HydroAlgorithmics Pty Ltd ● ABN 25 163 284 991
PO Box 241, Gerringong NSW 2534. Phone: +61(0)424 183 495

noel.merrick@hydroalgorithmics.com

DATE: 25 July 2022

TO: Jellinbah Group Pty Ltd
12 Creek Street
Brisbane QLD 4000

FROM: Dr Noel Merrick

RE: Lake Vermont Meadowbrook Project – Groundwater Peer Review

YOUR REF: AARC Job #339

OUR REF: HA2022/14a

---

1. Introduction

This report provides a peer review of the groundwater impact assessment (GIA) and associated modelling for the Lake Vermont Meadowbrook Project (the Project). The GIA has been prepared by JBT Consulting (JBT) for the client Jellinbah Resources (Jellinbah). The associated groundwater modelling has been undertaken by SLR Consulting Australia Pty Ltd (SLR).

The Project is a metallurgical coal mine within the Bowen Basin, Queensland, about 25 km north-east of Dysart, about 160 km south-west of Mackay, and about 4 km south and 12 km west of the recently-approved Olive Downs South Coking Coal Project. It also lies about 3 km due east of the Saraji East underground coal mine project and about 6 km east of the existing Saraji Open Cut coal mine.

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

- Life of Project approximately 25 years.
- One open cut pit mining the Vermont and Vermont Lower seams, with no final void.
- Underground mining of the Leichhardt Lower and Vermont Lower seams in the Rangal Coal Measures.
- Many surrounding coal mines and one coal seam gas operation to the east.

The Project is based on an extension to the north of the existing Lake Vermont Mine. Mining is to be at least 8 km from the Isaac River, and the southern edge of the Project will abut Phillips Creek. No alluvium will be intercepted.

2. Documentation

The review is based on the following report:

1. JBT, 2022. Meadowbrook Project Groundwater Impact Assessment. Report JBT01-076-006 prepared for Jellinbah Resources, 7 July 2022. x+117p (main) + 5 Appendices.

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

2. SLR, 2022. Meadowbrook Underground Groundwater Modelling Technical Report. Appendix A, 620.30592.00000-R01-v3.0 prepared for Jellinbah Group Pty Ltd, 1 July 2022. ix+104p + 5 Appendices.

Document #1 has the following major sections:

1. Introduction
2. Climate Data
3. Regional and Local Geology
4. Groundwater Data and Analysis
5. Groundwater Modelling
6. Potential Groundwater Impacts
7. Groundwater Management and Mitigation Measures
8. Conclusions
9. References

The Appendices are:

A. Groundwater Modelling Report
B. Bore Construction Logs – Meadowbrook Groundwater Monitoring Bores
C. Bore Construction Logs – LVN Groundwater Monitoring Bores
D. Groundwater Quality Data
E. Description of Landsat ETM Data

Document #2 is structured as follows:

1. Introduction
2. Model Construction and Development
3. Model Calibration
4. Predictive Modelling
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. Uncertainty Analysis Parameter Distribution
E. Model Layer Structure Contour and Isopach Maps

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 GIAs 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 at arms'-length at the end of the modelling process through reviewing several versions of complete reports. After each revision, a log of issues was prepared and updated for consideration in the preparation of the final reports, as well as progressive completion and disclosure of the Review Checklist. Video-conference discussions were held with the authors of the two reports on 13 April 2022 and 7 June 2022. All issues have been addressed satisfactorily.

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 Project.

