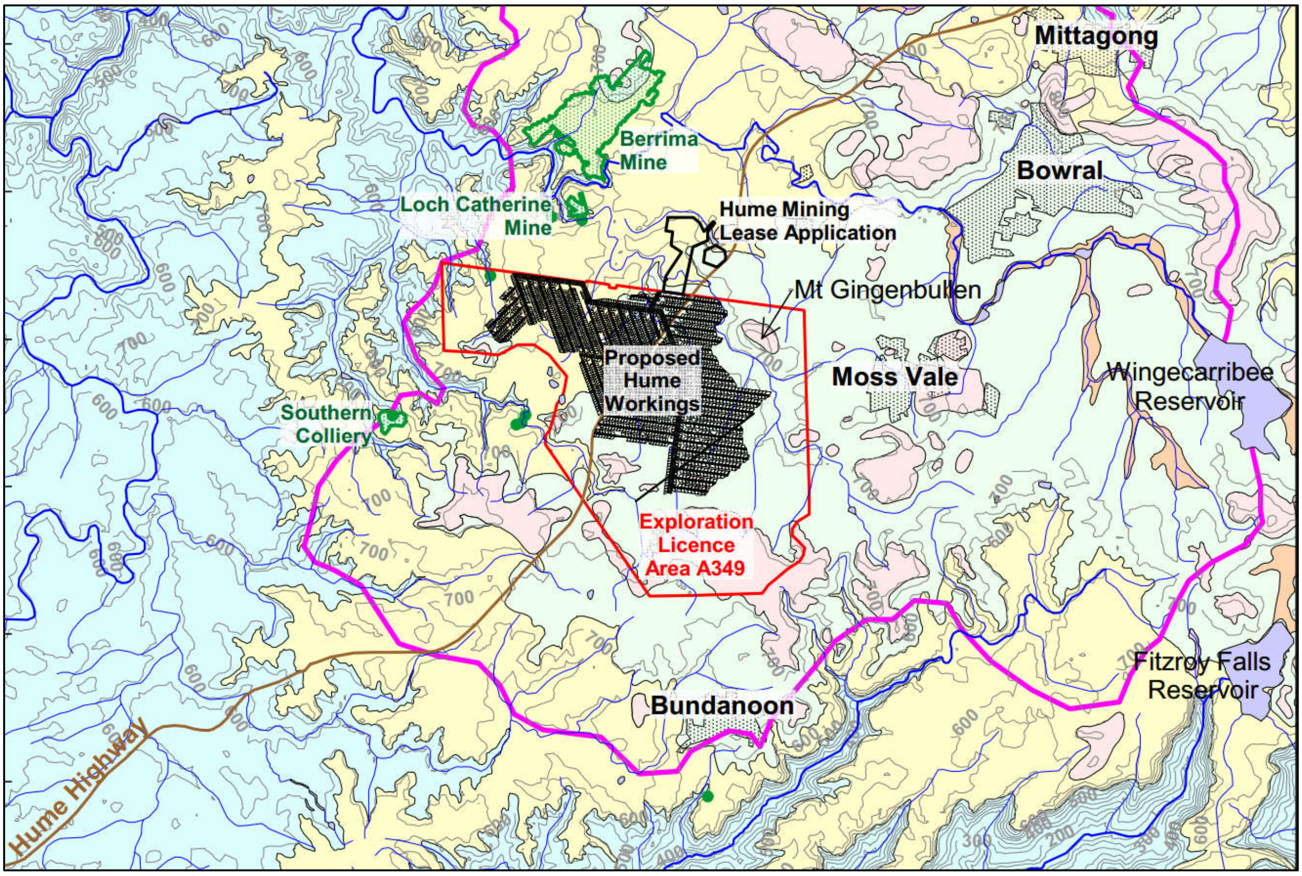
Hume Coal Project EIS
Independent Expert Review
Groundwater Modelling

Prepared for:	NSW Dept. Planning & Environment	16 October 2018



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Version 1	23 Oct. 2017	Draft report for discussion
Version 2	6 Dec. 2017	Updated report, after groundwater experts meeting 16 Nov. 2017
Version 3	6 August 2018	Updated review, considering HydroSimulations (June 2018) revised modelling
Version 4	17 August 2018	Updated with further detail on confidence level, impounded water & KPI table
Version 5	16 October 2018	Final edits (impoundment, geology, fracture height, calibration performance).

THIS REPORT SHOULD BE CITED/ATTRIBUTED AS:

Middlemis H (2018). Hume Coal Project EIS Independent Expert Review Groundwater Modelling. Prepared by Hydrogeologic for the NSW Department of Planning and Environment. 16 October 2018.

1. Introduction

This report presents the findings of an independent expert review of the groundwater and related modelling elements of the Environmental Impact Statement (EIS) submitted for the Hume Coal Project (SSD 7172) near Moss Vale in the Southern Coalfield of New South Wales. The review was commissioned by the NSW Department of Environment and Planning (DPE) and was carried out consistent with the peer review elements of the established best practice groundwater modelling guidelines (Barnett et al. 2012; Middlemis et al. 2001). Some commentary is also provided regarding reports prepared by others in response to the EIS.

This independent expert review report is presented as a combination of the review of the EIS modelling investigation (Coffey 2016b), as well the revised modelling (HydroSimulations 2018). While this forms a rather complicated presentation, it is necessary given that the revised modelling is stated to be "an adjunct to the EIS model report, not a replacement of it".

A key driver for this review is understood to be the extent and magnitude of groundwater drawdown predicted in the Environmental Impact Statement (EMM, 2017), in the range of 2 to 80 metres at 93 private bores on 71 properties in and around the project site, not including a further 6 bores owned by Hume Coal, giving a total of 99 bores affected (Coffey, 2016b). The cumulative impacts of Hume Coal plus Berrima Colliery plus private groundwater pumping was predicted to affect up to 115 bores. A key aim of this peer review is to identify whether the assessments made, or conclusions reached are supported by the evidence presented, and/or whether additional information, monitoring, assessment and/or modelling may be required.

This review report has been updated with consideration of the revised groundwater modelling (HydroSimulations, June 2018), which included uncertainty analysis indicating a 67% probability of 93 bores affected by at least 2 m drawdown, and a 10% probability that there may be up to 118 bores so affected (again, not including the 6 bores owned by Hume Coal). Subsequent analysis with updated bore datasets from DoI Water indicated that 94 bores were so affected (Table 5.1 of Hume Coal Project Response to Submissions Main Report, Volume 1, June 2018). Hence the HydroSimulations (2018) results have been incremented by one bore in the summary presented Table 1 below, which is based on the performance indicators listed in Table 24 of the revised modelling report, plus the 2016 EIS result for comparison. This review concludes that the revised modelling has improved the performance of the model (reduced mass balance discrepancy and scaled root mean square (SRMS) performance measures), the uncertainty analysis has quantified the likelihood of inflow volumes and drawdown impacts, and yet the results are essentially consistent with the 2016 EIS results.

Table 1 - Key groundwater modelling performance indicators for Hume Coal models

Hume Coal Model Review	2018 Revised Modelling Uncertainty Analysis Results		2016 EIS Result
Key Metric	67%ile	90%ile	
Number of Bores with Active Licence affected by 2m drawdown or more	94 + 6 = 100	119 + 6 = 124	93 + 6 = 99
Maximum mine inflow "to sump" (ML/day (ML/year))	2.8 (1017)	3.0 (1090)	2.7 (1000)
Maximum total mine inflow (ML/day (ML/year))	5.9 (2156)	6.4 (2336)	~7.8 (2860)
Calibration error (%SRMS)	11.03%	11.82%	11.9%
Model mass balance discrepancy (%)	<0.2%	<0.2%	4% - 6%

To aid interpretation, the "90%ile" indicates a 90% probability that the number of bores affected by more than 2 m of drawdown will be 124 or less. To put it another way, there is only a 10%

probability that the number of bores affected will be more than the 124 indicated (and similarly for the other metrics). The 2016 EIS result did not associate the impacts with a probability.

1.1 Review Scope and Evidentiary Basis

The Department of Planning and Environment has requested expert advice on the groundwater-related impact assessment in general, and on some issues in particular, including:

- the groundwater model, and whether its assumptions and resulting predictions are reasonable, especially in terms of dewatering volumes and drawdown extent/magnitude;
- the proposal for infilling some voids with co-disposed coal reject and/or excess mine water re-injection back into the workings down-dip from bulkheads, and the potential effect of these activities on groundwater quality;
- the potential effect of underground bulkhead failure on dewatering volumes and drawdown impacts (putting aside risk of occurrence of inrush and safety issues);
- the suitability of the make good provisions the mining company has proposed to mitigate groundwater impacts to private bores.

The main evidentiary basis for the expert review comprised several report volumes (components of the Hume Coal EIS, including the revised modelling in response to submissions on the EIS), with the following reports as the main targets:

- EMM (2017). Hume Coal Project Environmental Impact Statement Main Report. Prepared for Hume Coal Pty Limited, March 2017.
- Coffey (2016a) Groundwater Assessment Volume 1: Data Analysis. Prepared for Hume Coal Pty Limited, 17 November 2016.
- Coffey (2016b) Groundwater Assessment Volume 2: Numerical Modelling and Impact Assessment. Prepared for Hume Coal Pty Limited, 17 November 2016.
- HydroSimulations (2018). Hume Coal Project Revised Groundwater Modelling for Response to Submissions. Prepared for Hume Coal Pty Ltd, June 2018.

In addition, some other reports were considered, and some commentary is provided, notably:

- Department of Primary Industries (2017). Hume Coal Project (SSD 7172) and related Berrima Rail Project (SSD 7171). Comment on the Environmental Impact Statement (EIS). 16 July 2017.
- Pells, S. (2017) Groundwater Modelling of the Hume Coal Project. Prepared by Pells Consulting for the Coal Free Southern Highlands. 22 June 2017.
- Anderson, D. (2017). Hume Coal Project SSD 15_7172. Peer Review of Conceptual and Numerical Groundwater Modelling that predicted likely groundwater impacts. Prepared by the Water Research Laboratory, University of NSW, for the Coal Free Southern Highlands. Submitted online to the Dept of Planning and Environment via the Major Projects Portal. 23 June 2017.
- Lee, J (2017). Hume Coal Project SSD 15_7172: Southern Highlands NSW – Objection to Project Approval. Prepared by Hydroilex for Coal Free Southern Highlands. 30 June 2017.

1.2 Review Process, Issues Log and Status

The expert review process on the Hume Coal Project groundwater issues has comprised:

- a desktop review of key reports, leading to preparation of an issues log (11th August 2017), which was discussed briefly with DPE staff via telephone on 13th August 2017;
- clarification of various technical issues via telephone discussions between Mr Middlemis and key members of the Hume Coal groundwater assessment team:
  - Mr Paul Tammetta (Coffey) on 24th and 25th August 2017; and
  - Dr Noel Merrick (HydroSimulations) on 24th August and 7th and 9th September 2017;

- receipt of a response to the issues log from the Hume Coal groundwater assessment team (understood to have been prepared by Dr Merrick) on 5th October 2017;
- a face-to-face meeting between Mr Middlemis and Dr Merrick on 9th October 2017 at the DPE office to discuss the model refinements and additional scenarios in progress;
- update to the issues log on 11th October 2017 with this reviewer's responses, and final update in July 2018 with consideration of the Revised Groundwater Modelling (HydroSimulations 2018), concluding that all issues are now resolved (see Appendix A);
- groundwater experts meeting at DPE on 16 November 2017 (see agenda and attendee list in Appendix B);
- review of the Revised Groundwater Modelling report (HydroSimulations 2018), along with consideration of the revised water balance assessment (WSP 2018), and consideration of Core Issue #5 of the response to DP&E mining experts reports relating to impounded water and bulkheads, geological and interburden representations and aquifer parameters, height of fracturing, calibration performance (Hume Coal 2018); this included a telephone conference call on 5 October 2018 led by DPE and including the mining experts Prof. Ismet Canbulat and Emeritus Prof. Jim Galvin.
- brief telephone discussions with Dr Noel Merrick on 23 July and 3 August 2018, on some technical aspects of the revised groundwater modelling (HydroSimulations 2018); issues discussed included clarifications on the interpretation of the percentile likelihood of impacts, on details on the polynomial chaos expansion method of uncertainty analysis that was applied, and on whether the groundwater modelling allowed for the impoundment of water pumped directly from the mine sump to residual void space (it did not); the discussions included confirmation that issues outstanding from the previous review of the EIS modelling have been addressed by the revised modelling, as documented in the Issues Log in Appendix A.
- telephone conference call 12 September 2018 facilitated by DPE with representatives from DoI Water in attendance at DPE office;
- preparation and updating of this review report (refer to version table on contents page).

While the December 2017 version of this review found that the Hume Coal model itself is suitable for the mining impact assessment purpose (Class 2 confidence level), the EIS documentation was considered to not meet best practice groundwater modelling standards.

Subsequent model revisions (HydroSimulations 2018) have addressed the documentation issues and the technical issues, notably via the uncertainty and sensitivity analysis. The December 2017 review found that the EIS presented reasonable predictions of dewatering volumes and drawdown extent/magnitude. The revised modelling predictions (HydroSimulations 2018) can be characterised as indicating a similar range of impacts in terms of the key output metrics (e.g. as outlined in Table 1 above in terms of mine inflows, drawdowns, bores affected, baseflows), and with a quantified range in uncertainty. This updated review endorses the best practice methods applied to the revised modelling predictions and quantification of related uncertainties.

