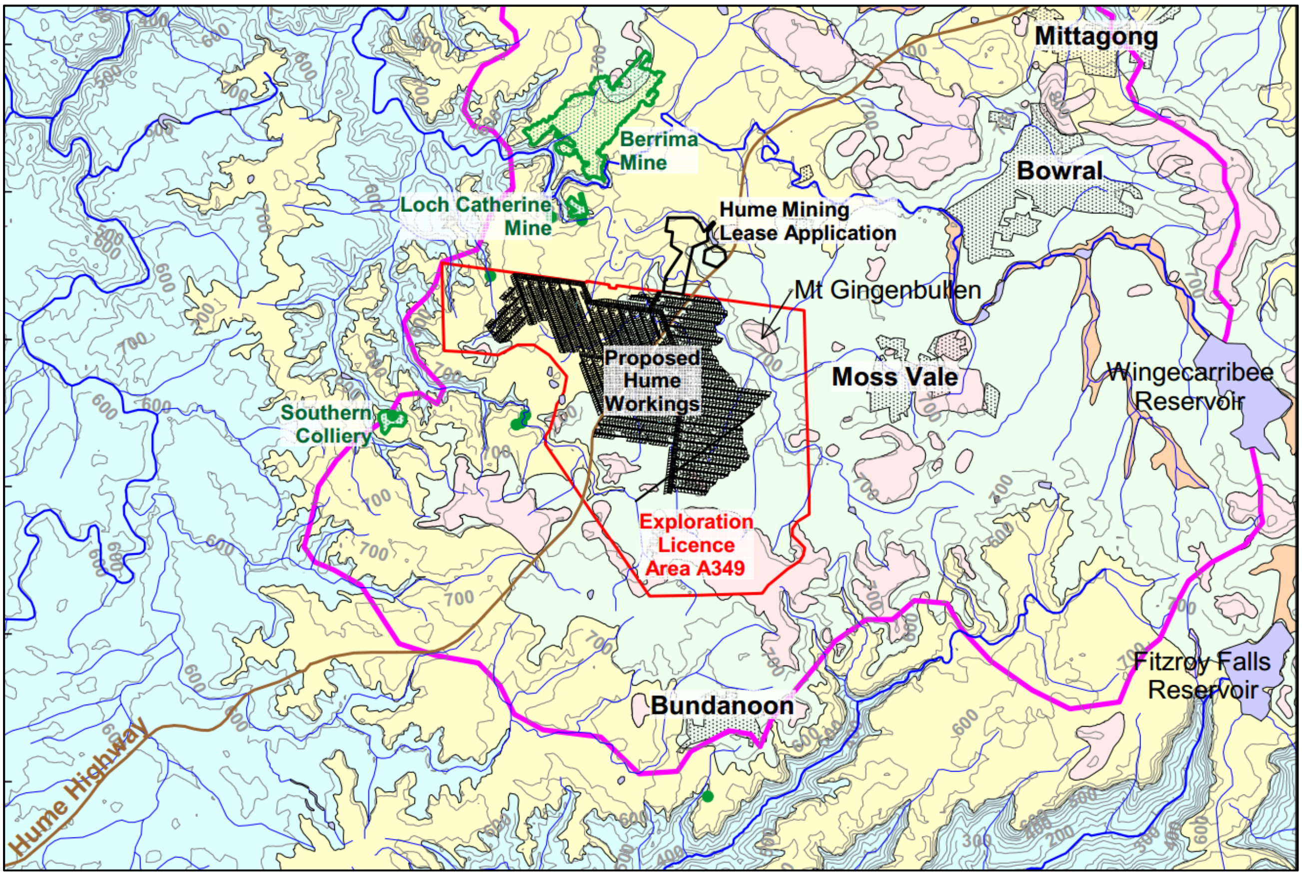
Hume Coal Project EIS
Independent Expert Review
Groundwater Modelling

Prepared for:	**NSW Dept. Planning & Environment**	6 Dec. 2017



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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 highlands 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.

A key driver for this review is understood to be the extent and magnitude of groundwater drawdown predicted, in the range of 2 to 80 metres at 93 private bores on 71 properties in and around the project site. 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.

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 to re-inject mine water back into the workings and cement seal the voids, 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), 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.