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 GIAs 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 1.2.1: 8 items.
1.2 Are the model objectives stated?	Y	Executive Summary: "The purpose of the model is to predict groundwater impacts and quantify groundwater take for proposed operations."
1.3 Is it clear how the model will contribute to meeting the project objectives?	Y	Four objectives (inflow, drawdown, water take, recovery)
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	S3.1: regional geology. Lake Vermont mine data included. Recognition of many neighbouring mines and combination of many geo-models.
2.2 Is the aquifer system adequately described?	Y	Good coverage of solid geology, faults, surface geology, Q and T alluvium maps.
2.2.1 hydrostratigraphy including aquifer type (porous, fractured rock ...)	Y	Three cross-sections N-S and W-E (Figs. 3-6, 3-7). All bore logs included.
2.2.2 lateral extent, boundaries and significant internal features such as faults and regional folds	Y	Faults addressed in S3.4, Fig.3-1. Compartmentalisation.
2.2.3 aquifer geometry including layer elevations and thicknesses	Y	Structure contours (Fig.3-5) for surface, Tertiary, Rewan, 3 coal seams. Depths of cover (2 seams): Fig.3-4. Thickness maps (Fig.3.3). 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	Alluvium mostly dry. 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?	N / Y	Mention of mine inflow experience at Lake Vermont; not for other coal mines. Little evidence found for Lake Vermont stress on groundwater levels; only 2183-VWP. No significant rainfall effect on hydrographs.
2.3.1 recharge from rainfall, irrigation, floods, lakes	Y	Rainfall & RRM; based on SILO data. Recharge potential analysed using chloride mass balance.
2.3.2 river or lake stage heights	Y	Several Isaac River gauges – ephemeral (flows 27% of time). Local streams ephemeral.
2.3.3 groundwater usage (pumping, returns etc)	Y	Section 4.6: database search – 17 bores; volumes not available.
2.3.4 evapotranspiration	Y	Potential only, not actual. Depth to water map – Fig.4-2 (9-28 mbgl); discussion S4.2.1.1.

Table 2. Review checklist (2012 National Guidelines)

(Main Report - black)

(Technical Report - purple)

Review questions	*Yes/No*	*Comment*
2.3.5 other?	Y	Landsat thematic mapper. Water quality.
2.4 Have groundwater level observations been collected and analysed?	Y	S4.1 groundwater monitoring network: 15 Meadowbrook sites; 10 LVN sites including 6 with VWPs. Many stacked standpipes. Meadowbrook data from Oct.2020. LVN data from Nov.2018. Good coverage of formations. Analysed in Section 4.2.1 – all quiescent. Very many monitoring bores at other mines
2.4.1 selection of representative bore hydrographs	Y	All.
2.4.2 comparison of hydrographs	Y	Done well, by site. No pattern to vertical head differences and potential flow directions.
2.4.3 effect of stresses on hydrographs	Y	Cause-and-effect – no evident response to rain. Lake Vermont mining impacts noted in bore 2183-VWP – hydrograph presented in Figure 4-7 with discussion in Section 4.2.1.2.
2.4.4 watertable maps/piezometric surfaces?	Y	Piezometric surfaces for Tertiary, Leichhardt Seam, Vermont Seam: Figures 4-10, 4-11, 4-12. EC map Figure 4-13.
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?	N	
2.5.1 baseflow in rivers	N/A	Local streams are ephemeral, losing not gaining. Isaac River flows only 27% of time and is likely to be 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	Anomalous data explained for one site (W11). 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	S4.4 demonstrates heterogeneity based on site hydraulic tests for 74 discrete intervals, Fig.4-18 map of spatial variability. K(z) decay is demonstrated (Fig.4-17) – extensive dataset.
2.6.3 interpolation algorithm(s) and uncertainty of gridded data?	Y	Standard kriging (S6.2.3), clipped to formation extents. Used Nearest Neighbour technique for interpolation, as this allowed for the use of fault traces as a limit on contouring.
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	S4.7 and S5.8. Substantial description.
2.8.1 Is there a graphical representation of the conceptual model?	Y	Two cross-sections: pre-mining (Fig. 4-17) & post-mining (Fig.5-15) showing cone of depression and fracture zone.
2.8.2 Is the conceptual model based on all available, relevant data?	Y	

Table 2. Review checklist (2012 National Guidelines)

(Main Report - black)

(Technical Report - purple)

