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Our ref: PSM3427-001R

26 September 2018

Coal Free Southern Highlands Incorporated
PO BOX 3168
EXETER NSW 2579

ATTENTION: PETER MARTIN

Dear Peter

RE: REVIEW OF HUME COAL PROJECT RESPONSE TO SUBMISSIONS JUNE 2018

For and on behalf of
PELLS SULLIVAN MEYNINK

STEVEN PELLS

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COAL FREE SOUTHERN HIGHLANDS INCORPORATED

REVIEW OF HUME COAL PROJECT RESPONSE TO SUBMISSIONS JUNE 2018

PSM3427 26 SEPTEMBER 2018

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1 INTRODUCTION

In June 2017, at the request of Coal Free Southern Highland Inc., I reviewed the groundwater studies that supported the EIS for the proposed Hume Coal Project. The impacts to groundwater from the proposed mine predicted in the EIS were significantly less than I had anticipated based on a study and numerical modelling I had previously undertaken in 2013 (Pells and Pells, 2013). A claim was made in the EIS that groundwater impacts had been significantly mitigated due to the proposed form of mining. I examined this claim by including the proposed mining procedure in the Pells Consulting numerical model and found that the method of mining did not result in significant mitigation of impacts. I explored these results, and found that the comparably smaller impacts presented in the EIS were due to different assumptions in modelling, stating:

1. Hume Coal adopted significantly lower hydraulic conductivity values for the coal measures and for formations just above the coal workings.
2. Hume Coal adopted very low aquifer storage values
3. Hume Coal adopted very low values of 'drain conductance' when representing the mine in the model
4. Hydraulic Model layering adopted by Hume Coal places emphasis of the presence and continuity of a thin claystone seam above proposed workings.

The effects of these four features were explored in the Pells Consulting report of 2017 using analytical solutions and conceptual models. I argued that insufficient justification had been given for these features, stating:

1. Hydraulic conductivity values adopted by Hume Coal did not accord with measured values presented by Hume Coal. There was also no representation of a known productive aquifer layer within the formation.
2. Storage values adopted by Hume Coal were shown to be mathematically untenable.
3. Drain conductance values adopted by Hume Coal effectively controlled flows into the mine, as if it were lined with a thick, compacted impermeable clay
4. It was questioned whether sufficient evidence exists to support the representation of the claystone (interburden) adopted by Hume Coal.

I also considered that insufficient sensitivity testing was presented by Hume Coal to examine these features, given that there is high uncertainty in these parameters, and that the parameters effectively control model outcomes.

In 2018 Hume released responses to submissions. The responses by Hume which I have reviewed, and which I discuss in the letter, are:

- HydroSimulations 2018 *Hume Coal Project – Revised Groundwater Modelling for Response to Submissions Report for Hume Coal* by NPM Technical Pty Limited trading as HydroSimulations HUM002 Report

HS2018/02 June 2018 included as Appendix F in Hume Coal EIS Response to Submissions

- EMM 2018 *Hume Coal Project Response to Submissions Critique of Pells Consulting Modelling Studies Report* for Hume Coal by EMM Dated 20 June 2018. Included as Appendix H in Hume Coal EIS Response to Submissions

The first of these reports presents revised groundwater modelling, with revised predictions of groundwater impacts from the proposed mine. The second report by EMM (2018) is a critique of my previous model studies.

I have worked through these documents to compile the technical responses that regard my previous findings listed above. I consider the responses, in turn, in Section 2 below. I have listed specific criticisms of my studies made by EMM (2018) in Appendix A of this present letter, providing a brief response to each.

In reading these two new reports by Hume, two other issues of significance arise, being: the calibration of groundwater models, and; the model 'class' according to the Australian Groundwater Modelling Guidelines. I discuss these below in Sections 3 and 4 respectively.

In Section 5 of this present report I provide a summary of matters that I consider require further clarification and / or justification.

2 CONSIDERATION OF RESPONSES BY HUME COAL, 2018

2.1 Hydraulic conductivity values

HydroSimulations (2018) presents revised hydraulic conductivity which are calculated as a function of depth. The relationship relies on “regression fit to field test results” (HydroSimulations 2018 pg. 36), where the field test data used was “packer and specific capacity field test data from the Hume Coal Project and neighbouring areas” (*ibid*).

Figure 2.7 of Pells and Pan (2017), which compared adopted hydraulic conductivity values, has been reproduced as Figure 1 below, but now also includes the mean hydraulic conductivity values reported in HydroSimulations (2018, Figure 18). It can be seen in Figure 1 that in this location the function of decreasing hydraulic conductivity with depth used by HydroSimulations (2018) approximates values adopted in the EIS studies previously presented by Hume Coal. Table 22 of HydroSimulations (2018) indicates that the vertical conductivity “Kv” is approximately equal to kh/50, which also approximates vertical conductivity used in the EIS studies previously presented by Hume Coal. The revisions in hydraulic conductivity, relative to the previous EIS studies, are considered by HydroSimulations (2018) to be small enough that “the model remains appropriately calibrated and is fit-for-purpose” (HydroSimulations, 2018 pg. 30). HydroSimulations (2018) have not revised calibration to Berrima colliery but attach the previous EIS model study, relying upon its calibration.

Hence, the criticism that I made previously of the hydraulic conductivity values remain. The criticisms have not been addressed and in some ways, as explained below, the problems have been exacerbated.

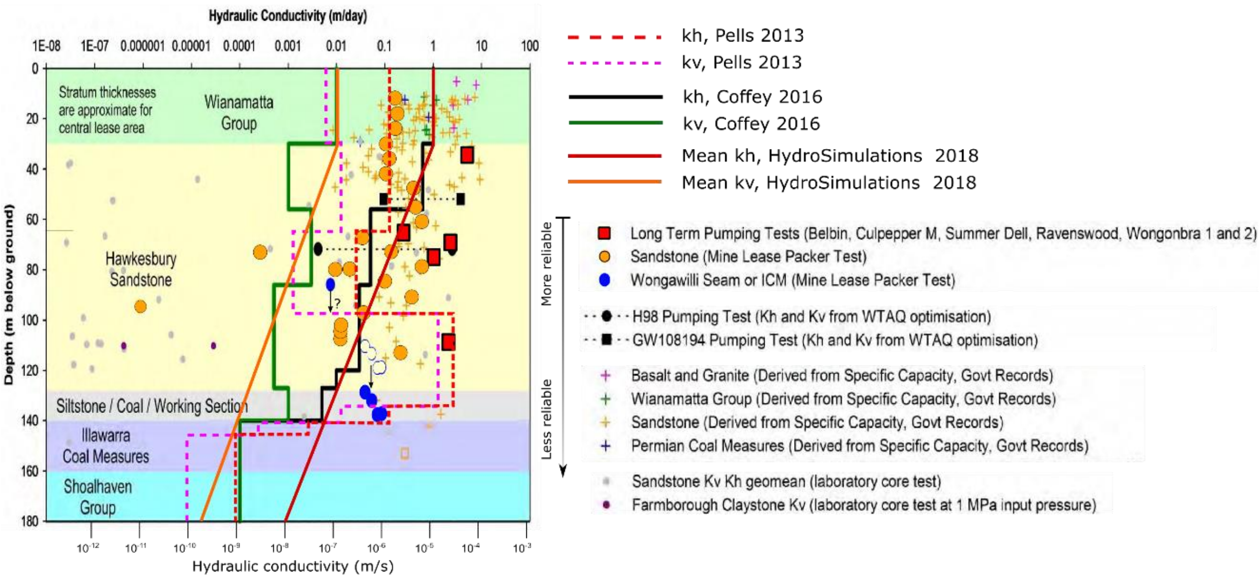

Figure 1 – Comparison of adopted hydraulic conductivity values

2.1.1 High yielding zone at base of Hawkesbury Sandstone

The conceptual model of Hume Coal gives no credence to observations of a higher yielding zone in the lower Hawkesbury Sandstone (e.g. Lee, 2000).

The HydroSimulations (2018) provides no response in this regard and makes no reference to hydraulic conductivity values determined from pumping tests[1], or to the local experience of higher yields from a higher conductivity formation above the Wongawilli seam (e.g. Lee, 2000). The regression analysis excludes pumping test data, and has adopted values that are orders of magnitude lower than those reported by the pumping test data.

EMM (2018) provided the following commentary regarding the experience of finding higher yields at depth in the Hawkesbury Sandstone (from Section 3.1 para.5):

> There are no compelling data sets to confirm that there is an increase in permeability of the sandstone strata at the base of the Hawkesbury sandstone … Yields from water bores that intercept deeper fractures can be very high yielding across localised areas of the Southern Highlands (URS Australia 2007 and Parsons Brinckerhoff 2009b). With the added advantage of significant available head, deep bores can pump high volumes (up to 50 L/s) at selected locations. This leads to the Hawkesbury Sandstone appearing to have higher hydraulic conductivity at depth however, this trend is more related to (localised) secondary permeability features such as fractures rather than high (regional) primary permeability.

EMM (2018) in Section 3.4 Para.3 also stated:

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

The works of John Lee (as reproduced in Pells and Pells, 2013 and published in Lee 2000) have documented consistently high yields from the Hawkesbury Sandstone Formation just above the Wongawilli Seam within the lease area. The dataset and local observations provided by Hydroilex are more comprehensive than “a few pumping tests” and should not be dismissed as such.

Data analysis in the EIS by Coffey Geoscience 2016a (attached as Appendix E to the HydroSimulations 2018) presented the spatial variation in hydraulic conductivity for the Hawkesbury Sandstone for an interval between 14m to 44m above its base, based on “*the large number of K measurements for the Hume lease*” (pg37). Results presented in Figure 5.6 of Coffey Geoscience (2016a) have been reproduced as Figure 2 below. Over the lease area, measured values of 0.8 to 1.5 m/day agree with the conceptualisation of Lee (2000), and are over 50 times larger than values adopted in modelling for the EIS.

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[1] The Hydrosimulations (2018) report makes repeated reference to storage values determined from pumping tests only.

