seam is generally dry at Russell Vale East.

9.3.5 Balgownie Seam

Mining in the Balgownie Seam at Russell Vale East occurred prior to the model start in 1990.

Therefore, enhanced hydraulic properties were included from the start of the model which are further impacted on from fracturing occurring in the Wongawilli Seam over LW4 and LW5 and to a lesser degree the limited longwall extraction in LW6 and is drained via connection with the Wongawilli Seam. **Figure 9-11** shows drawdown in the Balgownie Seam after completion of mining in comparison to the start of mining within the Wongawilli Seam. High drawdown over LW4, LW5 and LW6 reflects the fracture zone.

Figure 9-12 shows drawdown in the Balgownie Seam from start of mining to end of LW6.

Figure 9-13 shows drawdown from the End of Longwall 6 to the end of proposed mining. It shows drawdown over the proposed first workings mine plan is limited to a maximum of approximately 5m.

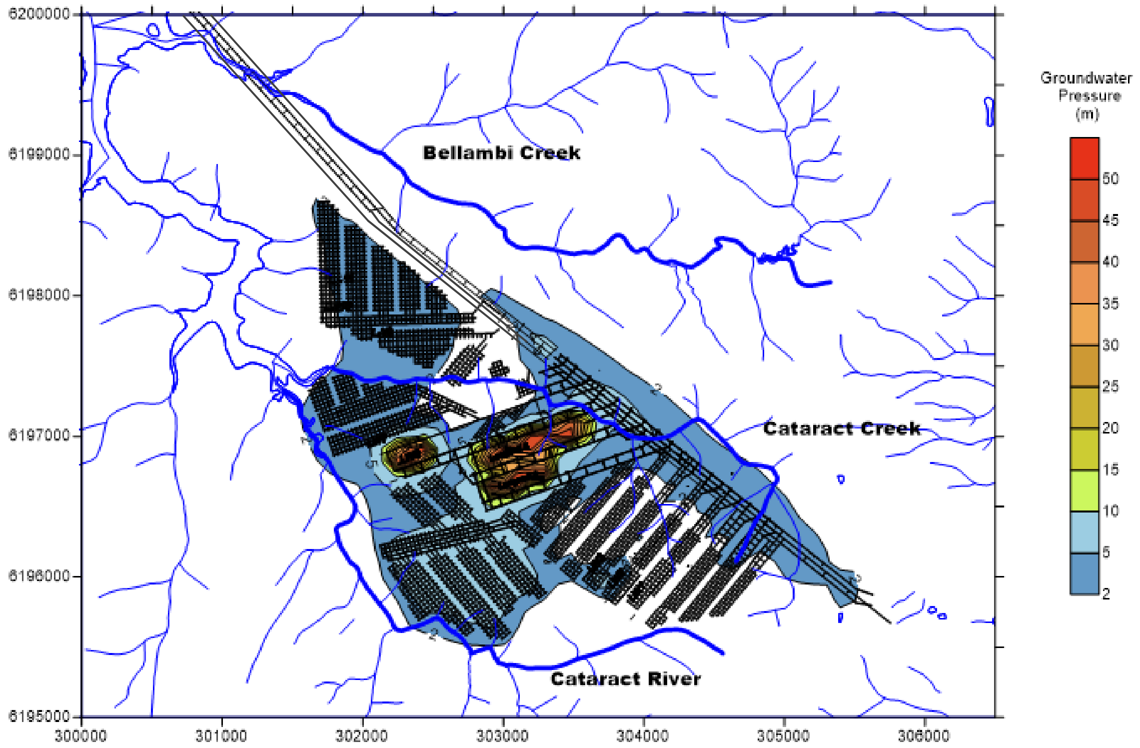


Figure 9-11 Drawdown In the Balgownie Seam after the Proposed Mining Relative to the Start of Mining in Wongawilli Seam

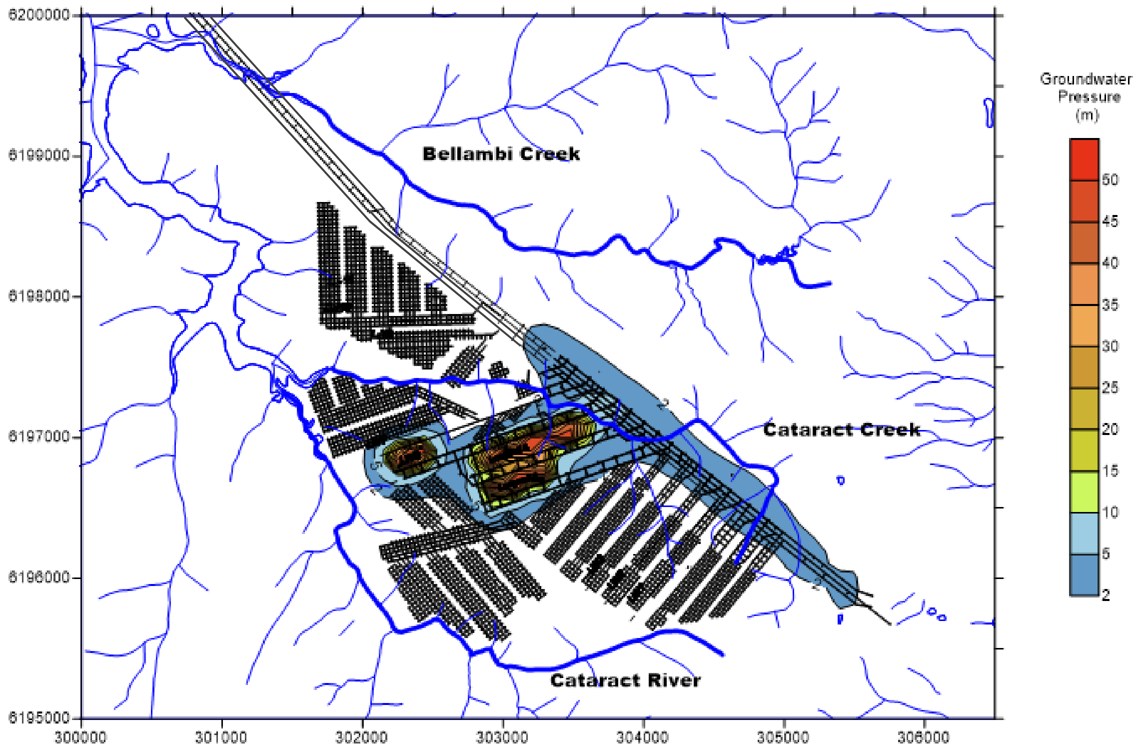


Figure 9-12 Drawdown within the Balgownie Seam after LW6 Relative to the Start of Mining in the Wongawilli Seam

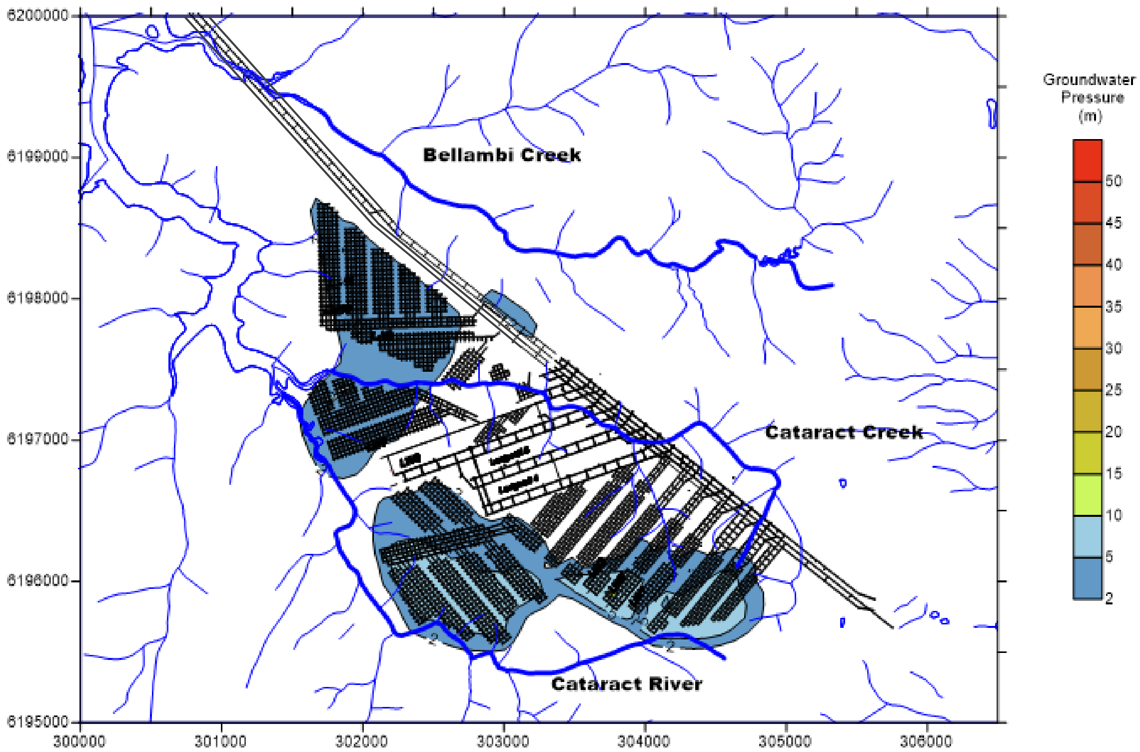


Figure 9-13 Drawdown within the Balgownie Seam after LW6 up to the end of the Proposed Mining

9.3.6 Wongawilli Seam

Drawdown occurs in the Wongawilli Seam at the end of the proposed first workings. The areal extent of the 2m drawdown contour at the end of the proposed mining extends a maximum of 0.5km to the north of the main headings as shown in **Figure 9-14**.

Figure 9-15 shows drawdown as a result of mining to date and highlights the drawdown over LW4, LW5 and LW6.

Figure 9-16 shows the drawdown resulting from the current proposal from the end of LW6 to the end of mining. Maximum drawdown of up to 50m above the Wongawilli Seam occurs just to the north of the Mains out to a distance of approximately 0.5km from the proposed workings.

As the depressurisation only progresses up to 50m above the Wongawilli Seam, there is no connective strata depressurisation up to surface as a result of the proposed workings.

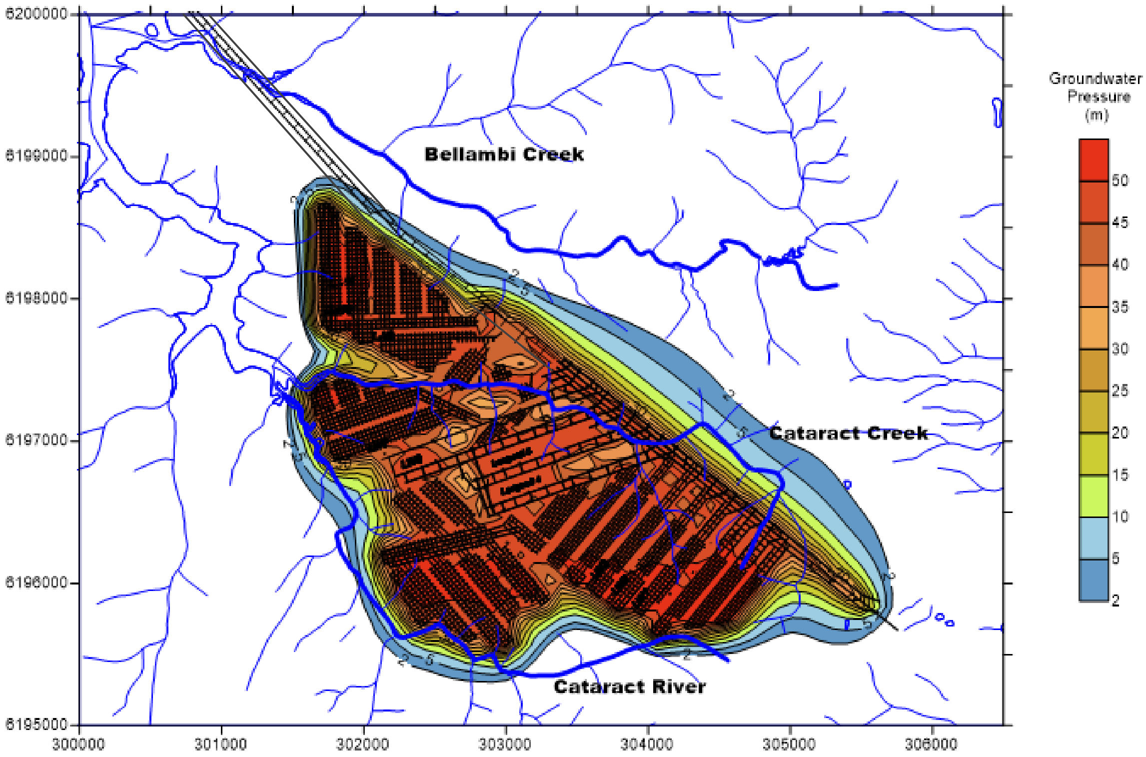


Figure 9-14 **Drawdown After the Proposed Mining Compared to Pre Wongawilli Seam Development**

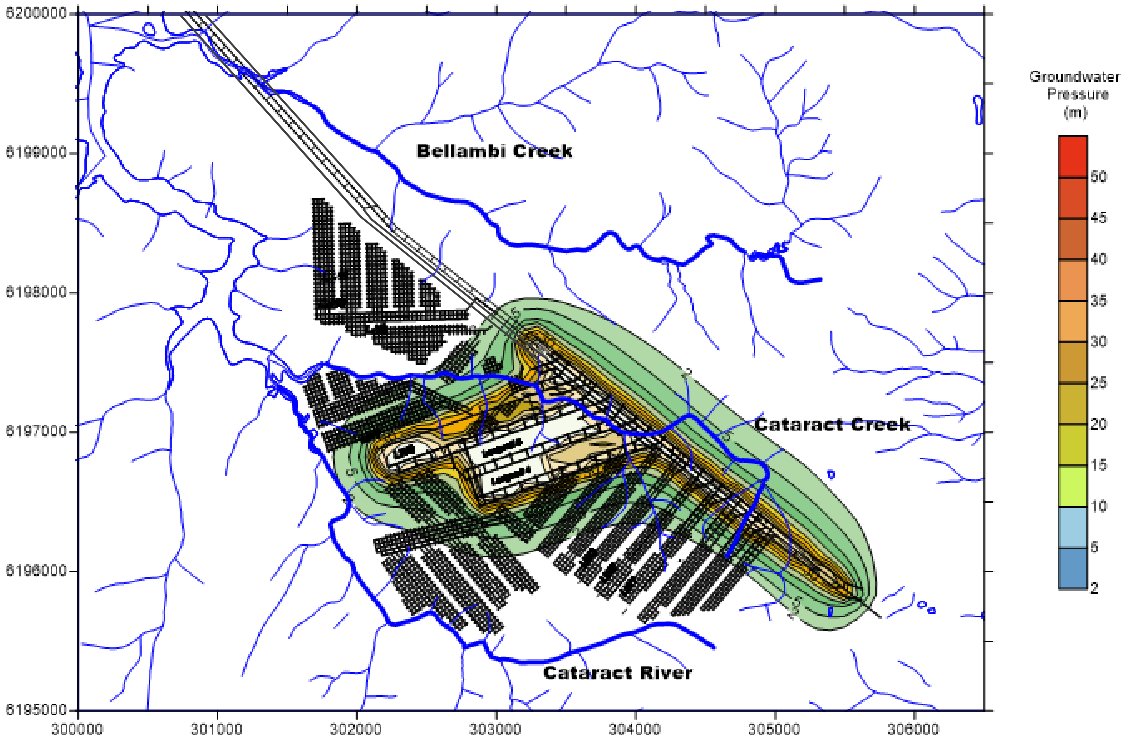


Figure 9-15 **Drawdown within the Wongawilli Seam after LW6 Relative to the Start of Mining in the Wongawilli Seam**

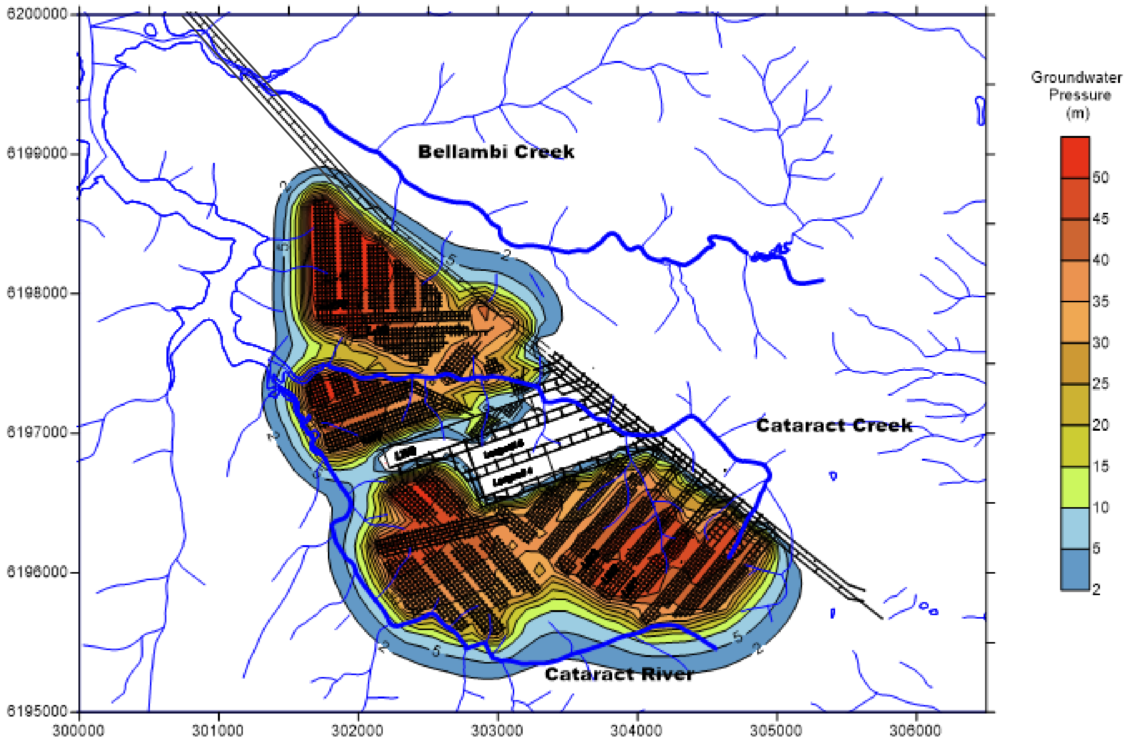


Figure 9-16 Wongawilli Seam Drawdown After the Proposed Mining Compared to the End of LW6

At 40 years after completion of mining, the Wongawilli Seam is predicted to recover by up to 45m in comparison to initial conditions over Russell Vale East as shown in **Figure 9-17** which is essentially close to a full recovery.

Groundwater levels at the escarpment are at pre-mining levels after 200 years. However, the lowest adit entry level are at 117m AHD. Groundwater levels recover well in excess of initial conditions as shown in **Figure 9-18** as the overlying Bulli Seam is also recovering above that of initial conditions.

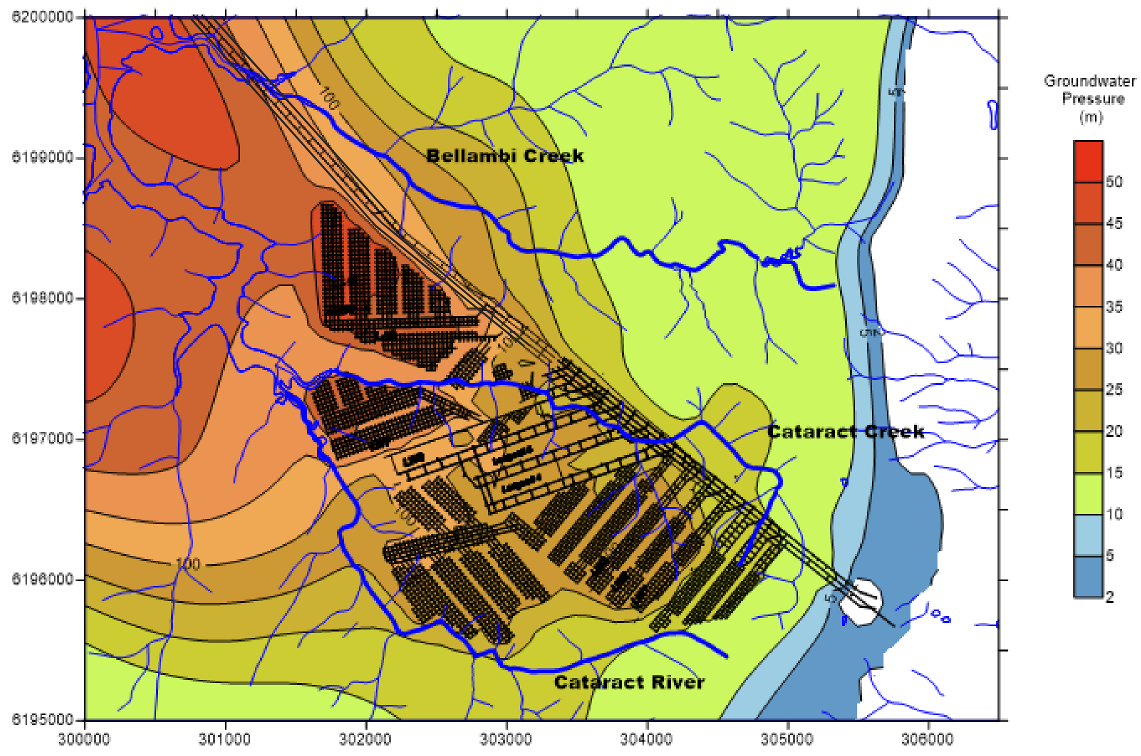


Figure 9-17 Wongawilli Seam Recovery 40 Years After Mining

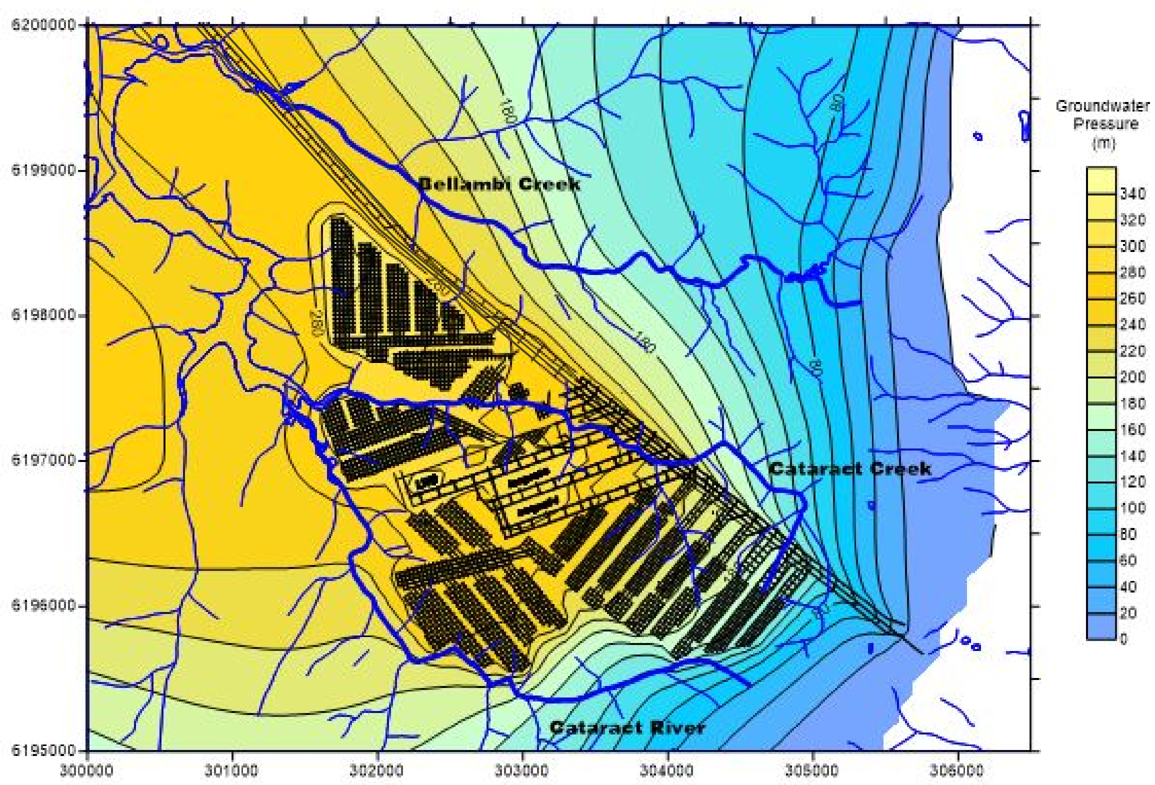


Figure 9-18 Wongawilli Seam Recovery 200 Years After Mining

The positive (groundwater level rise, or, groundwater level recovery) legend values in **Figure 9-17** and **Figure 9-18** occur as a result of the groundwater levels 40 and 200 years after cessation of mining being significantly higher than initial pre-mining Wongawilli Seam levels.

Figure 9-19 shows a simulated recovery hydrograph at the location of vibrating wire monitoring bore GW1. It demonstrates the permanent dewatering evident within the strata overlying the triple seam mined areas within the Wongawilli Seam up to and including the Bulgo Sandstone.

Depressurisation associated with the proposed first workings is only evident in the Wongawilli Seam, as the predicted impacts in other seams is linked to Longwalls 4, 5 and 6

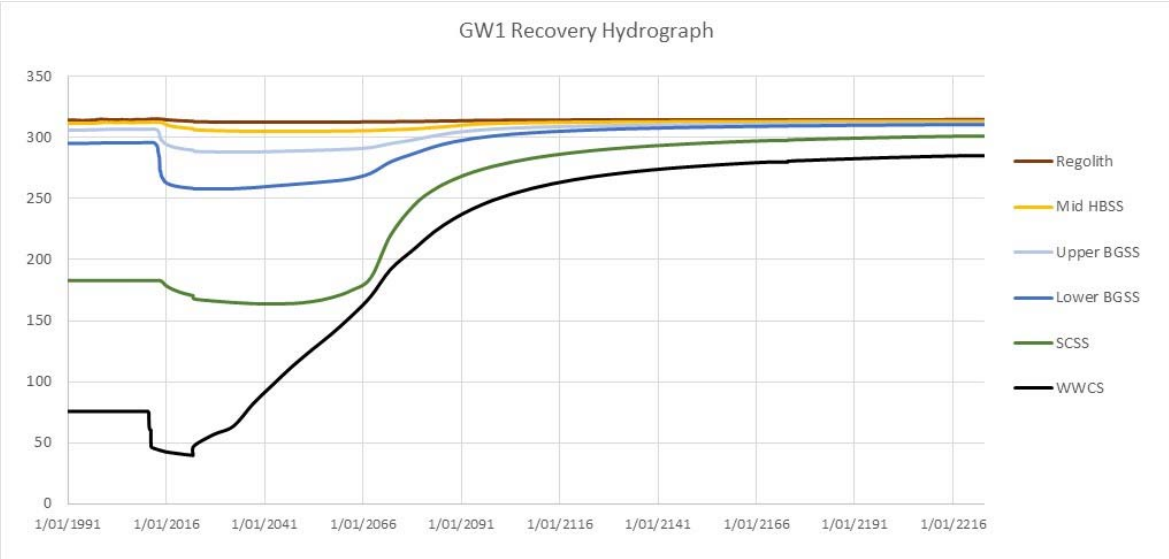


Figure 9-19 Modeled Recovery Hydrograph for GW1

9.4 Potential Loss of Bore Yield

There will be no loss of bore yield as there are no registered private bores or wells located within the Russell Vale lease area as a result of the proposed first workings.

9.5 Stream and Groundwater System Connectivity

A number of mechanisms can potentially occur to groundwater systems associated with streams:

- direct flow of surface water into mining induced fracture systems with vertical drainage into the shallow strata 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;

- reversal of water transfer from the shallow groundwater system to the "gaining" streams during periods of high recharge, or;
- reduction of the perched and highly variable shallow groundwater contribution to swamps, and, subsequently, the local streams.

9.5.1 Cataract Creek

The geotechnical subsidence assessment (SCT Operations, 2015) concluded the multi-seam mined Bulli and Balgownie Seam workings at Russell Vale East diminished the spanning capacity remaining in the Bulgo Sandstone directly above the proposed Wongawilli Seam first workings.

Observations over Longwall 4 indicate that due to the previously fractured nature of the overburden above the Bulli and Balgownie Seam workings, the subsidence "bowl" did not effectively extend outside of the Longwall 4 footprint (SCT Operations, 2019).

In the multi-seam mined area, even though horizontal bedding displacement may have extended up into the upper Bulgo Sandstone, this does not mean a direct, free vertical drainage hydraulic connection is present from the surface to the workings.

Monitoring of mine water balance (SCT Operations 2019B) has not detected any associated short term increase in mine water make from the current Russell Vale East workings following significant rain in the catchments over the Russell Vale East workings.

Monitoring of water level trends in piezometer NRE-A over the multi-seam mined area indicates the upper Hawkesbury Sandstone down to the Upper Bulgo Sandstone lithologies have an enhanced response to rainfall recharge. However, no adverse effect on stream flow has been observed as the headwater tributaries and main channel of Cataract Creek have had continuous flow throughout the monitoring period.

The bord and pillar mined areas represented by the open standpipe and vibrating wire piezometers at NRE B, C and D have a limited to minor response to rainfall recharge.

Where only Bulli seam first workings have been extracted, the proposed workings are not predicted to destabilise the Bulli seam pillars (SCT Operations 2019A) sufficiently to cause fracturing or displacement that will extend into the upper Bulgo Sandstone. This means there will be no predicted free drainage connection from surface to seam in these areas.

Beneath the plateau over the Bulli and Balgownie workings in the vicinity of Cataract Creek, extraction of the proposed first workings is modelled to not generate any observable depressurisation in Layer 1 at the end of the proposed first workings extraction.

As a result, there is no anticipated observable change in stream baseflow and seepage flow volumes to Cataract Reservoir.

It is possible, however, over the triple longwall mined area that, where they exist, or have been generated as a result of dilational movement of the hillslope after subsidence, perched and / or phreatic hillslope seepage outflow points may be relocated to lower elevations in the catchment. This would be due to the dilational fracturing of the hillslopes and associated hillslope basal shear zone movement as a result of valley closure.

No additional dilational shearing is anticipated to be generated as a result of the proposed first workings extraction.

Although the effect could not be addressed in the groundwater model due to the very thin zones of up to 10cm thickness (Mills, K.W, pers comm), the potential generation of a horizontal to sub-horizontal shear plane (or planes) in accordance with the theory of Mills (2007) in the perched hillslope aquifers and between 6 – 10m below the valley floor may lower the hillslope seepage outflow elevations. This could mean that the triple seam longwall affected baseflow seepage to the valley could occur lower down in the catchment, and could have generated a re-location in the transition point in the creek from ephemeral to intermittent / perennial flow.

It is also feasible that three stages of dilational, horizontal to sub-horizontal hillslope shear zones could have previously been generated following extraction of the secondary workings in the Bulli Seam, as well as after the Balgownie Seam Longwalls and Longwalls 4, 5 and 6 (340m) in the Wongawilli Seam.

It is anticipated that no additional incremental effect will be caused due to extraction of the proposed first workings, and they will not cause an observable change in overall stream discharge into Cataract Reservoir (in addition to any prior longwall related effects).

Mapping of the stream bed and tributaries indicates that baseflow seepage changes have probably occurred in Cataract Creek prior to extraction of Longwalls 4 to 6 (340m) in the Wongawilli Seam, based on the high degree of iron hydroxide seepage and precipitation present in the upper reaches all the way down to the Cataract Reservoir.

Due to the lack of stream bed, flow and chemistry monitoring prior to July 2008, quantification of the changes in water flow and chemistry in Cataract Creek due to mining the Bulli Seam and Balgownie Seam is not possible.

However, no observable change has been noted in the flow and chemistry of Cataract Creek due to extraction of Longwalls 4, 5 and 6 in the Wongawilli Seam (GeoTerra, 2017).

Stream flow modelling indicates the average daily stream flow from Cataract Creek to Cataract Reservoir is 13ML/d of which 4.1ML/d is baseflow, with a median baseflow of 2.9ML/d (WRM Water & Environment, 2015).

The groundwater modelling predicts a maximum of 0.027ML/day (9.91ML/year) transfer of stream flow from the stream beds to the underlying strata in the Cataract Creek, Cataract River and Bellambi Creek catchments primarily as a consequence of the combined impact of Longwalls 4 to 6 and the proposed first workings, as shown in **Table 7** and **Figure 9-20**.

It should be noted, however, that this does not mean that all of the stream flow is “lost” as flow into the reservoir, as a portion of the flow migrates to the reservoir via lower elevation, down-gradient, groundwater seeps into the lower catchments and reservoir. It is beyond the capacity of the groundwater or surface water models to specify how much of the 14.6ML will enter the reservoir via groundwater seepage from stream flows that were transferred from the stream bed into the underlying strata.

The maximum stream flow loss as a consequence of only the proposed first workings (only) is modelled to be 0.0006ML/day (0.22ML/yr) in Cataract Creek during 2073, which is essentially negligible.

9.5.2 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 Cataract Creek.

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 12** and **Figure 9-20**.

The modelling predicts a maximum reduction in stream flow, due only to the proposed first workings, of 0.0002ML/day (0.07ML/yr) in Cataract River (upstream of Cataract Reservoir) and 0.0005ML/day (0.18ML/yr) in Bellambi Creek during 2072 to 2088.

The modelled annual changes for the Cataract River and Bellambi Creek will also be practically unobservable.

Table 12 Cataract Creek, Cataract River and Bellambi Creek Stream Baseflow Changes

	Baseflow Loss Due to ALL Mining (ML/day) / (ML/year)	Maximum Baseflow Loss Due to the Proposed First Workings (ML/day) / (ML/year)
CATARACT CREEK (Upstream of Cataract Reservoir)		
End of LW6	0.001 / 0.37	-
Due to Proposed Mining	0.024 / 8.76	0.0006 / 0.22 (in 2073)
CATARACT RIVER (Upstream of Cataract Reservoir)		
End of LW6	0.0014 / 0.51	-
Due to Proposed Mining	0.003 / 1.09	0.0002 / 0.07 (in 2083)
BELLAMBI CREEK		
End of LW6	0.000025 / 0.0091	-
Due to Proposed Mining	0.00014 / 0.051	0.0005 / 0.18 (in 2072)
TOTAL	**0.027 / 9.91**	**0.0013 / 0.47**

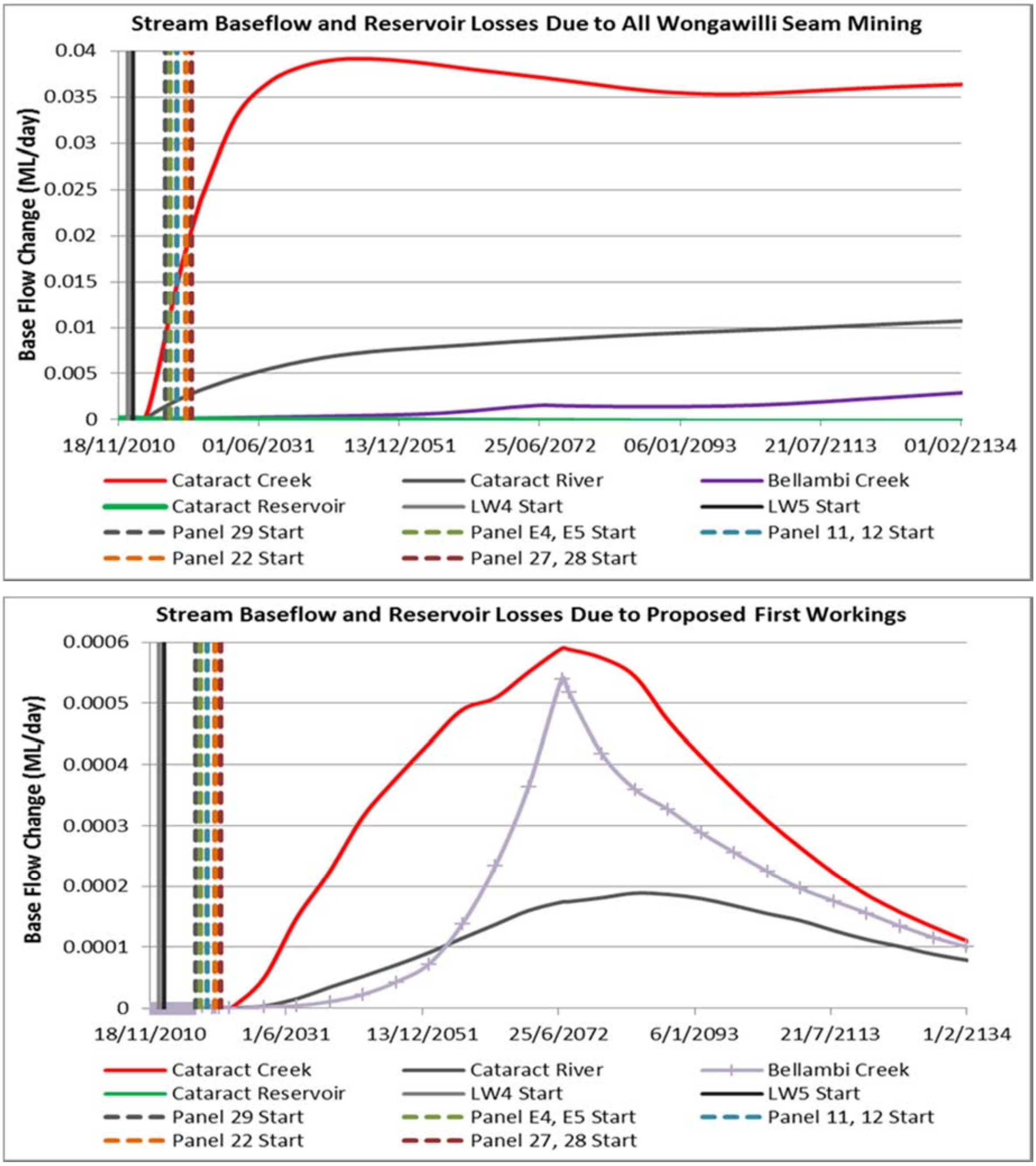


Figure 9-20 Russell Vale East Stream and Cataract Reservoir Depressurisation Related Base Flow Losses

9.5.3 Shallow Groundwater Contribution to Swamps

The volumetric contribution of shallow perched aquifer groundwater to swamps, and subsequently, as outflow drainage to the local streams is addressed in Biosis (2019) and WRM Water and Environment (2015).

Although no direct installation and monitoring of shallow ephemeral groundwater systems and their contribution to swamp water levels has been conducted to date, monitoring of piezometer water levels within swamps at Russell Vale East was assessed by Biosis (2014A), whilst their discharge outflow rates have been determined by WRM Water and Environment (2015).

Swamp water levels and outflows have subsequently been monitored by WCL (GeoTerra, 2017). This data indicates that the swamps are not, as is widely assumed, significant, long term contributors of baseflow to stream flow at Russell Vale East.

Monitoring to date (GeoTerra, 2017), indicates that tributary catchment flow sites downgradient of Longwalls 4, 5 and 6 (340m) do not have an observable baseflow reduction into Cataract Creek.

9.6 Cataract Reservoir

Cataract Reservoir has a full operating storage of 97,190ML. The lowest level of the storage as advised by Water NSW is 25,047ML or 25.8% capacity on 17 January 2020.

9.6.1 Stream Inflow

Due to the distance of the mined longwall panels (LW4, 5 and 6) and the proposed first workings from the Cataract Reservoir, and the lack of subsidence impacts from the proposed first workings, no adverse impacts on stored water quantity or quality have been observed, or are predicted to occur, as a result of the proposed first working extraction on, or in, Cataract Reservoir, based on the factors discussed in previous sections.