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), which was discussed briefly with DPE staff via telephone on 13th August;
- 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; and
  - Dr Noel Merrick (HydroSimulations) on 24th August and 7th and 9th September;
- 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;
- 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 with this reviewer's responses (see Appendix A);
- groundwater experts meeting at DPE on 16 November (see agenda and attendee list in Appendix B)
- preparation and updating of this review report.

While this review finds that the Hume Coal model itself is suitable for the mining impact assessment purpose (Class 2 confidence level), the EIS documentation does not meet best practice modelling standards. Some model improvements are warranted, notably to investigate uncertainty issues, but the EIS presents reasonable predictions of dewatering volumes and drawdown extent/magnitude. The review status is currently on hold, awaiting the results from a range of model refinements and additional scenarios in progress by HydroSimulations.

2. Model Refinements and Performance

The model refinements in progress by HydroSimulations (Dr Merrick, pers.comm.) are designed mainly to address issues identified via a model audit by Dr Merrick, and to address certain items in the issues log identified by this expert review (see Appendix A). The following points summarise the refinements in progress that were identified by Dr Merrick, and are endorsed as warranted by this review:

- improving model performance generally via trimming inactive grid cells, improving the solver settings, 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 0.5% and reduced the SRMS statistic to <10% (both within guideline criteria), and achieved faster run times;
- revising the relaxation zone above the Hume workings to account for where (thin) dummy layer thicknesses apply where lithological units pinch out;
- deactivating drain cells once a mined section is sealed, and directly injecting mine water from active dewatering into sealed sections if required for excess water management, and revising the water balance analyses.

The issues log (Appendix A) outlines a range of issues where this review has found that the EIS report documentation does 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 indicate 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) 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 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 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 has found that most of the items raised in the issues log (Appendix A) arise 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 do warrant model revisions (as well as report revisions), but it is understood that most of these model revisions were in progress already, 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).

3. Hume Coal Groundwater Model Review Summary

While we await a revised assessment based on the revised modelling, this report presents a summary of the review findings on the groundwater modelling impact assessment.

3.1 Model Confidence Level

The groundwater assessment report (Coffey, 2016b) claims a model confidence level of Class 2/3, suitable for an impact assessment purpose. This review finds that a Class 2 is justified, based on an independent assessment of the attribute weightings of the Hume Coal model as reported in Coffey (2016b) (Table 1).

Table 1 - Model confidence class characteristics - 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
	~	Some usage data/low volumes.	~	Short time record.	√	OK validation.	~	Mass balance < 1%
(impact asessment)	√	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)

Anderson (2017) disagreed with the groundwater assessment report statement of a Class 2/3 model, 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 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. An SRMS of more than 10% is indeed a Class 1 indicator, but there are very few other characteristics of the Hume Coal model that could reasonably be assessed as Class 1.

The model Class is important because DPI 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 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 1) devised by Dr Merrick, although there is no written evidence to that effect.

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 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 1% and the SRMS has been reduced to less than 10% during the model refinements in progress (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.

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 2 based on the findings of this expert review.

In summary, it is my professional opinion that the Hume Coal model is fundamentally consistent with best practice, although the EIS report documentation is deficient (not sufficiently clear on some details; see Appendix A). It is fit for mining impact prediction purposes. Certain model performance improvements are warranted, along with uncertainty analyses and updated reporting (it is understood that these are already in progress; see section 2 for details).

Table 2 - 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). Medium complexity model (Middlemis et al, 2001). Clearly described in model reports.
2. Are the objectives satisfied?	Yes	Adequate model calibration performance (latest/improved model shows <10% SRMS, improved from 11.9% in EIS reports). Reasonable time series matches. Impact assessments have been completed diligently, although report documentation is sometimes not crystal clear/transparent.
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 model report (Coffey, 2016b) is deficient in that it is sometimes inconsistent or not crystal clear in describing certain methods or results (e.g. commentary on interburden thickness treatments, water balances, and use of undefined terms such as "active stress period" and "transmissivity-weighted average drawdown"). In-house review by Dr Merrick and Dr Kalf. Dr Merrick completed a detailed model audit, and model refinements are in progress, with 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 refinements are using Modflow-USG, both industry-leading software, with USG adding the benefit of time-varying properties for subsidence issues. 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. Interburden treatments are not well described in the report, and refinements are in progress by Dr Merrick (see section 2).
6. Is the model calibration satisfactory?	Yes	Acceptable model calibration performance and good time series matches at most bores (except 2 of 6 VWPs, which is not unreasonable). EIS report states 11.9% SRMS, exceeding 10% criterion, but refinements have reduced SRMS to <10%, and water balance error terms to <0.5% (see section 2 and Appendix A), which is satisfactory. 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 remain, and as the evapotranspiration discharge (a riparian zone flux) is unconstrained by measurement or estimates, sensitivity testing is warranted on the maximum ET rate and extinction depth (especially in high relief areas, including parts of the riparian zone).
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. 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) is set at 5.10^{-7} m^{-1}. 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). Sensitivity testing is warranted (but results are probably not highly sensitive to Ss). Model refinements in progress by Dr Merrick (section 2) have applied higher Ss values, which will change the inflow volumes and drawdown effects.

