BHP Mitsubishi Alliance

Appendix J

Groundwater Modelling and Impact Assessment Peer Review Letter

HYDROALGORITHMICS

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DATE: 13 December 2023

TO: BM Alliance Coal Operations Pty Ltd
480 Queen Street
Brisbane QLD 4000

FROM: Dr Noel Merrick

RE: Blackwater Mine North Extension Project – Groundwater Peer Review

YOUR REF: PO 4511256650

OUR REF: HA2023/11

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1. Introduction

This report provides a peer review of the groundwater impact assessment (GIA) and associated modelling for the Blackwater Mine (BWM) North Extension Project (the Project), extending mining into Surface Area (SA) 10 on ML1759 and SA7 on ML1762. The GIA has been prepared by SLR Consulting Australia Pty Ltd (SLR) for the client BM Alliance Coal Operations Pty Ltd (BMA). The BWM has a number of open cut pits which produce metallurgical and thermal coal. The Project is located within the Bowen Basin, Queensland, about 25 km south of the township of Blackwater, and about 75 km east of Emerald.

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

- Life of Project approximately 61 years (2025-2085).
- Mining of the Aries (Top), Castor (Middle) and Pollux (Lower) seams in the Rangal Coal Measures (RCM).
- Four final voids.
- Several surrounding open cut and underground coal mines to the north and south.

The Project is based on an extension of existing BWM mining downdip to the east. Mining is to run approximately parallel to Blackwater Creek, at distances of about 6 km, but no alluvium will be intercepted.

2. Documentation

The review is based on the following report:

1. SLR, 2023, Blackwater Mine - North Extension Project Groundwater Impact Assessment. Report 620. 014601.00006-R01 Revision v2.3 prepared for BMA, 11 December 2023. 141p (main) + 5 Appendices.

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

2. SLR, 2023, Blackwater Mine - North Extension Project Groundwater Modelling Technical Report. Appendix B, 620.014601.00006-R02-v4.0 prepared for BMA, 29 November 2023. 97 + 4 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 Numerical Model
7. Impacts on Groundwater Resources
8. Management and Mitigation
9. Limitations
10. References

The Appendices are:

A1. Water Level Plots
A2. Water Quality Summary Tables and Box-and-Whisker Plots
A3. Existing Water Supply Bores in the Study area / Bore Census
A4. Groundwater Bore Installation Report
B. Groundwater Modelling Technical Report

Document #2 is structured as follows:

1. Introduction
2. Model Construction and Calibration
3. Predictive Modelling
4. Recovery Model
5. Sensitivity Analysis
6. Uncertainty Analysis
7. Model Confidence and Limitations
8. Conclusions
9. References.

The Appendices are:

A. Calibration Residuals
B. Calibration Hydrographs
C. Calibrated Hydraulic Parameters
D. Prior and posterior distribution plot (UA)

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.

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[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]. A revision was issued in July 2023 with less emphasis on checklists and more emphasis on *fitness for purpose* based on usability, reliability and feasibility[4]. This Explanatory Note recommends against continued use of the NWC confidence level as a measure of fitness for purpose, and also expunged the 10-question Compliance Checklist in NWC (2012) which examined “fatal flaws”.

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.

This review has been conducted progressively through attendance at three video-conference workshops with SLR and BMA at key GIA project milestones, and review of slideshow presentations and progress reports. After each meeting/report, a log of issues was prepared and updated for consideration in the preparation of the final GIA report. All issues have been addressed satisfactorily. Video-conference meetings were held on the following dates in 2023: 10 July, 12 September and 28 September.

4. Checklist

A detailed checklist assessment based on the NWC (2012) guide is provided in **Table 1**, excluding the inapplicable *Solute transport* set of questions.

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

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[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] Peeters LJM and Middlemis H (2023) *Information Guidelines Explanatory Note: Uncertainty analysis for groundwater modelling*. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of Climate Change, Energy, the Environment and Water, Commonwealth of Australia 2023.