It is anticipated, however, that the water is currently flowing via previously developed subsurface fractures and is discharging down gradient into the lower section of the streams, and / or into Cataract Reservoir. No change is anticipated, however, due to the proposed first workings.

The potentially extremely minor stream flow loss into Cataract Reservoir associated with the existing mining impacts is very small compared to the potential evaporation off the surface of the full reservoir of 120,700ML/year.

The mechanism addressed by the groundwater model is the impact relating to regional depressurisation of the underlying aquifers, with associated groundwater level reduction.

9.6.2 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 not measureable at the end of the proposed mining as shown in **Figure 9-20** and **Table 13**.

Table 13 Cataract Reservoir Storage Changes

	Loss Due to ALL Mining (ML/day) / (ML/year)	Loss Due to Proposed First Workings (ML/day) / (ML/year)
(End of LW6)	0.000065 / 0.024	-
End of Proposed Mining	0.000065 / 0.024	0.0 / 0.0

9.7 Subsidence Interaction with Faults and Dykes

The Corrimal Fault is mapped as crossing to the south of Longwalls 4 and 5 and fades out within Longwall 6 and is not anticipated to generate a hydraulic connection to the surface water system or Cataract Reservoir. The fault has been identified as a “hinge fault” with a varying throw of approximately 25m in the east, reducing to 1.8m at Maingate 5, and is predicted to reduce to no displacement north of Longwall 6.

Intersection of the Corrimal Fault during development of the Longwall 6(340m) indicates the fault zones contains three “normal” faults with up to 0.93m displacement, and associated smaller faults, with no associated groundwater inflow (Wollongong Coal, 2014).

This indicates that the Corrimal Fault “zone” is diminishing to the north and is anticipated to fade out before it underlies the reservoir. This observation indicates that the potential re-activation or displacement of the Corrimal Fault due to subsidence and, therefore, it’s potential to cause a significant hydraulic connection between the workings and the mine, or significant drainage from the reservoir to the mine, is not considered likely.

To date, mining in the Bulli seam on both sides of the Corrimal Fault (both first and second workings), has not resulted in observable increased flows to the mine workings (Gujarat NRE Coking Coal, 2013).

SCT Operations Pty Ltd Report WCRV4466A “Assessment of Corrimal Fault and Dyke D8 at Russell Vale East as Risks to the Stored Waters of Cataract Reservoir” (SCT 2015) concluded that there is no credible risk of inflow between the stored waters of Cataract Reservoir and the mining horizons through either the Corrimal Fault or Dyke D8 as a result of the proposed UEP-PPR mining layout for longwall extraction.

SCT Operations (2015) further concluded that any effects from mining first workings roadways in the Wongawilli Seam are expected to be generally limited to a few metres around the proposed roadways. No significant subsidence impacts or environmental consequences are expected from mining through or in the vicinity of the Corrimal Fault and Dyke D8 by the proposed first workings layout. The likelihood of impacts to the Corrimal Fault is considered to be very low. The consequences of any impacts to the Corrimal fault are expected to be negligible. Any impacts on groundwater are expected to be limited to the immediate vicinity of the Wongawilli Seam and only in the area of the proposed mining.

Based on past mining experience and interpretation of the mine water balance monitoring (SCT Operations, 2019), the faults in the Bulli / Balgownie workings are essentially dry and are not anticipated to provide enhanced permeability fluid pathways in the proposed mining area.

The thin (<1m wide) highly weathered dyke D8 is located over the Russell Vale East workings, however, due to its highly weathered clay state and associated low intrinsic permeability, undermining this structure is not anticipated to enhance its permeability or potential hydraulic connection to the surface water systems (including Cataract Reservoir).

No water inrush has been observed with mining through faults or dykes in the Bulli, Balgownie or Wongawilli Seam workings (S Wilson, pers comm).

9.8 Groundwater Inflow to the Workings

The predicted modelled groundwater inflows to the Russell Vale mine are shown in **Table 14** and **Figure 9-21**.

The proposed extraction at Russell Vale East will start with Panel 8 and progress to Panel 34.

A background groundwater inflow of 0.2ML/day is currently measured from the Bulli Seam workings including 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 0.6ML/day (219ML/year). These rates decrease in Russell Vale East as groundwater makes its way vertically down to the Wongawilli Seam workings.

However, it should be noted that approximately 0.6ML/day is pumped out at Russell Vale portal which originates from the Bulli seam workings at Russell Vale West. It is assumed that this includes 0.2ML/day (73ML/year) of inflow that is 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, which means that groundwater from the Corrimal workings flows south into the WCL workings, as the western EWCL Bulli Seam workings are in the order of 40m lower than the Corrimal workings.

The groundwater taken by the upgradient Corrimal underground workings, which subsequently flows into the WCL workings, should not be required to be licensed by WCL as well, as the Corrimal Lease holders are required to have a license for groundwater inflows that are initially and primarily generated by their workings.

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.

Groundwater discharge from the adit is only predicted to occur when the groundwater elevation reaches the spill point of the adit. Modelled groundwater inflows (and hence adit outflows) at this point are modelled as being approximately 0.3ML/day (110ML/year).

Table 14 Predicted Maximum Groundwater Mine Inflows

Stage	Bulli Seam Inflow (ML/day) and (ML/year)	Predicted Russell Vale East Inflow (ML/day) and (ML/year)	Total Mine Inflow (ML/day) and (ML/year)	Maximum Total Licensable Inflow (ML/year) (excluding up gradient inflow of 146ML/year)*
Pre Longwall 4	0.22 / 80	-	0.22 / 80	80
End of Longwall 6	0.22 / 80	0.43 / 157	0.65 / 237	237
After Proposed First Workings	0.25 / 91	0.53 / 193.5	9.79 / 288	288

*Source: (SCT Operations, 2019)

The predicted inflows shown in **Figure 9-21** includes cumulative inflows from the Bulli, Balgownie and Wongawilli Seams into the underground workings, and does not represent inflows solely due to the proposed first workings.

The predicted inflows in **Table 14** also include those from the relatively limited extent Balgownie Seam workings, which lie stratigraphically above the Bulli Seam and free drain to the Bulli Seam via installed drains between the Balgownie and Bulli workings, with the inflow from the Balgownie Seam workings being included in **Figure 9-21** at approximately 0.175ML/day.

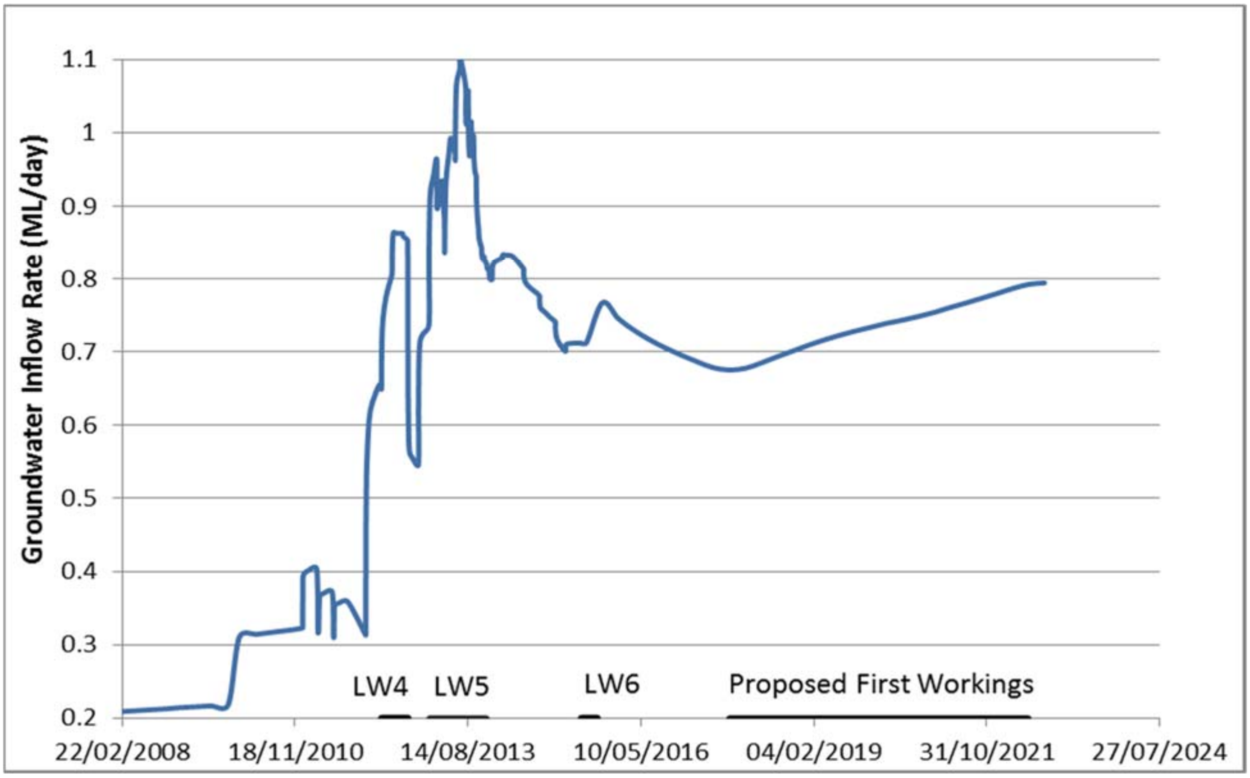


Figure 9-21 Simulated Historic and Predicted Total Groundwater Seepage Inflows

The total maximum groundwater flow that occurred in mid 2013 into the Russell Vale mine was measured and extrapolated / estimated at 1.1 ML/day (SCT Operations, 2019) or, if the peak inflow is extrapolated annually, 402 ML/year.

However, the predicted maximum groundwater inflow during and after the proposed 1st workings extraction period is predicted to be 288 ML/year.

9.8 Mine Water Level Recovery

The groundwater inflow rate gradually increases during extraction of the proposed first workings as they are dewatered. After the proposed first working mining activities are completed, the pumps are turned off and the mine gradually fills up and re-pressurises the overburden.

Figure 9-22 shows a simulated recovery hydrograph at the location of the mine entry adit for the Wongawilli Seam that daylights in the Illawarra Escarpment, which is located at the existing mine portal entry. It shows groundwater levels in the Wongawilli Seam recover to above the LW4, 5 and 6 and the proposed first workings pre-mining levels and that they reach the 117.5m AHD elevation of the escarpment adit at around 2057.

Figure 9-23 shows the modelled discharge rate out of the adit, with the outflow gradually increasing to a maximum of approximately 0.3ML/day as the mine and overburden re-saturates relatively quickly to adit level then stays there as it keeps draining out of the adit.

These outflow rates are similar to those predicted for the existing approved operations if Russell Vale were to close and the existing pumping were to cease.

In the model, the eastern most drain cell of the decline was left operational to simulate the recovering groundwater level reaching the portal entry elevation then free draining out of the mine.

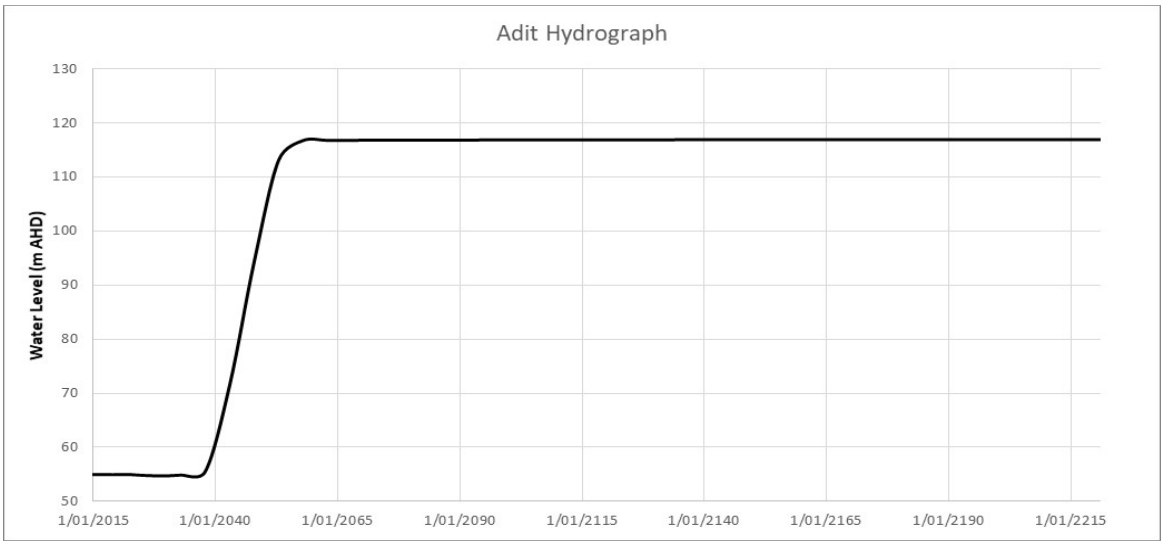


Figure 9-22 Modelled Recovery Hydrograph for Wongawilli Seam near the Illawarra Escarpment Adit

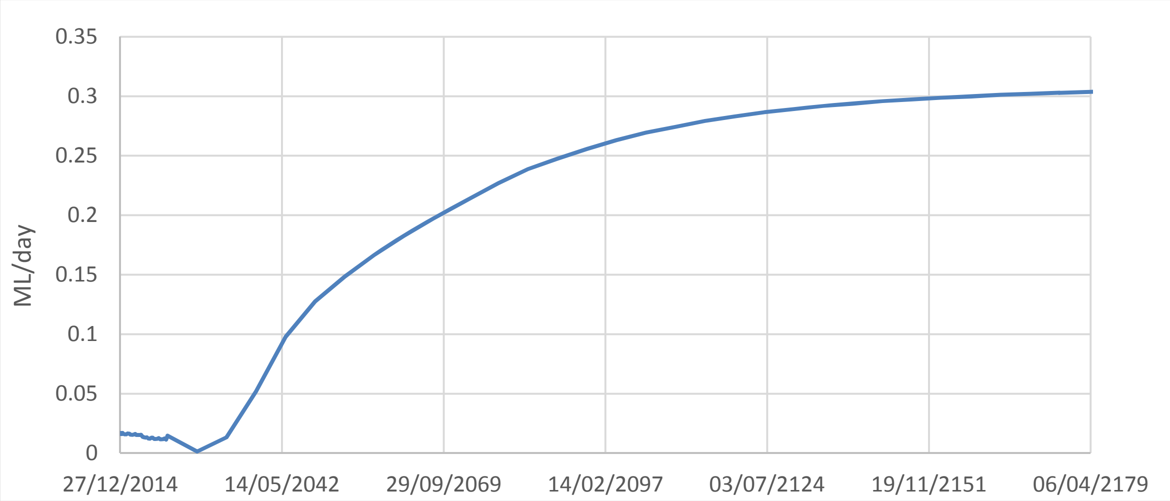


Figure 9-23 Illawarra Escarpment Adit Drainage

9.9 Groundwater Chemistry

Previous observations at Russell Vale indicate that groundwater quality within the regional groundwater system has not been adversely affected by mining, however there may be some localised increased iron hydroxide precipitation and limited lowering of pH if the groundwater is exposed to “fresh” surfaces in the strata through dissolution of unweathered iron sulfide or carbonate minerals.

In a general sense, the degree of iron hydroxide and pH change is difficult to predict, and can range from no observable effect to a distinct discolouration of the formation water. The discolouration does not pose a health hazard, however it can cause iron hydroxide precipitation at seepage points in local streams which can also be associated with algal matting and / or lowering of dissolved oxygen levels in the creek at the seepage point.

It should be noted that many Hawkesbury Sandstone aquifers in the Southern Coalfield already have significant iron hydroxide levels, and that ferruginous seeps can also be observed in previously un-subsided catchment areas.

Due to the very low level of predicted subsidence, and by association, the minimal overburden fracturing that could develop as a result of the proposed first workings, no observable pH or iron hydroxide changes are anticipated in the shallow strata layers.

Based on an extensive surface water and groundwater monitoring database, and on the observed and predicted impacts from historical and proposed subsidence, the proposal will not result in a reduction in the quality of surface and groundwater inflows to Cataract Reservoir.

9.9.1 Potential Future Adit Discharge Water Quality

Mine water sampling conducted between 2014 and 2017 (see Section 7.6.2) is indicative of the potential future discharge of groundwater from the existing Wongawilli adit in the Illawarra Escarpment:

- alkaline pH (8.4 – 8.55) and relatively fresh to brackish (1,390 – 2,210 µS/cm).

And, it could have:

- elevated bicarbonate alkalinity (HCO3), which forms the bulk of the salinity, as well as elevated sulfate, and be above the;
- ANZECC 2000 95% Level of Protection for fresh water species trigger for copper, nickel and zinc.

There is no reason to suspect that the Revised Preferred Project will result in any change to adit outflow water quality relative to what is currently approved.

Figure 9-24 shows a the monitoring results for Bellambi Creek at monitoring site LDP12, upstream of the current Pit Top disturbed area.

These potential receiving waters currently have an equal (or slightly higher) alkalinity (pH 5.3 – 8.97) and fresher salinity (213 – 913µS/cm).

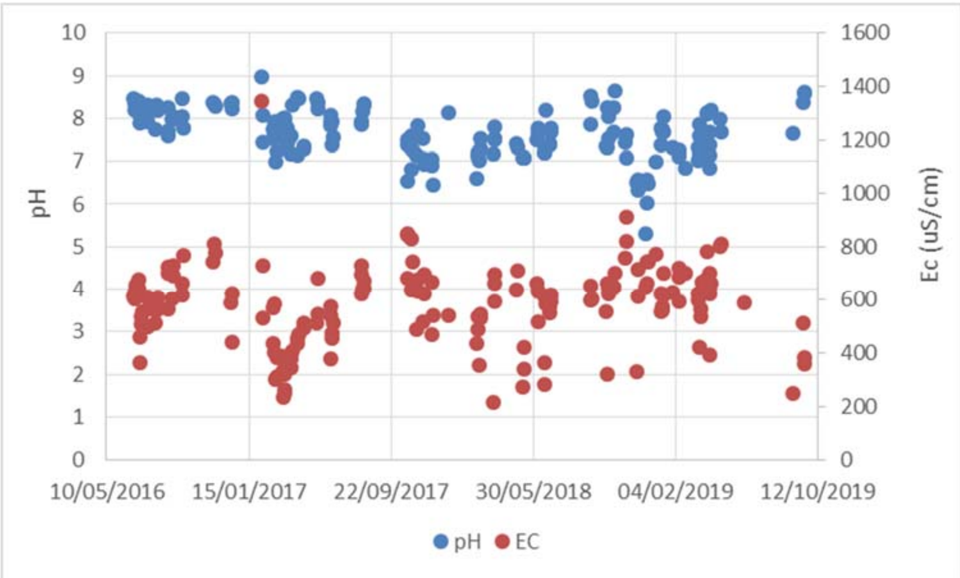


Figure 9-24 Bellambi Creek Chemistry

As a result of the slightly elevated salinity and above criteria metals (Cu, Ni, Zn), the potential future adit discharge may require treatment if it adversely impacts the receiving Bellambi Creek water quality and if the future Regulatory authority requires it to be treated.

Treatment of the adit water for a range of uses (including potable uses) is considered to be both reasonable and feasible if required.

10. CUMULATIVE GROUNDWATER RELATED IMPACTS

10.1 Upland Swamps

As outlined in Biosis (2014), no other adjoining mining operations provide a cumulative impact on, and no swamps are present downstream of, the Wollongong Coal Russell Vale lease area.

10.2 Strata Groundwater

The cumulative impact of the existing and proposed Russell Vale workings along with the surrounding mines has been assessed in the model runs by including the effects of:

- hydraulic permeability distribution over non-mining areas;
- subsidence, fracture propagation and associated hydraulic permeability distribution over bord and pillar, pillar extraction or longwalls on the regional groundwater pressure distribution;
- known or estimated degree of flooding in the adjoining workings, and;
- the separation distance from adjoining workings, where Appin / Westcliff / Northcliff / Metropolitan / Tahmoor mining areas were interpreted to be sufficiently distant from the existing and proposed Russell Vale Colliery workings to be discounted.

Groundwater modelling indicates that the influence of the proposed first workings can be broken down into the depressurisation of two separate regimes:

- within the Wongawilli Seam, and;
- overburden above the Wongawilli Seam.

The Wongawilli Seam and overburden immediately overhead would be depressurised to atmospheric pressure in the immediate footprint of the workings, however there would be minimal transgression of depressurisation above the Bulli Seam at the end of the mining period.

The overlying Balgownie and Bulli seams have previously been mined and therefore significant depressurisation has occurred historically.

The shallower surficial strata groundwater levels / pressures will be unaffected by the proposed first workings.

Regionally, the closest mining operations include those utilised for the model boundaries. The Appin Mine is located 13 km to the north-west operates within the Bulli Seam. Twelve kilometres to the south-west, Dendrobium Colliery is mining the Wongawilli Seam.

A review of the groundwater related studies undertaken for these projects indicates that regional drawdown at Appin extends approximately 2-3 km from the southern margins of the current operation (Heritage Computing 2009) and similarly at Dendrobium Colliery (Coffey Geotechnics, 2012).

As shown in **Figure 10.1**, there is a significant lack of cumulative strata depressurisation interference impact on the shallow (Hawkesbury Sandstone) aquifers at Russell Vale due to the significant separation distance and the lack of depressurisation migration toward the proposed Russell Vale first workings.

Modelling conducted for this study and previous studies in the Southern Coalfield indicates there will not be any superposition of drawdown cones between the Russell Vale and Appin / Dendrobium mining areas. Therefore, there is no cumulative depressurisation resulting from the proposed first workings and other adjoining mines.

Cumulative losses include the impacts from all of the adjoining historical, decommissioned mining areas as well as depressurisation due to the proposed Wongawilli Seam first workings extraction. These impacts, however, do not expand into, or interact with, the current or proposed mining operations at Appin Mine and Dendrobium Colliery as shown in **Figures 10-1** and **10-2**.

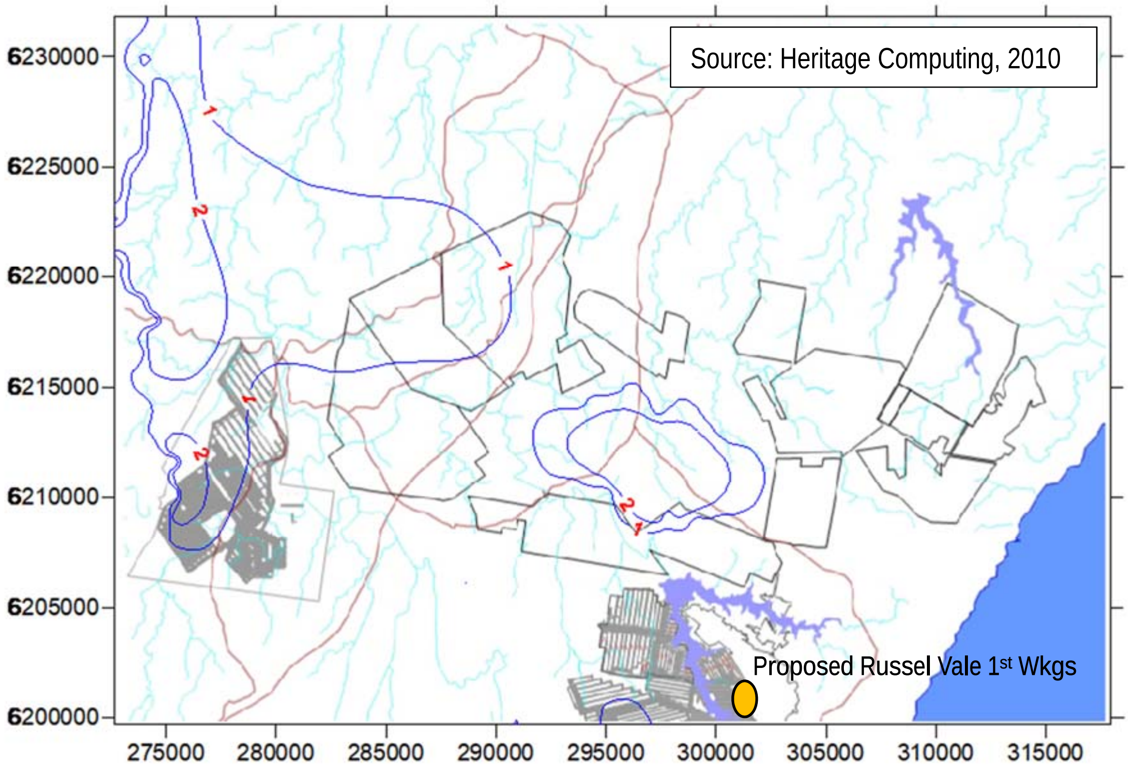


Figure 10-1 Predicted Bulli Seam Operations Mid Hawkesbury Sandstone Drawdown After 31 Years

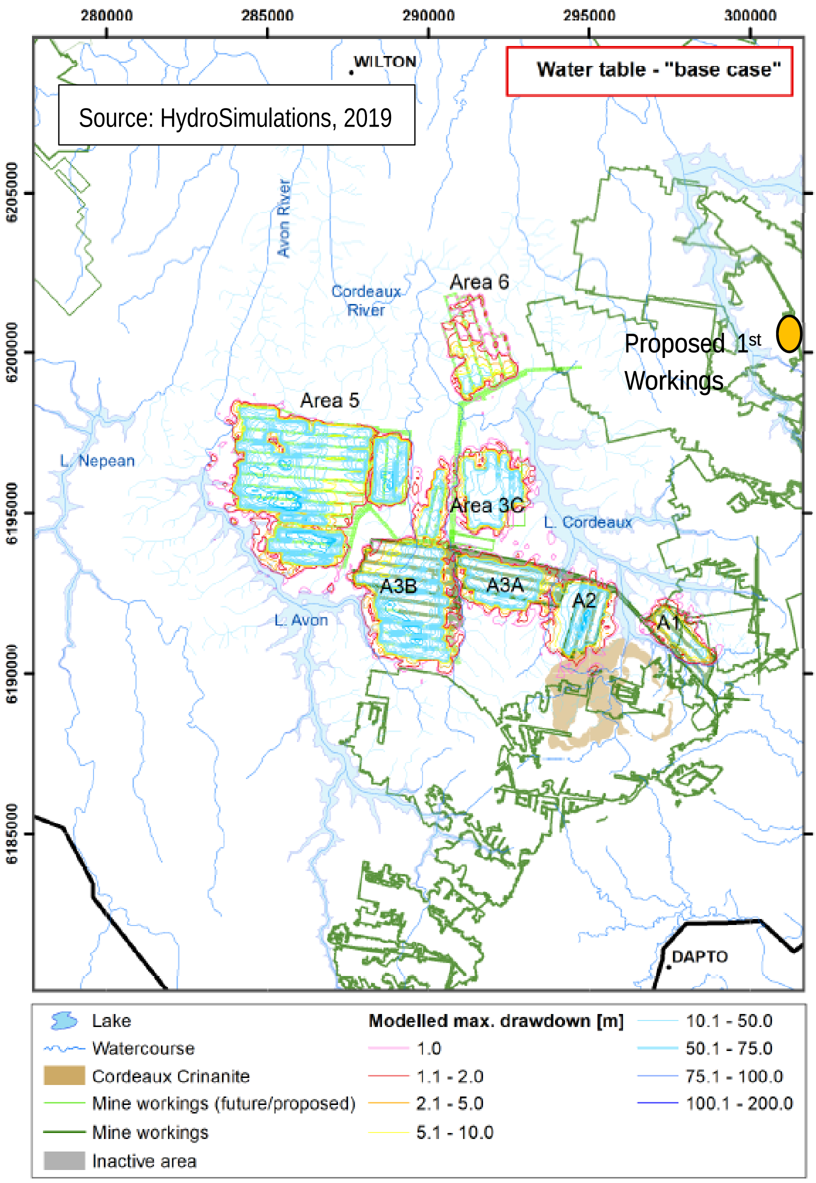


Figure 10-2 Predicted Dendrobium Mine Maximum Water Table Drawdown

11. MODELLING UNCERTAINTY

The Australian groundwater modelling guidelines provide a guiding principle in relation to model uncertainty as shown below:

"Models should be constructed to address specific objectives, often well-defined predictions of interest. Uncertainty associated with a model is directly related to these objectives" (SKM 2012).

All models contain uncertainty, with the Russell Vale groundwater model's predictive capacity being limited by the ability to simulate the Russell Vale east mining domain within the Application Area at a sufficiently detailed scale.

It should also be noted that the current modelling exercise was completed prior to release of the IESC Explanatory Guide on Uncertainty Analysis (IESC, 2019).

In the previous modelling exercise (GeoTerra / GES, 2015) sensitivity to various physical parameters was analysed with a focus on the possible connection of surface water features to a potential subsidence generated depressurisation field and subsequent depletion of stream flow.

Review of the previous model iteration highlighted the key uncertainty being associated with the fracture zone height and physical hydraulic parameters within the fracture zone causing potential connection with surface features.

11.1 Uncertainty Analysis

An Uncertainty Analysis was conducted by HydroAlgorithmics in 2020 to address parameter uncertainty by stochastic modelling using the *Monte Carlo* method through generating numerous alternative parameterisations of the deterministic flow model (realisations), executing the model independently for each, then aggregating the results for statistical analysis.

The analysis is presented in full in **Appendix C**.

AlgoCompute (*HydroAlgorithmics, 2019*; *Merrick, 2017*) was used as the platform for executing the model runs in parallel, with up to 100 realisations evaluated simultaneously, and with each being allocated to a single virtual machine in the cloud. The model-independent uncertainty quantification software HGSUQ (*Miller et al., 2018*) was used to generate the Monte Carlo parameter realisations and orchestrate the model runs within the AlgoCompute environment.

The original MODFLOW-SURFACT model was converted to an equivalent MODFLOW-USG model to allow model execution in the cloud.

Uncertainty was assessed on hydraulic conductivity, recharge, evapotranspiration, specific storage and specific yield properties throughout the model. Each property zone in the model was parameterised using pilot points, to allow the properties to vary spatially within each zone.

One hundred and one (101) pilot point locations were distributed approximately equidistantly around the edges of the model domain, and progressively densified closer to the proposed mine workings and nearby watercourses to increase the local resolution of the parameterisation in those areas.

To respect the configuration of the calibrated model, a separate zonation – and consequently a separate set of pilot points – was used for hydraulic conductivity parameters to the zonation used for storage parameters. Recharge and evapotranspiration parameters were applied at all pilot point locations in a single layer 1 zone. Coastal plains, void and fracture properties, and minor intrusives away from the mine were left fixed at their calibrated values and not varied for this analysis.

Hydraulic conductivity pilot points were each assigned two parameters: lateral conductivity (Kx) and vertical anisotropy (Kx/Kz). Storage pilot points were also assigned two parameters: specific storage (Ss) and specific yield (Sy). Recharge/evapotranspiration pilot points were assigned three parameters: fractional infiltration rate, evapotranspiration rate (ET rate) and evapotranspiration extinction depth (ET depth). Recharge rates generally were computed as rainfall multiplied by infiltration rate, and recharge along ridge areas was calculated at a fixed factor (~1.9x) multiplied by the general recharge rate, to match the base model.

A “prior” statistical distribution was assigned to each parameter based on the calibrated model values, from which randomly-sampled values were generated for each evaluated model realisation – subsequently interpolated to model cells by *kriging*.

The prior distributions are those from which the Monte Carlo process builds random samples for evaluation – as summarised in the previous section. The Monte Carlo process produces a finite number of sample sets (realisations). Additionally, some of these realisations are rejected during evaluation due to non-convergence or poor calibration. The posterior distributions represent the actual property distributions evaluated after sampling and rejection have taken place.

In total, 500 realisations were evaluated as part of the Monte Carlo process.

A calibration constraint on the scaled root-mean square (SRMS) error was applied such that any model with an SRMS of more than 5% was rejected. Of the 500 realisations, 141 (28.2%) were accepted and 359 (71.8%) were rejected because they exceeded the prescribed calibration constraint.

No model convergence failures occurred.

Three Kx parameter zones and one Kx/Kz zone showed greater than 10% difference in summary statistics. Storage, recharge, evapotranspiration, and all other hydraulic conductivity parameters show very little difference between prior and posterior.

Statistics on key predictive outputs were computed from the results of the 141 accepted model runs.

Percentile results were calculated from the Monte Carlo outputs strictly on a conservative “round to higher value” basis, and are represented as “probabilities of exceedance” in five categories: “very likely (90%) - **green**, “likely (67%)” - **light yellow-green**, “about as likely as not (50%)” - **black**, “unlikely (33%)” - **orange**, and “very unlikely (10%)” - **red**.

To clarify, a “very unlikely (10%)” probability of exceedance value of X for a metric should be interpreted to mean “10% of realisations from the set of accepted realisations resulted in a value for this metric larger than X”.

Drawdown, additional mine inflow and streamflow impact results were all computed on the difference between the *impacted* and *baseline* scenarios.

The impacted scenario simulates all mining, including the proposed new workings.

The baseline scenario simulates all prior and continuing mining except the proposed new workings, i.e. under the assumption that all Russell Vale mining stops after the cessation of longwall 6 mining.

Figure 11-1 shows total mine inflow over time to Russell Vale workings at 10%, 33%, 50%, 67% and 90% probabilities of exceedance, that were time-weighted averaged over 6-monthly periods.

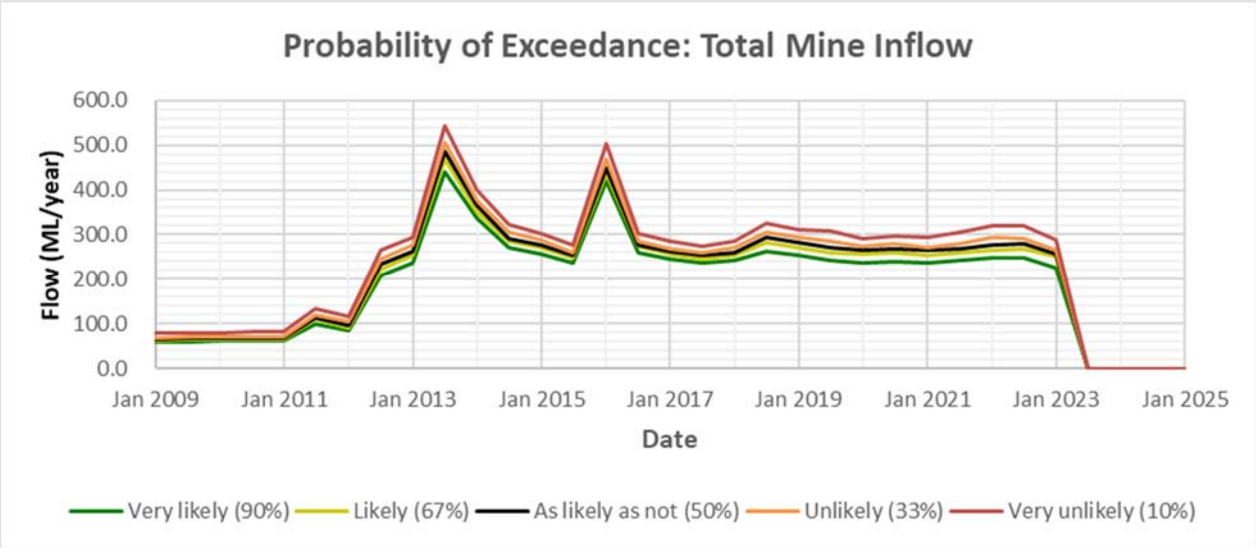


Figure 11-1 Time Series for Total Mine Inflow

Figure 11-2 shows additional mine inflow over time, due solely to the proposed new workings, at 10%, 33%, 50%, 67% and 90% probabilities of exceedance. The time-series inflows are time-weighted averaged over 6-monthly periods.

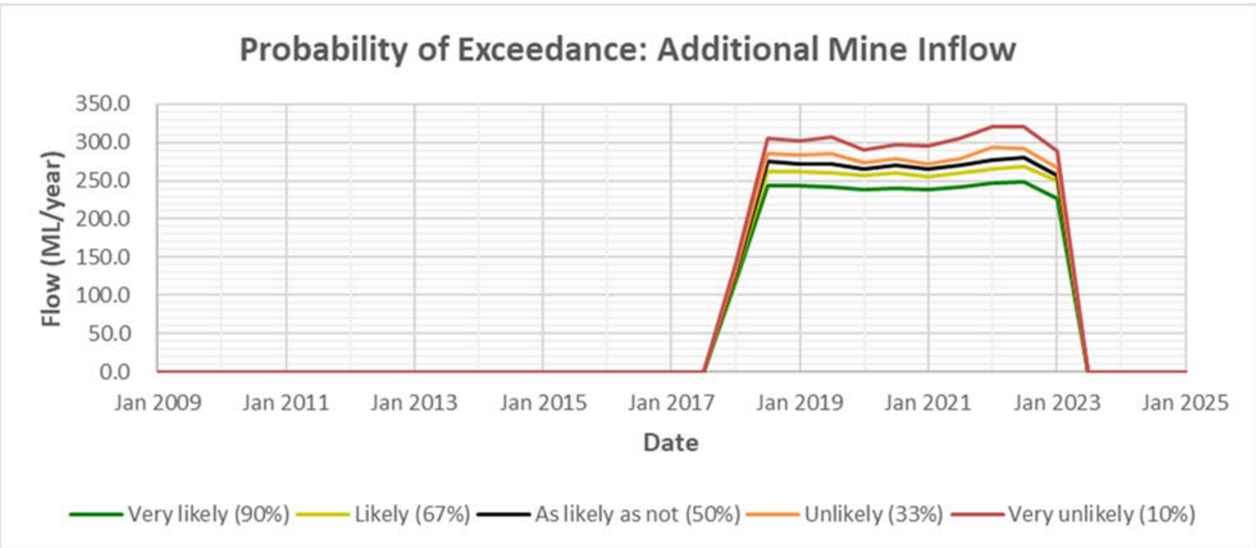


Figure 11-2 Time Series for Additional Mine Inflow due to the Proposed 1st Workings

Error! Reference source not found.**Figure 11-3** shows additional baseflow impact over time to Cataract River, due solely to the proposed new workings, at 10%, 33%, 50%, 67% and 90% probabilities of exceedance.

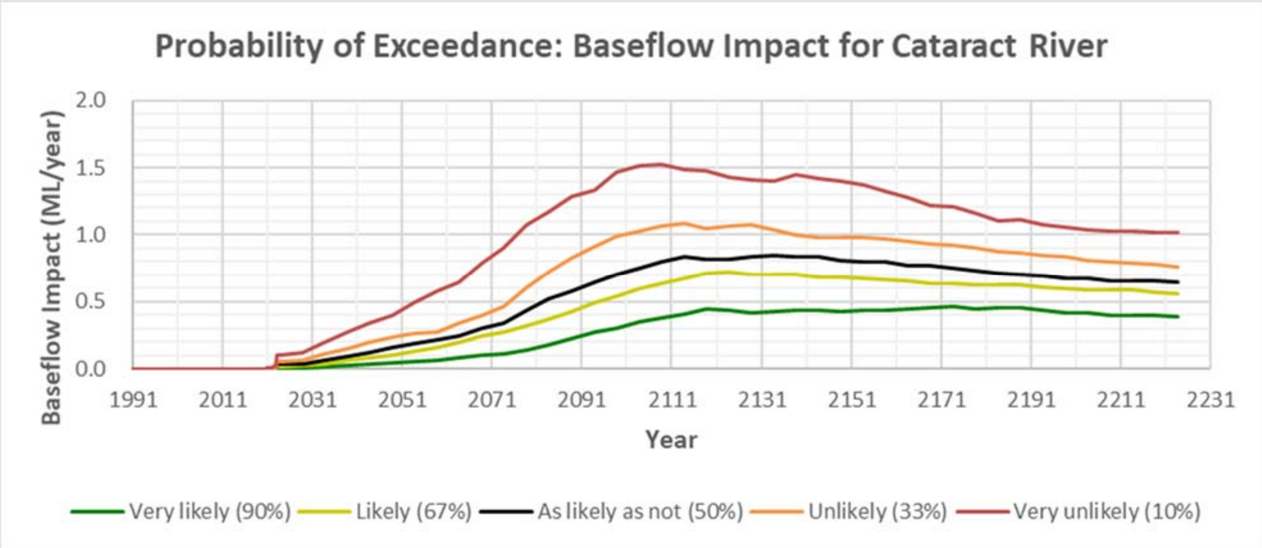


Figure 11-3 Time Series for Additional Baseflow Impact on the Cataract River

Figure 11-4 shows additional baseflow impact over time to Cataract Creek, due solely to the proposed new workings, at 10%, 33%, 50%, 67% and 90% probabilities of exceedance.

