HydroGeoLogic

HydroGeoLogic Pty Ltd (ABN 51 877 660 235)
PO Box 383, Highgate 5063, South Australia
0438 983 005 hugh@hydrogeologic.com.au

PEER REVIEW STATEMENT – FOUNTAIN HEAD GROUNDWATER MODEL

ATTENTION:	David Browne, Principal, ERIAS Group	
FROM:	Hugh Middlemis, Principal Groundwater Engineer, HydroGeoLogic (HGL)	
REFERENCES:	7 July 2022	Fountain Head Gold Project (NT)
SUBJECT:	Fountain Head Groundwater Model Update for Supplementary EIS Response - Peer Review	

Dear David

This report presents the findings of an independent peer review of the Fountain Head Groundwater Model Update. The 2022 model update builds on the 2021 model that supported the EIS process, with updates to address changes requested by the NT EPA. The modelling provides the quantitative basis for groundwater-related assessments to support the EIS process for the proposed Fountain Head Gold Project (FHGP) operated by PNX Metals Limited (PNX).

1. Scope of Work, Methodology and Peer Reviewer

This desktop peer review considered the CDM Smith groundwater assessment report:

- CDM Smith (2022a). Fountain Head Gold Project – Groundwater Model Update for Supplementary EIS Response 2022. Prepared for ERIAS Group and PNX Metals Limited. Draft version 24 May 2022, and updated version 16 June 2022.

The report details the understanding of the hydrogeological system and related groundwater-dependent ecosystems (GDEs), along with the conceptual model and design and development of a numerical groundwater flow model. A significant update in 2022 was the application of uncertainty analysis methodologies to calibration and prediction scenarios to investigate mine dewatering-drawdown effects and post-mining recovery, along with particle tracking simulations (transport and fate analysis).

This peer review was conducted in accordance with the principles and criteria outlined in the best practice Australian Groundwater Modelling Guidelines (‘AGMG’; Barnett et al. 2012), with consideration of the recent uncertainty analysis guidance (Middlemis et al., 2018, 2019). The review methodology evaluated whether best practice has been applied to the modelling study, with a focus on:

- the hydrogeological understanding and conceptualisation, and implementation in the numerical model, and its fitness for the purpose of groundwater impact assessment via simulations of mine dewatering effects and mine closure scenarios;
- conformance to best practice guidelines in relation to model calibration performance, with consideration of grid, domain, boundary conditions, layering, parameterisation and non-uniqueness, and to sensitivity analysis and predictive uncertainty scenarios;
- whether the assessments made, or conclusions reached, are supported by the evidence presented, and/or whether additional information, monitoring, assessment and/or modelling may be required to inform the assessment.

The peer review involved several video link and phone discussions with the ERIAS and CDM Smith teams, consistent with guideline principles, mainly on documentation issues arising from the initial review. The draft groundwater assessment report was updated accordingly, such that it adequately addressed the issues, and this peer review report was then finalised.

The peer review was conducted by Hugh Middlemis, who is familiar with Top End conditions, having lived at Katherine and Darwin, and has suitable skills and experience on NT projects:

- Hugh Middlemis holds a degree in civil engineering and a masters in hydrology and hydrogeology, with more than 40 years' experience. Hugh was principal author of the MDBA 2001 best practice groundwater modelling guidelines and of two reports on modelling uncertainty (for IESC in 2018 and NCGRT in 2019). Hugh established Hydrogeologic Pty Ltd in 2013, as an independent consultancy providing specialist advice on groundwater conceptualisation and model design, development and peer reviews.
- Relevant recent experience includes independent expert reviews of groundwater assessments and/or water management plans for several NT mining projects; Jervois Base Metals Groundwater Monitoring and Management Plan (2020); Cambrian Limestone Aquifer and Roper River Model (Daly/Roper Basin model review 2020); Tindall Limestone Aquifer (2020); Ammaroo Phosphate modelling (2017); Chandler Salt Water Management Plan (2017); Ranger Pit 1 (2016).
- Previously, Hugh was Technical Director on several Aquaterra projects in the NT, notably the following, which also involved site visits and investigations: Middle Point groundwater model (1999); Elizabeth River waterway project groundwater model (NT Dept of Transport, 1999); Woodcutters mine decommissioning (1999); Groote Eylandt mine dewatering and river-aquifer interactions (1998-2002); Angela uranium (2010-11); McArthur River mine dewatering and river-aquifer interactions (2012-13).

We assert no conflict of interest issues in relation to this work. Mr Middlemis has not worked on the Fountain Head project, nor for PNX nor CDM Smith, other than in a review role.

2. PEER REVIEW OUTCOME SUMMARY

This peer review finds that the groundwater assessment report has effectively addressed the request for model improvement and additional information issues raised by the NT EPA in relation to the groundwater modelling, as summarised in Table 1, although the EPA will make their own judgement on that.

