HUMECOAL PROJECT

VOLUME 2E

Hume Coal Project and Berrima Rail Project

Response to Submissions

Appendix 2

Prepared for Hume Coal Pty Limited
June 2018

EMM

VOLUME 1 Main Report

VOLUME 2A Appendices 1 to 2
Appendix 1 Register of submitters
Appendix 2 Hume Coal Project Revised Water Assessment
– Main report
– Appendices A to C

VOLUME 2B Appendix 2
Appendix 2 Hume Coal Project Revised Water Assessment
– Appendix D – Part 1

VOLUME 2C Appendix 2
Appendix 2 Hume Coal Project Revised Water Assessment
– Appendix D – Part 2

VOLUME 2D Appendix 2
Appendix 2 Hume Coal Project Revised Water Assessment
– Appendices E to F

VOLUME 2E Appendix 2
Appendix 2 Hume Coal Project Revised Water Assessment
– Appendices G to M

VOLUME 3 Appendices 3 to 7
Appendix 3 Aboriginal cultural heritage
– additional information
Appendix 4 Biodiversity
– additional information
Appendix 5 Hume Coal Project
– Response to community concerns regarding impacts on tourism (Judith Stubbs & Associates 2017)
Appendix 6 Hume Coal Project
– Response to community concerns regarding impacts on land values (Judith Stubbs & Associates 2017)
Appendix 7 Mine design additional information
– 3D numerical modelling

Appendix 2

Hume Coal Project
Revised Water Assessment
– Appendices G to M

Appendix G

EIS Groundwater Assessment peer review reports

HydroAlgorithmics Pty Ltd ● ABN 25 163 284 991
PO Box 241, Gerringong NSW 2534. Phone: (+61 2) 4234 3802

noel.merrick@hydroalgorithmics.com

DATE: 14 September 2016

TO: Luke Edminson
Manager - Environmental Planning
Hume Coal Project
Hume Coal Pty Limited
Suite 7&8 Clarence House,
9 Clarence Street
Moss Vale. NSW 2577

FROM: Dr Noel Merrick

RE: Hume Coal Project - Groundwater Impact Assessment Peer Review

OUR REF: HA2016/8: Peer Review of Hume Coal Groundwater Model

---

Introduction

This report is provided in response to a contract dated 29 October 2015 for conducting a peer review of the Hume Coal EIS groundwater impact assessment with emphasis on the numerical groundwater modelling being conducted by Coffey Geosciences.

The Scope of Services for the peer review is limited to:

- attendance at the Hume Water Strategy Meeting (Technical Groundwater Component) in Sydney;
- preliminary review of draft groundwater modelling documentation;
- preparation of discussion notes and comments based on the draft groundwater modelling documentation;
- attendance at a meeting in Sydney to discuss the draft groundwater modelling documentation, with emphasis on the robustness of work to date and notification of any areas requiring additional work;
- review of final groundwater modelling documentation; and
- preparation of a written peer review report.

The review has been conducted by Dr Noel Merrick in accordance with national groundwater modelling guidelines. It is understood that Dr Frans Kalf is undertaking a broader review of all aspects of the groundwater assessment, in parallel.

Documentation

At the time of writing, the following documents were available for review:

A. Coffey Geotechnics Pty Ltd, 2016, *Hume Coal Project Groundwater Assessment Volume 1: Data Analysis.* Report GEOTLCOV25281AB-ACA for Hume Coal Pty Ltd. 8 August 2016. 70p + 6 Appendices.

B. Coffey Geotechnics Pty Ltd, 2016, *Hume Coal Project Groundwater Assessment Volume 2: Numerical Modelling and Impact Assessment.* Report GEOTLCOV25281AB-ACB for Hume Coal Pty Ltd. 8 August 2016. 67p + 8 Appendices.

In each case, two earlier versions of Documents A and B were reviewed, with provision of verbal review comments only.

The reviewer was involved in various stages of the model development process:

- attendance at the Hume Water Strategy Meeting (Technical Groundwater Component) in Sydney on 28 July 2015;
- attendance at the water peer review meeting in St Leonards on 10 March 2016; and
- attendance at the groundwater model peer review meeting in St Leonards on 22 July 2016.

The major sections in Document A are:

Executive Summary
1. Introduction
2. Climate
3. Surface drainage
4. Geology
5. Subsurface hydraulic properties
6. Groundwater levels
7. Groundwater inflows to the Berrima mine void
8. Groundwater character
9. Groundwater use
10. Hydrogeological conceptual model
11. References

The Appendices for Document A are:

A. Baseflow Analysis
B. Specific Capacity Analysis
C. Additional Hydraulic Conductivity Analysis
D. Hydraulic Head Database
E. Hydraulic Head Surfaces
F. Hydraulic Head Data for the Southeastern Basalt Body

The major sections in Document B are:

Executive Summary
1. Introduction
2. Proposed mining
3. Model development
4. Model calibration
5. Predictive simulation
6. Predictive results
7. Impact assessment
8. Parameter sensitivity analysis
9. Conclusions
10. Limitations
11. References

The Appendices for Document B are:

A. Hume Mining Schedule and Mining Heights

B. Hydraulic Head Targets and Calibrated Hydrographs
C. Downdip and Updip Panel Areas
D. Total and Differential Drawdown of the Water Table and at the Base of the Hawkesbury Sandstone at Virtual Piezometers
E. Total Drawdown of the Water Table at 17 and 30 Years Since the Start of Mining
F. Semesterly Accounts for Intercepted Baseflow to Surface Water Sources and Induced Release from Groundwater Storage in Groundwater Sources
G. Private Water Bore Register, Locations, Results, and Drawdown Hydrographs
H. Basalt Model used to Assess Drawdown in Private Bore GW106103

Review Methodology

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 the newer 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 study.

The 2012 NWC guide builds on the 2001 MDBC guide, with substantial consistency in model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details. However, there is an expectation of more effort in uncertainty analysis, although the guide is not prescriptive as to which methodology should be adopted.

The groundwater model development has been reviewed according to the 2-page Model Appraisal checklist[3] 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, which are informed primarily by Document A.

A detailed assessment has been made in terms of the peer review checklist in **Table 2**. Supplementary comments are offered in the following sections. It should be noted that the verbal review comments offered at the various workshops and meetings have been adopted substantially within the final reports submitted for review.

Report Matters

Document A

Document A is a substantive report of 70 pages plus a 2-page Executive Summary and six appendices. It is well structured and well written with graphics of reasonably quality. It serves as a standalone report without any undue reliance on other reports or inaccessible data sources.

The purpose of the investigation is stated in the Executive Summary and in Section 1: “to support the development of a regional numerical groundwater flow model” and “to assess impacts on the groundwater system and dependent users from proposed mining”. The first objective is addressed in Document A by development of a competent defensible conceptual model that underpins the development of the numerical model addressed in Document B.

Document A follows a systematic methodology and relies upon innovative data analysis and interpretation.

Editorial suggestions:

[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] The NWC guide includes a more detailed checklist with yes/no answers but without the graded assessments of the 2001 checklist, which this reviewer regards as less academic and more informative for readers.

- Figure 3.1: Add creek names on the mine lease; Bong Bong Weir; Berrima Weir; Illawarra Highway.
- Table 3: Define WG and HAW in a footnote.
- Section 4.2: Define “MBA” upon first use.
- Section 4.3: Define “BCSC” and “IEC” upon first use.
- Kh and Kv are nowhere defined.
- Section 5.1: principle (horizontal stress) → principal
- Figure 5.4: Define the sigma terms.
- Section 5.2.1, paragraph 1: The final sentence on solar radiation seems superfluous.
- References: Add Coffey (2007).

Document B

Document B is a well-structured report of 67 pages and eight appendices, plus a 1-page Executive Summary. The graphics are of good quality. The report is not fully standalone as reliance on Document A is necessary to provide the conceptual underpinning for the numerical model.

The purpose of the investigation is stated in Section 1: “to assess impacts on the groundwater system and dependent users from proposed mining”. The objective is addressed in Document B by reporting on the construction, calibration and application of a numerical groundwater flow model. This model is used to predict environmental impacts due to mining, and to explore a number of drawdown mitigation options, namely:

- backfilling with co-disposed tailings;
- sealing individual mining panels; and
- injection of mine inflow water back into the void.

In the Executive Summary there is a statement that “the maximum total drawdown that is caused by Hume operations is 87%”. As readers might be confused by the difference between total drawdown and differential drawdown, it would be worth adding that groundwater extraction by private users will account for 13% of the drawdown to be experienced by the groundwater system.

Editorial suggestions:

- Section 3.2.4: “not considered a separate groundwater source” → “not considered by DPI Water a separate groundwater source”
- Section 4.3.2: Kh Large scale Kv → Large scale Kv
- Clarify whether 99 bores (page 60) or 117 bores (page 53) have more than 2 m drawdown.

Data Matters

Data collation, analysis and interpretation are covered in Document A.

This report covers data acquisition through investigations of climate, stream hydrology, drilling, geology, hydrogeology, hydrostratigraphy, aquifer and aquitard characterisation, piezometry, mine inflows, groundwater flow, water salinity and groundwater usage.

A very large groundwater database has been assembled. Water level information has been obtained at 59 sampling points across 24 sites. There are 46 standpipes at 19 sites, 11 vibrating wire piezometers (VWPs) at three sites, and two private water bores, in the groundwater monitoring network.

Extensive aquifer/aquitard characterisation has been achieved through 28 packer tests, 59 core tests at five sites, and two pumping tests. Coupled with other data drawn from the Southern Coalfield, the best available data has been used to characterise the hydraulic conductivity field in three dimensions (prior to model calibration).

In order to minimise the uncertainty in model predictions, the model has been constrained to replication of data types belonging to four disparate groups:

- groundwater level hydrographs;
- baseflow to streams;
- groundwater discharges to existing mines; and
- measured hydraulic conductivities.

The baseflow analysis provides an important upper limit on rainfall recharge rate, often a difficult parameter to quantify.

Adequate consideration is given to the possible effects of faults and intrusions (especially Mt Gingenbullen) on the groundwater regime. A couple of barrier faults were judged to be necessary inclusions in the numerical model.

In Section 6.2, there is an important observation that the drawdown effects due to the Berrima Mine are prevented from substantial migration to the south, but are unimpeded to the north. This shows that cumulative impacts from the two mines are likely to be limited.

Another important observation is noted in Figure 6.1 (and Figure 6.7), where two zones of desaturation are inferred beneath perched water tables in basalt and the Wianamatta Group shales. This effectively protects the upper formations from drawdown effects due to mining, as those effects cannot propagate upwards through unsaturated material. Document A notes that the "majority of private bores in the basalt are located here". In passing, it is noted that the extent of the desaturation could be due in part to pumping of groundwater for irrigation use.

Although substantial effort has been applied to estimation of groundwater use, the lack of metering on private bores and expected groundwater consumption by unregistered bores will compromise the calibration of a numerical model. To obviate this to some degree, local groundwater level reductions observed on monitoring hydrographs have provided some insight into whether particular bores are pumping close to entitlement allowances. A case in point is illustrated in Section 9.1 where a particular bore was inferred to be pumping 1.5 ML/day in light of observed drawdowns at monitoring bores H32, H35 and H73. Metering of bores is always preferable in order to minimise scientific uncertainty. Figure 9.1 shows that the number of known private water bores is huge.

Some suggested improvements to data analysis are offered here:

- Table 1: Updating the rainfall statistics beyond January 2015.
- Section 3.1: Justification for adoption of 0.0125 as the specific yield; this can probably be referenced to Tammetta and Hewitt (2004).
- Figure 4.2: Addition of groundwater flow directions for the benefit of general readership.
- Section 4.3.1: Explanation for the term "access gallery" for an intrusion.
- Section 5.1: What is the consequence for not correcting laboratory core measurements for overburden pressure?
- Section 5.3, Section 10.2: To honour the natural variability in measured hydraulic conductivities, the summary statements for Kh and Kv/Kh should note that the stated values have an uncertainty of about half an order of magnitude either way.
- Table 4, Section 8.1: Updating the EC and sulphate statistics beyond May 2014.

Document B relies on the data acquisition and data analysis reported in Document A. However, some additional data sources are introduced in Document B:

- Heights of desaturation above Berrima Mine.
- Reassessment of private bore pumping volumes.

Model Matters

Model Construction

The construction of the groundwater flow model is developed in Section 3 of Document B. The model extent is indicated clearly in Drawing 1, being about 32 km (east-west) and about 38 km (north-south). The cell sizes range from 50 m to 200 m, giving good spatial resolution where required. In all there are 15

layers in the model; six of these are applied to the Hawkesbury Sandstone in order to honour the known vertical head gradient across that formation, and two thin layers are allocated to the expected caving zone above the Wongawilli coal seam. Two layers beneath the coal seam permit potential propagation of drawdown effects beyond the outcrop limits of the coal seam.

MODFLOW-SURFACT is the software of choice, and this is appropriate and commonly used for groundwater models of mines. The use of the older version 3 precludes specification of time-varying properties, but for this particular model that option is not necessary.

No spatial variability is applied to the properties of a particular layer (apart from thickness). This is a common approach in groundwater models of mines. An assumption has been made that the occurrence of alluvium is so minor that it has not warranted separate specification. Its exclusion is unlikely to be significant, especially as the alluvium is not designated by DPI Water as a separate water source.

The boundary conditions are adequately justified. These are generally no-flow at distant borders, fixed head at Wingecarribee Reservoir, reference heads at streams (RIV and DRN), escarpment (DRN) and mines (DRN). All are appropriate. The river leakance value of 0.01 day^{-1} is considered high, but this is a conservative assumption that is likely to give an overestimation of mining induced losses from streams.

Specifically excluded from the model are:

- Robertson Basalt.
- Mt Gingenbullen intrusion.
- Cement Works Fault.
- Irrigation recharge.
- Alluvial zones.

However, an adequate defence is put forward for each omission, and this practice is supported by the Principle of Parsimony advocated in modelling guidelines.

Given the avoidance of land subsidence by the chosen mining method for the proposed mine, the height of drainage above caved workings is limited to two thin dedicated caving layers. This is appropriate.

The effect of background pumping by private groundwater users is accommodated in the model. As noted earlier, the lack of metering makes the estimation of pumped volumes and pumping patterns difficult. The estimation process is done as well as could be expected.

An additional local model was developed separately for the basalt outcrop, given that this was represented in the regional model only as a source of vertical recharge to the underlying regional water table. The purpose of the model was to check the likely drawdown at one private bore (GW106103), the only bore in basalt predicted to be drawn down by more than 2 m. The model extent is shown in Figure 1 of Appendix H, being about 6 km (east-west) and about 4 km (north-south). The cell size is uniformly 100 m, and there are two layers in the model. Calibration was limited to the steady-state responses at 25 private bores.

Transient Calibration

The flow model has been calibrated in transient mode from January 2011 to December 2014, and verified through to mid-2015. Monthly stress periods define the temporal resolution of the model, as is normally practised in groundwater models for mines during the calibration phase. There is a model “warm-up” phase from 1926 to the end of 2010, but the temporal resolution during this time is not clear.

As the aim of model calibration is to replicate observed responses, it is important that only reliable data be used. For this model, a thorough quality analysis has been done in order to excise unreliable data.

Several lines of evidence are provided in support of calibration in the form of a scatter plot at the end of the verification period (Figure 4.2), performance statistics at the end of the verification period, cross-section head contours (Figure 4.3), water table contours (Figure 4.4), consistency with field hydraulic conductivities (Figure 4.5), agreement with measured mine inflows (Figure 4.6), consistency with the conceptual flow budget magnitudes (Table 4) and individual hydrograph matches. No residual plots are shown; they would be useful in showing which areas of the model are well calibrated and which are poorly calibrated.

Normally, a scatter plot and performance statistics would be given for the entire calibration period, rather than at one date only. Based on the hydrographic comparisons, the transient flow calibration is considered reasonable in terms of groundwater heads as the observed trends are reproduced and absolute levels and vertical gradients are similar to those observed, though not perfect. The performance statistics at the verification end date are close to the limit of what is acceptable, being about 12 %RMS, 17 mRMS and 3.1 m residual mean. The performance statistics for the full calibration period are not disclosed. The performance is downgraded by the inclusion of several VWP records which are always difficult to replicate in complex mining groundwater models.

The scatter plot in Figure 4.2 shows symmetry about the diagonal line of best fit, indicating no undue bias to overestimation or underestimation of groundwater levels. Possible sources of error are offered in Section 5.3 of Document B.

Calibration to Berrima mine inflow is very good, and simulated baseflows are consistent with inferred rates. Spatial and vertical head patterns are also consistent with expectations.

The flow budget components in Table 4 of Document B compare favourably with pre-modelling estimates in Table 6 of Document A. Evapotranspiration is about three times what was expected, and private pumping is about 50% higher. The mass balance discrepancy of about 4% is higher than normal (1-2%). This indicates that the model must have had some difficulty with numerical convergence.

The calibrated hydraulic conductivity distributions in Figure 4.5 are well supported by field measurements at various scales.

Model Class

The NWC 2012 guide has the concept of "model confidence level", which is defined using a number of criteria that relate to data availability, calibration, prediction scenarios and key indicators. Document B assigns a class of 2-3, weighted about 70% to Class 3 and 30% to Class 2. That is sufficient and appropriate. This recognises correctly that, in practice, a model is likely to straddle two or more classes. The full decision table in Table 2-1 of the guidelines, or the simplified list in **Table 1** (supplied here), could be completed with ticks or highlights to indicate elements of the model that are Class 1, 2 or 3. The row with the most ticks can be argued to be the applicable class.

Table 1. Model Confidence Class Characteristics

CLASS	DATA	CALIBRATION	PREDICTION	INDICATORS
1	Not much. Sparse. No metered usage. Remote climate data.	Not possible. Large error statistic. Inadequate data spread. Targets incompatible with model purpose.	Timeframe >> calibration Long stress periods. Transient prediction but steady-state calibration. Bad verification.	Timeframe > 10x Stresses > 5x Mass balance > 1% (or single 5%) Properties <> field. Bad discretisation. No review.
2	Some. Poor coverage. Some usage info. Baseflow estimates.	Partial performance. Long-term trends wrong. Short time record. Weak seasonal replication. No use of targets compatible with model purpose.	Timeframe > calibration. Long stress periods. New stresses not in calibration. Poor verification.	Timeframe = 3-10x Stresses = 2-5x Mass balance < 1% Some properties <> field measurements. Some key coarse discretisation. Review by hydrogeo.
3	Lots. Good aquifer geometry. Good usage info. Local climate info. K measurements. Hi-res DEM.	Good performance stats. Long-term trends replicated. Seasonal fluctuations OK. Present day data targets. Head and flux targets.	Timeframe ~ calibration. Similar stress periods. Similar stresses to those in calibration. Steady-state prediction consistent with steady-state calibration. Good verification.	Timeframe < 3x Stresses < 2x Mass balance < 0.5% Properties ~ field measurements. Some key coarse discretisation. Review by modeller.

Scenario Analysis [Document B]

Table 8 in Document B provides a definition of the two prediction scenarios that differ according to the presence or absence of Hume mining. The base case includes co-disposed tailings emplacement filling 36% of the mined void. Variants of the base case examined other mitigation options, although their results are not reported.

Annual stress periods define the temporal resolution of the model, as is normally practised in groundwater models for mines during the prediction phase. The prediction period is 19 years, followed by 81 years of recovery for the adopted base case and null scenario.

Document B notes that there were many trial runs with various mitigation options to determine the required level of abstraction from Hume bores for mine water management.

Flow budgets (averaged over 19 years) are provided in Tables 10 and 11 for the base case and the null scenario, respectively.

Differential water table drawdown impacts are examined spatially (Figures 6.6 and 6.7) and temporally at representative sites (Figure 6.4). In accordance with the Aquifer Interference Policy (AIP), the extent of impact is displayed for drawdowns of 2 m or more.

The prediction scenarios are designed properly and the analysis of results is competent. The findings are focused on the minimal harm considerations of the AIP and the licensing requirements of water sharing plans. The primary AIP consideration is drawdown, which is assessed in terms of differential drawdown (relevant to the AIP) and total drawdown (relevant to practical considerations as to whether or when a particular private bore might go dry). The latter consideration goes beyond what is required by the AIP. There is no specific analysis of the water quality AIP minimal harm considerations for shift in beneficial use of groundwater and increase in stream salinity. The latter case is not applicable as no increased baseflow to streams would occur.

The potential drawdown impact zone is well defined. A total of 117 bores is likely to be affected beyond the AIP threshold, with only one of those bores situated in basalt (GW106103)[4]. Each potentially affected bore is listed in Table 1 of Appendix G and shown on Map 1 of the same appendix. The predicted temporal drawdown at each bore is illustrated in 24 charts.

For licensing purposes, complex disaggregation of model results was required for 16 designated water sources, 14 of which register some predicted take. The maximum groundwater take is 5.2 ML/day while the maximum surface water take (in the form of intercepted baseflow) is 0.9 ML/day (for Medway Rivulet) which is about one-third of the estimated average natural baseflow. The median maximum from the separate water sources is 0.04 ML/day. The takes are also reported temporally in 6-monthly steps.

Sensitivity Analysis [Document B]

Table 8 in Document B provides a definition of the three sensitivity prediction scenarios that assess the importance of key uncertain model parameters: A: caving height; B: vertical hydraulic conductivity; and C: mine drain conductance. The respective increases in mine inflow are about 4%, 28% and 0%. Only the vertical hydraulic conductivity is significant. As noted in Document B, this parameter is as well constrained as is possible through the calibration process.

There is no comment on whether the perturbations applied in the sensitivity analysis have compromised calibration performance. The sensitivity results are meaningful only if the model remains adequately calibrated.

Also, there is no examination of model outputs other than mine inflow. Does the sensitivity analysis result in any significant changes in the estimated drawdown and baseflow impacts?

There is no separate report section on uncertainty analysis. Explicitly, uncertainty in mine inflow is assessed through the sensitivity analysis. Implicitly, it is argued in Document B that uncertainty in model predictions is low because all model parameters are constrained through a multi-objective calibration process that honours heads

[4] However, the separate basalt model predicts less than 2 m drawdown at this bore.

and flows simultaneously.

Conclusion

The purpose of the reported groundwater investigation is an assessment of potential environmental impacts due to the Hume Coal mining method and mine plan, in the context of the minimal harm considerations of the Aquifer Interference Policy and the licensing requirements of water sharing plans. The modelling component of the investigation is also expected to comply with national guidelines for groundwater modelling.

The reviewer finds that the modelling study is fully compliant with guidelines, and often goes beyond state of the art techniques.

The reviewer also finds that there is a very thorough assessment of the complex licensing requirements in terms of 16 relevant water sources.

With respect to the requirements of the Aquifer Interference Policy, the drawdown minimal harm consideration is explored fully. The assessment of whether or when a particular private bore might go dry goes beyond what is required by the Aquifer Interference Policy. However, there is no specific analysis of the water quality minimal harm considerations for shift in beneficial use of groundwater and increase in stream salinity. The latter case is not applicable as no increased baseflow to streams would occur.

Accordingly, overall, the reviewer considers that the model is *fit-for-purpose*.

Table 2. MODEL APPRAISAL: **Hume Coal 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								
1.1	Is there a clear statement of project objectives in the modelling report?		Missing	Deficient	Adequate	Very Good			For both documents.
1.2	Is the level of model complexity clear or acknowledged?		Missing	No	Yes				70% Class 3 & 30% Class 2 confidence classification. What is achieved could be substantiated by ticking checklist attributes for all classes, as models will bridge several classes.
1.3	Is a water or mass balance reported?		Missing	Deficient	Adequate	Very Good			Doc B: Tables 4, 10, 11.
1.4	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	Very Good			AIP and WSP requirements are met. Drawdown mitigation options are explored.
1.5	Are the model results of any practical use?			No	Maybe	Yes			Adequately calibrated to multiple observation datasets. Reliability is thereby enhanced.
new	Is the model "fit-for-purpose"?			No	Maybe	Yes			Purpose is assessment of potential environmental impacts due to mining method and mine plan. Fitness is defended in Section 4.3.5.
2.0	DATA ANALYSIS								*Document A.*
2.1	Has hydrogeology data been collected and analysed?		Missing	Deficient	Adequate	Very Good			Large groundwater database: 59 sampling points at 24 sites. Extensive aquifer/aquitard characterisation by packer tests (28), core tests (59) and pumping tests (2). Good coverage of hydrostratigraphy and water quality.
2.2	Are groundwater contours or flow directions presented?		Missing	Deficient	Adequate	Very Good			Flow directions should be added to Figure 6.3: Wianamatta Group and Upper Hawkesbury Sandstone head surfaces. Similar maps in Appendix E for Lower Hawkesbury Sandstone and Wongawilli Seam.

2.3	Have all potential recharge data been collected and analysed? (rainfall, streamflow, irrigation, floods, etc.)		Missing	Deficient	Adequate	Very Good			Rainfall recharge is well constrained by baseflow analysis. Groundwater and creek water levels are examined to infer gaining/losing status.
2.4	Have all potential discharge data been collected and analysed? (abstraction, evapotranspiration, drainage, springflow, etc.)		Missing	Deficient	Adequate	Very Good			Substantial private abstraction – difficult to estimate.
2.5	Have the recharge and discharge datasets been analysed for their groundwater response?		Missing	Deficient	Adequate	Very Good			Limited illustration of cause-and-effect analysis (e.g. Figure 3.3 and commentary in Section 6.1). Hydrographs in Appendix D are not compared with rainfall residual mass. Vertical head gradients are considered (e.g. minor in Figure 6.6).
2.6	Are groundwater hydrographs used for calibration?			No	Maybe	Yes			Extensive monitoring network.
2.7	Have consistent data units and standard geometrical datums been used?			No	Yes				
3.0	CONCEPTUALISATION								*Document A.*
3.1	Is the conceptual model consistent with project objectives and the required model complexity?		Unknown	No	Maybe	Yes			Thorough development of conceptualisation.
3.2	Is there a clear description of the conceptual model?		Missing	Deficient	Adequate	Very Good			Most of Document A. Summarised in Section 10.
3.3	Is there a graphical representation of the modeller's conceptualisation?		Missing	Deficient	Adequate	Very Good			Figure 10.3.
3.4	Is the conceptual model unnecessarily simple or unnecessarily complex?			Yes	No				Some unnecessary features are justifiably excised.
4.0	MODEL DESIGN								*Document B.*
4.1	Is the spatial extent of the model appropriate?			No	Maybe	Yes			Dimensions 38 km x 32 km. Area 752 km^2. 379 columns x 425 rows x 15 layers. Cell sizes 50m to 200m. 6 layers in Hawkesbury Sandstone. Separate layers for caving. Local model: 6 km x 4 km. Area 15 km^2. 100 columns x 40 rows x 2 layers. Cell size 100m.

4.2	Are the applied boundary conditions plausible and unrestrictive?		Missing	Deficient	Adequate	Very Good			Generally no-flow at distant borders, fixed head at Wingecarribee Reservoir, reference heads at streams (RIV and DRN), escarpment (DRN) and mines (DRN). All appropriate. RIV leakance of 0.01 /day is high, hence likely to overestimate mining induced losses from streams (conservative assumption). Not included: Irrigation recharge; Cement Works Fault; Robertson Basalt; Mt Gingenbullen intrusion.
4.3	Is the software appropriate for the objectives of the study?			No	Maybe	Yes			MODFLOW SURFACT v3. There is a later v4 that allows time-varying properties; however, not necessary for this mine model.
5.0	CALIBRATION								*Document B.* 2011-2014: 4 years. Also 1926-2010 model warmup.
5.1	Is there sufficient evidence provided for model calibration?		Missing	Deficient	Adequate	Very Good			Several lines of evidence: scattergram; performance statistics for verification; hydrographs plots; spatial pattern; section head pattern; mine inflow; baseflows; K values. Did not use PEST. No indication of spatial distribution of residuals. No scattergram for full calibration period.
5.2	Is the model sufficiently calibrated against spatial observations?		Missing	Deficient	Adequate	Very Good			Spatial head pattern in Figure 4.4 is as expected. Section head pattern in Figure 4.3 is reasonable. Vertical head gradients on hydrographs – some good, some poor.
5.3	Is the model sufficiently calibrated against temporal observations?		Missing	Deficient	Adequate	Very Good			Mine inflow very good. Hydrographs for all bores are presented for comparison. Reasonable groundwater level matches and trends – simulated responses are quiescent. Some vertical gradients are reproduced.
5.4	Are calibrated parameter distributions and ranges plausible?		Missing	No	Maybe	Yes			Figure 4.5

5.5	Does the calibration statistic satisfy agreed performance criteria?		Missing	Deficient	Adequate	Very Good			3.1m residual mean; 17mRMS; 12 %RMS.
5.6	Are there good reasons for not meeting agreed performance criteria?		Missing	Deficient	Adequate	Very Good			Reasons given in Section 4.3.1 for VWP groundwater levels.
6.0	VERIFICATION								*Document B.* Jan-Aug. 2015: 8 months.
6.1	Is there sufficient evidence provided for model verification?		Missing	Deficient	Adequate	Very Good			Several lines of evidence: scattergram; performance statistics; hydrographs plots; spatial pattern; section head pattern; mine inflow; baseflows. No comparison offered with calibration performance. Short period of time (6-8 months).
6.2	Does the reserved dataset include stresses consistent with the prediction scenarios?		Unknown	No	Maybe	Yes			Short period of time (6-8 months).
6.3	Are there good reasons for an unsatisfactory verification?		Missing	Deficient	Adequate	Very Good			Reasons given in Section 4.3.1 for VWP groundwater levels.
7.0	PREDICTION								*Document B.*
7.1	Have multiple scenarios been run for climate variability?		Missing	Deficient	Adequate	Very Good			Average climate only.
7.2	Have multiple scenarios been run for operational /management alternatives?		Missing	Deficient	Adequate	Very Good			Mitigation options. But only the base case is reported.
7.3	Is the time horizon for prediction comparable with the length of the calibration / verification period?		Missing	No	Maybe	Yes			19 years' prediction. 5 years combined calibration and verification.
7.4	Are the model predictions plausible?			No	Maybe	Yes			Thorough investigation.
8.0	SENSITIVITY ANALYSIS								*Document B.*
8.1	Is the sensitivity analysis sufficiently intensive for key parameters?		Missing	Deficient	Adequate	Very Good			A: caving height; B: vertical hydraulic conductivity; and C: mine drain conductance.
8.2	Are sensitivity results used to qualify the reliability of model calibration?		Missing	Deficient	Adequate	Very Good			Not reported.
8.3	Are sensitivity results used to qualify the accuracy of model prediction?	N/A	Missing	Deficient	Adequate	Very Good			Only for mine inflow: 0-28% increase. Not reported for changes in drawdown and baseflow impacts.

9.0	UNCERTAINTY ANALYSIS								*Document B.*
9.1	If required by the project brief, is uncertainty quantified in any way?		Missing	No	Maybe	Yes			Based on sensitivity analysis for three model parameter perturbations. Not a formal uncertainty analysis. Only reported for mine inflow: 0-28% increase. Not reported for changes in drawdown and baseflow impacts.

KALF AND ASSOCIATES Pty Ltd
Hydrogeological, Numerical Modelling Specialists

KA Peer Review of Coffey Groundwater Modelling Assessment of the Hume Coal Project

Dr F. Kalf
B.Sc. M.App.Sc PhD
12 September 2016

Table of Contents

Background and Summary of Key Issues 3

Peer Review Assessment 4

- Previous Studies and Reviews 4
- Hydrogeological and Modelling Description 4
- Model Calibration and Prediction 5
- Sensitivity and Uncertainty 6
- Groundwater Monitoring and Mitigation 6
- Conclusions and Considerations 7

References 7

- Appendix: Model Appraisal 8

Background and Summary of Key Issues

This report is the Kalf and Associates Pty Ltd (KA) final peer review commissioned by Hume Coal Pty Ltd (Hume) for the Coffeys Geotechnics Pty Ltd (Coffey) hydrogeological and groundwater modelling assessment. This KA review of the Coffey reports (Volume 1 Data Analysis and Volume 2 numerical modelling) follows on from KA requested clarifications and comments about the earlier draft versions of those reports. For the modelling review herein the available Modelling Guideline documents (NWC 2012, MDBC 2001) content have been taken into consideration in this assessment. A modelling appraisal checklist is provided herein as an attached Appendix.

POSCO Australia proposes to develop and operate an underground mine that would extract coal from the Wongawilli Coal seam in the Permian Illawarra Coal Measures. Mining proposed is known as the Pine Feather (PF) method. This method uses non-caving first workings in order to restrict any subsidence of overlying strata. Longwall mining panels are therefore not to be employed and hence there would not be any development of goaf caving. The PF mining would involve construction of parallel but separated relatively small dimension tunnels ('plunges') extending either side of a 'panel' comprised of gate roads (Figure 1.1 Coffey 2016 Vol 1). The plunges would remain open post-mining with deformation extending to less than 3m into the overlying roof according to the Coffey report (Section 1.1 Coffey 2016 Vol 1). Further more detailed discussion on this deformation is provided in the same Coffey (2016) report in Section 10.5.

Mining is proposed for a period of 19 years followed by closure and rehabilitation over a two year period. During operations coal washery tailings are to be placed in the main mined out voids with subsequent sealing of 'panel' gate roads using bulkheads. Excess mine water will also be stored in the sub-surface workings.

The mining zone is situated within the Hawkesbury River Basin with Triassic Narrabeen and Hawkesbury Sandstone overlying the Coal Measures together with an isolated younger basalt area south of the Hume mining zone. Alluvial development is limited along the upstream reach of the Wingecarribee River, the main drainage within the region but is not a significant issue with regard to mining influence.

Modelling included using data from the Berrima mine that was active from 1926 to 2011 for setting up the starting hydraulic head distribution followed by transient calibration from 1 January 2011 to 31 December 2014.

The modelling results indicate that total drawdown within the sedimentary strata would affect 117 private bores with 99 private bores having a drawdown (i.e. 'differential drawdown') predicted greater than 2m or more due to only the Hume mining after 17 years of operation (Figure 6.6 Coffey 2016 Vol 2). Table 16 (Vol 2) indicates bores that may require replacement during mining as a consequence of drawdown influence.

No direct leakage from the Wingecarribee River flow due to the Hume Project is predicted although there would be some interception of about 0.85 ML/day of its baseflow at year 13. Interception of Medway Rivulet baseflow is predicted to be about 0.93 ML/day (Table 14 Coffey 2016 Vol 2).

The modelling results indicate shallow watertable drawdown greater than 2m that may

influence ecosystems. This influence, if any, is still to be determined by ecologistists.

Groundwater quality in the mine site area varies depending on lithology of the strata although the overall salinity is low and within the 'fresh' category. Hawkesbury Sandstone has the best quality with an average EC of 296 microSeimens, whilst the Wongawilli Coal seam has an average EC of 392 microSeimens.

Inflow rate to the mine steadily increases to a maximum in year 15 to about 6.3ML/day and then decreases more rapidly to less than 1.5 ML/day in year 22 (Figure 6.1 Coffey 2016 Vol 2). Inflow includes predominately intercepted groundwater storage in the sedimentary strata and some very minor baseflow volume. Total volume of intercepted water comprising almost all sedimentary strata groundwater is predicted to be about 33 GL during the active mine operation.

Peer Review Assessment

Previous Studies and Reviews

The surrounding region of the proposed Hume Coal Mine has had previous mining operations since the 1800s all of which have now been abandoned. These mines include the Berrima Mine (1926 to 2013); Loch Catherine Mine (1924 to 1958) beneath the Berrima Colliery Stockpile; Southern Colliery 5km from Hume site and several other smaller operational adits.

Parsons-Brinckerhoff (2015) prepared a fieldwork and monitoring report for Hume Coal Pty Ltd while Pritchard et al. (2004) provide a review of the status of groundwater resources in the Southern Highlands, NSW. Additional references on studies conducted in the region are provided in Coffey (2016 Vol1 and 2).

Hydrogeological and Modelling Description

Coffey (2016 Vol 1 and 2) have provided a detailed and informative exposition of the hydrogeology and modelling assessment of the impact of sub-surface mining at the proposed Hume Coal Project. The reports cover a wide range of topics that are included within the main headings as follows. ***Volume 1:*** *Executive Summary; Climate; Surface drainage; Geology; Subsurface hydraulic properties; Groundwater levels; Groundwater inflows to Berrima void; Groundwater character; Groundwater use; Hydrogeological conceptual model; References.* ***Volume 2:*** *Executive Summary; Proposed mining; Model development; Model Calibration; Predictive simulation; Predictive results; Flow budget; Drawdown; Impact assessment; Parameter sensitivity analysis; Conclusions; Limitations and References.*

Model Conceptualisation and Simulation Methods

Model pre-mine interpolated water table for the Hume Mine Project region by Coffey is shown in Figure 4.4 (Vol 1); pre-mine hydraulic heads in Sandstone and coal seam (Figure 6.3 and in Appendix E); hydraulic head section (Figure 6.1 Vol 1) and interpolated heads for the basalt flow unit cross-section in Figure 6.7 (Vol 1). No post-mine conceptual figure is provided.

A total of 13 active model layers (Coffey 2016 Vol 2, Table 2) were used for the Hume numerical model. They include layer 1 representing the Wianamatta Group (where present); layers 2 to 7 subdividing the Hawkesbury Sandstone into variable thickness layers; layer 8

comprising the Narrabeen Group interburden; layers 9 to 12 representing the Wongawilli Seam and Illawarra Coal Measures and basal layer 13 representing the Shoalhaven Group. This layer subdivision is considered to be suitable and provides sufficient vertical resolution of model hydraulic head calculation.

Coffey has used the well-known MODFLOW-SURFACT (MS) code for the Hume numerical model. No plan view of the cell mesh is provided because of unsuitable cell mesh print resolution according to Coffey. However, model area and the area of the proposed Hume workings within it are presented in Drawing 1 'Regional Locality Plan' (Volume 2) at the end of that report. The cell mesh is comprised of 379 columns and 425 rows with dimensions 50m x 50m over the Hume mine site expanding to 50m x 100m and 200m x 200m elsewhere. A representative cell mesh layering cross section is presented in Figure 3.1 (Coffey 2016 Vol 2).

The boundaries chosen for the model area are considered suitable. They included no-flow boundary along topographic divides; discharge zones along drainage channels; constant head of the Wingecarribee Reservoir and discharge zones at escarpments modelled as 'drain' cells. Remaining boundaries are at a sufficient distance not to interfere or influence drawdowns within or immediately surrounding the Hume proposed mining zone.

Depictions of the various ephemeral and perennial stream channels have been modelled using the MS 'River' package with the ability of the model to set stage such that the Wingecarribee River acts either as a gaining or losing stream. This package was also used for simulating Medway Dam heads. Remaining ephemeral channels were set using the 'drain' package. This approach is suitable for the modelled area.

The model applies recharge as a constant percentage of incident rainfall. Evapotranspiration rate was applied at a constant 3mm/day (1095.5 mm/year) with a 1.5m extinction depth. This extinction depth is quite shallow but its limited affect would be countered to a large extent by the relatively high potential ET rate applied.

Transient simulation over a long period (1926 to 2011) was used to set up initial historical heads followed by transient production simulation and a verification period. Initial hydraulic parameters were based on measured values of the mining site and elsewhere (Coffey 2016 Vol 1, Figures 5.1, 5.2).

Model Calibration and Prediction

The calibration simulations were conducted in two stages. The first stage included a transient simulation over the period of Berrima mining from 1926 to 2011 to provide a model area starting head distribution in lieu of the conventional 'Steady State' simulation. This was followed by a second stage during the end of mining period at Berrima from 1 January 2011 to 31 December 2014. Verification was conducted for a short period from 1 January 2015 to mid-2015. The approach used for calibration is considered by KA to be suitable for the hydrogeological conditions and mining activity in the area.

Calibration transient targets included hydrographs of one to three years duration at 49 points in the subsurface at 23 locations. In addition the DeBeaujeu bore (Figure D1 Appendix D Volume 1) was used for monitoring the Berrima mining influence. There is agreement that the groundwater level response hydrograph (Appendix D) of this bore is predominately due to mining influence but also with minor influence of recharge.

The hydrograph of Culpepper Production (C Prod) bore that is situated to the east of the DeBeaujeu bore indicates short intermittent to more intense intermittent pumping signatures

that has also been influenced by Berrima mining and to a minor extent due to lower rainfall period during 2012.

Calibrated hydraulic conductivity and storage parameters used in the model are provided in the Table 3 (Coffey 2016 Vol 2). A comparison of calibrated and *"observed",* that is hydraulic testing or core values, is provided in Figure 4.5 (Vol 2). All values of hydraulic conductivity and storage appear plausible.

The values for vertical hydraulic conductivity of model layers 4 and 5 that represent part of the subdivided Hawkesbury Sandstone are lower than in adjacent layers. Coffey contend these somewhat lower values are justified based on the calibration outcomes. Coffey has advised that if layers 4 and 5 had been given similar vertical hydraulic conductivity as adjacent layers the modelled base flows would have been too low and observed mine inflows too high. Also under these conductivity conditions shallow drawdown would have been too large and deeper drawdowns too small.

Calibration fit statistic for the modelled and observed hydraulic heads is about 12% SRMS (scaled root mean square) which just exceeds the 10% recommended by MDBC (2001) (Coffey 2016 Figure 4.2 Vol 2). But given the unknown precise mining activity over time at previous active mines this is acceptable.

A comparison made between measured and modelled head distribution section (Figure 4.3 Vol 2) on first inspection is considered to be only fair; however, it is noted that the sections are not equivalent but are offset from each other and the interpreted head distribution is based on relatively sparse manually interpolated data whilst the model heads are calculated at every cell mesh location yielding a much higher head resolution in the modelled section. Comparison between measured and simulated hydrographs is considered reasonable to quite good (Appendix B).

Model verification is considered by KA to be preliminary over the relatively short time period available from 1 January 2015 up to July 2015. Hence additional verification will require ongoing monitoring for a longer time period.

Sensitivity and Uncertainty

Several sensitivity runs were conducted that included changing the relaxation deformation height of the plunges; an increase in vertical hydraulic conductivity of model layers by a factor 3. As noted above, the implications independently of increasing model layers 4 and 5 vertical hydraulic conductivity was also assessed. In addition, sensitivity included a change in Hume mine drain conductance that yielded only a minor change in inflow. While there is no formal uncertainty analysis Coffey have outlined the sources of uncertainty in the hydraulic head targets and have confidence that the calibration and in particular the vertical hydraulic conductivity values *"have a high level of reliability"* and therefore reduce uncertainty in model outputs (Vol 2, Executive Summary and Section 8 – Coffey 2016).

Groundwater Monitoring and Mitigation

There is currently an extensive groundwater level and quality monitoring network operated by Hume (Volume 1 Executive Summary) and in addition, rainfall, and streamflow monitoring at four gauges is also conducted. It is understood this monitoring would continue prior to and during the mining project. The monitoring data, including where possible private bore water levels, would be adequate to validate the modelling predictions.

Mitigation measures (Section 5.3.1 Vol 2 Coffey 2016) would form an integral part of the mining project and include bulkhead sealing and tailings backfilling. In addition, injection of excess mine water back into the voids through the bulkheads is proposed.

It is understood that the fate of any injected water and any expression of tailings liquor will be assessed in a separate document by another consultant and KA understands that assessment be conducted using a suitable solute-transport numerical simulation code. Those outcomes are not part of the review presented herein nor was it included in the brief provided by Hume for inclusion in this review.

Although not specifically discussed in either report volumes there is a need to indicate what action Hume would take for those 99 private bores (Table 2, Vol 2 Appendix G, Coffey 2016) that will be affected due to Hume mine differential drawdown greater than the 'minimal harm' of 2m and how the projected 16 replacement bores (Table 16, Vol 2) would be assessed, constructed and tested.

Conclusions and Considerations

This peer review has assessed the adequacy of the hydrogeological data and the numerical model for predicting the drawdown influences of the proposed Hume coal mining project. The hydrogeological description, conceptualisation, model design, simulations have been conducted in a professional manner and the exposition of these activities in the two Coffey reports are described in detail. No major flaws in the hydrogeological information or the modelling have been detected in the reports Volumes 1 and 2.

Because of the influence of Hume mining is likely to affect a large number of bores, frequent monitoring of the groundwater system would need to be continued prior to and during mining operation operations and for some years post mining. Monitoring bore data should be reviewed and compared with modelling results every 2 years.

References

Coffey Geotechnics Pty Ltd (Coffey 2016) *Hume Coal Project Groundwater Assessment*. Reports *Volume 1 and 2 prepared for Hume Coal Pty Ltd. August.*

National Water Commission (NWC) 2012 *Australian Groundwater Modelling Guidelines. Report prepared by Barnett, B., et al. Waterlines Report Series No 82, June.*

Murray Darling Basin Commission (MDBC) 2001. *Groundwater Flow Modelling Guideline. Report prepared by Middlemis, H., Merrick, N., and Ross, J., Jan.*

Parsons-Brinckerhoff (2015) *Water Fieldwork and Monitoring Report. Draft Report2200539A-RES-REP-7812 RevA prepared for Hume Coal Pty Ltd. Nov*

Pritchard et al. (2004)*A review of the status of the groundwater resources in the Southern Highlands, NSW. NSW Department of Infrastructure, Planning and Natural Resources. May.*

APPENDIX

MODEL APPRAISAL

	ISSUES	Not applicable or Unknown					COMMENTS
1.0	**THE REPORT**						
1.1	Is there a clear statement of project objectives in the modelling report?		Missing	Deficient	Adequate	Very good	
1.2	Is the level of model complexity clear or acknowledged?		Missing	No	Yes		
1.3	Is a water or mass balance reported?		Missing	Deficient	Adequate	Very good	
1.4	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	Very good	
1.5	Are the model results of any practical use?			No	Maybe	Yes	
2.0	**DATA ANALYSIS**						
2.1	Has hydrogeology data been collected and analysed?		Missing	Deficient	Adequate	Very good	
2.2	Are groundwater contours or flow directions presented?		Missing	Deficient	Adequate	Very good	
2.3	Has all relevant potential recharge data been collected and analysed?		Missing	Deficient	Adequate	Very good	
2.4	Has all relevant potential discharge data been collected and analysed?		Missing	Deficient	Adequate	Very good	
2.5	Have the recharge and discharge datasets been analysed for their groundwater response?		Missing	Deficient	Adequate	Very good	
2.6	Are groundwater hydrographs used for calibration?			No	Maybe	Yes	
2.7	Have consistent data and standard elevation units 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	
3.3	Is there a graphical representation of the modeller's conceptualisation?		Missing	Deficient	Adequate	Very good	
3.4	Is the conceptual model unnecessarily simple or unnecessarily complex?			Yes	No		
4.0	**MODEL DESIGN**						
4.1	Is the spatial extent of the model appropriate?			No	Maybe	Yes	
4.2	Are the applied boundary conditions plausible and unrestrictive?		Missing	Deficient	Adequate	Very good	
4.3	Is the software appropriate for the objectives of the study?			No	Maybe	Yes	
5.0	**CALIBRATION**						
5.1	Is there sufficient evidence provided for model calibration?		Missing	Deficient	Adequate	Very good	
5.2	Is the model sufficiently calibrated against spatial observations?		Missing	Deficient	Adequate	Very good	

5.3	Is the model sufficiently calibrated against temporal observations?		Missing	Deficient	Adequate	Very good	
5.4	Are calibrated parameter distributions and ranges plausible?		Missing	No	Maybe	Yes	
5.5	Does the calibration statistic satisfy agreed performance criteria?		Missing	Deficient	Adequate	Very good	
5.6	Are there good reasons for not meeting agreed performance criteria?		Missing	Deficient	Adequate	Very good	Performance criteria have been met
6.0	**VERIFICATION**						
6.1	Is there sufficient evidence provided for model verification?		Missing	Deficient	Only just Adequate	Very good	Preliminary but much longer period would be desirable with ongoing monitoring.
6.2	Does the reserved dataset include stresses consistent with the prediction scenarios?		Unknown	No	Maybe	Yes	
6.3	Are there good reasons for an unsatisfactory verification?		Missing	Deficient	Adequate	Very good	
7.0	**PREDICTION**						
7.1	Have multiple scenarios been run for climate variability?		No	Deficient	Adequate	Very good	
7.2	Have multiple scenarios been run for operational management alternatives?		No	Deficient	Adequate	Very good	
7.3	Is the time period for prediction comparable with the duration of the calibration period?		Missing	Greater than	Similar to	Less than	
7.4	Are the model predictions plausible?			No	Maybe	Yes	
8.0	**SENSITIVITY 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	Yes	
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	Adequate	Yes	
9.2	**Is the model 'fit-for-purpose'?**			No		Yes	

Appendix H

Critique of Pells Consulting Modelling Studies

Critique of Pells Consulting Modelling Studies

Hume Coal Project | Response to Submissions

Prepared for Hume Coal EIS - Response to Submissions| 20 June 2018

Critique of Pells Consulting Modelling Studies

Hume Coal Project | Response to Submissions

Prepared for Hume Coal EIS - Response to Submissions | 20 June 2018

Ground Floor, Suite 01, 20 Chandos Street
St Leonards, NSW, 2065

T +61 2 9493 9500
F +61 2 9493 9599
E info@emmconsulting.com.au

www.emmconsulting.com.au

Critique of Pells Consulting Modelling Studies

Final

Report J14136 | Prepared for Hume Coal | 20 June 2018

Prepared by	**John Ross**	Approved by	**Liz Webb**
Position	Associate Hydrogeologist, National Technical Leader	Position	Director, Divisional Leader - Water and Land
Signature		Signature	
Date	20 June 2018	Date	20 June 2018

This report has been prepared in accordance with the brief provided by the client and has relied upon the information collected at the time and under the conditions specified in the report. All findings, conclusions or recommendations contained in the report are based on the aforementioned circumstances. The report is for the use of the client and no responsibility will be taken for its use by other parties. The client may, at its discretion, use the report to inform regulators and the public.

© Reproduction of this report for educational or other non-commercial purposes is authorised without prior written permission from EMM provided the source is fully acknowledged. Reproduction of this report for resale or other commercial purposes is prohibited without EMM's prior written permission.

Document Control

Version	Date	Prepared by	Reviewed by
1	20 April 2018	John Ross	Liz Webb, Nicola Fry
2	20 June 2018	John Ross	Liz Webb, Nicola Fry

T +61 (0)2 9493 9500 | F +61 (0)2 9493 9599

Ground Floor | Suite 01 | 20 Chandos Street | St Leonards | New South Wales | 2065 | Australia

www.emmconsulting.com.au

Table of contents

Chapter 1	Introduction	1
Chapter 2	Groundwater modelling guidelines	3
2.1	Model classes	3
2.2	Conceptualisation	4
2.3	Calibration	5
Chapter 3	Pells Consulting (2013)	7
3.1	Geological basis	7
3.2	Hydrogeological conceptual model	10
3.3	Model boundaries and layers	12
3.4	Model parameterisation and calibration	13
3.5	Model predictions	17
Chapter 4	Pells Consulting (2017)	19
4.1	Geological basis	20
4.2	Hydrogeological conceptual model	20
4.3	Model boundaries and layers	20
4.4	Model parameterisation and calibration	22
4.5	Model predictions	25
Chapter 5	Conclusions	27
References		30

Appendices

A Model confidence level classification

Tables

3.1 Reproduction of 'best estimate' aquifer parameter values from Pells and Pells, 2013 13

A.1 Peer Reviewer's Pells Consulting 2017 model confidence level assessment and classification A.1

Figures

3.1 Schematic cross-section showing variable permeability at depth 9

3.2 Interpreted initial groundwater head contours (after 19 in Pells and Pells, 2013) 15

3.3 RMS of Calculated Vs Observed Heads (original model) (after Fig 48 in Pells and Pells, 2013) 16

3.4 RMS of Calculated Vs Observed Heads (updated model) (after Fig 60 in Pells and Pells, 2013) 16

4.1 Comparison of hydraulic conductivity parameters adopted by Pells Consulting (2013) and the Hume Coal EIS model (Coffey 2016) 23

4.2 Simulated mine inflows using Pells Consulting model and variable hydraulic conductivity and drain conductance parameters (after Fig 4.4 in Pells and Pan 2017) 24

4.3 Predicted inflow, Scenarios 3, 7 and 8 showing the effect of changes to hydraulic conductivity (after Fig 5.6 in Pells and Pan 2017) 26

1 Introduction

Hume Coal Pty Limited (Hume Coal) proposes to construct and operate an underground coal mine and associated mine infrastructure in the Southern Coalfield of New South Wales (NSW) (the Hume Coal Project). Approval for the Hume Coal Project is being sought under Part 4 Division 4.1 (State significant development) of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act). The Secretary's Environmental Assessment Requirements (SEARs) for the project were issued by the NSW Department of Planning and Environment (DPE) on 20 August 2015. The environmental impact statement (EIS) for the Hume Coal Project was submitted to the DPE on 29 November 2016 for adequacy review, and then exhibited between 31 March 2017 and 30 June 2017.

As part of the response to submissions (RTS), this critique has been prepared by John Ross (National Technical Leader – Groundwater) of EMM Consulting (EMM) to consolidate review comments on the two numerical groundwater modelling reports prepared by Pells Consulting for the Southern Highlands Coal Action Group (SHCAG) in 2013 and Coal Free Southern Highlands Inc. (CFSH) in 2017 with respect to the Hume Coal Project (HCP).

This report is not a critique of the HCP EIS numerical groundwater model (the EIS model) (Coffey, 2016), nor is it an evaluation of the differences in the model conceptualisation, structure, parameters, calibration and predictions between the Pells Consulting model and the EIS model. A thorough (independent) assessment of the EIS model that highlights some of the key differences between the Pells Consulting model and the EIS model is provided in Hydrogeologic (2017).

Many of the submissions from the community and interest groups to the HCP EIS (EMM, 2017) were critical of the EIS numerical groundwater model and instead quoted the results of the numerical groundwater model constructed by Pells Consulting (primarily Pells and Pan 2017) as being more realistic. The main areas of dispute were:

- Pells Consulting model predicted a higher volume of mine inflow;
- Pells Consulting model predicted substantially more depressurisation from the mine (ie the drawdown area extended further and was greater in the vicinity of the mine);
- model parameters were different:
  - drain conductance in the Pells Consulting model was higher;
  - hydraulic conductivity in model layers in the Pells Consulting model was higher; and
  - specific yield and specific storage in the Pells Consulting model were higher.

The following documents were reviewed:

- Pells, SE & Pells, PJNP 2013, *Three dimensional groundwater model of Hume Coal Prospect, Southern Highlands NSW*, draft report by Pells Consulting prepared for Southern Highlands Coal Action Group. Ref P029.R1 (Draft B) dated 24 September 2013.
- Pells, SE & Pan, L 2017, *Groundwater Modelling of the Hume Coal Project*. Report by Pells Consulting prepared for Coal Free Southern Highlands Inc. Ref S025.R1 (Final) dated 22 June 2017.

The initial Pells Consulting model was developed in early to mid 2013 and the mine layout was based on an assumed footprint of 45 $km^2$and assumed a longwall mining extraction method. The model was then reviewed by staff at the University of NSW Water Research Laboratory (UNSW WRL). Subsequently, boundary conditions were changed, extra model layers were added, and changes were made to some model parameters before the 2013 model and report were finalised (Pells and Pells 2013). The model was further updated in 2017 when the HCP EIS was released. The model grid was slightly changed in the vicinity of the mine and an interpretation of the proposed mine plan and schedule using a panel mining approach was used (Pells and Pan 2017). Although mine conductance values were lowered, there were no other fundamental changes to the model boundaries, conceptualisation or parameterisation. The model was upgraded from MODFLOW 2000 modelling software to run in the newer MODFLOW-SURFACT modelling software.

This technical report summarises the reviewer's findings and highlights the technical inadequacies of both the Pells Consulting modelling reports (Chapters 3 and 4). To introduce the findings of the review, a brief summary of the Australian Groundwater Modelling Guidelines (AGMG) that discusses model classes and the stated requirements for conceptualisation and calibration is provided in Chapter 2.

2 Groundwater modelling guidelines

The Australian Groundwater Modelling Guidelines (AGMG) prepared by the National Water Commission (NWC) (Barnett et al. 2012) are intended as a reference document for groundwater modellers, project proponents (and model reviewers), regulators, community stakeholders and model software developers, who may be involved in the process of developing a model and/or modelling studies.

The AGMG provide a framework for a standardised approach for the development of groundwater models in Australia. The guidelines ”propose a point of reference and not a rigid standard” and provide direction on scope and approaches while acknowledging that techniques are continually evolving and innovation is to be encouraged.

The guidelines are structured to address:

- planning;
- conceptualisation;
- design and construction;
- calibration and sensitivity analysis;
- prediction;
- uncertainty;
- reporting; and
- reviews.

Guiding principles are highlighted at the start of each chapter relating to modelling to emphasise best practice. Several important elements of the AGMG are highlighted below; these particular requirements are deficient in the Pells Consulting model and the two modelling studies (Pells and Pells 2013 and Pells and Pan 2017).

The Pells Consulting 2013 numerical model/report and the Pells Consulting 2017 numerical model/report do not reference or acknowledge the requirements of the AGMG, nor do they follow the many guiding principles outlined in the AGMG.

2.1 Model classes

The guidelines provide a classification system that defines three different classes of a model:

- Class 1 – low confidence in model predictions, suitable for use in low value resource or low risk developments;
- Class 2 – high confidence in model predictions, suitable for use in high value resources or projects with medium to high risk developments; and
- Class 3 – high confidence in model predictions, suitable for use in high value resources and projects such as regional sustainable yield assessments.

The guidelines also provide information on the data requirements for each model class, such as spatial distribution of bores and temporal groundwater level data. Groundwater resource assessments at major development sites generally require the use of a Class 2 model. There are many characteristics and indicators that define whether a model is Class 1, 2 or 3. In most instances, models can have elements across a few classes, however the majority of acceptable indicators define the final model class. For instance, a model for a proposed development can have some Class 2 elements (such as groundwater head elevations) but is defined as a Class 1 model because it is poorly conceptualised and is not calibrated.

Most models that support mining and other infrastructure proposals should be Class 2 at the project assessment and planning approvals stage so that potential impacts can be clearly identified and any mitigation measures clearly articulated.

The onerous data requirements to achieve a Class 3 model (ie reliable metered extraction and the duration of the prediction to be not more than three times the calibration data period) mean that for most major projects (especially mining and infrastructure projects) a full Class 3 model is practically unattainable.

UNSW WRL (2013) assessed the 2013 Pells Consulting model (Pells and Pells 2013) and concluded that it demonstrated components of Class 1, 2 and 3 confidence models. On balance the review classified the Pells Consulting model as a Class 1 numerical model. Later changes to the model provided no fundamental improvements to the model. The 2017 Pells Consulting model (Pells and Pan 2017) remains a Class 1 model. The EMM peer reviewer agrees that the model is Class 1 and is unsuitable for detailed impact assessment of the proposed mine development.

The Hume Coal mining proposal is based on the premise of not causing any systemic caving of the strata overlying the Wongawilli coal seam and protecting the overlying Hawkesbury Sandstone aquifer system, so the Pells Consulting model does not reflect the proposed development but rather an extreme outcome associated with major fracturing and subsidence induced by the mine.

The Pells Consulting model is largely Class 1, with some characteristics of Classes 2 and 3, and is therefore considered to be a Class 1 model overall. The peer reviewer's assessment of the model confidence classification in line with the AGMG and the draft IESC Uncertainty Analysis Explanatory Note is provided in Appendix A.

2.2 Conceptualisation

A conceptual (hydrogeological) model is a descriptive or graphical representation of a groundwater system that incorporates an interpretation of the geological and hydrological conditions (Anderson & Woessner 1992). It consolidates the current understanding of the key processes of the groundwater system, including the influence of stresses (such as recharge, discharge, flow between aquifers and aquitards, groundwater abstractions and surface water-groundwater interaction), and assists in the understanding of possible future changes (related to activities such as climate change, pumping, mining, reinjection, etc.).

The development of the most appropriate conceptual model (or models) is required to ensure that the numerical modelling achieves its objectives. The conceptualisation process involves simplifying a groundwater system, which is inherently complex, in order to simulate the system's behaviours. If a model is conceptually poor, no amount of numerical modelling or calibration can fix it. This is the primary reason for paying strict attention to the conceptualisation process and why it is fundamental to the entire modelling process that the conceptualisation replicates the flow or solute transport processes as closely as possible.

In many cases the conceptual model when first developed may not be unique (ie different conceptual models can explain all current observations) and the AGMG encourage modellers to propose and maintain alternative conceptualisations for as long as possible through the modelling project until one approach clearly best replicates the system's behaviour.

There is no descriptive or graphic conceptual model in either of the Pells Consulting modelling reports that clearly articulates their conceptual understanding of the various groundwater systems and other hydrological features.

2.3 Calibration

Model calibration involves an iterative process to estimate parameters describing hydrogeological properties and boundary conditions so that the model's results closely match historical observations. The guidelines encourage the use of as many different datasets as possible for calibration. The challenge is to find parameter values that allow a model to fit historical measurements and align with the conceptual model, while preparing a model for use in predictions.

The Pells Consulting model was calibrated and validated against a replication of the regional water table in steady state, and against four short term pumping tests of deep Hawkesbury Sandstone water bores in transient mode. The replication of the regional water table (refer to Section 3.4) was poor, while the drawdowns at individual bores were mostly underestimated. This suggests there are fundamental issues with the adopted hydraulic conductivity values and/or specific storage. It was conceded by Pells Consulting that "the pumping tests represent highly localised stresses which are not necessarily simulated with accuracy by the regional-scale model" (Pells and Pells, 2013).

It is noted that calibration statistics are poor: 13.6-15.2 %RMS (Scaled Root Mean Square) and 31-33 mRMS (pers com Dr N Merrick). Neither model was calibrated to the recorded mine inflows at the Berrima Mine immediately to the north of the project area, and it appears that there was no analysis or refinement of the regional water table data and interpreted head contours.

The reviewer believes that the Pells Consulting model is poorly calibrated, and, as such, the predictive results cannot be relied upon.

3 Pells Consulting (2013)

This report presents the results of a three dimensional groundwater model developed prior to the release of Hume Coal's EIS and specialist groundwater studies (EMM 2017) which included the EIS numerical groundwater model (Coffey 2016). The model constructed by Pells Consulting in 2013 aimed to assess probable impacts from underground coal mining across the Hume Coal prospect (Coal Authorisation EL349) and adjacent areas in the Southern Highlands.

The model is based on geological data derived from multiple public and company databases, and hydrogeological data derived from drillers bore construction forms (DI Water (formerly NSW Office of Water (NOW)) database), some private (high yield) pumping tests, and limited company data. The variable quality of the records in the DI Water database is a result of information being supplied from drillers with varying levels of experience, and information accepted as submitted, which is not reviewed, edited or quality checked by the Government.

There is no recognition of the regional numerical groundwater model for the Kangaloon Borefield (Coffey Geotechnics 2008) that covered the eastern portion of this project area. While this regional model focused only on the Hawkesbury Sandstone, it is a calibrated model against rainfall, a known regional water table surface, and stream heights/flows and provides useful parameters for possible model inclusion/consideration.

There is also no literature review of other hydrogeological studies from across this area that may have better informed the model boundaries, construction and parameterisation (eg Parsons Brinckerhoff 2009a, URS Australia 2009, and Coffey Geosciences 2007).

3.1 Geological basis

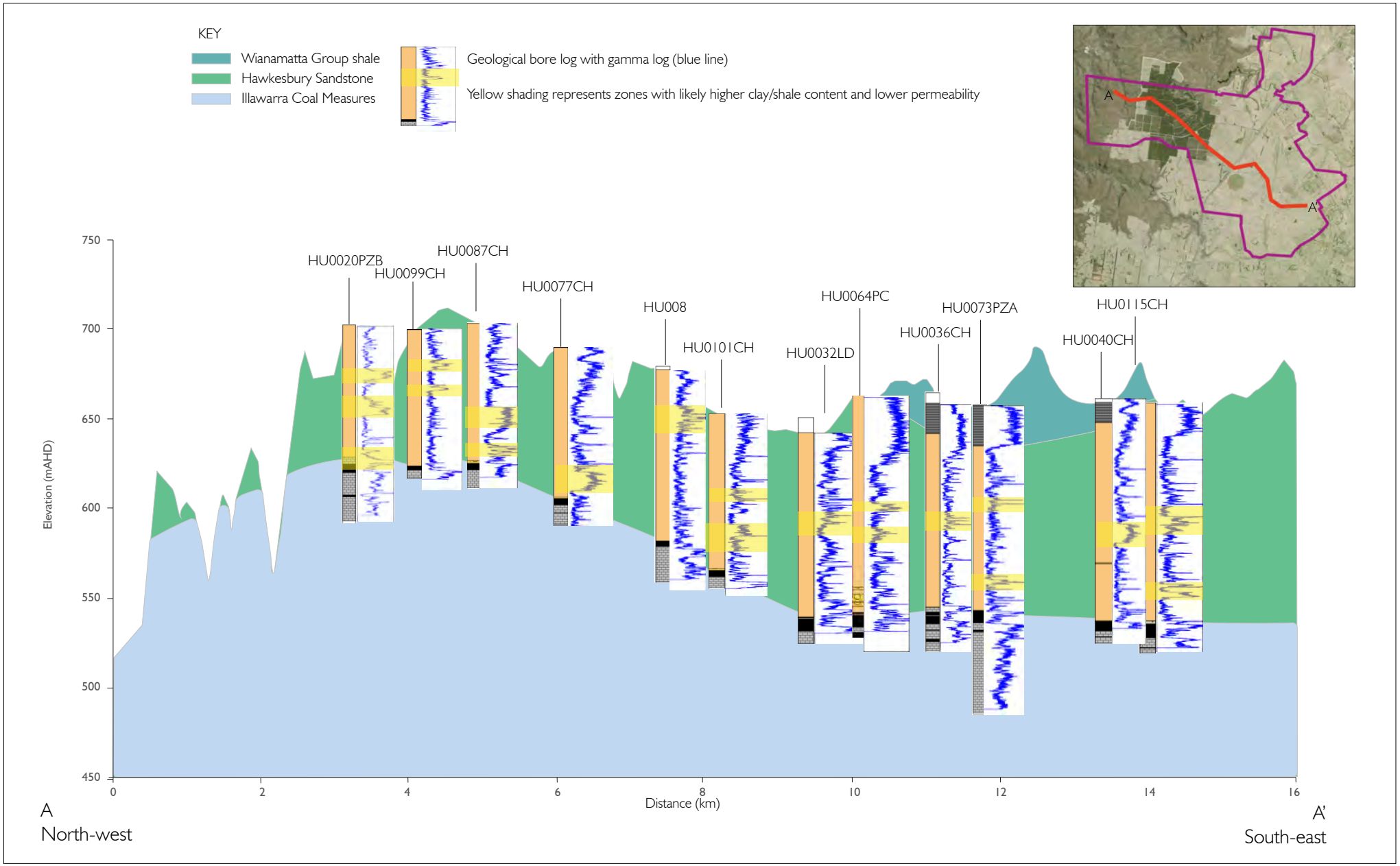
The basis of the regional geological model is reasonable. The geological units used in the construction of the numerical groundwater model are:

- Wianamatta Shale;
- Hawkesbury Sandstone;
- Illawarra Coal Measures (Wongawilli Seam and any rock between the seam and the base of the Hawkesbury Sandstone);
- Shoalhaven Group; and
- Basement.

In this area, Pells Consulting argues that the Narrabeen Group rocks (alternating cemented sandstones and claystones) are not known to occur between the Triassic Hawkesbury Sandstone and the Permian Illawarra Coal Measures, apart from some residual sub-crops in the east and north, hence this unit has been omitted from their geological model and numerical groundwater model.

In later modelling by Hume Coal (Coffey 2016) this interburden comprising claystone and thin coal plys (Narrabeen Group and uppermost Illawarra Coal Measure rocks above the Wongawilli Coal Seam) has been recognised as important and has been included in the EIS model. This layer has the same hydraulic properties as the overlying Hawkesbury Sandstone and is on average 2 m thick across the whole model area.

The sub-division of the Hawkesbury Sandstone into three consistent layers (A, B and C after Lee, 2009) across the whole of the Southern Highlands area is problematic as subtle facies changes are common for this braided stream deposit, and there is variable cementation of the bedding within the sandstone (ranging from siliceous to clayey and in many areas iron dominated). Figure 3.1 is an example demonstrating this variability that is visible in bore and gamma logs that extend through the whole Hawkesbury Sandstone.



Schematic cross-section showing variable permeability at depth

Critique of Pells Consulting Modelling Studies
Hume Coal Project
Figure 3.1

EMM

There are no compelling data sets to confirm there is an increase in permeability of the sandstone strata at the base of the Hawkesbury Sandstone. Regional studies completed for the Kangaloon Borefield project to the east of this area suggest that the permeability and yield from bores drilled through the whole Hawkesbury Sandstone sequence are not directly related to the depth of the bores, but to the degree and depth of fracturing and fracture interconnection (URS Australia 2007, URS Australia 2008).

Yields from water bores that intercept deeper fractures can be very high yielding across localised areas of the Southern Highlands (URS Australia 2007 and Parsons Brinckerhoff 2009b). With the added advantage of significant available head, deep bores can pump high volumes (up to 50 L/s) at selected locations. This leads to the Hawkesbury Sandstone appearing to have higher hydraulic conductivity at depth however, this trend is more related to (localised) secondary permeability features such as fractures rather than high (regional) primary permeability.

The rationale for sub-dividing the Shoalhaven Group rock types into A and B layers in the Pells Consulting model is not explained and is also problematic. There are no geological studies or known differences in the hydrogeological characteristics to justify sub-dividing this unit.

Basalt outcrops and volcanic intrusions that are residual across many of the higher ridgelines and pockets of sandy alluvium that have accumulated along some of the drainage lines within the project area have been ignored within the model. The basalts in particular can be important shallow local water resources where springs are present, and spring flows often contribute to stream flows (eg Pritchard 2004; Coffey Geosciences 2007).

No geological structure was incorporated into the model, which is considered a reasonable approach for this Class 1 model.

3.2 Hydrogeological conceptual model

One of the key concerns (a fatal flaw) in this initial numerical model is that there is no succinct hydrogeological conceptual model description for either a singular or multiple (different) groundwater flow scenarios, and there is limited information on the expected groundwater connectivity between hydrogeological units.

Drainage cells to represent seepage from the Hawkesbury Sandstone aquifer at the cliff faces were added to the model later for more realistic representation rather than having (unrealistic) constant head boundaries everywhere. This has resulted in estimations of rainfall recharge increasing from about 1% of average annual rainfall to about 5%. There is no differentiation in rainfall recharge rates between exposed and non-exposed sandstone areas, and no consideration of potentially higher recharge rates across the basaltic ridgelines. The Pritchard (2004) study assumed a recharge rate of 5% for exposed sandstone and 0.5% for non-exposed sandstone, the Kangaloon Borefield model (Coffey Geotechnics 2008) was calibrated with recharge rates of between 3% and 6% for exposed sandstone and 0.3% for non-exposed sandstone, while the Hume EIS model has assumed 1.8% for rainfall recharge (which is considered a reasonable estimate of average recharge across the areas of both exposed and non-exposed sandstone).

The adopted hydrogeological units (in order of increasing depth) for the Pells Consulting model are:

- Wianamatta Shale;
- Hawkesbury Sandstone C;
- Hawkesbury Sandstone B;

- Hawkesbury Sandstone A;
- Illawarra Coal Measures (including the target Wongawilli seam);
- Shoalhaven Group B;
- Shoalhaven Group A; and
- Basement.

The Wianamatta Shale occurs at surface and is highly eroded across the Southern Highlands and hence only partially exists across the project area.

There is no regional justification given for the layering in the Hawkesbury Sandstone or the Shoalhaven Group hydrogeological units across the broader Sydney Basin (see also discussion in Section 3.1), however subdividing the Hawkesbury Sandstone into multiple layers is a valid approach for numerical modelling purposes. Three layers are a minimum for resource models (eg the Kangaloon Borefield model - Coffey Geotechnics 2008) and the reviewer recommends a greater number of layers for coal mining projects where potential defects in the relaxed zone above the mined coal seam can induce permeability changes and greater vertical flow. The original Pells Consulting model has only three layers for the Hawkesbury Sandstone in the initial model construction.

After the original model was peer reviewed by UNSW Water Research Laboratory staff in August 2013 (UNSW WRL, 2013), the hydrogeological units were reviewed and the number of layers was increased from 8 to 12 with:

- Hawkesbury Sandstone geology represented by five layers (up from three): one for Unit C and two for each of Units B and A;
- Shoalhaven Group B geology represented by two layers (up from one layer); and
- Basement geology represented by two layers (up from one layer).

The stated purpose of these additional layers was to improve the resolution of vertical flow around the perimeters and into the mine. These layer improvements have no geological basis and limited hydrogeological basis.

Surface water flows in the Wingecarribee River and internal catchments with permanent flow, and a conceptual understanding of whether streams are gaining or losing streams, have not been considered in this initial modelling study. Groundwater levels were assumed to reflect the river stage at the boundary stream locations and constant head boundaries were applied.

In the remodelling, replacement of the assumed constant head boundaries in the original layers 7 and 8 (basement layers) with general head boundaries better reflects flow out of the model, and the insertion of 'drain' nodes around the perimeter of outcropping of original model layer 4 (Hawkesbury Sandstone Unit A) better represents likely cliff seepage faces. However the EMM reviewer considers that these late changes still do not accurately represent all the important features in the hydrological landscape and the boundary characteristics of the different hydrogeological units.

The surface water components of the water cycle are important omissions from the conceptual model behind this modelling study, and therefore the calibration and predictive results are likely to be poor and should not be relied upon.

Water balances are presented in an appendix in the report for pre-mining and mining scenarios, however, the in/out volumes cannot be interpreted and there is no discussion of gains or losses from individual surface water features in the main report.

A thorough explanation of the conceptualisation that was proposed (and then amended) and upon which the numerical groundwater model is built is essential. Without a schematic diagram and logical description of natural recharge, discharge and flow processes for each groundwater system (and their expected interconnectivity), and without properly modelling the boundary and internal hydrological features, the model is likely to produce poor and unrealistic predictive outcomes.

3.3 Model boundaries and layers

The perimeter of the chosen model domain is bounded by rivers or creeks and is larger than just EL349. The model boundaries were set about 10 km distant from probable mining which is considered reasonable, although the nature of the chosen boundaries is not clearly stated (all were apparently constant heads initially and after peer review the basal Hawkesbury Sandstone layer was remodelled as a drain at the perimeter).

The adopted model boundaries were initially:

- Wingecarribee River along the northern boundary (presumed to have constant head across all layers and based on river stage);
- Wingecarribee and Fitzroy Falls reservoirs along the eastern boundary (presumed to have constant head across all layers and based on full supply level);
- Black Bob's Creek along the western boundary (presumed to have constant head across all layers. Some drainage cells were assigned to the basal Hawkesbury Sandstone layer later); and
- Bundanoon Creek along the southern boundary (presumed to have constant head across all layers and some drainage cells assigned to the basal Hawkesbury Sandstone layer later).

The model extends across the major topographic divide between the Shoalhaven and the Hawkesbury-Nepean catchments (Bundanoon Creek is in the Shoalhaven catchment).

These boundaries are reasonable for basal layers in the model but are inadequate for modelling impacts to the Hawkesbury Sandstone groundwater system. For example, the northern boundary (the Wingecarribee River) in upstream areas is probably neither a recharge nor discharge boundary but rather a 'flow through' feature for this regional groundwater system, especially where there are pockets of alluvium and/or where the river is located on Wianamatta Shale and isn't incised to the Hawkesbury Sandstone.

Significantly, the northern boundary excludes the Berrima Mine workings immediately to the north. Therefore, the Pells Consulting model cannot use recorded mine inflows for calibration and cannot do required cumulative impact assessment.

The numerical model assumed eight layers initially (representing the main hydrogeological units) and the layers were defined as follows:

- Layer 1 – Wianamatta Shale.
- Layers 2, 3 and 4 – Hawkesbury Sandstone is subdivided into three layers:

- Layer 2 (upper – zone C) taken as 30% of the thickness of the total Hawkesbury Sandstone;
- Layer 4 (lower – zone A) taken as 25% of the thickness of the total Hawkesbury Sandstone;
- The remainder being Layer 3 (middle – zone B).

- Layer 5 – Illawarra Coal Measures.
- Layer 6 – Base of the Shoalhaven Group – Zone B at 30 m below base of the Illawarra Coal Measures.
- Layer 7 – Base of the Shoalhaven Group – Zone A at 100 m below base of the Illawarra Coal Measures.
- Layer 8 – Base of the model at 0 m AHD.

Model layers increased to 12 after the UNSW peer review (UNSW WRL 2013) but there is no explanation of the new layers and little discussion as to why additional layers were added. Drawdown maps for new Layer 6 are only presented in Appendix A2 with no description of the predictive results in the main report (Pells and Pells 2013).

Unfortunately the thin layer that comprises the mined section of the Wongawilli Seam within the Illawarra Coal Measures is not identified in the Pells Consulting model as a separate layer to effectively model the removal of coal in panels that are expected to be around 3.5 m in height. This is a major omission as simulated extraction will be applied to the wrong lithology over the wrong thickness. Also the interburden (comprising the upper Permian interburden (thin coal plys and the Farmborough Claystone) and Narrabeen Group (where present)) overlying the Wongawilli Seam hasn't been included in the Pell Consulting model as a separate layer.

Conceptually these are significant model omissions and the EMM peer reviewer believes they are fatal flaws.

3.4 Model parameterisation and calibration

A range of model parameters is provided for each of the eight model layers. Pump-test transmissivity data were analysed by Pells Consulting to interpret equivalent horizontal coefficients of permeability (hydraulic conductivity) for the basal Hawkesbury Sandstone. Design parameters for the other two horizons in the Hawkesbury Sandstone, and for the other units in the model, were derived mostly from literature studies. These are reproduced in Table 3.1 below.

Table 3.1 Reproduction of 'best estimate' aquifer parameter values from Pells and Pells, 2013

Layer	Formation	Horizontal hydraulic conductivity "k_h" m.s^{-1}	Anisotropy "k_u/k_h"	Porosity	Specific yield "S_y"	Modulus MPa	Specific storage m^{-1}
1	Wianamatta	1.5×10^{-6}	0.05	0.08	0.07	8000	1.59×10^{-4}
2	Hawkesbury Sandstone C	1.5×10^{-6}	0.1	0.15	0.14	6000	2.31×10^{-6}
3	Hawesbury Sandstone B	3×10^{-7}	0.05	0.12	0.11	10000	1.52×10^{-6}

Table 3.1 Reproduction of 'best estimate' aquifer parameter values from Pells and Pells, 2013

Layer	Formation	Horizontal hydraulic conductivity "k_h" m.s^{-1}	Anisotropy "k_u/k_h"	Porosity	Specific yield "S_y"	Modulus MPa	Specific storage m^{-1}
4	Hawkesbury Sandstone A	3 x 10^{-5}	0.5	0.20	0.18	8000	2.13 x 10^{-6}
5	Illawarra Coal Measures	1.5 x 10^{-6}	0.1	0.08	0.07	5000	2.32 x 10^{-6}
6	Shoalhaven B	3 x 10^{-8}	0.1	0.05	0.05	20000	7.16 x 10^{-7}
7	Shoalhaven A	1 x 10^{-9}	0.1	0.05	0.05	30000	5.52 x 10^{-7}
8	Base	5 x 10^{-10}	0.1	0.05	0.05	35000	5.05 x 10^{-7}

For the natural system, the assigned horizontal hydraulic conductivity values are reasonable first approximations for each of the layers (although the average Kh value for the basal Hawkesbury Sandstone layer (3 x 10^{-5} m/sec or 2.6 m/day) appears too high to be applied regionally). This value is two to three orders of magnitude higher that the horizontal conductivities for the basal sandstone layers in the calibrated EIS model (Coffey 2016) and two orders of magnitude greater than the regional background horizontal conductivity in the Kangaloon Borefield model (Coffey Geotechnics 2008).

Localised fractures and faults with high secondary permeability can skew the regional estimates of permeability. Upscaling of parameter estimates derived from a few pumping tests of deep water bores that have specifically targeted fracture zones to maximise yield should be viewed cautiously.

It is noted that the adopted specific yield values range from 5% to 18%, while specific storage ranges from about 5E-7 to about 2E-6 m^{-1}. The adopted specific yield values are higher than other calibrated models and would contribute to larger predicted mine water inflows.

Table 4 in the Pells Consulting report (Pells and Pells 2013) gives the adopted changes to hydraulic conductivity, and storage, due to fracturing and disturbance of the rocks above an assumed short-longwall mining layout. The report suggests that horizontal hydraulic conductivity values for the Hawkesbury Sandstone could increase 5 to 1000 times. The longwall mining assumption is wrong and the suggested changes in aquifer parameters are not supported by any technical argument or reference to previous site or relevant modelling studies in the Southern Coalfield.

There is some uncertainty in the model surrounding the adopted anisotropy, specific yield and specific storage estimates and likely changes due to mining. It also appears that fracturing has been assumed to extend to land surface, without any justification.

The calibration results (discussed below) reinforce the poor conceptualisation. There are some seemingly impossible results observed in the Pells Consulting report (Pells and Pells 2013). For example, in the area of the Belanglo Forest, the model report suggests initial groundwater elevations are at or below the observed coal seam floor elevations (RLs) (see Figure 3.2). Contours of the groundwater heads were produced from unreliable water bore data and unrealistic perimeter river stages, and have not been sanity checked prior to proceeding with the modelling.

This data suggests that the coal seam and overlying rock in this area is unsaturated yet the model predicts up to 160 m of drawdown in the basal Hawkesbury Sandstone. This is even less credible considering the fact that the coal seam is only 70-90 m below surface in this area.

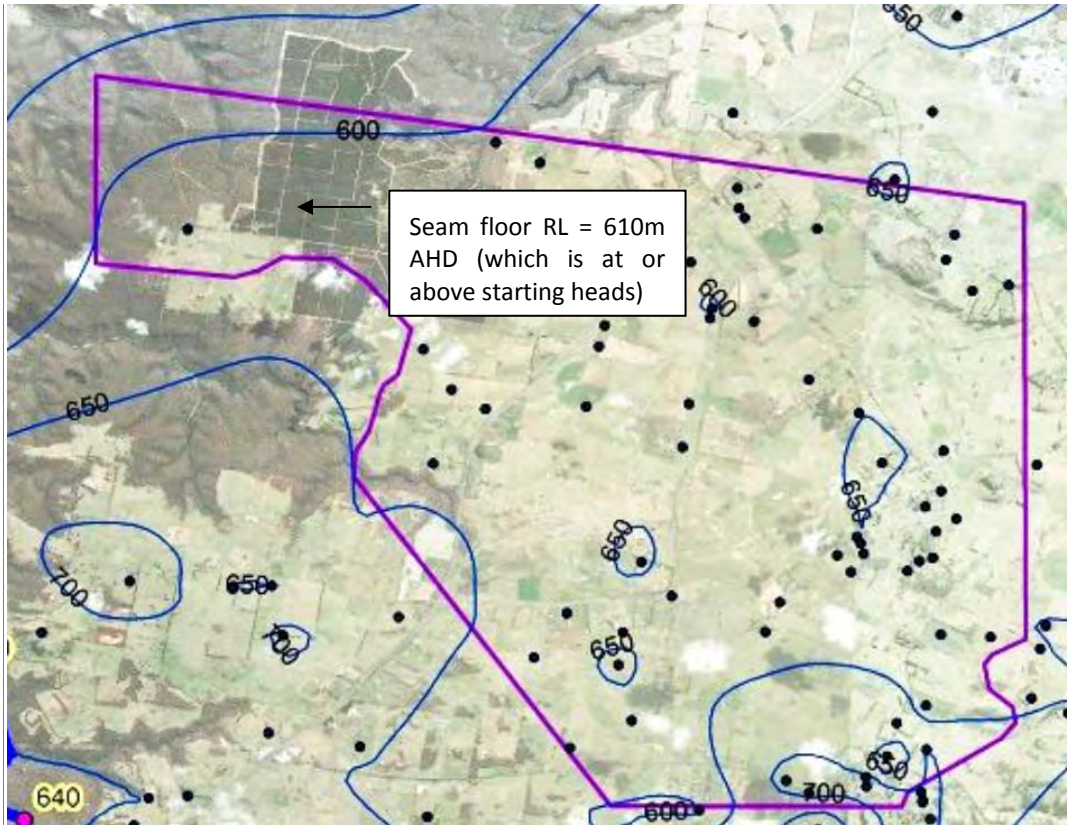


Figure 3.2 Interpreted initial groundwater head contours (after Figure 19 in Pells and Pells, 2013)

The steady state model calibration of heads across the model area with the initial model boundaries and parameters is very poor, as shown in Figure 3.3. Observed versus modelled heads are provided for each of the eight layers. Calibration is poorest for Layers 1 and 2, and there is no explanation for the derivation of the observed data for Layers 5 to 8.

There was no calibration improvement once the refined grid and revised boundary conditions were applied (Figure 3.4). Observed versus modelled heads are provided for ten layers although there are 12 layers in the revised model. There is no cross referencing of which model layer refers to which hydrogeological unit and again calibration is poorest for Layers 1 and 2, and there is no explanation for the derivation of the observed data for the other layers.

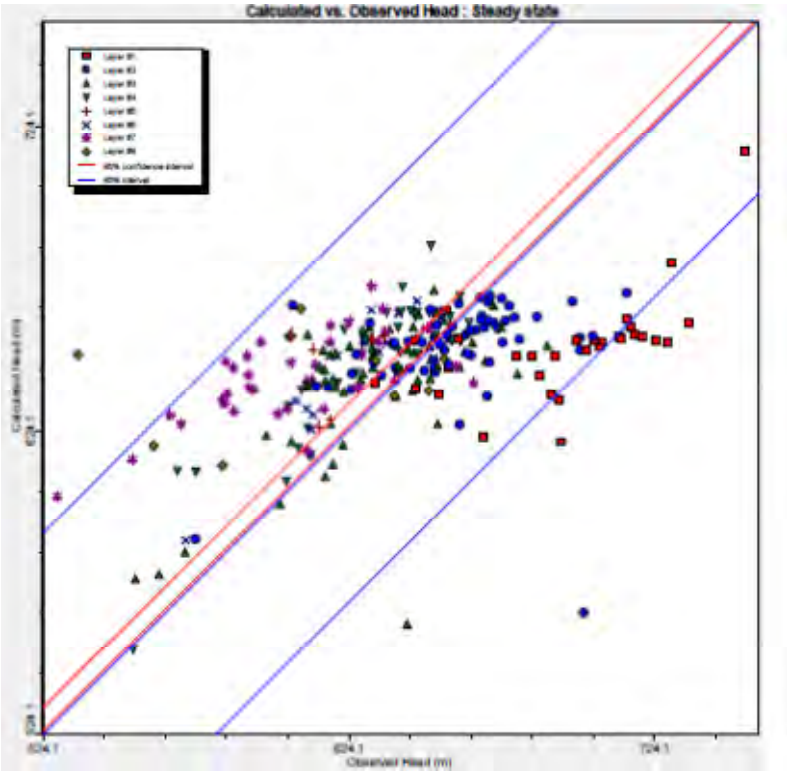


Figure 3.3 RMS of Calculated Vs Observed Heads (original model) (after Fig 48 in Pells and Pells, 2013)

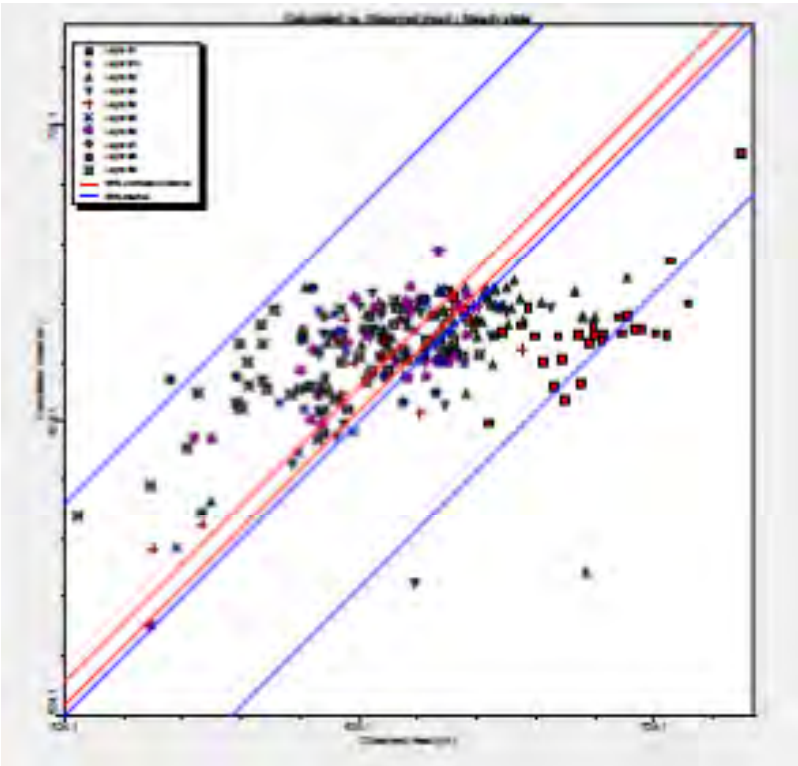


Figure 3.4 RMS of Calculated Vs Observed Heads (updated model) (after Fig 60 in Pells and Pells, 2013)

This model is a Class 1 model under the AGMG and given the poor conceptualisation and calibration, it is not fit for purpose, and therefore unsuitable for predicting drawdown impacts in bores, inflow volumes to the mine, or general impacts to the different groundwater systems and surface water resources across the modelled area.

3.5 Model predictions

A generic mine location and plan were used to simulate drawdowns and mine inflows. An assumed mining area of 45 km^2 was used for model simulations together with a 20 to 40 year mine life. The mine was modelled by the simultaneous one-off introduction of the mine within the model. It was recognised that this 'sudden' introduction of mine workings produces unrealistic estimates of mine inflow in the first instance but, over time, it was argued that the inflows converge to a more realistic figure and drawdown patterns approach a new steady state. However, an initial mining phase covering 4.5 km^2 was also modelled to examine the early effects of mining.

It is at this stage that some changes were made to the model boundaries and layers after a peer review by UNSW Water Research Laboratory staff (UNSW WRL 2013).

A very high conductance of 1000 m^2 per day was applied to simulate drainage and mine water inflows into base of the Illawarra Coal Measures (not just the (higher) Wongawilli Coal Seam). This high value was based on an assumption that longwall mining would be the preferred mining method, and there would be a substantial increase in hydraulic conductivities in the collapsed and relaxed zones above the mine workings. This assumption is wrong as the HCP EIS and supporting numerical model clearly indicate a non-caving, first workings panel extraction method is preferred to minimise roof collapse and to protect the overlying Hawkesbury Sandstone aquifer (EMM 2017).

Maps showing drawdown within Layer 4 for the initial modelling are presented in Appendix A1 (Pells and Pells 2013) together with drawdown maps for Layer 6 (the productive horizon of basal Hawkesbury Sandstone immediately above the Illawarra Coal Measures) in the updated model in Appendix A2 (Pells and Pells 2013). In both modelling scenarios, drawdown is observed to develop towards and reach the northern and southern boundaries, as these boundary heads are initially lower than the mine. In other regions (the eastern and western boundaries), the assumed constant head conditions are higher than the mine, and hence the groundwater level is maintained from inflows along these boundaries. Drawdown in the basal Hawkesbury Sandstone is modelled to be in excess of 90 m and up to 160 m over a wide area centred on the assumed location of the mine. This is impossible given that the total thickness of the Hawkesbury Sandstone across the project area is generally less than 120m and saturated thicknesses are less (Coffey 2016).

Drainage cells inserted in the updated model to simulate seepage from the Hawkesbury Sandstone aquifer in the western area appear to slightly increase drawdowns in this area in later simulations. Rainfall recharge had to be increased from 8 mm per annum to 50 mm per annum (approximately 5% of average annual rainfall) to maintain water levels in the updated model, but even so, water levels were still poorly calibrated with the observed regional flow net.

The drawdown pattern is highly constrained by the assumed nature of these boundaries and the high conductance values assumed for mine drainage strongly influence the predicted drawdown and mine inflows, hence these model predictions should be treated with extreme caution.

Predicted mine inflows of between 5.5 GL per annum and 29 GL per annum (15 ML per day to 80 ML per day) are provided in Figure 26 of Pells and Pells, 2013 based on the results of the initial modelling runs. No mine inflow estimates are provided for the updated model runs after the peer review.

Due to inadequate positioning of the northern edge of the model extent, the model cannot be used to verify simulated versus actual inflows at the Berrima Mine.

Inflow estimates are very large and should be considered extremely poor estimates given they are derived from a poorly calibrated model with low recharge estimates, inaccurate boundary conditions, assumed longwall mining and unrealistic mine conductance parameters.

There is an admission in Pells and Pan (2017) that the Pells Consulting (2013) model wrongly assumed permanently confined conditions in "many model layers". This would have the effect of not allowing desaturation to occur in response to mining, thereby giving grossly exaggerated mine inflows.

4 Pells Consulting (2017)

In the more recent report, the Pells Consulting 2013 model was updated to represent the current Hume Coal first workings mine plan, including the use of bulkheads to close panels after completion. The model structure was also updated and the following improvements made were:

- the 2013 model was updated to run in MODFLOW-SURFACT (compared to the previous MODFLOW 2000 solution); and
- the 2013 model was updated with various representations of model layer types, 'pseudo-soil' and unsaturated flow representations.

A small refinement to the grid was made so that the region with smaller (45 m by 45 m) cells covered the entire actual mine area. However the fundamentals of the 2013 Pells Consulting numerical model (model boundaries and formation parameters) were not updated or changed.

The Pells Consulting report (Pells and Pan 2017) mostly focuses on the actual mine plan and the reasons for discrepancies between the Pells Consulting model predictions and those by Hume Coal in their specialist EIS modelling report (Coffey 2016).

The reviewer has not analysed the differences in detail between the Hume Coal EIS model and the Pells Consulting 2017 model. An independent review of the EIS model (Coffey 2016) and report was commissioned by the NSW Government, and is provided by Middlemis (2017).

The comparison of the two numerical models in Pells and Pan, 2017 identified the following differences in parameterisation and conceptualisation, *with reviewer comments provided in italics*:

- Hume Coal adopted significantly lower hydraulic conductivity values for the coal measures and for formations just above (up to 2m) the coal workings. *These lower hydraulic parameters adopted by Coffey are supported by field data which is presented in the EIS for reference.*
- Hume Coal adopted lower aquifer storage values. *The EIS model is designed and calibrated in accordance with the AGMG; the adopted specific storage values are only one order of magnitude lower for the Hawkesbury Sandstone, Interburden and Wongawilli Seam and for other units are very similar to those assumed by Pells and Pells (2013) (Table 3.1 above). The reviewer understands that the importance of this parameter has been taken into account in subsequent modelling.*
- Hume Coal adopted lower values of 'drain conductance' when representing the mine in the model. *The EIS model is designed and calibrated in accordance with available data and the AGMG; the drain conductance value is informed by calibration to Berrima Mine inflows.*
- Hydraulic model layering adopted by Hume Coal places emphasis on the presence and continuity of a thin claystone seam above proposed workings. *The EIS model represents the interburden between the mined seam and the overlying Hawkesbury Sandstone (ie a thin - average 2m – layer), with Hawkesbury Sandstone properties and not with aquitard properties.*

The Hume Coal dataset used for the EIS model is more extensive than that used by Pells Consulting. It included model calibration using volumetric and hydraulic head data from the nearby Berrima Colliery in the northern part of the EIS model area. There is no new data presented by Pells Consulting in the 2017 version of their model, and it is uncertain how parameters have been assigned to the new modelling layers that were not included in their original 2013 model.

4.1 Geological basis

There is no change to the geological model adopted for the Pells Consulting 2013 numerical model.

4.2 Hydrogeological conceptual model

There is no succinct conceptual model articulated for the adopted hydrogeological units and the updated numerical model boundaries and layers. It appears there is no change from the conceptualisation adopted for the Pells Consulting 2013 numerical model.

4.3 Model boundaries and layers

The model boundaries remain unchanged for this Pells Consulting 2017 numerical model.

However the model domains (extents) for the Pells Consulting 2013/2017 numerical model and for the Hume Coal EIS model are quite different:

- The Pells Consulting model extends to include more of the Bundanoon Creek catchment in the Shoalhaven catchment to the south (ie beyond the Hawkesbury-Nepean and Shoalhaven catchment divide).
- The Pells Consulting model stops at the Wingecarribee River to the north (even though this is a flow through boundary in the upper catchment and a discharge boundary in the lower catchment for the Hawkesbury Sandstone and is not a boundary for any of the deeper hydrogeological units).
- The Pells Consulting model excludes the Berrima Colliery area.

The Hume Coal EIS model boundary conditions consist of:

- No-flow at topographic divides.
- Discharge zones at drainage channels (rivers).
- Local constant head at Wingecarribee Reservoir.
- Discharge zones at escarpments.

The Hume Coal EIS model boundaries are considered to better represent the hydrological characteristics and the regional hydrogeology especially to the north of the proposed mine.

In the Pells Consulting 2017 model there is reference to 12 layers being used to represent the hydrogeological units which aligns with updated changes to the Pells Consulting 2013 model which were adopted after improvements were recommended by a UNSW peer review. These layers are described in this latest report as:

- (Layer 1) Wianamatta Shale;
- (Layers 2, 3, 4, 5 and 6) Hawkesbury Sandstone subdivided into five layers:
    - Layer 2 (upper – zone C);
    - Layer 3 (middle – uppermost zone B);

- Layer 4 (middle – lowermost zone B);
- Layer 5 (lower – uppermost zone A);
- Layer 6 (lower – lowermost zone A);

- (Layer 7) Illawarra Coal Measures;
- (Layers 8, 9 and 10) Shoalhaven Group is subdivided into three layers:
  - Layer 8 (uppermost zone B);
  - Layer 9 (lowermost zone B);
  - Layer 10 (zone A);
- (Layer 11) Uppermost basement; and
- (Layer 12) Lowermost basement - Base of the model at 0 m AHD.

There is no discussion of the rationale behind the additional layers and the further sub-division of the Hawkesbury Sandstone and Shoalhaven Group hydrogeological units, and why the Illawarra Coal Measures is not sub-divided to accommodate the Wongawilli seam that is proposed to be mined.

The reviewer believes that the Hume Coal model layers (13 in total) better replicate the regional geology and the proposed mining of the Wongawilli Seam, and are more useful in understanding depressurisation and drawdown responses, and mine inflows. These layers are:

- (Layer 1) Wianamatta Shale;
- (Layers 2, 3, 4, 5, 6 and 7) Hawkesbury Sandstone subdivided into six layers:
  - Layer 2 (uppermost where overlain by Wianamatta Shale);
  - Layer 3 (uppermost where exposed and not overlain by Wianamatta Shale);
  - Layer 4 (middle);
  - Layer 5 (lowermost);
  - Layer 6 (lowermost);
  - Layer 7 (lowermost);
- (Layer 8) Interburden (Narrabeen Group, WWR Ply, and Farmborough Claystone);
- (Layer 9) Wongawilli Seam above mined section;
- (Layer 10) Wongawilli Seam above mined section;
- (Layer 10) Wongawilli Seam mined section;
- (Layer 12) Illawarra Coal Measures; and

- (Layer 13) Shoalhaven Group.

No alluvium, volcanic flows, igneous intrusions or geological structural features were included in either model. The reviewer agrees from a regional hydrogeological perspective; these features are relatively minor (or located some distance from the proposed mine) and therefore need not to be included in the respective models.

4.4 Model parameterisation and calibration

Parameters for hydraulic conductivity adopted by the Pells Consulting 2013 model (and used for the updated 2017 model) and by Hume Coal EIS are shown in Figure 2.6 of Pells Consulting (2017) which is reproduced in Figure 4.1. It can be seen that the choice of parameters differs between models, particularly:

- hydraulic conductivity values for the lower Hawkesbury Sandstone;
- specific yield values for the Hawkesbury Sandstone; and
- specific storage for the Hawkesbury Sandstone.

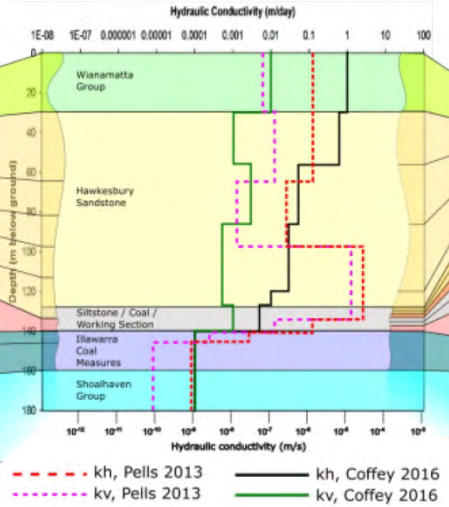
In particular, Pells Consulting maintains that the values adopted in the EIS model for drain conductance and hydraulic conductivity of the coal measures and layers directly above the mine are unrealistically low.

Pells Consulting states that the low hydraulic conductivity values adopted for the lower Hawkesbury Sandstone don't reflect the data from deeper water bores constructed and tested across the region. There is some merit in this interpretation based on the private pumping test data presented, however it is hard to justify a horizontal hydraulic conductivity of around 2.6 m per day for this layer across the whole area based on limited pumping tests at water bore sites that clearly indicate fracture flow dominating over porous flow. Only high yield water bore tests are presented for calibration purposes so there is a bias towards sites with significant fracture flow. Also there is no justification for a vertical hydraulic conductivity that is 50% of the horizontal hydraulic conductivity.

Pells and Pan (2017) were also critical of the specific storage values adopted in the Hume Coal model, on the basis of being "mathematically impossible" when the component parts of an unreferenced formula are considered (equation (1)). The three "mathematically impossible" values are 5E-7, 7E-7 and 1E-6 m^{-1}. However, it is noted in Table 3.1 (above) that the Pells Consulting model uses similar values: eg 5.05E-7, 5.52E-7, 7.16E-7, 1.52E-6 m^{-1}, etc.

Formation	Horizontal Hydraulic Conductivity "k_h" $m.s^{-1}$	Anisotropy "k_v/k_h"	Porosity	Specific Yield "S_y"	Modulus MPa	Specific Storage m^{-1}	Layer
Wianamatta	1.5×10^{-6}	0.05	0.08	0.07	8000	1.59×10^{-6}	1
Hawkesbury Sandstone C	1.5×10^{-6}	0.1	0.15	0.14	6000	2.31×10^{-6}	2
Hawkesbury Sandstone B	3×10^{-7}	0.05	0.12	0.11	10000	1.52×10^{-6}	3 4
Hawkesbury Sandstone A	3×10^{-5}	0.5	0.20	0.18	8000	2.13×10^{-6}	5 6
Illawarra Coal Measures	1.5×10^{-6}	0.1	0.08	0.07	5000	2.32×10^{-6}	7
Shoalhaven B	3×10^{-8}	0.1	0.05	0.05	20000	7.16×10^{-7}	8 9
Shoalhaven A	1×10^{-9}	0.1	0.05	0.05	30000	5.52×10^{-7}	10
							11

Pells, 2013



Model Layer	Average Depth to Base in Hume Lease (mbgl)	Kh[a] (m/day)	Kv[a] (m/day)	Specific storage (m^{-1})	Specific yield	Kv/Kh	Stratum
1	30	1	0.01	1×10^{-6}	0.01	0.01	Wianamatta Group
2	56	0.6	0.001	1×10^{-6}	0.01	0.0017	Hawkesbury Sandstone
3	86	0.05	0.003	7×10^{-7}	0.008	0.06	
4	120	0.03	0.0005	7×10^{-7}	0.008	0.017	
5	127	0.01	0.0005	7×10^{-7}	0.005	0.05	
6	129	0.005	0.001	5×10^{-7}	0.005	0.2	
7	131	0.005	0.001	5×10^{-7}	0.003	0.2	
8	133	0.005	0.001	5×10^{-7}	0.003	0.2	Interburden[a]
9	135	0.005	0.001	5×10^{-7}	0.003	0.2	Wongawilli Seam above mined section
10	137	0.005	0.001	5×10^{-7}	0.003	0.2	
11	140	0.005	0.001	5×10^{-7}	0.003	0.2	Wongawilli Seam mined section
12	160	0.0001	0.0001	5×10^{-7}	0.003	1	Illawarra Coal Measures
13	250	0.0001	0.0001	5×10^{-7}	0.003	1	Shoalhaven Group

Coffey, 2016

Figure 4.1 Comparison of hydraulic conductivity parameters adopted by Pells Consulting (2013) and the Hume Coal EIS model (Coffey 2016)

The argument advanced by Pells and Pan (2017) for a large drain conductance value is based on an incorrect conceptualisation of the drain (DRN) feature in MODFLOW. The conductance term, coupled with vertical head gradient, controls vertical flow. The term does not apply to side walls. Although a high value of 1000 m^2 per day was initially argued as appropriate, a drain conductance of 14.5 m^2 per day to the mine workings was adopted for the 2017 model baseline scenario (compared to the Coffey model range of 0.05 and 0.1 m^2 per day). Sensitivity to this baseline value adopted by Pells Consulting was tested with multiple model runs (0.05, 14.5, and 100 m^2 per day) using the MODFLOW 2000 software package. Strangely the model used was the original poorly calibrated 8 layer numerical model but with the current Hume EIS mine plan.

Figure 4.2 shows a comparison of the Pells Consulting model results (both 2013 and 2017) for mine inflows over a 30-year mine life using high drain conductance values compared to a model run with a low drain conductance value.

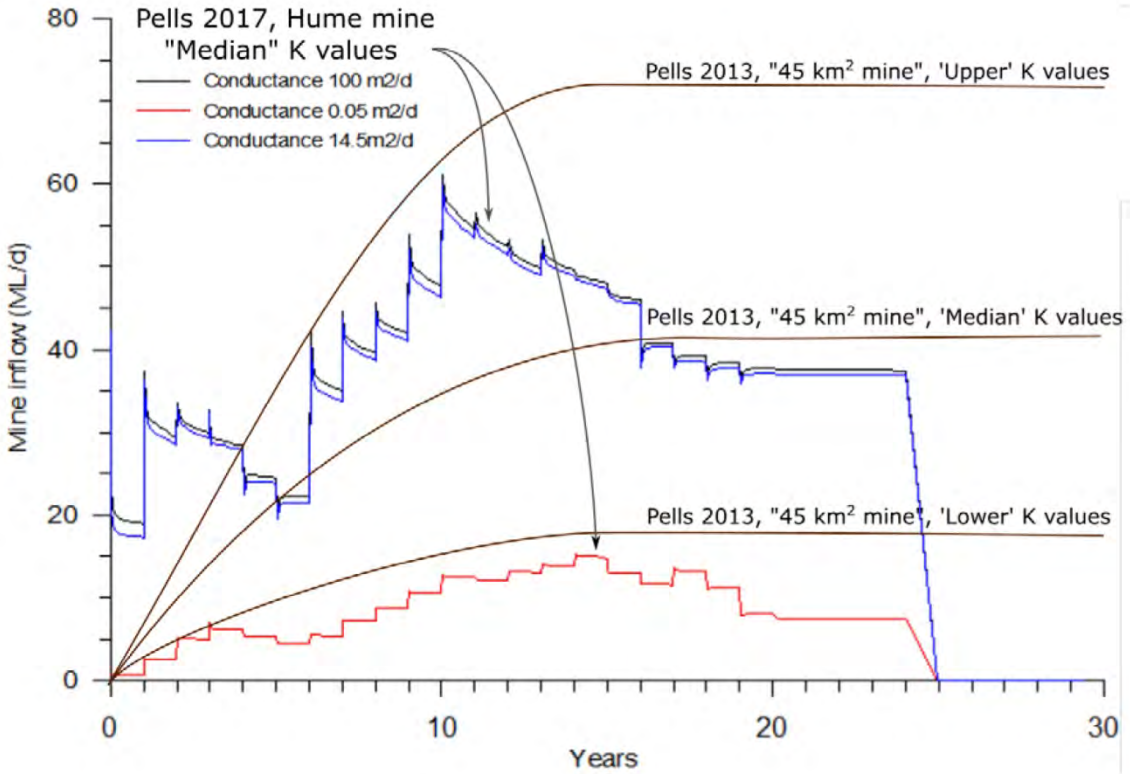


Figure 4.2 Simulated mine inflows using Pells Consulting model and variable hydraulic conductivity and drain conductance parameters (after Fig 4.4 in Pells and Pan 2017)

Eleven model runs were then completed using the MODFLOW-SURFACT software package with drain conductance values between 0.1 and 1000 m^2 per day to simulate mine water inflows. A conductance value of 14.5 m^2 per day was adopted as the baseline for 8 of the 11 model runs based on a vertical hydraulic conductivity (Kv) value of 1.5×10^{-7} m/sec (0.013 m/day) for the overlying strata. This Kv value is more than an order of magnitude higher than that adopted for the calibrated EIS model (0.001 m/day) for the overlying interburden and basal Hawkesbury Sandstone layers. In comparison for the Kangaloon Borefield model, the calibrated Kv (regional background) values for the Hawkesbury Sandstone ranged from 0.0002 m/day for the upper sandstone zone to 0.016 m/day for the deepest sandstone zone (derived from Table 8b in Coffey Geotechnics 2008).

Fracture flow dominates in the lower portions of the Hawkesbury Sandstone aquifer in this 'high-yield' area to the east. There is insufficient information presented in the Pells Consulting report to demonstrate that similar high permeabilities occur regionally across the Hume Coal area.

There is little justification for the moderate to high drain conductance values adopted in the revised Pells Consulting modelling whereas the Hume Coal EIS model (history match) calibration involved adjusting the drain conductance parameter to match the mine inflow and groundwater level data at the Berrima mine for a period of significant climate variability in recent years. The approach required simultaneous matches to stream baseflows, and is a good example of a best practice method that minimises non-uniqueness issues and supports a model Class 2 confidence level (Middlemis 2017).

The EIS model method justifies the drain feature conductance parameters applied to Berrima conditions. The application of the calibrated conductance parameter to HCP conditions involved appropriate adjustments to account for the different model cell size and extraction geometry at the mine compared to Berrima (Middlemis 2017).

4.5 Model predictions

With a moderate conductance of 14.5 m^2 per day used in the Pells Consulting 2017 model to simulate drainage and mine water inflows (rather than the earlier very high 1000 m^2 per day adopted value in the Pells Consulting 2013 model version) there are still large drawdowns predicted over an extensive area. The reviewer believes that all the drain conductance values used for the Pells Consulting simulations (except for the 0.1 m^2 per day scenario) are unrealistically high for undisturbed strata.

Maps showing drawdown within Layer 5 (uppermost zone A in the Hawkesbury Sandstone which is two zones above the Illawarra Coal Measures) are presented in the updated modelling report (although it is unclear why Layer 6 was not presented). For Scenario 3 which assumes median formation parameters and a baseline conductance value of 14.5 m^2 per day, drawdown is observed to develop eastwards and towards the northern boundary as shown in Figures 5.12 to 5.15 of the report but is less extensive than the 2013 drawdown predictions in a western and southern direction. Drawdowns in Layer 5 are predicted to be in excess of 40 m (rather than greater than 90 m) over a much smaller area than the original 2013 model predictions and are primarily centred on the actual location of the mine. However some scenarios still exhibit drawdown values greater than the possible saturated thickness of the actual layer.

Predicted mine water inflows for Scenario 3 (Figure 5.2 of Pells and Pan 2017) suggest that mine inflows would range between 7.3 GL per year and 26 GL per year (20 ML per day (Year 1) to 70 ML per day (Year 11)). These are similar to the inflow volumes predicted by the original Pells Consulting 2013 model using a very high mine conductance of 1000 m^2 per day (see Section 3.5). The reviewer is sceptical about the latest predicted mine inflows if the mine conductance has been reduced from 1000 m^2 per day to 14.5 m^2 per day. The Pells Consulting report states this is because "there is no difference in mine inflows for conductance values above the chosen value of 14.5 m^2 per day, showing that formation losses control inflows." In other words, mine inflow is insensitive to high values of drain conductance. However, it is sensitive to low values, as demonstrated in Figure 4.2. It follows that formation properties are not the sole determinants of mine inflow.

A comparison of inflows was also completed for a range of hydraulic conductivity values for all model layers. Upper, median and lower values of hydraulic conductivity (as defined in Tables 1 to 3 in Pells and Pells 2013) were used to derive the predicted inflow curves shown in Figure 4.3 (note that Table 2 is reproduced as Table 3.1 in this review report). The report concluded that larger hydraulic conductivity values are associated with larger inflows, and vice versa.

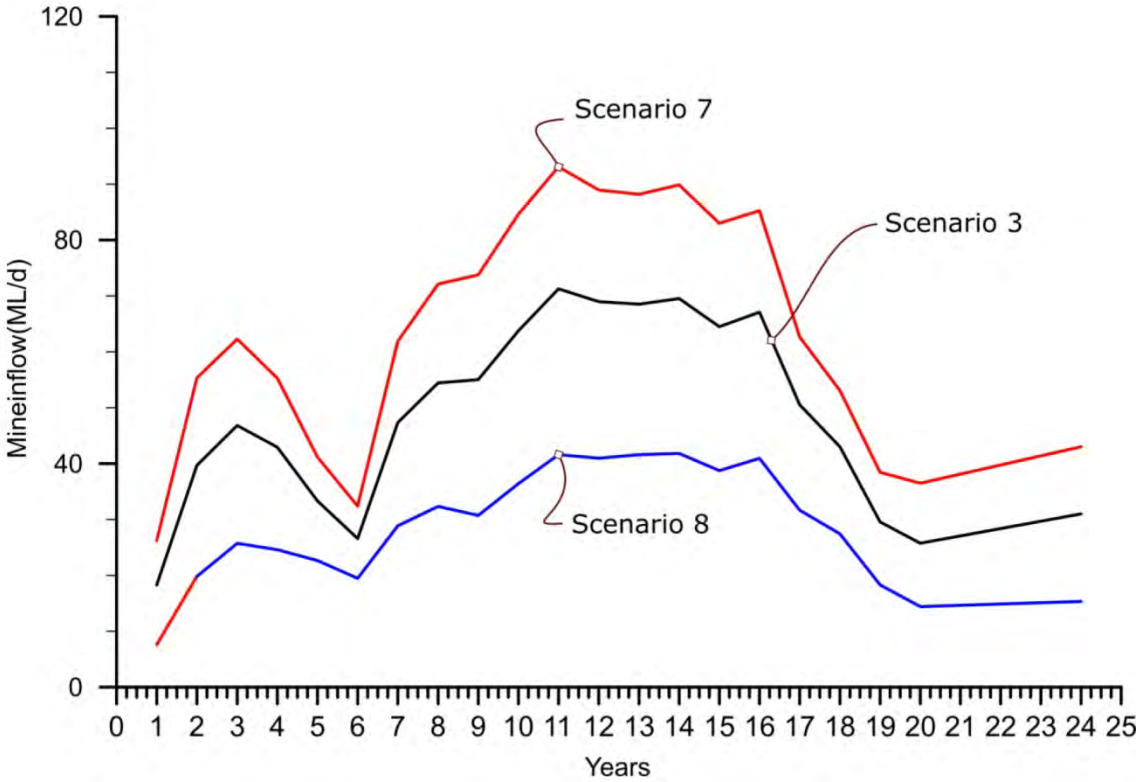


Figure 4.3 Predicted inflow, Scenarios 3, 7 and 8 showing the effect of changes to hydraulic conductivity (after Fig 5.6 in Pells and Pan 2017)

The drawdown pattern is highly constrained by the assumed nature of the model boundaries and the adopted hydraulic conductivity values. The assumed moderate mine conductance value strongly influences (overestimates) the most likely estimates of drawdown and mine inflows. Hence, the reviewer believes that these latest model predictions are also unreliable unless extensive defects were to appear in the relaxed strata above the mined coal panels.

5 Conclusions

The Pells Consulting model is a Class 1 model under the AGMG and given the poor conceptualisation and calibration, it is not fit for purpose (ie an independent impact assessment model), and therefore it is unsuitable for predicting drawdown impacts in bores, inflow volumes to the mine, or general impacts on the different groundwater systems and surface water resources across the modelled area.

It is at best, an initial assessment of the possible impacts from an underground mine in this area of the Southern Highlands if defects were to appear in the relaxed strata above the mine. Consequently all the predictive results are considered unreliable and should be disregarded.

References

Anderson & Woessner, 1992 Applied groundwater modeling, simulation of flow and advective transport, Academic Press, San Diego, USA.

Barnett B, Townley LR, Post V, Evans RE, Hunt RJ, Peeters L, Richardson S, Werner AD, Knapton A & Boronkay A, 2012 Australian Groundwater Modelling Guidelines. Waterlines report, National Water Commission dated June 2012.

Coffey Geosciences, 2007 Wingecarribee Swamp Hydrogeological Investigation – Stage 2 (Final Report). Report to Sydney Catchment Authority dated 10 July 2007.

Coffey Geotechnics, 2008 Transient Groundwater Modelling Study - Upper Nepean (Kangaloon) Borefield. Report to Sydney Catchment Authority dated 23 December 2008.

Coffey, 2016 Hume Coal Project - Groundwater Assessment Volume 1: Data Analysis and Volume 2 Numerical Modelling and Impact Assessment. Report to Hume Coal dated 20 November 2016.

EMM Consulting Pty Ltd (EMM), 2017 Hume Coal Project Environmental Impact Statement. Prepared by EMM for Hume Coal Pty Ltd.

Hydrogeologic, 2017 Hume Coal Project EIS Independent Expert Review Groundwater Modelling. Prepared by Hydrogeologic for the NSW Department of Planning and Environment. December 6, 2017.

Lee J, 2009 Regional Hydrostratigraphic Analysis of the Hawkesbury Sandstone. Paper presented at IAH NSW, Groundwater in the Sydney Basin Symposium, Sydney, NSW, Australia, 4-5 August 2009.

Parsons Brinckerhoff, 2009a Surface water-groundwater interaction in the sandstone aquifers of the Upper Nepean Catchment. Report to Sydney Catchment Authority dated February 2009.

Parsons Brinckerhoff, 2009b Wallacia Pilot Testing Program - Hydrogeological Analysis of Drilling and Testing Programs. Report to Sydney Catchment Authority dated June 2009.

Pells SE & Pells PJNP, 2013 Three dimensional groundwater model of Hume Coal Prospect, Southern Highlands NSW. Draft consultant's report by Pells Consulting for Southern Highlands Coal Action Group. Ref P029.R1 (Draft B) dated 24 September 2013.

Pells SE & Pan L, 2017 Groundwater Modelling of the Hume Coal Project. Consultants report by Pells Consulting for Coal Free Southern Highlands Inc. Ref S025.R1 (Final) dated 22 June 2017.

Pritchard S, Heir W, and Russell G, 2004 A review of the status of the groundwater resource in the Southern Highlands, NSW – Ensuring the sustainability of the water source. NSW Department of Infrastructure Planning and Natural Resources.

UNSW WRL, 2013 Peer Review of 3D Groundwater Model (Revision 2). Letter Report to SHCAG dated 13 December 2013.

URS Australia, 2007 Upper Nepean (Kangaloon) Trial Borefield Segment (Area 2). Drilling and Testing of Production and Monitoring Bores - Completion Report. Report to Sydney Catchment Authority dated 14 May 2007.

URS Australia, 2008 Upper Nepean (Kangaloon) Area 3 Trial Borefield Segment. Drilling of Production and Monitoring Bores - Completion Report. Report to Sydney Catchment Authority dated 20 February 2008.

URS Australia, 2009 Upper Nepean Groundwater Studies – Kangaloon Groundwater Levels Monitoring Program. June 2009 Annual Report. Report to Sydney Catchment Authority dated 3 June 2009.

Appendix A

Model confidence level classification

Table A.1 Peer Reviewer's Pells Consulting 2017 model confidence level assessment and classification

Class	Data		Calibration		Prediction		Quantitative indicators	
1 (simple)	√	Not much data (GW and SW)	√	Calibration not possible	-	Timeframe >> calibration	√	Timeframe >10 times calibration
	-	Sparse coverage	√	Large error statistic	-	Long stress periods	√	Stresses >5 times
	√	No metered usage	√	Inadequate data spread	√	Poor / no validation	-	Mass balance >1% (or one-off 5%)
	√	Low resolution topo DEM	-	Targets incompatible with model purpose	~	Transient prediction but only steady-state calibration	√	Properties <>field values
	√	Poor aquifer geometry					-	No review by hydro/modeller
	-	Remote climate data					√	Poor conceptualisation
2 (impact assessment)	~	Some data (GW and SW)	-	Partial calibration	√	Timeframe > calibration period	-	Timeframe = 3 – 10 times calibration
	√	OK coverage	-	Some long term trends wrong	√	Long stress periods	-	Stresses = 2-5 times
	-	Some usage data / low volumes	√	Short time record	-	OK validation	-	Mass balance <1%
	^	Baseflow estimates/ Some K & S measurements	-	Weak seasonal match	-	Transient calibration and prediction	-	Some properties <> field values
	-	Some high resolution topo DEM	-	No use of targets compatible with model purpose (heads & fluxes)	√	New stresses not in calibration	-	Review by hydrogeologist
							-	Some coarse discretisation in key areas of grid or at key times
	-	Reasonable aquifer geometry						
3 (complex simulator)	-	Lots of data with good coverage.	-	Good performance statistics	-	Timeframe approximates calibration	-	Timeframe <3 times calibration
	-	Good metered usage info.	-	Most long term trends matched	-	Similar stress periods	-	Stresses <2 times
	√	Local climate data	-	Most seasonal matches OK	-	Good validation	√	Mass balance <0.5%
	~	Kh, Kv, and Sy measurements from a range of tests	-	Present day data targets	-	Calibration & prediction consistent (transient or steady state)	-	Properties approximate field measurements
	-	High resolution DEM for all areas	-	Head and flux targets used to constrain calibration	-	Similar stresses to those in calibration	√	No coarse discretisation in key areas (grid of time)
	-	Excellent aquifer geometry.					√	Review by experienced modeller.

Notes: After Table 2.1 of Barnett et al. (2012) and Figure 5 of IESC 2018

Key:

√	*Satisfied*		
^	*Somewhat satisfied*	~	*Barely satisfied*
-	*Not satisfied*		

SYDNEY
Ground floor, Suite 01, 20 Chandos Street
St Leonards, New South Wales, 2065
T 02 9493 9500 F 02 9493 9599

NEWCASTLE
Level 1, Suite 6, 146 Hunter Street
Newcastle, New South Wales, 2300
T 02 4907 4800 F 02 4907 4899

BRISBANE
Level 4, Suite 01, 87 Wickham Terrace
Spring Hill, Queensland, 4000
T 07 3839 1800 F 07 3839 1866

www.emmconsulting.com.au

Appendix I

Hydrogeochemical Assessment

Geosyntec consultants

engineers | scientists | innovators

Hume Coal Project

Hydrogeochemical Assessment

Prepared for

Hume Coal Pty Limited
Unit 7-8, Clarence House, 9 Clarence Street
Moss Vale NSW 2577

Prepared by

Dr Lange Jorstad, Senior Hydrogeologist
Dr Bruce Sass, Principal Geochemist
Geosyntec Consultants Pty Ltd
PO Box 21
Cronulla NSW 2230

Project Number GSY0037

20 December 2016

TABLE OF CONTENTS

1. INTRODUCTION 6
1.1 Project Description 6
1.2 Project Area and Study Area 8
1.3 Objectives of Hydrogeochemical Assessment 8
1.4 Scope of Services 11
1.5 Project Team 11
1.6 Report Structure 12
1.7 Key Assessment Outcomes 12

2. PROJECT AREA DESCRIPTION AND ENVIRONMENTAL SETTING 17
2.1 General Site Description 17
2.2 Geology 18
2.2.1 Robertson Basalt 18
2.2.2 Wianamatta Group Shales 18
2.2.3 Hawkesbury Sandstone 18
2.2.4 Narrabeen Group 19
2.2.5 Illawarra Coal Measures 19
2.3 Hydrogeology 19
2.3.1 Hydraulic Conductivity 19
2.3.2 Groundwater Recharge and Discharge 20
2.3.3 Hydraulic Head Distribution 20
2.3.4 Groundwater Use 21
2.4 Sensitive Receptors 21

3. ASSESSSMENT REQUIREMENTS 23
3.1 Legislation, Policies and Guidelines 23
3.1.1 Water Act 1912 and Water Management Act 2000 23
3.1.2 Aquifer Interference Policy 23
3.1.3 Summary of Assessment Criteria 25
3.2 SEARs and Referral Authority Requirements 26

4. ASSESSMENT METHODOLOGY 30
4.1 Literature Review 30
4.2 Data Sources 30
4.3 Data Analysis and Interpretation 30

5. BASELINE HYDROGEOCHEMICAL CHARACTERISATION 32
5.1 Robertson Basalt 33
5.1.1 Summary of Monitoring Points 33

5.1.2 Field Water Quality Parameters 33
5.1.3 Major and Minor Ions 35
5.1.4 Metals and Metalloids 35
5.1.5 Nutrients 36
5.1.6 Organic Compounds 36
5.1.7 Beneficial Uses 36
5.2 Wianamatta Group Shales 36
5.2.1 Summary of Monitoring Points 36
5.2.2 Field Water Quality Parameters 36
5.2.3 Major and Minor Ions 38
5.2.4 Metals and Metalloids 38
5.2.5 Nutrients 39
5.2.6 Organic Compounds 39
5.2.7 Beneficial Uses 39
5.3 Hawkesbury Sandstone 39
5.3.1 Summary of Monitoring Points 39
5.3.2 Field Water Quality Parameters 39
5.3.3 Major and Minor Ions 41
5.3.4 Metals and Metalloids 43
5.3.5 Nutrients 43
5.3.6 Organic Compounds 43
5.3.7 Beneficial Uses 44
5.4 Wongawilli Seam 44
5.4.1 Summary of Monitoring Points 44
5.4.2 Field Water Quality Parameters 44
5.4.3 Major and Minor Ions 45
5.4.4 Metals and Metalloids 45
5.4.5 Nutrients 46
5.4.6 Organic Compounds 46
5.5 Illawarra Coal Measures 46
5.5.1 Summary of Monitoring Points 46
5.5.2 Field Water Quality Parameters 46
5.5.3 Major and Minor Ions 47
5.5.4 Metals and Metalloids 47
5.5.5 Nutrients 47
5.5.6 Organic Compounds 47

5.6 Spatial and Temporal Variability in Baseline Monitoring Data 47

6. PREDICTED INFLUENCE OF PROJECT ACTIVITIES 50
6.1 Water Quality Change from Induced Inter-Aquifer Transfer 50
6.1.1 Assessment Methodology and Assumptions 50
6.1.2 Modelling Results 50
6.1.3 Potential Impacts 53
6.1.4 Mitigation Measures 54
6.2 Water Quality Effects of Reject Slurry Emplacement in Underground Mine Voids 54
6.2.1 Process Description for the Management and Disposal of CPP Reject Material 54
6.2.2 Assessment Methodology and Assumptions 55
6.2.3 Assessment Results 56
6.2.4 Mitigation Measures 57
6.3 Water Quality Management for Surface Storage of CPP Reject Material 59
6.3.1 Description of Temporary Surface Storage of CPP Reject Material 59
6.3.2 Assessment Methodology and Assumptions 59
6.3.3 Assessment Results 60
6.3.4 Mitigation Measures 62
6.4 PWD Water Quality Assessment for Subsurface Disposal 64
6.4.1 Assessment Methodology and Assumptions 64
6.4.2 Assessment Results 65

7. CONCLUSIONS 70
7.1 Summary of Baseline Groundwater Quality Monitoring 70
7.2 Summary of Potential Impacts from Project Activities 70
7.3 Summary of Mitigation Measures 73
7.4 Recommended Monitoring Program 74

8. REFERENCES 76

9. LIMITATIONS 78

LIST OF TABLES

In text

Table 3.1: Secretary's environmental assessment requirements

Table 3.2: Referral authority environmental assessment requirements

Table 6.1: Underground reject storage - comparison of KLC 22 and 24 results with HAW and WWS groundwater quality

Table 6.2: Surface reject storage - comparison of KLC 10, 16 and 18 results with HAW groundwater quality

Table 6.3: Estimated PWD water quality based on average annual inputs, and comparison to WWS water quality

In Appendix

Table A1: Baseline groundwater monitoring results – Basalt

Table A2: Baseline groundwater monitoring results – Wianamatta Group Shale

Table A3: Baseline groundwater monitoring results – Hawkesbury Sandstone

Table A4: Baseline groundwater monitoring results – Illawarra Coal Measures

Table A5: Baseline groundwater monitoring results – Wongawilli Seam

Table A6: Baseline groundwater monitoring results – Tongarra Seam

Table A7: Monitoring well construction details

LIST OF FIGURES

Figure 1.1: Regional Context

Figure 1.2: Local Context

Figure 1.3: Indicative Mine Infrastructure Plan

Figure 1.4: Indicative Surface Infrastructure Plan

Figure 5.1: Groundwater monitoring network for the Study Area (from Coffey, 2016a)

Figure 5.2: Pourbaix diagram for major groundwater types in Hume Coal study area.

Figure 5.3: Histogram showing pH distribution in the Hawkesbury Sandstone, the Wongawilli Seam, and shale formations (all formations normalised to 100)

Figure 5.4: Histogram showing TDS distribution in the Hawkesbury Sandstone, the Wongawilli Seam, and shale formations (all formations normalised to 100)

Figure 5.5: EC and TDS trends for original and replacement wells H23B/C (Nov 2011 to May 2014) and H142B/C (Sept 2014 to Sept 2015), demonstrating a spike is solute load following installation of the replacement wells.

Figure 5.6: Piper plot of major ion data from most recent monitoring event for the HAW monitoring wells.

Figure 5.7: Temporal plot of major ion monitoring results for H18B.

Figure 5.8: Temporal plot of major ion monitoring results for H72C.

Figure 6.1: Extent of numerical model domain where a hydraulic connection exists between the WG shale and the underlying HAW.

Figure 6.2: Predicted (a) total flux and (b) incremental increase in groundwater flux from WG shale to upper HAW attributable to Hume Coal mining activities (active mining period in blue).

Figure 6.3: Pond water equilibration with atmospheric CO_2 and O_2.

Figure 6.4: Pond water pH and Eh evolution during equilibration with atmospheric gases.

Figure 6.5: Major mineral phase precipitation during pond water equilibration with atmospheric gases.

Figure 6.6: Depletion of Ca, Fe(2) and Mn in response to mineral precipitation in pond water.

LIST OF ACRONYMS AND ABBREVIATIONS

ADWG	Australian Drinking Water Guidelines
AI Policy	Aquifer Interference Policy
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
BOD	biological oxygen demand
BTEX	benzene, toluene, ethylbenzene and xylenes
CPP	coal processing plant
DO	dissolved oxygen
DPI	Department of Primary Industries
DRE	Department of Resources and Energy
EC	electrical conductivity
Eh	measure of the oxidation or reduction state of a solution, relative to the standard hydrogen electrode
EMM	EMM Consulting Pty Limited
GDE	groundwater dependent ecosystem
Geosyntec	Geosyntec Consultants Pty Limited
ha	hectare
HAW	Hawkesbury Sandstone
Hume Coal	Hume Coal Pty Limited
ICM	Illawarra Coal Measures
IESC	Independent Expert Scientific Committee
K	hydraulic conductivity
kg	kilogram
kg/L	kilograms per litre
KLC	kinetic leach column
km	kilometre
L	litre
LGA	local government area
LOR	limit of reporting
m	metre
m/day	metres per day
m/yr	metres per year
mbgl	metres below ground level
meq/L	milliequivalents per litre
µg/L	micrograms per litre
mg/L	milligrams per litre
ML	megalitre
ML/day	megalitres per day

mm	millimetres
µS/cm	microsiemens per centimetre; a measure of fluid electrical conductivity
Mt	million tonnes
Mtpa	million tonnes per annum
NHMRC	National Health and Medical Research Council
OCP	organochlorine pesticides
OEH	Office of Environment and Heritage
OPP	organophosphorus pesticides
ORP	oxidation-reduction potential (see also: Eh)
PAH	polycyclic aromatic hydrocarbons
PB	Parsons Brinckerhoff
pH	measure of acidity or alkalinity of a solution, expressed as -log[H^+]
PWD	Primary Water Dam
ROM	run of mine
SEARs	Secretary's Environmental Assessment Requirements
TDS	total dissolved solids
TRH	total recoverable hydrocarbons
WG	Wianamatta Group Shales
WMA	Water Management Act 2000
WSP	water sharing plan
WWS	Wongawilli Seam

EXECUTIVE SUMMARY

Geosyntec Consultants Pty Limited (Geosyntec) was commissioned by Hume Coal Pty Limited (Hume Coal) to undertake a hydrogeochemical assessment of groundwater and surface water resources within and in the vicinity of the Hume Coal Project (herein the "project"). The purpose of the assessment was:

- To document baseline groundwater quality conditions from monitoring data collected prior to the commencement of mining activities;
- To perform predictive assessment of potential changes to hydrogeochemical conditions arising from project activities;
- To propose mitigating actions for project activities with the potential to impact groundwater quality; and
- To propose ongoing monitoring to verify the performance of the project activities and mitigation actions with respect to baseline groundwater quality.