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

Table 1: Review checklist (2012 National Guidelines)

		Main Report [Doc #1]
		Modelling Technical Report [Doc #2]
Review questions	*Yes/No*	*Comment*
1. Planning		
1.1 Are the project objectives stated?	Y	Section 1.3 (14 scope items)
1.2 Are the model objectives stated?	Y	Section 1.0: 4 tasks.
1.3 Is it clear how the model will contribute to meeting the project objectives?	Y	Articulated in Appendix B of main report.
1.4 Is a groundwater model the best option to address the project and model objectives?	Y	No real alternative.
1.5 Is the target model confidence-level classification stated and justified?	N/A	The 2023 UA Guide recommends discontinuation of this feature.
1.6 Are the planned limitations and exclusions of the model stated?	Y	Table 7-1. Thorough analysis of shortcomings and suggestions for future improvements.
2. Conceptualisation		
2.1 Has a literature review been completed, including examination of prior investigations?	Y	Substantial reference list.
2.2 Is the aquifer system adequately described?	Y	Good coverage of solid geology and surface geology; one cross-section.
2.2.1 hydrostratigraphy including aquifer type (porous, fractured rock ...)	Y	One west-east cross-section (Figure 4-3). Each stratigraphic unit is described in terms of groundwater potential.
2.2.2 lateral extent, boundaries and significant internal features such as faults and regional folds	Y	The groundwater system is bounded regionally by basement outcrop (west) and a major fault (east). Many minor local faults suggest potential for compartmentalisation.
2.2.3 aquifer geometry including layer elevations and thicknesses	Y	Accommodated within the numerical model. Average thicknesses are tabulated. No structure contours or isopach maps.
2.2.4 confined or unconfined flow and the variation of these conditions in space and time?	Y	Some perching. 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	Rainfall, ET and creek stages OK.
2.3.1 recharge from rainfall, irrigation, floods, lakes	Y	Use of AWRA deep drainage. Use of CRD.
2.3.2 river or lake stage heights	Y	Ephemeral, with intermittent seepage but not perennial baseflow. Incision depth 3m. Relative Blackwater Creek water levels compared with daily rainfall (Figure 3-6).
2.3.3 groundwater usage (pumping, returns etc)	Y	Bore census (2019) and database search.
2.3.4 evapotranspiration	Y	SILO estimate. Assumed 2.5m and 7.5m extinction depths.
2.3.5 other?	Y	Estimates of historical mine inflow rates from reporting of associated water take.
2.4 Have groundwater level observations been collected and analysed?	Y	Substantial monitoring network: 43 bores, including two VWPs. Figure 5-1.
2.4.1 selection of representative bore hydrographs	Y	All are discussed, per stratigraphic unit.

Table 1: Review checklist (2012 National Guidelines)

		Main Report [Doc #1]
		Modelling Technical Report [Doc #2]
Review questions	*Yes/No*	*Comment*
2.4.2 comparison of hydrographs	Y	Hydrographs are stacked and compared with CRD for assessment of rainfall influence.
2.4.3 effect of stresses on hydrographs	Y	Proximity of mining or storages is noted in text.
2.4.4 watertable maps/piezometric surfaces?	Y	Aries Seam only. Alluvium is generally dry.
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	Historical mine inflow is used for *ad hoc* calibration control.
2.5.1 baseflow in rivers	N	No gauge data is supplied but relative stages are given for Blackwater Creek.
2.5.2 discharge in springs	N/A	
2.5.3 location of diffuse discharge areas?	N/A	
2.6 Is the measurement error or data uncertainty reported?	OK	Table 7-1. Not quantitative.
2.6.1 measurement error for directly measured quantities (e.g. piezometric level, concentration, flows)	N (piezo kevel) Y (concentration, flow)	OK for water quality limits of resolution.
2.6.2 spatial variability/heterogeneity of parameters	OK	Section 5.2 shows wide range in hydraulic properties collected by others, but not mapped spatially. Assumed depth dependence.
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	
2.8 Is there a clear description of the conceptual model?	Y	Section 5.6
2.8.1 Is there a graphical representation of the conceptual model?	Y	Figure 5-32: approved and proposed mining extents. Ecohydrological models: Figures 5-34, 5-35, 5-37, 5-38.
2.8.2 Is the conceptual model based on all available, relevant data?	Y	Including (1) depth-to-water map; (2) water quality analysis to infer low recharge rates.
2.9 Is the conceptual model consistent with the model objectives and target model confidence level classification?	Y	Consistent with Class 2 target and model objectives. The 2023 UA Guide recommends discontinuation of confidence level classification.
2.9.1 Are the relevant processes identified?	Y	The conceptual model diagram (Fig.5-32) does not indicate the direction(s) of creek/groundwater interaction. The groundwater model predicts more baseflow than leakage.
2.9.2 Is justification provided for omission or simplification of processes?	Y	All described physical processes will carry across to the numerical model other than perching. CSG is excluded, given its relative unimportance due to distance of active operations.
2.10 Have alternative conceptual models been investigated?	N	Not warranted, as only one numerical model should be built.
3. Design and construction		