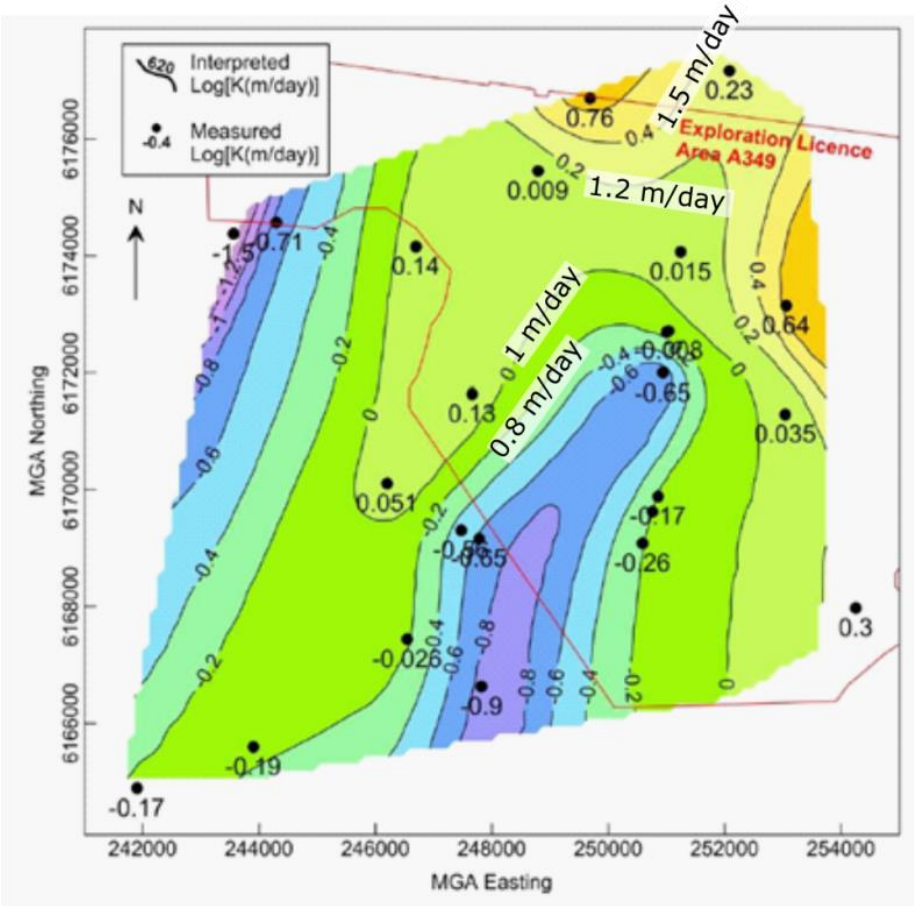


Figure 2 – Spatial variation in hydraulic conductivity in the lower Hawkesbury Sandstone (Coffey 2016a, Figure 5.6) – note edits have been made to reduce "logK" values to units of m/day

The EMM (2018) report suggests that the higher yields found in various boreholes reported by John Lee are due to these bores intersecting fractures. I agree that this is a possible interpretation of yields, at least for some of the bores, although it does not explain why higher yields are evident at depth[2] and does not explain the data in Figure 2 from the EIS. Vertical fractures within the Hawkesbury Sandstone are typically ubiquitous in the formation. If the high yields are from fractures they would occur at any depth, not just above the seam.

Nonetheless, if this is the interpretation to these borehole yields put forward by Hume Coal – i.e. fracturing of the formation above the mine - why was this interpretation not adopted within the Hume Coal modelling? Modelling in the EIS assumes no such fracturing or joint swarms. I contend that the presence of such features, as argued in the EIS, would significantly affect simulated inflows and drawdown.

[2] Increased hydraulic head at depth, as suggested by EMM, is insufficient to explain the observed increase in yields

2.1.2 Decreasing hydraulic conductivity with depth

Pells and Pan (2017) noted that increasing overburden is only one process contributing to hydraulic conductivity, but is often overcome by various other geological processes, as evidenced by the data shown above.

The EMM (2018) report also finds no basis for decreasing hydraulic conductivity with depth, stating "*permeability and yield of bores drilled through the whole Hawkesbury Sandstone sequence are not directly related to the depth of bores*" (Section 3.1 para.5)

2.1.3 Vertical anisotropy

The basis for a universal adoption a vertical hydraulic conductivity of 50 times less than horizontal is remains unclear.

2.1.4 Hydraulic conductivity of the coal seam and layers directly above the coal seam

Pells and Pan (2017) noted that values selected in the EIS do not reflect the available data for the coal seam and layers directly above the coal seam. They were over 20 times lower.

There is no response in HydroSimulations (2018) other than to assert that previous values were correct, stating "*Hydrogeologic (2017) review of also found that parameters applied to the interburden are representative of the aquifer tests for coal measures in the area*". No test data or data sources were given.

It is now noted that the vertical hydraulic conductivity adopted by HydroSimulations (2018) for these layers are now up to an order of magnitude lower than values defended in the original EIS study.

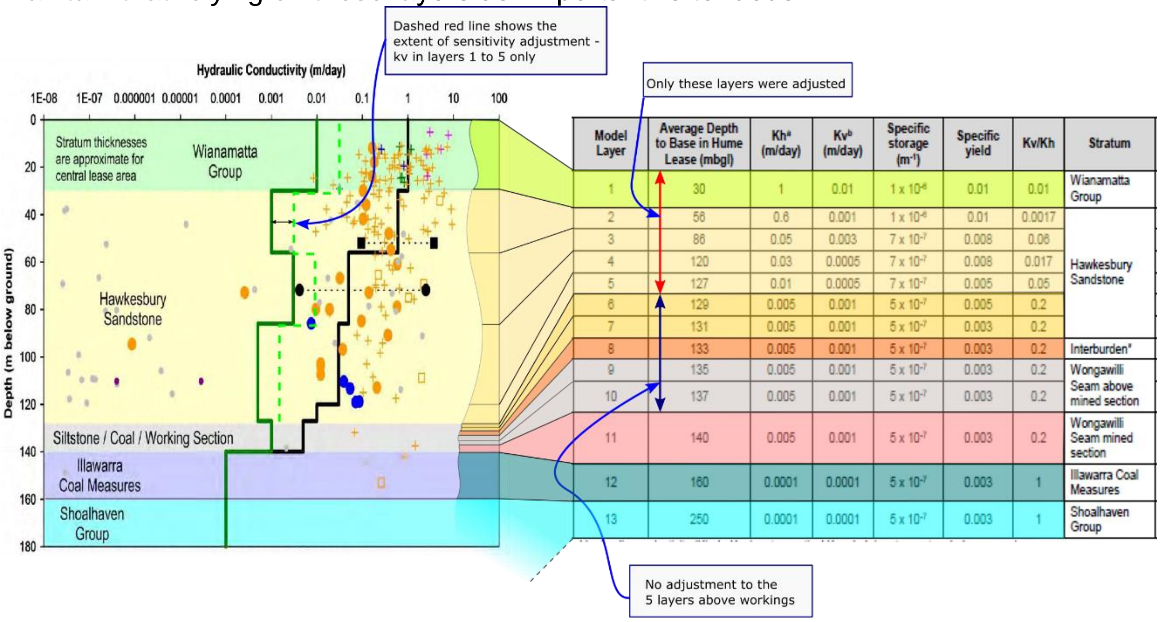
Pells and Pan (2017) argued that "*the hydraulic conductivity of the coal measures and formations directly above the mine adopted in the EIS are unrealistically low*" and that the results in the EIS were "*also reliant on the tenuous assumption of the lateral continuity and low permeability of an interburden layer*" (above the coal measures).

Hydraulic conductivity values adopted in the EIS studies are shown in Figure 3 below, and it can be seen that the EIS model incorporated a number of thinner layers (layers 6 to 8) above the coal measure layers (Layers 9 to 11). These layers all adopt a horizontal hydraulic conductivity of 0.005 m/day (6 x 10^{-8} m/s) and vertical hydraulic conductivity of 0.001 m/day (1 x 10^{-8} m/s). Pells and Pan (2017) argued that these values were too low for representation of coal measures, including data presented by Hume Coal (see blue dots in Figure 1 above), and are lower than values for Hawkesbury Sandstone above, constraining flow above the mine, without any test data as justification.

The response provided in HydroSimulations (2018) pointed out that the model layer labelled "interburden" (layer 8) in the EIS studies had the same hydraulic properties as neighbouring layers labelled as "Hawkesbury Sandstone" (6 to 7) and "Wongawilli Seam" (9 to 11), and therefore that "low permeability parameters had not been applied to the interburden within the model." (pg. .9). This answer just addresses a lax usage of the term "interburden", but does not answer either of the fundamental questions, being:

- What data support the lower values of formations (EIS layers 6 to 8) above the coal seam?, and;
- What data support the low values for the coal seam?

The presence of lower conductivity layers above the mine seam, whose parameters were controlled uniquely in modelling for the EIS, indicates interpretation that "*claystone and thin coal plies (Narrabeen Group and uppermost Illawarra Coal Measure rocks above the Wongawilli Coal Seam) has been recognised as important in the EIS model*" (EMM, 2017, pg. 7). Given the erratic occurrence of these formations in bores[3], and their likely disturbance from mining (even with the proposed 'first workings' methodology), I maintain that relying on these layers as 'important' is tenuous.



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 3 – Layering in the EIS groundwater model

2.2 Storage values

Pells and Pan (2017) demonstrated that specific storage values used in the EIS groundwater model were inconsistent with the definition of specific storage. I am satisfied that the adjusted specific storage values adopted by HydroSimulations (2018) are now consistent with the definition of specific storage.

HydroSimulations (2018) reports that these changes had only a minor effect on calibration to groundwater level observations over the calibration period (which is understood to be 4.7 years). Of more interest would be the effect of calibration to larger stresses, such as pumping tests data, and whether the change in storage values affects

[3] Pells and Pells (2013) (pg. 8) echoed the conclusions of McElroy and Bryan in 1980, finding records from over more 200 boreholes of the area showed direct contact between the Hawkesbury Sandstone and the Wongawilli Coal Seam in more than 90% of the holes.

the calibration against Berrima colliery. I also comment on the apparent minor effects of sensitivity testing in Section 2.4 below.

2.3 Drain conductance

Based on my reading of EMM (2017), it seems that the concept of hydraulic controls has not been appreciated. Hence I provide a further discussion in Appendix B of this present letter. I set out in Appendix B, as clearly as I can, the principles supporting my criticism of the drainage conductance values in the EIS study. Based on these principles, I show that drain conductance value presented in the EIS:

1. *Control inflows into the mine*.

   In Pells and Pan (2017) I showed that the EIS adopted drain conductance value was analogous to filling the mine void with compacted clay. A further analogy is the usage of a valve with a very small ‘opening’ (Figure B2). Both the reports by HydroSimulations (2018) and EMM (2018) were dismissive of my calculations, but provided no data, calculations or reasoning to support the dismissal. I have reviewed my calculations and consider them to be correct, and I also demonstrated them to be true from conceptual ‘test’ 3D models.

2. *Are not a transferable calibration parameter*.

   Following discussions with DPI Water (16 Nov 2017) I was led to the understanding that the EIS groundwater model had applied drain cells to multiple layers for simulation of flow into Berrima colliery. In this way, a comparatively larger discharge could be transmitted than would be inferred from a drain conductance in a single cell only (this is analogous to placing multiple slightly-open valves at the end of a pipe - e.g. see Figure B6)[4]. However, in this case, drain conductance ceases to be an independent, meaningful variable. As shown in Appendix B, using a DRAIN conductance value adjusted for calibration of flows through multiple layers at one mine is not a reliable predictor for flows at other mines.

   The EMM report (2018 Section 4.4 Para 10) states that *appropriate adjustments to account for the different model cell size* had been made. However, no such calculations have been presented. Given the fundamental aspect of this parameter, these calculations should be clearly presented for open review.

3. *Under-estimates drawdown*

   Where a low DRAIN conductance is used, an outlet controlled system is developed which under-estimates drawdown for a given flow as compared to a model in which identical flow rates are controlled by the formation. Based on the

[4] This may be the argument for dismissal of my “clay-filled” analogy above, as inflow would be increased in proportion to the number of drainage layers used. However, this is speculation my behalf, as no calculations were presented in the EIS and no presentation of the geometry of drainage boundaries is presented.

discussion in Appendix B, I suggest that using DRAIN conductance to control flows will result in under-estimation of drawdowns.