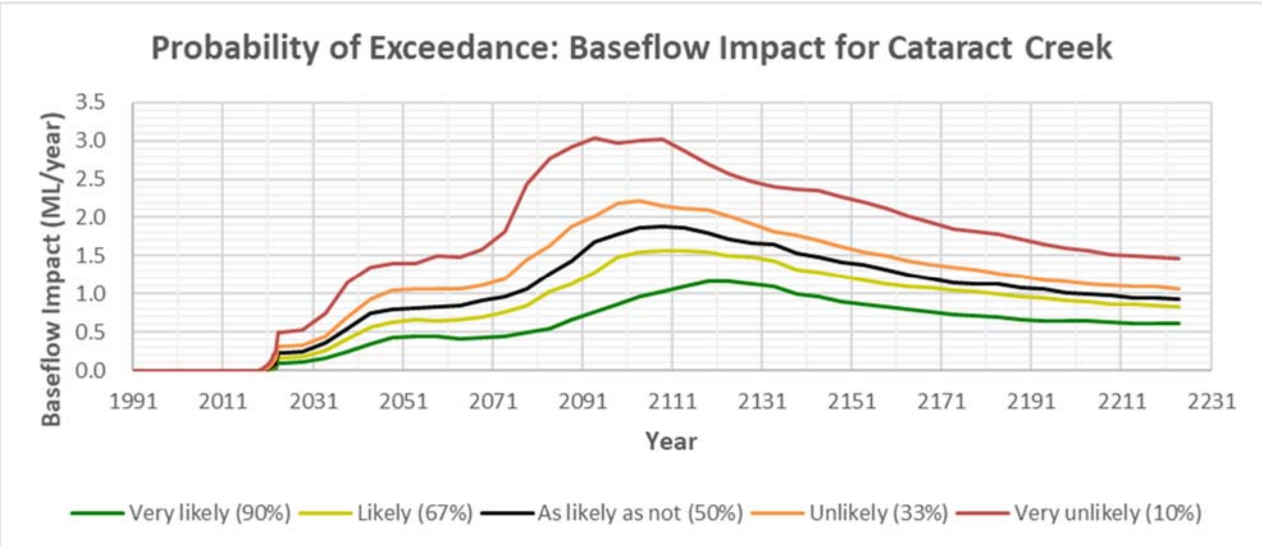


Figure 11-4 Time Series for Additional Baseflow Impact on Cataract Creek

Figure 11-5 shows additional baseflow impact over time to Bellambi Creek, due solely to the proposed new workings, at 10%, 33%, 50%, 67% and 90% probabilities of exceedance.

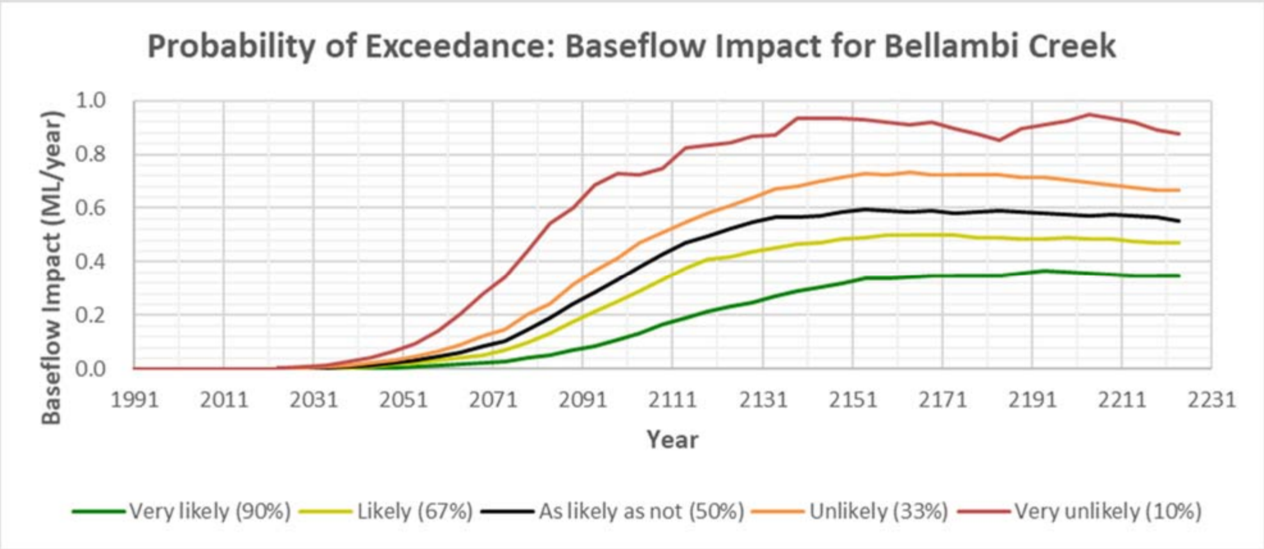


Figure 11-5 Time Series for Additional Baseflow Impact on Bellambi Creek

As a result of the Uncertainty Analysis, it has been established that the Russell Vale first workings proposal will have no observable potential hydraulic depressurisation connection impact on the surficial layers (model Layer 1) which contains the local streams and Cataract Reservoir, due to the minimal subsidence and the associated transmitted strata depressurisation impacts associated with the proposal.

A full description of the Uncertainty Analysis is presented in **Appendix C**.

11.2 Comparison with Model predictions

As identified in the peer review, baseflow impacts are predicted to be higher in the HydroAlgorithmics model runs used for the uncertainty analysis.

These changes are likely due to minor differences in the timing of drain cells being turned on/off in the two models. Both model outputs indicate very low cumulative impacts on baseflows (10-20ML/year maximum impact) with the Project resulting in only a 1-2ML/year increase in maximum take relative to existing approved operations.

These predicted impacts on baseflows are not considered to be significant and are unlikely to be measurable in the affected systems given the predicted cumulative impacts represent less than 0.5% of the annual flows from Cataract Creek alone.

Groundwater inflow rates are very similar with the inflow rates reported in this report being within the uncertainty range modelled.

12. MODEL LIMITATIONS

The adopted model has been designed to simulate the propagation of both near-field and far-field depressurisation effects throughout the regional aquifer system.

The model has not been designed to simulate the localised effects of near-surface tensile stream bed cracking due to valley closure and valley uplift effects on stream flow, nor has it been designed to assess subsidence effects on swamp water levels or discharge volumes.

The model does not include specific assessment of structural features such as faults and dykes which have the potential to compartmentalise or connect facets of sub-regional aquifers and also potentially surface water features to sub-surface strata.

However, as outlined in SCT Operations (2015) the potential impacts and environmental consequences of interaction with structures such as the Corrimal Fault are likely to be negligible.

The model has not assessed geological faults and structures due to the uncertainty in their location, vertical persistence, hydraulic parameters and their resultant attributes as post subsidence barriers or transmissive conduits.

The model has been designed with the main objectives being to simulate water level variability to mining stresses, to assess groundwater seepage to underground mining areas and to assess the potential impact with surface water features.

Outcomes from the model heavily relied on calibration against targets such as groundwater levels and mine water pumping rates which were supplied by the proponent and were recently reviewed and updated, but still have a degree of uncertainty due to their short period of reliable data records.

13. WATER LICENSING

13.1 Groundwater

The Project is covered by the *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011* (Groundwater WSP), which applies to 13 groundwater sources.

The current Water Access Licence (WAL) under the Water Management Act, 2000 is held by Wollongong Coal Ltd for 515 ML (units)/year (Licence No. WAL36488) and is located within Nepean Management Zone 2 of the Sydney Basin Nepean Groundwater Source.

Wollongong Coal Limited were advised by DPIE-Water during January 2020 that the Company has been successful in the bid for allocation under the Controlled Allocation Order 2017 for an additional 100 units (equates to 100 ML) within the Sydney Basin Nepean Groundwater Source – Nepean Management Zone 2.

Wollongong Coal Limited intend to apply the allocated 100 units to the existing WAL36488 to increase the entitlement held under this WAL to 615 ML (units)/ year.

Based on the predicted maximum groundwater inflow into the WCL workings of 288 ML/year, for the period during and after the proposed 1st workings extraction, Wollongong Coal currently hold a sufficient quanitity of units in their WAL.

In addition, the historical maximum groundwater inflow that was observed (and extrapolated) of 1.1 ML/day (approximately 402ML/year) in mid 2013 (SCT Operations, 2019) was also covered by the mine’s existing annual WAL volume.

The Sydney Basin Nepean Groundwater Source WSP limits the total share component for aquifer licences in this water source to 16,283 unit shares.

13.2 Surface Water

The Project is located within the area covered by the *Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011* (Unregulated River WSP). The Unregulated River WSP includes six water sources, with the Project situated entirely within the ‘Upper Nepean and Upstream Warragamba Water Source”.

Clause 4 of the Unregulated River WSP states that these water sources include all water:

- *Occurring naturally on the surface of the ground shown on the Registered Map; and*
- *In rivers, lakes, estuaries and wetlands in these water sources.*

Wollongong Coal currently does not hold any licences for surface water use for the region covering the proposed mining area and will need to obtain WALs for the total volume of surface water taken from the Upper Nepean and Upstream Warragamba Water Source.

The WSP limits the total share component for unregulated river licences in this water source to 15,540.2 unit shares.

Impacts that would give rise to licensing requirements include:

- reduction in base flows to streams due to drawdown;
- additional runoff that infiltrates into the groundwater system via subsidence induced shallow cracking;
- leakage from swamps; and
- loss of water from Cataract Reservoir due to depressurisation.

Cracking of streams may result in a reduction of stream flow through re-directing water into the bedrock. Although this water may re-emerge downstream, the water is deemed to have been "taken" as it is diverted from above to below the ground surface. Section 60I of the WM Act indicates that the water is deemed to be taken even if it is returned to the water source. Section 60I states:

"a person takes water in the course of carrying out a mining activity if, as a result of or in connection with, the activity or a past mining activity carried out by the person, water is removed or diverted from a water source (whether or not water is returned to that water source) or water is re-located from one part of an aquifer to another part of an aquifer".

The maximum predicted loss of stream baseflow due to strata depressurisation under the Cataract Creek, Cataract River and Bellambi Creek catchments within Management Zone 2 of the Sydney Basin Nepean Groundwater Source, as a result of the cumulative impacts from mining at Russell Vale, including the proposed first workings mining, is 9.91ML/yr at the end of mining as shown in **Table 15**.

Table 15 Surface Water Licensing Requirements

Surface Water Source	Predicted Cumulative Surface Water "Take" (ML/year)
Russell Vale East Stream Baseflow	9.91
Cataract Reservoir Leakage	0.13
(TOTAL)	**10.04**

Volumetric assessment of potential annual stream flow changes due to valley closure related cracking and transfer to sub-surface flow cannot be assessed by the groundwater model, nor can it be predicted by any other method as the response of a stream bed to valley closure and compressional / tensional cracking is highly site specific and highly variable within a stream bed due to up to 36 variable factors (Kay, D.R, Waddington, A.A,

2014) and (Barbato, J et al, 2014). It is noted however that the proposed first workings are not predicted to result in any subsidence related impacts in this regard.

Under the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources, which encompasses the overall Application Area and is contained within the Sydney Basin Nepean Groundwater Source Area, Wollongong Coal will require a WAL for the annual take of up to10.04 ML/yr of stream baseflow resulting from depressurisation of deeper aquifers.

14. NSW AQUIFER INTERFERENCE POLICY MINIMAL IMPACT CONSIDERATIONS

The Aquifer Interference policy (AIP) prescribes minimal impact considerations which must be satisfied.

The minimal impact considerations for a water source vary depending on the nature of the water source (i.e. alluvial, coastal, fractured rock etc) and whether it is “highly productive groundwater” or “less productive groundwater”.

The minimal impact considerations for less productive porous rock water sources are presented in **Table 16** and for the perched, ephemeral aquifers in **Table 17**.

The aquifers are not considered to be “highly” productive as although they contain total dissolved solids of less than 1500mg/L in the Hawkesbury Sandstone, there are no water supply works that yield water at a rate greater than 5L/sec in the Russell Vale East area.

Table 16 NSW Minimal Impact Considerations for Less Productive Porous Rock Water Sources

Minimal Impact Consideration	Proponent Response
Water Table – Level 1 Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan variations, 40m from any: a) high priority groundwater dependent ecosystem, or b) high priority culturally significant site listed in the schedule of the relevant water sharing plan, or A maximum of a 2 m decline cumulatively at any water supply work unless make good provisions should apply.	There are no: • high priority groundwater dependent ecosystems, or; • high priority culturally significant sites listed under Schedule 4 of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011. The swamps above the mine plan are not classified as Temperate Highland Peat Swamps on Sandstone (which is high priority GDE). There are no water supply works (i.e. groundwater bores) in the Russell Vale East proposal area that will undergo more than a 2m decline.
Water Table – Level 2 If more than 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40m from any: a) high priority groundwater dependent ecosystem; or b) high priority culturally significant site listed in the schedule of the relevant water sharing plan then appropriate studies will need to demonstrate to the Minister's satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site. If more than 2m decline cumulatively at any water supply work then make good provisions should apply.	Level 2 does not apply as Level 1 criteria is not exceeded
Water Pressure – Level 1 A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2m decline, at any water supply work.	There are no water supply works (i.e. groundwater bores) in the Russell Vale East proposal area that will undergo a greater than 40% post water sharing plan pressure head decline above the base of the water source, and no water supply work will undergo greater than 2m decline
Water Pressure – Level 2 If the predicted pressure head decline is greater than requirement 1 above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long-term viability of the affected water supply works unless make good provisions apply.	Level 2 does not apply as Level 1 criteria is not exceeded

Water Quality – Level 1 a) Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity, and b) No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. Redesign of a highly connected surface water source that is defined as a “reliable water supply” is not an appropriate mitigation measure to meet considerations 1(a) and 1(b) above. c) No mining activity to be below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a “reliable water supply”.	The beneficial use category of the groundwater source will not be changed beyond 40m from the Russell Vale East proposal area. There are no highly connected surface water sources (alluvial aquifers) in the Russell Vale East proposal area There are no highly connected alluvial surface water sources defined as a reliable water supply within the Russell Vale East proposal area
Water Quality – Level 2 If condition 1(a) is not met then appropriate studies will need to demonstrate to the Minister’s satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works. If condition 1(b) is not met then appropriate studies are required to demonstrate to the Minister’s satisfaction that the River Condition Index category of the highly connected surface water source will not be reduced at the nearest point to the activity. Condition 1(c) does not apply as there are no river bank or high wall instability risks and no need for low permeability barriers between the site and highly connected surface waters	Level 2 does not apply as Level 1 is not exceeded

Table 17 NSW Minimal Impact Considerations for Perched Ephemeral Aquifer Water Sources

Minimal Impact Consideration	Proponent Response
Water Table – Level 1 Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan variations, 40m from any: c) high priority groundwater dependent ecosystem, or d) high priority culturally significant site listed in the schedule of the relevant water sharing plan, or A maximum of a 2 m decline cumulatively at any water supply work unless make good provisions should apply.	There are no: • high priority groundwater dependent ecosystems, or; • high priority culturally significant sites listed under Schedule 4 of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011. The swamps above the mine plan are not classified as Temperate Highland Peat Swamps on Sandstone (which is high priority GDE). There are no water supply works (i.e. groundwater bores) in the Russell Vale East proposal area that will undergo more than a 2m decline.
Water Table – Level 2 If more than 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40m from any: c) high priority groundwater dependent ecosystem, or d) high priority culturally significant site listed in the schedule of the relevant water sharing plan then appropriate studies will need to demonstrate to the Minister's satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site. If more than 2m decline cumulatively at any water supply work then make good provisions should apply.	Level 2 does not apply as Level 1 criteria is not exceeded
Water Pressure – Level 1 A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2m decline, at any water supply work.	There are no water supply works (i.e. groundwater bores) in the Russell Vale East proposal area that will undergo a greater than 40% post water sharing plan pressure head decline above the base of the water source, and no water supply work will undergo greater than 2m decline
Water Pressure – Level 2 If the predicted pressure head decline is greater than requirement 1 above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long-term viability of the affected water supply works unless make good provisions apply.	Level 2 does not apply as Level 1 criteria is not exceeded

<u>Water Quality – Level 1</u> d) Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity; and e) No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity.	The beneficial use category of the groundwater source will not be changed beyond 40m from the Russell Vale East proposal area. There will be no increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity.
Re-design of a highly connected surface water source that is defined as a "reliable water supply" is not an appropriate mitigation measure to meet considerations 1(a) and 1(b) above. f) No mining activity to be below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply".	There are no highly connected alluvial surface water sources defined as a reliable water supply within the Russell Vale East proposal area There will be no mining activity below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source defined as a "reliable water supply".
<u>Water Quality – Level 2</u> If condition 1(a) is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works. If condition 1(b) is not met then appropriate studies are required to demonstrate to the Minister's satisfaction that the River Condition Index category of the highly connected surface water source will not be reduced at the nearest point to the activity. Condition 1(c) does not apply as there are no river bank or high wall instability risks and no need for low permeability barriers between the site and highly connected surface waters	Level 2 does not apply as Level 1 is not exceeded

15. ENVIRONMENTAL PLANNING AND ASSESSMENT ACT 1979 ASSESSMENT

15.1 State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011

Clause 10 of the State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011(Drinking Water SEPP) provides that:

a consent authority must not grant consent to the carrying out of development under Part 4 of the Act on land in the Sydney drinking water catchment unless it is satisfied that the carrying out of the proposed development would have a neutral or beneficial effect on water quality.

This is known as the Neutral or beneficial effect (NorBE) test.

As a Part 3A Project, the Drinking Water SEPP does not formally apply, however the NorBE test has been held by the NSW Land and Environment Court to be a relevant (but not mandatory) consideration for the Minister (or delegate) when determining a Part 3A Application.

As discussed in the following section in relation to the WaterNSW Principles for Mining and Coal Seam Gas Activities in Declared Catchment Areas, the Revised Preferred Project is predicted to have no (or a neutral) impact on water quality in the Cataract Reservoir and its tributaries.

Clause 11A of the Drinking Water SEPP is also relevant in that sets the context for the NorBE test in relation to existing mining operations where an application to extend mining is lodged prior to the expiry of the right to mine.

In these circumstances, the NorBE test considers the predicted impacts of the proposed project on water quality compared to the adverse impact that the continuing development would have if it were extended or expanded under similar conditions as the existing development consent.

As with clause 10, the application of this test is not mandatory to the Project in that it is a Part 3A Project application, however it is noted that the continuation of longwall mining is likely to have had a significantly greater adverse impact on water quality in Cataract Reservoir than the proposed project due to the potential impacts on swamps and creek systems that longwall mining in this area.

Table 18 presents an assessment of the impact against the *State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011*, in accordance with WaterNSW (2015).

Table 18 Neutral or Beneficial Effect Test Impact Assessment

Assessment Condition	Compliant	Impact Assessment
"A neutral or beneficial effect on water quality is satisfied if the development: (a) has no identifiable potential impact on water quality, or	Yes	the Revised Preferred Project is predicted to have no (or neutral) impact on water quality in the Cataract Reservoir and its tributaries
(b) will contain any water quality impact on the development site and prevent it from reaching any watercourse, waterbody or drainage depression on the site, or	Yes	The Revised Preferred Project will not result in any groundwater within the mine entering the Sydney Drinking Water Catchment. Outflows from the adit following re-pressurisation up to the elevation of the adit will be at a rate similar to currently approved operations. The predicted rate of outflows from the adit (approximately 0.3ML/day) are capable of being treated to an appropriate quality prior to any discharge to Bellambi Gully if reuse for industrial or other uses is not required
(c) will transfer any water quality impact outside the site where it is treated and disposed of to standards approved by the consent authority."	Yes	Not applicable

Accordingly, the Revised Preferred Project is considered to satisfy the NorBE Test as applied under clause 11A of the Drinking Water SEPP.

16. WATER NSW PRINCIPLES FOR MANAGING MINING AND COAL SEAM GAS IMPACTS IN DECLARED CATCHMENT AREAS

The Water NSW principles prescribing minimal impact considerations which must be satisfied in declared catchment areas for mining and coal seam gas activities and the proponent's response are outlined in **Table 19**.

Table 19 WaterNSW Principles for Mining and Coal Seam Gas Activities in Declared Catchment Areas

WaterNSW Principles for Mining and Coal Seam Gas Activities in Declared Catchment Areas	Proponent's Response in Regard to the Proposed First Workings Extraction of the Wongawilli Seam at Russell Vale East	Relevant Section or Associated Report
must not result in a reduction in the quantity of surface and groundwater inflows to storages or loss of water from storages or their catchments	The proposal will not result in an observable reduction in the quantity of surface or groundwater inflows to, or loss of water from, Cataract Reservoir	10.1, 10.4
must not result in a reduction in the quality of surface and ground water inflows to storages	The proposal will not result in a reduction in the quality of surface and groundwater inflows to Cataract Reservoir	10.9
must not pose increased risks to human health as a result of using water from the drinking water catchments	The proposal will not pose an increase in risk to human health as a result of using water from Cataract Reservoir	Section 5.2 – 5.3 of the Revised Preferred Project Report (Umwelt 2019).
The integrity of the WaterNSW's water supply infrastructure must not be compromised	The proposal will not compromise the integrity of WaterNSW water supply infrastructure	SCT Operations (2019)
The ecological integrity of the Special Areas must be maintained and protected	The proposal will maintain and protect the ecological integrity of the Cataract Reservoir Special Area	Section 5.5 Biosis (2019)
Information provided by proponents, including environmental impact assessments, must be detailed, thorough, scientifically robust and holistic. The potential cumulative impacts must be comprehensively addressed	Information provided in this assessment is detailed, thorough, scientifically robust and holistic and the potential cumulative impacts have been comprehensively addressed	11.0

17. MONITORING, CONTINGENCY MEASURES & REPORTING

Wollongong Coal will prepare a Water Management Plan in accordance with conditions of Project Approval.

The Water Management Plan will include a groundwater monitoring program, which will include monitoring of groundwater levels, water quality, pumping volumes and stream flows.

The ongoing collection and interpretation of the data will be used to update the TARP trigger levels and the groundwater model, as required.

17.1 Groundwater Levels

Piezometers to be included in the monitoring suite are shown in **Table 20**.

The suite is divided into standpipe and vibrating wire piezometers, with water level transducers and vibrating wire piezometers used to monitor standing water levels or pressure heads twice daily to assess variations in the colluvial and strata formations.

Table 20 Groundwater Level Monitoring Suite

	Piezometer Type
Strata	
NREA, C, D, E, G, NRE3, GW1A, RV18, 19, 21, 22A, 23A	Open Standpipe
NREA, B, D, NRE3, GW1, RV16, 17, 20, 22, 23	VWP

NOTE: VWP = vibrating wire piezometer

Monitoring will also involve bi-monthly manual standing water level measurement in all open standpipe piezometers, at which time the loggers will be downloaded and re-initiated as shown in **Table 21**.

Table 21 Standing Water Level Monitoring Method and Frequency

Monitoring Site	**Sampling Method**	**Frequency / Download**	**Units**
Open standpipe piezometers	Water level logger / dip meter	twice daily / bi-monthly	mbgl
Vibrating wire piezometer arrays	Vibrating wire piezometer	twice daily / quarterly	m head pressure

NOTE: mbgl = meters below ground level

17.2 Groundwater Quality

Tables 22 and **23** present the parameters to be measured, frequency of monitoring and sampling method for groundwater quality monitoring, with monitoring to continue for 12 months after mining has ceased.

Table 22 Groundwater Quality Monitoring Parameters

ANALYTES	Units	FREQUENCY
EC, pH	µS/cm, pH units	Bi - monthly
(EC, pH) + TDS, Na, K, Ca, Mg, F, Cl, SO4, HCO3, NO3, Total N, Total P, hardness, Cu, Pb, Zn, Ni, Fe, Mn, As, Se, Cd (metals filtered)	mg/L	Start / finish of panel for piezometers adjacent to a panel, or in an active mining area, otherwise 1 sample per year

The frequency of monitoring will be reassessed after mining is complete as it may be possible, depending on results, to lengthen the intervals. The frequency of monitoring and the parameters to be monitored may be varied by DPI-W once the variability of the groundwater quality is established.

Groundwater samples should be collected at the start and finish of each panel from piezometers either adjacent to an active panel, or within an active mining area, and should be analysed at a NATA registered laboratory for major ions and selected metals. Piezometers not within an active mining area should be sampled and analysed once per year.

It is anticipated that the groundwater monitoring program will be maintained in its current status, with a review of the program at the end of each AEMR reporting period all monitoring data has been conducted or in the event of TARPs triggers being exceeded.

Additional piezometers may be added to the existing suite if required.

The groundwater monitoring program is anticipated to be extended beyond the active mining period in order to assess the potential long term change in groundwater level recovery and quality changes for 12 months after completion of mining.

Table 23 Groundwater Quality Monitoring Method and Frequency

Monitoring Site	Sampling Method	Frequency
Open Standpipe Piezometers	Pumped field meter readings	Bi-monthly
Open Standpipe Piezometers	Pumped sample for laboratory analysis	Start / finish of each panel for piezometers adjacent to a panel or in an active mining area, otherwise 1 sample per year

17.3 Surface Water and Groundwater Connectivity

The potential for surface water and groundwater system hydraulic connectivity will be assessed through monitoring of stream flows in and near actively mined areas, as well as through monitoring and interpretation of the strata groundwater open standpipe and vibrating wire piezometers water levels / pressures and mine inflow changes.

17.4 Mine Water Pumping

The volume of water pumped into and out of the Russell Vale Colliery workings will be monitored daily to enable the differential groundwater seepage into the workings to be assessed.

In addition, completion of the pump calibration tests, ongoing QA / QC and regular assessment of the pumping data will be required to enable reliable assessment of mine groundwater make due to extraction of the proposed workings.

17.5 Cataract Reservoir Water Storage

Water stored within Cataract Reservoir and any potential adverse effects from the proposed mining will be managed through monitoring of the mine inflow volumes and piezometer water levels / heads between the proposed workings and the reservoir.

Any potential changes to the water quality of the reservoir will be monitored through assessment of the discharging stream water quality in Cataract Creek (Site CC8 and / or CC9) and in Cataract River at Site CR3 or CR4, depending on the height of the reservoir at the time of monitoring, along with at Site CD1 within the reservoir.

Specific details of the reservoir monitoring and management will be provided in a detailed monitoring and management plan that will be prepared and approved prior to commencement of the proposed mining.

17.6 Ground Survey

The ground surface over the proposed underground workings will be surveyed in accordance with the Extraction Plan (to be prepared in accordance with the conditions of Project Approval).

17.7 Rainfall

Daily rainfall data will be obtained from a local weather station for the duration of mining in the proposal catchment area.

17.8 Ongoing Monitoring

All results will be reviewed annually via the AEMR process and an updated monitoring and remediation program will be developed, if required, in consultation with DI-W and DRE.

17.9 Quality Assurance and Control

QA/QC should be attained by calibrating all measuring equipment, ensuring that sampling equipment is suitable for the intended purpose, using NATA registered laboratories for chemical analyses and ensuring that site inspections and reporting follow procedures outlined in the ANZECC 2000 Guidelines for Water Quality Monitoring and Reporting.

17.10 Impact Assessment Criteria

17.10.1 Groundwater Levels

Impact assessment criteria investigation trigger levels should be initially set where a groundwater level reduction exceeds more than 10% of the saturated aquifer thickness over a 12 month period, compared to the minimum height within the last 12 months of data, excluding any short term recharge peaks. Should the trigger be exceeded, the actual rate of change of water levels should be investigated to determine whether the change is solely subsidence induced or due to a range of other potential factors.

If a significant increase in the rate of water level decline is noted, based on interpretation by a qualified hydrogeologist, then an assessment should be conducted to determine the cause of the change (such as variation in climate or effects from adjacent mining operations) and to consider potential contingency measures that may be adopted.

17.10.2 Groundwater Quality

Proposed groundwater quality impact assessment investigation triggers are shown in **Table 24.**

Table 24 Groundwater Quality Impact Assessment Investigation Triggers

Indicator	Investigation Trigger
pH	Short term reduction in pH outside of baseline variability, with the effect not persisting after a significant rainfall recharge event
Conductivity / TDS	Short term increase in salinity / TDS outside of baseline variability, with the effect not persisting after a significant rainfall recharge event compared to previous data
Total Nitrogen	Short term increase in Total Nitrogen outside of baseline variability, with the effect not persisting after a significant rainfall recharge event compared to previous data
Total Phosphorus	Short term increase in Total Phosphorous outside of baseline variability, with the effect not persisting after a significant rainfall recharge event compared to previous data

A trigger to assess the cause and effects of adverse groundwater quality changes should be implemented when there is a prolonged and extended non-conformance of the outlined criteria at a particular piezometer. If a field parameter (pH, conductivity) is outside the designated criteria for at least six months in a sequence, or alternatively, exceeds its previous range of results by greater than a 10% variation for at least 4 months, then the cause should be investigated, and a remediation strategy should be proposed, if warranted.

The triggers should be reviewed after each 12 month block of data is interpreted and may be modified as appropriate, depending on the results.

If the impacts on the groundwater system resulting from future underground operations are demonstrated to be greater than anticipated, the proponent should:

- assess the significance of these impacts;
- investigate measures to minimise these impacts; and
- describe what measures would be implemented to reduce, minimise, mitigate or remediate these impacts in the future to the satisfaction of the Director-General, DPI-W and Water NSW.

17.11 Contingency Procedures

Contingency procedures should be developed as required, with the measures to be developed being dependent on the issue that requires addressing.

The procedures should be used to manage any impacts identified by monitoring that demonstrate the groundwater management strategies may not have adequately predicted or managed the groundwater system's anticipated response to mining.

Activation of contingency procedures should be linked to the assessment of monitoring results, including water quality, aquifer hydrostatic pressure levels and the rate of water level changes.

17.12 Piezometer Maintenance and Installation

The current network should be maintained by protecting the wellhead from damage by animals and scrub fires by maintaining their steel sealed wellheads.

If required, the piezometers may be cleaned out by air sparging if they become clogged.

In the event that any new piezometers are required, they should be installed by suitably licensed drillers after obtaining any required approvals from Water NSW and DPI-W.

17.13 Reporting

Following completion of each AEMR review, which should summarise all relevant monitoring to date, the report should also outline any changes in the groundwater system over the relevant mining area in the relevant prior period.

The report should contain an interpretation of the data along with:

- a basic statistical analysis (mean, range, variance, standard deviation) of the results for the parameters measured;
- an interpretation of water quality and standing water level changes supported with graphs or contour plots; and
- an interpretation and review of the results in relation to the impact assessment criteria.

17.14 Adaptive Management

An adaptive management plan should be developed to use the monitoring program to detect the need for adjustment to the mining operation so that the subsidence predictions are not exceeded and so that subsidence impacts creating a risk of negative environmental consequences do not occur.

The adaptive management procedures should be implemented to provide a systematic process for continually detecting impacts, validating predictions and improving mining operations to prevent further adverse impacts on the swamp and strata groundwater systems overlying the proposed mining domains.

Monitoring, evaluation, and reporting on management performance and ecological impact should be integrated into the site's core management systems to progress the technical understanding and predictive capability of subsidence effects, impacts and consequences on surface water systems.

An evidence-based approach should be used to validate the extent to which outcomes are being achieved, with the monitoring results being related to, and demonstrating how management strategies have been achieved or where improvements can be made.

Data gained from monitoring a suite of extensometers, vibrating wire piezometer arrays and open standpipe piezometers as well as geochemical monitoring of groundwater and surface water and stream flow regimes over the panels would then be able to be used to update the current geotechnical, hydrogeological and hydrological assessments for the proposed mining and to incorporate, if required, adaptive management measures for future mining.

Additional groundwater related monitoring that could be used to enhance the adaptive management process may include:

- continuation of the existing mine water pump monitoring and updating the mine water balance;
- additional drilling, with a range of vibrating wire piezometers and core testing to establish the mechanical and hydraulic properties of the overburden in proximity to water dependent systems in the catchments (including swamps);
- installation of additional deep vibrating wire piezometers and extensiometers to assess/quantify the impacts of fracturing within the subsidence zone;
- installation of paired shallow piezometers (where appropriate) targeting swamps and the underlying shallow Hawkesbury Sandstone aquifer to assess their hydraulic connection and climatic implications;
- sediment profiling in swamps to characterise type, thickness and sensitivity to differential subsidence; and
- updating of the numerical modelling when sufficient additional data becomes available to enhance the prediction of subsidence zone fracture distributions, connectivity and groundwater transmissivity capacities.

17.15 Future Model Review and Verification

In accordance with IEPMC (2019A, B), where required, the groundwater model should be periodically reviewed to assess its ability to represent monitoring based historic and to predict future potential groundwater levels, as well as mine inflows, stream and reservoir impacts.

The model should be verified, as required, after sufficient groundwater and surface water data is obtained, and where / if any structures of significance are identified that may impact on the modelling results which are not currently understood in sufficient detail.

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The findings contained in this report are the result of discrete / specific methodologies used in accordance with normal practices and standards. To the best of our knowledge, they represent a reasonable interpretation of the general condition of the site / sites in question. Under no circumstances, however, can it be considered that these findings represent the actual state of the site / sites at all points. Should information become available regarding conditions at the site, GeoTerra / GES reserve the right to review the report in the context of the additional information.

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Appendix A – Summary of Previous Russell Vale Groundwater Assessment

In December 2004, after a period of care and maintenance, the mine was sold to NRE by the former owners Bellpac Pty Ltd and the assets transferred to a company called Gujarat NRE Coking Coal Ltd.

Mining re-commenced in 2005, however the mine produced very little coal between 2004 and 2012 when mining re-commenced in the Wongawilli Seam.

The original Underground Expansion Project (UEP) application was submitted by Gujarat NRE Coking Coal Ltd in 2009, with a supporting Environmental Assessment publicly exhibited in 2013 (ERM, 2013). This application involved a substantial expansion of longwall mining in the Wongawilli Seam across the Wonga East area (11 longwall panels) and Wonga West area (seven longwall panels) to extract 31 million tonnes (Mt) of run-of-mine (ROM) coal over a project life of 18 years.

Jindal Steel and Power Limited acquired a majority stake in Gujarat NRE Coking Coal Ltd in October 2013 and subsequently, the name of the company, Gujarat NRE Coking Coal Ltd, was changed to WCL following the change in ownership.

In response to concerns from the public and government agencies, the original UEP application has been substantially revised over time to reduce the potential adverse impacts of the mine.

A Preferred Project including Response to Submissions (Natural Resources Environment (NRE) and the Residual Matters Report (Hansen Bailey, 2014) were then exhibited based on a reduced longwall mine plan of eight longwalls in the Wonga East area only.

The Preferred Project was referred to the Planning Assessment Commission (PAC) and the PAC released its first Review Report on the UEP Preferred Project in April 2015.

Response to the PAC's First Review Report Part 1 (Hansen Bailey, July 2015) and Part 2 (Hansen Bailey, September 2015) included an Independent Risk Assessment (Broadleaf, 2015) following consultation with various agencies.

The PAC report recommended that further work and assessments was required before a determination could be made.

In October 2015, the Minister referred the responses to the PAC for a second review, with the PAC report released in March 2016 requiring further consideration and assessment of water and subsidence, risks of water loss and impact to upland swamps, the estimated cost associated with water loss, and the noise assessment (PAC, 2016).

In regard to groundwater assessments, starting in 2009, the subsequent GeoTerra (2012) assessment conducted a detailed groundwater model and impact assessment for both the Russell Vale East and Russell Vale West proposed mining domains as part of the original Underground Expansion Project Part 3A (Pt3A) application.

GeoTerra / GES (2014) subsequently updated the 2012 groundwater model and associated reporting for the UEP Preferred Project Report.

GeoTerra / GES (2015) then subsequently updated the groundwater model and associated reporting again, with a further modified longwall extraction plan, which was not approved by the relevant authorities.

A key issue for the PAC in its consideration and review of the UEP Preferred Project was the uncertainty associated with subsidence and groundwater impacts potentially resulting from the proposed longwall mining in the multi-seam mining environment at Russell Vale, and in particular the Wonga East area.

In assessing the constraints and opportunities associated with each of the potential project alternatives outlined above, the need to reduce this uncertainty was considered a priority.

During the subsequent review process, it was considered unlikely that the options to amend the previous second workings mine plan would sufficiently resolve uncertainty to a level that was acceptable to the PAC.

Therefore, a mine plan option for long term stable first workings was considered the only feasible alternative, despite the lower production rates and resource recovery volumes resulting from this option.

GeoTerra Pty Ltd (GeoTerra) and Groundwater Exploration Services Pty Ltd (GES) were commissioned by WCL to undertake a revised groundwater modelling-based assessment and updated reporting of the regional groundwater system in the proposed first workings mining area prior to, during and after the proposed first workings extraction within the Wongawilli Seam (GeoTerra / GES, 2017) for the Russell Vale Revised Underground Expansion Project.

Desktop assessments, field monitoring, laboratory analysis and computer modelling studies were used to prepare a baseline assessment of the groundwater system, groundwater quality and aquifer hydraulic parameters within the proposed first workings mining area.

The current version of the GeoTerra / GES (2019) report and groundwater modelling assessment has, to date, been through five revision and updating stages since mid 2017.

B – Relevant NSW Groundwater Legislation and Guidelines

The current report has been prepared with reference to the following documents;

- Barnett et al, 2012, Australian Groundwater Modelling Guidelines, Water lines Report, National Water Commission, Canberra
- DECC, 2007 Submission on the Strategic Review of the Impacts of Underground Mining in the Southern Coalfield
- DECC, 2008 Ecological Impacts of Longwall Mining in the Southern Coalfields of NSW – A Review
- DECC-NOW Draft Guidelines for Groundwater Monitoring
- Dept of the Environment, 2013 Significant impact guidelines 1.3: Coal seam gas and large coal mining developments—impacts on water resources
- DIPNR, 2005 Management of Stream / Aquifer Systems in Coal Mining Developments, Hunter Region, Version 1 – April 2005
- IESC, 2014 Subsidence from coal mining activities, Background Review. Commonwealth of Australia.
- IESC, 2015 Information Guidelines for Independent Expert Scientific Committee Advice on Coal Seam Gas and Large Coal Mining Development Proposals
- IESC, 2019 Information Guidelines Explanatory Note - Uncertainty Analysis - Guidance for Groundwater Modelling Within a Risk Management Framework
- Murray-Darling Basin Commission Groundwater Quality Sampling Guidelines Technical Report No 3 (MDBC);
- Murray-Darling Basin Commission. Groundwater Flow Modelling Guideline (MDBC);
- National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia (ARMCANZ/ANZECC);
- NSW Aquifer Interference Policy (NOW)
- NSW Department of Planning, 2008 Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield – Strategic Review
- NSW State Groundwater Policy Framework Document (NSW Department of Land and Water Conservation [DLWC]);
- NSW State Groundwater Quality Protection Policy (DLWC);
- NSW Draft State Groundwater Quantity Management Policy (DLWC);
- NSW Groundwater Dependent Ecosystem Policy (DLWC);
- OEH 2012. Upland Swamp Environmental Assessment Guidelines. Guidance for the Underground Mining Industry Operating in the Southern Coalfield. Office of Environment and Heritage, Sydney. Draft August 2012.
- SCA NSW, 2007 The Design of a Hydrological and Hydrogeological Monitoring Program to Assess the Impact of Longwall Mining in SCA Catchments (Draft)
- Water Management Act 2000;
- Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 (NSW Office of Water – NOW).

