OUT19/5211

Professor Chris Fell
Independent Planning Commission NSW
Level 3, 201 Elizabeth Street
SYDNEY NSW 2000

Dear Professor Fell

Hume Coal Project

Thank you for your request dated 1st April 2019 seeking additional information about groundwater modelling and make good provisions in relation to the Hume Coal Project. I attach our advice in detail on these matters.

I note that the proponent is predicting significant impacts on a number of existing water users, and the value of this groundwater source is relatively high. As such, it is important that the assessment and the supporting modelling is robust.

While the model has improved from earlier models, the additional modelling and hydrogeology work to date has not improved upon a number of key indicators which are required to:

- predict water level and volume impacts to the water supply aquifer due to mine dewatering (to a sub metre scale resolution for drawdowns)
- allow assessment of volume losses at the resolution of individual agricultural users
- confirm licensed allocation volumes.

Yours sincerely

Mitchell Isaacs
Director Strategic Relations
24 April 2019

GPO Box 5477, Sydney NSW 2001, Australia
Level 49 MLC Centre, 19 Martin Place, Sydney NSW 2000, Australia,
Tel: +612 9338 6600 Fax: +612 9338 6860 www.industry.nsw.gov.au ABN: 72 189 919 072

Department of Industry (Water) additional technical advice to the Independent Planning Commission (IPC) about the Hume Coal Project

17th April 2019

In summary, the Department of Industry - Water considers there are significant uncertainties in the predictive capabilities of the model, and as such the risk to an important groundwater source is relatively high. The predictions of the proponent are not adequately supported by robust evidence when compared to the existing value of the aquifer to water users.

Question 1 - Has the class of the groundwater model been resolved in your opinion? We note there has been at least one meeting between modellers

While the model is significantly improved from earlier models, the confidence level classification has yet to be resolved.

DOI Water considers this latest model to be incomplete, with the model neither optimally using all the available field data nor incorporating prior recommendations. As such we do not consider it appropriate to be classified, however it resembles a Class 1 model with some higher class indicators. According to the checklist in the peer review the model incorporates some Level 2 and Level 3 elements. However that does not rationalise the overall classification to an acceptable degree. The Australian Groundwater Modelling Guidelines are clear on the distinction between levels based on reported error statistics falling within defined ranges. Failure to achieve error statistics within these ranges imply that, although parts of the model might be well developed, as a functional predictive tool the model is lacking in certain aspects. That position is supported by the range of error statistics that suggest the replication of existing conditions has not been reasonably achieved, and therefore the predictive capability is not certain.

The additional modelling and hydrogeology work by the proponent to date has not improved upon a number of key indicators. As such we do not consider the model to be fit for the purpose of a robust assessment of impacts to a highly developed aquifer used for agricultural and domestic groundwater supplies. The specific objectives required are:

- predicting water level and volume impacts to the water supply aquifer due to mine dewatering (to a sub-metre scale resolution for drawdowns)
- to allow assessment of volume losses at the resolution of individual agricultural users
- to confirm licensed allocation volumes.

DOI Water has the following concerns:

- The model is uncalibrated and calibration statistics require further explanation and improvement.
- The calibration methodology is unsound as it uses uncertain calibration targets.
- Some model parameters are outside the range of a reasonable hydrogeological analysis of field information and literature values.
- There remains conceptual geological uncertainty.
- The spatial refinement is too coarse in key parts of the model domain.
- There is inadequate uncertainty analysis of the parameters applied (narrow range).

There is uncertainty about recharge and manner in which evapotranspiration has been applied.

Question 2 - Do you have concerns on how the interburden layer was modelled in the upgraded Merrick (2018) model?

DoI Water has concerns on how the interburden has been represented. Questions remain as to the extent of the Narrabeen Formation directly above the coal seams and the adequate representation of this in the model (thickness of the interburden and hydraulic parameters chosen for the groundwater model).

With respect to the location and thickness of the interburden, there is continuing uncertainty with regards to the thickness of the interburden in the Modified EIS USG-T model. The thickness and therefore significance of the interburden is modelled differently to the conceptualization of it. (Figure 3 in HS2018/02 vs Figure 4.3 and 4.4 in GEOTLCOV25281AB-ACA). The numerical model interburden thickness attains 6 - 10 m while the conceptualization of it in the Coffey report barely attains 2 m thickness in the exploration licence area A349.