Review questions	*Yes/No*	*Comment*
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 objectives (S1.2.1).
2.9.1 Are the relevant processes identified?	Y	On Fig.4-17 and Fig.5-15.
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 ephemeral stream leakage and landholder pumping.
2.10 Have alternative conceptual models been investigated?	N	Not warranted, as only one numerical model should be built.
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 models prior to Caval Ridge and Meadowbrook applications; 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

Table 2. Review checklist (2012 National Guidelines)

(Main Report - black)

(Technical Report - purple)

Review questions	*Yes/No*	*Comment*
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		**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; 74 local sites. Fewer targets than predecessor models prior to Caval Ridge and Meadowbrook applications 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 (S3.3.2) – 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.
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 5.2 (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	Sections 3.2, 3.3.
4.4.1 Are there graphs showing modelled and observed hydrographs at an appropriate scale?	Y	Figures 3-6 to 3-12. All sites included in Appendix B.
4.4.2 Is it clear whether observed or assumed vertical head gradients have been replicated by the model?	Y	It is clear, but replication is not good.
4.4.3 Are calibration statistics reported and illustrated in a reasonable manner?	Y	Table 3-2, key statistics 5.4 %RMS, 12.5 mRMS (global), 17 %RMS, 9.2 mRMS (local).
4.5 Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently	Y	Scattergram: regional (Figure 3-1). Generally linear over a wide range of elevations (~100 m)

Table 2. Review checklist (2012 National Guidelines)

(Main Report - black)

(Technical Report - purple)

Review questions	*Yes/No*	*Comment*
calibrated?		– weaker at low levels <150 mAHD. Lake Vermont points do not follow the diagonal (sim ~160 but obs 110-170 mAHD). Histogram (Figure 3-3) shows bias to overprediction. Some large residuals locally, probably due to complex structural geology.
4.5.1 spatially	Y	Residuals by layer (Table 3-3) and by site (Table 3-4). Average residual spatial map (Fig.3-4) and Appendix A list per bore. Not clear how stacked bores are represented on residuals map (which is ion top?).
4.5.2 temporally	Y	Figures 3-6 to 3-12; and Appendix B.
4.6 Are the calibrated parameters plausible?	Y	Tables 3-7 to 3-9 (host units unchanged from Caval Ridge application). Recharge rates similar to predecessor models (0.01-0.52%) except Tertiary basalt (from 5% to 0.3%). Rewan permeabilities are higher than predecessor models and recent lab work in Galilee Basin. Fracture zone Kz is very high (100 m/day for 60m above seam, then decaying to 0.001 m/d at 130m altitude). Much uncertainty in assumed height of fracturing.
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 4-2), but slightly gaining for the null run (Table 4-4). 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 (S3.3.2) - of the right order.
4.8 has the model been verified?	N	No data have been withheld from calibration – normal practice.
5. Prediction		**2021-2060**
5.1 Are the model predictions designed in a manner that meets the model objectives?	Y	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	Long-term average (no seasonality).
5.4 Is a null scenario defined?	Y	No mining after Jan 2008.
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. Additional scenario in Main Report: Fracturing to surface (S5.5).
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	Some external underground mining within model domain, but mostly open cut. More uncertainty with u/g inflows.
5.5.2 Are well losses accounted for when estimating maximum pumping rates per well?	N/A	

Table 2. Review checklist (2012 National Guidelines)

(Main Report - black)

(Technical Report - purple)

Review questions	*Yes/No*	*Comment*
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 one period of 5 years. Then 500 years recovery.
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	
5.7 Are the components of the predicted mass balance realistic?	Y	In Section 4.2. There is a reality check for predicted mine inflow compared to historical takes (S3.3.2).
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 leakage of Isaac River 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 6-1 (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. (However, all targets have weight=1).
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	

Table 2. Review checklist (2012 National Guidelines)

(Main Report - black)

(Technical Report - purple)

