australia@cdmsmith.com
cdmsmith.com/en-AU/

# Memorandum

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| To: | Stuart Simmonds |
| From: | Vincent Puech |
| Date: | 13 November 2023 |
| Subject: | Review of the groundwater uncertainty analysis for the GHD numerical groundwater model for the Worsley Bauxite Alumna Expansion project |

# 1 Introduction

This memo detailed the independent peer-review of the “Groundwater uncertainty analysis to support addressing comments provided by the Office of Water Science” prepared by GHD and dated from August 7, 2023. The document was prepared by GHD in response to requirements by the office of Water Science. The uncertainty analysis detailed in the GHD document is a complement to the Worsley Mine Expansion groundwater numerical model report, developed by GHD (GHD, 2020). The three-dimensional numerical groundwater flow model was built to quantify potential groundwater related effects of the proposed mining activities, specifically changes to groundwater levels and fluxes, to inform the assessment of groundwater impacts (GHD, 2020).

The model review detailed in this memo encompasses the finding of the initial review of the original modelling report (GHD, 2020) to provide an overarching update on the suitability of the whole GHD model approach to successfully reach the model objectives. For reference, the original review is reported in the document:

- CDM Smith 2023. Independent Review of the Worsley Mine Expansion Groundwater Numerical Model - GHD’s responses to DCCEEW.

The purpose of the model review is to determine whether GHD’s groundwater model approach, including the predictive uncertainty analysis (PUA), is hydro-geologically sound and fit-for-purpose for addressing the requirements of the Environmental Protection Authority (EPA) as per the Environmental Scoping Document (Assessment Number 2216).

This report provides the independent model review results following the principle and guidance from the Australian Groundwater Modelling Guidelines (Barnett et al. 2012).

# 2 Key findings

The predictive uncertainty analysis (PUA) conducted by GHD is compliant with the Australians groundwater modelling guidelines (Barnett et Al. 2012) and offers one of the currently most elaborated way of addressing predictive uncertainty in groundwater modelling.

The PUA conducted by GHD adequately addresses the most relevant shortcomings identified by the initial review (CDM Smith 2023). In conclusion, it is the reviewer’s opinion that the modelling is suitable for its use in the regional assessment of water table mounding related to enhanced recharge associated with land clearing. As emphasized by GHD in section 3.2 of the PUA report (GHD 2023), the reviewer shares the opinion that the model was primarily designed for a regional assessment scope and that localised effect on Quindanning spider orchid specific locations would require a more targeted modelling approach, supported by further field data.

# 3 Detailed review

## 3.1 Groundwater Model Review Limitations

In accordance with Australian modelling guidelines, the review relies on reporting accuracy and considers only the supplied model reports and does not include the review of the model files (MODFLOW-USG files).

The review is limited to the evaluation of the suitability of the model to estimate regional mounding.

## 3.2 Australian modelling guidelines compliance checklist

The review of the complement document describing the PUA is reported using the compliance checklists recommended by the Australian modelling guidelines. The checklists are summarised in the following tables (from Table 1 to Table 8). The tables duplicate and update the findings of the original review (CDM Smith 2023). The changes related to the PUA document are highlighted in blue.