2. Model Refinements and Performance

The groundwater model refinements completed by HydroSimulations (2018) were designed to address issues identified via a model audit by Dr Merrick (HydroSimulations), and to address certain items in the issues log identified by this expert review (see Appendix A). The following points summarise the refinements implemented:

- improving model performance generally via trimming inactive grid cells, refining the solver settings and stress period timing, revising the aquifer storage parameters, and replacing Modflow-Surfact with Modflow-USG which allows the time-varying materials function to be used, as well as an improved pseudo-soil function; all of which has reduced the water balance discrepancy term to less than 0.2% and reduced the SRMS calibration performance statistic to around 11% (HydroSimulations 2018; Table 5 and section 7.1.2), and achieved faster run times;

- reviewing model layer thicknesses and revising the relaxation zone above the Hume workings to account for where (thin) dummy layer thicknesses apply where lithological units pinch out; this resulted in some areas where the lower Hawkesbury Sandstone is now in direct contact with mine workings;
- deactivating drain cells post-mining where mining continues up-dip, which allows inflows to potentially be impounded down-dip of the active mining face (although impoundment was not modelled as such); this drain cell treatment helped address and resolve water balance issues affecting the EIS model;
- reviewing the data on the variability of hydraulic conductivity spatially and with depth, and revising the parameters applied to the groundwater model; this provided an objective assessment of the effects of parameter variability that addressed an issue raised with the EIS model, and was foundational to the sensitivity and uncertainty analysis conducted via the revised modelling;
- running 108 climate scenarios to assess uncertainties in terms of mine inflows, drawdown and stream baseflow; this concluded that the results are largely insensitive to climate, and allowed comparison against the average climate scenario results outlined in the EIS;
- conducting a calibration-constrained Monte Carlo uncertainty analysis of aquifer hydraulic conductivity to investigate the effects on mine inflows, drawdown and stream baseflow; also conducting a sensitivity analysis into aquifer storage, drain conductance and evapotranspiration parameters, and the pseudo soil function and vertical barrier feature near Basalt outcrop; this approach has effectively addressed the sensitivity and uncertainty analysis issues raised re the EIS model.

The issues log (Appendix A) outlined a range of issues where the December 2017 review found that the EIS report documentation did not provide sufficient clarity, leading to potential misinterpretations of the model setup and/or performance.

A notable example relates to the water balance tables in the EIS report, which indicated a discrepancy term (difference between inputs and outputs) in the order of 5%. It is easy to misinterpret those tables as indicative of a poor model solution, given that the guidelines set a criterion of less than 1% discrepancy at any stress period during the simulation. However, the water balances are reported (somewhat confusingly) in the EIS as the “average flow budget” over a range of stress periods (e.g. calculated as a cumulative volume over 22 years of mining, divided by the 22 years; Paul Tammetta, pers.comm.). Although this is a little unusual (water balances are typically presented for specific stress periods), the water balance data presented in the EIS are consistent with aquifer storage depletion due to mine dewatering (at Berrima and/or Hume), so it is understandable that there is a significant average “discrepancy” shown over the mining period.

The reported water balance “discrepancy” is not indicative of fundamental flaws in the Hume Coal EIS model, contrary to review comments from DPI Water (2017) and Anderson (2017), and hence their downgrading to a Class 1 model confidence level 1 is invalid. Accordingly, any criticisms based on this invalid premise are also not necessarily valid.

This review found that most of the items raised in the issues log (Appendix A) arose from the less than transparently clear reporting (Coffey, 2016b). Most items have been clarified via technical discussions with the modellers (as suggested by the guidelines). Some residual issues warranted model revisions (as well as report revisions), but it is understood that most of these model revisions were in progress already (in late 2017), further to the model audit process by Dr Merrick. Some interim results from that process were presented and discussed at the meeting with Dr Merrick on 9th October 2017, confirming that the fundamental model setup and performance are indeed adequate in terms of guideline criteria (statistical and water balance measures).

The revised groundwater modelling report (HydroSimulations 2018) provides clear evidence that all the EIS issues have been addressed satisfactorily, notably including the water balance and the sensitivity and uncertainty analysis.

3. Hume Coal Groundwater Model Review Summary

This review report has been updated with consideration of the revised groundwater modelling (HydroSimulations 2018).

3.1 Model Confidence Level

The Model Confidence Level Classification is a key concept of the Australian Groundwater Modelling Guidelines (Barnett et al. 2012). It is used to provide a qualitative indication of the relative confidence of a model for predictions of groundwater system responses. The classification is based on a range of criteria related to the quality and quantity of data used to conceptualise and calibrate the model, the manner and outcome of the calibration procedure, and the hydrological stress magnitudes and durations (e.g. pumping) that are included in the predictive scenarios compared to the calibration scenarios. The assessment criteria are listed in Table 2-1 of the Guidelines. While it is now accepted that it is not necessary for a model to meet or pass all criteria for a given class of model (Middlemis and Peeters, 2018), the commentary in the guidelines does indicate otherwise, and this is often used to unjustifiably criticise modelling studies. The problem is the confusing commentary in the guidelines, not the criteria as such.

Rather than adopt a qualitative method to classify “confidence” in model results, current best practice (Middlemis and Peeters, 2018; Bennett et al. 2013) recommends that uncertainty analysis be applied, such the model results are accompanied by an objective or quantitative estimate of their likelihood, as has now been achieved with the revised modelling. However, the following review comments are retained to address the issues raised on the 2016 EIS.

The groundwater assessment reports (Coffey, 2016b; HydroSimulations, 2018) claim a model confidence level of Class 2/3, suitable for an impact assessment purpose. This review finds that a Class 2 is justified (with elements of Class 3), based on an independent assessment (Table 2) **of the attribute weightings of the Hume Coal model as reported in Coffey (2016b) and HydroSimulations (2018).**

Anderson (2017) disagreed with the groundwater assessment report statement of a Class 2/3 model for the EIS model version, suggesting a lower confidence Class 1 level. DPI Water (2017) also suggested Class 1, citing commentary in the modelling guideline (Barnett et al, 2012) that any element of Class 1 renders the entire model Class 1. These assessments were largely based on the relatively poor scaled root mean square (SRMS) statistic of 11.9% reported in the EIS (Figure 4.2 of Coffey, 2016b), and the (misinterpreted) water balance issues, discussed above in section 2. As explored in the best practice modelling guidelines (Barnett et al. 2012), an SRMS of more than 10% is indeed a Class 1 indicator (this also applies to the revised modelling which achieved around 11% SRMS; HydroSimulations 2018), but there are very few other characteristics of the Hume Coal model that could reasonably be assessed as Class 1. An SRMS in excess of 10% is acceptable in this case, because the calibration performance is based on not simply the SRMS, but simultaneously on 4 other key criteria, consistent with the guidelines: matches to baseflow and mine dewatering fluxes; aquifer parameters consistent with field measurements, and using a calibration history match period that includes substantial hydrological variability (climatic and mine dewatering stresses).

The model Class is important because DPI Water (now DoI water) and Anderson have relied heavily on the demonstrably false premise of a Class 1 model to base their initial claims of inadequate modelling for impact assessment purposes. It is understood that a meeting was held between DPI Water and Dr Merrick in late 2017 when the draft issues log (Appendix A) was discussed, and DPI Water have now agreed that a Class 2 level applies to the Hume Coal model, based on the attribute weighting approach (Table 2), although this review has not sighted written evidence to that effect.

Table 2 - Model confidence class characteristics (updated July 2018) - Hume Coal Project

Class		Data		Calibration		Prediction		Quantitative Indicators
1		Not much.		Not possible.		Timeframe >> Calibration		Timeframe >10x
		Sparse coverage.	~	Large error statistic.		Long stress periods.		Stresses >5x
	√	No metered usage.		Inadequate data spread.		Poor/no validation.		Mass balance > 1% (or one-off 5%)
(simple)		Low resolution topo DEM.		Targets incompatible with model purpose.		Transient prediction but steady-state calibration.		Properties <> field values.
		Poor aquifer geometry.						No review by Hydro/Modeller.
2		Some.	√~	Partial performance.	√	Timeframe > Calibration	√	Timeframe = 3-10x
		OK coverage.		Some long term trends wrong.		Long stress periods.	√	Stresses = 2-5x
(impact assessment)		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. Review by Hydrogeologist.
	√	Some high res. topo DEM &/or some aquifer geometry.		No use of targets compatible with model purpose (heads & fluxes).	√	New stresses not in calibration.		Some coarse discretisation in key areas of grid or at key times.
3		Lots, with good coverage.		Good performance stats.		Timeframe ~ Calibration		Timeframe < 3x
		Good metered usage info.	√~	Most long term trends matched.	√	Similar stress periods.		Stresses < 2x
	√	Local climate data.		Most seasonal matches OK.		Good validation.	√	Mass balance < 0.5%
(complex simulator)	√	Kh, Kv & Sy measurements from range of tests.	√	Present day data targets.		Calib. & prediction consistent (transient or steady-state).	√~	Properties ~ field measurements.
		High resolution DEM all areas.	√	Head & Flux targets used to constrain calibration.		Similar stresses to those in calibration.	√	No coarse discretisation in key areas (grid or time).
	√	Good aquifer geometry.					√	Review by experienced Modeller.

(after Table 2-1 of Barnett et al (2012) Australian Groundwater Modelling Guideline)

That the Hume EIS model can be improperly labelled Class 1 with apparent justification from the guidelines is not the fault of the model; it is due to misinterpretation of the guideline commentary on the model confidence level classification. That is, the model confidence level classification table in the guidelines is itself not unreasonable (Barnett et al, 2012; Table 2-1), but the related commentary and guidance is poor and self-contradictory. In this case, cherry-picking one guideline comment rather than considering all the attributes suggested in the table does not constitute a valid argument to support the claims by others of poor model performance.

In any event, the stress period water balance discrepancy term has been confirmed as less than 0.2% and the SRMS has been reduced to around 11% during the model refinements that were in progress in late 2017 (see section 2), and the water balance issue has been further clarified by this review, removing most of the grounds for the Class 1 claim by others. Finally, the revised modelling (HydroSimulations 2018) has addressed these issues satisfactorily.

3.2 Model Compliance Checklist - Hume Coal Project

In addition to the model confidence level classification assessment, the guidelines (Barnett et al, 2012) suggest a compliance checklist of 10 key questions to summarise review outcomes, which is presented in Table 3 based on the findings of this expert review (updated with consideration of the revised modelling of HydroSimulations 2018).

In summary, it is my professional opinion that the Hume Coal model is consistent with best practice, with satisfactory report documentation and detailed uncertainty and sensitivity analysis (HydroSimulations 2018). It is fit for mining impact prediction purposes.

Table 3 - Groundwater Model Compliance Checklist: 10-point essential summary

Question	Yes/No	Comments re Hume Coal Project groundwater model
1. Are the model objectives and model confidence level classification clearly stated?	Yes	Mining impact assessment context. Class 2 confidence level (Barnett et al, 2012), with elements of Class 3. Medium complexity model (Middlemis et al, 2001). Clearly described in model reports.
2. Are the objectives satisfied?	Yes	Adequate model calibration performance (revised model shows 10.8-11.3% SRMS (HydroSimulations 2018, Table 5 & Section 7.1.2, improved from 11.9% in EIS reports). Adequate time series matches. Impact assessments have been completed diligently, and report documentation has been improved.
3. Is the conceptual model consistent with objectives and confidence level classification?	Yes	Conceptualisation is sound. Model design of 50m grid (min.) and 13 active layers represents geological structure, coal seams and interburden. Calibration to existing nearby mining effects (Berrima) and recent climate variability address non-uniqueness issues and support a Class 2 confidence level.
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Yes	Reports describe previous investigations and data sources, with reviews at many stages, along with reference to relevant papers (e.g. on coal mine subsidence issues). Most assessment reports are very well presented, but the EIS model report (Coffey, 2016b) is somewhat deficient. Shortcomings have been addressed by revised groundwater modelling report (HydroSimulations 2018) (e.g. commentary on interburden thickness treatments, water balances, uncertainty and sensitivity analysis). In-house review of EIS model by Dr Merrick and Dr Kalf. Dr Merrick completed a detailed model audit, and subsequent model refinements addressed all issues and improved model performance outcomes (see section 2 for details).
5. Does the model design conform to best practice?	Yes	The model software, design, extent, grid, boundaries and parameters form a good example of best practice in design and execution. The EIS work used Modflow-Surfact and the revised modelling used Modflow-USG, both industry-leading software, with USG adding the benefit of time-varying properties for subsidence issues and improved dry cell treatment. The western boundary is somewhat close to the Hume and Berrima mine areas, but it is constrained to the up-dip extent of the coal measures, which seems appropriate.
6. Is the model calibration satisfactory?	Yes	Acceptable model calibration performance and good time series matches to trends at most bores (except 2 of 6 VWPs, which is not unreasonable). EIS report states 11.9% SRMS, which exceeds the 10% criterion, but refinements have reduced the SRMS to ~11%, and water balance error terms to <0.2% (see section 2 and Appendix A), which is satisfactory. Some 30% of the uncertainty analysis realisations achieved less than 10% SRMS. An SRMS in excess of 10% is acceptable in this case, because the calibration performance is based on not simply the SRMS, but simultaneously on 4 other key criteria, consistent with the guidelines: matches to baseflow and mine dewatering fluxes; aquifer parameters consistent with field measurements, and over a calibration history match period that includes substantial hydrological variability (climatic and mine dewatering stresses). Calibration of aquifer property values (Kh, Kv, S, Sy) has been well constrained by pumping test estimates of property values, and by simultaneously honouring observed groundwater levels, along with the measured Berrima mine inflow (deep system) and inferred stream baseflows (shallow system). This is a best practice approach that reduces model non-uniqueness problems (that many different sets of model inputs can produce nearly identical aquifer head distributions). Uncertainties have been adequately addressed by the revised groundwater modelling (HydroSimulations 2018).

