SARAJI EAST MINING LEASE PROJECT

Environmental Impact Statement

Appendix F-2

Groundwater Modelling Peer Review

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DATE: 14 June 2023

TO: AECOM Australia Pty Ltd
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FROM: Dr Noel Merrick

RE: **Saraji East Mining Lease Project** – Groundwater Model Peer Review

YOUR REF: Letter of Engagement 13 June 2022

OUR REF: HA2023/6

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1. Introduction

This report provides a peer review of the groundwater modelling technical assessment that underpins the groundwater impact assessment (GIA) for the Saraji East Mining Lease Project (SEMLP) (the Project). The technical assessment has been prepared by SLR Consulting Australia Pty Ltd (SLR) and the GIA has been prepared by AECOM Australia Pty Ltd (AECOM), for the client BM Alliance Coal Operations Pty Ltd (BMA). The Project is an underground metallurgical coal mine development within the Bowen Basin, Queensland, to the immediate east of BMA's Saraji open cut coal mines, and about 60 km south-east of Moranbah. It also lies about 3 km due west of the Lake Vermont Meadowbrook Project, about 160 km south-west of Mackay.

Updated groundwater modelling was undertaken to support responses to submissions received on the SEMLP Environmental Impact Statement approval submission prepared by AECOM (2019)[1].

The main elements of the Project that are relevant to groundwater assessment are:

- Life of Project approximately 21 years.
- Longwall mining with associated fracturing and land subsidence.
- Mining of the Dysart Lower D seam in the Moranbah Coal Measures.
- Many surrounding coal mines and one coal seam gas operation to the east.

The Project is a greenfield single-seam underground coal mine consisting of 17 longwall panels, adjacent to active open cut coal mines, targeting the Dysart Lower D seam (D14/D24) at the base of the Moranbah Coal Measures. Mining is to be at least 15 km from the Isaac River, and the northern longwall panels will pass beneath Boomerang Creek. No alluvium will be undermined.

It should be noted that the groundwater modelling technical assessment is not a full GIA, and consequently this review is limited in scope to the adequacy of the groundwater modelling component.

[1] AECOM, 2019. Saraji East Mining Lease Project, Environmental Impact Statement Appendix F-1, Groundwater Technical Report, Project No. 60507031

2. Documentation

This review is based on the following report:

1. SLR, 2023. Saraji East Mining Lease Project Groundwater Modelling Technical Report. Report 620.31025.00000-R01-v4.1 prepared for AECOM, May 2023. 101p (main) + 6 Appendices.

Previous modelling results as well as background information are in this report:

2. AECOM, 2019. Saraji East Mining Lease Project Groundwater Technical Report. Prepared for BM Alliance Coal Operations Pty Ltd. Project No. 60507031. Appendix F-1 in Environmental Impact Statement. February 2019. 123p (main) + 4 Appendices.

Document #1 has the following major sections:

1. Introduction
2. Model Construction and Development
3. Predictive Modelling
4. Recovery Model
5. Sensitivity Analysis
6. Uncertainty Analysis
7. Model Confidence Level Classification
8. Groundwater Model and Data Limitation
9. Conclusions
10. References

The Appendices are:

A. Calibration Residuals
B. Calibration Hydrographs
C. Hydraulic Parameters and Recharge Zone Distribution
D. Stress Periods and Simulated Active Mine Timings
E. Cumulative Drawdown Predictions
F. Uncertainty Analysis Parameter Distributions

Document #2 is structured as follows:

1. Introduction
2. Scope of assessment
3. Legislation and policy
4. Methodology
5. Description of environmental values
6. Potential impacts
7. Mitigation measures
8. Residual impacts
9. Summary and conclusion
10. References.

The Appendices are:

A. Water Quality Results
B. Simulated Water Level Hydrographs
C. Exploration Holes
D. Mine Ingress Sensitivity

This review is limited to Document #1. However, Document #2 provides relevant background information not included in Document #1.

3. Review Methodology

There are two accepted guides to the review of groundwater models: the Murray-Darling Basin Commission (**MDBC**) Groundwater Flow Modelling Guideline[2], issued in 2001, and guidelines issued by the National Water Commission (**NWC**) in June 2012 (Barnett *et al.*, 2012[3]).

The NWC national guidelines were built upon the original MDBC guide, with substantial consistency in the model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details.

