# Mulga Downs Groundwater Modelling
# Independent Peer Review

| Prepared for: | Roy Hill Iron Ore Pty Ltd | 28 April 2023 |
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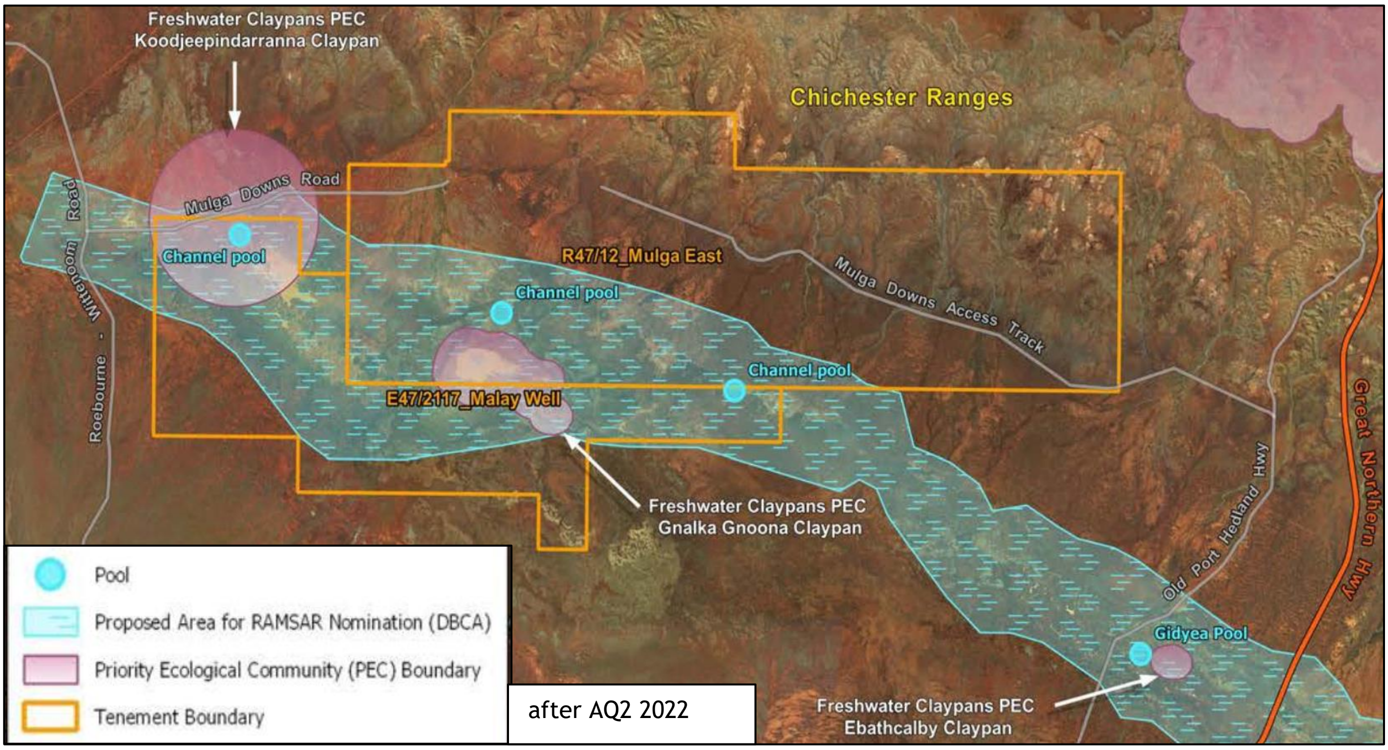


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**THIS REPORT SHOULD BE CITED/ATTRIBUTED AS:**

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# 1. INTRODUCTION

This report summarises the outcomes of an independent peer review into the groundwater modelling investigations conducted by consultants Groundwater Consulting and AQ2 for the Mulga Downs (East) Iron Ore Project in the Pilbara region of Western Australia (Figure 1).