The HydroSimulations (2018) report cited research that I had previously published on the effects of de-saturation in retarding vertical discharge, suggesting that the research supported their choice of DRAIN conductance. I know of no research that has been able to quantify this effect, or that would support that the very low conductance values adopted by HydroSimulations are appropriate representations of this effect.

The key justification provided in the EIS Responses to Submissions for the very low DRAIN conductance adopted by the proponent, is that the DRAIN conductance values were derived from calibration to inflows at Berrima colliery. I discuss this in Section 3 below.

2.4 Uncertainty and sensitivity testing

It is shown in Section 2.3 above that, where low drain conductance is used as the flow control, changes to formation parameters will have little effect on flows or pressures. For example, with reference to Figure B1, as stated, if the valve is opened a very small amount (e.g. the 'opening' in Figure B1 is set to a fraction of a millimetre), a small amount of flow will issue. Under this condition, the valve setting controls the flow such that (if no change is made to the valve opening) any increases to the pipe diameter or decrease in its roughness will not affect the flow rate or pressure within the pipe.

Section 7 of HydroSimulations (2018) presents a complex uncertainty analysis adopting a Monte Carlo method applied to hydraulic conductivity values, but not applying to drainage boundary conditions or conductance. These sensitivity tests have no value in a model that is outlet controlled, unless the outlet control (the drain conductance) is being simultaneously tested.

3 MODEL CALIBRATION

3.1 Calibration to inflows at Berrima

3.1.1 Berrima colliery

The location and extents of Berrima colliery and the Hume Coal prospect are presented in Figure 4.

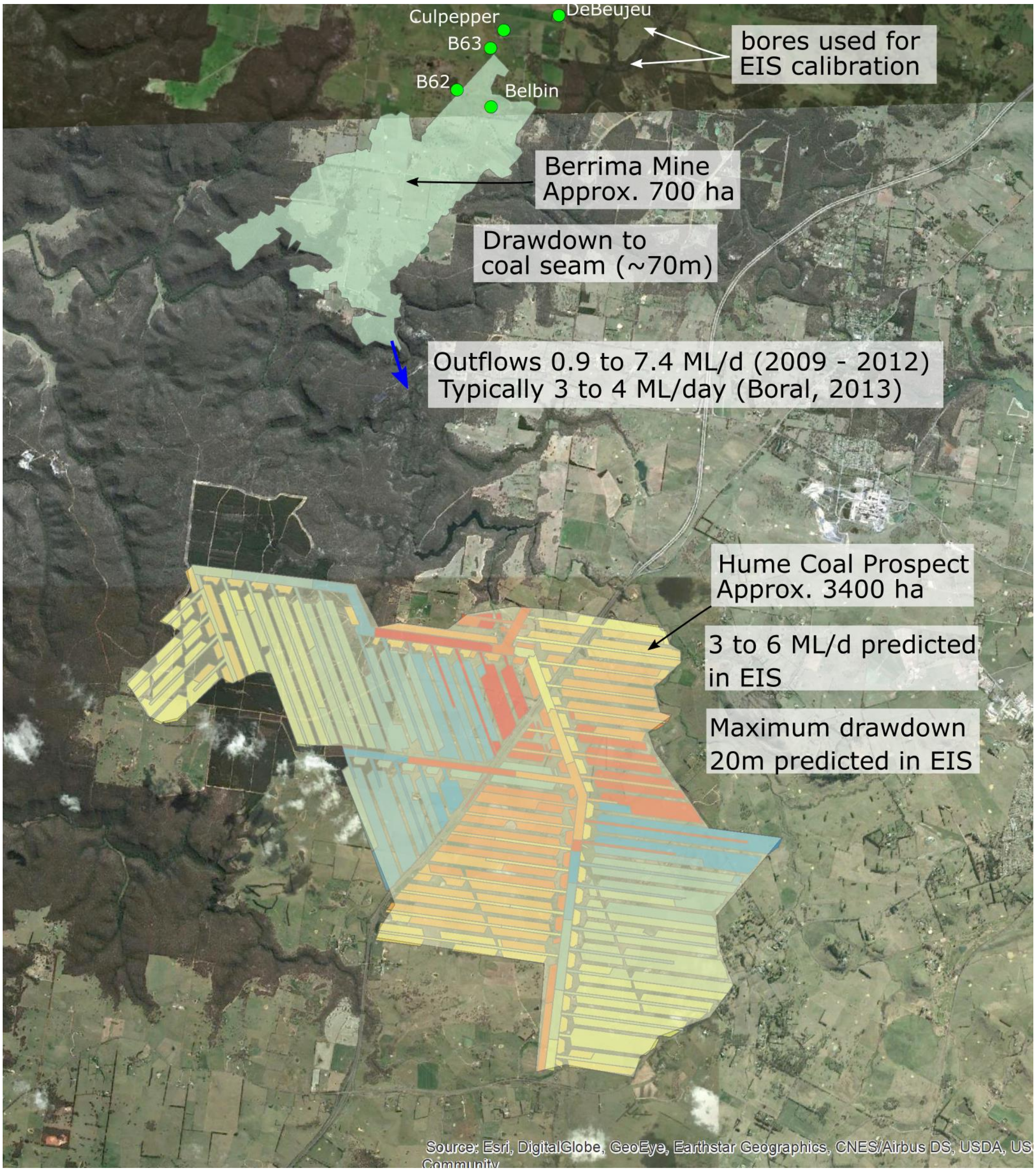


Figure 4 – Plan of Berrima colliery and Hume Coal prospect.

Berrima colliery mined the Wongawilli seam using underground methods from the late 1800's through to October 2013 (IEC, 2015). Various mining methods have been employed over this period. The total coal extraction ratio is generally less than 60% (David, 2015) – a polygon traced around the workings, as shown in Figure 4, shows the workings to cover an area of approximately 700 ha. The depth of cover is reported to be 125 to 190 metres (*ibid*). The coal seam dips to the south, and inflows to the seam flow along the dip and are collected and measured before discharge a single point at the southern extremity of workings (see Figure 4).

Monitoring has reported flows in the range from 0.8 to 7.4 ML/day, although this variability reflects operating of pumping (David, 2015). Outflow of 3 to 4 ML/day are reported in Boral (2013) and calibration of a groundwater model for Boral aimed at achieving inflows of around 4ML/d for the period 2010 to 2012 (Boral, 2013). Mine inflows between April to Nov 2014 are reported by David (2015) to be on average 2.7 ML/day plus minus 20%.

The Hume Coal prospect proposes to mine the same (Wongawilli) seam with first-workings mining covering approximately 3400 ha. Despite the Hume Coal Prospect workings covering an area of approximately 5 times the size of workings Berrima colliery, the inflows predicted in the EIS for the Hume Coal Prospect are similar to inflows at Berrima colliery and the predicted drawdowns for the Hume Coal Prospect are significantly less than those evident at Berrima colliery.

It should further be noted that gauged flows from Berrima colliery reflect outflows after decades of operation and significant drawdown and, as currently measured, after closure. Groundwater inflow to an underground cavern decreases over time. Inflows to a new mine would be expected to be relatively larger.

3.1.2 Calibration of Hume Prospect groundwater model

Figure 4.6 of Coffey Geosciences (2015b) demonstrates a reasonable match between simulated inflows to Berrima colliery and outflow monitoring at Berrima. As regards drawdown, Table B1 of Appendix B of Coffey Geosciences (2015b) stipulates that observations from 5 boreholes were used for calibration of groundwater levels at Berrima. The location of these bores are presented in Figure 4. The hydrographs presented for calibration are reproduced in Figure 5 below. The hydrographs extend for periods 1 to 3 years.

No plans or sections showing the groundwater model grid or layout or on the placement of drain boundaries are presented.

Previous groundwater models of Berrima colliery for Boral and Delta Mining showed maps of simulated groundwater levels over the colliery, demonstrating drawdown to seam level. No such plans showing model results over the Berrima colliery are presented in the EIS for Hume Coal. I cannot see from the provided information how groundwater levels over Berrima colliery were simulated. The calibration claimed in the EIS relies upon simulation of the hydrographs shown in Figure 5. It can be seen that groundwater levels are not accurately reproduced by the model in many cases – being up to 50m of discrepancy. Furthermore, it can be seen in Figure 4 that these bores are restricted to the northern perimeter of Berrima colliery. They are inadequate for characterisation of drawdown at Berrima mine.

Updated modelling by HydroSimulations 2018 provides no further information on calibration to Berrima colliery.

In summary, the information provided in the EIS does not provide confidence that Berrima colliery has been simulated appropriately.

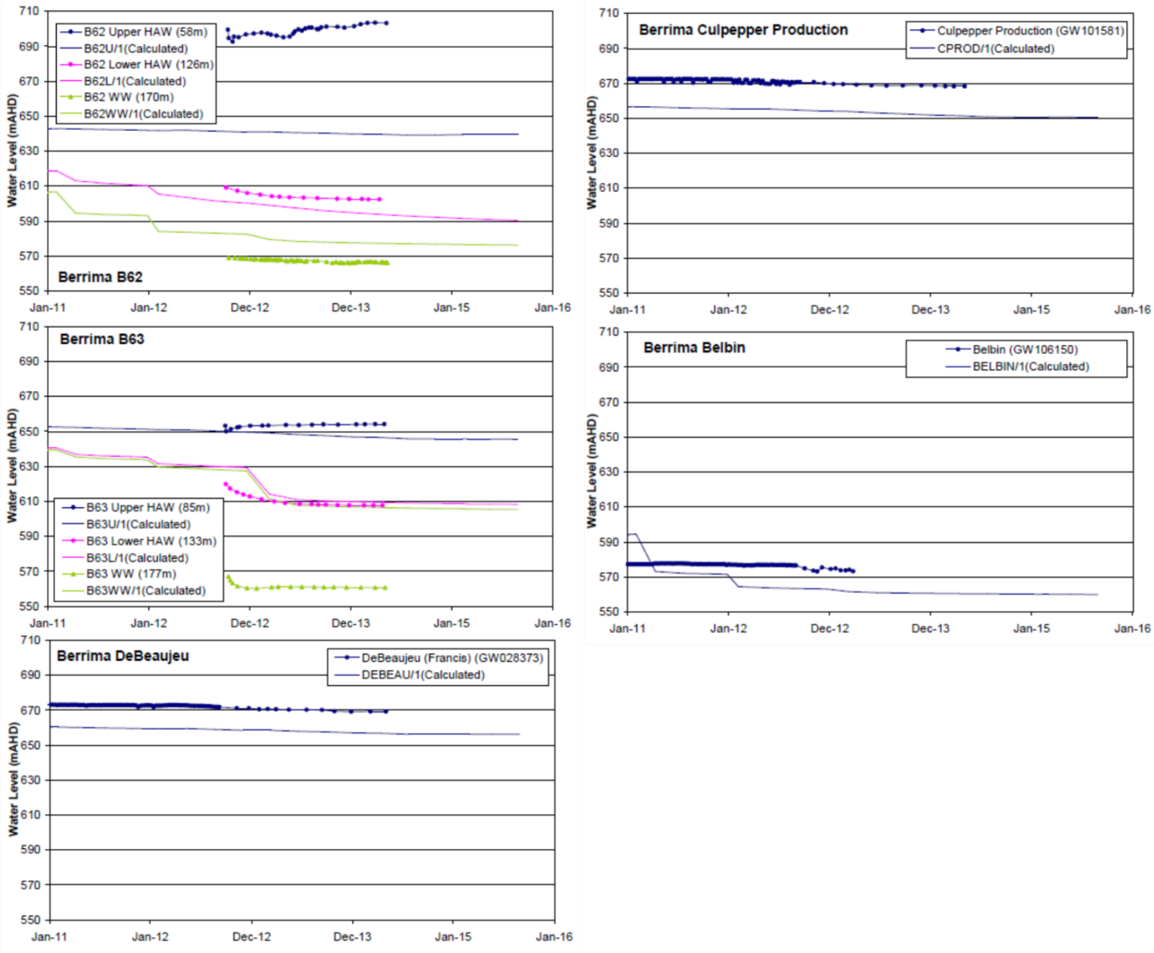


Figure 5 – Complete calibration to Berrima groundwater levels presented in the EIS

3.1.3 The problem with drain conductance as a calibration variable

Calibration to Berrima colliery is presented in the EIS studies as giving the critical justification for predictions of groundwater impacts from the Hume Coal prospect. The usage of drain conductance as a calibration variable is problematic.