The NWC guide promotes the concept of "model confidence level", which is defined using a number of criteria that relate to data availability, calibration, and prediction scenarios. The NWC guide is almost silent on coal mine modelling and offers no direction on best practice methodology for such applications. There is, however, an expectation of more effort in uncertainty analysis, although the guide is not prescriptive as to which methodology should be adopted.

Guidelines on uncertainty analysis for groundwater models were issued by the Independent Expert Scientific Committee (**IESC**) on Coal Seam Gas and Large Coal Mining Development in February 2018 in draft form and finalised in December 2018[4].

The groundwater guides include useful checklists for peer review. This groundwater assessment has been reviewed according to the 137-question Review Checklist in NWC (2012). This checklist has questions on (1) Planning; (2) Conceptualisation; (3) Design and construction; (4) Calibration and sensitivity; (5) Prediction; (6) Uncertainty; (7) Solute transport[5]; and (8) Surface water-groundwater interaction. In addition, this review includes the 10-question Compliance Checklist in NWC (2012).

This review has been conducted progressively through attendance at seven video-conference workshops at key project milestones, several direct discussions with the modelling team, and review of progress reports and slideshow presentations. Video-conference meetings were held on the following dates in 2022: 26 July, 4 August, 8 August, 25 August, 7 September, 26 October with a final discussion on 14 March 2023. A log of issues was prepared for consideration in the preparation of the final report. Most issues have been addressed satisfactorily, apart from inclusion of a conceptual model graphic and a map of the monitoring bore network.

4. Checklists

Checklist assessments are provided in **Table 1** and **Table 2**.

Table 1 is the NWC Compliance Checklist, which concludes that the groundwater model is “fit for purpose”, where the purpose is defined by the model objectives in Section 1.2 of Document #1:

- Estimate the groundwater inflow to the SEMLP mine workings as a function of mine position and timing.
- Simulate and predict the extent of groundwater level drawdown due to the SEMLP.
- Identify areas of potential environmental risk, where groundwater impact management measures may be necessary.

Table 2 provides a detailed assessment according to the NWC (2012) guide, excluding the inapplicable *Conceptualisation* and *Solute transport* sets of questions.

Supplementary comments are offered in Sections 5, 6 and 7.

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[2] MDBC (2001). Groundwater flow modelling guideline. Murray-Darling Basin Commission.

[3] Barnett, B, Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A. and Boronkay, A. (2012). *Australian Groundwater Modelling Guidelines*. Waterlines report 82, National Water Commission, Canberra.

[4] Middlemis H and Peeters LJM (2018) *Uncertainty analysis—Guidance for groundwater modelling within a risk management framework*. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy, Commonwealth of Australia 2018.

[5] Not relevant to this assessment (15 questions)

Table 1. Compliance Checklist

Question	***Yes/No***
1. Are the model objectives and model confidence level classification clearly stated?	(1) Yes (2) Yes
2. Are the objectives satisfied?	Yes
3. Is the conceptual model consistent with objectives and confidence level classification?	Yes
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Yes
5. Does the model design conform to best practice?	Yes
6. Is the model calibration satisfactory?	Yes
7. Are the calibrated parameter values and estimated fluxes plausible?	Yes
8. Do the model predictions conform to best practice?	Yes
9. Is the uncertainty associated with the predictions reported?	Yes
10. Is the model fit for purpose?	Yes

Table 2. Review checklist (2012 National Guidelines)

