Appendix J

Groundwater modelling peer review

EMM
creating opportunities

ILUKA

HydroGeoLogic

HydroGeoLogic Pty Ltd (ABN 51 877 660 235)
PO Box 383, Highgate 5063, South Australia
0438 983 005 / hugh@HydroGeoLogic.com.au

INDEPENDENT PEER REVIEW STATEMENT

ATTENTION:	Dr Doug Weatherill, Associate Groundwater Modeller, EMM Consulting	
FROM:	Hugh Middlemis, Principal Groundwater Engineer, HydroGeoLogic Pty Ltd	
REFERENCES:	**6 April 2022**	Balranald Mineral Sands Project MOD1 Groundwater Modelling
SUBJECT:	**Independent Peer Review of** Balranald MOD1 **Groundwater Model 'BAL3.0'**	

1. SUMMARY

This brief statement summarises the outcomes of a peer review of the 'BAL3.0' modelling conducted for the groundwater comparative impact assessment (GCIA) of the Balranald Mineral Sands Project Modification 'MOD1' project. MOD1 involves an innovative directional borehole underground mining method via pressure-neutral injection of process water and extraction of a sand-water slurry. While the pressure-neutral mining process itself is not simulated in the BAL3.0 model, the injection of sand fines into the stope voids is simulated, along with the subsidence induced changes to vertical hydraulic conductivity.

This peer review was conducted by Hugh Middlemis in March/April 2022 in accordance with the best practice principles of the Australian Groundwater Modelling Guideline ('AGMG'; Barnett et al. 2012). The peer review outcomes are summarised using the AGMG compliance summary checklist (after Table 9-1 of Barnett et al. 2012), presented as Table 1 below, with further discussion on some details outlined later.

The main evidentiary basis for this peer review was the report on the 'BAL3.0' model version that was developed specifically for the Balranald MOD1 project (EMM 2022), upgrading the BAL2 model (EMM 2015) that was also reviewed by Hugh Middlemis, confirming that it has been developed consistent with best practice groundwater modelling guidelines and is fit for the purpose of mining project impact assessment (HydroGeoLogic 2015a,b). The BAL2 model formed the quantitative basis for the groundwater assessment component of the 2015 environmental impact statement that resulted in project approval for SSD-5285. It is understood that the MOD1 changes require a groundwater comparative impact assessment (GCIA) to be conducted, with upper and lower range ('end-member') parameter values applied to BAL3.0 simulations, demonstrating that MOD1 groundwater effects are (much) less than the 2015 project approval assessment.

The BAL3.0 model purpose is to provide the quantitative basis for the GCIA by simulating the effects from MOD1 groundwater-affecting activities:

- injection of sand fines ('slimes') into the underground stope voids
- seepage from sand tailings emplaced at surface
- temporal changes to aquifer vertical hydraulic conductivity to represent subsidence due to mining
- groundwater supply pumping from the saline Loxton-Parilla Sands aquifer and the deeper brackish Olney Formation aquifer
- solute transport of PAX solute (potassium amyl xanthate) from tails deposition and fine sands injection.

The BAL3.0 groundwater modelling has been conducted consistent with best practice methods and a Class 2 model confidence level is well justified, confirming its fitness for mining project impact assessment and groundwater management purposes.

2. Model Design and Calibration

The BAL2.0 hydrogeochemically-constrained conceptual hydrogeological model (Jacobs 2015, figure 2.28) has been retained for BAL3.0, along with the numerical model domain, layer structure and boundary conditions from the BAL2 model (Figure 1). These aspects have previously been peer reviewed (Middlemis 2015a,b) and found to be fit for purpose.