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 are not presented clearly in the report. Awaiting further results from current model refinement and scenario analysis program (see section 2). 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. Latest model refinements (see section 2) of turning off drains when mined areas are sealed is more realistic. This work may require direct injection of mine water behind bulkheads (for mine water circuit management/balancing). Comparison of the EIS and latest results would allow "unpacking" of bulkhead failure effects, but a sensitivity-style run of the refined model to emulate the previous method is recommended.
9. Is the uncertainty associated with the predictions reported?	No/Yes (in progress)	No comprehensive uncertainty assessment was done for the EIS groundwater assessment. A sensitivity analysis was done on the identified sensitive parameters of relaxation height, mine drain conductance parameter and Hawkesbury Sandstone Kv (Coffey, 2016b). Uncertainty analysis is recommended, with minimum requirements being a composite sensitivity analysis and then selected uncertainty scenarios, preferably including horizontal hydraulic conductivity. A Monte-Carlo constrained calibration uncertainty assessment is reportedly in progress, which should largely address parameter uncertainty issues. DPI Water has also requested scenario analysis of 108 climate datasets (consistent with surface water assessments), and consideration of mine water management (e.g. to confirm low risk of excess water discharge), which should address other uncertainty issues. 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. It is noted that the recharge rates are relatively low (perhaps by a factor of 2) and the ET rates are not constrained, which means there is scope to further test uncertainty via an alternative model with higher recharge. An alternative model (e.g. with higher recharge and other changes) would form a best practice method to address structural model uncertainty (Barnett et al, 2012), even if that is done as a sensitivity test. It is understood that such tests may be in progress; further comment must await the results.
10. Is the model fit for purpose?	Yes	My professional opinion is that the Hume Coal model is fundamentally a good example of best practice in design and execution (let down by unclear report documentation). It is fit for mining project impact prediction purposes and the results presented are reasonable in terms of inflows and drawdown predictions. Refinements in progress (see section 2) are improving its performance, and uncertainty assessments are also in progress. Further comment must await the results.

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 (Appendix B).

4.1 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 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 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).

Consideration of groundwater engineering factors was applied to the 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, such investigations will need to consider local scale issues, 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).