Review questions	*Yes/No*	*Comment*
1. Planning		
1.1 Are the project objectives stated?	N/A	Relevant to a GIA only.
1.2 Are the model objectives stated?	Y	S1.2 Three objectives (inflow, drawdown, environmental risk)
1.3 Is it clear how the model will contribute to meeting the project objectives?	Y	
1.4 Is a groundwater model the best option to address the project and model objectives?	Y	No alternative
1.5 Is the target model confidence-level classification stated and justified?	Y	Table 7-1. Mostly Class 3. Counts: 1 (class 1), 5 (class 2), 11 (class 3).
1.6 Are the planned limitations and exclusions of the model stated?	Y	Table 8-1.
2. Conceptualisation		***Covered by AECOM (2019)***
3. Design and construction		
3.1 Is the design consistent with the conceptual model?	Y	Key processes are included.
3.2 Is the choice of numerical method and software appropriate?	Y	MODFLOW-USG + AlgoMesh + PEST.
3.2.1 Are the numerical and discretisation methods appropriate?	Y	Voronoi grid for internal spatial detail. Temporal periods are appropriate – quarterly for calibration; yearly for prediction.
3.2.2 Is the software reputable?	Y	State-of-art.
3.2.3 Is the software included in the archive or are references to the software provided?	OK	References. AlgoMesh is proprietary.
3.3 Are the spatial domain and discretisation appropriate?	Y	Total 1.36million cells.
3.3.1 1D/2D/3D		3D
3.3.2 lateral extent		About 60km x 95km
3.3.3 layer geometry?		19 layers.
3.3.4 Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model and target confidence level classification?	Y	Min 50m cell size.
3.3.5 Is the vertical discretisation appropriate? Are aquitards divided in multiple layers to model time lags of propagation of responses in the vertical direction?	Y N	19 layers. Aquitards are individual layers – a pragmatic compromise with so many layers and a model size already >1 million cells.
3.4 Are the temporal domain and discretisation appropriate?	Y	
3.4.1 steady state or transient		Both
3.4.2 stress periods	Y	58 SP for warm-up (20 yrs 1988-2007) and calibration (qtly Jan.2008-Dec.2021). Stress periods are suitable.
3.4.3 time steps?	Y	Model uses ATS (S2.5) – automatic time stepping – to set dynamic time steps.
3.5 Are the boundary conditions plausible and sufficiently unrestrictive?	Y	Same as Caval Ridge and Meadowbrook applications which were extended to north and west from prior models and reduced on eastern edge.

Table 2. Review checklist (2012 National Guidelines)

Review questions	*Yes/No*	*Comment*
3.5.1 Is the implementation of boundary conditions consistent with the conceptual model?	Y	
3.5.2 Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained?	Y	Sufficiently distant.
3.5.3 Is the calculation of diffuse recharge consistent with model objectives and confidence level?	Y	8 zones based on lithology.
3.5.4 Are lateral boundaries time-invariant?	Y	
3.6 Are the initial conditions appropriate?	Y	Based on steady-state pre-1988
3.6.1 Are the initial heads based on interpolation or on groundwater modelling?		Model
3.6.2 Is the effect of initial conditions on key model outcomes assessed?	N	But buffeted by intervening warm-up period
3.6.3 How is the initial concentration of solutes obtained (when relevant)?	N/A	
3.7 Is the numerical solution of the model adequate?	Y	
3.7.1 Solution method/solver		USG solver and options are not stated
3.7.2 Convergence criteria		Mass discrepancy 0.0%
3.7.3 Numerical precision		Assumed single
4. Calibration and sensitivity		**Jan.2008-Dec.2021**
4.1 Are all available types of observations used for calibration?	Y	Heads quantitatively and fluxes qualitatively.
4.1.1 Groundwater head data	Y	3,449 target heads at 281 bores; 34 local SEMLP sites. Fewer targets than predecessor models due to sampling density. Weights normalised to sampling frequency. *No map of monitoring bore network other than display of calibration residuals (Fig.2.9)*.
4.1.2 Flux observations	Y	Not sufficiently reliable for quantitative targets. Reality check carried out: list of predicted inflows to each of 7 mines (S2.6.5.2) – 0.3 to 1.6 ML/day.
4.1.3 Other: environmental tracers, gradients, age, temperature, concentrations etc.	N	No use of horizontal or vertical gradients for calibration. No statement on consistency of vertical gradients.
4.2 Does the calibration methodology conform to best practice?	Y	PEST + manual. Multiple calibrated model realisations (ensemble of 550 models; 95 calibration-constrained).
4.2.1 Parameterisation		Laterally uniform in lithologies (no pilot points). Vertical depth functions enable some spatial variability.
4.2.2 Objective function	Y	PEST phi (sum of squares) 275,360 m^2.
4.2.3 Identifiability of parameters	Y	Section 5.1.2 (GENLINPRED software).
4.2.4 Which methodology is used for model calibration?		PEST + manual.
4.3 Is a sensitivity of key model outcomes assessed against…?	Y	Section 5.1 (Identifiability).