Table 1 – summary of compliance with NT EPA request for model improvements and information

	CDM Smith summary of NT EPA requirements	Peer Review assessment of compliance
1	Improve the model calibration to be better constrained by groundwater level data and to reduce the scaled root mean square (sRMS) error criterion.	Additional data since 2008 used in model calibration, with performance greatly improved; mean sRMS has been reduced from >10% to a mean of 5.6% (Fig. 3-6), consistent with guideline criteria.
2	Refine the model parameterisation to more closely align with observed field data and literature.	Acceptable consistency between available data and key model parameters (hydraulic conductivity, specific yield, storativity and recharge), summarised in Tables 3-1 and 3-2 and Figures 3-7 to 3-11.
3	Reduce uncertainty and describe in greater detail the effects of model uncertainty on predictions.	Additional data and uncertainty analysis methodologies were applied, consistent with best practice guidance, to improve calibration performance (Figs. 3-5, 3-6, 3-7), reduce parameter uncertainty (Fig. 3-12), and to provide quantitative estimates on the effects of uncertainty (Figs. 3-13 to 3-22), along with insightful narrative on qualitative uncertainty.
4	Improve the understanding of the distribution and condition of groundwater-dependent ecosystems (ecological values that are reliant to some extent on groundwater), and the extent and magnitude of groundwater drawdown and water quality effects on GDEs due to mine-related water affecting activities.	Report provides considerable detail on GDEs in terms of the data available (Appendix A), their representation in the model (s2.4, s3.3.5) and the assessment of potential effects via predictions of drawdown, groundwater flow and particle tracking transport and fate (eg. Figs 3-15 to 3-21).
5	Provide predictions of groundwater level and flow to support water quality assessments of potential impacts on downstream environmental receptors.	See previous item.
6	Validate the groundwater fluxes predicted by the GoldSim water balance model (WBM) to reduce uncertainty in the dewatering requirements.	GoldSim WBM fluxes on pit inflows have been effectively validated by Modflow modelling (Fig. 3-6). Parameter values (Kh) are more consistent between the models. Note that consistent results generated by independent methods (ie. numerical Modflow and analytical GoldSim models) reduces uncertainty. Quantitative uncertainty analysis applied best practice PESTpp-IES methods.

Table 2 below presents a summary of the findings of this peer review, based on the compliance checklist from the Australian groundwater modelling guidelines ('AGMG'; Barnett et al. 2012).

Table 2 - Groundwater Model Compliance; 10-point essential summary; Fountain Head Model (2022)

Question	Y/N	Comments re Fountain Head groundwater model (2022)
1. Are the model objectives and model confidence level classification clearly stated?	Yes	Objectives: modelling investigation to support environmental approvals via predictive scenarios and uncertainty analysis of the effects on groundwater levels and flows due to mine dewatering and post-mining recovery including transport and fate of contaminants. Quantitative uncertainty analysis surpasses qualitative confidence level characterisation.
2. Are the objectives satisfied?	Yes	Expert model design and calibration. Surface and groundwater interactions and GDEs are well represented in the model. Prediction scenarios and uncertainty analysis demonstrate fitness for purpose.
3. Is the conceptual model consistent with objectives and confidence level?	Yes	Comprehensive hydrogeological analysis and conceptualisation, based on extensive field and modelling investigations and reports over many years, consistent with data and objectives. Quantitative uncertainty analysis surpasses the outmoded qualitative confidence level characterisation.
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Yes	Report summarises previous investigations and modelling, including a) regional groundwater data and aquifer parameter properties; b) monitoring from 6 bores since 2010 that effectively capture groundwater recovery from previous mining 2007-2009 (not used in 2021 work); c) historical pit lake water level data used to specify boundary conditions for pit lake for calibration 2008-2021; d) GoldSim model estimates of pit inflows used as calibration flux targets; e) GoldSim evaporation pond seepage input as recharge to Modflow model; f) evapotranspiration based on Douglas River FAO56 estimates; g) recharge benchmarked to CSIRO and BoM estimates. All combined to develop a sound conceptual model. Excellent presentations of geology, hydrology, groundwater flow system, GDEs, conceptual model (Figure 1 below) and associated narrative descriptions. Competent hydrogeologists and modellers have evaluated the data, conceptualisation, impact pathways, model design, execution, sensitivity/uncertainty assessments and outcomes.
5. Does the model design conform to best practice?	Yes	The model software (Vistas, Modflow-NWT), design, extent, layers (4), grid (25x25m to 50x50m), boundaries, parameters, inputs and outputs (including pit lake level data and GoldSim EP seepage) and uncertainty analysis methodology are consistent with best practice design and execution.
6. Is the model calibration satisfactory?	Yes	See also item 4 above re data for calibration targets. Additional data since 2008 used in 2022 Pest++ calibration. Transient sRMS error mean 5.6% over 100 realisations (range 5%-6.3%) with low water balance error terms meets guideline criteria. 245 time series level targets across 22 bores, plus 75 time series flux (pit inflow) targets reduces non-uniqueness. Groundwater level contour plans and time series plots show good matches.
7. Are the calibrated parameter values and estimated fluxes plausible?	Yes	Model parameter values are consistent with drilling, testing and previous investigations. Fluxes are consistent with recharge estimates and GoldSim model estimates of post-2009 pit inflows and evaporation pond seepage estimates. Effectively validated by good matches to water level data since 2010, notably including 6 bores near pit (Fig. 3-1, 3-2).
8. Do the model predictions conform to best practice?	Yes	Predictive uncertainty scenarios form a good example of best practice in design and execution. PESTpp-IES methods on 100 realisations used to quantify key quantities of interest; the 95th percentile drawdown impacts and the particle tracks of transport and fate.
9. Is the uncertainty associated with the simulations-predictions reported?	Yes	See also item 8. Sensitivity analysis demonstrated relative uncertainty reduction methods on the calibration scenarios. Quantitative predictive uncertainty analysis applied consistent with best practice guidance; implications are well documented.
10. Is the model fit for purpose?	Yes	The 2022 Fountain Head groundwater modelling has been conducted with a high degree of professionalism and meets best practice criteria for modelling and uncertainty analysis. It is fit for purpose to inform impact assessment, mitigation and management planning, and licensing and groundwater management strategies.