Table 1: Review checklist (2012 National Guidelines)

		Main Report [Doc #1]
		Modelling Technical Report [Doc #2]
Review questions	*Yes/No*	*Comment*
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 are provided and are readily accessible. AlgoMesh is proprietary.
3.3 Are the spatial domain and discretisation appropriate?	Y	Total 0.44million cells (moderate size).
3.3.1 1D/2D/3D		3D
3.3.2 lateral extent		About 50km (max) x 90km
3.3.3 layer geometry?		14 layers (with pinchouts).
3.3.4 Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model and target confidence level classification?	Y	Min 100m cell size. Features detailed at 100, 125, 150, 250, 350m.
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	14 layers. Separate layers for 3 coal seams. Aquitards are individual layers – a common pragmatic compromise with many layers.
3.4 Are the temporal domain and discretisation appropriate?	Y	
3.4.1 steady state or transient		Both
3.4.2 stress periods	Y	3 SP for warm-up (35 yrs 1970-2005); 74 SP for calibration (qtly Jan.2005-Jun.2023); 62 SP for prediction (annual Jul.2023-Jun.2085). 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 openly to north and south. Limited to east and west due to basement outcrop (west) and barrier fault (east) – forces narrowing to north. Rainfall recharge seasonality is included: quarterly averages of AWRA-L sequence – Australian Landscape Water Balance model. Blackwater Creek is simulated as always flowing – could overestimate losses in dry times.
3.5.1 Is the implementation of boundary conditions consistent with the conceptual model?	Y	Matches geology.
3.5.2 Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained?	Y	Sufficiently distant for incremental Project effects – other than natural narrowing to the north.
3.5.3 Is the calculation of diffuse recharge consistent with model objectives and confidence level?	Y	4 zones based on lithology.
3.5.4 Are lateral boundaries time-invariant?	Y	Time-invariant GHB on northern and southern edges.
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

Table 1: Review checklist (2012 National Guidelines)

		Main Report [Doc #1]
		Modelling Technical Report [Doc #2]
Review questions	*Yes/No*	*Comment*
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	Zero mass balance errors
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		**2005-2023**
4.1 Are all available types of observations used for calibration?	Y	Heads quantitatively. Mine inflow fluxes are used qualitatively.
4.1.1 Groundwater head data	Y	2,037 target heads at 68 bores. Head targets within 11 of 14 layers, indicating good depth coverage. None in local alluvium (dry where drilled); 2 in distant alluvium.
4.1.2 Flux observations	Y	AWT reports 2018/19 to 2021/22: Range 3.6 - 5.1 ML/day
4.1.3 Other: environmental tracers, gradients, age, temperature, concentrations etc.	N	No explicit use of horizontal or vertical gradients for calibration. No statement on consistency of predicted vertical gradients but VWP hydrographs at 19BWM02 (Fig.2-13; VWP19B02) are good initially (with compromised observed data in later years).
4.2 Does the calibration methodology conform to best practice?	Y	PEST ++ and 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) 269,670 m^2.
4.2.3 Identifiability of parameters	Y	Section 5.2 (calibration) & 5.3 (prediction) (GENLINPRED software).
4.2.4 Which methodology is used for model calibration?		PEST ++ and 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 2-12 (regolith) and 2-13 (Permian) for 8 sites. All sites shown in Appendix B.
4.4.2 Is it clear whether observed or assumed vertical head gradients have been replicated by the model?	N	Two VWP plots – one good (19BWM02), one poor (19BWM01). Predicted VWP vertical gradients at P19BW02 (Fig.2-13) are excellent initially. Two other dual sites shown in Appendix B – no predicted gradient.
4.4.3 Are calibration statistics reported and illustrated in a reasonable manner?	Y	Table 2-6, key statistics 6.4 %RMS, 11.7 mRMS.