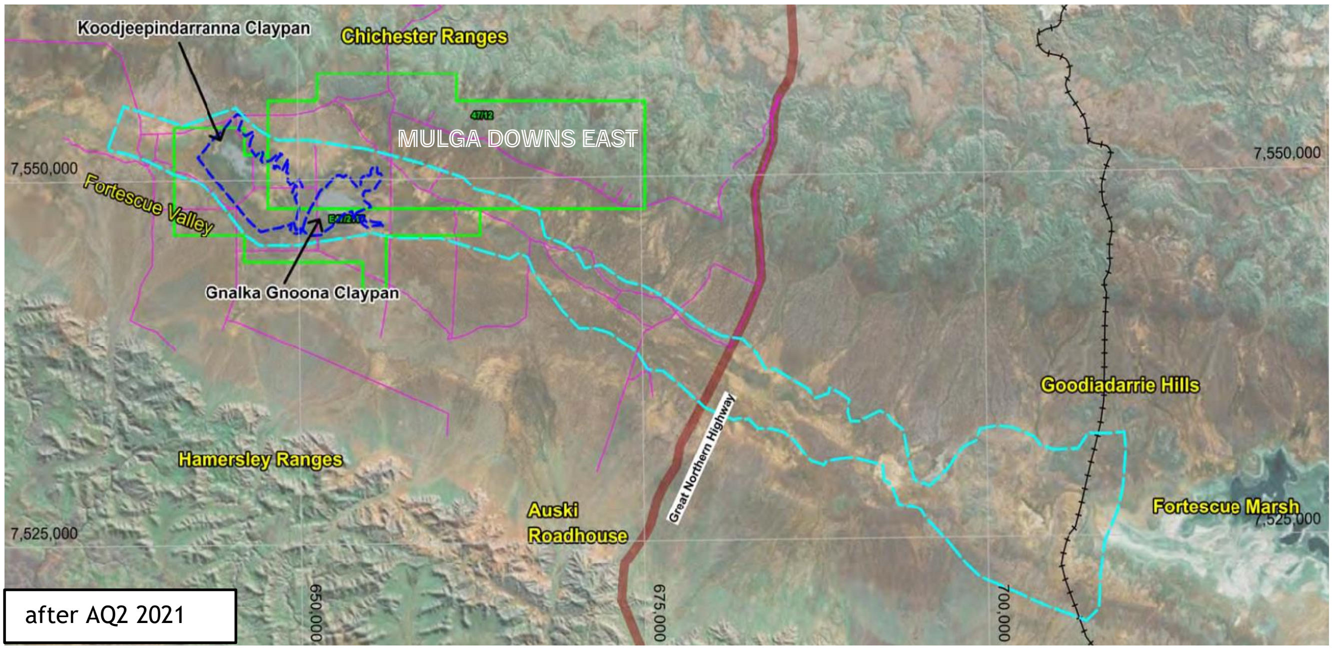


*Figure 1 – Mulga Downs East location in lower Fortescue Valley*

As the Mulga Downs East project involves some mining below water table, groundwater modelling is used to predict aquifer responses, providing information to support approvals and environmental management programs. Confidence in modelling results is required by Roy Hill Pty Ltd (and its parent company Hancock Prospecting Pty Ltd) for application to Mulga Hill project investment and management decisions, and confidence is also required by government agencies regarding the modelling fitness for purpose for the approvals assessment and environmental management process.

The Environmental Scoping Document for Mulga Downs (HPPL 2022a) was prepared in accordance with the EPA requirements for the Public Environmental Review. It states that a peer review be conducted of the groundwater modelling, which itself forms the quantitative basis for the PER assessment and Groundwater Management Plan to address:

- the extent and distribution of groundwater drawdown to assist in managing habitat requirements for subterranean fauna;
- environmental outcomes for the discharge of excess mine dewater via reinjection within the Malay Well and Mulga West Borefields;
- a cumulative impacts assessment (CIA) of environmental effects from activities within 100 km of the project, including emissions resulting from mining activities, and the effects from drawdown resulting from mine dewatering activities along the Fortescue River Valley.