7. Are the calibrated parameter values and estimated fluxes plausible?	Yes	Appropriate level of complexity in parameter distributions has been applied to achieve good calibration performance, including to effects of underground mining at Berrima, and application of Pilot Points methods to investigate uncertainties. Parameter values and fluxes are plausible and consistent with site-specific testing and literature values (e.g. relaxation heights; Tammetta, 2013, 2015). The EIS report claim of two “long term pumping tests” is exaggerated; a one-day test is not “long term” and the other test was only 7 days duration. However, the tests did give some information on the key/sensitive property value for vertical hydraulic conductivity (Kv). Specific storage (Ss) was set at 5.10^{-7} m^{-1} in the EIS model version. This is very low (almost at the physical limit for the compressibility of water). However, the confined storativity parameter (product of Ss and thickness) that is actually used in model calculations is reasonable (around 10^{-4} for the full thickness of Hawkesbury Sandstone). Model revisions (HydroSimulations 2018) set higher (appropriate) values for storativity, and conducted a sensitivity analysis, concluding the results are not highly sensitive.
8. Do the model predictions conform to best practice?	Yes	Prediction results are credible in terms of water volumes and drawdowns, but water balance descriptions were not presented clearly in the EIS report. Subsequent revised modelling (HydroSimulations 2018) conforms to best practice. Method applied in groundwater assessment EIS of leaving drain cells on (after mining and sealing panels) until residual void behind bulkheads is filled provides a prediction of the effect of bulkhead failure in terms of water take and drawdown. Revised model refinements (see section 2) of turning off drains behind active face when mining proceeds up-dip is more realistic. Uncertainty analysis shows the likely range of mine inflows (between the 10^{th} and 90^{th} percentile) is quite consistent with the EIS predictions
9. Is the uncertainty associated with the predictions reported?	Yes	No comprehensive uncertainty assessment was done for the EIS groundwater assessment (Coffey 2016b), but the revised modelling included a calibration-constrained Monte Carlo uncertainty analysis (HydroSimulations 2018). A sensitivity analysis was done for the EIS model on the identified sensitive parameters of relaxation height, mine drain conductance parameter and Hawkesbury Sandstone Kv (Coffey, 2016b), and this was expanded in the revised modelling (HydroSimulations 2018) to also consider evapotranspiration, geological structures and the pseudo-soil (dry cell) function. DPI Water (now DoI Water) requested scenario analysis of 108 climate datasets (consistent with surface water assessments), and consideration of mine water management. The results indicated low climate sensitivity and were presented along with the revised groundwater modelling and other sensitivity analysis (HydroSimulations 2018). EIS claimed that a well-constrained calibration to groundwater levels and to shallow and deep fluxes (Berrima inflows and stream baseflows) reduces uncertainty. While this is true, it does not eliminate uncertainty. The revised modelling has now completed an uncertainty analysis, along with additional sensitivity analyses (HydroSimulations 2018), that quantify the mine inflows and associated drawdowns and baseflow impacts in terms of probability of exceedance, consistent with best practice.
10. Is the model fit for purpose?	Yes	My professional opinion is that the Hume Coal model (in terms of the combination of the 2016 EIS and its adjunct the 2018 revised modelling) is a good example of best practice in design and execution. It is fit for mining project impact prediction purposes and the results presented are reasonable in terms of inflows and drawdown predictions and related uncertainties.

4. Impact Assessment Issues

The following points are provided in response to requests for information from the DPE and/or to summarise clarifications provided by Mr Middlemis at the independent expert meeting on 16 November 2017 (Appendix B), and/or regarding the revised modelling report (HydroSimulations 2018), and/or the teleconferences organised by DPE to facilitate discussions between the reviewer and DoI Water (12 September 2018) and the DPE mining experts (5 October 2018).

4.1 Interburden Layer Representation in Hume Coal Model

While this review found that the EIS reporting (Coffey 2016b) on this key topic is very unclear, confused, self-contradictory and sub-standard, the revised modelling report (HydroSimulations 2018) is clear and satisfactory. Pells (2017) and Anderson (2017) also raised questions about the interburden implementation in the EIS model, and this was discussed further at the meeting on 16 November 2017 (Appendix B); hence the discussion below is retained, for the record.

Dr Merrick indicated during review discussions (see Issues Log item 3 in Appendix A) that his internal review of the model identified issues with the implementation of the interburden (layer 8, comprising the combined Narrabeen Group, Wongawilli Ply and Farmborough Claystone) that warranted corrective action in terms of extending the relaxation zone up into layers 6 and 7 in some areas of interburden absence (Figure 1).

Dr Merrick confirmed that the interburden thickness (or absence in extensive areas) is represented properly in the model, and indicated (see Appendix A for details, and section 4.2 of HydroSimulations 2018) that:

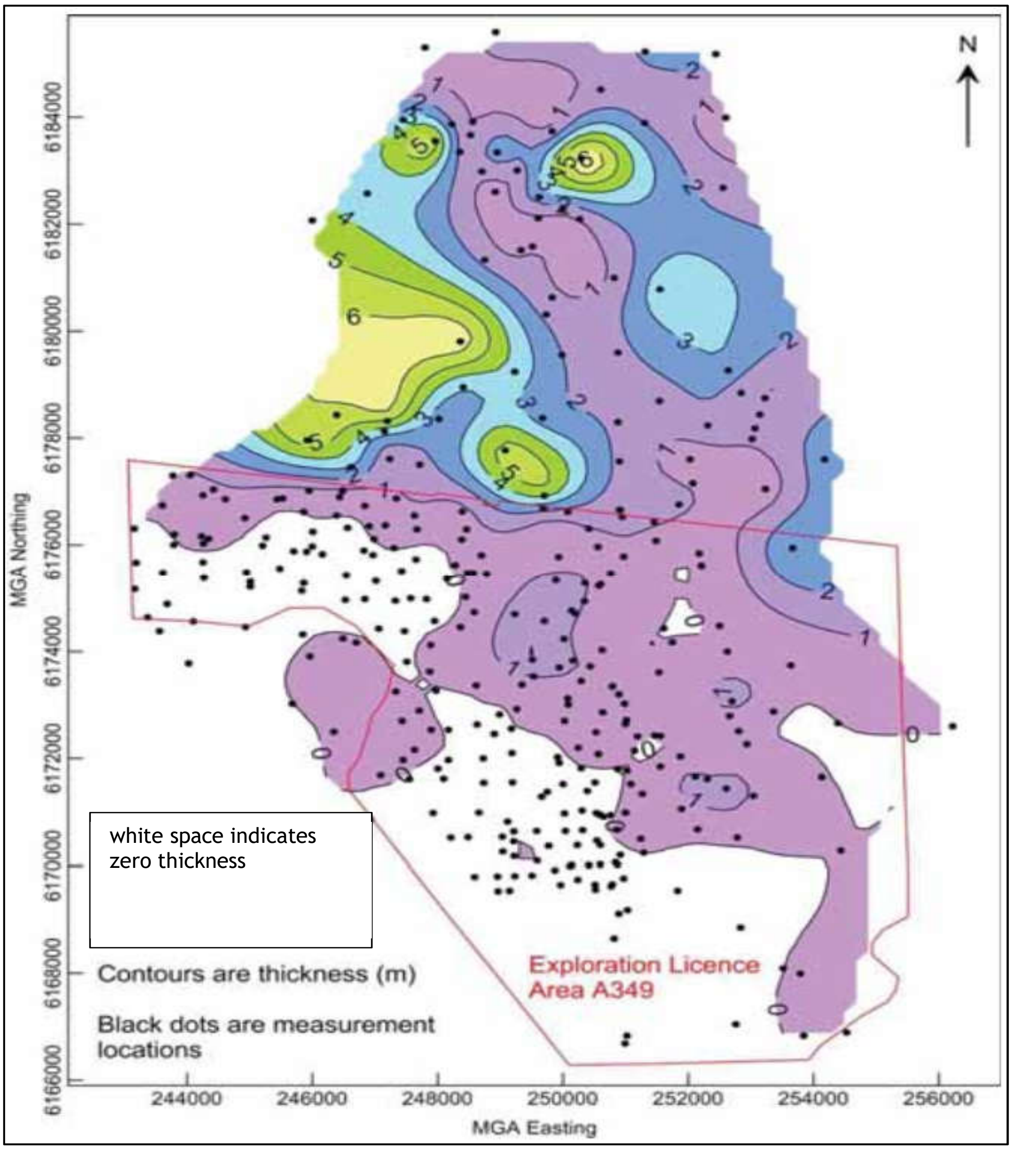
- a minimum thickness of 0.4m is applied to layer 8 (interburden) in areas where the interburden is absent (Figure 1), but in those areas, the parameters applied are the same as those for the Wongawilli mined seam;
- a minimum thickness of 0.29m is applied to the underlying layers 9 and 10 (the Permian units between the interburden and the mined seam);
- thus, a combined minimum thickness of 0.98m applies to layers 8 to 10, between the roof of the mined coal seam (top of layer 11) and the base of the Hawkesbury Sandstone, and all these layers have the same parameters as the mined seam.

The EIS report (Coffey, 2016b) had confusingly and erroneously described the thickness of the layer 8 interburden in various ways: average layer thickness of 4m and minimum thickness of 0.1m. Similarly, layers 9 and 10 are described as having an average thickness of 2m and a minimum thickness of 0.1m. This has been clarified satisfactorily in the revised modelling report.

It is worth pointing out that layers 6 and 7 (immediately above the interburden layer 8) have a thickness of 2m each. While layers 6 and 7 nominally represent the basal unit of the Hawkesbury Sandstone, their main purpose is to "*accommodate roof relaxation from mining where the interburden or plies above the working section are absent*" (Coffey, 2016b, section 3.1). This means that, where there is no interburden, the Hawkesbury Sandstone directly overlies the mined seam. In the model, that is represented via layers 6 to 10 with a combined minimum thickness of 5m and with parameters applied to match those for the Wongawilli mined seam.

The revised modelling applied corrective action to properly represent the relaxation zone height (HydroSimulations 2018, sections 3.1 and 5), and confirmed that there are areas of enhanced hydraulic conductivity that directly connect the lower Hawkesbury Sandstone to the mine workings. This is discussed further in the final two paragraphs of this section and in the subsequent section. It is also noted that the revised modelling (HydroSimulations 2018) conducted a sensitivity analysis on the drain conductance parameter that governs mine inflow predictions (in combination with the interburden units), expanding the sensitivity analysis conducted for the EIS model on relaxation height (increased from 2m to 4m above the workings roof), mine drain conductance parameter and Hawkesbury Sandstone Kv (Coffey, 2016b).

Figure 1 - Interburden thickness (after Coffey 2016a, Figure 4.3)



The discussion in the next three paragraphs applies mainly to the EIS model, but it is retained for the record, with updates regarding the revised modelling in subsequent paragraphs. The relaxation zone is represented in the EIS model by including drain features in layer 11 (the mined seam) and reportedly in overlying layers to the height of the relaxation zone (nominally up to 4m, although sensitivity tests indicated that a 2m height can be justified). This means that drain features (see section 4.2) could extend up into layer 6 or 7 in some areas of zero interburden thickness.

In other areas, the known interburden thickness (Figure 1) is applied to layer 8 of the EIS model, and similarly for the layers 9 and 10 thickness. However, the aquifer parameters applied to layers 6 to 11 are representative of the coal measures (Figure 2; see later). This means that low permeability parameters are not applied to the interburden layer in the EIS model, as illustrated in Figure 2 in terms of the model values for the interburden being higher than most of the test results for the deep units.

The areas of zero interburden thickness (Figure 1) align with areas where the mined coal seam thickness (layer 11) is less than 2.6m. Appendix A of Coffey (2016b) presents a figure showing areas of thin coal seams, such as on the eastern side near panels CE9 & CE10 (mined in 2029-31), and all along the western side of the mined area W18 (mined 2026-28); W12 (mined 2025-2027) and W23 (mined 2031-33). The times when those areas of thin coal seams and absent overburden are mined (mine years 10-16) align with the periods of peak inflow between 2030 to 2036 (Coffey, 2016b, Figure 6.1), as one would expect (and similarly for the revised modelling; HydroSimulations 2018). Interestingly, the Berrima area does not have these thin/absent interburden areas, illustrating at least one significant difference between some parts of the Hume area and the Berrima area.

The revised modelling (HydroSimulations 2018) confirmed that the interburden thickness and hydraulic conductivity properties are satisfactory, but that, in some areas, the drain cells (representing mine drainage) extended from layer 11 (the mined seam) only up to layer 10 in the EIS model. The revised modelling applied corrective action to extend the drain cells through the 2m height of the relaxation zone (i.e. to layer 7 in some areas). The revised modelling has also justified the application of satisfactory property values, while invoking a depth-dependent hydraulic conductivity relationship based on testing data from the Hume area and the Southern Coalfield. The results indicated relatively low sensitivity/uncertainty in terms of inflow volumes.