Review questions	*Yes/No*	*Comment*
8. Surface water–groundwater interaction		
8.1 Is the conceptualisation of surface water–groundwater interaction in accordance with the model objectives?	Y	• *"Estimate direct and indirect water take."* • *"Assess the frequency (and time lags if any), location, volume and direction of interactions between water resources, including surface water/groundwater connectivity…"*
8.2 Is the implementation of surface water–groundwater interaction appropriate?	Y	RIV for Isaac River. DRN for creeks. RIV for recovery in infilled void.
8.3 Is the groundwater model coupled with a surface water model?	Loosely	Non-Project final landform recovery is included using iterative exchange of model outputs.
8.3.1 Is the adopted approach appropriate?	Y	
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 GIA report is a high-quality document of about 120 pages length, with approximately an additional 100 pages in four Appendices (B-E) that contain information on monitoring bore details, groundwater quality, and Landsat data. A separate numerical modelling technical report (Appendix A) occupies another 220 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. The report includes an extensive Executive Summary of five pages and a Conclusions section of three pages with a summary of the findings of the groundwater impact assessment.

The technical modelling report also has an Executive Summary (of two pages) and a brief Conclusions chapter. It includes five Appendices that contain information on calibration residuals, hydrograph comparison, property fields, prior and posterior distributions for the uncertainty analysis, and layer geometry. 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 (e.g. fracture zone sensitivity analysis) are reported only in the main GIA report.

Progressive review comments on factual and editorial matters, on both reports, have been considered by JBT and SLR and have been accommodated satisfactorily in revisions of the reports[5].

The groundwater impact assessment objectives are stated clearly in the GIA at the outset (Section 1.2.1) in the form of eight dot points. One of the dot points summarises the modelling objectives:

- *Model and describe the inputs, movements, exchanges and outputs of groundwater that may be affected by the Project. Undertake model sensitivity analysis and uncertainty analysis.*

All objectives are met and are reported 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 are provided for five hydrogeological units plus topography, thickness maps are provided for Cainozoic sediments and the Rewan Group, and the geometry of the two target coal seams (Leichhardt, Vermont) is characterised by depths of cover (100-500m over the mine plan). Significant faulting disrupts the lateral continuity of Triassic and Permian units and enforces compartmentalisation of groundwater flow.

The Project is supported by an existing network for the Meadowbrook Project of 15 groundwater monitoring sites (installed October 2020) and 10 sites in the Lake Vermont North mine network including six multi-sensor vibrating wire piezometer (VWP) holes, commencing November 2018. Many sites have stacked standpipes which give information on local vertical gradients, but there seems no consistent pattern with upwards or downwards groundwater flow. There is an extensive regional network, maintained by numerous neighbouring mines, which has contributed groundwater level data used in model calibration. Calibration hydrographs are reported for a total set of 222 sensor locations.

[5] Some editorial issues still remain in Document #2.

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, based on 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 26 bores in Tertiary sediments, Triassic Rewan Group, Permian interburden, and each of four Permian coal seams. They are not compared with the rainfall residual mass in Figure 2-1 (Document #1), but the hydrographs are generally quiescent which indicates little response to rainfall events. Only the southern-most bore (2183-VWP) shows a response to mining at Lake Vermont North mine (Figure 4-7) (Document #1). This site has three VWP sensors which all show a decline in pressure head of about 5 m from 2018 to 2021.

A depth to the water table of 9 to 28 m, as shown in Figure 4-2 (Document #1), supports a lack of connectivity with watercourses, which are ephemeral, and limits the potential for groundwater dependent ecosystems supported by the regional water table. The Isaac River also is ephemeral but flows about 27% of the time; it generally has a “losing” condition.