Table 2. Review checklist (2012 National Guidelines)

Review questions	*Yes/No*	*Comment*
4.3.1 parameters	Y	Kx, Kz/Kx, Sy, Ss
4.3.2 boundary conditions	N	*Not essential*
4.3.3 initial conditions	N	*Not essential*
4.3.4 stresses	Y	Recharge
4.4 Have the calibration results been adequately reported?	Y	Section 2.6.
4.4.1 Are there graphs showing modelled and observed hydrographs at an appropriate scale?	Y	Figures 2-10 to 2-12; alluvium/Tertiary, Permian, other.
4.4.2 Is it clear whether observed or assumed vertical head gradients have been replicated by the model?	N	Not clear as multilevel/VWP plots are individual rather than stacked. Not clear which bores are paired. PZ09 (NW of longwalls) shows replicated vertical gradient. Bore PZ09A: obs.205->176; sim.210->201mAHD. Bore PZ09B: obs.166; sim.166mAHD. Bore PZ09C: obs.133; sim.133mAHD.
4.4.3 Are calibration statistics reported and illustrated in a reasonable manner?	Y	Table 2-5 (best calibrated model): key statistics 5.9 %RMS, 8.9 mRMS (global); <unstated> %RMS, 8.4 mRMS (local).
4.5 Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated?	Y	Scattergrams regional (Figure 2-6) and SEMLP only (Figure 2-7) – generally linear over a wide range of elevations (~100 m) – weaker at low levels <140 mAHD. Histogram (Figure 2-8). Calibration generally good close to SEMLP.
4.5.1 spatially	Y	Residuals by layer (Table 2-6) and by site (Table 2-7). SEMLP ranks 8th of 15 sites for average absolute residual (7.0 m). Average residual spatial map (Fig.2-9) and Appendix A table.
4.5.2 temporally	Y	Figures 2-10 to 2-12 (alluvium/Tertiary; Permian; other); Appendix B (259 calibration hydrographs).
4.6 Are the calibrated parameters plausible?	Y	Tables 2-11 to 2-13. Recharge rates similar to predecessor models (0.01-0.4%). Rewan (not at site) permeabilities are higher than predecessor models.
4.7 Are the water volumes and fluxes in the water balance realistic?	Y	In cumulative simulations 1988-2021, Isaac River is losing on the whole (Table 3-2; 2.6 ML/d), and losing a little less for the null run (Table 3-3; 2.1 ML/d). Total mine inflow 1988-2021 (6.3 ML/day average) is the sum of 7 mine inflows from 0.3 to 1.6 ML/day (S2.6.5) - of the right order.
4.8 has the model been verified?	N	No data have been withheld from calibration – normal practice.

Table 2. Review checklist (2012 National Guidelines)

Review questions	*Yes/No*	*Comment*
5. Prediction		**Jan.2021-Dec.2043 + recovery (2000 years)**
5.1 Are the model predictions designed in a manner that meets the model objectives?	Y	• *"estimate the groundwater inflow to the SEMLP mine workings as a function of mine position and timing;* • *simulate and predict the extent of groundwater level drawdown due to the SEMLP; and* • *identify areas of potential risk, where groundwater impact mitigation/control measures may be necessary."* All objectives are able to be assessed by the model design.
5.2 Is predictive uncertainty acknowledged and addressed?	Y	In Section 6.
5.3 Are the assumed climatic stresses appropriate?	OK	Not stated but normal practice is long-term average (no seasonality).
5.4 Is a null scenario defined?	Y	
5.5 Are the scenarios defined in accordance with the model objectives and confidence level classification?	Y	With and without Project including cumulative effects. Compared with null case.
5.5.1 Are the pumping stresses similar in magnitude to those of the calibrated model? If not, is there reference to the associated reduction in model confidence?	Y	Change of mining type from open cut to underground adds some uncertainty (esp. fracture height), but reduced by underground knowledge at neighbouring mines.
5.5.2 Are well losses accounted for when estimating maximum pumping rates per well?	N	Pre-drainage rates for gas wells are included for 8 years. Only 0.02 ML/d average over the period of underground mining.
5.5.3 Is the temporal scale of the predictions commensurate with the calibrated model? If not, is there reference to the associated reduction in model confidence?	Y	Calibration: quarterly. Prediction: annual and then 5-yearly to 2095 (unstated beyond then).
5.5.4 Are the assumed stresses and timescale appropriate for the stated objectives?	Y	
5.6 Do the prediction results meet the stated objectives?	Y	The three stated objectives at Q5.1 are assessed.
5.7 Are the components of the predicted mass balance realistic?	Y	In Section 3.2. There is a reality check for simulated mine inflow compared to historical takes during calibration (S2.6.5.2).
5.7.1 Are the pumping rates assigned in the input files equal to the modelled pumping rates?	N/A	
5.7.2 Does predicted seepage to or from a river exceed measured or expected river flow?	N	Exchange rates very much less than river flow. Predicted change in Isaac River leakage due to the Project is negligible. In cumulative simulations, Isaac River is losing on the whole (Table 3-2; 6.6 ML/d), and slightly losing for the null run (Table 3-3; 2.1 ML/d).