**Table 1 Compliance Checklist**

| Review Questions | Yes / Partly / No | Comment |
|---|---|---|
| 1. Are the model objectives and model confidence level classification clearly stated? | Yes | The model objectives and confidence level classification are stated at the start of the report. |
| 2. Are the objectives satisfied? | Yes<br>~~Partly~~ | The PUA provides confidence that the prediction can be used for the impact assessment.<br>The calibration performance complies with a Class 2. A class 2 model is appropriate within an impact assessment framework, and suitable for the current modelling objectives. |
| 3. Is the conceptual model consistent with objectives and confidence level classification? | Yes | The conceptualisation is described with relevant detail. |
| 4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer? | Yes ~~Partly~~ | It is reasonable to assume that no significant data was left out and therefore to assume that this objective is satisfactorily achieved.<br>The data is presented and provides a reasonable conceptual model. |
| 5. Does the model design conform to best practice? | Yes | The model conforms with appropriate standard practices and uses industry standard modelling software including MODFLOW-USG, AlgoMesh, PEST, over-parameterisation and regularisation techniques. |
| 6. Is the model calibration satisfactory? | Yes | The calibration statistics (SRMS of 4.3%) is indicatives of a suitable regional fit, with adequate representation of regional gradient.<br>Occasional local mismatch (e.g. bores AO4, F12, K13, MP17, P08, Q08, T07C, 61618103) are indicatives of some limitations for interpreting model results at a local scale, particularly in absolute values.<br>However, the calibration is acceptable for the current risk assessment purpose as:<br>- the impact analysis is based on relative values (difference between a base case and a mining scenarios) which are less affected by local mismatch than prediction in absolute values,<br>- the predictive uncertainty analysis by covering a wide range input parameters values makes-up for some local model inadequacies. |
| 7. Are the calibrated parameter values and estimated fluxes plausible? | Yes | Adequate |
| 8. Do the model predictions conform to best practice? | Yes | The reporting of model predictions conforms with best practices. Composite mounding figures generated by GHD are of great quality. |
| 9. Is the uncertainty associated with the predictions reported? | Yes ~~No~~ | The uncertainty is well reported and illustrated in the GHD document. GHD produced a state-of-the-art PUA using the null space Monte Carlo approach which generated 439 calibrated models, which is more than sufficient to assess the predictive uncertainty. |
| 10. Is the model fit for purpose? | Yes ~~Partly~~ | It is the opinion of the reviewer that the model is suitable for the impact assessment. |

### 3.2.1 Planning

The model process starts with planning, which focuses on gaining clarity on the intended use of the model, the questions at hand, the modelling objectives and the type of model needed to meet the project objectives (Barnett et al, 2012). The planning phase and that the modelling approach was suitable to reach the project objective.

It is not mentioned whether GHD had agreed to the proposed re-classification to class 2 by the reviewer. However, this is inconsequential as it is not the model classification that provides confidence in the modelling objective. The classification evaluates only the capacity of the model to have a low predictive error (and consequently a low distribution of predictive error). Within a risk assessment, conservatism is more relevant than model accuracy, and the added PUA provides the confidence that was initially lacking.

Table 2 summarises the model planning review.

**Table 2 Planning Review**

| Review Questions | Yes / Partly / No | Comment |
|---|---|---|
| 1.1 Are the project objectives stated? | Yes | The project objectives are stated at the start of the report. |
| 1.2 Are the model objectives stated? | Yes | The model objectives are stated at the start of the report. |
| 1.3 Is it clear how the model will contribute to meeting the project objectives? | Yes | The report defines how the model contributes to meet the project objective for example prediction of mounding and river baseflow. |
| 1.4 Is a groundwater model the best option to address the project and model objectives? | Yes | A regional numerical model is the best option available to address the project and model objectives. The model is required to account for the influence of aquifer geometry and distribution of parameters to evaluate propagation of mounding in a complex environment. |
| 1.5 Is the target model confidence-level classification stated and justified? | NA | The model more appropriately suits a class 2 modelling classification, which is perfectly suitable for the risk assessment. Within an environmental impact assessment framework, the model class and the high performance of the calibration are not critical criteria. A class 2 model is perfectly suitable (the guidelines don't require a class 3 model for an impact assessment). |
| 1.6 Are the planned limitations and exclusions of the model stated? | Yes | The planned limitations and exclusions of the model are stated. |

### 1.1.1 Conceptualisation

Conceptualisation is a process that provides the basis for model design and identify how the system works. The conceptual model should be developed collaboratively across relevant disciplines and project stakeholders (Barnett et al, 2012). The conceptualisation defines the foundation of any modelling approach and is the phase where relevant processes and properties of the natural system are identified and described.

The conceptualisation was developed appropriately for the complex environment including details on the landscape, climate, fractured rock aquifer system, surface water features and mining history. Resulting from the complexity, the groundwater system exhibits various behaviour in groundwater trends and salinity. The conceptualisation proposed in the report conforms to acceptable standard practices.

It is the reviewer opinion that the conceptualisation is fit for purpose and according to the industry standards.

Table 3 summarises the model conceptualisation review.