Table 1: Review checklist (2012 National Guidelines)

		Main Report [Doc #1]
		Modelling Technical Report [Doc #2]
Review questions	*Yes/No*	*Comment*
4.5 Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated?	Y	Scattergram Figure 2-9 – generally linear over a wide range of elevations (~180 m). Slight tendency to underestimation in alluvium and regolith, and overestimation in Rewan. Histogram (Figure 2-10) – slight bias to underprediction.
4.5.1 spatially	Y	Residuals by layer (Table 2-7). Average residual spatial map (Fig.2-11) and Appendix A table. The map has coincident blue & red dots, so impossible to match all data; underprediction and overprediction at the same spot in different bores.
4.5.2 temporally	Y	Figures 2-12 and 2-13; Appendix B.
4.6 Are the calibrated parameters plausible?	Y	Tables 2-10, 2-11 and 2-12. Recharge rates are plausible (0.1-1% of rainfall). Hydraulic conductivities cover expected ranges; anisotropy ratios Kx/Kz: 2 (coal) to 200 (overburden). Ss reasonable. Sy values are low but consistent with OGIA Surat model: 0.3% in Triassic and Permian; 0.2% weathered; 1-2% alluvium and Tertiary. Simulated inflows match expectation.
4.7 Are the water volumes and fluxes in the water balance realistic?	Y	Magnitude 5.3 ML/day average mine inflow across calibration period. Consistent with current mine takes in AWL reports (3.6-5.1 ML/day) for ML1759, ML1762, ML1862, ML1792, ML1767 and ML1907 over 4 years.
4.8 has the model been verified?	N	No data have been withheld from calibration – normal practice.
5. Prediction		**2023-2085**
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 of dewatering due to the Project and the level and rate of drawdown at specific locations.* • *Simulate the long-term impacts by running a recovery scenario.* • *Identify areas of potential risk, where groundwater impact mitigation 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	Normal practice is long-term average (no seasonality). Steady river stage is applied for Blackwater Creek.
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.

Table 1: Review checklist (2012 National Guidelines)

		Main Report [Doc #1]
		Modelling Technical Report [Doc #2]
Review questions	*Yes/No*	*Comment*
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. Recovery: 1, 5, 50, 35years (out to 200 years).
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 four stated objectives at Q5.1 are assessed.
5.7 Are the components of the predicted mass balance realistic?	Y	In Section 3.2: Tables 3-2, 3-3, 3-4. Sensible progression from null to approved to cumulative. The approved and cumulative cases have similar overall net storage gains (10-12 ML/day) due to spoil recharge. There is a reality check for predicted mine inflow compared to historical takes.
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?	Unknown	Null case baseflow to Blackwater Creek is 0.55 ML/day (6.4L/s). Cumulative: 0.36 ML/day (4.2 L/s) with double rain recharge. Approved: 0.37 ML/day (4.3 L/s). Other creeks: baseflow decline from 8.5 to 7.2 ML/day due to all mining. Predicted change in baseflow is small volume but large fraction.
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. Care has been taken to avoid coincident BCs.
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 7-1. 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 6-1 (pit inflow) and 6-2 (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 7-1. 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. Prior/posterior comparison in Appendix D – good agreement.

Table 1: Review checklist (2012 National Guidelines)