With all other things being equal, a drain-conductance controlled model will under-predict drawdown as compared to a formation-controlled model (See Section 2.3 and Appendix B). The models of Berrima colliery and Hume prospect presented in the EIS are drain-conductance controlled. The calibration to levels at Berrima presented in the EIS, based on 5 short records outside its northern extremity, is inadequate to demonstrate that a suitable drawdown response is being represented. This is why it is important that simulated levels over Berrima colliery are presented, as under-prediction here will be reflected in forecasts made for the Hume coal prospect.

Deeming the drain conductance used at Berrima colliery to be a 'calibrated parameter' for prediction of inflows to Hume Coal prospect is also problematic. I was advised (H. Middlemis pers. comm) that drains were placed in multiple model layers at Berrima to achieve this inflow. As adopted, the drain conductance is not an independent variable, and a value suitable for inflow replication at Berrima cannot be relied upon for predicting inflows to Hume.

Coffey Geosciences (2015b) provides no plans or sections presenting the locations and numbers of drain cells in either Berrima or the Hume prospect regions. No calculations supporting the transference of the conductance parameter from the Berrima colliery to the Hume prospect are presented. This is the critical parameter controlling predicted inflows at Hume Coal, and it cannot be reviewed with the information provided.

3.1.4 Other groundwater models of Berrima colliery

HydroSimulations (2018) defend the choice of drain conductance on the basis of calibration to Berrima colliery. However, other calibrated groundwater models of Berrima colliery, prepared for Delta Mining, have not required similarly low drainage conductance values to achieve calibration. A numerical groundwater model of Berrima colliery prepared for (then) owner Delta Mining by CDM Smith (2014) represented mine inflows to Berrima by applied drainage boundaries in two layers, each with conductance of 5000 m2/day. This indicates an absence of 'outlet control'. The model was calibrated to available inflows and level observations.

David (2015) also prepared a groundwater model of Berrima colliery for owner Boral and used drainage cells to the mine workings for simulation of inflow. In the Berrima colliery Water Management Plan (Boral, 2013) it is reported that the modelling of the Berrima colliery adopted a drain conductance value of 1000 m2/day. This similarly an absence of 'outlet control' and this model was also reported to be calibrated to available inflows and level observations.

4 MODEL CLASSES

The core of science is testable hypotheses. Criticisms of the Hume Coal groundwater modelling presented in Pells and Pan (2017) were based on various tests considering first principles of groundwater flow, linear elastic theory and hydraulics, such as the effects of hydraulic controls. The tests were supported by theoretical considerations, analytical mathematics and conceptual numerical models. Criticisms of the conceptual model geology were similarly based on cited geological and aquifer test data. Further such discussion is presented in this present letter. These testable arguments remain, regardless of how consultants to the proponent choose to classify the numerical modelling by Pells and Pells (2013) and Pells and Pan (2017) against guidelines.

Nonetheless, the numerical model predictions presented in Pells and Pells (2013) were subject to independent review, including application of the Australian Groundwater Modelling Guidelines. This review found the models of Pells and Pan (2013) to be fit for purpose and suitable for predicting drawdown impacts and inflow quantities.

5 SYNOPSIS

I am of the view that the HydroSimulations (2018) model does not properly predict impacts, or uncertainty of impacts, to groundwater from the Hume Coal Prospect, for the following reasons:

1. Inappropriate or unjustified hydraulic conductivity values in some aspects
2. Issues with the reliance of drain conductance
3. Overstated significance of calibration achieved at Berrima colliery
4. Representation of placement of bulkheads in the proposed mining procedure.

I present the following recommendations which I believe are necessary to address these issues.

5.1 Hydraulic conductivity values

1. High yielding formations at the base of the Hawkesbury Sandstone.

Hydraulic conductivity values adopted by HydroSimulations (2018) do not represent a higher yielding aquifer at the base of the Hawkesbury Sandstone. The values adopted by HydroSimulations (2018) are inconsistent with the observations and measurements published by Lee (2000) and also with the mapping of conductivity presented in the EIS (see Figure 2 above). The Hydrosimulation (2018) hydraulic conductivity values should be revised to better reflect these data. Values should not rely on a model where hydraulic conductivity is a function of depth only, as:

1. It is inappropriate to adopt a model of hydraulic conductivity that is independent of geology
2. Various data sources [e.g. Lee, 2000; Figure 5.6 from Coffey 2016a (reproduced as Figure 2 above), and; EMM 2018 (Section 3.1 para.5)] show this to not be the case

An argument forwarded in EMM (2017) is that observations by Lee (2000) represent intersection of the bores with fracturing. This possible interpretation should be represented within the HydroSimulations (2018) model, by representation of such fracturing as argued. As it stands, the HydroSimulations (2018) study just ignores the data in its entirety.

Further, the HydroSimulations (2018) model should be tested against or adjusted so that it can demonstrate calibration to the pumping tests within the mine region. The revised USG grid should be amenable to this task.

2. Coal measures and layers above the workings

Hydraulic conductivity values adopted by HydroSimulations (2018) do not reflect the available data for the coal seam and layers directly above the coal seam. They are over 20 times lower.

It was stated that values presented in previous modelling were found to be appropriate in the review by Hydrogeologic (2017), although no data were provided. HydroSimulations (2018) now adopt vertical conductivity values up to an order of magnitude lower than values reported to be accepted as appropriate by Hydrogeologic (2017).

The HydroSimulations (2018) model should either adopt values consistent with measured quantities or provide data that justifies the basis for not adopting these measurements. As it stands, there is no data provided to justify the choice.

3. Vertical anisotropy

Physical justification of the vertical anisotropy of 50 should be provided. If not provided, uncertainty estimates should consider a larger range of anisotropy.

5.2 Drain conductance values

The HydroSimulations (2018) model should be revised to reduce its reliance on drain conductance values as a control, because:

1. The values adopted strongly control inflows in a manner that is not physically justified.
2. The drain conductance value, as used, is not an independent parameter and a value applied as a control in multiple layers at one mine cannot be relied upon for prediction of inflows at another mine.
3. Models that have flows controlled by a low drain conductance will under-predict drawdown compared to a model that does not rely on drain conductance.

Figures should present how drain boundaries were applied at Berrima colliery and at the proposed Hume Coal project. Calculations to support the transference of drainage conductance from Berrima colliery to the proposed Hume Coal project should be presented.

5.3 Sensitivity and uncertainty

Uncertainty and sensitivity analyses must include simultaneous manipulation of formation parameters and the drainage conductance.

5.4 Calibration to Berrima colliery

Calibration to Berrima colliery must be demonstrated with more clarity, given the key role that calibration to Berrima colliery is given in the EIS, and should include:

1. Presentation of plans showing the model grid over Berrima colliery
2. Presentation of where drainage boundaries were placed, both in plan, and demonstrating which layers they were placed in, in section.
3. Presentation of simulated drawdown over the Berrima colliery during the calibration period

a. Comparison to drawdown simulations in numerical models of Berrima colliery undertaken by CDM Smith and David (2015) would be informative

4. Presentations to justify the transference of drainage conductance parameters from Berrima colliery to the Hume Coal Prospect, including:

   a. presentation of the placement (in plan, an in section) of how drain cells were similarly applied at Hume Coal

   b. Presentation of calculations of drainage conductance

The above should be presented for the current model adopted in the EIS.

5.5 Representation of the actions of bulkheads

HydroSimulations (2018) reporting of sensitivity testing to drainage conductance indicate increase in inflows to the drains, but decrease in inflows to the mine. These results are unclear to me, and in my understanding reflect the representation of placement of bulkheads in the model, and indicate that this representation is important to the assessed mine inflow.

Timing of the placement of bulkheads, and also their efficacy, may be subject to some uncertainty in the actual mining process. Groundwater modelling should assess this uncertainty, and reporting should clearly communicate how these bulkheads are assumed to operate in modelling.

For and on behalf of
PELLS SULLIVAN MEYNINK

STEVEN PELLS
BE (Civil) MEng. Sc. PhD

APPENDIX A

SPECIFIC RESPONSES TO CRITICISM IN EMM (2018)