The following Project related influences to groundwater quality were evaluated as the focus of this assessment:

- Changes to groundwater quality resulting from enhanced vertical flux of groundwater from saline shale formations to underlying sandstone formations;
- Water quality resulting from rainfall infiltration into surface stockpiles of mine reject material, and potential for leachate infiltration into shallow groundwater resources;
- Changes to groundwater quality resulting from groundwater flow through mine reject materials backfilled into the underground mine voids, and transport of derived solutes downgradient from the backfilled workings; and
- Changes to groundwater quality resulting from co-disposal of dam water from multiple sources via injection into sealed underground mine voids.

The outcomes of the assessment of these project activities are summarised below:

- The magnitude of mining-induced leakage from the Wianamatta Group Shales into the underlying Hawkesbury Sandstone was modelled to be small. A maximum increase of 9% above the baseline leakage rate was modelled (from 11.1 to 12.1 ML/day), most of which was predicted to occur between years 10 and 19 of the mine operation. Likewise, the salt flux (calculated from the average total dissolved solids [TDS] in shale groundwater) increased proportionally with groundwater leakage from 6,887,550 kg/year to 7,497,790 kg/yr, or 9% above baseline conditions. Over the full 74-year period during which the model results indicated an incremental increase in groundwater flux over baseline conditions (including the post-mining recovery period), the net increase in salt flux from the Wianamatta Group

Shales into the underlying Hawkesbury Sandstone is 1.3% above baseline conditions. The area of increased vertical leakage is likely to be limited to the immediate footprint of the underground operations. The incremental influence on the quality of the underlying Hawkesbury Sandstone groundwater resource was determined to be insufficient to impact on the beneficial uses of the resource (given that the baseline leakage rate has resulted in only a limited influence on the groundwater quality of the Hawkesbury Sandstone).

- During the initial 12-18 months of mine operation, mine reject material will be stored in a surface stockpile, until there is sufficient void space in the underground workings to commence underground emplacement of the reject material. Results from kinetic leach column (KLC) tests indicated the potential for acid generation and enhanced metals solubility when reject material is exposed to oxygen and oxygen-enriched water. The stockpile will be managed to minimise the potential for water ingress (including stormwater controls to prevent run on from adjacent land), such that water interaction with the stockpiled reject material should be limited to rainfall directly onto the stockpile. The potential for rainfall to infiltrate into the stockpile will be limited by contouring of the stockpile to promote surface runoff (to be captured and contained in the mine water management system), and through vegetation of the stockpile surface to promote evapotranspiration, the magnitude of which, on average, exceeds rainfall during eight months of the year. A further contingency will include addition of a limestone amendment to the reject material prior to stockpiling to buffer potential acid generation, which KLC tests have demonstrated to be an effective method for preventing the development of acidic and metalliferous drainage from the reject material. Close to the end of the mine life, the reject stockpile will be reprocessed through the coal processing plant (CPP) and pumped into underground mine voids for disposal.
- Once sufficient mine void space is available, mine reject material will be pumped directly from the CPP into the underground mine voids for final emplacement, avoiding the requirement for long-term surface storage or disposal of reject material. The reject material will be pumped into completed mine panels, which will be sealed with bulkheads and allowed to backfill with natural groundwater. Results from KLC tests indicated the potential for acid generation and enhanced metals solubility when reject material interacts with natural groundwater. The results of limestone amended KLC tests indicated a sufficient buffering capacity to mitigate the acid generation and associated metals solubility under fully saturated conditions (as will be the case in the underground void). The water quality results from the fully saturated, limestone amended KLC test were equivalent or superior to the average baseline groundwater quality in the Wongawilli Seam and Hawkesbury Sandstone. Accordingly, limestone

amendment of the reject material prior to underground emplacement is considered to be adequate to protect the beneficial uses of the receiving groundwater resources.

- The mine water management plan will include a portion of the water in the Primary Water Dam (PWD) being pumped into the sealed underground mine voids. The water balance for the site indicates that the average annual input to the PWD will comprise approximately 70% extracted groundwater, 20% rainfall, and 10% process water from the CPP and dust suppression returns. The water quality resulting from the proportional mixing of these end member waters was simulated using a mixing model, with KLC tests results, geochemical modelling and published rainfall quality data used to represent the end member water types. The mixed PWD water quality is predicted to exceed several beneficial use criteria for dissolved metals; however, comparison to the average WWS baseline groundwater quality (the "receiving environment" for water injected into the sealed panels) indicates similar exceedances of dissolved metals criteria, and a similar overall beneficial use profile. Two metals (nickel and copper) marginally exceeded the average WWS groundwater quality concentrations; however, these estimated concentrations are conservative for the following reasons:
    - the quality of the CPP process water that would report to the PWD (which was the driver for the elevated nickel and copper concentrations) was simulated by adopting "first flush" results from concentrated KLC leachate testing. The larger water-to-solids ratio in the CPP would be expected to produce a more dilute water quality than the KLC first flush results;
    - some of the dissolved metals load would be expected to adsorb onto precipitating iron oxide colloids in the PWD, which was not accounted for in the geochemical modelling; and
    - further dilution would occur when the PWD water mixes with natural groundwater in the sealed panel following injection;
    - In consideration of the bullet points above, there was considered to be a low risk of the injected PWD water impacting the beneficial use status of the WWS groundwater resource beyond the point of injection.

It is proposed that the mitigation measures discussed in the previous bullet points are supplemented by the continuation of the baseline groundwater monitoring program to verify the efficacy of the measures, and the ongoing suitability of the groundwater resources for their current beneficial uses. Robust environmental management systems should also be implemented to reduce the potential for incidental releases of hazardous substances used during mine operations (for example, fuels, oils or solvents used for operation or mechanical repair of plant), and to define a procedure to rapidly respond to incidental releases to minimise impact to the environment.

Following a detailed review of the potential groundwater quality influences of the proposed mining activities, the beneficial uses of the groundwater resources are expected to be maintained through a combination of:

- mine site environmental management measures to prevent releases of contaminating materials;
- specific mitigation measures to buffer the development of acid generation and enhanced metals solubility in reject material, and
- monitoring to verify the efficacy of the environmental management systems and mitigation measures.

1. INTRODUCTION

Geosyntec Consultants Pty Limited (Geosyntec) was commissioned by Hume Coal Pty Limited (Hume Coal) to undertake a hydrogeochemical assessment of groundwater and surface water resources within and in the vicinity of the Hume Coal Project (herein the "project"). The purpose of the assessment was to document baseline water quality conditions from monitoring data collected prior to the commencement of mining activities, and to perform predictive assessment of potential changes to hydrogeochemical conditions arising from project activities.

1.1 Project Description

The project area is approximately 100 km south-west of Sydney and 4.5 km west of Moss Vale town centre in the Wingecarribee LGA (refer to **Figure 1.1** and **Figure 1.2**). The project involves developing and operating an underground coal mine and associated infrastructure over a total estimated project life of 23 years. Indicative mine and surface infrastructure plans are provided in **Figure 1.3** and **Figure 1.4**. A full description of the project, as assessed in this report, is provided in Chapter 2 of the main EIS (EMM 2016a).

- In summary it involves:
- Ongoing resource definition activities, along with geotechnical and engineering testing and other low impact fieldwork to facilitate detailed design.
- Establishment of a temporary construction accommodation village.
- Development and operation of an underground coal mine, comprising of approximately two years of construction and 19 years of mining, followed by a closure and rehabilitation phase of up to two years, leading to a total project life of 23 years. Some coal extraction will commence during the second year of construction during installation of the drifts, and hence there will be some overlap between the construction and operational phases.
- Extraction of approximately 50 million tonnes (Mt) of run-of-mine (ROM) coal from the Wongawilli Seam, at a rate of up to 3.5 million tonnes per annum (Mtpa). Low impact mining methods will be used, which will have negligible subsidence impacts.
- Following processing of ROM coal in the coal preparation plant (CPP), production of up to 3 Mtpa of metallurgical and thermal coal for sale to international and domestic markets.
- Construction and operation of associated mine infrastructure, mostly on cleared land, including:
    - one personnel and materials drift access and one conveyor drift access from the surface to the coal seam;

  - ventilation shafts, comprising one upcast ventilation shaft and fans, and up to two downcast shafts installed over the life of the mine, depending on ventilation requirements as the mine progresses;
  - a surface infrastructure area, including administration, bathhouse, washdown and workshop facilities, fuel and lubrication storage, warehouses, laydown areas, and other facilities. The surface infrastructure area will also comprise the CPP and ROM coal, product coal and emergency reject stockpiles;
  - surface and groundwater management and treatment facilities, including storages, pipelines, pumps and associated infrastructure;
  - overland conveyors;
  - rail load-out facilities;
  - explosives magazine;
  - ancillary facilities, including fences, access roads, car parking areas, helipad and communications infrastructure; and
  - environmental management and monitoring equipment.
- Establishment of site access from Mereworth Road, and minor internal road modifications and relocation of some existing utilities.
- Coal reject emplacement underground, in the mined-out voids.
- Peak workforces of approximately 414 full-time equivalent employees during construction and approximately 300 full-time equivalent employees during operations.
- Decommissioning of mine infrastructure and rehabilitating the area once mining is complete, so that it can support land uses similar to current land uses.

The project area, shown in **Figure 1.2**, is approximately 5,051 hectares (ha). Surface disturbance will mainly be restricted to the surface infrastructure areas shown indicatively on **Figure 1.4**, though will include some other areas above the underground mine, such as drill pads and access tracks. The project area generally comprises direct surface disturbance areas of up to approximately 117 ha, and an underground mining area of approximately 3,472 ha, where negligible subsidence impacts are anticipated.

A construction buffer zone will be provided around the direct disturbance areas. The buffer zone will provide an area for construction vehicle and equipment movements, minor stockpiling and equipment laydown, as well as allowing for minor realignments of surface infrastructure. Ground disturbance will generally be minor and associated with temporary vehicle tracks and sediment controls as well as minor

works such as backfilled trenches associated with realignment of existing services. Notwithstanding, environmental features identified in the relevant technical assessments will be marked as avoidance zones so that activities in this area do not have an environmental impact.

Product coal will be transported by rail, primarily to Port Kembla terminal for the international market, and possibly to the domestic market depending on market demand. Rail works and use are the subject of a separate EIS and State significant development application for the Berrima Rail Project.

1.2 Project Area and Study Area

The project area defined in the previous section includes the above ground and underground footprint of the activities associated with the development of the mine. The study area for the hydrogeochemical assessment includes the project area, as well as areas down hydraulic gradient from the project area (i.e. areas with the potential to receive groundwater originating from the project area, the quality of which may be influenced by the project activities).

Given that the focus of the hydrogeochemical assessment is the potential influence of project activities on groundwater quality, the study area largely comprises the underground project area, and portions of the aquifers down hydraulic gradient from the underground workings.

1.3 Objectives of Hydrogeochemical Assessment

The overarching objective of the hydrogeochemical assessment was to assess the potential for changes to groundwater quality, and associated potential impacts to environmental values, arising from the Project activities. The following Project related influences to groundwater quality were evaluated as the focus of this assessment:

- Changes to groundwater quality resulting from enhanced vertical flux of groundwater from saline shale formations to underlying sandstone formations;
- Water quality resulting from rainfall infiltration into surface stockpiles of mine reject material, and potential for leachate infiltration into shallow groundwater resources;
- Changes to groundwater quality resulting from groundwater flow through mine reject materials backfilled into the underground mine voids, and transport of derived solutes downgradient from the backfilled workings; and
- Changes to groundwater quality resulting from co-disposal of dam water from multiple sources via injection into sealed underground mine voids.

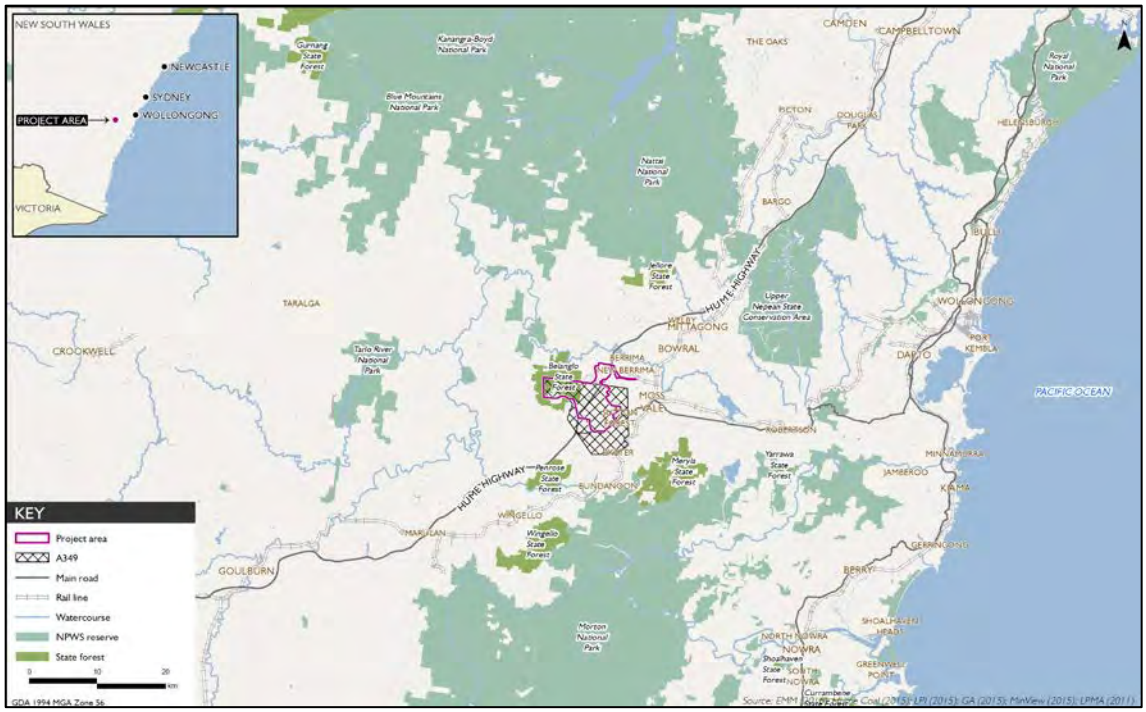


Figure 1.1. Regional context (from EMM, 2016b)

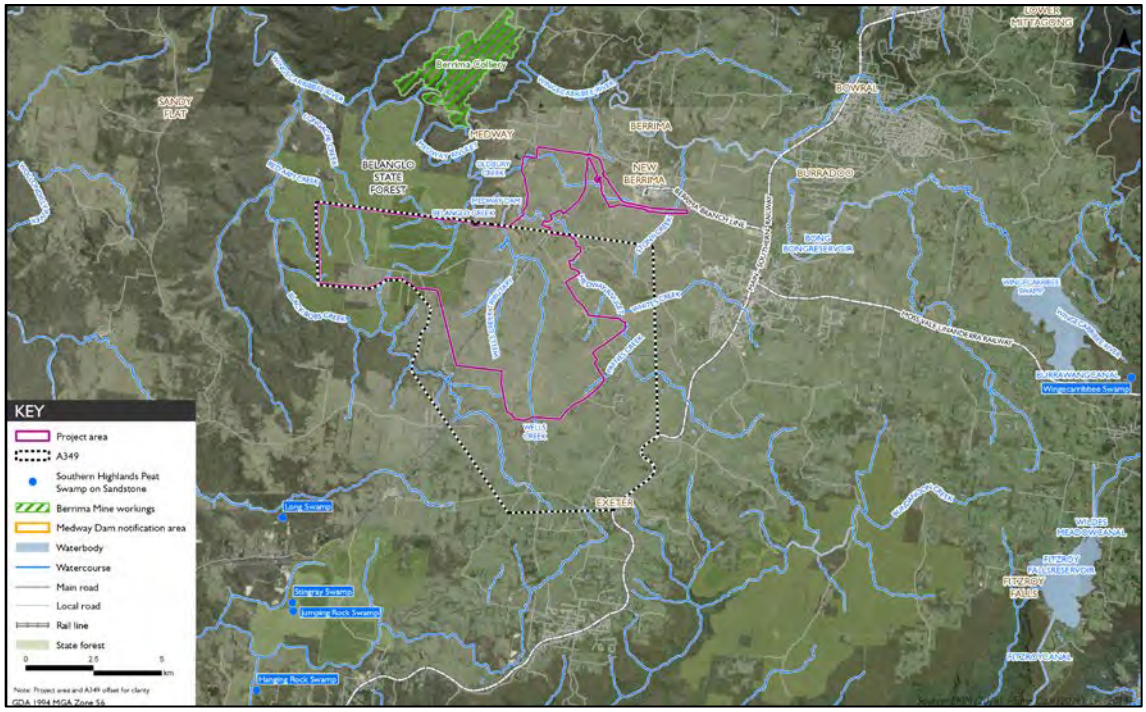


Figure 1.2. Local context (from EMM, 2016b)

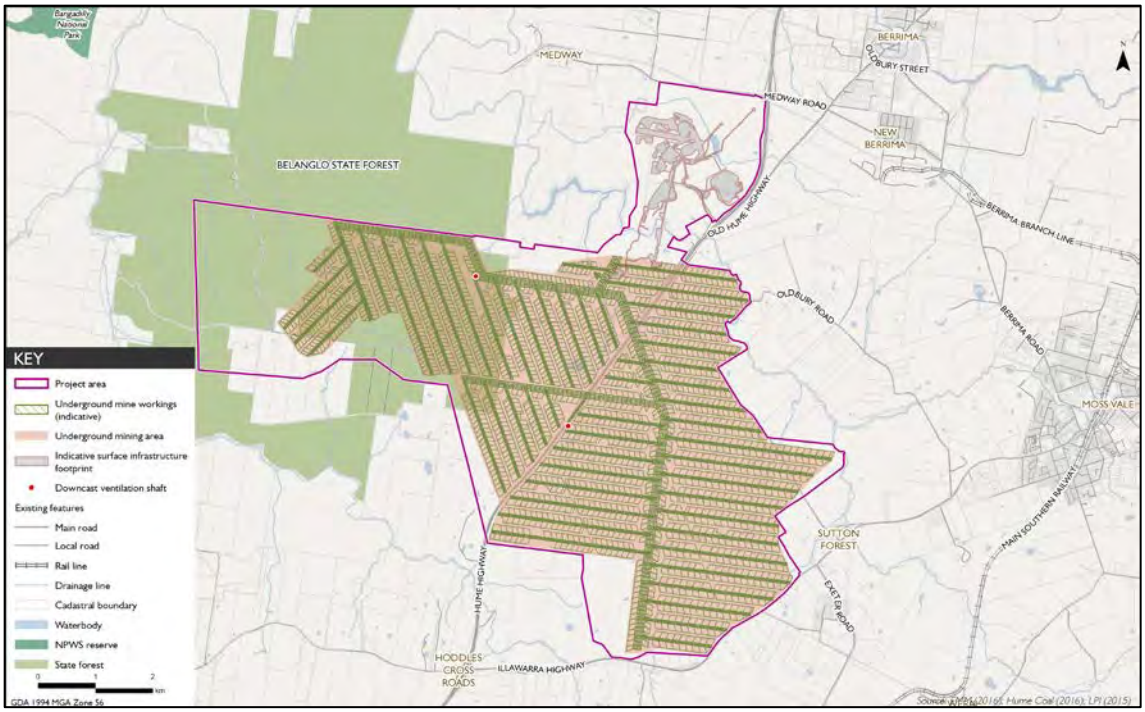


Figure 1.3. Indicative Mine Infrastructure Plan (from EMM, 2016b)

Figure 1.4. Indicative Surface Infrastructure Plan (from EMM, 2016b)

1.4 Scope of Services

The completion of the hydrogeochemical assessment comprised the following tasks:

- Literature review of available reports and monitoring data regarding groundwater quality within the Project area, as supplied by Hume Coal. The groundwater flow model report for the Project was also reviewed for context, and to assist with design of simulations to assess groundwater quality influences of Project activities;
- Review, organisation and hydrogeochemical analysis of existing water quality data to document baseline, pre-development conditions;
- Geochemical modelling to predict water quality evolution in the subsurface and in aboveground storage ponds in response to Project activities;
- Risk-based evaluation of the changes to water quality resulting from Project activities, in the context of the prevailing water quality regulatory legislation, policies and guidelines and with specific regard to relevant receptors; and
- Recommendations for monitoring and mitigation measures to reduce or manage potential adverse changes to groundwater quality resulting from Project activities.

1.5 Project Team

The key members of the hydrogeochemical assessment team and their qualifications are summarised as follows:

- **Dr Lange Jorstad**, Senior Hydrogeologist, Geosyntec – Dr Jorstad holds a BSc in geology from the University of California, Santa Barbara, and PhD in hydrogeochemistry from the University of New South Wales. He has 19 years' experience as a consulting hydrogeologist, is a NSW EPA accredited site auditor, a Registered Professional Geoscientist (hydrogeology) with the Australian Institute of Geoscientists, and is Vice President of the Australian Chapter of the International Association of Hydrogeologists.

- **Dr Bruce Sass**, Principal Geochemist, Geosyntec – Dr Sass holds a BS in geology from the State University of New York, an MSc in geochemistry from Washington State University, and a PhD in physical chemistry from the University of Pennsylvania. He has more than 25 years as a consulting environmental geochemist, with particular expertise in the analysis and modelling of the geochemical processes affecting leaching, fate, transport and sequestration of hazardous constituents from mine wastes and other waste materials.

1.6 Report Structure

The hydrogeochemical assessment provides a critical review of the baseline water quality conditions within and in the vicinity of the Project area, and predictive analysis of potential changes to groundwater quality arising from Project activities. The hydrogeochemical assessment report is structured as follows:

- **Section 2** provides a summary the environmental setting of the Project area, with a focus on the geology, hydrogeology and groundwater resource development, surface water features, and potential groundwater dependent ecosystems (GDEs);
- **Section 3** provides a summary of legislation, policies, guidelines, approval requirements and assessment criteria relevant to water quality within the study area;
- **Section 4** provides a description of the methodologies used to perform this hydrogeochemical assessment, including identification of the data sources used in this assessment;
- **Section 5** provides a baseline hydrogeochemical characterisation of groundwater associated with different geological units based on data provided from the baseline monitoring program;
- **Section 6** provides the details of the predicted influence of project activities on groundwater and surface water quality, and assessment of the potential for unacceptable impacts to the beneficial uses of the groundwater resource;
- **Section 7** provides a summary of the key conclusions from the hydrogeochemical assessment, including suggestions to mitigate or reduce potential unacceptable impacts associated with the Project activities;
- **Section 8** provides a list of references; and
- **Section 9** provides the limitations that apply to the assessment.

1.7 Key Assessment Outcomes

The hydrogeochemical assessment identified the following key outcomes with regard to the potential influence of Project activities on groundwater quality:

- The baseline quality of the groundwater resources of the Hawkesbury Sandstone and the Illawarra Coal Measures is broadly characterised by low TDS groundwater that is suitable to support most beneficial uses. Within each formation, a number of groundwater quality parameters and analytes

exceed or are outside the range of one or more beneficial use assessment criteria (for example, the pH of groundwater within the Hawkesbury Sandstone is generally below the trigger value range for protection of freshwater species in upland rivers in South-east Australia). However, the baseline water quality criteria exceedances are generally limited in number and only marginally exceed the relevant criteria, and are not considered to limit the beneficial uses of the resource as a whole. Within the study area, these two formations are accessed by approximately 90% of the water supply bores (for which screened interval data are available).

- Dewatering of underground mine voids during active mine operations will result in partial depressurisation[1] of some of the overlying water bearing formations. The downward vertical hydraulic gradients induced by depressurisation are predicted to result in a temporary increase in the flux of groundwater from the Wianamatta Group shales (where present) to the upper portion of the Hawkesbury Sandstone. Given the higher TDS of the shale groundwater, this phenomenon has the potential to temporarily raise the TDS of the upper Hawkesbury Sandstone groundwater. The numerical flow model for the study area (Coffey, 2016b) was used to estimate the magnitude of increased flux attributable to Hume Coal mining activities, which indicated a peak increase of 1 megalitre [ML] per day (ML/day) (9% increase from baseline), with the maximum effect occurring within a short duration during mining. Likewise, a proportional maximum increase in salt flux (as groundwater TDS) of 9% was also predicted to occur. A net salt flux increase of 1.3% over baseline conditions was calculated for the 74-year period during which modelling predicted an incremental increase in groundwater leakage (including active mining operations and post-mining recovery). The current influence of baseline groundwater flux from the shales to the underlying sandstone was reviewed for multi-level monitoring wells installed through the shale, which generally indicated a minor TDS difference relative to wells installed in sandstone outcrop areas. A mixing model was used to assess the water quality resulting from relative mixing proportions of the shale and sandstone groundwater, which indicated that an unrealistically large proportion (> 40%) of shale groundwater would be required to reduce the beneficial use status of the underlying Hawkesbury Sandstone groundwater resource.

- The results of kinetic leach column (KLC) testing were used to assess the potential change to groundwater quality resulting from groundwater

[1] Depressurisation refers to a decrease in hydrostatic pressure in a geological formation due to a release of groundwater storage; in this case due to drainage of groundwater from stratigraphically adjacent formations into the mine workings, which are dewatered for safety purposes.

interaction with mining reject material emplaced in the underground mine voids. The results of column leaching tests were selected from columns considered to best represent the expected subsurface conditions: simulated mine reject material generated from cores recovered from the Project area, leached with groundwater obtained from the Wongawilli Seam, as would occur in within the backfilled mine void. The "wet" KLC tests referenced in this assessment were maintained under a 100-mm water cover, and were not subjected to alternate wet/dry cycles or heating (as per the leachate generation assessment approach for surface storage of mine reject material). However, the oxygen saturation of the groundwater used as the leaching agent may have been higher (due to atmospheric exposure) than would be expected at depth in the subsurface, resulting in a conservative estimate of sulphide mineral oxidation. Data from two columns were considered; one with mine reject material amended with limestone as an additional alkalinity source, and the other unamended. The results were compared to baseline water quality for the Hawkesbury Sandstone and Wongawilli Seam to assess whether leaching from mine reject material would potentially result in degradation of the beneficial use status of the groundwater resources. The results of the unamended KLC test indicated leachate water quality exceeded one or more of the beneficial use criteria that were generally also exceeded in the baseline groundwater quality, although the magnitude of the exceedance was larger (by approximately an order of magnitude) for certain metals in the leachate results. The final leachate pH of the unamended column was relatively low, indicating a potential for acid generation. It should be noted that the potential for higher oxygen saturation in the groundwater sample used as the leaching agent, relative to the expected *in-situ* conditions in the subsurface, would introduce conservatism to the KLC test results with respect to sulphide mineral oxidation and hence acid generation. The leachate quality from the limestone amended reject material was very favourable, with approximately neutral pH values throughout the test, and with leachate analyte concentrations that were below most of beneficial use criteria, including many that were exceeded in the baseline groundwater quality. Accordingly, the assessment indicated that limestone amendment of the mine reject material prior to emplacement in the mine void is likely to produce leachate that is indistinguishable from native groundwater quality, and is considered unlikely to change the beneficial use status of the surrounding groundwater resources.

- During the initial 12-18 months as the project is developed, the coal reject generated from mining of the initial panels will be stored in a temporary coal reject stockpile adjacent to the CPP until sufficient void space is available underground, and the plant is commissioned to commence

production of the reject in a semi-liquid mixture (slurry) suitable for pumping for underground emplacement. In addition, if the slurry operation is interrupted, for example during maintenance, reject will be temporarily diverted to an emergency surface stockpile for later reprocessing. The fines managed on the surface in this manner will be dewatered via belt press filters (avoiding the need for a tailings dam) prior to being combined with the course reject. This combined reject will be placed for co-disposal on the temporary coal reject stockpile, which will be progressively constructed, contoured and when full, top dressed and revegetated. Once mining is completed, rejects stored at the surface will be removed, reprocessed and pumped underground to remaining voids. Surface emplacements will then be rehabilitated. The coal reject stockpile will be managed such that it does not receive run off from the surrounding mine site, however will still be exposed to rainfall that falls directly on the stockpile. To reduce the potential for acid generation and mobilisation of metals arising from oxidation of reject minerals in the stockpile, the reject will be amended with limestone prior to emplacement in the stockpile to buffer acid generation.

- The mine water management plan will include a portion of the water in the Primary Water Dam (PWD) being pumped into the sealed underground panels. The water balance for the site indicates that the average annual input to the PWD will comprise approximately 70% extracted groundwater, 20% rainfall, and 10% process water from the CPP and dust suppression returns. The water quality resulting from the proportional mixing of these end member waters was simulated using a mixing model, with data from KLC tests, geochemical modelling and published rainfall quality data used to represent the end member water types. The mixed PWD water quality exceeds a number of beneficial use criteria for dissolved metals; however comparison to the average WWS baseline groundwater quality (the "receiving environment" for water injected into the sealed panels) indicates similar exceedances of dissolved metals criteria, and a similar overall beneficial use profile. Two metals (nickel and copper) marginally exceeded the average WWS groundwater quality concentrations; however, these estimated concentrations are conservative for the following reasons:
    - the quality of the CPP process water that would report to the PWD (which was the driver for the elevated nickel and copper concentrations) was simulated by adopting "first flush" results from concentrated KLC leachate testing. The larger water-to-solids ratio in the CPP would be expected to produce a more dilute water quality than the KLC first flush results;

- some of the dissolved metals load would be expected to adsorb onto precipitating iron oxide colloids in the PWD, which was not accounted for in the geochemical modelling; and
- further dilution would occur when the PWD water mixes with natural groundwater in the sealed panel following injection.

2. PROJECT AREA DESCRIPTION AND ENVIRONMENTAL SETTING

2.1 General Site Description

The project area is approximately 100 km south-west of Sydney and 4.5 km west of Moss Vale town centre in the Wingecarribee LGA (refer to **Figure 1.1** and **Figure 1.2**). The nearest area of surface disturbance will be associated with the surface infrastructure area, which will be 7.2 km north-west of Moss Vale town centre. It is in the Southern Highlands region of NSW and the Sydney Basin Biogeographic Region.

The project area is in a semi-rural setting, with the wider region characterised by grazing properties, small-scale farm businesses, natural areas, forestry, scattered rural residences, villages and towns, industrial activities such as the Berrima Cement Work and Berrima Feed Mill, and some extractive industry and major transport infrastructure such as the Hume Highway.

Surface infrastructure is proposed to be developed on predominately cleared land owned by Hume Coal or affiliated entities, or for which there are appropriate access agreements in place with the landowner. Over half of the remainder of the project area (principally land above the underground mining area) comprises cleared land that is, and will continue to be, used for livestock grazing and small-scale farm businesses. Belanglo State Forest covers the north-western portion of the project area and contains introduced pine forest plantations, areas of native vegetation and several creeks that flow through deep sandstone gorges. Native vegetation within the project area is largely restricted to parts of Belanglo State Forest and riparian corridors along some watercourses. With some minor portions of forest in elevated positions such as Mt Gingenbullen.

The project area is traversed by several drainage lines including Oldbury Creek, Medway Rivulet, Wells Creek, Wells Creek Tributary, Belanglo Creek and Longacre Creek, all of which ultimately discharge to the Wingecarribee River, at least 5 km downstream of the project area (Figure 1.2). The Wingecarribee River's catchment forms part of the broader Warragamba Dam and Hawkesbury-Nepean catchments. Medway Dam is also adjacent to the northern portion of the project area (Figure 1.2).

Most of the central and eastern parts of the project area have very low rolling hills with occasional elevated ridge lines. However, there are steeper slopes and deep gorges in the west in Belanglo State Forest.

Existing built features across the project area include scattered rural residences and farm improvements such as outbuildings, dams, access tracks, fences, yards and gardens, as well as infrastructure and utilities including roads, electricity lines, communications cables and water and gas pipelines. Key roads that traverse the project area are the Hume Highway and Golden Vale Road. The Illawarra Highway borders the south-east section of the project area.

Industrial and manufacturing facilities adjacent to the project area include the Berrima Cement Works and Berrima Feed Mill on the fringe of New Berrima. Berrima Colliery's mining lease (CCL 748) also adjoins the project area's northern boundary. Berrima Colliery is currently not operating with production having ceased in 2013 after almost 100 years of operation. The mine is currently undergoing closure.

2.2 Geology

The study area is located in the south-western portion of the Sydney Basin, a regionally extensive sedimentary basin. The geology of the study area consists predominantly of a thick sedimentary sequence of the Sydney Basin, with more recent volcanic intrusions also present within the study area. The geology relevant to the study area is described in the following sections, in descending stratigraphic order.

2.2.1 Robertson Basalt

Volcanic activity during the late-Triassic to early-Jurassic periods resulted in basaltic intrusions (necks, sills, dykes and basalt surface flows) through the sedimentary geology of the Sydney Basin. The volcanic activity was particularly concentrated in the Southern Highlands, with basalt flows defining the surface geology along the southern portion of the exploration lease, and in other discrete areas within and around the study area.

2.2.2 Wianamatta Group Shales

The Wianamatta Group (WG) represents a late-Triassic marine depositional regime broadly consisting of two shale formations (Ashfield and Bringelly Shales) separated by the Minchinbury Sandstone. The shale formations are described as black to dark grey shale, claystone and laminite, while the intermediate Minchinbury Sandstone is described as a fine to medium grained lithic sandstone.

The WG shales are present in the eastern half of the study area, and have been eroded away in the west of the study area, exposing the underlying Hawkesbury Sandstone.

2.2.3 Hawkesbury Sandstone

The Hawkesbury Sandstone (HAW) was deposited during the Middle Triassic in a fluvatile (non-marine) depositional environment. The HAW is up to 250 m thick in the central Sydney Basin, and is approximately 100 m thick in the study area. It consists primarily of quartz, feldspar and mica in a kaolinitic clay matrix and is cemented by secondary quartz and siderite (Standard, 1969). The sandstone beds exhibit both sheet facies, characterised by cross-bedding, and massive facies that lack internal sedimentary structure, reflecting variable depositional processes. Minor clayey sandstone, siltstone and shale lenses may be present in the profile.

2.2.4 Narrabeen Group

The late-Permian to early-Triassic Narrabeen Group consists of a variable depositional sequence comprising interbedded sandstones, siltstones, claystones and conglomerates. The Narrabeen Group formations are mostly absent within the study area, with a maximum thickness of 6 m in the northern portion of the study area. Outside the study area the Narrabeen Group exceeds 300 m in thickness. Where the Narrabeen Group is absent, the HAW unconformably overlies the Illawarra Coal Measures.

2.2.5 Illawarra Coal Measures

The late-Permian Illawarra Coal Measures (ICM) are approximately 50 m thick in the study area, and consist of interbedded layers of sandstone, conglomerate, shale and coal. The ICM host the Wongawilli Seam, which is the mining target for the Hume Coal Project. The Wongawilli Seam occurs in the upper portion of the ICM, and is overlain unconformably by the HAW. At the top of the WWS there are, across most of the mine lease, carbonaceous to tuffaceous claystone layers.

The ICM overlies the Shoalhaven Group, consisting of marine sandstone interbedded with latite flows, which in turn overlies Palaeozoic basement formations.

2.3 Hydrogeology

A detailed review of the hydrogeology of the study area is available in the Coffey (2016) Groundwater Assessment report, including a review of baseline hydrogeological conditions (Vol.1), and predictive modelling of the influence of the mining activities on the local groundwater resources (Vol.2). The hydrogeology of the study area is summarised in this section based largely on hydrogeological conceptual model described in Coffey (2016).

The most important groundwater resource from a water supply perspective is associated with the HAW, which is accessed by approximately 90% of the private water supply bores in the study area. With the exception of the southern basalt intrusion, it is the shallowest fresh water supply, and the yields are sufficient to support most beneficial uses. The southern basalt intrusion is also a highly developed groundwater supply, with fresh groundwater quality and airlift yields in the rage of 10 to 20 L/sec.

2.3.1 Hydraulic Conductivity

The regional hydrogeology of the study area is characterised by fractured rock aquifer systems, with groundwater flow predominantly controlled by defects in the rock mass, including fractures, joints and bedding plane partings. The hydraulic conductivity of the rock mass is generally a function of defect spacing/frequency and aperture thickness, both of which decrease with depth. Hydraulic conductivity values in the study area generally range between 0.01 and 10 m/day, and are higher

than elsewhere in the Southern Coalfields where a large proportion of measured K values fall between 0.0001 and 0.01 m/day. The increased hydraulic conductivity in the vicinity of the study area is believed to be associated with tectonic disturbance of the rock mass during the period of intensive igneous intrusions, and may also have been influenced by the erosion of gorges to the north, west and south of the project area.

2.3.2 Groundwater Recharge and Discharge

Recharge to the local aquifers occurs primarily via rainfall infiltration. With respect to the HAW, the outcrop areas occur along the western portion of the study area, and are capped by the lower permeability WG shale formations in the eastern half of the study area. HAW also outcrops in the gorges to the south-east of the project area. Leakage from the Wingecarribee Reservoir some 15km to the east of the study area is also considered to contribute a reasonable component of groundwater recharge within the study area.

Groundwater discharge from the regional aquifer systems occurs as baseflow contribution to local watercourses, evapotranspiration of groundwater seepage (particularly at escarpment seepage faces), groundwater extraction for water supply and ongoing discharge to the mine voids of the Berrima and Loch Catherine mines, which still have strong inward hydraulic gradients associated with them.

2.3.3 Hydraulic Head Distribution

The hydraulic head[2] distribution in the study area is strongly influenced by the local topography and surface geology. Hydraulic head values are elevated in the outcropping sandstone along the western portion of the study area and around the Wingecarribee Reservoir in the southeast, with decreasing head values towards discharge points in the south (e.g. the deeply incised Bundanoon Creek valley) and the north (Medway Rivulet and the Berrima and Loch Catherine mine voids).

A detailed discussion of the interpreted head distribution was presented in Coffey (2016a). The general pattern consists of negligible vertical gradients[3] in the portion of the HAW beneath the WG shales, with downward vertical gradients developing close to escarpment discharge areas and above the Berrima Mine void, where a strong inward hydraulic gradient developed due to the propagation of depressurisation into the overlying HAW formation. In contrast to the HAW, a downward vertical gradient was inferred in the southern basalt intrusion and WG shale formations.

---

[2] Hydraulic head is a water level measurement in a well corrected to a common elevation reference (in this case, the Australian Height Datum). Groundwater generally flows from areas of higher hydraulic head to areas of lower hydraulic head.

[3] A hydraulic gradient is the groundwater equivalent of a topographic slope: it is the change in hydraulic head over a given distance. Hydraulic gradients are commonly expressed in terms of horizontal gradients (i.e. planar to ground surface), and vertical gradients (perpendicular to ground surface).

2.3.4 Groundwater Use

A total of 430 registered water supply bores were identified within the study area (i.e. within the boundary of the numerical flow model domain). The majority of these were registered for stock, domestic and/or irrigation use, with the balance comprising unspecified "industrial" use, mineral water extraction, and monitoring bores. Of these bores, 117 contained enough information to identify the formations in which they were screened. Approximately 90% of the bores were screened in the Hawkesbury Sandstone (HAW) and/or the Illawarra Coal Measures (ICM), with the balance screened in the Wianamatta Group shales or the basalt.

2.4 Sensitive Receptors

From a review of the environmental setting of the study area, the following receptors were identified:

- Coffey (2016a,b) reported the presence of several hundred registered private bores within and surrounding the project area. The depths of the majority of private bores within the A349 mine lease indicate that they are installed within the HAW, beneath a reasonable thickness of WG shales. The notable exception is a cluster of shallow bores installed within the basalt in the south-eastern portion of A349. Within the domain of the groundwater model (Coffey, 2016b), Coffey identified 83 private bores with water access licences for irrigation or industrial uses, with a combined allocation of 14.5 ML/day, and a further 299 unlicensed bores for stock and/or domestic use (landholder rights) with an assumed combined extraction rate of approximately 2.4 ML/day. As discussed in further detail later in this report, the water quality and yields from the HAW are sufficient to support most beneficial uses. The integrity of the groundwater resources within the study area, and the water supply bores that access them are considered to be the primary receptors of concern for any changes to groundwater quality resulting from mining activities;

- A number of rivers and creeks within the study area receive baseflow from groundwater, including the Wingecarribee River, Medway Rivulet, Lower Wollondilly River, and various creeks within these catchments. Accordingly, a change to groundwater quality from mining activities would have the potential to also affect baseflow quality and hence the aquatic ecology of the receiving water bodies; and

- Several other potential groundwater dependent ecosystems (GDEs) were identified within and surrounding the Hume Coal project area, generally comprising swamps and wetlands to the southwest of the project area (approximately 15 km from the boundary of A349), and Southern Highlands shale forest and woodland, portions of which are located within

the project area, but the majority is located to the west and southwest of the project area. It is understood that the potential GDEs are associated with areas of shallow groundwater, accordingly the groundwater quality accessed by the GDEs would be strongly influenced by recently recharged groundwater, rather than groundwater associated with the deeper strata in which the mine workings are proposed.

The assessment of potential changes to groundwater quality associated with mining activities considered the potential impacts to the receptors identified above.

3. ASSESSSMENT REQUIREMENTS

This assessment has been prepared in accordance with the relevant governmental assessment requirements, guidelines and policies, and in consultation with the relevant government agencies. The legislation, guidelines and policies relevant to the hydrogeochemical assessment are discussed in Section 3.1, followed by a summary of the Secretary's Environmental Assessment Requirements (SEARs), and those of referral authorities, specific to the project.

3.1 Legislation, Policies and Guidelines

3.1.1 Water Act 1912 and Water Management Act 2000

Surface water and groundwater resources in NSW are administered under the Water Act 1912 and the Water Management Act 2000 (WMA). The former jurisdiction of the Water Act 1912 has progressively been superseded by the WMA through the development of Water Sharing Plans (WSPs), which are regulatory instruments that set out the rules for managing the various water sources throughout NSW. WSPs for groundwater sources describe the nature and extent of the resource, the estimated volume in storage available for allocation as water supply, the portion of storage required for maintenance of environmental values (and therefore unavailable for licenced water supply), and the administrative process for licencing and managing allocation of the groundwater resource for water supply.

The study area is within the area covered by the WSP for the Greater Metropolitan Region Groundwater Sources 2011, issued under the WMA, which commenced on 1 July 2011. The jurisdiction of the WSP is divided into a number of groundwater source areas, of which the study area falls within the Sydney Basin Nepean Groundwater Source (Nepean Management Zone 1).

3.1.2 Aquifer Interference Policy

The Aquifer Interference (AI) Policy is the NSW Government policy for the licensing and assessment of aquifer interference activities. The AI Policy defines "aquifer interference" activities as those activities that involve:

- Penetration of an aquifer
- Interference with water in an aquifer
- Obstruction of groundwater flow
- Taking of water from an aquifer
- Disposal of taken groundwater

While the AI Policy applies to all aquifer interference activities, it was developed with particular regard to mining and extractive activities. Examples of activities

assessed under the policy include dewatering, water injection into aquifers and activities with the potential to impact groundwater quality or result in structural damage to an aquifer (e.g. compaction).

The AI Policy sets out a framework for assessing the impacts of aquifer interference activities on water resources as follows:

- Assessment of impacts to groundwater resources and related environmental values arising from the proposed activity;
- Quantification of the contribution of all water sources affected by the aquifer interference activity, and demonstrated ability to obtain the necessary licenses to account for the take of water from all affected water sources;
- Ability to demonstrate design to prevent the take of water where licensed allocations are not available;
- Ability to demonstrate that minimal impact considerations can be met; and
- Proposed remediation actions for impacts greater than those predicted as part of the relevant approval.

One of the key objectives of the AI Policy is to assess the potential impacts of projects relative to minimal impact considerations for the affected water sources. These considerations include:

- Threshold values with respect to changes to water tables (in unconfined aquifers), changes to water pressure (in confined aquifers) and changes to water quality arising from proposed aquifer interference activities;
- Two standards of minimal impact considerations developed for highly productive or less productive groundwater sources:
- Highly productive groundwater sources are defined as having total dissolved solids values less than 1,500 mg/L and are capable of yielding groundwater at a rate greater than 5 L/s. Within this category, minimal harm considerations have been developed for alluvial, coastal sand, porous and fractured rock water sources.
- Less productive groundwater sources are those that do not meet the above criteria, with separate considerations developed for alluvial and porous/fractured rock water sources.

- Minimal harm considerations which afford protection to specific environmental values of groundwater under the AI Policy, including groundwater sources, connected surface water sources, GDEs, groundwater dependent culturally significant sites and water users. The values are protected through the application of the previously mentioned threshold values, and vertical and horizontal buffers for certain activities (e.g. underground mining).

With minor exceptions, groundwater quality within the project area that will be subject to aquifer interference activities is characterised by TDS values less than 1500 mg/L, and includes water supply bores with yields greater than 5 L/sec, which classifies the groundwater sources as "highly productive" within the minimal impact assessment framework.

With regard to the assessment of project influences on groundwater quality, the following minimal impact considerations apply to highly productive porous and fractured rock groundwater sources under the AI Policy:

1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.
2. If condition 1 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.

3.1.3 Summary of Assessment Criteria

Ecological Water Quality Criteria

The methodology and criteria for ecological water quality assessment in Australia are presented in the Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) Australian and New Zealand Guidelines for Fresh and Marine Water Quality (herein ANZECC 2000).

The ANZECC 2000 guidelines present assessment criteria (referred to as "trigger values") for a range of organic and inorganic chemicals, which are applicable to both protection of aquatic ecology, and suitability for primary industries. While the guidelines are not specifically "groundwater criteria", they apply at the point of use or exposure and are therefore relevant where an aquatic ecosystem is partially or wholly dependent on groundwater, or where groundwater supply supports primary industry.

The relevant ANZECC 2000 water quality criteria for protection of aquatic ecosystems and suitability for primary industries are included in the baseline groundwater quality monitoring summary tables attached to this assessment.

Health-based Water Quality Criteria ADWG 2011

The methodology and criteria for health-based assessment of drinking water quality in Australia are presented in the National Health and Medical Research Council (NHMRC) and Natural Resource Management Ministerial Council (NRMMC) Australian Drinking Water Guidelines (ADWG, 2011). The ADWG (2011) lists health-based and aesthetic criteria for various organic and inorganic chemicals. Because aquifers within the study area are accessed for potable water supply, both the health-based and aesthetic criteria have been considered in this assessment.

3.2 SEARs and Referral Authority Requirements

The SEARs for the project were issued by the Secretary of the DPE in a letter dated 20 August 2015. The SEARs that are specific to the hydrogeochemical assessment are summarised in **Table 3.1**. These broad SEARs are addressed progressively throughout this report, and in particular **Section 6** with regard to impact assessment.

Table 3.1 Secretary's environmental assessment requirements

Requirement
An assessment of the likely impacts of the development on the quantity and quality of the region's surface and groundwater resources having regard to the EPA's, DPI's and Water NSW's requirements and recommendations.
An assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure, and other water users.

To inform preparation of the SEARs, DP&E invited other government agencies to recommend matters for address in the EIS. These matters were then taken into account by the Secretary for DP&E when preparing the SEARs. Copies of the government agencies' advice to DP&E was attached to the SEARs.

Four agencies, including the Department of Resources and Energy (DRE), Fisheries NSW, the NSW Office of Water under the Department of Primary Industries (DPI Water) and the Office of Environment and Heritage (OEH), raised matters relevant to the hydrogeochemical assessment. These were mainly their standard requirements for projects of this nature, though included some project-specific requirements. These matters are listed in Table 3.2 and Table 3.3, respectively, and have been taken into account in preparing this hydrogeochemical assessment, as indicated in the tables.

Table 3.2 Referral authority environmental assessment requirements

Requirement	Section addressed
DRE	
An assessment and life of mine management strategy of the potential for geochemical constraints to rehabilitation, particularly associated with the management of overburden/interburden and reject material. Based on this, the EIS should document the processes that will be implemented throughout the mine life to identify and appropriately manage geochemical risks that may affect the ability to achieve sustainable rehabilitation outcomes.	Section 6.2
A life of mine tailings management strategy which details measures to be implemented to avoid the exposure of potentially environmentally sensitive tailings material as well as promote geotechnical stability of the rehabilitated landform.	Section 6.2
DPI Water	
A detailed assessment against the NSW Aquifer Interference Policy (2012) using DPI Water's assessment framework.	Section 6
Assessment of impacts on surface and ground water sources (both quality and quantity), related infrastructure, adjacent licensed water users, basic landholder rights, watercourses, riparian land, wetlands, and groundwater dependent ecosystems, and measures proposed to reduce and mitigate these impacts.	Section 6 (groundwater only, surface water quality addressed in a separate report).
Proposed surface and groundwater monitoring activities and methodologies.	Section 7.4
Proposed management and disposal of produced or incidental water.	Section 6.3
Assessment of any potential cumulative impacts on water resources, and any proposed options to manage the cumulative impacts.	Sections 6 and 7
Sufficient baseline monitoring for groundwater quantity and quality for all aquifers and GDEs to establish a baseline incorporating typical temporal and spatial variations.	Section 5
The existing groundwater users within the area (including the environment), any potential impacts on these users and safeguard measures to mitigate impacts.	Sections 6 and 7

Requirement	**Section addressed**
An assessment of groundwater quality, its beneficial use classification and prediction of any impacts on groundwater quality.	Sections 5, 6 and 7, and Appendix A
An assessment of the potential for groundwater contamination (considering both the impacts of the proposal on groundwater contamination and the impacts of contamination on the proposal).	Sections 6 and 7
Measures proposed to protect groundwater quality, both in the short and long term.	Sections 6 and 7
Measures for preventing groundwater pollution so that remediation is not required.	Sections 6 and 7
Protective measures for any groundwater dependent ecosystems (GDEs).	Section 7.2
The results of any models or predictive tools used.	Sections 6 and 7
Where potential impact/s are identified the assessment will need to identify limits to the level of impact and contingency measures that would remediate, reduce or manage potential impacts to the existing groundwater resource and any dependent groundwater environment or water users, including information on: - Any proposed monitoring programs, including water levels and quality data. - Reporting procedures for any monitoring program including mechanism for transfer of information. - An assessment of any groundwater source/aquifer that may be sterilised from future use as a water supply as a consequence of the proposal. - Identification of any nominal thresholds as to the level of impact beyond which remedial measures or contingency plans would be initiated (this may entail water level triggers or a beneficial use category). - Description of the remedial measures or contingency plans proposed. - Any funding assurances covering the anticipated post development maintenance cost, for example on-going groundwater monitoring for the nominated period.	Sections 6 and 7

Requirement	Section addressed
OEH	
The EIS must describe background conditions for any water resource likely to be affected by the development, including: a. Existing surface and groundwater. b. Hydrology, including volume, frequency and quality of discharges at proposed intake and discharge locations. c. Water Quality Objectives (as endorsed by the NSW Government http://www.environment.nsw.gov.au/ieo/index.htm) including groundwater as appropriate that represent the community's uses and values for the receiving waters. d. Indicators and trigger values/criteria for the environmental values identified at (c) in accordance with the ANZECC (2000) Guidelines for Fresh and Marine Water Quality and/or local objectives, criteria or targets endorsed by the NSW Government.	Sections 5 and 6, and Appendix A
The EIS must assess the impacts of the development on water quality, including: a. The nature and degree of impact on receiving waters for both surface and groundwater, demonstrating how the development protects the Water Quality Objectives where they are currently being achieved, and contributes towards achievement of the Water Quality Objectives over time where they are currently not being achieved. This should include an assessment of the mitigating effects of proposed stormwater and wastewater management during and after construction. b. Identification of proposed monitoring of water quality.	Sections 6 and 7

4. ASSESSMENT METHODOLOGY

4.1 Literature Review

Information available for review as part of this assessment included hydrogeological and geochemical specialist reports prepared for the EIS, previous technical reports addressing groundwater quality in the study area, and tabulated baseline groundwater monitoring results. The information reviewed is detailed in the reference list in Section 8, and is discussed in further detail in the relevant portions of this assessment.

4.2 Data Sources

The primary data sources used for this study included the baseline groundwater monitoring data collected by Parsons Brinckerhoff (PB) and provided in electronic format by EMM, an environmental isotope study performed by PB (2012), and KLC test results from the RGS (2016) geochemical assessment.

Output was also provided from the Coffey (2016b) numerical model, indicating the extent of vertical hydraulic connectivity between the WG shale formations and the underlying HAW formations, as well as the predicted vertical groundwater flux (in megalitres [ML] per day for six-monthly time steps) between the WG and HAW, expressed both as a total flux and as the incremental increase attributable to mining activities.

4.3 Data Analysis and Interpretation

The available groundwater monitoring data are summarised in Tables A1 to A6 attached to this report. The data were grouped by representative formations, statistically assessed for variability across the monitoring period and for inter-formation comparison purposes, and compared to relevant published water quality guidelines to assess the baseline suitability of the groundwater resources for various beneficial uses.

Data from the RGS (2016) KLC test results were used for comparison to the baseline groundwater monitoring results, to evaluate the potential for changes to groundwater quality resulting from the emplacement of mine reject material in the underground voids.

The vertical flux data between the WG and HAW provided by Coffey (2016b) from their numerical flow model was compared to the natural aquifer recharge estimates for the study area, with proportional mixing calculations used to assess the potential change in water quality in the HAW that may occur because of the temporary increased flux of more saline groundwater from the WG to the HAW.

Finally, the predicted evolution of groundwater quality held in storage in a surface pond was modelled using PHREEQC (v. 3.3.8), which assumed an open-system gas exchange and equilibration (oxygen and carbon dioxide) with the atmosphere, and

calculation of the resulting change to water quality. This modelling was completed to support decisions for water reuse and disposal, in the event that surplus water was generated at any stage of the mining operation.

5. BASELINE HYDROGEOCHEMICAL CHARACTERISATION

Baseline groundwater monitoring was carried out between October 2011 and September 2015, using a network of monitoring wells installed in representative locations across the study area and screened within the relevant geological formations. The baseline groundwater monitoring network comprised 46 monitoring wells targeting the following formations:

- Robertson Basalt (2)
- Wianamatta Group shales (1)
- Hawkesbury Sandstone (23)
- Illawarra Coal Measures (3)
- Wongawilli Seam (15)
- Tongarra Seam (2)

Figure 5.1 presents the locations of the monitoring wells in the Study Area. Summary tables of the baseline groundwater monitoring results (by formation type) are attached (Tables A1 to A6, Appendix A). A tabulated summary of the well construction details, sourced from the Coffey (2016a) report, is also attached in Table A7 for reference.

The groundwater samples collected as part of the baseline monitoring program were analysed for most or all of the following analytes:

- Field water quality parameters:
    - Temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), oxidation-reduction potential (ORP)
- Major cations and anions:
    - Calcium, magnesium, sodium, potassium, chloride, sulphate, alkalinity (primarily bicarbonate), silica
- Dissolved metals and metalloids:
    - Aluminium, antimony, arsenic, beryllium, barium, boron, cadmium, chromium, cobalt, copper, iron (total and ferrous), lead, lithium, manganese, mercury, molybdenum, nickel, selenium, strontium, tin, uranium, vanadium and zinc
- Nutrients:
    - Ammonia, nitrite, nitrate, phosphorous (total and reactive)
- Other inorganics:
    - fluoride, cyanide, bromine, iodine

- Organic analytes:
    - Total recoverable hydrocarbons (TRH)
    - Benzene, toluene, ethylbenzene, xylenes (BTEX)
    - Polycyclic aromatic hydrocarbons (PAHs)
    - Phenolic compounds
    - Organochlorine (OC) and organophosphorus (OP) pesticides

5.1 Robertson Basalt

5.1.1 Summary of Monitoring Points

There are two piezometers installed within the Robertson Basalt (each in a separate occurrence of the basalt, located approximately 10 km apart). H56XC was sampled five times between December 2012 and February 2015. H136C was sampled four times between August 2014 and September 2015.

5.1.2 Field Water Quality Parameters

Water quality parameters are relatively consistent among the nine total measurements. The pH can be described as approximately neutral as values ranged from 6.07 to 7.74, with an average value of 6.75. Electrical conductivity (EC) ranged from 446 to 797 µS/cm, with the average being 653 µS/cm. Total dissolved solids (TDS) ranged from 261 to 518 mg/L, with an average of 421 mg/L. Dissolved oxygen (DO) ranged from 21 to 84 % saturated, with an average of 56 % sat. Redox potential ranged from -117 to +179 mV, with an average of 58 mV. Groundwater temperature ranged from 15.6 to 18.6 °C, with an average temperature of 17.2 °C.

The groundwater quality of the Robertson Basalt can be described as approximately neutral and having relatively low dissolved solids content. Despite the unsaturated DO measurements, the redox data portray the water as relatively oxidizing, a conclusion that is supported by low dissolved iron, which is described below. As shown by the Pourbaix diagram in **Figure 5.2** only two basalt groundwater samples plot near the phase boundary between ferrihydrite (amorphous ferric hydroxide) and a solution phase consisting mainly of ferrous [Fe(+2)] species. The majority of points plot in the ferrihydrite region indicating that dissolved iron primarily consists of ferric [Fe(+3)] species. Redox measurements were converted from an electrode (Ag/AgCl) reference to that of the standard hydrogen electrode.

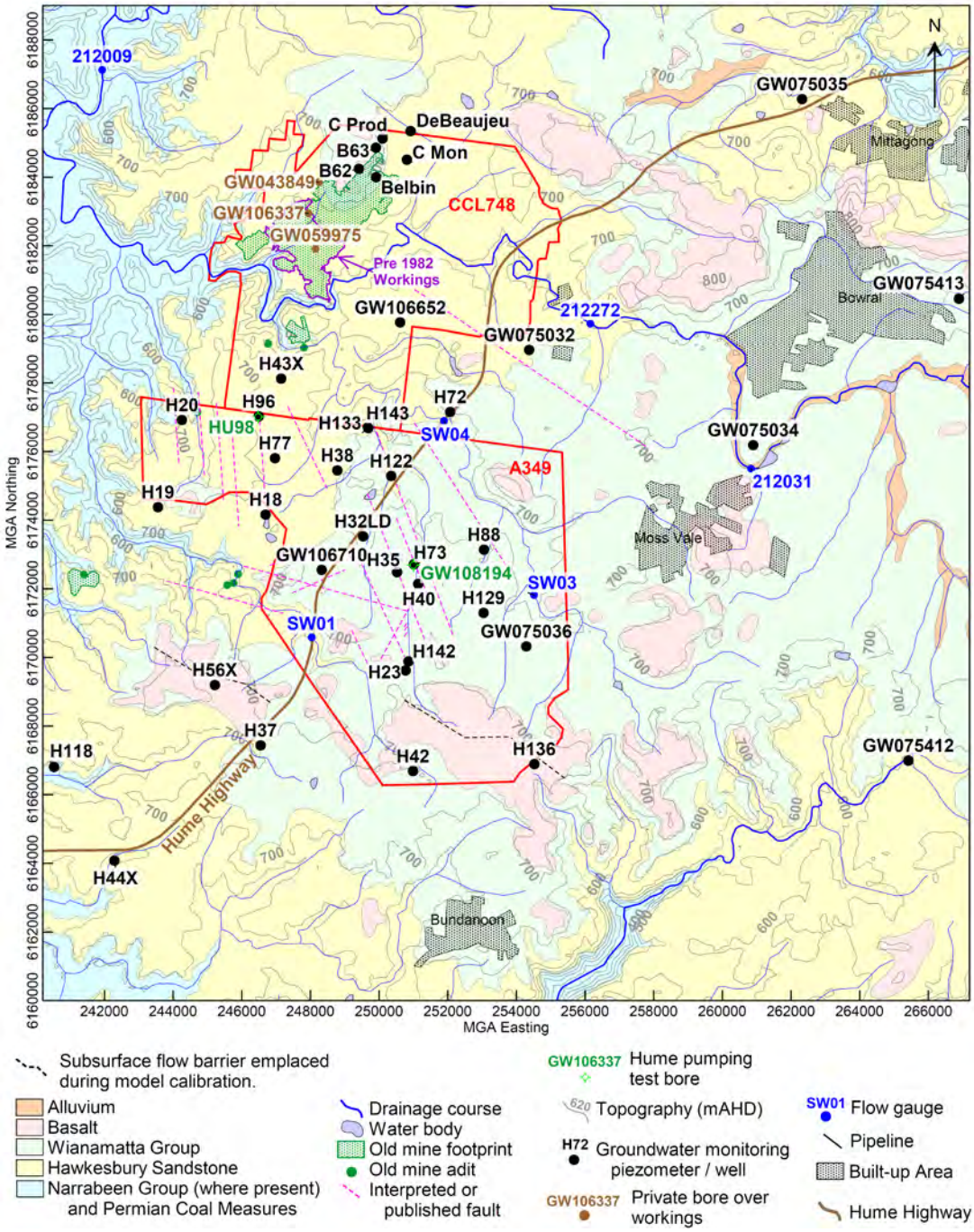


Figure 5.1. Groundwater monitoring network for the Study Area (from Coffey, 2016a).

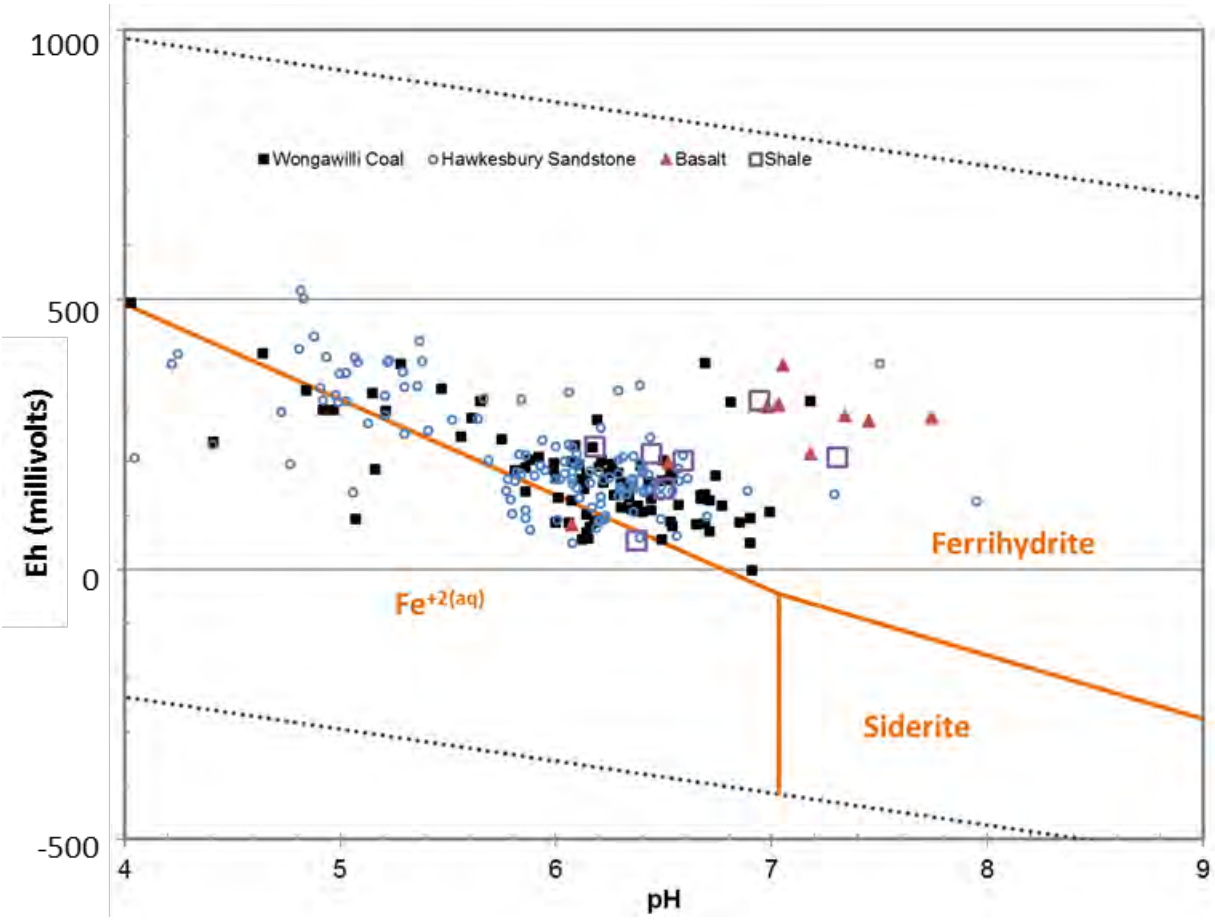


Figure 5.2. Pourbaix diagram for major groundwater types in Hume Coal study area.

5.1.3 Major and Minor Ions

The relatively low TDS of this groundwater is reflected in the low concentrations of primary groundwater constituents. Alkaline earth metals calcium and magnesium range from 30 to 61 mg/L and 25 to 57 mg/L, respectively. Alkali metal cations sodium and potassium range from 20 to 69 mg/L and 2 to 4 mg/L, respectively. Bicarbonate is the dominant anion, which is reflected in total alkalinity values ranging from 236 to 350 mg/L as $CaCO_3$. Chloride and sulphate range from 27 to 60 mg/L and 7 to 86 mg/L, respectively. Anions such as fluoride, cyanide and thiocyanate were not detected in these groundwater samples.

The dominant hydrochemical water type in the basalt was Mg-Ca-HCO_3-Cl, indicating that the water represents a mixture of rainfall recharge that has been influenced by mineral dissolution within the basalt matrix.

5.1.4 Metals and Metalloids

The dissolved metals content of the basalt tends to be quite low, with concentrations frequently below their respective laboratory limits of reporting (LOR). Although aluminium was above its detection limit of 0.01 mg/L in a few instances, the

solubility of aluminium at approximately neutral pH is several orders of magnitude below the reported concentrations, which suggests that the lab results may not represent true dissolved phase aluminium. Copper and nickel are reported slightly above their LOR of 0.001 mg/L in a few instances, but concentrations were below detection in other sampling periods. On the contrary, zinc was detected well above its LOR of 0.005 mg/L in five out of six sampling events.

Iron and manganese are useful indicators of redox conditions in groundwater. Both elements can have concentrations above 1 mg/L when the groundwater is anoxic (anaerobic), but concentrations are often very low under oxidizing conditions, which appears to be the situation throughout most of the sampling events in the basalt. Reduced (ferrous) iron was measured directly in one sampling event (23/9/2015), and found to be undetectable (<0.05 mg/L).

Other trace metals, antimony, arsenic, cadmium, chromium, cobalt, lead, molybdenum, and selenium, as well as boron, were below detection in all but a few instances. No groundwater data are available for the following elements: beryllium, barium, lithium, strontium, tin, uranium, vanadium, bromine, iodine, and mercury.

5.1.5 Nutrients

Analysis results for nutrients were not performed on the basalt groundwater.

5.1.6 Organic Compounds

Analysis results for organic compounds were not performed on the basalt groundwater.

5.1.7 Beneficial Uses

The groundwater quality of the basalt intrusions is characterised by relatively low TDS and approximately neutral pH, with very few exceedances of the water quality assessment criteria. Where exceedances occurred, they were generally associated with metals concentrations that were marginally above the ANZECC (2000) ecological criteria. Accordingly, groundwater associated with the basalt intrusions in the study area is likely to be suitable for a broad range of beneficial uses, from a water quality perspective.

5.2 Wianamatta Group Shales

5.2.1 Summary of Monitoring Points

There is one piezometer installed in the shale, H35B, which was sampled on seven occasions between December 2013 and September 2015. The water quality is similar to WG shale groundwater encountered in other portions of the Sydney Basin.

5.2.2 Field Water Quality Parameters

Water quality parameters are relatively consistent among the nine total measurements. The pH can be described as approximately neutral as values ranged from 6.18 to 7.30 with the most probable value being 6.8 (**Figure 5.3**).

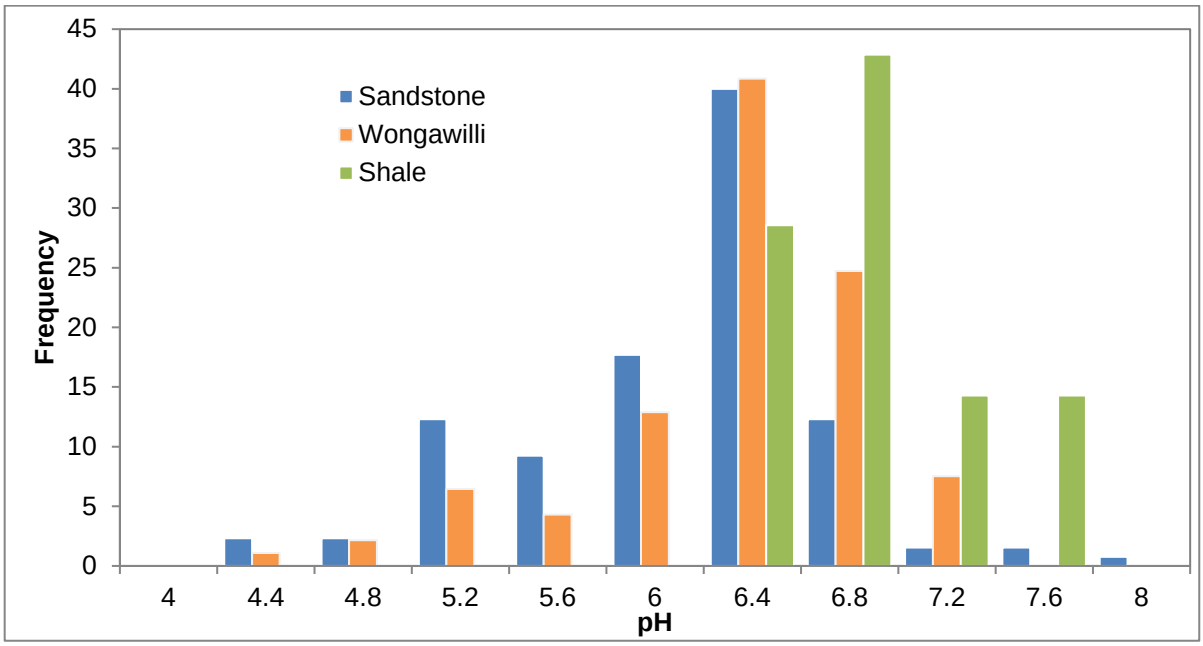


Figure 5.3. Histogram showing pH distribution in the HAW, the WWS, and WG Shale formations (all formations normalised to 100)

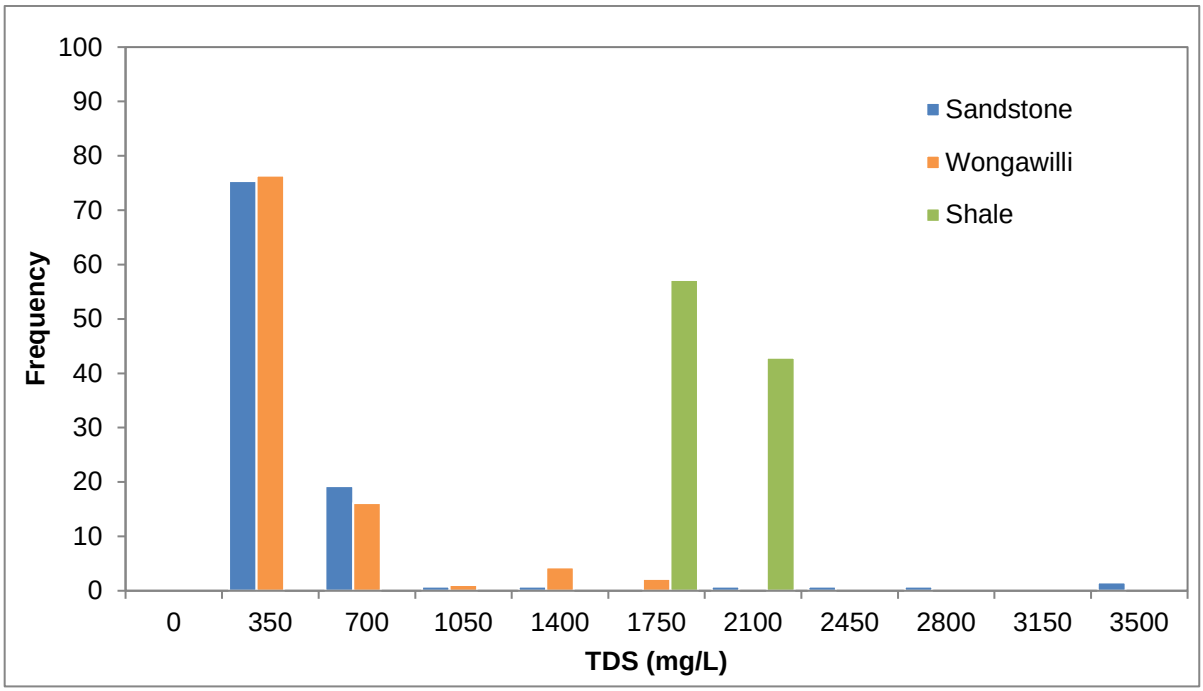


Figure 5.4. Histogram showing TDS distribution in the HAW, the WWS, and WG Shale formations (all formations normalised to 100)

EC ranged from 2364 to 2885 µS/cm, with the average being 2617 µS/cm. TDS ranged from 1,537 to 1,875 mg/L, with an average value of 1700 mg/L (**Figure 5.4**). DO ranged from 13 to 90% saturated, with an average of 50 % sat. Redox potential

ranged from -147 to +113 mV, with an average of -4 mV. Groundwater temperature ranged from 13.4 to 18.4 °C.

Like the Robertson Basalt, the pH range of the Wianamatta Group shales can be described as approximately neutral. However, unlike the basalt, the shales have significantly higher TDS load, which is characteristic of the marine origin of the basal shale formations. The Pourbaix diagram (**Figure 5.2**) shows that some of the shale groundwater is near the stability boundary between ferrihydrite [amorphous $Fe(OH)_3$] and a reducing groundwater that contains predominantly ferrous [Fe(+2)] iron.

5.2.3 Major and Minor Ions

Laboratory analysis was performed on six groundwater samples between December 2013 and September 2015. The moderately high TDS in the shale groundwater is reflected in the chloride content, which ranges from 528 to 707 mg/L and cations calcium, magnesium and sodium, which range from approximately 110 to 200 mg/L. Total alkalinity is also moderately high (258 to 380 mg/L) and suggests the presence of calcium carbonate in the shale. Sulphate is relatively low at 32 to 86 mg/L and potassium is minor (between 8 and 12 mg/L). Fluoride detections are coincident with the LOR (0.1 mg/L) and cyanide and thiocyanate were not analysed.

The predominant hydrochemical water type in the WG shale formation was Mg-Ca-Na-Cl-HCO_3. The strong chloride signal in the shale is likely to be associated with connate salts from its original marine deposition.

5.2.4 Metals and Metalloids

The dissolved metals content of the shale formations tends to be quite low, with many concentrations being below their respective detection limits. As noted above, the solubility of aluminium at approximately neutral pH is much lower than the detection limit of 0.01 mg/L. The fact that aluminium was not detected in all but one sampling event is consistent with aluminium chemistry. Therefore, the measurement on 12/13/2013, when the concentration of aluminium was 0.77 mg/L, is considered an outlier.

Molybdenum and copper are reported slightly above their LOR of 0.001 mg/L in a few instances, but were below detection in other sampling periods. The concentrations of cobalt and nickel were low but consistently above the LOR, where the average values were 0.024 and 0.037 mg/L, respectively. Iron and manganese concentrations range from 0.45 to 4.2 mg/L and 0.53 and 0.93 mg/L, respectively. Iron concentrations exceeded 1 mg/L only in the first two sampling events, and were less than 1 mg/L in subsequent events. Speciation analysis in two samples collected in 2015 showed ferrous iron content to be 0.19 and 0.48 mg/L.

Several metals are consistently above the LORs, including barium, strontium, zinc and lithium. Barium is frequently affected by the solubility of the mineral barite

($BaSO_4$) and strontium readily substitutes for calcium in calcite. Lithium and zinc can be present at trace levels in many types of minerals.

Other trace metals, antimony, arsenic, beryllium, cadmium, chromium, lead, and selenium, as well as boron, were below detection in all but a few instances.

5.2.5 Nutrients

Ammonium concentrations were 0.22 and 0.24 mg/L at the 2013 and 2015 sampling events. Ammonium contains a reduced form of nitrogen [N(-3)] and its presence is consistent with the absence of nitrate, which contains oxidized nitrogen [N(+5)]. Phosphorous was not detected in any of the three sampling events where it was analysed.

5.2.6 Organic Compounds

No organic compounds were detected above their respective LORs in shale groundwater.

5.2.7 Beneficial Uses

Groundwater associated with the WG shales is typically too saline, and the yield is to low, to support a broad range of beneficial uses. Although the TDS is relatively moderate with respect to shale groundwater in other parts of the Sydney Basin, it is still above the typical taste threshold for potable supply, and is generally considered to have limited potential as a groundwater resource.

5.3 Hawkesbury Sandstone

5.3.1 Summary of Monitoring Points

There are 23 monitoring wells screened in the HAW, as follows:

H18B	H37B	H56XB	H96C	H142B
H19B	H38C	H72B	H118A	H142C
H23B	H42C	H72C	H129B	H143C
H23C	H43B	H73C	H133C	
H32LDB	H44XB	H88B	H136B	

5.3.2 Field Water Quality Parameters

Water quality parameters were measured 130 times at 23 piezometers in HAW during several rounds of sampling between October 2011 and September 2015.

- The pH values among all samples ranged from 4.05 to 7.95, with the most probable value being 6.4 (**Figure 5.3**). The histogram shows that the pH range of the sandstone extends much lower than that of the shale. A slightly acid pH is characteristic of HAW groundwater in other parts of the Sydney Basin; the lower pH values generally correlate to the western portions of the

project area were the HAW is not overlain by the WG Shales or basalt bodies. The higher pH values in HAW wells installed below WG Shales or basalt bodies are similar to the pH values in the overlying formations, suggesting that acidic rainfall recharge is buffered in the WG Shales and basalt before infiltrating deeper into the underlying HAW formations.

- EC ranged from 41 to 4882 µS/cm, with an average value of 478 µS/cm, which represents a spread of over two orders of magnitude. TDS ranged from 27 to 3,172 mg/L, with a most probable value of 350 mg/L (**Figure 5.4**). The high end of the EC and TDS data range is very unusual for HAW groundwater, and all the unusually high values are associated with monitoring wells H142B and H142C, which were installed to replace wells H23B and H23C, respectively. A plot of EC and TDS values in these wells (**Figure 5.5**) clearly indicates a spike in the solute load when the replacement wells were installed, which raises the possibility that the elevated EC and TDS values are either an artefact of the well installation process. An alternative explanation is that the slight change in installation locations (approximately 250 m from the original H23B/C locations) encountered significantly different water quality conditions, which is difficult to reconcile with the otherwise consistent groundwater quality within the HAW. Assuming that the EC/TDS values from H142B and H142C are not representative of natural HAW aquifer groundwater quality, the average and maximum EC values would decrease to 307 µS/cm and 970 µS/cm, respectively, and average and maximum TDS values would decrease to 200 mg/L and 630 mg/L, respectively.
- DO ranged from 1.5 to 118.1 % sat, with an average of 31.1 % sat.
- Redox potential ranged from -151.9 to 315.3 mV, with an average of 14.6 mV.
- Groundwater temperature ranged from 12.4 to 33.1 °C, with the average being 18 °C. Four temperature measurements exceeded 25 °C, which upon evaluation are considered outliers (i.e. are likely to reflect conditions during sampling rather than conditions in-situ).

The HAW is a quartzose sandstone with major quartz and minor feldspar, clay, and iron compounds such as siderite. It follows that dissolved silica (SiO_2) would reflect equilibrium with respect to quartz and other silicate phases. The average concentration of SiO_2 is 10 mg/L in all the HAW groundwater samples. The total mass of dissolved ions is generally quite low, suggesting that soluble mineral phases are not especially prevalent in the permeable zones of the sandstone aquifer.

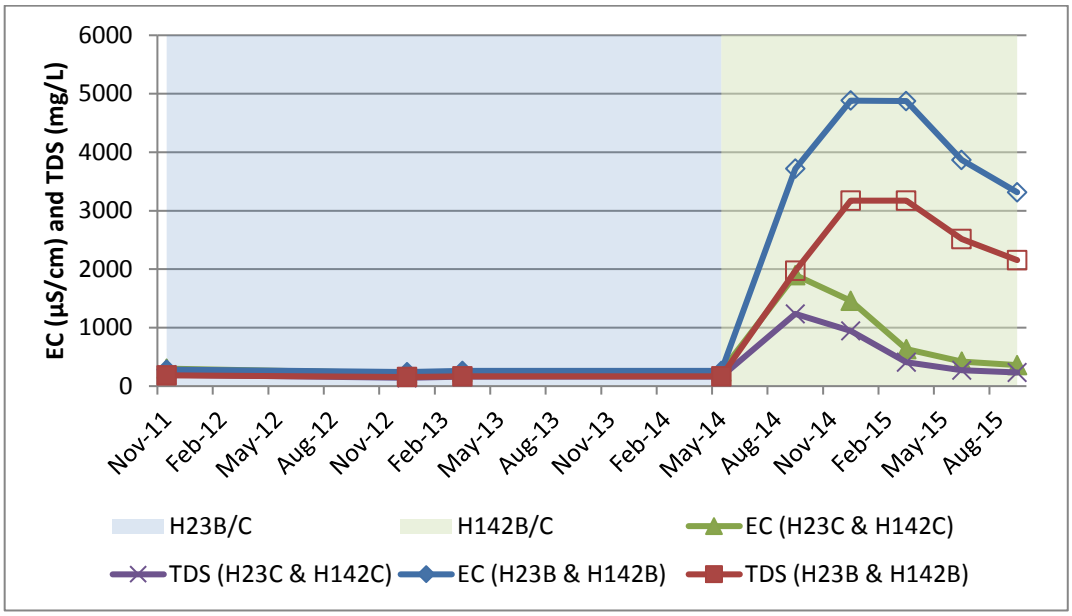


Figure 5.5. EC and TDS trends for original and replacement wells H23B/C (Nov 2011 to May 2014) and H142B/C (Sept 2014 to Sept 2015), demonstrating a spike is solute load following installation of the replacement wells.

5.3.3 Major and Minor Ions

It is evident that chloride is the predominant ion in the HAW. The negative charge due to chloride is approximately balanced by the combined equivalent concentrations of magnesium and sodium. Most of the alkalinity measurements are below 180 mg/L, whereas sulphate tends to be less than 50 mg/L. Calcium and magnesium may be as high as 200 mg/L, while sodium was reported to be as high as 600 mg/L. All of the major ions were non-detectable at some sampling events.

Figure 5.6 shows a Piper plot for the most recent sampling event in all HAW monitoring wells. The two trilinear (triangle) diagrams express the concentrations of major cations (calcium, magnesium and sodium + potassium) and anions (chloride, sulphate and bicarbonate + carbonate). The area shaped like a diamond is a projection of cation and anion concentrations: sulphate + chloride and calcium + magnesium increase toward the top of the diamond; and sodium + potassium and bicarbonate + carbonate increase toward the bottom of the diamond. Piper plots are useful for detecting and characterising mixing of two or more types of groundwater, assuming that such mixing occurs in the hydrogeological regime being investigated. The cation trilinear diagram shows a continuous range from magnesium-rich to sodium-rich groundwater, but none which are rich in calcium. The anion trilinear diagram shows two distinct distributions of groundwater types. One type consists of bicarbonate and chloride with very low sulphate (base of triangle) and the other consists of sulphate and bicarbonate without chloride (left side of triangle).

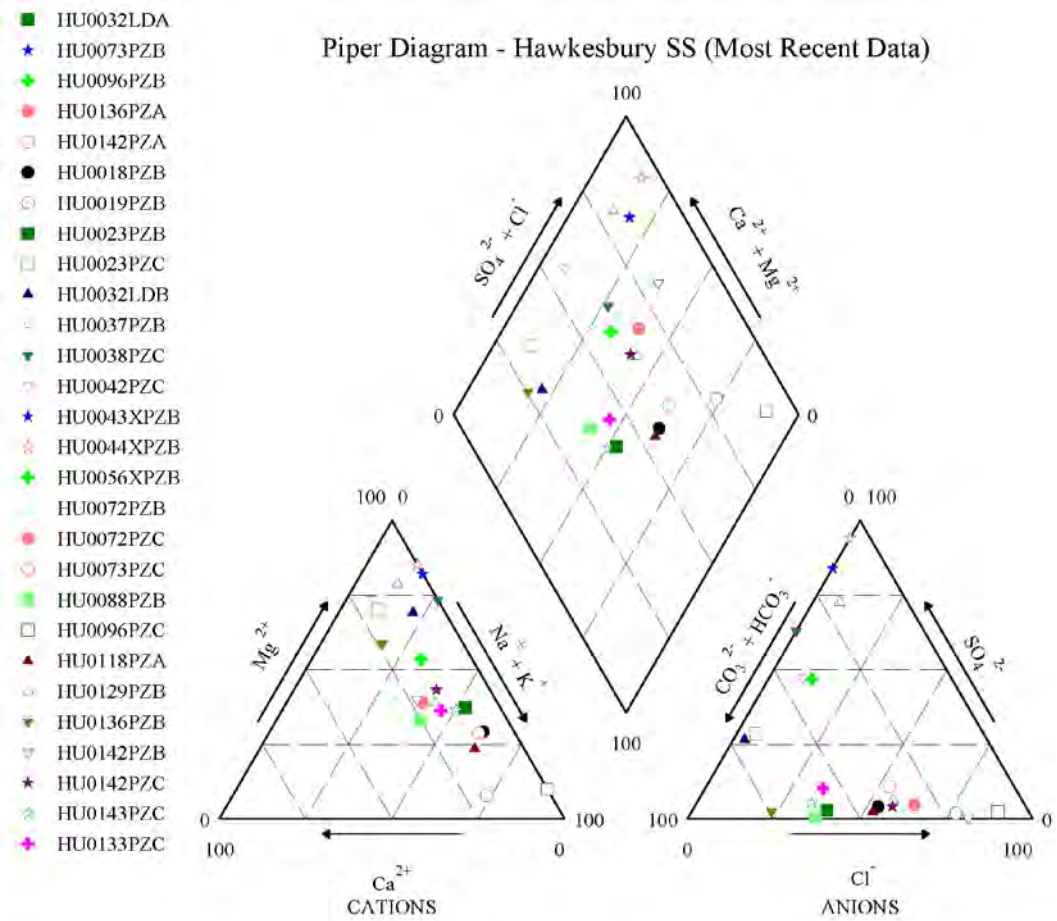


Figure 5.6. Piper plot of major ion data from most recent monitoring event for the HAW monitoring wells.

Projections of the cations and anions onto the diamond fill the upper half, which implies that the water sample range among three types: Mg–HCO_3, Na–Cl, and Mg–SO_4. A review of the locations of the various wells did not indicate clear distinctions based on the depth of the screened interval within the HAW, or the location within the study area, with the following exception: wells located on the outcropping sandstone recharge beds[4] tended to have a more dominant Na-Cl signature, whereas wells installed through outcropping shale tended to have a more dominant Mg-CO_3 signature.

The wells with sulfate-dominant anions were mixed between sandstone and shale surface geology, with no clear distinction about the source of the additional sulfate within the sandstone formations. However, these wells were generally also characterised by low EC values, low pH values, and generally low chloride and bicarbonate concentrations, suggesting that the sulfate-dominant waters may be associated with areas subject to efficient rainfall recharge.

[4] Recharge beds are surface outcrops of permeable geological formations that facilitate the efficient infiltration of surface water into the subsurface as groundwater recharge.

5.3.4 Metals and Metalloids

Concentrations of most dissolved metals are low, as is characteristic for groundwater with approximately neutral pH. Most aluminium measurements are below the LOR (0.01 mg/L), although a maximum of 0.41 mg/L was recorded in one instance. Aluminium concentrations above 0.01 mg/L are not representative of dissolved species and are believed to be outliers. Antimony is at or below 0.002 mg/L in all instances. Arsenic was not detectable in most cases (<0.001 mg/L), but averages 0.008 mg/L in samples that were above the LOR; the maximum concentration of arsenic was 0.044 mg/L. Selenium was below detection (<0.01 mg/L) in most cases, but reached a maximum of 0.16 mg/L in one instance. The average concentration of barium is 0.14 mg/L and was 0.83 mg/L in one instance. Cadmium, chromium, lead, molybdenum, tin, uranium, and mercury were typically below 0.001 mg/L.

Iron and manganese are redox-sensitive metals and tend to be quite soluble under reducing conditions. Iron concentrations range from non-detectable to 21.9 mg/L, with an average concentration of 7.2 mg/L. Similarly, manganese concentrations range from below the LOR to 1.73 mg/L, with an average concentration of 0.46 mg/L. The relatively elevated dissolved iron and manganese concentrations in groundwater suggest a reducing environment.

Other metals and metalloids associated with coal include cobalt and copper, which have maximum concentrations of 0.27 and 0.26 mg/L, respectively and nickel which has a maximum concentration of 0.63 mg/L. Boron was below the LOR in all samples. Strontium, which substitutes for calcium in many minerals phases, was elevated (1.5 mg/L) in one instance, and much lower in others. The highest concentrations of strontium (1.49 mg/L, vs the average value of 0.16 mg/L) and barium (0.83 mg/L, vs the average value of 0.14 mg/L) were both in well H142B, which exhibited the anomalously high EC and TDS values (**Figure 5.5**).

5.3.5 Nutrients

As the groundwater system is reducing, ammonia tended to dominate over nitrate and nitrite. However, the maximum values of ammonia and nitrate were between 0.77 to 0.78 mg/L. Total phosphorus ranged from <0.01 mg/L to 0.19 mg/L and the biochemical oxygen demand (BOD) was <2 mg/L.

5.3.6 Organic Compounds

All organic analytes were below the laboratory LORs with the following minor exceptions:

- One detection of 3- & 4-methylphenol in H38C (4.7 µg/L);
- Four detections of toluene (6 to 20 µg/L) in four different wells; and

- One detection of total recoverable hydrocarbons (TRH) in the F1 carbon range (C_6-C_{10} minus BTEX) of 20 µg/L, which is the same sample in which toluene was detected at 20 µg/L.

Organic compounds such as these have been reported to naturally occur within Permian coal measures in NSW (Volk et al, 2011); however, are unusual within the HAW in the absence of an anthropogenic (contamination) source. Another possibility, given the rare detections and low concentrations reported, is the potential for laboratory contamination, which occasionally occurs due to carry over on analytical instruments and glassware. Repeatability (or lack thereof) in future monitoring is likely to be the best indicator of whether these reported detections represent an actual presence in the HAW, or an artefact of the laboratory analyses.

5.3.7 Beneficial Uses

Groundwater in the HAW is an important local water supply resource, and according to the available bore registration and water access licence details is developed to support domestic, stock and irrigation supply. It is characterised by a low solute load and, in combination with relatively good yields, makes it suitable to support most beneficial uses.

5.4 Wongawilli Seam

5.4.1 Summary of Monitoring Points

Groundwater monitoring data were available from the following 15 monitoring wells:

H18A	H38A	H44XA	H88A	H136A
H23A	H42A	H72A	H96B	H142A
H32LDA	H43XA	H73B	H129A	H143B

5.4.2 Field Water Quality Parameters

Water quality parameters were measured a total of 130 times across the 15 monitoring wells in the Wongawilli Seam between October 2011 and September 2015. The pH values among all samples ranged from 4.03 to 7.18, with an average value of 5.5 (**Figure 5.3**). EC ranged from 40.8 to 2383 µS/cm, with the average being 469 µS/cm. TDS ranged from 46 to 1550 mg/L, while the average is 310 mg/L. As with the HAW monitoring wells, anomalously high ED and TDS values were reported for well H142A, which was installed as a replacement for H23A. The elevated EC and TDS values correlate to elevated barium and strontium concentrations, which may suggest a drilling fluid source.

DO ranged from 0.7 to 113% sat, with an average of 23% sat. Redox potential ranged from -202 to 294 mV, with an average of -30 mV. Temperature ranged from 11.5 to 25.2 °C, with an average value of 18.1 °C. As discussed for the HAW, the

reported temperatures are considered likely to reflect the ambient temperature during sample collection.

Dissolved silica (SiO_2) ranged from 7.4 to 34 mg/L with an average concentration of 11 mg/L. The concentration of dissolved ions is generally quite low, suggesting that minerals other than quartz are not especially prevalent in the permeable zones.

5.4.3 Major and Minor Ions

Laboratory analysis was performed on 93 groundwater samples between October 2011 and September 2015. Chloride is the dominant anion in the Wongawilli Seam, similar to the HAW. In the former, chloride concentrations ranged from 10 to over 500 mg/L. Total alkalinity ranges from non-detectable to 315 mg/L as $CaCO_3$. In one instance the alkalinity of a sample collected from H18A on 25/03/2015 was reported to be 1090 mg/L and appears to be an outlier. No specific interpretation has been attempted for this elevated alkalinity result, however the data point was not excluded from the set as it did not disproportionately influence the statistical assessment of the WWS groundwater data. Calcium and magnesium ranged from non-detectable to approximately 100 mg/L, whereas sodium was the dominant cation reaching concentrations of over 500 mg/L.

5.4.4 Metals and Metalloids

The dissolved metals content of the Wongawilli Seam tends to be quite low, with many concentrations being below their respective LORs. Most of the aluminium measurements were below the LOR of 0.01 mg/L, save a few that probably are not representative of the dissolved phase.

The concentrations of arsenic, cobalt, copper and molybdenum, were low but occasionally above the LORs. Iron and manganese concentrations were occasionally quite elevated: concentration maxima were as high as 4 and 20 mg/L, respectively. Speciation analysis in 12 samples showed ferrous iron content to be between 1.85 and 15 mg/L. The presence of ferrous iron and relatively high concentration of total iron and manganese suggest a reducing groundwater environment.

Several metals are consistently above LORs, including barium, strontium, zinc, and lithium. Barium is frequently affected by the solubility of the mineral barite ($BaSO_4$) and strontium readily substitutes for calcium in calcite. Lithium and zinc can be present at trace levels in many types of minerals. As previously mentioned, elevated barium and strontium concentrations in well H142A could potentially be attributable to drilling fluid use during well installation.

Antimony, cadmium, chromium, lead and uranium were below the LORs in all but a few instances. No detections above the LORs were reported for the following elements: beryllium, tin, vanadium and mercury.

5.4.5 Nutrients

Both ammonia and nitrate were reported above the respective LORs in 14 and 16 samples, respectively. None of the concentrations exceeded the assessment criteria. Total and reactive phosphorous were also detected above the LORs in nine and two samples, respectively. BOD was below the LOR in the three samples analysed.

5.4.6 Organic Compounds

All organic analytes were below the laboratory LORs with the following minor exceptions:

- One detection of phenol in H42A (1.3 µg/L);
- Four detections of toluene (2 to 62 µg/L) in four different wells;
- Two detections of TRH C_6-C_{10} (40 to 100 µg/L); and
- One detection of TRH F1 (40 µg/L).

As discussed in Section 5.3.6, organic compounds such as these have been reported to naturally occur within Permian coal measures in NSW (Volk et al, 2011). The majority of organic compound detections occurred during the same sampling events (December 2013 and February 2015), and involved wells that would have been sampled close to the same time (e.g. H42A and H42C; H88A and H88B), which raises the question of potential laboratory contamination. Repeatability (or lack thereof) in future monitoring is likely to be the best indicator of whether these reported detections represent an actual presence in groundwater, or an artefact of the laboratory analyses.

5.5 <u>Illawarra Coal Measures</u>

5.5.1 Summary of Monitoring Points

There were three monitoring wells installed in the ICM:

- H73A
- H143A
- H133A

5.5.2 Field Water Quality Parameters

Water quality parameters among the ICM are relatively consistent among the 14 total measurements. The pH can be described as approximately neutral as values ranged from 6.10 to 7.13. EC ranged from 243 to 1190 µS/cm, with the average being about 600 µS/cm. TDS ranged from 158 to 774 mg/L, with an average of 405 mg/L. DO ranged from 3 to 80% saturated, with an average of 24% sat. Redox potential ranged from -180 to +30 mV, with an average of -75 mV. Temperature of the groundwater ranged from 15.5 to 21.1 °C, with an average of 19 °C.

5.5.3 Major and Minor Ions

The dominant anion in the ICM groundwater is bicarbonate, as represented by total alkalinities ranging from 70 to 330 mg/L in 14 groundwater samples. Chloride (21 to 261 mg/L) and sulphate (4 to 119 mg/L) tended to be lower in concentration. Fluoride was detected in 7 rounds of sampling and ranged from 0.2 to 0.7 mg/L. Calcium (13 to 117 mg/L) and sodium (17 to 50 mg/L) were the dominant cations, while magnesium ranged from 8 to 47 mg/L and potassium was between 2 and 9 mg/L.

5.5.4 Metals and Metalloids

The dissolved metals concentrations in the ICM groundwater were relatively low, with many concentrations being below their respective LORs. The exceptions were iron (0.65 to 8.9 mg/L) and manganese (0.076 to 0.74 mg/L) which were somewhat elevated. Speciation analysis in four samples showed ferrous iron content to be between 0.88 to 6.4 mg/L. The presence of ferrous iron and relatively high concentration of total iron and manganese suggest a reducing groundwater environment.

Several metals are consistently above laboratory LORs, including barium (0.11 to 2.6 mg/L), strontium (0.12 to 0.60 mg/L), zinc (0.012 to 0.52 mg/L), and lithium (0.038 and 0.18 mg/L). Barium is frequently affected by the solubility of the mineral barite ($BaSO_4$) and strontium readily substitutes for calcium in calcite. Lithium and zinc can be present at trace levels in many types of minerals.

Cadmium, lead and uranium were below LORs in all instances. No groundwater data are available for the following elements: antimony chromium beryllium, tin, vanadium and mercury.

5.5.5 Nutrients

Ammonia was analysed in four samples and the concentrations ranged from 0.08 to 0.26 mg/L. Nitrate was analysed in one sample, but was not detected. Total phosphorus was measure in two samples and the concentrations were 0.06 and 0.13 mg/L.

5.5.6 Organic Compounds

All organic analytes were below the LOR in the ICM groundwater.

5.6 Spatial and Temporal Variability in Baseline Monitoring Data

As discussed in Section 5.3.3, the major ion data were reviewed with respect to the location of the wells across the study area. In particular, the data were evaluated to see if there was a difference in water types between wells installed in areas of HAW outcrop where substantial recharge occurs, and in areas of shale outcrop where less direct recharge influence is expected. The review indicated that, as expected, wells installed within the sandstone outcrop areas had a dominant Na-Cl signature, which is typical of rainfall recharge close to the coast. Wells installed where shale overlays

the sandstone had a dominant Mg-CO_3 signature, which is characteristic of older groundwater that reflects a greater degree of water-rock interaction in the aquifer.

Groundwater in the shale has a higher solute load than groundwater in the other formations, which is typical of the WG shales in Sydney basin. However, the salinity of the groundwater in the one monitoring well screened in the shale is only moderately higher than groundwater in the other formations; it would not be unusual for groundwater in thicker occurrences of the WG shales to have ED/TDS values an order of magnitude higher than those reported for the study area.

Groundwater quality in the HAW and the WWS are surprisingly similar. While it is common for groundwater in the HAW to have a low solute load, coal seam groundwater would typically be expected to be more distinct (greater solute load, greater variability in geochemical signature). There was no significant distinction noted between groundwater in the HAW, the WWS, the ICM and the basalt. This suggests a limited degree of soluble mineral phases in these formations, such that the groundwater retains a relatively similar geochemical signature. It is also possible that historical extraction from the deeper formations (WWS, ICM) resulted in induced infiltration from the overlying HAW, hence the geochemical similarity of the water types in these two formations.

Isotopic analysis of the groundwater in the HAW and WWS (PB, 2012) indicated that both water types retained an isotopic signature that was similar to the meteoric water line, indicating a rainfall origin with limited isotopic fractionation processes (evaporation, mixing) following recharge. Isotopic age dating of the HAW and WWS water samples indicated an increasing age with depth (approximately 4500 years before present [BP] in the HAW, and 6000 year BP in the WWS), with the water ages in both formations representing relatively modern water compared to the depositional age of the formations.

With minor exceptions, the groundwater quality appeared to remain relatively stable across the monitoring period. **Figures 5.7** and **5.8** demonstrate the consistency in major ion chemistry (expressed as milliequivalents per litre [meq/L]) over the monitoring period for two monitoring wells.

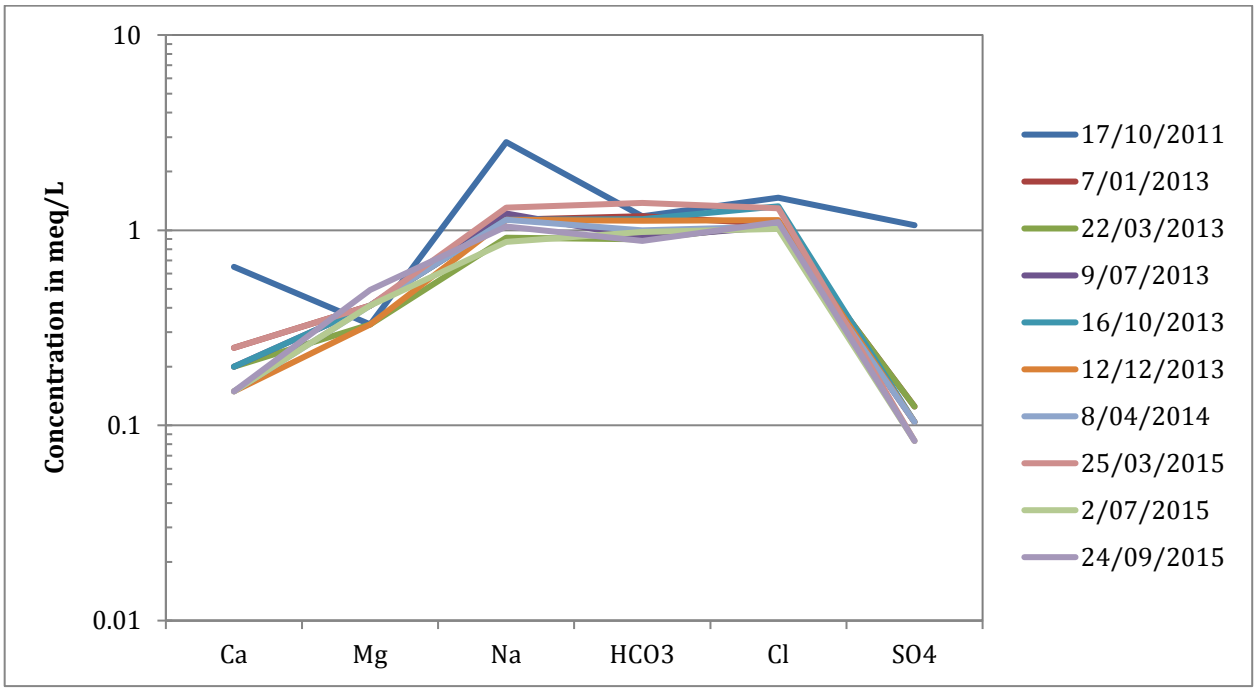


Figure 5.7. Temporal plot of major ion monitoring results for H18B.

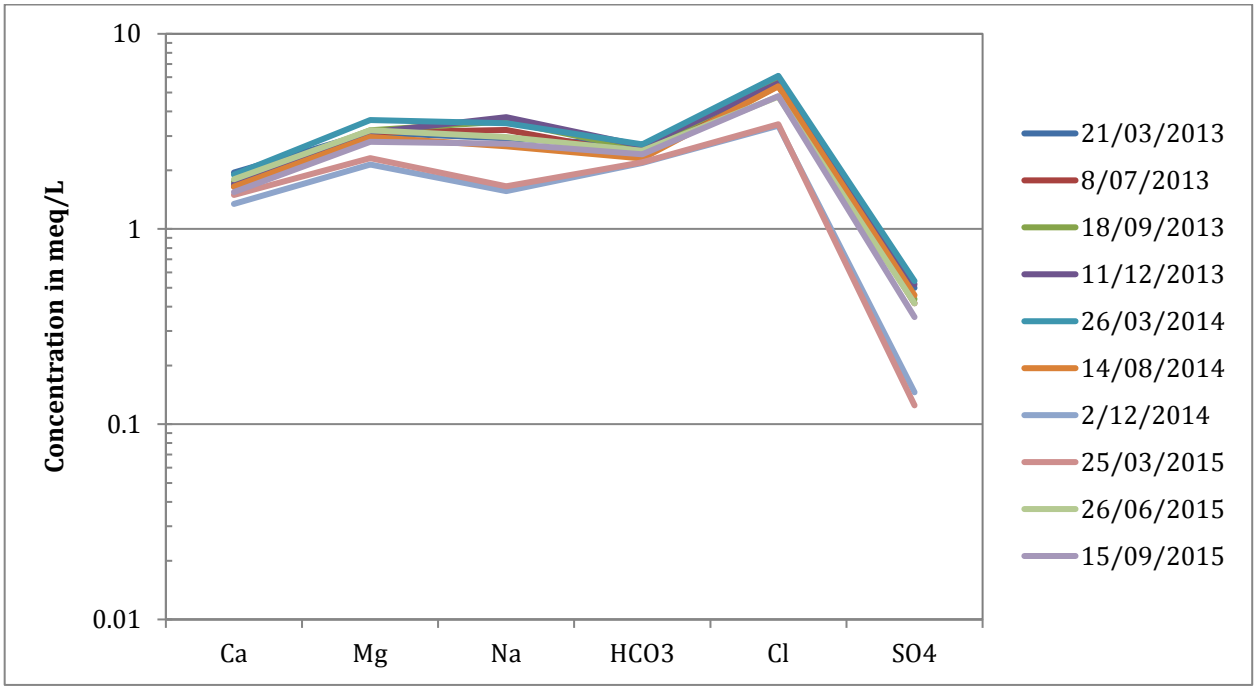


Figure 5.8. Temporal plot of major ion monitoring results for H72C.

6. PREDICTED INFLUENCE OF PROJECT ACTIVITIES

6.1 Water Quality Change from Induced Inter-Aquifer Transfer

6.1.1 Assessment Methodology and Assumptions

Dewatering of the underground mine voids during mining will result in temporary partial depressurisation of some of the overlying formations, which is predicted to temporarily increase the vertical (downward) hydraulic gradients in the water bearing formations above the mine footprint. The partial depressurisation effects in the HAW will result in a temporary increase in the vertical gradient between the WG shale formations and the HAW, with a resultant increase in the flux of groundwater from the shale formations downward into the upper portion of the HAW. This phenomenon is expected to be most pronounced during mining years 10 to 19, and will abate as mined panels are sealed and the panels are allowed to hydraulically re-equilibrate to background conditions.

To assess the magnitude of inter-aquifer transfer of higher TDS water from the WG shales into the upper HAW, time-integrated flux data was obtained from the numerical model for both the base case (i.e. no mining influence) and the in response to mining case, such that the incremental increase in inter-aquifer transfer attributable to mining activities could be evaluated. A mixing model was used to assess the groundwater quality that would result from mixing different proportions of groundwater from the WG shales and the HAW to assess the potential for the estimated flux increase to cause a decrease in the beneficial use category of the upper HAW groundwater resource.

This assessment conservatively assumes that there is a direct hydraulic connection between the base of the WG shale formation, and the underlying upper formations of the HAW. This is the assumption that was adopted in the numerical model conceptualisation, although it has also been interpreted from vertical head distributions that the two formations could be separated by a desaturated zone in some areas, in which case leakage from the shale into the underlying sandstone would be expected to already be occurring at its maximum flux rate.

6.1.2 Modelling Results

The Coffey (2016b) numerical flow model was used to quantify the simulated flux of groundwater between the WG shale formations and the upper HAW formation. Simulations were run for a 100-year period, both with and without the influence of the Hume Coal mining activities, to provide a baseline groundwater flux in the absence of Hume Coal mining influences, and a mining influenced flux, the difference of which represents the incremental induced flux from the mining activities. The area within the model domain inferred to have a direct hydraulic connection between the WG shales and the upper HAW formation is presented in **Figure 6.1**.

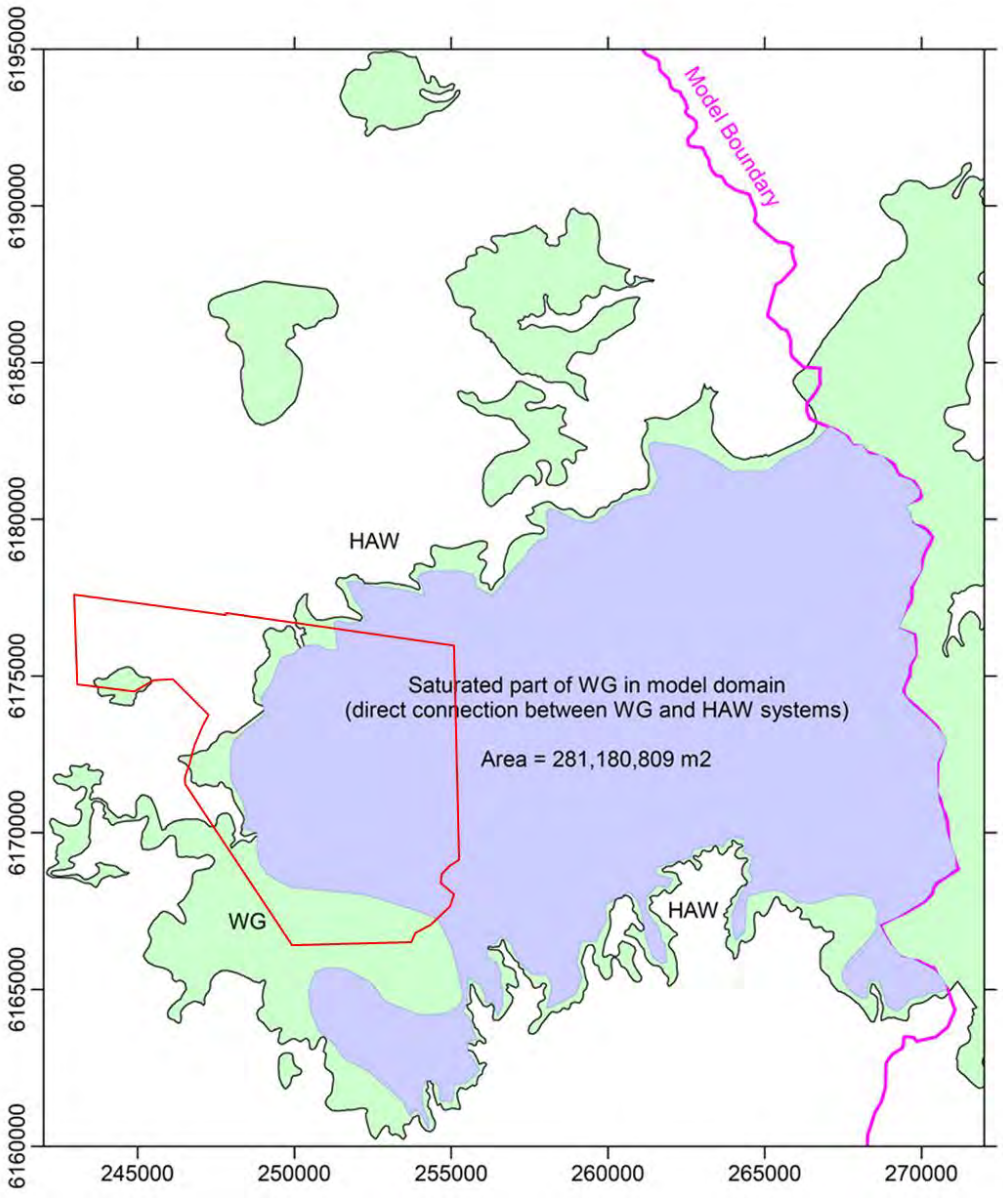


Figure 6.1. Extent of numerical model domain where a hydraulic connection exists between the WG shale and the underlying HAW.

In the absence of Hume Coal mining influences within the model domain, the baseline inter-aquifer transfer from the WG shales to the upper HAW was consistently around 11.1 ML/day for the entire simulation period. With the Hume Coal mining schedule activated, an incremental increase in the vertical flux was predicted between Years 1 and 74, peaking in the Year 14.5 time step at 12.1 ML/day, or a 1 ML (9%) increase over the baseline conditions. The incremental flux over the simulation period is presented in **Figure 6.2**.

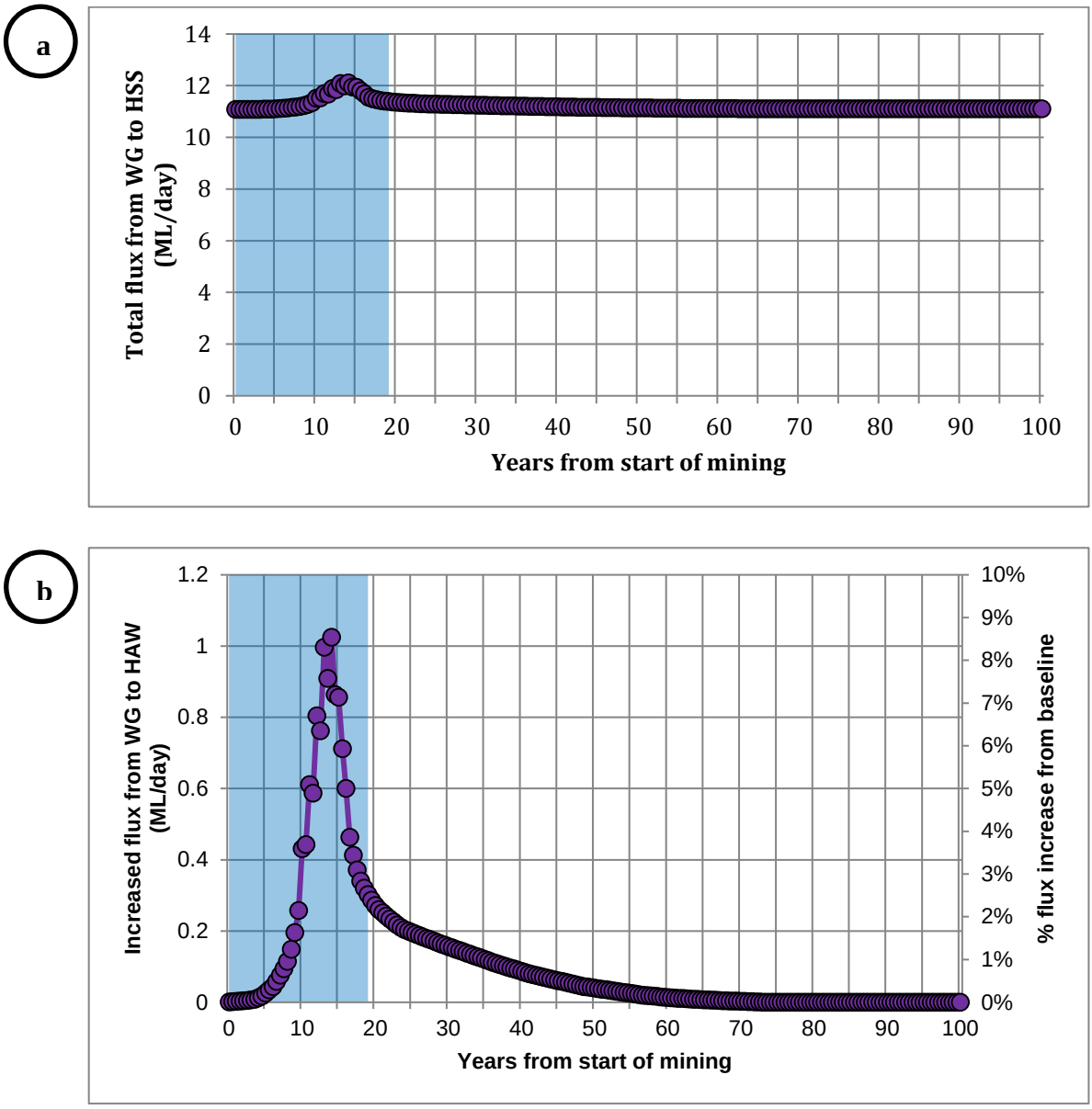


Figure 6.2. Predicted (a) total flux and (b) incremental increase in groundwater flux from WG shale to upper HAW attributable to Hume Coal mining activities (active mining period in blue).

In order to address the Independent Expert Scientific Committee (IESC) guidelines with regard to changes in the salt balance attributable to project activities, the groundwater flux model results were also used to estimate the salt load transferred from the WG shale formations to the underlying shallow HAW:

- Under baseline conditions, the groundwater flux from the WG shales to the HAW was 11.1 ML/day, with an average TDS of 1,700 mg/L. Hence the baseline salt transfer under pre-mining conditions equates to 18,870 kg/day, or 6,887,550 kg/year;

- Under mining influenced conditions, the increase in salt flux is proportional to the increase in groundwater flux, peaking at 7,497,790 kg/yr at the Year 14.5 time step (or 9% above baseline conditions). Over the full 74-year period during which the model results indicated an incremental increase in groundwater flux from mining influences (including the post-mining recovery period), the net increase in salt flux from the WG shale to the HAW is 1.3% above baseline conditions.

The groundwater quality implications of the increased vertical groundwater flux from the WG shales to the HAW attributable to mining activities is discussed in **Section 6.1.3** below.

6.1.3 Potential Impacts

The temporary increase in groundwater flux from the WG shale to the upper HAW would result in an increased solute load in the upper water bearing formations within the affected portion of the HAW.

The potential influence of the temporary increase in WG groundwater flux should be considered in the context of the baseline conditions. There is currently an 11.1 ML/day flux of groundwater between these two formations due to existing downward vertical hydraulic gradients. The downward gradients are attributable to the effects of mounding in recharge areas (e.g. elevated hydraulic head values due to surface water infiltration) and depressurisation from discharge as baseflow or from escarpment faces, as well as the ongoing depressurisation/ dewatering effects of the Berrima and Loch Catherine mine voids to the north.

Water quality from the multi-level monitoring wells installed in areas of shale surface geology was reviewed to assess whether the current baseline condition had resulted in an increased salinity signal in the underlying HAW. In all cases, the water quality in HAW wells installed beneath areas of shale outcrop were characterised by low TDS conditions suitable for most beneficial uses. Wells installed in areas of sandstone outcrop generally exhibited slightly lower TDS values, but all were within the range of very low to low EC with respect to the ANZECC (2000) irrigation criteria, and consistent with “good quality” drinking water according to the TDS criteria in the ADWG (2011). In addition, TDS concentrations were generally either stable or increasing with depth at each monitoring location, whereas the opposite distribution would be expected if the downward flux of shale groundwater were imparting a significant water quality effect on the underlying HAW.

A mixing model was used to assess solute concentrations that would result from mixing different proportions of WG and HAW groundwater, considering average groundwater quality from the two formations. With respect to the potential to diminish the beneficial uses of the HAW groundwater resource, EC and TDS were the most sensitive parameters, as the other analytes were generally substantially

below the relevant beneficial use criteria even when a high proportion of shale groundwater was considered in a mixing scenario. The mixing analysis indicated that a ratio consisting of >40% WG shale groundwater would be required to produce a mixed TDS value that exceeds 900 mg/L (the threshold at which groundwater is considered "poor quality" from a drinking water perspective). The same ratio would result in groundwater considered to be suitable for irrigation of "moderately tolerant crops", from an EC perspective.

Given that the predicted increase in groundwater flux between the WG shale and underlying HAW is a maximum of 9% with a short duration peak, and the current baseline flux has not significantly affected the underlying HAW water quality, it is considered unlikely that a material change to HAW groundwater quality with the potential to reduce the beneficial uses of the groundwater resource would occur as a result of the additional mining induced flux.

6.1.4 Mitigation Measures

The principal mitigation measure with respect to the temporary increase in groundwater flux from the WG shale to the upper HAW is the non-caving underground mining approach, which will minimise the deformation to the mine overburden, and also minimise the stress period over which the maximum depressurisation effects occur. The area of maximum drawdown from mining activities was also predicted to be limited to a relatively tight radius around the underground mining footprint (Coffey, 2016b), such that a relatively small portion of the study area is likely to be subject to a temporary increase in groundwater flux from the WG shale. No additional mitigation measure is considered to be warranted in light of the relatively low risk to the groundwater resource.

6.2 Water Quality Effects of Reject Slurry Emplacement in Underground Mine Voids

6.2.1 Process Description for the Management and Disposal of CPP Reject Material

The process of preparing the ROM coal for market involves a series of crushing, screening and "washing" processes in the CPP to separate the coal from the waste rock (reject) material. The coal preparation process generally consists of initial crushing of the ROM coal to limit the maximum size of the coal, followed by physical screening of the crushed ROM coal material into different particle size fractions, followed by a predominantly density-driven separation processes (washing) to separate the less dense coal from the denser waste rock in each grade. The reject material resulting from the washing process will include particle size fractions ranging from silt/clay ultrafines to coarse aggregate (8-16 mm topsize). The different reject grades will be mixed, amended with limestone ultrafines as a precautionary measure to buffer potential acid produced by prolonged exposure of sulphide minerals to oxygen, and pumped into completed underground mine panels for disposal.

Following emplacement of the waste in the underground panels, the panels will be sealed by bulkheads, dewatering of the sealed panel will be terminated, and the backfilled panels will naturally recharge with native groundwater. Until the backfilled panels are sealed, there will be an inward hydraulic gradient into the panels as a result of dewatering of the underground workings. Once the panels are sealed, hydraulic pressures will recover and natural groundwater flow conditions are expected to be re-established within the coal seam.

Once the backfilled and sealed panels have re-saturated with natural groundwater, it is expected that the groundwater will interact with the emplaced reject material, and any potentially dissolved species leached from the reject material will be transported with the natural flow of groundwater into the down hydraulic gradient portions of the coal seam. Accordingly, the anticipated change to groundwater quality arising from this process has been assessed through consideration of the geochemical testing results (specifically, KLC testing) reported by RGS (2016) using representative samples of reject material and groundwater for leaching.

For avoidance of doubt, with regard to the DRE environmental assessment requirement referencing overburden and interburden, the Hume Coal project is an underground mining operation that will not generate waste overburden/interburden. The only mining waste product will be the reject material, which is addressed in this assessment.

6.2.2 Assessment Methodology and Assumptions

The results of KLC testing were used as a conservative indication of the groundwater quality that would arise from interaction with the reject material emplaced in the underground voids. Data were selected from the leach columns that were considered to provide the closest representation to the expected conditions in the subsurface. Namely, columns were selected that used fine reject material (for conservatism), leached with groundwater obtained from the WWS, in fully saturated columns (i.e. as opposed to intermittently wet and dry columns, which was not considered to be a realistic occurrence in the subsurface). Data from two columns with these specifications were assessed: one column that was amended with limestone (KLC 24; as proposed for the reject material prior to emplacement), and one column without limestone amendment (KLC 22). The use of limestone is intended to increase the acid buffering capacity of the reject material, to prevent excessive generation of acidity and mobilisation of metals in groundwater if sulphide minerals in the rejects are subject to oxidation.

A detailed methodology for the KLC tests is provided in RGS (2016). As a general overview, the columns were prepared with representative samples of reject material generated from drill core recovered from the study area. The columns were then continuously saturated with groundwater sampled from the coal seam, and leachate samples were collected at the commencement of the test and then on a monthly basis for a period of six months. Samples were submitted to ALS Environmental, a NATA

accredited analytical laboratory, for analysis of pH, EC, major ions, speciated alkalinity, acidity and metals.

The results of the KLC tests were compared to groundwater quality in the WWS and the HAW from the baseline monitoring program, to assess whether the leachate from the KLC tests had the potential to degrade the natural groundwater quality and potentially reduce its beneficial uses. An important assumption is that under post-mining conditions, once hydraulic pressures are re-established, the groundwater that comes in contact with the emplaced mine rejects in the underground voids is likely to be groundwater flowing laterally through the WWS, and that will continue to flow through the WWS following contact with the reject materials. Hence, the receiving environment is considered to be the groundwater resources within the WWS, down hydraulic gradient from the emplaced reject materials. However, for conservatism, the KLC results were also compared to baseline HAW water quality as this is the primary groundwater resource accessed in the study area.

6.2.3 Assessment Results

The results of the assessment are summarised in Table 6.1. This table includes the water quality criteria for the foreseeable beneficial uses of groundwater in the study area, the results of the KLC tests for the limestone-amended and the unamended columns, and the average groundwater qualities for the HAW and WWS, calculated from the baseline monitoring data.

The periodic sampling of the KLCs generally indicated a slight “first flush” effect of more elevated solute concentrations in leachate, which stabilised after one or two sampling events. It is reasonable to assume that this phenomenon could occur in the subsurface following emplacement of the reject material. Accordingly, the average and final water qualities for the two KLC tests are included in Table 6.1 for comparison.

The results in Table 6.1 have been highlighted based on the highest concentration assessment criterion exceeded. The key observations are as follows:

- The baseline WWS and HAW groundwater quality exceeds assessment criteria for a number of metals. Most of the exceedances are of ANZECC (2000) criteria, which apply where groundwater discharges to an aquatic ecosystem. This occurs naturally in incised water courses and at the edge of the escarpment, where groundwater either seeps from the escarpment face or discharges as baseflow to the local water courses. The baseline groundwater quality also exceeds certain irrigation and drinking water criteria, although the exceedances are marginal and in some cases very rarely detected above the laboratory limit of reporting (LOR) (e.g. selenium);
- The average water quality results are generally higher than the final equilibrated water quality results for the two columns. This stands to reason as the average values take the first flush into consideration;

- In both cases, the EC values from the KLC tests are very close to the EC values of natural groundwater. The results suggest that leachate from both column scenarios would have a negligible influence on natural groundwater quality.
- The results for KLC 22, the unamended column, indicate that acid is generated through flushing of the unamended reject material by natural groundwater. The final pH value is 3.9, which is lower than even the slightly acidic pH values of the natural WWS and HAW groundwater. The reduced pH has evidently also resulted in mobilisation of certain metals in the leachate. Table 6.1 indicates exceedances of primarily ANZECC (2000) criteria for half of the metals analysed, including an exceedance of the drinking water guideline for nickel.
- The results for KLC 24, with limestone amendment, indicate that the buffering capacity of the limestone was sufficient to manage the acid generated though water-reject contact. The pH values remained close to neutral throughout the test, and the column leachate analytical results are actually substantially more favourable than the natural groundwater quality, with respect to water quality criteria exceedances. In fact, the final sample from KLC 24 only exceeded the selenium criterion because the LOR was higher than the criterion. All other analytes are below the various assessment criteria.

The results of the limestone-amended KLC test indicate that the expected leachate quality arising from groundwater interaction with the reject material presents a negligible risk to groundwater quality. In fact, even the unamended leachate results only differ marginally from the natural groundwater quality in terms of the particular metals exceeding the respective criteria (however certain metals such as manganese, nickel and zinc are approximately an order of magnitude higher than the average values in baseline groundwater).

6.2.4 Mitigation Measures

The KLC tests have clearly demonstrated the value of amending the reject material with limestone prior to emplacement in the subsurface, to provide the alkalinity required for acid buffering and to prevent increased metals solubility. It is recommended that this proposed approach be adopted during mining activities as a conservative safeguard for the quality of the local groundwater resource.

Table 6.1: Underground reject storage - comparison of KLC 22 and 24 results with HAW and WWS groundwater quality

Analytes	ANZECC (2000)			ADWG (2011)	KLC 22		KLC 24		WWS	HAW
	Aquatic	Irrigation	Livestock		Avg	Final	Avg	Final	Avg	Avg
EC	-	-	-	-	475	473	575	462	469	478
pH	-	-	-	-	4.3	3.9	7.4	7.6	5.5	5.3
Calcium	-	-	1000	-	16	15	66	48	24	22
Magnesium	-	-	-	-	13	14	10	7	15	23
Sodium	-	460	-	-	32	41	29	34	46	48
Potassium	-	-	-	-	2	2	2	2	4	5.3
Bicarbonate	-	-	-	-	9	<1	108	108	109	73
Chloride	-	700	-	-	84	73	78	66	78	105
Sulfate	-	-	1000	500	91	98	67	33	17	15
Aluminium	0.055	20	5	ID	0.178	0.140	<0.01	<0.01	0.103	0.053
Antimony	-	-	-	0.003	<0.001	<0.001	<0.001	<0.001	0.0025	0.002
Arsenic	0.013	2	0.5	0.01	<0.001	<0.001	0.005	0.006	0.012	0.008
Boron	0.37	5	5	4	<0.05	<0.05	<0.05	<0.05	0.33	--
Cadmium	0.0002	0.05	0.01	0.002	0.0021	0.0013	<0.0001	<0.0001	0.0037	0.0003
Chromium	0.001	1	1	0.05	<0.001	<0.001	<0.001	<0.001	0.002	0.003
Cobalt	-	0.1	1	-	0.149	0.118	0.024	0.002	0.010	0.015
Lead	0.0034	5	0.1	0.01	0.003	0.002	<0.001	<0.001	0.016	0.002
Copper	0.0014	5	1	2	0.019	0.003	<0.001	<0.001	0.008	0.015
Manganese	1.9	10	-	0.5	2.9	4.2	0.362	0.136	0.690	0.463
Molybdenum	-	0.05	0.15	0.05	<0.001	<0.001	0.017	0.022	0.014	0.004
Nickel	0.011	2	1	0.02	0.370	0.257	0.072	0.003	0.017	0.023
Selenium	0.005	0.05	0.02	0.01	<0.01	<0.01	<0.01	<0.01	0.06	0.14
Zinc	0.008	5	20	ID	0.993	0.620	0.093	<0.005	0.080	0.056
Fluoride	-	2	2	1.5	0.2	<0.1	0.4	0.4	0.16	0.1
Iron	-	10	-	-	9.99	4.55	<0.05	<0.05	7.67	8.8

6.3 Water Quality Management for Surface Storage of CPP Reject Material

6.3.1 Description of Temporary Surface Storage of CPP Reject Material

During the initial 12-18 months as the project is developed, the coal reject will be stored in a temporary coal reject stockpile adjacent to the CPP until sufficient void space is available underground, and the plant is commissioned to commence underground emplacement. During this initial period, the fines will be dewatered via belt press filters (avoiding the need for a tailings dam) prior to being combined with the course reject. This combined reject will be placed for co-disposal on the temporary coal reject stockpile, which will be progressively constructed, contoured and when full, top dressed and revegetated. At the end of the operational phase of the project the reject on the temporary coal reject stockpile will be put back through the reject plant and pumped underground prior to sealing the surface entries to the underground mine.

In addition, if the slurry operation is interrupted, for example during maintenance, reject will be temporarily diverted to an emergency surface stockpile for later reprocessing. This will allow coal washing to continue throughout any interruption. The belt press filters will be used for dewatering during these periods.

Stormwater controls will be implemented for the surface operations of the mine, including the coal reject stockpile location, to prevent the stockpile management area from receiving stormwater runoff from the surrounding areas. However the stockpile(s) will still be exposed to rainfall, a portion of which will have the potential to infiltrate into the stockpile, contribute to the oxidation of sulphide minerals present in the reject, and potentially mobilise acid and solutes generated from the water-reject interaction.

6.3.2 Assessment Methodology and Assumptions

As with the assessment of underground emplacement of coal reject material discussed in Section 6.2, the results of KLC testing were used as a conservative indication of the water quality that would result from the interaction of rainfall with the stockpiled reject material. Data were selected from the leach columns that were considered to provide the closest representation of intermittent rainfall on a reject stockpile. Namely, columns were selected that used fine reject material (for conservatism), leached with deionised water as a proxy for rain water, in intermittently wet and dry columns that approximate the conditions of periodic rainfall on the reject stockpile with drying cycles between storms. Data from three columns with these specifications were assessed:

- One column containing only the composite reject material (KLC 10);
- One column that was amended with 1% limestone (KLC 16); and
- One column that was amended with 2% limestone (KLC 18).

The use of limestone is intended to increase the acid buffering capacity of the reject material, to prevent excessive generation of acidity and mobilisation of metals in infiltrating rain water if sulphide minerals in the reject are subject to oxidation.