In summary, this review has found that the Hume Coal model (EIS and revised model versions) has been set up with an appropriate representation of the interburden properties (e.g. appropriate thicknesses and no low permeability parameters to limit the potential connection between the coal seams and the Hawkesbury Sandstone). The relaxation zone treatments applied to the EIS model received corrective action during the revised modelling, and the results indicate fairly low sensitivity/uncertainty in terms of key performance indicators (inflow volumes, drawdowns, bores affected and stream baseflow).

4.2 Drain Feature (Mine Inflows)

The Hume Coal model applies the “Drain” feature of Modflow to simulate groundwater inflows to the mine workings (a standard methodology); see also Figure 4 (later). The drain feature involves a conductance parameter that acts as a resistance to flow (i.e. lower values of conductance require higher groundwater gradients to result in the same amount of inflow).

The Hume Coal 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 calibration approach required simultaneous matches to stream baseflows (as well as the groundwater levels and mine inflows), and is a good example of a best practice method that minimises non-uniqueness issues and supports a model Class 2 confidence level. The method justifies the drain feature conductance parameters applied to Berrima conditions. The application of the calibrated conductance parameter to Hume conditions involved appropriate adjustments to account for the different model cell size at Hume compared to Berrima.

Pells (2017) and Anderson (2017) contend that the drain conductance parameter value is calculated incorrectly and is very low, with the implication that mine inflows may be under-estimated. The modelling guidelines (Barnett et al. (2012), section 11.3.5) state the following: “*Conductance as a model parameter cannot be measured directly. It is a surrogate for the combination of hydraulic conductivities and geometries that occur in the near field of the water body. A number of analytical solutions give guidance for this kind of conductance, but values are generally either assumed or chosen during model calibration.*” While this statement is made in the usual context of a model drain feature representing a water body, it is also applicable to a mine inflow feature. The analytical solutions mentioned include the methods applied by Pells to incorrectly infer that the mine workings are “sealed or surrounded by a thick layer of compacted clay” with an equivalent hydraulic conductivity of 2 x 10^{-5} m/d. Such an analogy may be hypothetically valid if one accepts the riverbed conceptualisation, but this review finds that concept is not applicable in this case, and is inferior to the best practice history match calibration methods applied to the Hume Coal model.

The revised groundwater modelling included a sensitivity analysis on drain conductance, with the results indicating low sensitivity.

4.3 Productive Hawkesbury Sandstone

Pells (2017) contends that the lower horizon of the Hawkesbury Sandstone is a "highly productive" unit (citing Lee, 2017), and should be represented with a high value for hydraulic conductivity, and with more sensitivity testing, than was applied to the Hume Coal model.

The example of the Rosedale bore (GW107535) is given to support the case for a highly productive Hawkesbury Sandstone. However, the Rosedale bore productivity (42 L/s or 3.6 ML/d) is attributed to an open fracture system encountered by the bore (Lee, 2017). **This is a local scale effect that is not representative of general conditions (if it were, there should be many more such productive bores), and thus it need not be represented as a key feature in an impact assessment model on this scale**.

The semi-regional scale Hume Coal model design and execution applies the principle of parsimony, with well-reasoned justification, consistent with the modelling guidelines Guiding Principle 3.1 and other statements (Barnett et al. 2012):

- 'The level of detail within the conceptual model should be chosen, based on the modelling objectives, the availability of quality data, knowledge of the groundwater system of interest, and its complexity.'
- 'In regional problems where the focus is on predicting flow, predictions depend on large scale spatial averages of hydraulic conductivity rather than on local variability. Moreover, in large regions there may be insufficient data to resolve or support a more variable representation of hydraulic conductivity. A parsimonious approach may be reasonable, using constant properties over large zones, or throughout a hydrostratigraphic unit.'
- 'Model predictions that integrate larger areas are often less uncertain because characterisation methods are well-suited to discern bulk properties, and field observations directly reflect bulk system properties.'

Interestingly, the Rosedale bore is located about 1400m west of the Wongonbra bore (GW108194), a less productive bore, but still capable of 20 L/s (1.7 ML/d). There is evidence of private pumping effects in the area of the Rosedale and Wongonbra bores of 1.0 to 1.5 ML/d (11 to 17 L/s) over the growing season (120 to 180 ML total volume) (Coffey, 2016a, section 9). This is relevant in the context of the "make good" discussion in section 4.4 below, in that it can be argued that an upper limit of 20 L/s should be sufficient capacity for most purposes.

Both bores are screened over the full thickness of the Hawkesbury Sandstone (36-122m Wongonbra; and 13-114m Rosedale; Coffey, 2016b, Appendix G, Table 1), and the evidence presented does not robustly justify the deep productive horizon conceptualisation on a general scale.

The basal unit of the Hawkesbury Sandstone is Layer 5 in the Hume Coal EIS model, nominally 7m thick and with a horizontal hydraulic conductivity (Kh) value of 0.01 m/d. This is a lower Kh than the overlying bulk thickness of Hawkesbury Sandstone layers 2 to 4 (Kh range from 0.6 to 0.03 m/d; Figure 2), consistent with the conceptualisation of decreasing permeability with depth (justified by information presented in Coffey, 2016a, Appendix C). The revised modelling (HydroSimulations 2018) conducted a detailed re-investigation of the Kh variations with depth based on the test results available at Hume and across the Southern Coalfield, justifying the parameterisation applied (Figure 3; see later) and the estimation of the uncertainties applying.

The underlying layers 6 & 7 are nominally described in the EIS as representing Hawkesbury Sandstone (e.g. Table 3 in Coffey, 2016b), but they are only 2m thick (maximum) and are effectively used to represent the complexities in the interburden sequence and relaxation zone between the Hawkesbury Sandstone and the working section mined panels (as discussed in section 4.1 above), rather than the Hawkesbury Sandstone as such.

The Hawkesbury Sandstone Kh values applied to the EIS model are reasonable in that they lie in the middle of the range of observed values (Figure 2); clearly not at the high end of the range as suggested by Pells (2017), but also not at the low end of values (mainly from core testing, indicated by grey dots in Figure 2; see also Figure 3). Most of the pumping tests on individual bores (open square symbols in Figure 2) do indicate higher range Kh values, but that is for tests mostly in the higher elevations of the Hawkesbury Sandstone, including the two tests on bores on the Hume lease (H98 and GW108194 indicated by the solid black symbols). Again, the model reflects this effect of higher Kh in shallower units. The exception is the high Kh for the (un-named) bore at about 110m depth.

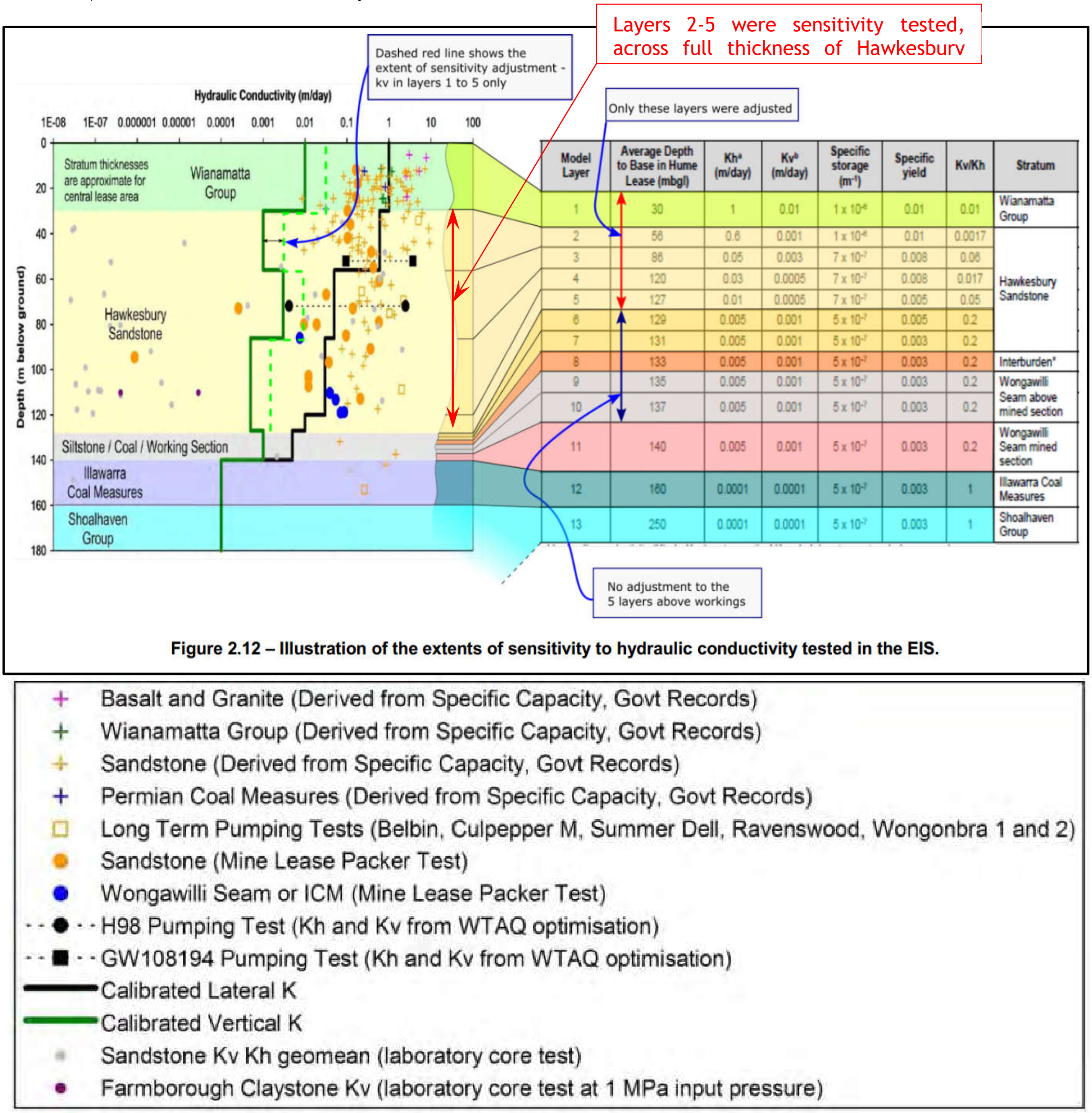


Figure 2 - observed and modelled hydraulic conductivity (after Coffey, 2016b, figure 4.5 and Pells, 2017, figure 2.12)

The EIS model has been tested for sensitivity to Hawkesbury Sandstone vertical hydraulic conductivity (Kv) across the full thickness of the Hawkesbury Sandstone (Figure 2), concluding that the mine inflow predictions are sensitive to Kv, as is often the case in practice.

While sensitivity to horizontal hydraulic conductivity was not tested for the EIS model (Coffey, 2016b), a rigorous uncertainty analysis on lateral and vertical hydraulic conductivity of the Hawkesbury Sandstone has been conducted during the revised modelling (HydroSimulations 2018), based on the relationship shown in Figure 3. The uncertainty analysis was conducted consistent with the principles in the latest guidance (Middlemis and Peeters 2018) and concluded the relatively low uncertainty/sensitivity effects on the predictions.

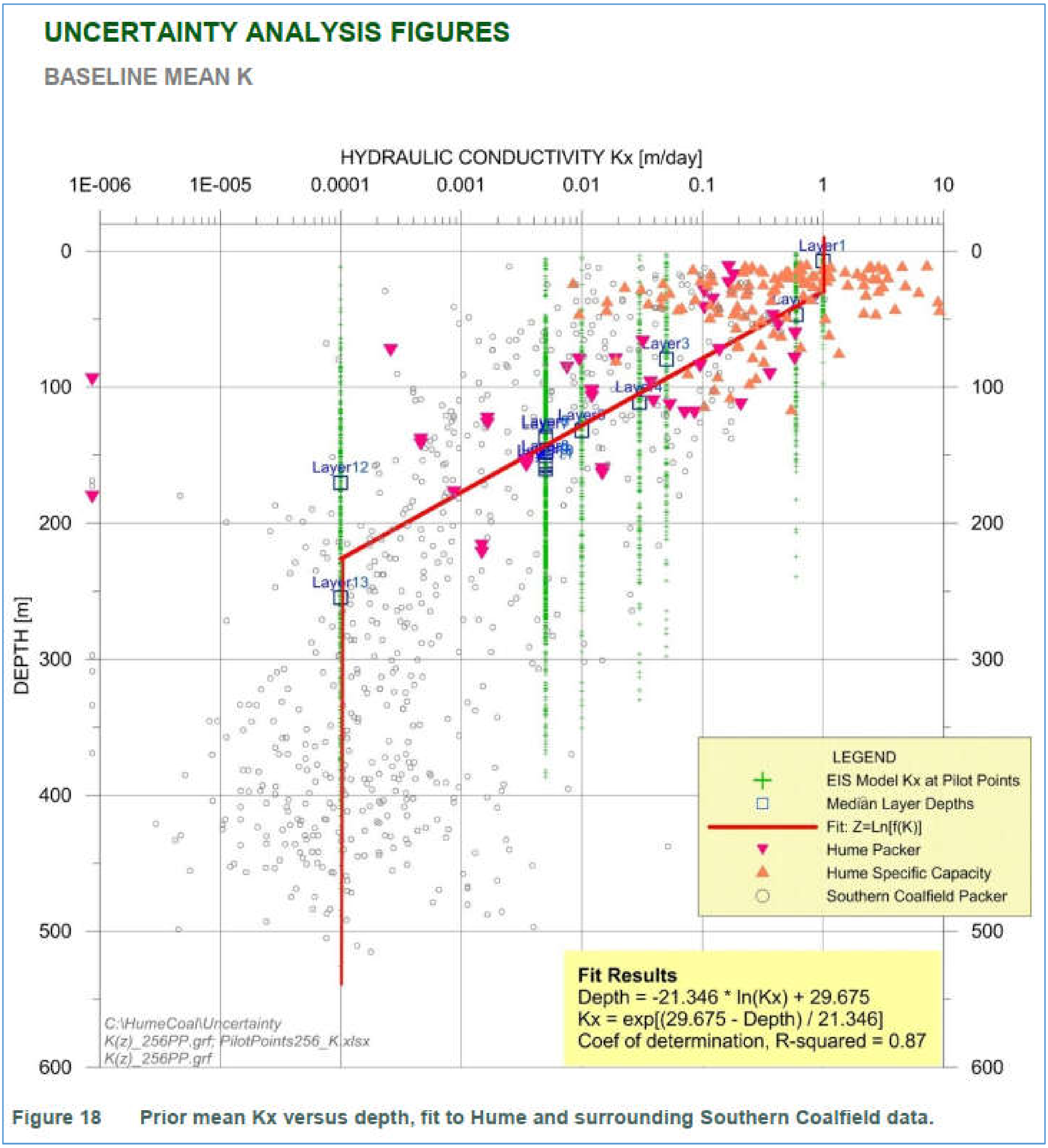


Figure 3 - variations of Kh with depth (after HydroSimulations 2018, Fig.18)