Groundwater flow directions can be inferred from groundwater head contours for Tertiary Sediments (Figure 4-10) (Document #1), the Leichhardt Seam (Figure 4-11) (Document #1), and the Vermont Seam (Figure 4-12) (Document #1). The alluvium is generally dry. Flow in the Permian units is compartmentalised between north-south trending faults with substantial throw. An electrical conductivity map (Figure 4-13) (Document #1) shows very saline groundwater, generally in excess of 20,000 µS/cm, except at shallow depths close to watercourses. This confirms weak rainfall recharge but supports episodic leakage when the watercourses are able to run.

Hydraulic conductivity estimates for modelling are informed by an extensive field investigation program at the Meadowbrook Project and at the Lake Vermont North mine, with site hydraulic tests for 74 discrete intervals. Slug tests were conducted at 42 sites and the balance consisted of packer tests in coal seams and Permian interburden. A distinct decline of horizontal hydraulic conductivity with depth is demonstrated in Figure 4-17 (Document #1), to a depth of about 500 m. This local dataset supports significant investigations for other mining projects, including core laboratory measurements and two packer tests into known faults elsewhere in the modelled area. Those 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.

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

Clear and defensible descriptions of hydrogeological conceptualisation are promoted in Section 4.7 of Document #1 for pre-mining conditions, and in Section 5.8 of Document #1 for post-mining conditions, illustrated by detailed schematics in cross-section which illustrate the key natural and mining-induced processes. All described physical processes have been carried across to the numerical model other than ephemeral stream leakage and landholder pumping.

7. Model Matters

The Meadowbrook 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 version used for the Caval Ridge Mine groundwater assessment was adopted without further change. Changes made for that model included extension to the north and north-west beyond Moranbah and also farther west from the Caval Ridge Mine. Model cell sizes were refined in advance across the Meadowbrook 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 Type IV identifiability analysis; the considered outputs are mine inflows and maximum cumulative drawdown; the storage properties of the Rangal Coal Measures coal and interburden units are isolated as having the potential to cause large changes in predicted mine inflows for small changes in their adopted values (that is, Type IV response; see Figure 5-8 of Document #2; the lateral hydraulic conductivity of faults also gives a Type IV response for predicted maximum cumulative drawdown; 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 two target coal seams in the Rangal Coal Measures (Leichhardt, Vermont), as well as four coal seams (Q, P, H, D) in the Moranbah Coal Measures relevant for neighbouring mines.

Many mapped faults are evident within the Meadowbrook mine area, and many structural faults are included in the wider model as zones of finer discretisation (~100 m). They are given hydraulic conductivity 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 5.2, Document #2).

In terms of model confidence level classifications, Document #2 states:

> "*The groundwater model developed for this Groundwater Assessment may be classified as primarily Class 2 (effectively "medium confidence") with some items meeting the higher Class 3 criteria, and therefore the model is considered fit for purpose 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 7-1 in Document #2. This classifies the model as about 65% Class 2, about 30% Class 3, and about 5% Class 1.

Regionally, 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, for 593 measurements at 74 bores, the absolute performance (9.2 mRMS) is not as good and the relative performance (17 %RMS) appears weak because the range in measured water levels is less, and this term acts as a divisor in scaling the mRMS value. Table 3-4 in Document #2 shows that the Meadowbrook site has the worst average residual (-8.7 m) and second worst absolute residual (9.8 m) statistics compared to the other included mines. This suggests that the structural complexity of the Meadowbrook site is affecting the ability of the model to replicate field measurements by simulation. Nevertheless, the degree of calibration is considered sufficient for indicative predictions of impacts due to the Project.

While the calibration scattergram is generally linear for the entire model area, the Lake Vermont data on Figure 3-1 (Document #2) show a horizontal trend, reflecting a simulation difficulty that is probably related to local structural complexity. The model has a weakness in not being able to replicate vertical head gradients in the Project area. It was noted earlier that the recorded stacked hydrographs do not show a consistent pattern for downwards or upwards flow.