		Main Report [Doc #1]
		Modelling Technical Report [Doc #2]
Review questions	*Yes/No*	*Comment*
6.5 Are there useful depictions of uncertainty?	Y	Compliant with IESC guide. Figure 6-3: mine inflow (large range). Figures 6-4 to 6-8: 1m drawdown extents.
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	A model objective was to *“Identify areas of potential risk, where groundwater impact mitigation measures may be necessary.”* Potential for baseflow loss is assessed as negligible for Project-only impact.
8.2 Is the implementation of surface water–groundwater interaction appropriate?	Y	RIV for Blackwater Creek with positive stage. RIV with zero stage (=DRN) for other creeks. Ephemeral watercourses are difficult to represent in a groundwater model, especially in predictive mode.
8.3 Is the groundwater model coupled with a surface water model?	Loosely	Only for final void recovery. Iterative exchange of model outputs until convergence of groundwater discharge to the voids.
8.3.1 Is the adopted approach appropriate?	Y	Groundwater discharge rates from groundwater model to surface water model. Final void water level(t) from surface water model (including climate change) to groundwater model. Implemented as CHD(t) across 4 final voids.
8.3.2 Have appropriate time steps and stress periods been adopted?	N/A	
8.3.3 Are the interface fluxes consistent between the groundwater and surface water models?	N/A	

5. Report Matters

The GIA report [Document #1] is a high-quality document of about 145 pages length, with additional material in five Appendices that contain information on monitoring bore hydrographs, groundwater quality, water supply bores and bore census survey, and monitoring bore installation details. A separate numerical modelling technical report [Document #2] forms the final Appendix and occupies another 97 pages plus four Appendices.

The main report is well-structured, well-written and the graphics are of 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 Conclusions section. Normally, there would be a summary of the findings of the groundwater impact assessment in terms of meeting the Project objectives. These objectives are expressed in Section 1.3 as a set of 14 tasks that aim to satisfy the scope of work. Although not addressed point by point, I consider the objectives to have been met satisfactorily.

The technical modelling report [Document #2] does have a Conclusions chapter which necessarily addresses satisfaction of the modelling objectives. However, some comments are offered on one of the Project objectives (groundwater drawdown impacts). Document #2 includes four Appendices that contain information on calibration residuals, hydrograph comparisons, property fields, and prior distributions for the uncertainty analysis; posterior distributions compare well with the prior equivalents. This report is structured appropriately with sufficient detail and disclosure of methods and results. It is not intended as a standalone report because some key information (e.g. field investigations and cause-and-effect analysis) is reported only in the main GIA report.

Progressive review comments on factual and editorial matters, on both reports, were provided by the reviewer in a log of issues spreadsheet. These comments have been considered by SLR and have been accommodated satisfactorily in revisions of the reports.

The modelling objectives are itemised in Section 6.1 of the main report, and in Section 1 of the technical appendix, in the form of five dot points:

- *“Prepare a calibrated numerical groundwater model to simulate the hydrogeological conditions across the Project area.*
- *Estimate 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.*
- *Simulate the post-mining recovery.*
- *Identify areas 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 target coal measures are confined within a narrow corridor of 25-40 km width, defined by basement outcrop on the western side and a major fault structure on the eastern side. The geology is well known at the Project site due to extensive exploration drilling associated with historical mining. Away from the site, the stratigraphy is well known but the geometry of the strata is available only through public domain documents where other mines have been approved. To the south of the site, the model developed for the Project has benefitted from overlap with the northern extremity of the Office of Groundwater Impact Assessment (OGIA) model for the Surat Cumulative Management Area.

The geology of the study area is illustrated by maps of outcropping geology, solid geology, structural faults and one cross-section (Figure 4-3). However, structure contours and thickness maps are not provided for any hydrostratigraphic units. The geometry of the three target coal seams is complicated by the coalescence of some seams and by seam splits (Figure 4-4). Many minor local faults suggest a potential for compartmentalisation in reality, but groundwater monitoring networks are rarely of a density where this expected behaviour can be observed. Given that the local fault structures have small throw, and they have no discernible effect on groundwater level patterns, a parsimonious approach has been followed in the modelling of them; this effectively assumes continuity of flow across the structures with neither barrier nor conduit behaviour.

The Project is supported by an existing network for the BWM of 43 groundwater monitoring sites including two multi-sensor vibrating wire piezometer (VWP) holes (installed November 2019 and March 2020); 17 of these bores are EA compliance bores. The network was established in 2011 and expanded in 2019-2020. The regional network is limited, with additional data available only from Curragh Mine to the north and Blackwater South to the south. Calibration hydrographs are reported for a total set of 46 monitoring sites.

The Project has also benefitted from considerable effort conducted by others in earlier field investigations involving aquifer tests and downhole geophysics. Recent downhole geophysical logs are included in Appendix A-4 of Document #1.