The more relevant State groundwater based Plans, Policies, Guidelines and Legislation are detailed in the following sections.

The Study Area aquifers are covered, as appropriate, by the generic State Groundwater Policy (DLWC, 1997), Groundwater Quality Protection Policy (DLWC, 1998).

The Study Area lies within Groundwater Flow System 5 (GFS5) Hawkesbury Sandstone - South-East (Grey and Ross, 2003) which includes the catchment of Cataract Dam. As the area is within the Sydney Catchment Authority controlled Metropolitan Special Area, no groundwater supply work development is permitted as it is a protected area. As such, there are no private bores. GFS5 has a sustainable yield estimate of 58,000 ML/year (Grey and Ross, 2003).

The *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011* encompasses the Study Area. The Study Area is within the Sydney Basin Nepean Groundwater Source Area.

The water sharing plan annual rainfall recharge in the Sydney Basin Nepean Groundwater Source Area is assessed at 224,483ML/year. This volume is subdivided into consumptive pool water and environmental water, with 124,915ML/year of the long term annual average recharge being reserved as environmental water. The remaining volume is classified as a sustainable yield or long term average extraction limit of 99,568ML/year.

The current extraction limits and groundwater entitlement volumes do not include all water taken through aquifer interference activities such as mine voids (remnant or otherwise).

Reservation of environmental water aims to support the long term viability of the aquifers and their dependent ecosystems.

While it does not extend into the Study Area, there is currently an embargo on further applications for sub-surface water licences in the Southern Coalfield (ordered under section 113A of the Water Act, 1912), for areas covering the:

- Nepean Sandstone Water Shortage Zone GWMA 607 (gazetted 8 June 2007); and
- NSW Southern Highlands (gazetted 21 May 2004 and 16 December 2005).

1.1 Water Management Act 2000

The *Water Management Act 2000* allows for the development fo water sharing plans (WSPs). The rules of WSPs determine how water is to be allocated between water users and the environment. WSPs include extraction limits to ensure that there is sufficient water in the water source to maintain environmental health.

In regard to swamps, the Water Management Act provides for protection of groundwater dependent ecosystems (GDEs) in Sections 3, 5 and 9. GDEs are also protected through clauses 8(1) and 9 as well as Schedule 4 of the WSP.

Upland Swamps within the Study Area are not representative of the Temperate Highland Peat Swamps on Sandstone (THPSS) EEC listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The listing advice for the THPSS EEC (TSSC 2005) contains a number of criteria not met by the upland swamps within the Study Area.

It is understood that the Department of Environment (DoE) are currently reviewing the listing of upland swamps, and that the new listing advice is likely to cover swamps on the Woronora plateau, as outlined in Biosis (2012).

Notwithstanding, the upland swamps within the Woronara Plateau were considered to be significant by the Office of Environment and Heritage (OEH)in the Bulli PAC report.

1.2 Water Sharing Plan for the Greater Metropolitan Region Groundwater Water Sources 2011

The water sharing plan also includes rules aimed at protecting Groundwater Dependent Ecosystems consistent with the Groundwater Dependent Ecosystem Policy (DLWC, 2002). The policy includes wetlands, terrestrial vegetation and caves or karst systems. In the proposed plan, terrestrial ecosystems are protected by a 200m stand off for new bores from any sandstone escarpment where hanging swamps or base flow to rivers is supported by groundwater. It should be noted, however, that no extraction bores are proposed and there are no “hanging” swamps, as opposed to “Upland” swamps in the Study Area

The Project is located within the Sydney Basin Nepean Groundwater Source (Management Zone 2) under the WSP. The rules of the WSP that may be relevant to the proposed mining include:

- A commercial access licence under a controlled allocation order may be made in relation to any unassigned water in this water source

To minimise interference between neighbouring works

Clause 39 of the WSP states that no water supply works (bores) to be granted or amended within the following distances of existing bores:

- 400m from an aquifer access licence bore on another landholding, or
- 100m from a basic landholder rights bore on another landholding, or
- 50m from a property boundary (unless written consent from neighbour), or
- 1,000m from a local or major water utility bore, or
- 200m from a NSW Office of Water monitoring bore (unless written consent from NSW Office of Water).

To protect bores located near contamination

Clause 40 of the WSP states that no water supply works (bores) are to be granted or amended within:

- 250m of contamination as identified in the WSP, or
- 250m to 500m of contamination as identified within the plan unless no drawdown of water will occur within 250m of the contamination source,
- a distance greater than 500m of contamination as identified within the plan if necessary to protect the water source, the environment or public health and safety.

To protect water quality

Pursuant to clause 40 of the WSP, to minimise the impact on water quality from saline interception in the shale aquifers overlying Sydney basin sandstone, the bore being used to take groundwater must be constructed with pressure cement to seal off the shale aquifer as specified by the Minister.

To protect bores located near sensitive environmental areas

Clause 41 of the WSP provides that no water supply works (bores) to be granted or amended within the following distances of high priority Groundwater Dependent Ecosystems (GDEs) (non Karst) as identified within the plan:

- 100m for bores used solely for extracting water under basic landholder rights, or
- 200m for bores used for all other access licences.

The above distance restrictions for the location of works from high priority GDEs do not apply where the GDE is a high priority endangered ecological vegetation community and the work is constructed and maintained using an impermeable pressure cement plug from the surface of the land to a minimum depth of 30m.

The Project is not located near any high priority GDEs listed under the WSP.

No water supply works (bores) to be granted or amended within the following distances from these identified features:

- 500m of high priority karst environment GDEs, or
- a distance greater than 500m of a high priority karst environment GDE if the Minister is satisfied that the work is likely to cause drawdown at the perimeter of the high priority karst GDE, or
- 40m of a river or stream or lagoon (3rd order or above),
- 40m of a 1st or 2nd order stream, unless drilled into underlying parent material and slotted intervals commence deeper than 30m. (30m may be amended if demonstrate minimal impact on base flows in the stream.), or
- 100m from the top of an escarpment.

To protect groundwater dependent culturally significant sites

Clause 42 of the WSP states that no water supply works (bores) to be granted or amended within the following distances of groundwater dependent culturally significant sites as identified within the plan: ,

- 100m for bores used for extracting for Basic Landholder Rights, or
- 200m for bores used for all other aquifer access licences.

The Project is not located near any groundwater dependent culturally significant sites under the WSP.

Rules for replacement groundwater works

Clause 38 of the WSP states that a replacement groundwater work must be constructed to take water from the same water source as the existing bore and to a depth specified by the Minister.

A replacement work must be located within:

- 20 metres of the existing bore; or
- If the existing bore is located within 40 metres of the high bank of a river the replacement bore must be located within 20 metres of the existing bore but no closer to the high bank of the river or a distance greater if the Minister is satisfied that it will result in no greater impact

Replacement works may be at a greater distance than 20 metres if the Minister is satisfied that doing so will result in no greater impact on the groundwater source and its dependent ecosystem.

The replacement work must not have a greater internal diameter or excavation footprint than the existing work unless it is no longer manufactured. If no longer manufactured the internal diameter of the replacement work must be no greater than 110% of the existing work.

To manage bores located near contaminated sites

Under clause 44 of the WSP, the maximum amount of water that can be taken in any one year from an existing work within 500 metres of a contamination source is equal to the sum of the share components of the access licences nominating that work at commencement of the plan.

To manage the use of bores within restricted distances

Under clause 44 of the WSP, the maximum amount of water that can be taken in any one year from an existing work within the restricted distances to minimise interference between works, protect sensitive environmental areas and groundwater dependant culturally significant sites is equal to the sum of the share component of the access licence nominating that work at commencement of the plan.

To manage the impacts of extraction

The Minister may impose restrictions on the rate and timing of extraction of water from a water supply work to mitigate the impacts of extraction.

Available Water Determinations

The Available Water Determination (AWD) represents the volume of water that can be taken per unit share. The maximum allowable AWD is 1 ML per share. The AWD for aquifer access licences in the Sydney Basin Nepean Groundwater Source is currently 1 ML per share.

AWDs are prescribed by NOW and may change in response to climatic conditions or growth in use.

Trading Rules

Section 71Q of the WM Act allows the Minister to alter the assignment of shares between multiple water access licences. That is, part of the share component from one licence can be assigned to the other licence. Share components can only be re-assigned between water access licences in the same water source.

Clause 47 of the WSP states that assignment of shares between licences is prohibited under certain circumstances. Relevantly, within the Sydney Basin Nepean Groundwater Source, an assignment of share from Management Zone 2 to Management Zone 1 is prohibited if the trade will cause the total share component for Management Zone 1 to exceed the total share component at the commencement of the plan. Trading within management zones permitted subject to local impact assessment.

Conversion to another category of access licence

Clause 46 of the WSP prohibits the conversion of water access licences from one category to another within the water sources that are subject to the WSP.

1.3 NSW Aquifer Interference Policy

The NSW Aquifer Interference Policy was released in September 2012.

Under the policy, and the associated WM Act, an aquifer is a geological structure or formation that is permeated with water or is capable of being permeated with water. Groundwater is defined as all water that occurs beneath the ground surface in the saturated zone. For the purpose of the policy, the term “aquifer” has the same meaning as groundwater system.

The *Water Management Act 2000* defines an aquifer interference activity as the:

- penetration of an aquifer,
- interference with water in an aquifer,
- obstruction of the flow of water in an aquifer,
- taking of water from an aquifer in the course of carrying out mining or any other activity prescribed by the regulations, and the;
- disposal of water taken from an aquifer in the course of carrying out mining or any other activity prescribed by the regulations.

A water licence is required under the *Water Management Act 2000,* unless an exemption applies or water is being taken under a basic landholder right, where any act by a person carrying out an aquifer interference activity causes the:

- removal of water from a water source;
- movement of water from one part of an aquifer to another part of an aquifer;
- movement of water from one water source to another water source, such as from an aquifer to an adjacent aquifer, an aquifer to a river/lake, or from a river/lake to an aquifer.

The Aquifer Interference Policy (AIP) lists a number of activities that are deemed to be minimal impact aquifer interference activities. In terms of mining, activities considered as having a minimal impact include:

- sampling and coring using hand held equipment;
- trenching and costeaning;
- access tracks;
- leachate ponds and sumps if constructed, operated and abandoned in accordance with appropriate standards and guidelines as determined by the Minister;
- construction and ongoing use of tailings and ash dams if lined with an impervious layer providing these are carried out in accordance with their planning and other approvals;
- caverns, tunnels, cuttings, trenches and pipelines (intersecting the water table) if a water access license is not required;

The AIP also states that monitoring bores are deemed to be minimal impact activities if the bores are:

- required by a development consent under Part 4 or an approval under Part 5.1, of the Environmental Planning and Assessment Act 1979,
- required or undertaken as a result of an environmental assessment under Part 5 of that Act,
- required by a condition of an environment protection license under the Protection of the Environment Operations Act 1997, or where;
- core holes, stratigraphic (chip) holes, geo-environmental and geotechnical bores, works or activities intersecting the water table if they are decommissioned in such a way as to restore aquifer isolation to that which existed prior to the construction of the bore, work or activity and that the decommissioning is conducted within a period of 28 days following completion of the bore, work or activity;

The *Water Management Act 2000* includes the concept of ensuring "no more than minimal harm" for both the granting of water access licenses and the granting of approvals. Water access licenses are not to be granted unless the Minister is satisfied that adequate arrangements are in force to ensure that no more than minimal harm will be done to any water source as a consequence of water being taken under the license.

Where a water access licence has been applied for by a method consistent with a controlled allocation process then adequate arrangements are in force to ensure that no more than minimal harm will occur. This is because the controlled allocation process allows for the allocation of a proportion of the unassigned water within the relevant water source using a conservative approach. Furthermore, unassigned water can only occur where total water requirements within a water source are less than the long-term average annual extraction limit specified in the relevant water sharing plan.

Where water is to be taken from a water source that has no unassigned water or insufficient unassigned water to account for any inflows to the activity, either surface or groundwater, then water entitlements will need to be purchased from an existing licensed user.

Any access licence dealing requiring the Minister's consent will need to consider the requirements of section 71Y of the *Water Management Act 2000,* including the water management principles that require water sources to be protected and social and economic benefits to be maximised.

Aquifer interference activities may induce flow from adjacent groundwater sources or flow from connected surface water sources to compensate for the water taken from the aquifer in which the activity is occurring or to fill the void created in the aquifer.

Where an aquifer interference activity is taking water from a groundwater source, and this causes movement from an adjacent, overlying or underlying groundwater source, separate aquifer access licenses are required for the groundwater source and for any adjacent, overlying or underlying groundwater sources.

Where an aquifer interference activity causes movement of water from a connected regulated or unregulated river water source into the groundwater source, then an access license in the regulated or unregulated river water source is required to account for the take of water from that water source and another access license in the groundwater source is required for the remainder of the take.

Where an aquifer interference activity is incidentally taking water from a river it must be returned to that river when river flows are at levels below which water users are not permitted to pump.

It is the proponent's responsibility to ensure that the necessary licenses are held with sufficient share component and water allocation to account for all water take, both for the life of the activity and after the activity has ceased.

In determining what licenses are required and which water source(s) the activity will take water from, the following need to be considered;

- prediction of the total amount of water that will be taken from each connected groundwater or surface water source on an annual basis as a result of the activity and after closure of the activity. Where required, predictions should be based on modeling conducted in accordance with the Australian Groundwater Modeling Guidelines;
- how and in what proportions this take will be assigned to the affected aquifers and

connected surface water sources;

- how any relevant license exemptions might relate to the water to be taken by the activity;
- whether the water is taken at a fixed or varying rate;
- whether sufficient entitlements and allocations are able to be obtained;
- consideration of water sharing plan rules;
- by what mechanism and license category the water will be obtained, consistent with any trading rules specified in either the Minister's access license dealing principles and/or relevant water sharing plans;
- the effect that activation of existing entitlement may have on future available water determinations for the proposed license category and entitlement volume;
- actions required both during operation and post-closure to minimise the risk of inflows to a mine void as a result of flooding. Set-back distances from rivers should be no less than that required to ensure structural integrity of the river bank during flooding events. Levee banks or landforms should also be constructed at the appropriate time to prevent at least a 1 in 100 year flood from entering the site either during or after operation, and;
- a strategy for accounting for any water taken beyond the life of the operation of the project, such as holding the appropriate entitlement or surrendering a component of the entitlement at the end of the project. Where a license or part of a license has been surrendered to the Minister, a security deposit or condition of consent under the EP&A Act may account for or require the upfront payment of fees and subsequently the license may be retained for the period of ongoing take of water or cancelled.

Where uncertainty in the predicted inflows may have a significant impact on the environment or other authorised water users, the applicant will need to report on:

- potential for causing or enhancing hydraulic connection between aquifers or between groundwater and surface water sources, and quantification of this risk;
- quantification of any other uncertainties in the groundwater or surface water impact modeling conducted for the activity; and
- strategies for monitoring actual and reassessing any predicted take and how changes will be accounted for, including analysis of water market depth and/or in situ mitigation and remediation options

Where there is ongoing take of water, the holder must retain a license until the system returns to equilibrium or surrender it to the Minister. Surrendering entitlements that adequately cover any likely future low available water determination periods is preferable.

The NSW Office of Water will assess the potential impacts of the aquifer interference activity against the minimal impact considerations, as well as any specific rules in a relevant water sharing plan

There are two levels of minimal impact considerations specified in **Table 1**.

Groundwater sources have been divided into "highly productive" and "less productive". Highly productive groundwater is defined as a source that is declared in the Regulations and:

- has total dissolved solids less than 1,500 mg/L, and
- contains water supply works that can yield water at a rate greater than 5 L/sec.

Highly productive groundwater sources are grouped into:

- Alluvial;
- Coastal sands;
- Porous rock;
    - o Great Artesian Basin - Eastern Recharge and Southern Recharge;
    - o Great Artesian Basin - Surat, Warrego and Central;
- other porous rock, and
- fractured rock

Less productive groundwater sources are grouped as:

- Alluvial;
- Porous rock, and;
- Fractured rock.

Table 1 Minimal Impact Considerations for Aquifer Interference Activities – Less Productive Porous Rock Groundwater Sources

Water Table	Water Pressure	Water Quality
LEVEL 1		
Less than or equal to 10% cumulative variation in the water table, allowing for typical post water sharing plan (WSP) variations, 40m from any: High priority groundwater dependent ecosystems, or High priority culturally significant site; listed in the schedule of the relevant WSP. A maximum of 2m decline cumulatively at any water supply work.	A cumulative pressure head decline of not more than 2m decline at any water supply work.	Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity.
LEVEL 2		
If there is more than 10% cumulative variation in the water table, then appropriate studies will need demonstrate to the ministers satisfaction that the variation will not prevent the long term viability of the dependent ecosystem or significant site If more than 2m decline cumulatively at any water supply work then make good provisions should apply.	If there is more than a 2m pressure head decline, then appropriate studies will need to demonstrate to the ministers satisfaction that the decline will not prevent the long term viability of the water supply works unless make good provisions apply	If the above condition is not met, then appropriate studies will need to demonstrate to the minister's satisfaction that the change in groundwater quality will not prevent the long term viability of the dependent ecosystem, significant site or affected water supply works.

If the predicted impacts are less than the Level 1 minimal impact considerations, then these impacts will be considered as acceptable.

Where an activity's predicted impacts are greater than Level 1, but they exceed it by no more than the accuracy of a robust model, then the project will be considered as having acceptable impacts, with monitoring, as well as potential mitigation or remediation required during operation.

If the predicted impacts exceed Level 1 by more than the accuracy of a robust model, then the assessment will need to involve additional studies, and if the impacts will not prevent the long-term viability of the water dependent asset, then the impacts will be considered acceptable.

A risk management approach to assessing the potential impacts of aquifer interference activities will be adopted, where the level of detail required is proportional to the likelihood of impacts occurring on water sources, users and dependent ecosystems and the potential consequences.

In addition to the volumetric water licensing considerations, a proponent will need to provide;

- baseline groundwater depth, quality and flow;
- a strategy for complying with any water access rules;
- potential water level, quality or pressure impacts on nearby water users, connected ground / surface water sources and groundwater dependent ecosystems;
- the potential for increased saline or contaminated water inflows to aquifers and highly connected river systems;
- the potential to cause or enhance hydraulic connection between aquifers;
- the potential for river bank instability, or high wall instability or failure to occur;
- the method for disposing of extracted water;
- contingency plans or remedial measures if impacts are outside of the licensing and approval requirements.

If a development consent under Part 4, Division 4.1 or Part 5.1 of the EP&A Act has been granted or for any approved mining or CSG production activity that was not subject to the Gateway process, the maximum predicted annual water quantities are to be licensed from the commencement of the activity.

Aquifer Interference Approval

Under the WM Act, an aquifer interference activity requires:

- The necessary volumetric WALs
- A separate aquifer interference approval.

An aquifer interference approval confers a right on its holder to carry out specified aquifer interference activities at a specified location or area.

Under section 91F of the WM Act, it is an offence to carry out an aquifer interference activity without an aquifer interference approval. An aquifer interference activity includes the penetration, interference or obstruction of flows within an aquifer or to take or dispose of waters from an aquifer.

However, section 91F of the WM Act does not currently apply. Section 88A provides that Part 3 of Chapter 3 (including section 91F) applies to each part of the State or each water source and each type or kind of approval that relates to that part of the State or that water source that is declared by proclamation. In essence, the AIP applies, however the approvals framework has not been finalised.

A framework for the implementation of the AIP was produced by NoW (October 2013) and this report addresses the key issues in this document.

Licences for Impacts on Stream Baseflow

Any reduction in baseflow as a result of depressurisation will also require a water access licence under the WSP for the unregulated rivers. The Project is located within the Upper Nepean and Upstream Warragamba water source under the *Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011*.

Any take of surface water / baseflow as a result of depressurisation of deeper aquifers will require a water access licence within this water source.

1.4 Environment Protection and Biodiversity Conservation Act 1999

The Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) is the main Commonwealth environmental legislation that provides legal framework to protect and manage matters of environmental significance including nationally and internationally important flora, fauna, ecological communities and heritage.

The EPBC Act was amended to introduce a new matter of national environmental significance named the *"Protection of Water Resources from Coal Seam Gas Development and Large Scale Coal Mining Development".*

Pursuant to the EPBC Act, an action that has, will have, or is likely to have a significant impact upon Matters of National Environmental Significance (MNES) is declared a "controlled action" and requires the approval of the Commonwealth Minister for Environment.

Approval under the Commonwealth EPBC Act is in addition to requirements under NSW State legislation.

The EPBC Act lists Matters of National Environmental Significance (MNES) that must be addressed when assessing the impacts of a proposal.

Water resources are also an MNES and the potential impact of the Project must be assessed in accordance with the Independent Expert Scientific Committee's Information Guidelines for *Proposals Relating to the Development of Coal Seam Gas and Large Coal Mines where there is a Significant Impact on Water Resources* (IESC, February 2013) and the *Significant Impact Guidelines 1.3: Coal Seam Gas and Large Coal Mining Developments – Impacts on Water Resources* (Department of Environment, December 2013). The criteria are presented below for;

Hydrological Characteristics, covering changes in the:

- water quantity, including the timing of variations in water quantity;
- integrity of hydrological or hydrogeological connections, including substantial structural damage (e.g. large scale subsidence), and;
- area or extent of a water resource.

Water Quality, in regard to, if;

- there is a risk that the ability to achieve relevant local or regional water quality objectives would be materially compromised;
- a project creates risks to human or animal health or to the condition of the natural environment as a result of the change in water quality;
- a project substantially reduces the amount of water available for human consumptive uses or for other uses, including environmental uses, which are dependent on water of the appropriate quality;
- a project could cause persistent organic chemicals, heavy metals, salt or other potentially harmful substances to accumulate in the environment;
- a project could seriously affect the habitat or lifecycle of a native species dependent on a water resource;
- there is a significant worsening of local water quality (where current local water quality is superior to local or regional water quality objectives), and if:
- high quality water is released into an ecosystem which is adapted to a lower quality of water

1.5 Southern Coalfields Inquiry, Metropolitan and Bulli Seam Operations Planning Assessment Commission

In addition to the policies and guidelines outlined in Section 2.0, the three following reports have also guided the current assessment:

- NSW Dept of Planning, 2008 Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield – Strategic Review;
- NSW Planning Assessment Commission, 2009 The Metropolitan Coal Project Review Report, and;
- NSW Planning Assessment Commission, 2010 Bulli Seam Operations PAC Report

The combined groundwater related issues highlighted in the above Planning Assessment Commission (PAC) reports that are addressed in this study are:

- the use of 3D groundwater numerical modelling that can adequately address high contrasts in hydraulic properties and steep hydraulic gradients in non-steady state flow domains
- aquifer numerical modelling used as a management tool for the ongoing prediction of impacts attributed to longwall extraction
- adequate density and duration of observations with respect to redirected surface flows and regional strata depressurisation, ideally with a minimum two years of baseline environmental data collected at appropriate frequency and scale
- the possibility of a fault or dyke, or other linear features providing a potential leakage conduit from surface to below the Bald Hill Claystone and development of a strategy to characterise the structure and determine the magnitude and extent of the leakage.

The reports indicate that groundwater monitoring regimes and impact assessments should be based on:

- shallow piezometers monitoring groundwater levels within significant upland swamps, drainages or connected alluvium with sufficient distribution to characterise the swamp with a high level of confidence in potentially affected areas. Water level measurements should be automated with daily or more frequent recording;
- sufficient piezometers in swamps and associated regional groundwater systems to verify perching and to monitor the underlying hardrock water table
- groundwater quality classification through regular sampling and analyses that can discriminate mining related impacts and ionic species attributable to new water/rock interactions;
- deep piezometer installations to monitor pore pressures in the natural rock strata with sufficient distribution to describe the distribution of deep aquifer pressures with a high level of confidence using automated daily or more frequent recording;
- strata porosity and permeability measurements used to calculate subsurface flows and presentation of a database to facilitate impact assessment using packer testing, variable head testing, test pumping, core analyses (matrix properties and defects inspections) and geophysical logging where appropriate; and
- a mine water balance (Beca, 2010) to confirm groundwater transmission characteristics of the coal seam, overburden and drainage characteristics of goaves and the overlying failure regimes. Use of a mine water balance can also indicate potentially anomalous mine water seepages that may be initiated by increased connectivity to surface drainage systems or in association with igneous intrusions. The water balance should account for water pumped into and out of the mine, coal moisture, ventilation moisture and any other exports. The capacity of the mine water management system to manage increased contributions from underground operations should also be addressed.
- use of airborne laser survey for detailed topographic mapping, GIS of groundwater systems assessment and management and consideration of data generated by other mine sites
- wireline geophysical logging (natural gamma; density (neutron), resistivity, sonic, acoustic scanner) to improve interpolation of measured permeability and porosity.

1.6 Water NSW Principles for Managing Mining and Coal Seam Gas Impacts in Declared Catchment Areas

WaterNSW was established to provide a safe and reliable supply of raw water suitable for treatment to drinking water standards. To meet this objective WaterNSW manages its land, the Sydney drinking water catchments and infrastructure including water storages, to protect water quality and quantity.

WaterNSW has formulated a number of principles that establish the outcomes WaterNSW considers essential to protect the drinking water supplies from the impacts of mining and coal seam gas activities. These principles are as outlined below;

- **Protection of water quantity**

In Declared Catchment Areas mining and coal seam gas activities must not result in a reduction in the quantity of surface and groundwater inflows to storages or loss of water from storages or their catchments.

- **Protection of water quality in Declared Catchment Areas**

In Declared Catchment Areas mining and coal seam gas activities must not result in a reduction in the quality of surface and ground water inflows to storages.

- **Protection of human health in Declared Catchment Areas**

Mining and coal seam gas activities must not pose increased risks to human health as a result of using water from the drinking water catchments.

- **Protection of water supply infrastructure**

The integrity of the WaterNSW water supply infrastructure must not be compromised.

- **Protection of ecological integrity in Special Areas**

The ecological integrity of the Special Areas must be maintained and protected.

- **Sound and robust evidence regarding environmental impacts**

Information provided by proponents, including environmental impact assessments for proposed mining and coal seam gas activities, must be detailed, thorough, scientifically robust and holistic. The potential cumulative impacts must be comprehensively addressed.

1.7 Independent Expert Scientific Committee

Table 1-5 lists the information requirements of the IESC in their assessment of large coal mining developments under the *Environment Protection and Biodiversity Conservation Act, 1999* (EPBC Act).

Further detail of the requirements is in Appendix A of the IESC Information Guideline (2018). Each category of information and current gaps with respect to information requirements are indicated.

The completed checklist is supplied separately.

Table 1-5 Information Requirements

IESC INFORMATION REQUIREMENT WHERE ADDRESSED

1. Description of proposed project This report, Section 1.

2. Description of impacts to water resources and water dependent assets. This report, Sections 2 to 5.

2.1. Conceptual model This report, Section 5.

2.2. Numerical Modelling Addressed in this report:

▪ Sections 6-7: model development and calibration.

▪ Section 8: model predictions.

▪ Section 9: sensitivity in model predictions (as per Middlemis and Peeters, 2018).

2.3. Water and salt balances Water balance would be presented in the Modelling report

3. Data management and monitoring Section 10 of this report

4. Cumulative impacts Cumulative impacts are considered in the numerical model: Sections 6-9.

5. Risk assessment A risk assessment is presented in a separate Risk Assessment report

Appendix C – Groundwater Model Uncertainty Analysis

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DATE: 30 January 2020

TO: Ron Bush
Group Environment and Approvals Manager
Wollongong Coal Ltd
PO Box 281
Fairy Meadow NSW 2519

FROM: Dr Damian Merrick

RE: Russell Vale Colliery Underground Expansion Project – Groundwater Uncertainty Analysis

YOUR REF: Email 7 November 2019

OUR REF: HA2020/02

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1. Introduction

GeoTerra Pty Ltd and Groundwater Exploration Services (GES) Pty Ltd have jointly undertaken the groundwater impact assessment for Russell Vale Colliery, which is located about 13 km to the north-west of Wollongong on the New South Wales South Coast. The subject of the assessment is the Russell Vale Colliery Underground Expansion Project. The Revised Preferred Project is proposed to adopt a non-caving first workings mining system in the Wongawilli Seam, with no further longwall mining. Under the previous approval, Longwalls 4 and 5 were mined, as well as the south-western 340 metres (m) of Longwall 6 (from April 2012 to July 2015).

Wollongong Coal Limited (WCL) has engaged HydroAlgorithmics Pty Ltd to conduct an IESC-compliant Uncertainty Analysis of outputs from the Russell Vale Groundwater Model. Uncertainty Analysis has been requested by DPIE-Water in their letter of 23 August 2019 to the NSW Department of Planning Industry and Environment (DPIE):

> *Impacts and takes are to be presented as the range of potential impact and take resulting from an uncertainty analysis in line with the 2018 IESC explanatory note, Uncertainty analysis—Guidance for groundwater modelling within a risk management framework. The P90 estimates should be relied on for impact and take predictions*.

Guidelines on uncertainty analysis for groundwater models were issued by the Independent Expert Scientific Committee (IESC) on Coal Seam Gas and Large Coal Mining Development in February 2018 in draft form and finalised in December 2018 (Middlemis and Peeters, 2018).

2. Methodology

This study addresses parameter uncertainty by stochastic modelling using the *Monte Carlo* method: generating numerous alternative parameterisations of the deterministic flow model (realisations), executing the model independently for each, and then aggregating the results for statistical analysis.

A traditional drawback to the Monte Carlo method is that its successful application often necessitates hundreds or thousands of model runs, each of which may take several hours of run time on a modern computer. More complex variants of Monte Carlo exist which aim to explore the parameter space more efficiently than the basic Monte Carlo approach, such as Null Space Monte Carlo (NSMC) (*Doherty, 2015*) and Markov Chain Monte Carlo (MCMC) approaches (e.g. *Vrugt et al., 2009*).

However, recent offerings in the field of cloud computing have greatly increased the availability and accessibility of computing resources, allowing hundreds of model runs to be evaluated simultaneously. Owing to this, we have elected to use the more basic Monte Carlo approach, which places no reliance on a linearisation of the model, allows for each individual model run to be kept relatively simple and with predictable run time (no additional calibration steps), and is free from the problem of autocorrelated samples that may occur with MCMC approaches.

AlgoCompute (*HydroAlgorithmics, 2019*; *Merrick, 2017*) was used as the platform for executing the model runs in parallel; up to 100 realisations were evaluated simultaneously, each being allocated to a single virtual machine in the cloud. The model-independent uncertainty quantification software HGSUQ (*Miller et al., 2018*) was used to generate the Monte Carlo parameter realisations and orchestrate the model runs within the AlgoCompute environment. The original MODFLOW-SURFACT model was converted to an equivalent MODFLOW-USG model to allow model execution in the cloud.

a. Parameters

Uncertainty was assessed on hydraulic conductivity, recharge, evapotranspiration, specific storage and specific yield properties throughout the model. Each property zone in the model was parameterised using pilot points, to allow the properties to vary spatially within each zone.

Pilot point locations were distributed approximately equidistantly around the edges of the model domain, and progressively densified closer to the proposed mine workings and nearby watercourses to increase the local resolution of the parameterisation in those areas. This was accomplished by starting with points placed in initially random locations within each zone of the model, and then using the optimisation algorithm for mesh generation in the AlgoMesh software tool (*Merrick and Merrick, 2015*) to distribute the points according to a prescribed distance function.

Figure 1 shows the set of 101 pilot point locations that were generated. From this set of locations, a pilot point was included in the parameterisation for each zone, wherever that location was sufficiently close[1] to that zone. To respect the configuration of the calibrated model, a separate zonation – and consequently a separate set of pilot points – was used for hydraulic conductivity parameters to the zonation used for storage parameters. Recharge and evapotranspiration parameters were applied at all pilot point locations in a single layer 1 zone. Coastal plains, void and fracture properties, and minor intrusives away from the mine were left fixed at their calibrated values and not varied for this analysis.

[1] A maximum distance of 1km was allowed between the pilot point and the closest model cell in the zone.

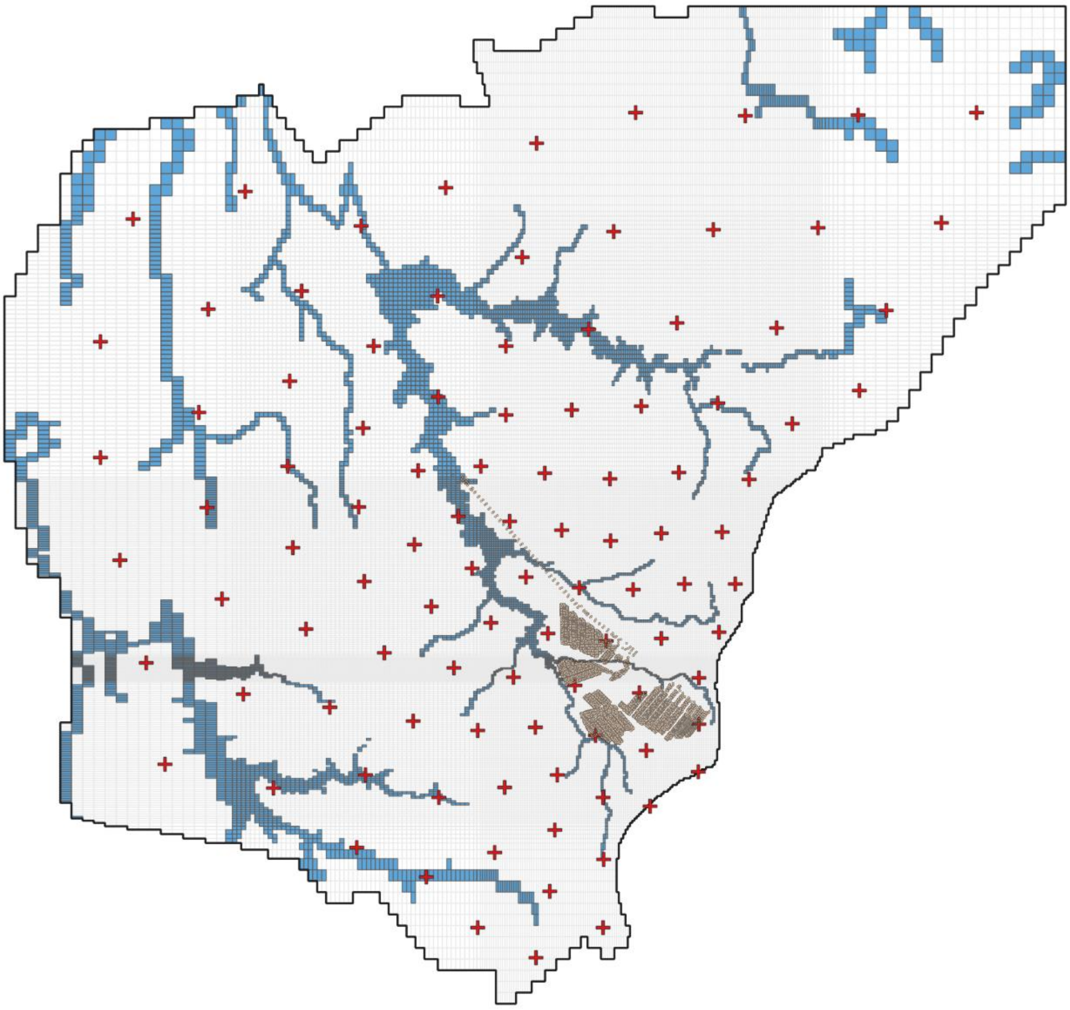

Figure 1: The set of 101 pilot point locations (depicted as red crosses) used for the spatially-varying model parameterisation.

Table 1 and **Table 2** list the model parameterisation zones for hydraulic conductivity and storage, respectively, and the corresponding number of pilot points in each. Hydraulic conductivity pilot points were each assigned two parameters: lateral conductivity (Kx) and vertical anisotropy (Kx/Kz). Storage pilot points were also assigned two parameters: specific storage (Ss) and specific yield (Sy). Recharge/evapotranspiration pilot points were assigned three parameters: fractional infiltration rate, evapotranspiration rate (ET rate) and evapotranspiration extinction depth (ET depth). Recharge rates generally were computed as rainfall multiplied by infiltration rate, and recharge along ridge areas was calculated at a fixed factor (~1.9x) multiplied by the general recharge rate, to match the base model.

A "prior" statistical distribution was assigned to each parameter based on the calibrated model values, from which randomly-sampled values were generated for each evaluated model realisation – subsequently interpolated to model cells by *kriging*.

Kx, Ss, and Sy values were assigned log-normal distributions with mean at the calibrated model value. An analysis of modelled values used for nearby Dendrobium and Metropolitan mines was conducted, and standard deviations of between one quarter of an order of magnitude and a whole order of magnitude are assigned to these distributions such that the range of modelled values was encompassed in the 95th percentile of the distributions[2].

[2] In a (log-)normal distribution, 95% of values lie within two standard deviations either side of the mean value.

Table 1: Hydraulic conductivity parameterisation zones and prior distributions. Mean values are presented non log-transformed. Units: m/day (Kx), - (Kx/Kz).

