HORSE PIT EXTENSION EPBC ACT REFERRAL

APPENDIX G

Groundwater Impact Assessment Third-Party Review Report

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DATE: 13 August 2021

TO: BM Alliance Coal Operations Pty Ltd
480 Queen Street
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FROM: Dr Noel Merrick

RE: Caval Ridge Mine Horse Pit Extension Project – Groundwater Peer Review

YOUR REF: PO 4510585992

OUR REF: HA2021/10

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1. Introduction

This report provides a peer review of the groundwater assessment (GA) and associated modelling for the Caval Ridge Mine (CVM) Horse Pit Extension (HPE) Project (the Project). The GA has been prepared by SLR Consulting Australia Pty Ltd (SLR) for the client BM Alliance Coal Operations Pty Ltd (BMA). The Project is a metallurgical open cut coal mine within the Bowen Basin, Queensland, about 5 km south of Moranbah, about 30 km north-west of the recently-approved Olive Downs South Coking Coal Project, and immediately north of the existing Peak Downs and Saraji coal mines.

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

- Life of Project approximately 30 years.
- One open cut pit with a single final void outside the floodplain, and one out-of-pit dump to the west.
- Mining of the Q, P, H and D seams in the Moranbah Coal Measures.
- Many surrounding coal mines and one coal seam gas operation to the east.

The Project is based on an extension of the existing Horse Pit to the east, at the northern end of the CVM. Mining is to run approximately parallel to Isaac River, at distances of about 5-9 km, but the alluvium of the Isaac River will not be intercepted.

2. Documentation

The review is based on the following report:

1. SLR, 2021, Caval Ridge Mine Horse Pit Extension Project Groundwater Assessment. Report 620.13593.00005-R01-v4.0 prepared for BMA, August 2021. 173p (main) + 5 Appendices.

Groundwater modelling details are in Appendix B of Document #1:

2. SLR, 2021, Caval Ridge Mine Horse Pit Extension Project Groundwater Modelling Technical Report. Appendix B, 620.13593.00005-R02-v5.0 prepared for BMA, August 2021. 110p + 5 Appendices.

Document #1 has the following major sections:

1. Introduction
2. Legislative Requirements and Relevant Guidelines
3. Existing Conditions
4. Geology
5. Hydrogeology
6. Groundwater Simulation Model
7. Impacts on Groundwater Resources
8. Management and Mitigation Measures
9. Limitations
10. References

The Appendices are:

- A1. CVM and Project Groundwater Monitoring Network
- A2. Groundwater Quality
- A3. CVM Bore Census Surveys
- A4. Groundwater Monitoring Well Drilling Reports
- B. Groundwater Modelling Technical Report

Document #2 is structured as follows:

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 Limitations
9. Conclusions
10. References.

The Appendices are:

- A. Calibration Residuals
- B. Calibration Hydrographs
- C. Hydraulic Parameters and Recharge Zone Distribution
- D. Cumulative Drawdown Predictions
- E. Uncertainty Analysis Parameters Distribution

3. Review Methodology

While there are no standard procedures for peer reviews of entire groundwater assessments, there are two accepted guides to the review of groundwater models: the Murray-Darling Basin Commission (**MDBC**) Groundwater Flow Modelling Guideline[1], issued in 2001, and guidelines issued by the National Water Commission (**NWC**) in June 2012 (Barnett *et al.*, 2012[2]). Both guides also offer techniques for reviewing the non-modelling components of a groundwater impact assessment.

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.

[1] MDBC (2001). Groundwater flow modelling guideline. Murray-Darling Basin Commission. URL: www.mdbc.gov.au/nrm/water_management/groundwater/groundwater_guides

[2] 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.

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[3].

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[4]; 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 six video-conference workshops at key GA project milestones, several direct discussions with the modelling team, and review of progress reports and slideshow presentations. After each meeting, a log of issues was prepared and updated for consideration in the preparation of the final GA report, as well as progressive completion and disclosure of the Review Checklist. All issues have been addressed satisfactorily. Video-conference meetings were held on the following dates in 2021: 23 February, 31 March, 28 April, 3 June, 10 June and 15 July.

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 the prediction of quantitative potential water level impacts and inferred qualitative potential water quality and ecosystem impacts due to the extension of mining at the CVM Horse Pit.

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

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

[3] 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.