**Table 3 Conceptualisation Review**

| Review Questions | Yes / Partly / No | Comment |
|---|---|---|
| 2.1 Has a literature review been completed, including examination of prior investigations? | Yes | GHD consulted existing literature to build up the conceptual model. |

| Review Questions | Yes / Partly / No | Comment |
|---|---|---|
| 2.2 Is the aquifer system adequately described? | Yes | The aquifer system is adequately described in Section 3 of the model report. |
| 2.2.1 hydrostratigraphy including aquifer type (porous, fractured rock ...) | Yes | As above. |
| 2.2.2 lateral extent, boundaries and significant internal features such as faults and regional folds | Yes | As above. |
| 2.2.3 aquifer geometry including layer elevations and thicknesses | Yes | The adopted hypothesis and data sources are stated. |
| 2.2.4 confined or unconfined flow and the variation of these conditions in space and time | Yes | Appropriately defined and described. |
| 2.3 Have data on groundwater stresses been collected and analysed? | Yes | The mine schedule is integrated in the conceptualisation and the effects of land clearance related to mining activity on infiltration is documented. |
| 2.3.1 recharge from rainfall, irrigation, floods, lakes | Yes | GHD provides a good description on the land clearing expected effects on aquifer recharge. |
| 2.3.2 river or lake stage heights | Yes | Adequate assumptions based on elevation model and Lidar data |
| 2.3.3 groundwater usage (pumping, returns etc) | Yes | Adequate |
| 2.3.4 evapotranspiration | Yes | Adequate |
| 2.3.5 other | n/a | n/a |
| 2.4 Have groundwater level observations been collected and analysed? | Yes | Adequate |
| 2.4.1 selection of representative bore hydrographs | Yes | An appropriate hydrographs selection is detailed. |
| 2.4.2 comparison of hydrographs | NA | All hydrographs are provided as individual figures. It's not detrimental to the site conceptualisation as vertical gradients are not a driver of the impact assessment |
| 2.4.3 effect of stresses on hydrographs | Yes | GHD provides plausible interpretation on the effect of stresses (e.g. climatic, mine related) on the hydrographs. |
| 2.4.4 water table maps/piezometric surfaces? | Yes | Presented in Figure A4 and A5 of the model report. |
| 2.4.5 If relevant, are density and barometric effects taken into account in the interpretation of groundwater head and flow data? | n/a | Not relevant. |
| 2.5 Have flow observations been collected and analysed? | Yes | Baseflow to mainstreams have been considered and data analysed. |
| 2.5.1 baseflow in rivers | Yes | As above. |
| 2.5.2 discharge in springs | n/a | n/a |
| 2.5.3 location of diffuse discharge areas | Yes | The enhance recharge in cleared areas has been appropriately defined and described. |
| 2.6 Is the measurement error or data uncertainty reported? | No | Inconsequential. Measurement error is not routinely known and reported. The measurement error, if known, can help justifying the calibration strategy (weighing) and the calibration performance. It is not detrimental to the project objective |

| Review Questions | Yes / Partly / No | Comment |
|---|---|---|
| 2.6.1 measurement error for directly measured quantities (e.g. piezometric level, concentration, flows) | No | As above. |
| 2.6.2 spatial variability/heterogeneity of parameters | Partly | The conceptualisation section mentions of the fractured nature of the bedrock but provides no analysis on the potential importance of heterogeneity. |
| 2.6.3 interpolation algorithm(s) and uncertainty of gridded data? | No | Inconsequential. The interpolation algorithm is not explicitly described, but the resulting map showing the distribution of hydraulic conductivity parameters indicates that the interpolation is standard (probably kriging) and suitable for the purpose of the model. |
| 2.7 Have consistent data units and geometric datum been used? | Yes | Adequate |
| 2.8 Is there a clear description of the conceptual model? | Yes | The conceptual model description is acceptable. |
| 2.8.1 Is there a graphical representation of the conceptual model? | Yes | Figure A16 of the report. |
| 2.8.2 Is the conceptual model based on all available, relevant data? | Yes | There is no mention of any data being left out of the assessment, and the available dataset is suitable for the assessment. |
| 2.9 Is the conceptual model consistent with the model objectives and target model confidence level classification? | NA | The model suits with a class 2 modelling classification (due to structural limitation), which is perfectly suitable for the risk assessment. |
| 2.9.1 Are the relevant processes identified? | Partly | DCCEEW indicated a potential gap in the conceptualisation relating to the flattening of surfaces that were previously steeper (DCCEEW, 2022) that could potentially influence the recharge rate. However, that risk is now covered by the PUA which explores a large variability of input parameters including recharge. |
| 2.9.2 Is justification provided for omission or simplification of processes? | Yes | A model is always a simplified representation of natural system and GHD provides sufficient details on the simplifications and assumptions they have made. |
| 2.10 Have alternative conceptual models been investigated? | NA | No alternative conceptual models were investigated. It is not a standard practice to develop alternative conceptualisation (due to the cost implication). The common practice is for all stakeholders to agree on the most appropriate conceptualisation. |