Layer	Zone	Description	# Pilot Points	Mean Kx	Stdev Log10 Kx	Min. Kx/Kz	Max. Kx/Kz
1	**1**	Upper Hawkesbury sandstone	67	3.0E-02	0.500	1.5	150
	23	Weathered Bald Hill claystone	74	4.0E-02	0.500	4	400
	24	Weathered Bulgo sandstone	44	4.0E-02	0.500	1	40
	100	Ridge	45	3.4E-02	0.500	1	34
	102	Ridge	5	5.0E-02	0.500	1	10
	141	Shallow alluvium	81	2.0E-01	0.500	1	20
2	**2**	Mid Hawkesbury sandstone	58	5.0E-04	0.750	5	500
	5	Upper Bulgo sandstone	44	6.0E-04	0.750	1	60
	6	Mid-lower Bulgo sandstone	9	9.0E-04	0.750	3	300
	18	Weathered Bald Hill claystone	74	8.0E-04	0.750	1.6	160
	101	Ridge	41	1.5E-02	0.750	1	48.33
	142	Deep alluvium	34	1.0E+00	0.750	1	10
3	**3**	Lower Hawkesbury sandstone	57	5.6E-04	0.750	1	80.43
	5	Upper Bulgo sandstone	50	6.0E-04	0.750	1	60
	6	Mid-lower Bulgo sandstone	9	9.0E-04	0.750	3	300
	19	Weathered Bald Hill claystone	74	7.0E-04	0.750	1	77.78
	100	Ridge	23	3.4E-02	0.750	1	34
	101	Ridge	20	1.5E-02	0.750	1	48.33
4	**4**	Bald Hill claystone	101	2.0E-05	0.750	1	20.23
	5	Upper Bulgo sandstone	62	6.0E-04	0.750	1	60
	6	Mid-lower Bulgo sandstone	9	9.0E-04	0.750	3	300
	100	Ridge	4	3.4E-02	0.750	1	34
5	**5**	Upper Bulgo sandstone	101	6.0E-04	0.750	1	60
6	**17**	Mid-upper Bulgo sandstone	101	7.0E-04	0.750	1	70
7	**6**	Mid-lower Bulgo sandstone	99	9.0E-04	0.750	3	300
	66	Intrusion	12	1.0E-04	0.750	1	12.5
8	**30**	Lower Bulgo sandstone	99	5.0E-04	0.750	5	500
	66	Intrusion (east)	12	1.0E-04	0.750	1	12.5
	77	Intrusion (west)	14	5.0E-04	0.750	1.25	125
9	**7**	Stanwell Park claystone (east)	79	1.4E-04	0.500	4.67	466.67
	66	Intrusion	12	1.0E-04	0.500	1	12.5
	95	Stanwell Park claystone (west)	27	1.4E-05	0.500	1.75	175
10	**8**	Scarborough sandstone	94	8.0E-04	0.750	8	800
	66	Intrusion	12	1.0E-04	0.750	1	12.5
11	**9**	Wombarra claystone	96	1.7E-05	0.750	1.12	111.73
	63	Intrusion	7	7.0E-03	0.750	7	700
12	**10**	Coal Cliff sandstone	99	4.0E-04	0.500	10	1000
	63	Intrusion	7	7.0E-03	0.500	7	700
13	**11**	Bulli seam (east)	87	9.5E-03	0.750	1	47.5
	90	Bulli seam (west)	26	2.0E-04	0.750	1	40
14	**12**	Interburden	101	1.5E-04	0.750	1	100
15	**13**	Balgownie seam	101	5.5E-04	1.000	1	55
16	**14**	Interburden	101	5.0E-05	0.500	1	50
17	**15**	Wongawilli seam	101	4.0E-04	1.000	1	44.44
18	**38**	Kembla sandstone	101	3.0E-04	0.750	1	33.33
19	**16**	Basement	101	1.0E-04	0.750	1	14.29

Table 2: Storage parameterisation zones and prior distributions.
Mean values are presented non log-transformed. Units: % (Specific yield), -/m (Specific storage).

Layer	Zone	Description	# Pilot Points	Mean Ss	Stdev Log_{10} Ss	Mean Sy	Stdev Log_{10} Sy
1	**1**	Upper Hawkesbury sandstone	67	1.0E-04	0.5	1.0%	0.25
	23	Weathered Bald Hill claystone	74	5.0E-04	0.5	2.0%	0.25
	24	Weathered Bulgo sandstone and ridge	44	5.0E-04	0.5	5.0%	0.25
	141	Shallow alluvium	81	1.0E-03	0.5	10.0%	0.25
2	**2**	Mid Hawkesbury sandstone	58	6.0E-06	0.5	1.1%	0.25
	24	Upper Bulgo sandstone	44	5.0E-04	0.5	5.0%	0.25
	100	Ridge	41	5.0E-04	0.5	2.0%	0.25
3	**3**	Lower Hawkesbury sandstone	57	6.0E-06	0.5	1.1%	0.25
	24	Upper Bulgo sandstone	50	5.0E-04	0.5	5.0%	0.25
	100	Ridge	23	5.0E-04	0.5	2.0%	0.25
4	**4**	Bald Hill claystone	101	6.0E-06	0.5	1.1%	0.25
	24	Upper Bulgo sandstone	62	5.0E-04	0.5	5.0%	0.25
5	**5**	Upper Bulgo sandstone	101	6.0E-06	0.5	1.1%	0.25
6	**6**	Mid-upper Bulgo sandstone	101	6.0E-06	0.5	1.1%	0.25
7	**6**	Mid-lower Bulgo sandstone	99	6.0E-06	0.5	1.1%	0.25
8	**6**	Lower Bulgo sandstone	99	6.0E-06	0.5	1.1%	0.25
9	**7**	Stanwell Park claystone	79	7.0E-06	0.5	0.3%	0.25
10	**8**	Scarborough sandstone	94	7.0E-06	0.5	1.0%	0.25
11	**9**	Wombarra claystone	96	6.0E-06	0.5	0.3%	0.25
12	**10**	Coal Cliff sandstone	99	2.5E-06	0.5	0.6%	0.25
13	**11**	Bulli seam	87	5.0E-06	0.5	0.2%	0.25
14	**12**	Interburden	101	4.0E-06	0.5	0.6%	0.25
15	**13**	Balgownie seam	101	7.0E-06	0.5	0.8%	0.25
16	**17**	Interburden	101	4.0E-06	0.5	0.5%	0.25
17	**17**	Wongawilli seam	101	4.0E-06	0.5	0.5%	0.25
18	**36**	Kembla sandstone	101	2.5E-06	0.5	0.5%	0.25
19	**19**	Basement	101	2.5E-06	0.5	0.5%	0.25

Kx/Kz, infiltration rate and ET rate parameters were assigned log-uniform distributions, and ET depth parameters were assigned uniform distributions; all of these are defined by specified minimum and maximum values. Kx/Kz ranges were calculated to allow a factor of 10 either side of the calibrated model value, bounded to a physically-reasonable minimum of 1.0, such that Kz never exceeds Kx.

Table 1 summarises the mean and standard deviations of all hydraulic conductivity parameters per zone. Storage parameter distributions are similarly summarised in **Table 2**.

At all 101 pilot point locations, infiltration rates were permitted to vary from 2% to 8% (a factor of 2 either side of the original model rate of 4%). A range of 0.001 m/day to 0.005 m/day was specified for ET rates, and a range of 2m to 8m for ET extinction depths.

b. Run procedure

For each Monte Carlo realisation, the following procedure was executed on a virtual machine in the cloud, initiated by a HGSUQ "slave" worker process:

1. Interpolate pilot point parameter values to model cells and produce corresponding LPF, RCH and EVT package input files.
2. Run transient model with proposed new workings *inactive* (baseline case).
3. Run transient model with proposed new workings *active* (impacted case).
4. Compute calibration statistics and predictive outputs (impacted minus baseline: drawdown, mine inflow, flow impacts) and return these to the HGSUQ “master” process for amalgamation with other run results.

c. Assumptions

The following assumptions should be noted in assessing the information presented in this report:

- The stochastic modelling performed was limited to the parameters listed in the *Parameters* section of this document. Uncertainty was not assessed on any other aspects of the model.
- Spatial variability was assessed only to the resolution of the pilot point set, and within the bounds of the parameter zones of the base model.
- Each calibrated realisation was assumed to be equally likely in the analysis of the model outputs, i.e. apart from rejecting particularly poorly-calibrated runs, no weighting was applied to distinguish models based on how well they fit the observed data.

3. Input Parameter Distributions

Two sets of parameter distributions are discussed in this section: *prior* and *posterior* distributions. The prior distributions are those from which the Monte Carlo process builds random samples for evaluation – as summarised in the previous section. The Monte Carlo process produces a finite number of sample sets (realisations). Additionally, some of these realisations are rejected during evaluation due to non-convergence or poor calibration. The posterior distributions represent the actual property distributions evaluated after sampling and rejection have taken place.

In total, 500 realisations were evaluated as part of the Monte Carlo process. A calibration constraint on the scaled root-mean square (SRMS) error was applied such that any model with an SRMS of more than 5% was rejected. Of the 500 realisations, 141 (28.2%) were accepted and 359 (71.8%) were rejected because they exceeded the prescribed calibration constraint. No model convergence failures occurred.

a. Prior and posterior distributions

Substantial differences between the posterior and prior distributions may indicate that part of the prior distribution resulted in poorly-calibrated or non-convergent models. **Table 3** compares the mean and standard deviation (*stdev*) of prior and posterior distributions for all hydraulic conductivity parameters, aggregated over all pilot points in each zone.

Table 4 similarly compares prior and posterior distributions of storage parameters, and

Table 5 provides a comparison for recharge and evapotranspiration parameters. Although only minimum and maximum values were required to form the prior for uniform and log-uniform distributions, these are listed in the tables with the expected mean and standard deviation values based on their respective uniform distributions, to allow for easier comparison with the posterior.

Three Kx parameter zones and one Kx/Kz zone showed greater than 10% difference in summary statistics.

These are presented for closer analysis in **Figure 2** through **Figure 5.** Storage, recharge, evapotranspiration, and all other hydraulic conductivity parameters show very little difference between prior and posterior.

The Kx posterior distribution charts show a minor tendency of higher values to produce calibrated models in layer 4, zone 100 (ridge) and layer 10, zone 66 (intrusion), and perhaps a very minor tendency to lower values in layer 4, zone 6 (mid-lower Bulgo sandstone). Vertical anisotropy (Kx/Kz) tends to higher values (lower Kz) in layer 12, zone 63 (intrusion).

Table 3: Summary statistics of posterior vs prior hydraulic conductivity distributions. Note that mean values are non log-transformed. ***Bold text*** *is used to highlight discrepancies of more than 10% between prior and posterior.*

Layer	Zone	Posterior Mean Kx	Posterior Stdev Log_{10} Kx	Posterior Mean Kx/Kz	Posterior Stdev Kx/Kz	Prior Mean Kx	Prior Stdev Log_{10} Kx	Prior Mean Kx/Kz	Prior Stdev Kx/Kz
1	1	3.1E-02	0.494	14.94	0.576	3.0E-02	0.500	15.00	0.577
	23	4.0E-02	0.493	40.02	0.576	4.0E-02	0.500	40.00	0.577
	24	4.0E-02	0.498	6.30	0.460	4.0E-02	0.500	6.32	0.462
	100	3.3E-02	0.490	5.83	0.442	3.4E-02	0.500	5.83	0.442
	102	5.1E-02	0.515	3.09	0.284	5.0E-02	0.500	3.16	0.289
	141	2.0E-01	0.500	4.46	0.377	2.0E-01	0.500	4.47	0.376
2	2	5.1E-04	0.760	49.07	0.575	5.0E-04	0.750	50.00	0.577
	5	6.2E-04	0.748	7.87	0.514	6.0E-04	0.750	7.75	0.513
	6	9.5E-04	0.756	30.31	0.585	9.0E-04	0.750	30.00	0.577
	18	8.0E-04	0.754	15.83	0.574	8.0E-04	0.750	16.00	0.577
	101	1.5E-02	0.760	7.00	0.486	1.5E-02	0.750	6.95	0.486
	142	9.7E-01	0.743	3.16	0.289	1.0E+00	0.750	3.16	0.289
3	3	5.7E-04	0.752	8.84	0.548	5.6E-04	0.750	8.97	0.550
	5	5.9E-04	0.753	7.94	0.509	6.0E-04	0.750	7.75	0.513
	6	9.0E-04	0.746	30.26	0.573	9.0E-04	0.750	30.00	0.577
	19	7.0E-04	0.752	8.86	0.548	7.0E-04	0.750	8.82	0.546
	100	3.3E-02	0.752	5.75	0.443	3.4E-02	0.750	5.83	0.442
	101	1.4E-02	0.756	6.81	0.481	1.5E-02	0.750	6.95	0.486
4	4	1.9E-05	0.751	4.50	0.377	2.0E-05	0.750	4.50	0.377
	5	5.8E-04	0.761	7.49	0.514	6.0E-04	0.750	7.75	0.513
	6	**8.0E-04**	0.753	30.16	0.582	**9.0E-04**	0.750	30.00	0.577
	100	**3.9E-02**	0.771	5.62	0.441	**3.4E-02**	0.750	5.83	0.442
5	5	5.9E-04	0.748	7.76	0.512	6.0E-04	0.750	7.75	0.513
6	17	6.9E-04	0.753	8.39	0.530	7.0E-04	0.750	8.37	0.533
7	6	8.7E-04	0.750	29.74	0.582	9.0E-04	0.750	30.00	0.577
	66	9.3E-05	0.747	3.45	0.310	1.0E-04	0.750	3.54	0.317
8	30	5.1E-04	0.752	50.64	0.574	5.0E-04	0.750	50.00	0.577
	66	1.0E-04	0.735	3.41	0.318	1.0E-04	0.750	3.54	0.317
	77	4.9E-04	0.740	12.36	0.576	5.0E-04	0.750	12.50	0.577
9	7	1.4E-04	0.499	47.76	0.580	1.4E-04	0.500	46.67	0.577
	66	9.9E-05	0.486	3.41	0.316	1.0E-04	0.500	3.54	0.317
	95	1.4E-05	0.484	18.01	0.580	1.4E-05	0.500	17.50	0.577
10	8	8.0E-04	0.755	79.91	0.578	8.0E-04	0.750	80.00	0.577
	66	**1.1E-04**	0.754	3.52	0.317	**1.0E-04**	0.750	3.54	0.317
11	9	1.7E-05	0.752	11.08	0.575	1.7E-05	0.750	11.17	0.577
	63	6.5E-03	0.740	71.42	0.582	7.0E-03	0.750	70.00	0.577
12	10	4.1E-04	0.500	101.22	0.576	4.0E-04	0.500	100.00	0.577
	63	6.4E-03	0.474	**79.35**	0.578	7.0E-03	0.500	**70.00**	0.577
13	11	9.4E-03	0.751	6.93	0.484	9.5E-03	0.750	6.89	0.484
	90	2.0E-04	0.763	6.22	0.462	2.0E-04	0.750	6.32	0.462
14	12	1.5E-04	0.745	9.97	0.578	1.5E-04	0.750	10.00	0.577
15	13	5.4E-04	0.998	7.37	0.500	5.5E-04	1.000	7.42	0.502
16	14	5.0E-05	0.500	7.09	0.494	5.0E-05	0.500	7.07	0.490
17	15	4.1E-04	1.004	6.77	0.478	4.0E-04	1.000	6.67	0.476
18	38	3.0E-04	0.758	5.77	0.443	3.0E-04	0.750	5.77	0.440
19	16	9.8E-05	0.751	3.80	0.334	1.0E-04	0.750	3.78	0.333

*Table 4: Summary statistics of posterior vs prior **storage** distributions. Note that mean values are non log-transformed.*

Layer	Zone	Posterior Mean Ss	Posterior Stdev Log_{10} Ss	Posterior Mean Sy	Posterior Stdev Log_{10} Sy	Prior Mean Ss	Prior Stdev Log_{10} Ss	Prior Mean Sy	Prior Stdev Log_{10} Sy
1	1	1.0E-04	0.501	0.99%	0.246	1.00E-04	0.500	1.00%	0.250
	23	5.1E-04	0.491	2.00%	0.248	5.00E-04	0.500	2.00%	0.250
	24	5.1E-04	0.507	5.06%	0.253	5.00E-04	0.500	5.00%	0.250
	141	9.9E-04	0.500	9.97%	0.249	1.00E-03	0.500	10.00%	0.250
2	2	5.9E-06	0.499	1.11%	0.250	6.00E-06	0.500	1.10%	0.250
	24	5.0E-04	0.505	4.99%	0.248	5.00E-04	0.500	5.00%	0.250
	100	5.0E-04	0.496	1.99%	0.255	5.00E-04	0.500	2.00%	0.250
3	3	6.1E-06	0.499	1.10%	0.249	6.00E-06	0.500	1.10%	0.250
	24	4.9E-04	0.503	4.99%	0.251	5.00E-04	0.500	5.00%	0.250
	100	4.9E-04	0.500	2.00%	0.248	5.00E-04	0.500	2.00%	0.250
4	4	5.9E-06	0.502	1.11%	0.251	6.00E-06	0.500	1.10%	0.250
	24	4.9E-04	0.499	4.96%	0.250	5.00E-04	0.500	5.00%	0.250
5	5	6.1E-06	0.498	1.10%	0.250	6.00E-06	0.500	1.10%	0.250
6	6	6.1E-06	0.500	1.10%	0.249	6.00E-06	0.500	1.10%	0.250
7	6	6.1E-06	0.503	1.11%	0.249	6.00E-06	0.500	1.10%	0.250
8	6	5.9E-06	0.505	1.10%	0.252	6.00E-06	0.500	1.10%	0.250
9	7	7.1E-06	0.500	0.25%	0.249	7.00E-06	0.500	0.25%	0.250
10	8	7.0E-06	0.502	1.00%	0.249	7.00E-06	0.500	1.00%	0.250
11	9	6.0E-06	0.501	0.25%	0.250	6.00E-06	0.500	0.25%	0.250
12	10	2.5E-06	0.505	0.60%	0.250	2.50E-06	0.500	0.60%	0.250
13	11	4.9E-06	0.499	0.20%	0.251	5.00E-06	0.500	0.20%	0.250
14	12	4.0E-06	0.497	0.60%	0.250	4.00E-06	0.500	0.60%	0.250
15	13	7.0E-06	0.502	0.81%	0.252	7.00E-06	0.500	0.80%	0.250
16	17	4.1E-06	0.503	0.50%	0.250	4.00E-06	0.500	0.50%	0.250
17	17	4.0E-06	0.503	0.50%	0.250	4.00E-06	0.500	0.50%	0.250
18	36	2.5E-06	0.500	0.50%	0.249	2.50E-06	0.500	0.50%	0.250
19	19	2.5E-06	0.501	0.50%	0.247	2.50E-06	0.500	0.50%	0.250

*Table 5: Summary statistics of posterior vs prior **recharge and evapotranspiration** distributions. Note that mean values are non log-transformed. Stdev values are log-transformed for infiltration rate and ET rate only (log-uniform distributions).*

Parameter	Posterior Mean	Posterior Stdev	Prior Mean	Prior Stdev
Infiltration rate *(log-uniform)*	3.97%	0.174	4.00%	0.174
ET rate *(log-uniform)*	0.002243m/day	0.202	0.002236m/day	0.202
ET extinction depth *(uniform)*	4.98m	1.729	5.00m	1.732

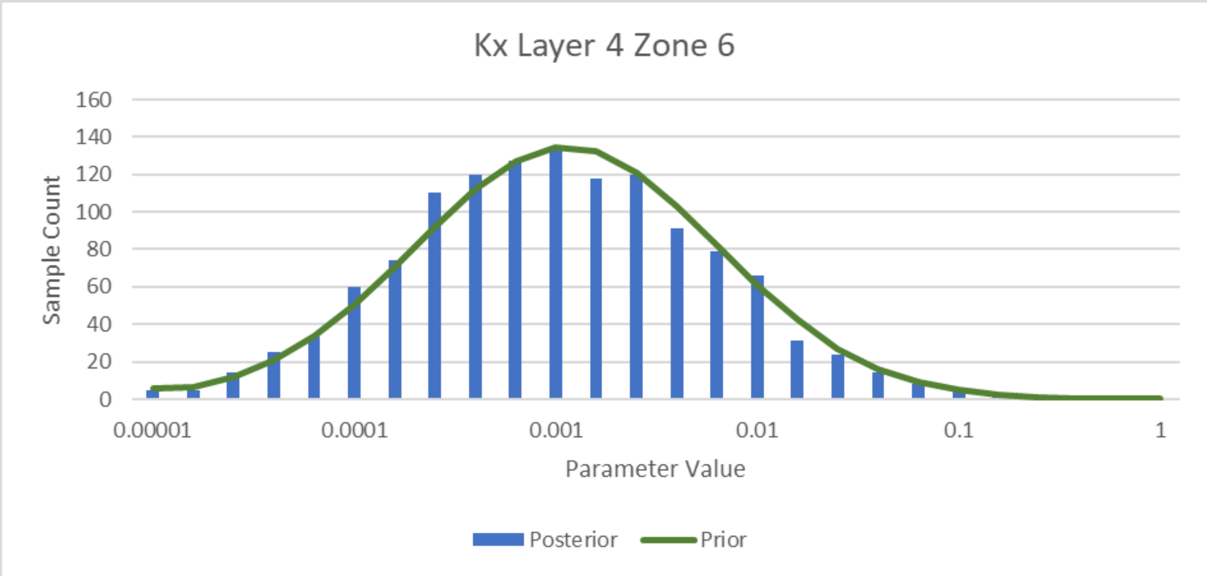

Figure 2: Posterior vs prior distribution for Kx in layer 4, zone 6 (Mid-lower Bulgo sandstone unit). Sample count includes all pilot points in the zone over all accepted random realisations.

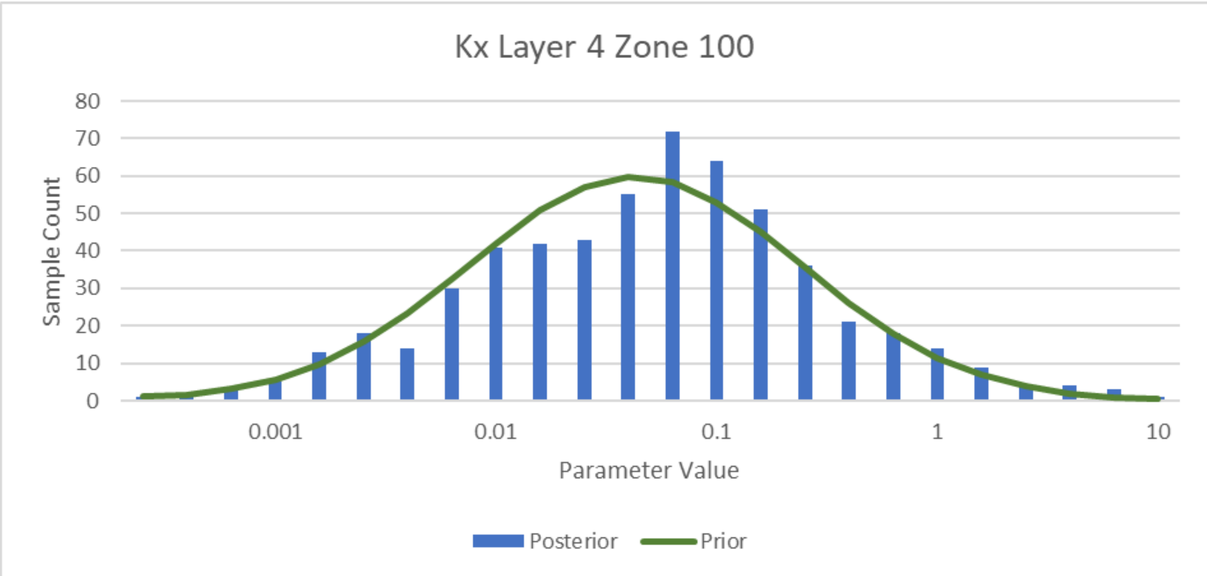

Figure 3: Posterior vs prior distribution for Kx in layer 4, zone 100 (Ridge unit). Sample count includes all pilot points in the zone over all accepted random realisations.

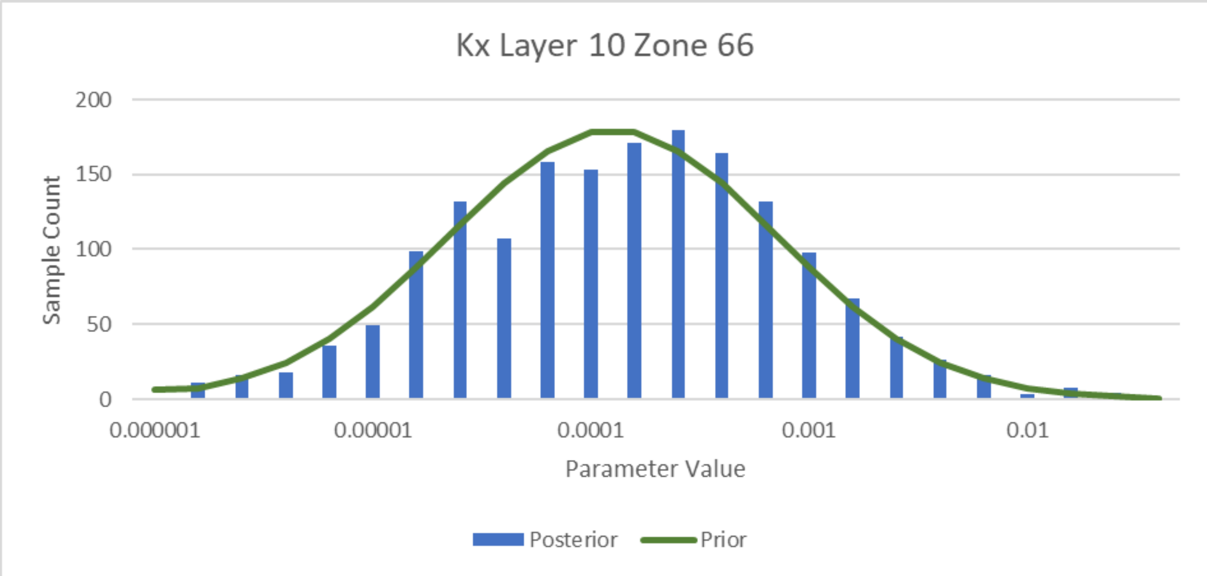

Figure 4: Posterior vs prior distribution for Kx in layer 10, zone 66 (Intrusion unit).
Sample count includes all pilot points in the zone over all accepted random realisations.

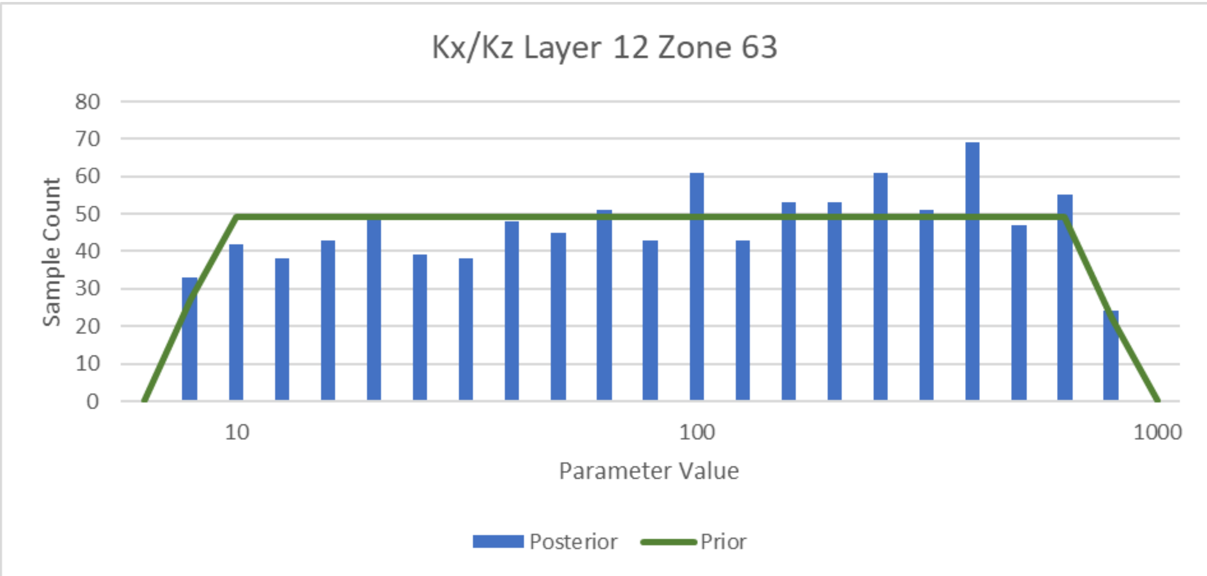

Figure 5: Posterior vs prior distribution for Kx in layer 12, zone 63 (Intrusion unit).
Sample count includes all pilot points in the zone over all accepted random realisations.

4. Results

Statistics on key predictive outputs were computed from the results of the 141 accepted model runs and are presented in this section. Percentile results were calculated from the Monte Carlo outputs strictly on a conservative “round to higher value” basis, and are represented as “probabilities of exceedance” in five categories: “very likely (90%) - **green**, “likely (67%)” - **light yellow-green**, “about as likely as not (50%)” - **black**, “unlikely (33%)” - **orange**, and “very unlikely (10%)” - **red**.

To clarify, a “very unlikely (10%)” probability of exceedance value of X for a metric should be interpreted to mean “10% of realisations from the set of accepted realisations resulted in a value for this metric larger than X”.

Drawdown, additional mine inflow and streamflow impact results were all computed on the difference between the *impacted* and *baseline* scenarios. The impacted scenario simulates all mining, including the proposed new workings. The baseline scenario simulates all prior and continuing mining except the proposed new workings, i.e. under the assumption that all Russell Vale mining stops after the cessation of Longwall 6 mining.

a. Key predictive outputs

Table 6 presents probabilities of exceedance for mine inflows and streamflow impacts. The distribution of model calibration error is also shown for reference. All flow results presented here are the maximum flow over time.

Note that each row of the table represents a different distribution of the Monte Carlo run results, wherein each percentile result is representative of a different subset of runs. As such, the results from different rows should be taken independently and may not be directly combined. For example, the set of runs for which calibration error was at most 3.91% does not necessarily correlate with the set of runs for which there was a peak total mine inflow rate of 447.3 ML/year, despite these values being presented in the same column of the table.

Table 6: Probability of exceedance of mine inflows and streamflow impacts, and the calibration error distribution.

	Very likely (90%)	Likely (67%)	About as likely as not (50%)	Unlikely (33%)	Very unlikely (10%)
Peak total mine inflow (ML/year**)**	447.3	471.6	487.2	507.7	543.8
Peak additional mine inflow due to proposed workings (ML/year**)**	261.9	281.3	293.7	305.7	325.6
Additional baseflow impact to Cataract river (ML/year**)**	0.6	0.8	1.0	1.2	1.6
Additional baseflow impact to Cataract creek (ML/year**)**	1.3	1.8	2.1	2.6	3.4
Additional baseflow impact to Bellambi creek (ML/year**)**	0.4	0.6	0.7	0.8	1.0
Calibration error (SRMS**)**	3.91%	4.37%	4.59%	4.74%	4.89%

The predicted impact on Cataract Reservoir is less than 1 ML/year for all statistics.

b. Time series flows: total mine inflow

Figure 6 shows total mine inflow over time to Russell Vale workings at 10%, 33%, 50%, 67% and 90% probabilities of exceedance. The time-series inflows are time-weighted averaged over 6-monthly periods.

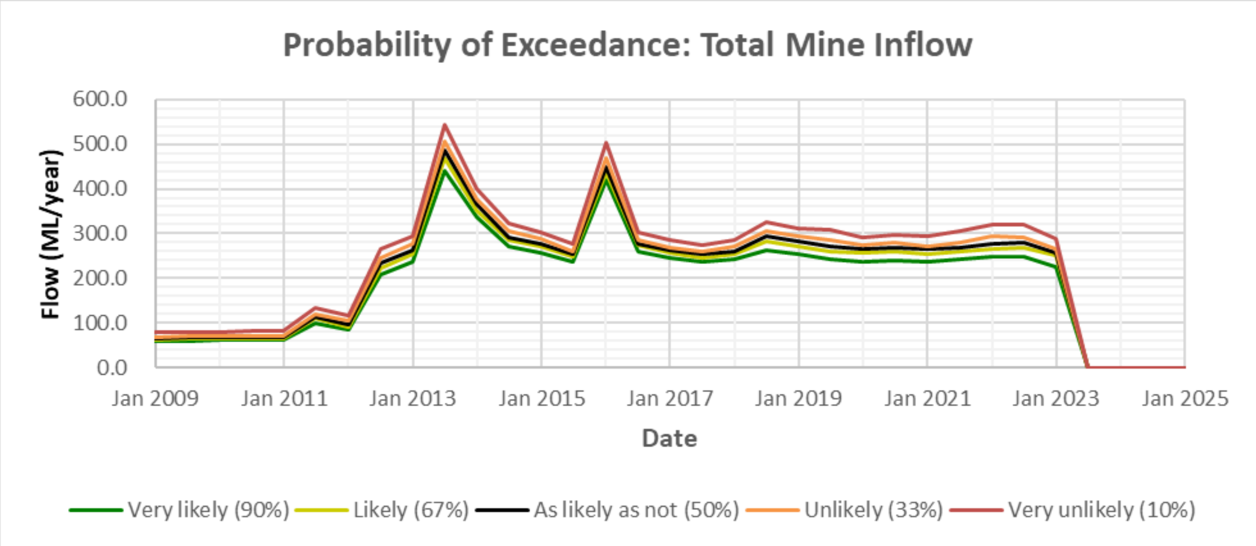

Figure 6: Time-series total mine inflow.

c. Time series flows: additional mine inflow

Figure 7 shows additional mine inflow over time, due solely to the proposed new workings, at 10%, 33%, 50%, 67% and 90% probabilities of exceedance. The time-series inflows are time-weighted averaged over 6-monthly periods.

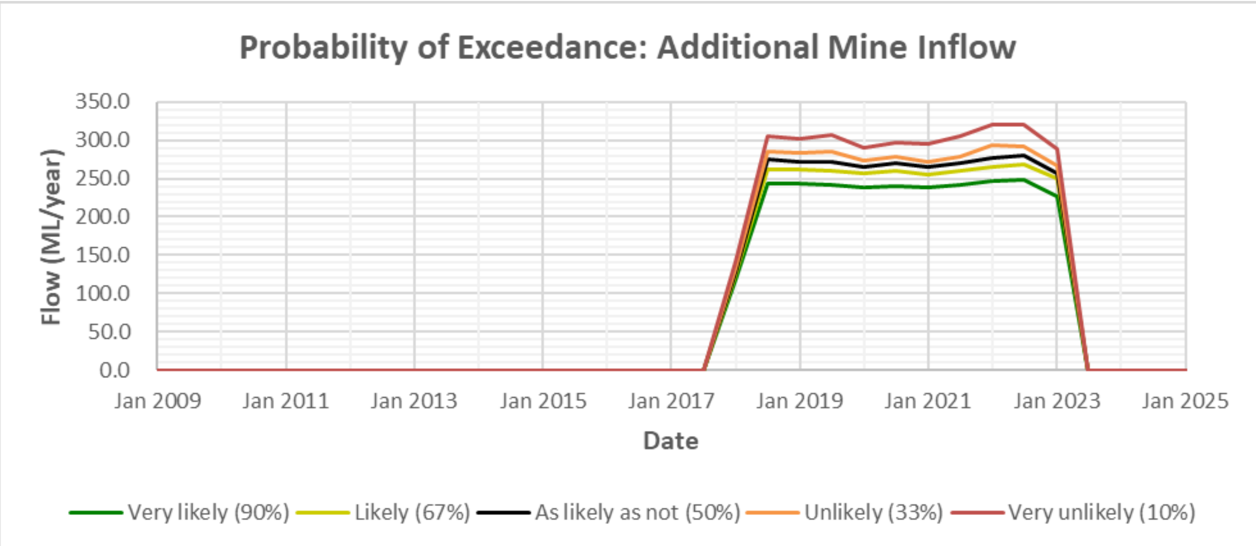

Figure 7: Time-series additional mine inflow due to proposed new workings.

d. Time series flows: additional baseflow impact to Cataract River

Figure 8 shows additional baseflow impact over time to Cataract River, due solely to the proposed new workings, at 10%, 33%, 50%, 67% and 90% probabilities of exceedance.

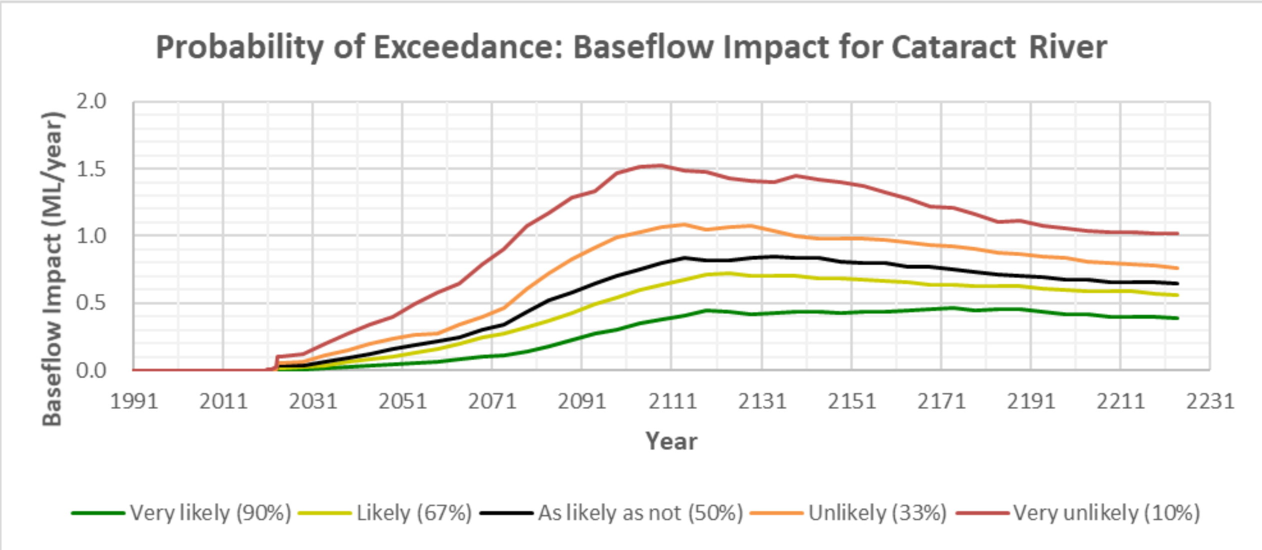

Figure 8: Time-series additional baseflow impact to Cataract River.

e. Time series flows: additional baseflow impact to Cataract Creek

Figure 9 shows additional baseflow impact over time to Cataract Creek, due solely to the proposed new workings, at 10%, 33%, 50%, 67% and 90% probabilities of exceedance.

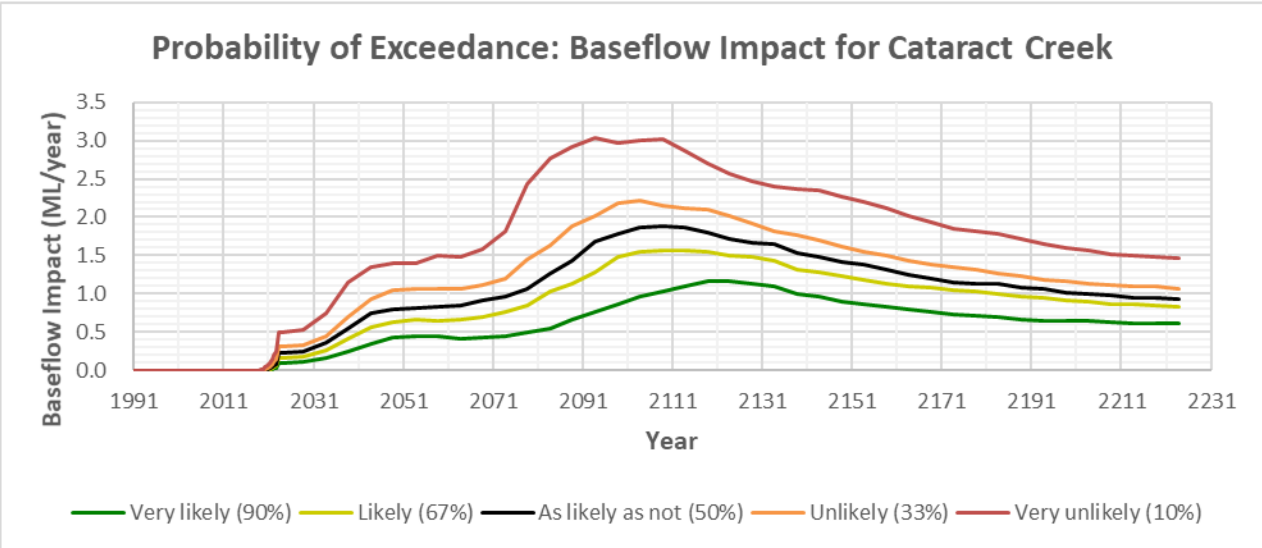

Figure 9: Time-series additional baseflow impact to Cataract Creek.

f. Time series flows: additional baseflow impact to Bellambi Creek

Figure 10 shows additional baseflow impact over time to Bellambi Creek, due solely to the proposed new workings, at 10%, 33%, 50%, 67% and 90% probabilities of exceedance.