Table 2. Review checklist (2012 National Guidelines)

Review questions	*Yes/No*	*Comment*
5.7.3 Are there any anomalous boundary fluxes due to superposition of head dependent sinks (e.g. evapotranspiration) on head-dependent boundary cells (Type 1 or 3 boundary conditions)?	N	Not evident.
5.7.4 Is diffuse recharge from rainfall smaller than rainfall?	Y	Percentage << 100%.
5.7.5 Are model storage changes dominated by anomalous head increases in isolated cells that receive recharge?	N	Not evident.
5.8 Has particle tracking been considered as an alternative to solute transport modelling?	N	Not required
6. Uncertainty		
6.1 Is some qualitative or quantitative measure of uncertainty associated with the prediction reported together with the prediction?	Y	Qualitative in Table 8-1. Quantitative stochastic analysis in Section 6.
6.2 Is the model with minimum prediction-error variance chosen for each prediction?	Y	"Most likely" prediction is based on model with lowest %RMS. Proof of convergence in Figures 6-7 (pit inflow) and 6-8 (max.drawdown).
6.3 Are the sources of uncertainty discussed?	Y	Quantified through identifiability analysis. Significance assessed by Type I – Type IV analysis (Figs.5-6,5-7).
6.3.1 measurement of uncertainty of observations and parameters	Y	Parameters, not observations – but QA performed.
6.3.2 structural or model uncertainty	Y	Discussed in Table 8-1. Normal practice is to implement a single model geometry.
6.4 Is the approach to estimation of uncertainty described and appropriate?	Y	Robust and extensive (IESC Type 3). Latin Hypercube Sampling.
6.5 Are there useful depictions of uncertainty?	Y	Compliant with IESC guide. Colour-coded graph and probability maps.
7. Solute transport	N/A	
8. Surface water–groundwater interaction		
8.1 Is the conceptualisation of surface water–groundwater interaction in accordance with the model objectives?	Y	• *"Identify areas of potential risk, where groundwater impact mitigation/control measures may be necessary."* Potential for enhanced leakage is assessed.
8.2 Is the implementation of surface water–groundwater interaction appropriate?	Y	RIV for Isaac River. DRN for creeks
8.3 Is the groundwater model coupled with a surface water model?	N/A	Project is an underground mine.
8.3.1 Is the adopted approach appropriate?		
8.3.2 Have appropriate time steps and stress periods been adopted?		
8.3.3 Are the interface fluxes consistent between the models?		

5. Report Matters

The reviewed report is a high-quality document of about 100 pages length, with an additional ~100 pages in six Appendices that contain information on model calibration performance, model parameterisation, modelled time periods, drawdown predictions and parameter distributions used in uncertainty analysis. The report is structured appropriately with sufficient detail and disclosure of methods and results. Posterior distributions for the uncertainty analysis are compared appropriately with prior distributions.

As the report is a technical modelling report, it is not a standalone document. It relies on earlier/concurrent groundwater assessments for reporting of groundwater data, development of hydrogeological conceptualisation and details of the groundwater monitoring network. Inclusion of a map of the monitoring network with bores classified as to screened formation would have been informative.

The report includes a *Conclusions* section with a summary of the key findings of the groundwater modelling; namely, predicted groundwater inflows to the Project's mine and consequent effects/impacts expressed as probabilistic groundwater drawdowns and changes in surface water – groundwater exchanges.

Progressive review comments on factual and editorial matters were considered by SLR and have been accommodated satisfactorily in revisions of the reports.

The groundwater modelling objectives are stated clearly in the report at the outset (Section 1.2) in the form of three dot points:

- *Estimate the groundwater inflow to the SEMLP mine workings as a function of mine position and timing.*
- *Simulate and predict the extent of groundwater level drawdown due to the SEMLP.*
- *Identify areas of potential environmental risk, where groundwater impact management measures may be necessary.*

The model has been constructed and applied to address these objectives satisfactorily.

Overall, there are no significant matters of concern in the report as to structure or depth of coverage.