## 1.1 Modelling accords with moderately low risk context

It is reasonable to generalise that best practice suggests that the level of detail applied to an investigation should be commensurate with the risks (Barnett et al. 2012; Middlemis and Peeters 2018). Although the hydrogeology and modelling reports do not attempt to frame the investigation in this way, this reviewer is satisfied that sufficient evidence has been presented in the reports to indicate that there is a moderately low risk of groundwater-related impact pathways. For example:

- there is poor hydraulic connection to Fortescue Marsh (see more detail below);
- the Goodiadarrie swamp freshwater claypans are supported mainly by surface water runoff (ie. no obligate GDEs);
- the depth to water table is typically 3-5 m across the valley floor, with seasonal responses typically less than 1 m since 2008, and the underlying water table has a salinity that ranges from moderate to high (typically 3000-17,000 mg/L);
- the few water users or GDEs would be adapted to these groundwater conditions.

In relation to cumulative effects, the EPBC Act referral notice (HPPL 2022b) notes this (refer to Figure 1 for locations):

> *'The Proposed Action is located within the Fortescue Valley, which is divided by the Goodiadarrie Hills into the eastern or Upper Fortescue River, which comprises the Fortescue Marsh, and the western or Lower Fortescue River Valley. The upper most portion of the Lower Fortescue River Valley comprises a network of interconnected ephemeral swamps, claypans and floodplains collectively known as the Goodiadarrie Swamp. The Fortescue Marsh is geographically and hydrogeologically separate to the Goodiadarrie Swamp. The Fortescue Marsh is outside the Proposed Action Area and inferred groundwater drawdown radius of influence.'*

This statement is justified by the evidence for limited hydraulic connection between the (lower Fortescue) Goodiadarrie swamp near Mulga Downs and the (upper) Fortescue Marsh, notably:

- EPA Report 1484 (2013) includes these statements:

> *'The Fortescue Marsh is a unique wetland formed at the terminus of the Upper Fortescue River as a result of the low permeability of the Goodiadarrie Hills.… The water regime of Fortescue Marsh is dominated by surface water run-off from the catchment and subsequent evaporative loss. … With restricted outflow from the system, evaporation processes dominate causing loss of water and the accumulation of salts.'*

- Skrzypek et al (2016) concluded that the high basement elevation at the western end of the Upper Fortescue Valley restricts lateral groundwater outflow to the lower Fortescue to less than 2 GL per year (<0.5% of inflow to the Marsh).

Furthermore, the hydrogeological investigation (AQ2 2022) reports that a surface water and groundwater divide exists to the west of Goodiadarrie Swamp, which hydraulically separates the project area from the (extended) Lower Fortescue Valley.

Apart from the latter (new) point, the above statements are also consistent with the findings of previous investigations that I have been involved with, notably the Central Pilbara Groundwater Study (Aquaterra, 2000; Johnson and Wright, 2000).

# 2. Peer Review

## 2.1 Methodology

This independent peer review was conducted consistent with best practice guidelines on groundwater modelling (Barnett et al. 2012) and uncertainty analysis (Middlemis and Peeters 2018, update in prep. 2023), to assess:

- the hydrogeological understanding and conceptualisation, and its implementation in numerical and/or analytical models;
- conformance to best practice guidelines for model calibration performance, considering domain, grid, boundary conditions, layering and parameterisation, non-uniqueness and sensitivity-uncertainty prediction scenarios and results;
- the fitness for purpose of the modelling tools for groundwater impact assessment simulations of dewatering and MAR effects and mine closure scenarios;
- whether the assessments and/or conclusions are supported by the evidence presented, and whether further investigations or modelling may be warranted.

## 2.2 Reports Reviewed

- AQ2 (2023) – *Numerical Groundwater Modelling*, presented as Appendix I to the Hydrology and Hydrogeology Pre-Feasibility Study (AQ2 2022); this report details the model development and history-match calibration.
- Groundwater Consulting (2023) – *Mulga Downs Groundwater Modelling*; this report is an adjunct to the AQ2 report, detailing the application of the groundwater model to the mining and post-mining predictive scenarios, including the assessment of salinity effects.