As previously requested by the department the geological cross-sectional and bore log data and analysis should be compared to the layering cross-sectional data applied in the model.

With respect to hydraulic parameters chosen by the report, there is evidence to support the Hawkesbury Sandstone hydraulic conductivity (K_h and K_v) being highest immediately above the coal seam to be mined. There are concerns about the adequate representation of this in the model. Alternative realizations of the model with higher K_v values applied were not presented as requested and agreed to during a meeting with the proponents modelling consultant.

Question 3 - The transfer of water from the primary water dam to underground voids was not included in the modelling due to lack of mining details. Middlemis (2018) says this makes the model conservative. What is your opinion?

The transfer of water is intended to re-pressurise the voids created by mining behind constructed bulkheads. There is considerable uncertainty around the success of this approach, in terms of the safety issues for those working in the underground mine, and in terms of the behaviour of the groundwater system. For example, the individual flooded voids could leak pressure to the surrounding rocks at different rates (due to variabilities in fracturing, porosity, permeability, etc.) therefore it would be difficult to predict the outcomes for each panel in the model. The lack of this aspect in the model does not necessarily make it conservative but reflects the difficulty in attempting to reasonably incorporate what could be extremely variable behaviour under pressurisation.

While it is true that the water transfer may provide some mitigation to depressurisation impacts, in reality the performance of the aquifer in this regard will only be known post-mining. The assumption that drawdowns or extraction volume impacts from the mining will be minimised because of the re-pressurized voids cannot be definite until they are observed in practice. Speculation about the impact of this issue is best performed with an appropriate sensitivity and uncertainty analysis on a fit for purpose model. The combination of insufficient information and model not being fit for purpose, does not allow an effective judgement of the degree of how conservative the model is.

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Question 4- The DI-W Nov 2018 submission indicated that there were inconsistencies between the geological and groundwater model. The DPE independent reviewer (Middlemis, 2018) has indicated that the 3D semi regional model of Merrick (2018) is fit for purpose. Does your recommendation to use 90th percentile predictions allay some of your concerns regarding lack of geological detail? Would the use of the 67th percentile predictions of impacts, also be acceptable?

Using the 90th percentile predictions does not sufficiently allay our concerns regarding the lack of geological detail and as a result DoI Water provided comprehensive recommendations to address this issue. Our recommendation with regards to the 90th percentile had as its intention only to highlight and recommend the resolution of water licensing and allocation shortages that required addressing.

Considering the current level of confidence in the model that DOI Water holds, it is our opinion that performing an uncertainty or sensitivity analysis on this current latest model would provide unreliable results. DOI Water considers that the model is not currently a suitable tool to predict and understand the likely impacts with a reasonable level of certainty for this project. DOI Water supports comprehensive uncertainty and sensitivity analyses being performed on a model that has been improved and fit for purpose. DOI Water provided recommendations about the methodology of the analyses which were not implemented.

Question 5- What is your opinion on hydraulic conductivity decreasing with depth, as modelled? Some groundwater specialists believe this interpretation is wrong.

In summary, we do not believe that the data presented by the proponent demonstrates clear field evidence for the assertion that hydraulic conductivity decreases with depth. In addition, we believe that the behaviour of hydraulic conductivity in the vertical and horizontal directions can vary significantly in the aquifers present in the Hume Coal project area.

The Hawkesbury Sandstone aquifer in the Hume Coal project area is primarily a fractured rock aquifer as well as a secondary porous rock aquifer. DOI Water experience from groundwater exploration drilling into fractured rock aquifer environments confirms that in such aquifers hydraulic conductivity in the vertical (K_v) and horizontal (K_h) directions is highly variable. In some situations K_v and K_h can be similar and in others K_v is higher than K_h . Increasing hydraulic conductivity with depth in such aquifers can also be common nor is it particularly rare even in primary porous aquifers.