A detailed methodology for the KLC tests is provided in RGS (2016). As a general overview, the columns were prepared with representative samples of reject material generated from drill core recovered from the study area. The columns were then flushed on a monthly basis, for a period of six months, with approximately 1 L of deionised water. The water that passed through the columns was sampled and submitted to ALS Environmental, a NATA accredited analytical laboratory, for analysis of pH, EC, major ions, speciated alkalinity, acidity and metals. Between monthly flushing cycles, heat lamps were used to dry the columns to minimise moisture retention and promote maximum exposure to atmospheric oxygen (conservatively enhancing the potential for sulphide mineral oxidation between flushing cycles).

The results of the KLC tests were assessed relative to the appropriate water quality criteria for drinking water, primary industries and aquatic ecosystems. The results were also compared to groundwater quality in the HAW from the baseline monitoring program, to assess whether the leachate from the KLC tests had the potential to degrade the natural groundwater quality and potentially reduce its beneficial uses if water from the reject stockpile drained into the underlying formation.

It is important to note that the assumption of monthly rainfall infiltration into the reject stockpile, particularly once it is top dressed and re-vegetated, is inherently conservative for the following reasons:

- Review of average rainfall and evaporation patterns in the study area presented in Coffey (2016a) indicated that a soil moisture deficit is likely to occur for eight months of an average year (from September to April), when pan evaporation exceeds the average monthly rainfall;
- The re-vegetation of the stockpile will also introduce transpiration as an added impediment to deep drainage of rainfall into the reject stockpile; and
- The stockpile will be contoured to promote efficient surface runoff of rainfall falling on the stockpile, further reducing the potential for rainfall infiltration into the reject stockpile.

6.3.3 Assessment Results

The results of the assessment are summarised in **Table 6.2**. This table includes the water quality criteria for the foreseeable beneficial uses of groundwater in the study area, the results of the KLC tests for the limestone-amended and the unamended columns, and the average groundwater quality for the HAW, calculated from the baseline monitoring data.

The periodic sampling of the KLCs generally indicated a slight "first flush" effect of more elevated solute concentrations in leachate, which stabilised after the first sampling event. Accordingly, the average and final water qualities for the KLC tests are included in **Table 6.2** for comparison.

The results in **Table 6.2** have been highlighted based on the highest concentration assessment criterion exceeded. The key observations are as follows:

- The baseline HAW groundwater quality exceeds assessment criteria for a number of metals. Most of the exceedances are of ANZECC (2000) criteria, which apply where groundwater discharges to an aquatic ecosystem. This occurs naturally in incised water courses and at the edge of the escarpment, where groundwater either seeps from the escarpment face or discharges as baseflow to the local water courses. The baseline groundwater quality also exceeds certain irrigation and drinking water criteria, although the exceedances are marginal and in some cases very rarely detected above the LOR (e.g. selenium);
- The average water quality results are generally higher than the final equilibrated water quality results for the three columns. This stands to reason as the average values take the first flush into consideration. It is noted that non-detect results were not factored into the "average" concentration calculations, and a number of analytes were only detected in one or two sampling events over the course of the six month trial;
- In all cases, the final EC values from the KLC tests were below the average baseline EC values of HAW groundwater. The higher average EC values for the limestone amended columns reflected the influence of enhanced limestone dissolution during the initial flushing events, which subsequently stabilised at EC values similar to HAW groundwater. The results suggest that leachate from the three column scenarios would have a negligible influence on natural groundwater quality.
- The results for KLC 10, the unamended column, indicated that acid is generated through exposure to atmospheric oxygen and flushing with oxidised water. The final pH value of 4.7, was slightly lower than even the slightly acidic pH value of the natural HAW groundwater (pH avg = 5.3). The lower pH evidently also resulted in mobilisation of certain metals in the leachate. **Table 6.2** indicates that approximately half of the metals analysed exceeded one or more of the beneficial use assessment criteria.
- The results for KLC 16 and 18, with 1% and 2% limestone amendment respectively, indicated that the buffering capacity of the limestone was sufficient to manage the acid generated though water-reject contact. The pH values remained close to neutral throughout the test, and the column leachate analytical results were similar to or more favourable than the natural

groundwater quality, with respect to water quality criteria exceedances. The final sample from KLC 16 presented an equivalent beneficial use status to the HAW groundwater. The final sample from KLC 18 only exceeded the selenium criterion because the LOR was higher than the criterion; all other analytes are below the various assessment criteria.

The results of the limestone-amended KLC tests indicated that the expected water quality resulting from rainfall infiltration into the reject stockpile presents a negligible risk to the baseline beneficial uses of HAW groundwater resource.

6.3.4 Mitigation Measures

The KLC tests have clearly demonstrated the value of amending the reject material with limestone prior to emplacement in a stockpile, to provide the alkalinity required for acid buffering and to prevent increased metals solubility. Given the increased potential for oxidation of sulphide minerals in a surface stockpile (relative to the fully saturated conditions for underground emplacement), the KLC with 2% limestone amendment outperformed the KLC with 1% limestone amendment in terms of final water quality; however the final water quality from the 1% limestone amendment resulted in the same beneficial use status as the baseline quality of the HAW groundwater. Accordingly, although there are multiple management measures proposed to reduce the potential for water infiltration into the reject stockpile, it is recommended that limestone amendment be adopted as a contingency measure to reduce the potential for drainage from the reject stockpile posing an unacceptable risk to the surrounding surface and groundwater resources.

Table 6.2: Surface reject storage - comparison of KLC 10, 16 and 18 results with HAW groundwater quality

Analytes	ANZECC (2000)			ADWG (2011)	KLC 10		KLC 16		KLC 18		HAW
	Aquatic	Irrigation	Livestock		Average	Final	Average	Final	Average	Final	Avg
EC					239	120	873	325	844	300	478
pH	-	-	-	-	4.6	4.7	7.3	7.8	7.5	7.9	5.3
Calcium	-	-	1000	-	14	6	132	46	120	25	22
Magnesium	-	-	-	-	12	6	18	3	17	2	23
Sodium	-	460	-	-	8	<1	11	2	10	1	48
Potassium	-	-	-	-	7	<1	3	2	3	<1	5.3
Bicarbonate	-	-	-	-	4	4	63	45	84	62	73
Chloride	-	700	-	-	56	24	146	21	143	19	105
Sulfate	-	-	1000	500	44	22	274	82	252	71	15
Aluminium	0.055	20	5	ID	0.369	0.059	0.161	0.161	<0.01	<0.01	0.053
Antimony	ID	-	-	0.003	<0.001	<0.001	0.001	0.001	0.001	<0.001	0.002
Arsenic	0.013	2	0.5	0.01	0.017	<0.001	0.006	0.004	0.006	0.002	0.008
Boron	0.37	5	5	4	0.058	<0.05	<0.05	<0.05	<0.05	<0.05	--
Cadmium	0.0002	0.05	0.01	0.002	0.0062	0.0032	0.0010	0.0004	0.0012	<0.0001	0.0003
Chromium	0.001	1	1	0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003
Cobalt	ID	0.1	1	-	0.197	0.090	0.069	0.002	0.104	<0.001	0.015
Copper	0.0014	5	1	2	0.069	0.029	0.020	0.056	0.001	0.001	0.015
Lead	0.0034	5	0.1	0.01	0.009	0.003	<0.001	<0.001	<0.001	<0.001	0.002
Manganese	1.9	10	-	0.5	1.7	1.3	0.55	0.03	0.59	0.01	0.46
Molybdenum	ID	0.05	0.15	0.05	<0.001	<0.001	0.036	0.051	0.043	0.034	0.004
Nickel	0.011	2	1	0.02	0.559	0.266	0.117	0.003	0.157	<0.001	0.023
Selenium	0.005	0.05	0.02	0.01	0.02	<0.01	0.03	<0.01	0.045	<0.01	0.14
Zinc	0.008	5	20	ID	1.63	0.939	0.152	0.006	0.132	<0.001	0.056
Fluoride	-	2	2	1.5	0.4	<0.1	0.7	0.8	0.7	0.8	0.1
Iron	ID	10	ID	ID	1.31	0.21	0.06	0.06	<0.05	<0.05	8.8

6.4 PWD Water Quality Assessment for Subsurface Disposal

6.4.1 Assessment Methodology and Assumptions

The water balance for the site indicates that the average annual input to the PWD will comprise approximately 70% extracted groundwater, 20% rainfall, and 10% process water from the CPP and dust suppression returns. The preferred disposal method for this water is injection into the underground workings (in sealed panels). Accordingly, Geosyntec was asked to consider a likely PWD water quality resulting from the mixture of the different end member water types, and the implications for injection into sealed panels.

The PWC water quality was estimated through simple mixing of end member waters based on the ratios indicated in the water balance. The quality of the end member water types was estimated as follows:

- Groundwater quality was estimated using geochemical modelling to simulate the effects of open-system equilibration with the atmosphere (described in further detail below);
- The CPP process water quality was estimated by averaging the "first flush" water quality results from two KLC tests (10, 20 and 22) that consisted of mine reject composite material without limestone amendment. This was considered to be a conservative approximation, as the small volume of water flushed through the columns during the KLC test resulted in a concentrated leachate, whereas the CPP processes should result in a more dilute solute load due to the greater water to rock ratio; and
- Rainfall quality was estimated from a CSIRO publication that included analytical results for 38 rainwater samples collected in Sydney between 2007 and 2011 (CSIRO, 2012).

The resulting PWD water quality resulting from the mixture of these water types was compared to average WWS water quality, to assess whether injection of the water into sealed underground panels would present a risk to the beneficial uses of the WWS groundwater resource.

6.4.1.1 Groundwater Quality Evolution in Contact with Atmosphere

The evolution of groundwater quality stored in a dam was assessed through geochemical modelling using PHREEQC (v. 3.3.8), based on typical groundwater quality from the WWS (baseline data from H18A was adopted for the modelling). The following assumptions were made with respect to the geochemical modelling approach:

- extracted groundwater would be stored in a dam allowing for "open system" interaction with the atmosphere;
- The groundwater would be stored long enough for gas exchange with the atmosphere to reach equilibrium;

- Precipitation of solids as a result of water chemistry changes in the pond would occur rapidly and would settle out as a sludge on the base on the pond (i.e. ongoing reaction with the pond water chemistry would be negligible);
- Mixing with other water types while in storage was not considered (e.g. rainfall or stormwater). However, this assumption is considered to be conservative, as mixing with rainfall or stormwater runoff would be expected to have a dilution effect with respect to groundwater quality; and
- Evaporation and recharge of pond water assumed to maintain constant volume (i.e. no evaporative concentration or dilution influences on the pond water quality).

Interaction between pond water and the atmosphere was simulated in two steps:

- Step 1: CO_2(g) exchange with atmosphere.
- Step 2: O_2(g) exchange with atmosphere.

After each step, minerals that were above saturation were allowed to precipitate (these become the sludge layer in the conceptual model). The simulations were performed in small, quasi-equilibrium increments: '–' signifies desorption of CO_2 and '+' signifies absorption of O_2.

6.4.2 Assessment Results

Selected outputs from the pond water equilibration modelling are presented in **Figures 6.3 to 6.6**. **Table 6.3** presents a summary of the end member water qualities reporting to the PWD, the resulting "mixed" water quality according to the average ratios in the site water balance, and the average WWS groundwater quality to represent the "receiving environment".

As the groundwater equilibrates with the atmospheric concentrations of CO_2 (400 ppmv) and O_2 (20% vol), **Figure 6.3** demonstrates how excess CO_2 from groundwater is vented to the atmosphere (Step 1), followed by diffusion of atmospheric oxygen into the pond water (Step 2).

The loss of CO_2 in Step 1 results in an increase in pH of the pond water and a decrease in the Eh, however the Eh spikes again in response to the O_2 influx during Step 2 (**Figure 6.4**). In response to the change in pH and Eh, siderite ($FeCO_3$) precipitates from solution, followed by ferrihydrite (FeOOH) precipitation in response to the oxygen influx oxidised Fe^{2+} to Fe^{3+}. During the final stages of pond water equilibration with the atmosphere, calcite ($CaCO_3$) may precipitate (**Figure 6.5**). The mineral precipitation causes the pond water to become depleted in dissolved calcium, iron and manganese (**Figure 6.6**). Many of the trace metals in the pond water will be similarly affected by the mineral precipitation reactions.

The major water quality changes resulting from equilibration of pond water with the atmosphere are an increased pH and Eh, and depletion of dissolved iron (due to iron mineral precipitation). It is similarly expected that a minor decrease in TDS would

occur due to mineral precipitation; however with the exception of groundwater associated with the WG shale formations, groundwater TDS in the study area is relatively low to begin with. The geochemical modelling has assumed equilibrium reactions occurring within a relatively short timeframe, however the reaction kinetics may be such that only a quasi-equilibrium would be achieved for certain reactions. In particular, the extent to which iron mineral phases will precipitate and drop out of suspension is unclear – it is possible that precipitating iron minerals could form colloids that could remain in suspension in the water column, despite not being in a dissolved phase.

The proportional mixing of end member waters resulted in an estimated average PWD water quality, as presented in **Table 6.3**. The mixed PWD water quality exceeds several beneficial use criteria for dissolved metals; however, a comparison to the average WWS baseline groundwater quality indicates similar exceedances of dissolved metals criteria, and a similar overall beneficial use profile.

Two metals (nickel and copper) marginally exceeded the average WWS groundwater quality concentrations; however, these estimated concentrations are conservative for the following reasons:

- the quality of the CPP process water that would report to the PWD (which was the driver for the elevated nickel and copper concentrations) was simulated by adopting “first flush” results from concentrated KLC leachate testing. The larger water-to-solids ratio in the CPP would be expected to produce a more dilute water quality than the KLC first flush results;
- some of the dissolved metals load would be expected to adsorb onto precipitating iron oxide colloids in the PWD, which was not accounted for in the geochemical modelling; and
- further dilution would occur when the PWD water mixes with natural groundwater in the sealed panel following injection.

In consideration of the bullet points above, there was considered to be a low risk of the injected PWD water impacting the beneficial use status of the WWS groundwater resource beyond the point of injection.

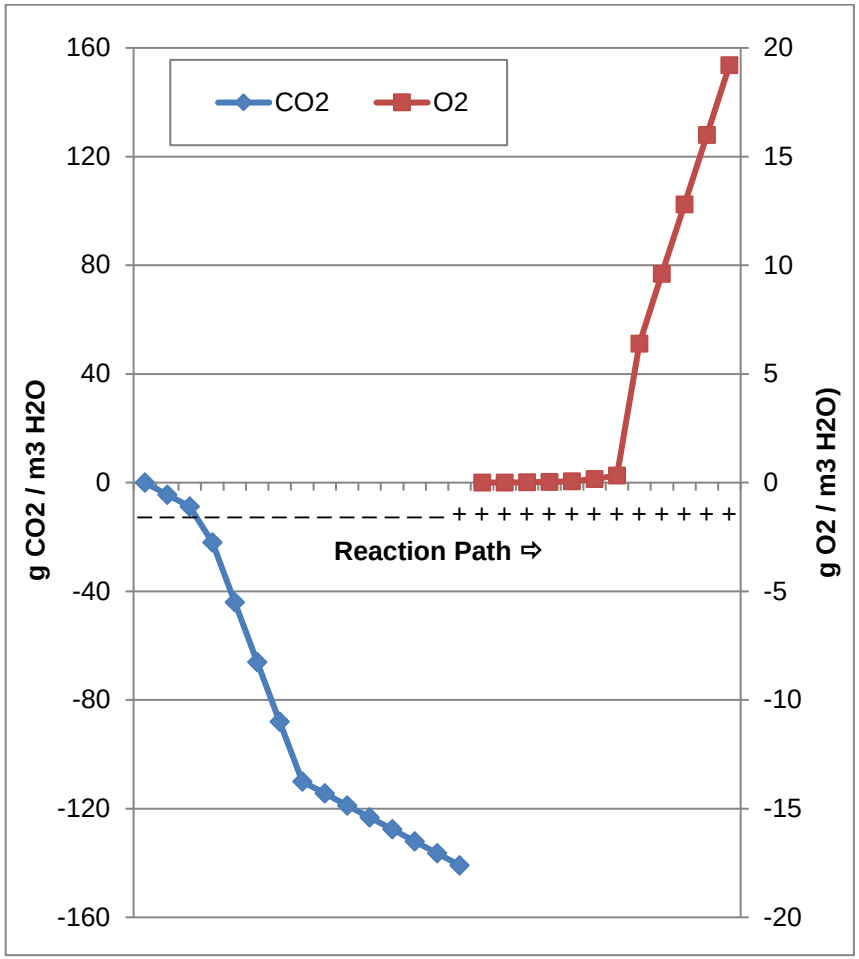


Figure 6.3. Pond water equilibration with atmospheric CO_2 and O_2.

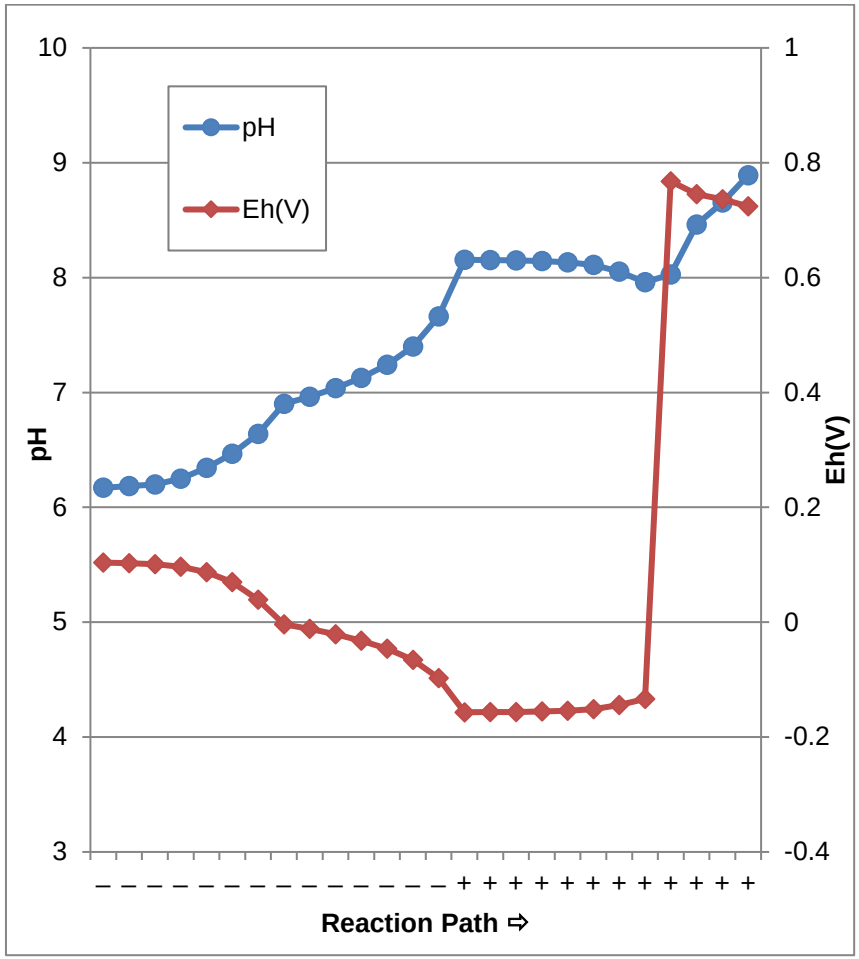


Figure 6.4. Pond water pH and Eh evolution during equilibration with atmospheric gases.

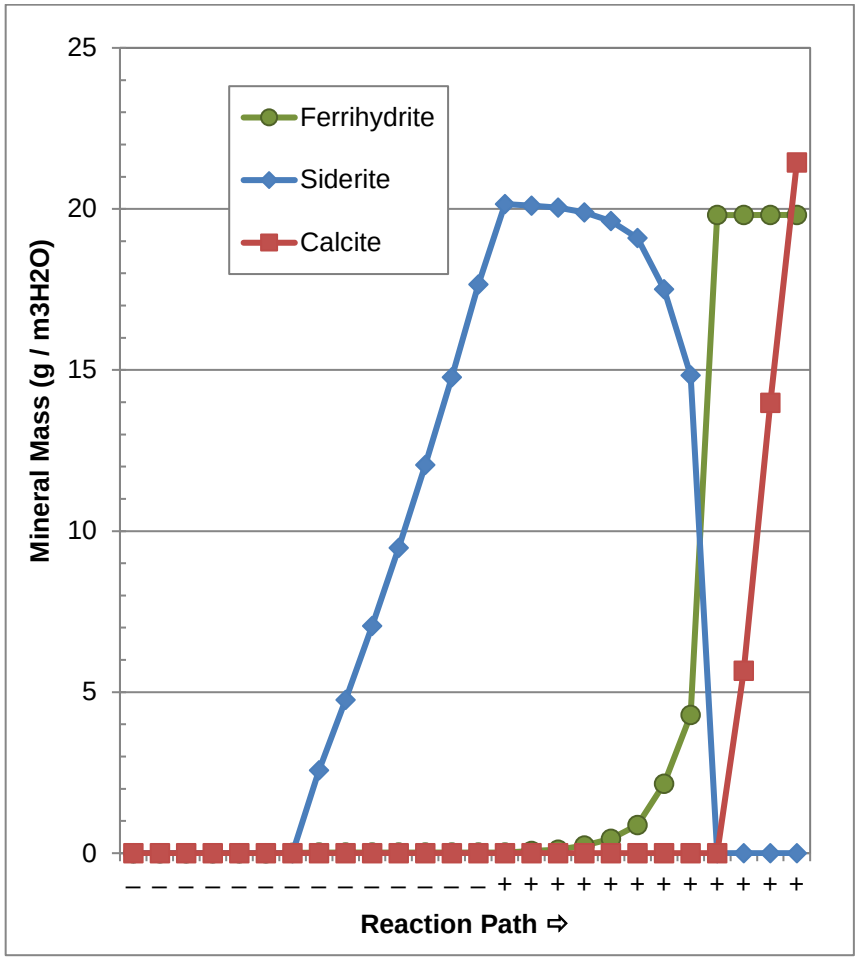


Figure 6.5. Major mineral phase precipitation during pond water equilibration with atmospheric gases.

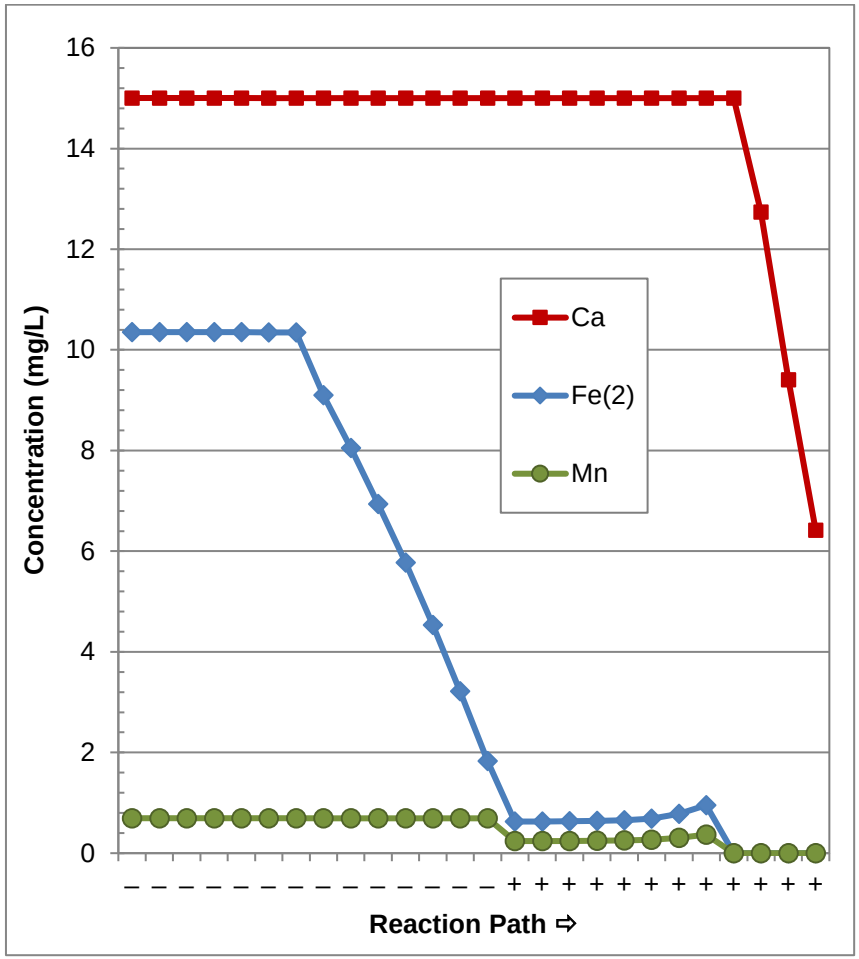


Figure 6.6. Depletion of Ca, Fe(2) and Mn in response to mineral precipitation in pond water.

Table 6.3: Estimated PWD water quality based on average annual inputs, and comparison to WWS water quality

Analytes	ANZECC (2000)			ADWG (2011)	CPP (10%)	GW (70%)	Rain (20%)	PWD mix	WWS (avg)
	Aquatic	Irrigation	Livestock						
pH	6.5-8.0	-	-	-	5.1	8.0	5.3	5.8	5.5
EC	-	-	-	-	565	227	97	235	469
Calcium	-	-	1000	-	28	15	2	14	24
Magnesium	-	-	-	-	22	NR	2	3	15
Sodium	-	460	-	-	21	48	12	38	46
Potassium	-	-	-	-	5	2	0.5	2	4
Bicarbonate	-	-	-	-	15	79	0.1	57	109
Chloride	-	700	-	-	128	39	23	45	78
Sulfate	-	-	1000	500	83	18	6	22	17
Aluminium	0.055	20	5	ID	0.76	NR	NR	0.076	0.103
Antimony	ID	-	-	0.003	<0.001	NR	<0.05	NA	0.003
Arsenic	0.013	2	0.5	0.01	0.008	0.009	<0.05	0.007	0.012
Boron	0.37	5	5	4	<0.05	NR	<0.1	NA	0.33
Cadmium	0.0002	0.05	0.01	0.002	0.0185	<0.0001	<0.05	0.0019	0.0037
Chromium	0.001	1	1	0.05	<0.001	0.0001	<0.05	0.0001	0.002
Cobalt	ID	0.1	1	-	0.323	0.008	<0.05	0.038	0.010
Copper	0.0014	5	1	2	0.154	0.007	0.051	0.031	0.008
Lead	0.0034	5	0.1	0.01	0.017	<0.001	<0.05	0.002	0.016
Manganese	1.9	10	-	0.5	1.78	0.06	0.06	0.229	0.69
Molybdenum	ID	0.05	0.15	0.05	<0.001	0.009	<0.05	0.006	0.014
Nickel	0.011	2	1	0.02	0.89	0.012	0.083	0.114	0.017
Selenium	0.005	0.05	0.02	0.01	0.01	NR	<0.05	0.001	0.06
Zinc	0.008	5	20	ID	2.132	0.024	0.215	0.273	0.080
Fluoride	-	2	2	1.5	0.3	0.16	0.164	0.2	0.16
Iron	ID	10	-	ID	2.2	0.0001	<0.1	0.2	7.67

7. CONCLUSIONS

7.1 Summary of Baseline Groundwater Quality Monitoring

- The baseline monitoring program for the project was considered to include adequate spatial (lateral and vertical) resolution across the project area, and to have covered a sufficient timeframe with adequate monitoring frequency to provide an acceptable baseline assessment of spatial and temporal variability in groundwater quality;

- The baseline quality of the groundwater resources of the HAW and the ICM is broadly characterised by low TDS groundwater that is suitable to support most beneficial uses. Within each formation, several groundwater quality parameters and analytes exceeded or were outside the range of one or more beneficial use assessment criteria (for example, the pH of groundwater within the HAW is generally below the trigger value range for protection of freshwater species in upland rivers in South-east Australia). However, the baseline water quality criteria exceedances are generally limited in number and only marginally exceed the relevant criteria, and are not considered to limit the beneficial uses of the resource (although may warrant localised treatment requirements for potable use). Within the study area, these two formations are accessed by approximately 90% of the registered water supply bores (for which screened interval data are available);

- The baseline groundwater quality of the WG shales is saline, and considered to be unsuitable for potable use and for irrigation of many crops. The typical low yields associated with the WG shales also limits the beneficial uses of the groundwater resource; and

- The groundwater quality associated with the shallow basalt groundwater resources, despite slightly higher TDS values than the HAW and ICM, was generally considered to be suitable to support most beneficial uses. This is supported by a cluster of shallow water supply bores installed within the basalt body on the south-eastern boundary of A349 (Figure 9.1 of Coffey, 2016a).

7.2 Summary of Potential Impacts from Project Activities

The following conclusions are made with regard to the potential influence of Project activities on groundwater quality:

- Dewatering of underground mine voids during active mine operations will result in partial depressurisation of some of the overlying water bearing formations. Modelling results indicated that the downward vertical

hydraulic gradients induced by depressurisation is expected to result in a temporary increase in the flux of groundwater from the WG shales (where present) to the upper portion of the HAW. Given the higher TDS of the shale groundwater, this phenomenon has the potential to temporarily raise the TDS of the upper HAW groundwater. The numerical flow model for the study area (Coffey, 2016b) was used to estimate the magnitude of increased flux attributable to Hume Coal mining activities, which indicated a peak increase of 1 ML/day (9% increase from baseline), with the maximum effect occurring within a short duration during mining. Likewise, a proportional maximum increase in salt flux (as groundwater TDS) of 9% was also predicted to occur. A net salt flux increase of 1.3% over baseline conditions was calculated for the 74-year period during which modelling predicted an incremental increase in groundwater leakage (including active mining operations and post-mining recovery). The current influence of baseline groundwater flux from the shales to the underlying sandstone was reviewed for multi-level monitoring wells installed through the shale, which generally indicated a minor TDS difference relative to wells installed in sandstone outcrop areas. A mixing model was used to assess the water quality resulting from relative mixing proportions of the shale and sandstone groundwater, which indicated that an unrealistically large proportion (> 40%) of shale groundwater would be required to reduce the beneficial use status of the underlying HAW groundwater resource.

- The results of KLC testing were used to assess the potential change to groundwater quality resulting from groundwater interaction with mining reject material emplaced in the underground mine voids. The results of column leaching tests were selected from columns considered to best represent the expected subsurface conditions: simulated mine reject material generated from cores recovered from the Project area, leached with groundwater obtained from the WWS, as would occur within the backfilled mine void. Data from two columns were considered; one with mine reject material amended with limestone as an additional alkalinity source, and the other unamended. The results were compared to baseline water quality for the Hawkesbury Sandstone and Wongawilli Seam to assess whether leaching from mine reject material would potentially result in degradation of the beneficial use status of the groundwater resources. The results of the unamended column leaching test indicated leachate water quality exceeded one or more of the beneficial use criteria that were generally also exceeded in the baseline groundwater quality, although the magnitude of the exceedance was substantially larger for certain metals in the leachate results. The final leachate pH of the unamended column was relatively low, indicating that acid generation was a potential concern. The

leachate quality from the limestone amended reject material was very favourable, with approximately neutral pH values throughout the test, and with leachate analyte concentrations that were below most of the beneficial use criteria, including many that were exceeded in the baseline groundwater quality. Accordingly, the assessment indicated that limestone amendment of the mine reject material prior to emplacement in the mine void is likely to produce leachate that is indistinguishable from natural groundwater quality, and is considered unlikely to change the beneficial use status of the groundwater resources.

- During the initial 12-18 months as the project is developed, the coal reject generated from mining of the initial panels will be stored in a temporary coal reject stockpile adjacent to the CPP until sufficient void space is available underground, and the plant is commissioned to commence underground emplacement. In addition, if the slurry operation is interrupted, for example during maintenance, reject will be temporarily diverted to an emergency surface stockpile for later reprocessing. The fines managed on the surface in this manner will be dewatered via belt press filters (avoiding the need for a tailings dam) prior to being combined with the course reject. This combined reject will be placed on the temporary coal reject stockpile, which will be progressively constructed, contoured and when full, top dressed and revegetated. Once mining is completed, rejects stored at the surface will be removed, reprocessed and pumped underground to remaining voids. Surface emplacements will then be rehabilitated. The coal reject stockpile will be managed such that it does not receive run off from the surrounding mine site, however will still be exposed to rainfall that falls directly on the stockpile. To reduce the potential for acid generation and mobilisation of metals arising from oxidation of reject minerals in the stockpile, the reject will be amended with limestone prior to emplacement in the stockpile to buffer acid generation.

- The mine water management plan will include a portion of the water in the PWD being pumped into the sealed underground panels. The water balance for the site indicates that the average annual input to the PWD will comprise approximately 70% extracted groundwater, 20% rainfall, and 10% process water from the CPP and dust suppression returns. The water quality resulting from the proportional mixing of these end member waters was simulated using a mixing model, with data from KLC tests, geochemical modelling and published rainfall quality data used to represent the end member water types. The mixed PWD water quality exceeds several beneficial use criteria for dissolved metals; however, comparison to the average WWS baseline groundwater quality (the

"receiving environment" for water injected into the sealed panels) indicates similar exceedances of dissolved metals criteria, and a similar overall beneficial use profile. Two metals (nickel and copper) marginally exceeded the average WWS groundwater quality concentrations. Considering the conservatism in estimating the quality of the CPP process water that would report to the dam (which was the driver for the elevated nickel and copper concentrations), the fact that some of the metals load would be expected to adsorb onto precipitating iron oxide colloids in the dam (which was not accounted for in the geochemical modelling) and the further dilution that would occur when the PWD water mixes with natural groundwater in the sealed panel following injection, there is considered to be a low risk of the injected PWD water causing a degradation of the beneficial use status of the WWS groundwater resource beyond the point of injection.

Regarding the requirements of the AI Policy in relation to groundwater quality, it is not anticipated that the project activities will result in a lowering of the beneficial use category of the groundwater source beyond 40 m from the activity, assuming the mitigation measures discussed in the following section are implemented. It follows from this conclusion that unacceptable cumulative impacts to groundwater quality are also not anticipated as a result of mining activities.

In addition, the (partial) groundwater dependency of GDEs identified in the study area is understood to be associated with shallow groundwater (i.e. <10 mbgl), whereas the subsurface project activities are associated with deeper strata. The project activities are not expected to produce a change to groundwater quality in the immediate footprint of the mining activities that could impact the biodiversity or biological function of a GDE at the point of groundwater discharge several kilometres away. Accordingly, GDEs in the study area are not considered to be at risk of harm from mining activities, from a groundwater quality perspective.

7.3 Summary of Mitigation Measures

Based on the evaluation of potential groundwater quality impacts resulting from Project activities, the Hume Coal project is considered to present a low risk to the groundwater resources of the mine lease and surrounding areas.

No specific mitigation measures are recommended regarding the temporary increase in groundwater flux from the WG shales to the HAW, as the magnitude and duration of the estimated additional flux are considered unlikely to result in a change to the beneficial use status of the underlying HAW groundwater resource.

Regarding emplacement of mine reject material in the underground mine voids, the results of KLC tests indicated the leachate quality benefit of amending the mine reject material with limestone prior to emplacement as a surplus alkalinity source. The resulting leachate quality retained a neutral pH throughout the test, and dissolved analyte concentrations in the leachate were generally lower than in the

baseline water quality from the HAW and the WWS. Accordingly, it is recommended that the limestone amendment of reject material is adopted as a precautionary measure, to provide confidence in safeguarding the quality of the groundwater resources of the lower HAW and WWS following emplacement of the mine reject material.

Regarding the prevention of groundwater contamination to preclude the need for remediation (DPI Water environmental assessment condition), the KLC test results suggest that limestone amendment should suffice to buffer acid generation and prevent solubilisation and mobilisation of metals at concentrations that would impact the beneficial uses of the groundwater resource. The storage and use of hazardous materials at the site (e.g. fuels, maintenance chemicals, etc), represents another potential source of groundwater contamination. Accordingly, environmental management systems should be implemented for the active mine operation for the transport, storage, handling and disposal of hazardous substances to prevent release to the environment. The relevant measures are discussed in further detail in the Hazard and Risk Assessment Report (EMM, 2016c).

7.4 Recommended Monitoring Program

It is recommended that the baseline groundwater monitoring program should continue during the operation of the mine, and for sufficient time during the post-closure period to confirm the efficacy of the limestone amendment in mitigating acid and metals mobilisation from the emplaced reject material.

It is recommended that the full monitoring network continues to be used, acknowledging that some of the wells may be destroyed during the course of mining. As discussed in the Water Assessment Report (EMM, 2016b), expansion of the monitoring network should be considered upon commencement of construction to provide compliance monitoring coverage close to potential sources of groundwater impact (for example, the mine reject temporary stockpile location).

It is recommended that monitoring continues on a quarterly basis until there is sufficient data to verify that mining activities are not resulting in unacceptable changes to groundwater quality.

The current analytical suite is considered to be sufficient for the purposes of assessing groundwater quality changes attributable to mining activities. Based on the baseline water quality results, it is considered that a reduced analytical suite would be adequate to assess the primary water quality risk of acid, salinity and metals mobilisation on a quarterly basis, and that organic analytes, and certain inorganic analytes, could be included in a “full” analytical suite annually. A summary is presented below:

- Quarterly field measurement of water quality parameters during purging and sampling (temperature, pH, EC, DO, ORP);

- Quarterly laboratory analysis for:
  - Major cations and anions
  - Dissolved metals and metalloids
- Annual laboratory analysis for:
  - TRH
  - BTEX
  - PAHs
  - Phenolic compounds
  - OCPs and OPPs
  - N and P based nutrients, fluoride and cyanide

It is considered unlikely that the project activities would present an increased risk of microbiological contamination (e.g. coliforms), which are typically associated with leaks from shallow septic tank systems or sewerage drains. Accordingly, there is limited value in continuing with the microbiological analyses.

It is good industry practice to review the monitoring program framework and results in detail on an annual basis, to assess whether the program should continue in its current form or if there is justification to modify the program. Any proposal to modify the program should be supported by a thorough analysis of the monitoring results in the context of the risks to water quality. The annual review should consider justification for increasing, maintaining or reducing monitoring locations, frequency and analytical suite in response to water quality trends, and potentially in response to loss of monitoring infrastructure.

It is recommended that there be a separate procedure for responding to and assessing specific incidents of potential environmental concern (e.g. spills or unintentional releases of hazardous substances, loss of containment of poor quality water, etc), which then triggers additional consideration of the ongoing groundwater quality monitoring program if warranted by the nature of the release. Additional monitoring requirements in response to incidents should be assessed and implemented as soon as possible following the incident, rather than postponing until the next annual review.

8. REFERENCES

ANZECC & ARMCANZ, 2000. National Water Quality Management Strategy Document 4: Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

Coffey, 2016a. Hume Coal Project, Groundwater Assessment Volume 1: Data Analysis (ref. GEOTLCOV25281AB-ACA), dated 8 August 2016.

Coffey, 2016b. Hume Coal Project, Groundwater Assessment Volume 2: Numerical Modelling and Impact Assessment (ref. GEOTLCOV25281AB-ACB), dated 8 August 2016.

Crosbie, R, Morrow, D, Cresswell, R, Leaney, F, Lamontagne, S and Lefournour, M, 2012. New insights into the chemical and isotopic composition of rainfall across Australia. CSIRO Water for a Healthy Country Flagship, Australia.

EMM Consulting Pty Limited (EMM), 2015. Hume Coal Project, Preliminary Environmental Assessment (ref. J12055, dated 17 July 2015).

EMM, 2016a. Hume Coal Project Environmental Impact Statement. Prepared for Hume Coal Pty Limited.

EMM, 2016b. Hume Coal Project Water Assessment, Appendix F of the Hume Coal Project Environmental Impact Statement. Prepared for Hume Coal Pty Limited.

EMM 2016c. Hume Coal Project Hazard and Risk Assessment Report. Appendix P of the Hume Coal Project Environmental Impact Statement. Prepared by EMM for Hume Coal Pty Ltd.

NHMRC & NRMMC, 2011. National Water Quality Management Strategy Document 6: Australian Drinking Water Guidelines. National Health and Medical Research Council and Natural Resource Management Ministerial Council.

Parsons Brinckerhoff, 2012. Hume Coal Project Area: hydrogeochemical and environmental isotope study (Ref. 2172599A-LT_1015), dated 21 March 2012.

Parsons Brinckerhoff, 2014. Assessment of mine inflow (groundwater) quality and suitability for reuse and disposal (Ref. 217599A-GW-REP-14901 Rev A), dated 4 September 2014.

RGS Environmental Pty Ltd, 2016. Hume Coal Project, Geochemical Assessment of Coal and Mining Waste Materials (Ref. 111232 report R001_A), dated 31 March 2016.

Volk, H, Pinetown, K, Johnston, C and McLean, W, 2011. A desktop study of the occurrence of Total Petroleum Hydrocarbon (TPH) and partially water-soluble organic compounds in Permian coals and associated coal seam groundwater. CSIRO Petroleum & Geothermal Research Portfolio, Open File Report EP-13-09-11-11, prepared for AGL Energy.

9. LIMITATIONS

The opinions provided in this report were based on review and analysis of data and specialist studies performed by third parties, and provided to Geosyntec by Hume Coal. Geosyntec has relied on the factual information provided as being a true and accurate representation of the conditions encountered at the site, and cannot be held liable for errors or omissions in third party information supplied as part of this study.

The necessity to rely on third party information results in an inherent level of uncertainty that exists despite Geosyntec's compliance with appropriate professional standards of care. In addition, the documents supplied to Geosyntec for review as part of these services may contain limitations statements. Accordingly, the advice developed on the basis of those documents is, by extension, subject to those same limitations.

The statement of limitations is not intended to reduce the confidence in the work product or the professional standard of care with which it was prepared. Rather it provides realistic expectations for those using the results of this study regarding the potential sources of uncertainty inherent in its preparation.

APPENDIX A

Tables

Table A1: Baseline Groundwater Monitoring Results - Basalt

Location			Water Quality Criteria				HU0056XPZC					HU0136PZC											
Date			ANZECC (2000)			ADWG (2011)	19/12/2012	19/12/2013	25/09/2014	13/11/2014	5/02/2015	29/08/2014	1/12/2014	4/02/2015	23/09/2015								
Analyte	**Units**	**LOR**	**Aquatic**	**Irrigation**	**Livestock**											**n**	**Detects**	**Exc**	**Min**	**Max**	**Avg**	**Geomean**	**Std Dev**
General field parameters																							
pH	pH units		6.5-7.5				6.52	7.74	7.45	7.34	7.18	7.05	7.03	6.98	6.07	9	9	2	6.07	7.74	6.75	7.04	0.50
Conductivity (field)	µS/cm		30-350	0-650 (v. low) >650-1300 (low) >1300-2900 (medium) >2900-5200 (high) >5200-8100 (v. high) >8100 (extreme)			757	738	797	446	643	620	619	623	631	9	9	9	446	797	653	645	103
Conductivity (lab)	µS/cm	1	30-350												612	1	1	1	612	612	612	612	
Total Dissolved Solids (field)	mg/L					<600 (good quality) 600-900 (fair quality) >900-1200 (poor quality) >1200 (unacceptable)	491	480	518	261	418	403	402	405	410	9	9		261	518	421	414.13	74.55
Total Dissolved Solids (lab)	mg/L	10													374	1	1		374	374	374	374	
Dissolved oxygen	% sat		90-110				38.6	21.3	51.8	57.7	67.8	58.6	66.4	84.3	61.6	9	9		21.3	84.3	56.5	53	18
Redox	mV						-1.5	82.0	76.1	85	14.8	178.6	105.7	101.5	-116.8	9	9		-116.8	178.6	58.4		84
Temperature	ºC						18.52	18.46	18.62	17.1	16.67	15.65	17.17	16.07	16.08	9	9		15.7	18.6	17.1	17	1
Suspended Solids	mg/L	5													<5	1	0						
Turbididty	NTU	0.1	2-25													0	0						
Major Ions																							
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1		<1	<1	<1	<1	<1	<1	8	0						
Carbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	8	<1		<1	<1	<1	<1	<1	<1	8	1						
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	281	245		350	311	253	256	254	236	8	8		236	350	273	271	39
Total Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	289	245		350	311	253	256	254	236	8	8		236	350	274	272	39
Acidity as $CaCO_3$	mg/L	1	-	-	-	-										0	0						
Sulfate as SO_4^{2-}	mg/L	1	-	-	1000	500	83	45		10	7	8	8	7	8	8	8	0	7	83	22.0	13	28
Chloride	mg/L	1	-	700	-	ID	54	60		27	33	50	57	57	50	8	8	0	27	60	48.5	47	12
Calcium	mg/L	1	-	-	1000	-	61	44		52	39	33	31	30	34	8	8	0	30	61	40.5	39	11
Magnesium	mg/L	1	-	-	ID	-	38	25		48	40	56	47	51	57	8	8		25	57	45.3	44	11
Sodium	mg/L	1	-	460	-	-	68	69		41	44	25	20	23	24	8	8	0	20	69	39.3	35	20
Potassium	mg/L	1	-	-	-	-	4	3		2	2	2	2	2	2	8	8		2	4	2.38	2	1
Silica/Silicon as SiO_2/Reactive silica	mg/L	0.1	-	-	-	-	24.2			35.8	37.2	52.2	44	43.8	42	7	7		24.2	52.2	39.9	39	9
Total Anions	meq/L	0.01	-	-	-	-	9.03	7.52		7.96	7.29	7.27	6.89	6.83	6.29								
Total Cations	meq/L	0.01	-	-	-	-	9.23	7.33		8.38	7.2	7.39	6.34	6.75	7.48								
Ionic Balance	%	0.01	-	-	-	-	1.12	1.32		2.53	0.62	0.84	4.2	0.62	8.63								
Other Inorganics																							
Flouride	mg/L	0.1	-	2	2	1.5										0	0						
Free cyanide	mg/L	0.004	0.007	-	-	0.08										0	0						
Total cyanide	mg/L	0.004	-	-	-	-										0	0						
Thiocyanate	mg/L	0.1	-	-	-	-										0	0						
Dissolved metals																							
Aluminium	mg/L	0.01	0.055	20	5	ID				0.04	0.01	0.04	<0.01	0.02	<0.01	6	4	0	0.01	0.04	0.03	0.02	0.02
Antimony	mg/L	0.001	ID	-	-	0.003				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	6	0						
Arsenic	mg/L	0.001	0.013	2	0.5	0.01				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	6	0						
Beryllium	mg/L	0.001	ID	0.5	ID	0.06										0	0						
Barium	mg/L	0.001	-	-	-	2										0	0						
Cadmium	mg/L	0.0001	0.0002	0.05	0.01	0.002				<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	6	0						
Chromium	mg/L	0.001	0.001	1	1	0.05				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	6	0						
Cobalt	mg/L	0.001	ID	0.1	1	-				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	6	0						
Copper	mg/L	0.001	0.0014	5	1#	2				0.007	0.003	0.003	0.002	0.002	<0.001	6	5	5	0.002	0.007	0.003	0.003	0.002
Lead	mg/L	0.001	0.0034	5	0.1	0.01				0.002	<0.001	<0.001	<0.001	<0.001	<0.001	6	1	0	0.002	0.002	0.002	0.002	
Lithium	mg/L	0.001	-	2.5	-	-										0	0						
Manganese	mg/L	0.001	1.9	10	-	0.5	0.051	0.189		0.006	0.027	0.003	0.002	0.001	<0.001	8	7	0	0.001	0.189	0.040	0.01	0.07
Molybdenum	mg/L	0.001	ID	0.05	0.15	0.05				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	6	0						
Nickel	mg/L	0.001	0.011	2	1	0.02				0.001	<0.001	0.002	<0.001	<0.001	<0.001	6	2	0	0.001	0.002	0.002	0.001	0.001
Selenium	mg/L	0.01	0.005	0.05	0.02	0.01				<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	6	0						
Strontium	mg/L	0.001	-	-	-	-										0	0						
Tin	mg/L	0.001	ID	-	-	-										0	0						
Uranium	mg/L	0.001	ID	0.1	0.2	0.017										0	0						
Vanadium	mg/L	0.01	ID	0.5	ID	-										0	0						
Zinc	mg/L	0.005	0.008	5	20	ID				0.012	0.029	0.01	0.006	0.007	<0.005	6	5	3	0.006	0.029	0.013	0.011	0.009
Boron	mg/L	0.05	0.37	5	5	4				<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	6	0						
Iron	mg/L	0.05	ID	10	ID	ID	0.49	0.08		0.08	<0.05	<0.05	<0.05	<0.05	<0.05	8	3	0	0.08	0.49	0.2	0.15	0.24
Ferrous iron	mg/L	0.05	-	-	-	-									<0.05	0	0						
Bromine	mg/L	0.1	-	-	-	-										0	0						
Iodine	mg/L	0.1	-	-	-	ID										0	0						
Mercury	mg/L	0.0001	0.00006	0.002	0.002	0.001										0	0						
Total metals																							
Aluminium	mg/L	0.01	-	-	-	-										0	0						
Manganese	mg/L	0.001	-	-	-	-									<0.001	1	0						
Iron	mg/L	0.05	-	-	-	-									<0.05	1	0						
Nutrients																							
Ammonia as N	mg/L	0.01	2.57													0	0						
Nitrite as N	mg/L	0.01			9											0	0						
Nitrate as N	mg/L	0.01			90											0	0						
Total phosphorous	mg/L	0.01														0	0						
Reactive phosphorous	mg/L	0.01														0	0						

Table A2: Baseline Groundwater Monitoring Results - Wianamatta Group Shale

Location			Water Quality Criteria				HU0035PZB													
Date			ANZECC (2000)			ADWG (2011)	13/12/2013	25/03/2014	25/07/2014	5/12/2014	4/02/2015	1/07/2015	22/09/2015							
Analyte	Units	LOR	Aquatic	Irrigation	Livestock									n	Detects	Exc	Min	Max	Avg	Geomean	Std Dev
General field parameters																					
pH	pH units		6.5-7.5				6.44	6.50	6.94	6.59	7.30	6.18	6.37	7	7	3	6.18	7.3	6.50	6.62	0.38
Conductivity (field)	µS/cm		30-350	0-650 (v. low) >650-1300 (low) >1300-2900 (medium) >2900-5200 (high) >5200-8100 (v. high) >8100 (extreme)			2365	2588	2409	2734	2732	2608	2885	7	7	7	2365	2885	2617	2612	185
Conductivity (lab)	µS/cm	1	30-350									2600		1	1	1	2600	2600	2600	2600	
Total Dissolved Solids (field)	mg/L					<600 (good quality) 600-900 (fair quality) >900-1200 (poor quality) >1200 (unacceptable)	1537	1673	1566	1778	1776	1696.5	1875	7	7		1537	1875	1700	1696.51	120.93
Total Dissolved Solids (lab)	mg/L	10										1480	1750	2	2		1480	1750	1615	1609	191
Dissolved oxygen	% sat		90-110				61.0	22.6	90.0	48.0	52.2	65.4	12.9	7	7		12.9	90	50.3	43	26
Redox	mV						15.3	-49	112.8	1.5	7.3	28.4	-146.7	7	7		-146.7	112.8	-4.3		79
Temperature	°C						15.49	16.26	15.58	17.00	18.40	13.50	13.43	7	7		13.4	18.4	15.7	16	2
Suspended Solids	mg/L	5										1350	1220	2	2		1220	1350	1285.00	1283	92
Turbididty	NTU	0.1	2-25										1050	1	1	1	1050	1050	1050.00	1050	
Major ions																					
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1		<1	<1	<1	6	0						
Carbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1		<1	<1	<1	6	0						
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	258	331	293		380	322	315	6	6		258	380	317	314	41
Total Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	258	331	293		380	322	315	6	6		258	380	317	314	41
Acidity as $CaCO_3$	mg/L	1	-	-	-	-						79		1	1		79	79	79.00	79	
Sulfate as SO_4^{2-}	mg/L	1	-	-	1000	500	73	86	76		63	44	32	6	6	0	32	86	62.3	59	21
Chloride	mg/L	1	-	700	-	ID	528	586	588		597	668	707	6	6	1	528	707	612.3	610	64
Calcium	mg/L	1	-	-	1000	-	141	166	167		177	180	170	6	6	0	141	180	166.8	166	14
Magnesium	mg/L	1	-	-	ID	-	127	144	141		152	159	149	6	6		127	159	145.3	145	11
Sodium	mg/L	1	-	460	-	-	108	127	136		157	160	257	6	6	0	108	257	157.5	151	52
Potassium	mg/L	1	-	-	-	-	8	8	11		8	8	12	6	6		8	12	9.17	9	2
Silica/Silicon as SiO_2/Reactive silica	mg/L	0.1	-	-	-	-	9.91	11.1	8		10.2	8.6	9.35	6	6		8	11.1	9.5	9	1
Total Anions	meq/L	0.01	-	-	-	-	21.6	24.9	24		25.7	26.2	26.9								
Total Cations	meq/L	0.01	-	-	-	-	22.4	25.9	26.1		28.4	29.2	32.2								
Ionic Balance	%	0.01	-	-	-	-	1.88	1.84	4.22		4.87	5.5	9.02								
Other Inorganics																					
Flouride	mg/L	0.1	-	2	2	1.5	0.1	0.1				0.1	0.1	4	4	0	0.1	0.1	0.10	0.10	0.00
Free cyanide	mg/L	0.004	0.007	-	-	0.08	<0.004							1	0	0	0				
Total cyanide	mg/L	0.004	-	-	-	-	<0.004							1	0		0				
Thiocyanate	mg/L	0.1	-	-	-	-	<0.1							1	0		0				
Dissolved metals																					
Aluminium	mg/L	0.01	0.055	20	5	ID	0.77	<0.01	<0.01		<0.01	<0.01	0.03	6	2	1	0.03	0.77	0.40	0.15	0.52
Antimony	mg/L	0.001	ID	-	-	0.003	<0.001	<0.001	0.001		<0.001	<0.001	<0.001	6	1		0.001	0.001	0.001	0.00	
Arsenic	mg/L	0.001	0.013	2	0.5	0.01	0.004	0.002	<0.001		0.001	0.001	<0.001	6	4	0	0.001	0.004	0.002	0.00	0.00
Beryllium	mg/L	0.001	ID	0.5	ID	0.06	<0.001	<0.001					<0.001	3	0		0				
Barium	mg/L	0.001	-	-	-	2	0.424	0.268				0.358	0.413	4	4		0.268	0.424	0.366	0.36	0.07
Cadmium	mg/L	0.0001	0.0002	0.05	0.01	0.002	<0.0001	<0.0001	0.0002		<0.0001	<0.0001	<0.0001	6	1	0	0.0002	0.0002	0.000	0.00	
Chromium	mg/L	0.001	0.001	1	1	0.05	0.002	<0.001	0.001		<0.001	<0.001	<0.001	6	2	1	0.001	0.002	0.002	0.00	0.00
Cobalt	mg/L	0.001	ID	0.1	1	-	0.026	0.03	0.016		0.025	0.015	0.033	6	6		0.015	0.033	0.024	0.02	0.01
Copper	mg/L	0.001	0.0014	5	1	2	0.011	0.011	0.004		0.004	<0.001	0.015	6	5	5	0.004	0.015	0.009	0.008	0.005
Lead	mg/L	0.001	0.0034	5	0.1	0.01	0.004	<0.001	<0.001		<0.001	<0.001	0.005	6	2	2	0.004	0.005	0.005	0.004	0.00
Lithium	mg/L	0.001	-	2.5	-	-	0.146						0.194	2	2		0.146	0.194	0.170	0.17	0.03
Manganese	mg/L	0.001	1.9	10	-	0.5	0.653	0.692	0.532		0.666	0.611	0.926	6	6	0	0.532	0.926	0.680	0.67	0.13
Molybdenum	mg/L	0.001	ID	0.05	0.15	0.05	0.001	0.002	0.005		0.008	0.003	0.005	6	6		0.001	0.008	0.004	0.00	0.00
Nickel	mg/L	0.001	0.011	2	1	0.02	0.042	0.042	0.036		0.034	0.025	0.041	6	6	6	0.025	0.042	0.037	0.036	0.007
Selenium	mg/L	0.01	0.005	0.05	0.02	0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	6	0		0				
Strontium	mg/L	0.001	-	-	-	-	0.309	0.325				0.343	0.323	4	4		0.309	0.343	0.325	0.32	0.01
Tin	mg/L	0.001	ID	-	-	-	<0.001						<0.001	2	0		0				
Uranium	mg/L	0.001	ID	0.1	0.2	0.017	0.002	0.001					<0.001	3	2	0	0.001	0.002	0.002	0.00	0.00
Vanadium	mg/L	0.01	ID	0.5	ID	-	<0.01	<0.01					<0.01	3	0	0	0				
Zinc	mg/L	0.005	0.008	5	20	ID	0.293	0.085	0.075		0.054	0.011	0.266	6	6	6	0.011	0.293	0.131	0.082	0.118
Boron	mg/L	0.05	0.37	5	5	4	0.06	0.07	0.06		0.06	<0.05	0.05	6	5	0	0.05	0.07	0.1	0.0596629	0.007071068
Iron	mg/L	0.05	ID	10	ID	ID	4.23	1.24	<0.05		0.56	0.5	0.45	6	5		0.45	4.23	1.4	0.92	1.62
Ferrous iron	mg/L	0.05	-	-	-	-						0.19	0.48	1	2		0.19	0.48	0.34	0.30	0.21
Bromine	mg/L	0.1	-	-	-	-	1.3	1.2					1	3	3		1	1.3	1.167	1.16	0.15
Iodine	mg/L	0.1	-	-	-	ID	0.5						0.1	2	2		0.1	0.5	0.3	0.22	0.28
Mercury	mg/L	0.0001	0.00006	0.002	0.002	0.001	<0.0001							1	0	1					
Total metals																					
Aluminium	mg/L	0.01	-	-	-	-	4.02						1.14	1	2		1.14	4.02	2.58	2.14	2.04
Manganese	mg/L	0.001	-	-	-	-	1.19					1.56	1.44	1	3		1.19	1.56	1.397	1.39	0.19
Iron	mg/L	0.05	-	-	-	-	20.4					42.9	19.9	1	3		19.9	42.9	27.7	25.92	13.14
Nutrients																					
Ammonia as N	mg/L	0.01	2.57				0.22						0.24	1	2	0	0.22	0.24	0.23	0.23	0.01
Nitrite as N	mg/L	0.01			9		<0.01	<0.01					0.01	1	1	0	0.01	0.01	0.01	0.01	
Nitrate as N	mg/L	0.01			90		0.03	0.02					0.01	1	3	0	0.01	0.03	0.02	0.02	0.01
Total phosphorous	mg/L	0.01					0.49							1	1		0.49	0.49	0.49	0.49	
Reactive phosphorous	mg/L	0.01					<0.01	<0.01					<0.01	1	0						

Table A2: Baseline Groundwater Monitoring Results - Wianamatta Group Shale

Location			Water Quality Criteria				HU0035PZB						
Date			ANZECC (2000)			ADWG (2011)	13/12/2013	25/03/2014	25/07/2014	5/12/2014	4/02/2015	1/07/2015	22/09/2015
Analyte	Units	LOR	Aquatic	Irrigation	Livestock								
Organochloride pesticides													
alpha-BHC	µg/L	0.5					<0.5						<0.5
Hexachlorobenzene (HCB)	µg/L	0.5					<0.5						<0.5
beta-BHC	µg/L	0.5					<0.5						<0.5
gamma-BHC	µg/L	0.5					<0.5						<0.5
delta-BHC	µg/L	0.5					<0.5						<0.5
Heptachlor	µg/L	0.5					<0.5						<0.5
Aldrin	µg/L	0.5					<0.5						<0.5
Heptachlor epoxide	µg/L	0.5					<0.5						<0.5
trans-Chlordane	µg/L	0.5					<0.5						<0.5
alpha-Endosulfan	µg/L	0.5					<0.5						<0.5
cis-Chlordane	µg/L	0.5					<0.5						<0.5
Dieldrin	µg/L	0.5					<0.5						<0.5
4.4`-DDE	µg/L	0.5					<0.5						<0.5
Endrin	µg/L	0.5					<0.5						<0.5
beta-Endosulfan	µg/L	0.5					<0.5						<0.5
4.4`-DDD	µg/L	0.5					<0.5						<0.5
Endrin aldehyde	µg/L	0.5					<0.5						<0.5
Endosulfan sulfate	µg/L	0.5					<0.5						<0.5
4.4`-DDT	µg/L	2					<2.0						<2.0
Endrin ketone	µg/L	0.5					<0.5						<0.5
Methoxychlor	µg/L	2					<2.0						<2.0
Total Chlordane (sum)	µg/L	0.5					<0.5						<0.5
Sum of DDD + DDE + DDT	µg/L	0.5					<0.5						<0.5
Sum of Aldrin + Dieldrin	µg/L	0.5					<0.5						<0.5
Organophosphorous pesticides													
Dichlorvos	µg/L	0.5					<0.5						<0.5
Demeton-S-methyl	µg/L	0.5					<0.5						<0.5
Monocrotophos	µg/L	2					<2.0						<2.0
Dimethoate	µg/L	0.5					<0.5						<0.5
Diazinon	µg/L	0.5					<0.5						<0.5
Chlorpyrifos-methyl	µg/L	0.5					<0.5						<0.5
Parathion-methyl	µg/L	2					<2.0						<2.0
Malathion	µg/L	0.5					<0.5						<0.5
Fenthion	µg/L	0.5					<0.5						<0.5
Chlorpyrifos	µg/L	0.5					<0.5						<0.5
Parathion	µg/L	2					<2.0						<2.0
Pirimphos-ethyl	µg/L	0.5					<0.5						<0.5
Chlorfenvinphos	µg/L	0.5					<0.5						<0.5
Bromophos-ethyl	µg/L	0.5					<0.5						<0.5
Fenamiphos	µg/L	0.5					<0.5						<0.5
Prothiofos	µg/L	0.5					<0.5						<0.5
Ethion	µg/L	0.5					<0.5						<0.5
Carbophenothion	µg/L	0.5					<0.5						<0.5
Azinphos Methyl	µg/L	0.5					<0.5						<0.5
Phenolic compounds													
Phenol	µg/L	1					<1.0						<1.0
2-Chlorophenol	µg/L	1					<1.0						<1.0
2-Methylphenol	µg/L	1					<1.0						<1.0
3- & 4-Methylphenol	µg/L	1					<2.0						<2.0
2-Nitrophenol	µg/L	2					<1.0						<1.0
2.4-Dimethylphenol	µg/L	1					<1.0						<1.0
2.4-Dichlorophenol	µg/L	1					<1.0						<1.0
2.6-Dichlorophenol	µg/L	1					<1.0						<1.0
4-Chloro-3-methylphenol	µg/L	1					<1.0						<1.0
2.4.6-Trichlorophenol	µg/L	1					<1.0						<1.0
2.4.5-Trichlorophenol	µg/L	1					<1.0						<1.0
Pentachlorophenol	µg/L	1					<2.0						<2.0
Polynuclear aromatic hydrocarbons													
Naphthalene	µg/L	1					<1.0						<1.0
Acenaphthylene	µg/L	1					<1.0						<1.0
Acenaphthene	µg/L	1					<1.0						<1.0
Fluorene	µg/L	1					<1.0						<1.0
Phenanthrene	µg/L	1					<1.0						<1.0
Anthracene	µg/L	1					<1.0						<1.0
Fluoranthene	µg/L	1					<1.0						<1.0
Pyrene	µg/L	1					<1.0						<1.0
Benz(a)anthracene	µg/L	1					<1.0						<1.0
Chrysene	µg/L	1					<1.0						<1.0
Benzo(b)fluoranthene	µg/L	1					<1.0						<1.0
Benzo(k)fluoranthene	µg/L	1					<1.0						<1.0
Benzo(a)pyrene	µg/L	0.5					<0.5						<0.5
Indeno(1.2.3.cd)pyrene	µg/L	1					<1.0						<1.0
Dibenz(a.h)anthracene	µg/L	1					<1.0						<1.0
Benzo(g.h.i)perylene	µg/L	1					<1.0						<1.0
Sum of polycyclic aromatic hydrocarbons	µg/L	0.5					<0.5						<0.5
Benzo(a)pyrene TEQ (zero)	µg/L	0.5					<0.5						<0.5
BTEX													
Benzene	µg/L	1					<1						<1
Toluene	µg/L	2	ID			800	<2						<2
Ethylbenzene	µg/L	2					<2						<2
meta- & para-Xylene	µg/L	2					<2						<2

Table A2: Baseline Groundwater Monitoring Results - Wianamatta Group Shale

Location			Water Quality Criteria				HU0035PZB						
Date			ANZECC (2000)			ADWG (2011)	13/12/2013	25/03/2014	25/07/2014	5/12/2014	4/02/2015	1/07/2015	22/09/2015
Analyte	Units	LOR	Aquatic	Irrigation	Livestock								
ortho-Xylene	µg/L	2					<2						<2
Total Xylenes	µg/L	2					<2						<2
Sum of BTEX	µg/L	1					<1						<1
Naphthalene	µg/L	5					<5						<5
Total petroleum hydrocarbons													
C6 - C9 Fraction	µg/L	20					<20						<20
C10 - C14 Fraction	µg/L	50					<50						<50
C15 - C28 Fraction	µg/L	100					<100						<100
C29 - C36 Fraction	µg/L	50					<50						<50
C10 - C36 Fraction (sum)	µg/L	50					<50						<50
Total Recoverable Hydrocarbons													
C6 - C10 Fraction	µg/L	20					<20						<20
C6 - C10 Fraction minus BTEX (F1)	µg/L	20					<20						<20
>C10 - C16 Fraction	µg/L	100					<100						<100
>C16 - C34 Fraction	µg/L	100					<100						<100
>C34 - C40 Fraction	µg/L	100					<100						<100
>C10 - C40 Fraction (sum)	µg/L	100					<100						<100
>C10 - C16 Fraction minus Naphthalene	µg/L	100					<100						<100
Microbiology													
Faecal coliforms	CFU/100 m	1					<2						<2
E coli	CFU/100 m	1					<2						<2
Total coliforms	CFU/100 m	1					~<2						<2

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0018PZB										HU0019PZB						HU0023PZB				HU0023PZC			
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	17/10/2011	7/01/2013	22/03/2013	9/07/2013	16/10/2013	12/12/2013	8/04/2014	25/03/2015	2/07/2015	24/09/2015	18/10/2011	29/08/2012	4/01/2013	17/12/2013	9/04/2014	4/02/2015	16/11/2011	18/12/2012	25/03/2013	21/05/2014	15/11/2011	18/12/2012	25/03/2013	21/05/2014
General field parameters																														
pH	pH units		6.5-7.5				6.04	5.79	5.84	5.86	5.93	6.08	5.78	6.08	5.82	5.86	6.89	6.23	7.29	6.59	5.29	6.29	6.2	6.21	6.04	6.33	6.1	5.77	5.9	6.08
Conductivity (field)	µS/cm		30-350	0-650 (v. low) >650-1300 (low) >1300-2900 (medium) >2900-5200 (high) >5200-8100 (v. high) >8100 (extreme)			333	254		251	261	245	237	221	228.5	230	390	490	287	364	227	254	281	241	259	260	302	219	246	248
Conductivity (lab)	µS/cm	1	30-350												224															
Total Dissolved Solids (field)	mg/L					<600 (good quality) 600-900 (fair quality) >900-1200 (poor quality) >1200 (unacceptable)	260	165	174	163	169	159	154	171	148.2	149	254	305	188	236	148	165	183	156.000	168.000	169.000	196	142.000	160.000	161.000
Total Dissolved Solids (lab)	mg/L	10													114	137														
Dissolved oxygen	% sat		90-110				18.3	3	5.3	9.8	14.4	27.2	8.8	10.5	16.4	10.4	118.1	18.3	25	34.4	57.4	61.7	16.7	15.2	13.1	81.8	23.9	13.2	20.6	29.1
Redox	mV						-0.9	-70.9	-23.2	10	-9.7	-18.3	-33	-42.1	-21.4	-106.2	-55.6	-107.9	-62.3	10.9	165	130.8	-110.9	-67.3	-23.1	-61.5	-9.2	-54.5	-27.2	-151.9
Temperature	°C						19.6	18.1	18.75	16.6	17.58	17.9	17.6	16.7	14	14.07	19.76	13.94	19.86	18.22	15.40	17.30	15.48	22.45	20.87	18.61	26.07	29.64	20.29	19.25
Suspended Solids (lab)	mg/L	5													<5	24														
Turbidity	NTU	0.1	2-25													8.3														
Major ions																														
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	59	59	45	46	57	56	50	69	49	44	95	28	30	78	10	24	70	71	69	63	60	60	66	67
Total Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	59	59	45	46	57	56	50	69	49	44	95	28	30	78	10	24	70	71	69	63	60	60	66	67
Acidity as $CaCO_3$	mg/L	1	-	-	-	-									103												3	4	4	2
Sulfate as SO_4^{2-}	mg/L	1	-	-	1000	500	51	6	6	5	5	5	5	4	4	4	32	7	1	2	2	2	11	5	5	3	38	22	28	28
Chloride	mg/L	1	-	700	-	ID	52	38	38	37	47	40	37	46	36	39	58	57	53	59	56	61	28	25	30	30	6	5	5	4
Calcium	mg/L	1	-	-	1000	-	13	5	4	4	4	3	3	5	3	3	27	10	9	20	6	8	11	8	6	4	11	10	10	9
Magnesium	mg/L	1	-	-	ID	-	4	5	4	5	5	4	5	5	5	6	2	2	2	3	2	2	11	12	11	9	25	18	16	20
Sodium	mg/L	1	-	460	-	-	65	26	21	28	26	26	26	30	20	24	63	34	35	41	33	36	24	22	17	24	1	<1	<1	<1
Potassium	mg/L	1	-	-	-	-	2	1	1	2	1	1	1	<1	<1	<1	1	2	2	1	1	<1	<1	1	<1	<1	9.7	9.4	8.9	9.5
Silica/Silicon as SiO_2/Reactive silica	mg/L	0.1	-	-	-	-	10.6	10.0	10.2	11	11.7	10.7	11.6	9.5	10.2	9.8	11.3	9.2	9.1	9.21	8.8	8.2	10.1	10.0	9.0	9.4				<0.1
Total Anions	meq/L	0.01	-	-	-	-	3.71	2.38	2.10	2.07	2.57	2.35	2.46	2.76	2.08	2.06	4.2	2.31	2.12	3.26	1.82	2.24	2.42	2.23	2.33	2.17	2.33	1.90	2.19	2.17
Total Cations	meq/L	0.01	-	-	-	-	3.86	2.51	2.28	1.88	2.46	2.29	2.58	2.69	1.43	1.69	4.28	2.19	2.19	3.14	1.92	2.13	2.50	2.37	2.40	2.36	2.32	1.86	2.27	2.27
Ionic Balance	%	0.01	-	-	-	-	1.94										0.9	-	-	1.97			-	-	-		-	-	-	
Other Inorganics																														
Flouride	mg/L	0.1	-	2	2	1.5						<0.1			<0.1	<0.1				<0.1						<0.1				
Free cyanide	mg/L	0.004	0.007	-	-	0.08						<0.004								<0.004										
Total cyanide	mg/L	0.004	-	-	-	-						<0.004								<0.004										
Thiocyanate	mg/L	0.1	-	-	-	-						<0.1								<0.1										
Dissolved metals																														
Aluminium	mg/L	0.01	0.055	20	5	ID						0.06	0.07	0.34	<0.01	<0.01				0.23	<0.01	0.02				0.41				0.03
Antimony	mg/L	0.001	ID	-	-	0.003						<0.001	<0.001	<0.001	<0.001	<0.001				0.002	<0.001	<0.001				<0.001				<0.001
Arsenic	mg/L	0.001	0.013	2	0.5	0.01						0.006	0.006	0.008	0.004	0.005				0.001	<0.001	<0.001				0.001				<0.001
Beryllium	mg/L	0.001	ID	0.5	ID	0.06						<0.001				<0.001				<0.001						<0.001				<0.001
Barium	mg/L	0.001	-	-	-	2						0.051			0.03	0.03				0.129						0.037				0.029
Cadmium	mg/L	0.0001	0.0002	0.05	0.01	0.002						<0.0001	<0.0001	0.0002	<0.0001	<0.0001				<0.0001	<0.0001	<0.0001				<0.0001				<0.0001
Chromium	mg/L	0.001	0.001	1	1	0.05						<0.001	<0.001	<0.001	<0.001	<0.001				0.008	<0.001	<0.001				<0.001				<0.001
Cobalt	mg/L	0.001	ID	0.1	1	-						0.016	0.021	0.016	0.02	0.017				0.017	0.006	0.006				0.002				0.002
Copper	mg/L	0.001	0.0014	5	1#	2						<0.001	<0.001	<0.001	<0.001	<0.001				0.257	0.095	0.084				0.002				<0.001
Lead	mg/L	0.001	0.0034	5	0.1	0.01						<0.001	<0.001	0.003	<0.001	<0.001				0.0033	0.006	0.002				0.001				<0.001
Lithium	mg/L	0.001	-	2.5	-	-						0.012				0.011				0.005						0.012				0.016
Manganese	mg/L	0.001	1.9	10	-	0.5	0.782	0.772	0.895	0.806	0.8	0.828	0.926	0.884	0.849	0.863	0.22	0.257	0.412	0.474	0.182	0.179	0.559	0.537	0.539	0.5	0.569	0.549	0.560	0.532
Molybdenum	mg/L	0.001	ID	0.05	0.15	0.05						0.009	0.005	0.003	0.003	0.004				0.001	<0.001	<0.001				0.011				0.001
Nickel	mg/L	0.001	0.011	2	1	0.02						0.026	0.032	0.026	0.03	0.025				0.023	0.02	0.01				0.014				0.011
Selenium	mg/L	0.01	0.005	0.05	0.02	0.01						<0.01	<0.01	<0.01	<0.01	<0.01				<0.01	<0.01	<0.01				<0.01				<0.01
Strontium	mg/L	0.001	-	-	-	-						0.055			0.036	0.036				0.192						0.055				0.046
Tin	mg/L	0.001	ID	-	-	-						<0.001				<0.001				0.001						<0.001				<0.001
Uranium	mg/L	0.001	ID	0.1	0.2	0.017						<0.001				<0.001				<0.001						<0.001				<0.001
Vanadium	mg/L	0.01	ID	0.5	ID	-						<0.01				<0.01				<0.01						<0.01				<0.01
Zinc	mg/L	0.005	0.008	5	20	ID						0.056	0.054	0.271	0.052	0.056				0.186	0.071	0.018				0.077				0.067
Boron	mg/L	0.05	0.37	5	5	4						<0.05	<0.05	<0.05	<0.05	<0.05				<0.05	<0.05	<0.05				<0.05				<0.05
Iron	mg/L	0.05	ID	10	ID	ID	6.92	12.8	13.70	15.2	12.8	12.2	15.9	13.3	13.7	13.2	0.15	<0.05	0.87	0.44	0.12	<0.05	7.78	8.92	8.54	7.4	9.67	9.48	9.37	8.12
Ferrous iron	mg/L	0.05	-	-	-	ID									15	14.2														
Bromine	mg/L	0.1	-	-	-	-						0.2				<0.1				0.1						0.1				<0.1
Iodine	mg/L	0.1	-	-	-	ID						<0.1				<0.1				<0.1						<0.1				<0.1
Mercury	mg/L	0.0001	0.00006	0.002	0.002	0.001						<0.0001								<0.0001										
Total metals																														
Aluminium	mg/L	0.01	-	-	-	-						0.29				0.25				0.85										
Manganese	mg/L	0.001	-	-	-	-						0.957			0.882	0.895				0.508										
Iron	mg/L	0.05	-	-	-	-						13.5			14.3	14.5				0.58										
Nutrients																														
Ammonia as N	mg/L	0.01	2.57									0.01				0.01				0.09										
Nitrite as N	mg/L	0.01			9							<0.01				<0.01				<0.01										
Nitrate as N	mg/L	0.01			90							0.02				<0.01				0.04										
Nitrite + Nitrate as N	mg/L	0.01																												
Total phosphorous	mg/L	0.01										0.03								0.15										
Reactive phosphorous	mg/L	0.01										<0.01				<0.01				<0.01										
Biochemical oxygen demand	mg/L	2														<2														
Isotopes																														
Oxygen-18	‰	0.01					-7.05										-6.53						-5.99				-6.41			
Deuterium	‰	0.1					-42.7										-43.4						-38.6				-39.1			
Carbon-13	‰	0.1					-16.6										-16.5						-12.3				-11.6			
Radiocarbon	pMC	0.1					44.18±0.14										66.0±0.17						30.55±0.11				33.26±0.11			
Radiocarbon Age (uncorrected)	yrs BP	1					6503±25										3279±20						9465±30				8783±25			
Tritium	TU	0.01					0.02±0.02^										0.14±0.03^						0.06±0.03^				0.01±0.03^			

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0032LDB				HU0037PZB				HU0038PZC								HU0042PZC					HU0043PZB			
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	12/12/2013	3/04/2014	26/03/2015	24/09/2015	29/08/2012	20/12/2012	18/12/2013	3/02/2015	24/07/2012	14/12/2012	11/12/2013	2/04/2014	15/08/2014	2/12/2014	12/02/2015	15/09/2015	26/03/2013	3/07/2013	19/08/2013	17/12/2013	2/02/2015	31/08/2012	3/01/2013	18/12/2013	5/02/2015
General field parameters																															
pH	pH units		6.5-7.5				5.95	5.69	5.80	5.86	5.21	4.05	5.38	5.23	5.21	5.13	5.07	4.88		5.30	5.00	5.06	6.08	6.25	6.31	6.57	5.3	5.67	4.91	5.52	5.03
Conductivity (field)	µS/cm		30-350	0-650 (v. low) >650-1300 (low) >1300-2900 (medium) >2900-5200 (high) >5200-8100 (v. high) >8100 (extreme)			112	113	110	115	124	108	115	125	44	46	43	42.8		51	41	45	575	503	481	471	401	64	66	79	63
Conductivity (lab)	µS/cm	1	30-350					113		91								42				36									
Total Dissolved Solids (field)	mg/L					<600 (good quality) 600-900 (fair quality) >900-1200 (poor quality) >1200 (unacceptable)	72	73	71	74	81	70.000	74.000	81.000	28.600	31.000	28.000	30.000		34	27	29	374	327	313	306	260	42	43	51	41
Total Dissolved Solids (lab)	mg/L	10						60		46								24			30	32									
Dissolved oxygen	% sat		90-110				24.5	8.3	29.8	14.5	41.3	49.3	72.2	63.7	50.0	49.3	68.2	60.0		54.0	65.2	71.4	22.1	34	29.5	43.4	38.6	34.4	86.3	68.2	89.2
Redox	mV						-18.0	0.8	-97.1	-91.8	85.1	5.3	183.8	186.7	120.8	68.9	191.2	230.9		136.7	161.3	-58.3	25.1	-30.7	-54.4	-37.2	50.7	115	135.5	75.5	163.9
Temperature	°C						18.01	18.6	16.7	14.55	15.16	33.10	17.09	21.48	16.00	19.37	17.33	18.40		22.15	18.50	19.87	18.06	13.3	16.04	19.02	17.32	12.37	32.54	24.54	22.62
Suspended Solids (lab)	mg/L	5																													
Turbidity	NTU	0.1	2-25																												
Major ions																															
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	31	23	27	30	9	7	8	11	18	5	4	4	4	7	6	5	126	96	91	81	75	4	2	10	5
Total Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	31	23	27	30	9	7	8	11	18	5	4	4	4	7	6	5	126	96	91	81	75	4	2	10	5
Acidity as $CaCO_3$	mg/L	1	-	-	-	-	5	4	4	4	<1	<1	1	<1	<1	1	1	<1	<1	1	<1	<1	24	16	13	12	6	2	2	2	2
Sulfate as SO_4^{2-}	mg/L	1	-	-	1000	500	11	10	24	11	25	27	30	38	5	7	6	6	8	20	6	8	79	82	87	81	79	14	14	13	25
Chloride	mg/L	1	-	700	-	ID	1	1	2	1	4	2	1	3	1	<1	<1	<1	<1	1	<1	<1	18	19	13	11	12	<1	<1	3	<1
Calcium	mg/L	1	-	-	1000	-	2	2	2	2	3	3	2	3	<1	<1	<1	<1	<1	1	<1	<1	18	18	18	15	14	<1	<1	<1	<1
Magnesium	mg/L	1	-	-	ID	-	8	10	9	9	13	14	16	16	7	6	5	6	6	6	6	6	44	2	50	41	34	8	9	10	10
Sodium	mg/L	1	-	460	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	28	43	2	<1	2	<1	<1	<1	<1
Potassium	mg/L	1	-	-	-	-	9.14	8.9	8.3	8.6	9.4	8.9	8.46	8	8.4	7.4	7.76	7.8	8.3	7.6	7.67	7	9.1	9.3	9.5	9.7	8.4	7.7	7.7	-	6.7
Silica/Silicon as SiO_2/Reactive silica	mg/L	0.1	-	-	-	-	<0.1	<0.1					<0.1				<0.1	<0.1			<0.1					<0.1					
Total Anions	meq/L	0.01	-	-	-	-	1.03	0.82	1.3	0.99	0.89	0.90	1.03	1.29	0.5	0.32	0.27	0.25	0.31	0.72	0.29	0.32	5.25		4.54	4.15	3.85	0.52	0.48	0.61	0.85
Total Cations	meq/L	0.01	-	-	-	-	1.09	0.65	1.16	0.6	1.01	0.96	0.91	1.09	0.35	0.26	0.22	0.26	0.26	0.39	0.26	0.26	5.13		4.59	4.09	3.58	0.35	0.39	0.58	0.43
Ionic Balance	%	0.01	-	-	-	-					6.32	3.23	6.19		17.65	10.34	10.20	1.96					1.13		0.52	0.75	3.72	-	-	-	
Other Inorganics																															
Flouride	mg/L	0.1	-	2	2	1.5	<0.004						<0.004				<0.004				<0.004					<0.004					
Free cyanide	mg/L	0.004	0.007	-	-	0.08	<0.004						<0.004				<0.004				<0.004					<0.004					
Total cyanide	mg/L	0.004	-	-	-	-	<0.1						<0.1				<0.1				<0.1					<0.1					
Thiocyanate	mg/L	0.1	-	-	-	-																									
Dissolved metals																															
Aluminium	mg/L	0.01	0.055	20	5	ID	0.05	<0.01	0.08	<0.01			0.03	0.01			0.02	0.02	<0.01	0.03	<0.01	<0.01				<0.01	<0.01				0.01
Antimony	mg/L	0.001	ID	-	-	0.003	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				<0.001	<0.001				<0.001
Arsenic	mg/L	0.001	0.013	2	0.5	0.01	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				<0.001	<0.001				<0.001
Beryllium	mg/L	0.001	ID	0.5	ID	0.06	<0.001						<0.001				<0.001				<0.001					<0.001					
Barium	mg/L	0.001	-	-	-	2	0.046						0.015				0.016				0.003					0.073					
Cadmium	mg/L	0.0001	0.0002	0.05	0.01	0.002	<0.0001	<0.0001	<0.0001	<0.0001			<0.0001	<0.0001			<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001				<0.0001	<0.0001				<0.0001
Chromium	mg/L	0.001	0.001	1	1	0.05	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				<0.001	<0.001				<0.001
Cobalt	mg/L	0.001	ID	0.1	1	-	0.009	0.01	0.01	0.009			<0.001	<0.001			<0.001	<0.001	<0.001	0.001	<0.001	<0.001				<0.001	<0.001				<0.001
Copper	mg/L	0.001	0.0014	5	1#	2	<0.001	<0.001	<0.001	<0.001			0.002	0.005			0.008	0.026	0.007	0.02	0.01	<0.001				0.002	<0.001				0.011
Lead	mg/L	0.001	0.0034	5	0.1	0.01	<0.001	<0.001	0.002	<0.001			<0.001	<0.001			0.002	0.001	<0.001	<0.001	<0.001	<0.001				<0.001	<0.001				<0.001
Lithium	mg/L	0.001	-	2.5	-	-	0.004						0.003				0.001	-			<0.001					0.018					
Manganese	mg/L	0.001	1.9	10	-	0.5	0.634	0.647	0.526	0.563	0.032	0.019	0.015	0.017	0.080	0.076	0.037	0.036	0.028	0.062	0.041	0.029	0.740	0.654	0.689	0.647	0.436	0.075	0.056	0.030	0.034
Molybdenum	mg/L	0.001	ID	0.05	0.15	0.05	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				<0.001	<0.001				<0.001
Nickel	mg/L	0.001	0.011	2	1	0.02	0.009	0.01	0.014	0.01			0.022	0.022			0.001	0.001	0.002	0.002	0.001	0.001				0.005	0.007				0.004
Selenium	mg/L	0.01	0.005	0.05	0.02	0.01	<0.01	<0.01	<0.01	<0.01			<0.01	<0.01			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				<0.01	<0.01				<0.01
Strontium	mg/L	0.001	-	-	-	-	0.018						0.028				0.012				0.004					0.195					
Tin	mg/L	0.001	ID	-	-	-	<0.001						<0.001				<0.001				<0.001					<0.001					
Uranium	mg/L	0.001	ID	0.1	0.2	0.017	<0.001						<0.001				<0.001				<0.001					<0.001					
Vanadium	mg/L	0.01	ID	0.5	ID	-	<0.01						<0.01				<0.01				<0.01					<0.01					
Zinc	mg/L	0.005	0.008	5	20	ID	0.205	0.03	0.074	0.027			0.162	0.224			0.071	0.014	0.022	0.012	0.011	<0.005				0.144	0.079				0.226
Boron	mg/L	0.05	0.37	5	5	4	<0.05	<0.05	<0.05	<0.05			<0.05	<0.05			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05				<0.05	<0.05				<0.05
Iron	mg/L	0.05	ID	10	ID	ID	9.83	11.2	9.36	10.5	<0.05	0.14	0.05	<0.05	0.06	0.08	<0.05	<0.05	<0.05	0.07	<0.05	<0.05	2.25	8.50	12.20	9.79	5.51	0.40	0.34	0.08	0.1
Ferrous iron	mg/L	0.05	-	-	-	ID				11.0																					
Bromine	mg/L	0.1	-	-	-	-	0.3						<0.1				<0.1				<0.1					0.2					
Iodine	mg/L	0.1	-	-	-	ID	<0.1						<0.1				<0.1				<0.1					<0.1					
Mercury	mg/L	0.0001	0.00006	0.002	0.002	0.001	<0.0001						<0.0001				<0.0001				<0.0001					<0.0001					
Total metals																															
Aluminium	mg/L	0.01	-	-	-	-	0.28						0.22				0.01				<0.01					0.02					
Manganese	mg/L	0.001	-	-	-	-	0.665			0.574			0.016				0.043				0.042	0.027				0.717					
Iron	mg/L	0.05	-	-	-	-	11.7			11.5			0.14				<0.05				<0.05	<0.05				11.6					
Nutrients																															
Ammonia as N	mg/L	0.01	2.57				<0.01						0.78				0.03				0.1					<0.01					
Nitrite as N	mg/L	0.01			9		<0.01	<0.01					<0.01				<0.01	<0.01			<0.01					<0.01					
Nitrate as N	mg/L	0.01			90		0.01	0.02					0.25				0.08	0.08			0.08					0.02					
Nitrite + Nitrate as N	mg/L	0.01																													
Total phosphorous	mg/L	0.01					0.03						0.02				<0.01	-			<0.01					<0.01					
Reactive phosphorous	mg/L	0.01					<0.01	<0.01					<0.01				<0.01	<0.01			<0.01					<0.01					
Biochemical oxygen demand	mg/L	2																													
Isotopes																															
Oxygen-18	‰	0.01					-7.32																								
Deuterium	‰	0.1					-43.38																								
Carbon-13	‰	0.1																													
Radiocarbon	pMC	0.1																													
Radiocarbon Age (uncorrected)	yrs BP	1																													
Tritium	TU	0.01					<0.05±0.08																								

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0044XPZB									HU0056XPZB					HU0072PZB									
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	23/08/2012	14/12/2012	26/03/2013	2/07/2013	18/09/2013	10/12/2013	25/03/2014	24/07/2014	3/02/2015	19/12/2012	19/12/2013	25/09/2014	13/11/2014	5/02/2015	21/03/2013	8/07/2013	18/09/2013	11/12/2013	26/03/2014	14/08/2014	2/12/2014	25/03/2015	26/06/2015	17/09/2015
General field parameters																														
pH	pH units		6.5-7.5				4.22	4.41	4.73	4.99	5.36	5.08	5.22	4.94	5.37	5.94	6.06	5.64	5.41	7.95	6.23	6.29	6.49	6.7	6.3	6.39	6.35	6.41	6.41	6.36
Conductivity (field)	µS/cm		30-350	0-650 (v. low) >650-1300 (low) >1300-2900 (medium) >2900-5200 (high) >5200-8100 (v. high) >8100 (extreme)			83	81	72	55.9	79	66	61	63	60	114	128	118	131.9	161	510	628	635	626	630	634	652	650	626	637
Conductivity (lab)	µS/cm	1	30-350										59												632				650	614
Total Dissolved Solids (field)	mg/L					<600 (good quality) 600-900 (fair quality) >900-1200 (poor quality) >1200 (unacceptable)	54	53	46	30	52	43	39	41	39	74	83	76	71	105	425	409	413	407	410	412	424	422	410	414
Total Dissolved Solids (lab)	mg/L	10											46												364				357	312
Dissolved oxygen	% sat		90-110				31.5	3.16	32.8	-	68.2	76.4	52.7	63.7	72.5	10.6	34.6	26.7	17.5	33.5	1.5	18.0	10.7	29.3	8.3	14.0	18.4	13.8	10.7	5.7
Redox	mV						180.3	30.1	91.3	109	138.6	182.9	183.2	192.3	221.8	37.8	126.5	77.8	56	-74.9	-100.8	-64.8	-107.9	-101.9	-48	-4.9	-36.1	-54.0	-58.2	-95.0
Temperature	°C						12.77	17.6	18.35	13.80	15.02	17.47	19.25	13.34	19.72	20.64	19.54	16.96	24.5	16.48	19.15	16.8	16.28	17.14	17.59	16.88	24.43	17.3	15.6	14.84
Suspended Solids (lab)	mg/L	5																											<5	<5
Turbidity	NTU	0.1	2-25																											
Major ions																														
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	3.0	2	2	4	8	2	3	2	2	24	32	21	21	27	110	104	103	104	108	100	114	114	107	106
Total Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	3.0	2	2	4	8	2	3	2	2	24	32	21	21	27	110	104	103	104	108	100	114	114	107	106
Acidity as $CaCO_3$	mg/L	1	-	-	-	-	3	2	<1	<1	<1	<1	<1	<1	<1	9	8	8	7	6									36	
Sulfate as SO_4^{2-}	mg/L	1	-	-	1000	500	18	14	14	21	21	13	10	13	25	18	20	16	17	30	12	5	5	7	5	7	6	6	6	7
Chloride	mg/L	1	-	700	-	ID	1	<1	<1	1	3	<1	<1	<1	<1	4	3	2	3	6	125	133	135	126	131	132	127	133	127	126
Calcium	mg/L	1	-	-	1000	-	2	<1	<1	<1	<1	<1	<1	<1	<1	4	2	3	4	5	37	30	30	29	25	29	32	33	33	33
Magnesium	mg/L	1	-	-	ID	-	11	12	11	<1	11	8	8	10	9	11	14	10	17	11	27	28	28	26	28	28	27	29	30	28
Sodium	mg/L	1	-	460	-	-	<1	<1	<1	8	<1	<1	<1	<1	<1	1	5	2	2	4	33	44	44	39	42	39	37	42	43	38
Potassium	mg/L	1	-	-	-	-	5.8	5.7	6.0	5.5	5.7		6.40	5.7	5.4	11.0		9.8	9.2	14.2	3	4	4	3	3	3	3	3	3	3
Silica/Silicon as SiO_2/Reactive silica	mg/L	0.1	-	-	-	-							<0.1				<0.1				8.5	8.9	8.4	8.5	8.6	9.4	8.3	8	8.4	8.2
Total Anions	meq/L	0.01	-	-	-	-	0.63	0.48	0.43		0.75	0.41	0.34	0.41	0.75	1.17	1.37	1.04	1.04	1.51	5.97	5.93	5.97	5.78	5.96	5.870	5.990	6.15	5.84	5.82
Total Cations	meq/L	0.01	-	-	-	-	0.69	0.52	0.48		0.63	0.35	0.35	0.43	0.39	1.03	1.05	0.83	1.27	1.29	5.89	5.82	5.82	5.56	5.71	5.800	5.760	6.19	6.06	5.68
Ionic Balance	%	0.01	-	-	-	-															0.75	0.98	1.29	1.94	2.15	0.560	1.950	0.26	1.83	1.19
Other Inorganics																														
Flouride	mg/L	0.1	-	2	2	1.5																		0.1	0.1				0.1	
Free cyanide	mg/L	0.004	0.007	-	-	0.08																		<0.004						
Total cyanide	mg/L	0.004	-	-	-	-																		<0.004						
Thiocyanate	mg/L	0.1	-	-	-	-																		<0.1						
Dissolved metals																														
Aluminium	mg/L	0.01	0.055	20	5	ID							0.02	0.02	0.02			<0.01	0.06	0.08				<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01
Antimony	mg/L	0.001	ID	-	-	0.003							<0.001	<0.001	<0.001			<0.001	<0.001	<0.001				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic	mg/L	0.001	0.013	2	0.5	0.01							<0.001	<0.001	<0.001			<0.001	<0.001	0.002				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Beryllium	mg/L	0.001	ID	0.5	ID	0.06							<0.001											<0.001	<0.001					
Barium	mg/L	0.001	-	-	-	2							0.013											0.215	0.177				0.18	
Cadmium	mg/L	0.0001	0.0002	0.05	0.01	0.002							<0.0001	<0.0001	<0.0001			<0.0001	<0.0001	<0.0001				<0.0001	<0.0001	<0.0001	<0.0001	0.0004	<0.0001	<0.0001
Chromium	mg/L	0.001	0.001	1	1	0.05							<0.001	<0.001	<0.001			<0.001	<0.001	0.001				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cobalt	mg/L	0.001	ID	0.1	1	-							<0.001	<0.001	<0.001			0.002	0.001	0.002				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper	mg/L	0.001	0.0014	5	1#	2							0.012	0.004	0.006			0.005	0.001	0.013				<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001
Lead	mg/L	0.001	0.0034	5	0.1	0.01							0.002	<0.001	0.001			<0.001	<0.001	<0.001				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lithium	mg/L	0.001	-	2.5	-	-																		0.042						
Manganese	mg/L	0.001	1.9	10	-	0.5	0.027	0.020	0.009	0.006	0.009	0.080	0.026	0.013	0.009	0.152	0.042	0.201	0.175	0.168	0.318	0.287	0.273	0.323	0.27	0.278	0.294	0.242	0.262	0.253
Molybdenum	mg/L	0.001	ID	0.05	0.15	0.05							<0.001	<0.001	<0.001			<0.001	<0.001	<0.001				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel	mg/L	0.001	0.011	2	1	0.02							<0.001	0.014	<0.001			0.004	0.004	0.006				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Selenium	mg/L	0.01	0.005	0.05	0.02	0.01							<0.01	<0.01	<0.01			<0.01	<0.01	<0.01				<0.01	<0.01	0.110	<0.01	<0.01	<0.01	<0.01
Strontium	mg/L	0.001	-	-	-	-							0.004											0.169	0.144				0.132	
Tin	mg/L	0.001	ID	-	-	-																		<0.001						
Uranium	mg/L	0.001	ID	0.1	0.2	0.017							<0.001											<0.001	<0.001					
Vanadium	mg/L	0.01	ID	0.5	ID	-							<0.01											<0.01	<0.01					
Zinc	mg/L	0.005	0.008	5	20	ID							0.096	0.143	0.019			0.012	0.014	0.02				0.008	0.041	<0.005	0.010	0.064	<0.005	<0.005
Boron	mg/L	0.05	0.37	5	5	4							<0.05	<0.05	<0.05			<0.05	<0.05	<0.05				<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Iron	mg/L	0.05	ID	10	ID	ID	<0.05	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.56	<0.05	1.36	1.94	5.17	5.72	5.6	5.18	4.2	4.71	5.180	4.730	4.89	4.94	4.94
Ferrous iron	mg/L	0.05	-	-	-	ID																							5.59	5.35
Bromine	mg/L	0.1	-	-	-	-							<0.1											0.4	0.4					
Iodine	mg/L	0.1	-	-	-	ID																		<0.1						
Mercury	mg/L	0.0001	0.00006	0.002	0.002	0.001																		<0.0001						
Total metals																														
Aluminium	mg/L	0.01	-	-	-	-																		0.02						
Manganese	mg/L	0.001	-	-	-	-																		0.309					0.275	0.269
Iron	mg/L	0.05	-	-	-	-																		6.71					5.48	5.45
Nutrients																														
Ammonia as N	mg/L	0.01	2.57																					0.1						
Nitrite as N	mg/L	0.01			9								<0.01											<0.01	<0.01					
Nitrate as N	mg/L	0.01			90								0.77											0.02	0.05					
Nitrite + Nitrate as N	mg/L	0.01																												
Total phosphorous	mg/L	0.01																						0.02						
Reactive phosphorous	mg/L	0.01											<0.01											<0.01	<0.01					
Biochemical oxygen demand	mg/L	2																												
Isotopes																														
Oxygen-18	‰	0.01																												
Deuterium	‰	0.1																												
Carbon-13	‰	0.1																												
Radiocarbon	pMC	0.1																												
Radiocarbon Age (uncorrected)	yrs BP	1																												
Tritium	TU	0.01																												

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0072PZC										HU0073PZC									HU0088PZB				
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	21/03/2013	8/07/2013	18/09/2013	11/12/2013	26/03/2014	14/08/2014	2/12/2014	25/03/2015	26/06/2015	15/09/2015	27/03/2013	7/08/2013	15/10/2013	10/12/2013	3/04/2014	5/12/2014	26/03/2015	29/06/2015	21/09/2015	10/12/2013	2/04/2014	26/09/2014	3/12/2014	11/02/2015
General field parameters																														
pH	pH units		6.5-7.5				6.17	6.16	6.36	6.4	6.08	6.29	6.36	6.29	6.31	6.39	5.81	6.06	6.22	6.00	6.10	6.36	6.19	6.11	6.01	6.40	6.40	6.46	6.49	6.43
Conductivity (field)	µS/cm		30-350	0-650 (v. low) >650-1300 (low) >1300-2900 (medium) >2900-5200 (high) >5200-8100 (v. high) >8100 (extreme)			923	877	910	944	970	851	613	602	843	831	252	207	231	221	218	211	214.2	210.6	209	424	418	416	380	402
Conductivity (lab)	µS/cm	1	30-350								981				880	814					203			198			440			
Total Dissolved Solids (field)	mg/L					<600 (good quality) 600-900 (fair quality) >900-1200 (poor quality) >1200 (unacceptable)	600	572	592	614	630	553	398	390	546	540	163	118	150	142	143	137	139	137	136	275	268	270	247	231
Total Dissolved Solids (lab)	mg/L	10									598				498	492					111		112	101	113		169			172
Dissolved oxygen	% sat		90-110				5.5	14.4	8.5	11	9.1	7.1	14.50	25.4	7.2	20.6	3.3	24.6	22.3	27	11.7	15.5	12.3	17	11.6	17.0	14.1	21.2	14.2	23.7
Redox	mV						-85.9	-41.0	8.1	-16.0	-33.5	2.1	-33.4	-24.4	7.3	-142.4	-36.3	30	-35.8	-34.1	-50	-44.2	-124.6	-68.5	-109.2	-22.3	-17.2	-43.7	-47.0	-25.8
Temperature	°C						17.72	16.5	15.62	16.38	16.81	16.05	21.54	17.6	14.9	13.33	19.2	20.2	18.21	18.52	18.7	19.26	18.5	15.5	16.9	19.32	19.00	19.07	21.82	23.50
Suspended Solids (lab)	mg/L	5													<5	<5								<5	<5					
Turbidity	NTU	0.1	2-25																											
Major ions																														
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	134	120	128	133	136	115	109	110	126	121	46	68	62	52	41	57	54	58	28	130	110	136	119	125
Total Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	134	120	128	133	136	115	109	110	126	121	46	68	62	52	41	57	54	58	28	130	110	136	119	125
Acidity as $CaCO_3$	mg/L	1	-	-	-	-									46									64						
Sulfate as SO_4^{2-}	mg/L	1	-	-	1000	500	24	20	21	25	26	22	7	6	20	17	8	6	4	6	6	8	5	5	8	4	2	<1	2	1
Chloride	mg/L	1	-	700	-	ID	198	192	203	198	216	191	120	122	169	170	41	33	36	28	32	24	36	26	29	51	53	54	44	52
Calcium	mg/L	1	-	-	1000	-	39	33	35	34	38	33	27	30	36	31	6	4	4	4	4	4	7	4	3	19	19	20	21	19
Magnesium	mg/L	1	-	-	ID	-	38	38	39	38	44	36	26	28	39	34	6	5	5	5	4	5	5	5	5	15	16	17	14	15
Sodium	mg/L	1	-	460	-	-	67	74	82	86	80	61	36	38	68	63	18	19	18	19	23	20	19	17	20	35	37	37	25	32
Potassium	mg/L	1	-	-	-	-	4	4	4	4	4	3	3	3	3	3	<1	<1	<1	<1	<1	<1	<1	<1	<1	4	5	6	10	7
Silica/Silicon as SiO_2/Reactive silica	mg/L	0.1	-	-	-	-	9.0	8.6	8.5	8.6	8.8	9.1	8.2	7.6	8.4	8.7	8.4	9.1	10.4	9.6	9.3	8.7	9.52	9.3	9.18	7.2	8.2	8.3	8.1	8.35
Total Anions	meq/L	0.01	-	-	-	-	8.76	8.23	8.72	8.76	9.35	8.14	5.71	5.76	7.70	7.57	2.24	2.41	2.34	1.95	1.85	1.98	2.2	2		4.12	3.95	4.24	3.66	3.99
Total Cations	meq/L	0.01	-	-	-	-	8.52	8.1	8.63	9.03	9.10	7.74	5.43	5.85	8.04	7.16	2.31	2.52	2.37	1.96	1.53	1.48	2.37	1.35		3.98	4.00	4.16	3.54	3.88
Ionic Balance	%	0.01	-	-	-	-	1.40	0.83	0.55	1.5	1.37	2.49	2.53	0.70	2.16	2.75	-	-	-	-			-	-		1.78	0.61	0.97	1.63	1.35
Other Inorganics																														
Flouride	mg/L	0.1	-	2	2	1.5				<0.1	0.1				0.1					<0.1	<0.1		<0.1	0.1	<0.1	0.1	0.1			<0.1
Free cyanide	mg/L	0.004	0.007	-	-	0.08				<0.004										<0.004			<0.004			<0.004				<0.004
Total cyanide	mg/L	0.004	-	-	-	-				<0.004										<0.004			<0.004			0.004				<0.004
Thiocyanate	mg/L	0.1	-	-	-	-				<0.1										<0.1			<0.1			<0.1				<0.1
Dissolved metals																														
Aluminium	mg/L	0.01	0.055	20	5	ID				0.02	0.02	<0.01	<0.01	<0.01	<0.01	<0.01				<0.01	<0.01	0.01	0.01	<0.01	<0.01	0.02	<0.01	0.02	0.05	<0.01
Antimony	mg/L	0.001	ID	-	-	0.003				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic	mg/L	0.001	0.013	2	0.5	0.01				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				0.002	0.002	0.001	0.002	0.002	0.001	0.009	0.026	0.04	0.02	0.029
Beryllium	mg/L	0.001	ID	0.5	ID	0.06				<0.001	<0.001									<0.001			<0.001		<0.001	<0.001				<0.001
Barium	mg/L	0.001	-	-	-	2				0.297	0.311				0.255					0.028			0.042	0.021	0.02	0.336				0.261
Cadmium	mg/L	0.0001	0.0002	0.05	0.01	0.002				<0.0001	<0.0001	<0.0001	<0.0001	0.0004	<0.0001	<0.0001				<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	0.00	<0.0001	<0.0001
Chromium	mg/L	0.001	0.001	1	1	0.05				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cobalt	mg/L	0.001	ID	0.1	1	-				0.004	0.003	0.00	<0.001	<0.001	0.002	<0.001				0.008	0.005	0.003	0.002	0.004	0.005	0.179	0.066	0.03	0.02	0.01
Copper	mg/L	0.001	0.0014	5	1#	2				0.002	0.001	<0.001	0.00	0.002	<0.001	0.007				0.001	<0.001	0.005	<0.001	<0.001	<0.001	0.002	<0.001	0.00	0.01	<0.001
Lead	mg/L	0.001	0.0034	5	0.1	0.01				<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lithium	mg/L	0.001	-	2.5	-	-				0.049										0.012			0.011		0.012	0.052				0.042
Manganese	mg/L	0.001	1.9	10	-	0.5	0.646	0.464	0.53	0.604	0.646	0.44	0.29	0.244	0.49	0.274	1.150	0.780	0.718	0.912	0.793	0.616	0.823	0.644	0.627	0.65	0.228	0.15	0.15	0.103
Molybdenum	mg/L	0.001	ID	0.05	0.15	0.05				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				0.004	0.004	<0.001	<0.001	0.002	0.001	<0.001	<0.001	0.00	0.00	<0.001
Nickel	mg/L	0.001	0.011	2	1	0.02				0.006	0.007	0.004	<0.001	<0.001	0.005	0.015				0.009	0.007	0.006	0.005	0.005	0.006	0.217	0.083	0.03	0.02	0.013
Selenium	mg/L	0.01	0.005	0.05	0.02	0.01				<0.01	<0.01	0.16	<0.01	<0.01	<0.01	<0.01				<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Strontium	mg/L	0.001	-	-	-	-				0.213	0.193				0.153					0.034			0.037	0.02	0.024	0.197				0.145
Tin	mg/L	0.001	ID	-	-	-				<0.001										<0.001			<0.001		<0.001	<0.001				<0.001
Uranium	mg/L	0.001	ID	0.1	0.2	0.017				<0.001	<0.001									<0.001			<0.001		<0.001	<0.001				<0.001
Vanadium	mg/L	0.01	ID	0.5	ID	-				<0.01	<0.01									<0.01			<0.01		<0.01	<0.01				<0.01
Zinc	mg/L	0.005	0.008	5	20	ID				0.017	0.117	<0.005	0.01	0.04	<0.005	0.041				0.021	0.017	0.012	0.013	0.006	0.006	0.214	0.072	0.08	0.03	0.019
Boron	mg/L	0.05	0.37	5	5	4				<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05				<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Iron	mg/L	0.05	ID	10	ID	ID	8.08	6.64	6.6	5.88	6.15	6.22	5.57	5.89	5.79	0.98	13.60	15.50	18.10	21.9	15.9	16.4	14.5	15.8	13.5	2.41	3.11	2.98	1.74	2.38
Ferrous iron	mg/L	0.05	-	-	-	ID									6.59	3.97									16.1					
Bromine	mg/L	0.1	-	-	-	-				0.3	0.6									0.4			<0.1		<0.1	0.3				0.1
Iodine	mg/L	0.1	-	-	-	ID				<0.1										<0.1			<0.1		<0.1	<0.1				<0.1
Mercury	mg/L	0.0001	0.00006	0.002	0.002	0.001				<0.0001										<0.0001			<0.0001			<0.0001				<0.0001
Total metals																														
Aluminium	mg/L	0.01	-	-	-	-				<0.01										<0.01			0.12	0.647	<0.01	<0.01				0.87
Manganese	mg/L	0.001	-	-	-	-				0.6					0.507	0.451				0.898			0.809	15.9	0.684	0.659				0.128
Iron	mg/L	0.05	-	-	-	-				6.83					6.56	6.07				22			16.4	17.1	16.2	2.6				6.77
Nutrients																														
Ammonia as N	mg/L	0.01	2.57							0.13										<0.01			<0.1		0.02	0.16				0.14
Nitrite as N	mg/L	0.01			9					<0.01	<0.01									<0.01	<0.01		<0.1		<0.01	<0.01	<0.01			<0.01
Nitrate as N	mg/L	0.01			90					0.02	<0.01									0.02	0.01		0.02		<0.01	0.02	<0.01			0.02
Nitrite + Nitrate as N	mg/L	0.01																												
Total phosphorous	mg/L	0.01								0.04										<0.01			0.04			<0.01				0.04
Reactive phosphorous	mg/L	0.01								<0.01	<0.01									<0.01	<0.01		<0.01		<0.01	<0.01	<0.01			<0.01
Biochemical oxygen demand	mg/L	2																												
Isotopes																														
Oxygen-18	‰	0.01																												
Deuterium	‰	0.1																												
Carbon-13	‰	0.1																												
Radiocarbon	pMC	0.1																												
Radiocarbon Age (uncorrected)	yrs BP	1																												
Tritium	TU	0.01																												

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0096PZC								HU0118PZA				HU0129PZB				HU0133PZC	HU0136PZB			HU0142PZB				
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	8/08/2013	16/10/2013	9/12/2013	31/03/2014	5/12/2014	27/03/2015	7/07/2015	22/09/2015	20/03/2014	25/08/2014	1/12/2014	6/02/2015	22/05/2014	10/02/2015	24/06/2015	16/09/2015	23/05/2014	29/08/2014	1/12/2014	4/02/2015	24/09/2014	1/12/2014	26/03/2015	30/06/2015	17/09/2015
General field parameters																															
pH	pH units		6.5-7.5				5.03	4.92	4.81	4.25	4.98	4.83	4.82	4.77	6.44	5.84	6.02	5.83	6.16	6.20	6.21	6.21	5.95	7.50	6.39	7.03	6.49	6.61	6.57	6.54	6.56
Conductivity (field)	µS/cm		30-350	0-650 (v. low) >650-1300 (low) >1300-2900 (medium) >2900-5200 (high) >5200-8100 (v. high) >8100 (extreme)			84	120	110	111.5	115	116	116	118	192	186	182	177	520	513	485	518	189	591	589	566	3717	4882	4875	3866	3313
Conductivity (lab)	µS/cm	1	30-350							118			112								486	460								3870	
Total Dissolved Solids (field)	mg/L					<600 (good quality) 600-900 (fair quality) >900-1200 (poor quality) >1200 (unacceptable)	48	78	71	72	75	75	75	77	125	121	118	115	338	333	315	336	123	384	383	368	1970	3172	3172	2516	2154
Total Dissolved Solids (lab)	mg/L	10								70		100	52	53							194	284	92						2430	2090	2070
Dissolved oxygen	% sat		90-110				56.6	51.9	66.7	50.2	56.3	57.4	82	70.6	36	11.8	48.4	24.0	13.5	25.6	8.9	18.9	31.9	96.3	77.0	92.6	12.4	21.2	19.8	13.9	14.0
Redox	mV						110	111.7	208.2	197.9	122.5	301.6	315.3	-5.2	43.8	113.3	-33.4	11.8	-18.9	-20.6	-79.8	-111.6	-10.2	179.6	140.2	100.4	-64.3	-32.9	-13.3	-54.5	-138.7
Temperature	°C						18.7	17.29	18.22	17.8	22.14	13.9	13.8	14.25	19	15.16	13.82	14.35	19.35	17.33	14.9	17.9	18.12	18.24	22.35	17.54	20.41	23.43	20.60	16.10	16.38
Suspended Solids (lab)	mg/L	5											<5	19							<5	<5								<5	<5
Turbidity	NTU	0.1	2-25											8.8																	13.2
Major ions																															
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	6	4	3	4	3	<1	2	4	31	28	29	43	100	83	68	81	57	316	238	232	339	446	377	362	299
Total Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	6	4	3	4	3	<1	2	4	31	28	29	43	100	83	68	81	57	316	238	232	339	446	377	362	299
Acidity as $CaCO_3$	mg/L	1	-	-	-	-							53								47										
Sulfate as SO_4^{2-}	mg/L	1	-	-	1000	500	2	1	1	1	<1	<1	1	1	3	1	1	2	10	10	10	13	10	159	8	7	8	11	6	6	4
Chloride	mg/L	1	-	700	-	ID	28	36	29	32	23	35	27	29	31	29	37	35	96	97	92	87	25	40	47	51	1020	1150	1300	1030	925
Calcium	mg/L	1	-	-	1000	-	1	<1	<1	<1	<1	<1	<1	<1	7	2	3	3	15	15	17	17	4	34	34	29	145	198	182	168	148
Magnesium	mg/L	1	-	-	ID	-	<1	<1	<1	<1	1	1	1	1	3	2	3	3	19	20	20	22	5	42	40	44	188	229	236	201	158
Sodium	mg/L	1	-	460	-	-	17	16	18	22	19	17	16	17	19	15	13	15	45	46	42	45	12	29	20	24	326	406	391	322	275
Potassium	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	2	<1	<1	<1	1	2	2	2	<1	2	2	2	9	9	11	8	6
Silica/Silicon as SiO_2/Reactive silica	mg/L	0.1	-	-	-	-	7.8	8.2	7.5	7.5	7.6	8.01	7.4	7.46	8.7	9.4	8.6	7.9	13.8	13.0	13.3	13.0	8.42	14.3	48.3	49.4	9.2	8.9	9.64	10	9.68
Total Anions	meq/L	0.01	-	-	-	-	0.95	1.12	0.90	1.00	0.71	0.99	0.82	0.92	1.56	1.4	1.64	1.89	4.91	4.6	4.16	4.34	2.05	10.8	6.25	6.22	35.7	41.6	44.3	36.4	32.2
Total Cations	meq/L	0.01	-	-	-	-	0.83	0.85	0.78	0.96	0.91	0.82	0.78	0.82	1.47	1.2	1.88	1.99	4.77	4.45	4.37	4.67	2.02	6.47	5.91	6.16	37.1	46.6	45.8	39.1	32.5
Ionic Balance	%	0.01	-	-	-	-	-	-	-										1.54	1.74	2.46	3.59		24.9	2.79	0.47	1.93	5.71	1.63	2.18	0.55
Other Inorganics																															
Flouride	mg/L	0.1	-	2	2	1.5			<0.1	<0.1		<0.1	<0.1	<0.1					0.1	<0.1	<0.1		<0.1						<0.1	<0.1	<0.1
Free cyanide	mg/L	0.004	0.007	-	-	0.08			<0.004			<0.004											<0.004						<0.004		
Total cyanide	mg/L	0.004	-	-	-	-			<0.004			<0.004											<0.004						<0.004		
Thiocyanate	mg/L	0.1	-	-	-	-			<0.1			1.2											<0.1						<0.1		
Dissolved metals																															
Aluminium	mg/L	0.01	0.055	20	5	ID			0.02	0.04	0.07	0.05	0.02	0.02	0.02	0.02	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	0.02	0.07	<0.01	<0.01	<0.01	0.02	<0.01	<0.01
Antimony	mg/L	0.001	ID	-	-	0.003			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic	mg/L	0.001	0.013	2	0.5	0.01			<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.02	0.015	0.016	0.016	0.002	0.003	<0.001	<0.001	0.002	<0.001	<0.001	0.001	0.002
Beryllium	mg/L	0.001	ID	0.5	ID	0.06			<0.001			<0.001		<0.001					<0.001	<0.001			<0.001						<0.001		<0.001
Barium	mg/L	0.001	-	-	-	2			0.012			0.019	0.012	0.011					0.153	0.112	0.108		0.04						0.825	0.654	0.532
Cadmium	mg/L	0.0001	0.0002	0.05	0.01	0.002			<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0008	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001
Chromium	mg/L	0.001	0.001	1	1	0.05			<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.002	<0.001	<0.001	<0.001	<0.001	<0.001
Cobalt	mg/L	0.001	ID	0.1	1	-			0.002	0.002	0.003	0.002	0.002	0.003	0.001	<0.001	<0.001	<0.001	0.036	0.005	0.005	0.005	0.015	0.274	0.002	<0.001	0.009	0.005	0.005	0.006	0.005
Copper	mg/L	0.001	0.0014	5	1#	2			0.004	0.005	0.009	0.002	<0.001	0.002	0.003	0.002	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	0.014	<0.001	<0.001	<0.001	0.003	0.007	<0.001	<0.001
Lead	mg/L	0.001	0.0034	5	0.1	0.01			<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lithium	mg/L	0.001	-	2.5	-	-			0.001			0.001		<0.001					0.021	0.023			0.009						0.147		0.101
Manganese	mg/L	0.001	1.9	10	-	0.5	0.053	0.039	0.043	0.04	0.073	0.043	0.039	0.078	0.405	0.41	0.427	0.452	0.656	0.54	0.571	0.565	1.24	0.278	0.02	0.001	1.25	1.21	1.19	1.27	1.48
Molybdenum	mg/L	0.001	ID	0.05	0.15	0.05			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.006	0.004	0.005	0.004	<0.001	0.004	<0.001	<0.001	0.001	0.002	<0.001	0.001	<0.001
Nickel	mg/L	0.001	0.011	2	1	0.02			0.002	0.002	0.004	0.001	0.001	0.003	0.008	0.003	<0.001	<0.001	0.043	0.01	0.013	0.011	0.02	0.627	0.009	<0.001	0.02	0.011	0.009	0.01	0.011
Selenium	mg/L	0.01	0.005	0.05	0.02	0.01			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Strontium	mg/L	0.001	-	-	-	-			0.008			0.007	0.005	0.006					0.105	0.096	0.085		0.037						1.49	1.11	0.959
Tin	mg/L	0.001	ID	-	-	-			<0.001			<0.001		<0.001					<0.001	<0.001			<0.001						<0.001		<0.001
Uranium	mg/L	0.001	ID	0.1	0.2	0.017			<0.001			<0.001		<0.001					<0.001	<0.001			<0.001						0.001		<0.001
Vanadium	mg/L	0.01	ID	0.5	ID	-			<0.01			<0.01		<0.01					<0.01	<0.01			<0.01						<0.01		<0.01
Zinc	mg/L	0.005	0.008	5	20	ID			0.045	0.063	0.028	0.028	0.008	0.019	0.226	0.019	0.02	0.016	0.023	0.013	0.023	0.015	0.053	0.318	0.026	<0.005	0.024	0.021	0.021	0.011	0.007
Boron	mg/L	0.05	0.37	5	5	4			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Iron	mg/L	0.05	ID	10	ID	ID	0.07	<0.05	<0.05	<0.05	0.14	<0.05	<0.05	<0.05	0.8	16.4	17.1	17.3	8.14	9.41	10.4	11.1	15.1	<0.05	0.16	<0.05	4.35	0.86	0.93	1.98	3.16
Ferrous iron	mg/L	0.05	-	-	-	ID							<0.05	<0.05							11.4	10.9								2.57	3.37
Bromine	mg/L	0.1	-	-	-	-			0.1			<0.01		<0.1					0.3	0.2			<0.1						3.2		2.3
Iodine	mg/L	0.1	-	-	-	ID			<0.1			<0.01		<0.1					<0.1	<0.1			<0.1						<0.1		<0.1
Mercury	mg/L	0.0001	0.00006	0.002	0.002	0.001			<0.0001			<0.0001											<0.0001						<0.0001		
Total metals																															
Aluminium	mg/L	0.01	-	-	-	-			0.41			1.90		0.20									<0.01						0.99		0.02
Manganese	mg/L	0.001	-	-	-	-			0.05			0.06	0.043	0.08							0.576	0.549	1.24						1.38	1.28	1.34
Iron	mg/L	0.05	-	-	-	-			0.21			1.03	0.12	0.09							11.2	10.7	15.6						7.1	2.18	3.01
Nutrients																															
Ammonia as N	mg/L	0.01	2.57						0.04			<0.01		<0.01									<0.01						0.21		0.11
Nitrite as N	mg/L	0.01			9				<0.01	<0.01		<0.01		0.02									<0.01						<0.01		<0.01
Nitrate as N	mg/L	0.01			90				0.15	0.19		0.15		0.11									0.02						<0.01		0.01
Nitrite + Nitrate as N	mg/L	0.01																													0.01
Total phosphorous	mg/L	0.01							0.06			0.19											<0.01						0.08		
Reactive phosphorous	mg/L	0.01							<0.01	<0.01		<0.01		<0.01									<0.01						<0.01		<0.01
Biochemical oxygen demand	mg/L	2												<2																	<2
Isotopes																															
Oxygen-18	‰	0.01																													
Deuterium	‰	0.1																													
Carbon-13	‰	0.1																													
Radiocarbon	pMC	0.1																													
Radiocarbon Age (uncorrected)	yrs BP	1																													
Tritium	TU	0.01																													

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0142PZC					HU0143PZC									
Analyte	Units	LOR	Aquatic	ANZECC (2000) Irrigation	Livestock	ADWG (2011)	24/09/2014	3/12/2014	26/03/2015	30/06/2015	17/09/2015	4/12/2014	25/03/2015	25/06/2015	23/09/2015	n	Detects	Exc	Min	Max	Avg	Geomean	Std Dev
General field parameters																							
pH	pH units		6.5-7.5				6.36	6.43	6.30	6.11	6.08	6.1	6.21	6.00	5.88	130	130	119	4.05	7.95	5.34	5.91	0.66
Conductivity (field)	µS/cm		30-350	0-650 (v. low) >650-1300 (low) >1300-2900 (medium) >2900-5200 (high) >5200-8100 (v. high) >8100 (extreme)			1900	1458	634	420.1	357	214	202.8	177.5	174	129	129	50	41	4882	480	259	801
Conductivity (lab)	µS/cm	1	30-350							416				165	140	23	23	11	36	3870	511	268	787
Total Dissolved Solids (field)	mg/L					<600 (good quality) 600-900 (fair quality) >900-1200 (poor quality) >1200 (unacceptable)	1236	947	409	273	232	139	132	115	113	130	130		27	3172	308	168.11	506.45
Total Dissolved Solids (lab)	mg/L	10							339	220	170			69	84	35	35		24	2430	349	158	594
Dissolved oxygen	% sat		90-110				7.3	23.9	10.6	25.1	15.1	2.50	19.9	7.4	10.5	130	129		1.5	118.1	31.1	22	25
Redox	mV						-52.1	-52.9	-53.6	-4.7		12.8	61.3	26.3	-127.6	129	129		-151.9	315.3	14.6		100
Temperature	°C						19.97	22.77	18.5	15.8	16.39	21.51	19.2	15.6	15.45	130	130		12.4	33.1	18.2	18	3
Suspended Solids (lab)	mg/L	5								<5	<5			14	25	18	4		14	25	20.50	20	5
Turbidity	NTU	0.1	2-25								3.5					4	4	0	3.5	13.2	8.45	8	4
Major ions																							
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	131	0						
Carbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	131	0						
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	185	170	98	83	59	50	48	41	47	131	130		2	446	73	36	80
Total Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	185	170	98	83	59	50	48	41	47	131	130		2	446	73	36	80
Acidity as $CaCO_3$	mg/L	1	-	-	-	-				74				54		51	36		1	103	17.58	7	25
Sulfate as SO_4^{2-}	mg/L	1	-	-	1000	500	6	19	6	4	6	7	4	5	4	131	128	0	1	159	14.9	8	21
Chloride	mg/L	1	-	700	-	ID	514	339	129	69	62	21	32	19	18	131	116	5	1	1300	104.7	33	223
Calcium	mg/L	1	-	-	1000	-	68	54	23	12	10	12	13	4	3	131	105	0	1	198	22.1	11	36
Magnesium	mg/L	1	-	-	ID	-	92	58	28	20	17	5	4	5	5	131	126		1	236	23.1	11	40
Sodium	mg/L	1	-	460	-	-	165	114	49	29	30	14	13	12	13	131	99	0	1	406	47.9	27	74
Potassium	mg/L	1	-	-	-	-	4	4	2	1	1	<1	<1	<1	<1	129	96		1	14.2	5.35	4	3
Silica/Silicon as SiO_2/Reactive silica	mg/L	0.1	-	-	-	-	9.8	10	9.2	9.6	9.04	8	7.1	8	7.8	98	88		7.1	49.4	10.1	9	6
Total Anions	meq/L	0.01	-	-	-	-	18.3	13.4	5.72	3.69	3.05	1.74	1.95	1.46	1.53								
Total Cations	meq/L	0.01	-	-	-	-	18.2	12.5	5.63	3.53	3.23	1.62	1.66	1.13	1.13								
Ionic Balance	%	0.01	-	-	-	-	0.21	3.19	0.77	2.18	2.79												
Other Inorganics																							
Flouride	mg/L	0.1	-	2	2	1.5			<0.1	<0.1	<0.1			<0.1		40	9	0	0.1	0.1	0.10	0.10	0.00
Free cyanide	mg/L	0.004	0.007	-	-	0.08			<0.004							18	0	0					
Total cyanide	mg/L	0.004	-	-	-	-			<0.004							18	1		0.004	0.004	0.00	0.004	
Thiocyanate	mg/L	0.1	-	-	-	-			<0.1							13	1		1.2	1.2	1.20	1.2	
Dissolved metals																							
Aluminium	mg/L	0.01	0.055	20	5	ID	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	88	41	10	0.01	0.41	0.05	0.03	0.08
Antimony	mg/L	0.001	ID	-	-	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	88	2	0	0.002	0.002	0.002	0.00	0.00
Arsenic	mg/L	0.001	0.013	2	0.5	0.01	0.001	0.001	0.001	0.001	<0.001	0.001	<0.001	<0.001	<0.001	88	34	8	0.001	0.044	0.008	0.00	0.01
Beryllium	mg/L	0.001	ID	0.5	ID	0.06			<0.001		<0.001					30	0						
Barium	mg/L	0.001	-	-	-	2			0.079	0.055	0.046			0.024		39	39	0	0.003	0.825	0.136	0.06	0.19
Cadmium	mg/L	0.0001	0.0002	0.05	0.01	0.002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	88	9	4	0.0001	0.0008	0.000	0.00	0.00
Chromium	mg/L	0.001	0.001	1	1	0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	88	5	3	0.001	0.008	0.003	0.00	0.00
Cobalt	mg/L	0.001	ID	0.1	1	-	0.008	0.005	0.004	0.006	0.006	0.005	0.003	0.004	0.005	88	61	2	0.001	0.274	0.015	0.01	0.04
Copper	mg/L	0.001	0.0014	5	1#	2	<0.001	0.002	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	88	43	39	0.001	0.257	0.015	0.005	0.042
Lead	mg/L	0.001	0.0034	5	0.1	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	88	12	1	0.001	0.006	0.002	0.002	0.00
Lithium	mg/L	0.001	-	2.5	-	-			0.02		0.013					28	25	0	0.001	0.147	0.026	0.01	0.03
Manganese	mg/L	0.001	1.9	10	-	0.5	1.63	1.73	1.14	1.3	1.34	0.932	0.784	1	1.02	131	131	0	0.001	1.73	0.463	0.24	0.40
Molybdenum	mg/L	0.001	ID	0.05	0.15	0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	88	22	0	0.001	0.011	0.004	0.00	0.00
Nickel	mg/L	0.001	0.011	2	1	0.02	0.015	0.016	0.008	0.009	0.01	0.009	0.006	0.009	0.008	88	74	25	0.001	0.627	0.023	0.009	0.076
Selenium	mg/L	0.01	0.005	0.05	0.02	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	88	2	2	0.11	0.16	0.135	0.13	0.04
Strontium	mg/L	0.001	-	-	-	-			0.154	0.088	0.074			0.026		39	39		0.004	1.49	0.164	0.06	0.31
Tin	mg/L	0.001	ID	-	-	-			<0.001		<0.001					27	1		0.001	0.001	0.001	0.001	
Uranium	mg/L	0.001	ID	0.1	0.2	0.017			<0.001		<0.001					30	1	0	0.001	0.001	0.001	0.00	
Vanadium	mg/L	0.01	ID	0.5	ID	-			<0.01		<0.01					30	0						
Zinc	mg/L	0.005	0.008	5	20	ID	0.026	0.012	0.01	0.017	0.012	0.028	0.025	0.013	0.012	88	81	75	0.006	0.318	0.056	0.032	0.069
Boron	mg/L	0.05	0.37	5	5	4	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	88	0	0					
Iron	mg/L	0.05	ID	10	ID	ID	7.74	8.5	5.88	7.56	8.32	11.5	2.17	14.4	14.2	131	105	30	0.05	21.9	7.2	3.56	5.49
Ferrous iron	mg/L	0.05	-	-	-	ID				8.87	8.39			15.6	15.4	18	16	8	2.57	16.1	9.64	8.36	4.72
Bromine	mg/L	0.1	-	-	-	-			0.3		0.2					30	19		0.1	3.2	0.526	0.30	0.81
Iodine	mg/L	0.1	-	-	-	ID			<0.1		<0.1					27	0						
Mercury	mg/L	0.0001	0.00006	0.002	0.002	0.001			<0.0001							18	0	0					
Total metals																							
Aluminium	mg/L	0.01	-	-	-	-			1.86		0.02					24	18		0.01	1.9	0.50	0.19	0.59
Manganese	mg/L	0.001	-	-	-	-			1.35	1.35	1.29			1.06	1.07	38	38		0.016	15.9	1.040	0.42	2.52
Iron	mg/L	0.05	-	-	-	-			9.32	8.02	8.26			16.9	17.1	38	35		0.09	22	8.8	4.88	6.06
Nutrients																							
Ammonia as N	mg/L	0.01	2.57						0.01		0.02					23	16	0	0.01	0.78	0.12	0.06	0.19
Nitrite as N	mg/L	0.01			9				<0.01		<0.01					31	1	0	0.02	0.02	0.02	0.02	
Nitrate as N	mg/L	0.01			90				<0.01		0.01					31	25	0	0.01	0.77	0.09	0.04	0.16
Nitrite + Nitrate as N	mg/L	0.01									0.01					2	2		0.01	0.01	0.01	0.01	0.00
Total phosphorous	mg/L	0.01							0.18							19	12		0.02	0.19	0.07	0.05	0.06
Reactive phosphorous	mg/L	0.01							<0.01		<0.01					31	0						
Biochemical oxygen demand	mg/L	2									<2					4	0						
Isotopes																							
Oxygen-18	‰	0.01																					
Deuterium	‰	0.1																					
Carbon-13	‰	0.1																					
Radiocarbon	pMC	0.1																					
Radiocarbon Age (uncorrected)	yrs BP	1																					
Tritium	TU	0.01																					