3. 'MODEL CONFIDENCE LEVEL' AND QUANTITATIVE UNCERTAINTY ANALYSIS

The 'model confidence level classification' set out in the Australian Groundwater Modelling Guidelines ('AGMG'; Barnett et al. 2012) is an outmoded qualitative assessment of the level of data available, especially aquifer responses to hydrological stresses, as well as the conceptualisation and calibration process and performance, and the manner in which the predictions are formulated. The AGMG also set out some basic guidance on the uncertainty analysis methods that were in the early stages of the model development at that time (a decade ago). The AGMG is being revised and this qualitative assessment is being discontinued.

It is a common misconception that the model confidence level assessment is mandatory for every model, noting that the AGMG actually recommends the confidence level method for application to situations when a formal uncertainty analysis has not been conducted. In this case, an uncertainty analysis has been conducted, so the confidence level scheme is not strictly applicable. The 2022 Fountain Head groundwater assessment report does not discuss the model confidence level classification. However, as the NT EPA requested that the model calibration should conform to 'Class 2' criteria, this review has considered the issues and has concluded that the model calibration conforms to the AGMG performance criteria (eg. sRMS, matches to groundwater level and flux data, model water balance), and notes that additional monitoring data has been used in the 2022 update such that it is nominally adequate for 'Class 2'.

Having said that, the uncertainty guidance provided in the 2012 AGMG was recently augmented and updated by Middlemis et al. (2018 and 2019), including 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 were being used inappropriately in some cases to justify 'indiscriminate complexification' of models, rather than the 'effective simplification' that is warranted for application to quantitative uncertainty analysis.

The 2018 guidance frames uncertainty analysis as an integral part of risk management, in that it informs and complements other aspects such as risk assessment, mitigations/treatments, 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' scheme and its formal replacement with uncertainty analysis methodologies. The quantitative uncertainty analysis conducted for the 2022 Fountain Head modelling is consistent with existing guidance and should be consistent with the new guides (expected in late 2022).

4. MODEL CAPABILITY

A key element of any groundwater model is the conceptual hydrogeological model that describes the geological framework, aquifer structure and the key flow system processes of natural and managed recharge, discharge and surface-groundwater interactions (GDEs) and related water quality characteristics, as illustrated in Figure 1 (after Li, 2022). In this case, the conceptual hydrogeological model is mature, based on extensive field and modelling investigations over a number of years.