## 2.3 Peer Reviewer

This desktop peer review was conducted in March-April 2023 by independent consultant Mr Hugh Middlemis (Principal Groundwater Engineer, HydroGeoLogic):

- Hugh holds a degree in civil engineering and a masters in hydrology and hydrogeology, with more than 40 years' experience, the last 10 years as an independent specialist. Hugh was principal author of the first Australian groundwater modelling guidelines (Middlemis et al. 2001), which formed the basis for the latest guidelines (Barnett et al. 2012), and he is co-author of recent guidance reports on modelling uncertainty (Middlemis et al. 2018, 2019).
- Hugh has extensive project experience in the Pilbara region, including:
    - Principal Modeller based in Perth at AGC Woodward-Clyde and Aquaterra over the period 1995-2002, working on Pilbara projects such as at Marillana Creek and Mining Area C (for BHP), Hope Downs, plus the Central Pilbara Study (for WRC, 2001) that provided a water balance estimate for Fortescue Marsh.
    - Technical reviews for Rio Tinto on modelling for Fortescue Marsh (Koodaideri borefield; 2020); West Angelas (2022); Silvergrass (2018-2020); Yandi/Billiards (2018).
- Hugh has conducted recent peer reviews for DWER (Collie, 2020; Myalup, 2021).

- Hugh is currently a member of state level expert panels, such as;
    - Mining and Petroleum Gateway Panel (NSW, 2021-24);
    - Groundwater Technical Review Panel (DEECA Victoria, 2021-24);
    - Independent Technical Review Panel, Barwon Downs and Big Swamp Remediation and Environment Protection Plan (Southern Rural Water, Victoria, 2019-23).

## 2.4 Declaration

**We assert no conflict of interest in relation to this work.**

Mr Middlemis has not worked on the Mulga Downs Project, nor for its consultants (AQ2; Groundwater Consulting; DarkWater Consulting).

We note that Mr Middlemis was part of the project teams that included current AQ2 staff members then employed at AGC Woodward-Clyde and Aquaterra in Perth in the late 1990s that worked on the Hope Downs project for Hancock Prospecting Pty Ltd (owner of Roy Hill Iron Ore). Mr Middlemis established HydroGeoLogic as an independent consultancy in 2013 and has not worked for HPPL entities since then.

We note that Mr Middlemis has been engaged by Kite Gold since 2021 on a groundwater modelling investigation at the Four Eagles gold prospect in Victoria. Kite Gold is a subsidiary of Catalyst Metals, which is the joint venture partner on the Four Eagles prospect along with Gold Exploration Victoria, itself a subsidiary of HPPL.

# 3. MULGA DOWNS PEER REVIEW OUTCOME SUMMARY

The modelling guideline compliance summary checklist is presented in Table 1 (after Table 9-1 of Barnett et al. 2012), with further discussion in later sections.

It is worth noting that the modelling has been well designed and executed to investigate the potential for project impacts via groundwater pathways, such as due to mine dewatering and managed aquifer recharge (MAR) to dispose of excess water. It should not be inferred from my previous review comments (in section 1.1, about an arguably moderately low risk of groundwater-related impacts) that the model design and execution is not fit for the impact assessment purpose. While there are limitations in any modelling investigation, this study has presented adequate detail in terms of justifying key assumptions, design/execution factors and constraints; for example:

- the northern boundary is quite close to mine dewatering, but the drawdown contours do not reach it, and the water balance shows those inflows don't change;
- the eastern boundary is mostly inflow, but during very wet periods it can become an outflow boundary, but at small rates that would not affect Fortescue Marsh;
- the dewatering/MAR implementation involves constraints to ensure practicable extraction/injection rates and limited mounding/evapotranspiration impacts.

*Table 1 - Groundwater Model Compliance: 10-point essential summary: Mulga Downs East*