[4] 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)

(Main Report - black)

(Technical Report - purple)

Review questions	*Yes/No*	*Comment*
1. Planning		
1.1 Are the project objectives stated?	Y	Section 1.3
1.2 Are the model objectives stated?	Y	S1. Three objectives (inflow, drawdown, management measures)
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 2. Counts: 1 (class 1), 12 (class 2), 6 (class 3).
1.6 Are the planned limitations and exclusions of the model stated?	Y	Table 8-1.
2. Conceptualisation		
2.1 Has a literature review been completed, including examination of prior investigations?	Y	S5.2: prior hydraulic tests; neighbouring mine investigations. Fig.5-3. App.A2. S5.2.3: review of fault papers.
2.2 Is the aquifer system adequately described?	Y	Good coverage of solid geology and surface geology with maps of elevations and thicknesses or depths, and two cross-sections.
2.2.1 hydrostratigraphy including aquifer type (porous, fractured rock ...)	Y	Two cross-sections N-S and W-E (Figs. 4-6, 4-7). Categorised in S5.
2.2.2 lateral extent, boundaries and significant internal features such as faults and regional folds	Y	Faults addressed in S4.2.4 and S5.2.3. Maps show extents of target coal seams.
2.2.3 aquifer geometry including layer elevations and thicknesses	Y	Structure contours and formation thicknesses: Surficial units, Triassic (Figs.4-5, 4-9). Structure contours and depth of cover: 4 coal seams (Figs.4-10 to 4-13). Average thicknesses for 19 layers (Table 2-1).
2.2.4 confined or unconfined flow and the variation of these conditions in space and time?	OK	Some perching (S5.3.1.2). Unconfined or confined conditions are self-evident. Potentiometric levels and vertical gradients are discussed.
2.3 Have data on groundwater stresses been collected and analysed?	Y	CVM inflow ~1100 ML/a (Table 5-5). CVM + Peak Downs + Saraji ~9000 ML/a in 2019-20 (Table 5-6). 16 other coal mines (13 OC, 3 UG) & Bowen Gas Project CSG; 10 included for cumulative assessment.
2.3.1 recharge from rainfall, irrigation, floods, lakes	Y	Rainfall & RMC; stations and SILO. Recharge described in S5.3.1.2, etc., per formation.
2.3.2 river or lake stage heights	Y	Several Isaac River gauges – ephemeral (flows 27% of time). Generally losing conditions near the Project. Graphs of stage and discharge included.
2.3.3 groundwater usage (pumping, returns etc)	Y	Section 5.5: database search; volumes not available. Landholder bores mentioned S5.3.1.2. Censuses: Figure 5-32. Project census (26 bores) in App.A3 – insignificant usage.
2.3.4 evapotranspiration	Y	Potential & actual. Discharge described in S5.3.1.2, etc., per formation.

Table 2. Review checklist (2012 National Guidelines)

(Main Report - black)

(Technical Report - purple)

Review questions	*Yes/No*	*Comment*
2.3.5 other?	Y	Land use. Water quality. Leachate analysis. Stygofauna.
2.4 Have groundwater level observations been collected and analysed?	Y	S5.1 groundwater monitoring network: 47 sites; 2008 & 2019-2020; 9 separate formations. Very many at other mines (Table 5-3). Analysed in Section 5. Not all alluvial bores respond to rainfall.
2.4.1 selection of representative bore hydrographs	Y	All.
2.4.2 comparison of hydrographs	Y	Done well, by formation.
2.4.3 effect of stresses on hydrographs	Y	Cause-and-effect analysis via RMC and mining proximity.
2.4.4 watertable maps/piezometric surfaces?	Y	Piezometric surfaces for all formations Figures 5-6, 5-8, 5-9, 5-14 to 5-18. TDS map Figure 5-31.
2.4.5 If relevant, are density and barometric effects taken into account in the interpretation of groundwater head and flow data?	N/A	
2.5 Have flow observations been collected and analysed?	Y	Inflow rates stated for CVM, Peak Downs, Saraji. Not for CSG produced water (to east).
2.5.1 baseflow in rivers	N/A	Isaac River flows only 27% of time and is losing near the Project. Baseflow is not occurring (except as rare events) and cannot be used for calibration.
2.5.2 discharge in springs	N/A	
2.5.3 location of diffuse discharge areas?	OK	Self-evident. Surface geology map.
2.6 Is the measurement error or data uncertainty reported?	OK	Some mentions of anomalous data. Qualitative comments on data limitations in Table 8-1.
2.6.1 measurement error for directly measured quantities (e.g. piezometric level, concentration, flows)	N	
2.6.2 spatial variability/heterogeneity of parameters	Y/N	S5.2 demonstrates heterogeneity based on site hydraulic tests, but maps of spatial variability are not included. K(z) decay is demonstrated (Fig.5-3).
2.6.3 interpolation algorithm(s) and uncertainty of gridded data?	N	Assumed kriging (of minor importance).
2.7 Have consistent data units and geometric datum been used?	Y	Metric and AHD.
2.8 Is there a clear description of the conceptual model?	Y	S5.7.
2.8.1 Is there a graphical representation of the conceptual model?	Y	Three cross-sections (Figs. 5-34. 5-35, 5-36) – before, during, and after. Very good.
2.8.2 Is the conceptual model based on all available, relevant data?	Y	
2.9 Is the conceptual model consistent with the model objectives and target model confidence level classification?	Y	Consistent with Class 2 target (Table 7-1) and model objectives (S1).
2.9.1 Are the relevant processes identified?	Y	On Figs. 5-34. 5-35, 5-36
2.9.2 Is justification provided for omission or simplification of processes?	OK	All described physical processes will carry across to the numerical model other than perching (although, in theory, MODFLOW-USG could handle this – but unwarranted).
2.10 Have alternative conceptual models been investigated?	N	Not warranted, as only one numerical model should be built.