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0018PZB										HU0019PZB						HU0023PZB				HU0023PZC			
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	17/10/2011	7/01/2013	22/03/2013	9/07/2013	16/10/2013	12/12/2013	8/04/2014	25/03/2015	2/07/2015	24/09/2015	18/10/2011	29/08/2012	4/01/2013	17/12/2013	9/04/2014	4/02/2015	16/11/2011	18/12/2012	25/03/2013	21/05/2014	15/11/2011	18/12/2012	25/03/2013	21/05/2014
Organochloride pesticides																														
alpha-BHC	µg/L	0.5										<0.5				<0.5				<0.5										
Hexachlorobenzene (HCB)	µg/L	0.5										<0.5				<0.5				<0.5										
beta-BHC	µg/L	0.5										<0.5				<0.5				<0.5										
gamma-BHC	µg/L	0.5										<0.5				<0.5				<0.5										
delta-BHC	µg/L	0.5										<0.5				<0.5				<0.5										
Heptachlor	µg/L	0.5										<0.5				<0.5				<0.5										
Aldrin	µg/L	0.5										<0.5				<0.5				<0.5										
Heptachlor epoxide	µg/L	0.5										<0.5				<0.5				<0.5										
trans-Chlordane	µg/L	0.5										<0.5				<0.5				<0.5										
alpha-Endosulfan	µg/L	0.5										<0.5				<0.5				<0.5										
cis-Chlordane	µg/L	0.5										<0.5				<0.5				<0.5										
Dieldrin	µg/L	0.5										<0.5				<0.5				<0.5										
4.4`-DDE	µg/L	0.5										<0.5				<0.5				<0.5										
Endrin	µg/L	0.5										<0.5				<0.5				<0.5										
beta-Endosulfan	µg/L	0.5										<0.5				<0.5				<0.5										
4.4`-DDD	µg/L	0.5										<0.5				<0.5				<0.5										
Endrin aldehyde	µg/L	0.5										<0.5				<0.5				<0.5										
Endosulfan sulfate	µg/L	0.5										<0.5				<0.5				<0.5										
4.4`-DDT	µg/L	2										<2.0				<2.0				<2.0										
Endrin ketone	µg/L	0.5										<0.5				<0.5				<0.5										
Methoxychlor	µg/L	2										<2.0				<2.0				<2.0										
Total Chlordane (sum)	µg/L	0.5										<0.5				<0.5				<0.5										
Sum of DDD + DDE + DDT	µg/L	0.5										<0.5				<0.5				<0.5										
Sum of Aldrin + Dieldrin	µg/L	0.5										<0.5				<0.5				<0.5										
Organophosphorous pesticides																														
Dichlorvos	µg/L	0.5										<0.5				<0.5				<0.5										
Demeton-S-methyl	µg/L	0.5										<0.5				<0.5				<0.5										
Monocrotophos	µg/L	2										<2.0				<2.0				<2.0										
Dimethoate	µg/L	0.5										<0.5				<0.5				<0.5										
Diazinon	µg/L	0.5										<0.5				<0.5				<0.5										
Chlorpyrifos-methyl	µg/L	0.5										<0.5				<0.5				<0.5										
Parathion-methyl	µg/L	2										<2.0				<2.0				<2.0										
Malathion	µg/L	0.5										<0.5				<0.5				<0.5										
Fenthion	µg/L	0.5										<0.5				<0.5				<0.5										
Chlorpyrifos	µg/L	0.5										<0.5				<0.5				<0.5										
Parathion	µg/L	2										<2.0				<2.0				<2.0										
Pirimphos-ethyl	µg/L	0.5										<0.5				<0.5				<0.5										
Chlorfenvinphos	µg/L	0.5										<0.5				<0.5				<0.5										
Bromophos-ethyl	µg/L	0.5										<0.5				<0.5				<0.5										
Fenamiphos	µg/L	0.5										<0.5				<0.5				<0.5										
Prothiofos	µg/L	0.5										<0.5				<0.5				<0.5										
Ethion	µg/L	0.5										<0.5				<0.5				<0.5										
Carbophenothion	µg/L	0.5										<0.5				<0.5				<0.5										
Azinphos Methyl	µg/L	0.5										<0.5				<0.5				<0.5										
Phenolic compounds																														
Phenol	µg/L	1										<1.0				<1.0				<1.0										
2-Chlorophenol	µg/L	1										<1.0				<1.0				<1.0										
2-Methylphenol	µg/L	1										<1.0				<1.0				<1.0										
3- & 4-Methylphenol	µg/L	1										<2.0				<2.0				<2.0										
2-Nitrophenol	µg/L	2										<1.0				<1.0				<1.0										
2.4-Dimethylphenol	µg/L	1										<1.0				<1.0				<1.0										
2.4-Dichlorophenol	µg/L	1										<1.0				<1.0				<1.0										
2.6-Dichlorophenol	µg/L	1										<1.0				<1.0				<1.0										
4-Chloro-3-methylphenol	µg/L	1										<1.0				<1.0				<1.0										
2.4.6-Trichlorophenol	µg/L	1										<1.0				<1.0				<1.0										
2.4.5-Trichlorophenol	µg/L	1										<1.0				<1.0				<1.0										
Pentachlorophenol	µg/L	1										<2.0				<2.0				<2.0										
Polynuclear aromatic hydrocarbons																														
Naphthalene	µg/L	1										<1.0				<1.0				<1.0										
Acenaphthylene	µg/L	1										<1.0				<1.0				<1.0										
Acenaphthene	µg/L	1										<1.0				<1.0				<1.0										
Fluorene	µg/L	1										<1.0				<1.0				<1.0										
Phenanthrene	µg/L	1										<1.0				<1.0				<1.0										
Anthracene	µg/L	1										<1.0				<1.0				<1.0										
Fluoranthene	µg/L	1										<1.0				<1.0				<1.0										
Pyrene	µg/L	1										<1.0				<1.0				<1.0										
Benz(a)anthracene	µg/L	1										<1.0				<1.0				<1.0										
Chrysene	µg/L	1										<1.0				<1.0				<1.0										
Benzo(b)fluoranthene	µg/L	1										<1.0				<1.0				<1.0										
Benzo(k)fluoranthene	µg/L	1										<1.0				<1.0				<1.0										
Benzo(a)pyrene	µg/L	0.5										<0.5				<0.5				<0.5										
Indeno(1.2.3.cd)pyrene	µg/L	1										<1.0				<1.0				<1.0										
Dibenz(a.h)anthracene	µg/L	1										<1.0				<1.0				<1.0										
Benzo(g.h.i)perylene	µg/L	1										<1.0				<1.0				<1.0										
Sum of polycyclic aromatic hydrocarbon	µg/L	0.5										<0.5				<0.5				<0.5										
Benzo(a)pyrene TEQ (zero)	µg/L	0.5										<0.5				<0.5				<0.5										

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0032LDB				HU0037PZB				HU0038PZC								HU0042PZC					HU0043PZB			
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	12/12/2013	3/04/2014	26/03/2015	24/09/2015	29/08/2012	20/12/2012	18/12/2013	3/02/2015	24/07/2012	14/12/2012	11/12/2013	2/04/2014	15/08/2014	2/12/2014	12/02/2015	15/09/2015	26/03/2013	3/07/2013	19/08/2013	17/12/2013	2/02/2015	31/08/2012	3/01/2013	18/12/2013	5/02/2015
Organochloride pesticides																															
alpha-BHC	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Hexachlorobenzene (HCB)	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
beta-BHC	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
gamma-BHC	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
delta-BHC	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Heptachlor	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Aldrin	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Heptachlor epoxide	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
trans-Chlordane	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
alpha-Endosulfan	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
cis-Chlordane	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Dieldrin	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
4.4`-DDE	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Endrin	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
beta-Endosulfan	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
4.4`-DDD	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Endrin aldehyde	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Endosulfan sulfate	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
4.4`-DDT	µg/L	2					<2.0						<2.0				<2.0				<2.0					<2.0					
Endrin ketone	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Methoxychlor	µg/L	2					<2.0						<2.0				<2.0				<2.0					<2.0					
Total Chlordane (sum)	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Sum of DDD + DDE + DDT	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Sum of Aldrin + Dieldrin	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Organophosphorous pesticides																															
Dichlorvos	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Demeton-S-methyl	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Monocrotophos	µg/L	2					<2.0						<2.0				<2.0				<2.0					<2.0					
Dimethoate	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Diazinon	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Chlorpyrifos-methyl	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Parathion-methyl	µg/L	2					<2.0						<2.0				<2.0				<2.0					<2.0					
Malathion	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Fenthion	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Chlorpyrifos	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Parathion	µg/L	2					<2.0						<2.0				<2.0				<2.0					<2.0					
Pirimphos-ethyl	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Chlorfenvinphos	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Bromophos-ethyl	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Fenamiphos	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Prothiofos	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Ethion	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Carbophenothion	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Azinphos Methyl	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Phenolic compounds																															
Phenol	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
2-Chlorophenol	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
2-Methylphenol	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
3- & 4-Methylphenol	µg/L	1					<2.0						<2.0				<2.0				4.7					<2.0					
2-Nitrophenol	µg/L	2					<1.0						<1.0				<1.0				<1.0					<1.0					
2.4-Dimethylphenol	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
2.4-Dichlorophenol	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
2.6-Dichlorophenol	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
4-Chloro-3-methylphenol	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
2.4.6-Trichlorophenol	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
2.4.5-Trichlorophenol	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
Pentachlorophenol	µg/L	1					<2.0						<2.0				<2.0				<2.0					<2.0					
Polynuclear aromatic hydrocarbons																															
Naphthalene	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
Acenaphthylene	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
Acenaphthene	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
Fluorene	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
Phenanthrene	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
Anthracene	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
Fluoranthene	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
Pyrene	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
Benz(a)anthracene	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
Chrysene	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
Benzo(b)fluoranthene	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
Benzo(k)fluoranthene	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
Benzo(a)pyrene	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Indeno(1.2.3.cd)pyrene	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
Dibenz(a.h)anthracene	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
Benzo(g.h.i)perylene	µg/L	1					<1.0						<1.0				<1.0				<1.0					<1.0					
Sum of polycyclic aromatic hydrocarbor	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					
Benzo(a)pyrene TEQ (zero)	µg/L	0.5					<0.5						<0.5				<0.5				<0.5					<0.5					

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0044XPZB									HU0056XPZB					HU0072PZB									
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	23/08/2012	14/12/2012	26/03/2013	2/07/2013	18/09/2013	10/12/2013	25/03/2014	24/07/2014	3/02/2015	19/12/2012	19/12/2013	25/09/2014	13/11/2014	5/02/2015	21/03/2013	8/07/2013	18/09/2013	11/12/2013	26/03/2014	14/08/2014	2/12/2014	25/03/2015	26/06/2015	17/09/2015
Organochloride pesticides																														
alpha-BHC	µg/L	0.5																						<0.5						
Hexachlorobenzene (HCB)	µg/L	0.5																						<0.5						
beta-BHC	µg/L	0.5																						<0.5						
gamma-BHC	µg/L	0.5																						<0.5						
delta-BHC	µg/L	0.5																						<0.5						
Heptachlor	µg/L	0.5																						<0.5						
Aldrin	µg/L	0.5																						<0.5						
Heptachlor epoxide	µg/L	0.5																						<0.5						
trans-Chlordane	µg/L	0.5																						<0.5						
alpha-Endosulfan	µg/L	0.5																						<0.5						
cis-Chlordane	µg/L	0.5																						<0.5						
Dieldrin	µg/L	0.5																						<0.5						
4.4`-DDE	µg/L	0.5																						<0.5						
Endrin	µg/L	0.5																						<0.5						
beta-Endosulfan	µg/L	0.5																						<0.5						
4.4`-DDD	µg/L	0.5																						<0.5						
Endrin aldehyde	µg/L	0.5																						<0.5						
Endosulfan sulfate	µg/L	0.5																						<0.5						
4.4`-DDT	µg/L	2																						<2.0						
Endrin ketone	µg/L	0.5																						<0.5						
Methoxychlor	µg/L	2																						<2.0						
Total Chlordane (sum)	µg/L	0.5																						<0.5						
Sum of DDD + DDE + DDT	µg/L	0.5																						<0.5						
Sum of Aldrin + Dieldrin	µg/L	0.5																						<0.5						
Organophosphorous pesticides																														
Dichlorvos	µg/L	0.5																						<0.5						
Demeton-S-methyl	µg/L	0.5																						<0.5						
Monocrotophos	µg/L	2																						<2.0						
Dimethoate	µg/L	0.5																						<0.5						
Diazinon	µg/L	0.5																						<0.5						
Chlorpyrifos-methyl	µg/L	0.5																						<0.5						
Parathion-methyl	µg/L	2																						<2.0						
Malathion	µg/L	0.5																						<0.5						
Fenthion	µg/L	0.5																						<0.5						
Chlorpyrifos	µg/L	0.5																						<0.5						
Parathion	µg/L	2																						<2.0						
Pirimphos-ethyl	µg/L	0.5																						<0.5						
Chlorfenvinphos	µg/L	0.5																						<0.5						
Bromophos-ethyl	µg/L	0.5																						<0.5						
Fenamiphos	µg/L	0.5																						<0.5						
Prothiofos	µg/L	0.5																						<0.5						
Ethion	µg/L	0.5																						<0.5						
Carbophenothion	µg/L	0.5																						<0.5						
Azinphos Methyl	µg/L	0.5																						<0.5						
Phenolic compounds																														
Phenol	µg/L	1																						<1.0						
2-Chlorophenol	µg/L	1																						<1.0						
2-Methylphenol	µg/L	1																						<1.0						
3- & 4-Methylphenol	µg/L	1																						<2.0						
2-Nitrophenol	µg/L	2																						<1.0						
2.4-Dimethylphenol	µg/L	1																						<1.0						
2.4-Dichlorophenol	µg/L	1																						<1.0						
2.6-Dichlorophenol	µg/L	1																						<1.0						
4-Chloro-3-methylphenol	µg/L	1																						<1.0						
2.4.6-Trichlorophenol	µg/L	1																						<1.0						
2.4.5-Trichlorophenol	µg/L	1																						<1.0						
Pentachlorophenol	µg/L	1																						<2.0						
Polynuclear aromatic hydrocarbons																														
Naphthalene	µg/L	1																						<1.0						
Acenaphthylene	µg/L	1																						<1.0						
Acenaphthene	µg/L	1																						<1.0						
Fluorene	µg/L	1																						<1.0						
Phenanthrene	µg/L	1																						<1.0						
Anthracene	µg/L	1																						<1.0						
Fluoranthene	µg/L	1																						<1.0						
Pyrene	µg/L	1																						<1.0						
Benz(a)anthracene	µg/L	1																						<1.0						
Chrysene	µg/L	1																						<1.0						
Benzo(b)fluoranthene	µg/L	1																						<1.0						
Benzo(k)fluoranthene	µg/L	1																						<1.0						
Benzo(a)pyrene	µg/L	0.5																						<0.5						
Indeno(1.2.3.cd)pyrene	µg/L	1																						<1.0						
Dibenz(a.h)anthracene	µg/L	1																						<1.0						
Benzo(g.h.i)perylene	µg/L	1																						<1.0						
Sum of polycyclic aromatic hydrocarbor	µg/L	0.5																						<0.5						
Benzo(a)pyrene TEQ (zero)	µg/L	0.5																						<0.5						

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0072PZC										HU0073PZC									HU0088PZB				
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	21/03/2013	8/07/2013	18/09/2013	11/12/2013	26/03/2014	14/08/2014	2/12/2014	25/03/2015	26/06/2015	15/09/2015	27/03/2013	7/08/2013	15/10/2013	10/12/2013	3/04/2014	5/12/2014	26/03/2015	29/06/2015	21/09/2015	10/12/2013	2/04/2014	26/09/2014	3/12/2014	11/02/2015
Organochloride pesticides																														
alpha-BHC	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Hexachlorobenzene (HCB)	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
beta-BHC	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
gamma-BHC	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
delta-BHC	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Heptachlor	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Aldrin	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Heptachlor epoxide	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
trans-Chlordane	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
alpha-Endosulfan	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
cis-Chlordane	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Dieldrin	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
4.4`-DDE	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Endrin	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
beta-Endosulfan	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
4.4`-DDD	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Endrin aldehyde	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Endosulfan sulfate	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
4.4`-DDT	µg/L	2								<2.0										<2.0			<2.0		<2.0					<2.0
Endrin ketone	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Methoxychlor	µg/L	2								<2.0										<2.0			<2.0		<2.0					<2.0
Total Chlordane (sum)	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Sum of DDD + DDE + DDT	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Sum of Aldrin + Dieldrin	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Organophosphorous pesticides																														
Dichlorvos	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Demeton-S-methyl	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Monocrotophos	µg/L	2								<2.0										<2.0			<2.0		<2.0					<2.0
Dimethoate	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Diazinon	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Chlorpyrifos-methyl	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Parathion-methyl	µg/L	2								<2.0										<2.0			<2.0		<2.0					<2.0
Malathion	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Fenthion	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Chlorpyrifos	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Parathion	µg/L	2								<2.0										<2.0			<2.0		<2.0					<2.0
Pirimphos-ethyl	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Chlorfenvinphos	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Bromophos-ethyl	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Fenamiphos	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Prothiofos	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Ethion	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Carbophenothion	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Azinphos Methyl	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Phenolic compounds																														
Phenol	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
2-Chlorophenol	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
2-Methylphenol	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
3- & 4-Methylphenol	µg/L	1								<2.0										<2.0			<2.0		<2.0					<2.0
2-Nitrophenol	µg/L	2								<1.0										<1.0			<1.0		<1.0					<1.0
2.4-Dimethylphenol	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
2.4-Dichlorophenol	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
2.6-Dichlorophenol	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
4-Chloro-3-methylphenol	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
2.4.6-Trichlorophenol	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
2.4.5-Trichlorophenol	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
Pentachlorophenol	µg/L	1								<2.0										<2.0			<2.0		<2.0					<2.0
Polynuclear aromatic hydrocarbons																														
Naphthalene	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
Acenaphthylene	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
Acenaphthene	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
Fluorene	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
Phenanthrene	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
Anthracene	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
Fluoranthene	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
Pyrene	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
Benz(a)anthracene	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
Chrysene	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
Benzo(b)fluoranthene	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
Benzo(k)fluoranthene	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
Benzo(a)pyrene	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Indeno(1.2.3.cd)pyrene	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
Dibenz(a.h)anthracene	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
Benzo(g.h.i)perylene	µg/L	1								<1.0										<1.0			<1.0		<1.0					<1.0
Sum of polycyclic aromatic hydrocarbor	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5
Benzo(a)pyrene TEQ (zero)	µg/L	0.5								<0.5										<0.5			<0.5		<0.5					<0.5

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0096PZC								HU0118PZA				HU0129PZB				HU0133PZC	HU0136PZB			HU0142PZB				
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	8/08/2013	16/10/2013	9/12/2013	31/03/2014	5/12/2014	27/03/2015	7/07/2015	22/09/2015	20/03/2014	25/08/2014	1/12/2014	6/02/2015	22/05/2014	10/02/2015	24/06/2015	16/09/2015	23/05/2014	29/08/2014	1/12/2014	4/02/2015	24/09/2014	1/12/2014	26/03/2015	30/06/2015	17/09/2015
Organochloride pesticides																															
alpha-BHC	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Hexachlorobenzene (HCB)	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
beta-BHC	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
gamma-BHC	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
delta-BHC	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Heptachlor	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Aldrin	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Heptachlor epoxide	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
trans-Chlordane	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
alpha-Endosulfan	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
cis-Chlordane	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Dieldrin	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
4.4`-DDE	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Endrin	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
beta-Endosulfan	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
4.4`-DDD	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Endrin aldehyde	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Endosulfan sulfate	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
4.4`-DDT	µg/L	2							<2.0			<2.0		<2.0															<2.0		<2.0
Endrin ketone	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Methoxychlor	µg/L	2							<2.0			<2.0		<2.0															<2.0		<2.0
Total Chlordane (sum)	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Sum of DDD + DDE + DDT	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Sum of Aldrin + Dieldrin	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Organophosphorous pesticides																															
Dichlorvos	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Demeton-S-methyl	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Monocrotophos	µg/L	2							<2.0			<2.0		<2.0															<2.0		<2.0
Dimethoate	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Diazinon	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Chlorpyrifos-methyl	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Parathion-methyl	µg/L	2							<2.0			<2.0		<2.0															<2.0		<2.0
Malathion	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Fenthion	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Chlorpyrifos	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Parathion	µg/L	2							<2.0			<2.0		<2.0															<2.0		<2.0
Pirimphos-ethyl	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Chlorfenvinphos	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Bromophos-ethyl	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Fenamiphos	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Prothiofos	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Ethion	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Carbophenothion	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Azinphos Methyl	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Phenolic compounds																															
Phenol	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
2-Chlorophenol	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
2-Methylphenol	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
3- & 4-Methylphenol	µg/L	1							<2.0			<2.0		<2.0															<2.0		<2.0
2-Nitrophenol	µg/L	2							<1.0			<1.0		<1.0															<1.0		<1.0
2.4-Dimethylphenol	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
2.4-Dichlorophenol	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
2.6-Dichlorophenol	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
4-Chloro-3-methylphenol	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
2.4.6-Trichlorophenol	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
2.4.5-Trichlorophenol	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
Pentachlorophenol	µg/L	1							<2.0			<2.0		<2.0															<2.0		<2.0
Polynuclear aromatic hydrocarbons																															
Naphthalene	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
Acenaphthylene	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
Acenaphthene	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
Fluorene	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
Phenanthrene	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
Anthracene	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
Fluoranthene	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
Pyrene	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
Benz(a)anthracene	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
Chrysene	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
Benzo(b)fluoranthene	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
Benzo(k)fluoranthene	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
Benzo(a)pyrene	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Indeno(1.2.3.cd)pyrene	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
Dibenz(a.h)anthracene	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
Benzo(g.h.i)perylene	µg/L	1							<1.0			<1.0		<1.0															<1.0		<1.0
Sum of polycyclic aromatic hydrocarbor	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5
Benzo(a)pyrene TEQ (zero)	µg/L	0.5							<0.5			<0.5		<0.5															<0.5		<0.5

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0142PZC					HU0143PZC										
Analyte	Units	LOR	Aquatic	ANZECC (2000) Irrigation	Livestock	ADWG (2011)	24/09/2014	3/12/2014	26/03/2015	30/06/2015	17/09/2015	4/12/2014	25/03/2015	25/06/2015	23/09/2015	n	Detects	Exc	Min	Max	Avg	Geomean	Std Dev
Organochloride pesticides																							
alpha-BHC	µg/L	0.5							<0.5		<0.5					21	0						
Hexachlorobenzene (HCB)	µg/L	0.5							<0.5		<0.5					21	0						
beta-BHC	µg/L	0.5							<0.5		<0.5					21	0						
gamma-BHC	µg/L	0.5							<0.5		<0.5					21	0						
delta-BHC	µg/L	0.5							<0.5		<0.5					21	0						
Heptachlor	µg/L	0.5							<0.5		<0.5					21	0						
Aldrin	µg/L	0.5							<0.5		<0.5					21	0						
Heptachlor epoxide	µg/L	0.5							<0.5		<0.5					21	0						
trans-Chlordane	µg/L	0.5							<0.5		<0.5					21	0						
alpha-Endosulfan	µg/L	0.5							<0.5		<0.5					21	0						
cis-Chlordane	µg/L	0.5							<0.5		<0.5					21	0						
Dieldrin	µg/L	0.5							<0.5		<0.5					21	0						
4.4`-DDE	µg/L	0.5							<0.5		<0.5					21	0						
Endrin	µg/L	0.5							<0.5		<0.5					21	0						
beta-Endosulfan	µg/L	0.5							<0.5		<0.5					21	0						
4.4`-DDD	µg/L	0.5							<0.5		<0.5					21	0						
Endrin aldehyde	µg/L	0.5							<0.5		<0.5					21	0						
Endosulfan sulfate	µg/L	0.5							<0.5		<0.5					21	0						
4.4`-DDT	µg/L	2							<2.0		<2.0					21	0						
Endrin ketone	µg/L	0.5							<0.5		<0.5					21	0						
Methoxychlor	µg/L	2							<2.0		<2.0					21	0						
Total Chlordane (sum)	µg/L	0.5							<0.5		<0.5					21	0						
Sum of DDD + DDE + DDT	µg/L	0.5							<0.5		<0.5					21	0						
Sum of Aldrin + Dieldrin	µg/L	0.5							<0.5		<0.5					21	0						
Organophosphorous pesticides																							
Dichlorvos	µg/L	0.5							<0.5		<0.5					21	0						
Demeton-S-methyl	µg/L	0.5							<0.5		<0.5					21	0						
Monocrotophos	µg/L	2							<2.0		<2.0					21	0						
Dimethoate	µg/L	0.5							<0.5		<0.5					21	0						
Diazinon	µg/L	0.5							<0.5		<0.5					21	0						
Chlorpyrifos-methyl	µg/L	0.5							<0.5		<0.5					21	0						
Parathion-methyl	µg/L	2							<2.0		<2.0					21	0						
Malathion	µg/L	0.5							<0.5		<0.5					21	0						
Fenthion	µg/L	0.5							<0.5		<0.5					21	0						
Chlorpyrifos	µg/L	0.5							<0.5		<0.5					21	0						
Parathion	µg/L	2							<2.0		<2.0					21	0						
Pirimphos-ethyl	µg/L	0.5							<0.5		<0.5					21	0						
Chlorfenvinphos	µg/L	0.5							<0.5		<0.5					21	0						
Bromophos-ethyl	µg/L	0.5							<0.5		<0.5					21	0						
Fenamiphos	µg/L	0.5							<0.5		<0.5					21	0						
Prothiofos	µg/L	0.5							<0.5		<0.5					21	0						
Ethion	µg/L	0.5							<0.5		<0.5					21	0						
Carbophenothion	µg/L	0.5							<0.5		<0.5					21	0						
Azinphos Methyl	µg/L	0.5							<0.5		<0.5					21	0						
Phenolic compounds																							
Phenol	µg/L	1							<1.0		<1.0					21	0						
2-Chlorophenol	µg/L	1							<1.0		<1.0					21	0						
2-Methylphenol	µg/L	1							<1.0		<1.0					21	0						
3- & 4-Methylphenol	µg/L	1							<2.0		<2.0					21	1		4.7	4.7	4.7		
2-Nitrophenol	µg/L	2							<1.0		<1.0					21	0						
2.4-Dimethylphenol	µg/L	1							<1.0		<1.0					21	0						
2.4-Dichlorophenol	µg/L	1							<1.0		<1.0					21	0						
2.6-Dichlorophenol	µg/L	1							<1.0		<1.0					21	0						
4-Chloro-3-methylphenol	µg/L	1							<1.0		<1.0					21	0						
2.4.6-Trichlorophenol	µg/L	1							<1.0		<1.0					21	0						
2.4.5-Trichlorophenol	µg/L	1							<1.0		<1.0					21	0						
Pentachlorophenol	µg/L	1							<2.0		<2.0					21	0						
Polynuclear aromatic hydrocarbons																							
Naphthalene	µg/L	1							<1.0		<1.0					21	0						
Acenaphthylene	µg/L	1							<1.0		<1.0					21	0						
Acenaphthene	µg/L	1							<1.0		<1.0					21	0						
Fluorene	µg/L	1							<1.0		<1.0					21	0						
Phenanthrene	µg/L	1							<1.0		<1.0					21	0						
Anthracene	µg/L	1							<1.0		<1.0					21	0						
Fluoranthene	µg/L	1							<1.0		<1.0					21	0						
Pyrene	µg/L	1							<1.0		<1.0					21	0						
Benz(a)anthracene	µg/L	1							<1.0		<1.0					21	0						
Chrysene	µg/L	1							<1.0		<1.0					21	0						
Benzo(b)fluoranthene	µg/L	1							<1.0		<1.0					21	0						
Benzo(k)fluoranthene	µg/L	1							<1.0		<1.0					21	0						
Benzo(a)pyrene	µg/L	0.5							<0.5		<0.5					21	0						
Indeno(1.2.3.cd)pyrene	µg/L	1							<1.0		<1.0					21	0						
Dibenz(a.h)anthracene	µg/L	1							<1.0		<1.0					21	0						
Benzo(g.h.i)perylene	µg/L	1							<1.0		<1.0					21	0						
Sum of polycyclic aromatic hydrocarbon	µg/L	0.5							<0.5		<0.5					21	0						
Benzo(a)pyrene TEQ (zero)	µg/L	0.5							<0.5		<0.5					21	0						

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0018PZB										HU0019PZB						HU0023PZB				HU0023PZC			
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	17/10/2011	7/01/2013	22/03/2013	9/07/2013	16/10/2013	12/12/2013	8/04/2014	25/03/2015	2/07/2015	24/09/2015	18/10/2011	29/08/2012	4/01/2013	17/12/2013	9/04/2014	4/02/2015	16/11/2011	18/12/2012	25/03/2013	21/05/2014	15/11/2011	18/12/2012	25/03/2013	21/05/2014
BTEX																														
Benzene	µg/L	1										<1				<1				<1										
Toluene	µg/L	2	ID			800						<2				<2				<2										
Ethylbenzene	µg/L	2										<2				<2				<2										
meta- & para-Xylene	µg/L	2										<2				<2				<2										
ortho-Xylene	µg/L	2										<2				<2				<2										
Total Xylenes	µg/L	2										<2				<2				<2										
Sum of BTEX	µg/L	1										<1				<1				<1										
Naphthalene	µg/L	5										<5				<5				<5										
Total petroleum hydrocarbons																														
C6 - C9 Fraction	µg/L	20										<20				<20				<20										
C10 - C14 Fraction	µg/L	50										<50				<50				<50										
C15 - C28 Fraction	µg/L	100										<100				<100				<100										
C29 - C36 Fraction	µg/L	50										<50				<50				<50										
C10 - C36 Fraction (sum)	µg/L	50										<50				<50				<50										
Total Recoverable Hydrocarbons																														
C6 - C10 Fraction	µg/L	20										<20				<20				<20										
C6 - C10 Fraction minus BTEX (F1)	µg/L	20										<20				<20				<20										
>C10 - C16 Fraction	µg/L	100										<100				<100				<100										
>C16 - C34 Fraction	µg/L	100										<100				<100				<100										
>C34 - C40 Fraction	µg/L	100										<100				<100				<100										
>C10 - C40 Fraction (sum)	µg/L	100										<100				<100				<100										
>C10 - C16 Fraction minus Naphthalene	µg/L	100										<100				<100				<100										
Microbiology																														
Faecal coliforms	CFU/100 mL	1										<1				<1				<1										
E coli	CFU/100 mL	1										<1				<1				<1										
Total coliforms	CFU/100 mL	1										<1				<1				<1										

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0032LDB				HU0037PZB				HU0038PZC								HU0042PZC					HU0043PZB			
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	12/12/2013	3/04/2014	26/03/2015	24/09/2015	29/08/2012	20/12/2012	18/12/2013	3/02/2015	24/07/2012	14/12/2012	11/12/2013	2/04/2014	15/08/2014	2/12/2014	12/02/2015	15/09/2015	26/03/2013	3/07/2013	19/08/2013	17/12/2013	2/02/2015	31/08/2012	3/01/2013	18/12/2013	5/02/2015
BTEX																															
Benzene	µg/L	1					<1						<1				<1				<1					<1					
Toluene	µg/L	2	ID			800	<2						7				<2				<2					20					
Ethylbenzene	µg/L	2					<2						<2				<2				<2					<2					
meta- & para-Xylene	µg/L	2					<2						<2				<2				<2					<2					
ortho-Xylene	µg/L	2					<2						<2				<2				<2					<2					
Total Xylenes	µg/L	2					<2						<2				<2				<2					<2					
Sum of BTEX	µg/L	1					<1						7				<1				<1					20					
Naphthalene	µg/L	5					<5						<5				<5				<5					<5					
Total petroleum hydrocarbons																															
C6 - C9 Fraction	µg/L	20					<20						<20				<20				<20					40					
C10 - C14 Fraction	µg/L	50					<50						<50				<50				<50					<50					
C15 - C28 Fraction	µg/L	100					<100						<100				<100				<100					<100					
C29 - C36 Fraction	µg/L	50					<50						<50				<50				<50					<50					
C10 - C36 Fraction (sum)	µg/L	50					<50						<50				<50				<50					<50					
Total Recoverable Hydrocarbons																															
C6 - C10 Fraction	µg/L	20					<20						<20				<20				<20					40					
C6 - C10 Fraction minus BTEX (F1)	µg/L	20					<20						<20				<20				<20					20					
>C10 - C16 Fraction	µg/L	100					<100						<100				<100				<100					<100					
>C16 - C34 Fraction	µg/L	100					<100						<100				<100				<100					<100					
>C34 - C40 Fraction	µg/L	100					<100						<100				<100				<100					<100					
>C10 - C40 Fraction (sum)	µg/L	100					<100						<100				<100				<100					<100					
>C10 - C16 Fraction minus Naphthalene	µg/L	100					<100						<100				<100				<100					<100					
Microbiology																															
Faecal coliforms	CFU/100 mL	1					<1						<1				<1				<1					<1					
E coli	CFU/100 mL	1					<1						<1				<1				<1					<1					
Total coliforms	CFU/100 mL	1					<1						~1				10				11					<1					

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0044XPZB									HU0056XPZB					HU0072PZB									
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	23/08/2012	14/12/2012	26/03/2013	2/07/2013	18/09/2013	10/12/2013	25/03/2014	24/07/2014	3/02/2015	19/12/2012	19/12/2013	25/09/2014	13/11/2014	5/02/2015	21/03/2013	8/07/2013	18/09/2013	11/12/2013	26/03/2014	14/08/2014	2/12/2014	25/03/2015	26/06/2015	17/09/2015
BTEX																														
Benzene	µg/L	1																						<1						
Toluene	µg/L	2	ID			800																		<2						
Ethylbenzene	µg/L	2																						<2						
meta- & para-Xylene	µg/L	2																						<2						
ortho-Xylene	µg/L	2																						<2						
Total Xylenes	µg/L	2																						<2						
Sum of BTEX	µg/L	1																						<1						
Naphthalene	µg/L	5																						<5						
Total petroleum hydrocarbons																														
C6 - C9 Fraction	µg/L	20																						<20						
C10 - C14 Fraction	µg/L	50																						<50						
C15 - C28 Fraction	µg/L	100																						<100						
C29 - C36 Fraction	µg/L	50																						<50						
C10 - C36 Fraction (sum)	µg/L	50																						<50						
Total Recoverable Hydrocarbons																														
C6 - C10 Fraction	µg/L	20																						<20						
C6 - C10 Fraction minus BTEX (F1)	µg/L	20																						<20						
>C10 - C16 Fraction	µg/L	100																						<100						
>C16 - C34 Fraction	µg/L	100																						<100						
>C34 - C40 Fraction	µg/L	100																						<100						
>C10 - C40 Fraction (sum)	µg/L	100																						<100						
>C10 - C16 Fraction minus Naphthalene	µg/L	100																						<100						
Microbiology																														
Faecal coliforms	CFU/100 mL	1																						<1						
E coli	CFU/100 mL	1																						<1						
Total coliforms	CFU/100 mL	1																						<1						

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0072PZC										HU0073PZC									HU0088PZB				
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	21/03/2013	8/07/2013	18/09/2013	11/12/2013	26/03/2014	14/08/2014	2/12/2014	25/03/2015	26/06/2015	15/09/2015	27/03/2013	7/08/2013	15/10/2013	10/12/2013	3/04/2014	5/12/2014	26/03/2015	29/06/2015	21/09/2015	10/12/2013	2/04/2014	26/09/2014	3/12/2014	11/02/2015
BTEX																														
Benzene	µg/L	1								<1										<1			<1		<1					<1
Toluene	µg/L	2	ID			800				<2										<2			<2		<2					6
Ethylbenzene	µg/L	2								<2										<2			<2		<2					<2
meta- & para-Xylene	µg/L	2								<2										<2			<2		<2					<2
ortho-Xylene	µg/L	2								<2										<2			<2		<2					<2
Total Xylenes	µg/L	2								<2										<2			<2		<2					<2
Sum of BTEX	µg/L	1								<1										<1			<1		<1					6
Naphthalene	µg/L	5								<5										<5			<5		<5					<5
Total petroleum hydrocarbons																														
C6 - C9 Fraction	µg/L	20								<20										<20			<20		<20					<20
C10 - C14 Fraction	µg/L	50								<50										<50			<50		<50					<50
C15 - C28 Fraction	µg/L	100								<100										<100			<100		<100					<100
C29 - C36 Fraction	µg/L	50								<50										<50			<50		<50					<50
C10 - C36 Fraction (sum)	µg/L	50								<50										<50			<50		<50					<50
Total Recoverable Hydrocarbons																														
C6 - C10 Fraction	µg/L	20								<20										<20			<20		<20					<20
C6 - C10 Fraction minus BTEX (F1)	µg/L	20								<20										<20			<20		<20					<20
>C10 - C16 Fraction	µg/L	100								<100										<100			<100		<100					<100
>C16 - C34 Fraction	µg/L	100								<100										<100			<100		<100					<100
>C34 - C40 Fraction	µg/L	100								<100										<100			<100		<100					<100
>C10 - C40 Fraction (sum)	µg/L	100								<100										<100			<100		<100					<100
>C10 - C16 Fraction minus Naphthalene	µg/L	100								<100										<100			<100		<100					<100
Microbiology																														
Faecal coliforms	CFU/100 mL	1								<1										<1			<1		<1					<1
E coli	CFU/100 mL	1								<1										<1			<1		<1					<1
Total coliforms	CFU/100 mL	1								<1										<1			<1		<1					–1

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0096PZC								HU0118PZA				HU0129PZB				HU0133PZC	HU0136PZB			HU0142PZB				
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	8/08/2013	16/10/2013	9/12/2013	31/03/2014	5/12/2014	27/03/2015	7/07/2015	22/09/2015	20/03/2014	25/08/2014	1/12/2014	6/02/2015	22/05/2014	10/02/2015	24/06/2015	16/09/2015	23/05/2014	29/08/2014	1/12/2014	4/02/2015	24/09/2014	1/12/2014	26/03/2015	30/06/2015	17/09/2015
BTEX																															
Benzene	µg/L	1							<1			<1		<1															<1		<1
Toluene	µg/L	2	ID			800			<2			<2		8															<2		<2
Ethylbenzene	µg/L	2							<2			<2		<2															<2		<2
meta- & para-Xylene	µg/L	2							<2			<2		<2															<2		<2
ortho-Xylene	µg/L	2							<2			<2		<2															<2		<2
Total Xylenes	µg/L	2							<2			<2		<2															<2		<2
Sum of BTEX	µg/L	1							<1			<1		8															<1		<1
Naphthalene	µg/L	5							<5			<5		<5															<5		<5
Total petroleum hydrocarbons																															
C6 - C9 Fraction	µg/L	20							<20			<20		<20															<20		<20
C10 - C14 Fraction	µg/L	50							<50			<50		<50															<50		<50
C15 - C28 Fraction	µg/L	100							<100			<100		<100															<100		<100
C29 - C36 Fraction	µg/L	50							<50			<50		<50															<50		<50
C10 - C36 Fraction (sum)	µg/L	50							<50			<50		<50															<50		<50
Total Recoverable Hydrocarbons																															
C6 - C10 Fraction	µg/L	20							<20			<20		<20															<20		<20
C6 - C10 Fraction minus BTEX (F1)	µg/L	20							<20			<20		<20															<20		<20
>C10 - C16 Fraction	µg/L	100							<100			<100		<100															<100		<100
>C16 - C34 Fraction	µg/L	100							<100			<100		<100															<100		<100
>C34 - C40 Fraction	µg/L	100							<100			<100		<100															<100		<100
>C10 - C40 Fraction (sum)	µg/L	100							<100			<100		<100															<100		<100
>C10 - C16 Fraction minus Naphthalene	µg/L	100							<100			<100		<100															<100		<100
Microbiology																															
Faecal coliforms	CFU/100 mL	1							<1			<2		<1															<2		<1
E coli	CFU/100 mL	1							<1			<2		<1															<2		<1
Total coliforms	CFU/100 mL	1							~<1			<2		<1															54		~1

Table A3: Baseline Groundwater Monitoring Results - Hawkesbury Sandstone

			Water Quality Criteria				HU0142PZC					HU0143PZC									
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	24/09/2014	3/12/2014	26/03/2015	30/06/2015	17/09/2015	4/12/2014	25/03/2015	25/06/2015	23/09/2015						
BTEX																					
Benzene	µg/L	1							<1		<1					21	0						
Toluene	µg/L	2	ID			800			<2		<2					21	4		6	20	10.25		
Ethylbenzene	µg/L	2							<2		<2					21	0						
meta- & para-Xylene	µg/L	2							<2		<2					21	0						
ortho-Xylene	µg/L	2							<2		<2					21	0						
Total Xylenes	µg/L	2							<2		<2					21	0						
Sum of BTEX	µg/L	1							<1		<1					21	4		6	20	10.25		
Naphthalene	µg/L	5							<5		<5					21	0						
Total petroleum hydrocarbons																							
C6 - C9 Fraction	µg/L	20							<20		<20					21	1		40	40	40		
C10 - C14 Fraction	µg/L	50							<50		<50					21	0						
C15 - C28 Fraction	µg/L	100							<100		<100					21	0						
C29 - C36 Fraction	µg/L	50							<50		<50					21	0						
C10 - C36 Fraction (sum)	µg/L	50							<50		<50					21	0						
Total Recoverable Hydrocarbons																							
C6 - C10 Fraction	µg/L	20							<20		<20					21	1		40	40	40		
C6 - C10 Fraction minus BTEX (F1)	µg/L	20							<20		<20					21	1		20	20	20		
>C10 - C16 Fraction	µg/L	100							<100		<100					21	0						
>C16 - C34 Fraction	µg/L	100							<100		<100					21	0						
>C34 - C40 Fraction	µg/L	100							<100		<100					21	0						
>C10 - C40 Fraction (sum)	µg/L	100							<100		<100					21	0						
>C10 - C16 Fraction minus Naphthalene	µg/L	100							<100		<100					21	0						
Microbiology																							
Faecal coliforms	CFU/100 mL	1							<2		<1					21	0						
E coli	CFU/100 mL	1							<2		<1					21	0						
Total coliforms	CFU/100 mL	1							<2		<1					21	3		10	54	25		

Table A4: Baseline Groundwater Monitoring Results - Illawarra Coal Measures

Location			Water Quality Criteria				HU0073PZA									HU0143PZA				HU0133PZA								
Date			ANZECC (2000)			ADWG (2011)	27/03/2013	6/08/2013	15/10/2013	10/12/2013	3/04/2014	5/12/2014	26/03/2015	29/06/2015	21/09/2015	4/12/2014	25/03/2015	25/06/2015	23/09/2015	23/05/2014								
Analyte	Units	LOR	Aquatic	Irrigation	Livestock																n	Detects	Exc	Min	Max	Avg	Geomean	Std Dev
General field parameters																												
pH	pH units		6.5-7.5				6.93	7.01	7.13	6.99	7	7.12	6.67	6.97	7.09	6.10	6.45	6.66	6.50	6.35	14	14	3	6.1	7.13	6.65	6.78	0.33
Conductivity (field)	µS/cm		30-350	0-650 (v. low) >650-1300 (low) >1300-2900 (medium) >2900-5200 (high) >5200-8100 (v. high) >8100 (extreme)			770	652	740	703	670	811	1190	600	607	243	640	397.5	324	255	14	14	11	243	1190	614	562	251
Conductivity (lab)	µS/cm	1	30-350								713			607				384	290		4	4	3	290	713	499	469	195
Total Dissolved Solids (field)	mg/L					<600 (good quality) 600-900 (fair quality) >900-1200 (poor quality) >1200 (unacceptable)	501	401	481	456	442	527	773.5	390	345	158	416	397	211	166	14	14		158	774	405	372	159
Total Dissolved Solids (lab)	mg/L	10									355		909	308	346			164	156	141	7	7		141	909	340	277	268
Dissolved oxygen	% sat		90-110				3.3	8.5	17.2	14.6	12.1	21.2	16.3	15.7	10.3	62.4	12.8	80.6	12.0	44.5	14	14		3.3	80.6	23.7	17	23
Redox	mV						-128	11	-71.5	-79.4	-102.5	-81.8	1.45	-130.1	-179.5	29.5	-99.2	-47	-139	-36.3	14	14		-179.5	29.5	-75.2		61
Temperature	ºC						20.82	20.4	19.82	21.1	20	19.4	18.8	16.7	17.96	19.47	18.4	15.5	16.14	21.1	14	14		15.5	21.1	19.0	19	2
Suspended Solids	mg/L	5												<5	<5			<5	21		4	1		21	21	21.0	21	
Turbididty	NTU	0.1	2-25				2-25														1	0						
Major Ions																												
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	14	0						
Carbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	14	0						
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	275	336	314	282	272	293	273	302	275	71	174	109	115	84	14	14		71	336	227	202	94
Total Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	275	336	314	282	272	293	273	302	275	71	174	109	115	84	14	14		71	336	227	202	94
Acidity as $CaCO_3$	mg/L	1	-	-	-	-								23				18			2	2		18	23	21	20	4
Sulfate as SO_4^{2-}	mg/L	1	-	-	1000	500	42	16	15	12	9	22	7	10	8	28	119	36	16	4	14	14	0	4	119	24.6	16	29
Chloride	mg/L	1	-	700	-	ID	63	46	51	47	44	78	261	25	26	27	39	33	21	30	14	14	0	21	261	56.5	44	61
Calcium	mg/L	1	-	-	1000	-	85	79	76	74	74	70	117	71	66	18	44	24	22	13	14	14	0	13	117	59.5	39	31
Magnesium	mg/L	1	-	-	ID	-	31	30	28	26	27	33	47	24	25	8	26	14	14	8	14	14		8	47	24.4	22	11
Sodium	mg/L	1	-	460	-	-	23	25	28	24	28	46	50	22	26	18	40	34	26	17	14	14	0	17	50	29.1	28	10
Potassium	mg/L	1	-	-	-	-	7	8	8	6	9	6	8	7	7	2	4	3	3	3	14	14		2	9	5.79	5	2
Silica/Silicon as SiO_2/Reactive silica	mg/L	0.1	-	-	-	-	6.7	8.4	9.4	8.7	9.3	10.6	11.8	9.2	9.52	9.3	13.7	9.9	9.4	9.95	14	14		6.7	13.7	9.7	10	2
Total Anions	meq/L	0.01	-	-	-	-	8.15	8.34	8.02	7.21	7.11	8.51	13	6.95		2.76	7.05	3.86	3.22	2.61								
Total Cations	meq/L	0.01	-	-	-	-	7.97	8.02	7.72	7.03	7.36	8.36	12.1	6.65		2.39	6.66	3.9	3.46	2.42								
Ionic Balance	%	0.01	-	-	-	-	1.06	2.01	1.96	1.25	1.77	0.88	3.47	2.15			2.93	0.6	3.5									
Other Inorganics																												
Flouride	mg/L	0.1	-	2	2	1.5				0.6	0.6		0.4	0.6	0.7			0.2		0.3	7	7		0.2	0.7	0.5	0.4	0.2
Free cyanide	mg/L	0.004	0.007	-	-	0.08				<0.004			<0.004							<0.004	3	0						
Total cyanide	mg/L	0.004	-	-	-	-				<0.004			<0.004							<0.004	3	0						
Thiocyanate	mg/L	0.1	-	-	-	-				<0.1			<0.1							<0.1	3	0						
Dissolved metals																												
Aluminium	mg/L	0.01	0.055	20	5	ID				<0.01	0.06	<0.01	0.04	<0.01	<0.01	0.02	0.01	<0.01	<0.01	0.02	11	5	1	0.01	0.06	0.03	0.02	0.02
Antimony	mg/L	0.001	ID	-	-	0.003				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	11	0						
Arsenic	mg/L	0.001	0.013	2	0.5	0.01				0.016	0.013	0.004	0.001	0.011	0.012	0.002	0.022	0.027	0.013	0.001	11	11		0.001	0.027	0.01	0.01	0.01
Beryllium	mg/L	0.001	ID	0.5	ID	0.06				<0.001			<0.001		<0.001					<0.001	4	0						
Barium	mg/L	0.001	-	-	-	2				1.05			2.59	0.939	0.978			0.131		0.106	6	6		0.106	2.59	0.97	0.57	0.90
Cadmium	mg/L	0.0001	0.0002	0.05	0.01	0.002				<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	11	1		0.0002	0.0002	0.00	0.00	#DIV/0!
Chromium	mg/L	0.001	0.001	1	1	0.05				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	11	0						
Cobalt	mg/L	0.001	ID	0.1	1	-				0.003	0.002	0.001	0.002	<0.001	<0.001	0.009	0.016	0.006	0.004	0.003	11	9		0.001	0.016	0.005	0.004	0.005
Copper	mg/L	0.001	0.0014	5	1#	2				0.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.002	<0.001	<0.001	<0.001	11	3	3	0.002	0.002	0.002	0.002	0.0
Lead	mg/L	0.001	0.0034	5	0.1	0.01				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	11	1	0	0.001	0.001	0.001	0.001	
Lithium	mg/L	0.001	-	2.5	-	-				0.18			0.143		0.181					0.038	4	4		0.038	0.181	0.136	0.115	0.067
Manganese	mg/L	0.001	1.9	10	-	0.5	0.330	0.162	0.143	0.165	0.113	0.377	0.586	0.104	0.076	0.563	0.744	0.365	0.3	0.406	14	14	0	0.076	0.744	0.317	0.254	0.206
Molybdenum	mg/L	0.001	ID	0.05	0.15	0.05				0.004	0.003	0.002	<0.001	0.004	0.005	<0.001	0.002	<0.001	<0.001	0.002	11	7		0.002	0.005	0.003	0.003	0.001
Nickel	mg/L	0.001	0.011	2	1	0.02				0.003	0.002	0.004	0.004	<0.001	<0.001	0.038	0.029	0.012	0.008	0.006	11	9	3	0.002	0.038	0.012	0.007	0.013
Selenium	mg/L	0.01	0.005	0.05	0.02	0.01				<0.01	<0.01	<0.01	<0.1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	11	0						
Strontium	mg/L	0.001	-	-	-	-				0.433			0.602	0.33	0.357			0.158		0.116	6	6		0.116	0.602	0.333	0.287	0.179
Tin	mg/L	0.001	ID	-	-	-				<0.001			<0.001		<0.001					<0.001	4	0						
Uranium	mg/L	0.001	ID	0.1	0.2	0.017				0.002			<0.001		<0.001					<0.001	4	1		0.002	0.002	0.002	0.002	
Vanadium	mg/L	0.01	ID	0.5	ID	-				<0.01			<0.1		<0.01					<0.01	4	0						
Zinc	mg/L	0.005	0.008	5	20	ID				0.012	0.013	<0.005	0.019	<0.005	<0.005	0.517	0.04	0.012	0.026	0.012	11	8	8	0.012	0.517	0.081	0.034	0.176
Boron	mg/L	0.05	0.37	5	5	4				0.07	<0.05	<0.05	<0.05	<0.05	0.08	<0.05	<0.05	<0.05	<0.05	<0.05	11	2		0.07	0.08	0.075	0.075	0.007
Iron	mg/L	0.05	ID	10	ID	ID	1.59	1.03	0.84	1.16	1	2.16	5.28	0.86	0.65	0.84	8.9	5.48	4.75	4.23	14	14	0	0.65	8.9	2.8	2.59	2.53
Ferrous iron	mg/L	0.05	-	-	-	ID								1.17	0.88			6.4	5.16		4	4		0.88	6.4	3.40	2.41	2.79
Bromine	mg/L	0.1	-	-	-	-				0.5			0.6		0.2					0.1	4	4		0.1	0.6	0.4	0.3	0.2
Iodine	mg/L	0.1	-	-	-	ID				<0.1			<0.1		<0.1					<0.1	4	0						
Mercury	mg/L	0.0001	0.00006	0.002	0.002	0.001				<0.0001			<0.0001							<0.0001	3	0						
Total metals																												
Aluminium	mg/L	0.01	-	-	-	-				0.02			0.36		<0.01					0.03	4	3		0.02	0.36	0.14	0.06	0.19
Manganese	mg/L	0.001	-	-	-	-				0.166			0.588	0.103	0.094			0.366	0.316	0.398	7	7		0.094	0.588	0.290	0.238	0.181
Iron	mg/L	0.05	-	-	-	-				1.06			7.23	1.11	0.97			6.19	5.79	4.65	7	7		0.97	7.23	3.86	2.81	2.74
Nutrients																												
Ammonia as N	mg/L	0.01	2.57							0.25			0.26		0.23					0.08	4	4		0.08	0.26	0.21	0.19	0.08
Nitrite as N	mg/L	0.01			9					<0.01	<0.01		<0.1		<0.01					<0.01	5	0						
Nitrate as N	mg/L	0.01			90					0.03	<0.01		<0.01		<0.01					<0.01	5	1		0.03	0.03	0.03	0.03	
Total phosphorous	mg/L	0.01								0.06			0.13							<0.01	3	2		0.06	0.13	0.10	0.09	0.05
Reactive phosphorous	mg/L	0.01								<0.01	<0.01		<0.01		<0.01					<0.01	5	0						

Table A4: Baseline Groundwater Monitoring Results - Illawarra Coal Measures

Location			Water Quality Criteria				HU0073PZA									HU0143PZA				HU0133PZA
Date			ANZECC (2000)			ADWG (2011)	27/03/2013	6/08/2013	15/10/2013	10/12/2013	3/04/2014	5/12/2014	26/03/2015	29/06/2015	21/09/2015	4/12/2014	25/03/2015	25/06/2015	23/09/2015	23/05/2014
Analyte	Units	LOR	Aquatic	Irrigation	Livestock															
Organochloride pesticides																				
alpha-BHC	µg/L	0.5								<0.5			<0.5		<0.5					
Hexachlorobenzene (HCB)	µg/L	0.5								<0.5			<0.5		<0.5					
beta-BHC	µg/L	0.5								<0.5			<0.5		<0.5					
gamma-BHC	µg/L	0.5								<0.5			<0.5		<0.5					
delta-BHC	µg/L	0.5								<0.5			<0.5		<0.5					
Heptachlor	µg/L	0.5								<0.5			<0.5		<0.5					
Aldrin	µg/L	0.5								<0.5			<0.5		<0.5					
Heptachlor epoxide	µg/L	0.5								<0.5			<0.5		<0.5					
trans-Chlordane	µg/L	0.5								<0.5			<0.5		<0.5					
alpha-Endosulfan	µg/L	0.5								<0.5			<0.5		<0.5					
cis-Chlordane	µg/L	0.5								<0.5			<0.5		<0.5					
Dieldrin	µg/L	0.5								<0.5			<0.5		<0.5					
4.4`-DDE	µg/L	0.5								<0.5			<0.5		<0.5					
Endrin	µg/L	0.5								<0.5			<0.5		<0.5					
beta-Endosulfan	µg/L	0.5								<0.5			<0.5		<0.5					
4.4`-DDD	µg/L	0.5								<0.5			<0.5		<0.5					
Endrin aldehyde	µg/L	0.5								<0.5			<0.5		<0.5					
Endosulfan sulfate	µg/L	0.5								<0.5			<0.5		<0.5					
4.4`-DDT	µg/L	2								<2.0			<2.0		<2.0					
Endrin ketone	µg/L	0.5								<0.5			<0.5		<0.5					
Methoxychlor	µg/L	2								<2.0			<2.0		<2.0					
Total Chlordane (sum)	µg/L	0.5								<0.5			<0.5		<0.5					
Sum of DDD + DDE + DDT	µg/L	0.5								<0.5			<0.5		<0.5					
Sum of Aldrin + Dieldrin	µg/L	0.5								<0.5			<0.5		<0.5					
Organophosphorous pesticides																				
Dichlorvos	µg/L	0.5								<0.5			<0.5		<0.5					
Demeton-S-methyl	µg/L	0.5								<0.5			<0.5		<0.5					
Monocrotophos	µg/L	2								<2.0			<2.0		<2.0					
Dimethoate	µg/L	0.5								<0.5			<0.5		<0.5					
Diazinon	µg/L	0.5								<0.5			<0.5		<0.5					
Chlorpyrifos-methyl	µg/L	0.5								<0.5			<0.5		<0.5					
Parathion-methyl	µg/L	2								<2.0			<2.0		<2.0					
Malathion	µg/L	0.5								<0.5			<0.5		<0.5					
Fenthion	µg/L	0.5								<0.5			<0.5		<0.5					
Chlorpyrifos	µg/L	0.5								<0.5			<0.5		<0.5					
Parathion	µg/L	2								<2.0			<2.0		<2.0					
Pirimphos-ethyl	µg/L	0.5								<0.5			<0.5		<0.5					
Chlorfenvinphos	µg/L	0.5								<0.5			<0.5		<0.5					
Bromophos-ethyl	µg/L	0.5								<0.5			<0.5		<0.5					
Fenamiphos	µg/L	0.5								<0.5			<0.5		<0.5					
Prothiofos	µg/L	0.5								<0.5			<0.5		<0.5					
Ethion	µg/L	0.5								<0.5			<0.5		<0.5					
Carbophenothion	µg/L	0.5								<0.5			<0.5		<0.5					
Azinphos Methyl	µg/L	0.5								<0.5			<0.5		<0.5					
Phenolic compounds																				
Phenol	µg/L	1								<1.0			<1.0		<1.0					
2-Chlorophenol	µg/L	1								<1.0			<1.0		<1.0					
2-Methylphenol	µg/L	1								<1.0			<1.0		<1.0					
3- & 4-Methylphenol	µg/L	1								<2.0			<2.0		<2.0					
2-Nitrophenol	µg/L	2								<1.0			<1.0		<1.0					
2.4-Dimethylphenol	µg/L	1								<1.0			<1.0		<1.0					
2.4-Dichlorophenol	µg/L	1								<1.0			<1.0		<1.0					
2.6-Dichlorophenol	µg/L	1								<1.0			<1.0		<1.0					
4-Chloro-3-methylphenol	µg/L	1								<1.0			<1.0		<1.0					
2.4.6-Trichlorophenol	µg/L	1								<1.0			<1.0		<1.0					
2.4.5-Trichlorophenol	µg/L	1								<1.0			<1.0		<1.0					
Pentachlorophenol	µg/L	1								<2.0			<2.0		<2.0					
Polynuclear aromatic hydrocarbons																				
Naphthalene	µg/L	1								<1.0			<1.0		<1.0					
Acenaphthylene	µg/L	1								<1.0			<1.0		<1.0					
Acenaphthene	µg/L	1								<1.0			<1.0		<1.0					
Fluorene	µg/L	1								<1.0			<1.0		<1.0					
Phenanthrene	µg/L	1								<1.0			<1.0		<1.0					
Anthracene	µg/L	1								<1.0			<1.0		<1.0					
Fluoranthene	µg/L	1								<1.0			<1.0		<1.0					
Pyrene	µg/L	1								<1.0			<1.0		<1.0					
Benz(a)anthracene	µg/L	1								<1.0			<1.0		<1.0					
Chrysene	µg/L	1								<1.0			<1.0		<1.0					
Benzo(b)fluoranthene	µg/L	1								<1.0			<1.0		<1.0					
Benzo(k)fluoranthene	µg/L	1								<1.0			<1.0		<1.0					
Benzo(a)pyrene	µg/L	0.5								<0.5			<0.5		<0.5					
Indeno(1.2.3.cd)pyrene	µg/L	1								<1.0			<1.0		<1.0					
Dibenz(a.h)anthracene	µg/L	1								<1.0			<1.0		<1.0					
Benzo(g.h.i)perylene	µg/L	1								<1.0			<1.0		<1.0					
Sum of polycyclic aromatic hydrocarbons	µg/L	0.5								<0.5			<0.5		<0.5					
Benzo(a)pyrene TEQ (zero)	µg/L	0.5								<0.5			<0.5		<0.5					

Table A4: Baseline Groundwater Monitoring Results - Illawarra Coal Measures

Location			Water Quality Criteria				HU0073PZA									HU0143PZA				HU0133PZA
Date			ANZECC (2000)			ADWG (2011)	27/03/2013	6/08/2013	15/10/2013	10/12/2013	3/04/2014	5/12/2014	26/03/2015	29/06/2015	21/09/2015	4/12/2014	25/03/2015	25/06/2015	23/09/2015	23/05/2014
Analyte	Units	LOR	Aquatic	Irrigation	Livestock															
BTEX																				
Benzene	µg/L	1								<1			<1		<1					
Toluene	µg/L	2	ID			800				<2			<2		<2					
Ethylbenzene	µg/L	2								<2			<2		<2					
meta- & para-Xylene	µg/L	2								<2			<2		<2					
ortho-Xylene	µg/L	2								<2			<2		<2					
Total Xylenes	µg/L	2								<2			<2		<2					
Sum of BTEX	µg/L	1								<1			<1		<1					
Naphthalene	µg/L	5								<5			<5		<5					
Total petroleum hydrocarbons																				
C6 - C9 Fraction	µg/L	20								<20			<20		<20					
C10 - C14 Fraction	µg/L	50								<50			<50		<50					
C15 - C28 Fraction	µg/L	100								<100			<100		<100					
C29 - C36 Fraction	µg/L	50								<50			<50		<50					
C10 - C36 Fraction (sum)	µg/L	50								<50			<50		<50					
Total Recoverable Hydrocarbons																				
C6 - C10 Fraction	µg/L	20								<20			<20		<20					
C6 - C10 Fraction minus BTEX (F1)	µg/L	20								<20			<20		<20					
>C10 - C16 Fraction	µg/L	100								<100			<100		<100					
>C16 - C34 Fraction	µg/L	100								<100			<100		<100					
>C34 - C40 Fraction	µg/L	100								<100			<100		<100					
>C10 - C40 Fraction (sum)	µg/L	100								<100			<100		<100					
>C10 - C16 Fraction minus Naphthalene (F	µg/L	100								<100			<100		<100					
Microbiology																				
Faecal coliforms	CFU/100 m	1								<1			<2		<1					
E coli	CFU/100 m	1								<1			<2		<1					
Total coliforms	CFU/100 m	1								<1			~<2		~<1					

Table A5: Baseline Groundwater Monitoring Results - Wongawilli Seam

Location			Water Quality Criteria				HU0018PZA										HU0023PZA				HU0032LDA				HU0038PZA							
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	17/10/2011	7/01/2013	22/03/2013	9/07/2013	17/10/2013	12/12/2013	8/04/2014	25/03/2015	2/07/2015	24/09/2015	16/11/2011	17/12/2012	25/03/2013	21/05/2014	12/12/2013	3/04/2014	26/03/2015	24/09/2015	24/07/2012	14/12/2012	11/12/2013	2/04/2014	15/08/2014	2/12/2014	12/02/2015	15/09/2015
General field parameters																																
pH	pH units		6.5-7.5				6.41	6.28	6.18	6.44	6.34	6.24	6.01	6.91	6.07	6.00	6.9	6.43	6.34	6.53	6.20	5.81	5.86	6.16	6.18	6.27	6.12	6.00	6.11	5.92	5.99	6.12
Conductivity (field)	µS/cm		30-350	0-650 (v. low) >650-1300 (low) >1300-2900 (medium) >2900-5200 (high) >5200-8100 (v. high) >8100 (extreme)			509	425	419	504	437	329	260	1090	265	255	1706	540	356	406	158	159	160.4	162	208	210	201	197	187	260	222	191
Conductivity (lab)	µS/cm	1	30-350												256							152		125				207				152
Total Dissolved Solids (field)	g/L					<600 (good quality) 600-900 (fair quality) >900-1200 (poor quality) >1200 (unacceptable)	330	276	272	327	284	214	169	1047	172	166	1109	351	231	264	103	105	104	105	136	137	131	127	121	189	144	124
Total Dissolved Solids (lab)	mg/L	10										195			135	104						88		93							110	98
Dissolved oxygen	% sat		90-110				19.1	3.5	7.7	20.5	19.6	10.4	16	5.3	30.9	10.3	11.4	16.2	16	29.1	21.6	18.8	26.9	10.5	3.5	12.8	17.4	16.8	6.5	24.6	27.5	11.0
Redox	mV						-16	-191.6	-98.7	-89.7	-52.3	-93.5	-66.9	-201.6	-72.3	-114.0	-150.5	-37.6	-67.6	-25.1	-10.6	-16.5	-56.7	-121.2	-110.5	-61.9	-33.0	-31.7	-6.7	7.7	-15.5	-144.7
Temperature	°C						14.76	22.4	18.59	16.6	20.02	21.64	18.2	16.1	13.4	14.08	17.17	15.03	21.38	15.87	18.51	19.1	16.3	16.88	17.30	19.65	19.90	19.70	19.13	20.58	18.00	19.10
Suspended Solids	mg/L	5										36			60	52																
Turbidity	NTU	0.1	2-25													17.9																
Major Ions																																
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	7	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	114	131	101	147	120	95	64	1090	71	57	208	125	93	130	36	29	40	40	39	47	43	35	41	62	44	44
Total Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	114	131	101	147	120	95	64	1090	71	57	208	132	93	130	36	29	40	40	39	47	43	35	41	62	44	44
Acidity as $CaCO_3$	mg/L	1	-	-	-	-									99																	
Sulfate as SO_4^{2-}	mg/L	1	-	-	1000	500	130	34	31	29	18	14	6	<1	6	6	58	4	6	2	9	8	7	7	6	7	7	7	4	6	4	3
Chloride	mg/L	1	-	700	-	ID	49	40	38	39	48	42	34	100	35	37	376	106	42	47	24	24	28	16	27	25	31	29	24	34	31	28
Calcium	mg/L	1	-	-	1000	-	32	22	21	19	15	7	9	28	11	8	57	30	19	25	1	2	2	1	10	7	6	6	5	16	12	6
Magnesium	mg/L	1	-	-	ID	-	2	4	3	4	3	2	3	3	4	4	50	20	11	11	2	2	2	3	3	2	2	3	2	4	3	3
Sodium	mg/L	1	-	460	-	-	105	57	55	80	64	49	29	555	23	28	213	56	23	34	11	14	17	12	18	18	19	19	15	23	26	15
Potassium	mg/L	1	-	-	-	-	2	4	1	3	<1	<1	1	2	<1	<1	8	2	2	2	<1	<1	<1	<1	1	<1	<1	1	<1	1	<1	<1
Silica/Silicon as SiO_2/Reactive silica	mg/L	0.1	-	-	-	-	11.4	11.4	10.6	11.8	11.9	10.9	11.2	30.3	10.5	9.8	10.5	10.0	10.3	10.5	8.72	8.3	8.2	8.3	10.2	8.9	9.09	8.7	10	9.3	9.49	9
Total Anions	meq/L	0.01	-	-	-	-	6.37	4.45	7.66	4.64	4.13	3.38	2.65	24.6	2.53	2.31	16	5.71	3.17	3.96	1.58	1.65	1.73	1.4	1.67	1.79	1.88	1.66	1.58	2.32	1.84	1.73
Total Cations	meq/L	0.01	-	-	-	-	6.38	4.58	7.50	4.83	4.06	3.31	2.68	25.9	1.88	1.95	16.4	5.63	3.28	3.84	1.58	1.91	1.92	0.82	1.55	1.75	2.02	1.4	1.71	2.15	1.98	1.95
Ionic Balance	%	0.01	-	-	-	-	0.08	1.44	1.06	2	0.88	0.97	-	2.51			1.41	0.72	1.77	1.58	-		-		3.73	1.13	3.59	8.50				
Other Inorganics																																
Flouride	mg/L	0.1	-	2	2	1.5						<0.1			<0.1	<0.1				<0.1	<0.1	<0.1					<0.1	0.2			0.2	
Free cyanide	mg/L	0.004	0.007	-	-	0.08						<0.004									<0.004						<0.004				<0.004	
Total cyanide	mg/L	0.004	-	-	-	-						<0.004									<0.004						<0.004				<0.004	
Thiocyanate	mg/L	0.1	-	-	-	-						<0.1									<0.1						<0.1				<0.1	
Dissolved metals																																
Aluminium	mg/L	0.01	0.055	20	5	ID						0.06	0.06	0.18	<0.01	<0.01				0.01	0.01	<0.01	0.08	<0.01			0.01	0.03	<0.01	0.02	<0.01	<0.01
Antimony	mg/L	0.001	ID	-	-	0.003						<0.001	<0.001	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic	mg/L	0.001	0.013	2	0.5	0.01						0.012	0.01	0.002	0.007	0.006				0.002	<0.001	0.001	0.002	0.002			<0.001	0.001	<0.001	0.001	<0.001	<0.001
Beryllium	mg/L	0.001	ID	0.5	ID	0.06						<0.001				<0.001				<0.001	<0.001						<0.001				<0.001	
Barium	mg/L	0.001	-	-	-	2						0.118			0.105	0.079				0.063	0.084						0.085				0.116	
Cadmium	mg/L	0.0001	0.0002	0.05	0.01	0.002						<0.0001	<0.0001	<0.0001	<0.0001	<0.0001				<0.0001	<0.0001	<0.0001	<0.0001	<0.0001			<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.001	0.001	1	1	0.05						0.002	<0.001	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cobalt	mg/L	0.001	ID	0.1	1	-						0.008	0.008	<0.001	0.008	0.009				<0.001	0.004	0.005	0.006	0.005			<0.001	0.001	<0.001	<0.001	<0.001	<0.001
Copper	mg/L	0.001	0.0014	5	1#	2						<0.001	0.007	<0.001	<0.001	<0.001				<0.001	<0.001	0.002	0.001	<0.001			0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lead	mg/L	0.001	0.0034	5	0.1	0.01						<0.001	<0.001	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lithium	mg/L	0.001	-	2.5	-	-						0.013				0.01				0.018	0.012						0.019				0.014	
Manganese	mg/L	0.001	1.9	10	-	0.5	0.506	0.653	0.573	0.623	0.621	0.732	0.800	0.215	0.754	0.798	0.786	0.531	0.478	0.342	0.929	1	0.915	0.932	0.674	0.660	0.624	0.654	0.578	0.768	0.693	0.606
Molybdenum	mg/L	0.001	ID	0.05	0.15	0.05						0.013	0.008	<0.001	0.008	0.007				0.008	0.003	0.002	0.004	0.002			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel	mg/L	0.001	0.011	2	1	0.02						0.014	0.01	<0.001	0.011	0.012				0.002	0.006	0.007	0.009	0.007			0.002	0.002	<0.001	<0.001	<0.001	<0.001
Selenium	mg/L	0.01	0.005	0.05	0.02	0.01						<0.01	<0.01	<0.01	<0.01	<0.01				<0.01	<0.01	<0.01	<0.01	<0.01			<0.01	<0.01	0.02	<0.01	<0.01	<0.01
Strontium	mg/L	0.001	-	-	-	-						0.125			0.092	0.069				0.112	0.035						0.09				0.109	
Tin	mg/L	0.001	ID	-	-	-						<0.001				<0.001				<0.001	<0.001						<0.001				<0.001	
Uranium	mg/L	0.001	ID	0.1	0.2	0.017						<0.001				<0.001				<0.001	<0.001						<0.001				<0.001	
Vanadium	mg/L	0.01	ID	0.5	ID	-						<0.01				<0.01				<0.01	<0.01						<0.01				<0.01	
Zinc	mg/L	0.005	0.008	5	20	ID						0.014	0.033	0.005	0.014	0.033				0.031	0.213	0.018	0.015	<0.005			0.01	0.022	0.006	0.008	0.007	<0.005
Boron	mg/L	0.05	0.37	5	5	4						<0.05	<0.05	0.33	<0.05	<0.05				<0.05	<0.05	<0.05	<0.05	<0.05			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Iron	mg/L	0.05	ID	10	ID	ID	2.44	10.6	5.08	9.62	5.17	11.9	13.1	0.95	13	14.3	6.03	6.54	7.06	2.94	16.5	20.5	17	17.9	14.4	14.00	12	13.6	12.8	15.4	13.8	14
Ferrous iron	mg/L	0.05	-	-	-	ID									14.6	15.0								19.0								
Bromine	mg/L	0.1	-	-	-	-						0.1				0.1				0.2	0.6						0.1				<0.1	
Iodine	mg/L	0.1	-	-	-	ID						0.4				<0.1				<0.1	0.2						<0.1				<0.1	
Mercury	mg/L	0.0001	0.00006	0.002	0.002	0.001						<0.0001									<0.0001						<0.0001				<0.0001	
Total metals																																
Aluminium	mg/L	0.01	-	-	-	-						0.46				0.94					0.06						0.03				0.45	
Manganese	mg/L	0.001	-	-	-	-						0.83			0.777	0.794					0.99			0.945			0.663				0.6	0.645
Iron	mg/L	0.05	-	-	-	-						14.1			14.6	14.9					19.6			19.1			13.6				13.7	14.2
Nutrients																																
Ammonia as N	mg/L	0.01	2.57									<0.01				0.02					<0.01						0.02				0.04	
Nitrite as N	mg/L	0.01			9							<0.01				<0.01					<0.01	<0.01					<0.01	<0.01			<0.01	
Nitrate as N	mg/L	0.01			90							0.02				0.06					0.02	0.01					0.02	<0.01			0.02	
Nitrite + Nitrate as N	mg/L	0.01																														
Total phosphorous	mg/L	0.01										0.04									0.02						<0.01	-			0.02	
Reactive phosphorous	mg/L	0.01										<0.01				0.02					<0.01	<0.01					<0.01	<0.01			<0.01	
Biochemical oxygen demand	mg/L	2														<2																
Isotopes																																
Oxygen-18	‰	0.01					-6.94										-6.47				-7.26											
Deuterium	‰	0.1					-42.6										-39.3				-42.67											
Carbon-13	‰	0.1					-14.9										-11.5															
Radiocarbon	pMC	0.1					30.74±0.11										44.31±0.13															
Radiocarbon Age (uncorrected)	yrs BP	1					9416±30										6478±28															
Tritium	TU	0.01					0.04±0.03^										0.05±0.03^				0.14±0.08											

Table A5: Baseline Groundwater Monitoring Results - Wongawilli Seam

Location			Water Quality Criteria				HU0042PZA						HU0043XPZA				HU0044XPZA								HU0072PZA									
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	23/08/2012	19/12/2012	3/07/2013	19/08/2013	17/12/2013	2/02/2015	30/08/2012	3/01/2013	17/12/2013	5/02/2015	24/08/2012	14/12/2012	2/07/2013	18/09/2013	10/12/2013	20/03/2014	28/07/2014	18/02/2015	21/03/2013	8/07/2013	18/09/2013	11/12/2013	26/03/2014	14/08/2014	2/12/2014	25/03/2015	26/06/2015	15/09/2015
General field parameters																																		
pH	pH units		6.5-7.5				6.5	6.25	6.3	6.67	6.99	6.09	6.52	6.17	6.26	5.88	5.65	4.41	5.61	4.64	4.84	4.03	5.16	5.75	6.38	6.44	6.69	6.85	6.35	6.19	6.49	6.14	6.54	6.49
Conductivity (field)	µS/cm		30-350	0-650 (v. low) >650-1300 (low) >1300-2900 (medium) >2900-5200 (high) >5200-8100 (v. high) >8100 (extreme)			496	344	444	479	467	453	224	129	115	112	202	246	218	350	332	355	379	371	618	640	634	621	594	597	636	615	585	592
Conductivity (lab)	µS/cm	1	30-350																										588				603	566
Total Dissolved Solids (field)	g/L					<600 (good quality) 600-900 (fair quality) >900-1200 (poor quality) >1200 (unacceptable)	324	224	289	311	303	295	145	83	75	73	131	160	121	228	216	231	247	241	402	416	412	404	384	388	409	397	380.2	385
Total Dissolved Solids (lab)	mg/L	10																											384				336	332
Dissolved oxygen	% sat		90-110				8.6	44.3	24	28.4	40.7	20.3	22.3	17.3	28.9	51.5	33.7	38.4	-	31.5	41.2	26.7	25.1	113.2	1.7	7.3	19.7	26.8	3.9	27.2	17.8	16.0	7.3	47.4
Redox	mV						1.2	-22.2	-85.3	-62.9	-93.1	29.0	-34.7	25.6	-4.3	3.8	112.1	36.5	81	200.1	130.7	293.6	-15.5	41.7	-81.8	-68.5	-114.8	-112.6	-88.3	77	-35.4	-98.1	-120	-144.6
Temperature	°C						18.05	19.23	14.4	13.91	16.44	16.39	15.27	20.21	20.97	22.53	11.47	17.04	15.1	15.96	16.02	19.3	15.87	16.49	19.82	18.4	16.85	18.37	17.10	17.61	21.82	18.5	16.2	16.19
Suspended Solids	mg/L	5																															10	<5
Turbidity	NTU	0.1	2-25																															
Major Ions																																		
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1				<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1				<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	133	103	104	142	130	130	55	30	12	24	28	5				<1	<1	<1	135	124	133	136	118	111	138	130	116	114
Total Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	133	103	104	142	130	130	55	30	12	24	28	5				<1	<1	<1	135	124	133	136	118	111	138	130	116	114
Acidity as $CaCO_3$	mg/L	1	-	-	-	-																											30	
Sulfate as SO_4^{2-}	mg/L	1	-	-	1000	500	40	7	15	4	6	6	23	5	3	2	22	49				136	149	131	9	17	11	7	4	6	5	5	4	3
Chloride	mg/L	1	-	700	-	ID	54	45	56	60	55	64	18	12	11	23	24	15				10	15	10	100	113	114	108	110	111	110	115	100	106
Calcium	mg/L	1	-	-	1000	-	32	18	19	36	28	28	16	6	4	3	10	6				10	8	9	35	33	33	31	32	31	37	34	34	33
Magnesium	mg/L	1	-	-	ID	-	18	16	16	15	13	17	2	2	2	2	3	6				19	17	20	23	24	24	22	25	24	23	28	27	26
Sodium	mg/L	1	-	460	-	-	39	28	4	29	28	32	23	10	10	9	15	13				14	16	19	36	54	54	50	37	38	37	44	40	38
Potassium	mg/L	1	-	-	-	-	3	3	41	4	5	4	<1	<1	<1	4	9	3				3	3	2	6	6	6	5	4	4	4	4	4	4
Silica/Silicon as SiO_2/Reactive silica	mg/L	0.1	-	-	-	-	11.0	9.5	8.9	10.1	9.7	8.7	10.1	9.1	-	7.4	14.0	17.0				13.5	14.0	18.6	9.1	9.5	9.3	9.3	9.2	9.8	9	8.6	8.9	8.7
Total Anions	meq/L	0.01	-	-	-	-	5.01	3.47		4.61	4.27	4.53	2.09	1.04	0.61	1.17	1.69	1.54				3.11	3.53	3.01	5.71	6.02	6.10	5.91	5.54	5.470	5.960	5.95	5.22	5.33
Total Cations	meq/L	0.01	-	-	-	-	4.85	3.51		4.45	4.11	4.46	1.96	0.09	0.8	1.17	1.63	1.44				3.09	2.57	2.97	5.55	6.12	6.12	5.83	5.37	5.280	5.650	6.8	5.76	5.54
Ionic Balance	%	0.01	-	-	-	-	1.65	0.51		1.79	2.01	0.77										0.30			1.37	0.87	0.18	0.68	1.62	1.820	2.720	6.84	4.91	1.95
Other Inorganics																																		
Flouride	mg/L	0.1	-	2	2	1.5					<0.1																	0.2	0.1				0.1	
Free cyanide	mg/L	0.004	0.007	-	-	0.08					<0.004																	<0.004						
Total cyanide	mg/L	0.004	-	-	-	-					<0.004																	<0.004						
Thiocyanate	mg/L	0.1	-	-	-	-					<0.1																	<0.1						
Dissolved metals																																		
Aluminium	mg/L	0.01	0.055	20	5	ID					0.02	<0.01				<0.01						0.12	0.14	0.07				0.03	0.01	<0.01	0.100	0.04	<0.01	<0.01
Antimony	mg/L	0.001	ID	-	-	0.003					<0.001	<0.001				<0.001						<0.001	<0.001	<0.001				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic	mg/L	0.001	0.013	2	0.5	0.01					<0.001	0.002				<0.001						<0.001	<0.001	<0.001				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Beryllium	mg/L	0.001	ID	0.5	ID	0.06					<0.001																	<0.001	<0.001					
Barium	mg/L	0.001	-	-	-	2					0.411																	0.274	0.227				0.234	
Cadmium	mg/L	0.0001	0.0002	0.05	0.01	0.002					<0.0001	<0.0001				<0.0001						0.0007	0.00	<0.0001				<0.0001	<0.0001	<0.0001	<0.0001	0.0305	<0.0001	<0.0001
Chromium	mg/L	0.001	0.001	1	1	0.05					<0.001	<0.001				<0.001						<0.001	<0.001	<0.001				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cobalt	mg/L	0.001	ID	0.1	1	-					<0.001	0.002				<0.001						0.033	0.03	0.029				<0.001	<0.001	<0.001	<0.001	0.005	<0.001	<0.001
Copper	mg/L	0.001	0.0014	5	1#	2					0.002	<0.001				0.005						0.004	0.01	0.013				0.002	<0.001	0.001	<0.001	0.061	<0.001	<0.001
Lead	mg/L	0.001	0.0034	5	0.1	0.01					<0.001	<0.001				<0.001						0.017	0.05	0.004				<0.001	<0.001	<0.001	<0.001	0.041	<0.001	<0.001
Lithium	mg/L	0.001	-	2.5	-	-					0.072																	0.054						
Manganese	mg/L	0.001	1.9	10	-	0.5	0.594	0.399	0.407	0.419	0.331	0.279	0.252	0.404	0.590	0.538	0.547	2.37				3.79	4.25	4.22	0.216	0.167	0.186	0.191	0.203	0.209	0.252	0.265	0.199	0.189
Molybdenum	mg/L	0.001	ID	0.05	0.15	0.05					<0.001	0.001				<0.001						<0.001	<0.001	<0.001				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel	mg/L	0.001	0.011	2	1	0.02					0.002	0.011				0.01						0.056	0.06	0.05				0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001
Selenium	mg/L	0.01	0.005	0.05	0.02	0.01					<0.01	<0.01				<0.01						<0.01	<0.01	<0.01				<0.01	<0.01	0.100	<0.01	<0.01	<0.01	<0.01
Strontium	mg/L	0.001	-	-	-	-					0.374																	0.274	0.171				0.155	
Tin	mg/L	0.001	ID	-	-	-					<0.001																	<0.001						
Uranium	mg/L	0.001	ID	0.1	0.2	0.017					<0.001																	<0.001	<0.001					
Vanadium	mg/L	0.01	ID	0.5	ID	-					<0.01																	<0.01	<0.01					
Zinc	mg/L	0.005	0.008	5	20	ID					0.014	0.01				0.111						0.534		0.198				0.473	0.036	0.014	0.010	1.57	<0.005	0.008
Boron	mg/L	0.05	0.37	5	5	4					<0.05	<0.05				<0.05						<0.05		<0.05				<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Iron	mg/L	0.05	ID	10	ID	ID	5.11	6.23	6.46	6.86	5.3	3.17	1.79	6.79	10.60	6.76	4.50	19.30				1.4		0.29	3.63	2.75	3.18	3.03	3.34	3.620	3.740	3.68	3.55	3.62
Ferrous iron	mg/L	0.05	-	-	-	ID																											4.05	3.82
Bromine	mg/L	0.1	-	-	-	-					0.1																	0.4	0.3					
Iodine	mg/L	0.1	-	-	-	ID					<0.1																	<0.1						
Mercury	mg/L	0.0001	0.00006	0.002	0.002	0.001					<0.0001																	<0.0001						
Total metals																																		
Aluminium	mg/L	0.01	-	-	-	-					0.11																	0.02						
Manganese	mg/L	0.001	-	-	-	-					0.381																	0.191					0.207	0.211
Iron	mg/L	0.05	-	-	-	-					6.24																	3.2					4.03	3.71
Nutrients																																		
Ammonia as N	mg/L	0.01	2.57								0.11																	0.17						
Nitrite as N	mg/L	0.01			9						<0.01																	<0.01	<0.01					
Nitrate as N	mg/L	0.01			90						0.01																	0.02	0.2					
Nitrite + Nitrate as N	mg/L	0.01																																
Total phosphorous	mg/L	0.01									<0.01																	0.02						
Reactive phosphorous	mg/L	0.01									<0.01																	<0.01	<0.01					
Biochemical oxygen demand	mg/L	2																																
Isotopes																																		
Oxygen-18	‰	0.01																																
Deuterium	‰	0.1																																
Carbon-13	‰	0.1																																
Radiocarbon	pMC	0.1																																
Radiocarbon Age (uncorrected)	yrs BP	1																																
Tritium	TU	0.01																																

Table A5: Baseline Groundwater Monitoring Results - Wongawilli Seam

Location			Water Quality Criteria				HU0073PZB									HU0088PZA					HU0096PZB								HU0129PZA			
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	27/03/2013	7/08/2013	15/10/2013	10/12/2013	3/04/2014	5/12/2014	26/03/2015	29/06/2015	21/09/2015	11/12/2013	2/04/2014	26/09/2014	3/12/2014	11/02/2015	8/08/2013	16/10/2013	9/12/2013	31/03/2014	5/12/2014	27/03/2015	7/07/2015	22/09/2015	22/05/2014	10/02/2015	24/06/2015	16/09/2015
General field parameters																																
pH	pH units		6.5-7.5				5.86	5.99	6.22	6.13	6.13	6.30	6.40	6.14	6.06	6.69	6.67	6.71	6.74	6.54	4.92	5.21	5.15	4.97	5.56	5.47	5.28	5.07	6.34	6.29	6.18	6.15
Conductivity (field)	µS/cm		30-350	0-650 (v. low) >650-1300 (low) >1300-2900 (medium) >2900-5200 (high) >5200-8100 (v. high) >8100 (extreme)			457	195	223	210	219	237	233	209.6	209	486	520	481	40.8	519	84	142	131	130	146	155.2	132.6	130	595	493	466.8	468
Conductivity (lab)	µS/cm	1	30-350								197			187			550							139			129				469	432
Total Dissolved Solids (field)	g/L					<600 (good quality) 600-900 (fair quality) >900-1200 (poor quality) >1200 (unacceptable)	298	111	145	136	143	154	152	136.5	136	315	338	312	265	337	46	92	85	83.5	95	100.8	86.4	84	387	320	303.6	304
Total Dissolved Solids (lab)	mg/L	10									102		104	94	90		224			246				69		115	65	60			203	258
Dissolved oxygen	% sat		90-110				0.7	23.6	16.4	15.9	11.4	16	13.9	108.8	12.6	29.8	21.0	26.1	25.6	35.4	9.6	13.5	17.6	10.8	12.4	23.2	32	14.4	16.1	21.3	27	10.3
Redox	mV						-11.6	-4	-39.6	-43.4	-51	-39.1	-93.7	-25.6	-112.7	-61.0	-69.3	-72.2	-25.6	-31.2	95	93.6	126.1	95.7	45.2	134.6	181.1	-107.6	-63.5	-20.9	-114.0	-143.0
Temperature	°C						20.97	21.5	19.98	19.88	20.4	19.28	18.0	15.3	19.38	19.6	19.5	19.0	19.4	24.97	19.8	18.29	18.73	18.2	18.32	14.9	14.1	15.27	20.34	16.82	15.5	16.32
Suspended Solids	mg/L	5												10	<5												<5	<5			<5	<5
Turbidity	NTU	0.1	2-25																									2.3				
Major Ions																																
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	41	65	55	41	34	66	64	51	30	165	157	171	165	168	7	9	8	6	15	16	8	8	154	91	80	80
Total Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	41	65	55	41	34	66	64	51	30	165	157	171	165	168	7	9	8	6	15	16	8	8	154	91	80	80
Acidity as $CaCO_3$	mg/L	1	-	-	-	-								45													55				51	
Sulfate as SO_4^{2-}	mg/L	1	-	-	1000	500	26	7	8	10	10	4	6	9	9	1	2	2	<1	2	2	2	2	1	<1	2	2	1	18	13	11	10
Chloride	mg/L	1	-	700	-	ID	80	28	33	27	30	21	34	25	28	54	60	54	43	57	32	40	33	35	27	39	30	31	87	87	86	78
Calcium	mg/L	1	-	-	1000	-	13	6	6	5	5	12	10	6	6	33	38	33	28	30	<1	<1	<1	<1	4	2	<1	<1	33	18	16	16
Magnesium	mg/L	1	-	-	ID	-	12	4	5	4	4	7	7	5	5	16	20	17	11	15	2	2	2	1	2	2	2	2	24	19	19	18
Sodium	mg/L	1	-	460	-	-	32	17	16	16	20	14	15	14	16	33	36	41	31	41	18	18	19	22	23	21	17	18	40	48	45	39
Potassium	mg/L	1	-	-	-	-	1	1	1	<1	1	2	2	1	1	6	6	6	7	6	<1	<1	<1	<1	<1	<1	<1	<1	2	2	1	2
Silica/Silicon as SiO_2/Reactive silica	mg/L	0.1	-	-	-	-	8.9	8.6	9.9	9.2	8.7	9.6	8.73	9	9.09	9.8	10	9.2	9.4	9.7	8.7	9.1	8.4	8.4	8.7	9.1	8.1	8.32	14.8	13.9	13	12.5
Total Anions	meq/L	0.01	-	-	-	-	3.62	2.23	2.20	1.79	1.73	1.99	2.36	1.91		4.84	5.14	4.98	4.51	5.01	1.08	1.35	1.13	1.13	1.06	1.46	1.05	1.06	5.91	4.54	4.25	4.01
Total Cations	meq/L	0.01	-	-	-	-	3.63	2.25	2.22	1.68	1.47	1.84	2.43	1.34		4.70	5.26	4.98	3.95	4.73	1.02	1.07	0.99	1.04	1.36	1.28	0.9	0.95	5.66	4.6	4.34	4.03
Ionic Balance	%	0.01	-	-	-	-	0.22									1.49	1.19	<0.01	6.7	2.85	-	-	-			-	-		2.19	0.62	1.06	0.25
Other Inorganics																																
Flouride	mg/L	0.1	-	2	2	1.5				<0.1	<0.1		<0.1	0.1	<0.1	0.3	0.3			0.2			<0.1	<0.1		<0.1	<0.1	<0.1	0.1	<0.1	0.1	
Free cyanide	mg/L	0.004	0.007	-	-	0.08				<0.004			<0.004			<0.004				<0.004			<0.004			<0.004						
Total cyanide	mg/L	0.004	-	-	-	-				<0.004			<0.004			<0.004				<0.004			<0.004			<0.004						
Thiocyanate	mg/L	0.1	-	-	-	-				<0.1			<0.1			<0.1				<0.1			<0.1			<0.1						
Dissolved metals																																
Aluminium	mg/L	0.01	0.055	20	5	ID				<0.01	0.03	0.03	0.02	<0.01	<0.01	0.04	<0.01	0.01	0.01	<0.01			0.02	0.02	0.05	0.02	0.02	0.02	<0.01	<0.01	<0.01	<0.01
Antimony	mg/L	0.001	ID	-	-	0.003				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001
Arsenic	mg/L	0.001	0.013	2	0.5	0.01				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.014	0.008	0.011	0.004	0.004			0.01	<0.001	0.002	<0.001	<0.001	<0.001	0.057	0.047	0.041	0.038
Beryllium	mg/L	0.001	ID	0.5	ID	0.06				<0.001			<0.001		<0.001	<0.001				<0.001			<0.001			<0.001		<0.001	<0.001	<0.001		
Barium	mg/L	0.001	-	-	-	2				0.098			0.194	0.115	0.106	0.357				0.401			0.026			0.036	0.02	0.016	0.296	0.15	0.124	
Cadmium	mg/L	0.0001	0.0002	0.05	0.01	0.002				<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001			<0.0001	<0.0001	0.0003	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.001	0.001	1	1	0.05				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cobalt	mg/L	0.001	ID	0.1	1	-				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	0.005	0.003	0.001	0.001			0.004	0.003	0.004	0.003	0.004	0.003	0.046	0.024	0.015	0.013
Copper	mg/L	0.001	0.0014	5	1#	2				0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.003	<0.001	0.001	<0.001	<0.001			<0.001	0.001	0.03	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lead	mg/L	0.001	0.0034	5	0.1	0.01				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lithium	mg/L	0.001	-	2.5	-	-				0.022			0.03		0.024	0.095				0.114			0.006			0.004		<0.001	0.019	0.021		
Manganese	mg/L	0.001	1.9	10	-	0.5	1.240	0.562	0.556	0.636	0.619	0.527	0.519	0.553	0.576	0.259	0.179	0.251	0.134	0.159	0.140	0.146	0.179	0.124	0.187	0.144	0.113	0.124	0.514	0.649	0.603	0.53
Molybdenum	mg/L	0.001	ID	0.05	0.15	0.05				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.089	0.016	0.014	0.012
Nickel	mg/L	0.001	0.011	2	1	0.02				0.001	0.002	0.003	0.013	0.001	0.002	0.008	0.007	0.006	0.006	0.008			0.005	0.004	0.009	0.004	0.003	0.003	0.108	0.044	0.03	0.026
Selenium	mg/L	0.01	0.005	0.05	0.02	0.01				<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Strontium	mg/L	0.001	-	-	-	-				0.045			0.064	0.04	0.042	0.227				0.14			0.014			0.021	0.01	0.006	0.174	0.114	0.096	
Tin	mg/L	0.001	ID	-	-	-				<0.001			<0.001		<0.001	<0.001				<0.001			<0.001			<0.001		<0.001	<0.001	<0.001		
Uranium	mg/L	0.001	ID	0.1	0.2	0.017				<0.001			<0.001		<0.001	<0.001				<0.001			<0.001			<0.001		<0.001	0.001	<0.001		
Vanadium	mg/L	0.01	ID	0.5	ID	-				<0.01			<0.01		<0.01	<0.01				<0.01			<0.01			<0.01		<0.01	<0.01	<0.01		
Zinc	mg/L	0.005	0.008	5	20	ID				0.015	0.017	0.01	0.053	<0.005	<0.005	0.085	0.005	0.026	0.006	0.067			0.056	0.054	0.118	0.073	0.026	0.023	0.01	0.008	0.006	0.039
Boron	mg/L	0.05	0.37	5	5	4				<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Iron	mg/L	0.05	ID	10	ID	ID	10.80	14.50	14.60	20.8	14.1	14	12.2	13.6	12.8	2.57	2.01	1.71	2.17	1.18	1.52	2.20	2.37	2.13	1.74	1.88	1.61	1.76	3.83	8.06	9.5	8.93
Ferrous iron	mg/L	0.05	-	-	-	ID								14.8	15.2												2.02	1.85			10.5	9.89
Bromine	mg/L	0.1	-	-	-	-				0.8			0.1		0.1	0.4				0.1			0.2			<0.1		<0.1	0.3	0.2		
Iodine	mg/L	0.1	-	-	-	ID				<0.1			<0.1		<0.1	<0.1				<0.1			<0.1			<0.1		<0.1	<0.1	<0.1		
Mercury	mg/L	0.0001	0.00006	0.002	0.002	0.001				<0.0001			<0.0001			<0.0001				<0.0001			<0.0001			<0.0001						
Total metals																																
Aluminium	mg/L	0.01	-	-	-	-				0.59			0.53		0.04	0.04				0.44			0.04			0.33		0.02				
Manganese	mg/L	0.001	-	-	-	-				0.733			0.522	0.557	0.602	0.234				0.178			0.184			0.151	0.116	0.124			0.634	0.567
Iron	mg/L	0.05	-	-	-	-				21.4			14.4	14.2	15.1	2.79				4.08			2.66			5.28	1.89	1.84			10.4	9.62
Nutrients																																
Ammonia as N	mg/L	0.01	2.57							0.01			0.02		0.05	0.18				0.13			0.01			0.01		<0.01				
Nitrite as N	mg/L	0.01			9					<0.01	<0.01		<0.01		<0.01	<0.01	<0.01			<0.01			<0.01	<0.01		<0.01		0.01				
Nitrate as N	mg/L	0.01			90					0.02	0.01		<0.01		0.01	0.01	<0.01			<0.01			0.01	0.05		<0.01		<0.01				
Nitrite + Nitrate as N	mg/L	0.01																														
Total phosphorous	mg/L	0.01								0.01			0.03			<0.01				0.03			<0.01			0.04						
Reactive phosphorous	mg/L	0.01								<0.01	<0.01		<0.01		<0.10	<0.01	<0.01			<0.01			<0.01	<0.01		<0.01		<0.01				
Biochemical oxygen demand	mg/L	2																										<2				
Isotopes																																
Oxygen-18	‰	0.01																														
Deuterium	‰	0.1																														
Carbon-13	‰	0.1																														
Radiocarbon	pMC	0.1																														
Radiocarbon Age (uncorrected)	yrs BP	1																														
Tritium	TU	0.01																														

Table A5: Baseline Groundwater Monitoring Results - Wongawilli Seam

Location			Water Quality Criteria				HU0136PZA				HU0142PZA					HU0143PZB			
Analyte	Units	LOR	ANZECC (2000) Aquatic	ANZECC (2000) Irrigation	ANZECC (2000) Livestock	ADWG (2011)	29/08/2014	1/12/2014	4/02/2015	23/09/2015	24/09/2014	1/12/2014	26/03/2015	30/06/2015	17/09/2015	4/12/2014	18/02/2015	25/06/2015	23/09/2015
General field parameters																			
pH	pH units		6.5-7.5				6.69	7.18	6.81	6.90	6.71	6.77	6.65	6.53	6.57	6.07	6.21	6.39	6.14
Conductivity (field)	µS/cm		30-350	0-650 (v. low) >650-1300 (low) >1300-2900 (medium) >2900-5200 (high) >5200-8100 (v. high) >8100 (extreme)			574	557	556	538	2311	2383	2075	2139	1928	317	255	277.1	258
Conductivity (lab)	µS/cm	1	30-350							521				2120				267	227
Total Dissolved Solids (field)	g/L					<600 (good quality) 600-900 (fair quality) >900-1200 (poor quality) >1200 (unacceptable)	373	362	362	350	1502	1550	1352	1391	1253	206	166	180	168
Total Dissolved Solids (lab)	mg/L	10								267			1180	1200	1140			119	143
Dissolved oxygen	% sat		90-110				45.7	27.7	61.3	42.1	9.0	21..2	21.5	20.4	25.1	46	14.4	15.8	9.5
Redox	mV						182.2	112.3	110.4	-105.2	-130.5	-81.6	-116.0	-111.7	-80.4	0.7	1.34	-8.8	-130.9
Temperature	ºC						16.67	22.57	17.71	16.26	23.57	25.2	19.0	15.9	16.9	20.20	19.20	13.60	16.49
Suspended Solids	mg/L	5												16	78			<5	6
Turbidity	NTU	0.1	2-25												71.5				
Major Ions																			
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	237	234	236	205	292	315	266	280	187	83	74	72	69
Total Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	237	234	236	205	292	315	266	280	187	83	74	72	69
Acidity as $CaCO_3$	mg/L	1	-	-	-	-								60				34	
Sulfate as SO_4^{2-}	mg/L	1	-	-	1000	500	10	12	10	10	92	43	32	10	11	3	4	8	4
Chloride	mg/L	1	-	700	-	ID	44	47	48	40	542	521	476	548	495	42	35	36	32
Calcium	mg/L	1	-	-	1000	-	35	35	32	32	92	122	106	127	105	30	14	18	15
Magnesium	mg/L	1	-	-	ID	-	43	38	42	41	80	74	83	86	67	6	8	7	8
Sodium	mg/L	1	-	460	-	-	22	19	22	20	272	237	187	176	160	18	18	18	20
Potassium	mg/L	1	-	-	-	-	2	2	2	2	7	5	5	4	4	<1	2	1	2
Silica/Silicon as SiO_2/Reactive silica	mg/L	0.1	-	-	-	-	32.2	29.8	33.9	31	11.2	12.2	10.8	10.3	8.6	8.8	9.4	9.2	8.6
Total Anions	meq/L	0.01	-	-	-	-	6.18	6.25	6.28	5.43	23	21.9	19.4	21.3	17.9	2.91	2.55	2.62	2.36
Total Cations	meq/L	0.01	-	-	-	-	6.29	5.75	6.06	5.89	23.2	22.6	20.4	21.2	17.8	2.77	2.19	2.28	2.33
Ionic Balance	%	0.01	-	-	-	-	0.86	4.17	1.76	4.05	0.31	1.64	2.45	0.2	0.3				
Other Inorganics																			
Flouride	mg/L	0.1	-	2	2	1.5							0.1	0.2	0.1			0.1	
Free cyanide	mg/L	0.004	0.007	-	-	0.08							<0.004						
Total cyanide	mg/L	0.004	-	-	-	-							<0.004						
Thiocyanate	mg/L	0.1	-	-	-	-							<0.1						
Dissolved metals																			
Aluminium	mg/L	0.01	0.055	20	5	ID	2.04	0.02	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.04
Antimony	mg/L	0.001	ID	-	-	0.003	0.003	0.003	0.003	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic	mg/L	0.001	0.013	2	0.5	0.01	0.01	0.012	0.011	0.006	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Beryllium	mg/L	0.001	ID	0.5	ID	0.06							<0.001		<0.001				
Barium	mg/L	0.001	-	-	-	2							0.455	0.664	0.651			0.104	
Cadmium	mg/L	0.0001	0.0002	0.05	0.01	0.002	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.001	0.001	1	1	0.05	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cobalt	mg/L	0.001	ID	0.1	1	-	0.028	0.034	0.029	0.012	0.001	0.002	0.001	<0.001	<0.001	0.012	0.001	0.002	0.002
Copper	mg/L	0.001	0.0014	5	1#	2	0.003	0.012	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001
Lead	mg/L	0.001	0.0034	5	0.1	0.01	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lithium	mg/L	0.001	-	2.5	-	-							0.054		0.038				
Manganese	mg/L	0.001	1.9	10	-	0.5	0.026	0.004	0.002	0.001	1.26	2.35	1.92	2.22	2.33	1.03	0.614	0.66	0.582
Molybdenum	mg/L	0.001	ID	0.05	0.15	0.05	0.023	0.037	0.02	0.017	0.002	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel	mg/L	0.001	0.011	2	1	0.02	0.085	0.102	0.072	0.045	0.009	0.004	0.01	0.009	0.002	0.01	0.003	0.002	0.003
Selenium	mg/L	0.01	0.005	0.05	0.02	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Strontium	mg/L	0.001	-	-	-	-							1.53	2.01	1.91			0.1	
Tin	mg/L	0.001	ID	-	-	-							<0.001		<0.001				
Uranium	mg/L	0.001	ID	0.1	0.2	0.017							0.002		<0.001				
Vanadium	mg/L	0.01	ID	0.5	ID	-							<0.01		<0.01				
Zinc	mg/L	0.005	0.008	5	20	ID	0.038	0.033	0.045	0.087	0.008	0.01	0.015	<0.005	0.007	0.11	0.011	0.011	0.017
Boron	mg/L	0.05	0.37	5	5	4	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Iron	mg/L	0.05	ID	10	ID	ID	0.42	<0.05	<0.05	<0.05	4.58	7.16	5.82	8.44	13.8	0.13	9.88	9.16	8.69
Ferrous iron	mg/L	0.05	-	-	-	ID				<0.05				9.85	14.5			10.6	9.12
Bromine	mg/L	0.1	-	-	-	-							1.2		1.2				
Iodine	mg/L	0.1	-	-	-	ID							<0.1		<0.1				
Mercury	mg/L	0.0001	0.00006	0.002	0.002	0.001							<0.0001						
Total metals																			
Aluminium	mg/L	0.01	-	-	-	-							17.2		0.76				
Manganese	mg/L	0.001	-	-	-	-				0.059			2.43	2.32	2.2			0.671	0.606
Iron	mg/L	0.05	-	-	-	-				0.64			15.6	8.91	13.4			10	9.57
Nutrients																			
Ammonia as N	mg/L	0.01	2.57										0.04		0.06				
Nitrite as N	mg/L	0.01			9								<0.01		<0.01				
Nitrate as N	mg/L	0.01			90								<0.01		0.03				
Nitrite + Nitrate as N	mg/L	0.01													0.03				
Total phosphorous	mg/L	0.01											0.12						
Reactive phosphorous	mg/L	0.01											0.1		<0.01				
Biochemical oxygen demand	mg/L	2													<2				
Isotopes																			
Oxygen-18	‰	0.01																	
Deuterium	‰	0.1																	
Carbon-13	‰	0.1																	
Radiocarbon	pMC	0.1																	
Radiocarbon Age (uncorrected)	yrs BP	1																	
Tritium	TU	0.01																	

n	Detects	Exc	Min	Max	Avg	Geomean	Std Dev
93	93	69	4.03	7.18	5.52	6.14	0.58
93	93	45	40.8	2383	464	341	470
19	19	8	125	2120	415.11	304	449
93	93		46	1550	307	228	311
28	28		60	1200	270	175	331
93	91		0.7	113.2	23.0	18	18
93	93		-201.6	293.6	-29.5		91
93	93		11.47	25.2	18.08	18	3
15	8		6	78	33.50	23	27
3	3	0	2.3	71.5	30.57	14	36
90	0						
90	1		7	7	7.00	7	
90	87		5	1090	109.22	71	128
90	87		5	1090	109.30	71	128
7	7		30	99	53.43	50	23
90	87	0	1	149	17.21	8	30
90	90	0	10	548	77.76	48	116
90	84	0	1	127	24.12	15	25
90	90		1	86	15.32	8	19
90	90	1	4	555	46.16	29	73
90	64		1	41	3.86	3	5
90	89		7.4	33.9	11.25	11	5
33	15	0	0.1	0.3	0.16	0.15	0.07
13	0	0					
13	0						
13	0						
63	33	9	0.01	2.04	0.10	0.03	0.35
63	6		0.001	0.003	0.003	0.00	0.00
63	28	5	0.001	0.057	0.012	0.01	0.02
21	0						
28	28	0	0.016	0.664	0.200	0.13	0.18
63	9	4	0.0001	0.0305	0.004	0.00	0.01
63	3	2	0.001	0.002	0.002	0.00	0.00
63	40	0	0.001	0.046	0.010	0.01	0.01
63	22	14	0.001	0.061	0.008	0.00	0.01
63	7	4	0.002	0.045	0.016	0.01	0.02
20	19	0	0.004	0.114	0.034	0.02	0.03
90	90	8	0.001	4.25	0.690	0.40	0.80
63	21	1	0.001	0.089	0.014	0.01	0.02
63	53	14	0.001	0.108	0.017	0.01	0.03
63	2	2	0.02	0.1	0.060	0.04	0.06
28	28		0.006	2.01	0.291	0.10	0.55
20	0						
21	2	0	0.001	0.002	0.002	0.00	0.00
21	0						
62	56	45	0.005	1.57	0.080	0.03	0.23
62	1	0					
89	86	29	0.13	20.8	7.7	5.36	5.47
16	15	8	1.85	19	10.32	8.43	5.35
21	18		0.1	1.2	0.361	0.24	0.36
20	2		0.2	0.4	0.3	0.28	0.14
13	0						
17	17		0.02	17.2	1.30	0.19	4.11
30	30		0.059	2.43	0.671	0.46	0.62
30	30		0.64	21.4	10.1	7.69	5.98
17	14	0	0.01	0.18	0.06	0.04	0.06
23	1	0	0.01	0.01	0.01	0.01	
23	16	0	0.01	0.2	0.03	0.02	0.05
1	1		0.03	0.03	0.03	0.03	
14	9		0.01	0.12	0.04	0.03	0.03
23	2		0.02	0.1	0.06	0.04	0.06
3	0						
3	3						
3	3						
2	2						
2	0						
2	0						
3	0						

Table A5: Baseline Groundwater Monitoring Results - Wongawilli Seam

Location			Water Quality Criteria				HU0018PZA										HU0023PZA				HU0032LDA				HU0038PZA							
Analyte	Units	LOR	Aquatic	ANZECC (2000) Irrigation	Livestock	ADWG (2011)	17/10/2011	7/01/2013	22/03/2013	9/07/2013	17/10/2013	12/12/2013	8/04/2014	25/03/2015	2/07/2015	24/09/2015	16/11/2011	17/12/2012	25/03/2013	21/05/2014	12/12/2013	3/04/2014	26/03/2015	24/09/2015	24/07/2012	14/12/2012	11/12/2013	2/04/2014	15/08/2014	2/12/2014	12/02/2015	15/09/2015
Organochloride pesticides																																
alpha-BHC	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Hexachlorobenzene (HCB)	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
beta-BHC	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
gamma-BHC	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
delta-BHC	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Heptachlor	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Aldrin	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Heptachlor epoxide	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
trans-Chlordane	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
alpha-Endosulfan	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
cis-Chlordane	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Dieldrin	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
4.4`-DDE	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Endrin	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
beta-Endosulfan	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
4.4`-DDD	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Endrin aldehyde	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Endosulfan sulfate	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
4.4`-DDT	µg/L	2										<2.0				<2.0					<2.0						<2.0				<2.0	
Endrin ketone	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Methoxychlor	µg/L	2										<2.0				<2.0					<2.0						<2.0				<2.0	
Total Chlordane (sum)	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Sum of DDD + DDE + DDT	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Sum of Aldrin + Dieldrin	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Organophosphorous pesticides																																
Dichlorvos	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Demeton-S-methyl	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Monocrotophos	µg/L	2										<2.0				<2.0					<2.0						<2.0				<2.0	
Dimethoate	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Diazinon	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Chlorpyrifos-methyl	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Parathion-methyl	µg/L	2										<2.0				<2.0					<2.0						<2.0				<2.0	
Malathion	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Fenthion	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Chlorpyrifos	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Parathion	µg/L	2										<2.0				<2.0					<2.0						<2.0				<2.0	
Pirimphos-ethyl	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Chlorfenvinphos	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Bromophos-ethyl	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Fenamiphos	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Prothiofos	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Ethion	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Carbophenothion	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Azinphos Methyl	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Phenolic compounds																																
Phenol	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
2-Chlorophenol	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
2-Methylphenol	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
3- & 4-Methylphenol	µg/L	1										<2.0				<2.0					<2.0						<2.0				<2.0	
2-Nitrophenol	µg/L	2										<1.0				<1.0					<1.0						<1.0				<1.0	
2.4-Dimethylphenol	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
2.4-Dichlorophenol	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
2.6-Dichlorophenol	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
4-Chloro-3-methylphenol	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
2.4.6-Trichlorophenol	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
2.4.5-Trichlorophenol	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
Pentachlorophenol	µg/L	1										<2.0				<2.0					<2.0						<2.0				<2.0	
Polynuclear aromatic hydrocarbons																																
Naphthalene	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
Acenaphthylene	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
Acenaphthene	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
Fluorene	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
Phenanthrene	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
Anthracene	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
Fluoranthene	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
Pyrene	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
Benz(a)anthracene	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
Chrysene	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
Benzo(b)fluoranthene	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
Benzo(k)fluoranthene	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
Benzo(a)pyrene	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Indeno(1.2.3.cd)pyrene	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
Dibenz(a.h)anthracene	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
Benzo(g.h.i)perylene	µg/L	1										<1.0				<1.0					<1.0						<1.0				<1.0	
Sum of polycyclic aromatic hydrocarbons	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	
Benzo(a)pyrene TEQ (zero)	µg/L	0.5										<0.5				<0.5					<0.5						<0.5				<0.5	

Table A5: Baseline Groundwater Monitoring Results - Wongawilli Seam

Location			Water Quality Criteria				HU0042PZA						HU0043XPZA				HU0044XPZA								HU0072PZA									
Analyte	Units	LOR	Aquatic	ANZECC (2000) Irrigation	Livestock	ADWG (2011)	23/08/2012	19/12/2012	3/07/2013	19/08/2013	17/12/2013	2/02/2015	30/08/2012	3/01/2013	17/12/2013	5/02/2015	24/08/2012	14/12/2012	2/07/2013	18/09/2013	10/12/2013	20/03/2014	28/07/2014	18/02/2015	21/03/2013	8/07/2013	18/09/2013	11/12/2013	26/03/2014	14/08/2014	2/12/2014	25/03/2015	26/06/2015	15/09/2015
Organochloride pesticides																																		
alpha-BHC	µg/L	0.5									<0.5																	<0.5						
Hexachlorobenzene (HCB)	µg/L	0.5									<0.5																	<0.5						
beta-BHC	µg/L	0.5									<0.5																	<0.5						
gamma-BHC	µg/L	0.5									<0.5																	<0.5						
delta-BHC	µg/L	0.5									<0.5																	<0.5						
Heptachlor	µg/L	0.5									<0.5																	<0.5						
Aldrin	µg/L	0.5									<0.5																	<0.5						
Heptachlor epoxide	µg/L	0.5									<0.5																	<0.5						
trans-Chlordane	µg/L	0.5									<0.5																	<0.5						
alpha-Endosulfan	µg/L	0.5									<0.5																	<0.5						
cis-Chlordane	µg/L	0.5									<0.5																	<0.5						
Dieldrin	µg/L	0.5									<0.5																	<0.5						
4.4`-DDE	µg/L	0.5									<0.5																	<0.5						
Endrin	µg/L	0.5									<0.5																	<0.5						
beta-Endosulfan	µg/L	0.5									<0.5																	<0.5						
4.4`-DDD	µg/L	0.5									<0.5																	<0.5						
Endrin aldehyde	µg/L	0.5									<0.5																	<0.5						
Endosulfan sulfate	µg/L	0.5									<0.5																	<0.5						
4.4`-DDT	µg/L	2									<2.0																	<2.0						
Endrin ketone	µg/L	0.5									<0.5																	<0.5						
Methoxychlor	µg/L	2									<2.0																	<2.0						
Total Chlordane (sum)	µg/L	0.5									<0.5																	<0.5						
Sum of DDD + DDE + DDT	µg/L	0.5									<0.5																	<0.5						
Sum of Aldrin + Dieldrin	µg/L	0.5									<0.5																	<0.5						
Organophosphorous pesticides																																		
Dichlorvos	µg/L	0.5									<0.5																	<0.5						
Demeton-S-methyl	µg/L	0.5									<0.5																	<0.5						
Monocrotophos	µg/L	2									<2.0																	<2.0						
Dimethoate	µg/L	0.5									<0.5																	<0.5						
Diazinon	µg/L	0.5									<0.5																	<0.5						
Chlorpyrifos-methyl	µg/L	0.5									<0.5																	<0.5						
Parathion-methyl	µg/L	2									<2.0																	<2.0						
Malathion	µg/L	0.5									<0.5																	<0.5						
Fenthion	µg/L	0.5									<0.5																	<0.5						
Chlorpyrifos	µg/L	0.5									<0.5																	<0.5						
Parathion	µg/L	2									<2.0																	<2.0						
Pirimphos-ethyl	µg/L	0.5									<0.5																	<0.5						
Chlorfenvinphos	µg/L	0.5									<0.5																	<0.5						
Bromophos-ethyl	µg/L	0.5									<0.5																	<0.5						
Fenamiphos	µg/L	0.5									<0.5																	<0.5						
Prothiofos	µg/L	0.5									<0.5																	<0.5						
Ethion	µg/L	0.5									<0.5																	<0.5						
Carbophenothion	µg/L	0.5									<0.5																	<0.5						
Azinphos Methyl	µg/L	0.5									<0.5																	<0.5						
Phenolic compounds																																		
Phenol	µg/L	1									1.3																	<1.0						
2-Chlorophenol	µg/L	1									<1.0																	<1.0						
2-Methylphenol	µg/L	1									<1.0																	<1.0						
3- & 4-Methylphenol	µg/L	1									<2.0																	<2.0						
2-Nitrophenol	µg/L	2									<1.0																	<1.0						
2.4-Dimethylphenol	µg/L	1									<1.0																	<1.0						
2.4-Dichlorophenol	µg/L	1									<1.0																	<1.0						
2.6-Dichlorophenol	µg/L	1									<1.0																	<1.0						
4-Chloro-3-methylphenol	µg/L	1									<1.0																	<1.0						
2.4.6-Trichlorophenol	µg/L	1									<1.0																	<1.0						
2.4.5-Trichlorophenol	µg/L	1									<1.0																	<1.0						
Pentachlorophenol	µg/L	1									<2.0																	<2.0						
Polynuclear aromatic hydrocarbons																																		
Naphthalene	µg/L	1									<1.0																	<1.0						
Acenaphthylene	µg/L	1									<1.0																	<1.0						
Acenaphthene	µg/L	1									<1.0																	<1.0						
Fluorene	µg/L	1									<1.0																	<1.0						
Phenanthrene	µg/L	1									<1.0																	<1.0						
Anthracene	µg/L	1									<1.0																	<1.0						
Fluoranthene	µg/L	1									<1.0																	<1.0						
Pyrene	µg/L	1									<1.0																	<1.0						
Benz(a)anthracene	µg/L	1									<1.0																	<1.0						
Chrysene	µg/L	1									<1.0																	<1.0						
Benzo(b)fluoranthene	µg/L	1									<1.0																	<1.0						
Benzo(k)fluoranthene	µg/L	1									<1.0																	<1.0						
Benzo(a)pyrene	µg/L	0.5									<0.5																	<0.5						
Indeno(1.2.3.cd)pyrene	µg/L	1									<1.0																	<1.0						
Dibenz(a.h)anthracene	µg/L	1									<1.0																	<1.0						
Benzo(g.h.i)perylene	µg/L	1									<1.0																	<1.0						
Sum of polycyclic aromatic hydrocarbons	µg/L	0.5									<0.5																	<0.5						
Benzo(a)pyrene TEQ (zero)	µg/L	0.5									<0.5																	<0.5						

Table A5: Baseline Groundwater Monitoring Results - Wongawilli Seam

Location			Water Quality Criteria				HU0073PZB									HU0088PZA					HU0096PZB								HU0129PZA			
Analyte	Units	LOR	Aquatic	ANZECC (2000) Irrigation	Livestock	ADWG (2011)	27/03/2013	7/08/2013	15/10/2013	10/12/2013	3/04/2014	5/12/2014	26/03/2015	29/06/2015	21/09/2015	11/12/2013	2/04/2014	26/09/2014	3/12/2014	11/02/2015	8/08/2013	16/10/2013	9/12/2013	31/03/2014	5/12/2014	27/03/2015	7/07/2015	22/09/2015	22/05/2014	10/02/2015	24/06/2015	16/09/2015
Organochloride pesticides																																
alpha-BHC	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Hexachlorobenzene (HCB)	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
beta-BHC	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
gamma-BHC	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
delta-BHC	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Heptachlor	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Aldrin	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Heptachlor epoxide	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
trans-Chlordane	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
alpha-Endosulfan	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
cis-Chlordane	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Dieldrin	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
4.4`-DDE	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Endrin	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
beta-Endosulfan	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
4.4`-DDD	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Endrin aldehyde	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Endosulfan sulfate	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
4.4`-DDT	µg/L	2								<2.0			<2.0		<2.0	<2.0				<2.0			<2.0			<2.0		<2.0				
Endrin ketone	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Methoxychlor	µg/L	2								<2.0			<2.0		<2.0	<2.0				<2.0			<2.0			<2.0		<2.0				
Total Chlordane (sum)	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Sum of DDD + DDE + DDT	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Sum of Aldrin + Dieldrin	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Organophosphorous pesticides																																
Dichlorvos	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Demeton-S-methyl	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Monocrotophos	µg/L	2								<2.0			<2.0		<2.0	<2.0				<2.0			<2.0			<2.0		<2.0				
Dimethoate	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Diazinon	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Chlorpyrifos-methyl	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Parathion-methyl	µg/L	2								<2.0			<2.0		<2.0	<2.0				<2.0			<2.0			<2.0		<2.0				
Malathion	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Fenthion	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Chlorpyrifos	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Parathion	µg/L	2								<2.0			<2.0		<2.0	<2.0				<2.0			<2.0			<2.0		<2.0				
Pirimphos-ethyl	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Chlorfenvinphos	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Bromophos-ethyl	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Fenamiphos	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Prothiofos	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Ethion	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Carbophenothion	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Azinphos Methyl	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Phenolic compounds																																
Phenol	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
2-Chlorophenol	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
2-Methylphenol	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
3- & 4-Methylphenol	µg/L	1								<2.0			<2.0		<2.0	<2.0				<2.0			<2.0			<2.0		<2.0				
2-Nitrophenol	µg/L	2								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
2.4-Dimethylphenol	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
2.4-Dichlorophenol	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
2.6-Dichlorophenol	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
4-Chloro-3-methylphenol	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
2.4.6-Trichlorophenol	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
2.4.5-Trichlorophenol	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
Pentachlorophenol	µg/L	1								<2.0			<2.0		<2.0	<2.0				<2.0			<2.0			<2.0		<2.0				
Polynuclear aromatic hydrocarbons																																
Naphthalene	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
Acenaphthylene	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
Acenaphthene	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
Fluorene	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
Phenanthrene	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
Anthracene	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
Fluoranthene	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
Pyrene	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
Benz(a)anthracene	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
Chrysene	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
Benzo(b)fluoranthene	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
Benzo(k)fluoranthene	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
Benzo(a)pyrene	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Indeno(1.2.3.cd)pyrene	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
Dibenz(a.h)anthracene	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
Benzo(g.h.i)perylene	µg/L	1								<1.0			<1.0		<1.0	<1.0				<1.0			<1.0			<1.0		<1.0				
Sum of polycyclic aromatic hydrocarbons	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				
Benzo(a)pyrene TEQ (zero)	µg/L	0.5								<0.5			<0.5		<0.5	<0.5				<0.5			<0.5			<0.5		<0.5				

Table A5: Baseline Groundwater Monitoring Results - Wongawilli Seam

Location			Water Quality Criteria				HU0136PZA				HU0142PZA					HU0143PZB								
Analyte	Units	LOR	Aquatic	ANZECC (2000) Irrigation	Livestock	ADWG (2011)	29/08/2014	1/12/2014	4/02/2015	23/09/2015	24/09/2014	1/12/2014	26/03/2015	30/06/2015	17/09/2015	4/12/2014	18/02/2015	25/06/2015	23/09/2015	n	Detects	Exc	Min	Max	Avg	Geomean	Std Dev
Organochloride pesticides																											
alpha-BHC	µg/L	0.5											<0.5		<0.5					17	0						
Hexachlorobenzene (HCB)	µg/L	0.5											<0.5		<0.5					17	0						
beta-BHC	µg/L	0.5											<0.5		<0.5					17	0						
gamma-BHC	µg/L	0.5											<0.5		<0.5					17	0						
delta-BHC	µg/L	0.5											<0.5		<0.5					17	0						
Heptachlor	µg/L	0.5											<0.5		<0.5					17	0						
Aldrin	µg/L	0.5											<0.5		<0.5					17	0						
Heptachlor epoxide	µg/L	0.5											<0.5		<0.5					17	0						
trans-Chlordane	µg/L	0.5											<0.5		<0.5					17	0						
alpha-Endosulfan	µg/L	0.5											<0.5		<0.5					17	0						
cis-Chlordane	µg/L	0.5											<0.5		<0.5					17	0						
Dieldrin	µg/L	0.5											<0.5		<0.5					17	0						
4.4`-DDE	µg/L	0.5											<0.5		<0.5					17	0						
Endrin	µg/L	0.5											<0.5		<0.5					17	0						
beta-Endosulfan	µg/L	0.5											<0.5		<0.5					17	0						
4.4`-DDD	µg/L	0.5											<0.5		<0.5					17	0						
Endrin aldehyde	µg/L	0.5											<0.5		<0.5					17	0						
Endosulfan sulfate	µg/L	0.5											<0.5		<0.5					17	0						
4.4`-DDT	µg/L	2											<2.0		<2.0					17	0						
Endrin ketone	µg/L	0.5											<0.5		<0.5					17	0						
Methoxychlor	µg/L	2											<2.0		<2.0					17	0						
Total Chlordane (sum)	µg/L	0.5											<0.5		<0.5					17	0						
Sum of DDD + DDE + DDT	µg/L	0.5											<0.5		<0.5					17	0						
Sum of Aldrin + Dieldrin	µg/L	0.5											<0.5		<0.5					17	0						
Organophosphorous pesticides																											
Dichlorvos	µg/L	0.5											<0.5		<0.5					17	0						
Demeton-S-methyl	µg/L	0.5											<0.5		<0.5					17	0						
Monocrotophos	µg/L	2											<2.0		<2.0					17	0						
Dimethoate	µg/L	0.5											<0.5		<0.5					17	0						
Diazinon	µg/L	0.5											<0.5		<0.5					17	0						
Chlorpyrifos-methyl	µg/L	0.5											<0.5		<0.5					17	0						
Parathion-methyl	µg/L	2											<2.0		<2.0					17	0						
Malathion	µg/L	0.5											<0.5		<0.5					17	0						
Fenthion	µg/L	0.5											<0.5		<0.5					17	0						
Chlorpyrifos	µg/L	0.5											<0.5		<0.5					17	0						
Parathion	µg/L	2											<2.0		<2.0					17	0						
Pirimphos-ethyl	µg/L	0.5											<0.5		<0.5					17	0						
Chlorfenvinphos	µg/L	0.5											<0.5		<0.5					17	0						
Bromophos-ethyl	µg/L	0.5											<0.5		<0.5					17	0						
Fenamiphos	µg/L	0.5											<0.5		<0.5					17	0						
Prothiofos	µg/L	0.5											<0.5		<0.5					17	0						
Ethion	µg/L	0.5											<0.5		<0.5					17	0						
Carbophenothion	µg/L	0.5											<0.5		<0.5					17	0						
Azinphos Methyl	µg/L	0.5											<0.5		<0.5					17	0						
Phenolic compounds																											
Phenol	µg/L	1											<1.0		<1.0					17	1		1.3	1.3	1.3		
2-Chlorophenol	µg/L	1											<1.0		<1.0					17	0						
2-Methylphenol	µg/L	1											<1.0		<1.0					17	0						
3- & 4-Methylphenol	µg/L	1											<2.0		<2.0					17	0						
2-Nitrophenol	µg/L	2											<1.0		<1.0					17	0						
2.4-Dimethylphenol	µg/L	1											<1.0		<1.0					17	0						
2.4-Dichlorophenol	µg/L	1											<1.0		<1.0					17	0						
2.6-Dichlorophenol	µg/L	1											<1.0		<1.0					17	0						
4-Chloro-3-methylphenol	µg/L	1											<1.0		<1.0					17	0						
2.4.6-Trichlorophenol	µg/L	1											<1.0		<1.0					17	0						
2.4.5-Trichlorophenol	µg/L	1											<1.0		<1.0					17	0						
Pentachlorophenol	µg/L	1											<2.0		<2.0					17	0						
Polynuclear aromatic hydrocarbons																											
Naphthalene	µg/L	1											<1.0		<1.0					17	0						
Acenaphthylene	µg/L	1											<1.0		<1.0					17	0						
Acenaphthene	µg/L	1											<1.0		<1.0					17	0						
Fluorene	µg/L	1											<1.0		<1.0					17	0						
Phenanthrene	µg/L	1											<1.0		<1.0					17	0						
Anthracene	µg/L	1											<1.0		<1.0					17	0						
Fluoranthene	µg/L	1											<1.0		<1.0					17	0						
Pyrene	µg/L	1											<1.0		<1.0					17	0						
Benz(a)anthracene	µg/L	1											<1.0		<1.0					17	0						
Chrysene	µg/L	1											<1.0		<1.0					17	0						
Benzo(b)fluoranthene	µg/L	1											<1.0		<1.0					17	0						
Benzo(k)fluoranthene	µg/L	1											<1.0		<1.0					17	0						
Benzo(a)pyrene	µg/L	0.5											<0.5		<0.5					17	0						
Indeno(1.2.3.cd)pyrene	µg/L	1											<1.0		<1.0					17	0						
Dibenz(a.h)anthracene	µg/L	1											<1.0		<1.0					17	0						
Benzo(g.h.i)perylene	µg/L	1											<1.0		<1.0					17	0						
Sum of polycyclic aromatic hydrocarbons	µg/L	0.5											<0.5		<0.5					17	0						
Benzo(a)pyrene TEQ (zero)	µg/L	0.5											<0.5		<0.5					17	0						

Table A5: Baseline Groundwater Monitoring Results - Wongawilli Seam

Location			Water Quality Criteria				HU0018PZA										HU0023PZA				HU0032LDA				HU0038PZA							
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	17/10/2011	7/01/2013	22/03/2013	9/07/2013	17/10/2013	12/12/2013	8/04/2014	25/03/2015	2/07/2015	24/09/2015	16/11/2011	17/12/2012	25/03/2013	21/05/2014	12/12/2013	3/04/2014	26/03/2015	24/09/2015	24/07/2012	14/12/2012	11/12/2013	2/04/2014	15/08/2014	2/12/2014	12/02/2015	15/09/2015
BTEX																																
Benzene	µg/L	1										<1				<1					<1						<1				<1	
Toluene	µg/L	2	ID			800						3				<2					<2						<2				2	
Ethylbenzene	µg/L	2										<2				<2					<2						<2				<2	
meta- & para-Xylene	µg/L	2										<2				<2					<2						<2				<2	
ortho-Xylene	µg/L	2										<2				<2					<2						<2				<2	
Total Xylenes	µg/L	2										<2				<2					<2						<2				<2	
Sum of BTEX	µg/L	1										3				<1					<1						<1				2	
Naphthalene	µg/L	5										<5				<5					<5						<5				<5	
Total petroleum hydrocarbons																																
C6 - C9 Fraction	µg/L	20										<20				<20					<20						<20				<20	
C10 - C14 Fraction	µg/L	50										<50				<50					<50						<50				<50	
C15 - C28 Fraction	µg/L	100										<100				<100					<100						<100				<100	
C29 - C36 Fraction	µg/L	50										<50				<50					<50						<50				<50	
C10 - C36 Fraction (sum)	µg/L	50										<50				<50					<50						<50				<50	
Total Recoverable Hydrocarbons																																
C6 - C10 Fraction	µg/L	20										<20				<20					<20						<20				<20	
C6 - C10 Fraction minus BTEX (F1)	µg/L	20										<20				<20					<20						<20				<20	
>C10 - C16 Fraction	µg/L	100										<100				<100					<100						<100				<100	
>C16 - C34 Fraction	µg/L	100										<100				<100					<100						<100				<100	
>C34 - C40 Fraction	µg/L	100										<100				<100					<100						<100				<100	
>C10 - C40 Fraction (sum)	µg/L	100										<100				<100					<100						<100				<100	
>C10 - C16 Fraction minus Naphthalene (F2)	µg/L	100										<100				<100					<100						<100				<100	
Microbiology																																
Faecal coliforms	CFU/100 mL	1										<1				–<1					<1						<1				<2	
E coli	CFU/100 mL	1										<1				–<1					<1						<1				<2	
Total coliforms	CFU/100 mL	1										<1				<1					<1						<1				46	

Table A5: Baseline Groundwater Monitoring Results - Wongawilli Seam

Location			Water Quality Criteria				HU0042PZA						HU0043XPZA				HU0044XPZA								HU0072PZA								
Analyte	Units	LOR	Aquatic	ANZECC (2000) Irrigation	Livestock	ADWG (2011)	23/08/2012	19/12/2012	3/07/2013	19/08/2013	17/12/2013	2/02/2015	30/08/2012	3/01/2013	17/12/2013	5/02/2015	24/08/2012	14/12/2012	2/07/2013	18/09/2013	10/12/2013	20/03/2014	28/07/2014	18/02/2015	21/03/2013	8/07/2013	18/09/2013	11/12/2013	26/03/2014	14/08/2014	2/12/2014	25/03/2015	26/06/2015	15/09/2015
BTEX																																	
Benzene	µg/L	1									<1																	<1						
Toluene	µg/L	2	ID			800					26																	<2						
Ethylbenzene	µg/L	2									<2																	<2						
meta- & para-Xylene	µg/L	2									<2																	<2						
ortho-Xylene	µg/L	2									<2																	<2						
Total Xylenes	µg/L	2									<2																	<2						
Sum of BTEX	µg/L	1									26																	<1						
Naphthalene	µg/L	5									<5																	<5						
Total petroleum hydrocarbons																																	
C6 - C9 Fraction	µg/L	20									40																	<20						
C10 - C14 Fraction	µg/L	50									<50																	<50						
C15 - C28 Fraction	µg/L	100									<100																	<100						
C29 - C36 Fraction	µg/L	50									<50																	<50						
C10 - C36 Fraction (sum)	µg/L	50									<50																	<50						
Total Recoverable Hydrocarbons																																	
C6 - C10 Fraction	µg/L	20									40																	<20						
C6 - C10 Fraction minus BTEX (F1)	µg/L	20									<20																	<20						
>C10 - C16 Fraction	µg/L	100									<100																	<100						
>C16 - C34 Fraction	µg/L	100									<100																	<100						
>C34 - C40 Fraction	µg/L	100									<100																	<100						
>C10 - C40 Fraction (sum)	µg/L	100									<100																	<100						
>C10 - C16 Fraction minus Naphthalene (F2)	µg/L	100									<100																	<100						
Microbiology																																	
Faecal coliforms	CFU/100 mL	1									<1																	<1						
E coli	CFU/100 mL	1									<1																	<1						
Total coliforms	CFU/100 mL	1									<1																	<1						

Table A5: Baseline Groundwater Monitoring Results - Wongawilli Seam

Location			Water Quality Criteria				HU0073PZB									HU0088PZA					HU0096PZB								HU0129PZA			
Analyte	**Units**	**LOR**	**Aquatic**	**ANZECC (2000) Irrigation**	**Livestock**	**ADWG (2011)**	27/03/2013	7/08/2013	15/10/2013	10/12/2013	3/04/2014	5/12/2014	26/03/2015	29/06/2015	21/09/2015	11/12/2013	2/04/2014	26/09/2014	3/12/2014	11/02/2015	8/08/2013	16/10/2013	9/12/2013	31/03/2014	5/12/2014	27/03/2015	7/07/2015	22/09/2015	22/05/2014	10/02/2015	24/06/2015	16/09/2015
BTEX																																
Benzene	µg/L	1								<1			<1		<1	<1				<1			<1			<1		<1				
Toluene	µg/L	2	ID			800				<2			<2		<2	<2				62			<2			<2		<2				
Ethylbenzene	µg/L	2								<2			<2		<2	<2				<2			<2			<2		<2				
meta- & para-Xylene	µg/L	2								<2			<2		<2	<2				<2			<2			<2		<2				
ortho-Xylene	µg/L	2								<2			<2		<2	<2				<2			<2			<2		<2				
Total Xylenes	µg/L	2								<2			<2		<2	<2				<2			<2			<2		<2				
Sum of BTEX	µg/L	1								<1			<1		<1	<1				62			<1			<1		<1				
Naphthalene	µg/L	5								<5			<5		<5	<5				<5			<5			<5		<5				
Total petroleum hydrocarbons																																
C6 - C9 Fraction	µg/L	20								<20			<20		<20	<20				100			<20			<20		<20				
C10 - C14 Fraction	µg/L	50								<50			<50		<50	<50				<50			<50			<50		<50				
C15 - C28 Fraction	µg/L	100								<100			<100		<100	<100				<100			<100			<100		<100				
C29 - C36 Fraction	µg/L	50								<50			<50		<50	<50				<50			<50			<50		<50				
C10 - C36 Fraction (sum)	µg/L	50								<50			<50		<50	<50				<50			<50			<50		<50				
Total Recoverable Hydrocarbons																																
C6 - C10 Fraction	µg/L	20								<20			<20		<20	<20				100			<20			<20		<20				
C6 - C10 Fraction minus BTEX (F1)	µg/L	20								<20			<20		<20	<20				40			<20			<20		<20				
>C10 - C16 Fraction	µg/L	100								<100			<100		<100	<100				<100			<100			<100		<100				
>C16 - C34 Fraction	µg/L	100								<100			<100		<100	<100				<100			<100			<100		<100				
>C34 - C40 Fraction	µg/L	100								<100			<100		<100	<100				<100			<100			<100		<100				
>C10 - C40 Fraction (sum)	µg/L	100								<100			<100		<100	<100				<100			<100			<100		<100				
>C10 - C16 Fraction minus Naphthalene (F2)	µg/L	100								<100			<100		<100	<100				<100			<100			<100		<100				
Microbiology																																
Faecal coliforms	CFU/100 mL	1								<1			<1		<1	<1				<1			<1			<2		<1				
E coli	CFU/100 mL	1								<1			<1		<1	<1				<1			<1			<2		<1				
Total coliforms	CFU/100 mL	1								<2			<1		−1	−1				140			<1			<2		<1				