### 1.1.2 Design and construction

The design stage involves describing how the modeller intends to represent the conceptual model in a quantitative (mathematics-based) framework (Barnett et al, 2012). Construction is the implementation of that approach in that a model is created through the use of appropriate software (model code and graphical user interface (GUI)) (Barnett et al, 2012). The following summarises the model design and construction plan:

- Supported the processes described in the conceptual model.
- Completed according to acceptable standard practices.
- Suitable to achieve the model objectives.

Table 4 summarises the model design and construction review.

Table 4 **Design and Construction**

| Review Questions | Yes / Partly / No | Comment |
|---|---|---|
| 3.1 Is the design consistent with the conceptual model? | Yes | Adequate |
| 3.2 Is the choice of numerical method and software appropriate (Table 4-2)? | Yes | The model conforms with acceptable standard practices and uses industry standard modelling software including MODFLOW-USG, AlgoMesh, PEST, over-parameterisation and regularisation techniques.<br>Algomesh (gridding) for spatial discretisation.<br>PEST for parameter estimation. |
| 3.2.1 Are the numerical and discretisation methods appropriate? | Yes | Adequate |
| 3.2.2 Is the software reputable? | Yes | Adequate |
| 3.2.3 Is the software included in the archive or are references to the software provided? | Yes | Adequate |
| 3.3 Are the spatial domain and discretisation appropriate? | Yes | Adequate refinement around stream and not over-discretised. |
| 3.3.1 1D/2D/3D | Yes | Adequate, 3D |
| 3.3.2 lateral extent | Yes | Adequate |
| 3.3.3 layer geometry? | Yes | Adequate, based on limited available data. |
| 3.3.4 Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model and target confidence level classification? | Yes | Adequate |
| 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? | Yes | Adequate |
| 3.4 Are the temporal domain and discretisation appropriate? | Yes | Adequate |
| 3.4.1 steady state or transient | Yes | Uses both steady state for establishing initial conditions and transient for the calibration (quarterly stress periods to replicate seasonal variations). |
| 3.4.2 stress periods | Yes | Yearly (1975-1993) then quarterly (1993-2018) for representing seasonality. |
| 3.4.3 time steps? | Yes | Automatic time stepping. |
| 3.5 Are the boundary conditions plausible and sufficiently unrestrictive? | Yes | Adequate |
| 3.5.1 Is the implementation of boundary conditions consistent with the conceptual model? | Yes | Adequate |
| 3.5.2 Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained? | Yes | Adequate |
| 3.5.3 Is the calculation of diffuse recharge consistent with model objectives and confidence level? | Yes | Adequate |
| 3.5.4 Are lateral boundaries time-invariant? | Yes | Adequate |

| Review Questions | Yes / Partly / No | Comment |
|---|---|---|
| 3.6 Are the initial conditions appropriate? | Yes | Defined by a steady state initial stress period. |
| 3.6.1 Are the initial heads based on interpolation or on groundwater modelling? | Yes | Groundwater modelling. |
| 3.6.2 Is the effect of initial conditions on key model outcomes assessed? | Yes | Adequate |
| 3.6.3 How is the initial concentration of solutes obtained (when relevant)? | n/a | n/a |
| 3.7 Is the numerical solution of the model adequate? | Yes | Adequate |
| 3.7.1 Solution method/solver | Yes | SMS Solver for MODFLOW-USG. |
| 3.7.2 Convergence criteria | Yes | Heads within 0.001m for convergence. |
| 3.7.3 Numerical precision | Yes | Adequate |

### 1.1.3 Calibration and Sensitivity

The calibration of the model occurs through a process of matching model outputs to a historical record of observed data and the sensitivity analysis aims at identifying how much each individual parameter is constrained by the calibration.