Cause-and-effect analysis of groundwater hydrographs has been presented separately for bores in Tertiary sediments, Triassic Rewan Group, Permian Rangal Coal Measures (northern, central and southern areas), and the Burngrove Formation. In each case, comparison is made with the Cumulative Rainfall Departure (CRD) curve to infer potential relationships with infiltrating rain water. Proximity of a bore to water storages or mining activity is given consideration in teasing out infrastructure or mining effects from a climatic signature. The earliest measurements in the region date from 2011. Limited grouped bores indicate the potential for upwards flow from the Permian to the Rewan Group [Table 5-6; Document #1]. The Blackwater Creek stream hydrograph for the 2010-2020 decade is compared with daily rainfall and creek bed elevation to demonstrate the ephemeral seasonal nature of flow [Figure 3-6; Document #1].

Water balance estimates of BWM inflow are available for two years as a constraint on otherwise poorly-controlled model predictions of pit inflows. The Associated Water Licence (AWL) reports are summarised in Document #2 rather than Document #1.

Groundwater flow directions in the coal measures can be inferred from groundwater head contours for the Aries Seam [Figure 5-12, Document #1]. The ambient flow directions are controlled strongly by historical mining.

A thorough analysis is presented for groundwater quality signatures, primarily using Piper diagrams. Water quality analysis suggests low rainfall recharge.

A clear and defensible description of hydrogeological conceptualisation is promoted in Section 5.6 of Document #1, illustrated by schematics for current-mining and future-mining conditions in cross-section. On Figure 5-31 (Document #1), however, additional arrows could indicate the direction of flow in units other than the coal measures, and the direction of creek-alluvium water exchange.

Substantial discussion of conceptual ecohydrological models is provided in Section 5.7.4 (Document #1), informed by a companion ecological study. Four types of potential Terrestrial GDEs are examined and illustrated in Figures 5-34, 5-35, 5-36 and 5-37 (Document #1).

7. Model Matters

There appears to be no prior groundwater model for the BWM, other than some overlap of the southern end of the study area with the OGIA model for the Surat Cumulative Management Area. 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;
- application of a fairly new approach to estimation of dynamic rainfall recharge, being a scaled representation of the Australian Landscape Water Balance (AWRA-L) Deep Drainage model;
- conventional PEST calibration for steady-state and transient conditions;
- application of two procedures (Relative Composite Sensitivity Analysis and Identifiability Analysis) during the calibration process to replace sensitivity analysis by perturbation, so that 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, hydraulic conductivity depth gradient, specific storage, specific yield and diffuse 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, alluvial water exchanges and maximum cumulative drawdown; for its effect on drawdown and pit inflow, the specific yield of the Rewan Formation is inferred to have the potential to cause large changes in predictions for small changes from its adopted value of 0.3%; and
- a *monte carlo* style rigorous procedure for uncertainty analysis.

Being naturally constrained by geological boundaries, the model extent is not as large as most similar regional coal mining models, being about 15-50 km in an east-west direction and about 90 km in a north-south direction. With 14 layers and a minimum cell dimension of 100 m, a total cell count of 0.44 million cells gives the model a readily manageable size. Cell refinement is intense along mapped faults, Blackwater Creek and within mining leases, and grid design takes into account a large number of drainage lines (e.g. Figure 6-1, Document #1). Separate layers are designated for the three target coal seams [Aries (Top), Castor (Middle) and Pollux (Lower)] in the Rangal Coal Measures. Minor faults are not accommodated separately, other than through the control they exert on geometry. This means that coal seams are assumed to have continuity when in reality they might be truncated, and consequently Project drawdowns could prove to be more localized in reality than are predicted by the model.