4.4 Make Good Arrangements

Arrangements have been proposed by Hume Coal for making good on impacts greater than the stated minimal impact criteria (EMM, 2017). The assessment of the third party bores potentially affected by drawdown due to Hume Coal Project dewatering appears to have been undertaken thoroughly and with careful consideration of groundwater engineering principles. The strategies proposed for making good include bore headworks engineering, borehole workovers and/or re-drilling, or providing alternate water supplies or compensation, along with dispute resolution processes. All these arrangements are reasonable in principle, and are consistent with make good arrangement guidelines in Queensland, for example, although those are mostly applicable to CSG projects (DEHP, 2016).

The Hume Coal make good consultation process includes a proposed verification visit to affected properties to obtain specific and objective information on the current bore status. This is a necessary step for an effective make good process, although it does depend on the ability of a proponent to access private properties for that purpose. This review makes no comment regarding NSW government policy or regulations on making good, on access to property, or the acceptability of these arrangements to any party.

This discussion is constrained to technical issues regarding borehole workovers or re-drilling, and whether access to alternative groundwater supplies is feasible. In principle, dewatering of one horizon within the aquifer (e.g. the mined coal seam) does not necessarily preclude the occurrence of saturated aquifer conditions above and/or below that horizon. Further, depressurisation does not dewater an aquifer unit; it simply lowers the groundwater pressure level, which can leave areas of saturated aquifer laterally adjacent to the workings that can support groundwater pumping (and/or habitat for stygofauna, for example).

Coffey (2016a) present information in section 6.1 on two bores close to the Berrima mine workings, which confirms that good quality groundwater at adequate yields can be obtained above and below mined coal seams. The information presented on the Belbin bore is consistent with my statement to the Land and Environment Court in 2014 on the Berrima Colliery (case number 12/10752). The “Belbin” bore (GW106150) is located on the northern corner of the Berrima mine workings. It was re-drilled in 2008 because the original Hawkesbury Sandstone bore (115 m depth) was impacted by mining (i.e. the groundwater level fell below the base of the bore due to undermining). The re-drilled Belbin bore is 186 metres deep (60 metres below the Wongawilli seam) and it is screened in the Permian Illawarra Coal Measures (132-186 metres). Its groundwater level is around 115 m below ground level, and its salinity is less than 500 mg/L.

Examples such as this do not guarantee that similar results would be obtained everywhere on the Hume Coal lease (although the conditions would suggest that it is likely). However, it does demonstrate that depressurisation and/or dewatering of coal seams does not preclude access to viable aquifer resources via workovers or re-drilling, even within the mine area. Such bores should yield adequate supplies of low salinity water, suitable for stock and domestic purposes at least, and perhaps for low volume irrigation licences, but likely not adequate for high volume irrigation licences.

The Hume modelling study diligently represented the effects of private bore pumping, although some private bores did “go dry” during the EIS simulations due to the combination of mining and private pumping stresses (i.e. water levels drew down below the base of some bores). The associated reduction in private bore pumping amounted to only about 15% (estimated as follows), which should not materially affect the cumulative impact drawdown assessment. Coffey (2016b) state (section 3.2.6) that there are 83 high extraction private bores within the model domain with a combined entitlement of 5300 ML/a (14.5 ML/d). The 299 stock and domestic bores were assumed to pump at 2 ML/a each, giving a combined volume of 598 ML/a (1.6 ML/d). Pumping from private bores was simulated at 14.1 ML/d during the history match calibration, but that decreased during the 22-year mining period to between 11 ML/d (scenario with the Hume mine simulated) and 13 ML/d (null scenario without the Hume mine), or about a 15% reduction (water budget tables 10 & 11; Coffey, 2016b). The water balance information presented in the revised modelling report (HydroSimulations 2018) indicates that private bore extraction amounted to about 15% of groundwater outputs from the model (or 8-10 ML/d, depending on the model run).

Consideration of groundwater engineering factors was applied to the EIS drawdown prediction results to identify make good works that may be required (Coffey, 2016b, section 7 and Appendix G). This is an appropriate assessment at this stage, but further detailed investigations will be required in due course.

In addition to the lessons learned from the Belbin bore outlined above, the make good investigations will need to consider local scale issues in order to succeed, such as:

- increasing the bore yield potential by targeting the full thickness of the Hawkesbury Sandstone (i.e. avoiding the limitations of shallow bores), and by targeting zones more distant from the mined panels if possible (drawdown impacts reduce rapidly with lateral distance from the mine workings);
- the occurrence of open fractures on a local scale that would enhance bore yields if encountered (e.g. the 'Rosedale' bore example outlined in Lee, 2017) but which cannot be adequately characterised in a groundwater model (mainly because there is no information of the distribution of such features);
- the revised modelling presents a contour plan (HydroSimulations 2018; Figure 42) that shows areas where the maximum drawdown (likely 67% probability) is expected to lie between 2-10 metres and 10-20 m (affecting about 60 and 22 bores respectively); these areas would be suitable/worthy of investigation for making good via groundwater engineering (e.g. residual aquifer thickness should allow for deepening bores, etc); however, for the smaller central area where the drawdown is predicted to exceed 20 m (about 11 bores), it is likely that alternative water supply arrangements may need to be investigated.

There is evidence of private pumping effects in the area of the Rosedale and Wongonbra bores (GW107535 and GW108194) of 1.0 to 1.5 ML/d (11-17 L/s) over the growing season (120 to 180 ML total volume) (Coffey, 2016a, section 9). This gives some indication of practical bore and irrigation capacities of less than 20 L/s that may also be relevant to make good considerations, notwithstanding that some licence volumes may exceed 180 ML.

4.5 Implications arising from Bulkhead Failure

DPE has received expert advice on the potential for bulkhead failure and the subsequent inrush to the workings of water stored behind bulkheads in previously mined panels. This review makes no comment on the probability of such an occurrence, but does point to published reports that provide examples where carefully designed and constructed underground structures have effectively controlled water diversions for many decades (Younger and Wolkersdorfer, 2004).

The groundwater-related effects of potential bulkhead failure were not specifically considered in the EIS, but the results that have been provided can be interpreted to provide some useful information on the issue. The EIS groundwater assessment modelling method included leaving drain cells active after mining until the residual void behind the bulkhead is filled, and then de-activating the drain cells (Figure 4), although this was changed for the revised modelling.

The EIS method allowed unpacking of the volumes reporting "to void" (which in reality would become part of aquifer storage post-mining) separately from the volumes "to sump" (which are used in the mine water management circuit). The volumes "to void" can be considered to be a prediction of the effect of bulkhead failure in terms of water take and drawdown, because the model is actually removing the "to void" volumes from the model via the drain cells, rather than allowing the volumes to become part of the post-mining aquifer storage (as would happen when the drain cells are turned off). Hence the predicted drawdown using this method actually provides an assessment of the drawdown impacts due to the void volume being removed from the model (i.e. as if a bulkhead failure had occurred; or, more correctly, as if every bulkhead fails in turn), because this is what the model drain features effectively do.

It should be noted that the drawdown pattern predicted by the EIS model was affected by improper operation of the SURFACT3 package (e.g. purple contours shown in Figure 34 of HydroSimulations 2018). However, the revised modelling was not affected, and that work involved some early test simulations that adopted the EIS method of leaving drains active after mining (HydroSimulations 2018, sections 1.1.2 and 4.1). This means that, if an estimate is required of the potential drawdown and water balance effects due to bulkhead failure, then the relevant simulation results from the revised modelling should be used, rather than the EIS results.

The revised modelling method applied involves turning off model drain cells when mining is completed, such as when mining up-dip obviates the need for drain cells down-dip behind the more rapidly advancing mine face (HydroSimulations 2018). The de-activation of drain cells post-mining is a more realistic method, in that the model allows post-mining inflows to become part of the void element of aquifer storage, while the water balance analysis in the revised modelling allows for detailed reporting of the "to void" and the "to sump" volumes. See also commentary in the next section about the modelling of underground water impoundments.

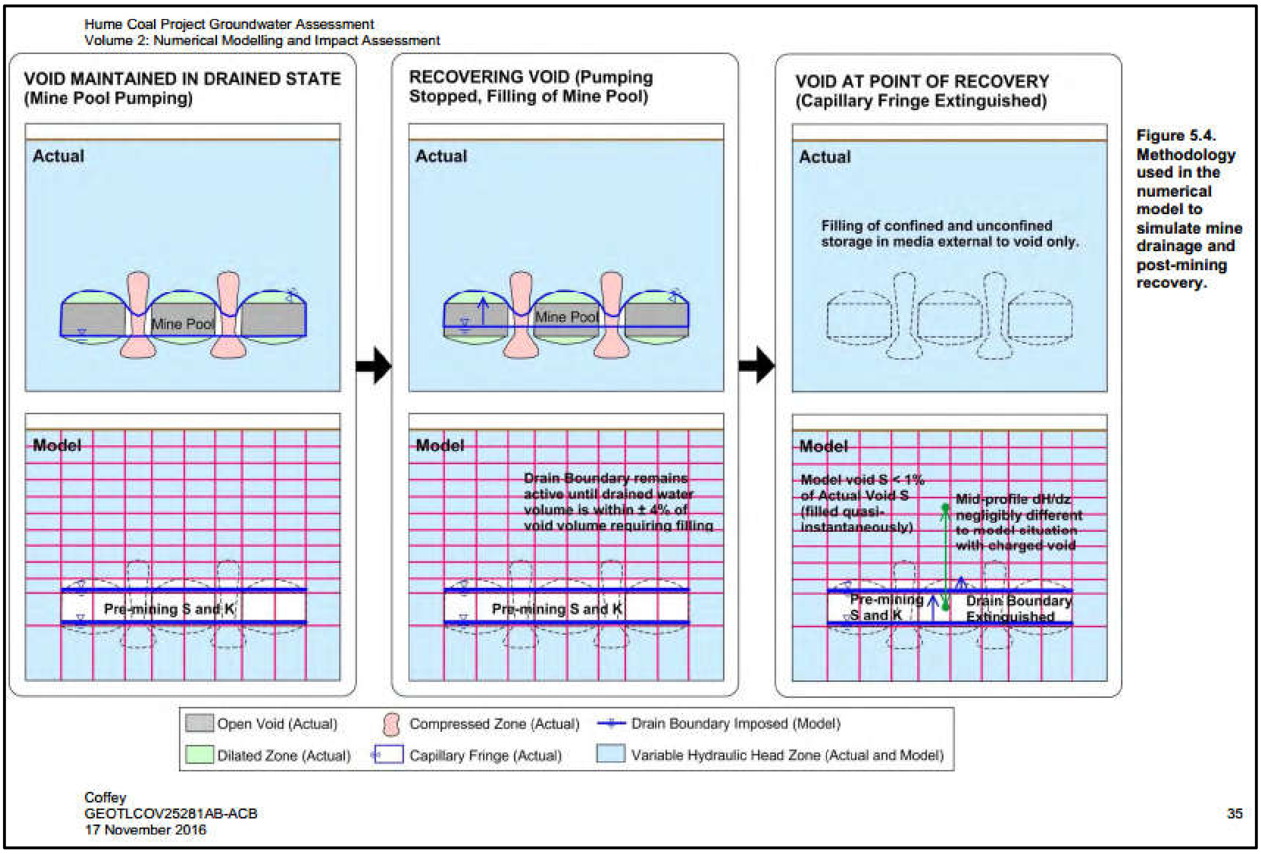


Figure 4 - mine drainage feature (after Coffey 2016b, Figure 5.4)

4.6 Issues relating to water impoundment and co-disposed waste rock

Concurrent with the revised drain cell method described above, the direct injection of mine water to the void space created by mining ("impoundment") may be required during mine operations to manage mine water balances (this was reportedly not required previously; Coffey, 2016b). If so, it would warrant some form of treatment to reduce any water quality issues (e.g. turbidity, hydrocarbons) arising from contact with mining operations. If, however, the water can be intercepted before such contact, then the direct injection of mine water should not cause groundwater quality issues.