REPORT SECTION	COMMENT (EMM, 2018)	RESPONSE
SECTION 2.1	The Hume Coal mining proposal is based on the premise of not causing any systemic caving of the strata overlying the Wongawilli coal seam and protecting the overlying Hawkesbury Sandstone aquifer system, so the Pells Consulting model does not reflect the proposed development but rather an extreme outcome associated with major fracturing and subsidence induced by the mine.	Scenarios in Pells and Pan (2013) examined mine inflows and drawdown with and without fracturing and subsidence assumed. Inflow and drawdown predictions presented in Pells and Pan (2017) studies did not assume fracturing or subsidence.
SECTION 2.2, PARA. 4	There is no descriptive or graphic conceptual model in either of the Pells Consulting modelling reports that clearly articulates their conceptual understanding of the various groundwater systems and other hydrological features.	Both reports clearly present the interpretation of geology, including sources of data, and parameters assumed, and include presentation using maps and cross sections. Boundary conditions are also clearly presented. See also comments for Section 3.2 para. 12.
SECTION 2.3, PARA. 2	The Pells Consulting model was calibrated and validated against a replication of the regional water table in steady state, and against four short term pumping tests of deep Hawkesbury Sandstone water bores in transient mode. The replication of the regional water table (refer to Section 3.4) was poor, while the drawdowns at individual bores were mostly underestimated. This suggests there are fundamental issues with the adopted hydraulic conductivity values and/or specific storage.	The replication of regional water table in the model was commensurate with uncertainty in the dataset. As discussed in Pells and Pells (2013), calibration to a point source was subject to larger uncertainty using the structured grid solutions available at that time.
SECTION 2.3, PARA. 3A	It is noted that calibration statistics are poor: 13.6-15.2 %RMS (Scaled Root Mean Square) and 31-33 mRMS (pers com Dr N Merrick).	Interpreted regional water table data were presented in Figure 19 of Pells and Pells (2013). Discussion of the available data was presented in Section 2.5 of Pells and Pells (2013), showing that, although it was a large data set, individual measurements were likely subject to scatter generally within +/- 20 m, but in some cases larger. Overall, the data was considered indicative of regional long term groundwater conditions, and the calibration approach was to obtain a system-plausible replication of these conditions. The calibration statistics were commensurate with the dataset uncertainty. Achievement of calibration statistics better than data uncertainty is not evidence of a better model.
S ECTION 2.3, PARA. 3B	Neither model was calibrated to the recorded mine inflows at the Berrima colliery immediately to the north of the project area.	This is correct. A discussion of calibration to Berrima colliery is given in Section 4 of this present letter report.
SECTION 2.3, PARA. 3C	There was no analysis or refinement of the regional water table data and interpreted head contours.	Interpreted regional water table data were presented in Figure 19 of Pells and Pells (2013). Discussion of the available data was presented in Section 2.5 of Pells and Pells (2013).
SECTION 2.3, PARA. 4	The reviewer believes that the Pells Consulting model is poorly calibrated, and, as such, the predictive results cannot be relied upon.	See comments for Section 5 para. 1.
SECTION 3.1, PARA. 2	In this area, Pells Consulting argues that the Narrabeen Group rocks (alternating cemented sandstones and claystones) are not known to occur between the Triassic Hawkesbury Sandstone and the Permian Illawarra Coal Measures, apart from some residual sub-crops in the east and north, hence this unit has been omitted from their geological model and numerical groundwater model.	This is correct. This is discussed on Page 8 of Pells and Pells (2013).
SECTION 3.1 PARA. 5	There are no compelling data sets to confirm there is an increase in permeability of the sandstone strata at the base of the Hawkesbury Sandstone.	The conceptual model for Hawkesbury Sandstone and associated hydrogeological parameters relied upon the local experience, interpretation and data from Mr John Lee, including data from installation and testing of over 28 water bores in and around the lease area. These bores have consistently targeted the sandstone strata at the base of the Hawkesbury Sandstone to achieve high yields.[5]

[5] Lee, 2000 "*Hydrogeology of the Hawkesbury Sandstone in the Southern Highlands of NSW in Relation to Mesozoic Horst-Graben Tectonics and Stratigraphy*" in Boyd,R et al (ed) Proceedings of the Thirty Fourth Newcastle Symposium on Advances in the Study of the Sydney Basin, July 6, 2000, University of Newcastle

[5] Stratigraphic demarcation of the Permian members are presented in notes on the Geological of Wollongong 1:100,000 Sheet. See also detailed stratigraphy presented in McElroy Bryan and Associates (1980) South-West Coal Project, Geological Summary Report and Lee, 2000 "*Hydrogeology of the Hawkesbury Sandstone in the Southern Highlands of NSW in Relation to Mesozoic Horst-Graben Tectonics and Stratigraphy*" in Boyd,R et al (ed) Proceedings of the Thirty Fourth Newcastle Symposium on Advances in the Study of the Sydney Basin, July 6, 2000, University of Newcastle.

SECTION 3.2, PARA. 1	One of the key concerns (a fatal flaw) in this initial numerical model is that there is no succinct hydrogeological conceptual model description for either a singular or multiple (different) groundwater flow scenarios, and there is limited information on the expected groundwater connectivity between hydrogeological units.	See comments for Section 2.2 para. 4. and Section 3.2 para. 12.
SECTION 3.2, PARA. 5	There is no regional justification given for the layering in the Hawkesbury Sandstone or the Shoalhaven Group hydrogeological units across the broader Sydney Basin (see also discussion in Section 3.1),	See comments for Section 3.1 para 5 and Section 3.1 para. 7.
SECTION 3.2, PARA. 8	Surface water flows in the Wingecarribee River and internal catchments with permanent flow, and a conceptual understanding of whether streams are gaining or losing streams, have not been considered in this initial modelling study.	The influence of perimeter surface water features were simulated and examined with the chosen perimeter boundary conditions. Some influence of internal streams is inferred from topography. I do not accept that lack of detailed (or coupled) representation of internal surface streams is grounds for dismissal of the study findings.
SECTION 3.2, PARA. 10	The surface water components of the water cycle are important omissions from the conceptual model behind this modelling study, and therefore the calibration and predictive results are likely to be poor and should not be relied upon	
SECTION 3.2, PARA. 12	A thorough explanation of the conceptualisation that was proposed (and then amended) and upon which the numerical groundwater model is built is essential. Without a schematic diagram and logical description of natural recharge, discharge and flow processes for each groundwater system (and their expected interconnectivity), and without properly modelling the boundary and internal hydrological features, the model is likely to produce poor and unrealistic predictive outcomes.	See comments for Section 2.2 para. 4. The desire to perceive groundwater in separate ‘systems’ and perceive their ‘connectivity’ is a heuristic which is a hangover from times when the equations of groundwater flow could not be solved directly, and such simplifications were required to allow 1D analytical solutions to be applied. As the equations of groundwater flow can now be solved, such a heuristic is neither required nor helpful.
SECTION 3.3 PARA. 4	These boundaries are reasonable for basal layers in the model but are inadequate for modelling impacts to the Hawkesbury Sandstone groundwater system. For example, the northern boundary (the Wingecarribee River) in upstream areas is probably neither a recharge nor discharge boundary but rather a ‘flow through’ feature for this regional groundwater system, especially where there are pockets of alluvium and/or where the river is located on Wianamatta Shale and isn’t incised to the Hawkesbury Sandstone.	These assumptions were tested with alternative general head boundaries, as presented in Section 5.2 of Pells and Pells (2013). Representation of the Wingecarribee River as a ‘flow through’ feature was found to increase mine inflow predictions. Drawdown was found to be insensitive to the various boundary conditions.
SECTION 3.3 PARA. 5	The northern boundary excludes the Berrima colliery workings immediately to the north. Therefore, the Pells Consulting model cannot use recorded mine inflows for calibration and cannot do required cumulative impact assessment.	This is correct. A discussion of calibration to Berrima colliery is given in Section 4 of this present letter report.
SECTION 3.3 PARA. 7	Model layers increased to 12 after the UNSW peer review (UNSW WRL 2013) but there is no explanation of the new layers and little discussion as to why additional layers were added.	As stated in Section 5 of Pells and Pells (2017) “The purpose of this was to improve the resolution of vertical flow around the perimeters and into the mine”
SECTION 3.3 PARA. 8A	Unfortunately the thin layer that comprises the mined section of the Wongawilli Seam within the Illawarra Coal Measures is not identified in the Pells Consulting model as a separate layer to effectively model the removal of coal in panels that are expected to be around 3.5 m in height. This is a major omission as simulated extraction will be applied to the wrong lithology over the wrong thickness.	This a matter of nomenclature. The layer labelled at “Illawarra Coal Measures” in Pells and Pells (2013) and Pells and Pan (2017) represented the Wongawilli Seam. This layer had a thickness representing isopachs of the Wongawilli seam as interpreted in Austen and Butta, 1982 (see Figure 13 in Pells and Pells, 2013).
SECTION 3.3 PARA. 8B	The interburden (comprising the upper Permian interburden (thin coal plys and the Farmborough Claystone) and Narrabeen Group (where present)) overlying the Wongawilli Seam hasn’t been included in the Pell Consulting model as a separate layer.	This is correct and reflects the conclusions of McElroy and Bryan in 1980, and our finding that borehole records from the pre-1985 investigations of the area (more than 200 boreholes) showed direct contact between the Hawkesbury Sandstone and the Wongawilli Coal Seam in more than 90% of the holes. This is discussed on Page 8 of Pells and Pells (2013).

SECTION 3.4 PARA. 2	For the natural system, the assigned horizontal hydraulic conductivity values are reasonable first approximations for each of the layers (although the average Kh value for the basal Hawkesbury Sandstone layer (3 x 10-5 m/sec or 2.6 m/day) appears too high to be applied regionally). This value is two to three orders of magnitude higher that the horizontal conductivities for the basal sandstone layers in the calibrated EIS model (Coffey 2016) and two orders of magnitude greater than the regional background horizontal conductivity in the Kangaloon Borefield model (Coffey Geotechnics 2008).	See comment for Section 3.1 para. 5.
SECTION 3.4 PARA. 3	Localised fractures and faults with high secondary permeability can skew the regional estimates of permeability. Upscaling of parameter estimates derived from a few pumping tests of deep water bores that have specifically targeted fracture zones to maximise yield should be viewed cautiously.	I agree with this comment in principle. However, the dataset and local observations provided by Hydroilex are more comprehensive than "a few pumping tests" and should not be dismissed as such.
SECTION 3.4 PARA. 4	The adopted specific yield values are higher than other calibrated models and would contribute to larger predicted mine water inflows.	Comment can be made upon review of the stated "other calibrated models".
SECTION 3.4 PARA. 5 AND PARA. 6	Table 4 in the Pells Consulting report (Pells and Pells 2013) gives the adopted changes to hydraulic conductivity, and storage, due to fracturing and disturbance of the rocks above an assumed short-longwall mining layout. The report suggests that horizontal hydraulic conductivity values for the Hawkesbury Sandstone could increase 5 to 1000 times. The longwall mining assumption is wrong and the suggested changes in aquifer parameters are not supported by any technical argument or reference to previous site or relevant modelling studies in the Southern Coalfield. There is some uncertainty in the model surrounding the adopted anisotropy, specific yield and specific storage estimates and likely changes due to mining. It also appears that fracturing has been assumed to extend to land surface, without any justification.	The parameters in Table 4 in the Pells Consulting report (Pells and Pells 2013) are based on research presented in Pells and Pells 2012. These parameters were applied in some scenarios in Pells and Pan (2013) to examine mine inflows and drawdown with and without fracturing and subsidence. Inflow or drawdown predictions presented in Pells and Pan (2017) studies did not assume fracturing or subsidence.
SECTION 3.4 PARA. 7A	There are some seemingly impossible results observed in the Pells Consulting report (Pells and Pells 2013). For example, in the area of the Belanglo Forest, the model report suggests initial groundwater elevations are at or below the observed coal seam floor elevations (RLs) (see Figure 3.2).	The cited data are not results from modelling, but show contouring of the available groundwater observation data.
SECTION 3.4 PARA. 7B	Contours of the groundwater heads were produced from unreliable water bore data and unrealistic perimeter river stages, and have not been sanity checked prior to proceeding with the modelling.	River stages were selected with reference to topography data from a digital elevation model with 28.7m grid and are considered to represent river stage with sufficient accuracy. The accuracy of bore data was discussed in Section 2.5 of Pells and Pells (2013),
SECTION 3.4 PARA. 8	This data suggests that the coal seam and overlying rock in this area is unsaturated yet the model predicts up to 160 m of drawdown in the basal Hawkesbury Sandstone. This is even less credible considering the fact that the coal seam is only 70-90 m below surface in this area.	There were no groundwater observations in the Belanglo State Forest locality and few in adjacent regions. The few records available showed groundwater levels to be above the coal seam. The extensive mine causes drawdown in the Belanglo State Forest area to extend below the coal seam, reflecting flow to the eastern portions of the mine, where the coal seam is over 100m below the seam elevation at Belanglo.
SECTION 3.4 PARA. 9	The steady state model calibration of heads across the model area with the initial model boundaries and parameters is very poor, as shown in Figure 3.3. Observed versus modelled heads are provided for each of the eight layers. Calibration is poorest for Layers 1 and 2, and there is no explanation for the derivation of the observed data for Layers 5 to 8.	See comment for Section 2.3 para. 3.
SECTION 3.4 PARA. 11	This model is a Class 1 model under the AGMG and given the poor conceptualisation and calibration, it is not fit for purpose, and therefore unsuitable for predicting drawdown impacts in bores, inflow volumes to the mine, or general impacts to the different groundwater systems and surface water resources across the modelled area.	The Pells Consulting model was subject to independent review, which found that it is fit for purpose, and is suitable for predicting drawdown impacts and inflow quantities.