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

- groundwater level at end of mining in alluvium, regolith and Fort Cooper Coal Measures overburden (model layer 9) with and without the Project;
- maximum incremental drawdown (due to the Project alone) for regolith and each of the two target seams (Leichhardt, Vermont); and
- maximum cumulative drawdown for alluvium, regolith, and each of the two target seams in the Rangal Coal Measures.

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

- end of mining drawdown, maximum drawdown, and post-closure equilibrium drawdown (due to the Project alone) for alluvium, Tertiary sediments, Rewan Group and each of the two target seams; and
- end of mining Project drawdown versus cumulative drawdown for Tertiary sediments, Rewan Group and each of the two target seams.

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 mine inflows and maximum drawdown.

The base case model has a very similar mine inflow to the 50^{th} percentile of the 250 realisations. This indicates that the base case model is sufficient as a predictor of the most likely impacts due to the Project.

The temporal uncertainty results are presented in Document #2 as 5th, 33rd, 50th, 66th and 95th percentiles for progressive mine inflow (Figure 6-3) and alluvial groundwater take (Figure 6-4). The spatial uncertainty results are presented in Document #2 in Figures 6-5 to 6-8 as 5th, 50th and 95th percentile probabilities of exceeding 2 m drawdown in alluvium, regolith, Leichhardt seam and Vermont seam; the base case extent is also shown. Similar probabilistic drawdown maps are not included in Document #1, as the base case model is considered sufficient for the groundwater impact assessment.

The final void for the satellite open cut mine is to be infilled to leave a final landform depression that is likely to host occasional ponding of relatively fresh water (less than 1,000 mg/L). Recovery has been simulated in the groundwater model in two steps using initially the “high-K” lake approach, and subsequently time-varying specified heads (RIV stages) provided from the surface water model. The reviewer endorses deference to surface water modelling for a more robust analysis of final open water levels than is readily achievable in a groundwater model.

The groundwater model predicts groundwater mounding beneath the final landform with an equilibrium groundwater head of about 162 mAHD, compared to a minimum land surface elevation of about 160 mAHD in the final landform depression. Groundwater is expected to flow away from the mound into the Tertiary sediments to the north, south-west and south-east (Figure 6-1, Document #1). The expected low salinity of the mounded groundwater (from vertical recharge of fresh rain water) and the predicted low salinity of pooled water indicate that the naturally high salinity of groundwater in the Tertiary sediments will be diluted close to the final landform.

There is uncertainty over the height of the groundwater mound beneath the final landform. The final height will depend on the final recovered groundwater levels above the underground mines, which are predicted to be 161 mAHD in the northern area and 160.5 mAHD in the southern area. The model therefore has an hydraulic gradient away from the final landform towards the two underground areas. The final predicted groundwater levels above the underground areas depend on the assumptions made for the fractured zone, especially the height of fracturing and the adopted permeabilities. The adopted heights of fracturing are 120 m for the southern single-seam area and 180 m for the dual-seam northern area, based on geotechnical advice. It is noted that an alternative algorithm (Ditton and Merrick, 2014)[6] estimates 140-220 m for the southern single-seam area and 230-340 m for the dual-seam northern area, considerably higher than has been adopted in the model. As the fracture zone could be higher than simulated, and the fracture zone is more permeable than host rocks, the equilibrium groundwater levels could be lower than predicted above the underground areas. This would tend to also lower the equilibrium groundwater level beneath the final landform. On the other hand, the model currently applies enhanced permeabilities in the adopted fracture zone that are much higher than is normally warranted with other groundwater models calibrated to known mine inflow. The assumption of more reasonable, but still conservative, vertical hydraulic conductivities is tested in Table 5-2 and Figure 5-11 (Document #1) where it is noted that the average mine inflow would reduce by a factor of four (23 L/s to 6 L/s).

An extreme sensitivity analysis has been conducted for full fracturing to land surface. While it is recognised that some fractures could reach land surface, along the edges of the fracture network paraboloid, a groundwater model should assess only the zone of intense connected fracturing, otherwise the whole volume of rock between land surface and the coal seam is assumed to be draining. The results for the full fracturing scenario, illustrated in Document #1 at Figures 5-8 to 5-10, show that differential effects are largely confined to the mining footprint with only minor off-site effects due to the assumption relied upon for the height of fracturing.