The revised water balance assessment (WSP 2018) allowed for the emplacement of co-disposed coal reject into some voids, and this was also allowed for in the revised groundwater modelling (i.e. reducing the volume of voids available for potential impoundment of water). The revised modelling used the time-varying materials (TVM) software package of Modflow-USG to change aquifer properties to account for the co-disposed coal reject emplacement as distinct from the residual void space (HydroSimulations 2018, Table 9).

The water balance assessment (WSP 2018) also allowed for surplus mine water to be pumped from the underground sump to available mine voids during some very wet periods when the Primary Water Dam storage reached 124 ML (WSP 2018, sections 3.2.2.3 and 3.2.2.5). This simulated "impoundment" of water estimated by the water balance assessment ranged from 1865 ML to 4255 ML over the 107 climate sequences considered, amounting to an average of 2899 ML over 19 year mine operation period. **The minimum annual volume impounded was zero, during the first five years of mining when void space is limited**, and the maximum annual volume was 959 ML in mine year 18, when the available residual void space is 3049 ML (WSP 2018, Table 3.3 and Figure 3.4).

While the revised groundwater modelling (HydroSimulations 2018) allowed for the emplacement of coal reject, it did not simulate the re-injection of mine water to the available void space. However, the water balance assessment (WSP 2018) showed that the impounded water (pumped from the sump to the void) during the wettest climate sequence still resulted in a residual void space of up to 2500 ML (WSP 2018, Figure 3.4).

It can be concluded that the revised groundwater modelling suffers from a minor limitation (in terms of groundwater inflows and drawdown impact assessments) of not simulating the water impoundment (pumped from the sump to the residual voids), in the sense that it is not completely physically realistic.

However, the approach applied provides a conservative over-estimate of the mine water inflow/take and thus the resulting drawdowns (i.e. careful simulation of the re-injection requirements would have resulted in increases to the level of water in the voids and thus would have slightly reduced the hydraulic gradients, and resulting inflows and drawdowns).

Discussion with Dr Merrick on this issue on 23 July and 3 August 2018 elicited the point that the groundwater modelling study was not specifically requested to simulate the impoundment of water underground (only the coal reject was modelled), and that a map and schedule of the impoundment volumes was not provided to the groundwater modellers. The lack of such modelling is a minor limitation in terms of groundwater inflows and drawdown impacts, and any implications in terms of the water balance assessment involving storage of all excess water above ground during the first 5 years of mining will be addressed by the surface water experts. There are potential implications for mining safety and bulkhead integrity, and while such matters are also outside the scope of this review, it is noted that bulkhead integrity and mine safety issues would become very important considerations if the distribution and schedule of impoundment showed that there are areas/occasions where there is water impounded behind bulkheads that are also up-dip from actively worked panels.

4.7 Uncertainty Analysis

Before discussing the Hume Coal uncertainty analysis, it is worth noting that there is no agreement within the industry on any particular approach that should be adopted for modelling or assessing the uncertainties associated with underground mining and subsidence-related issues. For example, there are at least two conceptualisations of the height of the fracture zone (e.g. Tammetta, 2013; Ditton and Merrick, 2014; but there are others), and there is no consensus within the industry on which is best. Similarly, there is no agreement on how models should represent or investigate the variability or uncertainty in aquifer properties associated with underground mining and subsidence processes.

Given this uncertainty in how to conduct a modelling investigation or an uncertainty analysis for an underground mine, the draft IESC Explanatory Note on uncertainty analysis (Middlemis and Peeters, 2018; which is consistent with the best practice general guidelines of Barnett et al. 2012) recommends consultation with regulators to agree on a suitable assessment approach for any particular site.

As indicated in previous sections, and in the Issues Log (Appendix A), regulator consultation has been conducted for the Hume Coal project, and the revised modelling report (HydroSimulations 2018) provides details on the Monte Carlo methodology applied, the model setup and the parameter ranges. The results are presented in terms of mine inflows, drawdown and water balances (including stream baseflow), and the probabilities of exceedance.

Furthermore, sensitivity analyses have also been conducted into other specific aspects that were not investigated by the uncertainty analysis (reportedly in consultation with DoI Water), such as various modelling software options (e.g. MODFLOW-SURFACT v3 and v4; MODFLOW-USG; pseudo-soil function; Pilot Point distributions) and parameter values (e.g. aquifer storativity, drain conductance, relaxation zone above working zone; evapotranspiration, climate scenarios, stage height in Wingecarribee River, Medway Dam features, Basalt and related horizontal flow barrier features). This combination of uncertainty and sensitivity analysis, in consultation with the regulator, is consistent with the latest best practice (Middlemis and Peeters, 2018).

While the revised modelling report and figures are well presented, the following explanation is offered as an aid to help understanding and interpretation of the results of what is a highly complex uncertainty analysis. The revised modelling results have been presented with the aid of a “traffic light” colour spectrum, as recommended in guidelines, and with careful wording on the probabilities of exceedance applied in the associated text. However, to put it in very simple terms, the green (lower) and red (upper) lines on the various plots (Figures 43-62 of HydroSimulations 2018) can be considered to be the lower and upper limits of mine inflows and baseflows. In simple terms, there is a 10% probability that inflows may be lower than the green line and a 10% probability that inflows may be higher than the red line. Put another way, it is most likely (80%) that inflows and baseflows will lie between the green and red lines. For the drawdown plots (Figures 16, 34, 41 & 42), either the 67th percentile or the 67th-90th percentile is appropriately selected as indicating the likely drawdown (i.e. there is a 33% chance of drawdown exceedance of the 67th percentile, or a 10% chance of exceedance of the 90th percentile). This assessment has been conducted consistent with best practice, and the results will aid decision-making and risk assessment/management in that they quantify the effects of uncertainty on the groundwater-related impacts due to the Hume Coal project.

In summary, this review finds that Hume Coal groundwater modelling uncertainty analysis and sensitivity analysis has been conducted consistent with best practice (Barnett et al, 2012; Middlemis and Peeters, 2018), and presented the results in terms of the probabilities associated with mine inflows, drawdowns, bores affected and stream baseflows, in a best practice manner that provides information to support decision-making on licensing and like matters.

5. Conclusions

The reported water balance "discrepancy" in the EIS model is not indicative of fundamental flaws in the Hume Coal model, contrary to review comments from DPI Water (2017) and Anderson (2017), and hence their downgrading to a Class 1 model confidence level 1 is invalid. Accordingly, any criticisms based on this invalid premise are not necessarily valid. The revised groundwater modelling (HydroSimulations 2018) achieves a Class 2 confidence level, is consistent with best practice and addressed the documentation, water balance and sensitivity/uncertainty issues.

In summary, it is my professional opinion that the Hume Coal model (in terms of the combination of the 2016 EIS and its adjunct the 2018 revised modelling) is consistent with best practice in design and execution. It is fit for mining project impact prediction purposes, the results presented are reasonable in terms of inflows and drawdown predictions and related uncertainties, providing suitable information for decision-making and licensing.

6. Declaration

For the record, the peer reviewer, Mr Hugh Middlemis, is a civil engineer, hydrogeologist and independent modelling specialist with more than 35 years' experience. Hugh was principal author of the MDBA groundwater modelling guidelines (Middlemis et al. 2001) and was awarded a Churchill Fellowship in 2004 to benchmark groundwater modelling against international best practice.

Mr Middlemis has not undertaken any work at the Hume Coal Project, although he has undertaken investigations nearby at the Berrima Colliery on behalf of Boral Limited, which included an inspection of the underground workings in November 2012 and several site visits to the area. Mr Middlemis appeared as an expert witness to the NSW Land and Environment Court on the Berrima Colliery groundwater issues (case number 12/10752, hearings in 2014).

Mr Middlemis has also completed independent review tasks of investigations by various parties who are now engaged in various roles in relation to the Hume Coal project, including:

- EMM on the Chandler Salt Project in the Northern Territory in 2016, and on the Snowy 2.0 pumped hydro EIS investigation in 2018.
- Dr Noel Merrick (HydroSimulations) on the Wambo longwall panel 10A expansion in 2015. This also involved discussions with Mr John Williams (NSW Office of Water). Mr Middlemis also completed an independent review of the HydroSimulations report on the Mulgrave River model in June 2016 (the modeller involved was Chris Nicol).
- Joint expert conferencing on the Berrima Colliery case at the NSW Land and Environment Court with Mr John Lee (Hydroilex) in 2014.

Previously, Mr Middlemis has worked with Noel Merrick, notably:

- to write the 2001 guidelines on groundwater modelling and prepare and deliver some related conference papers;
- for a few semesters across about 1996-2005, Mr Middlemis worked as the distance education tutor for Dr Merrick's Groundwater Modelling subject at UTS (i.e. marking assignments and helping students via email and telephone);
- during parts of the period 1986-1989 when Mr Middlemis worked at the Department of Water Resources and he was seconded from the Hydrology unit to work in the Hydrogeology Unit on groundwater modelling projects under Mr Merrick.

Dr Merrick has completed independent reviews of groundwater models developed for catchment and salinity management purposes in South Australia and Victoria by Aquaterra when Mr Middlemis was Technical Director (Adelaide Plains solute transport model (2011); Padthaway solute transport model (2008); Eastern Mallee model EM2.1 (2008) and EM2.3 in 2009).

Having outlined recent experience on projects in the area and with certain parties now engaged in some role with regard to the Hume Coal Project, we assert no conflict of interest in relation to this independent review task.