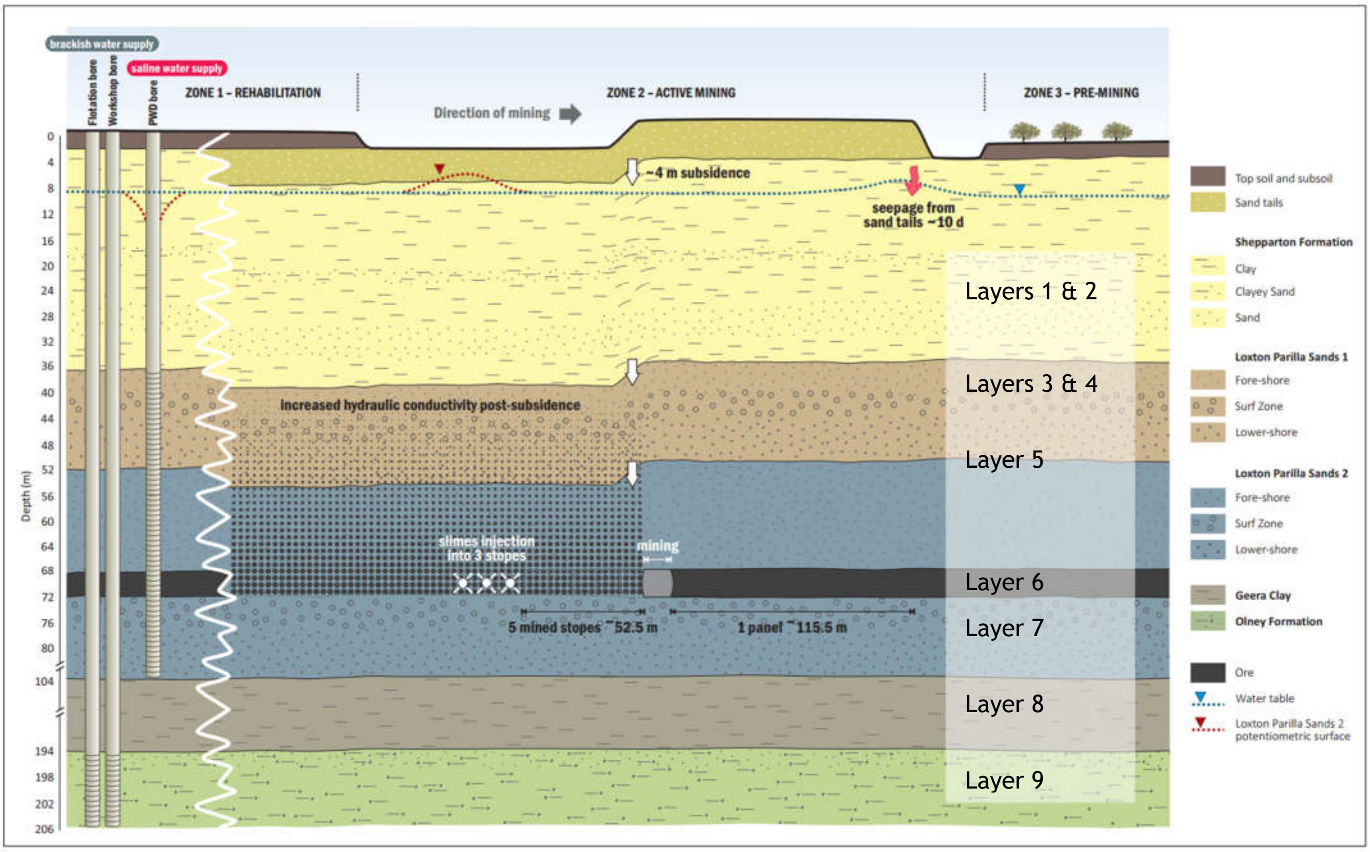

Figure 1 - BAL3.0 conceptual model, with layers indicated schematically (after EMM 2022 Figure 1.3)

The numerical modelling package has been upgraded for BAL3.0, from the Modflow-Surfact used for BAL2 to the latest and industry-leading Modflow-USG (fulfilling a recommendation from the previous peer reviews; Middlemis 2015a,b).

The previous rectangular grid has been upgraded to a well-designed Voronoi polygon mesh with cell sizes of about 1000 m regionally, reducing to 100 m near rivers, 50 m across the lease areas outside the MOD1 area, 10.5 m within the MOD1 area and 0.25 m at abstraction and injection wells used for history-matching. The new mesh allows for the integration within the BAL3.0 model of the previous local scale models at the various test/trial sites (TN5, TN1, LTT, Nanda, Upson Downs, T3), and for the actual pinching out of aquifer layers rather than the 'thin dummy layer' approach applied previously.