6. Model Matters

The SEMLP groundwater model has developed from the well-received groundwater model for the approved Olive Downs South Coking Coal Project to the east of the Project. This foundational model has undergone a number of updates for more precise geometry at individual coal mines. For this Project, the model has retained the same extent as for a recent investigation for the Caval Ridge Mine, which at that time was extended to the north and north-west beyond Moranbah and also farther west. Model cell sizes vary spatially across the modelled area, with 100 m cell dimensions applied for the Project longwalls.

The reviewer concurs with the entire modelling methodology described in Document #1 and recognises it as "state-of-art".

Key features of the modelling approach are:

- MODFLOW-USG plus AlgoMesh software platform for better mass balance and better spatial resolution;

- conventional PEST calibration for steady-state and transient conditions;

- application of an identifiability procedure during the calibration process to replace sensitivity analysis by perturbation, in which many more model properties can be included, and relative sensitivities are produced as a matter of course; the downside is an absence of reporting on calibration performance (if a sensitive parameter were varied); the considered parameters are horizontal hydraulic conductivity, hydraulic conductivity anisotropy, specific storage, specific yield and diffuse recharge; the highest identifiabilities were found for horizontal hydraulic conductivity and recharge;

- assessment of the sensitivity of the magnitude of key model predicted outputs by a Type I to IV identifiability analysis; the considered outputs are pit inflows and maximum cumulative drawdown; for pit inflows, four anisotropies and one specific yield are significant as having the potential to cause large changes in predictions for small changes in their adopted values; for maximum drawdown, two anisotropies, two specific yields and two specific storages are found to present risk; and

- a *monte carlo* style rigorous procedure for uncertainty analysis.

The model extent is necessarily large, being about 60 km in an east-west direction and about 95 km in a north-south direction. Given the large area and 19 layers, a minimum cell dimension of 50 m, and incorporation of many neighbouring open cut and underground mines, a total cell count of 1.36 million remains efficient but is close to the limit of a manageable model size. Separate layers are designated for four coal seams (Q, P, H, D) in the Moranbah Coal Measures, seam D being the underground mining target. Many structural faults are included in the wider model as zones of finer discretisation (100 m) with properties separate from the host materials. Consideration was given to the likely presence/absence of the nearest fault that is positioned along the eastern edge of the Project longwalls; it has been given a substantial length in the model, as was originally applied in the Olive Downs model.

Comparison of Tables 2-10 and 2-11 for the best calibrated model suggests similar horizontal permeability in the Moranbah Coal Measures and the faults, but generally higher permeability in the faults than in younger formations overlying the Moranbah Coal Measures. However, Section 5.1.1 notes that "*The horizontal hydraulic conductivity of most of the faults generally has not been able to be constrained well during calibration, relative to their surrounding unit*". The average horizontal hydraulic conductivity ranges from 0.0019 m/day in Layer 19 to 0.0098 m/day in Layer 3, with assumed log-linear decay through intervening layers. During calibration-constrained uncertainty analysis, no conceptual constraint was placed on faults as to whether they might be barriers or conduits.

Modelling of underground mines requires assumptions as to the degree of fracturing above the mined coal seam and the enhancement of permeabilities and storage properties in the fracture zone. As the longwall panel width is broad (320 m) and the cutting height is high (3.6 m), a substantial vertical fracture zone is to be expected. A separate subsidence assessment by Minserve (2022)[6] based on FLAC-3D geotechnical modelling provided estimates of the degree of subsurface fracturing and surface cracking, as well as estimates of enhanced permeabilities and porosities. A simplification has been adopted in the groundwater model, generally complying with Minserve's advice. The fracture zone is taken to merge with the cracking zone for D-seam depths of cover less than 300 m, giving continuous vertical connectivity over most of the southern panels and the western half of the northern panels. As surface cracks are assumed not to heal in the groundwater model, and to be pervasive over the mining footprint, the simulated effects of fracturing/cracking are likely to be highly conservative in the opinion of this reviewer. A uniform multiplier of 100 for the vertical hydraulic conductivity in the fracture zone adds to the degree of conservatism.

In terms of model confidence level classifications, Document #1 states:

[6] Minserve, 2022. Subsidence over Longwall Panels Saraji East Underground Mine. Report for AECOM Australia Pty Ltd. 20 May 2022.

"...the SEMLP groundwater model can be classified as primarily Class 3 using the 2012 Australian Groundwater Modelling Guidelines classification system (effectively "high confidence"), with some aspects meeting the lower Class 2 ("medium confidence") criteria."