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Appendix A

Hume Coal Model Issues Log

Issues Log **Hume Coal Project (SSD 7172) - Groundwater Model**

Item	Context	Comment/Question/Issue from Independent Peer Review by Hugh Middlemis (HM) August 2017, updated 5 & 11 October 2017. Updated August 2, responding to revised modelling report.	Response from Groundwater Assessment Team (5 Oct 2017)
1	Evidentiary Basis	Coffey (2016) Groundwater Assessment Volume 2: Numerical Modelling and Impact Assessment; supported by: Coffey (2016) Groundwater Assessment Volume 1: Data Analysis. HydroSimulations (2018) Hume Coal Project Revised Groundwater Modelling for Response to Submissions. Prepared for Hume Coal. June 2018. WSP (2018). Hume Coal Project Response to Submissions - Revised Surface Water Assessment. Prepared for Hume Coal. June 2018.	*not required*
2	Model Confidence Class (s.4.3.5)	Report claims Class 2/3 (30%/70%). DPI disagrees, suggesting Class 1, citing 2012 guideline commentary that any element of Class 1 renders entire model Class 1. Important because DPI rely on this demonstrably false premise to base their claims of inadequate modelling. Merrick concurs with Class 2/3, suggesting weighted score of decision table in guidelines. Independently assessed by HM (see tab "Class" herein), indicating Class 2 overall (with some Class 1 and some Class 3 elements), and thus appropriate for impact assessment. That the Hume model can be improperly labelled Class 1 with apparent justification from the guidelines is not the fault of the model; it is fault of the inadequate guidelines and their internally inconsistent commentary on the model confidence classification. The guidelines Table 2.1 on model confidence level classification is itself not unreasonable, but the related commentary and guidance is poor & internally inconsistent, such that cherry-picking one comment (rather than considering the table attributes) does not constitute a valid argument.	We agree that the Groundwater Modelling Guidelines are in error in regard to labelling a model as Class 1 on these stated grounds: "If a model falls into a Class 1 classification for either the data, calibration or prediction sectors, it should be given a Class 1 model, irrespective of all other ratings." This statement is inconsistent with other statements in the same guide; e.g. "In general, it should be acknowledged that if a model has any of the characteristics or indicators of a Class 1 model it should not be ranked as a Class 3 model, irrespective of all other considerations." This implies that a model could be labelled as Class 2, though it has Class 1 characteristics. Our assessment (adjacent) shows 16% Class 1, 36% Class 2, 48% Class 3. Two of the Class 1 attributes have moved to higher classes following model revision by HydroSimulations: mass balance is now Class 3 and performance (excluding unreliable VWP measurements) is <10%RMS (Class 2).
3	Implementation of mining s.3.2.5	Good calibration to effects of mining at Berrima (inflows, heads, dewatering /depressurisation) gives confidence that such mining features applied to Hume would be adequate, except for unclear reporting of implementation at Hume re volumes. s.3.2.5 outlines some introductory info on non-caving workings, including that the conductance of drains is used to simulate mine openings and the overlying drained zones; illustrated later in fig 5.4 (see "mining" tab). OK. s.5.3 confirms that pre-mining parameters apply to the horizon from surface to mined zone, with drain features/parameters used to represent drained zone. OK subject to subsidence report. Drained zone comprises mine opening excavation of 3.5m (thickness of Layer 11) plus relaxation zone of 2m (s.3.2.5), which would be Layer 10 generally (2m thick and present in Hume lease area; see Table 2). Layer 8 (Interburden), and Layers 9 & 10 are all present in Hume lease area (see Table 2, s.3.1). OK in principle, but s.4.1 of Volume 1 (groundwater data) states that Interburden is absent in south-western half of lease (see also Fig.4.3 of Vol.1; see "params" tab). However, Fig 4.3 of Vol.1 shows bore HU0016CH has 1.3m of Interburden although Fig.4.1 shows it within the zero interburden thickness. Reports do not state what happens to Layers 9 & 10 where Interburden (Layer 8) is absent, and this needs clarification, as the interburden thickness/extent is a significant point of difference between Hume and Berrima, and it has hydrological effects in situ, and affects how the drained zone should be represented in the model. Fig 5.2 (see "mining" tab) indicates that relaxation zone extends up into layer 8 in some areas(?), which is not consistent with text (which is itself inconsistent). For example, s.3.1. says layers 6 & 7 accommodate roof relaxation where interburden layer 8 is absent, but relaxation should be hosted in Layer 10 as it is 2m thick generally (Table 2 in s.3.1). Fig 5.4 does not specify which layers drain treatments are applied to. Q&A needed. Subsequent comment (Oct 2017): The title of Table 2 (Appendix I, groundwater model) is "Model layer thicknesses", but the column heading in the table does say "average layer thickness". This is not as clear as it should be. Table 2 data indicates that layers 9 & 10 are 2m thickness in the Hume lease area and layer 8 is 4m thick, and the footnote indicates "minimum model layer thickness is 0.1m". This is not consistent with Groundwater Assessment Team response opposite, including that minimum layer thickness is 0.4m (Triassic) or 0.29m (Permian). There are other references in report to effect that "constant offsets" were used to establish layer top/bottom surfaces, and "proportional thicknesses" although that term is not explained. It is report content such as this that causes confusion and reduces confidence in the modelling tool. Having said that, the model audit explanations in the response, and the additional figures, do provide good detail, confirming the need for model revision as outlined. Further review required once results are available. August 2018: Revised Groundwater Modelling report has clarified/resolved these issues (s.1.1.2; s2.2.2; s.3; s.4.2; s.5; s.8.2; Tables 8 & 9; Figures 3, 19-25, 56-57), hence green traffic light.	Agreed that Berrima Mine provides the best control on likely inflows at Hume Mine. Table 2, s.3.1 gives indicative thicknesses for Layers 8-10 in the Hume lease area, whereas reviewers have interpreted these as constant values. A model audit shows that the thicknesses vary over the lease area and over the model extent (see Tab "New_Figures"). Triassic interburden [Layer 8] geometry: thickness is spatially variable and is consistent with Figure 4.3 (Vol.1). In the model, a minimum thickness of 0.4m is applied; as the properties are those of lower Hawkesbury Sandstone, the absence of interburden (as in Figure 4.3 of Vol.1) is represented properly. The thicknesses of Layers 9 and 10 (Permian above the coal seam) are a minimum of 0.29m each. Allowing for the minimum thickness of Layer 8, there is at least 0.99m between the roof of the coal seam and the base of the Hawkesbury Sandstone layer. Figure 4.1 (Vol.1) shows a log of HU0016CH but the thickness of 1.3m is not associated with this bore but is stated as an overage "over the mine lease". Section 3.1: "The bottom two layers for the Hawkesbury Sandstone (Layers 6 and 7) are to accommodate roof relaxation from mining where the interburden or plies above the working section are absent." - a check of the model shows that Drains have been applied only to Layers 10 and 11 in the model. Over a small area (see Q10 below) drain cells should have been applied to Layers 7-11. This will be corrected in the revised modelling.
4		Conductance (C) of drains used to simulate mine openings (layer 11) and overlying drained zones (nominally layer 10, 2m thick). s.5.1: Calibrated C = 0.05 m^2/d (suggests very low K=6.e-5m/d for cell size of 50x50m and assumed thickness of 3m). May be OK? s.5.3: Drains set to 0.1m above floor in any layer/cell intersected by drained zone in mined zone and above (see also fig.5.1). s.5.3.1: No material volumes of injection of water to bulkheads (so only tailings volumes injected). s.5.3.1: Backfilling of co-disposed tailings comprise 36% of void volume (Table 7) and reported as inert re groundwater fluxes (non-draining/non-storing). Extraction from recovering voids (behind bulkheads): s.5.2.1 & fig.5.3 very confusing - see "mining" tab herein. Key issue: s.5.3.1. states that drain cells active only for time for total drained water volume to match residual void after co-disposal of tailings. This suggests that model does not simulate dewatering of excavation and 3m relaxed zone, but that it limits the volume drained to the volume of the excavation. Could this be part of the explanation as to why the drawdown pattern (figures 6.6 & 6.7) is so chaotic? Discussion and clarification required. Subsequent comment (Oct 2017): the application of the DRN facility for the immediate post-mining period until the residual void volume has been extracted was also clarified (in a similar way) in discussion with Paul Tammetta. This reviewer was confused by the less than crystal clear reporting (e.g. including descriptions of DRN features post-mining (s.5.3.1) within a discussion of the implementation of mining in the model in s.5.3). Further review needed when the corrected drawdown plots are available (hence orange "traffic light" colour retained). August 2018: Revised Groundwater Modelling report has clarified/resolved these issues (s.1.1.3; s2.2.2; s.3; s.4.2; s.5; s.8.2; Tables 8, 9 & 27), hence green traffic light.	Drain conductance: It is not correct to assume the full cell area in converting conductance to hydraulic conductivity (K), or leakage coefficient (K/b). Allowance must be made for the dimensions of the plunges, and for the much smaller area of seeps in the roof of a void. A comparison of adopted leakage coefficients at other mines in the Southern Coalfield (adjacent) shows that a conductance of 0.05 m2/day is comparable with other mines when a correction is made for actual void width. The conclusion that the model "limits the volume drained to the volume of the excavation" is not correct. The model extracts water during the period of excavation, and then the DRN facility is used to calculate the time required for the void to fill with water. This volume is incorrectly withdrawn from the groundwater system in the model, whereas in reality the water remains in the void. The unusual drawdown patterns in Figures 6.6 and 6.7 are due to the descent of the water table through different layers in the model. This requires correction, as the drawdown of the water table should be smooth.
5	Water Balance Tables 4, 10 & 11	Refer to tab "WatBal" for questions about water balance issues that require discussion/explanation please. 1. Inconsistent water balance effects need discussion and explanation. 2. What does "period of active stress" really mean? [Table 9] Is it the period when drain cells are active to represent mining? 3. Is active stress limited to the volume of the excavation void? The language/terminology is not clear and transparent (but it needs to be). Subsequent comment (Oct 2017): in discussion with Paul Tammetta, it is understood that the (previously) reported water balances were not direct outputs from the model at specific stress periods (recommended in the guidelines to assess model performance with a criterion of discrepancy less than 1%). Rather, they were calculated as cumulative volumes (presumably between stress periods) divided by elapsed time. Hence the "discrepancy" term was not an indication of potential problems with the mass balance in model performance terms (rather it was an indication of either mining-induced or post-mining recovery changes to aquifer storage). It is good to note that re-running the model resolved the question of the model mass balance performance, which also appeared to confuse third parties reviewing the reports. Also good to have a clear explanation of the "active stress" term, and clarification of how the DRN facility is used during and post-mining (i.e. to address issue 3). Details should appear in the model audit report. The revised model approach outlined is sound and endorsed for implementation, with the results requiring further review (hence orange "traffic light" colour retained). August 2018: Revised Groundwater Modelling report has clarified/resolved these issues (s.1; s2; s.3.1.1; s.4.1; s.5-s.8; Tables 3, 4, 6, 7, 14, 15, 17, 19, 24; Figure 56), hence green traffic light.	1. Inconsistent water budgets: A re-run of the calibration, null and prediction models with improved solver settings (and finer time steps) gives consistent water balance components (see adjacent) with very low mass balance discrepancy (0.15-0.19%). Previously reported water balances had high discrepancies of 4.1-6.8%. 2. 'Active stress' consists of two periods during which DRN cells are active in the model: (1) During mining, giving "to sump" volumes; (2) Post-mining until the local void fills with water, giving "to void" volumes. 3. The "to void" volume is limited to the volume of the excavation void, allowing for the portion of the void occupied by waste. The two volumes are accounted and reported independently in the model. The "to sump" volume is considered taken from the groundwater source and used for mining, whereas the "to void" volume remains in the groundwater system and is available for other users. Post-mining DRN cells are really a convenient accounting method for calculating the time taken for the void to fill with water, after which time the DRN cells are removed and the water in the model can recover rapidly (in the void) at host properties. More realistic void properties were not applied because the TMP facility in SURFACT was not available to the modeller. A better approach, being adopted in the model revision, is to have DRN cells active only during mining with recovery allowed immediately afterwards in the void at enhanced permeabilities and specific yields using the TMP facility in SURFACT or the TVM facility in MODFLOW-USG. There is no need to calculate the "to void" volume. The "to void" volume is wrongly reported by MODFLOW as a loss from the groundwater system. It is not pumped out, in reality, and remains underground. The revised modelling will deactivate drain cells as soon as a mined section is sealed. Hume Coal will license both the "sump water inflow" and the "void water inflow" as per the AIP requirements. This is a very conservative approach as there is no precedent (at other mines) for regarding void-refill as licensable. In order to calculate the "to void" volume, one run will be conducted for prolonged drain cells post-mining. The model audit report will revise and re-word the language/terminology on water balance concepts so they are clearer and more transparent to a reader.
6	Topography	SRTM data (+/-8m), reportedly benchmarked to Lidar on lease, but acknowledged as inaccurate. Hence data uncertainty on bore levels, stream drainage levels, EVT process. Hence uncertainty applies to water balances and analyses, although scenario difference method reduces uncertainties. Links to water balance issues. Subsequent comments (Oct 2017): a) in high risk context projects such as this, where surface-groundwater interaction is a critical issue (evapotranspiration and stream baseflow are the major discharge elements in the model water balance), this reviewer considers that the cost of high accuracy Lidar data is warranted to reduce uncertainties b) the merging of Lidar with SRTM products is indeed "normal practice" but that is not best practice in my view in a high risk context (coal mining in high value agricultural/natural areas with strong surface and groundwater interactions); subsequent info from Noel Merrick indicates that Lidar covers main area of interest of the model (see graphic opposite); OK/adequate c) issues 7 and 8 below allude to the potential for an alternative model arrangement (conceptualisation and/or parameterisation), one that has higher recharge, which could still be benchmarked against the very good baseflow estimates (and the Berrima mine flows) by allowing for some variation in the relatively uncertain evapotranspiration rates, especially with the benefit of improved Lidar topography in the riparian zones; investigation of such an alternative arrangement would be a reasonable way to investigate uncertainties, and is recommended. After meeting Dr Merrick on 9 October: plans to run 130 climate scenarios and to do a formal uncertainty analysis, with some further selected sensitivity runs should address this "alternative model" issue (hence orange "traffic light" colour retained). August 2018: Revised Groundwater Modelling report has clarified/resolved these issues, especially with sections 3.1.7 and 8.4 on the recharge and ET sensitivity analysis, and section 6 on the Climate Scenario Analysis (s.1.1; s.3.1.7; s.5-s.7; s.8.4; Tables 8 & 9), hence green traffic light.	The model topography is based on merging the 1 arc-second (~30m) gridded smoothed version of DEM-S Version 1.0 obtained from the Shuttle Radar Topographic Mission (SRTM) with LiDAR that covers an approximate 400 sq km over the proposed mining area and adjacent surrounds. This is normal practice. The more accurate (and expensive) LiDAR data are not usually available over areas broader than a mining lease. The LiDAR survey has a stated accuracy of +/-150 mm. Geoscience Australia: "DEM-S represents ground surface topography, excluding vegetation features, and has been smoothed to reduce noise and improve the representation of surface shape. An adaptive smoothing process applied more smoothing in flatter areas than hilly areas, and more smoothing in noisier areas than in less noisy areas." Geoscience Australia determined the accuracy relative to permanent survey marks as 1.3m mean, 1.7m median and 7.6m at the 95th percentile (GA, 2011, 1Second SRTM Derived Products User Guide). Cell sizes of 50-200m necessarily add approximation to the single topographic level that must be applied in the model over the entire area of a cell.

