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Re: Wongawilli Colliery North West Mains Modification groundwater modelling independent review

1 Summary

This letter presents the findings of a peer review of numerical groundwater flow modelling of the Wongawilli Colliery North West Mains modification (MOD2). The model was initially developed by SLR Consulting Australia Pty Ltd (SLR) for Wollongong Coal Limited (WCL) to support the MOD2 proposal. The SLR modelling and assessment was documented in a report, dated 12 November 2020. Peer review, by Dr Doug Weatherill of EMM Consulting Pty Ltd (EMM), was summarised in a report dated 13 November 2020. Following comments and advice from NSW Department of Planning Industry and Environment (DPIE) and Water NSW on the SLR modelling and report, it was agreed that an updated, standalone supplementary report would be prepared. This work has been undertaken by Umwelt Environmental and Social Consultants (Umwelt) and is the focus of this review.

This review focusses on the numerical groundwater modelling carried out in support of the groundwater impact assessment. It does not focus on the field testing, data collection and analysis used in support of the groundwater model.

The review was carried out by Dr Doug Weatherill of EMM Consulting Pty Ltd in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al. 2012).

Discussions were held between Umwelt and the peer reviewer throughout the update process, during which comparison was made between modelled outputs over the history-matching period with data from Dendrobium Mine, additional scenarios (requested by DPIE) were developed to increase the rigour of the uncertainty analysis, and an updated report was written.

Draft documentation was provided by Umwelt for review as follows:

- 18 August 2021: Introduction, Background and Numerical Groundwater Model chapters (up to the start of predictive modelling); and
- 3 September 2021: complete draft report.

The final supplementary groundwater impact assessment (Umwelt 2021) was delivered on 16 September 2021 and forms the basis for this peer review.

The Australian Groundwater Modelling Guidelines (Barnett et al. 2012) suggests a compliance checklist to summarise key review findings. This is presented in Table 1.1.

It is my view that, despite some limitations in the local site data and model calibration, which are expected to be addressed with an expanded monitoring network, extended monitoring period and future model updates, the modelling is fit for purpose for scenario modelling to inform groundwater impact assessment and water licensing.

Table 1.1 Groundwater Model Compliance Checklist: 10-point essential summary

Question	Y/N	Comments re Wongawilli groundwater model
1. Are the model objectives and model confidence level classification clearly stated?	Yes	Yes. The report indicates the model is best described by a Class 2 confidence level with a number of attributes of a Class 3 model. The peer reviewer's own assessment is provided in Table 2.1, which suggests the model aligns best with a Class 2 confidence classification.
2. Are the objectives satisfied?	Yes	The groundwater assessment lists a number of tasks. Specific to the numerical modelling they are: 1) Quantify the groundwater inflows to the previously approved NWM and proposed NWMD, as a function of time; 2) Predict the extent and area of influence of dewatering and the level and drawdown around the Project; and 3) Identify areas of potential risk, where the mitigation of groundwater impacts may be required.
3. Is the conceptual model consistent with objectives and confidence level?	Yes	Conceptual model is sound, based on data and local mining experience, modelling objectives and for impact assessment and licensing purposes.
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Yes	The conceptual model refers to groundwater investigations from previous mining and modelling in the area and uses two previous numerical models (GeoTerra 2010 and HydroSimulations 2019) as its basis. The conceptualisation considers ranges of hydraulic property values from field testing as well as previous modelling. Current, during and post-project conceptualisations are presented.
5. Does the model design conform to best practice?	Yes	Industry-leading software (MODFLOW-USG in combination with a flexible Voronoi polygon mesh) is applied. Model domain is sufficiently large to encompass predicted project impacts but does display impacts of other projects at boundaries. Alternative boundary conditions have been tested to identify the consequence of this aspect. Layers, mesh and boundary conditions generally consistent with best practice.
6. Is the model calibration satisfactory?	Yes	Calibration performance is acceptable. SRMS errors of 10.1% (steady state) and 8.44% (transient) are okay, but strongly skewed by a 250 m range in hydraulic head across monitoring locations. Although calibrated in transient mode, the model does not display a good match to seasonality. Only one location, Nebo 1D (Bulli Coal seam) displays a clear response to mining. The model simulates drawdown at this location, but less than measured, and matches the zero impact at the overlying watertable measured at Nebo 1S. The update since the previous modelling (SLR 2020) now makes use of data from Dendrobium, as recommended by this reviewer. These data are employed as what is effectively a regional history-matching verification dataset, as these data were not employed as targets during the history-matching process. The model has a SRMS error of 11.1% when compared to Dendrobium data. Whilst higher than would be generally targeted, this is unsurprising given the complex groundwater affecting activities occurring in that area, and the fact that the model was not tailored to match measurements in that area specifically.
7. Are the calibrated parameter values and estimated fluxes plausible?	Yes	Calibrated parameter values are generally consistent with ranges of hydraulic conductivity and effective porosity from testing and previous modelling. Values are presented as min, mean and max with reference to tested values. Indicating model values lie within measured ranges. Spatial distributions are presented for pre-mining hydraulic conductivity in the Bulli and Wongawilli coal seams. Recharge rates, assigned as a percentage of rainfall, are plausible. The high recharge assigned in swamp areas (45% of rainfall) may be reflective of seepage from ponded water rather than episodic rainfall. Modelled historical mine inflows are compared to average measured inflows, with some modelled values above and some below measured average fluxes.
8. Do the model predictions conform to best practice?	Yes	Mining and post-mining periods are simulated with appropriate boundary conditions to represent mining such that predictions of drawdown impacts and mine inflows can be made.