Table A5: Baseline Groundwater Monitoring Results - Wongawilli Seam

Location			Water Quality Criteria				HU0136PZA				HU0142PZA					HU0143PZB			
Analyte	Units	LOR	Aquatic	ANZECC (2000) Irrigation	Livestock	ADWG (2011)	29/08/2014	1/12/2014	4/02/2015	23/09/2015	24/09/2014	1/12/2014	26/03/2015	30/06/2015	17/09/2015	4/12/2014	18/02/2015	25/06/2015	23/09/2015
BTEX																			
Benzene	µg/L	1											<1		<1				
Toluene	µg/L	2	ID			800							<2		<2				
Ethylbenzene	µg/L	2											<2		<2				
meta- & para-Xylene	µg/L	2											<2		<2				
ortho-Xylene	µg/L	2											<2		<2				
Total Xylenes	µg/L	2											<2		<2				
Sum of BTEX	µg/L	1											<1		<1				
Naphthalene	µg/L	5											<5		<5				
Total petroleum hydrocarbons																			
C6 - C9 Fraction	µg/L	20											<20		<20				
C10 - C14 Fraction	µg/L	50											<50		<50				
C15 - C28 Fraction	µg/L	100											<100		<100				
C29 - C36 Fraction	µg/L	50											<50		<50				
C10 - C36 Fraction (sum)	µg/L	50											<50		<50				
Total Recoverable Hydrocarbons																			
C6 - C10 Fraction	µg/L	20											<20		<20				
C6 - C10 Fraction minus BTEX (F1)	µg/L	20											<20		<20				
>C10 - C16 Fraction	µg/L	100											<100		<100				
>C16 - C34 Fraction	µg/L	100											<100		<100				
>C34 - C40 Fraction	µg/L	100											<100		<100				
>C10 - C40 Fraction (sum)	µg/L	100											<100		<100				
>C10 - C16 Fraction minus Naphthalene (F2)	µg/L	100											<100		<100				
Microbiology																			
Faecal coliforms	CFU/100 mL	1											<2		<2				
E coli	CFU/100 mL	1											<2		<2				
Total coliforms	CFU/100 mL	1											<2		<2				

BTEX							
17	0						
17	4		2	62	23.3		
17	0						
17	0						
17	0						
17	0						
17	4		2	62	23.3		
17	0						
Total petroleum hydrocarbons							
17	2		40	100	70		
17	0						
17	0						
17	0						
17	0						
Total Recoverable Hydrocarbons							
17	2		40	100	70		
17	1		40	40	40		
17	0						
17	0						
17	0						
17	0						
17	0						
Microbiology							
17	0						
17	0						
17	2		46	140	93		

Table A6: Baseline Groundwater Monitoring Results - Tongarra Seam

Location			Water Quality Criteria				HU0096PZA								HU0133PZB							
Date			ANZECC (2000)			ADWG (2011)	8/08/2013	16/10/2013	9/12/2013	31/03/2014	5/12/2014	27/03/2015	7/07/2015	22/09/2015	23/05/2014							
Analyte	Units	LOR	Aquatic	Irrigation	Livestock											n	Detects	Exc	Min	Max	Avg	Geomean	Std Dev
General field parameters																							
pH	pH units		6.5-7.5				6.08	6.25	6.22	6.10	6.09	6.01	6.16	6.10	6.22	9	9	9	6.01	6.25	6.13	6.14	0.08
Conductivity (field)	µS/cm		30-350	0-650 (v. low) >650-1300 (low) >1300-2900 (medium) >2900-5200 (high) >5200-8100 (v. high) >8100 (extreme)			192	238	225	223	231	213.3	222.7	224	262	9	9	0	192	262	226	225	19
Conductivity (lab)	µS/cm	1	30-350							223			214			2	2	0	214	223	219	218	
Total Dissolved Solids (field)	mg/L					<600 (good quality) 600-900 (fair quality) >900-1200 (poor quality) >1200 (unacceptable)	0.110	0.155	0.147	0.145	0.150	0.139	0.145	0.145	0.170	9	9		0.11	0.17	0	0.14	0.02
Total Dissolved Solids (lab)	mg/L	10								113		107	103	108	116	5	5		103	116	109	109	
Dissolved oxygen	% sat		90-110				16.8	15.2	25.3	8.5	21.7	37.2	26.4	12.4	23.8	9	9		8.5	37.2	20.8	19	9
Redox	mV						27	8.8	-15	0.2	-3.2	19.3	-5	-133.5	-42.6	9	9		-133.5	27.0	-16.0		48
Temperature	°C						20.00	19.90	20.36	19.30	19.00	14.2	14.6	15.44	20.32	9	9		14.2	20.4	18.1	18	3
Suspended Solids	mg/L	5											<5	<5		2	0						
Turbidity	NTU	0.1	2-25											3.3		1	1						
Major Ions																							
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	9	0						
Carbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	9	0						
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	69	64	53	46	63	53	64	58	87	9	9		46	87	62	61	12
Total Alkalinity as $CaCO_3$	mg/L	1	-	-	-	-	69	64	53	46	63	53	64	58	87	9	9		46	87	62	61	12
Acidity as $CaCO_3$	mg/L	1	-	-	-	-							65			1	1		65	65	65	65	
Sulfate as SO_4^{2-}	mg/L	1	-	-	1000	500	5	3	4	5	2	5	4	4	8	9	9	0	2	8	4.4	4	2
Chloride	mg/L	1	-	700	-	ID	30	37	34	34	25	40	28	30	30	9	9	0	25	40	32.0	32	5
Calcium	mg/L	1	-	-	1000	-	10	9	9	7	7	6	8	8	13	9	9	0	6	13	8.6	8	2
Magnesium	mg/L	1	-	-	ID	-	6	6	6	6	6	6	6	6	8	9	9		6	8	6.2	6	1
Sodium	mg/L	1	-	460	-	-	15	14	16	18	14	15	13	15	19	9	9	0	13	19	15.4	15	2
Potassium	mg/L	1	-	-	-	-	2	2	2	2	2	2	2	2	3	9	9		2	3	2.11	2	0
Silica/Silicon as SiO_2/Reactive silica	mg/L	0.1	-	-	-	-	9.0	9.6	8.2	8.8	9	9.42	8.9	8.79	9.62	9	9		8.21	9.62	9.0	9	0
Total Anions	meq/L	0.01	-	-	-	-	2.33	2.38	2.10	2.22	2.01	2.29	2.15	2.09	2.75								
Total Cations	meq/L	0.01	-	-	-	-	2.35	2.13	2.05	2.32	1.5	2.21	1.51	2.24	2.69								
Ionic Balance	%	0.01	-	-	-	-						1.8											
Other Inorganics																							
Flouride	mg/L	0.1	-	2	2	1.5			0.2	0.2		<0.1	0.1	0.2	0.1	6	5		0.1	0.2	0.2	0	0
Free cyanide	mg/L	0.004	0.007	-	-	0.08			<0.004			<0.004			<0.004	3	0						
Total cyanide	mg/L	0.004	-	-	-	-			<0.004			<0.004			<0.004	3	0						
Thiocyanate	mg/L	0.1	-	-	-	-			<0.1			<0.1			<0.1	3	0						
Dissolved metals																							
Aluminium	mg/L	0.01	0.055	20	5	ID			<0.01	<0.01	0.01	0.02	<0.01	<0.01	0.06	7	3	1	0.01	0.06	0.03	0.02	0.03
Antimony	mg/L	0.001	ID	-	-	0.003			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	7	0						
Arsenic	mg/L	0.001	0.013	2	0.5	0.01			<0.001	0.002	0.001	0.001	0.001	<0.001	<0.001	7	4		0.001	0.002	0.001	0.001	0.001
Beryllium	mg/L	0.001	ID	0.5	ID	0.06			<0.001			<0.001		<0.001	<0.001	4	0						
Barium	mg/L	0.001	-	-	-	2			0.099			0.057	0.07	0.067	0.116	5	5		0.057	0.116	0.082	0.079	0.025
Cadmium	mg/L	0.0001	0.0002	0.05	0.01	0.002			<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	7	0						
Chromium	mg/L	0.001	0.001	1	1	0.05			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	7	0						
Cobalt	mg/L	0.001	ID	0.1	1	-			0.003	0.002	0.001	<0.001	<0.001	<0.001	0.002	7	4		0.001	0.003	0.002	0.002	0.001
Copper	mg/L	0.001	0.0014	5	1#	2			<0.001	<0.001	0.01	0.003	<0.001	<0.001	<0.001	7	2	2	0.003	0.01	0.007	0.005	0.005
Lead	mg/L	0.001	0.0034	5	0.1	0.01			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	7	0						
Lithium	mg/L	0.001	-	2.5	-	-			0.058			0.035		0.042	0.039	4	4		0.035	0.058	0.044	0.043	0.010
Manganese	mg/L	0.001	1.9	10	-	0.5	0.493	0.527	0.708	0.565	0.651	0.734	0.561	0.558	0.482	9	9	0	0.482	0.734	0.587	0.58	0.09
Molybdenum	mg/L	0.001	ID	0.05	0.15	0.05			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	7	0						
Nickel	mg/L	0.001	0.011	2	1	0.02			0.005	0.004	0.007	0.003	0.001	0.001	0.002	7	7	0	0.001	0.007	0.003	0.003	0.002
Selenium	mg/L	0.01	0.005	0.05	0.02	0.01			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	7	0						
Strontium	mg/L	0.001	-	-	-	-			0.056			0.034	0.035	0.036	0.104	5	5		0.034	0.104	0.053	0.048	0.030
Tin	mg/L	0.001	ID	-	-	-			<0.001			<0.001		<0.001	<0.001	4	0						
Uranium	mg/L	0.001	ID	0.1	0.2	0.017			<0.001			<0.001		<0.001	<0.001	4	0						
Vanadium	mg/L	0.01	ID	0.5	ID	-			<0.01			<0.01		<0.01	<0.01	4	0						
Zinc	mg/L	0.005	0.008	5	20	ID			0.043	0.042	0.054	0.02	0.006	<0.005	0.023	7	6	5	0.006	0.054	0.031	0.025	0.018
Boron	mg/L	0.05	0.37	5	5	4			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	7	0						
Iron	mg/L	0.05	ID	10	ID	ID	7.96	9.76	12.4	11.8	11.1	13.3	12.6	12.0	8.02	9	9	6	8.0	13.3	11.0	10.8	2.0
Ferrous iron	mg/L	0.05	-	-	-	ID							13.4	13.1		0	2		13.1	13.4	13.3	13.2	0.2
Bromine	mg/L	0.1	-	-	-	-			0.5			<0.1		<0.1	0.1	4	2		0.1	0.5	0.3	0.2	0.3
Iodine	mg/L	0.1	-	-	-	ID			<0.1			<0.1		<0.1	<0.1	4	0						
Mercury	mg/L	0.0001	0.00006	0.002	0.002	0.001			<0.0001			<0.0001			<0.0001	3	0						
Total metals																							
Aluminium	mg/L	0.01	-	-	-	-			<0.01			0.62		<0.01	0.08	4	2		0.1	0.6	0.4	0.2	0.4
Manganese	mg/L	0.001	-	-	-	-			0.697			0.724	0.575	0.584	0.48	5	5		0.5	0.7	0.6	0.6	0.1
Iron	mg/L	0.05	-	-	-	-			13.8			15.3	13	12.2	8.31	5	5		8.3	15.3	12.5	12.3	2.6
Nutrients																							
Ammonia as N	mg/L	0.01	2.57						0.03			<0.01		0.02	0.07	4	3		0.02	0.07	0.04	0.03	0.03
Nitrite as N	mg/L	0.01			9				<0.01	<0.01		<0.01		<0.01	<0.01	5	0						
Nitrate as N	mg/L	0.01			90				0.02	<0.01		<0.01		<0.01	0.01	5	2		0.01	0.02	0.02	0.01	0.01
Total phosphorous	mg/L	0.01							<0.01			0.06			<0.01	3	1		0.06	0.06	0.06	0.06	
Reactive phosphorous	mg/L	0.01							<0.01	<0.01		<0.01		<0.01	<0.01	5	0						
Biochemical oxygen demand	mg/L	2												<2									

Table A6: Baseline Groundwater Monitoring Results - Tongarra Seam

Location			Water Quality Criteria				HU0096PZA								HU0133PZB
Date			ANZECC (2000)			ADWG (2011)	8/08/2013	16/10/2013	9/12/2013	31/03/2014	5/12/2014	27/03/2015	7/07/2015	22/09/2015	23/05/2014
Analyte	Units	LOR	Aquatic	Irrigation	Livestock										
Organochloride pesticides															
alpha-BHC	µg/L	0.5							<0.5			<0.5		<0.5	
Hexachlorobenzene (HCB)	µg/L	0.5							<0.5			<0.5		<0.5	
beta-BHC	µg/L	0.5							<0.5			<0.5		<0.5	
gamma-BHC	µg/L	0.5							<0.5			<0.5		<0.5	
delta-BHC	µg/L	0.5							<0.5			<0.5		<0.5	
Heptachlor	µg/L	0.5							<0.5			<0.5		<0.5	
Aldrin	µg/L	0.5							<0.5			<0.5		<0.5	
Heptachlor epoxide	µg/L	0.5							<0.5			<0.5		<0.5	
trans-Chlordane	µg/L	0.5							<0.5			<0.5		<0.5	
alpha-Endosulfan	µg/L	0.5							<0.5			<0.5		<0.5	
cis-Chlordane	µg/L	0.5							<0.5			<0.5		<0.5	
Dieldrin	µg/L	0.5							<0.5			<0.5		<0.5	
4.4´-DDE	µg/L	0.5							<0.5			<0.5		<0.5	
Endrin	µg/L	0.5							<0.5			<0.5		<0.5	
beta-Endosulfan	µg/L	0.5							<0.5			<0.5		<0.5	
4.4´-DDD	µg/L	0.5							<0.5			<0.5		<0.5	
Endrin aldehyde	µg/L	0.5							<0.5			<0.5		<0.5	
Endosulfan sulfate	µg/L	0.5							<0.5			<0.5		<0.5	
4.4´-DDT	µg/L	2							<2.0			<2.0		<2.0	
Endrin ketone	µg/L	0.5							<0.5			<0.5		<0.5	
Methoxychlor	µg/L	2							<2.0			<2.0		<2.0	
Total Chlordane (sum)	µg/L	0.5							<0.5			<0.5		<0.5	
Sum of DDD + DDE + DDT	µg/L	0.5							<0.5			<0.5		<0.5	
Sum of Aldrin + Dieldrin	µg/L	0.5							<0.5			<0.5		<0.5	
Organophosphorous pesticides															
Dichlorvos	µg/L	0.5							<0.5			<0.5		<0.5	
Demeton-S-methyl	µg/L	0.5							<0.5			<0.5		<0.5	
Monocrotophos	µg/L	2							<2.0			<2.0		<2.0	
Dimethoate	µg/L	0.5							<0.5			<0.5		<0.5	
Diazinon	µg/L	0.5							<0.5			<0.5		<0.5	
Chlorpyrifos-methyl	µg/L	0.5							<0.5			<0.5		<0.5	
Parathion-methyl	µg/L	2							<2.0			<2.0		<2.0	
Malathion	µg/L	0.5							<0.5			<0.5		<0.5	
Fenthion	µg/L	0.5							<0.5			<0.5		<0.5	
Chlorpyrifos	µg/L	0.5							<0.5			<0.5		<0.5	
Parathion	µg/L	2							<2.0			<2.0		<2.0	
Pirimphos-ethyl	µg/L	0.5							<0.5			<0.5		<0.5	
Chlorfenvinphos	µg/L	0.5							<0.5			<0.5		<0.5	
Bromophos-ethyl	µg/L	0.5							<0.5			<0.5		<0.5	
Fenamiphos	µg/L	0.5							<0.5			<0.5		<0.5	
Prothiofos	µg/L	0.5							<0.5			<0.5		<0.5	
Ethion	µg/L	0.5							<0.5			<0.5		<0.5	
Carbophenothion	µg/L	0.5							<0.5			<0.5		<0.5	
Azinphos Methyl	µg/L	0.5							<0.5			<0.5		<0.5	
Phenolic compounds															
Phenol	µg/L	1							<1.0			<1.0		<1.0	
2-Chlorophenol	µg/L	1							<1.0			<1.0		<1.0	
2-Methylphenol	µg/L	1							<1.0			<1.0		<1.0	
3- & 4-Methylphenol	µg/L	1							<2.0			<2.0		<2.0	
2-Nitrophenol	µg/L	2							<1.0			<1.0		<1.0	
2.4-Dimethylphenol	µg/L	1							<1.0			<1.0		<1.0	
2.4-Dichlorophenol	µg/L	1							<1.0			<1.0		<1.0	
2.6-Dichlorophenol	µg/L	1							<1.0			<1.0		<1.0	
4-Chloro-3-methylphenol	µg/L	1							<1.0			<1.0		<1.0	
2.4.6-Trichlorophenol	µg/L	1							<1.0			<1.0		<1.0	
2.4.5-Trichlorophenol	µg/L	1							<1.0			<1.0		<1.0	
Pentachlorophenol	µg/L	1							<2.0			<2.0		<2.0	
Polynuclear aromatic hydrocarbons															
Naphthalene	µg/L	1							<1.0			<1.0		<1.0	
Acenaphthylene	µg/L	1							<1.0			<1.0		<1.0	
Acenaphthene	µg/L	1							<1.0			<1.0		<1.0	
Fluorene	µg/L	1							<1.0			<1.0		<1.0	
Phenanthrene	µg/L	1							<1.0			<1.0		<1.0	
Anthracene	µg/L	1							<1.0			<1.0		<1.0	
Fluoranthene	µg/L	1							<1.0			<1.0		<1.0	
Pyrene	µg/L	1							<1.0			<1.0		<1.0	
Benz(a)anthracene	µg/L	1							<1.0			<1.0		<1.0	
Chrysene	µg/L	1							<1.0			<1.0		<1.0	
Benzo(b)fluoranthene	µg/L	1							<1.0			<1.0		<1.0	
Benzo(k)fluoranthene	µg/L	1							<1.0			<1.0		<1.0	
Benzo(a)pyrene	µg/L	0.5							<0.5			<0.5		<0.5	
Indeno(1.2.3.cd)pyrene	µg/L	1							<1.0			<1.0		<1.0	
Dibenz(a.h)anthracene	µg/L	1							<1.0			<1.0		<1.0	
Benzo(g.h.i)perylene	µg/L	1							<1.0			<1.0		<1.0	
Sum of polycyclic aromatic hydrocarbons	µg/L	0.5							<0.5			<0.5		<0.5	
Benzo(a)pyrene TEQ (zero)	µg/L	0.5							<0.5			<0.5		<0.5	

Table A6: Baseline Groundwater Monitoring Results - Tongarra Seam

Location			Water Quality Criteria				HU0096PZA								HU0133PZB
Date			ANZECC (2000)			ADWG (2011)	8/08/2013	16/10/2013	9/12/2013	31/03/2014	5/12/2014	27/03/2015	7/07/2015	22/09/2015	23/05/2014
Analyte	Units	LOR	Aquatic	Irrigation	Livestock										
BTEX															
Benzene	µg/L	1							<1			<1		<1	
Toluene	µg/L	2	ID			800			<2			<2		<2	
Ethylbenzene	µg/L	2							<2			<2		<2	
meta- & para-Xylene	µg/L	2							<2			<2		<2	
ortho-Xylene	µg/L	2							<2			<2		<2	
Total Xylenes	µg/L	2							<2			<2		<2	
Sum of BTEX	µg/L	1							<1			<1		<1	
Naphthalene	µg/L	5							<5			<5		<5	
Total petroleum hydrocarbons															
C6 - C9 Fraction	µg/L	20							<20			<20		<20	
C10 - C14 Fraction	µg/L	50							<50			<50		<50	
C15 - C28 Fraction	µg/L	100							<100			<100		<100	
C29 - C36 Fraction	µg/L	50							<50			<50		<50	
C10 - C36 Fraction (sum)	µg/L	50							<50			<50		<50	
Total Recoverable Hydrocarbons															
C6 - C10 Fraction	µg/L	20							<20			<20		<20	
C6 - C10 Fraction minus BTEX (F1)	µg/L	20							<20			<20		<20	
>C10 - C16 Fraction	µg/L	100							<100			<100		<100	
>C16 - C34 Fraction	µg/L	100							<100			<100		<100	
>C34 - C40 Fraction	µg/L	100							<100			<100		<100	
>C10 - C40 Fraction (sum)	µg/L	100							<100			<100		<100	
>C10 - C16 Fraction minus Naphthalene	µg/L	100							<100			<100		<100	
Microbiology															
Faecal coliforms	CFU/100 m	1							<1			−10		<1	
E coli	CFU/100 m	1							<1			−10		<1	
Total coliforms	CFU/100 m	1							<1			34		<1	

Table A7: Monitoring Well Construction Details (from Coffey, 2016a)

Piezometer	Easting (MGA)	Northing (MGA)	RL Ground (mAHD)	RL Casing (mAHD)	Drilled Depth (mbgl)	Screen (mbgl) From	Screen (mbgl) To	Sandpack (mbgl) From	Sandpack (mbgl) To	Screened Stratum	L (m)	Comment
H18A	246696	6174166	691.74	691.67	108	96	99	95	99	WW	4	
H18B	246695	6174159	691.97	691.89	114	75	88	73	88	HAW	15	
H19A	243557	6174381	720.65	720.55	108	100	103	100	103	WW	3	
H19B	243562	6174379	720.46	720.36	88	70	81	69	81	HAW	12	
H20A	244258	6176920	703.25	703.18	80	71	77	71	77	HAW	6	Dry (SWL < 626 mAHD)
H20B	244255	6176930	703.67	703.59	114	80	86	78	86	WW	8	
H23A	250769	6169622	680.47	680.38	140	135	138	135	138	WW	3	
H23B	250763	6169620	680.63	680.55	132	118	130	116	130	HAW	14	Decommissioned. Replaced by H142A to H142C
H23C	250755	6169617	680.76	680.69	100	84	97	82	97	HAW	15	
H32LDA	249532	6173533	646.6	646.78	152	108	114	106	117	WW	11	A and B in same hole
H32LDB	249532	6173533	646.6	646.73	152	57	88	54	89	HAW	35	
H35A	250523	6172486	681.43	682.16	152	53	77	50	78	HAW	28	
H35B	250531	6172487	680.84	681.52	35	15	34	14	35	WG	21	
H37A	246551	6167440	703.79	703.7	111	101	105	101	107	ICM	6	WW absent
H37B	246546	6167438	703.77	703.69	90	72	87	70	90	HAW	20	
H38A	248783	6175453	658.53	657.67	117	105	108	103	110	WW	7	
H38B	248788	6175452	658.44	658.33	78	74	77	72	78	HAW	6	
H38C	248793	6175452	658.31	658.17	63	55	62	52	63	HAW	11	
H42A	250988	6166688	702.5	702.43	173	156	159	153	161	WW	8	
H42C	250985	6166678	702	701.92	150	142	150	135	150	HAW	15	
H43XA	247147	6178127	692.04	691.96	111	95	101	93	103	WW	10	
H43XB	247152	6178133	691.77	691.69	87	77	86	75	87	HAW	12	
H44XA	242285	6164084	641.94	641.92	12	8	11	7	12	WW	5	
H44XB	242281	6164077	647	646.96	5	4	5	3.5	5	HAW	2	
H56XB	245225	6169198	735.45		140	132	140	130	140	HAW	10	
H56XC	245234	6169198	735.51		26	19	25	17	26	Basalt	9	
H72A	252074	6177157	640.12	640.05	129	124	128	121	129	WW	8	
H72B	252083	6177169	640.43	640.36	99	92	98	88	98	HAW	10	
H72C	252091	6177180	640.85	640.77	46	39	45	35	46	HAW	11	
H73A	251015	6172718	656.46	657	172	151	169	149	172	ICM Lower	23	
H73B	251029	6172717	655.78	656.35	124	119	123	117	124	WW	7	
H73C	251035	6172717	655.5	656.13	86	79	85	77	86	HAW	9	
H88A	253059	6173144	655.44	655.37	156	143	146	141	148	WW	7	
H88B	253059	6173144	655.33	655.26	150	121	126	119	128	HAW	9	
H96A	246489	6177025	699.21	699.14	147	111	120	108	120	ICM Lower	12	
H96B	246491	6177029	699.1	699	101	92	98	91	101	WW	10	
H96C	246494	6177045	683	682.94	89	69	87	67	89	HAW	22	
H118A	240529	6166811	612.5		15.3	7	13	5	15.3	HAW	10	Near swamp (under peat)
H129A	253042	6171301	679.1	679.04	177	166	170	165	171	WW	6	
H129B	253044	6171306	679.2	679.11	177	146	153	146	153	HAW	7	
H133A	249685	6176683	648.15	647.98	141	119	126	115	127	ICM Lower	12	
H133B	249688	6176688	648.17	648.04	113	108	113	108	113	WW	5	Decommissioned. Replaced by H143A to H143C
H133C	249690	6176694	648.03	647.94	84	80	83	77	84	HAW	7	
H136A	254521	6166894	718.49	718.36	216	199	203	196	203	WW	7	
H136B	254517	6166890	718.52	718.4	168	157	168	155	168	HAW	13	
H136C	254513	6166887	718.51	718.4	60	52	59	50	60	Basalt	10	
H142A	250856	6169881	672.43		130.8	127	130	126	131	WW	5	Replacement for H23A
H142B	250855	6169886	672.32		119.8	112	118	110	120	HAW	10	Replacement for H23B
H142C	250855	6169892	672.23		86.8	81	84	79	86.8	HAW	8	Replacement for H23C
H143A	249671	6176708	649.55		125.8	115	125	116	126	ICM Lower	10	Replacement for H133A
H143B	249672	6176703	649.59		113	109	112	107	113	WW	6	Replacement for H133B
H143C	249673	6176697	649.45		95.9	92	95	88	95.9	HAW	8	Replacement for H133C
H40_1	251140	6172143	656.51	656.51	129	120	120	VWP	VWP	WW	Point	Packer testing. Core K.
H40_2	251140	6172143	656.51	656.51	129	107	107	VWP	VWP	HAW	Point	
H40_3	251140	6172143	656.51	656.51	129	81	81	VWP	VWP	HAW	Point	
H40_4	251140	6172143	656.51	656.51	129	39	39	VWP	VWP	HAW	Point	
H77_1	246966	6175811	689.74	689.74	98	87	87	VWP	VWP	WW	Point	Packer testing. Core K.
H77_2	246966	6175811	689.74	689.74	98	72	72	VWP	VWP	HAW	Point	
H77_3	246966	6175811	689.74	689.74	98	58	58	VWP	VWP	HAW	Point	
H122_1	250352	6175286	634.5	634.5	120	112	112	VWP	VWP	WW	Point	Packer testing. Core K.
H122_2	250352	6175286	634.5	634.5	120	86	86	VWP	VWP	HAW	Point	
H122_3	250352	6175286	634.5	634.5	120	45	45	VWP	VWP	HAW	Point	
H122_4	250352	6175286	634.5	634.5	120	15	15	VWP	VWP	HAW	Point	
GW106652	250614	6179763	652.32	652.85	120	25	120	Open hole		HAW	95	Intersects WW seam.
GW106710	248326	6172551	672.39	672.7	115	64	108	Open hole		HAW	44	

Appendix J

Hydrogeochemical modelling assessments

LEADERS IN MINING GEOCHEMISTRY

Hume Coal Hydrogeochemical Modelling Assessments

Prepared for: **Hume Coal Pty Ltd**

by**: RGS Environmental Pty Ltd**

February 2018

Hume Coal Hydrogeochemical Modelling Assessments

Prepared for: Hume Coal Pty Ltd

DOCUMENT CONTROL			
Report Title	Hume Coal Hydrogeochemical Modelling Assessments		
Project Name			
Job Number	2017054	**Client**	Hume Coal Pty Ltd

© RGS Environmental Pty Ltd, 2018. .....123 Wynne St, Sunnybank Hills, QLD 4109 www.rgsenv.com

Limitations and disclaimer:

This report documents the work undertaken by RGS Environmental Pty Ltd (RGS. This report should be read in full. While the findings presented in this report are based on information that RGS considers reliable unless stated otherwise, the accuracy and completeness of source information cannot be guaranteed, although RGS has taken reasonable steps to verify the accuracy of such source data. RGS has made no independent verification of this information beyond the agreed scope of works and RGS assumes no responsibility for any inaccuracies or omissions outside of RGS's direct control. Furthermore, the information compiled in this report addresses the specific needs of the client, so may not address the needs of third parties using this report for their own purposes. Thus, RGS and their employees accept no liability for any losses or damage for any action taken or not taken on the basis of any part of the contents of this report. Those acting on information provided in this report do so entirely at their own risk.

This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

EXECUTIVE SUMMARY

RGS Environmental Pty Ltd (RGS) was commissioned by Hume Coal Pty Limited (Hume Coal) to undertake an independent hydrogeochemical modelling assessment in response to specific submissions/comments related to the Hume Coal EIS (EMM, 2017) and the Hydrogeochemical Assessment undertaken by Geosyntec Consultants (Geosyntec, 2016). The specific comments related to:

- Predicting water quality evolution in the primary water dam; and,
- Groundwater response to underground placement of the reject slurry.

Several hydrogeochemical models were constructed in Geochemist's Workbench (GWB) and PHREEQC to ultimately estimate the range of water qualities likely to exist in the primary water dam (PWD) over the life-of-mine, and to determine the likely water qualities resulting from the placement of reject slurries (reject porewater + PWD water) into mined-out voids (panels) and subsequent rebound of groundwater.

There were several components to the modelling, each required to provide the necessary inputs to the next model. The components included:

- Modelling stockpile seepage and runoff for the temporary reject stockpile, run-of-mine pad and product stockpiles;
- Modelling stormwater basins (SB) and mine water dam (MWD) water qualities to determine the surface water quality contribution to the PWD;
- Modelling the range of PWD water qualities;
- Modelling reject slurry water qualities for two different scenarios; and,
- Modelling the interaction of reject slurry with groundwater in a mined-out void (panel).

The key results for the modelling are summarised in the following points:

- The PWD modelled water qualities are circum neutral (pH 6.03 to 8.25) and are likely to remain neutral over the mine life. There are several dissolved metal(loid)s which exceed either the ADWG and/or ANZECC water quality criteria for modelled scenarios and sensitivities (i.e. Al, Cu, Cr, Cd, Co, Ni, Pb, Se and Zn). However, although some of the metal(loid) concentrations exceed guideline values, nearly all metal(loids) (excluding Cr and some Ni) are within the range of baseline groundwater conditions for the Wongawilli Coal Seam.

- The placement of a reject slurry (PWD water + reject porewater) in a mined-out void (panel) was modelled for two separate scenarios:

    - Scenario 1: Operation phase - freshly produced reject material treated with 1% limestone, mixed with PWD water to produce a reject slurry which is emplaced in a panel and interacted with groundwater; and,

    - Scenario 2: After mining has been completed - aged reject material treated with 2% limestone and temporarily stockpiled for ~20 years, mixed with PWD water to produce a reject slurry, which is emplaced in a panel and interacted with groundwater.

- **Scenario 1:**
  - The modelled groundwater conditions within a backfilled panel after emplacement of the reject slurry are circumneutral (pH 6.06 to 6.11).
  - The concentration of dissolved metal(loid)s within a backfilled panel exceed either the ADWG and/or ANZECC criteria for Cu, Mn, Ni, Se and Zn. However, when compared to average baseline groundwater concentrations for the Wongawilli Coal Seam, all modelled Cu, Mn, Se and some Ni concentrations are below average values.
- **Scenario 2:**
  - The modelled groundwater conditions within a backfilled panel after emplacement of the reject slurry are also circum neutral (pH 6.03 to 6.10).
  - The concentration of dissolved metal(loid)s within a backfilled panel exceed either the ADWG and/or ANZECC criteria for Cu, Ni, Se and Zn. However, when compared to average baseline groundwater concentrations for the Wongawilli Coal Seam, all modelled Cu, Se and Zn concentrations are below/equal to baseline values.
- Therefore, for both scenarios, the modelled concentrations resulting from the emplacement of reject slurry in a mined-out void, and subsequent groundwater interaction are generally lower than or equal to baseline groundwater conditions for the Wongawilli Coal Seam. The only exception is for some Ni scenarios/sensitivities, which are still within the range of baseline concentrations reported for the Wongawilli Seam.
- The modelling inputs are typically conservative, with rainfall and groundwater inputs utilising the 95th percentile values of each dataset. Similarly, some minerals were supressed (prevented from precipitating) during the modelling based on observations of the KLC tests and RGS's technical experience, which may result in higher dissolved metal(loid)s than would occur in field conditions.
- If the coal rejects are managed appropriately the potential for adverse impacts to receiving groundwater is considered low as the water quality resulting from reject slurry emplacement is similar to the natural groundwater quality of the Wongawilli Coal Seam.

TABLE OF CONTENTS

1.0 Introduction 1
1.1 Project Background 1
1.2 Project Objectives 5
1.3 Hydrogeochemical Conceptual Model and Assumptions 6
2.0 Background Data 7
2.1 Characterisation of coal and mining waste 7
2.2 Climate: Rainfall and evapotranspiration 10
2.3 Hydrochemistry: Hydrogeochemical modelling input 11
3.0 Modelling Stockpile Geochemical Response 17
3.1 Water Quality Model 17
3.2 Model Construction 17
3.3 Overview and Assumptions in the Conceptual Geochemical Model 18
3.4 Modelling Results and Discussion 21
4.0 Modelling Stormwater Basin and Mine Water Dam Water Qualities 30
4.1 Water Quality Model 30
4.2 Model Construction 30
4.3 Overview and Assumptions in the Conceptual Geochemical Model 30
4.4 Modelling Results and Discussion 33
5.0 Modelling PWD Water Qualities 38
5.1 Water Quality Model 38
5.2 Model Construction 38
5.3 Overview and Assumptions in the Conceptual Geochemical Model 38
5.4 Modelling Results and Discussion 41
6.0 Modelling slurry water quality and interaction with groundwater 45
6.1 Water Quality Model 45
6.2 Model Construction 45
6.3 Overview and Assumptions in the Conceptual Geochemical Model 47
6.4 Modelling Results and Discussion 49
7 Conclusions 56
8 References 59
9 Limitations 60

LIST OF FIGURES

Figure 1-1: Location map (regional settings)

Figure 1-2: Location map (local settings)

Figure 1-3: Indicative mine and surface infrastructure plans

Figure 1-4: Indicative surface infrastructure layout

Figure 1-5: Indicative Site Water Management

Figure 1-6: Hydrogeochemical modelling conceptual design

Figure 3-1: Hydrogeochemical modelling conceptual design for stockpiles

Figure 3-2: Reject stock pile seepage concentration for select metal(loid)s versus time (end of year 1 – year 19). Porosity = 30%; infiltration 55%; and, high rainfall (1,250mm) scenario.

Figure 3-3: Reject stock pile seepage: Mineral saturation (Q/K) versus time (end of year 1 – year 19). Porosity = 30%; infiltration 55%; and, high rainfall (1,250mm) scenario.

Figure 3-4: ROM pad: Mineral saturation (Q/K) versus time. Porosity = 35%; infiltration 67%; and, high rainfall (1,250mm) scenario.

Figure 4-4: ROM pad: Mineral saturation (Q/K) versus time. Porosity = 35%; infiltration 67%; and, high rainfall (1,250mm) scenario.

Figure 3-4: ROM pad: Mineral saturation (Q/K) versus time. Porosity = 35%; infiltration 67%; and, high rainfall (1,250mm) scenario.

Figure 5-1: Simulated daily inflows to the PWD (from PB, 2016). Dashed vertical line represents modelled years.

Figure 6-1: Illustration of scenario 1 simplified modelling steps.

Figure 6-2: Illustration of scenario 2 simplified modelling steps.

Figure 6-3: Conceptual model of reject slurry emplacement in a mined-out panel.

LIST OF TABLES

Table 1-1: Kinetic Column Leach Samples

Table 2-2: Summary climate statistics for Hume Coal Project site

Table 2-3: Hydrochemical Parameters Analysed/Measured

Table 2-4: Groundwater summary statistics for Wongawilli Seam bore (HU0018PZA)

Table 2-5: Summary of key mine material average leachate concentrations

Table 2-6: Summary of key mine material average and 95th Percentile loading rates (mg/kg/month)

Table 2-7: Summary of rainfall water quality inputs

Table 3-1: Mineral reaction rates

Table 3-2: Geochemist's Workbench model parameters

Table 3-3: Modelling results for reject stockpile seepage water quality for end of year 1 (67% infiltration; no cover) for various reject porosities.

Table 3-4: Modelling results for reject stockpile runoff water quality for end of year 1 (33% runoff; no cover) for various reject porosities.

Table 3-5: Modelling results for covered reject stockpile seepage water quality for select years with average rainfall conditions (820mm).

Table 3-6: Modelling results for reject stockpile seepage water quality for high rainfall scenario (95th percentile; 1,200mm)

Table 3-7: Run of Mine stockpile results for various scenarios

Table 3-8: Product Stockpile estimated seepage and runoff water qualities for various scenarios

Table 4-1: Stormwater basin and mine water dam catchment areas and contributions to surface water which will ultimately report to the PWD.

Table 4-2: Catchment contributions to surface water quality input to PWD.

Table 4-3: Estimated SB01 water qualities for various scenarios.

Table 4-4: Estimated SB02 water qualities for various scenarios

Table 4-5: Estimated surface water quality inputs to PWD for various scenarios

Table 5-1: Contribution of water (ML) to the PWD on an annual basis.

Table 5-2: Percentage (%) contribution of key water input to the PWD on an annual basis.

Table 5-3: Groundwater equilibrated with atmospheric conditions.

Table 5-4: PWD water qualities for various scenarios

Table 6-1: Modelling scenarios and sensitivities

Table 5-4: PWD water qualities for various scenarios

Table 5-4: PWD water qualities for various scenarios

Table 6-2: Estimated slurry (PWD + reject) water qualities during operation.

Table 6-3: Estimated slurry (PWD + temporary reject stockpile) water qualities after operation

Table 6-4: Estimate slurry water quality/ groundwater quality mix during operation.

Table 6-5: Estimated slurry water quality/ groundwater quality mix after operation

LIST OF ATTACHMENTS

Attachment A: Figures

Attachment B: Hydrogeochemical Modelling Results

1.0 Introduction

Hume Coal Pty Ltd (Hume Coal) proposes to develop and operate an underground coal mine and associated mine infrastructure (the 'Hume Coal Project') in the Southern Coalfield of New South Wales (NSW). The underground mine will be developed within A349 and associated surface infrastructure facilities will be developed within and north of A349. The project area and its regional and local setting are shown in **Figures 1-1** and **Figure 1-2 (Attachment A),** respectively.

Hume Coal is seeking State significant development consent under Division 4.1 of Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act), and as such has submitted an environmental impact statement (EIS) as a requirement of the approval processes. As part of the EIS, RGS Environmental Pty Ltd (RGS) was commissioned to complete a geochemical assessment of coal and mining waste materials likely to be generated from mining and processing activities at the Hume Coal Project. The aim of the work program was to characterise coal and mining waste materials likely to be generated by the project and assess the potential for these materials to impact the immediate and surrounding environment (RGS, 2016). Similarly, Geosyntec Consultants Pty Limited (Geosyntec) was commissioned by Hume Coal to undertake a hydrogeochemical assessment of groundwater and surface water resources within, and in the vicinity of, the Hume Coal Project to assess the potential for any impacts to surface and groundwater resources from the coal and mining waste materials (Geosyntec, 2016).

Following the public exhibition of Hume Coal's EIS, there were several submissions/comments received pertaining to the Hume Coal EIS (EMM, 2017). Two specific 'issues' were identified by RGS, EMM Consulting and Geosyntec; and include:

- predicting water quality evolution in the primary water dam (PWD); and,
- the groundwater response to underground placement of the reject slurry

To address some of the EIS submissions/comments, RGS was requested by Hume Coal to undertake simplified hydrogeochemical modelling; this report summarises the methods and results of this modelling.

1.1 Project Background

1.1.1 Project Description

The project involves developing and operating an underground coal mine and associated infrastructure over a total estimated project life of 23 years. Indicative mine and surface infrastructure plans are provided in **Figures 1-3 (Attachment A).** A full description of the project, as assessed in this report, is provided in Chapter 2 of the main EIS (EMM, 2017). In summary the project involves:

- Ongoing resource definition activities, along with geotechnical and engineering testing, and other low impact fieldwork to facilitate detailed design.
- Establishment of a temporary construction accommodation village.
- Development and operation of an underground coal mine, comprising of approximately two years of construction and 19 years of mining, followed by a closure and rehabilitation phase of up to two years, leading to a total project life of 23 years. Some coal extraction will commence during the second year of construction during installation of the underground

access drifts, and hence there will be some overlap between the construction and operational phases.

- Extraction of approximately 50 million tonnes (Mt) of run-of-mine (ROM) coal from the Wongawilli Seam, at a rate of up to 3.5 million tonnes per annum (Mtpa). Low impact mining methods will be used, which will have negligible subsidence impacts.
- Following processing of ROM coal in the coal preparation plant (CPP), production of up to 3 Mtpa of metallurgical and thermal coal for sale to international and domestic markets.
- Construction and operation of associated mine infrastructure, mostly on cleared land, including:
    - one personnel and materials drift access and one conveyor drift access from the surface to the coal seam;
    - ventilation shafts, comprising one upcast ventilation shaft and fans, and up to two downcast shafts installed over the life of the mine, depending on ventilation requirements as the mine progresses;
    - a surface infrastructure area, including administration, bathhouse, washdown and workshop facilities, fuel and lubrication storage, warehouses, laydown areas, and other facilities. The surface infrastructure area will also comprise the CPP and ROM coal, product coal and emergency reject stockpiles;
    - surface and groundwater management and treatment facilities, including storages, pipelines, pumps and associated infrastructure;
    - overland conveyors;
    - rail load-out facilities;
    - explosives magazine;
    - ancillary facilities, including fences, access roads, car parking areas, helipad and communications infrastructure; and
    - environmental management and monitoring equipment.
- Establishment of site access from Mereworth Road, and minor internal road modifications and relocation of some existing utilities.
- Coal reject emplacement underground, in the mined-out voids.
- Peak workforces of approximately 414 full-time equivalent employees during construction and approximately 300 full-time equivalent employees during operations.
- Decommissioning of mine infrastructure and rehabilitating the area once mining is complete, so that it can support land uses that are similar to current land uses.

The project area, shown in **Figure 1-3 (Attachment A)**, is approximately 5,051 hectares (ha). Surface disturbance will mainly be restricted to the surface infrastructure areas shown indicatively on **Figure 1-4 (Attachment A)**, though will include some other areas above the underground mine, such as drill pads and access tracks. The project area generally comprises direct surface disturbance areas of up to approximately 117 ha, and an underground mining area of approximately 3,423 ha, where negligible subsidence impacts are anticipated.

A construction buffer zone will be provided around the direct disturbance areas. The buffer zone will provide an area for construction vehicle and equipment movements, minor stockpiling and equipment laydown, as well as allowing for minor realignments of surface infrastructure. Ground disturbance will generally be minor and associated with temporary vehicle tracks and sediment controls as well as minor works such as backfilled trenches associated with realignment of existing services.

Environmental features identified in the relevant technical assessments will be marked as avoidance zones so that activities in this area do not have an environmental impact.

Product coal will be transported by rail, primarily to Port Kembla terminal for the international market, and possibly to the domestic market depending on market demand. Rail works and use are the subject of a separate EIS and State significant development application for the Berrima Rail Project.

1.1.2 Mining Method

Hume Coal has adopted a number of leading practices to result in a mine design that avoids and minimises impacts to the environment. Extensive technical investigations have taken place over several years to develop and refine the Project and arrive at the current design. Some of the measures Hume Coal has committed to set a new benchmark for underground coal mining in NSW. A detailed description of the mining method is in the Hume Coal EIS submission (EMM, 2017) from which the following section is summarised.

Mining is planned to occur sequentially in panels (mined out voids) that are separated from each other by solid barriers of unmined coal. The proposed method is low impact and will have negligible surface and subsurface subsidence, and minimal overburden fracturing. Individual mining panels will be separated by wide, solid (unmined) barrier pillars to prevent direct hydraulic connection between panels. The approximately 50 m wide barrier pillars will also aid geotechnical stability.

Once mined, the panels will contain open voids that will be used for the emplacement of coal reject (the coarse and fine rock separated out of the coal during processing) materials. All coal rejects will be alkaline amended with limestone (to buffer any potential acid generation) and mixed with water from the coal preparation plant (CPP) (initially 60:40; solid: liquid) before being returned underground to partially backfill mined-out voids, rather than leaving them in large above-ground emplacements or trucking them off-site to remote emplacements. It is estimated that coal reject and other rock wastes will fill some 36% of the total mined volume (Coffey, 2016a). This technology has so far only been adopted at one other Australian underground coal mine and is considered to be leading international practice. Whilst more complex and expensive than surface emplacement, it was selected to give the following environmental and social benefits:

- eliminates permanent tailings ponds or cells on the surface;
- significantly reduces the potential for visual, dust and noise impacts compared to conventional surface emplacements;
- reduced surface disturbance by avoiding the need for large reject stockpiles;
- allows groundwater to recover more rapidly;
- additional ground support and pillar confinement is available in backfilled areas; and
- directly responds to the preferences of regulatory officials to minimise above-ground reject stockpiles.

For the first ~18 months of operation, while underground void space is being created, coal rejects will be alkaline amended (2% limestone) and stored in a temporary surface emplacement (stockpile) which will be progressively re-shaped, top dressed and re-vegetated. Once mining is completed, rejects in the temporary surface emplacement will be placed underground in the remaining voids. The surface emplacement area(s) will then be rehabilitated to integrate with the natural landform.

After the initial ~18 months of operation, emplacement of co-disposed coal reject into underground mine voids will commence. After mining and backfilling operations are complete, individual panels will be sealed at the entrance with permanent seals (bulkheads) designed to

sustain anticipated groundwater pressures, at an appropriate factor of safety (nominally a factor of four). Water may be added to the sealed void before total filling or abstracted thereafter through valves constructed in the bulkheads.

Active pumping of water behind the bulkheads will occur from year three (i.e. once the first bulkhead is sealed) through to year 19 of mining, resulting in a decreased volume of groundwater inflow to the workings and faster recovery post mining. Once mining ceases (end of year 19) groundwater inflow to the void is expected to continue for three years (i.e. until all panels are full) (Coffey, 2016b).

Once panels are sealed and flooded, the void will become part of the greater groundwater system. Relocating mine sump water into the underground sealed voids averts the need for management and or release of that water at the surface. Facilitating groundwater storage behind the bulkheads naturally and via pumping will also greatly decrease groundwater depressurisation and speed up the groundwater recovery time.

The reject co-disposal process forms the basis for the hydrogeochemical modelling assessments.

1.1.3 Water Management System

The water management system for the project is detailed in the Hume Coal Project Water Balance Assessment Report (PB, 2016) and based on the infrastructure layout plan and flowchart prepared by Arkhill Engineers (included in Appendix D (PB, 2016)).

The water management system will be implemented during operation to prevent contamination of local waterways and will aim to use mine water as a priority to meet all demands over imported water. If the water demand cannot be fully met from the harvested rainfall runoff and the groundwater collected from the mine sump, the water supply will be supplemented by harvested water from the sealed voids. Surface water runoff from areas of the site in direct contact with coal and coal waste (reject) will be fully contained within the mine water management system to prevent discharge to local waterways. The water management objectives are to reuse water on site and minimise the release to more sensitive environmental areas (EMM, 2017).

The site water management involves:

- Runoff from undisturbed areas being diverted around or away from the infrastructure into natural watercourses via clean water diversion drains.
- Runoff from disturbed areas within the mine infrastructure footprint being directed to the stormwater basins (SBs), mine water dam (MWDs) and the primary water dam (PWD) for storage and reuse.
- Runoff from areas where there is a low risk of coal contact (i.e. runoff from areas that do not contain coal stockpiles or the processing plant but that could contain small amounts of coal due to mine vehicle traffic) may be released to local creeks after collection of the first flush has been diverted into storage and reuse dams, and monitoring shows that post first flush runoff is of an acceptable quality to release.
- Runoff from areas where there is a low risk of coal contact and that does not meet the adopted first flush criteria being transferred to the PWD for storage.
- Sewage from the administration and workshop area being treated and reused on site during operation. Grey water will be subject to primary treatment and reused. Black water will be subject to tertiary treatment and reused in the CPP.

The site water management is summarised schematically in **Figure 1-5** (**Appendix A**) with a description of the various SB and MWD components in **Table 1-1**. A more detailed description of the SBs and MWDs is in **Section 4.3**.

Table 1-1. Stormwater basin and mine water dam description

SB/MWD	Description
SB01	Proposed stormwater basin capturing runoff from product stockpile and temporary reject stockpile area.
SB02	Proposed stormwater basin capturing runoff from CPP and ROM areas.
SB03	Proposed stormwater basin capturing runoff from Administration and Workshop Area.
SB04	Proposed stormwater basin capturing runoff from mine road and conveyor embankment.
MWD05	Proposed mine water dam capturing runoff from north of Medway Rivulet - overland conveyor no. 1.
MWD06	Proposed mine water dam capturing runoff from south of Medway Rivulet - conveyor portal.
MWD07	Proposed mine water dam capturing runoff from ventilation shaft pad dam.
MWD08	Proposed mine water dam capturing runoff from water treatment area.
PWD	Proposed primary water dam storing mine water pumped from stormwater basins, mine water dams and underground mine sump dewatering.

1.2 Project Objectives

The aims of the project include:

- Construction of simplified numerical hydrogeochemical models to:
    - forward predict PWD water quality for several mixing scenarios under different climatic conditions (rainfall and evaporation) and compare to ANZECC & ARMCANZ (2000) water quality criteria; and,
    - determine the likely water qualities resulting from the placement of a reject slurry into underground workings and interaction with groundwater from the receiving formation (Wongawilli Seam).
- Assess whether the predicted water quality resulting from placement of reject slurry into underground workings varies significantly from baseline groundwater quality in the Wongawilli Seam, or would impact the beneficial uses of the groundwater resource.

1.2.1 Scope of Works

The proposed scope of works to address the project objectives has been developed based on RGS's understanding of the Hume Coal Project and discussions with Hume Coal. The scope-of-works includes:

- Review all related reports/data pertaining to the *Hume Coal Environmental Impact Statement* and recommend additional testing required to populate hydrogeochemical models.
- Use deterministic hydrogeochemical modelling to simulate the mixing of three different water qualities at different ratios and under different climatic conditions (rainfall and

evaporation). Compare the resulting water qualities from above surface water quality modelling to ANZECC & ARMCANZ (2000) water quality guidelines.

- Use simplified hydrogeochemical modelling to estimate the likely water qualities resulting from the mixing of the reject material/porewater with PWD water to produce a 'slurry' water quality.
- Model the interaction of the slurry with groundwater within an underground backfilled panel.
- Compare the resulting water qualities with receiving environment groundwater quality.

1.3 Hydrogeochemical Conceptual Model and Assumptions

The purpose of the conceptual model is to describe the nature of the interactions that are likely to occur between the solid phase materials (e.g. temporary reject stockpile, ROM and Product Ore stockpile), the water that is in contact with the materials (e.g. rainwater) and the associated geochemical reactions. The conceptual model accounts for acid generation and neutralisation, soluble minerals and some of the changing environmental conditions (e.g. rainfall and temperature), from which the material contribution to drainage quality is to be established.

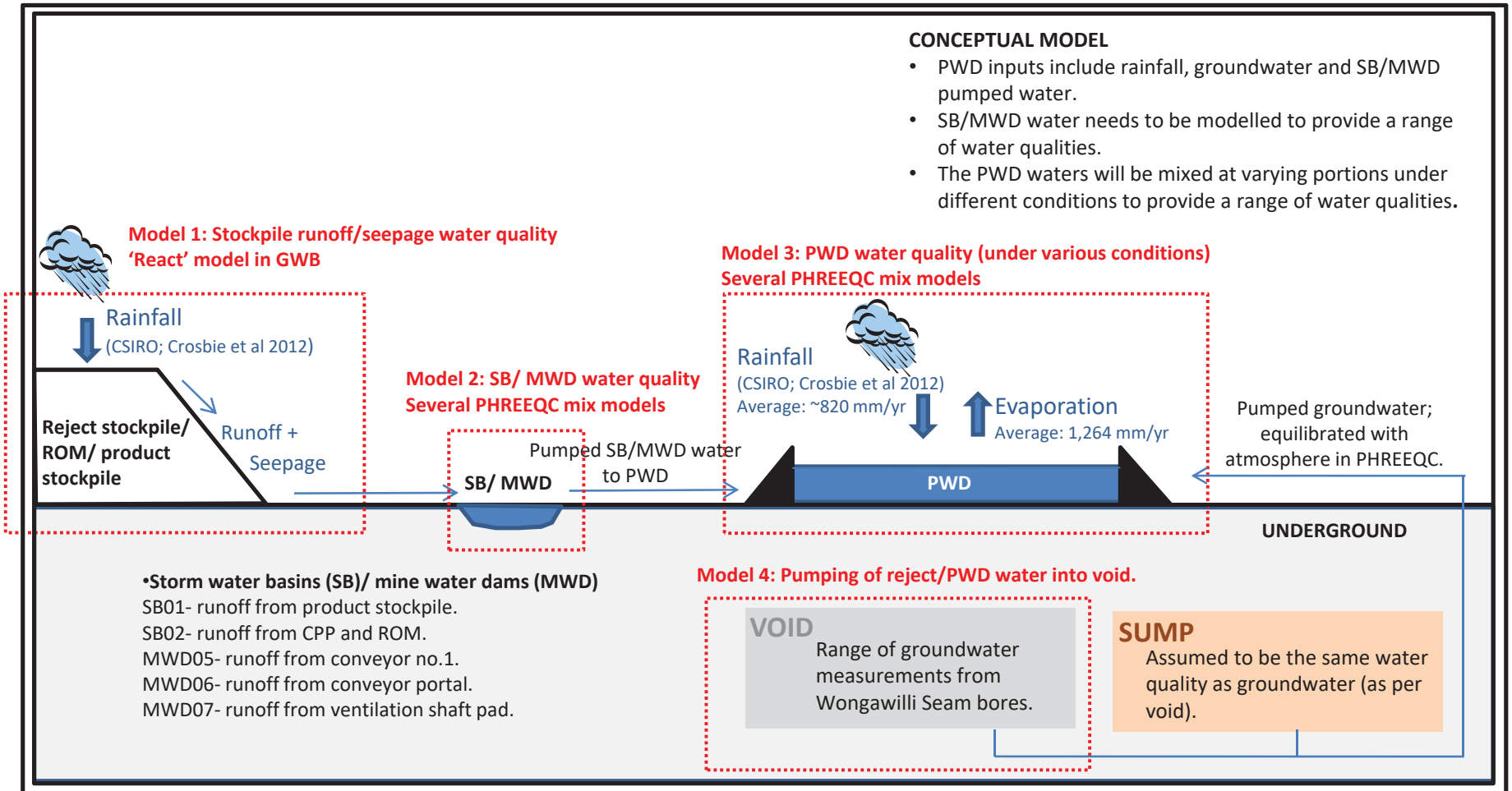
All geochemical models are based on a set of assumptions. The details of the assumptions applicable to the conceptual model are outlined below (**Section 1.3.1**) and in the following sections. Where possible, these assumptions were chosen to represent RGS's understanding of the site and to be inherently conservative. They are consistent with Hume's approach to environmental management outlined in the Environmental Impact Statement (EMM, 2017) for this stage of the Project. As such they may predict higher concentrations of dissolved elements in the seepage from material than would occur under site conditions if the planned and committed mitigation measures are put in place to limit the reactivity of the material. The assumptions made in this report have been documented and provided to Hume Coal prior to proceeding with the hydrogeochemical modelling.

The range of values determined through geochemical modelling are indicative and can be used to assess the likely processes and the geochemical response so that the management plans can be adequately informed.

1.3.1 Hydrogeochemical Models

There are several components to the modelling, with each component requiring its own set of steps to achieve the desired objective. Each of the components are outlined in the conceptual design (**Figure 1-6**) and summarised below:

- **Modelling stockpile geochemical response**: These sets of models estimate water quality resulting (seepage and runoff) from the interaction of annual rainfall on the various proposed stockpiles (temporary reject stockpile, ROM pad and product stockpile). Discussed in Section 3 of this report.
- **Modelling storm water basins (SB) and mine water dam (MWD) water qualities**: There are several catchments in the surface infrastructure area, with rainfall runoff in each catchment captured by either an SB or MWD. Rainfall intercepted by stockpiles or infrastructure within a catchment is to be collected by the network of SBs and MWDs. Several sets of models were constructed to estimate annual water quality for each catchment, which were mixed in proportions determined by the assumptions from the site water balance (PB, 2016) to provide quality of rainfall mixed with runoff (e.g. runoff from reject stockpile) pumped to the PWD. Discussed in Section 4 of this report.

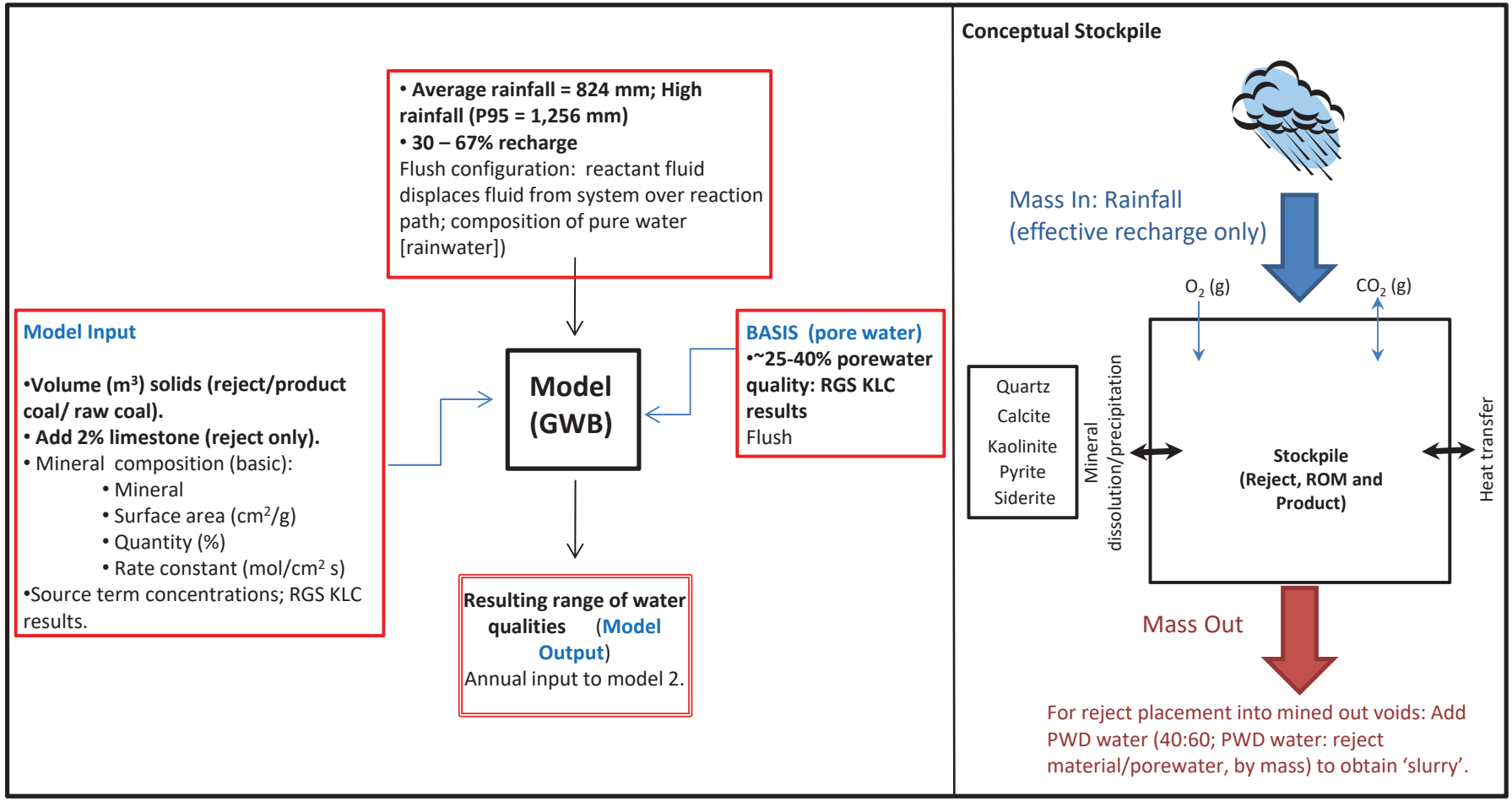


Note: Assumed SB03 and SB04 storm water basins will meet water quality criteria and released to Oldbury Creek. Any water that does not meet first flush criteria (i.e. 20mm) is assumed to have negligible impact on the PWD water quality.
Assumed there is no residence time of water in the SBs and MWDs (i.e. water collected is pumped directly to PWD).

Client	HUMECOAL PROJECT
Project	Hume Coal Hydrogeochemical Modelling
Title	Conceptual Geochemical Model
Project No.	2017054
Fig No.	Figure 1-6

RGS

Model 1: Stockpile water quality models. Seepage and Runoff undertaken separately.
'React' model in GWB
Separate models constructed for temporary reject, ROM and product stockpiles.



Note: Mineralogical assemblage simplified for the modelling. Pyrite and dolomite/calcite content will be inferred from sulfide and carbonate geochemical data, respectively. Mineral data will be updated after review of literature.
Mineral surface area and reaction rates will be obtained from the literature.

Client	HUMECOAL PROJECT
	RGS
Project	Hume Coal Hydrogeochemical Modelling
Title	Conceptual Geochemical Model: Reject Stockpile
Project No.	2017054
Fig No.	Figure 3-1

- **Modelling PWD water qualities**: These sets of models estimate water quality resulting from the mixing of all annual inputs to the PWD (i.e. direct rainfall and runoff, SB/MWD input and groundwater input). Select models were also used to assess the effects of changing climatic conditions on PWD water quality (e.g. removal of water to reflect extended dry periods with increased evapo-concentration). Discussed in Section 5 of this report.
- **Modelling slurry water quality:** These set of models replicate the mixing of the reject material (fresh reject or temporarily stockpiled reject) with PWD water. Discussed in Section 6 of this report.
- **Modelling interaction of slurry with groundwater in a mined-out void (panel):** These sets of models estimate water quality resulting from the mixing of slurry water/solids with groundwater after being backfilled in the mined-out voids. Discussed in Section 6 of this report.

For each of the main models, there are several 'support' models used to provide additional input (e.g. equilibration of groundwater with atmospheric conditions). Results of the modelling have been output for select years to provide a range of estimated water qualities.

2.0 Background Data

The following information is relevant to the key input parameter to the modelling.

2.1 Characterisation of coal and mining waste

RGS completed a geochemical assessment of coal and mining waste materials likely to be generated from mining and processing activities at the Hume Coal Project. The objective of the RGS work program was to characterise coal and mining waste materials likely to be generated by the project and assess the potential for these materials to impact the immediate and surrounding environment. As part of the geochemical assessment program, a total of 25 coal and coal reject samples and 53 drift spoil samples (i.e. 78 samples of representative coal and mining waste materials) were collected from 12 drill hole locations across the project site. A series of static and kinetic geochemical tests were performed as part of the assessment process. In addition to the geochemical dataset generated from the aforementioned samples, a large database of total sulfur concentrations exists for coal and potential coal reject materials tested at ALS Laboratories. The dataset comprises 5,148 samples obtained from 136 drill holes locations at the project.

The geochemical test program was designed to assess the degree of risk from oxidation of sulfide, acid generation, and the leaching of soluble metals and salts. The assessments also included characterisation of standard soil parameters including pH, salinity, and major metal compositions. The static testing analysis included pH/EC ($_{1:5;\ w:v}$), total sufur, acid neutralisation capacity (ANC) and net acid production potential (NAPP), while select samples were tested for chromium reducible sulfur (CRS), multi-element testing of the soluble fraction and exchangeable ions.

A total of 25 Kinetic Leach Column (KLC) tests were completed on various composite coal, coal reject and drift spoil materials obtained from the project (**Table 2-2**). The details of the KLC tests, together with the static test results, are summarised in the report: *Geochemical Assessment of Coal and Mining Waste Materials* (RGS, 2016). The KLC tests were operated over six months with generally monthly leaching events (i.e. 7 leaches, including week 0). The

representative samples of the various coal and mining waste material types likely to be generated at the project included:

1. product coal from various plies within the Wongawilli Coal Seam likely to report to the stockpile area after CPP processing;

2. potential coal reject (including roof, parting and floor materials) that are likely to report to the Run-of-Mine (ROM) stockpile along with raw coal;

3. simulated coarse reject, fine reject (tailings) and combined reject materials likely to be generated from the CPP); and,

4. drift spoil materials likely to be generated by the proposed drift access to the underground mine and potentially used as part of various infrastructure and rehabilitation activities at the project.

A detailed methodology for the KLC tests is provided in RGS (2016). As a general overview, the columns were leached with deionised water or groundwater (sampled from the Wongawilli Coal Seam), and leachate samples were collected at the commencement of the test and then on a monthly basis for a period of six months. Some columns were subject to alternating wet/dry cycles, while some samples were kept saturated by maintaining a 100mm cover of water ("wet" columns). Leachate samples were submitted to ALS Environmental, a NATA accredited analytical laboratory, for analysis of pH, EC, major ions Cl^-, SO_4^2, Na^+, Ca^{2+}, Mg^{2+}, K^+, F^- and B, acidity and alkalinity (HCO_3^-, CO_3^-, OH^-) and a selected suite of major, minor and trace elements (25 in total). Several columns were operated to best represent site conditions and expected management strategies (e.g. limestone amendment; operation of columns under saturated conditions with Wongawilli Coal Seam groundwater); these results were typically used for hydrogeochemical modelling (**section 2.3.2**). It should also be highlighted that several of the reject samples were aged for more than 1 year prior to KLC tests and are expected to have been significantly oxidised; the results from these samples are therefore conservative.

2.1.1 Coal and Coal Reject Geochemical Management

The conclusions and recommendations for coal and coal reject management, suggested by RGS (RGS, 2016), is summarised in the following points.

- Coal and coal reject materials represent a range of geochemical material types ranging from non-acid forming (NAF) to potentially acid forming (PAF). Based on the samples tested, there is a risk of acid generation associated with some of the coal seam roof, product coal and tailings materials, compared to the coal seam floor and coarse reject materials, which carry a lower level of risk. Notwithstanding, static and kinetic testing indicate that most of the sample materials already have an acidic pH value (< pH 5), although in some cases this is due to a very low ANC value rather than elevated sulfide sulfur content.
- Coal reject materials will need to be managed to reduce the risk of acid and metalliferous drainage (AMD) and/or saline drainage (SD) and/or neutral mine drainage (NMD). RGS proposed the addition of an alkaline material (e.g. crushed limestone/stone dust) to control/neutralise any acidity that could potentially be generated from these materials.
- Management practices adopted at coal stockpiles and also for the long-term storage of coarse and fine reject materials will need to accommodate the potential for acid generation from these materials if stored for long periods of time.
- For coal stockpiles, standard water management and monitoring practices are likely to be sufficient to manage the risk of AMD, as these materials will only be present at the project

for a limited period of time prior to dispatch to market. However, the addition of alkaline materials (e.g. alkaline stone dust) to coal contact water collection ponds may need to be considered to control acid generation, if water quality monitoring results indicate that this is required.

- The addition of alkaline materials (e.g. stone dust) to coal reject materials has been shown to maintain pH levels in the neutral pH range, and in the process, avoid any potential environmental impacts.
- The unsaturated, free-draining conditions that simulate weathering of surface materials in this assessment were completed under conservative laboratory-controlled conditions (finely crushed sample, exposure to light, elevated temperature and wetting and drying cycles). Notwithstanding, some of the samples of coal seam roof material tested were found to be acid forming (AF) and/or PAF and therefore there is potential for some parts of the underground workings to become a temporary source of acidity until these workings become oxygen deficient (remnant coal adsorbs oxygen (Yuan and Smith, 2009)) or become flooded with water.
- As backfilling of underground workings with coal rejects is the preferred method of permanent storage, the addition of alkaline material may need to be considered if there is any potential for connectivity with groundwater (or downstream surface water) resources. The periodic coating of stone dust (finely crushed limestone) to the roof and sides of the underground workings for explosion suppression throughout the mine will likely have a similar effect to the addition of alkalinity to the reject materials in this regard.

Several of the above-mentioned recommendations have been implemented by Hume Coal and form part of the proposed mine operations (refer to Section 1.1.2); the temporary coal reject stockpile and fresh reject material will be treated with 2% limestone and 1% limestone, respectively, to buffer the potential for acid generation (which also limits mobilisations of metal(loid)s).

Table 2-1: Kinetic Leach Column Samples

Stage	KCL Test	KCL material	KCL description
Stage 1	KCL 1	Coal Reject (Roof, Seam, Parting and Floor)	Crushed to pass 5 mm; free draining (alternating wet and dry)
	KCL 2	Coal Reject (Roof)	Crushed to pass 5 mm; free draining (alternating wet and dry)
	KCL 3	Product Coal	Crushed to pass 5 mm; free draining (alternating wet and dry)
	KCL 4	Coal Reject (Floor)	Crushed to pass 5 mm; free draining (alternating wet and dry)
	KCL 5	Simulated Coarse Reject	Crushed to pass 5 mm; free draining (alternating wet and dry)
	KCL 6	Simulated Fine Reject	Crushed to pass 5 mm; free draining (alternating wet and dry)
Stage 2	KCL 7	Drift Spoil (Sandstone)	Crushed to pass 50 mm; free draining (alternating wet and dry)
	KCL 8	Drift Spoil (Siltstone)	Crushed to pass 50 mm; free draining (alternating wet and dry)
	KCL 9	Drift Spoil (Sandstone)	Crushed to pass 50 mm; free draining (alternating wet and dry)
Stage 3	KCL 10	Reject Composite	Crushed to pass 600 µm; free draining (alternating wet and dry)
	KCL 11	Reject Composite	Crushed to pass 600 µm; fully saturated
	KCL 12	Reject Composite	Crushed to pass 600 µm; free draining (alternating wet and dry); 1% lime addition
	KCL 13	Reject Composite	Crushed to pass 600 µm; fully saturated; 1% lime addition

Stage	KCL Test	KCL material	KCL description
	KCL 14	Reject Composite	Crushed to pass 600 µm; free draining (alternating wet and dry); 2% lime addition
	KCL 15	Reject Composite	Crushed to pass 600 µm; fully saturated; 2% lime addition
	KCL 16	Reject Composite	Crushed to pass 600 µm; free draining (alternating wet and dry); 1% limestone addition
	KCL 17	Reject Composite	Crushed to pass 600 µm; fully saturated; 1% limestone addition
	KCL 18	Reject Composite	Crushed to pass 600 µm; free draining (alternating wet and dry); 2% limestone addition
	KCL 19	Reject Composite	Crushed to pass 600 µm; fully saturated; 2% limestone addition
Stage 4	KCL 20	Reject Composite	Crushed to pass 600 µm; free draining (alternating wet and dry with Hawksbury Sandstone groundwater)
	KCL 21	Reject Composite	Crushed to pass 600 µm; fully saturated with Hawksbury Sandstone groundwater
	KCL 22	Reject Composite	Crushed to pass 600 µm; free draining (alternating wet and dry with Wongawilli Seam groundwater)
	KCL 23	Reject Composite	Crushed to pass 600 µm; fully saturated with Wongawilli Seam groundwater
	KCL 24	Reject Composite	Crushed to pass 600 µm; free draining (alternating wet and dry with Wongawilli Seam/Hawksbury Sandstone groundwater); 1% limestone addition
	KCL 25	Reject Composite	Crushed to pass 600 µm; fully saturated with Wongawilli Seam/Hawksbury Sandstone groundwater; 1% limestone addition

2.2 Climate: Rainfall and evapotranspiration

Climatic data was used in accordance with the water balance report (PB, 2016). A continuous record of rainfall and potential evaporation data was obtained from SILO (Scientific Information for Land Owners), which is a database of historical climate records for Australia. SILO provides historical daily weather records for Australia from 1889 to present. A daily time series of data at a point location consisting entirely of interpolated estimates (data drill).

The data were taken from the gridded datasets and are available at any grid point over the land area of Australia. SILO datasets are constructed from observational records provided by the Bureau of Meteorology (BOM). A continuous gap-free time series of rainfall, potential evaporation and lake surface evaporation for 127 years from 1889 to 2015 were obtained for the grid specified by latitude -34.50º and longitude 150.30º. The Data Drill location is 0.5 km north of SB01 and SB02 and was adopted as the key data location for the project surface infrastructure area.

Lake evaporation data was used in the water balance to estimate evaporation from storages and evapotranspiration data was used for other areas (**Table 2-2**).

Table 2-2 Summary climate statistics for Hume Coal Project site (from PB, 2016)

Statistic	Annual Rainfall (mm)	Annual Potential Evapotranspiration[1] (mm)
Minimum	393	878
5th percentile (dry)	525	930
10th percentile	564	946
50th percentile (median)	800	1,016
90th percentile	1,120	1,109
95th percentile (wet)	1,256	1,122
99th percentile	1,380	1,150
Maximum	1,550	1,180
Average	824	1,021
Standard deviation	220	60

[1]potential evapotranspiration calculated using the Penman-Monteith formula.

2.3 Hydrochemistry: Hydrogeochemical modelling input

The hydrogeochemical data used in several of the hydrogeochemical models is summarised in the following sections.

2.3.1 Groundwater: Wongawilli Coal Seam

Product coal will be mined from the Wongawilli Coal Seam, leaving a void space (panel) where reject slurry will be backfilled. Therefore, groundwater quality of the Wongawilli Seam is a key input parameter to the hydrogeochemical modelling, and a key water quality "performance indicator" for some of the modelling water quality results. A total of 130 water quality parameters have been measured from 15 monitoring bores from October 2011 to September 2015; the hydrochemical analysis suite is displayed in **Table 2-3**. The water quality summary statistics for bore HU0018PZA (average and 95th Percentile), used for the hydrogeochemical modelling, is displayed in **Table 2-4.** A detailed description of the hydrochemistry is summarised in the *Hume Coal Project: Hydrogeochemical Assessment* (Geosyntec, 2016). RGS has assumed that groundwater samples were collected using suitable groundwater sampling methods and the data reflects the *in-situ* groundwater conditions.

As a general overview, the baseline/background groundwater quality has an EC of 40.8 to 2,383 µS/cm (average = 469 µS/cm), corresponding to a range of fresh to brackish water quality. The elevated EC values correspond with bore H142A and are due to elevated barium and strontium concentrations, which may suggest a drilling fluid source. The pH values among all samples ranged from 4.03 to 7.18 (average = 5.5) and are acidic to neutral. The dissolved oxygen (DO) content ranged from 0.7 to 113% (average = 23%) with a redox potential ranging from -202 to 294 mV (average = -30 mV); therefore, the groundwater was typically reducing. This is further supported by the presence of ferrous iron and elevated concentrations of total iron and manganese, which suggests a reducing groundwater environment.

The groundwater major ion composition was dominated by bicarbonate (HCO_3), sodium (Na), chloride (Cl) and sulfate (SO_4) with lesser calcium (Ca), silica (Si), iron (Fe), magnesium (Mg) and potassium (K). The concentration of dissolved metals and metalloids is generally low with many concentrations being below the limits of reporting (LOR).

There are several measured metal concentrations in the baseline Wongawilli Seam groundwater which typically exceed either the Australian drinking water criteria (NHMRC, 2011) or the Australian and New Zealand Environment and Conservation Council (ANZECC)

Guidelines (95% species protection level) (ANZECC, 2000) for either aquatic, irrigation or livestock use. Comparison of average Wongawilli Seam groundwater concentrations shows exceedances for: Al, Cd, Cr (assuming all Cr is present as the Cr^{6+} species, which is very unlikely in a natural setting), Cu, Mn, Ni, Pb, Se and Zn for ANZECC (2000) aquatic criteria; Cd, Mn, Pb and Se for ADWG (2011); and, Se for ANZECC (2000) irrigation.

Chromium (Cr) is most frequently found in the environment in the trivalent (Cr^{+3}) form and lesser in the hexavalent (Cr^{+6}) form. The hexavalent state is considered toxic, while the trivalent form is considered non-toxic and the most likely form in natural settings. Therefore, the assumption that all Cr present is in the form of the Cr^{6+} species is overly conservative.

Table 2-3 Hydrochemical Parameters Analysed/ Measured.

Parameter	Constituents for Analysis
Major Ions	Ca, Mg, K, Na, Cl, $SO4_2^-$, Alkalinity
Minor Ions	Br, F, I
Physico-chemical (Field)	pH, Conductivity, dissolved oxygen (DO), oxidation-reduction potential (ORP)
Physico-chemical (Lab)	pH, Conductivity TSS, TDS
Dissolved Metals and Metalloids	Al, As, B, Ba, Be, Cd, Cr, Co, Fe (total and ferrous), Pb, Li, Mn, Mo, Ni, Se, Si, Sr, Sn, U, V, Zn and Hg
Nutrients	NO_3, NO_2, NH_3, Total P, Reactive P, Biochemical oxygen demand
PAHs	Phenols and Polycyclic Aromatic hydrocarbons
Isotopes	Oxygen -18, Deuterium, Carbon-13, Radiocarbon and Tritium
TPH	Total Petroleum Hydrocarbons
OCP's and OPP's	Organochloride pesticides and Organophosphorous pesticides
TRH	Total Recoverable Hydrocarbons
BTEXN	Benzene, Toluene, Ethylbenzene, Xylene, Naphthalene
Other Inorganics	Free and Total CN, SCN^-

Table 2-4: Groundwater summary statistics for Wongawilli Seam bore (HU0018PZA).

Analyte	Units	LOR	Avg.	95th Percentile
General field parameters				
pH	pH units		6.19	6.70
Conductivity (field)	µS/cm		449	829
Total Dissolved Solids (field)	mg/L		326	724
Dissolved oxygen	% sat		14.33	26.22
Redox	mV		-99.66	-32.34
Major Ions				
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	199	666
Total Alkalinity as $CaCO_3$	mg/L	1	199	666
Sulfate as SO_4^{2-}	mg/L	1	30.44	91.60
Chloride	mg/L	1	46.2	77.1
Calcium	mg/L	1	17.2	30.2
Magnesium	mg/L	1	3.2	4.0
Sodium	mg/L	1	104.5	352.5
Potassium	mg/L	1	2.17	3.55
Silica/Silicon as SiO_2/Reactive silica	mg/L	0.1	12.98	22.02
Other Inorganics				

Analyte	Units	LOR	Avg.	95th Percentile
Fluoride	mg/L	0.1	<0.1	<0.1
Dissolved metals				
Aluminium	mg/L	0.01	0.062	0.156
Antimony	mg/L	0.001	<0.001	<0.001
Arsenic	mg/L	0.001	0.0074	0.0116
Beryllium	mg/L	0.001	<0.001	<0.001
Barium	mg/L	0.001	0.101	0.117
Cadmium	mg/L	0.0001	<0.0001	<0.0001
Chromium	mg/L	0.001	0.0008	0.0017
Cobalt	mg/L	0.001	0.0083	0.0089
Copper	mg/L	0.001	0.0018	0.0057
Lead	mg/L	0.001	<0.001	<0.001
Lithium	mg/L	0.001	0.012	0.013
Manganese	mg/L	0.001	0.628	0.799
Molybdenum	mg/L	0.001	0.007	0.012
Nickel	mg/L	0.001	0.010	0.014
Selenium	mg/L	0.01	<0.01	<0.01
Strontium	mg/L	0.001	0.095	0.122
Tin	mg/L	0.001	<0.001	<0.001
Uranium	mg/L	0.001	<0.001	<0.001
Vanadium	mg/L	0.01	<0.01	<0.01
Zinc	mg/L	0.005	0.0198	0.033
Boron	mg/L	0.05	0.086	0.269
Iron	mg/L	0.05	8.62	13.76
Ferrous iron	mg/L	0.05	14.80	14.98
Bromine	mg/L	0.1	0.1	0.1
Iodine	mg/L	0.1000	0.4000	0.4000
Mercury	mg/L	0.0001	<0.0001	<0.0001

2.3.2 Mine material porewater content

The mine material (product coal, ROM and coal reject) initial porewater content was determined from the KLC tests (**Table 1-2**) under different conditions (e.g. saturated, un-saturate, limestone amended, etc.). The results from the KLC tests of the various materials were also used in this investigation to determine the rate at which acidity and salinity is produced and to determine the concentration of metals leached. From these results, the metal, acidity and salinity loading (production) rates (mg/kg/month) were determined which was used as input to the hydrogeochemical modelling.

Time and mass dependent loading rates are calculated by multiplying the leachate concentrations by the leachate volume (material) and dividing by the sample mass and the sample interval to produce a mg/kg/month value, Equation 1.

$$\boldsymbol{Loading\ Rate} = \frac{[X]v}{\frac{m}{t}} \qquad \text{Equation 1}$$

where X is the concentration in the leachate, v is the volume of leachate, m is the mass of source term used (rock mass) and t is the period of time over since the last measurement was taken.

Three loading rates are calculated for each parameter for each of the materials: The base case, upper bound, and first flush load. The base case is taken as being the average values of the loading rates and the upper bound as being the 95th percentile (P95) of the loadings rates. First flush Loads, in this instance the first two leaches, represent periods of low precipitation or loads associated with the first rainfall event of a season.

The initial porewater concentrations and loading rate input for the various material types under different conditions used in the hydrogeochemical modelling are summarised in **Table 2-5** and **Table 2-6**, respectively.

Table 2-5: Summary of key mine material average KLC leachate concentrations (mg/L).

Material Type		Reject 2% lime	Reject 1% lime addition		ROM	Product
Description		unsaturated; 2%	unsaturated; 1% lime		unsaturated	unsaturated
Parameter	**Unit**	**Average**	**Average**	**P95**	**Average**	**Average**
pH		7.35	7.731	8.656	3.36	3.26
Aluminium (Al)	mg/L	0.005	0.024	0.076	1.36	0.96
Arsenic (As)	mg/L	0.016	0.003	0.004	0.05	0.013
Boron (B)	mg/L	0.0025	0.014	0.0355	0.0025	0.0025
Calcium (Ca)	mg/L	368	57.200	116.1	12	12
Cadmium (Cd)	mg/L	0.0023	0.00007	0.00016	0.0078	0.006
Chloride (Cl)	mg/L	465	52.26	122.7	87	85
Cobalt (Co)	mg/L	0.287	0.0011	0.0023	0.82	0.736
Chromium (Cr)	mg/L	0.0005	0.0005	0.0005	0.0005	0.0005
Copper (Cu)	mg/L	0.001	0.0043	0.0182	0.104	0.087
Fluoride (F)	mg/L	0.2	0.453	1.1	0.2	0.2
Iron (Fe)	mg/L	0.0025	0.0123	0.0355	22.8	16
Potassium (K)	mg/L	10	1.267	2	0.5	0.5
Magnesium (Mg)	mg/L	80	5.700	11.9	17	14
Manganese (Mn)	mg/L	3.61	0.0687	0.2511	4.190	3.5
Molybdenum	mg/L	0.015	0.0221	0.0461	0.001	0.0005
Sodium (Na)	mg/L	26	10.33	33.2	0.5	3
Nickel (Ni)	mg/L	0.883	0.0024	0.0062	2.220	1.87
Lead (Pb)	mg/L	0.0005	0.0005	0.0005	0.008	0.023
Sulfate (SO_4)	mg/L	589	116.467	266.1	87	63
Antimony (Sb)	mg/L	0.002	0.0009	0.0022	0.0005	0.0005
Selenium (Se)	mg/L	0.07	0.006	0.01	0.12	0.005
Zinc (Zn)	mg/L	0.32	0.0036	0.0076	2.790	2.15

Note: Numbers is red are half LOR.

Table 2-6: Summary of key mine material average and 95th Percentile (P95) KILC loading rates (mg/kg/month).

Material Type		Coal Reject		Reject 2% limestone		Reject 1% limestone		ROM		Product Coal	
Description		unsaturated		unsaturated; 2% limestone		unsaturated; 1% limestone		unsaturated		unsaturated	
KLC numbers		#10, #20, #22		#14, #18		#12, #16, #25		#1, #2, #3, #4		#3	
Parameter	Units	Average	P95	Average	P95	Average	P95	Average	P95	Average	P95
Aluminium (Al)	mg/kg/month	0.251	0.509	0.009	0.013	0.016	0.035	0.155	0.222	0.011	0.017
Arsenic (As)	mg/kg/month	0.001	0.001	0.002	0.003	0.002	0.003	0.003	0.008	0.0003	0.001
Boron (B)	mg/kg/month	0.026	0.036	0.017	0.018	0.018	0.023	0.010	0.010	0.0003	0.0003
Calcium (Ca)	mg/kg/month	14.744	24.3	42.2	88.7	39.4	78.1	4.1	4.8	0.14	0.15
Cadmium (Cd)	mg/kg/month	0.004	0.007	0.0001	0.0001	0.0001	0.0001	0.821	0.001	0.000	0.000
Chloride (Cl)	mg/kg/month	75.6	104.8	38.9	102.8	41.9	91.5	21.0	25.7	1.0	1.2
Cobalt (Co)	mg/kg/month	0.164	0.287	0.001	0.004	0.001	0.002	0.137	0.171	0.009	0.011
Chromium (Cr)	mg/kg/month	0.001	0.001	0.0003	0.0003	0.0003	0.0004	0.0002	0.0002	0.00001	0.00001
Copper (Cu)	mg/kg/month	0.033	0.097	0.0005	0.001	0.002	0.008	0.123	0.140	0.001	0.001
Fluoride (F)	mg/kg/month	0.088	0.173	0.283	0.377	0.237	0.359	0.029	0.040	0.002	0.003
Iron (Fe)	mg/kg/month	6.268	9.984	0.017	0.018	0.018	0.022	2.036	3.073	0.178	0.289
Potassium (K)	mg/kg/month	2.153	3.595	0.504	0.844	0.852	1.258	0.673	0.922	0.012	0.023
Magnesium (Mg)	mg/kg/month	12.8	19.1	2.7	6.9	4.2	8.6	4.7	6.0	0.2	0.2
Manganese (Mn)	mg/kg/month	2.936	4.500	0.022	0.054	0.065	0.168	1.742	0.923	0.038	0.054
Molybdenum (Mo)	mg/kg/month	0.001	0.001	0.026	0.036	0.012	0.018	0.000	0.000	0.000	0.000
Sodium (Na)	mg/kg/month	26.2	32.7	1.0	2.3	6.2	8.4	1.1	1.4	0.0	0.1
Nickel (Ni)	mg/kg/month	0.432	0.849	0.002	0.008	0.002	0.006	0.453	0.548	0.022	0.029
Lead (Pb)	mg/kg/month	0.003	0.007	0.0003	0.0003	0.0003	0.0004	0.057	0.089	0.000	0.001
Sulfate (SO_4)	mg/kg/month	77.3	104.9	81.5	152.5	74.5	143.5	19.9	26.2	0.7	1.1
Antimony (Sb)	mg/kg/month	0.001	0.002	0.0004	0.0005	0.0004	0.0004	0.0002	0.0002	0.00001	0.00001
Selenium (Se)	mg/kg/month	0.008	0.020	0.005	0.008	0.005	0.008	0.008	0.023	0.0003	0.001
Zinc (Zn)	mg/kg/month	1.243	2.480	0.005	0.012	0.004	0.008	0.434	0.576	0.025	0.036

2.3.3 Rainwater

Rainwater quality was measured from 38 rainwater samples collected in Sydney between 2007 - 2011 (Crosbie et al., 2012) (**Table 2-7**). The average and 95th percentile results from the CSIRO publication were used as a guide to select representative rainwater input to the models (8th Jan; 10th August), with sensitivity analysis undertaken for selected models. Note that the zinc concentrations in the rainwater samples are elevated relative to the average and 95th percentile groundwater concentrations (**Table 2-4**).

Table 2-7: Summary of rainfall water quality inputs (Crosbie et al., 2012)

Rainfall	Average	Maximum	Minimum	Model input (average) (Jan -08)	Model input (P95) (Aug-10th)
pH	5.34	6.7	4.55	5.1	5.7
EC	99.3	470	30	110	270
Total Alkalinity	0.05	0.12	0.006	0.04	0.05
F	0.16	0.56	0.07	<0.05	<0.05
Cl	22.5	120	4.9	23	67
Br	0.096	0.18	0.05	<0.05	0.18
NO_3	1.87	7.4	0.08	1.3	<0.05
SO_4	5.5	25	1.6	5	12
Ca	1.48	8.18	0.29	0.879	2.59
K	0.48	1.97	0.13	0.456	1.37
Mg	1.48	8.3	0.27	1.47	4.5
Na	11.7	65.5	2.16	13.7	35.7
S	1.83	8.06	0.65	2.1	4
Al	<0.05	<0.05	<0.05	<0.05	<0.05
As	<0.05	<0.05	<0.05	<0.05	<0.05
B	<0.1	<0.1	<0.1	<0.1	<0.1
Cd	<0.05	<0.05	<0.05	<0.05	<0.05
Co	<0.05	<0.05	<0.05	<0.05	<0.05
Cr	<0.05	<0.05	<0.05	<0.05	<0.05
Cu	0.051	0.051	0.051	<0.05	<0.05
Fe	<0.1	<0.2	<0.3	<0.1	<0.1
Mn	0.056	0.056	0.056	<0.05	<0.05
Mo	<0.05	<0.06	<0.07	<0.05	<0.05
Ni	0.082	0.089	0.076	<0.05	<0.05
P	<0.1	<0.1	<0.1	<0.1	<0.1
Pb	<0.05	<0.05	<0.05	<0.05	<0.05
Sb	<0.05	<0.05	<0.05	<0.05	<0.1
Se	<0.05	<0.05	<0.05	<0.05	<0.05
Si	0.31	1.57	0.06	<0.05	0.204
Sr	0.053	0.053	0.053	<0.05	<0.05
Zn	0.21	0.87	0.063	0.186	0.23

3.0 Modelling Stockpile Geochemical Response

3.1 Water Quality Model

Geochemical modelling was undertaken to provide an indication of the likely impacts of the mined/processed materials (rejects, raw ore and product coal) on water quality reporting to the SBs and MWDs. This modelling utilised the data obtained in the static and kinetic leach column (KLC) geochemical tests and expected site rainfall data (**section 2**) and was undertaken using the hydrogeochemical modelling software Geochemist's Workbench (GWB) (Bethke, 2016) and PHREEQC (Parkhurst and Appello, 1995).

These models compare measured water quality data with theoretical solubility limits of a number of minerals (within a selected database such as phreeqc.dat) under different conditions (e.g. variations in pH, redox and temperature). The saturation index (SI) of a mineral is calculated under these conditions. The SI value of a particular mineral is indicative of whether a mineral will precipitate or dissolve out of solution. If the SI value is negative, then the mineral is undersaturated in solution and therefore may dissolve. However, if the SI of a mineral is positive, then the mineral is supersaturated and likely to precipitate out of solution; these dissolution/precipitation reactions may affect concentrations of elements in the water.

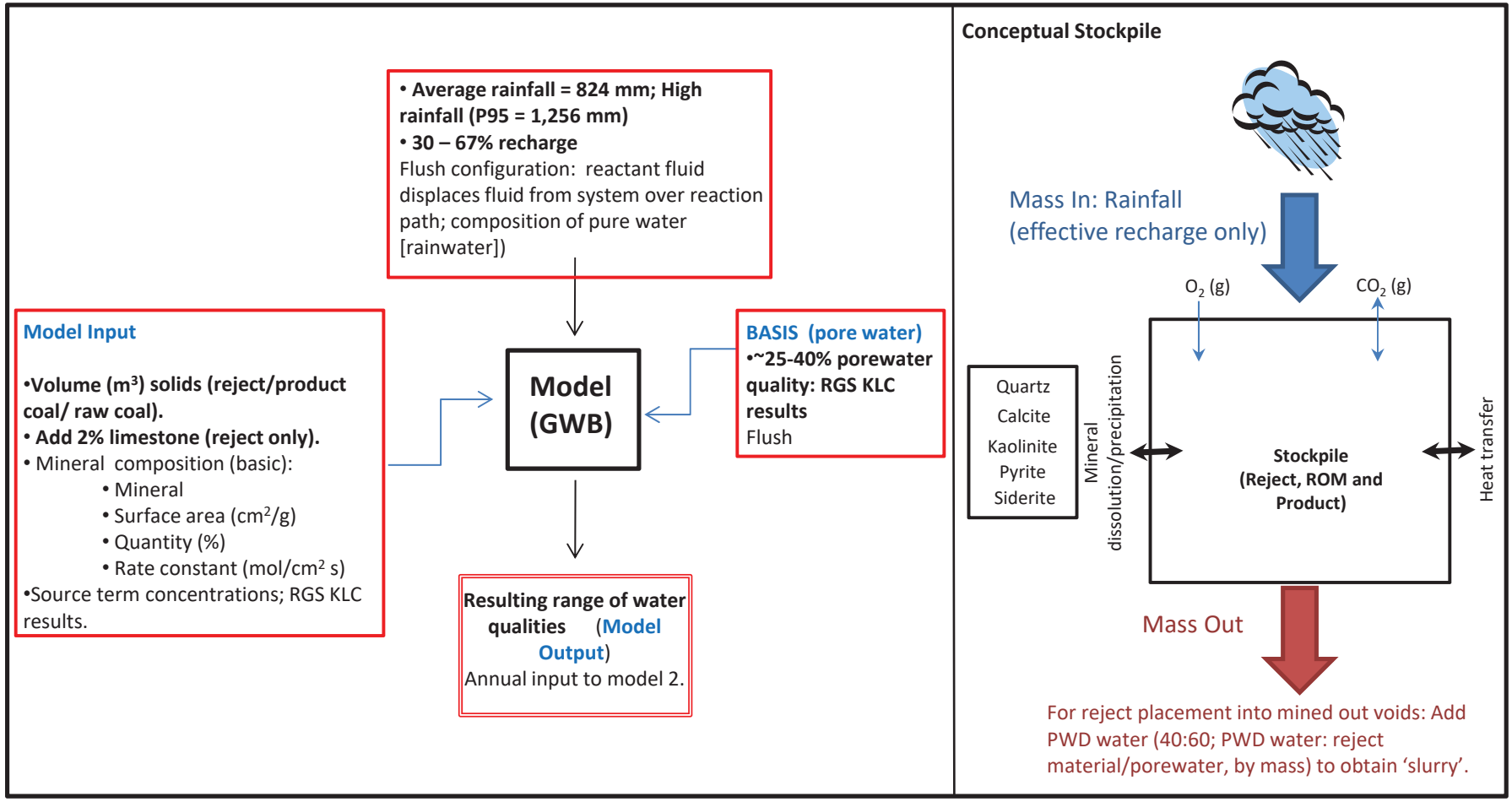
3.2 Model Construction

Figure 3-1 provides a conceptual overview of the models. The models were constructed using the "React" module in the modelling platform Geochemist's Workbench (GWB; Bethke, 2009). GWB allows for the construction of equilibrium reactions based on water quality and mineralogy. The interaction of water and material involves dissolution and precipitation of minerals (based on mineral solubilities), which is influenced by factors such as pH and Eh (redox) variations; the theoretical solubility limits of minerals are built into the GWB software. The functions and parameters of each model include:

- *Basis:* The basis relates to the hydrochemical properties of the initial water quality prior to reactions occurring (i.e. pore water). The pore water quality was determined from leachate results (refer to **section 2.3.2**).
- *Reactants:* Depending on the simulation, the reactants include the simplified mineralogical assemblages of each of the stockpiled materials (if available). For each mineral in the assemblage a specific surface area value, quantity (%) and rate constant is included. Water is also added to the mineral assemblage in proportions consistent with the material quantity/material infiltration rate to replicate the stockpiled materials interacting with water (on an annual basis). In addition, oxygen and carbon dioxide are defined by expected partial pressures of these gases.
- The reactant fluid (rainwater) mixes with and displaces an equivalent volume of the initial water fluid (i.e. pore water) from the system over the reaction path. The fluid volume and waste volume (water to rock ratio) is scaled according to the expected water balance of the material stockpiled.
- The displaced fluid represents the resulting seepage/runoff water quality.

A seepage and runoff model were constructed for each of the stockpiles (temporary reject stockpile, product stockpile and ROM stockpile). The resulting seepage and runoff water

Model 1: Stockpile water quality models. Seepage and Runoff undertaken separately.
'React' model in GWB
Separate models constructed for temporary reject, ROM and product stockpiles.



Note: Mineralogical assemblage simplified for the modelling. Pyrite and dolomite/calcite content will be inferred from sulfide and carbonate geochemical data, respectively. Mineral data will be updated after review of literature.
Mineral surface area and reaction rates will be obtained from the literature.

Client	HUMECOAL PROJECT
	RGS
Project	Hume Coal Hydrogeochemical Modelling
Title	Conceptual Geochemical Model: Reject Stockpile
Project No.	2017054
Fig No.	Figure 3-1

qualities from the models for a particular stockpile (at a set time) were mixed using PHREEQC to provide the stockpile "contact" water contribution to a particular catchment.

The modelled geochemical interactions are dictated by both the physical (e.g. particle size, stockpile construction methods, etc.) and geochemical attributes. Since the modelling only takes into consideration the geochemical attributes, the modelling results are not exact and only the geochemical trends should be considered.

3.3 Overview and Assumptions in the Conceptual Geochemical Model

The conceptual geochemical model and the set of assumptions for the interaction of rainwater with the various site stockpiles (temporary reject stockpile, product stockpile and ROM stockpile) include the following:

- The mineralogical composition of the stockpiles was simplified in the models to only include minerals which are reactive and likely to contribute to water quality (e.g. pyrite and calcite). The mineralogical composition of the different stockpiles was compiled from a combination of semi-quantitative X-ray diffraction (XRD) (Golder, 2014) and inferred from acid base accounting (ABA) results and the total chemical analysis.
- The carbonate mineral contribution (e.g. calcite) and the sulfide mineral contribution (i.e. pyrite) were inferred from ABA data (maximum potential acidity [MPA] and acid neutralisation capacity [ANC]) and whole rock chemistry results (S and Ca). The carbonate and sulfide minerals were below the detection limits of XRD (for the reject materials); however, these small quantities play an important role in the acid and metal leaching characteristics of a material. The inferences made on carbonate and sulfide mineral content allow for quantities below XRD detection limits to be included in the geochemical models.
- Some metals may be associated with minerals which were not identified by XRD, either because they are below instrumental detection limits, or they are amorphous. Similarly, some metals may be associated with minerals via surface adsorption or structural incorporation. Therefore, not all the 'host' minerals for trace metals have been accounted for within the model, so these metals are added to the model as individual reactants (mg/kg/month) based on kinetic data (refer to loading rates; **section 2.3.2**).
- The rate of reaction of one mineral may differ significantly to another, and may be dependent on a number of factors including temperature, surface area and the availability of oxidant and protons. Therefore, a reaction rate law is assigned to each mineral reaction to account for dissimilar properties. A rate law for each mineral in the mineralogical assemblage was selected from several references (**Table 3-1**).
- Pyrite was added into the model as a kinetic redox reaction, based on the equation:

  Pyrite (FeS_2) + 3.5*O_2(aq) + H_2O > Fe^{2+} + 2*SO_4^{2-} + 2*H^+, with the reaction of pyrite dependent on H^+ (protons) and O_2 availability.
- Limestone is typically dominated by the calcium carbonate minerals calcite ($CaCO_3$) and aragonite ($CaCO_3$). For the limestone treatment scenarios (i.e. limestone dosing of coal reject), the assumption is that calcite is the only mineral form of limestone added, and that limestone is mixed homogenously with the material while passing through the Coal Preparation Plant (CPP). During this process, precipitation of supersaturated iron (oxy)hydroxide minerals (e.g. goethite, hematite and ferrihydrite) is allowed.

- The partial pressures of O_2 (g) and CO_2 (g) were fixed, and the stockpile fugacity of CO_2 (g) was set to -log 3.5 (atmospheric). The models allow for supersaturated minerals to precipitate and undersaturated minerals to dissolve.
- Select minerals were 'suppressed' (prevented from precipitating) based on observations of the KLC tests and RGS's experience with secondary mineral precipitates in mining waste materials. For example, select Co, Mn and Ni bearing minerals (e.g. Birnessite Bixbyite, $Co(FeO_2)_2$, Co_2SiO_4, Co_3O_4, Hausmannite Manganite, Pyrolusite, Todorokite and $NiSiO_4$) were supressed in the temporary reject stockpile, to reflect the concentrations observed in the KLC tests. Iron was supressed in the ROM and product stockpiles under acidic conditions. The net effect of suppresing mineral precipitation during geochemical modelling is a conservative estimate of the dissolved metals concentrations.
- The stockpile porosity was different for each of the stockpile types. The temporary reject stockpile was assumed to be ~30%, so in the model porosity was varied between 25-35%, with traffic compaction of the rehabilitated surface expected to be ~5% lower. The porosity of the ROM and product stockpile is expected to be ~35%, so sensitivity analysis was undertaken between 30-40%.
- The water to solids ratio and quantity was adjusted to simulate variations in the interaction of water with the stockpiles at various stages of infiltration. The water to solid ratio was calculated from the following parameters:
    - Stockpile volume (outline in **Table 3-2** and adjusted from QCC Resources, 2015);
    - Stockpile footprint (surface area) (**Table 3-2)**;
    - Stockpile recharge (varied as sensitivity); and,
    - Annual and 95th percentile rainfall which was ~ 820 mm/ year and 1250 mm/ year, respectively (PB, 2016).
- The ROM and product stockpiles have been conservatively assumed to reach 75% capacity within the first year of production which is maintained throughout production. This is expected to be conservative as the stockpiles will typically only reach 50% capacity, and at times will have no material stockpiled.
- The temporary reject stockpile will be progressively shaped into a stable landform with 1H:4L slopes. During the initial ~18 months it has conservatively been assumed that the shaped temporary reject stockpile will not be covered (even though it will be progressively re-shaped, top dressed and re-vegetated) and thus expect infiltration to be 67% and runoff 33%; this is consistent with the water balance modelling which adopted these values for a bare spoil based on Australian Coal Industry's Research Program (ACARP) paper 'Water Quality and Discharge Prediction for Final Void and Spoil Catchments' (PPK, 2001). It is anticipated that for the re-shaped, top dressed and re-vegetated temporary reject stockpile infiltration will be somewhat limited. For the modelling, it has been assumed that at the end of the first 18 months, the temporary reject stockpile infiltration rate is assumed to be reduced to between 30% - 55% with runoff being 70% - 45%, respectively. Both of the infiltration/runoff scenarios were modelled as sensitivities,
- The temporary reject stockpile model was run for 18 months uncovered (commencing at year 0; 2020); at the end of the model run, the seepage water quality was used as the starting pore water for the re-shaped, top dressed and re-vegetated reject stockpile models. This model was then run for 18 years (year 2039), which represents the expected

residence of the stockpile at the surface before it is emplaced in underground mine voids towards the end of mining operations.

- It is expected that the ROM and product stockpiles will be turned over (replenished) every 7 days and 52 days, respectively. Therefore, the seepage and runoff results from the ROM model were reported at 7 days, while the seepage results for the product stockpiles was reported at 52 days. Since the stockpiled material is constantly being replemished, it is assumed that the seepage/runoff water qualities will remain consistent over the operation of the mine.
- Climatic data was used according to the inputs used in the water balance modelling (PB, 2016); summarised in **section 2.2**. Model simulations were run separetely for both the average (820 mm) and 95th percentile (1,250 mm) rainfall data.
- Rainwater quality used in the modelling is discussed in **section 2.3.3**.
- Results of the modelling are reported for the end of years 1 (2020), 5 (2025), 8 (2028), 12 (2032), 15 (2035) and 19 (2039). These years were selected because they represent times for the greatest variability in proportional inputs to the PWD, which is important for subsequent modelling steps.

Table 3-1. Mineral reaction rates

Mineral	Reaction Rate (mol/ cm^2 sec)
Quartz	4.20×10^{-18}
Calcite	6.457×10^{-07} (activity H^+ [0.5])
Kaolinite	1.00×10^{-17}
Pyrite	8.7×10^{-12} (activity O_2 [0.5], H^+ [-0.11])

Table 3-2 Geochemist's Workbench model parameters

Parameter	Stockpile/material	Description/ sensitivity
Model run time	-	1 year for each model
Porosity	-	25 – 40%; depending on material type
Maximum stockpile Mass (model input)	Reject material	350,000 t
	Run-of-mine material	60,000 t (45,000 t = 75%)
	Product Stockpile	300,000 t (225,000 t = 75%)
Maximum stockpile Volume (model input)	Reject material	231,788 m^3
	Run-of-mine material	40,540 m^3 (30,405 m^3 = 75%)
	Product Stockpile	202,700 m^3 (152,027 m^3 = 75%)
Stockpile footprint	Reject material - shaped	38,900 m^2 + 17,800 m^2 (56, 700 m^2)
	Run-of-mine material	9,500 m^2
	Product Stockpile	17,400 m^2 + 15,600 m^2 (33, 000 m^2)
Mineral Surface Area	-	10 – 100 cm^2/g^{-1}

3.4 Modelling Results and Discussion

The results from modelling the geochemical response of the various stockpiles (temporary reject stockpile, run-of-mine pad and product stockpile) are summarised in the following sections. The results include the predicted seepage and runoff water qualities, which in subsequent steps are added at appropriate proportions to produce the 'contact' water qualities for a particular catchment. Mixed solutions of seepage and runoff are reported in **Appendix B**.

Results of the modelling are reported for the end of Years 1 (2020), 5 (2025), 8 (2028), 12 (2032), 15 (2035) and 19 (2039).

3.4.1 Temporary reject stockpile

The model predictions for seepage and runoff water quality from the temporary reject stockpile for the end of Year 1 (non-covered stockpile) are displayed in **Table 3-3** and **Table 3-4**, respectively. The model predictions beyond Year 1 (re-shaped, top dressed and re-vegetated) are displayed for select years in **Table 3-5** and **Table 3-6**, for average and high rainfall scenarios, respectively. The combined seepage and runoff water qualities (contact water) are displayed in **Appendix B**. The key results are summarised in the following points:

- The modelling results for each of the simulations indicate that the temporary reject stockpile is likely to produce circum neutral (pH 7.73 – 8.22) seepage and runoff water quality which is maintained through the mine-life (up to year 2039). This is due to the addition of 2% limestone within the CPP circuit, added to neutralise any acid (H_2SO_4) which may be produced due to the oxidation of pyrite (FeS_2) present in the coal reject. The results are consistent with KLC tests for limestone amended coal reject (RGS, 2016).
- The major ion and metal(loid) concentrations vary between model sensitivities, mainly due to dilution effects caused by a combination of rainfall (i.e. high rainfall and infiltration results in more dilute leachates), infiltration volume and porosity. The dilution effect is more pronounced for major ions, such as Ca and SO_4, where, with time, soluble salts are flushed from the stockpile.
- The seepage metal(loid) concentrations generally increase with time. This is particularly evident for metal(loid)s which are mobile under neutral pH conditions (e.g. Se and Zn) (**Figure 3-2**). This also reflects the fact that some metal(loid)s were added to the model as separate reactants based on loading rate data calculated from KLC tests. For these particular metals, the leachate concentrations gradually increase with time up to a point at which they may become supersaturated and the corresponding minerals precipitate out of solution, which suppresses the concentration (i.e. concentration plateaus with time). Se and Zn concentrations reach a steady-state (plateau; **Figure 3-2**); however, there is no evidence to suggest these metals are supersaturated with corresponding minerals below saturation.
- The mineral saturation indices (SI) for select minerals are shown in **Figure 3-3**. The saturation state of a particular mineral (shown here as *Q/K*) is indicative of whether a mineral will precipitate or dissolve into solution. If the *Q/K* value is < 1, then the mineral is undersaturated in solution and may dissolve. However, if the *Q/K* value of a mineral is ≥ 1, then the mineral is supersaturated and likely to precipitate out of solution causing a decrease in the dissolved ions that make-up the particular mineral. The model SI results

frequently indicate that a number of minerals are at equilibrium throughout the simulations (e.g. gibbsite, hematite and calcite).

- Iron and aluminium concentations are particularly low in the temporary reject stockpile seepage/runoff due to the precipitation of hematite and gibbsite which occurs after the addition of limestone in the CPP and the subsequent shift in pH from acidic to neutral conditions (also occuring in the CPP). Although precipitation of some minerals may reduce seepage concentrations, these minerals remain, and may accumulate, in the stockpile and can potentially leach at a later time step, particularly if there are changes in pH or redox. This highlights the importance of the addition of limestone and the need to maintain neutral conditions over the life of mine.
- It is important to note that although the modelling results indicate that concentrations (mg/L) for higher rainfall scenarios result in lower seepage concentrations, the chemical load (mg/kg) may be higher.
- The runoff water quality results are the similar regardless of varying reject stockpile porosity. After the temporary reject stockpile is re-shaped, top dressed and vegetated (~18 months), it is assumed the runoff water quality will be of the same quality as rainwater.

Table 3-3: Modelling results for reject stockpile seepage water quality for end of Year 1 (67% infiltration; no cover) for various reject porosities.

End of Year 1 (67% infiltration; no cover)							
Sensitivity →		Average Rainfall = 820mm			High Rainfall (95th Percentile) = 1,250mm		
Parameter	Units	Porosity = 30%	Porosity = 25%	Porosity = 35%	Porosity = 30%	Porosity = 25%	Porosity = 35%
pH		7.75	7.73	7.76	7.78	7.81	7.77
Al	mg/l	0.011	0.011	0.012	0.012	0.013	0.012
Alkalinity	mg/l	21.4	21.0	21.9	22.7	23.5	22.1
As	mg/l	0.0020	0.0026	0.0022	0.0019	0.0017	0.0021
B	mg/l	0.0003	0.0003	0.0002	0.0013	0.0011	0.0014
Ca	mg/l	292.9	311.7	268.6	232.8	204.1	255.8
Cd^	mg/l	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Cl	mg/l	298	318	273	235	205	259
Co	mg/l	0.20	0.21	0.18	0.16	0.14	0.17
Cr	mg/l	3.21E-4	3.42E-4	2.94E-4	2.53E-4	2.21E-4	2.79E-4
Cu	mg/l	6.42E-4	6.84E-4	5.87E-4	5.07E-4	4.42E-4	5.59E-4
F	mg/l	0.13	0.14	0.12	0.1013	0.0884	0.1117
Fe	mg/l	3.60E-8	3.60E-8	3.59E-8	3.57E-8	3.59E-8	3.56E-8
K	mg/l	6.42	6.84	5.87	5.1	4.4	5.6
Mg	mg/l	20.4	21.6	18.8	16.4	14.4	17.9
Mn	mg/l	2.5	2.7	2.3	2.0	1.8	2.2
Na	mg/l	16.69	17.78	15.27	13.2	11.5	14.5
Ni	mg/l	0.50	0.53	0.46	0.404	0.349	0.444
Pb	mg/l	3.21E-4	3.42E-4	2.94E-4	0.0003	0.0002	0.0003
SO_4	mg/l	378.1	402.8	345.9	298.4	260.3	329.0
Se	mg/l	0.073	0.076	0.069	0.062	0.057	0.066
Zn	mg/l	0.51	0.53	0.49	0.46	0.43	0.48

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

Table 3-4: Modelling results for reject stockpile runoff water quality for end of year 1 (33% runoff; no cover) for various reject porosities.

End of Year 1 (33% runoff; no cover)			
Sensitivity →		**Average Rainfall = 820mm**	**High Rainfall (95th Percentile) = 1,250mm**
Parameter	**Units**		
pH		7.76	7.80
Al	mg/l	0.006	0.005
Alkalinity	mg/l	22.3	24.6
As	mg/l	0.010	0.007
B	mg/l	0.001	0.001
Ca	mg/l	245	174
Cd^	mg/l	0.001	0.001
Cl	mg/l	249	174
Co	mg/l	0.155	0.108
Cr	mg/l	0.00026	0.00018
Cu	mg/l	0.001	0.00037
F	mg/l	0.107	0.075
Fe	mg/l	0.000	0.000
K	mg/l	5.36	3.75
Mg	mg/l	17.2	12.3
Mn	mg/l	1.94	1.36
Na	mg/l	13.95	9.75
Ni	mg/l	0.477	0.333
Pb	mg/l	0.000	0.000
SO_4	mg/l	316	221
Se	mg/l	0.040	0.029
Zn	mg/l	0.362	0.310

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

Table 3-5 Modelling results for covered reject stockpile seepage water quality for select years with average rainfall conditions (820mm).

Sensitivity		End of year 5 - 19 (30% porosity; 55% infiltration; covered)					End of year 5 - 19 (30% porosity; 30% infiltration; covered)				
Year/ Date		Year 5 (2025)	Year 8 (2028)	Year 12 (2032)	Year 15 (2035)	Year 19 (2039)	Year 5 (2025)	Year 8 (2028)	Year 12 (2032)	Year 15 (2035)	Year 19 (2039)
Parameter	Units										
pH		7.97	8.10	8.19	8.21	8.22	7.87	7.96	8.06	8.10	8.16
Al	mg/l	0.018	0.023	0.028	0.029	0.030	0.015	0.017	0.021	0.023	0.027
Alkalinity	mg/l	31.7	41.3	49.3	51.6	52.6	26.4	31.1	37.9	41.0	46.9
As	mg/l	0.0008	0.0005	0.0004	0.0004	0.0004	0.0013	0.0011	0.0009	0.0009	0.0008
B	mg/l	0.0001	0.00002	0.000005	0.000002	0.0000004	0.0001	0.0001	0.00003	0.00002	0.00001
Ca	mg/l	78.2	37.7	23.8	21.3	20.3	138.9	83.2	47.5	38.5	27.2
Cd^	mg/l	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Cl	mg/l	91.7	45.8	28.3	24.8	23.4	170.6	107.0	64.8	53.5	38.7
Co	mg/l	0.078	0.054	0.045	0.043	0.043	0.131	0.107	0.091	0.087	0.081
Cr	mg/l	0.00007	0.00002	0.00001	0.000002	0.0000004	0.00013	0.00007	0.00003	0.00002	0.00001
Cu	mg/l	0.00014	0.00005	0.00001	0.000004	0.000001	0.00027	0.00015	0.00007	0.00005	0.00002
F	mg/l	0.030	0.010	0.002	0.001	0.0002	0.058	0.032	0.014	0.010	0.004
Fe	mg/l	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001
K	mg/l	1.98	0.99	0.61	0.54	0.51	3.37	2.07	1.21	0.98	0.68
Mg	mg/l	6.18	3.03	1.83	1.59	1.50	10.63	6.49	3.74	3.01	2.04
Mn	mg/l	1.15	0.88	0.77	0.75	0.74	1.88	1.65	1.49	1.45	1.39
Na	mg/l	17.58	14.98	14.00	13.80	13.72	21.24	17.83	15.57	14.97	14.17
Ni	mg/l	0.18	0.11	0.09	0.09	0.08	0.30	0.24	0.19	0.18	0.16
Pb	mg/l	0.000069	0.000023	0.000005	0.000002	0.0000004	0.000135	0.000074	0.000033	0.000023	0.000008
SO_4	mg/l	44.0	30.5	18.0	18.0	18.0	181.6	104.9	54.1	40.5	22.6
Se	mg/l	0.128	0.145	0.152	0.153	0.154	0.175	0.223	0.255	0.264	0.275
Zn	mg/l	0.580	0.595	0.601	0.602	0.602	0.750	0.840	0.900	0.916	0.937

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

Table 3-6 Modelling results for reject stockpile seepage water quality for high rainfall scenario (95th percentile; 1,200mm)

Sensitivity		End of year 5 - 19 (30% porosity; 55% infiltration; covered)					End of year 5 - 19 (30% porosity; 30% infiltration; covered)				
Year/ Date		Year 5 (2025)	Year 8 (2028)	Year 12 (2032)	Year 15 (2035)	Year 19 (2039)	Year 5 (2025)	Year 8 (2028)	Year 12 (2032)	Year 15 (2035)	Year 19 (2039)
Parameter	Units										
pH		8.09	8.19	8.22	8.22	8.22	7.97	8.08	8.17	8.19	8.21
Al	mg/l	0.023	0.029	0.030	0.030	0.030	0.018	0.022	0.027	0.028	0.030
Alkalinity	mg/l	40.6	50.1	53.0	53.4	53.4	31.7	39.7	47.5	49.6	51.9
As	mg/l	0.00044	0.00030	0.00027	0.00027	0.00027	0.00090	0.00066	0.00054	0.00052	0.00050
B	mg/l	0.00011	0.00002	0.000002	0.0000004	0.00000004	0.00029	0.00012	0.00003	0.00002	0.000004
Ca	mg/l	39.3	23.0	20.0	19.7	19.6	78.6	41.8	26.2	23.5	21.0
Cd^	mg/l	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Cl	mg/l	48.2	27.7	23.5079	23.0922	23.0103	92.1	50.4	31.2	27.5	23.9872
Co	mg/l	0.0415	0.0304	0.0281	0.0278	0.0278	0.0818	0.0632	0.0546	0.0530	0.0514
Cr	mg/l	0.00002	0.000004	0.0000004	0.0000001	0.00000001	0.00006	0.00002	0.00001	0.000004	0.000001
Cu	mg/l	0.00005	0.00001	0.000001	0.0000002	0.00000002	0.00015	0.00006	0.00002	0.000010	0.000002
F	mg/l	0.0107	0.0020	0.0002	0.00004	4.39E-06	0.0294	0.0117	0.0035	0.0019	0.0004
Fe	mg/l	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001
K	mg/l	1.036	0.601	0.5108	0.5020	0.5002	2.0	1.084	0.674	0.596	0.521
Mg	mg/l	3.2	1.7929	1.5046	1.4763	1.4707	6.2	3.3	2.0268	1.7768	1.5372
Mn	mg/l	0.649	0.515	0.487	0.485	0.484	1.220	1.020	0.927	0.909	0.892
Na	mg/l	15.112	13.966	13.728	13.705	13.701	17.572	15.237	14.158	13.953	13.755
Ni	mg/l	0.092	0.062	0.055	0.055	0.055	0.188	0.135	0.111	0.106	0.101
Pb	mg/l	0.00002	0.000004	0.0000004	0.0000001	0.00000001	0.00006	0.00002	0.00001	0.000004	0.000001
SO_4	mg/l	99.2	40.9	30.8	18.7	18.0	99.6	46.8	22.4	19.6	17.9
Se	mg/l	0.096	0.100	0.100	0.100	0.100	0.148	0.170	0.180	0.182	0.184
Zn	mg/l	0.458	0.458	0.458	0.458	0.458	0.617	0.658	0.677	0.680	0.684

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

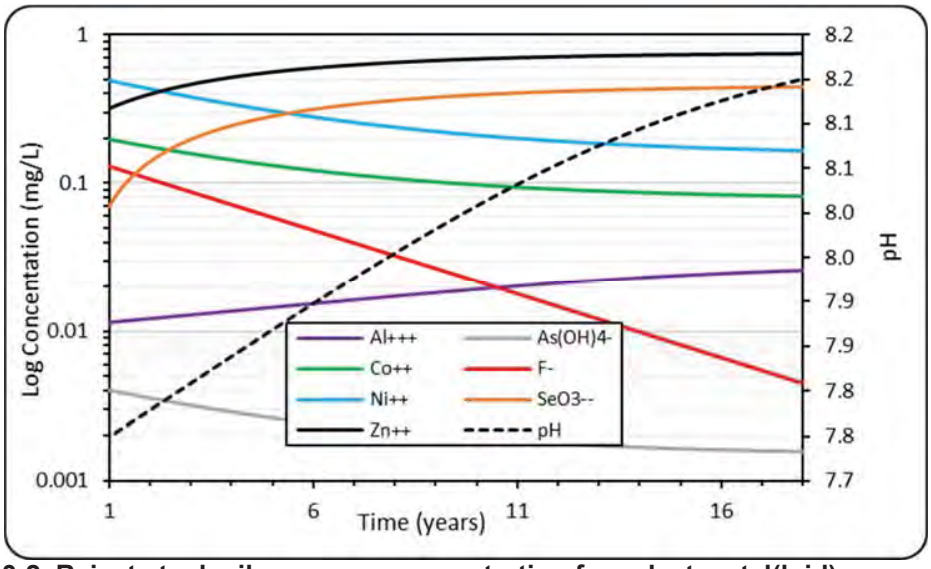


Figure 3-2. Reject stock pile seepage concentration for select metal(loid)s versus time (end of year 1 – year 19). Porosity = 30%; infiltration 55%; and, high rainfall (1,250mm) scenario.

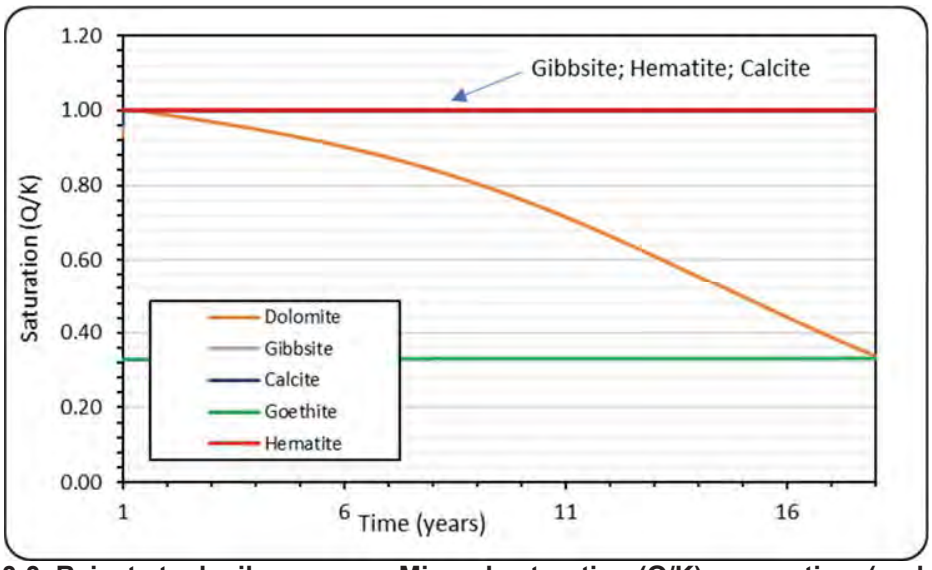


Figure 3-3. Reject stock pile seepage: Mineral saturation (Q/K) versus time (end of year 1 – year 19). Porosity = 30%; infiltration 55%; and, high rainfall (1,250mm) scenario.

3.4.2 Run-of-Mine and Product Stockpile

The model predictions for seepage and runoff water qualities from the ROM pad and the product stockpiles are displayed in **Table 3-7** and **Table 3-8**, respectively. The results for the ROM pad are reported for a stockpile which has reacted for one week, which is the expected turn over time for the ROM pad during operation. The product stockpile results are reported for a stockpile which has reacted for 52 days, which is the expected turnover time for the product stockpiles. The key results are summarised in the following points:

- The modelling results for each of the simulations indicate that both the ROM pad and product stockpiles are likely to produce acidic seepage and runoff water qualities through the mine-life (up to year 2039). The estimated ROM pad pH values range from pH 4.34 – 4.74, while the product stockpile pH values range from pH 3.92 – 4.08 for the different sensitivities. This is due to the presence of pyrite (FeS_2), which oxidises to produce acid (H_2SO_4), and the fact that there are negligible acid buffering minerals (acid neutralising capacity) present within the ROM or product stockpile materials. The results are consistent with static and KLC tests results for coal roof, seam, parting and floor materials from site (RGS, 2016).

- The major ion and metal(loid) concentrations only vary slightly between model sensitivities. All the models begin with the same porewater quality, and since the models are only run for a short period of time (7 days/52 days) there is limited rainwater flushing and thus minor concentration changes between sensitivities. Similar to the temporary reject stockpile results, these slight variations in concentration between sensitivities are due to minor dilution effects caused by a combination of rainfall, infiltration volume and porosity. However, it is important to note that although the modelling results indicate that concentrations (mg/L) for higher rainfall scenarios result in lower seepage concentrations, the chemical load (mg/kg) may be higher.

- Due to the acidic nature of the seepage and runoff water qualities, the metal(loid) concentrations are elevated for some metal(loid)s (e.g. Co, Cu, Ni, Pb, Se and Zn) relative to baseline groundwater conditions for the Wongawilli Coal Seam (**Table 3-7**). The seepage metal(loid) cocnetations are in the same order as those measured using KLC tests for coal roof, seam, parting and floor materials from site (RGS, 2016).

- An example of the mineral saturation indices (SI) for select minerals are shown in **Figure 3-4** (for a ROM pad simulation with 35% porosity, 67% infiltration and high rainfall). The model SI results frequently indicate that jarosite ($KFe_3(SO_4)_2(OH)_6$) is at equilibrium throughout the simulations. Jarosite is a secondary mineral precipitate formed due to the oxidation of sulfides (namely pyrite) and is commonly associated with AMD at very low pH. Jarosite is a temporary store for non-sulfidic acidity which may be released upon re-dissolution.

- There is generally limited changes to the saturation state of minerals for the various simulations and sensitivities because the geochemical conditions (pH and redox) remain relatively consitent and the models are only run for a short period of time (ie. 7 and 52 days for the ROM and product stockpiles, respectively), so there are only small changes to seepage and runoff concentration with time.

Table 3-7 Run of Mine stockpile results for various scenarios

Results reported for 7th day (stockpile turnover); 67% infiltration; no cover									
Sensitivity		Average Rainfall = 820mm				High Rainfall (95th Percentile) = 1,250mm			
Paramete	Unit	Porosity = 35%	Porosity = 30%	Porosity = 40%	Runoff	Porosity = 35%	Porosity = 30%	Porosity = 40%	Runoff
pH		4.42	4.42	4.26	4.73	4.32	4.42	4.34	4.74
Al	mg/l	1.39	1.38	1.39	1.05	1.38	1.37	1.38	1.00
Alkalinity	mg/l	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
As	mg/l	0.0265	0.0264	0.0265	0.0201	0.0263	0.0263	0.0264	0.0192
B	mg/l	0.0004	0.0004	0.0004	0.0003	0.0004	0.0004	0.0004	0.0003
Ca	mg/l	15.00	15.49	14.62	18.20	14.21	14.58	13.94	15.26
Cd^	mg/l	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Cl	mg/l	86.40	86.30	86.47	65.50	86.31	86.19	86.39	62.79
Co	mg/l	0.846	0.845	0.847	0.645	0.837	0.836	0.838	0.612
Cr	mg/l	0.0005	0.0005	0.0005	0.0004	0.0005	0.0005	0.0005	0.0004
Cu	mg/l	0.132	0.132	0.132	0.104	0.125	0.125	0.125	0.094
F	mg/l	0.206	0.205	0.206	0.157	0.204	0.203	0.204	0.149
Fe	mg/l	17.37	16.91	17.71	15.97	20.74	20.72	20.35	16.63
K	mg/l	0.50	0.50	0.50	0.38	0.50	0.50	0.50	0.36
Mg	mg/l	16.88	16.86	16.90	12.80	16.86	16.84	16.88	12.27
Mn	mg/l	4.57	4.57	4.57	3.51	4.46	4.46	4.47	3.29
Na	mg/l	0.497	0.496	0.497	0.376	0.496	0.495	0.497	0.361
Ni	mg/l	2.31	2.31	2.31	1.76	2.28	2.28	2.28	1.67
Pb	mg/l	0.162	0.161	0.162	0.124	0.158	0.158	0.158	0.116
SO_4	mg/l	86.40	86.30	86.47	65.50	86.31	86.19	86.39	62.79
Se	mg/l	0.076	0.075	0.076	0.057	0.075	0.075	0.075	0.055
Zn	mg/l	3.056	3.052	3.058	2.373	3.028	3.024	3.031	2.263

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

Table 3-8 Product Stockpile estimated seepage and runoff water qualities for various scenarios

Results reported for 52 days; 67% infiltration; no cover									
Sensitivity		Average Rainfall = 820mm				High Rainfall (95th Percentile) = 1,250mm			
Parameter	Units	Porosity = 35%	Porosity = 30%	Porosity = 40%	Runoff	Porosity = 35%	Porosity = 30%	Porosity = 40%	Runoff
pH		3.95	4.00	3.92	3.97	3.90	4.00	3.92	4.08
Al	mg/l	1.91	1.90	1.92	0.53	1.88	1.87	1.89	0.33
Alkalinity	mg/l	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
As	mg/l	0.015	0.015	0.015	0.004	0.014	0.014	0.014	0.003
B	mg/l	0.0004	0.0004	0.0004	0.0001	0.0004	0.0004	0.0004	0.0000
Ca	mg/l	14.57	14.98	14.26	1.56	14.29	14.65	14.02	0.49
Cd^	mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cl	mg/l	82.00	81.51	82.37	10.06	80.45	79.71	81.00	3.18
Co	mg/l	1.15	1.14	1.15	0.27	1.13	1.12	1.14	0.16
Cr	mg/l	0.0007	0.0007	0.0007	0.0001	0.0007	0.0007	0.0007	0.0001
Cu	mg/l	0.136	0.135	0.136	0.032	0.134	0.133	0.134	0.019
F	mg/l	0.276	0.274	0.277	0.059	0.271	0.269	0.273	0.033

Results reported for 52 days; 67% infiltration; no cover									
Sensitivity		Average Rainfall = 820mm				High Rainfall (95th Percentile) = 1,250mm			
Parameter	Units	Porosity = 35%	Porosity = 30%	Porosity = 40%	Runoff	Porosity = 35%	Porosity = 30%	Porosity = 40%	Runoff
Fe	mg/l	22.56	22.45	22.64	6.69	22.22	22.06	22.34	3.61
K	mg/l	0.482	0.479	0.485	0.059	0.473	0.469	0.476	0.019
Mg	mg/l	13.51	13.43	13.57	1.66	13.25	13.13	13.34	0.52
Mn	mg/l	12.17	12.13	12.21	4.15	12.03	11.96	12.08	2.79
Na	mg/l	2.89	2.88	2.91	0.35	2.84	2.81	2.86	0.11
Ni	mg/l	2.94	2.93	2.95	0.70	2.90	2.88	2.91	0.41
Pb	mg/l	0.043	0.043	0.043	0.012	0.042	0.042	0.042	0.007
SO_4	mg/l	65.78	65.41	65.05	12.45	64.63	64.08	65.04	7.35
Se	mg/l	0.019	0.018	0.019	0.007	0.018	0.018	0.018	0.005
Zn	mg/l	3.554	3.537	3.566	0.990	3.502	3.478	3.521	0.658

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

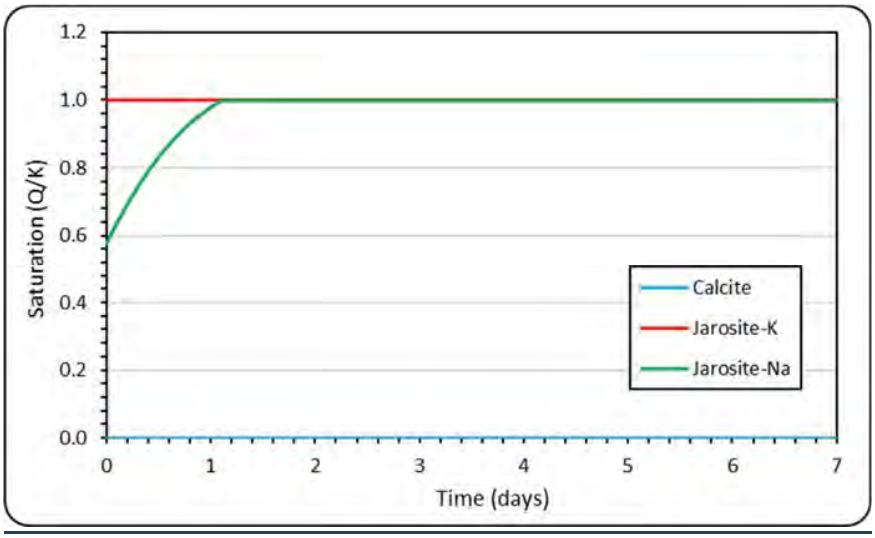


Figure 3-4. ROM pad: Mineral saturation (Q/K) versus time. Porosity = 35%; infiltration 67%; and, high rainfall (1,250mm) scenario.