SECTION 3.5 PARA. 2	A very high conductance of 1000 m2 per day was applied to simulate drainage and mine water inflows into base of the Illawarra Coal Measures (not just the (higher) Wongawilli Coal Seam). This high value was based on an assumption that longwall mining would be the preferred mining method, and there would be a substantial increase in hydraulic conductivities in the collapsed and relaxed zones above the mine workings. This assumption is wrong as the HCP EIS and supporting numerical model clearly indicate a non-caving, first workings panel extraction method is preferred to minimise roof collapse and to protect the overlying Hawkesbury Sandstone aquifer (EMM 2017).	The drain conductance of 1000 m^2/day is a symbolic number indicating that flows are controlled by the formation, as originally stated and as discussed in Section 2.3 of this present report. This is a common modelling approach, and Pells and Pan (2017) cited 6 other reports where this approach had been adopted for underground mining, including reports by HydroSimulations and their reviewers. In these cases, modellers had similarly adopted a symbolic value of 1000m^2/day. This conductance value does not necessitate longwall mining. For example, the model of first workings at Berrima colliery by CDM Smith for Delta Mining was calibrated to observations and assumed a drain conductance value of 5000m^2/day. A calibrated groundwater model of Berrima colliery developed for Boral by David and Middlemis (the peer reviewer for Hydrosimulations 2018) adopted a drain conductance value of 1000m^2/day. Scenarios in Pells and Pan (2013) examined mine inflows and drawdown with and without longwall mining effects assumed. Inflow or drawdown predictions presented in Pells and Pan (2017) studies did not assume effects of longwall mining.
SECTION 3.5 PARA. 3	Drawdown in the basal Hawkesbury Sandstone is modelled to be in excess of 90 m and up to 160 m over a wide area centred on the assumed location of the mine. This is impossible given that the total thickness of the Hawkesbury Sandstone across the project area is generally less than 120m and saturated thicknesses are less (Coffey 2016).	See comment on Section 3.4 para. 8.
SECTION 3.5 PARA. 5	The drawdown pattern is highly constrained by the assumed nature of these boundaries and the high conductance values assumed for mine drainage strongly influence the predicted drawdown and mine inflows, hence these model predictions should be treated with extreme caution.	The effects of boundary conditions were tested with alternative general head boundaries, as presented in Section 5.2 of Pells and Pells (2013).
SECTION 3.5 PARA. 6	No mine inflow estimates are provided for the updated model runs after the peer review.	They are presented in Figure 41, p41 of Pells and Pan (2013).
SECTION 3.5 PARA. 9	There is an admission in Pells and Pan (2017) that the Pells Consulting (2013) model wrongly assumed permanently confined conditions in "many model layers". This would have the effect of not allowing desaturation to occur in response to mining, thereby giving grossly exaggerated mine inflows.	It was found in Pells and Pan (2017) that layer properties as reported did not exhibit a large influence on results. The representation of layers in Pells and Pan (2017) is nonetheless preferable.
SECTION 4.2	There is no succinct conceptual model articulated for the adopted hydrogeological units and the updated numerical model boundaries and layers.	See comment for Section 2.2 para. 4
SECTION 4.3	There is no discussion of the rationale behind the additional layers and the further sub-division of the Hawkesbury Sandstone and Shoalhaven Group hydrogeological units, and why the Illawarra Coal Measures is not sub-divided to accommodate the Wongawilli seam that is proposed to be mined.	See comments for Section 3.3 para's. 7 and 8a.
SECTION 4.4 PARA. 3	Pells Consulting states that the low hydraulic conductivity values adopted for the lower Hawkesbury Sandstone don't reflect the data from deeper water bores constructed and tested across the region. There is some merit in this interpretation based on the private pumping test data presented, however it is hard to justify a horizontal hydraulic conductivity of around 2.6 m per day for this layer across the whole area based on limited pumping tests at water bore sites that clearly indicate fracture flow dominating over porous flow. Only high yield water bore tests are presented for calibration purposes so there is a bias towards sites with significant fracture flow. Also there is no justification for a vertical hydraulic conductivity that is 50% of the horizontal hydraulic conductivity.	The work of John Lee (as reproduced in Pells and Pells, 2013 and published in Lee 2000) have documented consistently high yields from the Hawkesbury Sandstone Formation just above the Wongawilli Seam within the lease area. Data analysis in the EIS by Coffey Geoscience 2016a (attached as Appendix E to the HydroSimulations 2018) presented the spatial variation in hydraulic conductivity for the Hawkesbury Sandstone for an interval between 14m to 44m above its base, based on "*the large number of K measurements for the Hume lease*" (pg37). Results presented in Figure 5.6 of Coffey Geoscience (2016a) has been reproduced as Figure 2 in this present report above. Over the lease area, measured values of 0.8 to 1.5 m/day agree with the conceptualisation of Lee (2000), and are over 50 times larger than values adopted in modelling for the EIS. It is accepted that fracturing or joint swarms in the vicinity of bores will cause higher yields, and is a possible alternative interpretation, at least for some bores. However, the EIS has not adopted this alternative explanation, but has ignored these data.

SECTION 4.4 PARA. 4	Pells and Pan (2017) were also critical of the specific storage values adopted in the Hume Coal model, on the basis of being "mathematically impossible" when the component parts of an unreferenced formula are considered (equation (1)). The three "mathematically impossible" values are 5E-7, 7E-7 and 1E-6 m-1. However, it is noted in Table 3.1 (above) that the Pells Consulting model uses similar values: e.g. 5.05E-7, 5.52E-7, 7.16E-7, 1.52E-6 m-1, etc.	The 'unreferenced formula' is the definition of specific storage. It is presented in most hydrogeological texts[6]. The definition of specific storage given in HydroSimulations 2018 is the verbal expression of this equation. Terms defining the density and compressibility of water are known with some accuracy, and the terms defining elasticity of rock masses (e.g. ν and E) have been explored and documented from physical tests and measurements of settlement and subsidence in underground works. Specific storage values adopted in the EIS were not consistent with these measured characteristics and did not honour the definition of specific storage or elastic theory. This error is not rectified by conflating values that are appropriate for some formations with those that are inappropriate for others.
SECTION 4.4 PARA. 5	The argument advanced by Pells and Pan (2017) for a large drain conductance value is based on an incorrect conceptualisation of the drain (DRN) feature in MODFLOW. The conductance term, coupled with vertical head gradient, controls vertical flow. The term does not apply to side walls. Although a high value of 1000 m2 per day was initially argued as appropriate, a drain conductance of 14.5 m2 per day to the mine workings was adopted for the 2017 model baseline scenario (compared to the Coffey model range of 0.05 and 0.1 m2 per day). Sensitivity to this baseline value adopted by Pells Consulting was tested with multiple model runs (0.05, 14.5, and 100 m2 per day) using the MODFLOW 2000 software package. Strangely the model used was the original poorly calibrated 8 layer numerical model but with the current Hume EIS mine plan.	I have reviewed my calculations and scientific arguments and confirm them to be correct. At no time have I considered or presented the term to apply to side walls. The 8 layer model referred to is a conceptual model presented for the purposes of testing and illustrating the influence of drain conductance and the principles of hydraulic control.
SECTION 4.4 PARA. 8	Fracture flow dominates in the lower portions of the Hawkesbury Sandstone aquifer in this 'high-yield' area to the east. There is insufficient information presented in the Pells Consulting report to demonstrate that similar high permeabilities occur regionally across the Hume Coal area.	See comment to Section 4.4 para. 3. It is noted that the EIS models do not represent regions of 'fracture-flow' dominated 'high yield' lower portions.
SECTION 4.4 PARA. 9	There is little justification for the moderate to high drain conductance values adopted in the revised Pells Consulting modelling whereas the Hume Coal EIS model (history match) calibration involved adjusting the drain conductance parameter to match the mine inflow and groundwater level data at the Berrima colliery	Comprehensive justification was provided, including testing its effects through analytical solutions and conceptual numerical models. Further discussion is presented in Section 2.3 of this present letter. Discussion of calibration to Berrima colliery is presented in Section 3 of this present letter.
SECTION 4.4 PARA. 10	The EIS model method justifies the drain feature conductance parameters applied to Berrima conditions. The application of the calibrated conductance parameter to HCP conditions involved appropriate adjustments to account for the different model cell size and extraction geometry at the mine compared to Berrima (Middlemis 2017).	No such calculations have been presented in the EIS or supporting documents.
SECTION 4.5 PARA. 1	With a moderate conductance of 14.5 m2 per day used in the Pells Consulting 2017 model to simulate drainage and mine water inflows (rather than the earlier very high 1000 m2 per day adopted value in the Pells Consulting 2013 model version) there are still large drawdowns predicted over an extensive area. The reviewer believes that all the drain conductance values used for the Pells Consulting simulations (except for the 0.1 m2 per day scenario) are unrealistically high for undisturbed strata.	See comment for Section 3.5 para. 2.
SECTION 4.5 PARA. 2	Some scenarios still exhibit drawdown values greater than the possible saturated thickness of the actual layer.	Layer thickness does not define the limits of drawdown. I reviewed this claim in detail, including re-exporting all results to GIS for examination of overburden thicknesses, saturated thicknesses and drawdown. I found that the model results were consistent with the geometry and I could not find regions where an "impossible" drawdown was presented.

[6] A derivation of the equation is presented in the classical text "Groundwater" by Freeze and Cherry (1979), where it expressed as $S_s = \rho_w g[\alpha + n\beta]$. Classical elasticity theory shows $\alpha = \frac{(1+\nu)(1-2\nu)}{E(1-\nu)}$. The term α is derived in most geotechnical textbooks (but is commonly assigned the term 'm_v').