With regards to groundwater flow in fractures, surrounded by bulk porous matrix, hydraulic conductivity is greater parallel to the fracture than normal to it. In a primarily vertical fracture network connected to a dewatered void at depth, groundwater would predominantly flow vertically downward at a greater rate than horizontally. Therefore the direction of conductivity is a key parameter that requires careful evaluation and sensitivity testing. The situation in the field is far more heterogeneous as described above and therefore DOI Water recommended sensitivity and uncertainty analyses on the full range of hydraulic conductivity for both K_v and K_h. These were not undertaken.

Middlemis (2018) concurs that the mine inflow predictions are sensitive to K_v (Pg. 16, Middlemis_2018_Hume_Coal_review_v5.docx). However during the sensitivity analysis, K_v was not varied over a sufficient range (towards higher, more reasonable vertical hydraulic conductivity values), resulting in the model results not being sensitive to the narrow and unsuitable K_v range applied. DoI Water recommended that an uncertainty and sensitivity analysis on K_v be performed on the entire range of values with a maximum K_v of 10 m/d to be applied.

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Attention is drawn to Figure 4.5 of GEOTLCOV25281AB-ACB plus Figures 5.1 and 5.2 of GEOTLCOV25281AB-ACA. It is clearly observed that predominantly in the Hawkesbury Sandstone (but also in the Basalts, Wianamatta Group and Wongawilli seam):

- K values in the range 0.01 – 5 m/day occur to depths of between 120 - 160 m and are numerous.

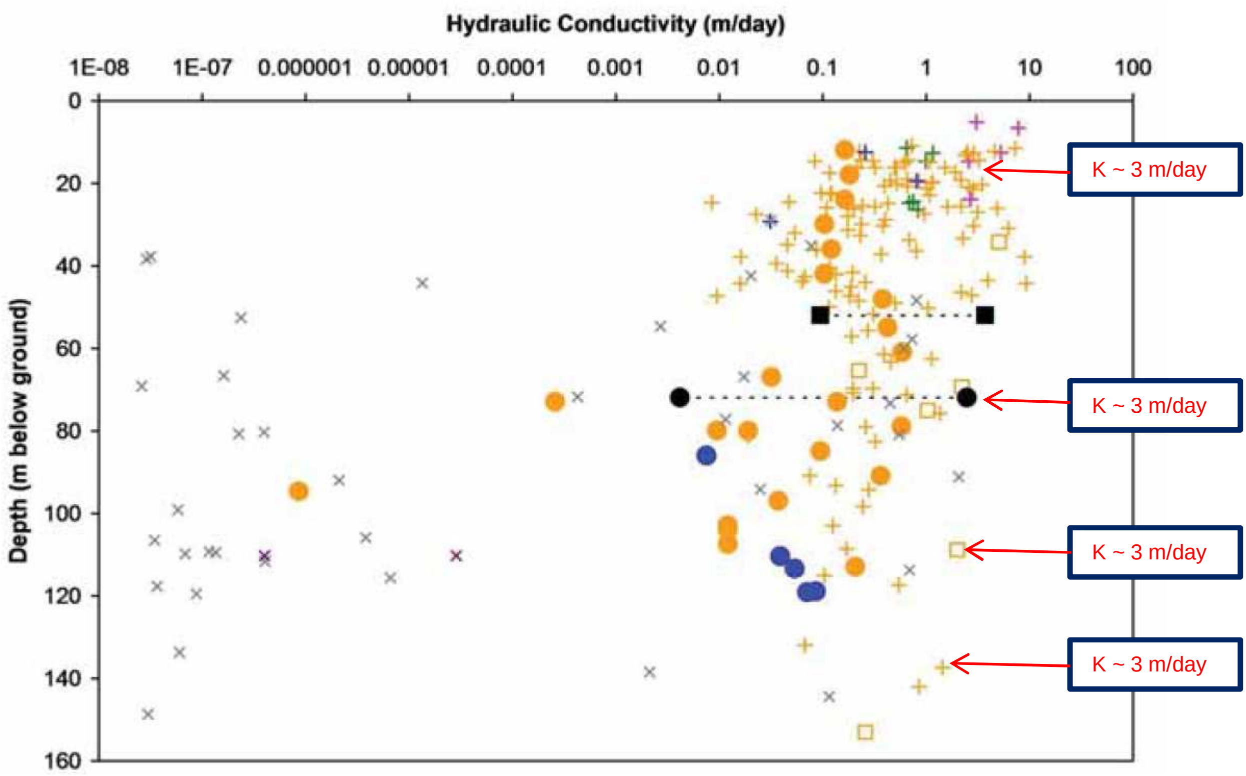

Figure 1 - Figure 5.1 of GEOTLCOV25281AB-ACA, Hume Coal Project, Groundwater Assessment Volume 1: Data Analysis 17 November 2016. *Note red arrows and boxes added by DoI Water*.