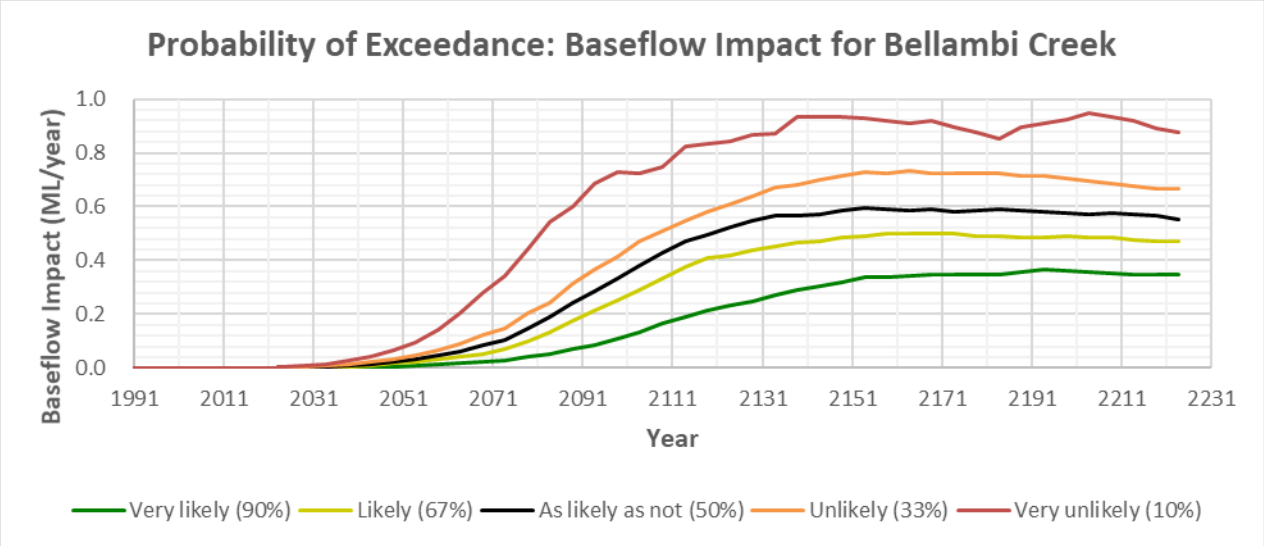

Figure 10: Time-series additional baseflow impact to Bellambi Creek.

g. Spatial drawdown: probability of exceedance

Spatial drawdown statistics computed on a cell-by-cell basis are contoured on "probability of exceedance" basis in

Figure 11 and

Figure 12, for the watertable and layer 17 (Wongawilli seam), respectively. The value of each contour represents the probability of drawdown exceeding 2m inside the area of the contour at any time during mine operation or post-closure. Contour lines are presented at 10%, 33%, 50%, 67% and 90% probabilities.

Note that the baseline model used for additional drawdown calculations makes the assumption that if the proposed new workings are not approved, dewatering would cease at Russell Vale West at the time that the proposed workings would have commenced. This would allow groundwater levels to commence recovery. In the impacted case, in contrast, the dewatering at Russell Vale West is assumed to continue. As such, the additional drawdown to Layer 17 shown in

Figure 12 includes a component attributable to Russell Vale West dewatering, in addition to the proposed new workings.

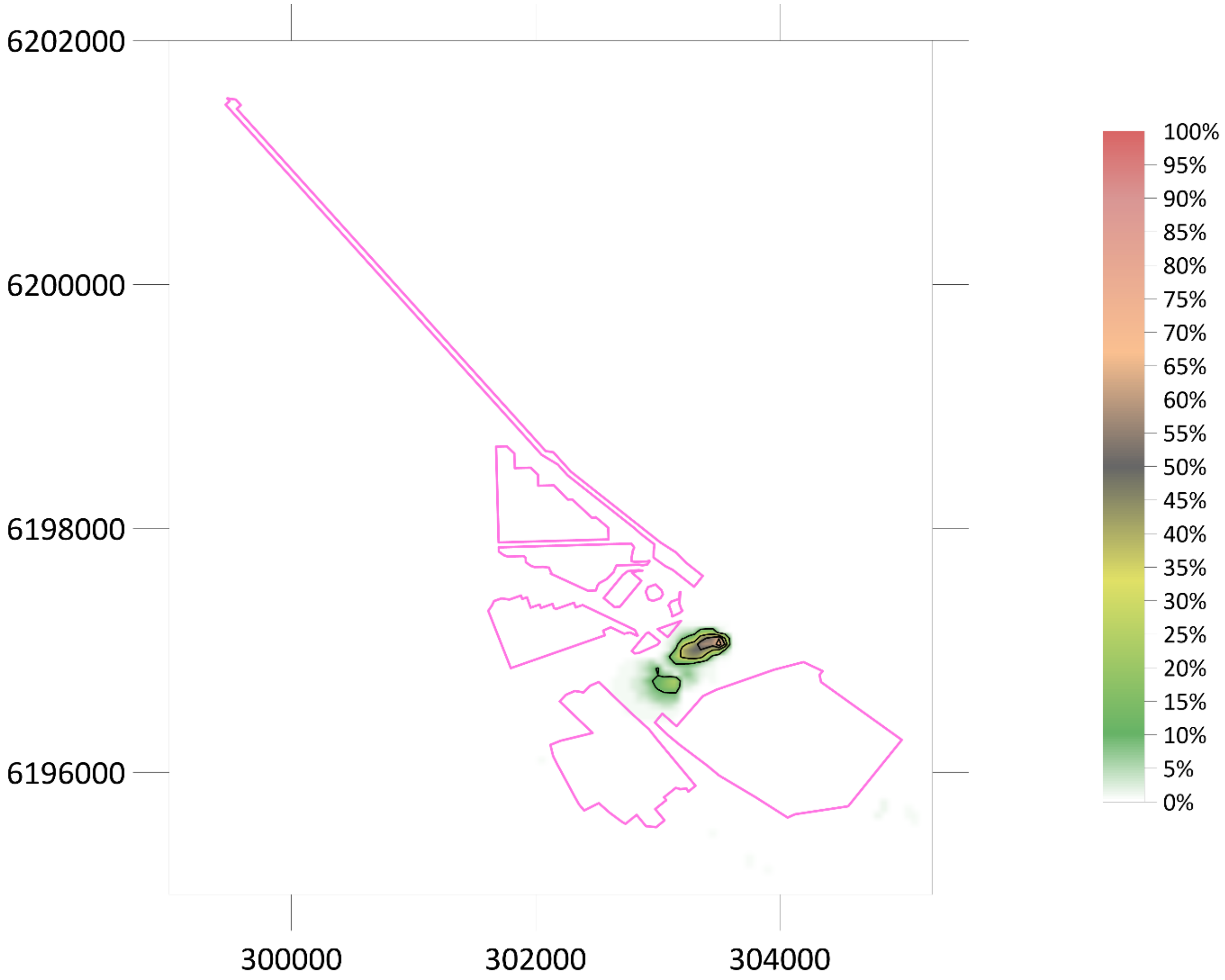

*Figure 11: Probability of exceedance of 2m additional drawdown to the **watertable**.*

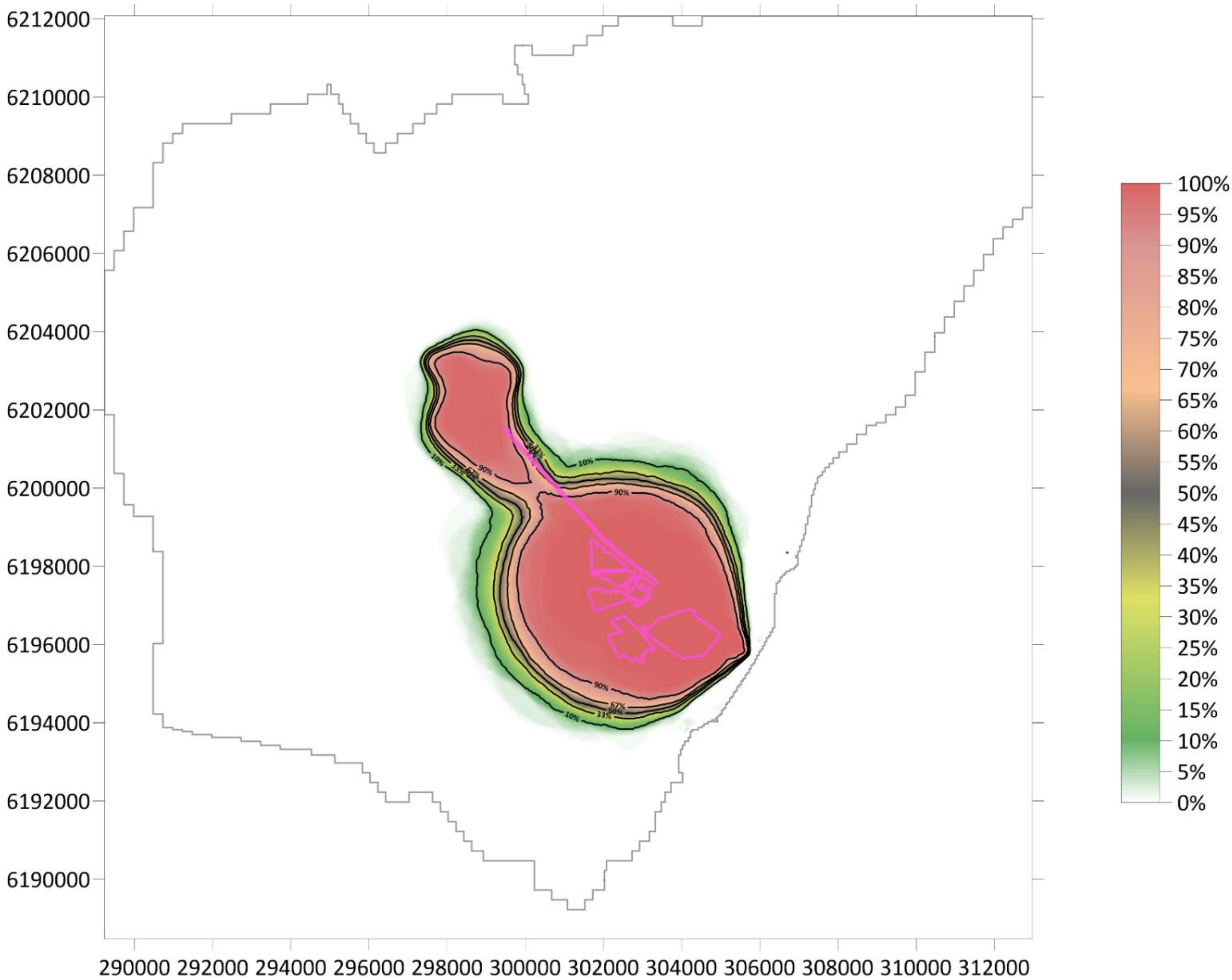

Figure 12: Probability of exceedance of 2m additional drawdown in layer 17

h. Spatial drawdown: maximum drawdown at percentiles

Figure 13 through

Figure 18 show contours of maximum drawdown (over all simulation time) at 10th, 50th and 90th percentiles for the watertable and layer 17 (Wongawilli seam).

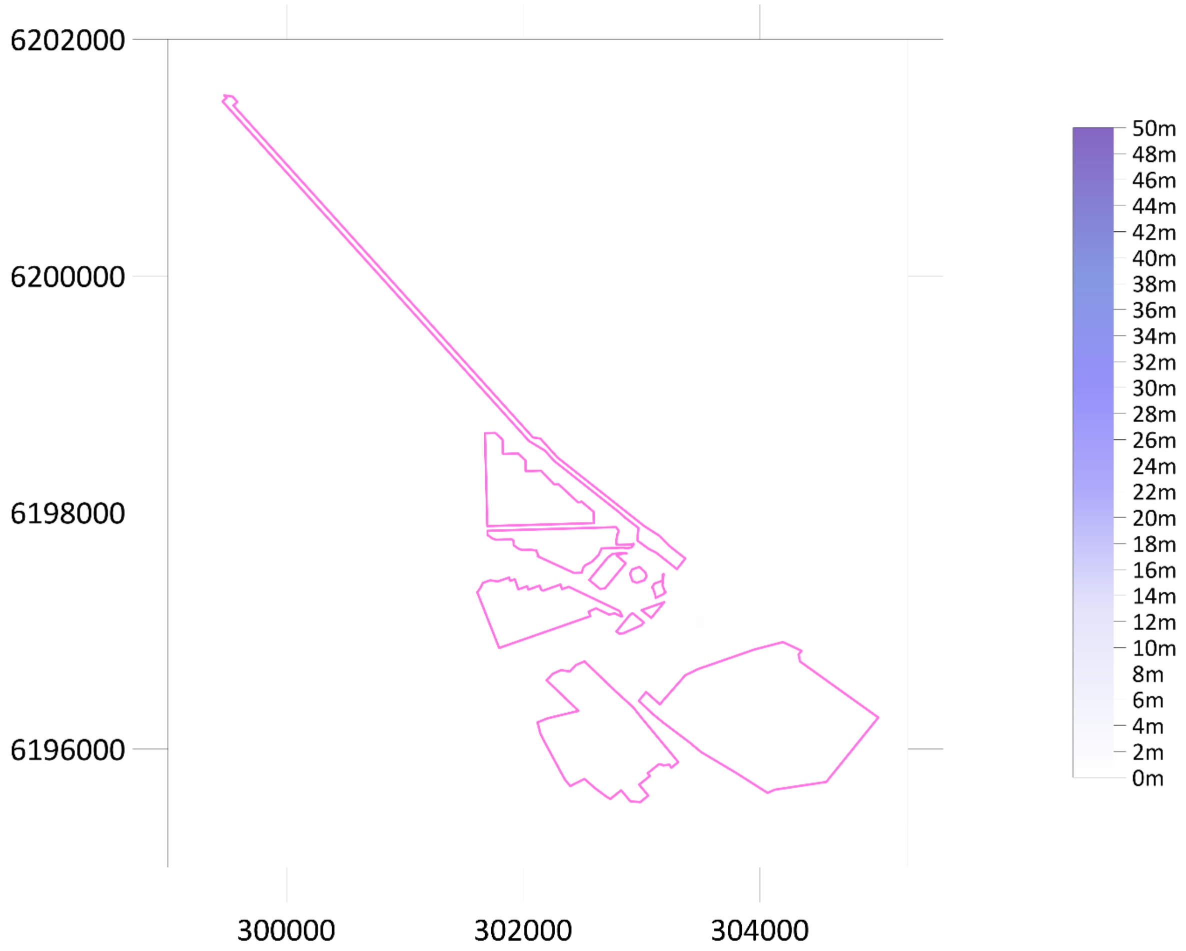

*Figure 13: **10th percentile** maximum additional drawdown (over all time) to the **watertable**. Light grey contours are at 2m intervals and black contours are at 10m intervals.*

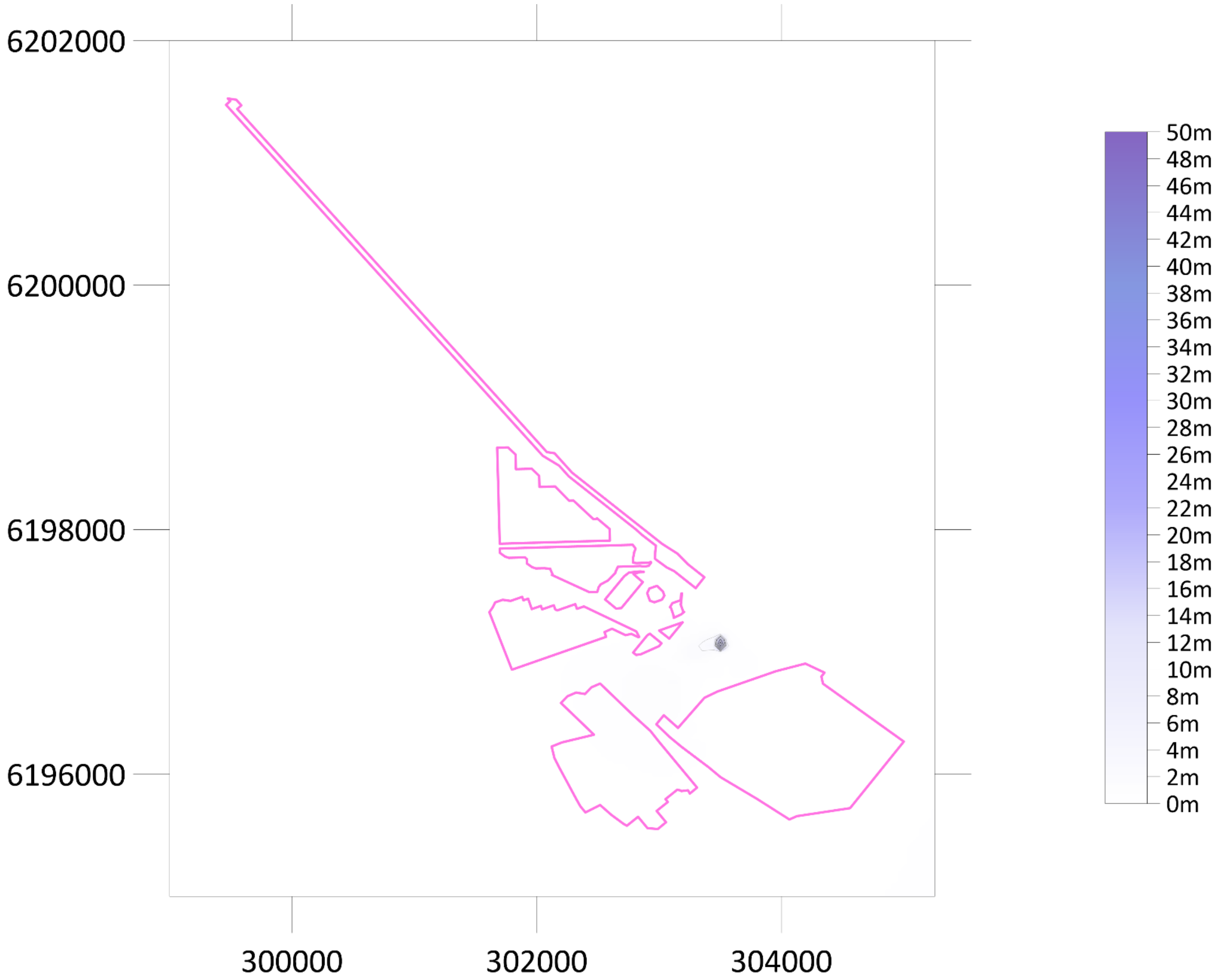

Figure 14: 50th percentile maximum additional drawdown (over all time) to the watertable. Light grey contours are at 2m intervals and black contours are at 10m intervals.

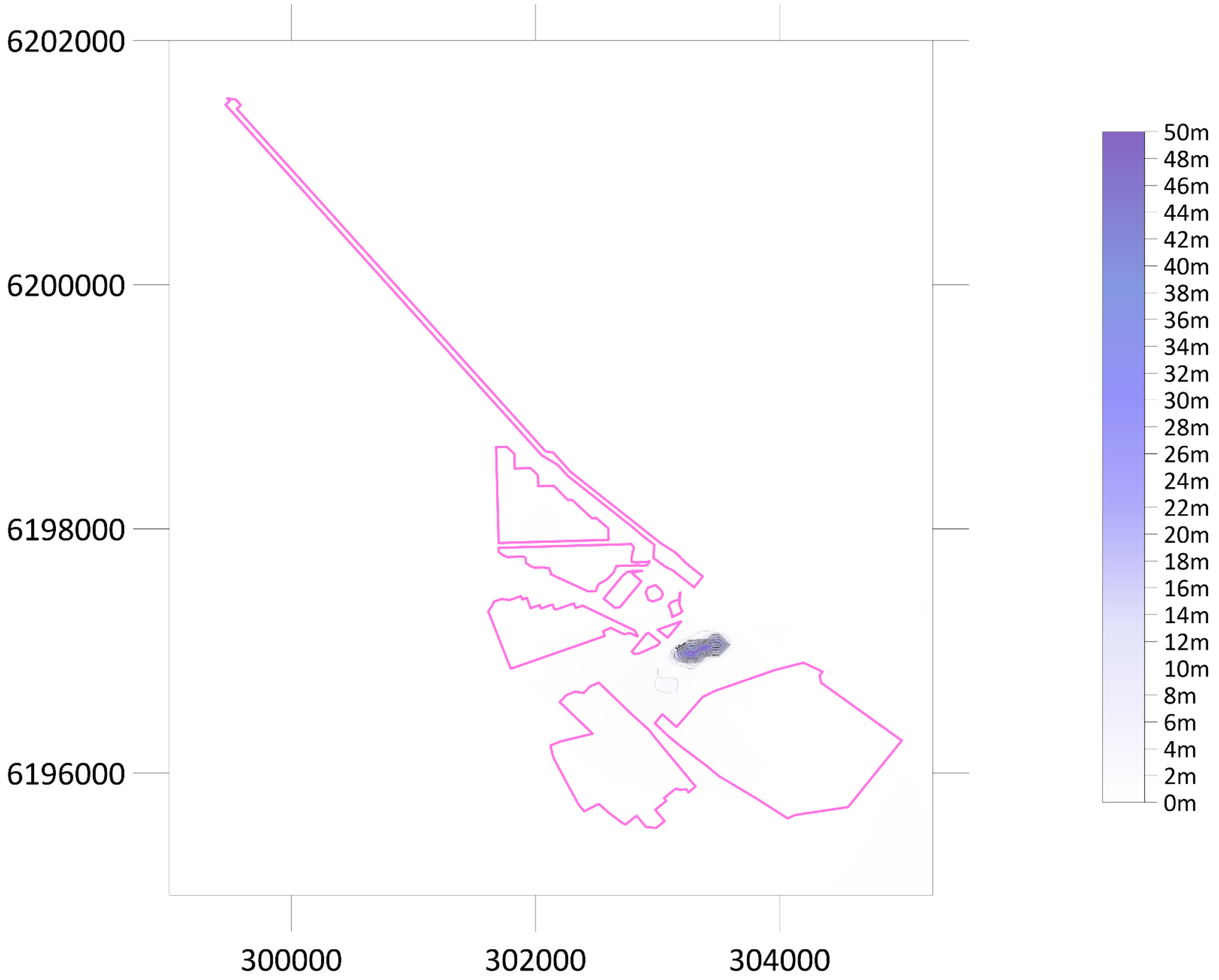

*Figure 15: **90th percentile** maximum additional drawdown (over all time) to the **watertable**. Light grey contours are at 2m intervals and black contours are at 10m intervals.*

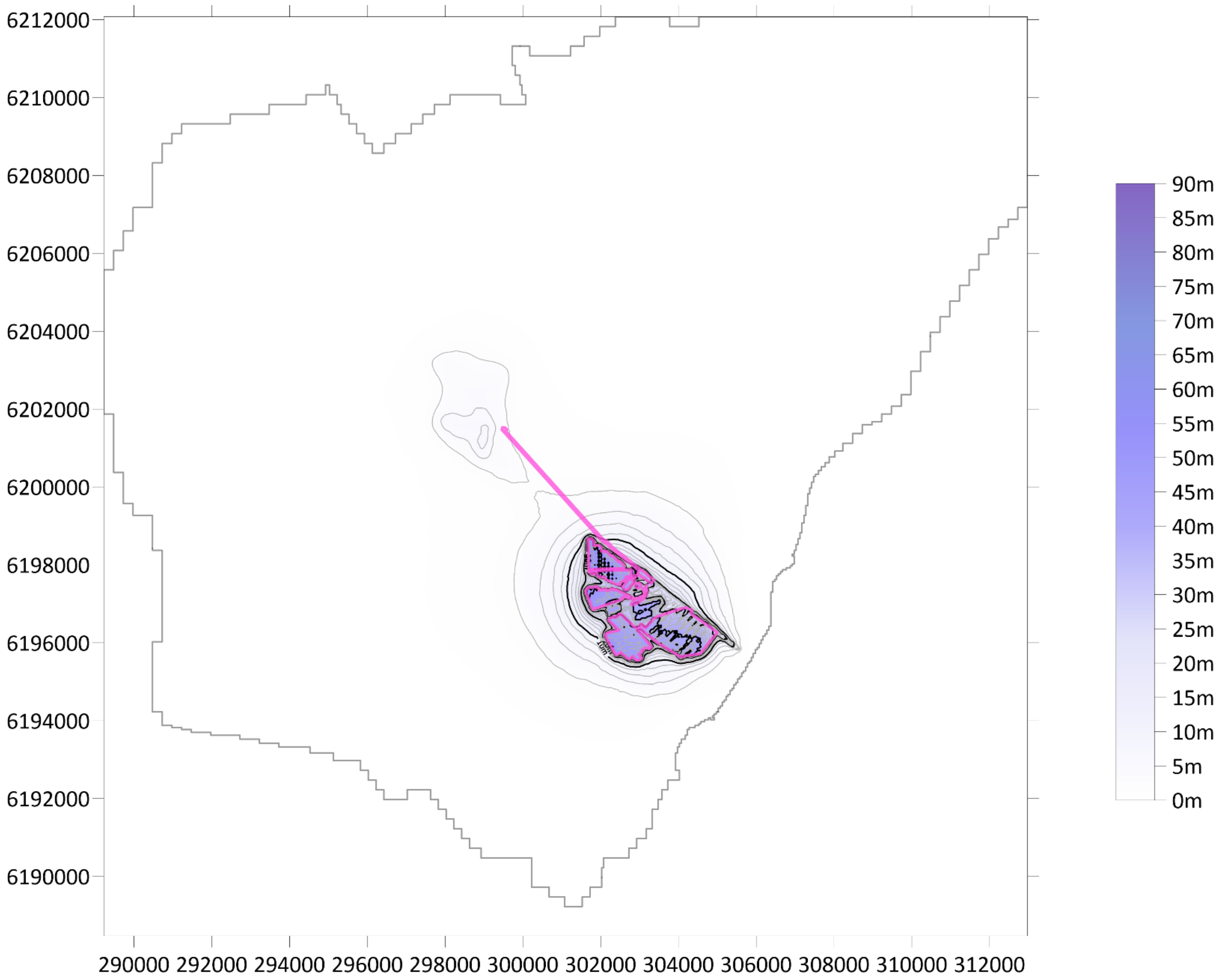

*Figure 16: **10th percentile** maximum additional drawdown (over all time) in **layer 17**. Light grey contours are at 2m intervals and black contours are at 10m intervals.*

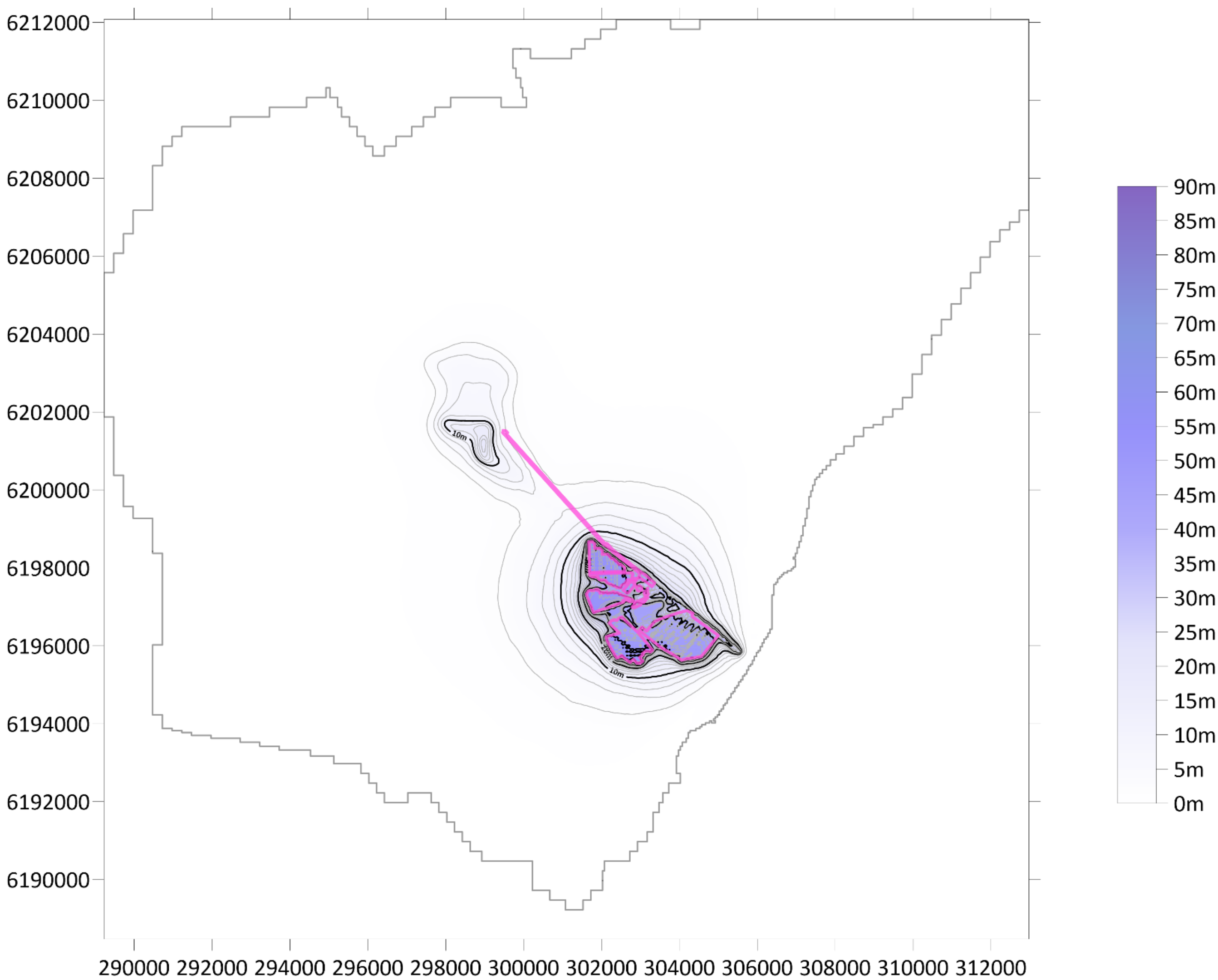

*Figure 17: **50th percentile** maximum additional drawdown (over all time) in **layer 17**. Light grey contours are at 2m intervals and black contours are at 10m intervals.*

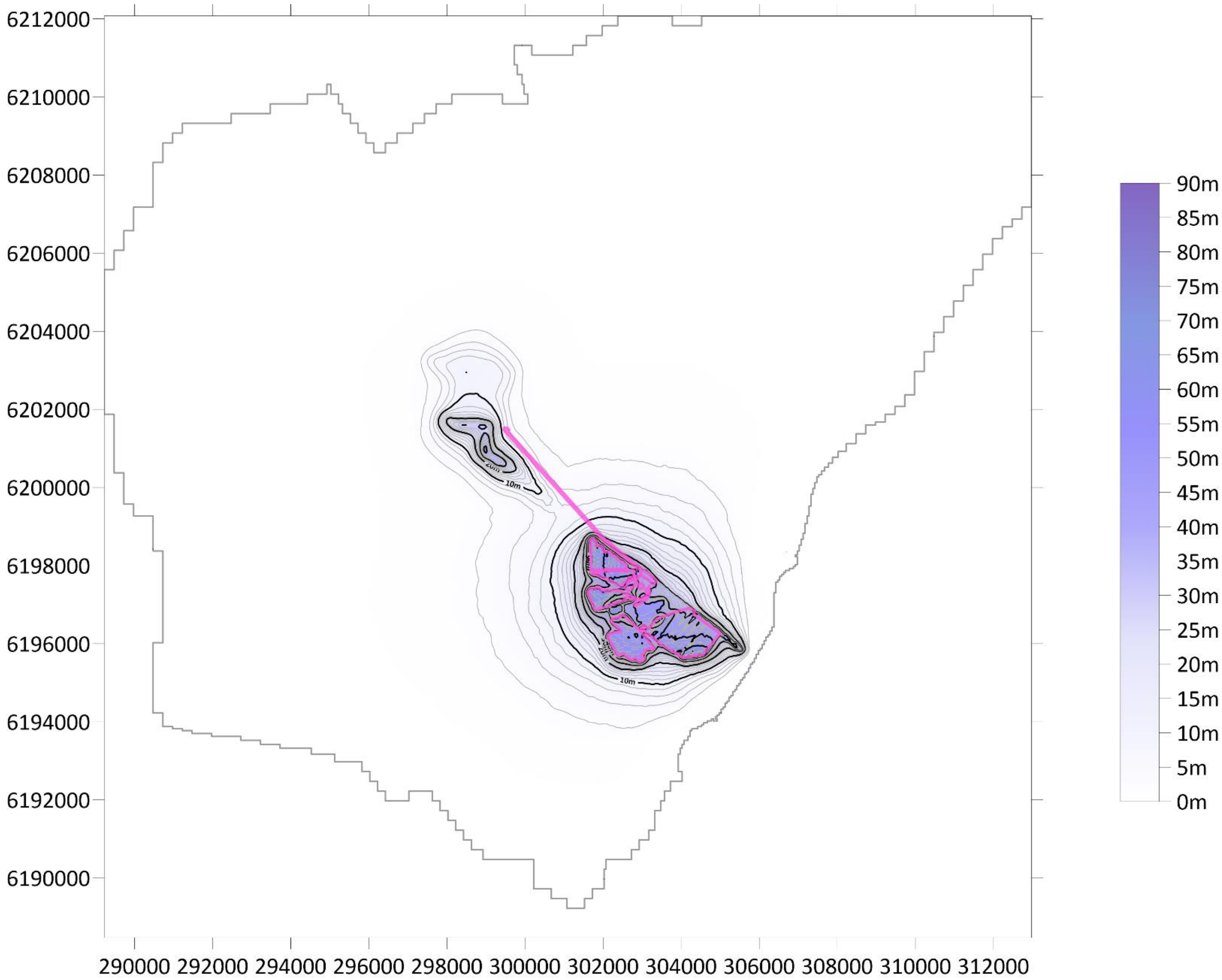

Figure 18: ***90th percentile*** *maximum additional drawdown (over all time) in* ***layer 17****. Light grey contours are at 2m intervals and black contours are at 10m intervals.*

5. Monte Carlo convergence

When conducting stochastic modelling, it is important to ensure that enough realisations are evaluated such that the results reported are accurate – that is, that the stochastic process has *converged* to within an acceptable probabilistic margin of error.

To gain confidence that the reported results were sufficiently close to their correct values, 99.7% confidence intervals were computed for the 10%, 33%, 50%, 67% and 90% probabilities of exceedance of selected aggregate metrics.

Confidence interval bounds for the $(100 \times p)^{\text{th}}$ percentile may be approximated by the formula $p \pm \sqrt{p(1-p)c^2/n}$, where c is the desired confidence in standard deviations of the normal distribution – $c = 3$ for 99.7% confidence – and n is the number of runs (see e.g. *Mood et al., 1974* for derivations of confidence interval bounds). For example, it may be said with 99.7% confidence after 312 successful runs that the true 90$^{\text{th}}$ percentile value lies between the 84.9$^{\text{th}}$ and 95.1$^{\text{st}}$ percentile estimates ($= 100 \times \left(0.9 \pm \sqrt{0.9 \times 0.1 \times 9/312}\right)$).

In this section, charts are presented illustrating the convergence of selected key metrics to illustrate the convergence of the Monte Carlo process. Two types of chart are presented. The first shows the values of the 10$^{\text{th}}$, 33$^{\text{rd}}$, 50$^{\text{th}}$, 67$^{\text{th}}$ and 90$^{\text{th}}$ percentiles as they evolve with the number of runs evaluated. The second shows the 10$^{\text{th}}$, 50$^{\text{th}}$ and 90$^{\text{th}}$ percentile values surrounded by their computed 99.7% confidence intervals, also as they evolve with respect to the number of runs evaluated. Note that 33$^{\text{rd}}$ and 67$^{\text{th}}$ percentile confidence intervals have been omitted from these charts to ease readability; the intervals in these cases were similar or narrower in width than those of the 10$^{\text{th}}$, 50$^{\text{th}}$ and 90$^{\text{th}}$ percentiles shown.

The colour coding of the convergence charts follows the same categorisation as in the other charts presented: “very likely (90%) - **green**, “likely (67%)” - **light yellow-green**, “about as likely as not (50%)” - **black**, “unlikely (33%)” - **orange**, and “very unlikely (10%)” - **red**. Solid lines in the convergence charts represent the actual sampled percentile values, and dashed lines represent the 99.7% confidence intervals of the percentile corresponding to their colour.

a. Peak total mine inflow

Figure 19 and **Figure 20** illustrate the change in percentiles of peak total mine inflow with respect to the number of Monte Carlo realisations evaluated. The 99.7% confidence intervals indicate that the reported values are within 20.3 ML/year of the true values with high probability; that is, the error band is about 5%.

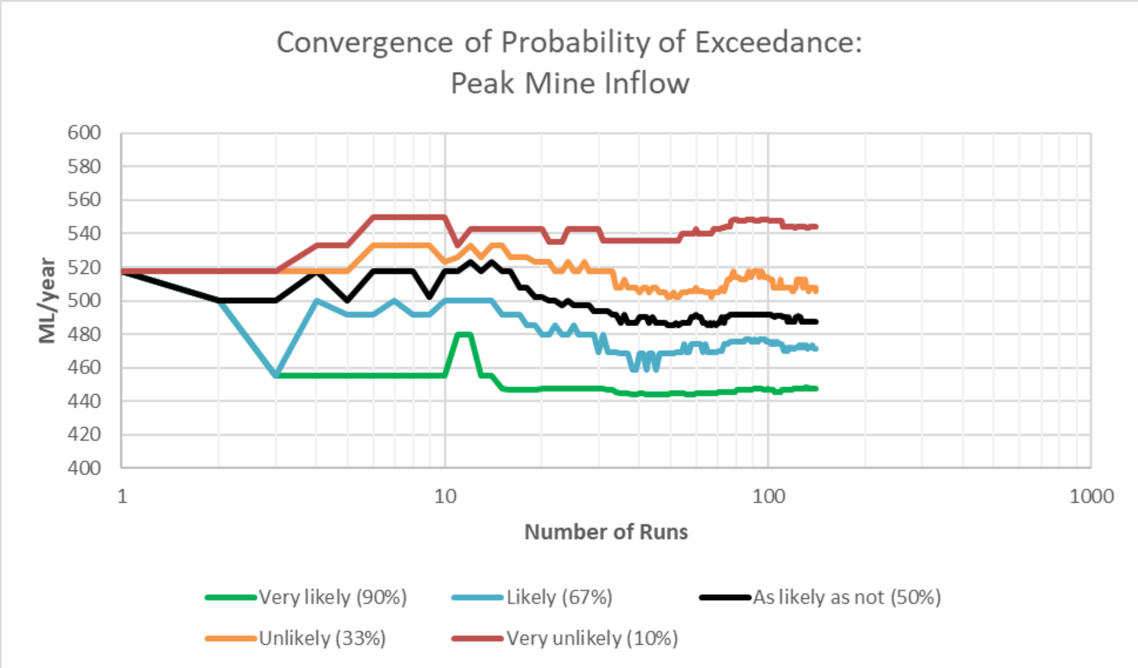

Figure 19: Change in peak mine inflow percentiles with number of Monte Carlo runs.