4.0 Modelling Stormwater Basin and Mine Water Dam Water Qualities

4.1 Water Quality Model

The modelling results discussed in **Section 3** of this report provides the key inputs to modelling the SB and MWD water qualities (mine water management system). The intent of this modelling step was to determine the range of water qualities likely to report to each of the SBs and MWDs, so that his data can be used to determine the quality of water inputs to the PWD.

4.2 Model Construction

There are several catchments which may contain infrastructure or stockpiled material at a particular point in the mine life (e.g. temporary reject stockpile, run-of-mine pad and product stockpiles). As part of the mine management system (**section 1.1.3**), the rainfall runoff from each of these catchments report to either a SB or MWD. This includes rainfall intercepted by stockpiles ("contact" water) or infrastructure within a catchment and also direct rainfall which falls within a catchment but may not come into contact with a stockpile. The contact water and direct rainfall runoff reporting to several of the SBs and MWDs will collectively make up the surface water component pumped to the PWD.

The models were constructed using PHREEQC (Parkhurst and Appello, 1995), to simulate the effects of mixing (a) rainwater falling directly on the catchment (but not intersecting a stockpile) with stockpile seepage and runoff water to produce a SB or MWD water quality, and (b) variable fractions of the resulting SB and MWD water qualities which are to report to the MWD.

Each contributing catchment water quality is first calculated separately based on catchment size and stockpile footprint (if present within a catchment); for examples, for SB01, this would be the temporary reject stockpile seepage and runoff water (at select years) + product stockpile seepage and runoff + direct rainfall. Secondly, all the SB and MWD water qualities are added at correct proportions to produce the PWD input (**Section 4**).

4.3 Overview and Assumptions in the Conceptual Geochemical Model

The conceptual geochemical model and the set of assumptions used in the modelling include the following:

- The SB and MWD catchments used in the modelling were taken from the report: *Water Balance Assessment for Hume Coal* (PB, 2016), and are summarised in **Section 1.1.3** (**Table 1-1)**. As part of the mine management system, not all SBs and MWDs are expected to materially contribute to the composition of the PWD water. The following assumptions were made for each of the SBs and MWDs:
    - **SB01**: Collects runoff/seepage from the temporary reject stockpile (treated with 2% limestone) and product stockpile. This water will report to the PWD.
    - **SB02**: Collects runoff/seepage from the ROM pad. This water will contribute to the PWD water composition.
    - **SB03**: Collects runoff from the Administration and Workshop Area, and is expected to be at low risk of being contaminated by coal contact (PB, 2016b). If water quality targets

are met and rainfall meets first flush criteria, then the water is released to Oldbury Creek. For simplicity, it is assumed that all water will be released to Oldbury Creek and none of this water will contribute to the PWD composition. Any water that does not meet first flush criteria (i.e. 20mm) is assumed to have negligible impact on the PWD water quality.

- **SB04**: Collects runoff from the mine road and conveyor corridor area, and is expected to be at low risk of being contaminated by coal contact (PB, 2016b). If water quality targets are met and rainfall meets first flush criteria, then the water is released to Oldbury Creek. It is assumed that all water will be released to Oldbury Creek and none of this water will contribute to the process water composition. Any water that does not meet first flush criteria (i.e. 20mm) is assumed to have negligible impact on the PWD water quality.
- **MWD05**: Collects runoff from the overland conveyor number 1 corridor. A belt cleaning station will be used at the head end of the conveyor to limit coal carryback on the return belt to negligible quantities, and the conveyor will be covered with a roof that will prevent direct rainfall interaction with any minor spillages before they can be cleaned up, should they occur. Therefore, all runoff will have the water quality characteristics of rainfall and contribute to the PWD composition. Water captured by this catchment is only small (1.2%) in comparison to other catchments.
- **MWD06**: Collects runoff from the area in between the conveyor portal and the overland conveyor number 1 corridor. It is assumed that appropriate management practices will be put in place to inhibit contact of water with material quantities of coal. Therefore, all runoff will have the water quality characteristics of rainfall and contribute to the process water composition. Water captured by this catchment is also only small (4.9%) in comparison to other catchments.
- **MWD07**: Collects runoff from the ventilation shaft pad area and transfer it to the underground mine sump. This water is then pumped to the PWD along with any groundwater reporting to the sump.
- **MWD08**: Purpose is to store and treat any excess water before it can be released to Oldbury Creek. This dam is included as provisionary infrastructure, and based on the PB water balance modelling will not be required, so is not included in this assessment.

- The SB and MWD catchment areas (**Table 4-1**) were used to determine the contribution (%) of water from a particular SB or MWD to the surface water input to the PWD. The bulk of the water contributing to the surface water composition is from SB01 and SB02. Both SB01 and SB02 receive contact water from stockpiles, however, the majority of the water composition is made-up off direct rainfall runoff (**Table 4-2**). SB03, SB04 and MWD08 are not expected to contribute to the surface water composition, while MWD05, MWD06 and MWD07 only contribute direct rainfall runoff (**Table 4-2**).

- As mentioned above, the water quality for individual catchments (SB or MWD) were determined by mixing the direct rainfall contribution with stockpile (if present) intercepted rainfall which reports as either seepage or runoff. The direct rainfall proportion is calculated as the catchment size minus the stockpile footprint, while the stockpile contribution is proportioned to the footprint (**Table 4-2).**

- For the purpose of the modelling, it has been assumed that there is no residence time of water in each of the SBs and MWDs, with water pumped instantly to the PWD. Therefore, there are no inputs/outputs due to climatic effects (e.g. rainfall dilution and evapo-concentration). This assumption is in line with the plan of operations whereby the SBs and MWDs will be maintained at low volumes at all times.
- Several simulations will be undertaken with different rainfall criteria based on the rainfall statistics discussed in **Section 2.1.4**.
- Direct rainwater runoff utilises the 95th percentile water quality (**Section 2.3.3**) which is considered conservative.
- The modelling utilises the water quality outputs from previous modelling steps (**Section 3.0**). Not all the previous sensitivities were incorporated within this step.

Table 4-1. Stormwater basin and mine water dam catchment areas and contributions to surface water which will ultimately report to the PWD.

SB/ MWD	Catchment Area (ha)	Volume (%) contribution to surface water reporting to PWD^
SB01	26.36	48.0%
SB02	22.64	41.2%
SB03*	5.91	-
SB04*	14.73	-
MWD05	0.64	1.2%
MWD06	2.69	4.9%
MWD07	2.6	4.7%
MWD08*	0.27	-

*Note: SB03, SB04 and MWD08 are not contributing to PWD composition.

^Volume contribution reporting to PWD does not include direct rainfall intersected by PWD.

Table 4-2. Catchment contributions to surface water quality input to PWD.

Catchment	Contributing stockpiles	Stockpile footprint (ha)	% contact water contribution to catchment	% direct rainfall runoff (non-contact)
SB01	Reject material (re-shaped landforms)	5.67	21.5%	66%
	Product stockpiles	3.3	12.5%	
SB02	Run-of-mine material	0.95	4.2%	95.8%
MWD05	NA	-	0%	100%
MWD06	NA	-	0%	100%
MWD07	NA	-	0%	100%

4.4 Modelling Results and Discussion

The model predicted water qualities for catchments SB01 and SB02 for various scenarios are displayed in **Table 4-3** and **Table 4-4**, respectively. The water qualities for catchment MWD05, MWD06 and MWD07 are not shown because these catchments only receive direct rainfall runoff water quality. The model predicted surface water quality inputs to the PWD are displayed in **Table 4-5**.

Results of the modelling are reported for the end of Years 1 (2020), 5 (2025), 8 (2028), 12 (2032), 15 (2035) and 19 (2039) because these years provide the greatest variability in various water quality inputs to the PWD. The key results are summarised in the following points:

- The SB01 modelled water qualities are slightly acidic with a range of pH values from 4.93 to 5.09 for the various sensitivity analysis. The acidic pH values reflect the contribution of water from the product stockpiles. Although the product stockpiles only contribute 12.5% to SB01 water quality, they have a high acidity load due to low pH (~pH 3.95) and elevated dissolved ions when compared to rainfall which is the major contributing water type (66%) and has negligible acid buffering capacity/alkalinity.

- The major ion and metal(loid) concentrations are essentially a diluted combination of the temporary reject stockpile and product stockpiles seepage/runoff water qualities. The metal(loid) concentrations vary slightly between model sensitivities; which is expected as the only difference between the modelled years is the water quality input from the temporary reject stockpile (which changes on an annual basis). More pronounced variations in water quality between sensitivities are observed for some of the major ions such as Ca, Cl and SO_4; once again, this reflects annual changes to the temporary reject stockpile water quality input.

- Although the SB01 water quality is significantly diluted with direct rainfall (66%) some metal(loid) concentrations remain elevated relative to average baseline groundwater conditions for the Wongawilli Coal Seam (e.g. Ni, Cr, Pb, Se, Co and Zn). However, several of these metal(loid)s (Pb, Se and Zn) are within the baseline range. The partially elevated Zn concentrations (0.49-0.54 mg/L Zn) partly reflect the rainwater input (95th percentile = 0.23 mg/L Zn).

- The SB02 modelled water qualities are slightly acidic with a range of pH values from 5.05 to 5.13 for the various sensitivity analysis. For SB02, the acidic pH values reflect the contribution of water from the ROM pad, which only contributes 4.2% to SB02 water quality; however, once again, the ROM pad contributes a high acidity load due to low pH (pH 4.39 – 4.49) and the moderate dissolved ions content when compared to rainfall which has negligible alkalinity.

- The ROM pad seepage/runoff contribution to SB02 is only 4.2% with the only other contributing water quality being direct rainfall, so the major ion and metal(loid) concentrations are a diluted version of the ROM pad seepage/runoff water qualities. The metal(loid) concentrations only vary slightly between model sensitivities; because of the low ROM pad seepage/runoff contribution.

- The modelled surface water quality inputs to the PWD are slightly acidic with a range of pH values from 4.96 to 5.04 for the various sensitivity analysis.

- The collective surface water quality contribution to the PWD (**Table 4-5**) includes ~18% contact water from either the ROM pad (1.7%), product stockpile (6%) or temporary reject stockpile (10.3%), with the majority of water quality input from direct rainfall runoff. Therefore, the major ion and metal(loid) concentrations are essentially a proportional combination of these waters, with some metal(loid)s elevated (e.g. Co, Cr,Cu, Ni, Pb and Zn) relative to average baseline groundwater conditions for the Wongawilli Coal Seam.

Table 4-3: Estimated SB01 water qualities for various scenarios

SB01		End of Year 1 - 19 (Average rainfall = 820 mm)						End of Year 1 - 19 (95th Percentile rainfall =1,250 mm)					
Year/ Date		Year 1 (2021)	Year 5 (2025)	Year 8 (2028)	Year 12 (2032)	Year 15 (2035)	Year 19 (2039)	Year 1 (2021)	Year 5 (2025)	Year 8 (2028)	Year 12 (2032)	Year 15 (2035)	Year 19 (2039)
Parameter	Units												
pH		5.01	4.98	5.03	5.07	5.08	5.09	4.93	4.93	4.97	4.99	4.99	4.99
Al	mg/l	0.201	0.203	0.204	0.204	0.204	0.204	0.190	0.193	0.194	0.194	0.194	0.194
Alkalinity	mg/l	9.12	8.20	9.33	10.28	10.56	10.67	9.47	9.26	10.38	10.73	10.76	10.77
As	mg/l	0.011	0.011	0.011	0.011	0.011	0.011	0.010	0.011	0.011	0.011	0.011	0.011
B	mg/l	0.006	0.007	0.007	0.007	0.007	0.007	0.006	0.007	0.007	0.007	0.007	0.007
Ca	mg/l	62.80	12.40	7.60	5.96	5.66	5.55	48.91	7.72	5.79	5.44	5.40	5.39
Cd^	mg/l	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Cl	mg/l	114.40	64.24	58.47	56.30	55.87	55.70	95.85	55.57	53.02	52.49	52.44	54.98
Co	mg/l	0.164	0.136	0.133	0.132	0.132	0.132	0.148	0.125	0.124	0.124	0.124	0.124
Cr	mg/l	0.017	0.019	0.019	0.019	0.019	0.019	0.017	0.019	0.019	0.019	0.019	0.019
Cu	mg/l	0.029	0.032	0.032	0.032	0.032	0.032	0.029	0.031	0.031	0.031	0.031	0.031
F	mg/l	0.068	0.048	0.046	0.045	0.045	0.044	0.060	0.044	0.043	0.043	0.043	0.043
Fe	mg/l	2.20	2.20	2.20	2.20	2.20	2.20	2.04	2.05	2.05	2.05	0.04	2.05
K	mg/l	2.25	1.25	1.14	1.09	1.08	1.08	1.94	1.14	1.09	1.08	1.08	1.08
Mg	mg/l	8.34	5.16	4.79	4.65	4.62	4.61	7.35	4.74	4.58	4.54	4.54	4.54
Mn	mg/l	1.71	1.35	1.31	1.30	1.30	1.30	1.53	1.22	1.20	1.20	1.20	1.20
Na	mg/l	27.20	27.71	27.41	27.29	27.27	27.26	26.38	27.41	27.27	27.25	27.24	27.24
Ni	mg/l	0.398	0.316	0.308	0.306	0.305	0.305	0.359	0.290	0.286	0.286	0.285	0.285
Pb	mg/l	0.021	0.023	0.023	0.023	0.023	0.023	0.020	0.023	0.023	0.023	0.023	0.023
SO_4	mg/l	90.99	26.51	19.60	16.98	16.45	16.25	71.71	19.04	15.30	15.26	15.26	15.25
Se	mg/l	0.025	0.029	0.031	0.032	0.032	0.032	0.022	0.025	0.025	0.026	0.026	0.026
Zn	mg/l	0.591	0.599	0.602	0.602	0.602	0.602	0.561	0.567	0.567	0.567	0.567	0.567

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

Table 4-4: Estimated SB02 water qualities for various scenarios

SB02 Parameter	Units	End of Year 1 - 19 (Average rainfall = 820 mm)	End of Year 1 - 19 (95th Percentile rainfall =1,250 mm)
pH		5.13	5.05
Al	mg/l	0.078	0.0765
Alkalinity	mg/l	0.076	0.075
As	mg/l	0.026	0.025
B	mg/l	0.048	0.048
Ca	mg/l	3.156	3.093
Cd^	mg/l	0.024	0.024
Cl	mg/l	65.145	65.15
Co	mg/l	0.057	0.056
Cr	mg/l	0.024	0.0239
Cu	mg/l	0.029	0.0287
F	mg/l	0.032	0.0317
Fe	mg/l	0.758	0.861
K	mg/l	1.332	1.33
Mg	mg/l	4.964	4.95
Mn	mg/l	0.201	0.195
Na	mg/l	34.21	34.21
Ni	mg/l	0.113	0.111
Pb	mg/l	0.03	0.03
SO_4	mg/l	14.836	14.79
Se	mg/l	0.029	0.026
Zn	mg/l	0.339	0.337

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

Table 4-5: Estimated surface water quality inputs to PWD for various scenarios

All SBs + MWDs (PWD input)		End of Year 1 - 19 (Average rainfall = 820 mm)						End of Year 1 - 19 (95th Percentile rainfall =1,250 mm)					
Year/ Date		Year 1 (2021)	Year 5 (2025)	Year 8 (2028)	Year 12 (2032)	Year 15 (2035)	Year 19 (2039)	Year 1 (2021)	Year 5 (2025)	Year 8 (2028)	Year 12 (2032)	Year 15 (2035)	Year 19 (2039)
Parameter	Units												
pH		5.03	5.00	5.04	5.08	5.08	5.09	4.96	4.96	4.99	5.00	5.00	5.01
Al	mg/l	0.125	0.126	0.126	0.127	0.127	0.127	0.121	0.122	0.122	0.122	0.122	0.122
Alkalinity	mg/l	4.08	3.67	4.17	4.59	4.71	4.76	4.23	4.14	4.63	4.79	4.80	4.80
As	mg/l	0.012	0.013	0.013	0.013	0.013	0.013	0.012	0.013	0.012	0.012	0.012	0.012
B	mg/l	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008
Ca	mg/l	29.43	7.15	5.02	4.30	4.16	4.11	23.32	5.10	4.25	4.09	4.08	4.07
Cd^	mg/l	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Cl	mg/l	86.98	64.79	62.24	61.28	61.09	61.02	79.90	62.09	60.96	60.72	59.57	60.70
Co	mg/l	0.100	0.087	0.086	0.086	0.086	0.086	0.093	0.083	0.083	0.082	0.082	0.082
Cr	mg/l	0.021	0.022	0.022	0.022	0.022	0.022	0.021	0.022	0.022	0.022	0.022	0.022
Cu	mg/l	0.029	0.030	0.030	0.030	0.030	0.030	0.028	0.029	0.029	0.029	0.029	0.029
F	mg/l	0.047	0.038	0.037	0.037	0.037	0.037	0.044	0.037	0.036	0.036	0.036	0.036
Fe	mg/l	1.35	1.35	1.35	1.35	1.35	1.35	1.24	1.24	1.24	1.24	0.35	1.24
K	mg/l	1.74	1.30	1.25	1.23	1.23	1.23	1.61	1.25	1.23	1.22	1.22	1.22
Mg	mg/l	6.40	4.99	4.83	4.76	4.75	4.75	5.96	4.81	4.73	4.72	4.72	4.72
Mn	mg/l	0.85	0.68	0.67	0.66	0.66	0.66	0.77	0.63	0.62	0.62	0.62	0.62
Na	mg/l	31.29	31.52	31.38	31.33	31.32	31.31	30.93	31.38	31.32	31.31	31.31	31.31
Ni	mg/l	0.227	0.191	0.188	0.186	0.186	0.186	0.211	0.180	0.179	0.178	0.178	0.178
Pb	mg/l	0.025	0.026	0.026	0.026	0.026	0.026	0.025	0.026	0.026	0.026	0.026	0.026
SO_4	mg/l	47.86	18.87	15.82	14.66	14.43	14.33	39.63	15.86	14.50	14.22	14.19	14.19
Se	mg/l	0.020	0.022	0.023	0.024	0.024	0.024	0.020	0.021	0.021	0.021	0.021	0.021
Zn	mg/l	0.441	0.441	0.444	0.444	0.444	0.444	0.424	0.426	0.427	0.426	0.426	0.426

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

5.0 Modelling PWD Water Qualities

5.1 Water Quality Model

The modelling results discussed in **Section 4** of this report provide some of the key inputs to modelling the Primary Water Dam (PWD) water quality. Several PHREEQC and GWB models were constructed to estimate water quality resulting from the mixing of all inputs to the PWD (i.e. direct rainfall, process water and groundwater) for select years. Select models were also used to assess the effects of climatic conditions on PWD water quality (e.g. temperature, rainfall and evaporation).

5.2 Model Construction

The models were constructed to simulate the effects of mixing variable fractions of direct rainwater (minus evaporation), surface water (collective runoff from the catchments) and groundwater under atmospheric conditions (pCO_2 $10^{-3.5}$ atm) in the PWD.

Several scenarios were also modelled to reflect different operational and climatic conditions. This included, modelling a range of proportional mixtures which considers all expected variations in proportions over the mine life, and using the same models, the effects of seasonal variations in rainfall (by varying proportional mixtures) and evaporation (by removal of water).

The saturation states of minerals were also determined using these models. PHREEQC geochemical modelling assesses the potential mineralogical controls on the PWD water qualities for the different mixing proportions. Therefore, being able to identify the minerals which may act as buffering agents (to acidification or alkalinity) or reduce elemental concentration in water through mineral precipitation. Previous investigations (Geosyntec, 2016) have indicated that iron (oxy)hydroxides may precipitate out of solution in the PWD with the potential for dissolved metals/metalloids to co-precipitate or adsorb to the surface.

5.3 Overview and Assumptions in the Conceptual Geochemical Model

The conceptual geochemical model and the set of assumptions used in the modelling include the following:

- PWD inflows were based on the values reported in the *Water Balance Assessment for Hume Coal* (PB, 2016) which defines the annual inflows for the SBs and MWDs, sump, void, and rainfall/ runoff on an annual basis (**Table 5-1** and **Table 5-2**). RGS has assumed that the void and sump flows are of the same quality as groundwater associated with the Wongawilli Coal Seam.
- Groundwater quality for the Wongawilli Coal Seam is discussed in **section 2.3.1**. The average and 95th percentile water quality characteristics of bore HU0018PZA was used for most of the models. RGS has assumed that groundwater samples were collected using suitable groundwater sampling methods and the data reflects the *in-situ* groundwater conditions.
- GWB modelling was used to equilibrate groundwater with atmospheric conditions (pCO_2 = $10^{-3.5}$ atm) and checked using PHREEQC. Typically, groundwater pCO_2 is orders of magnitude higher than atmospheric air values; therefore, when groundwater is exposed to surface conditions, the water will 'loose' CO_2 gas to the atmosphere. This results in the pH

of water rising due to loss of carbonic acid. During this process, several minerals were suppressed (prevented from precipitating).

- Rainwater quality input used in the modelling is explained in **Section 2.3**
- It was assumed that the starting water quality of the PWD (year 2020) consists of the same proportional inputs as for year 2021. For the following years, there is a 'carry-over' contribution of water which reflects the water remaining in the PWD at the end of each year (**Table 5-1** and **Table 5-2**); these values were taken from the water balance (PB, 2016).
- It needs to be highlighted that there are negative rainfall and runoff values reported for year 2037-2039 corresponding to a historical dry climatic event where evaporation exceeds precipitation and runoff (PB, 2016). In this case, water was removed from the models to simulate evapo-concentration.
- Select annual water qualities were estimated and reported for the life of the mine; these years were selected based on the variability of the PWD contributions to model a range of potential water qualities expected for the PWD (**Figure 5-1**). For example, as the mine life progresses, the contribution of groundwater becomes more pronounced while surface water inputs decrease. The years modelled include 2021, 2025, 2028, 2032, 2035 and 2039; highlighted in **Table 5-2**.
- Several simulations were undertaken to show extreme events, which were not reported in the water balance (e.g. evaporation of 10% water).

Table 5-1: Contribution of water (ML) to the PWD on an annual basis.

Year	PWD Inflows (ML)						
	SBs and MWDs		Sump and Void*	Direct rainfall and runoff	Total annual Project demand	Start of year	End of year
	Stockpile contact runoff/seepage	Non-contact runoff					
2021	12.56	151.74	150.5	1.8	274.7	124	165.90
2022	18.07	218.33	443.8	4.2	726.7	165.9	123.60
2023	21.80	263.40	792.5	6.1	1116.4	123.6	91.00
2024	20.71	250.19	775.3	6.4	1053.9	90.9	89.60
2025	21.68	261.92	1020.8	6.6	1311.7	89.6	88.90
2026	22.44	271.06	1223.8	6.2	1523.8	88.8	88.50
2027	22.62	273.28	1299.6	5.3	1595.6	88.6	93.80
2028	22.66	273.74	1363.2	5.6	1670	93.9	89.10
2029	23.15	279.65	1339.6	5.6	1647.9	89.1	89.20
2030	21.48	259.52	1051.7	5.1	1337.2	89.3	89.90
2031	20.92	252.78	964.7	4.8	1242.2	89.9	90.90
2032	21.56	260.44	1082.6	4.1	1369	90.8	90.50
2033	22.55	272.45	1168.4	3.7	1468	90.5	89.60
2034	22.56	272.54	1266.7	3.9	1567	89.6	88.30
2035	21.63	261.27	1365.9	3.7	1652.2	88.3	88.60
2036	20.05	242.25	992	1.5	1227.6	88.6	116.80
2037	21.64	261.36	1029.6	-4.1	1297.2	116.8	128.10
2038	19.85	239.75	791.9	-1.2	1055	128.2	123.50
2039	14.91	180.09	349	-2.2	532	123.5	133.30

Table 5-2: Percentage (%) contribution of key water input to the PWD on an annual basis.

End of Year	Percentage contribution				
	SBs and MWDs		Groundwater	Direct rainfall and runoff	PWD (previous year carry over)
	Stockpile contact runoff/seepage	Non-contact runoff			
2021	3.97%	47.93%	47.54%	0.57%	0.00%
2022	2.13%	25.68%	52.19%	0.49%	19.51%
2023	1.81%	21.82%	65.64%	0.51%	10.24%
2024	1.81%	21.88%	67.80%	0.56%	7.95%
2025	1.55%	18.70%	72.88%	0.47%	6.40%
2026	1.39%	16.81%	75.90%	0.38%	5.51%
2027	1.34%	16.18%	76.93%	0.31%	5.24%
2028	1.29%	15.56%	77.49%	0.32%	5.34%
2029	1.33%	16.10%	77.12%	0.32%	5.13%
2030	1.51%	18.18%	73.69%	0.36%	6.26%
2031	1.57%	18.96%	72.37%	0.36%	6.74%
2032	1.48%	17.84%	74.18%	0.28%	6.22%
2033	1.45%	17.49%	75.01%	0.24%	5.81%
2034	1.36%	16.46%	76.52%	0.24%	5.41%
2035	1.24%	15.01%	78.46%	0.21%	5.07%
2036	1.49%	18.02%	73.79%	0.11%	6.59%
2037	1.52%	18.34%	72.24%	-0.29%	8.19%
2038	1.68%	20.34%	67.20%	-0.10%	10.88%
2039	2.24%	27.07%	52.46%	-0.33%	18.56%

Note: grey shading represents years selected for the modelling scenarios.

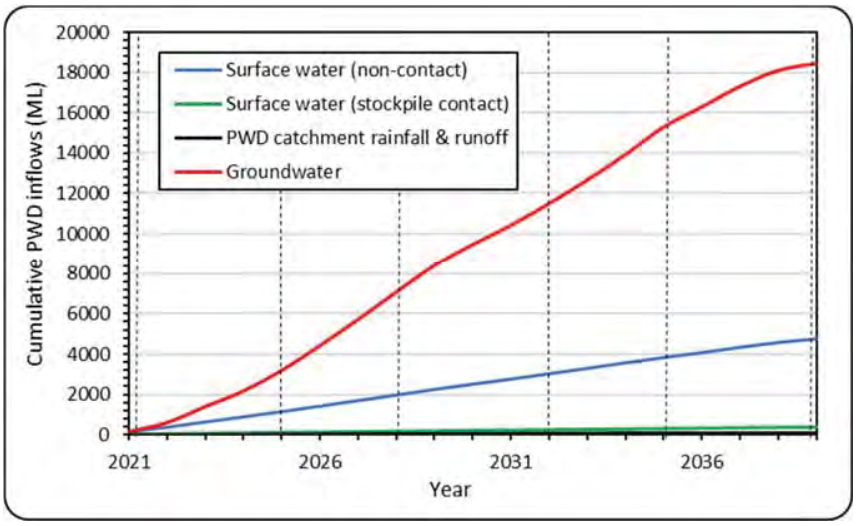


Figure 5-1. Simulated daily inflows to the PWD (from PB, 2016). Dashed vertical line represents modelled years.

5.4 Modelling Results and Discussion

The results from equilibrating groundwater with atmospheric conditions ($pCO_2 = 10^{-3.5}$ atm) are displayed in **Table 5-3**. The equilibration process results in a change in the redox condition of the water from reducing to oxidising, an increase in pH from an average value of 6.19 to 8.26, and a decrease in alkalinity, which is consistent with the PHREEQC modelling undertaken by Geosyntec (2016). These trends reflect the loss of CO_2 gas to the atmosphere and thus a decrease in carbonic acid. Furthermore, there are significant decreases in Fe and Mn concentrations due to precipitation of Fe and Mn (oxy)hydroxide minerals (e.g. hematite, goethite and pyrolusite amongst others). There are also less significant decreases in the concentrations of Al, B, Ca, Cl, Mg, Na, Pb and Se. Some metal(loid)s may co-precipitate with the Fe and Mn (oxy)hydroxide minerals or adsorb to the surface of minerals reducing their concentrations in the water. To be conservative, co-precipitation and surface adsorption was not included in the model simulations.

Precipitation of minerals from the equilibrated groundwater will occur gradually within the PWD. Several minerals were suppressed (including: Co_2SiO_4, Cr_2O_3, Cuprite, $FeCr_2O_4$, Gibbsite, $MgCr_2O4$ and $ZnCr_2O4$) because it not clear whether these minerals would precipitate. Allowing these minerals to precipitate will result in a reduction in the corresponding dissolved metal(loid) concentrations (e.g. Al, Co, Cr and Zn) in the PWD; however, for the sake of conservatism, this metals removal mechanism was not allowed to occur in the modelled simulations.

Table 5-3: Groundwater equilibrated with atmospheric conditions.

Groundwater equilibrated with atmosphere ($pCO_2 = 10^{-3.5}$)			
Parameter	**Units**	**Average**	**95th Percentile**
pH	mg/L	8.263	8.971
Al	mg/L	0.04	0.034
Alkalinity	mg/L	61.41	336
As	mg/L	0.0074	0.006
B	mg/L	0.0148	0.046
Ca	mg/L	14.51	1.027
Cd	mg/L	0.00005	0.00005
Cl	mg/L	45.42	76.01
Co	mg/L	0.007	0.008
Cr	mg/L	0.0008	0.0016
Cu	mg/L	0.0017	0.00079
F	mg/L	0.049	0.049
Fe	mg/L	0.0001	0.0001
K	mg/L	2.14	3.33
Mg	mg/L	1.66	0.067
Mn	mg/L	0.0001	0.0001
Na	mg/L	103.2	348
Ni	mg/L	0.0095	0.0128
Pb	mg/L	0.0005	0.00049
SO_4	mg/L	30.44	91.61
Se	mg/L	0.003	0.003
Si	mg/L	6.28	3.336
Zn	mg/L	0.019	0.032

The model predicted water qualities for the PWD for various scenarios are displayed in **Table 5-4 (Table 5-4A** average groundwater input and **Table 5-4B** 95th Percentile groundwater input). The results are compared to the Australian drinking water guidelines (ADWG) (NHMRC, 2011) and the Australian and New Zealand Environment and Conservation Council (ANZECC) Guidelines (95% species protection level) (ANZECC, 2000) for aquatic, irrigation and livestock use. The key results are summarised in the following points:

- The PWD modelled water qualities are circum neutral with a range of pH values from 6.03 to 8.25 for the various sensitivity analysis. Based on the water quality inputs, the PWD water quality is likely to remain neutral over the mine life, including during the modelled extreme dry period when evaporation (and thus evapo-concentration) is dominant. The pH values for the scenarios involving average groundwater input are lower (pH 6.03-6.83) than the 95th percentile scenarios (pH 6.93-8.25) due to the high alkalinity content of the 95th percentile groundwater (336 mg/L) compared to average groundwater (61 mg/L).

- The neutral pH values reflect the large contribution of circum neutral groundwater (48 – 78%) and non-contact rainfall/runoff (15.22 - 48.5%) over the mine life, with only small contributions of slightly acidic surface water (1.24 – 3.97%) from some of the SBs (namely SB01 and SB02 as contributions from the MWDs are all circum neutral).

- The PWD water major ion composition is dominated by chloride (Cl), sodium (Na), bicarbonate (HCO_3), sulfate (SO_4) and calcium (Ca) with lesser magnesium (Mg) and potassium (K). There are several elements which exceed either the ADWG and/or ANZECC criteria for modelled scenarios and sensitivities. All of the predicted Ni concentrations, and some of the Cd and Pb values exceed the ADWG; all predicted Co concentrations for each of the scenarios exceed the ANZECC criterion for irrigation; while all of the predicted Cu, Cr, Cd, Pb and Zn concentrations, and some of the Al and Se concentrations exceed ANZECC criteria for freshwater aquatic ecosystems. None of the modelled metal(loid) concentrations exceeded ANZECC criteria for livestock.

- Although some of the metal(loid) concentrations exceed guideline values, nearly all metal(loids) (excluding Cr and Ni) are within the range of baseline groundwater conditions for the Wongawilli Coal Seam.

- The Cr concentration exceedance criteria for ANZECC guidelines is associated with the Cr^{6+} species, which was applied to the modelled total Cr concentrations. The presence of Cr^{3+} is more common under the modelled conditions and considered non-toxic. This is relevant for all of the modelling steps under oxidising conditions and results for Cr.

- The metal(loid) concentrations vary considerably between model sensitivities. The variations typically reflect the stockpile contact water input which varies between 1.24 and 3.97%, and/or whether the groundwater input are average values or 95th percentile values.

- Under periods of high evapotranspiration, concentrations of dissolved ions and metal(loid)s may become significantly elevated (evapo-concentration) and become supersaturated and thus precipitate out of solution in the PWD. These minerals will settle-out over time and may re-dissolve with changes to environmental conditions (e.g. pH and redox).

Table 5-4A PWD water qualities for various scenarios: Average groundwater input. Shaded cells represent guideline exceedances.

Analytes	Units	Guideline Values				End of Year 1 - 19 (Average rainfall = 820 mm; Average groundwater)							End of Year 1 - 19 (95th Percentile rainfall =1,250 mm; Average groundwater)					
		ANZECC (2000)			ADWG (2011)	Year 1 (2021)	Year 5 (2025)	Year 8 (2028)	Year 12 (2032)	Year 15 (2035)	Year 19 (2039)	Extreme evap (-10%)	Year 1 (2021)	Year 5 (2025)	Year 8 (2028)	Year 12 (2032)	Year 15 (2035)	Year 19 (2039)
		Aquatic	Irrigation	Livestock														
pH		6.5-8.0	-	-	-	6.12	6.65	6.80	6.74	6.83	6.47	6.47	6.03	6.56	6.71	6.64	6.74	6.38
Al	mg/l	0.055	20	5	ID	0.084	0.060	0.056	0.058	0.055	0.068	0.001	0.082	0.059	0.055	0.057	0.054	0.067
Alkalinity	mg/l	-	-	-	-	31	47	51	49	51	43	47	31	47	51	49	51	43
As	mg/l	0.13	2	0.5	0.01	0.004	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.003	0.003	0.003	0.003	0.003
B	mg/l	0.37	5	5	4	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Ca	mg/l	-	-	-	-	22.19	13.46	12.82	12.40	12.70	11.14	12.22	19.02	12.84	12.66	12.35	12.68	11.17
Cd^	mg/l	0.0002	0.05	0.01	0.002	0.003	0.001	0.001	0.001	0.001	0.002	-	0.003	0.001	0.001	0.001	0.001	0.002
Cl	mg/l	-	700	-	-	109	118	121	119	121	110	121	105	117	120	118	121	110
Co	mg/l	ID	0.1	1	-	0.056	0.027	0.022	0.024	0.021	0.033	0.035	0.052	0.026	0.021	0.023	0.021	0.032
Cr	mg/l	0.001	1	1	0.05	0.011	0.006	0.005	0.005	0.005	0.008	0.008	0.011	0.006	0.005	0.005	0.005	0.008
Cu	mg/l	0.0014	5	1	2	0.016	0.008	0.007	0.008	0.007	0.011	0.012	0.016	0.008	0.007	0.007	0.007	0.011
F	mg/l	-	2	2	1.5	0.048	0.047	0.047	0.047	0.047	0.045	0.049	0.046	0.046	0.047	0.047	0.047	0.045
Fe	mg/l	ID	10	-	ID	0.70	0.32	0.25	0.28	0.23	0.44	0.48	0.64	0.29	0.22	0.25	0.07	0.38
K	mg/l	-	-	-	-	1.93	1.95	1.98	1.95	1.98	1.84	2.02	1.86	1.94	1.97	1.95	1.98	1.85
Mg	mg/l	-	-	-	-	4.13	2.51	2.25	2.30	2.20	2.66	2.92	3.91	2.46	2.23	2.29	2.20	2.66
Mn	mg/l	1.9	10	-	0.5	0.44	0.17	0.12	0.14	0.11	0.21	0.23	0.40	0.15	0.11	0.13	0.11	0.20
Na	mg/l	-	460		-	65.49	85.94	89.95	88.29	90.61	79.85	87.58	65.30	85.90	89.93	88.28	90.60	80.11
Ni	mg/l	0.011	2	1	0.02	0.123	0.054	0.042	0.046	0.040	0.067	0.073	0.114	0.051	0.040	0.044	0.039	0.064
Pb	mg/l	0.0034	5	0.1	0.01	0.013	0.007	0.005	0.006	0.005	0.009	0.010	0.013	0.007	0.005	0.006	0.005	0.009
SO_4	mg/l	-	-	1000	500	39.38	28.59	27.82	27.18	27.64	25.23	28.82	35.11	27.70	27.55	27.08	27.60	25.26
Se	mg/l	0.005	0.05	0.02	0.01	0.007	0.004	0.004	0.004	0.004	0.006	0.006	0.007	0.004	0.003	0.004	0.003	0.005
Zn	mg/l	0.008	5	20	ID	0.220	0.112	0.091	0.100	0.087	0.146	0.160	0.214	0.109	0.088	0.097	0.085	0.142

Table 5-4B PWD water qualities for various scenarios: 95th Percentile groundwater input. Shaded cells represent guideline exceedances.

Analytes	Units	Guideline Values				End of Year 1 - 19 (Average rainfall = 820 mm; 95th percentile groundwater)							End of Year 1 - 19 (95th Percentile rainfall =1,250 mm; 95th percentile groundwater)					
		ANZECC (2000)			ADWG (2011)	Year 1 (2021)	Year 5 (2025)	Year 8 (2028)	Year 12 (2032)	Year 15 (2035)	Year 19 (2039)	Extreme evap (-10%)	Year 1 (2021)	Year 5 (2025)	Year 8 (2028)	Year 12 (2032)	Year 15 (2035)	Year 19 (2039)
		Aquatic	Irrigation	Livestock														
pH		6.5-8.0	-	-	-	6.93	7.86	8.25	8.08	8.31	7.45	7.45	7.64	8.01	7.83	7.83	8.09	7.30
Al	mg/l	0.055	20	5	ID	0.081	0.056	0.051	0.053	0.050	0.064	0.035	0.055	0.050	0.052	0.052	0.049	0.063
Alkalinity	mg/l	-	-	-	-	161	255	275	267	278	229	254	256	275	267	267	278	229
As	mg/l	0.13	2	0.5	0.01	0.004	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.003	0.002	0.003
B	mg/l	0.37	5	5	4	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Ca	mg/l	-	-	-	-	15.78	3.22	1.82	1.71	1.58	2.04	2.24	2.60	1.66	1.66	1.66	1.56	2.02
Cd^	mg/l	0.0002	0.05	0.01	0.002	0.003	0.001	0.001	0.001	0.001	0.002	-	0.001	0.001	0.001	0.001	0.001	0.002
Cl	mg/l	-	700	-	-	178	228	239	234	241	209	229	228	239	234	234	241	209
Co	mg/l	ID	0.1	1	-	0.056	0.028	0.023	0.025	0.022	0.034	0.037	0.027	0.022	0.024	0.024	0.022	0.033
Cr	mg/l	0.001	1	1	0.05	0.012	0.007	0.005	0.006	0.005	0.008	0.009	0.007	0.005	0.006	0.006	0.005	0.008
Cu	mg/l	0.0014	5	1	2	0.015	0.008	0.006	0.007	0.006	0.010	0.011	0.008	0.006	0.007	0.007	0.006	0.010
F	mg/l	-	2	2	1.5	0.048	0.047	0.047	0.047	0.047	0.045	0.049	0.046	0.047	0.047	0.047	0.047	0.045
Fe	mg/l	ID	10	-	ID	0.701	0.319	0.245	0.277	0.234	0.440	0.483	0.292	0.225	0.254	0.254	0.070	0.376
K	mg/l	-	-	-	-	2.50	2.86	2.95	2.90	2.96	2.66	2.92	2.84	2.95	2.90	2.90	2.96	2.66

Guideline Values						End of Year 1 - 19 (Average rainfall = 820 mm; 95th percentile groundwater)							End of Year 1 - 19 (95th Percentile rainfall =1,250 mm; 95th percentile groundwater)					
Analytes	Units	ANZECC (2000)			ADWG (2011)	Year 1 (2021)	Year 5 (2025)	Year 8 (2028)	Year 12 (2032)	Year 15 (2035)	Year 19 (2039)	Extreme evap (-10%)	Year 1 (2021)	Year 5 (2025)	Year 8 (2028)	Year 12 (2032)	Year 15 (2035)	Year 19 (2039)
		Aquatic	Irrigation	Livestock														
Mg	mg/l	-	-	-	-	3.38	1.30	0.95	1.04	0.89	1.59	1.74	1.25	0.93	1.03	1.03	0.88	1.58
Mn	mg/l	1.9	10	-	0.5	0.439	0.167	0.122	0.136	0.115	0.215	0.236	0.153	0.113	0.127	0.127	0.107	0.202
Na	mg/l	-	460		-	181.93	271.92	289.71	282.42	292.67	246.23	269.80	271.88	289.69	282.42	282.42	292.67	246.21
Ni	mg/l	0.011	2	1	0.02	0.124	0.056	0.045	0.048	0.043	0.069	0.076	0.053	0.043	0.047	0.047	0.041	0.067
Pb	mg/l	0.0034	5	0.1	0.01	0.013	0.007	0.005	0.006	0.005	0.009	0.010	0.007	0.005	0.006	0.006	0.005	0.009
SO_4	mg/l	-	-	1000	500	68.49	75.08	77.76	75.71	78.15	66.85	74.22	74.20	77.49	75.61	75.61	78.11	66.80
Se	mg/l	0.005	0.05	0.02	0.01	0.007	0.004	0.004	0.004	0.004	0.006	0.006	0.004	0.003	0.004	0.004	0.003	0.005
Zn	mg/l	0.008	5	20	ID	0.227	0.122	0.101	0.110	0.098	0.155	0.170	0.119	0.099	0.107	0.107	0.096	0.151

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

6.0 Modelling slurry water quality and interaction with groundwater

6.1 Water Quality Model

The modelling results discussed in the previous sections **(Section 3** and **Section 5)** of this report provides the key inputs to modelling reject/PWD slurry water qualities and slurry interaction with groundwater in underground mine voids.

The method of mining and emplacement of coal reject is summarised in **Section 1.1.2**. During the operational phase of the mine and after there is sufficient mined out void space for reject placement, freshly produced reject material will be treated with 1% limestone, mixed with PWD water and pumped into mined out void panels. Once mining is completed, rejects stored in the temporary reject stockpile will be placed underground in the remaining voids. The individual panels will be sealed at the entrance and groundwater will recover with time mixing with the emplaced reject porewater.

Therefore, the first step of the modelling involves the estimation of a range of slurry water qualities for two different scenarios:

- **Scenario 1 - Operation phase:** freshly produced reject material treated with 1% limestone, mixed with PWD water.
- **Scenario 2 - After mining has completed:** aged reject material treated with 2% limestone and temporarily stockpiled for ~20 years, mixed with PWD water.

After modelling the slurry compositions, the second step of modelling involves the placement of the reject slurries in an underground mined-out panel and interaction of the material with groundwater (within the panel). The resulting water qualities within the panel have been reported and compared to ADWG (NHMRC, 2011), ANZECC guidelines (ANZECC, 2000) and the baseline groundwater quality for the Wongawilli Seam.

6.2 Model Construction

The models were constructed using the “React” module in GWB with certain parameters checked using PHREEQC. Initially the model was fixed to atmospheric conditions to simulate mixing of the slurry on the ground surface. GWB enables the user to ‘pick-up’ an entire reacted system (e.g. minerals and porewater); RGS has utilised this key function for several of the modelling steps.

As summarised in earlier sections (**section 3.2**), the *basis* relates to the hydrochemical properties of the initial water quality prior to reactions occurring (i.e. reject pore water or PWD water). For Scenario 1 (**Figure 6-1**), the freshly produced reject material porewater was determined from statistics of the KLC tests (**section 2.3.2**) and equilibrated. The equilibrated porewater was then picked-up and used as the *reactants* in a second model. The second model includes the PWD water (as the *basis*), which is mixed (i.e. initially 40:60; liquid:solids slurry) under atmospheric conditions to produce the slurry water quality (reported herein).

For Scenario 2 (**Figure 6-2**), the already constructed reject stockpile seepage water quality models was run for the mine life (until year 2039); at which point the entire system (reacted reject porewater and solids) was picked-up and used as the *reactants* in a second model. The reacted minerals from the reject stockpile (namely pyrite) and the porewater are automatically

included as *reactants*. PWD water was then added to the *basis* of the second model and mixed with the *reactants* (i.e. initially 40:60; liquid:solids slurry) under atmospheric conditions to produce the slurry water quality (reported herein).

The slurry water qualities from each of the scenarios is then picked-up and reacted with groundwater in proportions consistent with the expected volumes to occur within a single panel. The mixing reactions occur under measured aquifer conditions (i.e. reducing environment) in the presence of pyrite which may be present on the surface of the mined-out void.

The modelling steps mentioned above were replicated several times for select scenarios with some sensitivity analysis.

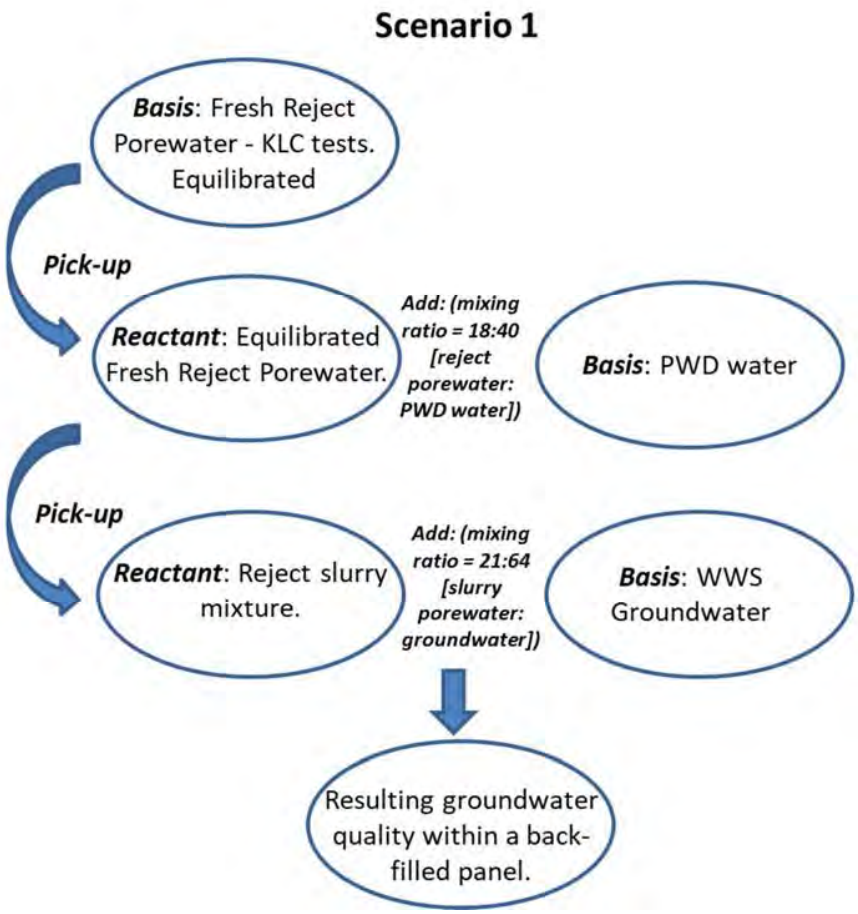


Figure 6-1. Illustration of scenario 1 simplified modelling steps.

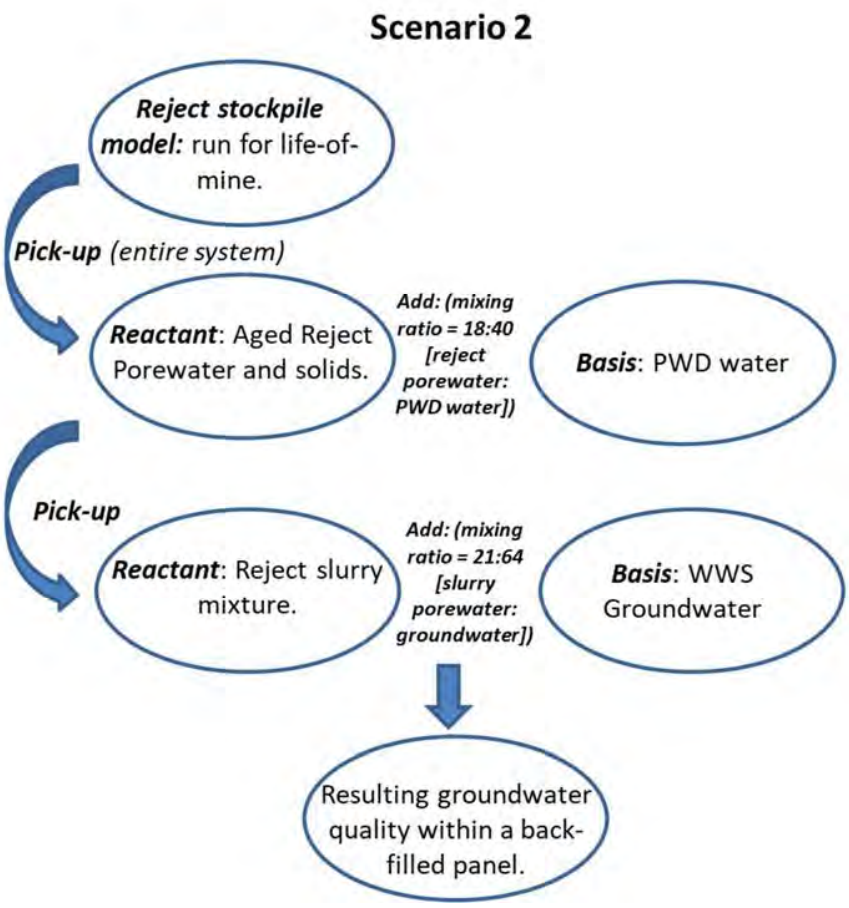


Figure 6-2. Illustration of scenario 1 simplified modelling steps.

6.3 Overview and Assumptions in the Conceptual Geochemical Model

The conceptual geochemical model and the set of assumptions used in the modelling include the following:

6.3.1 Mixing Slurry

- The starting reject porewater content (for scenario 1) was obtained from the KLC tests for reject materials treated with 1% limestone (**section 2.3.2**). Model sensitivities were run for the average and 95th percentile porewater concentrations.
- The starting reject porewater content (for scenario 2) was obtained from a temporary reject stockpile that has 30% porosity and 30% infiltration.
- The expected mixing ratio for the slurry is initially (60:40; reject; PWD water) which is later decantated to 70:30 (reject; PWD water). The porosity of the reject material is

approximately 30%, therefore, assuming the rejects are saturated, the actual slurry mixture would initially be 18:40 (reject porewater: PWD water) (i.e. 30% [porosity] of 60% [reject solids] = 18% [porewater]).

- The mixing sensitivities were selected in order to represent the range of water qualities likely to be expected. For scenario 1, key metal(loid) contents were summed for each of the modelled PWD water qualities (**section 5**); the maximum (year 1) and minimum (year 15) concentrations were selected for scenario 1 mixing models. For scenario 2, an additional simulation was run in case the mine ceased mining after 8 years. This is again to provide a representative range of water qualities that may be encountered.
- A list of the modelling scenarios and sensitivities is provided in **Table 6-1**.

6.3.2 Slurry and Groundwater interaction

- Groundwater quality for the Wongawilli Coal Seam is discussed in **section 2.3.1**. The average and 95th percentile water quality characteristics of bore HU0018PZA was used for most of the models. The redox environment of the groundwater was set to a pe of between -0.5 and -2 (reducing environment).
- Once the slurry is placed in the mined-out void, the rejects will settle, and the porewater/solution will act as a saturated cover preventing further oxidation/reaction of reject material. The contribution of acidity/metals/salinity from the exposed coal face which may have accumulated after mining is not considered as part of this investigation. However, pyrite has been added to the model as a redox reaction to account for any pyrite that may be exposed on the coal face. The interaction of reject porewater with groundwater is the focus of this investigation.
- It is estimated that the reject slurry will fill 36% of the total mined volume (Coffey, 2016a). Therefore, it is assumed that the remaining void space will be filled with groundwater (64%), giving a 36: 64 (reject slurry: groundwater) mixture. Since the reject material will settle, only the reject slurry porewater (PWD water + reject porewater = 21% of panel) will interact with groundwater (**Figure 6-1**). This is equivalent to a mixture of 21:64 (porewater: groundwater),

Table 6-1 Modelling scenarios and sensitivities

Scenario	Model	Description
Scenario 1	Slurry 1A	Average reject porewater (KLC) + Year 1 (2021) PWD water (maximum)
	Slurry 1B	Average reject porewater (KLC) + Year 15 (2021) PWD water (minimum)
	Slurry 1C	95th Percentile reject porewater (KLC) + Year 1 (2021) PWD water (maximum)
	Slurry 1D	96th Percentile reject porewater (KLC) + Year 15 (2021) PWD water (minimum)
Scenario 2	Slurry 2A	End of mine life (year 2039) PWD + reject seepage water qualities (Average rainfall)
	Slurry 2B	End of mine life (year 2039) PWD + reject seepage water qualities (95th Percentile rainfall)
	Slurry 2C	Middle mine life (year 2028) PWD and reject seepage water qualities (Average rainfall)
	Slurry 2D	Middle mine life (year 2028) PWD and reject seepage water qualities (95th Percentile rainfall)

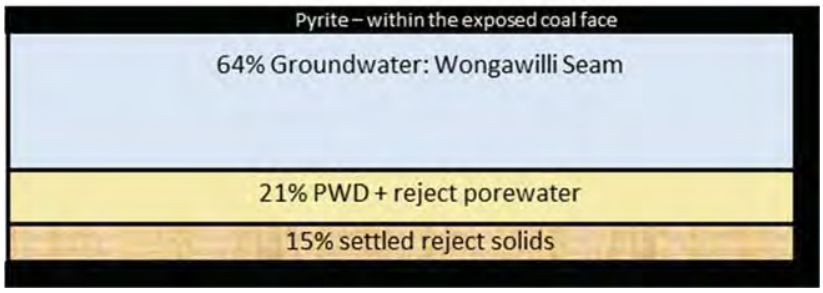


Figure 6-3 Conceptual model of reject slurry emplacement in a mined-out panel.

6.4 Modelling Results and Discussion

6.4.1 Mixing Slurry

The model predicted water qualities for the reject slurry (reject porewater + PWD water) for various scenarios are displayed in **Table 6-2** and **Table 6-3** for scenario 1 and scenario 2, respectively. The results are compared to the Australian drinking water guidelines (ADWG) (NHMRC, 2011) and the Australian and New Zealand Environment and Conservation Council (ANZECC) Guidelines (95% species protection level) (ANZECC, 2000) for aquatic, irrigation and livestock use. The key results are summarised in the following points:

- The modelled slurry water qualities during normal operations (scenario 1) are circum neutral with a range of pH values from 6.33 to 6.82 for the various sensitivity analysis. The modelled slurry water qualities for the temporarily stockpiled reject material (post mining; scenario 2) is also circum neutral, with a range of pH values from 6.57 to 8.09. The neutral pH values for each of the scenarios and sensitivities reflect the circum neutral PWD water and reject porewater qualities since the reject material is treated with 1% and 2% limestone for scenario 1 and scenario 2, respectively.
- The model predicted slurry water qualities for normal operations are dominated by chloride (Cl), sulfate (SO_4), sodium (Na), bicarbonate (HCO_3) and calcium (Ca) with much lesser magnesium (Mg) and potassium (K). There are several elements which exceed either the ADWG and/or ANZECC criteria for modelled scenarios and sensitivities. All of the predicted Ni concentrations exceed the ADWG; while all of the predicted Cd, Cr (assuming all Cr is present as the Cr^{6+} species), Cu, Ni, Pb, Se and Zn, and some Al concentrations exceed ANZECC criteria for freshwater aquatic ecosystems. None of the modelled metal(loid) concentrations exceeded ANZECC criteria for livestock or irrigation.
- The model predicted slurry water qualities for post mining operations (scenario 2) is dominated by chloride (Cl), sodium (Na), bicarbonate (HCO_3), sulfate (SO_4), and calcium (Ca) with much lesser magnesium (Mg) and potassium (K). There are several elements exceeding either the ADWG and/or ANZECC criteria for modelled scenarios and sensitivities. All of the predicted Ni concentrations exceed the ADWG; all of the Se concentrations exceed ANZECC criteria for irrigation; while predicted Cu, Cd, Cr, Ni, Pb, Se and Zn concentrations exceed ANZECC criteria for freshwater aquatic ecosystems. None of the modelled metal(loid) concentrations exceeded ANZECC criteria for livestock.

- Although slurry water qualities exceed several ANZECC and ADWG guideline values, it needs to be highlighted that the baseline groundwater (Wongawilli Coal Seam) in which the slurries will be placed show exceedances for: Al, Cr, Cd, Cu, Mn, Ni, Pb, Se and Zn for ANZECC (2000) aquatic criteria; Cd, Mn, Pb and Se for ADWG (2011); and, Se for ANZECC (2000) irrigation.
- The model predicted slurry water qualities are low in Al and Fe concentrations due to precipitation of Al and Fe (oxy)hydroxides such as gibbsite ($Al(OH)_3$) and hematite (Fe_2O_3), respectively. Although these minerals may precipitate and reduce Al and Fe concentrations in the slurry mixture, they will still form part of the slurry contribution and be placed underground in the mined-out voids where they may re-dissolve under different conditions (refer to **section 6.4.2**).

6.4.2 Slurry and Groundwater interaction

The model predicted water qualities resulting from the interaction of the reject slurry (reject porewater + PWD water) with Wongawilli Coal Seam groundwater for various scenarios are displayed in **Table 6-4** and **Table 6-5** for scenario 1 and scenario 2, respectively. The results are compared to the Australian drinking water guidelines (ADWG) (NHMRC, 2011), the Australian and New Zealand Environment and Conservation Council (ANZECC) Guidelines (95% species protection level) (ANZECC, 2000) for aquatic, irrigation and livestock use, and the baseline groundwater conditions for the Wongawilli Coal Seam.

The groundwater contribution of the PWD is 47.54 – 78.46% which equates to 32.8 – 54% of the reject slurry. Therefore, the final groundwater component of the backfilled panel is 70.8 – 75.3%.

The key results are summarised in the following points:

Scenario 1

- The modelled groundwater conditions within a backfilled panel, during normal operations (scenario 1), are circum neutral with a range of pH values from 6.06 to 6.11 for the various sensitivity analysis. The values are close to the initial average groundwater pH (average pH = 5.5) for the Wongawilli Coal Seam.
- The resulting groundwater qualities are dominated by bicarbonate (HCO_3) alkalinity, chloride (Cl), sodium (Na), sulfate (SO_4) and calcium (Ca) with much lesser magnesium (Mg) and potassium (K). There are several elements exceeding either the ADWG and/or ANZECC criteria for the modelled scenario and sensitivities. Some of the predicted Ni and Mn concentrations exceed the ADWG; while all/some predicted Cu, Cr, Ni, Se and Zn concentrations exceed ANZECC criteria for freshwater aquatic ecosystems. None of the modelled metal(loid) concentrations exceeded ANZECC criteria for livestock or irrigation.
- Although some of the model predicted water qualities exceed either ADWG or ANZECC guideline values, the concentrations are generally lower than or equal to average baseline groundwater conditions for the Wongawilli Coal Seam. For example, Al, As, Cd, Cr, Cu, Se and Zn, all of which exceed guideline values for the initial average groundwater in some form, typically decrease in concentration as a result of the reject slurry placement. Furthermore, As, Al, Cd and some Cr concentrations drop below all guideline values because of the reject slurry placement.

- Conversely, some of the modelled Ni concentrations in the panel increase slightly above the average baseline concentration for the Wongawilli Coal Seam as a result of reject slurry placement; however, the predicted Ni concentrations are still within the range of baseline concentrations reported for the Wongawilli Seam, with higher baseline Ni reported several times at three of the monitoring wells.
- The concentrations of Fe and Al are lower in concentration under oxidising conditions because the majority precipitates out of solution as Fe and Al (oxy)hydroxides, while under reducing conditions, such as applies to the groundwater, they remain in solution.

Scenario 2

- The modelled groundwater conditions within a backfilled panel for the placement of the limestone amended temporary reject stockpile/PWD slurry (scenario 2), are circum neutral with a range of pH values from 6.03 to 6.10 for the various sensitivity analysis. These values are also close to the initial average groundwater pH (average pH = 5.5) for the Wongawilli Coal Seam.
- The resulting ground water qualities are dominated by chloride bicarbonate (HCO_3) alkalinity, (Cl), sodium (Na), sulfate (SO_4) and calcium (Ca) with much lesser magnesium (Mg) and potassium (K). The are several elements exceeding either the ADWG and/or ANZECC criteria for the modelled scenario and sensitivities. All of the predicted Se concentrations exceed the ANZECC criteria for irrigation and livestock; while all the predicted Se and Ni concentrations exceed ADWG; All Cu, Ni, Se and Zn concentrations for different sensitivities exceed ANZECC criteria for freshwater aquatic ecosystems.
- It needs to be highlighted again that although some of the model predicted water qualities exceed either ADWG or ANZECC guideline values, the concentrations are generally lower than or equal to average groundwater conditions for the Wongawilli Coal Seam. For example, As, Al, Cd, Cr, Mn, Pb, Se and Zn all of which exceed guideline values for the initial average groundwater in some form, typically generally decrease in concentration as a result of the reject slurry placement. Furthermore, As, Al, Cd, Mn and Pb concentrations drop below all guideline values because of the reject slurry placement.
- Nickel concentrations in the backfilled panel groundwater increase slightly above the average baseline concentration for the Wongawilli Coal Seam as a result of the slurry placement. Once again, the predicted Ni concentrations are still within the range of baseline concentrations reported for the Wongawilli Seam, with higher baseline Ni reported several times at three of the monitoring wells.

Table 6-2 Estimated slurry (PWD + reject) water qualities during operation. Shaded cells represent guideline exceedances.

Guideline Values						Scenario 1: Slurry (PWD + reject material during operation)			
Analytes	Units	ANZECC (2000)			ADWG (2011)	Slurry 1A	Slurry 1B	Slurry 1C	Slurry 1D
						Average reject porewater		P95 reject porewater	
		Aquatic	Irrigation	Livestock		1 yr (2021) (max.) PWD water	15 yr (2035) (min.) PWD water	1 yr (2021) (max.) PWD water	15 yr (2035) (min.) PWD water
pH		6.5-8.0	-	-	-	6.43	6.80	6.33	6.82
Al	mg/l	0.055	20	5	ID	0.061	0.041	0.061	0.041
Alkalinity	mg/l	-	-	-	-	31	49	40	52
As	mg/l	0.13	2	0.5	0.01	0.0039	0.0044	0.0041	0.0047
B	mg/l	0.37	5	5	4	0.005	0.007	0.011	0.013
Ca	mg/l	-	-	-	-	30.86	26.51	57.82	53.47
Cd^		0.0002	0.05	0.01	0.002	0.00051	0.00051	0.00023	0.00023
Cl	mg/l	-	700	-	-	91.39	99.67	113.03	121.31
Co	mg/l	ID	0.1	1	-	0.036	0.014	0.036	0.014
Cr	mg/l	0.001	1	1	0.05	0.0079	0.0033	0.0079	0.0033
Cu	mg/l	0.0014	5	1	2	0.0124	0.0062	0.0116	0.0054
F	mg/l	-	2	2	1.5	0.172	0.173	0.373	0.374
Fe	mg/l	ID	10	-	ID	0.443	0.161	0.443	0.161
K	mg/l	-	-	-	-	1.70	1.77	1.93	2.00
Mg	mg/l	-	-	-	-	4.46	3.29	6.04	4.87
Mn	mg/l	1.9	10	-	0.5	0.27	0.08	0.27	0.08
Na	mg/l	-	460		-	48.24	65.69	55.34	72.78
Ni	mg/l	0.011	2	1	0.02	0.079	0.028	0.080	0.029
Pb	mg/l	0.0034	5	0.1	0.01	0.0091	0.0036	0.0091	0.0036
SO	mg/l	-	-	1000	500	60.35	55.18	104.91	99.73
Se	mg/l	0.005	0.05	0.02	0.01	0.007	0.006	0.007	0.006
Zn	mg/l	0.008	5	20	ID	0.15	0.06	0.15	0.06

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

Table 6-3 Estimated slurry (PWD + temporary reject stockpile) water qualities after operation. Shaded cells represent guideline exceedances.

Guideline Values						Scenario 2: Slurry (PWD + temporary reject stockpile material)			
Analytes	Units	ANZECC (2000)			ADWG (2011)	Slurry 2A	Slurry 2B	Slurry 2C	Slurry 2D
						Year 19 (2039) PWD (LOM)		Year 8 (2028) PWD (mid-mine life)	
		Aquatic	Irrigation	Livestock		Average rainfall	P95 rainfall	Average rainfall	P95 rainfall
pH		6.5-8.0	-	-	-	6.57	7.35	6.76	8.09
Al	mg/l	0.055	20	5	ID	0.050	0.049	0.040	0.038
Alkalinity	mg/l	-	-	-	-	49	178	47	195
As	mg/l	0.13	2	0.5	0.01	0.0049	0.0043	0.0040	0.0035
B	mg/l	0.37	5	5	4	0.002	0.005	0.002	0.005
Ca	mg/l	-	-	-	-	16.10	7.90	34.65	14.21
Cd^		0.0002	0.05	0.01	0.002	0.00075	0.00075	0.00075	0.00075
Cl	mg/l	-	700	-	-	87.87	151.60	116.66	180.49
Co	mg/l	ID	0.1	1	-	0.023	0.024	0.015	0.016
Cr	mg/l	0.001	1	1	0.05	0.0053	0.0057	0.0033	0.0037
Cu	mg/l	0.0014	5	1	2	0.0076	0.0069	0.0049	0.0042
F	mg/l	-	2	2	1.5	0.032	0.031	0.042	0.036
Fe	mg/l	ID	10	-	ID	0.302	0.303	0.169	0.169
K	mg/l	-	-	-	-	1.45	2.02	2.02	2.34
Mg	mg/l	-	-	-	-	2.47	1.58	3.56	1.68
Mn	mg/l	1.9	10	-	0.5	0.15	0.15	0.08	0.08
Na	mg/l	-	460		-	59.43	173.94	67.53	204.06
Ni	mg/l	0.011	2	1	0.02	0.082	0.059	0.103	0.073
Pb	mg/l	0.0034	5	0.1	0.01	0.0062	0.0062	0.0035	0.0035
SO_4	mg/l	-	-	1000	500	24.39	51.63	51.73	68.18
Se	mg/l	0.005	0.05	0.02	0.01	0.059	0.063	0.073	0.057
Zn	mg/l	0.008	5	20	ID	0.33	0.26	0.26	0.22

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

Table 6-4 Estimate slurry water quality/ groundwater quality mix during operation. Shaded cells represent guideline exceedances.

Guideline Values						Baseline Groundwater (WWS)			Scenario 1: Slurry interaction with 95th percentile groundwater			
Analytes	Units	ANZECC (2000)			ADWG (2011)	Average WWS	Max. WWS	Min. WWS	Slurry 1A + GW	Slurry 1B + GW	Slurry 1C + GW	Slurry 1D + GW
		Aquatic	Irrigation	Livestock								
pe									-1.80	-2.00	-1.80	-2.02
pH		6.5-8.0	-	-	-	5.5	7.18	4.03	6.06	6.10	6.06	6.11
Al	mg/l	0.055	20	5	-	0.103	2.04	0.01	0.004	0.001	0.006	0.005
Alkalinity	mg/l	-	-	-	-	109	1090	5	178	184	179	185
As	mg/l	0.13	2	0.5	0.01	0.012	0.057	0.001	0.0005	0.0064	0.0063	0.0065
B	mg/l	0.37	5	5	4	0.05	0.33	<0.05	0.060	0.060	0.062	0.062
Ca	mg/l	-	-	-	-	24	127	<1	21.60	20.20	30.29	28.89
Cd^	mg/l	0.0002	0.05	0.01	0.002	0.0037	0.0305	<0.0001	0.000138	0.000138	0.00008	0.00008
Cl	mg/l	-	700	-	-	78	548	10	60.77	63.44	67.75	70.41
Co	mg/l	-	0.1	1	-	0.01	0.046	<0.001	0.017	0.010	0.017	0.010
Cr	mg/l	0.001	1	1	0.05	0.002	0.002	<0.001	0.0009	0.0009	0.0031	0.0016
Cu	mg/l	0.0014	5	1	2	0.008	0.061	<0.001	0.0039	0.0028	0.0050	0.0030
F	mg/l	-	2	2	1.5	0.16	0.3	<0.1	0.089	0.090	0.154	0.154
Fe	mg/l	-	10	-	-	7.67	20.8	0.13	5.98	5.84	5.98	5.89
K	mg/l	-	-	-	-	4	41	<1	2.02	2.04	2.09	2.12
Mg	mg/l	-	-	-	-	15	86	<1	3.61	3.23	4.12	3.74
Mn	mg/l	1.9	10	-	0.5	0.69	4.25	0.001	0.51	0.45	0.51	0.45
Na	mg/l	-	460		-	46	555	4	44.02	49.69	44.83	50.51
Ni	mg/l	0.011	2	1	0.02	0.017	0.108	<0.001	0.032	0.015	0.032	0.016
Pb	mg/l	0.0034	5	0.1	0.01	0.016	0.045	<0.001	0.0003	0.0014	0.0033	0.0015
SO_4	mg/l	-	-	1000	500	17	149	<1	40.03	38.40	54.45	52.79
Se	mg/l	0.005	0.05	0.02	0.01	0.06	0.1	<0.01	0.006	0.005	0.006	0.005
Zn	mg/l	0.008	5	20	-	0.08	1.57	<0.005	0.028	0.029	0.061	0.033

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

Table 6-5 Estimated slurry water quality/ groundwater quality mix after operation. Shaded cells represent guideline exceedances.

Guideline Values						Baseline Groundwater (WWS)			Scenario 2: Slurry interaction with 95th percentile groundwater			
Analytes	Units	ANZECC (2000)			ADWG (2011)	Avg. WWS	Max. WWS	Min. WWS	Slurry 2A + GW	Slurry 2B + GW	Slurry 2C + GW	Slurry 2D + GW
		Aquatic	Irrigation	Livestock								
pe									-2.00	-2.20	-2.02	-2.20
pH		6.5-8.0	-	-	-	5.5	7.18	4.03	6.09	6.03	6.10	6.35
Al	mg/l	0.055	20	5	-	0.103	2.04	0.01	0.003	0.003	0.003	0.054
Alkalinity	mg/l	-	-	-	-	109	1090	5	183	225	184	237
As	mg/l	0.13	2	0.5	0.01	0.012	0.057	0.001	0.0063	0.0064	0.0063	0.0061
B	mg/l	0.37	5	5	4	0.05	0.33	<0.05	0.059	0.060	0.059	0.060
Ca	mg/l	-	-	-	-	24	127	<1	16.84	14.19	22.82	16.24
Cd^	mg/l	0.0002	0.05	0.01	0.002	0.0037	0.0305	<0.0001	0.00019	0.00019	0.00019	0.00019
Cl	mg/l	-	700	-	-	78	548	10	59.63	80.18	68.91	89.49
Co	mg/l	-	0.1	1	-	0.01	0.046	<0.001	0.013	0.013	0.011	0.011
Cr	mg/l	0.001	1	1	0.05	0.002	0.002	<0.001	0.0022	0.0024	0.0016	0.0017
Cu	mg/l	0.0014	5	1	2	0.008	0.061	<0.001	0.0028	0.0034	0.0028	0.0026
F	mg/l	-	2	2	1.5	0.16	0.3	<0.1	0.044	0.044	0.048	0.046
Fe	mg/l	-	10	-	-	7.67	20.8	0.13	5.94	5.94	5.90	5.90
K	mg/l	-	-	-	-	4	41	<1	1.94	2.12	2.12	2.22
Mg	mg/l	-	-	-	-	15	86	<1	2.96	2.68	3.32	2.71
Mn	mg/l	1.9	10	-	0.5	0.69	4.25	0.001	0.47	0.47	0.45	0.45
Na	mg/l	-	460		-	46	555	4	46.04	83.09	49.13	93.90
Ni	mg/l	0.011	2	1	0.02	0.017	0.108	<0.001	0.033	0.025	0.039	0.030
Pb	mg/l	0.0034	5	0.1	0.01	0.016	0.045	<0.001	0.0023	0.0023	0.0015	0.0015
SO_4	mg/l	-	-	1000	500	17	149	<1	28.36	37.17	37.20	42.61
Se	mg/l	0.005	0.05	0.02	0.01	0.06	0.1	<0.01	0.022	0.024	0.027	0.022
Zn	mg/l	0.008	5	20	-	0.08	1.57	<0.005	0.035	0.023	0.023	0.083

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

7 Conclusions

Several hydrogeochemical models were constructed in GWB and PHREEQC to ultimately estimate the range of water qualities likely to exist in the primary water dam (PWD) over the life-of-mine, and to determine the likely water qualities resulting from the placement of reject slurries (reject porewater/PWD water) into mined-out voids (panels) and subsequent rebound of groundwater.

There are several components to the modelling, each required to provide the necessary inputs to next model. The components included:

- Modelling stockpile seepage and runoff for the temporary reject stockpile, run-of-mine pad and product stockpiles.
- Modelling SB and MWD water qualities to determine the surface water quality contribution to the PWD.
- Modelling the range of PWD water qualities.
- Modelling reject slurry water qualities for two different scenarios.
- Modelling the interaction of reject slurry with groundwater in a mined-out void (panel).

The key results for the modelling are summarised in the following points:

- The modelling results for the PAF and NAF rejects in the temporary reject stockpile simulations indicate seepage and runoff water qualities with circum neutral pH (pH 7.73 – 8.22) which is maintained through the mine-life (up to year 2039). This is due to the addition of 2% limestone within the CPP circuit, added to neutralise any acid (H_2SO_4) which may be produced due to the oxidation of pyrite (FeS_2) present in the coal reject. The major ion and metal(loid) concentrations are moderate and are essentially 'flushed' from the temporary reject stockpile with time. However, some seepage metal(loid) concentrations are elevated and generally increase with time. This is particularly evident for metal(loid)s which are mobile under neutral pH conditions (e.g. Al, Se and Zn).

- The modelling results for each of the ROM pad and product stockpiles simulations indicate that both are likely to produce acidic seepage and runoff water qualities through the mine-life (up to year 2039), with estimated ROM pad pH values ranging from pH 4.34 – 4.74, while the product stockpile pH values range from pH 3.92 – 4.08. This is due to the presence of pyrite (FeS_2), which oxidises to produce acid (H_2SO_4), and the fact that there are negligible acid buffering minerals (acid neutralisation capacity) present within the ROM or product stockpile materials. Due to the acidic nature of the seepage and runoff water qualities, the metal(loid) concentrations are higher than for the limestone amended temporary reject stockpile.

- The surface water input to the PWD is composed of ~89% SB01 and SB02, of which 18% is contact water (seepage and runoff) from either the temporary reject stockpile, ROM pad or product stockpiles. The SB01 modelled water qualities are slightly acidic with a range of pH values from 4.93 to 5.0, while the SB02 modelled water qualities are also slightly acidic with a range of pH values from 5.05 to 5.13. The major ion and metal(loid) concentrations are essentially a diluted combination of the temporary reject stockpile, ROM pad and product stockpiles seepage/runoff water qualities.

- The collective surface water quality contribution to the PWD includes ~18% contact water from either the ROM pad (1.7%), product stockpile (6%) or temporary reject stockpile (10.3%), with the majority of surface water quality input from direct rainfall runoff.

Therefore, the modelled surface water quality inputs to the PWD are slightly acidic (pH 4.96 to 5.04), and the major ion and metal(loid) concentrations are essentially a proportional combination of these waters, with some metal(loid)s elevated (e.g. Co, Cr, Cu, Ni, Pb and Zn) relative to average baseline groundwater conditions for the Wongawilli Coal Seam.

- The partial pressure of CO_2 (gas) in groundwater is orders or magnitude higher than atmospheric air values; so, when groundwater is exposed to surface conditions, the water will 'loose' CO_2 gas to the atmosphere. Therefore, the Wongawilli Coal Seam groundwater was equilibrated with atmospheric conditions, to represent the groundwater added to the PWD. The equilibration process results in a change in the redox condition of the water from reducing to oxidising, an increase in pH (pH 6.19 to 8.26), and a decrease in alkalinity, Furthermore, there are significant decreases in Fe and Mn concentrations due to precipitation of Fe and Mn (oxy)hydroxide minerals (e.g. hematite, goethite and pyrolusite amongst others). There are also less significant decreases in the concentrations of Al, B, Ca, Cl, Mg, Na, Pb and Se. Some metal(loid)s may co-precipitate with the Fe and Mn (oxy)hydroxide minerals or adsorb to the surface of minerals reducing their concentrations in the water.
- The PWD modelled water qualities are circum neutral (pH 6.03 to 8.25) and based on the modelled inputs, is likely to remain neutral over the mine life. There are several elements which exceed either the ADWG and/or ANZECC criteria for modelled scenarios and sensitivities with all of the predicted Ni concentrations, and some of the Cd and Pb values exceeding the ADWG; all predicted Co concentrations for each of the scenarios exceed the ANZECC criteria for irrigation; while all of the predicted Cd, Cu Cr, Pb and Zn concentrations, and some of the Se and Al concentrations exceed ANZECC criteria for freshwater aquatic ecosystems. However, although some of the metal(loid) concentrations exceed guideline values, nearly all metal(loids) (excluding Cr and Ni) are within the range of baseline groundwater conditions for the Wongawilli Coal Seam.
- The neutral pH values and metal(loid) concentrations of the modelled PWD water reflect the large contribution of circum neutral groundwater (47.54 – 78.46%) and non-contact rainfall/runoff (15.22 - 48.5%) over the mine life, with only small contributions of slightly acidic surface water (1.24 – 3.97%) from some of the SBs (namely SB01 and SB02 as contributions from the MWDs are all circum neutral).
- The modelled reject slurry water qualities for both scenarios (scenario 1: temporary reject stockpile porewater + PWD water; scenario 2: fresh reject porewater = PWD water) are circum neutral with a range in pH from 6.33 to 6.82 and pH 6.57 to 8.09, for scenario 1 and scenario 2, respectively.
- For scenario 1, the concentration of dissolved metal(loid)s sometimes exceed either the ADWG and/or ANZECC criteria for modelled scenarios and sensitivities. All of the predicted Ni concentrations exceed the ADWG; while all of the predicted Cd, Cr (assuming all Cr is present as the Cr^{6+} species), Cu, Ni, Pb, Se and Zn, and some Al concentrations exceed ANZECC criteria for freshwater aquatic ecosystems. However, it needs to be highlighted that although slurry water qualities may exceed several ANZECC and ADWG guideline values, the receiving groundwater (Wongawilli Coal Seam) in which the slurries will be placed already show exceedances for: Al, Cd, Cr, Cu, Mn, Ni, Pb Se and Zn for ANZECC (2000) aquatic criteria; Cd, Mn, Pb and Se for ADWG (2011); and, Se for ANZECC (2000) irrigation.

- For scenario 2, the concentration of dissolved metals and metalloids are also generally low to moderate, with several elements exceeding either the ADWG and/or ANZECC criteria for modelled scenarios and sensitivities. All of the modelled Ni concentrations exceed the ADWG; all of the Se concentrations exceed ANZECC criteria for irrigation; while predicted Cd, Cr, Cu, Ni, Pb, Se and Zn concentrations exceed ANZECC criteria for freshwater aquatic ecosystems. Again, it needs to be highlighted that the receiving groundwater (Wongawilli Coal Seam) in which the slurries will be placed already show exceedances for: Al, Cd, Cr, Cu, Mn, Ni, Pb Se and Zn for ANZECC (2000) aquatic criteria; Cd, Mn, Pb and Se for ADWG (2011); and, Se for ANZECC (2000) irrigation.
- For scenario 1, the modelled groundwater conditions within a backfilled panel are circum neutral (pH 6.06 to 6.11). Similarly, for scenario 2, the modelled groundwater conditions are circum neutral (pH 6.03 to 6.10). These values are close to the initial average groundwater pH (average pH = 5.5) for the Wongawilli Coal Seam.
- For scenario 1, the concentration of several dissolved metal(loid)s within a backfilled panel are exceeding either the ADWG and/or ANZECC criteria. Some of the predicted Ni and Mn concentrations exceed the ADWG; while some/all predicted Cu, Cr, Ni, Se and Zn concentrations exceed ANZECC criteria for freshwater aquatic ecosystems.
- For scenario 2, the concentration of several dissolved metals and metalloids within a backfilled panel are exceeding guideline values. All of the predicted Se concentrations exceed the ANZECC criteria for irrigation and livestock; while all the predicted Se and Ni concentrations exceed ADWG; All Cu, Cr, Ni, Se and Zn concentrations for different sensitivities exceed ANZECC criteria for freshwater aquatic ecosystems.
- Although some of the model predicted water qualities exceed either ADWG or ANZECC guideline values, the concentrations are generally lower than or equal to average baseline groundwater conditions for the Wongawilli Coal Seam. For example, for scenario 1, Al, As, Cd, Cr, Cu, Se and Zn, all of which exceed guideline values for the initial average groundwater in some form, typically decrease in concentration as a result of the reject slurry placement. Furthermore, As, Al, Cd and some Cr concentrations drop below all guideline values because of the reject slurry placement. For scenario 2, As, Al, Cd, Cr, Mn, Pb, Se and Zn all of which exceed guideline values for the initial average groundwater in some form, typically decrease in concentration as a result of the reject slurry placement. Furthermore, As, Al, Cd, Mn and Pb concentrations drop below all guideline values because of the reject slurry placement.
- Only Ni increases in concentration relative to the average baseline Wongawilli Coal Seam concentrations. However, the predicted Ni concentrations are still within the range of baseline concentrations reported for the Wongawilli Seam, with higher baseline Ni reported several times at three of the monitoring wells.
- The modelling inputs are typically conservative with rainfall and groundwater inputs utilising the 95th percentile values.

8 References

ANZECC & ARMCANZ, 2000. National Water Quality Management Strategy Document 4: Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

Bethke and Yeakel (2009) The Geochemist's Workbench release collection of manuals, Rockware Inc., Golden, CO

Coffey, 2016a. Hume Coal Project, Groundwater Assessment Volume 1: Data Analysis (ref. GEOTLCOV25281AB-ACA), dated 8 August 2016.

Coffey, 2016b. Hume Coal Project, Groundwater Assessment Volume 2: Numerical Modelling and Impact Assessment (ref. GEOTLCOV25281AB-ACB), dated 8 August 2016.

Crosbie, R, Morrow, D, Cresswell, R, Leaney, F, Lamontagne, S and Lefournour, M, 2012. New insights into the chemical and isotopic composition of rainfall across Australia. CSIRO Water for a Healthy Country Flagship, Australia. Hume Coal Project Water Balance Assessment Report (PB, 2016)

EMM, 2017. Hume Coal Project Environmental Impact Statement. Prepared for Hume Coal Pty Limited.

Geosyntec Consultants, 2016. Hume Coal Project: Hydrogeochemical Assessment. Prepared for Hume Coal Pty Limited.

Golder Associates, 2014. X-ray Diffraction – Mineralogical Assessment. Technical Memorandum Prepared for Hume Coal Pty Limited.

NHMRC & NRMMC, 2011. National Water Quality Management Strategy Document 6: Australian Drinking Water Guidelines. National Health and Medical Research Council and Natural Resource Management Ministerial Council.

Parsons Brinckerhoff, 2014. Assessment of mine inflow (groundwater) quality and suitability for reuse and disposal (Ref. 217599A-GW-REP-14901 Rev A), dated 4 September 2014.

Parkhurst, D.L., Appelo, C. (1999) User's Guide to PHREEQC (Version 3.4.0) -A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport,and Inverse Geochemical Calculations. USGS, Denver, Colorado, USA, water-Resources Investigations Report 99-4259.

RGS Environmental Pty Ltd, 2016. Hume Coal Project, Geochemical Assessment of Coal and Mining Waste Materials (Ref. 111232 report R001_A), dated 31 March 2016.

Yuan L. and Smith A.C. 2009. CFD Modelling of Spontaneous Heating in a Large-Scale Coal Chamber. J. Loss Prev. Process Ind. 22(4) pp 426-433 July. Published by Elsevier Ltd.

9 Limitations

This report has been prepared by RGS for the use of Hume Coal. It is based on accepted consulting practices and standards and no other warranty is made as to the professional advice included in this report.

This report was prepared from September 2017 to February 2018 and is based on the information provided by Hume Coal at the time of preparation. RGS disclaims responsibility for any changes that may have occurred after this time.

The sources of information and methodology used by RGS are outlined in this report and no independent verification of this information has been made. RGS assumes no responsibility for any inaccuracies or omissions, although no indication was found that any information contained in this report as provided to RGS was incorrect.

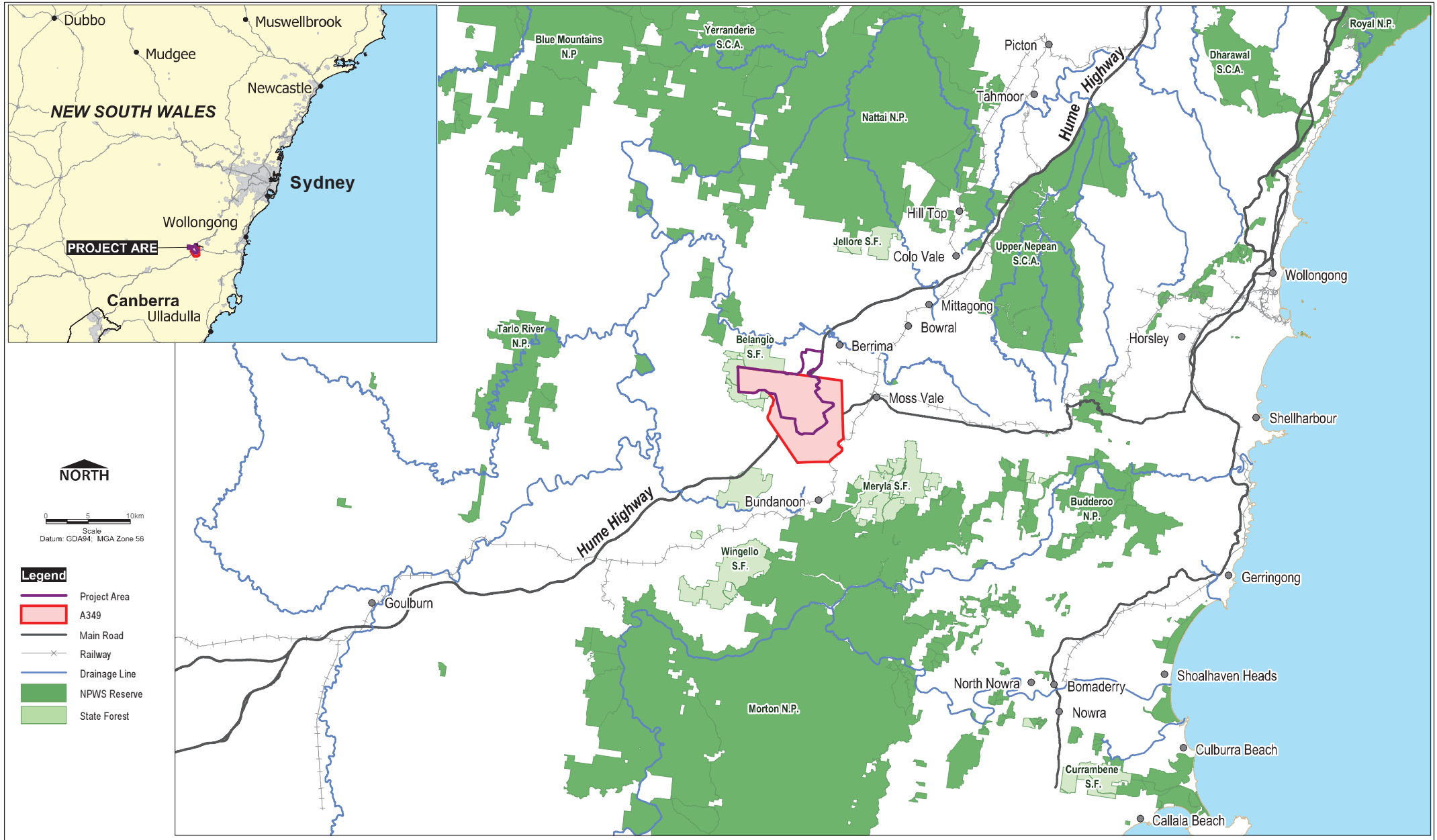
This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not provide legal advice, which can only be given by qualified legal practitioners.

If you have any questions regarding the information presented in this report, please contact Dr Alan Robertson (Principal Geochemist/Director) on (+617) 3344 1222 or Dr Matt Landers (Senior Geochemist) on (+61) 439 936 765.

Attachment A

Figures

Figure 1-1: Location map (regional settings)
Figure 1-2: Location map (local settings)
Figure 1-3: Indicative mine and surface infrastructure plans
Figure 1-4: Indicative surface infrastructure layout
Figure 1-5: Indicative Site Water Management



Data Source: Data Client Supplied, October 2016. (EMM (2016); GA (2016); MinView (2015); LPMA (2011))

RGS Environmental Pty Ltd
123 Wynne Street
Sunnybank Hills QLD 4109
Australia

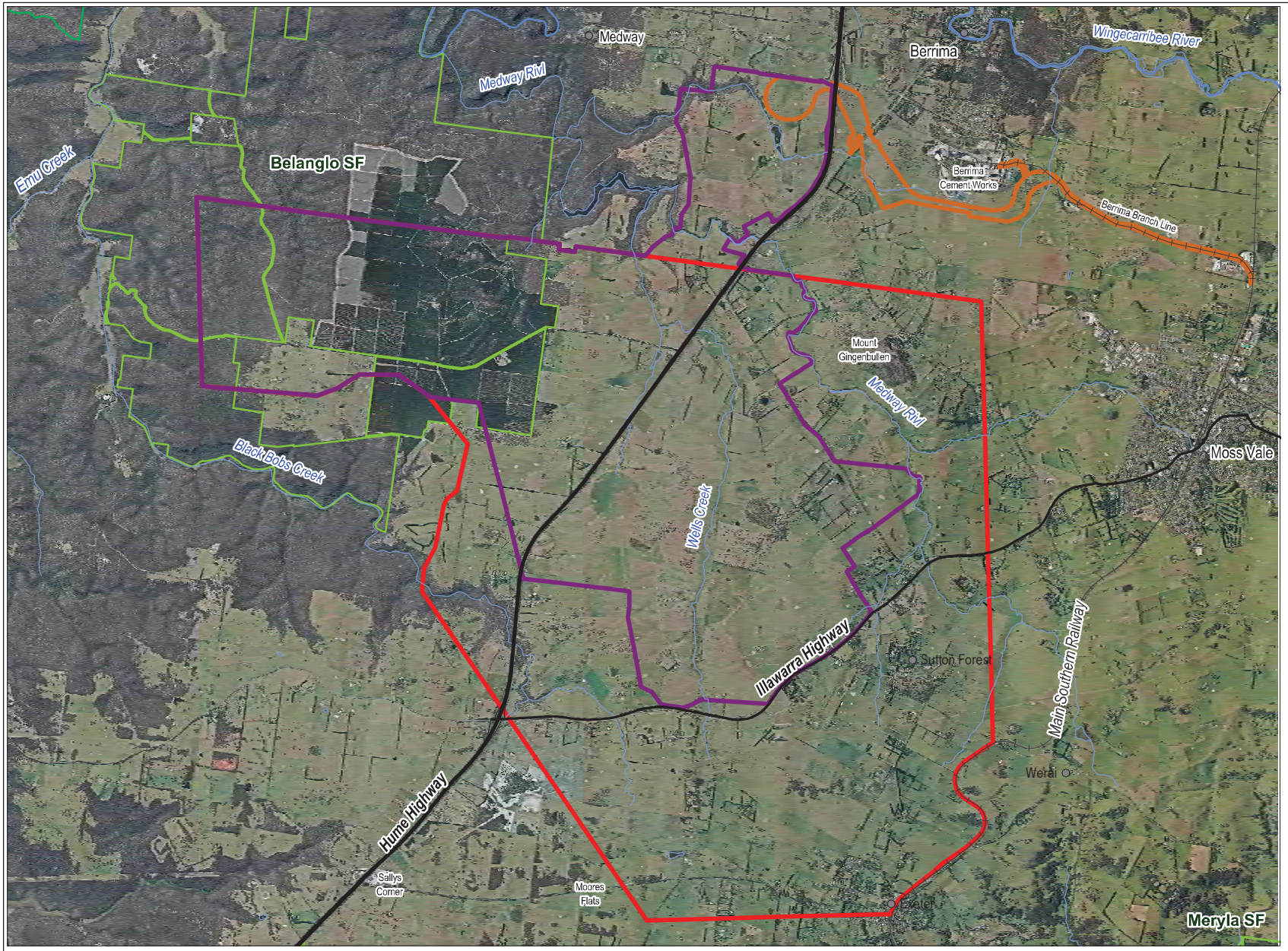
File: 111232-011 - A4
Date: 19/10/2016

HUME COAL PTY LTD

HUME COAL PROJECT
GEOCHEMICAL ASSESSMENT OF COAL AND MINING WASTE MATERIALS

Figure: **1-1**

REGIONAL CONTEXT



NORTH

0 1 2km
Scale
Datum: GDA94; MGA Zone 56

Legend

- Project Area
- Berrima Rail Project Area
- A349
- Main Road
- Railway
- Drainage Line
- NPWS Reserve
- State Forest

Data Source: Data Client Supplied, October 2016 - [EMM (2016); Hume Coal (2016); LPI (2015)]

RGS Environmental Pty Ltd
123 Wynne Street
Sunnybank Hills QLD 4051
Australia

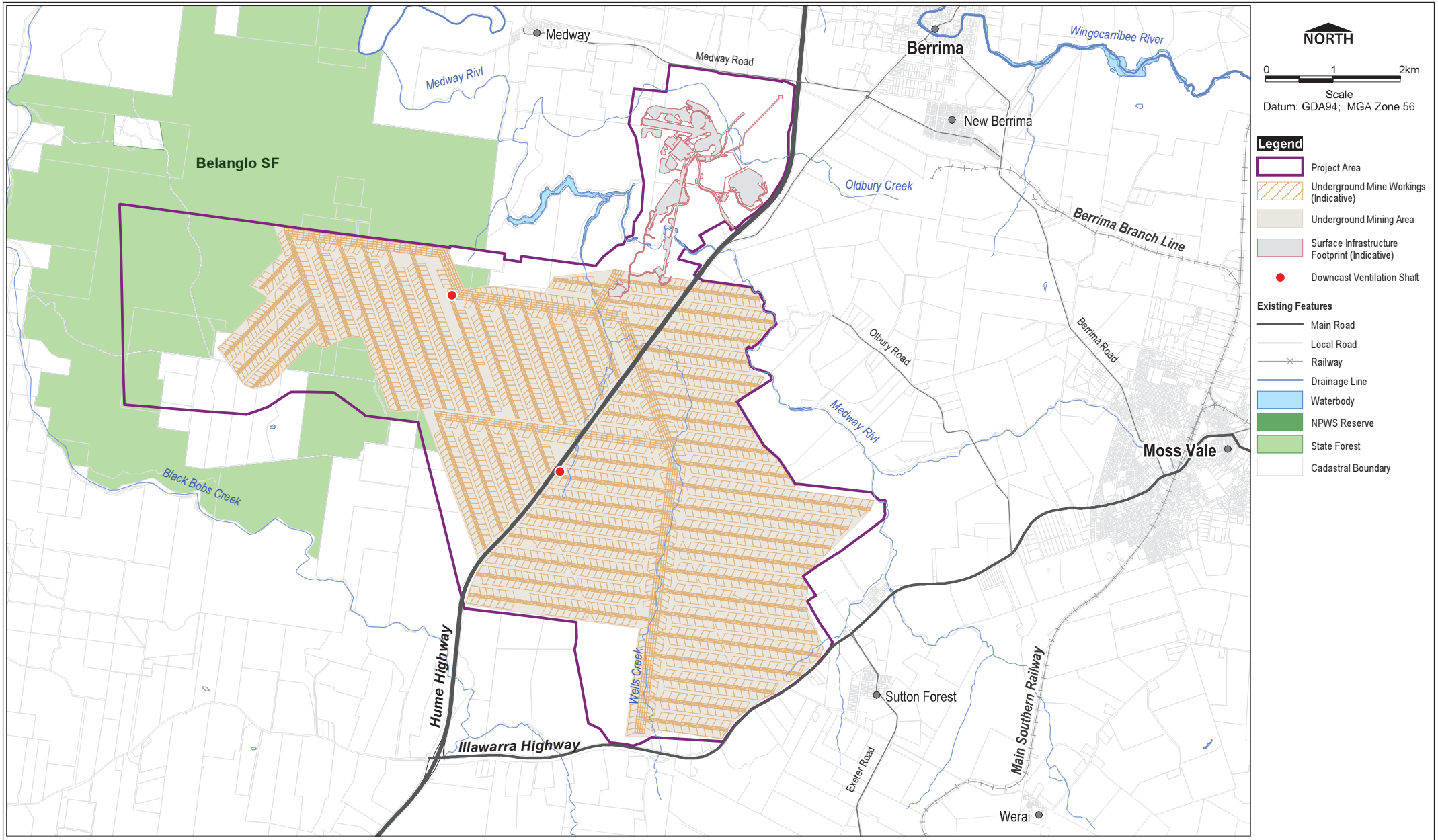
File: 111232-012 - A4
Date: 19/10/2016

HUME COAL PTY LTD

HUME COAL PROJECT
GEOCHEMICAL ASSESSMENT OF COAL AND MINING WASTE MATERIALS

Figure: **1-2**

LOCAL CONTEXT



Data Source: Data Client Supplied, October 2016.

RGS Environmental Pty Ltd
123 Wynne Street
Sunnybank Hills QLD 4109
Australia

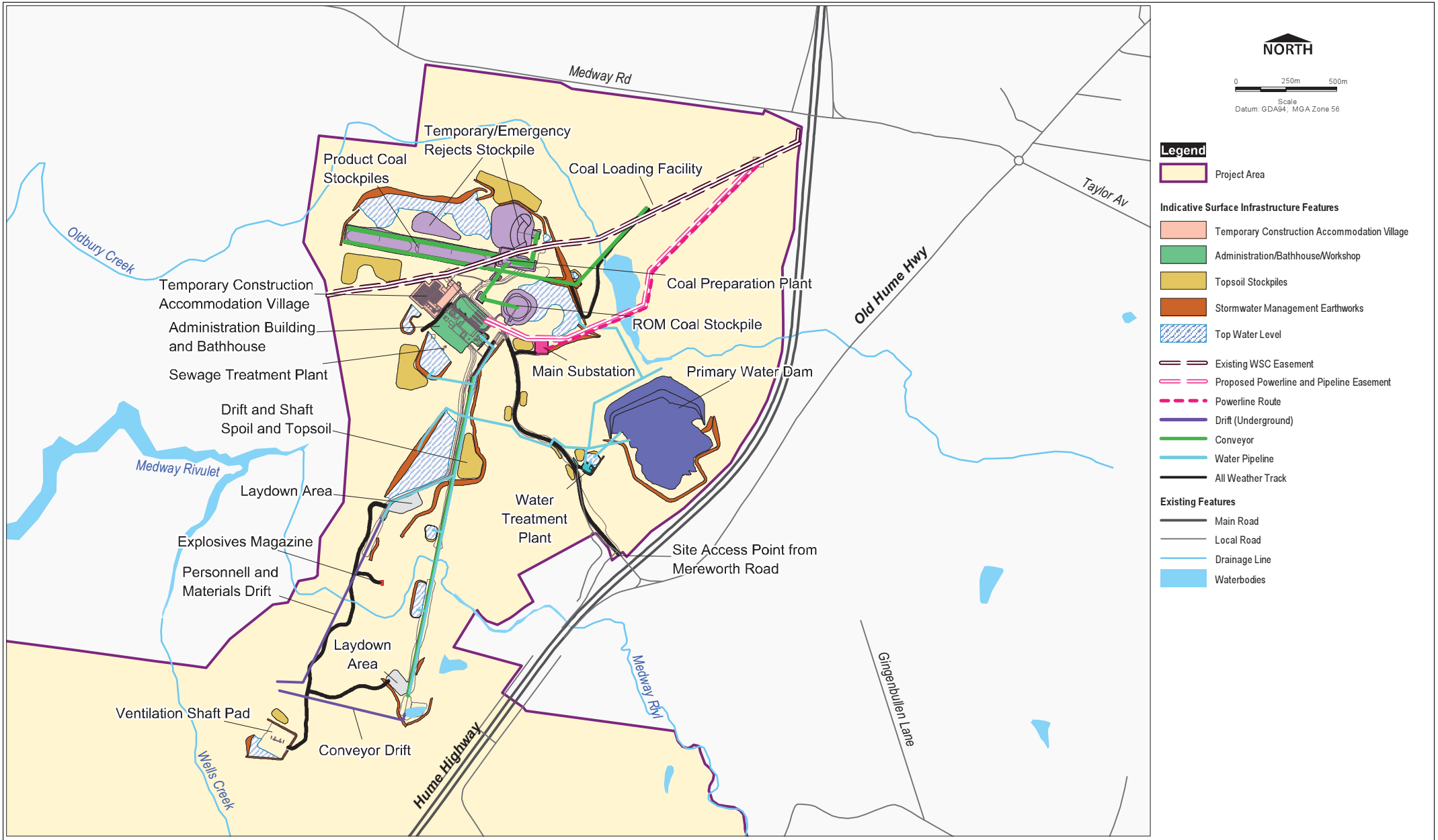
File: 111232-013 - A4
Date: 19/10/2016

HUME COAL PTY LTD

HUME COAL PROJECT
GEOCHEMICAL ASSESSMENT OF COAL AND MINING WASTE MATERIALS

Figure: **1-3**

INDICATIVE PROJECT LAYOUT



Data Source: Data Client Supplied, October 2016.

RGS Environmental Pty Ltd
123 Wynne Street
Sunnybank Hills QLD 4109
Australia

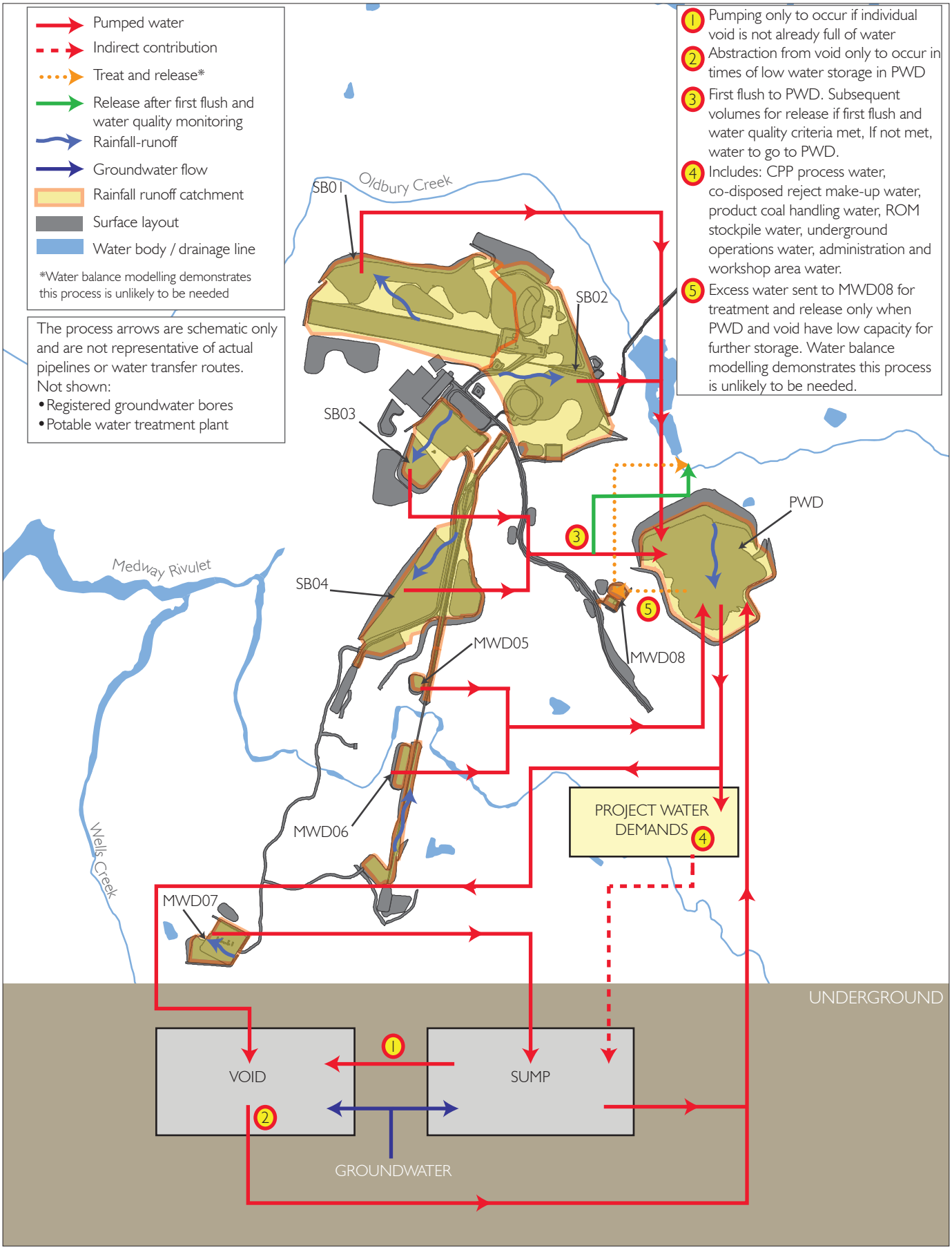
File: 111232-014 - A4
Date: 19/10/2016

HUME COAL PTY LTD

HUME COAL PROJECT
GEOCHEMICAL ASSESSMENT OF COAL AND MINING WASTE MATERIALS

Figure: **1-4**

INDICATIVE SURFACE INFRASTRUCTURE LAYOUT



Water management schematic

Hume Coal Project

Revised Water Assessment

Figure 1.5

Attachment B

Select hydrogeochemical modelling results

Table 1A: Modelled runoff + seepage water qualities for the temporary reject stockpile (Year 1 – uncovered

Table 2A: Modelled runoff + seepage water qualities for the temporary reject stockpile (Year 5 – year 19 – covered); Average rainfall scenario.

Table 3A: Modelled runoff + seepage water qualities for the temporary reject stockpile (Year 5 – year 19 – covered); High rainfall scenario.

Table 4A: Modelled runoff + seepage water qualities for ROM pad

Table 5A: Modelled runoff + seepage water qualities for the product stockpiles

Table 1A: Modelled runoff + seepage water qualities for the temporary reject stockpile (Year 1 – uncovered)

End of Year 1 (67% infiltration; no cover)							
Sensitivity		Average Rainfall = 820mm			High Rainfall (95th Percentile) = 1,250mm		
Parameter	Units	Porosity = 30%	Porosity = 25%	Porosity = 35%	Porosity = 30%	Porosity = 25%	Porosity = 35%
pH		7.76	7.76	7.77	7.81	7.82	7.80
Al	mg/l	0.010	0.010	0.010	0.010	0.010	0.010
Alkalinity	mg/l	21.77	21.51	22.11	23.37	23.90	22.97
As	mg/l	0.006	0.007	0.006	0.005	0.004	0.005
B	mg/l	0.002	0.002	0.001	0.001	0.001	0.001
Ca	mg/l	277.61	290.30	261.58	213.50	194.13	228.86
Cd^	mg/l	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Cl	mg/l	304.76	318.94	286.86	232.82	210.66	249.73
Co	mg/l	0.18	0.19	0.17	0.14	0.13	0.15
Cr	mg/l	0.0003	0.0003	0.0003	0.0002	0.0002	0.0002
Cu	mg/l	0.0006	0.0006	0.0006	0.0005	0.0004	0.0005
F	mg/l	0.12	0.13	0.11	0.09	0.08	0.10
Fe	mg/l	3.5E-08	3.5E-08	3.5E-08	3.5E-08	3.5E-08	3.5E-08
K	mg/l	6.07	6.36	5.71	4.63	4.20	4.98
Mg	mg/l	19.35	20.15	18.28	15.08	13.74	16.08
Mn	mg/l	2.35	2.45	2.21	1.81	1.64	1.93
Na	mg/l	15.81	16.54	14.87	12.06	10.92	12.93
Ni	mg/l	0.49	0.51	0.47	0.38	0.34	0.41
Pb	mg/l	0.0003	0.0003	0.0003	0.0002	0.0002	0.0002
SO_4	mg/l	357.66	374.37	336.29	272.52	247.15	293.22
Se	mg/l	0.09	0.10	0.09	0.08	0.07	0.08
Zn	mg/l	0.46	0.47	0.45	0.41	0.39	0.42

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

Table 2A: Modelled runoff + seepage water qualities for the temporary reject stockpile (Year 5 – year 19 – covered); Average rainfall scenario.

Sensitivity		End of year 5 - 19 (30% porosity; 55% infiltration; covered)				
Year/ Date		Year 5 (2025)	Year 8 (2028)	Year 12 (2032)	Year 15 (2035)	Year 19 (2039)
Parameter	Units					
pH		7.74	7.88	7.97	7.99	8.00
Al	mg/l	0.021	0.024	0.027	0.027	0.028
Alkalinity	mg/l	17.48	22.72	27.16	28.43	28.97
As	mg/l	0.012	0.012	0.012	0.012	0.012
B	mg/l	0.023	0.023	0.023	0.023	0.023
Ca	mg/l	43.70	21.41	13.78	12.38	11.85
Cd^	mg/l	0.001	0.001	0.001	0.001	0.001
Cl	mg/l	71.99	45.23	35.14	33.12	32.34
Co	mg/l	0.054	0.041	0.036	0.035	0.035
Cr	mg/l	0.011	0.011	0.011	0.011	0.011
Cu	mg/l	0.011	0.011	0.011	0.011	0.011

Sensitivity		End of year 5 - 19 (30% porosity; 55% infiltration; covered)				
Year/ Date		Year 5 (2025)	Year 8 (2028)	Year 12 (2032)	Year 15 (2035)	Year 19 (2039)
Parameter	Units					
F	mg/l	0.028	0.017	0.013	0.012	0.011
Fe	mg/l	0.023	0.023	0.023	0.023	0.023
K	mg/l	1.43	0.89	0.68	0.64	0.62
Mg	mg/l	4.61	2.88	2.22	2.09	2.04
Mn	mg/l	0.65	0.49	0.44	0.42	0.42
Na	mg/l	18.19	16.77	16.22	16.12	16.07
Ni	mg/l	0.11	0.07	0.06	0.06	0.06
Pb	mg/l	0.011	0.011	0.011	0.011	0.011
SO_4	mg/l	58.37	26.29	14.10	11.65	10.70
Se	mg/l	0.13	0.14	0.15	0.15	0.15
Zn	mg/l	0.51	0.51	0.52	0.52	0.52

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

Table 3A: Modelled runoff + seepage water qualities for the temporary reject stockpile (Year 5 – year 19 – covered); High rainfall scenario.

Sensitivity		End of year 5 - 19 (30% porosity; 55% infiltration; covered)				
Year/ Date		Year 5 (2025)	Year 8 (2028)	Year 12 (2032)	Year 15 (2035)	Year 19 (2039)
Parameter	Units					
pH		7.86	7.97	8.00	8.00	8.00
Al	mg/l	0.024	0.027	0.028	0.028	0.028
Alkalinity	mg/l	22.38	27.58	29.21	29.38	29.41
As	mg/l	0.012	0.012	0.012	0.012	0.012
B	mg/l	0.023	0.023	0.023	0.023	0.023
Ca	mg/l	22.27	13.32	11.65	11.49	11.46
Cd^	mg/l	0.001	0.001	0.001	0.001	0.001
Cl	mg/l	45.84	33.99	31.55	31.31	31.26
Co	mg/l	0.03	0.03	0.03	0.03	0.03
Cr	mg/l	0.011	0.011	0.011	0.011	0.011
Cu	mg/l	0.011	0.011	0.011	0.011	0.011
F	mg/l	0.017	0.012	0.011	0.011	0.011
Fe	mg/l	0.02	0.02	0.02	0.02	0.02
K	mg/l	0.91	0.67	0.62	0.62	0.62
Mg	mg/l	2.97	2.20	2.04	2.03	2.03
Mn	mg/l	0.37	0.29	0.28	0.28	0.28
Na	mg/l	16.84	16.21	16.08	16.06	16.06
Ni	mg/l	0.06	0.05	0.04	0.04	0.04
Pb	mg/l	0.011	0.011	0.011	0.011	0.011
SO_4	mg/l	27.98	13.71	10.75	10.46	10.41
Se	mg/l	0.098	0.101	0.101	0.101	0.101
Zn	mg/l	0.44	0.44	0.44	0.44	0.44

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

Table 4A: Modelled runoff + seepage water qualities for ROM pad

35% Porosity			
Parameter	**Units**	**Ave. Rain = 820mm**	**P95 Rain = 1,250mm**
pH		4.49	4.39
Al	mg/l	1.28	1.25
Alkalinity	mg/l	0.694	0.692
As	mg/l	0.0244	0.0240
B	mg/l	0.0004	0.0004
Ca	mg/l	16.06	14.56
Cd^	mg/l	0.005	0.005
Cl	mg/l	53.00	54.00
Co	mg/l	0.780	0.763
Cr	mg/l	0.00048	0.00047
Cu	mg/l	0.123	0.115
F	mg/l	0.190	0.186
Fe	mg/l	16.90	19.37
K	mg/l	0.46	0.45
Mg	mg/l	15.54	15.35
Mn	mg/l	4.22	4.08
Na	mg/l	0.46	0.45
Ni	mg/l	2.13	2.08
Pb	mg/l	0.15	0.14
SO_4	mg/l	79.51	78.56
Se	mg/l	0.07	0.07
Zn	mg/l	2.83	2.78

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

Table 5A: Modelled runoff + seepage water qualities for the product stockpiles

35% Porosity			
Parameter	**Units**	**Ave. Rain = 820mm**	**P95 Rain = 1,250mm**
pH		3.95	3.94
Al	mg/l	1.45	1.37
Alkalinity	mg/l	0.69	0.70
As	mg/l	0.011	0.011
B	mg/l	0.0003	0.0003
Ca	mg/l	10.28	9.74
Cd^	mg/l	0.005	0.005
Cl	mg/l	63.57	59.68
Co	mg/l	0.86	0.81
Cr	mg/l	0.0005	0.0005
Cu	mg/l	0.102	0.096
F	mg/l	0.204	0.193
Fe	mg/l	17.31	16.07
K	mg/l	0.343	0.323
Mg	mg/l	9.60	9.05
Mn	mg/l	9.53	8.98
Na	mg/l	2.06	1.94
Ni	mg/l	2.20	2.08

35% Porosity		Ave. Rain = 820mm	P95 Rain = 1,250mm
Parameter	**Units**		
Pb	mg/l	0.033	0.031
SO_4	mg/l	48.19	45.73
Se	mg/l	0.015	0.014
Zn	mg/l	2.71	2.56

^Cd cannot be modelled in GWB, so estimated from KLC data and PHREEQC modelling.