The model calibration assisted by PEST reached a scaled root mean squared error (sRMS) of 4.3%. This is usually considered an acceptable calibration standard. The acceptable RMS statistic is aided by the wide distribution of head targets ranging from about 200 to nearly 500mAHD (approximately 300mAHD difference). The review of the calibrated model hydrographs shows that regional gradients are usually acceptable with occasionally some important discrepancies (e.g., the heads at bore Q07 are off by more than 20m). GHD did not make any comment on those locally important discrepancies or their predictive implications. However, it is reasonable to assume that the addition of the PUA compensates some shortcomings of the calibration mismatch. Indeed, by using 439 calibrated models, it is expected that some models would improve calibration at some bores that were not well calibrated in the original model while being worse at other locations that were better calibrated originally. It is expected that the ensemble of all the calibrated models, by covering a wide range of parameters combinations, offers an increased chance to eventually get more accurate representation of aquifer behaviour across the model domain. Representing the calibration hydrographs for all the target bores would have allowed to visually assess that point and identify more accurately zones of irreducible model mismatch due to structural or conceptual shortcomings.

The sensitivity results consist of PEST “composite sensitivity” output. This only allows comparative comparison of the various parameters between them but does not allow to quantify nor visualise the effect each parameter has on the calibration.

Table 5 summarises the model calibration and sensitivity review.

**Table 5 Calibration and Sensitivity**

| Review Questions | Yes / Partly / No | Comment |
|---|---|---|
| 4.1 Are all available types of observations used for calibration? | Yes | Heads and baseflow only. No other flux available. |
| 4.1.1 Groundwater head data | Yes | 105 bores (10,563 head observation targets). |
| 4.1.2 Flux observations | Yes | Baseflow to main streams and seepage rates at Boddington Gold Mine. Pumping rates at 26 pumping bores. |
| 4.1.3 Other: environmental tracers, gradients, age, temperature, concentrations etc. | n/a | n/a |
| 4.2 Does the calibration methodology conform to best practice? | Yes | Adequate |
| 4.2.1 Parameterisation | Yes | Over-parameterisation of hydraulic conductivity with pilot point. |
| 4.2.2 Objective function | Yes | Integrated heads difference as calibration target. |
| 4.2.3 Identifiability of parameters | Yes | No map of parameter identifiability. |
| 4.2.4 Which methodology is used for model calibration? | Yes | PEST acceptable calibration standard. |

| Review Questions | Yes / Partly / No | Comment |
|---|---|---|
| 4.3 Is a sensitivity of key model outcomes assessed against? | Yes | Calibration sensitivity results were provided by PEST. This is the minimum standard. It allows to comparatively compare the various parameters. |
| 4.3.1 parameters | Yes | Provided display of calibrated parameter in comparison with allowed range and resulting parameter distribution. |
| 4.3.2 boundary conditions | Yes | Adequate |
| 4.3.3 initial conditions | Yes | Adequate |
| 4.3.4 stresses | Yes | Adequate |
| 4.4 Have the calibration results been adequately reported? | Partly | Not in sufficient detail, commentary or discussion.<br>The model fails to reproduce most seasonal variation (for the period post 1998 when the model uses quarterly stress periods to replicate the seasonality of the system).<br>The model also fails to reproduce some of the groundwater trends observed in the data presented. |
| 4.4.1 Are there graphs showing modelled and observed hydrographs at an appropriate scale? | Yes | Provided hydrographs of the calibrated model in the appendices.<br>It would be valuable to add an appendix with the hydrographs for the 439 calibrated models. |
| 4.4.2 Is it clear whether observed or assumed vertical head gradients have been replicated by the model? | NA | No available vertical gradient data. Vertical gradient is not a relevant feature of the groundwater system studied in this assessment |
| 4.4.3 Are calibration statistics reported and illustrated in a reasonable manner? | Partly | Displayed calibration results in a favourable manner showing only the scatter plot (with the sRMS statistics which benefited from the wide distribution of heads).<br>Adding a distribution of heads residuals would have added to transparency. |
| 4.5 Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated? | Partly ~~No~~ | The calibration shortcomings are not detrimental provided that the model inadequacies are not leading to an underestimation of impact. Within an impact assessment framework, the critical element is to provide strong and defensible evidence that the predicted model impacts are overestimated, i.e. that the model is conservative. By providing the results of 439 calibrated models, the approach offers a wide range of plausible parameters that compensated the shortcoming of the initial approach (without the PUA) that was relying solely on two calibrated models. |
| 4.5.1 spatially | No | No figure or map showing the distribution of residuals. |
| 4.5.2 temporally | Partly | Seasonality is not well replicated, and some trends not replicated. |
| 4.6 Are the calibrated parameters plausible? | Yes | Adequate |
| 4.7 Are the water volumes and fluxes in the water balance realistic? | Yes | Adequate |
| 4.8 has the model been verified? | No | Not a common practice. |