Calibration performance is generally good in most areas of the model, based on more than 2,000 measurements of groundwater level at 68 sensors, with overall unweighted statistics of 6.4 %RMS and 11.7 mRMS. The scattergram [Figure 2-9, Document #2] is generally linear with no significant bias towards overestimation or underestimation of heads at any elevation. There is a slight bias to underestimation of groundwater levels in Quaternary and Tertiary materials, and a slight bias to overestimation in the Rewan Formation. The average calibration residual, reported layer by layer, is least in the model layers representing alluvium, Aries coal seam and the Aries/Castor interburden of the Rangal Coal Measures. Spatially, the average calibration residual is distributed fairly evenly along the length of the study area. There remains, however, a paucity of calibration points in alluvium. Those in the calibration dataset are in the alluvium of Sirius Creek south-west of ML1762 and in the alluvium of

Blackwater Creek north of ML1759. Consequently, the model has low reliability for predicted groundwater levels elsewhere along the watercourses.

For the two VWP target bores, calibration is good at one and poor at the other. The predicted VWP vertical gradients at P19BW02 (Figure 2-13, Document #2) are excellent. For standpipe bores, there is a mixture of “good” and “poor” matches but the trends are generally replicated. It should be noted that failure to match absolute magnitudes has little effect on the reliability of the predicted impacts of a model; as drawdown is the difference between two model runs, this procedure effectively cancels out any error in magnitude.

The simulated pit inflow for the calibration period accords very well with independent water balance estimates at the BWM (4-5 ML/day).

The primary predictive results are presented in Document #2 as maps of:

- groundwater level at end of mining in alluvium and Tertiary (Layer 1), regolith (Layer 2), Clematis Sandstone (Layer 3) and the deepest Pollux Seam (Layer 12) with and without the Project;
- maximum incremental drawdown (due to the Project alone) for Tertiary (Layer 1), regolith (Layer 2), Aries Seam (Layer 8), Pollux Seam (Layer 12) and the Burngrove Formation (Layer 14); and
- maximum cumulative drawdown (due to all mines) for Tertiary (Layer 1), regolith (Layer 2), Aries Seam (Layer 8), Pollux Seam (Layer 12) and the Burngrove Formation (Layer 14).

Recovery in the presence of four final voids 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 each final void is predicted to be much more than 10 m, giving confidence that each will remain as a perpetual groundwater sink. A post-closure map of equilibrium water table levels is presented at Figure 4-3 (Document #2) to show the permanent effect of four final voids, demonstrating their status as groundwater sinks with no prospect of escape of hypersaline pit lake water.

A comprehensive IESC-compliant Type-3 uncertainty analysis has been undertaken by means of a *monte carlo* technique, using 354 alternative calibrated realisations out of a trial set of 1,000 selections (obtained by Latin Hypercube Sampling). A reasonable threshold was imposed on each simulation which required the calibration statistic to be no more than 7 %RMS, compared to the base case model with 6.4 %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); this ensures that 95% of samples will lie within one order of magnitude either side of the base value (the mode). Proof of convergence, as encouraged by the IESC Explanatory Note on Uncertainty Analysis, is offered for total pit inflow and maximum drawdown; there is little change in predicted median values for more than about 200 realisations.

Appendix D (Document #2) presents the probability distribution for each uncertain parameter, both *prior* distributions for the initial 1000 realisations and *posterior* distributions for the 354 calibrated realisations. As they agree well, the prior distributions have been sampled adequately.

The temporal uncertainty results are presented in both documents as 10th, 33rd, 66th and 90th percentiles, and minimum and maximum, for progressive pit inflow. The base case model has about the same inflow as the 66th percentile. This indicates that the base case model, on it own, is a good indicator of likely pit inflow and probably of likely impacts.

The spatial uncertainty results are presented in both documents as 10%, 50% and 90% probabilities of exceeding 1 m drawdown in Tertiary (Layer 1), weathered zone (Layer 2), Aries Seam (Layer 8), Pollux Seam (Layer 12) and the Burngrove Formation (Layer 14). At the 95th percentile, no third party bore is predicted to be affected by the Project by more than 1 m drawdown. One bore in the Burngrove Formation is predicted to be affected under cumulative stresses.

A map of the maximum water table drawdown due to the Project is presented at Figure 7-1 (Document #1) as an aid for assessment of GDE effects by the ecological team.