Table 1.1 Groundwater Model Compliance Checklist: 10-point essential summary

Question	Y/N	Comments re Wongawilli groundwater model
9. Is the uncertainty associated with the simulations/predictions reported?	Yes	A series of deterministic predictions with selected alternative hydraulic properties was run. The updated modelling now incorporates realisations in which modelled values of multiple parameters are varied simultaneously, in response to a request for this by DPIE. Overall, the approach can be described as providing predictive sensitivity and aligns best with type 1 uncertainty analysis as outlined in the IESC explanatory note on uncertainty analysis (Middlemis & Peeters 2018).
10. Is the model fit for purpose?	Yes	It is my opinion that the model is fit for the purpose of predicting drawdown impacts and mine inflows for licensing purposes.

2 Model confidence level classification

The Australian Groundwater Modelling Guidelines (Barnett et al. 2012) provides a classification system that takes into account data used to inform the model conceptualisation, model design, calibration and predictive scenarios. Most models will have attributes that align with more than one class and, generally, the overall confidence level class is determined by the clustering of attributes.

The peer reviewer's assessment of the model using a modified version of the classification table is presented in Table 2.1. This assessment indicates that the model best aligns with a Class 2 description, with some attributes of a Class 3 model. This classification indicates that the modelling conducted for Wongawilli Colliery North West Mains Modification is suitable for impact assessment scenario modelling.

Table 2.1 Model Confidence Class characteristics

Class	Data	Calibration	Prediction	Quantitative Indicators
	Not much / Sparse coverage	Not possible	Timeframe >> Calibration	Predictive Timeframe >10x Calib'n
	No metered usage	Large error statistic	Large stresses/periods	Predictive Stresses >5x Calib'n
1	Low resolution topo DEM	Inadequate data spread	Poor/no verification	Mass balance > 1% (or one-off <5%)
	Poor aquifer geometry	Targets incompatible with model purpose	Transient prediction but steady-state calibration	Properties <> field values
	Basic/Initial conceptualisation			Poor performance stats / no review
	Some data / OK coverage	Weak seasonal match	Predictive Timeframe > Calib'n	Predictive Timeframe = 3-10x Calib'n
	Some usage data	Some long-term trends wrong	Different stresses &/or periods	Predictive Stresses = 2-5x Calib'n
2	Some baseflow estimates and some K & S measurements	Partial performance (eg some stats / part record / model-measure offsets)	No verification but key simulations constrained by data	Mass balance < 1% (all periods)
	Some high res. topo DEM and adequate aquifer geometry	Head & Flux targets constrain calibration	Calib. & prediction consistent (transient or steady-state)	Some properties maybe <> field values.
	Sound conceptualisation, reviewed & stress-tested	Non-uniqueness, sensitivity and qualitative uncertainty addressed	Magnitude & type of stresses outside range of calib'n stresses	Some poor performance or coarse discretisation in key areas/times
	Plenty data, good coverage	Good performance statistics	Timeframe ~ Calibration	Predictive Timeframe <3x Calib'n
	Good metered volumes (all users)	Most long-term trends matched	Similar stresses &/or periods	Predictive Stresses <2x Calib'n
	Local climate data & baseflows	Most seasonal matches OK	Good verification or all simulations constrained by data	Mass balance < 0.5% (all periods)
3	Kh, Kv & Sy measurements from range of tests	Calibration to present day head and flux targets	- Steady state prediction only when calibration in steady state	Properties ~ field measurements
	High res. topo DEM all areas & good aquifer geometry	Non-uniqueness minimised &/or parameter identifiability &/or minimum variance or RCS assessed	Suitable computational methods applied & parameters are consistent with conceptualisation	No poor performance or coarse discretisation in key areas (grid/time)
	Mature conceptualisation	Sensitivity &/or Qualitative Uncertainty	Quantitative uncertainty analysis	Review by experienced Hydro/Modeller

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

Legend

Criterion met at higher Class	Criterion partially met at the relevant Class	Criterion met at the relevant Class	Criterion not met

3 Discussion

The supplementary groundwater assessment report (Umwelt 2021) covers the broad aspects expected in a modelling report, including project background and modelling objectives, conceptualisation, model design, history matching/calibration and associated sensitivity analysis, predictive modelling and uncertainty analysis. This updated assessment, in the reviewer's opinion, provides substantially better documentation of the numerical groundwater modelling and a more thorough handling of impact assessment and water licencing, with reference to the relevant regulatory assessment criteria than the previously reviewed assessment report.