RGS

LEADERS IN MINING
GEOCHEMISTRY

Appendix K

Bore logs

BORE COMPLETION REPORT

Lithology Key

	Basalt		Granite		Sandstone
	Carbonaceaous Shale		Mudstone		Shale
	Clay		No sample		Siltstone
	Claystone		Peat		Topsoil
	Coal		Quartz		Tuff
	Conglomerate		Sand		Unknown

Formation Key

RB	Robertson Basalt	FCM	Farmborough Claystone Member
WG	Wianamatta Group	TG	Tongarra Seam
HS	Hawkesbury Sandstone	ICM	Illawarra Coal Measures
WW	Wongawilli Seam		

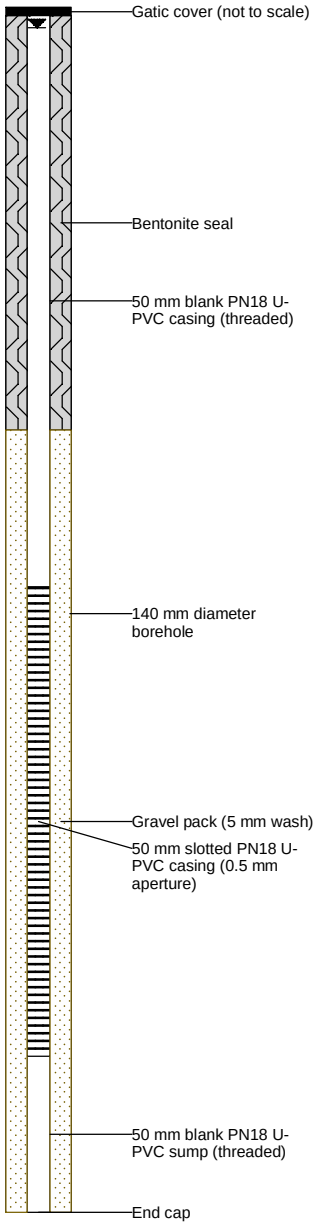
BORE COMPLETION REPORT

HU00118PZA

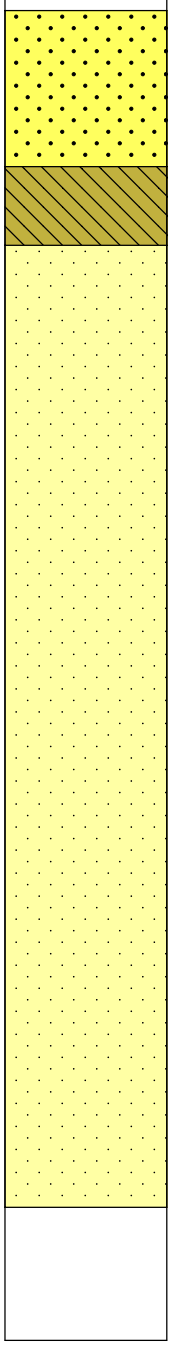
Project: Hume Coal Project
Easting: 240529 **Northing:** 6166811 **(MGA Zone 56)**
Top of casing: 612.415 mAHD
Ground level: 612.5 mAHD
Static water level: 0.16 mbgl **Date:** 1/12/2014

Completion date: 22/01/2014
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 7.3 - 13.3 mbgl
Gravel pack: 5.3 - 15.3 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

QA

HS

DEPTH (m)

0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17

WATER QUALITY / INFLOW

pH: 6.47, EC: 185 µS/cm, Temp: 19.75 °C, Redox: 22.9 mV, DO: 65.2 % Sat, TDS: 0.12 ppm, Cut: 0.54 L/s

pH: 6.37, EC: 167 µS/cm, Temp: 16.72 °C, Redox: -15.7 mV, DO: 52.1 % Sat, TDS: 0.108 g/L, Cut: 0.5 L/s

pH: 6.52, EC: 164 µS/cm, Temp: 18.88 °C, Redox: -25.1 mV, DO: 51.6 % Sat, TDS: 0.107 g/L, Cut: 0.3 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU00118PZA - Bore construction	
Revision: A	Date drawn: 6/11/14
Drawn by: K. Maher	Checked by: E. Kwantes
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

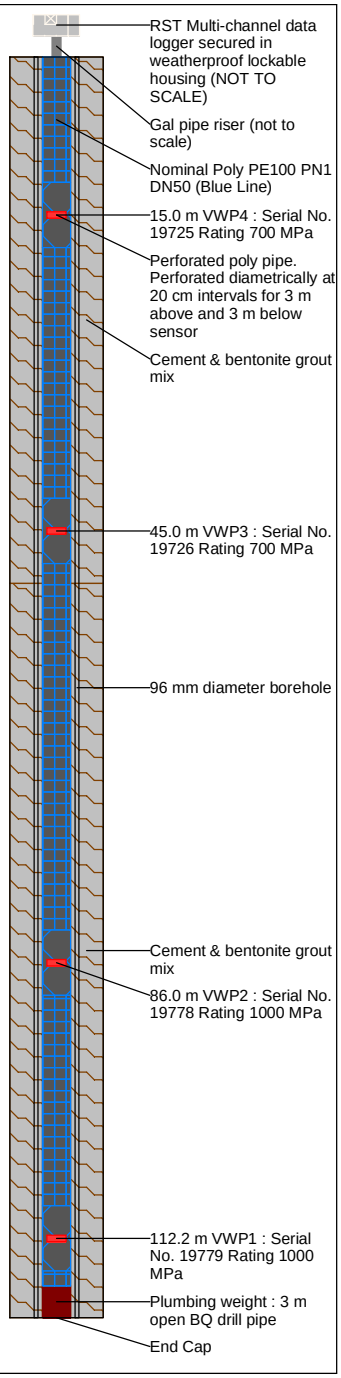
BORE COMPLETION REPORT

HU0122CH

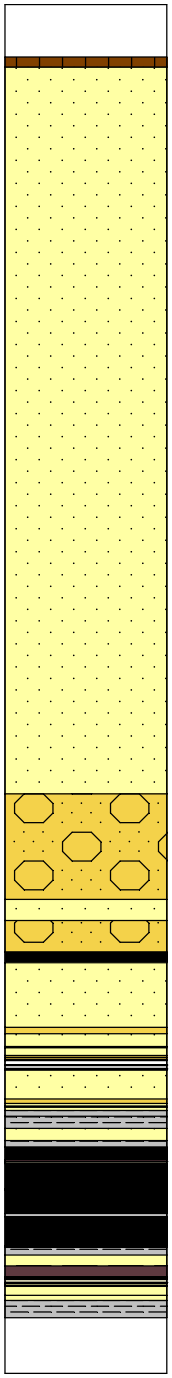
Project: Hume Coal Project
Easting: 250352 **Northing:** 6175286 **(MGA Zone 56)**
Top of casing: n/a
Ground level: 634.5 mAHD
Static water level: n/a **Date:** n/a

Completion date: 08/05/2014
Drlling company: Highland Drilling
Drlling method: Patrial core
Screened interval: n/a (VWP array)
Gravel pack: n/a (VWP array)

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

WW

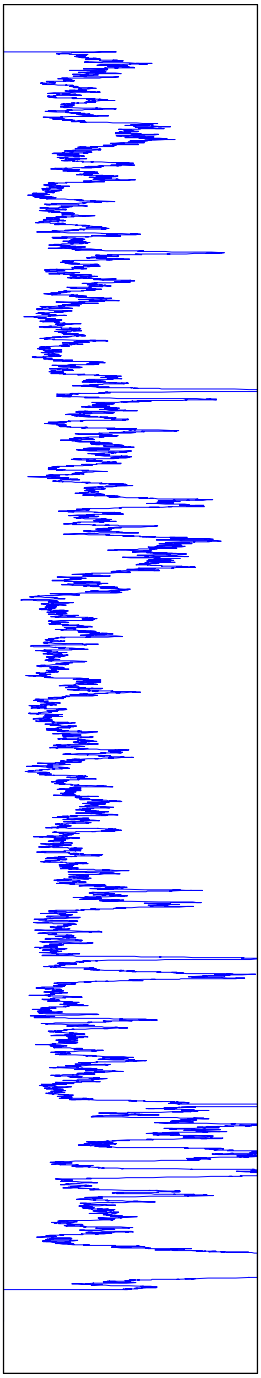
ICM

DEPTH (m)

0 10 20 30 40 50 60 70 80 90 100 110 120

GAMMA (API-Gr)

0 250



WATER QUALITY / INFLOW

***Note: no water quality data due to drilling method

PARSONS BRINCKERHOFF	Drawing No.: HU0122CH - VWP construction	
	Revision: A	Date drawn: 27/3/14
	Drawn by: K. Maher	Checked by: L. Rochford
	Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

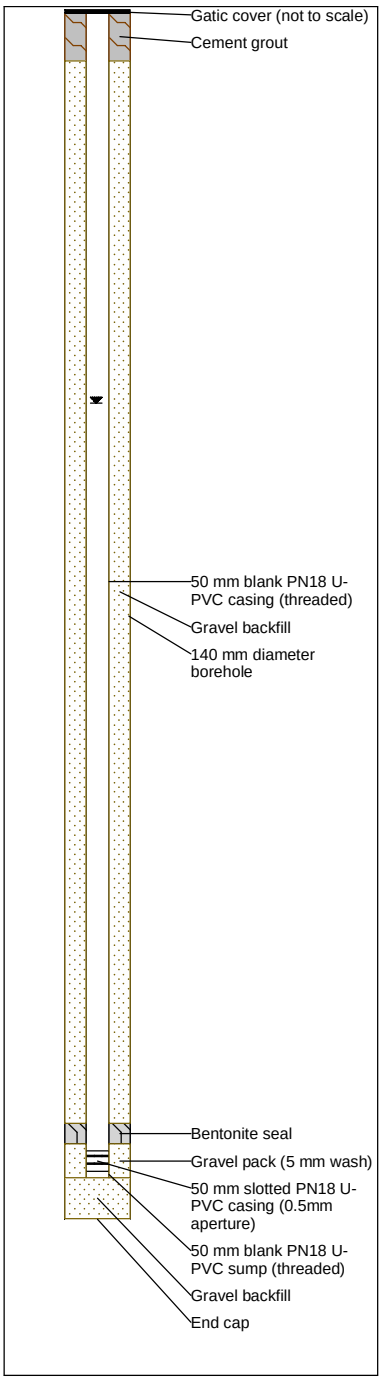
BORE COMPLETION REPORT

HU0129PZA

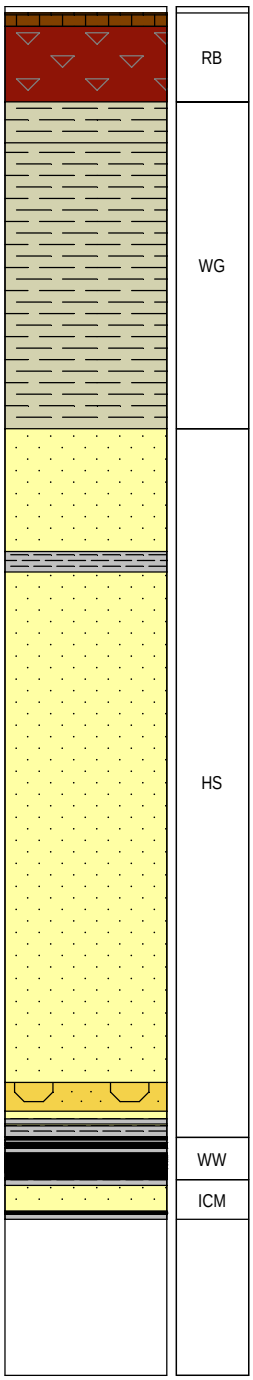
Project: Hume Coal Project
Easting: 253042 **Northing:** 6171301 **(MGA Zone 56)**
Top of casing: 679.035 mAHD
Ground level: 679.1 mAHD
Static water level: 57.235 mbgl **Date:** 14/11/2014

Completion date: 11/3/2014
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 167 - 170 mbgl
Gravel pack: 166 - 171 mbgl

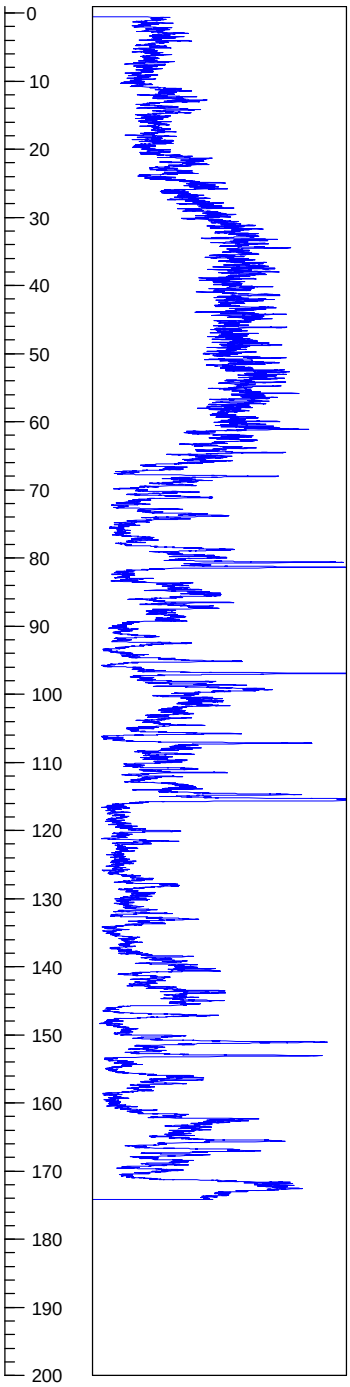
BORE CONSTRUCTION



LITHOLOGY



DEPTH (m)



GAMMA (API-Gr)

0 — 250

WATER QUALITY / INFLOW

pH: 6.57, EC: 650 µS/cm, Temp: °C, Redox: 86 mV, DO: 91.3 % Sat, TDS: 0.443 ppm, Cut: 5.6 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0129PZA - Bore construction	
Revision: A	Date drawn: 30/6/2014
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

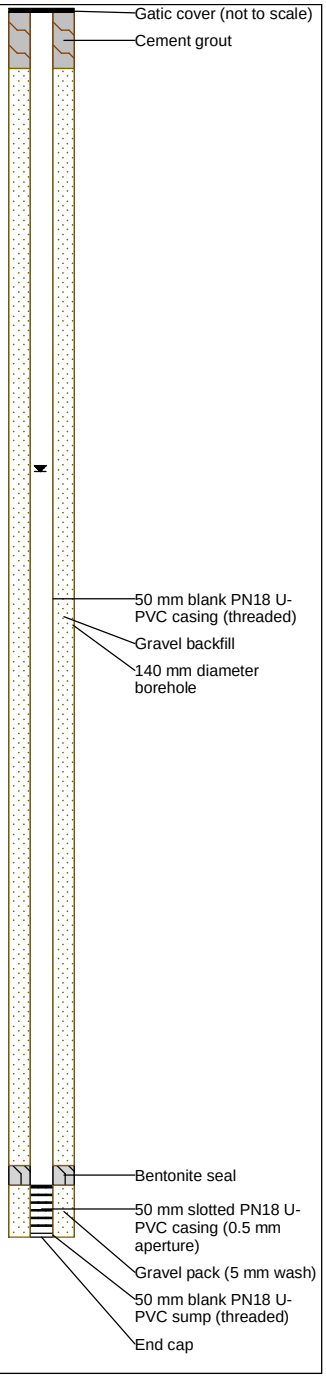
BORE COMPLETION REPORT

HU0129PZB

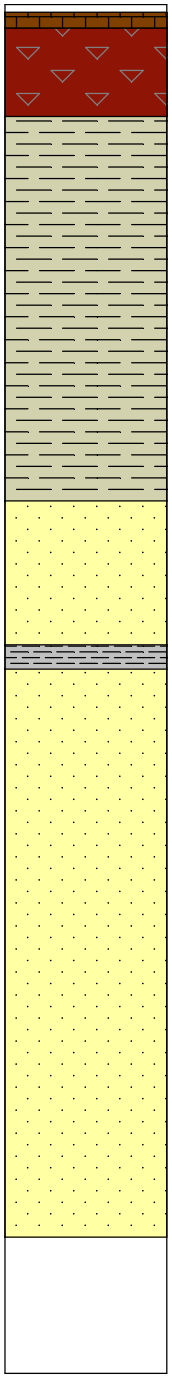
Project: Hume Coal Project
Easting: 253044 **Northing:** 6171306 **(MGA Zone 56)**
Top of casing: 679.11 mAHD
Ground level: 679.2 mAHD
Static water level: 57.36 mbgl **Date:** 14/11/2014

Completion date: 01/04/2014
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 146.5 - 152.5 mbgl
Gravel pack: 146.5 - 153 mbgl

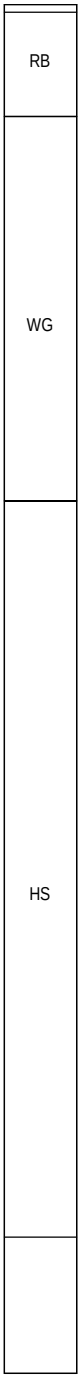
BORE CONSTRUCTION



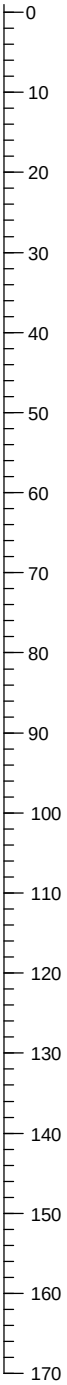
LITHOLOGY



FORMATION



DEPTH (m)



WATER QUALITY / INFLOW

pH: 7.87, EC: 619 µS/cm, Temp: 24.3 °C, Redox: 59.4 mV, DO: 77 % Sat, TDS: 0.403 ppm, Cut: L/s

pH: 7.41, EC: 480 µS/cm, Temp: 23.8 °C, Redox: 49 mV, DO: 18 % Sat, TDS: 0.319 ppm, Cut: L/s

pH: 7.07, EC: 346 µS/cm, Temp: 22.4 °C, Redox: 53.8 mV, DO: 15 % Sat, TDS: 0.225 ppm, Cut: L/s

pH: 7.21, EC: 374 µS/cm, Temp: 20.9 °C, Redox: 50.1 mV, DO: 20 % Sat, TDS: 0.243 ppm, Cut: L/s

pH: 7.39, EC: 363 µS/cm, Temp: 22.3 °C, Redox: 38.8 mV, DO: 53 % Sat, TDS: 0.235 ppm, Cut: L/s

pH: 7.29, EC: 329 µS/cm, Temp: 21.6 °C, Redox: 35.1 mV, DO: 65 % Sat, TDS: 0.215 ppm, Cut: 0.91 L/s

pH: 7.2, EC: 483 µS/cm, Temp: 20.8 °C, Redox: 35.4 mV, DO: 69 % Sat, TDS: 0.313 ppm, Cut: 1.11 L/s

pH: 7.22, EC: 597 µS/cm, Temp: 18.27 °C, Redox: 116.9 mV, DO: 70 % Sat, TDS: 0.386 ppm, Cut: 0.91 L/s

pH: 7.49, EC: 552 µS/cm, Temp: 17.59 °C, Redox: 97 mV, DO: 67 % Sat, TDS: 0.359 ppm, Cut: 1.67 L/s

pH: 7.81, EC: 714 µS/cm, Temp: 19.1 °C, Redox: 123.2 mV, DO: 77 % Sat, TDS: 0.462 ppm, Cut: 3.33 L/s

pH: 7.74, EC: 636 µS/cm, Temp: 17.8 °C, Redox: 85 mV, DO: 79 % Sat, TDS: 0.416 ppm, Cut: 3.33 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0129PZB - Bore construction	
Revision: A	Date drawn: 30/6/2014
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

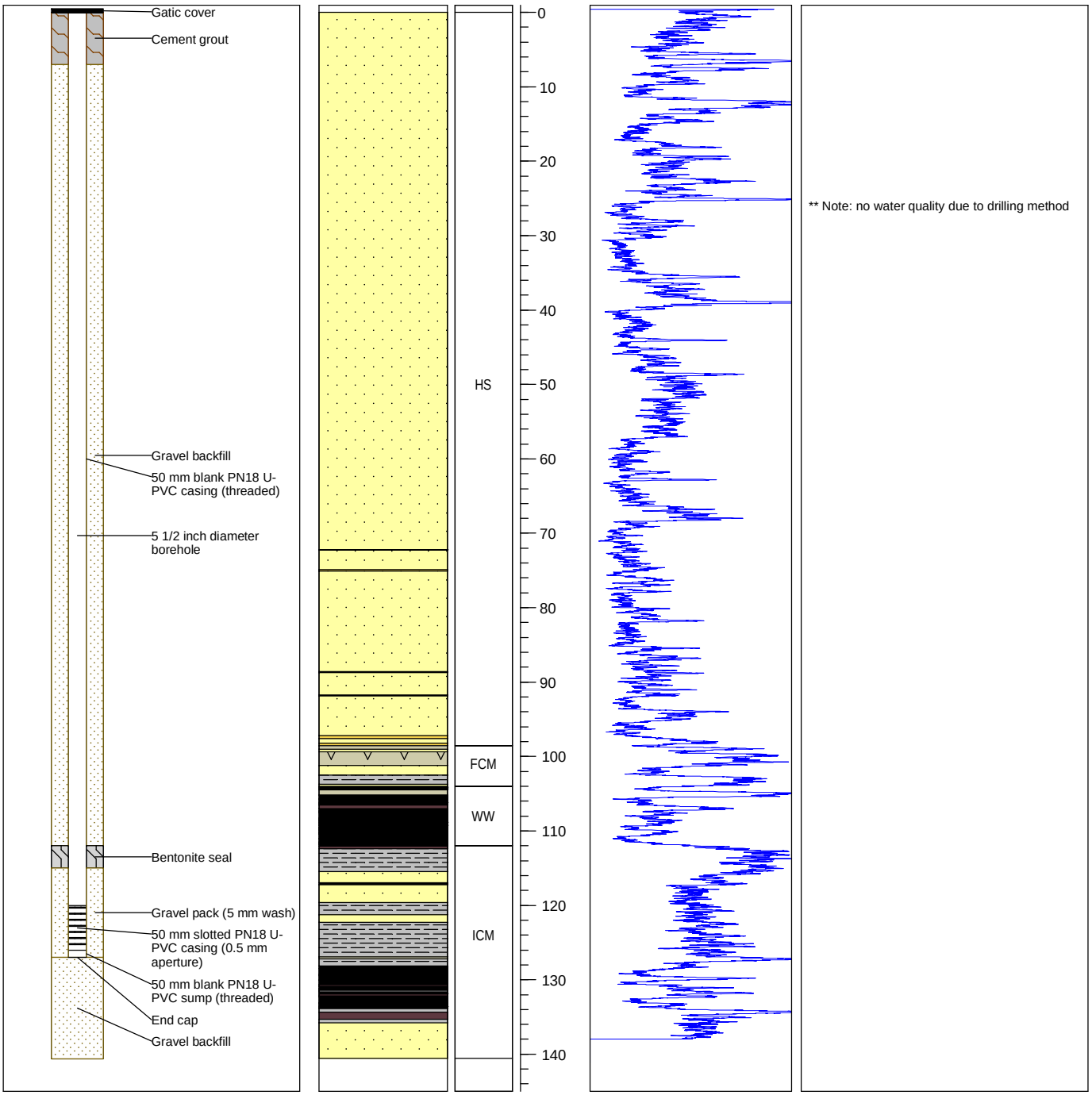
BORE COMPLETION REPORT

HU0133PZA (Decommissioned)

Project: Hume Coal Project
Easting: 249685 **Northing:** 6176683 **(MGA Zone 56)**
Top of casing: 647.98 mAHD
Ground level: 648.15 mbgl
Static water level: 22.265 mbgl **Date:** 21/05/2014

Completion date: 29/4/14
Drlling company: Highland Drilling
Drlling method: Patial core
Screened interval: 120 - 126 mbgl
Gravel pack: 115 - 127 mbgl

BORE CONSTRUCTION	LITHOLOGY	FORMATION	DEPTH (m)	GAMMA (API-Gr) 0 – 250	WATER QUALITY / INFLOW



PARSONS BRINCKERHOFF	Drawing No.: HU0133PZA - Bore construction	
	Revision: A	Date drawn: 2/6/14
	Drawn by: K. Maher	Checked by: L. Rochford
	Project No. 2172599A	

HUMECOAL PROJECT

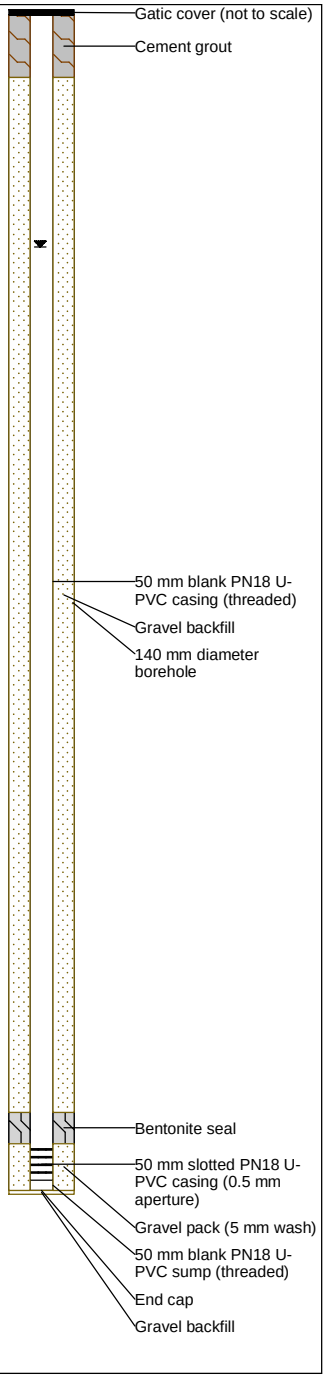
Hume Coal Pty Ltd

BORE COMPLETION REPORT — HU0133PZB (Decommissioned)

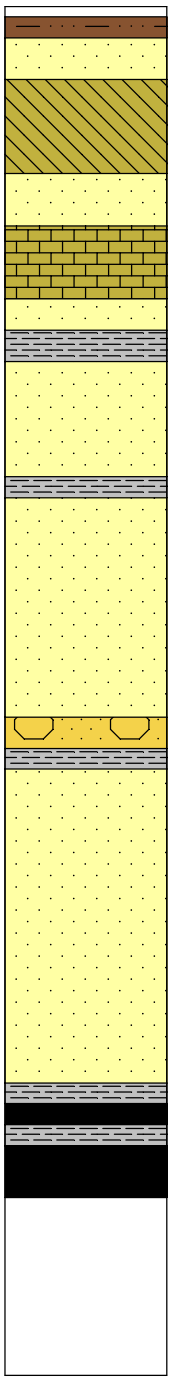
Project: Hume Coal Project
Easting: 249688 **Northing:** 6176688 **(MGA Zone 56)**
Top of casing: 648.07 mAHD
Ground level: 648.2 mAHD
Static water level: 22.22 mbgl **Date:** 21/05/2014

Completion date: 29/4/2014
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 108.5 - 111.5 mbgl
Gravel pack: 108 - 112.5 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

FCM

WW

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130

WATER QUALITY / INFLOW

pH: 5.68, EC: 171 µS/cm, Temp: 24.9 °C, Redox: 42.8 mV, DO: 66.2 % Sat, TDS: 0.111 g/L, Cut: 0.42 L/s

pH: 5.59, EC: 152 µS/cm, Temp: 21.7 °C, Redox: 117.4 mV, DO: 73.7 % Sat, TDS: 0.0995 g/L, Cut: 0.63 L/s

pH: 5.89, EC: 131 µS/cm, Temp: 19.7 °C, Redox: -28.5 mV, DO: 65 % Sat, TDS: 0.0845 g/L, Cut: 1.67 L/s

pH: 5.9, EC: 163 µS/cm, Temp: 16.8 °C, Redox: -40.9 mV, DO: 78.6 % Sat, TDS: 0.0891 g/L, Cut: 5 L/s

pH: 5.88, EC: 165 µS/cm, Temp: 16.2 °C, Redox: -32.3 mV, DO: 72.4 % Sat, TDS: 0.107 g/L, Cut: 6.67 L/s

pH: 6.17, EC: 165 µS/cm, Temp: 15.9 °C, Redox: -47.2 mV, DO: 72.8 % Sat, TDS: 0.107 g/L, Cut: 10 L/s

pH: 6.25, EC: 158 µS/cm, Temp: 16.3 °C, Redox: -22.4 mV, DO: 74.5 % Sat, TDS: 0.107 g/L, Cut: 10 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0133PZB - Bore construction	
Revision: A	Date drawn: 2/6/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

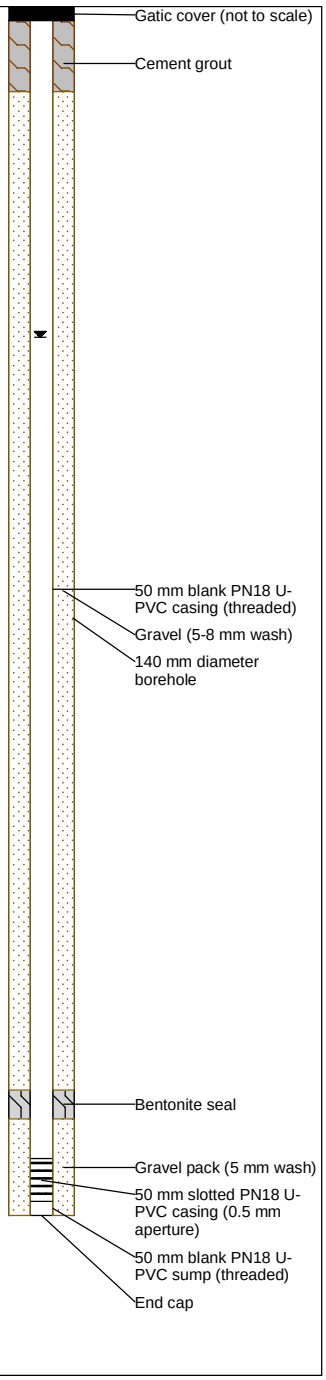
Hume Coal Pty Ltd

BORE COMPLETION REPORT — HU0133PZC (Decommissioned)

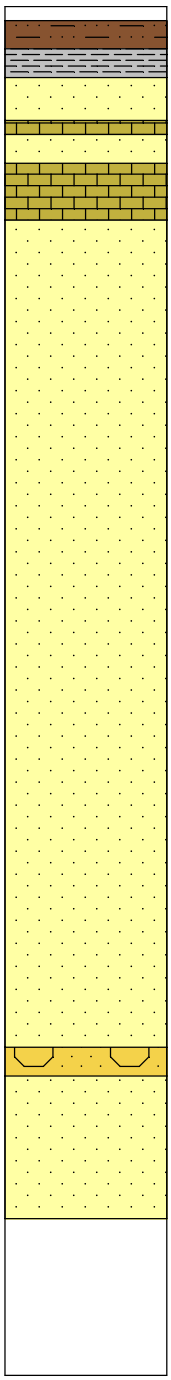
Project: Hume Coal Project
Easting: 249690 **Northing:** 6176694 **(MGA Zone 56)**
Top of casing: 647.91 mAHD
Ground level: 648 mAHD
Static water level: 22.22 mbgl **Date:** 21/05/2014

Completion date: 05/05/2014
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 79.8 - 82.8 mbgl
Gravel pack: 77 - 83.8 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90

WATER QUALITY / INFLOW

pH: 5.71, EC: 152 µS/cm, Temp: 19.2 °C, Redox: 100.8 mV, DO: 76.4 % Sat, TDS: 0.099 ppm, Cut: 0.33 L/s

pH: 6.03, EC: 172 µS/cm, Temp: 19.6 °C, Redox: 83.8 mV, DO: 73.5 % Sat, TDS: 0.112 ppm, Cut: 0.37 L/s

pH: 6.32, EC: 164 µS/cm, Temp: 19.3 °C, Redox: -8.3 mV, DO: 69.1 % Sat, TDS: 0.107 ppm, Cut: 0.59 L/s

pH: 6.33, EC: 163 µS/cm, Temp: 17.5 °C, Redox: -0.7 mV, DO: 76.3 % Sat, TDS: 0.106 ppm, Cut: 0.67 L/s

pH: 6.17, EC: 147 µS/cm, Temp: 15.1 °C, Redox: -29 mV, DO: 72.9 % Sat, TDS: 1.147 ppm, Cut: 1.67 L/s

pH: 6.28, EC: 99 µS/cm, Temp: 15.7 °C, Redox: -19.4 mV, DO: 68.6 % Sat, TDS: 0.064 ppm, Cut: L/s

pH: 6.21, EC: 144 µS/cm, Temp: 15 °C, Redox: -45 mV, DO: 69.7 % Sat, TDS: 0.094 ppm, Cut: 3.33 L/s

pH: 6.27, EC: 161 µS/cm, Temp: 15.3 °C, Redox: -49.9 mV, DO: 68.1 % Sat, TDS: 0.104 ppm, Cut: 5 L/s

PARSONS BRINCKERHOFF	Drawing No.: HU0133PZC - Bore construction	
	Revision: A	Date drawn: 2/6/14
	Drawn by: K. Maher	Checked by: L. Rochford
	Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

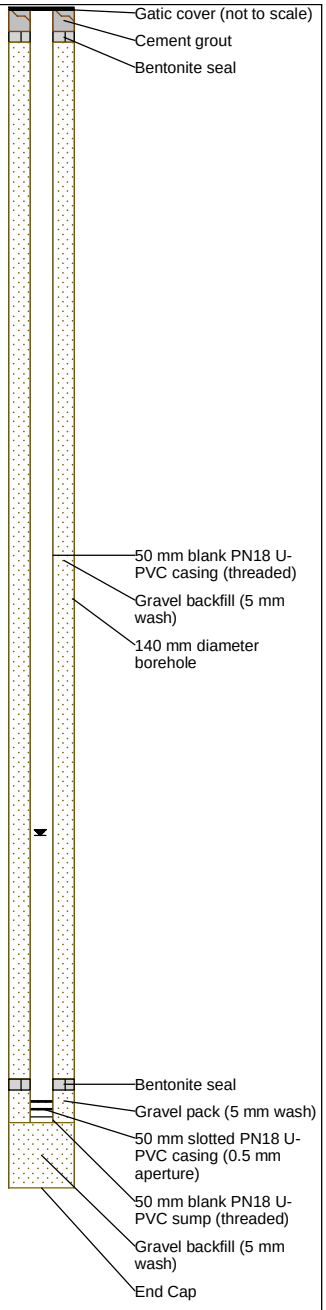
BORE COMPLETION REPORT

HU0136PZA

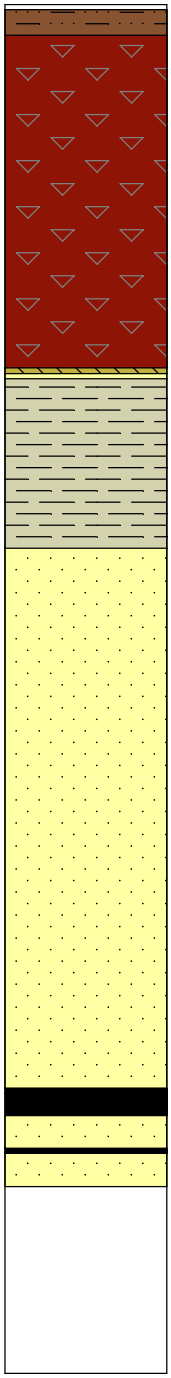
Project: Hume Coal Project
Easting: 254521 **Northing:** 6166894 **(MGA Zone 56)**
Top of casing: 718.36 mAHD
Ground level: 718.49 mAHD
Static water level: 151.39 mbgl **Date:** 1/12/2014

Completion date: 29/04/2014
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 200 – 203 mbgl
Gravel pack: 198 - 204 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

RB
WG
HS
WW
ICM

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230, 240, 250

WATER QUALITY / INFLOW

pH: 6.67, EC: 557 µS/cm, Temp: 16.35 °C, Redox: 186.2 mV, DO: 99 % Sat, TDS: 0.362 ppm, Cut: >10 L/s

pH: 7.89, EC: 513 µS/cm, Temp: 15.98 °C, Redox: 157.3 mV, DO: 112.1 % Sat, TDS: 0.333 g/L, Cut: 8 L/s

pH: 7.85, EC: 506 µS/cm, Temp: 15.64 °C, Redox: 103.7 mV, DO: 94.7 % Sat, TDS: 0.329 g/L, Cut: 5 L/s

pH: 7.56, EC: 571 µS/cm, Temp: 15.02 °C, Redox: 181 mV, DO: 80.7 % Sat, TDS: 0.37 g/L, Cut: 5 L/s

pH: 7.85, EC: 503 µS/cm, Temp: 15.82 °C, Redox: 146 mV, DO: 83.5 % Sat, TDS: 0.327 g/L, Cut: 5 L/s

pH: 7.95, EC: 519 µS/cm, Temp: 16.53 °C, Redox: 161.5 mV, DO: 87.6 % Sat, TDS: 0.338 g/L, Cut: 5 L/s

pH: 7.89, EC: 500 µS/cm, Temp: 16.66 °C, Redox: 124.2 mV, DO: 84.2 % Sat, TDS: 0.325 g/L, Cut: 5 L/s

pH: 7.88, EC: 519 µS/cm, Temp: 16.67 °C, Redox: 190.6 mV, DO: 79.9 % Sat, TDS: 0.337 g/L, Cut: 5 L/s

pH: 7.76, EC: 506 µS/cm, Temp: 16.23 °C, Redox: 272.2 mV, DO: 86.4 % Sat, TDS: 0.329 g/L, Cut: 5 L/s

pH: 6.55, EC: 511 µS/cm, Temp: 15.54 °C, Redox: 218.5 mV, DO: 82.2 % Sat, TDS: 0.332 g/L, Cut: 5.5 L/s

pH: 7.82, EC: 500 µS/cm, Temp: 15.46 °C, Redox: 147.5 mV, DO: 70.8 % Sat, TDS: 0.325 g/L, Cut: 5.5 L/s

pH: 7.96, EC: 489 µS/cm, Temp: 16.01 °C, Redox: 193.2 mV, DO: 95.8 % Sat, TDS: 0.324 g/L, Cut: 5.5 L/s

EC: 515 µS/cm, Temp: 16.87 °C, Redox: 194.8 mV, DO: % Sat, TDS: 0.335 g/L, Cut: 6 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0136PZA - Bore construction	
Revision: A	Date drawn: 2/6/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

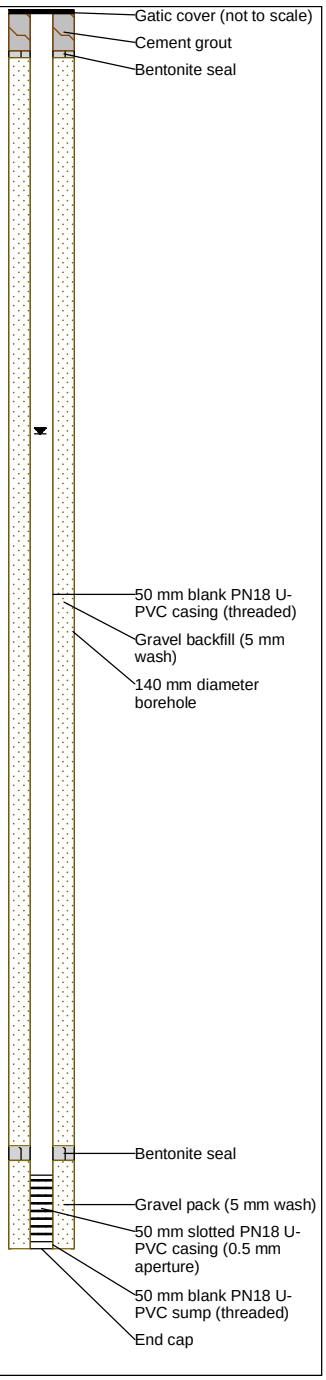
BORE COMPLETION REPORT

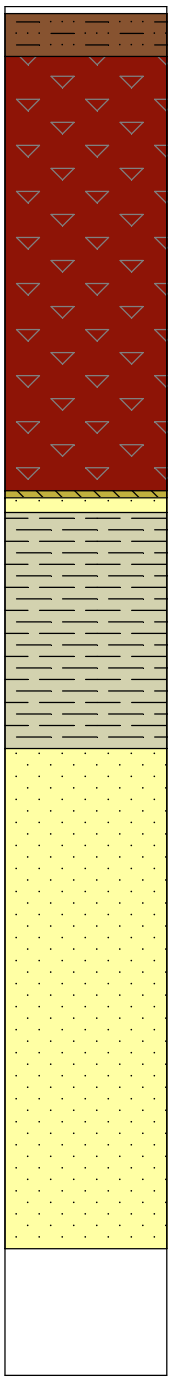
HU0136PZB (Decommissioned)

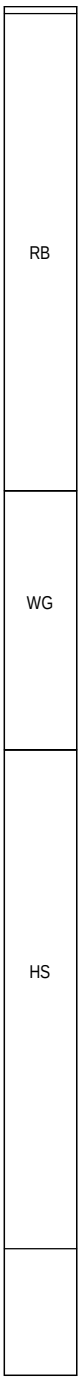
Project: Hume Coal Project
Easting: 254517 **Northing:** 6166890 **(MGA Zone 56)**
Top of casing: 718.404 mAHD
Ground level: 718.52 mAHD
Static water level: 57.085 mbgl **Date:** 1/12/2014

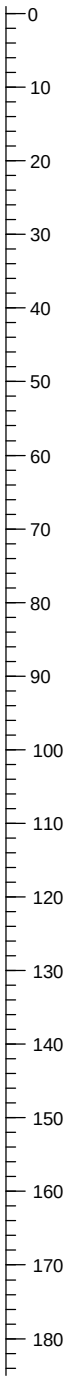
Completion date: 6/05/2014
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 157.8 - 166.8 mbgl
Gravel pack: 156 - 167.8 mbgl

BORE CONSTRUCTION	LITHOLOGY	FORMATION	DEPTH (m)	WATER QUALITY / INFLOW









DEPTH (m)	WATER QUALITY / INFLOW
30	pH: 7, EC: 617 µS/cm, Temp: 16.42 °C, Redox: 12.8 mV, DO: 85.3 % Sat, TDS: 0.401 ppm, Cut: 0.5 L/s
40	pH: 8.07, EC: 597 µS/cm, Temp: 16.92 °C, Redox: 94.3 mV, DO: 86.7 % Sat, TDS: 0.388 ppm, Cut: 0.5 L/s
60	pH: 8.04, EC: 549 µS/cm, Temp: 15.08 °C, Redox: 129.6 mV, DO: 74.9 % Sat, TDS: 0.357 ppm, Cut: 3.3 L/s
70	pH: 8.08, EC: 557 µS/cm, Temp: 14.28 °C, Redox: 99.8 mV, DO: 73.8 % Sat, TDS: 0.362 ppm, Cut: 3.3 L/s
80	pH: 7.52, EC: 543 µS/cm, Temp: 14.94 °C, Redox: 266.1 mV, DO: 77.5 % Sat, TDS: 0.353 ppm, Cut: 5 L/s
90	pH: 7.94, EC: 530 µS/cm, Temp: 14.86 °C, Redox: 152.3 mV, DO: 86.2 % Sat, TDS: 0.345 ppm, Cut: 5 L/s
100	pH: 8.04, EC: 531 µS/cm, Temp: 15.33 °C, Redox: 105.9 mV, DO: 77 % Sat, TDS: 0.345 ppm, Cut: 5 L/s
110	pH: 8.04, EC: 543 µS/cm, Temp: 16.08 °C, Redox: 140.8 mV, DO: 81.7 % Sat, TDS: 0.355 ppm, Cut: 5 L/s
120	pH: 8.09, EC: 525 µS/cm, Temp: 15.75 °C, Redox: 136.6 mV, DO: 73.8 % Sat, TDS: 0.341 ppm, Cut: 5 L/s
130	pH: 8.03, EC: 527 µS/cm, Temp: 15.25 °C, Redox: 98.7 mV, DO: 65.5 % Sat, TDS: 0.343 ppm, Cut: 5 L/s
150	pH: 8.01, EC: 546 µS/cm, Temp: 15.43 °C, Redox: 137.5 mV, DO: 81.9 % Sat, TDS: 0.355 ppm, Cut: 5 L/s
170	pH: 8.09, EC: 543 µS/cm, Temp: 15.1 °C, Redox: 115.3 mV, DO: 72.1 % Sat, TDS: 0.353 ppm, Cut: 5 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0136PZB - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

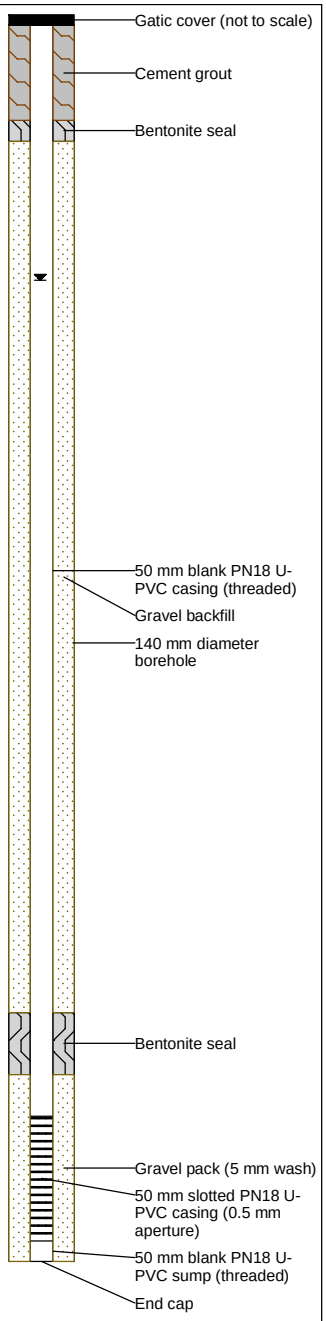
BORE COMPLETION REPORT

HU0136PZC

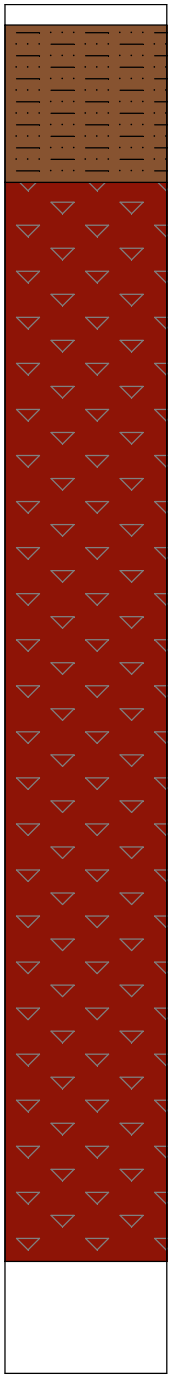
Project: Hume Coal Project
Easting: 254513 **Northing:** 6166887 **(MGA Zone 56)**
Top of casing: 718.402 mAHD
Ground level: 718.51 mAHD
Static water level: 12.305 mbgl **Date:** 1/12/2014

Completion date: 9/05/2014
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 52.6 - 58.6 mbgl
Gravel pack: 51 - 59.6 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

RB

DEPTH (m)

0, 10, 20, 30, 40, 50, 60

WATER QUALITY / INFLOW

pH: 6.47, EC: 587 µS/cm, Temp: 16.53 °C, Redox: 109.9 mV, DO: 75.4 % Sat, Cut: 0.5 L/s

pH: 7.69, EC: 544 µS/cm, Temp: 16.63 °C, Redox: 190 mV, DO: 72 % Sat, Cut: 0.5 L/s

Cut: <0.3 L/s

pH: 7.32, EC: 411 µS/cm, Temp: 18.95 °C, Redox: 253.5 mV, DO: 64 % Sat, Cut: 0.5 L/s

pH: 8.16, EC: 322 µS/cm, Temp: 17.6 °C, Redox: 187.3 mV, DO: 66.6 % Sat, Cut: 0.5 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0136PZC - Bore construction	
Revision: A	Date drawn: 2/6/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

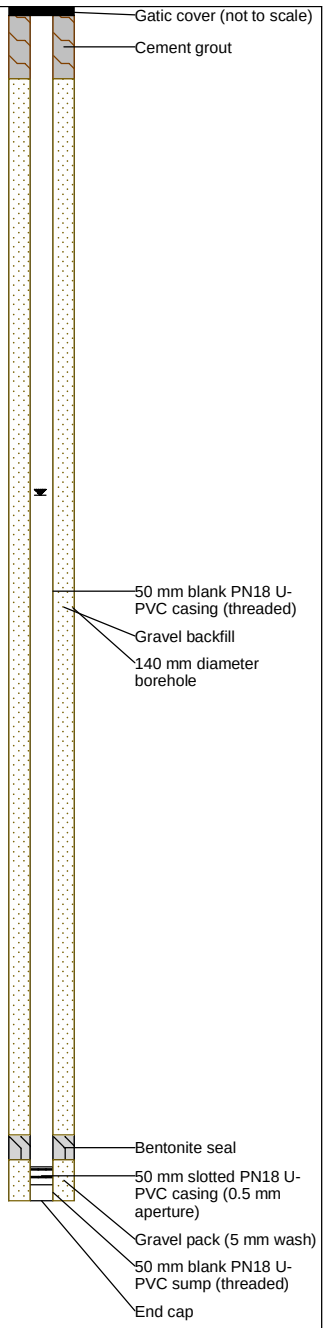
BORE COMPLETION REPORT

HU0142PZA

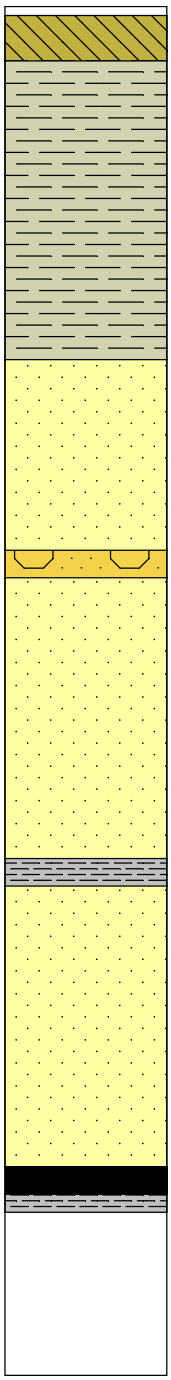
Project: Hume Coal Project
Easting: 250855.82 **Northing:** 6169880.69 **(MGA Zone 56)**
Top of casing: 672.34 mAHD
Ground level: 672.43 mAHD
Static water level: 52.95 mbTOC **Date:** 23/09/2014

Completion date: 10/7/2014
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 127 – 129 mbgl
Gravel pack: 126.2 - 130.7 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

WG

HS

WW

ICM

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150

WATER QUALITY / INFLOW

Cut: 0.36 L/s, Temp: 19 °C, EC: 2585 µS/cm, TDS: 1.898 g/L, DO: 55.2 %, DO: 5.02 ppm, pH: 6.1, ORP: 182.7 mV

Cut: 0.63 L/s, Temp: 19.1 °C, EC: 1740 µS/cm, TDS: 1.274 g/L, DO: 56.3 %, DO: 5.21 ppm, pH: 7.11, ORP: 137.3 mV

Cut: 1.67 L/s, Temp: 15.9 °C, EC: 690 µS/cm, TDS: 0.546 g/L, DO: 64.5 %, DO: 6.34 ppm, pH: 6.94, ORP: -77.1 mV

Cut: 3.33 L/s, Temp: 16.1 °C, EC: 1058 µS/cm, TDS: 0.832 g/L, DO: 56.2 %, DO: 5.52 ppm, pH: 5.69, ORP: -13.4 mV

Cut: 3.33 L/s, Temp: 17.3 °C, EC: 526 µS/cm, TDS: 0.403 g/L, DO: 59.4 %, DO: 5.63 ppm, pH: 6.87, ORP: -85.1 mV

Cut: 4.35 L/s, Temp: 17.7 °C, EC: 390 µS/cm, TDS: 0.294 g/L, DO: 56 %, DO: 4.52 ppm, pH: 6.82, ORP: -70 mV

Cut: 5 L/s, Temp: 16.9 °C, EC: 415 µS/cm, TDS: 0.318 g/L, DO: 58.7 %, DO: 5.62 ppm, pH: 6.83, ORP: -70.4 mV

PARSONS BRINCKERHOFF

Drawing No.: HU0133PZA - Bore construction	
Revision: A	Date drawn: 22/07/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

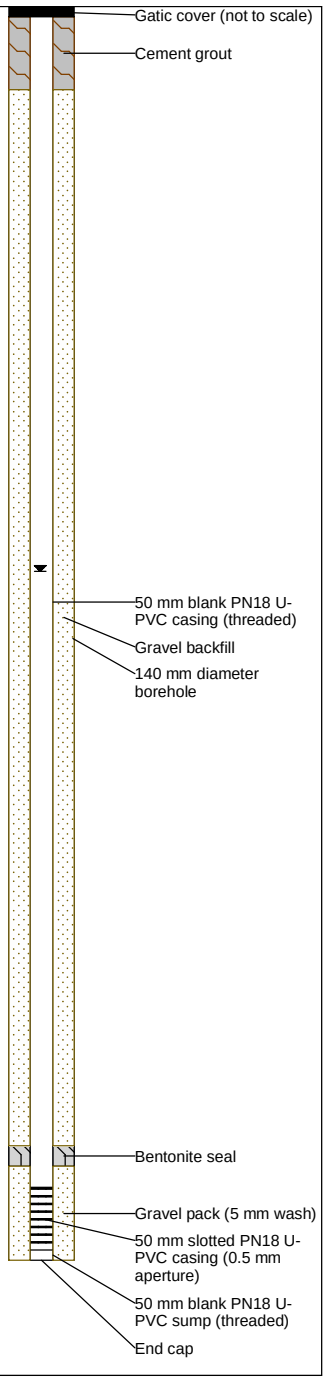
BORE COMPLETION REPORT

HU0142PZB

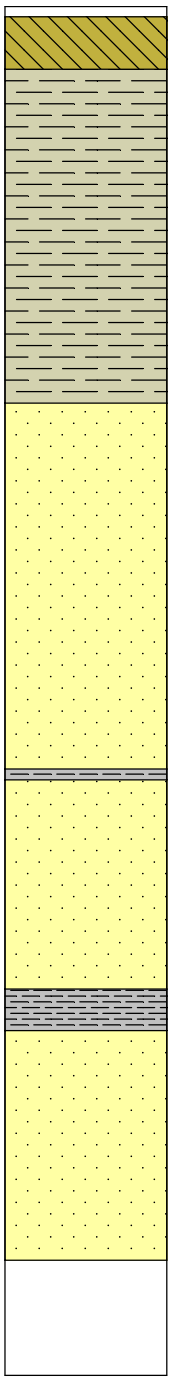
Project: Hume Coal Project
Easting: 250855 **Northing:** 6169886 **(MGA Zone 56)**
Top of casing: 672.23 mAHD
Ground level: 672.32 mAHD
Static water level: 53.05 mbTOC **Date:** 23/09/2014

Completion date: 14/07/2014
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 112 - 118 mbgl
Gravel pack: 110 - 119 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

WG

HS

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130

WATER QUALITY / INFLOW

Cut: 0.31 L/s, Temp: 21.9 °C, EC: 544 µS/cm, TDS: 1.898 g/L, DO: 55.2 %, DO: 5.72 ppm, pH: 6.93, ORP: 182.7 mV

Cut: 0.6 L/s, Temp: 19.3 °C, EC: 406 µS/cm, TDS: 1.274 g/L, DO: 56.3 %, DO: 6.49 ppm, pH: 7.24, ORP: 137.3 mV

Cut: 0.9 L/s, Temp: 20.3 °C, EC: 323 µS/cm, TDS: 1.008 g/L, DO: 56.1 %, DO: 7.02 ppm, pH: 7.31, ORP: -16 mV

Cut: 3.03 L/s, Temp: 16.8 °C, EC: 1271 µS/cm, TDS: 0.546 g/L, DO: 64.5 %, DO: 6.23 ppm, pH: 6.93, ORP: -77.1 mV

Cut: 3.7 L/s, Temp: 17.1 °C, EC: 925 µS/cm, TDS: 0.416 g/L, DO: 66.7 %, DO: 7.29 ppm, pH: 7.17, ORP: -75.3 mV

Cut: 3.85 L/s, Temp: 16.3 °C, EC: 722 µS/cm, TDS: 0.832 g/L, DO: 56.2 %, DO: 7.17 ppm, pH: 7.13, ORP: -13.4 mV

Cut: 4.17 L/s, Temp: 16.4 °C, EC: 759 µS/cm, TDS: 0.494 g/L, DO: 60.5 %, DO: 7.14 ppm, pH: 6.89, ORP: -89.7 mV

Cut: 5 L/s, Temp: 16.9 °C, EC: 692 µS/cm, TDS: 0.403 g/L, DO: 59.4 %, DO: 7.93 ppm, pH: 7.06, ORP: -85.1 mV

Cut: 5 L/s, Temp: 15.3 °C, EC: 627 µS/cm, TDS: 0.294 g/L, DO: 56 %, DO: 6.9 ppm, pH: 6.24, ORP: -70 mV

PARSONS BRINCKERHOFF

Drawing No.: HU0133PZA - Bore construction	
Revision: A	Date drawn: 22/07/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

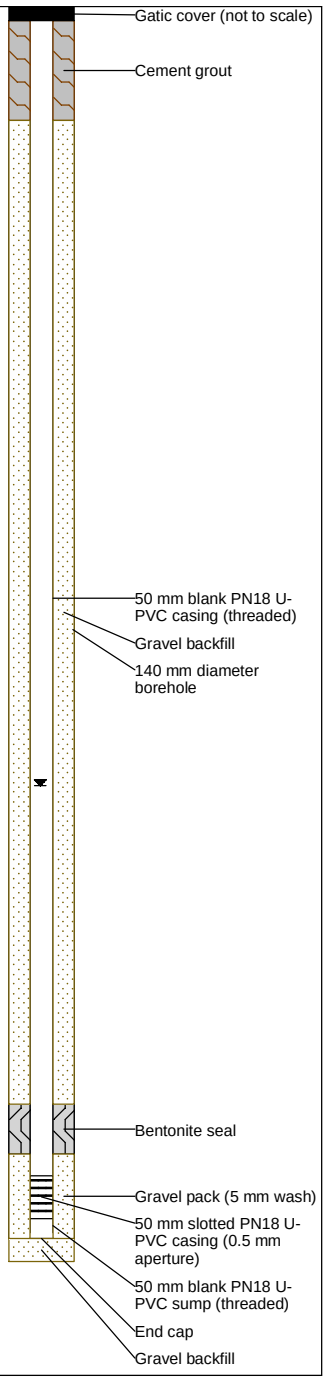
BORE COMPLETION REPORT

HU0142PZC

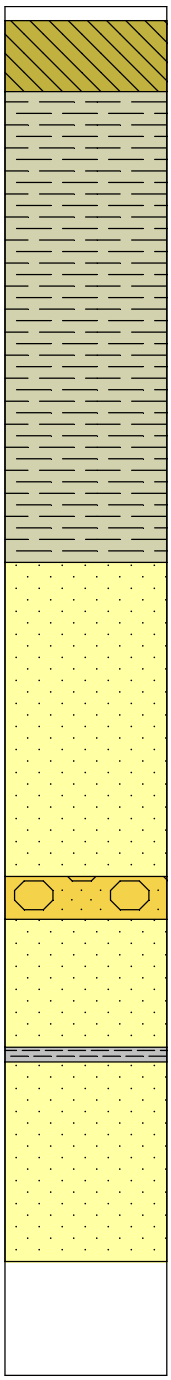
Project: Hume Coal Project
Easting: 250855 **Northing:** 6169892 **(MGA Zone 56)**
Top of casing: 672.15 mAHD
Ground level: 672.23 mAHD
Static water level: 53.64 mbTOC **Date:** 23/09/2014

Completion date: 16/07/2014
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 81 - 84 mbgl
Gravel pack: 80 - 85 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

WG

HS

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90

WATER QUALITY / INFLOW

Cut: 0.26 L/s, Temp: 22.9 °C, EC: 7530 µS/cm, TDS: 5.11 g/L, DO: 56.9 %, DO: 4.72 ppm, pH: 7.25, ORP: 54 mV

Cut: 0.5 L/s, Temp: 21.3 °C, EC: 5760 µS/cm, TDS: 4.024 g/L, DO: 63.3 %, DO: 5.5 ppm, pH: 7.63, ORP: -79 mV

Cut: 0.43 L/s, Temp: 22.7 °C, EC: 6426 µS/cm, TDS: 4.361 g/L, DO: 55.8 %, DO: 4.89 ppm, pH: 7.84, ORP: -103.5 mV

Cut: 0.48 L/s, Temp: 22.4 °C, EC: 5650 µS/cm, TDS: 3.874 g/L, DO: 68 %, DO: 5.76 ppm, pH: 7.71, ORP: -60.5 mV

Cut: 0.33 L/s, Temp: 25.6 °C, EC: 5000 µS/cm, TDS: 3.211 g/L, DO: 42.3 %, DO: 3.37 ppm, pH: 7.53, ORP: -10.5 mV

Cut: 0.53 L/s, Temp: 21 °C, EC: 2532 µS/cm, TDS: 1.781 g/L, DO: 62.1 %, DO: 5.51 ppm, pH: 7.61, ORP: -6.8 mV

Cut: 0.77 L/s, Temp: 19.6 °C, EC: 1702 µS/cm, TDS: 1.235 g/L, DO: 58.1 %, DO: 5.28 ppm, pH: 7.61, ORP: -99.4 mV

Cut: 1 L/s, Temp: 19.4 °C, EC: 1425 µS/cm, TDS: 1.04 g/L, DO: 60.5 %, DO: 5.55 ppm, pH: 7.43, ORP: -104 mV

Cut: 2.5 L/s, Temp: 17 °C, EC: 1217 µS/cm, TDS: 0.936 g/L, DO: 61.1 %, DO: 5.72 ppm, pH: 7.13, ORP: -104.2 mV

PARSONS BRINCKERHOFF

Drawing No.: HU0133PZA - Bore construction	
Revision: A	Date drawn: 22/07/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

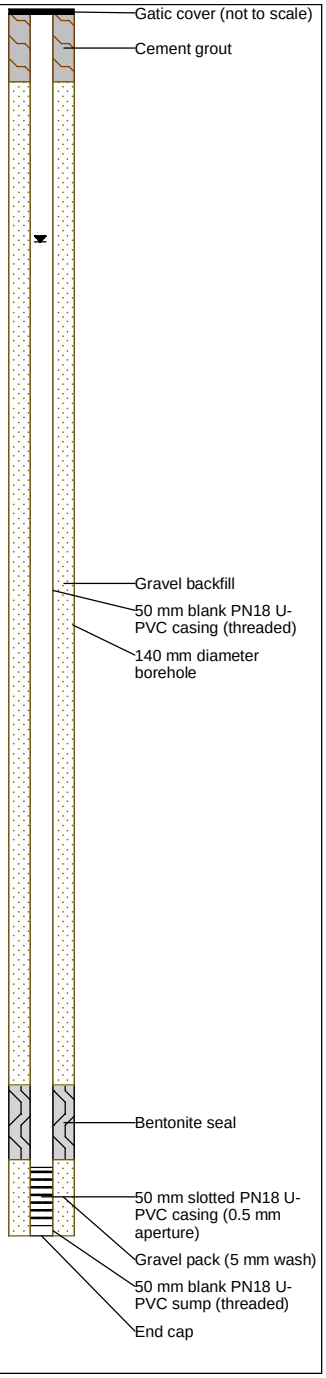
BORE COMPLETION REPORT

HU0143PZA

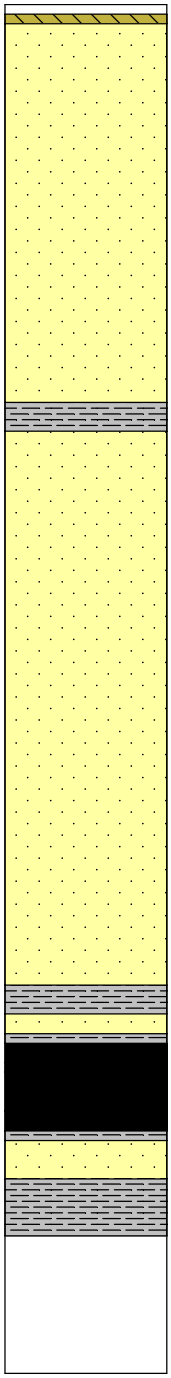
Project: Hume Coal Project
Easting: 249671 **Northing:** 6176708 **(MGA Zone 56)**
Top of casing: 649.45 mAHD
Ground level: 649.545 mAHD
Static water level: 23.465 mbTOC **Date:** 4/12/2014

Completion date: 24/9/14
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 118.8 - 124.8 mbgl
Gravel pack: 116.0 - 125.8 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

FCM

WW

ICM

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140

WATER QUALITY / INFLOW

Cut: 0.3 L/s, Temp: 21 °C, EC: 195 µS/cm, TDS: 0.127 g/L, DO: 84.6 %, DO: 6.96 ppm, pH: 5.47, ORP: 91.3 mV

Cut: 0.66 L/s, Temp: 21.5 °C, EC: 118 µS/cm, TDS: 0.077 g/L, DO: 73.8 %, DO: 6.01 ppm, pH: 5.69, ORP: 32.1 mV

Cut: 3.33 L/s, Temp: 20.76 °C, EC: 141 µS/cm, TDS: 0.091 g/L, DO: 61.5 %, DO: 5.51 ppm, pH: 5.91, ORP: 14 mV

Cut: 5 L/s, Temp: 18.56 °C, EC: 150 µS/cm, TDS: 0.098 g/L, DO: 58.6 %, DO: 5.47 ppm, pH: 6.02, ORP: -29.4 mV

Cut: 8 L/s, Temp: 16.88 °C, EC: 158 µS/cm, TDS: 0.103 g/L, DO: 46 %, DO: 4.39 ppm, pH: 6.24, ORP: -36.7 mV

Cut: 8 L/s, Temp: 16.73 °C, EC: 156 µS/cm, TDS: 0.101 g/L, DO: 45 %, DO: 4.32 ppm, pH: 6.24, ORP: -16.9 mV

Cut: 8 L/s, Temp: 17.45 °C, EC: 158 µS/cm, TDS: 0.102 g/L, DO: 38.9 %, DO: 3.69 ppm, pH: 6.14, ORP: -38.6 mV

PARSONS BRINCKERHOFF

Drawing No.: HU0143PZA - Bore construction	
Revision: A	Date drawn: 16/10/2015
Drawn by D. Watson	Checked by: E. Kwantes
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

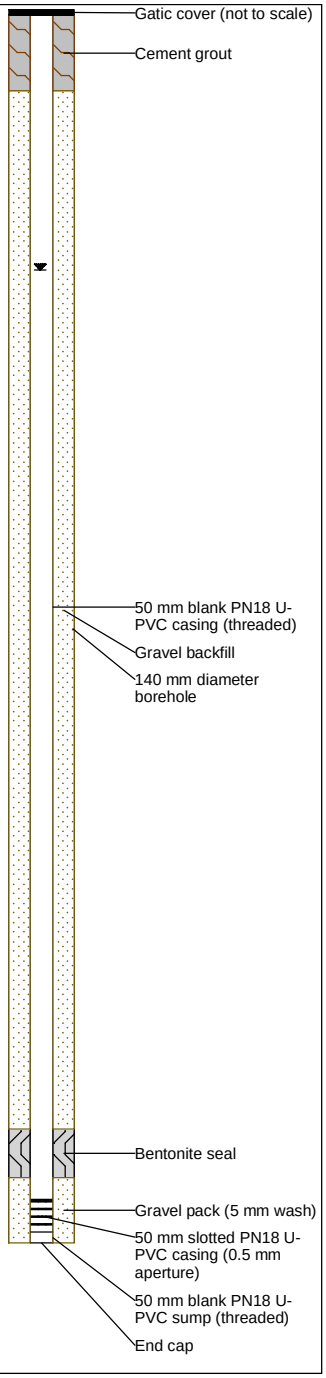
BORE COMPLETION REPORT

HU0143PZB

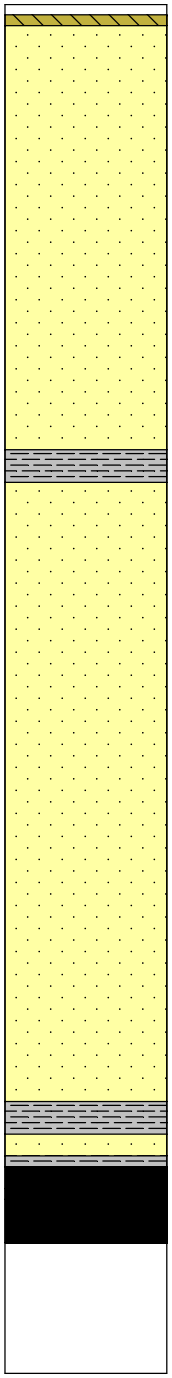
Project: Hume Coal Project
Easting: 249672 **Northing:** 6176703 **(MGA Zone 56)**
Top of casing: 649.503 mAHD
Ground level: 649.59 mAHD
Static water level: 23.44 mbTOC **Date:** 25/03/2015

Completion date: 29/9/14
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 109 - 112 mbgl
Gravel pack: 107 - 113 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

FCM

WW

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120

WATER QUALITY / INFLOW

Cut: <0.1 L/s, Temp: 20.41 °C, EC: 162 µS/cm, TDS: 0.105 g/L, DO: 89.1 %, DO: 7.95 ppm, pH: 7.52, ORP: -109.8 mV

Cut: <0.1 L/s, Temp: 25.91 °C, EC: 139 µS/cm, TDS: 0.09 g/L, DO: 102.6 %, DO: 8.62 ppm, pH: 6.59, ORP: 5.2 mV

Cut: 0.3 L/s, Temp: 24.97 °C, EC: 106 µS/cm, TDS: 0.069 g/L, DO: 92.1 %, DO: 7.65 ppm, pH: 5.15, ORP: 16.4 mV

Cut: 1 L/s, Temp: 20.29 °C, EC: 101 µS/cm, TDS: 0.066 g/L, DO: 110 %, DO: 9.84 ppm, pH: 6.4, ORP: -21.9 mV

Cut: 4.1 L/s, Temp: 16.88 °C, EC: 154 µS/cm, TDS: 0.1 g/L, DO: 112.1 %, DO: 10.71 ppm, pH: 6.33, ORP: -42.5 mV

Cut: 5.5 L/s, Temp: 17.13 °C, EC: 159 µS/cm, TDS: 0.103 g/L, DO: 101.2 %, DO: 9.7 ppm, pH: 6.27, ORP: -42.7 mV

Cut: 3 L/s, Temp: 17.25 °C, EC: 166 µS/cm, TDS: 0.108 g/L, DO: 95.7 %, DO: 8.71 ppm, pH: 6.32, ORP: -47.7 mV

Cut: 5.55 L/s, Temp: 17.8 °C, EC: 160 µS/cm, TDS: 0.104 g/L, DO: 96.6 %, DO: 8.17 ppm, pH: 6.29, ORP: -45.4 mV

PARSONS BRINCKERHOFF

Drawing No.: HU0143PZB - Bore construction	
Revision: A	Date drawn: 16/10/2015
Drawn by D. Watson	Checked by: E. Kwantes
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

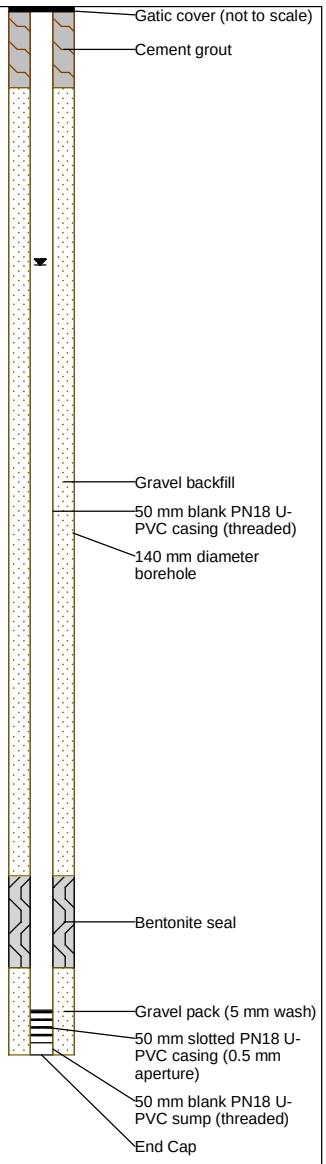
BORE COMPLETION REPORT

HU0143PZC

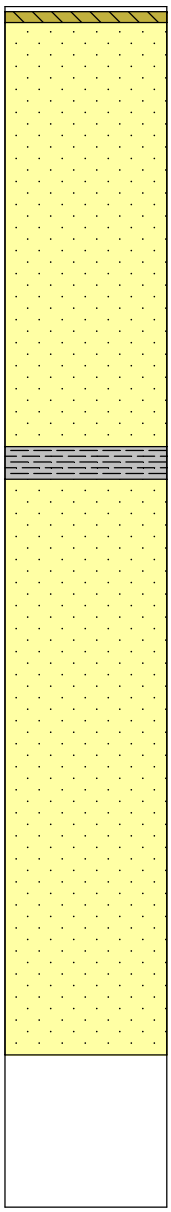
Project: Hume Coal Project
Easting: 249673 **Northing:** 6176697 **(MGA Zone 56)**
Top of casing: 649.36 mAHD
Ground level: 649.45 mAHD
Static water level: 23.315 mbTOC **Date:** 25/03/2015

Completion date: 2/10/2014
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 91.9 - 94.9 mbgl
Gravel pack: 88 - 95.9 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110

WATER QUALITY / INFLOW

Cut: - L/s, Temp: 19.41 °C, EC: 118 µS/cm, TDS: 0.077 g/L, DO: 90.4 %, DO: 8.26 ppm, pH: 6.35, ORP: -1.2 mV

Cut: 0.3 L/s, Temp: 20.78 °C, EC: 102 µS/cm, TDS: 0.066 g/L, DO: 78 %, DO: 6.98 ppm, pH: 5.76, ORP: 112.5 mV

Cut: 0.125 L/s, Temp: 20 °C, EC: 163 µS/cm, TDS: 0.106 g/L, DO: 68.8 %, DO: 6.27 ppm, pH: 6.3, ORP: 11.9 mV

Cut: 0.1 L/s, Temp: 20.86 °C, EC: 151 µS/cm, TDS: 0.096 g/L, DO: 83.6 %, DO: 7.43 ppm, pH: 6.45, ORP: -29.3 mV

Cut: 0.7 L/s, Temp: 17.45 °C, EC: 127 µS/cm, TDS: 0.082 g/L, DO: 86.6 %, DO: 8.24 ppm, pH: 6.45, ORP: -13.5 mV

Cut: 0.12 L/s, Temp: 16.65 °C, EC: 105 µS/cm, TDS: 0.069 g/L, DO: 87.1 %, DO: 8.25 ppm, pH: 6.49, ORP: -24.6 mV

Cut: 2 L/s, Temp: 16.27 °C, EC: 123 µS/cm, TDS: 0.08 g/L, DO: 84.1 %, DO: 8.25 ppm, pH: 6.34, ORP: -34.2 mV

Cut: 5 L/s, Temp: 15.6 °C, EC: 149 µS/cm, TDS: 0.097 g/L, DO: 86.5 %, DO: 8.59 ppm, pH: 6.3, ORP: -42.6 mV

Cut: 6.6 L/s, Temp: 15.02 °C, EC: 133 µS/cm, TDS: 0.086 g/L, DO: 88 %, DO: 8.85 ppm, pH: 6.3, ORP: -38.3 mV

Cut: 7.14 L/s, Temp: 15.58 °C, EC: 157 µS/cm, TDS: 0.102 g/L, DO: 80.2 %, DO: 7.98 ppm, pH: 6.31, ORP: -47 mV

Cut: 8.3 L/s, Temp: 16.51 °C, EC: 155 µS/cm, TDS: 0.1 g/L, DO: 87.4 %, DO: 8.52 ppm, pH: 6.32, ORP: -47.1 mV

PARSONS BRINCKERHOFF

Drawing No.: HU0143PZC - Bore construction	
Revision: A	Date drawn: 16/10/2015
Drawn by D. Watson	Checked by: E. Kwantes
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

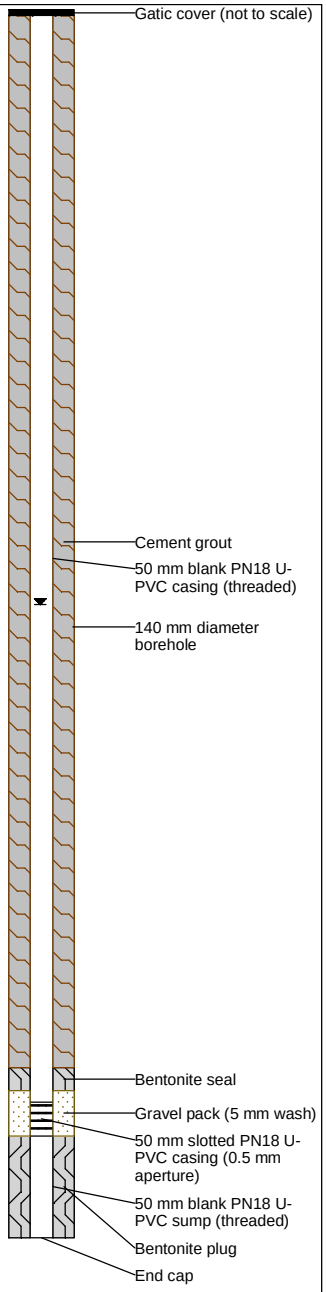
BORE COMPLETION REPORT

HU0018PZA

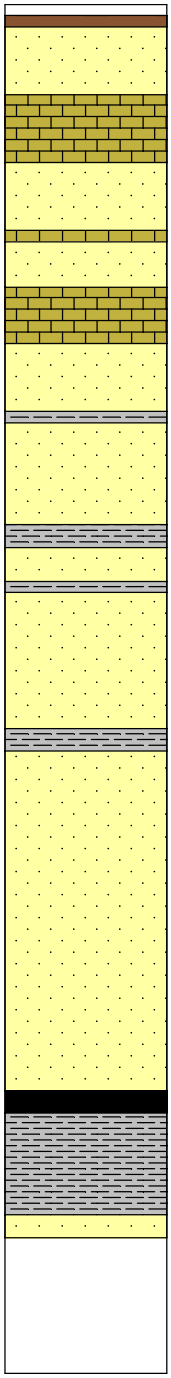
Project: Hume Coal Project
Easting: 246696 **Northing:** 6174166 **(MGA Zone 56)**
Top of casing: 691.67 mAHD
Ground level: 691.74 mAHD
Static water level: 52.065 mbgl **Date:** 4/12/2014

Completion date: 20/09/2011
Drlling company: Highland Drilling
Drlling method: Air Rotary
Screened interval: 96 - 99 mbgl
Gravel pack: 95.0 - 99.0 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

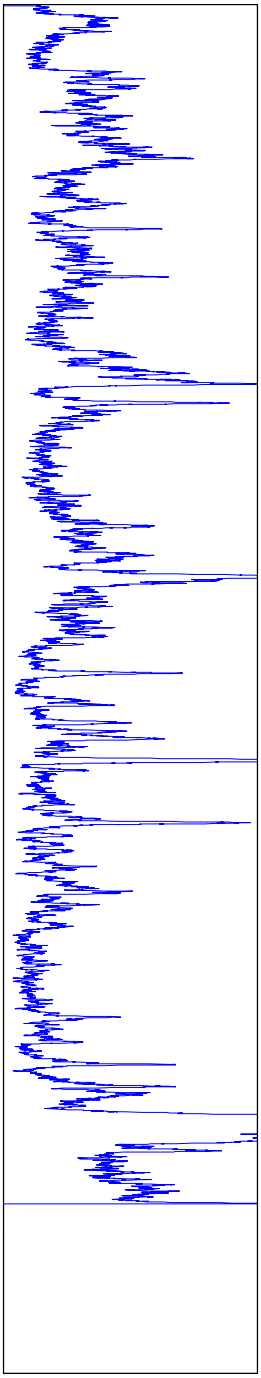
WW

ICM

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120

GAMMA (API-Gr)



WATER QUALITY / INFLOW

pH: 6.43, EC: 255 µS/cm, Temp: 24.48 °C, Redox: 84.4 mV, DO: 167 % Sat, Cut: <0.1 L/s

pH: 6.36, EC: 266 µS/cm, Temp: 22.86 °C, Redox: 91.5 mV, DO: 186.3 % Sat, Cut: 0.15 L/s

pH: 6.8, EC: 195 µS/cm, Temp: 19.16 °C, Redox: 76.2 mV, DO: 212 % Sat, Cut: 0.3 L/s

pH: 6.42, EC: 169 µS/cm, Temp: 16.96 °C, Redox: 61.6 mV, DO: 188.5 % Sat, Cut: 1 L/s

pH: 6.57, EC: 191 µS/cm, Temp: 16.25 °C, Redox: 30.2 mV, DO: 177.5 % Sat, Cut: 2 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0018PZA - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

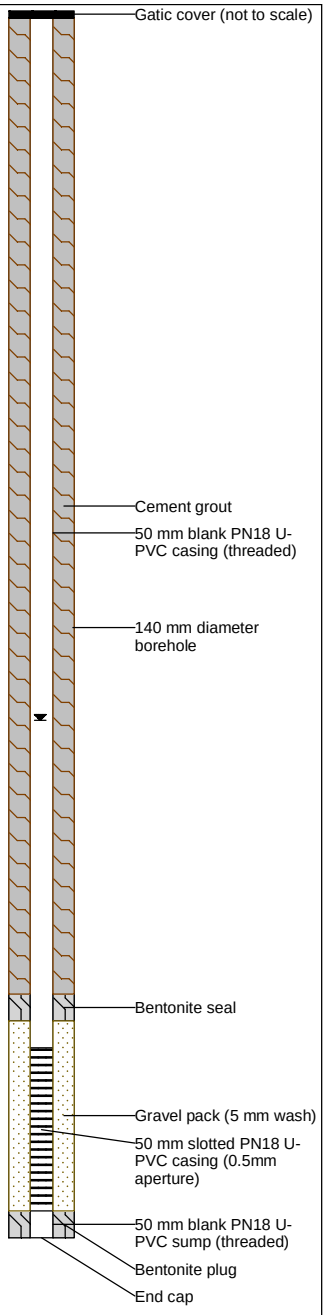
BORE COMPLETION REPORT

HU0018PZB

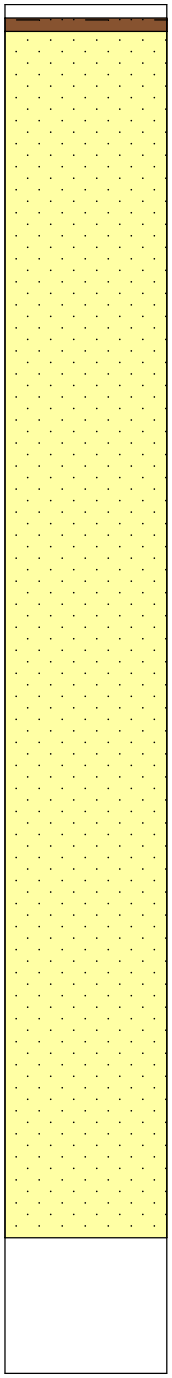
Project: Hume Coal Project
Easting: 246695 **Northing:** 6174159 **(MGA Zone 56)**
Top of casing: 691.89 mAHD
Ground level: 691.97 mAHD
Static water level: 51.84 mbgl **Date:** 4/12/2014

Completion date: 20/09/2011
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 76 - 88 mbgl
Gravel pack: 74 - 88 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100

WATER QUALITY / INFLOW

pH: 6.21, EC: 320 µS/cm, Temp: 22.52 °C, Redox: 38.7 mV, DO: % Sat, Cut: 0.02L/s

pH: 6.45, EC: 200 µS/cm, Temp: 18.4 °C, Redox: 40.9 mV, DO: 222 % Sat, Cut: 1.1 L/s

pH: 6.62, EC: 187 µS/cm, Temp: 16.94 °C, Redox: 32.2 mV, DO: 245 % Sat, Cut: 2 L/s

pH: 6.7, EC: 198 µS/cm, Temp: 16.25 °C, Redox: -10.4 mV, DO: 176.9 % Sat, Cut: 3.6L/s

pH: 6.75, EC: 201 µS/cm, Temp: 15.91 °C, Redox: -15 mV, DO: 232.3 % Sat, Cut: 5L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0018PZB - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

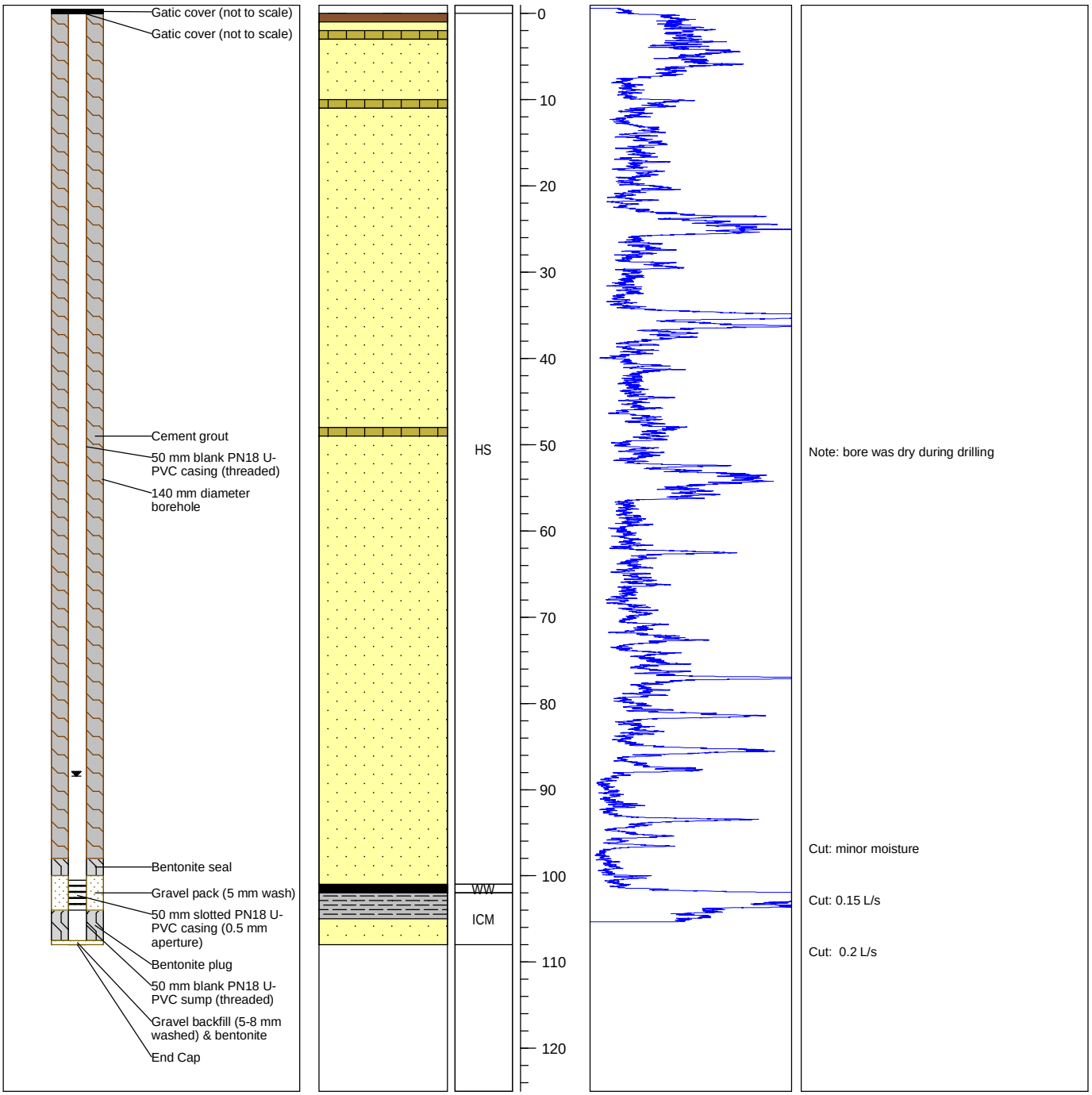
Hume Coal Pty Ltd

BORE COMPLETION REPORT

HU0019PZA

Project: Hume Coal Project
Easting: 243557 **Northing:** 6174381 **(MGA Zone 56)**
Top of casing: 720.55 mAHD
Ground level: 720.65 mAHD
Static water level: 88.445 mbgl **Date:** 17/11/2014

Completion date: 23/09/2011
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 100.5 - 103.5 mbgl
Gravel pack: 100 - 107 mbgl



PARSONS BRINCKERHOFF	Drawing No.: HU0019PZA - Bore Construction	
	Revision: A	Date drawn: 5/3/14
	Drawn by: K. Maher	Checked by: L. Rochford
	Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

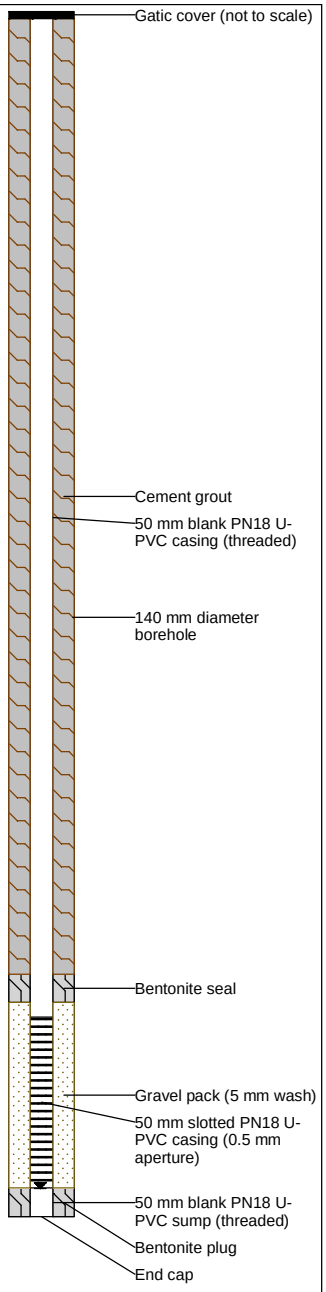
BORE COMPLETION REPORT

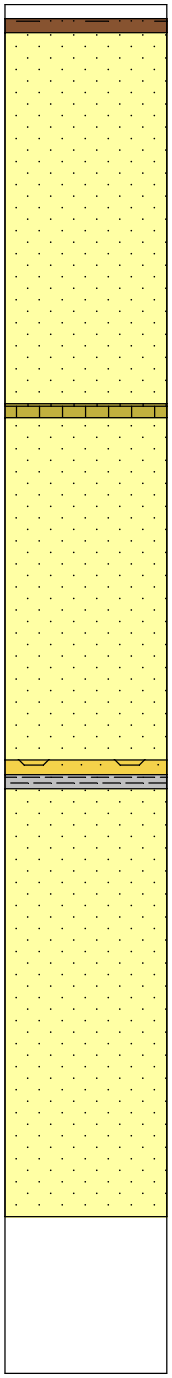
HU0019PZB

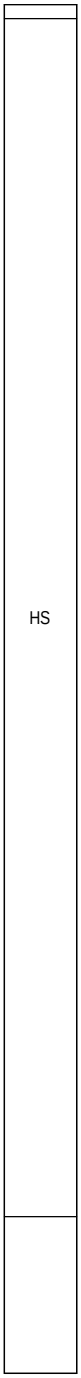
Project: Hume Coal Project
Easting: 243562 **Northing:** 6174379 **(MGA Zone 56)**
Top of casing: 720.335 mAHD
Ground level: 720.46 mAHD
Static water level: 82.05 mbgl **Date:** 17/11/2014

Completion date: 26/09/2011
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 70 - 82 mbgl
Gravel pack: 69.0 - 82.5 mbgl

BORE CONSTRUCTION	LITHOLOGY	FORMATION	DEPTH (m)	WATER QUALITY / INFLOW







Note: Bore was dry during drilling

PARSONS BRINCKERHOFF	Drawing No.: HU0018PZB - Bore Construction	HUMECOAL PROJECT
	Revision: A / Date drawn: 5/3/14	
	Drawn by: K. Maher / Checked by: L. Rochford	Hume Coal Pty Ltd
	Project No. 2172599A	

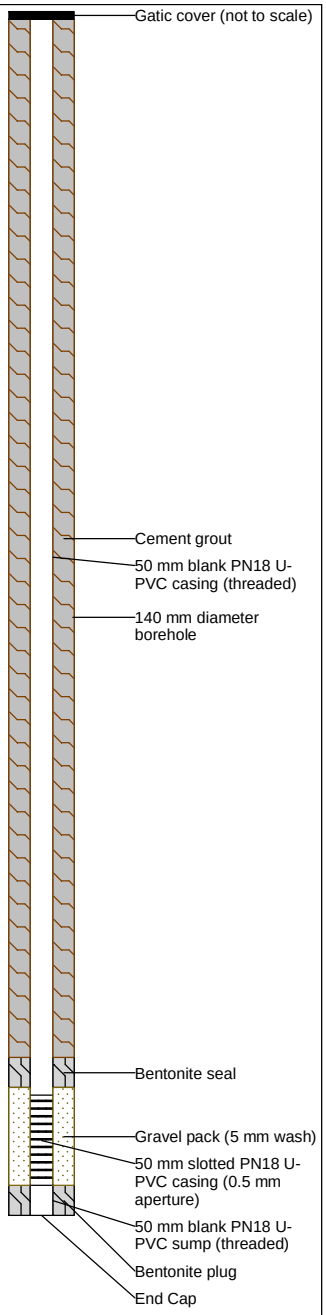
BORE COMPLETION REPORT

HU0020PZA

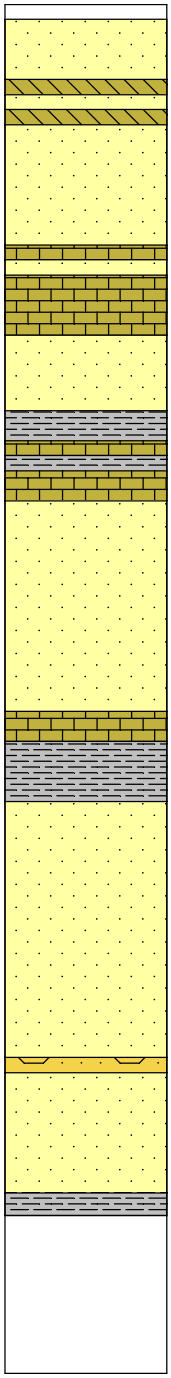
Project: Hume Coal Project
Easting: 244258 **Northing:** 6176920 **(MGA Zone 56)**
Top of casing: 703.18 mAHD
Ground level: 703.25 mAHD
Static water level: DRY **Date:** N/A

Completion date: 27/09/2011
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 71.5 - 77.5 mbgl
Gravel pack: 71.0 - 78 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

ICM

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90

WATER QUALITY / INFLOW

**Note: bore was dry dring drilling

PARSONS BRINCKERHOFF	Drawing No.: HU0020PZA - Bore construction	
	Revision: A	Date drawn: 5/3/14
	Drawn by: K. Maher	Checked by: L. Rochford
	Project No. 2172599A	

HUMECOAL PROJECT

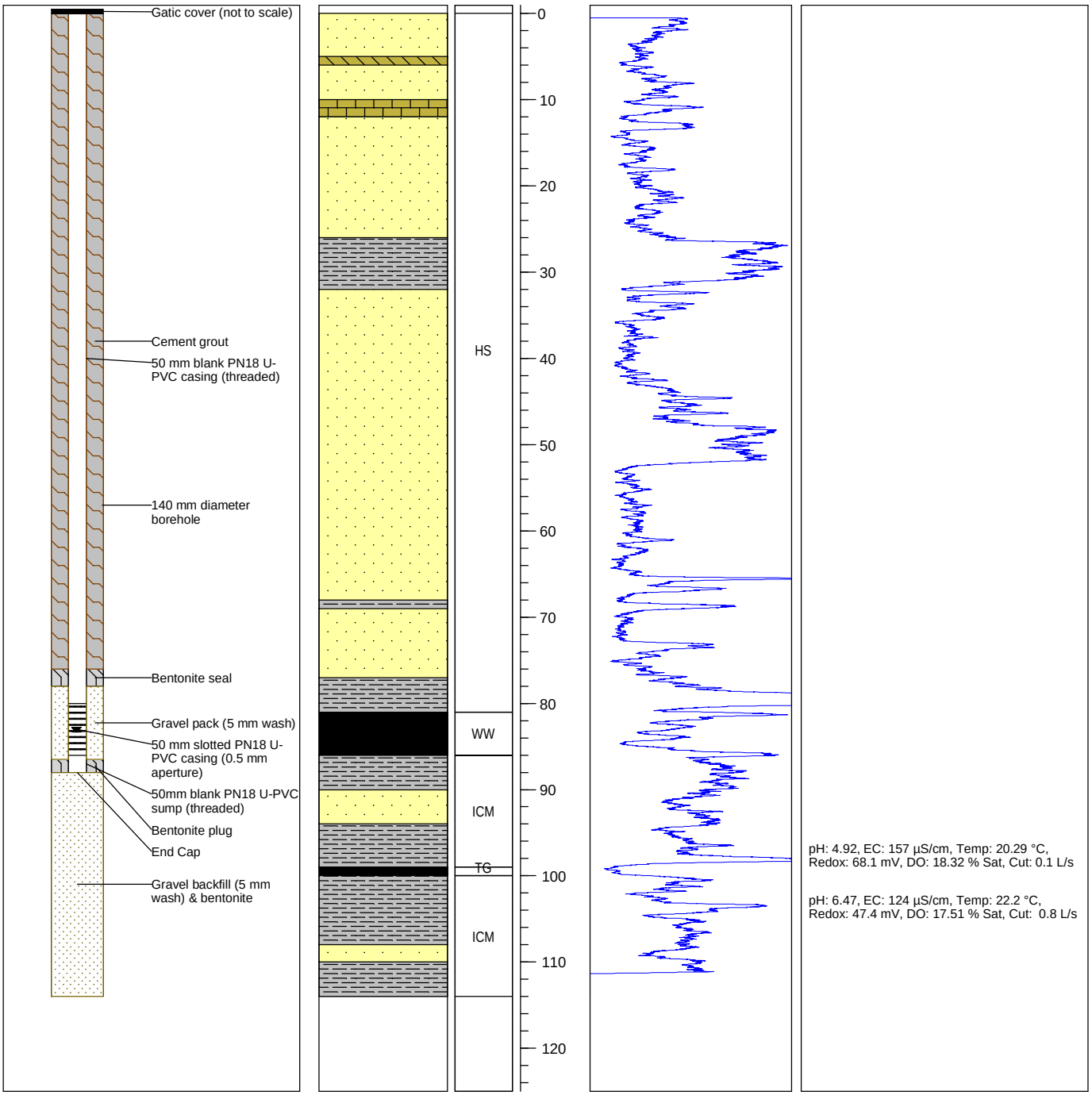
Hume Coal Pty Ltd

BORE COMPLETION REPORT

HU0020PZB

Project: Hume Coal Project
Easting: 244255 **Northing:** 6176930 **(MGA Zone 56)**
Top of casing: 703.59 mAHD
Ground level: 703.67 mAHD
Static water level: 83.335 mbgl **Date:** 17/11/2014

Completion date: 28/09/2011
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 80 - 86 mbgl
Gravel pack: 78.0 - 86.5 mbgl



PARSONS BRINCKERHOFF	Drawing No.: HU0020PZB - Bore construction	
	Revision: A	Date drawn: 5/3/14
	Drawn by: K. Maher	Checked by: L. Rochford
	Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

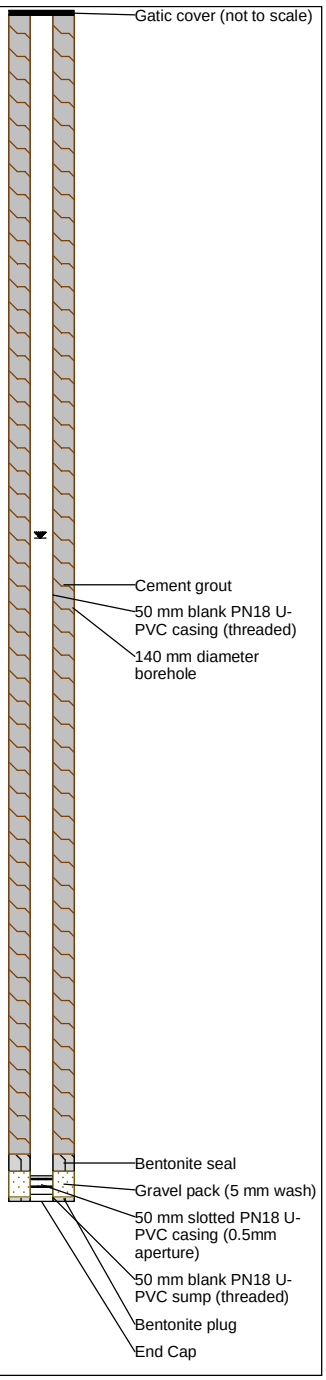
BORE COMPLETION REPORT

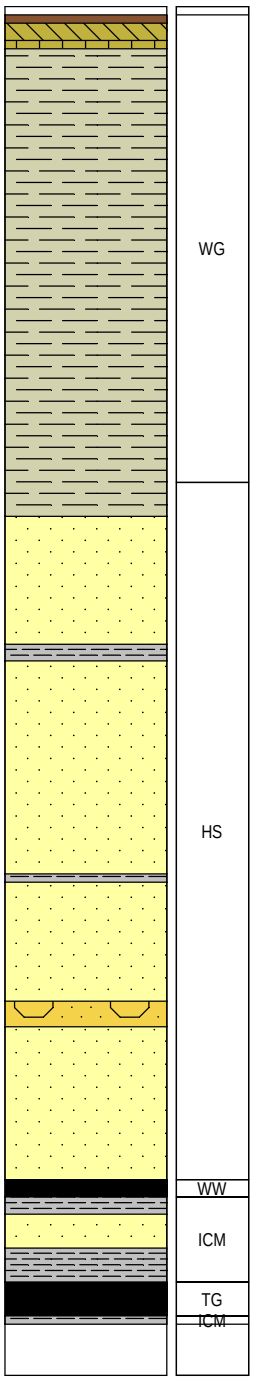
HU0023PZA (Decommissioned)

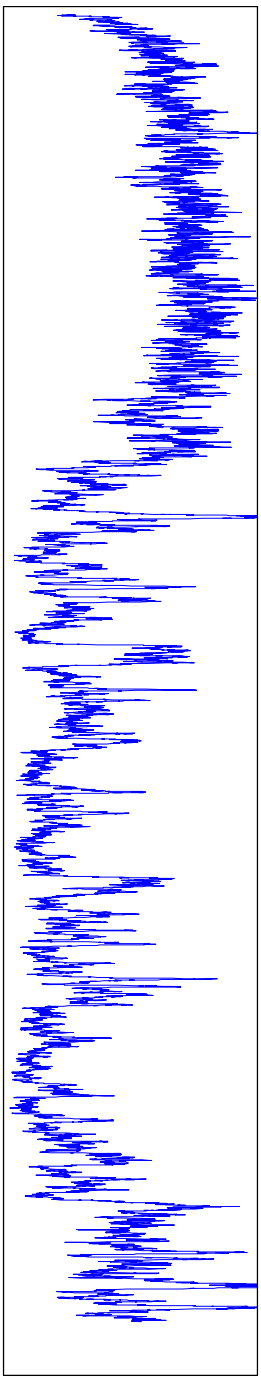
Project: Hume Coal Project
Easting: 250769 **Northing:** 6169622 **(MGA Zone 56)**
Top of casing: 680.38 mAHD
Ground level: 680.47 mAHD
Static water level: 61.55 mbgl **Date:** 21/05/2014

Completion date: 20/10/2011
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 136.5 - 138.7 mbgl
Gravel pack: 136.0 - 139.0 mbgl

BORE CONSTRUCTION	LITHOLOGY	FORMATION	DEPTH (m)	GAMMA (API-Gr) 0 – 250	WATER QUALITY / INFLOW







pH: 7.96, EC: 1851 µS/cm, Temp: 20.88 °C, Redox: -14.7 mV, DO: 158.2 % Sat, TDS: 1.204 g/L, Cut: 0.1 L/s
Cut: 0.1 L/s

pH: 8.03, EC: 1022 µS/cm, Temp: 21.2 °C, Redox: -14.3 mV, DO: 175 % Sat, TDS: 0.662 g/L, Cut: 0.1 L/s

pH: 7.98, EC: 481 µS/cm, Temp: 22.21 °C, Redox: -16.7 mV, DO: 159.4 % Sat, TDS: 0.312 g/L, Cut: 0.2 L/s
Cut: 0.5 L/s

pH: 7.47, EC: 253 µS/cm, Temp: 18.96 °C, Redox: -62.5 mV, DO: 122 % Sat, TDS: 0.166 g/L, Cut: 1.4 L/s

pH: 6.84, EC: 194 µS/cm, Temp: 18 °C, Redox: -47.1 mV, DO: 152 % Sat, TDS: 0.126 g/L, Cut: 2 L/s

pH: 6.71, EC: 197 µS/cm, Temp: 17.92 °C, Redox: -62.3 mV, DO: 6.71 % Sat, TDS: 0.136 g/L, Cut: 4 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0023PZA - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

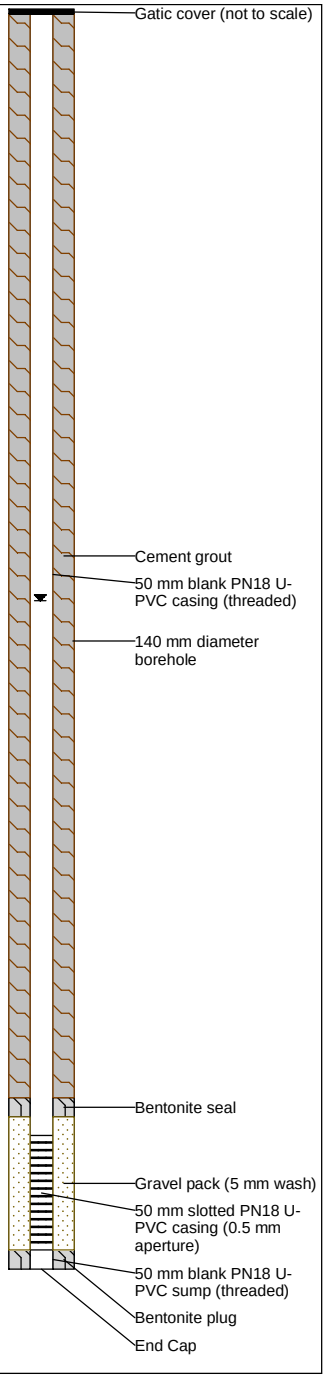
Hume Coal Pty Ltd

BORE COMPLETION REPORT — HU0023PZB (Decommissioned)

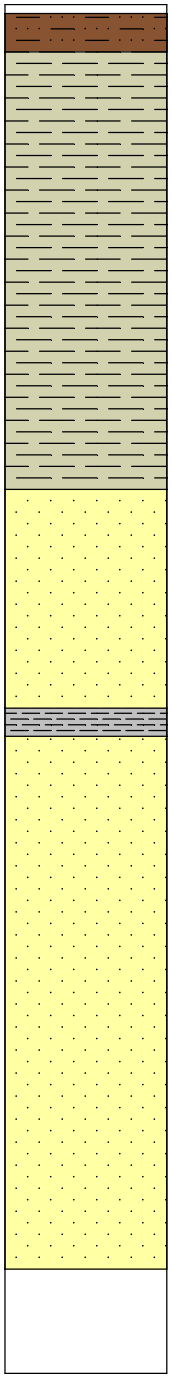
Project: Hume Coal Project
Easting: 250763 **Northing:** 6169620 **(MGA Zone 56)**
Top of casing: 680.55 mAHD
Ground level: 680.63 mAHD
Static water level: 61.7 mbgl **Date:** 21/05/2014

Completion date: 24/10/2011
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 118.0 - 130.0 mbgl
Gravel pack: 116.0 - 130.0 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

WG

HS

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140

WATER QUALITY / INFLOW

pH: 7.03, EC: 172 µS/cm, Temp: 25.1 °C, Redox: 41.3 mV, DO: 86.5 % Sat, TDS: 0.112 g/L, Cut: 0.5 L/s

pH: 6.66, EC: 186 µS/cm, Temp: 19.12 °C, Redox: -60.6 mV, DO: 25.5 % Sat, TDS: 0.123 g/L, Cut: 2.1 L/s

pH: 6.84, EC: 183 µS/cm, Temp: 19.35 °C, Redox: -11.4 mV, DO: 191.2 % Sat, TDS: 0.118 g/L, Cut: 3 L/s

pH: 6.71, EC: 196 µS/cm, Temp: 19.25 °C, Redox: -63.3 mV, DO: 230.7 % Sat, TDS: 0.129 g/L, Cut: 4 L/s

pH: 6.67, EC: 197 µS/cm, Temp: 19.45 °C, Redox: -61.4 mV, DO: 740.8 % Sat, TDS: 0.127 g/L, Cut: 5 L/s

PARSONS BRINCKERHOFF	Drawing No.: HU0023PZB - Bore construction	
	Revision: A	Date drawn: 5/3/14
	Drawn by: K. Maher	Checked by: L. Rochford
	Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

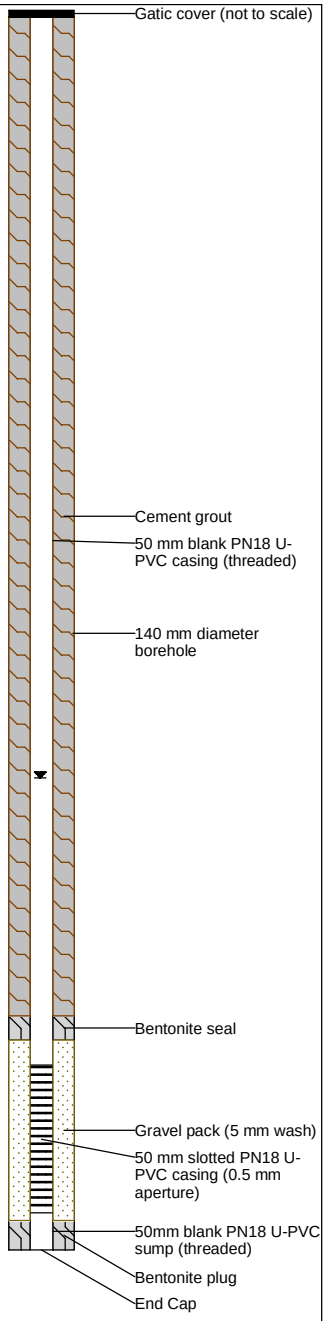
BORE COMPLETION REPORT

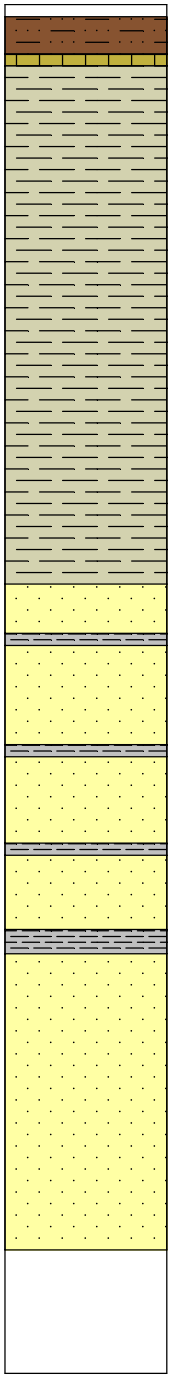
HU0023PZC (Decommissioned)

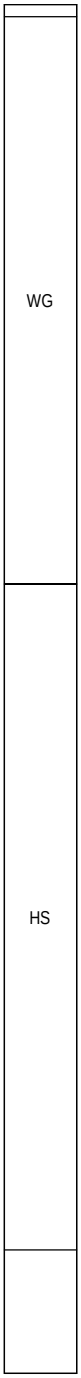
Project: Hume Coal Project
Easting: 250754 **Northing:** 6169617 **(MGA Zone 56)**
Top of casing: 680.69 mAHD
Ground level: 680.76 mAHD
Static water level: 61.72 mbgl **Date:** 21/05/2014

Completion date: 21/10/2011
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 85.0 - 97.0 mbgl
Gravel pack: 83.0 - 97.6 mbgl

BORE CONSTRUCTION	LITHOLOGY	FORMATION	DEPTH (m)	WATER QUALITY / INFLOW







pH: 6.87, EC: 179 µS/cm, Temp: 19.26 °C, Redox: -2 mV, DO: 129.2 % Sat, TDS: 0.115 g/L, Cut: 3 L/s

PARSONS BRINCKERHOFF	Drawing No.: HU0023PZC - Bore construction	
	Revision: A	Date drawn: 5/3/14
	Drawn by: K. Maher	Checked by: L. Rochford
	Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

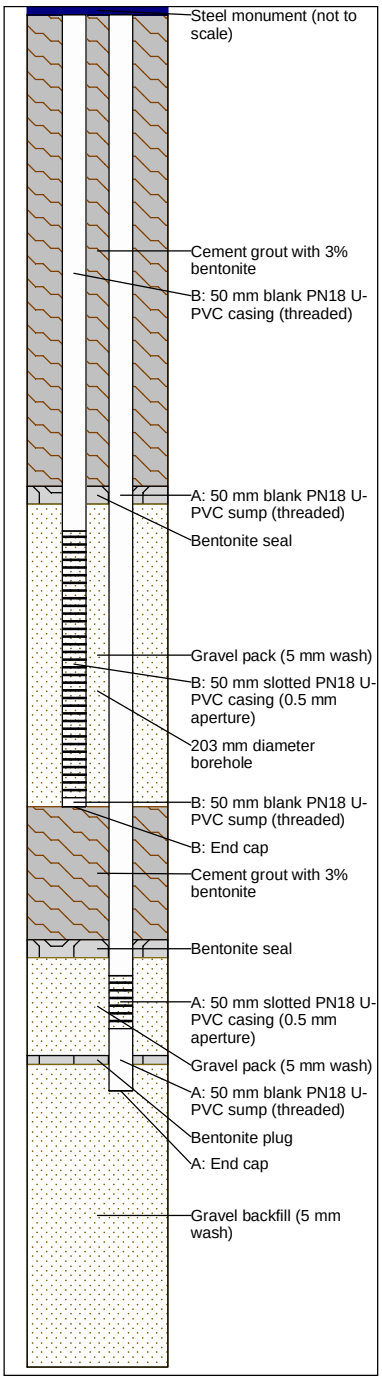
BORE COMPLETION REPORT

HU0032LDA/B

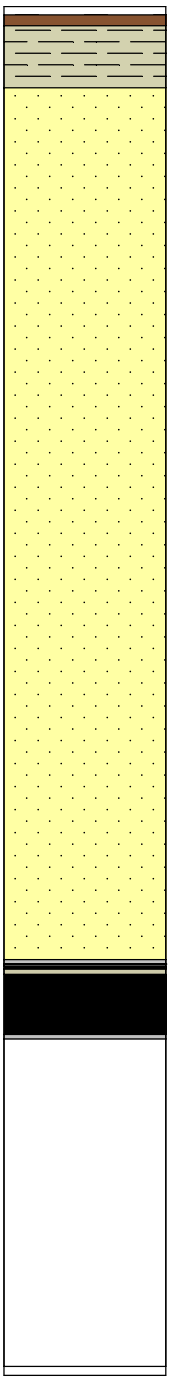
Project: Hume Coal Project
Easting: 249532 **Northing:** 6173533 **(MGA Zone 56)**
Top of casing: A - 646.775 / B - 646.725 mAHD
Ground level: 646.6 mAHD
Static water level: A - 10.19 / B - 10.2 mbgl **Date:** 17/11/2014

Completion date: 29/03/2012
Drlling company: Highland Drilling
Drlling method: Mud rotary
Screened interval: B: 58.0 - 88.0 mbgl / A: 108.0 - 114.0 mbgl
Gravel pack: B: 55.0 - 89.0 mbgl / A: 106.0 - 117.0 mbgl

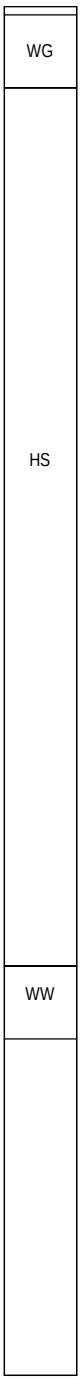
BORE CONSTRUCTION



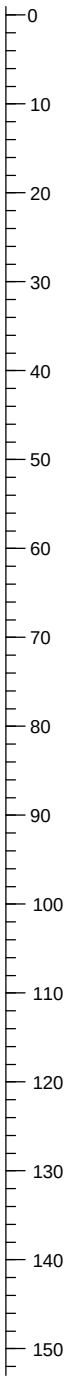
LITHOLOGY



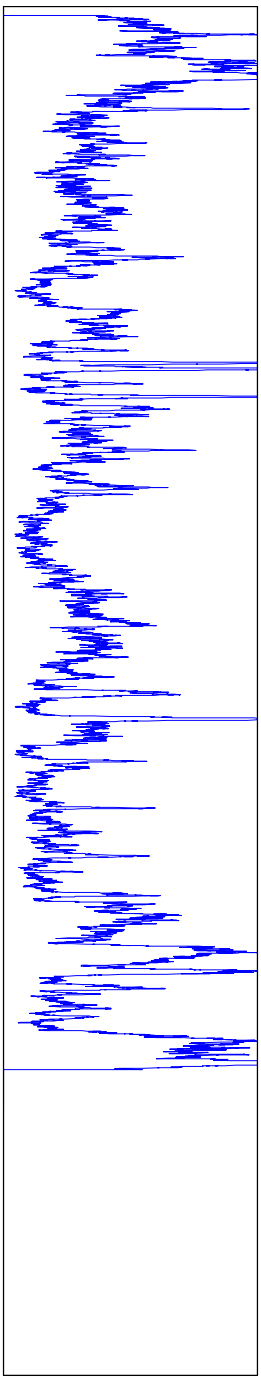
FORMATION



DEPTH (m)



GAMMA (API-Gr)



WATER QUALITY / INFLOW

***Note: no water quality due to drilling method

PARSONS BRINCKERHOFF	Drawing No.: HU0032LDA/B - Bore construction	
	Revision: A	Date drawn: 5/3/14
	Drawn by: K. Maher	Checked by: L. Rochford
	Project No. 2172599A	

HUMECOAL PROJECT

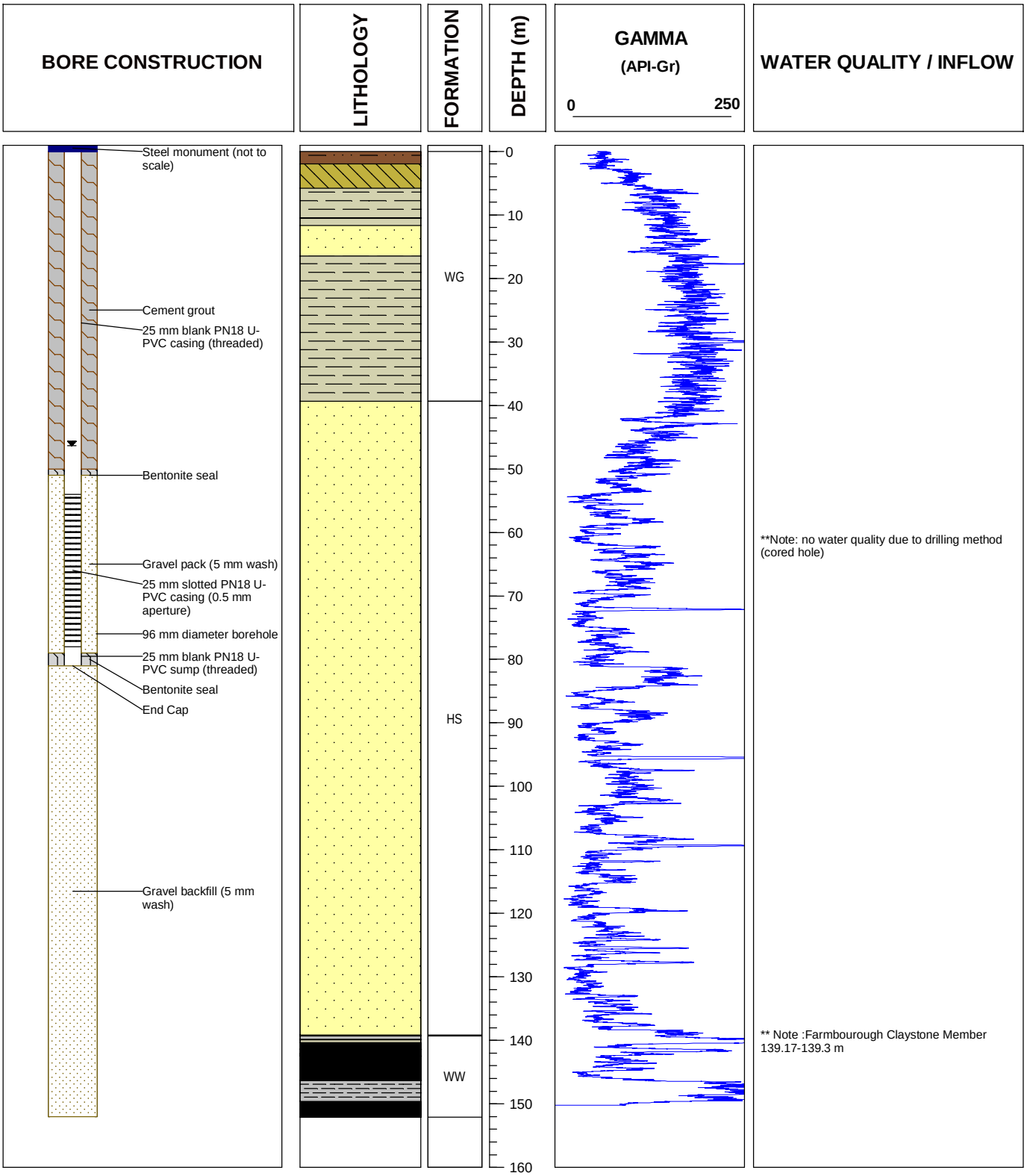
Hume Coal Pty Ltd

BORE COMPLETION REPORT

HU0035PZA

Project: Hume Coal Project
Easting: 250523 **Northing:** 6172486 **(MGA Zone 56)**
Top of casing: 682.158 mAHD
Ground level: 681.43 mAHD
Static water level: 46.322 mbgl **Date:** 17/11/2014

Completion date: 29/03/2012
Drlling company: Highland Drilling
Drlling method: Mud rotary
Screened interval: 54 - 78 mbgl
Gravel pack: 52 - 79 mbgl



PARSONS BRINCKERHOFF	Drawing No.: Hu0035PZA - Bore construction	
	Revision: A	Date drawn: 5/3/14
	Drawn by: K. Maher	Checked by: L. Rochford
	Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

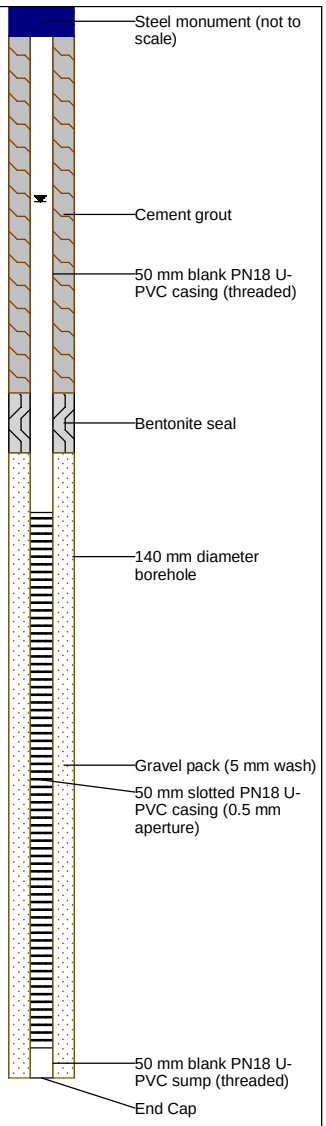
BORE COMPLETION REPORT

HU0035PZB

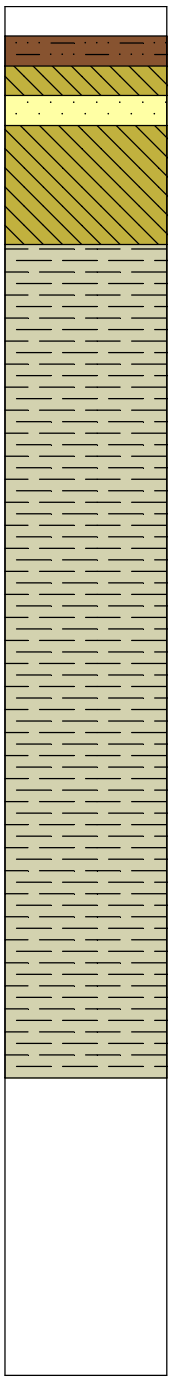
Project: Hume Coal Project
Easting: 250531 **Northing:** 6172487 **(MGA Zone 56)**
Top of casing: 681.517 mAHD
Ground level: 680.84 mAHD
Static water level: 5.563 mbgl **Date:** 17/11/2014

Completion date: 29/03/2012
Drlling company: Highland Drilling
Drlling method: Mud rotary
Screened interval: 16 – 34 mbgl
Gravel pack: 14.0 - 35.0 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

WG

DEPTH (m)

0
10
20
30
40

WATER QUALITY / INFLOW

**Note: no water quality due to drilling method (mud rotary)

PARSONS BRINCKERHOFF	Drawing No.: HU0035PZB - Bore construction	
	Revision: A	Date drawn: 5/3/14
	Drawn by: K. Maher	Checked by: L. Rochford
	Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

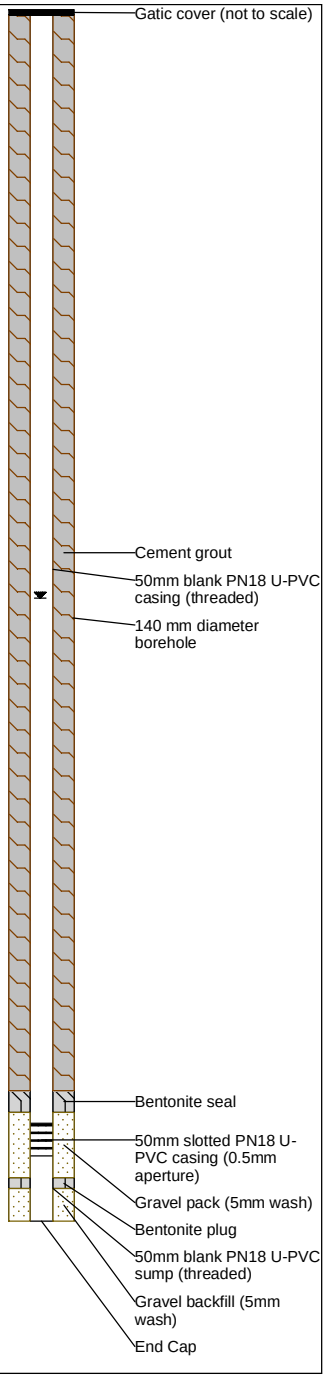
BORE COMPLETION REPORT

HU0037PZA

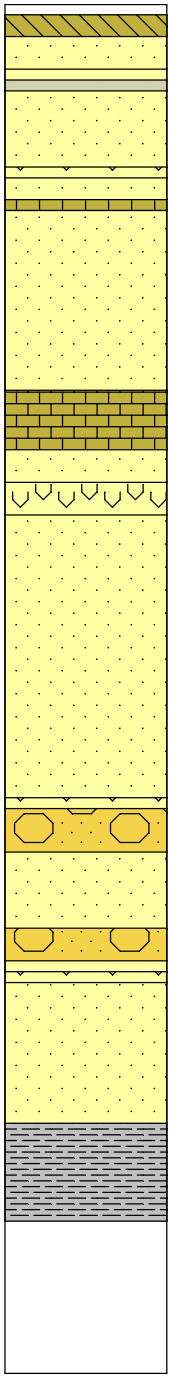
Project: Hume Coal Project
Easting: 246551 **Northing:** 6167440 **(MGA Zone 56)**
Top of casing: 703.7 mAHD
Ground level: 703.79 mAHD
Static water level: 53.64 mbgl **Date:** 13/11/2014

Completion date: 20/04/2012
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 102 – 105 mbgl
Gravel pack: 101 - 107 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

ICM

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120

WATER QUALITY / INFLOW

pH: 5.74, EC: 240 µS/cm, Temp: 19.39 mV, Redox: 83.2 % Sat, DO: 92.5 g/L, Cut: <0.01 L/s

pH: 6.18, EC: 112 µS/cm, Temp: 19.63 mV, Redox: 61.1 % Sat, DO: 96.3 g/L, Cut: 0.1 L/s
pH: 5.76, EC: 109 µS/cm, Temp: 19.01 mV, Redox: 104.8 % Sat, DO: 100.4 g/L, Cut: 0.1 L/s

pH: 5.8, EC: 114 µS/cm, Temp: 23.03 mV, Redox: 102.8 % Sat, DO: 97 g/L, Cut: 0.2 L/s
pH: 6.02, EC: 103 µS/cm, Temp: 19.22 mV, Redox: 85.5 % Sat, DO: 108 g/L, Cut: 0.2 L/s

pH: 6.29, EC: 99 µS/cm, Temp: 19.02 mV, Redox: 51.5 % Sat, DO: 115.3 g/L, Cut: 1 L/s

pH: 6.45, EC: 114 µS/cm, Temp: 19.34 mV, Redox: 33.6 % Sat, DO: 105 g/L, Cut: 1 L/s

pH: 6.74, EC: 109 µS/cm, Temp: 16.23 mV, Redox: -15.1 % Sat, DO: 106 g/L, Cut: 1-1.5 L/s

pH: 6.62, EC: 105 µS/cm, Temp: 17.19 mV, Redox: 1.7 % Sat, DO: 85.2 g/L, Cut: 1.5-2 L/s

pH: 6.6, EC: 103 µS/cm, Temp: 16.17 mV, Redox: 26.8 % Sat, DO: 102.5 g/L, Cut: 1.5-2 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0037PZA - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

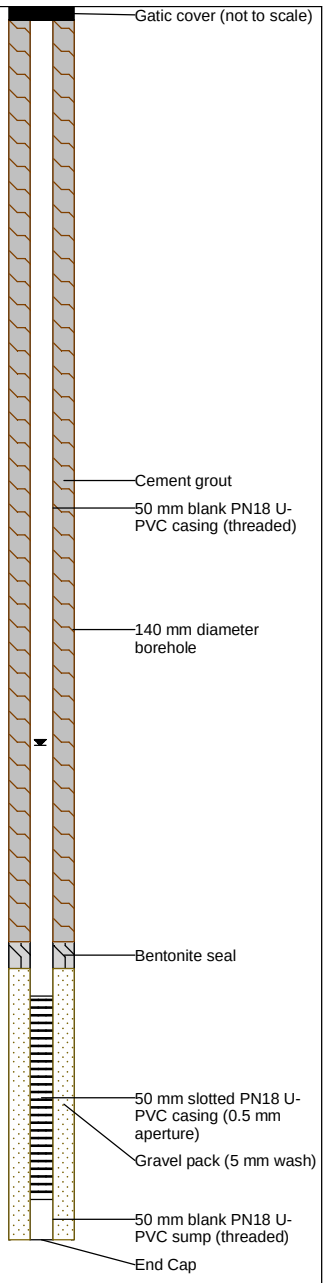
BORE COMPLETION REPORT

HU0037PZB

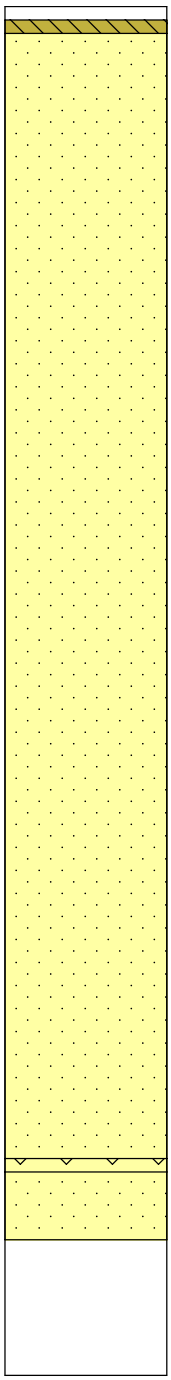
Project: Hume Coal Project
Easting: 246546 **Northing:** 6167438 **(MGA Zone 56)**
Top of casing: 703.694 mAHD
Ground level: 703.77 mAHD
Static water level: 53.536 mbgl **Date:** 13/11/2014

Completion date: 20/04/2012
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 72 – 87 mbgl
Gravel pack: 70 - 90 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100

WATER QUALITY / INFLOW

pH: 5.65, EC: 322 µS/cm, Temp: 24.8 mV, Redox: 75.6 % Sat, Cut: <0.1L/s

pH: 5.52, EC: 233 µS/cm, Temp: 25.57 mV, Redox: 99.5 % Sat, Cut: <0.1L/s

pH: 5.82, EC: 135 µS/cm, Temp: 22.53 mV, Redox: 100.7 % Sat, Cut: 0.1L/s

pH: 6.34, EC: 135 µS/cm, Temp: 19.42 mV, Redox: 39.7 % Sat, Cut: 0.1L/s

pH: 6.5, EC: 126 µS/cm, Temp: 18.4 mV, Redox: 27.1 % Sat, Cut: 0.5-1L/s

pH: 6.55, EC: 121 µS/cm, Temp: 18.36 mV, Redox: 22.5 % Sat, Cut: 2L/s

pH: 6.55, EC: 113 µS/cm, Temp: 17.07 mV, Redox: 21.9 % Sat, Cut: 2L/s

pH: 6.6, EC: 122 µS/cm, Temp: 17.5 mV, Redox: 19.3 % Sat, Cut: 2L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0037PZB - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

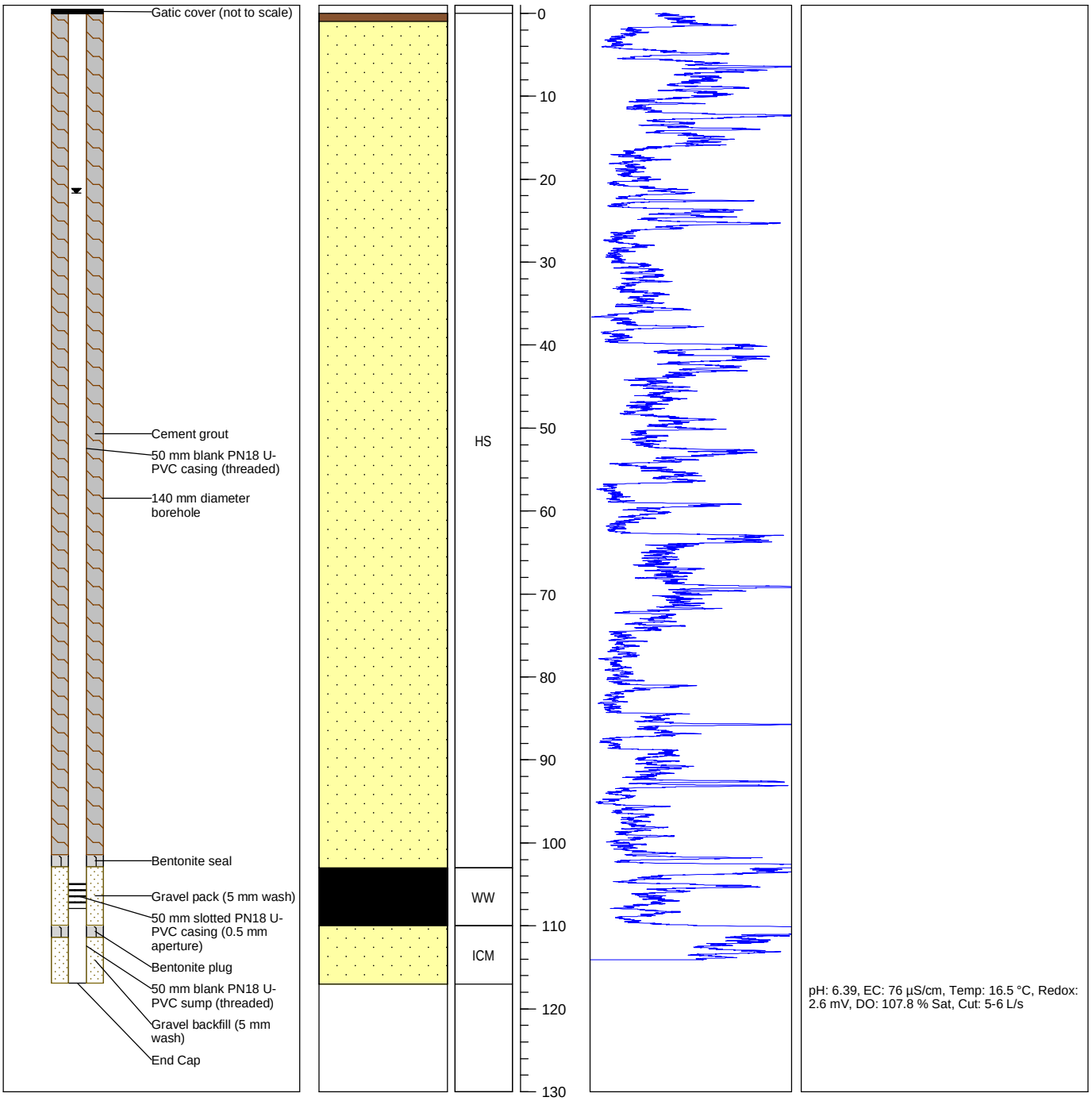
Hume Coal Pty Ltd

BORE COMPLETION REPORT

HU0038PZA

Project: Hume Coal Project
Easting: 248783 **Northing:** 6175453 **(MGA Zone 56)**
Top of casing: 658.44 mAHD
Ground level: 658.53 mAHD
Static water level: 20.895 mbgl **Date:** 2/12/2014

Completion date: 8/05/2012
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 104.9 – 107.9 mbgl
Gravel pack: 102.9 - 110 mbgl



PARSONS BRINCKERHOFF	Drawing No.: HU0038PZA - Bore construction	
	Revision: A	Date drawn: 5/3/14
	Drawn by: K. Maher	Checked by: L. Rochford
	Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

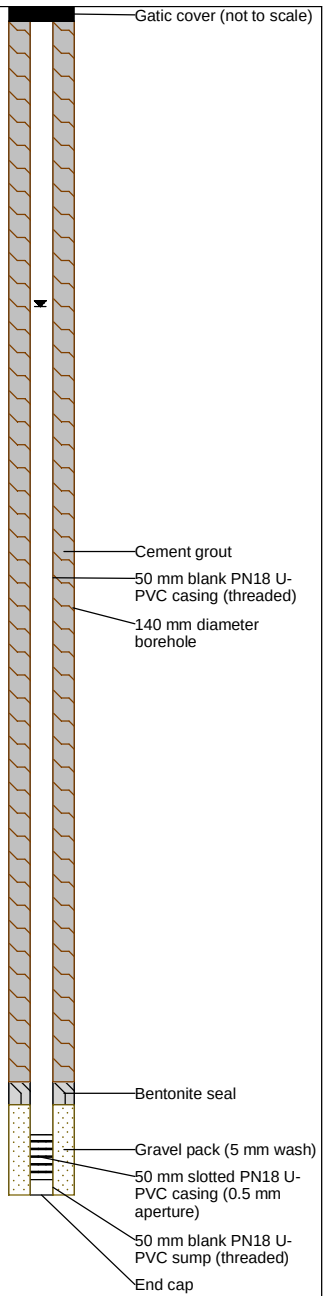
BORE COMPLETION REPORT

HU0038PZB

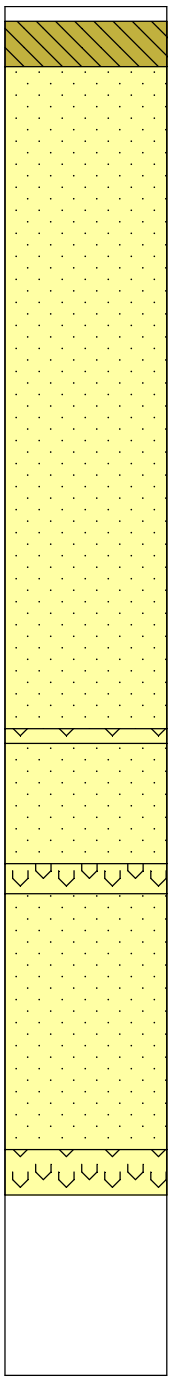
Project: Hume Coal Project
Easting: 248788 **Northing:** 6175452 **(MGA Zone 56)**
Top of casing: 658.332 mAHD
Ground level: 658.44 mAHD
Static water level: 18.968 mbgl **Date:** 2/12/2014

Completion date: 10/05/2012
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 74 – 77 mbgl
Gravel pack: 72 - 78 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90

WATER QUALITY / INFLOW

pH: 6.77, EC: 101 µS/cm, Temp: 17.73 °C, Redox: 122.8 mV, DO: 119.1 % Sat, Cut: 1 L/s

pH: 5.72, EC: 84 µS/cm, Temp: 18.68 °C, Redox: 141.7 mV, DO: 9.53 % Sat, Cut: 0.3 L/s

pH: 5.63, EC: 75 µS/cm, Temp: 19.42 °C, Redox: 133.1 mV, DO: 8.94 % Sat, Cut: 0.5 L/s

pH: 5.64, EC: 74 µS/cm, Temp: 17.17 °C, Redox: 117.4 mV, DO: 10.45 % Sat, Cut: 1-1.5 L/s

pH: 6.04, EC: 76 µS/cm, Temp: 19.94 °C, Redox: 77.2 mV, DO: 8.51 % Sat, Cut: 1-1.5 L/s

pH: 6.2, EC: 64 µS/cm, Temp: 18.1 °C, Redox: 61.3 mV, DO: 9.93 % Sat, Cut: 2.5-3 L/s

pH: 6.17, EC: 63 µS/cm, Temp: 16.98 °C, Redox: 68.4 mV, DO: 9.23 % Sat, Cut: 2.5-3 L/s

pH: 6.18, EC: 64 µS/cm, Temp: 17.46 °C, Redox: 55.3 mV, DO: 9.73 % Sat, Cut: 3-4 L/s

pH: 5.87, EC: 71 µS/cm, Temp: 16.38 °C, Redox: 100 mV, DO: 109.7 % Sat, Cut: 5-6 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0038PZB - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

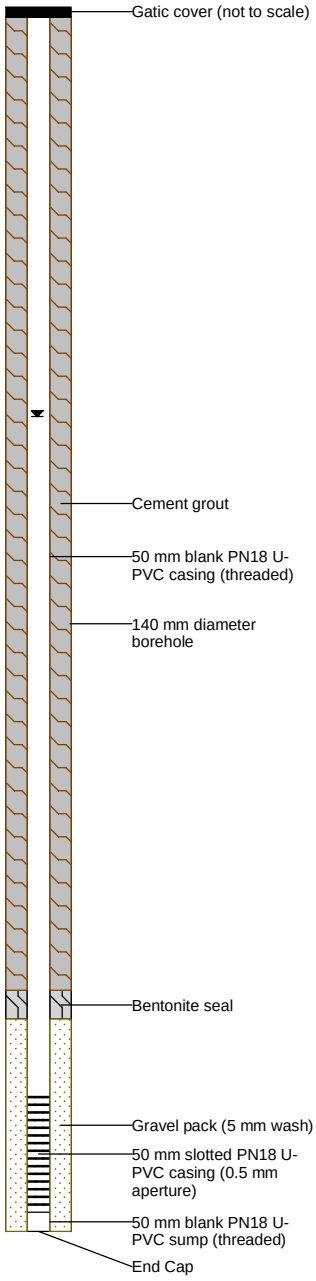
BORE COMPLETION REPORT

HU0038PZC

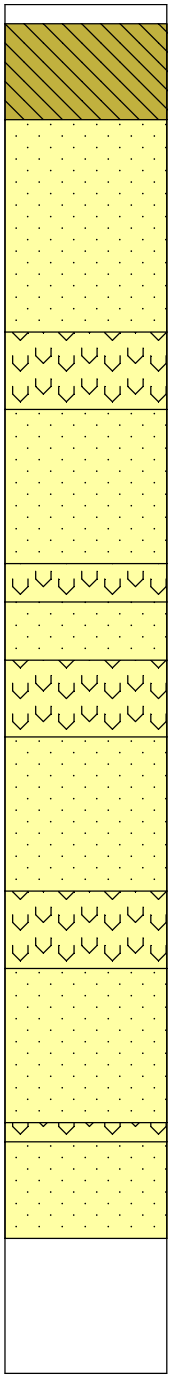
Project: Hume Coal Project
Easting: 248793 **Northing:** 6175452 **(MGA Zone 56)**
Top of casing: 658.172 mAHD
Ground level: 658.31 mAHD
Static water level: 20.738 mbgl **Date:** 2/12/2014

Completion date: 15/05/2012
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 56 – 62 mbgl
Gravel pack: 52 - 63 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70

WATER QUALITY / INFLOW

pH: 5.56, EC: 120 µS/cm, Temp: 21.9 °C, Redox: 139.7 mV, DO: 75.9 % Sat, TDS: 0.082 g/L, Cut: 0.7 L/s

pH: 5.42, EC: 53 µS/cm, Temp: 18.32 °C, Redox: 138.1 mV, DO: 120.6 % Sat, TDS: 0.039 g/L, Cut: 1.5 L/s

pH: 5.68, EC: 52 µS/cm, Temp: 19.79 °C, Redox: 139.5 mV, DO: 97.4 % Sat, TDS: 0.038 g/L, Cut: 1.5 L/s

pH: 5.88, EC: 47 µS/cm, Temp: 19.04 °C, Redox: 92.9 mV, DO: 95 % Sat, TDS: 0.035 g/L, Cut: 1.5 L/s

pH: 5.85, EC: 42 µS/cm, Temp: 16.84 °C, Redox: 95.8 mV, DO: 106.3 % Sat, TDS: 0.033 g/L, Cut: 2-3 L/s

pH: 6.34, EC: 43 µS/cm, Temp: 16.42 °C, Redox: 73.1 mV, DO: 91.7 % Sat, TDS: 0.033 g/L, Cut: 3.7 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0038PZC - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

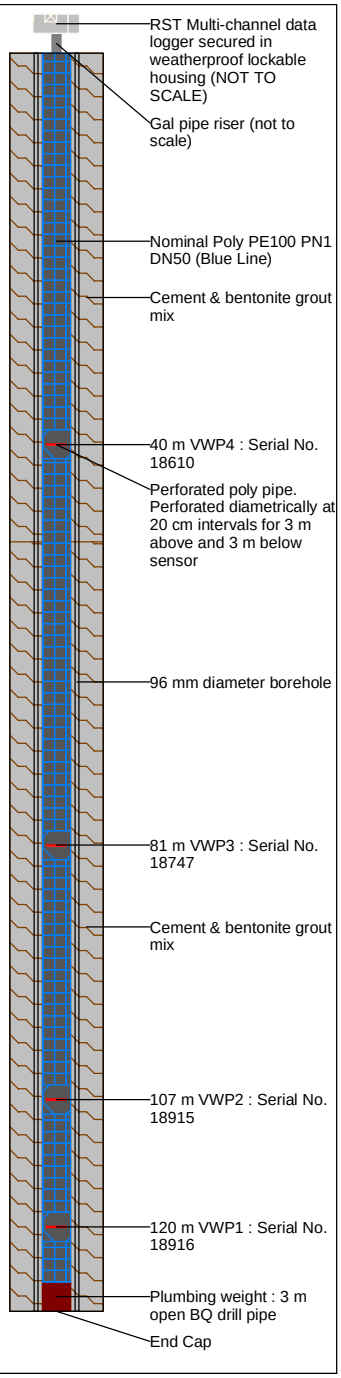
BORE COMPLETION REPORT

HU0040CH

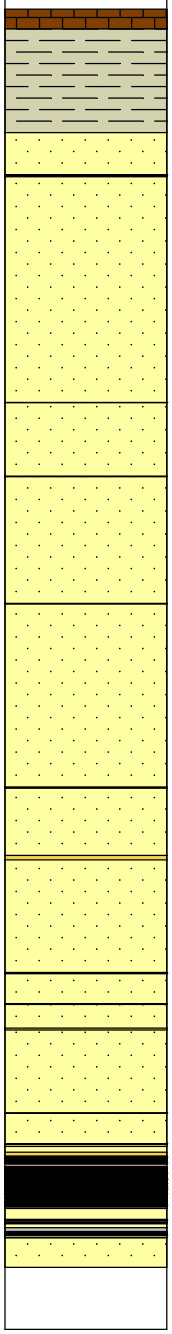
Project: Hume Coal Project
Easting: 251140 **Northing:** 6172143 **(MGA Zone 56)**
Top of casing: n/a
Ground level: 656.51 mAHD
Static water level: n/a **Date:** n/a