| Question | Y/N | Comments re Mulga Downs modelling (by AQ2 and GWC, 2023) |
|---|---|---|
| 1. Are the model objectives and model confidence level classification clearly | Yes | Objectives clearly stated for groundwater modelling and assessment of the effects of mining activities. Qualitative model confidence level framework is now regarded as outmoded (see section 4.1). For the record, level 2 is appropriate and justified. |
| 2. Are the objectives satisfied? | Yes | Modelling design and execution consistent with best practice, noting moderately low risk context (Goodiadarrie swamp freshwater claypans supported mainly by surface water runoff; >3m depth to water table with salinity 3000-17,000 mg/L; few users or GDEs other than those adapted to these groundwater conditions; poor connection to Fortescue Marsh). |
| 3. Is the conceptual hydrogeological model (CHM) consistent with objectives and confidence level? | Yes | CHM consistent with data and objectives, suitable for mining project impact assessment. CHM integrates data on geology, hydrogeology and hydrochemistry, along with environmental factors relating to Goodiadarrie Swamp and MAR disposal options. Qualitative confidence level now outmoded but CHM OK. |
| 4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer? | Yes | Extensive knowledge base from investigations since 2009. More detail since 2018 (eg. 51 bores at 23 sites; 7 surface water sites). Plus deep knowledge base on regional Pilbara conditions. Extensive good quality reporting on groundwater, surface water and related ecosystems. Expert reviews in-house, plus this review. |
| 5. Does the model design conform to best practice? | Yes | The model software (Modflow-Surfact), extent (~94 x 30 km), boundaries, 11 layers (mostly 10m thick), parameters, overall design and methodology are consistent with best practice design/execution, noting moderately low risk context. Eastern boundary fixed head inflow/outflow results OK, but recommended change to head-dependent flow condition is endorsed. Northern boundary close to dewatering effects, but in low permeability Jeerinah unit and water balance shows no changes with time. Surface-groundwater interactions represented adequately. Assumptions / limitations documented and reasonable/justified. |
| 6. Is the model calibration satisfactory? | Yes | Basecase & alternate (high K) parameters helps test uncertainty. Long term transient performance 1960-2021 is OK (sRMS 6-7%); benchmarks to bore data since 2008. Level mismatches ≤1m for all but one bore, seasonal responses OK. Pump test matches not close, esp. pumping bores, not unusual for regional model (OK). |
| 7. Are the calibrated parameter values and estimated fluxes plausible? | Yes | Model parameter values consistent with testing. Base case and alternate scenario indicates some parameter/model equivalence. Comprehensive uncertainty analysis warranted next stage. |
| 8. Do the model predictions conform to best practice? | Y/N (except porosity for solute trans.) | Scenario differencing with/without mine dewatering and MAR well constrained and executed. Modelling optimised mining scenarios to minimise impacts. Some features not assessed (tailings, time-varying properties for pit backfill); likely low sensitivity. Aquifer recharge OK, predictions using post-1960 climate good surrogate for climate change. Zero salinity eastern inflow boundary questionable, but results show little effect. High porosity base case and low porosity sensitivity test; little material TDS change. |
| 9. Is the uncertainty associated with the simulations/predictions reported? | Yes | Sensitivity analysis conducted rather than uncertainty analysis, but justified for moderately low risk context. Extensive parameter ranges tested, mostly low sensitivity. Recommendations for field testing justified (frac. Marra Mamba; undiff. Tertiary). |
| 10. Is the model fit for purpose? | Yes | The Mulga Downs groundwater modelling and assessment has been conducted competently and consistent with best practice, noting the moderately low groundwater impact risk context. Recommendations for further work are endorsed. |

# 4. DISCUSSION

The groundwater modelling reports (AQ2 2022, 2023; GWC 2023) are adequately documented, with good quality graphics (mostly) and explanations of the hydrogeological setting, the conceptual model, the computational model design and execution, the hydrological stresses and simulations, the sensitivity analyses and the predicted impacts. Adequate details have generally been provided and no material omissions have been identified.

## 4.1 'Model Confidence Level' and Sensitivity Analysis

The 'model confidence level classification' of the Australian Groundwater Modelling Guidelines ('AGMG'; Barnett et al. 2012) is an outmoded qualitative characterisation that is reportedly being revised. The classification considers the level of data available, responses to hydrological stresses, the conceptualisation and calibration process and performance, and the manner in which the predictions are formulated. The AGMG is reportedly being revised and this qualitative assessment will likely be discontinued.

The uncertainty guidance provided in the AGMG was updated and augmented in the recent uncertainty analysis guidance report (Middlemis and Peeters, 2018). This included the important principle that "a model should be able to quantify its own reliability [via a well-executed uncertainty analysis], rather than relying on the AGMG confidence level scheme, which is prone to misinterpretation". This was warranted in the sense of concerns that the AGMG was being used inappropriately in some cases to justify 'indiscriminate complexification' of models, rather than the 'effective simplification' that is warranted for application to uncertainty analysis.