Table 2. Review checklist (2012 National Guidelines)

(Main Report - black)

(Technical Report - purple)

Review questions	*Yes/No*	*Comment*
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 1.14m cells.
3.3.1 1D/2D/3D		3D
3.3.2 lateral extent		About 62km 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	54 SP for warm-up (20 yrs 1988-2007) and calibration (qtly Dec.2007-Dec.2020). 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	Extended to north and west from existing model; reduced on eastern edge.
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%

Table 2. Review checklist (2012 National Guidelines)

(Main Report - black)

(Technical Report - purple)

Review questions	*Yes/No*	*Comment*
3.7.3 Numerical precision		Assumed single
4. Calibration and sensitivity		**2008-2020**
4.1 Are all available types of observations used for calibration?	Y	Heads quantitatively and fluxes qualitatively.
4.1.1 Groundwater head data	Y	4,342 target heads at 400 bores; 47 local CVM sites. Fewer targets than predecessor models due to sampling density
4.1.2 Flux observations	Y	Not sufficiently reliable for quantitative targets. Reality check carried out: list of predicted inflows to each mine (S2.6.3.2) – 0.1 to 1.8 ML/day.
4.1.3 Other: environmental tracers, gradients, age, temperature, concentrations etc.	N	No use of horizontal or vertical gradients for calibration. Statement on consistent vertical gradients.
4.2 Does the calibration methodology conform to best practice?	Y	PEST + manual.
4.2.1 Parameterisation		Laterally uniform in lithologies (no pilot points). Vertical depth functions.
4.2.2 Objective function	Y	PEST phi (sum of squares) 651,580 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 (Relative Composite Sensitivity).
4.3.1 parameters	Y	Kx, Kz/Kx, K(z)_slope, 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 2-9 to 2-12.
4.4.2 Is it clear whether observed or assumed vertical head gradients have been replicated by the model?	N	Not clear as VWP plots are individual rather than stacked. Bore 1235C: obs.115-140; sim.153mAHD. Bore 2183: obs.135-155; sim.168mAHD. Bore 2218: obs.148-152; sim.164mAHD. Bore 2226: obs.154-162; sim.167mAHD. Bore 2372: obs.142-150; sim.160mAHD. Bore 2375: obs.140-145; sim.160mAHD. S2.6.2.2 notes a simulated vertical gradient at the Project, as observed.
4.4.3 Are calibration statistics reported and illustrated in a reasonable manner?	Y	Table 2-5, key statistics 5.4 %RMS, 12.5 mRMS (global), 9.8 %RMS, 5.6 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 2-5) and CVM only (Figure 2-6) – generally linear over a wide range of elevations (~100 m) – weaker at low levels <150 mAHD. Histogram (Figure 2-7). Calibration generally good close to CVM.