Conceptualisation of the groundwater system covers the geological setting, hydraulic properties of the hydrostratigraphic units, climate, surface water, historical mining activities, measured groundwater responses and aspects of water quality. The modelling then focusses on hydraulics only.

The model is built using the MODFLOW-USG numerical groundwater modelling code in combination with a flexible Voronoi polygon mesh. The option to pinch out/deactivate model cells where units are absent is employed for more numerically efficient solution than older MODFLOW codes, whilst enabling greater spatial resolution in areas of interest (25 m node spacing at proposed mining areas and 100 m or less at major rivers/creeks, the escarpment and historical mines). The model is discretised vertically into 18 model layers that enable representation of the variability in hydraulic properties, hydraulic head and groundwater flow in the different units. The report does not present the data sources used to define the geometry of the layers but indicates that geological models were used for the coal seams in the project area and the Dendrobium model (HydroSimulations 2019) was used outside of that.

Boundary conditions around the model edge are assigned using the Constant Head (CH) package (ocean and Lake Illawarra), General Head Boundary (GHB) package (inland boundaries) or are no flow boundaries. In response to review by DPIE, the supplementary report includes modelling of alternative boundary conditions to identify the consequence of boundary condition choice. Surface water features are represented with the River (RIV) package and stage is allowed to vary over time based on gauge data. Conductance is calculated in a meaningful way, using properties of the individual features represented. Recharge from rainfall and evapotranspiration are represented using the Recharge (RCH) and Evapotranspiration (EVT) packages and the values adopted are reasonable. Inflow to mine voids is simulated with the Drain (DRN) package. The reviewer has confirmed that the implemented boundary conditions do effectively dewater the coal seams during periods of active mining, thereby implementing the localised hydraulic stresses that will be induced by excavation activities. Hydraulic properties are changed over time to represent mining, goaf and fracture zones using the Time-Variant Materials (TVM) package.

Transient hydraulic head monitoring data from five open standpipes and 54 vibrating wire piezometers (VWPs) were used to compile a calibration target dataset. The selected monitoring locations are focussed around the project area and do not provide good coverage of the whole model domain. An independent check by the reviewer of the available data on the BoM Australian Groundwater Explorer online database (BoM 2020) confirmed that, although there are many bores registered, they do not have recorded hydraulic head data in their records. A data sharing agreement meant that WCL has access to groundwater monitoring data for the Dendrobium mine. The supplementary report has made use of these data to quantify model performance against this additional dataset, in what is effectively a verification of the model on a broader spatial scale than the site data alone allow.

There appears to be significant "noise" in the measured data for the monitoring sites used as calibration targets. Some of this may be due to VWP stabilisation following installation, recovery from previous mining or underground water storage activity.

The model was calibrated to transient hydraulic head data using an automated approach. The model generally predicts stable head values at the target sites, not producing a great match to apparent seasonality. However, the model does simulate drawdown at the one monitoring location, Nebo 1D, that does show an apparent measured response to mining. The overlying watertable monitoring site, Nebo 1S, displays no evidence of impact from mining and this is replicated by the model. The key finding is that underground mining has not impacted shallow groundwater monitoring sites and the model is able to simulate this.

Despite the limitations of the calibration dataset (local sites only, only one site with mining impact and “noise” in measured data), the hydraulic parameters employed in the model were initially based on those from the Dendrobium model (HydroSimulations 2019) which has been calibrated to a more substantial dataset displaying impacts of underground mining. Whilst the parameter values were allowed to vary in the calibration process, they should only have done so to improve the fit to the selected calibration dataset and hydraulic conductivity was not allowed to diverge from the Dendrobium model values more than half an order of magnitude.

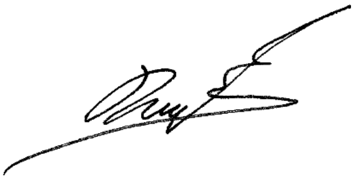
Predictive scenarios are conducted for a null case, approved mining and approved mining plus the project. These scenarios enable identification of groundwater impacts both cumulatively (ie total impact) and incrementally (ie additional impact due to the project). This is consistent with best practice and reduces uncertainty in the results.

Uncertainty analysis is conducted in a simple manner, with somewhat arbitrary variations in selected hydraulic properties that are not based on outcomes of the calibration sensitivity analysis. The supplementary report has added further model runs to expand the uncertainty analysis to explore simultaneous variation of modelled values of multiple parameters. The adopted approach best aligns with type 1 uncertainty analysis as outlined in the IESC explanatory note on uncertainty analysis (Middlemis & Peeters 2018). This approach is appropriate in this case given the low risk to third party groundwater users and groundwater dependent ecosystems sensitive to watertable drawdown. This is largely due to the presence of three aquitards overlying the coal seams proposed to be mined. These are the Bald Hill Claystone, Stanwell Park Claystone and Wombarra Claystone.

4 Conclusion

It is my professional opinion that, despite some limitations in the local site data and model calibration, the modelling is fit for purpose for scenario modelling to inform groundwater impact assessment and water licensing.

Yours sincerely



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5 References

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