The 2018 uncertainty guidance frames uncertainty analysis as an integral part of risk management, in that it informs and complements other aspects such as risk assessment, investigating mitigations/treatments, developing management and monitoring plans, communicating outcomes and prioritising efforts to reduce uncertainty. It requires a balance to be struck between model simplicity and complexity for the purpose of uncertainty evaluation, commensurate with the risk/consequence profile of the project.

The 2012 AGMG and the 2018 uncertainty guidance are both in the process of being updated. This peer reviewer is advised that the AGMG revision will involve the rejection of the 'model confidence level' framework and its formal replacement with uncertainty analysis methodologies.

For Mulga Downs, a targeted sensitivity analysis has been conducted rather than a quantitative uncertainty analysis, although that is a reasonably justified investigation effort that is commensurate with the fairly low level of risk (see section 1.1), and thus is consistent with uncertainty analysis principles (Middlemis and Peeters 2018).

## 4.2 Model Design and Parameterisation

The finite difference model software applied (Modflow-Surfact) is a well-tested, documented and respected package that is suitable for application to this investigation. That said, the recommendation by AQ2 (2023) to update the software to the Modflow-USG platform is endorsed, mainly because it provides improved facilitation of uncertainty analysis methods that are recommended for the next stages of investigation.

An equivalent porous medium (EPM) modelling approach has been applied to the groundwater flow system, which includes fractured rock aquifer units, an approach commonly applied in the Pilbara. It is consistent with best practice principles and is justified with reference to the hydrogeological investigations and conceptualisation.

A parsimonious approach has been applied to the model design and parameterisation, in terms of the spatially uniform aquifer property zones, consistent with best practice modelling principles (Barnett et al. 2012; Guiding Principle 3.1 and related commentary):

- ‘The level of detail within the conceptual model should be chosen, based on the modelling objectives, the availability of quality data, knowledge of the groundwater system of interest, and its complexity.’
- ‘In regional problems where the focus is on predicting flow, predictions depend on large scale spatial averages of hydraulic conductivity rather than on local variability. Moreover, in large regions there may be insufficient data to resolve or support a more variable representation of hydraulic conductivity. A parsimonious approach may be reasonable, using constant properties over large zones, or throughout a hydrostratigraphic unit.’
- ‘Model predictions that integrate larger areas are often less uncertain because characterisation methods are well-suited to discern bulk properties, and field observations directly reflect bulk system properties.’

The parsimonious approach applied in this case can be described as consistent with basic best practice, in that it was common practice at the time when the 2012 guideline was published.

However, best practice has since moved on to embrace quantitative uncertainty analysis methods, which typically use multiple realisations of spatially complex aquifer parameter distributions. That said, the approach adopted is reasonably justified in terms of traditional best practice principles as well as the latest effective simplicity approaches (Doherty and Moore, 2021), even if quantitative uncertainty analysis was not (yet) applied in this case. It is recommended that improved uncertainty analysis be conducted in the next stage of modelling.

The parameterisation values applied are consistent with drilling and testing data, and the parameter ranges applied to the sensitivity analysis have been carefully constrained, with conservative assumptions applied, such as high values for hydraulic conductivity in some key units (with suitable justification) that would tend to over-estimate drawdown impacts.

## 4.3 Groundwater Dependent Ecosystems (GDEs)

The EPBC referral (HPPL 2022b) indicates that potential facultative phreatophytic Eucalyptus camaldulensis and E. victrix occur in the general project region, but not specifically in the tenements for the Mulga Downs East project. The main hydrogeology report (AQ2 2022) indicates that potential GDEs are present in the Mulga Downs West area, in the form of riparian vegetation, and similarly there is no mention of such GDEs in the Mulga Downs East area.

More detail is provided in the Ecohydrology report (AQ2 2020), which identified scattered E. victrix in the Mulga Downs East area, associated with claypans. These claypans are Priority 1 Priority Ecological Communities, predominantly support by rainfall-runoff. Detailed investigations and ecohydrological water balance modelling confirmed that groundwater did not contribute to tree evapotranspiration at the sites investigated, except possibly at one site at the Gnalka Gnoona claypan. However, the analysis concluded that the E. victrix at that site is unlikely to be obligate phreatophytic.