Table 2. Review checklist (2012 National Guidelines)

(Main Report - black)

(Technical Report - purple)

Review questions	*Yes/No*	*Comment*
4.5.1 spatially	Y	Residuals by layer (Table 2-6) and by site (Table 2-7). Average residual spatial map (Fig.2-8) and Appendix A table.
4.5.2 temporally	Y	Figures 2-9 to 2-12; Appendix B.
4.6 Are the calibrated parameters plausible?	Y	Table 2-12. Recharge rates similar to predecessor models (0.01-0.52%) except Tertiary basalt (from 5% to 0.3%). 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, Isaac River is losing on the whole (Table 3-2), but slightly gaining for the null run (Table 3-4). Total mine inflow 1988-2020 (6.3 ML/day average) is the sum of 9 mine inflows from 0.1 to 1.8 ML/day (S2.6.3.2) - of the right order.
4.8 has the model been verified?	N	No data have been withheld from calibration – normal practice.
5. Prediction		**2021-2055 + recovery (200-500 years)**
5.1 Are the model predictions designed in a manner that meets the model objectives?	Y	• *"Assess the groundwater inflow to the mine workings as a function of mine position and timing;* • *Simulate and predict the extent and area of influence of dewatering, and the level and rate of drawdown at specific locations; and* • *Identify areas of potential risk, where groundwater impact mitigation/control measures may be necessary."* All objectives 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	Continuation of mining.
5.5.2 Are well losses accounted for when estimating maximum pumping rates per well?	N/A	
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.
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 predicted mine inflow compared to historical takes (S2.6.3.2).

Table 2. Review checklist (2012 National Guidelines)

(Main Report - black)

(Technical Report - purple)

Review questions	*Yes/No*	*Comment*
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. Isaac River is said to be losing near the Project. Predicted change in leakage is negligible.
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	Proof of convergence in Figures 6-6 (pit inflow) and 6-7 (max.drawdown).
6.3 Are the sources of uncertainty discussed?	Y	Quantified through identifiability analysis. Significance assessed by Type I – Type IV analysis.
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. Latin Hypercube Sampling.
6.5 Are there useful depictions of uncertainty?	Y	Compliant with IESC guide.
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 and reduced flow duration are 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?	Loosely	Only for final void recovery. Iterative exchange of model outputs.
8.3.1 Is the adopted approach appropriate?	Y	Stage-discharge curve from groundwater model to surface water model. Final void water level(t) from surface water model to groundwater model. Implemented as CHD(t).
8.3.2 Have appropriate time steps and stress periods been adopted?	N/A	
8.3.3 Are the interface fluxes consistent between the models?	N/A	

5. Report Matters

The GA report is a high-quality document of about 170 pages length, with an additional 770 pages in four Appendices that contain information on monitoring bore details, groundwater quality, bore census surveys and field investigations. A separate numerical modelling technical report occupies another 200 pages approximately.

The main report is well-structured, well-written and the graphics are of very high quality and designed to ease understanding by readers. The report serves well as a standalone document, with no undue dependence on earlier work. However, the report is missing an Executive Summary and a Conclusion section for a summary of the findings of the groundwater assessment. This summation could be in the over-arching main approvals documentation not seen by this reviewer.

The technical modelling report does have a Conclusions chapter and includes five Appendices that contain information on calibration residuals, hydrograph comparison, property fields, cumulative drawdown predictions and posterior distributions for the uncertainty analysis (although prior distributions are not compared). This report is structured appropriately with sufficient detail and disclosure of methods and results. It is not intended as a standalone report because some of the key results are reported only in the main GA report.

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

The groundwater assessment objectives are stated clearly in the GA at the outset (Section 1.3) in the form of 15 dot points. Although the objectives are met, there is no Conclusion section that addresses those objectives in summary form.

The modelling objectives are itemised in Section 6.1.1 of the main report, and in Section 1 of the technical appendix, in the form of three dot points:

- *"assess the groundwater inflow to the mine workings as a function of mine position and timing;*
- *simulate and predict the extent and area of influence of dewatering, and the level and rate of drawdown at specific locations; and*
- *identify areas of potential risk, where groundwater impact mitigation/control 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 reports as to structure or depth of coverage, and there is a clear focus on regulatory requirements.

6. Data Matters

The geology, though complex, is reasonably well known as a result of the extensive mining and exploration history in this part of the Bowen Basin. It is illustrated by maps of outcropping geology, solid geology, structural faults and cross-sections. Structure contours and thickness maps are provided for Superficial and Triassic units, while the geometry of the four target coal seams is characterised by structure contours and depths of cover.

The Project is supported by an existing network for the Caval Ridge Mine of 47 groundwater monitoring sites including three multi-sensor vibrating wire piezometer (VWP) holes (installed November 2020). The network was established in 2008 and expanded in 2019-2020. This network supplements an extensive regional network associated with neighbouring mines consisting of 78 monitoring sites (67 listed standpipes and 11 VWP bores). Calibration hydrographs are reported for a total set of 222 sensor locations.