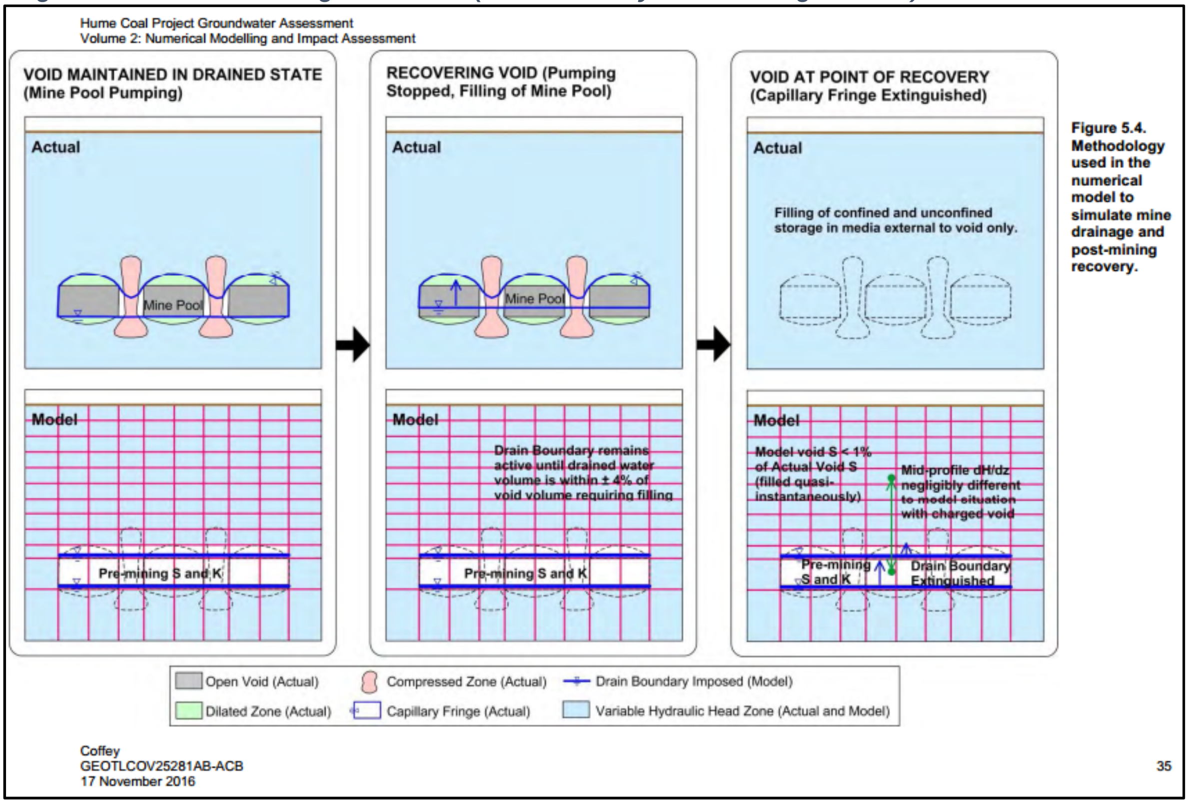
There is evidence of private pumping effects in the area of the Rosedale and Wongonbra bores (GW107535 and GW108194) of 1.0 to 1.5 ML/d over the growing season (120 to 180 ML total volume) (Coffey, 2016a, section 9). This gives some indication of practical bore and irrigation capacities that may also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

4.2 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 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 1).

Figure 1 - mine drainage feature (after Coffey 2016b, Figure 5.4)



This 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).

An alternative modelling method has been applied in the latest refinements (see section 2). The revised method involves turning off model drain cells when the mined areas are sealed. 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 once a mined panel is sealed.

Concurrent with the revised drain cell method, the direct injection of mine water to the aquifer may be required 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.

Comparison of the results from Coffey (2016b) and the latest refinements from HydroSimulations would allow assessment of the various effects relating to potential bulkhead failure. However, it is recommended (i.e. it may be simpler) to run a sensitivity-style simulation of the refined model, emulating the previous arrangement of leaving drain cells on post-mining until the voids are filled.

4.3 Interburden Layer Representation in Hume Coal Model

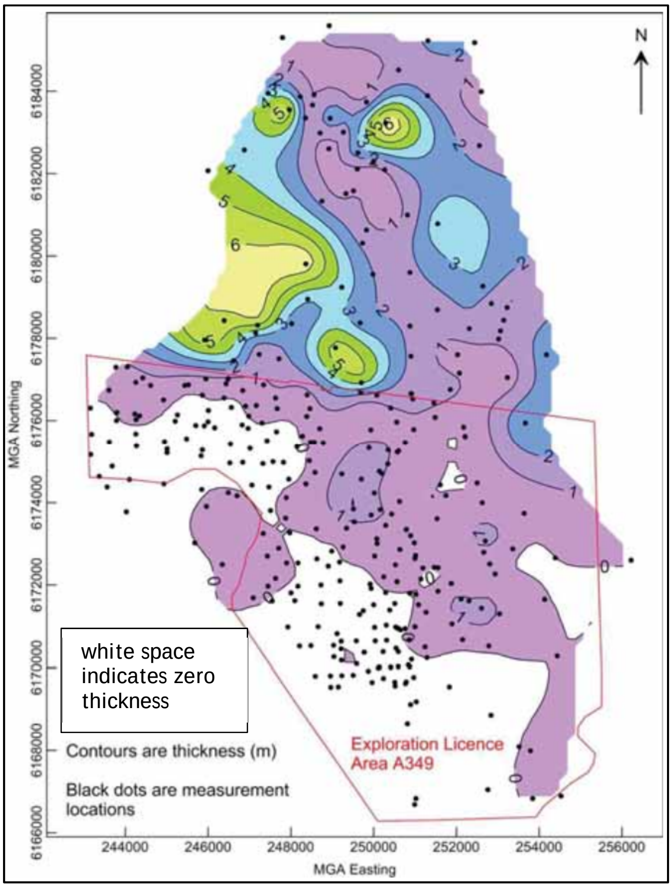
This review finds the reporting on this key topic is very unclear, confused, self-contradictory and sub-standard. Pells (2017) and Anderson (2017) also raised questions about the interburden implementation, and this was discussed further at the meeting on 16 November (Appendix B).