The groundwater modelling includes depth-dependent evapotranspiration (‘ET’) across the valley floor, consistent with best practice methods, and with parameterisation that is suitable to represent the terrestrial vegetation GDE functionality and to assess potential impacts. A key data requirement for this feature is accurate topography, but the SRTM (lowish resolution) data that is available and was applied invokes a data uncertainty, which should be addressed with LiDAR data (an acknowledged limitation in AQ2 2023).

The modelling results show a wide variation in ET rates across the model for the no development case, ranging from 15,000 to 37,000 kL/d for dry to wet conditions (AQ2 2023, Table 2.4). For the basecase mining scenario, the average ET is predicted increase due to MAR mounding, from 14,589 to 16,590 kL/d (GWC 2023, Table 2-6), an increase of about 2000 kL/d (14%). Detail is not provided on changes to ET in the Gnalka Gnoona claypan, but results are presented in terms predicted maximum drawdown of about 16m over the first 9 years of mining (GWC 2023 Figure A66), and subsequent almost complete recovery by the end of mining, presumably due to MAR mounding. There is also a gradual salinity decrease from about 12,000 to 8,000 mg/L during the mining period for the base case (Figure C23).

In summary, the modelling is well designed and executed in terms of terrestrial GDE criteria. It is understood that the modelling should also be suitable for detailed impact assessment by subterranean fauna specialists.

## 4.4 Scenario Modelling

While the model ‘calibration’ to pumping test data does not show a close match, this is usual for regional scale models and is not a modelling flaw as such. The parameter values obtained from the traditional detailed analysis of pumping test data have been used to constrain parameters in the modelling, consistent with best practice.

The model calibration is commendable in presenting a basecase scenario along with an 'uncertainty' case that has higher permeability values applied to the CID/Pisolite units and lower permeability applied to the Marra Mamba / West Angela ore units. The apparent equivalence in model results is described in the report as 'equally well matched', but it is possible that the extensive fixed head boundary conditions may be having too much of a constraining effect on the modelled flow system. Further sensitivity/uncertainty testing of boundary conditions may be warranted in the next phase or work, especially on the eastern boundary (the water balance shows that the northern and southern boundary fluxes do not materially change).

The predictive scenario modelling investigation of the proposed mining operation (GWC 2023) is commendable for identifying the optimal mine development scenario (west to east) that minimises impacts, including groundwater mounding due to MAR. Post-mining predictive scenarios were also run, assuming that the backfilled pits have the same aquifer parameters as the in situ properties, which is not unreasonable, but future work programs should improve the parameterisation with time-varying properties options to investigate sensitivities/uncertainties and any implications.

## 4.5 Salinity Assessment

The mining scenario salinity assessment is based on solute transport simulations (GWC 2023), which requires parameter values for aquifer porosity, as this governs advective mass flow rates. The model development report (AQ2 2023, Table 2.3) presented the adopted porosity values (generally 10% to 35%), but these values are very high in comparison to the specific yield (Sy) values (generally 0.1% to 1%). It is commonly assumed that, except for clay units, specific yield is a reasonable basis for an effective porosity value (although this is not actually recommended as best practice). The porosity values are not constrained by the flow model calibration (as acknowledged in AQ2 2023).

Accordingly, the solute transport runs evaluate the effects of high and low porosity values (GWC 2023). As described in the GWC report, high porosity values result in lower groundwater flow velocities, which has implications for the salinity assessment, especially the dynamic timing of salinity changes. The lower porosity values applied to the sensitivity run resulted in more rapid salinity changes, as expected, although the predicted range of salinity values is not materially affected.

# 5. CONCLUSIONS

This review finds that the Mulga Downs East groundwater modelling and assessment has been conducted competently and is justifiably consistent with best practice methods. A sensitivity analysis has been conducted rather than a quantitative uncertainty analysis, but this is reasonable given the conditions applying. The salinity assessment considers high and low porosity values and demonstrates that the predicted salinity changes are not materially affected.

Ongoing monitoring and other investigations will provide additional data for future model refinements, improvements in performance and further uncertainty analysis. Such progressive updates would help support future monitoring and management.

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