The Project has also benefitted from considerable effort conducted by others for neighbouring groundwater assessments with regard to resolution of different interpretations of alluvial extent associated with the Isaac River, included geophysical surveys (AgTEM and DC resistivity), slope break analysis, CSIRO regolith inference, LiDAR and bore logs.

Cause-and-effect analysis of groundwater hydrographs has been presented separately for bores in alluvium, regolith, basalt, Permian interburden, and each of the four Permian coal seams, compared in each case with rainfall residual mass to infer potential relationships with infiltrating rain water. The earliest measurements in the region date from 2008. The Isaac River stream hydrograph is compared with a near-river bore hydrograph to infer groundwater / surface water connectivity, demonstrating that the Isaac River generally has a “losing” status.

Groundwater flow directions can be inferred from groundwater head contours for alluvium (Figure 5-8, Document #1) and the Moranbah Coal Measures (Figure 5-14, Document #1).

Hydraulic conductivity estimates for modelling are informed by significant investigations for other mining projects and by slug tests, core laboratory measurements and two packer tests into known faults elsewhere in the modelled area. The packer tests found hydraulic conductivity values in the faulted material of the order of 10^{-4} to 10^{-3} m/day. There is now a large database of hydraulic conductivity values in this part of the Bowen Basin. Overall, there is a clear expression of decrease with depth (Figures 2-13 and 2-14 in Document #2).

A thorough analysis is presented for groundwater quality signatures, primarily using Piper diagrams.

A clear and defensible description of hydrogeological conceptualisation is promoted in Section 5.7 of Document #1, illustrated by schematics for pre-mining, during-mining and post-mining conditions in cross-section.

7. Model Matters

The CVM groundwater model has developed from the well-received groundwater model for the recently-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 required extension to the north and north-west beyond Moranbah and also farther west from the Caval Ridge Mine. Model cell sizes have been refined across the CVM site, and an extra five layers were added in the model to give better vertical resolution of the strata within the Moranbah Coal Measures.

The reviewer concurs with the entire modelling methodology described in Document #2 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; the storage properties of two layers in the Moranbah Coal Measures interburden are isolated as having the potential to cause large changes in predictions for small changes

in their adopted values; and

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

The model extent is necessarily large, being about 50-70 km in an east-west direction and about 90 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 1.14 million remains efficient but is nearing the limit of a manageable model size. Separate layers are designated for the four target coal seams (Q, P, H, D) in the Moranbah Coal Measures. Although there are no mapped faults within the CVM mine area, many structural faults are included in the wider model as zones of finer discretisation (100 m) with properties separate from the host materials. Conceptualisation of faults as barriers was supported during previous PEST calibration which allowed faults to range from a strong barrier to a conduit, although their identifiability proved subsequently to be low except for the Isaac fault zone (Section 5.1.2, Document #2).

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

> *"...the groundwater model developed for this Groundwater Assessment may be classified as primarily Class 2 (effectively "medium confidence") with some items meeting Class 3 criteria, which is considered an appropriate level for this Project context."*

The reviewer agrees with this conclusion. Although Class 2 is appropriate, 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 6-1 in Document #1. This classifies the model as about 65% Class 2, about 30% Class 3, and about 5% Class 1.

Visual hydrographic history matching is exceptionally good at CVM Permian monitoring sites, as illustrated in Figures 2-10 and 2-11 of Document #2. Elsewhere, calibration performance is generally good in most areas of the model, based on about 4,300 measurements of groundwater level at 400 sites, with overall unweighted statistics of 5.4 %RMS and 12.5 mRMS. Locally, the absolute performance (5.6 mRMS) is better but the relative performance (9.8 %RMS) appears larger because the range in measured water levels is less (about 60 m compared to about 150 m regionally). Table 2-7 in Document #2 shows that the CVM site has better average residual (-0.2 m) and average absolute residual (4.3 m) statistics than any of the other included mines. Scattergrams are generally linear with a mild tendency to over-estimation of heads, especially at lower elevations. The model still has a weakness in not replicating vertical head gradients well in areas of the model distant from the Project.

The primary predictive results are presented in Document #2 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 regolith and each of the four target seams;
- maximum cumulative drawdown for alluvium, regolith, each of the four target seams, and the two mined seams (Leichhardt and Vermont) in the Rangal Coal Measures to the east.