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 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 BWM. Detailed objectives are listed in Document #1:

- *Summarise the relevant Queensland and Commonwealth environmental regulatory framework.*
- *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).*
- *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 surface water and groundwater.*
- *Construct and calibrate a numerical groundwater flow model suitable for the 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-mining.*
- *Perform predictive modelling of the cumulative impacts of the Project and surrounding mines.*
- *Assess the extent of groundwater impacts due to the Project, including long-term impacts on regional groundwater interception, groundwater drawdown, incidental water impact and post mining equilibrium.*
- *Document any groundwater dependant ecosystems (GDEs) in the vicinity of the Project that could be impacted by the Project resulting from short and/or long-term changes in the quantity and quality of groundwater.*
- *Assess potential third-party impacts (i.e. privately-owned bores) as a result of changes to the regional groundwater system.*
- *Develop reasonable and practicable mitigation and management strategies where potential adverse impacts are identified.*
- *Outline proposed groundwater monitoring network and groundwater management.*

The groundwater modelling has been conducted to a 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 *Groundwater Model and Data Limitations* summarised in Table 7-1 of Document #2. The modelling objectives are listed in Document #2:

- *Assess the groundwater inflow to the mine workings as a function of mine position and timing.*

- *Simulate and predict the extent of dewatering due to the Project and the level and rate of drawdown at specific locations.*
- *Simulate the long-term impacts by running a recovery scenario.*
- *Identify areas of potential risk, where groundwater impact management measures may be necessary.*

The reviewer supports adoption of the *Principle of Parsimony* for representation of local fault structures that have small throw, with no discernible effect on groundwater level patterns. This effectively assumes continuity of flow across the structures without the need to make an assumption of either barrier or conduit behaviour.

The primary output of the uncertainty analysis, with respect to potential off-site impacts, is presented in both the main GIA report and the modelling technical appendix as 10%, 50% and 90% probabilities of exceeding 1 m drawdown in five distinct hydrostratigraphic units, the upper two of relevance to potential ecosystem impacts. No third-party water supply bore in the study area is likely to be impacted by the Project, in terms of trigger thresholds, with a maximum predicted drawdown of about 0.07 m due to the Project at one bore. This is considerably less than the *Water Act 2000* threshold of 5 m for bores in consolidated formations. No material impact on Blackwater Creek baseflow or seepage is anticipated.

In terms of ecosystem impacts, a groundwater model is limited to prediction of changes in depths to the *regional* water table, with deference to ecologists for an opinion on potential impacts. A regional groundwater model is not appropriate for assessing potential effects on shallow terrestrial and subterranean GDEs reliant on perched water tables, as the unsaturated soil zone cannot be represented in detail. Conceptually, however, as perched and regional water tables are independent of each other, mining could not have any appreciable effect on a perched system.

A groundwater model also has difficulty in representing ephemeral watercourses. Normal practice is to include them as drains so they will accept baseflow whenever groundwater levels rise above creek bed elevations; they are normally excluded as potential sources of water supply via vertical seepage to the groundwater system, as such seepage from an ephemeral creek is more likely to top up a perched water table. If they are included in a groundwater model, they will be given an assumed depth of open water (or stage) that applies for the full length of a model stress period, and that is usually a month or three months during calibration, and annual or longer for pre-calibration and predictive periods.

For the subject model, Blackwater Creek is ephemeral and flows only a few days each year. In the model, however, it is given its average historical stage over each stress period. Consequently, it is a permanent source of water to the regional water table, rather than an intermittent source to a perched water table. This is believed to be the reason for probable overestimation of water table elevations along Blackwater Creek where there is an absence of groundwater measurements beyond the ML boundaries.

As recommended by the most recent (July 2023) Uncertainty Analysis guideline, the model's fitness for purpose is assessed in terms of usability (relevance to decision-makers), reliability (consistency with knowledge and datasets) and feasibility (balanced trade-offs cognisant of risk). The groundwater model associated with this GIA is likely to be the first to give specific consideration to these new concepts [see Section 7 in Document #2]. The reviewer considers that all three attributes are met adequately.

The recent (July 2023) Uncertainty Analysis guideline also recommends declaration, at the outset, of the Quantities of Interest (QoIs) that will be the focus for assessing uncertainty. They are declared in Section 1.0 of Document #2 as groundwater inflows (to the mine) and predicted drawdowns in multiple strata.

The reviewer supports the validity of the conclusions reached in the GIA.

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