Completion date: 10/9/2013
Drlling company: Highland Drilling
Drlling method: Diamond core
Screened interval: n/a (VWP array)
Gravel pack: n/a (VWP array)

BORE CONSTRUCTION



LITHOLOGY



FORMATION

WG

HS

WW

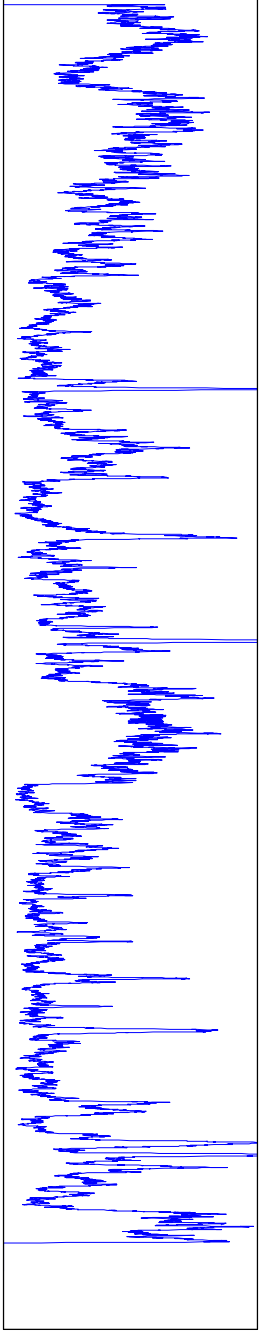
ICM

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130

GAMMA (API-Gr)

0 — 250



WATER QUALITY / INFLOW

***Note: no water quality due to drilling method and VWP installation

PARSONS BRINCKERHOFF	Drawing No.: HU0040CH - VWP construction	
	Revision: A	Date drawn: 5/3/14
	Drawn by: K. Maher	Checked by: L. Rochford
	Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

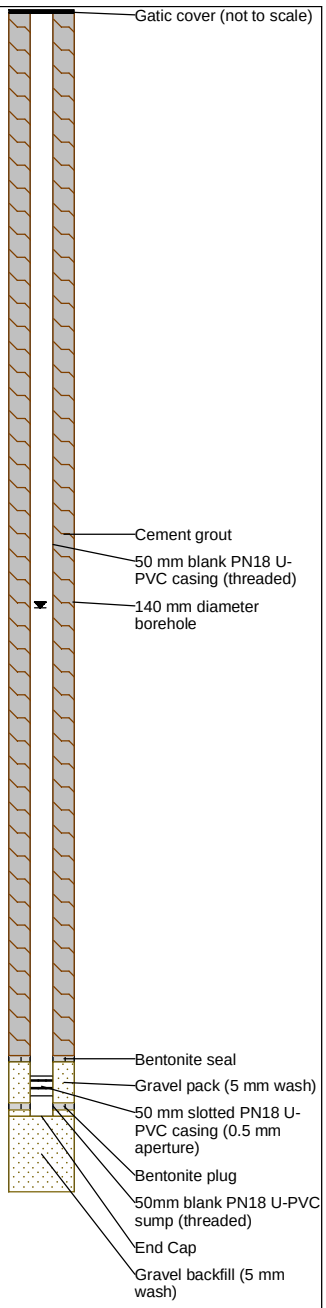
BORE COMPLETION REPORT

HU0042PZA

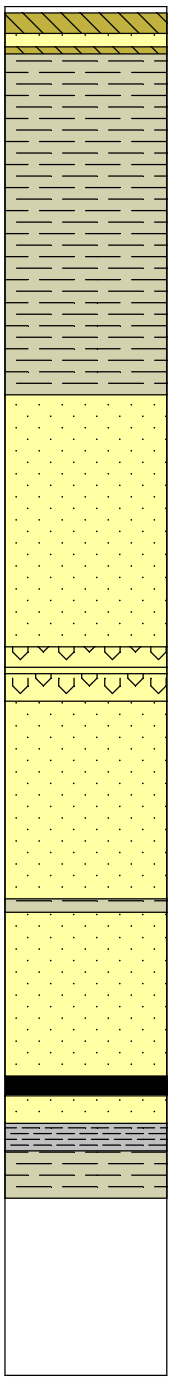
Project: Hume Coal Project
Easting: 250988 **Northing:** 6166688 **(MGA Zone 56)**
Top of casing: 702.432 mAHD
Ground level: 702.5 mAHD
Static water level: 87.268 mbgl **Date:** 17/11/2014

Completion date: 25/07/2012
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 156 - 159 mbgl
Gravel pack: 154 - 160 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

WG

HS

WW

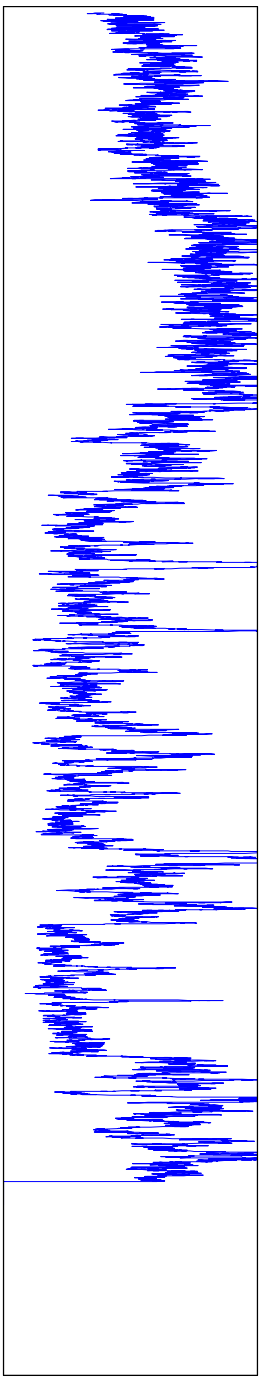
ICM

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200

GAMMA (API-Gr)

0 — 250



WATER QUALITY / INFLOW

pH: 6.12, EC: 197 µS/cm, Temp: 18.95 °C, Redox: 57.9 mV, DO: 51 % Sat, TDS: 0.128 g/L, Cut: <0.1 L/s

pH: 6.54, EC: 171 µS/cm, Temp: 15.56 , Redox: 45.2 mV, DO: 57.6 % Sat, TDS: 0.112 g/L, Cut: 0.1 L/s

pH: 6.64, EC: 187 µS/cm, Temp: 15.06 , Redox: 43.5 mV, DO: 57.4 % Sat, TDS: 0.122 g/L, Cut: 0.2 L/s

pH: 6.33, EC: 292 µS/cm, Temp: 17 , Redox: 23 mV, DO: 56.3 % Sat, TDS: 0.19 g/L, Cut: 0.5-1 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0042PZA - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

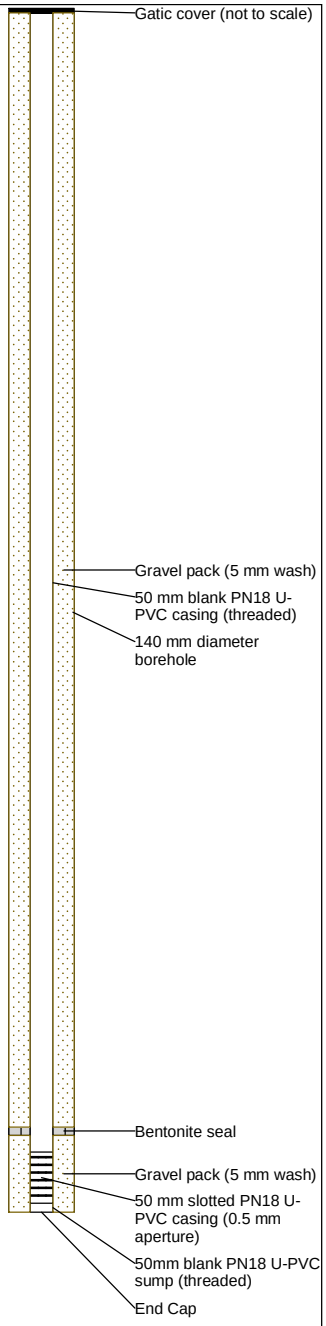
BORE COMPLETION REPORT

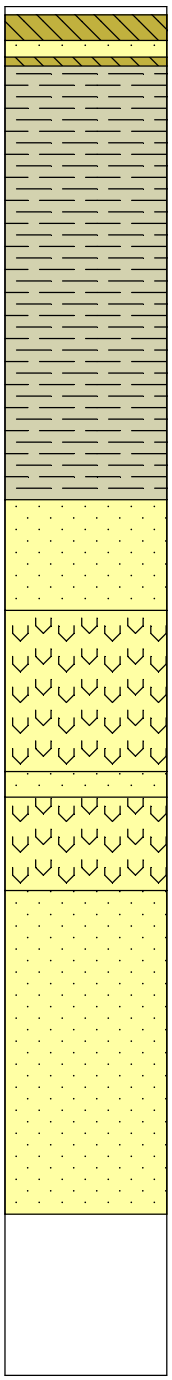
HU0042PZB (Abandoned)

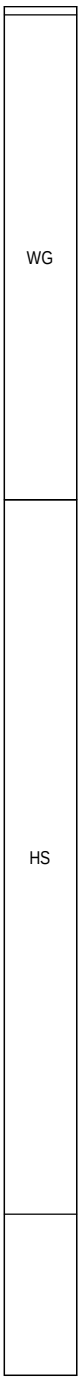
Project: Hume Coal Project
Easting: 250990 **Northing:** 6166681 **(MGA Zone 56)**
Top of casing: 702.63 mAHD
Ground level: 702.7 mAHD
Static water level: n/a **Date:** n/a

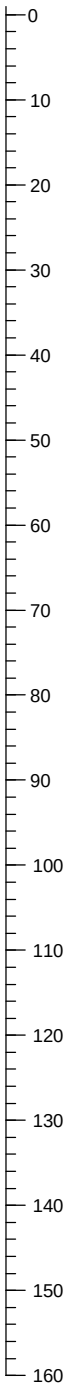
Completion date: 30/07/2012
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 134 - 140 mbgl
Gravel pack: 132 - 141 mbgl

BORE CONSTRUCTION	LITHOLOGY	FORMATION	DEPTH (m)	WATER QUALITY / INFLOW









pH: 5.93, EC: 167 µS/cm, Temp: 12.36 °C, Redox: 93.3 mV, DO: 42.4 % Sat, TDS: g/L, Cut: 0.01 L/s

pH: 6.5, EC: 149 µS/cm, Temp: 14.16 , Redox: 61 mV, DO: 44.1 % Sat, TDS: g/L, Cut: <0.1 L/s

pH: 6.7, EC: 143 µS/cm, Temp: 12.95 , Redox: 56.1 mV, DO: 35.6 % Sat, TDS: g/L, Cut: <0.1 L/s

pH: 6.6, EC: 131 µS/cm, Temp: 16.3 , Redox: 47.8 mV, DO: 32.1 % Sat, TDS: g/L, Cut: <0.1 L/s

pH: 6.59, EC: 140 µS/cm, Temp: 18.3 , Redox: 55.3 mV, DO: 28.8 % Sat, TDS: g/L, Cut: <0.1 L/s

pH: 6.07, EC: 162 µS/cm, Temp: 17.29 , Redox: 62.5 mV, DO: 40.6 % Sat, TDS: g/L, Cut: 0.25 L/s

pH: 6.44, EC: 405 µS/cm, Temp: 17.65 , Redox: 14.4 mV, DO: 34 % Sat, TDS: 0.263 g/L, Cut: 1.7 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0042PZB - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

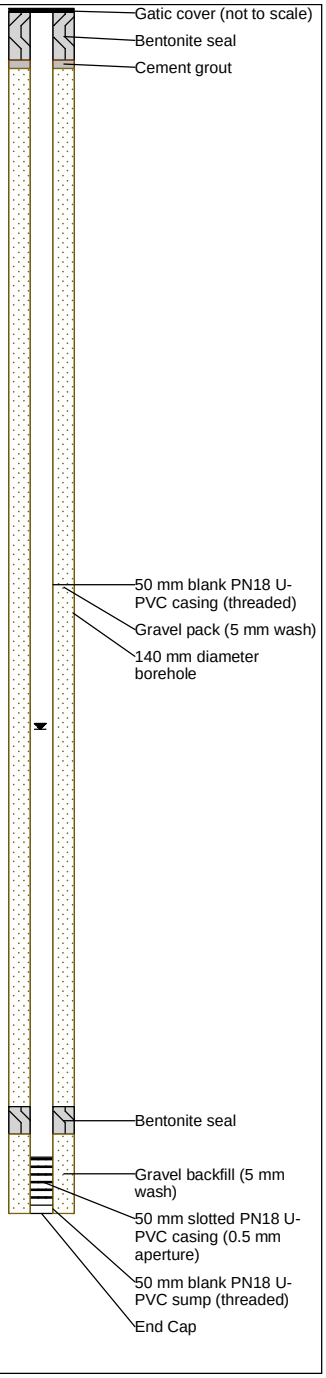
BORE COMPLETION REPORT

HU0042PZC

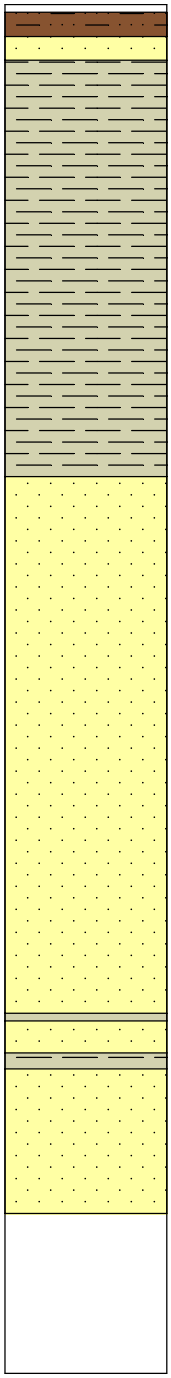
Project: Hume Coal Project
Easting: 250985 **Northing:** 6166678 **(MGA Zone 56)**
Top of casing: 701.918 mAHD
Ground level: 702 mAHD
Static water level: 89.517 mbgl **Date:** 17/11/2014

Completion date: 12/02/2013
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 143 - 149 mbgl
Gravel pack: 140 - 150 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

WG

HS

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170

WATER QUALITY / INFLOW

pH: 6.88, EC: 148 µS/cm, Temp: 25.3 °C, Redox: 116 mV, DO: 5.45 ppm, Cut: <0.1 L/s

pH: 7.31, EC: 245 µS/cm, Temp: 24.6 °C, Redox: 102 mV, DO: 6.21 ppm, Cut: <0.1 L/s

pH: 7.26, EC: 201 µS/cm, Temp: 25.9 °C, Redox: 88 mV, DO: 4.08 ppm, Cut: <0.1 L/s

pH: 7.34, EC: 202.2 µS/cm, Temp: 26.7 °C, Redox: 76 mV, DO: 2.03 ppm, Cut: 0.1 L/s

pH: 7.24, EC: 251 µS/cm, Temp: 26.5 °C, Redox: 74 mV, DO: 4.83 ppm, Cut: 0.3 L/s

pH: 7.41, EC: 400 µS/cm, Temp: 27.8 °C, Redox: 81 mV, DO: 4.22 ppm, Cut: 0.4 L/s

pH: 7.31, EC: 391 µS/cm, Temp: 26.1 °C, Redox: 84 mV, DO: 4.48 ppm, Cut: 0.75 L/s

pH: 6.6, EC: 406 µS/cm, Temp: 20.3 °C, Redox: 82 mV, DO: 7.06 ppm, Cut: 2.1 L/s

pH: 6.7, EC: 388 µS/cm, Temp: 17.5 °C, Redox: 68 mV, DO: 5.65 ppm, Cut: 5 L/s

pH: 6.65, EC: 406 µS/cm, Temp: 19.4 °C, Redox: 42 mV, DO: 7.2 ppm, Cut: 2.3 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0042PZC - Bore construction	
Revision: A	Date drawn: 5/3/18
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

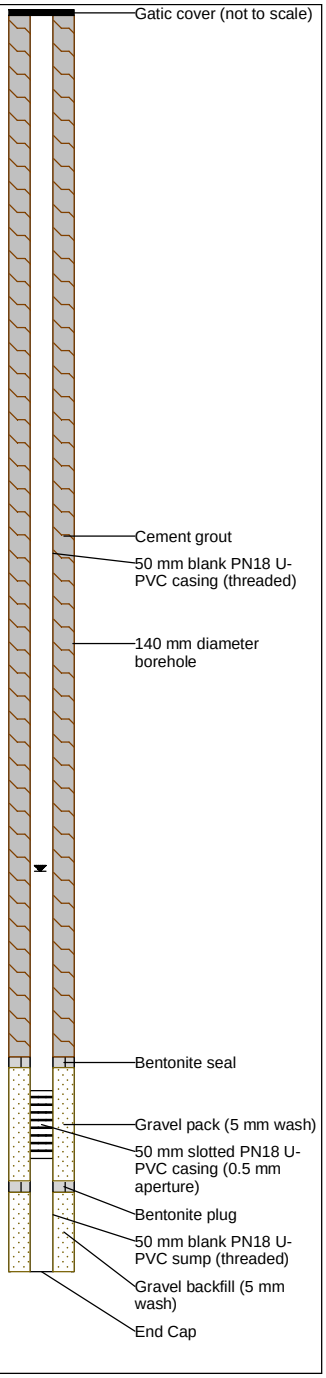
BORE COMPLETION REPORT

HU0043XPZA

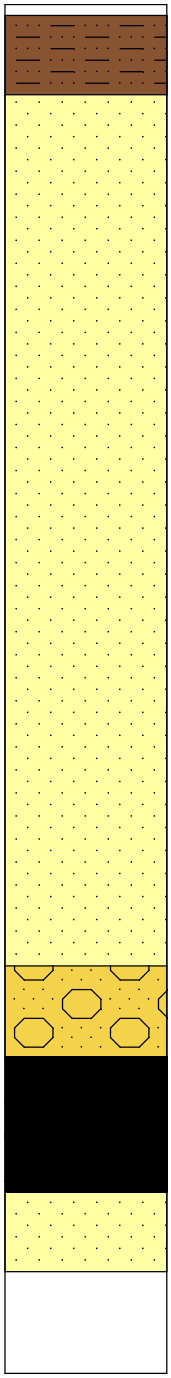
Project: Hume Coal Project
Easting: 247147 **Northing:** 6178127 **(MGA Zone 56)**
Top of casing: 691.96 mAHD
Ground level: 692.04 mAHD
Static water level: 75.62 mbgl **Date:** 5/02/2015

Completion date: 7/08/2012
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 95 - 101 mbgl
Gravel pack: 93 - 103 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

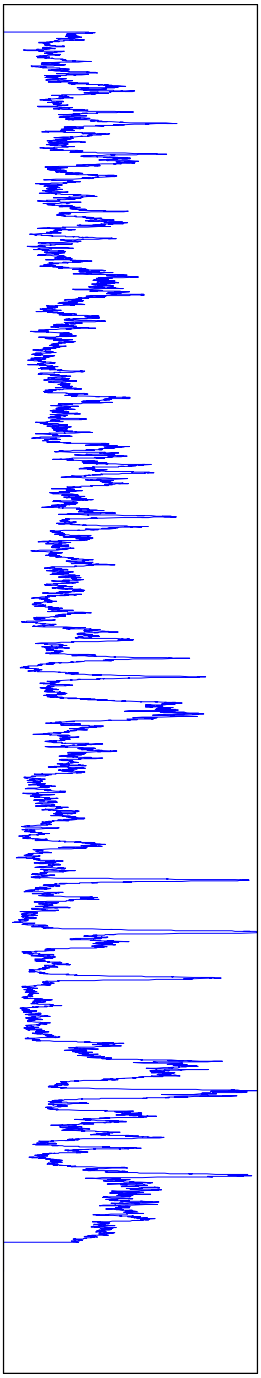
WW

ICM

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120

GAMMA (API-Gr)



WATER QUALITY / INFLOW

pH: 5.45, EC: 116 µS/cm, Temp: 10.42 °C, Redox: 144.7 mV, DO: 48.3 % Sat, TDS: 0.075 g/L, Cut: <0.1 L/s

pH: 5.42, EC: 81 µS/cm, Temp: 12.76 °C, Redox: 119.7 mV, DO: 47.5 % Sat, TDS: 0.053 g/L, Cut: <0.1 L/s

pH: 5.79, EC: 69 µS/cm, Temp: 18.8 °C, Redox: 116.9 mV, DO: 21 % Sat, TDS: 0.045 g/L, Cut: 0.7 L/s

pH: 5.74, EC: 71 µS/cm, Temp: 18.35 °C, Redox: 97.2 mV, DO: 25.2 % Sat, TDS: 0.046 g/L, Cut: 0.7 L/s

pH: 5.67, EC: 69 µS/cm, Temp: 16.26 °C, Redox: 122.2 mV, DO: 32.4 % Sat, TDS: 0.045 g/L, Cut: 0.7 L/s

pH: 5.54, EC: 91 µS/cm, Temp: 17.51 °C, Redox: 135.1 mV, DO: 22.9 % Sat, TDS: 0.058 g/L, Cut: 0.8 L/s

pH: 5.98, EC: 78 µS/cm, Temp: 17.48 °C, Redox: 79.3 mV, DO: 21.8 % Sat, TDS: 0.051 g/L, Cut: 1 L/s

pH: 6.42, EC: 81 µS/cm, Temp: 17.28 °C, Redox: 18.3 mV, DO: 21 % Sat, TDS: 0.053 g/L

PARSONS BRINCKERHOFF

Drawing No.: HU0043XPZA - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

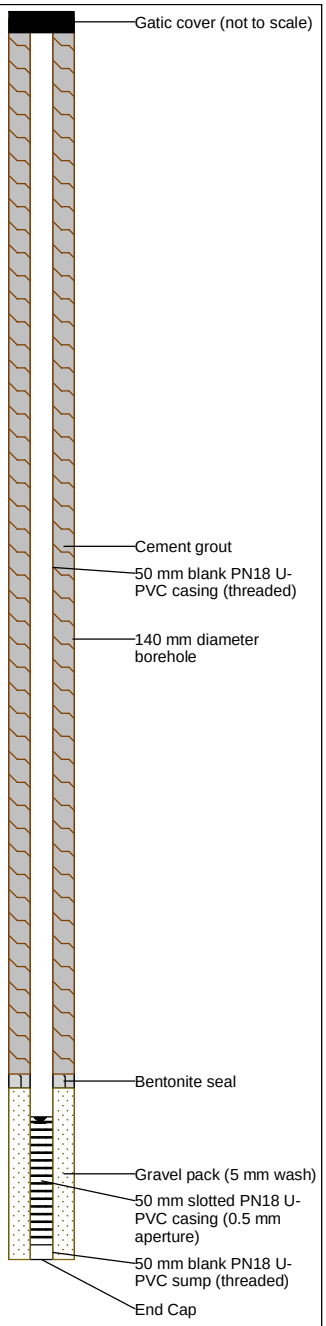
BORE COMPLETION REPORT

HU0043XPZB

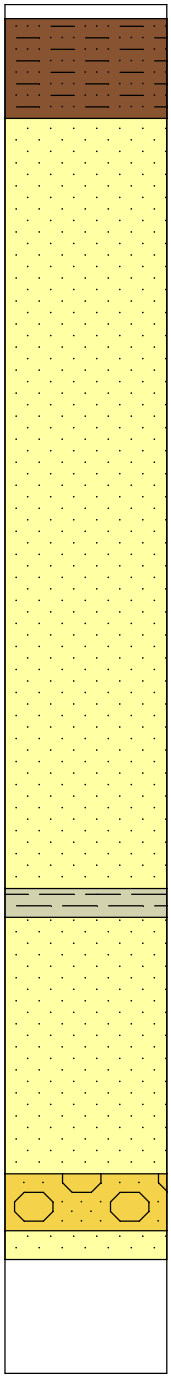
Project: Hume Coal Project
Easting: 247152 **Northing:** 6178133 **(MGA Zone 56)**
Top of casing: 691.69 mAHD
Ground level: 691.77 mAHD
Static water level: 77.465 mbgl **Date:** 5/02/2015

Completion date: 3/08/2012
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 77 - 86 mbgl
Gravel pack: 75 - 87 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90

WATER QUALITY / INFLOW

pH: 5.6, EC: 140 µS/cm, Temp: 17.21 °C, Redox: 119.1 mV, DO: 46.7 % Sat, TDS: 0.089 g/L, Cut: <0.1 L/s

pH: 5.66, EC: 81 µS/cm, Temp: 18.18 °C, Redox: 98.6 mV, DO: 30..4 % Sat, TDS: 0.054 g/L, Cut: <0.1 L/s

pH: 5.72, EC: 69 µS/cm, Temp: 17.08 °C, Redox: 106.8 mV, DO: 29.6 % Sat, TDS: 0.045 g/L, Cut: <0.1 L/s

pH: 6.4, EC: 61 µS/cm, Temp: 14.23 °C, Redox: 85.7 mV, DO: 22.3 % Sat, TDS: 0.04 g/L

PARSONS BRINCKERHOFF

Drawing No.: HU0043PZB - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

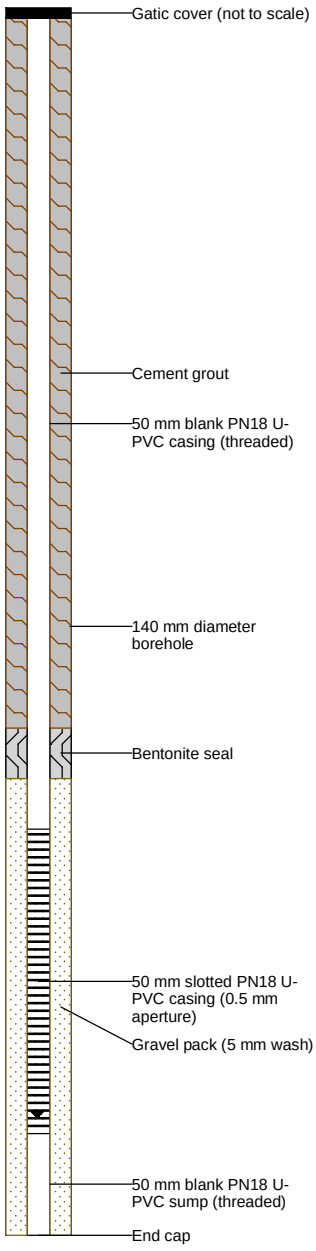
BORE COMPLETION REPORT

HU0044XPZA

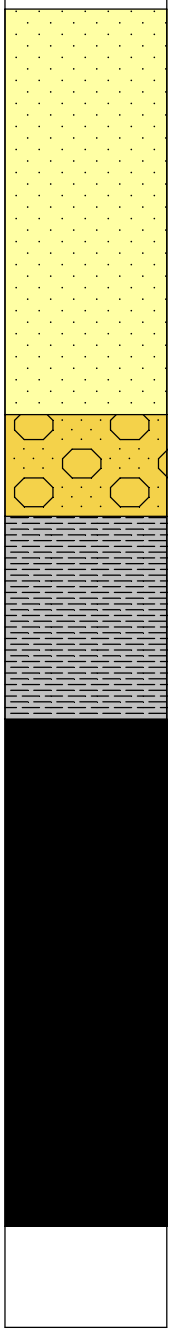
Project: Hume Coal Project
Easting: 242285 **Northing:** 6164084 **(MGA Zone 56)**
Top of casing: 641.915 mAHD
Ground level: 641.94 mAHD
Static water level: 10.84 mbgl **Date:** 13/11/2014

Completion date: 9/08/2012
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 8 – 11 mbgl
Gravel pack: 7.5 - 12.0 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

WW

DEPTH (m)

0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13

WATER QUALITY / INFLOW

pH: 5.56, EC: 87 µS/cm, Temp: 17.67 °C, Redox: 126.8 mV, DO: 58.8 % Sat, TDS: 0.056 g/L, Cut: <0.1 L/s

pH: 5.64, EC: 77 µS/cm, Temp: 20.53 °C, Redox: 127.1 mV, DO: 55.5 % Sat, TDS: 0.05 g/L, Cut: 0.1-0.2 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0044XPZA - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

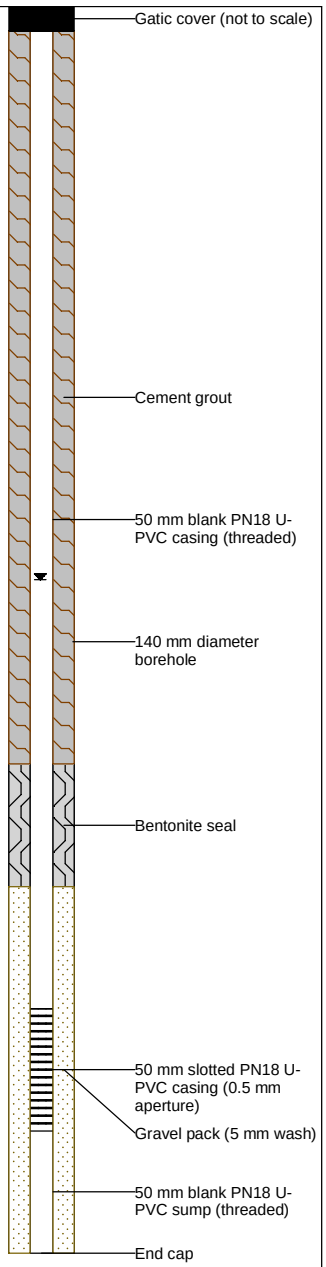
BORE COMPLETION REPORT

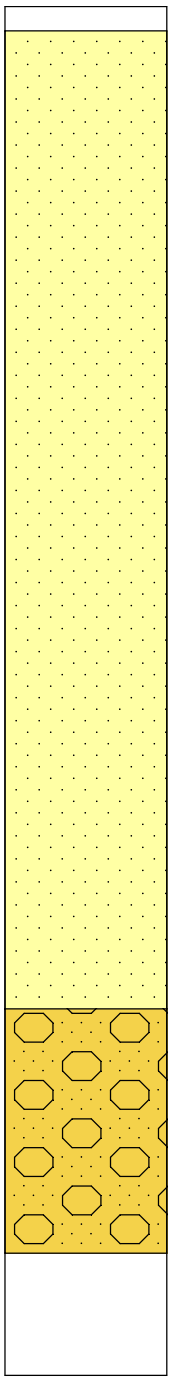
HU0044XPZB

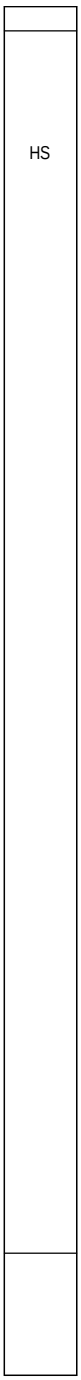
Project: Hume Coal Project
Easting: 242281 **Northing:** 6164077 **(MGA Zone 56)**
Top of casing: 646.96 mAHD
Ground level: 647 mAHD
Static water level: 2.245 mbgl **Date:** 13/11/2014

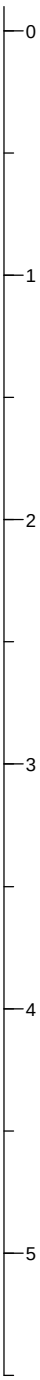
Completion date: 9/08/2012
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 4 – 4.5 mbgl
Gravel pack: 3.5 - 5.0 mbgl

BORE CONSTRUCTION	LITHOLOGY	FORMATION	DEPTH (m)	WATER QUALITY / INFLOW









pH: 5.23, EC: 69 µS/cm, Temp: 20.63 °C, Redox: 116.8 mV, DO: 50.2 % Sat, TDS: 0.045 g/L, Cut: 0.1 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0044XPZB - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

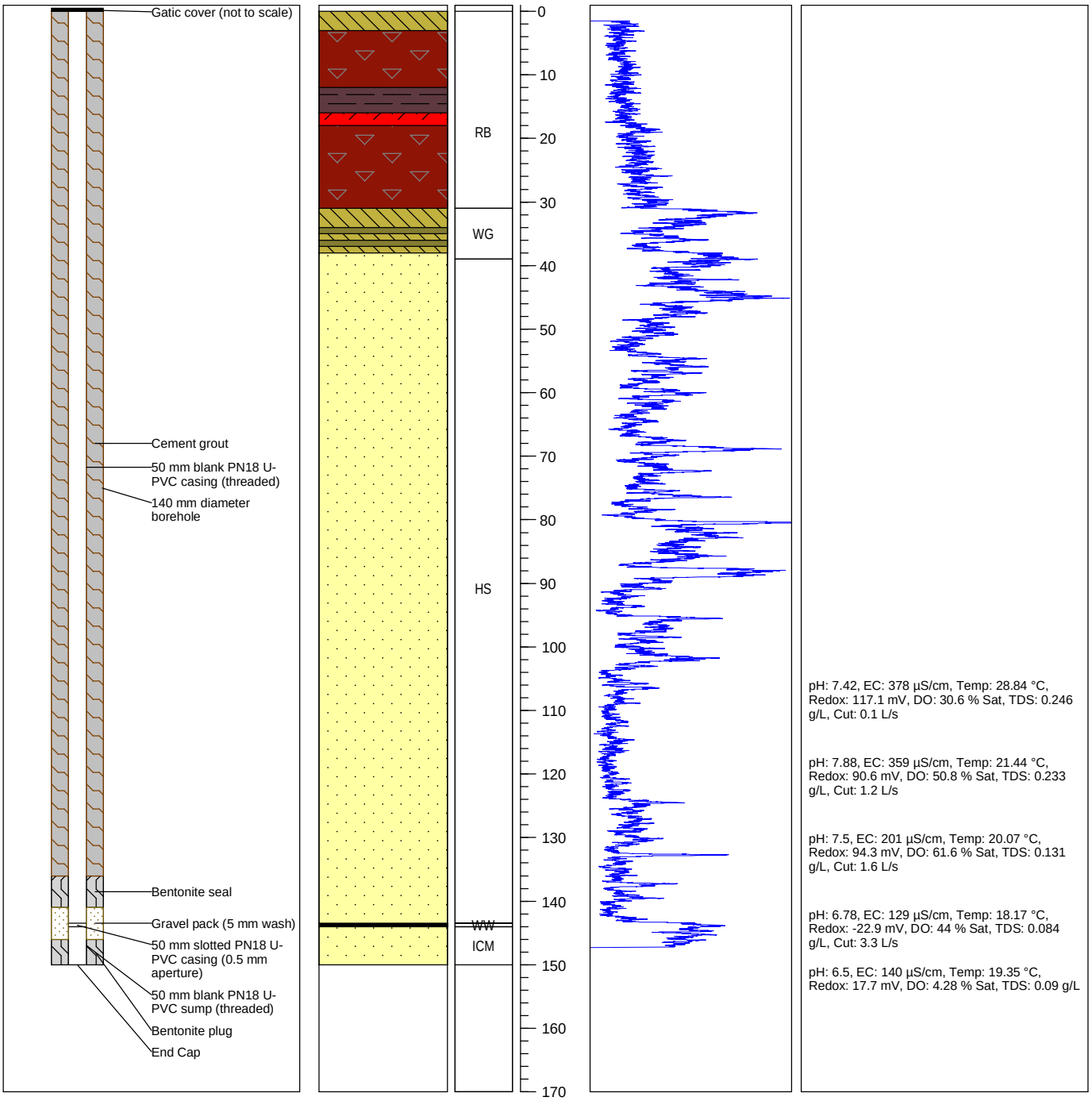
Hume Coal Pty Ltd

BORE COMPLETION REPORT

HU0056XPZA (Abandoned)

Project: Hume Coal Project
Easting: 245214 **Northing:** 6169199 **(MGA Zone 56)**
Top of casing: 735.30 mAHD
Ground level: 735.38 mAHD
Static water level: n/a **Date:** n/a

Completion date: 17/10/2012
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 143.5 - 144 mbgl
Gravel pack: 141 - 146 mbgl



PARSONS BRINCKERHOFF

Drawing No.: HU0056XPZA - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

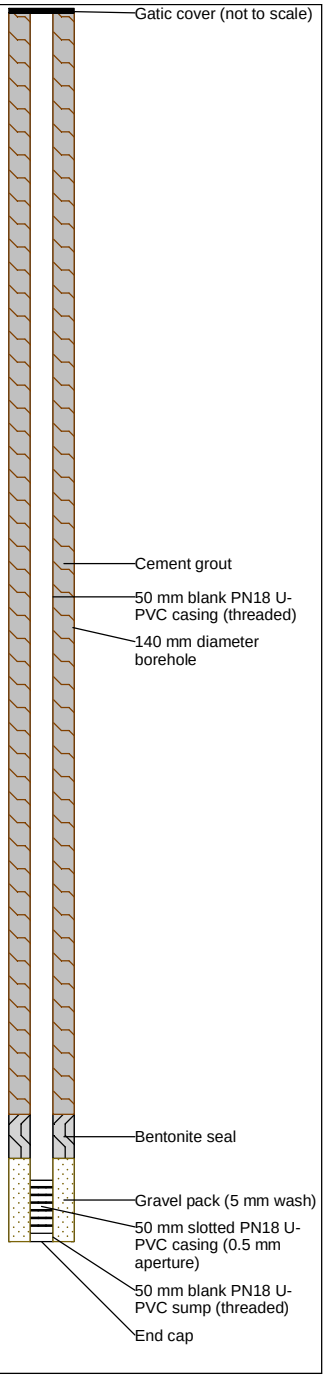
BORE COMPLETION REPORT

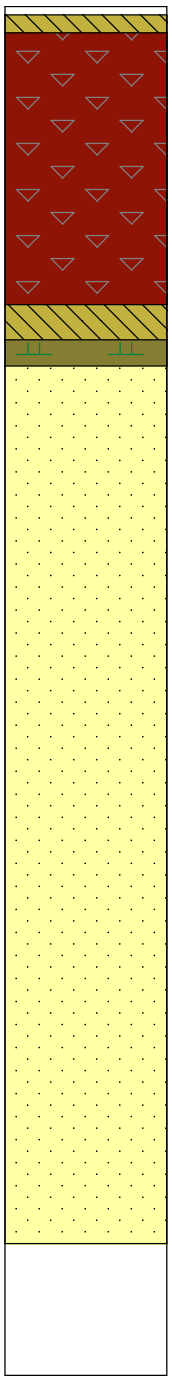
HU0056XPZB

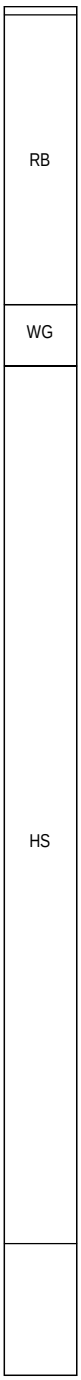
Project: Hume Coal Project
Easting: 245225 **Northing:** 6169198 **(MGA Zone 56)**
Top of casing: 735.37 mAHD
Ground level: 735.45 mAHD
Static water level: 92.01 mbTOC **Date:** 05/02/2015

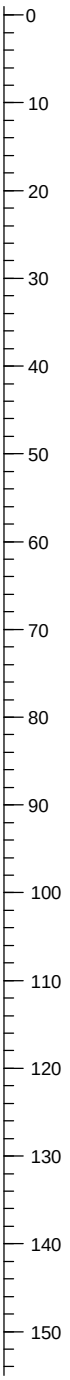
Completion date: 19/10/2012
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 133 – 139 mbgl
Gravel pack: 130.5 - 140 mbgl

BORE CONSTRUCTION	LITHOLOGY	FORMATION	DEPTH (m)	WATER QUALITY / INFLOW









pH: 8.72, EC: 745 µS/cm, Temp: 22.23 °C, Redox: 53.5 mV, DO: 43.7 % Sat, TDS: 0.485 g/L, Cut: <0.1 L/s

pH: 8.52, EC: 519 µS/cm, Temp: 22.81 °C, Redox: 33.4 mV, DO: 50.7 % Sat, TDS: 0.337 g/L, Cut: <<0.1 L/s

pH: 7.34, EC: 474 µS/cm, Temp: 23.38 °C, Redox: 100.9 mV, DO: 18.7 % Sat, TDS: 0.308 g/L, Cut: <0.1 L/s

pH: 7.88, EC: 459 µS/cm, Temp: 23.56 °C, Redox: 77.2 mV, DO: 50.1 % Sat, TDS: 0.299 g/L, Cut: 0.1 L/s

pH: 7.97, EC: 294 µS/cm, Temp: 18.05 °C, Redox: 90.9 mV, DO: 51.4 % Sat, TDS: 0.193 g/L, Cut: 1.7 L/s

pH: 7.79, EC: 215 µS/cm, Temp: 19.57 °C, Redox: 66.9 mV, DO: 57.2 % Sat, TDS: 0.14 g/L, Cut: 2 L/s

pH: 7.78, EC: 217 µS/cm, Temp: 19.4 °C, Redox: 54.7 mV, DO: 49.1 % Sat, TDS: 0.141 g/L, Cut: 2 L/s

pH: 7.2, EC: 142 µS/cm, Temp: 18.25 °C, Redox: -23.9 mV, DO: 54.2 % Sat, TDS: 0.093 g/L

PARSONS BRINCKERHOFF	Drawing No.: HU0056XPZB - Bore construction	
	Revision: A	Date drawn: 5/3/14
	Drawn by: K. Maher	Checked by: L. Rochford
	Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

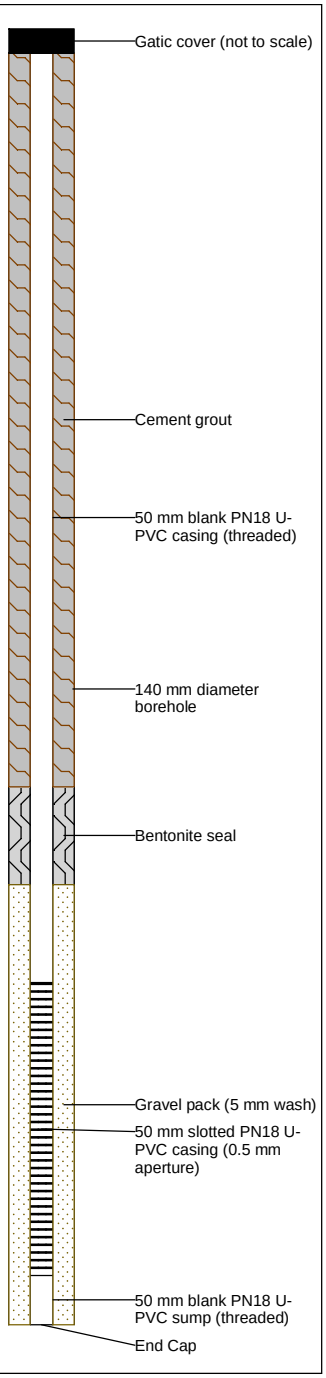
BORE COMPLETION REPORT

HU0056XPZC

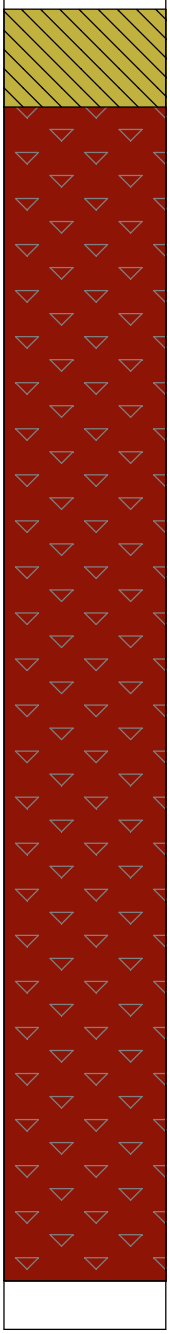
Project: Hume Coal Project
Easting: 245234 **Northing:** 6169198 **(MGA Zone 56)**
Top of casing: 735.43 mAHD
Ground level: 735.51 mAHD
Static water level: 18.245mbTOC **Date:** 05/02/2015

Completion date: 22/10/2012
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 19 – 25 mbgl
Gravel pack: 17 - 26 m

BORE CONSTRUCTION



LITHOLOGY



FORMATION

RB

DEPTH (m)

0
10
20

WATER QUALITY / INFLOW

pH: 8.13, EC: 725 µS/cm, Temp: 19.59 °C, Redox: 85.9 mV, DO: 47.9 % Sat, TDS: 0.471 g/L, Cut: <0.1 L/s

pH: 8.26, EC: 714 µS/cm, Temp: 20.89 °C, Redox: 83.9 mV, DO: 43.1 % Sat, TDS: 0.464 g/L, Cut: <0.1 L/s

pH: 8.11, EC: 665 µS/cm, Temp: 21.47 °C, Redox: 93 mV, DO: 45.9 % Sat, TDS: 0.433 g/L, Cut: 0.1 L/s

pH: 8.32, EC: 917 µS/cm, Temp: 21.37 °C, Redox: 89.3. mV, DO: 56.4 % Sat, TDS: 0.596 g/L

PARSONS BRINCKERHOFF

Drawing No.: HU0056XPZC - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

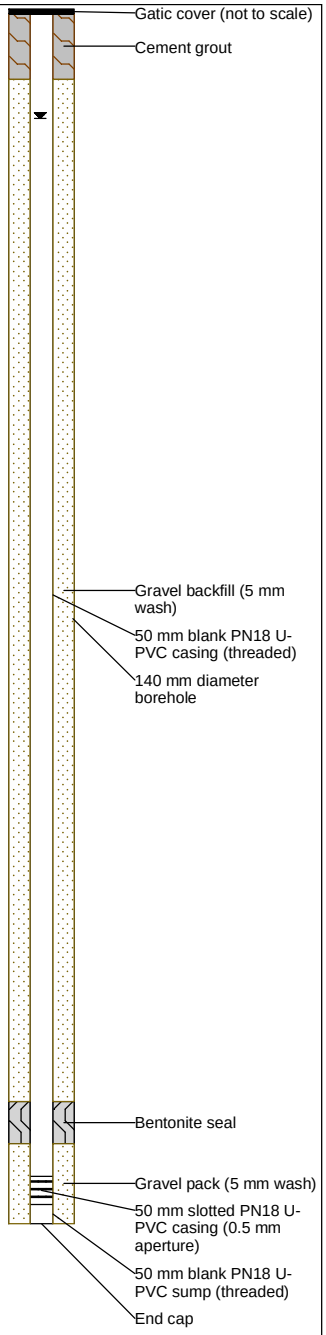
BORE COMPLETION REPORT

HU0072PZA

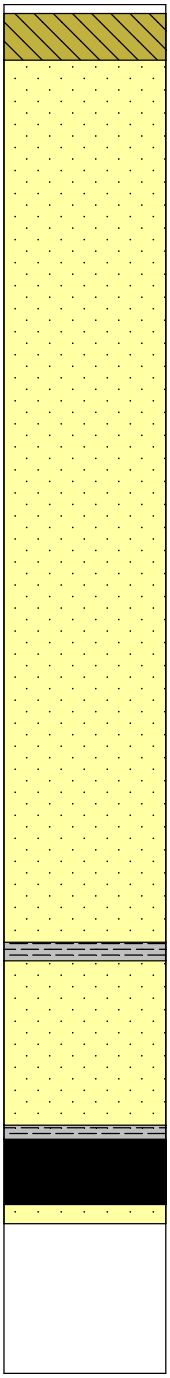
Project: Hume Coal Project
Easting: 252074 **Northing:** 6177157 **(MGA Zone 56)**
Top of casing: 640.054 mAHD
Ground level: 640.12 mAHD
Static water level: 11.196 mbgl **Date:** 2/12/2014

Completion date: 19/02/2013
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 124 - 127 mbgl
Gravel pack: 120.5 - 129 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

Fill

HS

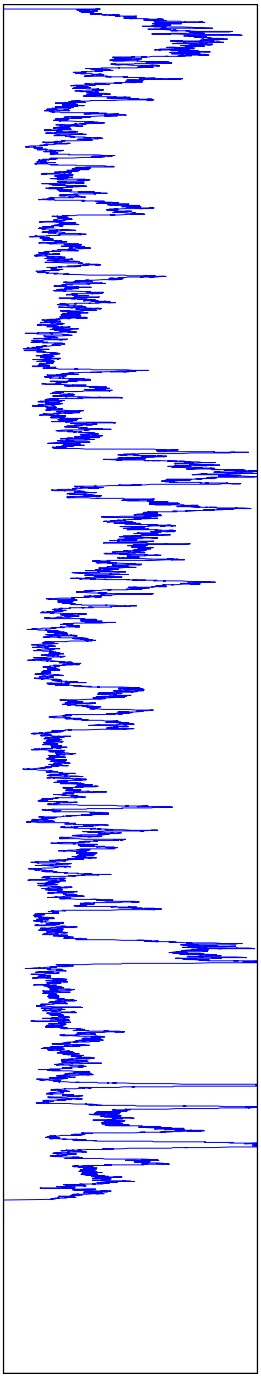
WW

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140

GAMMA (API-Gr)

0 — 250



WATER QUALITY / INFLOW

pH: 6.49, EC: 717 µS/cm, Temp: 20.53 °C, Redox: 44.4 mV, DO: 4.39 ppm, Cut: <0.1 L/s

pH: 7.03, EC: 772 µS/cm, Temp: 19.75 °C, Redox: -31.9 mV, DO: 4.66 ppm, Cut: 1 L/s

pH: 6.78, EC: 883 µS/cm, Temp: 18.94 °C, Redox: -19.4 mV, DO: 6.91 ppm, Cut: 1.4 L/s

pH: 6.94, EC: 795 µS/cm, Temp: 17.5 °C, Redox: -51.9 mV, DO: 7.64 ppm, Cut: 3.3 L/s

pH: 6.95, EC: 743 µS/cm, Temp: 17.24 °C, Redox: -50.6 mV, DO: 6.21 ppm, Cut: 4 L/s

pH: 6.97, EC: 699 µS/cm, Temp: 17.66 °C, Redox: -55.5 mV, DO: 6.25 ppm, Cut: 5 L/s

pH: 6.68, EC: 589 µS/cm, Temp: 17.63 °C, Redox: -15.4 mV, DO: 6.4 ppm, Cut: 8 L/s

pH: 7.63, EC: 502 µS/cm, Temp: 18.03 °C, Redox: -20.3 mV, DO: 6.49 ppm, Cut: 10 L/s

pH: 6.9, EC: 512 µS/cm, Temp: 16.45 °C, Redox: -45.5 mV, DO: 7.28 ppm, Cut: 10 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0072PZA- Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

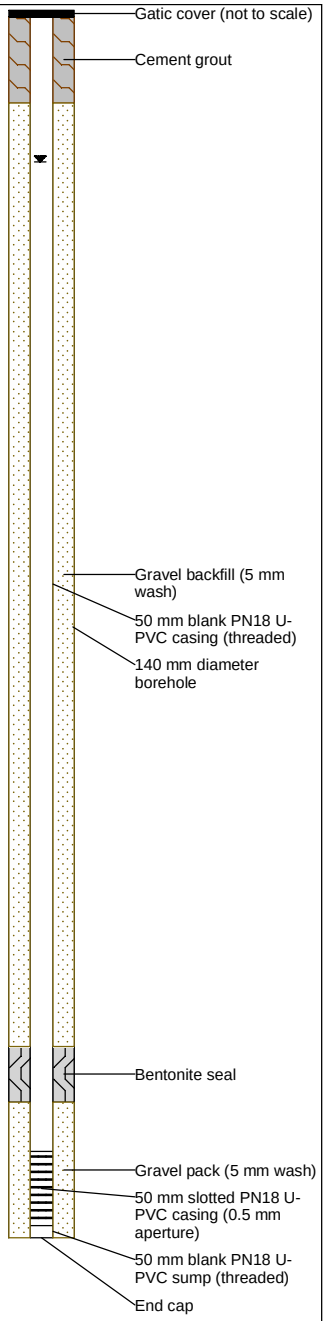
BORE COMPLETION REPORT

HU0072PZB

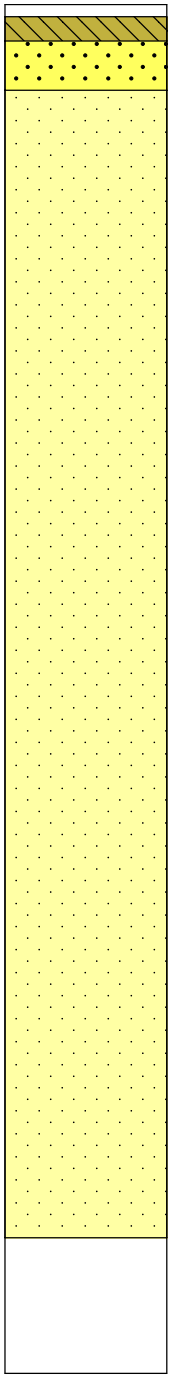
Project: Hume Coal Project
Easting: 252083 **Northing:** 6177169 **(MGA Zone 56)**
Top of casing: 640.416 mAHD
Ground level: 640.49 mAHD
Static water level: 11.804 mbgl **Date:** 2/12/2014

Completion date: 25/02/2013
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 92 - 98 mbgl
Gravel pack: 88 - 99 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

Fill

HS

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110

WATER QUALITY / INFLOW

pH: 5.65, EC: 819 µS/cm, Temp: 26.61 °C, Redox: 119.3 mV, DO: 59.7 % Sat, TDS: 0.531 g/L, Cut: 0.2 L/s

pH: 5.9, EC: 1288 µS/cm, Temp: 23.83 °C, Redox: 35.7 mV, DO: 59.5 % Sat, TDS: 0.836 g/L, Cut: 0.9 L/s

pH: 6.81, EC: 1179 µS/cm, Temp: 22.07 °C, Redox: -42.4 mV, DO: 55.4 % Sat, TDS: 0.766 g/L, Cut: 1.4 L/s

pH: 7.02, EC: 1136 µS/cm, Temp: 22.92 °C, Redox: -47 mV, DO: 57.3 % Sat, TDS: 0.738 g/L, Cut: 1.2 L/s

pH: 7.13, EC: 1029 µS/cm, Temp: 22.52 °C, Redox: -27.4 mV, DO: 54 % Sat, TDS: 0.668 g/L, Cut: 1.2 L/s

pH: 7.1, EC: 851 µS/cm, Temp: 19.41 °C, Redox: -39.6 mV, DO: 49.7 % Sat, TDS: 0.546 g/L, Cut: 2.5 L/s

pH: 7.11, EC: 716 µS/cm, Temp: 18.6 °C, Redox: -48.5 mV, DO: 57.6 % Sat, TDS: 0.465 g/L, Cut: 5 L/s

pH: 6.98, EC: 648 µS/cm, Temp: 18.77 °C, Redox: -40.3 mV, DO: 58.6 % Sat, TDS: 0.421 g/L, Cut: 10 L/s

pH: 7.15, EC: 659 µS/cm, Temp: 22.26 °C, Redox: -13 mV, DO: 49.7 % Sat, TDS: 0.428 g/L, Cut: 10 L/s

pH: 7.08, EC: 655 µS/cm, Temp: 18.58 °C, Redox: -39.1 mV, DO: 56.3 % Sat, TDS: 0.426 g/L, Cut: 10 L/s

pH: 7.11, EC: 666 µS/cm, Temp: 19.45 °C, Redox: -45.6 mV, DO: 57.3 % Sat, TDS: 0.433 g/L, Cut: 10 L/s

pH: 6.57, EC: 685 µS/cm, Temp: 16.95 °C, Redox: -33.1 mV, DO: 55.5 % Sat, TDS: 0.416 g/L, Cut: 10 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0072PZB - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

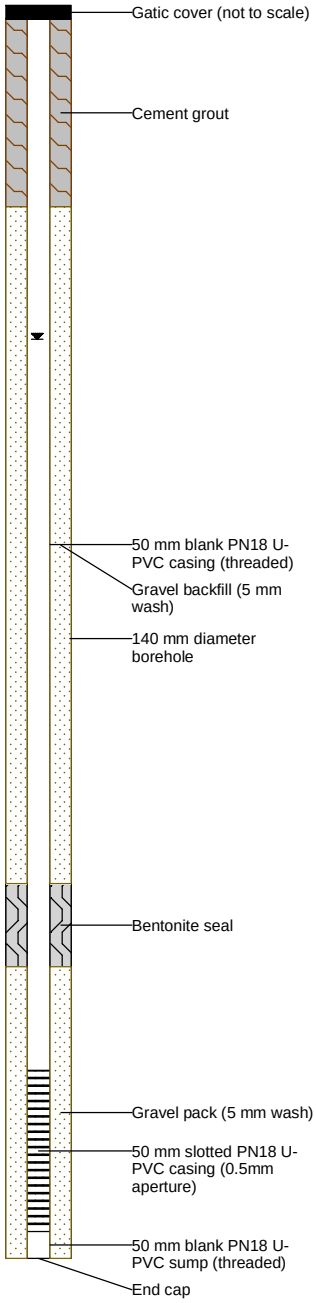
BORE COMPLETION REPORT

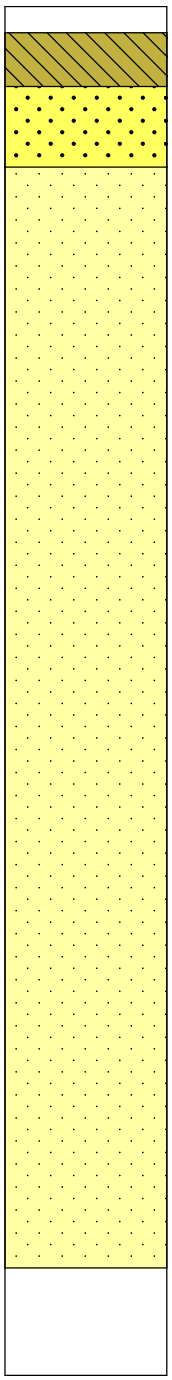
HU0072PZC

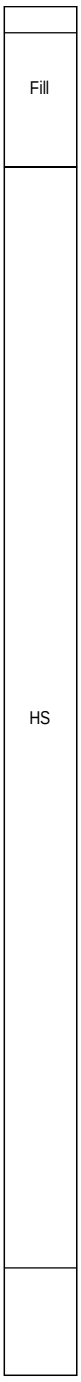
Project: Hume Coal Project
Easting: 252091 **Northing:** 6177180 **(MGA Zone 56)**
Top of casing: 640.767 mAHD
Ground level: 640.85 mAHD
Static water level: 11.933 mbgl **Date:** 2/12/2014

Completion date: 20/02/2013
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 39 - 45 mbgl
Gravel pack: 35.3 - 46.2 mbgl

BORE CONSTRUCTION	LITHOLOGY	FORMATION	DEPTH (m)	WATER QUALITY / INFLOW







pH: 6.26, EC: 870 µS/cm, Temp: 27.62 °C, Redox: 23.7 mV, DO: 57.6 % Sat, TDS: 0.566 g/L, Cut: 0.15 L/s

pH: 6.29, EC: 979 µS/cm, Temp: 22.31 °C, Redox: -48.8 mV, DO: % Sat, TDS: 0.635 g/L, Cut: 1.5 L/s

pH: 6.71, EC: 955 µS/cm, Temp: 20.21 °C, Redox: -51.4 mV, DO: 65 % Sat, TDS: 0.62 g/L, Cut: 1.7 L/s

pH: 7.04, EC: 945 µS/cm, Temp: 21.81 °C, Redox: -54.5 mV, DO: 66.5 % Sat, TDS: 0.614 g/L, Cut: 2 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0072PZC - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

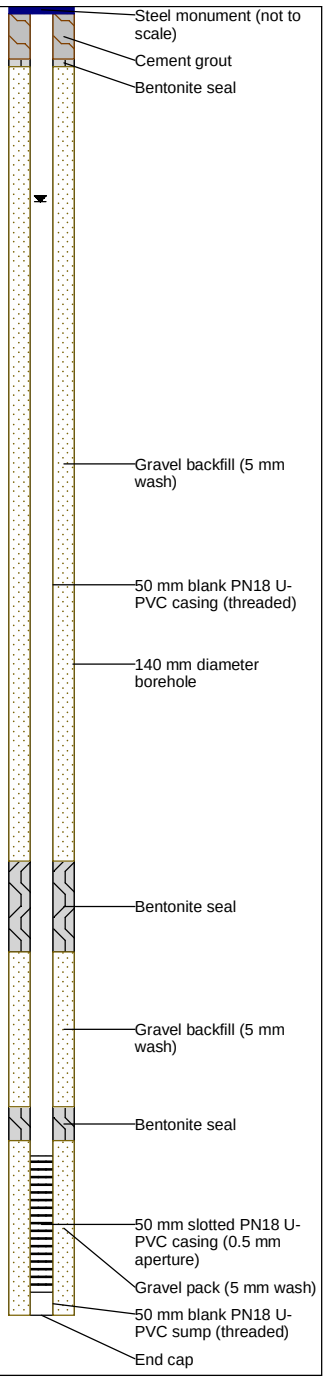
BORE COMPLETION REPORT

HU0073PZA

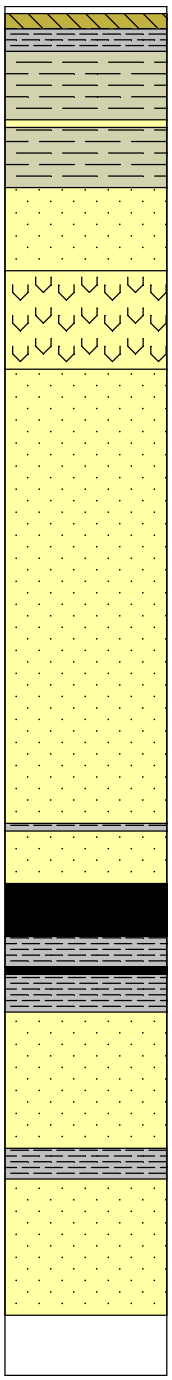
Project: Hume Coal Project
Easting: 251015 **Northing:** 6172718 **(MGA Zone 56)**
Top of casing: 656.371 mAHD
Ground level: 655.83 mAHD
Static water level: 24.87 mbgl **Date:** 5/12/2014

Completion date: 28/02/2012
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 151 – 169 mbgl
Gravel pack: 149 - 172 mbgl

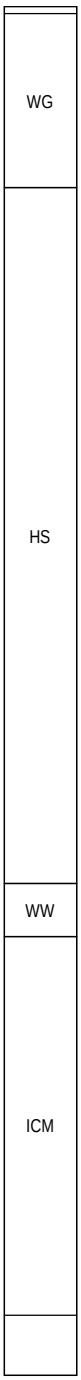
BORE CONSTRUCTION



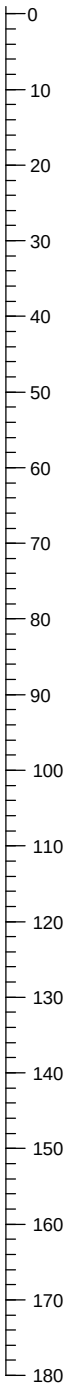
LITHOLOGY



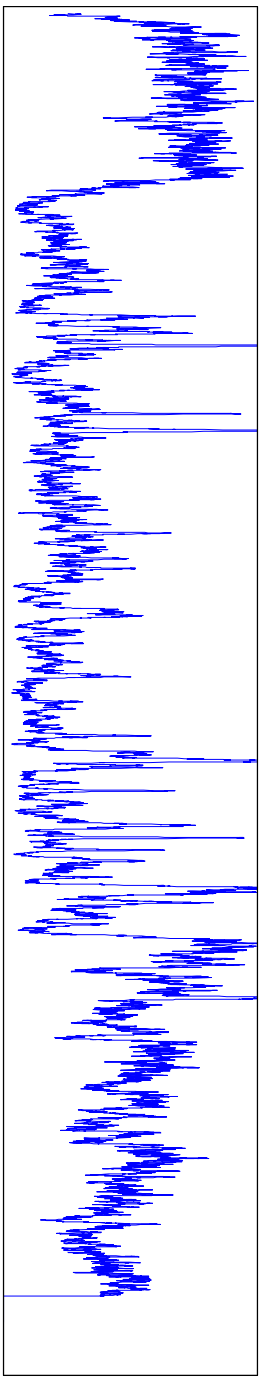
FORMATION



DEPTH (m)



GAMMA (API-Gr)



WATER QUALITY / INFLOW

pH: 5.41, EC: 348 µS/cm, Temp: 18.49 °C, Redox: 44.5 mV, DO: 62.2 % Sat, TDS: 0.225 g/L, Cut: 1 L/s

pH: 6.03, EC: 362 µS/cm, Temp: 18.66 °C, Redox: -1.7 mV, DO: 70.4 % Sat, TDS: 0.233 g/L, Cut: 2 L/s

pH: 6.14, EC: 399 µS/cm, Temp: 19.36 °C, Redox: -24.6 mV, DO: 69 % Sat, TDS: 0.246 g/L, Cut: 2 L/s

pH: 6.07, EC: 330 µS/cm, Temp: 17.29 °C, Redox: -4.3 mV, DO: 77.8 % Sat, TDS: 0.214 g/L, Cut: 3 L/s

pH: 6.18, EC: 285 µS/cm, Temp: 17.26 °C, Redox: -10.8 mV, DO: 63.2 % Sat, TDS: 0.185 g/L, Cut: 5 L/s

pH: 6.13, EC: 175 µS/cm, Temp: 17.49 °C, Redox: -13.5 mV, DO: 65.3 % Sat, TDS: 0.113 g/L, Cut: 6.6 L/s

pH: 6.52, EC: 175 µS/cm, Temp: 17.94 °C, Redox: -22.2 mV, DO: 62 % Sat, TDS: 0.114 g/L, Cut: 6.6 L/s

pH: 6.21, EC: 177 µS/cm, Temp: 17.79 °C, Redox: -7.7 mV, DO: 60.7 % Sat, TDS: 0.115 g/L, Cut: 7.1 L/s

pH: 6.5, EC: 156 µS/cm, Temp: 18.07 °C, Redox: -33.2 mV, DO: 52.4 % Sat, TDS: 0.102 g/L, Cut: 7.1 L/s

pH: 6.82, EC: 234 µS/cm, Temp: 17.44 °C, Redox: -36.3 mV, DO: 59.8 % Sat, TDS: 0.152 g/L, Cut: 7.1 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0073PZA - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

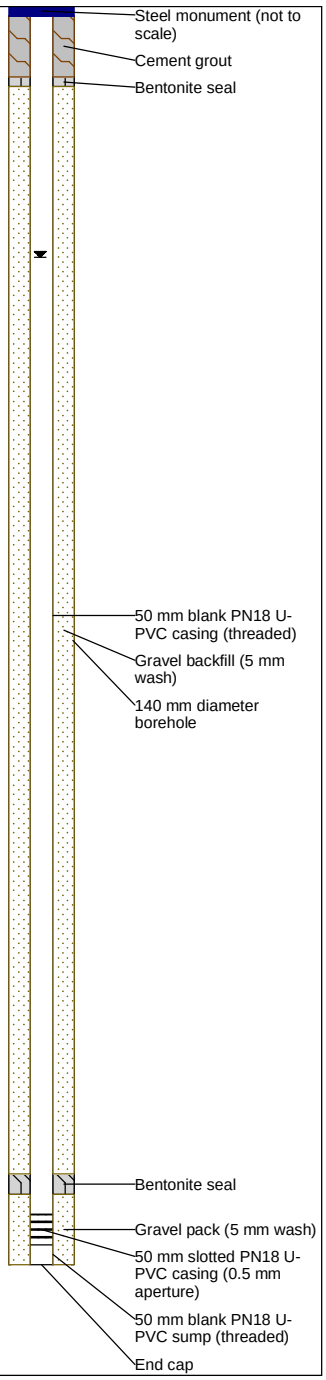
BORE COMPLETION REPORT

HU0073PZB

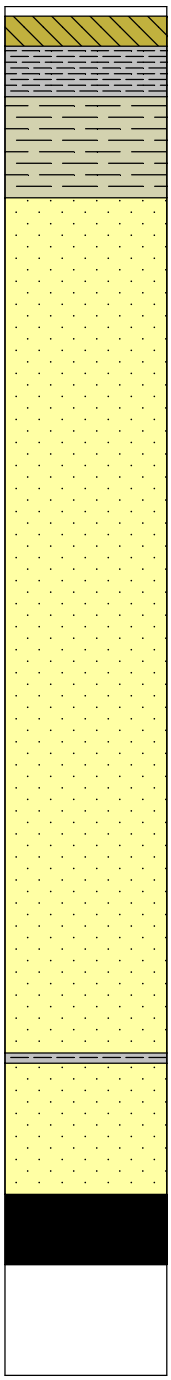
Project: Hume Coal Project
Easting: 251029 **Northing:** 6172717 **(MGA Zone 56)**
Top of casing: 655.65 mAHD
Ground level: 655.08 mAHD
Static water level: 23.925 mbgl **Date:** 5/12/2014

Completion date: 8/03/2013
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 119 - 122 mbgl
Gravel pack: 117 - 124 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

WG

HS

WW

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130

WATER QUALITY / INFLOW

pH: 6.28, EC: 811 µS/cm, Temp: 19.34 °C, Redox: 129.7 mV, DO: 67.4 % Sat, TDS: 0.527 g/L, Cut: 0.75 L/s

pH: 6.28, EC: 527 µS/cm, Temp: 17.98 °C, Redox: 24.9 mV, DO: 64 % Sat, TDS: 0.342 g/L, Cut: 2.5 L/s

pH: 6.52, EC: 428 µS/cm, Temp: 17.39 °C, Redox: -1 mV, DO: 67.2 % Sat, TDS: 0.278 g/L, Cut: 2.5 L/s

pH: 6.68, EC: 412 µS/cm, Temp: 18.04 °C, Redox: -21.8 mV, DO: 60.3 % Sat, TDS: 0.268 g/L, Cut: 33 L/s

pH: 6.33, EC: 236 µS/cm, Temp: 18.09 °C, Redox: -24.4 mV, DO: 55 % Sat, TDS: 0.153 g/L, Cut: 4 L/s

pH: 6.21, EC: 208 µS/cm, Temp: 17.33 °C, Redox: -16.8 mV, DO: 59.8 % Sat, TDS: 0.135 g/L, Cut: 6.6 L/s

pH: 6.15, EC: 191 µS/cm, Temp: 17.56 °C, Redox: -13 mV, DO: 46.1 % Sat, TDS: 0.124 g/L, Cut: 7.6 L/s

pH: 6.15, EC: 170 µS/cm, Temp: 18.03 °C, Redox: -14.5 mV, DO: 35.2 % Sat, TDS: 0.11 g/L, Cut: 7.6 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0073PZB - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

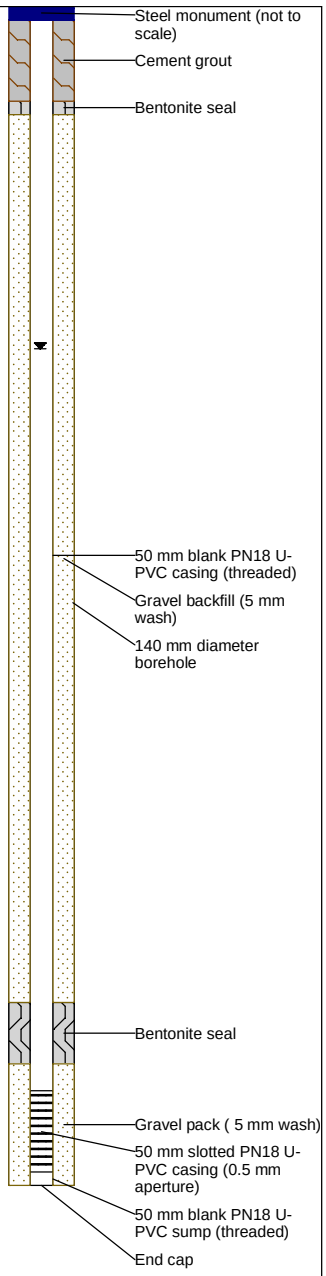
BORE COMPLETION REPORT

HU0073PZC

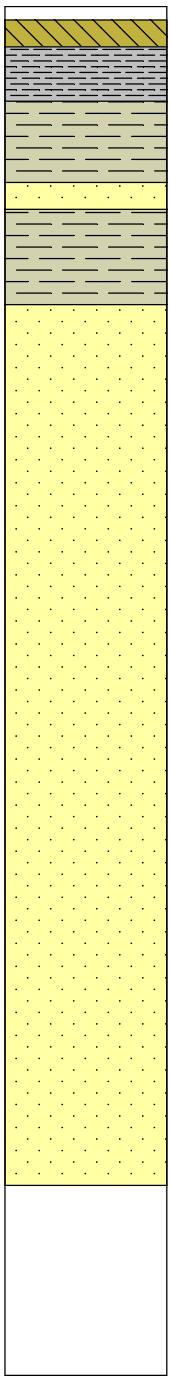
Project: Hume Coal Project
Easting: 251035 **Northing:** 6172717 **(MGA Zone 56)**
Top of casing: 655.499 mAHD
Ground level: 654.87 mAHD
Static water level: 24.238 mbgl **Date:** 5/12/2014

Completion date: 3/06/2013
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 79 - 85 mbgl
Gravel pack: 77 - 86 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

WG

HS

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100

WATER QUALITY / INFLOW

pH: 5.64, EC: 335 µS/cm, Temp: 21.08 °C, Redox: 18.1 mV, DO: 50.9 % Sat, TDS: 0.217 g/L, Cut: 0.5 L/s

pH: 5.89, EC: 377 µS/cm, Temp: 18.27 °C, Redox: -8.4 mV, DO: 50.4 % Sat, TDS: 0.245 g/L, Cut: 1 L/s

pH: 6.02, EC: 329 µS/cm, Temp: 18.63 °C, Redox: -17.3 mV, DO: 50.9 % Sat, TDS: 0.214 g/L, Cut: 2 L/s

pH: 6.27, EC: 357 µS/cm, Temp: 20.02 °C, Redox: -18.1 mV, DO: 43 % Sat, TDS: 0.232 g/L, Cut: 2 L/s

pH: 6.32, EC: 343 µS/cm, Temp: 19.31 °C, Redox: -17.1 mV, DO: 53.4 % Sat, TDS: 0.223 g/L, Cut: 2 L/s

pH: 6.31, EC: 344 µS/cm, Temp: 18.13 °C, Redox: -14.4 mV, DO: 52.8 % Sat, TDS: 0.258 g/L, Cut: 3.3 L/s

pH: 6.37, EC: 306 µS/cm, Temp: 17.7 °C, Redox: -19.9 mV, DO: 55.6 % Sat, TDS: 0.199 g/L, Cut: 3.3 L/s

pH: 6.29, EC: 288 µS/cm, Temp: 17.89 °C, Redox: -22 mV, DO: 59.3 % Sat, TDS: 0.187 g/L, Cut: 4 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0073PZC - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

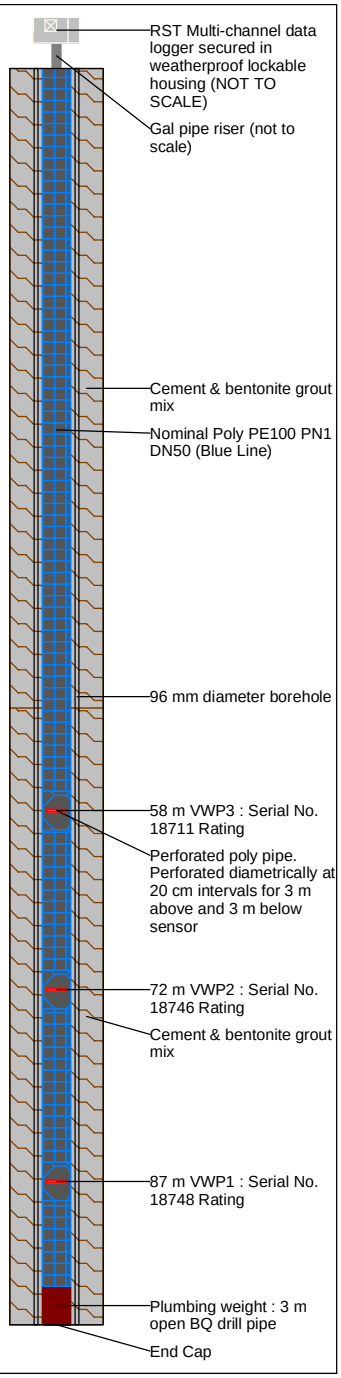
BORE COMPLETION REPORT

HU0077CH

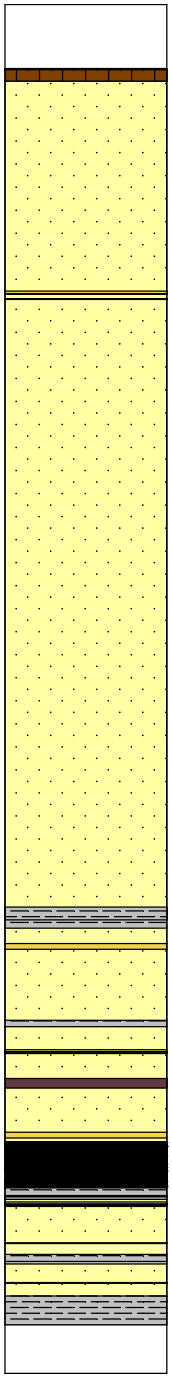
Project: Hume Coal Project
Easting: 246966 **Northing:** 6175811 **(MGA Zone 56)**
Top of casing: n/a
Ground level: 689.74 mAHD
Static water level: n/a **Date:** n/a

Completion date: 10/09/2013
Drlling company: Highland Drilling
Drlling method: Diamond core
Screened interval: n/a (VWP array)
Gravel pack: n/a (VWP array)

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

WW

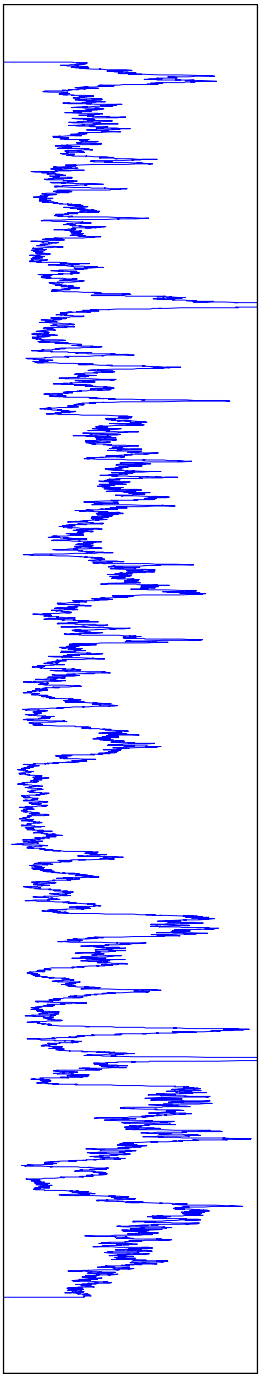
ICM

DEPTH (m)

0 10 20 30 40 50 60 70 80 90 100

GAMMA (API-Gr)

0 250



WATER QUALITY / INFLOW

***Note: no water quality data due to drilling method

***Note: no water quality data due to drilling method

***Note: no water quality data due to drilling method

***Note: no water quality data due to drilling method

PARSONS BRINCKERHOFF	Drawing No.: HU0040CH - VWP construction	
	Revision: A	Date drawn: 5/3/14
	Drawn by: K. Maher	Checked by: L. Rochford
	Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

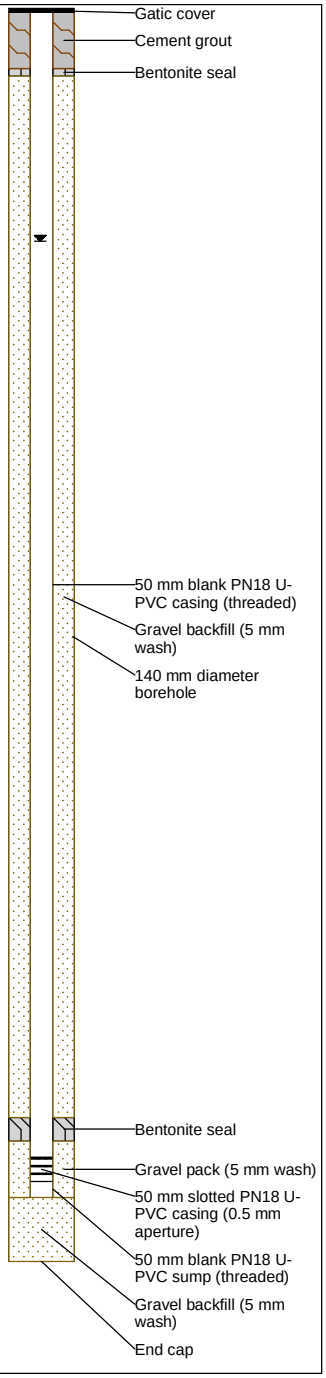
BORE COMPLETION REPORT

HU0088PZA

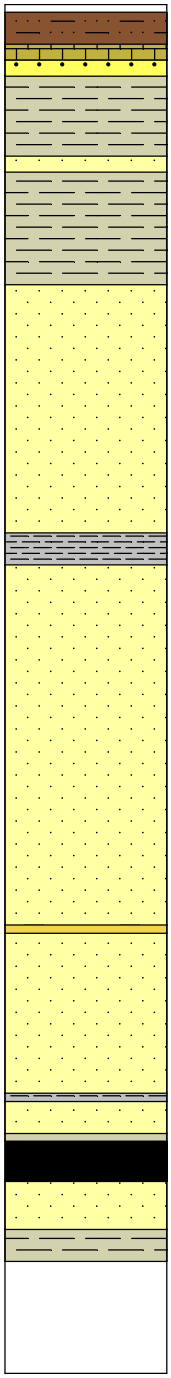
Project: Hume Coal Project
Easting: 253058.95 **Northing:** 6173143.73 **(MGA Zone 56)**
Top of casing: 655.37 mAHD
Ground level: 655.44 mAHD
Static water level: 28.63 mbgl **Date:** 3/12/2014

Completion date: 3/06/2013
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 143 - 146 mbgl
Gravel pack: 141 - 148 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

WG

HS

WW

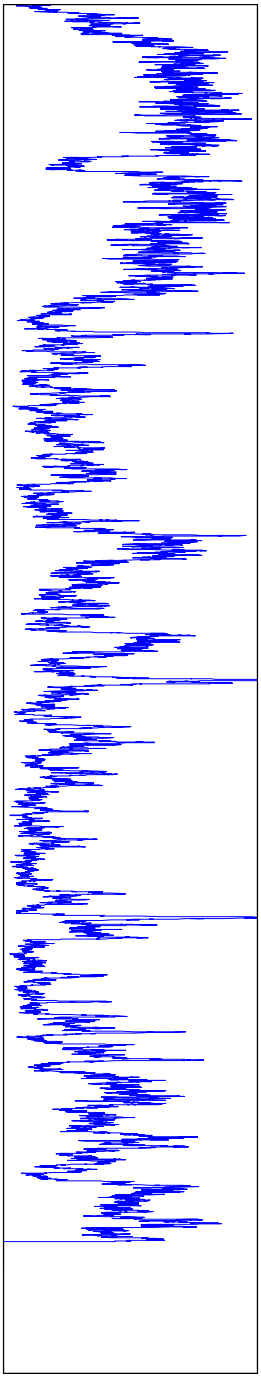
ICM

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170

GAMMA (API-Gr)

0 — 250



WATER QUALITY / INFLOW

pH: 7.27, EC: 988 µS/cm, Temp: 21.91 °C, Redox: 60.9 mV, DO: 56.7 % Sat, TDS: 0.641 g/L, Cut: 0.1 L/s

pH: 7.73, EC: 533 µS/cm, Temp: 19.31 °C, Redox: 64.6 mV, DO: 57.6 % Sat, TDS: 0.347 g/L, Cut: 0.6 L/s

pH: 7.7, EC: 419 µS/cm, Temp: 16.03 °C, Redox: -64.4 mV, DO: 51.3 % Sat, TDS: 0.273 g/L, Cut: 1.6 L/s

pH: 7.49, EC: 530 µS/cm, Temp: 16.52 °C, Redox: -107.8 mV, DO: 51.8 % Sat, TDS: 0.346 g/L, Cut: 3.3 L/s

pH: 7.21, EC: 417 µS/cm, Temp: 16.26 °C, Redox: -104.2 mV, DO: 55.2 % Sat, TDS: 0.271 g/L, Cut: 4 L/s

pH: 6.75, EC: 426 µS/cm, Temp: 15.86 °C, Redox: -63.1 mV, DO: 58.1 % Sat, TDS: 0.277 g/L, Cut: 7 L/s

pH: 7.31, EC: 410 µS/cm, Temp: 16.32 °C, Redox: -98 mV, DO: 37.8 % Sat, TDS: 0.266 g/L, Cut: 8 L/s

pH: 7.16, EC: 417 µS/cm, Temp: 15.39 °C, Redox: -59.4 mV, DO: 43.6 % Sat, TDS: 0.271 g/L, Cut: 11 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU008PZA - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

BORE COMPLETION REPORT

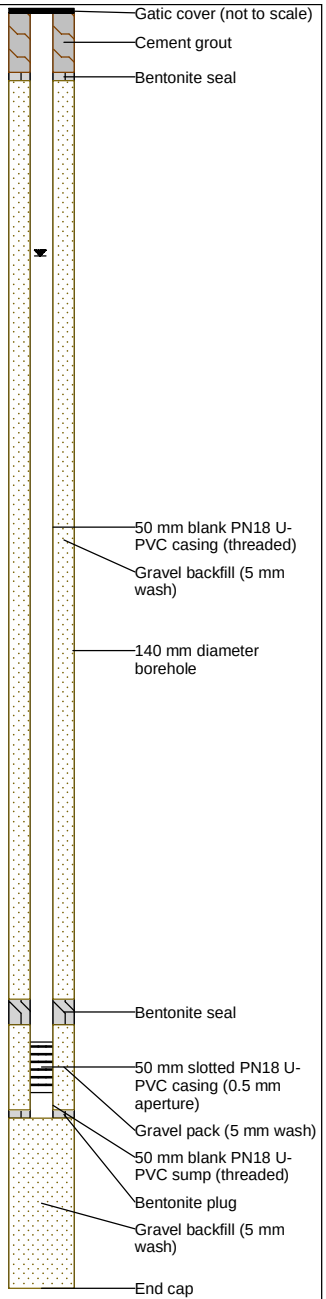
HU0088PZB

Project: Hume Coal Project
Easting: 253059 **Northing:** 6173144 **(MGA Zone 56)**
Top of casing: 655.26 mAHD
Ground level: 655.33 mAHD
Static water level: 28.565 mbgl **Date:** 3/12/2014

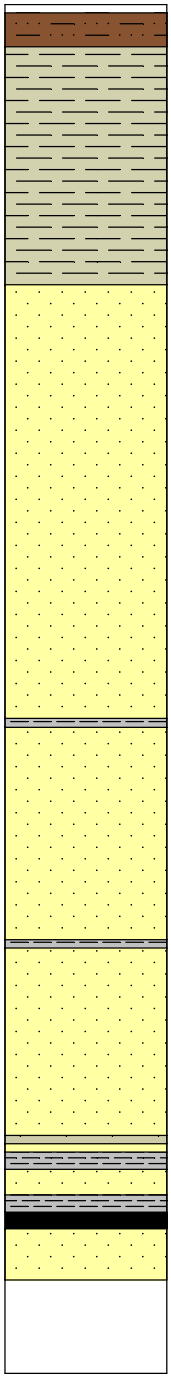
Completion date: 4/07/2013
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 121 - 127 mbgl
Gravel pack: 119 - 129 mbgl

DRAFT

BORE CONSTRUCTION



LITHOLOGY



FORMATION

WG

HS

WW

ICM

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160

WATER QUALITY / INFLOW

pH: 6.6, EC: 533 µS/cm, Temp: 16.89 °C, Redox: -28.2 mV, DO: 40.3 % Sat, TDS: g/L, Cut: 0.2 L/s

pH: 7.61, EC: 480 µS/cm, Temp: 15.19 °C, Redox: -36.4 mV, DO: 38.4 % Sat, TDS: g/L, Cut: 0.2 L/s

pH: 7.85, EC: 350 µS/cm, Temp: - °C, Redox: -89.1 mV, DO: - % Sat, TDS: g/L, Cut: 1.4 L/s

pH: 7.89, EC: 325 µS/cm, Temp: - °C, Redox: -74.6 mV, DO: 42.82 % Sat, TDS: g/L, Cut: 1.6 L/s

Cut: 2 L/s

Cut: 2.5 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0088PZB - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

BORE COMPLETION REPORT

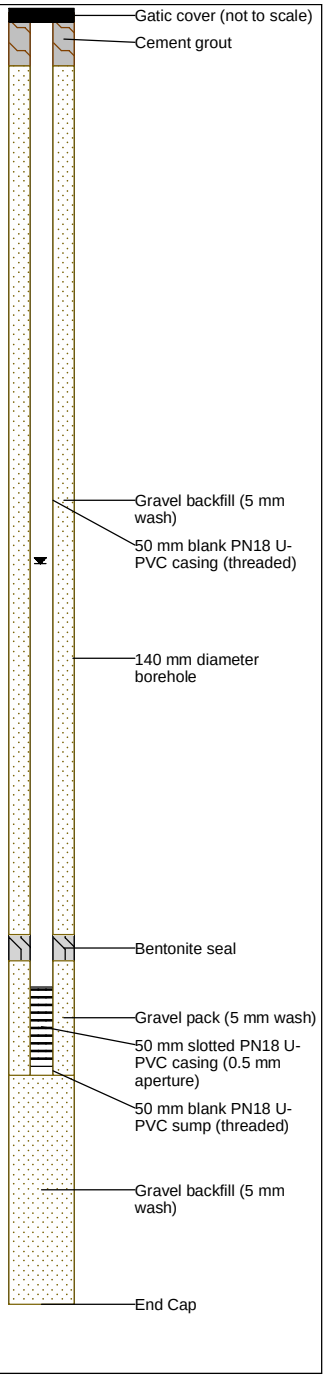
HU0096PZA

Project: Hume Coal Project
Easting: 246488.51 **Northing:** 6177025.44 **(MGA Zone 56)**
Top of casing: 699.14 mAHD
Ground level: 699.21 mAHD
Static water level: 62.76 mbgl **Date:** 5/12/2014

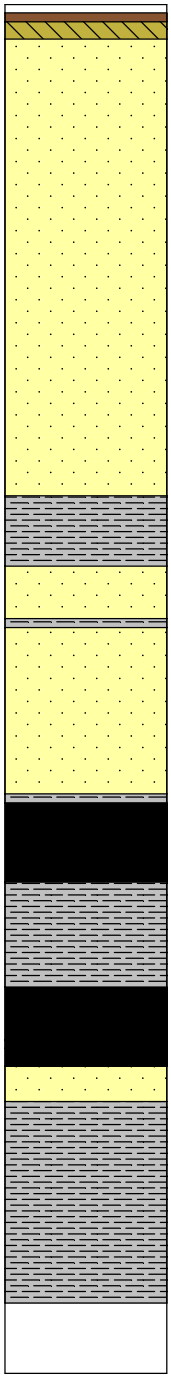
Completion date: 18/03/2013
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 111 - 120 mbgl
Gravel pack: 108 - 121 mbgl

DRAFT

BORE CONSTRUCTION



LITHOLOGY



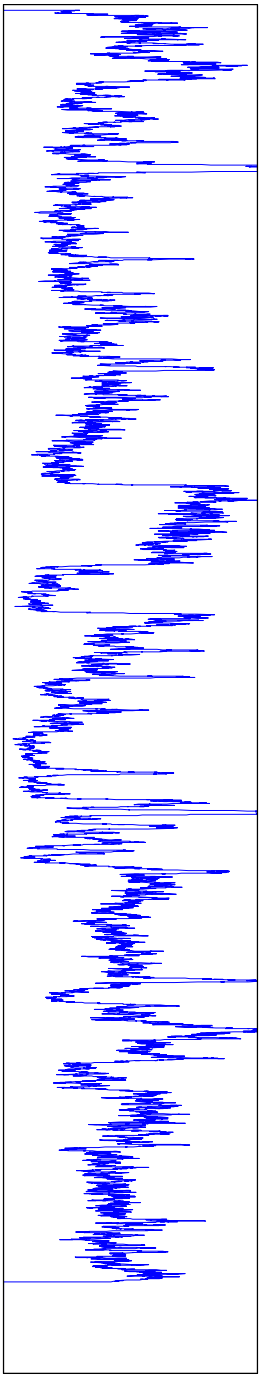
FORMATION

HS
WW
ICM
TG
ICM

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150

GAMMA (API-Gr)



WATER QUALITY / INFLOW

pH: 6.54, EC: 111.6 µS/cm, Temp: 21.6 °C, Redox: -38.7 mV, DO: - % Sat, TDS: 72.8 g/L, Cut: 0.2 L/s

pH: 6.98, EC: 109.1 µS/cm, Temp: 16 °C, Redox: 7 mV, DO: - % Sat, TDS: 70.85 g/L, Cut: 3.3 L/s

pH: 6.96, EC: 109.5 µS/cm, Temp: 15.45 °C, Redox: 66.7 mV, DO: 70.7 % Sat, TDS: 70.95 g/L, Cut: 4 L/s

pH: 6.97, EC: 109.3 µS/cm, Temp: 15.6 °C, Redox: 85.7 mV, DO: - % Sat, TDS: 70.85 g/L, Cut: 4.54 L/s

pH: 6.92, EC: 121.3 µS/cm, Temp: 15.56 °C, Redox: 65.4 mV, DO: - % Sat, TDS: 79.3 g/L, Cut: 4.54 L/s

pH: 6.97, EC: 139 µS/cm, Temp: 15.72 °C, Redox: 8 mV, DO: - % Sat, TDS: 8.09 g/L, Cut: 4.54 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0096PZA - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

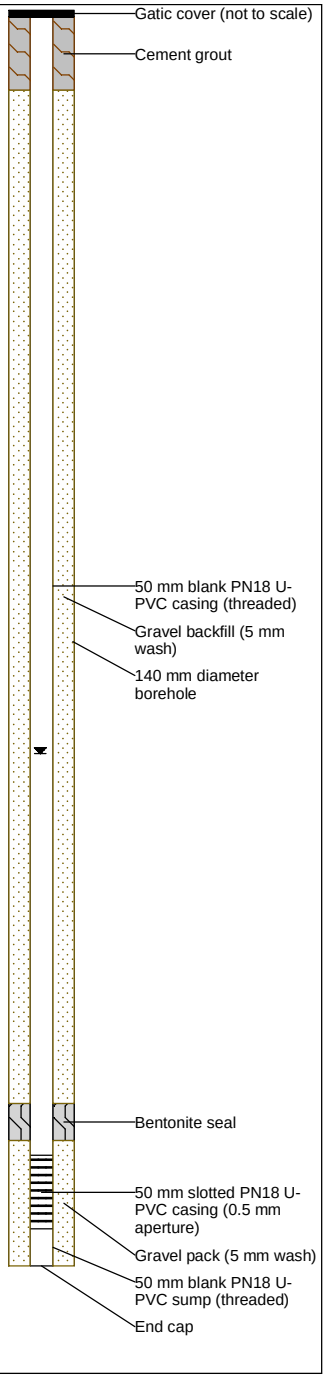
BORE COMPLETION REPORT

HU0096PZB

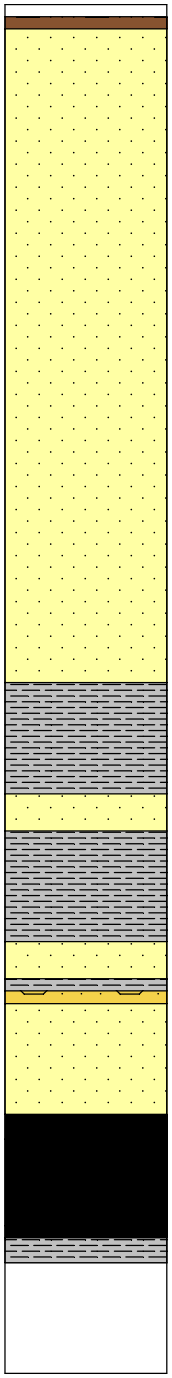
Project: Hume Coal Project
Easting: 246491 **Northing:** 6177029 **(MGA Zone 56)**
Top of casing: 699.0 mAHD
Ground level: 699.1 mAHD
Static water level: 59.76 mbgl **Date:** 5/12/2014

Completion date: 23/07/2013
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 92.3 - 98.3 mbgl
Gravel pack: 91.1 - 101.3 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

WW

ICM

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110

WATER QUALITY / INFLOW

EC: 86 µS/cm, Temp: 12.96 °C, Redox: 61.2 mV, DO: 41.1 % Sat, TDS: 0.074 g/L, Cut: 2.3 L/s

pH: 6.58, EC: 91 µS/cm, Temp: 15.44 °C, Redox: 128 mV, DO: 46.5 % Sat, TDS: 0.073 g/L, Cut: 2.9 L/s

EC: 92 µS/cm, Temp: 15.41 °C, Redox: 61.9 mV, DO: 38.9 % Sat, TDS: 0.073 g/L, Cut: 3.3 L/s

EC: 93 µS/cm, Temp: 15.48 °C, Redox: 185 mV, DO: 56.7 % Sat, TDS: 0.074 g/L, Cut: 3.6 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0096PZB - Bore constrution	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

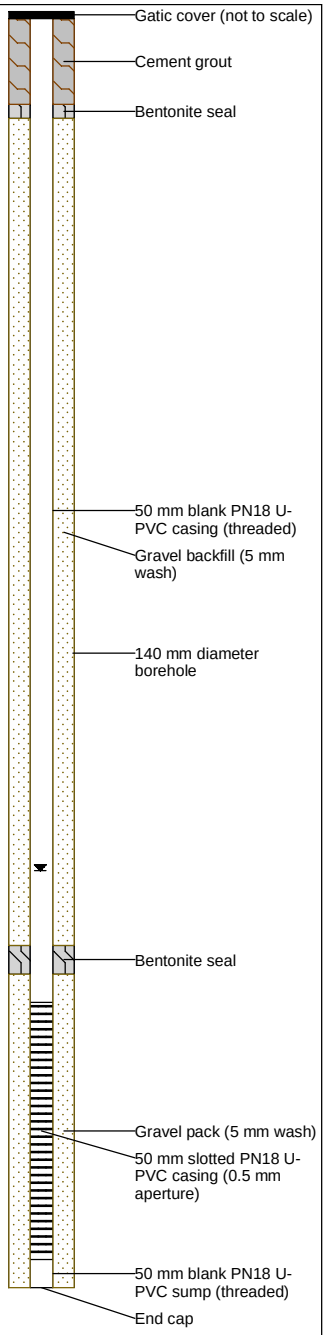
BORE COMPLETION REPORT

HU0096PZC

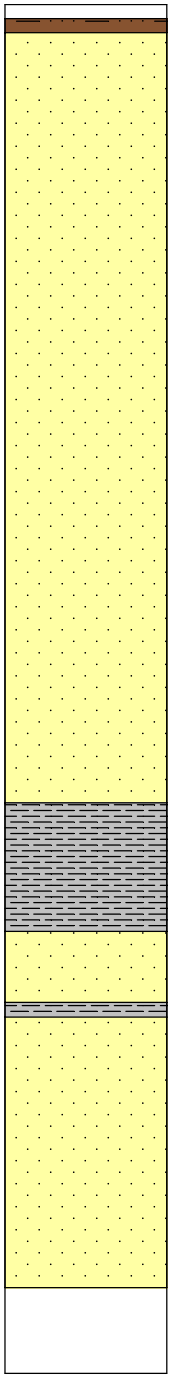
Project: Hume Coal Project
Easting: 246494 **Northing:** 6177045 **(MGA Zone 56)**
Top of casing: 698.98 mAHD
Ground level: 699.04 mAHD
Static water level: 59.73 mbgl **Date:** 5/12/2014

Completion date: 25/07/2013
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 69 - 87 mbgl
Gravel pack: 67 - 89 mbgl

BORE CONSTRUCTION



LITHOLOGY



FORMATION

HS

DEPTH (m)

0, 10, 20, 30, 40, 50, 60, 70, 80, 90

WATER QUALITY / INFLOW

pH: 6.78, EC: 127.8 µS/cm, Temp: 15 °C, Redox: 10.8 mV, DO: 103.6 % Sat, TDS: 105.7 ppm, Cut: 3.4 L/s

PARSONS BRINCKERHOFF

Drawing No.: HU0096PZC - Bore construction	
Revision: A	Date drawn: 5/3/14
Drawn by: K. Maher	Checked by: L. Rochford
Project No. 2172599A	

HUMECOAL PROJECT

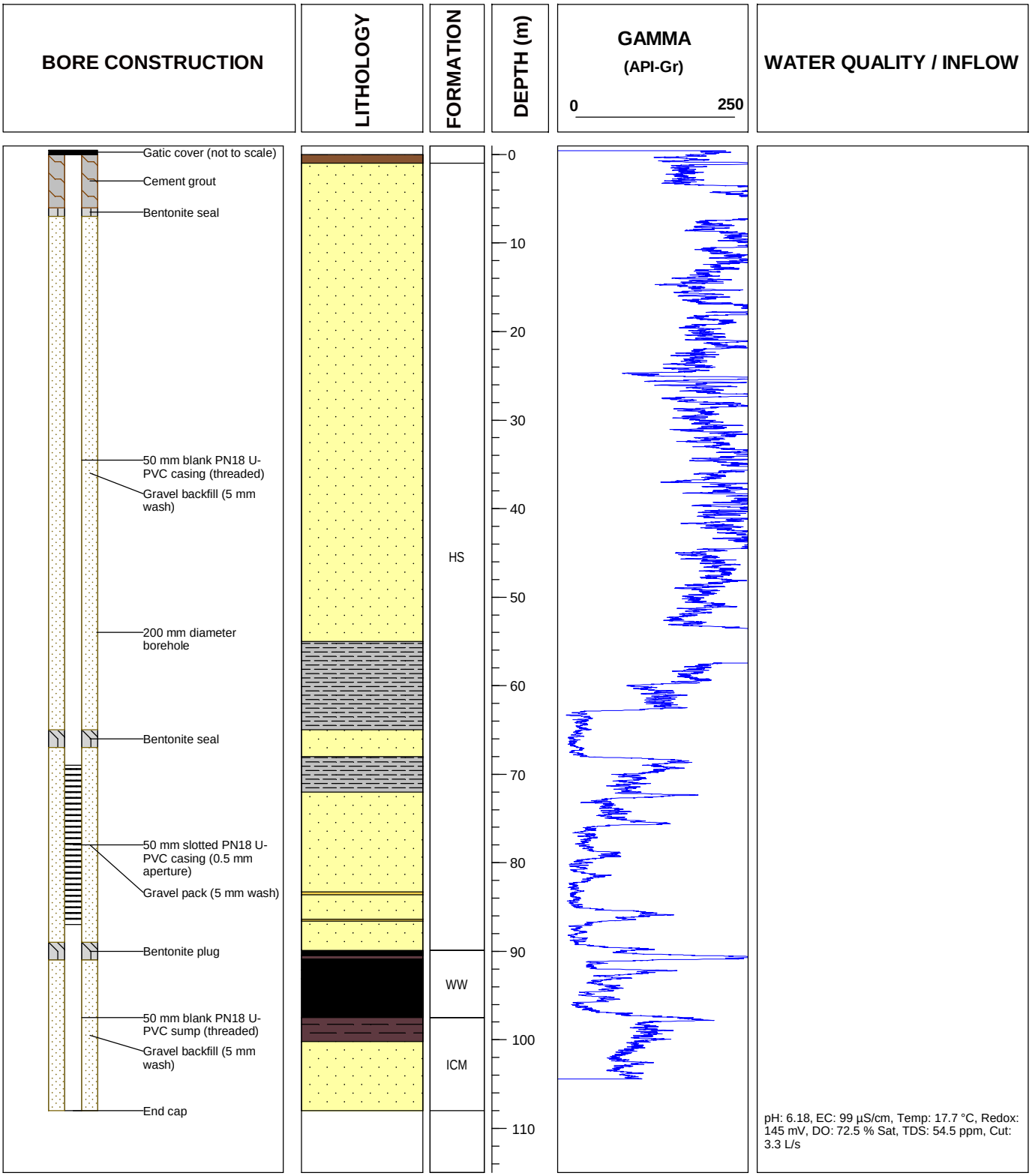
Hume Coal Pty Ltd

BORE COMPLETION REPORT

HU0098LD

Project: Hume Coal Project
Easting: 246477 **Northing:** 6177009 **(MGA Zone 56)**
Top of casing: -
Ground level: 699.06 mAHD
Static water level: - **Date:** -

Completion date: 05/08/2013
Drlling company: Highland Drilling
Drlling method: Air rotary
Screened interval: 69.0 - 87.0 mbgl
Gravel pack: 67.0 - 89.0 mbgl



PARSONS BRINCKERHOFF	Drawing No.: HU0098LD - Bore construction	
	Revision: A	Date drawn: 5/3/14
	Drawn by: K. Maher	Checked by: L. Rochford
	Project No. 2172599A	

HUMECOAL PROJECT

Hume Coal Pty Ltd

WATER MONITORING BORE LOG

Bore ID: HU0147PZA

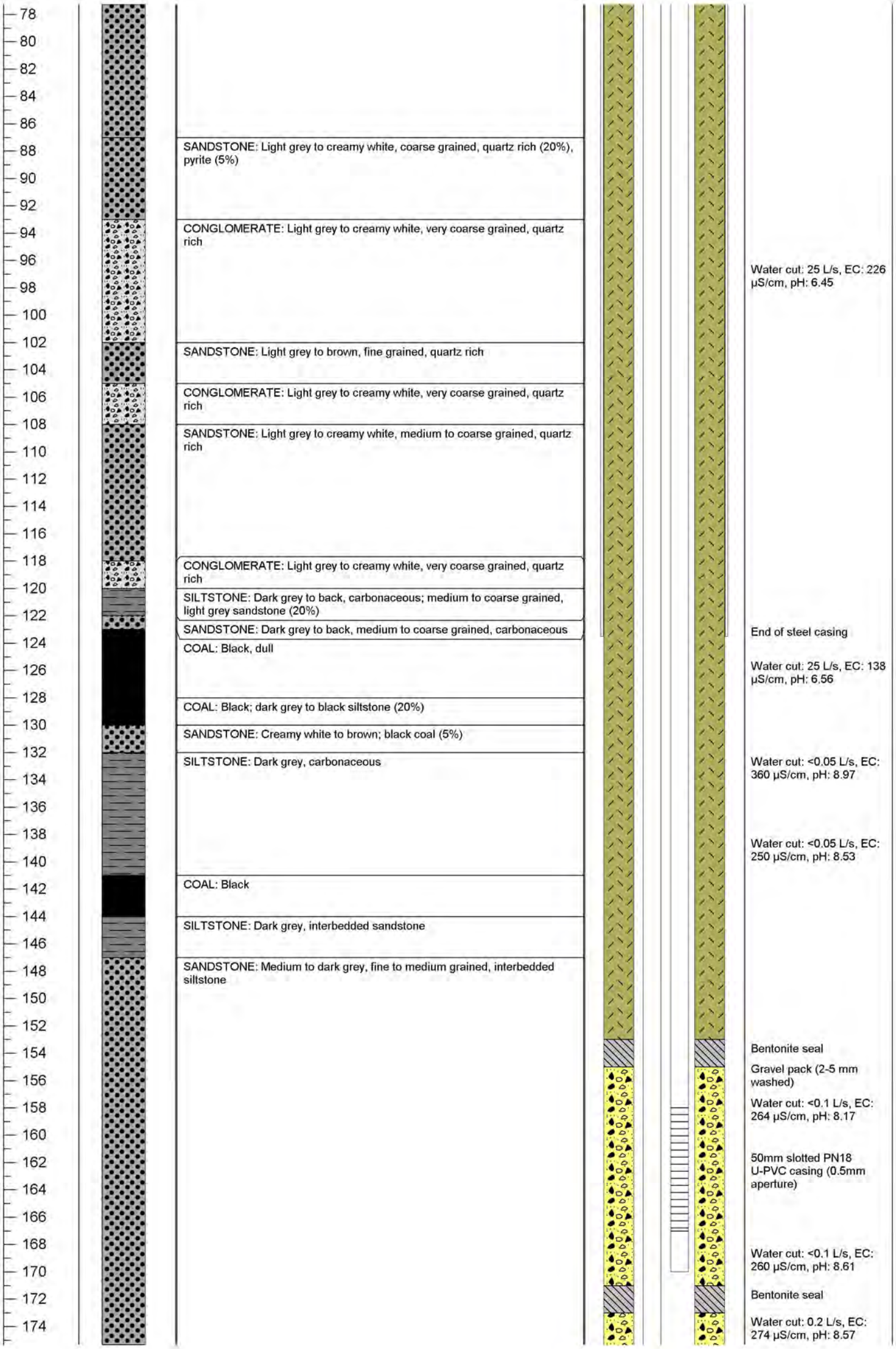
EMM
www.emmconsulting.com.au
Suite 01, 20 Chandos Street
St Leonards NSW 2065
T: 02 9493 9500
F: 02 9493 9599

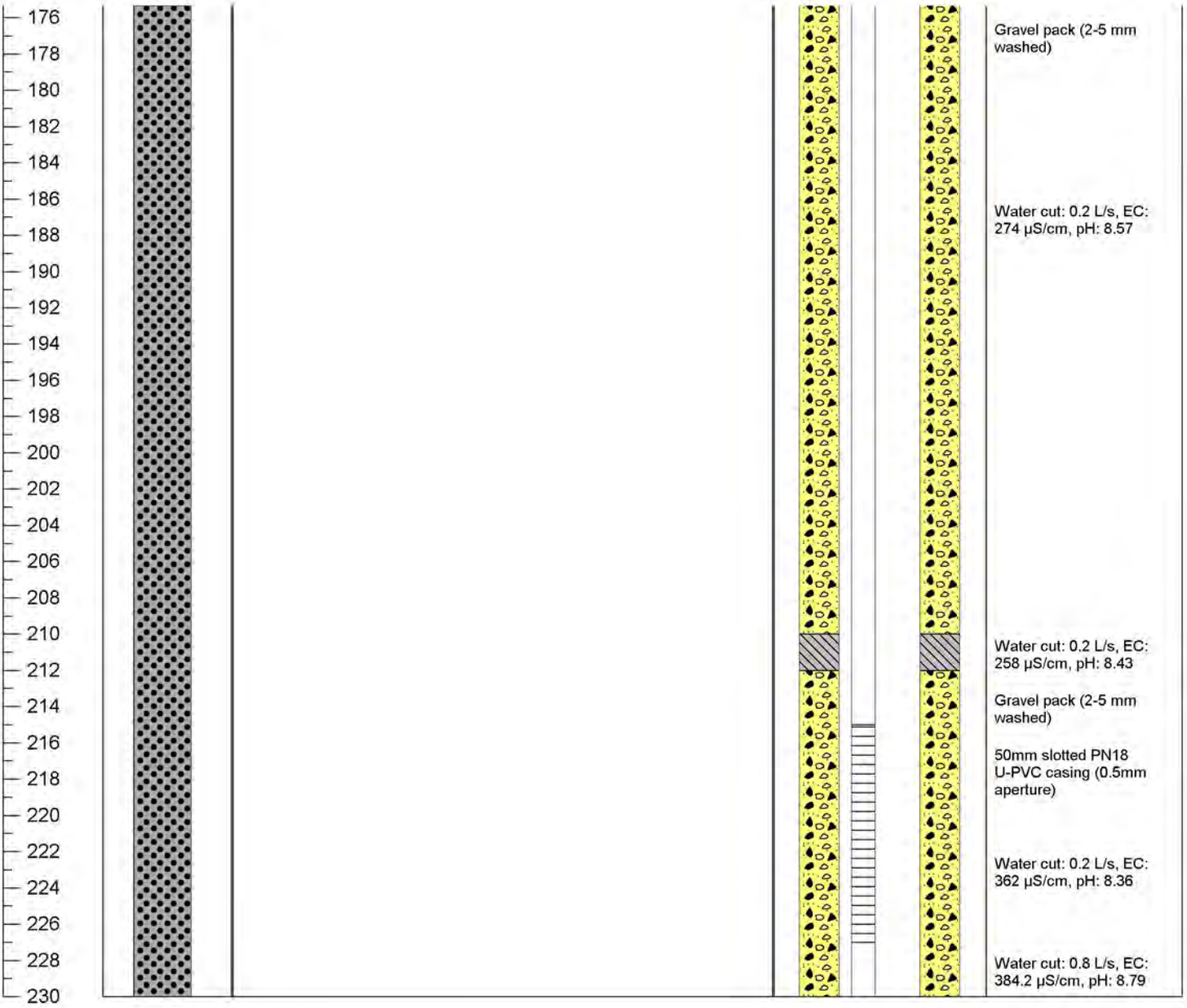
Client: Hume Coal Pty Limited
Project: Hume Coal Project

Date completed: 3/11/17
Drilling contractor: Highland Drilling
Drilling method: Rotary drilling
Hydrogeologist: Kele Maher
Static Water Level: A = 17.44 mbgl / B = 16.83 mbgl

Project number: J17221
Elevation (mAHD): 651.8
Easting (MGA 56): 249956.4
Northing (MGA 56): 6173396.7
Date: 3/11/17

Depth (mbgl)	Lithology Graphic	Description	Bore Completion Diagram: Diagram	Bore Completion Diagram: Design notes
0–2		CLAY: Orange, highly weathered	A B	8" steel casing
2–4		SHALE: Medium to dark grey, angular		Cement grout
4–6				Backfill
6–8				
8–10				
10–12				50mm blank PN18 U-PVC sump (threaded)
12–14				
14–16				
16–18				
18–20				
20–22		SILTSTONE: Medium to dark grey, dark grey sandstone (10%)		
22–24				
24–26		SANDSTONE: Light to medium grey, very fine grained, medium to dark grey shale (10%)		
26–28				
28–30				
30–32				Water cut: <0.01 L/s
32–34				
34–36		SANDSTONE: Light grey, fine to medium grained		
36–38				Water cut: 3 L/s, EC: 504 µS/cm, pH: 6.44
38–40				
40–42				
42–44				Water cut: 3 L/s, EC: 459 µS/cm, pH: 6.59
44–46				
46–48				
48–50				
50–52				
52–54				
54–56				Water cut: 6 L/s, EC: 336 µS/cm, pH: 6.61
56–58		SANDSTONE: Light grey to creamy white, fine to medium grained, quartz rich		
58–60				
60–62				
62–64				
64–66				
66–68				
68–70				
70–72				
72–74				Water cut: 25 L/s, EC: 269 µS/cm, pH: 6.57
74–76				


78
80
82
84
86
88
90
92
94
96
98
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
130
132
134
136
138
140
142
144
146
148
150
152
154
156
158
160
162
164
166
168
170
172
174
SANDSTONE: Light grey to creamy white, coarse grained, quartz rich (20%), pyrite (5%)
CONGLOMERATE: Light grey to creamy white, very coarse grained, quartz rich
SANDSTONE: Light grey to brown, fine grained, quartz rich
CONGLOMERATE: Light grey to creamy white, very coarse grained, quartz rich
SANDSTONE: Light grey to creamy white, medium to coarse grained, quartz rich
CONGLOMERATE: Light grey to creamy white, very coarse grained, quartz rich
SILTSTONE: Dark grey to back, carbonaceous; medium to coarse grained, light grey sandstone (20%)
SANDSTONE: Dark grey to back, medium to coarse grained, carbonaceous
COAL: Black, dull
COAL: Black; dark grey to black siltstone (20%)
SANDSTONE: Creamy white to brown; black coal (5%)
SILTSTONE: Dark grey, carbonaceous
COAL: Black
SILTSTONE: Dark grey, interbedded sandstone
SANDSTONE: Medium to dark grey, fine to medium grained, interbedded siltstone
Water cut: 25 L/s, EC: 226 µS/cm, pH: 6.45
End of steel casing
Water cut: 25 L/s, EC: 138 µS/cm, pH: 6.56
Water cut: <0.05 L/s, EC: 360 µS/cm, pH: 8.97
Water cut: <0.05 L/s, EC: 250 µS/cm, pH: 8.53
Bentonite seal
Gravel pack (2-5 mm washed)
Water cut: <0.1 L/s, EC: 264 µS/cm, pH: 8.17
50mm slotted PN18 U-PVC casing (0.5mm aperture)
Water cut: <0.1 L/s, EC: 260 µS/cm, pH: 8.61
Bentonite seal
Water cut: 0.2 L/s, EC: 274 µS/cm, pH: 8.57


176
178
180
182
184
186
188
190
192
194
196
198
200
202
204
206
208
210
212
214
216
218
220
222
224
226
228
230
Gravel pack (2-5 mm washed)
Water cut: 0.2 L/s, EC: 274 µS/cm, pH: 8.57
Water cut: 0.2 L/s, EC: 258 µS/cm, pH: 8.43
Gravel pack (2-5 mm washed)
50mm slotted PN18 U-PVC casing (0.5mm aperture)
Water cut: 0.2 L/s, EC: 362 µS/cm, pH: 8.36
Water cut: 0.8 L/s, EC: 384.2 µS/cm, pH: 8.79

WATER MONITORING BORE LOG

Bore ID: HU0147PZB

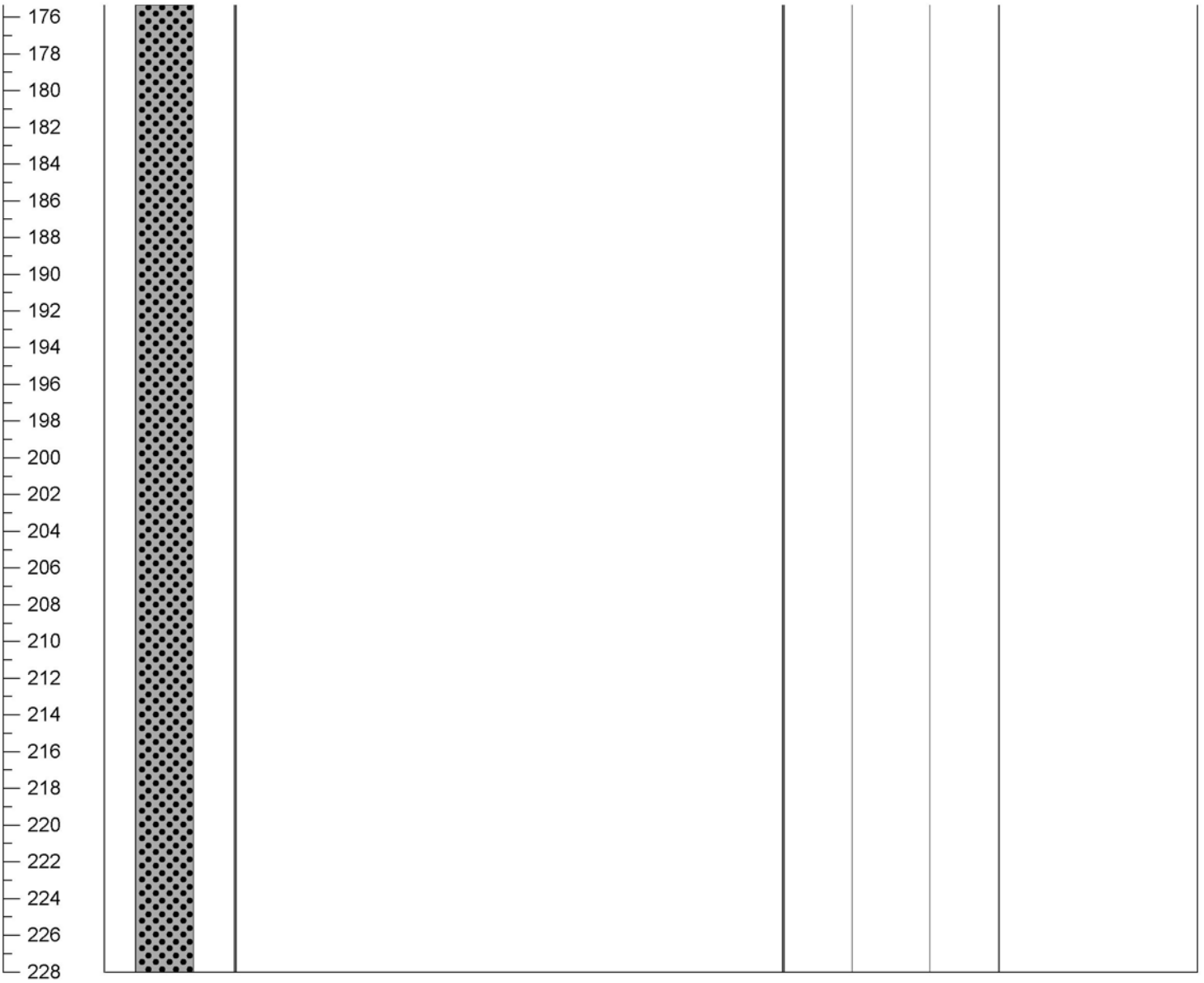
EMM
www.emmconsulting.com.au
Suite 01, 20 Chandos Street
St Leonards NSW 2065
T: 02 9493 9500
F: 02 9493 9599

Client: Hume Coal Pty Limited **Project:** Hume Coal Project

Date completed:	26/10/17	**Project number:**	J17221
Drilling contractor:	Highland Drilling	**Elevation (mAHD):**	652.6
Drilling method:	Rotary drilling / core drilling	**Easting (MGA 56):**	249966.9
Hydrogeologist:	Kele Maher / Carolina Sardella	**Northing (MGA 56):**	6173383.4
Static Water Level:	N/A	**Date:**	N/A

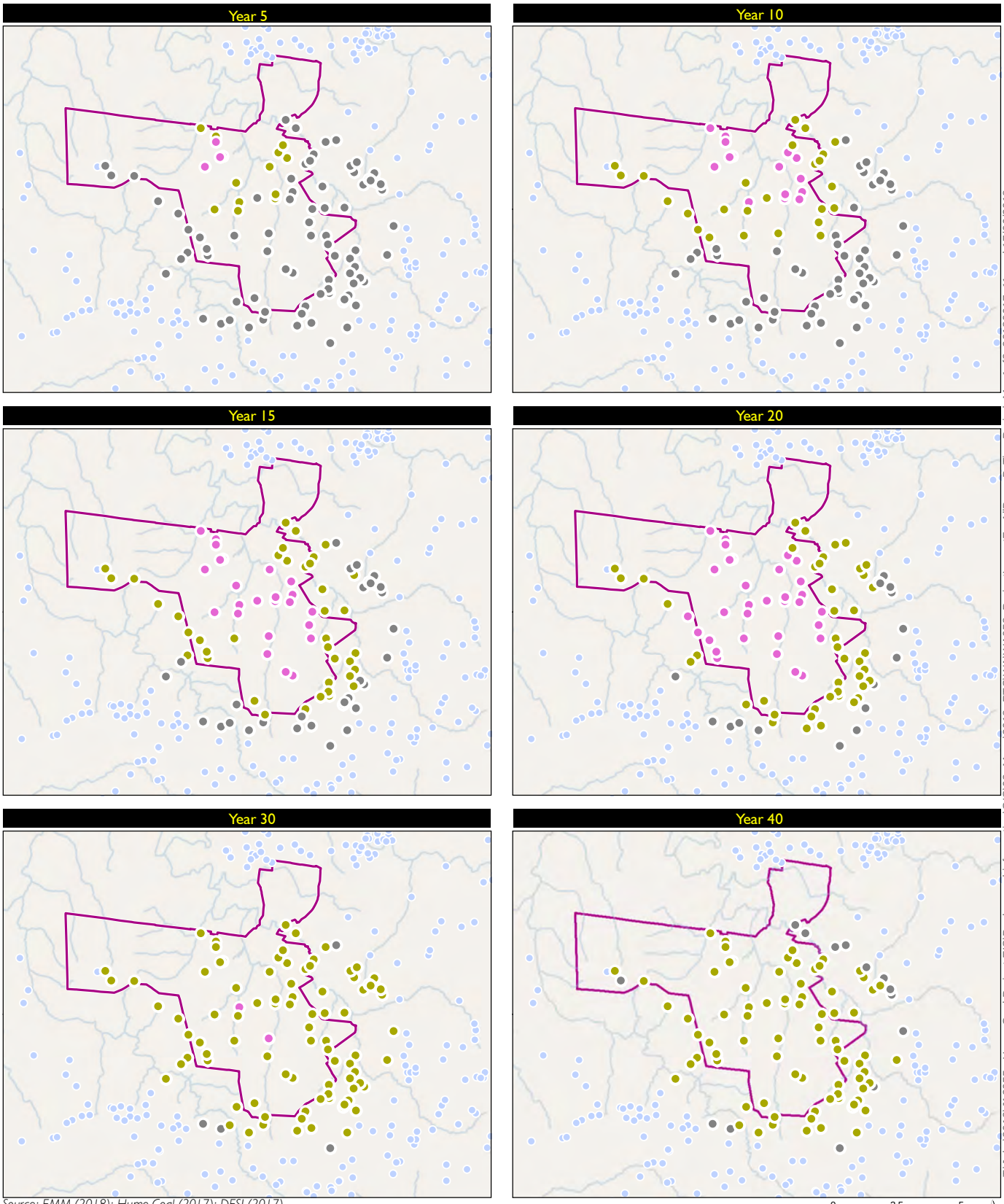
Depth (mbgl)	Lithology Graphic	Description	Bore Completion Diagram: Diagram	Bore Completion Diagram: Design notes
0–2		Clay: Orange, highly weathered		No monitoring bore installed
2–20		Shale: Medium to dark grey, angular		
20–24		SILTSTONE: Medium to dark grey, dark grey sandstone (10%)		
24–36		SANDSTONE: Light to medium grey, very fine grained, medium to dark grey shale (10%)		
36–56		SANDSTONE: Light grey, fine to medium grained		Water cut: 1 L/s, EC 345.3 µS/cm, pH 8.56
56–76		SANDSTONE: Light grey to creamy white, fine to medium grained, quartz rich		

78		
80		Water cut: 2 L/s, EC 287.6 µS/cm, pH 6.78
82		
84		
86		
88	SANDSTONE: Light grey to creamy white, coarse grained, quartz rich (20%), pyrite (5%)	
90		
92		
94	CONGLOMERATE: Light grey to creamy white, very coarse grained, quartz rich	
96		
98		
100		
102	SANDSTONE: Light grey to brown, fine grained, quartz rich	
104		Water cut: 3 L/s, EC 174.8 µS/cm, pH 6.57
106	CONGLOMERATE: Light grey to creamy white, very coarse grained, quartz rich	
108	SANDSTONE: Light grey to creamy white, medium to coarse grained, quartz rich	
110		
112		
114		
116		Water cut: 3 L/s, EC 172.8 µS/cm, pH 6.48
118	CONGLOMERATE: Light grey to creamy white, very coarse grained, quartz rich	Start core drilling
120	SILTSTONE: Dark grey to back, carbonaceous; medium to coarse grained, light grey sandstone (20%)	
122	SANDSTONE: Dark grey to back, medium to coarse grained, carbonaceous	
124	COAL: Black, dull	
126		
128		
130	COAL: Black; dark grey to black siltstone (20%)	
132	SANDSTONE: Creamy white to brown; black coal (5%)	
134	COAL: Black	
136	SILTSTONE: Dark grey, carbonaceous	
138		
140	COAL: Black	
142		
144	SILTSTONE: Dark grey, interbedded sandstone	
146		
148	SANDSTONE: Medium to dark grey, fine to medium grained, interbedded siltstone	
150		
152		
154		
156		
158		
160		
162		
164		
166		
168		
170		
172		
174		


176
178
180
182
184
186
188
190
192
194
196
198
200
202
204
206
208
210
212
214
216
218
220
222
224
226
228

Appendix L

Landholder bore drawdown over time



Source: EMM (2018); Hume Coal (2017); DFSI (2017)

KEY

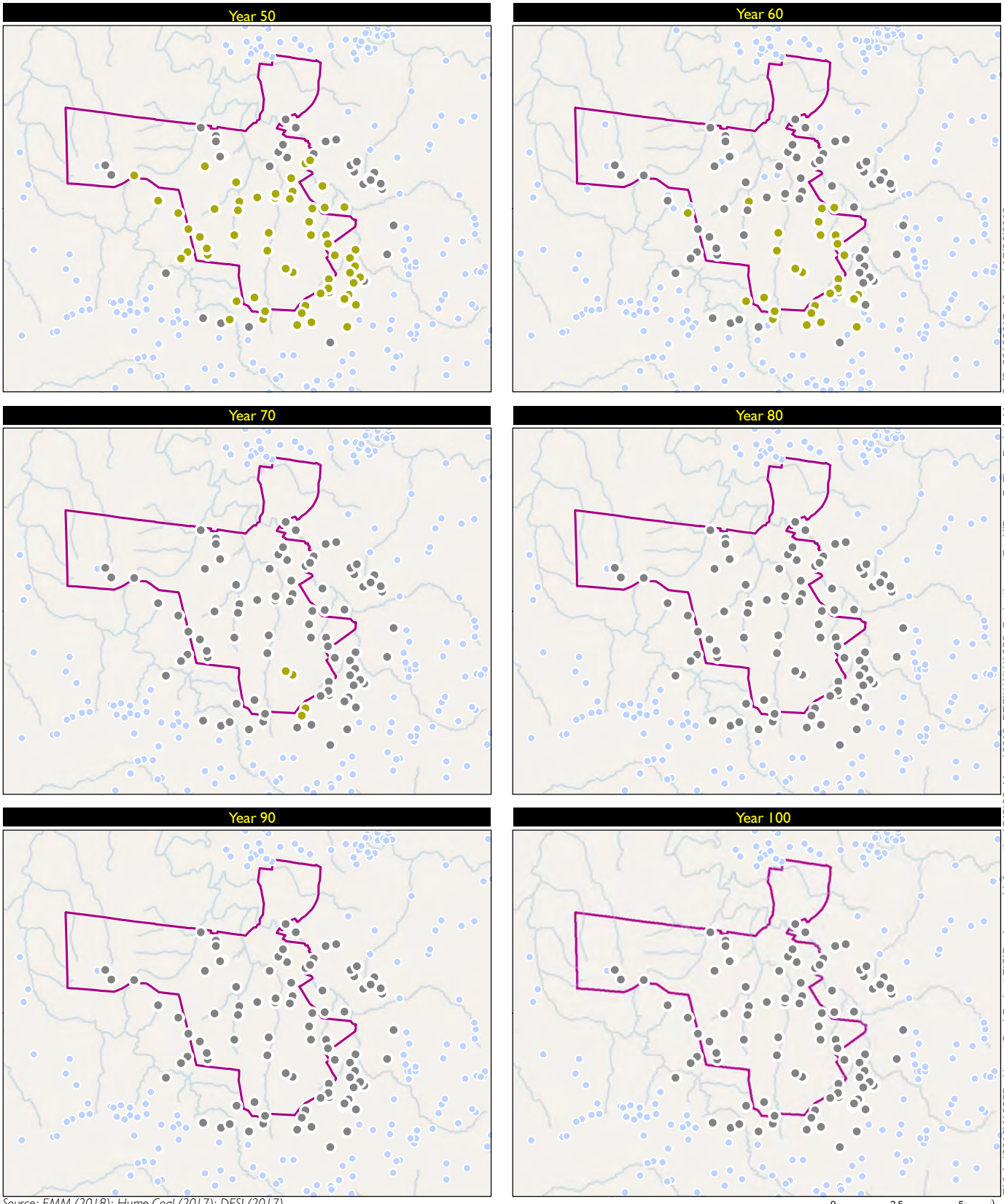
- Project area
- Drainage line
- Landholder bores - no impact

Impacted landholder bores - drawdown

- <2 m
- 2-10 m
- >10 m

Drawdown at landholder bores, at selected years since commencement of mining

Hume Coal Project
Revised Water Assessment
Figure L.1a



Source: EMM (2018); Hume Coal (2017); DFSI (2017)

KEY

- Project area
- Drainage line
- Landholder bores - no impact

Impacted landholder bores - drawdown

- <2 m
- 2 - 10 m
- >10 m

Drawdown at landholder bores, at selected years since commencement of mining

Hume Coal Project
Revised Water Assessment
Figure L.1b