The reviewer agrees with this conclusion. Although Class 2 is sufficient for mining impact assessment, all models are in fact mixtures of Class 1, Class 2 and Class 3. The relative proportions of the different classes have been established by annotating the classification table of attributes in the IESC Explanatory Note on Uncertainty Analysis, reproduced as Table 7-1 in Document #1. This classifies the model as about 65% Class 3, about 29% Class 2, and about 6% Class 1.

Visual hydrographic history matching is exceptionally good at Permian monitoring sites affected by Saraji open cut mining, as illustrated in Figure 2-11 of Document #1. Elsewhere, calibration performance is generally good in most areas of the model, based on 3,449 measurements of groundwater level at 281 sites, with overall statistics of 5.9 %RMS and 8.9 mRMS (similar to predecessor models). Locally, at 34 sites, the absolute performance (8.4 mRMS) is better but the relative performance (in %RMS) is not stated. Table 2-7 in Document #1 shows that the SEMLP site ranks 8th of 15 sites in terms of average absolute residual (7.0 m). Scattergrams are generally linear with a mild tendency to over-estimation of heads at elevations lower than about 140 mAHD. Although the report has not focused on vertical head gradients, they are well replicated at site PZ09 which is near the north-western corner of the longwalls.

The primary predictive results are presented in Document #1 for the best calibrated model as maps of:

- groundwater level at end of mining in alluvium, regolith and D Seam with and without the Project;
- maximum incremental drawdown (due to the Project alone) for alluvium, regolith and each of the four coal seams in the Moranbah Coal Measures;
- maximum cumulative drawdown for alluvium, regolith, each of the four seams in the Moranbah Coal Measures, and two mined seams (Leichhardt and Vermont) in the Rangal Coal Measures to the east.

A comprehensive IESC-compliant Type-3 uncertainty analysis has been undertaken by means of a *monte carlo* technique, using 95 alternative calibrated realisations out of a trial set of 550 selections (obtained by Latin Hypercube Sampling). The threshold imposed on each simulation required the calibration statistic to be no more than about 30% above the best model, giving a calibration performance range from 5.9 %RMS to 7.9 %RMS. The parameters subject to variation were horizontal hydraulic conductivity, hydraulic conductivity anisotropy, specific yield, specific storage and diffuse recharge. The assumed standard deviations were 0.5 (log10 space) for all properties, which is the standard being adopted by industry practitioners (in the absence of guidelines on this aspect). Proof of convergence, as encouraged by the IESC Explanatory Note on Uncertainty Analysis, is demonstrated for total pit inflow and maximum drawdown.

For progressive pit inflow, the temporal uncertainty results are presented in Document #1 in Figure 6-4 as 10th, 33rd, 50th, 67th and 90th percentiles. The base case model has very similar pit inflow to the 50th percentile of the 95 realisations. This supports, in hindsight, the adoption of the best-calibrated model for demonstrating the most likely spatial drawdowns for a single deterministic model.

The spatial uncertainty results are presented in Document #1 in Figures 6-5 to 6-8 as 5%, 50% and 95% probabilities of exceeding 1 m drawdown in alluvium, regolith, Q and D seams. This establishes areas of potential environmental risk for subsequent assessment of impacts and management measures.

7. Conclusion

The reviewer is of the opinion that the documented groundwater modelling is best practice and concludes that the model is *fit for purpose*, where the purpose is defined by the objectives listed in Document #1:

- Estimate the groundwater inflow to the SEMLP mine workings as a function of mine position and timing.
- Simulate and predict the extent of groundwater level drawdown due to the SEMLP.
- Identify areas of potential environmental risk, where groundwater impact management measures may be necessary.

The groundwater modelling has been conducted to a very high standard and a rigorous *monte carlo* uncertainty analysis offsets much of the uncertainty that is inherent in a groundwater model, as noted in the Limitations Section 8 of Document #1.

The primary output of the uncertainty analysis, with respect to potential off-site impacts, is presented in Document #1 in Figures 6-5 to 6-8 as 5%, 50% and 95% probabilities of exceeding 1 m drawdown in alluvium, regolith, Q and D seams. There is no discernible drawdown in the alluvium at any level of probability. Also, no material impacts on Isaac River seepage or the overlying Boomerang Creek alluvium are anticipated at any level of probability.

The reviewer supports the validity of these conclusions.

NPMerrick

Dr Noel Merrick