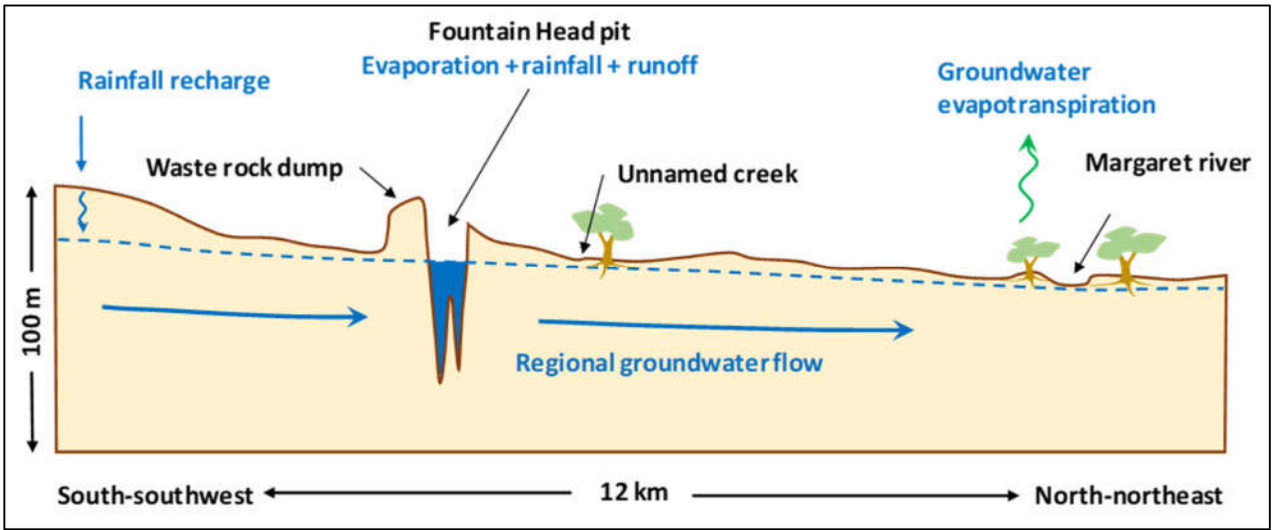

Figure 1 - Fountain Head conceptual model for (after Li, 2022, Fig. 2-7)

The groundwater modelling report is well-written and provides lucid explanations of the hydrogeological understanding, previous investigations and modelling campaigns (eg. s.3.2). The numerical groundwater model implementation and the results and interpretations are clearly explained. The model domain, layer setup, grid design, boundary conditions and parameters applied are consistent with the available information and conceptualisations. The assumptions and limitations are cogently described, and the scenarios for sensitivity and uncertainty analysis are well-executed and the implications are clearly discussed.

The model calibration performance is sound, with a mean scaled RMS of 5.6% (range 5.0% to 6.3% across 100 model realisations; Fig. 3-6), reduced from more than 10% for the 2021 model. Additional data extending back to 2008 has been used in the 2022 calibration, involving a total of 245 time series level targets across 22 bores (Fig. 3-2) and new data on 75 time series flux targets estimated from the GoldSim model (eg. Fig. 3-7), reducing non-uniqueness.

Note that the Modflow model applied suitable boundary conditions to represent:

- pit lake levels 2008-2022, based on pit lake level monitoring data,
- pit dewatering during the operations and post-mining periods, based on GoldSim predictions.

The GoldSim estimates of inflows were used as flux target constraints throughout the simulations of pit lake recovery (calibration), and dewatering and post-mining (prediction). GoldSim estimates of seepage from the evaporation pond were input to the Modflow model as recharge fluxes throughout these simulations. In summary, the combination of monitoring level data and GoldSim estimated fluxes has been used to constrain the simulations in a manner consistent with best practice guidance on modelling and uncertainty analysis.

Other monitoring data includes six bores near the open pit that show recovering groundwater levels from 2010 following the cessation of previous mining in 2009, along with pit lake levels (Fig. 3-2). This effectively forms a large scale pumping test as groundwater levels recovered and the pit filled with water, which addresses EPA concerns about the previously much more limited data used for the 2021 model. Good matches were achieved to groundwater levels and trends for the majority of the 22 bores (Appendix C), and the modelled groundwater flow contour patterns reflect the hydrogeological conceptualisation (Fig. 3-12). The calibration period includes highly variable climatic conditions, and a wide range hydrological stresses, which also helps reduce non-uniqueness.

The accompanying report on geochemistry (CDM Smith 2022b) concluded that (paraphrasing) the pit lake water quality is predicted to be better than the current pit lake water quality, which means that there is effectively a benign ‘source’ term in the sense of the source-pathway-receptor model of impact assessment.

The particle tracking scenarios have been conducted consistent with best practice, and implementing uncertainty analysis methods (100 realisations), combined with a detailed GDE assessment (Appendix A), indicating a range of outcomes and a very low likelihood of impacts.

Climate change effects have been assessed, subject to some simple but reasonably justified assumptions, although this reviewer considers that climate change assessment is not really warranted given the short time frame of mining (5 years).

5. CONCLUSION

My professional opinion is that the 2022 Fountain Head groundwater modelling investigation has been conducted and documented with a high degree of professionalism and meets best practice criteria for modelling and uncertainty analysis.

The Fountain Head groundwater model is fit for purpose to inform impact assessment, mitigation and management planning, and licensing, and for further development to investigate sensitivities and uncertainties under future work programs.

Yours sincerely,

HydroGeoLogic

Hugh

Hugh Middlemis,

Director / Principal Groundwater Engineer.

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