The numerical solution parameters were carefully designed in terms of the temporal discretisation for the various tests/trials, including using adaptive time-stepping, to carefully represent the underground mining process, along with the advanced Modflow-USG SMS solver and sub-millimetre head change criteria. The water balance documentation provides evidence of accurate simulations (EMM 2022, section 3.3). The calibrated aquifer parameter values are consistent with the known regional property values and the values from the site-specific testing conducted since 2009 (Jacobs 2015; EMM 2022).

The previous SRTM topography dataset has been updated with more accurate LiDAR data and a 5 metre DEM that was re-sampled directly at the model nodes. This significantly improves the simulation of dynamic surface-groundwater interactions (eg. depth-dependent evapotranspiration, river-aquifer exchanges).

The BAL3.0 steady state model calibration performance was benchmarked to the BAL2 model in terms of the scaled RMS value (11.3% for BAL3.0 and 11.2% for BAL2; EMM 2022, Figure 3.6). It is noted that the steady state calibration is designed simply to establish the initial conditions for the transient simulations.

Although the steady state calibration scaled RMS value slightly exceeds the nominal 10% criterion (Barnett et al. 2012), the steady state performance is acceptable for the stated purpose (noting also that the transient calibration scaled RMS performance is less than the preferred 5% criterion).

The BAL3.0 transient model calibration to data at the various test/trial site data (TN5, TN1, LTT, Nanda, Upson Downs) is very similar to that for BAL2 (EMM 2022, Table 3.1). The time series matches are also very similar to BAL2, improved in some cases, although poor matches apply to data from some pumping or injection bores, which is a common model limitation and the justifications provided are adequately explained. The transient calibration has a justified emphasis on matching later time data from the T3

The T3 trial of the innovative directional borehole underground mining method in 2020 provided site-specific data on groundwater responses and associated subsidence effects expected for MOD1, including the injection of fine sands to underground stopes and seepage from sand tails at the surface. This has allowed calibration of the BAL3.0 time-varying materials (TVM) changes, notably increased vertical hydraulic conductivity for LPS in layers 4 and 5 (see EMM 2022, Table 3.3), and confirmation of the model fitness for purpose and performance for MOD1 effects. There is reportedly no evidence of change to the horizontal hydraulic conductivity parameters due to the mining process and the associated injection of fine sands to the underground stopes. For the T3 trial, the BAL3.0 transient model scaled RMS is 4.5% (EMM 2022, Table 3.1), with mostly very good time series matches. Some early time data from the T3 test was reasonably removed from the calibration assessment at some bores, because the T3 test procedure had not yet achieved the reliable methods of ensuring pressure-neutral conditions that were subsequently assured.

These improvements mean that the BAL3.0 model is now suitable for regional and local scale investigations of traditional mining or innovative underground mining effects, with greatly improved run times that will facilitate efficient uncertainty analysis. Overall, the model calibration performance is sound and the BAL3.0 model is fit for the intended purposes.

3. Solute Transport and End-member Sensitivity Analysis

The BAL3.0 base case predictions (indicative of 'most likely' effects) have a focus on the propagation of piezometric levels (drawdown and mounding), and comparison with the previous BAL2 assessment (ie. as required for the MOD1 groundwater comparative impact assessment). This is supported by the solute transport simulations of PAX migration associated with seepage from the sand tails deposited at the surface and the sand fines injected to the underground stopes. The key solute transport parameters were adequately justified in terms of the first order decay half-life (12 weeks), dispersivity (100m horizontal and 10m vertical) and porosity (15%).

Predictive uncertainty was evaluated via alternative parameter or 'alt-par' simulations that applied end-member values to represent high throughput (alt par 1) and low throughput (alt par 2), where throughput refers to dewatering and injection, and with a third very conservative scenario of solute transport without first-order decay. The report adequately justifies the base case and the three extreme 'alt-par' scenarios as providing predictions that bookend the MOD1 effects in terms of the comparative groundwater impact assessment, consistent with recent guidance on uncertainty analysis (Middlemis and Peeters, 2018). The qualitative uncertainty analysis narrative (EMM 2022, sections 4.2, 4.3.2) is also insightful.