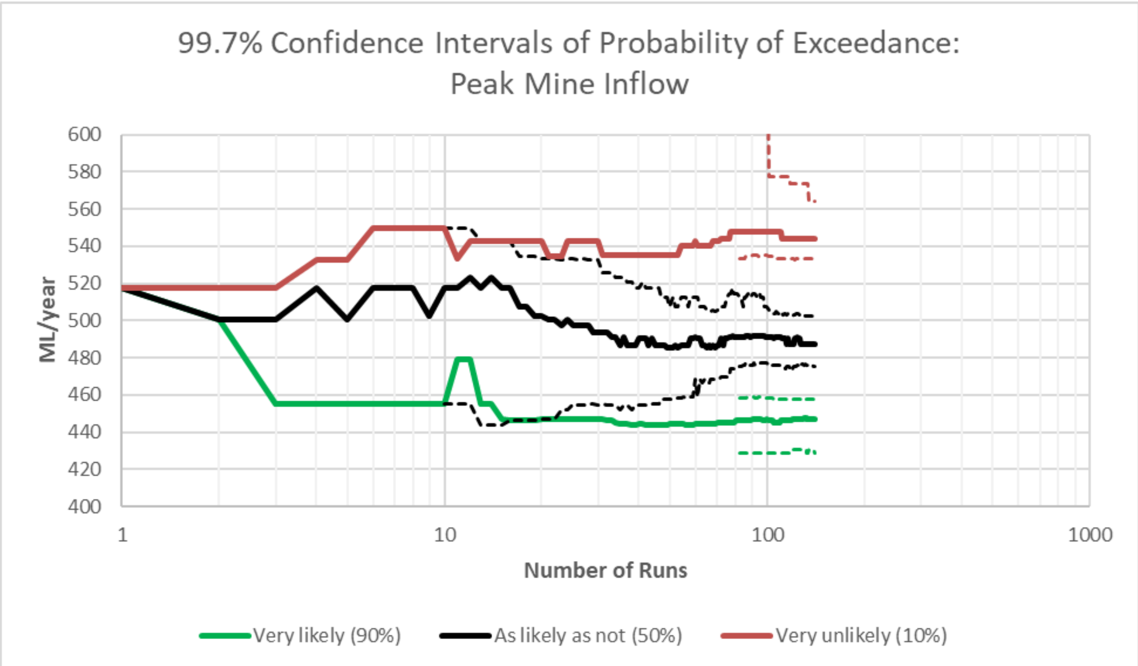

Figure 20: 99.7% confidence intervals for peak mine inflow percentiles.

b. Additional mine inflow due to proposed workings

Figure 21 and **Figure 22** illustrate the change in percentiles of additional mine inflow with respect to the number of Monte Carlo realisations evaluated. The 99.7% confidence intervals indicate that the reported values are within 25.8 ML/year of the true values with high probability.

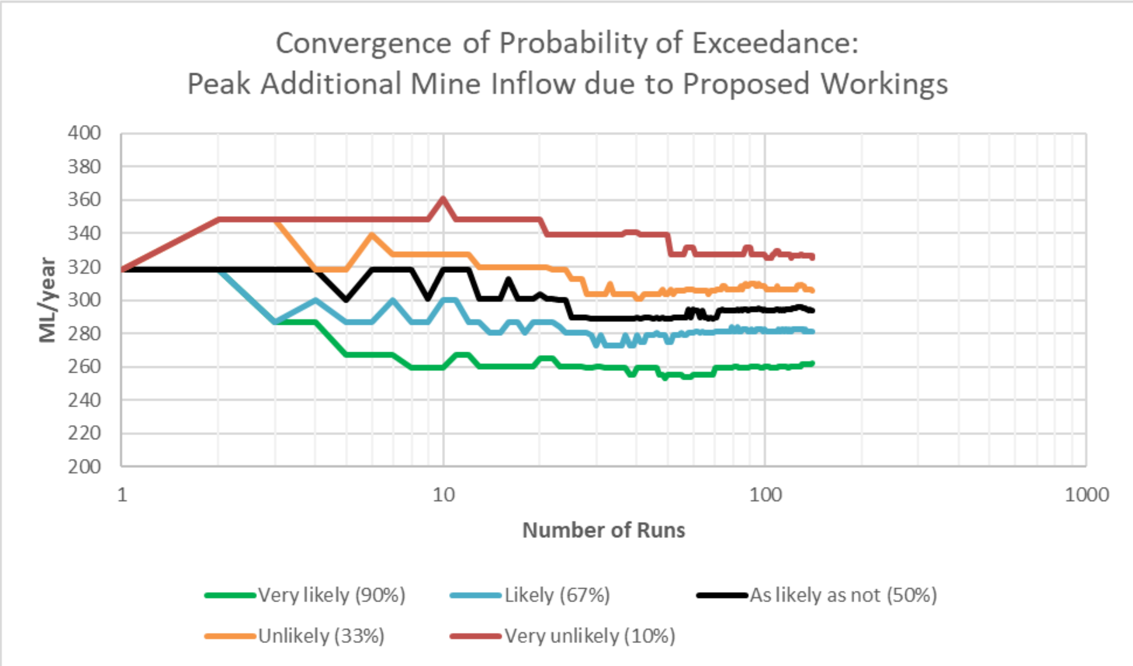

Figure 21: Change in additional mine inflow percentiles with number of Monte Carlo runs.

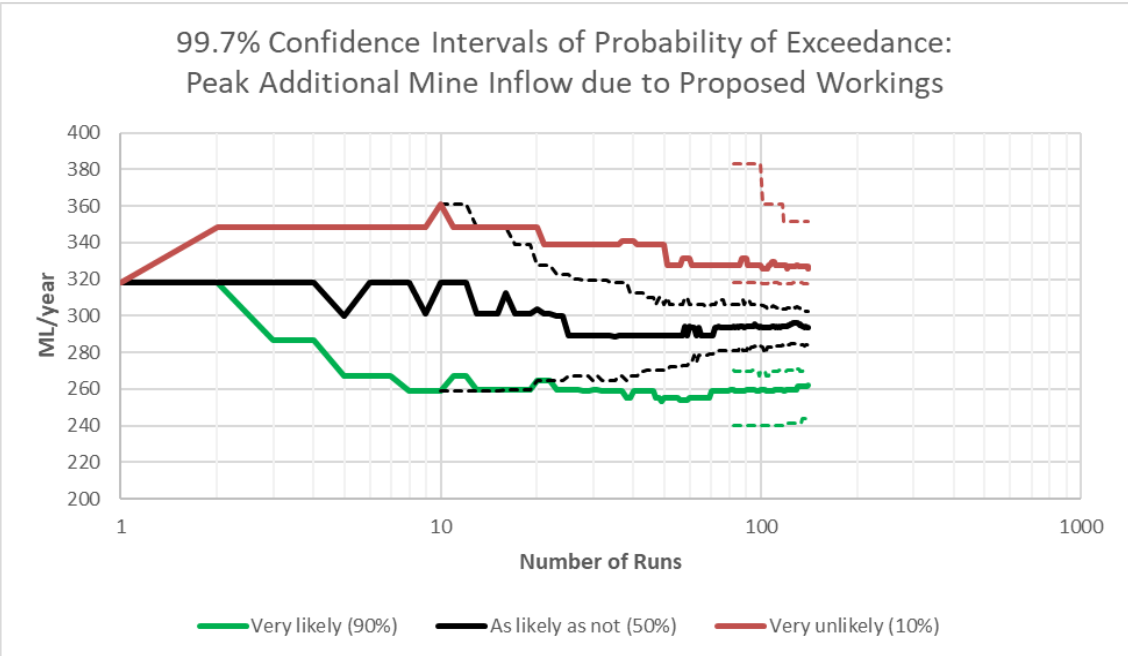

Figure 22: 99.7% confidence intervals for additional mine inflow percentiles.

c. Additional baseflow impact to Cataract River

Figure 23 and **Figure 24** illustrate the change in percentiles of additional baseflow impact to Cataract River with respect to the number of Monte Carlo realisations evaluated. The 99.7% confidence intervals indicate that the reported values are within 0.34 ML/year of the true values with high probability.

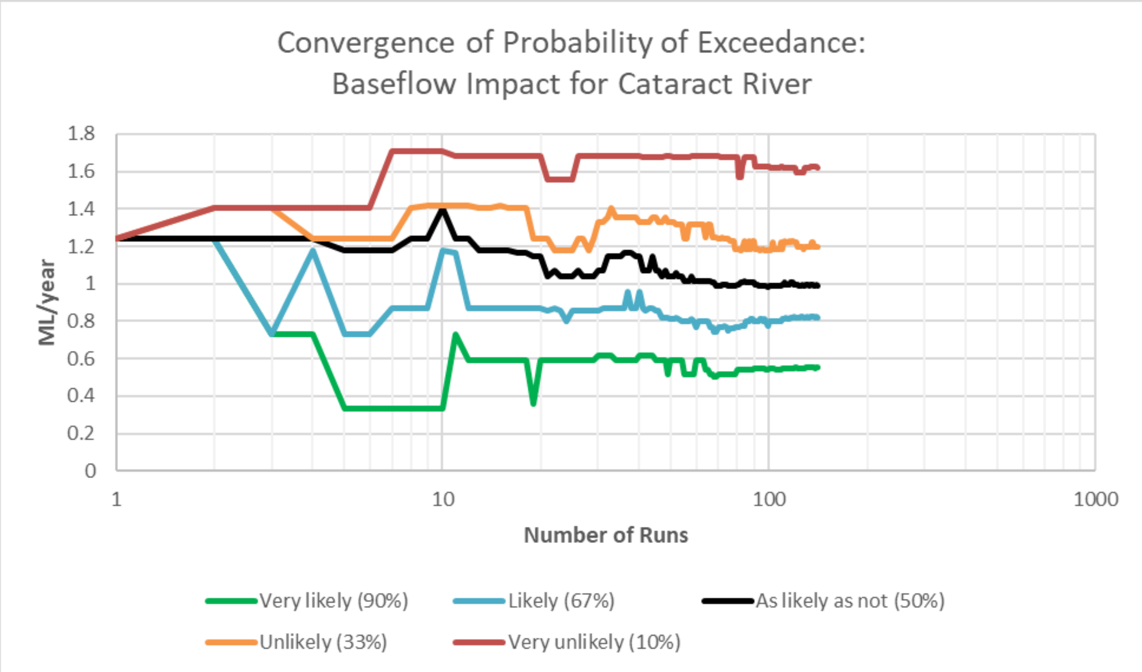

Figure 23: Change in additional baseflow impact to Cataract River percentiles with number of Monte Carlo runs.

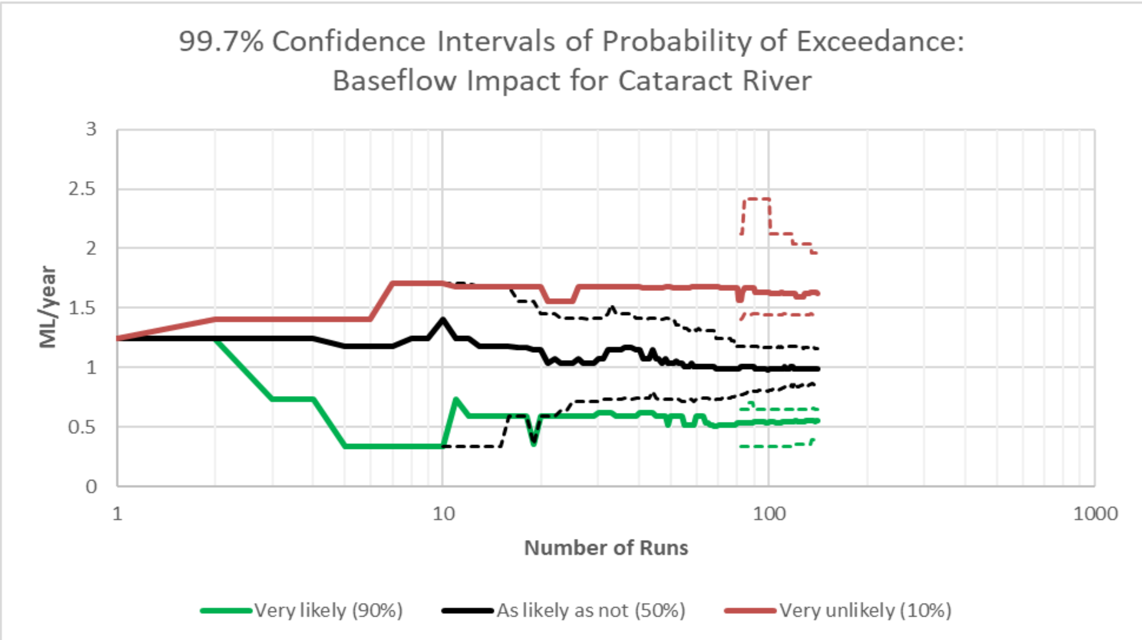

Figure 24: 99.7% confidence intervals for additional baseflow impact to Cataract River percentiles.

d. Additional baseflow impact to Cataract Creek

Figure 25 and **Figure 26** illustrate the change in percentiles of additional baseflow impact to Cataract Creek with respect to the number of Monte Carlo realisations evaluated. The 99.7% confidence intervals indicate that the reported values are within 0.98 ML/year of the true values with high probability.

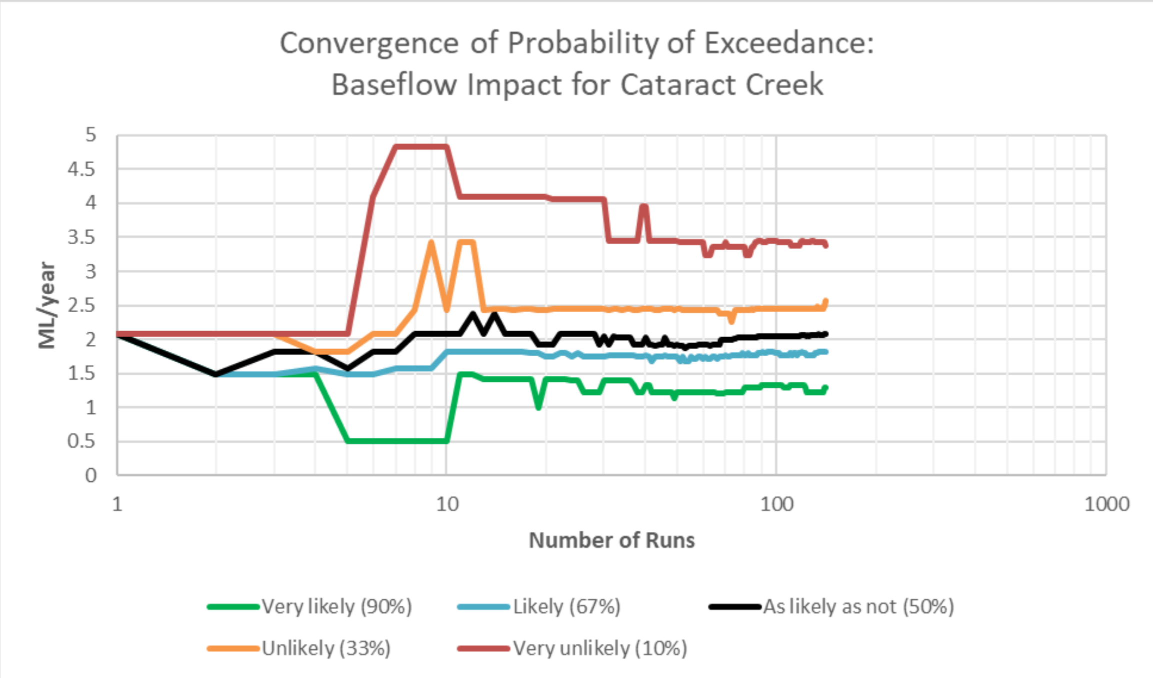

Figure 25: Change in additional baseflow impact to Cataract Creek percentiles with number of Monte Carlo runs.

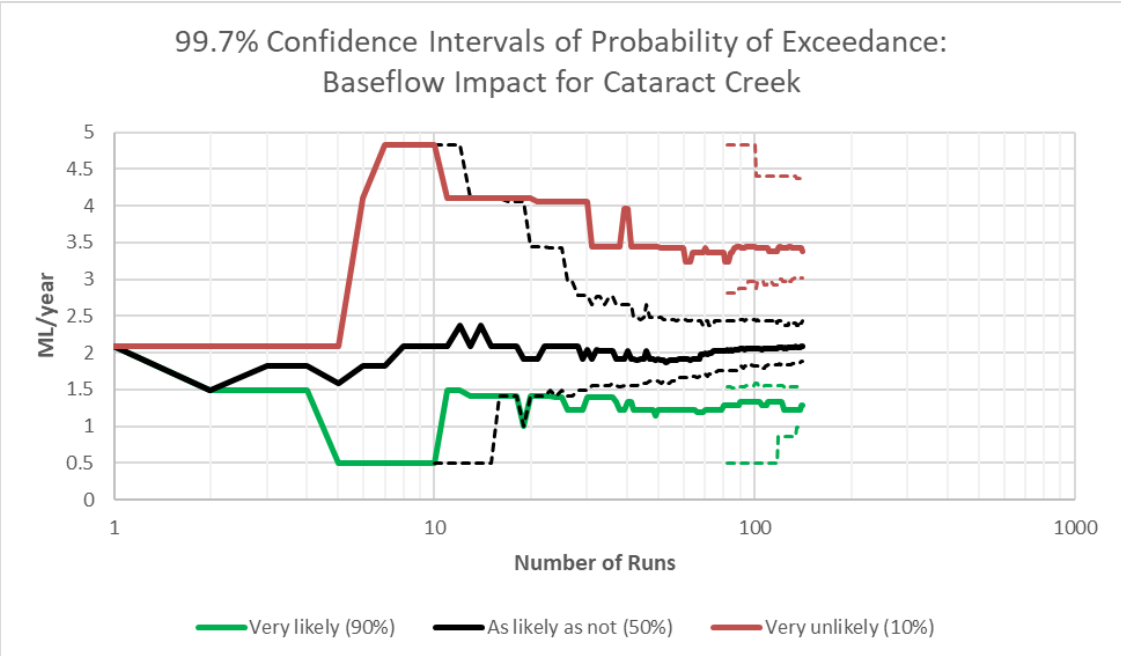

Figure 26: 99.7% confidence intervals for additional baseflow impact to Cataract Creek percentiles.

e. Additional baseflow impact to Bellambi Creek

Figure 27 and **Figure 28** illustrate the change in percentiles of additional baseflow impact to Bellambi Creek with respect to the number of Monte Carlo realisations evaluated. The 99.7% confidence intervals indicate that the reported values are within 0.35 ML/year of the true values with high probability.

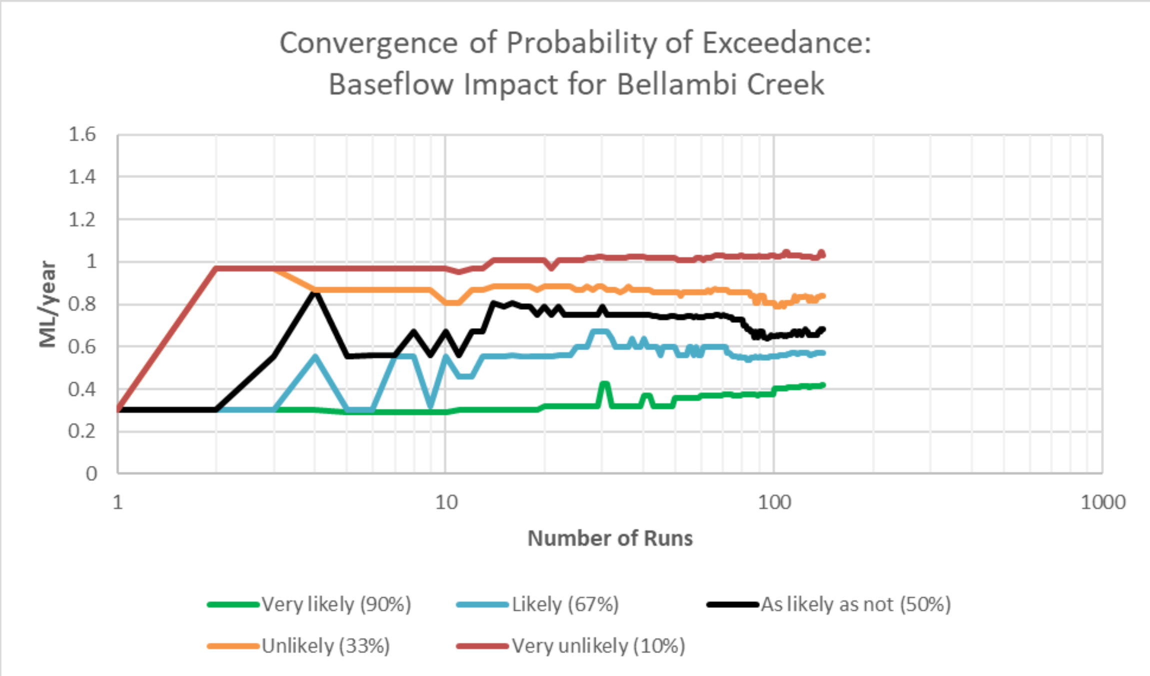

Figure 27: Change in additional baseflow impact to Bellambi Creek percentiles with number of Monte Carlo runs.

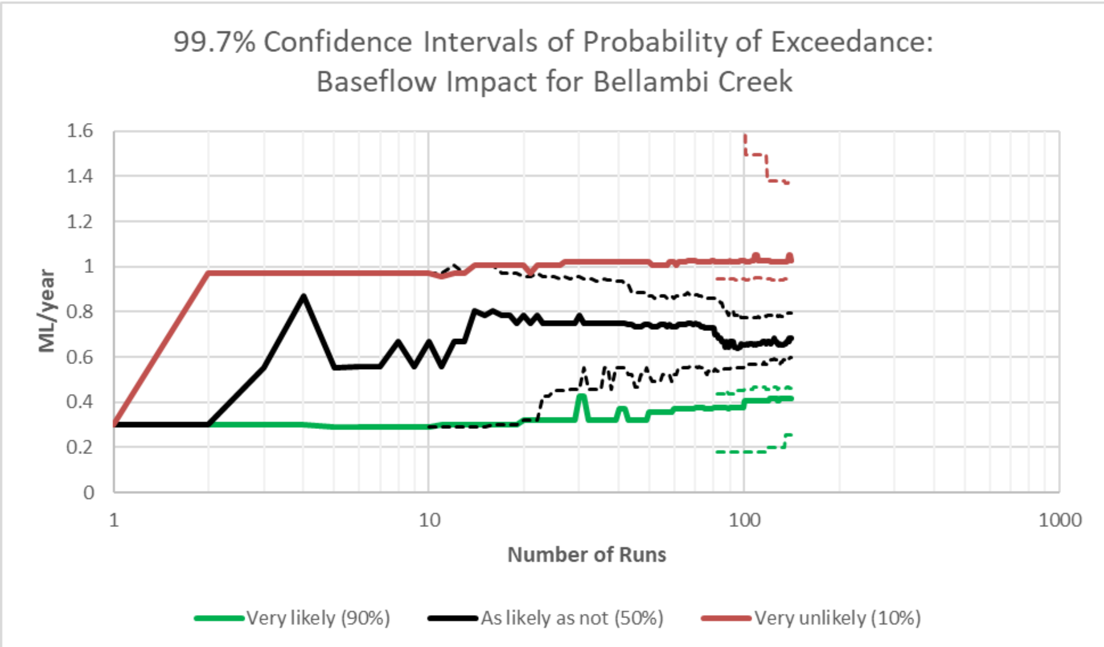

Figure 28: 99.7% confidence intervals for additional baseflow impact to Bellambi Creek percentiles.

6. Peer review

An independent peer review has been conducted by Dr Frans Kalf (2020), of Kalf and Associates Pty Ltd, based on an earlier version of this UA report. He concluded that "*overall, the analysis by HydroAlgorithmics (HA) is considered to be suitable and valid*". Since the review, no significant changes have been made to the analysis that was reviewed.

Dr Kalf cautioned that: "*once mining proceeds … the response of the hydrogeological system could lie to some extent outside the predicted drawdown and flow rate influence generated in the type of analysis presented. This could be the result of changes in mining procedure, unaccounted structural features in the hydrogeological layers, and new data from additional drilling etc.".*

Dr Kalf also noted that some specific storage (Ss) values in upper model layers exceeded the value of 1.3×10^{-5} m^{-1} which is claimed by Rau *et al.* (2018) to be "the physically plausible upper limit of specific storage for unconsolidated materials…". It should be noted that this paper has not achieved universal acceptance, and Rau *et al.* (2018) admit that "It is common for literature values of specific storage of aquifers to be above the theoretical maximum". Also, no explanation is offered by Rau *et al.* (2018) for an inconsistency with publications from the same University of NSW research group (e.g. Anderson and Howe, 2019) that identifies regions of physical plausibility and implausibility on a diagram of Young's Modulus versus specific storage; the purported maximum Ss value plots in the area of *physical implausibility* for typical values of Young's Modulus for alluvial sediments.

Values greater than the purported maximum were applied in 9 of 27 property zones, and only in the upper four layers of the model. The prior distribution mean values were aligned properly with the values calibrated by the Russell Vale modeller, which were obtained long before the Rau *et al.* (2018) paper was published. Dr Kalf acknowledges that use of values higher than the purported maximum "would not be significant" in affecting model results.

7. Conclusion

A rigorous uncertainty analysis for the Revised Preferred Project has been conducted according to the Type 3 category of methods advocated by the IESC guidelines (Middlemis and Peeters, 2018). Uncertainty has been examined for mine inflow, baseflow impacts and groundwater drawdown subject to realistic ranges of variations in hydraulic conductivity (horizontal and vertical), storage properties (specific storage and specific yield), rainfall recharge rate, maximum evapotranspiration rate and extinction depth. Only calibrated model realisations were retained for analysis. Despite the rejection of poorly calibrated runs (exceeding 5 %RMS), good agreement was attained between prior and posterior distributions, indicating that the parameter space has been sampled without bias.

A major finding is that there is expected to be negligible drawdown, even at the 90th percentile, of the water table in surficial layers in contact with local streams and the cataract Reservoir.

The range in total mine inflow in any one year from 2011 to 2023 is expected to be tight, with predicted values being about ±10% from the median. A similar bandwidth is expected for the additional mine inflow caused only by the Revised Preferred Project, with maximum inflows in the range of 262 ML/year (*very likely* to be exceeded) to 326 ML/year (*very unlikely* to be exceeded). The predicted take is fairly stable from year to year for the Revised Preferred Project.

For reductions in baseflow to the three major local streams, the uncertainty bandwidths are wide but the impact magnitudes are small. Even at the “very unlikely to be exceeded” level, the worst-case impact is about 3 ML/year at Cataract Creek. The worst-case predicted impact on Cataract Reservoir is less than 1 ML/year.

8. References

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APPENDIX 2

Revised Groundwater Assessment Peer Review Report

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DATE: 3 February 2020

TO: Ron Bush
Group Environment and Approvals Manager
Wollongong Coal Ltd
PO Box 281
Fairy Meadow NSW 2519

FROM: Dr Noel Merrick

RE: Russell Vale Colliery Underground Expansion Project – Groundwater Peer Review

YOUR REF: Email 10 October 2019

OUR REF: HA2020/02

1. Introduction

GeoTerra Pty Ltd and Groundwater Exploration Services (GES) Pty Ltd have jointly undertaken the Groundwater Assessment (GA) for Russell Vale Colliery, which is located about 13 km to the north-west of Wollongong on the New South Wales South Coast. The subject of the assessment is the Russell Vale Colliery Underground Expansion Project. The Revised Preferred Project is proposed to adopt a non-caving first workings mining system in the Wongawilli Seam, with no further longwall mining. Under the previous approval, Longwalls 4 and 5 were mined, as well as the south-western 340 metres (m) of Longwall 6 (from April 2012 to July 2015).

Wollongong Coal Limited (WCL) has engaged HydroAlgorithmics Pty Ltd to conduct an independent peer review of the GA, focusing on the numerical groundwater modelling.

On 3 October 2019, DPIE-Water sent a 4-page letter to the Planning and Assessment Group of NSW Department of Planning Industry and Environment (DPIE), in which three major concerns were raised with the Revised Preferred Project Report dated July 2019. One of the issues concerned a groundwater model peer review. As the GA report was submitted at the time without a written peer review, DPIE-Water now requires a peer review to be completed. DPIE provided additional comments on the GA report in a 31-page Water Assessment Record dated 18 September 2019.

It should be noted that the initial GA report dates back to June 2017, as a revision of the assessment for an earlier mine plan based on Longwalls 1, 2, 3, 6, 7, 9, 10 and 11. The reviewer prepared a peer review report on the earlier application in September 2015, and on an even earlier application in June 2014. As the model did not change appreciably from 2015 to 2017, a formal peer review was bypassed.

As the GA report that was reviewed by DPIE-Water has been restructured and updated, the current peer review has been undertaken on the latest GA report issued in January 2020.

2. Documentation

The following report comprises the GA documentation that has been reviewed:

1. GeoTerra and GES, 2020, Russell Vale Colliery Underground Expansion Project Russell Vale East First Workings Groundwater Assessment, Bellambi, NSW. Report NRE16 - R1F for Wollongong Coal Ltd., 29 January 2020.

It is understood that slight changes have been made to the report, prior to submission to DPIE, that have no material effect on this review.

This report makes some reference to the earlier assessment where no significant change had occurred:

2. GeoTerra and GES, 2015, Russell Vale Colliery Underground Expansion Project Russell Vale East Revised Groundwater Assessment, Bellambi, NSW. Report NRE12 - R1A G for Wollongong Coal Ltd., 18 August 2015.

Electronic model files were provided and examined. The reviewer had several telephone discussions with the GES modeller (Andrew Fulton, GES) in recent months, and met with him on a number of occasions during early development of the model in 2014-2015.

Document #1 has the following report structure, with 18 major sections:

1. Introduction
2. Regulatory Context
3. Historic Mining at Russell Vale
4. The Revised Preferred Project
5. Site Context
6. Potential Strata Deformation and Associated Groundwater Effects
7. Hydrogeological Investigations
8. Groundwater Modelling
9. Predictive Modelling
10. Cumulative Groundwater Related Impacts
11. Modelling Uncertainty
12. Model Limitations
13. Water Licensing
14. NSW Aquifer Interference Policy Minimal Impact Considerations
15. Environmental Planning and Assessment Act 1979 Assessment
16. Water NSW Principles for Managing Mining and Coal Seam Gas Impacts in Declared Catchment Areas

17. Monitoring, Contingency Measures & Reporting
18. References.

3. Review Methodology

While there are no standard procedures for peer reviews of entire groundwater assessments, there are two accepted guides to the review of groundwater models: the Murray-Darling Basin Commission (**MDBC**) Groundwater Flow Modelling Guideline[1], issued in 2001, and guidelines issued by the National Water Commission (**NWC**) in June 2012 (Barnett *et al.*, 2012[2]). Both guides also offer techniques for reviewing the non-modelling components of a groundwater impact assessment.

The NWC national guidelines were built upon the original MDBC guide, with substantial consistency in the model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details.

The NWC guide promotes the concept of "model confidence level", which is defined using a number of criteria that relate to data availability, calibration, and prediction scenarios. The NWC guide is almost silent on coal mine modelling and offers no direction on best practice methodology for such applications. There is, however, an expectation of more effort in uncertainty analysis, although the guide is not prescriptive as to which methodology should be adopted.

Guidelines on uncertainty analysis for groundwater models were issued by the Independent Expert Scientific Committee (**IESC**) on Coal Seam Gas and Large Coal Mining Development in February 2018 in draft form and finalised in December 2018[3]. It should be noted that this post-dates the time at which the modelling by GES was done. Nevertheless, an IESC-compliant uncertainty analysis is now included in Document #1.

The groundwater guides include useful checklists for peer review. This groundwater impact assessment has been reviewed according to the 36-question Model Appraisal checklist[4] in MDBC (2001). This checklist has questions on (1) The Report; (2) Data Analysis; (3) Conceptualisation; (4) Model Design; (5) Calibration; (6) Verification; (7) Prediction; (8) Sensitivity Analysis; and (9) Uncertainty Analysis. Non-modelling components of the groundwater impact assessment are addressed by the first three sections of the checklist.

The review has also considered whether compliance with the minimal impact considerations of the NSW *Aquifer Interference Policy* (AIP) (NSW Government, 2012[5]) has been addressed adequately.

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

[2] Barnett, B, Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A. and Boronkay, A. (2012). *Australian Groundwater Modelling Guidelines*. Waterlines report 82, National Water Commission, Canberra.

[3] Middlemis H and Peeters LJM (2018) *Uncertainty analysis—Guidance for groundwater modelling within a risk management framework*. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy, Commonwealth of Australia 2018.

[4] The NWC guidelines include a more detailed checklist with yes/no answers but without the graded assessments of the MDBC checklist, which this reviewer regards as more informative for readers.

[5] NSW Government, 2012, NSW Aquifer Interference Policy – NSW Government policy for the licensing and assessment of aquifer interference activities. Office of Water, NSW Department of Primary Industries, September 2012.

It should be recognised that the effort put into the modelling component of a groundwater impact assessment is very dependent on possible timing and budgetary constraints that are generally not known to a reviewer. However, this is less of an issue with a progressive review.

This review has not been conducted progressively. However, a meeting of all parties was held at DPIE premises on 21 October 2019. Previous verbal and written review comments, provided to GeoTerra, have been addressed satisfactorily.

A detailed assessment has been made in terms of the peer review checklist in **Table 1**. Supplementary comments are offered in the following sections.

4. Report Matters

Document #1 is a good quality document of 142 pages length plus three appendices that contain a history of groundwater assessments, a summary of regulatory policies, and full uncertainty analysis. The report is well structured and the graphics are mostly of high quality. The report commences with a 4-page Executive Summary that adequately summarises the assessment and its findings. This substitutes for a missing Summary or Conclusion section.

The objectives of the assessment are clearly stated:

- “identify potential groundwater dependent ecosystems;
- collate and review mine water management data;
- collate and review additional data from adjacent mines and government agencies;
- develop a conceptual groundwater model and represent the Application Area with a numerical MODFLOW SURFACT groundwater model to assess potential underground mining impacts on the local and regional groundwater system;
- provide a qualitative and quantitative assessment of cumulative impacts from adjacent existing and approved mines;
- assess post mining groundwater impacts in regard to groundwater level recovery;
- develop measures to avoid, mitigate and/or remediate potential impacts on groundwater resources, and;
- indicate groundwater monitoring methods that will measure any impacts on the local and regional groundwater system.”

The main objectives of the modelling are said to be: ”to simulate water level variability to mining stresses, to assess groundwater seepage to underground mining areas and to assess the potential impact with surface water features”.

Given the incremental nature of this GA, some information is not supplied in Document #1 but reference is made to Document #2. Examples of missing information are: (1) simulated versus observed hydrographs; (2) calibrated hydraulic conductivity fields; (3) adopted spatial rainfall recharge distribution; (4) historical mining drain cell distributions and timing.

The Russell Vale model type is Moderate Complexity (under the MDBC guidelines) and Class 2 Confidence Level (under the NWC guidelines). This is the appropriate level for a groundwater impact assessment for a mining development.

The conceptual model graphic in Figure 8-1 focusses on previous Bulli Seam and triple seam longwall mining but does not separately consider the first workings of the Revised Preferred Project. This diagram is a carry-over from previous assessments for longwall mining.

In general, the report has more focus on the longwall mining that has already occurred, rather than the first workings of the Revised Preferred Project. While longwall effects are pertinent to cumulative assessment, often the effects of the Project are not emphasised. As an example, the text associated with Figures 9-5 and 9-6, which are meant to show what is likely to happen to pressure heads and groundwater levels from the end of Longwall 6 to the end of the first workings of the Project, comments are made only on the fracture zone of the triple seam mining being fully developed. There is no comment on the obviously minimal additional effects from the first workings.

5. Data Matters

The main features of the data analysis presented in Document #1 are:

- The coverage of geology and hydrogeology is particularly good.
- The rainfall residual mass (cumulative deviation from the mean) curve has been used effectively to show often strong correlation with groundwater hydrographs.
- There is a very thorough cause-and-effect analysis of hydrographic responses.
- Comparison of standpipe and VWP correlation at similar locations and depths.
- The water table pattern in Figure 7-6, based on measurements and inferred levels, is sensible as it suggests logical groundwater flow from ridges to drainage lines.
- A thorough analysis of mine inflow components (Section 7.5).
- Cross-sections of pre-Project pressure heads show substantial prior depressurisation due to neighbouring mining (Figures 9-1, 9-2).
- The conceptualisation based on the field investigations and data analysis is justified and well illustrated graphically in Figure 8-1 for a mining situation.
- The adopted conceptual model is consistent with other studies in the Southern Coalfield.
- Strong evidence is presented for geological faults and other structures having no significant role in the groundwater regime.

Document #2 provides extra information on:

- Field-derived permeabilities.

At site GW1, the standpipe screened at 21-27 m and the VWP sensor at 30 m have groundwater levels in good agreement (Figure 7-17).

6. Model Matters

The GA model uses MODFLOW-SURFACT software with the pseudo-soil algorithm instead of the van Genuchten algorithm, as required by a previous PAC review. For the uncertainty analysis performed by HydroAlgorithmics, it was necessary for HydroAlgorithmics to convert the model to MODFLOW-USG software so that hundreds of simultaneous simulations could be run in the cloud using AlgoCompute software. MODFLOW-SURFACT has a licensing constraint that prohibits multiple runs in the cloud. HydroAlgorithmics staff verified the equivalence of outputs from the two models. In some cases, this step uncovered errors in some of the plots and tables in the July 2019 GA report.

A structured grid design has been used with variable grid cell resolution ranging from 25 m to 250 m, across 19 model layers. The number of model cells is 1.02 million, very close to the recommended maximum for efficient simulation.

The adopted evapotranspiration (ET) rate (0.005 m/day = 1,825 m/year) has not changed and still is considered too high as it reflects evaporation rather than actual ET. The Bureau of Meteorology provides estimates of actual ET (limited by water availability) across Australia. Allowance should always be made for MODFLOW's weak linear representation of the ET process, which means that evaporation rates will always be too high as a surrogate for ET. However, this is not considered a serious issue, as the ET process will be activated in the model only where the water table comes within a few metres of ground surface.

<u>Calibration</u>

Since the previous peer review, more effort has been put into better calibration of the VWP responses at bore GW1. The result, shown in Figure 8-5, is extremely good, as simultaneous matching of multiple VWP sensors is notoriously difficult. A good explanation is offered as to why it is always difficult to match VWP responses at any one monitoring site.

Overall, the calibration performance of the model is much the same, with some deterioration from 3.1 %RMS to 3.4 %RMS in relative terms, but the absolute error has remained the same (8.0 mRMS), for calibration to groundwater levels.

It is noted that there are no head calibration targets below the Scarborough Sandstone [model layer 10]. However, the calibration to mine inflows is quite good [Figure 8-7 compared with Figure 7-20].

Simulated versus observed hydrographs are not provided in Document #1 but they are in Document #2. Overall, the degree of visual calibration is acceptable.

<u>Prediction</u>

Many informative figures for the effects on the groundwater system of past and future mining are presented from Figure 9-1 to Figure 9-18, expressed in the form of pressure heads (in metres), potentiometric heads (in mAHD) and drawdowns (in metres). North-South and East-West cross sections are provided pre-mining, at the end of Longwall 6 and at the end of first workings Project mining. Plan views of drawdowns are provided at the start of Wongawilli Seam mining, at the end of mining Longwall 6, at the end of Project mining, and 40 years and 200 years after completion of Project mining, for model layer 1 (upper Hawkesbury Sandstone), model layer 15 (Balgownie Seam) and model layer 17 (Wongawilli Seam).

In Document #2, pressure head plan views were also provided pre-mining and at the completion of mining for model layer 1 (upper Hawkesbury Sandstone), model layer 3 (lower Hawkesbury Sandstone), model layer 5 (upper Bulgo Sandstone) and model layer 17 (Wongawilli Seam).

Appin, Tahmoor and Dendrobium neighbouring mines are represented simply as time-invariant boundary conditions using GHB (Dendrobium and Tahmoor) or CHD (Appin) features. Figures 10-1 and 10-2, taken from earlier independent groundwater assessments by other consultants, demonstrate that cumulative effects at the level of the water table would not be a concern, as there is no simulated interference between the drawdown extents of the four mines. The reviewer considers this to be an adequate cumulative impact assessment.