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:

- *"Describe and map in plan and cross-sections the surficial and solid geology and landforms, including catchments, of the project area. Show geological structures, such as aquifers, faults and economic resources that could have an influence on, or be influenced by, the project's activities.*
- *Identify and describe the environmental values and characteristics of groundwaters (including seasonal variation) within the area potentially affected by the Project (on and off-site) and at suitable reference locations. Define the relevant water quality objectives applicable to the environmental values.*
- *Describe the quality, quantity and significance of groundwater in areas potentially affected by the Project.*
- *Describe present and potential users and uses of water in areas potentially affected by the Project, and the 'make good' provisions for water users adversely impacted by the Project.*
- *Model and describe the inputs, movements, exchanges and outputs of groundwater that may be affected by the Project. Undertake model sensitivity analysis and uncertainty analysis*

[6] Ditton, S. and Merrick, N. 2014, A new subsurface fracture height prediction model for longwall mines in the NSW coalfields. Geological Society of Australia, 2014 Australian Earth Sciences Convention (AESC), Sustainable Australia. Abstract No 03EGE-03 of the 22nd Australian Geological Convention, Newcastle City Hall and Civic Theatre, Newcastle, New South Wales. July 7 - 10. Page 136.

- *Assess the frequency (and time lags if any), location, volume and direction of interactions between water resources, including surface water/groundwater connectivity and inter-aquifer connectivity, and provide input to conceptual models for groundwater dependent ecosystems.*
- *Describe the potential impacts (short-term and long-term), including direct, in-direct and cumulative impacts, of the Project on groundwater (and resultant impact to assets dependent on the resource including groundwater-dependent ecosystems) at the local scale and in a regional context.*
- *Detail the proposed measures to avoid, minimise, mitigate and monitor impacts on environmental values (including measurable criteria, standards and/or indicators, and corrective actions), and demonstrate how the relevant environmental objectives and performance outcomes will be met."*

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 #2.

The primary output of the uncertainty analysis, with respect to potential off-site impacts, is presented in Document #2 in Figures 6-5 to 6-8 as 5th, 50th and 95th percentile probabilities of exceeding 2 m drawdown in alluvium, regolith, Leichhardt seam and Vermont seam. The near-coincidence of the base-case prediction and the median (50th percentile) prediction indicates that the base case model is an adequate predictor of the most likely future behaviour of the groundwater system in response to Project mining.

The main findings are:

- One registered private bore in Tertiary sediments is likely to be impacted (more than 2 m maximum drawdown).
- No registered private bore in Triassic sediments is likely to be impacted (more than 5 m maximum drawdown).
- No registered private bore in Permian sediments is likely to be impacted (more than 5 m maximum drawdown).
- To assess whether unregistered private bores exist with the predicted drawdown extents, mainly to the east and to the north, Document #1 includes a recommendation for a targeted bore census in those areas.
- Given the naturally deep water table (measured as 9 to 28 m), no groundwater dependent ecosystems are likely to be affected by Project mining. Ecosystems dependent on perched groundwater would not be affected, due to the natural disconnection between different groundwater systems.
- Project mining-induced losses from alluvium and watercourses would be negligible.
- During operations, the predicted underground mine inflow would average about 2.0 ML/day for an extremely permeable fracture zone, or about 0.6 ML/day for a more realistic condition.
- During operations, the loss from the groundwater system to the open cut pit would average about 0.7 ML/day (prior to evaporation accounting).
- No water quality impact is expected from the final landform depression, other than probable freshening of ambient groundwater in the Tertiary sediments.

The reviewer supports the validity of the conclusions of the groundwater impact assessment.

[signature] NP Merrick

Dr Noel Merrick