Issues Log **Hume Coal Project (SSD 7172) - Groundwater Model**

Item	Context	Comment/Question/Issue from Independent Peer Review by Hugh Middlemis (HM) August 2017, updated 5 & 11 October 2017. Updated August 2, responding to revised modelling report.	Response from Groundwater Assessment Team (5 Oct 2017)
7	Recharge (RCH) s.4.3.3.	Report states RCH at 1.8% of annual average rainfall (no seasonality, no climate change effects). RCH benchmarked to baseflow and weighted a little higher to allow for recharge from basalt (both worthy methods). RCH lower than applied to Berrima model (4% general, 8% over mine). WSP assumes 6%. Would higher average RCH and/or seasonality (as an uncertainty assessment) result in increased or decreased mine inflow and drawdown impacts? Subsequent comment (Oct 2017): the climate scenarios will assess uncertainties relating to recharge (and, presumably, evaporation), but the alternative arrangement suggested above (issue 6) would test uncertainties to parameterisation (noting that recharge is correlated with Kh). For example, the model should arguably be used to provide objective evidence (results of scenarios) that pose questions such as: - what parameter value/combination would increase the current prediction of third party bores affected, and how likely is such a set of parameters? - what higher dewatering rate/duration would it take for the mine water balance to be compromised (in terms of zero discharge aims), and what parameters (or combinations) would cause those higher dewatering volumes/durations, how likely is that eventuality and what would be the regional impacts?. To discuss October 9th. Subsequently: see comment at issue 6. August 2018: Revised Groundwater Modelling report has clarified/resolved these issues, especially with sections 3.1.7 and 8.4 on the recharge and ET sensitivity analysis, and section 6 on the Climate Scenario Analysis (s.1.1; s.3.1.7; s.5-s.7; s.8.4; Tables 8 & 9; Figures 16, 34, 41-44, 56-57), hence green traffic light.	This study has ground-truthed rainfall recharge against baseflow analysis for consistency. Other referenced recharge estimates do not have this control. Seasonality is considered during calibration but not during prediction, but the fraction of rainfall remains the same. Climate scenario analysis is to be undertaken (for 108 climate sequences) to assess the uncertainty in mine inflow and baseflow impacts.
8	Aquifer parameters s.4.3.2, Table 3, Figure 4.5	Kh arguably a little on the low side (reasonable given RCH arguably a bit low). Kv a bit on the high side, hence Kv/Kh high at 0.2 in model, compared to 0.02-0.002 from pump tests. Higher Kv arguably OK given number of boreholes in area. Specific storage (Ss) value of 5.e-7 m^-1 is arguably too low in a physical sense (compressibility of water alone yields Ss of approx. 4.5e-7 m^-1). Pells 2017 in his fig.2.8 suggests Ss too low by far, but this is relevant only to software based on compressibility (bulk modulus values not specified by Pells and warrant double-checking). However, in this case the Ss value is valid and acceptable, in that Modflow is a quasi-3D model (does not work on basis of compressibility) that coverts Ss to S by multiplying by layer thickness. The values of S used by Modflow are thus reasonable in a composite and individual layer sense (e.g. composite S = 1.e-4 for layers 2-5 (124m thick), and S = 1.e-5 for layers 6-11 (17.5m thick), but S = 1.e-6 for 2m thick interburden layers). OK. Subsequent comment (Oct 2017): Discussion around parameters not unreasonable, and points re Ss and Poissons Ratio appear quite valid (i.e. Pells argument is questionable and hence so is some of UNSW review comment, especially inconsistent references to specific storage and confined storage values). Monte Carlo calibration-constrained uncertainty analysis results required to provide objective information on review comments about potential for alternative conceptualisation or parameterisation to result in significantly different impact assessments. Adoption of Ss at 5.e-7 m^-1 is almost at low end of physical limit, and pumping test results provided (thank you) indicate Ss in order of 3.e-6 m^01. This suggests that the uncertainty effects of a higher confined storage (by a factor of 10) have not yet been explored. In other words, despite the well-constrained calibration achieved, and given the feedback loops between parameter settings, impact predictions with Ss at least a factor of 10 higher may be warranted. Having said that, dewatering volumes are likely insensitive to confined storage values (but may be sensitive to unconfined specific yield values). Uncertainty analysis would have provided the information in question. For discussion on 9 October. Subsequently: uncertainty analysis in progress OK (but orange "traffic light" colour retained accordingly). August 2018: Revised Groundwater Modelling report has clarified/resolved these issues, especially with sections 3.1.7 and 8.4 on the recharge and ET sensitivity analysis, and section 6 on the Climate Scenario Analysis (s.2.2.4; s.3.1.8; s.5; s.7; Tables 8 & 9, 10-14; Figures 16, 34, 41-44, 56-57), hence green traffic light status.	Field K values always cover several orders of magnitude. The applicable regional K values are best determined by calibration to broad groundwater levels and hydraulic gradient patterns. The calibrated Kh values [Figure 4.5] lie roughly in the middle of the field K spread. Kv is generally 1-2 orders of magnitude lower. In this study, the choice of aquifer property values has been constrained considerably due to the three-pronged approach of simultaneously honouring observed groundwater levels, measured Berrima mine inflow and inferred steam baseflows. Accordingly, Hume Coal is confident that there is strong support for the adopted K values but recognise uncertainty and non-uniqueness as being ever-present. It is not unusual in mining models to allocate a single K value per model layer, as long as the RMS calibration statistic is acceptable (9%RMS without VWP measurements). Monte Carlo calibration-constrained uncertainty analysis is planned to assess the effects of spatial variability. The adopted Ss and inferred S values are similar in magnitude to those adopted in other mining models. Generally, the unavailability of geotechnical tests precludes direct calculation of Ss from one of many empirical relationships. The Pells argument is based on an assumed Poisson's Ratio (PR) of 0.2. This could be higher, in which case the model-adopted values are closer to theoretical expectations. The literature has many reported values of similar magnitude (and lower) to those adopted. The adjacent graph of Bulk modulus vs Specific storage shows extreme bounding lines for PR of 0.31 (blue) and 0.40 (red); also literature values (green spade), incompressible limit (red spade), and pumping test (blue spade - accurate to no better than a half order of magnitude).
9	Pumping Tests and Berrima Inflows	1-day test at H98, 7-day test at GS108194 (Wongonbra). Sy = 0.015 (incorrectly listed as 0.15 in draft issues log), Ss = 3.e-6 m^-1, Kv/Kh = 0.002-0.02. No details of pumping tests provided, and no long term tests undertaken (other than one 7-day test at Wongonbra). However, good calibration to Berrima mine inflows and to baseflow estimates, along with head values. Berrima inflows similar in scale to predicted Hume inflows. Subsequent comments (Oct 2017): - thank you for providing the pumping test information from PB memo of 2014 ("pumping_tests" tab) - agree Sy should have been indicated as 0.015 in draft issues log comment (my mistake) - 2 pumping tests, but only one "long term" test, of 7-days duration (i.e. report in s.5.1.1. is exaggerating the "long term pumping test" claim); not questioning the other tests, just pointing out that there is little by way of a large scale stress test on the aquifer (only the one 7-day test) - note that Ss from 7-day test over a 100m interval resulted in Ss value of 3.e-6 m^-1, which is 10 times higher than the Ss applied to the model of 5.10-7 m^-1; the S values obtained from the test of 3.e-4 and 1.e-5 are not inconsistent with the model-calculated composite S value for layers 2-5 (124m thick) of 1.e-4, and 1.e-5 for layers 6-11 (nominally 17.5m thick). Key issue is that, while the S parameter used in the model is consistent with pumping test data, uncertainties have not been investigated. For discussion 9th October. Subsequently: a sensitivity run is planned to evaluate effect of a higher Ss value - need to review results in due course. August 2018: Revised Groundwater Modelling report has clarified/resolved these issues (s.2.2.4; s.3.1.6; s.3.1.8; s.5.1; s.7; Tables 8 & 9, 10-14; Figures 34, 41-44, 56-57), hence green traffic light.	Volume 1 notes 28 packer tests, two long-term pumping tests on the lease (pumping bores HU0098 and GW108194 (Wongonbra) with multiple observation piezometers monitored), six long-term pumping tests from private bores in the wider area, 129 estimates of hydraulic conductivity from specific capacity data in government records for private water bores, and laboratory tests on 39 cores. Details of the two pumping tests are summarised in a Memo from Parsons Brinckerhoff dated 19 December 2014. Data were analysed using Aqtesolve software assuming either unconfined or leaky-confined conditions, and also analysed using MODFLOW-USG on an 8-layer model for the longer pumping test. Of interest for the latter analysis is an interpreted storage coefficient of 5E-6, suggesting a specific storage an order of magnitude lower (consistent with what has been adopted in the model). The field data and Aqtesolv analyses are at Tab "Pumping_Tests". Coffey re-interpreted the pumping test data using USGS WTAQ software. The field data and WTAQ analyses are at Tab "Pumping_Tests". Of interest is an interpreted specific storage of 3E-6 m^-1 and specific yield of 0.015 (not 0.15).
10	Calibration Performance s.4.3	Performance stated for validation period to August 2015: SRMS = 12% exceeds guideline upper limit of 10%, but probably affected by outliers B62 upper and B63 lower (not unreasonable that there is a poor match to 2 VWPs out of 6 VWPs at Berrima), and given topo data issue. What is performance statistic excluding outliers? Time series plots show some good matches, some poor; overall OK (given data issues). Figure 4.6 shows reasonable calibration match to post-2012 measured flows at Berrima gauge (when good data quality available from cut-throat weir). What is performance during warm-up model run to 2011 (match to factored gauge data shown by purple line on fig. 4.6 - see "Berrima" tab herein) ? No presentation of model performance at Dec 2014 (end of calibration) in terms of groundwater contours and head residuals plot; this would be helpful to judge performance. Subsequent comment (Oct. 2017): changed issue colour to green based on extra info provided (thank you), even though data on Berrima flows pre-2011 was not provided. August 2018: Revised Groundwater Modelling report has further clarified/resolved these issues (SRMS ～11%), and conducted a comprehensive sensitivity and uncertainty analysis, hence green traffic light status	VWP data are commonly known to vary by up to 10m. In the model two VWPs are outliers and do not calibrate well. When these are removed the SRMS is reduced to 9.0% (and 12.9 mRMS). All head calibration data at 2432 points are now included in the calculation of performance statistics. The scattergram is adjacent. Groundwater head contours (water table) and head residuals are provided in the "New_Figures" tab.
11	Reporting	s.7.1.1 Model Results: "indicate that 98% of total inflow to Hume mine workings is satisfied by interception of baseflow to streams and release of groundwater storage". No mention of recharge, which would presumably play a role as a component of inflow. Explanation required please as to how this statement is justified. s.7.2, last para needs explanation please: "drawdown calculated as transmissivity-weighted average of drawdown in each model layer intersected by bore hydraulic interval". s.8 Parameter Sensitivity; bullet 2, sub-bullet 2: report asserts that calibrated Kv of layers 1-5 comprise Wianamatta Group and Hawkesbury SST between water table and mine workings, but Hawkesbury SST extends to layer 7, and then layer 8 is the interburden (relaxation zone in some areas?). This sensitivity run does not test Kv profile to the top of the workings as suggested by the text. Potential for fracturing to extend up into layers 6 & 7 is arguably high, hence this sensitivity run may not explore uncertainty adequately. May need discussion. Subsequent comment (Oct 2017): issue colour changed to orange - s.7.1.1. Appendix I (model report) section 7.1.1 does indeed state 98%. The statement in the report is lacking the explainer provided in the response that is linking mine inflows to dependencies on mine activity. Recharge also plays a role in mining-induced impacts in terms of the long term regional extent and magnitude of the cone of depression, which is a key issue given the number of third party bores affected; mainly an issue of report clarity (not material) - s.7.2 - would it not be better to interrogate the model and report the water table drawdown at the bore location, rather than a "transmissivity-weighted drawdown"? For example, in groundwater engineering terms, water is lifted from the water table (not the screened interval of the bore), and the predicted water table is a robust indicator in this case of water accessibility for 3rd parties. - s.8 revised modelling results are required to provide objective information on impacts (hence orange "traffic light" colour retained). August 2018: Revised Groundwater Modelling report has further clarified/resolved these issues, especially sections 1.1, 2.2, 3.1.3, 3.1.4, 4.2, Tables 8 & 9 and Figures 34 & 41-44. Further, a comprehensive sensitivity and uncertainty analysis has been conducted (section 7; Figures 41-62). Hence green traffic light status.	s.7.1.1: There is no mention of "98%" in the report. The water entering the mine comes directly from storage in adjacent rocks, which are replenished in part by baseflow losses and rainfall recharge. The latter, however, is independent of the mining activity. s.7.2: Table 1 in Appendix G shows the model layers that are "open" to each production bore. The model returns a separate drawdown in each layer. In reality, a bore would experience a single drawdown, and that value is best estimated as some average of the reported layer drawdowns; instead of a simple average, the drawdowns have been weighted according to transmissivity as thicker and more permeable layers would dominate the actual drawdown in a bore. s.8: It is acknowledged that the full extent of Hawkesbury Sandstone was not included in the sensitivity analysis for Kv. The thickness of material between the roof of the coal seam and the floor of the Hawkesbury Sandstone ranges up to 8m (see adjacent contours). It is true that DRN cells should have been placed in Layers 7, 8 and/or 9 for a small portion of the mine plan. In the revised modelling, enhanced time-varying properties will be applied in those layers where required.

Appendix B

Hume Coal Project Independent Expert Roundtable Meeting 16 November 2017

Hume Coal Project – Independent Expert Roundtable Meeting

Thursday 16 November 2017: 11.00am – 2.45 pm (lunch at 1 pm)

Dainun Room, Level 30, 320 Pitt Street Sydney

Attendees:

Facilitator	Anuj Saraogi (DPC)
DPE	Hugh Middlemis (Hydrogeologic)
Community	Dr Stephen Pells (Pells Consulting), John Lee (Hydroilex), Chris Jewell (CM Jewell & Assoc)
Agencies	Alison Collaros (CL&W), Malcolm Hughes (WaterNSW)
Observers	Clay Preshaw (DPE), Paul Freeman (DPE) Peter Martin (CFSH), Alan Lindsay (CFSH)

AGENDA

11 – 11.15	Welcome and Introductions – Tim Kirby
11.15 – 11.45	Briefing on investigations and key findings - Hugh Middlemis
11.45 – 2.30	Key discussion items – All
11.45 – 12.10	a) *Groundwater model* - conceptual geological and hydrogeological model - modelling assumptions based on the conceptual model - class/confidence level - the use of “average flow budget” over a range of stress periods - water balance average discrepancy term of 5% - Scaled Root Mean Squares values greater than 10%
12.10 – 12.35	b) *Dewatering volumes and extent of drawdown* - potential take from aquifers above/below the target coal seam - sensitivity analysis - any additional bores affected – volumes and time periods
12.35 – 1	c) *Technical feasibility of make good for private bores*
1 – 1.30	LUNCH
1.30 – 2.00	d) *Underground bulkheads* - model conceptualisation of aquifer storage in mined voids behind bulkheads - any implications for groundwater model - any further modelling required - potential surface water issues e.g. treatment/discharge
2 – 2.30	Recap of residual issues – All
2.30 – 2.45	Conclusion and key actions – Tim Kirby