Uncertainty Analysis

Sensitivity analysis was reported in the June 2014 GA report, where results were shown for 31 alternative model parameterisations, selected from the packer test database of horizontal hydraulic conductivities.

In the current GA report, an IESC-compliant uncertainty analysis supersedes earlier sensitivity analysis. The uncertainty analysis is summarised in Section 11. Due to a potential perception of conflict of interest, the reader is referred to an independent review of this material by Dr Frans Kalf of Kalf and Associates. Suffice to say that a major finding is that there is expected to be negligible drawdown, even at the 90th percentile, of the water table in surficial layers in contact with local streams and the Cataract Reservoir.

The range in total mine inflow in any one year from 2011 to 2023 is expected to be tight, with predicted values being about ±10% from the median. A similar bandwidth is expected for the additional mine inflow caused only by the Revised Preferred Project, with maximum Project inflows in the range of 262 ML/year (very likely to be exceeded) to 326 ML/year (very unlikely to be exceeded). The predicted take is fairly stable from year to year for the Revised Preferred Project. This range compares favourably with the GA estimate of 288 ML/year for the basecase model.

Mine Inflow

Figure 1 shows a comparison of the mine inflow variations with time using the GA SURFACT model and the HydroAlgorithmics USG model. The patterns are broadly similar but the magnitudes differ at times, although the GeoTerra results show a rising tail (due to some Drain cells being kept active). The differences are not likely due to the different software packages, but to uncertainty as to which mines and coal seam layers are included in the calculation, in the durations of various Drain cells, and in the method of calculation. **Figure 1(b)** includes the Wongawilli Seam (Layer 17) longwalls (reach 1502) and first workings (reach 1500), as well as contributions from the Bulli Seam (Layer 13; reaches 1107 and 1117) and the Balgownie Seam (Layer 15, reach 1330). The inflows in **Figure 1(b)** are 3-point smoothed time-weighted averages over quarters. It is likely that the inflows in **Figure 1(a)** are not time-weighted and the degree of smoothing is unknown.

The corresponding uncertainty analysis mine inflows (Figure 11-1) are 6-monthly time-weighted averages. They agree well with **Figure 1(b).**

Baseflow Impacts

For reductions in baseflow to the three major local streams, the uncertainty bandwidths are wide but the impact magnitudes are small. Even at the "very unlikely to be exceeded" level, the worst-case impact is about 3 ML/year at Cataract Creek for the Revised Preferred Project. The worst-case predicted impact on Cataract Reservoir is less than 1 ML/year.

The GA report and independent simulation of the basecase model by HydroAlgorithmics (**Figures 2, 3 and 4**) show an apparent inconsistency. This is believed to be due to the GA report's subtraction of baseflows at different times (e.g. end of Longwall 6 compared to end of first workings), whereas the HydroAlgorithmics approach was to subtract baseflows at the same point in time from two null models, one with no Wongawilli Seam mining, the other with Longwalls 4-6 active. The flow values for the HydroAlgorithmics model are 6-monthly time-weighted averages for the first 33 years, then 5-yearly time-weighted averages. The GA flows are likely to be instantaneous values, in which case peaks would appear more pronounced.

For individual streams, the peaks from a single basecase model run are higher than the uncertainty analysis peaks which are composites of 141 simulations[6]. The lower peak and slower recovery evident in the probability of exceedance flow figures indicate that the time of peak flow impact is affected by varying the hydraulic parameter fields. This results in a smoother, flatter flow impact curve when aggregated over all accepted Monte Carlo realisations and suggests that there is some uncertainty in the timing of the peak flow impacts.

The "All Wongawilli Mining" impacts agree quite well at the peak, but the Project-only impacts are half-to-one order of magnitude higher using the HydroAlgorithmics model.

The combined total impacts for all three streams are shown in **Figure 5**. The peak reduction in baseflow for all three streams is 20.9 ML/year. This is apportioned as 18.6 ML/year for existing Wongawilli Seam mining and 2.3 ML/year for the Revised Preferred Project. This compares with an estimate of 9.9 ML/year for all three streams for the maximum cumulative impact.

Model Properties

The reviewer has compared the hydraulic conductivities adopted at Russell Vale with those at Metropolitan Colliery and Dendrobium Mine. There is an expectation by some that the values should be similar, but there are many reasons why lithological characteristics could vary in the same basin over distances of many kilometres. Results are summarised in the table below.

	Russell Vale & Metropolitan		Russell Vale & Dendrobium	
	Kx	Kz	Kx	Kz
Within 1 order of magnitude	56%	63%	69%	75%
Within 1.5 orders of magnitude	100%	94%	100%	94%

[6] The uncertainty analysis results should be compared ONLY with the "Proposed vs Existing Wongawilli Mining" case. Uncertainty results for "Proposed vs No Wongawilli Mining" would require repeating all 500 runs.

This table shows that the majority of both horizontal and vertical layer hydraulic conductivities lie within one order of magnitude of each other at the respective mines. Nearly all values agree within 1.5 orders of magnitude.

Some of the specific storage (Ss) values in upper model layers exceed the value of 1.3 x 10^{-5} m^{-1} which is claimed by Rau *et al*. (2018[7]) to be "the physically plausible upper limit of specific storage for unconsolidated materials…". It should be noted that this paper has not achieved universal acceptance, and Rau *et al.* (2018) admit that "It is common for literature values of specific storage of aquifers to be above the theoretical maximum". Also, no explanation is offered by Rau *et al*. (2018) for an inconsistency with publications from the same University of NSW research group (e.g. Anderson and Howe, 2019) that identifies regions of physical plausibility and implausibility on a diagram of Young's Modulus versus specific storage; the purported maximum Ss value plots in the area of physical implausibility for typical values of Young's Modulus for alluvial sediments.

The values calibrated by the GA modeller were obtained long before the Rau *et al.* (2018) paper was published and it is the reviewer's opinion that the values are legitimate and more than an order of magnitude shift in an Ss value would be required before any differential effects would be noticeable.

8. Conclusion

The main objectives of the modelling are said to be: "to simulate water level variability to mining stresses, to assess groundwater seepage to underground mining areas and to assess the potential impact with surface water features". More broadly, the groundwater assessment is required to fulfil aspects of the Director General's Requirements, especially "the potential impacts of the project on the quantity, quality and long-term integrity of the groundwater resources in the project area", and the additional regulatory requirements since submission of the Revised Preferred Project Report.

The impacts of importance are stipulated in the Aquifer Interference Policy, especially drawdown impacts on GDEs and private bores, and water quality departures from beneficial use. In addition, the volumetric takes of water are to be determined (and partitioned where necessary) for licensing purposes. The groundwater assessment includes two tables (Table 14 and Table 15) that address the minimal impact considerations for less productive porous rock water sources and perched ephemeral aquifer water sources. Each consideration is addressed in full. This reviewer concurs with the finding that no Level 2 impacts have been identified.

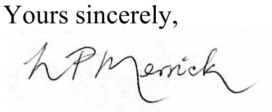
It is the reviewer's opinion that all objectives have been met satisfactorily. Furthermore, it is the reviewer's opinion that the Russell Vale Groundwater Model has been developed competently and is "fit for purpose" for addressing the potential environmental impacts from the proposed underground mining operations and for estimating indicative dewatering rates. Independent assessment of water takes indicates close agreement for the nominated porous rock water take during Project mining, but about double the take from the surface water source due to reduction of baseflow reporting to the three major relevant streams, due to all Wongawilli Seam mining.

The uncertainty in modelling predictions has been assessed by a rigorous IESC-compliant Monte Carlo uncertainty analysis.

[7] Rau, G.C., Acworth, R.I., Halloran, L.J.S., Timms, W.A. and Cuthbert, M.O., 2018. Quantifying compressible groundwater storage by combining cross-hole seismic surveys and head response to atmospheric tides. *Journal of Geophysical Research: Earth Surface*, **123**, 1910-1930.

Due to the substantial depressurisation that has been caused by earlier mining at the subject mine, and at neighbouring historical mines, the additional effects of mining the Wongawilli Seam with non-caving first workings are considered minor.

Yours sincerely,



Dr Noel Merrick

Table 1. Model Appraisal: Russell Vale Colliery Groundwater Model

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
1.0	THE REPORT								142p text. 3 App.
1.1	Is there a clear statement of project objectives in the modelling report?		Missing	Deficient	Adequate	Very Good			Section 1.3 - Scope of Work. Section – modelling.
1.2	Is the level of model complexity clear or acknowledged?		Missing	No	Yes				Reference to new national guidelines. Class 2 confidence classification. Equivalent to Impact Assessment Model, medium complexity.
1.3	Is a water or mass balance reported?		Missing	Deficient	Adequate	Very Good			Done for transient calibration period. Not globally for Prediction – only for components.
1.4	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	Very Good			"...address any potential groundwater impacts relating to the proposed extraction and associated subsidence..."
1.5	Are the model results of any practical use?			No	Maybe	Yes			Quantitative impact assessment with uncertainty. Aquifer Interference Policy checked for minimal impact compliance.
2.0	DATA ANALYSIS								
2.1	Has hydrogeology data been collected and analysed?		Missing	Deficient	Adequate	Very Good			Sections 5, 6, 7. Good overviews of geology and hydrogeology. Field-derived permeability in previous report.
2.2	Are groundwater contours or flow directions presented?		Missing	Deficient	Adequate	Very Good			Includes map of observed water level contours (Figure 7-6) (Simulated pattern not checked against this.) Figures 9-1, 9-2 give initial pore pressures on S-N and W-E sections.
2.3	Have all potential recharge data been collected and analysed? (rainfall, streamflow, irrigation, floods, etc.)		Missing	Deficient	Adequate	Very Good			Rainfall in Section 5.2.5-1. Rainfall residual mass (CRD) in Figure 5-3. Stream flow in Section 5.8 - no statistics.

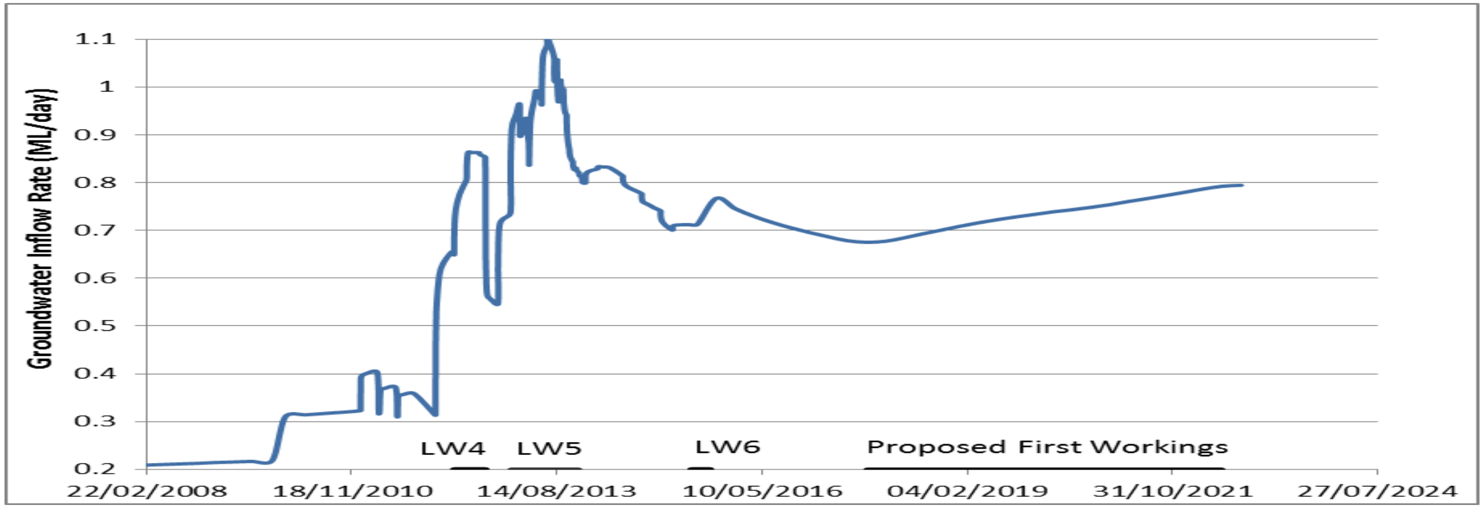
2.4	Have all potential discharge data been collected and analysed? (abstraction, evapotranspiration, drainage, springflow, etc.)		Missing	Deficient	Adequate	Very Good			Field assessment of gaining/losing. No abstraction by bores. Cataract Dam evaporation records. Missing: could cite BoM actual ET estimate for region - model ET rate seems high. Expect a summary of stream baseflow or flow duration percentiles.
2.5	Have the recharge and discharge datasets been analysed for their groundwater response?		Missing	Deficient	Adequate	Very Good			Standpipe and VWP hydrographs are related to CRD (useful in discriminating climate effects - good correlation) and longwall dates. Mine water balance (Figure 7-20) has detailed partitioning of components.
2.6	Are groundwater hydrographs used for calibration?			No	Maybe	Yes			13 Standpipes and 12 VWPs. Hydrograph comparison plots are not included.
2.7	Have consistent data units and standard geometrical datums been used?			No	Yes				
3.0	CONCEPTUALISATION								
3.1	Is the conceptual model consistent with project objectives and the required model complexity?		Unknown	No	Maybe	Yes			
3.2	Is there a clear description of the conceptual model?		Missing	Deficient	Adequate	Very Good			Sections 5.3 to 5.5, etc.
3.3	Is there a graphical representation of the modeller's conceptualisation?		Missing	Deficient	Adequate	Very Good			Figure 8-1. Good for longwall fracturing, but not updated for first workings.
3.4	Is the conceptual model unnecessarily simple or unnecessarily complex?			Yes	No				Consistent with detail in other Southern Coalfield models.
4.0	MODEL DESIGN								
4.1	Is the spatial extent of the model appropriate?			No	Maybe	Yes			Dimensions about 23 km x 23 km. Finite differences. 19 layers. Includes many historical mines. 25m to 250m cell size.

4.2	Are the applied boundary conditions plausible and unrestrictive?		Missing	Deficient	Adequate	Very Good			Mostly controlled by seam heads in mines around the boundary. Topo divide along open western boundary. Cross-sections of initial conditions are given as pressure heads. Streams use RIV. Mines use DRN. Neighbouring active mines represented by GHB and CHD. ET maximum rate is quite high for MODFLOW linear decay. Variable stress periods. Strong argument for excluding faults.
4.3	Is the software appropriate for the objectives of the study?			No	Maybe	Yes			MODFLOW-SURFACT with pseudo-soil. Time-varying properties (TMP) for fractured zone. MODFLOW-USG for uncertainty analysis.
5.0	CALIBRATION								**Jan.1993-June 2017**
5.1	Is there sufficient evidence provided for model calibration?		Missing	Deficient	Adequate	Very Good			**Steady-state**: missing. Should give RMS statistics and show watertable contours to compare with Figure 7-6. No scattergram. Steady-state = 1991: CRD (Figure 5-3) justifies "average" conditions. **Transient**: adequate. Two attributes: heads and mine inflow - no check on baseflow. Evidence = scattergram; mRMS and %RMS; hydrograph comparison shown only for GW1. Historical mine inflow matched in transient calibration. No spatial residual map to see where calibration is poor.
5.2	Is the model sufficiently calibrated against spatial observations?		Missing	Deficient	Adequate	Very Good			Steady state: ??%RMS, ??mRMS. 32 sites, unknown number of points. Cannot compare pattern with observed/inferred contours. Vertical head separation very good at VWPs. Transient scattergram centred on 45 degree line.

5.3	Is the model sufficiently calibrated against temporal observations?		Missing	Deficient	Adequate	Very Good			Adequate, based on hydrograph comparisons in previous report. Trends generally OK. Fluctuations not reproduced. VWP matches as good as can be expected. Statistical performance is good: 3.4%RMS, 8mRMS. 832 data points. 64 sensors at 32 sites. Mine inflow well matched. Scattergram (Figure 8-4) reinforces lack of amplitude matching (horizontal lines at some sites).
5.4	Are calibrated parameter distributions and ranges plausible?		Missing	No	Maybe	Yes			Table 10. Kx and Kz are mostly within 1 OoM of model values at Metropolitan & Dendrobium mines. Ss acceptable. Recharge 4% & 6% of rain.
5.5	Does the calibration statistic satisfy agreed performance criteria?		Missing	Deficient	Adequate	Very Good			<10 %RMS.
5.6	Are there good reasons for not meeting agreed performance criteria?		Missing	Deficient	Adequate	Very Good			Difficulties acknowledged and discussed: VWP stability; compression effects; steep terrain.
6.0	VERIFICATION								**No need. Better to use all data.**
6.1	Is there sufficient evidence provided for model verification?	N/A	Missing	Deficient	Adequate	Very Good			
6.2	Does the reserved dataset include stresses consistent with the prediction scenarios?	N/A	Unknown	No	Maybe	Yes			
6.3	Are there good reasons for an unsatisfactory verification?	N/A	Missing	Deficient	Adequate	Very Good			
7.0	PREDICTION								**July 2018-Dec.2022: 5.5 years. Recovery for 200years.**
7.1	Have multiple scenarios been run for climate variability?		Missing	Deficient	Adequate	Very Good			Average rain - normal practice. No climate change scenario.
7.2	Have multiple scenarios been run for operational /management alternatives?		Missing	Deficient	Adequate	Very Good			One mine plan - normal practice. Impacts presented for Project (first workings) and for completed Wongawilli longwalls (LW4 – LW6).

7.3	Is the time horizon for prediction comparable with the length of the calibration / verification period?		Missing	No	Maybe	Yes			~8 years effective calibration. 5.5 years prediction.
7.4	Are the model predictions plausible?			No	Maybe	Yes			Drawdown magnitudes and mine inflows seem reasonable. Maximum baseflow effect ~2 ML/a for Project and ~21 ML/a cumulative (3 streams total). Negligible reservoir effect. No third party bores of concern. Good pressure head sections. Zero pressure gets close to surface above longwall panels but no visual effect from first workings.
8.0	SENSITIVITY ANALYSIS								**Replaced by uncertainty analysis.**
8.1	Is the sensitivity analysis sufficiently intensive for key parameters?		Missing	Deficient	Adequate	Very Good			
8.2	Are sensitivity results used to qualify the reliability of model calibration?		Missing	Deficient	Adequate	Very Good			
8.3	Are sensitivity results used to qualify the accuracy of model prediction?		Missing	Deficient	Adequate	Very Good			
9.0	UNCERTAINTY ANALYSIS								
9.1	If required by the project brief, is uncertainty quantified in any way?		Missing	No	Maybe	Yes			141 Monte Carlo realisations. Tight mine inflow range. Broader baseflow range but small magnitude. Comparable prior and posterior probability distributions.
	TOTAL SCORE								PERFORMANCE:

[a]



[b]

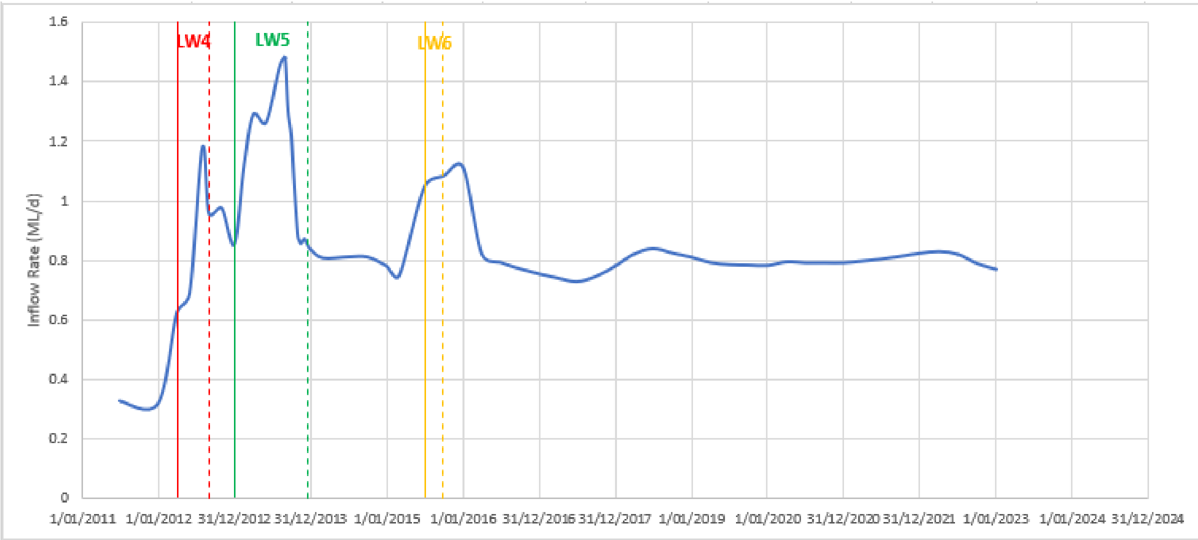


Figure 1. Comparison of mine inflow estimates by (a) GeoTerra SURFACT model; (b) HydroAlgorithmics USG model

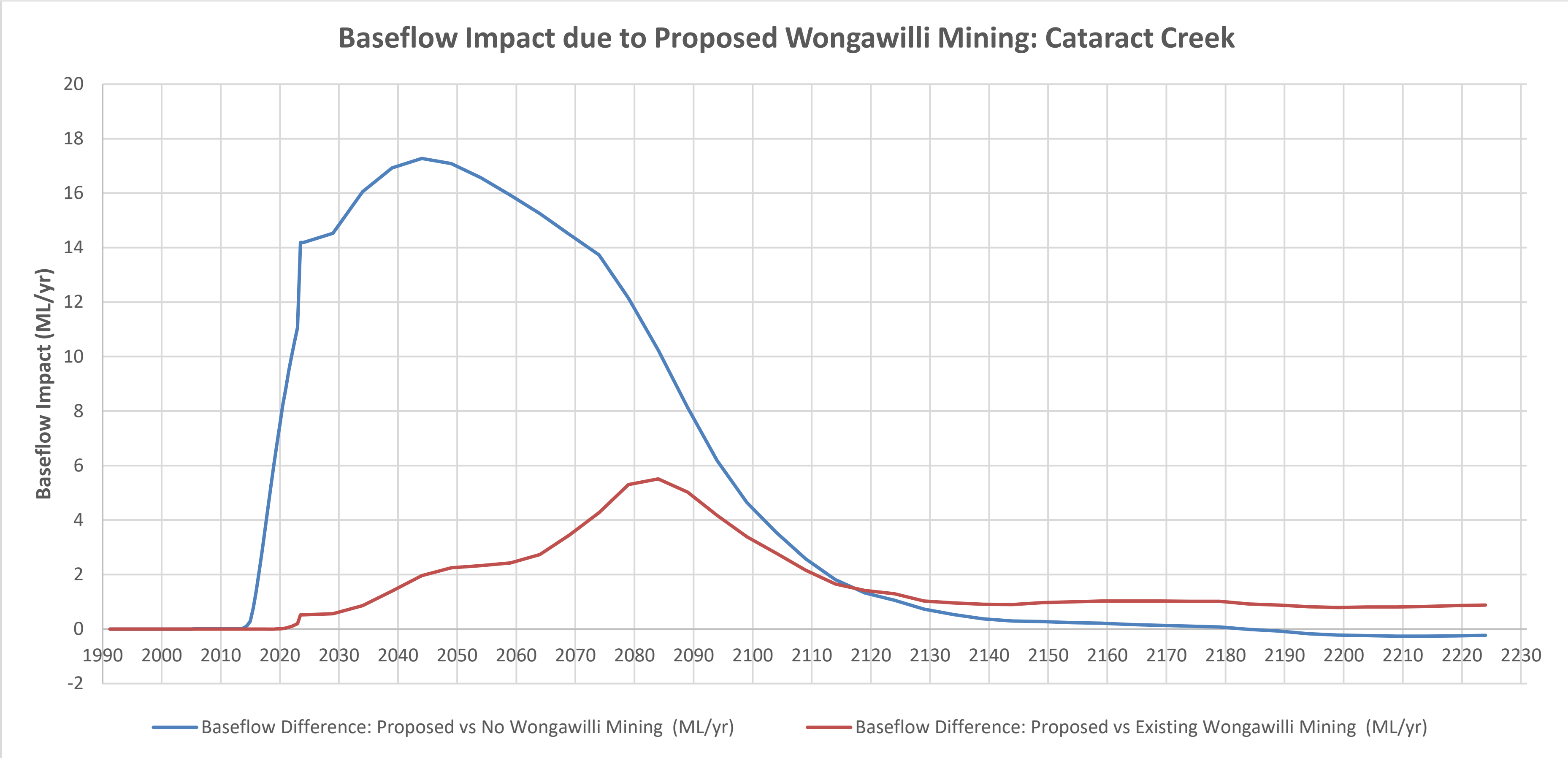


Figure 2. Impacts on Cataract Creek baseflow: Longwalls 4-6 and first workings (blue); First workings only (red)

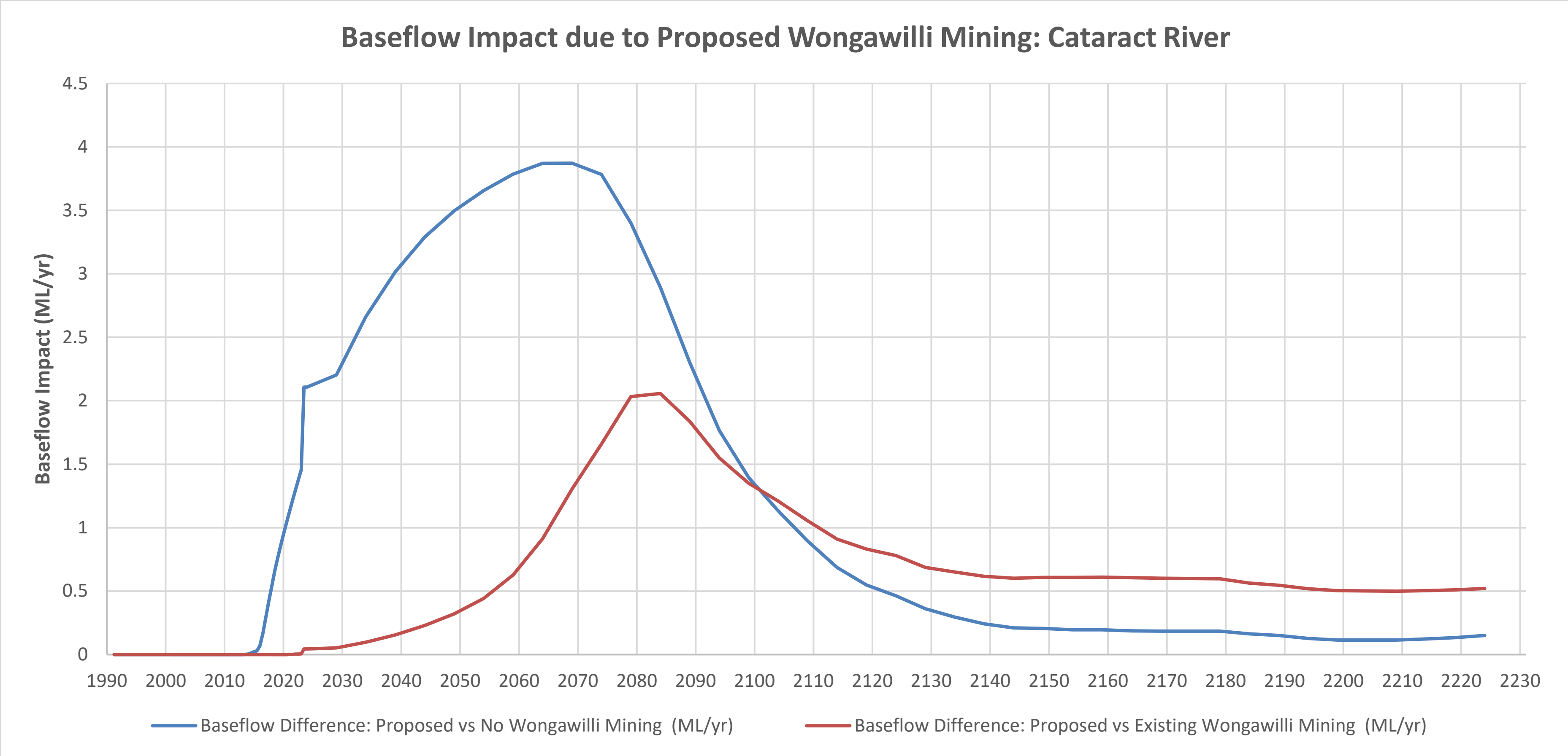


Figure 3. Impacts on Cataract River baseflow: Longwalls 4-6 and first workings (blue); First workings only (red)

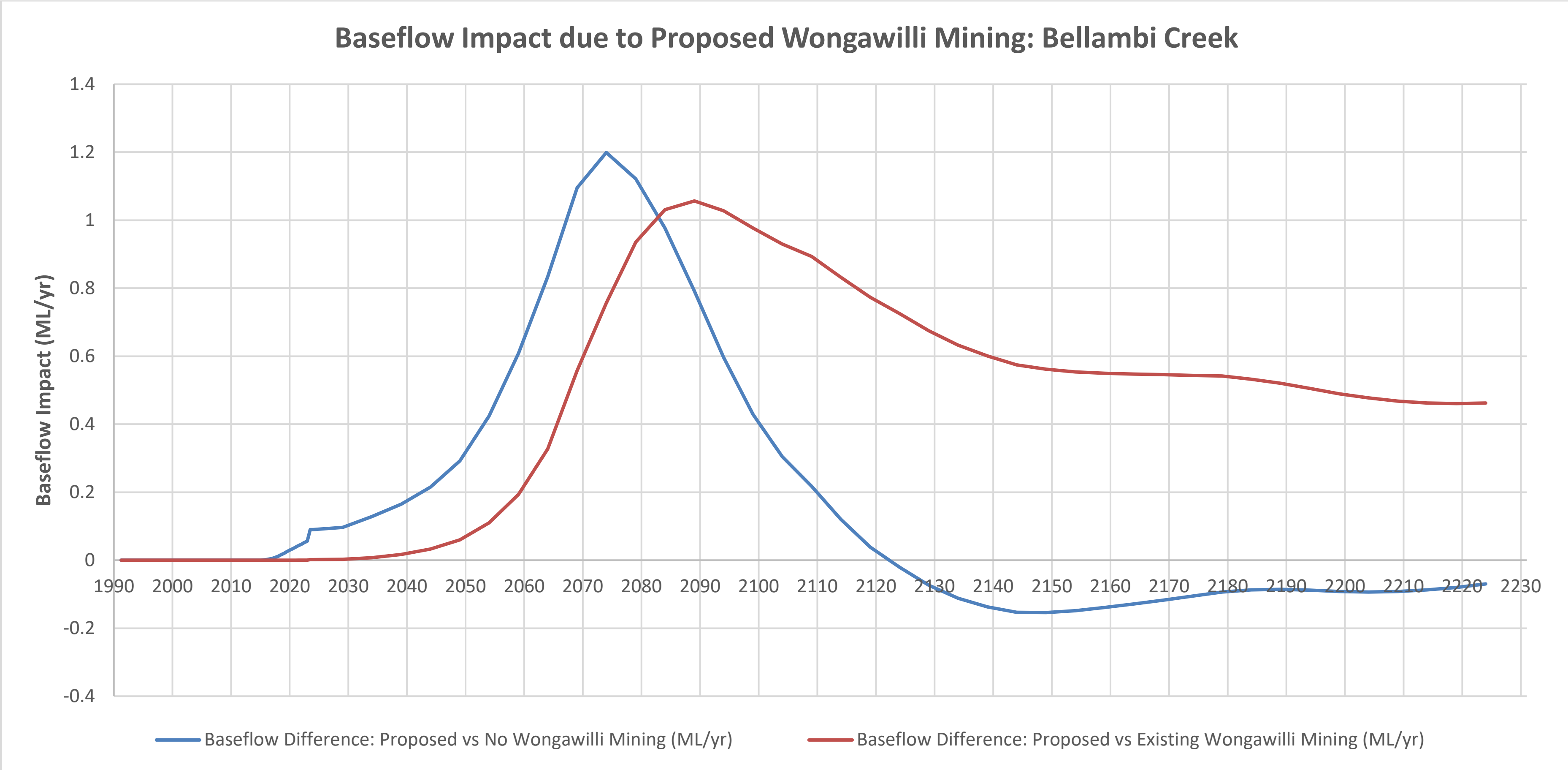


Figure 4. Impacts on Bellambi Creek baseflow: Longwalls 4-6 and first workings (blue); First workings only (red)

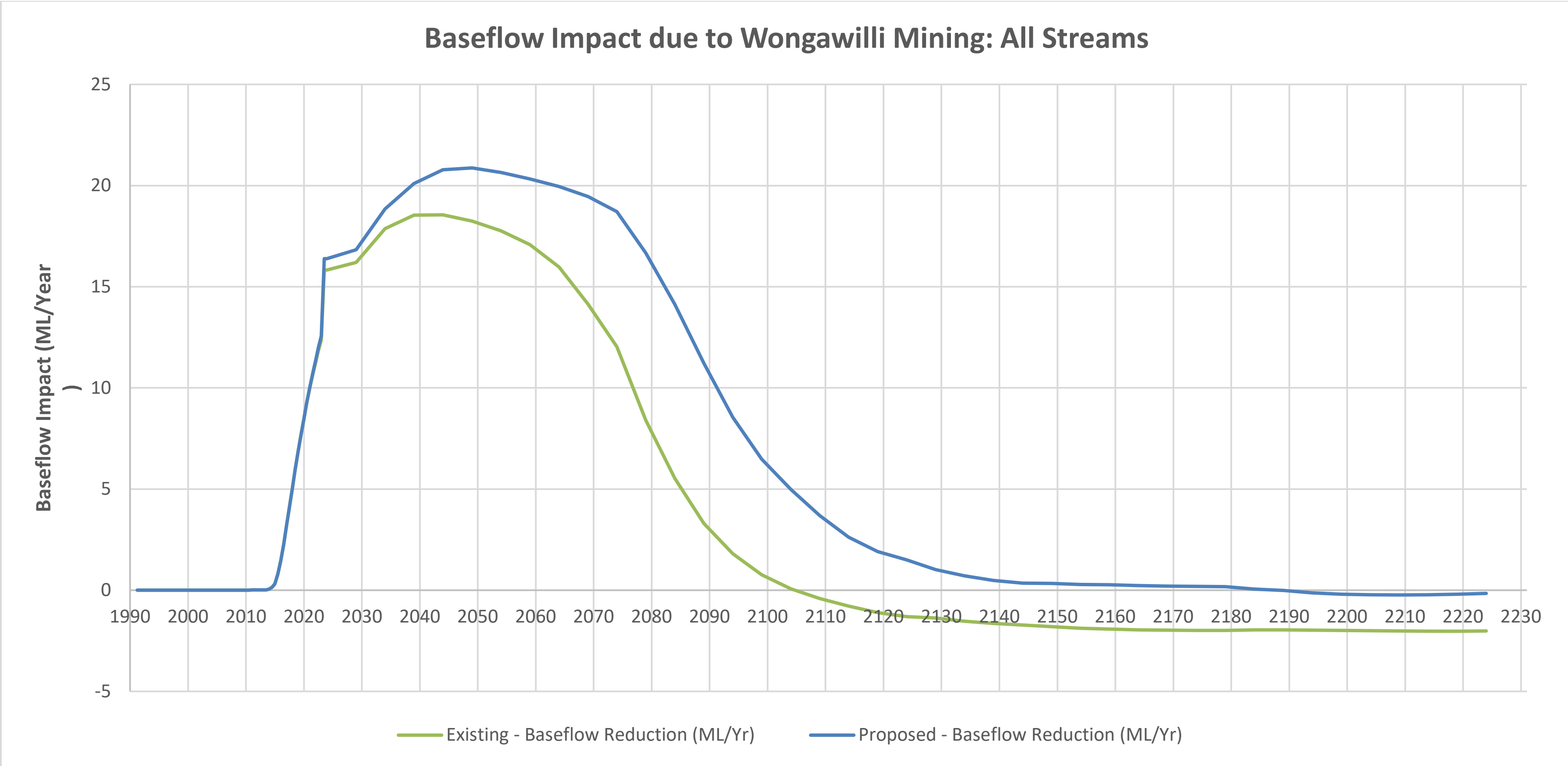


Figure 5. Impacts on total baseflow: Longwalls 4-6 only (green); Longwalls 4-6 and first workings (blue)

APPENDIX 3

Frans Kalf Review of the Russell Vale Model Uncertainty Analysis

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KA Review of the Russell Vale Model Uncertainty Analysis

HydroAlgorithmics (HA) have provided Kalf and Associates with a 28 page document that describes parameter uncertainty of the Russell Vale Colliery mine workings modelling results. The report states that the uncertainty was conducted using Monte Carlo method with numerous alternative parameterisations of the deterministic flow model. Each realisation was generated independently and results were then aggregated for statistical analysis.

While it is evident that considerable effort was applied to the analysis. KA has noted some discrepancies in the choice of specific storage values used in the analysis. On page 4 mean values of specific storage are listed with values for Hawkesbury Sandstone, weathered Bald Hill claystone and weathered Bulgo Sandstone, and also upper Bulgo sandstone assigned with values of 5×10^{-4} m^{-1}.

Recently Rau et al 2018, in particular have indicated that specific storage has physical upper and lower limits in the range 1.3×10^{-5} m^{-1} to 10^{-7} m^{-1}. The value applied therefore for Bulgo Sandstone of 5×10^{-4} m^{-1} and upper Hawkesbury sandstone in the report therefore exceeds this range. The question arises however, whether this would substantially change results derived. KA is of the opinion that it would not be significant. Nevertheless the report leaves it open to criticism for adopting a value outside of the recommended range.

The value for alluvium 10^{-3} m^{-1} is likely to be somewhat higher than recommended although its response would be controlled under drawdown conditions by the specific yield.

The HA report indicates that Monto Carlo method (MCM) requires hundreds of thousands of model runs. And also more complex variants of MCM are also available that in particular includes the *Null Space Monte Carlo (NSMC) method. NSMC* has the advantage of selecting only those cases that calibrate the model while rejecting those cases that do not. The report however has adopted a more straight forward approach by choosing "*for each individual model run to be kept relatively simple*" which allowed the AlgoCompute calibrated realisations to be applied. Run times were significantly reduced in this way although as expected the array generated contained many examples that failed calibration. These cases of non-calibration were rejected (71%).

The report also states that *"each property zone in the model was parametrised using pilot points to allow the properties to vary spatially within each zone*". Pilot points create a smoothing representation of actual field parameters over a region and therefore disregard individual value variations over short to medium distances of parameters. Perhaps the AC modeller could comment on the effect of pilot points smoothing on the overall set of results.

The subsequent section on Monte Carlo convergence in the report is considered to be of value.

It has to be realised however that once mining proceeds that the response of the hydrogeological system could lie to some extent outside the predicted drawdown and flow rate influence generated in the type of analysis presented. This could be the result of changes in mining procedure, unaccounted structural features in the hydrogeological layers, and new data from additional drilling etc. (Caers 2011). Hence on-going monitoring of drawdown response remains the method over time to determine response that may not be accounted for in the analysis presented.

Nevertheless, overall the analysis presented by HydroAlgorithmics (HA) is considered to be suitable and valid.

REFERENCES

Caers 2011. *Modeling Uncertainity in the Earth Sciences.* Wiley-Blackwell

Rau G. C. et al. 2018 *Quantifying Compressible Groundwater Storage by Combining Cross-Hole Seismic Surveys and Head Response to Atmospheric Tides.*AGU100 Journal of Geophysical Research: Earth Surface.

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