### 1.1.4 Predictions

All model parameters must be defined to prepare a model for making predictions (Barnett et al, 2012). Models are developed to provide predictions that cannot be obtained by observing the natural system. The groundwater model was developed to predict the propagation of mounding and change of baseflow relating to the enhanced recharge triggered by land clearing.

As per the model calibration, the development of predictive scenarios relies on the conceptual model which identified the processes that need to be represented for the model predictions. The model prediction was based on a suitable conceptualisation appropriately translated into model features. The predictive results are provided through high quality figures and illustrations.

Table 6 summarises the model prediction review.

**Table 6 Prediction**

| Review Questions | Yes / Partly / No | Comment |
|---|---|---|
| 5.1 Are the model predictions designed in a manner that meets the model objectives? | Yes | Adequate |
| 5.2 Is predictive uncertainty acknowledged and addressed? | Yes ~~No~~ | The PUA generated 439 calibrated models that were used to appropriately quantify parameter uncertainty. |
| 5.3 Are the assumed climatic stresses appropriate? | Yes | The climatic stresses are well conceptualised and represented. |
| 5.4 Is a null scenario defined? | Yes | The model offers comparison of mining scenarios to a non-mining scenario. |
| 5.5 Are the scenarios defined in accordance with the model objectives and confidence level classification? | Yes | Adequate |
| 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? | Yes | Adequate |
| 5.5.2 Are well losses accounted for when estimating maximum pumping rates per well? | n/a | 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? | Yes | Adequate |
| 5.5.4 Are the assumed stresses and timescale appropriate for the stated objectives? | Yes | Adequate |
| 5.6 Do the prediction results meet the stated objectives? | Yes | The predictive model results are appropriately mapped to represent the risk to GDEs. |
| 5.7 Are the components of the predicted mass balance realistic? | Yes | Adequate |
| 5.7.1 Are the pumping rates assigned in the input files equal to the modelled pumping rates? | Yes | Adequate |
| 5.7.2 Does predicted seepage to or from a river exceed measured or expected river flow? | Yes | Modelled the groundwater-surface water interaction. Evaluated the magnitude of baseflow match to monitored rivers regime. |
| 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)? | No | Adequate |
| 5.7.4 Is diffuse recharge from rainfall smaller than rainfall? | Yes | Calibrated diffuse rainfall recharge using a multiplier. Diffuse rainfall recharge is less than rainfall. |
| 5.7.5 Are model storage changes dominated by anomalous head increases in isolated cells that receive recharge? | No | Adequate |

| Review Questions | Yes / Partly / No | Comment |
|---|---|---|
| 5.8 Has particle tracking been considered as an alternative to solute transport modelling? | No | No particle tracking was modelled nor required as the impact analysis is related to the mounding generated by the increased recharge. |

### 1.1.5 Uncertainty Analysis

In modelling, uncertainties arise at each step of the modelling workflow, and it is important to either quantify uncertainty or to control uncertainty by developing a conservative model approach, that maintains uncertainty on the side of impact overestimation.

In a risk assessment framework, as it is for this project, it is a suitable approach to design a model which overestimates the predictions. If the overestimated model predictions are within acceptable limits, the modelling uncertainty has satisfied the objective.

The Null Space Monte Carlo analysis developed by GHD is a state-of-the-art way to quantify parameter uncertainty. GHD produced 439 calibrated models which is more than enough to provide reliable post-distribution of predictions and a reliable way to estimate what are a reasonable upper bound of expected mounding.

Despite a thorough parameter predictive uncertainty, GHD doesn't discuss the potential effects of the model structural uncertainties. Structural uncertainties are reflective of the extent to which a model differs from the real system it is intended to represent. A structural defect may impact the model to obtain a better calibration (e.g., bore Q07, are off by more than 20m). This is possibly due to a structural defect of the model, potentially due to spatial discretisation, hydro stratigraphic unit misrepresentation, or vertical discretisation. A portion of the 439 calibrated models may be better calibrated at those location (e.g., bore Q07) showing that the mismatch is part of the model parameterisation. GHD could have displayed the resulting hydrographs distribution for all the calibrated model to identify more clearly some of the structural limitations of the model, that could require more specific scrutiny for potential future refinement.