SECTION 4.5 PARA. 3	The reviewer is sceptical about the latest predicted mine inflows if the mine conductance has been reduced from 1000 m2 per day to 14.5 m2 per day. The Pells Consulting report states this is because “there is no difference in mine inflows for conductance values above the chosen value of 14.5 m2 per day, showing that formation losses control inflows.” In other words, mine inflow is insensitive to high values of drain conductance. However, it is sensitive to low values, as demonstrated in Figure 4.2. It follows that formation properties are not the sole determinants of mine inflow.	The results described here are consistent with the principles of hydraulic control. See discussion in Section 2.3 of this present report above.
SECTION 4.5 PARA. 5	The assumed moderate mine conductance value strongly influences (overestimates) the most likely estimates of drawdown and mine inflows. Hence, the reviewer believes that these latest model predictions are also unreliable unless extensive defects were to appear in the relaxed strata above the mined coal panels.	As per Section 2.3 of this present report, drain conductance strongly influences estimated drawdown and inflows only where the values are low enough to act as a hydraulic control. EMM (2018) here assumes the EIS model to be the benchmark, with alternative results described a ‘influenced’. Pells and Pan (2017) demonstrated, and explained through analysis and test, why drain conductance does not have a large influence on their model results. The ‘strong influence’ being described here is the influence imposed by the very low drain conductance adopted in the EIS model.
SECTION 5 PARA. 1	The Pells Consulting model is a Class 1 model under the AGMG and given the poor conceptualisation and calibration, it is not fit for purpose (i.e. an independent impact assessment model), and therefore it is unsuitable for predicting drawdown impacts in bores, inflow volumes to the mine, or general impacts on the different groundwater systems and surface water resources across the modelled area.	See comment for Section 3.4 para. 11.
SECTION 5 PARA. 2	It is at best, an initial assessment of the possible impacts from an underground mine in this area of the Southern Highlands if defects were to appear in the relaxed strata above the mine. Consequently, all the predictive results are considered unreliable and should be disregarded.	See comments for Section 3.4 para. 11.and Section 2.1.

APPENDIX B

HYDRAULIC CONTROLS AND THE DRAINAGE BOUNDARY

B.1. Hydraulic control principles

Consider a pipe attached to the underside of a tank, as shown in Figure B1 below. The pipe has a valve (e.g. a 'tap') on its end.

If the valve is fully opened (or removed), flow will pass rapidly through the pipe. Under this condition, the rate of flow (the 'discharge') could only be controlled by adjusting the resistance to flow imposed by the pipe, namely: the diameter 'd' of the pipe and the roughness of the inside surface of the pipe. This condition is referred to as channel or pipe controlled.

If the valve is fully closed, there will be no flow. If the valve is opened a very small amount (e.g. the 'opening' in Figure B1 is set to a fraction of a millimetre), a small amount of flow will issue. Under this condition, the valve setting controls the flow such that (if no change is made to the valve opening) any increases to the pipe diameter or decrease in its roughness will not affect the flow rate or pressure within the pipe. This condition is referred to in hydraulics as an 'outlet control'.

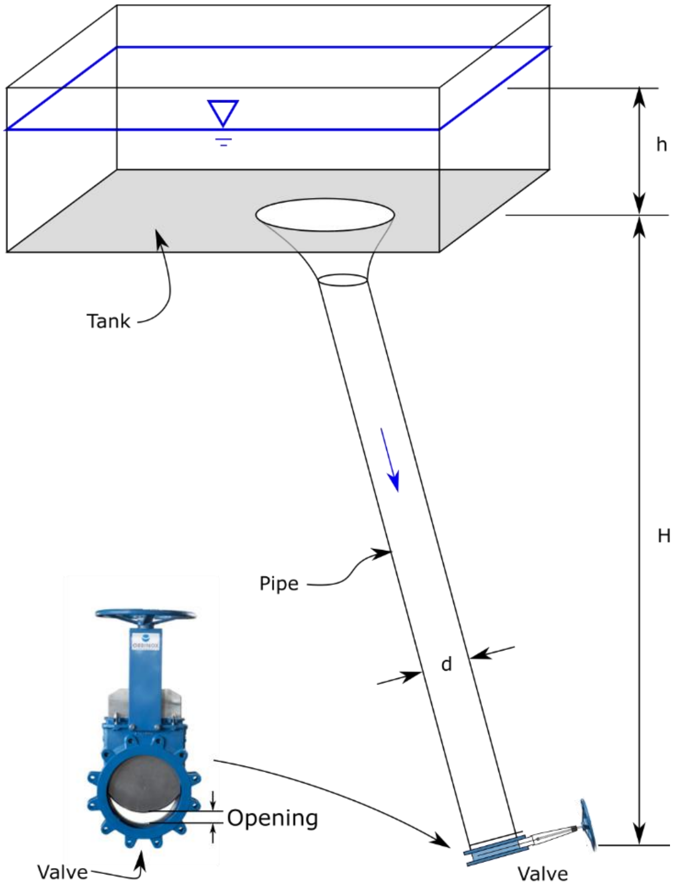


Figure B1 – Pipe flow system illustration

Further opening of the valve will cause further increase in discharge and, for a range of valve settings, the flow will be controlled by both the pipe resistance and the valve setting. Above a certain valve opening, the discharge becomes controlled by pipe resistance again, and any further increases in valve opening (or indeed removing the valve completely) will no longer control the flow rate.

The last, but perhaps most important, aspect of this analogy is in considering the pressures within the pipe. A certain discharge could be achieved in the pipe system in two ways – controlling the valve opening, or; controlling the characteristics of the pipe. While the same discharge would be achieved in either case, the pressure profile within the pipeline would be different in each case. Where the pipe characteristics control the flow, there would be a reduction in pressure throughout the whole pipeline. Where the valve controls the flow, pressures are reduced (‘drawn-down’) primarily in the vicinity of the valve. This is illustrated in Figure B2.

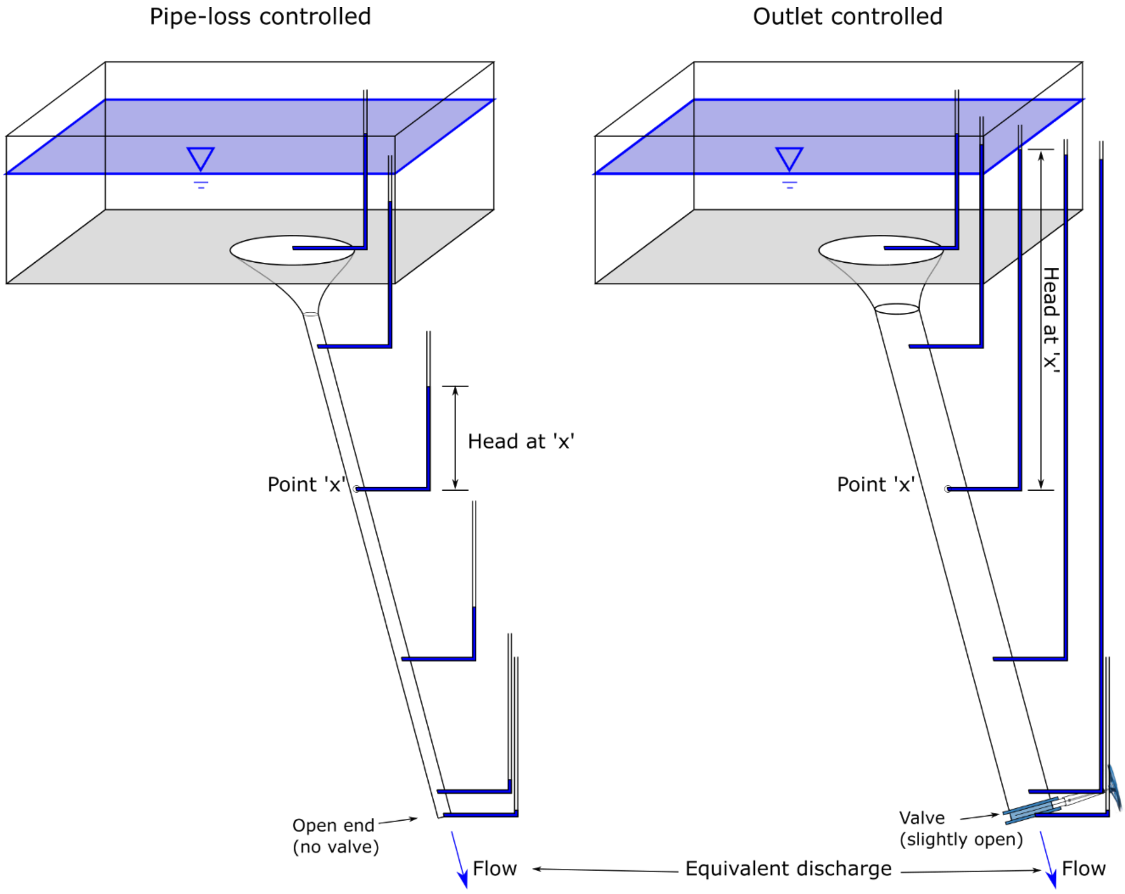


Figure B2 – Comparison of pressure distribution under equivalent discharge for pipe-loss controlled and outlet controlled flow systems.

In MODFLOW, flows into the mine are made via a “DRAIN” boundary condition. This boundary condition is placed at the end of the flow system to the mine, and is analogous to the placement of the valve in the pipe system described above. MODFLOW offers a facility to “control” the valve opening by a parameter in the DRAIN boundary condition called “conductance”.

B.2 Illustration of suitability of the pipe analogy to groundwater

Visual MODFLOW Classic was used to examine the effect of drain conductance value on discharge and pressure. The aim of the comparison is to show that a same discharge can be achieved with different pressure distribution, with a drainage ‘outlet’ control exhibiting reduced drawdown, consistent with the analogy in Figure B2.

Two concept models were built for comparison, adopting the geometry indicated in Figure B3 and Table B1.

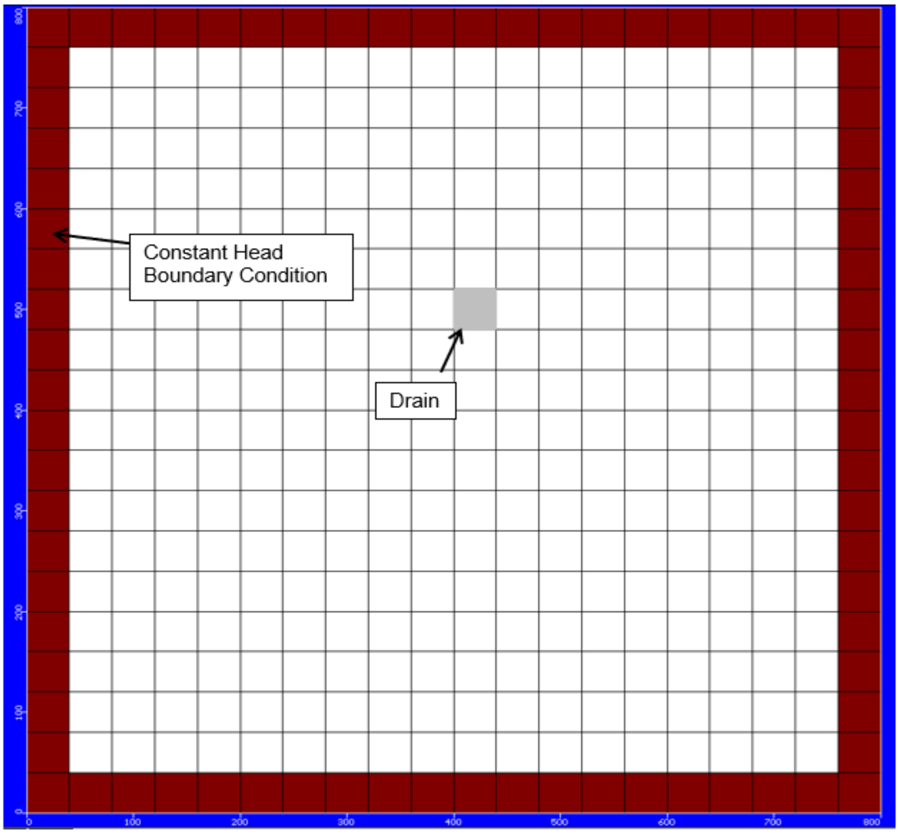


Figure B3 – Model setup

Model 1 was associated with high conductance for the drain cell, to represent a formation control case (the discharge is controlled by the hydraulic conductivity, K). Model 2 was associated with low conductance for the drain cell, to represent a conductance controlled case (the discharge is controlled by the drain conductance). Also, higher hydraulic conductivity was used for model 2 to highlight that the discharge will be controlled by the conductance value. Table B1 below shows the model set up, input parameters and results for both models, indicating that an equivalent discharge can be achieved for each conceptualisation. Cross-sections through each model presented in Figures B4 and B5 illustrate how different pore pressure distributions (and hence drawdown) are associated with each conceptualisation, with the drain conductance controlled model exhibiting little change in the water table under the same discharge