The prediction scenarios show a small-range variability in results, and comparatively much less than the previous BAL2 impact assessment (Jacobs 2015).

4. Model Confidence Level Classification

The AGMG sets out a model confidence classification schema that aims to describe the resources applied to the modelling and accordingly evaluate the degree of confidence in model predictions. The evaluation is based on considerations of the hydrogeological conceptual model and the data available, especially aquifer responses to hydrological stresses, as well as the model design, construction and performance. It is expected that any model will have attributes that fall into more than one 'class', with the overall 'confidence level' indicated from the weight of criteria that are met.

This review conducted an independent assessment of the model confidence level, consistent with the AGMG and applying the refinements outlined in the IESC uncertainty guidance (Middlemis and Peeters 2018). A Class 2 model confidence level is well justified, confirming its fitness for purpose.

Yours sincerely,

HydroGeoLogic Pty Ltd

Hugh Middlemis

(Principal Groundwater Engineer)

5. References

Barnett B, Townley L, Post V, Evans R, Hunt R, Peeters L, Richardson S, Werner A, Knapton A and Boronkay A. (2012). Australian Groundwater Modelling Guidelines. Waterlines report 82, National Water Commission, Canberra. http://webarchive.nla.gov.au/gov/20160615064846/http://archive.nwc.gov.au/library/waterlines/82.

EMM (2022). Balranald Mineral Sands Project MOD1 Groundwater Modelling. Prepared for Iluka Resources Limited. April 2022.

Jacobs (2015). Balranald Project DFS1 Groundwater Modelling. Impact Assessment Modelling. Prepared for Iluka Resources. Jacobs document no. T18466, draft revision B, dated 23 February, 2015.

Middlemis H. (2015a). Balranald Project Groundwater Model Review (BAL2.0, March 2015). Prepared for Iluka Resources Limited.

Middlemis H. (2015b). Balranald Project Groundwater Model Review (BAL2.1, May 2015). Prepared for Iluka Resources Limited.

Middlemis H and Peeters LJM. (2018; update in prep. 2022). Uncertainty analysis - Guidance for groundwater modelling within a risk management framework. Prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development. http://www.iesc.environment.gov.au/publications/information-guidelines-explanatory-note-uncertainty-analysis

Middlemis H, Walker G, Peeters L, Richardson S, Hayes P, Moore C. (2019). Groundwater modelling uncertainty – implications for decision making. Summary report of the national groundwater modelling uncertainty workshop, 10 July 2017, Sydney, Australia. Flinders University, National Centre for Groundwater Research and Training. http://groundwater.com.au/news_items/groundwater-modelling-uncertainty

Middlemis H, Merrick N, Ross J, and Rozlapa K. (2001). Groundwater Flow Modelling Guideline. Prepared for Murray–Darling Basin Commission by Aquaterra, January 2001. www.mdba.gov.au/sites/default/files/archived/mdbc-GW-reports/2175_GW_flow_modelling_guideline.pdf

6. Declaration

For the record, the reviewer, Hugh Middlemis, is an independent modelling specialist with a bachelor degree in engineering and a masters in hydrogeology, and more than 40 years' Australian and international experience. Hugh established HydroGeoLogic as an independent consultancy in 2013, with core business including independent peer reviews for government and catchment management authorities, mining companies and consulting firms, and contributing to expert panels and providing expert witness services.

Hugh was principal author of the first Australian groundwater modelling guidelines (Middlemis et al. 2001) that formed the basis for the latest guidelines (Barnett et al. 2012) and was awarded a Churchill Fellowship in 2004 to benchmark groundwater modelling best practice. He is principal author on two guidance reports on modelling uncertainty (Middlemis and Peeters 2018 (update in prep. 2022); and Middlemis et al. 2019).

We assert no conflict of interest in relation to this work. The peer reviewer, Hugh Middlemis, has not worked directly on the Balranald Mineral Sands Project, nor for Iluka Resources, nor for EMM Consulting, other than as an independent reviewer.

We note that the peer reviewer's son (Roger Middlemis) has worked for EMM Consulting since March 2019 as an environmental engineer in their Adelaide office, and we understand that he did contribute to the groundwater modelling and reporting tasks.