- The data presented by the proponent does not demonstrate clear field evidence for the assertion that hydraulic conductivity decreases with depth. In contrast as demonstrated in the above figure, conductivity remains high at depth. The upper range values are of approximately 3 m/day occurring to depths of 140 m.

- The linear regression as applied by the proponents modelling consultant to prove a decrease of hydraulic conductivity with depth is in the opinion of DoI Water an unreasonable and inappropriate fit of the data.

DoI Water highlights that K_v and K_h values used in the model and also in the uncertainty analysis and sensitivity testing did not adequately range over the field values with depth. A model must reasonably represent field values, including with depth, and in this case the model clearly falls short of demonstrating this.

The geology also indicates the presence of geological intrusions such as dykes, sills, laccoliths, diatremes and plutons plus faulting in multiple orientations (Figures 4.5 – 4.8 of GEOTLCOV25281AB-ACA). It has been indicated that many of the dykes are vertical and weathered to significant depth indicating groundwater presence. It has also been indicated that haloes or zones around the intrusions are known to yield higher quantities of groundwater. Some of the fault orientations are likely to be open allowing groundwater flow. These features provide further justification for performing a complete sensitivity analysis on K_v over the entire range of field obtained values.

There seems to be no clear justification to not test the model for the full range of K_h and K_v uncertainty and sensitivities for all layers (including the Wongawilli seam), as was recommended by DoI Water.

Question 6 - What is your opinion on the approach taken to decide on the drain conductance values used in the modelling?

The drain sensitivity analysis has highlighted incomplete follow up modelling tasks that should have been performed to decrease the uncertainty about mine inflows and their impacts onto drawdowns affecting other water users.

The conductance equation is sensitive to its inputs derived from an equation that considers hydraulic conductivity, length and width of a cell boundary condition and the thickness. The conductance value is potentially sensitive to each of these. DoI Water was specifically concerned about the hydraulic conductivity and thickness applied in the equation used in order to assess the suitability of the drain conductance value used.

DoI Water requested further information about the drain conductance parameter and the derivation of its value. DoI Water also recommended that wells are alternatively used also, instead of drains to effect dewatering. This is so that it can be determined what is the real rate that the geological formation can provide water to the unrestricted wells in the model, as opposed to the modeller imposed rate assigned to the drains. Currently the restrictive drains act as the bottleneck control on the volumes of water allowed to exit the geological formation in the model, as opposed to the more physically naturally accurate formation rate, freely flowing into a well that can only pump water that is available to the pump, even if the pumping rate assigned to the well is excessively high. This was recommended in order to eliminate the confusion about the drain conductance value and its sensitivity to grid scale features.

- Drain conductance values were found by Merrick (2018) (Section 8.2) to be highly sensitive to an order of magnitude change nearly doubling the inflow intercepted by the drains.
- In contrast Middlemis (2018) (Section 4.2) stated in his review of Merrick's 2018 work, *"The revised groundwater modelling included a sensitivity analysis on drain conductance, with the results indicating low sensitivity"*.
- However Merrick (2018) presents Table 27, which DoI Water considers shows overall very large differences (which imply an area of uncertainty that should be diminished and addressed in detail) and yet claims, *"model is overall not particularly sensitive to changes in mine drain conductance".*

Question 7 - The updated model is said by Middlemis (2018) to be a best practice model as it is simultaneously calibrated to four data sets and contains a detailed uncertainty analysis. What is your opinion?

DoI Water notes that Middlemis (2018) states the calibration to be acceptable in this case because of simultaneous calibration performance on four other key criteria:

a) matches to baseflow

b) matches to mine dewatering fluxes

c) aquifer parameters consistent with field measurements

d) a calibration history match.