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 2).

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) that:

- a minimum thickness of 0.4m is applied to layer 8 (interburden) in areas where the interburden is absent (Figure 2), 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 0.99m 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.

Figure 2 - Interburden thickness (after Coffey 2016a, Figure 4.3)



The report (Coffey, 2016b) confusingly and erroneously describes 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.

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.

Dr Merrick also identified that corrective action is being taken to refine the model to properly represent the relaxation zone (see Appendix A for details). The relaxation zone is represented by including drain features in layer 11 (the mined seam) and in overlying layers to the height of the relaxation zone (nominally 4m). This means that drain features should extend up into layer 6 in some areas of zero interburden thickness. The implication is that inflow volumes may increase, but objective analysis must await the results of the model updates.

In other areas, the known interburden thickness (Figure 2) is applied to layer 8 of the 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 3). This means that low permeability parameters are not applied to the interburden layer in the model, as illustrated in Figure 3 in terms of the model values for the interburden being much higher than most of the test results for the deep units.

The areas of zero interburden thickness (Figure 2) 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. 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.

In summary, this review has found that the Hume Coal model 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). Action is in progress by the Hume Coal Groundwater Assessment Team to improve the implementation of the relaxation zone, and action should also be taken to revise the confusing report documentation.

4.4 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.

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). 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.

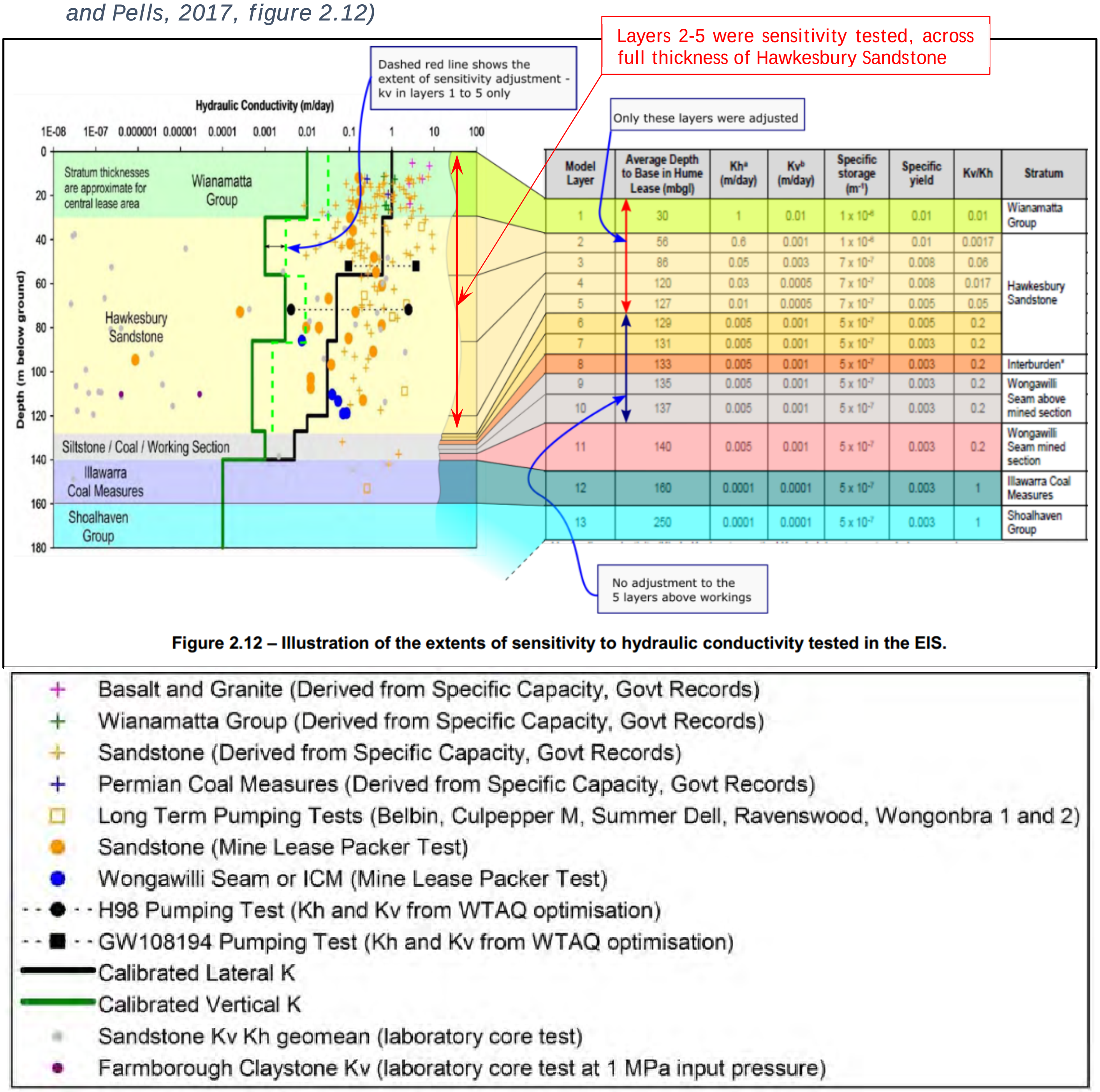
The basal unit of the Hawkesbury Sandstone is Layer 5 in the Hume Coal model, nominally 7m thick and with a horizontal hydraulic conductivity (Kh) value of 0.01 m/d. This is a lower Kh than the overlying bulk thickness of Hawkesbury Sandstone layers 2 to 4 (Kh range from 0.6 to 0.03 m/d; Figure 3), consistent with the conceptualisation of decreasing permeability with depth (justified by information presented in Coffey, 2016a, Appendix C).