Table 7 summarises the model uncertainty review.

**Table 7 Uncertainty**

| Review Questions | Yes / Partly / No | Comment |
|---|---|---|
| 6.1 Is some qualitative or quantitative measure of uncertainty associated with the prediction reported together with the prediction? | Yes | GHD produced 439 calibrated models through null space Monte Carlo uncertainty analysis allowing a suitable quantification of parameter uncertainty. |
| 6.2 Is the model with minimum prediction-error variance chosen for each prediction? | n/a | n/a |
| 6.3 Are the sources of uncertainty discussed? | Yes ~~Partly~~ | All relevant parameters of the model calibration were adequately included in the uncertainty analysis. |
| 6.3.1 measurement of uncertainty of observations and parameters | Yes ~~Partly~~ | GHD provided illustration of prior and post distributions of all parameters and also representation of mounding at Quindanning spider orchid sites. |
| 6.3.2 structural or model uncertainty | No | Structural uncertainty is not detailed. By representing all the hydrographs, GHD could provide more insight into the residual structural uncertainty of the model. This aspect is not a showstopper as the model is suitable for a regional scope but would allow to identify more clearly localised areas that would require added scrutiny in future investigations. |
| 6.4 Is the approach to estimation of uncertainty described and appropriate? | Yes ~~Partly~~ | Adequate |
| 6.5 Are there useful depictions of uncertainty? | Yes ~~Partly~~ | Illustrations prepared by GHD are suitable to depict the uncertainty. |

### 1.1.6 Solute Transport

No solute transport was conducted, and the section is not relevant for the review.

The risk of potential contamination and the geochemical processes (e.g. solubilisation of potential contaminants) that may occur following the blasting of the top surface may have been addressed in another scope of work.

### 1.1.7 Surface Water - Groundwater Interaction

Representation of surface water–groundwater interaction is required in increasing detail in modelling studies. An interaction assessment should outline the type of interaction between surface water and groundwater systems in terms of their connectedness and whether they are gaining or losing systems (Barnett et al, 2012).

Surface water-groundwater interactions are relevant to the project objectives. GHD provided adequate level of detail to represent the surface water groundwater interaction and calibrating baseflow. A figure illustrating longitudinal stream profile and potential structural uncertainty discussion would have improved the quality of the assessment.

Table 8 summarises the model surface water groundwater interaction review.

**Table 8 Surface Water-Groundwater Interaction**

| Review Questions | Yes / Partly / No | Comment |
|---|---|---|
| 8.1 Is the conceptualisation of surface water–groundwater interaction in accordance with the model objectives? | Yes | Adequate |
| 8.2 Is the implementation of surface water–groundwater interaction appropriate? | Yes | Adequate with the use of MODFLOW Stream package. |
| 8.3 Is the groundwater model coupled with a surface water model? | No | Not required. The surface water (apart from baseflow) regime is not relevant for reaching the model objective. |
| 8.3.1 Is the adopted approach appropriate? | Yes | Adequate |
| 8.3.2 Have appropriate time steps and stress periods been adopted? | Yes | Appropriate time steps and stress periods were adopted. |
| 8.3.3 Are the interface fluxes consistent between the groundwater and surface water models? | Yes | Adequate |

# 4 Reference

CDM Smith 2023. Independent Review of the Worsley Mine Expansion Groundwater Numerical Model - GHD's responses to DCCEEW.

DCCEEW 2022. Attachment 1: Department of Climate Change, Energy, the Environment and Water (DCCEEW) review of ERD Rev 3 (EPBC 2019/8437). Worsley Mine Expansion, Attachment 1, DCCEEW. 6 September 2022

GHD, 2020. Worsley Mine Expansion - Revised Proposal South32 Worsley Alumina Pty Ltd. EPA Assessment No. 2216 EPBC Reference No. 2019/8437. Appendix I1 - Groundwater and Surface Water Studies.

GHD 2023. Technical memorandum. Groundwater uncertainty analysis to support addressing comments provided by the Office of Water Science