A sub-set of maps is presented in Document #1 with additional post-closure maps:

- maximum incremental drawdown (due to the Project alone) for regolith and each of the four target seams;
- maximum cumulative drawdown for alluvium, regolith, each of the four target seams, and the two mined seams (Leichhardt and Vermont) in the Rangal Coal Measures to the east;
- groundwater level at equilibrium in alluvium, regolith and each of the four mined seams in the Moranbah Coal Measures.

A comprehensive IESC-compliant Type-3 uncertainty analysis has been undertaken by means of a *monte carlo* technique, using 250 alternative calibrated realisations out of a trial set of 1,100 selections (obtained by Latin Hypercube Sampling). A severe threshold was imposed on each simulation which required the calibration statistic to be better or the same as the base case model (5.4 %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 offered for total pit inflow and maximum drawdown.

The base case model has ~30% less pit inflow than the 50th percentile of the 250 realisations. This could be due to the imposition of many constraints on the selection of parameters for a realisation. In other words, parameters cannot be chosen with full freedom from their designated distributions. See Tables 6-1 to 6-5 in Document #2.

The temporal uncertainty results are presented in Document #2 in Figure 6-1 as 5th, 33rd, 50th, 66th and 95th percentiles for progressive pit inflow. The spatial uncertainty results are presented in Document #2 in Figures 6-2 to 6-4 as 5%, 50% and 95% probabilities of exceeding 1 m drawdown in regolith and Q and H seams; the base case extent is also shown. The same drawdown maps are included as Figures 6-25 to 6-27 in Document #1.

Recovery in the presence of a final void has been modelled in two steps using initially the "high-K" lake approach, and subsequently time-varying constant heads provided from the surface water model. The reviewer endorses deference to surface water modelling for a more robust analysis of final void behaviour than is readily achievable in a groundwater model. The freeboard in the single final void is predicted to be about 100 m, giving confidence that it will remain as a perpetual groundwater sink.

8. Conclusion

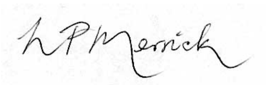
The reviewer is of the opinion that the documented groundwater assessment is best practice and concludes that the model is *fit for purpose*, where the purpose is defined by the objectives listed in Document #1:

- *"Review relevant groundwater, geotechnical and environmental reports to characterise the geological and hydrogeological setting of the Project.*
- *Review publicly available hydrogeological data such as the Queensland Government's spatial data system (Queensland Globe) and the Bureau of Meteorology's (BoM) National Groundwater Information System (NGIS) (BoM, 2019).*
- *Undertake a census of groundwater supply bores near to the Project to confirm locations, usage and groundwater quality.*
- *Characterise the existing groundwater resources, including properties and quality.*
- *Conceptualise the groundwater regime of the Project Area and Study Area.*
- *Assess the potential interaction between the alluvium of proximal watercourses (Cherwell Creek, Horse Creek and Isaac River) and the Project.*
- *Identify the potential for groundwater dependent ecosystems (GDEs) to occur in proximity to the project.*
- *Construction and calibration of a numerical groundwater flow model suitable for assessment of potential impacts of the Project, in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al., 2012) and Murray Darling Basin Commission guidelines (Middlemis et al., 2001).*
- *Perform predictive modelling for the scale and extent of mining impacts upon groundwater levels, groundwater quality and groundwater users at various stages during mine operations and post closure.*
- *Model the cumulative impacts of Project and surrounding existing and proposed mines.*

- *Assess the extent of groundwater impacts as a result of the operation of the Project; including long-term impacts on regional groundwater levels, water quality impacts on environmental flows and baseflows.*
- *Assess potential impacts on GDEs resulting from short and/or long-term changes in the quantity and quality of groundwater.*
- *Assess the potential third party impacts (i.e. private bores) as a result of changes to the regional groundwater system.*
- *Develop feasible mitigation and management strategies where potential adverse impacts are identified.*
- *Develop a groundwater monitoring program and management measures."*

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 9 of Document #1.

The primary output of the uncertainty analysis, with respect to potential off-site impacts, is presented in Document #1 in Figures 6-25 to 6-27 as 5%, 50% and 95% probabilities of exceeding 1 m drawdown in regolith and Q and H seams. Two water supply bores in the model layer above the Q Seam are unlikely to be impacted by the Project, with a near-maximum predicted drawdown of about 1.5 m due to the Project, but this is less than the *Water Act 2000* threshold of 5 m for bores in consolidated formations. No alluvial bores are predicted to be impacted by the Project and no material impact on Isaac River seepage is anticipated. The reviewer supports the validity of these conclusions.



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