The underlying layers 6 & 7 are nominally described 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 4.3 above), rather than the Hawkesbury Sandstone as such.

The modelled Hawkesbury Sandstone Kh values are reasonable in that they lie in the middle of the range of observed values (Figure 3); 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 3). Most of the pumping tests on individual bores (open square symbols in Figure 3) 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.

The model has been tested for sensitivity to Hawkesbury Sandstone vertical hydraulic conductivity (Kv) across the full thickness of the Hawkesbury Sandstone (Figure 3), 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 (Coffey, 2016b), it is recommended that uncertainty analysis on horizontal hydraulic conductivity of the Hawkesbury Sandstone should be undertaken (it is understood that this is currently being evaluated as part of the model refinements in progress by Dr Merrick in response to discussions with DPI Water).

Figure 3 - observed and modelled hydraulic conductivity (after Coffey, 2016b, figure 4.5 and Pells, 2017, figure 2.12)



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

Figure 2.12 – Illustration of the extents of sensitivity to hydraulic conductivity tested in the EIS.

4.5 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 1. The drain feature involves a conductance parameter that acts as a resistance to flow (i.e. lower values of conductance require higher groundwater levels 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 approach required simultaneous matches to stream baseflows, and is a good example of a best practice method that minimises non-uniqueness issues and supports a model Class 2 confidence level. 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.

5. Conclusions

The reported water balance "discrepancy" 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 also not necessarily valid.

The groundwater assessment report (Coffey, 2016b) claims a model confidence level of Class 2/3 (30%/70%), suitable for an impact assessment purpose. This review finds that at Class 2 is justified, based on an independent assessment of the attribute weightings of the Hume Coal model as reported in Coffey (2016b) (Table 1).

In summary, it is my professional opinion that the Hume Coal model is fundamentally consistent with best practice in design and execution, although the EIS documentation is deficient (not sufficiently clear on some details; see Appendix A). It is fit for mining project impact prediction purposes. Certain model performance improvements are warranted, along with uncertainty analyses and updated reporting (it is understood that these are in progress; see section 2 for details).

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.
- 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

Appendix B

Hume Coal Project Independent Expert Roundtable Meeting 16 November 2017