DoI Water does not agree that the model is calibrated to four datasets simultaneously.

The calibration of the model against four data sets does not necessarily reflect the quality of the model in replicating the existing environment or predicting future impacts. It does serve to constrain the model to certain parametric fields that are of importance to groundwater behaviour. However, this means that other parameters in the model that are not constrained may have to be varied across unnaturally large ranges to achieve some form of calibration. It is also not clear how parameters might have been lumped together to enable the modelling to progress in the absence of specific data (e.g. specific storage values derived from site investigations), and whether these are a significant part of the four data sets being calibrated against.

DoI Water notes that a visual analysis of the calibration hydrographs concludes that the vast majority of bores are uncalibrated. A residual of far less than 2 m for the majority of the bores would be regarded as more acceptable to assess drawdown impact and impact on private bores (refer to response to Question 8 for more details).

<u>Matches to baseflow</u>

DoI Water considers that there has been insufficient detailed information provided about this criteria, showing the match. Apart from this, the model is not considered fit for purpose and therefore DoI Water regards the current results as unreliable.

<u>Matches to mine dewatering fluxes at Berrima mine</u>

DoI Water does not consider this a reliable calibration parameter. The use of drains to represent mine voids at Hume Coal voids is not adequately clarified to understand the details of the drain parameters selected for matching to a pre-selected flow at Berrima mine.

DOI Water highlights that the Berrima mine is in a very different hydrogeological situation:

1. Berrima mine occupies a much smaller footprint and therefore a smaller groundwater catchment; the implication with the Hume Coal mine project area, with a greater groundwater catchment area, is that relatively far greater volumes and perhaps rates of water are potentially available to the Hume Coal voids in a fractured rock environment. Without the specific mining plan details being applied to a fit for purpose Hume Coal model, using the Berrima mine inflows is tenuous and doesn't provide a high degree of confidence.
2. Berrima is a much older mine closer to steady state in terms of groundwater inflows, with decades of dewatering behind it and lowered water levels providing a lower gradient to flow. To use inflows from Berrima is inapplicable to a greenfield site like Hume Coal which will likely not reach the same degree of equilibrium for several decades. The Hume Coal mine has a larger volume of water immediately available to it than Berrima. In the initial years, inflows into Hume Coal mine would be far larger than the Berrima mine after decades of dewatering.
3. Geological heterogeneity almost ensures that hydrogeologically, the sites are incomparable in how water flows into a resulting mine void when comparing the two mine sites. There is uncertainty with regards to the presence, extent or differences between the thickness of the Narrabeen Group over the Hume and Berrima sites and the effect this has on potential recharge to the mine voids. DoI Water has recommended detailed clarification about the details of all aquifers, aquitards and

faults above both mines to allow full assessment of the hydrogeology and its eventual proper inclusion in the model.

<u>Aquifer parameters consistent with field measurements</u>

DOI Water does not consider the model parameters to be consistent with field measurements (refer also to earlier response to questions).

<u>Calibration history match</u>

DOI Water does not consider the model to be calibrated to monitoring well water levels (refer to response to questions below).

Question 8 - What does the error statistic SRMS of 10.7% tell you about the model accuracy?

DOI Water continues to have concerns about the calculation of the SRMS error statistic at over 10%. It is good practice to also apply the error statistic to individual aquifers, as opposed to averaging it across all the model layers and assess the aquifers separately to gain a deeper insight. DOI Water recommended further clarification and without this information, is not in a position to comment further apart from providing the following points:

- The error statistic provides an aggregated measure of the calibration but does not indicate the spatial or temporal distribution of the error. The error statistic should be less than 5% for a model destined for the purpose stated earlier.
- DoI Water considers the model to be unacceptably calibrated as a direct consequence of the unsuitability of indicators/elements referred to in our reply to the first question from the IPC. DoI Water does not therefore consider the model (the improved Modified EIS USG-T model nor MEAN K model) to be fit for the purpose of assessing drawdown impacts resulting from mining, to an adequate level of certainty for decision taking purposes for this project.
- A visual analysis of the calibration hydrographs concludes that the vast majority of bores are uncalibrated. A residual of far less than 2 m for the majority of the bores would be regarded as more acceptable and should be achievable using PEST pilot points and spatially varying hydraulic parameters within reasonably possible ranges as has been recommended as a result of reviews of the modelling work to date.
- Only 21% of all the calibration bores have a residual that is less than 2 m between the observed field measurement and modelled results. This is important because the modelling is expected to provide information about drawdowns within that range at surface. This is an insufficient number of calibrated bores to provide confidence in the model predictions.
- 79% of all calibration bores exceed 2 m residual between the observed and modelled results. The vast majority of bores are therefore uncalibrated.
- 64.5% of the bores exceed 4 m residual between the observed and modelled results.
- 50 % of the bores exceed 10 m residual between the observed and modelled results.
- The calibration statistics provided require a deeper exploration and explanation to determine the consistency of the weighting applied to model parameters.

It is uncertain why the large dataset private bores were also not used within PEST to obtain a base case calibrated model.

The error statistic does not indicate adequate accuracy for a model with a requirement of being fit for predicting the impacts at this site. A visual analysis of the individual calibration hydrograph reveals also consistent issues with precision as observed in differences between both phase and amplitude between the measured and calculated water level observations.

Question 9 -Do you have concerns with the make good strategy for affected bore owners?

While there is no clear policy on how make good should be achieved, DoI Water recommends that where impacts are known or likely, users should have pre-agreed make good measures in place before mining commences.

a. Do you think the affected irrigation bore owners can obtain an equivalent water supply from the strata below the Hawkesbury sandstone?

Whilst it might be possible for affected landholders to obtain a similar supply from strata beneath the Hawkesbury Sandstone under undisturbed conditions, the availability of groundwater during and following mining is not known. There is also a question around the loss of opportunity for landholders as opposed to the loss of current supply. For example, a landholder that might currently only use part of the water from a well-constructed and efficient bore for stock and domestic purposes could be denied the future opportunity to develop a commercial business dependent on the full supply that the bore could provide. A deepened or replacement bore may need to be demonstrably equivalent in that regard, not just ‘equivalent’ to the current purpose for which it is being used.

There is currently little knowledge about the water supply quality of yields available from deeper formations to satisfy the demands of the current irrigation bore owners. Determining this would involve drilling, aquifer testing and monitoring of wells.

b. What yields and water quality are likely from the deeper formations?

Typically bores that penetrate through the Hawkesbury Sandstone are lower yield and poorer quality. The Southern Highlands district in which the proposed mine is located is typically quite productive in terms of bore water supplies, due to a combination of influences including the structural setting, the recharge zone location and enhanced permeability of the Hawkesbury Sandstone.

The Illawarra Coal Measures unconformably underlying the Hawkesbury Sandstone tend to host groundwater that contains dissolved constituents derived from the coal seams and include other layers that are tighter, more massive, and with higher fines content. These conditions are common for undisturbed areas, however it is not clear how the proposed mining will impact the availability or quality of the deeper geological formations. In particular, the development of localised failure planes, the repressurisation of mined voids and the possible activation of major geological structures arising as a result of the proposed mining could all affect both yield and quality of the Hawkesbury Sandstone and the underlying coal measure formations in unforeseen ways.

c. Do you consider the direct supply of water should be included in the make good options?

Due to the significance of impacts on groundwater resulting from this project there is the requirement for make good provisions to apply according to the NSW Aquifer Interference Policy. The intent of this is for the affected party to have a comparable water supply made available, or other suitable arrangements, however how this is to be achieved is not specified. Direct supply of water may be a valid option in some circumstances however DoI

Water notes there are likely to be practical constraints or barriers to providing large volumes of water to a large number of impacted users.

In this case initial information indicates a third may require additional operating costs, a third may require deepening of bores and a third may require an alternate supply. Specific detail on these requirements is awaiting further individual bore assessments and development of viable make good measures.

Therefore DOI Water recommends viable measures need to be developed to address the make good provision requirement. The measures used are likely to vary and for example for some high yield irrigation bores, the ability to provide a viable make good option is yet to be confirmed.