Table B1 – Model setup conditions

	MODEL 1 (FORMATION CONTROL)	MODEL 2 (CONDUCTANCE CONTROL)
Model Setup		
Cell size (m) (x/y/z)	40/40/20	
# of Layers	5	
constant head around the model's boundaries	80	
drain elevation	0.1	
bottom elevation (m)	0	
Input Parameters		
K (m/s) (*Kh*=*Kv*=*Kz*)	1 x 10^{-7}	1 x 10^{-5}
Conductance (m2/day)	1600	0.25
Results		
Q (m3/day)	19.82	19.87

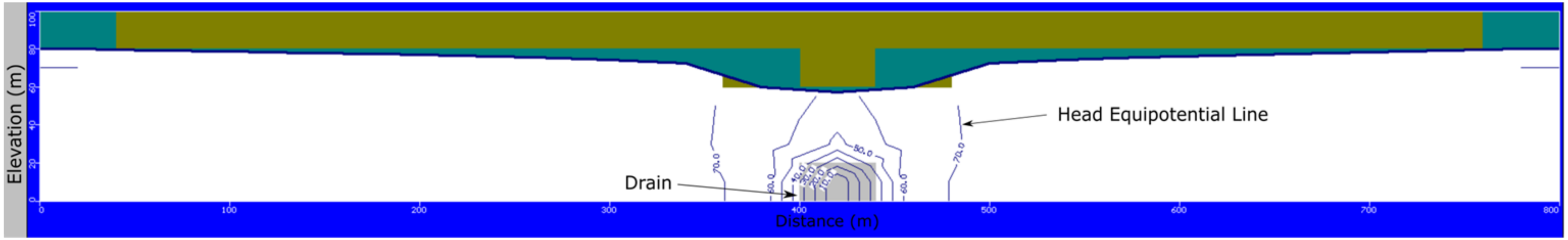


Figure B4 – Model 1 output cross-section

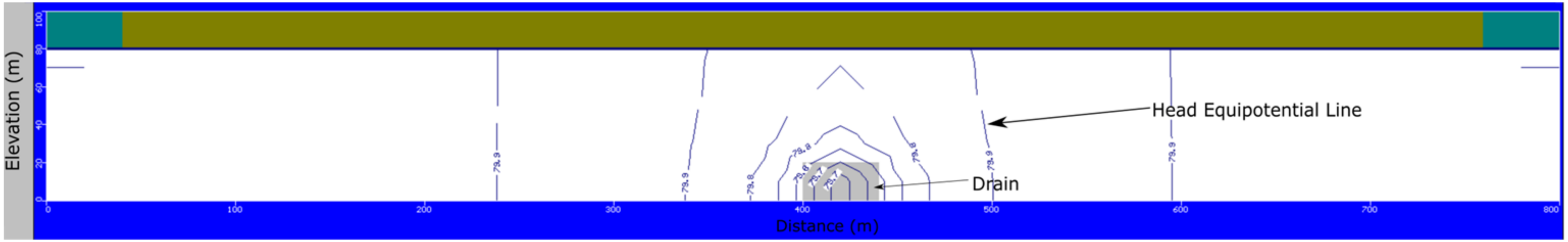


Figure B5 – Model 2 output cross-section

B3 Application of Drain Boundaries in modelling of the Hume Coal Prospect

In the modelling in Pells and Pan (2017), I elected a high conductance value for drain boundary conditions - as if the valve were fully open or removed. This creates a channel or pipe-controlled system – i.e. inflows are controlled by resistance to flow from the 'pipe' – in this case flow to the mine is controlled by the hydraulic conductivity of the geology.

It is important to note that once the drain conductance is set above a certain value (i.e. the valve is opened enough), the system becomes formation controlled (i.e. "channel or pipe controlled"). Once this is achieved, further increased in the DRAIN conductance make no difference (i.e., because the conductance is no longer the control). In Pells and Pan (2017) I demonstrated this effect with various 2D and 3D conceptual models, showing that for the cell size I had adopted, the drain boundary only began to control mine inflows for conductance values less than about 10 m^2/day. The value of 1000m^2/day that I chose was simply to clearly represent that my DRAIN boundary condition imposed no outlet control. As stated in Pells and Pan (2017), this is a common modelling approach, and I cited 6 other reports where this approach had been adopted for underground mining, including reports by HydroSimulations and their reviewers. In these cases, modellers had similarly adopted a symbolic value of 1000m^2/day. Notably, the model of Berrima colliery, supervised by HydroSimulations peer reviewer (Middlemis) adopted drain conductance of 1000m^2/day for simulation of inflows, and was reported to produce a calibrated model of Berrima colliery. It should nonetheless be noted that it would not have mattered if I had chosen values of 100, 1000 or 500000 m^2/day, for instance. This follows the principal of hydraulic controls, as illustrated above.

In contrast, the modelling presented for Hume Coal represents an outlet-controlled system. I argued, and showed through analyses and through 2D and 3D conceptual models, that their adopted conductance value of 0.05 m^2/day controls the predicted mine inflows.

The key justification provided in the EIS Responses to Submissions for the very low DRAIN conductance adopted by the proponent, is that the DRAIN conductance values were derived from calibration to inflows at Berrima colliery. Following discussions with DPI Water (Nov 2017) I was led to the understanding that the EIS groundwater model had applied drain cells to multiple layers for simulation of flow into Berrima colliery. In this way, a comparatively larger discharge could be transmitted than would be inferred from a drain conductance in a single cell only (this is analogous to placing multiple slightly-open valves at the end of a pipe - e.g. see Figure B6). In this case, drain conductance ceases to be an independent, meaningful variable. For example, manipulation of valve 'opening' in Figure B6 could replicate a certain flow. This valve setting could, in one sense, be considered as 'calibrated' to that flow. However, the valve setting would only be applicable for other systems with an equivalent configuration of valves. One could not directly apply this 'calibrated' valve opening 'conductance' to achieve a calibrated total discharge in a different system.

In my analyses, I also demonstrated that the value of 0.05 m^2/day was untenably low, being analogous to filling the mine void with a compacted clay. A further analogy is the usage of a valve with a very small 'opening' (Figure B1). Both the reports by HydroSimulations (2018) and EMM (2018) were dismissive of my calculations, but I have reviewed my calculations and consider them to be correct, and I also demonstrated them to be true from conceptual 'test' 3D models.

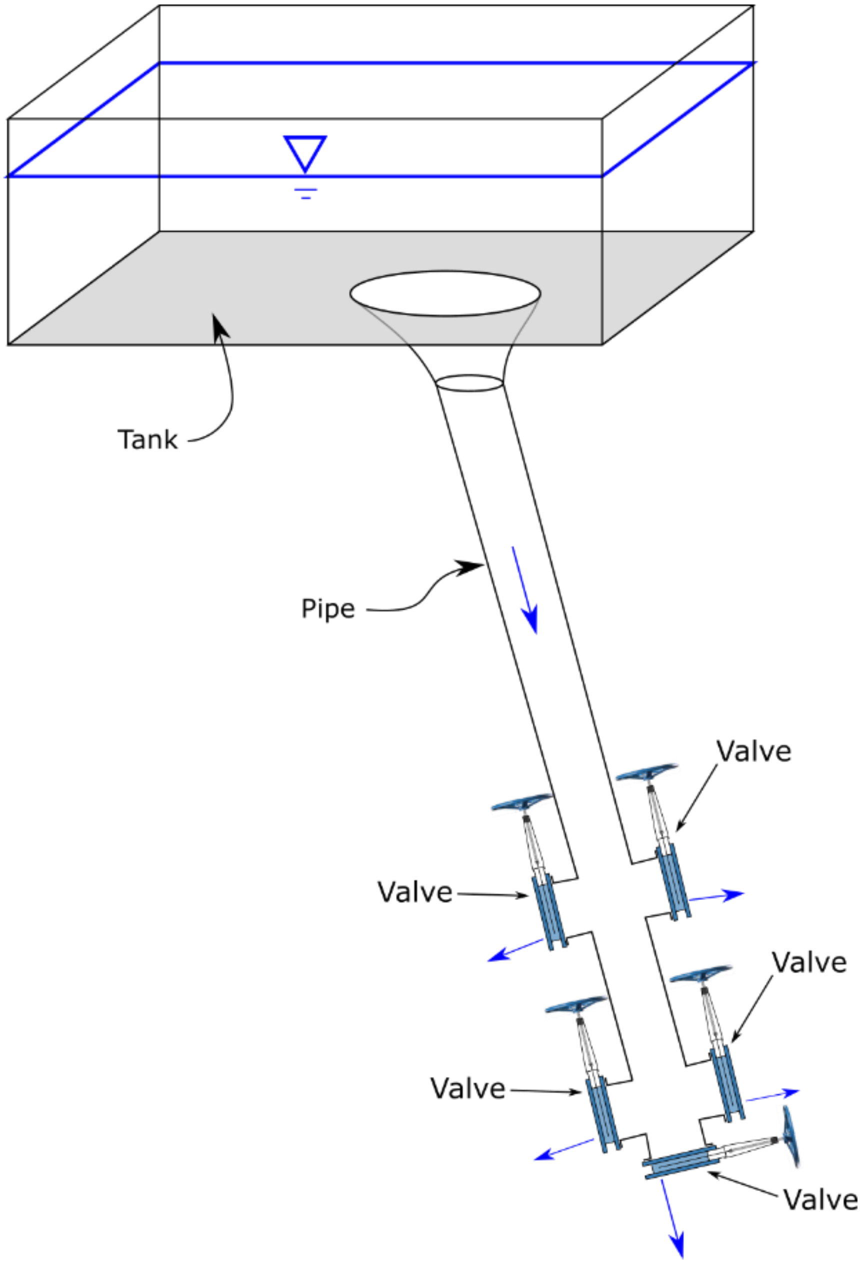


Figure B6 – Example of a multiple control outlet, being analogous to placement of multiple 'drains' to simulate inflow to Berrima colliery